# SB2009 Proposal Document

**vers. 20091201A**

## 1 Introduction

Primary authors: Project Managers;  Assistant authors: Toge

This report documents the resulting proposal from the Project Management Design Team for fundamental changes to the published RDR baseline, in accordance with the goals of the published GDE R&D Plan [ref]. It represents the culmination of approximately one-year of study and includes new results from the on-going risk-mitigating R&D, as well as a critical review of the existing Reference Design.

At the end of Technical Design (TD) Phase in 2012 the GDE will publish a Technical Design Report (TDR), which will contain a description of the ILC design in enough detail to support an updated VALUE estimated. The updated reference design will be based on the existing published Reference Design (RDR), but will include results from on-going risk-mitigating R&D and Accelerator Design and Integration (AD/I) studies. A primary goal of the TD Phase is to constrain the VALUE estimate to the RDR value of 6.6 BILCU.

With these goals it mind, it seems prudent to make use of the available (and limited) design resources during the last two-years to review the RDR design in the hope of establishing a better, more cost-effective baseline by the end of TD Phase 1 (2010). The resulting modified baseline will form the basis for the following two-years of detailed design and cost work foreseen for the TDR, during which time the baseline will be maintained and will evolve under strict change control.

With nearly all ILC worldwide resources focused on the risk mitigating R&D (most notably SCRF), a strategic decision was made to focus the available resources on those top-level design elements of the RDR baseline which have a large cost leverage (at the level of a few % each), and where potential alternate designs which provide a more cost-effective solution exist. The rationale for this approach is based on an assumption that the RDR design – although sound – is both overly conservative in many of its design decisions, relatively immature from a detailed engineering standpoint, and is fundamentally “performance-driven” as opposed to cost optimised. Conventional Facilities and Siting (CFS) was identified early on as a strong focus for design optimisation; in particular the reduction of

**コメント [n1]:** I find this section text somewhat repetitive. I also prefer to see this section begins with a line which says "This document is ..." upfront. Perhaps we can come back to this later, when the dust settles in other areas.

**コメント [NW2]:** Have made one iteration. Still think it can be made better, but suggest we leave this now until final editing. Note this intro is very important (IMO).

underground civil construction, achieved by a critical re-evaluation of the criteria driven by the accelerator design assumptions.

As a result, several fundamental design elements have been identified which should provide both a simplification of the scope of the construction project and a possible cost reduction of up to one-billion ILCU, while maintaining a level of technical risk consistent with the RDR baseline (and in some cases potentially reducing it). Cost-reduction at this level will supply margin for possible cost inflation incurred during TD Phase 2 (most likely at the unit cost level).

Further to the basic (and in many respects generic) accelerator layout, the study has also began to address in a more realistic way the impact of potential site constraints, and the need to allow flexibility in design decisions to support any future host site. This aspect is considered fundamental to the proposed approach and will be reflected in the Project Implementation Plan to be published as part of the TDR.

Although the primary focus has been on developing an alternative layout, the process of reviewing the RDR design assumptions has itself lead to the identification of several issues with the RDR design, which have begun to be addressed as part of this study. This process will naturally lead to a better, more cost-optimised design, which in many respects is more complete and mature than the RDR.

The following sections are not intended to be a detailed design report, but contain a relatively conceptual description of the proposed modifications to the RDR baseline. It is acknowledged that not all questions raised have been answered at this juncture, but enough of the key issues have been addressed to be able to propose these modifications based on sound judgement. Many of the remaining issues (details) – as well as new R&D required as a result of the proposal – will feedback into the GDE R&D Plan (to be updated at the end of TD Phase 1).

The Proposal document for the new baseline modifications will be submitted to the Project Director for analysis and review in early 2010, before beginning TD Phase 2. In due course, reviews, high-level approval, and possible refinements are expected before the establishment of the new baseline configuration.

# 2 SB2009 Overview

Primary authors: Project Managers; Assistant authors: Toge

In this section, we will provide a summary overview of the key SB2009 elements and their rationale. Section 2.1 introduces the overall approach and goals of the Accelerator Design and Integration (AD/I) process. Section 2.2 introduces the key proposed top-level baseline modifications and then summarises each of them.

More complete technical details can be found in Section 3, while Sections 4 and 5 cover the cost and risk impacts respectively.

## 2.1 *Rationale and Methodology*

The baseline modifications described in this document were arrived at with several specific goals in mind:

- **Overall cost reduction** - Any opportunities for cost reduction should be taken, in as much as they do not impare performance or unacceptably increase technical risk.
- **Improved cost balancing** - Cost margins created as part of the cost-reduction exercise, can be made available for other subsystems which incurr increased (estimated) construction costs.
- **Improved understanding of system functionality** - Understanding of any performance impact forces a careful analysis of systems' functionalities, strengths and vulnerabilities; this has a critical value on its own beyond cost-reduction.
- **More complete and robust design** - Revisiting many of the design and implementation details that were not completely covered during the RDR design phase. These efforts, if done appropriately, are expected to improve the overall robustness of the ILC systems design.
- **Reoptimised R&D plans** - Improved understanding of the system functionalities and performance issues will help the Project Management to produce a reoptimised and more effective global R&D plan to pursue in TD Phase 2.

The key design elements for the studies were primarily identified by their cost impact (based on the RDR VALUE estimate). The list of proposed design modifications were iterated and reviewed during the second-half of 2008, resulting in a final set of proposals for study published in November 2008[1]. Further studies and refinements evolved into a proposal by the Project Management for a straw-man baseline (SB2009) in May 2009[2]. The baseline modifications proposed in this document are the end

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[1] http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=*865085

[2] http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=*879845

result of iteration by the design team, as well as input from various external reviews and the broader ILC community.

An international Accelerator Design & Integration (AD/I) Team led by the GDE Project Managers carried out the design work. The team includes:

- A set of key leaders around the Project Managers who organized the efforts and led the overall discussion and direction.
- Individual “area” and “global” groups who are responsible for specific accelerator subsystems or accelerator-wide facility systems.
- The costing group who are responsible for collecting and organizing the cost implications.
- Ad-hoc groups formed under the leadership of the Project Managers to address the risks in terms of technical development toward construction of the ILC and the systems availability.

The work was orchestrated around several GDE workshops and special face-to-face focus meetings, as well as numerous weekly teleconferences.

## 2.2 *Summary of Proposed Changes*

Figures 2-1 shows an approximate comparison of the overall ILC layout as documented in RDR and as put forth in the proposed new baseline.

**コメント [n3]:** We might say somewhere that these 7 changes are stacked on top of other smaller changes since RDR (e.g. DR shape etc) etc. This is so as to prepare the readers with a cleaner idea before they move on to the downstream sections, in particular the costing section.

**コメント [NW4]:** I don’t think this is necessary and will only confuse things.

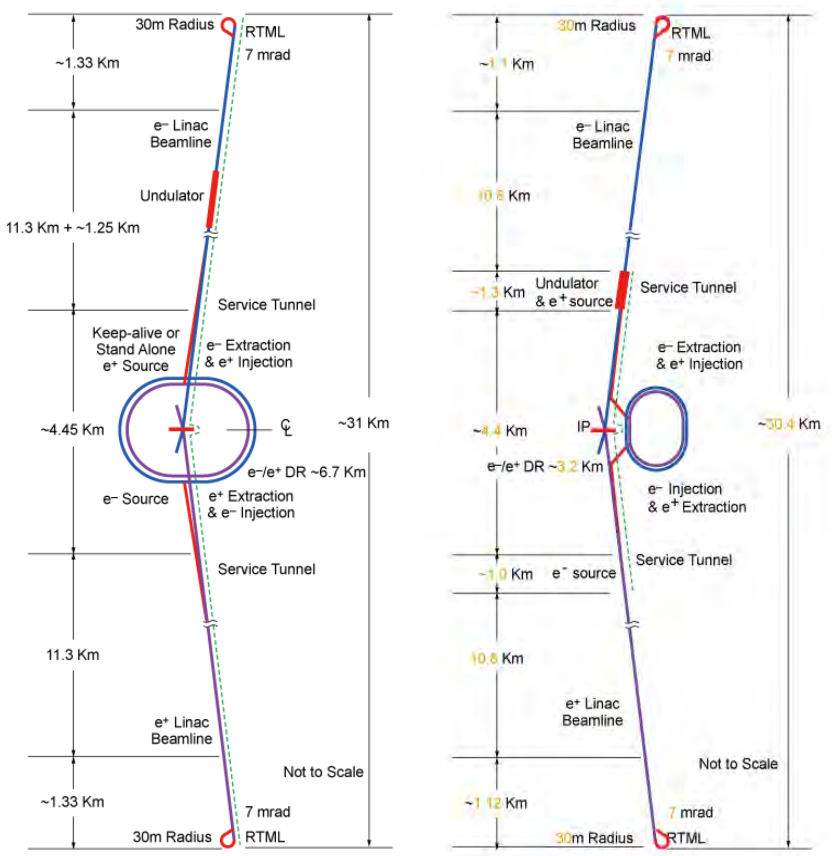

Figure 2-1: RDR layout (left) and the re-baseline layout in proposal (right).

Both the RDR layout and the proposed new layout require a site footprint of approximately 31km length, consistent with a maximum operational beam energy of 250 GeV. Both layouts support a single detector hall, which can accommodate two detector systems that alternately share the beamtime.

The following changes are proposed for the ILC design baseline configuration as described in the RDR:

1. A main linac length consistent with an **average accelerating gradient** justified by the results of the on-going R&D.
2. An HLRF solution which supports a statistical spread in cavity-to-cavity gradient, with sufficient overhead and margin.

**コメント [n5]:** We should also make statements on other aspects of the ILC design which does not change. The notable two are: the top energy being 250 x 2 with some overhead (or whatever), undulator energy loss compensation (if we do). Of course, we need confirmation / consultation by PMs first, though.

**コメント [n6]:** This is the spirit of what we like to pursue in TDP2, I think. But this prop doc, on its own, is not quite putting forward a specific scheme yet. See Nick's NW3. We have to figure out how best to state this.

**コメント [NW7]:** Agreed. Numbers (WA) missing. See my proposed text later.

**コメント [NW8]:** Note I split this off as a separate entry, as the gradient and power-overhead/HLRF are really two separate issue – especially given our recent "debates".

3. **Single-tunnel solution** for the main linacs and RTML, with two possible variants for the HLRF - Klystron cluster scheme and Distributed RF System scheme.
4. **Reduced beam-power parameter set** with respect to RDR nominal parameters, with one-half of the number of bunched per pulse ($n_b$ = 1312).
5. Approximately **3.2 km circumference damping rings** at 5GeV (made possible by the the reduced number of bunches). A **6 mm bunch length** is also assumed (independent of the 3.2 km requirement).
6. **Central Region Integration** off the e+ and e- sources into a common "central region beam tunnel", sharing common underground structures with the BDS, via an overall consolidation of support tunnel, shafts etc.
7. **Undulator-based e+ source** located at the end of the electron main linac (i.e. 250GeV, as part of the Central Region Integration). The source assumes a capture device based on a quarter-wave transformer, an option considered conservative compared with the Flux Concentrator proposed in the RDR, which remains an important R&D item (along with other higher-performance alternatives).
8. **Single-stage bunch compressor**, with a compression ratio of 1/20 (resulting in 0.3 mm bunch length at the IP).

The key top-level design parameters for the SB2009 proposal are summarised and compared to the RDR nominal parameters in Table 1.

**Table 1: Selected design parameters for SB2009 compared to the RDR nominal parameter set.**

| | | RDR | SB2009 |
|---|---|---|---|
| Beam and RF Parameters | | | |
| No. of bunches | | 2625 | 1312 |
| Bunch spacing | ns | 370 | 740 |
| beam current | mA | 9 | 4.5 |
| Avg. beam power (250 GeV) | MW | 10.8 | 5.4 |
| Accelerating gradient | MV/m | 31.5 | 31.5 |
| Pfwd / cavity (matched) | kW | 294 | 147 |
| Qext (matched) | | 3.00E+06 | 3.00E+06 |
| Tfill | ms | 0.62 | 1.13 |
| RF pulse length | ms | 1.6 | 2 |
| RF to beam efficiency | % | 61 | 44 |

| IP Parameters | | | |
|---|---|---|---|
| Norm. horizontal emittance | mm.mrad | 10 | 10 |
| Norm. vertical emittance | mm.mrad | 0.040 | 0.035 |
| bunch length | mm | 0.3 | 0.3 |

**コメント [NW9]:** Note that the RF and beam parameters need updating to be consistant with the proposal by Chris of a 30% (not 50%) reduction in the number of klystrons.

**Update:** given our discussion on this topic last week I nolonger know how to proceed here. I have made my proposal but the design has clearly forked. Should try and resolve this at DESY.

**コメント [n10]:** Agree with NW2. Are the PMs requesting CA/CN to get you the numbers, however?

**コメント [n11]:** Appreciate the comment NW5. See n1 above, and please check my email of Thu, 26 Nov 2009 13:12:28 +0900 (JST).

**コメント [NW12]:** My understanding is that we will stay with 31.5 MV/m for the interim, and that this should be the parameter in the new baseline. We have stated that this parameter will necessarily be continually reviewed as the R&D results are updated. We have also stated that the impact of a gradient change of the order of <=10% to first-order only effects the length of the linac which can be easily scaled. I believe this is the approach we should adopt in this proposal. “To Be Determined” should rather be “Until Further Notice”. All of this things are basically Working Assumptions to get the CFS people going.

. . . [1]

| | | | | |
|---|---|---|---|---|
| horizontal â* | mm | 20 | 11 | |
| horizontal beam size | nm | 640 | 470 | |
| | | | no trav. focus | with trav. focus |
| vertical â* | mm | 0.4 | 0.48 | 0.2 |
| vertical beam size | nm | 5.7 | 5.8 | 3.8 (?) |
| Dy | | 19 | 25 | 21 |
| äEBS/E | % | 2 | 4 | 3.6 |
| Avg. $P_{BS}$ | kW | 260 | 200 | 194 |
| Luminosity | cm -2 s -1 | 2.00E+34 | 1.50E+34 | 2.00E+34 |

### 2.2.1 Main linac – SCRF: choice of operational accelerating gradient

The most highly leveraged R & D that has the greatest potential return is the development of cavity gradient. The cost impact is seen primarily in the linac length required to achieve 500 GeV in the center of mass. In 2005, a goal of an operational accelerating gradient of 31.5 MV/m per cavity was adopted for the Referece Design, with a cavity production specification of ≥35 MV/m in a low-power vertical acceptance test. These parameters were adopted within the paradigm of developing a forward-looking design, and assumed a worldwide R&D effort to routinely establish these parameters. This R&D is currently on going and represents the largest fraction of the global ILC R&D resources.

As of writing – and in lieu of expected developments in the SCRF R&D – it is proposed to leave the accelerating gradient and $Q_0$ unchanged at this time, thus retaining the global CFS requirements (linac length, cryogenic requirements) as in the RDR. The SB2009 working assumption for the accelerating gradient is primarily to allow the CFS groups to continue with their design and cost plans. It is assumed that any subsequent change in accelerating gradient arising from review of the R&D status will to first-order result in a scaling of the main linac length, which is relatively straight-forward, and will not require major re-evaluation of the design[3].

**コメント [NW13]:** Changed from “cavity R&D” to reflect more globally the need to include the chain right up to systems tests with beam (a subtle point only we will appreciate I’m sure).

**コメント [NW14]:** Attempt to shift the emphasis back to SB2009 – which was never really supposed to deal with the gradient directly (IMO) but is more concerned with single tunnels etc.

In contrast to the RDR baseline, however, we propose the HLRF systems support a spread of operational gradients from cavity to cavity. This will allow lower performance cavities to be utilised, assuming that high-performing ones maintain the average. The approach has impact on both the definition of cavity production yield and acceptance criteria, which is currently being evaluated by the global R&D groups. Currently every indication is that this will provide a better cost optimised

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[3] This is based on the assumption that the choice of gradient is unlikely to change by more than the order of 10%.

system, albeit at the expense of a more complex HLRF distribution system and lower overall RF-to-beam power efficiency.

**コメント [n15]:** As a follow up to n6, I suggest we insert line(s) like the following: However, aforementioned R&D program on the cavity gradient and Q value performance will continue to its fullest, so as to ....

The final choice of average operating gradient will be taken in TD Phase 2 after review of the worldwide R&D status. (An interim review is currently on going.) The choice of parameters must necessarily include an analysis of cavity and cryomodule production statistics, as well as results of operational overhead under full beamloading conditions. The choice will also be influenced by production models, assumed yield distributions and must be cost-optimised and justifiable. Finally, it should also take into account the projected trends in the R&D beyond the TDR, given the uncertainty in the start of construction of the project. The on going SCRF R&D will be tailored in TD Phase 2 to address these critical cost and performance issues.

For SB2009 it is acknowledged that working assumptions for several key margin and overhead parameters still need to be addressed. The exact amount of gradient and RF power overhead required for operational margin remains to be specified. The choices made at this juncture should be consistant with the goals proposed for the TD Phase 2 R&D Plans, but should maintain as realisticly as possible the ‘forward looking’ paradigm established during the RDR.

**コメント [NW16]:** Note this paragraph is specifically concerned with SB2009 and the stated WA (the previous paragraph was more about R&D plans and future work).

**コメント [NW17]:** These are the two critical paragraphs that we will no doubt discuss further.

It is important to keep focused (in this document) on the SB2009 issues.

I again re-state most emphatically my objection to suggesting any change in operational accelerating gradient at this time.

I do agree that all considerations of margin, overhead etc. need to be reviewed and considered. But this should be done later, and only once, and only after the completion of our R&D plans.

Basically I still want to punt.

Akira, I did not like your proposed text because it still states we are going to reduce the gradient (even if it doesn’t give a number).

### 2.2.2 Main linac – Single tunnel configuration

Foremost among the proposed changes is the adaptation of the main linac tunnel configuration to one with only a single, accelerator-enclosure tunnel, which does not have the support equipment tunnel proposed in the Reference Design. Several key studies and strategic initiatives make it advisable to propose this change for the new baseline:

1. The single tunnel configuration is a simpler underground construction, effectively removing 20 km of underground tunnel.
2. Safety studies commissioned in each region (Asia /Japan, Americas/US and Europe / CERN) indicate that valid single-tunnel life safety egress strategies can be realised in each of the regional locations studied (allowing for some variations according to local constraints).
3. Recent studies on High Level RF power sources and distribution have resulted in feasible new concepts for these systems that are much more suited to a single-tunnel solution than those proposed in the RDR.
4. Availability studies of the Main Linac using the proposed single-tunnel and new HLRF systems configurations show an acceptable performance can be achieved with appropriate engineering of sub-system designs.

The study of the single-tunnel configuration has lead to two possible novel solutions for the HLRF, namely the Klystron Cluster Scheme (KCS) and the Distributed RF Source (DRFS) scheme. (Both are described in detail in section 3.x.) The relatively different approaches support options for specific sites where local constraints may favour one solution over the other. More detailed discussions of the safety aspects have also emphasised the need to support two or more options where different regional constraints are likely to exist. Allowing such flexibility in the designs (multiple configurations) goes beyond the “generic site” approach used in the RDR. Dealing with the realitites of the requirements of potential national hosts and their proposed host-sites (so-called “bid-to-host”) is an important aspect of the Project Implemention Plan. However, the recognised need to support multiple configurations to maintain flexibility in the number of possible sites must be counterbalanced by finite global design resources: hence the desire to maintain as far as possible a single design in both layout and the core technologies remains paramount, while accepting that cost-effective solutions may differ from site to site.

### 2.2.3 Reduced beam-power parameter set

The proposed baseline change with largest anticipated cost saving (both construction and operation) is the reduction of the beam-power by 50%. The beam-power scales as $N\ n_b$, where N is the single bunch charge, and $n_b$ the number of bunches per pulse. Since the luminosity $L \propto N^2\ n_b$ it is proposed to halve the number of bunches keeping the single bunch intensity the same as that of the 2007 Reference Design. A factor-of-two reduction in $n_b$ allows:

- a reduction in the number of klystrons and modulators (peak current/power reduction), in this case by ~30% over the RDR number;
- the possibility to reduce the circumference of the damping rings by factor-of-two to approximately 3.2 km.

The luminosity can be recovered in general pushing the beam-beam parameters, which – although a potential increase in performance risk – are not considered a major cost driver.

The significant reduction in RF power source together with the smaller damping rings offer a considerable cost-reduction and overall simplification (lower parts count). For the RF power source at least, the option is attractive as it opens up the possibility to restore the “missing klystrons” at a later stage – possible during operations – as a possible luminosity upgrade path. This particular option is attractive since commissioning the machine will almost certainly be at a reduced power while experience is gained. The amount of infrastructure (conventional facilities) included during the construction phase to support this upgrade still requires study and is a matter of cost-optimisation.

However, collective effects in the smaller circumference damping rings (most notably e-cloud) may well be a bottleneck to increasing the number of bunches, and is currently under study (part of the on-going e-cloud R&D programme).

The obvious cost and construction scope benefits for this option must be weighed against a perceived higher risk in achieving the design luminosity due to the more demanding beam-beam parameters. The impact of the higher beamstrahlung on the detectors and physics programme must also be reviewed. Finally, the effective lower beam current reduces the overall RF to beam power efficiency, and so the reduction in average RF power is not a full factor-of-two but closer to 35%.

There has been a conscious decision to not lower (below the current Reference Design) the power handling capability of beam dumps, positron target and capture, etc, and other systems which might be difficult to upgrade later and after some time in operation. Thus technical risk is reduced for these complex, high-radiation components. The benefits of initially over-rating these systems while supporting possible future beam-power upgrade are considered to out-weigh any possible cost saving.

### 2.2.4 Central Region Integration

**コメント [n18]:** You are putting together the proposal #4 and proposal #5. shall we leave it like this? it is mildly confusing to the readers...

The motivation for the Central Region Integration component of the proposed baseline is the simplification of the central region tunneling and civil engineering. By combining functions within a single underground enclosure, the complexity of the underground excavation in the central region can be substantially reduced. Thus a total reduction in tunnel length of xxx is realized and the number of tunnel intersections is reduced by nnn. (Section 3).

The primary modifications compared to the Reference Design are:

- The Damping Rings have been moved vertically into the same plane as the BDS and shifted horizontally to avoid the Detector Hall (see Figure 2.1 right). This removes the need for the long (x.x km) vertically sloping beam tunnel (so-called elevator), which can be replaced by much shorter horizontal transfer tunnels. The Damping Rings tunnel can now also share one shaft with the Detector Hall.

- Since the BDS magnets do not require a large amount of transverse tunnel space, it appears feasible to house the electron source and the 5 GeV injector linac in the same tunnel as the positron BDS, thus removing the need for a separate tunnel.

**コメント [n19]:** We might say somewhere that we do maintain a 416m long drift on the e+ side BDS for bunch collision matching.

- Similarly, the undulator-based positron source and associated 5 GeV booster linac can be more efficiently accommodated at the exit of the main electron linac (electron BDS, see Section 2.2.5 for more details).
- An additional 416 m beam path length is maintained in the positron system for bunch timing.
- Finally, an additional 500 MeV linac can be incorporated into the e+ source region which, when used in conjunction with the e+ source photon target, can be used as an low charge auxillary source for commissioning and tuning etc.

In addition to the simplifications in civil construction and the associated cost saving, the proposed scheme further consolidates sources of high-radiation hazard into the central region, which is considered beneficial when considering environmental impact.

Although a significant simplification in the scope of the civil construction and overall layout, the need to support multiple beamlines and their support infrastructure in a single tunnel is challenging. Availability and operational issues (impact of PPS zoning) needs to be reviewed. Use of 3D-CAD is essential in understanding both the topology of the accelerator beamlines and issues such as installation, safety etc. Initial studies in support of this proposal indicate that acceptable solutions exist.

Because of the multiple beamlines – including the two superconducting 5 GeV booster linacs – it has been initially decided to retain a parallel service tunnel in this region to house the power supplies, klystrons etc. As the 3D-CAD work evolves and becomes more detailes, this will be reviewed and cost-optimised.

### 2.2.5 Changes to the undulator-based e+ source

The motivation for moving the undulator-based positron source from the 150 GeV point to the end (250 GeV) point in the electron Main Linac is primarily to consolidate technical systems and radiation sources as already discussed briefly in Section 2.2.4. However, there are several additional impacts of this particular modification that merit additional attention.

Several “system integration” aspects are direct benefits of moving the source to the end of the Main LInac:

- Machine protection of the undulator is combined with machine protection of the Beam Delivery system, resulting in a net beamline length reduction of about 400 m
- The low energy un-damped positron transport system is shortened by several kilometres.

- The positron source – a high radiation environment – moves within ±2.5 km of the centre of the accelerator complex where other high-radiation sub-systems (the main dumps) are located; this feature which may be advantageous for some potential site, consolidating most of the radiation hazard into a "central campus area".
- The beam-line 'chicane' required in the RDR design to keep the upstream and downstream linacs co-axial can be replaced by a simpler dogleg, and better integrated into the BDS lattice. The energy acceptance 'bottleneck' is also moved to the BDS where there is already a natural bandwidth limit of a few percent; this greatly facilitates beam-based alignment in the linac.

An additional proposed modification, which is independent of the central region integration, is the adoption of a simpler capture magnet (Quarter Wave Transformer, QWT) immediately after the pair-production target. This simpler magnet is clearly feasible, and represents a more concervative (reduced-risk) option in comparison with the Flux Concentrator (FC) assumed in the RDR. However, use of a QWT reduces the capture yield by a factor of 2 when compared to the Flux Concentrator – a difference that must be mitigate by a significantly longer undulator, resulting in higher incident power on the production target. For this reason, the FC is still a very desirable option and continues to be a priority R&D item.

One fundamental ramification of the relocation of the source is the need to run it at varying electron energies, depending on the required centre-of-mass energy. Specifically, the impact on luminosity below centre-of-mass energies of 250-300 GeV, where the positron yield drops rapidly. In this region, double-pulsing schemes can be implemented to regain the luminosity (to within a factor of two) of the $1/\gamma$ scaling value. For detector calibration at the Z pole, the proposed low-charge auxillary source will be sufficient.

At higher energies, the higher-energy electron beam becomes an advantage, offering very large production margins (up to a factor of 5 at 250 GeV), giving further risk reduction at the higher centre-of-mass energies where luminosity is likely to be at a premium. For the same reasons, this opens up the potential for very high-polarised beams at these top-range energies.

Finally, it should be noted that the original RDR concept was based on decelerating the beam at centre-of-mass energies lower than 300 GeV. While conceptual possible, this mode of operation is not without difficulties and still requires careful study.

### 2.2.6 Single Stage bunch compressor (6 mm bunch length)

Adoption of a new lattice for the Damping Rings has reduced the extracted bunch length from the RDR value of 9 mm to 6 mm. (This modification has been implemented both for a 6.7 km ring and the current proposed 3.2 km ring.) The shorter bunch length opens up the possibility to adopt a simpler single-stage compressor with a compression ration of 20, still achieving the nominal RDR value of 0.3 mm at the Interaction Point.

The benefit of this is overall simplification of the compressor system, as well as a saving in cost (mostly tunnel length). Beam dynamics studies have also shown that the emittance degradation is reduced. The disadvantage is the loss of flexibility in bunch length tuning and the ability to reduce the bunch length to 150 μm. These aspects can be seen as reducing the operational risk margin.

**ページ 6: [1] コメント [NW12]　　　Nicholas Walker　　　2009/11/29 18:13:00**

My understanding is that we will stay with 31.5 MV/m for the interim, and that this should be the parameter in the new baseline. We have stated that this parameter will necessarily be continually reviewed as the R&D results are updated. We have also stated that the impact of a gradient change of the order of <=10% to first-order only effects the length of the linac which can be easily scaled. I believe this is the approach we should adopt in this proposal. “To Be Determined” should rather be “Until Further Notice”. All of this things are basically Working Assumptions to get the CFS people going.

**Update:** I still stand by this. See my proposal for the text later in the document.

# 3 Layout

In this section we present an overview of the changes which are considered in the ILC layout. While some of these changes are consequences of the proposed changes in the subsystem designs and are integral part of the SB2009 proposal, some have come about through continuing system design and development prior to the SB2009 re-baseline studies.

Figure 3.1 shows schematic layouts of the ILC as proposed in the Reference Design Report (RDR), and as foreseen today in the SB2009 proposed new baseline.

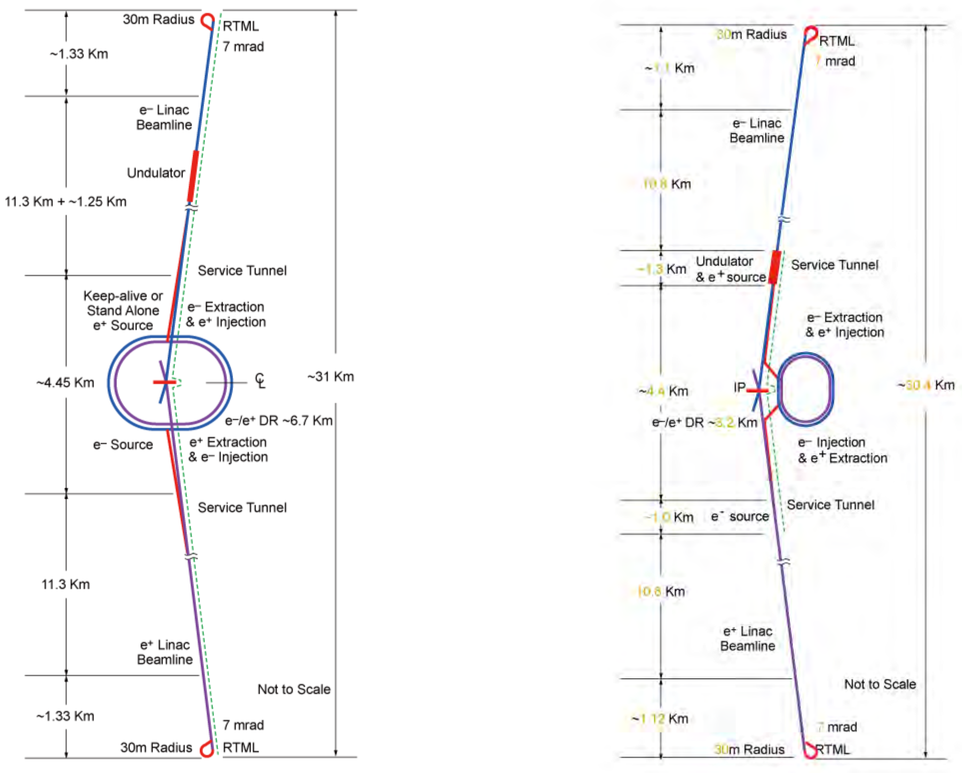


Figure 3.1: Schematic layouts of the ILC as proposed in the Reference Design Report (RDR) on the left, and as foreseen today in the SB2009 proposed new baseline on the right.

The most obvious changes are in the central region, or specifically, the Damping Rings (DRs). Shortly after the publication of the RDR, the circumference of the DR's was changed from 6.7 to 6.4 km to correct a inconsistency between the orbital revolution frequency of the rings and the RF frequencies of the injector buncher systems. This 6.4 km, six-fold symmetric ring design was located around the interaction region and elevated by 10 m above the Beam Delivery systems along with the e- injector and e+ KAS, (keep alive source). This allowed some independence in operation of the injectors and rings from personnel access to the Beam Delivery Systems (BDS).

When considering the detail component layout of the six-fold ring, which has to accommodate RF systems, wigglers, circumference chicanes and injection and extraction systems, a different philosophy was explored. It is a two-fold design 'race track geometry' with long straight sections which included the same systems as in the previous design. The lattice of the arc sections was changed to a new very flexible one, where the emittance and momentum compaction could be separately adjusted. These changes were accepted in 2008 before the SB2009 formal process was begun. For further detail regarding DR component layouts, see Section 4.5.

These changes in geometry stimulated discussions regarding alternate layouts of the central region. Of particular interest are the changes made possible with the race track design, where the beam injection and extraction occur at nearly the same point in the center locations of one of the two long straight sections. Therefore, one can consider a DR to offset horizontally from the BDS and Interaction Region, but in the same plane, with short beam transfer lines between them. This, then, led to discussions of a compact and *efficient* central region, which incorporated all of the E+/- injection systems, DR's, BDS and Interaction Region in a single central campus. The long linac tunnels containing both the main linac and RTML beamlines would then extend outwards in either direction without interruptions. Here, the use of the word *efficient* refers to minimizing the necessary underground volume of tunnels, caverns and shafts.

These ideas were combined with the construction scheme of the main linacs on the basis of the single-tunnel scheme, the Low Power option and Single Stage Bunch Compression into the AD&I Studies and the SB2009 Design.

The single-tunnel linac layout incorporates the proposed single-stage bunch compressor. This single-stage bunch compressor ends up with the beams at ~ 5GeV as opposed to 15 GeV in the two-stage design. However, the changes of the geometry (distance along the beam line) to reach 15 GeV is minimall. The major change is that in the E- linac the total E+ generating system is moved to the central region, and therefore, the E- and E+ linacs are now identical, except for a short extra linac hardware to compensate for the beam energy loss incurred by the use of undulator to produce photons for positron generation. (the 2009 e+ conservative design has ~ 1.5 GeV more loss than the RDR). This means that changes in accelerating gradient, gradient distribution or maximum design energy, are easily accommodated. Changes of gradient of the order of 10% would not require little in the way of fundamental changes in the layout or of infrastructure support from CF&S.

The central region is more complex and more difficult to describe. It is also difficult to display schematically unless a large artificial ratio is used between the longitudinal and transverse scales. Figure 3.2 shows the concept of beam lines which share tunnels in this region and these are included in the real tunnel schematics which can be found at ILC layout diagrams at http://ilc.kek.jp/SB2009/TUNNEL%20DRAWING%20SET%20(11-20-2009).pdf .

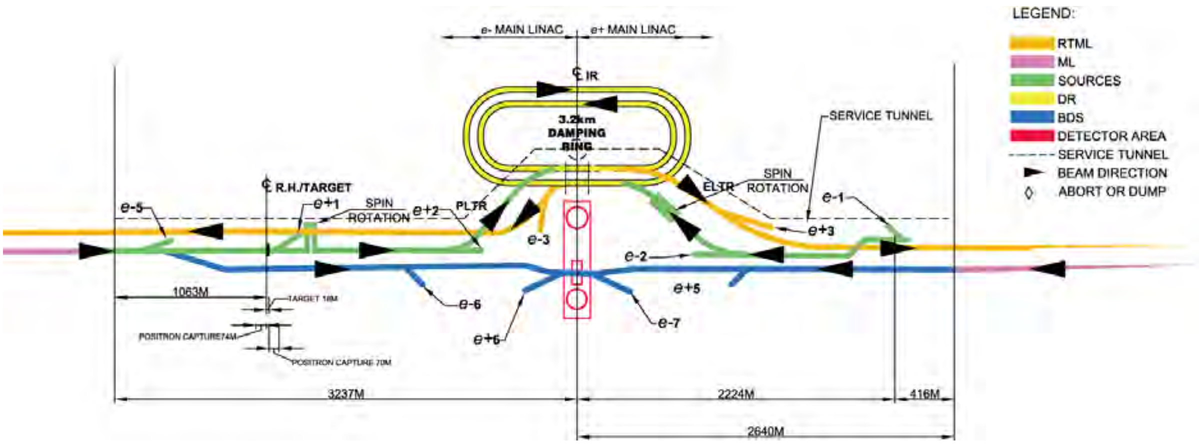


Figure 3.2: Topological diagram of the beamlines in the ILC central area.

Many of the design details and changes of these systems are described in Section 4. The following is a discussion of the general layout and the design philosophy.

The goal was to minimize the underground volume, as stated above, while developing the individual system designs and interfaces with CF&S beyond where they were at the time of the RDR. As the injectors and beam delivery systems which share beam line tunnels, are very varied in there support requirements (power supplies, RF, instrumentation etc), it was decided at an early stage of the studies that there would continue to be a single support tunnel for the central region. This is unlike the linac where each of the ~10+ km linac is comprised of repetitive units each extending over ~30 m. Even in the presence of this support tunnel, there is a reduction of ~5 km out of ~14 km in tunnel length in central region, not including the DR's.

The "Low Power" option, with half the number of bunches, enables, but does not require, a half circumference damping ring. This layout accommodates either of 3.2 or 6.4 km rings. It is because the 1 km straight section, which includes the injection and extraction from both rings, does not change in location or geometry with a change in circumference. The larger ring would have arcs with an increased radius, and again, an almost identical straight section for the RF and wigglers.

Much of the effort to date has been on the region where the E+ production systems and the beam delivery systems co-exist. In the RDR, the E+ production system had to co-exist with the 150 GeV E- beam which after the E+ system continued on to the IR. There were conceptual designs at the time of the RDR, whereas today, the designs now address many more practical engineering issues. For example, there are short sections of tunnel which will need "alcoves". The alcoves will require to implement locally different tunnel cross-sections which are dependant on the local geology. Many of these issues were duplicated in the "Keep alive source" (KAS) in the RDR. The KAS has now been replaced by an "Auxiliary Source", where an E- beam uses the same target, capture, booster systems as the gamma beam from the undulator. In the SB2009 design, now, there is only one vault which is designated to handle high radiation environment. (still to be determined but see below on MPS)

The transition from a linac with a wide acceptance in energy and transverse phase space, to a small acceptance undulator or to a tight BDS requires both protection collimation and abort systems. In SB2009 a single section of collimation and abort system will protect both the undulator and the BDS in an integrated fashion, since the undulator is located at the end of the linac leading into the BDS. This is expected to offer an improvement in day to day operation which is difficult to quantify

The E- injector easily fits into the SB2009 layout, whose geometry choice is primarily determined by the requirements from the E+ injector side. A natural asymmetry in the length of E- and E+ sides is exploited to incorporate a E+/- timing delay drift length which is expected to amount to a few hundred meters. It is highly desirable as stated in the RDR, that one injects into (fills) an empty DR bucket which has just been empted by extraction. This puts constraints on the difference in path lengths travelled by the electrons and positrons through the RTMLs, linacs and BDS's and the DR circumference. At the time of the RDR, while this issue was well known, a fully worked-out beamline implementation solution was not presented, because with that layout and 6.4 km DR's the path length correction had to be kilometers. In the SB2009 layout and with the 3.2 km rings, this correction can now be a few hundred meters.

There are other examples where the SB2009 designs and layouts are more complete and detailed than the RDR. This is due to both the continuing design work over the time since the RDR but also driven by the AD&I studies of the SB2009 proposal. In some places this complicates comparisons. The detail system designs and their pro's and con's are based on these layouts and are discussed in detail in the following sections. Figure 3.3 shows the overall schematic machine layout and Figure 3.45 gives the schematic directional beamline layout.

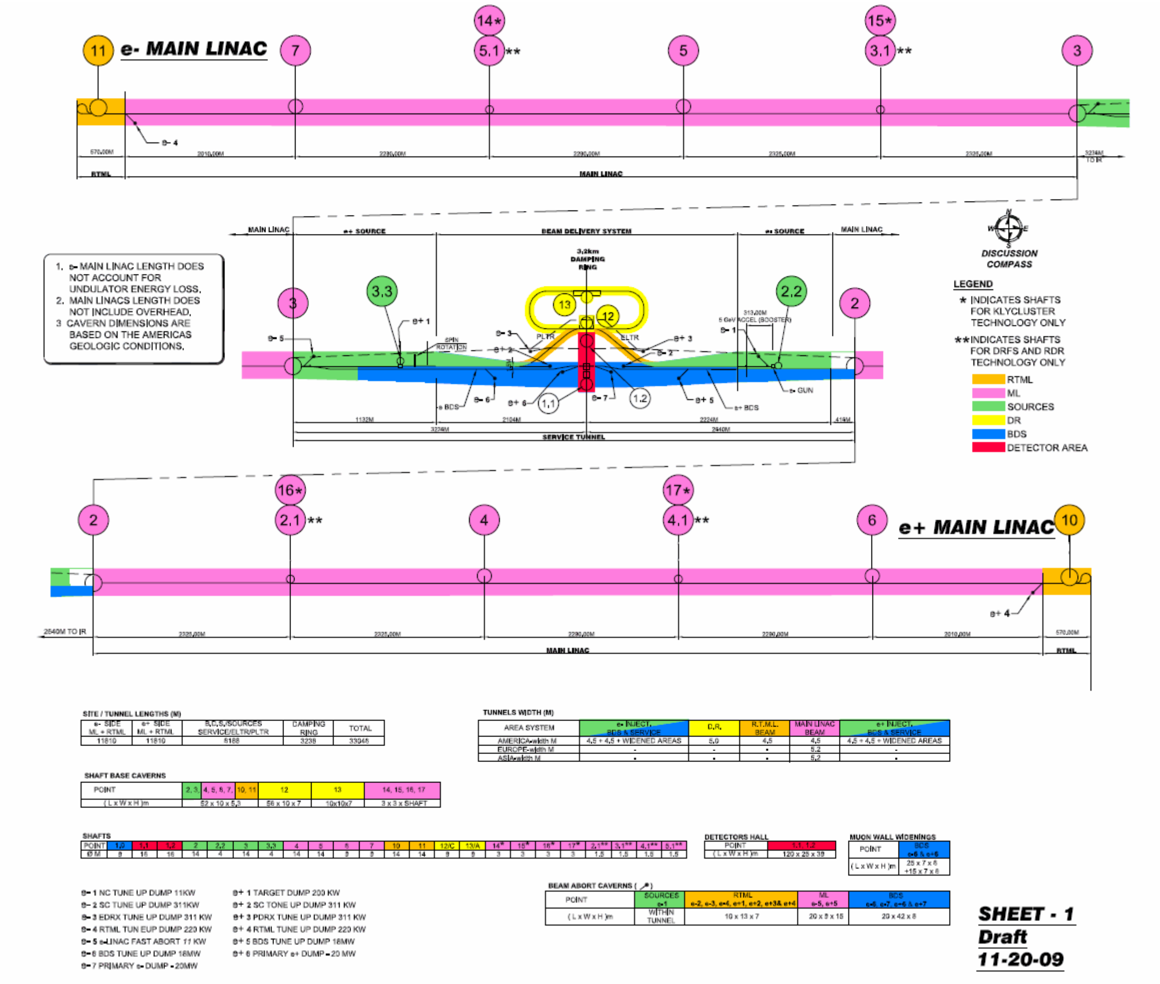


Figure 3.3: Overall Schematic Machine Layout

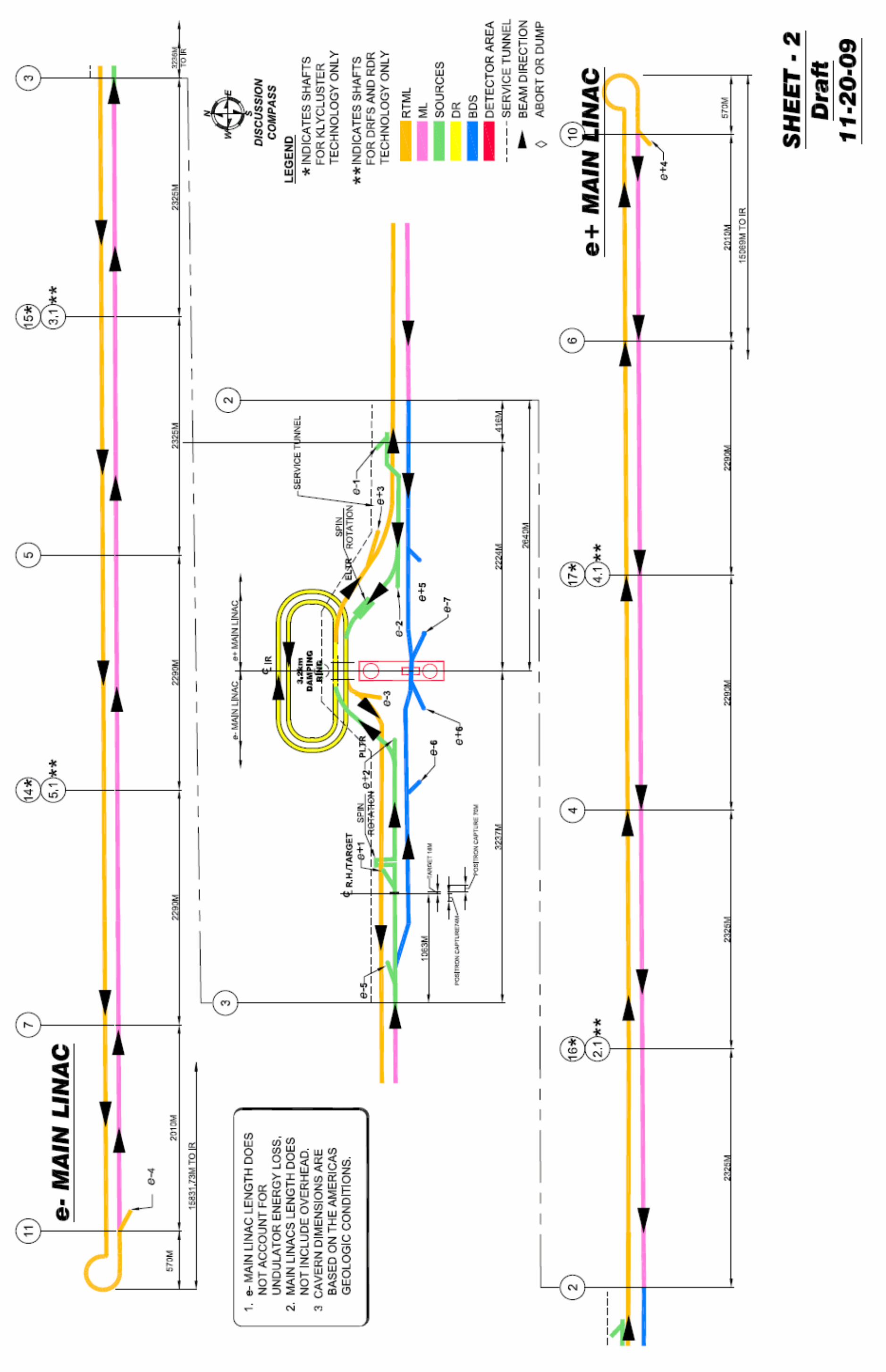


Figure 3.4: Schematic Directional Beamline Layout

# 4 SB2009 Proposal

## *4.1 Issues of Main Linac Accelerating Field*

### 4.1.1 Status of Cavity Field Gradient:

In 2005, the performance goal for each of the 9-cell cavities to use at ILC main linacs was defined as ≥35 MV/m with $Q_0 \geq 8 \times 10^9$ in low-power vertical acceptance tests, so as to ensure an average accelerating gradient of 31.5 MV/m with $Q_0 \geq 1^{10}$ in cavities installed in horinzontal cryomodules. The world-wide R&D effort ensued with these goals. This R&D is currently still ongoing, and it represents the largest fraction of the global ILC R&D effort.

As part of the TD Phase-1 baseline review and subsequent re-baselining effort (including SB2009 proposal), it was agreed appropriate to review the choice of accelerating gradient, in the light of present and prospective outcome from the R&D programs, together with the specific system implemenations and operational models of the main linacs. The total number of 9-cell cavities processed and RF tested in TDP-1 is expected to reach xxx for gradient yield evaluation. One of the critical exercises, therefore, is to catalogue and analyse the production statistics of the 9-cell cavities and their performance by putting together all the available data from all three regions in a scientifically consistent fashion.

**コメント [RG1]:** It seems to me we need to give the expected number of processed and tested 9-cell cavities in TDP-1.

For this purpose, as reported in the ILC Newlines (July 31, 200), a new taskforce was commissioned to to create a global database for ILC cavity test results. This task force, under supervision of the ML-SCRF Cavity Technical Area Group Leader, Rongli Geng (JLab), is led by Camille Ginsburg (Fermilab) and includes the following members: Sebastian Aderhold (DESY), Zack Conway (Cornell), and Yasuchika Yamamoto (KEK).

The mandate of this taskforce team is to:

1. Collect and verify the global cavity R&D information;
2. Create and maintain a global database for the ILC-related cavity performance;
3. Analyse the database to understand the global progress in improving cavity performance;
4. Assist the Project Managers through analysis of these results and in re-evaluation and projection of future cavity performance during TDP-II and the future production phase.

It is critically important to understand the performance yields of SCRF cavities and our progress on the field gradient with a global perspective. This is so as to help develop suitable models in the years to come that describe our technical and scientific outlook. The team produced an interim, progress report to us at the Linear Collider Workshop of the Americas (ALCPG) and GDE meeting held in Albuquerque, New Mexico in the fall of 2009. Figure 4.1.1 shows the status summary as given by the team, including the cavity gradient performances in the first and second pass including the chemical process and cold vertical tests for the cavities manufactured by well experienced/established venders (ACCEL/RI and Zanon) and processed and tested by DESY and JLab. An updated version is expected shortly to reflect the rapid progress made in cavity processing at ANL/FNAL and KEK and cavity manufacturing at new vendors, such as AES and MHI. The global yield evaluation is expected to include more cavities for improved statistics at the end of TDP-1.

**コメント [RG2]:** It is worthwhile to mention number of cavities manufactured by these established vendors for TTF and FLASH and the coming XFEL to give a sense of the industrial experience in 9-cell production. We need comments from DESY.

**削除:** It shows

**コメント [RG3]:** I believe this is the intend of the discussion at SRF09.

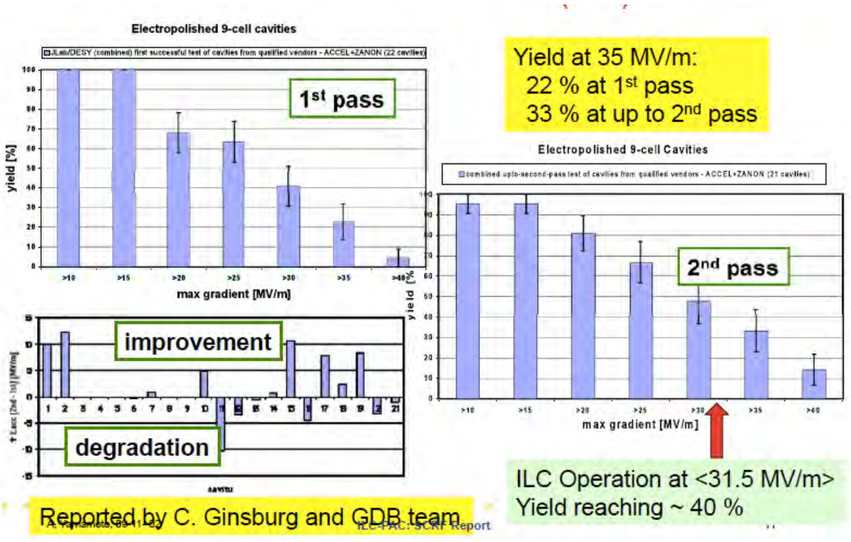


Figure 4.1.1: New production yield after the 1st and 2nd Pass process and vertical test (with low power RF), with available data, July 2009

The expected production cavity gradient and yield are two of the most important parameters in the ML-SCRF technical area to be provided in the evaluation process, as well as in the the studies of the overall construction cost and plans in relationship with the Conventional Facilities & Siting Group and Accelerator System areas. This calls for a detailed yield scatter analysis to understand the incremental cost of acceptable gradient variability. Thanks very much to the team members for their efforts to create the global database system that we can use to provide this input in a clear and well-documented manner. (Further description is to be added, after receiving the status report by the team in the DESY meeting to be held on Dec. 2-3, 2009. Thanks in advance for further input by Camille and her team).

**コメント [RG4]:**

**コメント [n5]:** this subparagraph will be replaced soon after the DESY face-to-face, I guess.

### 4.1.2 Issues of Main Linac System Design

In conjunction with the (GDE and AAP) review process in 2010, we propose an operational accelerating gradient to be kept at <31.5 MV/m> in the SB2009 draft, as of today (Dec. 2, 2009) to be discussed in the DESY meeting (Dec. 2-3) for very cautious discussion for such critically major parameter. We would also need to call for your attention, however, to re-evaluate the operational field gradient and to prepare for the number, in well advance to the production phase. It should be reasonably lower than 31.5 MV/m including dynamic tuning and practical operational margin for the long-term stability and with realizing sufficiently high availability of the cavity performance itself (as the most fundamental term for the accelerator system operation and availability), thus adjusting the global CFS requirements including linac length, RF, and cryogenic requirements from the parameters given in the RDR.

One of the issues to pursue during TDP2 is a more systematic survey of how the system design would deal with variations of the cavity performance, namely the gradient limit and the Q value. For sake of cost-effective RF power system, more than a few cavities (26 in case of RDR, 4 or 8 in case of DRFS and ~400 in case of KCS) are driven by a unit RF source. In order to ensure a good flattop time characateritics for acceleration of multibunch beams over 1ms, as detailed in RDR, a vector-sum technique is deployed in the low-level RF (LLRF) system to control the phase and amplide of the klystron drive. Development of this vector sum technique has been pioneered by  FLASH at DESY, and its working performance has been demonstrated there as well as at KEK.

The vector-sum technique has a flexibility in the sense that even if the individual cavities have substantial performance variations, the system can produce a desired flattop by monitoring the vector sum signals from the grouped cavity set in question and controlling the RF drive accordingly. An issue, however, is that unless the fractional power to be delievered to the cavities are  individually adjusted, the average field gradient to achieve would be generally limited by the lowest-performing cavity. Another issue, is that some of the cavities during the RF pulse could approach the gradient limit, unless some protective measures are taken, since it is the vector sum that is controlled to be "flat", not the invidivual time patterns of the individual cavities.

It is noted that adjustment work of the power distribution system to match the invididual cavities is certainly technically possible. However, the cost associated with this tuning work during installation or during commissioning has to be uderstood and be accounted for. It is also noted that the magnitude of this type of "tuning" work will depend on multiple elements, such as the specific number of cavities to be driven by a single RF source, the power distribution scheme, and the average performance of the cavities, its variation and the accelerating gradient to achieve in regular operation.

Generally speaking, lowering the accelerating gradient to achieve in regular operation will make the system implementation easier and more reliable. Or, setting a higher field goal during cavity vertical testing for their performance validation would make the system more reliable. Likewise, introducing an advanced tunability in the power distribution system would allow more efficient use of cavities with varying performance characteristics. However, all such measures would push the project cost higher.

**コメント [n6]:** this is a good "call for opinions" toward the DESY face-to-face, but is not something to maintain in our SB2009 proposal document.

**コメント [n7]:** In blue is Toge's attempt at expressing what I think Yamamoto wants to say, without expressly stating "we will re-examine the field gradient spec and possibly lower it etc". I am not adjusting its matching w.r.t the downstream text yet.

The strategy we propose to take is while maintaining the R&D goals for the cavity performance as unchanged as stated in 4.1.1, we also vigorously analyze this issue of linac system implementation in combination with the anticipated cavity performance variation and cost differentials associated with various possible solutions during TDP2.

We propose further that the HLRF systems support a spread of operational gradients from cavity to cavity. This allows lower performance cavities to be utilised, assuming that high-performing ones maintain the average. This approach has impact on both the definition of cavity production yield and acceptance criteria, which is currently being evaluated by the global R&D groups. Currently every indication is that this will provide a better cost optimised system, albeit at the expense of a more complex HLRF distribution system and lower overall RF-to-beam power efficiency.

The exact amount of RF power and gradient overhead required for operational margin (for tuning, and dynamic variation of the power distribution, such as in case of a quench) remains to be determined. The FLASH beam test with a prototype cryomodule operation will give us further details.

The current SB2009 working assumption for the accelerating gradient is to require the HLRF/LLRF and CFS groups to extend their study necessary adjustment of their design parameters and cost plans. It is assumed that any subsequent, further change in accelerating gradient arising from review of the R&D status will to first-order result in a scaling of the main linac length which is relatively straight-forward, and will not require major re-evaluation of the design. (This is based on an assumption that the choice of gradient is unlikely to change by more than the order of 10 %). We will investigate also assumption of the cost with the usable cavity fraction of 80 % (125 % in order to get 100 %) in RDR, and it may be improved to be a level of 90 % including all effects described above. It may help us intending to keep overall cost for ML-SCRF to remain within the value estimate in RDR.

**コメント [RG8]:** Am I right that the SB2009 focuses on 500 GeV layout and will not discuss possible energy upgrade scenario?

Table 4.1.1 summarizes the status of the field gradient milestone being taken in the TDP phase 1, and the necessary study and discussion in our further process.

Table 4.1.1: Milestones for the SCRF R&D Program (see: TDP R&D plan, V. 4, July 2009).

| R&D Goals in TD Phase 1 and 2 (given in TDP R&D plan) | |
|---|---|
| High-gradient cavity performance at 35 MV/m according to the specified chemical process with a process yield of 50% in TDP1, and with a production yield of 90% in TDP2 (S0) | 2010<br>2012 |
| Cavity-string performance in one cryomodule with the average gradient 31.5 MV based on a global effort (S1 and S1-global) | 2010 |

**コメント [MCR9]:** Since rel.2 – we have separated process-yield and full fab-yield. That should be indicated here.

| | |
|---|---|
| Cryomodule-string performance achieving the average gradient 31.5 MV/m with full-beam loading and handling (S2) | 2012 |
| Operational Gradient for the ILC ML, in the Project Phase (added to be discussed) | |
| (> 1,000) Cryomodule-string performance to be stably operated with sufficiently high availability, including dynamic tuning and operational margin and with sufficient redundancy,<br>Operational gradient to be ?? (S3?, can it be the same as S1 and S2?) | To be well discussed in advance to TDP-2 |

## *4.2 Electron Source*

### 4.2.1 Overview:

The proposed changes in the SB2009 design have two notable implications to the electron source system:

- The low-P parameter set, which is the proposed baseline, increases the bunch spacing by a factor ~2. Increased bunch spacing will reduce the challenges for the source drive laser system, due to more favorable population inversion dynamics in the Ti:Sapphire laser medium.
- Change in the damping ring design, combined with the revised layout of the central injector complex (shown in Figure 4.2.1), will affect geometry of the transport lines, including their lengths.

However, at the level of subsystem design, the ILC SB 2009 results in *no fundamental changes to the polarized electron source*. The source parameters are essentially the same. They are summarized in the Table 4.2.1. The fundamentals of the laser system design would also remain essentially the same.

Table 4.2.1: Source parameters

| **Parameter** | **Symbol** | **Value** | **Unit** | **Comments** |
|---|---|---|---|---|
| Electrons per bunch (at gun exit) | $n_e$ | $4*10^{10}$ | Number | Same as RDR |
| Electrons per bunch (at DR injection) | $n_e$ | $2*10^{10}$ | Number | Same as RDR |
| *Number of bunches* | $N_e$ | *~ 1312 (was ~2625 in RDR)* | *Number* | *Low-P parameter; new baseline* |
| bunch repetition rate | $F_{\mu b}$ | 1.5 (was 3 in RDR) | MHz | *Low-P prameter; new baseline* |
| bunch train repetition rate | $F_{mb}$ | 5 | Hz | Same as RDR |
| bunch length at source | $\Delta t$ | ~ 1ns | ns | Same as RDR |
| Peak current in bunch at source | $I_{avg}$ | 3.2 | A | Same as RDR |
| Energy stability | S | < 5 | % rms | Same as RDR |
| Polarization | Pe | 80 (min) | % | Same as RDR |
| Photocathode Quantum Efficiency | QE | 0.5 | % | Same as RDR |
| Drive laser wavelength | $\Lambda$ | 780-810 (tunable) | nm | Same as RDR |
| single bunch laser energy | E | 5 | μJ | Same as RDR |

### 4.2.2 Design Work to Pursue during TDP2

It should be pointed out that further optimization would be needed in the beamline design during TDP2. For instance, for the finalized tunnel design, a re-optimization of the electron source transport lattice is required. One critical item to note is the maintenance and control of spin polarization. Correct bend angles and arc radii for most transport lines have to be established . The resultant constraints have to be an integral part ofthe overall design of the central region, including the Source, RTML and BDS.

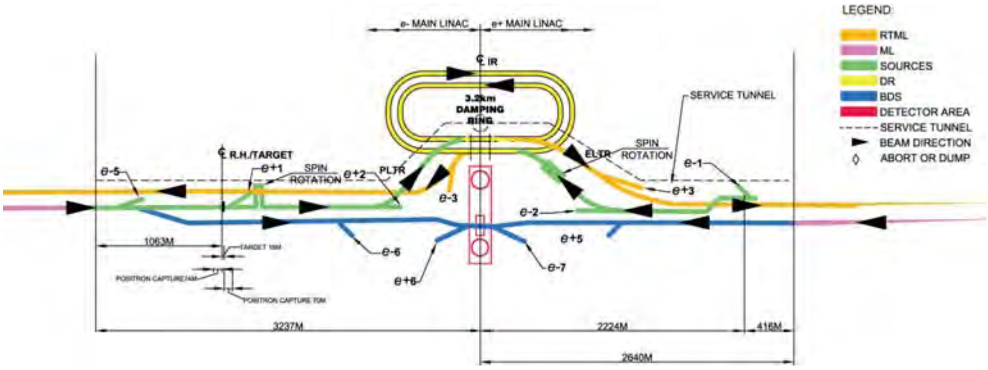


Figure 4.2.1: Layout of the central region

Recently, a new option for the electron spin rotation from longitudinal to transverse has been discussed (Figure 4.2.2). The proposal is to use a Wien filter, to be introduced immediately downstream of the electron gun. The Wien filter would replace the two spin rotating superconducting solenoids in the electron to ring transfer line. This would result in a small cost saving for the electron source. However, an additional drift space is required in a neighborhood of the gun. It is desirable to keep a short as possible drift length from the electron gun to the subharmonic buncher system, so as to reduce the growth of longitudinal emittance due to space charge inherent to the electron at the design gun energy. Further simulations are needed to verify the feasibility of this option, and this work is expected to conitnue during TDP2.

**コメント [n1]:** Could you quote a reference for this?

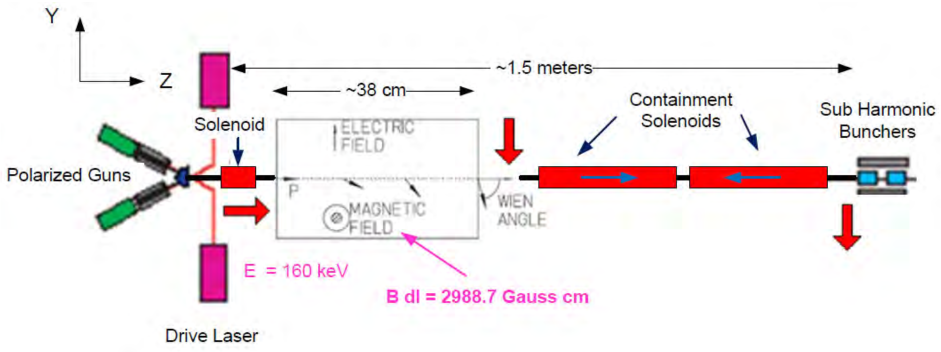


Figure 4.2.2: Schematic view of Wien filter proposal

### 4.2.3 R&D Work to Pursue during TDP2

コメント [n2]: Could you fill in a bit more substances here?

We intend to continue the current R&D programs into TDP2:

- Laser System development
- Gun Development
- Photocathode development

These three focus areas are needed to demonstrate an ILC beam according to the source parameters. Most serious unknown issue is the cathodes surface charge limit (SCL) under operational conditions at the ILC. To the first order, the laser system is needed in combination with the existing SLC polarized gun to determine if the SCL requires further cathode development work is needed. It is anticipated to demonstrate the source system with a higher voltage gun currently under development.

コメント [n3]: These two lines are a bit difficult to understand for uninitiated. Can you elaborate, or can you quote a ref to look up?

### 4.2.4 Summary

The fundamental design of the polarized electron source remains largely identical to the RDR design. Minor changes are due to the low-P parameter set, which will reduce some technical challenges for the laser system. Layout changes of the central region will require a relatively minor effort in beam line redesign work. A low energy spin rotation option is currently proposed and its feasibility will be investigated in the future.

コメント [n4]: Does this mean a specific change to the hardware design or does it only consitute revision of the operating parameter and the R&D goal? Could you clarify?

## *4.3 Positron Source*

### 4.3.1 Overview

In addition to changes in some aspects of the beam parameters, the SB2009 proposes some major changes to the system implementation of the undulator-based positron source at the ILC:

- **Relocation of the undulator:** The new machine layout relocates the undulator from the 150GeV energy point in the main electron linac to its end. This means that the energy of the electron beam passing though the undulator will no longer be fixed, and it has some implications for the positron source performance. This issue is discussed more, together with the proposed solution, in the latter part of this section.

- **Adoption of a simpler capture magnet (Quarter Wave Transformer, QWT):** The QWT would be implemented immediately after the pair-production target. This magnet is technically simpler and more feasible than the flux concentrator that was previously considered during RDR. Therefore, this change contributes positively to reduction of the overall technical risk of the system. This is accomplished at the cost of reduced positron capture, however, and a subsequent increase in the the undulator length is introduced to make up for the loss. Our strategy is to maintain the QWT-based scheme as the baseline, while continuing the R&D effort on the flux contcentrator. The flux concentrator may be adopted again in the future, once a feasible design has been established.

- **Removal of an independent Keep Alive source:** The positron Keep Alive Source in the RDR was based on an *independent* 500MeV electron drive beam, target, capture RF, remote handling, etc. In the proposed new baseline, an Auxiliary Source will be constructed instead by making use of a 500MeV electron drive beam but while sharing the same target, capture RF, etc as the undulator based source. It is this Auxiliary Source that would be used in the commissioning or system check-out purposes for the downstream positron systems such as the positron damping ring, the positron RTML and the positron main linac.

The pertinent parameters for the SB2009 positron source system are summarized and compared with the RDR in Table 4.3.1.

Table 4.3.1: Comparison of the RDR and SB2009 positron source parameters

| Parameter | RDR | SB2009 | Units |
|---|---|---|---|
| Positrons per bunch at the IP | 2 x $10^{10}$ | 1 to 2 x $10^{10}$ (see Figure 4.3.2 for details) | |
| Bunches per pulse | 2625 | 1312 | |
| Pulse repetition rate | 5 | 5 (125 to 250GeV)<br>2.5 (50 to 125GeV) | Hz |
| Positron energy (DR Injection) | 5 | 5 | GeV |
| DR transverse acceptance | 0.09 | 0.09 | m-rad |
| DR energy acceptance | ±0.5 | ±0.5 | % |
| Electron drive beam energy | 150 | 125 to 250 | GeV |
| Electron energy loss in undulator | 3.01 | 0.5 to 4.9 (see Figure 4.3.5 for details) | GeV |
| Undulator period | 11.5 | 11.5 | mm |
| Undulator strength | 0.92 | 0.92 | |
| Active undulator length | 147 (210 after polarisation upgrade) | 231 (maximum, not all used when >150GeV) | m |
| Field on axis | 0.86 | 0.86 | T |
| Beam aperture | 5.85 | 5.85 | mm |
| Photon Energy (1st harmonic) | 10 | 1.1 (50 GeV) to 28 (250 GeV) | MeV |
| Photon beam power | 131 | 102 at 150 GeV (less at all other energies) | kW |
| Target material | Ti – 6%Al – 4%V | Ti – 6%Al – 4%V | |
| Target thickness | 14 | 14 | mm |
| Target power adsorption | 8 | 8 | % |

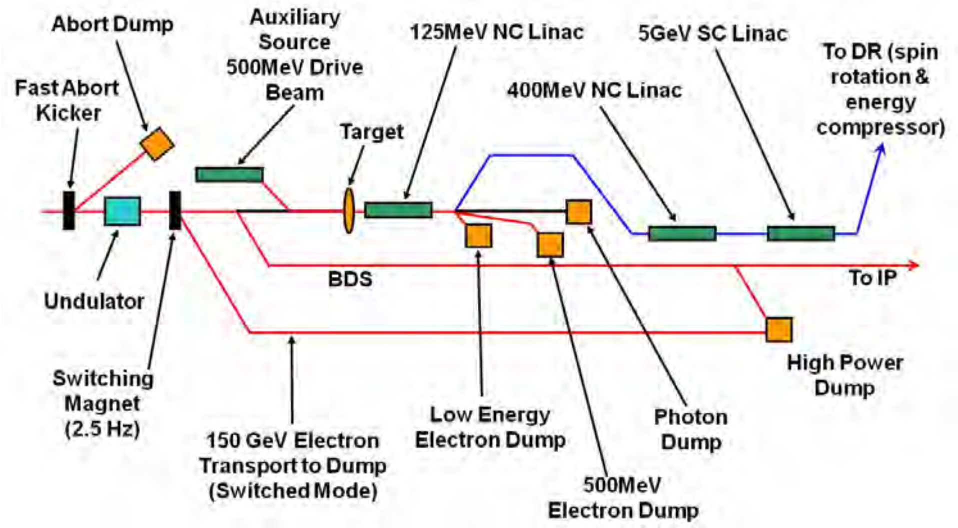


Figure 4.3.1: Conceptual layout of the positron source region. The electron beam is travelling from left to right. Red lines indicate electrons, blue lines indicate positrons and black lines indicate photons.

### 4.3.2 Positron Yield and Operational Scheme for Low Energy

The main issue with the SB2009 positron source is the yield variation as a function of electron beam energy.

Figure 4.3.2 shows how the yield varies for the RDR undulator parameters (0.86T on-axis field and 11.5mm period) as the electron energy changes. The design yield is 1.5 (i.e. 1.5 positrons will be available within the damping ring acceptance at 5GeV for every electron that passes through the undulator). This is the number that is achieved at 150GeV with a 147m long undulator. In the SB2009 an undulator length of 231m is required instead of 147m for the RDR, so as to compensate for the reduced positron capture with the quater wave transformer.

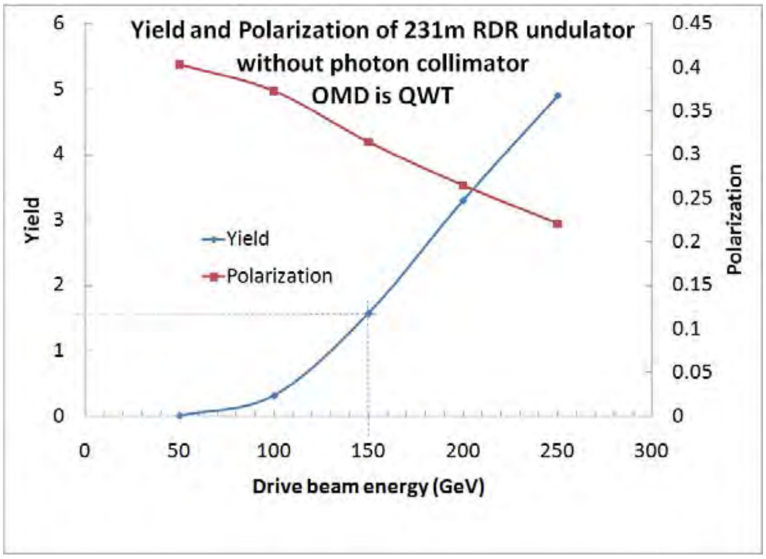


Figure 4.3.2: The positron yield vs electron energy in the RDR positron system.

Figure 4.3.2 indicates that as the electron energy increases beyond 150GeV, the yield increases quite significantly, reaching a value of 4.9 at 250 GeV. In such cases, in practice, some sections of the undulator would be switched off in order to bring the yield back towards 1.5. On the other hand, as the electron energy reduces below 150GeV the yield drops, reaching 0.75 at 125GeV. At this energy there will only be 1 x $10^{10}$ positrons per bunch at the IP instead of 2 x $10^{10}$ as at all energies above 150GeV.

The solution proposed for this issue of lower-energy operation is as follows. At beam energies of 125GeV and below the operation of the ILC will be configured, such that alternate macropulses (this corresponds to one train of 1312 bunches over 970ms) will either be transported to the IP or be used to generate positrons. This will be achieved by accelerating alternate macropulses to different energies. One macropulse will operate at 150GeV and will generate positrons as normal. Then the next macropulse will be accelerated to the low energy required at the IP and will not be used to generate positrons. With this pulse switching scheme the number of positrons available at the IP will be 2 x $10^{10}$ per bunch but the macropulse rate will effectively be 2.5 Hz.

The implementation of this pulse switching scheme will mean that pulsed steering magnets will be required to ensure that both beams pass through the electron linac and undulator correctly. Additionally, a new transport line for the high energy beam will be required to carry the electrons at 150GeV from the exit of the undulator to the electron BDS tune-up dump. The number of positrons at the IP from the SB2009 as a function of electron energy is summarised in Figure 4.3.2, to be compared with the result for the RDR (Figure 4.3.4).

The electrons will lose energy as they travel through the undulator and emit synchrotron radiation. This energy loss needs to be compensated for by the upstream main electron linac. Figure 4.3.5 shows how the energy loss varies with the electron energy.

A second consequence of the emission of synchrotron radiation is an increase in the energy spread of the electron bunch. Figure 4.3.6 illustrates how the relative energy spread changes with electron energy for the RDR and SB2009 cases. The RDR case assumes a relative energy spread of 1.5% at 15 GeV (at the entrance to the main linac) and the SB2009 case assumes a relative energy spread of 1.08%.

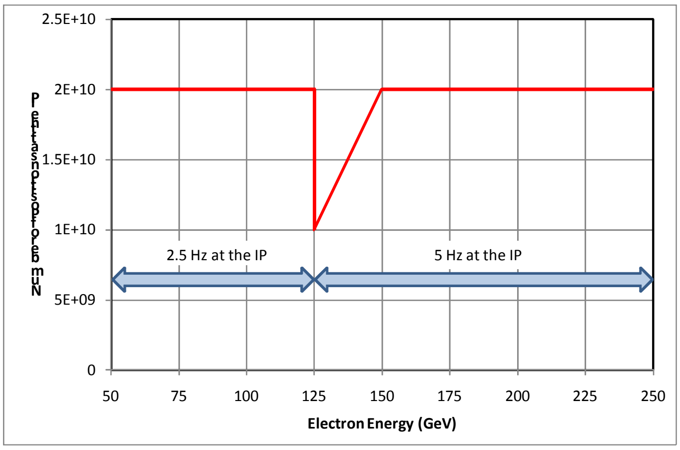


Figure 4.3.2: Number of positrons at the IP vs electron energy for the SB2009 scheme

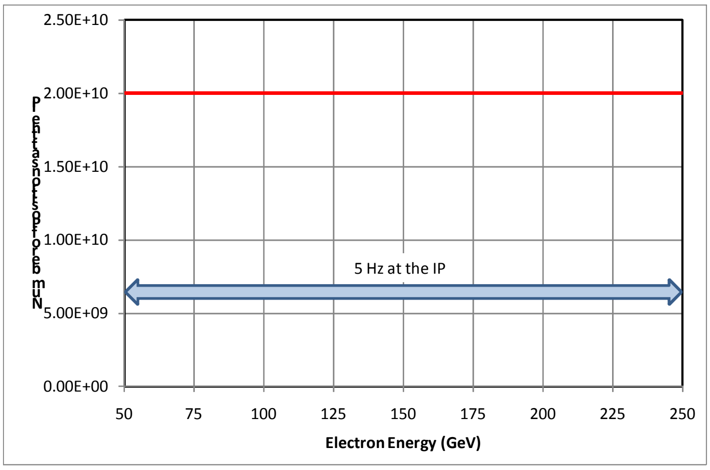


Figure 4.3.4: Number of positrons at the IP vs electron energy for the RDR scheme

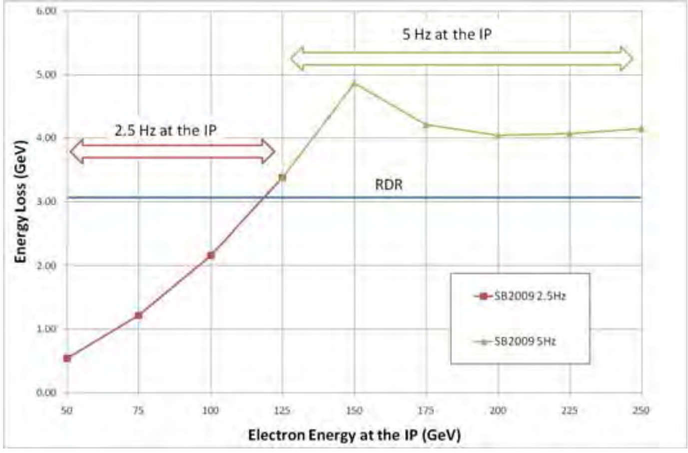


Figure 4.3.5: Energy loss due to emission of SR in the undulator vs electron energy

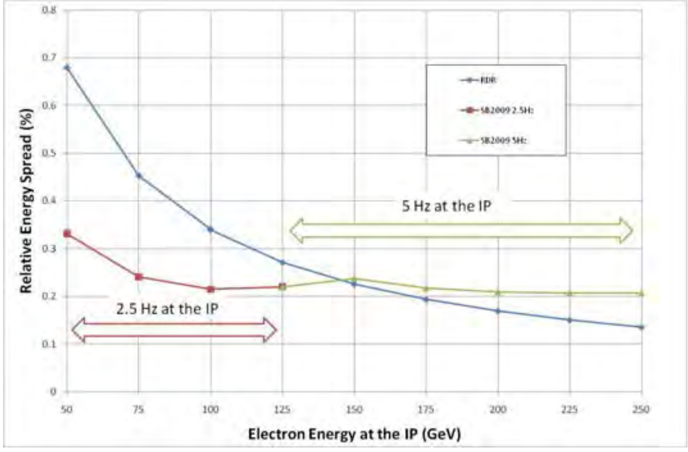


Figure 4.3.6: Relative energy spread for the electron beam vs electron energy

### 4.3.3 Polarized Positrons

Generation of polarised positrons is not part of the baseline solution. However it is a required upgrade. Nevertheless, the RDR baseline generates 34% positron polarisation which will be of benefit to the physics programme.

In the SB2009, polarised positrons will also be generated but the rate of polarisation will vary with energy, as shown in Figure 4.3.7. The upgrade path to the desired 60% polarisation level is to either -

- Install an extra ~200m of undulator and to then use collimation to remove the photons with the wrong polarisation characteristics, or

- Rely upon the development of the flux concentrator which increases the capture so much that it is equivalent to the installation of extra undulator length.

The latter scheme of changing the capture magnet for a more efficient device is the presently assumed option. The exact polarization level that will be achieved with this option has not yet been evaluated as function of electron energy.

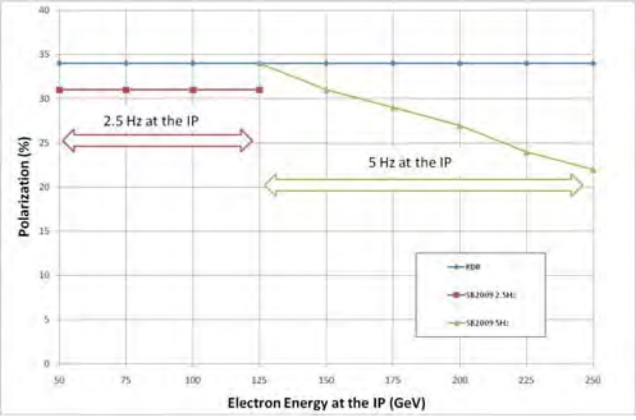


Figure 4.3.7: Positron polarisation vs electron energy for the RDR and SB2009 in the baseline configuration. Much higher polarisation levels are achievable in both layouts following a simple upgrade of the positron source.

### 4.3.4 R&D and Design Work to Pursue during TDP2

Main areas of work to pursue during TDP2 with the ILC positron system include the following five:

- Target system R&D
- Undulator magnets
- Flux concentrator
- Remote handling
- Engineering integration

The main area of risk for the SB2009 is with the target. The adoption of the QWT increases the length of the undulator and this enhances the peak photon beam power on the target. Fortunately the reduction in the number of bunches by a factor of two reduces the average power on the target.

Nevertheless, a number of issues still remain to be resolved and the solutions be validated. They include: the pressure shock wave impact to be confirmed as reasonable, the eddy current effect to be simulated (an experiment is ongoing to confirm this), and the rotating vacuum seals to be confirmed suitable. Another important issue which needs careful assessment is the performance of the target when it is used as the Auxiliary Source in conjunction with a 500MeV electron beam.

Another area requiring study is the performance of the positron source with realistic undulator magnets. Now that two full length undulators have been constructed and tested [J Rochford et al, PAC 2009], it is possible to evaluate the actual spectral output from these devices. A simulation is required of a 230m long undulator with the level of errors measured. This is so as to determine how the trajectory wander and phase error will impact on the positron yield and polarisation output. The full-scale undulator cryomodule should still be used in electron beam tests to check for unexpected issues, such as vessel heating or emittance growth.

Since the best route to polarised positrons is through the flux concentrator, this device should continue to be studied. A feasible solution is still to be generated, although the latest findings are encouraging. A prototype demonstration will be necessary. Even better capture efficiency will be possible with a liquid lithium lens system. Studies of such a device have been carried out and these should be continued as the rewards of a working system would be significant.

The remote handling region will be an important part of the positron source. This will contain the upstream collimator, target, QWT, and capture linacs. The shielding thickness has been assessed and the present assumption of 1m appears to be more than adequate providing the correct grade of concrete is used. The remote handling unit still needs careful design and the operating scenarios need to be assessed in more detail.

The engineering integration of the positron source with the BDS and RTML in particular has started. It needs to draw more attention during TDP2. The additional dump line (for the 150GeV electron beam) due to the pulse switching mode during low energy operation (below 125GeV) needs to be added and similarly a dump line for the 500MeV electron drive beam for the Auxiliary Source also needs to be added.

Finally, during TDP2, some alternative approach to the positron system design will also be pursued, such as the use of liquid lead target or a hybrid target system utilizing the photon channelling technique.

# *4.4 Damping Rings*

## 4.4.1 Overview

The Low Power option, with a factor of two reduction in the number of bunches, allows a corresponding factor of two reduction in the circumference of the damping rings, leading to a major cost saving. Thus, the SB2009 proposal includes a new damping ring design.

This section describes the proposed new design for the damping rings with the circumference of 3.2km with a racetrack shape [1]. Following the publication of RDR which assumed 6.7km rings with roughly hexagonal shapes, in discussion at GDE meeting (TILC08) [2,3], a racetrack ring shape was adopted with 6.4 km circumference and a different arc lattice. The main reason for this choice was tunnel simplification and reduction of the number of shafts and caverns in order to improve operational efficiency and reduce costs. The difference between the new 6.4km arc lattice and the RDR one has been driven by the decision of reducing the rms length of the bunches from 9mm to 6mm. This reduction has major benefits for the bunch compressors downstream of the damping rings. To achieve a shorter bunch length, for fixed RF voltage and frequency, a lattice with a smaller and flexibly adjustable momentum compaction factor has been chosen [4]

Aside from the reduced circumference the fundamental technical design and implementation of the damping rings remain the same as or similar to previous designs. For instance, the bunch separation and the number of particles per bunch remain the same, and the beam current in the ring is the same. Therefore, we expect similar overall performance from the beam optics or beam dynamics viewpoint. Table 4.4.1 summarizes the pertinent parameters for the new damping ring design in comparison with both the RDR and the TILC08 version of the design. 4.4

Table 4.4.1: Parameter list for the 6.4km damping ring adopted for the RDR and for the SB2009 3.2 km ring.

| | RDR | TILC08 | SB2009 |
|---|---:|---:|---:|
| Circumference (m) | 6695 | 6476 | 3238 |
| Energy (GeV) | 5 | 5 | 5 |
| Bunch number | 2625 | 2610 | 1305 |
| N particles/bunch | $2\times10^{10}$ | $2\times10^{10}$ | $2\times10^{10}$ |
| Damping time $\tau_x$ (ms) | 25.7 | 21 | 24 |
| Emittance $\varepsilon_x$ (nm) | 0.51 | 0.48 | 0.53 |
| Emittance $\varepsilon_y$ (pm) | 2 | 2 | 2 |
| Momentum compaction | $4.2\times10^{-4}$ | $1.7\times10^{-4}$ | $1.3\times10^{-4}$ |
| Energy loss/turn (MeV) | 8.7 | 10.3 | 4.4 |
| Energy spread | $1.3\times10^{-3}$ | $1.3\times10^{-3}$ | $1.2\times10^{-3}$ |
| Bunch length (mm) | 9 | 6 | 6 |
| RF Voltage (MV) | 24 | 21 | 7.5 |
| RF frequency (MHz) | 650 | 650 | 650 |
| B wiggler (T) | 1.67 | 1.6 | 1.6 |
| Lwig total | 200 | 216 | 78 |
| Number of wigglers | 80 | 88 | 32 |

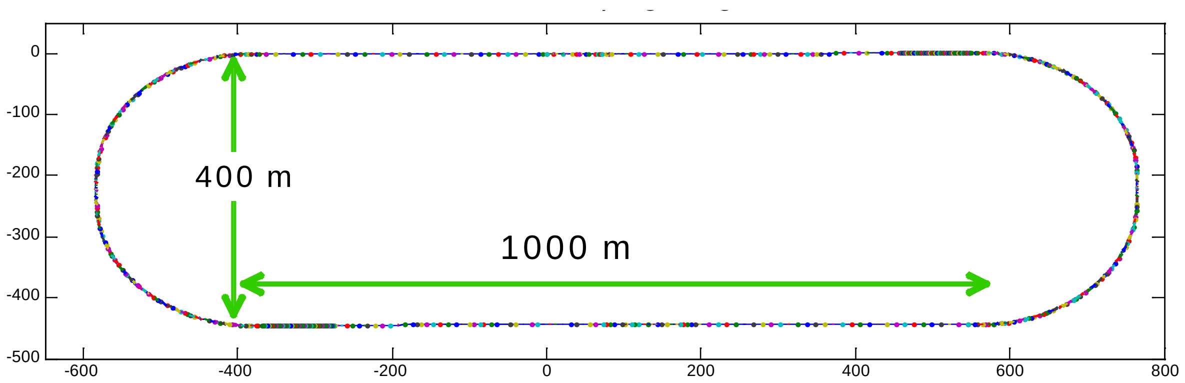


Figure 4.4.1: Layout of the 3.2km damping rings.

Figure 4.4.1 shows the layout of the 3.2km damping rings. The electron and positron rings are to be stacked in a common damping ring tunnel located in the central part of the ILC accelerator complex. This construction is fundamentally the same as that put forth in RDR.

The technical work done for the long ring can be easily applied to the short one. The lattice still needs some optimization work and then it will be used to evaluate the expected beam performance.

### 4.4.2 Ring Description

The electron and positron ring are arranged one on top of the other with counter-rotating beams. Injection and extraction for each ring are located in the same straight section. The injection line entering the electron ring is superimposed on the positron extraction line and vice versa. RF cavities and wigglers are in the opposite straight section with respect to injection and extraction. The wiggler straight is located downstream of the RF cavities in order to avoid damage by synchrotron radiation. The RF cavities for each ring are offset from the center of the straight so that the cavities for the two rings are not superimposed on top of each other.

In the SB2009 lattice, the reduction of the energy radiated per turn and of momentum compaction allows to achieve a shorter bunch length with less than half the number of RF cavities with respect to the RDR. The number of wiggler magnets is 32 instead of 80, less than half, due to the higher field in the arc dipoles.

The lattice in the arcs is based on the SuperB arc cells, two adjacent cells with very similar but with different phase advance (see Fig.4.4.2): one is $\pi$ and the other ~0.75$\pi$. By tuning the phase advance in the second cell, the emittance and momentum compaction of the lattice can be tuned. The lattice of the straight sections is made of the same building blocks as used in the longer racetrack lattice, including phase trombone sections to adjust the tunes and chicanes for path length tuning. The new lattice is still in a preliminary stage of development and requires further optimization of the dynamic aperture and evaluation of the effects of magnetic errors and alignment errors. Based on the experience gained with the present reference lattice, we are confident that by proper tuning the straight sections, phase advances and the sextupole distribution, an adequate dynamic aperture for the large injected emittance of the positron beam can be achieved. At the same time, work is in progress at IHEP Beijing on an alternative lattice design using FODO cells. The optimal lattice design will be selected similarly to how it was done for the previous longer lattice [3].

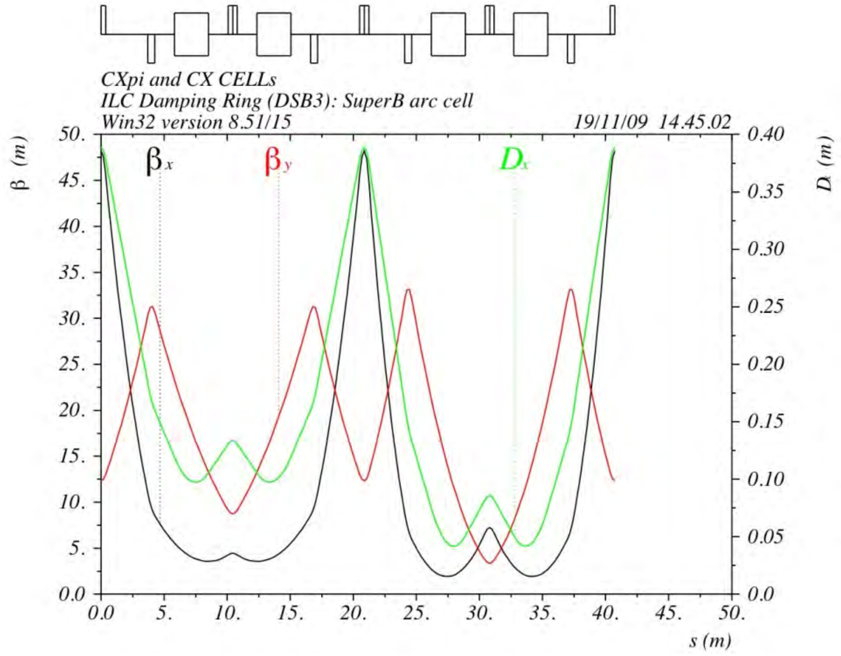


Figure 4.4.2: Optical functions of the 3.2km damping ring arc cells.

## 4.4.3 Work to Pursue during TDP2

The main challenges for the damping rings are with the fast kickers, low emittance tuning and controlling collective effects, in particular electron cloud and fast ion instability. As mentioned earlier, the bunch separation and the number of particles are bunch remain the same as or very similar to RDR/TILC08. Therefore, the magnitude of technical challenges associated with them would remain essentially the same. As a consequence, in TDP2 it is considered adequate to continually pursue the already ongoing technical R&D programs from the TDP1 period into TDP2, as they are. They include the work being done at dedicated test facilities such as CesrTA and ATF and at many laboratories invoved in the ILC collaboration. An important goal of TDP2 is to evaluate the performance of the SB2009 damping ring design with respect to all the limiting effects, on the basis of these experimental and theoretical efforts.

**Kickers**

The required kicker pulse length is given by the bunch separation, 6 ns, for the nominal parameter set (1300 bunches) which is the same as the RDR. In case 2600 bunches are needed for the luminosity upgrade, the bunch distance would be 3ns as in the “low charge” parameter set in the RDR. Fast kickers with rise/fall times shorter than 3 ns have been measured at KEK ATF. Further R&D is needed to demonstrate kickers satisfying all the DR specifications including repetition rate, amplitude stability, field uniformity, strength and operational reliability.

All of the kicker specifications are the same for the short and long rings, except for the repetition frequency within the pulse, which is less demanding for the shorter ring.

**Low emittance tuning**

For the low emittance tuning we do not expect significant differences between the two rings even though the sensitivity to alignment errors of the new lattice remains to be evaluated. For both rings the steps to achieve the ultra-low emittance are the same: the definition of the required alignment precision and stability, the precision and sensitivity of the beam position monitors and of the beam size monitors, the effectiveness of the tuning algorithms.

**Collective effects**

Collective effects need to be re-evaluated for the SB2009 design, including the fast ion instability space charge incoherent tune shifts and intrabeam scattering. We do not expect a big difference from previous evaluations since these effects depend mainly on the ring currents that are the same as for the RDR. The shorter bunch length poses more stringent requirements on the vacuum chamber impedances. First estimates indicate that the nominal operating parameters are below the thresholds for microwave instabilities [5]. Special attention, however, must be paid to the effect of the electron cloud instability.

**Electron cloud for 1300 bunches (6 ns bunch spacing)**

For the nominal configuration with 1300 bunches and 6ns bunch spacing, electron cloud mitigation techniques are needed both for the RDR and the SB2009 rings. R&D is in progress at the dedicated test facility, CesrTA, and at other labs. Results are promising and a range of mitigation methods are being tested. We have convened a working group to apply the results of the R&D to the DR design. The findings will be used as input for the ring design that will be chosen for the new baseline. Given the same current and bunch distance we expect similar or even higher instability threshold for the shorter ring [M. Pivi presentation at LCWA09].

**Electron cloud for 2600 bunches (3ns bunch spacing): luminosity upgrade**

The parameter set for the SB2009 luminosity upgrade consists of 2600 bunches with $2\times10^{10}$ particles per bunch, i.e. 3 ns bunch spacing and twice the nominal current. We expect the electron cloud build-up to be more severe with the shorter bunch spacing. Thus this configuration is much more challenging than the RDR parameter set with double number of bunches which employs 5200 bunches with 3 ns bunch spacing and $1\times10^{10}$ particles per bunch, i.e. it has the same current as the nominal RDR parameter set.

Achieving the performance of the SB2009 ring for the luminosity upgrade will require additional simulation studies, improved mitigation techniques, a more expensive vacuum design, etc. Further work on mitigation techniques is needed to significantly increase our level of confidence when dealing with this parameter set. In the event that effective EC mitigations cannot be devised, a back-up option would be to add a second positron damping ring.

## References

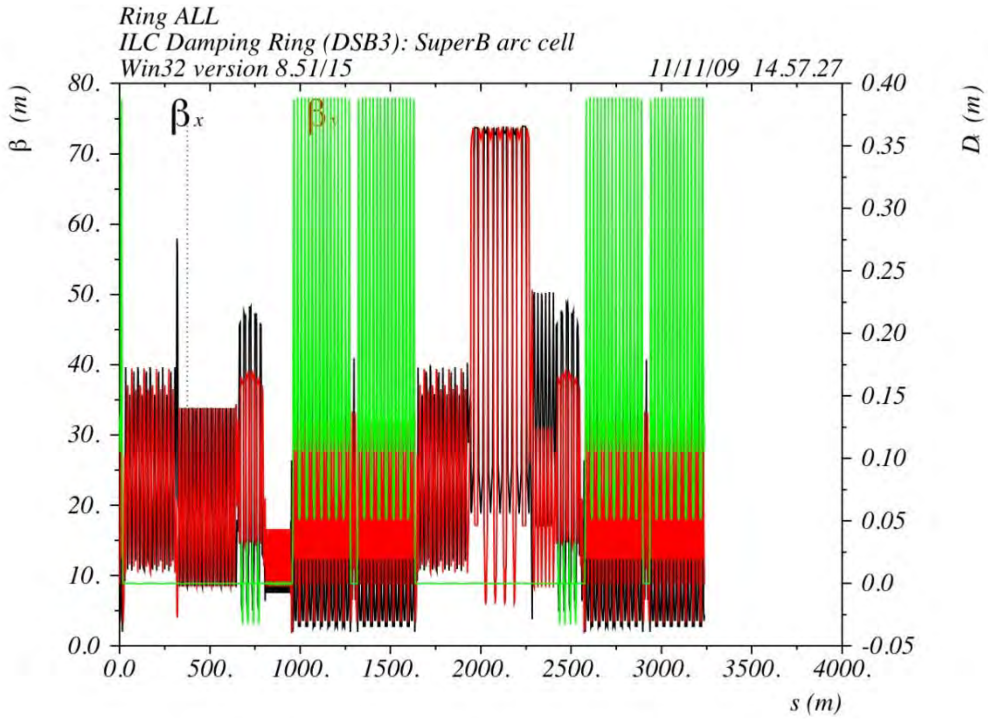
[1] M.E.Biagini, “First Look at a 3 km Damping Ring”, LCWS08 ,November 16-20, 2008, UIC Chicago, http://ilcagenda.linearcollider.org/materialDisplay.py?contribId=516&sessionId=11&materialId=slides&confId=2628

[2] A. Wolski, Specifications for the ILC Damping Rings EDR Baseline Lattice, https://wiki.lepp.cornell.edu/ilc/pub/Public/DampingRings/LatEvalPage/EDRLatticeSpecifications.pdf

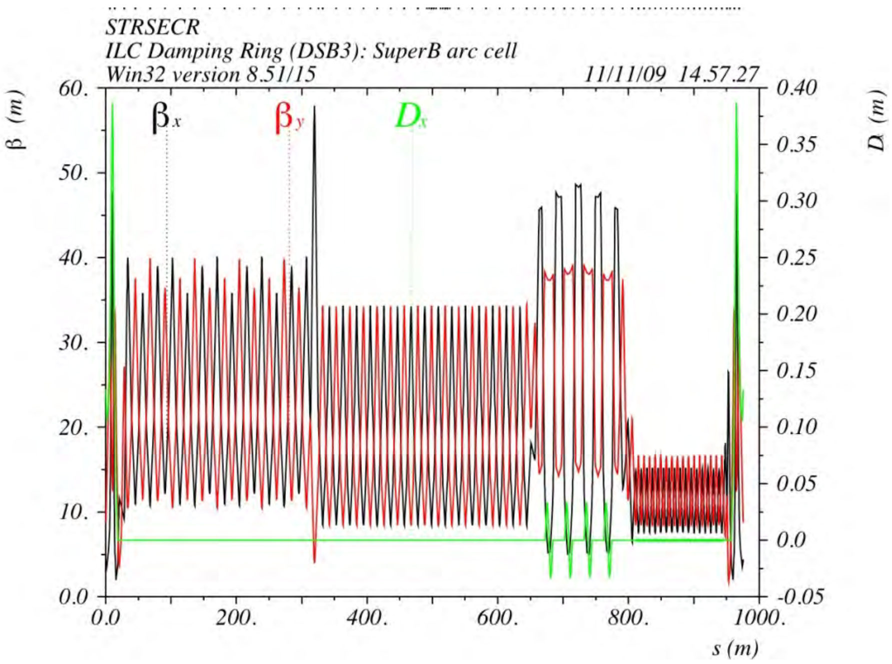
[3] M. Palmer, "ILC Damping Rings Lattices Evaluation", GDE Meeting TILC08, 3-6 March 2008, Sendai, Japan http://ilcagenda.linearcollider.org/getFile.py/access?contribId=187&sessionId=63&resId=2&materialId=paper&confId=2432

[4] A. Wolski, M. Korostelev, "ILC Damping Rings Lattice DCO", GDE Meeting TILC08, 3-6 March 2008, Sendai, Japan http://ilcagenda.linearcollider.org/materialDisplay.py?contribId=185&sessionId=63&materialId=slides&confId=2432

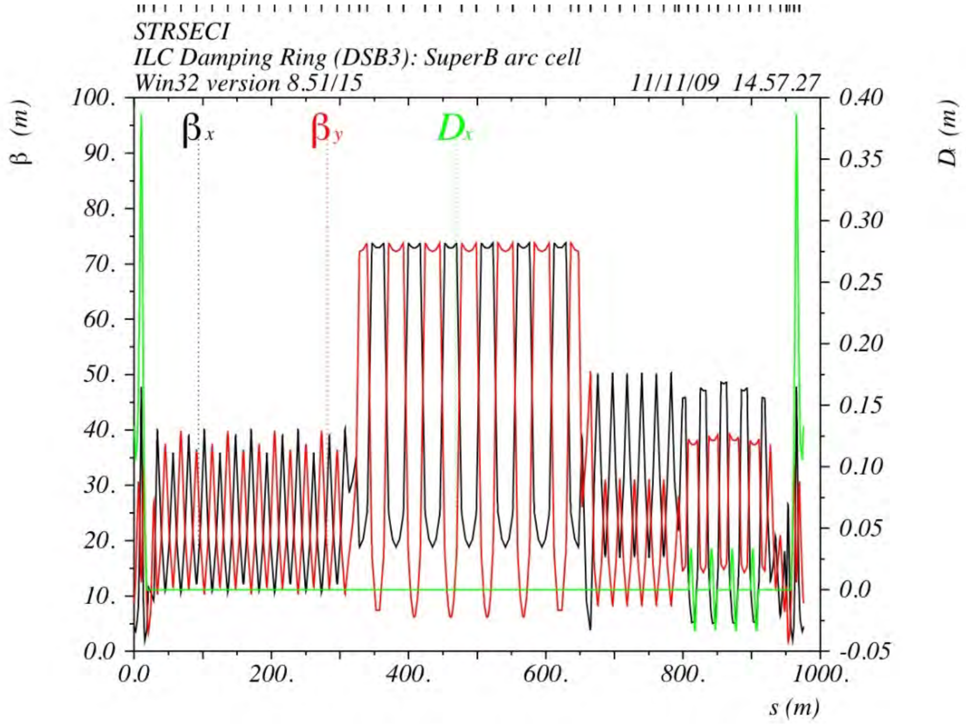
[5] G. Stupakov, "Status and future plans for instability studies for the ILC damping rings," presented at ILCDR07-KEK (December 2007). https://wiki.lepp.cornell.edu/ilc/pub/Public/DampingRings/KEKWorkshopTalks/Stupakov.pdf



Optical functions of the 3.2km damping ring



Optical functions of the 3.2km damping ring RF and wiggler section



Optical functions of the 3.2km damping ring injection and extraction section

## *4.5 Bunch Compressors*

### 4.5.1 Overview

This section describes the proposed changes in the bunch compressor systems (also called, the ring-to-main-linac - RTML systems). Major modifications proposed for the RTML are:

- Adoption of the single-stage bunch compressor scheme, removal of one (per side) of the 220kW dump and associated components, and removal of one section (per side) of beam diagnostics.
- Redesign of the second extraction line downstream of the bunch compressor to accommodate larger energy spread.
- Redesign of the RTML lattice in the central injector complex, associated with new layouts of the damping rings, particle sources and the beam delivery systems.

Replacement of the previous two-stage bunch compressor (BC) with a single-stage BC is motivated by a large cost saving. While this change limits the available compression ratio to 1/20, it is considered acceptable in the light of the bunch length of 6mm from the exit of damping rings and the nominal bunch length of 300 μm as required at the beam interaction point (IP). Removal of one (per side) of the 220 kW dump and associated dump line components (located downstream of the 2nd compressor in the RDR design) offers another set of significant cost savings.

The remaining extraction line and 220kW dump, located after the new single stage compressor has to be redesigned, since the beam energy spread would be increased from ~2.5% to ~4%. Cost saving is also possible by shortening of the diagnostics and matching sections (5 GeV instead of 15 GeV in baseline design).

Proposed changes in the damping rings and the e+/e- sources will affect the design and length of the RTML line from DR tunnel to main tunnel in non-significant ways.

Figure 4.5.1 shows a revised schematic diagram of RTML, indicating the various elements described in the text.

### 4.5.2 Single-Stage Bunch Compressor

The baseline (RDR) design included a two-stage compressor, facilitating an overall maximum bunch compression ratio of a factor of ~45. The main arguments in support of a two-stage compressor have been:

- Support of the parameter plane (flexibility): Assuming the RDR 9 mm damping bunch length, the two-stage compressor system can achieve bunch lengths of 200 μm (low-P parameter set).
- Reduced RMS energy-spread at the entrance to the Main Linac (at 15 GeV) significantly reducing the emittance growth in the Main Linacs due to chromatic aberrations. (This must be offset by the problems arising from cavity tilts and long bunches in the extended bunch compressor itself.)

However, with the adoption of a damping ring lattice capable of achieving a 6 mm bunch length, it is now possible to reconsider the possibility of a single-stage compressor with an overall reduction in compression ratio. Figure 4.5.1 compares the geometry of the RDR two-stage system with a possible single-stage system which is capable of a factor of 20 compression. The compression factor 20 is sufficient for achieving the nominal bunch length of 300 μm at the interaction point. This bunch compressor will not support bunch length of 200 μm.

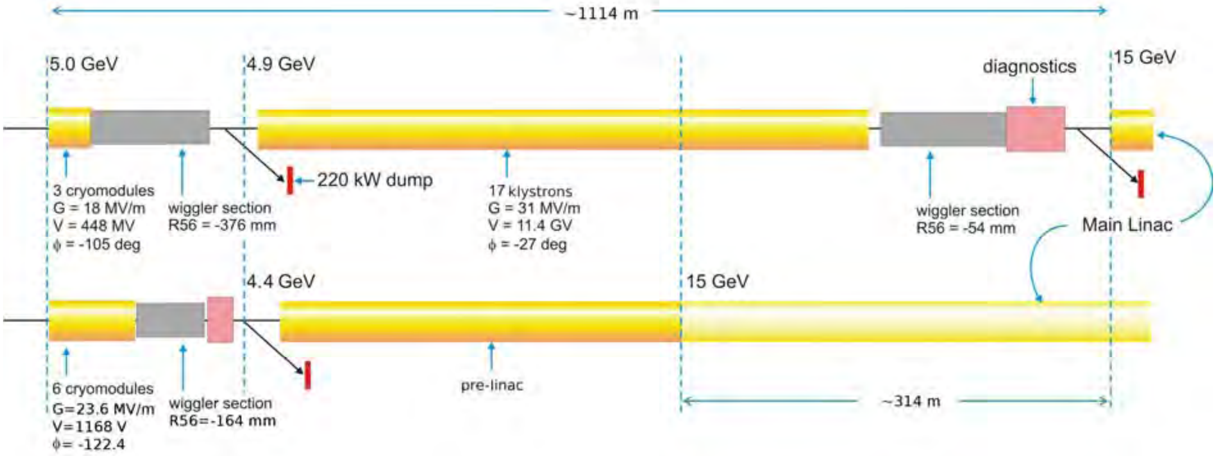


Figure 4.5.1: Comparison of the geometry of the RDR two-stage system (top) with a possible single-stage system (bottom) capable of a factor of 20 compression.

The bunch exits the single-stage compressor with energy of 4.37 GeV. Then it is accelerated up to 15 GeV in pre-linac. Configuration and parameters of pre-linac is identical to those of main linac and we can consider post-acceleration linac as an extension of the main linac. However, for comparison with RDR bunch compressor, we are counting here components of pre-linac as part of single-stage BC design. Single-stage compressor and pre-linac are 800 meters long. Compared with the 1114 meters length of the two-stage compressor, the single-stage compressor scheme offers a saving of about 314 meters of the beamline. The number of components in two-stage compressor (BC1 and BC2) single-stage and pre-linac is presented on Table 4.5.1:

Table 4.5.1: Beamline lengths and component counts in the two-stage and single-stage bunch compressor systems.

| | BC1+BC2 | BC1S+preLinac |
|---|---|---|
| Length, m | 1114 | 800 |
| RF units/klystrons | 16/17 | 14 |
| Cryomodules | 48 | 42 |
| Cavities | 414 | 360 |
| Quadrupoles | 88 | 61 |
| BPMs | 84 | 59 |

The parameters of the RF section and wigglers have been optimized to match the bunch length and energy spread requirements. The cost advantages of the single-stage system are:

- Reduction in beamline and associated tunnel length (314 meters)
- Removal of the second 220 kW/15 GeV beam dump and extraction line components

- Removal of one section of the beam diagnostics

### 4.5.3 Extraction Lines

In RDR design, the RTML contains three 220 kW extraction lines per linac for beam tune-up and emergency abort:

1) after DR (5GeV, dE/E=0.15%)
2) after BC1 (5GeV, dE/E=0.15% and 2.5%)
3) after BC2 (15GeV, dE/E=1.5%).

In case of single-stage compressor, there are no needs for the 15 GeV extraction line 3). However, the BC1 extraction line 2) has to be redesigned to accommodate larger energy spread in the beam coming after single-stage bunch compressor. Few possible designs were proposed and studied in FY2009. The best of them was accepted as a basic for further studies and cost estimations.

### 4.5.4 New RTML Lattice in the Central Area

In the minimum cost machine proposal, the damping ring circumference has been reduced from 6.4 km to 3.2 km. The RDR design foresaw the ring extraction point to be located at about 1 km from the central region in the direction of the turnaround. Now, the DR extraction is expected to take place at about 100 meters from the central area. This change necessitates a complete redesign of the beamlines, affecting the required number of horizontal and vertical doglegs. Fortunately this change simplifies the overall layout of the central area. Only two doglegs are used as shown in Fig. 4.5.2. Lattice files includes extraction line, in the vertical dogleg, skew correction section beam diagnostics (emittance measurement station and beam profile monitor) and the collimation section. The new layout is not expected to cause increase performance risk in terms of low emittance transport. Continued error analysis and development of beam tuning techniques are planned during TDP2.

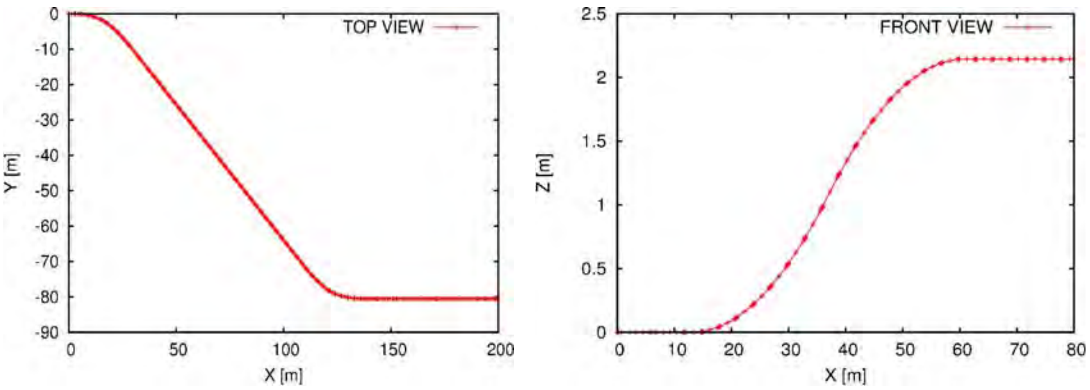


Figure 4.5.2: Central Area beamline footprint: the left hand plot shows the view from top. The slope of the central straight section is determined by the spin rotator at injection. The right hand plot shows the vertical dogleg along the central straight section.

### 4.5.5 Proposed Relevant Studies

Studies of single-stage bunch compressor will include the following packages:

- Refined lattice design of a single-stage bunch compressor, diagnostics section and matching section.
- Beam physics simulation to study effect of coupler RF kick, alignment and phase/amplitude stability of the RF system and provide requirements. The goal to demonstrate that RTML emittance budget can be achieved and beam parameters at the exit of RTML system provide acceptable emittance budget in Main Linac.
- Re-design and evaluation of the extraction line and 220kW dump with higher energy spread beams after compressor.
- Development of CAD models and cost estimations for single-stage bunch compressors: wiggler type design and ultra-short chicane type design.
- Experimental studies of amplitude and phase stability, required for single-stage bunch compressor at FLASH/DESY facility (9 mA studies).
- Re-design of the RTML section from DR tunnel to ML tunnel. This task can be completed after more detailed configuration of other area systems: DR and sources (FNAL).

It is the intention of the RTML area group to continue these efforts during TDP2.

## 4.6 Main Linacs

### 4.6.1 Overview:

**コメント [n1]:** This is a quick and dirty mock-up by NKT. Please, check and give feedback for refinment, soon!

This section describes the proposed changes to the technical implementation of the main linac systems, as associated with adaptation of the single-tunnel scheme.

At this moment two schemes are considered for RF power generation and distributions onto individual cavities. One is called the "Klystron Cluster System" (KCS) in which all the equipment to generate the L-band RF power is situated on surface buildings rather than in the underground tunnels. RF waveguides are implemented to connect the power sources outside the tunnels and the cavities inside the tunels. The other is called the "Distributed RF System" (DRFS) in which all the equipemtn to generate the RF power is situlated inside the undergroud tunnel, together with the RF waveguides.

In cases of both the KCS and DRFS schemes, the technical implementation of the cavity packages, including those of couplers and tuners, within the cryomodules, would remain common. Likewise, the segmentation of the cryomodules, cryomodule strings, and cryogenic systems remain fundamentally common. However, there will be certain differences in ways that the low-level RF systems (LLRF) operate, since the numbers of cavities driven under one RF power source group would be different.

Key features of the two systems are summarized in Table 4.6.1.1.

Table 4.6.1.1: Summary of key features of KCS and DRFS which are considered for the proposed new main linac RF power system implementation.

| | Klystron Cluster System | Distributed RF System |
|---|---|---|
| Klystrons / Modulators | RDR-like 10MW klystrons + modulators on surface | Smaller ~700kW klystrons + modulators in tunnel |
| Surface Buildings | Surface building & shafts every ~2 km, each housing 2 clusters of 35 klystrons | - |
| RF power delivery | From surface building into the tunnels via cricular TE01 waveguide (0.48m ϕ); After power splitting at circular tap-offs (CTO), RDR-like power distribution with revised design. | Waveguide system inside the tunnel local to each of the klystrons and the cavities associated with them. |
| Cavity / Klystron | 806 cavities to be driven by RF powr combined from 35 units | 4 cavities to be driven by one |

| | | |
|---|---|---|
| population ratio | of 10MW klystrons. | unit of ~700kW klystron |
| | | |

コメント [n2]: This sounds "high-current". Should stick to the "low current as the baseline"!!!!!!!!

Both the KCS and DRFS are considered to have good enough reasons to claim their technical feasibility and worth for R&D into the TDP2 period. Both systems seem capable of fitting into the signel main linacs of an inner diameter of ~5m, as will be discussed in Section 4.9. In the following, we discuss the specifics of the technical implementation, known issues and plans for their development and system validation to pursue in TDP2.

コメント [n3]: Need a statement on the RF pulse length issue associated with operation with the lower beam current. MCR is known to have contacted CA to draft a paragraph for it. 20091127

### 4.6.2 Klystron Cluster System (KCS)

**OUTLINE:**

コメント [n4]: I tried to make the OUTLINE more symmetric between KCS and DRFS. Please, check and respond if they are OK with you.

- **Concept**
- **System description and Components**
    - **Klystrons & Modulators**
    - **Combining**
    - **Main Waveguide**
    - **CTO**
    - **Local PDS**
- **Tunnel Layout**
- **Cost Considerations**
- **Operational and Availability Considerations**
- **R&D Plan and Schedule**

#### Concept of Klystron Cluster System

The Klystron Cluster System, or KCS, is one of two conceptual schemes under consideration for powering a single-tunnel main linac layout, the other being DRFS. In KCS, the rf power is generated on the surface and transported down to the linac tunnel. To minimize the number of additional shafts required, multiple sources are clustered together and their power combined into a single, overmoded waveguide (referred to as the main waveguide). This power is then tapped off in equal portions at intervals along the linac equal to the RDR klystron spacing (see Fig. 1). In addition to eliminating the need for a service tunnel, this scheme brings much of the heat load associated with rf generation to the surface.

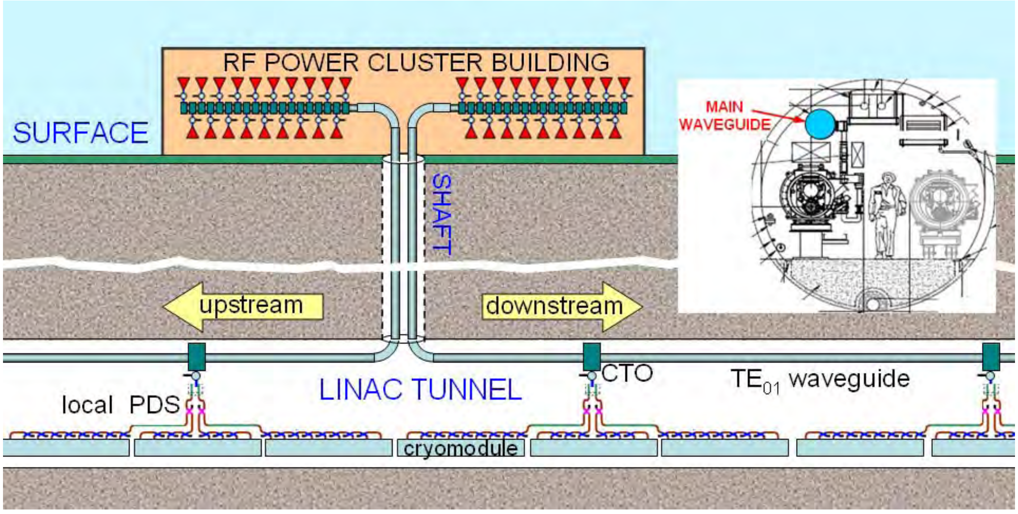


Figure 4.6.2.1: Basic schematic layout of the Klystron Cluster System (KCS) with inset of tunnel cross-section. High-power rf is produced in surface buildings. Power from many sources is combined into an overmoded waveguide and brought down to the linac. There it is evenly distributed through graduated tap-offs at 38 m intervals along lengths exceeding a kilometer. Two systems running in opposite directions can share one building and shaft.

## System Description and System Components

**Power sources in the surface buildings:**

**コメント [n5]:** I have introduced small headings for each topic. Please, check if they are adequate, and respond.

Surface buildings containing power supplies, modulators, LLRF, rf drive, and klystrons are situated roughly 2.4 km apart along each linac. The source specifications are essentially unchanged by this scheme, except for a 38% increase in pulse duration to accommodate the increased cavity fill time due to the lower linac beam current. The modulators, either of the TESLA design described in the RDR or the more recently developed Marx design, provide 120 kV pulses. The klystrons, presumably solenoid focused, six-beam MBK's, (though possibly sheet-beam klystrons) are assumed to generate the nominal 10 MW, 1.3 GHz, 2.2 ms long pulses at a 5 Hz repetition rate.

**Waveguides into the tunnels:**

Dual outputs from each klystron are coupled symmetrically into the main waveguide through circulators and vacuum windows. Although loads on the circulators should largely absorb any reflected power, waveguide valves must be included in each of these connecting arms to allow safe replacement of a failed klystron during operation.

For power handling considerations, the main waveguide is evacuated and operated in the circular TE$_{01}$ mode, which has no electric fields on the wall. To couple into this overmoded circular waveguide, an in-line component referred to as a coaxial tap-off (CTO) is used. Efficient coupling to the circular waveguide requires that the power fed into the CTO's two input ports have equal amplitude and phase of the appropriate values compared to what's already flowing in the waveguide from the upstream klystrons. As the power builds up along the main waveguide, the CTO's have progressively smaller coupling ratios.

Two 90° bends are required to bring the rf power from a klystron cluster down to and along the accelerator tunnel. Bending is non-trivial in overmoded waveguide. These must carry the maximum power and preserve mode purity at the end. A design solution might use corrugated circular waveguide in a carefully profiled bend (a prototype exists at X-band). Designing and demonstrating a very high power $TE_{01}$ bend is part of KCS R&D program envisioned in the next few years.

For the main waveguide, a diameter of 0.48 m is a good choice as it is below the cutoff diameter of $TE_{02}$ and the attenuation is modest, about 13% over 1.25 km in aluminum (or about 7% on average). Due to the danger of transferring power into the 20 parasitic modes that propagate at this diameter, a fairly tight tolerance (~1 mm) must be kept on the cross-section. Matched step tapers are used to connect it to the 0.35 m diameter circular ports of the CTO's.

**Circular Tap-offs:**

The main impact on the tunnel cross-section (inset in Fig. 4.6.2.1) is the presence of this main waveguide with insulated cooling, mounted near the ceiling. It is interrupted periodically by vacuum pumpout sections with associated pumps and by CTO's connecting to the local distribution circuit. Additional hardware formerly located in the RDR service tunnel, such as beam and rf diagnostic electronics, will also need to be fit in the main tunnel, with appropriate shielding.

At intervals of about 38 m, equivalent to the three cryomodule rf unit length in the RDR, high-power rf is tapped off from the main waveguide through a CTO. The linac CTO's are the same as those used for combining, but oriented oppositely as tap-offs and sequenced in order of increased coupling as the power is depleted. Thus the output ports of the CTO's replace the feeds from local klystrons in the RDR design.

The CTO interior (see Fig. 4.6.2.2) has a diameter step up which couples nearly half the power into the $TE_{02}$ mode. A tube is then introduced at the original diameter to divide the volume between inner circular waveguide and an outer coaxial region. The mix of circular modes causes a radial beating in field intensity so the location of this tube relative to the step up determines the power split between the regions, and hence the coupling. The coaxial guide is shorted and coupled through eight azimuthally distributed slots to a wrap-around waveguide. The outer wall of the latter opens into two WR650 ports. Here rf windows terminate the vacuum envelope.

Pumpout ports are easily incorporated at the CTO ports, just before the windows. Further pumping through special pumpout inserts will be required directly on the main waveguide. Based on experience with the overmoded SLED II system at SLAC, having a port with ion pumps every 10 m should reduce the main waveguide pressure to below $10^{-6}$ torr initially and down to $10^{-8}$ torr over time. A pressurized line would be preferable, but it is not clear that the expected peak field levels, approaching 4 MV/m, could be sustained in nitrogen at one or two bars absolute pressure. As part of the R&D program, operation under both vacuum and pressure will be evaluated.

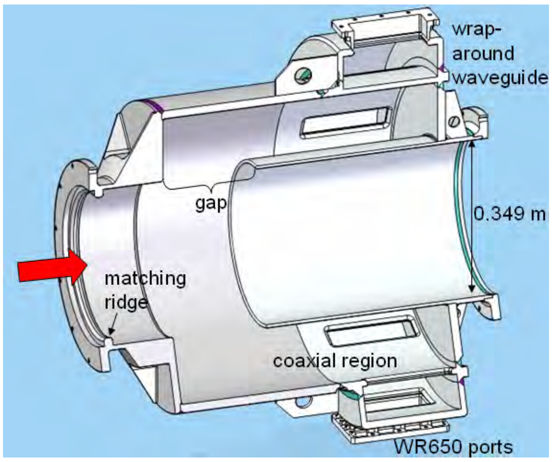


Figure 4.6.2.2: $TE_{01}$-mode Coaxial Tap-Off (CTO) with wrap-around power extraction. Only the gap and matching ridge vary for different couplings (3 dB pictured). For combining, it is used in reverse.

**Power distribution onto cavities:**

From the CTO, power is fanned out through a local power distribution system to 26 cavities. Whereas the RDR has fixed coupling hybrids for each cavity feed, adjustable couplers will likely be required, as the acceptance of a relatively large spread in cavity gradients is being considered to increase yield. The Variable Tap-Off (VTO) developed at SLAC, or its equivalent, would be used to optimize the power to individual or pairs of cavities. Also, the three-stub tuners will be replaced by phase shifters, which, with the tunable power coupler antennae, will allow independent phase and $Q_L$ adjustment.

If each cluster combines 17 ten megawatt klystrons and has a 93% average transport efficiency, then it can power 32 rf units (1.2 km long) with 4.9 MW each (for half current operation relative to the RDR). With the KCS, a klystron failure does not bring down an rf unit as it does in the RDR, but rather reduces power uniformly along the fed linac section. However, due to the nature of the combining circuit, the available power goes as the square of the fraction that are operational. For example, one klystron failure out of 17 results in 150.6 MW in the main waveguide and 9.4 MW misdirected into loads. For improved reliability, each cluster would include 19 klystrons with one left off as a reserve. If one fails, the spare would be turned on, maintaining the full power of $(18/19)^2 \times 19 \times 10$ MW = 170.5 MW. A repair/replacement can presumably be made before a second failure occurs in a given cluster.

**Component counts:**

Two clusters collocated in a single rf power building would power about 2.4 km of linac, one feeding upstream and the other downstream. Being on the surface allows easy air cooling of the rf sources, and two or three floor levels could used to minimize the overall building footprint. With slight adjustments to the current shaft locations and two additional small diameter shafts per linac, the main linacs can each be powered through five shafts by nine KCS systems.

| | |
|---|---|
| # of KCS per main linac | 9 |
| # of rf units per system | 32 |
| # of cryomodules per system | 96 |
| # of cavities per system | 832 |
| # of klystrons/modulators per system | 19 (36) |
| peak rf power per system (MW) | 170 (34) |

Table 4.6.2.1: Nominal parameters for the klystron cluster rf power distribution system. Numbers in parentheses are for the upgrade 9 mA beam current.

**RF controls:**

The beam-to-rf timing will vary by 0.9 microsecond for the downstream run and 8.8 microseconds for the upstream run. Centered, the latter represents ± 0.4% of nominal cavity fill time. Flat gradient along the bunch train can be maintained locally by using $Q_L$ to tailor the cavity fill times accordingly. With 18 klystrons serving as a single source, the low level rf system will have to work with vector sums from 832 cavities, rather than 26, in controlling each cluster. These sums would be computed locally for each cryomodule and then sent in real time to the cluster building, where a redundant summing and processing system (2 or 3 majority logic) would be used to adjust the klystron drive pulses.

**Heat load issues:**

The additional heat load presented by the main waveguide varies along the tunnel as the power is depleted from ~230 W/m to ~6.3 W/m, averaging ~114 W/m (for 170 MW-2.2 ms-5 Hz operation). This does not include the heat load of the local distribution systems. Presumably, the main waveguide will be cooled via water tubing attached to the pipe inside an insulating wrap. (The cooling should be sufficient to handle the 45% increase for a 9 mA beam current upgrade.) To absorb longitudinal waveguide thermal expansion, alignment-maintaining bellows must be included at flange joints. Five 5 mm gaps (virtually invisible to the $TE_{01}$ mode) per 38 m rf unit at room temperature could absorb up to 50°F temperature change. Phase stability will nevertheless be at the level of 10°/°F at the farthest point (1.2 km) due to diameter expansion. This can be tracked and compensated by the local phase shifters (the circular waveguide water cooling system should minimize the slow temperature variations to below 1°F).

For a high current ILC upgrade, the number of klystrons, modulators, and associated hardware per KCS would be increased from 19 to 36, with the cluster buildings and their electrical and cooling systems expanded accordingly. The tunnel layout would be unaffected by the upgrade in beam power, always distributing the available power evenly among the rf units. In particular, the cooling system in the tunnel would be initially sized for full current operation.

## Tunnel Layout

...

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## Cost Considerations

The cost benefit of Klystron Cluster System is primarily realized in the elimination of the service tunnel. A secondary cost benefit comes from the simplification of the electrical and cooling systems that have been moved to the surface. The fiscal impact has been estimated to be about a 300 M$ savings. It does, however, entail added complications and risks beyond those of just combining the service and beam tunnels in the RDR. These include:

- Four more 4-m-diameter shafts are needed (two per linac), and the surface presence of the machine is increased.
- Efficiently combining tens of rf sources efficiently into overmoded waveguide is a challenge.
- The waveguide bends may be difficult to build.
- Although the surface electric fields in the KCS system are relatively low, if there is a breakdown, the high stored energy (1.4 kJ maximum, based on the round-trip time to shutoff the rf sources at upgrade beam current) may cause surface damage. However, waveguide arcs are usually highly reflective.
- The LLRF control architecture has to be more robust and the system provides less local control of the energy variation along the linac

## Operational and Availability Issues

The impact of the rf system on machine availability is considered negligible. Redundancy will be built in to the low level rf, the high power systems contain spare sources, and the distribution waveguide is assumed to be robust against breakdown.

## R&D Plan and Schedule

As a first step toward demonstrating feasibility of the KCS, a 10 m run of the main overmoded distribution waveguide and two CTO’s are being built. These components will first be configured to measure the transmission through the system and the power handling capability of the wrap-around waveguide and coaxial section. They will also be high power tested by resonating the line with a short at one end and a CTO at the other end that is terminated by a shorted waveguide segment to give the desired coupling. With input power of about a megawatt, standing wave peak fields equivalent to those of a 330 MW traveling wave will be produced. This test will be done both with the system under vacuum and filled with nitrogen at 2 bar absolute pressure. Future tests should include demonstrating the tap-off and combining functions of the CTO, developing and testing a bend, and perhaps building a 200 m resonant ring.

These issues are also addressed during TDP2.

## 4.6.3 Distributed RF System (DRFS)

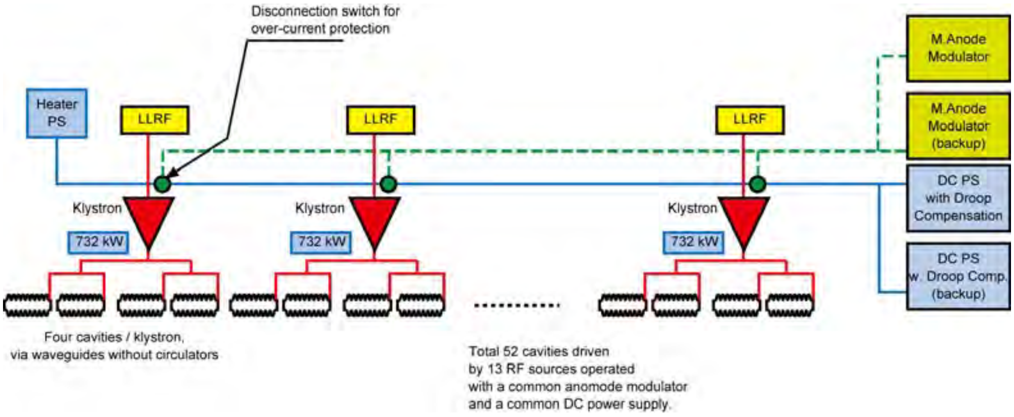
**Outline**

- **Concept**
- **System Description**
- **System Component**
- **Tunnel Layout**
- **Cost Considerations**
- **Operational and Availability Issues**
- **R&D Schedule**

**コメント [n7]:** I tried to make the OUTLINE more symmetric between KCS and DRFS. Please, check and respond if they are OK with you.

### Concept of Distributed RF System

The Distributed RF System (DRFS) is another possibility for a cost-effective solution in support of a single Main Linac tunnel design. In the proposed baseline implementation of DRFS, one unit of 750 kW Modulating Anode (MA) klystron would drive four cavities. In case of the high current option, two cavities will be driven by a 750kW klystron. Figure 4.6.3.1 shows the conceptual diagram of the DRFS.The DRFS is based on much simpler and more compact HLRF and LLRF units than the RDR baseline or the KCS, and it offers a good operational flexibility in coping with performance variations of individual cavities. This section discusses the technical implementation scheme for the DRFS that have been developed so far. Because of the increased number of components involved, it is recognized that the total system cost and the total system reliability are potential concerns, although the unit cost of the components is expected to be low and the reliaiblity of individual components at their lower RF power expected to be reasonably good. These issues have been examined, and will be discussed. Finally, the ongoing R&D efforts on the DRFS and the system prototyping work is discussed, together with the near-future development plans.



Four cavities / klystron,
via waveguides without circulators

Total 52 cavities driven
by 13 RF sources operated
with a common anomode modulator
and a common DC power supply.

Figure 4.6.3.1 : Schematics of the DRFS concept.

## System Description

In the RDR scheme, three units of ILC cryomodules, containing 26 cavities in total, are driven by the RF power from one unit of 10MW L-band klystron. In the proposed new baseline scheme of DRFS, four cavities are driven by one unit of 750kW L-band MA klystron. Therefore, one would see that three cryomodules with 26 cavities will be driven by six and a half units of MA klystrons. In a practical implementation, the proposed scheme of DRFS is to use 13 units of MA klystrons to drive six cryomodules, containing 52 cavities.

The DC power and anode modulation for a group of 13 units of klystrons are provided by one common DC power supply and one common anode modulator (MA modulator). In order to realize high reliability, each of the DC power supplies and MA modulators is associated with one backup unit, which will be designed and implementated to be "hot-swappable". Each of the power and voltage distribution circuits will have a high-voltage SW, which switches off the line when over current failures are detected.

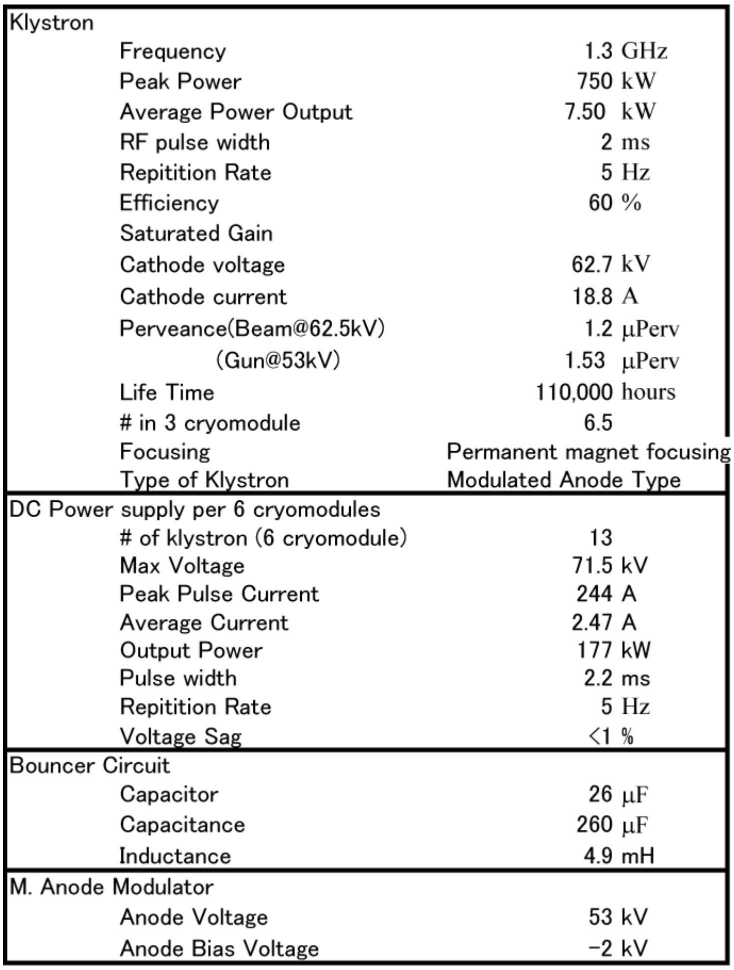
A DC power supply has a bouncer circuit which compensates for the dropping of the pulse flat top. This can be accomplished by a relatively small capacitor bank. The charger of a DC power supply comprises of a bundle of several units of identical switching PS. This allows us to increase its electrical power with ease, simply by adding more switching PS units, in case a doubled DC power is needed, when the high-current option is deployed. A common heater power supply feeds the klystron filament power similarly. Another measure toward high reliability is the use of permanent focusing magnets for MA klystrons. This eliminates the power supply for klystron solenoids and associated sources of failures and electricity demand.

An MA klystron is operated with a beam voltage of 65kV, with a micro-perveance of 1.2. It has an efficiency of 60%. Due to the low field gradient in the klystron gun and the low cathode loading, a long klystron life is expected. On the basis of KEK's of operation of klystrons over the past ~20 years, an MTBF of 120khrs is estimated.

The Power Distribution System (PDS) is relatively simple; PDS components include: directional couplers (DC), flexible wave guides, fixed phase shifter and three magic tee type power dividers. The RF power from a MA klystron is divided into four feeds through two magic tees and brought to four cavities. Circulators are not necessary, since the reflected powers from two cavities are not reflected to the klystron, since they cancelled at the magic tees which offer a high degree of isolation. A dummy load which is shunted to magic tees will absorb the reflected power from the cavities. An average length of wave guide for each klystron is 2 m. The corresponding average loss is estimated to be 0.8 kW. The specifications of these components are tabulated in Table 4.6.3.1.

In case of a high-current (9mA) operation which is envisaged as a future upgrade possibility, the population of the MA klystrons will be doubled, thereby each MA klystron feeds the RF power onto two cavities, or conversely, 26 units of MA klystrons drive six cryomodules with 52 cavities.

Table 4.6.3.1: Pertinent specification parameters for the DRFS.



| | | | |
|---|---|---|---|
| Klystron | | | |
| | Frequency | 1.3 | GHz |
| | Peak Power | 750 | kW |
| | Average Power Output | 7.50 | kW |
| | RF pulse width | 2 | ms |
| | Repitition Rate | 5 | Hz |
| | Efficiency | 60 | % |
| | Saturated Gain | | |
| | Cathode voltage | 62.7 | kV |
| | Cathode current | 18.8 | A |
| | Perveance(Beam@62.5kV) | 1.2 | μPerv |
| | (Gun@53kV) | 1.53 | μPerv |
| | Life Time | 110,000 | hours |
| | # in 3 cryomodule | 6.5 | |
| | Focusing | Permanent magnet focusing | |
| | Type of Klystron | Modulated Anode Type | |
| DC Power supply per 6 cryomodules | | | |
| | # of klystron (6 cryomodule) | 13 | |
| | Max Voltage | 71.5 | kV |
| | Peak Pulse Current | 244 | A |
| | Average Current | 2.47 | A |
| | Output Power | 177 | kW |
| | Pulse width | 2.2 | ms |
| | Repitition Rate | 5 | Hz |
| | Voltage Sag | <1 | % |
| Bouncer Circuit | | | |
| | Capacitor | 26 | μF |
| | Capacitance | 260 | μF |
| | Inductance | 4.9 | mH |
| M. Anode Modulator | | | |
| | Anode Voltage | 53 | kV |
| | Anode Bias Voltage | −2 | kV |

A notably advantageous feature of the DRFS is with the LLRF control. The number of cavities to be involved in one unit of vector sum control is only four (will be two in case of high-current option), as opposed to 26 with RDR or much more with KCS. With relatively unsophiscated sorting of the cavities in accordance with their performance, a highly efficient operation of these SC cavities is expected to achieve a high average accelerating gradient. The DRFS also offers a robust system platform where, in case of failures of cavities, couplers or tuners, the affected number of cavity units is well contained (limited to four or two).

## System Components

Figure 4.6.3.2 shows the configuration of rf units in the baseline case. Table 4.6.3.2 gives the component counts.For comparison with the RDR design, the numnbers are quoted for a sytem which correspond to three units of cryomodules.

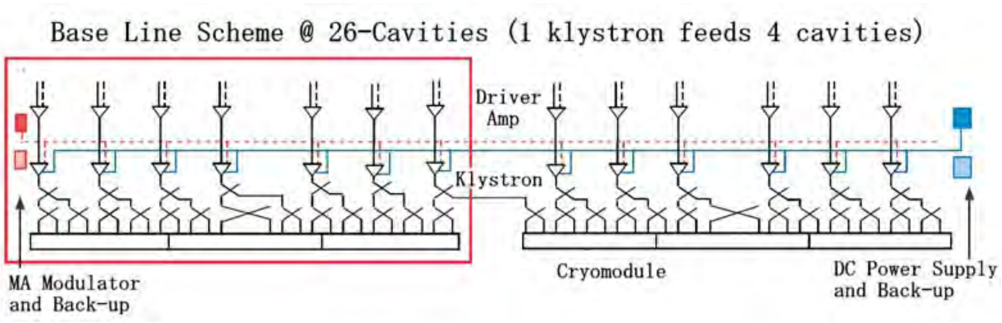
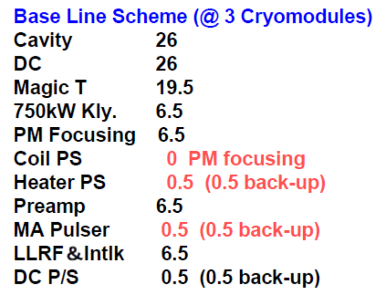


Figure 4.6.3.2 : System configuration of DRFS in the baseline case.



**Base Line Scheme (@ 3 Cryomodules)**

| | |
|---|---|
| Cavity | 26 |
| DC | 26 |
| Magic T | 19.5 |
| 750kW Kly. | 6.5 |
| PM Focusing | 6.5 |
| Coil PS | 0 PM focusing |
| Heater PS | 0.5 (0.5 back-up) |
| Preamp | 6.5 |
| MA Pulser | 0.5 (0.5 back-up) |
| LLRF&Intlk | 6.5 |
| DC P/S | 0.5 (0.5 back-up) |

Table 4.6.3.2: The component count for the DRFS in the baseline case. For comparison with the RDR. The numbers are quoted for a group of three cryomodules.

Figure 4.6.3.3 shows the reconfigured system in case of high current option. Table 4.6.3.3 gives the component counted associated with each configuration.

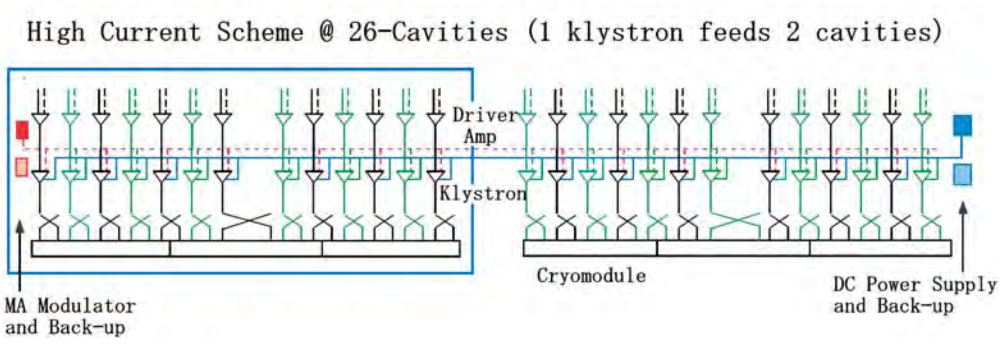
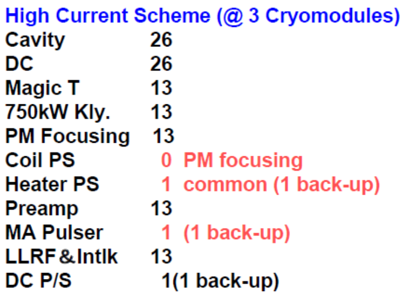


Figure 4.6.3.3 : System configuration of DRFS in the baseline case.



| High Current Scheme (@ 3 Cryomodules) | | |
|---|---|---|
| Cavity | 26 | |
| DC | 26 | |
| Magic T | 13 | |
| 750kW Kly. | 13 | |
| PM Focusing | 13 | |
| Coil PS | 0 | PM focusing |
| Heater PS | 1 | common (1 back-up) |
| Preamp | 13 | |
| MA Pulser | 1 | (1 back-up) |
| LLRF&Intlk | 13 | |
| DC P/S | 1(1 back-up) | |

Table 4.6.3.3: The component count for the DRFS in the high-current case. For comparison with the RDR, the numbers are quoted for a group of three cryomodules.

## Tunnel Layout

Studies of hardware installation of DRFS in the single-tunnel scheme so far have been made, and so far it is known to be accommodated within a tunnel diameter of 5.2m. Figure 4.6.3.3 shows a cross sectional view of such an installation layout.

Cryomodule is hung down from the ceiling. The support structure with suitable vibration suppression needs to be worked out and this is an issue to pursue during TDP2.

RF sources are nearly uniformly distributed the tunnel: the modulators, DC power supplies, LLRF rack units and other electrical devices are installed inside a shielded area for protection from the radiation exposure. Thickness of the shield structure and materials are currently considered as per similar implementation considered at EuroXFEL. They will be examined more closely during TDP2. Underneath the floor the air ducts will be deployed with a total cross section exceeding 1 m$^2$.

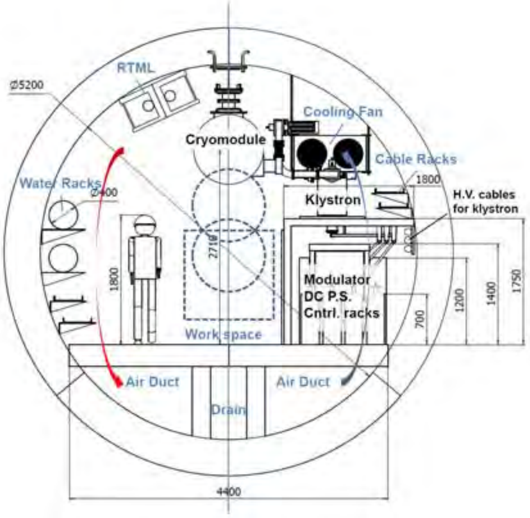


Figure 4.6.3.3: A cross section view of a possible DRFS installation in a main linac tunnel.

Figure 4.6.3.3 includes a working space for the traffic of transport girders to carry the cryomodules and RF components. Figure 4.6.3.4 shows a three-dimensional isometric view of the DRFS installation which is introduced by Figure 4.6.3.3. In addition to the scheme of Figure 4.6.3.3, a few other installation layouts are under study: one having the cryomodules installed on the floor in a 5.75m tunnel, and another having cryomodule placed on top of the shield structructure within a 5.2m tunnel.

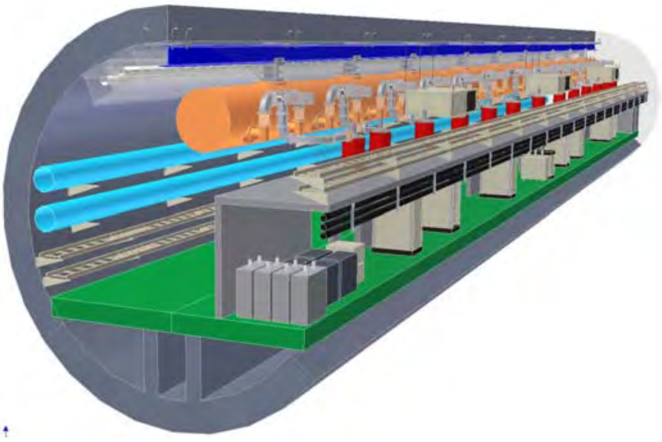
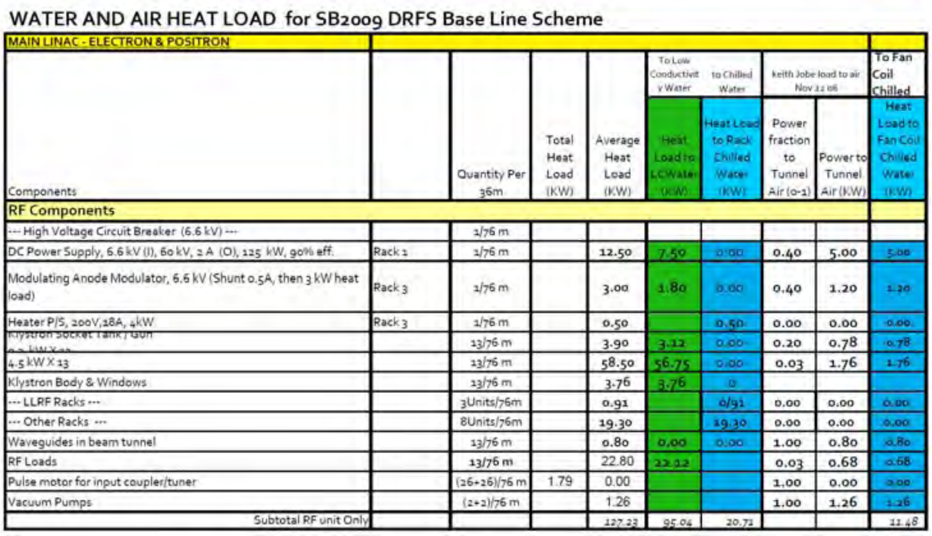


Figure 4.6.3.4: A 3D isometric view of the DRFS installation illustration the scheme given in Figure 4.6.3.3.

One of the potential issues in hardware implementation of the DRFS is the heat dessipation by the components in the single main linac tunnels. Table 4.6.3.4 summarizes the present estimate of pertinent parameters which are taken into condiration for the civil and tunnel engineering design as discussed in Section 5 of this document.

Table 4.6.3.4: Summary of current estimate of heat water load and heat load due the DRFS components .



WATER AND AIR HEAT LOAD for SB2009 DRFS Base Line Scheme

| MAIN LINAC - ELECTRON & POSITRON | | | | | To Low Conductivity Water | to Chilled Water | keith Jobe load to air Nov 11 06 | | To Fan Coil Chilled |
|---|---|---|---|---|---|---|---|---|---|
| Components | | Quantity Per 36m | Total Heat Load (KW) | Average Heat Load (KW) | Heat Load to LCWater (KW) | Heat Load to Rack Chilled Water (KW) | Power fraction to Tunnel Air (0-1) | Power to Tunnel Air (KW) | Heat Load to Fan Coil Chilled Water (KW) |
| **RF Components** | | | | | | | | | |
| --- High Voltage Circuit Breaker (6.6 kV) --- | | 1/76 m | | | | | | | |
| DC Power Supply, 6.6 kV (I), 60 kV, 2 A (O), 125 kW, 90% eff. | Rack 1 | 1/76 m | | 12.50 | 7.50 | 0.00 | 0.40 | 5.00 | 5.00 |
| Modulating Anode Modulator, 6.6 kV (Shunt 0.5A, then 3 kW heat load) | Rack 3 | 1/76 m | | 3.00 | 1.80 | 0.00 | 0.40 | 1.20 | 1.20 |
| Heater P/S, 200V,18A, 4kW | Rack 3 | 1/76 m | | 0.50 | | 0.50 | 0.00 | 0.00 | 0.00 |
| Klystron Socket Tank / Gun | | 13/76 m | | 3.90 | 3.12 | 0.00 | 0.20 | 0.78 | 0.78 |
| 4.5 kW X 13 | | 13/76 m | | 58.50 | 56.75 | 0.00 | 0.03 | 1.76 | 1.76 |
| Klystron Body & Windows | | 13/76 m | | 3.76 | 3.76 | 0 | | | |
| --- LLRF Racks --- | | 3Units/76m | | 0.91 | | 0/91 | 0.00 | 0.00 | 0.00 |
| --- Other Racks --- | | 8Units/76m | | 19.30 | | 19.30 | 0.00 | 0.00 | 0.00 |
| Waveguides in beam tunnel | | 13/76 m | | 0.80 | 0.00 | 0.00 | 1.00 | 0.80 | 0.80 |
| RF Loads | | 13/76 m | | 22.80 | 22.12 | | 0.03 | 0.68 | 0.68 |
| Pulse motor for input coupler/tuner | | (26+26)/76 m | 1.79 | 0.00 | | | 1.00 | 0.00 | 0.00 |
| Vacuum Pumps | | (2+2)/76 m | | 1.26 | | | 1.00 | 1.26 | 1.26 |
| Subtotal RF unit Only | | | | 127.23 | 95.04 | 20.71 | | | 11.48 |

## Cost Considerations

コメント [n8]: Have to figure out how we want to retain this stuff here or not. Maybe later.

The DRFS requires a large number of DC power supplies and MA klystrons. The reduction of the cost is a key issue to validate its merit as a system solution. The following considerations are given.

### MA Klystrons

The total of 4200 MA klystrons need to be manufactured during a construction period of 5 years (850/year). During the subsequent operation period, approximately 200 MA klystrsons need to be produced per year. The perceived cost reduction measures are as follows:

- For klystrons after the assembly, the vendors would only perform the baking of completed klystrons, yet no HV processing. The HV/RF processing of the klystrons are to be done on the ILC site. Consequently/RF, no modulators are to be maintained for HV/RF processing in the vendor's site,.
- Deployment of hydro-forming techniques for manufacturing common parts of the klystrons.
- Deployment of auto tuning machines for tuning of the cavities to use in the klystron body.
- Elimination of ion pumps on the klystrons. Deployment of getter pumps.
- Elimination of lead shield,.
- Elimination of solenoid focusing magnets. Deployment of permanent magnet focusing.

### DC Power Supplies and Modulators

As stated earlier, one common MA modulator and one common DC power supply, with one backup unit each to ensure the system reliability, will drive 13 units of klystrons for cost saving. A bouncer circuit is introduced in the DC power supply. This can be done with small capacitors in this application. Since the MA modulator does not supply the pulsed power, its cost can be kept low.

**Power Distribution**

Very simple power distribution system, which results in cost reduction, is possible in this scheme; no circulator, a power divider employing Magic-T with a high isolation for space saving, one phase-shifter with symmetric PDS between couplers or asymmetric PDS with a phase-fixed waveguide for cost saving and 750 kW RF propagation in the dry air without any extra ceramic window.

Taking into account the above mentioned considerations, our present estimation of the construction cost for the RF system for DRFS is approximately 2/3 of what has been evaluated for the RDR HLRF/LLRF systems. The reason why it is not 1/2 is due to the conservative approach that we currently take toward the costing of MA klystrons with permanent magnet focusing. The costing of MA klystrons, and its reduction, is one of the issues that will be pursued in TDP2.

## Operational and Availability Issues

One of the main availability issues for DRFS is the radiation damage of components. Almost all DRFS components will be installed in the tunnel where we need to examine the potential radiation hazard which is caused by acceleration of the dark current. The data concerning this issue is unfortunately scarse. At this moment, we follow the considerations given in case of the EuroXFEL project, and assume to introduce radiation shield of 10cm-thick concrete and 1cm-thick lead.

Another important availaiblity issue is the maintenabnce of HLRF components, in particular the klystrsons. A large number of klystrons are use in the main linac tunnels, as one klystron feeds its power to four cavities, as opposed to 26 cavities by one klystron in RDR. A longer MTBF for klystrons is expected to be realized with the measures as described before. However, maintainability of klystrons and other components remains to be a key issue. In the following, the maintenance scenario for the DRFS and the associated workload are examined.

As discussed in Appendix 1, the operation schedule is assumed to consist of a repetition of 2-week continuous operation (312 hrs) interreupted by one-day maintenance in between. The numbers of failed components, which require replacement or repair, after each of the 2-week operation, are estimated and are summarized in Table 4.6.3.2. The MTBF assumed in the estimates are also indicated.

Table 4.6.3.2: Estimated number of HLRF components across the entire ILC requiring replacement or repair, after completion of each of the 2-week operation period:

| Component | # of units requiring replacment or repair | MTBF assumed | Total # of units deployed at the ILC |
|---|---|---|---|
| DC power supply | 2 | 50,000 hours | 325 |
| MA modulator | 1.5 | 70,000 hours | 325 |

| | | | |
|---|---|---|---|
| MA klystron | 12 | 110,000 hours | 4225 |

It should be noted that the scheme taken with redundant DC PS and MA modulator will provide substantially longer "system" MTBFs for the DC power supplis and MA modulators than what are quoted in Table 4.6.3.2. The MTBF quoted for the klystrons is based on the operational experience of KEKB linac, where 4.7 million hours of cumulative operation time has been logged at 60 klystron sockets. BI (barium-impregnated) cathode and lower cathode loading, which assure longer life time of klystron, are adopted for this project.

In order to estimate the human resources that are required during each of the one-day maintenance, the time that it takes to replace each of the components in question has been examined. Table 4.6.3.3 shows the summary of this study.

Table 4.6.3.3: Estimated times for the repair work of DRFS.

| Action | Time for unit piece of work | Rationale |
|---|---|---|
| Transportation of klystron | 0.5 person-hours / tube | 2 person in 2 hours could bring 8 tubes on one carrier. |
| Removal of a failued klystron and installation of a replacement klystron | 4 person-hours / tube | 2 hours with 2 persons |
| Time for personnel to move from one point of repair to another | 2/3 person-hours / tube | 20 minutes with 2 persons |
| Replacment of a MA modulator | 6.67 person-hours / modulator | |
| Replacement of a DC power supply | 27 person-hours / DC power supply | |

As a consequence, the human resource that it takes to replace the 12 MA klystrons on each of the one-day maintenance day would amount to 62 person-hours. Likewise, 1.5 MA modulators will require 10 person-hours, and 2 DC power supplies will take 54 hours to repair.

In summary, the required human resource for HLRF during maintenance is calculated to be 126 person-hour, which corresponds to 16 person-days. This is likely to be manageable in the light of other work that would be necessary during maintenance days.

## R&D Plan and Schedule

Although the technologies of individual components for the DRFS are fairly conventional, it is still important to demonstrate its system functionality by operating at least a few number of units.

Therefore, a task force has been commissioned at KEK in 2008 to pursue the R&D relevant to the DRFS RF system.

Prototype RF components of a MA klystron together with parts of power supply and MA modulator will be manufactured in JFY09 and further R&D will ensue. A prototype unit DRFS will be operated and evaluated in the S1 global test at KEK in 2010, first with MA klystrons based on solenoid magnet focusing. This system is expected to continue operation for the buncher section of the STF2 at KEK. The goal is to accumulate operational experience in a semi-real-life working conditions through 2011-2012. The DRFS to be tested in this STF2 operation will be two units of MA klystrons driving eight cavities, and/or four units of MA klystrons driving eight cavities. Development of permanent magnet focusing for the MA klystrons will be pursued in JFY2010 and beyond.

As for the system implementation aspects, a more thorough cost study will be made together with the CFS team during TDP2. Potential vibration issues of cryomodules, when they are hung off the tunnel ceiling, will be studied, too.

## 4.7 Beam Delivery Systems

### 4.7.1 Overview

This section describes the design changes in the Beam Delivery Systems (BDS) of the ILC considered as a response to the proposed changes of the design baseline. The elements in the baseline changes which are of particular relevance to BDS are the following two:

- Changes in the subsystem integration of the central region: As of the RDR, the BDS, the electron source and the damping rings are clustered in the central region of the ILC accelerator complex. The proposed changes in the baseline envisage relocation of the positron source system to the downstream end of the electron main linac, so that they also join this central region. This impacts the subsystem layout in ways that affect the implementation of electron side BDS.
- Changes in the baseline parameter set: Proposed adoption of the low power beam parameter set (same machine pulse repetition rate and the same bunch intensity, but a reduced number of bunches per pulse) leads to a desire to push the beam-beam parameter, so that the same luminosity as in RDR can be achieved. As a solution the so-called *travelling focus scheme* is being considered.

However, in terms of beam energy handling, similar to the RDR design, the BDS design remains compatible with 1 TeV CM upgrade which is expected to be accomplished by installing additional dipoles and replacing the final doublet.

In what follows, the revised design solutions to adopt in the BDS and their technical feasibilities are presented.

### 4.7.2 System Layout

The central integration includes the sources in the same tunnel as the BDS. Relocation of the positron production system to the downstream end of the electron linac means placing it just before the beginning of the electron BDS. These changes need suitable design modifications to the layout of this area. . Figure 4.7.1 shows the proposed new layout of the electron BDS.

(I am not sure that we need to show all these distances (and upto the third decimal) on 4.7.1. I had included this figure in the initial draft as there were few confusions about this layout. Nobu, please let me know how you would like this figure to be modified and I will send you an update).

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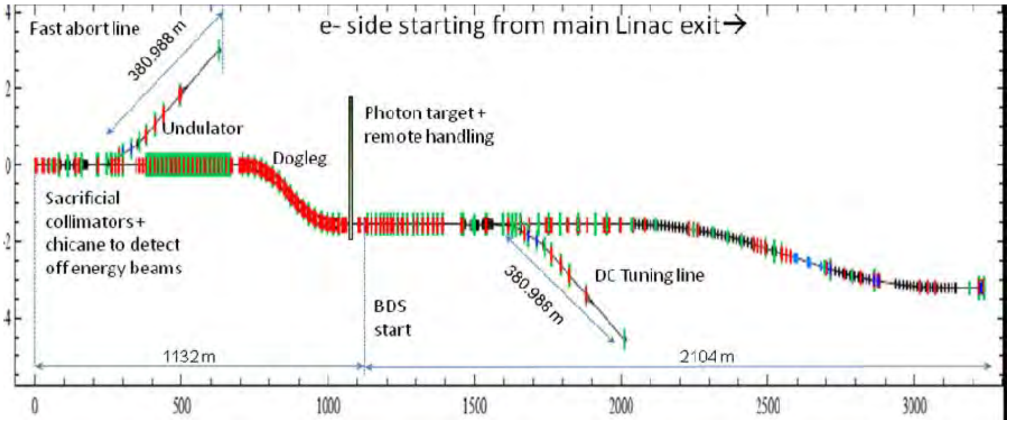

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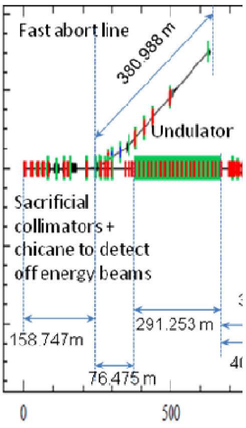

Figure 4.7.1: Proposed new layout of the electron BDS.

The most notable feature of the new electron BDS layout is the introduction of the dogleg (~680m point in Figure 4.7.1) so as to create the required transverse offset between the electron beamline and the positron photon target. Another important consideration is the protection of the undulator from miss-steered as well as an electron beam with significant energy errors. These changes apply only to the electron side. The positron beam delivery system design remains almost the same as in the RDR excepting few modifications such as separating the combined functionalities of the machine protection energy chicane, the upstream polarisation measurements and the laser wire detection, which was found to be problematic to both polarimeter and laser wire detection purposes. These changes were agreed to be implemented on both the electron and positron BDS designs in the TDP2 phase irrespective of rebaselining SB2009. The increase in the length caused due to separating these functionalities will be absorbed by slightly shortening the BDS final focus designs allowing slightly more emittance growth due to emission of synchrotron radiation at 1 TeV CM. These and other features in the new electron BDS are summarized below:

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1. **Sacrificial collimator now located at the linac end (~0m point in Figure 4.7.1) rather than in the BDS upstream end:** The RDR has sacrificial collimators in the beginning of e- and e+ BDS to protect the BDS from any beam with error to enter from the large aperture of the main linac (r=70mm) into small aperture (r=10mm) of the BDS. In the new layout, the small aperture undulator (~8mm full) is located immediately after the linac and thus it needs to be protected against any error beam entering the undulator. This is done by moving the sacrificial collimator section and an energy chicane to detect the off energy beam in front of the undulator which reduced the electron BDS length to 2104m from 2226m as shown in Figure 4.7.1. Any beam

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entering this section with errors will be detected and sent to the fast abort line just before entering the undulator. The fast abort line is presently the same length as the RDR abort line, which was designed as a fast abort + tuning line (the positron BDS side still has this combined functionality), however the fast abort beam dump needs to be able to take only the number of bunches between abort signal and stopping the beam at the extraction of the damping ring (or somewhere in the upstream linac abort dump (Is this planned in the layout? If not need to remove this statement)) and does not need to be a full power beam dump. For this low power (? (this number needs to come from PMs)KW) beam dump, the fast abort line may be shortened.

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2. **Matching line (~300m point in Figure 4.7.1) after the fast abort detection energy chicane into the undulator and design requirements for positron target location:** The matching line to the undulator needs to allow sufficient transverse separation for the abort line and then matches into the undulator FODO cells. The photons generated in the undulator will pass through a drift length of 400m up to the positron target (~1070m point in Figure 4.7.1). To implement the positron target and the remote handling of the components in this area, a transverse offset of 1.5m is required between the electron beamline and the photon target. The remote handing area needs a drift space of approximately 40m in length. No BDS component can be placed in this space. This is achieved by using a matching section after the undulator to match into a dogleg, a dogleg itself giving a transverse offset of 1.5m and a 40m long drift at the end.

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3. **Dogleg lattice (~700-1000m point in Figure 4.7.1) to create the required separation between the photon target and the electron beamline:** The dogleg lattice has been designed to be a TME (Theoretical Minimum Emittance) lattice. This keeps the emittance growth due to synchrotron radiation at 1 TeV CM to be within few percent. The dogleg provides an offset of 1.5m in 400m as required and the emittance growth at 1 TeV CM is ~3.8%. The dipoles in the dogleg are presently not decimated but can be decimated similar to the rest of the BDS so that only few dipoles are installed at 250 GeV. The beam dynamics and tuning effects on the BDS due to the presence of the dogleg need to be assessed.

4. **Matching section into the BDS diagnostics section (~1100m point in Figure 4.7.1):** The 40m long drift is followed by a matching section into the skew and coupling correction section, chicane for detection of the laser wire photons and a slow tuneup (DC tuning) line leading to a full power beam dump. Since the fast abort functionality is being taken care of by the fast abort line before the undulator, the energy acceptance of the DC tuning line is much reduced and thus the DC tuning line can be shortened using only DC magnets. This optimisation will be done during the TDP2 phase.

5. **Polarimeter chicane, collimation, energy spectrometer and final focus:** The polarimeter chicane will be located just after the take-off section for the tuning line, which is not shown in the layout. This will need some additional length but will be accommodated by slightly reducing the final focus length allowing some emittance growth at 1 TeV CM. The polarimeter chicane will be followed by the betatron and energy collimation, energy spectrometer and final focus sections similar to the RDR.

6. **Post collision extraction line and main dump:** The post collision extraction line remains similar to the RDR and will be terminated in to a full power beam dump. The power of the main dumps remains at 17 MW, as in the RDR, to allow future upgrades in the beam parameters.

The layouts to combine the full power tuning dump and the main extraction line full power beam dump will be studied during the TDP for both the positron as well as electron BDS designs

### 4.7.3 Travelling Focus Scheme

The proposed new machine parameters have been discussed in Section 4.1. In the context of restoring the RDR luminosity, while adopting the low-beam current option as the baseline, the use of the travelling focus [Ref-1] scheme has been considered.

The travelling focus is a technique in which the focussing of opposing bunches is longitudinally controlled so as to defeat the hourglass effect and to restore the luminosity. The matched focusing condition is provided by a dynamic shift of the focal point to coincide with the head of the opposing bunch. The longer bunch helps to reduce the beamstrahlung effect and improvement of background conditions is expected. Similar to the nominal 500GeV CM case, the 250GeV CM parameters would also benefit from application of travelling focus – the work on development of a corresponding parameter set is ongoing.

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The travelling focus can be created in two ways:

1. Method 1 is to have small uncompensated chromaticity and coherent E-z energy shift $\delta E/\delta z$ along the bunch. The required energy shift in this case is a fraction of a percent.
2. Method 2 is to use a transverse deflecting cavity giving a z-x correlation in one of the Final Focus sextupoles and thus a z-correlated focusing. The needed strength of the travelling focus transverse cavity was estimated to be about 20% of the nominal crab cavity.

At this moment, since the increased energy spread in method 1 is a potential issue for physics research, method 2 is the preferred focus of studies. Detailed evaluation of the transverse cavity design and dynamics of the beam is ongoing.

### 4.7.4 R&D and Design Work to Pursue in TDP2

Optimal conditions of the travelling focus calls us to be in a regime of higher disruption. This results in a higher sensitivity to any beam offsets. Thus, operation of the intra-train feedback and intra-train luminosity optimization becomes more important and more challenging than in the case of RDR. Although the increased bunch spacing by a factor of two would help in the performance of the bunch feedback system, it has been estimated that in order to contain the luminosity loss within 5%, a bunch-to-bunch jitter in the train needs to be less than 0.2nm at the IP. The parameter sets also have twice as small vertical betatron functions at the IP which imply tighter collimation, with gaps 40% closer to the beam core. The effect of wakefields arising due to these smaller collimator apertures on the beam emittance, and hence the luminosity, needs evaluation. The amount of generated muons may be increased, which may require installation of additional sections of the muon walls (two alcoves, for 5m and 18m walls are foreseen in the RDR, while initial installation was foreseen with just a single 5m set of walls). Quantitative studies of those issues are the subject of work to pursue in TDP2.

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In addition, the operability and ability to commission the entire system continue to be investigated during TDP2. Further design integration and careful planning of the orchestration of the activities in the central area are envisaged.

[Ref-1] V. Balakin, Travelling focus, LC-91, 1991.

## *4.8 Conventional Facilities*

### 4.8.1 Overview:

This section discusses the revison of the conventional facilities design to take place as a result of proposed changes of the design baseline (SB2009 Working Assumptions), as discussed in previous sections of this document.

The SB 2009 Working Assumptions proposed in the Accelerator Design and Integration (AD&I) effort affected all of the major cost drivers in the RDR Conventional Facilities design solution, and the cost associated with it. Those cost drivers were the Underground and Surface Civil Construction, Mechanical Support Systems and Electrical Distribution. By far, the most important single contributor to the CFS cost is the underground volume required in the reference design, and thus, the reduction of the underground volume and the corresponding reduction in cost is the primary focus of this CFS AD&I effort. In addition, issues concerning Life Safety and Egress requirements also required fundamental review, during the Conventional Facilities AD&I effort.

It should be noted, however, that prior to the start of the AD&I work, the Conventional Facilities Group conducted a comprehensive Value Engineering (VE) Review of the Process Water and HVAC design contained in the Reference Design Report. A document that describes the VE process, entitled "ILC Process Water and Air Treatment VE Cost Evaluation" dated November 25, 2008, was completed by the CFS Group. As a result of this review and subsequent analysis of the alternatives indentified, a decision was made by the ILC Project Managers to accept a Process Water design solution that was based on a larger system ΔT. This change to the RDR Conventional Facilities Design became the baseline for the analysis of the SB 2009 Working Assumptions and the AD&I process.

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### 4.8.2 CFS Analysis and Review Process

Table 4.8.1 lists the proposed SB 2009 Working Assumptions (WA) as reference to the description of the CFS approach.

Table 4.8.1: Labels for proposed baseline changes (SB2009 Working Assumptions), as referenced in discussion of the conventional facility designs.

WA1. A Main Linac length consistent with an optimal choice of average accelerating gradient (currently 31.5 MV/m, to be re-evaluated)

WA2. Single-tunnel solution for the Main Linacs and RTML, with two possible variants for the HLRF

(a) Klystron Cluster scheme
(b) DRFS scheme

WA3. Undulator-based e+ source located at the end of the electron Main Linac (250 GeV)

WA4. Reduced parameter set (with respect to the RDR) with $n_b = 1312$ and a 2ms RF pulse.

WA5. ~3.2 km circumference damping rings at 5 GeV, 6 mm bunch length.

WA6. Single-stage bunch compressor with a compression factor of 20.

WA7. Integration of the e+ and e- sources into a common “central region beam tunnel”, together with the BDS.

The CFS approach to the analysis of these working assumptions was basically three-fold:

1. WA 2a and 2b were reviewed by each of the three regions. The focus of this review was to develop a single tunnel solution that would accommodate both the Klystron Cluster and DRFS schemes for supplying RF power to the cryomodules in the Main Linac tunnels. It quickly became apparent that geological conditions and life safety and egress requirements would not only have a direct impact but would also lead to different design solutions in each of the three regions (Asia, Americas and Europe). In addition, a regional preference for one or the other of the proposed RF schemes was identified as a result of the analysis. Both proposed RF schemes will be reviewed in each of the three regions, however the Asian Region prefers the Distributed RF scheme, the Americas Region will evaluate both proposed RF schemes and the European Region prefers the Klystron Cluster RF scheme.

2. WA 1, 3, 5, 6 & 7 were combined into a single design solution based on the input from the Technical Area Systems. This effort to reposition components and reduce the overall circumference of the Damping Ring were combined into a comprehensive new Central Region design and evaluated as a single CFS design solution.

3. WA 4, which is the reduced parameter set, or “low power” option was reviewed as a single item.

In the subsequent sections the CFS analyses are given to each of these WA groups to outline the corresponding technical solutions, considerations and cost estimates.

### 4.8.3 WA 2a & 2b CFS Analysis

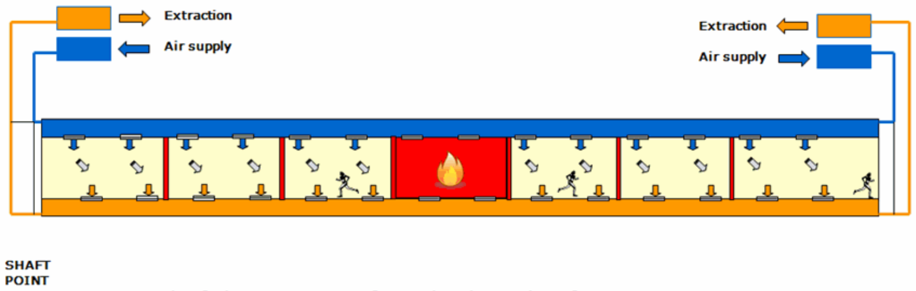
### Asian Region

The Asian Region has chosen the Distributed RF scheme, rather than the Klystron cluster scheme, as the technical implementation of the accelerator system to focus, when developing a single tunnel solution for the Main Linac tunnels. This is because of the characteristics of the Asian sample site which assumes mountainous or hilly geography:

- The hilly or mountainous geography favors the use of sloped or near horizontal path ways rather than vertical shafts as access routes to the Main Linac tunnel complex.
- While the horizontal access tunnels provided “grade level” access, they tend to be much longer than the vertical shaft access adopted in the other two regions.
- The long access path ways lead to a problematic implementation of the Klystron Cluster scheme where large, long high-power waveguides have to share the same space as the traffic for installation and maintenance.
- In addition, all surface buildings which would house the Klystron Cluster would necessarily need to be located at the entrances to the access path ways.

The Distributed RF system is free from these issues.

In the single-tunnel scheme of the Main Linacs with DRFS, a system was developed to “compartmentalize” the Main Linac tunnel into ~500m sections, as shown in Figure 4.8.1. These sections are separated by fire walls and doors. A ventilation system will be provided to isolate the incident section and supply fresh air to the rest of the tunnel and a safe pathway is retained to the next available access to the surface. These offer a reasonable solution to the requirements for life safety and egress.



- Control of the pressure from both ends of a sector.
- Control of the pressure (overpressure or underpressure in each area).
- Fire detection per sector compatible to fire fighting via water mist.

Figure 4.8.1: Example of Asian and European “Compartmentalized” Tunnel Layout

As shown by Figure 4.8.2, in the current DRFS solution by the Asian CFS team the cryomodules will be suspended from the ceiling of the Main Linac tunnel. Supporting RF equipment is arranged below the cryomodules. Additionally the floor space is allotted for movement of equipment and personnel access. The whole set of hardware equipment and space is known to fit within a Main Linac tunnel with a diameter of 5.2m. Optimization of the tunnel size, in particular its reduction, is an issue to be examined more closely during TDP2.

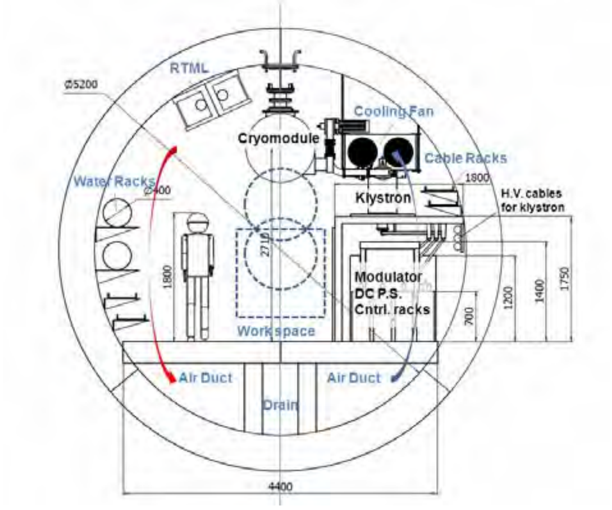


Figure 4.8.2: Asian Region Main Linac Tunnel Cross Section

The Asian Region is also reviewing the implications and design with the Klystron Cluster scheme for their sample site configurations. However, the solution in this case might result in a less than an optimal design for the Asian sample site.

In consideration of specific characteristics of the sites to consider, the following additional issues remain to be examined:

- The specifics of the access methods to the single main tunnels have to be worked out. The RDR design assumed the use of sloped access path ways every ~5km along the main tunnels. A design optimization will be required in TDP2 by taking advantage of a mixture of vertical, sloped and horizontal access paths.

- The specific details in the facility design have to be developed. During the RDR period, the facility system designs were worked out with an assumption that a world-common solution would apply, except those for the civil construction and high-voltage power distribution. During TDP2, specific design solutions have to be developed on the surface buildings, electricity, cooling and air-conditioning.

It is the intention of the Asian Group to address these issues during TDP2.

## Americas Region

The Americas Region initially focused on utilizing the Klystron Cluster RF scheme to develop a single tunnel design for the Main Linac tunnel. Figure 4.8.3 shows a cross section view of the KCS implementation in the main linac single-tunnel, as considered by the Americas regional team. However, both the Klystron Cluster and DRFS schemes can be accommodated in a single tunnel solution for the Americas sample site.

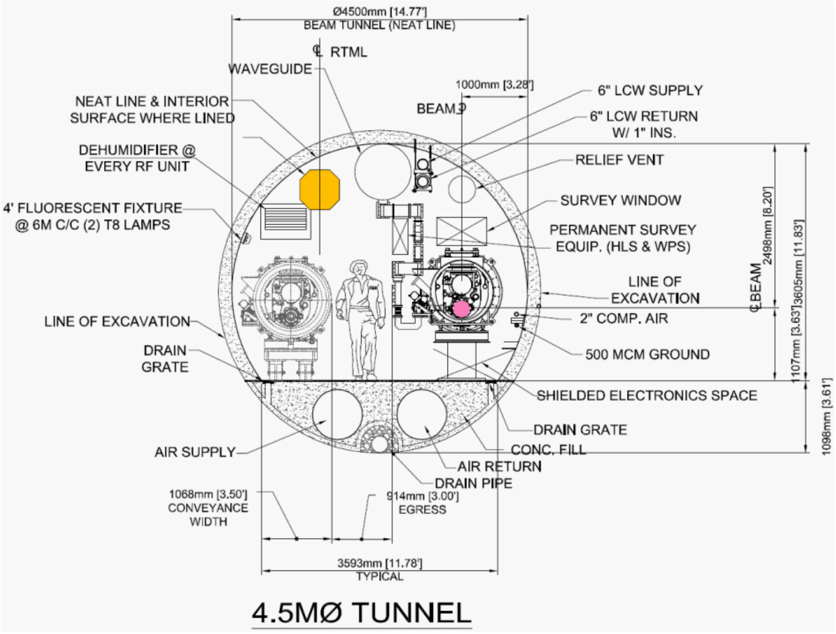


Figure 4.8.3: Americas Region Main Linac Tunnel Cross Section

The Americas reference design incorporates all vertical shafts of similar length for access to the Main Linac tunnel. This arrangement is conducive to relatively uniform waveguide lengths using the Klystron Cluster scheme for RF distribution. The increase in the surface building footprint at vertical shafts to accommodate the new location of the Klystron Clusters can be problematic in denser urban areas. However, there is no fundamental constraint that would preclude the Klystron Cluster or Distributed RF scheme in the Americas Region. Specific characteristics of the Americas site include:

- Relatively uniform surface elevation which allows for vertical shafts of similar length for underground access.
- This configuration provides the opportunity for fairly uniform waveguide lengths for the Klystron Cluster RF option, but does not preclude use of the DRFS RF option.

- The Americas sample site is in a relatively populated area. However, the central region and related surface presence can be contained within the Fermilab site boundaries.
- Shafts located beyond the Fermilab site will necessarily require acquisition of suface area. However, positioning of the alignment can take advantage of existing open areas and industrial sites and minimize the impact on reseidential communities.

With respect to life safety and egress, the Americas Region is subject to a more rigorous environment of regulatory and code oversight. After identifying and then reviewing available code information, a viable and compliant design solution was identified and applied to the single tunnel design for the Main Linac.

The solution is based on the isolation of fire loads resulting from oil filled equipment primarily located in the caverns at the base of the vertical access shafts. This isolation is accomplished through the use of fire walls and doors which allows the majority of the underground space to be used as a safe pathway to the next available vertical access to the surface. Use of the Klystron Cluster RF scheme produced a solution with floor-supported cryomodules, floor space allotted for equipment movement and personnel access. This tunnel cross section design results in a Main Linac tunnel with a diameter of 4.5m, as shown in Figure 4.8.3. For the analysis of the DRFS scheme, the Americas region utilized the Asian tunnel layout and will use the same 5.2m tunnel diameter for the Main Linac.

## European Region

The European Region also initially focused on the Klystron Cluster RF scheme to develop a single tunnel design for the Main Linac tunnel. This decision was fundamentally driven by the geologic constraints of the European sample site. The structural capacity of the rock in which the tunnel will be constructed as well as the requirement for transverse ventilation ductwork at the tunnel ceiling makes it difficult to support any substantial load, like a cryomodule, from the tunnel ceiling.

Based on this constraint, the Klystron Cluster RF system is the primary RF system currently being considered for the European sample site. Although, transferring more equipment to the surface will create additional environmental concerns, it is not possible to measure the impact of this change at this stage. Figure 4.8.4 shows a cross section view of the KCS implementation in the main linac single-tunnel, as considered by the Americas regional team.

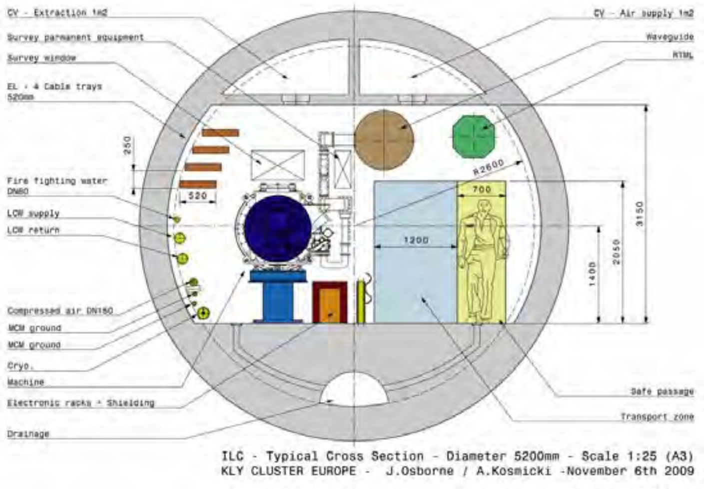


Figure 4.8.4: European Region Main Linac Tunnel Cross Section

With respect to the requirements for life safety and egress, the European Region uses the same general approach (Figure 4.8.1) as the Asian Region. The concept is consistent with single tunnel designs for CLIC and XFEL. Specific characteristics of the European sample site include:

- The current alignment for the European sample site follows a path under a low mountain range.
- Shafts are positioned along the alignment to take advantage of minimum shaft lengths resulting in distances that can accommodate the Klystron Cluster RF option.
- In general, the surface area above the alignment is basically rural in nature, but attention must be provided to existing farms and vineyards.
- Geologic conditions, as well as the ventilation ductwork located at the ceiling of the tunnel and enclosures, preclude the mounting of Cyromodules at the ceiling which then favors the Klystron Cluster RF option at the present time.

The Main Linac tunnel is compartmentalized into 500m sections with fire walls and doors separating adjacent area. A similar ventilation system to the Asian Region solution was provided to isolate the incident section and provide fresh air to the rest of the tunnel and a safe pathway to the next available access to the surface. Like the Americas Region, the European Region utilized the Klystron Cluster RF scheme system which produced a solution with floor supported cryomodules, floor space allotted for equipment movement and personnel access. Due to the need for supply and return ductwork at the crest of the tunnel section, this tunnel cross section design results in a Main Linac tunnel with a diameter of 5.2m. The European Region is also reviewing the implications and design for using the DRFS scheme for their sample site configuration, although this solution is likely to result in a less than optimal design for the European sample site.

## WA2summary

In summary, a single tunnel solution has been developed in each of the three regions for the respective sample site. Each sample site has incorporated a preferred RF Distribution System, and Life Safety and Egress solution that best accommodates local geologic constraints and regulatory guidance and provides a defendable solution for a single tunnel design. All available information regarding machine component size has been taken into consideration in the development of tunnel cross sections and enclosure areas and volumes. Table 4.8.2 gives a brief summary of safety considerations given by the three regional teams in connection with the single-tunnel solutions for the main linac systems.

**コメント [n3]:** I think we said we are going to put together the safety related refs and quote its URI. Do we have it ready?

Table 4.8.2: Safety considerations given so far to the single-tunnel solutions for the main linac systems.

| | Asia | Americas | Europe |
|---|---|---|---|
| HLRF scheme examined so far | Primarily DRFS. | Primarity KCS. | Primarity KCS |
| Isolation of incident location | Firewalls / doors every 500 m along the tunnels, and selective closure of the airflow. | Utilize caverns at the vertical shaft bases for isolating oil-filled equipment. | Firewalls / doors every 500 m along the tunnels |
| Safe pathways | Rest of the tunnels. | Most of the tunnels. | Rest of the tunnels. |

As the component design becomes more defined, these requirements will be revisited, however we believe the current design provides ample space for all required beamline components and large increases in size requirements are unlikely. In addition, space has been made available in the tunnel cross sections and enclosure areas and volumes to accommodate process water and HVAC equipment and electrical distribution components based on the criteria provided to date from the various Area and Technical Systems. While the preliminary designs will be further developed in the course of TDP II, like the technical components, we believe that ample space has been identified and that large increases in sixe requirements are unlikely.

### 4.8.4 WA 1, 3, 5, 6 & 7 CFS Analysis

Major changes of the accelerator system layout in the SB2009, relative to the RDR design are as follows:

- Relocation of the Undulator based Positron Source to the end of the Electron Main Linac
- Reduction of the Damping Ring Length to 3.2 km
- Single stage Bunch Compressor in the RTML
- Integration of the e+ and e- Sources into the central region Beam Delivery System area
- Repositioning of the Damping Ring configuration completely to one side of the Interaction Region
- Positioning the Aborts and Dumps to point in the direction away from the Damping Ring side of the Interaction Region
- Relocating the BDS service tunnel to the Damping Ring side of the Interaction Region
- Relocating the access aisle in the BDS areas to the service tunnel side of the BDS tunnel
- Combing the existing shaft access to the BDS service tunnel with one of the existing Damping Ring access shafts

With regards to the machine central area, as described above, all of these working assumptions were combined into a single revised CFS solution. The primary focus for this effort, from the CFS point of view, was to shorten the overall tunnel length and reduce the required underground volume. It should be noted that although WA 1 was a part of this design review, the preferred cavity gradient was maintained at 31.5 mv/m for the purpose of this analysis.

The input to the CFS Group came from the Technical Area Systems in the form of a beam layout drawing that was compiled at the Daresbury Laboratory and based on available beam lattice files and other technical input. In the course of developing a new design layout, various components from different area systems were now found to be located in the same physical area which required a cavern larger than the normal bored tunnel cross section. However, the final design result produced an overall reduction in the underground volume required. In addition to the repositioning of area system components, the location of the beam aborts and dumps required between the end of the respective Main Linacs and the Interaction point was more clearly defined than in the RDR and incorporated into the central region design.

Figure 4.8.5 shows the resultant topological diagrmf of the beamlines in the central area.

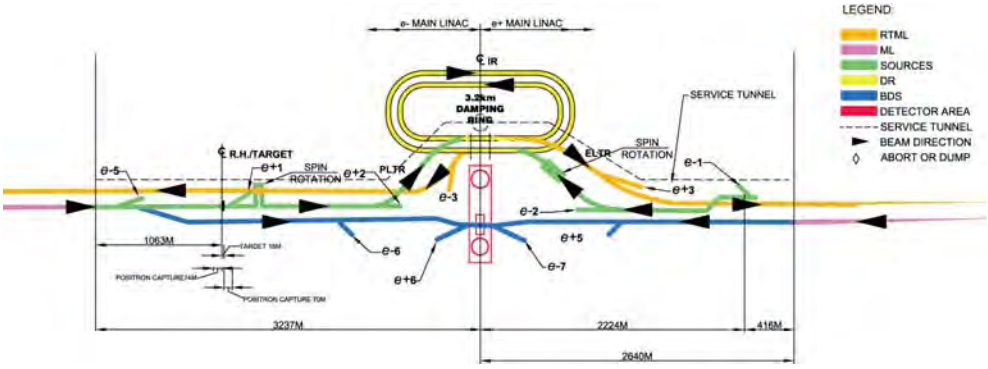


Figure 4.8.5: Topological diagram of the beamlines in the ILC central area.

To assist the members of both the area system groups and the CFS group in the SB2009 decision making process, a set of 3D models have also been developed to assist in the SB2009 decision making process. Figure 4.8.6 shows an example of such a model.

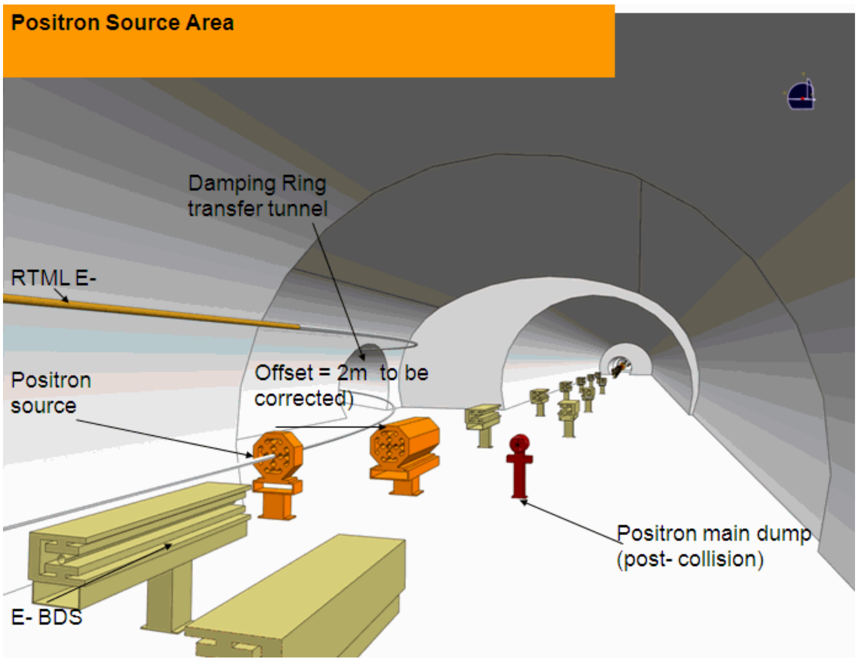


Figure 4.8.6: Example of 3D Enclosure Drawing

### 4.8.5 WA 4 CFS Analysis

The reduced parameter set or “low power” option for RF configuration was reviewed by the CFS Group under the assumption that the election power capacity and distribution would be installed to permit a relatively easy transition to a “full power” upgrade at some time in the future. As a result of this assumption, the electrical distribution system did not differ in any great detail from the RDR design. There was some reduction in the overall electrical distribution cost and some savings identified in the process cooling water system, but overall the CFS contribution to cost savings for this item was less than might have been expected. This approach put more emphasis and importance on the transition to full power at a later date with minimum machine downtime to accomplish the transition. Therefore, all transformer and conductor capacity are installed in the initial construction. To design and install an electrical distribution system that only provided enough capacity for the low power option would save on initial capital costs. However the upgrade to the full power electrical capacity would require not only demolition of the lower power transformer and conductor capacity and installation of upgraded equipment, but it would also entail a lengthier machine downtime to accomplish the task.

### 4.8.6 Summary

The CFS Group has evaluated all of the SB 2009 Working Assumptions, and have produced a solutions set to further pursue in TDP2. Figure 4.8.7 shows the overall schamatic machine layout and Figure 4.8.8 gives the schematic directional beamline layout.

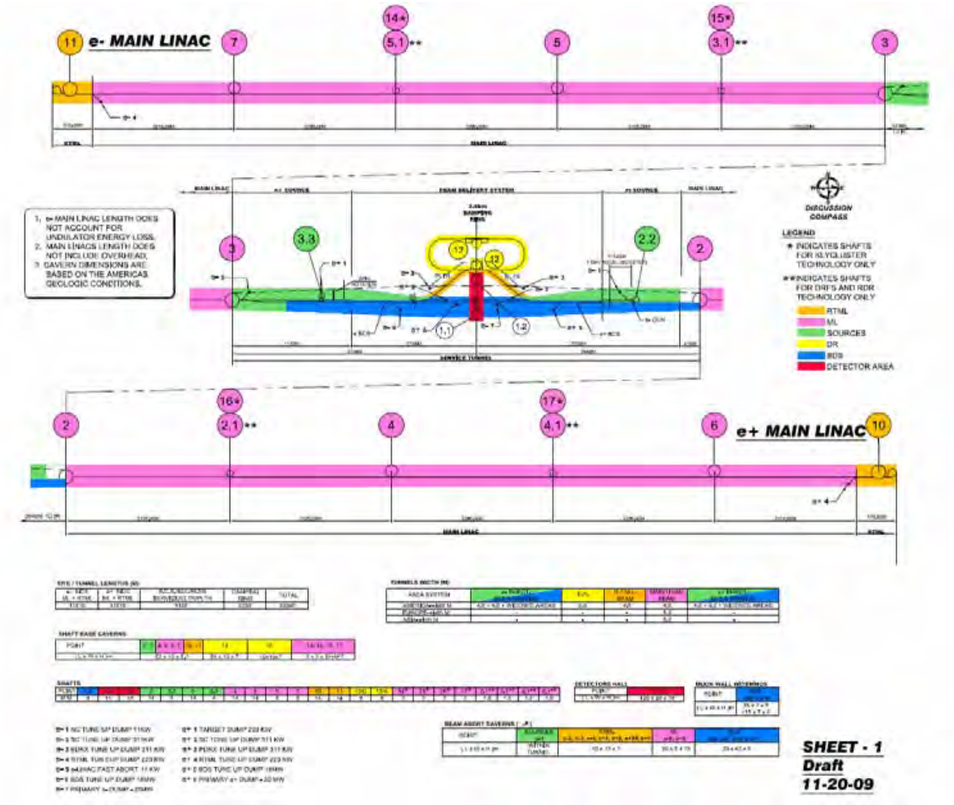


Figure 4.8.7: Overall Schematic Machine Layout

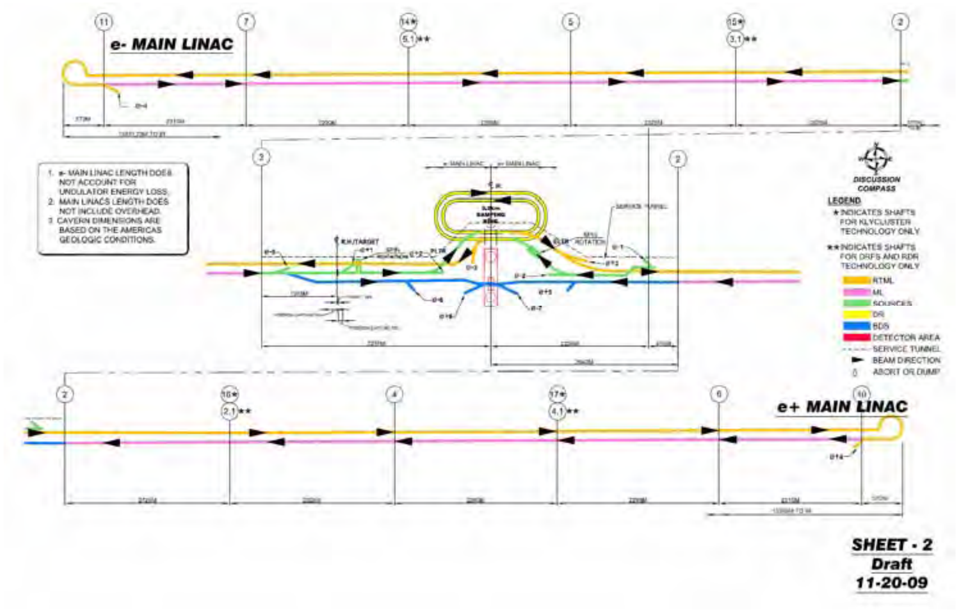


Figure 4.8.8: Schematic Directional Beamline Layout

Overall this present solution has brought a substantial amount of cost reduction, as will be summarized in Section 5. By far, the largest single contribution was the elimination of the Main Linac service tunnels and the establishment of a single tunnel Main Linac design solution. Although geologic limitations have necessarily required local tunnel and enclosure design, each of the three regions have developed a single tunnel solution based on the most appropriate RF distribution scheme for each respective sample site. Each solution has been reviewed and provides a Life Safety and Egress configuration that is compliant with local experience and known regulatory requirements.

The new central region layout has been established and will become the basis for the overall machine design in all three regions. As with the Main Linac tunnel, the enclosures and caverns for the central region layout will necessarily require adaptation to each region's geologic requirements, but the beamline layout will remain the same for all three regions.

The "low power" option for the electrical distribution did not generate a great deal of CFS cost savings due to the assumption that the disruption to machine running during the eventual upgrade to "full power" operation should be minimized. This is an issue that could be revisited in the future, however not in the timeframe of this proposal. CFS cost savings were identified and will be added to the technical system cost savings for an overall total savings for WA 4.

One final point needs to be addressed. No further work has been initiated since the RDR effort by the CFS Group regarding single tunnel installation issues and scheduling. This remains an open issue that will be studied as part of TDP II.

# 5 Cost Differentials

Primary authors: PHG; Associate authors: Bialowons, Shidara

## *5.1 Purpose*

This section describes the studies that have been made so far on the cost differentials that would result from the changes of the design baseline that are presented in an earlier part of this proposal document. The primary focus of this costing exercise, at this stage, is to understand and support the cost changes in the context of overall evaluation of the design changes. Therefore, no re-evaluations are considered for the costing numbers that were already presented in the RDR. The results presented here, together with those from risk assessment, after due review process, would then form the basis for the baseline assumptions in TDP2, where the full technical design and cost estimating work will be built upon.

## *5.2 Methodology*

**Unit costs of individual components:** The same unit cost numbers as RDR are used, whenever the same components are used in the proposed new baseline scheme. Exceptions are the Klystron Clusters and Disributed RF Systems (DRFS) for the main linacs where radically new components which did not appear in RDR are introduced. For these, the unit cost numbers were evaluated for each of the new components and are used to estimate the relevant system cost. Otherwise, no new new unit costs are generated, and relatively straightforward updates from the RDR estimate are made, whenever possible. Part of this work include some scaling or parameterization from RDR unit costs or summary costs.

**Technical systems and conventional facilities:** The ILC RDR estimate had a single design and a single cost estimate for the technical elements, such as power supplies, magnets, RF components, vacuum systems, control systems and others. However, for the conventional facilities and civil construciton, the RDR studies were made on the three regional sample sites, separately, to account for effects of differing geologies and geographies and differing conventional construction and facilities designs.

The estimates for the SB2009 studies address two technical approaches and configurations for the RF power source systems for the main linacs, i.e. the Klystron Clusters and DRFS. They are both considered for each of the three regional sample sites. It is noted, however, that for these considerations, there are some known inter-dependence between a particular site and a preferred technical approach or configuration.

**Cost differentials:** To help understand the cost impacts of the proposed design changes which consist of a multiple number of elements, we choose to present here the cost *differentials* relative to the "reference point" (starting point). The reference point is defined as follows:

Reference point = RDR + Corrections + 6.4 km racetrack DR + single-stage Bunch Compressor

The cost differentials quoted with respect to this "reference point" is expected allow examination and comparison of various elements within the proposed design changes in a more coherent fashion. In many cases, the design changes can be said to have cost impacts in an "orthogonal manner" which can be factored. For instance, adopting a single tunnel and Klystron Cluster/DRFS for the Main Linac does not affect the DR configuration or associated cost differencials. However, exceptions also exist.

For example, the choice of a 3.4 km Damping Ring may make it difficult to adopt the Full Power (2625 bunches/train) option for the ML.

## *5.3 Scenarios Being Estimated*

(will include not only estimates or differentials, but a few words on each)

**Base => RDR estimate**

**$ 6,618 M = avg of 3 regions, $ 6,677 M = Americas' regional estimate <=**

**Two adjustments to the RDR Estimate =>**

Correction of America's CFS/Civil: Shaft Base Cavern Volumes (RTML & ML) and Concrete Floor (RTML)

**-$ XY M -a.b%**

Value Engineering Optimization for Higher ΔT Cooling Water (ML only)

**-$ XY M -a.b%**

**Two actions previously accepted at Sendai, March 2008 =>**

DR: 6.4 KM Racetrack – Full Power – reduces bunch length 9 mm => 6 mm enabling 1-stage BC in RTML

Reduced tunnel from 6695 meters (RDR hexagonal DR) => 6476 meters

per ring: # RF cavities/CM = 18, # Klystrons & Modulators = 5, # wigglers = 88 (from 80 in RDR)

**+ $ XY M + a.b %**

Single Stage Bunch Compressors for RTML – each side reduced from 16 RF units to 14 RF units and only need one diagnostic and tune-up/abort dump section per side

**-$ XY M - a.b % CUMULATIVE: -$ XYZ M -a.b %**

**Starting Point for SB2009 Studies => *Differential Costs Start HERE!***

Klystron Cluster (ML only) – Full Power – Single Tunnel

**-$ XYZ M -a.b %**

Distributed RF System (DRFS) (ML only) – Full Power - Single Tunnel

**-$ XYZ M - a.b % 31oct09 – corrected for Fukuda-san RF pulse distribution**

Klystron Cluster (ML only) – Low Power – Single Tunnel

**-$ XYZ M - a.b % don't forget costs of traveling focus (see below) to restore Luminosity**

Distributed RF System (DRFS) (ML only) – Low Power - Single Tunnel

**-$ XYZ M - a.b % don't forget costs of traveling focus (see below) to restore Luminosity**

**31oct09 – corrected for Fukuda-san RF pulse distribution**

DR: 6.4 KM Racetrack – Low Power

6474 m & per ring: # RF cavities/CM = 10, # Klystrons & Modulators = 3, # wigglers = 88

**-$ XYZ M -a.b % wrt Sendai 6.4 KM Racetrack DR (normal power)**

**– this Sendai change was already credited**

or **-$ XYZ M** wrt RDR 6.7 KM Hexagonal DR (normal power) – in case tempted to double-count!

**don't forget costs of traveling focus (see below) to restore Luminosity**

DR: 3.2 KM Racetrack – inherently Low Power:

3238 m & per ring: # RF cavities/CM = 8 # Klystrons & Modulators = 2, # wigglers = 32

**-$ XYZ M -a.b % wrt Sendai 6.4 KM Racetrack DR (normal power)**

**– this Sendai change was already credited**

or **-$ XYZ M** wrt to DR 6.7 KM Hexagonal DR (normal power)

**don't forget costs of traveling focus (see below) to restore Luminosity**

Travelling Focus – cavities, RF system, LLRF, and cryogenics distribution

**+ $ XY M +a.b% don't forget costs of traveling focus (see below) to restore Luminosity**

This should be added once if any of the four Low-Power options are included: Klystron Cluster Low-P, DRFS Low-P, 6.4 KM DR Low-P, or 3.2 KM DR

Add 3-4 % Energy Redundancy in ML to maintain Machine Availability at top energy – 1nov09

**+a.b%** for **3.5% energy redundancy** for A" => 2 tunnels

**+a.b% to + c.d%**f or **3.5% energy redundancy** for Single Tunnel:

Klystron Cluster, DRFS, and Low-Power versions of both

**Differentials Still Needed:**

Central Region Optimization: (all of these assume 500+500 GeV Full Power beam dumps)

Move Undulator Positron Source to end of e- ML (250 GeV point)

**"energy collimation" needed before Undulator and BDS – 1 or 2 on e- side?**

Reduced length BDS (but include 250 GeV e- bypass around Positron source)

Join to (any) Racetrack DR closer to IP (~ +/- 100 m compared to ~ +/- 900 m for RDR)

**416 m "timing drift" on e+ BDS side**

**Energy margin or redundancy of ~4% (RDR had 394 m empty tunnels, no elements, for this ~ 3.5%)**

## *5.4 Issues with the Cost Study*

**Issues with the current cost study:** New Electrical Power estimates have not being done completely. There has not been an electrical engineer assigned to the ILC-GDE CFS team since John Pedersen (CERN) was reassigned and John Santic (Fermilab) passed away, both over two years ago. An electrical engineer has recently been assigned at Fermilab. Only the impact on the electrical power equipment cost estimate for the Low Power option for the Klystron Cluster has been evaluated at this time. Similarly, due to lack of available personnel, the impacts on the Cryogenics estimates have only been evaluated in a parametric scaling manner for these new scenarios. It is unlikely that the impact in these areas will be fully evaluated for consideration by the SB2009 studies. However, it is anticipated that adequate electrical and cryogenic engineering will be available for the Technical Design Phase.

**Issues with the forthcoming cost study in TDP2:** ...