RDR Report Writing

Nan Phinney
SLAC
for RDR team of editors

ILC Documents

Brochure – non-technical audiences, ready now

"Quantum Universe" level booklet ~30 pages

Executive Summary ~ 30 pages

Physics motivation, accelerator and detectors

RDR Report ~ 300 pages

high level description of the accelerator

DCR Report ~ 250 pages

physics and detectors

RDR Editors:

Nan Phinney (SLAC), Nobu Toge (KEK), Nick Walker (DESY)

RDR Report

RDR is a high level description of the accelerator, CFS, sites and costs
  - similar to 2001 Tesla TDR or 2003 GLC Report

A snapshot of what we propose to build
  - not a history of R&D, design evolution, and alternatives

Original schedule was complete draft now, but has been pushed back because of cost iterations

We have in hand a working outline for the RDR and outlines or drafts of many sections

Draft Outline (1)

I) RDR Introduction

RDR Org and process (Walker)	5 pages	

II) Accelerator Design

1.	ILC Parameters (Yokoya)	5 pages	
2.	Electron Source (Brachmann)	10 pages	✓
3.	Positron Source (Bharadwaj)	15 pages	✓
4.	Damping Rings (Gao)	20 pages	✓
5.	RTML (Tenenbaum)	10 pages	✓
6.	Main Linacs (Adolphsen)	20 pages	
7.	Beam Delivery (Seryi)	20 pages	✓
8.	Beam Dynamics (Schulte)	10 pages	✓
9.	Operations and Availability (Himel)	15 pages	✓

Draft Outline (2)

III) Technical and Global Systems

1.	Magnets (Tartaglia)	5 pages	✓
2.	Vacuum (Noonan)	5 pages	✓
3.	Modulator (Larsen)	5 pages	✓
4.	Klystron (Larsen)	5 pages	✓
5.	Power distribution (Larsen)	5 pages	✓
6.	Cavities (Mammosser)	10 pages	
7.	Cryomodules (Carter)	10 pages	
8.	Cryogenics (Peterson)	10 pages	✓
9.	LLRF (Simrock)	5 pages	✓
10.	Control & Timing Systems(Carwardine)	15 pages	✓
11.	Instrumentation (Burrows)	10 pages	
12.	Dumps and Collimators (Markiewicz)	5 pages	

Draft Outline (3)

IV) Conventional facilities

1.	Introduction	5 pages
2.	Site layout	10 pages
3.	Tunnel layout	5 pages
4.	AC Power distribution	3 pages
5.	Cooling water and Air conditioning	3 pages
6.	Safety systems	3 pages
7.	Metrology and Alignment	5 pages
8.	Construction plan and installation	5 pages

V) Sample Sites

1.	Americas (Kuchler)	5 pages
2.	Asia (Enomoto)	5 pages
3.	Europe – Germany (Baldy)	5 pages
4.	Europe – Switzerland (Baldy)	5 pages

Draft Outline (4)

VI) Cost 20 pages

1. Introduction – Methods and Assumptions
2. Overview
3. Accelerator
4. Conventional Facilities
5. Construction Cost Summary
6. Operating Costs

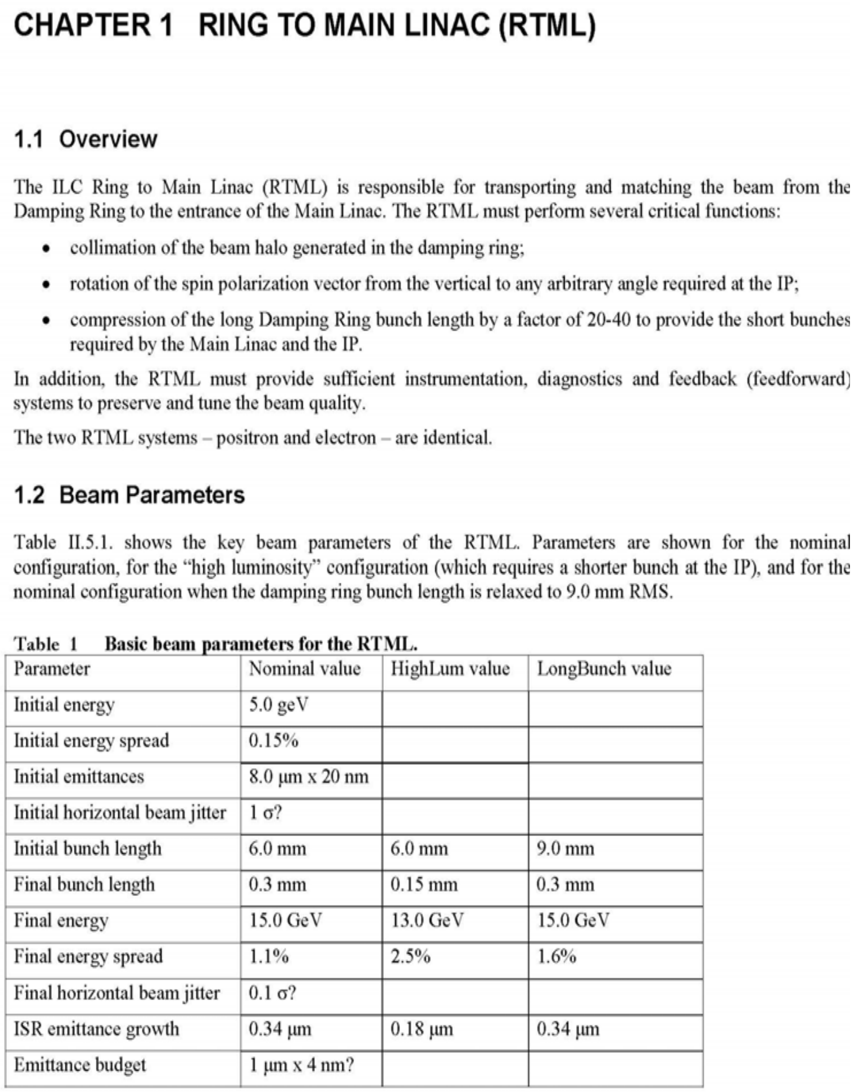
VII) EDR R&D Plan 20 pages

1. Overview (Foster)
2. R&D issues (RDB)

Accelerator Design Section

- Overview – high level requirements
- Key Parameter table
- System description
  - Layout schematic
  - Subsystem 1
    - include graphics or tables as needed
  - Subsystem 2, etc.
- Optics and accelerator physics issues
- Technical systems issues
    - mention any interesting technical components
- Tables summarizing components, lengths
    - magnets, diagnostics, rf, etc.

RTML Section



CHAPTER 1 RING TO MAIN LINAC (RTML)

1.1 Overview

The ILC Ring to Main Linac (RTML) is responsible for transporting and matching the beam from the Damping Ring to the entrance of the Main Linac. The RTML must perform several critical functions:

- collimation of the beam halo generated in the damping ring;
- rotation of the spin polarization vector from the vertical to any arbitrary angle required at the IP;
- compression of the long Damping Ring bunch length by a factor of 20-40 to provide the short bunches required by the Main Linac and the IP.

In addition, the RTML must provide sufficient instrumentation, diagnostics and feedback (feedforward) systems to preserve and tune the beam quality.

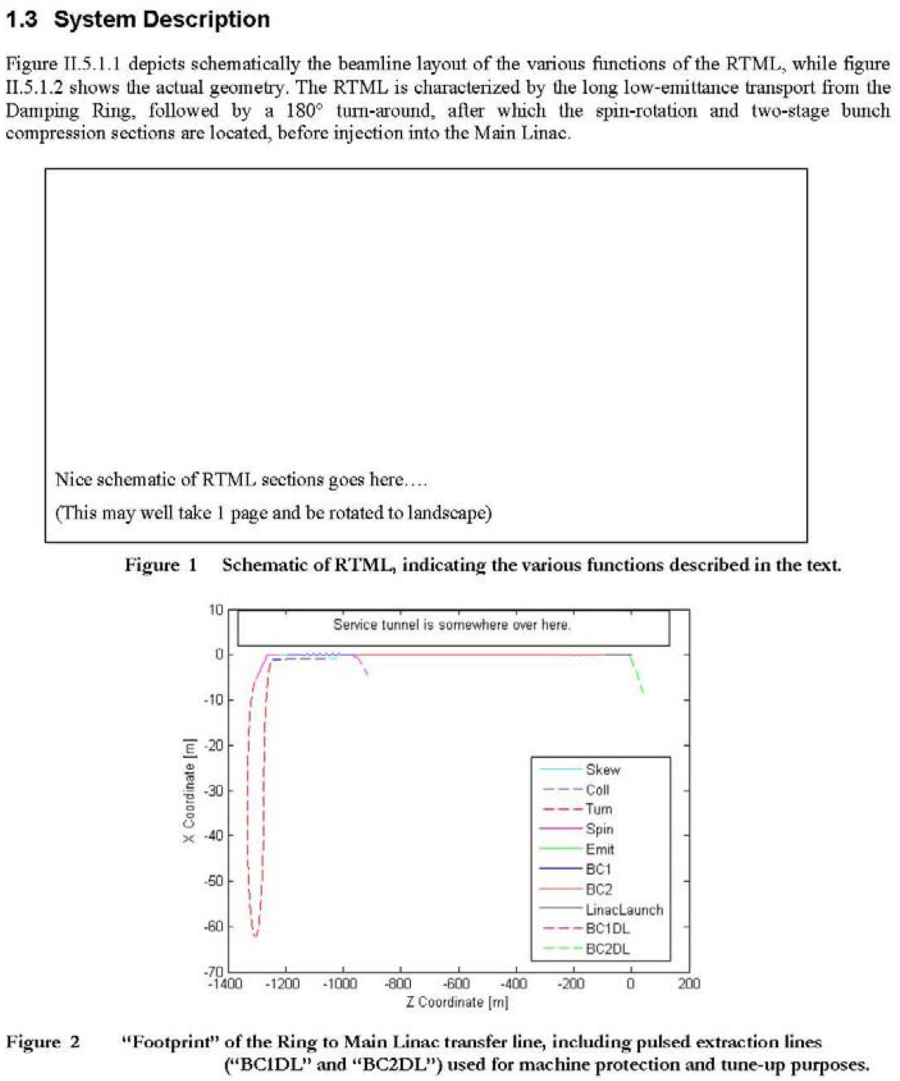
The two RTML systems – positron and electron – are identical.

1.2 Beam Parameters

Table II.5.1. shows the key beam parameters of the RTML. Parameters are shown for the nominal configuration, for the "high luminosity" configuration (which requires a shorter bunch at the IP), and for the nominal configuration when the damping ring bunch length is relaxed to 9.0 mm RMS.

Table 1 Basic beam parameters for the RTML.

Parameter	Nominal value	HighLum value	LongBunch value
Initial energy	5.0 geV		
Initial energy spread	0.15%		
Initial emittances	8.0 µm x 20 nm		
Initial horizontal beam jitter	1 σ?		
Initial bunch length	6.0 mm	6.0 mm	9.0 mm
Final bunch length	0.3 mm	0.15 mm	0.3 mm
Final energy	15.0 GeV	13.0 GeV	15.0 GeV
Final energy spread	1.1%	2.5%	1.6%
Final horizontal beam jitter	0.1 σ?		
ISR emittance growth	0.34 µm	0.18 µm	0.34 µm
Emittance budget	1 µm x 4 nm?		



1.3 System Description

Figure II.5.1.1 depicts schematically the beamline layout of the various functions of the RTML, while figure II.5.1.2 shows the actual geometry. The RTML is characterized by the long low-emittance transport from the Damping Ring, followed by a 180° turn-around, after which the spin-rotation and two-stage bunch compression sections are located, before injection into the Main Linac.

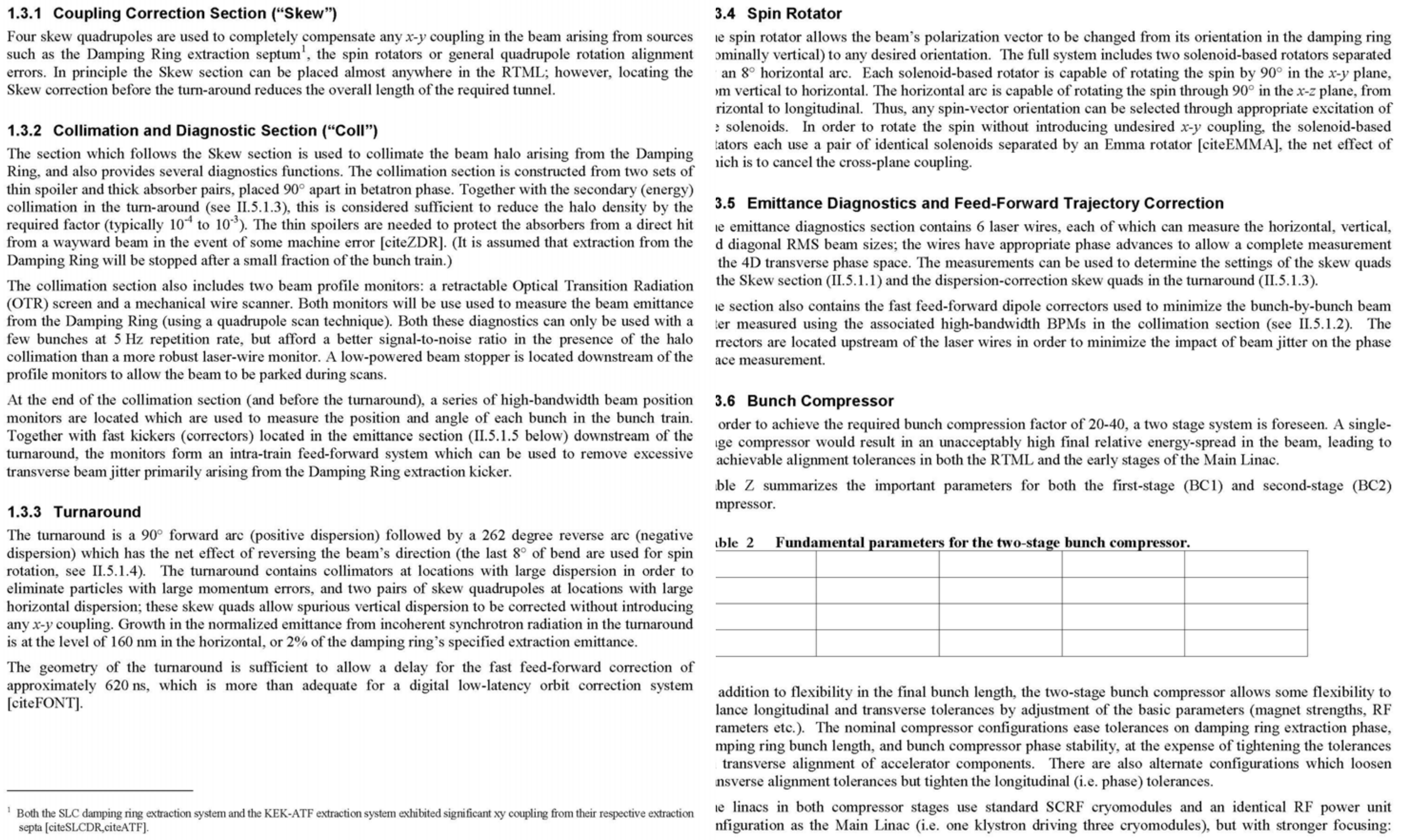
Nice schematic of RTML sections goes here….

(This may well take 1 page and be rotated to landscape)

Figure 1 Schematic of RTML, indicating the various functions described in the text.

Figure 2 "Footprint" of the Ring to Main Linac transfer line, including pulsed extraction lines ("BC1DL" and "BC2DL") used for machine protection and tune-up purposes.

RTML Section 2



1.3.1 Coupling Correction Section ("Skew")

Four skew quadrupoles are used to completely compensate any x-y coupling in the beam arising from sources such as the Damping Ring extraction septum[1], the spin rotators or general quadrupole rotation alignment errors. In principle the Skew section can be placed almost anywhere in the RTML; however, locating the Skew correction before the turn-around reduces the overall length of the required tunnel.

1.3.2 Collimation and Diagnostic Section ("Coll")

The section which follows the Skew section is used to collimate the beam halo arising from the Damping Ring, and also provides several diagnostics functions. The collimation section is constructed from two sets of thin spoiler and thick absorber pairs, placed 90° apart in betatron phase. Together with the secondary (energy) collimation in the turn-around (see II.5.1.3), this is considered sufficient to reduce the halo density by the required factor (typically 10^{-4} to 10^{-3}). The thin spoilers are needed to protect the absorbers from a direct hit from a wayward beam in the event of some machine error [citeZDR]. (It is assumed that extraction from the Damping Ring will be stopped after a small fraction of the bunch train.)

The collimation section also includes two beam profile monitors: a retractable Optical Transition Radiation (OTR) screen and a mechanical wire scanner. Both monitors will be use used to measure the beam emittance from the Damping Ring (using a quadrupole scan technique). Both these diagnostics can only be used with a few bunches at 5 Hz repetition rate, but afford a better signal-to-noise ratio in the presence of the halo collimation than a more robust laser-wire monitor. A low-powered beam stopper is located downstream of the profile monitors to allow the beam to be parked during scans.

At the end of the collimation section (and before the turnaround), a series of high-bandwidth beam position monitors are located which are used to measure the position and angle of each bunch in the bunch train. Together with fast kickers (correctors) located in the emittance section (II.5.1.5 below) downstream of the turnaround, the monitors form an intra-train feed-forward system which can be used to remove excessive transverse beam jitter primarily arising from the Damping Ring extraction kicker.

1.3.3 Turnaround

The turnaround is a 90° forward arc (positive dispersion) followed by a 262 degree reverse arc (negative dispersion) which has the net effect of reversing the beam's direction (the last 8° of bend are used for spin rotation, see II.5.1.4). The turnaround contains collimators at locations with large dispersion in order to eliminate particles with large momentum errors, and two pairs of skew quadrupoles at locations with large horizontal dispersion; these skew quads allow spurious vertical dispersion to be corrected without introducing any x-y coupling. Growth in the normalized emittance from incoherent synchrotron radiation in the turnaround is at the level of 160 nm in the horizontal, or 2% of the damping ring's specified extraction emittance.

The geometry of the turnaround is sufficient to allow a delay for the fast feed-forward correction of approximately 620 ns, which is more than adequate for a digital low-latency orbit correction system [citeFONT].

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[1] Both the SLC damping ring extraction system and the KEK-ATF extraction system exhibited significant xy coupling from their respective extraction septa [citeSLCDR,citeATF].

3.4 Spin Rotator

e spin rotator allows the beam's polarization vector to be changed from its orientation in the damping ring ominally vertical) to any desired orientation. The full system includes two solenoid-based rotators separated an 8° horizontal arc. Each solenoid-based rotator is capable of rotating the spin by 90° in the x-y plane, m vertical to horizontal. The horizontal arc is capable of rotating the spin through 90° in the x-z plane, from rizontal to longitudinal. Thus, any spin-vector orientation can be selected through appropriate excitation of solenoids. In order to rotate the spin without introducing undesired x-y coupling, the solenoid-based ators each use a pair of identical solenoids separated by an Emma rotator [citeEMMA], the net effect of ich is to cancel the cross-plane coupling.

3.5 Emittance Diagnostics and Feed-Forward Trajectory Correction

e emittance diagnostics section contains 6 laser wires, each of which can measure the horizontal, vertical, d diagonal RMS beam sizes; the wires have appropriate phase advances to allow a complete measurement the 4D transverse phase space. The measurements can be used to determine the settings of the skew quads the Skew section (II.5.1.1) and the dispersion-correction skew quads in the turnaround (II.5.1.3).

e section also contains the fast feed-forward dipole correctors used to minimize the bunch-by-bunch beam ter measured using the associated high-bandwidth BPMs in the collimation section (see II.5.1.2). The rrectors are located upstream of the laser wires in order to minimize the impact of beam jitter on the phase ace measurement.

3.6 Bunch Compressor

order to achieve the required bunch compression factor of 20-40, a two stage system is foreseen. A single-ge compressor would result in an unacceptably high final relative energy-spread in the beam, leading to achievable alignment tolerances in both the RTML and the early stages of the Main Linac.

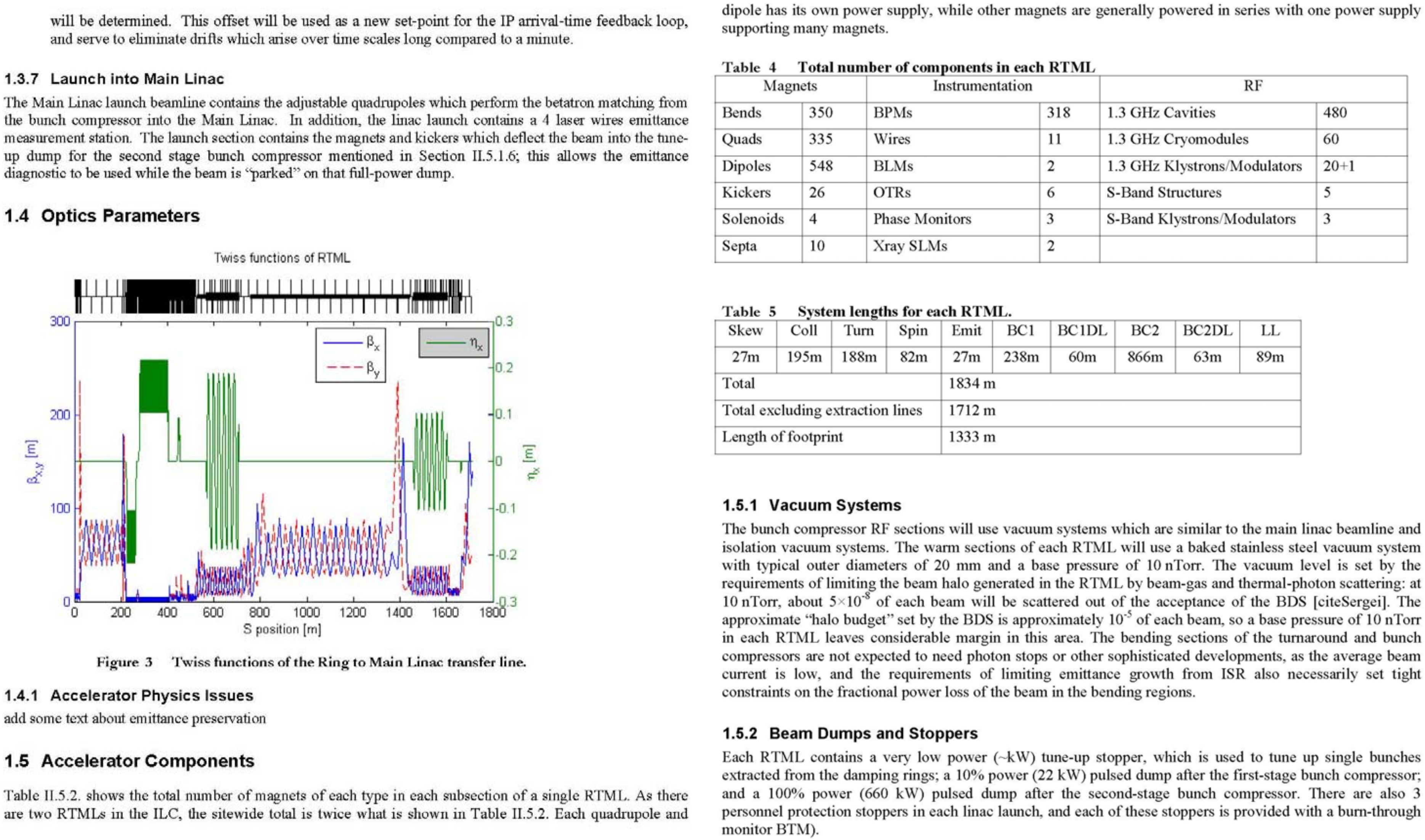
ble Z summarizes the important parameters for both the first-stage (BC1) and second-stage (BC2) mpressor.

ble 2 **Fundamental parameters for the two-stage bunch compressor.**

addition to flexibility in the final bunch length, the two-stage bunch compressor allows some flexibility to lance longitudinal and transverse tolerances by adjustment of the basic parameters (magnet strengths, RF rameters etc.). The nominal compressor configurations ease tolerances on damping ring extraction phase, mping ring bunch length, and bunch compressor phase stability, at the expense of tightening the tolerances transverse alignment of accelerator components. There are also alternate configurations which loosen nsverse alignment tolerances but tighten the longitudinal (i.e. phase) tolerances.

e linacs in both compressor stages use standard SCRF cryomodules and an identical RF power unit nfiguration as the Main Linac (i.e. one klystron driving three cryomodules), but with stronger focusing:

RTML Section 3



will be determined. This offset will be used as a new set-point for the IP arrival-time feedback loop, and serve to eliminate drifts which arise over time scales long compared to a minute.

1.3.7 Launch into Main Linac

The Main Linac launch beamline contains the adjustable quadrupoles which perform the betatron matching from the bunch compressor into the Main Linac. In addition, the linac launch contains a 4 laser wires emittance measurement station. The launch section contains the magnets and kickers which deflect the beam into the tune-up dump for the second stage bunch compressor mentioned in Section II.5.1.6; this allows the emittance diagnostic to be used while the beam is "parked" on that full-power dump.

1.4 Optics Parameters

Figure 3 Twiss functions of the Ring to Main Linac transfer line.

1.4.1 Accelerator Physics Issues

add some text about emittance preservation

1.5 Accelerator Components

Table II.5.2. shows the total number of magnets of each type in each subsection of a single RTML. As there are two RTMLs in the ILC, the sitewide total is twice what is shown in Table II.5.2. Each quadrupole and dipole has its own power supply, while other magnets are generally powered in series with one power supply supporting many magnets.

Table 4 Total number of components in each RTML

Magnets		Instrumentation		RF	
Bends	350	BPMs	318	1.3 GHz Cavities	480
Quads	335	Wires	11	1.3 GHz Cryomodules	60
Dipoles	548	BLMs	2	1.3 GHz Klystrons/Modulators	20+1
Kickers	26	OTRs	6	S-Band Structures	5
Solenoids	4	Phase Monitors	3	S-Band Klystrons/Modulators	3
Septa	10	Xray SLMs	2		

Table 5 System lengths for each RTML.

Skew	Coll	Turn	Spin	Emit	BC1	BC1DL	BC2	BC2DL	LL
27m	195m	188m	82m	27m	238m	60m	866m	63m	89m
Total				1834 m					
Total excluding extraction lines				1712 m					
Length of footprint				1333 m					

1.5.1 Vacuum Systems

The bunch compressor RF sections will use vacuum systems which are similar to the main linac beamline and isolation vacuum systems. The warm sections of each RTML will use a baked stainless steel vacuum system with typical outer diameters of 20 mm and a base pressure of 10 nTorr. The vacuum level is set by the requirements of limiting the beam halo generated in the RTML by beam-gas and thermal-photon scattering: at 10 nTorr, about 5×10^{-8} of each beam will be scattered out of the acceptance of the BDS [citeSergei]. The approximate "halo budget" set by the BDS is approximately 10^{-5} of each beam, so a base pressure of 10 nTorr in each RTML leaves considerable margin in this area. The bending sections of the turnaround and bunch compressors are not expected to need photon stops or other sophisticated developments, as the average beam current is low, and the requirements of limiting emittance growth from ISR also necessarily set tight constraints on the fractional power loss of the beam in the bending regions.

1.5.2 Beam Dumps and Stoppers

Each RTML contains a very low power (~kW) tune-up stopper, which is used to tune up single bunches extracted from the damping rings; a 10% power (22 kW) pulsed dump after the first-stage bunch compressor; and a 100% power (660 kW) pulsed dump after the second-stage bunch compressor. There are also 3 personnel protection stoppers in each linac launch, and each of these stoppers is provided with a burn-through monitor BTM).

Technical Section

Overview - High level description of components

Technical Issues

- Major classes considered, issues, how evaluated
- Special challenges, solutions

Cost Estimation with Table of components

Example: Vacuum

- >100 km of beamlines under vacuum, mostly conventional
- issues – Cryomodules, electron & positron source, DR, …
  - how issues were addressed in design
  - approach used to develop costs

not a catalog of every system but a discussion of issues and solutions

Vacuum Section

CHAPTER 1 VACUUM SYSTEMS

1.1 Overview

The ILC has over 100 km of beamlines which must be kept under vacuum to limit the beam-gas scattering. Different areas of the machine present different challenges but fortunately, there is an experience base at existin accelerators for essentially all of the systems, to facilitate design and costing. The largest and most complex are the vacuum systems for the cryomodules containing superconducting cavities that accelerate the beam. In addition to the ~1800 cryomodules in the main linacs, there are similar cryomodules in the electron and positron booster linacs and bunch compressors. There are also single cavity cryomodules in the damping rings and beam delivery systems. These cryogenic units require separate vacuum systems for the beam line, the insulating vacuum and the waveguides.

Other beamlines throughout the ILC pose particular challenges. The lifetime of the electron source photocathod requires a vacuum in the range of a nano-torr. The superconducting undulator for the positron source is a warm bore chamber with a very small aperture. Chambers for bending magnets in the damping rings and elsewhere require antechambers and photon absorbers for the synchrotron radiation. The presence of electron cloud in the positron damping ring and ions in the electron damping ring can seriously impact performance and requires mitigation. Beam-gas scattering in the beam delivery must be limited to reduce backgrounds in the experimental detectors. The designs for each system and costing approach are discussed in more detail below.

1.2 Technical Issues

1.2.1 Linac cryomodules

There are ~30 km of cryomodules in the main linac and ~ another km of modules in the sources and bunch compressors. Each cryomodules has separate vacuum systems for the accelerating structures, the insulating vacuum and the transmission waveguides. The structure vacuum vessel holds the niobium cavities and is at 2K cryogenic temperature. This system must produce very low quantities of particulates as these can contaminate the cavities causing field emission and lowering the available gradient. The system must also be able to produce ultra-high vacuum at room temperature so eliminate the risk of residual gases condensing on the niobium wallls during cooldown. The beamline vacuum is segmented into strings of 142 m. Each string has an insulating vacuum break and a port for valves and ion pumps. Every other string has additional valves, pumps, leak detection, and vacuum diagnostics. Each group of 4 strings (571 m) has cold vacuum isolation valves. A vacuum/diagnostics station is installed between every 16 strings (2,288 m). These stations have slow start turbo molecular pumps, leak detection, clean venting systems, and warm isolation valves.

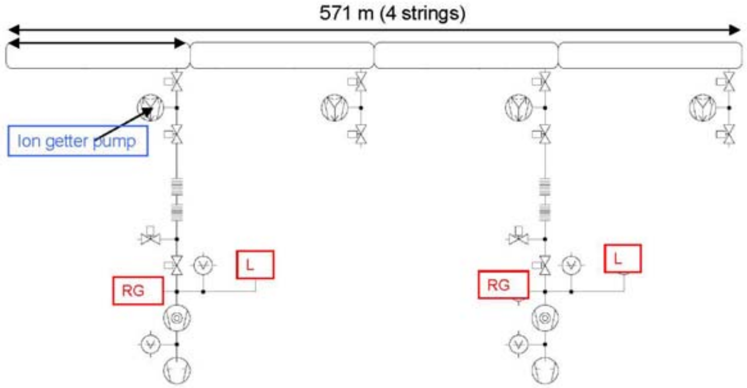


Figure 1 Beamline vacuum system - 2 TMP pumping units with high sensitivity LD and RGA, safety, clean venting system, slow start pumping etc.

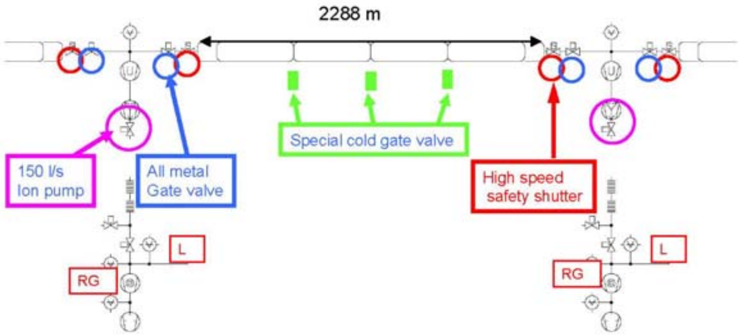


Figure 2 Beamline vacuum system gates and valves

The insulating vacuum system must maintain a typical pressure of ~0.1 mTorr, a regime where high voltage breakdown is a serious issue. It is complicated by the pump cabling from the main system which must pass through the insulating vacuum. The system is segmented into 142m strings consistent with the beamline vacuum. Each string has valves, a turbomolecular pump, and bypass valves. Every other string additionally has a leak detector and a large screw pump.

Vacuum Section 2

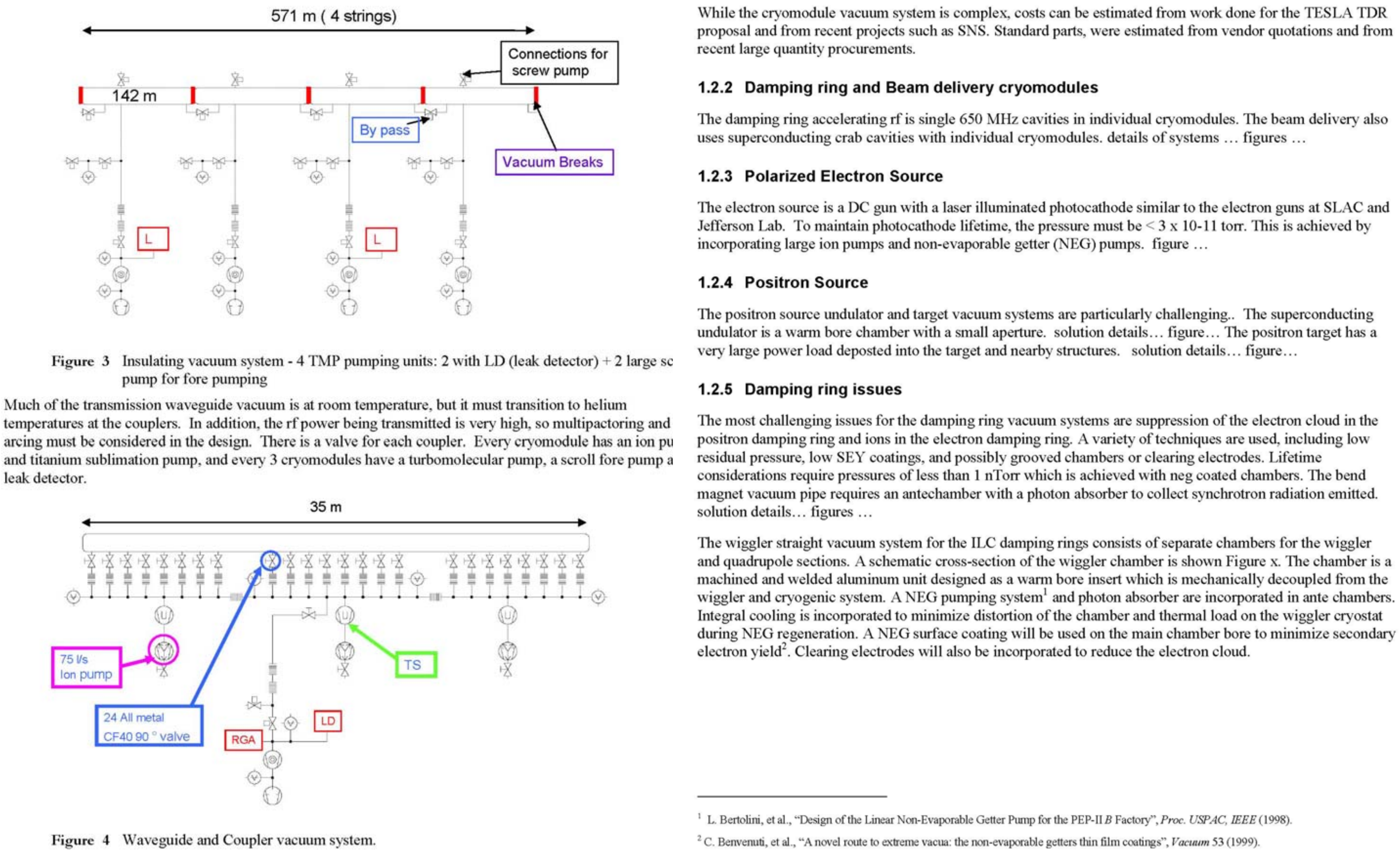


Figure 3 Insulating vacuum system - 4 TMP pumping units: 2 with LD (leak detector) + 2 large sc pump for fore pumping

Much of the transmission waveguide vacuum is at room temperature, but it must transition to helium temperatures at the couplers. In addition, the rf power being transmitted is very high, so multipactoring and arcing must be considered in the design. There is a valve for each coupler. Every cryomodule has an ion pu and titanium sublimation pump, and every 3 cryomodules have a turbomolecular pump, a scroll fore pump a leak detector.

Figure 4 Waveguide and Coupler vacuum system.

While the cryomodule vacuum system is complex, costs can be estimated from work done for the TESLA TDR proposal and from recent projects such as SNS. Standard parts, were estimated from vendor quotations and from recent large quantity procurements.

1.2.2 Damping ring and Beam delivery cryomodules

The damping ring accelerating rf is single 650 MHz cavities in individual cryomodules. The beam delivery also uses superconducting crab cavities with individual cryomodules. details of systems … figures …

1.2.3 Polarized Electron Source

The electron source is a DC gun with a laser illuminated photocathode similar to the electron guns at SLAC and Jefferson Lab. To maintain photocathode lifetime, the pressure must be < 3 x 10-11 torr. This is achieved by incorporating large ion pumps and non-evaporable getter (NEG) pumps. figure …

1.2.4 Positron Source

The positron source undulator and target vacuum systems are particularly challenging.. The superconducting undulator is a warm bore chamber with a small aperture. solution details… figure… The positron target has a very large power load deposted into the target and nearby structures. solution details… figure…

1.2.5 Damping ring issues

The most challenging issues for the damping ring vacuum systems are suppression of the electron cloud in the positron damping ring and ions in the electron damping ring. A variety of techniques are used, including low residual pressure, low SEY coatings, and possibly grooved chambers or clearing electrodes. Lifetime considerations require pressures of less than 1 nTorr which is achieved with neg coated chambers. The bend magnet vacuum pipe requires an antechamber with a photon absorber to collect synchrotron radiation emitted. solution details… figures …

The wiggler straight vacuum system for the ILC damping rings consists of separate chambers for the wiggler and quadrupole sections. A schematic cross-section of the wiggler chamber is shown Figure x. The chamber is a machined and welded aluminum unit designed as a warm bore insert which is mechanically decoupled from the wiggler and cryogenic system. A NEG pumping system[1] and photon absorber are incorporated in ante chambers. Integral cooling is incorporated to minimize distortion of the chamber and thermal load on the wiggler cryostat during NEG regeneration. A NEG surface coating will be used on the main chamber bore to minimize secondary electron yield[2]. Clearing electrodes will also be incorporated to reduce the electron cloud.

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[1] L. Bertolini, et al., "Design of the Linear Non-Evaporable Getter Pump for the PEP-II *B* Factory", *Proc. USPAC, IEEE* (1998).

[2] C. Benvenuti, et al., "A novel route to extreme vacua: the non-evaporable getters thin film coatings", *Vacuum* 53 (1999).

Vacuum Section 3

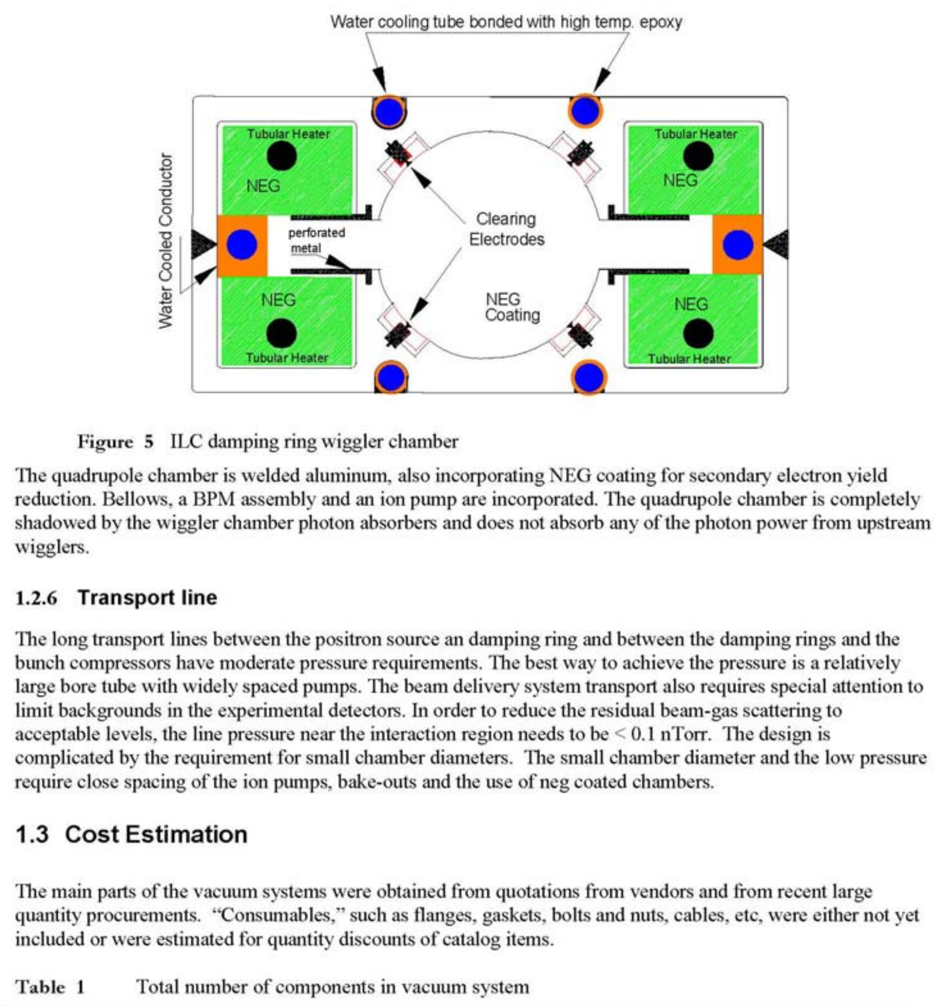

Figure 5 ILC damping ring wiggler chamber

The quadrupole chamber is welded aluminum, also incorporating NEG coating for secondary electron yield reduction. Bellows, a BPM assembly and an ion pump are incorporated. The quadrupole chamber is completely shadowed by the wiggler chamber photon absorbers and does not absorb any of the photon power from upstream wigglers.

1.2.6 Transport line

The long transport lines between the positron source an damping ring and between the damping rings and the bunch compressors have moderate pressure requirements. The best way to achieve the pressure is a relatively large bore tube with widely spaced pumps. The beam delivery system transport also requires special attention to limit backgrounds in the experimental detectors. In order to reduce the residual beam-gas scattering to acceptable levels, the line pressure near the interaction region needs to be < 0.1 nTorr. The design is complicated by the requirement for small chamber diameters. The small chamber diameter and the low pressure require close spacing of the ion pumps, bake-outs and the use of neg coated chambers.

1.3 Cost Estimation

The main parts of the vacuum systems were obtained from quotations from vendors and from recent large quantity procurements. "Consumables," such as flanges, gaskets, bolts and nuts, cables, etc, were either not yet included or were estimated for quantity discounts of catalog items.

Table 1 Total number of components in vacuum system

CFS, Sites, Costs

CFS

- High level description of design
- Leave technical details for ILC notes, wiki

Sites

- Description of site, unique features, constraints

Costs

- Description of approach, assumptions, guidelines
- Technical system approaches

EDR R&D Plan

- Roadmap to EDR, description of R&D needed

Plans until Beijing (Feb. '07)

November | December | January | February

2006 | 2007

Valencia

Further cost consolidation
CCR preparation & submission

Cost & Design Freeze 30/11

Prepare for Full Cost Review

SLAC Cost Review 14-16/12

Final cost corrections and documentation

MAC 10-12/01/07

Agency cost briefings

RDR prepare 1st drafts

RDR final editing

Beijing: RDR draft published

New RDR Schedule

Now: Document and most section outlines in hand, editors to iterate content with section authors

mid-Dec: 1st drafts of Executive Summary and all area, technical, CFS and cost sections

early Jan: Complete draft for review by ILC MAC and discussions with funding agencies

Feb: Draft available in PDF and on web, pending final revisions before publication

Summer 07: Published version

Logistics

- RDR Wiki site to be created this week with
  - Outline, templates, examples, areas for each section
- Password protected with access for RDR_Leaders
  - and additional authors as needed
- Given the tight schedule, we plan to assemble the final document in Latex (like the DCR)
- Authors submit text and figures in either Word or Latex and iterate text with editors, with interim versions viewable in PDF
- Conversion to Latex (+ PDF) only when nearly final

Final Comments

We have a lot to do in a very short time

We need to ask for your full cooperation (and forgiveness)

Your RDR Editorial team

N^3