PAC November Questions / GDE Responses

8-May-10

1. Why are the cost savings only ~ 3% in going from 2 tunnels to 1? Do such seemingly small savings justify the increased reliability risks inherent in a single tunnel scheme? Also, why are the cost savings only ~ 3% in going from ~6 Km damping rings to ~ 3 Km ones?

Although, in an absolute sense, the cost of underground construction is quite expensive, those underground tunnels are filled with expensive high-tech equipment that still must be provided and housed in any alternative configuration. The value estimate in the ILC Reference Design Report (RDR) was 6.6 B ILCUs. Of this total, only 6.25% was for the tunnels for the Main Linac (45 km sum for four tunnels, all approximately equal in length: e- main linac beam tunnel, e- main linac service tunnel, e+ main linac beam tunnel, and e+ main linac service tunnel) and 1.01% was for the damping rings (6.7 km circumference). So, at first view, cutting the tunnel lengths in half for both main linac and damping rings, total estimate is expected to drop by approximately 3% and 0.5%, respectively.

For the main linac, the Klystron Cluster proposal is to reposition the modulators and klystrons from the main linac service tunnel to new, additional service buildings clustered on the surface. The main linac service tunnels; personnel, waveguide, and instrumentation/control penetrations; and much of the conventional underground waveguide would not be needed. However, the special over-moded RF waveguide pipe and both special input and output RF power couplers are needed to distribute the RF power from the surface buildings to the Cryomodules would be added to the cost. Summing these plus and minuses, the total cost difference, assuming still the full power configuration including all the klystron, results in an overall savings about approximately 3.2% of the RDR estimate, or 5.4% of the RDR estimate for the Main Linac. Since the Klystron Cluster would have the same beam-on accessibility to klystrons and modulators located in surface buildings, it should have approximately the same machine availability as having the klystrons and modulators located in a separate service tunnel.

For the Damping Ring, the reduction of the tunnel length provides an overall savings of only 0.5%. Additional savings are provided by less length for vacuum systems and magnet cables, fewer wigglers (2*80 => 2*32), and fewer RF cavities (2*18 => 2*8), fewer controls, diagnostics, and instrumentation. Finally there are less conventional power and cooling and cryogenics required for the shorter DR. Some of the quadrupole magnets for the 3.2 km rings have increased in cost. This results in an overall project savings of 2.9% and a particular savings of 29% for the DR.

For the DR discussion above, the nomenclature is that 2*80 wigglers means there are 80 wigglers in each of the identical e- DR and e+ DR.

Much more detail (spreadsheets) can be provided.

2. How feasible are each of the two rf distribution systems proposed for the single tunnel option?

At first, we need to understand that the motivation for each RF distribution system has a strong site-dependence in relation to the CFS design, and for this reason, both should be pursued in our future technical design efforts.

The Klystron Cluster System (KCS) is feasible, in principle, because it is a passive system in the tunnel. It should be basically identical to the RDR RF distributing system, beyond the general RF distribution line coming down from surface. Having the large RF station with all the active instrumentation being on the surface is an advantage for a flat-land shallow or deep site. The R&D program to demonstrate the RF transmission line is in progress at SLAC to confirm feasibility. A large-scale RF power station with large stored energy may be a next step of demonstration to be considered.

The principle of Distributed RF System (DRFS) has been practically demonstrated in CEBAF (at JLab) and SNS (ORNL), so is well established. In this view, this option is feasible, and it has an advantage for a mountain site to minimize big construction of the RF station and transmission line in the mountain region. The feasibility of the layout, installation and repair-work in tunnel are practical R&D subjects and two prototype DRFS klystrons are under development to be examined in the S1-Global cryomodule tests at KEK, and it has been included in the experimental plan. A further long term test is planned to be realized in 'Quantum Beam Project' in which two 9-cell cavities are to be operated by using on DRFS klystrons for longer term demonstration (~ half year or more). Therefore, the feasibility of the DRFS system with underground tunnel layout shall be experimentally verified at KEK by 2011. The radiation hardness and control/tuning capability with large amount of HLRF/LLRF equipment in the tunnel are another subjects to be overcome.

In parallel to the above efforts, we are planning to organize the 1st Baseline Assessment Workshop (1st BAW) to discuss 'Single Tunnel HLRF' system to be held at KEK on Sept. 7-8, 2010. We are inviting physics/detector groups and external experts to participate and discuss and evaluate the technical feasibility. It will give us appropriate advice and confirmation of feasibility.

3. What is the effect on the electron beam emittance of having the positron source at the end of the electron linac? What is the effect of this positron source location on the experiments when they run at cm energies below ~ 250 GeV?

There are two parts to this question that are best dealt with separately. Since the impact on low-energy centre-of-mass running is the more critical, we will deal with it first.

Low Energy Running

The RDR solution placed the undulator source at the nominal 150 GeV point of the main linac where it was driven at constant electron beam energy, providing a constant positron yield. The remaining ~100 GeV of the main linac downstream of the source was assumed to be adjusted to deliver the desired beam energy at the interaction point, which required deceleration of the beam for centre-of-mass energies below ~300 GeV. The design parameters for the source itself were based on a theoretical positron yield of 1.5 e+ per e- (1 is required, with 50% margin). The SB2009 solution places the undulator at the exit of the linac, and assumes the same yield with an electron beam energy of 150 GeV (i.e. E_{cm} = 300 GeV). This infers the same basic arrangement and parameters as for the RDR solution. For 300 GeV < E_{cm} < 500 GeV, the positron yield will be maintained constant by switching off undulator sections ($L_{und} \alpha E^{-2}$ for an assumed fixed undulator field). Thus for this region no loss of luminosity from the RDR solution is expected.

For E_{cm} < 300 GeV the performance of the source deteriorates rapidly due to the threshold for pair production. For 250 GeV and below, an alternative pulsing scheme has been proposed, where separate beam pulses are used for positron production (with a beam energy of 150 GeV) and luminosity production (100-150 GeV). This scheme is currently under study, and recently it has become clear that it is possible to run the machine at these lower energies (lower linac gradients) at 8Hz with no additional power or cooling requirements for the electron Main Linac. This results in a 4Hz collision rate with full positron current supplying 80% of the luminosity expected with the source located at the RDR location (assuming no other changes in beam parameters at the IP). It may be possible to recover the entire 5Hz operation (100% compared to the RDR location). While there are still further studies to be made, initial considerations of the impact of this operation mode across all subsystems (including the damping ring) have indicated no major problems (or cost).

Impact on emittance

Fundamentally the undulator source damps the emittance on the order of ~1%, and this is expected to increase at the higher beam energy. Studies of RW

(Resistive Wall) wakes for the RDR beam parameters indicated no issues, and these too will be better at the higher beam energy.

The remaining primary emittance issue comes from alignment errors and the additional energy spread generated by the undulator (chromatic emittance growth). At the top beam energy of 250 GeV, the undulator placed at the exit of the linac increases the single-bunch energy spread by roughly 50% (0.13% to 0.19%). In principle this would increase the chromatic component of emittance growth in the BDS by a factor of 2 but this is tolerable. This effect must be compared to the additional emittance growth in the last 100 GeV of Main Linac due to the increased energy spread from the undulator placed at the 150 GeV point (also a factor of two effect). From these considerations there appears to be no serious degradation in overall emittance, although further simulation studies are probably merited to better quantify the effects.

The impact of the increased 50% energy spread on the physics case is being evaluated.

It should also be noted that the SB2009 scheme improves the beam energy spread (and therefore emittance growth) for centre-of-mass energies below 250 GeV, due to the alternate pulsing scheme described above. This may likely also have positive impact on the physics at low centre-of-mass energies.

4. How is the lack of significant R&D on the undulator positron source affecting confidence in this source design?

R&D on the undulator positron source is aimed at 1) the superconducting helical undulator, 2) the rotating target and 3) the short, pulsed, matching device that follows the target. A key beam-based experiment, E-166 at SLAC, was completed in 2005 and demonstrated the production of polarized positrons from helical undulator radiation. (Physical Review Letters Vol. 100, p 210801 (2008)).

Recently, two full-scale undulators were built and successfully tested at Rutherford Lab. In addition, a rotating wheel, the same size and geometry as the baseline target mechanism, was been built at Daresbury Lab for studying Eddy current effects. Both of these UK-funded programs are expected to conclude in the coming year.

To complement and extend that work, two efforts were started at Livermore Lab in late 2009. One is aimed at studies and tests of the rotating target vacuum seal. In the baseline design this seal uses ferro-fluid technology. Ferro-fluid technology is well proven in technical applications but will require testing in strong magnetic fields and ionizing radiation environments. We expect to complete long term (6 month) and high magnetic field testing by the end of 2012.

The second effort is aimed at developing the pulsed matching device (tapered field pulsed solenoid or flux concentrator) design through electro-mechanical modeling. The 3.5 T flux concentrator design under development is very similar to a 9 T device built at SLAC in 1965. It is based on a stack of single-turn split-ring washers each carrying 1ms long 100 kA pulses. The device would dissipate about 10kW average when operated at a cryogenic temperature (70 K, for reduced resistive loss). In the next 2 years, we expect to complete the conceptual design and develop plans for a single-section test.

While the above will strengthen the baseline positron source design, consideration of alternate designs and related beam testing, possibly extending beyond 2012, is under discussion.

5. How practical is the traveling focus concept, and what studies give confidence in its use in the ILC?

The concept of ‘beating the hour-glass effect’ by effectively using a chirped focusing along the bunch length has been successfully demonstrated in the ‘crab waist scheme’ implemented in the DAFNE storage ring. Although clearly not in the same parameter (high-disruption) regime as the proposed travelling focus for the ILC, the DAFNE result nonetheless shows a proof of principle from the perspective of implementation. The methods and additional hardware required to achieve the beam parameters – in particular the chirped focusing – are well understood and available. There appears to be nothing fundamental in producing the required beam phase space at the IP.

The primary issues arise from the beam-beam interaction itself, and the very high disruption regime of the proposed parameters. There is currently no way foreseen to directly test the TF approach in a regime close to the ILC specifications. Therefore further studies rely entirely on the use of beam-beam simulation codes such as GUINEA PIG or CAIN. This is however generally true for a linear collider, where a typical factor of ~2 in the design luminosity arises from the strong beam-beam pinch enhancement.

With the very strong disruption, the stability of the collision becomes very sensitive to offsets and distortions of the phase-space (both transverse and longitudinal). This will put tighter tolerances on feedback systems, fast kicker systems *etc*. to stabilise the beams to the required level. All of this requires considerably more detailed simulation studies, including understanding how the beam-beam parameters are initially tuned-up. Because of the sensitivity to the beam phase space, full start-to-end simulations will need to be made. A programme of these studies will be defined and carried out over the next ~year. Options for possible beam-tests at ATF2 are also being explored, but these will only address the phase-space tuning aspects of TF, and not the beam-beam aspects, which are probably of more concern.

The cost of supporting TF is negligible, and inclusion of the additional hardware in the baseline design at this juncture seems prudent so as not to exclude its possible implementation. (It is certainly something that would be tried in the real machine, as a possible improvement to the luminosity.) The current studies are too immature and the perceived risk too high to base the luminosity baseline parameters on this technique at this time. A final decision will be made early in 2011, after suitable conclusion of the studies programme and an evaluation of the results.

6. Are there any concerns about the apparent complexity of the proposed tunnel layout in the BDS/DR/IR region?

Yes, there have been concerns about the tunnel layouts of the central region. For this reason the design of this region has been a major emphasis of studies between the CFS and Technical Groups over the last 12 months and the first region chosen for 3D modeling. These have been very productive and have shown that practical layouts are possible after minor modifications of the original concepts, many of which are common to both the RDR and SB2009 designs. For example, the most complex region, which is the positron source, requires special tunnel modifications and component layouts which would be almost the same for a positron source in the middle of the linac. (It should be noted that the central region layouts maintain a support tunnel.) This work continues and will study issues of installation and repair and will be adjusted to accommodate whatever future baseline changes are made. Example solutions will be shown at the upcoming PAC meeting in Valencia.

7. How much can one rely on the program evaluating the machine availability?

The simulation program, *Availsim*, is a tool for comparing the availability of 1) different machine configurations, 2) the impact of different component sub-systems and 3) different operations and maintenance scheduling and management schemes. It also allows study of the interactions between these. While the simulation itself was written by the linear collider team, the concept is not unique to us. Please see the IEEE Gold Book™ IEEE Std 493™-2007 - Recommended Practice for the Design of Reliable Industrial & Commercial Power Systems, section 2.9.

The greatest benefit of the simulation during the project design phase is to provide an assessment of a given design, so that engineers and designers can interpret and adjust component lifetime specifications and component 'accessibility' as installed in the machine. It was used in this fashion, for example, to suggest to the Distributed RF System designers a target klystron lifetime and to allow the development of a maintenance model that shows how many klystrons are to be changed out during a given maintenance interval and how many people are required for that effort. Each of the three features listed above figure in this process. For this specific task the program should be quite reliable since it includes all relevant aspects of the maintenance process.

Nevertheless, important aspects of overall availability, such as allowances for occupational safety, general system logistics, (such as the interference between different maintenance activities), and radiation effects to electronics have not been directly included. We hope to be able to work on these in the coming years, through the end of the technical design phase. Also, the program does not account for 'burn-in' or infant failures that tend to occur during the initial stage of operation. The program is limited to the assessment of component failures and the issues associated with replacing or fixing components.

Availsim has provided a model of a very large complex that is operated with the kind of equipment and engineering practice developed in the last decade or so for the third generation light sources and B factories. During that time, except for the LHC, no large HEP accelerator system has been constructed. At this time, we know very little about the steady-state availability performance of the LHC. Experience with older systems, such as the Tevatron, gave inputs for the model and, in comparison with more modern machines, allowed the development of a list of subsystems that need study.