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Functional Requirements on the Design of the Detectors and the Interaction Region of an e^+e^- Linear Collider with a Push-Pull Arrangement of Detectors

B.Parker (BNL), A.Mikhailichenko (Cornell Univ.), K.Buesser (DESY),
J.Hauptman (Iowa State Univ.), T.Tauchi (KEK), P.Burrows (Oxford Univ.), T.Markiewicz,
M.Oriunno, A.Seryi (SLAC)

Abstract

The Interaction Region of the International Linear Collider [1] is based on two experimental detectors working in a push-pull mode. A time efficient implementation of this model sets specific requirements and challenges for many detector and machine systems, in particular the IR magnets, the cryogenics and the alignment system, the beamline shielding, the detector design and the overall integration. This paper attempts to separate the functional requirements of a push pull interaction region and machine detector interface from the conceptual and technical solutions being proposed by the ILC Beam Delivery Group and the three detector concepts [2]. As such, we hope that it provides a set of ground rules for interpreting and evaluation the MDI parts of the proposed detector concept's Letters of Intent, due March 2009. The authors of the present paper are the leaders of the IR Integration Working Group within Global Design Effort Beam Delivery System and the representatives from each detector concept submitting the Letters Of Intent.

INTRODUCTION

The Reference Design Report (RDR) [1] of the International Linear Collider (ILC) specifies that the site will have one interaction region (IR) with the facilities to support two independent detectors that time-share the interaction point (IP) in a so-called push-pull arrangement. Three detector collaborations (named ILD, SiD and 4th) have submitted expressions of interest (EOI) to the ILC Research Director (RD) and have agreed to supply the director with Letters of Intent (LOI), describing their detector concept and its physics measurement potential. These are to be evaluated by the International Detector Advisory Group (IDAG).

Thus, in addition to the usual handshake required between the accelerator and detector design, the machine detector interface (MDI), the ILC will need to provide the physical and administrative infrastructure to allow two competing teams of physicists with distinct and complementary detectors fair and equal access to beam collisions with minimal down-time overhead. At this point in the life cycle of the ILC, the site, the time scale for construction, and the final selection of detector concepts have not been made. In order to proceed, the RD has appointed a panel comprised of two MDI representatives from each of the three detector concepts and three representatives of the ILC's Beam Delivery System (BDS) which is charged with the design of the IR. These are the authors of this report.

This document is meant to be the mechanism by which the four groups involved mutually define the MDI and Detector-to-Detector Interface (DDI) requirements by which the relevant parts of their respective LOIs can be evaluated. While the unknowns mentioned above, as well as the lack of engineering resources to date, preclude any definitive decisions, all parties involved see the merit in having the current set of agreed-to assumptions, goals and requirements documented. These should be as minimal as possible. It is neither the purpose of this report to prescribe the technology to be used [2] to achieve the requirements nor to list the myriad site-dependent safety requirements (O_2 deficiency, adequate emergency egress, non-flammable materials, etc.) to which the detectors must conform. Collaboratively developed technical solutions and interfaces between the three possible sets of partners (SiD-ILC-ILD, SiD-ILC-4th, and ILD-ILC-4th) will be developed in the post-LOI time frame.

FUNCTIONAL REQUREMENTS

In this section we will try to list the minimal functional requirements to which all detector concepts agree to be bound. Given our current state of knowledge we will need to introduce the concept of a “goal” as opposed to a requirement and the concept of a “working value” for a parameter that will eventually need to be specified but cannot yet be specified. In all cases we will try to list the assumptions behind requirement, goal, or parameter working value.

Final Doublet

It is a fundamental assumption that a rapid exchange of detectors is possible only if the IP-side element of the magnetic doublet that provides the final focus for the beam, called QD0, moves with and is supported by the detector, while the partner magnet, QF1, remains stationary during a detector exchange. QF1 may reside in the beam tunnel or on a pier projecting into the IR Hall, but we assume, per the RDR, that it begins magnetically at 9.5m from the IP. In the RDR design, QF1 is a compact superconducting (SC) magnet whose cryostat extends another 25cm toward the IP. As a pair of vacuum valves bracketing short bellows on both the incoming and outgoing beamlines will also be needed to isolate the detector and beamline vacuum systems when the detectors interchange, there will be approximately 18m of working length at the disposal of each detector concept when in its normal, data-taking state.

The QF1 to IP distance of 9.5m is the result of a study [3] that looked at luminosity as a function of energy and extraction line losses for QF1 L*=9.5m and QD0 L* and L^*_{ext} values of 3.51m/5.5m, 4.0m/5.95m and 4.5m/6.3m. This study sets the range of allowable QD0 L* to $3.5m < L^* < 4.5m$ for the LOI. Each concept may choose an L* appropriate for their design within this range and the ILC BDS will construct a corresponding detector specific QD0 cryostat package and spool piece to mate to QF1. The spool piece will house the kicker required for beam-beam deflection based luminosity feedback.

The superconducting final doublets, consisting of the QD0 and QF1 quadrupoles and sextupoles SD0 and SF1 are grouped into two independent cryostats, with QD0 cryostat penetrating almost entirely into the detector. The QD0 cryostat is specific for the detector design and moves together with detector during push-pull operation, while the QF1 cryostat is common and rests in the tunnel.

It is further assumed that QD0 is connected to a service cryostat located within approximately 10m of QD0 and from which it is rarely, if ever, disconnected. The service cryostats for each side of the IP are assumed to move with the detector. Proof of principle engineering designs of QD0 and its cryostat exist [4]. These designs assume that single phase liquid helium at 4°K is input and low pressure helium gas returned from the service cryostat. It, in turn, provides 1.9°K superfluid helium to the QD0 magnet package and can handle 14W of static heat load and 1W dynamic heat load.

The 4-th concept has intention to attach the QF1 cryostat to its detector frame after 4th detector arrived at working position. This will require minimal modifications of cryostat and will be resolved with other detector team.

The cryogenic design assumption of 14W static heat load comes from an engineering estimate by BNL [4]. The 1 W dynamic heat load is the result of GEANT studies [5] of the pair background energy deposition in QD0.

Elapsed time for an exchange of detectors

Given the immaturity of the IR and detector designs it is premature to specify a maximum time requirement for a detector interchange. Rather, at this point, it is preferable to agree on how roll out time and roll in time are to be measured and then to ask the concept groups to supply credible estimates of the required times that can be used as figures of merit in the evaluation of the concept. These periods are agreed to count against the beam time allotted to the moving detector and it is naturally assumed that the two detectors will share beam time equally. It is clearly in the best interests of all concerned to minimize the time that the ILC is not delivering luminosity. A working assumption is that the scheduled “time on beamline” would be about 25x the ~~length~~ duration of time required for a detector exchange; thus a 1 day turnaround would allow a detector interchange approximately every month and 1 week turnaround would mean one data run per detector per year.

Roll Out Time

Roll out time would begin with the preannounced end of ILC operations and would end when the detector leaving the zone could grant safe beneficial occupancy of the agreed on floor area and any shared resources (e.g. crane) to the entering detector. It would include any time required to dismantle and store shielding that had been required to keep the off-beamline detector safe in its waiting position (herewith labeled its "garage.") The condition of the floor area at the time of the transfer of occupancy remains a subject of discussion as it couples to the motion and guidance schemes preferred and being developed by each concept. At this point we can only assume that it will be possible to eventually specify a condition for the IR zone's floor and walls that preserves those elements common to the needs of both detectors; those features unique to the departing detector would need to be removed.

Roll in Time

Roll in time would begin with granting of beneficial occupancy to the on-beamline floor area and would end when the appropriate safety authorities allowed personnel access to newly garaged detector independent of the program of the newly installed detector. It would include any time to shield the garaged detector from radiation. Time required to align the final doublet or detectors and to make the IR safe for beam delivery would eat into the pre-allotted running time as would any special beam requests (e.g. calibration running at the Z). Radiation safety could be achieved through integrated shielding, external shielding walls or denial of personnel access, according to the desires of the detector residing on the IP. At this point it is assumed that the time required to recommission the ILC to nominal luminosity is short and has been worked into the allowed time on beamline.

Cryogenic Safety Assumptions

Allowing for push-pull times in the order of one day requires the de-energized magnet systems of the superconducting solenoids and the QD0 magnets to be moved cold. This could be realized by either using adequately engineered flexible cryogenic low-pressure transfer lines, or by moving the cold boxes together with the detectors. In the latter case adequately engineered warm helium transfer lines could be used. Both solutions seem to be feasible but more engineering design and evaluation is required before to finalize this very important issue.

To speed up the process of roll in/out, the 4th will use the platform also. The dimensions of tracks and size of platform will be unified with the other detector.

Vacuum

The main vacuum system interface requirement is that each concept provides an appropriate valve at its junction to the QF1 cryostat and a system to pump down the detector-resident portion of the beamline after it is reconnected to BDS. Vacuum in the BDS upstream of the detectors will be provided by the BDS. One analysis [6] of the effect of beam gas interactions on detector backgrounds set the required vacuum level at 1 nTorr in the 200m upstream of the IP and 10nTorr in the remainder of the BDS system. This paper did not attempt to specify the maximum permissible vacuum pressure in the 18m zone of the detector itself. It is assumed that each detector concept will investigate this limit and provide a technical means of providing it within the space constraints of their detector design.

Beam Feedback System

Luminosity feedback as described in the RDR [1] is required for luminosity optimization at the ILC. This imposes two interface requirements on each concept. The spool piece mating the back end of the QD0 cryostat to the QF1 cryostat houses a stripline kicker to correct the beam position. Given the allowed variation in QD0 longitudinal position (L*) and the fixed position of QF1, the length of this spool piece and perhaps of the kicker itself is variable. Similarly, the feedback system required a background free BPM signal sensitive to beam centroid position after the beam-beam deflection. The canonical position for this BPM is after any "BeamCal" device and before the QD0 cryostat. Space for this BPM, nominally set at about 10cm length, must be incorporated into the beamline design of each concept.

Beam-Beam parameter space

Each detector concept must be able to function when the beams are tuned to the nominal IP parameters specified in the RDR [1]. This requirement effectively defines the minimum beam pipe radius at the IP and the size of the exit apertures in the forward BeamCal, given the sensitivity and integration time of the concept's chosen detector technologies to background hits. Discussions to expand the beam-beam parameter space to include, for example those labeled in the RDR as Low N, Large Y and Low P, as well as to develop parameter sets for other center of mass energies, are ongoing. For the LOI, it has been agreed that each concept comment on the impact the non-nominal parameter sets might have on detector performance.

QD0 support and alignment

Each concept must present a credible scheme to guarantee that the detector-carried QD0 cryostat is adequately aligned and stable. There are two basic requirements. The first is that the detector brings the QD0 magnet to a position close enough to the BDS beamline, as defined by a line through the stationary QF1 magnets, that beam based alignment can begin. The second is that the detector provides a means to finely adjust the QD0 package using the beam to bring it within the capture range of the inter-bunch feedback system.

Given variations in floor height under load and with time it is assumed that each detector will have a large range but coarse means (shims, jacks, etc.) of bringing the QD0 cryostat to a position close enough to the QF1(e+)-QF1(e-) defined beamline that a finer resolution limited range alignment system can bring the cryostat to its final pre-beam position. Seemingly reasonable working values are

- Detector axis alignment accuracy: ± 1 mm and 100 μrad from a line determined by QF1s
- Detector height adjustment range: +/- several cm, tbd after site selection and geologic study
  - Floor height motion after removal of rock overburden was +nn mm at CMS/ATLAS

A detector mounted alignment system for QD0 (functionally equivalent to the eccentric cam based mover system [7] developed for the FFTB and LCLS and used as well at ATF2) should have the following specifications:

- Number of degrees of freedom: 5
- Range per degree of freedom: ± 2mm
- Step size per degree of freedom of motion: 0.05 μm

Before low intensity beams are allowed to pass through QD0 for high precision beam-based alignment, the mechanical mover system will be required to bring QD0 into alignment with an

- Accuracy per degree of freedom: ± 50 μm

The QD0 mechanical alignment accuracy and stability after beam-based alignment and the QD0 vibration stability requirement are set by the capture range and response characteristics [8] of the inter-bunch feedback system.

- QD0 alignment accuracy: ± 200 nm and 5 μrad from a line determined by QF1s, stable over the 200ms time interval between bunch trains
- QD0 vibration stability: Δ(QD0(e+)-QD0(e-)) < 50 nm within 1ms long bunch train

We note that control of this mover system will remain under control of the BDS system during operation and that alignment of other parts of the detector with respect to the QD0 cryostats is an issue that may need careful consideration. The movers may be periodically adjusted during a run to keep luminosity at its maximum value. Operational examples of such positioning of SC FF quads exist [14]-[16].

> *Verification of Alignment before beam operations*
>
> It is assumed that each detector will provide a means of verifying the alignment of the QD0 cryostat to the stated accuracy before low current beam operations begin. While a frequency scanning interferometer system that would require the detector's flux return to accommodate four optical paths between each QD0 cryostat and the floor is being proposed [9] for such a purpose, it is also possible that a simpler less invasive verification scheme can be employed.

Length of IR Hall perpendicular to the beamline belonging to the "on-beam" detector

As each proposed detector has a ~~yoke~~ half-width of roughly 8m, as a starting point for discussion we assume that once the off-beamline detector has moved so as to clear 15m of floor space from the beamline it is in its safe "garaged" location. A definite minimum distance is required so that the radiation and magnetic environment in the "garage" can be calculated. It is imagined that the demarcation line is set by a simple fence or, if required for radiation safety, by a radiation shielding wall. In choosing 15m as a working number we assume that 7m is adequate for the shielding that would be required by the non-self-shielded “4th Concept.”

Beam height above the reinforced floor of the IR cavern

While this dimension cannot be known until the two detector concepts are selected and an engineering plan for moving the detectors (rollers, air pads, or sliding platform, for example) negotiated, it is clear that one detector might have a smaller vertical dimension than the other. It only makes sense to require the smaller detector to provide the support to come up to nominal beam height. For completeness we assume a working number of 10-12m for the beam height above the IR caverns’s bare steel-reinforced floor.

Radiation environment

Radiation shielding is essential with two detectors occupying the same Interaction Region hall. The on-beamline detector should either be self-shielded or it will need to assume responsibility for additional local fixed or movable shielding (walls). Whatever the technical choice, the running detector is responsible to provide radiation safety without access control to the personnel maintaining the off beamline detector.

The choice of self or external shielding is likely to have significant impact on the design of the IR Hall and its services and on the time required to exchange detectors. For the purposes of this document we assume that each detector should simply state the expected impact on the IR Hall infrastructure (storage space for shielding, crane coverage and capacity, etc.) and to include shielding considerations in their analysis of the ~~length~~ duration of time required to move onto or off of the beamline. Assumptions that require cooperation with the other chosen detector concept should be stated along with any agreements that have been made on a bilateral level.

The final radiation safety criteria will be developed in consultations with the relevant regional authorities (see for example [10]) and will include criteria for both normal operation and for protection in the event of the worst case beam loss accident. For the LOI, we propose to base the shielding design on those criteria described in [11] and summarized below.

- Normal operation: the dose anywhere beyond the 15m zone housing the off-beamline detector should be less than 0.5 μSv/hour.
- Accidental beam loss: is defined as the simultaneous loss of both e+ and e- beams at 250 GeV/beam anywhere, at maximum beam power described in by the RDR. In that case, the dose for occupational workers in zones with permitted access should be less than 250mSv/h and the integrated dose less than 1mSv per accident. The implied emergency beam shut-off system is assumed to stop beam delivery after 1 beam train.

These criteria are consistent with the off-beamline ‘garage area’ being classified as supervisor access according to KEK and CERN rules, and GERT access according to SLAC and FNAL rules.

We assume that each concept will present the results of a credible simulation to estimate compliance with these criteria for their design. The simulation needs to include all realistic cable and cryogenics openings in the detector or shielding.

While radiation safety in the area controlled by the on-beamline detector will be governed by the same criteria listed above, the on-beamline detector may chose to satisfy them through some use of administrative access control and/or engineering control, depending on the level of access they feel is desirable or required while the detector is running. We assume that each concept will address this issue and incorporate its effects on the time required to ready the detector for data taking with beam.

Magnetic environment

The requirements on the magnetic field outside of detector operating on the beamline will define the amount of iron in the detector or degree of compensation of an iron-free detector design. Three zones of interest are apparent.

- The garage area housing the off beamline detector
- The beamline
- The area on and around the on beamline detector

While regional authorities will ultimately dictate the upper limits for personal safety, we agree to base our working numbers for these limits at this time on the values in force at CERN [12]:

- 5 Gauss (0.5 mTesla) for people wearing pacemakers
- 100 Gauss (10 mTesla) for the general public
- 2000 Gauss (200 mTesla) for occupational exposure.

The garage area housing the off beamline detector

A magnetic environment suitable for personnel access to the off-beamline detector, or any other non-restricted area, during beam collisions must be guaranteed by the beamline detector using their chosen solution. We take the limiting field as 50 Gauss, which will allow the use of iron-based tools [13], and assume that individuals wearing pacemakers will be excluded from this area when the on-beamline detector is operational.

The beamline

We assume that effects of any static field outside of detector on the incoming beams can be corrected. There is thus NO restriction being placed for this value.

The area around the on beamline detector

From the MDI interface perspective, there are no functional requirements placed on the area operated and controlled by the on-beamline detector. Engineering or administrative protocols (denial of access) can be used to satisfy the final safety codes or operational limits. We take these to be:

- Human Safety: 2000 Gauss, with denial of access for people with pacemakers and the general public
- Operation of magnetically sensitive equipment: at the complete discretion of the detector group

The off-beamline detector may wish to operate its solenoid while in its garage for measurement or test purposes. While the quality of any measurement outside the passive magnetic environment of the on-beamline position may be a concern to the off-beamline detector, the distortion of the magnetic field map of the on-beamline detector due to such operation must be less than 0.01% of the field anywhere inside the on-beamline detector's tracking volume.

These magnetic field requirements must remain satisfied both for steady state operation and during any planned or unplanned transitory event, such as ramp-up or an unforeseen quench of a superconducting solenoid. While administrative and engineering protocols can be used to protect personnel in the zone of a detector exercising its magnetic field, it is incumbent on that detector (normally the on-beamline detector) to guarantee the safety of personnel working in the zone of the second detector (normally the off-beamline detector) against any transitory event that could conceivably provoke an accident.

DISCUSSION

To progress in many of these areas a degree of mutual cooperation and discussion between pairs of detectors who propose to share the IR is required. It seems likely at this point that both the eventual detectors will need to agree on a common technology for locomotion; a moveable platform does not appear to be compatible with a detector which rolls on a bare flow on either rollers or air pads. The ILC and SiD concepts which present themselves as "self-shielded" need to discuss which elements of their shielding mate. Each of these two concepts need to ~~seriously~~ engage the advocates of the iron-free 4th Concept to understand the impact of shielding blocks on hall size and crane capacity and coverage. While these discussions may occur after the delivery of the LOI and choice of two concepts, the evaluation of the concepts would be certainly aided by any agreed technical solutions that could be described.

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