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

Parker, B (BNL) *et al*

10 February 2010

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579.

This work is part of EuCARD Work Package **9: Technology for normal conducting higher energy linear accelerators**.

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), T.Markiewicz, M.Oriunno, A.Seryi (SLAC)

Abstract

The Interaction Region of the International Linear Collider 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 [1] attempts to separate the functional requirements of a push-pull interaction region and machine detector interface from any particular conceptual or technical solution that might have been proposed to date by either the ILC Beam Delivery Group or any of the three detector concepts.

INTRODUCTION

The Reference Design Report (RDR) 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 push-pull arrangement. Three detector concept study groups (named ILD, SiD and 4th) have submitted Letters of Intent (LOI) to the ILC Research Director (RD) describing their detector and its physics measurement potential. These are to be evaluated by the International Detector Advisory Group.

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 differing detector designs fair and equal access to beam collisions with minimal down-time overhead. At this point, 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 a minimal set of MDI and Detector-to-Detector Interface (DDI) requirements by which the relevant parts of their respective LOIs can be evaluated. Collaboratively developed technical solutions and interfaces between the three possible pairs of detectors will be developed in the post-LOI time frame.

FUNCTIONAL REQUREMENTS

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 its magnetic field focuses the beam between 9.5m and 11.5m 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 data-taking state.

The QF1 to IP distance of 9.5m is the result of a study 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, driven by a BPM that must fit in front of the QD0 cryostat.

The SC 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. [2]

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. 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.

---

*Work supported in part by US DOE contract DE-AC02-76-SF00515.

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, it is preferable to agree on how roll-out time and roll-in time are to be measured and then to ask the concepts to supply credible estimates of the required times that can be used as figures of merit in the concept evaluation. 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 off.

- *Roll-Out Time*

Roll out time begins with the 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 labelled 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.

- *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.

QD0 Support and Alignment

Each concept must present a credible scheme to guarantee that the two detector-carried QD0 cryostats are adequately aligned and stable. There are two basic requirements. The first is that the detector brings its axis, defined as a line connecting the centers of the two QD0 cryostats, to a position close enough to the BDS beamline, defined by a line through the center of the stationary QF1 cryostats, 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 BDS 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, to be determined after site selection and geologic study

A detector mounted alignment system for QD0 should fulfil the following requirements:

- Number of degrees of freedom: 5 (horizontal x, vertical y, roll α, pitch ϕ, yaw ψ)
- Range per x,y degree of freedom: ± 2mm
- Range per α,ϕ,ψ degrees of freedom: ± 30 mrad (roll), ±1 mrad (pitch and yaw)
- 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 x,y degree of freedom: ± 50 µm
- Accuracy per α,ϕ,ψ degree of freedom: ±20 mrad (roll), ± 20 µrad (pitch and yaw)

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

- QD0 alignment accuracy: ± 200 nm and 0.1 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

As the movers may be periodically adjusted to maximize luminosity, alignment of detector elements with respect to QD0 must be carefully considered. 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.

Length of IR Hall Perpendicular to the Beamline

As each proposed detector has a half-width of ~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, 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.

Beam Height Above the Floor of the IR Cavern

While this dimension is knowable until the two detector concepts are selected and an engineering plan for moving the detectors negotiated, it is clear that one detector might have a smaller vertical dimension than the other. For completeness we assume a working number of 10-12m as the beam height above the bare steel-reinforced floor.

Radiation Environment

Radiation shielding is essential with two detectors occupying the same IR 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). It is the responsibility of the running detector 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 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 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 the following:

- 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 rate 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.

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.

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:

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

Three zones of interest are apparent.

- *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, 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.

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 to guarantee the safety of personnel working in the zone of the second detector.

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. The ILD and SiD concepts which present themselves as "self-shielded" need to discuss which elements of their shielding mate. Each of these two concepts needs to engage the advocates of the iron-free 4th Concept to understand the impact of shielding blocks on hall size and crane capacity and coverage.

REFERENCES

[1] See ILC-Note-2009-050 and references therein: http://ilcdoc.linearcollider.org/record/21354.

[2] The 4th concept intends to attach the QF1 cryostat to its detector frame while it is in beamline position.