PROCEEDINGS OF SCIENCE

A detector concept proposal for a circular e^+e^- collider

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Future circular e^+e^- colliders pose very specific requirements on the detectors. In several cases they differ from those adopted in recent years for the linear colliders ILC and CLIC. In the paper these differences are examined and a proposal for a detector optimized for circular e^+e^- accelerators is presented. Ongoing R&D efforts on the required technologies are also discussed.

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1. Detector requirements

A very large amount of work has been done over the past couple of decades to optimize detector configurations for the proposed future linear colliders ILC [1] and CLIC [2]. While some of those detector performance requirements can be extended from linear to circular e^+e^- colliders, such as FCC-ee [3] and CEPC [4], there are significant differences between these two classes of accelerators that imply different detector optimizations.

A key difference is the maximum acceptable detector solenoid magnetic field, that is very constrained in the planned circular machines. An optimal field of 2 Tesla is normally assumed to preserve the beam emittance and therefore the luminosity, especially at the lower energy. An increase of the field to 3 Tesla would decrease the luminosity by approximately a factor of two when running on the Z pole. Having a small solenoid field, a larger tracking radius is required for a good tracking resolution. An even larger tracking radius is achievable if the detector solenoid can be made sufficiently thin and light to allow the calorimeter to be placed behind the magnet.

Another notable difference is the time structure of the beam. Linear collider beams are characterized by bursts of bunches followed by long time gaps with no beam. These gaps allow pulsing of the power to the detectors, thus significantly reducing their cooling requirements. This is not possible in circular machines, where the bunch spacing is approximately constant and comparable to that of hadron colliders (20 nsec for E_{CM} = 90 GeV), and poses major cooling issues for vertex detectors and high granularity calorimeters. The use of time projection chambers is also made less favorable due space charge buildup and ion back-flow.

A comparison of the expected luminosity per interaction point for linear and circular machines is shown in fig. 1. Two features are clearly indicated by this plot: 1) linear colliders can reach much

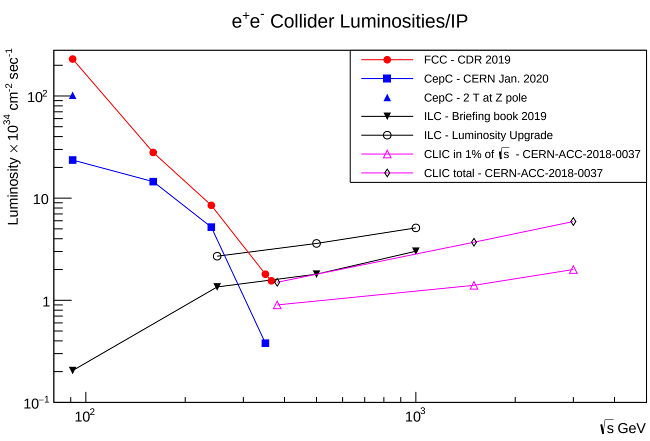

Figure 1: *Comparison of linear and circular e^+e^- collider luminosities [5].*

higher energies and their luminosity grows with energy; 2) circular colliders provide much higher luminosity at low energy, about three orders of magnitude higher at the Z pole, and it decreases with energy, reaching a performance similar to linear machines around the top quark pair production threshold. These features have implications on the detector optimization, in particular on the tracking systems, since at low energy the multiple scattering contribution to the track parameter resolution becomes important, while at high energies the asymptotic terms are more relevant.

The extreme luminosity at the Z pole achievable in circular machines generates a physics event rate of ~100 kHz, thus a fast detector that can resolve events a few μsec apart is preferable. The resulting very large Z boson statistics allows high accuracy measurements of electro-weak parameters limited primarily by systematic errors, in particular the uncertainty in the acceptance determination, that is a challenge for the detectors. It also opens the possibility to compete with the super B factory [6] and the LHCb upgrade [7] on heavy flavor physics. A good particle ID capability and EM calorimetry is needed order to make the best use of this potential.

2. The IDEA detector concept

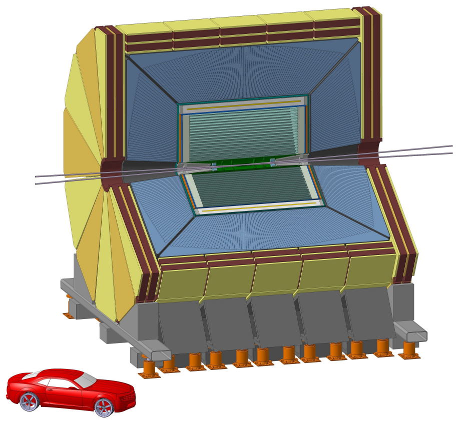

Figure 2: *3D view of the IDEA detector concept.*

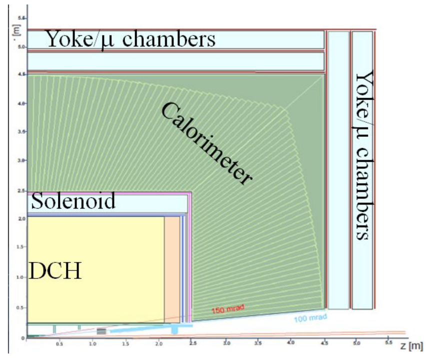

Figure 3: *IDEA detector longitudinal section.*

A detector concept optimized for circular e^+e^- colliders is shown in figure 2 and 3. It's called IDEA, that stands for *Innovative Detector for Electron-positron Accelerator*.

The innermost detector, surrounding a 1.5 cm radius beam pipe, consists of a five layer vertex detector based on active pixels of 20 μm size that can provide a space point resolution of 3 μm in both directions delivering an asymptotic track impact parameter resolution of 2 μm. Outside the vertex detector a 4 m long cylindrical drift chamber is found. It starts from a radius of 35 cm and extends until 2 m. The chamber can be made extremely light, with low mass wires and operation on 90% helium gas; less than 1% X_0 is considered feasible for 90° tracks. Additional features of this chamber are a good spatial resolution, <100 μm, dE/dx resolution at the 2% level using cluster counting and a maximum drift time of ~400 nsec. It is worth noting that the design of this chamber is the evolution of work done over many years on two existing chambers installed in the KLOE [8] and the MEG-II [9] experiments.

A double layer of silicon micro-strips surrounds the chamber in the barrel and end-cap regions to improve momentum resolution and acceptance determination.

A solenoidal magnet surrounds the tracking system. Presently planned dimensions are 5 m of length and 4.2 m inner diameter. The rather low two Tesla field and the small dimensions have important implications on the overall magnet package thickness, that can be kept at the 30 cm level, and on the size of the flux return yoke, which scales linearly with the field and the square of the coil diameter. Given these dimensions a yoke thickness of less than 100 cm of iron is sufficient to completely contain the magnetic flux and provide adequate filtering and support for the muon chambers. Engineering studies indicate that a magnet mass equivalent to less than 0.76 X_0 at 90° is achievable.

A pre-shower is located just behind the magnet. This detector is based on μ-Rwell chambers [10] and is primarily designed to enhance the accuracy in the determination of the acceptance for photons. The same chamber technology with a different optimization for the spatial resolution is used for three layers of muon chambers embedded in the magnet yoke.

A dual readout fiber calorimeter [11] is located behind the pre-shower. A total calorimeter depth of 2 m is assumed, corresponding to approximately eight pion interaction lengths. This calorimeter provides an excellent hadronic jet resolution and at the same time an electromagnetic resolution of $\sim 11\%/\sqrt{E}$. The intrinsic high transverse granularity provides a good matching of showers to tracks and pre-shower signals. The option of adding a thin crystal EM calorimeter inside the coil is currently under study to reach an extreme EM energy resolution of less that $5\%/\sqrt{E}$. This calorimeter would need to provide a dual readout to allow combining its data with the external fiber calorimeter without spoiling the jet energy measurement performance.

2.1 Performance

A few performance benchmarks of the proposed detector concept are now discussed.

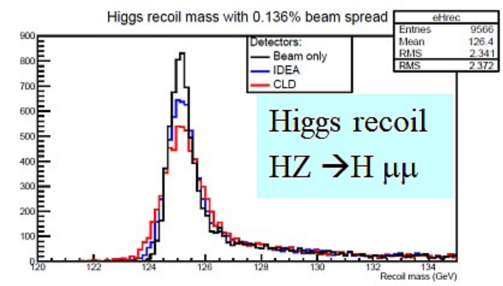

Figure 4: *Recoil mass distribution: (black) perfect detector, (blue) IDEA, (red) CLD.*

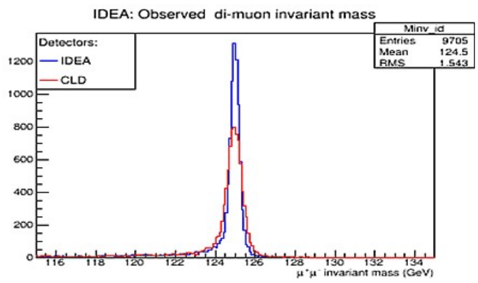

Figure 5: *Higgs invariant mass: (blue) IDEA, (red) CLD.*

A key measurement of the e^+e^- Higgs factories is the total cross section of ZH production. This is done measuring the Z momentum and analyzing the recoil mass while using the collision energy as a constraint. In the case of circular colliders the beam energy spread is very small, $\Delta E/E \sim 10^{-3}$, thus spoiling it with poor detector resolution should be avoided. In figure 4 the recoil mass distribution expected with a perfect knowledge of the Z momentum is shown and compared to expectations with the IDEA and CLD [12] tracking systems, when the Z decays to two muons. The tracker performance in measuring the Higgs invariant mass in its two muon decay mode is shown in figure 5.

An important benchmark for the calorimeter is the identification of W, Z and H through their decays to hadronic jets. The expected separation with the IDEA dual readout calorimeter has been

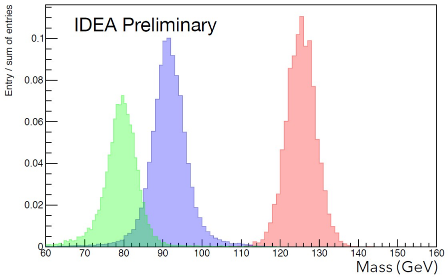

Figure 6: *Jet-jet invariant mass spectrum for W (green), Z (blue) and Higgs (red).*

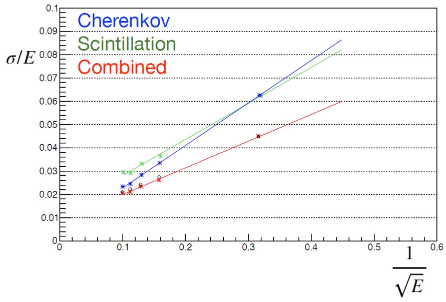

Figure 7: *IDEA dual readout calorimeter EM resolution for cherenkov (blue) and scintillator (green) components, and the combination of the two (red).*

studied with a GEANT4 simulation [13] and the results are shown in figure 6. In addition to a good jet energy resolution this calorimeter must also provide adequate EM resolution. In figure 7 we show the result of a full simulation study [13] resulting in $\Delta E/E = 11\%/\sqrt{E} \oplus 0.8\%$.

3. R&D in progress

Many R&D efforts are currently in progress to fully develop the IDEA detector concept.

Silicon pixel sensors for the vertex detector have been studied extensively. In our case low power, high speed CMOS DMAPS with stitching capability are preferred. A very significant work in this area is being pursued in the context of the ARCADIA project [14, 15].

The long wires of the drift chamber require the development of special wires, in particular metal coating of carbon fiber filaments is being studied. The identification of ionization clusters requires on-detector feature extraction from the signal waveform. Dedicated electronics and the associated firmware is being developed [16].

The dual readout calorimeter still requires extensive R&D in several areas [17]: a scalable mechanical structure needs to be optimized, a compact coupling of SiPM to fibers is being developed and, most of all, a reasonably priced front end and readout electronics needs to be finalized. Several options are currently under study and new prototypes are being built for tests with beam during 2021.

Extensive work is also in progress to transfer to industry the μ-Rwell chamber technology in order to allow for future mass production at a convenient cost.

4. Conclusions

The IDEA detector concept has been studied and appears to deliver all needed features for the future e^+e^- circular colliders. Several R&D efforts are currently in progress to further optimize the detector and resolve all pending technical issues.

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