PROCEEDINGS OF SCIENCE

A proposal of a drift chamber for the IDEA detector concept for a future e^+e^- collider

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An ultra-low mass Tracking Chamber with Particle Identification capabilities is proposed for a future e^+e^- collider.
Details about the construction parameters of the drift chamber including both the inspection of new material for the wires, of new techniques for soldiering the wires, the development of an improved schema for the drift cell and the choice of a gas mixture are described. The performance of the tracking are studied together with the Improved particle identification capabilities obtained by using a cluster counting technique.

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1. FCC-e^+e^- and the tracking requirements

The FCC-ee high-luminosity circular electron-positron collider, with tunable center-of-mass energies from 91.2 GeV to 365 GeV (fig. 1), optimised to study with high precision the Z, W, Higgs and top particles, with samples of 5×10^{12} Z bosons, 10^8 W pairs, 10^6 Higgs bosons and 10^6 top quark pairs. The FCC-ee offers unprecedented sensitivity to signs of new physics, appearing in the form of small deviations from the Standard Model, of forbidden decay processes, or of production of new particles with very small couplings. As a predecessor of a new 100 TeV proton-proton collider, the FCC-ee collider is foreseen to be placed in a 100 km tunnel in Geneva area.

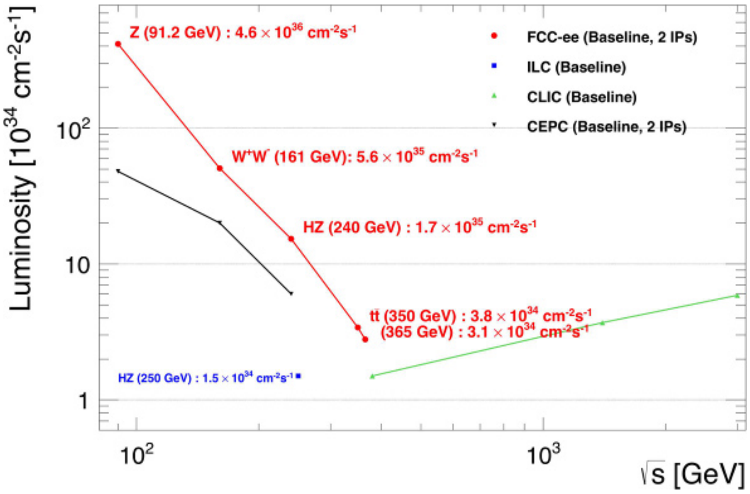

Figure 1: Baseline luminosities expected to be delivered (summed over all interaction points) as a function of the centre-of-mass energy $\sqrt{s}$, at each of the four worldwide e^+e^- collider projects, more details are reported in [1].

Concerning the detectors, they must satisfy the constraints imposed by machine performance and interaction region layout and for the tracking systems they can be summarized as following:

- for the Central tracker:
  - state-of-the-art momentum and angular resolution for charged particles ($\sigma(1/p_T) \lesssim 3 \times 10^{-5}$ (GeV/c)$^{-1}$ and $\sigma(\Theta, \phi) \sim 0.1$ mrad for 45 GeV muons);
  - B field limited to ~ 2 T to contain the vertical emittance at Z pole. Large tracking radius needed to recover momentum resolution;
  - High transparency required given typical momenta in Z, H decays (far form the asymptotic limit where the Multiple Scattering contribution is negligible);
  - Particle ID is a valuable additional ability;
- for the Vertex tracker:
  - excellent b-and c-tagging capabilities : few µm precision for charged particle origin;
  - small pitch, thin layers, limited cooling, first layer as close as possible to IP.

Physics event rates up to 100 kHz (at Z pole) put strict constraints on sub-detectors and DAQ systems.

2. The Innovative Detector for Electron-positron Accelerators detector concept

The IDEA detector is a general purpose detector designed for experiments at future e^+e^- colliders. It comprises a silicon pixel vertex detector, a large-volume extremely light drift chamber surrounded by a layer of silicon micro-strip detectors, a thin, low-mass superconducting solenoid coil, a preshower detector, a dual-readout calorimeter, and a muon system inside the magnet return yoke, as outlined in Fig 2. The tracking system is based on all detectors inside the calorimeter.

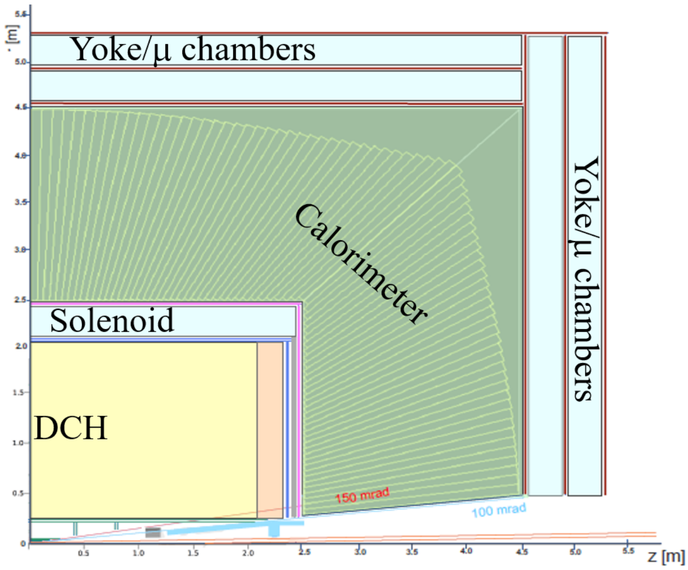

Figure 2: Schematic layout of the IDEA detector.

The vertex detector is based on the silicon pixel detectors planned for the ALICE inner tracker system (ITS) upgrade [2]. The recent results on the ALICE ITS upgrade, indicate an excellent ($\lesssim 5$ µm) resolution, high efficiency at low power consumption and very light detectors, 0.3–0.5% X_0 per layer. This would be a good starting point for the IDEA vertex detector.

The central tracker is based on a drift chamber (DCH) designed to provide good tracking, high-precision momentum measurement and excellent particle identification by cluster counting. The main peculiarity of this chamber is its high transparency, in terms of radiation lengths. The total amount of material in the radial direction towards the barrel calorimeter is of the order of 1.6% X_0, whereas, in the forward direction, it is about 5% X_0, including the endplates instrumented with the front-end electronics.

A layer of a Si micro-strip tracker will surround the DCH to provide an additional accurate space point ($\sim$ 15 µm on the transverse plane), as well as to precisely defining the tracker acceptance.

A pre-shower detector is located between the magnet and the calorimeter in the barrel region and between the drift chamber and the end–cap calorimeter in the forward region. In the barrel region, the magnet coil works as an absorber of about 1 X_0 and is followed by a layer of MPGD (Micro-Pattern Gaseous Detector) chambers; a second layer of chambers follows after another 1 X_0 of lead. A similar construction occurs in the forward region, however, here with both absorber layers made from lead. The MPGD chamber layers provide a precise acceptance determination and increase the tracking resolution.

3. The IDEA drift chamber

3.1 Layout and construction technique

The Central Drift chamber (CDCH) is a unique-volume, high granularity, fully stereo, low-mass cylindrical drift chamber, co-axial with the 2 T solenoid field. It extends from an inner radius $R_{in} = 0.30$ m to an outer radius $R_{out} = 2$ m, for a length $L = 4$ m and consists of 112 co-axial layers, at alternating-sign stereo angles, arranged in 24 identical azimuthal sectors. The stereo angles range from 50 mrad to 250 mrad. The square cell size varies between 12.0 mm and 14.5 mm for a total of 56,448 drift cells. Each cell is designed with a ratio of field to sense wires equal to 5:1 to ensure the proper electrostatic configuration, and is composed by one anode and two cathode sub-layers, as sketched in Fig. 3-Top. The anodes are 20 μm diameter tungsten wires, while the cathodes are 40 and 50 μm light aluminum alloy wires. In total, the CDCH is made with 56,448 sense wires, 285,504 cathode wires and 2,016 guard wires to equalize the gain of the innermost and outermost layers.

The construction of the IDEA CDCH could be possible only by adopting the novel approach for the wiring and for the assembly procedures [3][4] developed for the construction of the CDCH of MEG II experiment. It was recently built (fig.3-Bottom) and now is under commissioning for the MEG II experiment [5] at PSI.

Furthermore, CDCH will adopt the cluster counting and timing techniques, which allow for particle identification with unprecedented resolutions, where it is assumed that one can reach a relative resolution on the measurement of the number of primary ionisation clusters, N_{cl}, equal to $1/\sqrt{N_{cl}}$. Typically it is expected a factor two better than the traditional dE/dx technique, and for improving, well below 100 μm for short drift cells, the spatial resolution obtainable with the conventional measurement of the fastest drifting electron. The IDEA CDCH active volume is confined within a

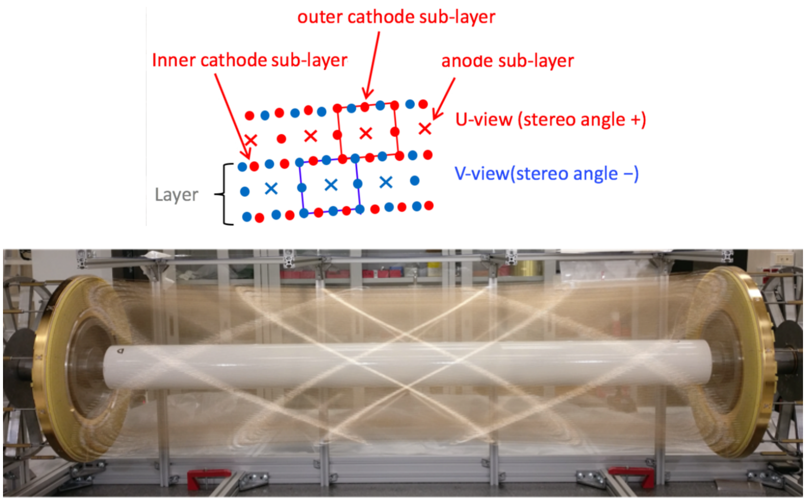

Figure 3: Top: a sketch of the drift cells within two alternating sign stereo layers. Bottom: the fully wired MEG II CDCH on the assembly structure.

cylindrical carbon fiber shells at the outer and inner radius with equivalent thicknesses respectively of 1.2% X_0 and 0.08% X_0. The CDCH gas mixture is 90/10 He/i-C_4H_{10}, chosen for the low

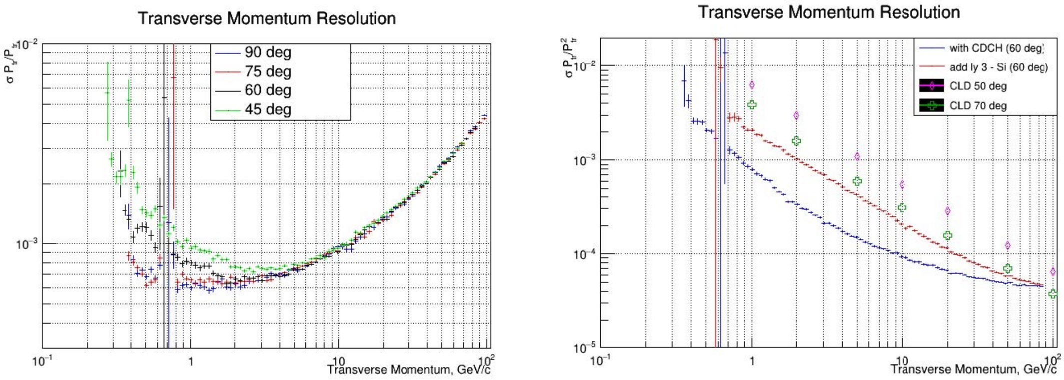

Figure 4: Left: Transverse momentum resolutions of the IDEA tracking system, evaluated for tracks with θ of 45°, 60°, 75° and 90°. Right: Transverse momentum resolutions of the IDEA tracking system respect to a full Si based tracking system like the CLD detecor one [1].

radiation length (~ 1400 m), a fast enough average drift velocity (~ 2 cm/μs) corresponding to a maximum drift time less than 400 ns, and a good spatial resolution (110 μm, [6]).
The number of ionisation clusters generated by a minimum ionizing particle (m.i.p.) is about 12.5 cm^{-1}, allowing for efficiently exploiting the cluster counting/timing techniques to improve both spatial resolution ($\sigma_{r\phi} < 100$ μm) and particle identification ($\sigma(dN_{cl}/dx)/(dN_{cl}/dx) < 3.6\%$).

3.2 Expected performance

A Geant4 simulation has been performed to estimate the performance of the IDEA tracking system. Assuming a single cell resolution of 100 μm for the CDCH and conservative spatial resolution (pitch/$\sqrt{12}$) for Si detectors, the IDEA tracking system meets the expected performance, fig. 4-Left. Moreover, the resolution at 100 GeV/c can be improved (from 4×10^{-5} to 2.9×10^{-5} usign a less conservative spatial resolution for the Si detectors). The lightness of the drift chamber allows to the IDEA tracking system to gain almost a factor ~ 3 in momentum resolution respect to a full Si tracker system up to ~ 50 GeV/c, fig. 4-Right.
Details of ionisation clustering were not simulated, so an analytical calculations for the expected performance relating to particle separation is presented. In Fig. 5-Left the expected particle separation (μ/π in red, π/K in blue, K/p in green) performance in terms of numbers of standard deviation is illustrated as a function of momentum (for $\theta = 40°$). Solid curves refer to separation with the cluster counting technique and dashed curves refer to the optimal energy loss truncated mean technique. A cluster counting efficiency of 80% is assumed in the calculations. To be noticed the relative gain of a factor 2, in terms of particle separation, of the cluster counting technique with respect to dE/dx. Only in a limited range of momentum, between 0.85 GeV/c and 1.05 GeV/c, a different technique for PID is needed, as an example a 3σ separation for π/K can be obtained by using the Time Of Flight technique having a time resolution of ~ 100 ps.

Preliminary study of the machine background induced occupancy on the CDCH, indicate that, it will be not an issue. However, they have a relevant impact on the expected data throughput at Z pole for the CDCH that is expected to be of ~ 800 GB/s. Even if it could be manageable a reduction to a data rate of ~ 60 GB/s is possible by using an only processing by using the Cluster Counting

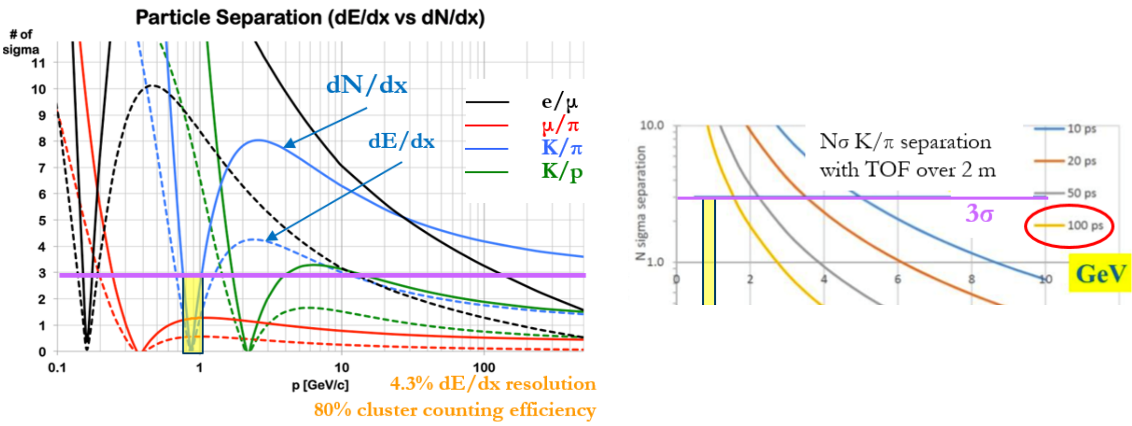

Figure 5: Left: The expected particle separation (μ/π in red, π/K in blue, K/p in green) performance in terms of numbers of standard deviation as a function of momentum (for $\theta = 40°$). Solid curves refer to separation with the cluster counting technique and dashed curves refer to the optimal energy loss truncated mean technique. The region between 0.85 GeV/c and 1.05 GeV/c where a different technique is needed is highlighted in yellow. Right: PID performance as function of the time resolution by using a TOF technique to recover the PID in the range 0.85 GeV/c and 1.05 GeV/c.

technique [8].

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