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Cluster counting drift chamber as high precision tracker for ILC experiments

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ABSTRACT

Precision measurements at the International Linear Collider on physics channels of crucial interest are demanding for resolution of the order of $\delta p_T/p_T^2 = 10^{-5}\,\mathrm{GeV}^{-1}\,c$ up to momenta as high as $50\,\mathrm{GeV}\,c^{-1}$. A light weight He-based drift chamber with full stereo wires is proposed together with a cluster counting technique, performing potentially better than state-of-the-art TPCs. Detailed studies on the implementation of cluster counting and realization of custom front-end electronics is in advancement. Experimental tools for space resolution measurements with $10\,\mu\mathrm{m}$ precision is being set up, in preparation of an extensive program of cosmic rays and beam tests.

1. Precision of p_T measurements at linear colliders

All HEP community being waiting for closer and closer discoveries from the first collisions at LHC, the same level of attention is paid to the further precision measurements on such discoveries which linear colliders, namely the International Linear Collider (ILC), will have to produce in the future. As a very instructive example of such precision measurements, one can consider process of production of the standard model Higgs, $e^+e^- \rightarrow ZH \rightarrow l^+l^- + X$. From an experimentalist's point of view this is an essentially unbiased process, since, regardless of the decay channel of the Higgs, and owing to the constrained kinematics, one can reconstruct the mass spectrum of the recoiling particle without ambiguities, if he measures with sufficient precision the invariant mass of the l^+l^- system, and knows the energy of the beams collision with comparable accuracy, as it will be the case at ILC. The analysis of this golden measurement at ILC [1] shows that a momentum resolution at the level of $\delta p_T/p_T^2 = 5 \times 10^{-5}\,\mathrm{GeV}^{-1}\,c$ is required in order to get a striking measurement. So far, the elective choice which has been mostly proposed to reach such performances, has been the state-of-the-art TPC, with GEM readout and possibly a few extra layers of Si tracking devices. However, an exercise on the specific case of the ILC 4th Concept shows that the TPC solution suffers of an irreducible degradation of its resolution due to multiple scattering, because of the gas used, the mechanical structure, the high density front-end electronics, and the additional use of at least five layers of Si-strips.

2. The *CluCou* drift chamber for the ILC 4th Concept

In order to check if any improvement in momentum measurement resolution can be achieved with a classic drift chamber in the ILC 4th Concept [1] apparatus, a simulation has been performed in the ILCRoot framework, developed from the architecture of AliRoot [2]. The study was done in the momentum range up to $50\,\mathrm{GeV}\,c^{-1}$, based on a $100\,\mu\mathrm{m}$ spatial resolution, typical of a KLOE-like drift chamber. The chamber here designed draws advantage [3] from the use of very light gas mixture, 90% He + 10% iso-C_4H_{10}, together with $20\,\mu\mathrm{m}$ thick tungsten sense wires and $80\,\mu\mathrm{m}$ thick aluminum field wires. The resulting cells, sketched in Fig. 1, are arranged in 20 super-layers, with full stereo angles $\pm 72-180$ mrad. Given the dimension of the drift chamber, having a radius of 1.5 m, the dimension of cells (0.6–0.7 cm) and the consequent number of wires (60 000 sense and 120 000 field), the resulting multiple scattering effective thickness of the chamber is as low as $5.5 \times 10^{-3} X_0$, mostly due to the wires. The mechanics of the chamber is, in addition, based on carbon fiber technology for both barrel and endcaps, thus introducing a further perturbation as low as $4 \times 10^{-2} X_0$, which does not harm the subsequent calorimeters position resolution. Results from the first exercise, based on the previous input parameters for the drift chamber, are illustrated in Fig. 2 (red points and curve), where the improvement of resolution for momenta up to $\sim 25\,\mathrm{GeV}\,c^{-1}$ is direct consequence of the damping of the multiple scattering along the particle path, as compared to the TPC (black points and

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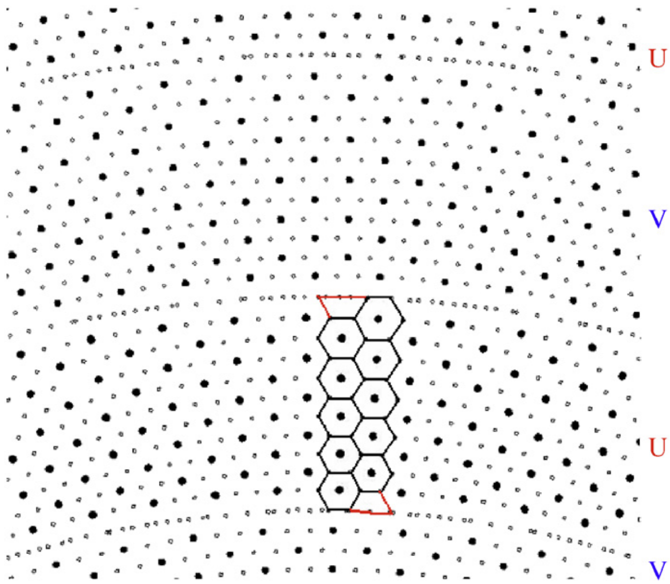

Fig. 1. Drift cells layout of the *CluCou* chamber.

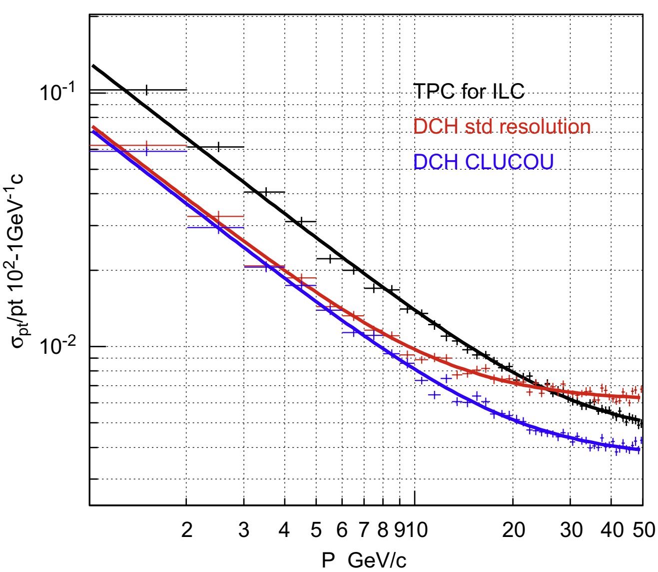

Fig. 2. Momentum resolution comparison in the 4th Concept central tracker. In black, the simulation for the TPC plus five layers of Si strips. In red, a light weight KLOE-like drift chamber with $\sigma = 100\,\mu$m. In blue, the same drift chamber with cluster counting and $\sigma = 50\,\mu$m.

curve, simulated within the same framework with identical benchmark tracks). Based on the discussions reported in Refs. [3,4] the *CluCou* drift chamber proposal, in addition, aims at further improvement of resolution at high momentum, by pushing the point position resolution to the ultimate level of 50 μm by means of the cluster counting technique. This improvement (blue points and curve in Fig. 2) would be of great advantage in the $25-50\,\mathrm{GeV}\,c^{-1}$ momentum range, where goldplated measurements at ILC are expected. As illustrated in Ref. [3,4] by taking advantage of the sufficiently low electron drift velocity, together with the low enough ionization density along the track in He-based mixtures, if the signal read-out is performed with a ~1 ns resolution on the individual sense wire, then the single electron structure of the signal can be analyzed. To perform this efficiently, one has to rely on the gas mixture properties, as well as on a signal sampling rate $\geqslant 2\,\mathrm{GSa\,s^{-1}}$ and a bandwidth of the order of 1 GHz to preserve the single electron pulses risetime. The measurement of the drift times of all clusters will provide one with a number N_{cl} of independent measurements of the impact parameter per cell, thus potentially improving the spatial resolution to the physical limit for drift chambers. The *CluCou* program is studying these potentialities, by means of simulations, development of appropriate front-end electronics and experimental tools in preparation of prototyping the drift chamber.

3. Simulation and experimental status of the *CluCou* R&D program

The *CluCou* program is studying the potentialities discussed in the previous section, by means of simulations, development of appropriate front-end electronics, and experimental tools in preparation of prototyping the drift chamber.

3.1. Simulation: from gas parameters to signal analysis

Extensive simulations have been performed and are in progress by means of consolidated standard tools, like Garfield with Magboltz [5], in order to gain control of all relevant parameters: gas drift velocity, gain, cluster statistics; electrical characterization of drift cells; measurability of single electrons; front-end electronics transfer function. Algorithms for signal analysis and peak counting are under development (current efficiency with noise is at the level of 94%) and show that we get results consistent with expectations. In fact, the cluster number distributions (Fig. 3) and the electron number statistics (Fig. 4) for He-based gas mixtures with different isobutane content show typical poissonian character and Landau-shaped behavior, respectively.

3.2. Progress on experimental tools preparation

The experimental approach to the cluster counting problem has been based on the use of drift tubes, beginning from a simple setup for cosmic rays measurements made of trigger scintillators, one drift tube and a digital scope with high sampling rate, allowing us to acquire and store waveforms for off-line analysis. The signal is picked up from the sense wire through a 10× amplifier with 500 MHz bandwidth. Slow control parameters (high voltage, low voltage, pressure, gas flow) is continuously monitored. Preliminary measurements with such a simple device are consistent with simulations, as illustrated (Fig. 5) for a measurement of the drift time spectrum with a 1.4 cm radius tube in helium/isobutane 90/10 mixture. As the next step, a microstrip Si telescope is being prepared, in order to have precision tracking measurements at the level of 30 μm for an independent impact parameter measurement. The mechanical assembly of the telescope is ready, and the read-out is in development. The experimental plan devises detailed studies with the Si strip telescope using drift tubes until a small-scale prototype of the drift chamber is ready (Fig. 6).

3.3. The front-end chip

For the implementation of the cluster counting technique on a large-scale drift chamber, a low-cost, high-speed front-end electronics is needed. A CMOS 0.13 μm integrated circuit with a core area of $2.4\,\mathrm{mm}^2$, made of a fast preamplifier section plus a 1 GSa/s 6-bit ADC has been designed [6]. The preamplifier yields a programmable DC-gain between 0 and 20 dB, a 500 MHz bandwidth at −3 dB, an input-referred noise of $52\,\mu V_{\mathrm{rms}}$ versus a