TPC with GEM readout for TESLA

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Abstract. A Time Projection Chamber (TPC) is proposed as the main tracking device for the detector at the future e^+e^- linear accelerator now studied in Europe. The performance requirements and the basic design using a Gas Electron Multiplier (GEM) as the readout device are described. Some preliminary R&D results are discussed.

MOTIVATION AND PHYSICS REQUIREMENTS

A TPC as main tracker has several advantages compared to other detector technologies. It minimizes the amount of dead material limiting the energy measurement in the calorimeters and momentum resolution due to multiple scattering for low track momenta. It provides a large number of true 3-dimensional space points up to large radii leading to a highly redundant and efficient tracking (see [1]). The tracking up too large radii will allow to search for new long-lived particles, creating V^0 signatures or kink tracks in the TPC volume for neutral or charged particles, respectively. The proposed TPC allows particle identification via dE/dx measurements with a resolution of $\approx 5\%$ (see [2]). This will help identifying and analyzing heavy flavor decays, improve the energy flow algorithm and may provide the only way to identify new stable heavy particles. The overall momentum resolution of the whole tracking is $0.6 \times 10^{-4}(\mathrm{GeV/c})^{-1}$, which will allow e.g. a reconstruction of the invariant di-muon mass in $e^+e^- \to ZH \to \mu^+\mu^- H$ events with a mass resolution one order of magnitude smaller than the natural width of the Z boson. This requires a momentum resolution of 2.8×10^{-4} $(\mathrm{GeV/c})^{-1}$ for the TPC alone which corresponds to a point resolution $\sigma_{r-\phi} = 160$ μm for a magnetic field of 3T and 118 points measured along the track. The resolution in z should be better than 1 mm and the double track resolutions better than 3.3 mm (14 mm) in $r - \phi$ (z), respectively.

Machine backgrounds are a particular challenge to the operation of a TPC at TESLA due to its long memory time of ≈ 50 μs. This means one TPC “picture” corresponds to about 150 bunch crossings (BX). Careful and detailed studies of various backgrounds have been performed (see [3]). The number of hits in the TPC for 150 BX is of the order 80000, leading to an occupancy of well below 1%, which seems easily handable in the track reconstruction (see [1]).

GEM READOUT

In conventional TPCs, the electron signal is read out after gas amplification via a system of proportional wires and cathode pads. An attractive alternative is based on recently developed gas electron multipliers (GEM) [4]. They have the potential of substantially improving the TPC tracking resolution by eliminating several systematic effects present in the wire readout ($\vec{E} \times \vec{B}$ effects, ion tail, broad induction signal), allow the possibility of lower mass endcaps (no support for wire tension) and have a natural suppression of the ion feedback into the drift volume to the per-cent level [5]. Gains up to a few thousand have been reached with a single GEM, but it is advantageous to cascade two GEMs to obtain higher gains at lower operating voltages and more stable operation conditions. The level of ion feed back under TESLA operating conditions as well as the stability and uniformity of the gain will be addressed by ongoing R&D in the near future.

CONCEPTUAL DESIGN

The TPC for TESLA extends radially from 132 to 180 cm and 2×2.8 m in z direction. The design of the **field cage** is based on experience gained at LEP [7] and recent developments for the ALICE and STAR experiments [8]. A cross section of the vessel is shown in figure 1. The thickness of both fieldcages at 90 degree is approximately 3% of radiation length. The fieldcage is designed to hold high voltages up to 100 kV and good mechanical stability.

The **endplate** has to support the readout chambers and electronics and has to make the gas-seal for the TPC volume with minimum material possible. The design proposed is a very modular one, which will allow to selectively remove parts of the endplate, for repair of the endplate itself and access to the field cage. The endplate is subdivided in eight approximately wedge-shaped sectors in ϕ, on which 2-3-4 (in r) readout modules of size 40×40 cm are arranged. The conceptual design of a GEM module is based on the technology developed at CERN for the COMPASS experiment [6]. The two GEMs, the read out board with pads and possibly the additional gating device are mounted on fiberglass frames (fig.1 right). The grid might be a third GEM operating at unity gain or a carbon fiber grid seperated by about 1 cm from the upper GEM. The gate will be opened for the whole bunch train of 1 ms. With this self supporting system the GEM tower needs to be surrounded by only few mm of dead material, thus optimizing the sensitive area of the endplate.

Each endplate will have 750k readout channels (pad area 10 mm^2). The very dense electronics mounted on the endplate will perform the sampling, digitization and zero suppression as early as possible and has to operate continously during a bunchtrain of 1 ms. The design is thought to be an upgrade of the STAR type electronics [9].

Pad geometry: Since the transverse diffusion is suppressed in a high magnetic field, the electron avalanche charge will be collected by a single 1-2 mm wide pad in the GEM readout especially for short drift distances, degrading the point resolution

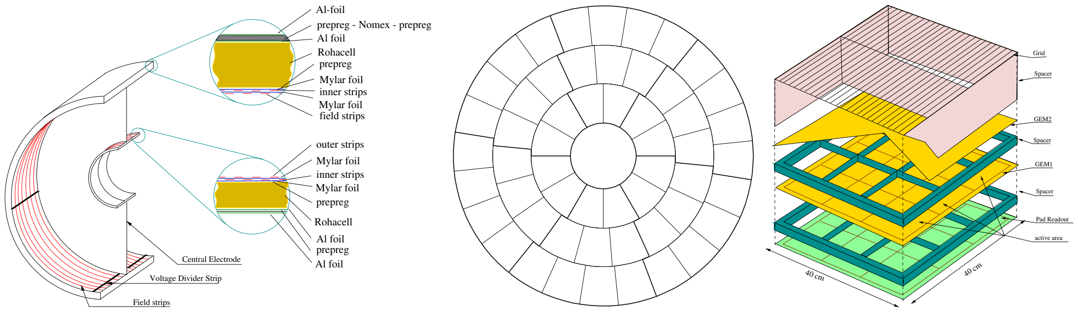

FIGURE 1. *Conceptual design of field cage (left), endplate sectors (middle) and GEM module (right).*

because no charge centroid can be calculated. A number of design options for pad geometries have been investigated in simulations to increase the amount of charge sharing between neighboring pads and to minimize the dependence on the drift length. These include narrow rectangular pads, and specially diamond or chevron shaped pads. The results are shown in figure 2 for $1{\times}10$ mm^2 pads (left) and $2{\times}5$ mm^2 pads (right). The more sophisticated pad geometries improve the resolution significantly for small drift length and both pad width reach the required momentum resolution taking into account the doubled number of track points for the $2{\times}5$ mm^2 option, which in addition will improve the dE/dx resolution from 4.6 to 4.1 % (see [2]). Another alternative of using the induction signal on neighboring pads has been discussed during this conference [10].

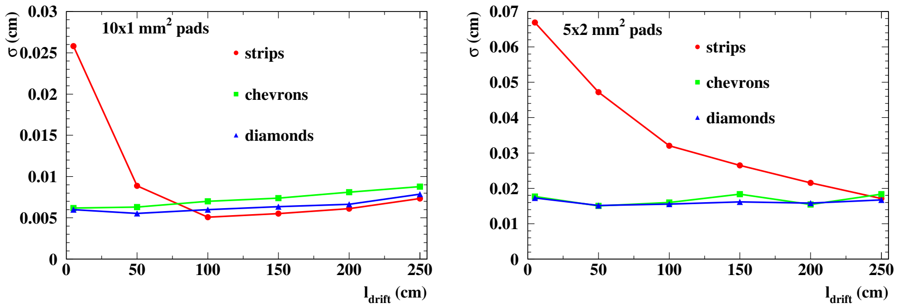

FIGURE 2. *Point resolution depending on driftlength: 1×10 mm^2 pads (left) and 2×5 mm^2 pads (right) for three different pad geometries.*

TPC WITH GEM READOUT R&D AT DESY

A TPC with a drift length of 105 cm and a double GEM structure for the readout ($10{\times}10$ cm^2 covering 8 pads) is currently under investigation at DESY. The TPC is operated at a field of $\approx$ 200 V/cm and with a gas mixture of Ar:CO_2:CH_4=(93:2:5)%. The two GEMs and the readout board are separated by 2 mm and the fields in this gaps are about 1 kV/cm. First basic measurements with cosmic muons have been performed. A signal to noise ratio of better than 40 has been observed and the uniformity and the stability of the gain has been found to be on the few per cent level. The effective gain shows the expected exponential increase with the voltages applied (fig. 3 left). The z resolution for tracks under 90 degree averaged over all drift length has been determined to be $\sigma_Z = 1.5$ mm (fig. 3 right).

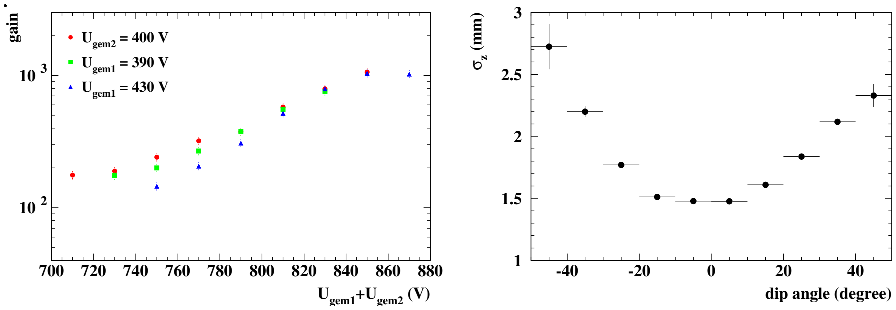

FIGURE 3. *Effective gain of double GEM structure depending on voltages applied (left) and z resolution depending on polar angle of muon tracks (right).*

CONCLUSION AND ACKNOWLEDGEMENTS

The basic design of a TPC with GEM readout for TESLA has been described and the performance goals have been specified which can be met or even be improved with the GEM readout option.

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