Studies on GEM modules for a Large Prototype TPC for the ILC.

Dimitra Tsionou
On behalf of the LCTPC Collaboration
VCI 2016 - Vienna, 19-Feb-2016
Outline

- A time projection chamber for the ILC
- Performance
- Ongoing optimisation studies
Outline

- A time projection chamber for the ILC
  
  Performance

  Ongoing optimisation studies
The International Large Detector (ILD) is one detector concept for the International Linear Collider (ILC).

- **Momentum resolution:**
  - \( \sigma(\Delta p_T/p_T^2) = 2 \cdot 10^{-5} \text{ GeV}^{-1} \)
  - TPC alone: \( 10^{-4} \text{ GeV}^{-1} \)

- **Tracking efficiency**
  - Close to 100% down to low momenta for Particle Flow

- **Minimum material**

- **Full angular coverage and high hermeticity**

- **TPC dimensions**
  - \( \pm 2.35 \text{ m in } z, 1.8 \text{ m outer radius} \)

- **The TPC provides**
  - \( \sim 200 \) space points along the track
  - \( \sigma \sim 100 \mu \text{m} \) in the \( r\phi \) plane (full drift)
  - \( \sigma \sim 400 \mu \text{m} \) in the \( z \) direction at zero drift and 1.4mm at full drift
  - \( \text{dE/dx} \) measurement for PID
  - \( 5\% X_0 \) for barrel & \( 25\% X_0 \) for endcaps
Large Prototype TPC

- Large Prototype TPC built and installed by the LCTPC collaboration in order to test different readout technologies and scale up to dimensions relevant to the ILD

- Technologies under investigation: GEMs, InGrid, Micromegas

- LP field cage parameters:
  - Length: 61 cm, Diameter: 72 cm
  - Up to 25 kV $\rightarrow E_{\text{drift}}$ up to 350 V/cm
  - Wall material budget: 1.3% $X_0$

- The endplate is able to host 7 readout modules (dimensions $\sim$22x17 cm$^2$)
ILD TPC – MPGD Readout Technologies Overview

- **Micro-Mesh Gaseous Detectors** (Saclay, Carleton, SINP)
- **GridPix** (Bonn, Nikhef, Saclay, Siegen)
  - Micromegas with pixel readout
- **Gas Electron Multipliers** (DESY, Japan, Bonn, Lund)

Talk by J. Kaminski on Thursday
 Goals

- Maximum active area
- Minimum material budget
- Field and high gain homogeneity
  → Flatness of GEMs
- Minimal field distortions (field shaping wire/strips)

 GEM module design and characteristics

- Ceramic grid frame (integrated support structure)
- Anode divided into 4 sectors
- No division on cathode side
- Triple GEM stack (→ stable operation at high gain and flexibility)
- Pad size 1.26 x 5.85 mm² (~5k pads per module)
Outline

A time projection chamber for the ILC

Performance

Ongoing optimisation studies
Test beam infrastructure & Current Improvements

➢ Infrastructure includes a large bore 1T magnet
  ▪ 20% $X_0$ material budget

➢ Ongoing effort to build an external Silicon tracker to provide reference tracks for the TPC

➢ Motivation: ability to study field distortions and alignment and measure the momentum resolution during combined test beams with the TPC system

➢ Challenge: Si tracker needs to fit in the existing TPC infrastructure (3.5 cm gap)

→ Stringent requirement on sensor spatial resolution: better than 10 $\mu$m
Field Distortions

- Inhomogeneities in the electric field can result in loss of signal and have an impact on the resolution.

- Electric field distortions more pronounced at module edges.
  - Guard ring introduced to minimise local field distortions at module borders.

- Loss of signal close to module edge partially recovered when introducing a guard ring.
Test beam setup

- DESY GEM module test beam campaign 2013

- Experimental setup
  - 3 GEM modules, partly equipped with readout electronics (~7k channels)
  - 20 MHz sampling frequency
  - Gas mixture: 95% Ar, 3% CF4, 2% iC4H10
  - Default drift field 240 V/cm (maximum drift velocity) or 130 V/cm (minimal diffusion)

- Goal
  - Validation of module design and performance understanding
  - Test of field shaping approach
  - Calibration of alignment schemes

50 cm track length
Alignment & Distortions Corrections

- Displacement and rotation of GEM module
- Use B=0 T data where ExB effects not present
- Corrections up to 0.1 mm and a few mrad

- Field distortion caused by inhomogeneities in magnetic and drift fields
  - ExB terms pronounced at module edges
- Distortions derived from 10% of events and applied to the rest
Analysis & Resolution

Selection requirements

- Track has at least 60 hits (out of 71 operational rows)
- Track is perpendicular to the pad rows
- Events with only one track are considered

Single point resolution

$\sigma_{r\phi/z}(z) = \sqrt{\sigma^2_{0,r\phi/z} + \frac{D^2_{t/t}}{N_{\text{eff}} e^{-A z} z}}$

- Intrinsic resolution of the readout at zero drift distance in $r\phi/z$
- Effective number of primary signal electrons
- Transverse and longitudinal diffusion
- Attachment of electrons to gas molecules during drift
Resolution

> Single point resolution

\[
\sigma_{r\phi/z}(z) = \sqrt{\sigma_{0,r\phi/z}^2 + \frac{D_{t/l}^2}{N_{eff} \cdot e^{-Az}}}
\]

> The ILD TPC requirement of \(r\phi\) resolution <100 \(\mu\)m for full drift distance at 4T corresponds to an \(r\phi\) resolution <150 \(\mu\)m for the large prototype TPC at 1T

<table>
<thead>
<tr>
<th>(\sigma)</th>
<th>(\sigma_{0,r\phi/z}[\mu\text{m}])</th>
<th>(N_{\text{eff}})</th>
<th>(A[\text{m}^{-1}])</th>
<th>(D_{t/l}[\text{mm}/\sqrt{\text{cm}}]) (fixed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(r\phi)</td>
<td>71.0 ± 1.2</td>
<td>39.8 ± 2.0</td>
<td>0.495 ± 0.097</td>
<td>0.103</td>
</tr>
<tr>
<td>(z)</td>
<td>306.3 ± 0.8</td>
<td>39.5 ± 1.6</td>
<td>0.529 ± 0.084</td>
<td>0.226</td>
</tr>
</tbody>
</table>

> \(z\) resolution \(~300\ \mu\text{m at zero drift distance}\) (ILD TPC requirement)
Comparison between different MPGD technologies

- Different modules in the LP compared under similar conditions and reconstructed with the same tools

\[ E_{\text{low}} = 130-140 \ \text{V/cm} \rightarrow \text{minimal transverse diffusion} \]

\[ E_{\text{high}} = 230-240 \ \text{V/cm} \rightarrow \text{maximum drift velocity} \]

- All modules show comparable resolution
Extrapolation of the $r_\phi$ resolution from the Large Prototype conditions to the planned ILD detector

- 3.5 T magnetic field and 2.35 m drift length

To reach the ILD goal of 100 $\mu$m at full drift distance, gas quality and purity need to be tightly controlled at ILD
Outline

A time projection chamber for the ILC

Performance

➤ Ongoing optimisation studies
GEM stability

- Observed discharges & destructive discharges during extreme conditions
- Investigate and improve long-term stability to demonstrate suitable performance for the ILD TPC
  - Optical and electrical observations of sparks of single GEMs in module-like setup
  - Simulations of the system to understand the behaviour
- Double and triple trips have been observed
  - No correlation with destructive charges observed
GEM stability (2)

- Discharge causes current oscillations on GEM surface in different sectors (CST® simulations)

- Test setup using an R-C circuit to damp the oscillations and reduce the number of double discharges
  - Further ongoing studies to decide whether this will be included in the next module iteration

![Graph showing comparison between tripping sector without RC circuit and with RC circuit]
GEM stability (2)

> Discharge causes current oscillations on GEM surface in different sectors (CST® simulations)

> Test setup using an R-C circuit to damp the oscillations and reduce the number of double discharges

- Further ongoing studies to decide whether this will be included in the next module iteration

![Tripping sector without RC circuit](image1)

![Tripping sector with RC circuit](image2)
GEM stability (3)

- Trips concentrated close to the frame
- Glueing/frame/stretching effects?
- Ongoing optimisation of glueing procedure for the next module iteration
GEM flatness

- Flatness of GEMs guarantees
  - a uniform gain distribution → precise dE/dx measurements
  - electric field homogeneity between the GEMs and in the field cage

- Measurements performed on XYZ table using a laser measurement head
  - GEM mounted on a precise plate

- Flatness of current GEM structure is at the level of 150 μm (rms)
GEM flatness (2)

- 3 GEM profiles used to simulate an operating GEM module
- RMS of effective/nominal gain ~6%

- Considering new ceramic frame design
- Developing optimised tools and procedures & reproducible mounting and glueing process
Conclusions

- Successful previous test beam campaign
  - Showing excellent performance of the LPTPC and GEM modules
  - Understanding of the system
  - Extrapolation shows we can achieve the resolution requirements of the ILD TPC

- Ongoing optimisation process for Large Prototype TPC and GEMs
  - Long-term stability of GEMs: Detailed ongoing simulation studies and measurements
  - Investigating optimised ceramic frame design and mounting procedure to improve flatness of GEMs

- These topics are under investigation in order to be included in the next TPC test beam campaign at DESY (2016)

- Infrastructure at DESY is constantly improved
BackUp
Silicon telescope – Requirements

➢ Simulation studies to decide on sensor characteristics and system geometry

➢ Sensors with spatial resolution better than 10 \( \mu \text{m} \) are needed
  - Driven mainly by the limited available space

➢ Coverage area of the system (simulation)
  - Minimum area 2x2 cm\(^2\) for the front and 4x10 cm\(^2\) for the back sensors

![Graph showing hits on front and back sensors with coverage area and percentage of events]
Resolution – Φ dependence

For inclined tracks, a dependence of the resolution on the azimuthal angle $\alpha = \phi_{\text{pad}} - \phi_{\text{track}}$ is expected.

$$\sigma_{r\phi}(z, \alpha) \approx \sqrt{\sigma_{r\phi}^2(z) + \frac{L^2}{12\hat{N}_{\text{eff}}}} \tan^2 \alpha$$

Tracks for short (10 cm) and long (40 cm) drift distances are shown.

$\tan(\Phi)$ behaviour as expected.
GEM flatness (2)

- 3 GEM profiles used to simulate an operating GEM module
- RMS of effective/nominal gain ~6%

- Considering new ceramic frame design
- Developing optimised tools and procedures & reproducible mounting process