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

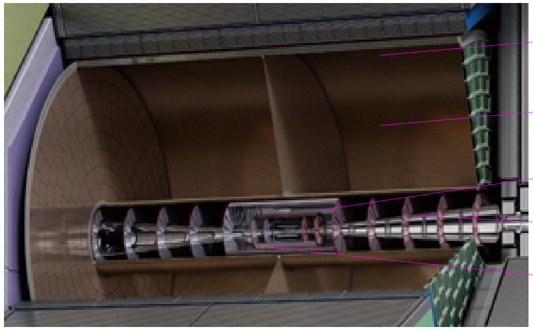
- A time projection chamber for the ILC
- Performance
- Ongoing optimisation studies

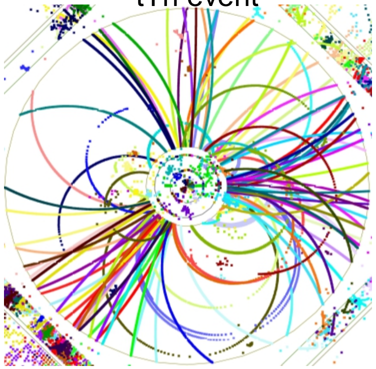
Outline

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

International Large Detector – Tracking Requirements

- The International Large Detector (ILD) is one detector concept for the International Linear Collider (ILC)



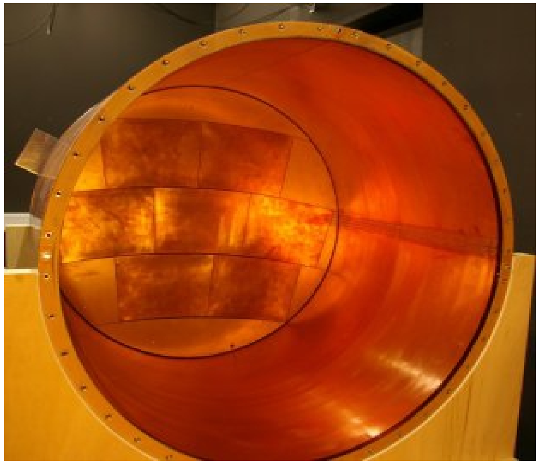


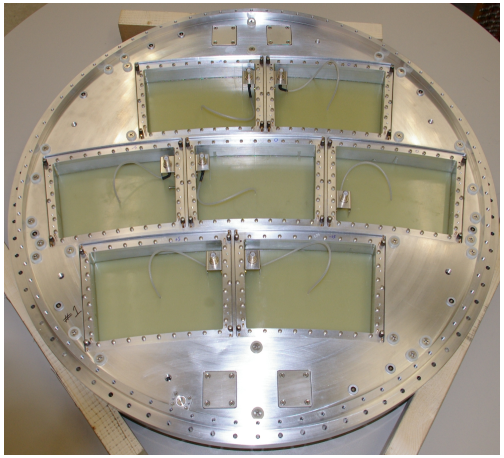
- Momentum resolution:
  - $\sigma(\Delta p_T/p_T^2) = 2 \cdot 10^{-5}\ \mathrm{GeV}^{-1}$
  - TPC alone: $10^{-4}\ \mathrm{GeV}^{-1}$
- Tracking efficiency
  - close to 100% down to low momenta for Particle Flow
- Minimum material
- Full angular coverage and high hermeticity

- TPC dimensions
  - ±2.35 m in z, 1.8 m outer radius
- The TPC provides
  - ~200 space points along the track
  - σ~100 μm in the rφ plane (full drift)
  - σ~400 μm in the z direction at zero drift and 1.4mm at full drift
  - dE/dx measurement for PID
  - 5% X_0 for barrel & 25% X_0 for endcaps

Large Prototype TPC

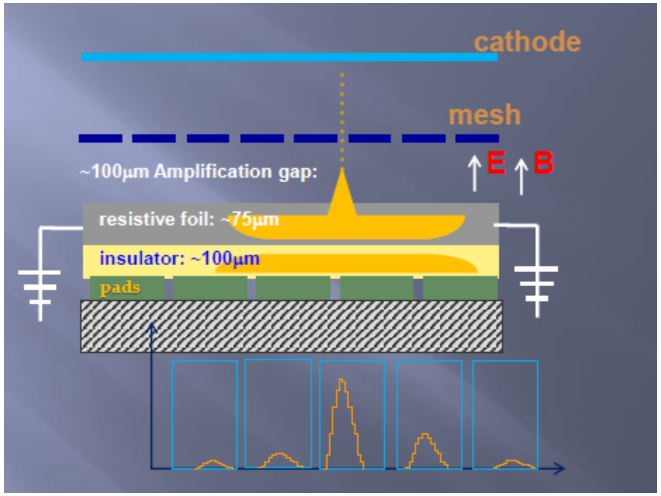
- Large Prototype TPC built and installed by the LCTPC collaboration in order to test different readout technologies and scale up to dimensions relevant to the ILD
- Technologies under investigation: GEMs, InGrid, Micromegas
- LP field cage parameters:
  - Length: 61 cm, Diameter: 72 cm
  - Up to 25 kV → E_{drift} up to 350 V/cm
  - Wall material budget: 1.3% X_0
- The endplate is able to host 7 readout modules (dimensions ~22x17 cm^2)



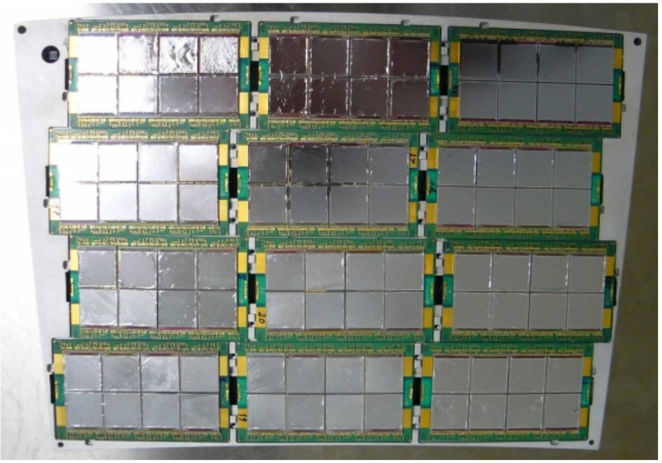


ILD TPC – MPGD Readout Technologies Overview

- Micro-Mesh Gaseous Detectors (Saclay, Carleton, SINP)

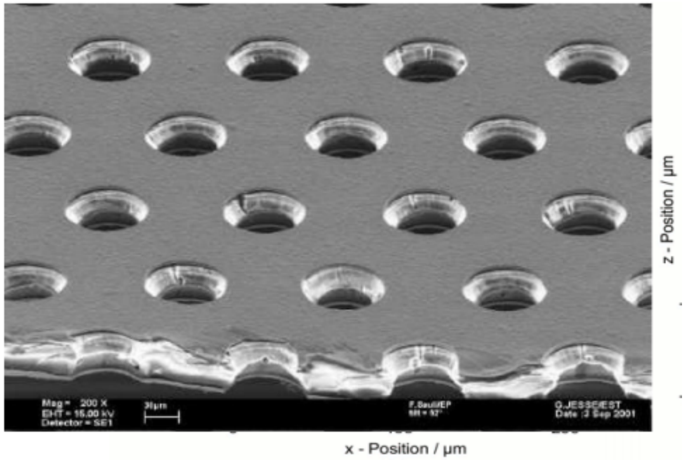


- GridPix (Bonn, Nikhef, Saclay, Siegen)
  - Micromegas with pixel readout



Talk by J. Kaminski on Thursday

- Gas Electron Multipliers (DESY, Japan, Bonn, Lund)

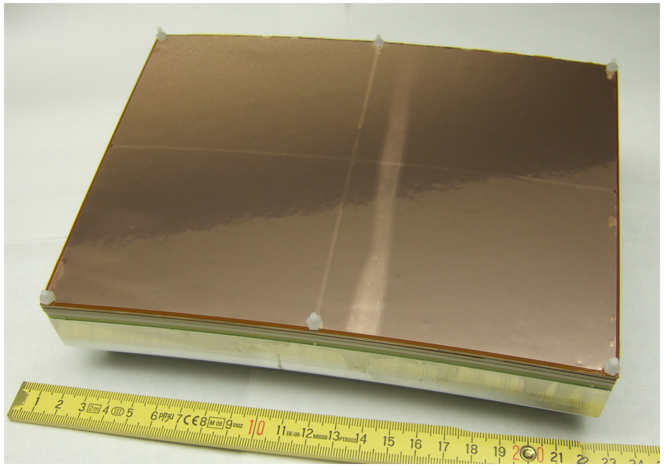


DESY GEM module

> Goals

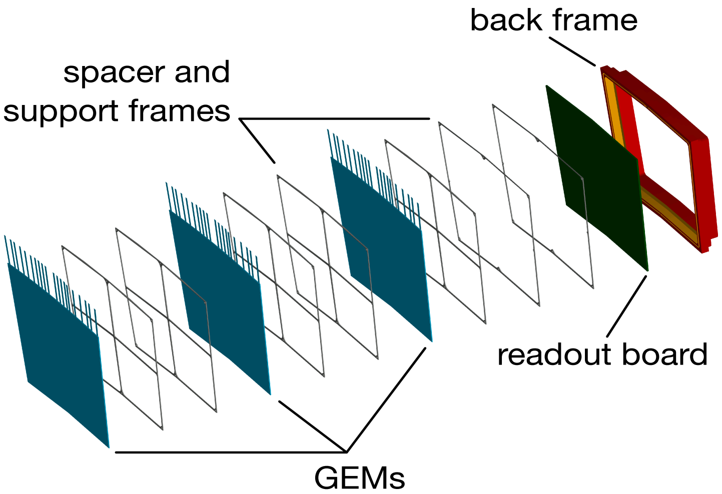
- Maximum active area
- Minimum material budget
- Field and high gain homogeneity

  → 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 mm^2 (~5k pads per module)



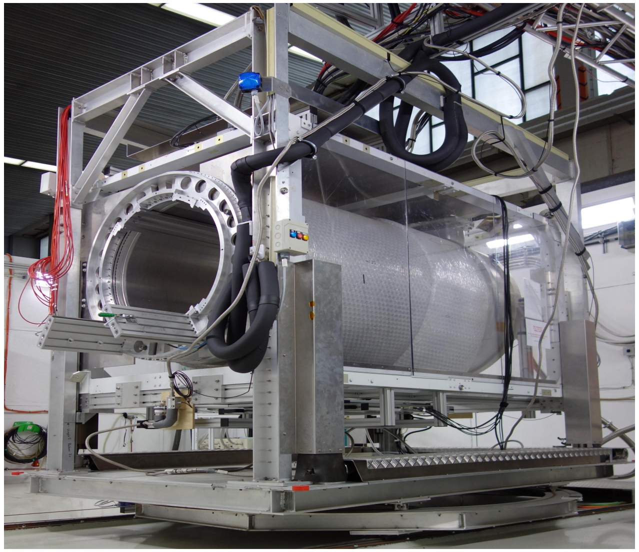
Outline

A time projection chamber for the ILC

> Performance

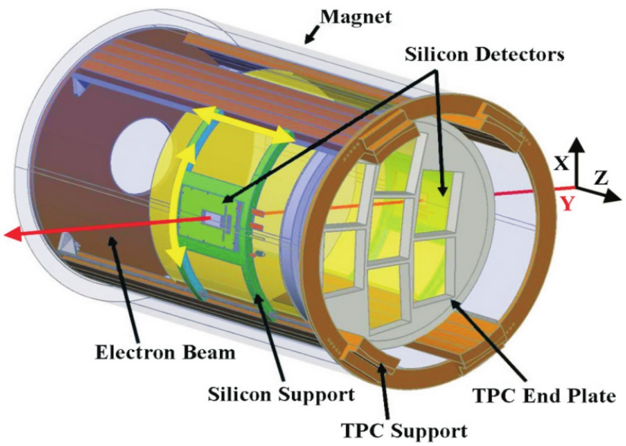
Ongoing optimisation studies

Test beam infrastructure



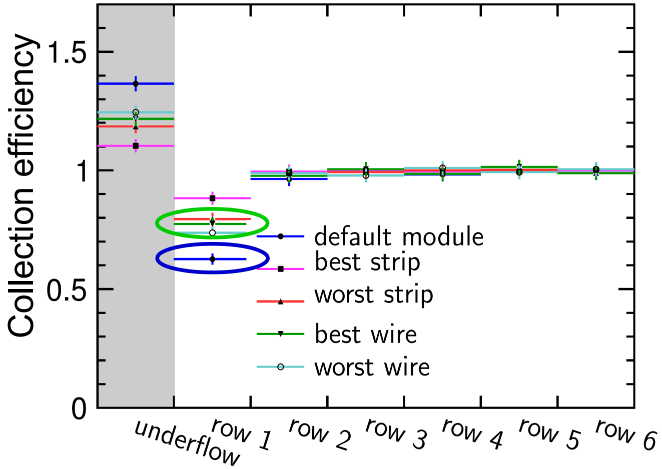
- Infrastructure includes a large bore 1T magnet
  - 20% X_0 material budget
- Ongoing effort to build an external Silicon tracker to provide reference tracks for the TPC
- Motivation: ability to study field distortions and alignment and measure the momentum resolution during combined test beams with the TPC system
- Challenge: Si tracker needs to fit in the existing TPC infrastructure (3.5 cm gap)

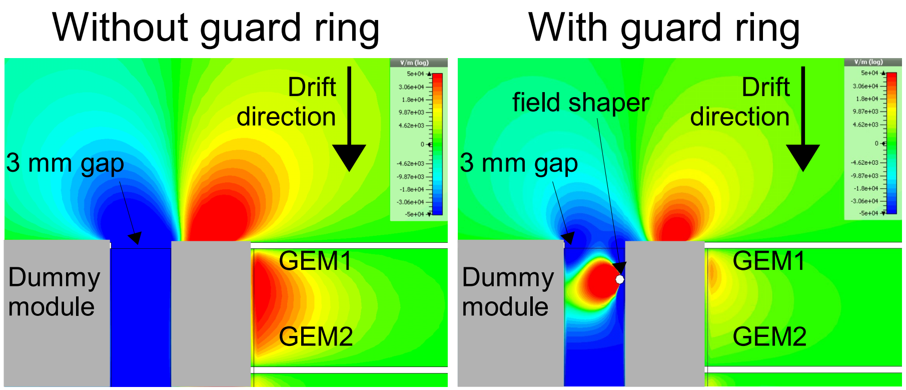
  → Stringent requirement on sensor spatial resolution: better than 10 μm



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





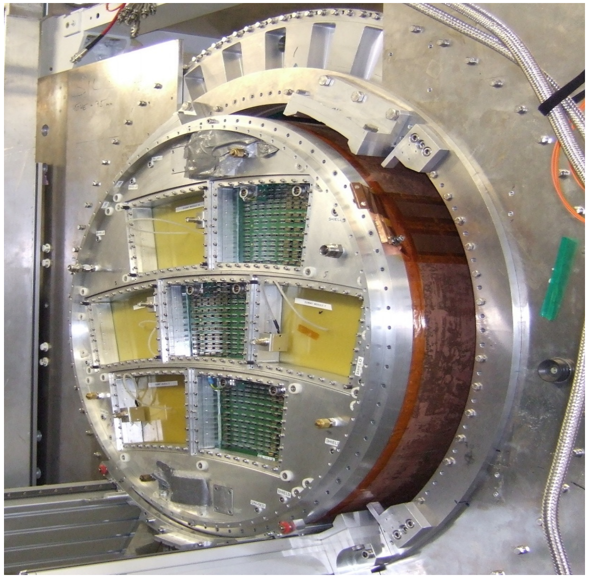
- Loss of signal close to module edge partially recovered when introducing a guard ring

Test beam setup

> DESY GEM module test beam campaign 2013

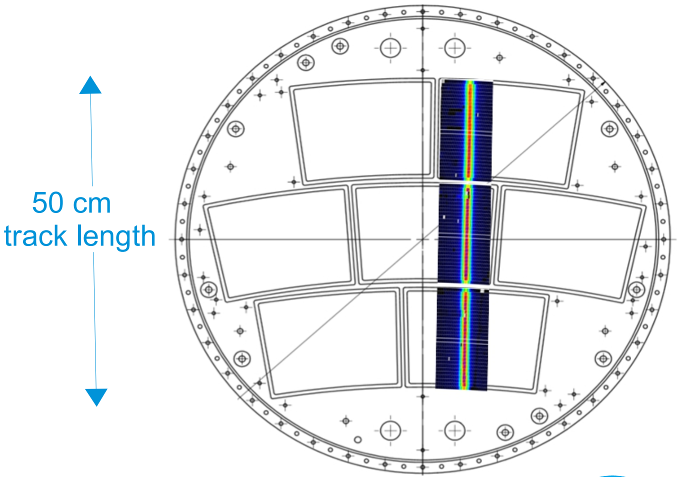
> Experimental setup

- 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)

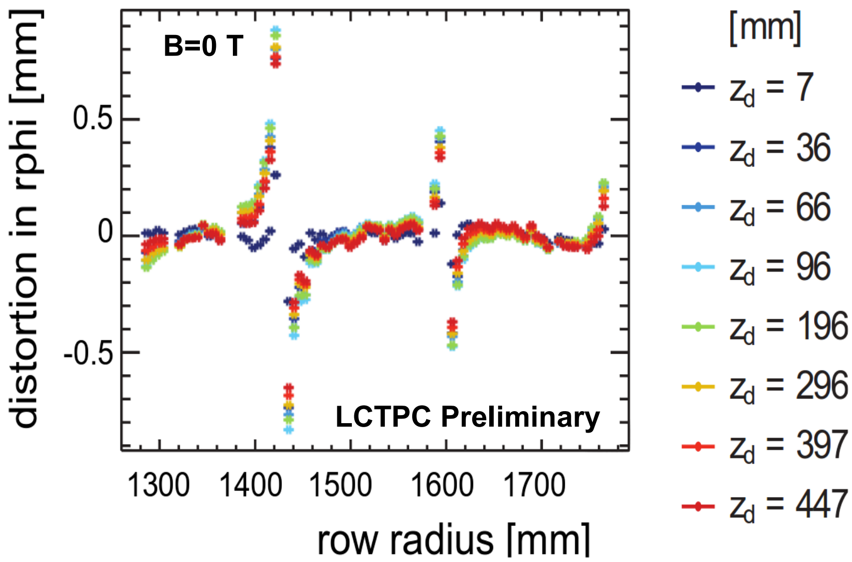


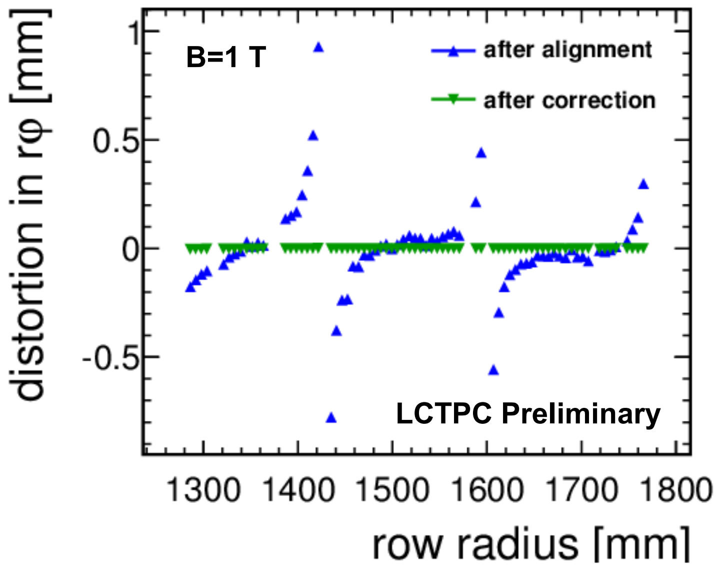
> Goal

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



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 pads
- Events with only one track are considered

> Single point resolution

$$\sigma_{r\varphi/z}(z) = \sqrt{\sigma^2_{0,r\varphi/z} + \frac{D^2_{t/l}}{N_{\mathrm{eff}} \cdot e^{-Az}} z}$$

Transverse and longitudinal diffusion

Attachment of primary electrons to gas molecules during drift

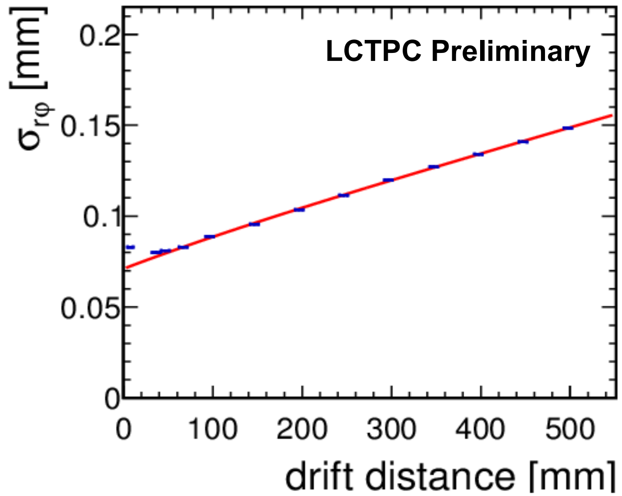
Intrinsic resolution of the readout at zero drift distance in rφ/z

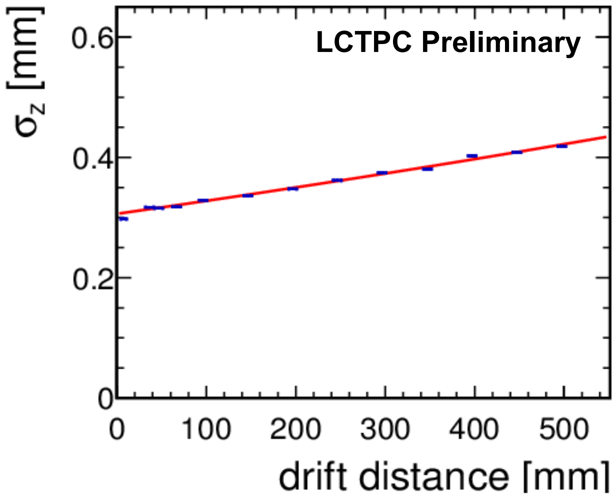
Effective number of primary signal electrons

Resolution

- Single point resolution

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



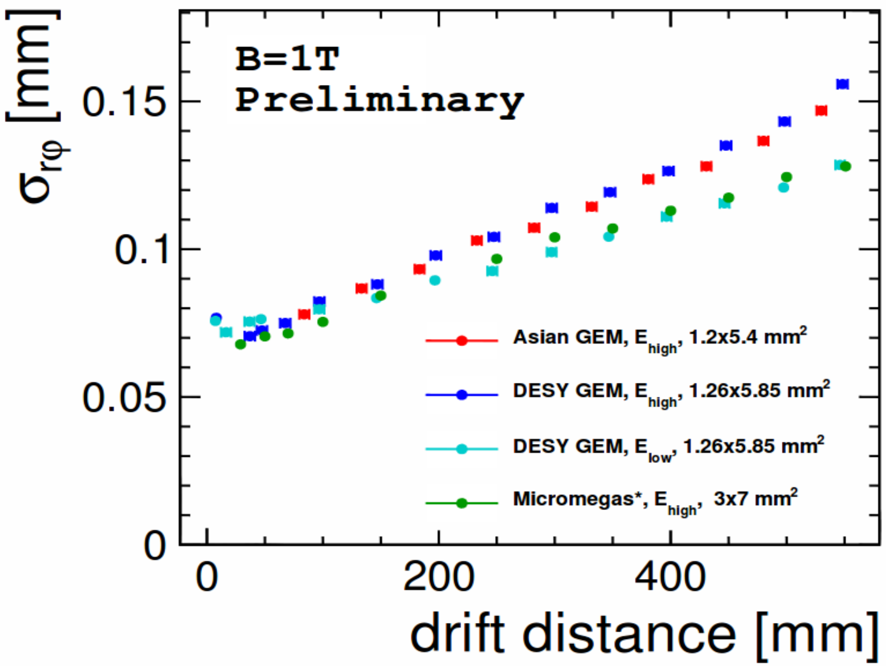


σ	$\sigma_{0,r\varphi/z}[\mu\text{m}]$	N_{eff}	$A[\text{m}^{-1}]$	$D_{t/l}[\text{mm}/\sqrt{\text{cm}}]$ (fixed)
$r\varphi$	71.0 ± 1.2	39.8 ± 2.0	0.495 ± 0.097	0.103
z	306.3 ± 0.8	39.5 ± 1.6	0.529 ± 0.084	0.226

- The ILD TPC requirement of rφ resolution <100 μm for full drift distance at 4T corresponds to an rφ resolution <150 μm for the large prototype TPC at 1T
- z resolution ~300 μm 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

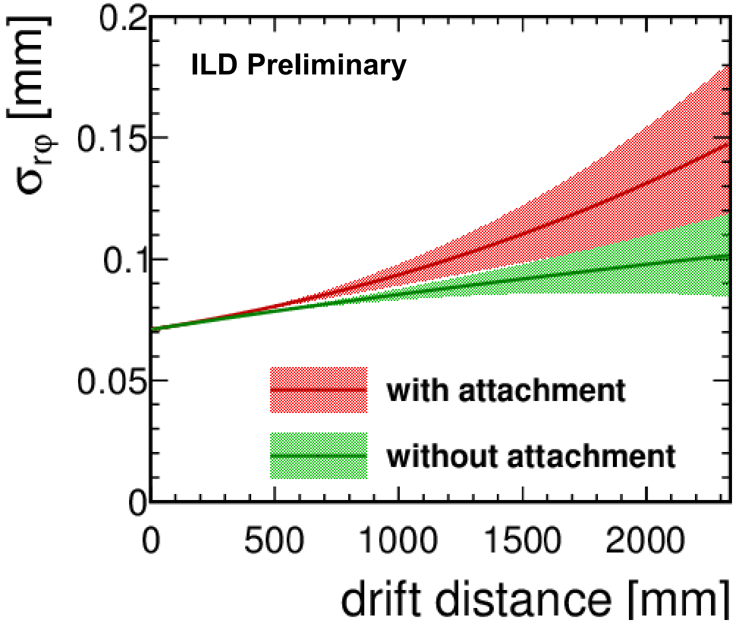


E_{low} = 130-140 V/cm
→ minimal transverse diffusion

E_{high} = 230-240 V/cm
→ maximum drift velocity

- All modules show comparable resolution

Resolution – Extrapolation to ILD scale



- Extrapolation of the rφ 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 um at full drift distance, gas quality and purity need to be tightly controlled at ILD

Outline

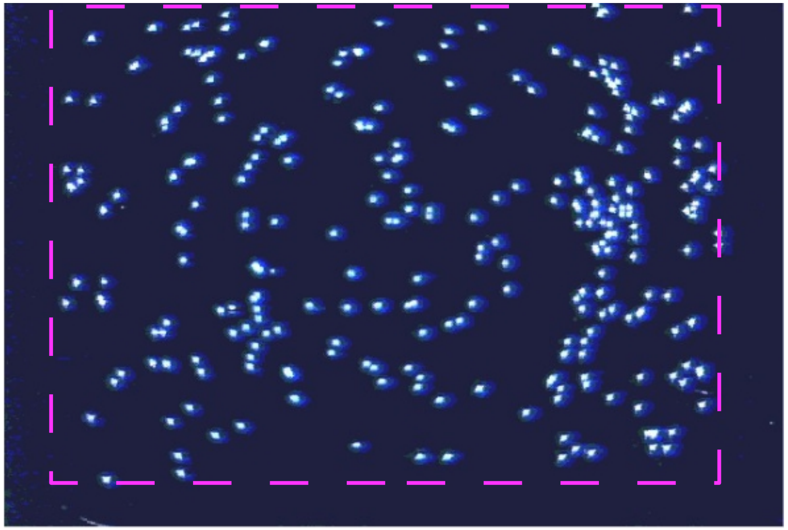
A time projection chamber for the ILC

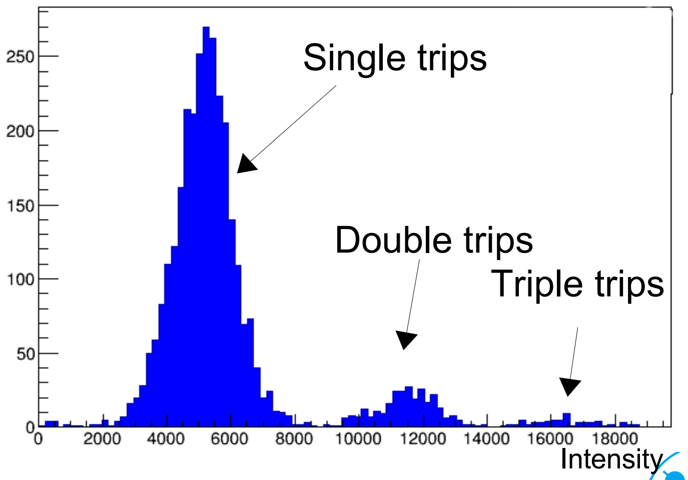
Performance

> Ongoing optimisation studies

GEM stability

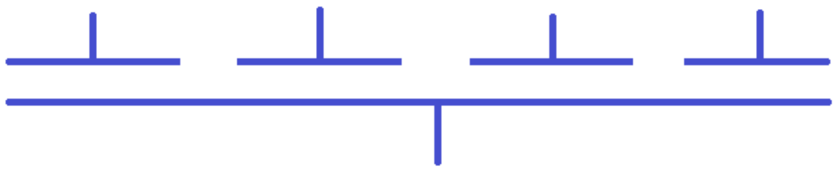
- Observed discharges & destructive discharges during extreme conditions
- Investigate and improve long-term stability to demonstrate suitable performance for the ILD TPC
  - Optical and electrical observations of sparks of single GEMs in module-like setup
  - Simulations of the system to understand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

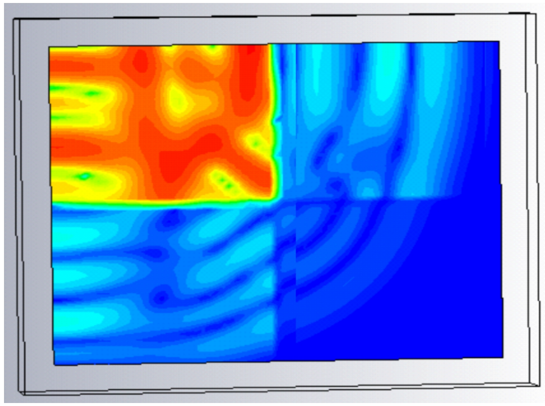




GEM stability (2)

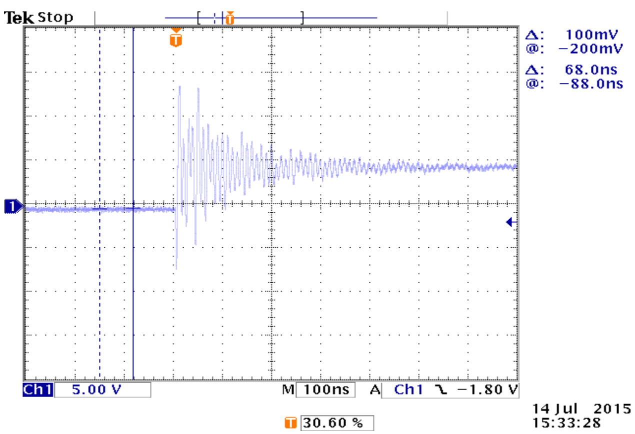
- Discharge causes current oscillations on GEM surface in different sectors (CST® simulations)



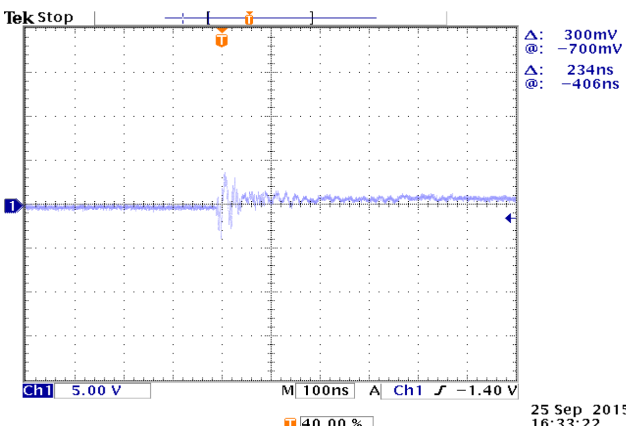


- Test setup using an R-C circuit to damp the oscillations and reduce the number of double discharges
  - Further ongoing studies to decide whether this will be included in the next module iteration

Tripping sector without RC circuit

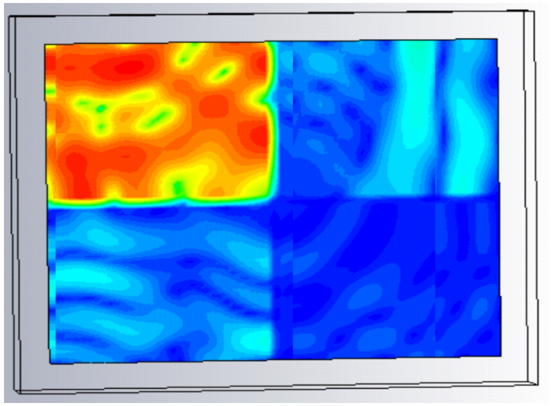


Tripping sector with RC circuit



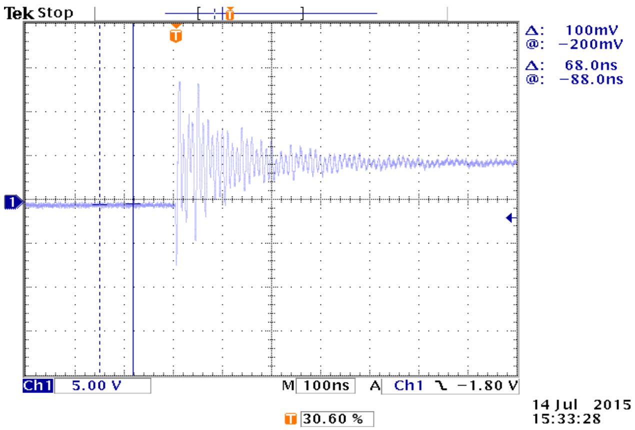
GEM stability (2)

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

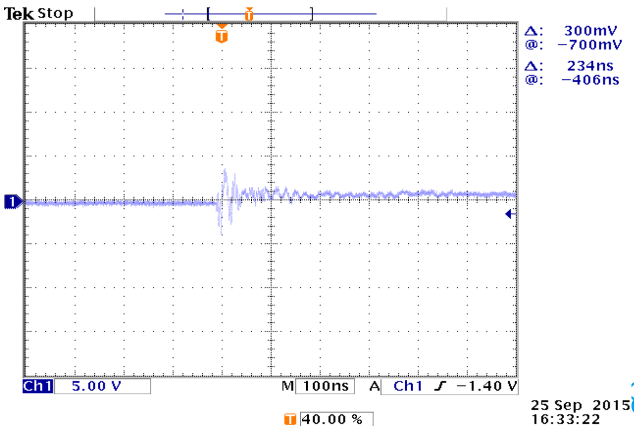


- Test setup using an R-C circuit to damp the oscillations and reduce the number of double discharges
  - Further ongoing studies to decide whether this will be included in the next module iteration

Tripping sector without RC circuit

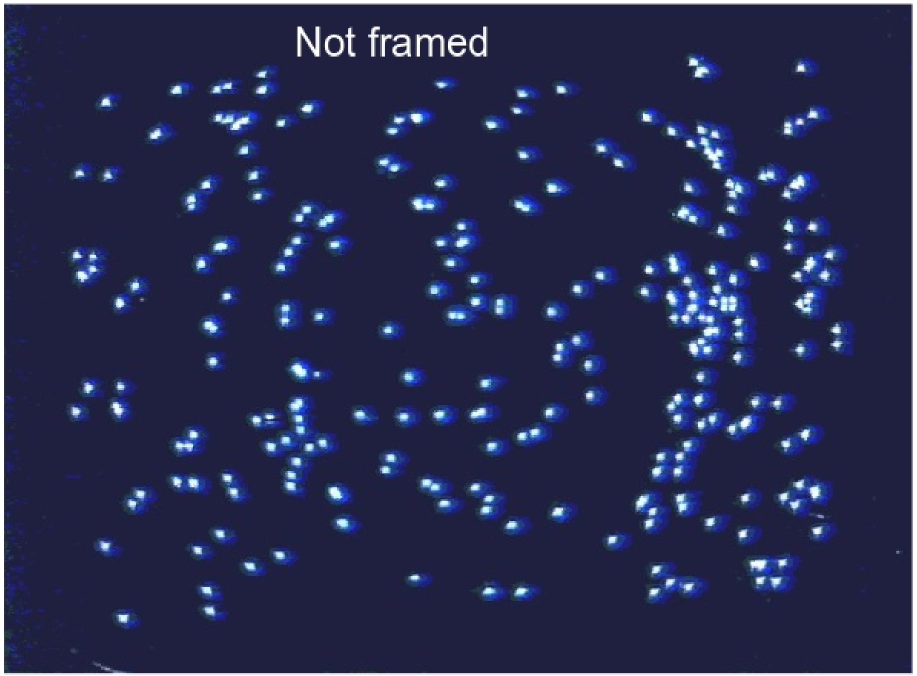


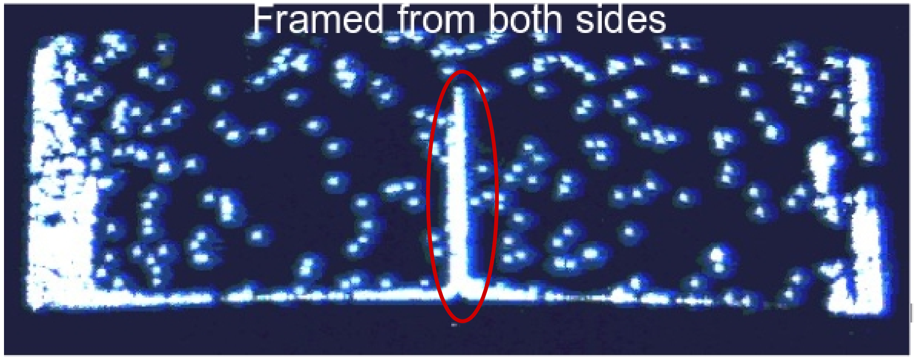
Tripping sector with RC circuit



GEM stability (3)

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

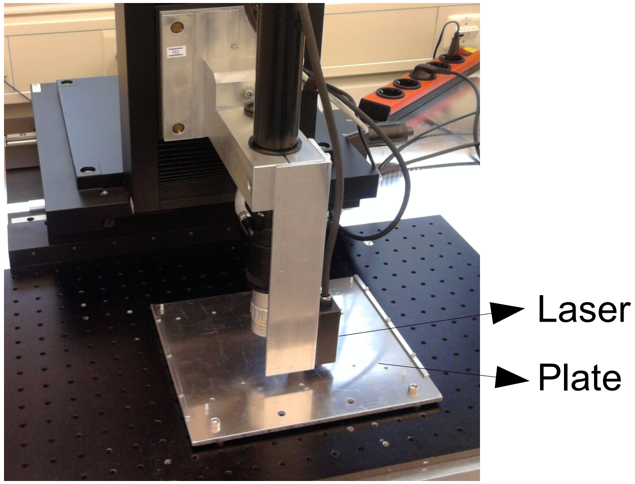




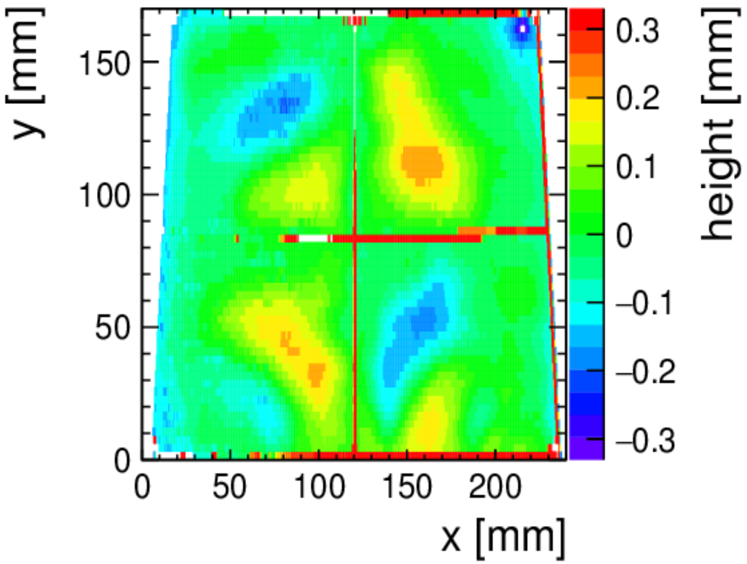
GEM flatness

- 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

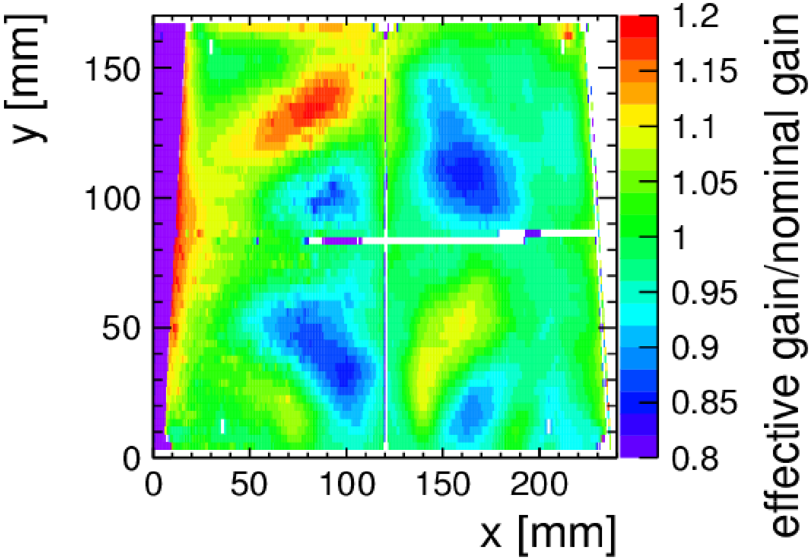


- Flatness of current GEM structure is at the level of 150 µm (rms)



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

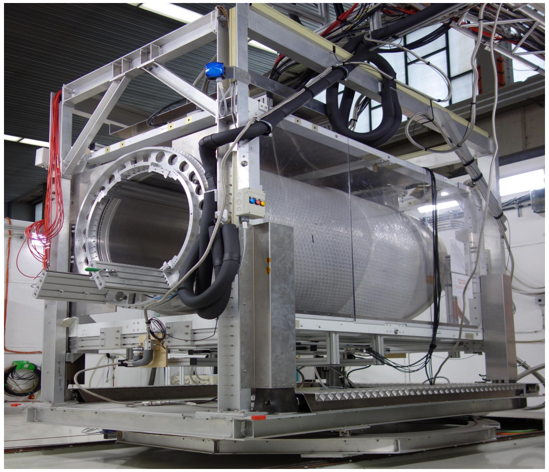
- Successful previous test beam campaign
  - Showing excellent performance of the LPTPC and GEM modules
  - Understanding of the system
  - Extrapolation shows we can achieve the resolution requirements of the ILD TPC
- Ongoing optimisation process for Large Prototype TPC and GEMs
  - Long-term stability 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

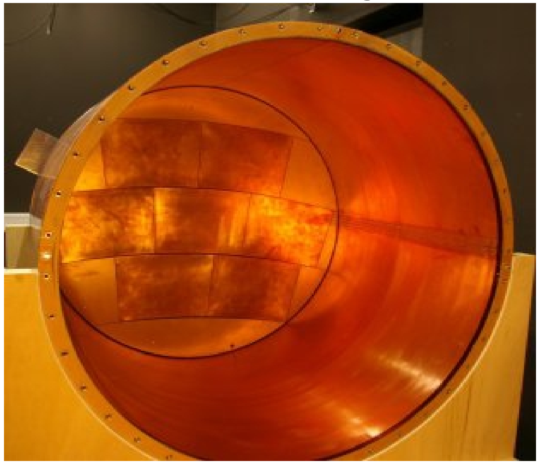
Large Prototype TPC

- 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

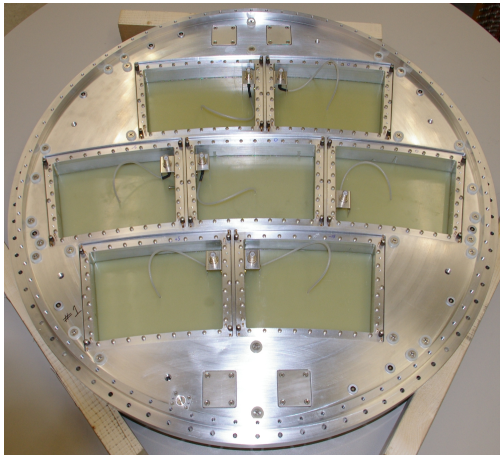
- Infrastructure includes a large bore 1T magnet
  - 20% X_0 material budget



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

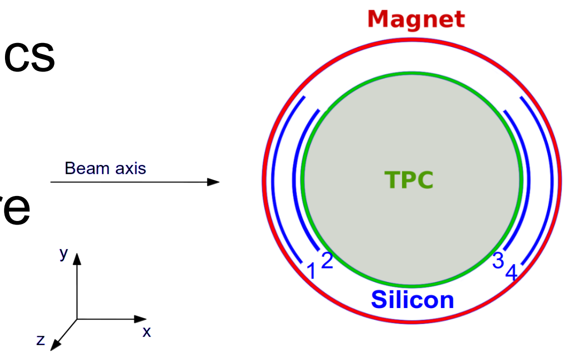


- The endplate is able to host 7 readout modules (dimensions ~22x17 cm^2)

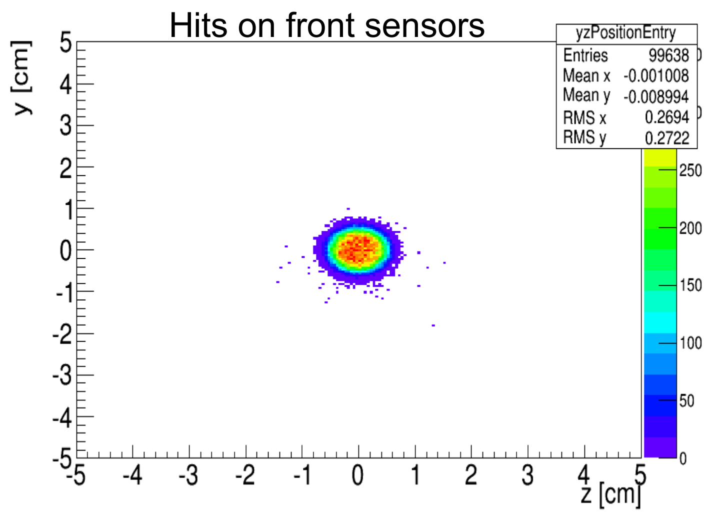


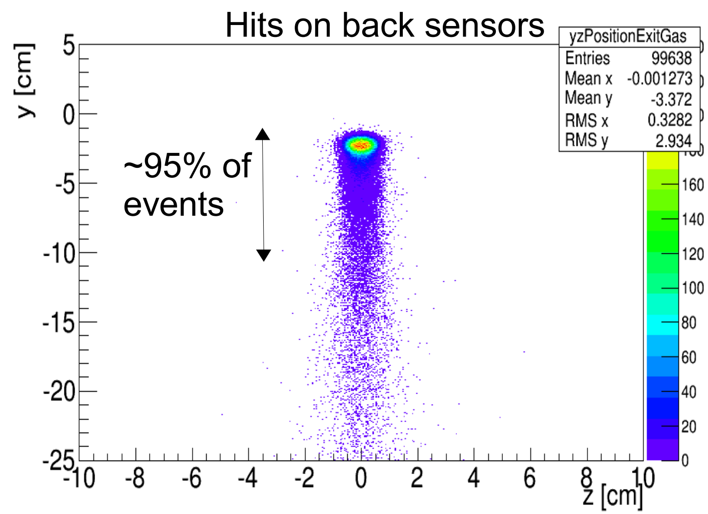
Silicon telescope – Requirements

- Simulation studies to decide on sensor characteristics and system geometry
- Sensors with spatial resolution better than 10 um 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

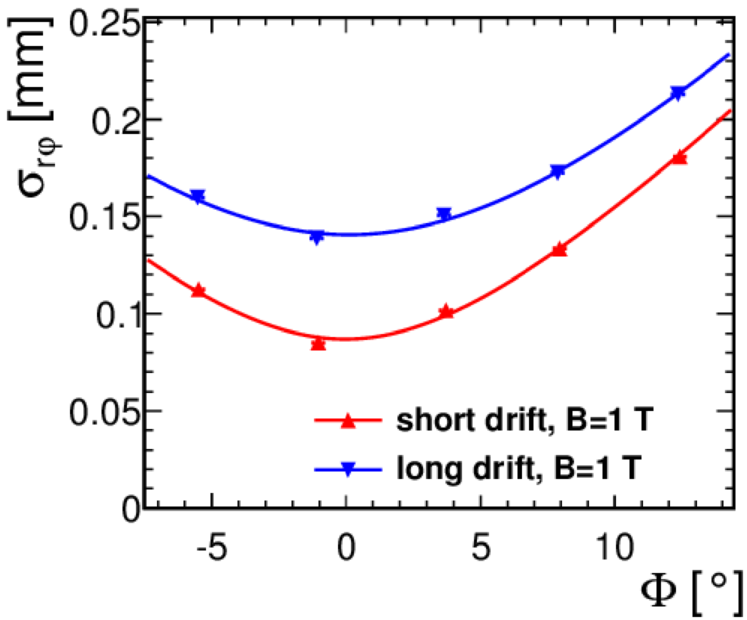




Resolution – Φ dependence

- For inclined tracks, a dependence of the resolution on the azimuthal angle Φ is expected

$$\sigma_{r\varphi}(\Phi) = \sqrt{\sigma^2_{0_{r\phi}}(z) + \frac{L^2}{12\hat{N}_{\text{eff}}}\tan^2(\Phi)}$$

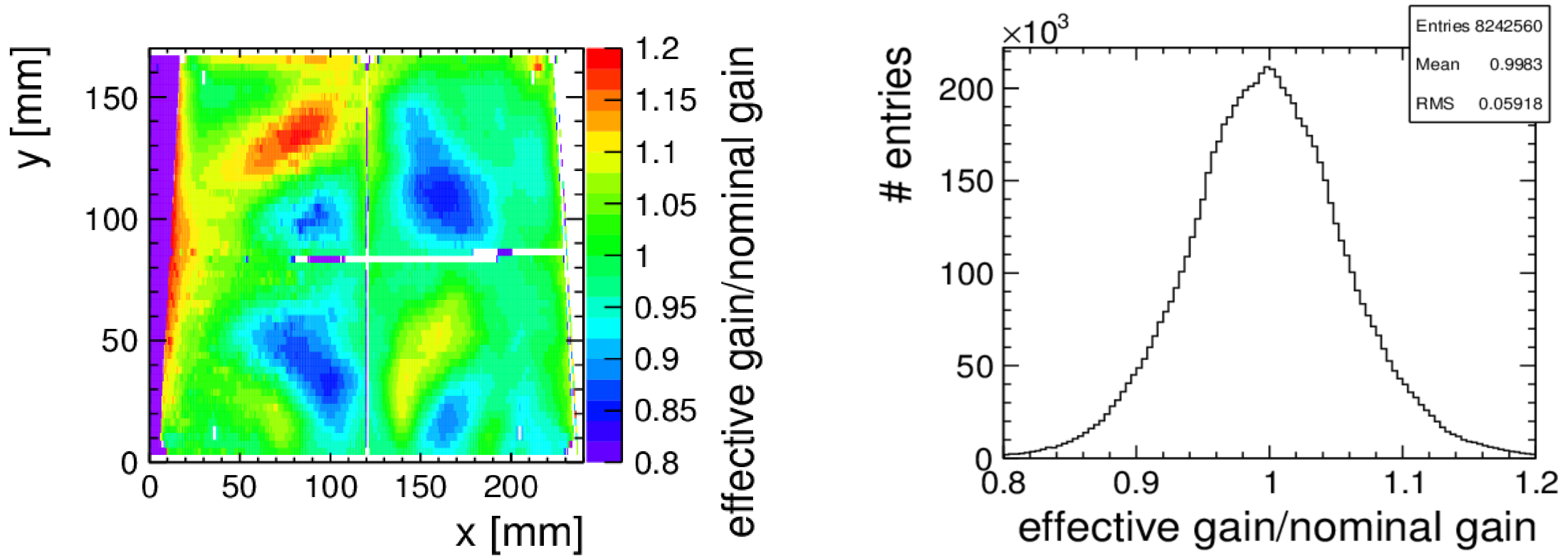


- Tracks for short (10 cm) and long (40 cm) drift distances are shown

- tan(Φ) 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