A GEM Time Projection Chamber for the International Large Detector

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Student Seminar on Detector Development
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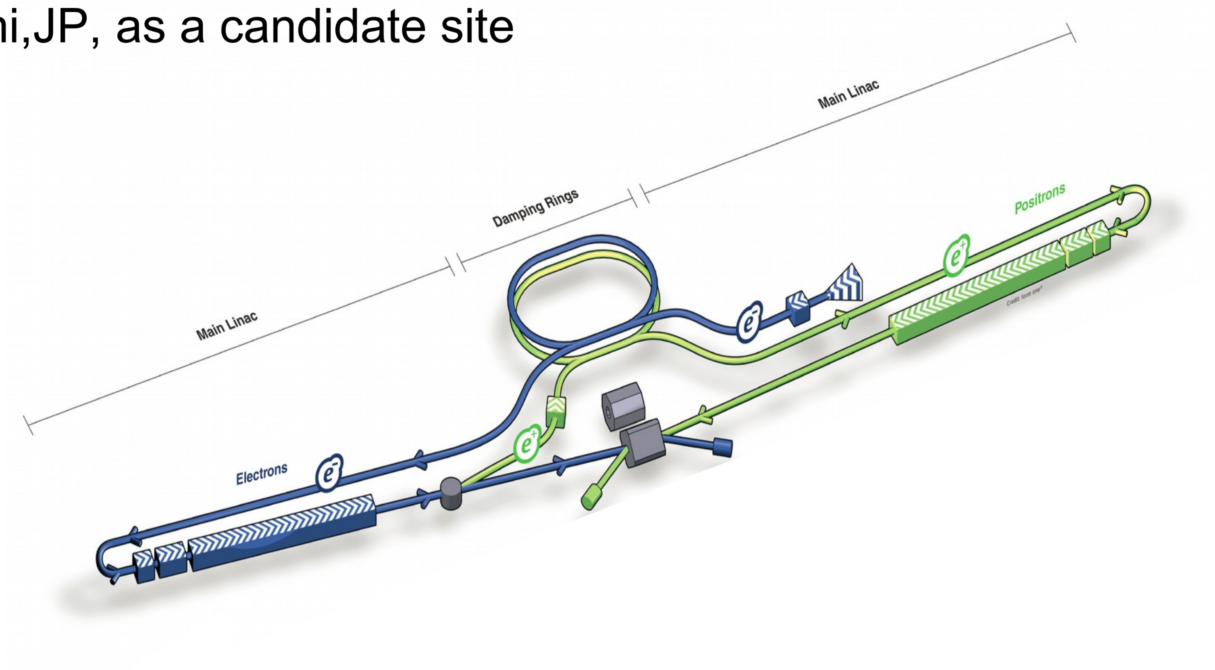
Content

- International Linear Collider and International Large Detector
- Time Projection Chambers
- Micro Pattern Gaseous Detectors
- DESY GridGEM Module
- Analysis of Test Beam Data

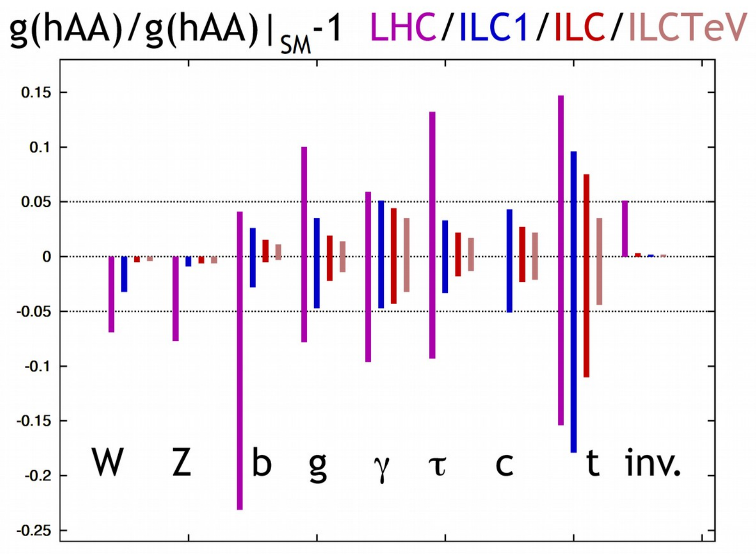
International Linear Collider

- Planned e^+e^- linear accelerator
- Center of mass energy of 250-500 GeV (Upgrade to 1 TeV)
- Length: ~31 km, superconductive cavities
  - XFEL: technology prototype
- Two detectors interchangeable at the interaction point
- Kitakami,JP, as a candidate site

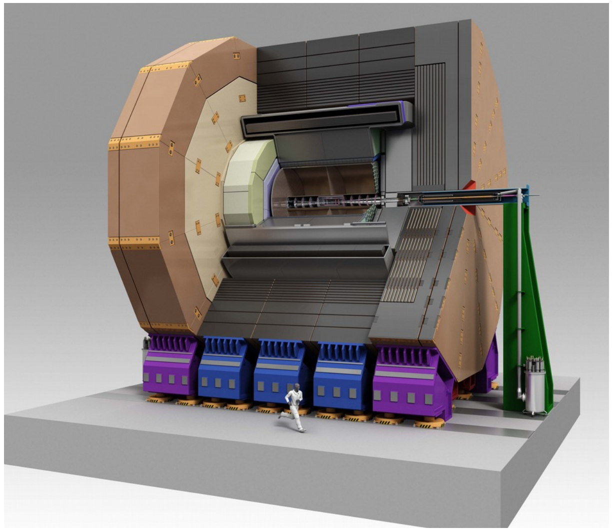


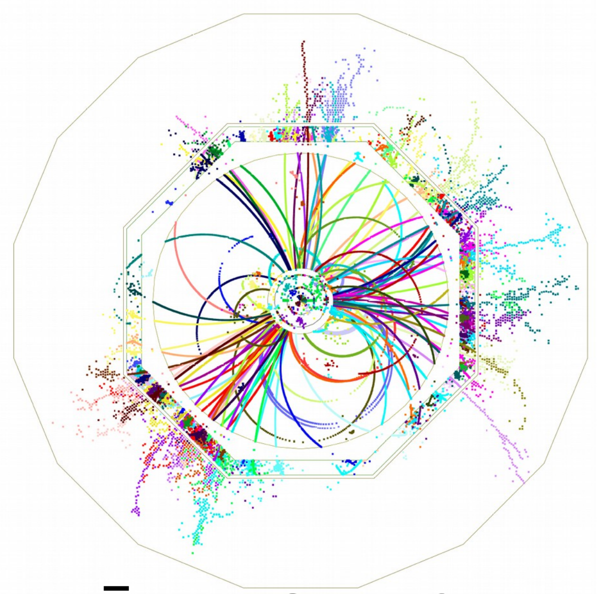
Why ILC

- "Higgs" Boson found at the LHC
- Is it the Standard Model Higgs?
  - Spin
  - Coupling to Masses
  - Branching ratios
- Precision measurements of Higgs Boson possible at the ILC
  - Discovery capabilities in BSM searches
  - W, Z and top precision measurements



International Large Detector





$t\bar{t} \rightarrow 6q$ @ 500 GeV

> Particle Flow Algorithm (PFA)

- Use detector with best resolution for each particle in a jet (reconstruct every particle)

> Requirements on the tracker:

- Very high tracking efficiency, also for low momentum particles
- Minimal material budget in front of the highly granular calorimeter
- Momentum resolution:

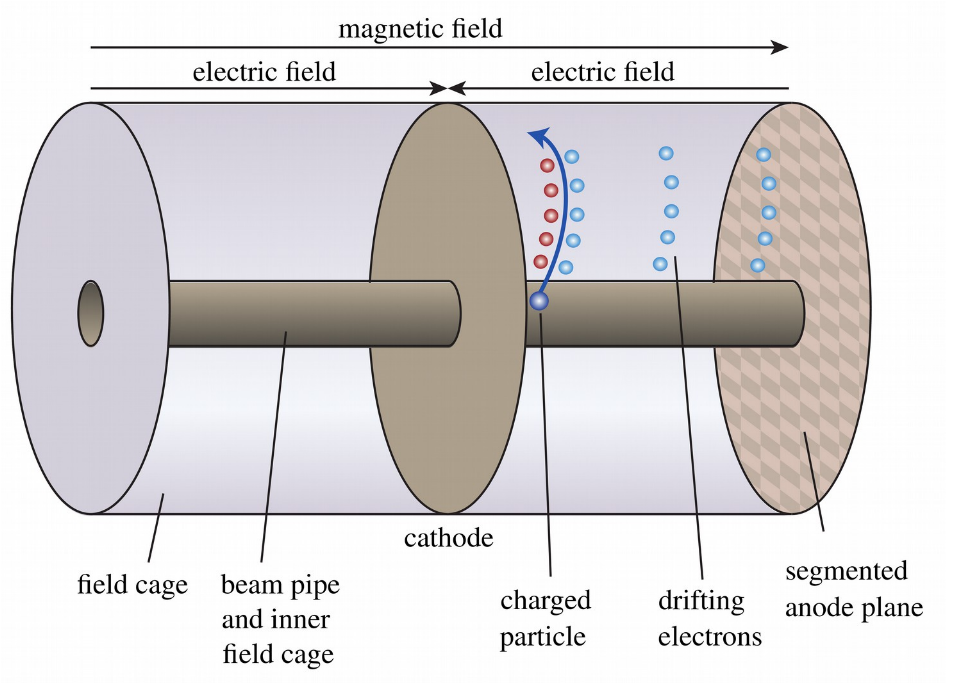
  $\sigma(1/pt) \sim 2 \times 10^{-5}$ /GeV and
  $\sigma(1/pt) \sim 10^{-4}$ /GeV for TPC alone

> Solution Time Projection Chamber

- ~ 200 track points → continuous tracking
- Single point resolution $\sigma_{r\varphi} < 100$ µm
- Lever arm of ~ 1.2 m in a magnetic field of 3.5 – 4 T

Time Projection Chamber

- Functionality of a Time Projection Chamber (TPC):
  - Charged particles travel through the sensitive volume and ionize the gas along their path
  - The electron/ions drift toward the anode/cathode due to the electric field
  - The signal of the electrons is amplified and read out at the readout plane
  - From the drift time and drift velocity one can reconstruct the 3rd dimension

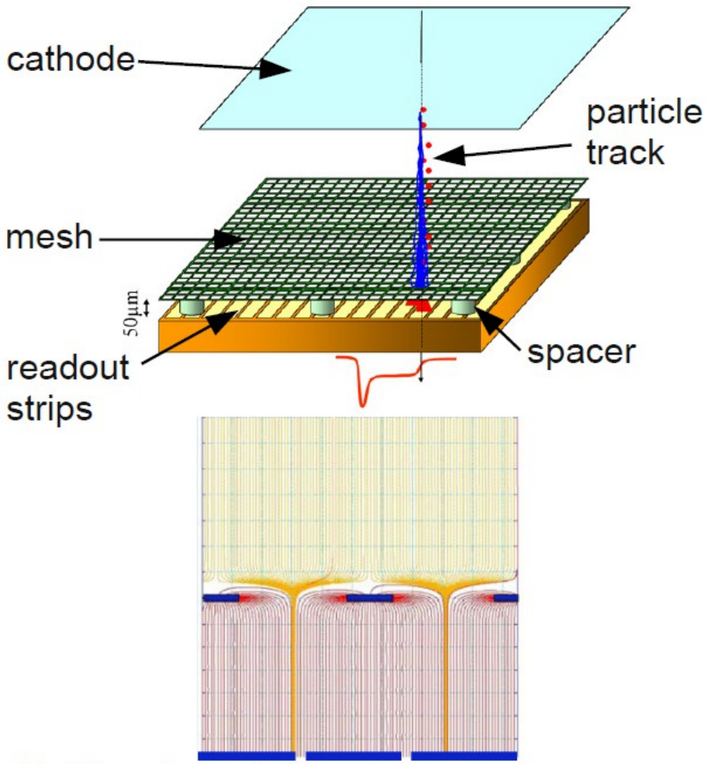


- Magnetic field to
  - Reconstruct the momentum of the particles
  - Reduce the diffusion during the drift
- Particle identification from energy loss measurement (dE/dx)

Micro Pattern Gaseous Detectors

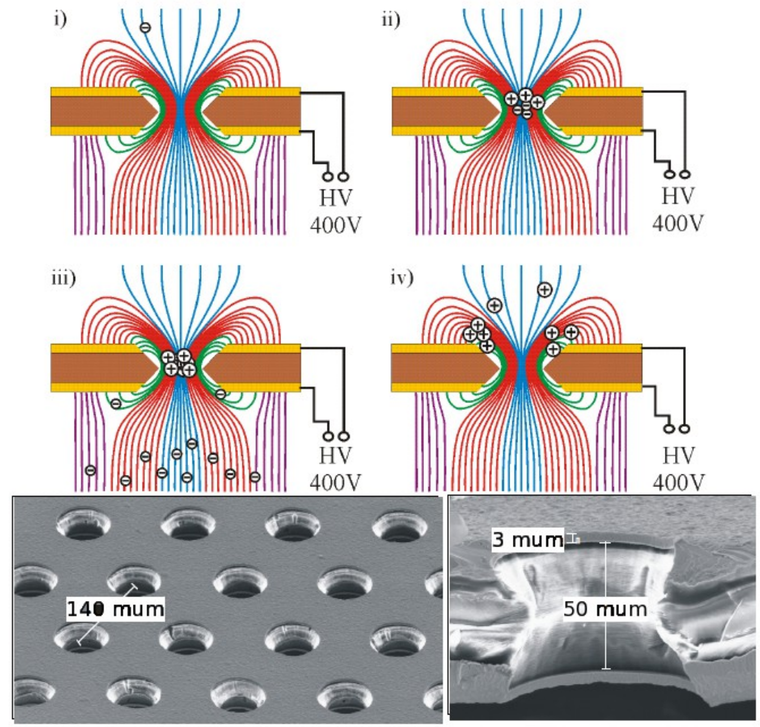
- Wire amplification not useable to achieve the desired resolution
- New amplification technologies: MPGDs

Micro-Mesh Gaseous Detectors



Y., Giomataris et al.,
Nucl. Instrum. Meth. A376:29-35,1996.

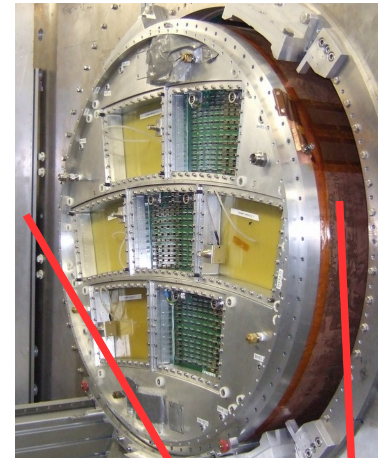
Gas Electron Multipliers

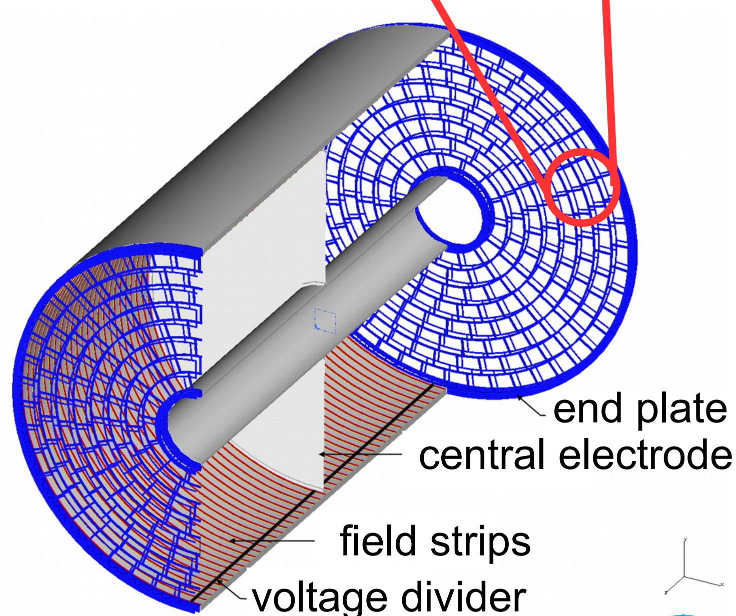


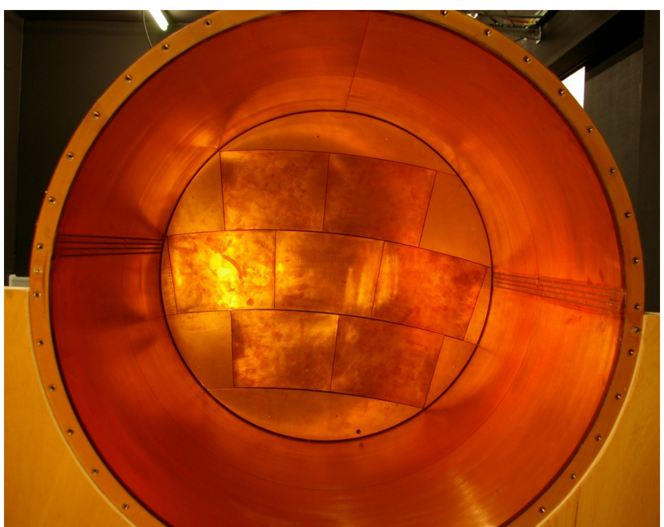
F. Sauli, Nucl. Instrum. Meth. A386:531-534,1997.

Large Prototype

- Large prototype to compare different readout technologies and address integration issues
- LP parameters:
  - Length ~ 60 cm
  - Diameter ~72 cm
  - Up to 25 kV → E = 400 V/cm
  - Material budget 1.23 % X_0
- Modular end plate for up to 7 modules

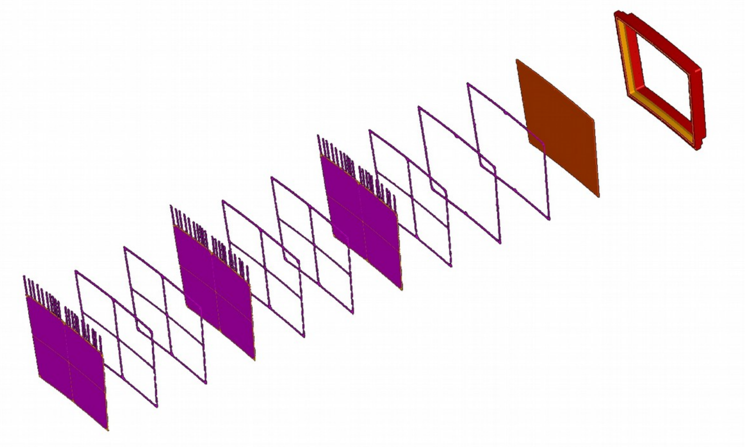


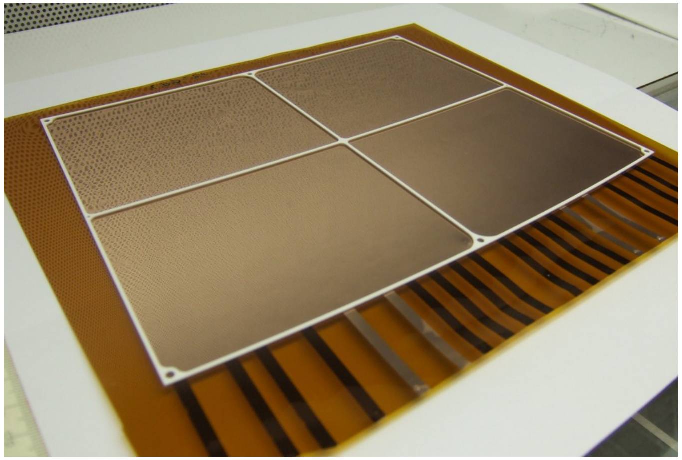


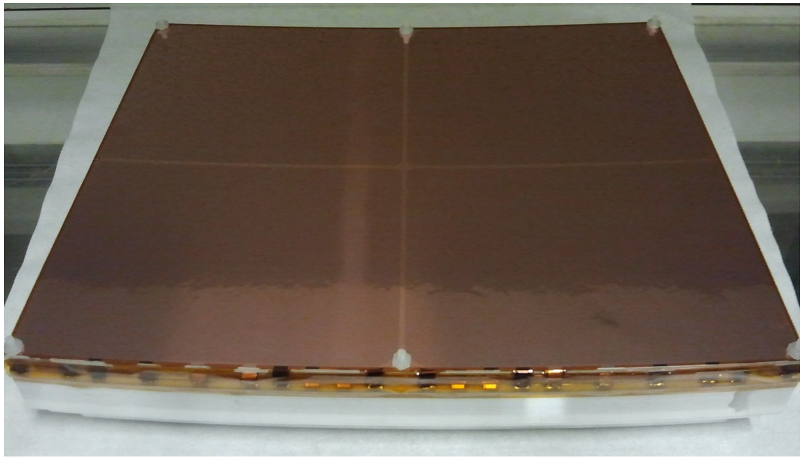


DESY GridGEM Module

- Triple GridGEM module with an integrated support structure
- Aluminum oxide grid
  - Minimal dead space
  - Minimal material budget but high rigidity
- Flatness of the GEMs
  - More homogenous electric field
  - Less gain fluctuations → better dE/dx resolution

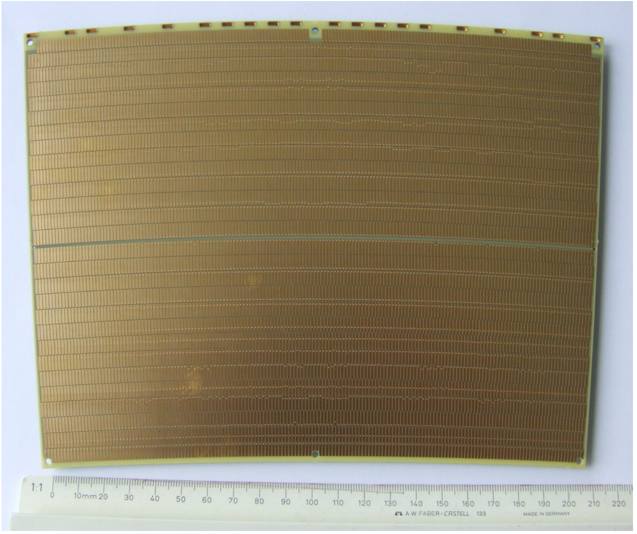


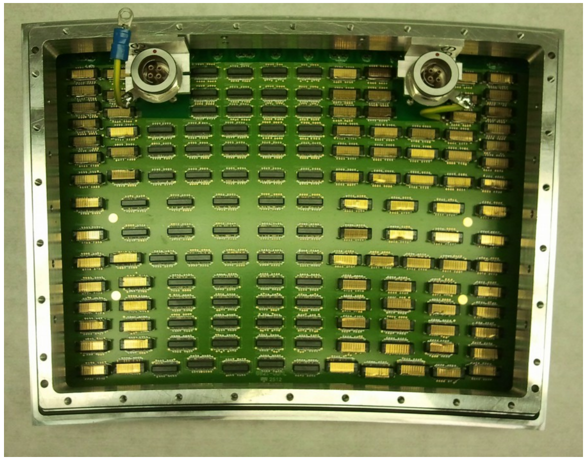


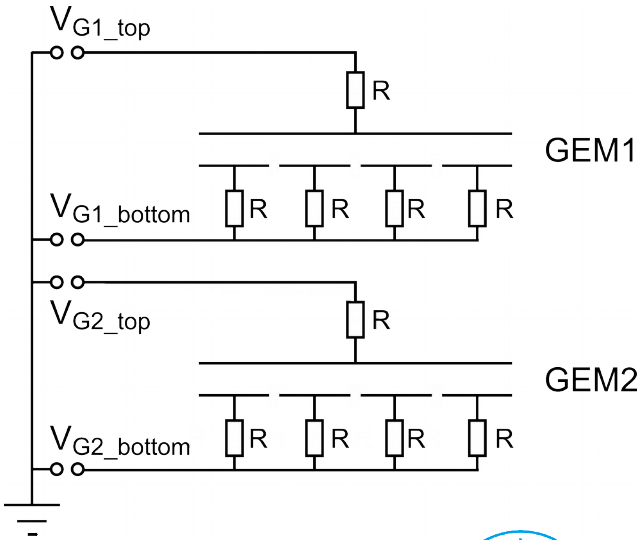


DESY GridGEM Module

- Bottom of the GEMs divided in four sectors
  - Reduction of the stored energy per sector
- Top is not divided to ensure an homogeneous drift field
- Each GEM side is attached to its own channel
- Active area of ~ 23 x 17 cm^2
- ~4800 pads with a size of 1.25 x 5.85 mm² (designed at the University of Bonn)

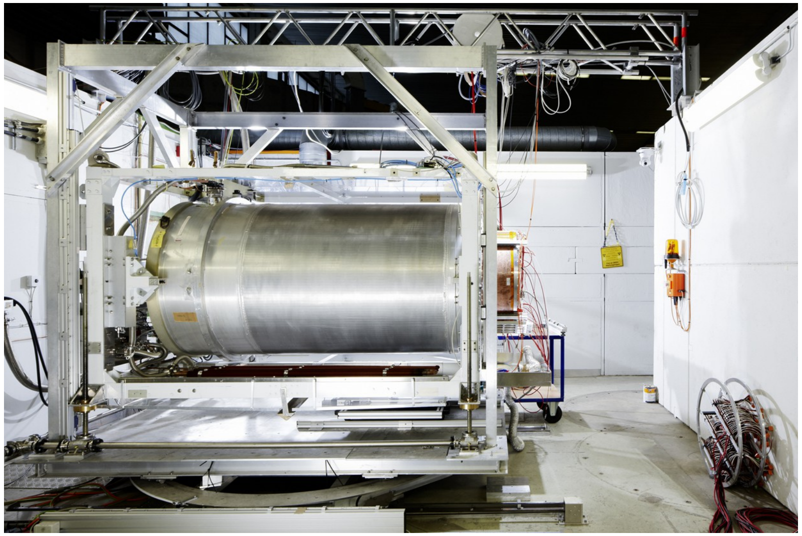


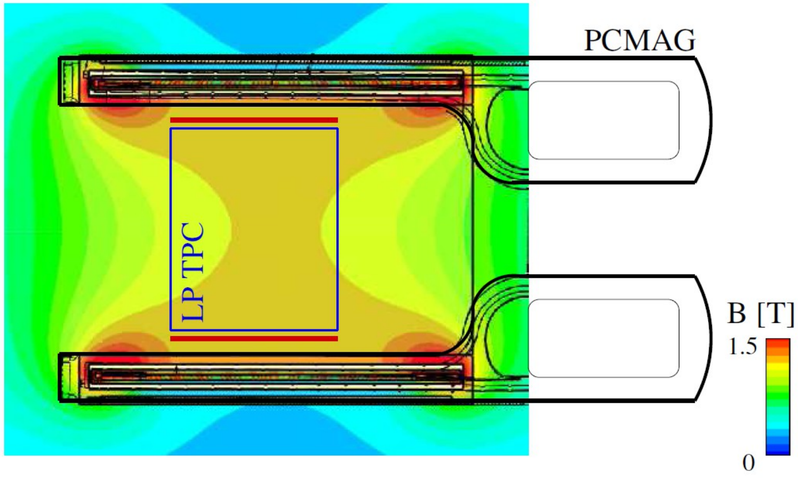




DESY II Test Beam

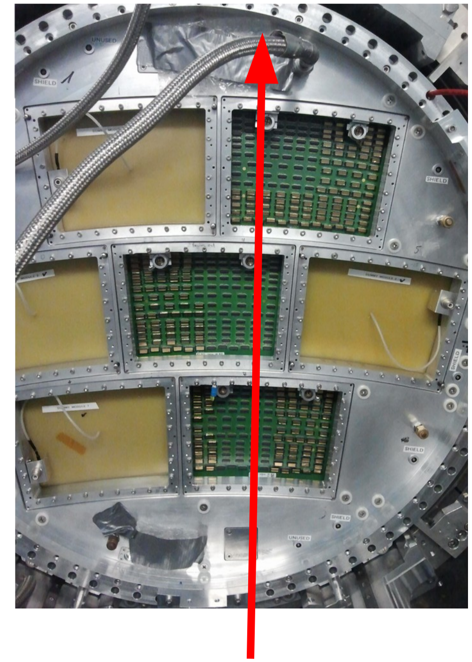
- DESY II test beam, area T24/1
  - e^+/e^- from 1 GeV to 6 GeV
- PCMAG Magnet (1 T)
- Movable stage
- HV and gas system and slow control



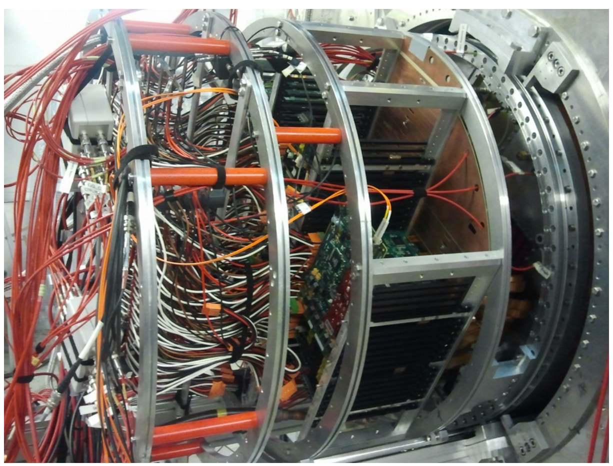


Test Beam Setup

- Three modules in the LP
- Half of the channels connected, due to space constraints
  - Along the beam profile
  - Lever arm of ~ 50 cm
  - ~8000 channels



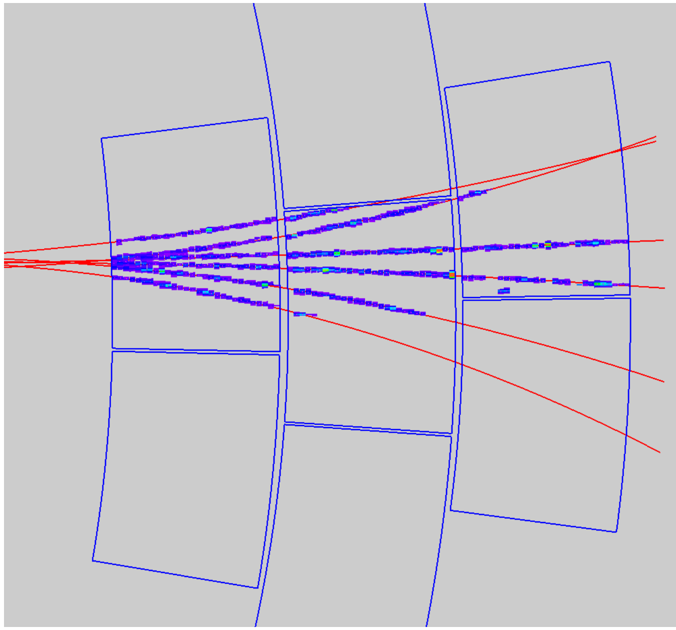
beam direction



Electronics and LV supply
(designed at the University of Lund)

Test Beam Measurements March 2013

- Goal of the measurements:
  - Validation of the module design
  - Understanding field distortions
  - First studies concerning the momentum resolution of the system
- Working point:
  - ~240 V/cm Drift field (maximum drift velocity in T2K gas (Ar:CF4:iC4H10 95:3:2))
  - Voltage across the GEMs: 250 V
  - Transfer field: 1500 V/cm
  - Induction field: 3000 V/cm

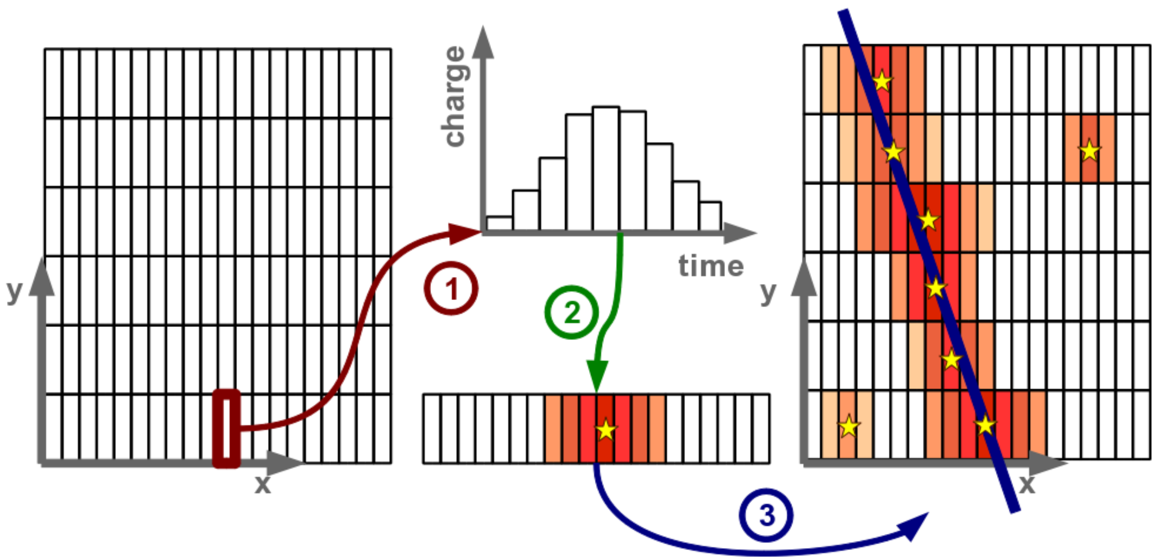


Track Reconstruction

1) Find a rise of the charge spectrum on the single pads (pulse)

2) Combine neighboring pads with pulses to single hits

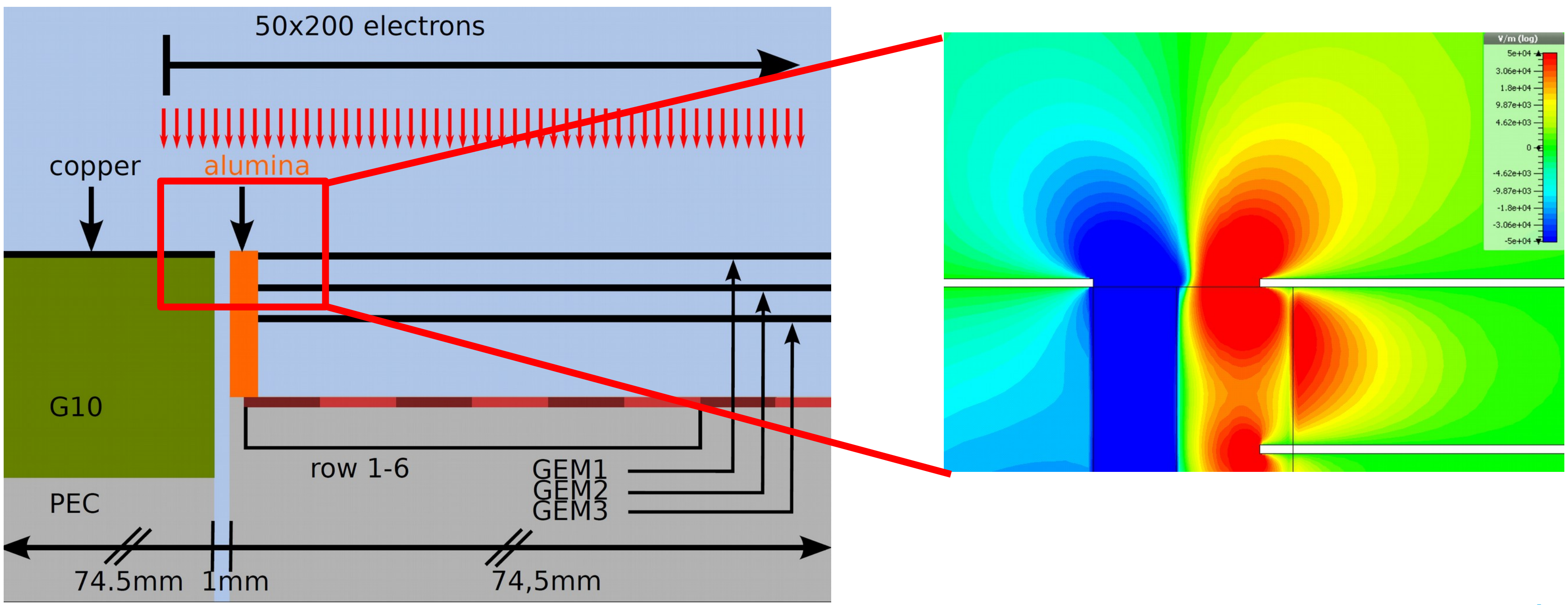
3) Combine the hits on the rows to single tracks



- Track finding: Fast Hough transformation
- Track fitting: General Broken Lines

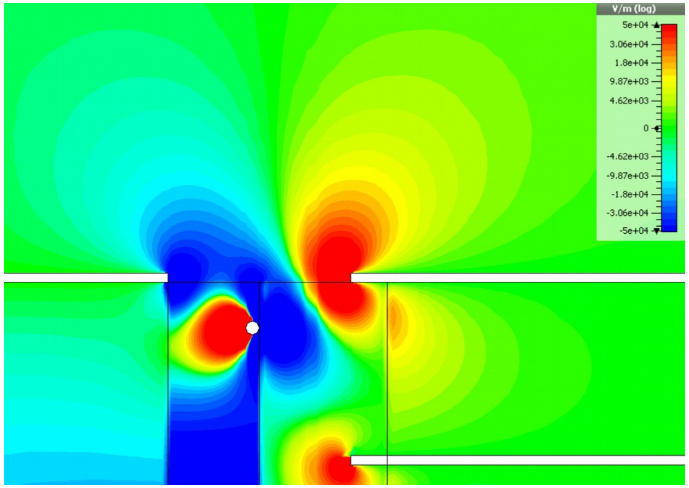
Field Distortions

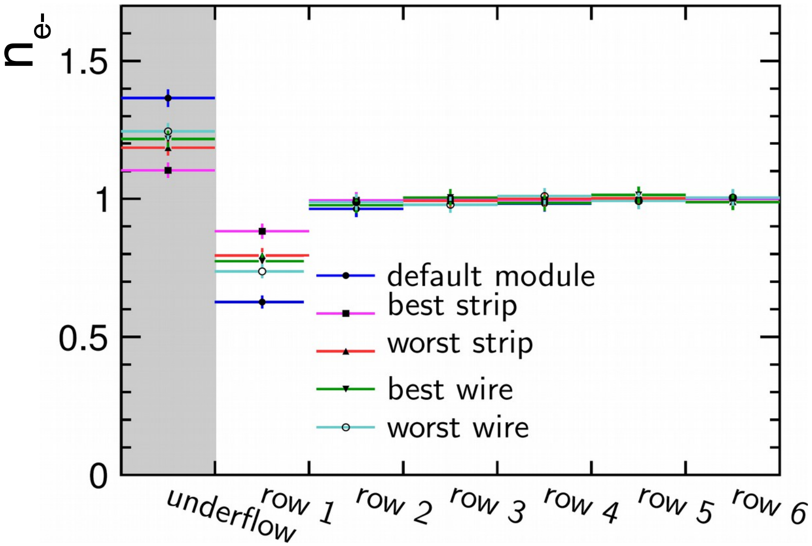
- Previous module iterations showed distortions at the border of the module
- Simulation study to understand the observed behavior (Klaus Zenker)
- Simulate the electric field at the border of a module
- Field distortions are visible due to the gap between the modules



Guard Ring

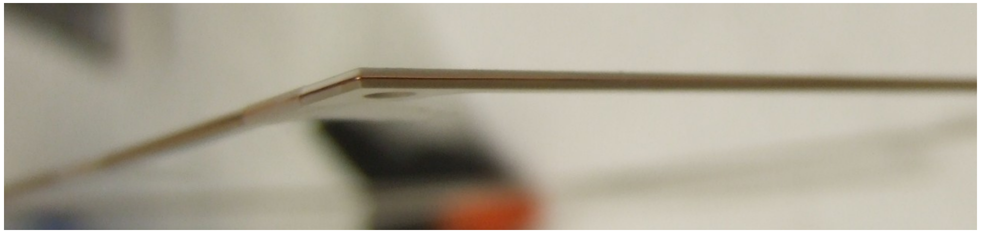
- Introduce a guard ring to suppress field distortions
  - Wire and strip solutions simulated
- Simulate the electron collection efficiency
- Retrieve up to 30 % collection efficiency on the first row with the guard ring



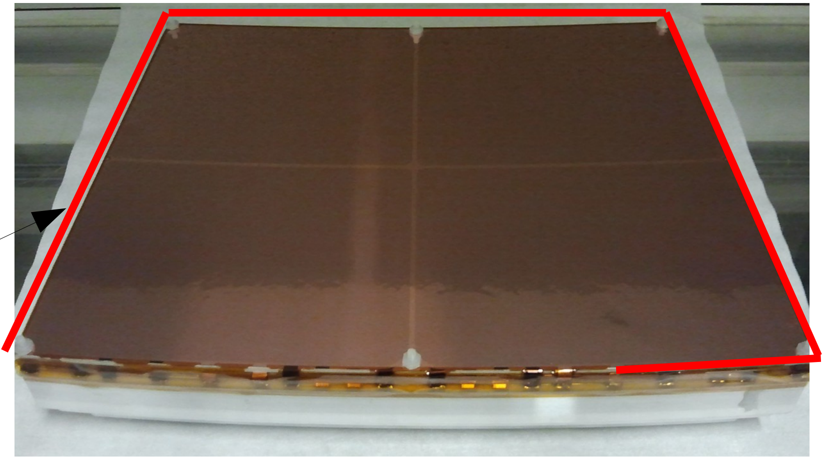


Field Distortions

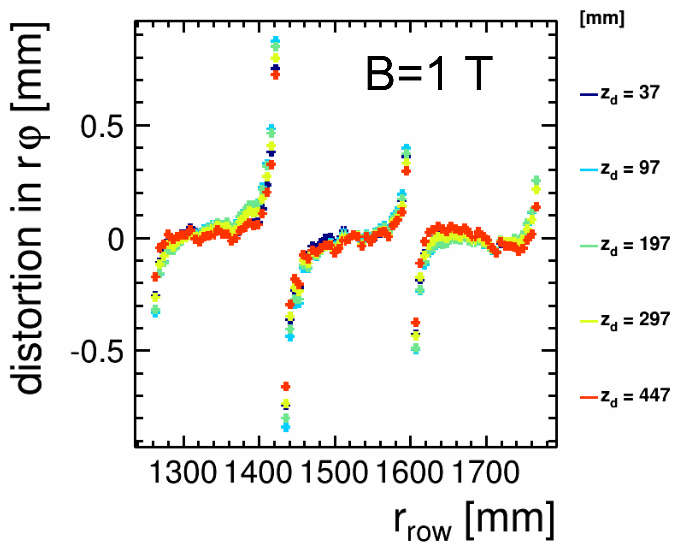
> Chosen Solution: additional wire at the top most GEM

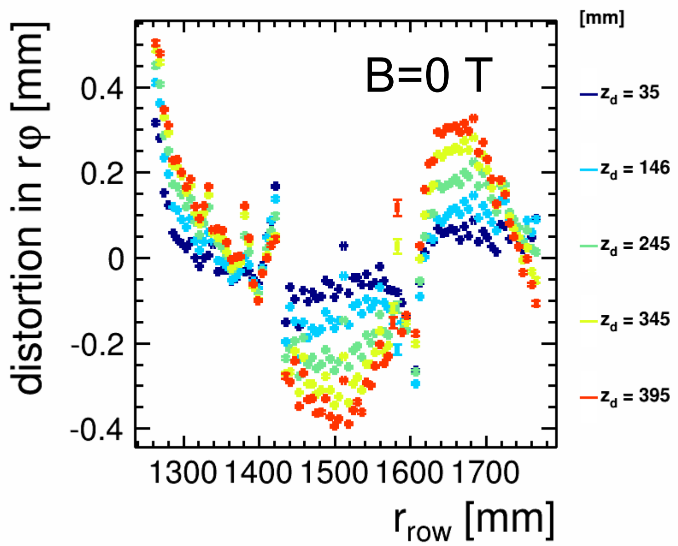


Position of the Wire



Field Distortions





- Field distortions originate from:
  - Inhomogeneity of the drift field
  - Inhomogeneity of the magnetic field

    → (ExB)-effects alter the path of the primary electrons
- Working hypothesis:
  - Largest influence from the gap between the modules

    → Large Distortions at the border of the modules

    → No dependence on the drift distance
- BUT: Drift dependence visible and needs to be understood

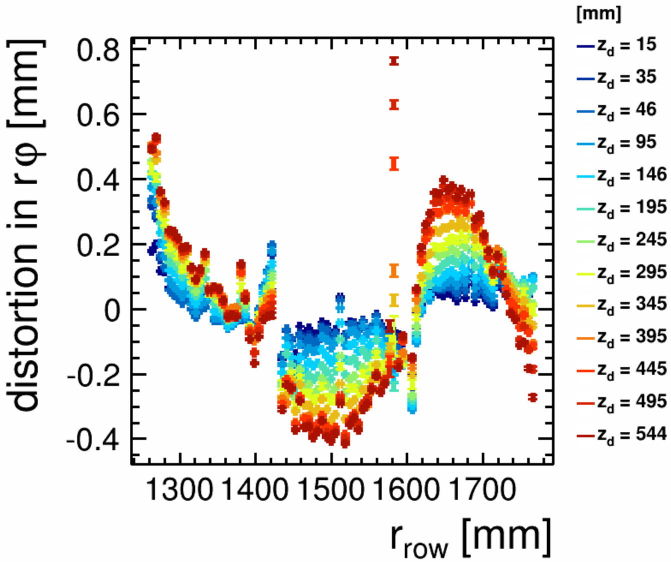
Module Alignment

- Use Millepede II for alignment study
- Simultaneous fit of all alignment and track parameters of the complete input
- Rotations and translations of the modules
- Field distortions due to the E x B effects influence the alignment results
- Use only B = 0 T data
- Convergence after two iterations

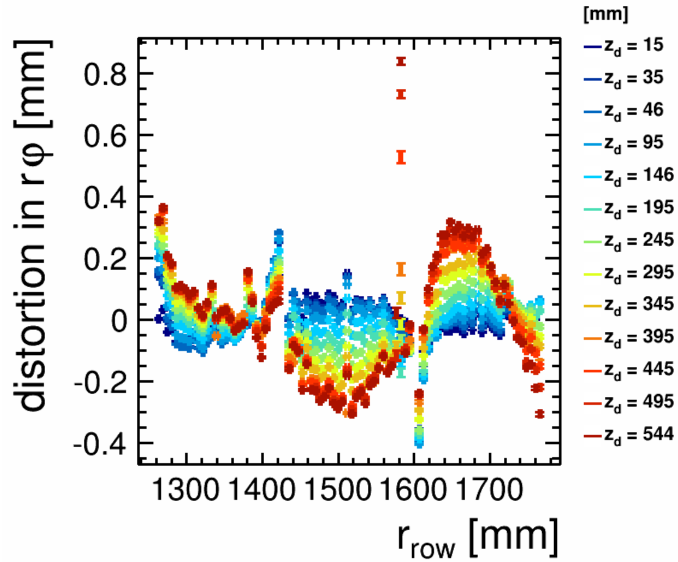
Module Alignment

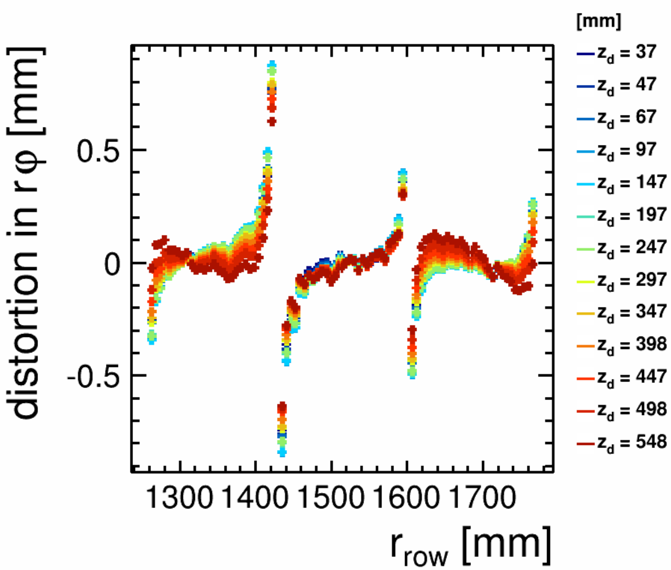
Before alignment

After alignment

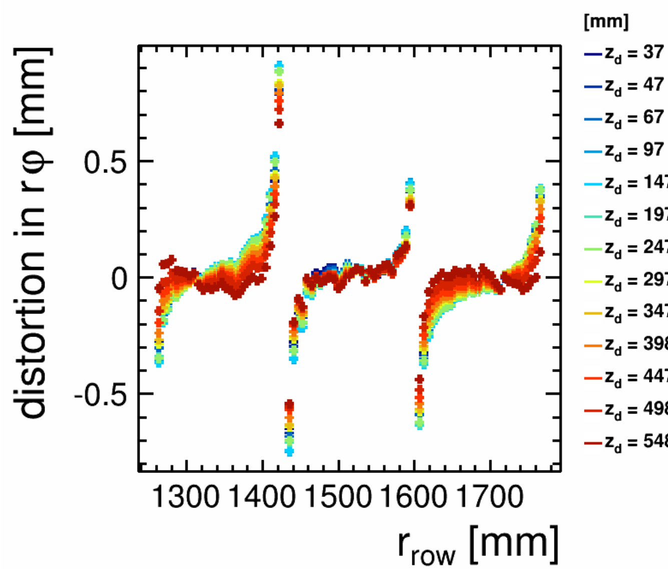


B = 0 T

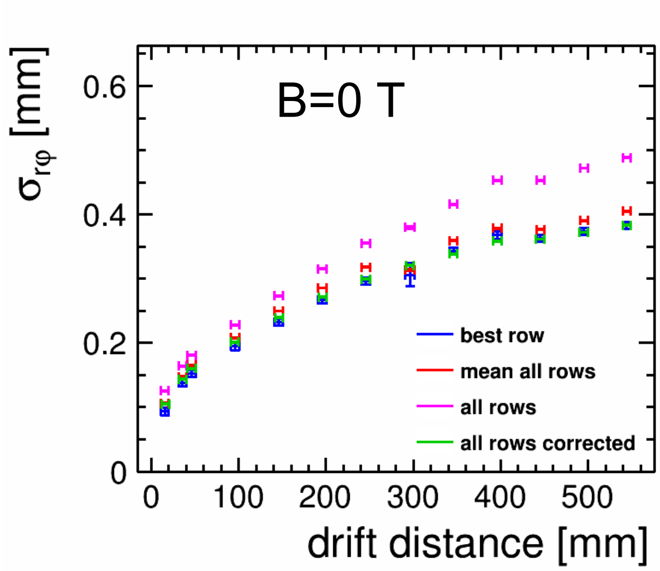


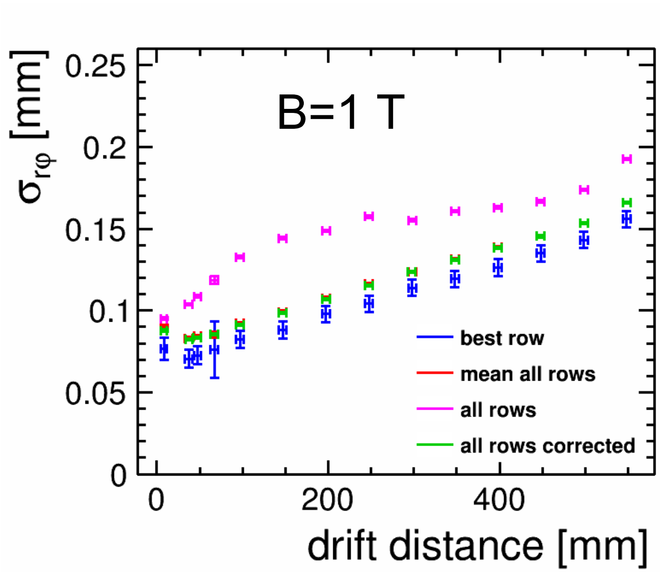


B = 1 T

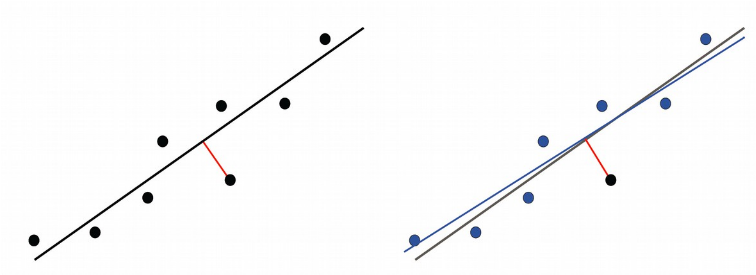


Transverse Point Resolution



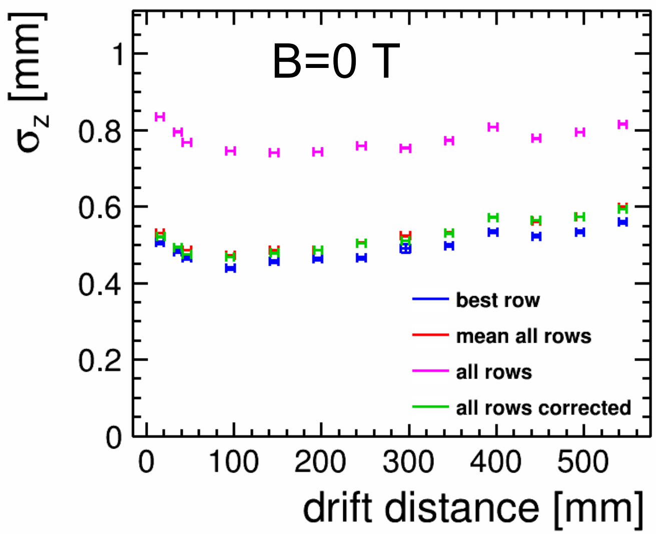


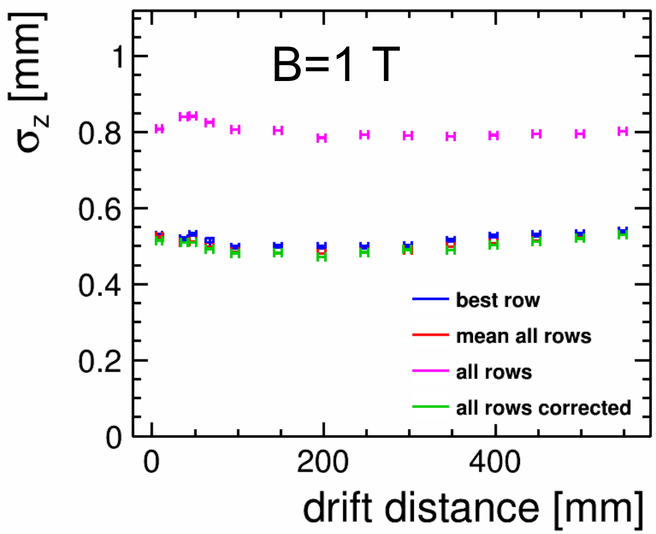
- Determination of the resolution without an external reference
  - Use the track point for the track fit and determine the residuals
  - Remove the track point from the track fit and determine the residuals
  - The geometric mean of the width of the two distributions → resolution



- Transverse point resolution shows the expected behavior
- Hodoscope effect visible for short drift distances (narrow signal due to small diffusion)

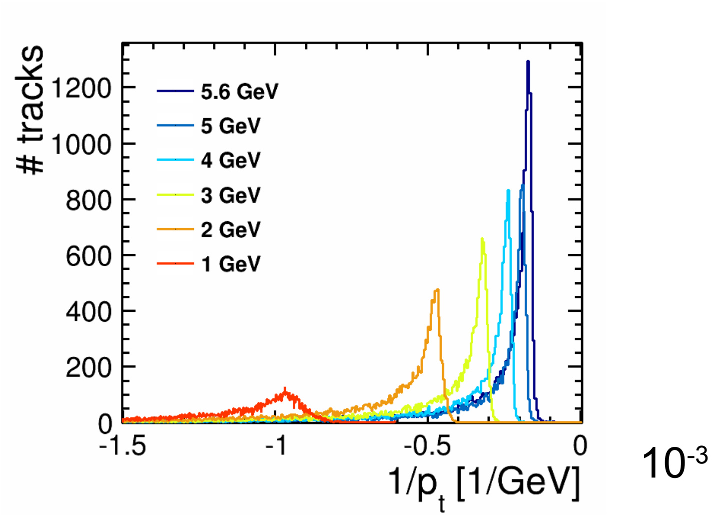
Longitudinal Point Resolution

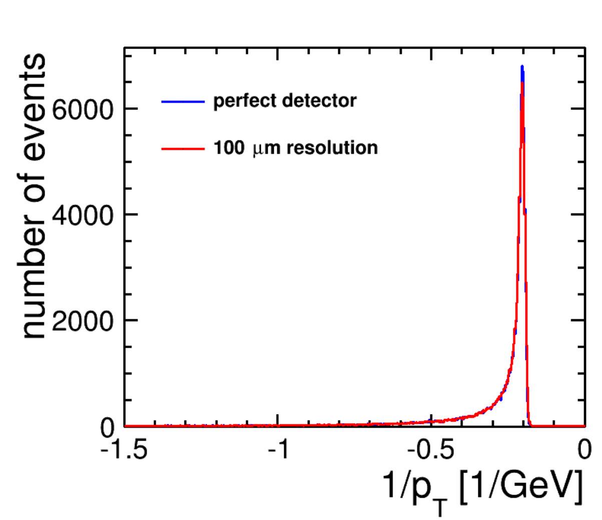




- Small dependence on the drift length due to readout electronics

Momentum Resolution





- Determine momentum resolution of the detector
- Gluckstern formula:

$$\sigma_{p_T} = \sqrt{\frac{720}{n+4}}\,\frac{\sigma\cdot p_T^2}{0.3\,B\,L^2} \qquad \text{(m, GeV/c, T))}$$

- Field distortions could alter the momentum determination
- Broad energy spectra created by:
  - Energy spread of the beam
  - Energy loss in the magnet

$\rightarrow$ need reference detector

  - External silicon tracker

Summary and Outlook

Summary

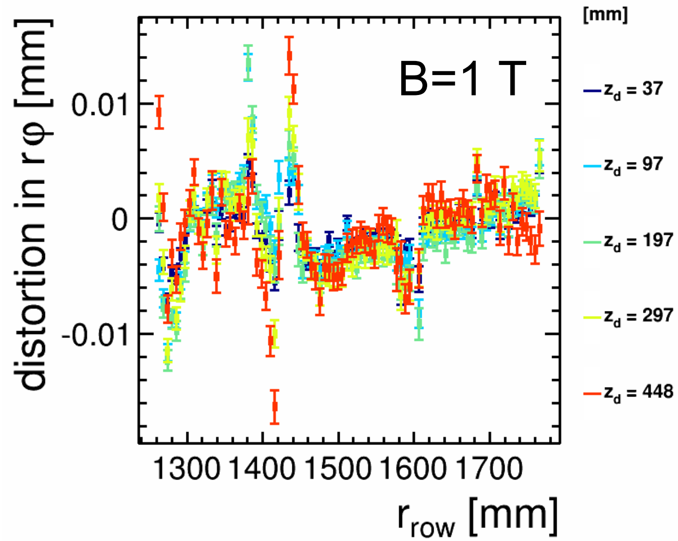
- The LCTPC collaboration develops a new TPC for the ILD with unprecedented resolution
- A successful test beam period was performed with three DESY GridGEM modules in March 2013
- We can achieve the desired point resolution
  - But field distortions at the border of the modules deteriorate the performance of the modules

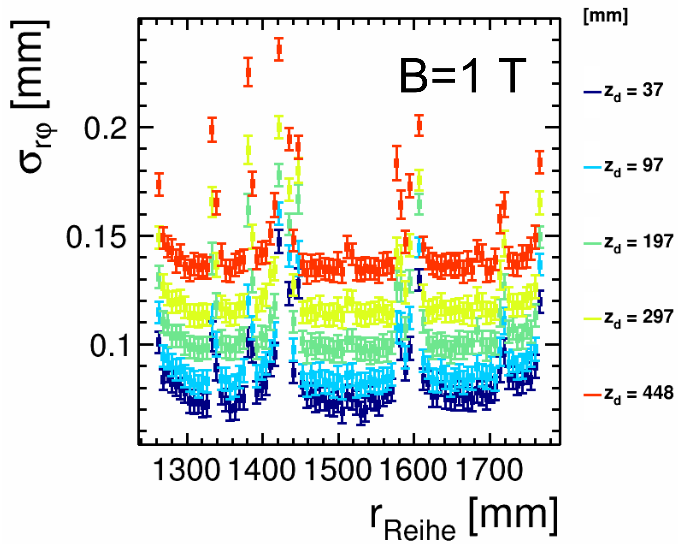
Outlook

- Long term stability of the module needs to be demonstrated
- The momentum resolution needs to be evaluated using an external reference

Backup

Distortion Corrections





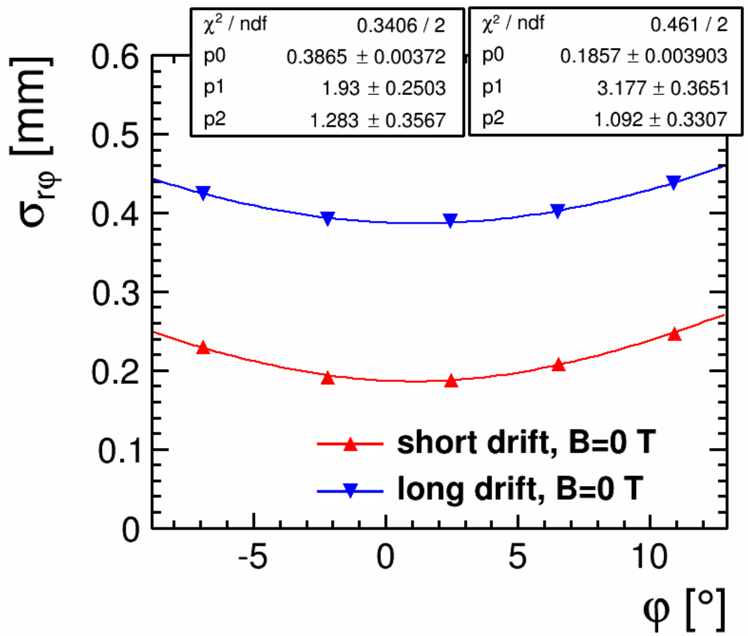
- First ansatz:
  - move the track points along the rows according to the residuals
  - Redo track search and fit
- Residuals consistent with zero
- Width of the distribution is not influenced

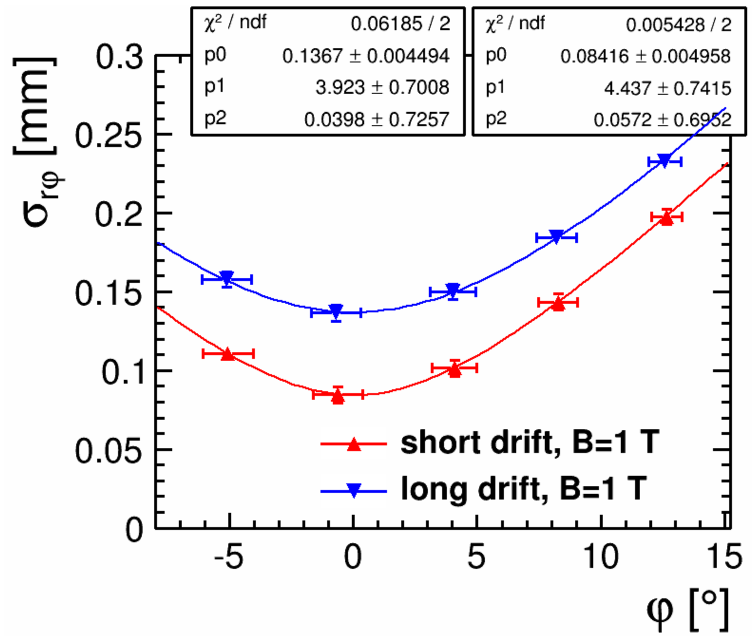
  → Distortions cannot be described by a simple translation

Angle Dependence

- Angle between the track and the pad
- Good agreement with the data

$$\sigma_{r\phi}(\phi, z) = \sqrt{\sigma_{r\phi}^2(z) + \frac{L_{pad}^2}{12 \cdot N_{eff}} \cdot \tan^2(\phi - \phi_0)}$$





z-Distortions

> Relative slow sampling clock 20 MHz → 3 mm drift per time bin