Test Beam Measurements with the DESY GridGEM TPC Prototype Module

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MT Student Retreat
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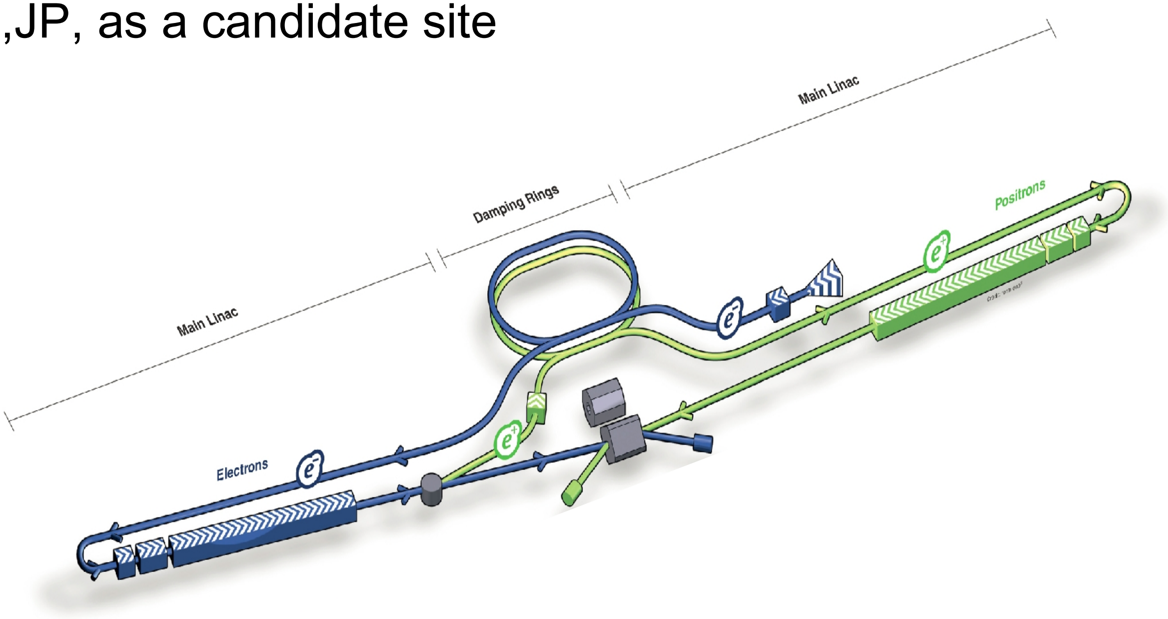
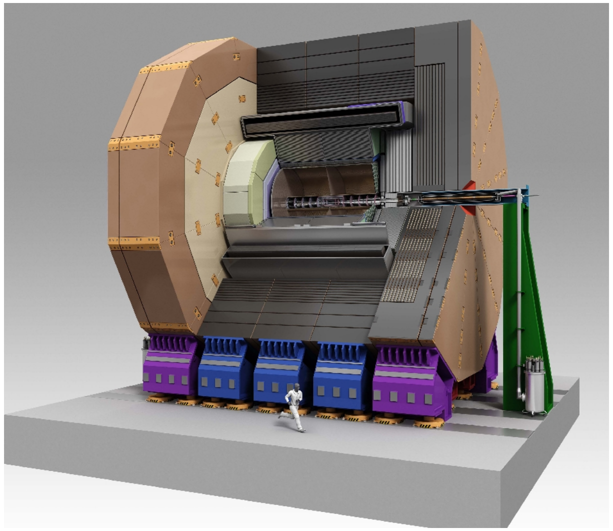
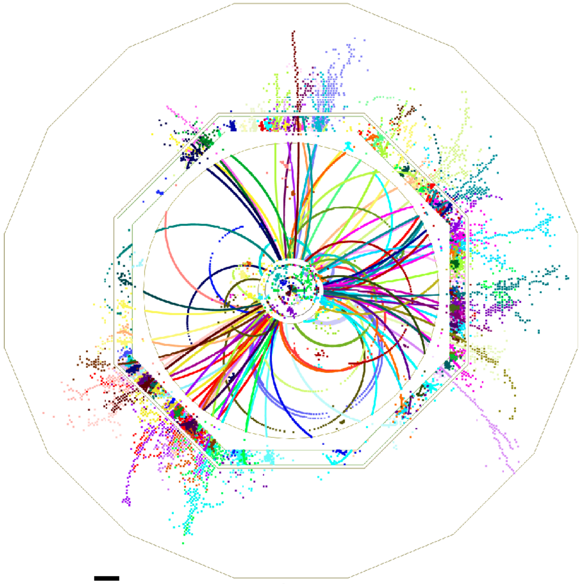
International Linear Collider

- 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



International Large Detector





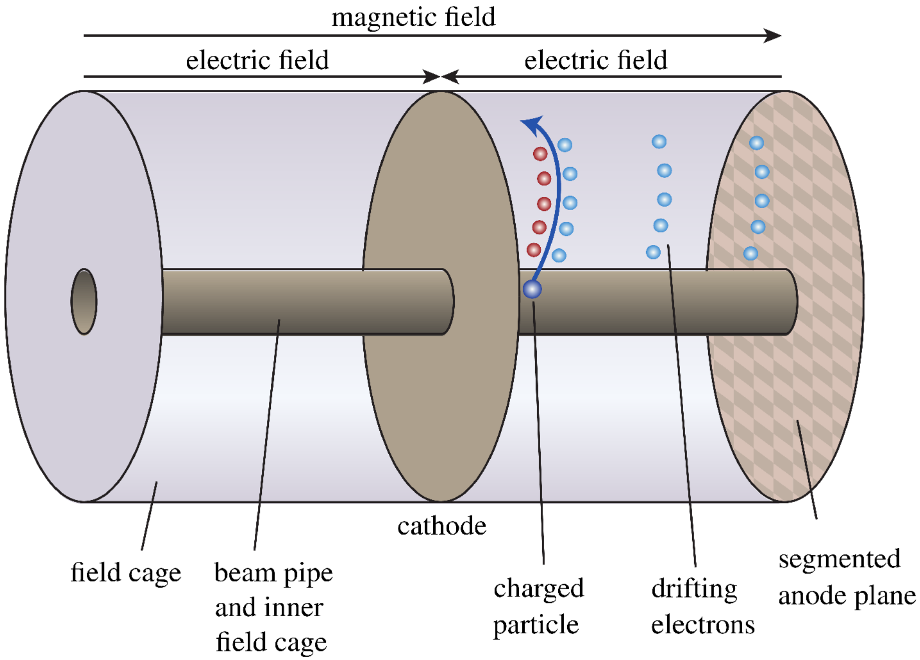
$t\bar{t} \rightarrow 6q$ @ 500 GeV

- 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
- Solution Time Projection Chamber
  - $\sigma(1/pt) \sim 10^{-4}$ /GeV for TPC alone
  - ~ 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

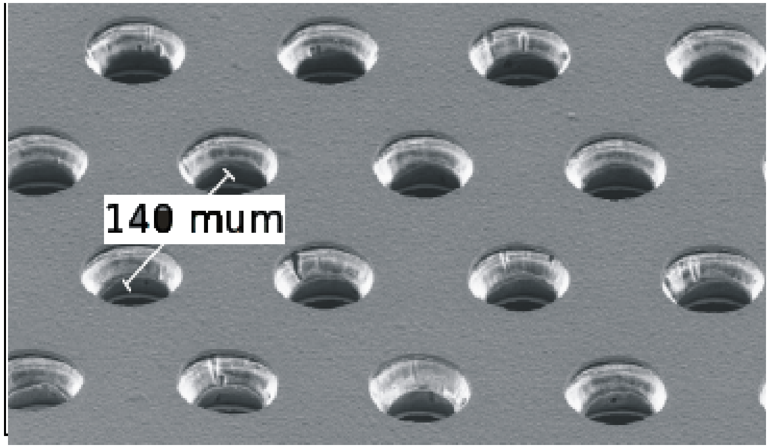
Time Projection Chamber

- 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

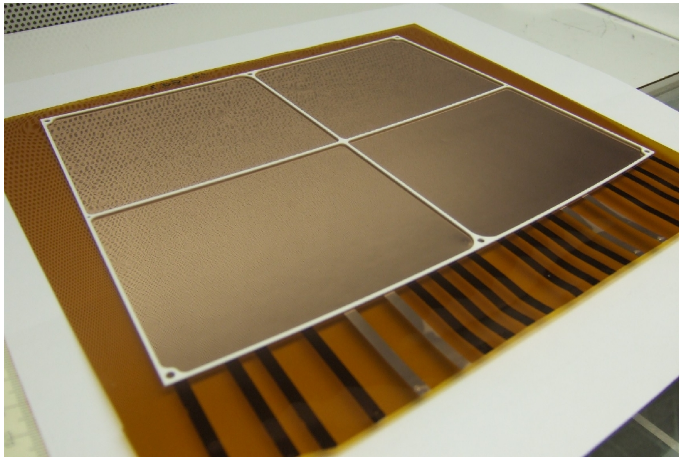


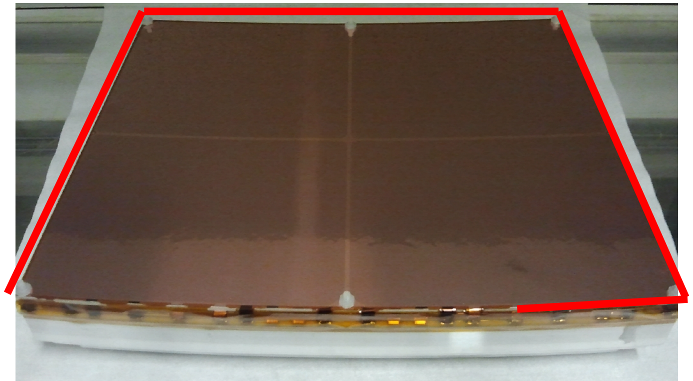
- Magnetic field to
  - Reconstruct the momentum of the particles
  - Reduce the diffusion during the drift
- Particle identification from energy loss measurement (dE/dx)

DESY GridGEM Module



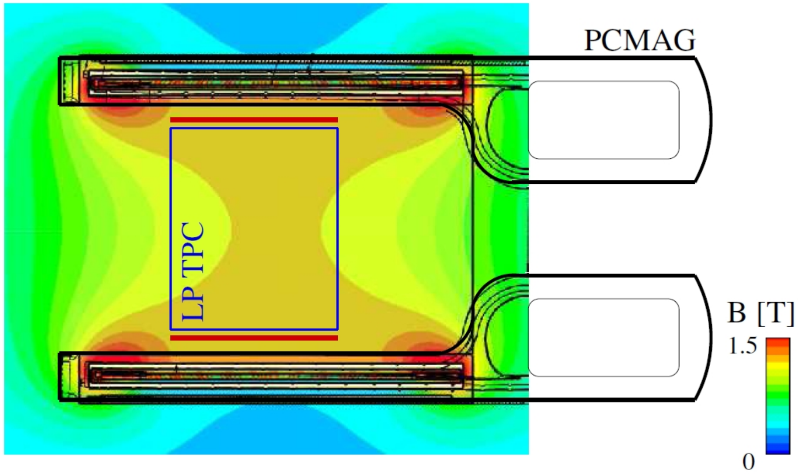
- Goals:
  - Minimal dead space and material budget
  - Homogeneous GEM surface
  - Stable operation
- Solution:
  - Triple GridGEM module with an integrated support structure
  - Thin aluminum oxide grid
  - 4829 pads (1.25 x 5.85 mm²)
  - Field shaping wire
  - Anode side divided into 4 sectors

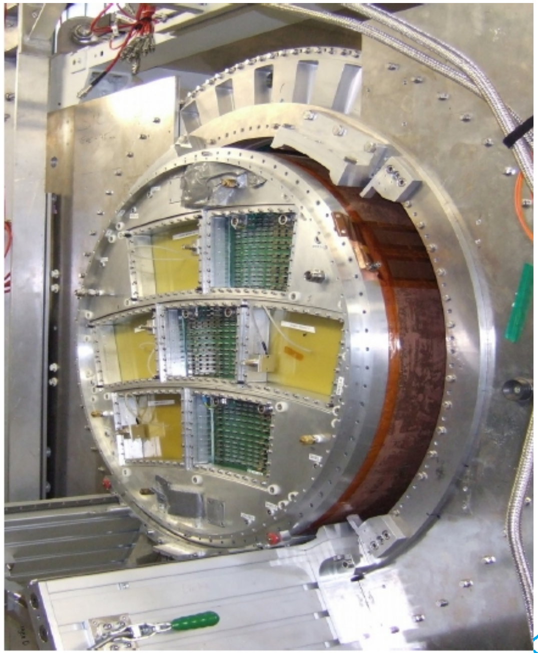




DESY II Test Beam

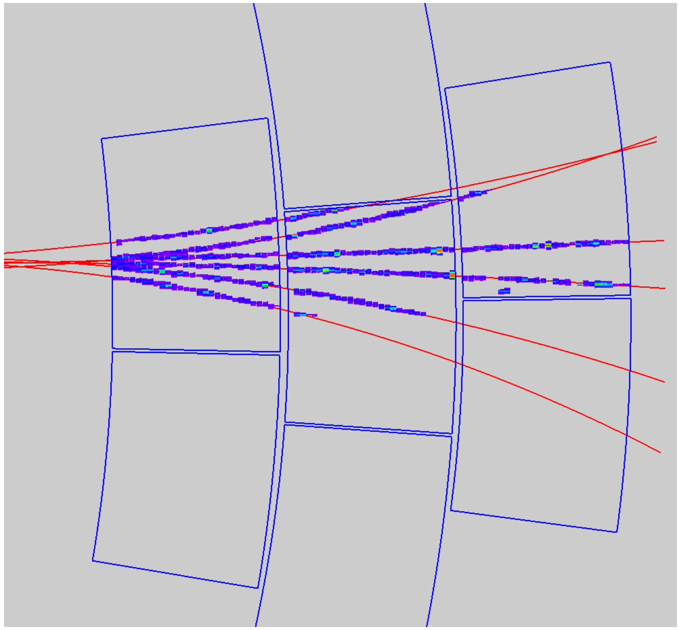
- March 2013 DESY II test beam
  - e^+/e^- from 1 GeV to 6 GeV
- PCMAG Magnet (1 T)
- Three modules in a large prototype TPC
  - Diameter ~ 60 cm
  - Maximal drift length ~ 50 cm
- Half of the channels connected, due to space constraints and limited number of channels available
  - Along the beam profile
  - Lever arm of ~ 50 cm
  - ~8000 channels
- November 2013 Laser measurements





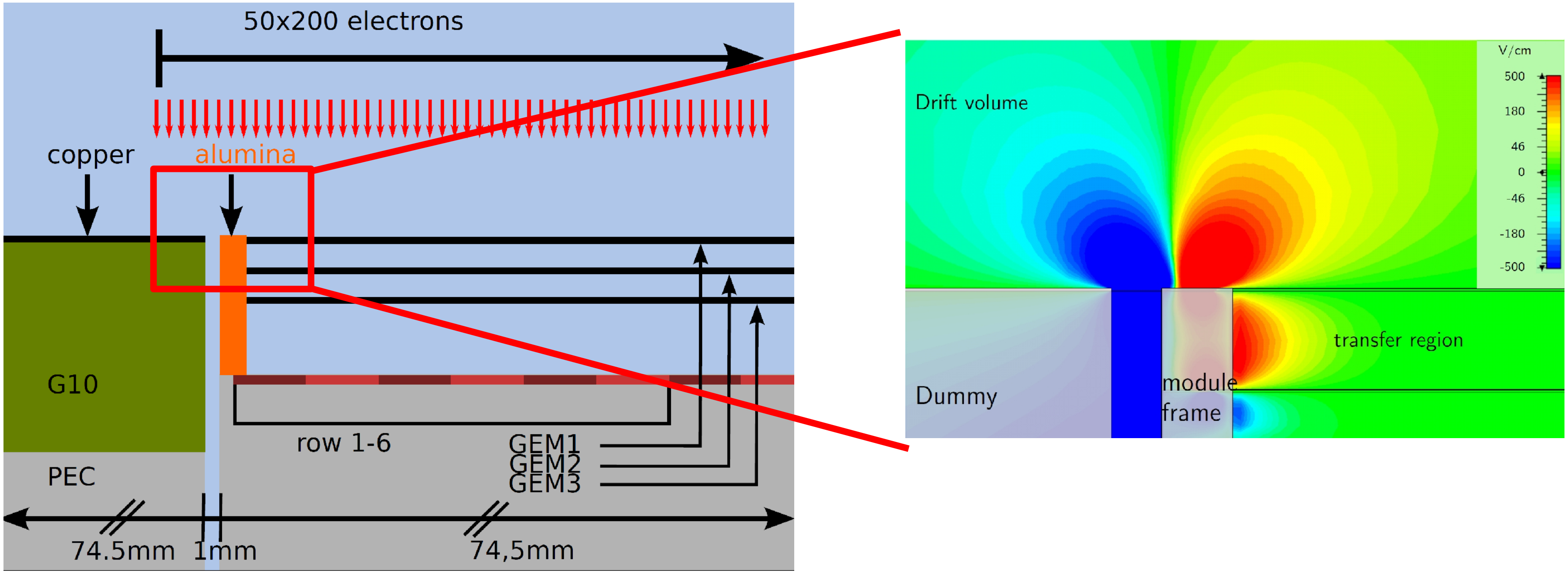
Test Beam Measurements March 2013

- Goal of the measurements:
  - Validation of the module design
  - Understand 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



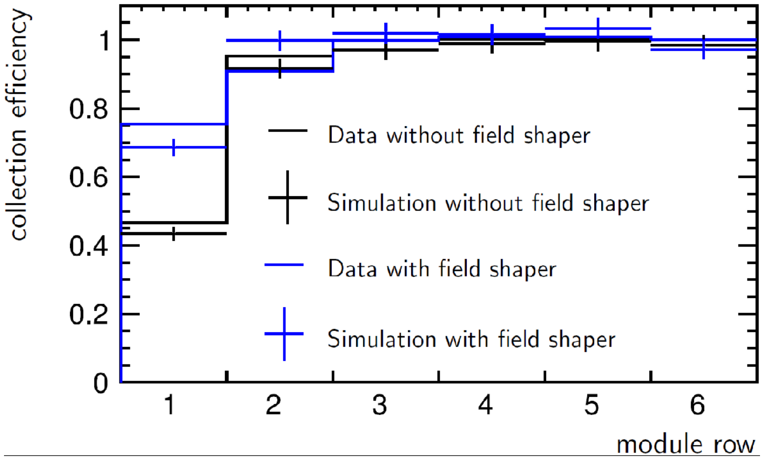
Field Distortions

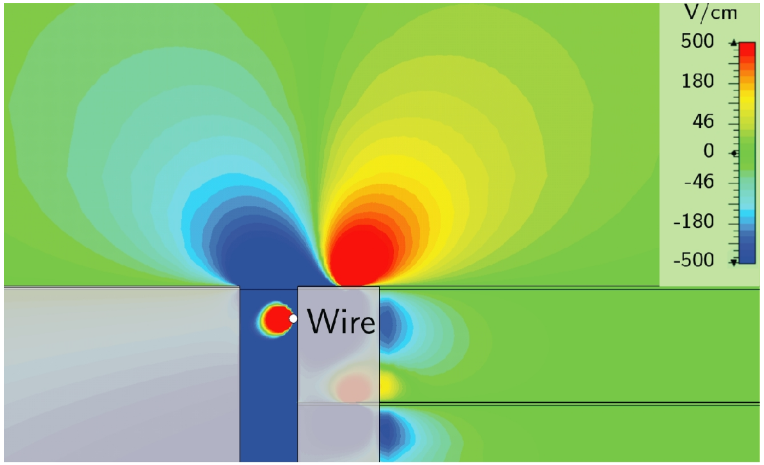
- Previous module iterations showed distortions at the border of the module
- Simulation study to understand the observed behavior
- Simulate the electric field at the border of a module
- Field distortions are visible due to the gap between the modules



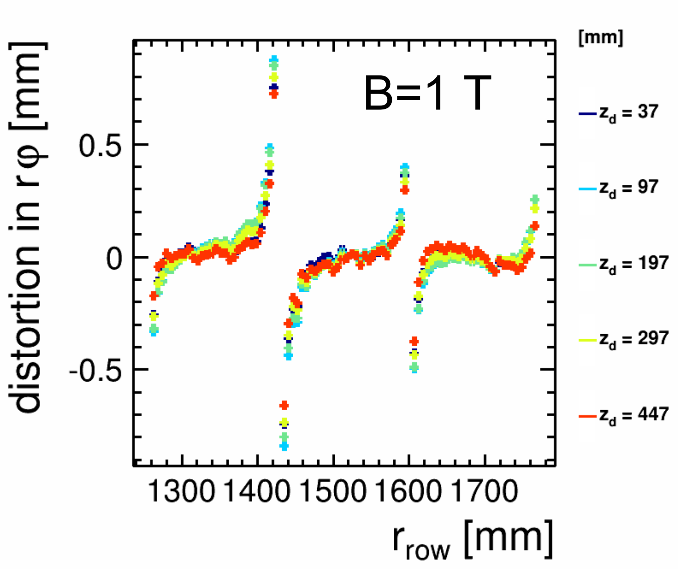
Guard Ring

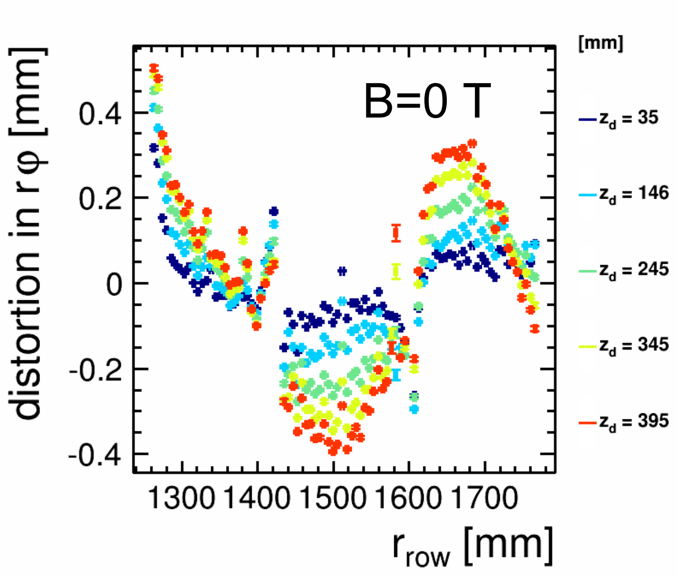
- Introduce a guard ring to suppress field distortions
  - Wire and strip solutions simulated
- Simulate the electron collection efficiency
- Retrieve up to 30 % collection efficiency on the first row with the guard ring





Field Distortions





- Field distortions originate from:
  - Inhomogeneity of the drift 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

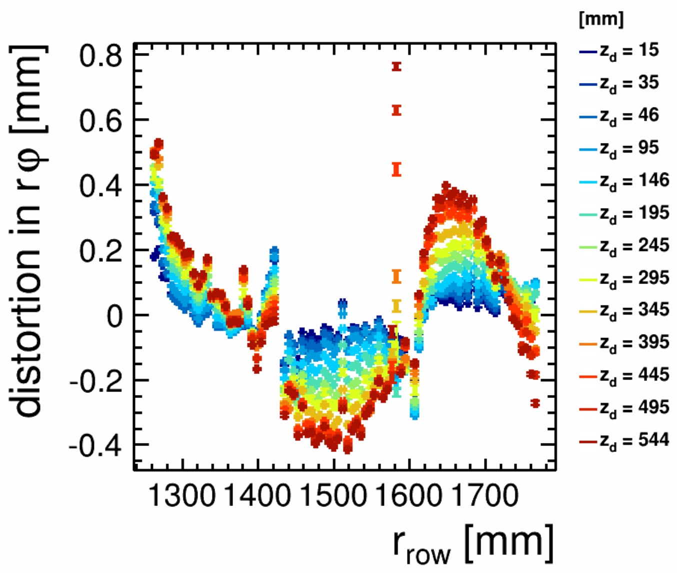
Module Alignment

- 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

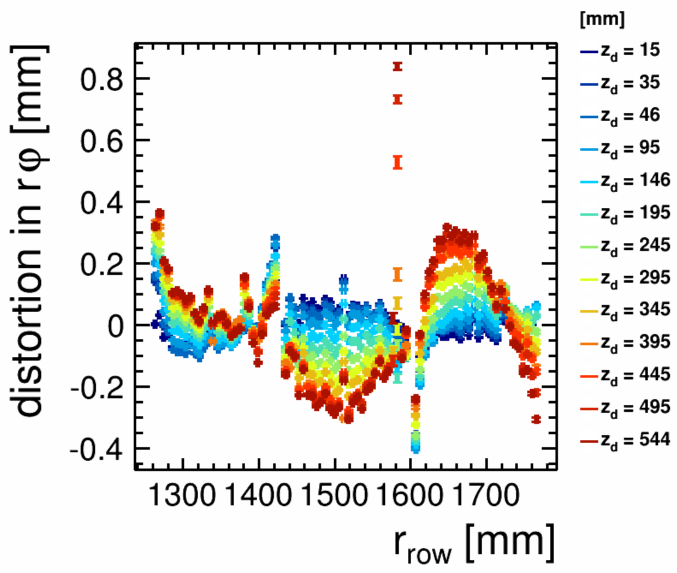
Module Alignment

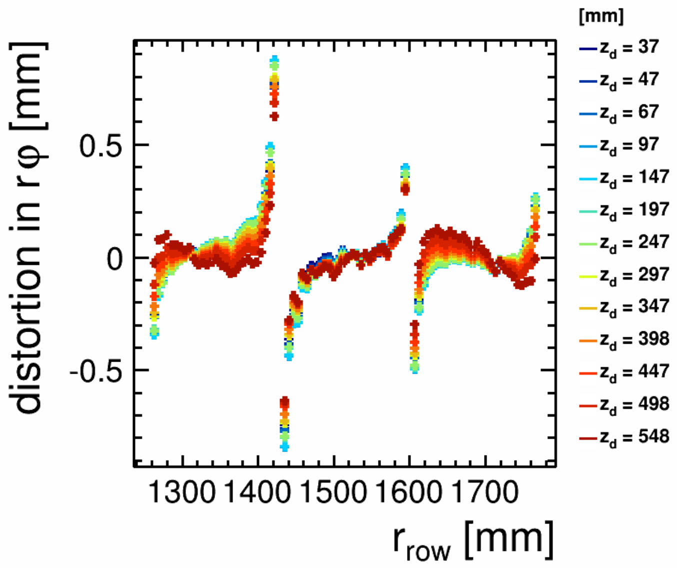
Before alignment

After alignment

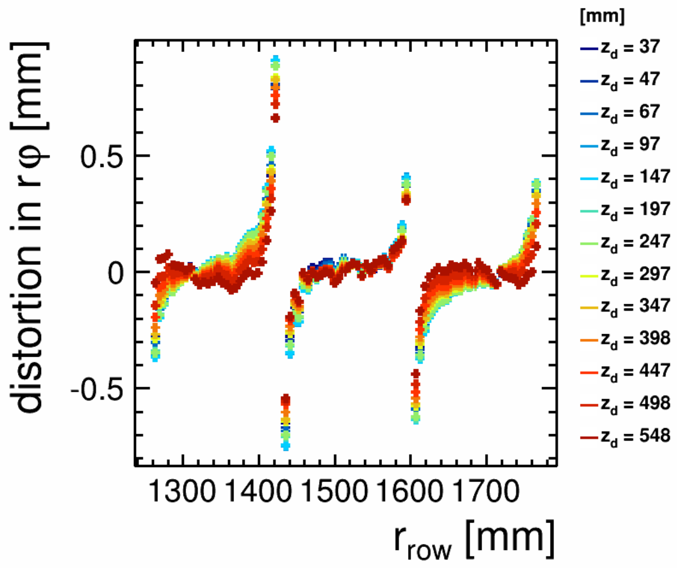


B = 0 T

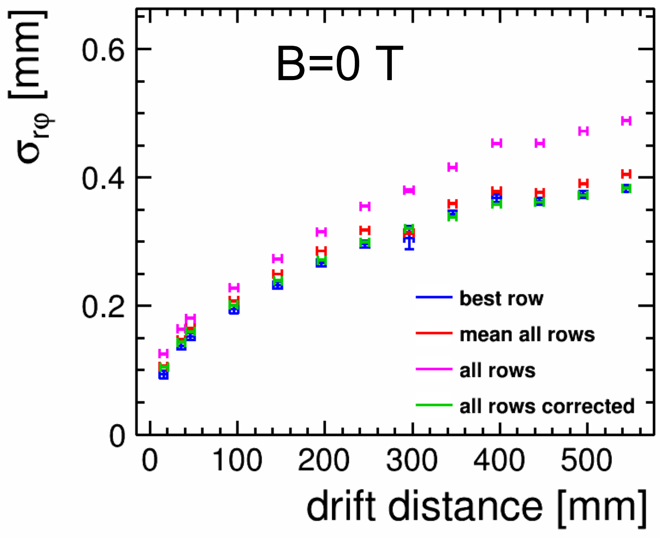


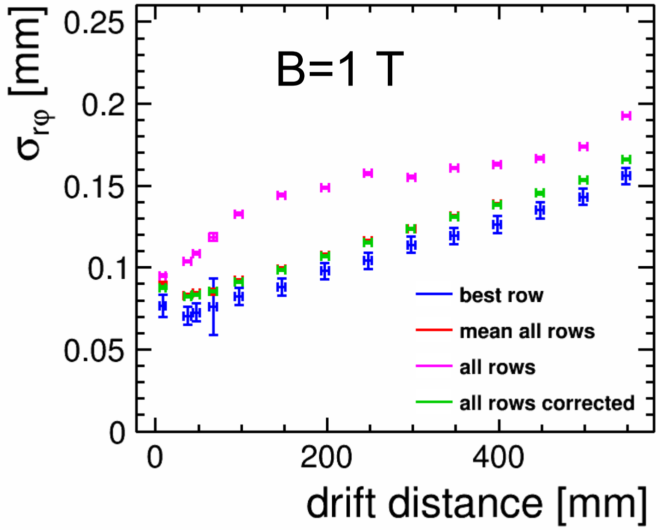


B = 1 T

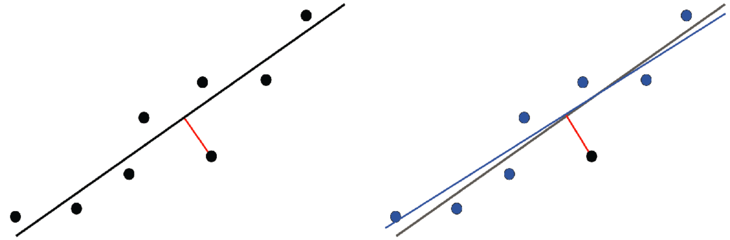


Transverse Point Resolution



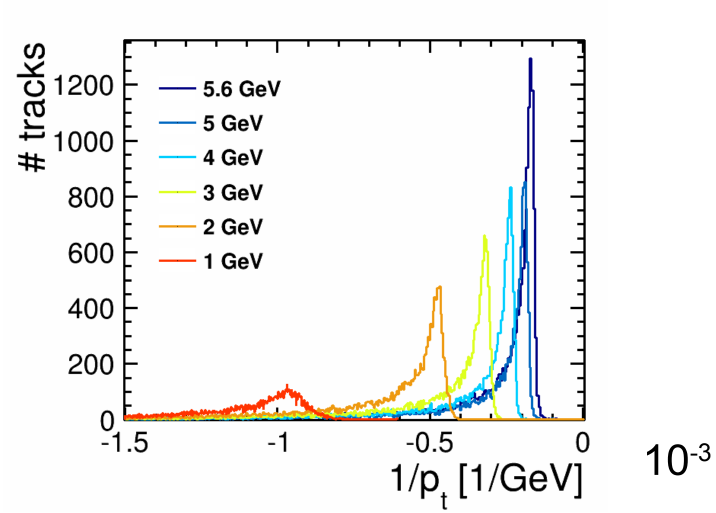


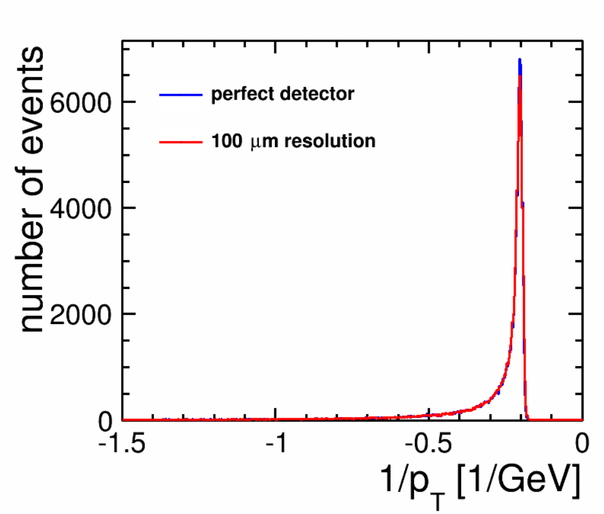
- Determination of the resolution without an external reference
  - Use the track point for the track fit and determine the residuals
  - Remove the track point from the track fit and determine the residuals
  - The geometric mean of the width of the two distributions → resolution



- Transverse point resolution shows the expected behavior
- Extrapolation to 3.5 T and full ILD drift length close to 100 µm

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

→ need reference detector

  - External silicon tracker

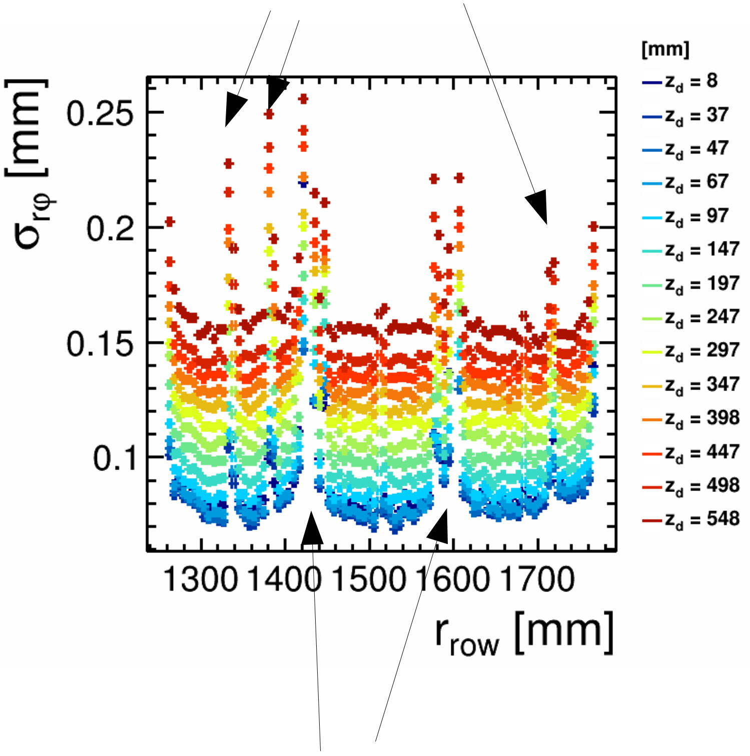
Summary

- Time projection chambers with an point resolution of better than 100 µm over two meters drift can be build
- A successful test beam period was performed with three DESY GridGEM modules
- A good point resolution was achieved and studies concerning field distortions were performed
  - Field distortions at the border of the modules deteriorate the performance of the modules
  - Some long term stability issues were observed

Backup

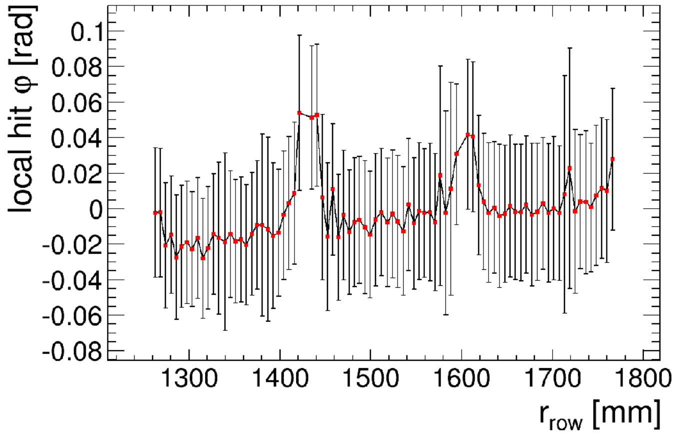
Transverse Point Resolution

- Worse point resolution at the border of the module
- Field distortions
  - Worsen the resolution
  - Create a local track angle
- Determine the local hit angle by extrapolation the closest it



Dead pads

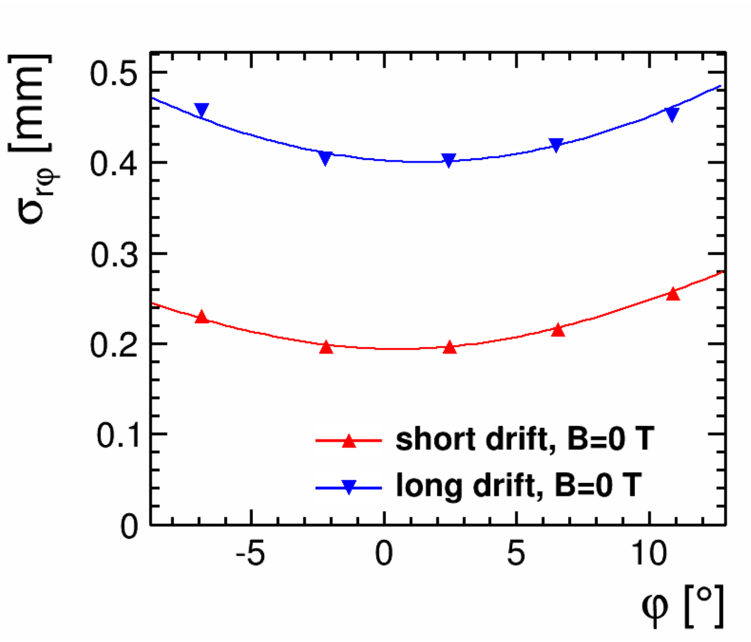
Module boundaries

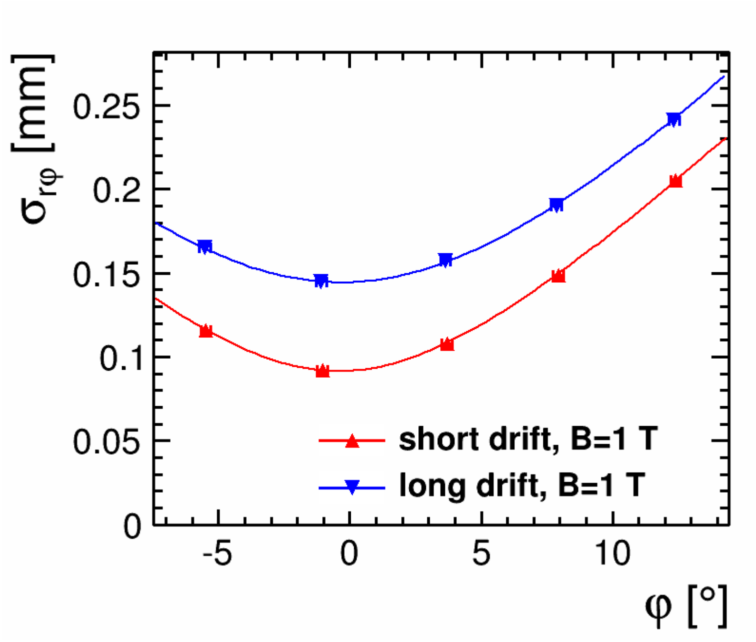


Angle Dependence

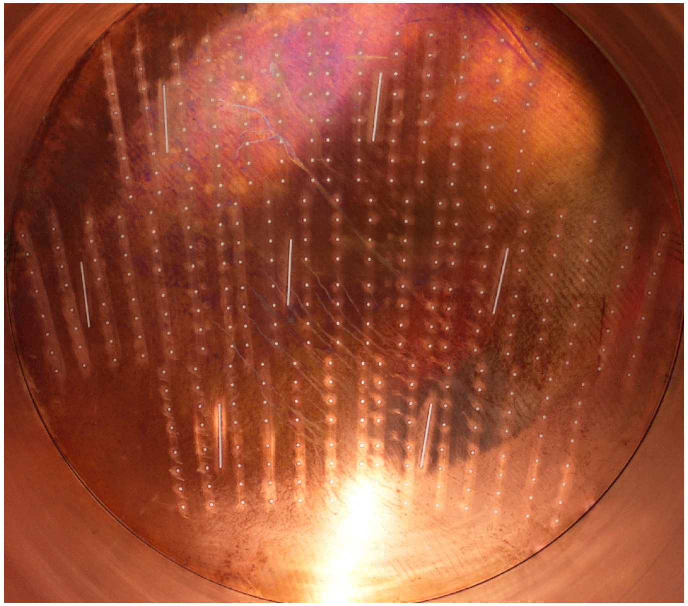
- Angle between the track and the pad
- Good agreement with the data

$$\sigma_{r\varphi}(\varphi, z) = \sqrt{\sigma_{r\varphi}^2(z) + \frac{L_{pad}^2}{12 \cdot N_{eff}} \cdot \tan^2(\varphi - \varphi_0)}$$

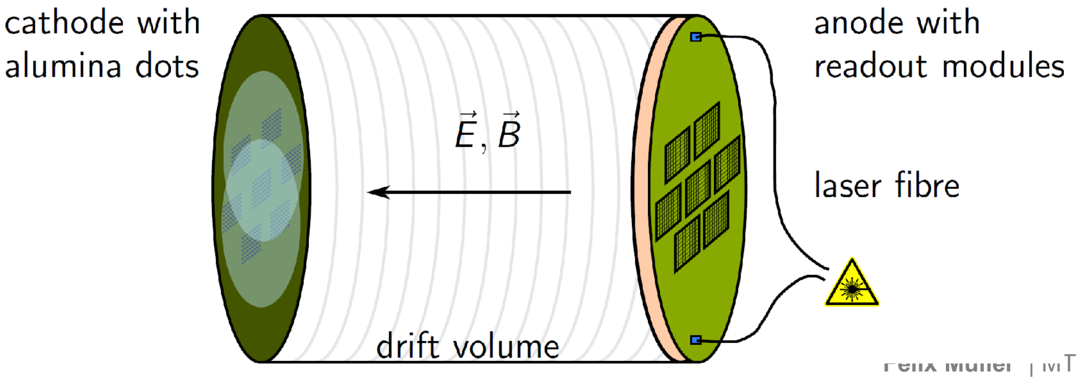




Photodot Measurements

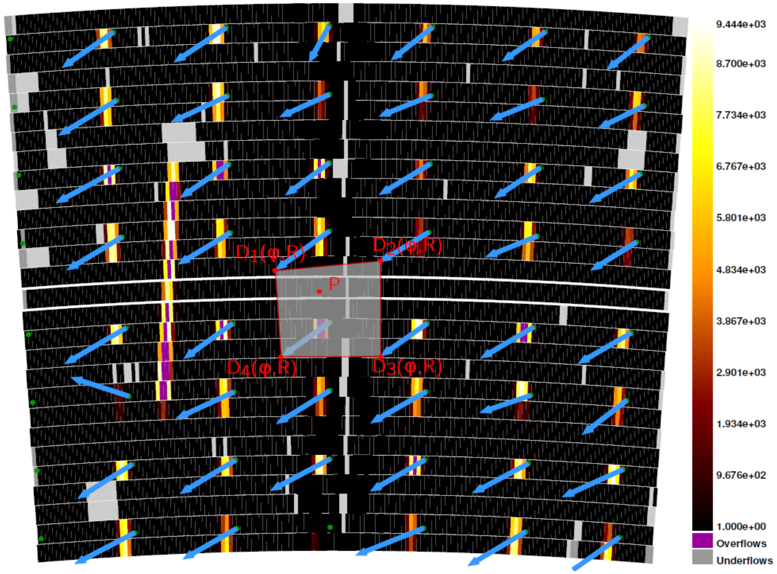


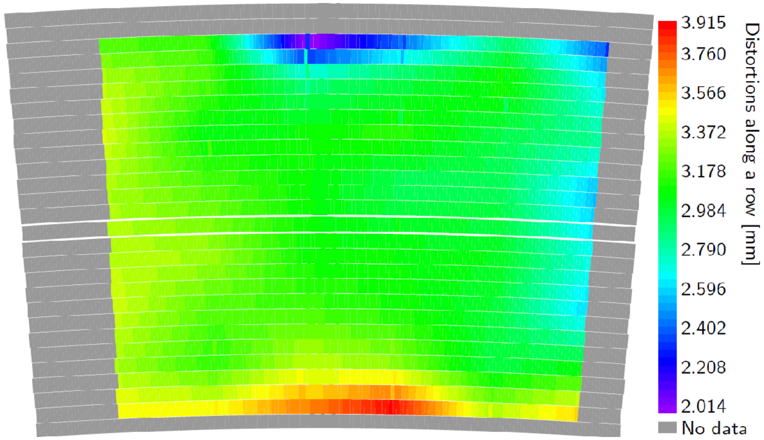
- Calibration system for the TPC
  - Monitor gas parameter
  - Monitor gain distribution
  - Perform alignment
  - Measure field distortions
- Aluminum dots and lines on the cathode
- UV-laser to create photo electrons from alumina
  - Difference between true and reconstructed position describes field distortion



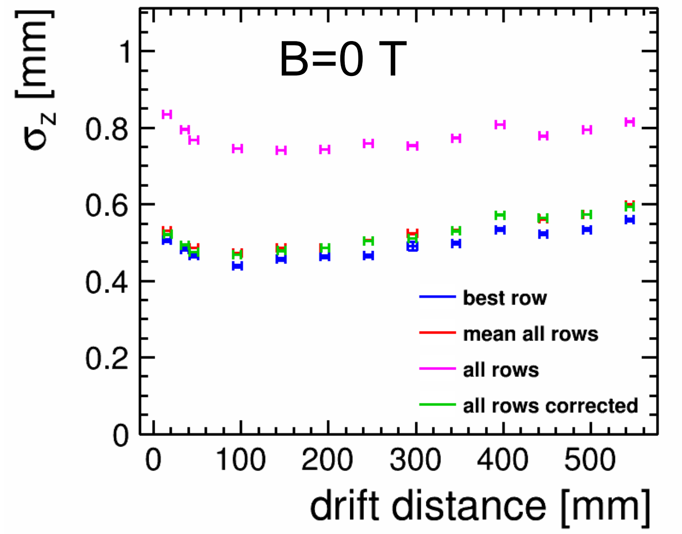
Photodot Measurements

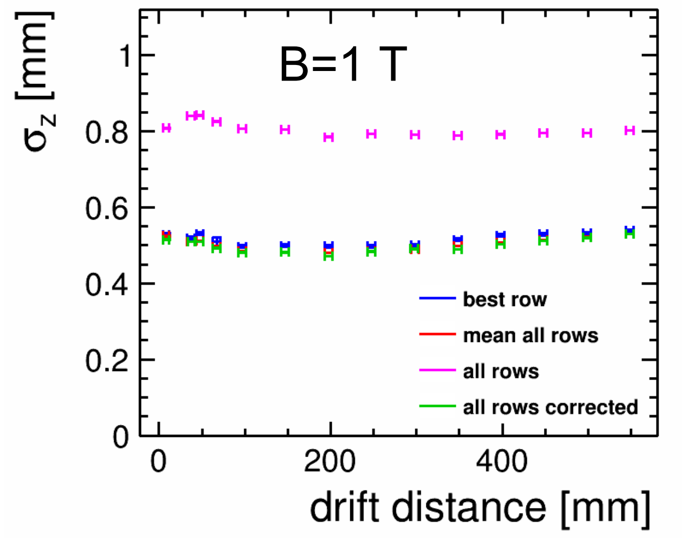
- Constant distortions from the E-field alone
    - Redesign of the prototype ongoing
- Tool to correct the field distortion at maximal drift
- Outlook:
    - Tune simulation to match data → correct distortions at every drift position
    - Need to know the E-field and B- field very precise
    - Knowledge of E-field distortion missing





Longitudinal Point Resolution



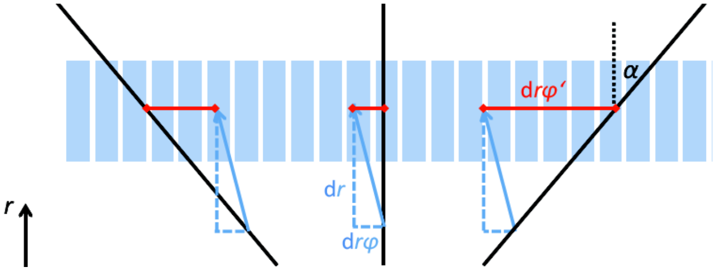


- Expected a larger dependence on the drift length (diffusion)
- Correlation of the hits depending on the readout cards is visible
- The electronics seems to be the reason

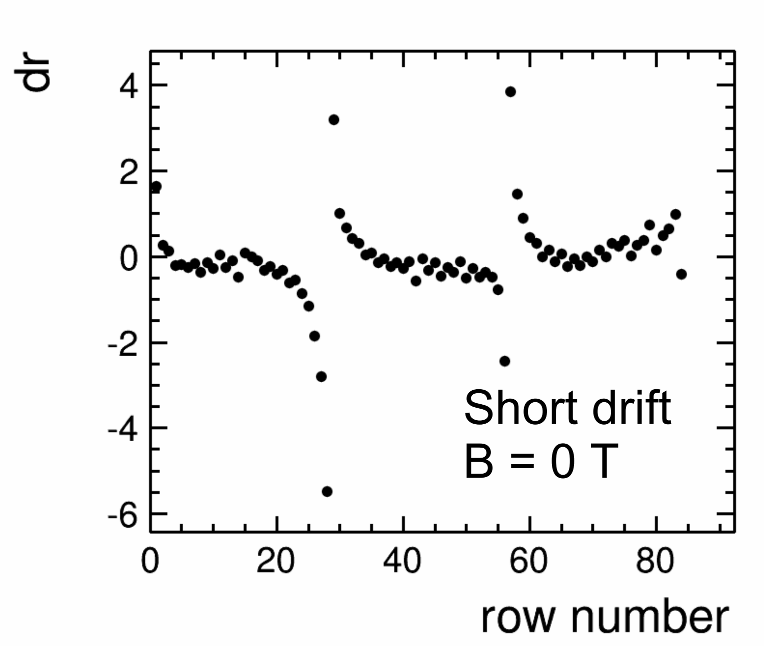
Radial Distortions

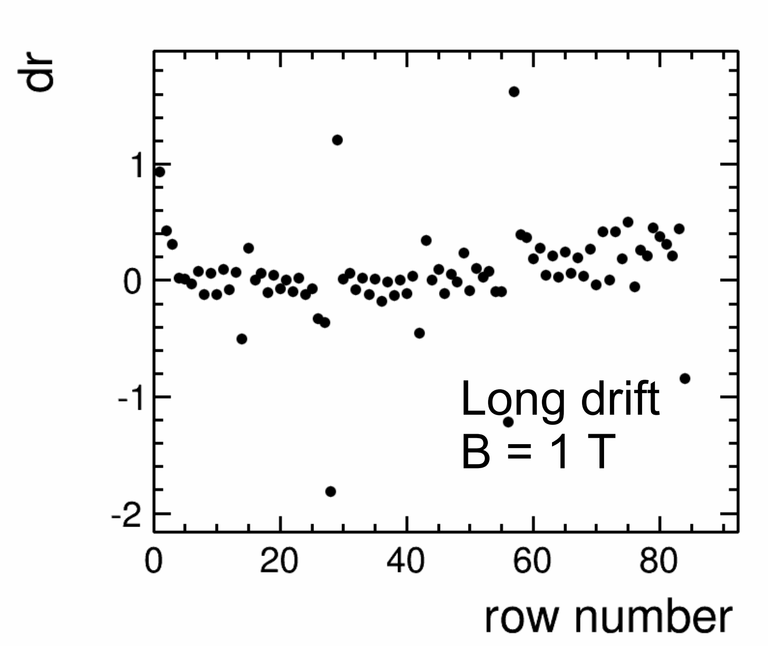
- The measured rφ distortion depends on the track angle due to field distortions in r

$$dr\varphi' = dr\varphi + dr \cdot \tan a$$

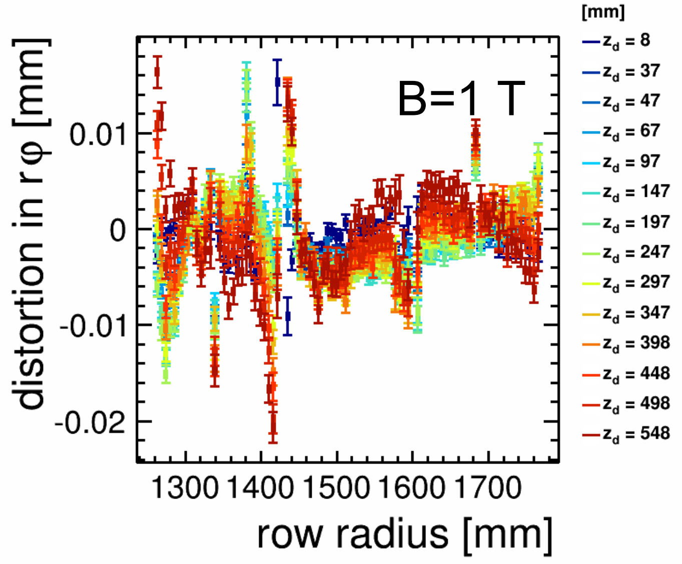


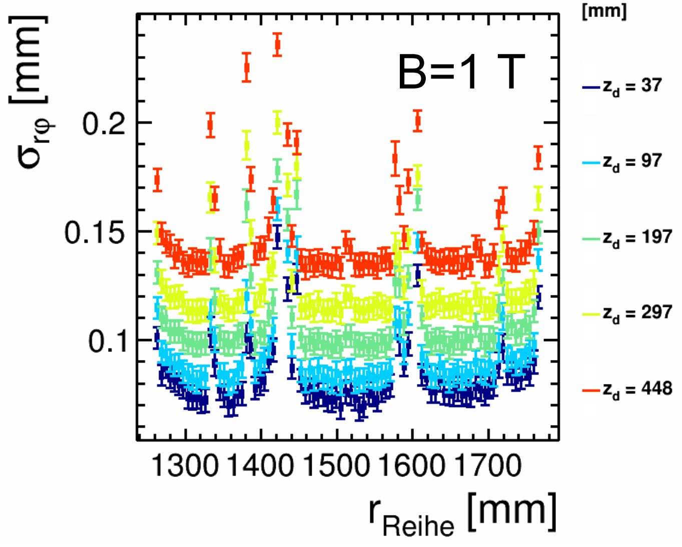
- Radial distortions are reduced for B = 1T because the electrons follow the magnetic field
- The horizontal bar of the ceramic grid is visible in the data





Distortion Corrections



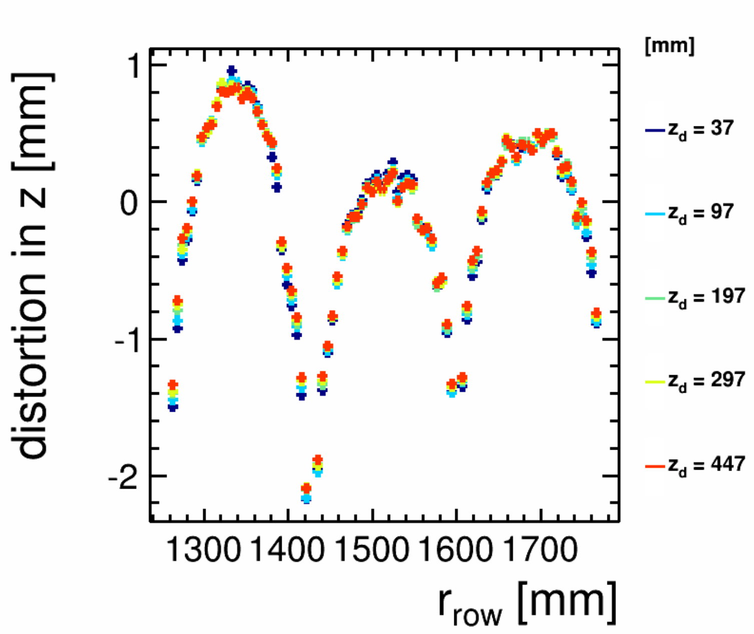


- First ansatz:
  - Move the track points along the rows according to the residuals
  - Redo track search and fit
- Residuals consistent with zero
- Width of the distribution is not influenced

→ Distortions cannot be described by a simple translation

z-Distortions

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

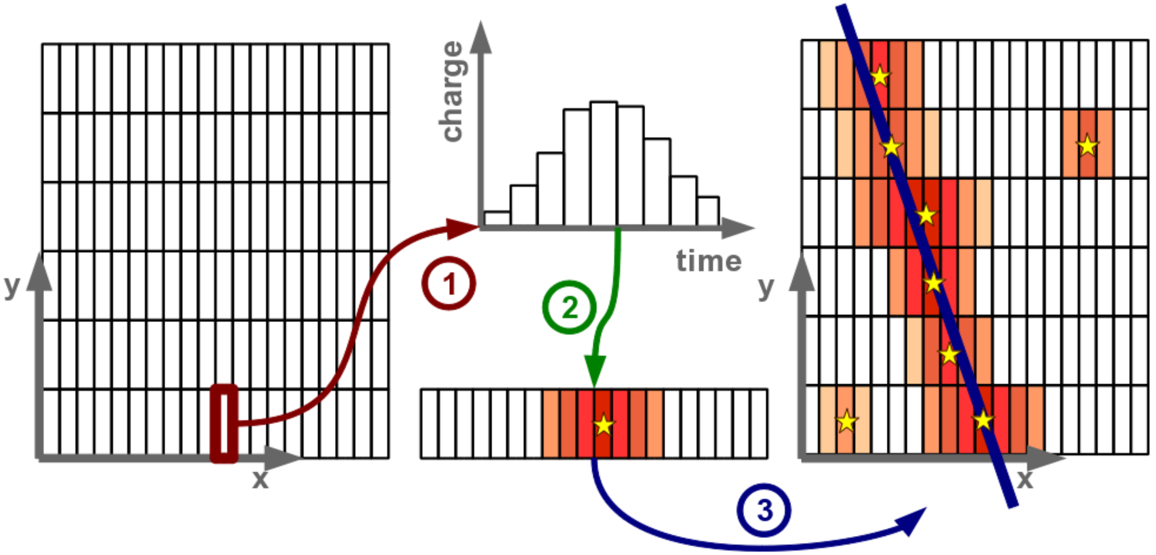


Track Reconstruction

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

2) Combine neighboring pads with pulses to single hits

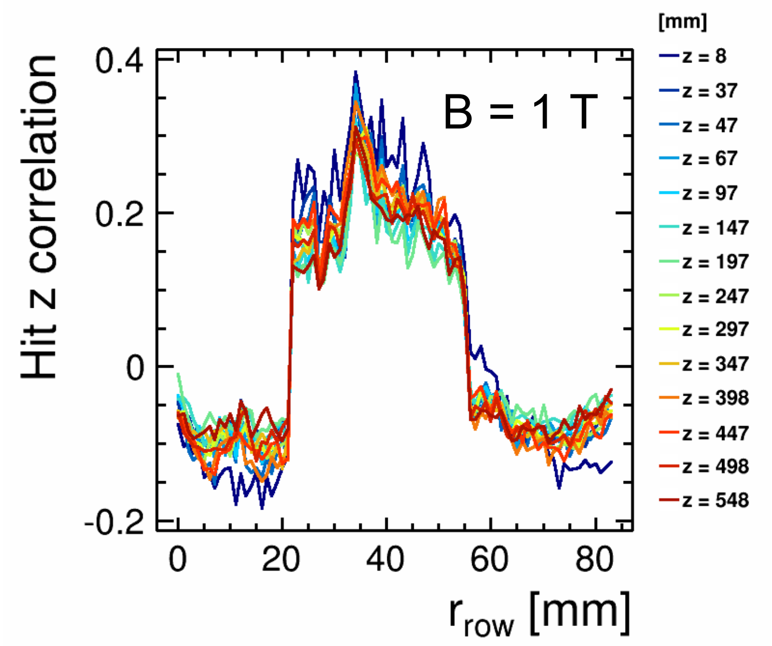
3) Combine the hits on the rows to single tracks

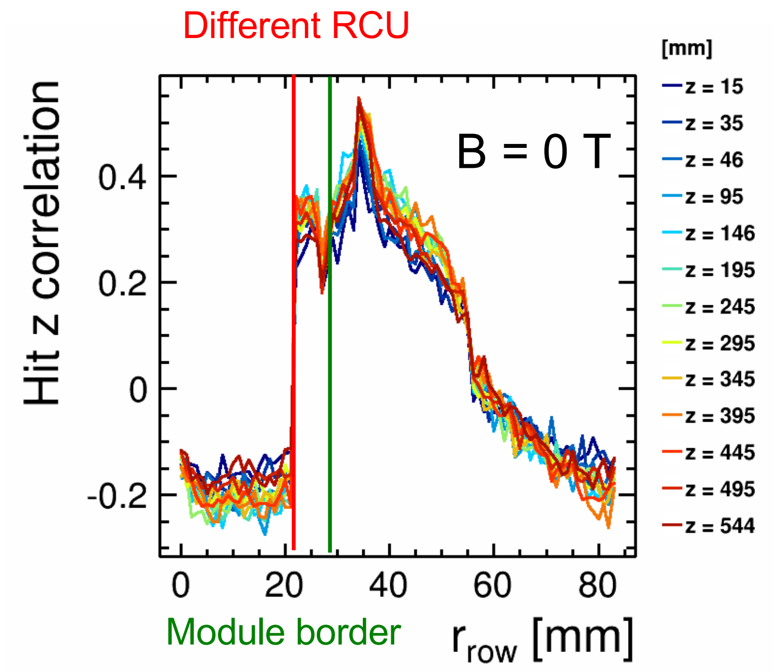


- Track finding: Fast Hough transformation
- Track fitting: General Broken Lines

Correlation Coefficient

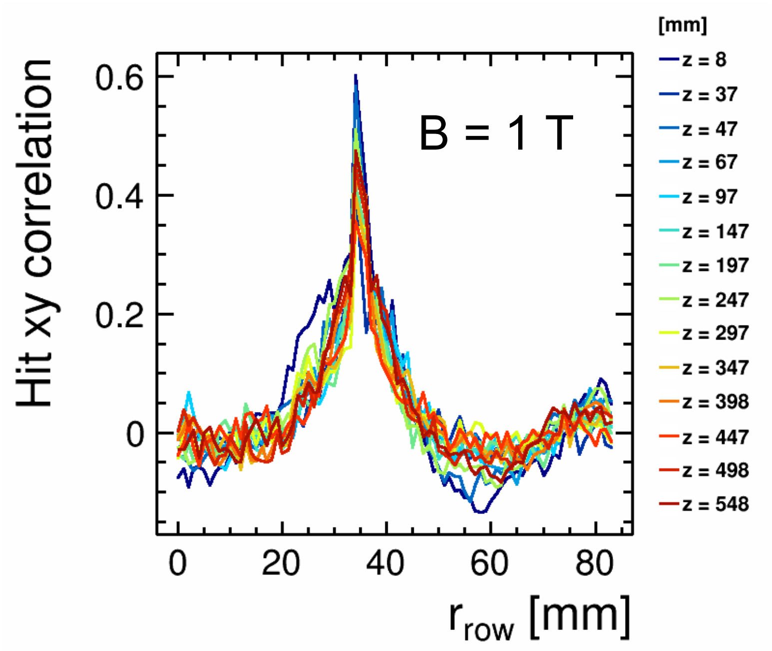
- Similar shape and but slightly lager correlations without B-field
- Not dependent on the diffusion

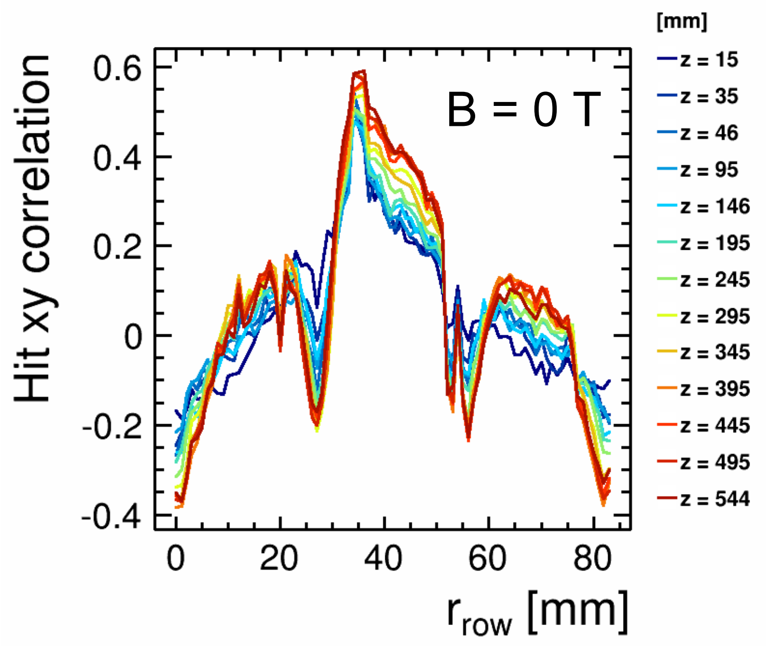




Hit Correlation

- Hit correlation relative to row 35
- Different shapes
- Drift dependence visible for B=0T

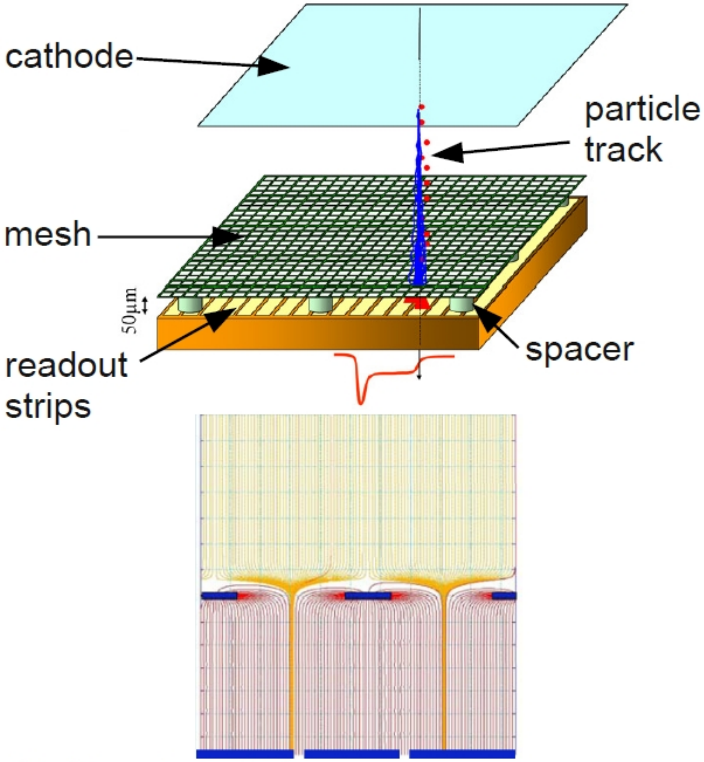




Micro Pattern Gaseous Detectors

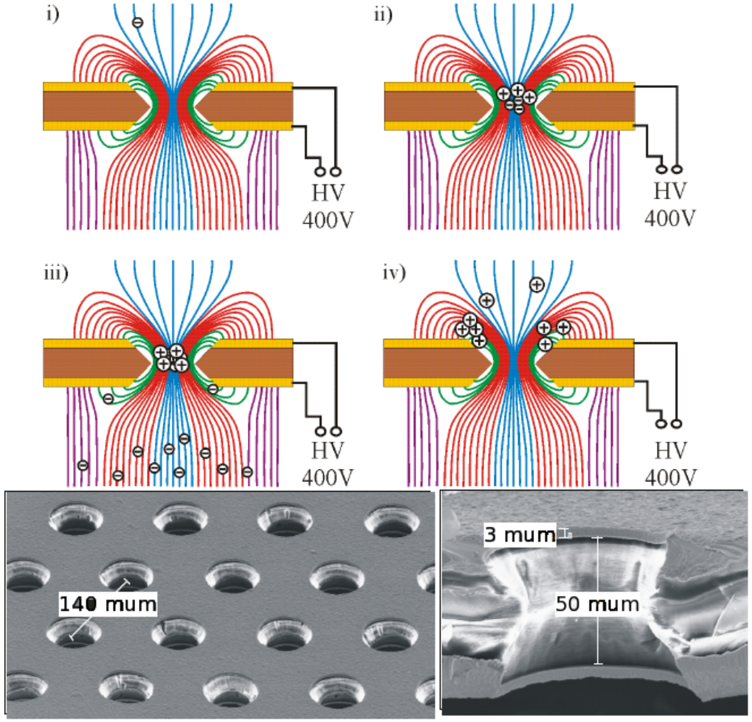
- Wire amplification not useable to achieve the desired resolution
- New amplification technologies: MPGDs

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.