Entwicklung und Beamtestergebnisse eines GEM-basierten TPC-Auslesesystems

Development and Beam-Test Results of a GEM based TPC Readout.

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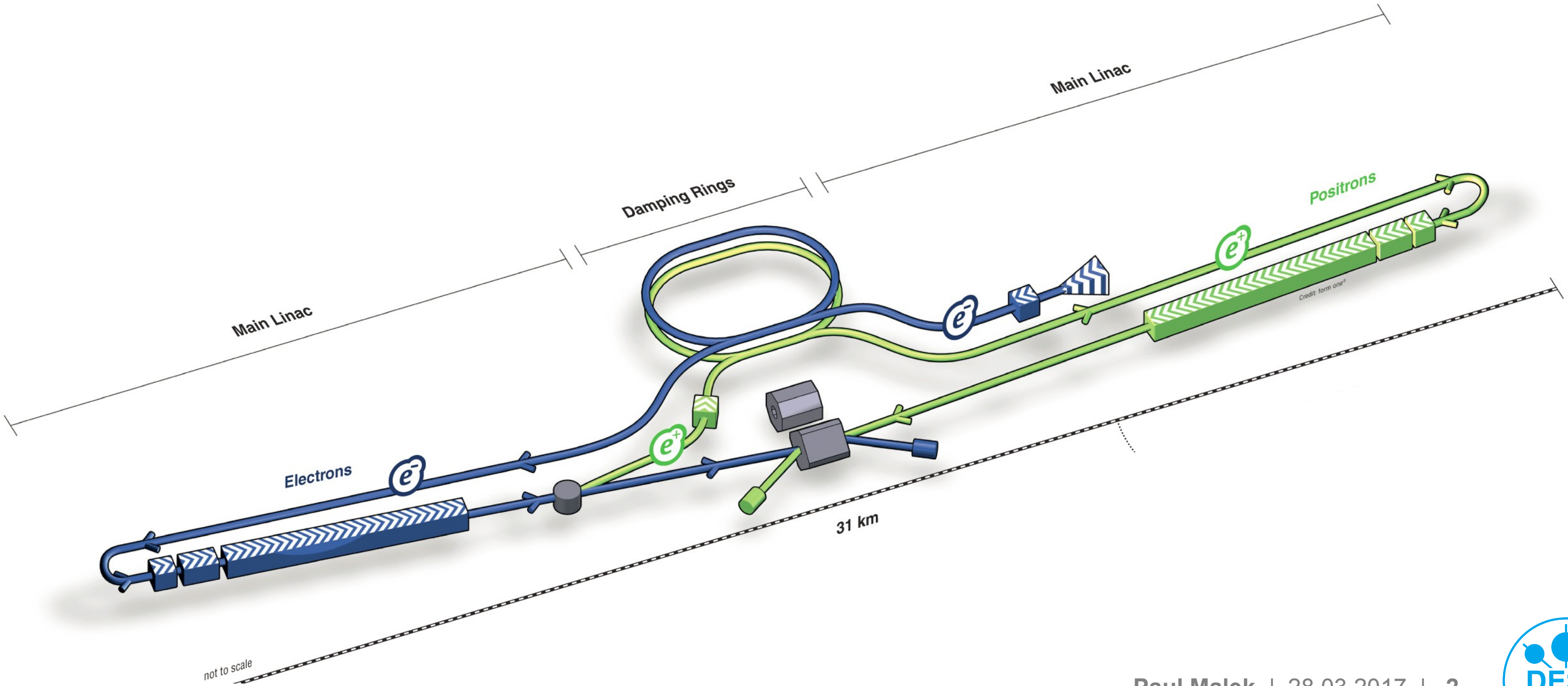
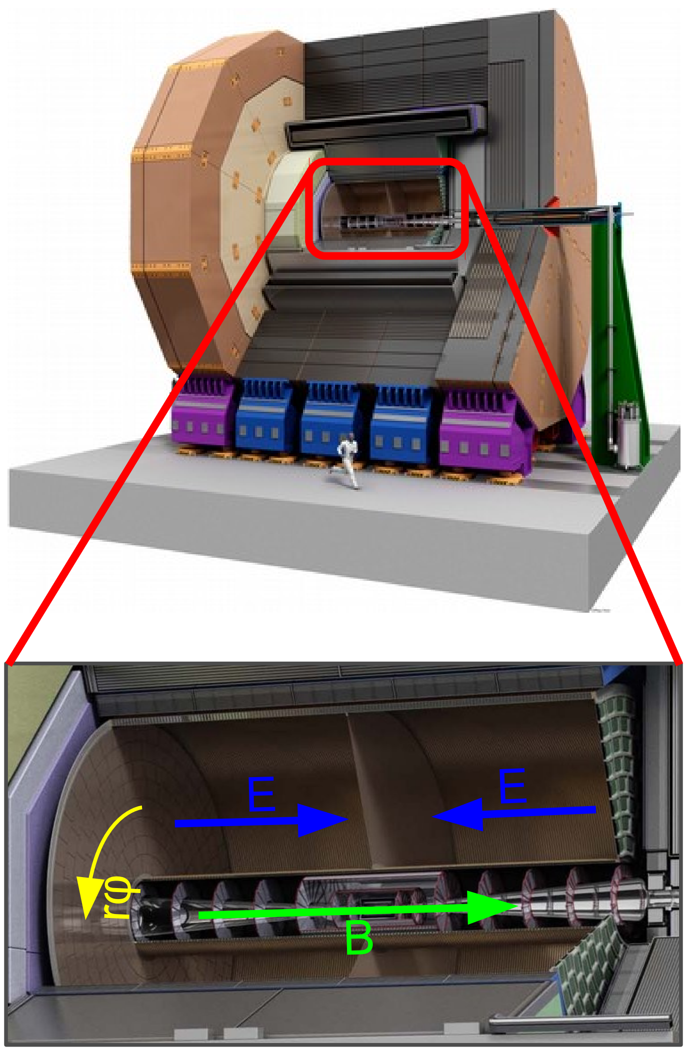
International Linear Collider

- ILC is a planned linear e^+e^- collider.
- 250-500 GeV collision energy (1 TeV extension).
- Two detectors to be used alternating.
- Under political consideration in Japan.



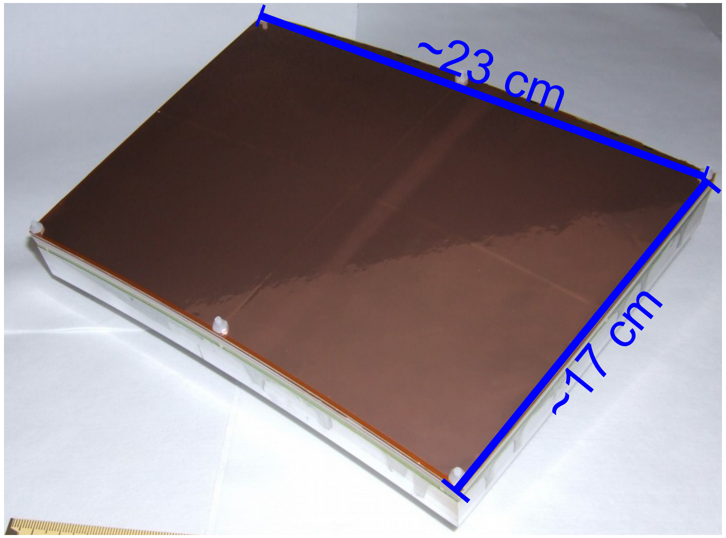
International Large Detector

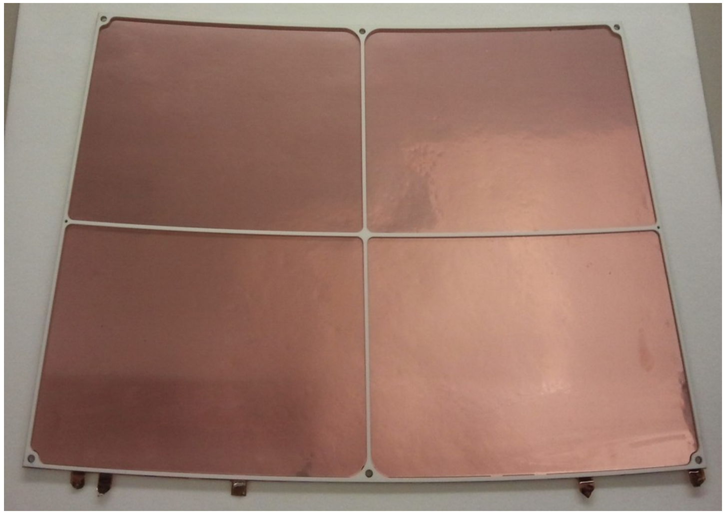
- Developed for precision measurements at ILC.
  - Reconstruction of each particle with the best suited subdetector.
- Time Projection Chamber (TPC) as central tracking detector.
  - Tracking efficiency near 100% even for low momentum particles.
  - Minimal material budget:
    5% X_0 barrel, 25% X_0 end plates.
  - 1,8 m outer radius, ~200 track points
  - 3,5 T solenoid field
  - Required momentum resolution (TPC only)
    $\sigma_{1/p_T} < 10^{-4}\,\mathrm{GeV}^{-1}$
    → point resolution in rφ $\sigma_{r\varphi} < 100\ \mu m$
    (compare ALICE: 400-800 µm)
  - Readout with Micropattern Gas Detectors (MPGD): Micromegas or GEMs

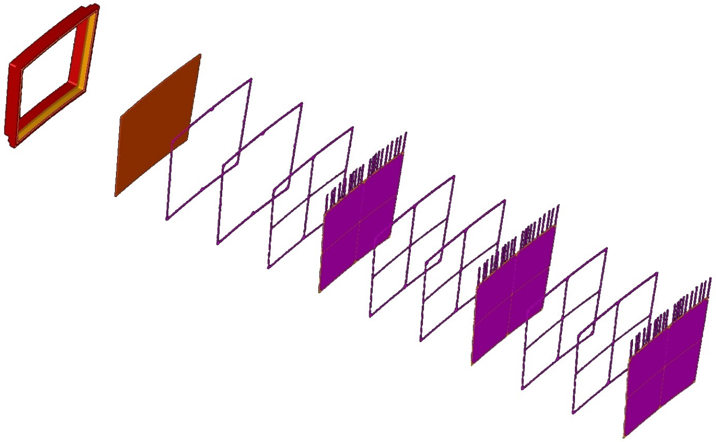


DESY GridGEM Module

- Triple-GEM module with integrated support structure.
- GEMs mounted on thin, self supporting alumina-ceramic (Al_2O_3) frames.
  - high stiffness
  - minimal inactive area and material
- ~5000 readout pads in 28 rows
  - 1.26 x 5.85 mm² pad pitch







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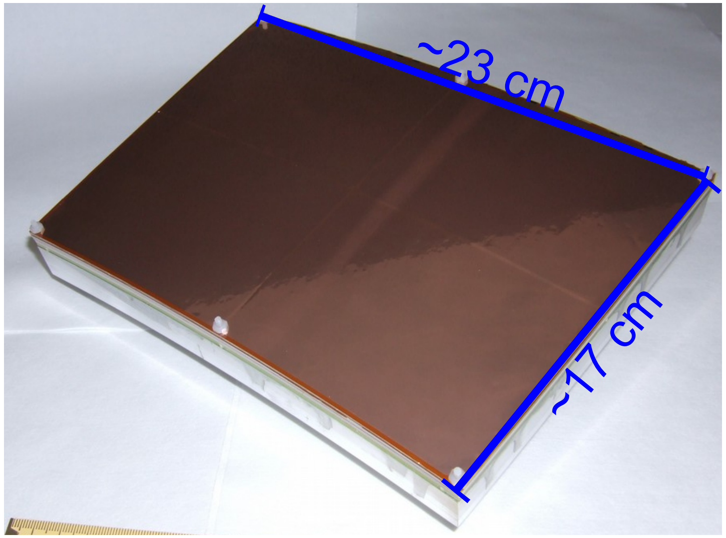
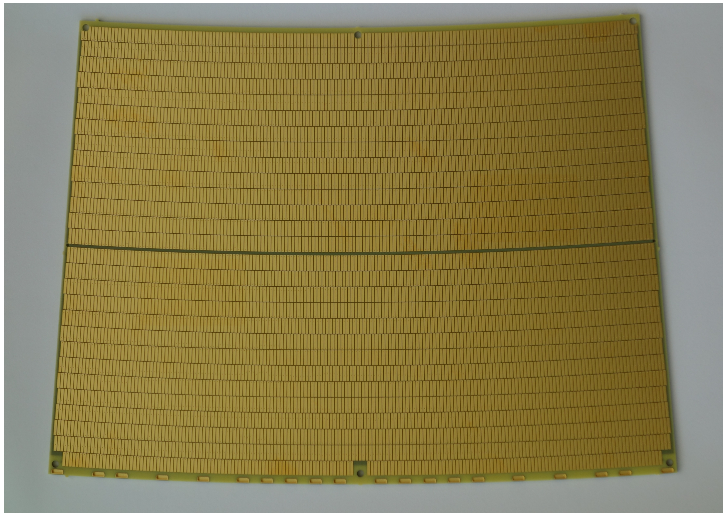
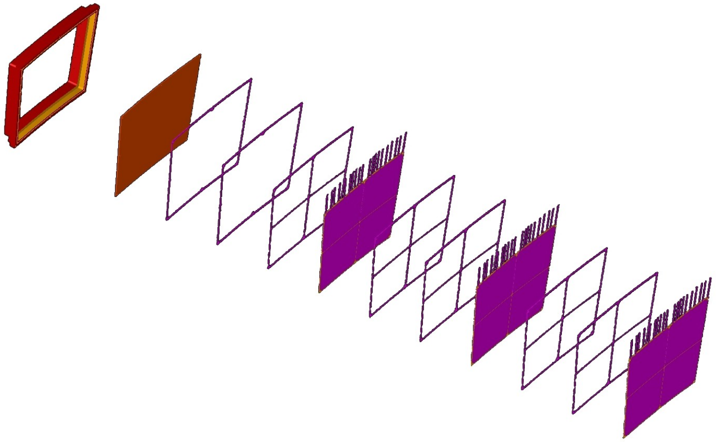
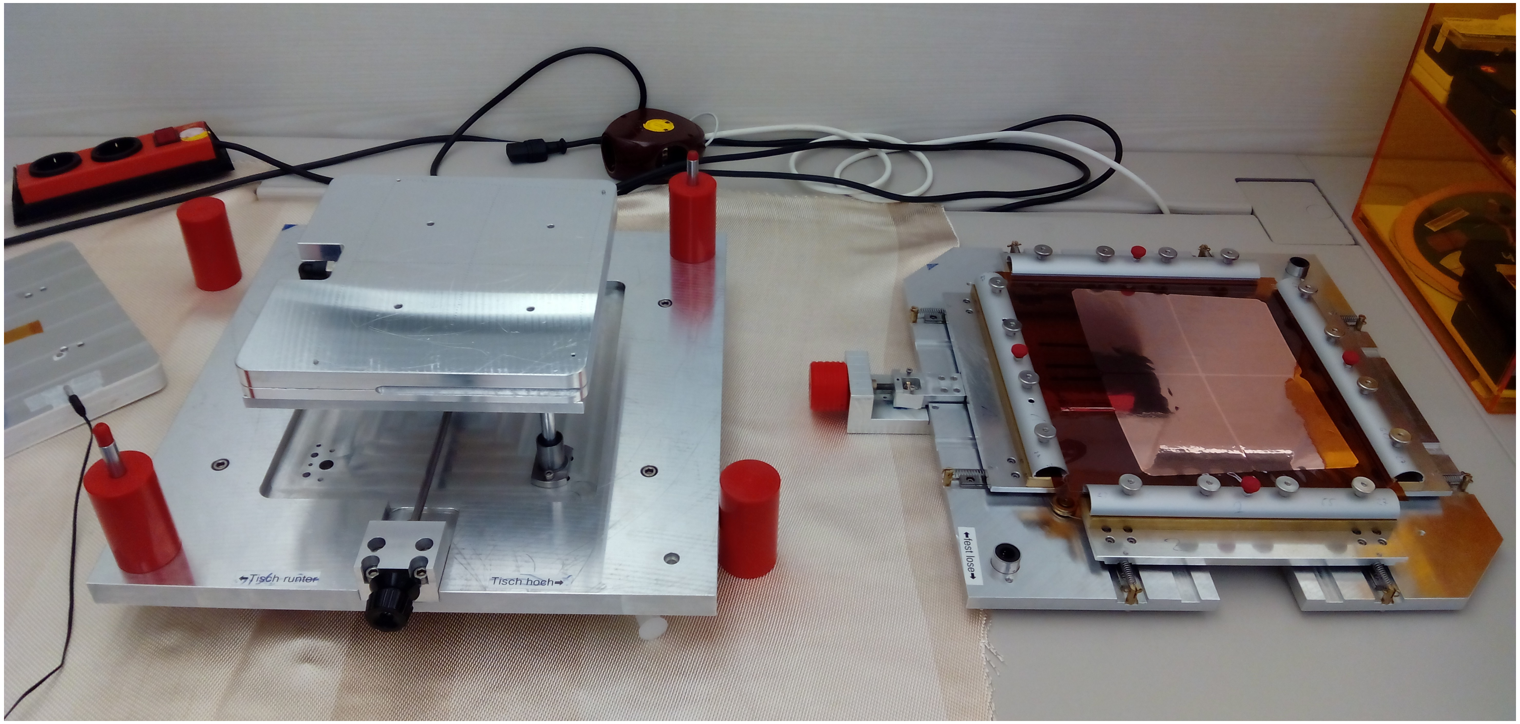




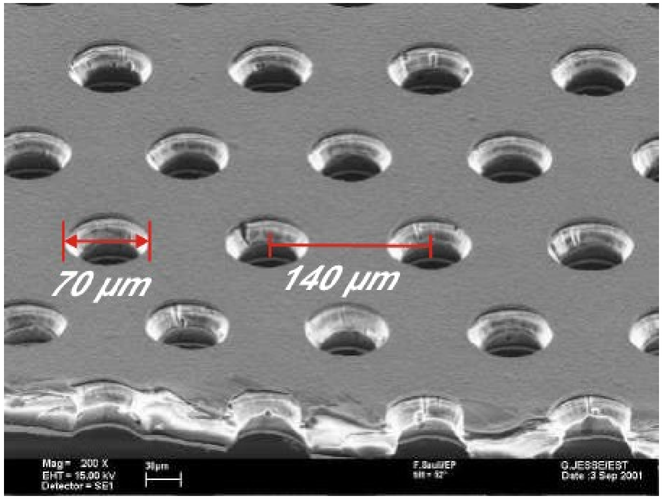


Revised GEM Framing Process

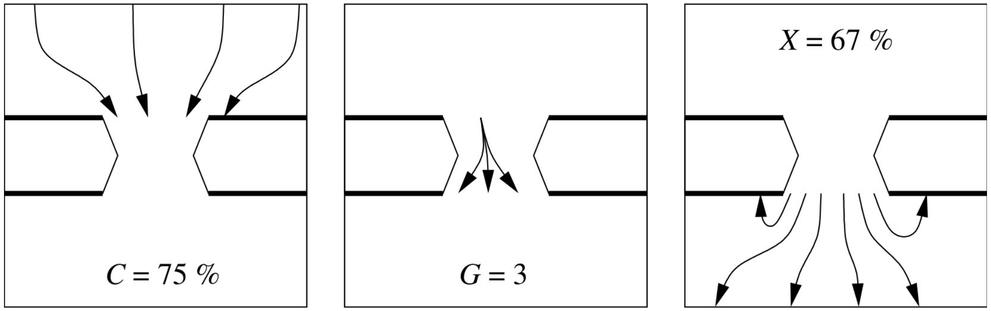
- New tool to join GEM and frame during gluing has been commissioned.
- Previously: Manual GEM stretching and mounting.
- Now: Reliable, controlled foil mounting ensuring a consistent high quality.



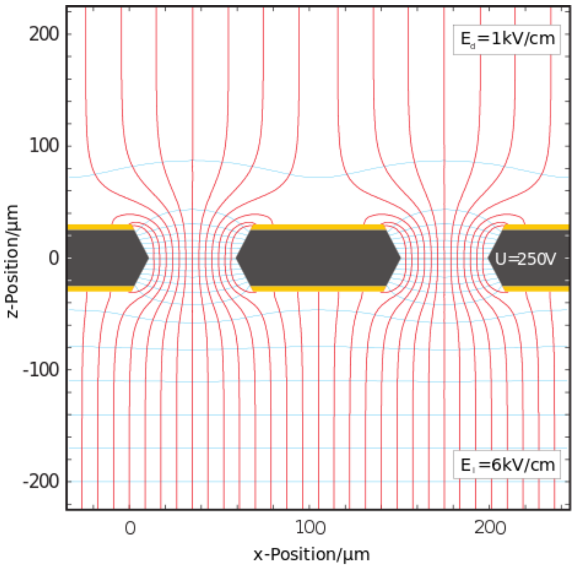
Gas Amplification with GEMs



[http://gdd.web.cern.ch/GDD/]



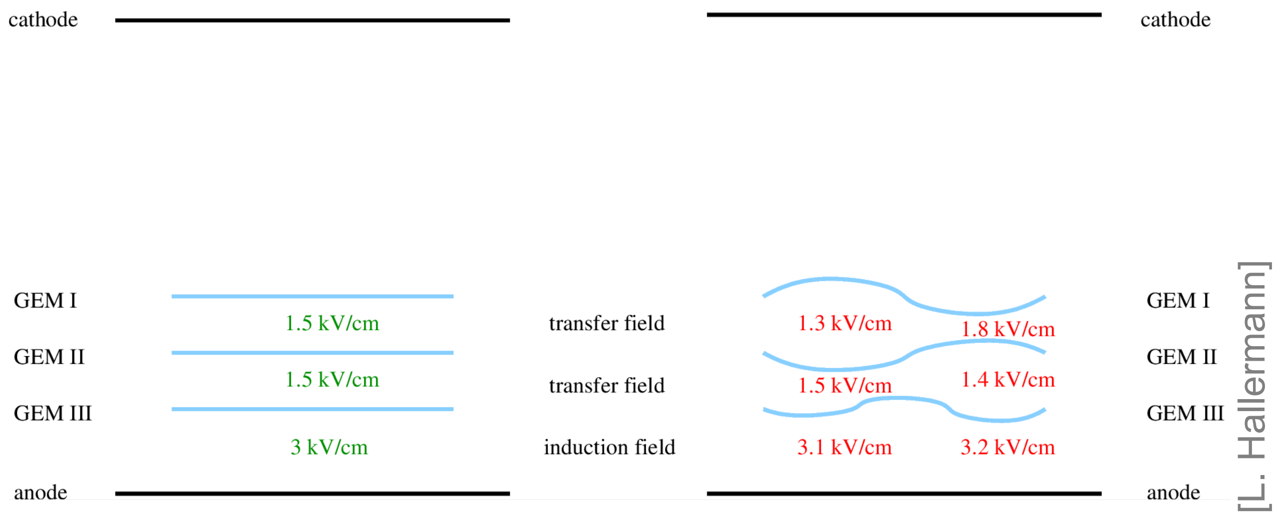
[A. Vogel]



[B. Sobloher & O. Schäfer]

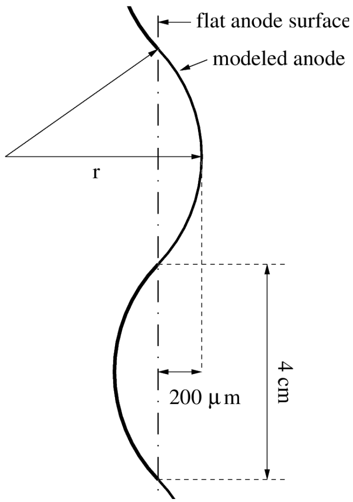
- Thin insulator copper coated on both sides.
- Moderate voltages between copper surfaces lead to strong fields inside GEM holes → gas amplification.
- Electron capture / extraction efficiencies depend on ratio of the external to hole field strength.
- Effective GEM gain modified by changes in external fields.

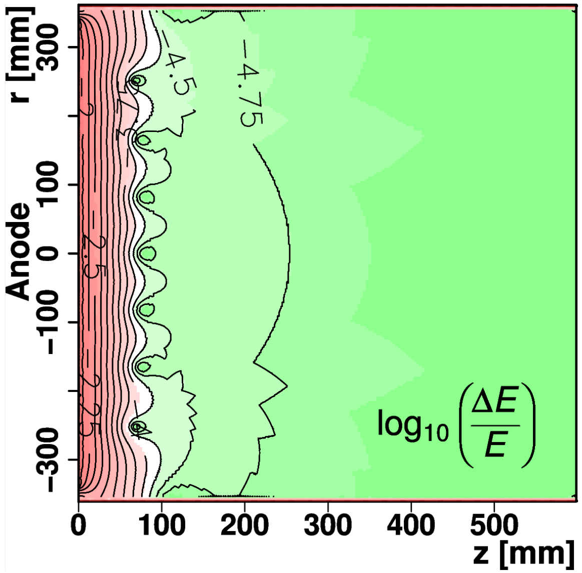
Impact of GEM Deflections on dE/dx Resolution



- Deflections of GEMs locally change electrical fields between GEMs.
- GEM distances: O(mm); GEM deflections: O(100µm) → regional gain changes of a few percent
  - Potential to create regional / angular bias on dE/dx.
- Statistical fluctuations of gas amplification and electronics gain differences are also in this range, each.
- dE/dx resolution dominated by uncertainty on primary ionization

Impact of GEM Deflections on Point Resolution

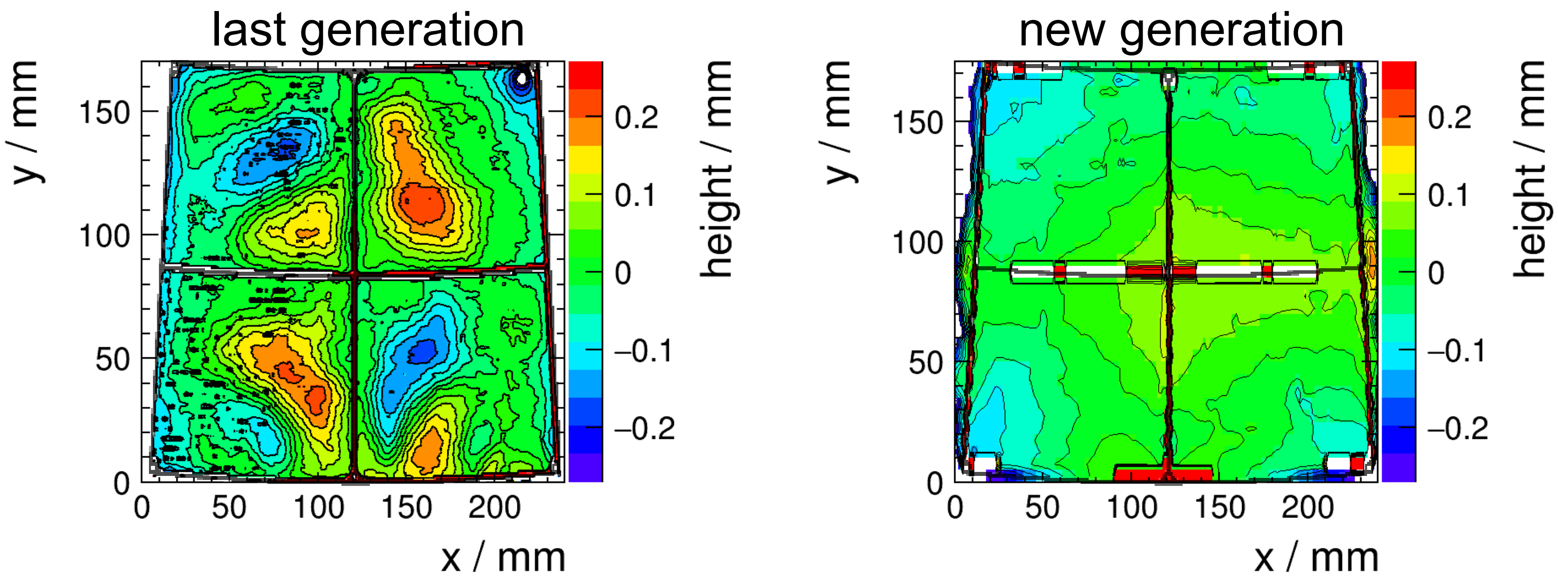




[P. Schade & L. Hallermann]

- Deflection of GEMs → drift field inhomogeneities
  - $\Delta E/E > 10^{-4}$ over ~80 mm drift length at the anode
- Degradation of point resolution: ~3%
  - 100µm ILD-TPC design ⊕ 25µm from field distortions = 103.1µm
- Other field distortions add up (i.e. ion back-flow).
- Important to keep all sources in check.

GEM Flatness Comparison



- Last generation height RMS_{95}: 74µm
  - 50-90µm single GEM spread
- New generation RMS_{95}: 33µm
  - 20-50µm single GEM spread
- New generation consistently more flat by about factor two.

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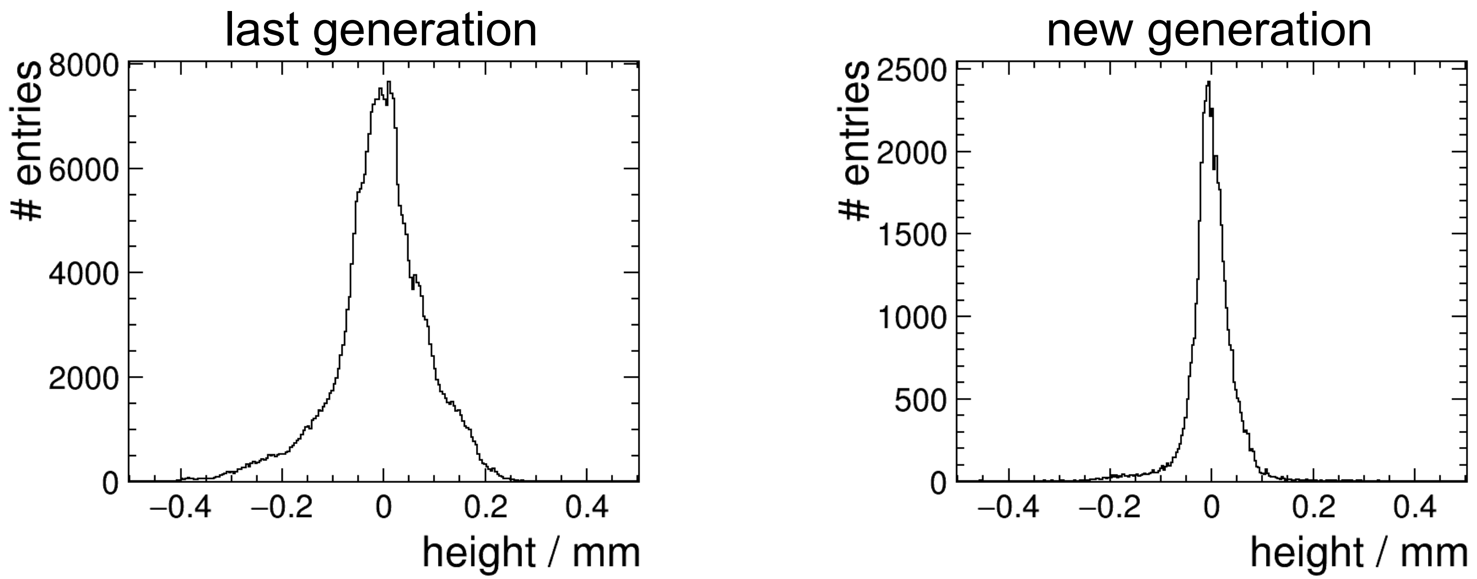

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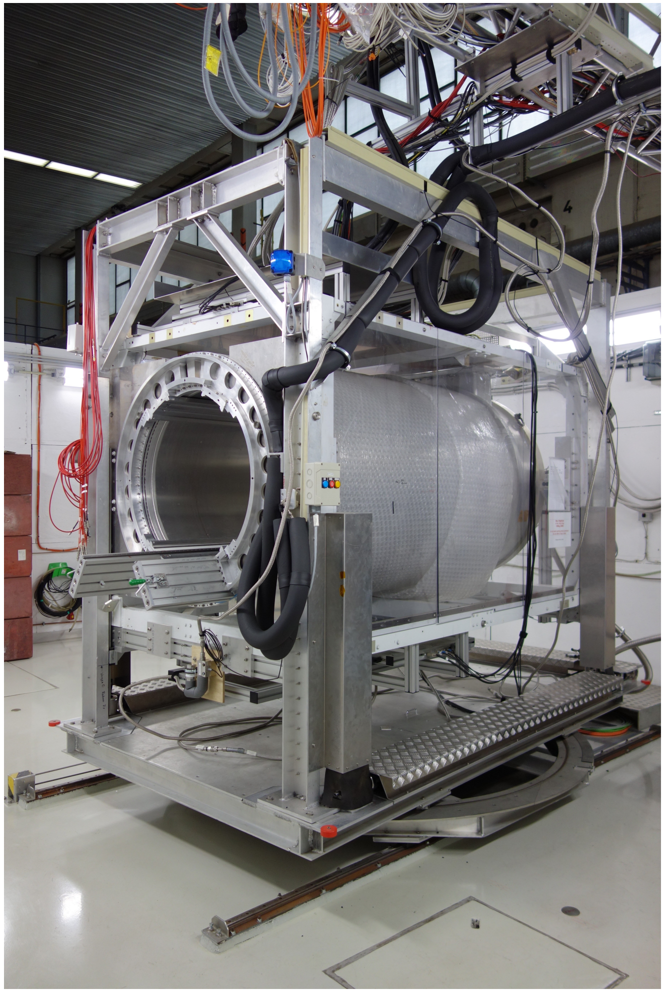
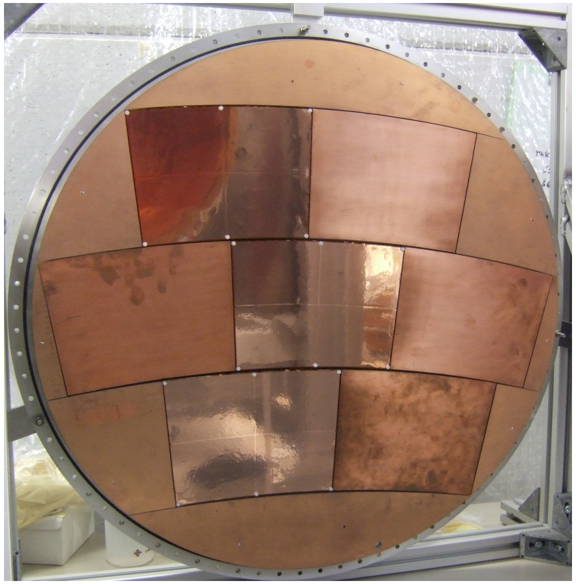
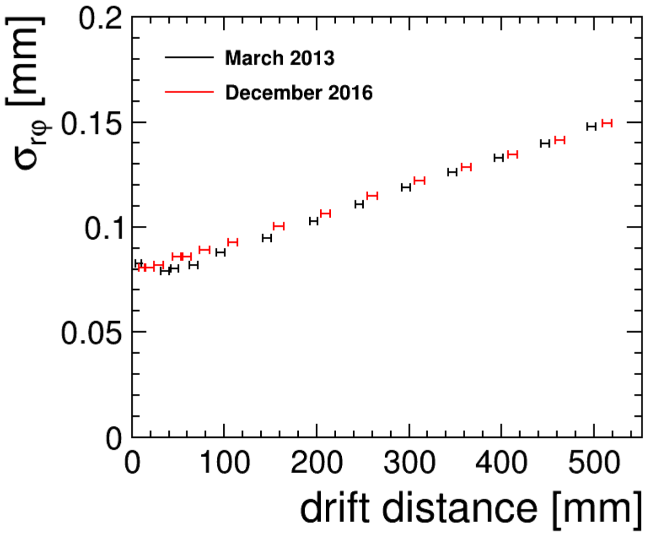
Tests at the DESY II Testbeam.

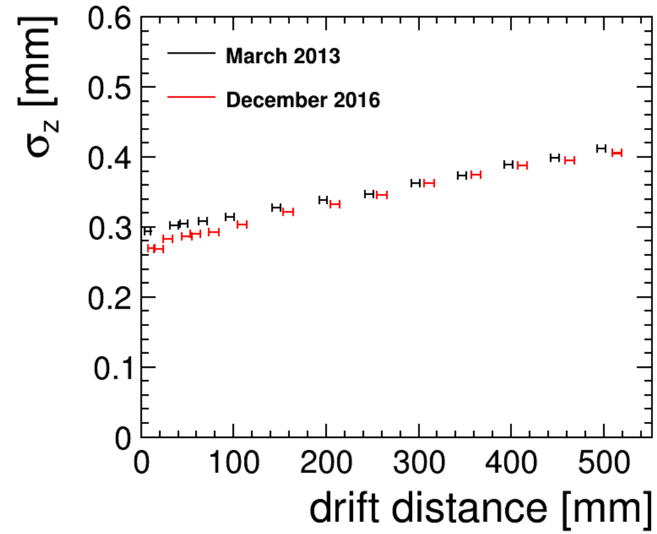
- 1-6 GeV electron beam
- 1 T superconducting solenoid (PCMAG)
  - 85 cm diameter bore
  - material budget: $0.2X_0$
- Large TPC prototype:
  - 57 cm drift length, 72 cm diameter
  - three rows of modules (7 module slots)

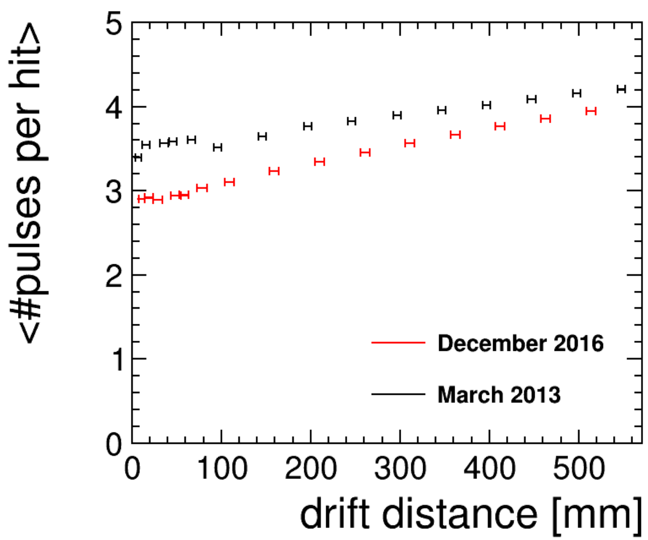




Comparison with previous Data







- Comparing to data from previous beam test.
- Point resolution in row and drift direction similar in old and new data.
- Minor differences at lower drift distances.
- On average smaller hits. ← lower diffusion

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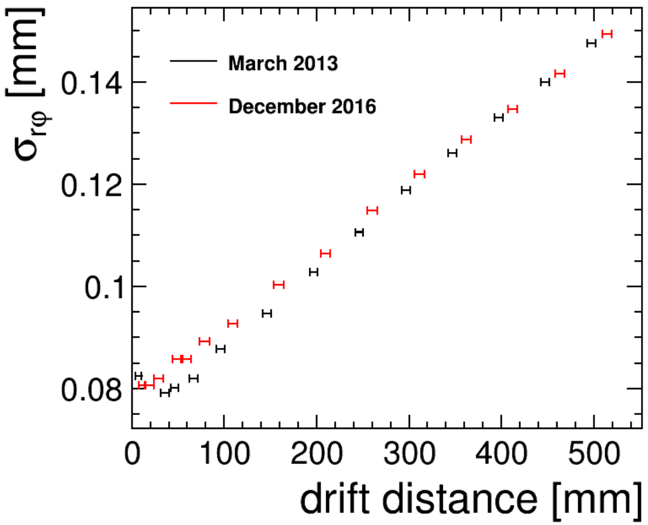

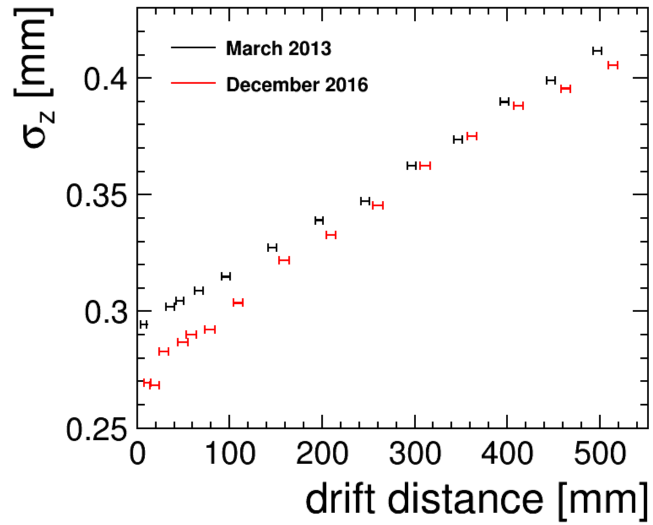

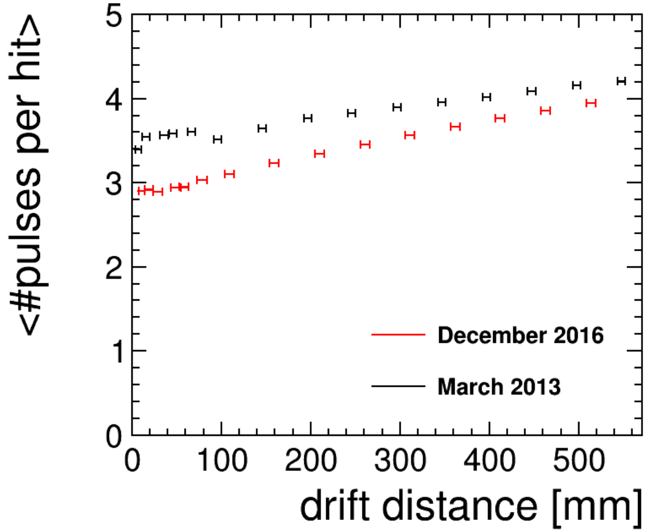

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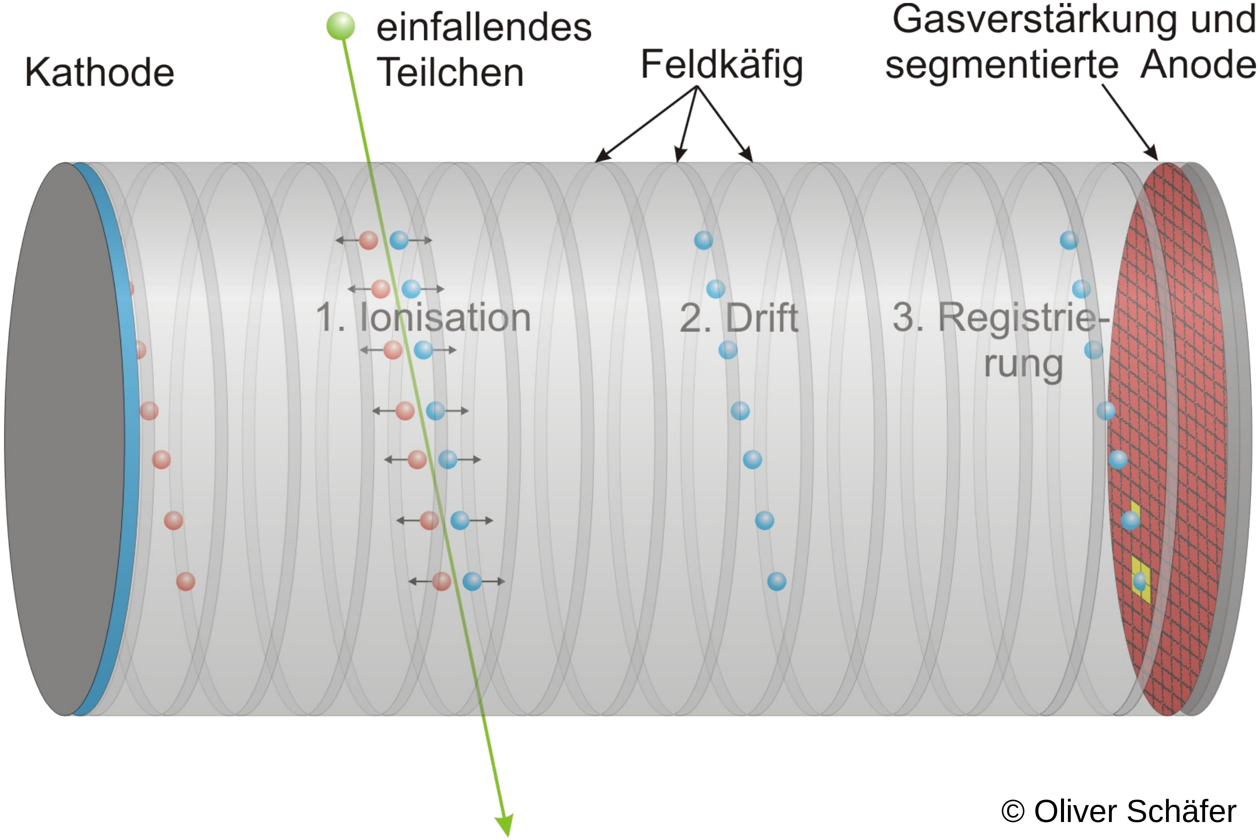
Summary

- An improved process for mounting GEMs to ceramic frames was successfully applied.
- Sophisticated tooling replaces manual GEM mounting → ensures reliable, controlled mounting and consistent high quality.
- First analysis results from a beam test with newly constructed readout modules are consistent with data from a previous beam test.
- Data analysis is ongoing:
  - Establish double hit and dE/dx resolution based on the new data.

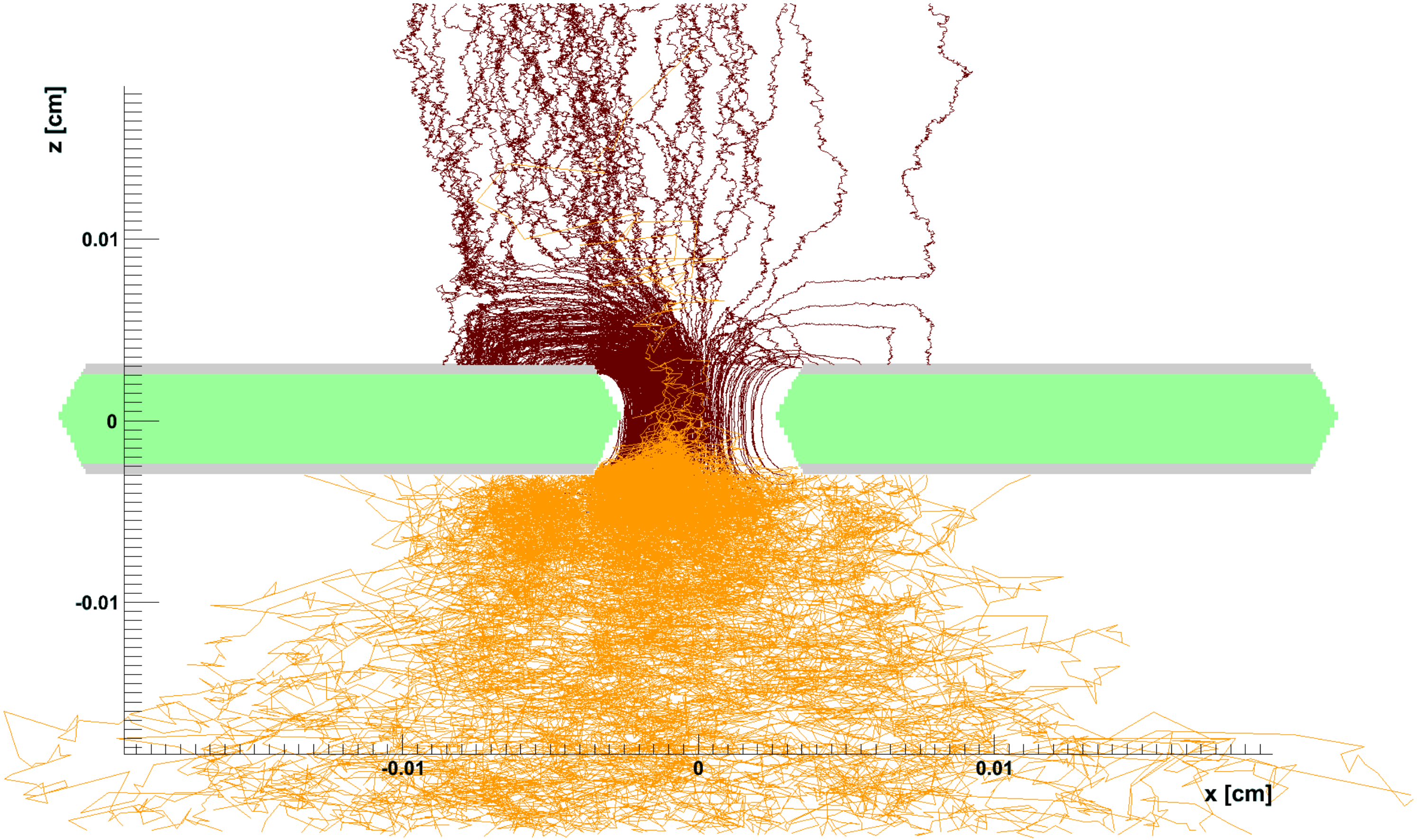
Backup

TPC

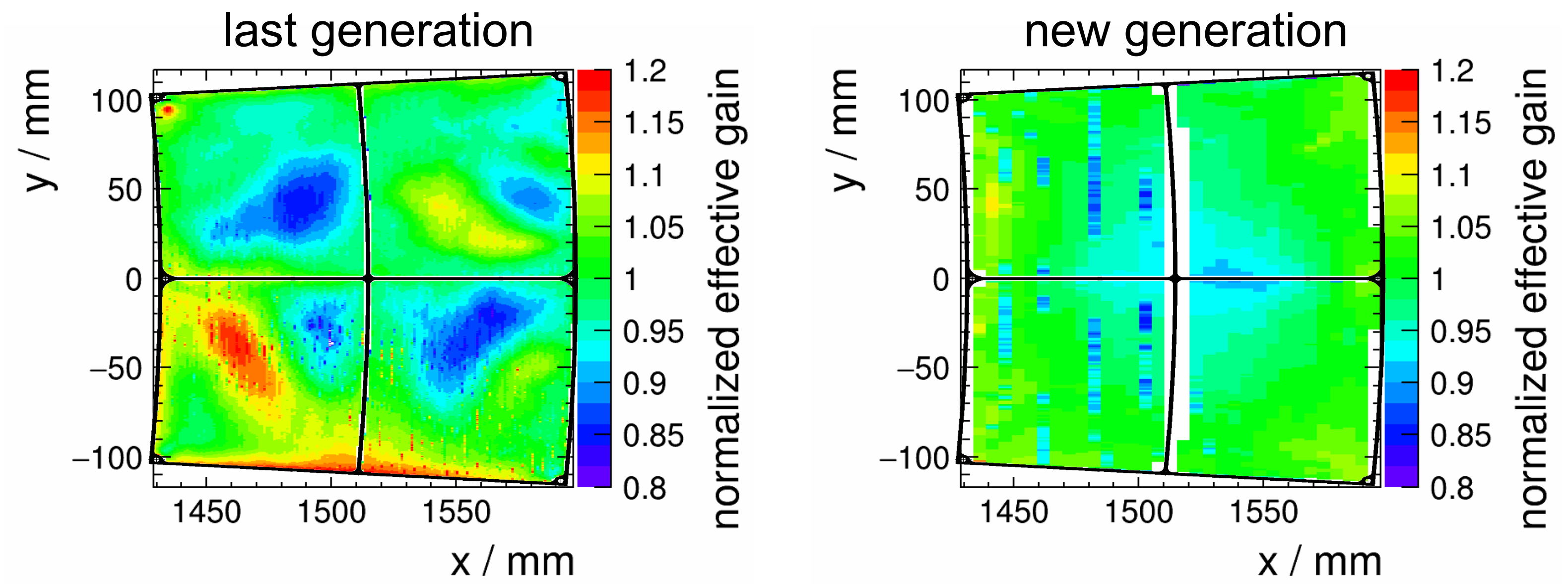


einfallendes Teilchen
Kathode
Feldkäfig
Gasverstärkung und segmentierte Anode
1. Ionisation
2. Drift
3. Registrie-rung

GEM



Calculated Gain Deviation



- Calculated gain distribution for triple GEM stacks from measured GEMs.
- Gain RMS of combined distribution for last generation: 8.8%
- Combined gain RMS for new generation GEMs: 4.2%

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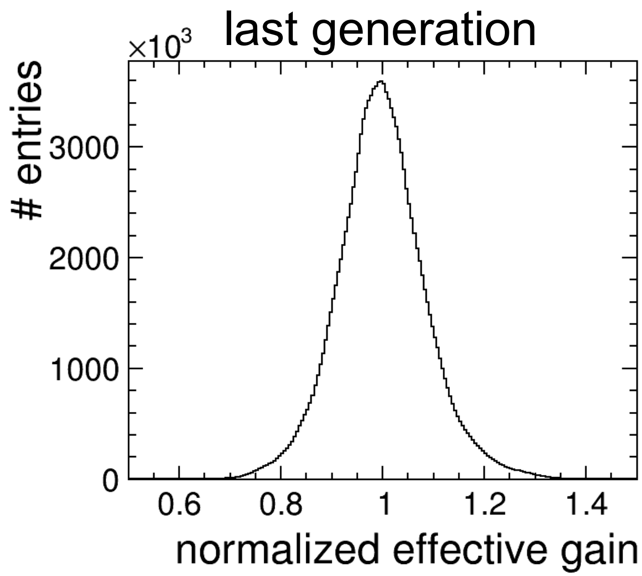

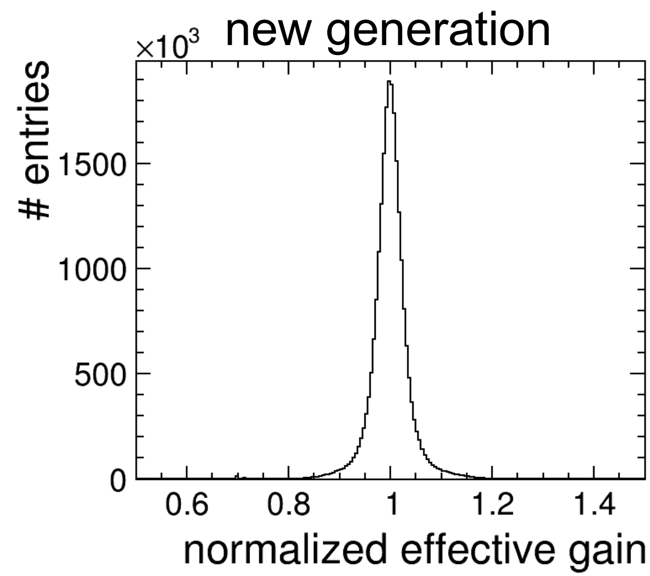

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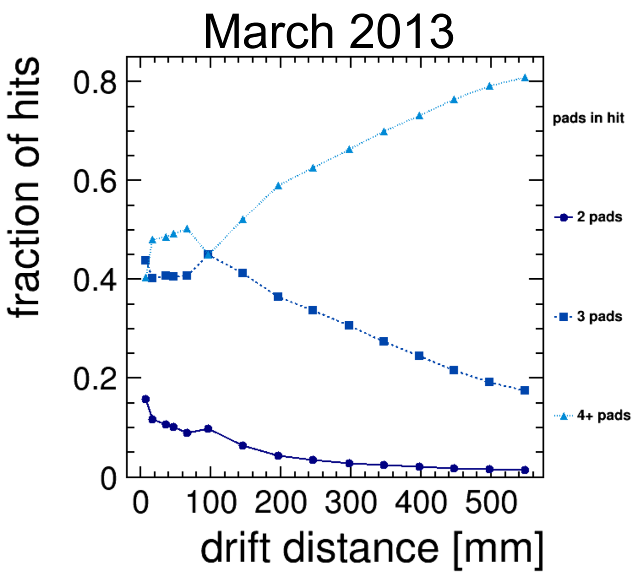
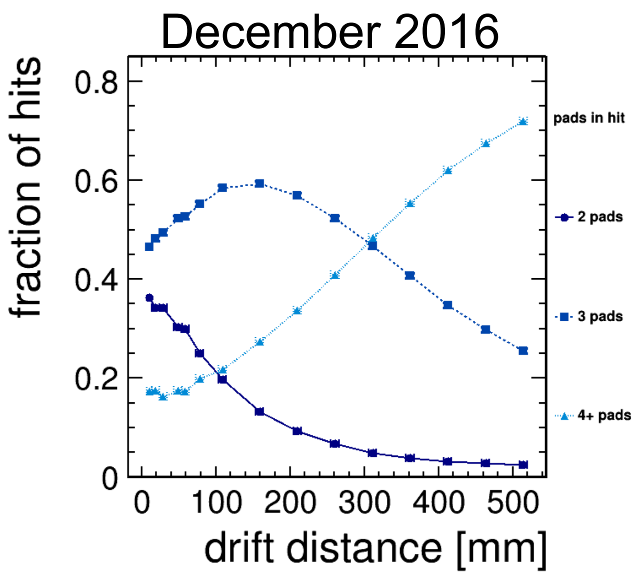
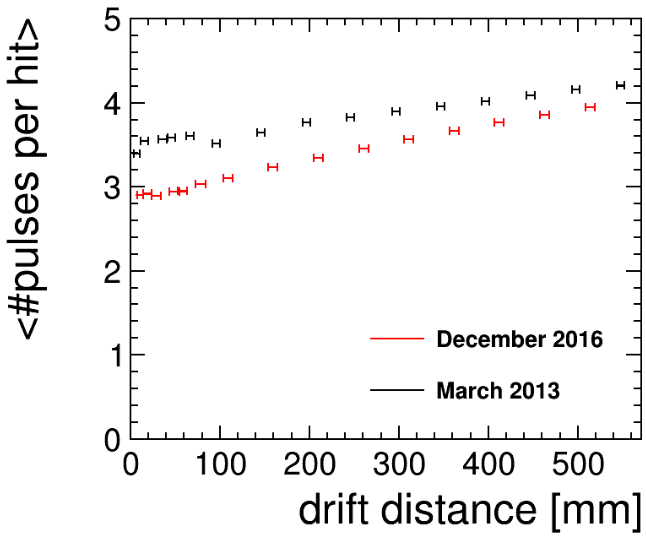
Universität Hamburg

DESY

Number of Pulses in a Hit

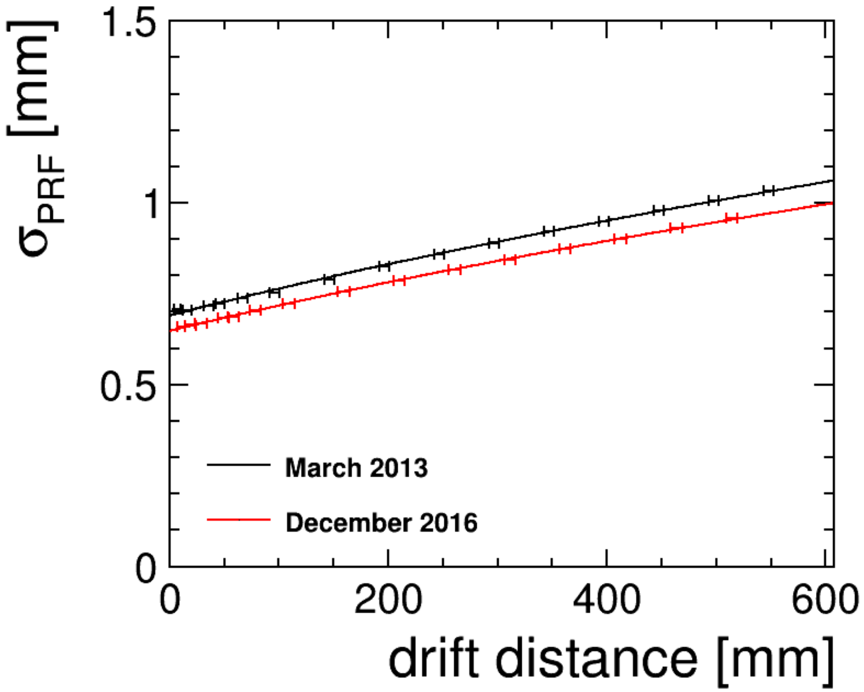






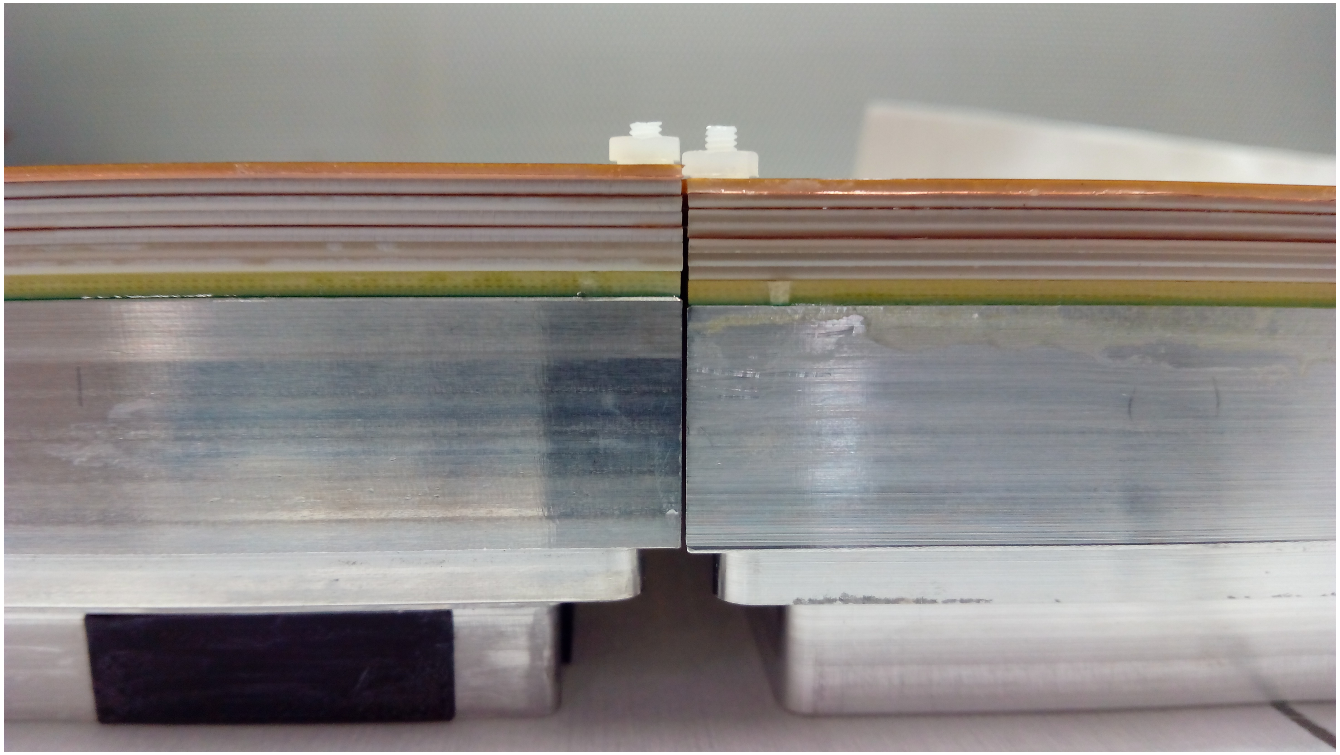
- Used as a data quality check.
- Lower Diffusion in the GEM stack $\rightarrow$ On average smaller hits in new data.
- Explains differences in resolution in both directions.

Diffusion



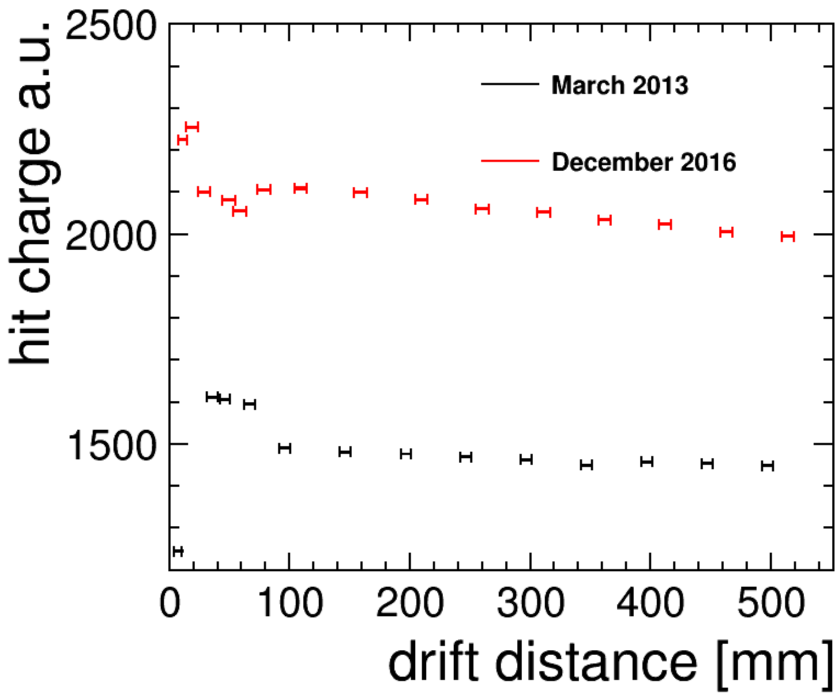
- March 2013:
  - $\sigma_{0,PRF}$ = 690.3 ± 2.6 μm
  - D_t = 0.1032 ± 0.0004 mm/$\sqrt{cm}$
- December 2016
  - $\sigma_{0,PRF}$ = 648.0 ± 2.9 μm
  - D_t = 0.0976 ± 0.0008 mm/$\sqrt{cm}$

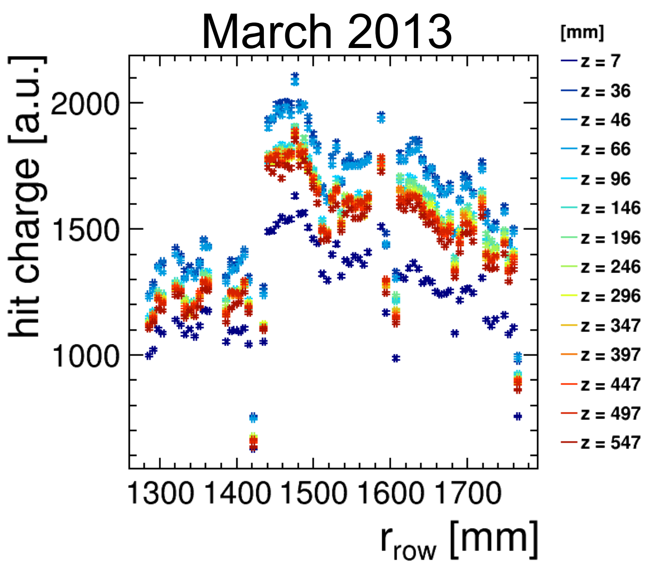
GEM Stack Height

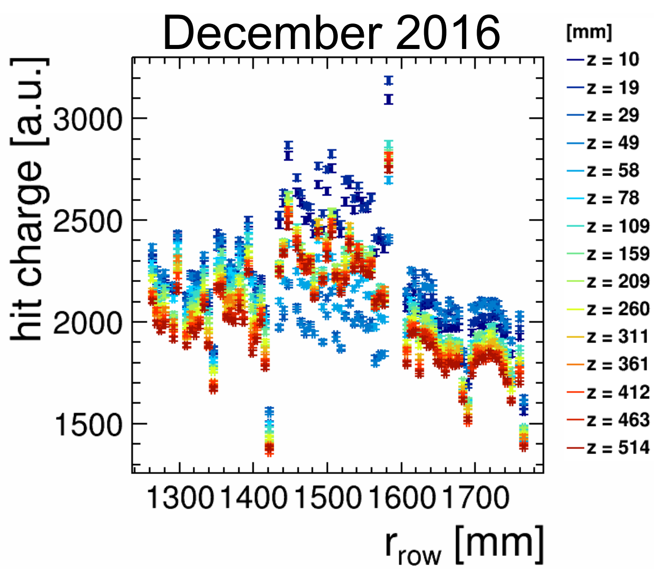


- Height comparison of new (left) and old (right) module.
- Stack of the new module is ~0.5mm higher.
  - Including PCB and aluminium back-frame.

Hit Charge

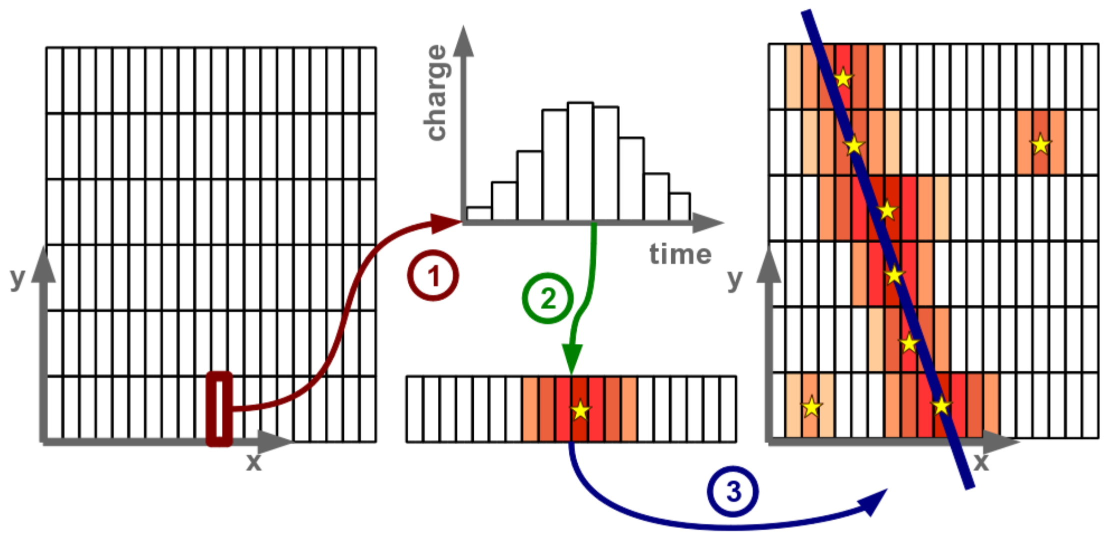

hit charge a.u.
2500
2000
1500
March 2013
December 2016
0
100
200
300
400
500
drift distance [mm]


March 2013
hit charge [a.u.]
2000
1500
1000
1300 1400 1500 1600 1700
r_{row} [mm]
[mm]
z = 7
z = 36
z = 46
z = 66
z = 96
z = 146
z = 196
z = 246
z = 296
z = 347
z = 397
z = 447
z = 497
z = 547

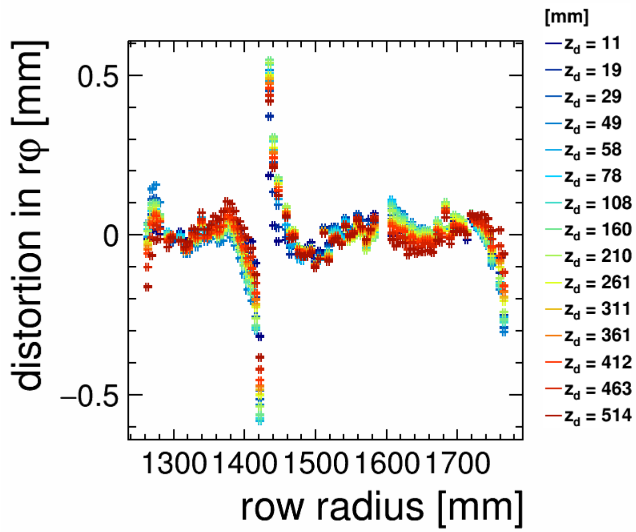

December 2016
hit charge [a.u.]
3000
2500
2000
1500
1300 1400 1500 1600 1700
r_{row} [mm]
[mm]
z = 10
z = 19
z = 29
z = 49
z = 58
z = 78
z = 109
z = 159
z = 209
z = 260
z = 311
z = 361
z = 412
z = 463
z = 514

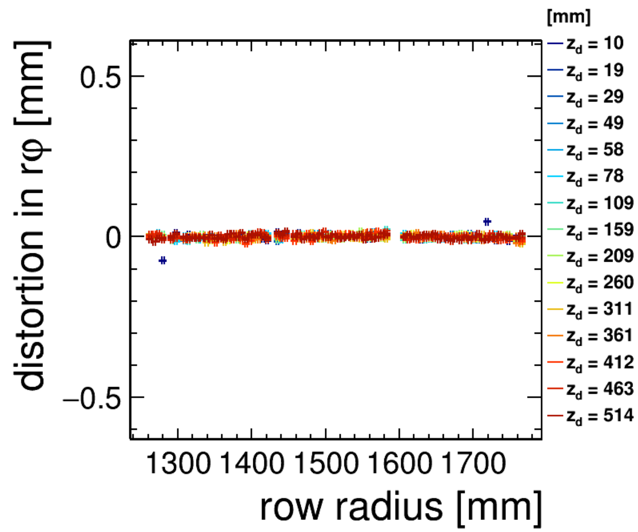
Reconstruction Procedure

- Find charge pulses in raw data.
- Build hits out of neighboring pulses in a pad row.
- Find tracks in hits & fit the found tracks.
- Calculate distortions in rφ- and z-direction based on track residuals.
- Apply calculated distortion corrections to hits.
- Find and fit tracks again.

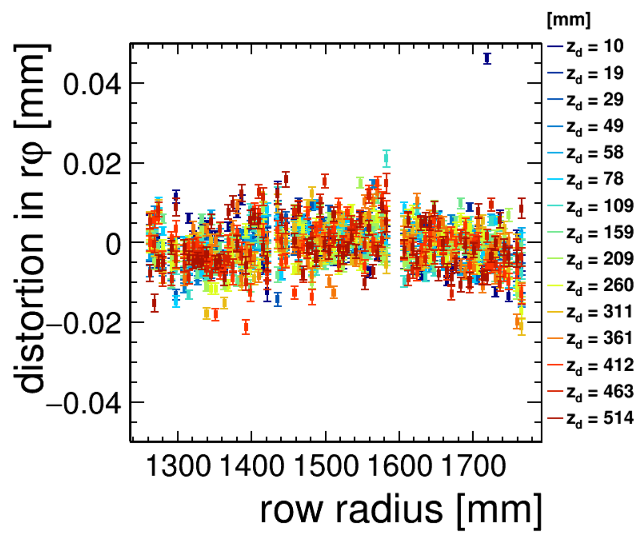


Distortion Correction

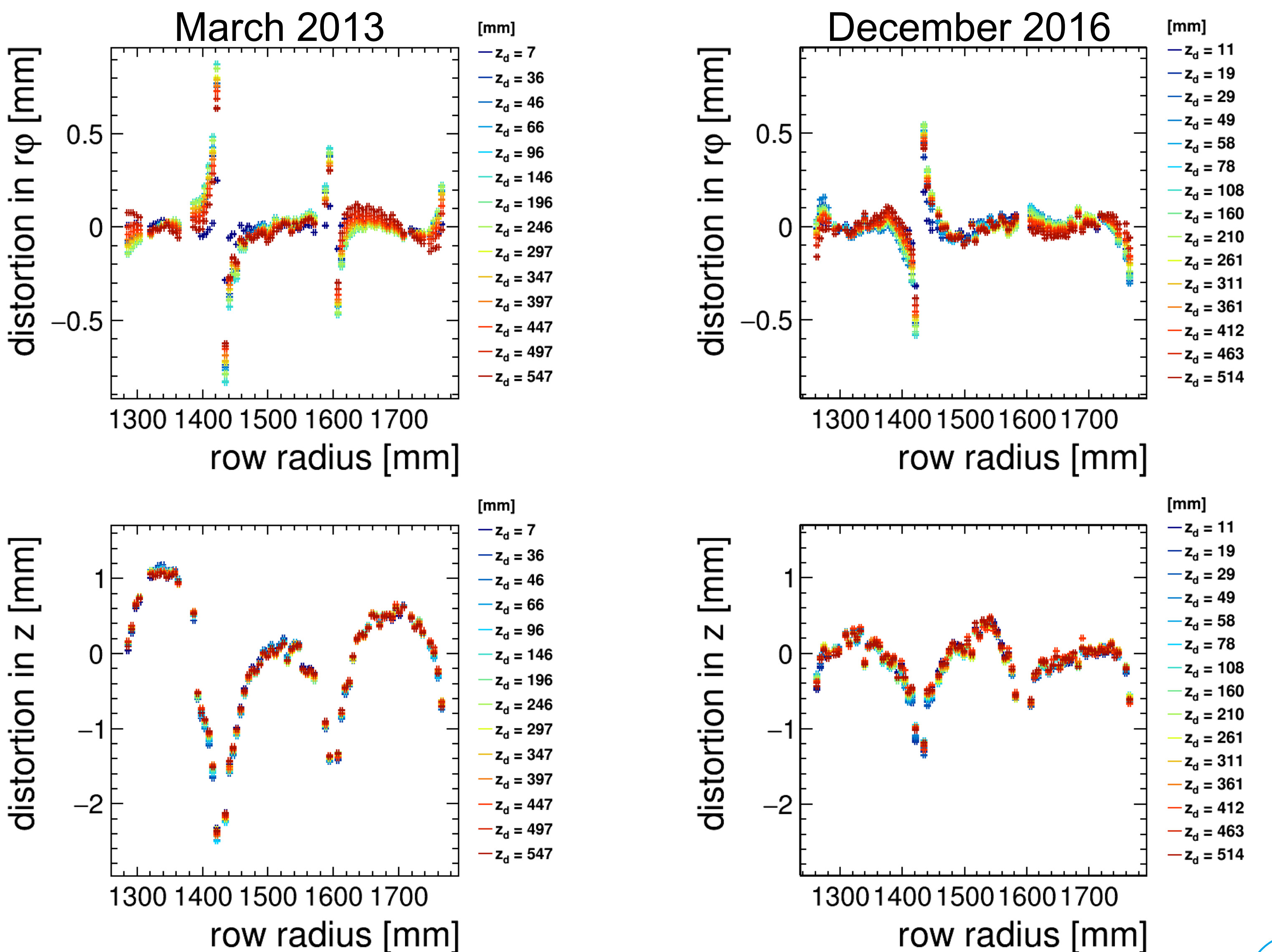




- Distortions are calculated from the mean of the track residuals.
- Hits in each row are then shifted by the calculated amount.
- Tracks are refitted afterwards.



Distortion Comparison



LCTPC

- DESY
  - GEM-Stapel mit 3 GEMs, Pads (1.26 x 5.85 mm^2), ALTRO Readout
- Japan
  - GEM-Stapel mit 2 GEMs, Pads, ALTRO Readout
- Saclay
  - Micromegas, Pads (3 x 7 mm^2) + resistive Beschichtung, AFTER Readout
- Bonn, NIKHEF, Freiburg
  - Micromegas direkt auf Timepix Chip → InGrid
  - Tests mit GEMs + Timepix