The Pixel-TPC: a Feasibility Study

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University of Bonn
On behalf of the LCTPC collaboration

Outline:

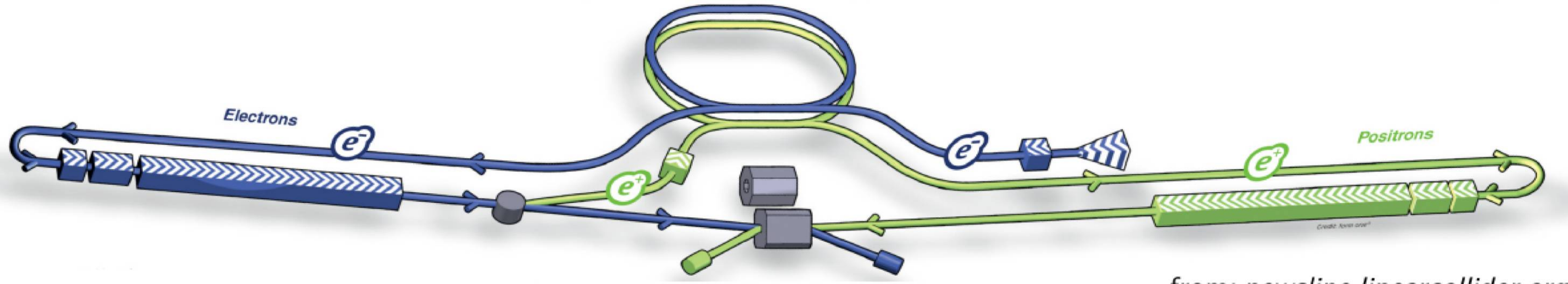
- Pixel-TPC: Motivation
- Timepix and InGrid
- R&D project
- Test beam results

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

IEEE NSS, November 2, San Diego

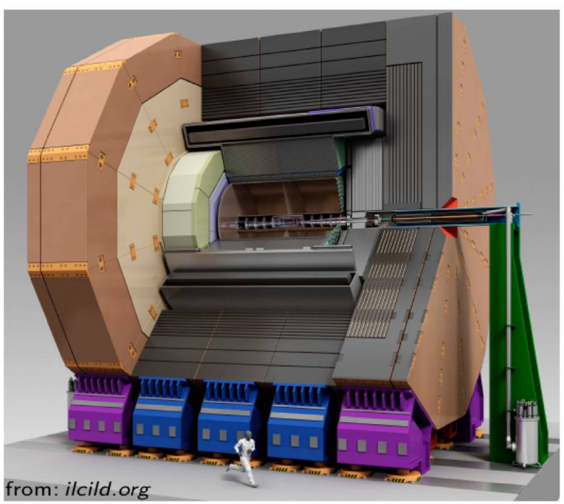
Motivation

Context: The International Linear Collider



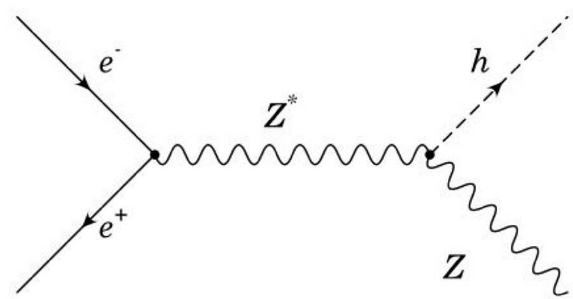
from: *newsline.linearcollider.org*

The ILD detector at ILC foresees a TPC as main tracker



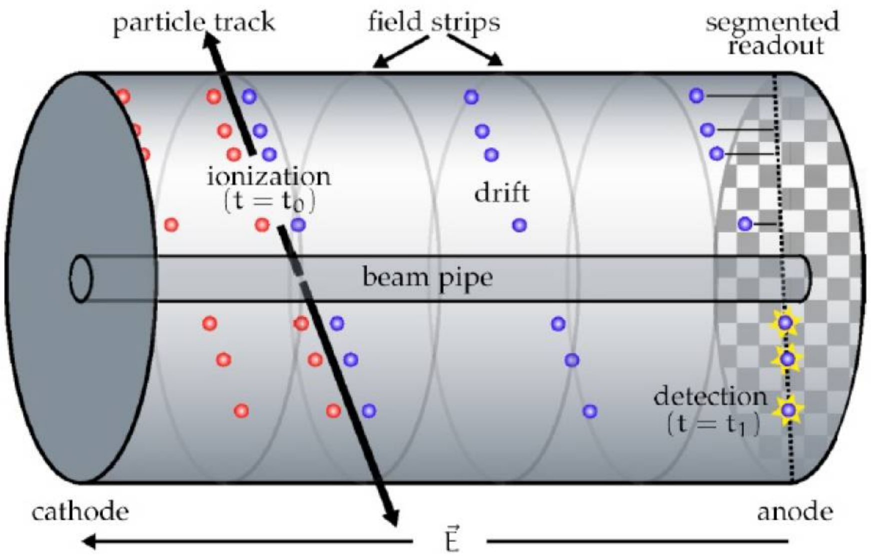
High precision physics at ILC requires new detector technology.

Requirement for tracker alone: $\sigma(1/P_t) < 10^{-4}$ /GeV/c



Motivation

TPC: new technology required for endplate design



- Replace traditional wire based gas amplification structure by micro-pattern gaseous detectors
  - Higher granularity
  - Better resolution
  - Lower ion backflow → higher rate

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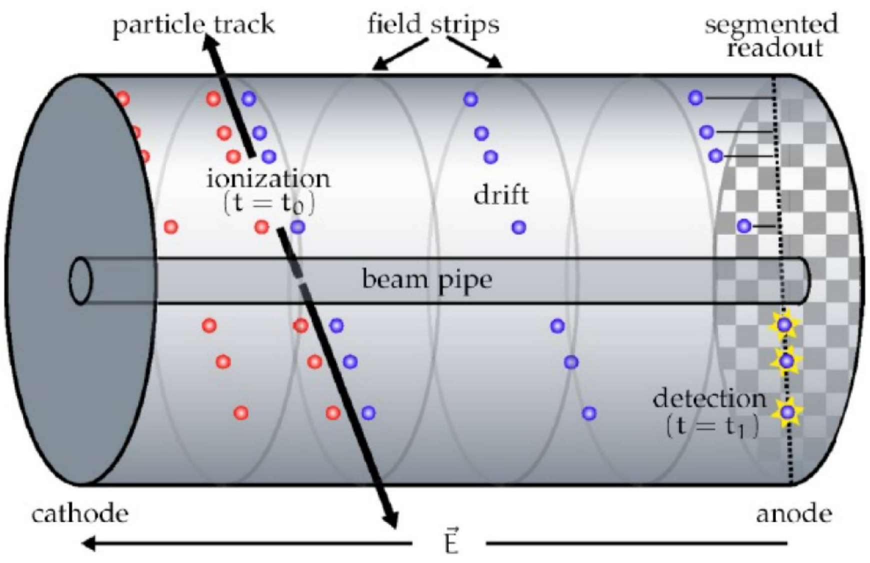

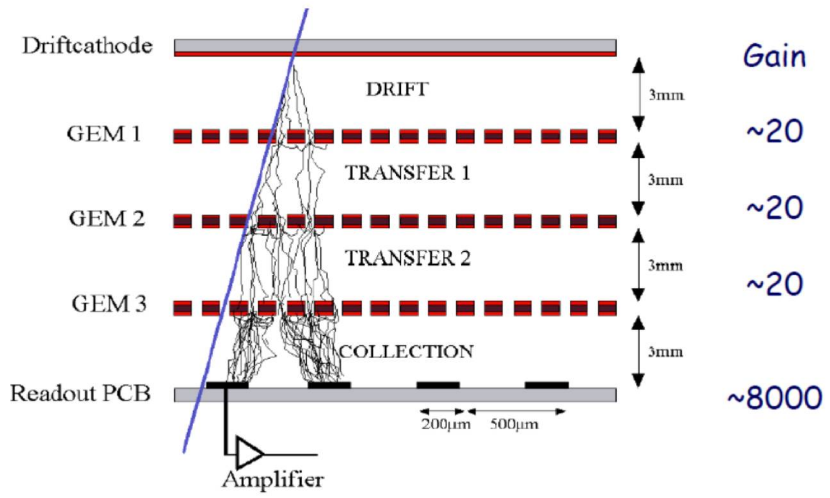

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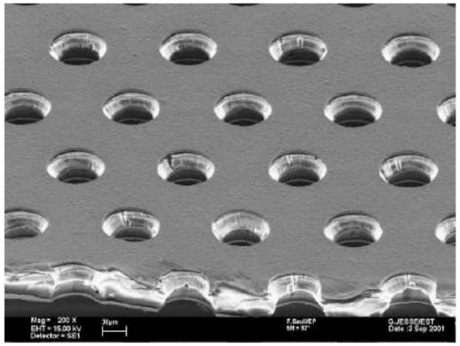
  - Most advanced: GEM



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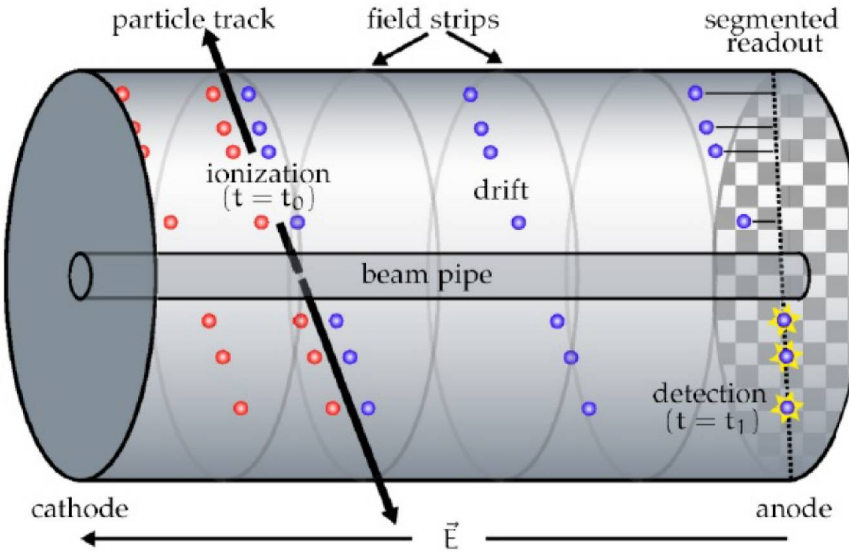

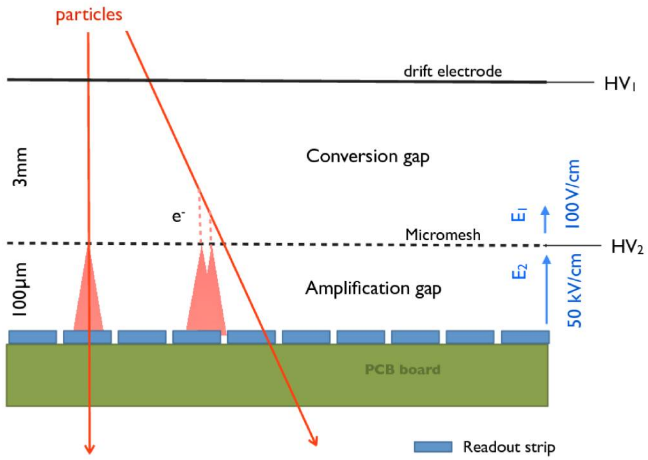

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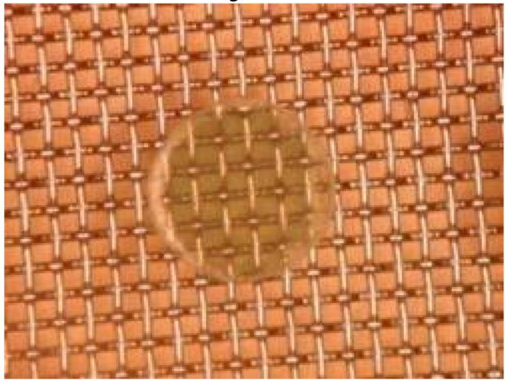

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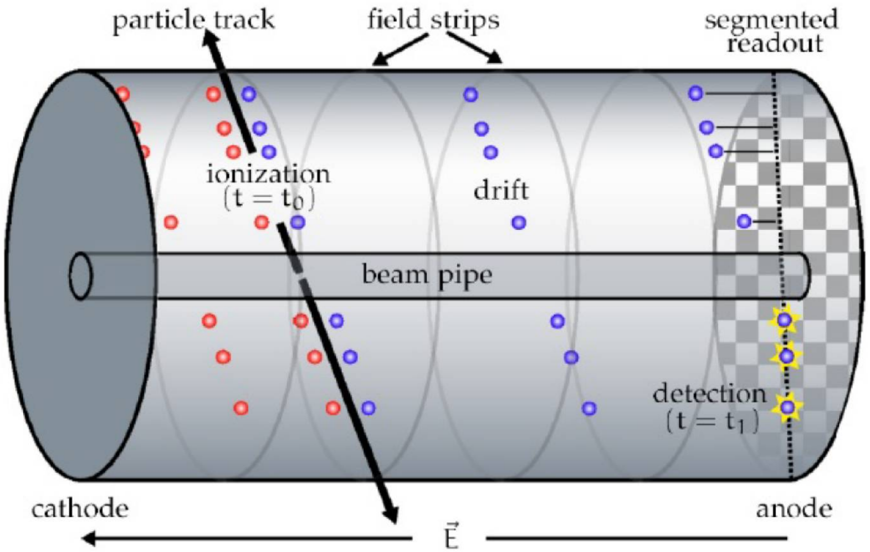

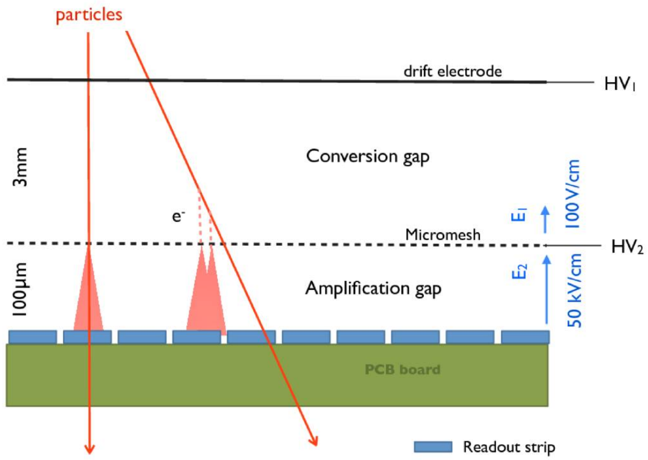

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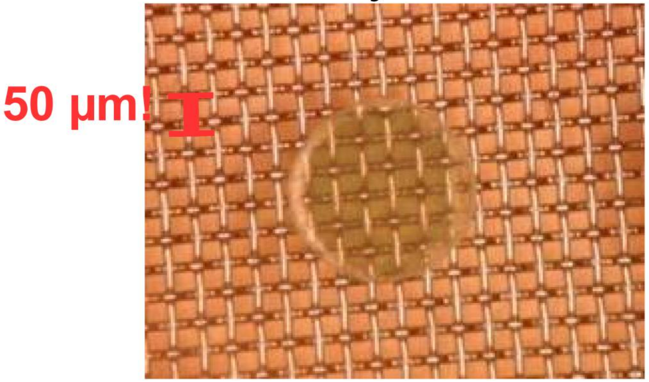


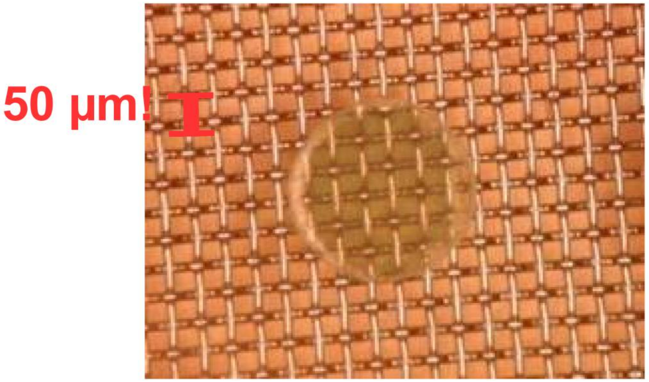
Motivation

MPGDs: very fine grained gas amplification structures

→ High intrinsic resolution, resolves single electrons from primary ionisations

→ Anode segmentation should not spoil this resolution

Traditional readout: pads with rectangular shape



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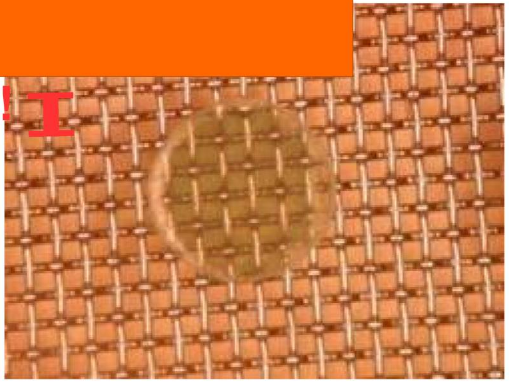
Pad 1x3 mm² to scale of mesh



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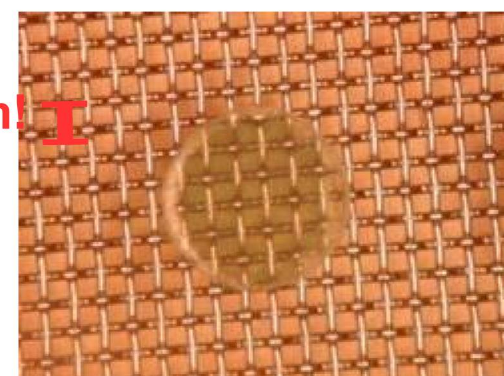
New approach: match readout segmentation to MPGD cell size

I ■ PIXELS

50 µm!



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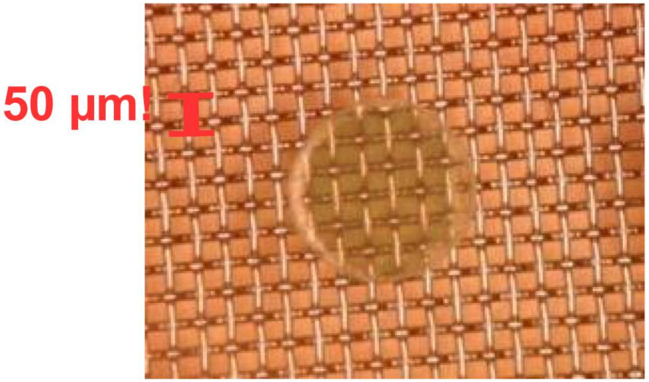
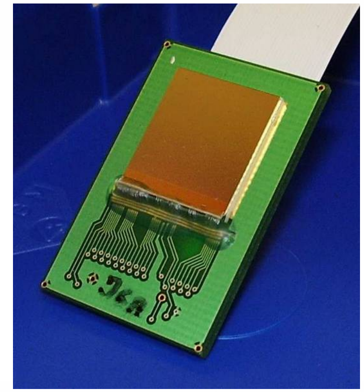
Use ASIC with charge sensitive pixels:

- Charge treated in analogue section
- Digital output
- High density electronics
- At best: include gas amplification stage → monolithic device

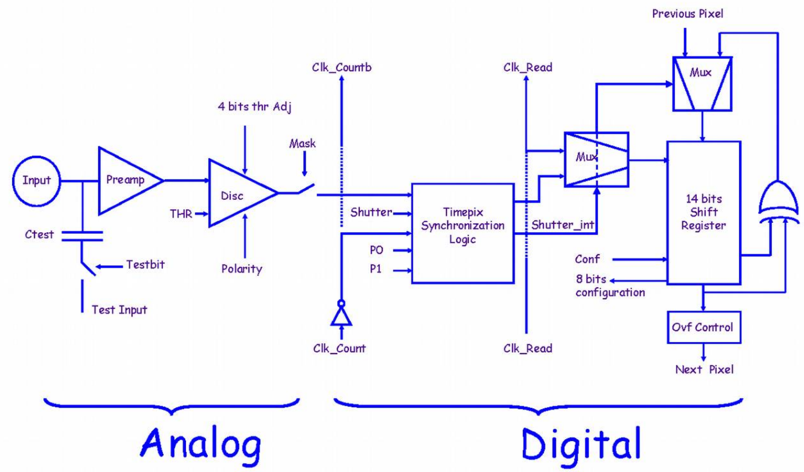


Basis: The Timepix ASIC

- Charge sensitive digital readout chip



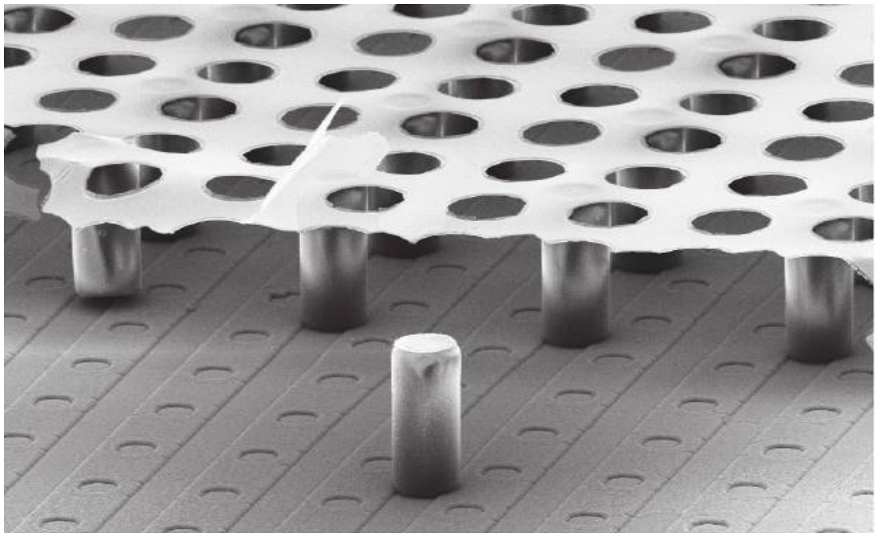
- Properties
  - 1.4 x 1.4 cm² active surface
  - 256 x 256 pixel matrix
  - CMOS 250 nm technology, IBM
  - 55 x 55 µm² per pixel
  - Amplifier, discriminator in each pixel
  - 14 bits count clock cycles
    → TOT(charge) or TOA(arrival time)
  - clock up to 100 MHz in every pixel
  - threshold level ~ 500 e^- (90 e^- ENC)



- Use bump bond pads as readout anode in gaseous detectors

Timepix+Micromegas=InGrid

- Aluminium mesh on chip
  - Hole to pixel alignment
  - Pillar height uniformity



- Use photolithographic process
  - Pioneered and optimised by NIKHEF and University of Twente
  - Production on single chip basis → monolithic device

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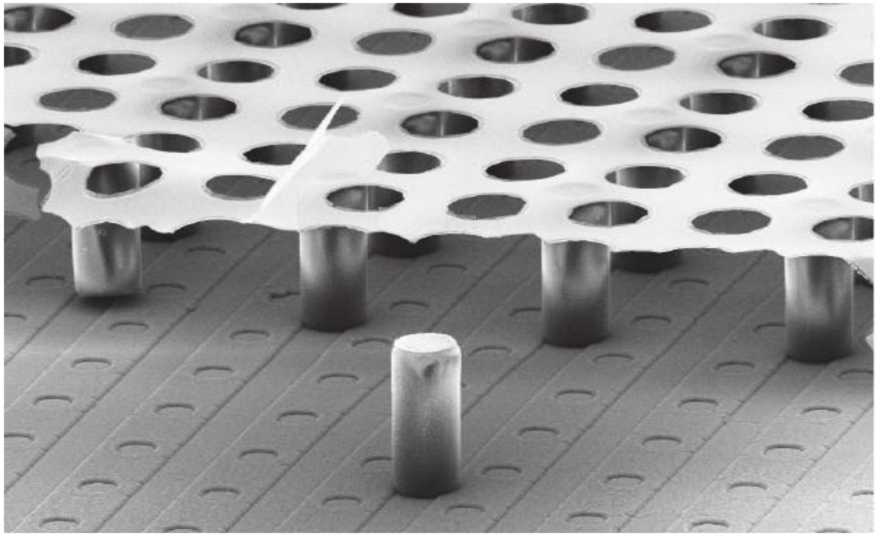

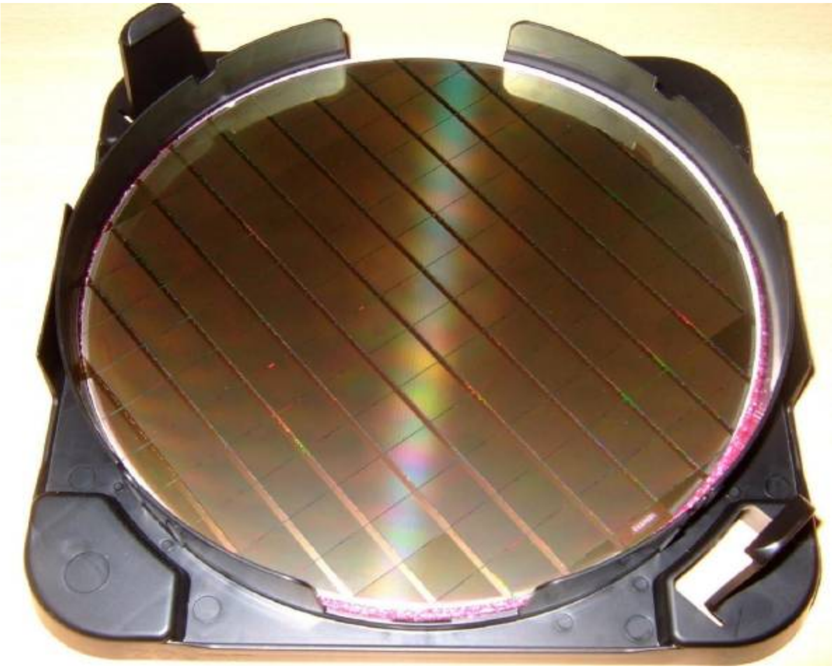

- Use photolithographic process
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  - Production on single chip basis → monolithic device
- High demand for InGrid chips:
  - R&D groups
  - Equipment of larger surfaces → Production on wafer scale
- Wafer processing at IZM Berlin

Pixel-TPC

Idea: Equip endplate of TPC with InGrids

- Problem: InGrid: 2cm², TPC endplate: 10m²

  → Need many InGrids

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  → Demonstrator:
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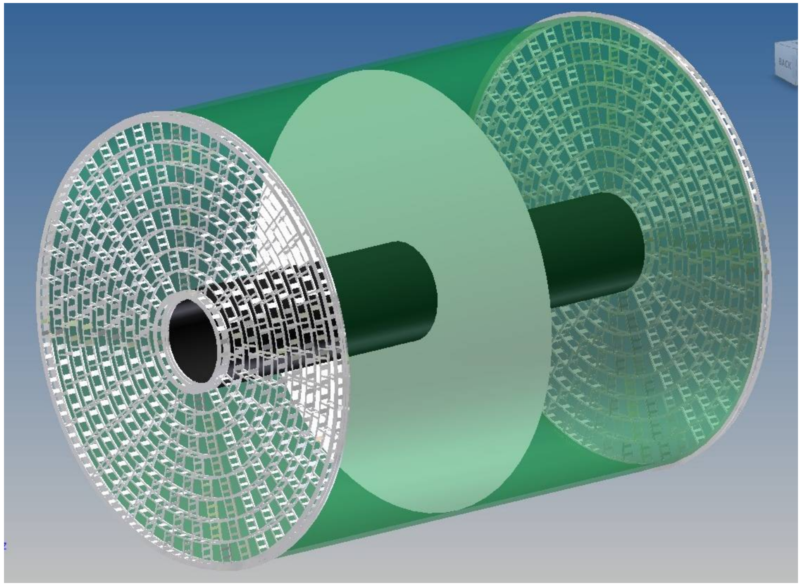

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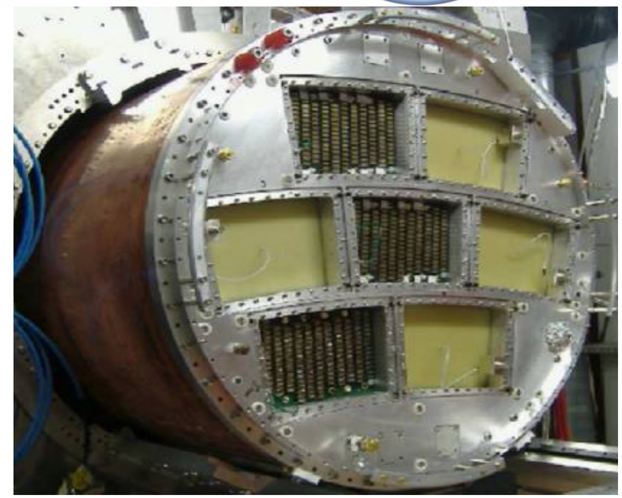
- Test beam site: DESY II synchrotron
  LCTPC large TPC prototype
  - Endplate for 7 ILD like modules
  - 56 cm drift, diameter: 75 cm
  - 1 T magnet
  - Movable stage
  - e^- beam up to 6 GeV



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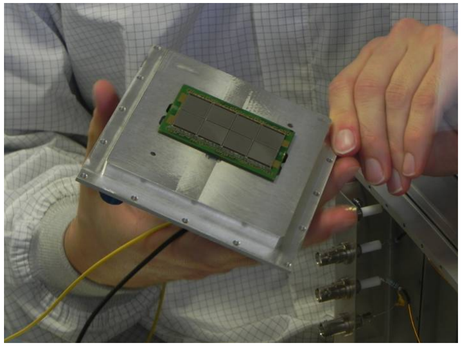
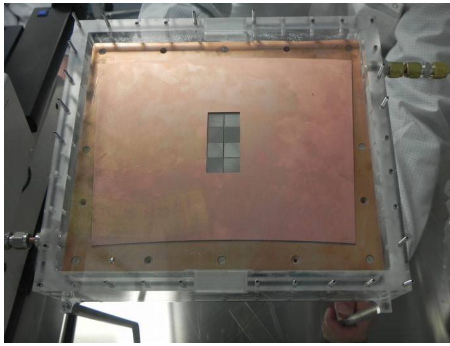
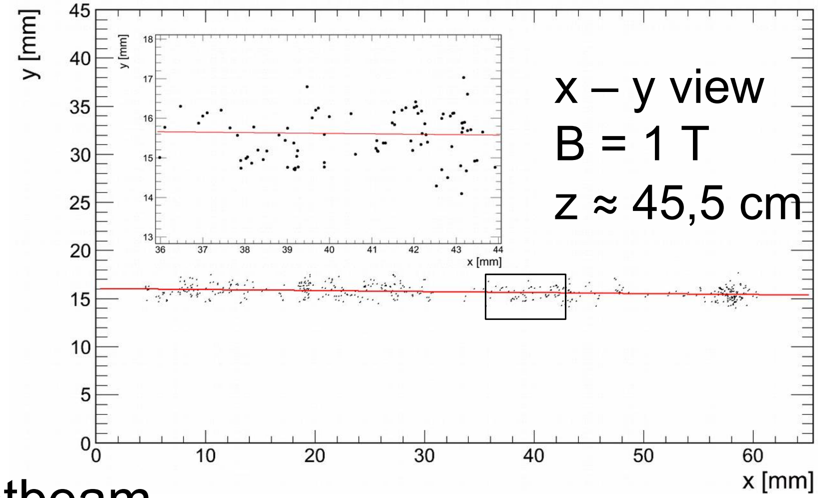
  - e^- beam up to 6 GeV
- Intermediate step (2013): 8-InGrid testbeam
  → successful, learned a lot



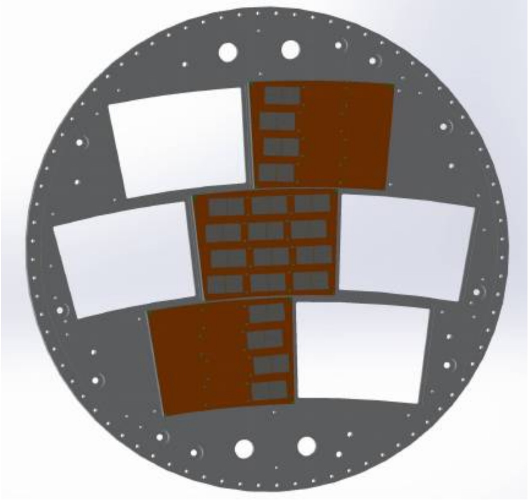




2015 test beam

The Pixel-TPC demonstrator

- 160 InGrids on 3 modules
  → 10.5 mio. channels
- Dedicated power supply
- Water cooling
- Full, fast, reliable readout system



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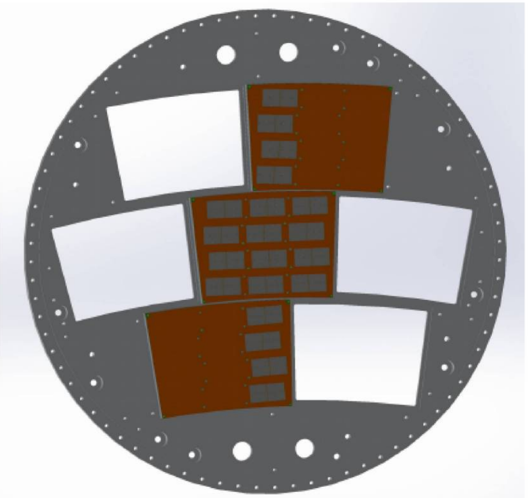
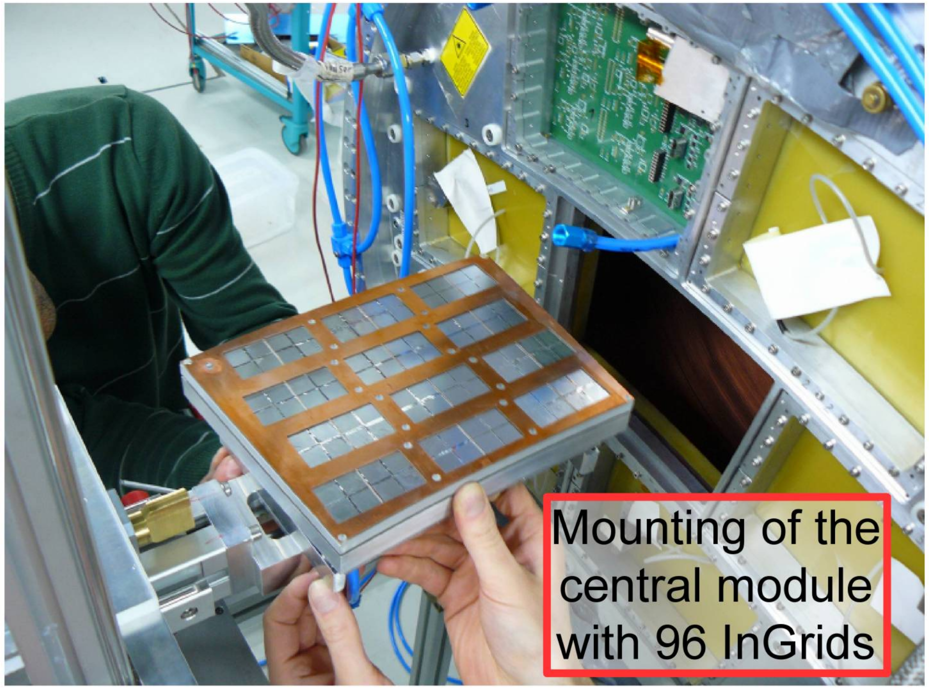
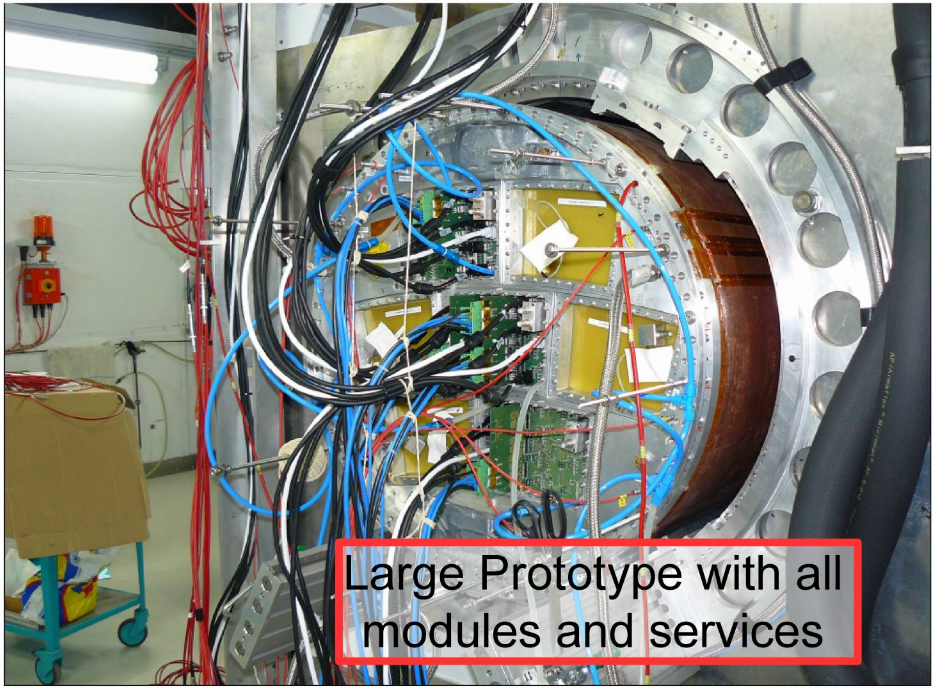




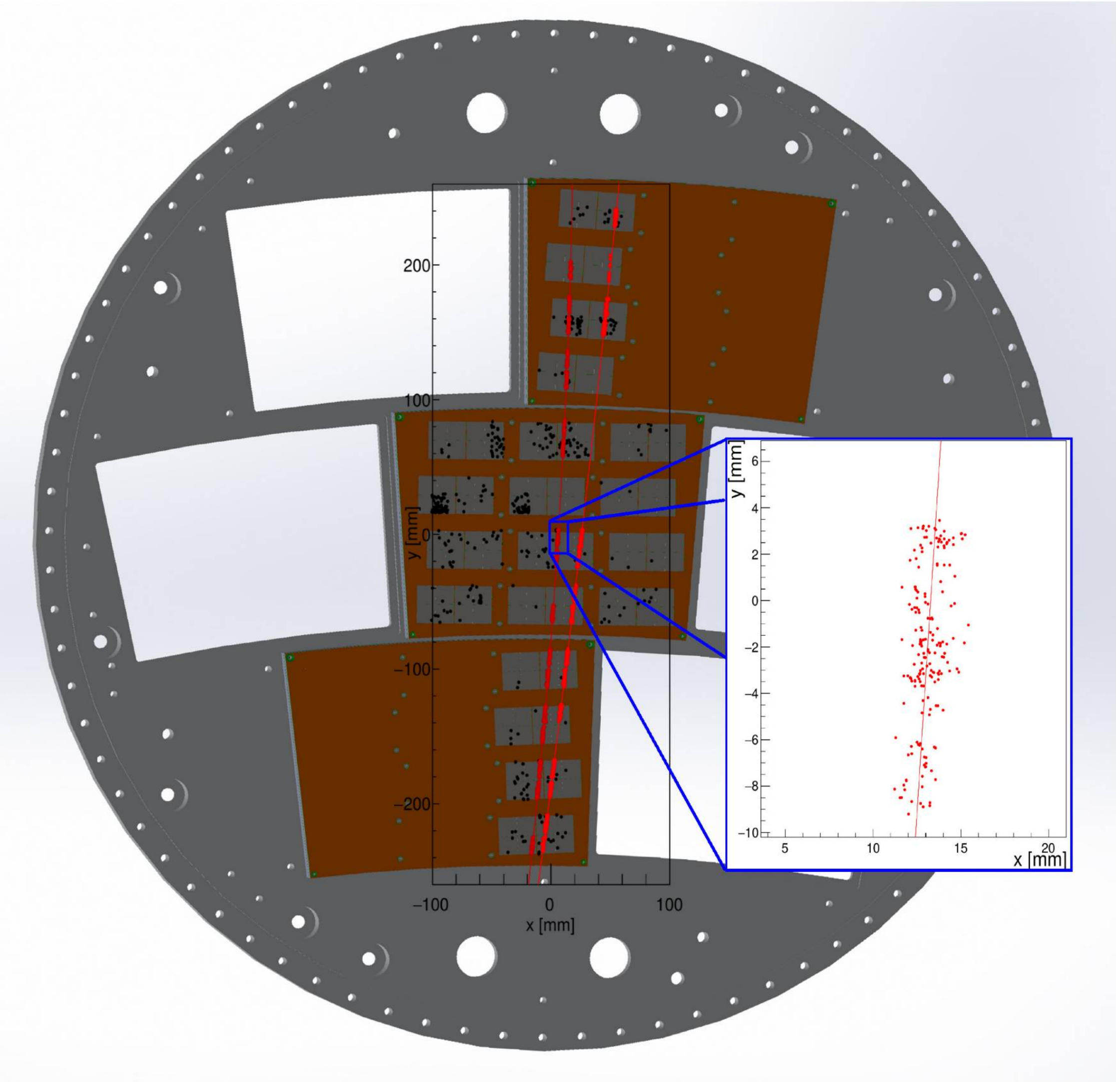
Mounting of the central module with 96 InGrids



Large Prototype with all modules and services

Test beam results

CAD drawing of endplate with reconstructed double track event



50 cm track length with about 3000 hits, each representing an electron from the primary ionisation.

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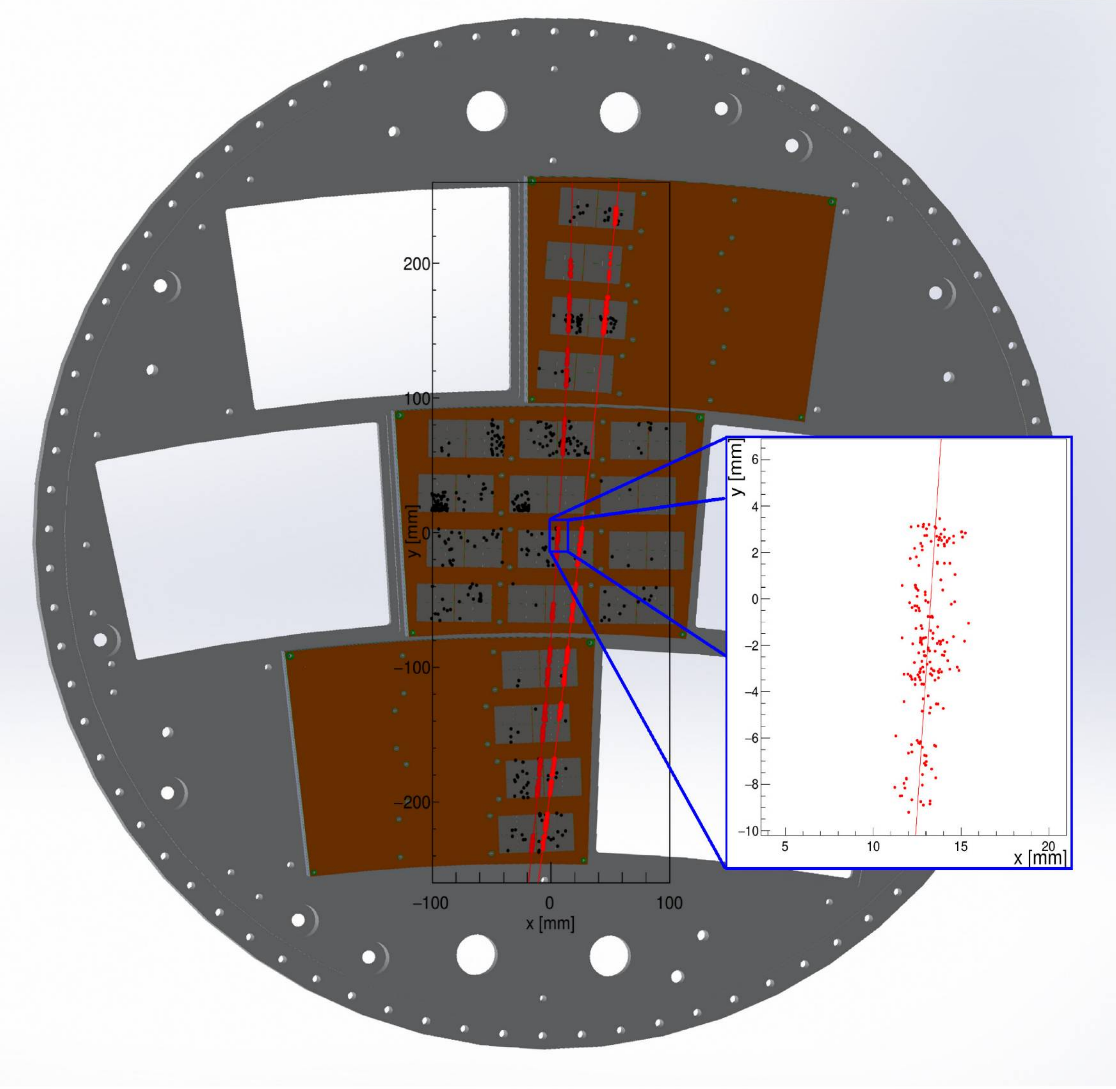

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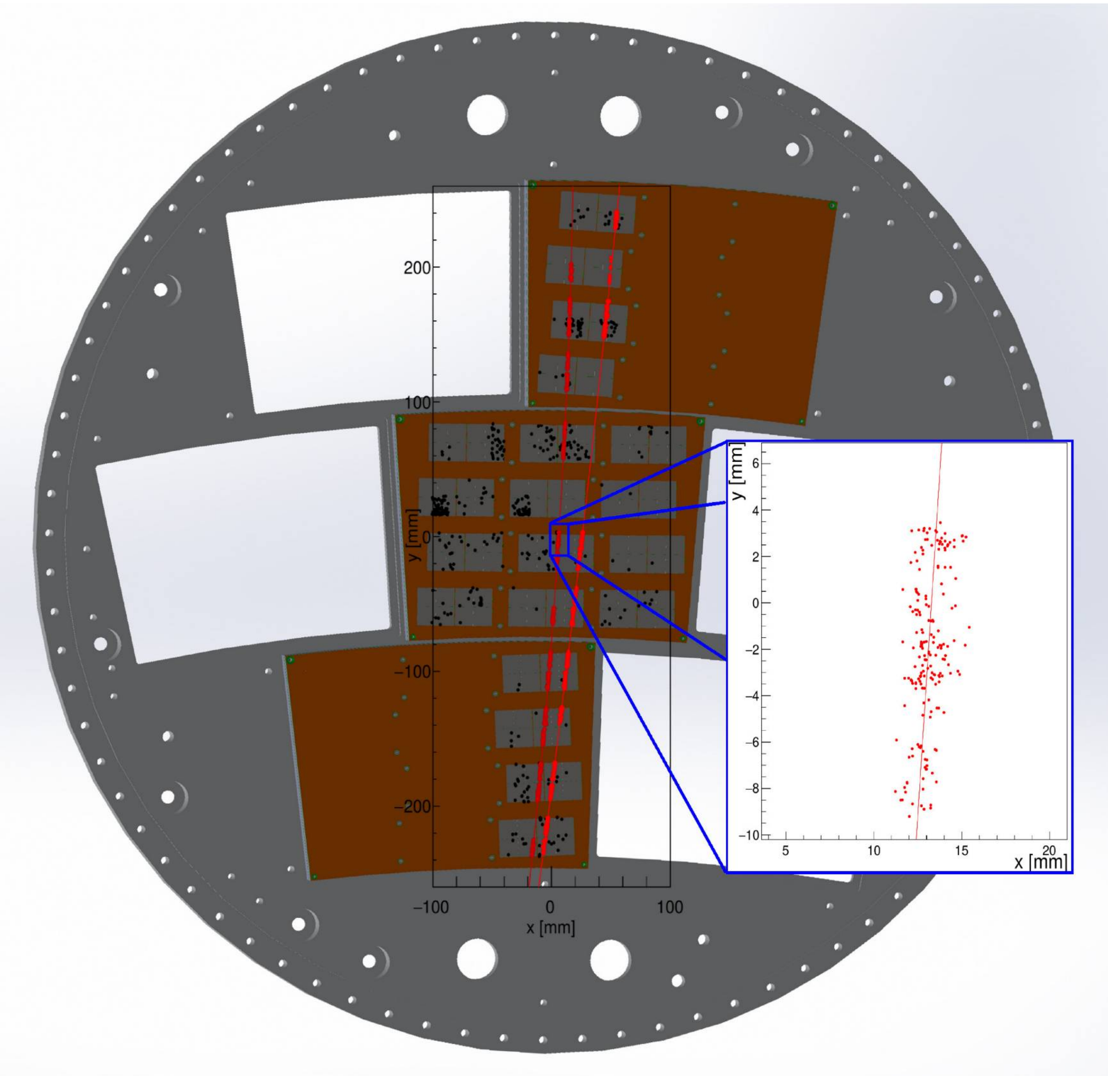

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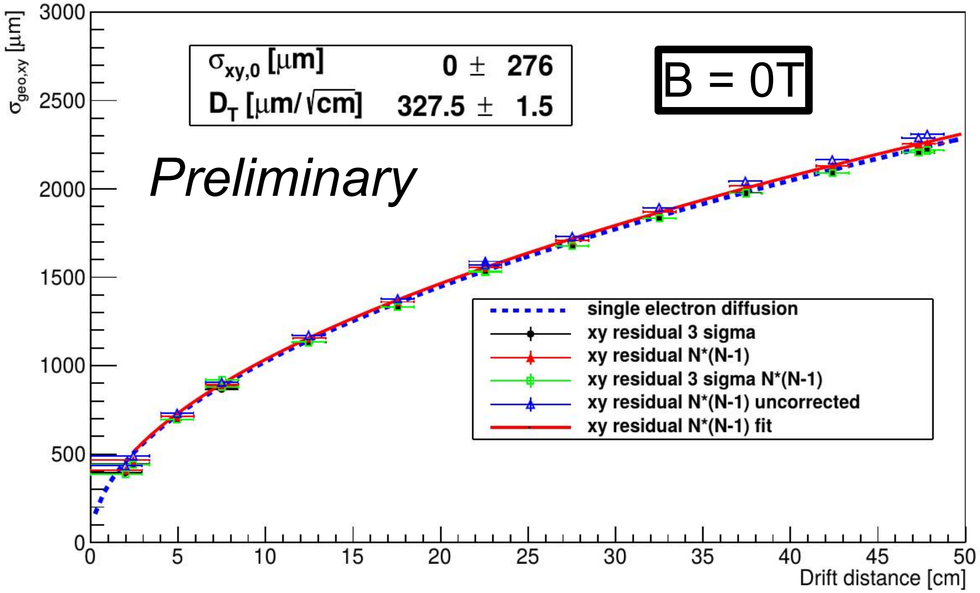
→ preliminary analysis:

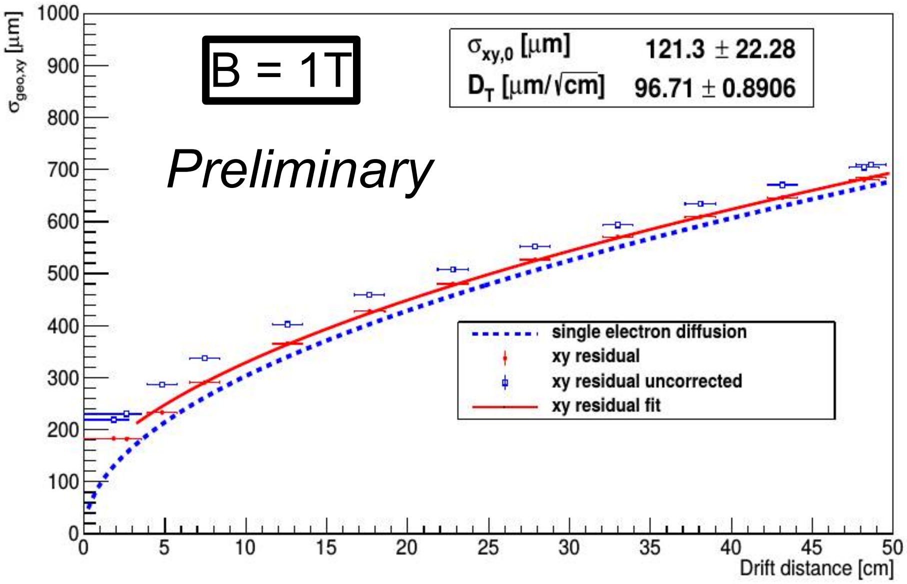
- Drift velocity
- Field distortions
- dE/dx resolution
- Single point resolution
- Track angular effect

Test beam results

Spatial resolution:

In x-y plane, from residuals





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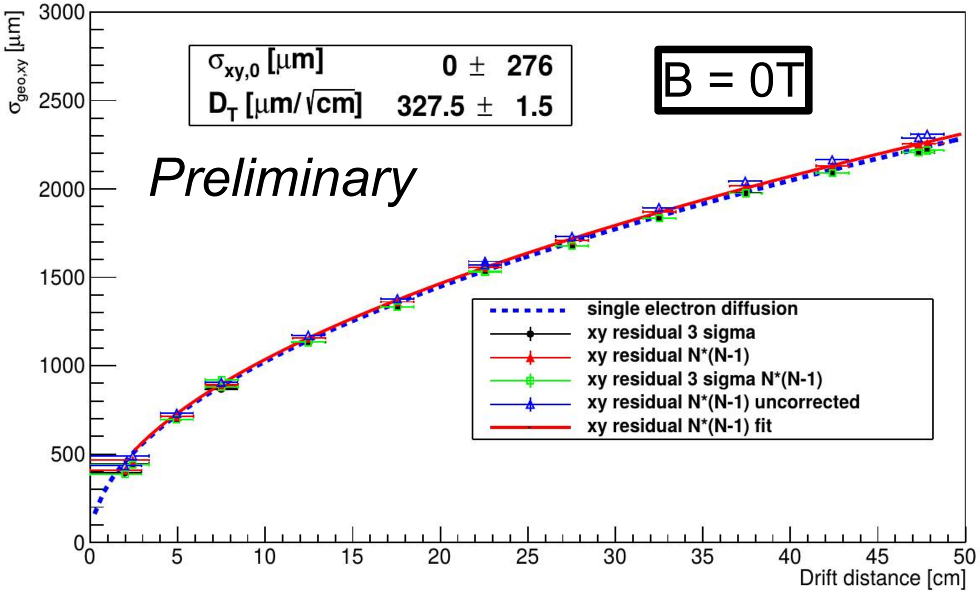
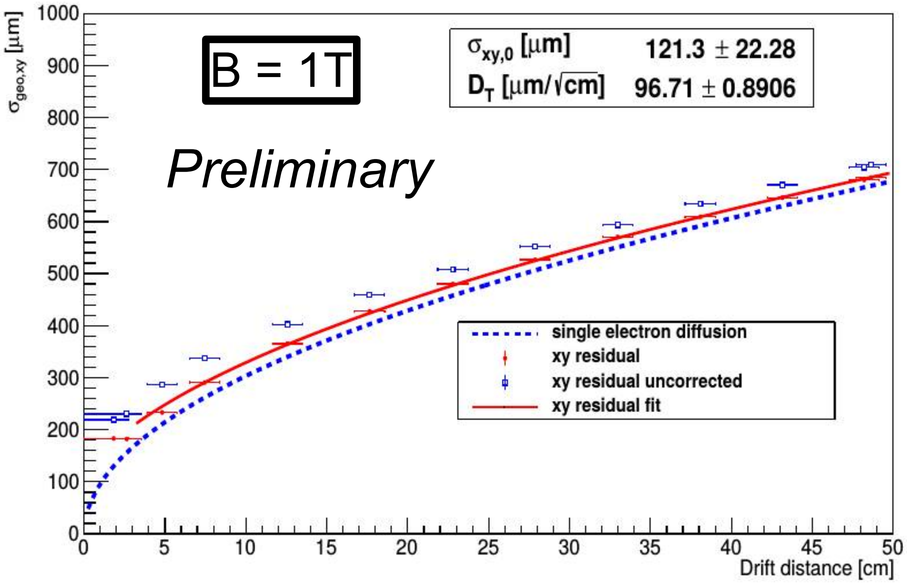




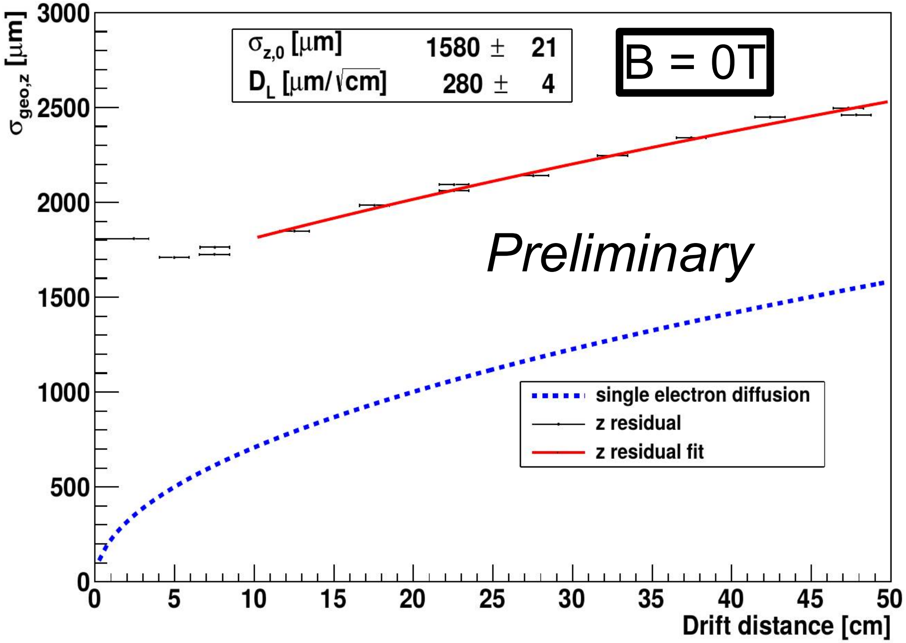
Transverse spatial resolution follows diffusion of single electrons.

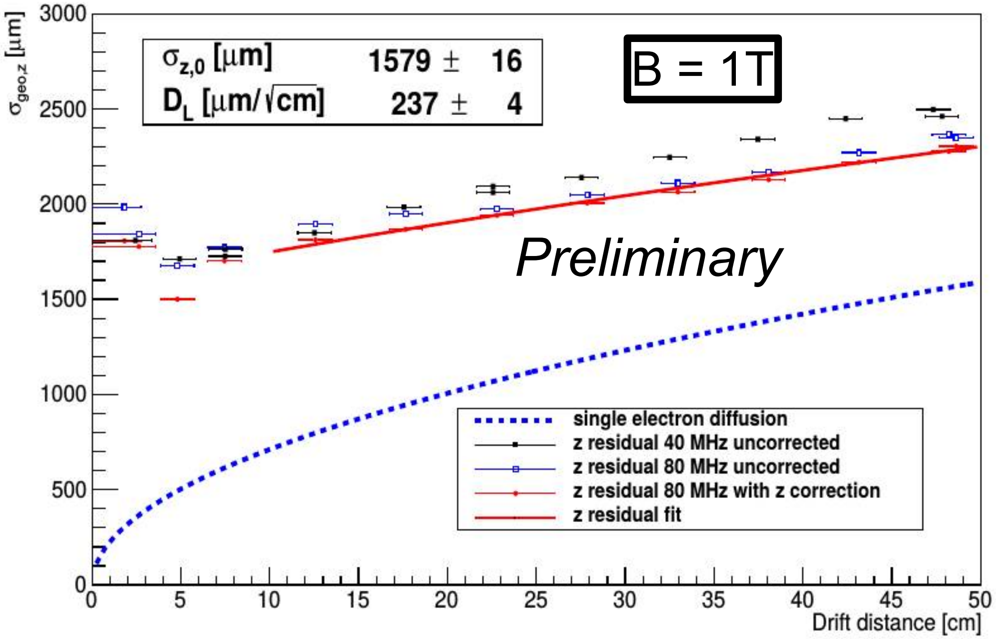
Reconstructed diffusion constants in agreement with simulations.

Test beam results

Spatial resolution:

In z-direction, from residuals





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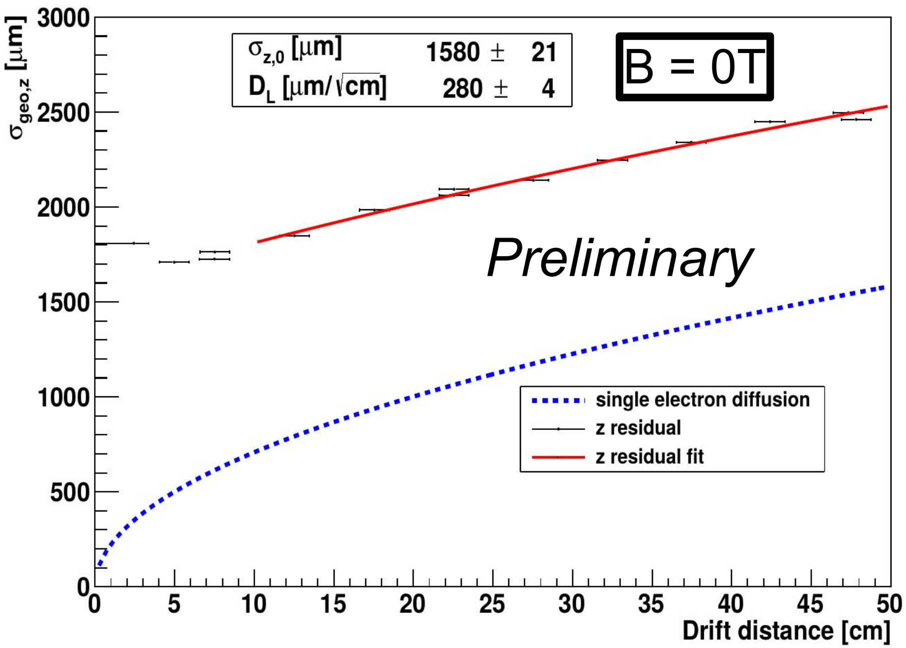
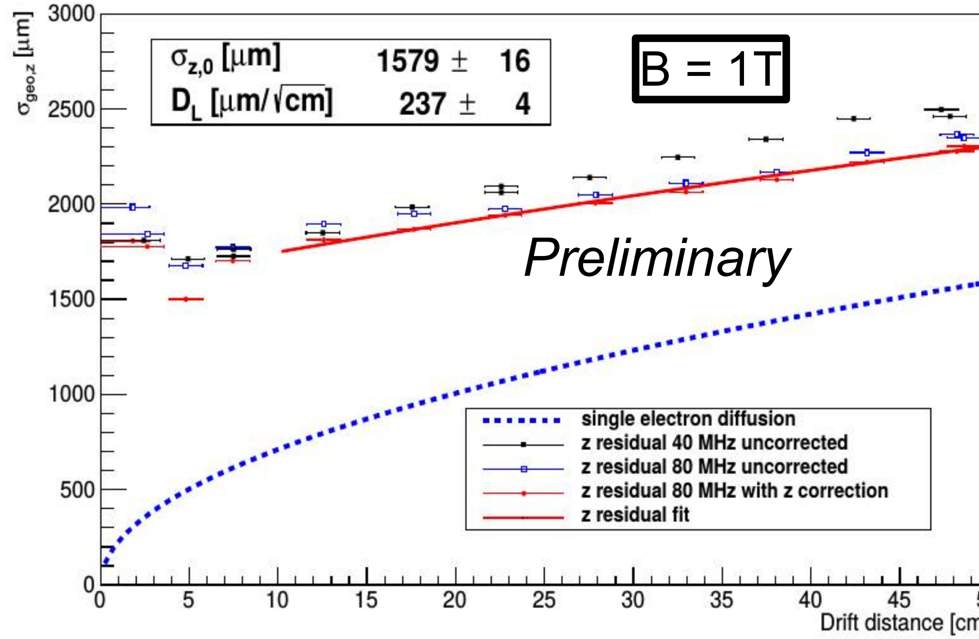




Longitudinal spatial resolution differs from diffusion of single electrons.

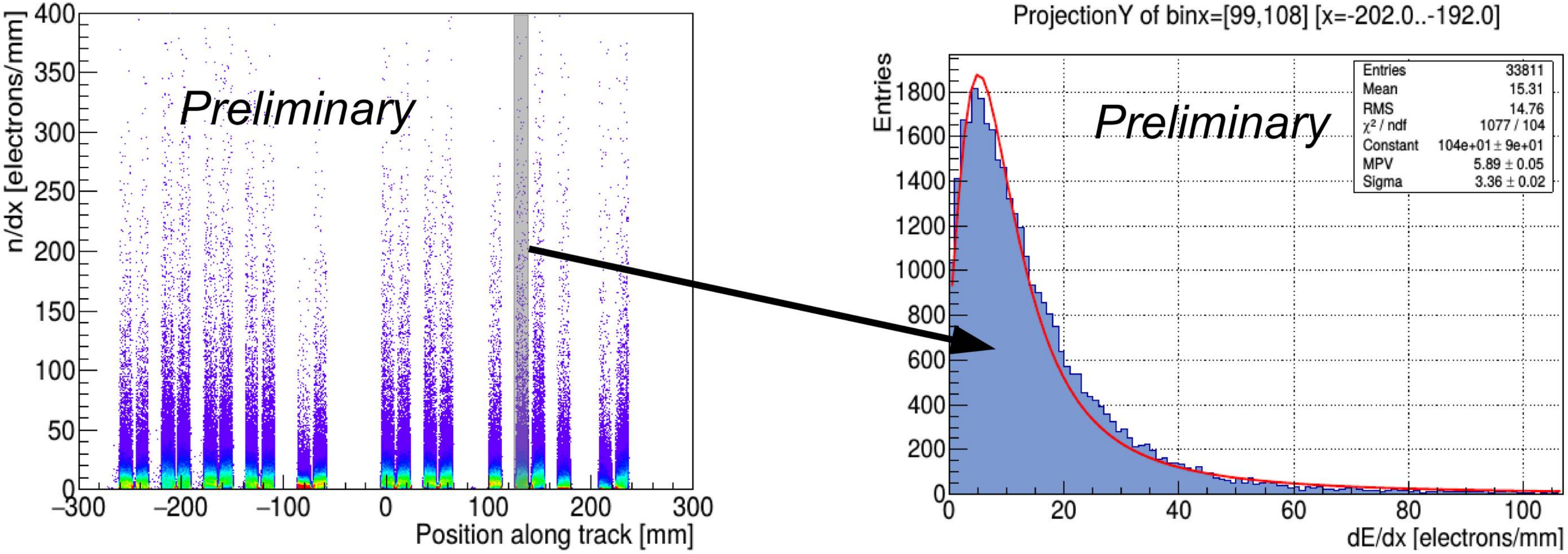
Reconstructed diffusion constants not in agreement with simulations.

Many degrading effects: Time walk, low time resolution, field distortions

Test beam results

Energy loss resolution:

Use thin slices of 1mm track length, count number of hits (primary electrons)



Landau like distribution when hits in a 10mm interval of chip centre is projected

Test beam results

Energy loss resolution:

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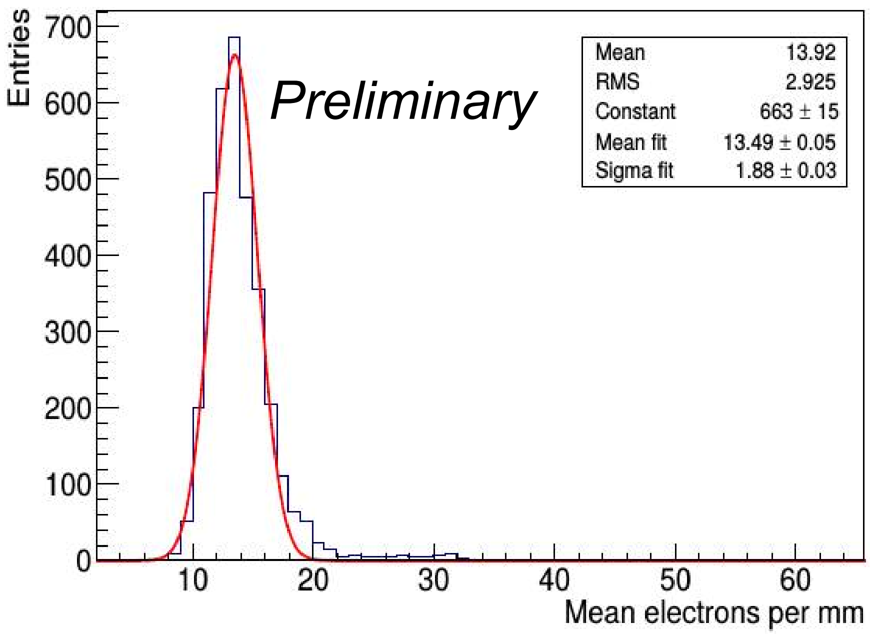
Plot average number of hits for all tracks of a run → measure for dE/dx



Mean number of hits in intervals of 1 mm along the track with a resolution of (14.0 ± 0.3) % in the peak fitted by a Gaussian distribution.

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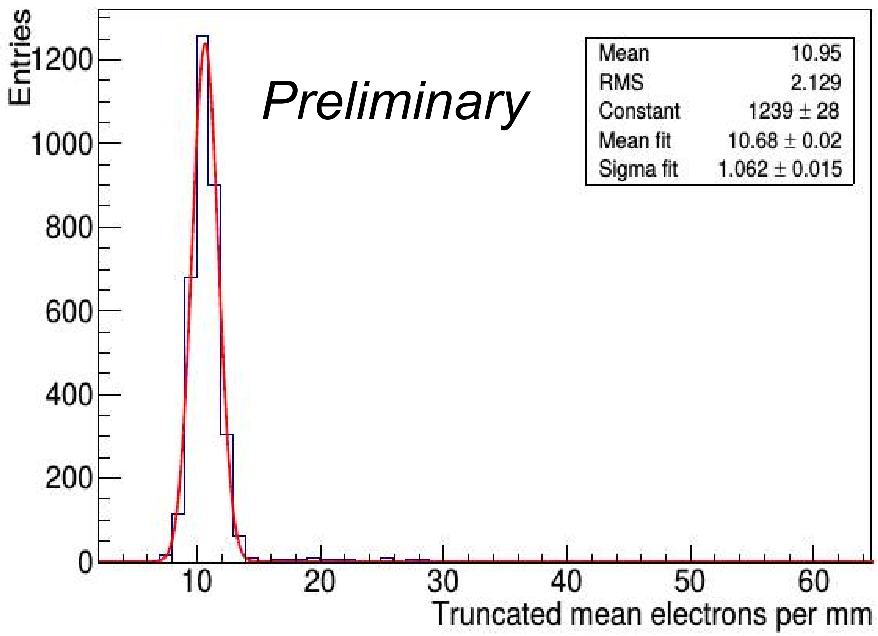


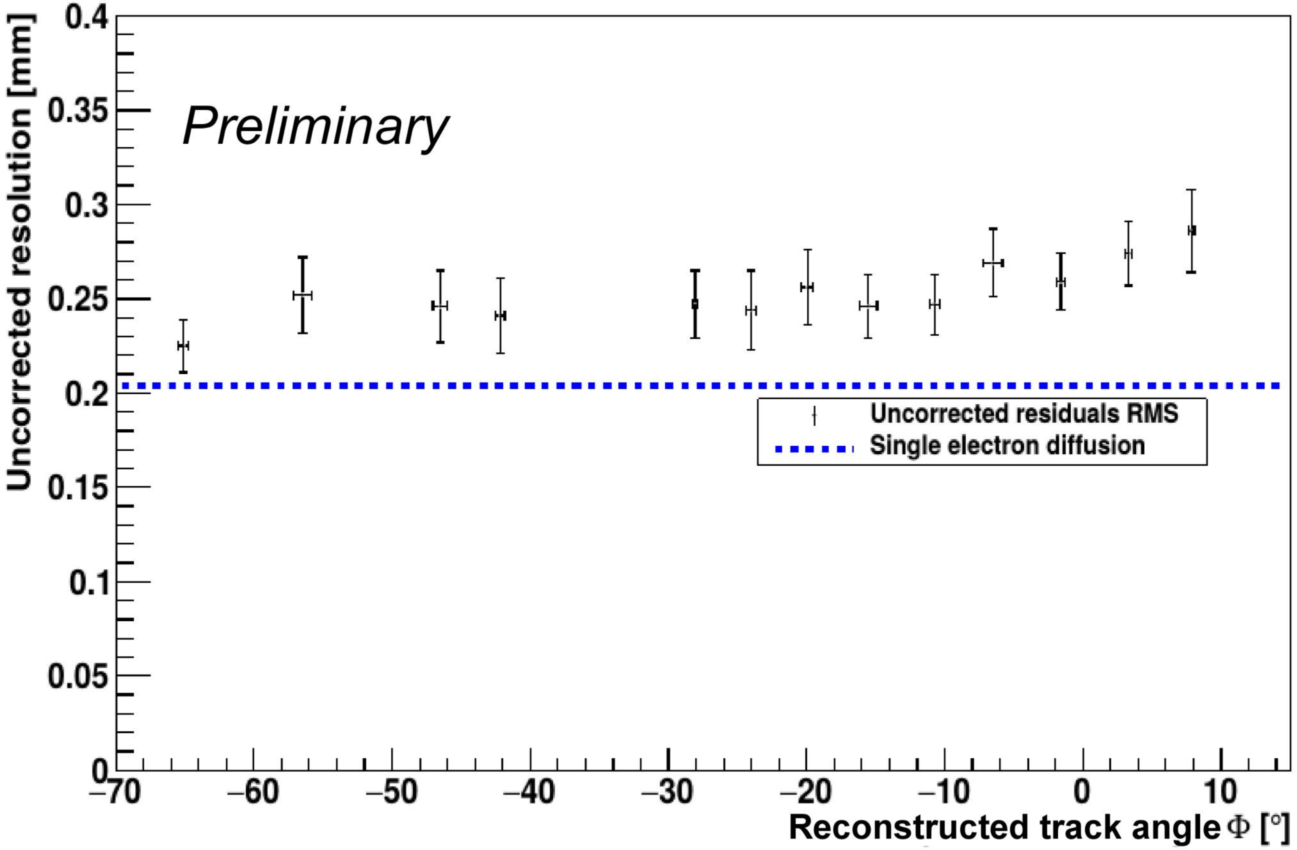
Truncated mean (reject 5% highest, 5 % lowest means) number of hits in intervals of 1 mm along the track with a resolution of (9.9 ± 0.5) % in the peak fitted by a Gaussian distribution.

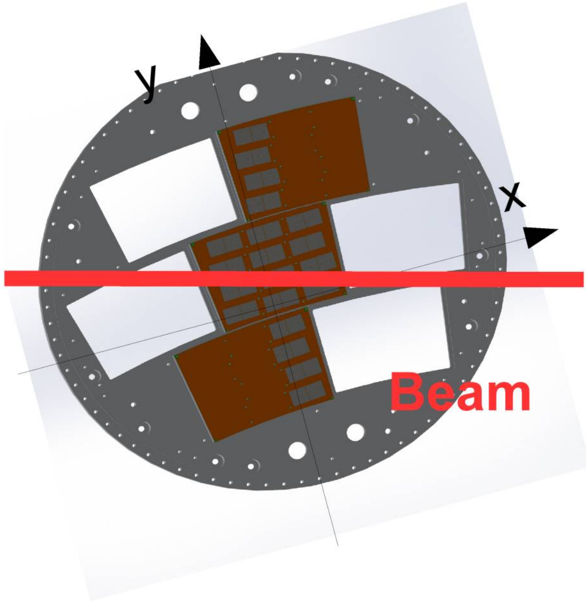
Expected: 7.57 % → 31 % off/room for improvement

Still: When extrapolated to full ILD TPC 5.71% could be achieved (4.36 % expected)

Test beam results

Single point resolution of the detector for different track angles with respect to the y-axis (= rotation of the endplate with respect to the beam-axis)





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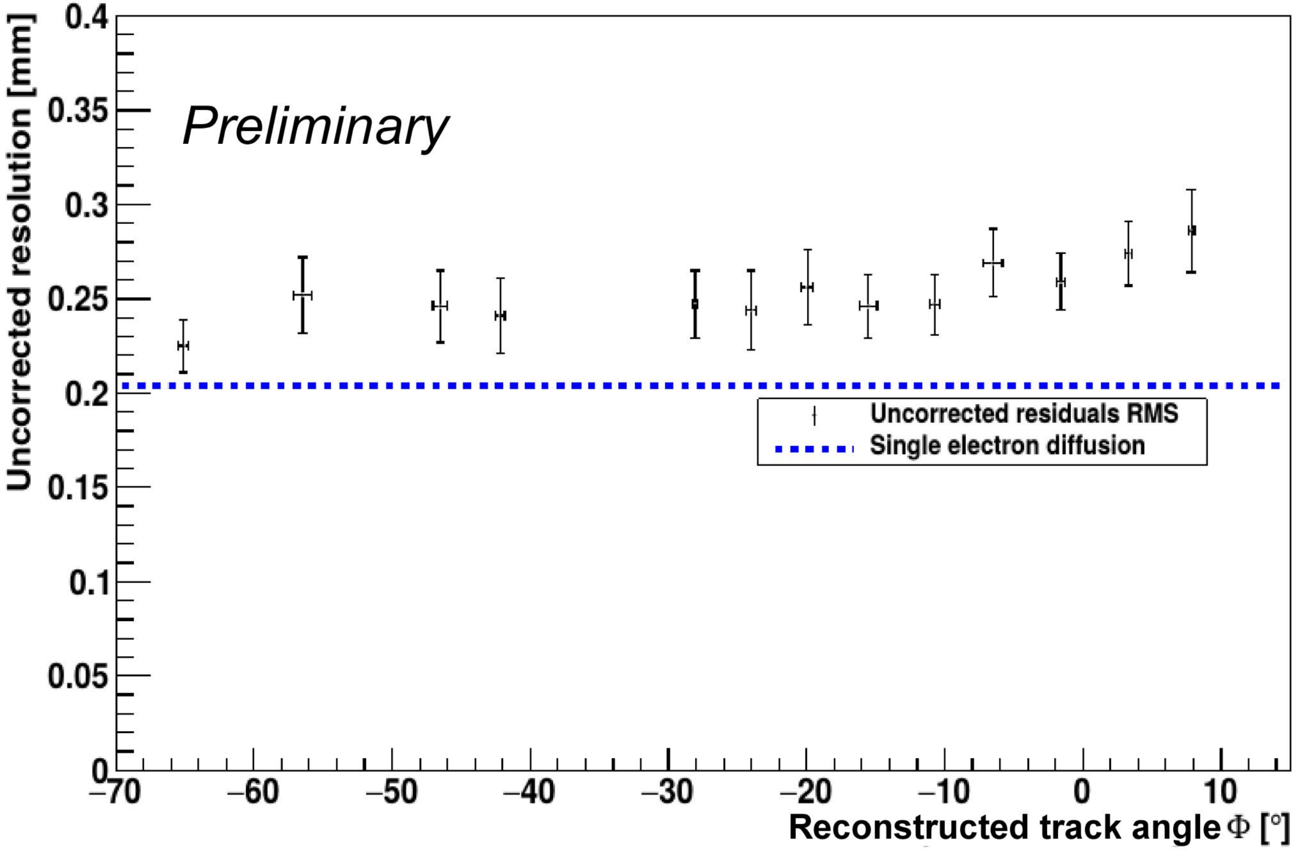
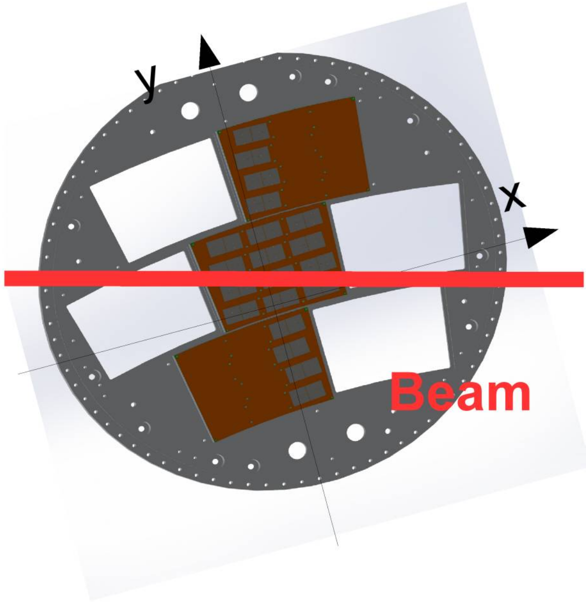
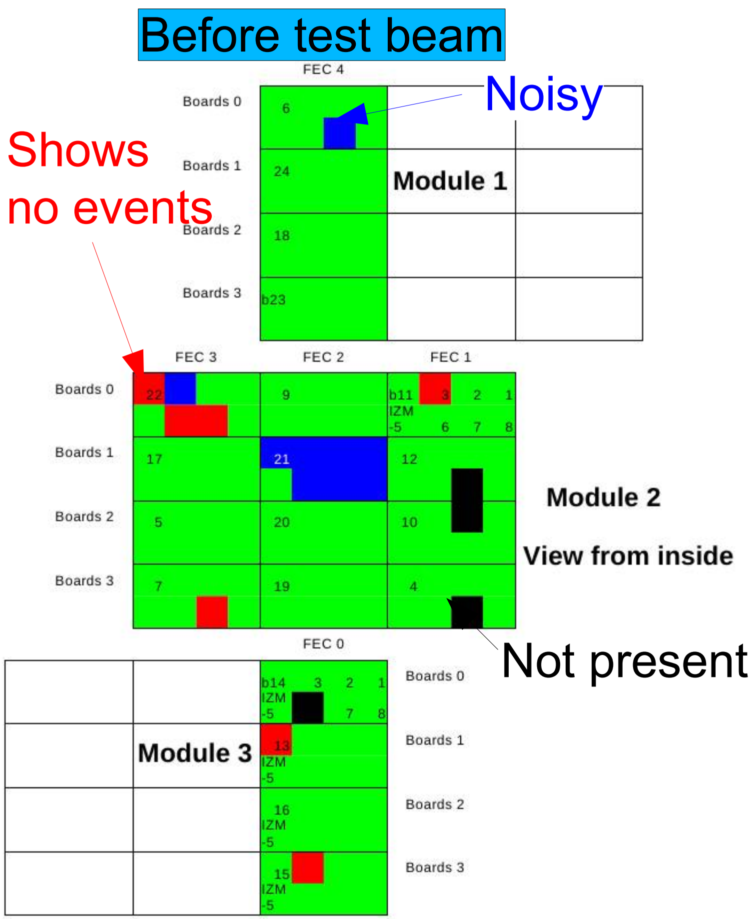




As expected for Pixel-TPC, no dependence was observed.

Reliability of chips

Not functioning chips



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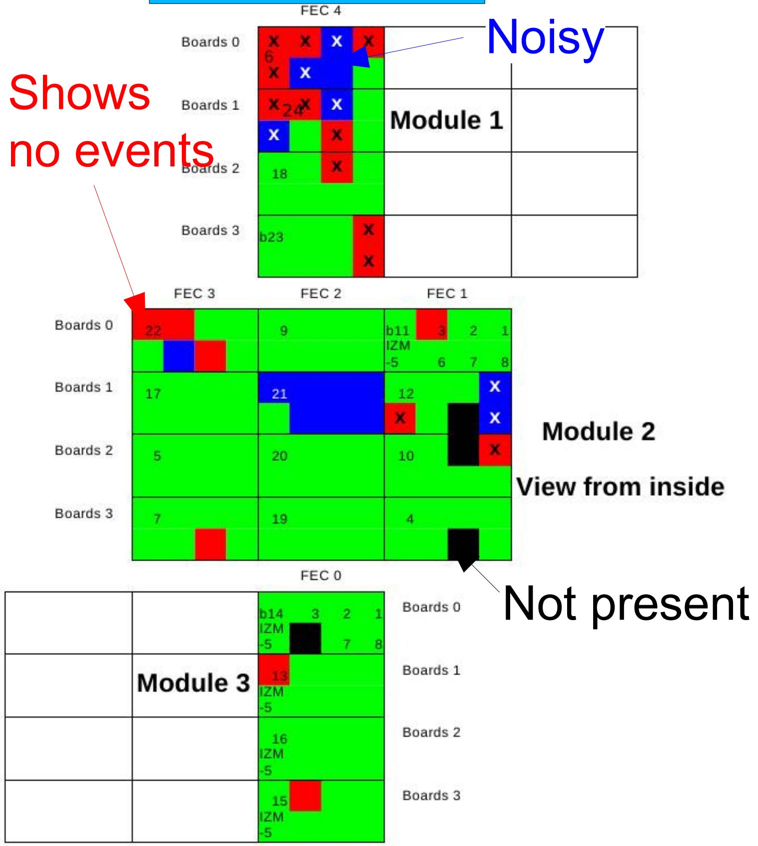
Not functioning chips

x: additional dead/noisy

After test beam



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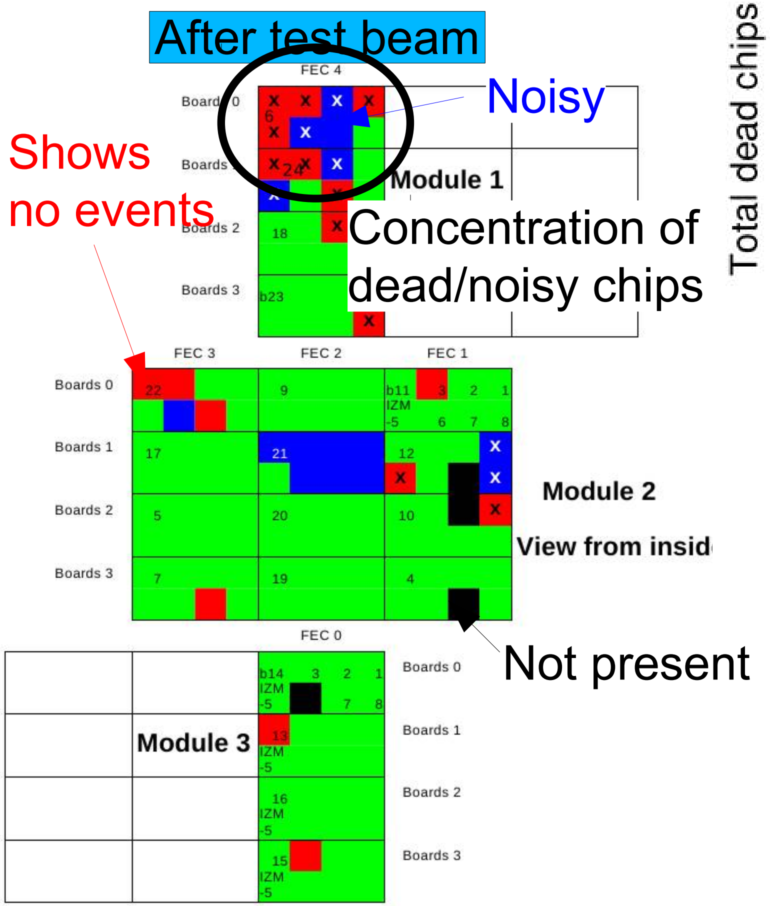

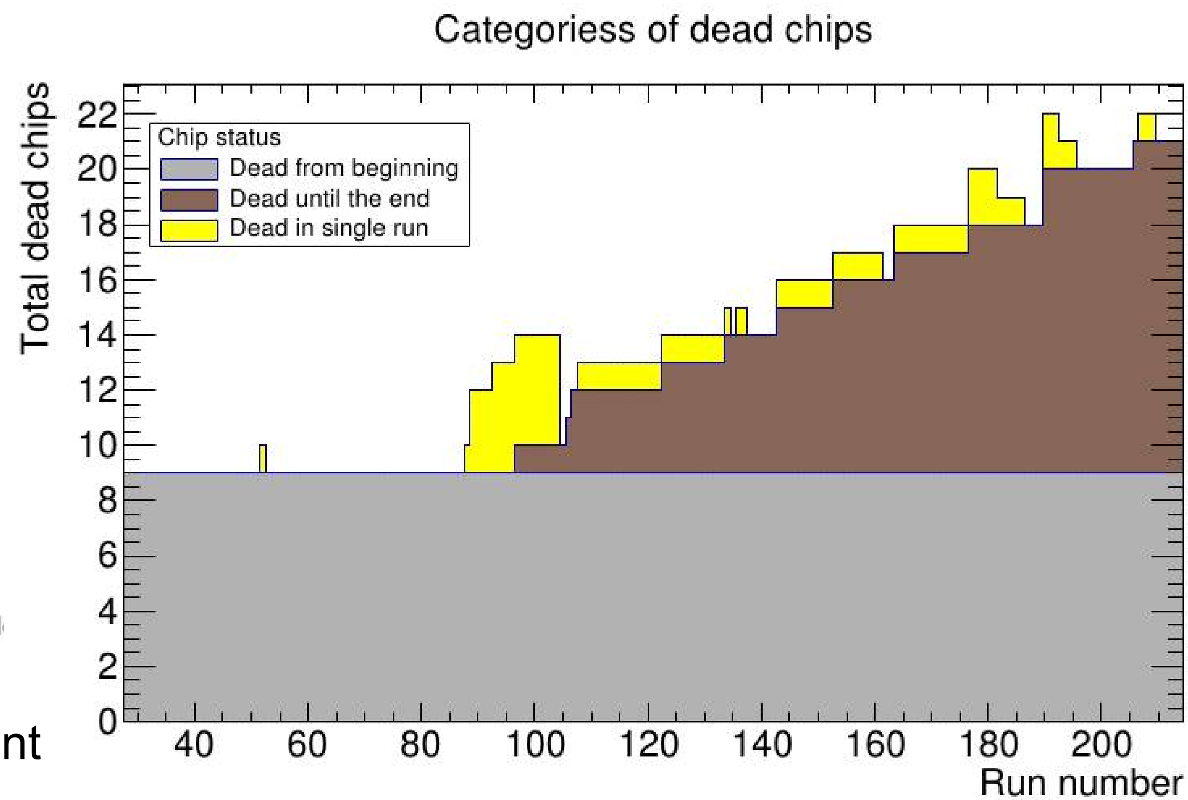

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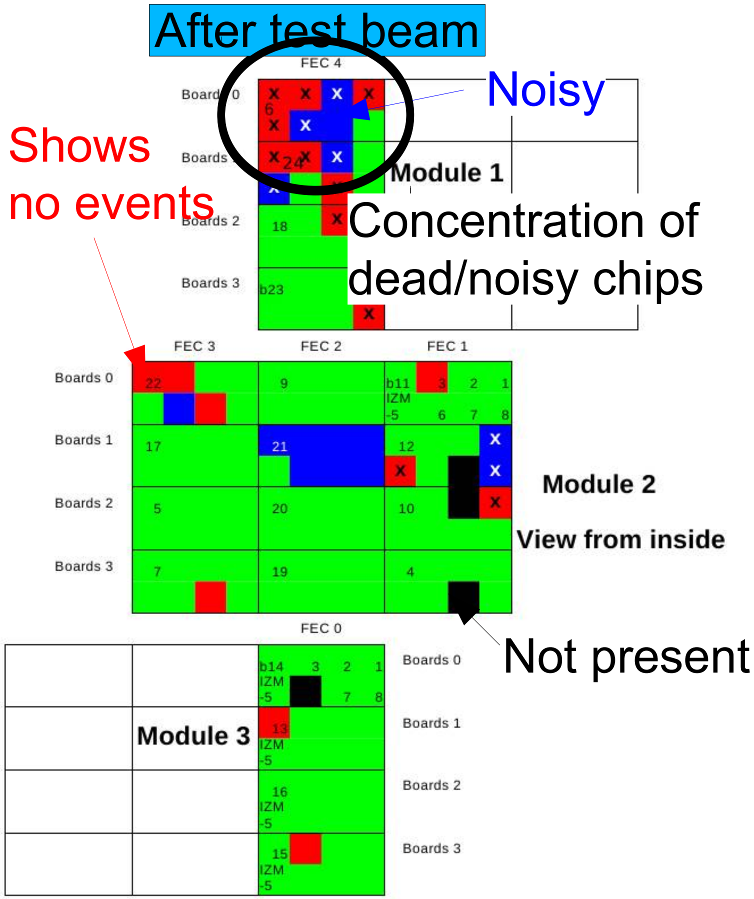
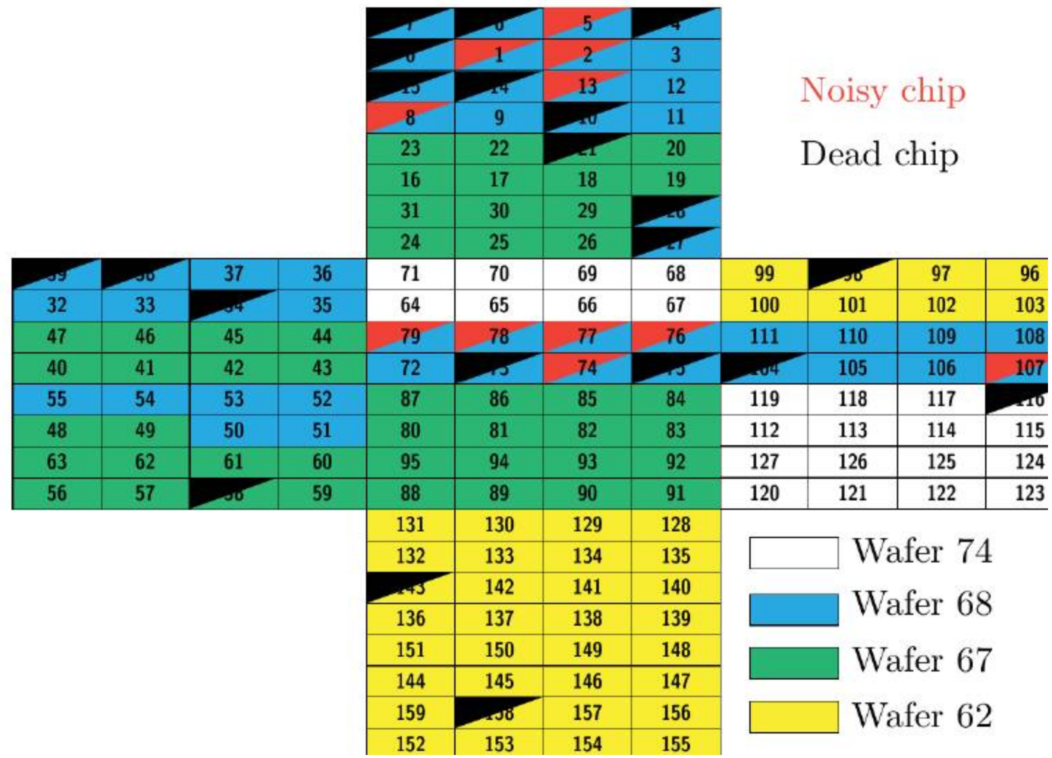


Correlation with wafer number



Taking into account chips which have to be replaced during production:
W62: 12% bad, W67: 30% bad,
W68: 60% bad, W74: 35% bad

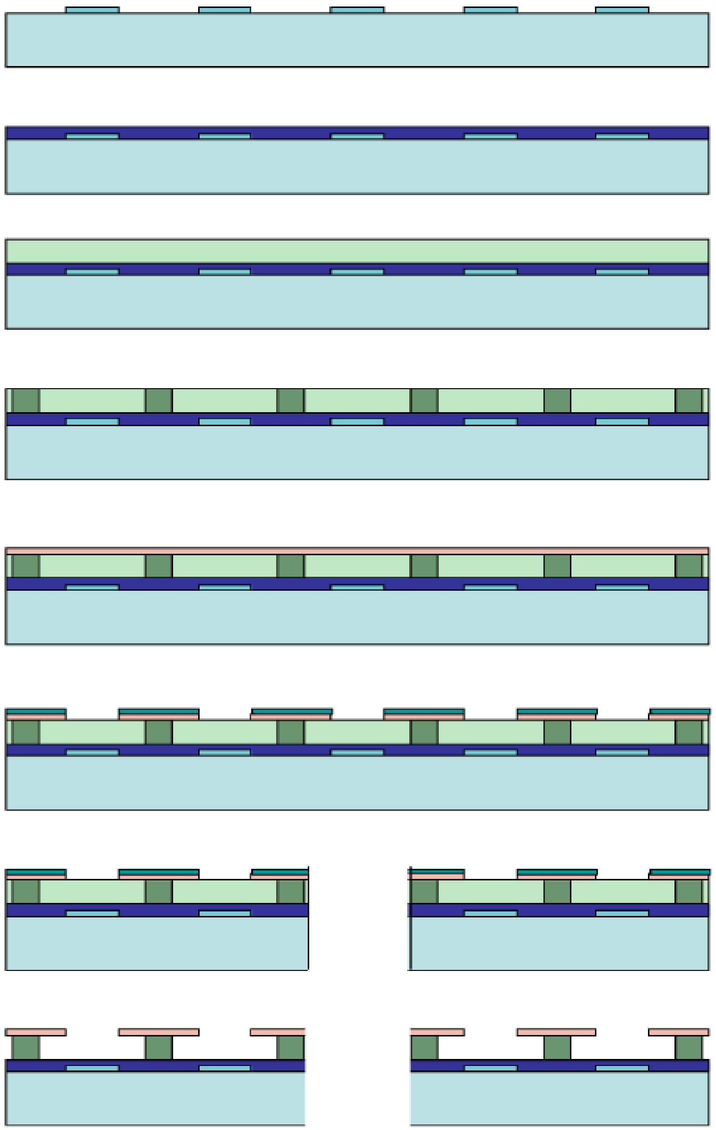
Summary

- Combination of MPGDs with pixel ASIC can improve detector performance
- Pixel-TPC: Many monolithic pixelised gaseous detectors at endplate
- R&D for a demonstrator module: successful test beams 2013 and 2015
- Test beam 2015: Demonstrator with 160 InGrids on 3 modules
  - Preliminary results from analysis: excellent single point resolution (independent of track angle), excellent dE/dx resolution
  - Uncorrected field distortions degrade some results

→ Feasibility of Pixel-TPC has been proven!

Further R&D especially for reliability of InGrids needed.

Production on wafer scale



1) Probing and cleaning of the wafer
2) Adding $Si_x N_y$ protection layer
3) Application of the SU-8
4) UV-Exposure of the SU-8
5) Application of the grid
6) Patterning of the grid
7) Dicing of the wafer
8) Development of the SU-8

Data analysis

MarlinTPC & LCIO

Modular Analysis & Reconstruction for the Linear Collider

- Developed within the LCTPC collaboration
- Data processing is highly modular
- Each algorithm is encapsulated in a processor
- Unified data model LCIO is used
- Sequence and parameter of individual processors are defined in a XML steering file

Data analysis

1. Data cleaning (noisy chips, not properly functioning chips)
2. Drift time spectrum analysis → drift velocity

Data analysis

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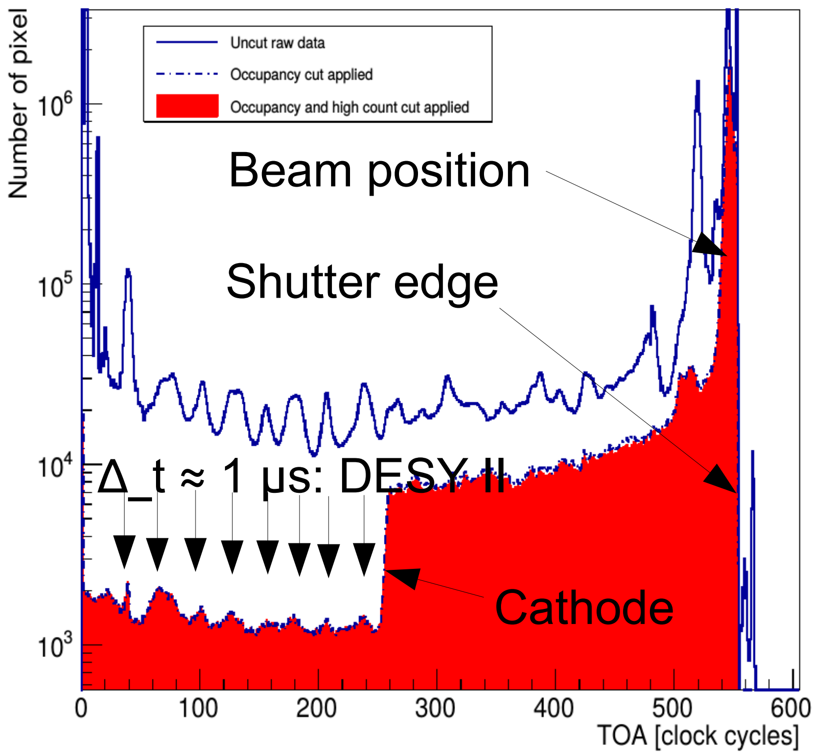

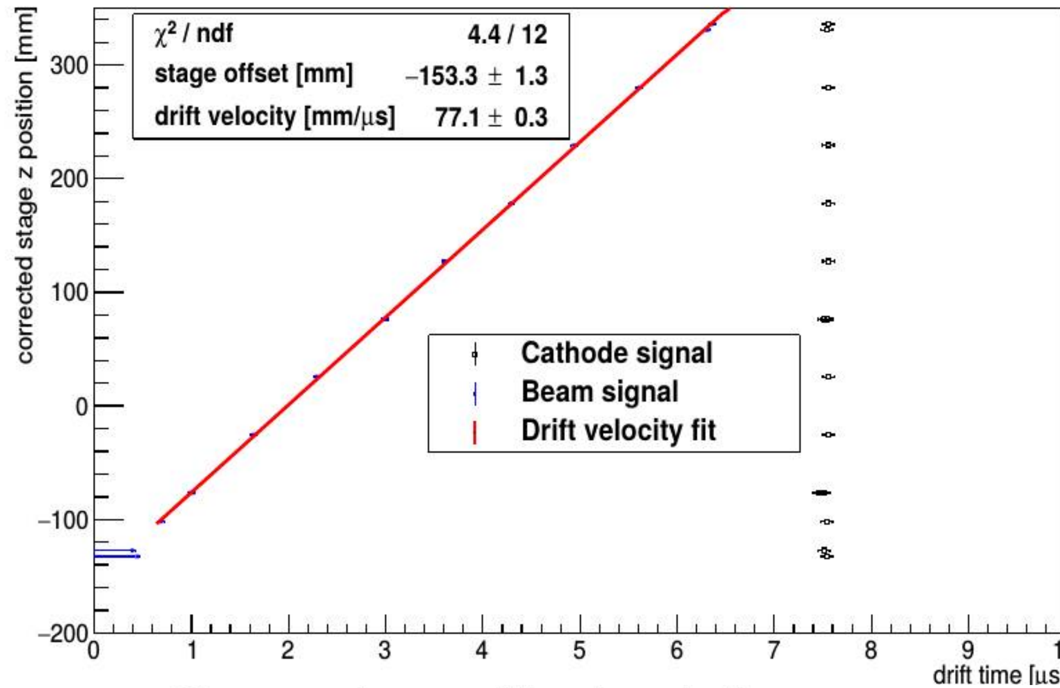

Comparison with simulation:

Condition	Simulation	Measurement
E=130 V/cm, B= 0T	5.64±0.01 cm/μs	5.50 ±0.08 cm/μs
E=230 V/cm, B= 0T	7.64±0.01 cm/μs	7.56 ±0.1 cm/μs
E=230 V/cm, B= 1T	7.64±0.01 cm/μs	7.55 ±0.09 cm/μs

Data analysis

1. Data cleaning (noisy chips, not properly functioning chips)
2. Drift time spectrum analysis → drift velocity
3. Track reconstruction
    a) straight tracks
    b) curved tracks
4. Physics properties analysis