TPC Readout with TimePix + 3GEMs

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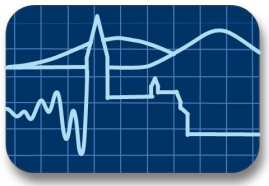

University of Freiburg

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GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

Overview

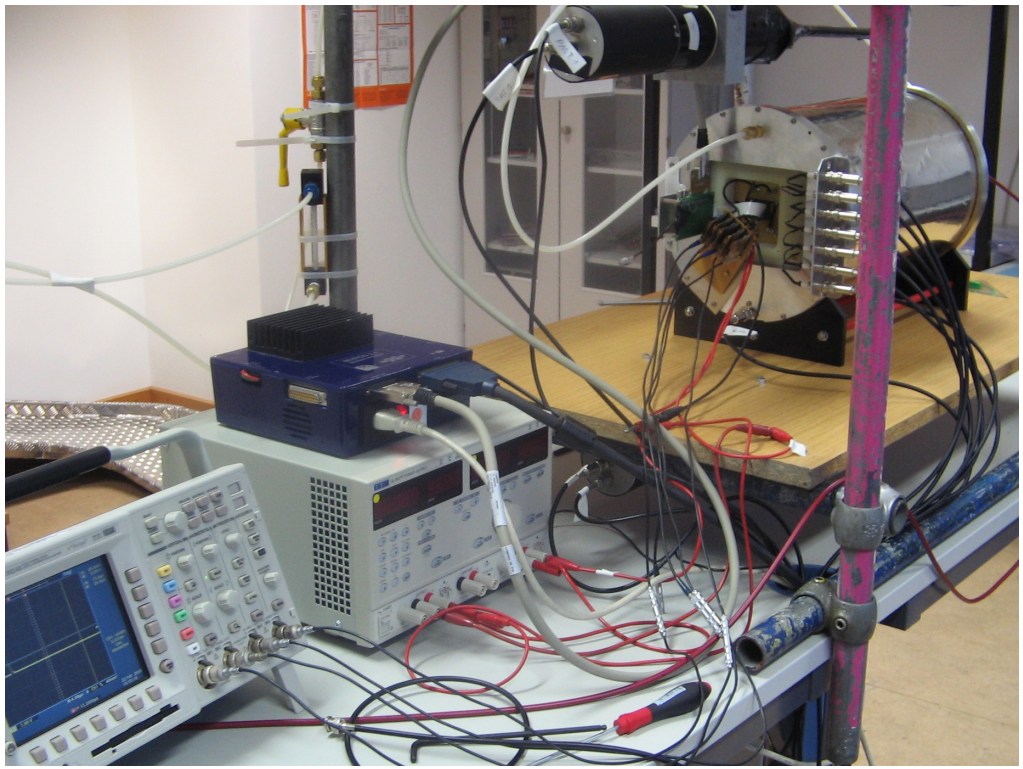
Goal

- A readout module with 8 TimePix chips and 3 GEM gas amplification for the EUDET Large Prototype TPC

Steps

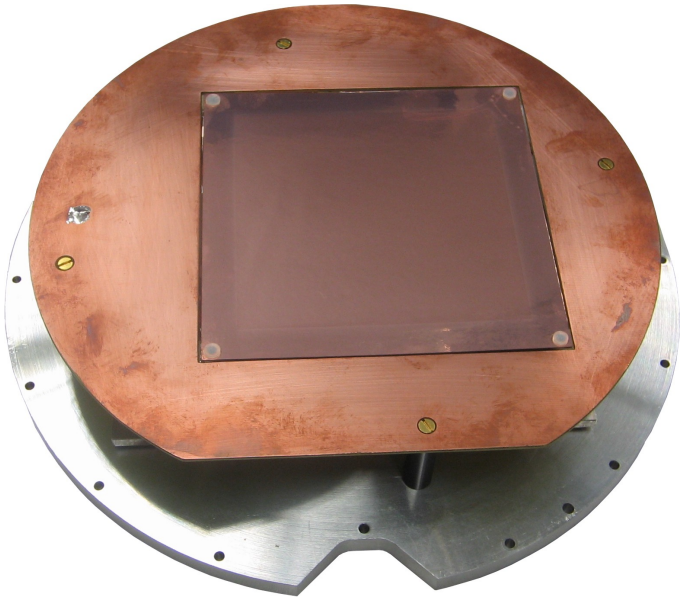
- Operate small prototype with TimePix + 3GEM
- Set up software reconstruction chain
- Build LP Module

TPC Test Setup

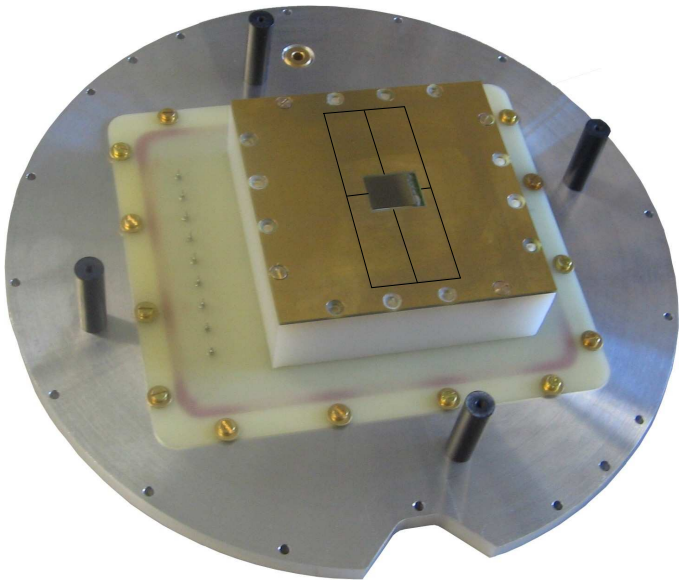


- Field cage designed and produced in Aachen
  - 26 cm diameter
  - 26 cm drift distance
  - Low material budget: 1 % X_0
  - Drift field up to 1 kV/cm
  - Fits into 5 T magnet at DESY
- Trigger for cosmic muons: Scintillators above and below the chamber
  - Veto circuit: Only one shutter window per recorded frame
- TimePix readout with Muros and PixelMan

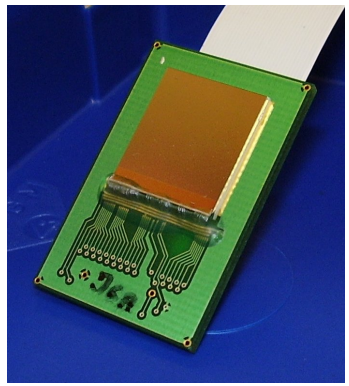
Gas Amplification and Readout



- Triple-GEM stack
- 1 mm transfer gaps and induction gap
- 390 V across each GEM
- Transfer field 2500 V/cm
- Induction field 3000 V/cm



- TimePix
  - 256×256 Pixel^2
  - 55×55 µm^2 pixel size
  - Active area 14×14 mm^2
- Single chip board
  Modified Freiburg design to glue board into readout plane from the back
- 4 large pads, connected to preamps and oscilloscope

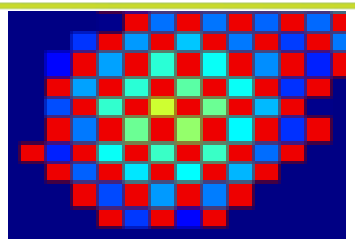


Measurements

40,000 cosmics tracks
40,000 test beam tracks

TimePix operated in "Mixed Mode":
Chequerboard pattern with pixels alternating in

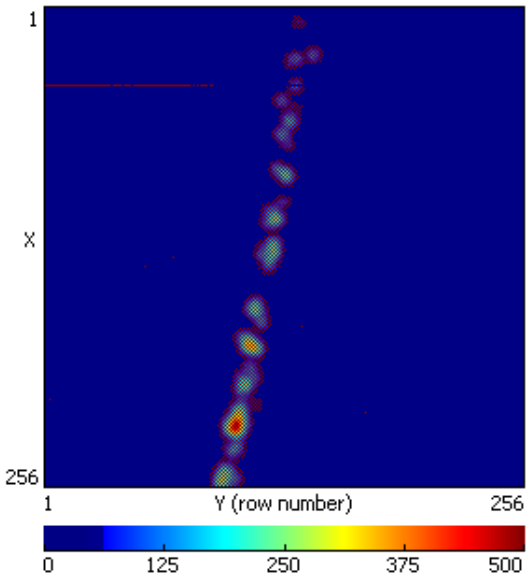
- Time Mode
- Time-Over-Threshold Mode
  proportional to charge



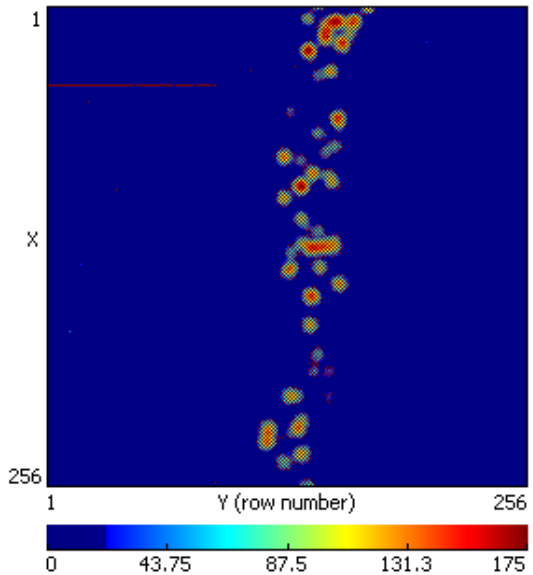
Cluster recorded in mixed mode

- Red: Time
- Blue to green: Charge

- Gas: Ar/CO_2 70/30
- Drift field: 500 V/cm
- GEM voltages: 390 V
- Transfer fields: 2500 V/cm
- Induction field: 3000 V/cm



short drift distance



long drift distance

PixelMan Event Display

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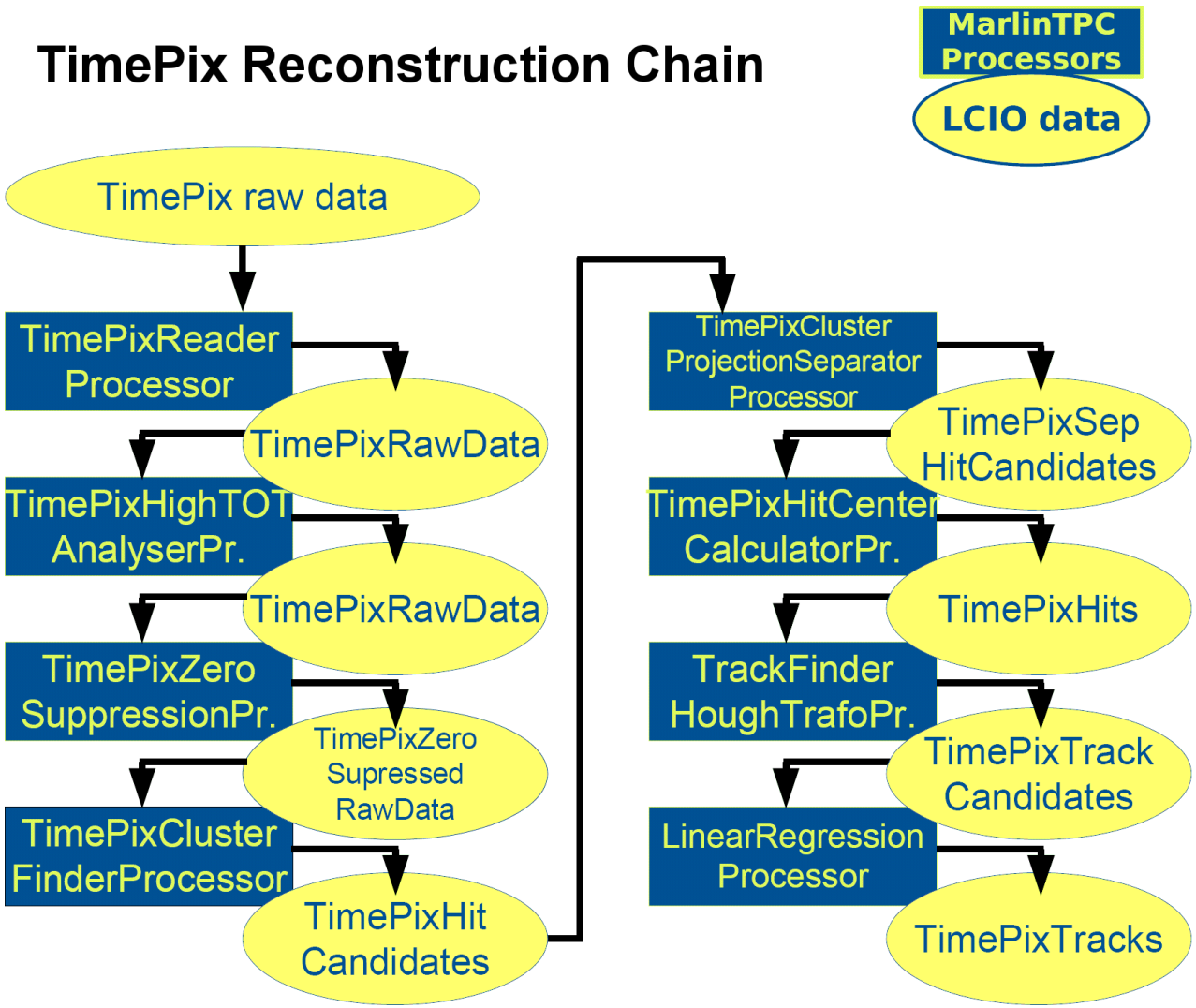
Reconstruction and Analysis: MarlinTPC

MarlinTPC is the TPC simulation, digitisation, reconstruction and analysis package for the Marlin framework

TimePix Reconstruction Chain



Very modular with more than 50 processors, suited for all kinds of TPC readout (GEMs/Micromegas, ADCs, TDCs, TimePix)

- Reader for TimePix data from PixelMan
- Complete TimePix reconstruction chain
- Analysis processors (e. g. to determine spatial resolution)
- TimePix digitisation

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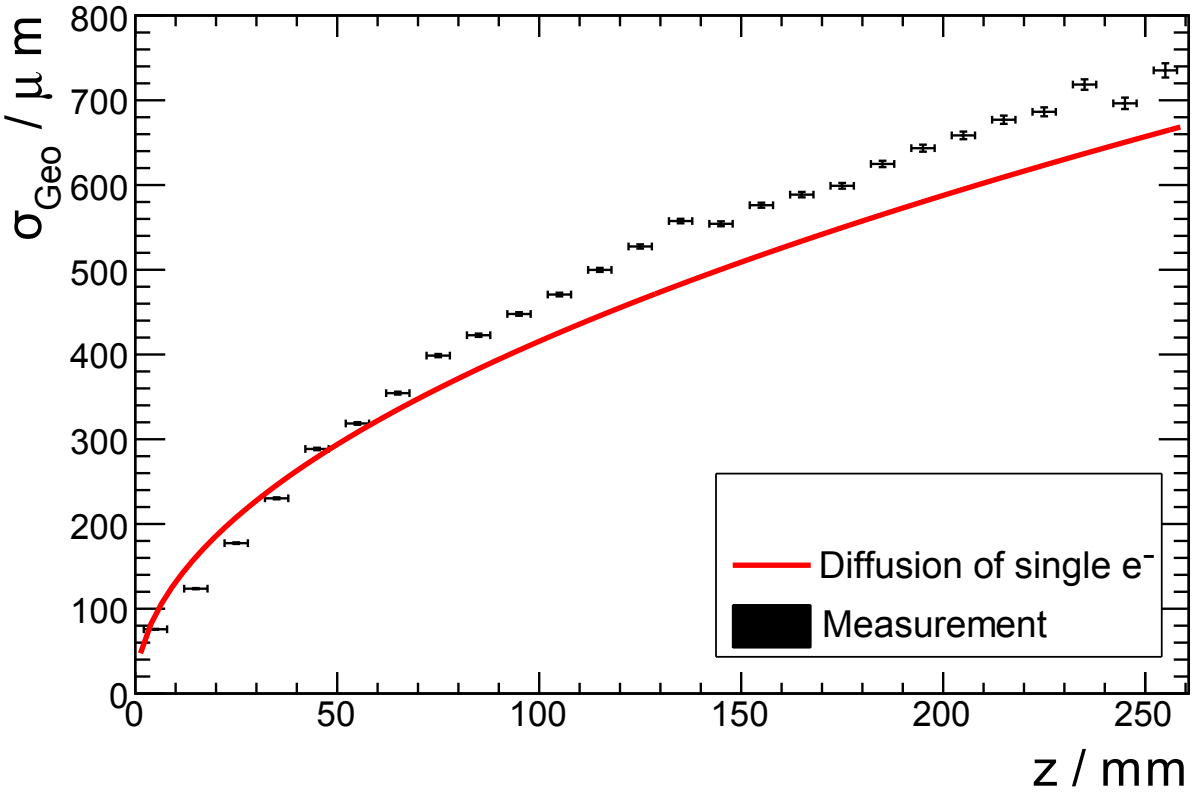
Spatial Resolution



Current interpretation:

- Short drift distances: Multi-electron clusters
- Long drift distances: Single-electron clusters?

Spatial Resolution

Single electrons

$$\sigma = \sqrt{D_t^2 z}$$

D_t = Transverse diffusion in $\mu m/\sqrt{cm}$

More realistic assumption

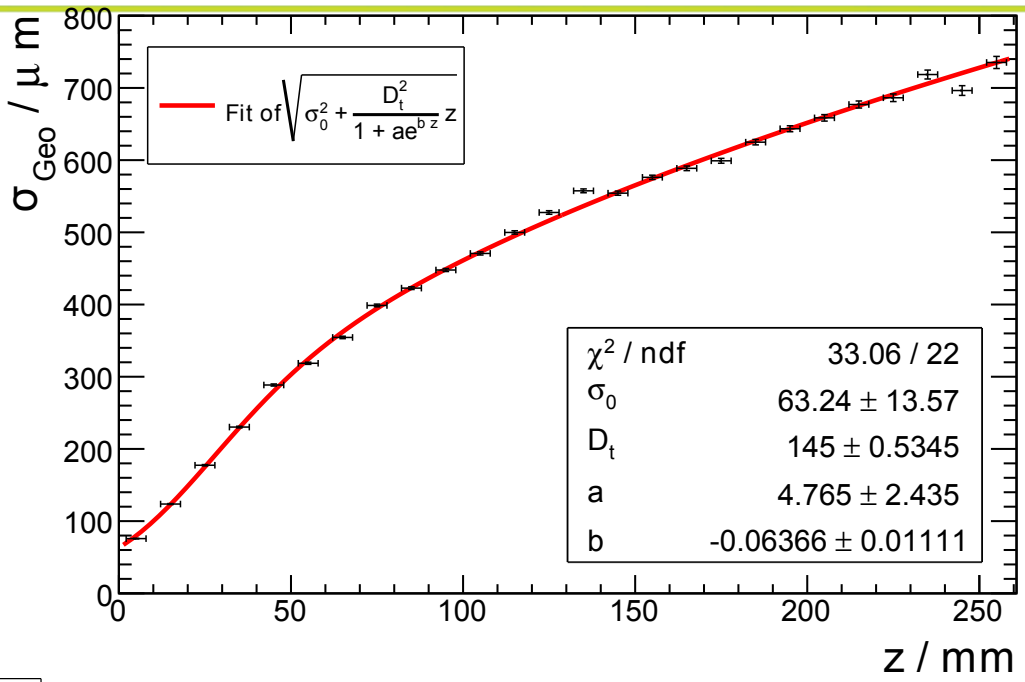
$$\sigma = \sqrt{\sigma_0^2 + \frac{D_t^2}{n_{ele}} z}$$

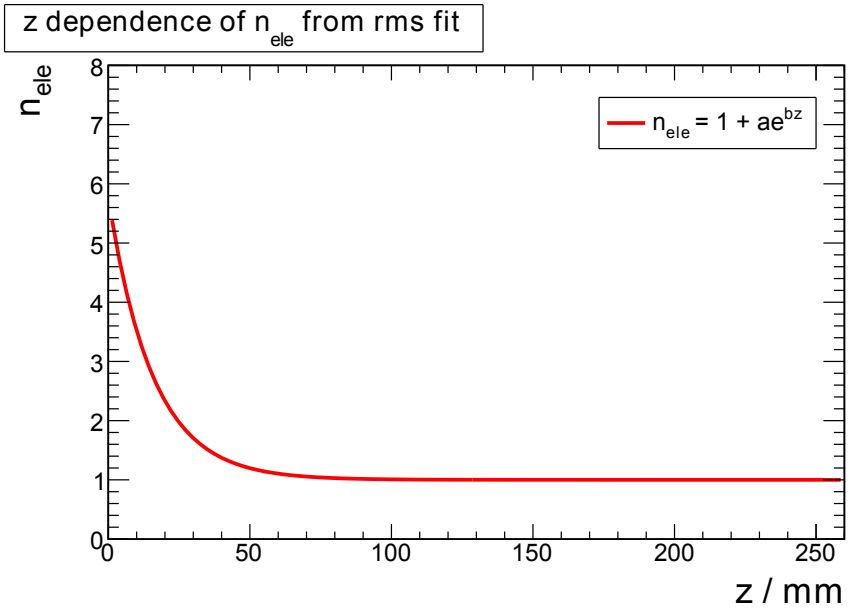
σ_0 = Intrinsic detector resolution

$n_{ele} = 1 + a\, e^{-bz}$

= Number of primary electrons contributing to recorded cluster

Spatial Resolution





- $n_{\text{ele,max}} = 5.7$
- $\bar{n}_{\text{primary}} \approx 3$

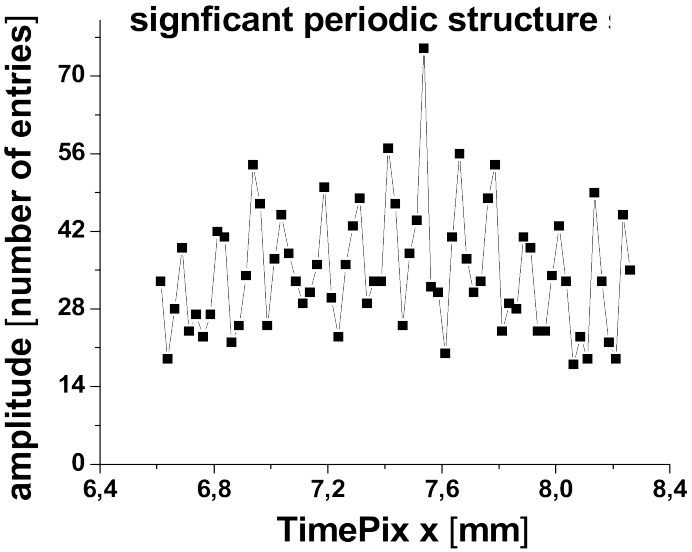
$\Rightarrow$ 1.9 *primary ionisation clusters* in one *recorded cluster*

Not understood yet:

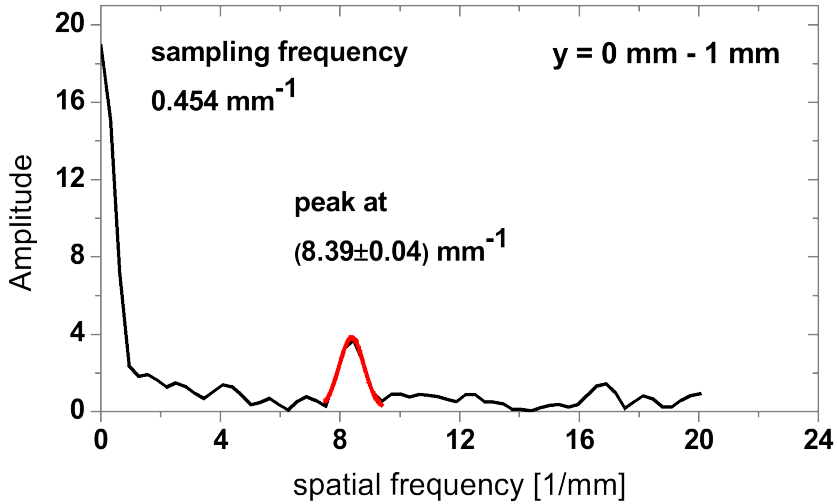
- Number of recorded clusters is too low
- Diffusion is not consistent with Magboltz ($131.4\ \mu\text{m}/\sqrt{\text{cm}}$)

Results from Freiburg Test Beam

GEM structure shows up in reconstructed data



Fourier analysis



- Fourier transform: Period is 119 ± 6 µm (GEM pitch in x-projection is 120 µm)
- Signal only shows up in first millimetre
- For larger drift distances signal is smeared out due to diffusion

- Drift gap 6 mm
- Transfer gaps 2 mm each
- Induction gap 1 mm

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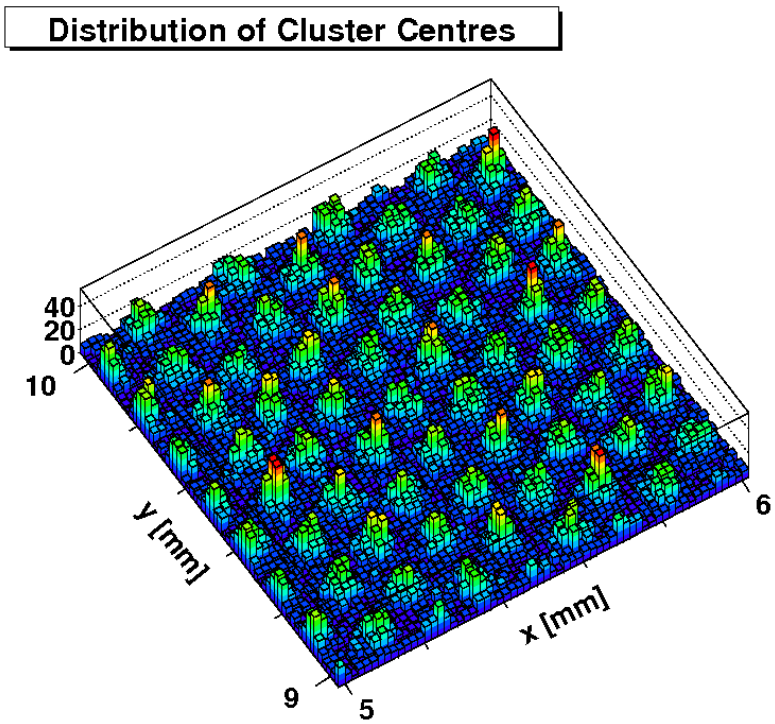
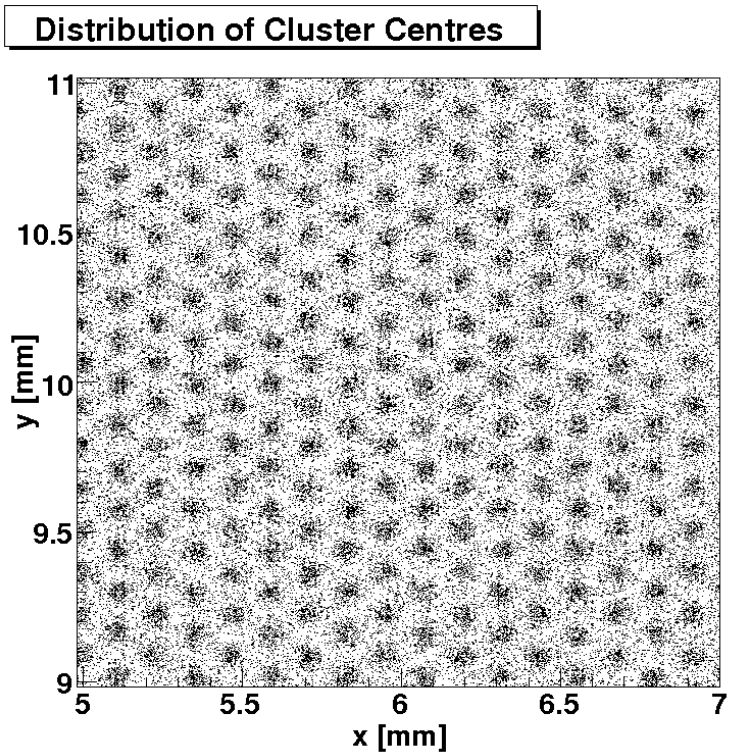
GEM structure measured in Bonn

- Dedicated high statistics run with ^{90}Sr source untriggered, no z information available
- Long drift distance $\approx$25 cm
- GEM spacing: 1 mm transfer gaps and induction gap

GEM structure measured in Bonn

- Dedicated high statistics run with ^{90}Sr source untriggered, no z information available
- Long drift distance ≈25 cm
- GEM spacing: 1 mm transfer gaps and induction gap





We can see every single GEM hole!

Measurement of GEM Structure

Current interpretation:
Spatial separation of the electrons originating from multiple-electron clusters occurs due to the transverse diffusion.

- Very small drift distances:
  All electrons of a primary cluster pass through the same GEM hole,
  GEM structure shows up
- Medium drift distances:
  Electrons of a primary cluster pass through neighbouring GEM holes,
  GEM structure is washed out
- Long drift distances:
  Individual electrons can be separated,
  GEM structure shows up

Problems with this interpretation:

- Number of reconstructed clusters at large drift distances is smaller than expected number of primary electrons (about 1/3)
  - Attachment?
  - Low single electron efficiency?
  - Do reconstructed clusters contain only single electrons?

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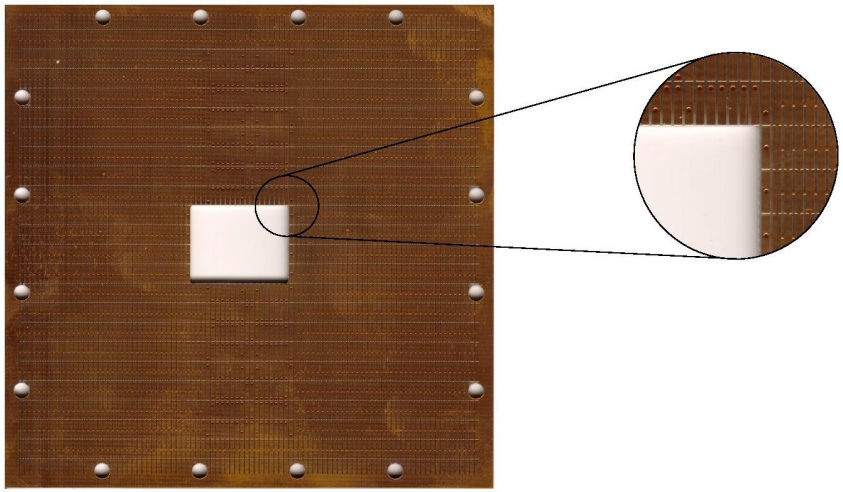
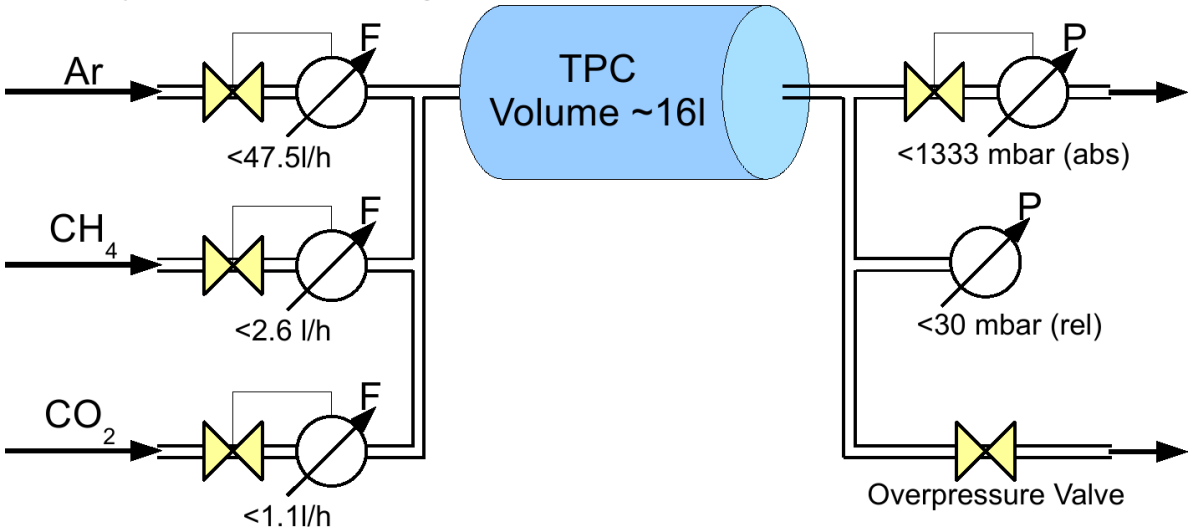
Next Steps

- Combined readout:
  Pad plane with 256 pads, 1×4 mm^2 + TimePix



- Gas system to mix gases and keep pressure constant



Post-Processing of TimePix

Freiburg group is testing MediPix chips with enlarged pixels ($110 \times 110\ \mu m^2$), post-processed on per chip level by FMF (Freiburger Metallforschungszentrum)

Bonn has established first contact with IZM:
Institut für Zuverlässigkeit und Mikrointegration, Berlin

Institut
Zuverlässigkeit und
Mikrointegration

Post-Processing of TimePix chips — on wafer level:

- **Enlarging pixel size**
  by adding metal pads on a passivation
- **Silicon through vias**:
  replacing wire bonds by bump bonds
- **InGrid** — plans to learn technology from Twente University

Contributions to the development of a TimePix successor chip.

LP Module with 3GEM + TimePix

- 3 standard GEMs 10 $\times$ 10 cm^2
- 1 mm transfer gaps and induction gap
- Two quad-boards (NIKHEF) with 4 TimePix chips each

- Two Prague USB 1.22 readout modules, read out by Pixelman

anode plane

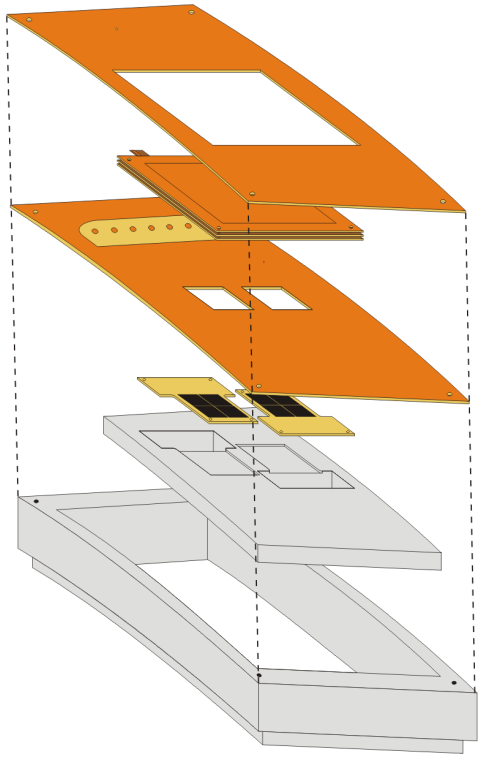
GEMs

readout plane

quad-boards

reinforcement of anode plane

redframe



Status

Module

- All components are in house
- GEMs have to be glued

QuadBoards

- One QuadBoard is fully equipped and bonded
- QuadBoard worked fine except for a broken bond
  (could not read DAC values from second chip)
- After fixing the bond the board does not answer any more
- Probed the individual chips: All chips are dead!

Problem not understood!

- New QuadBoard is being prepared

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Dummy Modules

Status

- First module is produced and being surveyed
- Six further modules are in production
- All dummy modules will be ready for closing of the LP in week 44

Summary

Prototype in Bonn

- 26 cm TPC with single TimePix + 3GEM
- 40.000 cosmics tracks + 40.000 test beam tracks
- Resolution limited by GEMs + diffusion
- Indications that we see single electron clusters

MarlinTPC

- TimePix reconstruction chain is ready to use
- For LP: Need multi-chip capability

LP Modules

- Dummy modules in production, will be ready for LP
- TimePix + 3GEM module: QuadBoards are being tested

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