A TPC with Triple-GEM Gas Amplification and TimePix Readout

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Outline

- TPC for the ILC
- GEMs and TimePix
- Freiburg setup
  - Test beam at Desy
  - Resolution studies on test beam data
- Bonn setup
  - Measurements with cosmics and ^{90}Sr-β^--source
  - Resolution studies and “Declustering”
- Summary
  - Results
  - Outlook

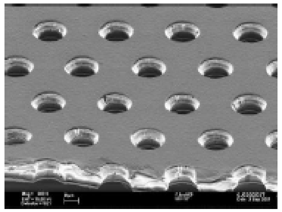
A TPC at the ILC (…or at CLIC)

Traditional TPC with MWPC:

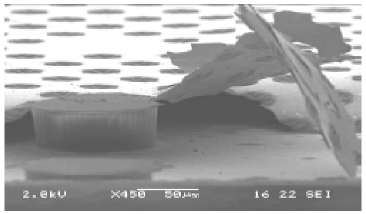
- limited space resolution
- No true 2D symmetry : ExB effects

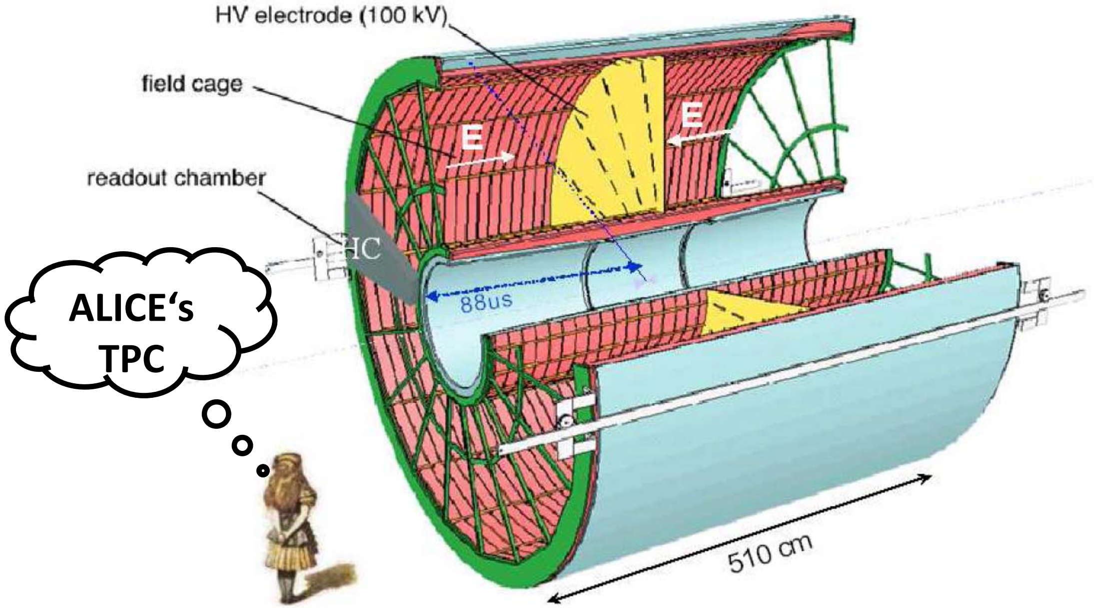
⇒ use Micro-Pattern Gas Detectors (MPGD) (“micro” = 50-150 µm)

GEM



Micromegas





Requirements for ILC:

- Momentum Resolution $\delta(1/pt) < 10^{-4}$ / GeV
- Single point resolution in r-ϕ ≤ 100 µm, r-z < 2 mm
- 2 track resolution in r- ϕ < 2mm, r-z < 5mm
- TPC:
  - Expect ≈ 1% occupancy for ILC
  - STAR/ALICE: high precision/efficiency in backgrounds with >10% total occupancy

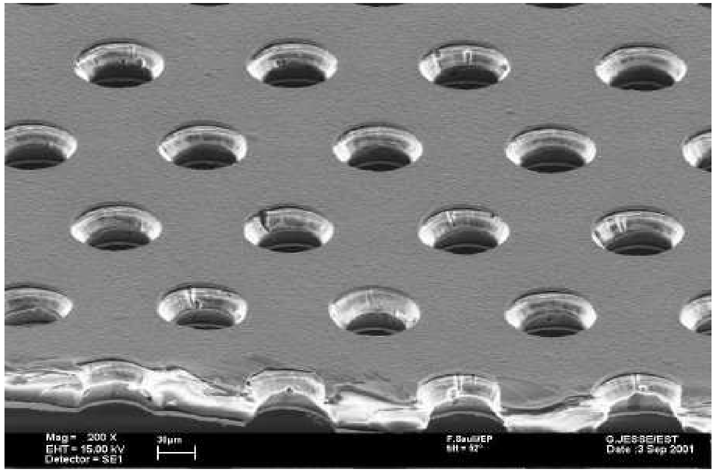
A TPC at an ILC would have:

- R ≈ 2 m
- L ≈ 4-5 m

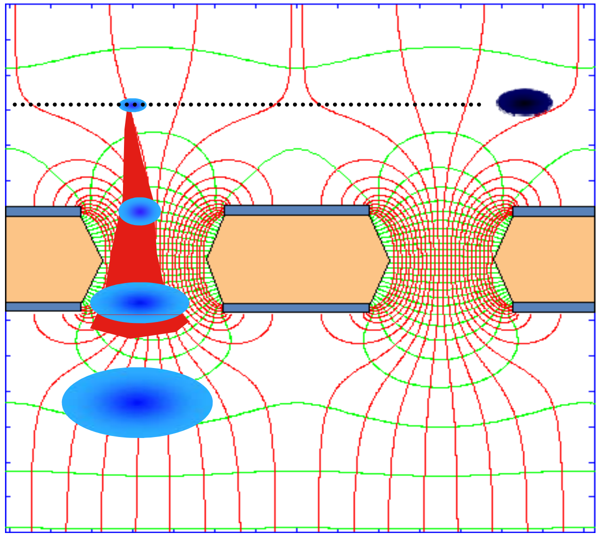
GEMs

Principle

- 2 layers Cu each 5 µm thick, separated from each other by 50 µm Kapton.
- Conical etched holes largest Ø70 µm, diagonal distance of holes 140 µm.



F. Sauli, http://www.cern.ch/GDD



Advantages of Triple-GEM-setup

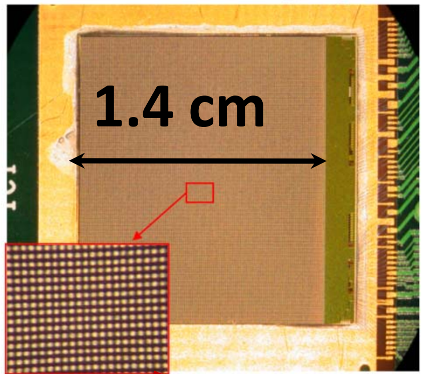
- Gas gain up to 10^5 in $ArCO_2$

  ⇒Necessary because charge is typically spread over several pixels (>> 50 pixels)

- Minimizing the positive ion backdrift
- Localized region of amplification
- Reliable operation, only few sparks

TimePix

TimePix is used as highly segmented charge collecting anode

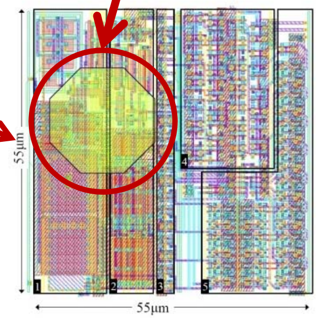


X. Llopart Cudie, CERN-THESIS-2007-062

Dimensions

- 256 x 256 pixels^2
- 55 x 55 µm^2 pixel size
- 14 x 14 mm^2 active area

Charge directly collected on pixel



Single pixel cell

Four recording modes

- Time Over Threshold (TOT)
- TIME
- Hit counting
- Hit yes/no

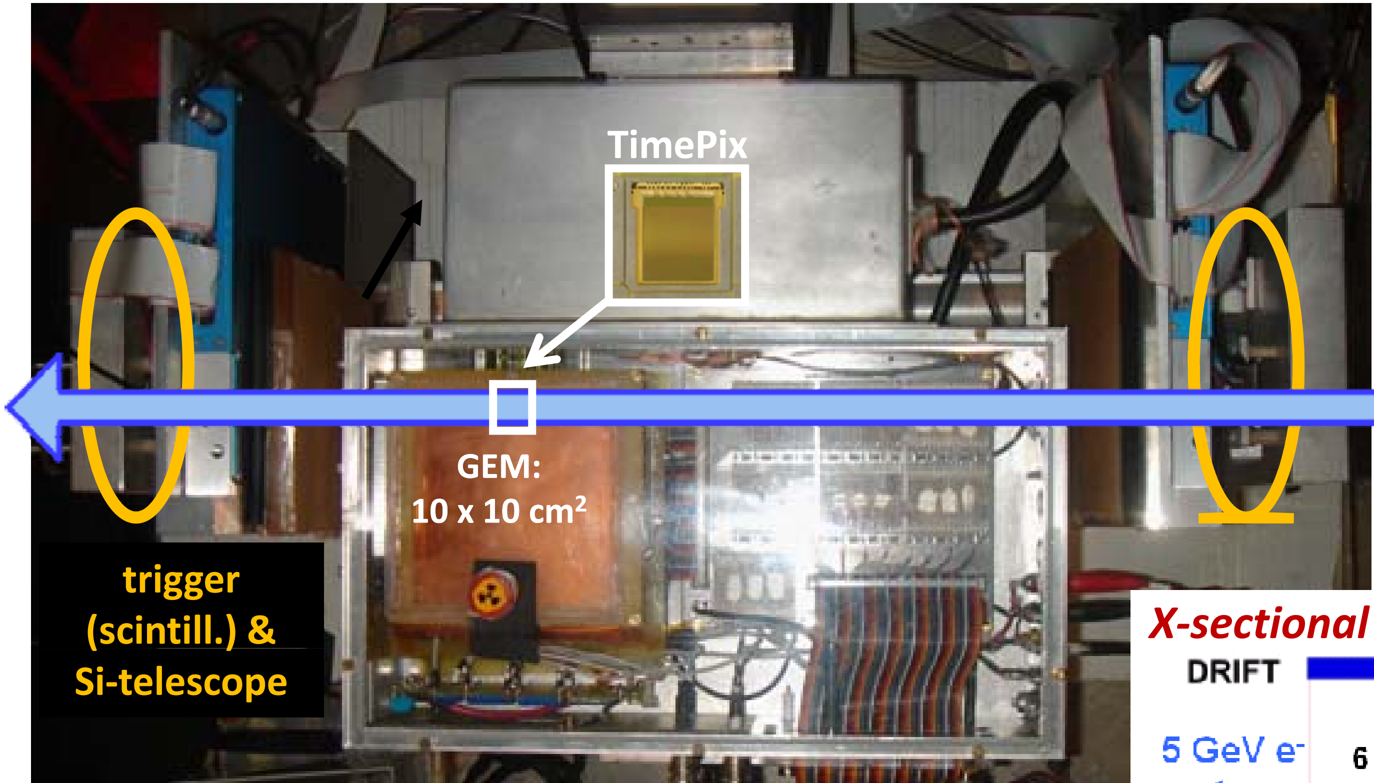
Must select one per pixel

Mixed Mode

- Alternating pixels are set to TOT and TIME mode
- Results in a checker board like fashion.
- Missing neighbors in TOT or TIME data are interpolated.

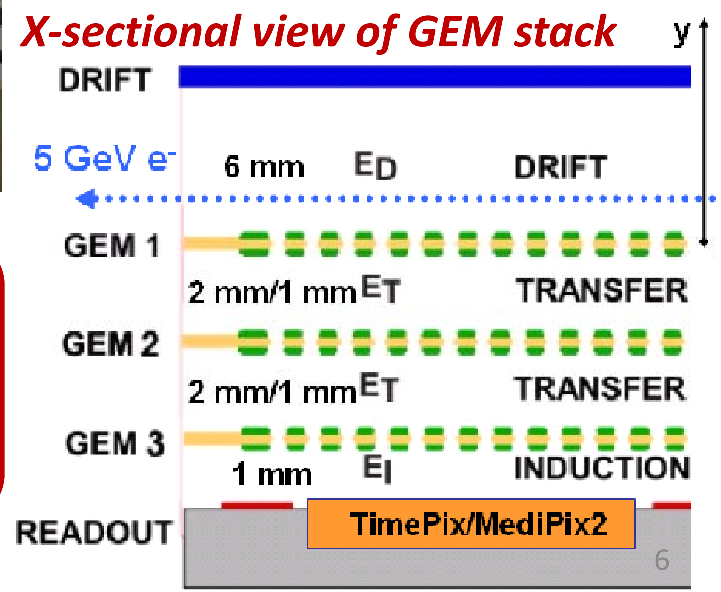
TOT	TIME	TOT
TIME	TOT	TIME
TOT	TIME	TOT

DESY Test Beam June 2007



Robust and stable operation of TimePix-GEM-setup

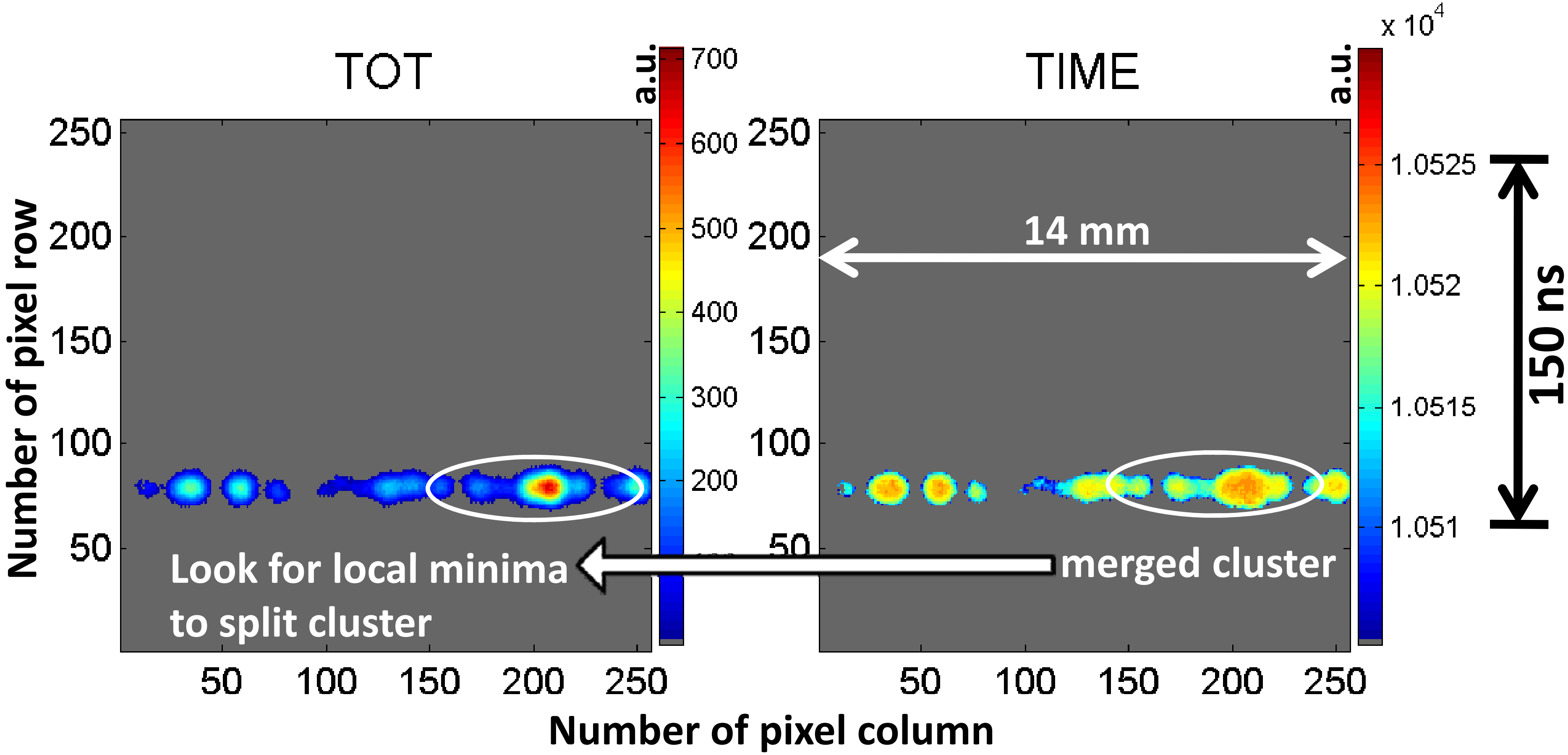
5 GeV e^- beam at DESY



Two different GEMs:

- Standard **100x100 mm²** GEMs with **140 µm hole pitch**
- Small GEMs **24x28 mm²** with a fine pitch of **50 µm**

Typical Event



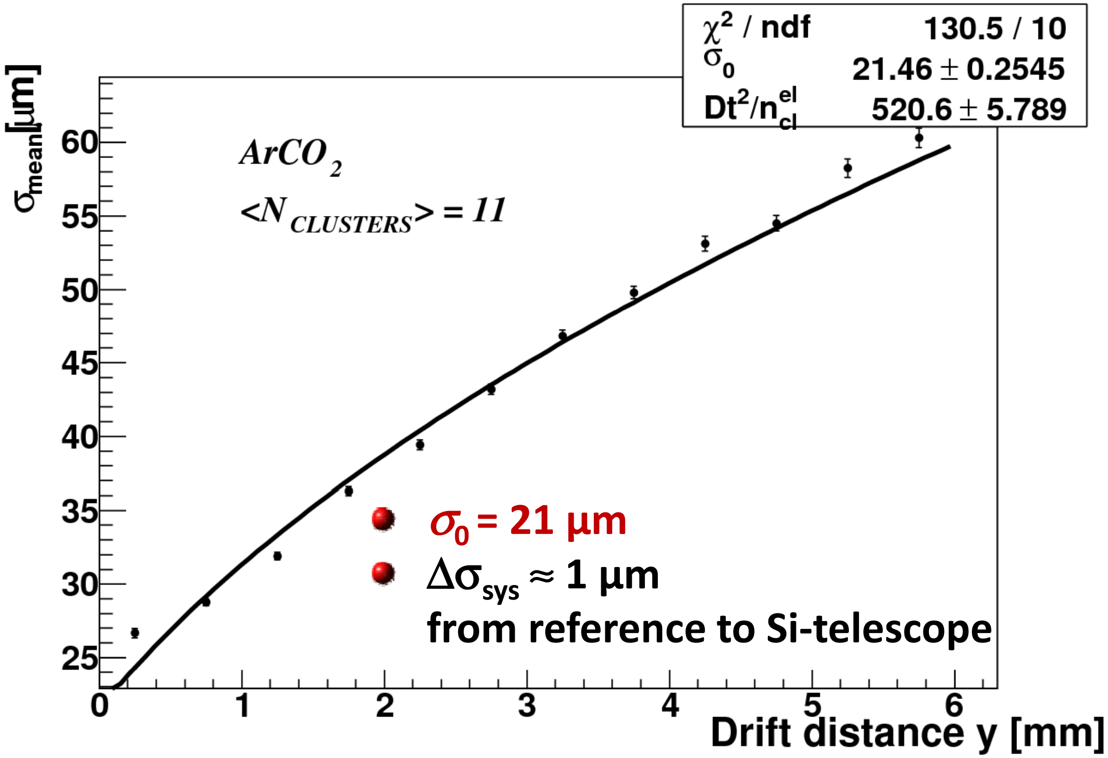
1. For cluster reconstruction search for contiguous areas .
2. Use TOT-information to separate merged clusters
3. Resolution is given by the residuals from a straight line fit.

Resolution Standard GEMs

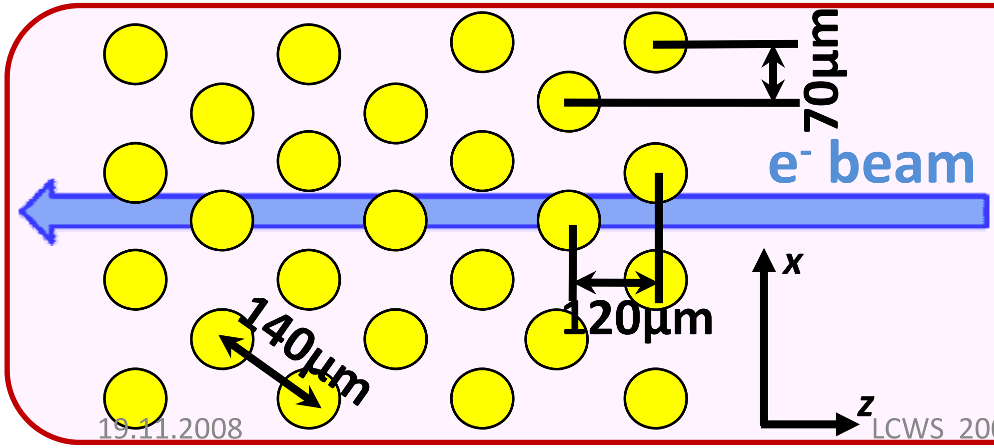
Resolution as function of drift distance

$$\sigma(y) = \sqrt{\sigma_0^2 + \frac{D_t^2}{n_{el}} y}$$

- σ_0 = intrinsic detector resolution
- D_t = transverse diffusion constant
- n_{el} = # of primary e^- contributing to recorded cluster

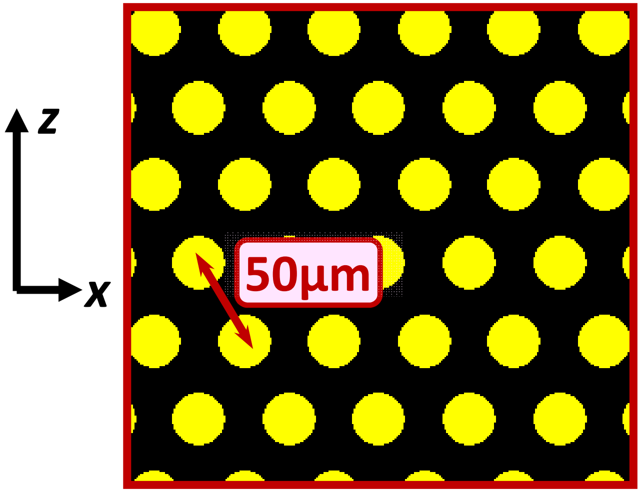


- σ_0 = 21 µm
- $\Delta\sigma_{sys} \approx$ 1 µm from reference to Si-telescope

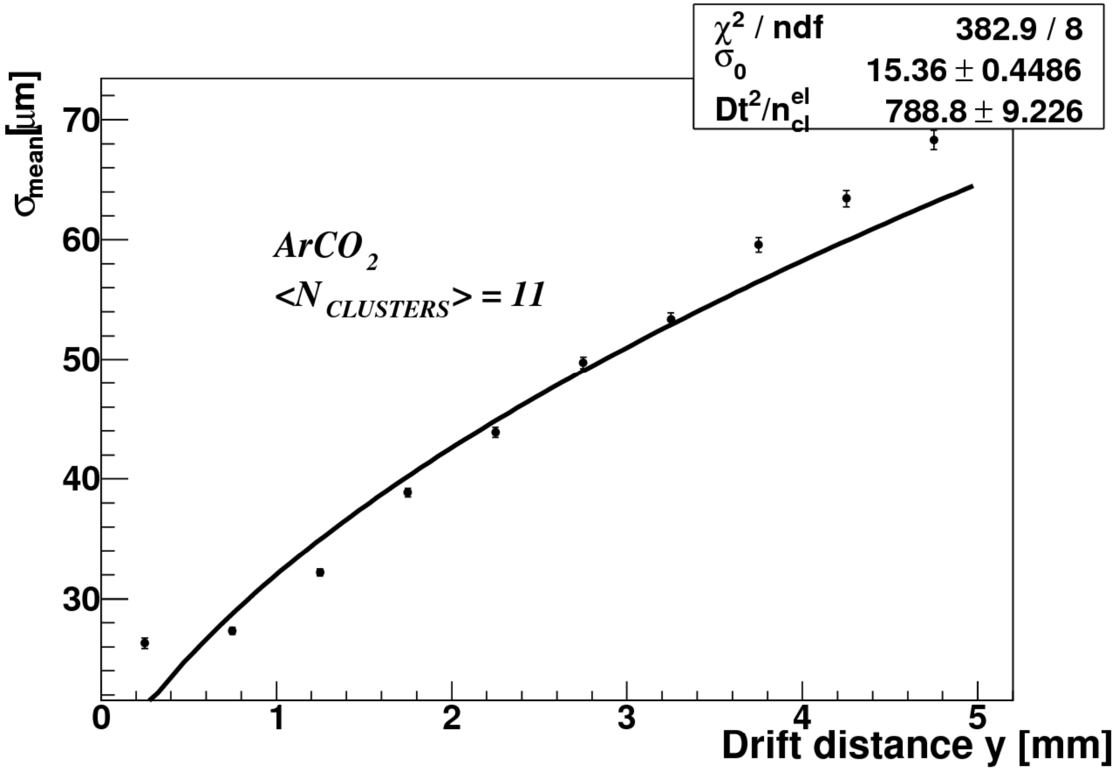


- 70µm projected hole w.r.t. to beam
- Rotate GEM by 90°
  - 120µm projected hole pitch
  - σ_0 degrades by $\approx$ 2 µm – 3 µm

Spatial Resolution Small Pitched GEMs



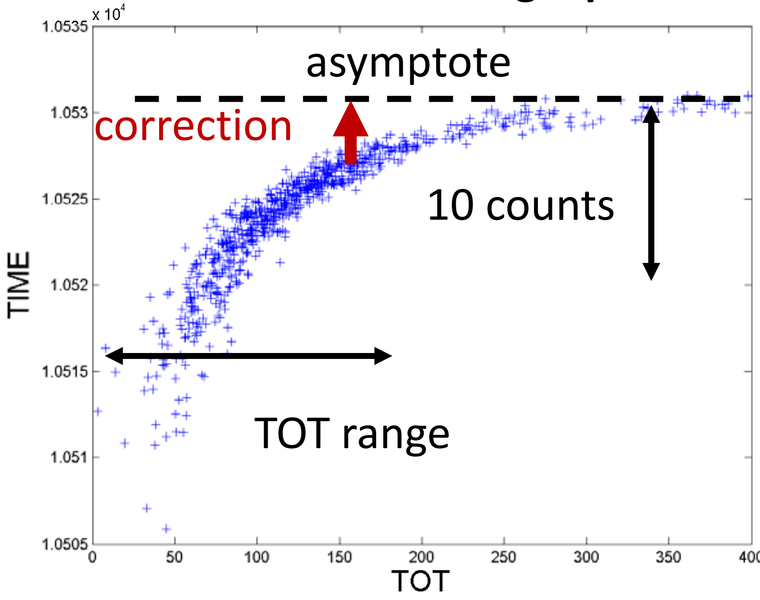
- Outer hole diameter ≈ 30µm
- Inner hole ≈ 17µm-21µm
- Diagonal hole pitch 50µm
  - Projected in x ≈ 43µm
  - Projected in z ≈ 25µm



- Improved resolution
- Simple model of σ(y) not describing data

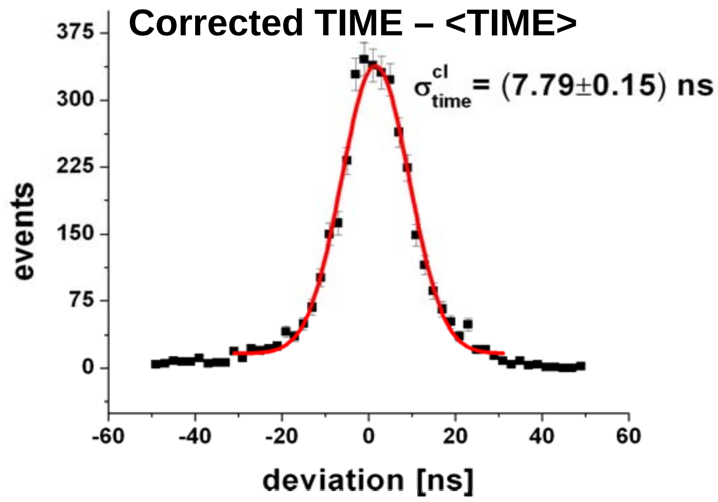
Time Resolution

TIME vs. TOT for single pixels



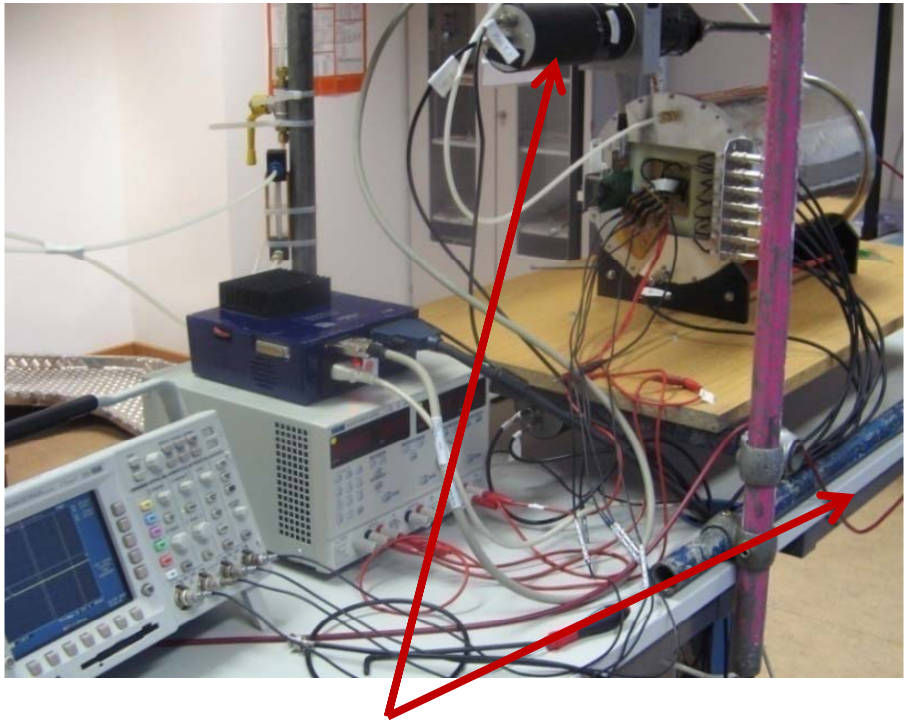
- Strong correlation of TIME and pulse height (~TOT) →"time walk"
- Use TOT –TIME relation to correct for observed time walk
- Typical TOT at cluster centers > 300

1. Take TIME at cluster centroid
2. Correct with TOT at same postition
3. Determine mean of corrected TIME values in an event <TIME>$_{mean}$
4. Calculate TIME - <TIME>$_{mean}$



- After correction **time resolution** as good as **8 ns** @100 MHz clock frequency.
- Improvement due to correction ≈ 2%
- With $v_{drift} \approx$ 30 µm/ns ⇒ $\sigma_{drift} \approx$ 240 µm

Bonn Setup

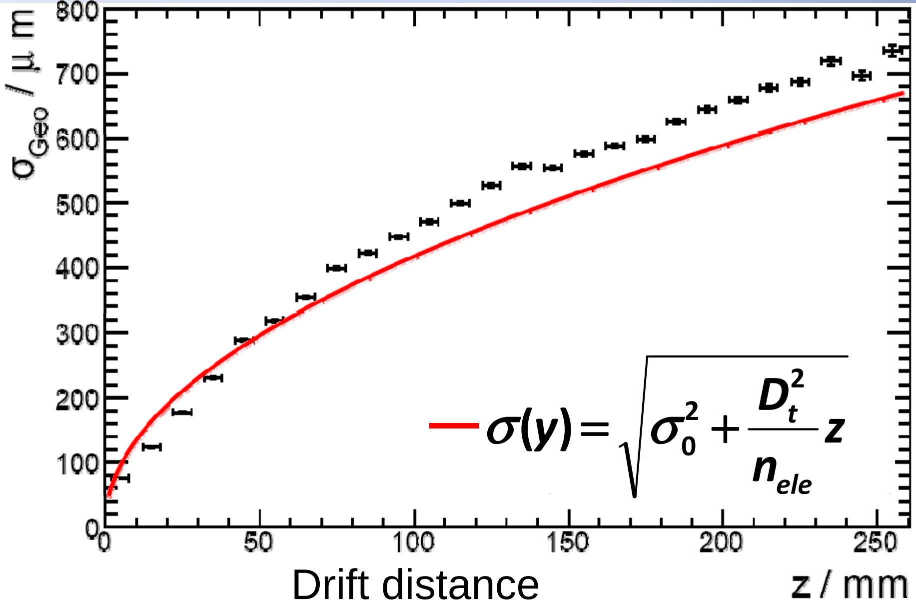


Scintillators for data taking with cosmics

- 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

- Measurements with ^{90}Sr β^--source
- Measurements with cosmic muons

Spatial Resolution



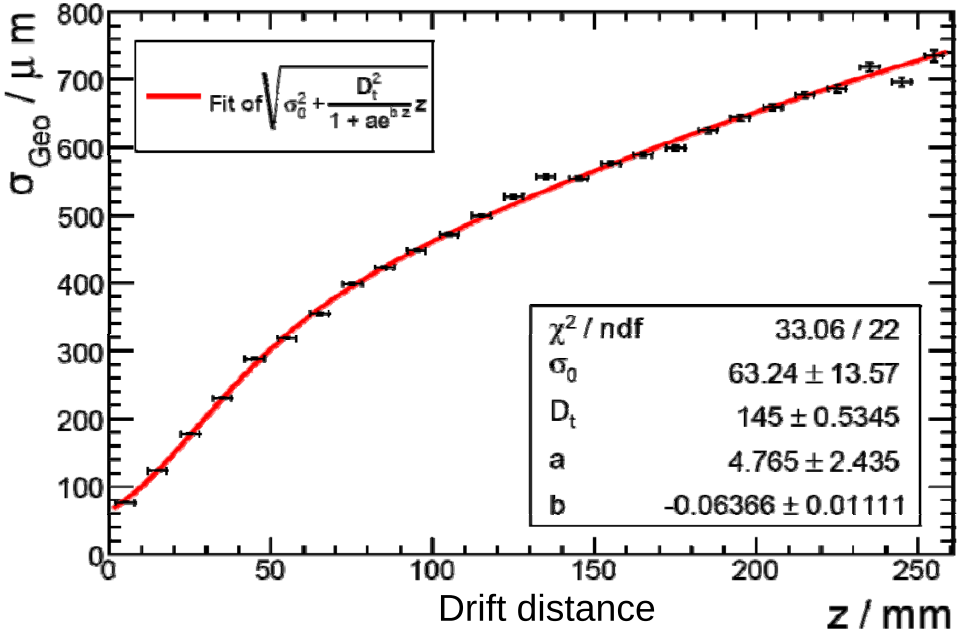
More realistic assumption

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

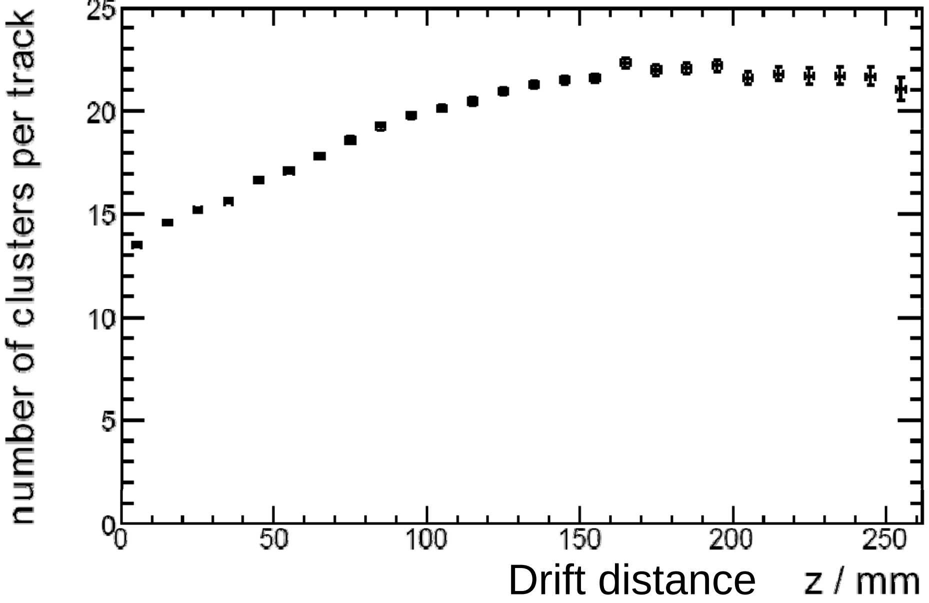
- $n_{ele}(z) = 1 + a \cdot e^{-bz}$
  - $z \to \infty$: $n_{ele}=1$
  - $z \to 0$: $n_{ele}= 5.8$

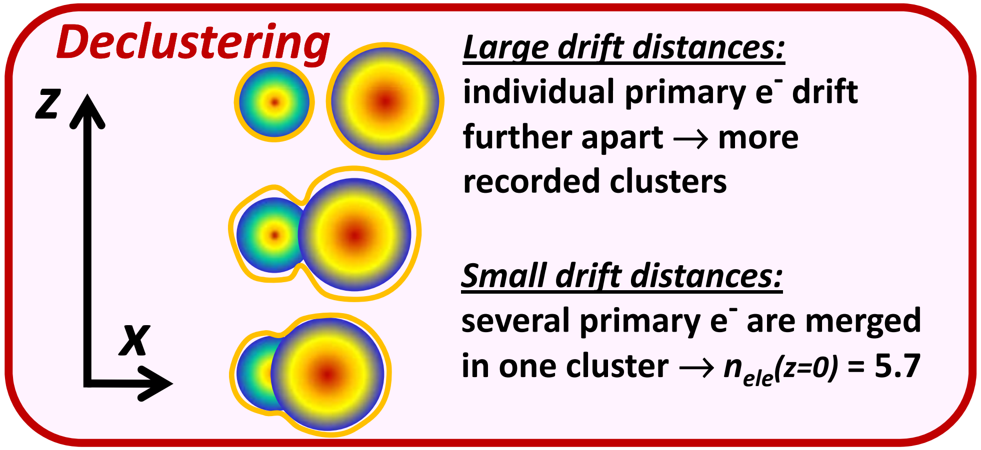
- $n_{ele,\,max} = 5.7$, $z=0$
- $\bar{n}_{primary} \approx 3$

up to ***1.9 primary clusters*** in a ***recorded cluster***

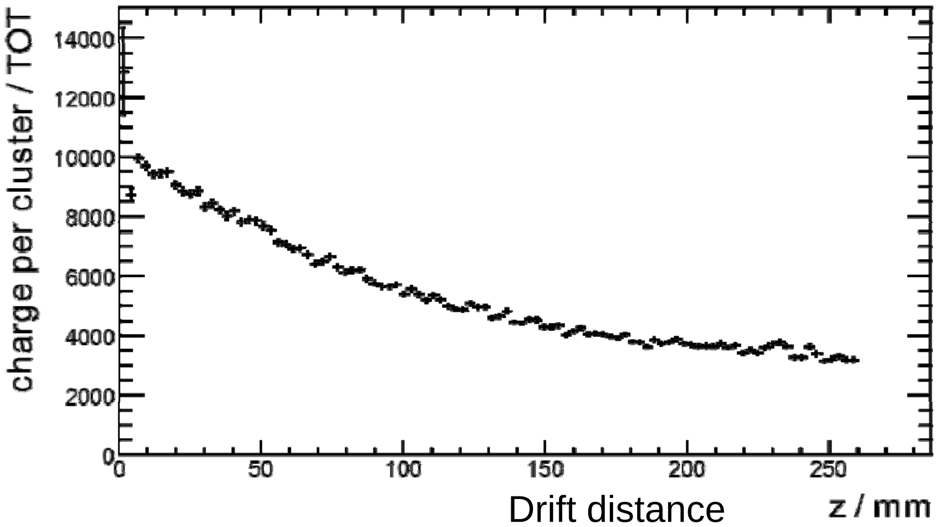


Declustering

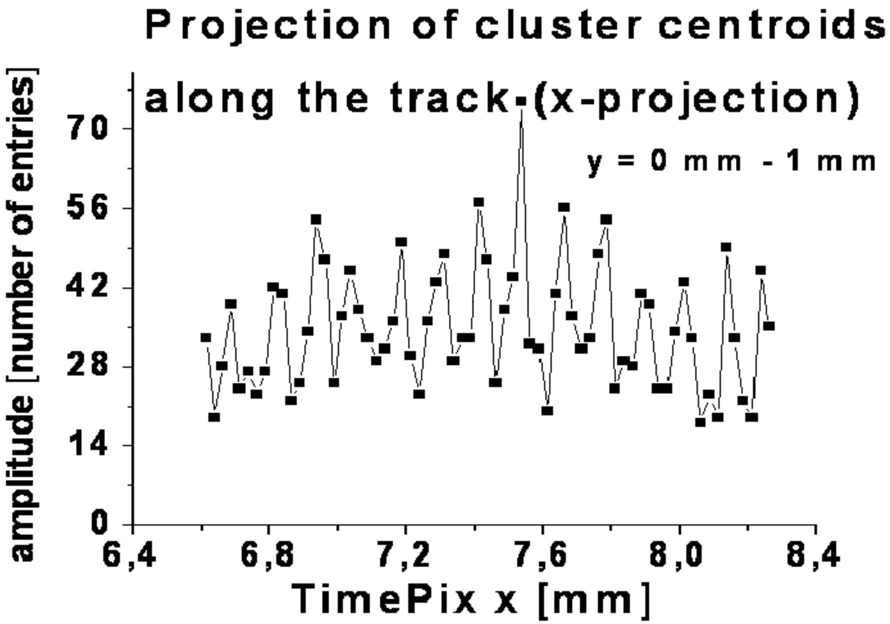




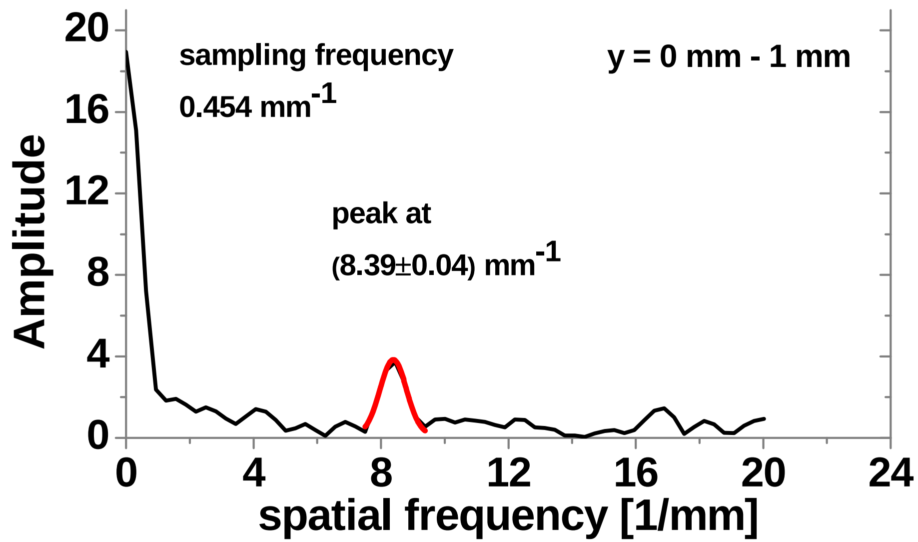
- **Number of clusters is increasing with *z***
- **Charge per cluster decreasing with *z***
- **Long drift distances (> several cms):**
  - **Larger transverse diffusion**
  - **Single electrons start to be well separated**
  - **Can be reconstructed as individual clusters**



Effects of GEM Structure - Freiburg data



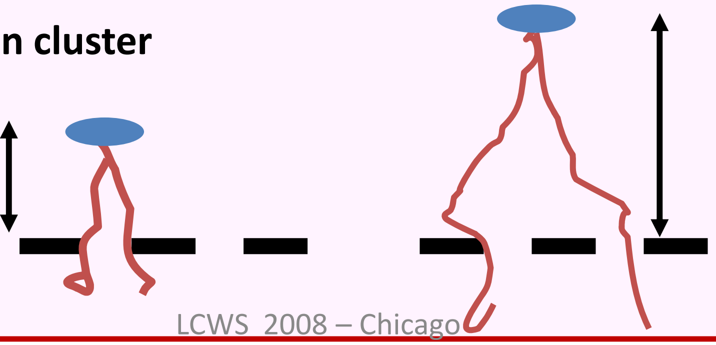
Fourier Transform of projected cluster centroid distribution (x-projection)



- GEM pitch 120 µm w.r.t. e$^-$-beam ⇔ Periodic structure at 1/(8.39 mm) corresponds to 119 ± 6 µm
- Signal appears only in within 1 mm above the first GEM
- For larger drift distances signal smeared out due to diffusion:

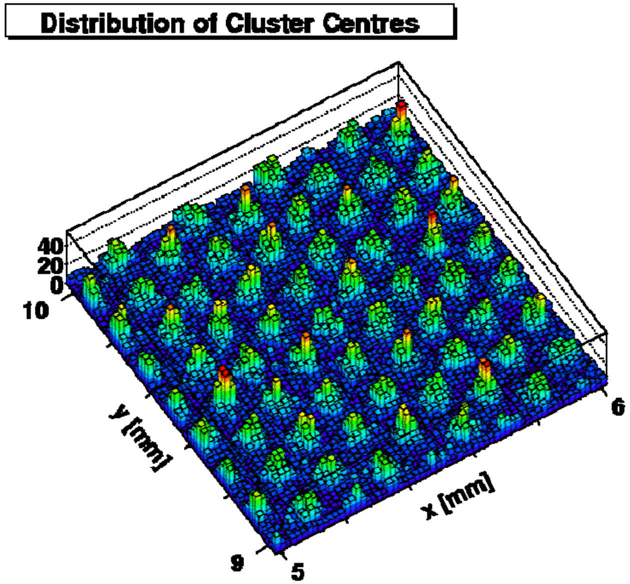
≥ 2 primary e$^-$ in cluster

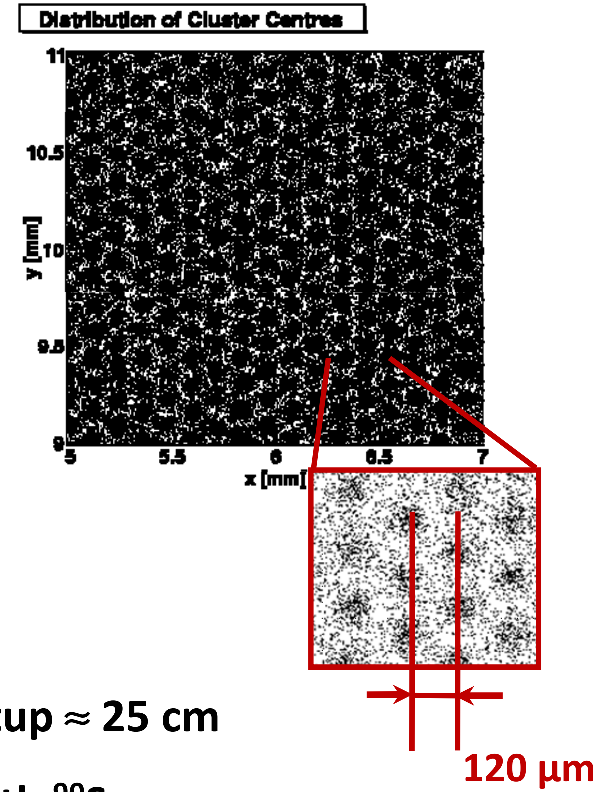
1 mm: all e$^-$ from (same) cluster go through one GEM-hole



2 mm: Single e$^-$ go through neighboring holes

Effects of GEM Structure - Bonn data





- Long drift distances in Bonn setup ≈ 25 cm
- Dedicated high statistics run with ^{90}Sr source
- Homogenous irradiation of active area (14x14 mm^2 of TimePix)
- Reconstruct cluster centroids
- GEM structure (holes & pitch) are clearly visible

Summary

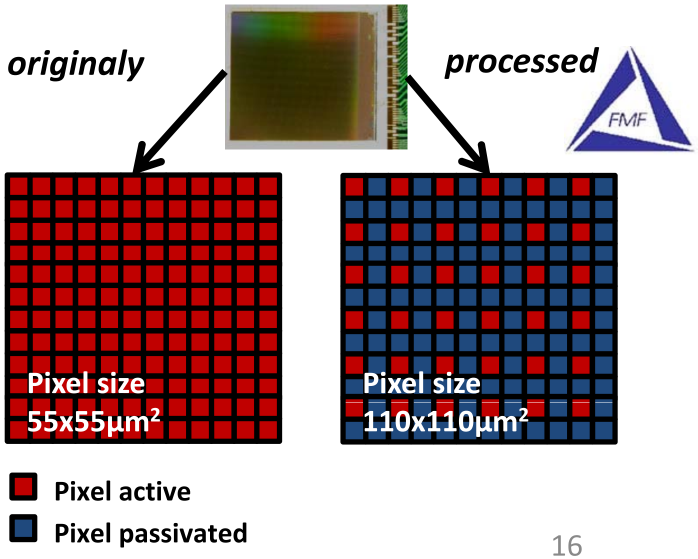
Results

- Point Resolution of $\sigma_0 \approx 20$ µm achieved
- Time Resolution of as good as 8 ns $\Rightarrow \sigma_{drift} \approx 240$ µm
- Declustering studied in detail
- Indications for sensitivity to single electron clusters
- Resolution limited by GEM structure + diffusion

Outlook

- Increase pixel size
- Collect more charge per pixel
- Reduce of effective threshold

  $\Rightarrow$Can work at lower gas gain?



Modern Particle Identification