# Simulation Studies for a triple-GEM and a MicroMegas Set-up with MediPix Detector

- Simulations based on HEED + MAGBOLTZ
- Two Set-ups studied
  - Freiburg triple-GEM + MediPix
  - NIKHEF MicroMegas + MediPix
- (Some) conclusions

# Introduction

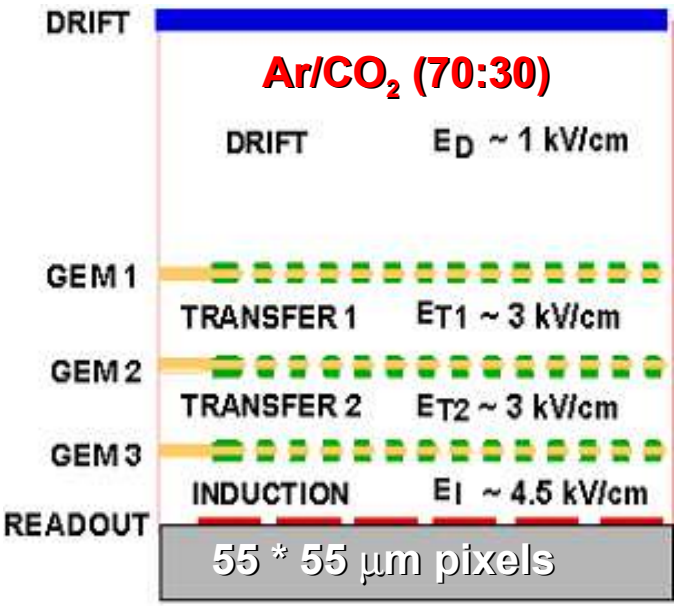
- **Recent R&D work on GEMs/MicroMegas + MediPix are an important step towards a "digital TPC" = the electronic bubble chamber**
  - **does allow to resolve individual ionisation clusters = the most basic piece of information along a track**
    - **unprecedented potential for pattern (track) recognition and track fitting in dense track environments**
    - **dE/dx measurement by cluster counting provides factor two better resolution compared to classical charge determination**
- **Results already promising but needs better (deeper) understanding and lots of parameters to be optimized**
  - **Gas properties (cluster density, electrons per cluster, diffusion)**
  - **Gas amplification (GEMs vs MicroMegas, # of GEMs, E-field, gas gain)**
  - **MediPix (noise, thresholds)**
- **Simulations can help a lot**

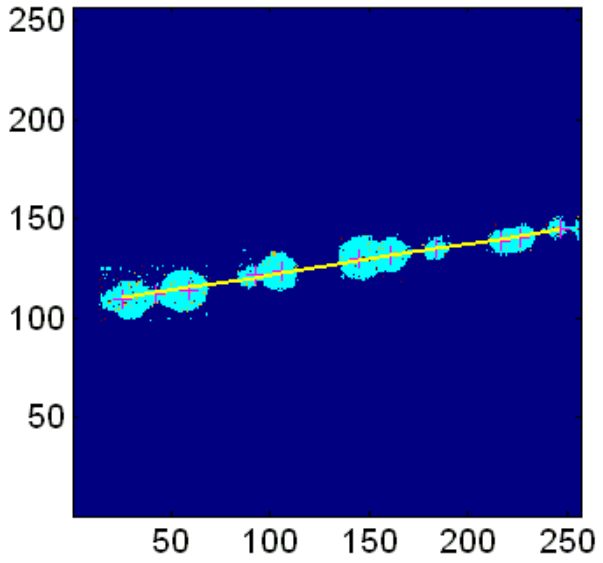
# Simulation Tool (Clusco)

- Generates ionization clusters/electrons along tracks and drifts electrons towards GEMs/MicroMegas structures
  - HEED (I. Smirnov) for cluster generation (including $\delta$-electrons)
  - MAGBOLTZ (S. Biagi) for gas properties (diffusion, drift velocity)
- "Squeeze" electrons through GEM/MicroMegas holes and perform gas amplification
  - use simple geometric transformations, no detailed E-field simulation
  - exponential gas gain distribution
    - measurements from Aachen group indicate exponential distribution
    - gas gain on wires more follows Polya distribution
- Drift ALL electrons created in gas amplification to next GEM or MediPix (can be several Millions in total)
- Count electrons collected on MediPix, generate noise + apply detection thresholds (digitization step)

# Freiburg triple-GEM set-up

- Nice "blobs" seen along tracks from $^{106}$Ru source ($\beta$ with 3.5 MeV max.)
- Are "blobs" = clusters?
- Most likely, but
  - often holes in between blobs visible
  - blob density significantly lower than expected cluster density
- Cluster density for Ar/$CO_2$ (70:30) and a few MeV electrons (~m.i.p.)
  - expect: ~30 clusters/cm
  - seen: about half or less of expected value

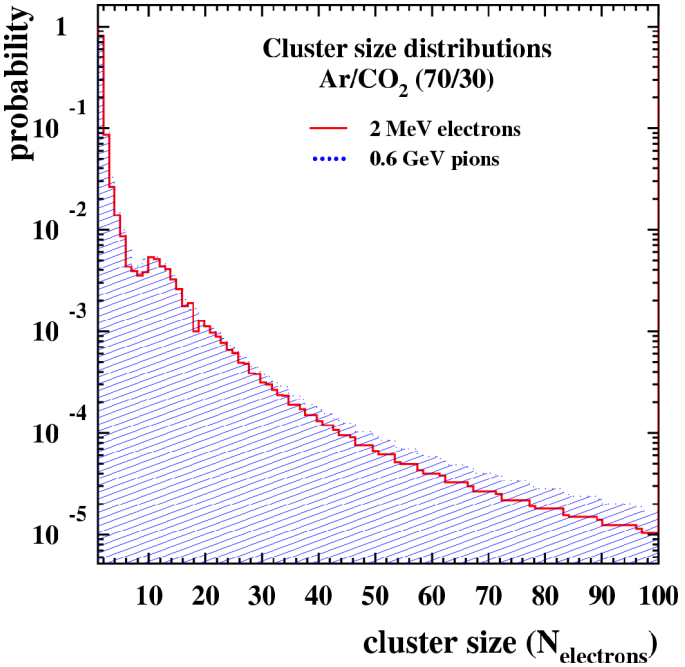


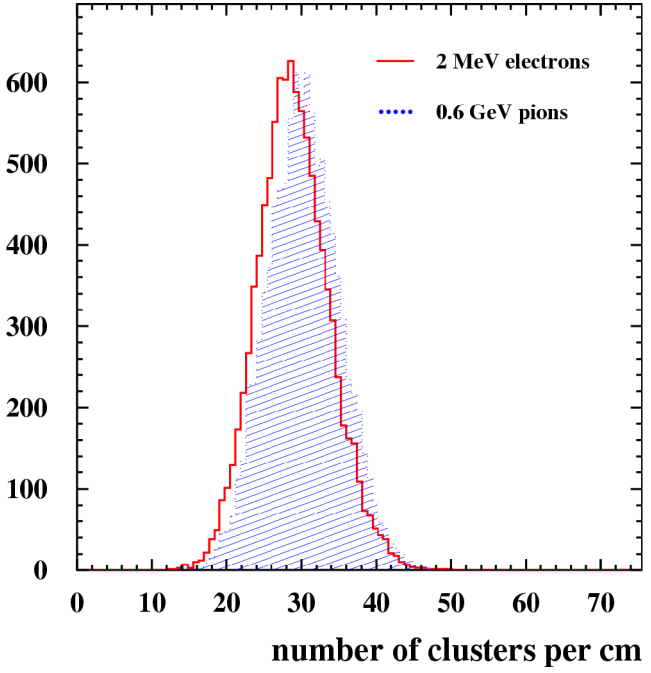



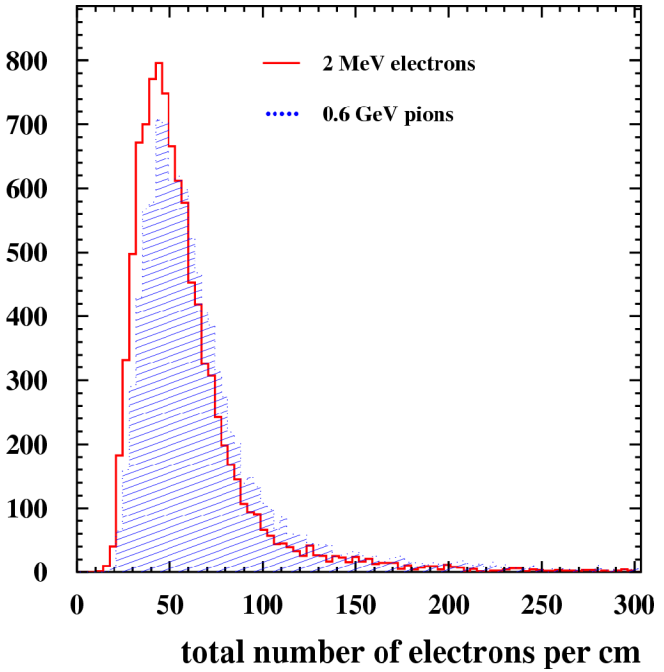
# Cluster Distributions

- **Cluster density of a few MeV electrons from source different to "high energy" m.i.p. (~0.6 GeV pions)?**
  - **NO, about the same, just total number of electrons differs**
    - **2 MeV electrons: 28.9 ± 0.3 clusters/cm, 62.8 ± 0.6 electrons/cm**
    - **0.6 GeV pions: 30.3 ± 0.3 clusters/cm, 76.4 ± 0.6 electrons/cm**
  - **probability for single electron cluster: ~80%**

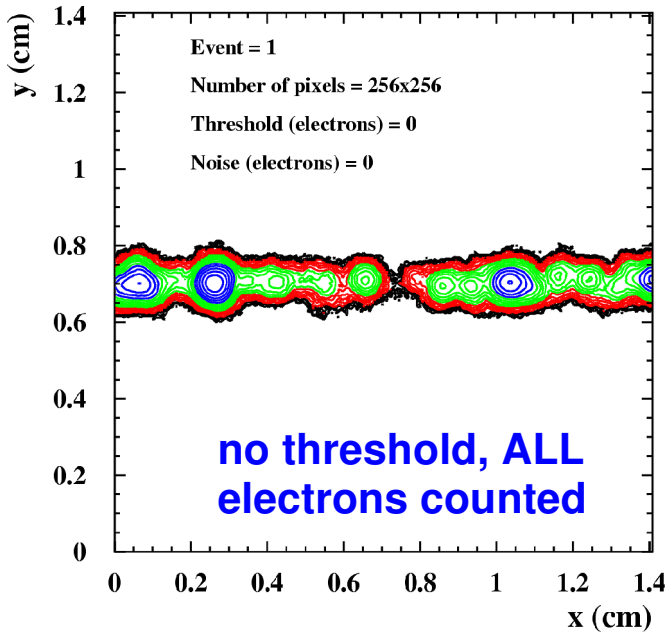
**fewer δ-electrons for 2 MeV electrons**



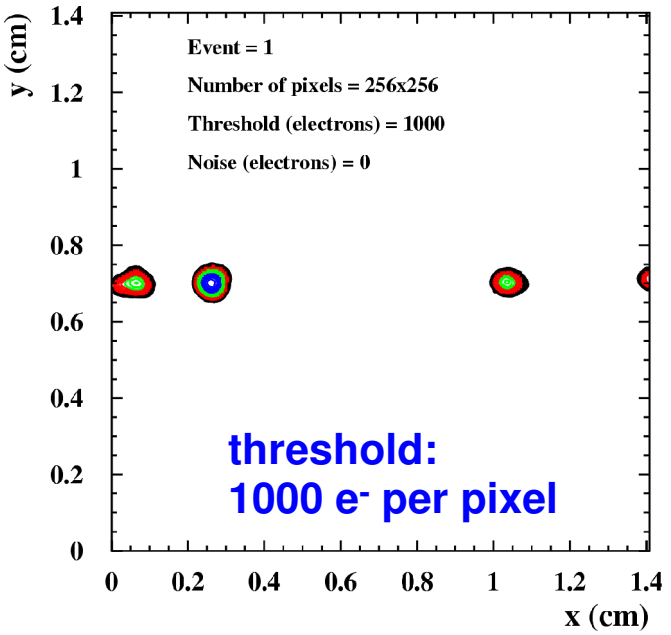



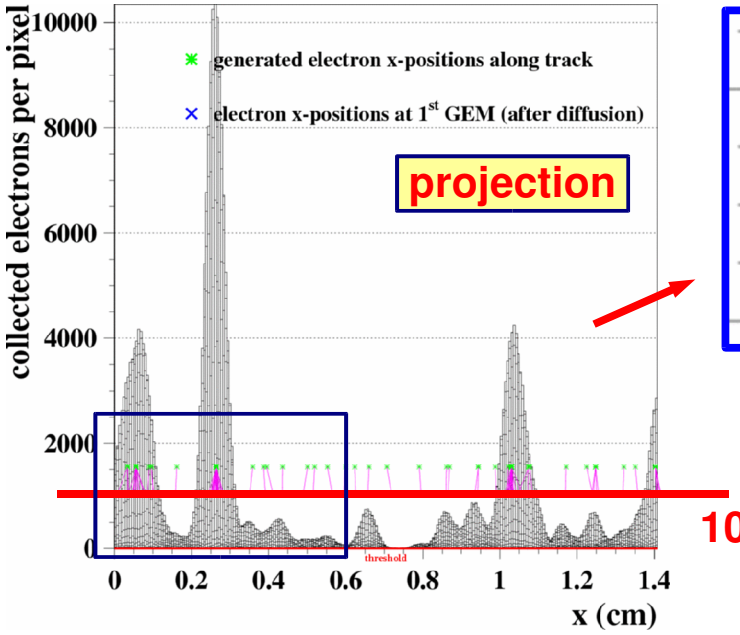
# Electron Charge Distributions



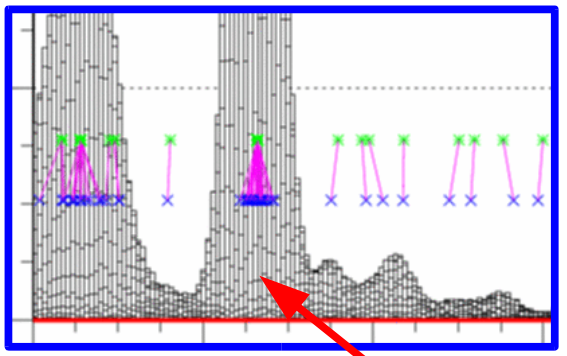

**electron charge distribution on MediPix surface**

**with typical MediPix threshold of ~1000 e⁻ most pixels stay below threshold**




**1000 e⁻ threshold**



**generated e⁻ positions**

**e⁻ positions after diffusion (on top of first GEM)**

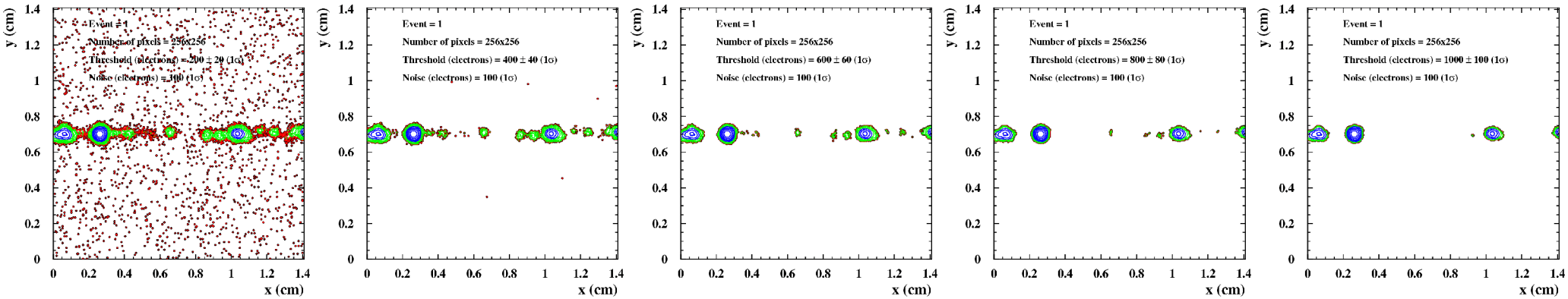
**multi-electron cluster, only clusters with > 1 electron reach the MediPix threshold**
**(or many dense single-electron clusters)**

# Threshold Scan

- **At lower threshold more clusters become visible**
  - **but then running into noise problem**

**detection thresholds per pixel (allow 10% variation):**

**200 ± 20 e⁻** **400 ± 40 e⁻** **600 ± 60 e⁻** **800 ± 80 e⁻** **1000 ± 100 e⁻**




**noise: 100 e⁻**

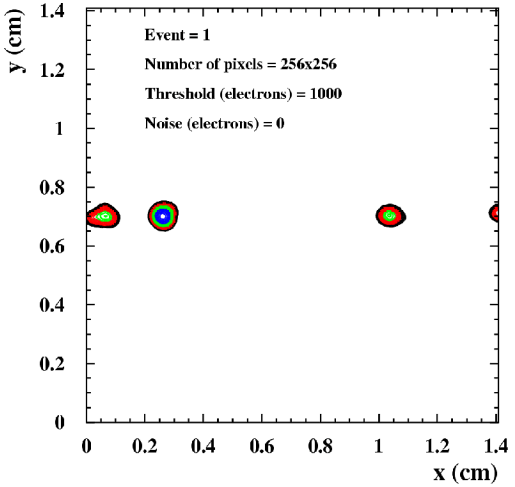
  - **Even with very low threshold sensitivity not sufficient**

- **Basic reason**
  - **diffusion in between GEMs and to MediPIx too large (blobs too large)**
  - **electron charge cloud diluted, too few electrons per pixel**

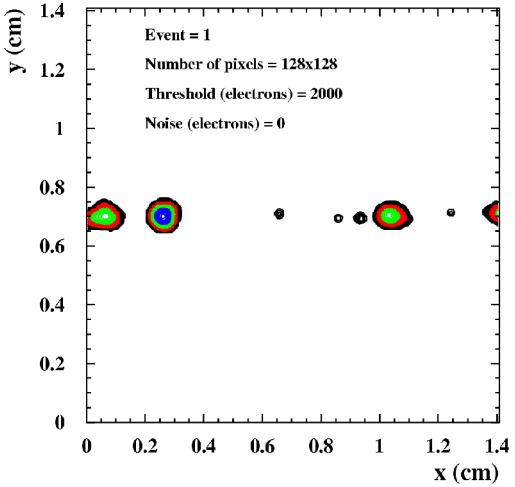
# Larger Pixels

- **Possible solutions**
  - higher gas amplification (but already operating at gas gain of 40000)
  - lower diffusion gas (in E-field range of 5 kV/cm)
  - change GEM set-up, fewer GEMs?, optimize E-field for lower diffusion?
  - have larger pixels, assume noise ~ √(surface area)

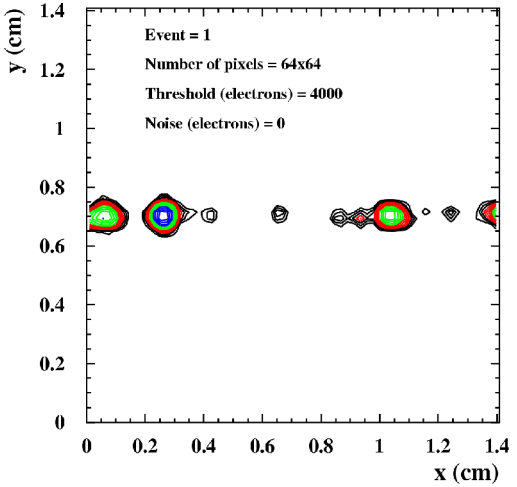
256x256 pixels (55x55 µm²)
threshold: 1000 e⁻




128x128 pixels (110x110 µm²)
threshold: 2000 e⁻



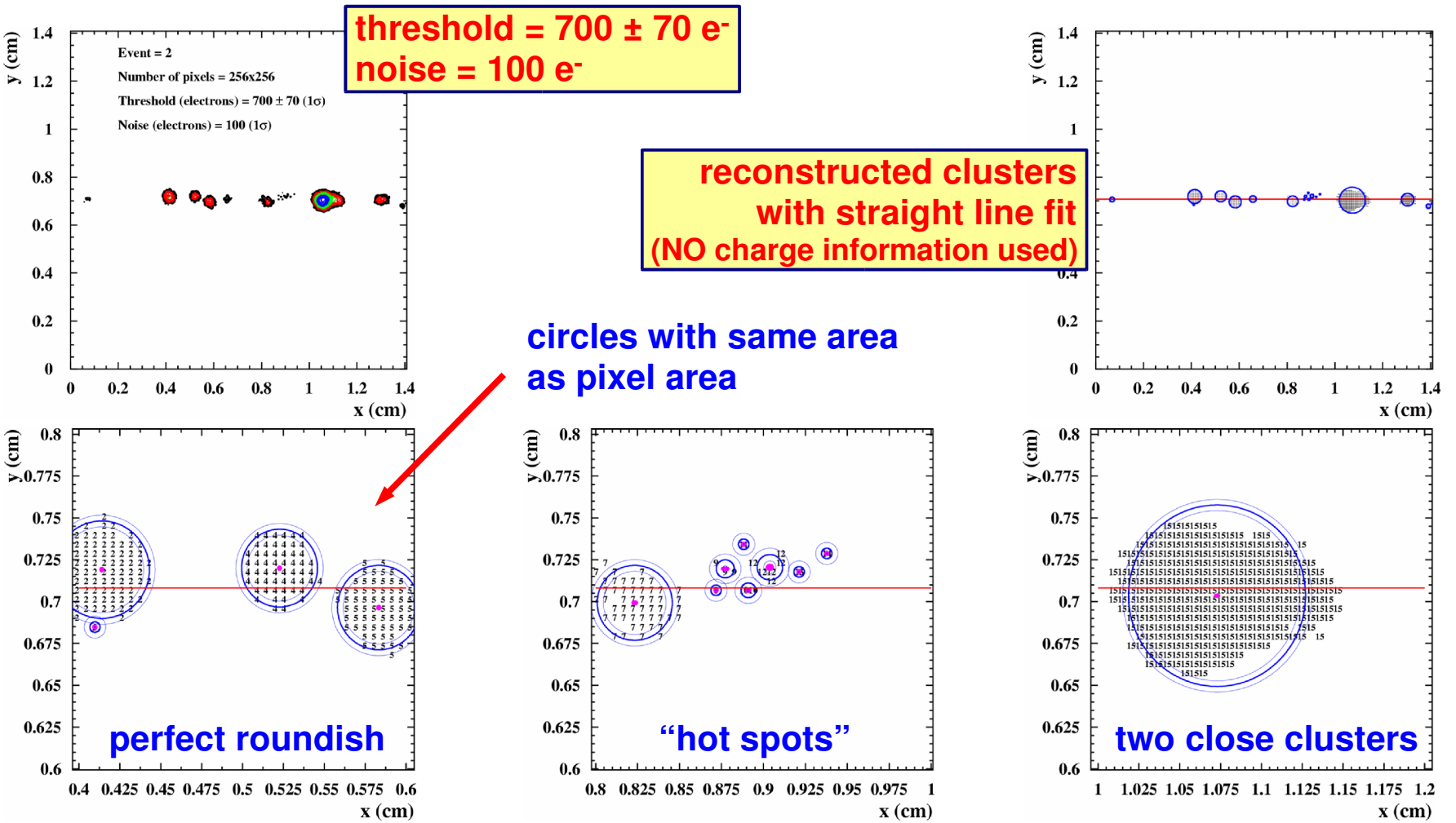

64x64 pixels (220x220 µm²)
threshold: 4000 e⁻



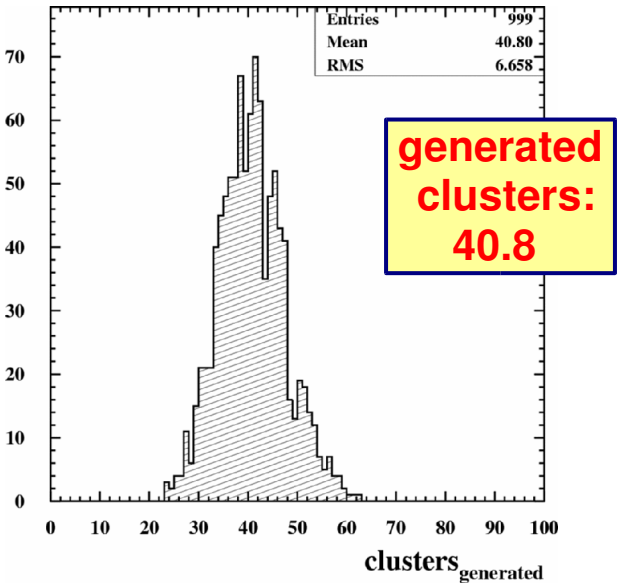

- **Combining pixels helps**
  - more clusters visible, granularity still sufficient for large blobs

# Cluster Finding

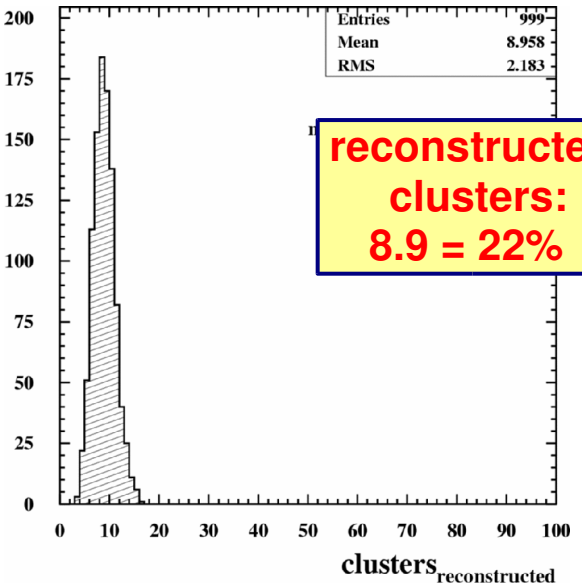
- **Apply simple cluster finding algorithm + check performance**
  - **search for simply connected areas, use center-of-gravity**



# Reconstructed Clusters + Residuals

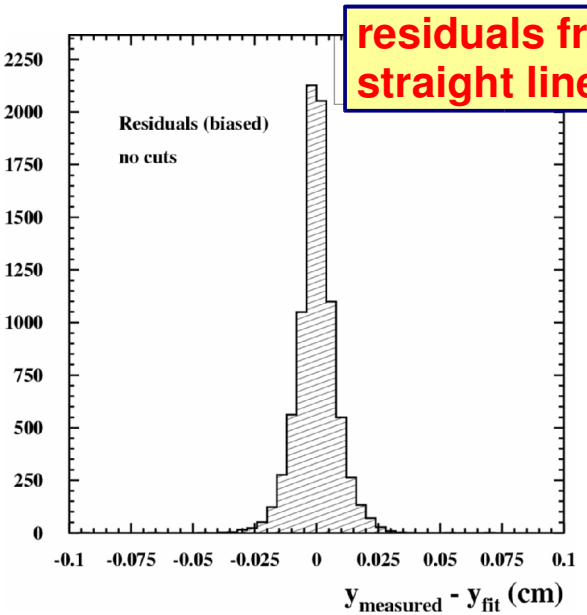



generated clusters: 40.8




reconstructed clusters: 8.9 = 22%

only ~22% of all generated clusters reconstructed, agrees roughly with number of multi-electron clusters



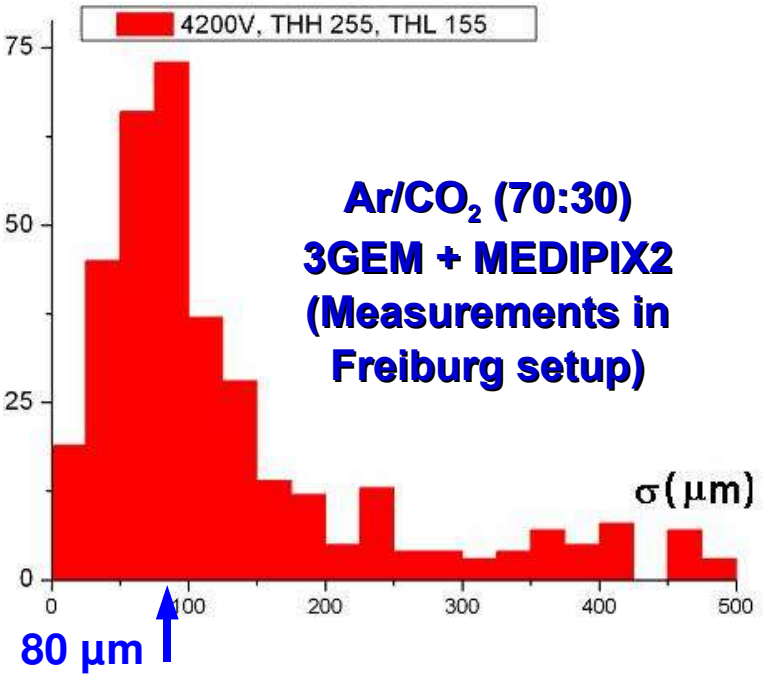

residuals from straight line fit

**Standard deviation from straight line fit:**

| RMS | |
|---|---|
| biased: | 80 µm |
| unbiased: | 98 µm |

point in question not inclued in fit

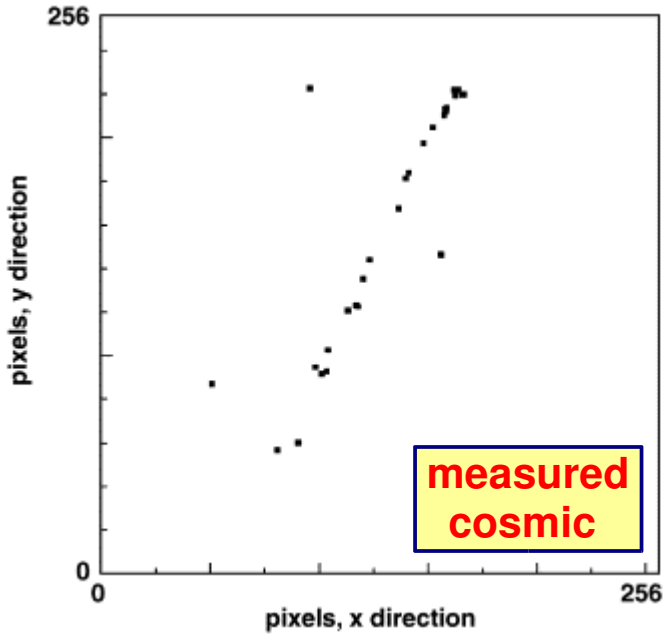
nice agreement with measurements in Freiburg

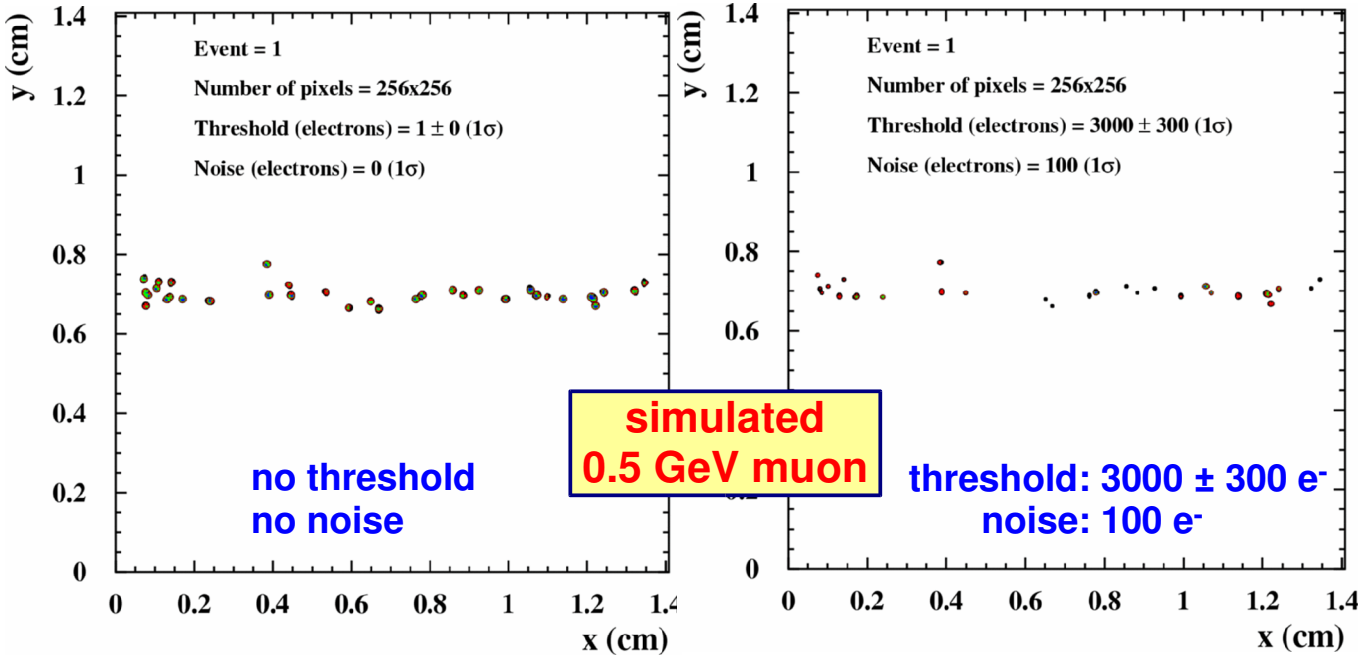



Ar/$CO_2$ (70:30)
3GEM + MEDIPIX2
(Measurements in Freiburg setup)

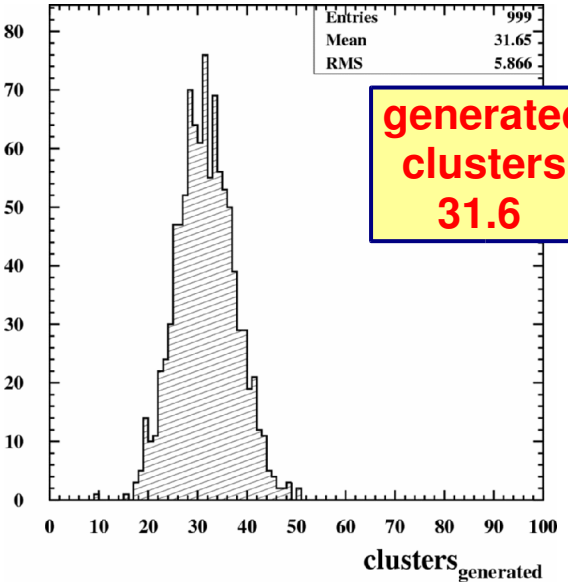
# MicroMegas I

- **Main differences between GEMs (Freiburg) + MicroMegas (NIKHEF) set-up**
  - only 50 µm gap + high E-field (70 kV/cm) from MicroMegas to MediPix, ~5 mm at ~4.5 kV/cm from first GEM to MediPix
  - ➡ much lower diffusion in MicroMegas case ⇒ expect (much) smaller blobs
  - $Ar/CO_2$ (70:30) used in GEM set-up, He/i-$C_4H_{10}$ (80:20) in MicroMegas set-up
  - ➡ more diffusion in drift space, He/i-$C_4H_{10}$: 220 µm, $Ar/CO_2$: 107 µm

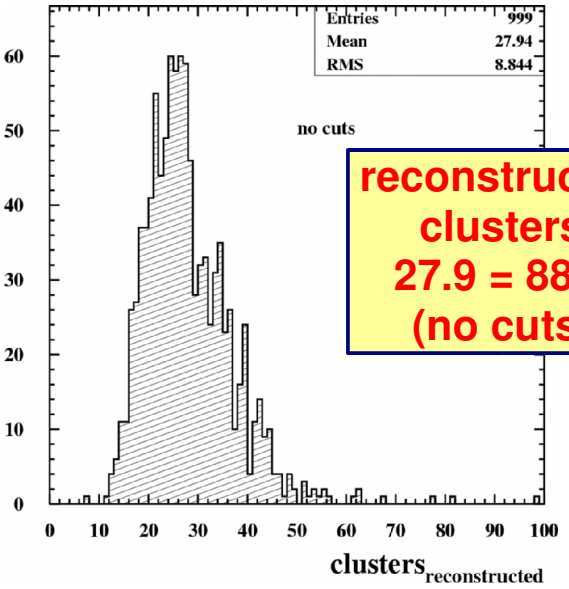


# MicroMegas II

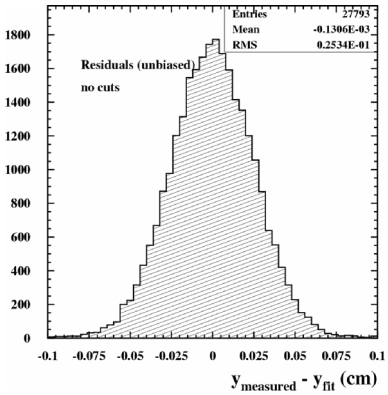



generated clusters: 31.6




reconstructed clusters: 27.9 = 88% (no cuts)

- **More reconstructed clusters w.r.t. GEMs**
  - 88% of all generated clusters (no cuts)
  - 48% of all clusters with > 1 pixel
    - eliminates noise
- **Larger residuals:**
  - 237 µm biased, 253 µm unbiased




- **Some discrepancies to NIKHEF simulations**

| | NIKHEF | HEED |
|---|---|---|
| generated cluster density: | 1.4 cl./mm | 2.25 cl./mm |
| electrons per cluster: | 3.16 | 1.42 |
| electron density: | 4.42 $e^-$/mm | 3.20 $e^-$/mm |

  - to be understood

# Conclusions

- **GEMs + MediPix**
  - large "blobs" because of large diffusion among GEMs and to MediPix
    - electron cloud diluted over too many pixels, many pixels below threshold, single electrons clusters mainly undetected
  - solutions
    - reduce diffusion (optimize gas, E-field, GEM set-up)
    - use larger pixels, granularity still good enough for large "blobs"
- **MicroMegas + MediPix**
  - rather small "blobs" because of low diffusion between MicroMegas and MediPix
    - efficient to detect individual electrons, need to keep small pixel size
- **GEMs vs MicroMegas**
  - GEMs good to detect whole clusters, Micromegas single electrons
  - What do we need?
    - e.g. dE/dx needs cluster counting, not counting of electrons

# Outlook

- **...at the ILC...**
  - **100 GeV muon, B = 4 T, TESLA-TDR gas, 100 cm drift**

**identical events: same generated primary clusters/electrons**