Spatial Resolution Studies for a Time Projection Chamber with GEM Technology in Karlsruhe

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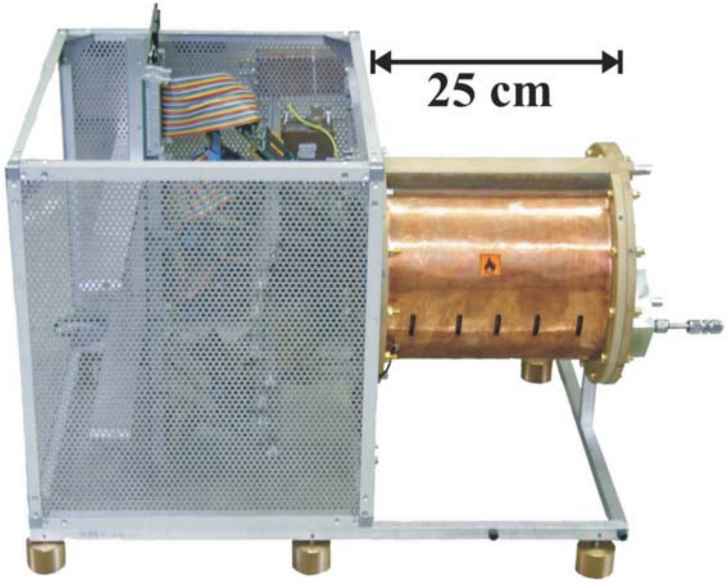
The Karlsruhe GEM-TPC Prototype



Drift Cylinder:

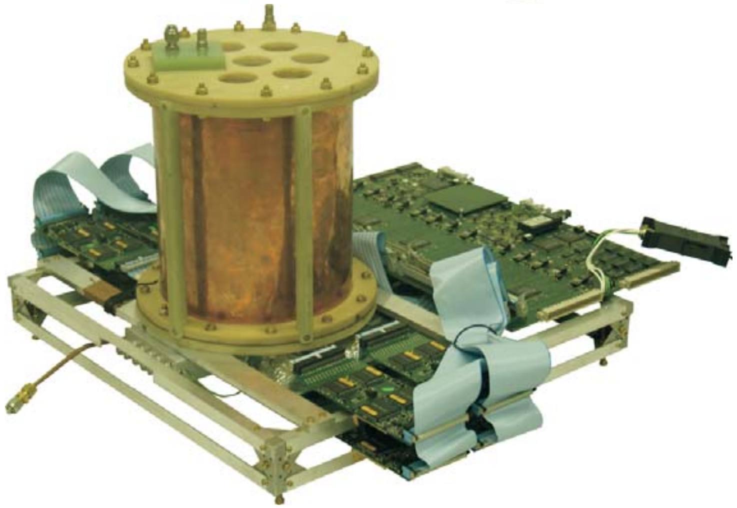
- Inner diameter d=20cm, length l=25cm
- Double field cage (Field homogeneity)

End caps:

- Detector can be equipped with different MPGD types and readout structures

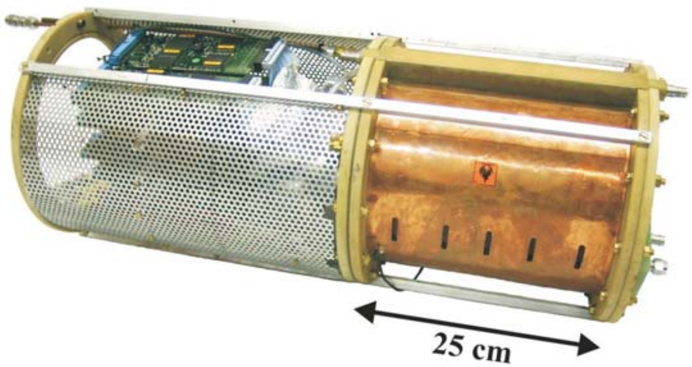
Readout electronics:

- Some modified channels from the STAR exp.
- Low-noise highly-integrated front-end electronics
- Sampling rate: 19.6 MHz, shaping time: 180 ns

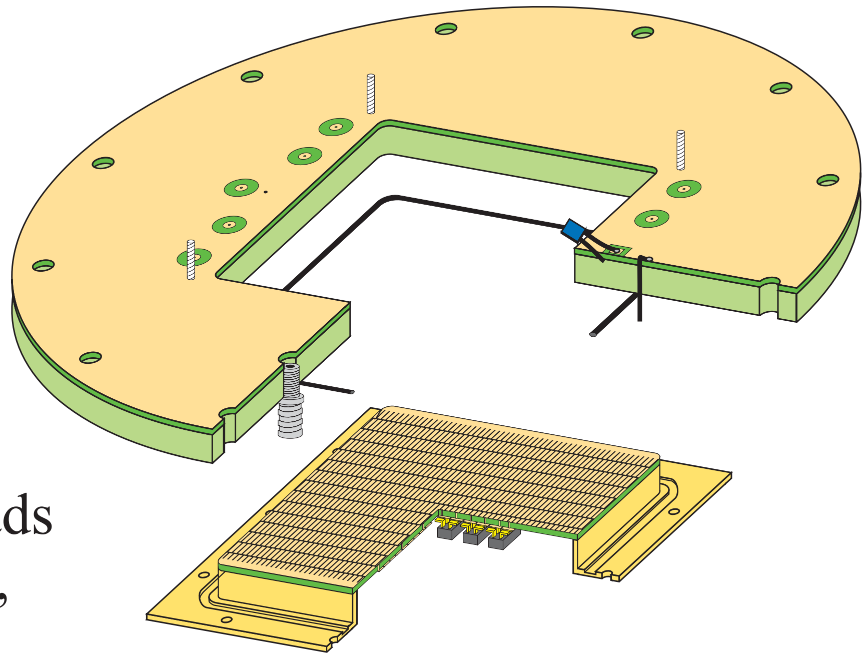


Support structures for measurements:

- Different support structures for measurements at CERN, Karlsruhe and DESY



The Karlsruhe GEM-TPC Prototype

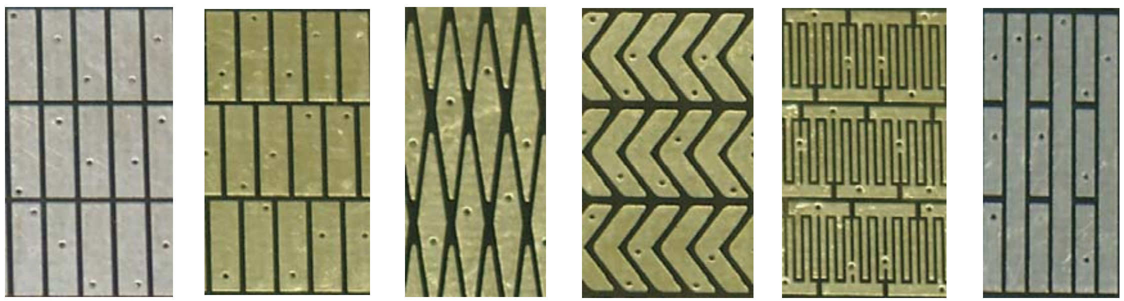


Used gas amplification stage:

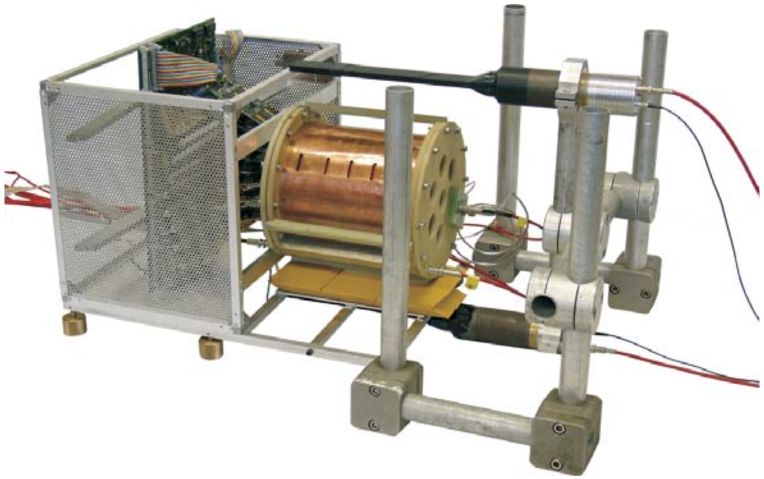
- Double GEM structure
- Standard GEMs (p:140µm, D=70µm, d=60µm)
- Active area: 10x10 cm²
- 2mm gaps (E_T=2.5kV/cm, E_I=3.5kV/cm)

Existing readout geometries:

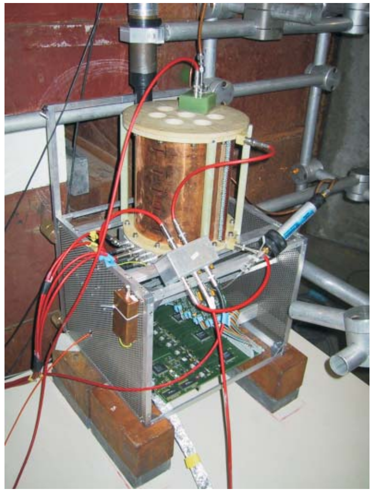
- Pad size: 1.27*12.5 mm²; normal rectangular pads
- Pad size: 2.0*6.0 mm²; normal rectangular pads, staggered pads, rhombic, chevrons, combs, 3and1
- Additionally planned for simulation: variations of combs and chevrons, different pad widths



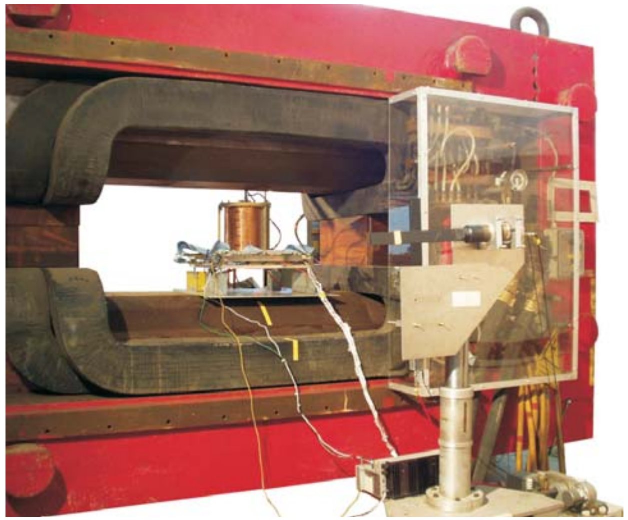
Measurements (Karlsruhe, CERN, DESY)



Karlsruhe: cosmics
=> First tests, large diffusion



CERN proton synchrotron, pions, well-defined tracks
=> Spatial Resolution, large diffusion

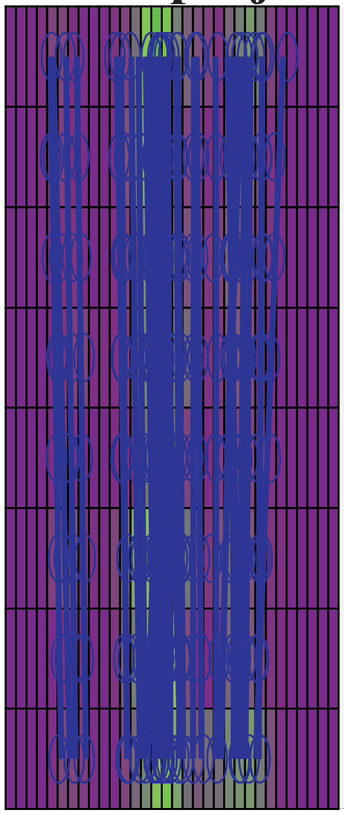


DESY testbeam and 1T magnet
=> combination, spatial resolution studies for different pad structures

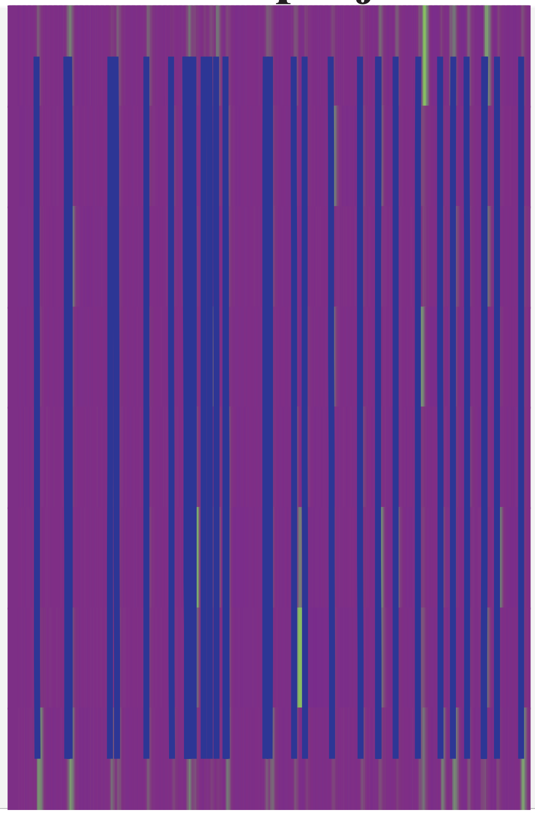
DESY 5.5T magnet, cosmics
=> small diffusion TDR gas at 4T as in TESLA-TDR, only short drift dstances

The TPC Reconstruction and Analysis package

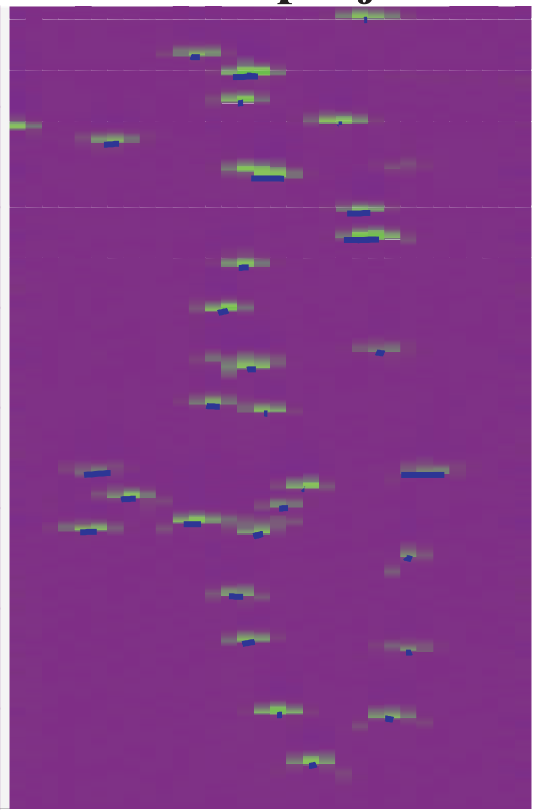
X-Y proj.



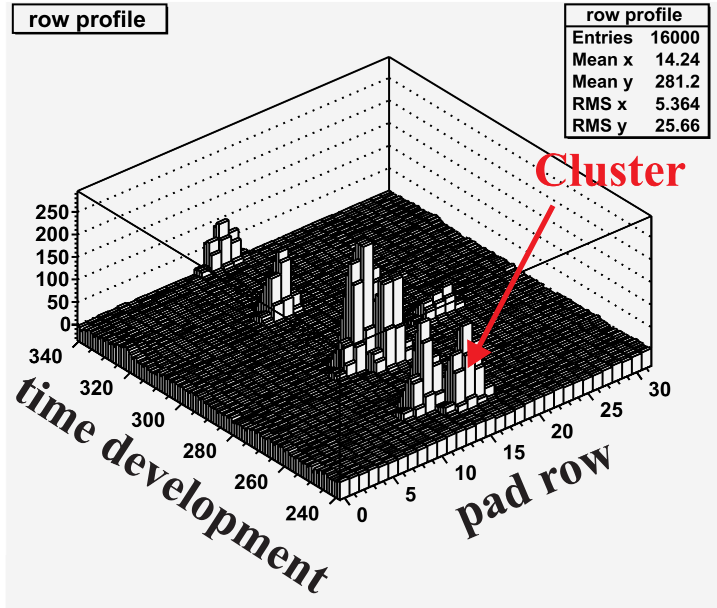
Z-Y proj.



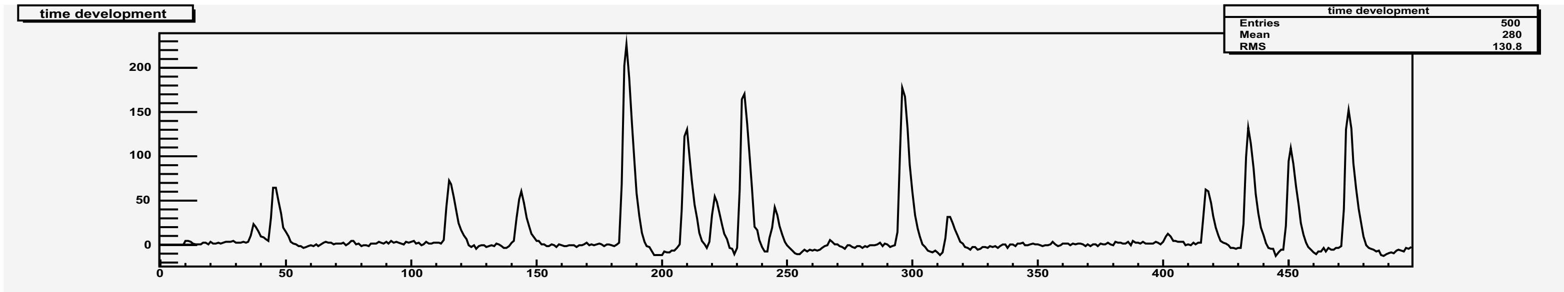
X-Z proj.



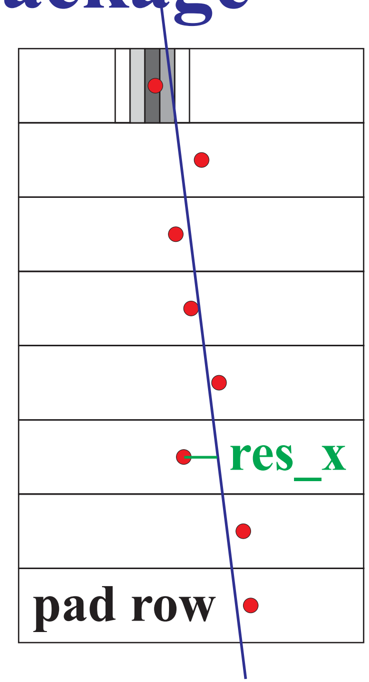
Cutout of a pad row profile:



Time development of one pad:



The TPC Reconstruction and Analysis package



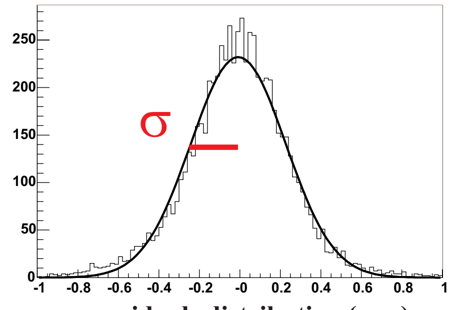
Cluster determination:
- position by COG, width by RMS (alternatively Gaussian Fit)

Track determination:
- combinatorical track finder
- linear or parabolic regression (alternatively Fit)

Residuals determination:
- distance of cluster position to track (indep. for x- and z-direction)

Spatial resolution:
- Gaussian width of residual distribution
- "geometric mean" method*:

$$\textbf{s.r.} = \sqrt{\sigma_{\textbf{incl}}\ \sigma_{\textbf{excl}}}$$

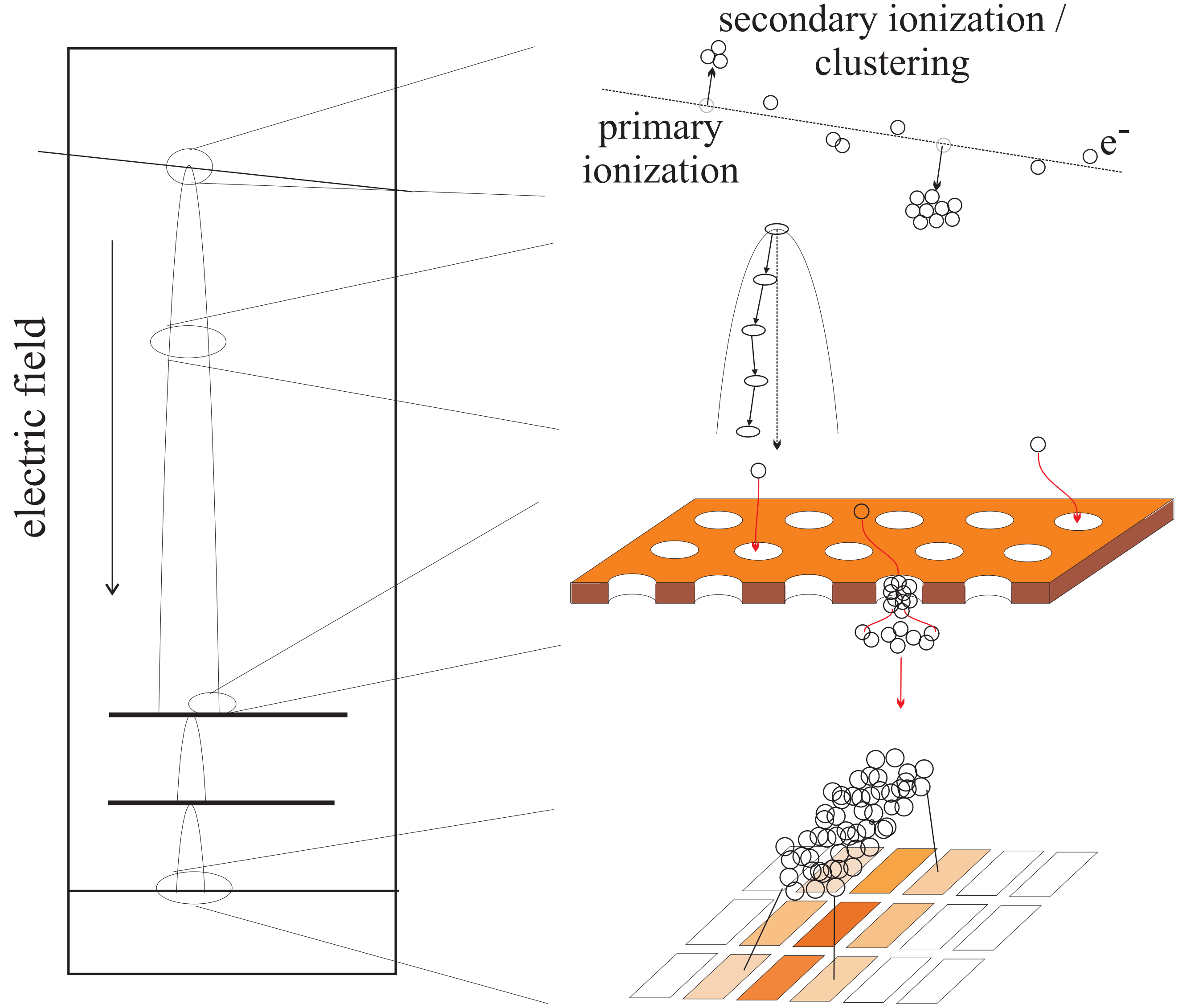


σ_{incl}: residual width of track with test cluster (included)
σ_{excl}: residual width of track without track cluster (excluded)

Theory and comparison with simulated data show best agreement with this method

*** (Carnegie et al., "Resolution studies of cosmic-ray tracks in a TPC with GEM readout", NIM A 538)**

The TPC MonteCarlo Simulation package



Calculation of trajectory
Distribution of electrons
- **Clustering**
- **Range of secondary electrons**

Diffusion in the drift volume

Allocation to holes of GEM1
Amplification in GEM holes
Broadening after GEM1

Diffusion in the transfer gap

GEM2

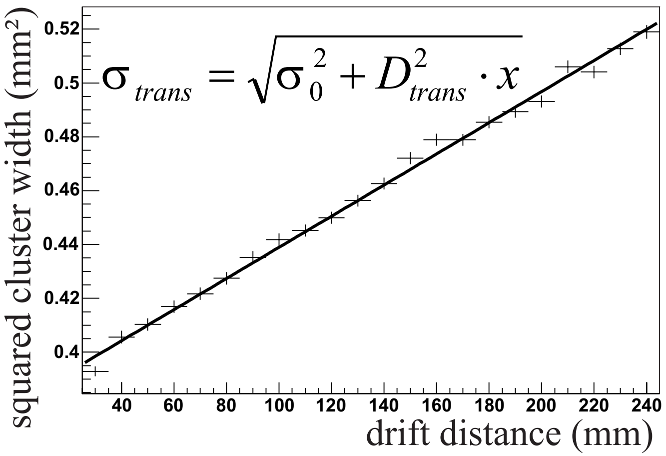
Diffusion in the induction gap

Allocation to pads

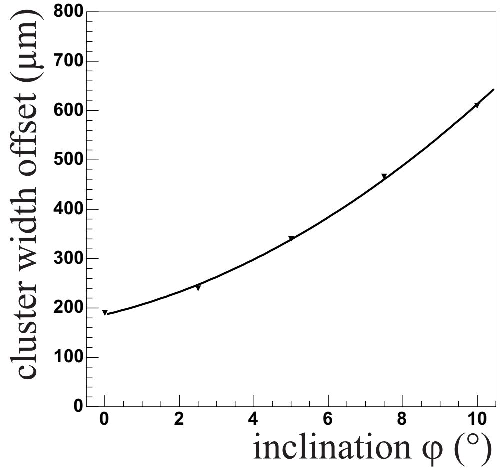
Diffusion: Coefficient and Offset

Cosmics measurements: Diffusion coefficients => too low; Offset => too high
Suggestion: Generated by noise and inclination => no problem
Tested with simulated data:

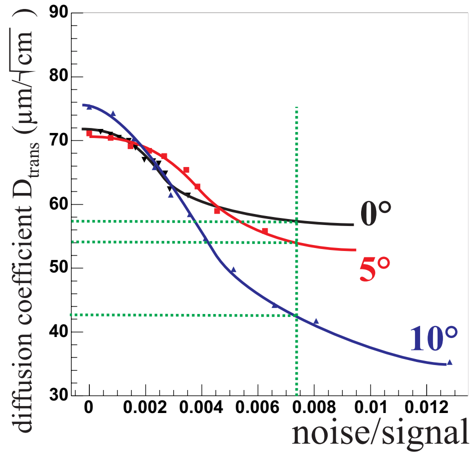
Typical diffusion measurement:



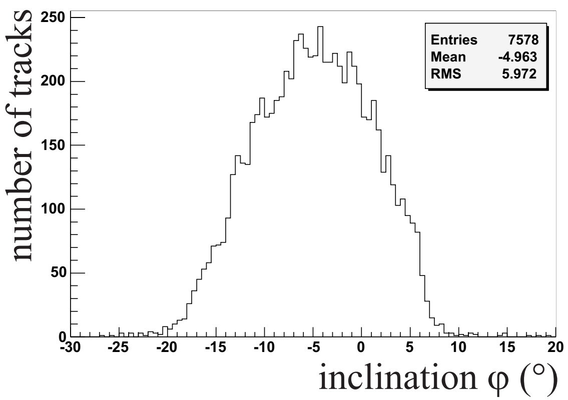
Offset σ_0 as function of φ



D_{trans} as function of S2N



Used "real" data sample:



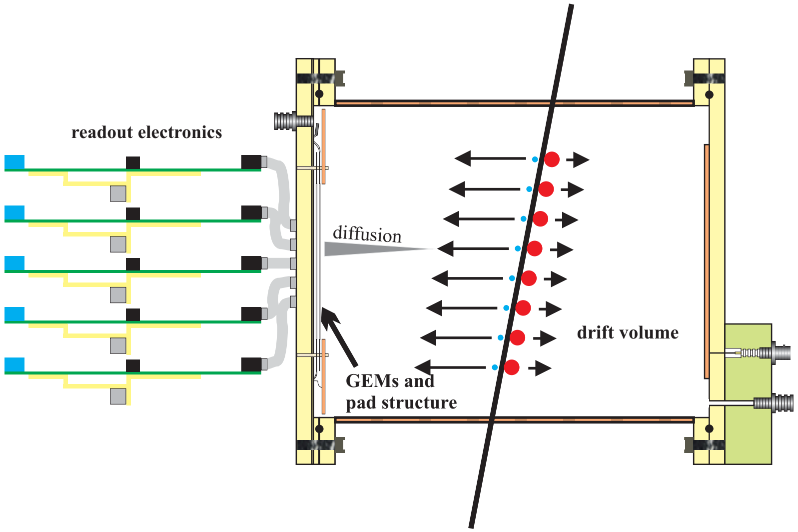
Measured: σ_0 = 487.62 µm; D_{trans} = 51.15 µm/√cm

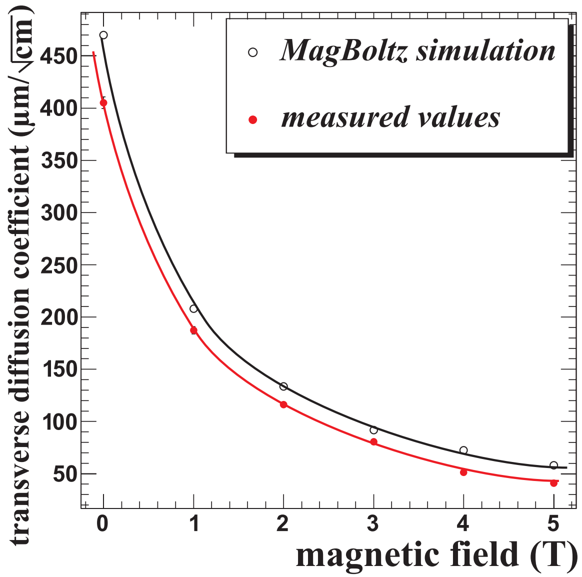
σ_{tot} of added Gaussians

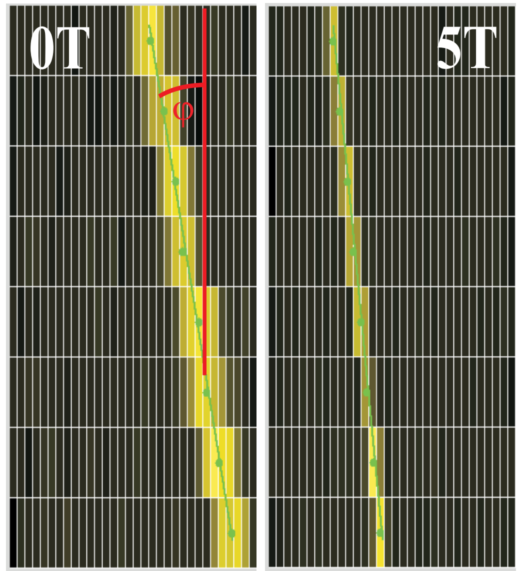
=> Approx: $\sigma_{tot} = \Sigma\, n(\varphi)*\sigma(\varphi)^2 \,/\, \Sigma\, n(\varphi)*\sigma(\varphi)$

σ_0(approx) = 483 µm; D_{trans}(approx) = 52.6 µm/√cm

What happens in the magnetic field?







$$\sigma_{trans} = \sqrt{\sigma_0^2 + D_{trans}^2 \cdot x}$$

Vertical tracks with TDR 4T:

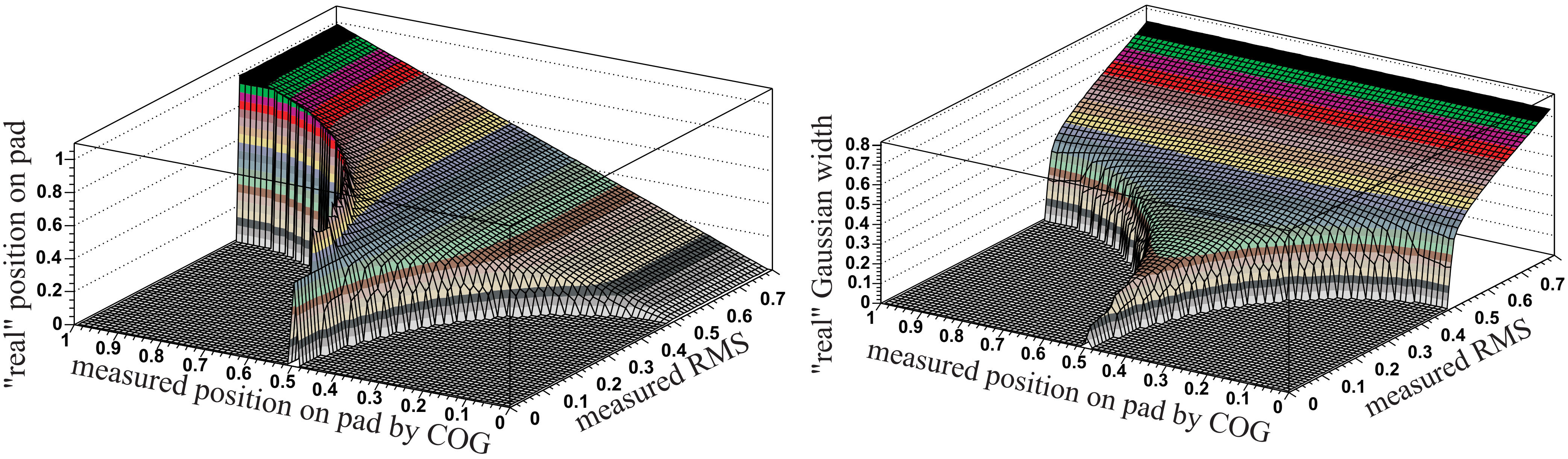
$$\sigma_0 = 200\,\mu m \Rightarrow \sigma_{trans}(4T) < 300\,\mu m$$

=> Very often only 1 or 2 pads hit, especially for 2x6mm² pads

=> $res_{trans} \rightarrow \frac{padwidth}{\sqrt{12}} = 367\,/\,577\,\mu m$ **(else:** $\frac{\text{primary cluster width}}{\sqrt{\text{e\_per\_pad}}}$ **)**

AND: COG and RMS do not work properly with few pads

Method 1: Direct COG and width correction



Interesting region: "real width" in units of pad widths smaller than 0.32

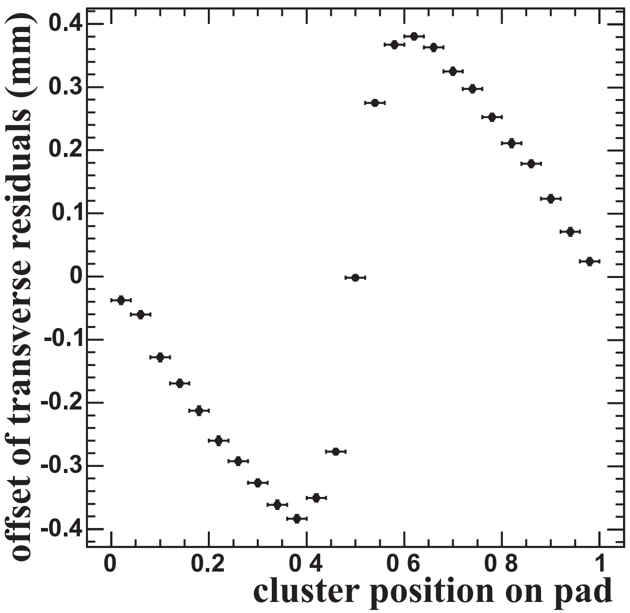
Possible ways out:

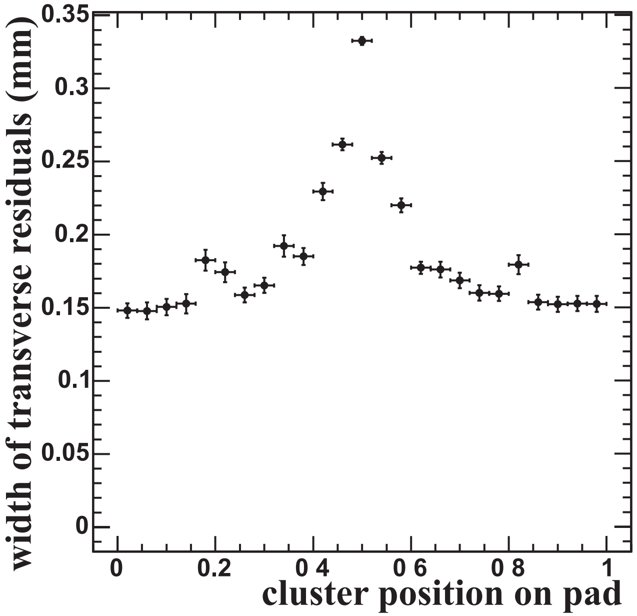
- **larger clusters (e.g. broadening by larger induction gap)**
- **narrow pads (here 1.27 mm absolute minimum)**
- **immense S2N ratio (not reasonable)**
- **new pad geometries (better charge sharing, see below)**

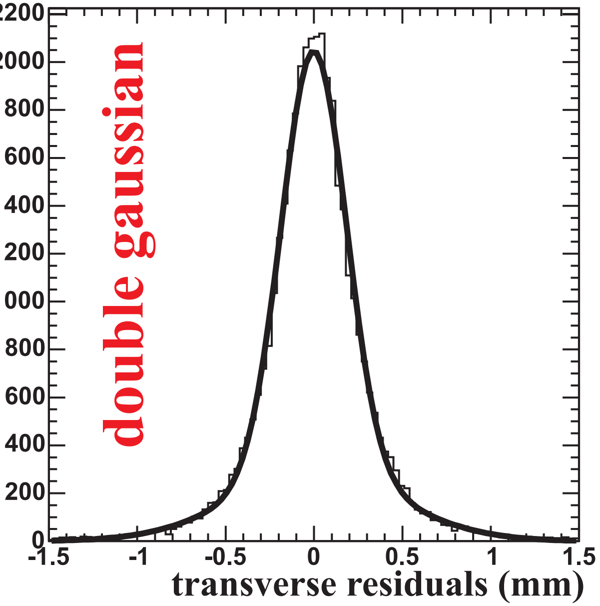
Planned: simulations with various induction gaps or different pad widths

Method 2: Correction by remaining track

Easier for our analysis, but not possible for real experiment !







Drawbacks:

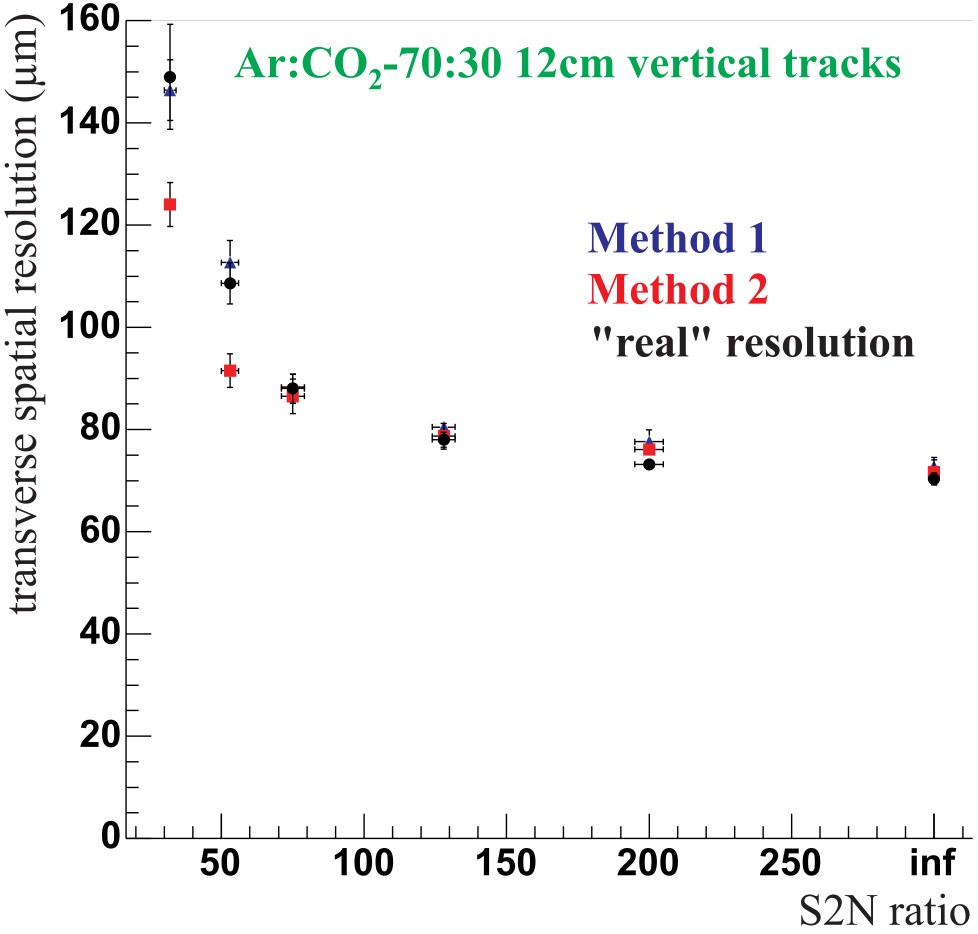
problems in the same region as other method

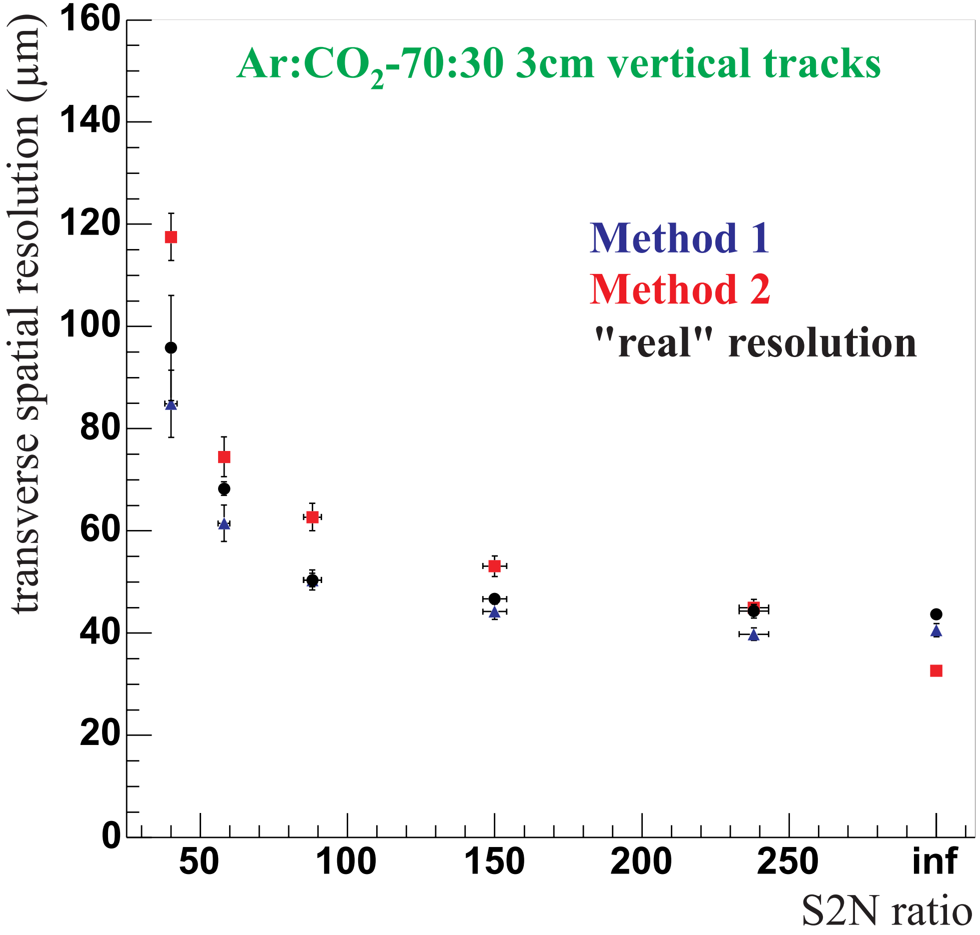
vertical tracks are shifted to pad center

=> possible overestimation of spatial resolution

UNIVERSITÄT KARLSRUHE (TH)

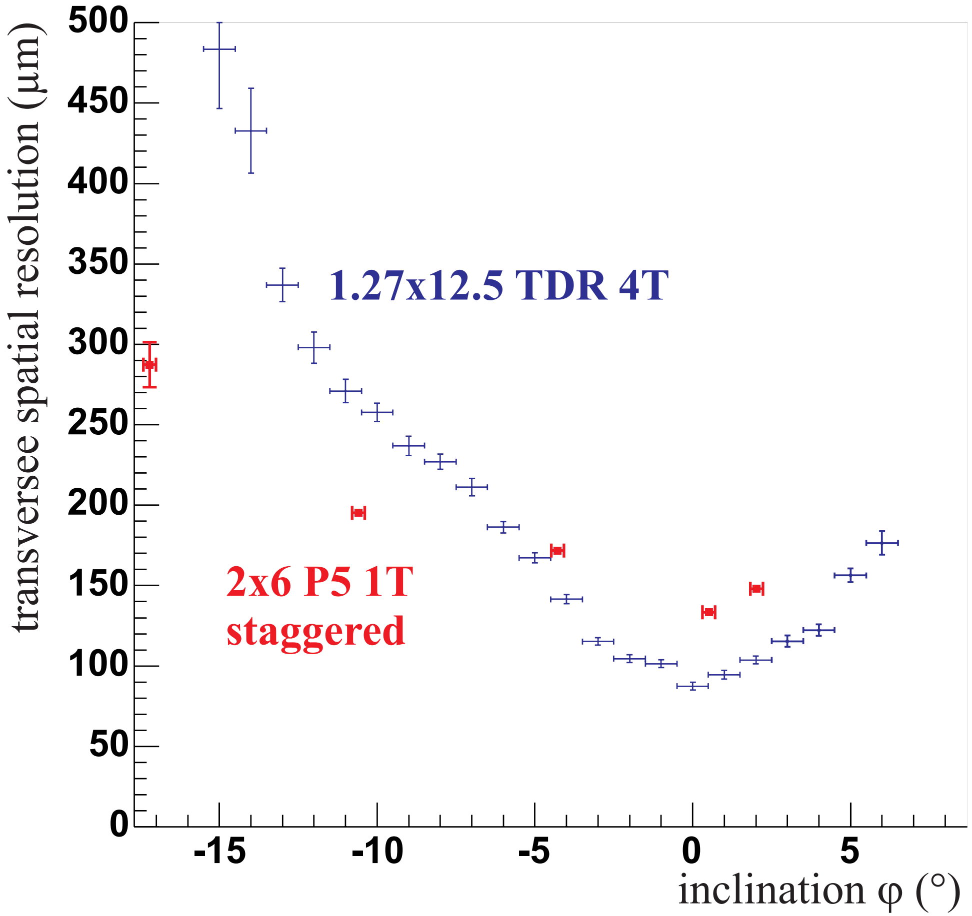
Comparison with simulated data

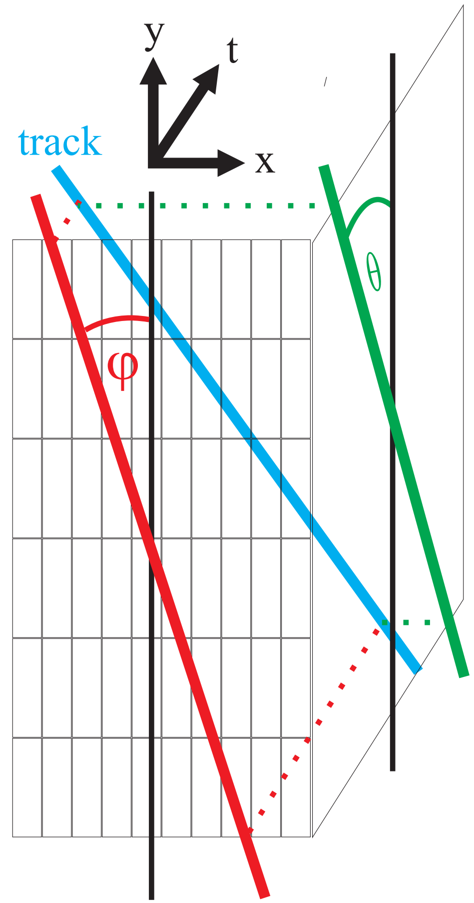




=> Both methods okay,
Method 1 a bit better, but also overestimation below 60µm resolution

Spatial Resolution: Dependency on inclination φ

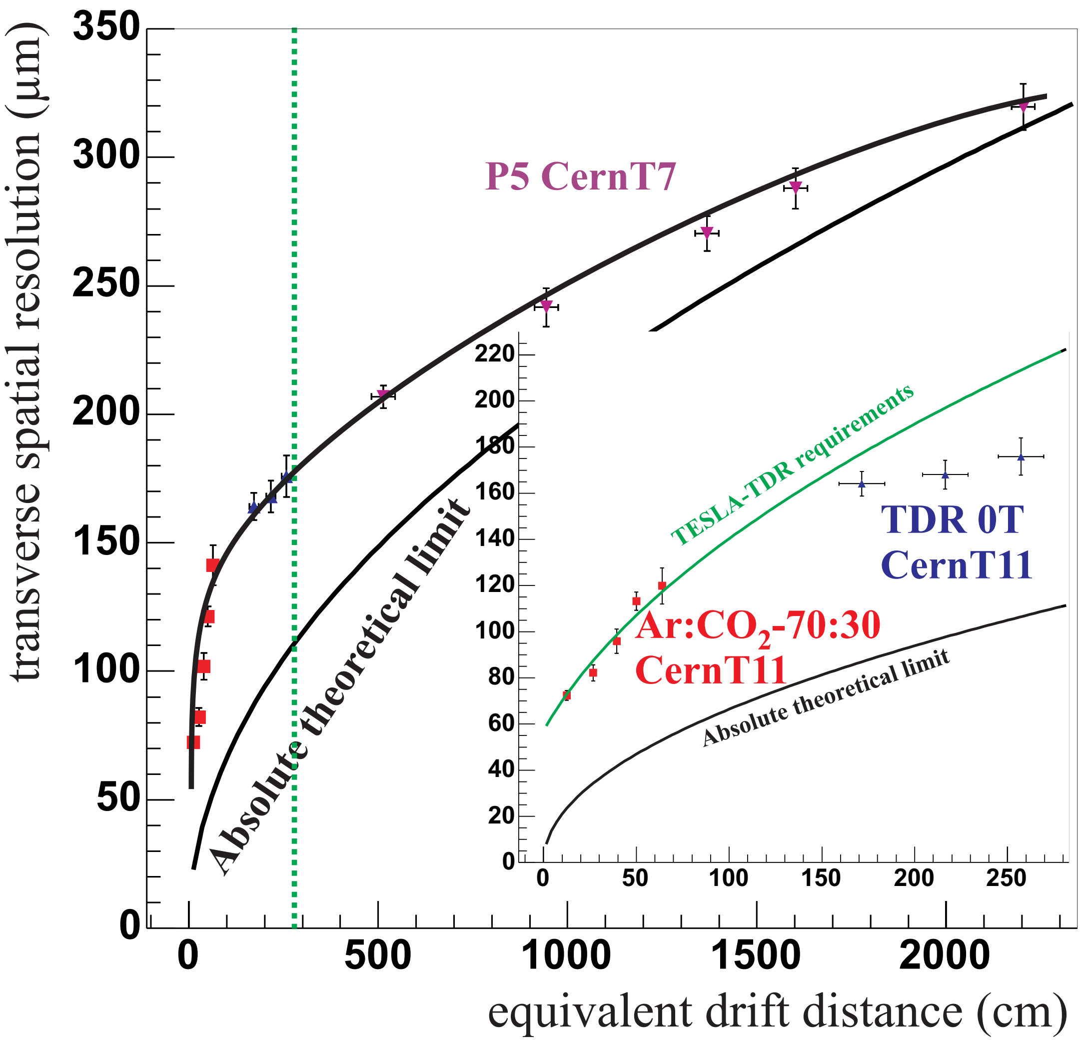




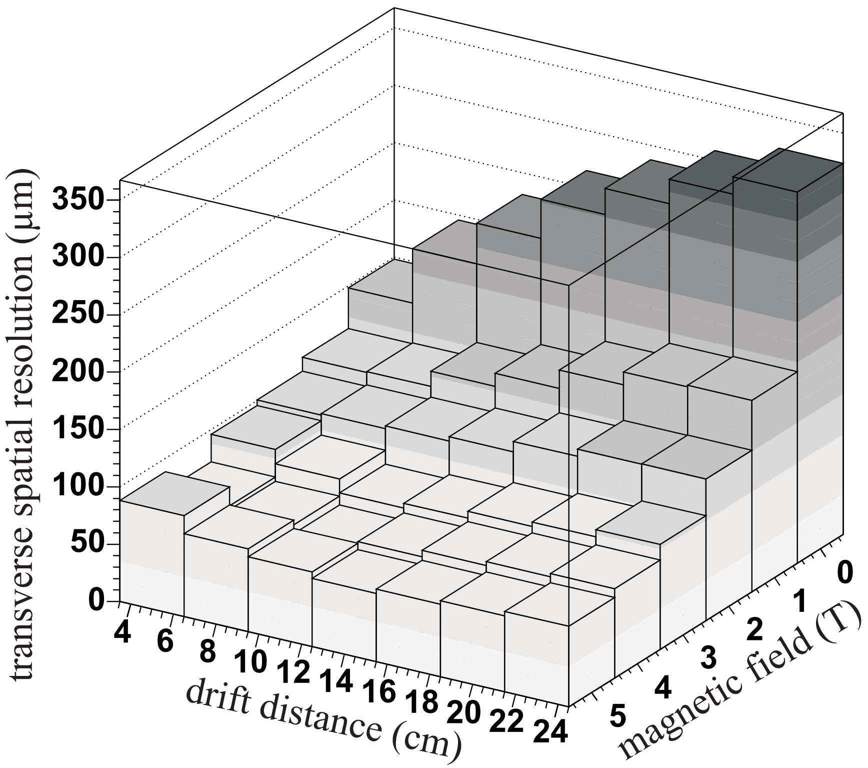
2x6mm² pads better than 1.27x12.5 mm² pads referring to inclined tracks.

Spatial Resolution: Dependency on drift distance

Several test beam measurements at 0T:



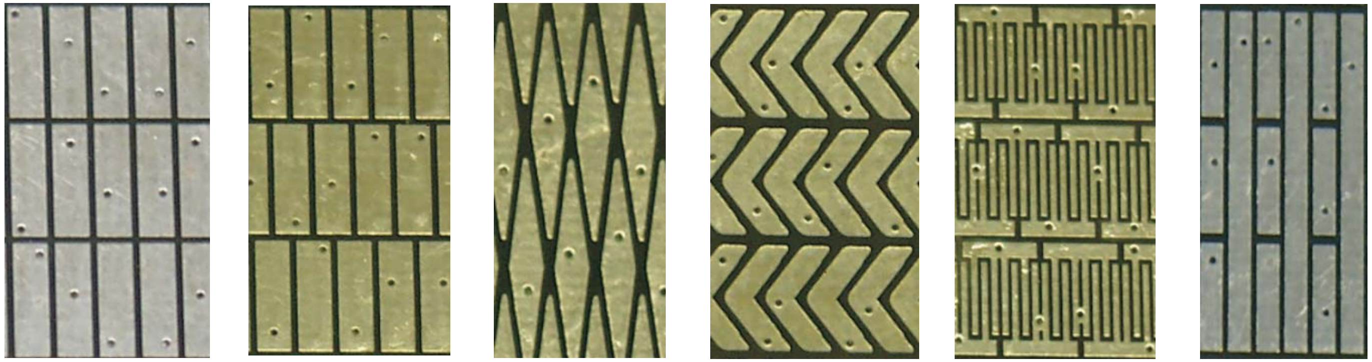
Magnet test at DESY => TDR gas



Values at 4T fit exactly with left curve!

But all measurements: 1.27 x 12.5 pads!

Studies with different pad structures: Measurements



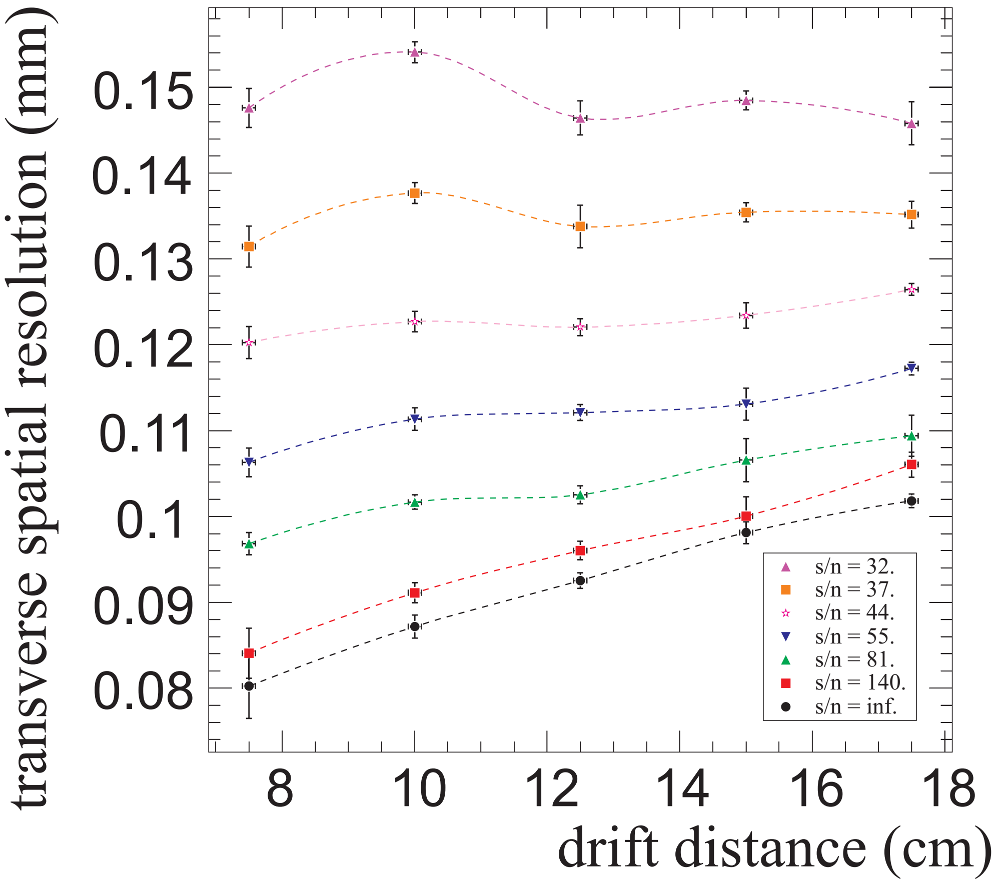
geometry	t.s.r. (7.5 cm) in µm	t.s.r. (17.5 cm) in µm	t.s.r. (gain = 10^4) in µm	t.s.r. ($\phi = 10°$) in µm	fraction of clusters (1 pad/cl.)
rectangular	172	190	158	186	0.15
staggered	146	126	119	189	0.211
rhombic	179	150	130	232	0.141
chevron	265	250	220	286	0.078
comblike	315	231	260	437	0.039
3 + 1	178	191	174	445	0.074

=> best resolution for 2x6mm² staggered pads

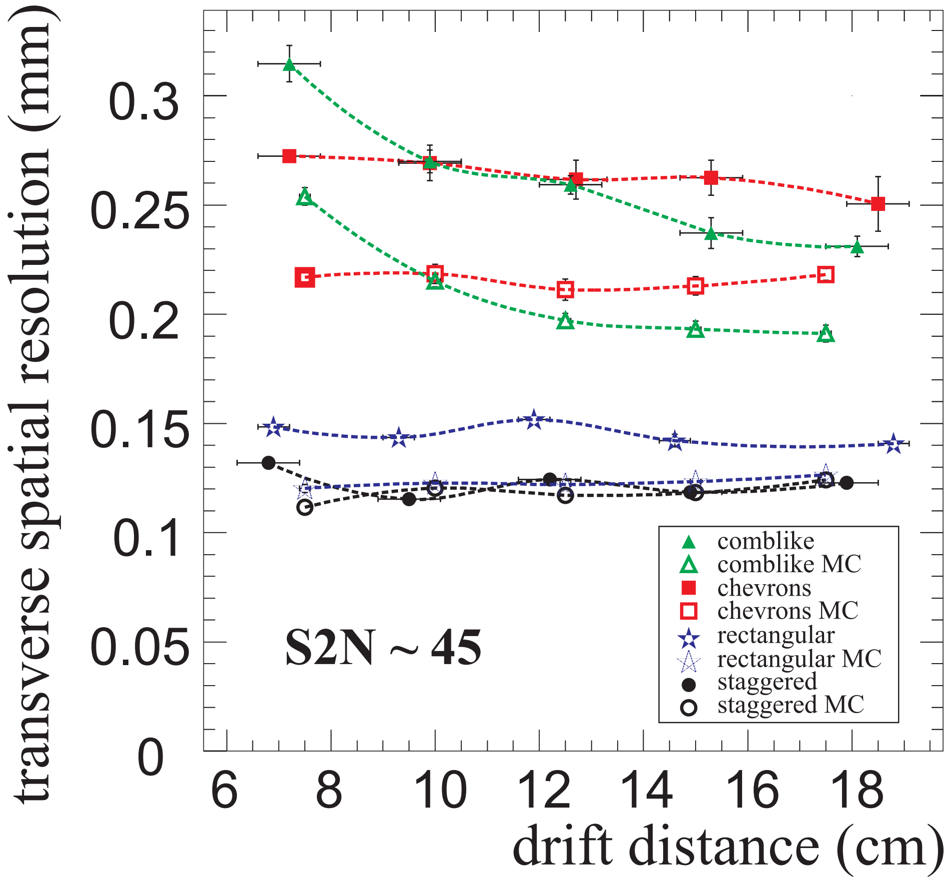
BUT: Variations of other geometries under investigation with MonteCarlo data

Comparison to MonteCarlo simulated data

Dependency on S2N ratio:



Comparison different pad geometries:



Perfect agreement for staggered pads, discrepancies for other geometries
Resolution not "in saturation" for S2N ratio of measurements

Summary and Outlook

- In Karlsruhe a TPC prototype was built, equipped with GEM foils and was operated reliably in various test setups
- Spatial Resolution Studies for the ILC detector: TESLA TDR requirements can be fulfilled
- Pad geometry study with 7 different geometries: $2x6mm^2$ staggered pads showed best performance
- $2x6mm^2$ pads need higher gains and stronger cluster broadening (=> 3 GEMs, larger transfer/induction gap)
- MonteCarlo simulation works properly and can be used for further investigations
- Not shown: Longitudinal spatial resolution, dE/dx, efficiency, ...
- In progress:
  - Further simulations for optimization of pad geometry and amplification stage.
  - Multi hit resolution studies

The ILC Project: *The International Linear Collider*

Ziel: Precision measurements of (possible) new physics after the LHC

International Technology Recommendation Panel (ITRP): "... we recommend that the linear collider will be based on superconducting technology. … This technology has features, that the Panel considered attractive and will facilitate the future design…"

=> All stated numbers => TESLA-TDR

Requirements on the Central Tracking Detector:

Momentum Resolution $\Delta p_t/p_t^2 < 2 \cdot 10^{-4}$/GeV

Multi-Hit Resolution: 2.3 mm in r-φ, 10 mm in z

Precise dE/dX-Measurement: $\sigma_E/E < 5$ %

Possible Choice (see TESLA-TDR): Time Projection Chamber

Sensitive Volume of 2x 2.50m length, 1.62 m outer and 0.32 m inner radius

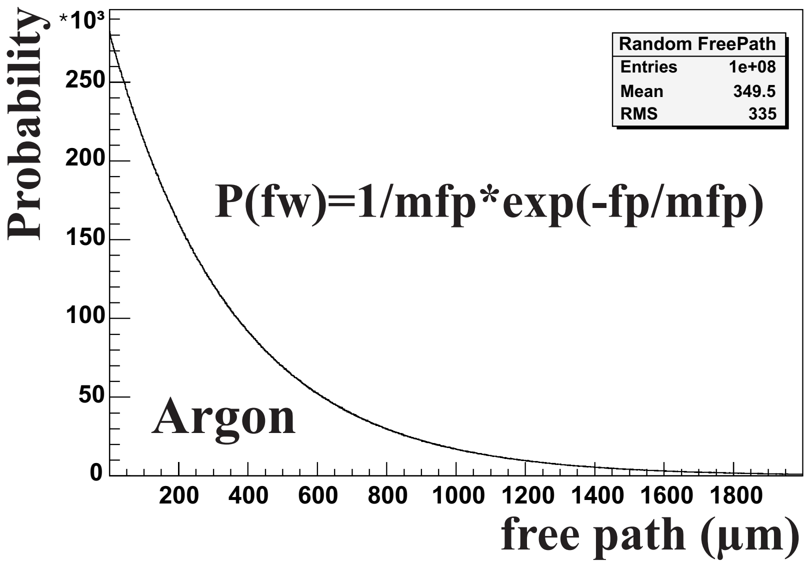
Magnetic Field: 4T; Drift Field: 240 V/cm; Gas: $Ar:CO_2:CH_4$ – 93:2:5 (TDR gas)

Expected Spatial Resolution $\sigma_{r\text{-}\varphi}$: 70µm (for d=0.1m); 190µm (for d=2.0m)

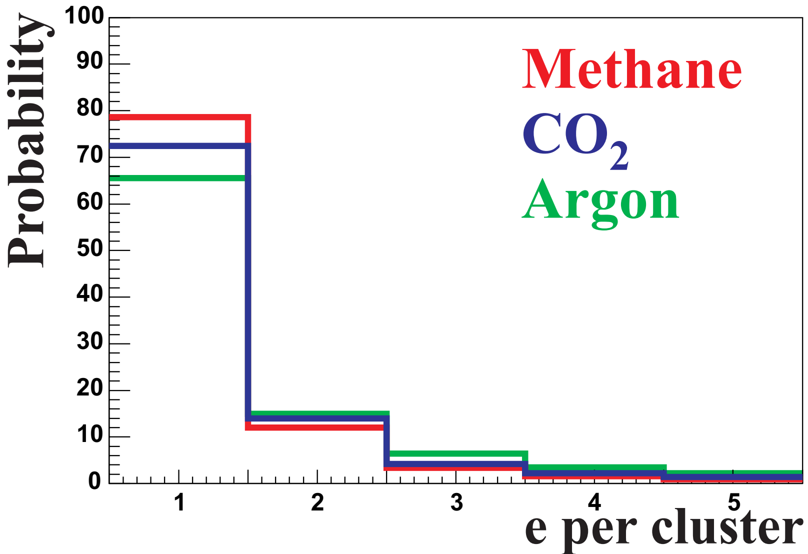
Gas ampflication stage: GEMs

MonteCarlo: Distribution functions

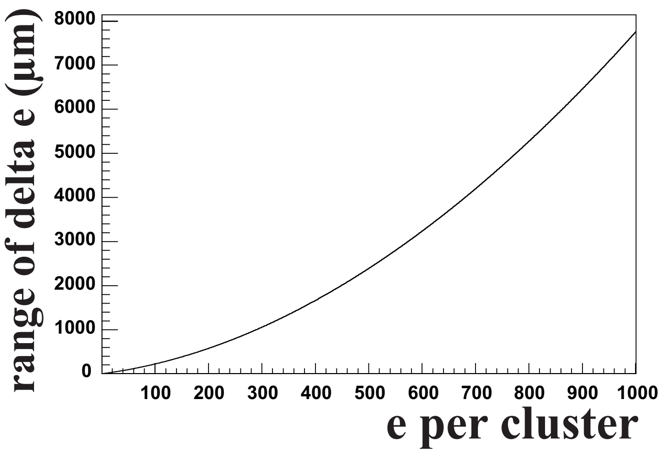
Free path length distribution:

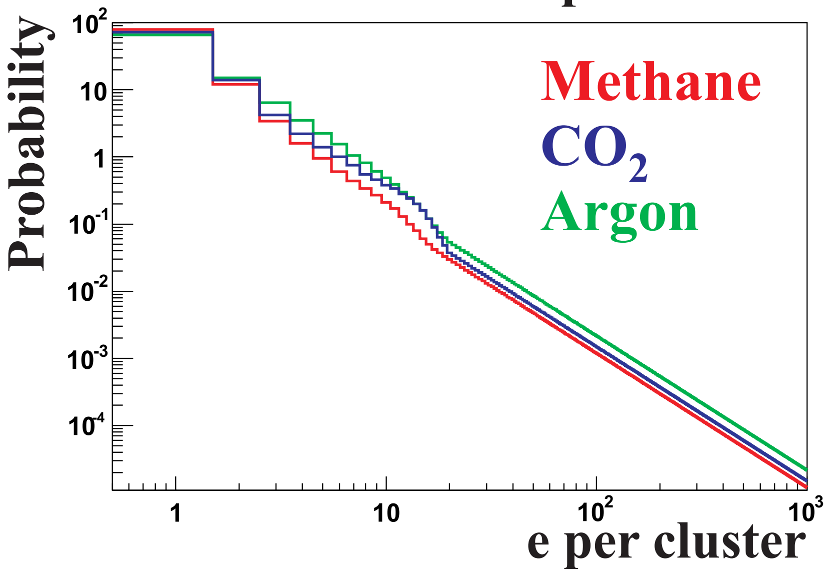


Distribution of electrons per cluster:



Range of primary electrons:

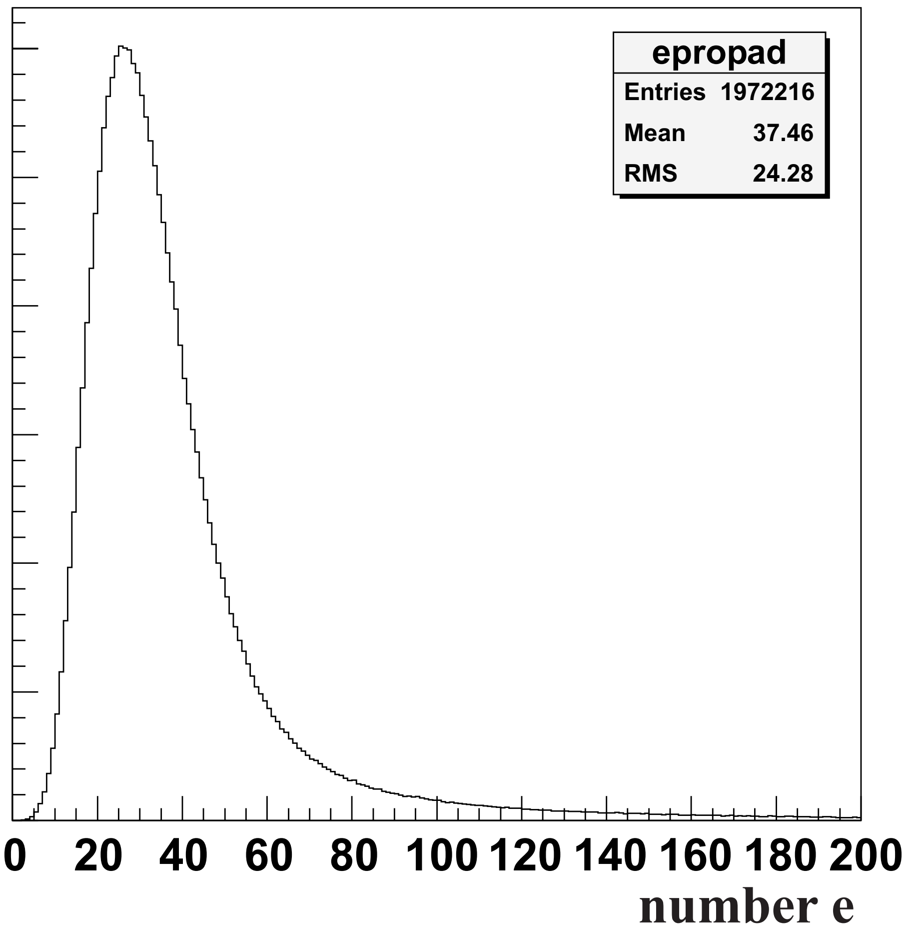




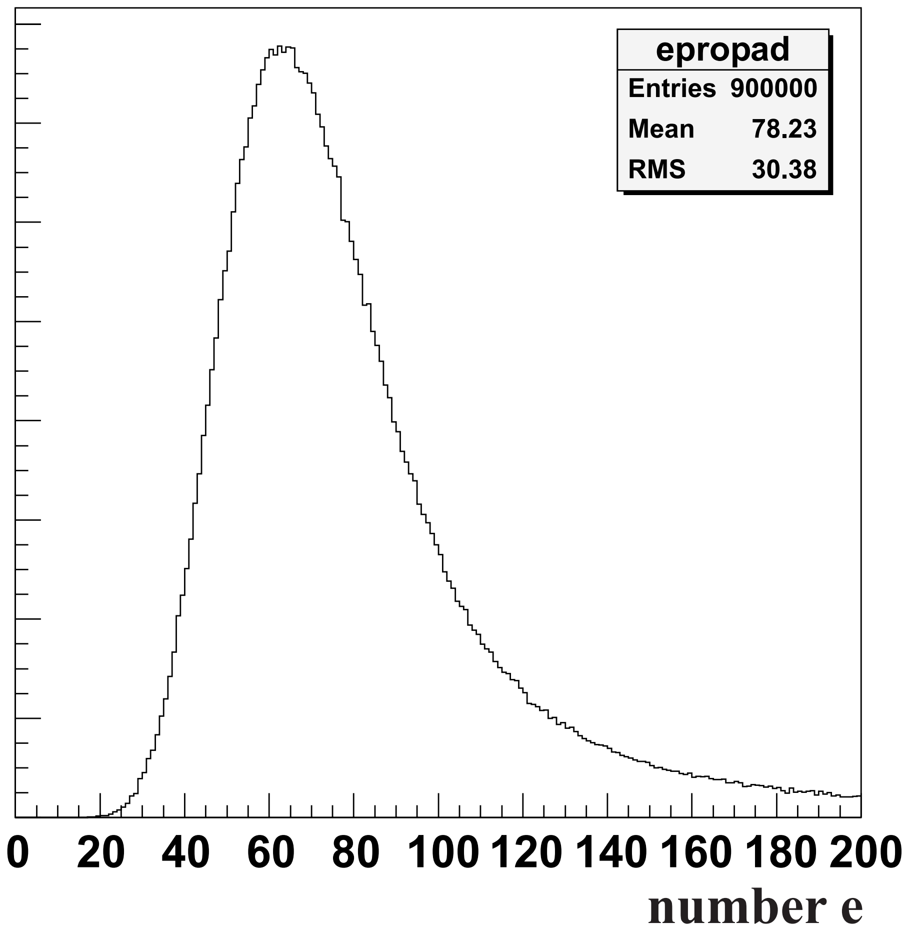
Blum, Rolandi, "Particle Detection"

MonteCarlo: Resulting distribution functions

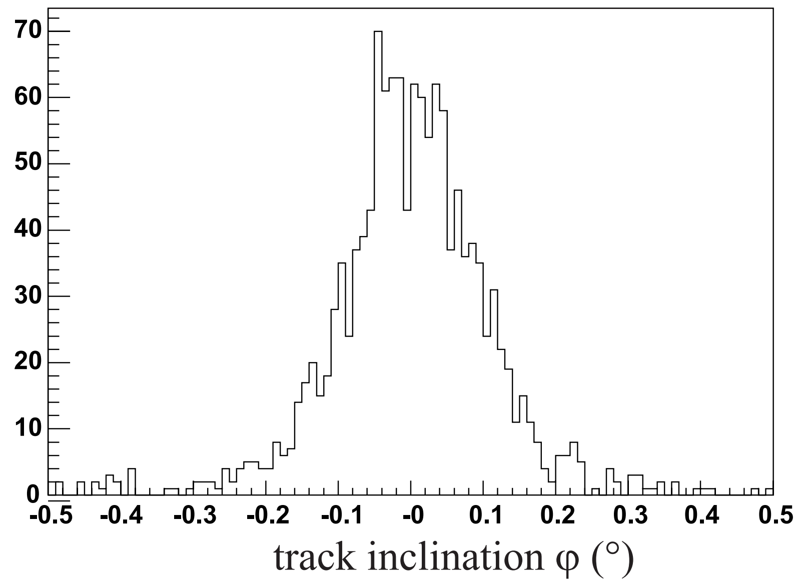
Number of electrons per 6mm pads:

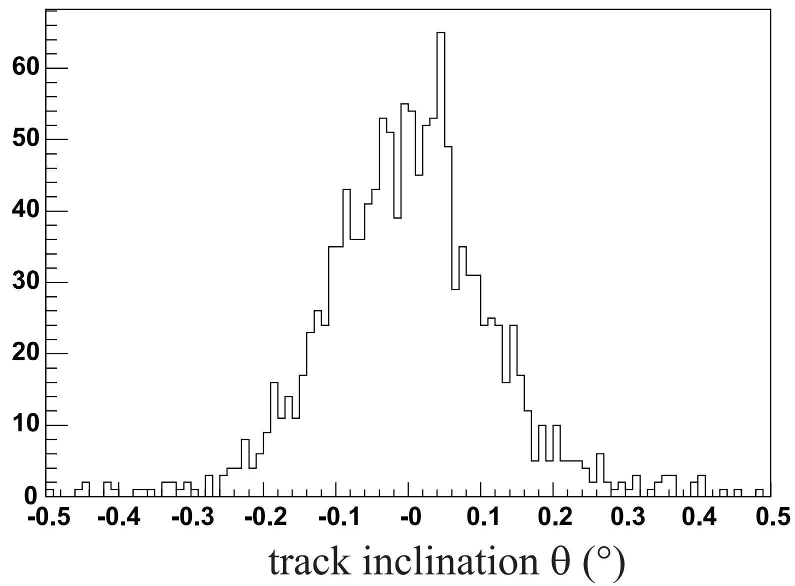


Number of electrons per 12.5mm pads:



MonteCarlo: Comparison to reconstruction





Ar:CO_2-70:30 12cm