Performance of the PANDA GEM-TPC Prototype

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On behalf of the GEM-TPC collaboration

Outline

- Motivation
- Mechanical design of the prototype
- Commissioning with cosmics
- Measurements with beam
- Summary and Outlook

Motivation for a GEM-TPC

A TPC is one of the options for the central tracker for PANDA@GSI/FAIR

TPC: - ideal for tracking of charged particles
- ideal for dE/dx measurement thanks to high number of measured points

Requirements:

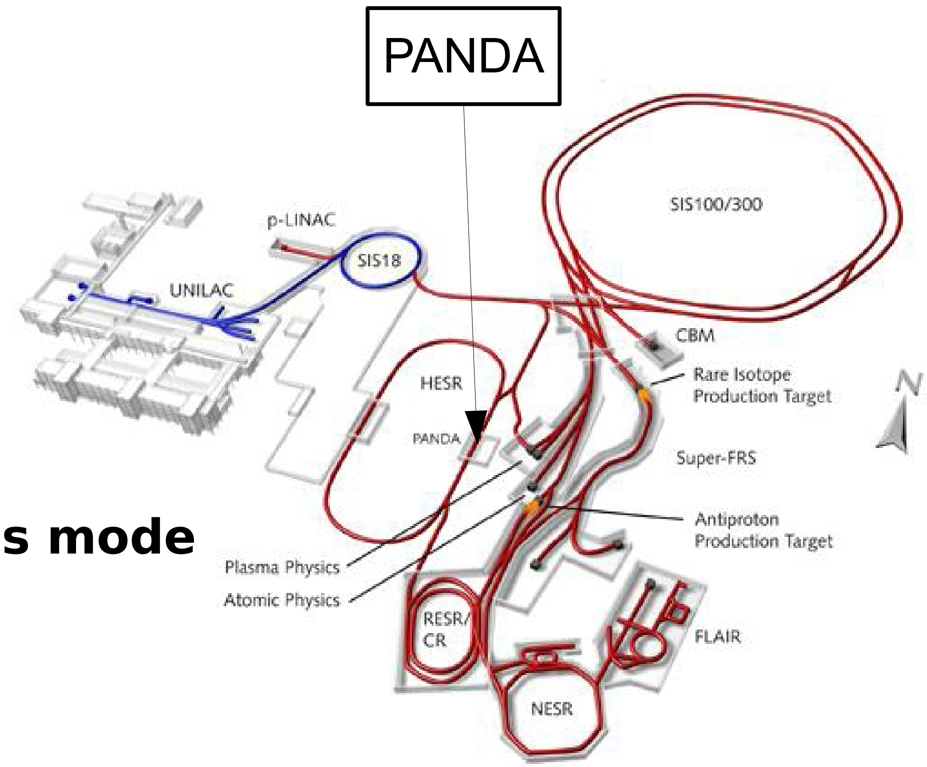
- Momentum resolution : 1%
- dE/dx resolution: 7%
- Spatial resolution: ~200 µm

High luminosity at PANDA (10^{32} $cm^2 s^{-1}$)

10^7 $\overline{p}\,p$ annihilations/s

Continuous beam in storage ring

➡ **TPC has to operate in a continuous mode**

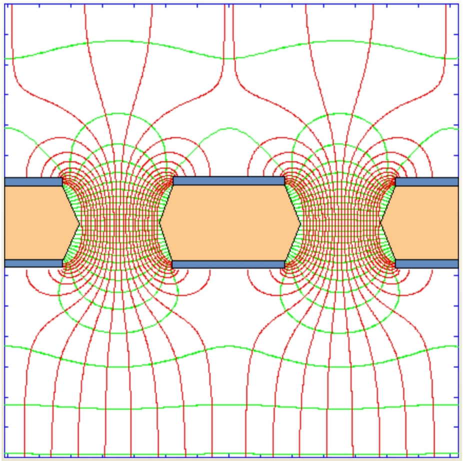


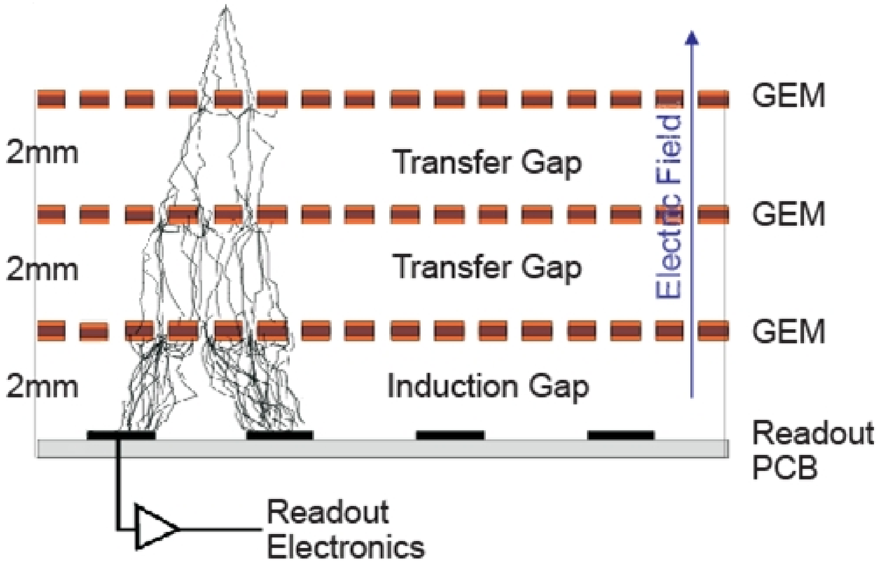
Possible solution:

GEM-foils instead of MWPC's

➡ Intrinsic suppression of back drifting ions

GEM
Gas Electron Multiplier





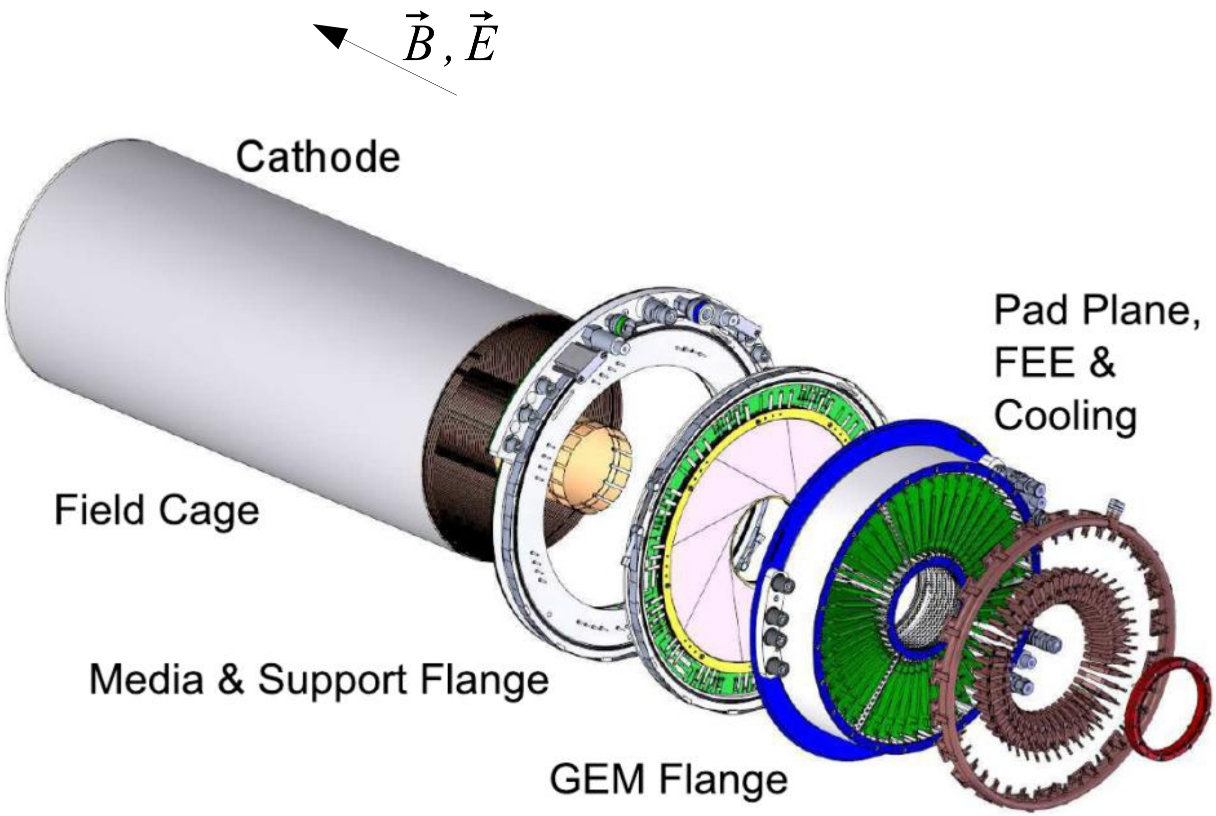
- ~400V potential difference → 50 kV/cm
- Higher extraction field
- Ions are collected on upper side
- Electrons are extracted very effectively

- Amplification G_{eff} = several 10^3
  (with 3 GEM's in a stack)
- Ion feedback suppressed by $1/G_{eff}$
- Until now no aging visible
  (GEM's in Compass since 8 years)
  M. Altunbas et al., Nucl. Instr. Meth. A 515, 249 (2003).
- Very uniform spatial resolution
  (triple GEM's ~ 69.6 μm)
- Small **E**x**B** effect
- Fast e^- signal
- Low discharge probability

Fabio Sauli, The Gas Electron Multiplier (GEM), Nucl. Instr. and Meth. A 386 (1997) 531-534

The GEM-TPC Prototype

The GEM-TPC Prototype

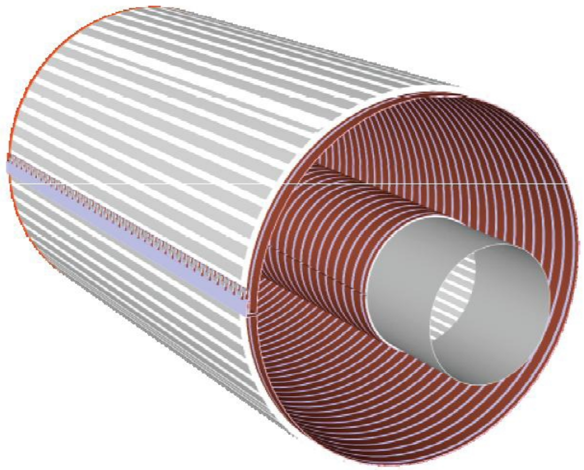


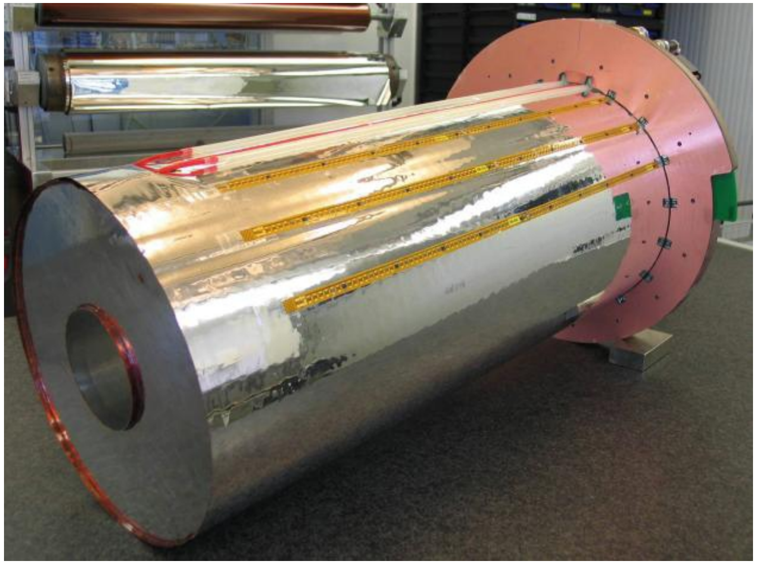
(GEM-TPC) NIM A 628, 204 (2011)

Construction completed in fall '10

- Modular design:
  - Media flange for supplies
  - GEM-flange
  - Read out flange with water cooling
- Geometry:
  - 72.8 cm drift length
  - 30 cm outer diameter
  - 10.5 cm inner diameter
- Field cage
  - 792 strips
  - Smd-resistor voltage divider
  - 4 mm thick → ~1% X/X_0
- 10254 hexagonal read out pads
  - 1.5 mm radius

The GEM-TPC Prototype





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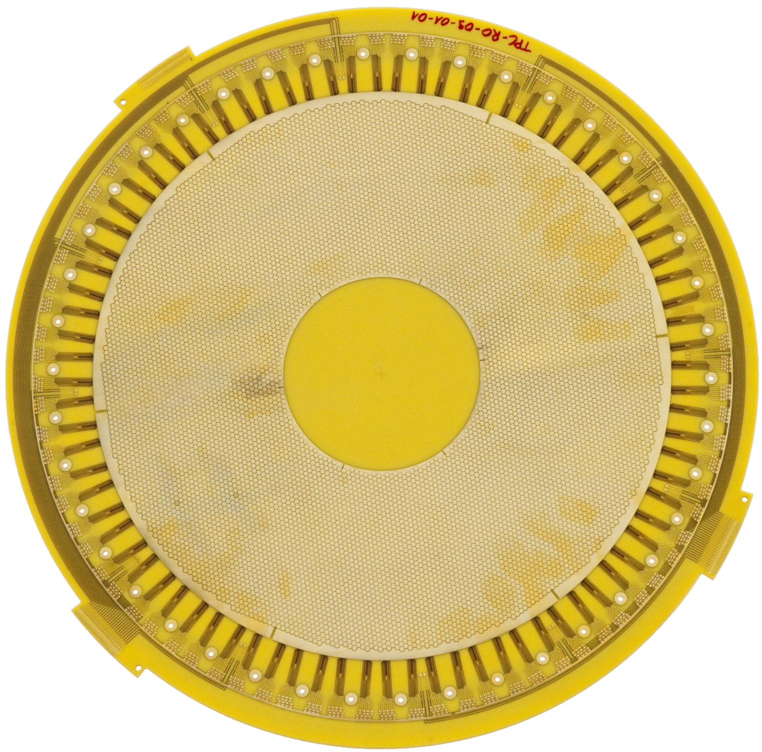

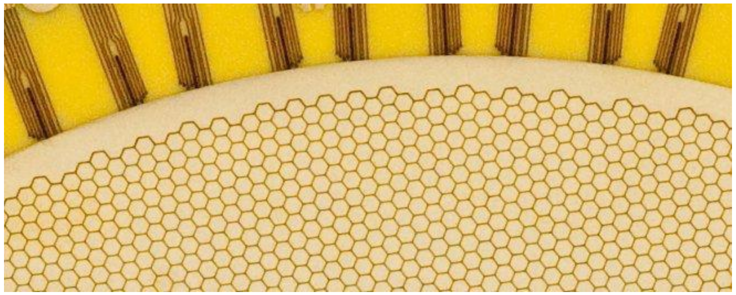

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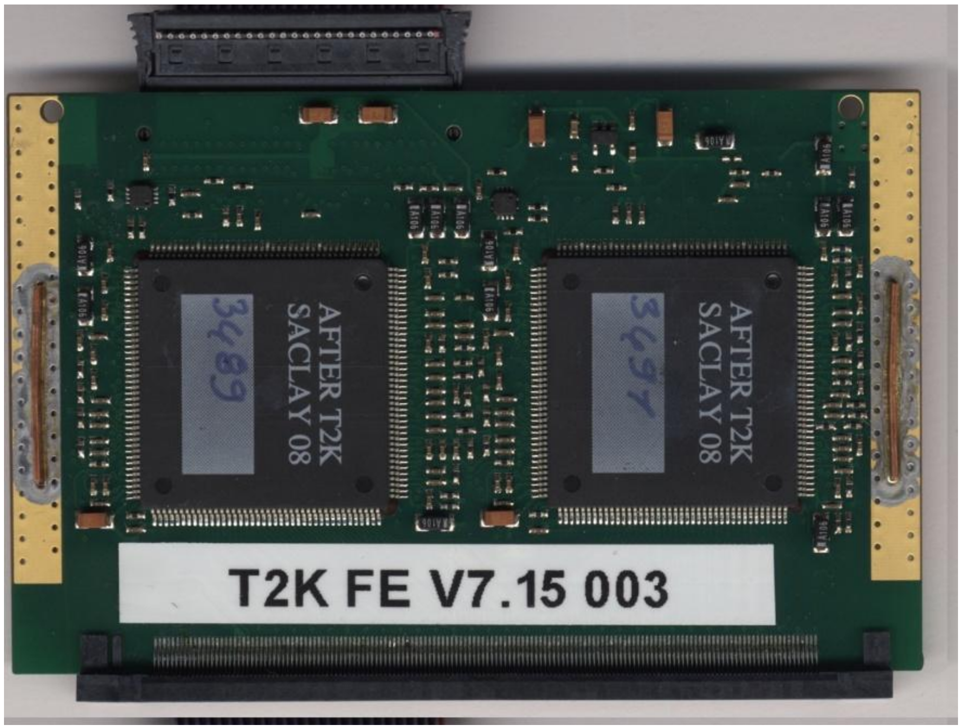
Front-End Electronics

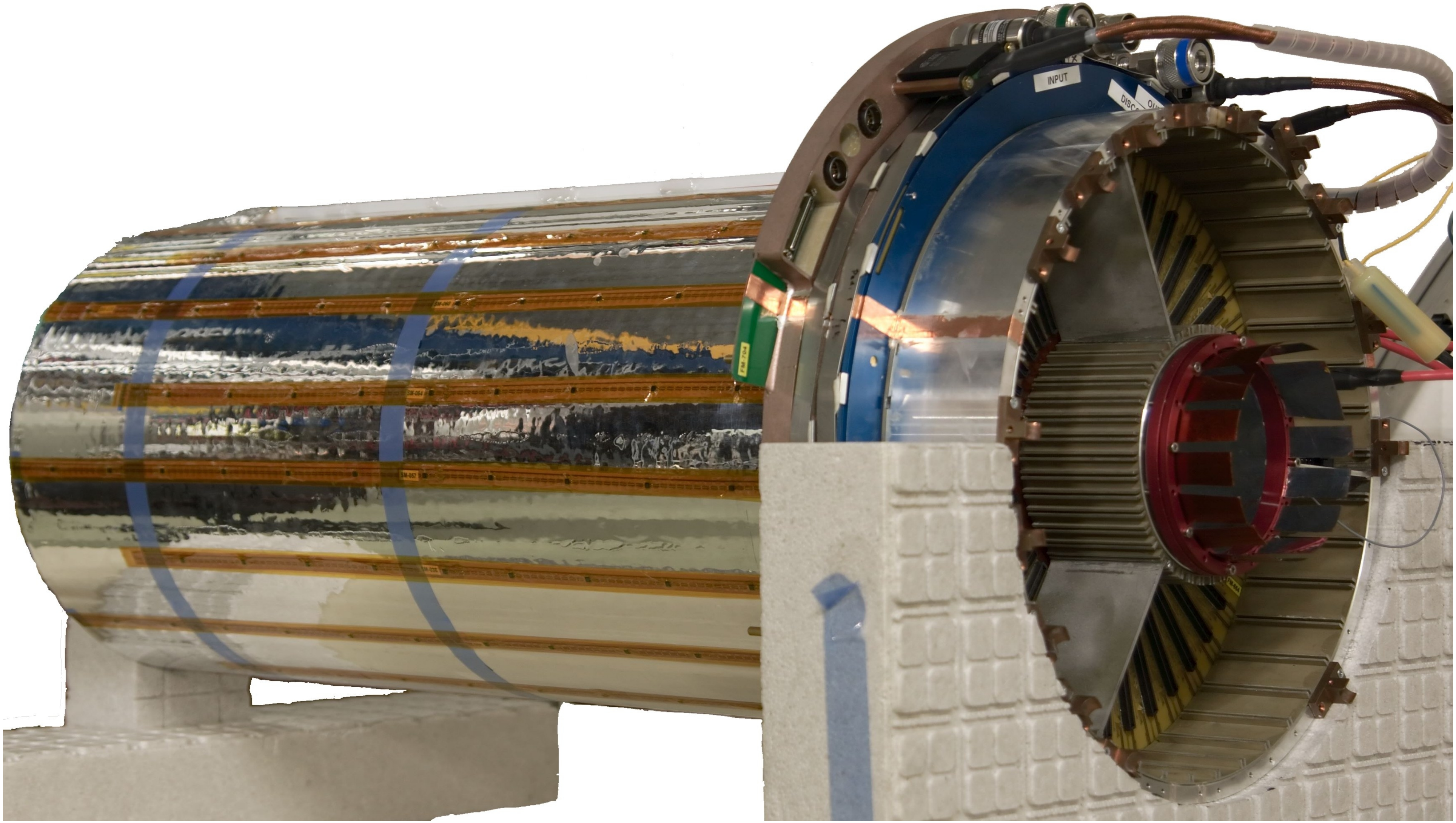


After/T2K based FE chip

- 10-50 MHz sampling
- Both signal polarities
- 72(64) channels
- Noise: ~700 e^- ENC (connected to prototype)
- Adjustable shaping time: 100 ns – 2 µs
- Tunable dynamic range
- 511 cell ringbuffer
- ~0.8 W/chip
- 2.5 ms deadtime

P. Baron et al., IEEE Trans. Nucl. Sci. 55, 1744 (2008).

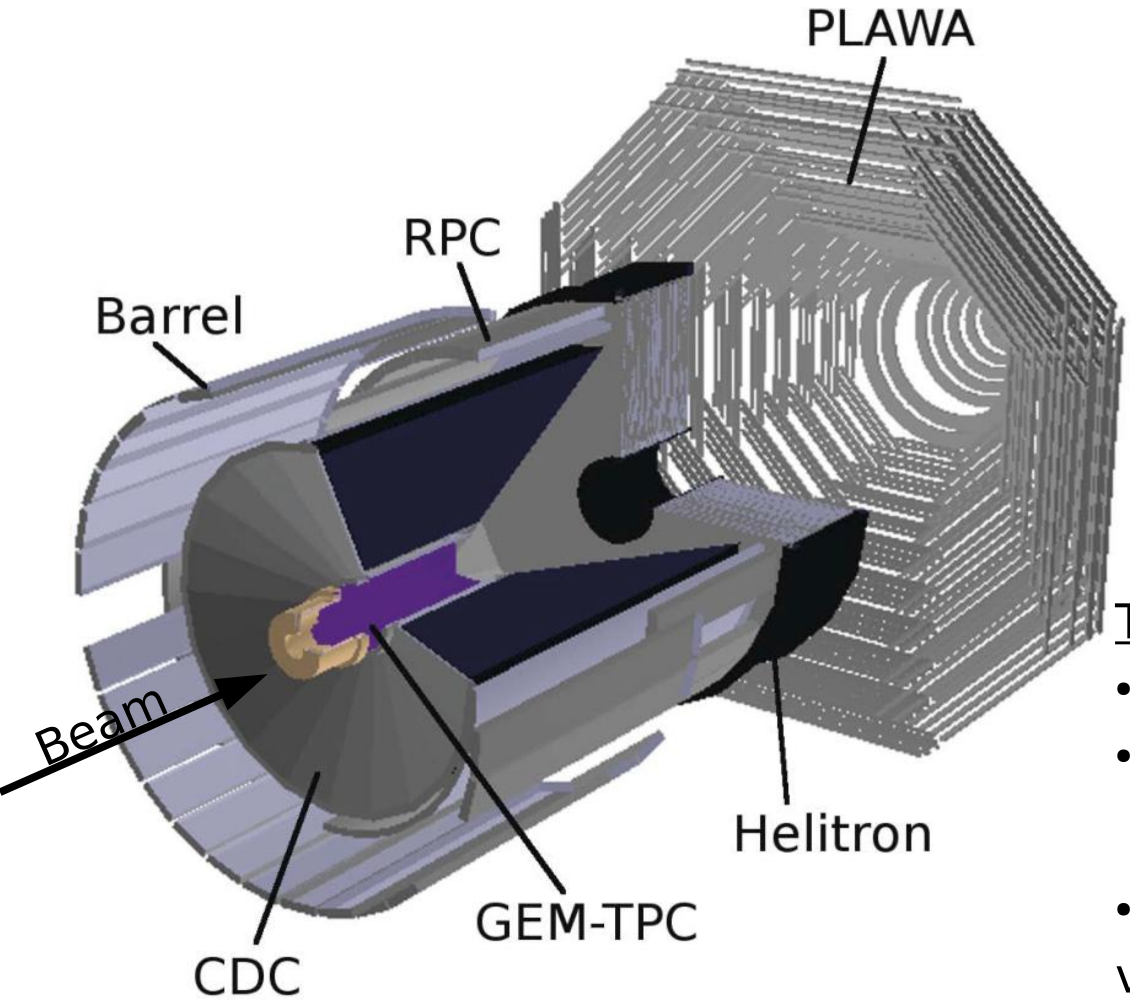
The Prototype



Measurements inside FOPI

The FOPI Spectrometer

Heavy Ion Spectrometer at GSI



K. Hildenbrand, GSI Nachr. 91-02, 6 (1992)

FOPI:

- Momentum resolution: ~7%
- Time-of-flight resolution: 120 - 250 ps
- Vertex resolution: 5 mm (XY-Plane)
- Z-resolution: ~10 cm

TPC as upgrade for FOPI:

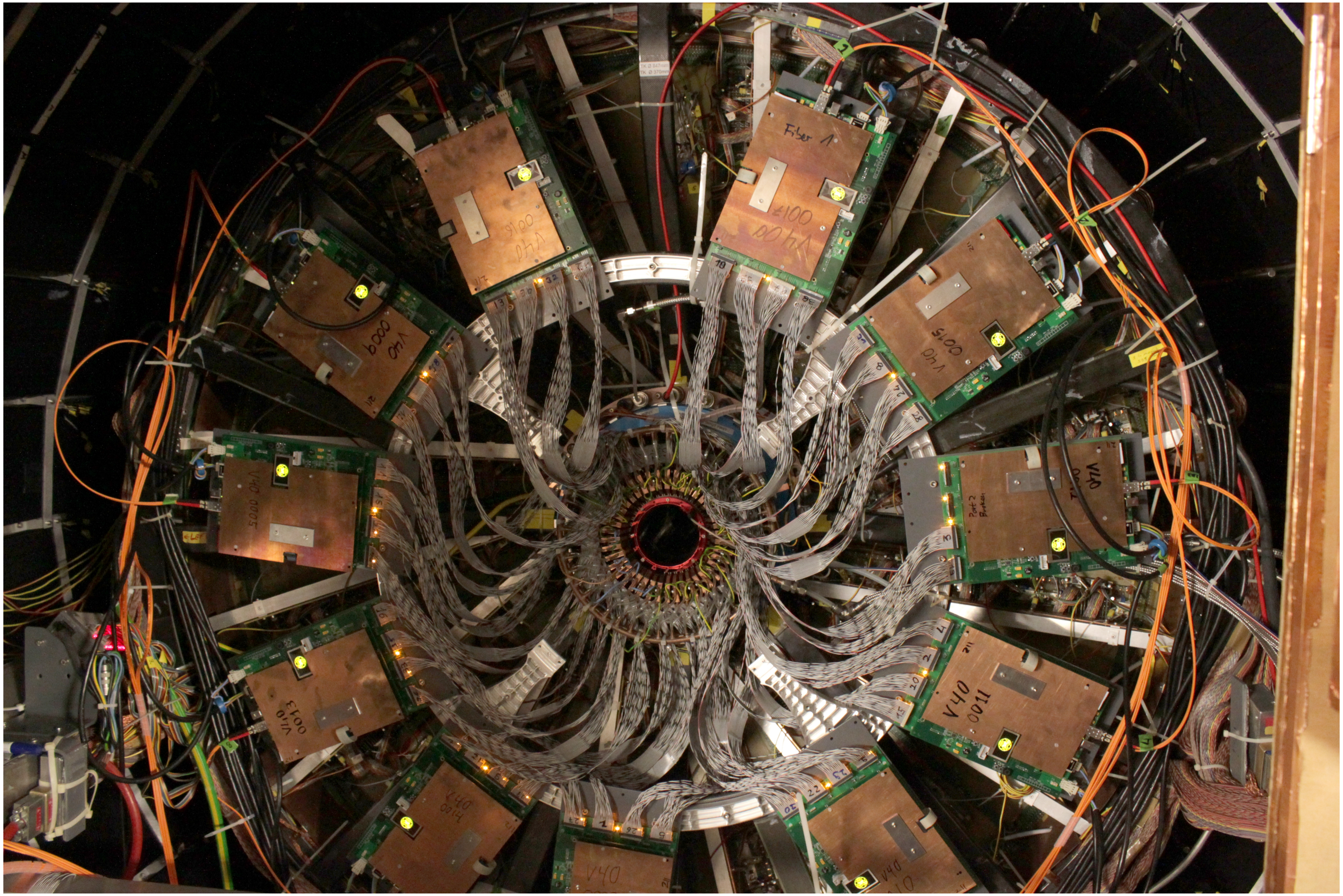
- Vertex resolution: ~1 mm in X,Y + Z
- Larger geometrical acceptance for:
  - Λ and K^0_s
- Improved resolution of secondary vertices (min factor 10)

→ good for weakly decaying resonances

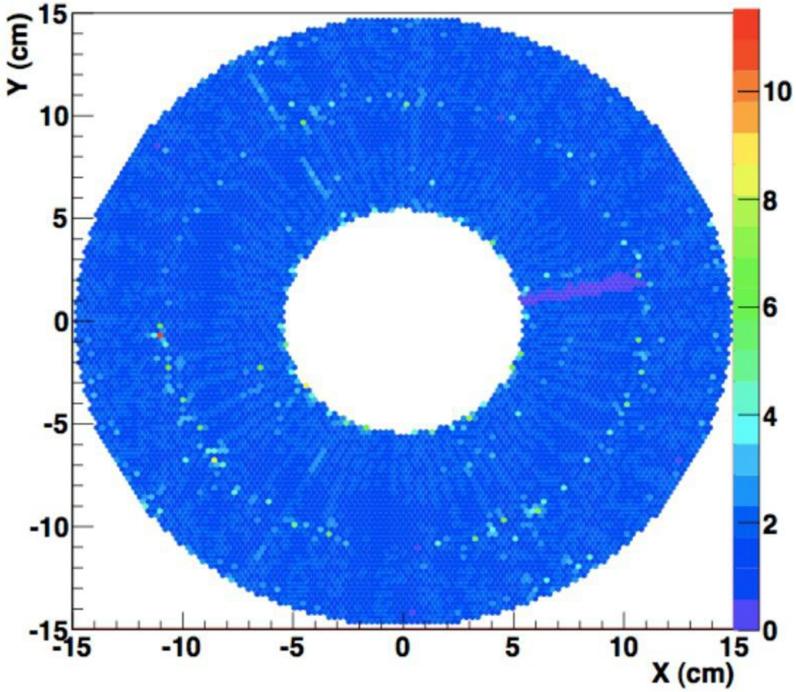
Measurements done with the Prototype

- Prototype commissioned with cosmics
- Commissioning campaign:
  - ^{84}Kr (E_{kin}=1.2 AGeV)
  - ^{197}Au (E_{kin}=1.0 AGeV)
  - ^{22}Ne (E_{kin}=1.7 AGeV)
  - ^{14}N (E_{kin}=2.0 AGeV)
  - 2% Al-target
- Gain uniformity calibration using Krypton
- Different gases: Ar/CO_2 and Ne/CO_2 (90/10)
- 3 weeks physics run with π-beam

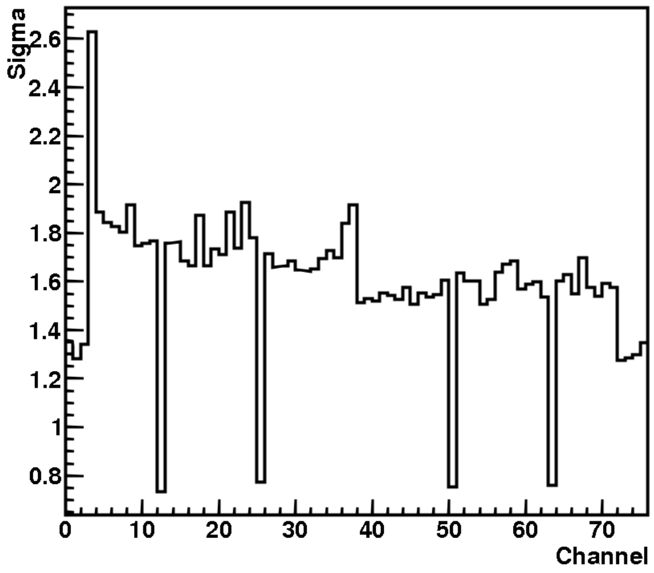
The TPC inside FOPI



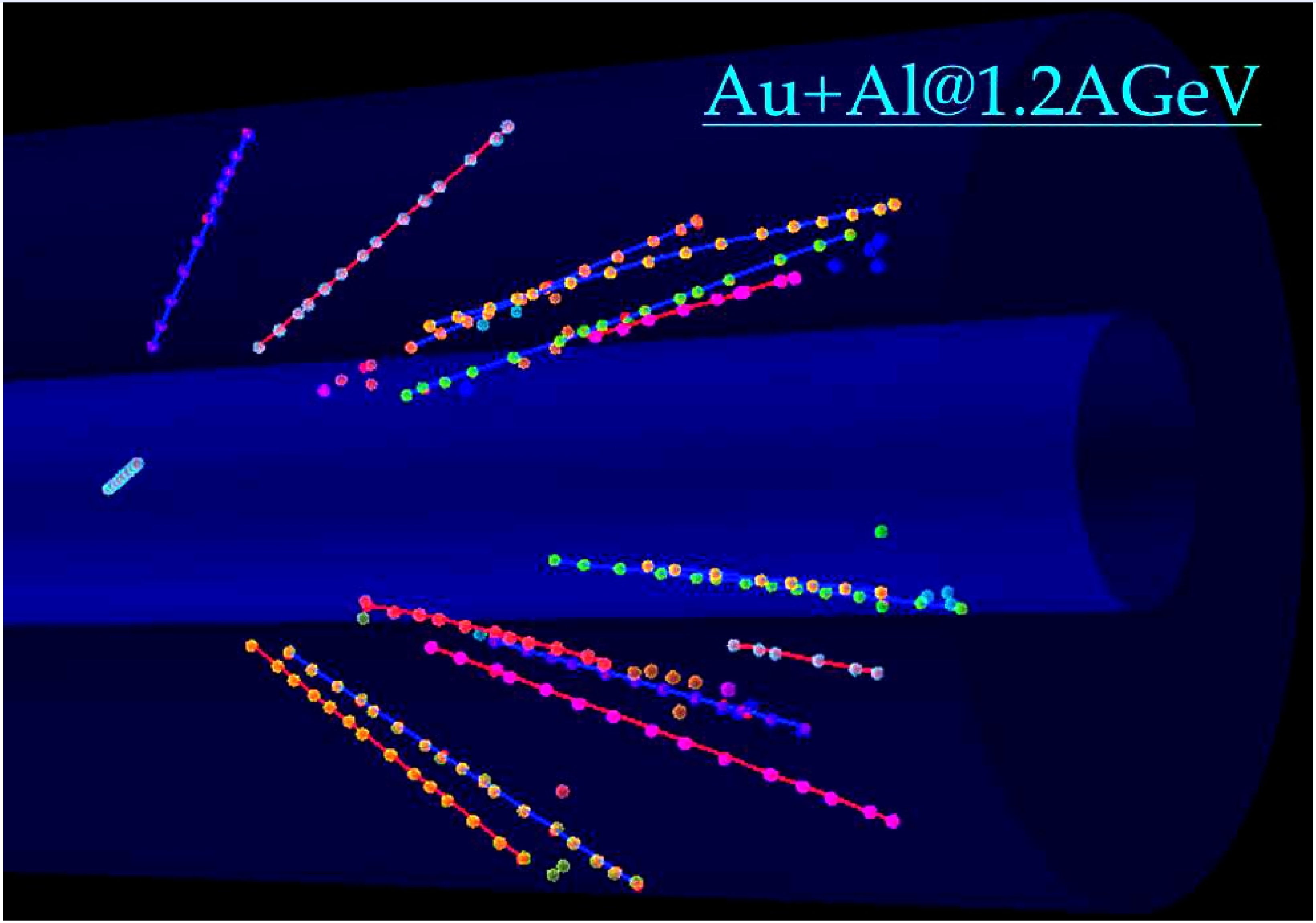
Noise Uniformity



- 42 front end cards
- In total 12768 channels read out
- 1 ADC channel = ~400 e^- ENC
- Average noise at ~700 e^- ENC



Pattern Recognition



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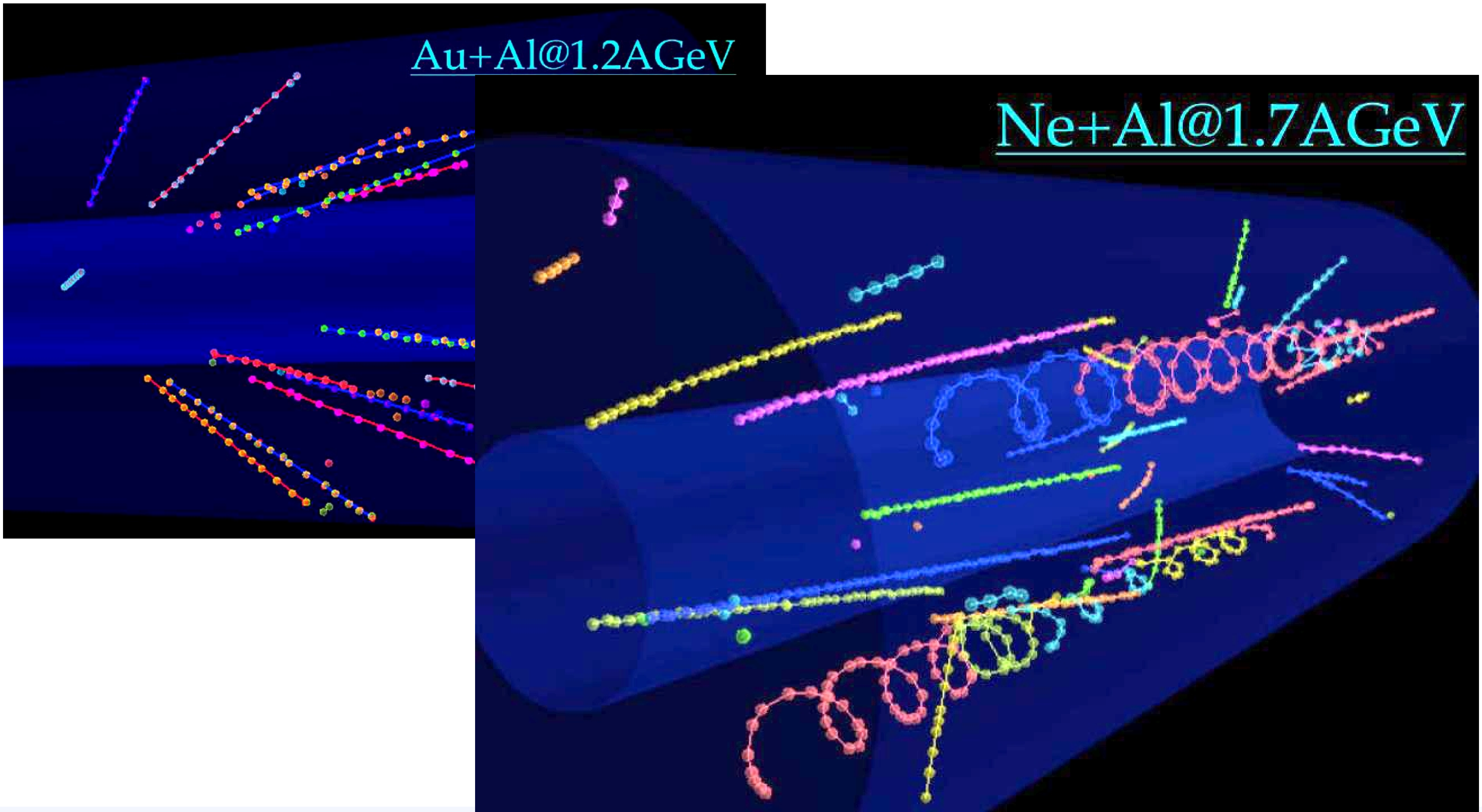
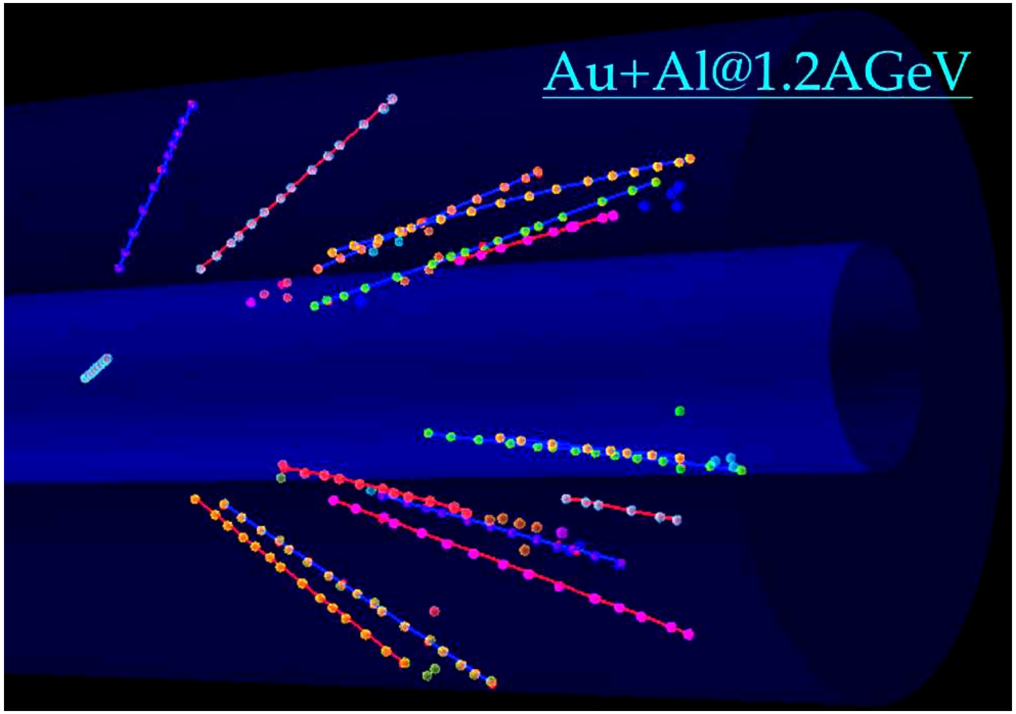
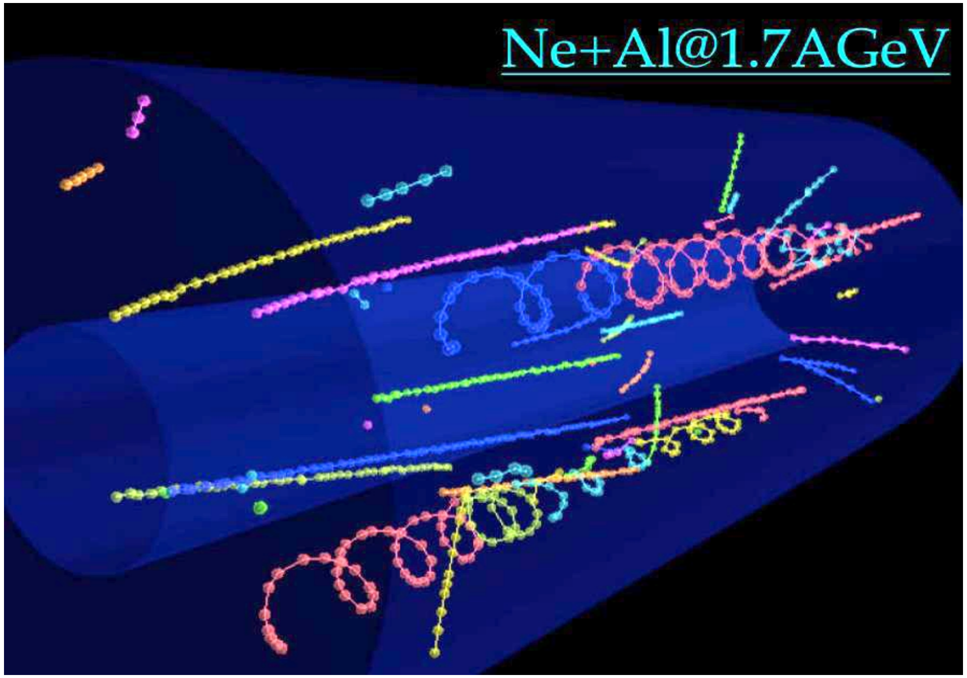


Pattern Recognition

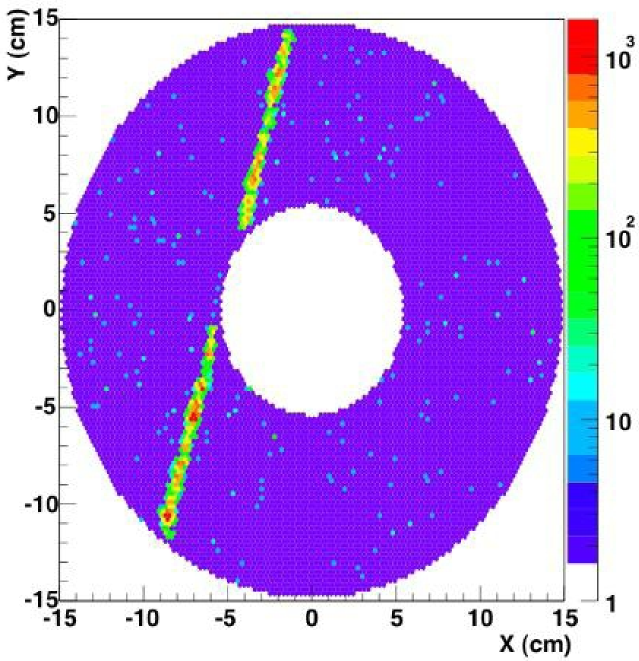


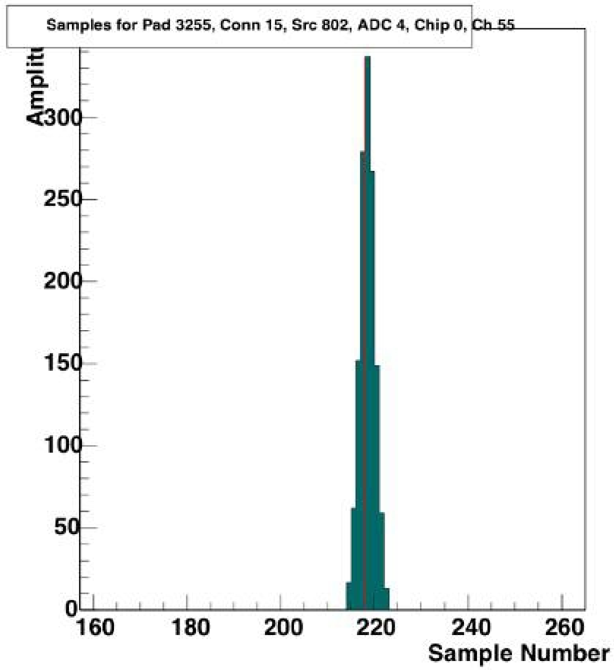
- Analysis done in PANDAROOT
- 3D Clustering
- Riemann pattern recognition
- Track fitting: Genfit (Kalman filter)

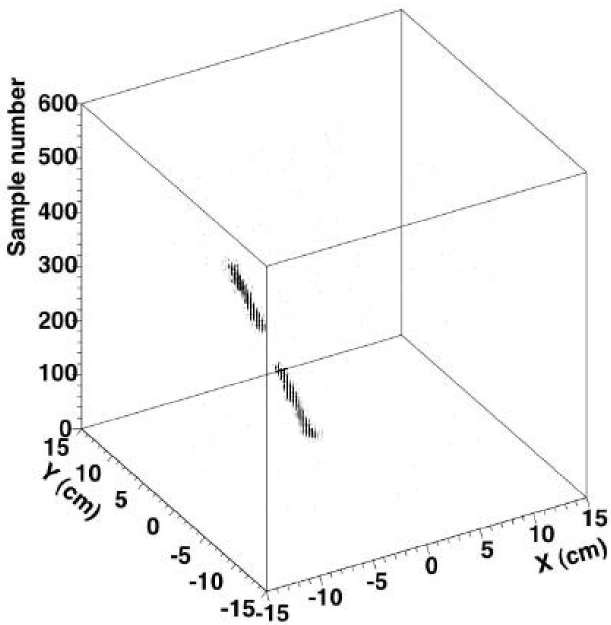


C. Höppner, S. Neubert, B. Ketzer, and S. Paul, Nuclear Instruments and Methods in Physics Research A 620, 518 (2010).

Cosmic Track







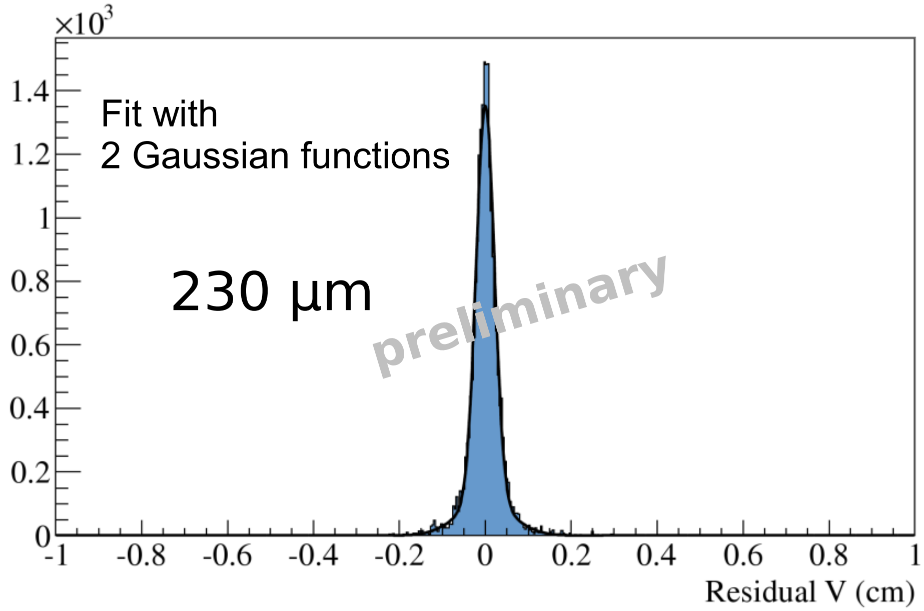
GEM-TPC Online Monitoring:

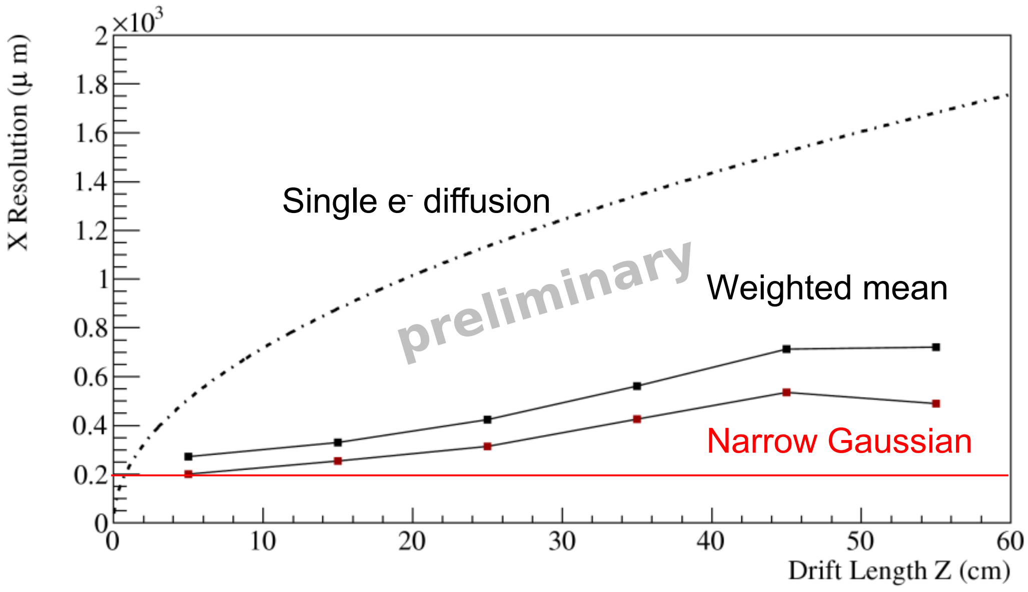
Left: 2D-projection with sample amplitude

Middle: Amplitude of one pad

Right: Full 3D-view of samples

Spatial Resolution from Cosmics

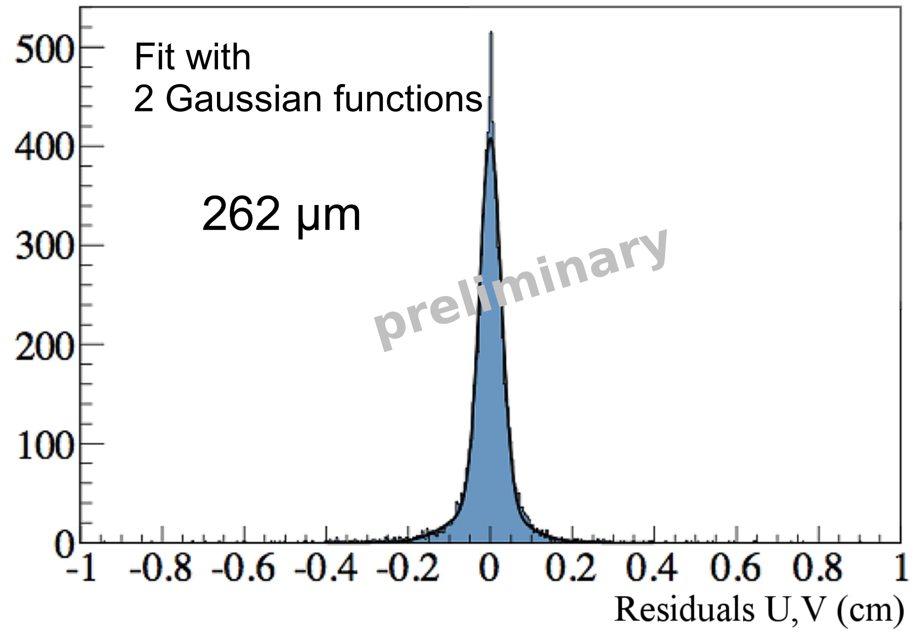


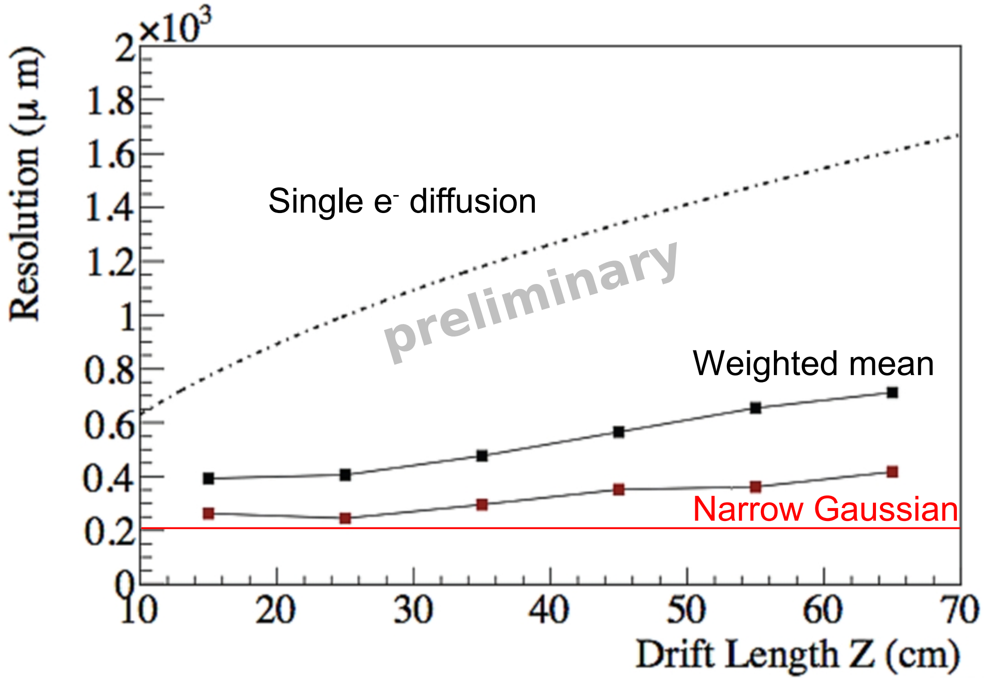


Settings:

- Ar/CO_2(90/10)
- Drift field: 360 V/cm
- Gain: 3800
- No magnetic field

Spatial Resolution from Cosmics

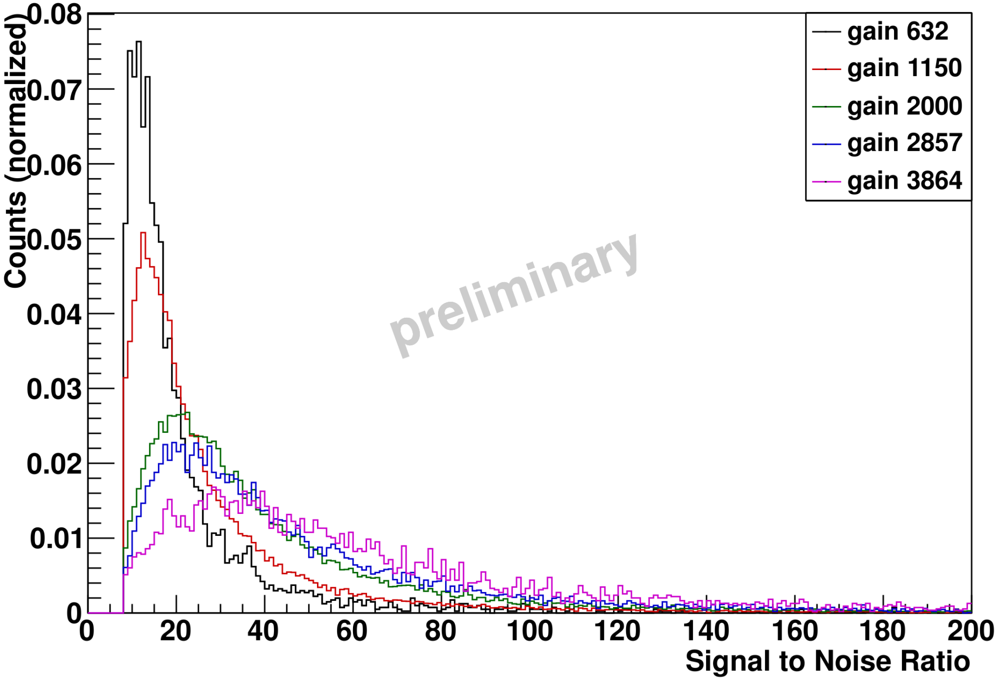




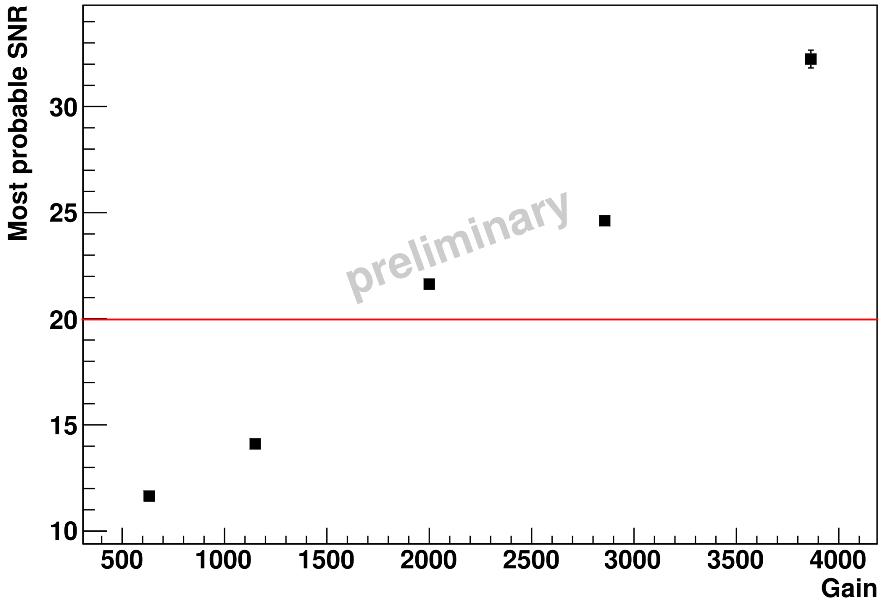
Settings:

- Ne/CO2(90/10)
- Drift field: 360 V/cm
- Gain: 3000
- With 0.6 T magnetic field

Signal to Noise Ratio from Cosmics

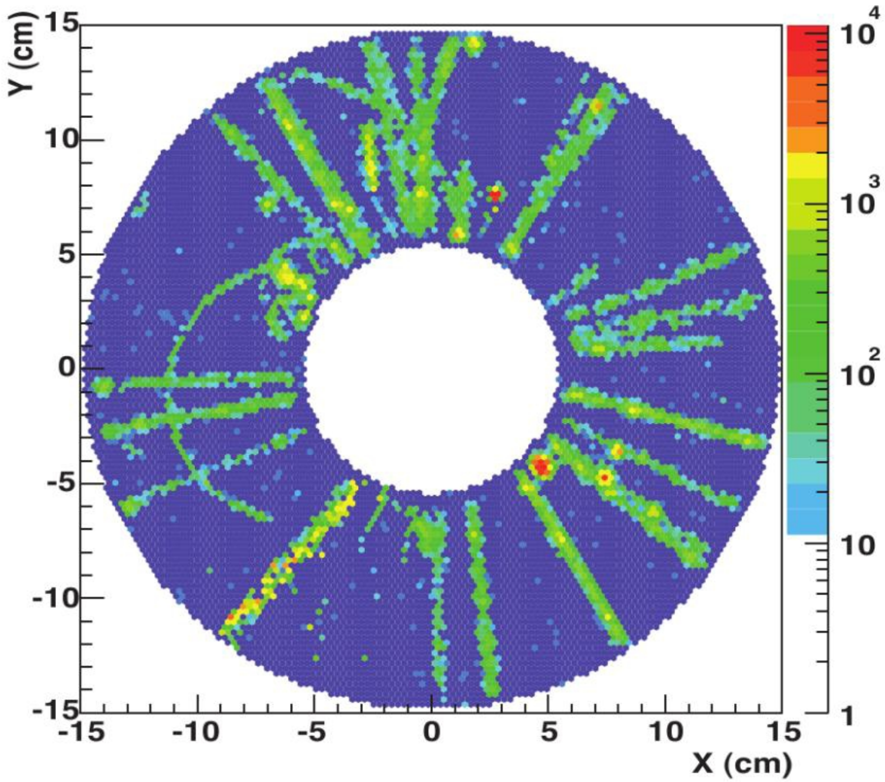


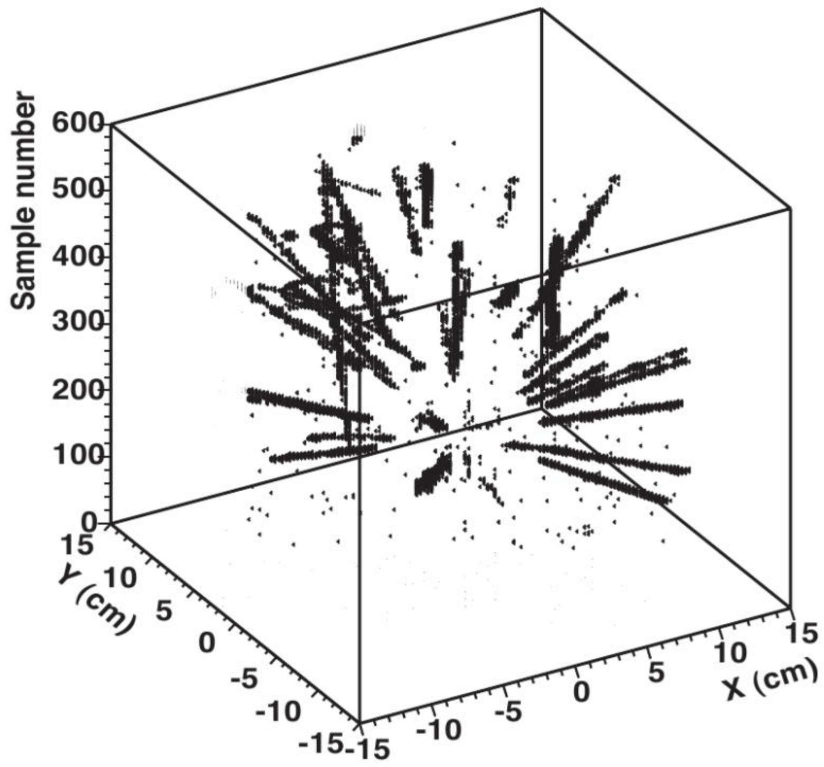
Ne/CO2
360 V/cm drift field
With magnetic field



SNR above 20 is envisaged

Beam Data





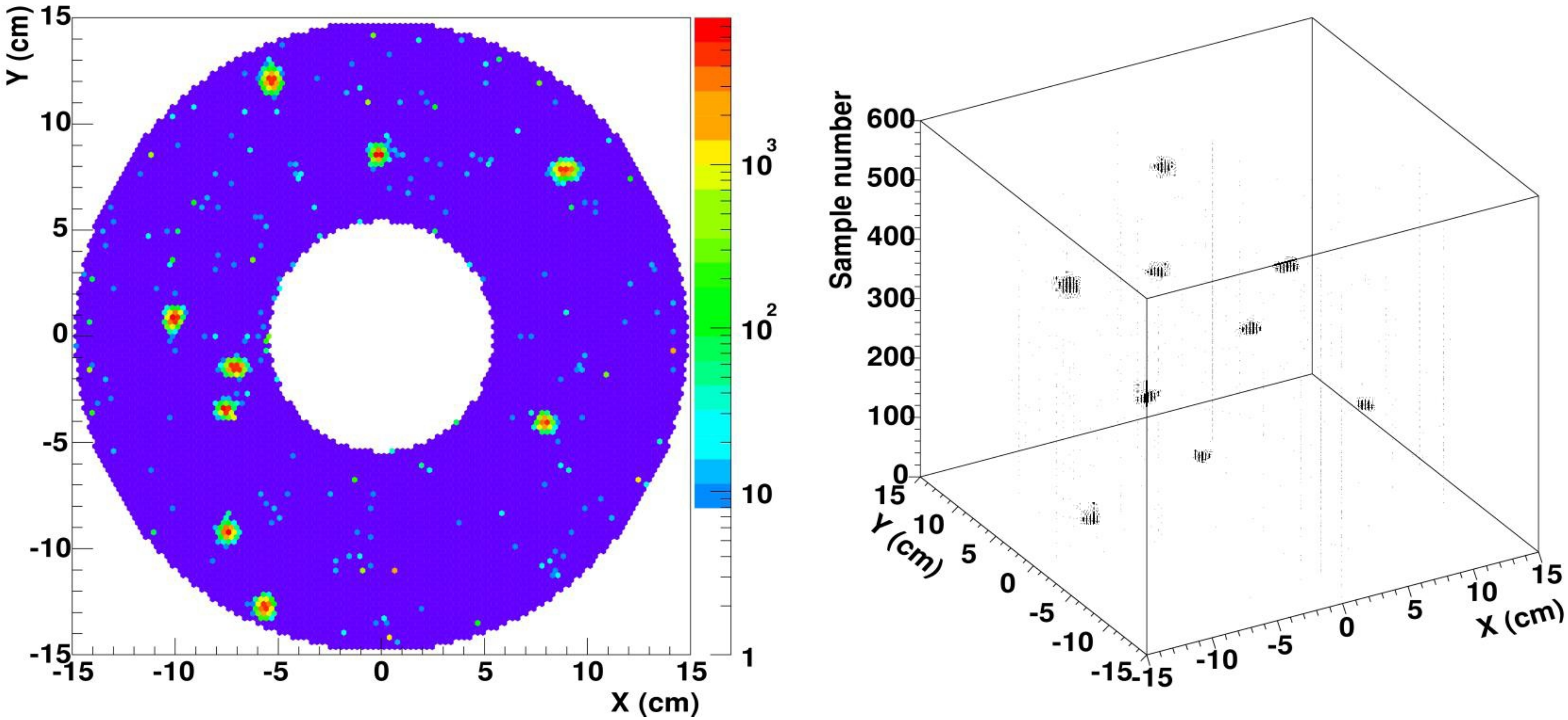
^{22}Ne beam on Al target

Up to $5*10^6$ parts/spill

spill=10s

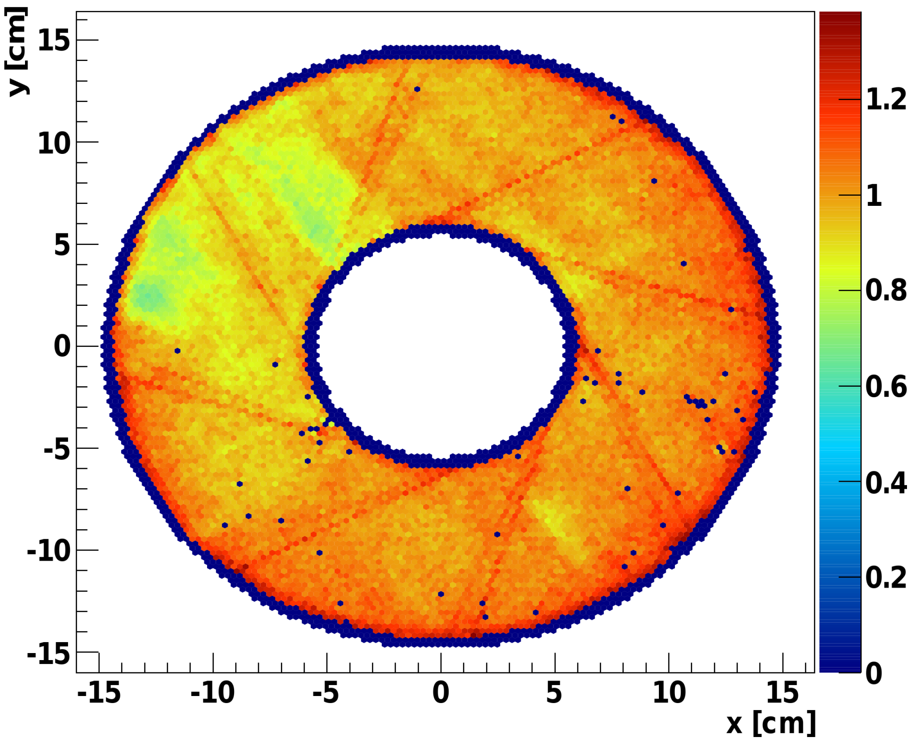
Rate is limited by readout

Krypton Calibration

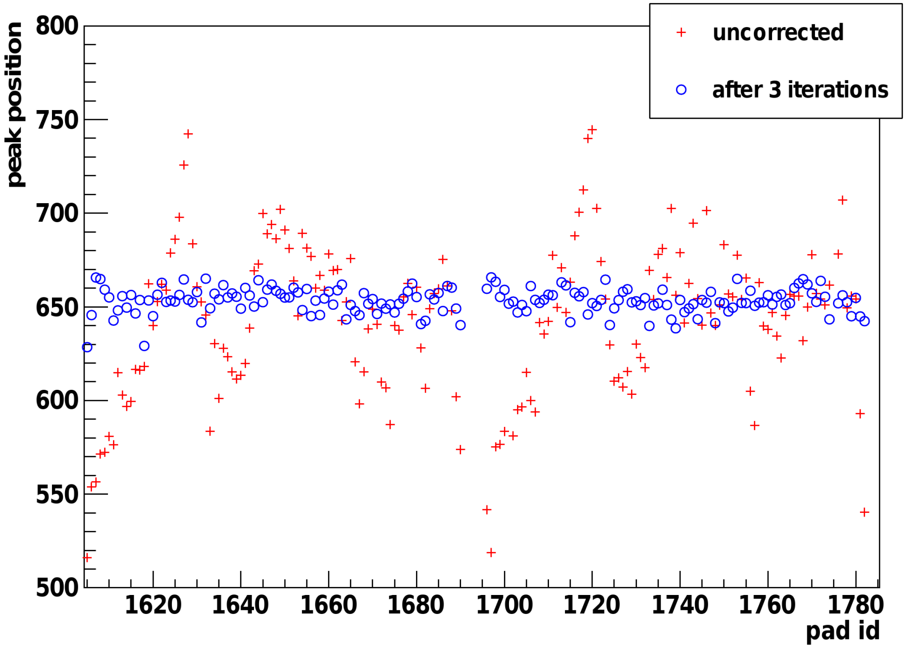


^{83}Kr decaying inside the TPC

Gain Calibration



- Equalize gain variation across the GEM surface
- Energy calibration to improve dE/dx
- ^{83}Kr lines: 10-40 keV
- Ar/CO_2: Gain = 850-3770
- Ne/CO_2: Gain = 850

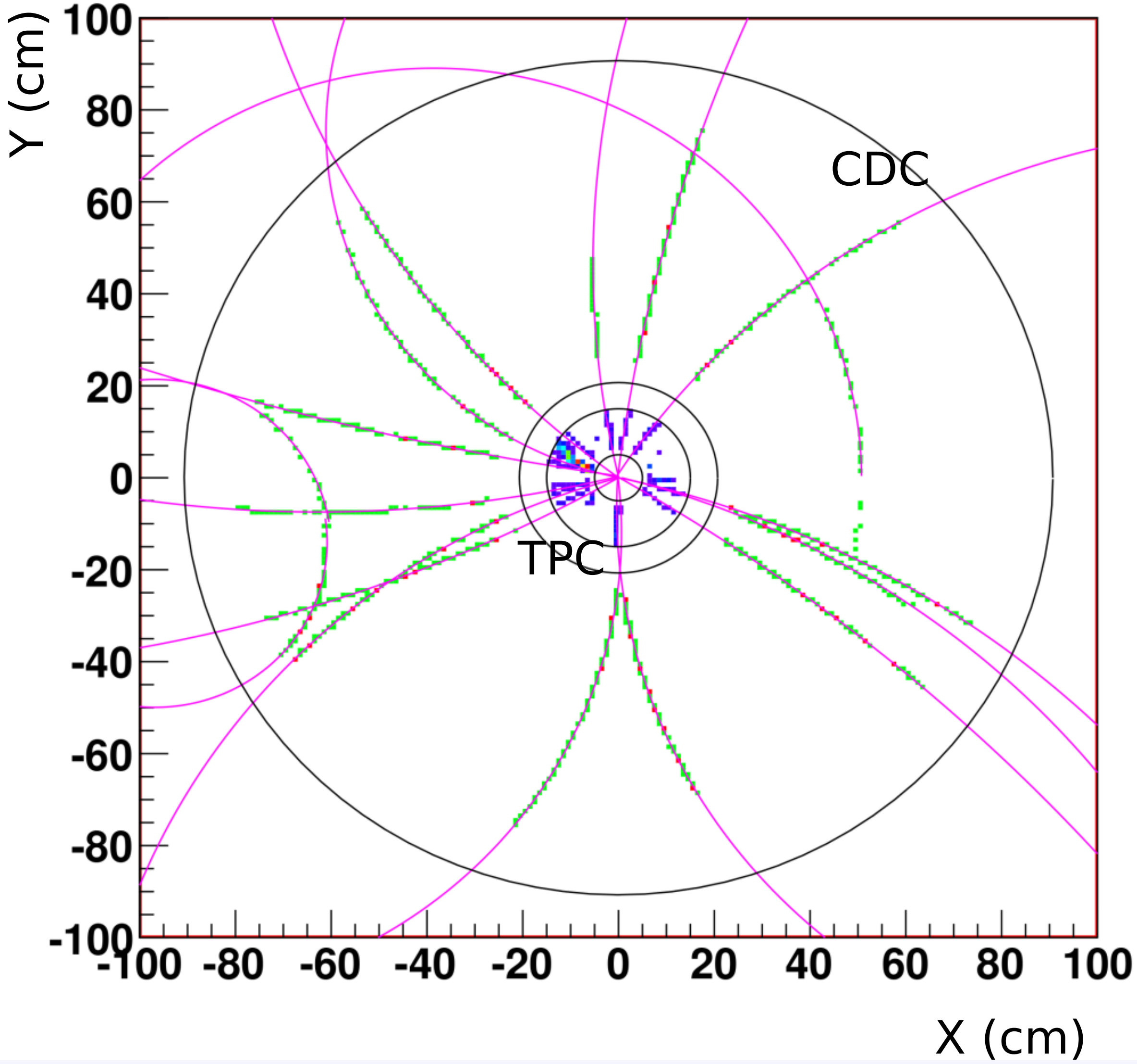


For details: Poster (Id 118) of Roman Schmitz

Gain uniformity after calibration: 1-2%

FOPI and the TPC

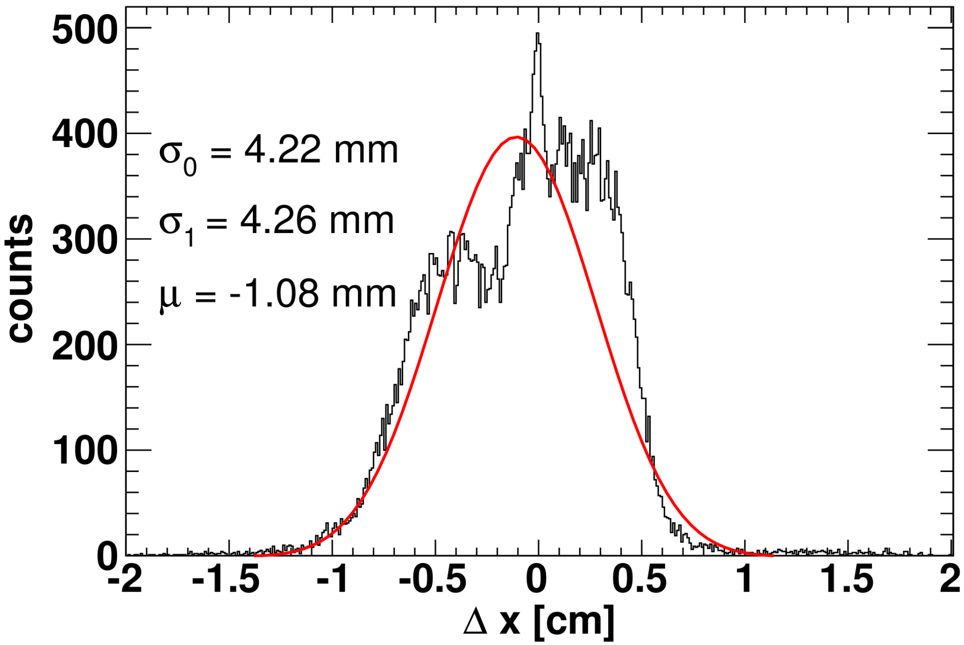
FOPI and the TPC



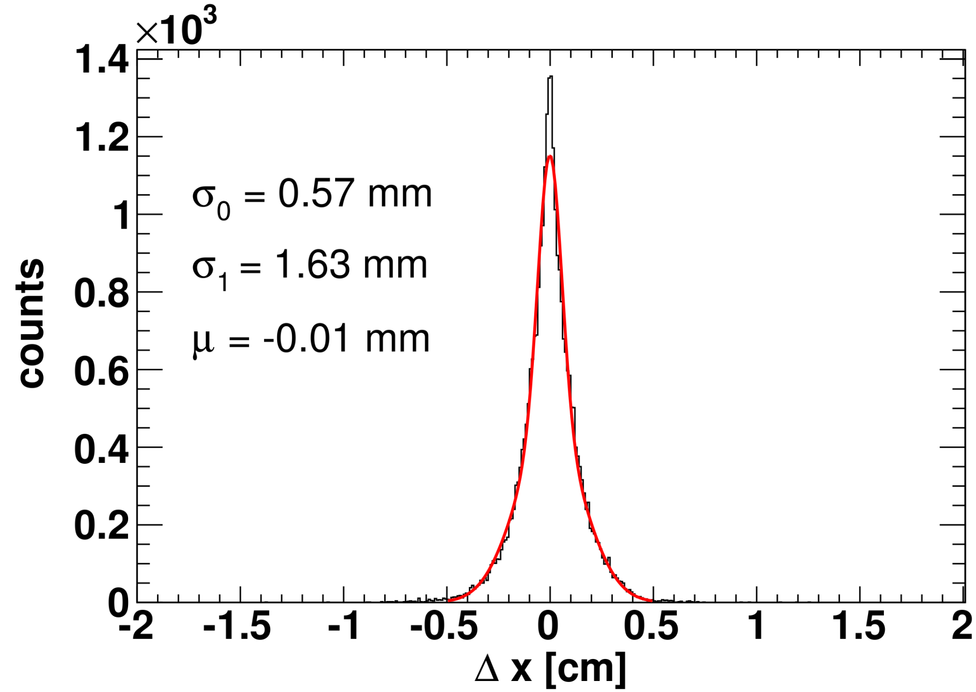
Correlations between CDC (Central Drift Chamber) of FOPI and the TPC

FOPI and the TPC

Residuals to extrapolated CDC tracks



Before alignment



After alignment

Summary and Outlook

- The largest GEM-TPC of this kind was build and successfully commissioned
- It was commissioned with several varying parameters
- The specifications match the PANDA requirements

- Further analysis ongoing:
  - momentum resolution
  - dE/dx measurement
- Review design of the prototype
- Introduce drift distortion calibration system
- Analyze π-beam data
- LOI for further experiments at SIS18 aiming at hypernuclei and double strange clusters in preparation

The GEM-TPC Collaboration

TU München, E18
H. Angerer, M. Ball, F. Böhmer, S. Dørheim,
C. Höppner, B. Ketzer, I. Konorov, S. Neubert,
S. Paul, J. Rauch, S. Uhl, M. Vandenbroucke

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M. Berger, J. Chen, F. Cusanno,
L. Fabbietti, R. Münzer

HISKP Bonn
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Schmitz D. Walther, A. Winnebeck

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H. Risch, C. Schmidt, S. Schwab,
D. Soyk, B. Voss, J. Voss, J. Weiner
[1] also at RBI Zagreb

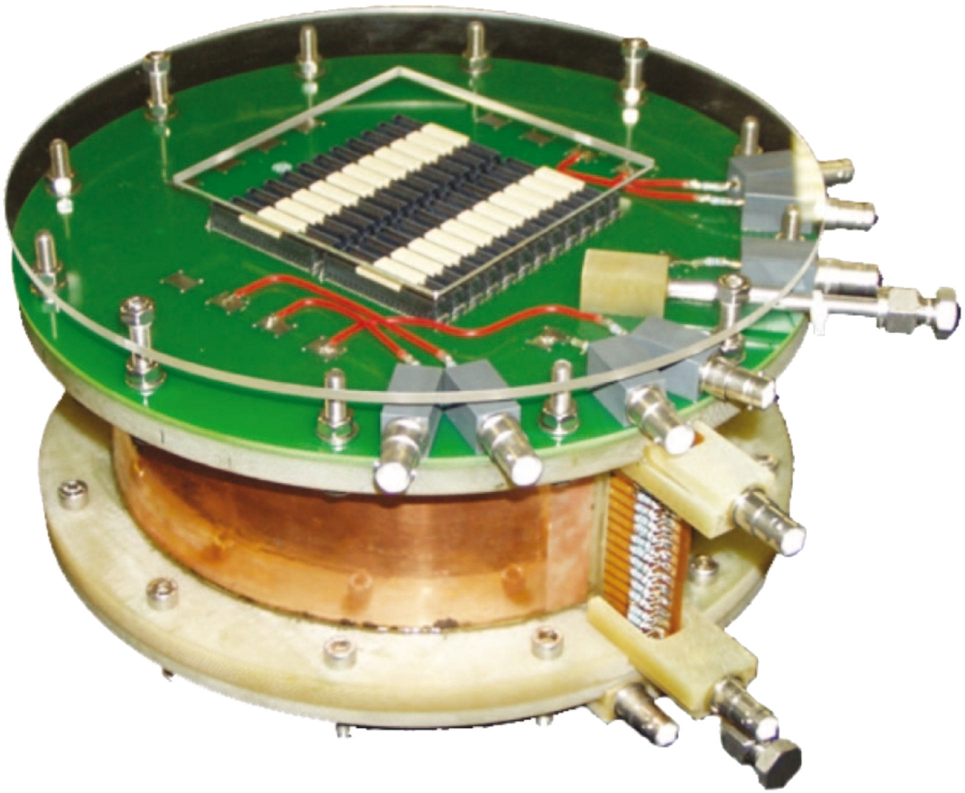
Stefan-Meyer-Institut, Wien
P. Müllner, K. Suzuki, J. Zmeskal

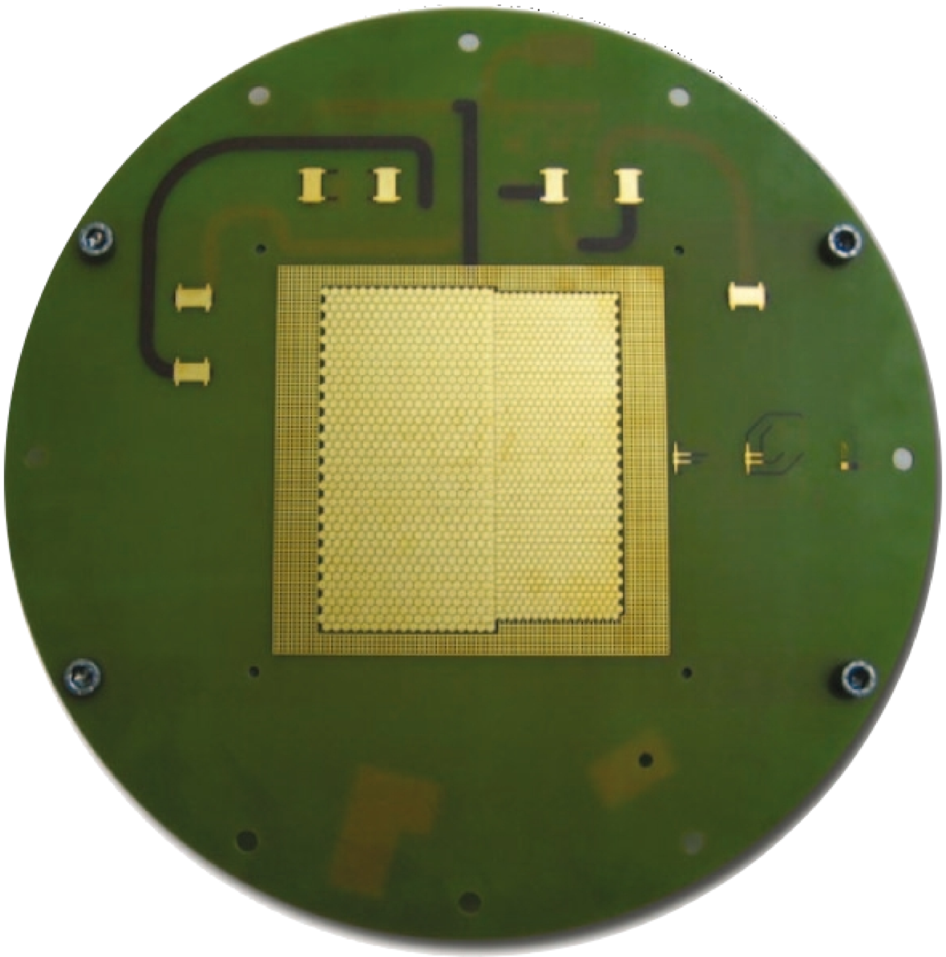
Universität Heidelberg
N. Herrmann

Universität Frankfurt / IKF
R. Arora, K. Peters

Backup

Testbench in Bonn@ELSA

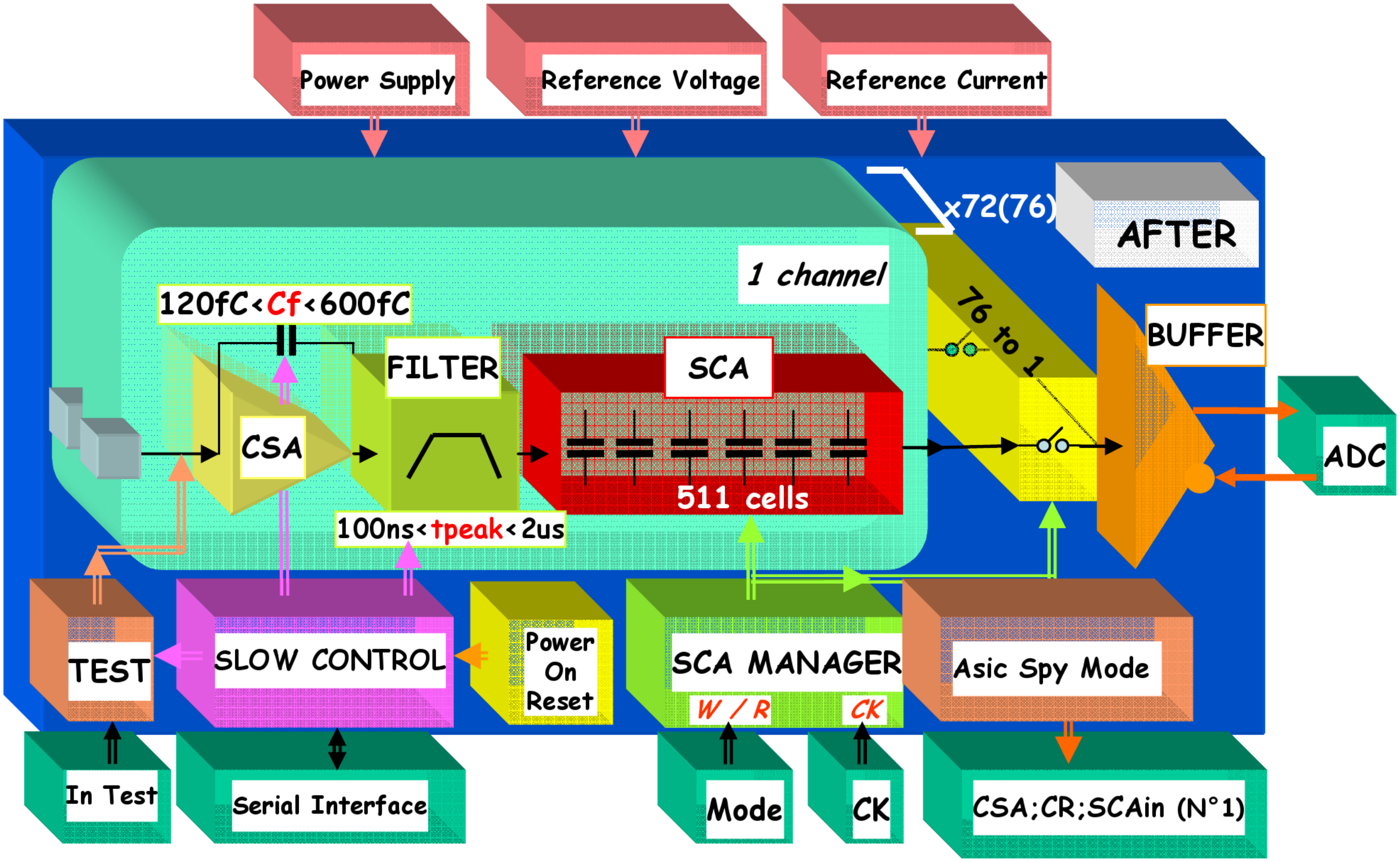




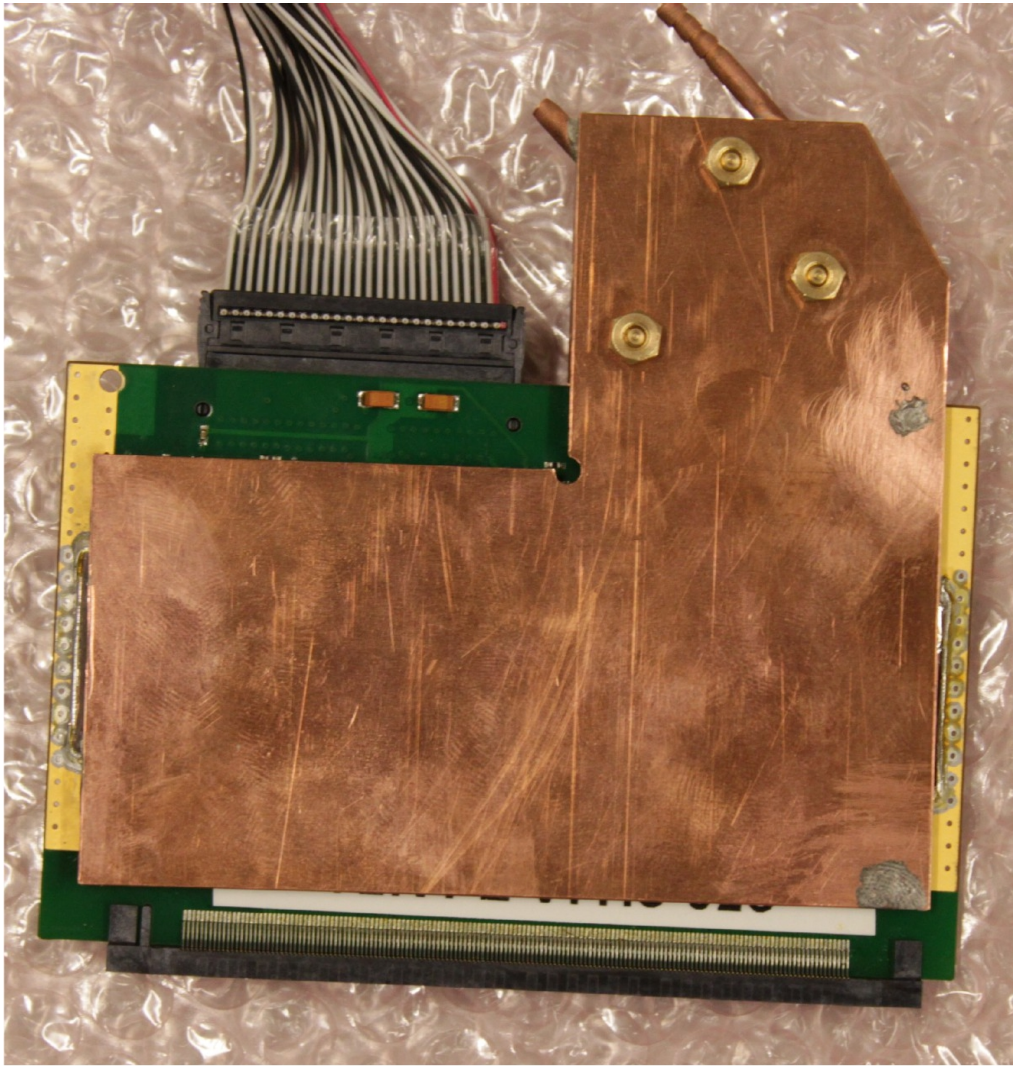
7cm drift-length
Active area 10x10 cm^2
Drift field= 250 V/cm
ArC02 (70/30)

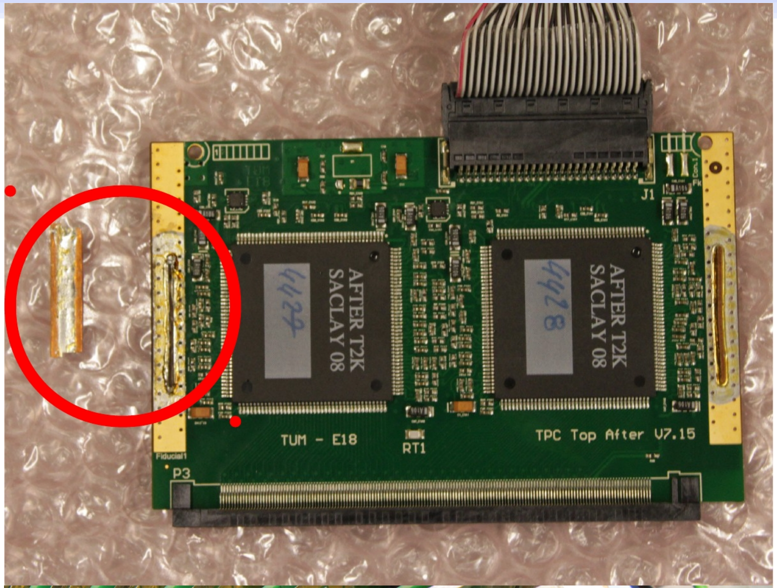
Hexagonal pads:
768 pads with outer radius = 1.5 mm
768 pads with outer radius = 1.25 mm
Triple-Gem stack

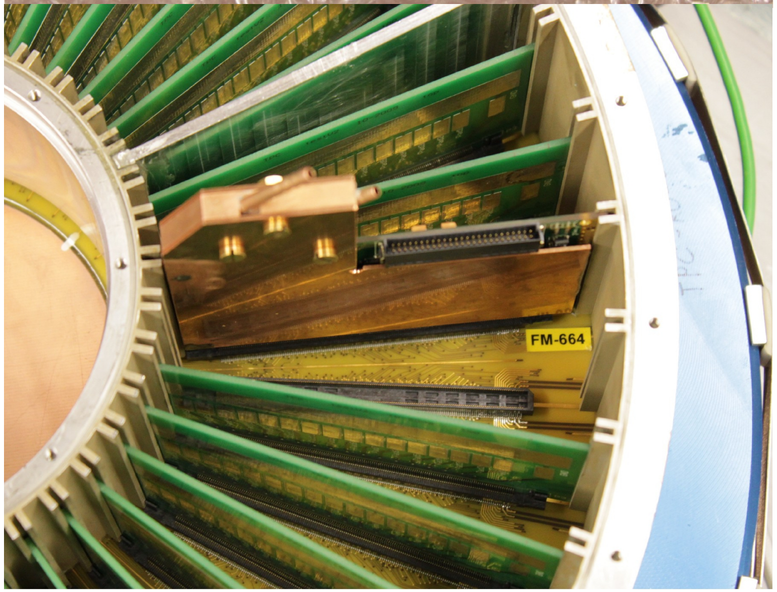
Front-end Electronics



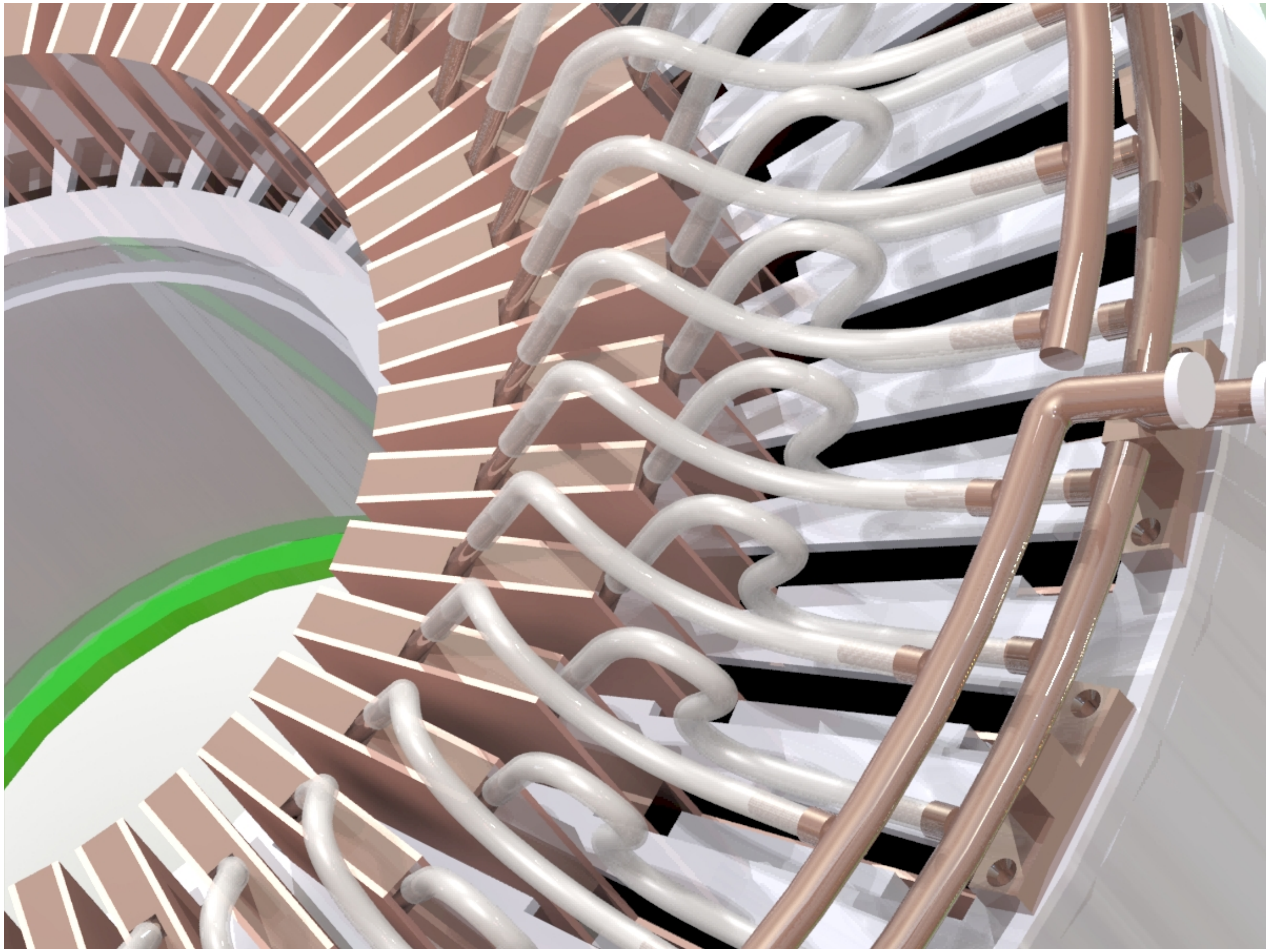
Front-end Electronics



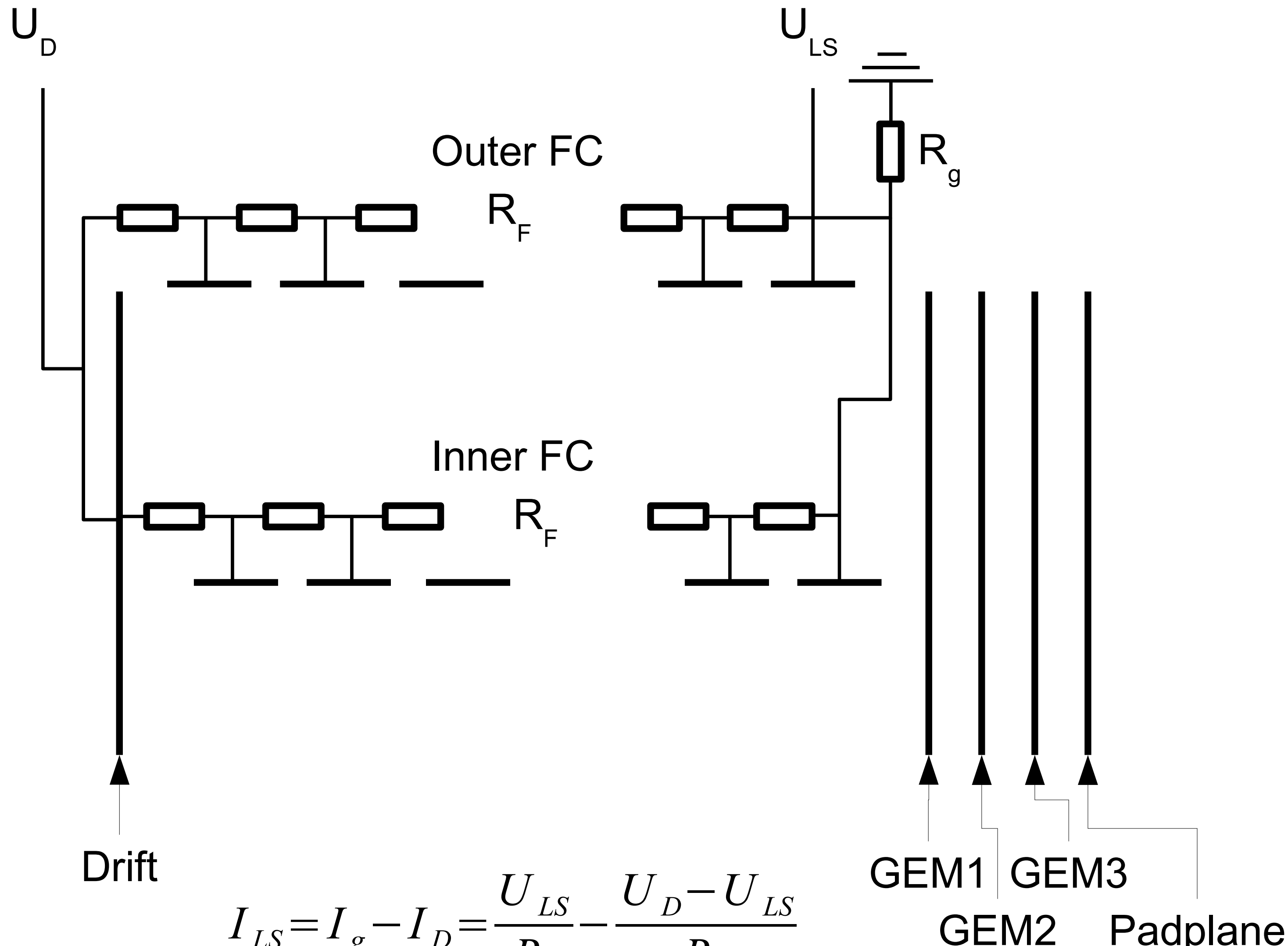




FE-Cooling



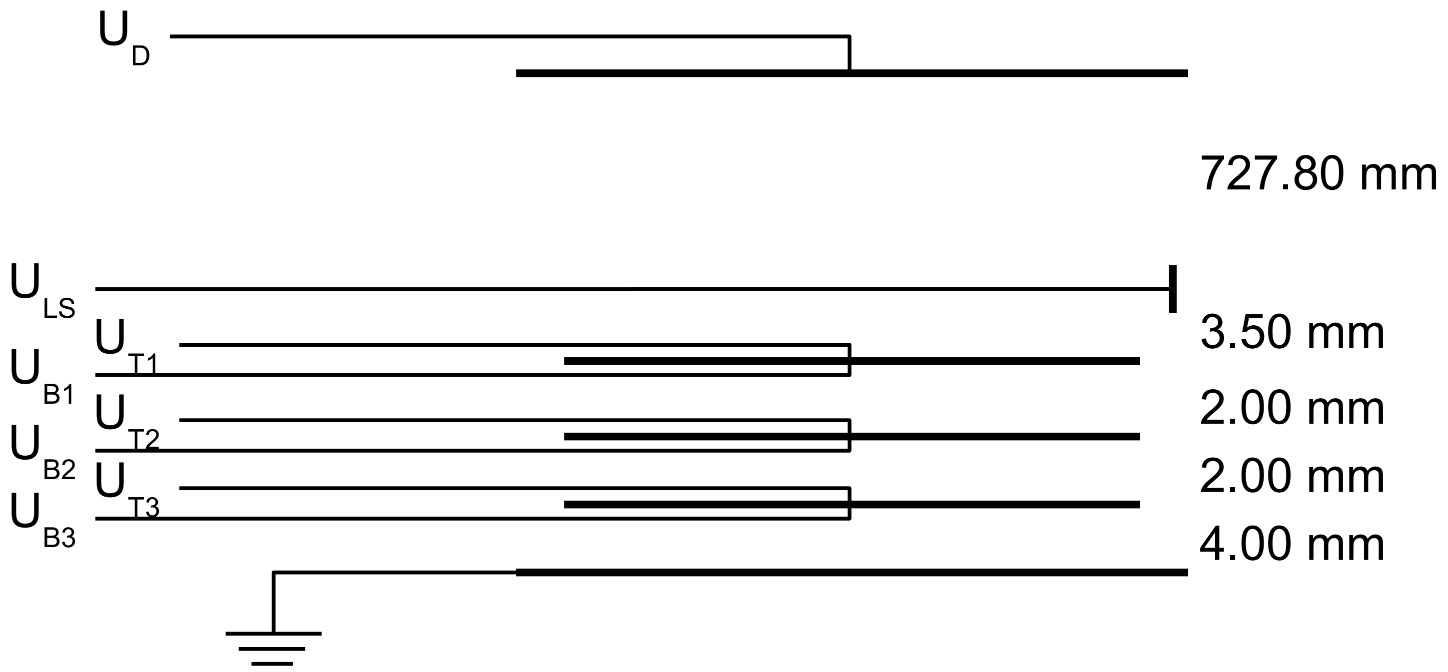
Electrical Design of Fieldcage



$$I_{LS} = I_g - I_D = \frac{U_{LS}}{R_g} - \frac{U_D - U_{LS}}{R_F}$$

Electrical Design of GEM-Stack

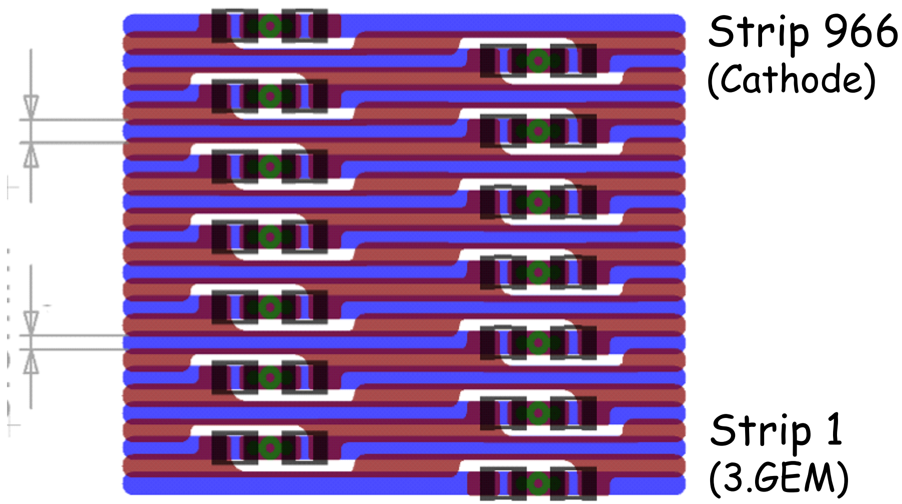
$$E = \frac{U}{d} \Rightarrow U = E \cdot d$$



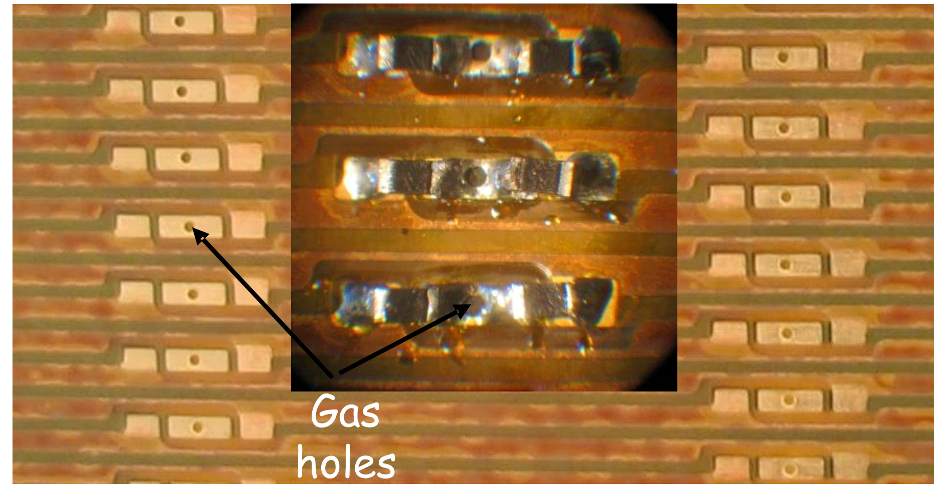
V_{drift} = 2.7 cm/ms @ 360 V/cm Ar/CO_2 90/10

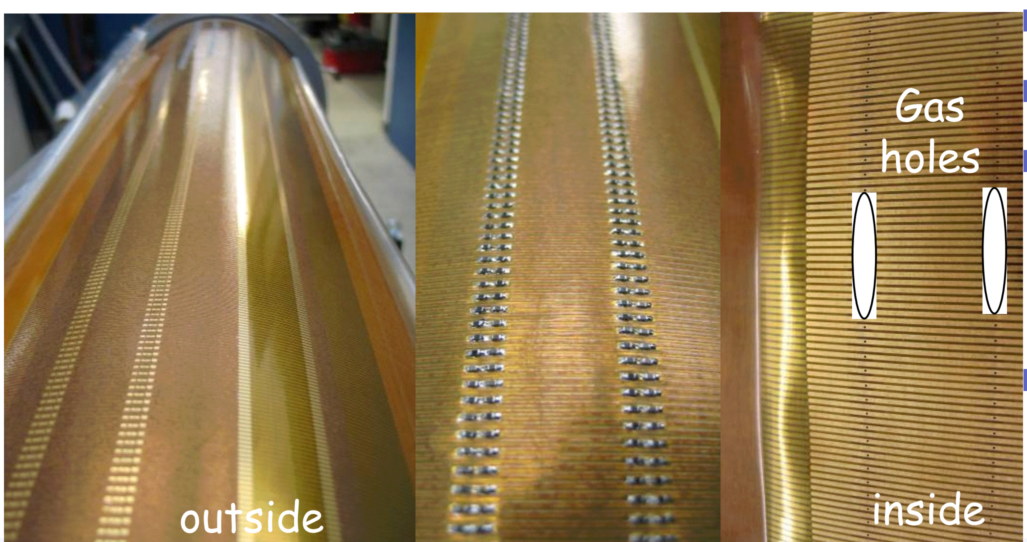
V_{drift} = 2.4 cm/ms @ 360V/cm Ne/CO_2 90/10

The Strip Foil



- Cu (2x25µm incl. Au-plating & Coverlay) on Kapton (≈50µm)





- Good shape conformity
- Manual soldering takes 162h / field cage
- Done sucessfully:
  - Test on flat samples
    stitching, mech. stability, gas penetration, HV-Stability, part mounting, handling etc.
- Next steps:
  - Production & test of full-size samples
  - Semi-automatic part mounting

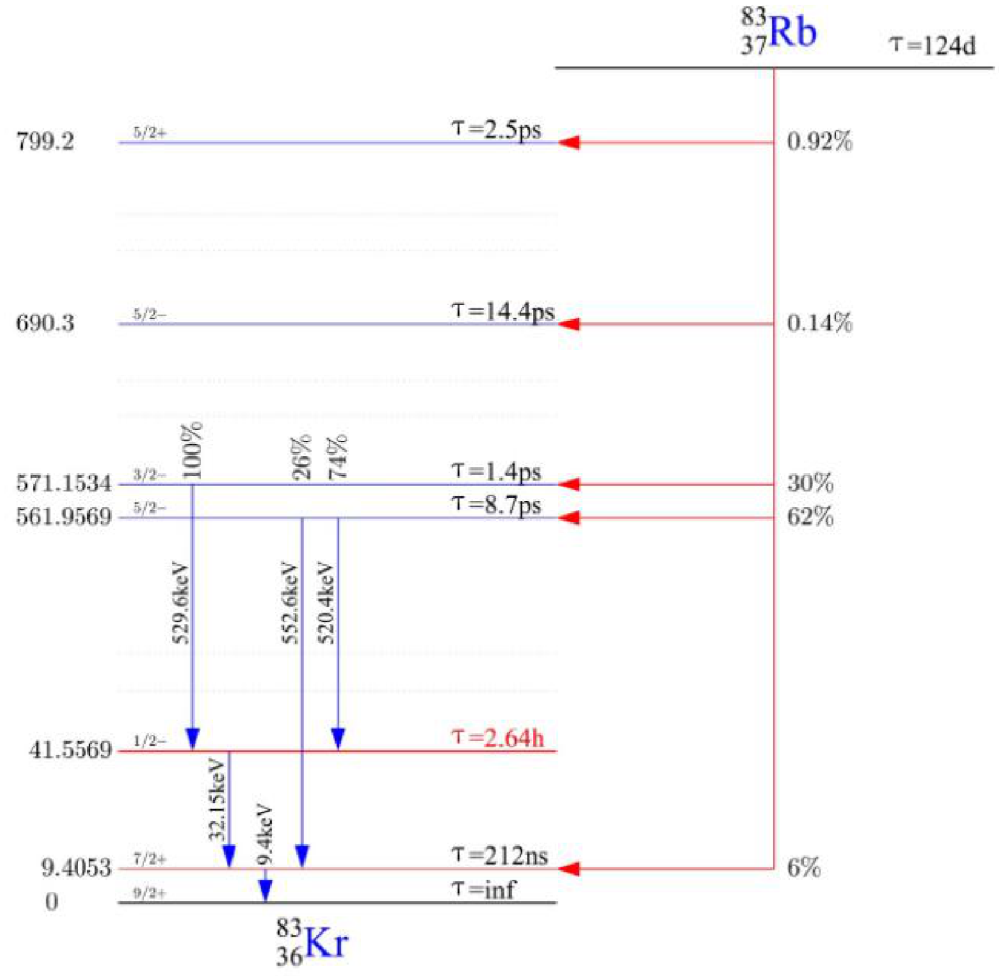
Krypton Test

The 41.6 KeV state decays via the 9.4 keV state into the ground state, dominantly by Internal Conversion.

The knocked out shell electrons are filled up from higher shells and either result in Auger electrons or X-rays

A rich energy spectrum of photon- and electron lines are available.

Electron lines in the energy range of 9.4 keV up to 41.5 keV are visible.

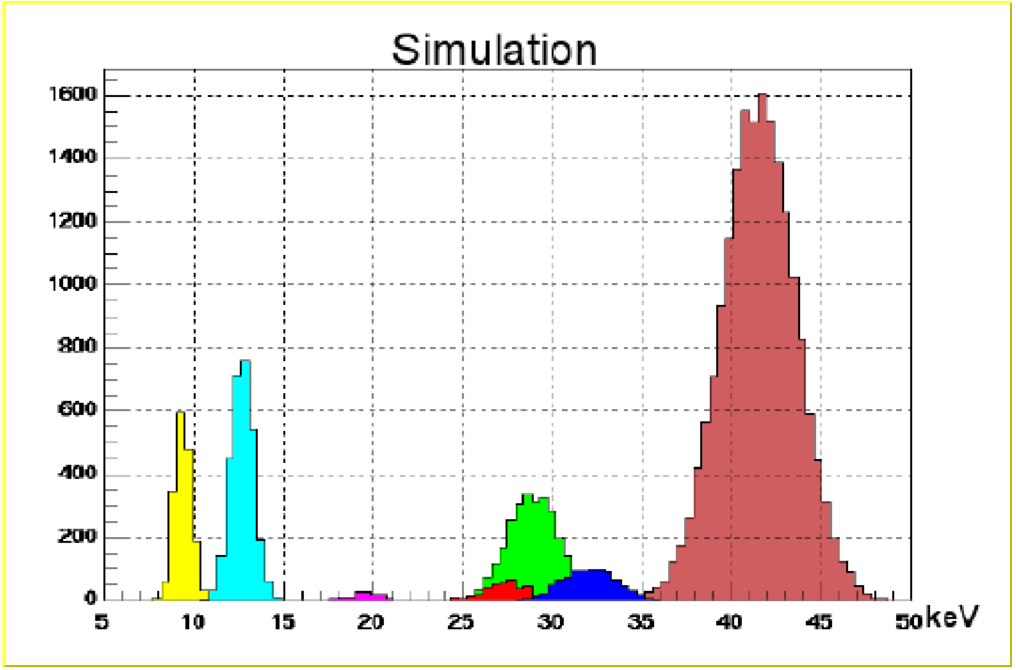


Krypton Test

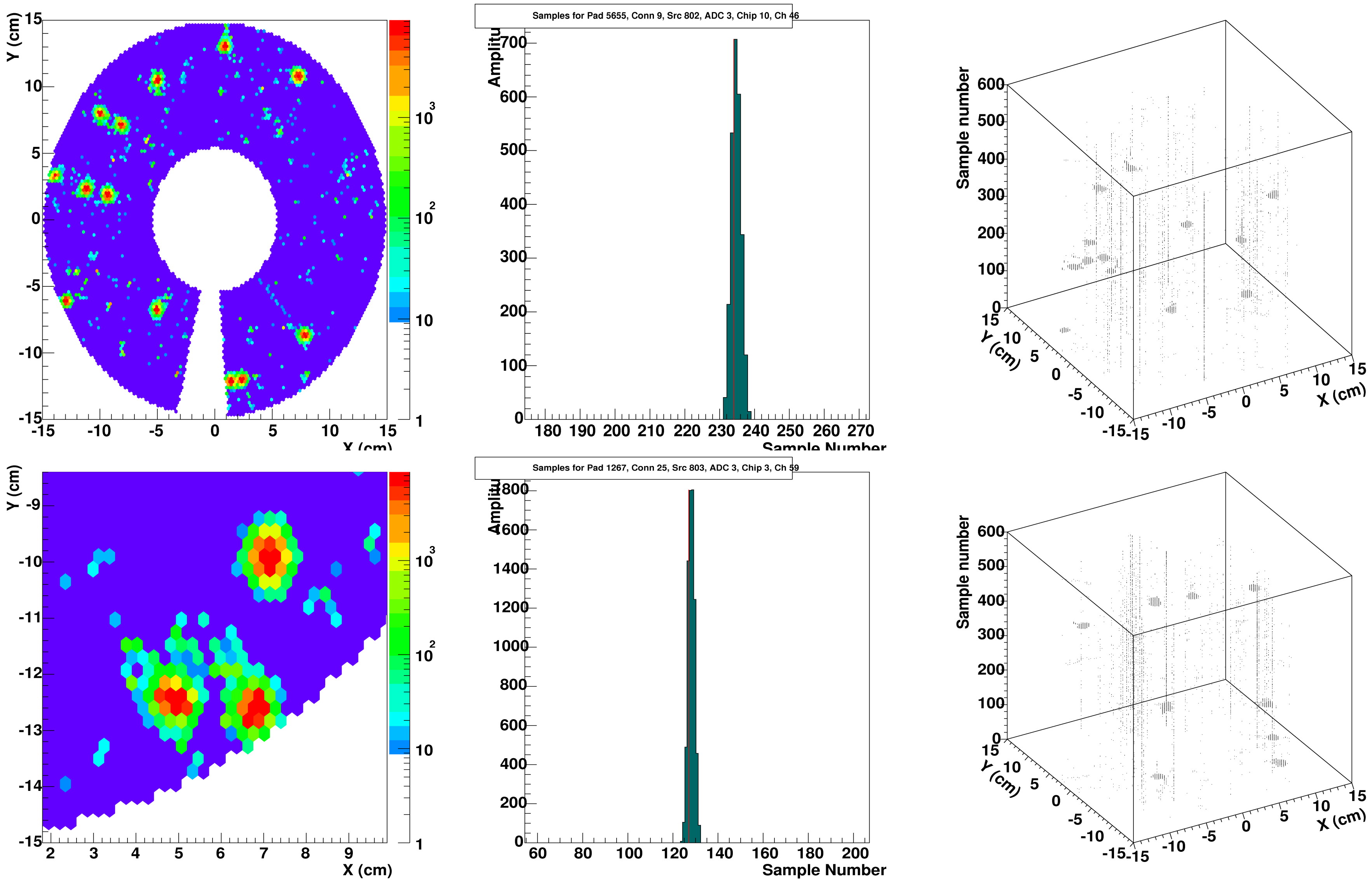
Energy(keV)	Fraction(%)
9.4	6.3
12.7	10.7
19.5	0.5
27.5	1.5
28.9	10.1
32.1	3.3
41.5	67.5

Electron energy spectrum

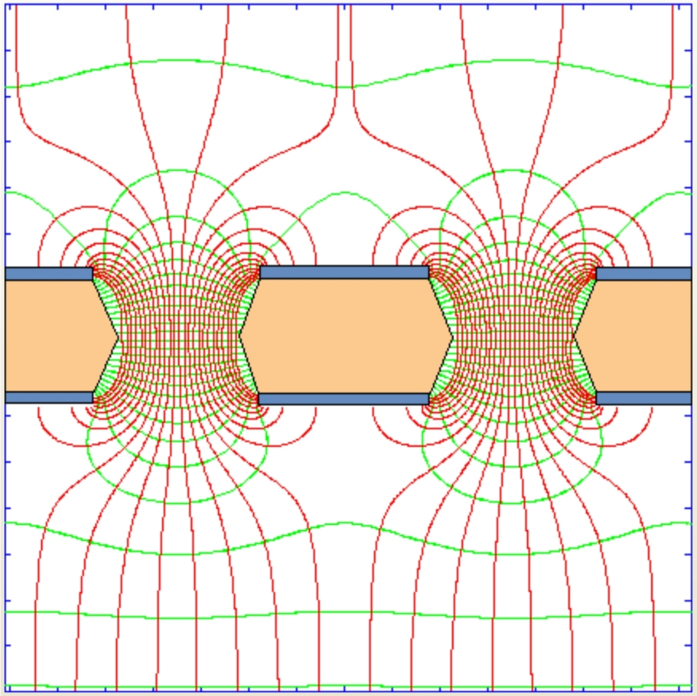
See diploma thesis of T. Eggert or talk of J. Wiechula

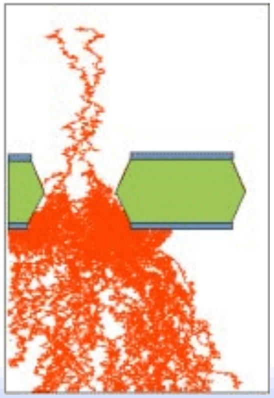


First Krypton Test



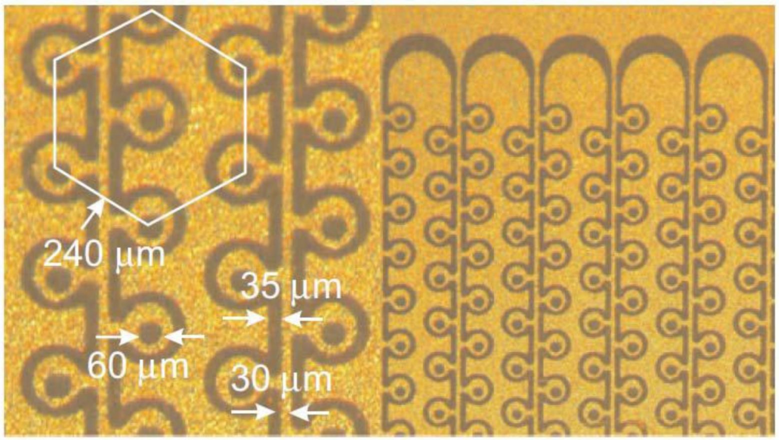
GEM
Gas Electron Multiplier

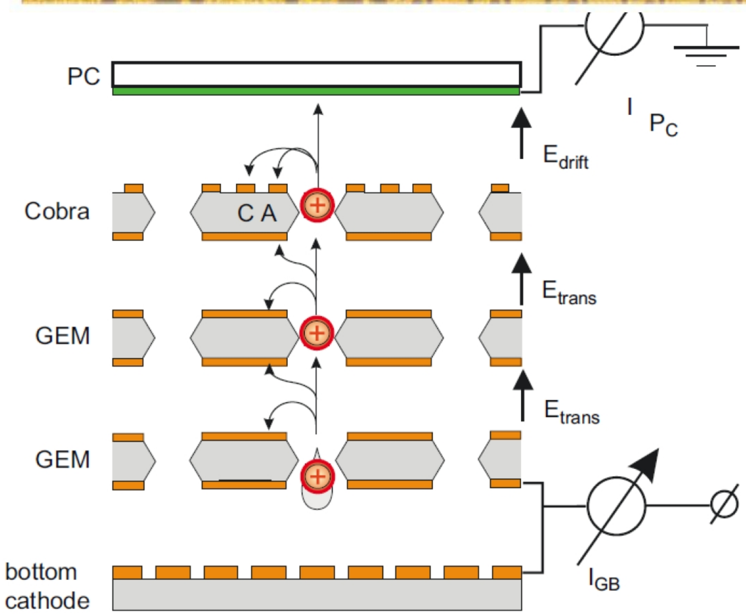


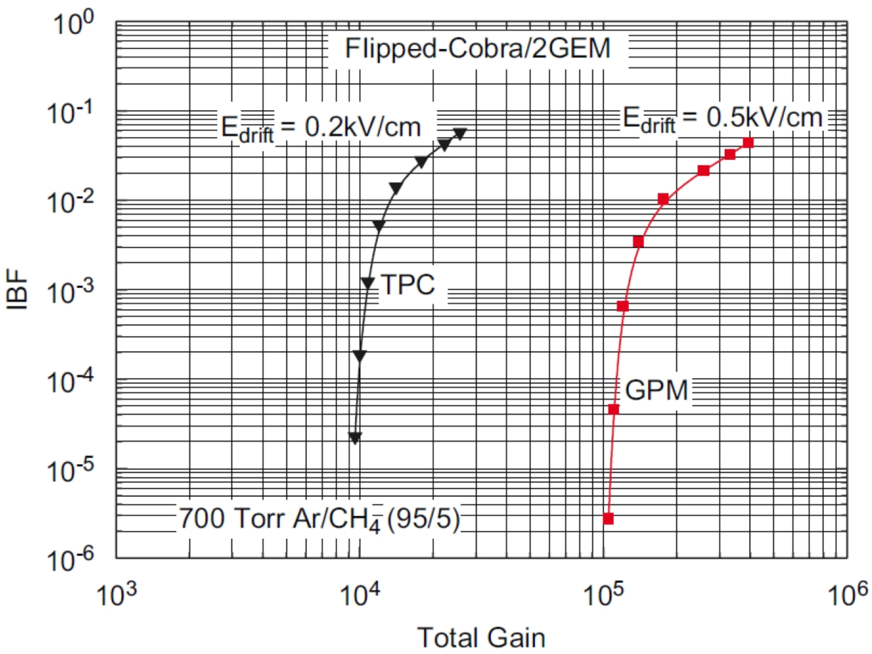


- ~400V potential difference → 50 kV/cm
- Amplification G_{eff} = several 10^3 (with 3 GEMS in a stack)
- Higher extraction field
- Ions are collected on upper side
- Electrons are extracted very effective
- Ion feedback suppressed by $1/G_{eff}$
- Until now no aging visible (GEM's in Compass since 8 years)
- Very uniform spatial resolution (triple GEM's ~ 69.6 µm)

Cobra gems



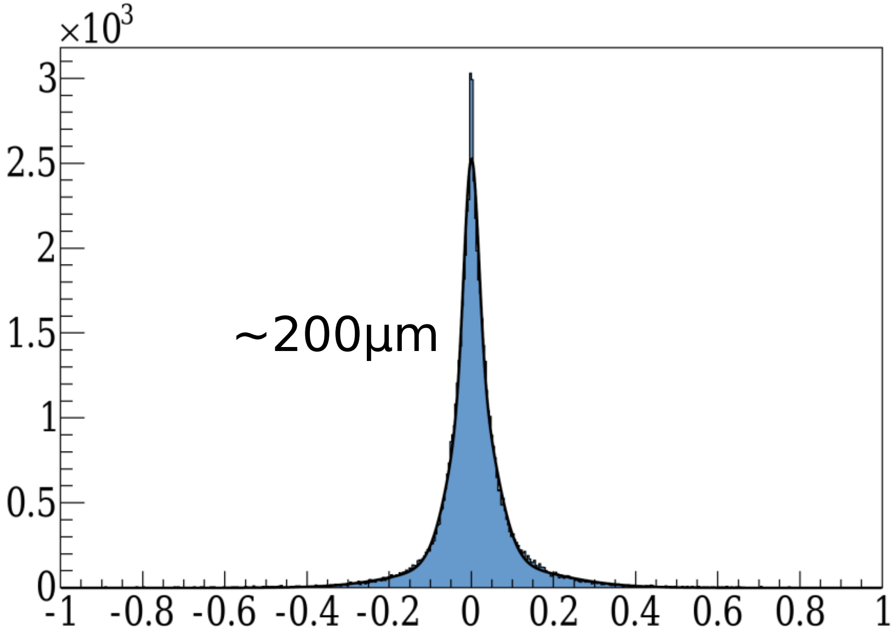


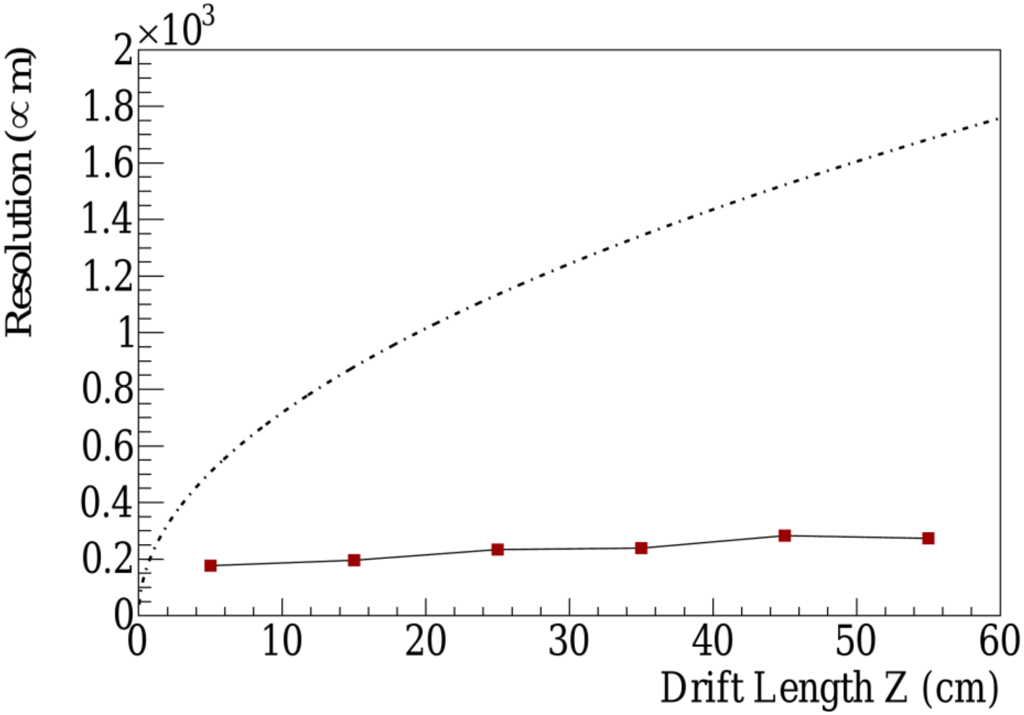


[A. Lyashenkoet al., NIM A 598 (2009) 116–120]
IB =2.7 · 10^{-5} reached

Studies on effect on spatial, momentum and energy resolution needed.

Spatial Resolution from Beam Events





Ar/CO_2 (90/10)

- Drift field: 360V/cm,
- Gain: 5100
- Beam: Ne^{22}