Ion Backflow Studies for TPCs in high Rate Experiments

Markus Ball

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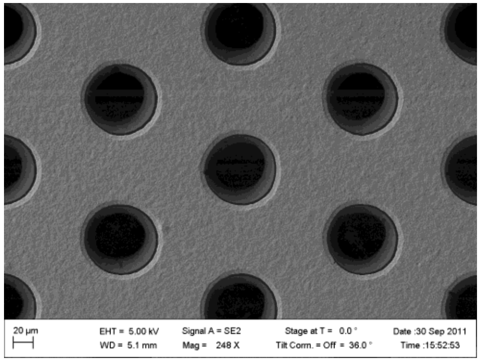
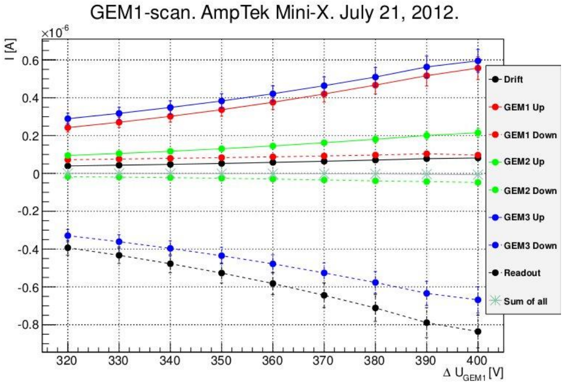
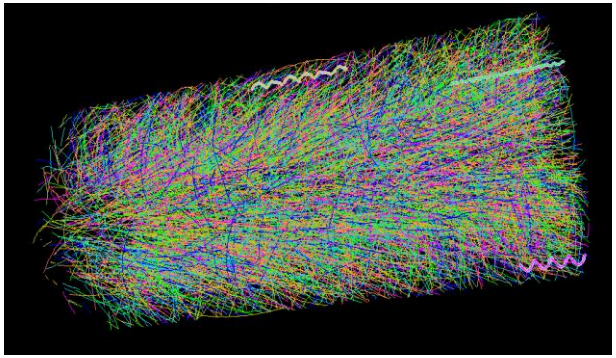






Outline

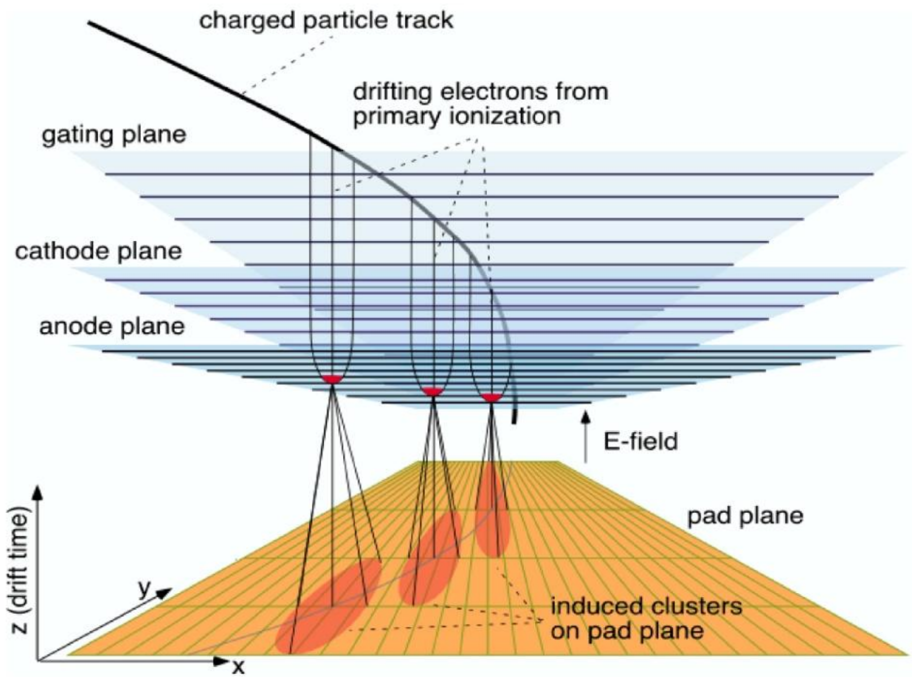
- Introduction
- Ion Backflow Suppression with GEMs
- The Setup at TUM
- IB Results for Ar/CO_2 (70/30) and Ne/CO_2 (90/10)
- Conclusions and Outlook

Time Projection Chamber

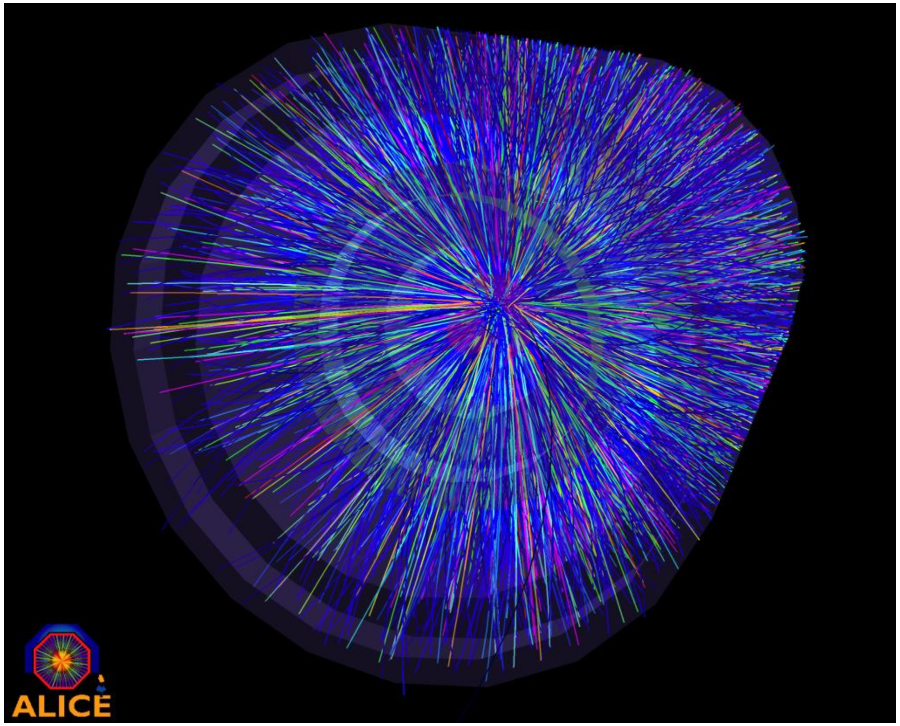
Time Projection Chamber [D.R. Nygren et al., Phys. Today 31, 46 (1978)]

Combination of MWPC and Drift Chamber: 3-D tracking device

- long drift path (~m) in gas-filled volume ⇨ z coordinate
- MWPC + pads perpendicular to drift path ⇨ x,y coordinates



Advantages and Limitations of a TPC



An (almost) ideal tracking detector:

- Large acceptance
- Large active volume
- Low material budget
- 3D hits ⇨ simple pattern recognition
- Extremely high particle densities
- Good momentum resolution
- Particle identification

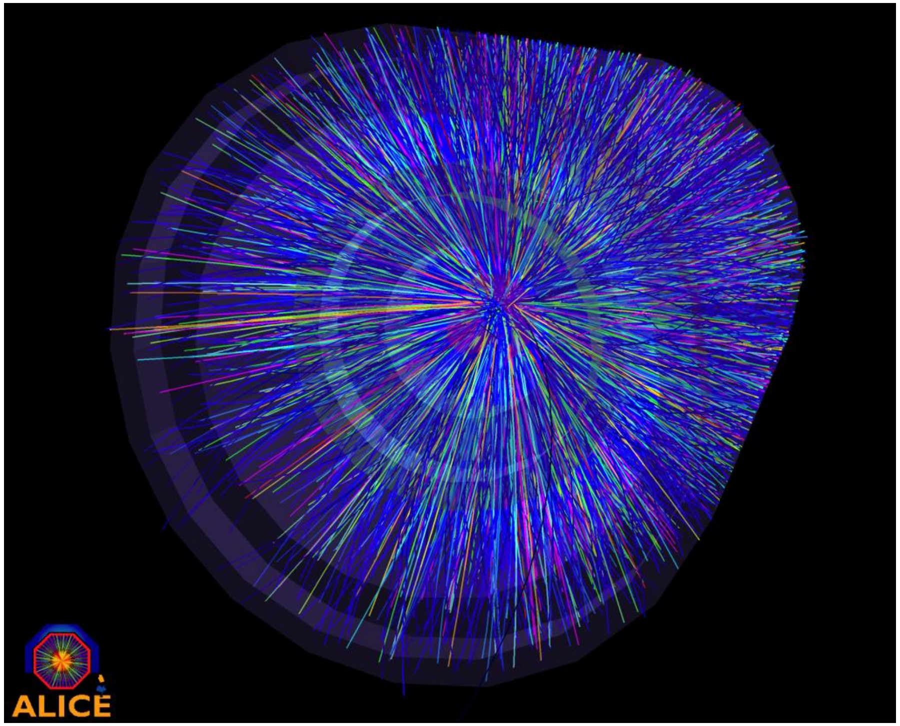
Limitations:

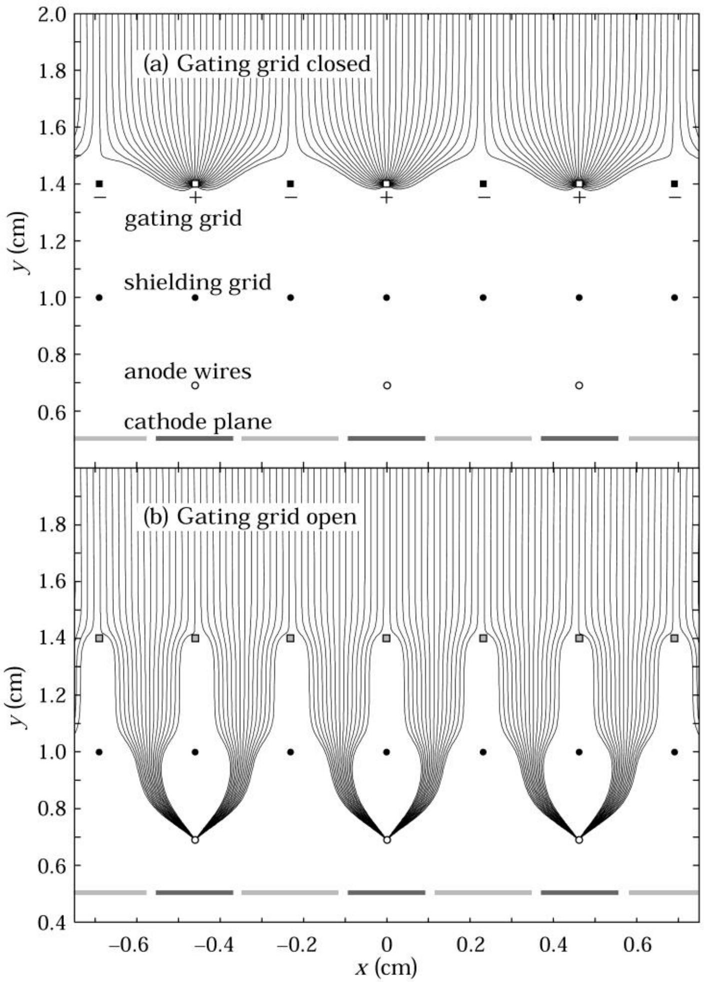
- Calibration very demanding
- Drift distortions due to ion backflow
- Gating ⇨ low trigger rates

Examples:

- STAR (420 cm × 400 cm)
- ALICE (500 cm × 500 cm)
- ILC (360 cm x 460 cm)

Advantages and Limitations of a TPC



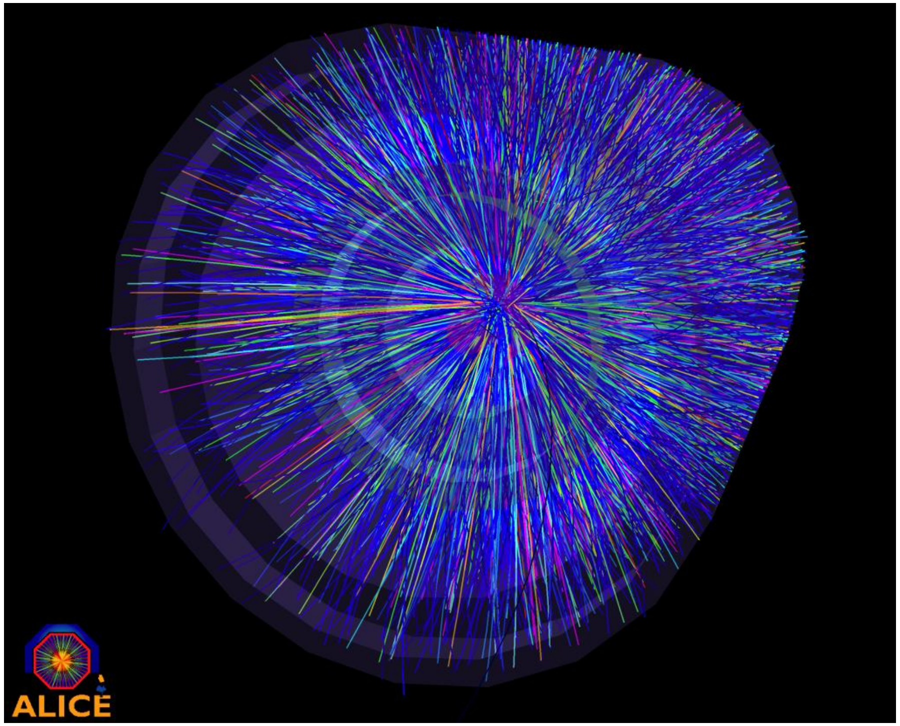


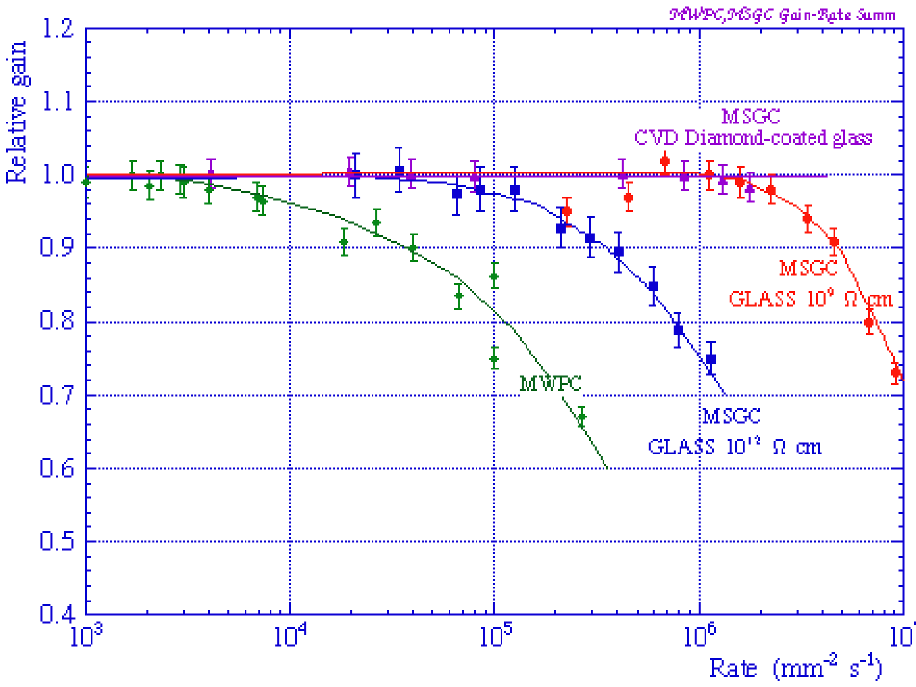
Limitations:

- Calibration very demanding
- Drift distortions due to ion backflow
- Gating ➩ low trigger rates ~ 1 kHz

Ion Backflow suppression of a MWPC with Gating grid ~ 10^{-5} !

Advantages and Limitations of a TPC





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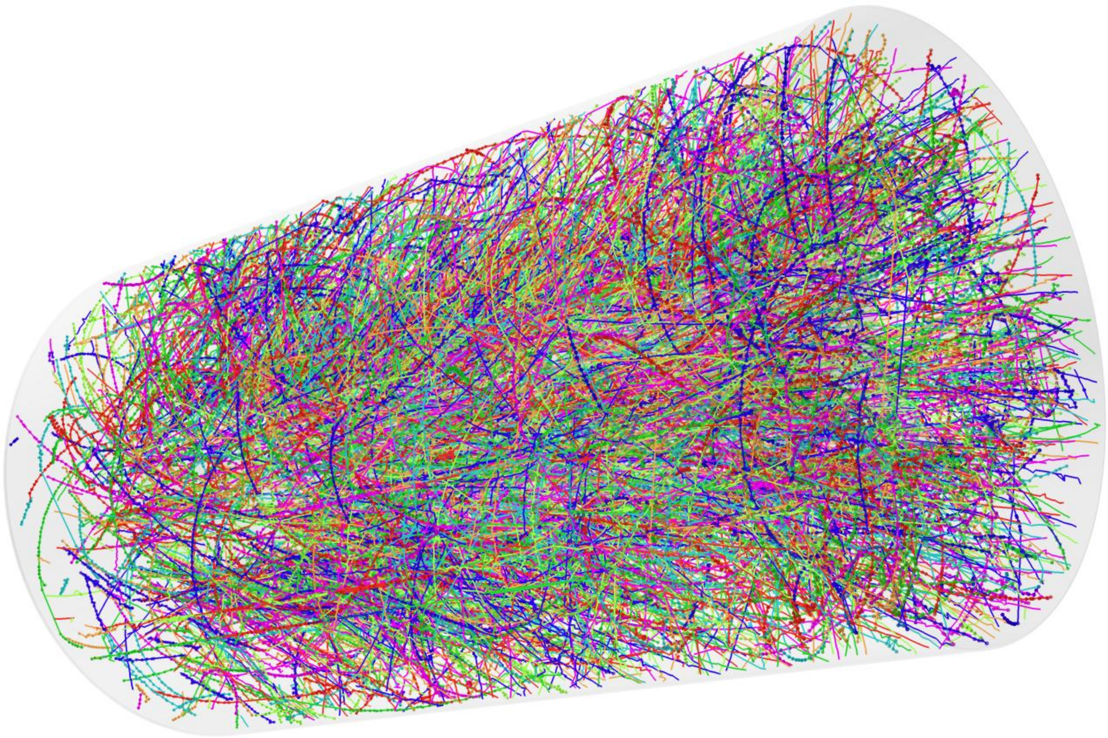
Operation at High Rates

High rates: drift time > 1 / event rate ⇨ overlapping events

Goal: operate TPC continuously ⇨ analog event pipeline



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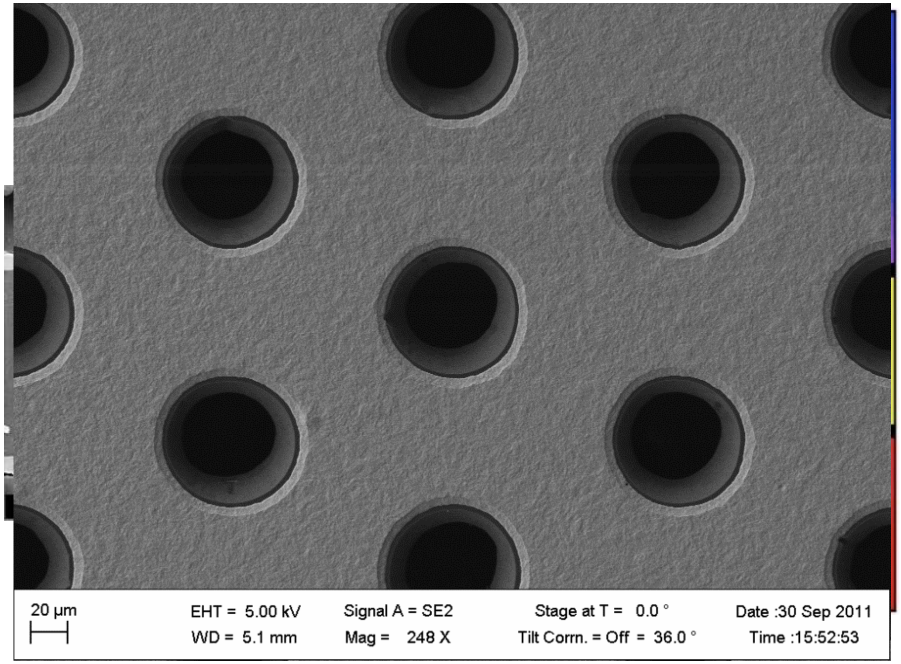
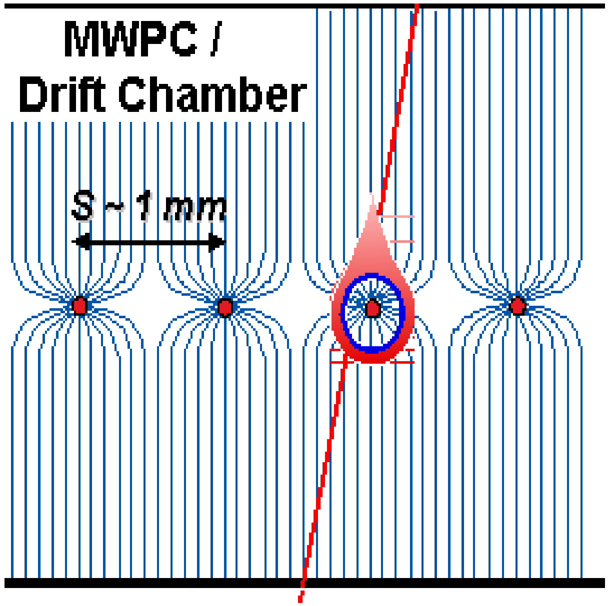
Gas Electron Multiplier (GEM)





- GEM: **G**as **E**lectron **M**ultiplier

[F. Sauli, NIM A386, 531 (1997)]

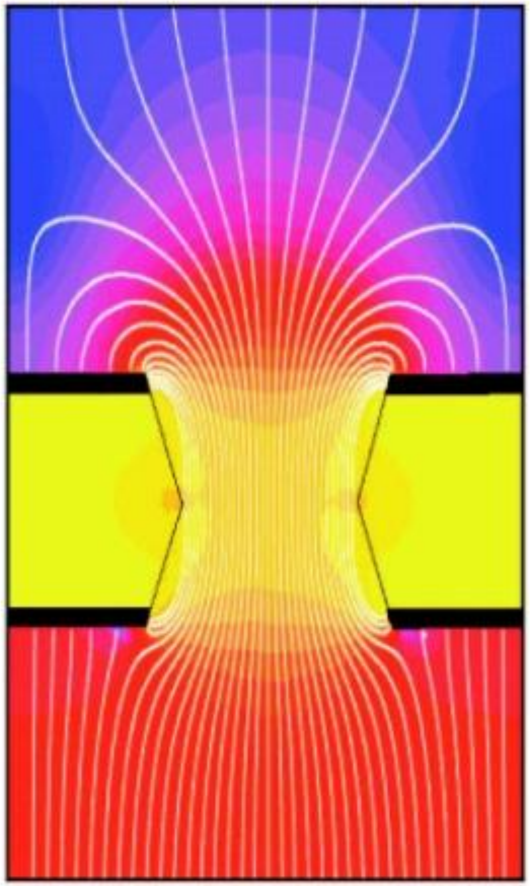
- Thin polyimide foil, typ. 50 μm
- Cu-clad on both sides, typ. 5 μm
- Photolithography: ~ 10^4 holes/cm^2
- Granularity 10 × higher than MWPC

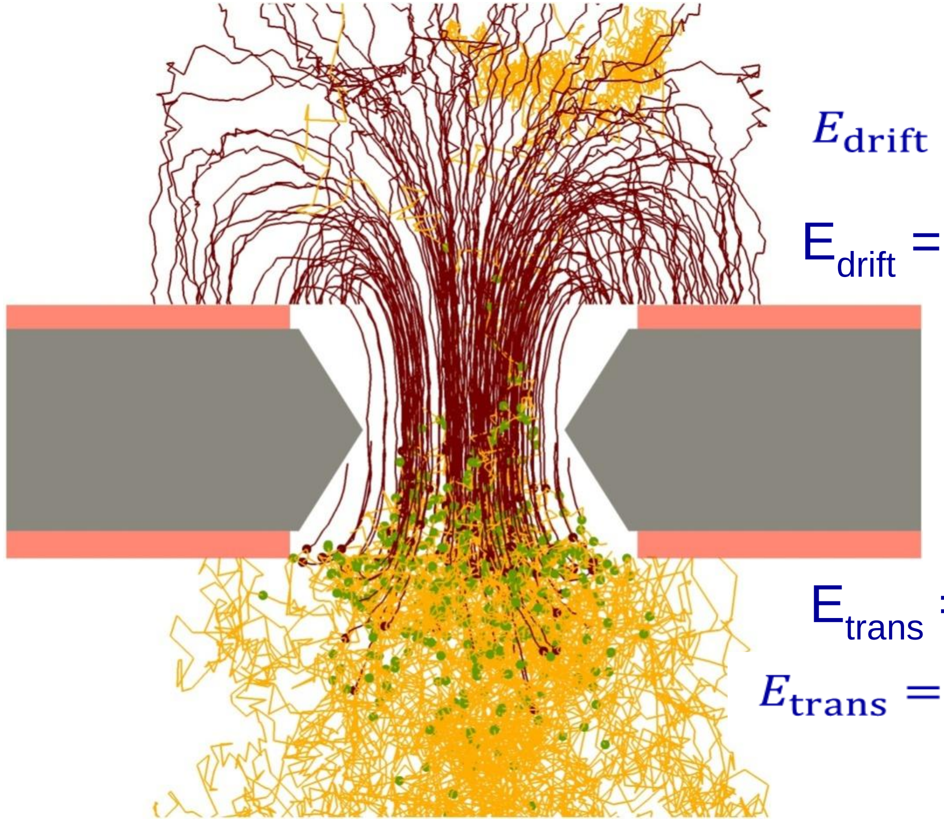
- ΔU=300-500 V

⇨ high E-field: ~50 kV/cm

⇨ avalanche multiplication

Ion Backflow





$E_{\text{drift}} = 250\ \text{V/cm}$

E_{drift} = 250 V/cm

E_{trans} = 3.75 kV/cm

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GARFIELD/MAGBOLTZ simulation: two electrons arriving at GEM hole

GARFIELD/MAGBOLTZ simulation: two electrons arriving at GEM hole

- $E_{\text{hole}} \gg E_{\text{drift}}$ ⇨ most of the ions are collected on the top side of the GEM
- $E_{\text{trans}} > E_{\text{drift}}$ ⇨ electron extraction is improved

Ion Backflow - Definition

Ion Back-Flow

Ion Back-Flow is the ratio

$$\frac{\text{Ions arriving at the cathode}}{\text{Electrons arriving at the anode}}.$$

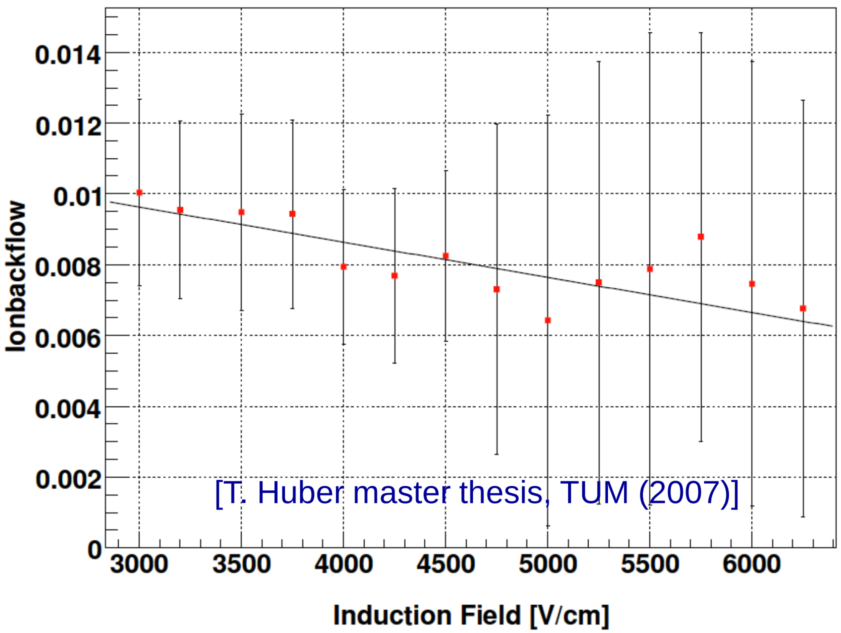
In the following presentation the ratio of currents

$$\text{IB} = \frac{I_{\text{drift}}}{I_{\text{readout}}}$$

defines the ion backflow under the assumption, that fluctuations of currents are negligible

Current Limits on Ion Backflow

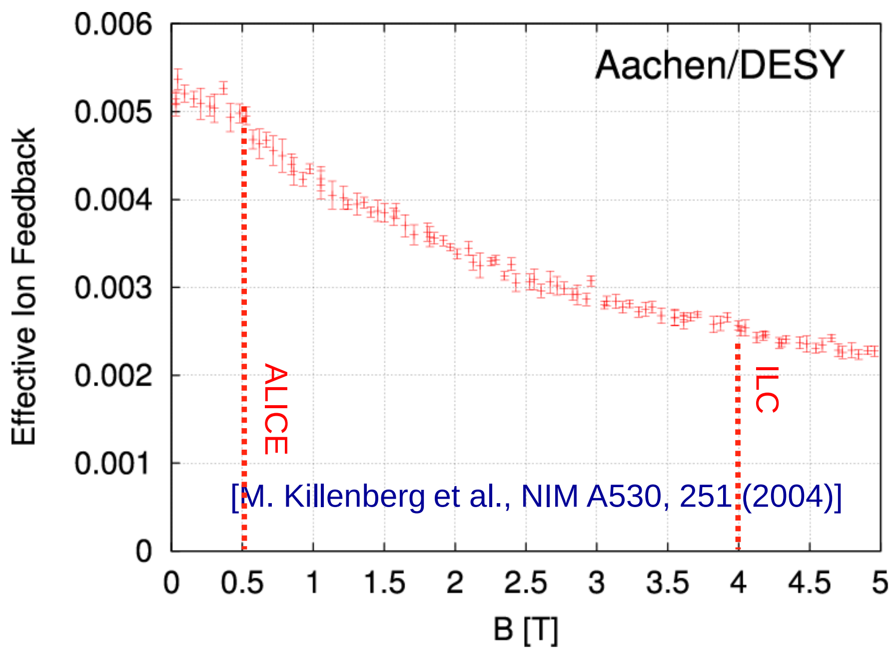
Ar/CO_2(70/30)



GEM voltage settings		*Detector field settings*	
GEM1	330 V	E_{Drift}	0.25 kV cm^{-1}
GEM2	375 V	E_{T1}	6.00 kV cm^{-1}
GEM3	450 V	E_{T2}	0.16 kV cm^{-1}
		E_{Ind}	5.00 kV cm^{-1}

$Ar/CO_2/CH_4$(93/2/5)

$V_{drift} \sim E + \omega\tau\,(E \times B) + (\omega\tau)^2 (EB)B$



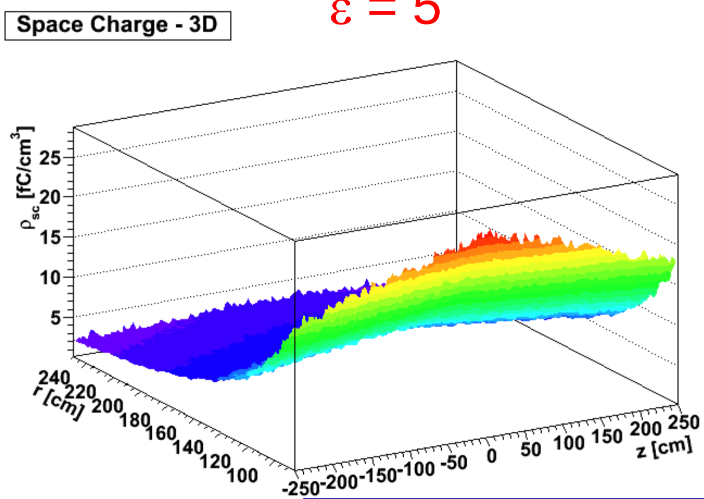
GEM voltage settings		*Detector field settings*	
GEM1	310 V	E_{Drift}	0.2 kV cm^{-1}
GEM2	310 V	E_{T1}	6.00 kV cm^{-1}
GEM3	350 V	E_{T2}	0.06 kV cm^{-1}
		E_{Ind}	8.00 kV cm^{-1}

Triple GEM with an IB=0.25 % realistic: ε=4 at G=2000

Space Charge Effects at ALICE

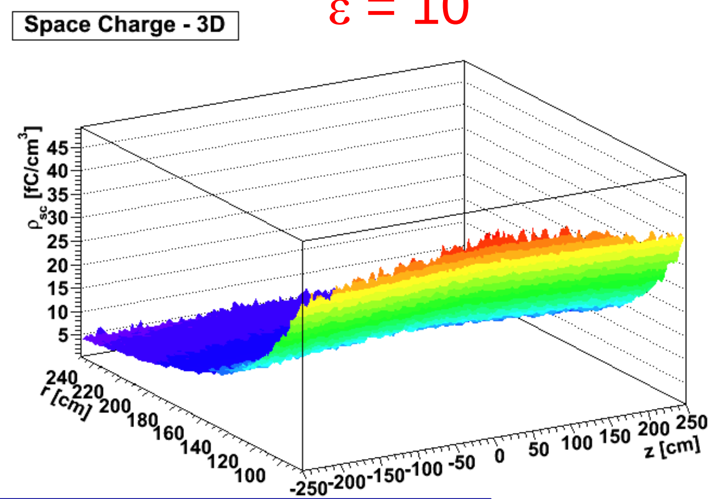
[CERN-LHCC-2012-012 / LHCC-1-022]

$\varepsilon = 5$



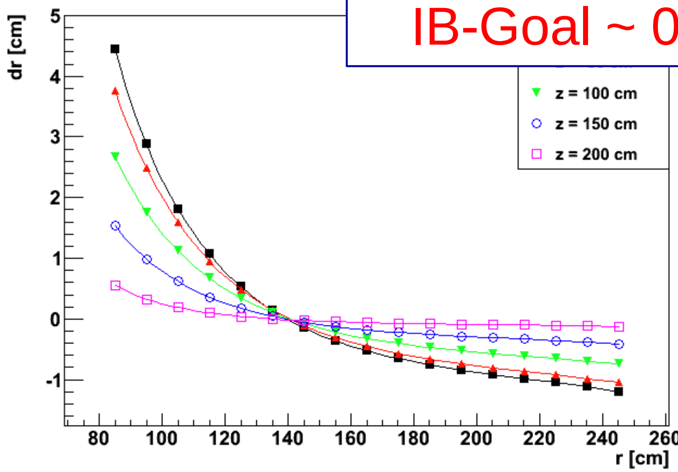
[CERN-LHCC-2012-012 / LHCC-1-022]

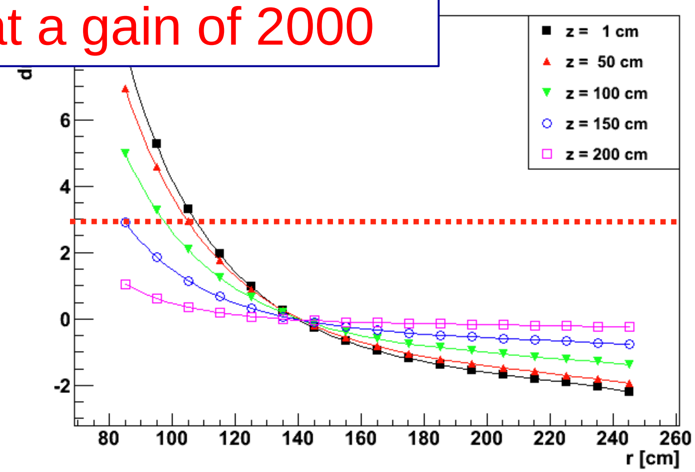
$\varepsilon = 10$



Resulting distortions ~ 5 cm can be corrected

IB-Goal ~ 0.5 % (ε = 10) at a gain of 2000





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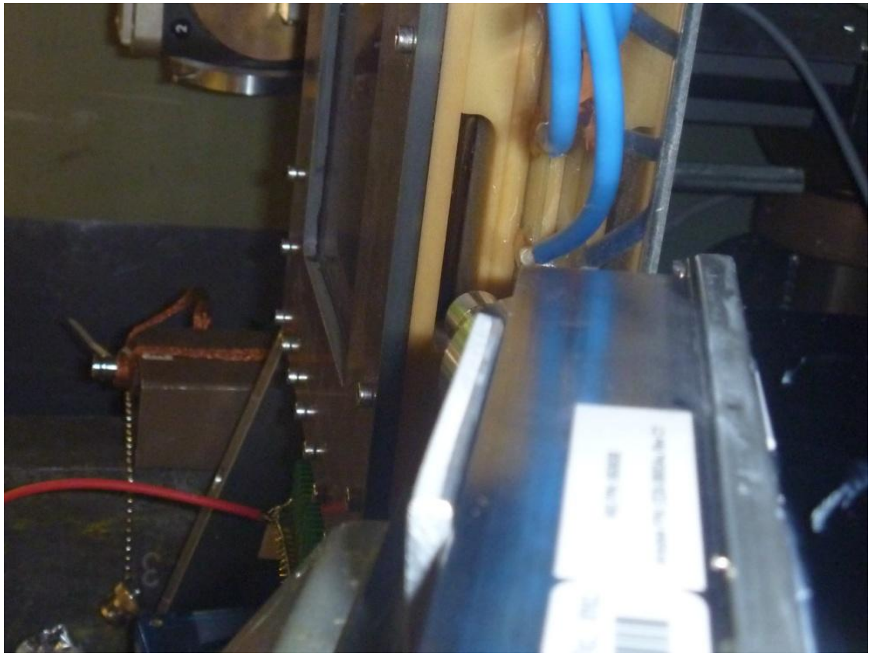


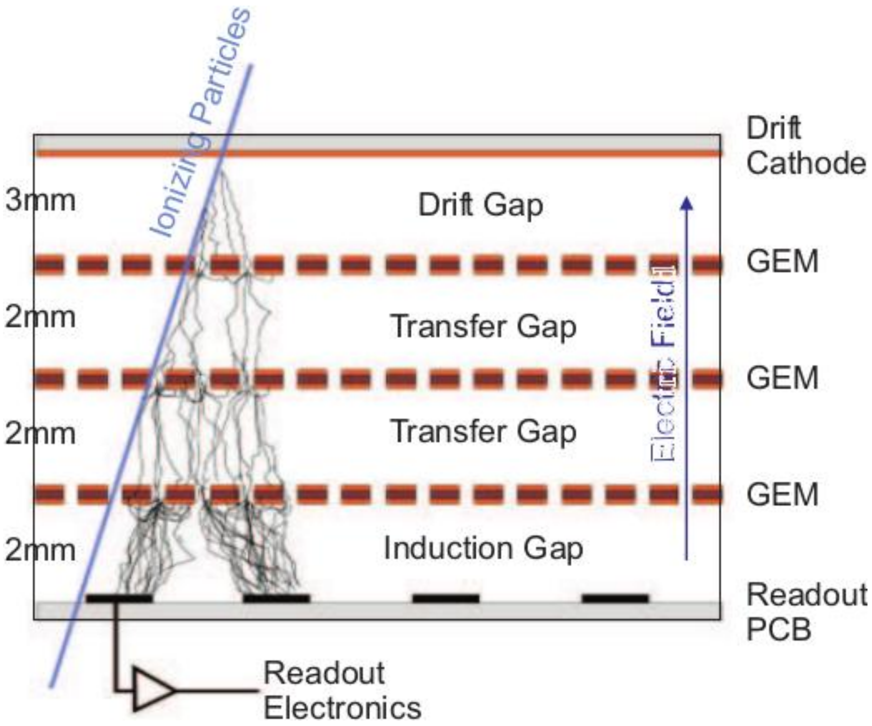
Low ion backflow requires

- low drift field
- very asymmetric transfer fields
- highest amplification in 3rd GEM

Conflicting requirements:

- diffusion, attachment
- energy resolution
- stability

Ion Backflow



Standard Settings

GEM voltage settings		*Detector field settings*	
GEM1	400 V	E_{Drift}	$0.4\,\mathrm{kV\,cm^{-1}}$
GEM2	372 V	E_{T1}	$3.8\,\mathrm{kV\,cm^{-1}}$
GEM3	322 V	E_{T2}	$3.8\,\mathrm{kV\,cm^{-1}}$
		E_{Ind}	$3.8\,\mathrm{kV\,cm^{-1}}$

Ion Backflow Settings (Aachen)

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Ion Backflow

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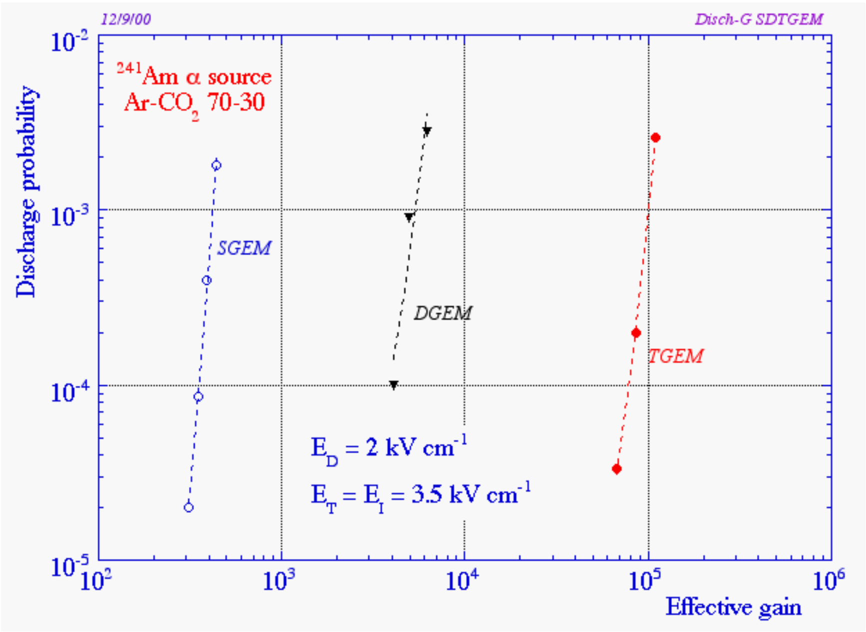
[S. Bachmann et al., NIM A479, 294 (2002)]



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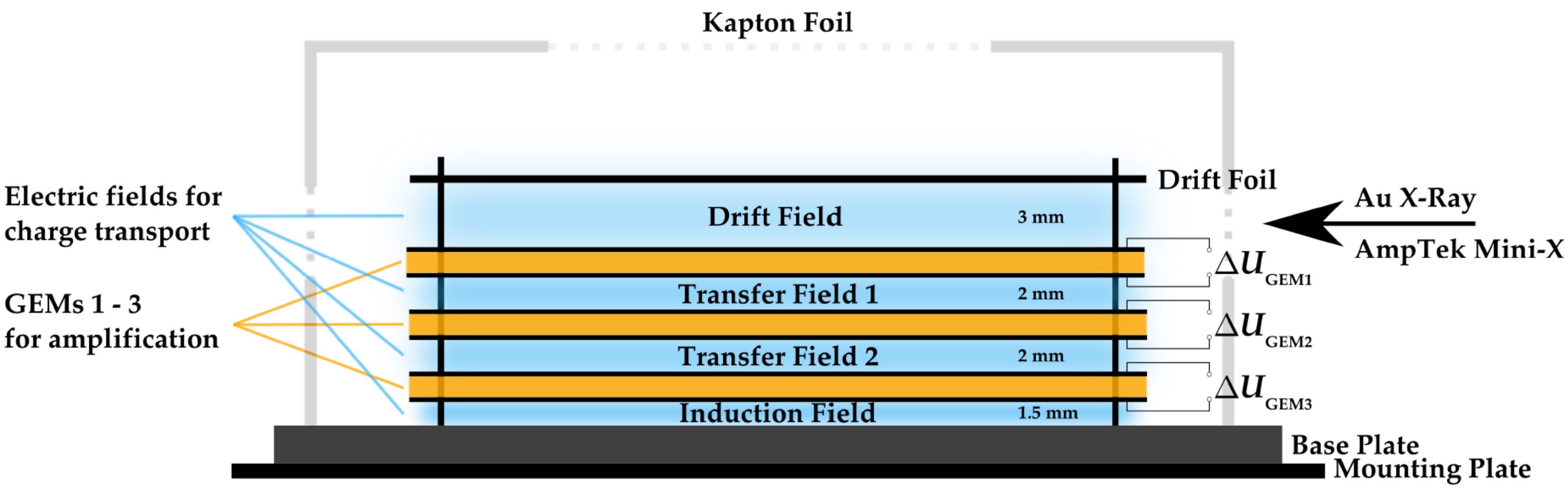
TUM Setup - Detector



- Small drift volume of 3 mm
- Triple GEM structure
- Gas gain around 2000
- Strip readout (512 strips)
- X-Rays enter from side window to avoid conversion between the GEMs

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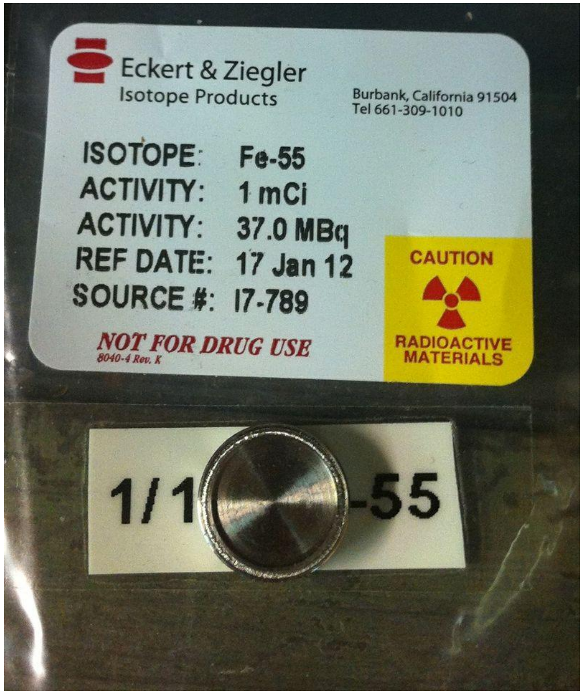
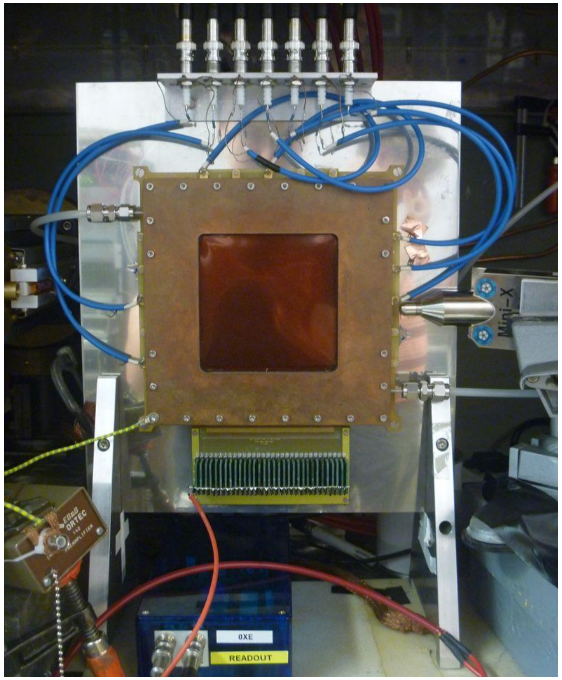
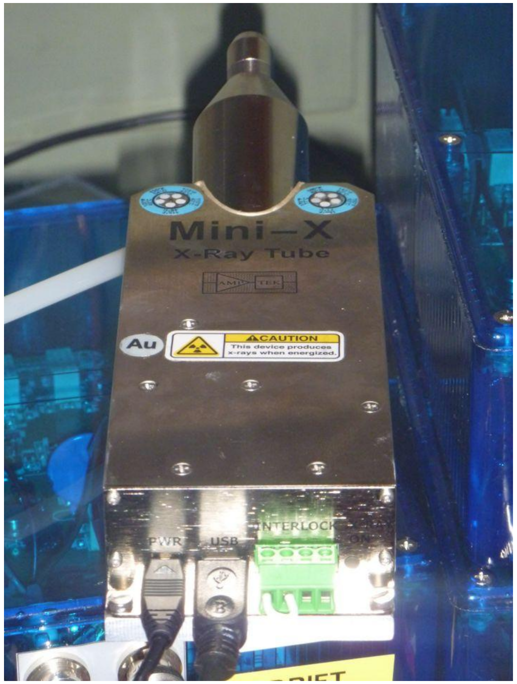






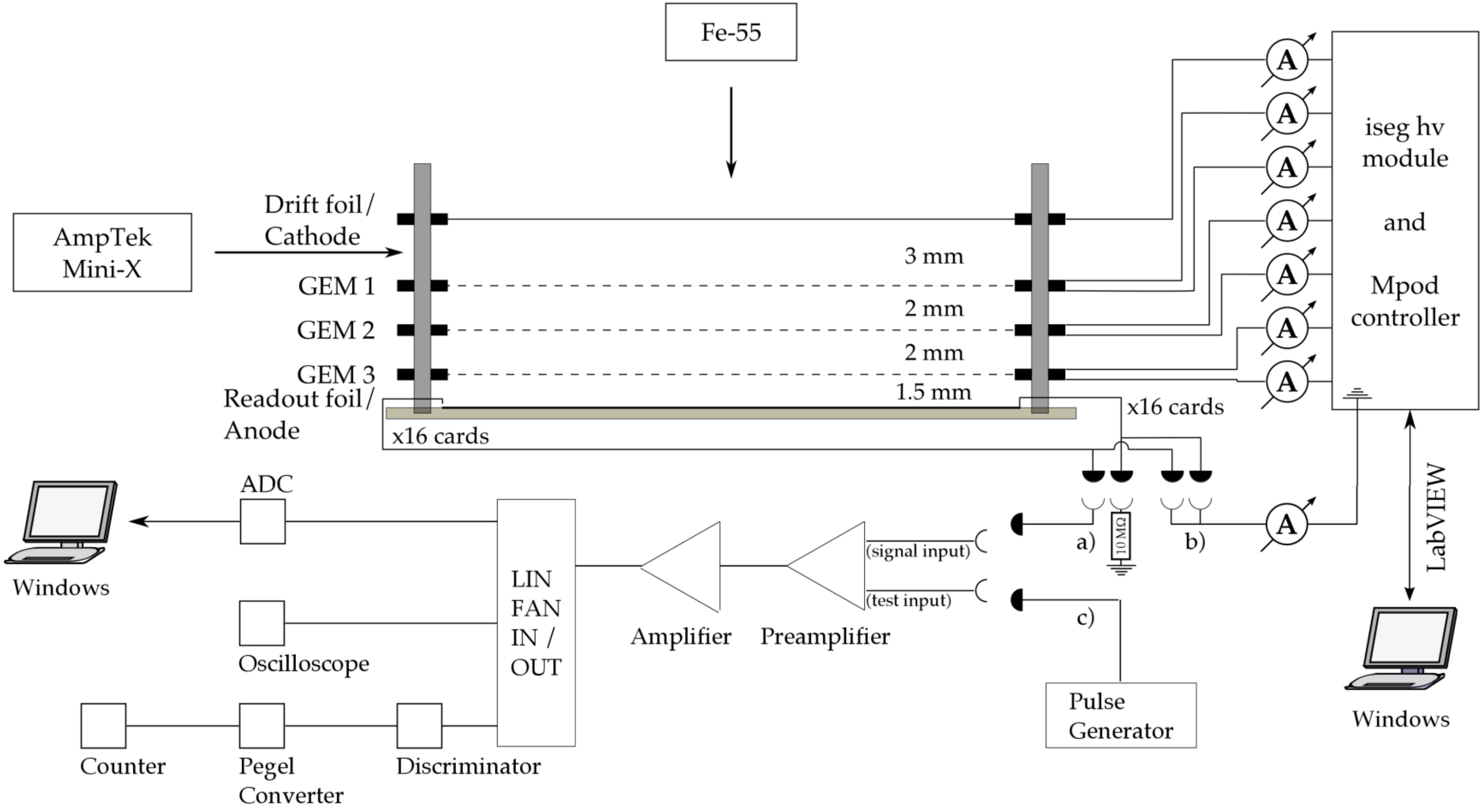
^{55}Fe with an activity of 37 MBq

- Well defined energy
  ⇨ excellent for measurements of energy resolution and gain

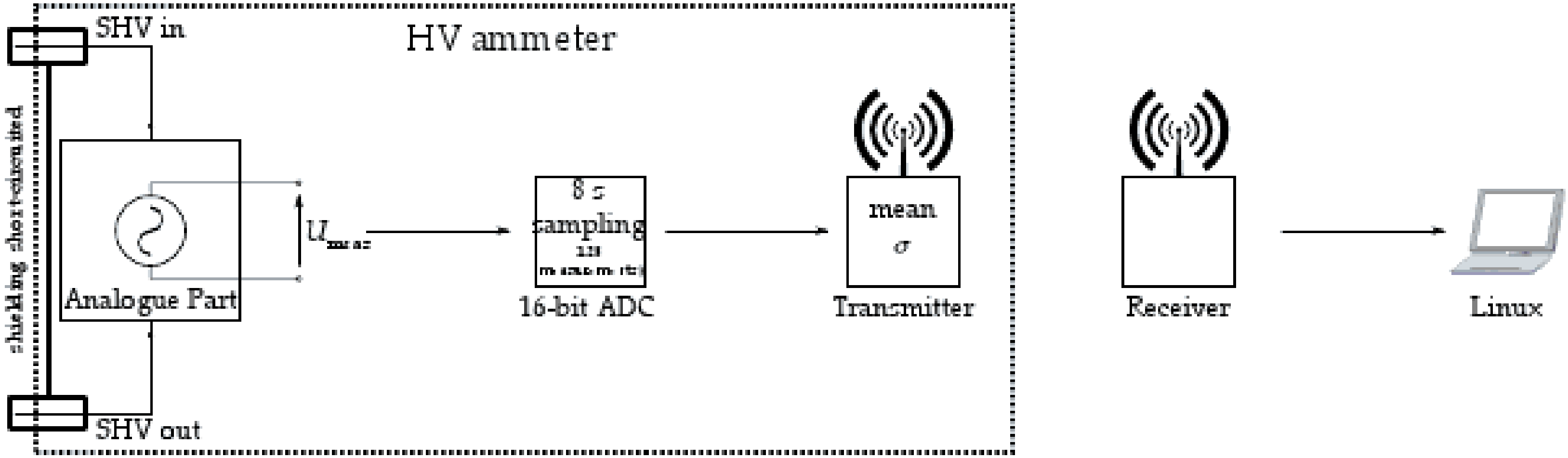
Amptek Mini-X Au (4 W)

- High rates
  ⇨ high currents at the GEMs (μA), but energy spectrum is deteriorated by Bremsstrahlung

TUM Setup - Readouts



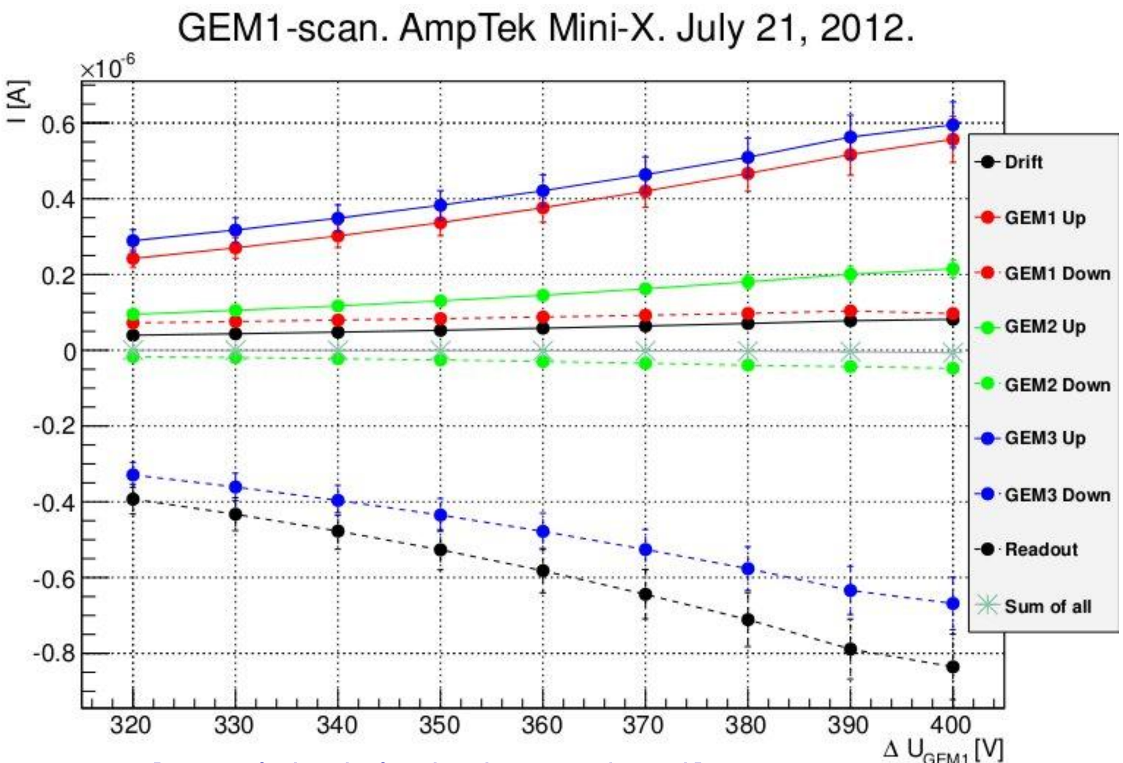
TUM Setup – Ampere Meters



Measurement Procedure:

- Analogue part with four measurement ranges: 10 nA, 1 µA, 100 µA, 10 mA
- Voltage drop on the shunt digitized by a 16 bit ADC
- 128 measurements are sampled (~ 8 s)
- Mean and sigma averaged out of these 128 samples
- Data wireless transmitted to a receiver connected to a pc

TUM Setup - Detector

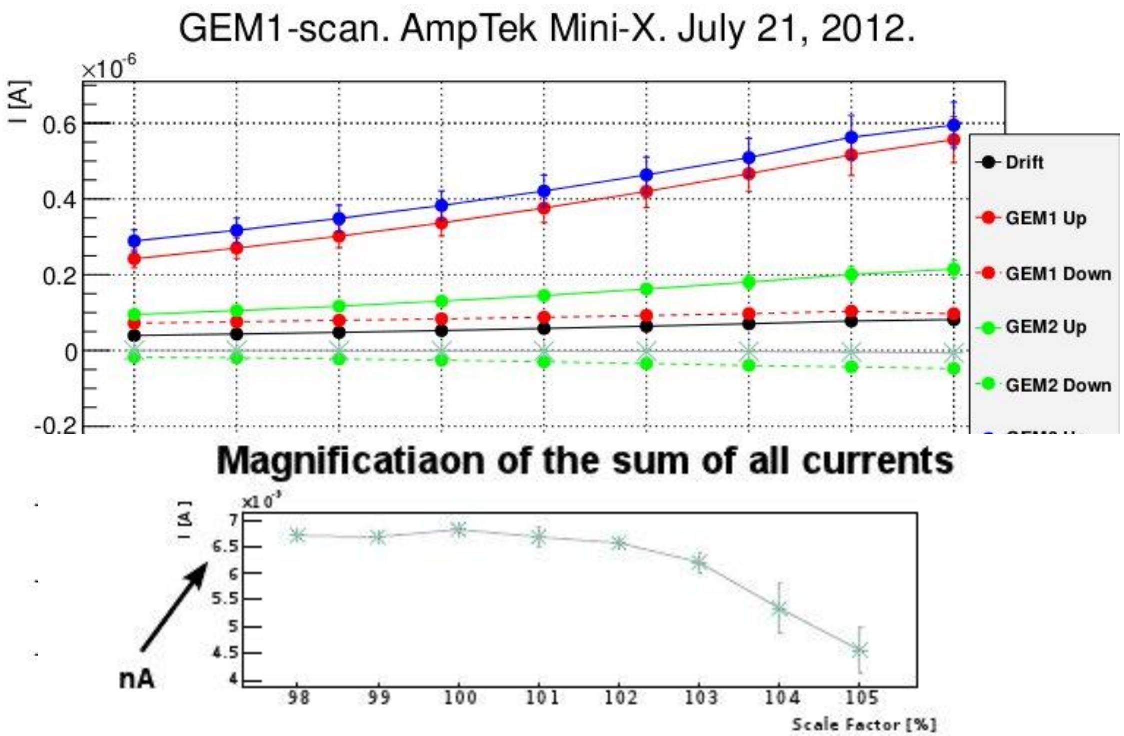


[A. Hönle bachelor thesis, TUM (2012)]

- E_{Drift} = 400V/cm
- ΔU_{GEM1} = 400 V
- ΔU_{GEM2} = 372 V
- ΔU_{GEM3} = 322 V
- $E_{T1} = E_{T2} = E_{Ind}$
- = 3.8 kV/cm

- Sum of all currents has to be zero ⇨ good handle on systematics
- Every measurement has an negligible statistical uncertainty and a 10 %systematic uncertainty due to fluctuations on the x-ray current
- Offset in the order of some nA

TUM Setup - Detector



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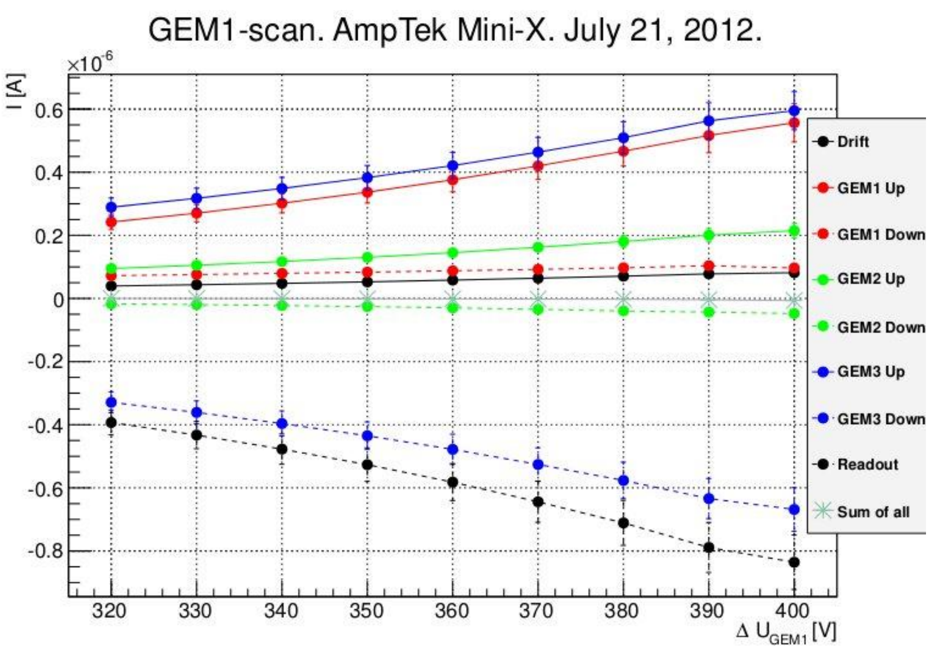
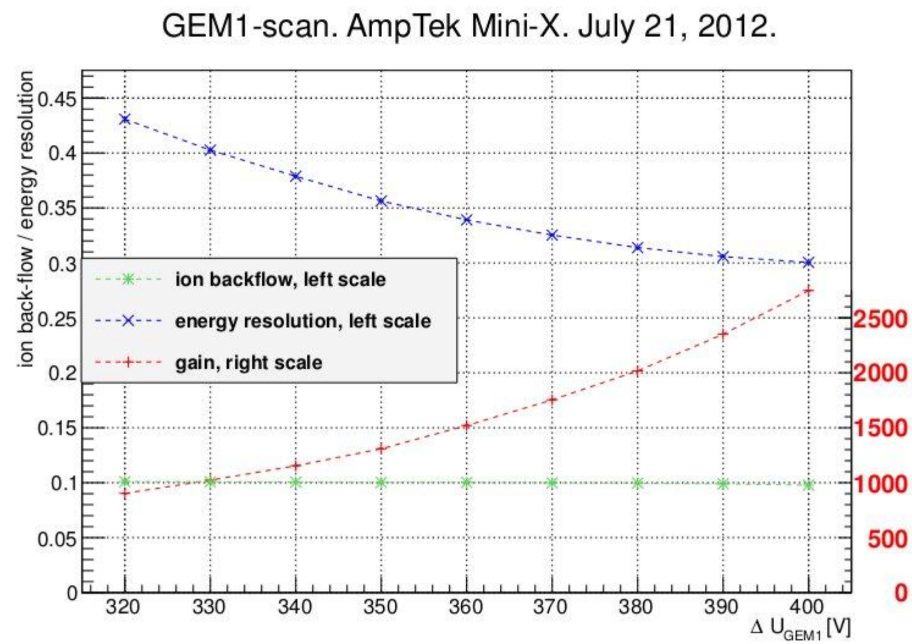
Ion Backflow

Ar/CO_2(70/30) with standard settings (not ion backflow optimized)





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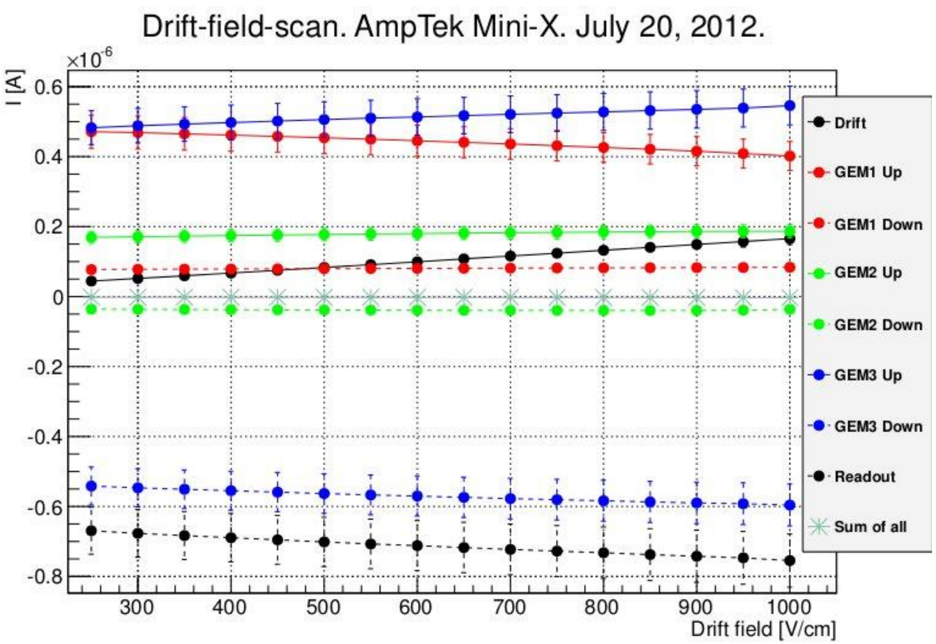

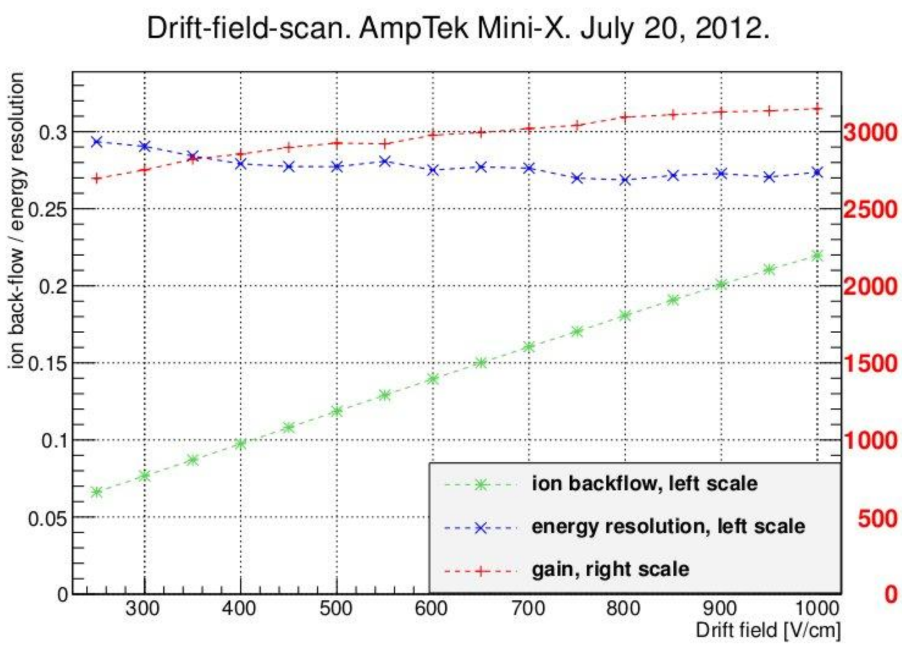

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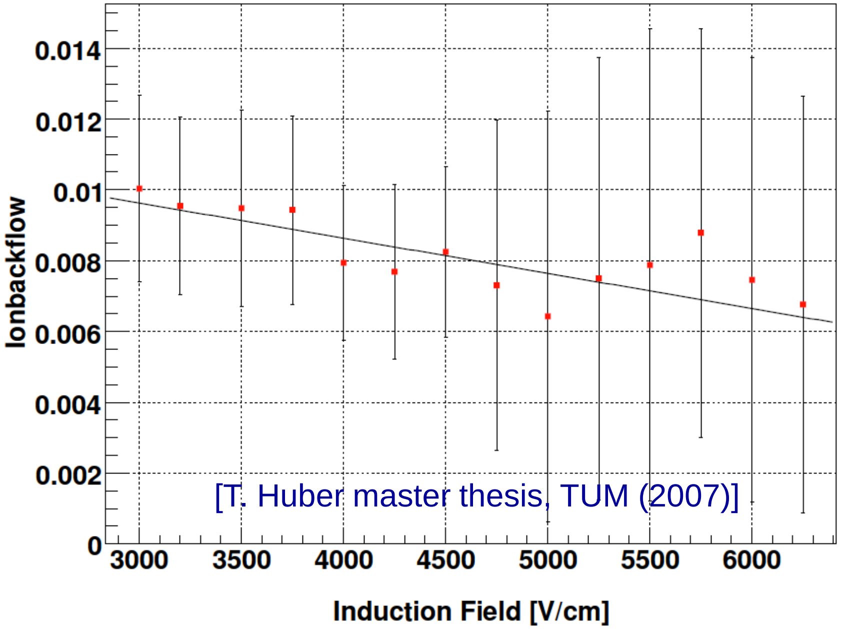
Ion Backflow – Rate Dependency

Ar/CO_2(70/30)



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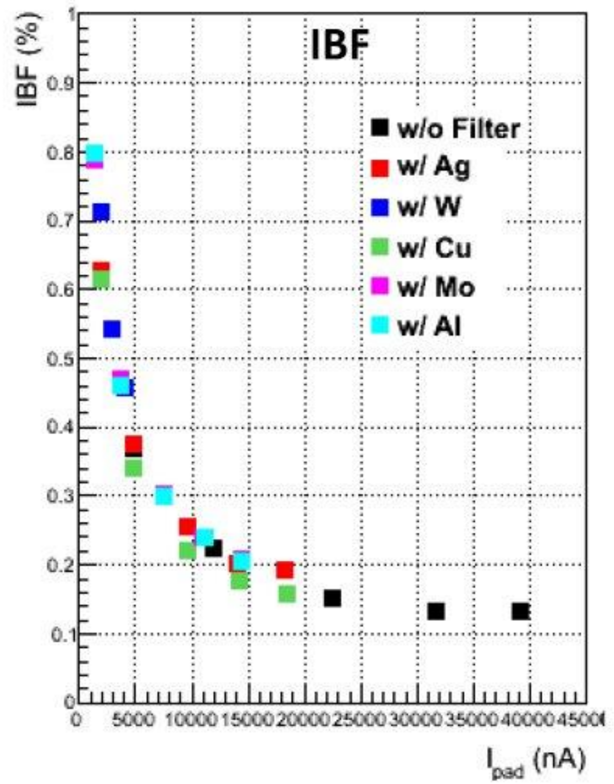
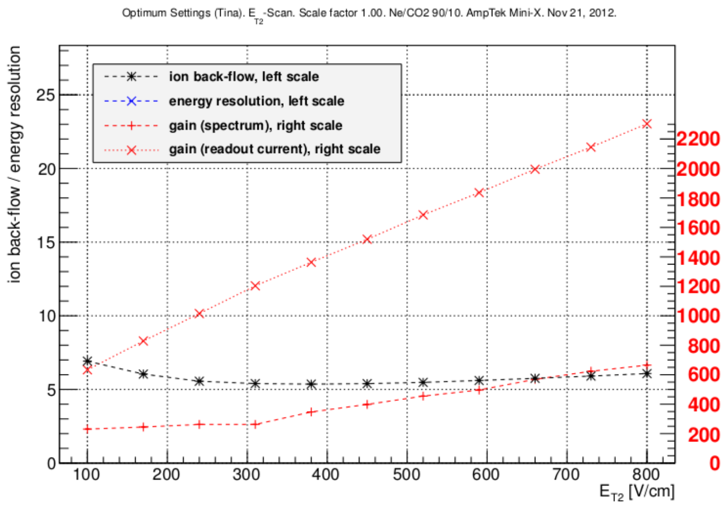


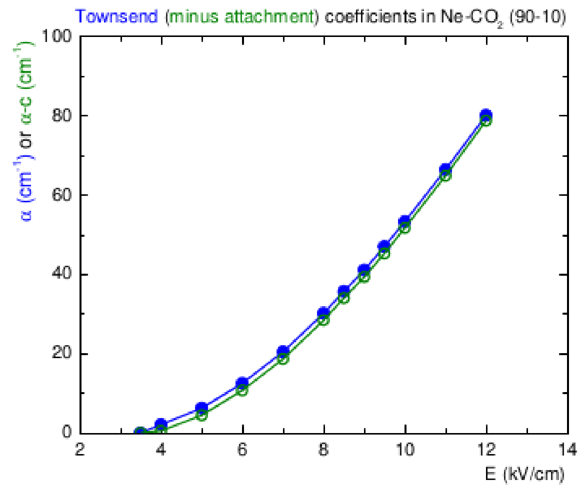
[C. Garabatos, Y. Yamaguchi, CERN (2012)]

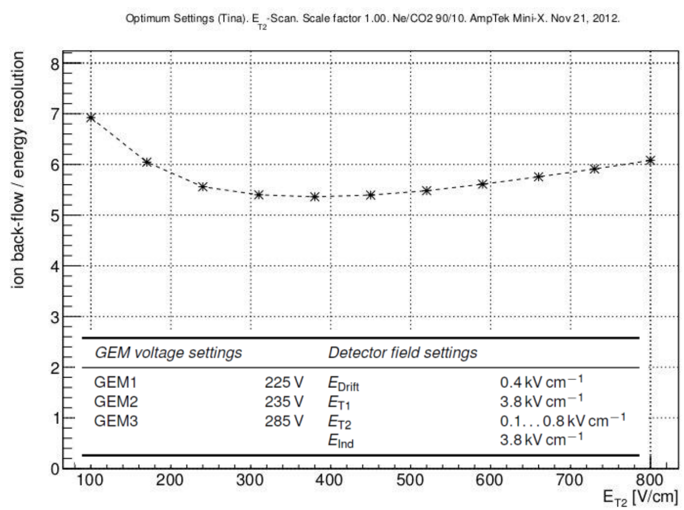
Agreement of IB for low rates between TUM and CERN measurements, but mechanism So far not understood (Space Charges ?).

Fundamental difference drift length TUM (3mm) CERN (80 mm).

Ion Backflow in Ne/CO_2 (90/10)







Mandatory changes for Ne/CO_2 (90/10)

- Drift field is fixed to 0.4 $kV \cdot cm^{-1}$
- Fields above 4 $kV \cdot cm^{-1}$ start to produce gas amplification
- With 5.5 % IB and a gas gain 1000 n_{tot} = 55 ions

Ion Backflow in Ne/CO_2 (90/10)

GEM voltage settings		*Detector field settings*	
GEM1	225 V	E_{Drift}	$0.4\,\mathrm{kV\,cm^{-1}}$
GEM2	235 V	E_{T1}	$3.8\,\mathrm{kV\,cm^{-1}}$
GEM3	285 V	E_{T2}	$0.1\ldots0.8\,\mathrm{kV\,cm^{-1}}$
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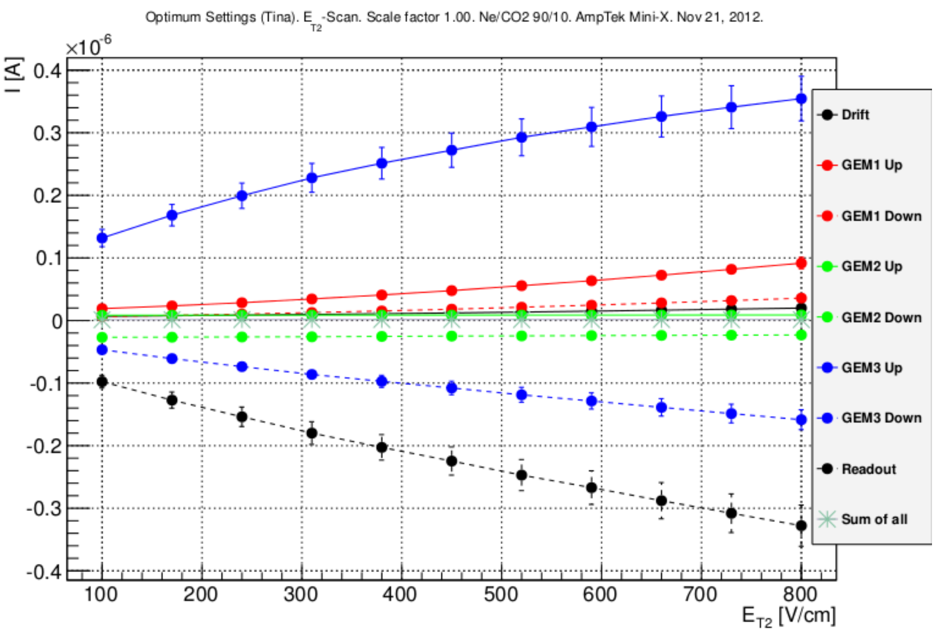
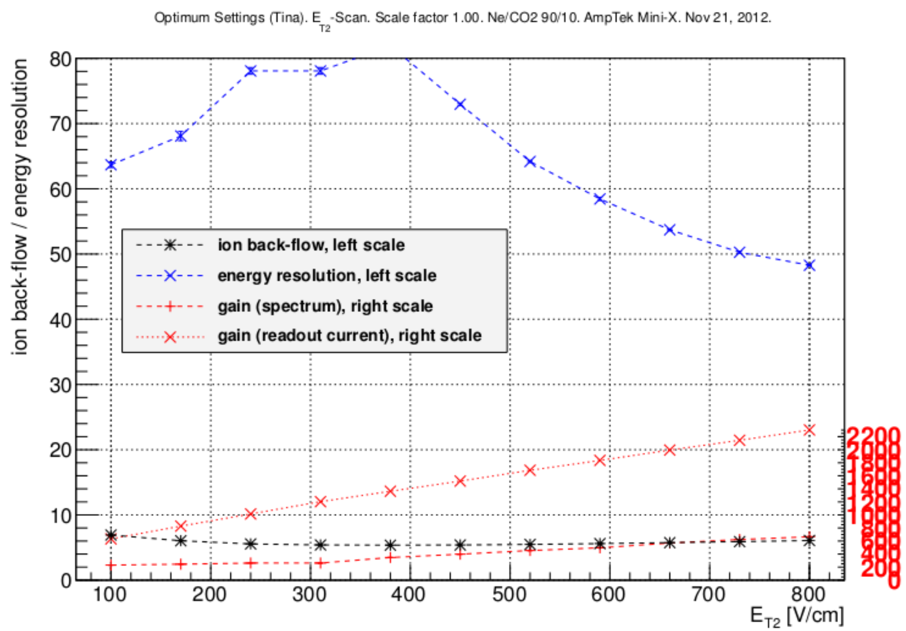
Scale 1.00





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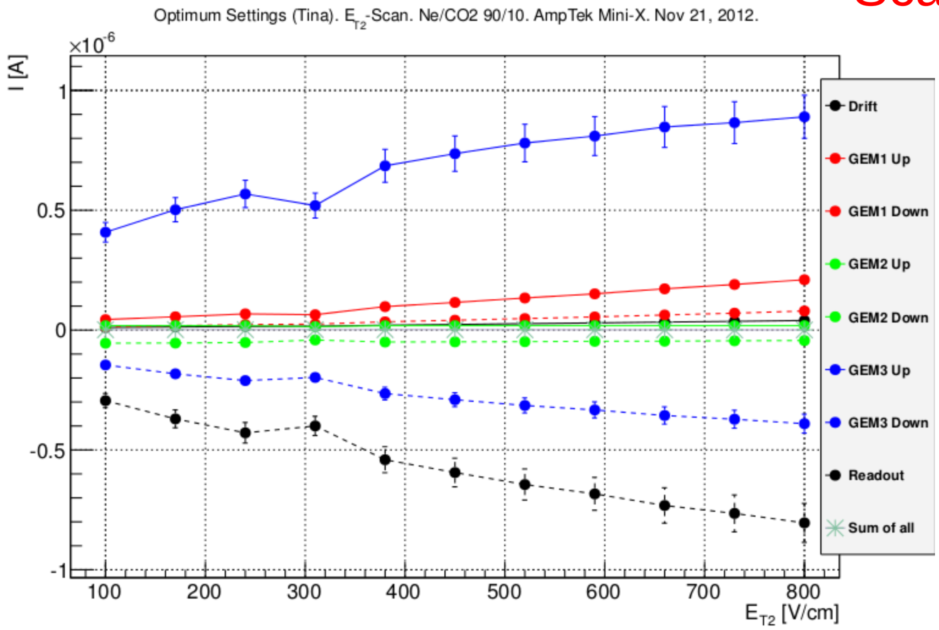
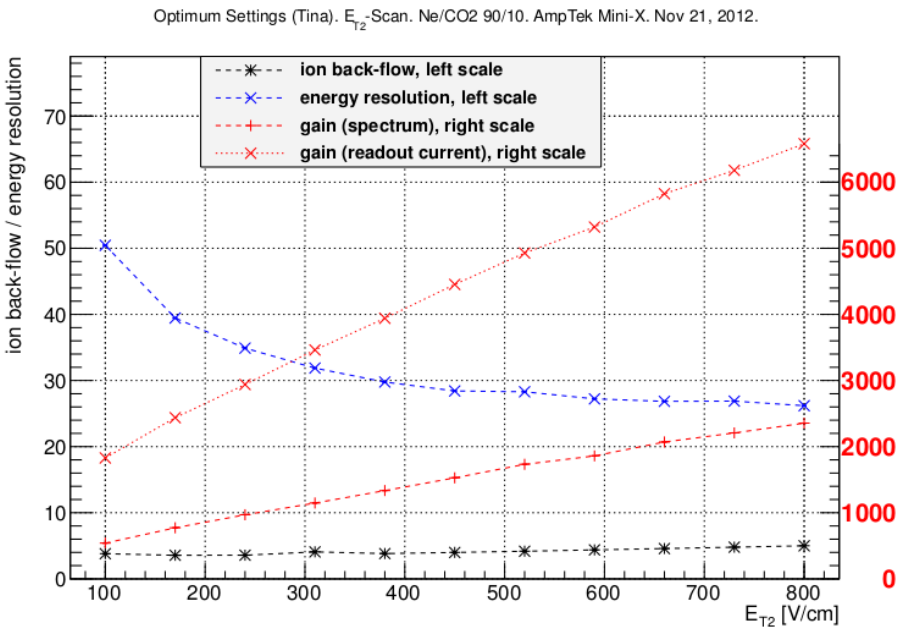
Scale 1.07

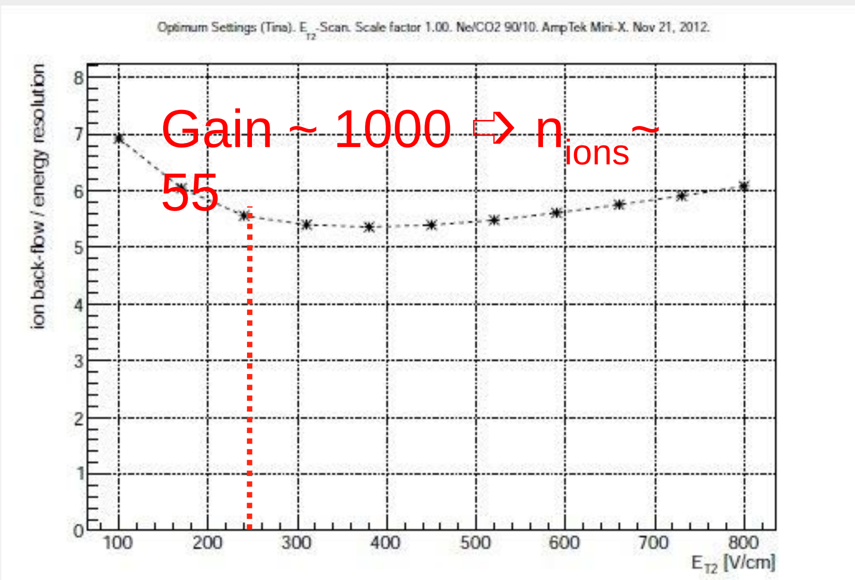




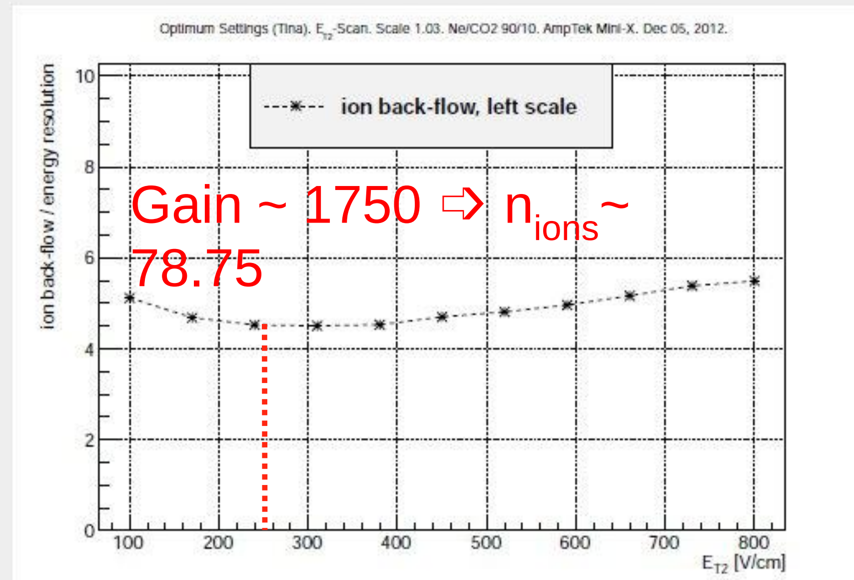
Ion Backflow in Ne/CO_2 (90/10)

GEM voltage settings		*Detector field settings*	
GEM1	225 V	E_{Drift}	$0.4\,kV\,cm^{-1}$
GEM2	235 V	E_{T1}	$3.8\,kV\,cm^{-1}$
GEM3	285 V	E_{T2}	$0.1\ldots0.8\,kV\,cm^{-1}$
		E_{Ind}	$3.8\,kV\,cm^{-1}$

Scale factor 1.00



Scale factor 1.03

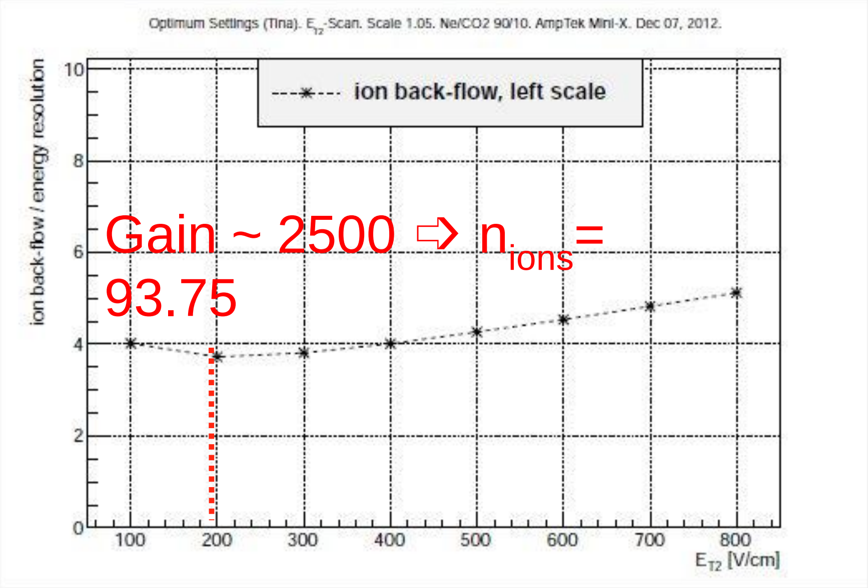


Ion Backflow in Ne/CO_2 (90/10)

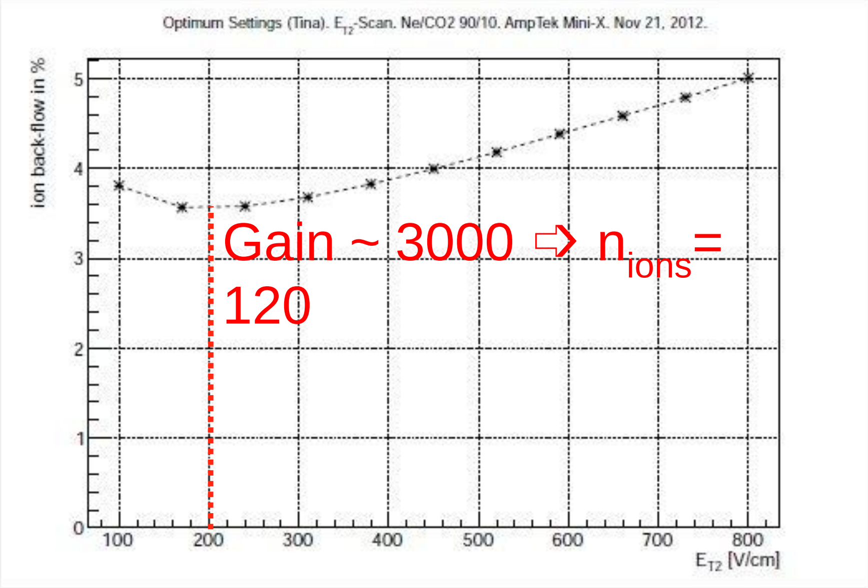
Technische Universität München

GEM voltage settings		*Detector field settings*	
GEM1	225 V	E_{Drift}	$0.4\,kV\,cm^{-1}$
GEM2	235 V	E_{T1}	$3.8\,kV\,cm^{-1}$
GEM3	285 V	E_{T2}	$0.1 \ldots 0.8\,kV\,cm^{-1}$
		E_{Ind}	$3.8\,kV\,cm^{-1}$

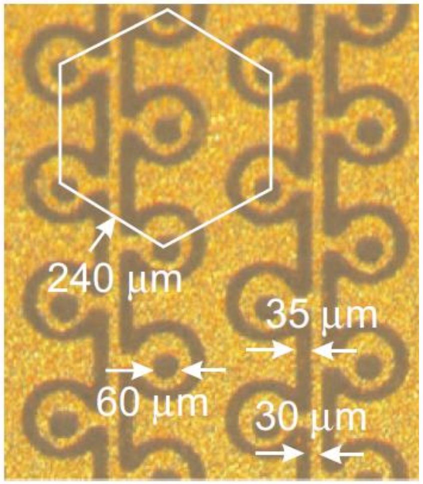
Scale factor 1.05

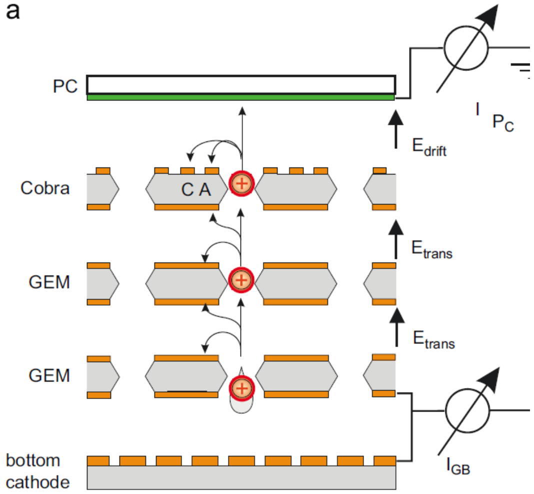


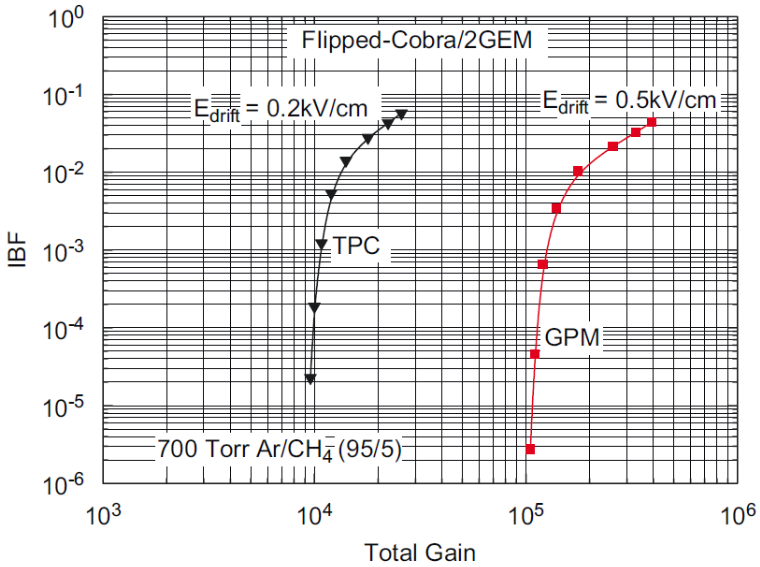
Scale factor 1.07



Further Ideas of IB suppression







IB = $2.7 \cdot 10^{-5}$!

[A. Lyashenko et al., NIM A 598 (2009) 116–120]

Advantage

➪ problem of IB completely eliminated

Disadvantages

➪ e- transparency might suffer, so far not applicable to large size

Conclusion

- IB for a conventional triple GEM stack and given boundary conditions factor 5-10 too high (Ne/CO_2 90/10)
- Conventional approach: Small modifications
  - Use extraction fields slightly above 4 kV/cm
  - Use Ne/CO_2/N_2 (90/10/5) ⇨ smaller Townsend Coefficient
  - Use GEM with different aspect ratio (smaller and larger holes)
  - Use 4th GEM
- Alternative approach: COBRA or MHSP or ?

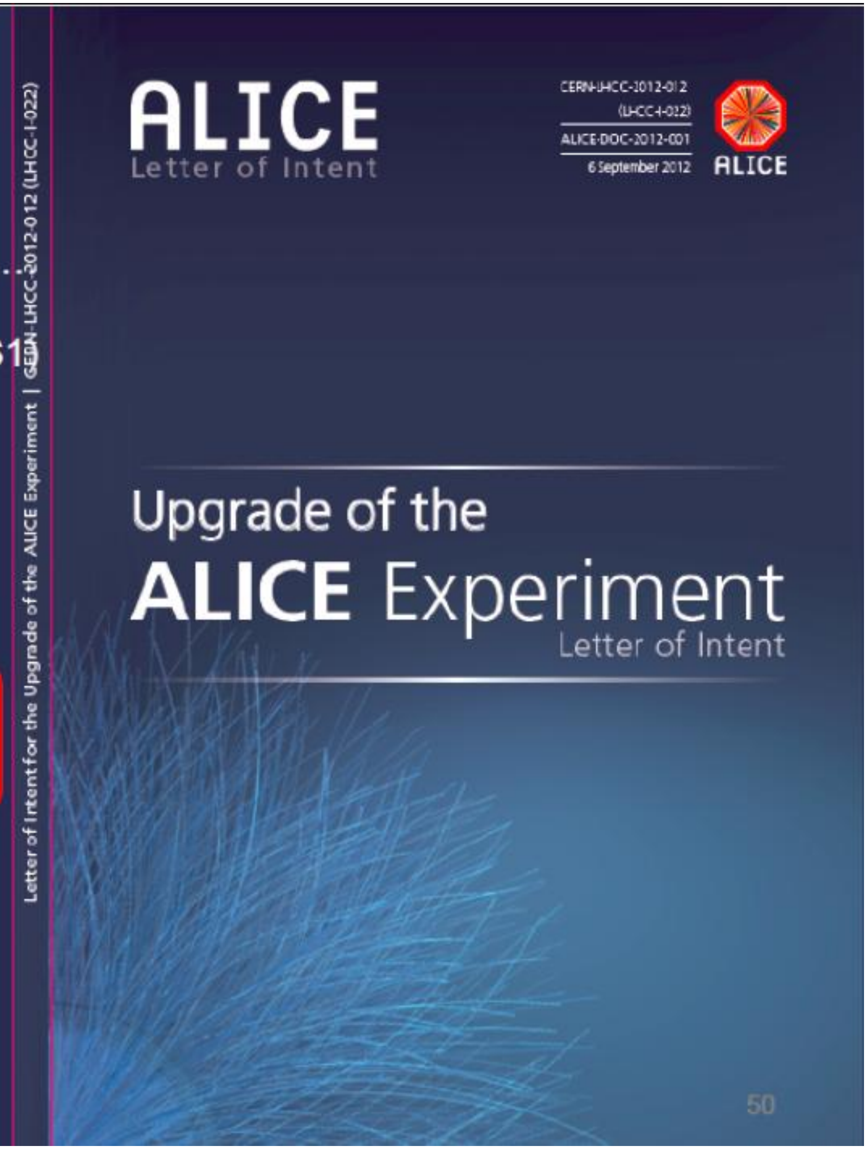
  (see Taku Gunji's slides in Rob Veenhofs talk)
- Systematics have to be understood (rate dependency)

Outlook

- 2013: **pPb and Pbp**
  initial state effects, shadowing...
- 2013-14: LHC Long Shutdown 1 (LS1)
- 2015-17: **FULL ENERGY !!**
  pp @ 7 TeV,
  PbPb @ √sNN = 5.5 TeV
- 2018: LHC Long Shutdown 2
- ≥ 2019: **HIGH LUMINOSITY**
  50 kHz PbPb collisions

ALICE UPGRADES

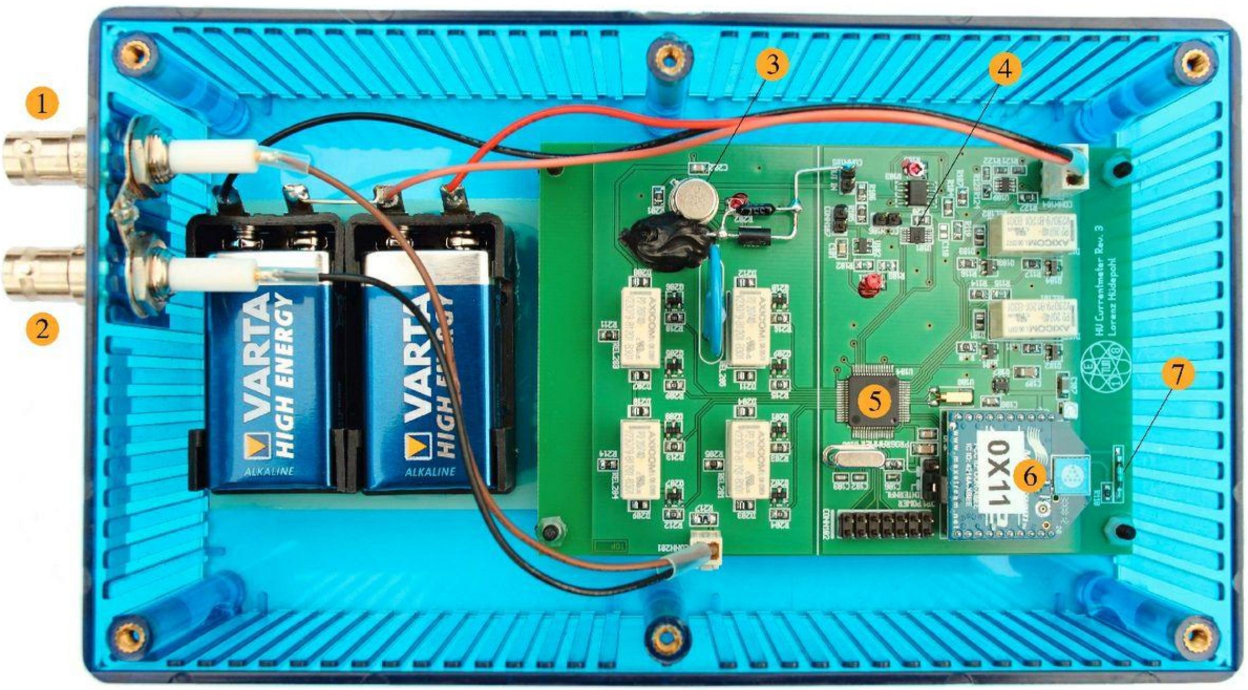
- New vertex detectors
- Faster readout, high level triggers...
- TPC with continuous readout ...



Thank you for your attention!

Backup Slides

TUM Setup – Ampere Meters I

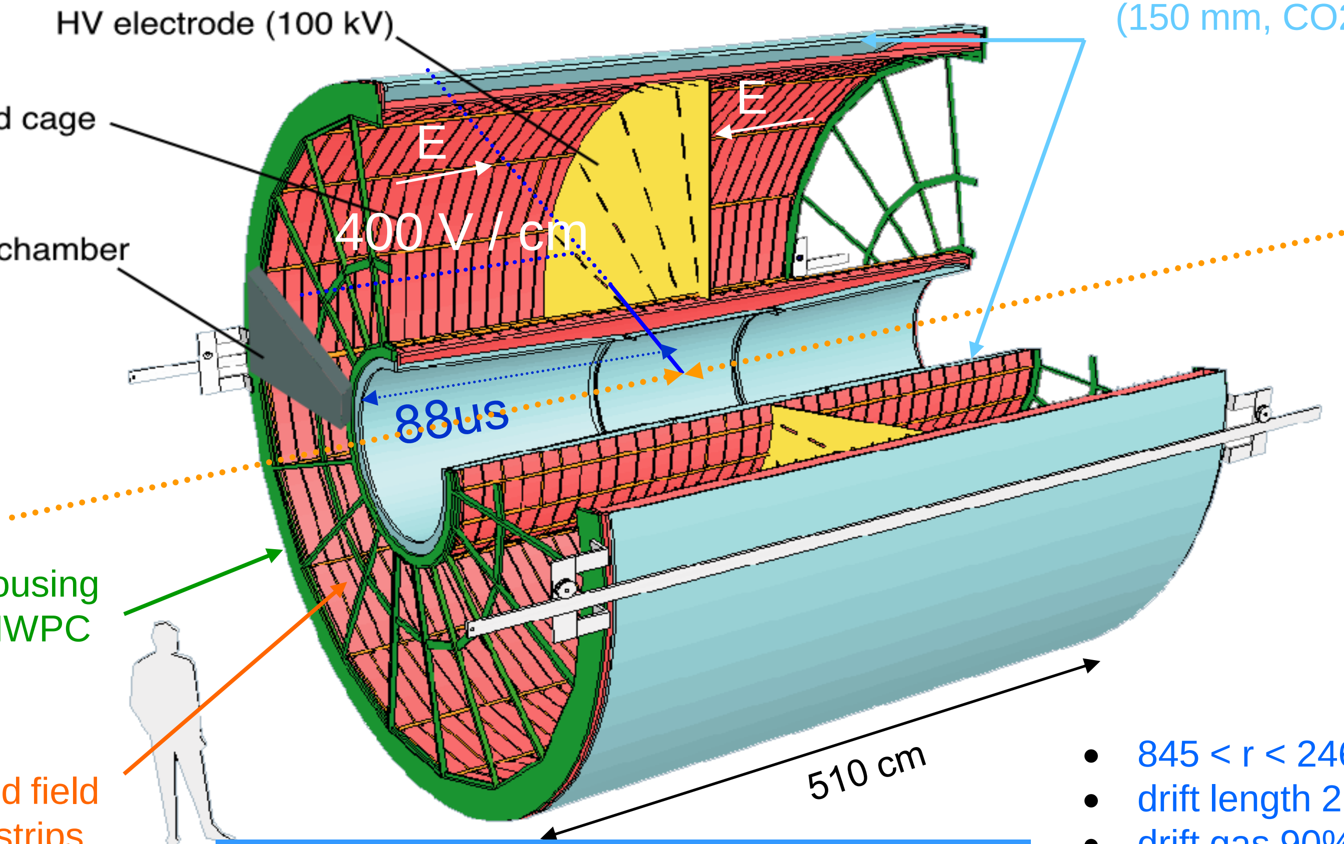


1. HV in
2. HV out
3. Non inverting
 operational amplifier
1. 16-bit ADC
2. Microcontroller
3. Wireless transceiver
4. Read switch

ALICE Upgrade during LS2

- TPC needs to cope with high rates
  - 2 MHz in p+p, 50 kHz in Pb+Pb collisions ⇨ 100 × higher than present
  - No gating and continuous readout
- GEMs as replacement for MWPC
  - Rate capability ok
  - Ion backflow suppression critical !!!
  - Operation at lower gain ~ 1000 due to fast electron signal + low noise
- Issues for Upgrade
  - dE/dx resolution for PID ⇨ PS test beam end of 2012
  - Stability under LHC conditions ⇨ just finished in Jan/Feb 2013
  - Gain stability ⇨ laboratory measurements of charging up, long-term
  - Ion backflow ⇨ laboratory measurements, simulations
  - New front-end and readout electronics

The ALICE TPC



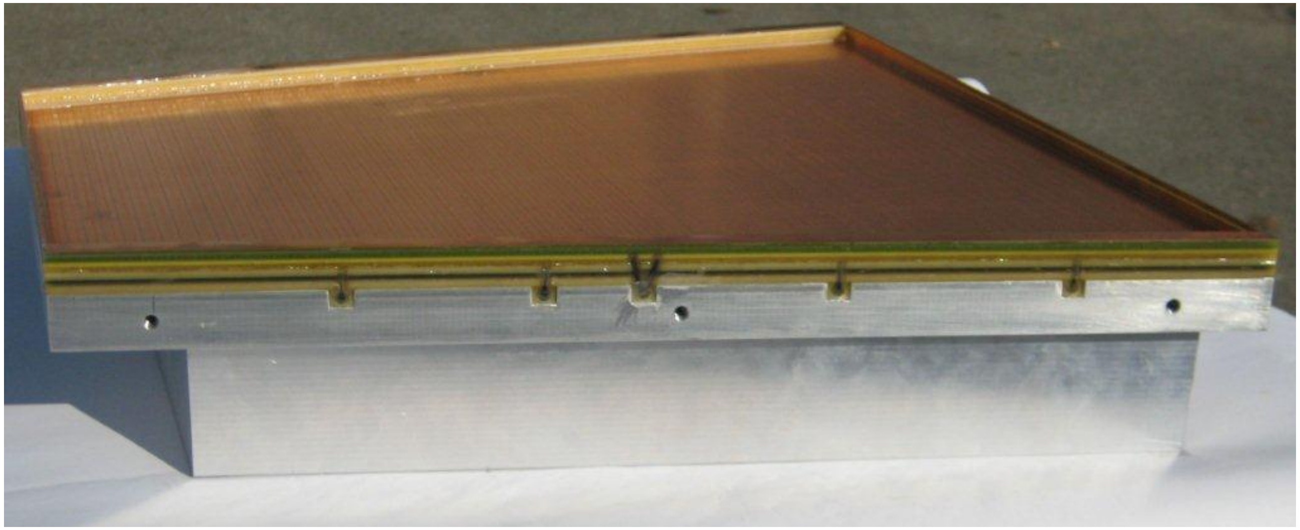
- 845 < r < 2466 mm
- drift length 2 x 2500 mm
- drift gas 90% Ne – 10% CO_2
- gas volume 88 m^3
- 557568 readout pads

ALICE TPC CHALLENGES

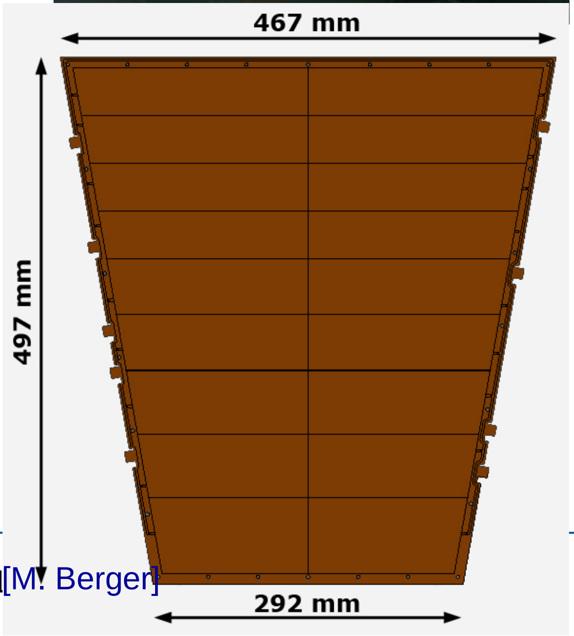
up to 2×10^4 charged particles in TPC

[L. Musa, CERN]

ALICE IROC Prototype

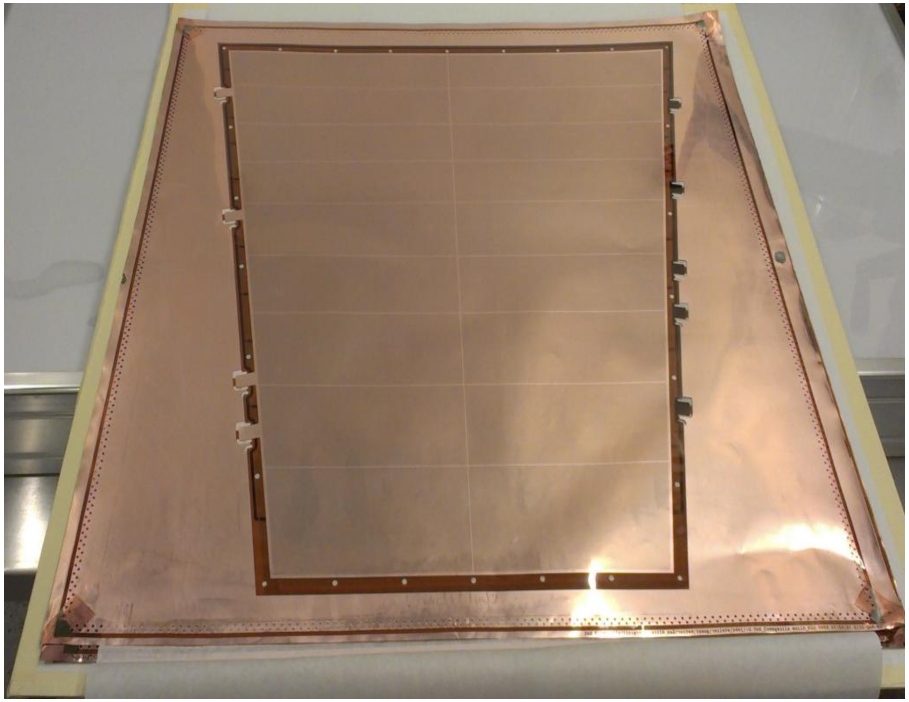


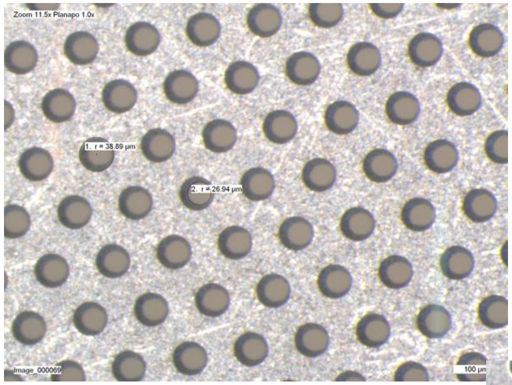
- 3 large-size GEM foils: single-mask
- 18 sectors (top side), ~ 100cm2 each
- bias resistors 10/1MO
- 2mm frames glued on bottom side
- spacer grid: 400mm thickness
- additional frame for induction gap: 4mm

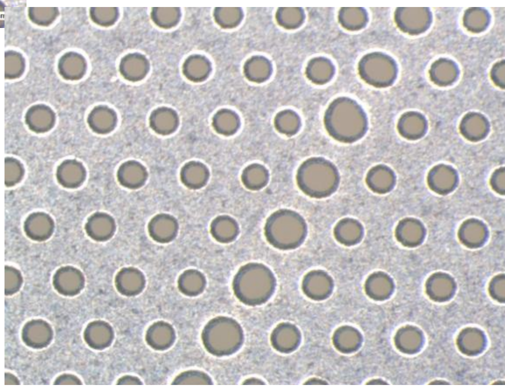


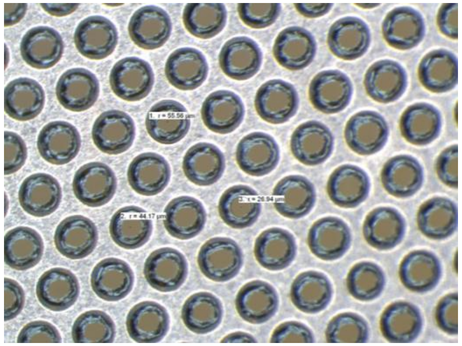
[M. Berger]

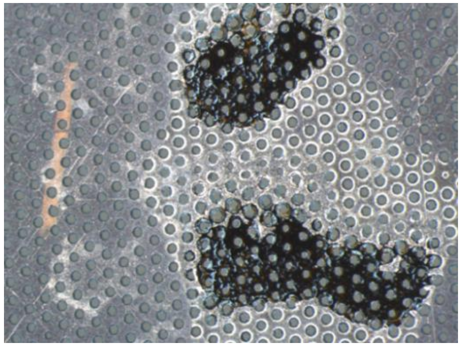
Single-mask GEM Foils

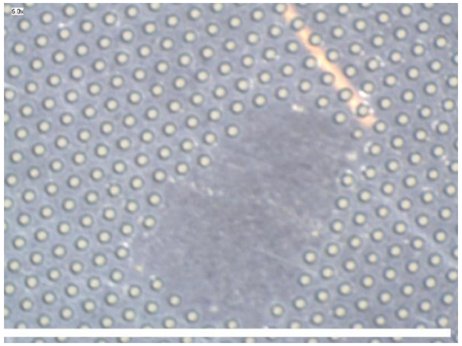


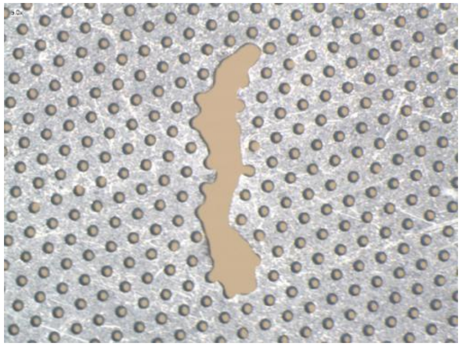




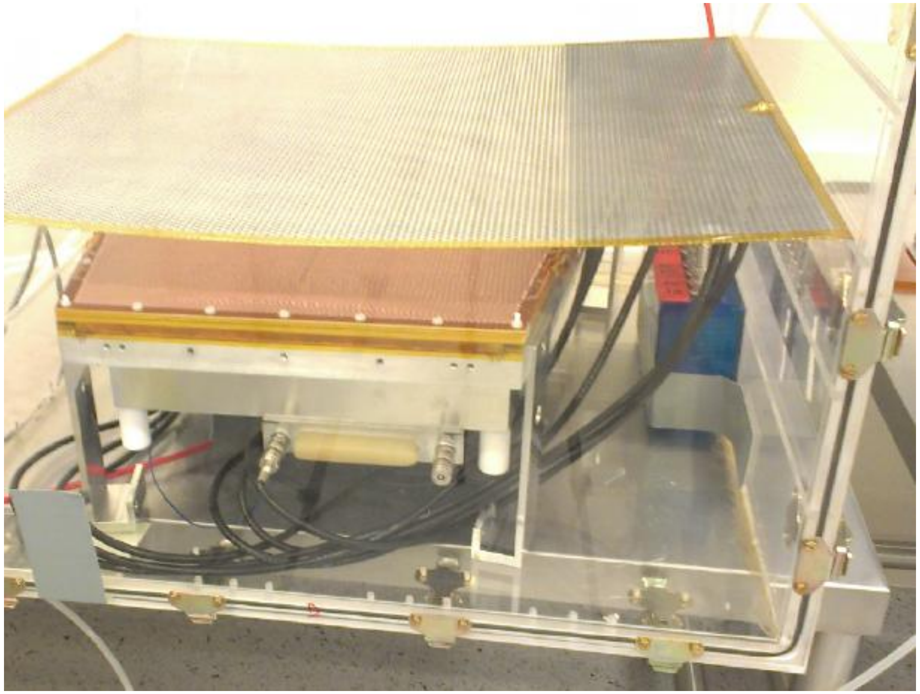




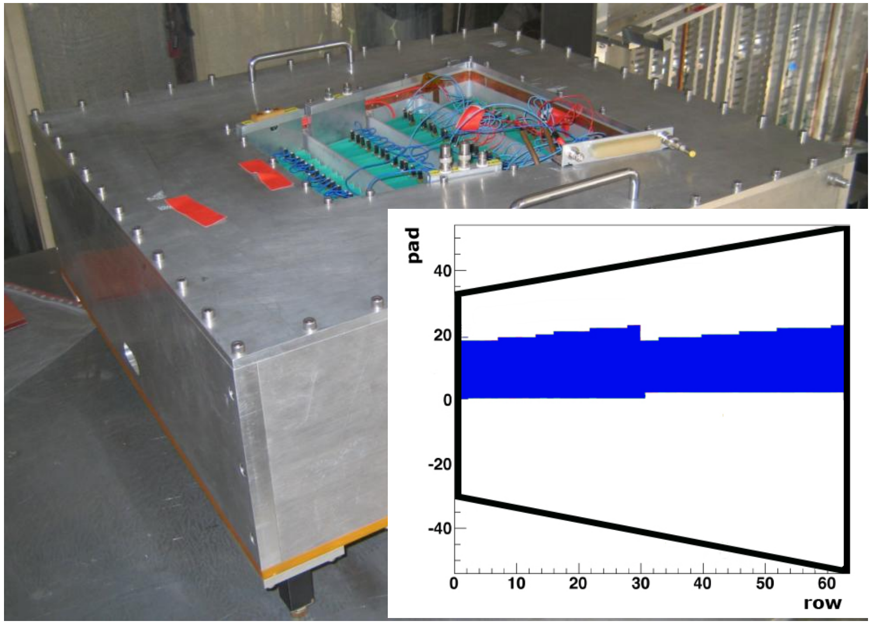




ALICE IROC with GEMs



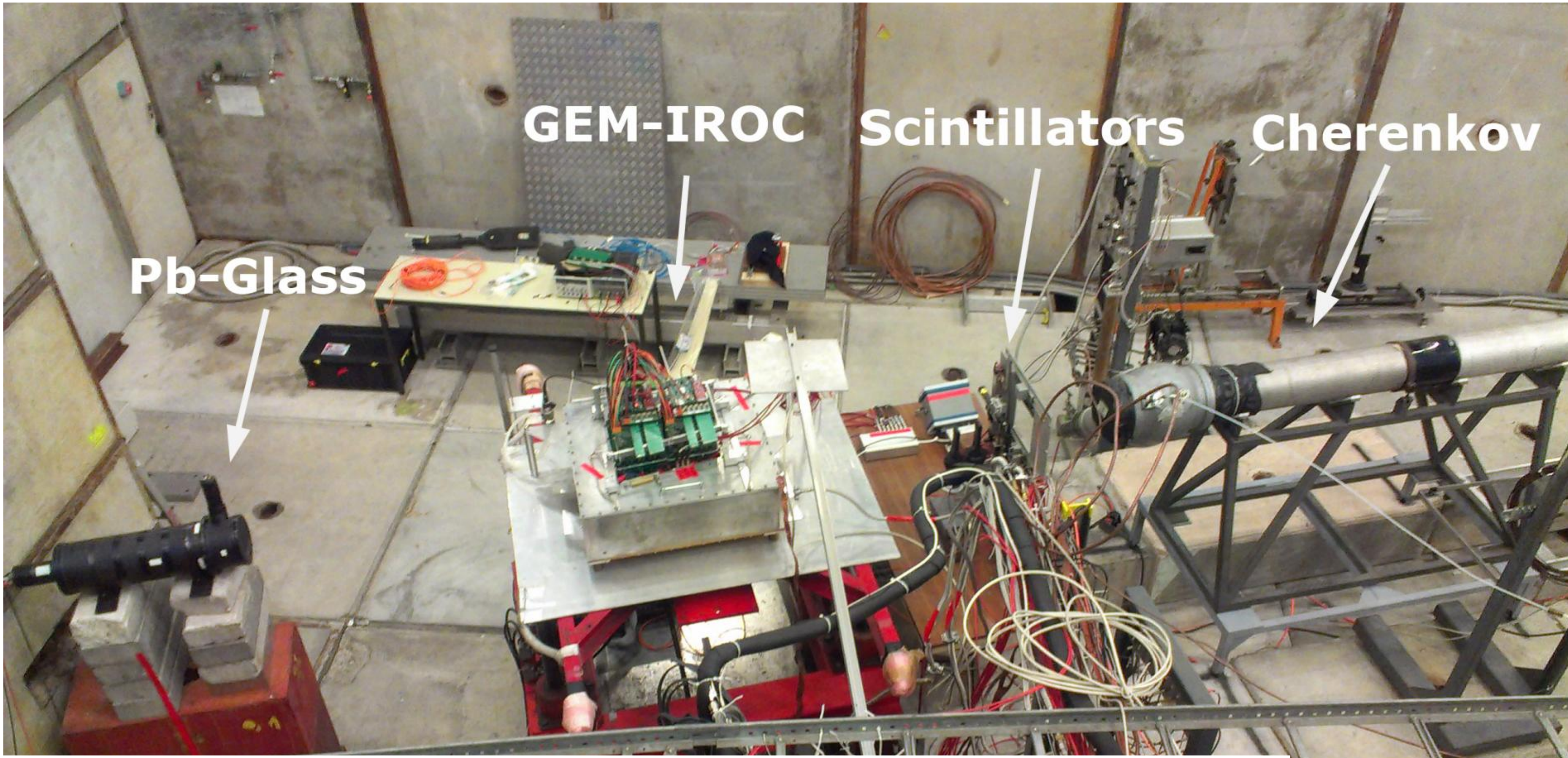
Test in flush box with “cathode”



IROC mounted inside field cage

- Drift length 11.5 cm, 400 V/cm
- Gas Ne/CO2 (90/10)
- 64 rows with pads
- FEE: PCA16 / ALTRO (LCTPC)
- ENC: 500 – 600 e-

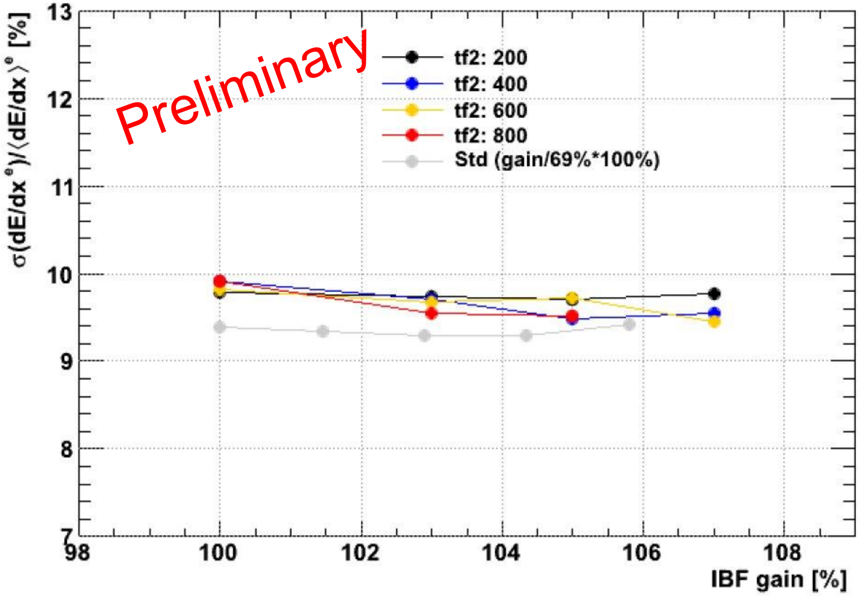
IROC Beam Test at CERN PS

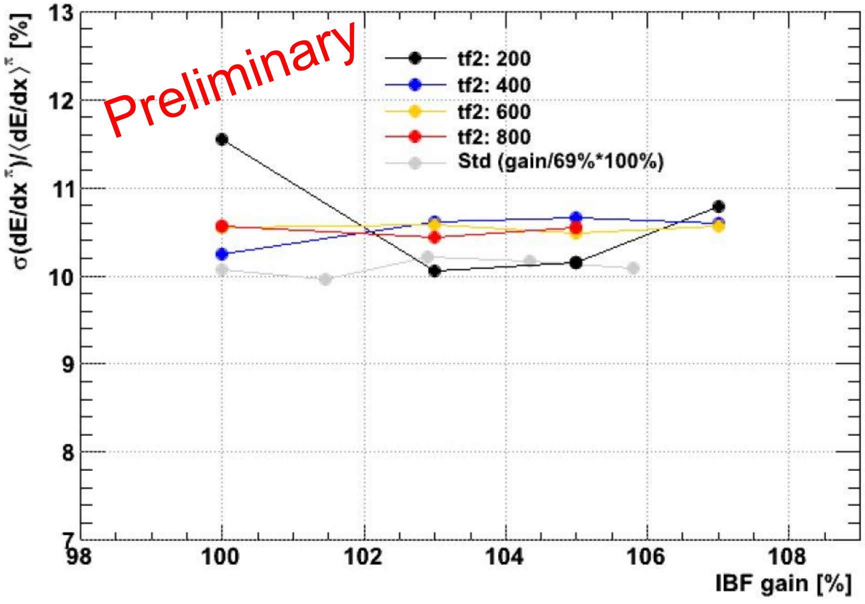


- p, $\pi\pm$, $e\pm$ beam, 1/2/3/6 GeV/c
- 2000 particles / 0.5s
- Cherenkov and Pb glass detectors for external reference PID
- Goal: measure separation power for different GEM settings

dE/dx Results

dE/dx resolution of 1 GeV electrons and pions for different IBF settings and as a function of gain

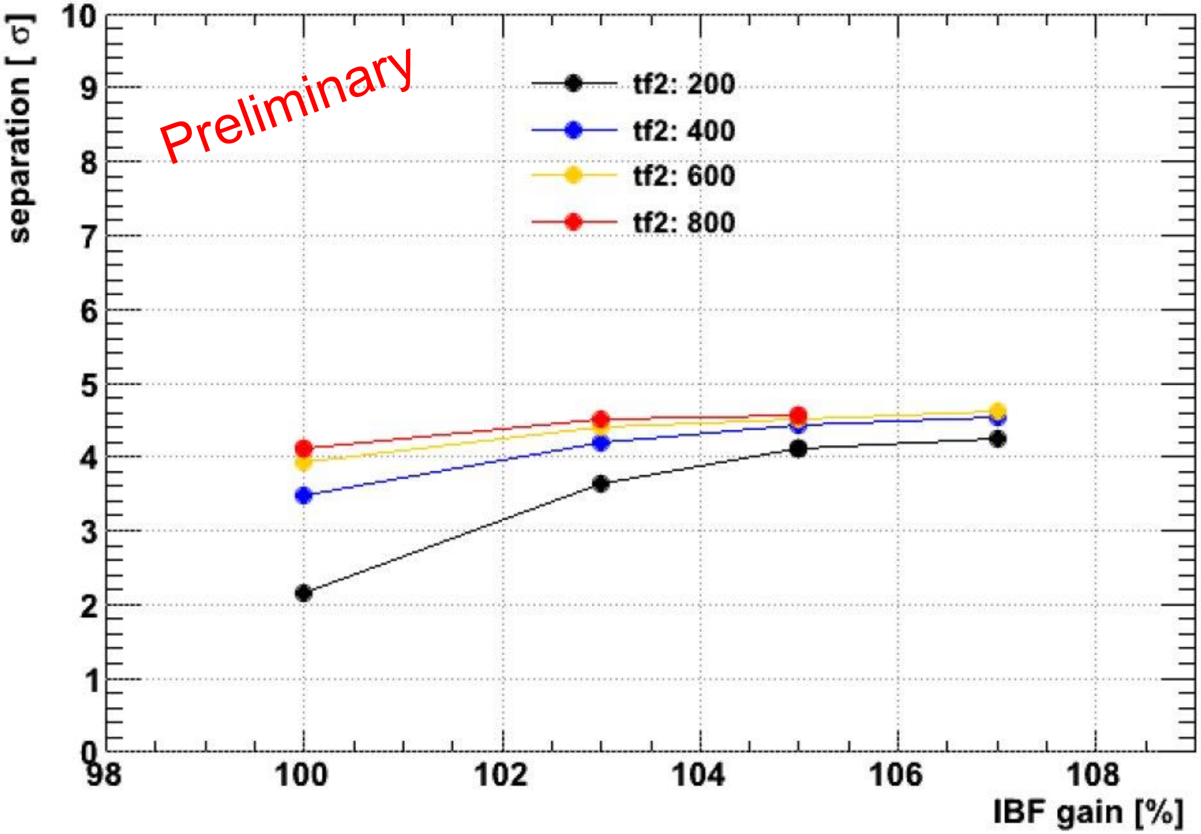




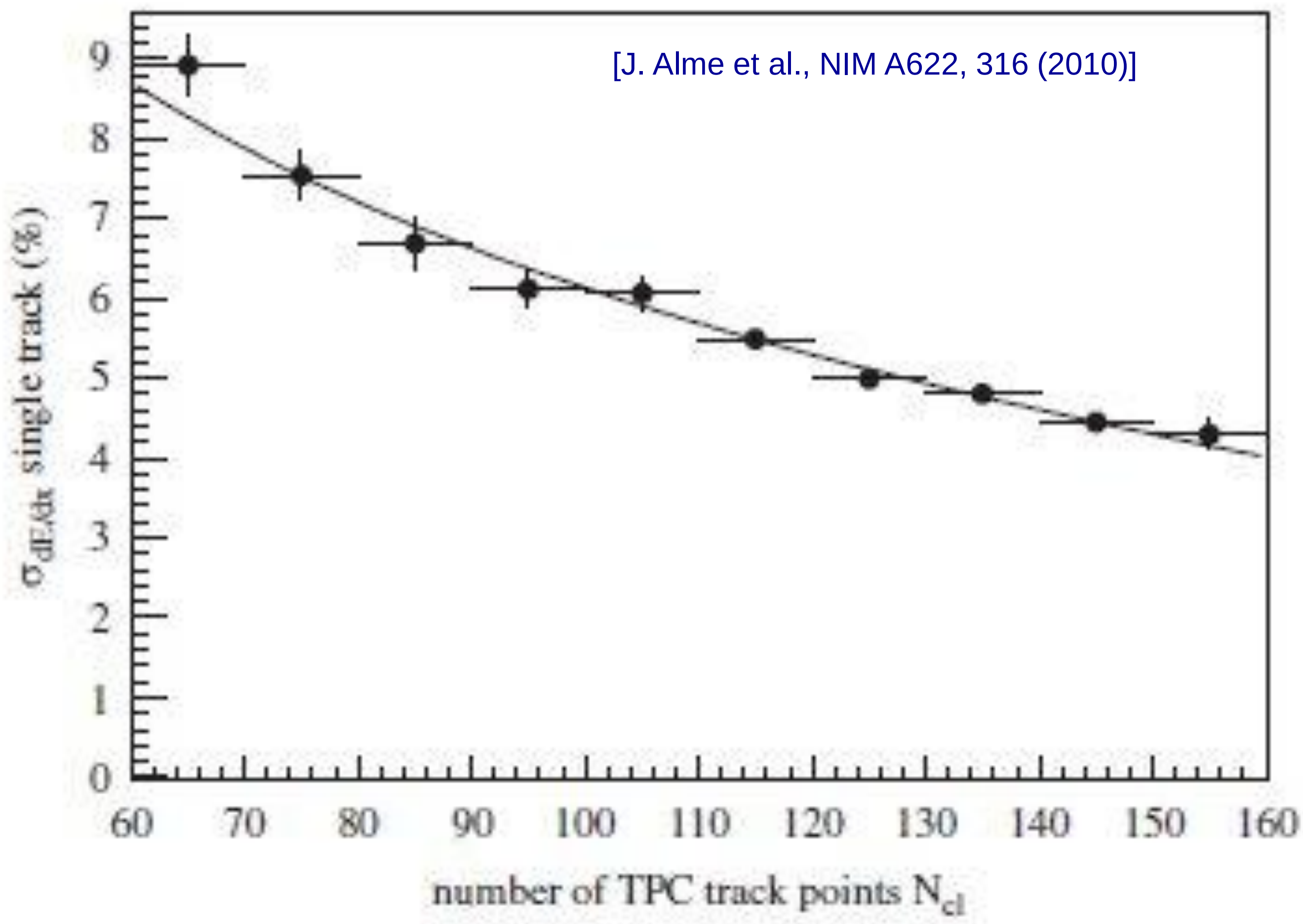
dE/dx resolution for e^- ~ 9.5 % for 10 %

dE/dx Results

dE/dx separation of 1 GeV electrons and pions
for different IBF settings and as a function of gain



dE/dx Results



dE/dx-resolution achieved with the GEM IROC with 64 rows looks promising to satisfy the performance for the full TPC

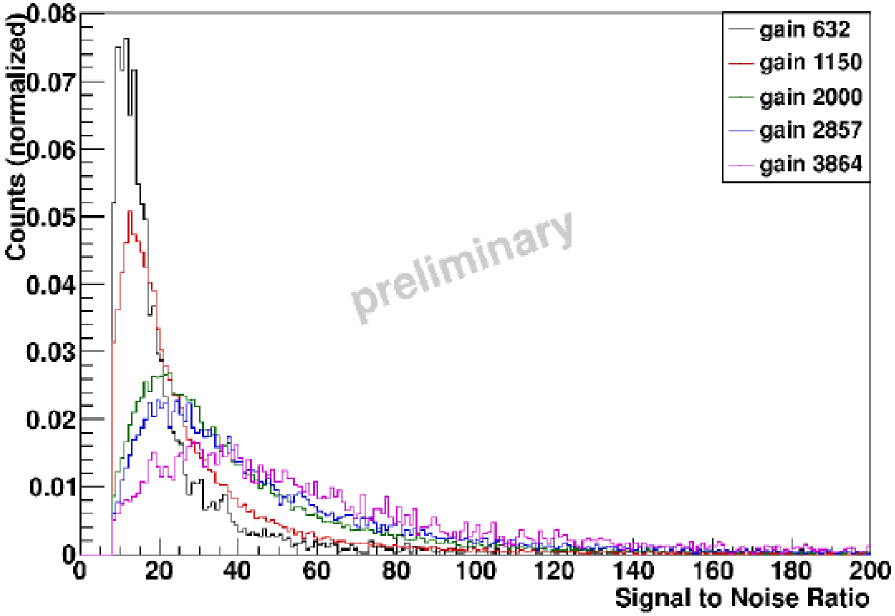
Conclusion II

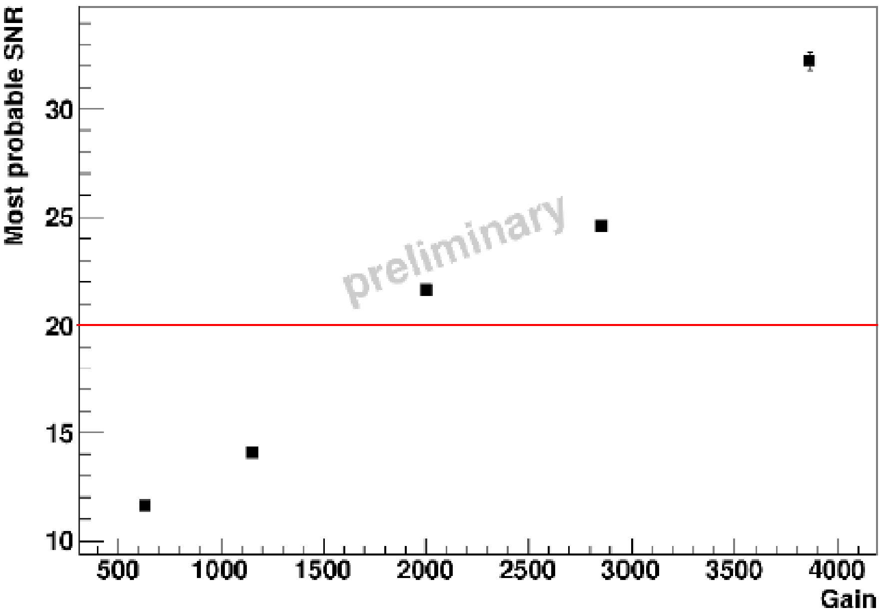
- An IROC has been set up with a triple GEM readout
- Physics Performance run in the PS with 2000 channels from LC TPC
- Measurement of the Specific Energy Loss (dE/dx) quite successful (e^- and π^- ~ 9.5 – 10 %)
- Close to the current dE/dx limit of ALICE TPC (even in IB mode)
- Upcoming TDR for the TPC upgrade including GEM-Implementation, IB as well as Detector Performance planned for August this year

Still a lot of work to do !!!

Backup Slides

Signal-to-Noise Ratio

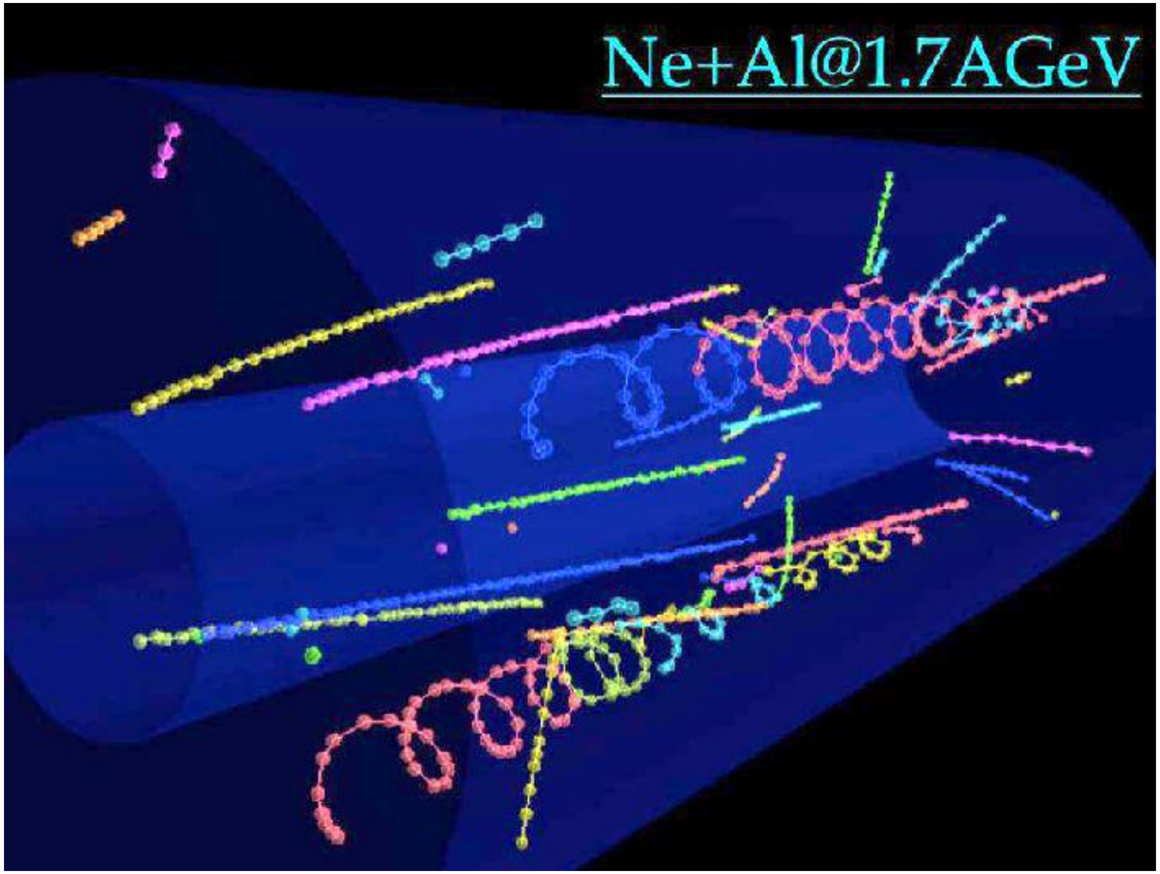




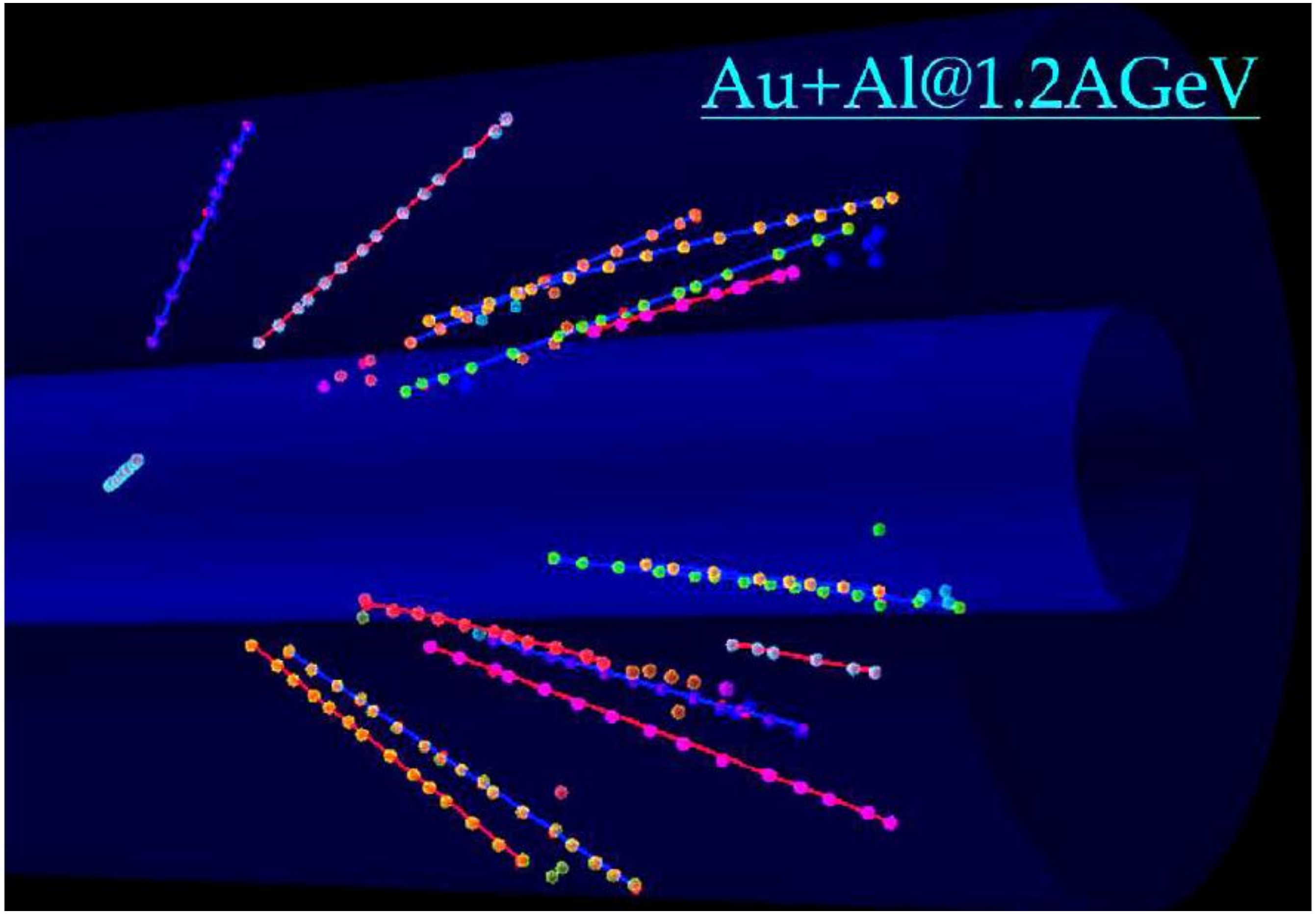
SNR above 20
envisaged

Setting:
- Ne/CO_2 (90/10)
- 360 V/cm drift field
- 0.6 T

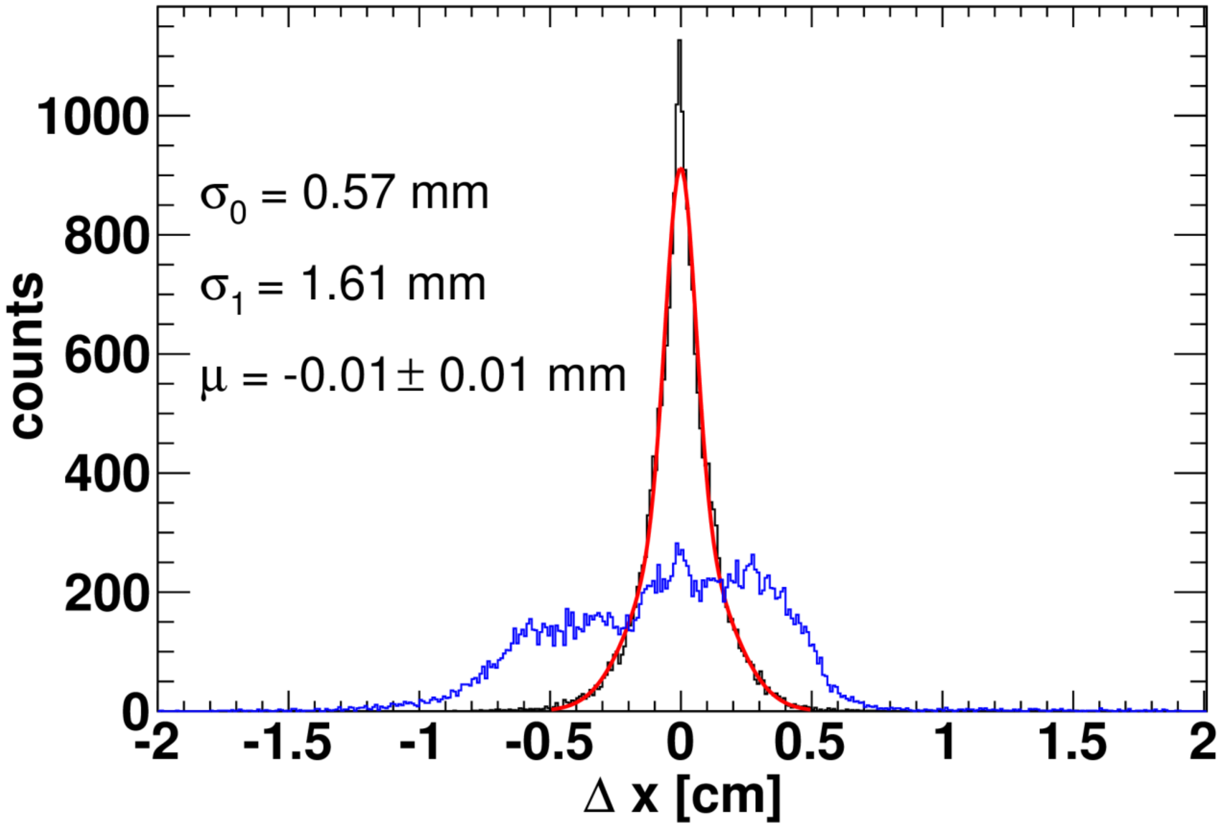
Pattern Recognition



Pattern Recognition

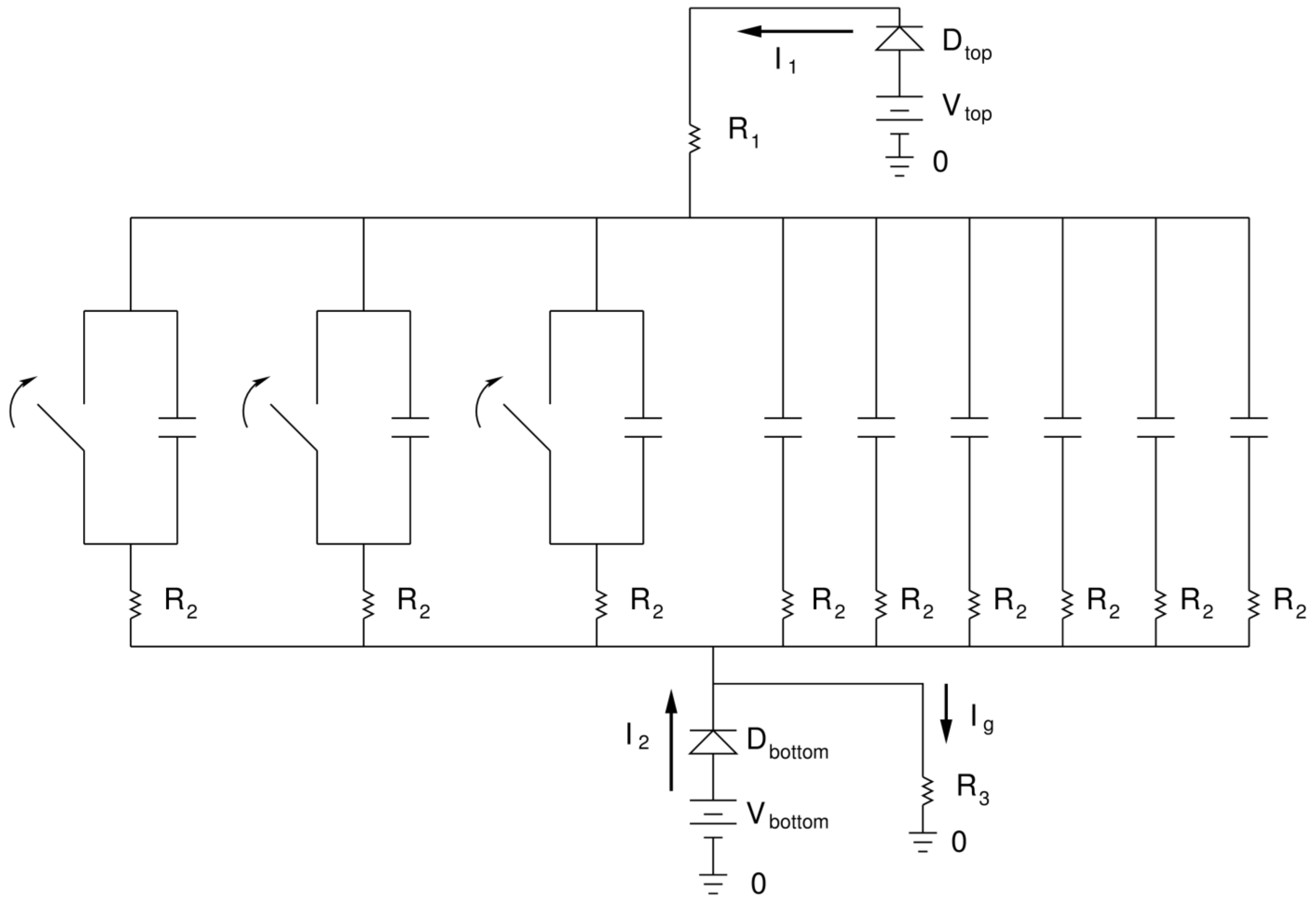


Alignment

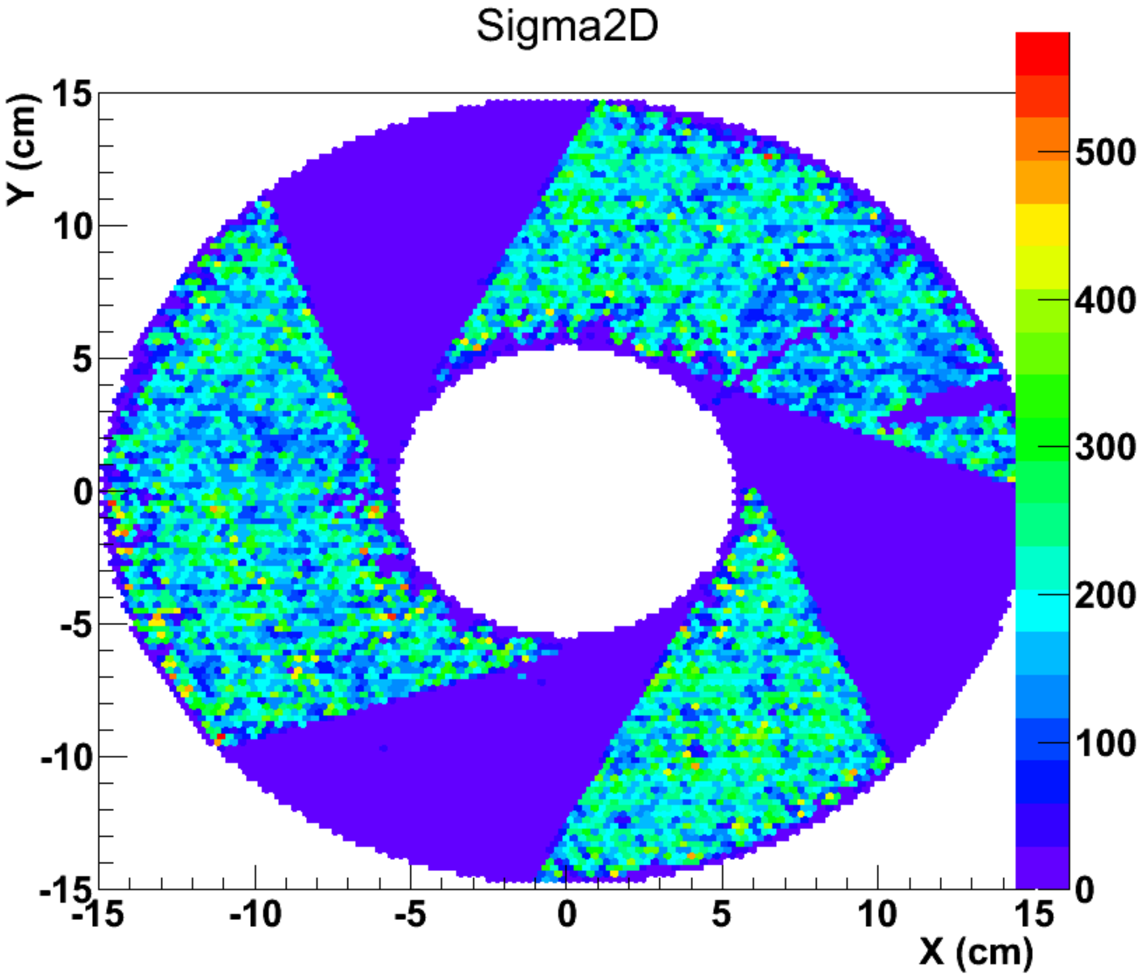


Residuals to extrapolated CDC tracks
Systematical error of mean: ~0.1 mm

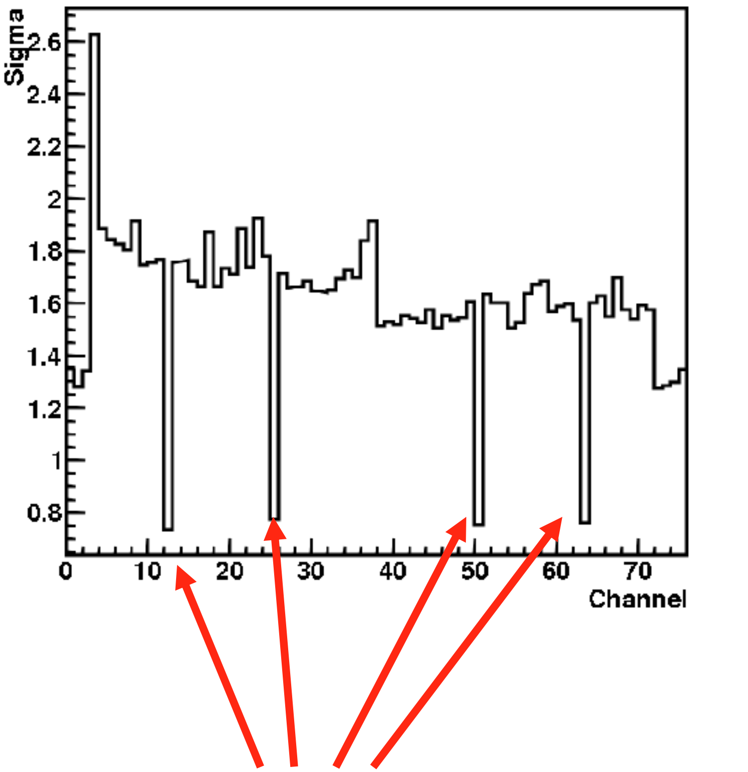
HV scheme of the GEM stack



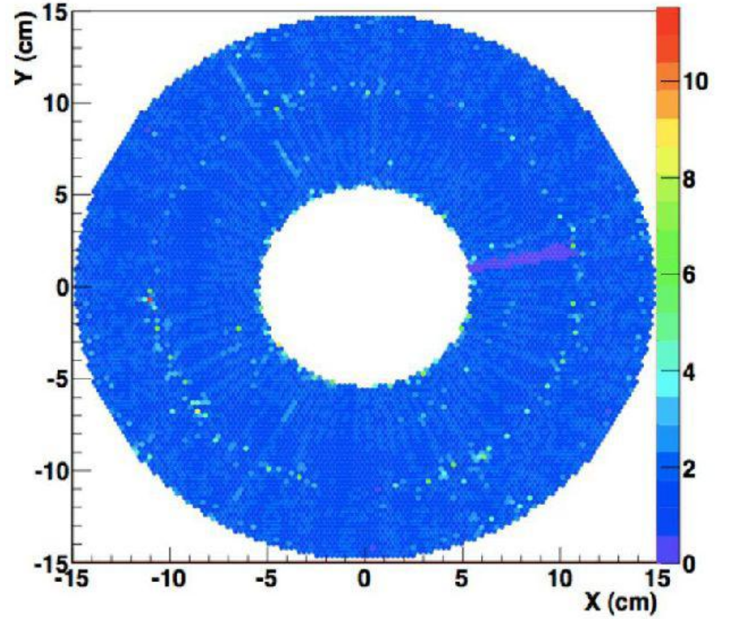
The GEM Stack (with three dead sectors)



Noise Measurement



Four channels not connected
To measure the electronic noise



- 42 front-end cards
- 12768 readout channels
- 16 – 20 MHz sampling
- 1 ADC channel ~ 400 e^- ENC
- Average noise ~ 700 e^- ENC

Front End Electronics

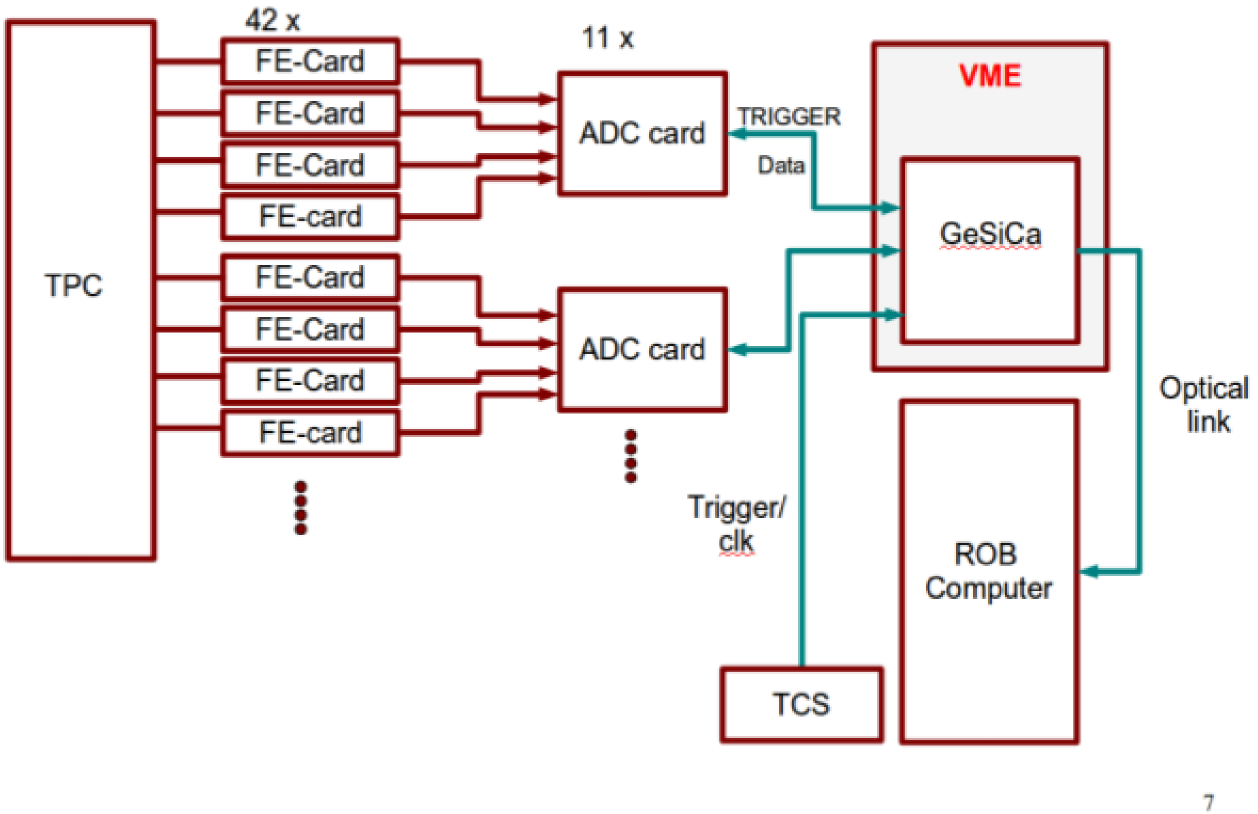
FE cards based on AFTER chip (T2K)

- 10 - 50 MHz sampling
- Noise: ~ 700 e^- ENC on detector
- 100 ns – 2 ms shaping time
- ~ 0.8 W/chip
- ~ 2.5 ms dead-time

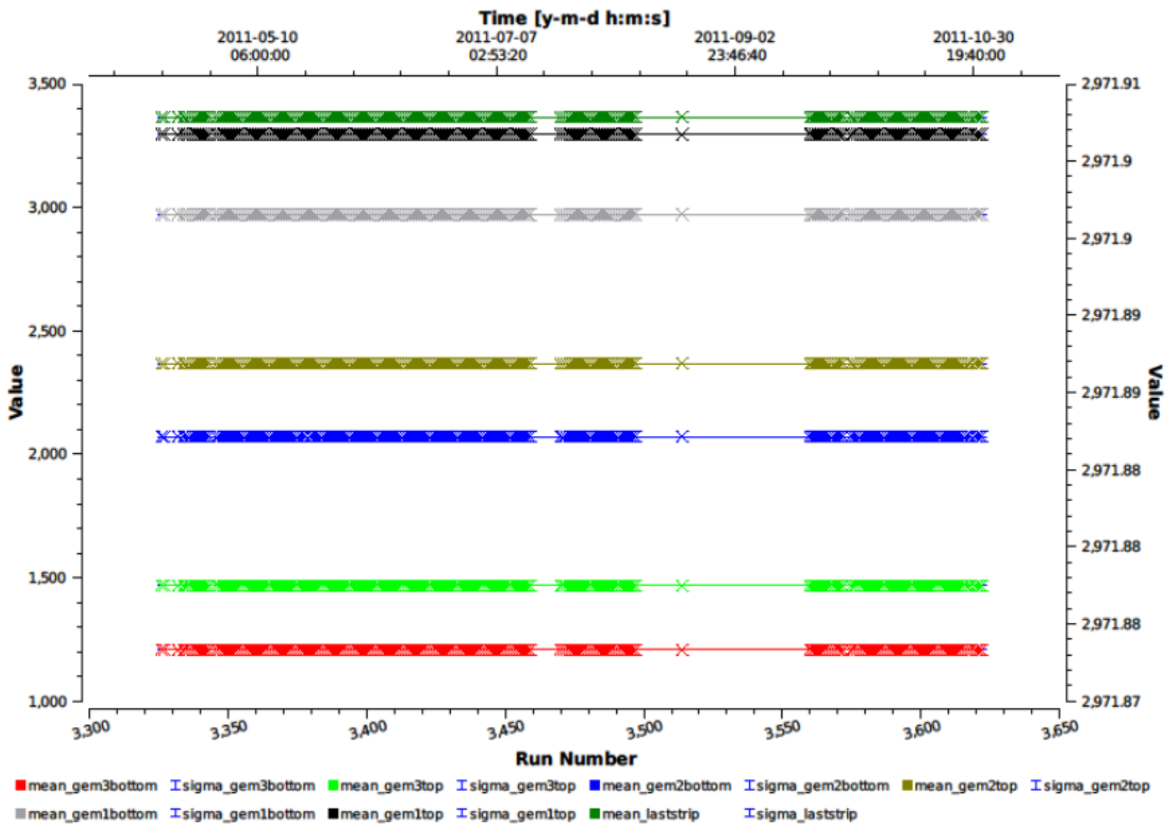
- 511 ring-buffer cells
- Both signal polarities
- Tunable dynamic range
- 72 (64) input channels

P. Baron et al, IEEE Trans Nucl Sci 55 (208)

Readout scheme



GEM-Stability



Temperature Measurements