Development of the GEM-based Read-Out Chambers for the ALICE TPC

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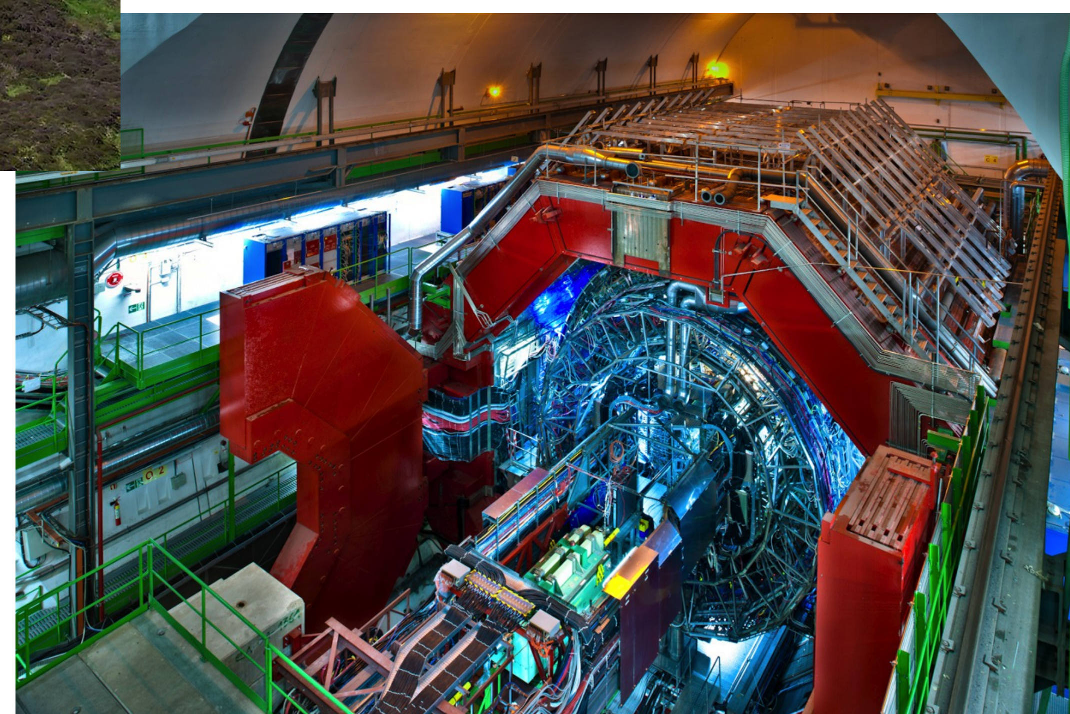
A Large Ion Collider Experiment at CERN

- Study the physics of strongly interacting matter at extreme energy densities (QGP)

- Comprehensive study of the hadrons, electrons, muons and photons produced in the collisions

- Investigation of the Pb-Pb collisions at a center-of-mass energy of 5.5 TeV per nucleon pair

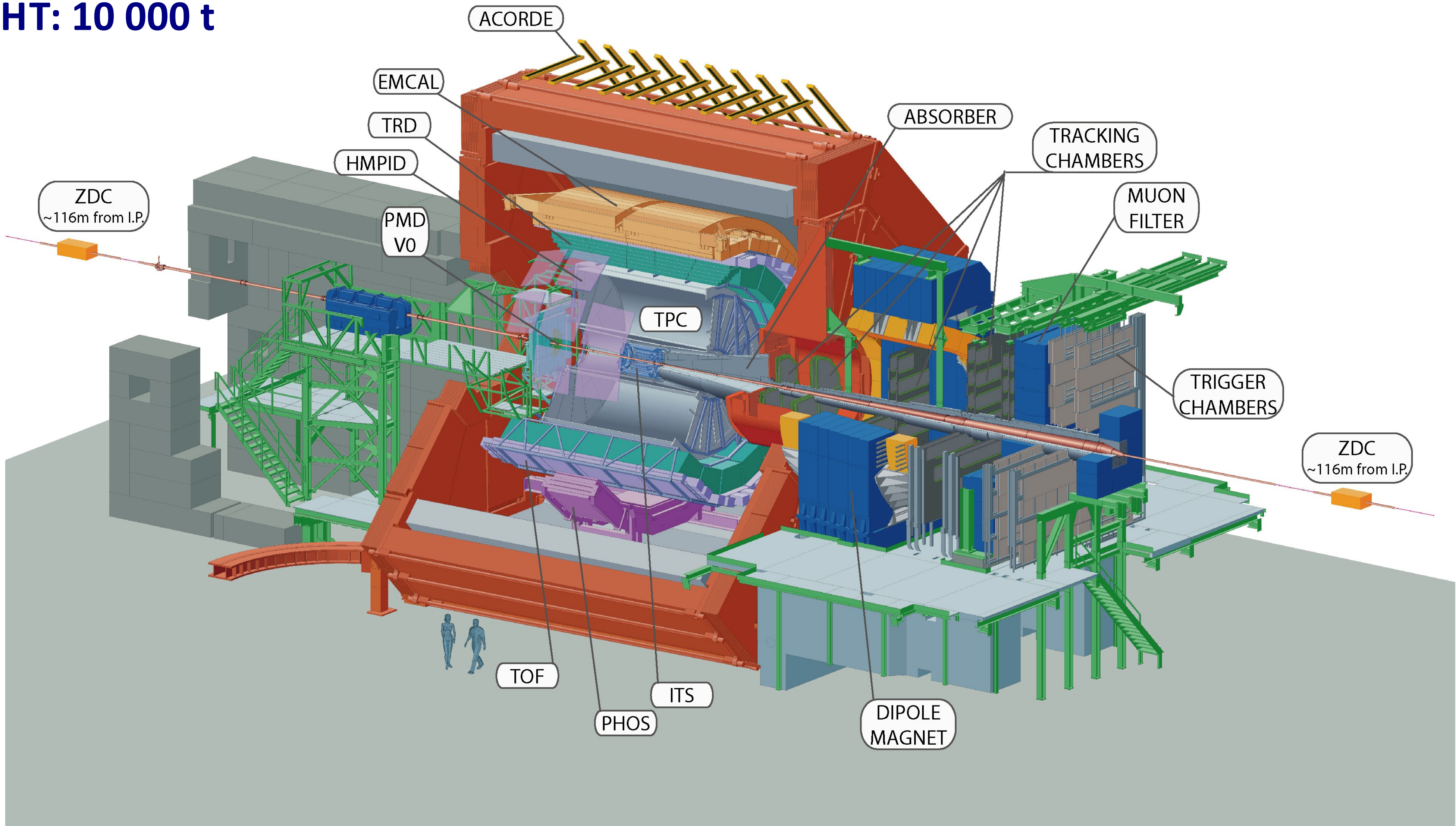
- Study of the p-p collisions both as a comparison with Pb-Pb collisions and in physics areas where Alice is competitive with other LHC experiments.



ALICE detector

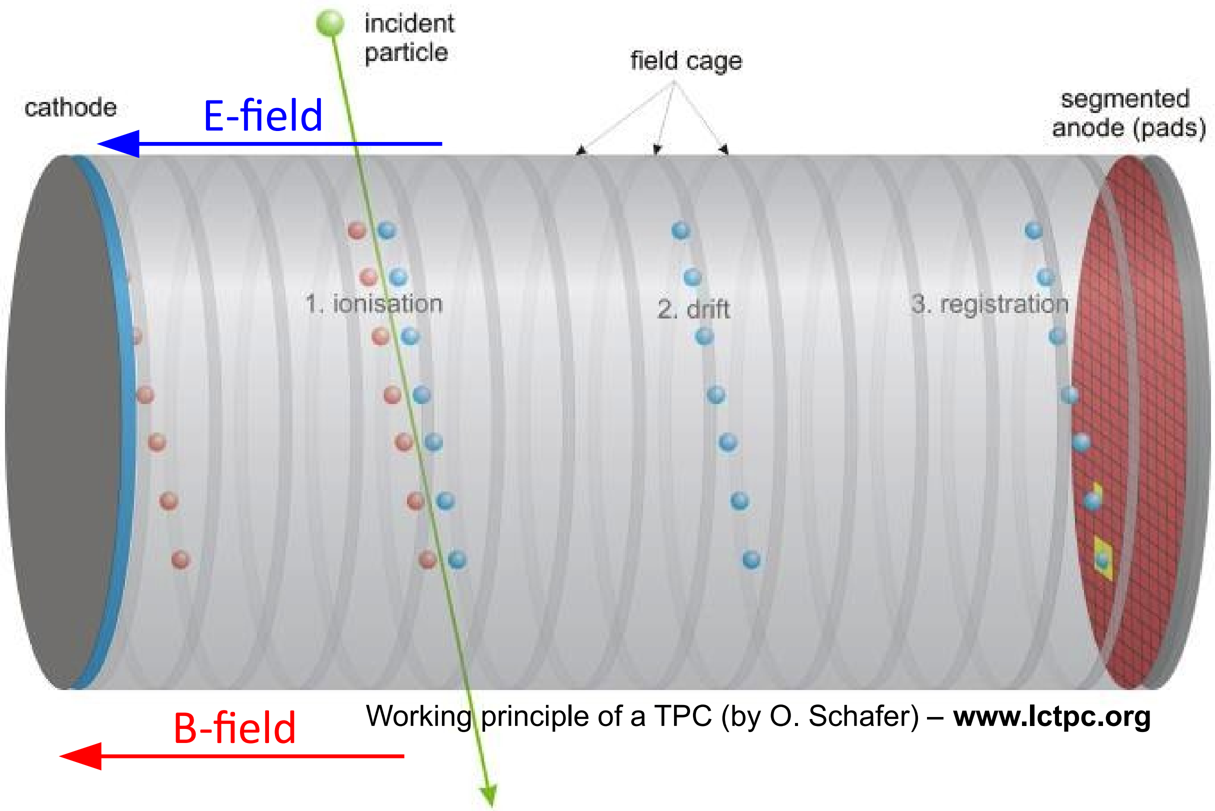
SIZE: 16 x 16 x 26 m

WEIGHT: 10 000 t



TPC (Time Projection Chamber) – main device in the ALICE “central barrel” for tracking and PID

TPC principles



Working principle of a TPC (by O. Schafer) – **www.lctpc.org**

Perfect for HI Collisions:

- almost whole volume is acti
- minimal radiation length (FC, gas)
- easy pattern recognition (continuous tracks)
- PID information from ionizat measurements

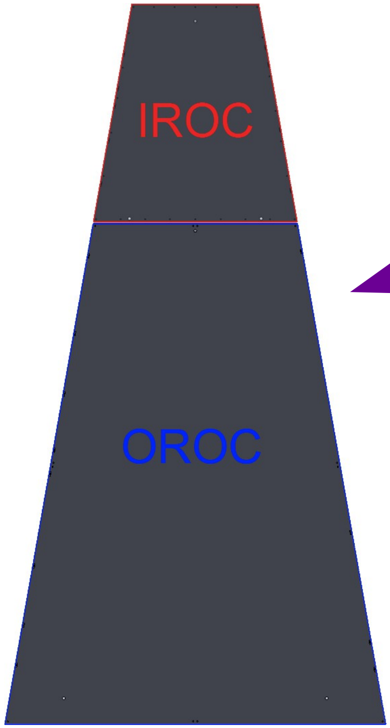
- Two coordinates ***(x,y)*** given by the projection on the pad plane
- Third coordinate ***(z)*** given by drift time and drift velocity v_{drift} ($z = t\,v_{drift}$)

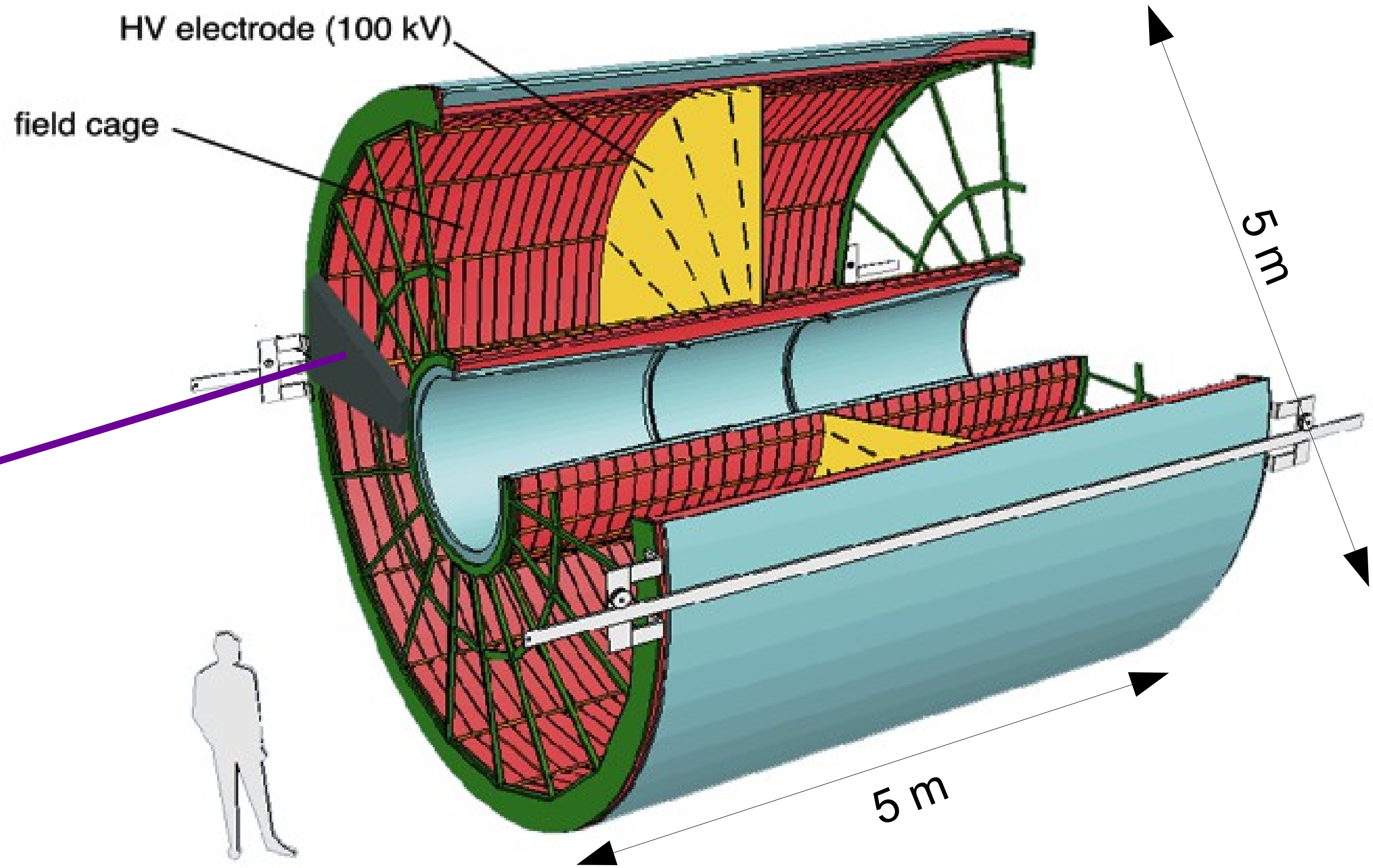
ALICE TPC

2 x 18 IROCs

Inner **R**ead **O**ut **C**hambers

50 cm × 47 cm (29 cm)





2 x 18 OROCs

Outer **R**ead **O**ut **C**hambers

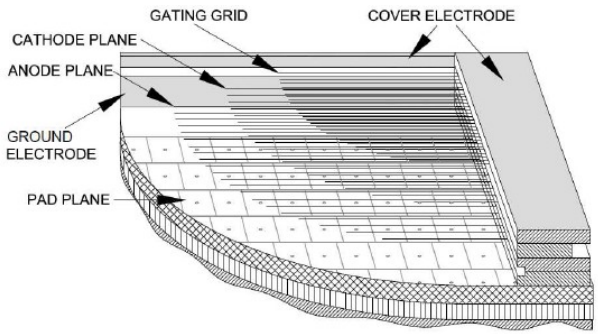
114 cm × 87 cm (47 cm)

GAS:

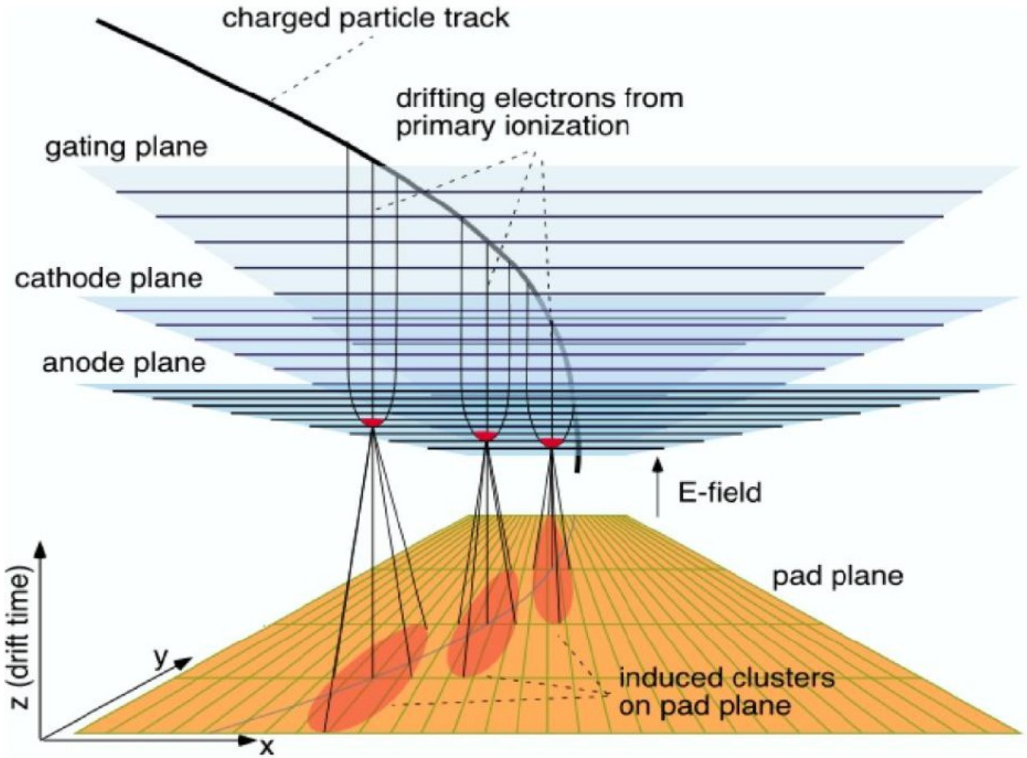
- Ne-CO_2 (90-10)
- 90 m^3
- v_{drift} = 2.73 cm/µs (@ 400 V/cm)

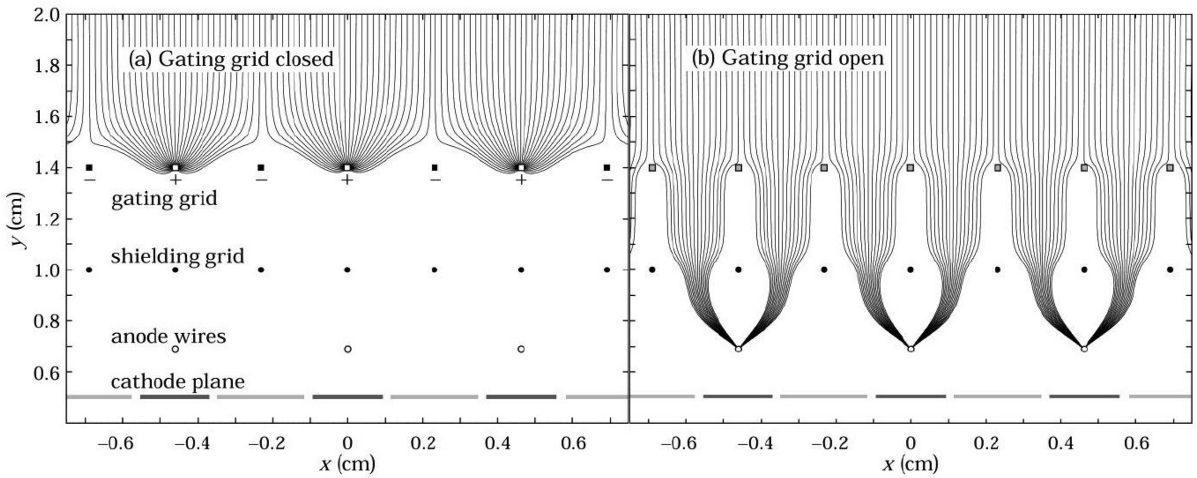
MWPC readout

- **Multi Wire Proportional Chamber** with pad readout
- 3 wire planes: gating, cathode, anode



- Gating-wire grid prevents back drifting ions from the amplification stage to distort the drift field (IBF suppression ~ 10^{-5})
- Nominal gain: 7 – 8 k
- Gating → low trigger rates:
  - 300 Hz for Pb-Pb
  - 1.4 kHz for p-p





ALICE upgrade plans after LS2*

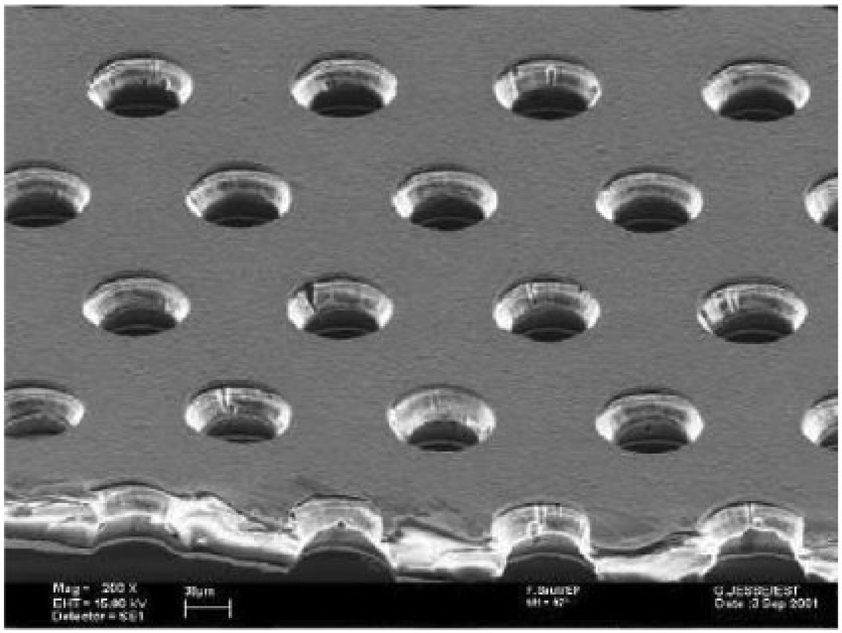
*”The proposed upgrade of ALICE would facilitate **read-out at 50kHz**, which necessitates a **major upgrade of the TPC**, namely the replacement of the existing readout chambers with **Gas Electron Multiplier (GEM) detectors**. Furthermore, all central detectors will require an (electronics) upgr*
*switching to **fully pipelined** read”*

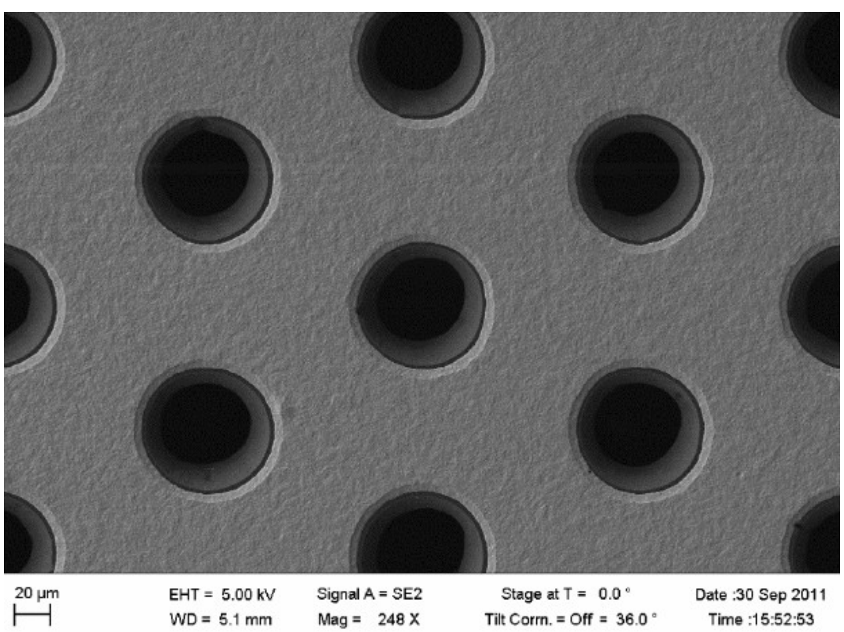
Minutes of the 109th LHC Committee meeting, 22.03.2012

* LS2 – 2nd Long Shutdown of the LHC (2017-2018), when the LHC will be upgraded to the highest luminosities.

Gas Electron Multiplier

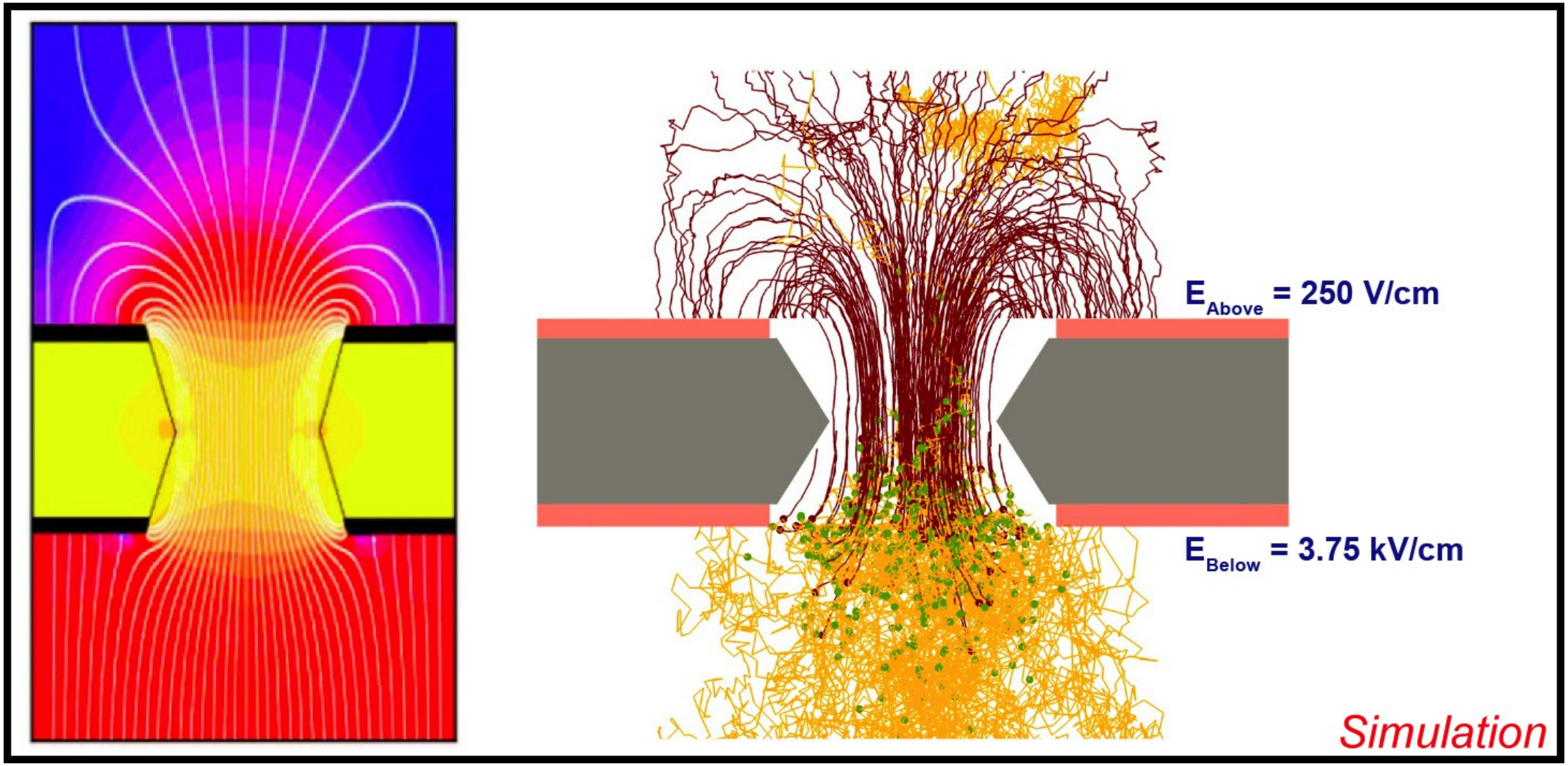
F. Sauli, NIM A 386 (1997) 531





- Thin polyimide foil (Kapton®)
  ~ 50 μm
- Cu-clad on both sides
  ~ 5 μm
- Photolithography:
  ~ 10^4 holes/cm^2
- <u>“Standard” GEM foil:</u>
  - Inner/Outer hole diameter
    50/70 µm
  - Pitch
    140 µm

GEM principles



GARFIELD/MAGBOLTZ simulation: 2 e^- entering the GEM hole

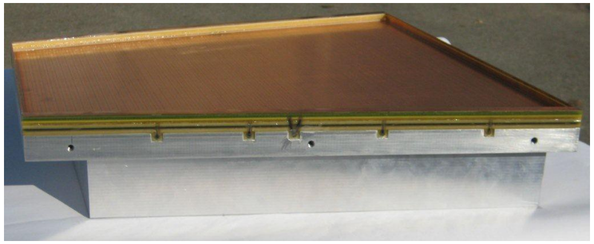
- E_{hole} up to 100 kV/cm with ΔV_{GEM} = 500 V (hole-size dependency)
- $E_{hole} >> E_{above}$ → most of the ions are collected on the top side of GEM
- $E_{below} > E_{above}$ → electron extraction is improved

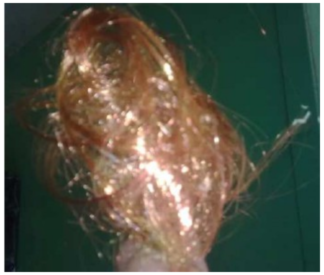
Introduction summary

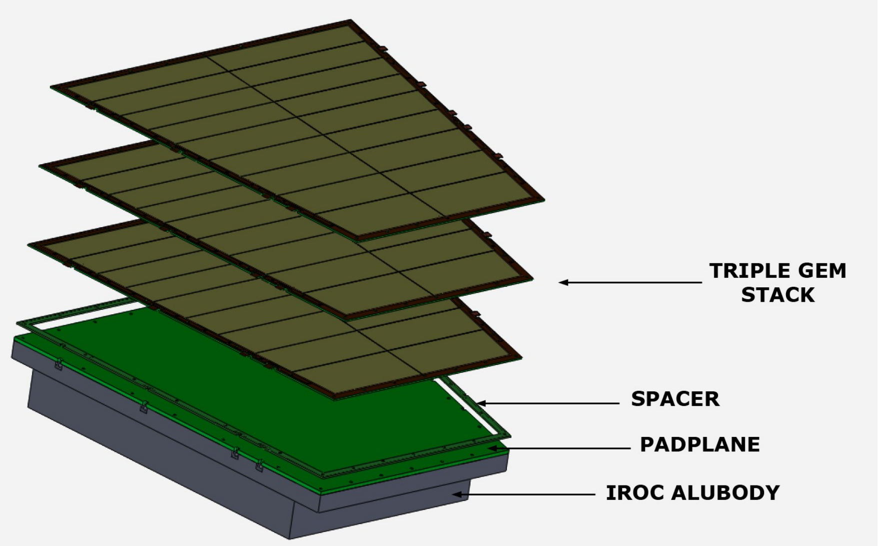
- **ALICE TPC will operate at a factor 100 higher readout rate after LS2**
  - 2 MHz in p-p and 50 kHz in Pb-Pb collisions
  - no gating and continuous readout
- **GEMs as an alternative for MWPC readout**
  - no issue with rate capability
  - possibility to efficiently block ions
  - lower (effective) since signal is produced by electrons (fast) + lower noise
- **Issues for GEM upgrade**
  - **dE/dx resolution for PID (Nov./Dec. 2012)**
  - **stability under LHC conditions (Jan./Feb. 2013)**
  - gain stability (charging up, rate dependence)
  - **IBF** (ongoing measurements, simulations)
  - new electronics (polarity, continuous readout)

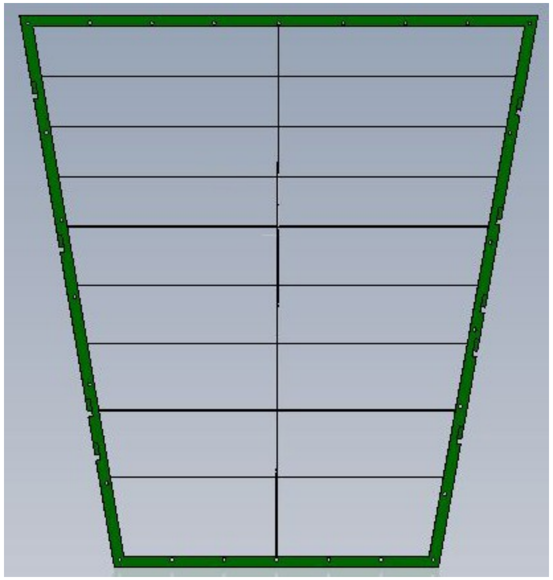
GEM – IROC prototype @ TUM

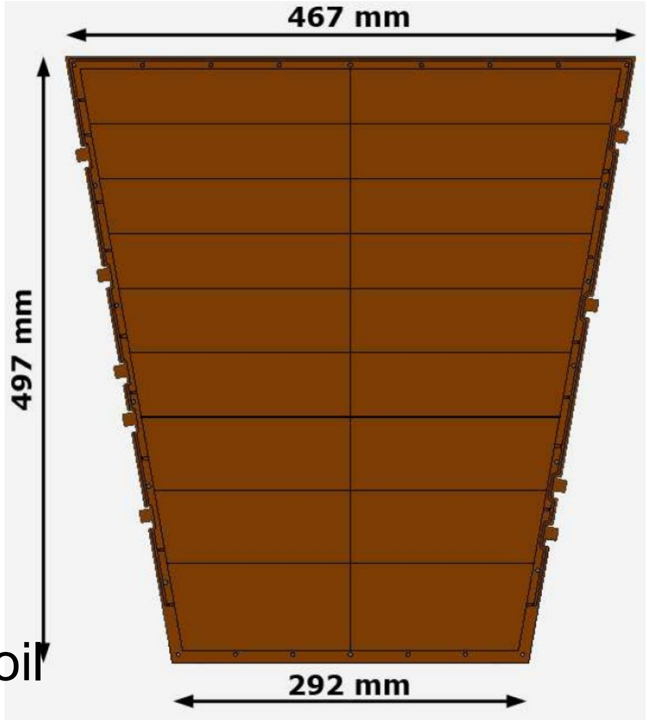
Excellence Cluster Universe









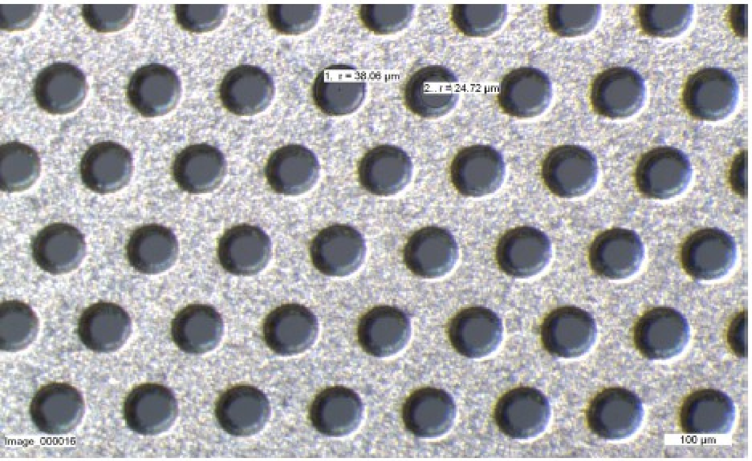


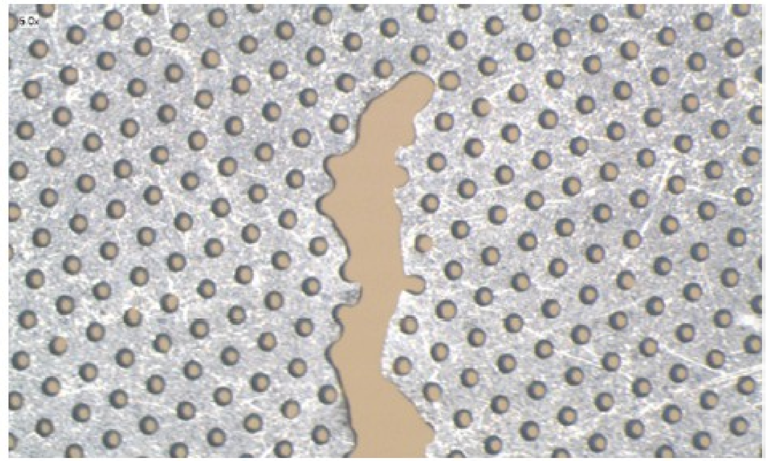
GEM foils for IROC prototype

- 3 single-mask, large-size foils
- **Inner/Outer hole diameter: 50/70 μm**
- **Pitch: 140 μm**
- **18 sectors** (top side segmented), **~100 cm² each**
- **2 mm frames (G10 fiber glass) glued on bottom side**
- Additional frame (spacer) between pad plane and bottom foil

Quality Assurance

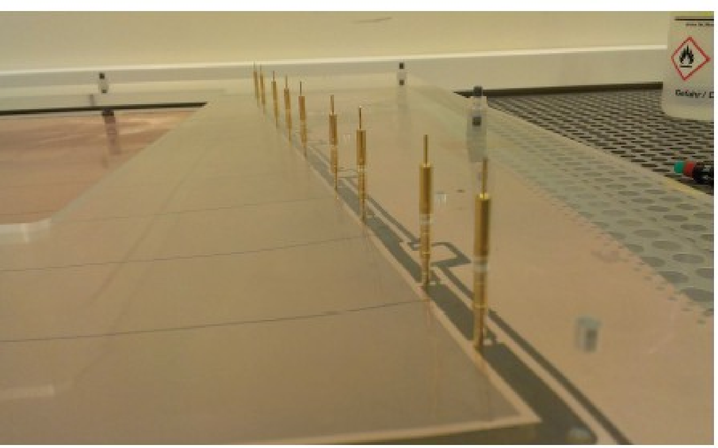
MICROSCOPE CHECK

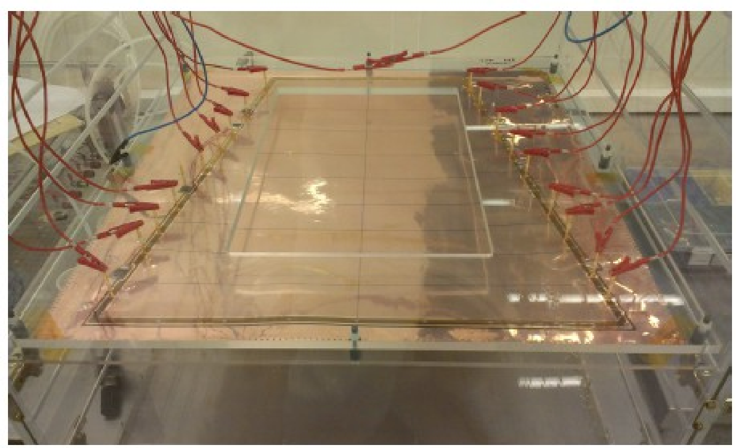




- hole size measurement
- search for defects

HV TESTS

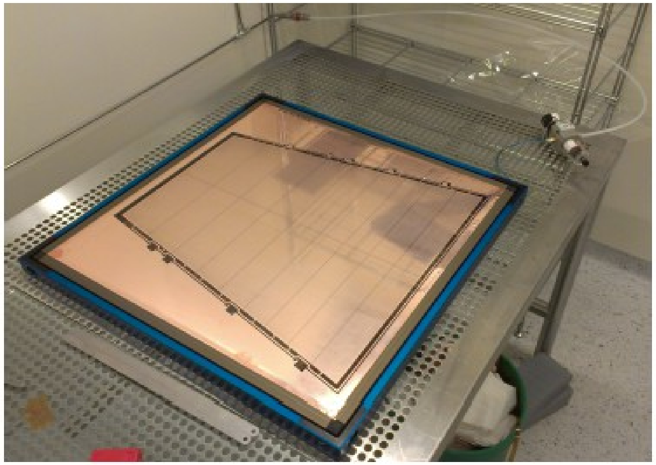




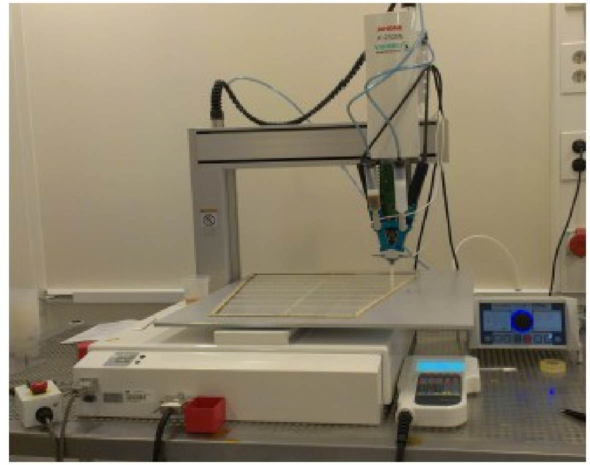
- tests in box flushed with N_2
- 550V (max. 600V) applied
- leakage current measured

Gluing procedure

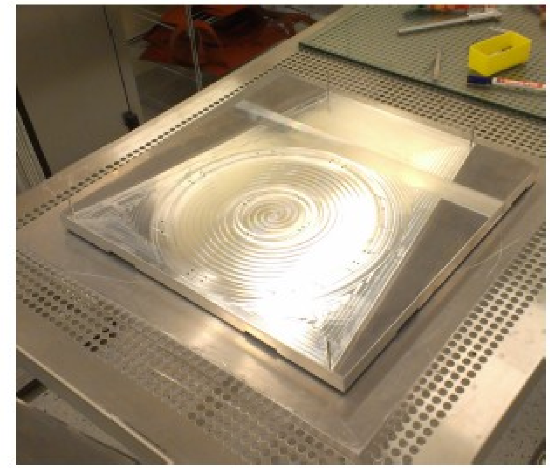
1. Stretching (DEK frame, 10 N/cm)



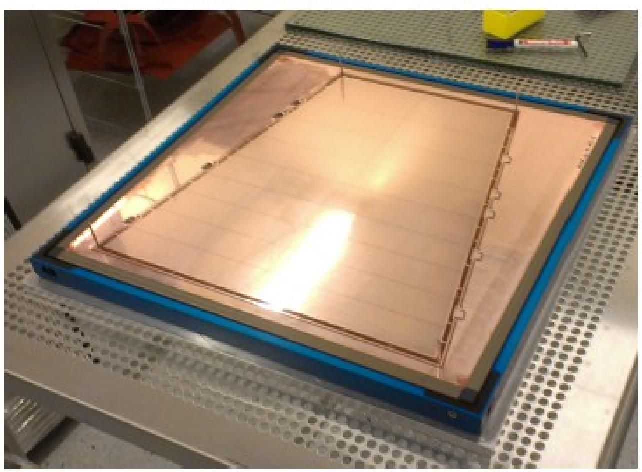
2. Glue dispensing (ARALDIT 2011)



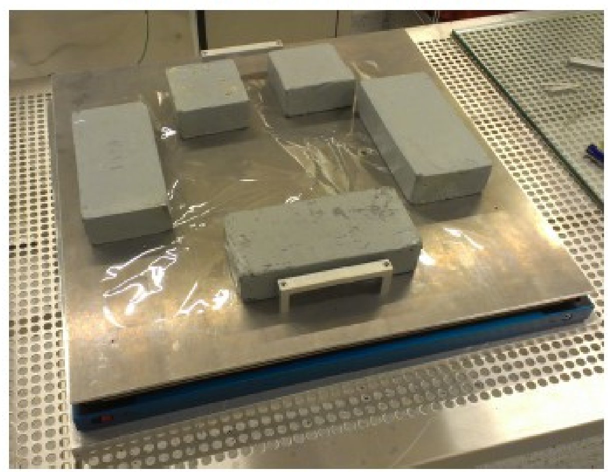
3. Alignment tool



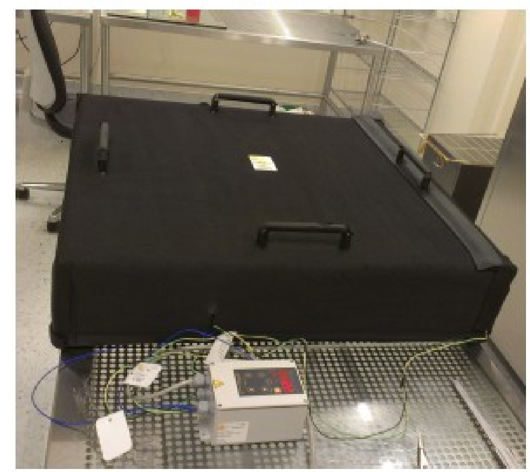
4. Foil glued onto the frame



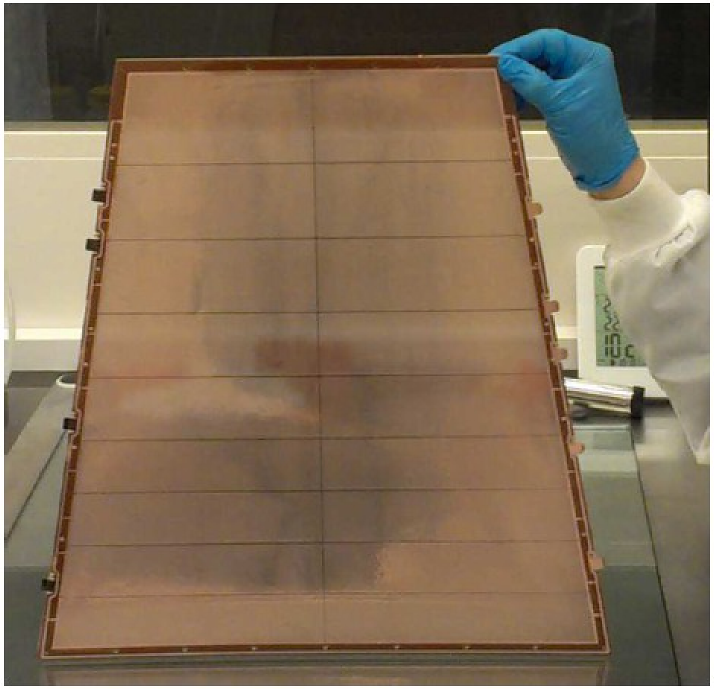
5. Counterweight for gluing

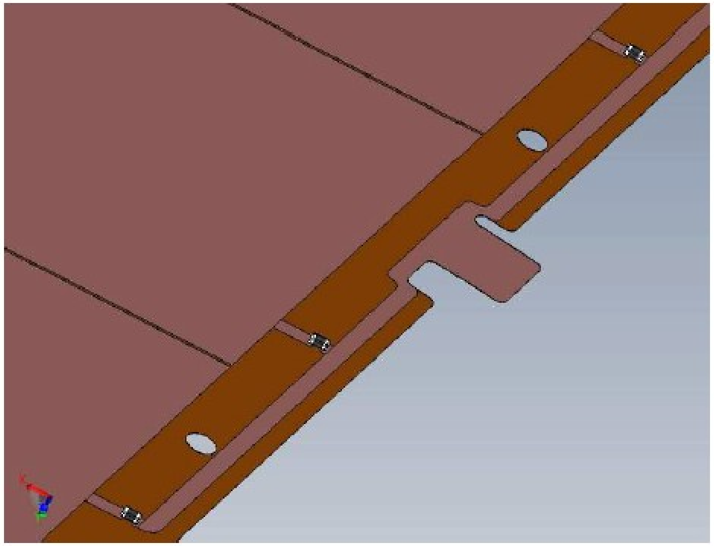


6. Curing the glue (70° C for 20h)



Framed GEM foil

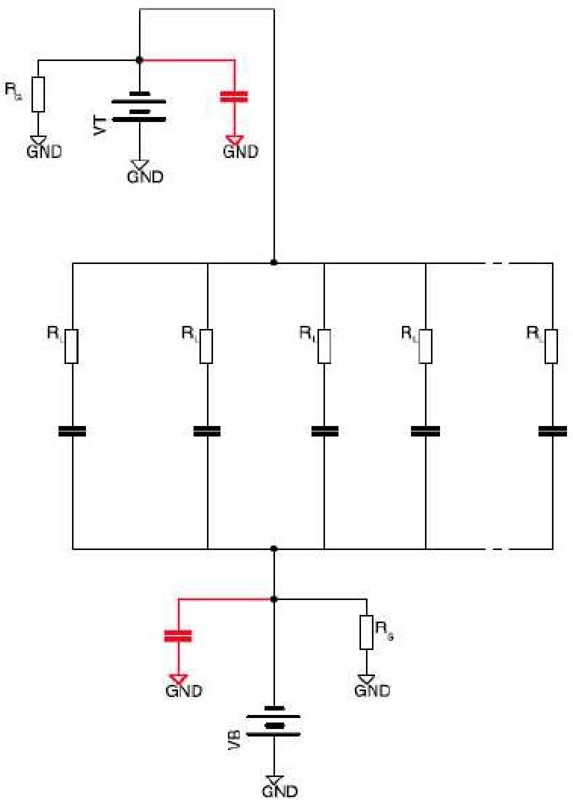


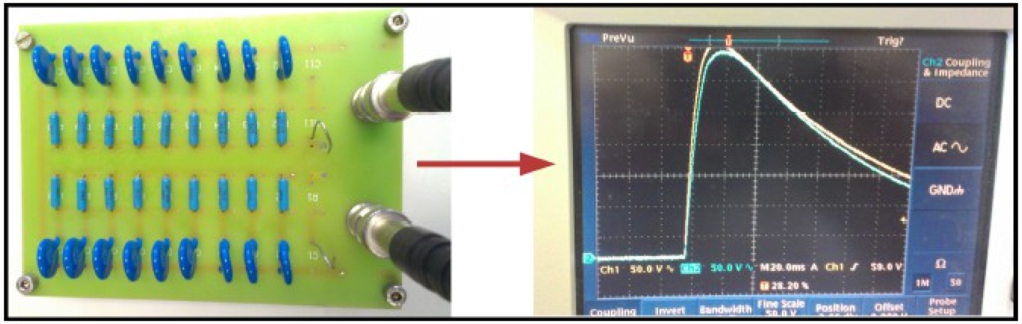


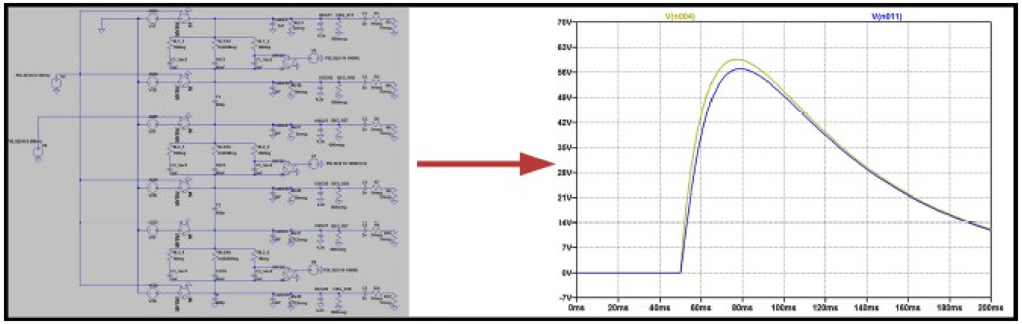
- raw material is cut off
- HV tests → foils are more stable after gluing/heating procedure
- loading resistors (SMD) are soldered
- flaps used for HV connection (with Kapton wires) after mounting GEMs on the Alubody

HV supply

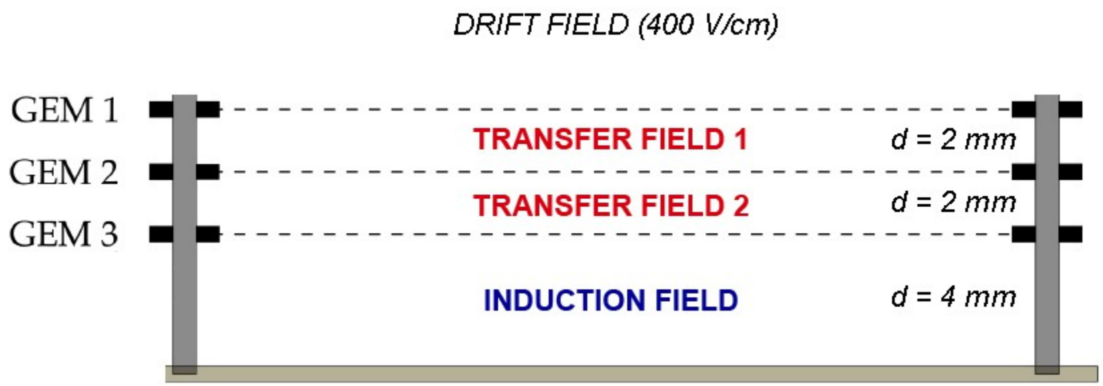
- Loading resistors
  - 10 MΩ for top (**G1**) and middle (**G2**) foils
  - 1 MΩ for bottom (**G3**) foil
- Each side powered independently (6 HV channels)
  - ΔV across the GEM must not increase after the trip
  - top side must discharge faster than bottom
  - crucial role of parasitic capacitances (cables!)
- Grounding resistors
  - **G1T** → 5 MΩ; **G1B** → 10 MΩ
  - **G2T** → 5 MΩ; **G2B** → 10 MΩ
  - **G3T** → 3.3 MΩ; **G3B** → 3.3 MΩ
- Tested with GEM-model and simulations







HV settings



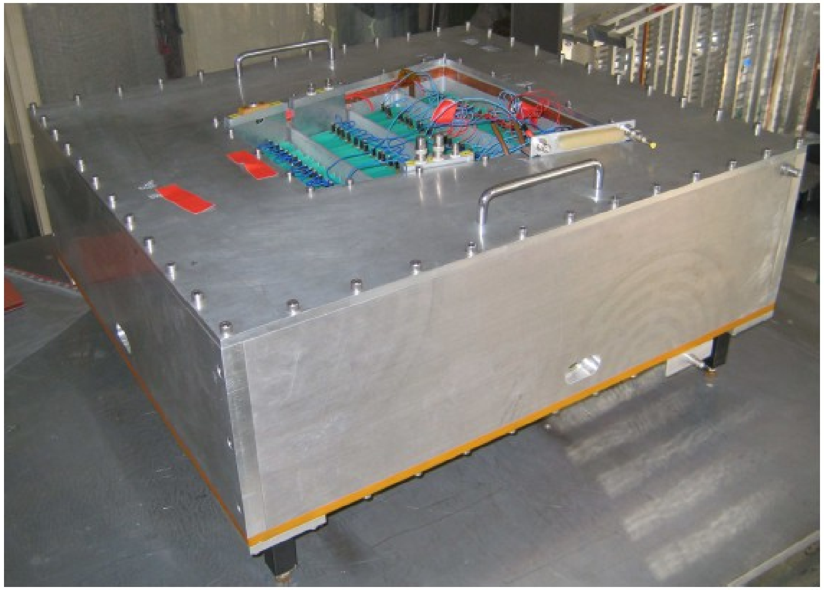
HV settings for a gain of 2000 in Ne-CO_2 (90-10)

“Standard” settings
- stability-optimized
- decreasing gain in GEMs
- moderate transfer fields

	Standard	IBF
Drift Field	0.4 kV/cm	0.4 kV/cm
ΔU_{GEM1}	276 V	225 V
Transfer Field 1	2.57 kV/cm	3.8 kV/cm
ΔU_{GEM2}	252 V	235 V
Transfer Field 2	2.57 kV/cm	0.60 kV/cm
ΔU_{GEM3}	221 V	285 V
Induction Field	2.57 kV/cm	3.8 kV/cm

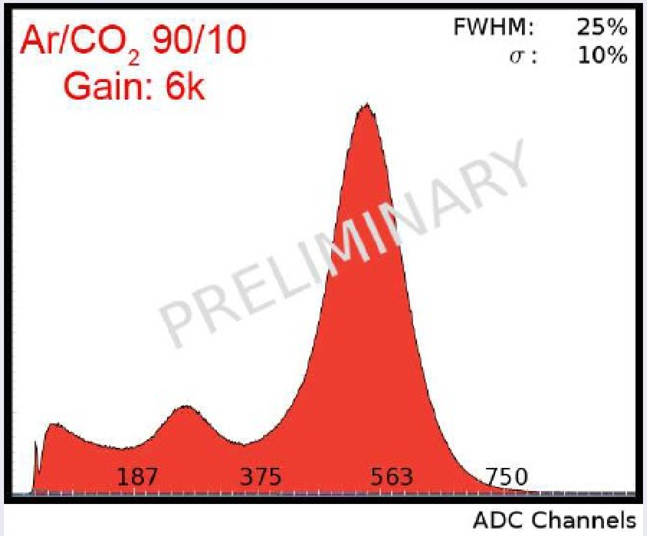
“IBF” settings
- IBF optimized (4 %)
- increasing gain in GEMs
- high filed assymmetry
  (low TRANSFER2 field)

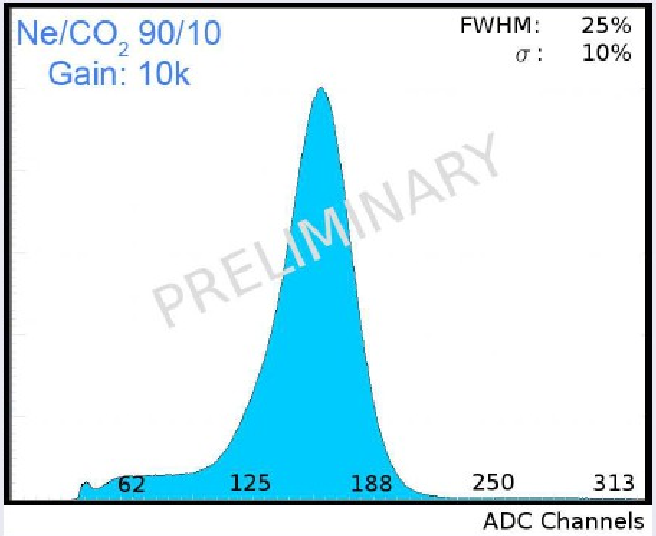
Commissioning in the lab



- IROC in the testbox with Field Cage
  - **Drift field**: 400 V/cm
  - **Drift length:** ≈ 11.5 cm
- Readout: ca. 250 pads (out of 5500) connected to the preamplifier (~ 75 cm^2)

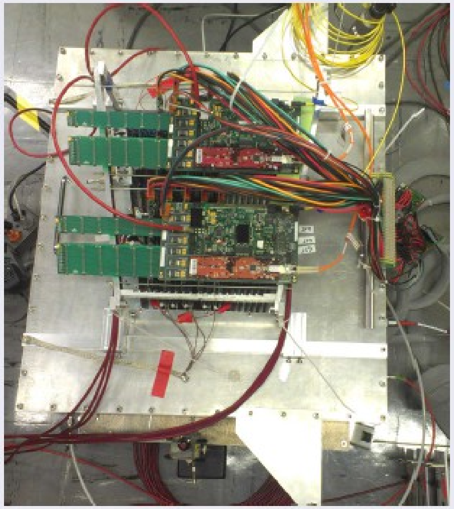
First ^{55}Fe spectra

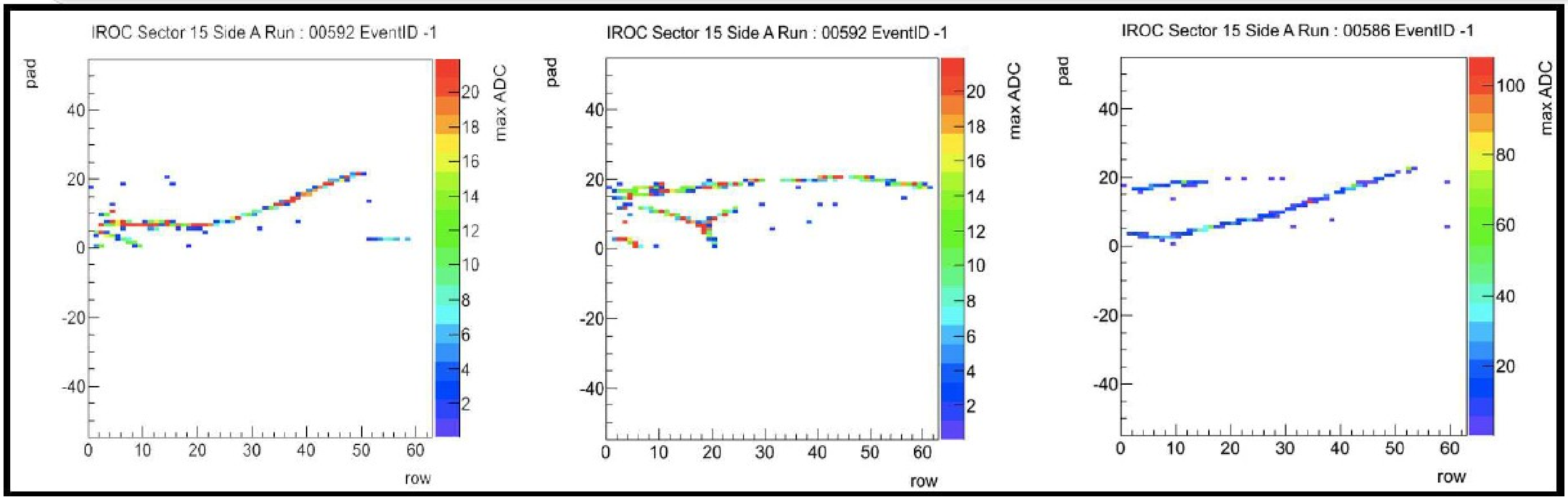




Readout

- **10 Front-End Cards** (borrowed from the LCTPC Collaboration via Lund):
  - 16 to 18 pads (size 4×7.5 mm^2, 320 cm^2 in total) on 64 pad rows
  - region covered ∼ 6 cm wide
  - average noise (ENC) at the level of 500 – 600 e^-
- **EUDET Front-End Card:**
  - programmable charge preamplifier: PCA16
  - digitization and signal processing: ALTRO
  - same backplane and readout as in ALICE



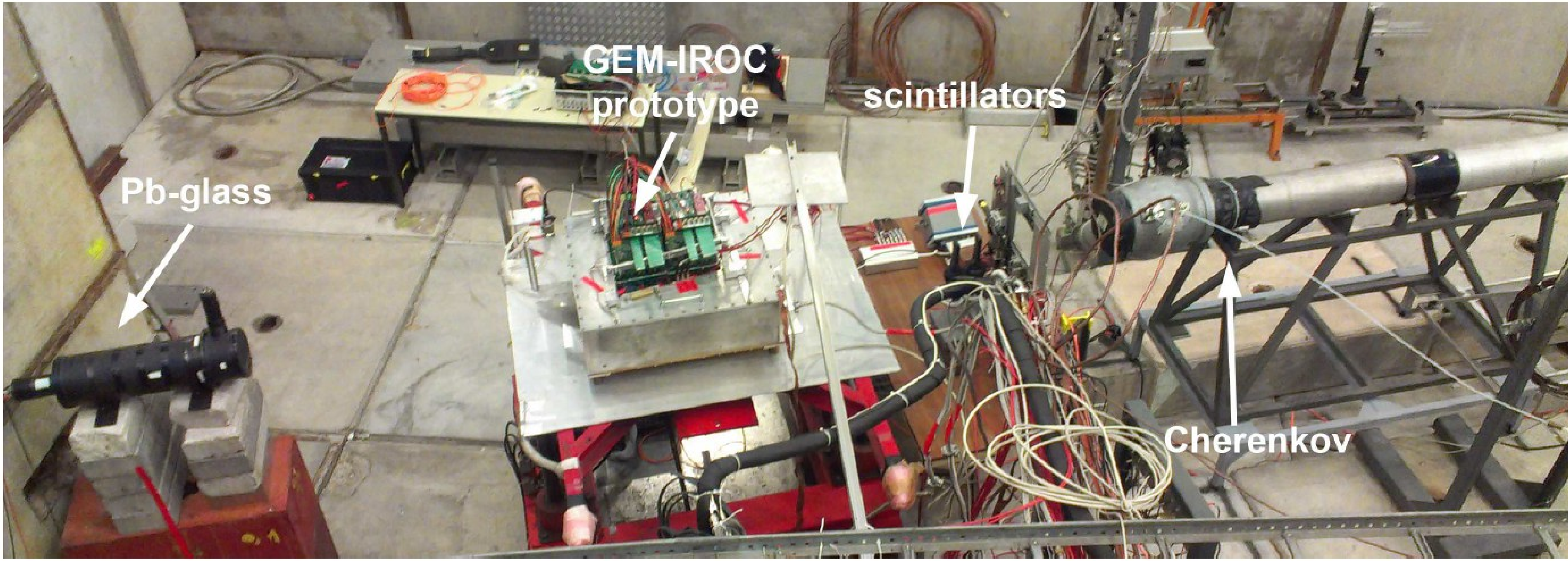


→ **First tracks**

→ Ne/CO_2 (90/10)

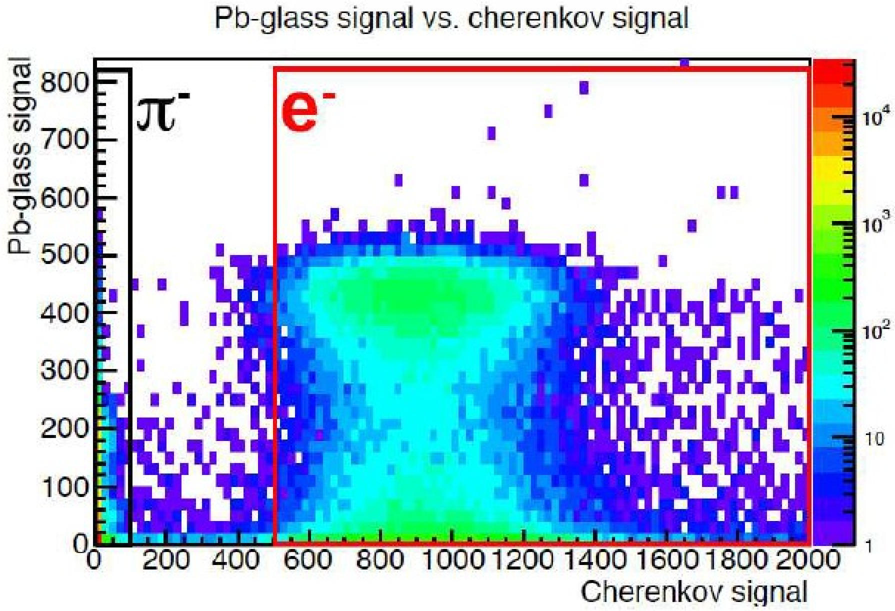
→ ^{90}Sr source

PS test beam



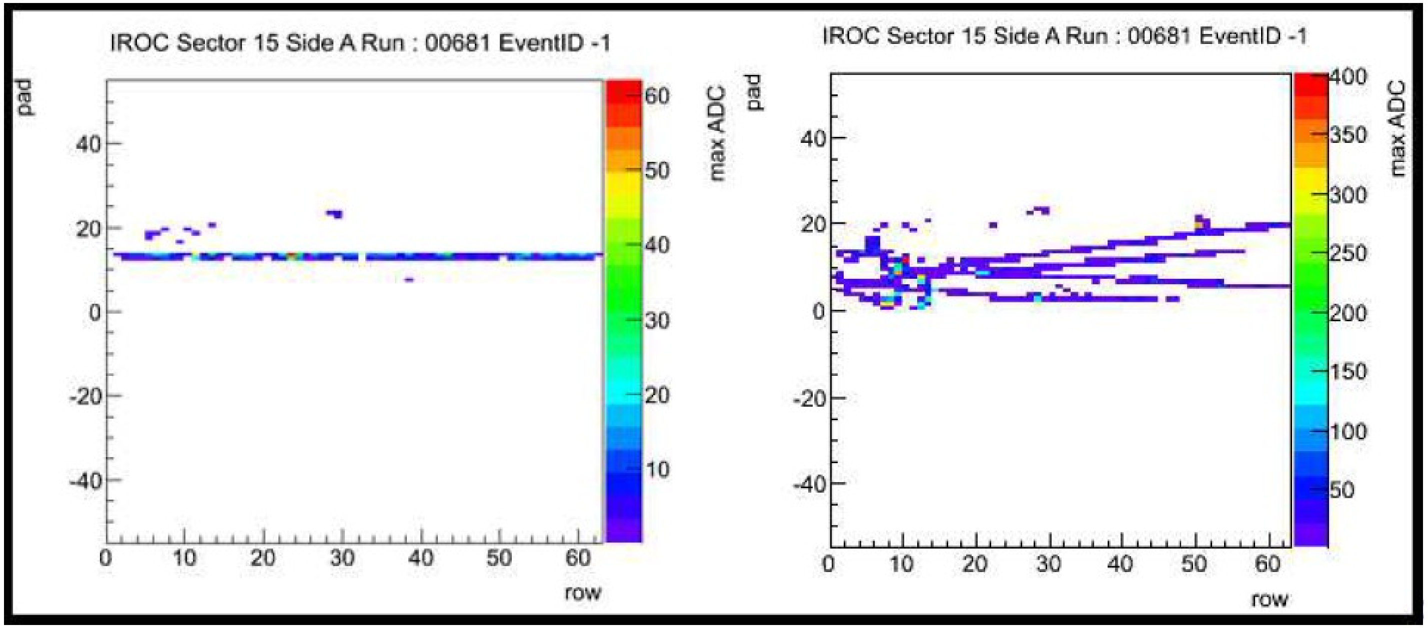
- Average beam rate: 2000 particles/spill (0.5 s)
- DAQ rate: 500 events/spill
- **Data taken for different beam settings:**
  - 1 GeV/c, 2 GeV/c, 3 GeV/c negative (e^-, π^-)
  - 1 GeV/c, 6 GeV/c positive (e^+, π^+, p)
  - "high-rate" run, 1 GeV/c negative, 5000 particles/spill
  - shaping time analysis $\rightarrow$ different settings for moderate gains (1 – 2 k)
- **Data taken for different GEM settings:** "Standard" and "IBF"
- **Gas mixture:** Ne/CO_2 (90/10)

PS test beam

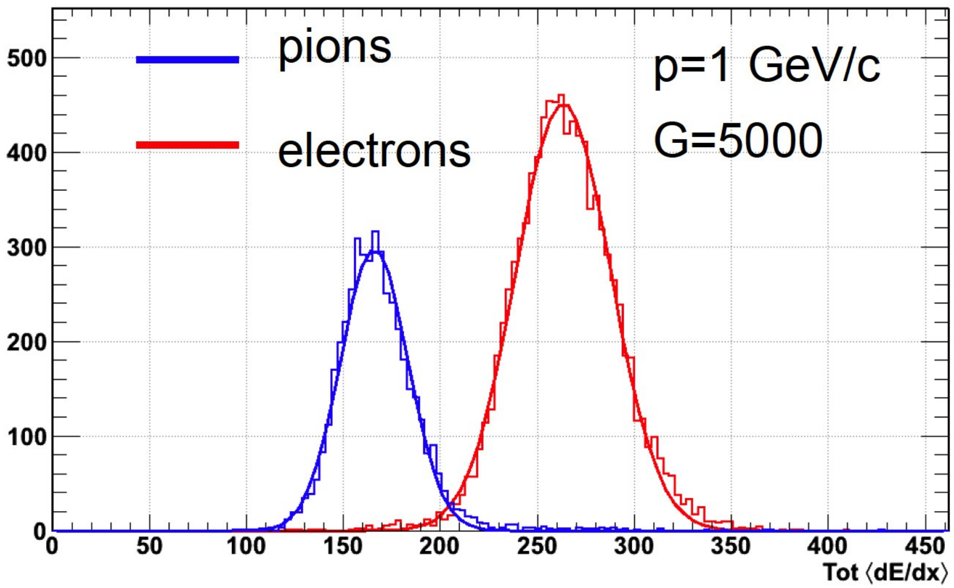


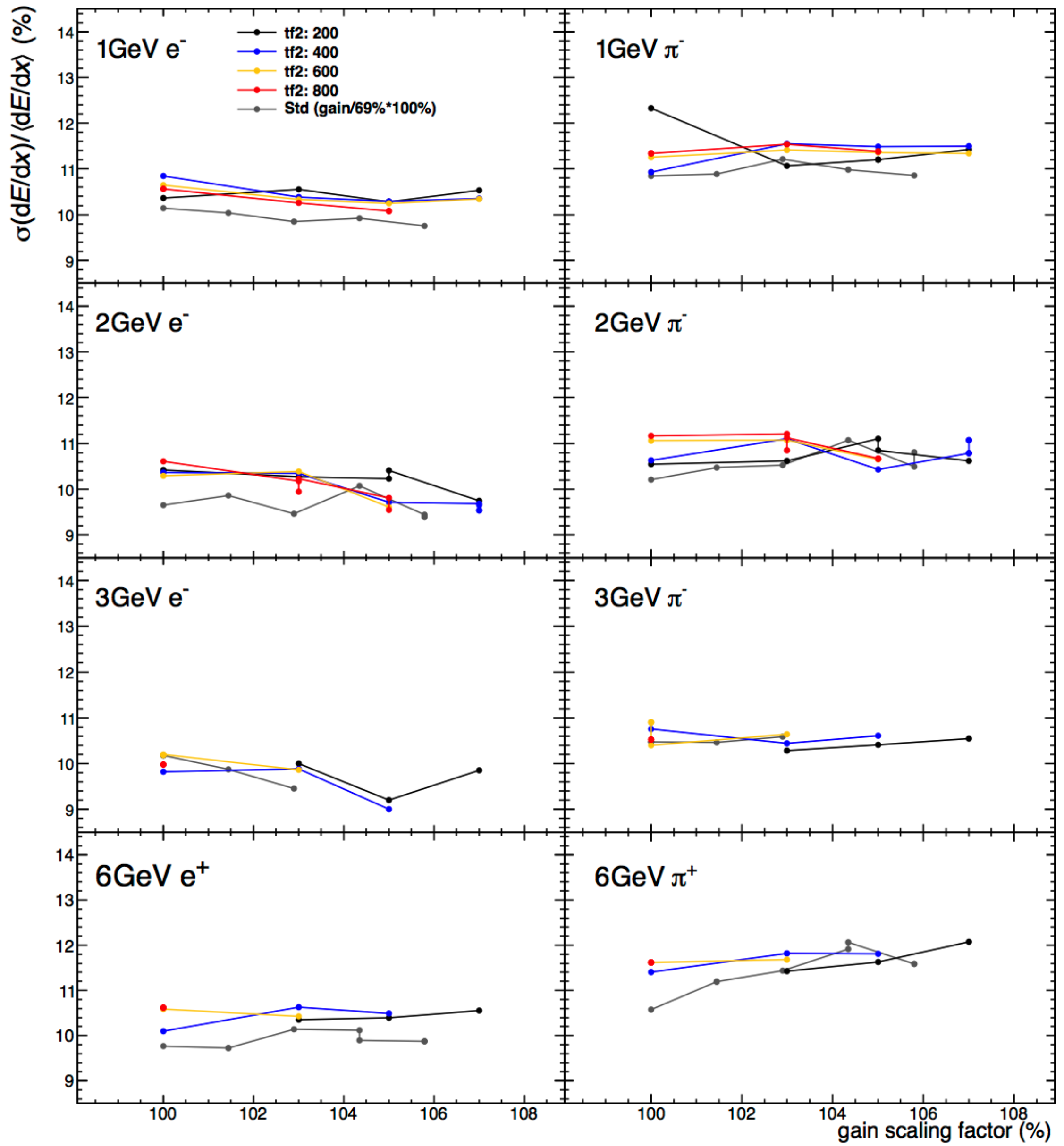
- Separation between pions and electrons (Pb-glass vs. Cherenkov)

- Beam tracks



dE/dx measurements

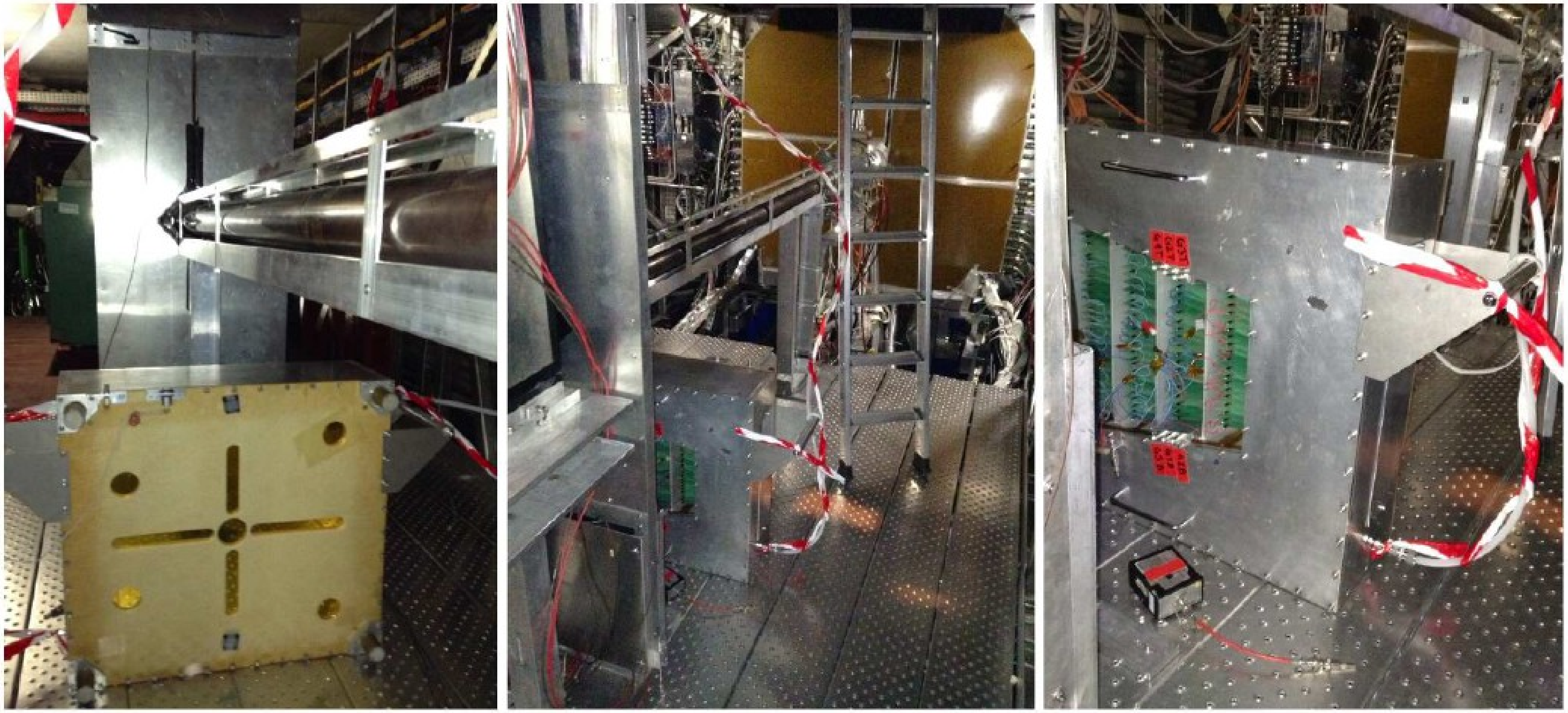




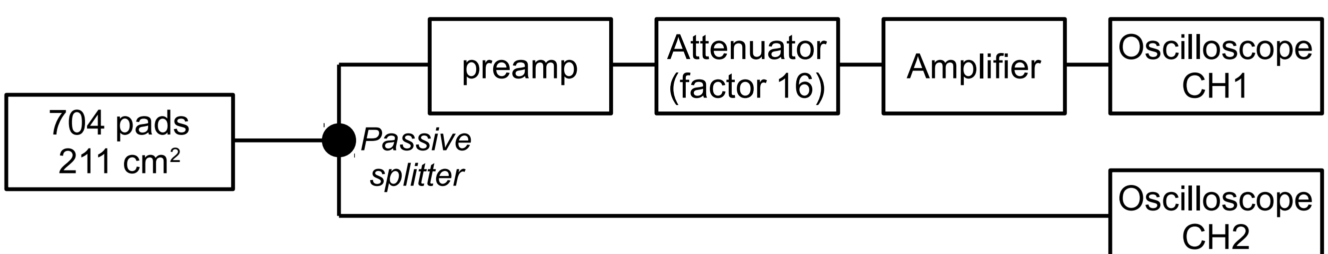
***dE/dx* measurements**

- Gain equalization using tracks
- No T/P correction
- Truncated mean of cluster charge (5 - 70 %)
- For comparison:
  IROC only in ALICE TPC $\sigma_E/E \approx 9.5$ % (high η)

Test under LHC conditions

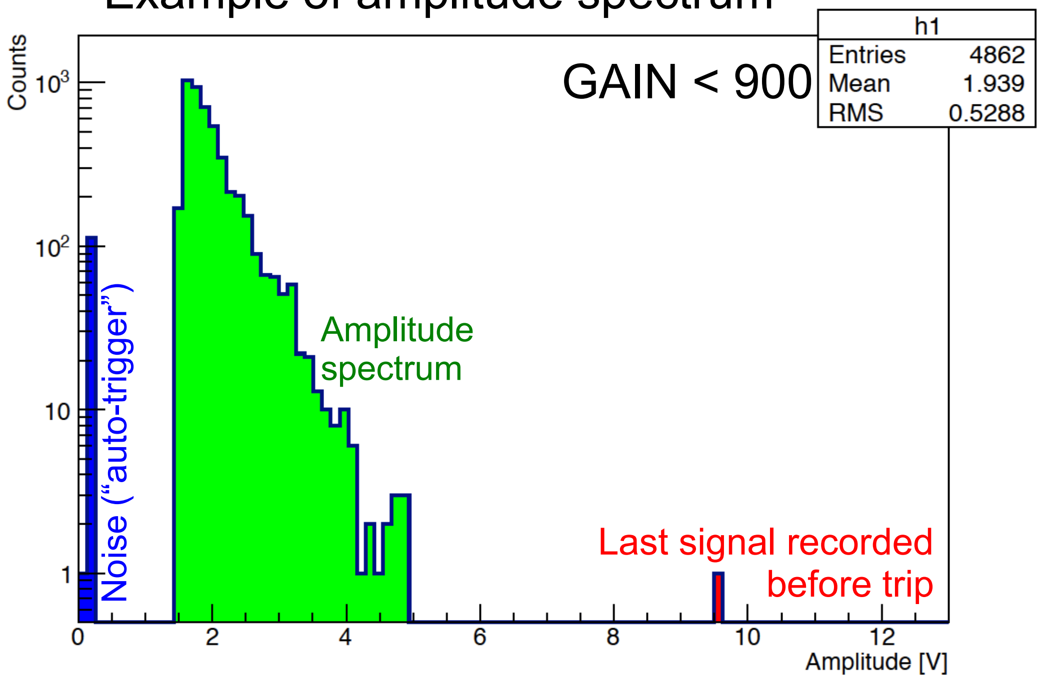


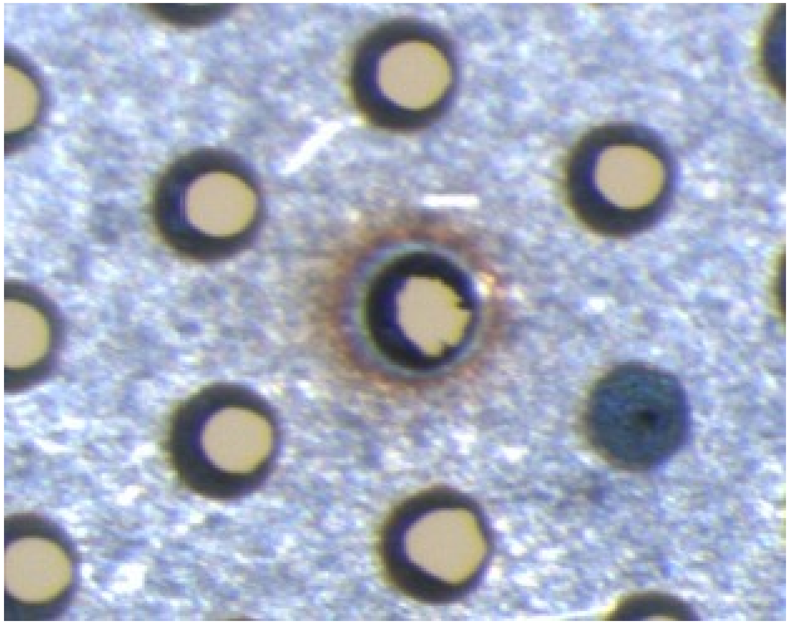
- p-Pb period 2013 (3 weeks)
- Prototype installed at the ALCIE cavern under the beam pipe ($\eta \approx 2.6$)
- 200 kHz interaction rate
- Particle rate ~5000 kHz per rapidity unit
- Standalone readout: waveforms, discharges, trips
  - Trig. Rate < 10 Hz (recording highest signals)



LHC beamtime

Example of amplitude spectrum





- **23 HV trips occurred**
  (+ 8 during the PS beamtime)
  - 20 at lowest "IBF" settings, 2 at "standard", 1 while ramping up
  - 21 with beam, 2 without
  - All including G1 (absolute voltages?)
  - Highly ionizing particles? (heavy fragments)

- **7 "shorts" developed in the GEM-foils**
  - 1 x GEM1; 3 x GEM2; 3 x GEM3;
  - **Shorts developed in the sectors with problems at the QA – HV step;**
  - **No correlations with foil defects found**

Importance of QA

summary & outlook
– but not finish yet –

- First GEM IROC prototype for ALICE designed, assembled and operat
- Good d*E*/d*x* resolution has been demonstrated with beams at the CERN
- Stability under LHC conditions tested during p-Pb beamtime

- Issues to be addressed:
  - **Stability of the GEM system** (TUM, CERN)
    - discharge probability
    - discharge propagation (FEE protection)
  - **IBF –** optimization in progress (TUM, CERN, Frankfurt)
  - **HV supply**
- Definition of assembly procedure for IROCs and OROCs under way

IB for triple GEM

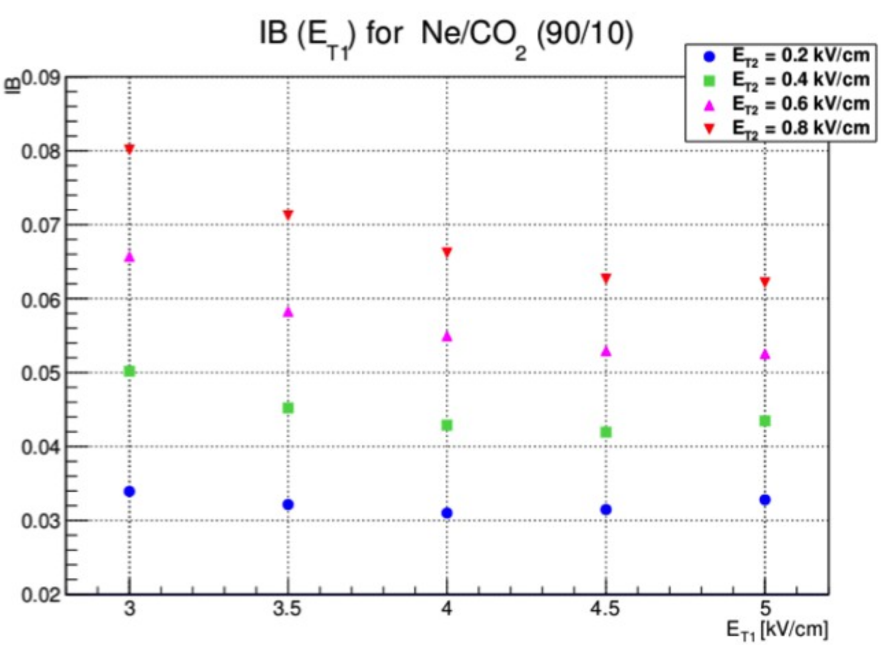
<u>*Number of ions drifting back from the amplification stage to the active volume of the detector should be minimized in order to avoid major distortions of the drift field*</u>

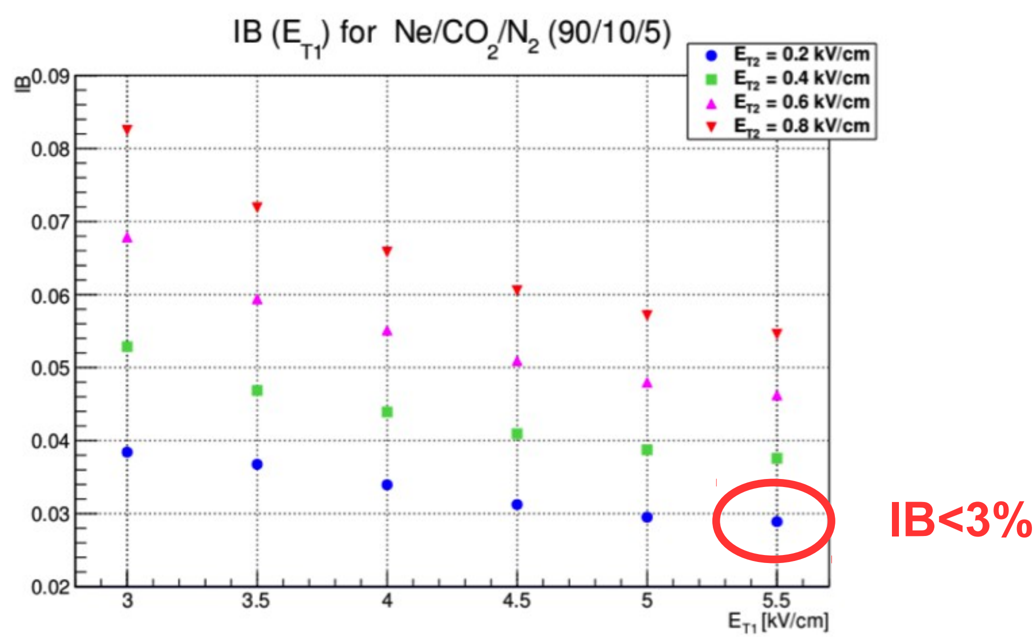
Ion Backflow (IB) = $\frac{\text{Number of ions arriving at the cathode}}{\text{Number of electrons arriving at the anode}}$

$\varepsilon = IB \times GAIN - 1$

<u>*Expectations for the ALICE TPC upgrade:*</u>

- **GAIN = 1k – 2k**
- **ε = 5 – 10**
- **IB = 0.5 – 1.0 % (GAIN=1k)**
- **IB = 0.25 – 0.5 % (GAIN=2k)**





M. Ball et al. (TUM)

IB for quadruple GEM

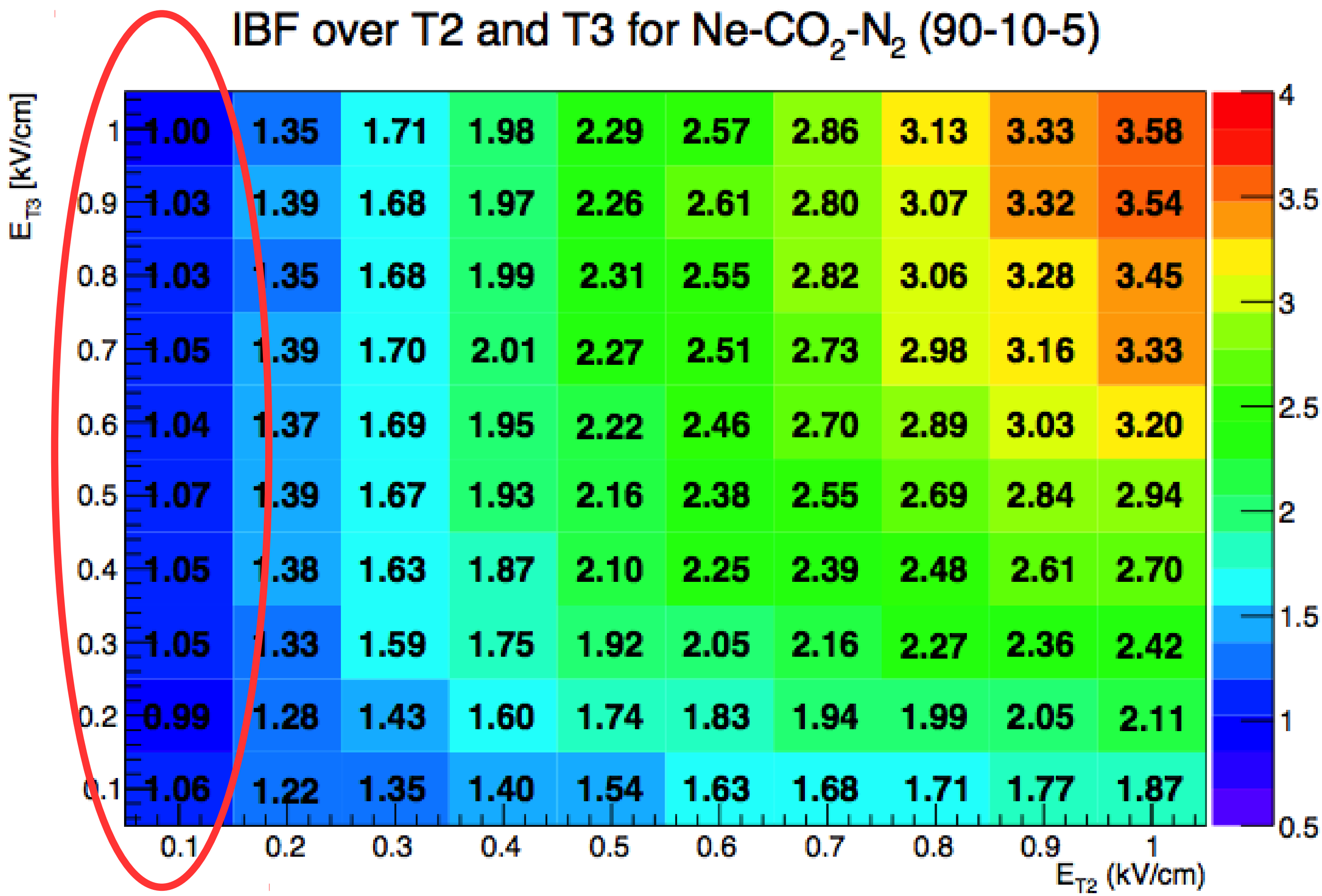
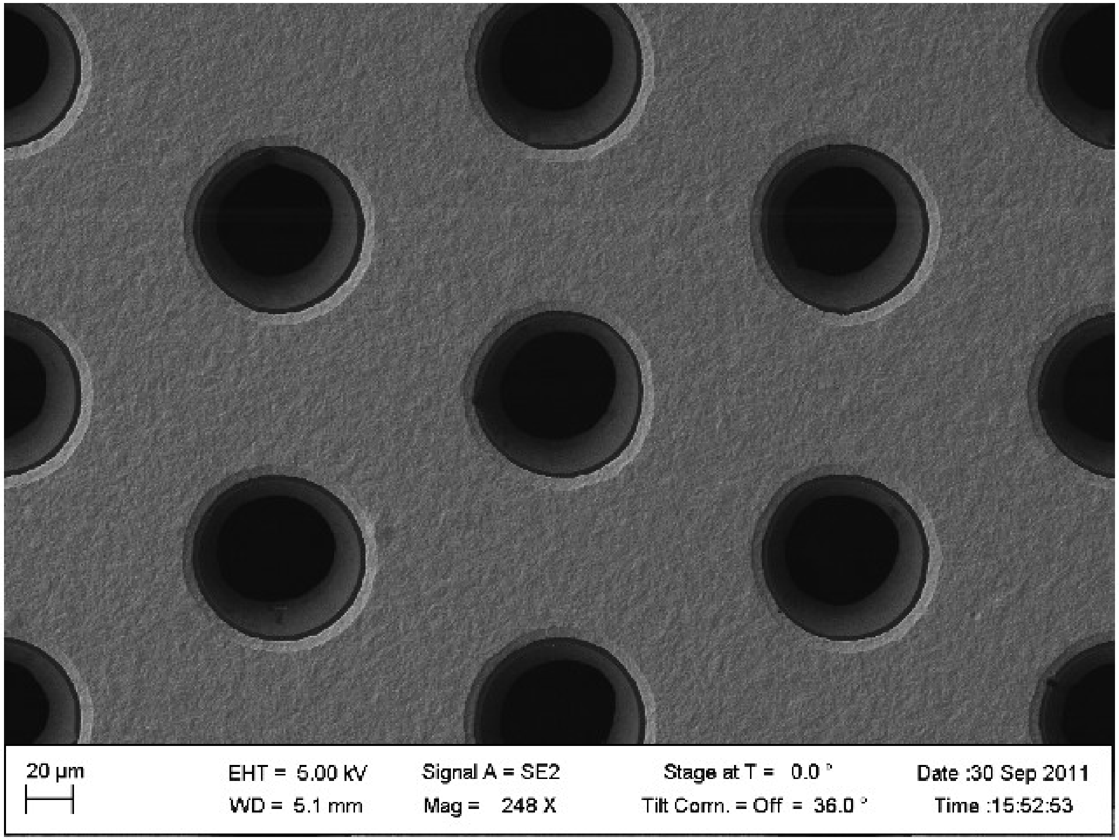


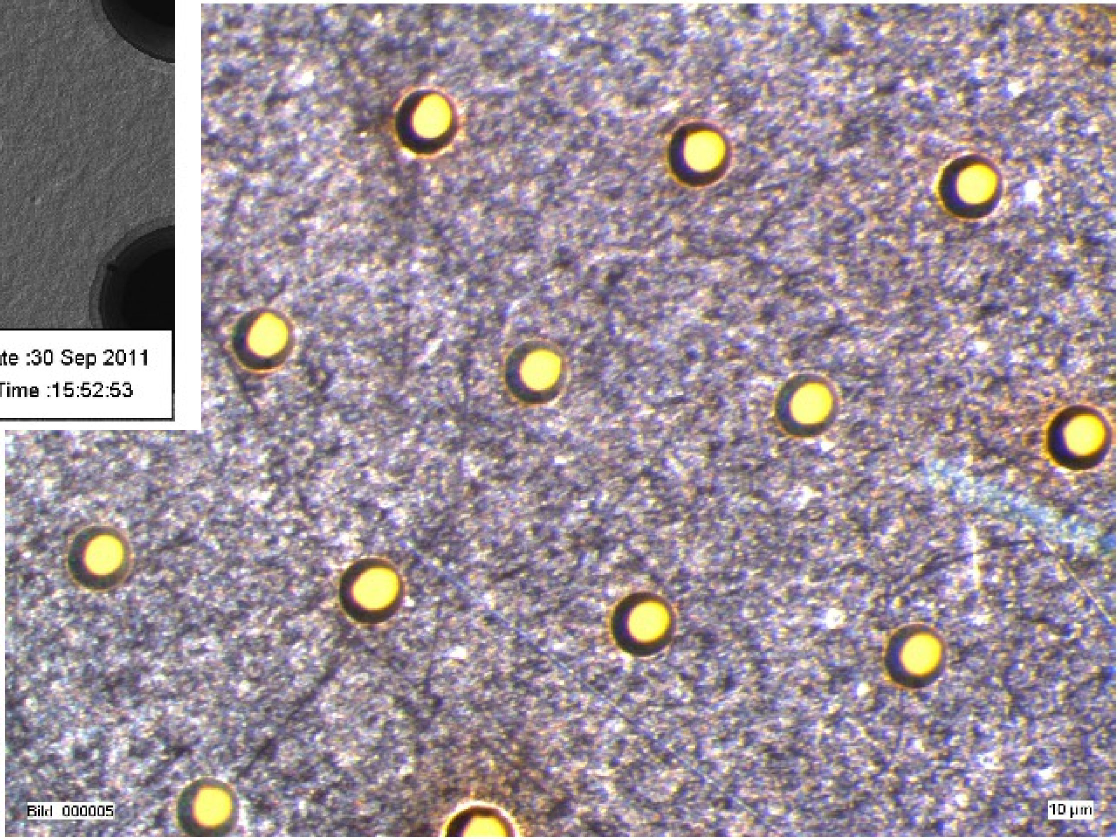
Figure 5.5: Two-dimensional scan of the Ion backflow in a quadruple stack of standard GEMs (S-S-S-S) as a function of E_{T2} and E_{T3}. E_{T1} and E_{Ind} are both 4 kV/cm, and the voltages across the GEMs are in increasing sequence to achieve an effective gain of 2000.

Picture from the TDR

Standard vs. Large Pitch GEMs

140 um vs. 280 um

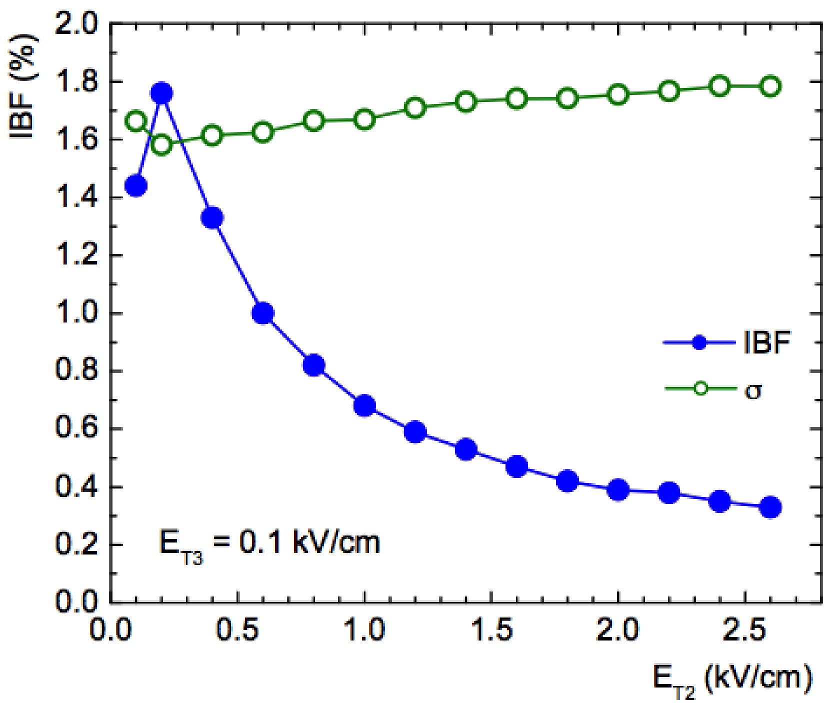


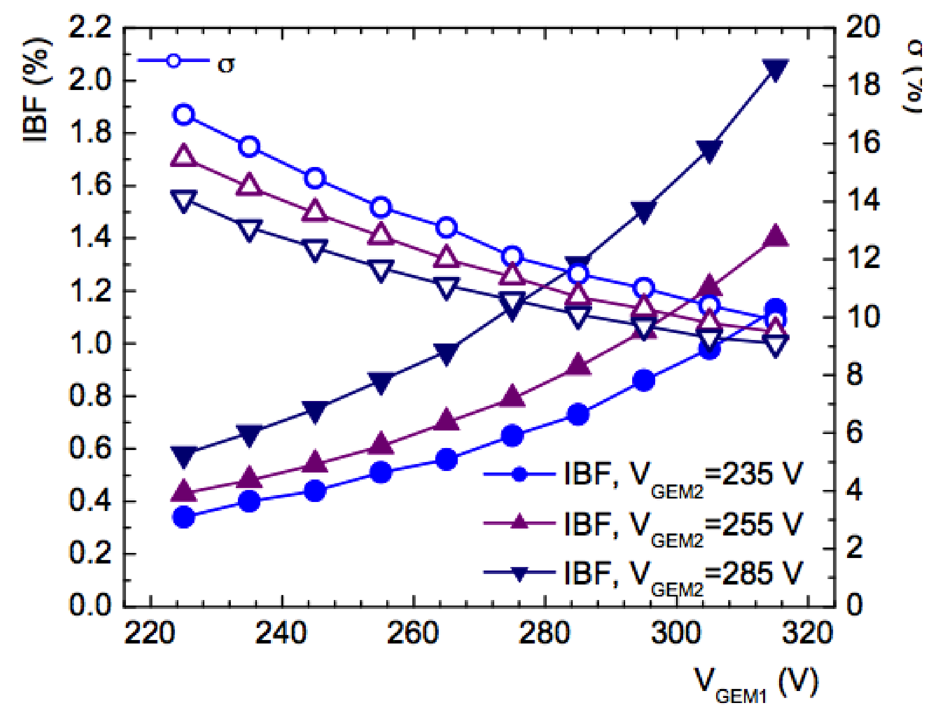


"Better" holes misalignment can be achieved in combination of standard (S) and Large Pitch (LP) GEMs

Best IB up to date
(S-LP-LP-S)

IB ~ 0.3%



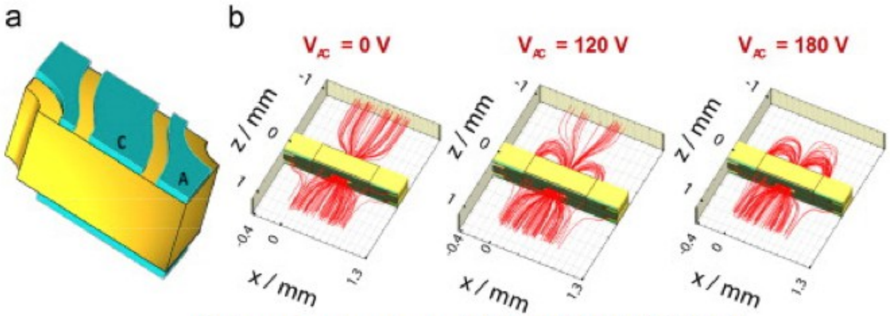


Pictures from the TDR,

Still, optimization (improvement) in energy resolution AND stability needed

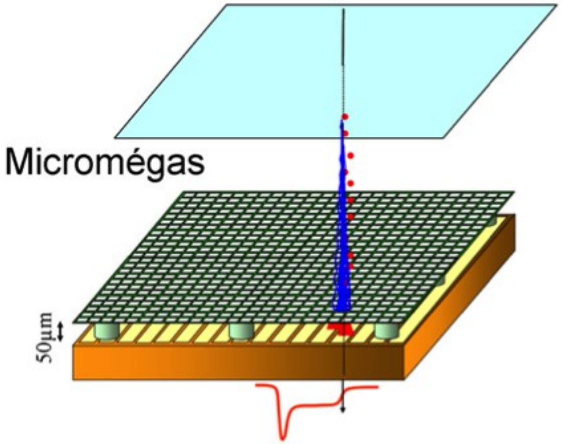
Further IB minimization?

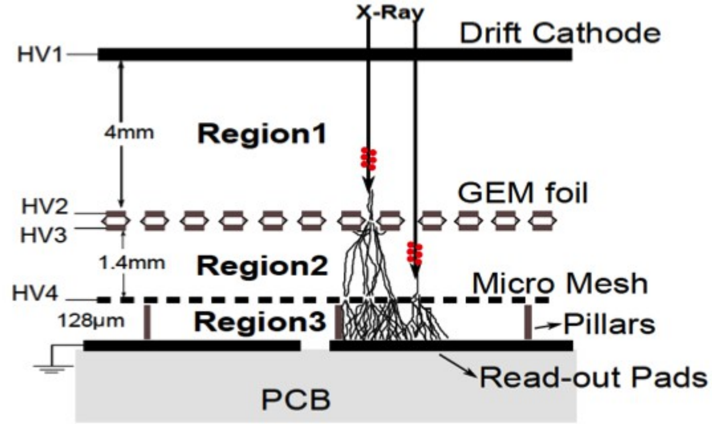
- COBRA



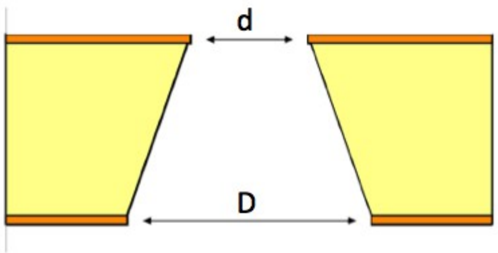
A. Lyashenko et al., NIM A 598 (2009) 116

- MICROMEGAS

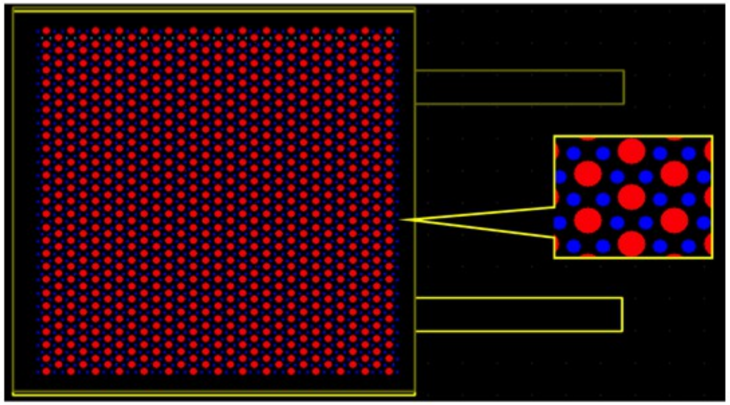




- DIFFERENT GEOMETRIES



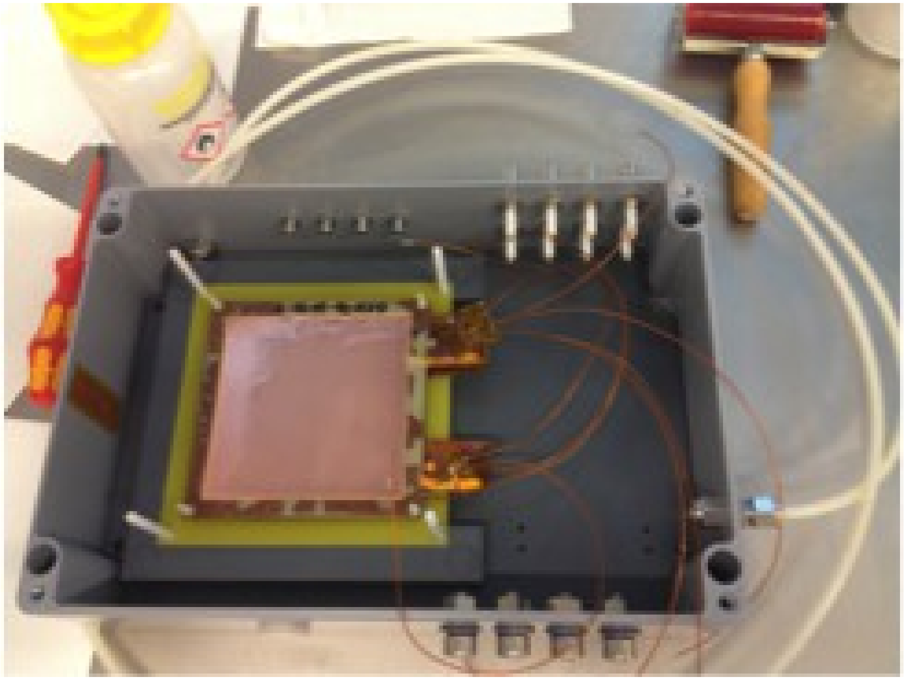
Conical GEM

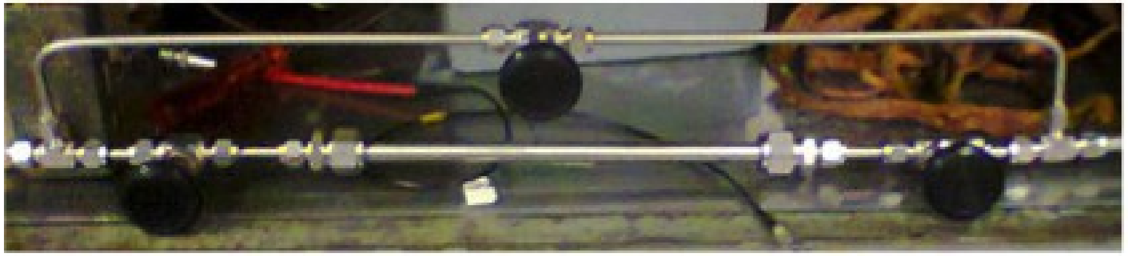


"Flower" THGEM

Discharge probability studies at TUM

10x10 cm^2
Modular detector





Alpha source – gas mantle enriched in Thorium

First results – Ar-CO_2 (70-30)

- RATE 1.8 Hz
- Measurement at G ≈ 1.2×10^5 (108%)
  - Discharge probability: $(1.0\pm0.1)\times10^{-3}$
- Measurement at G ≈ 7.5×10^4 (107%)
  - Discharge probability: $(3\pm2)\times10^{-5}$
- Measurement at G ≈ 5×10^4 (105%)
  - Discharge probability < 2.5×10^{-6}

COMPARISON TO THE PUBLISHED DATA:
S. Bachmann et al., NIM A 479 (2002) 294

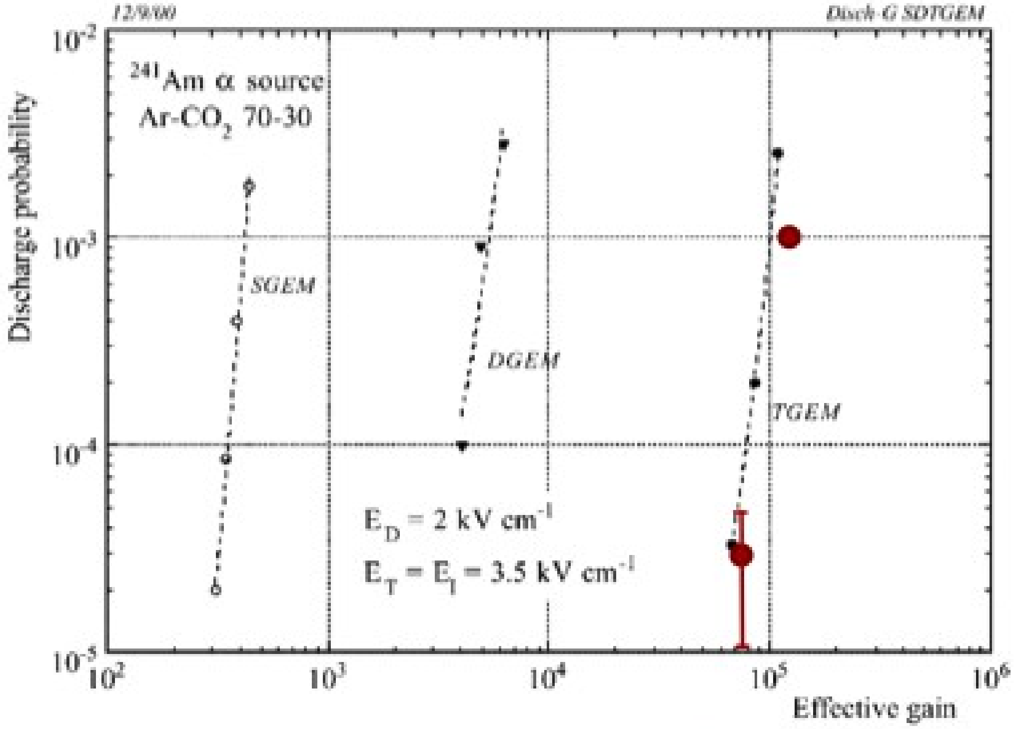
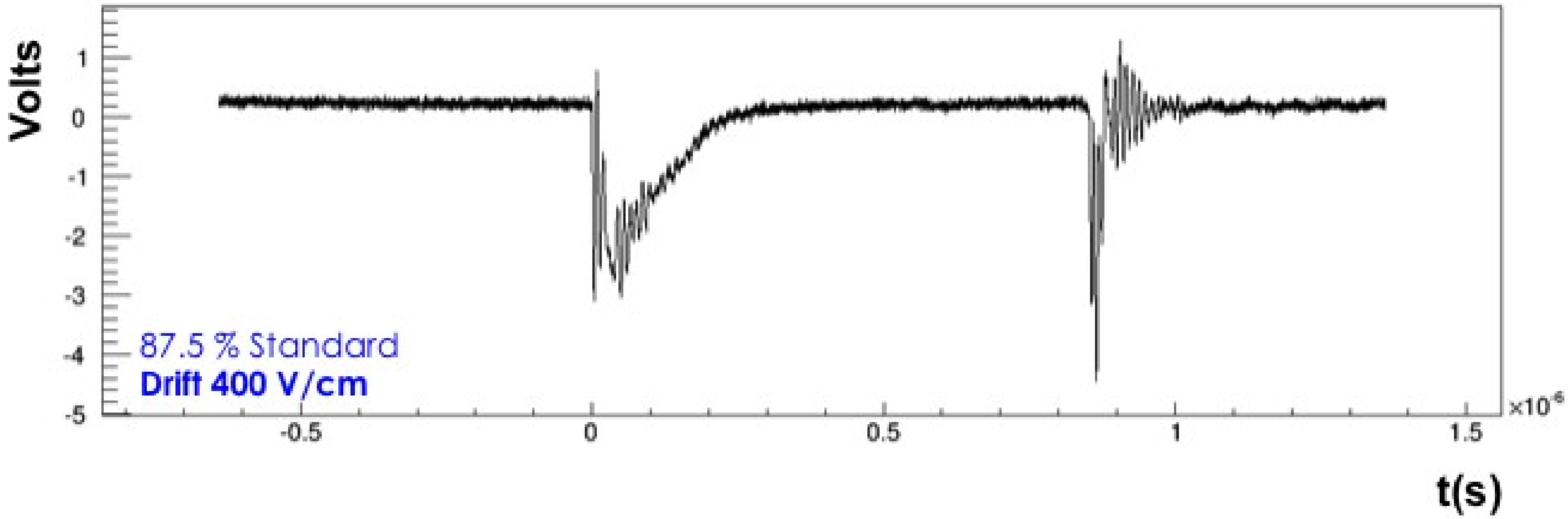


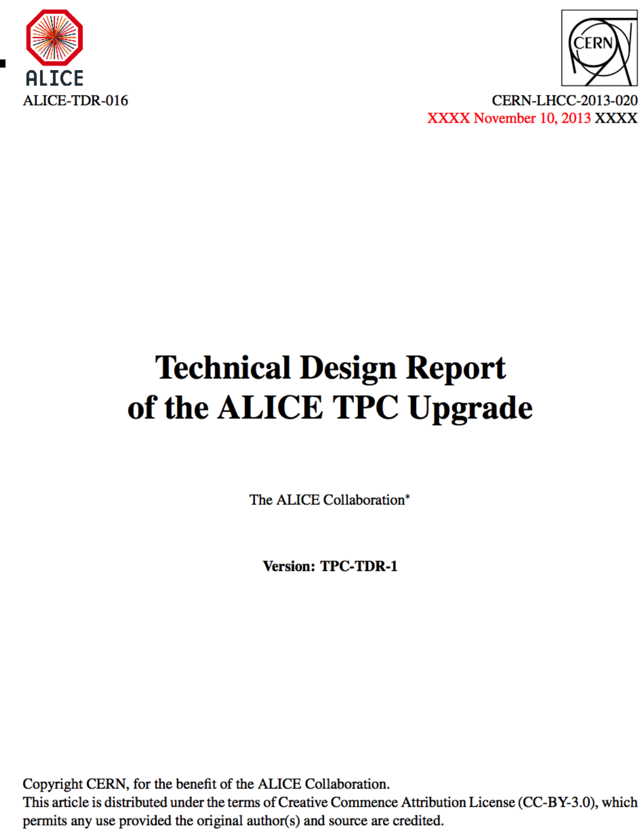
Fig. 8. Discharge probability as a function of total effective gain for single, double and triple GEM detectors.

- **In progress**
  - Ne-CO_2, Ne-CO_2-N_2
  - 3- and 4-GEM stack
  - IBF vs standard settings
  - Many other parameters



TDR – baseline solutions

- Baseline solution, presented in the T
  - 4 GEMs (stability + IB)
  - Ne-CO_2-N_2 (90-10-5) (stability + IB)



ALICE

ALICE-TDR-016

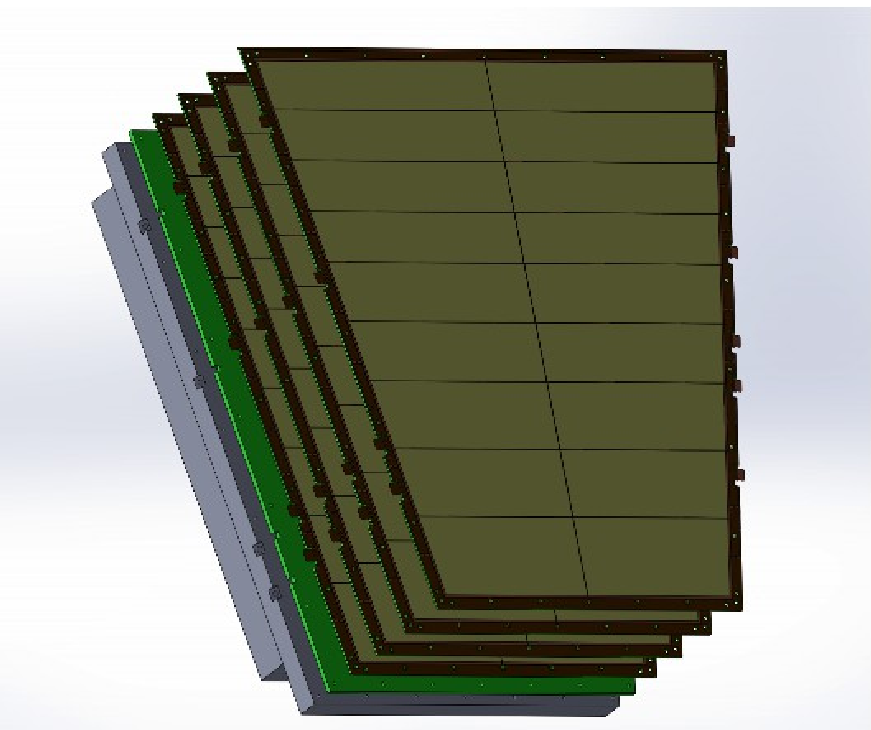
CERN-LHCC-2013-020

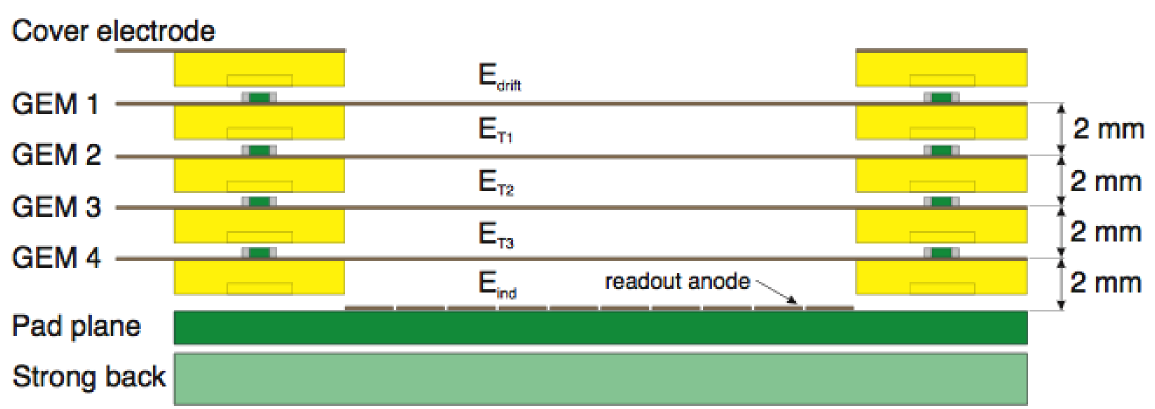
XXXX November 10, 2013 XXXX

Technical Design Report of the ALICE TPC Upgrade

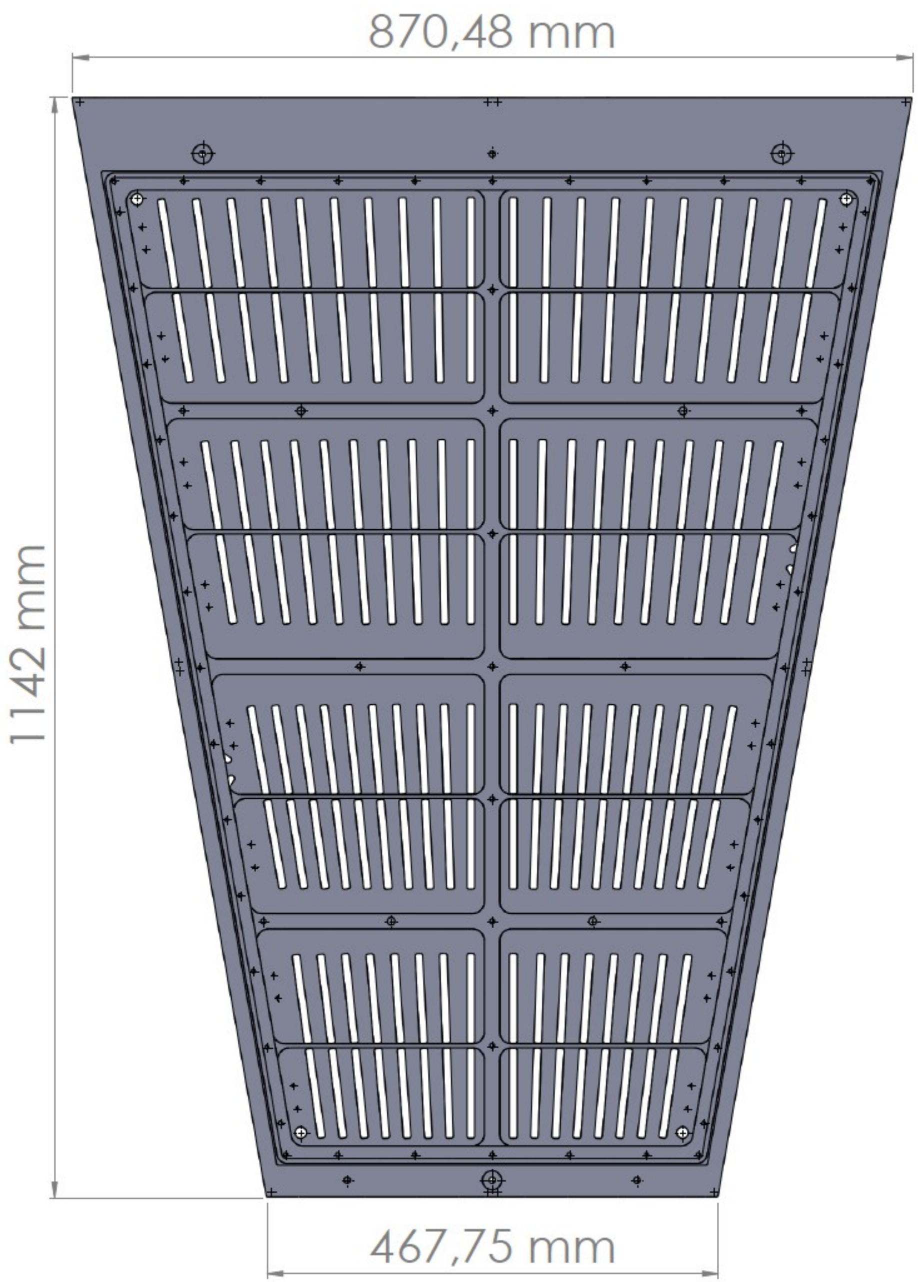
The ALICE Collaboration*

Version: TPC-TDR-1

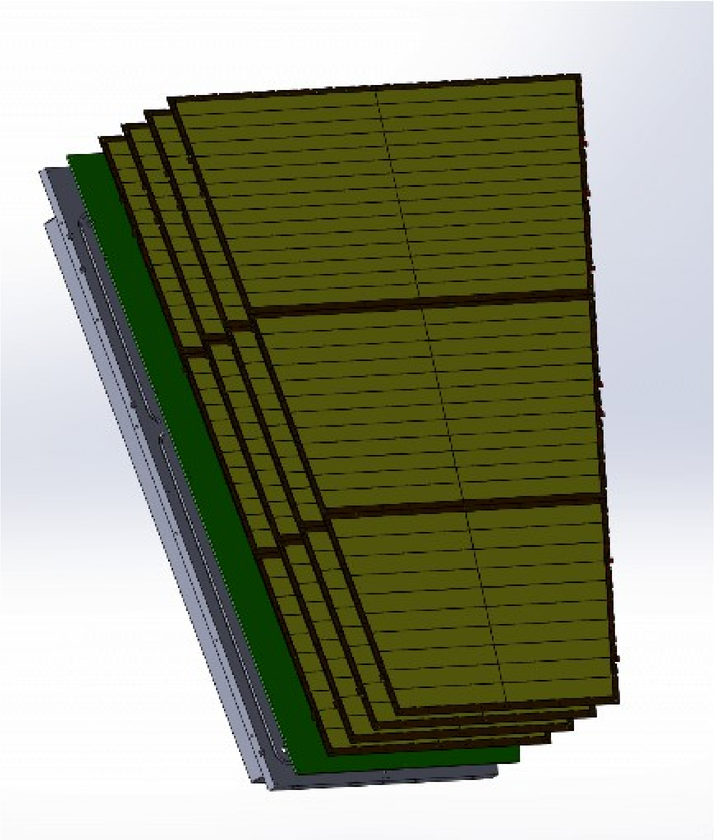




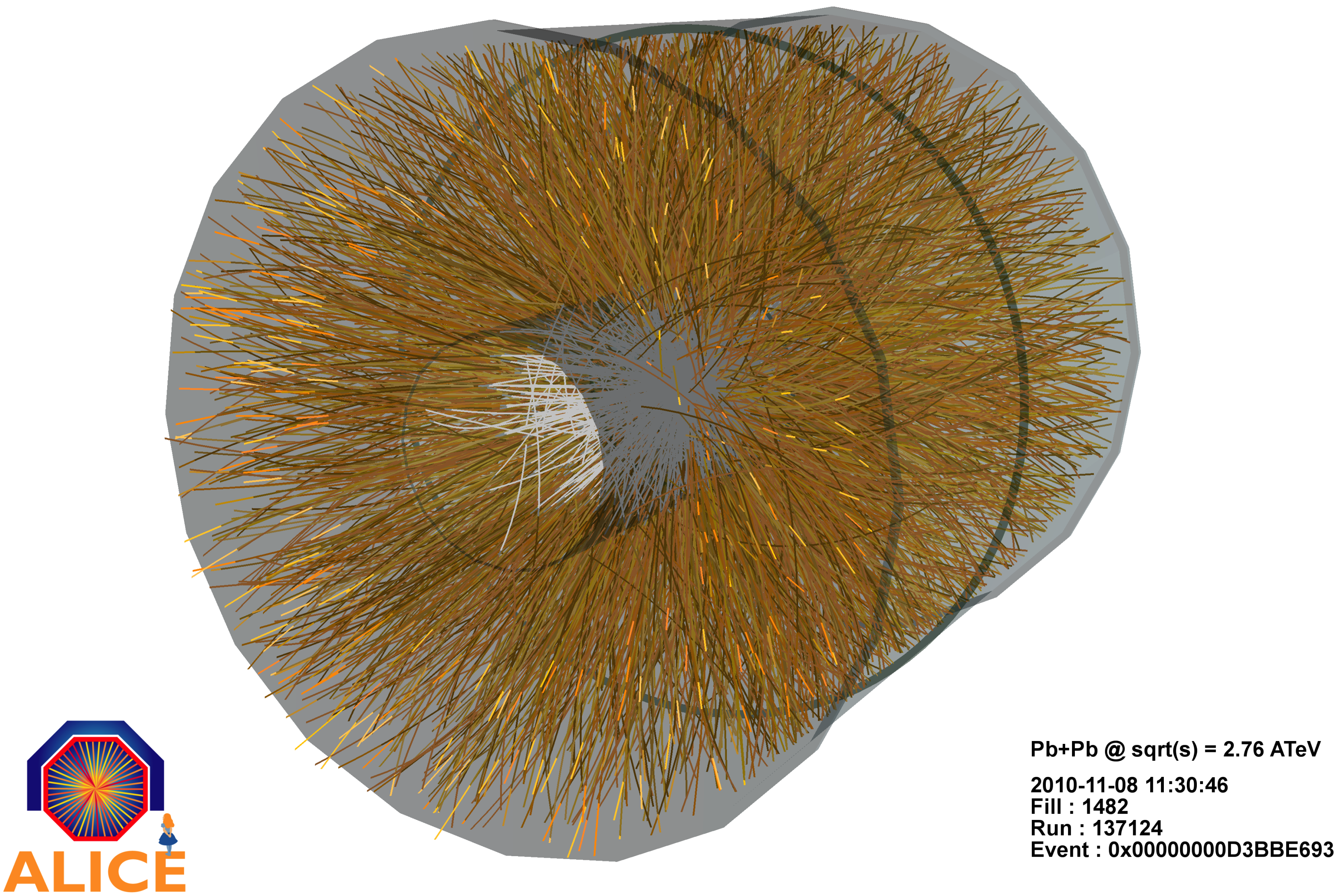
Coming soon: GEM-OROC



- 4 times larger than IROC!!!
- **3 independent foils (frames) per amplification stage**



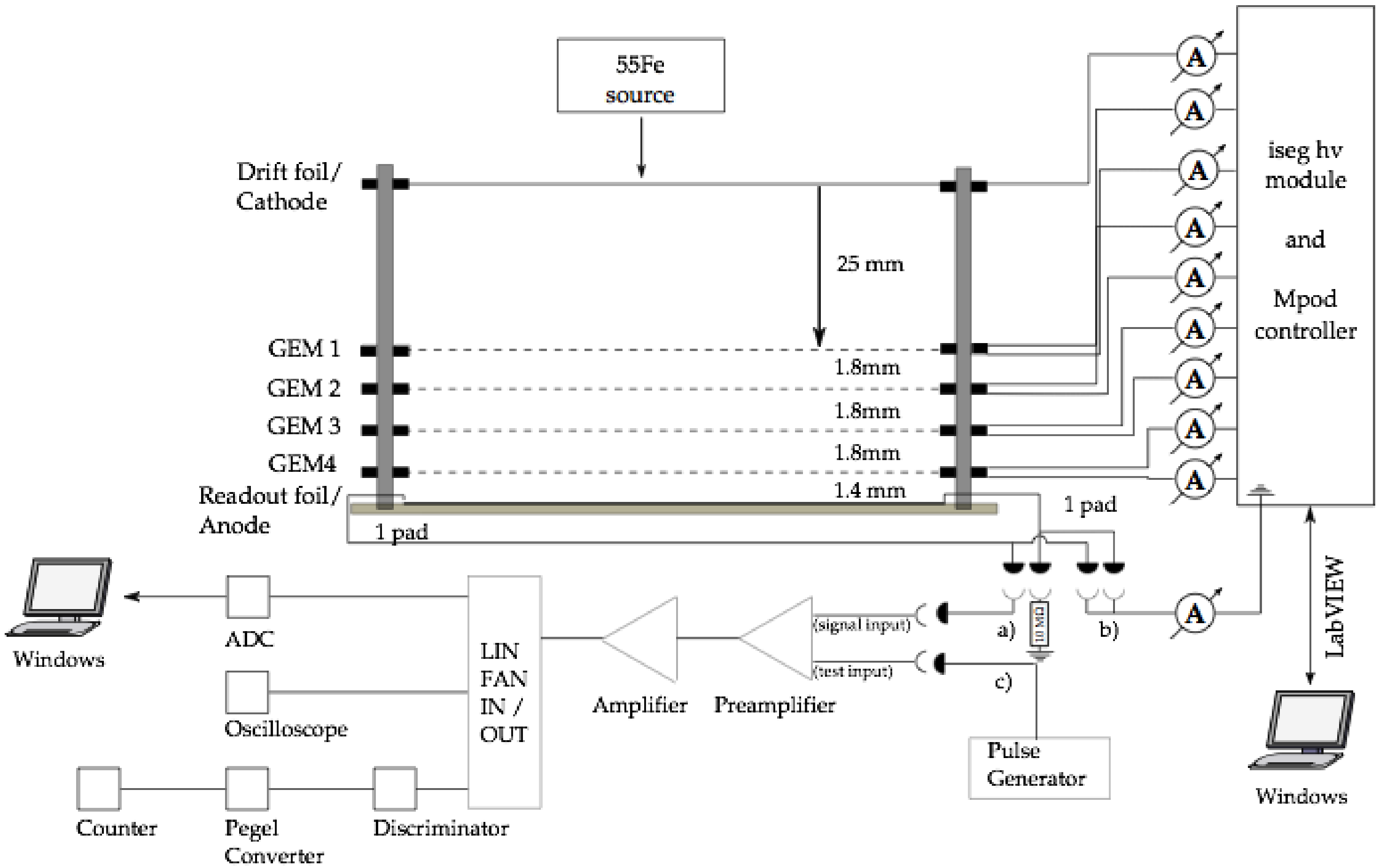
GRACIAS!



- Designed to cope with rapidity densities approaching $dN_{ch}/dy = 8000$ at $\sqrt{s} = 5.5$ TeV
- Including secondaries, this amounts to 20000 tracks in one interaction in the TPC acceptance

- **ION BACKFLOW**
- Definitions
  - Effective gain $$G_{\text{eff}} = \frac{I_{\text{anode}}}{eN_{\text{ion}}R}$$
  - Ion Backflow $$IB = \frac{I_{\text{cathode}}}{I_{\text{anode}}} = \frac{1+\varepsilon}{G_{\text{eff}}}$$
  - Epsilon – *number of ions drifting back into the drift region from the amplification stage per incoming electron*
- Expectations (LoI): 0.25% at the gain of 2000

IB measurements



Picture from the TDR

Ampere-meters

Figure 3.5: High-voltage (HV) current meter with wireless readout (open lid). (1) HV in; (2) HV out; (3) non-inverting operational amplifier (AD549L); (4) 16-bit ADC (AD7790); (5) microcontroller (MSP430); (6) XBee® wireless transceiver; (7) reed switch. [Hö12]

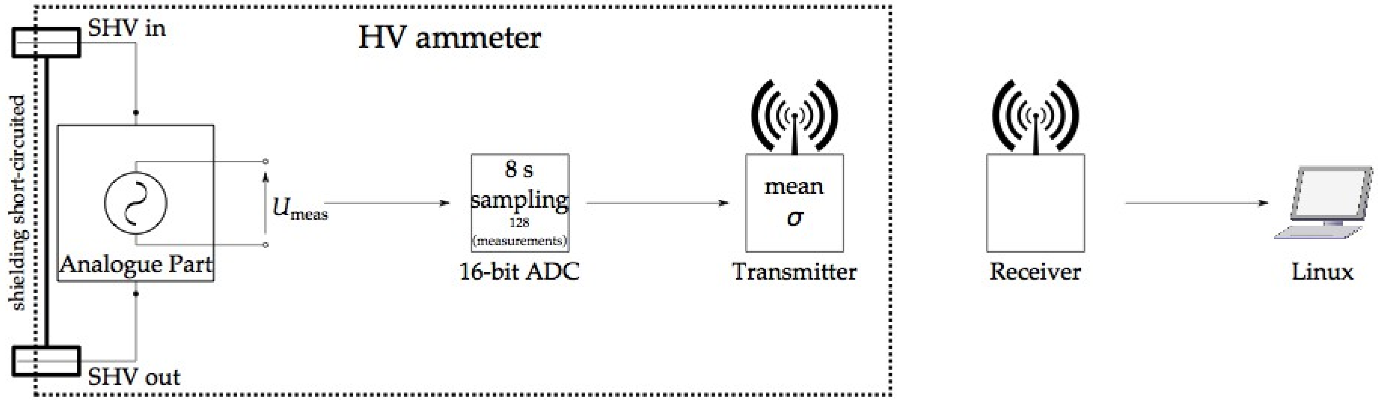
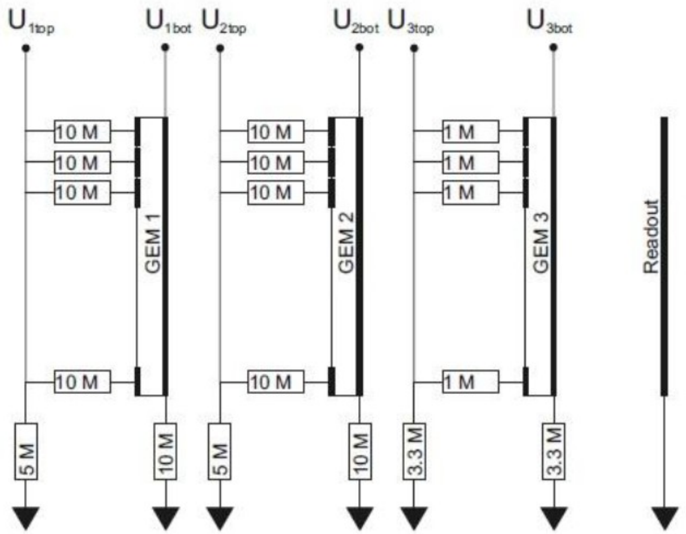


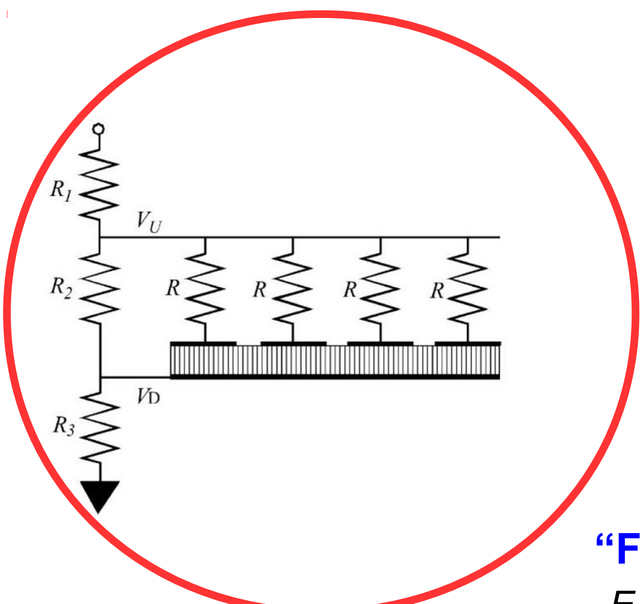
Figure 3.6: Principle of current measurement with the new ammeters.

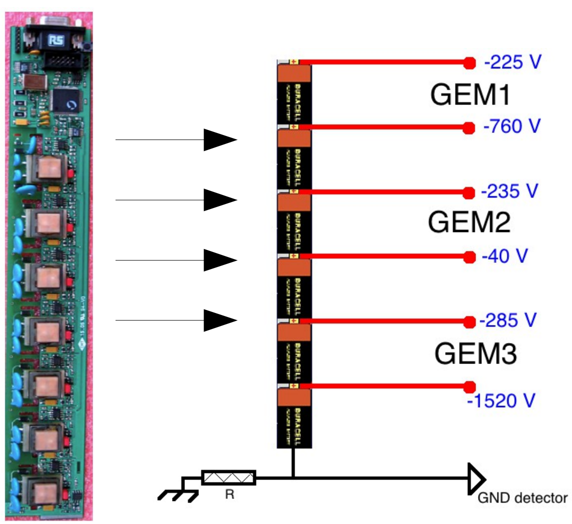
New batch (after some improvements) in preparation at TUM/E18

Stability and long-term operation

- **HV Supply**
  → safe trip after the discharge
  - Independent HV channels
  - Resistor chain
  - Active HV divider
  - **+ fast shutdown**

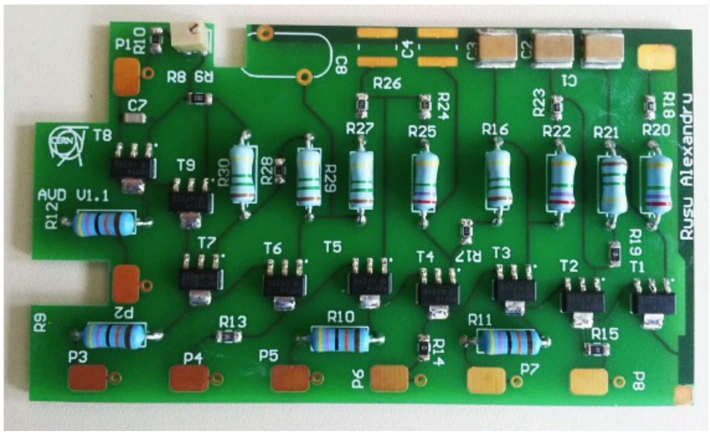






"Frascati" Active HV Divider

E. Corradi et al., NIM A 572 (2007) 96



SRS AVD

H. Muller, RD51 Miniweek, 23.04.2013