Quality control experience with foils of the ALICE TPC prototype

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ALICE

Excellence Cluster Universe

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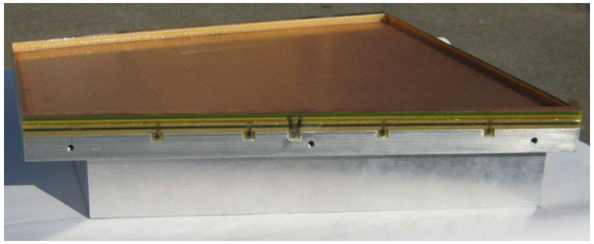
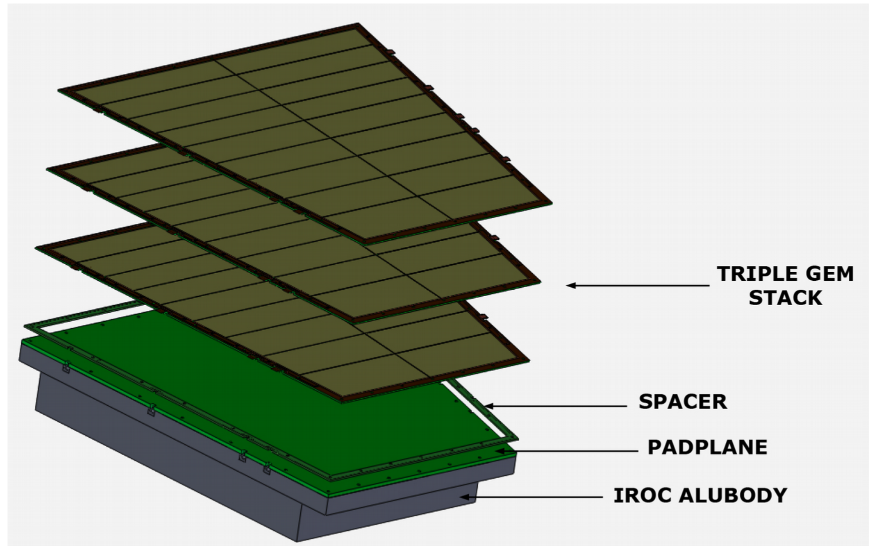
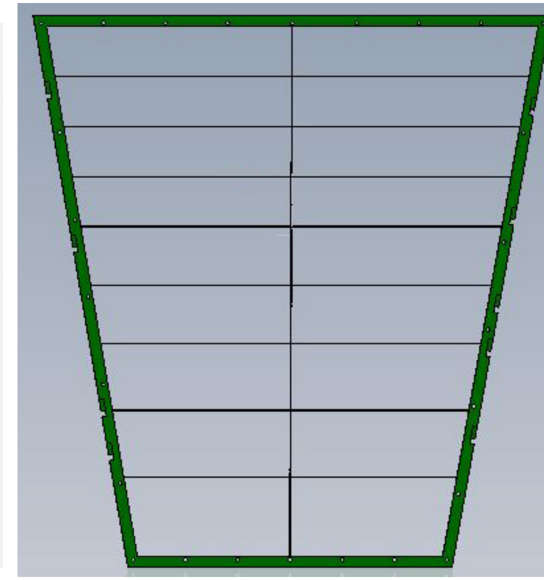
GEM Inner Read-Out Chamber prototype

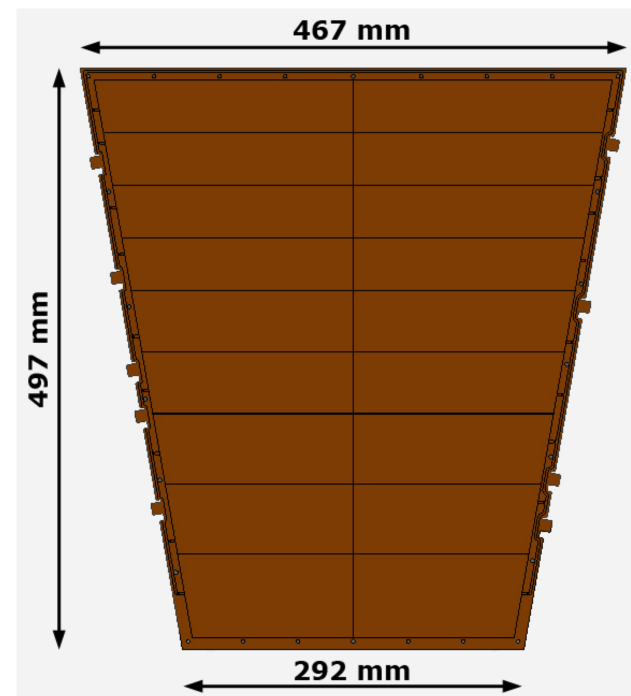




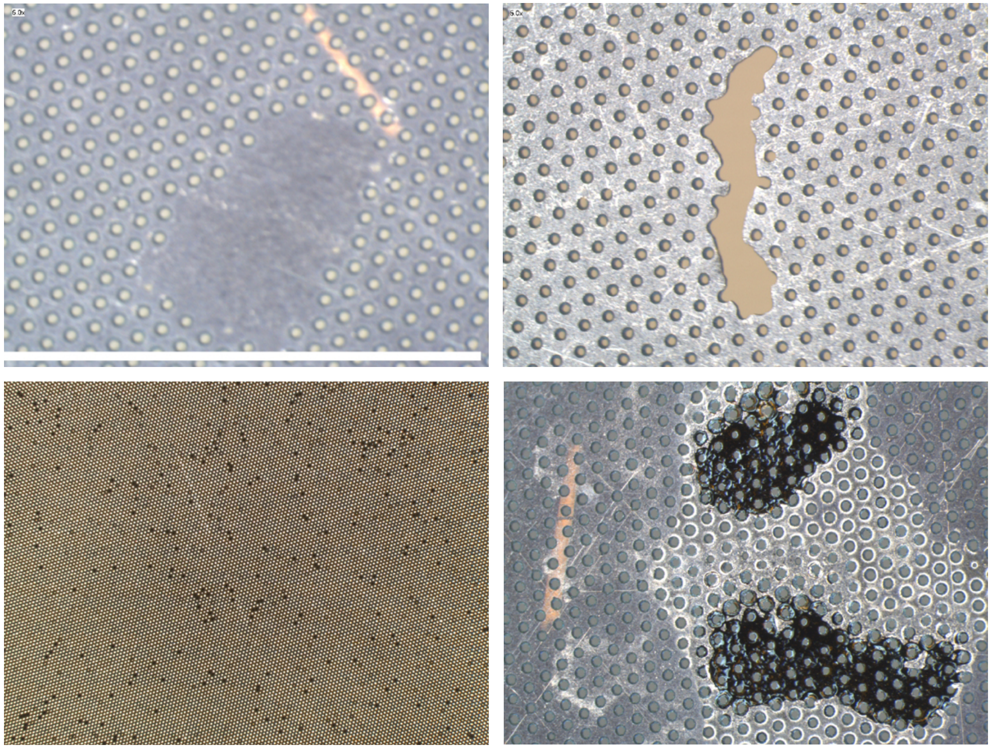


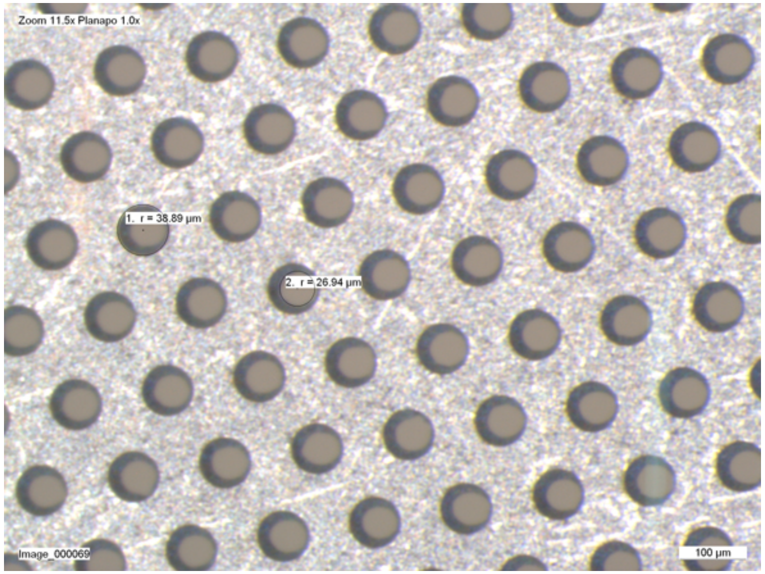
GEM foils for IROC prototype:

- 3 single-mask large-size foils
- 18 sectors (top side segmented), ~100 cm^2 each
- Inner/outer diameter: 50/70-80 µm, pitch 140 µm
- 2mm frames (G-10 fiberglass) glued on bottom sides
- Thickness of spacer grid – 400 µm
- Additional frame between padplane and bottom foil



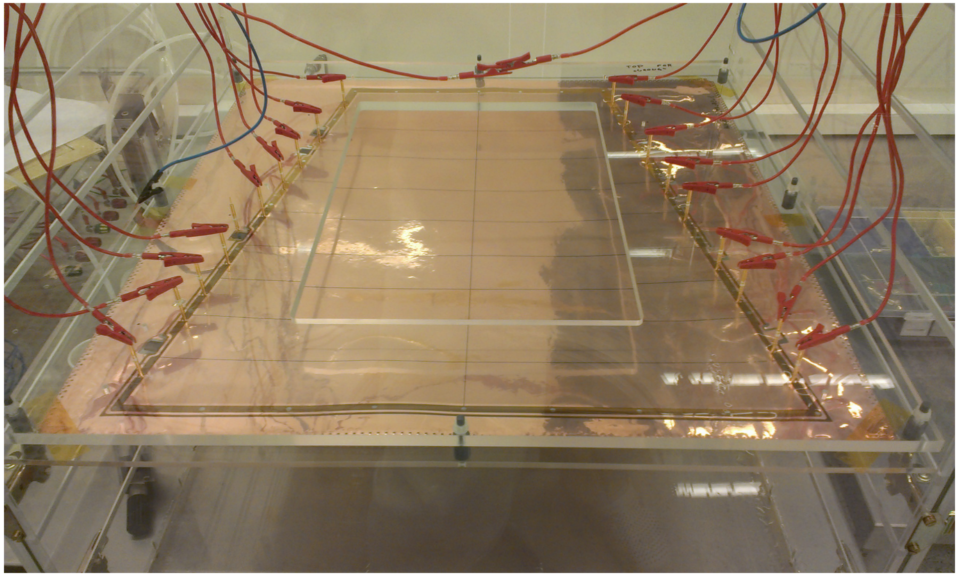
QA – Microscope Check

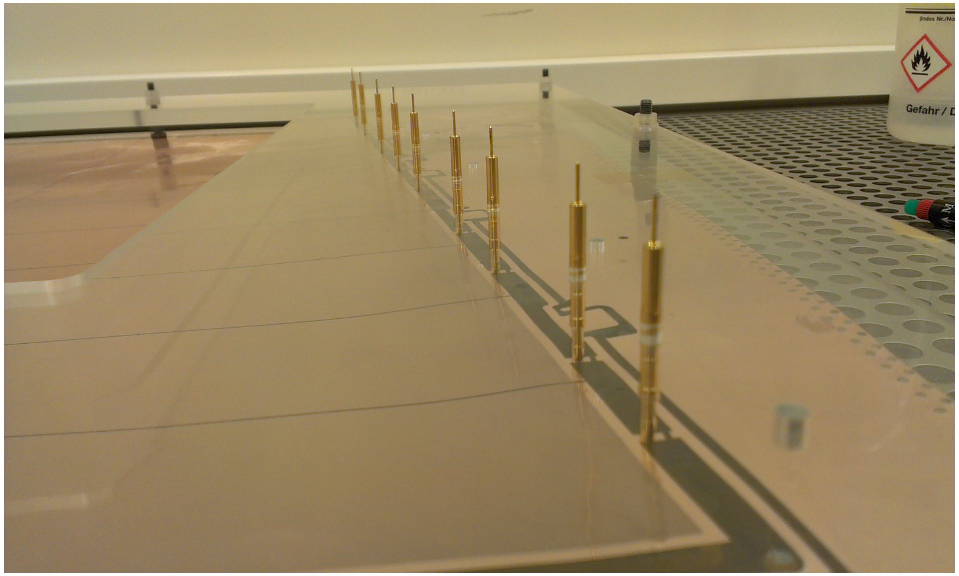




- **Each foil is checked under the microscope**
  - in search of larger defects
  - measurement of holes size/pitch

QA – HV tests

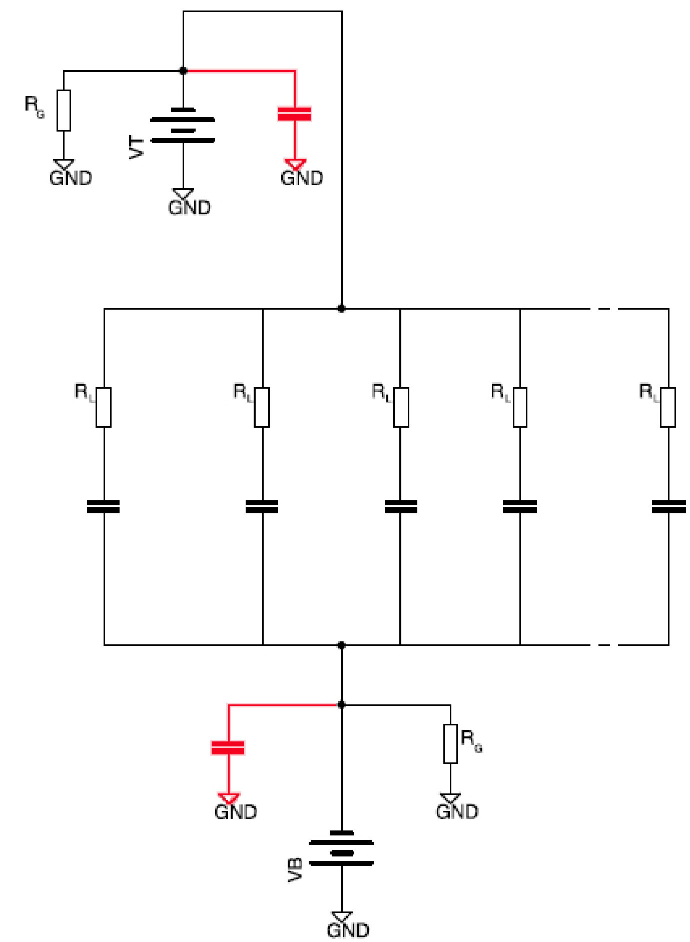


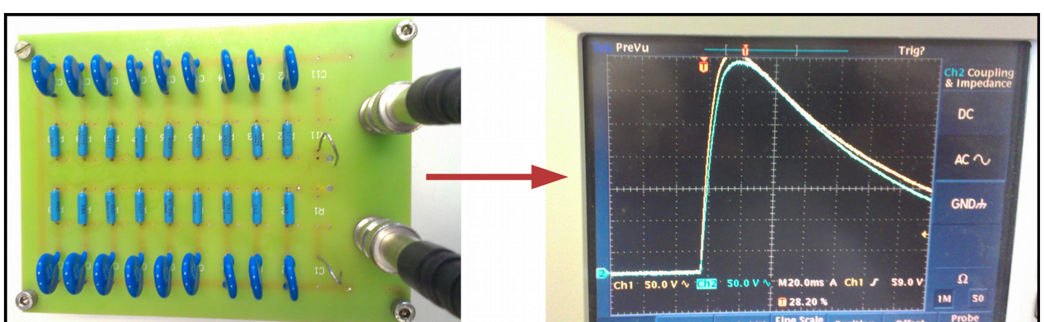


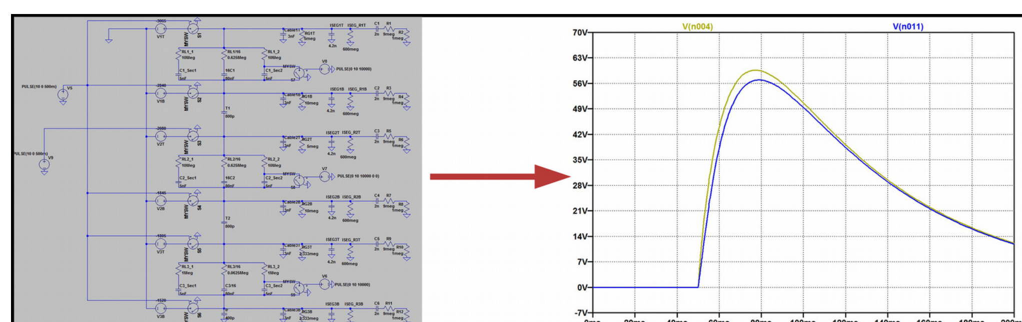
- **Foil in box flushed with N_2**
- **1st step:** **each sector is ramped up to 550 V in steps: 300, 400, 450, 500, 550 V**
  - leakage current measured at each step (max. 5 nA)
  - trips counted at each step (max. 3)
- **2nd step:** **ramping up directly to 550 V**
  - leakage current measured
  - trips counted
  - test passed if sector stable for 3 min
- **Tests performed at each step of assembly**

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

"Standard" settings (100% for Ar/CO_2 – 70/30)

Transfer Field 1 = 3730 V/cm
Transfer Field 2 = 3730 V/cm
Induction Field = 3730 V/cm

GEM1 = 400 V
GEM2 = 365 V
GEM3 = 320 V

- Scaling factors: 69%, 70%, 71%, 72%, 73% (scaling both GEMs and Fields)
- Resulting gains: ~ 1500 – 6000

"IBF" settings – 4x4 matrix

Transfer Field 1 = 3800 V/cm
Transfer Field 2 = 200 V/cm
Induction Field = 3800 V/cm

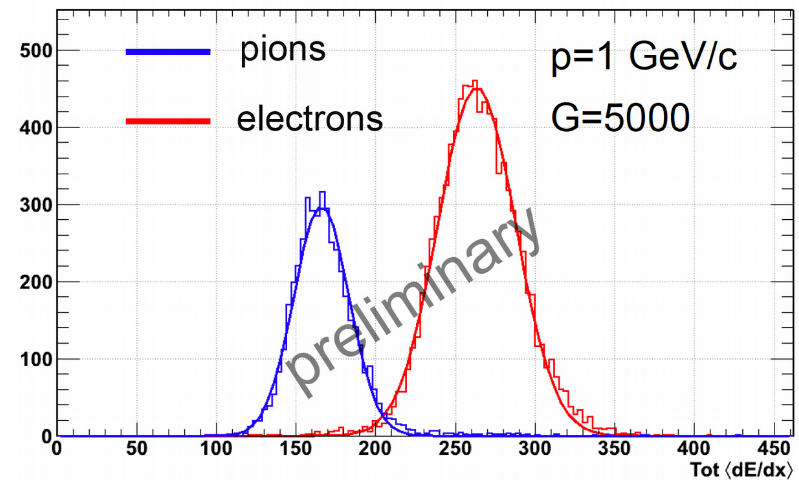
GEM1 = 225 V
GEM2 = 235 V
GEM3 = 285 V

- Scaling factors: 100%, 103%, 105%, 107% (scaling only GEMs)
- Transfer Field 2: 200, 400, 600, 800 V/cm
- Resulting gains: ~ 900 – 6600

PS beamtime (Nov./Dec. 2012)

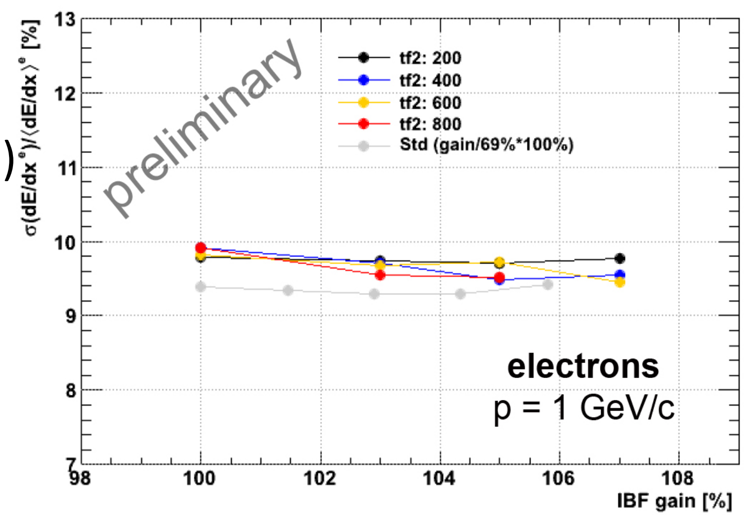
PS East Areas – T10 beamline

- Average beam rate: 4 kHz
- Beam: 1 - 6 GeV/*c* $e^{\pm}$, $\pi^{\pm}$, p
- GEM settings: "standard" and "IBF"
- Gas mixture: Ne/CO_2 (90/10)
- Additional detectors for PID: Cherenkov and Pb-glass



***dE/dx* measurements**

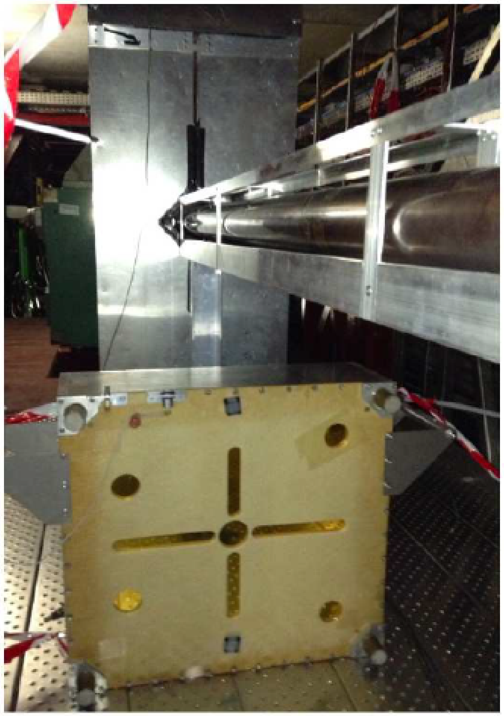
- Gain equalization using tracks
- No T/P correction
- Truncated mean of cluster charge (5 – 70 %)
- For comparison: IROC only in ALICE TPC $\sigma_E/E \approx 9.5$ % (for high η)

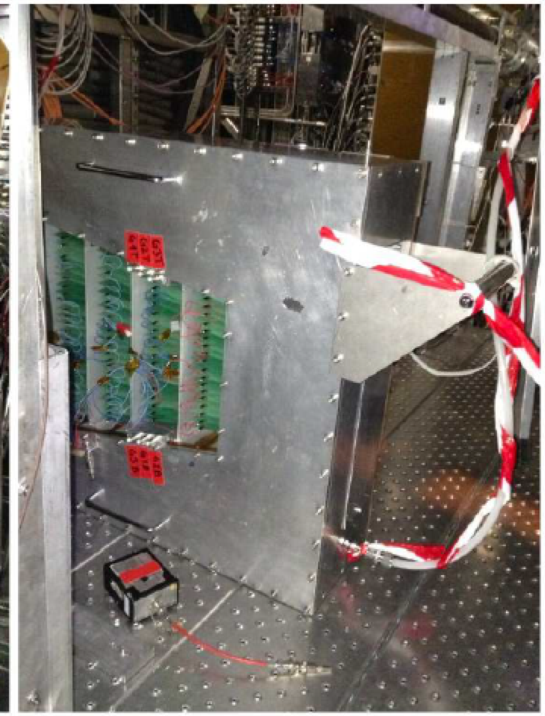


TRIPS:

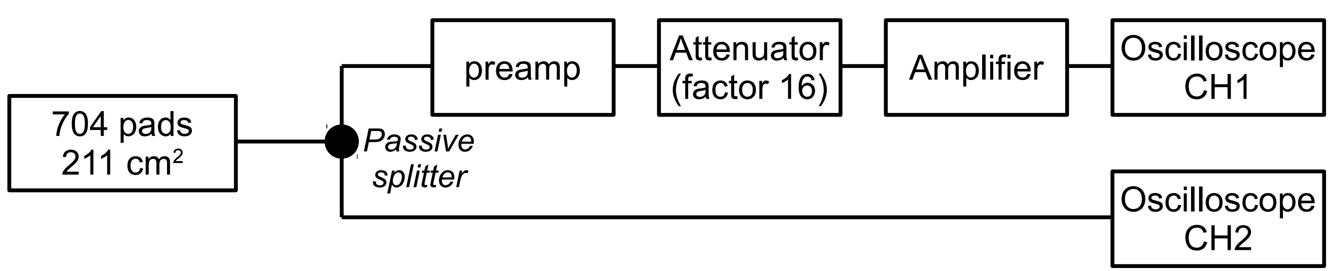
- **8 trips during PS beamtime**
- **No harm to the foils**
- Always included GEM1
- Trips occurred at the highest absolute potentials (3.2 kV at GEM1) – "IBF" settings
- Didn't occur at similar gains with "standard" configuration (lower absolute potentials)
- All trips during the beam
- **7 electronic channels damaged (in 3 trips) – no signature on padplane!**

LHC test: ALICE p-Pb beamtime



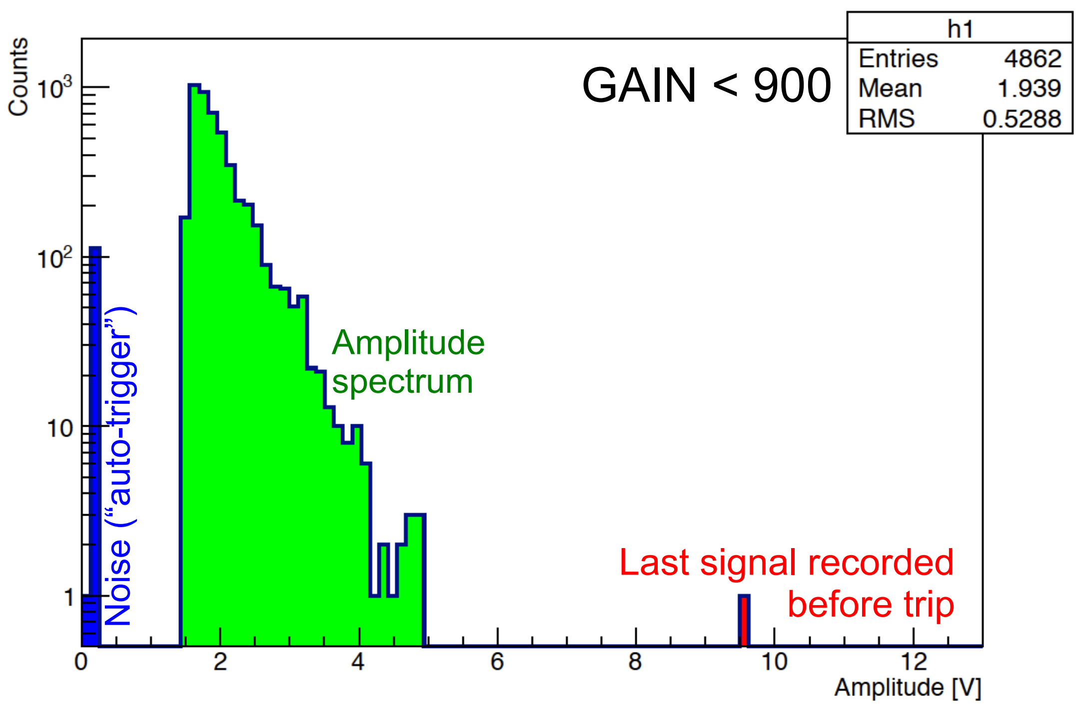


- Chamber installed on A-side underneath LHC beampipe ($\eta \approx 2.6$)
- > 3 weeks under LHC conditions
  - 200 kHz interaction rate (10 kHz during first couple of days)
  - Particle rate ~ 5000 kHz per unit
- Standalone readout: waveforms, discharges, trips
  - Trig. Rate < 10 Hz (recording highest signals)

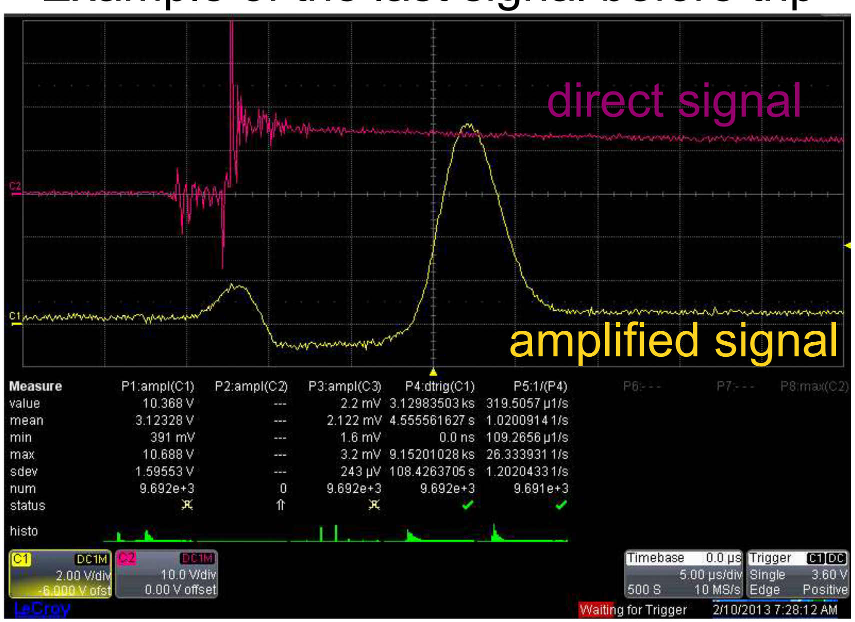


Trips @ LHC

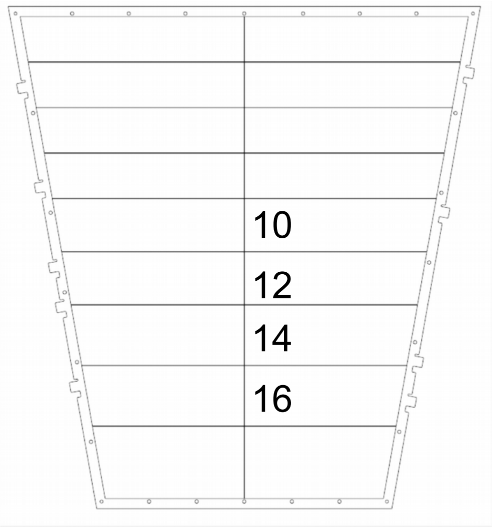
- **23 trips occurred**
  - 20 at lowest "IBF" settings, 2 at "standard", 1 while ramping up
  - 21 with beam, 2 without
  - No correlation found with beam conditions
  - All included G1
  - 1st trip already while running with 10 kHz coll. rate
- 7 shorts developed!
  - 1 x GEM1; 3 x GEM2; 3 x GEM3;



Example of the last signal before trip



Shortened sectors vs. QA HV tests

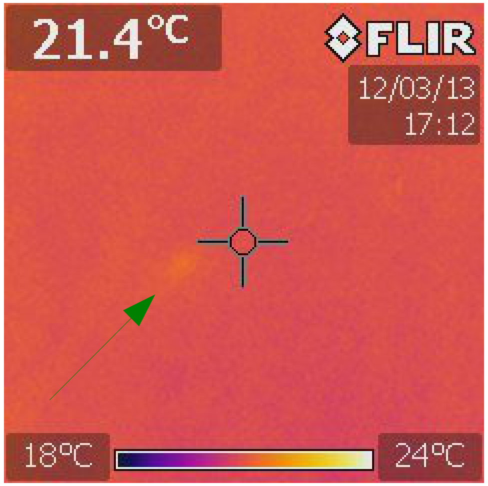


- **TOP GEM – 1 short**
  - Sec. 10 → 50.3 kΩ;
    - Sector OK before/after framing the foil
    - Peaks of high leakage current before mounting → OK after some time
    - In this foil 3 other sectors were problematic (high I_{LEAK}, trips) before framing
- **MIDDLE GEM – 3 shorts**
  - Sec. 12 → 6.6 MΩ; Sec. 14 → 2.5 MΩ; Sec. 16 → 0.5 MΩ
    - Sectors 14 and 16 were tripping (3x each) at "3min@550V" test before framing
    - Sectors OK after framing
    - Problems before mounting → high leakage current (from U=400V) and trips < 500 V
    - Problem solved by applying the HV with opposite polarity – foil OK
    - In this foil only 1 more sector was problematic before framing (trips)
- **BOTTOM GEM – 3 shorts**
  - Sec. 12 → 75 kΩ; Sec. 14 → 265 kΩ; Sec. 16 → 600 kΩ
    - Sectors were tripping at 550V before framing (no "3min" test)
    - Sec. 12 and 14. OK after framing
    - Sec. 16 – high leakage current – gone after several trips
    - Foil OK before mounting
    - In this foil only 1 more sector was problematic before framing (trips)

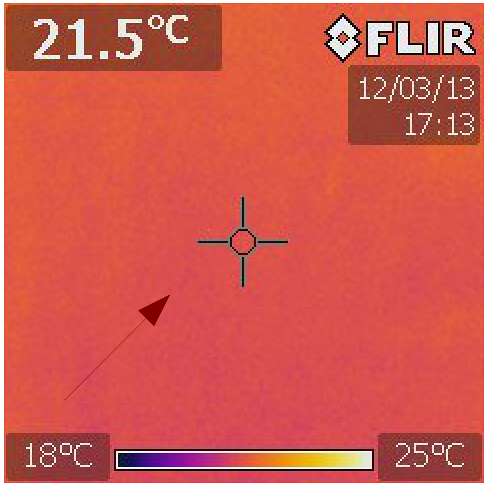
- ***Significant correlation between shortened sectors and problems from QA***

Short identification

- **Search for suspicious places (discharge spot)**
- **Identification:**
  - Thermographic camera



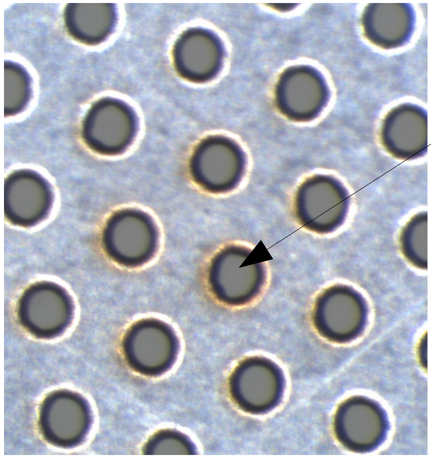
Voltage ON

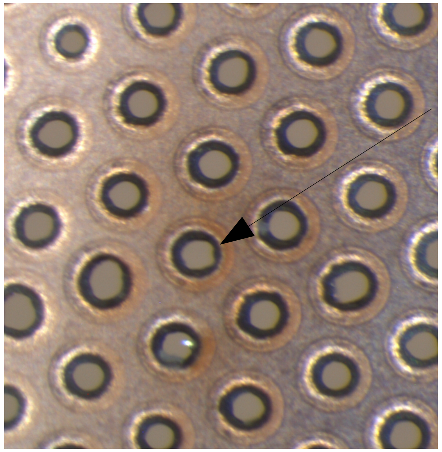


Voltage OFF

R = 0.5 MΩ
V = 20 - 40 V
I = 40 - 80 μA

  - Irregular shape of inner hole → black pieces (carbon?) sticking out





Here, in addition, light color pieces found nearby (photoresistive?)

- **Final identification:** discharge/explosion while burning with high current (see next slides)

Position of shorts

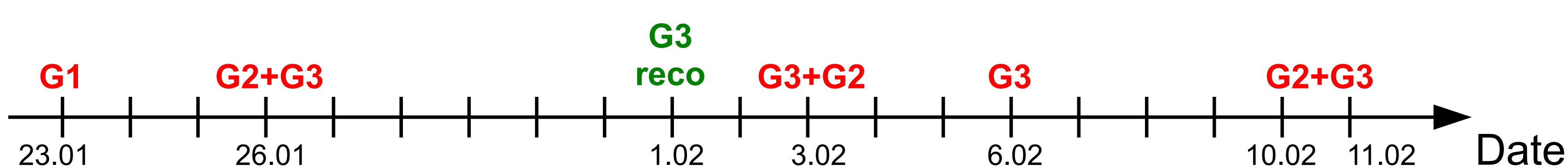
Shorts in MIDDLE and BOTTOM foils are in the same positions (± 0.5mm).

SECTOR 12:
- 1st coordinate differs by 0.07 mm (measured with microscope+PC)
- 2nd coordinate: same ±0.5 mm (measured with microscope+ruler)

SECTOR 14:
- 1st coordinate: same hole-row
- 2nd coordinate: same ±0.5 mm

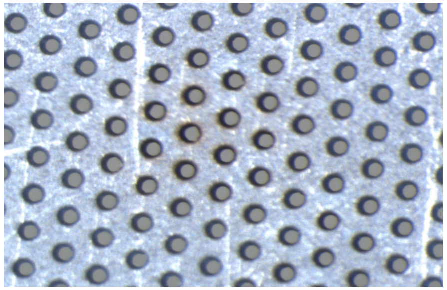
SECTOR 16:
- 1st coordinate: short in the next next hole-row (< 300 μm difference)
- 2nd coordinate: same ±0.5 mm

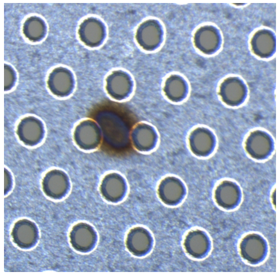
- **Alignment of shorts in both foils:** discharge propagation?
  - In "IBF" settings TRANSFER2 field **increases** after the trip of PS (R_{LOAD} configuration)
    - 200 V/cm → 1500 V/cm (not an amplification region (~ 4 kV/cm for Ne/CO_2)
    - May be enhanced if the tripping times (for different PS channels) differ
    - Depends also on the position of first discharge (middle or bottom foil)
  - **BUT**, first short in MIDDLE foil developed after the trip at "standard" settings
  - No signs on pads
- **Shorts in G2 and G3 were noticed one by one (not at the same time after one discharge) but close together**
  - propagated discharges started damaging (burning Kapton?) the hole which later transformed into the short (?)
  - produced together but one with high resistance, therefore skipped (resistance changed later on) (?)



Schorts/Discharges vs. foil quality

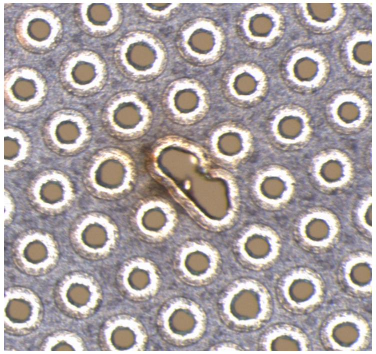
- Places, where discharge occured, were search all over the foils (**TOP side only**)
- Identification by brown spots around or nearby the holes



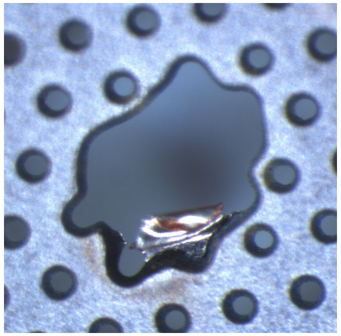


- Discharges from HV tests, LAB tests, 2 Beamtimes (PS+LHC)

- **TOP GEM**: 73 places (N_{min}= 0, N_{max}= 10; <N/sector> = 4; 40 trips at QA)
- **MID GEM**: 70 places (N_{min}= 1, N_{max}= 8; <N/sector> = 4; 62 trips at QA)
- **BOT GEM**: 124 places (N_{min}= 3, N_{max}= 20; <N/sector> = 7; 60 trips at QA)



ONE discharge found at the hole with a defect



- Another discharge nearby the defect was found in one of the new foils (not yet used)
- Reason is rather clear (Copper sticking out at one side of the foil)

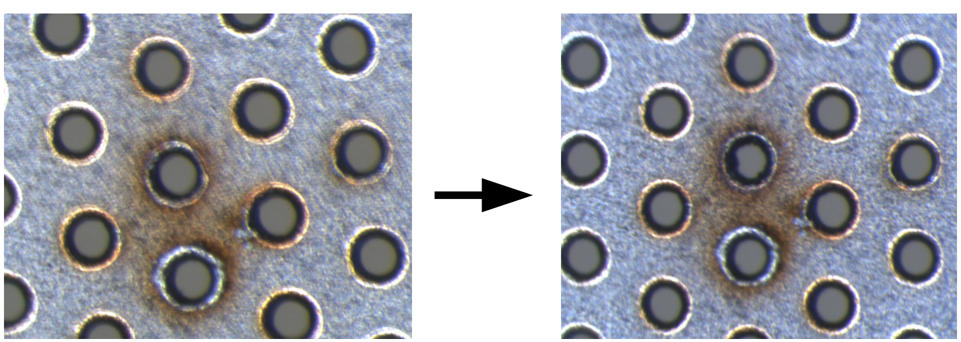
Fighting with shorts

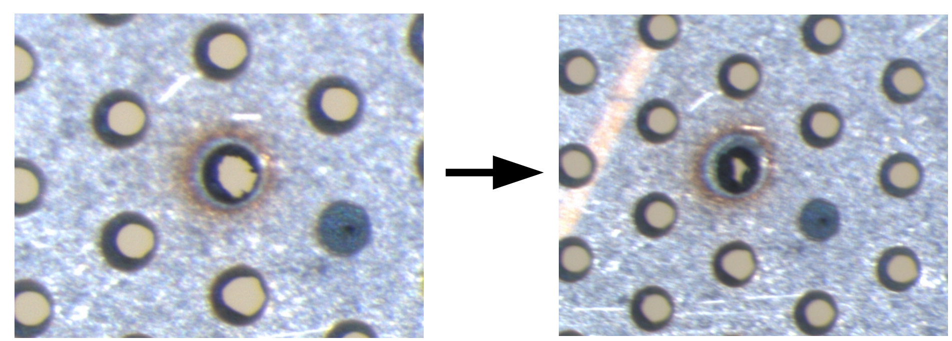
Burning with high current

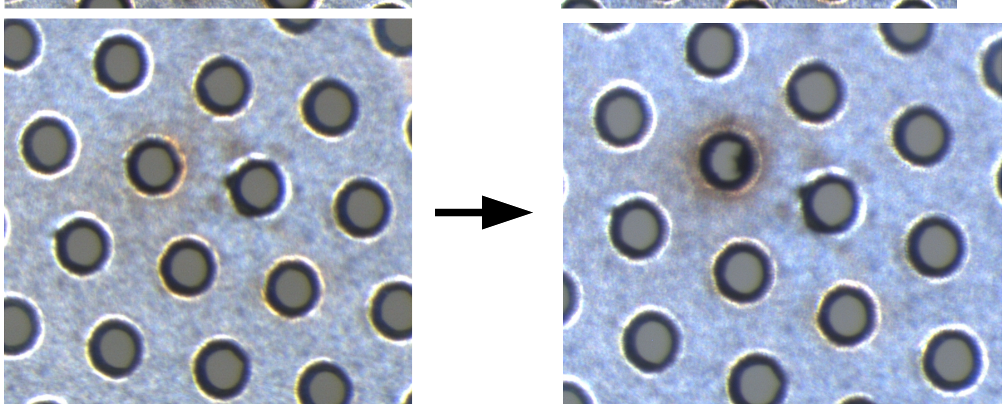
- Resistance change (>30 MΩ) after applying 20 – 30 V (I_{LIMIT} = 1 – 2 A)
  - usually „explosion” of short seen
  - more carbon in hole after burning procedure

- Leakage current „re-appear” with higher voltages,
  - usually trip around 50V (R_{LOAD} = 0)
  - „re-produce” a short with R_{SHORT} ~ 1kΩ

- **Procedure repeated several times per short → result always the same**







Fighting with shorts

Cleaning with CO_2 particles

- While fast decompression of CO_2 solid micro-particles are created

- Cleaning procedure → several "shots", from close distance
- High pressure (high flux) leaves an imprint on the foil
- Hole seems to be cleaner, carbon is not visible

- Starting point: R_S = 9.3 kΩ
- Resistance of the short **increases** after each cleaning: 3.5…10…18…>30MΩ
- Ramping up → leakage current **decreases** after each cleaning
    - **after 9 „shots"**, I_{leak} = 0.7 nA at 100 V (with R_{LOAD}=100 MΩ)
    - usually $I_{LEAKAGE}$ < 0.5 nA at 550 V

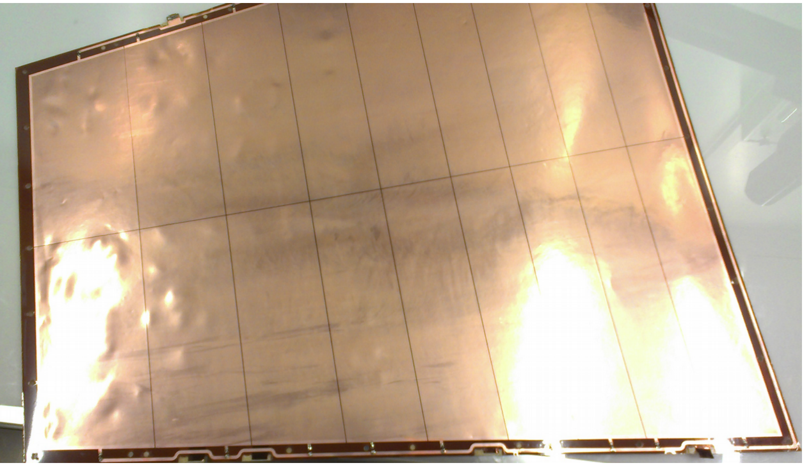
Removing carbon with 30µm bonding wire

- Possible to remove only "big" pieces of carbon
  - Short not removed completely (although resistance may increase)
  - Low resistance re-appear after applying HV
- The hole may be destroyed

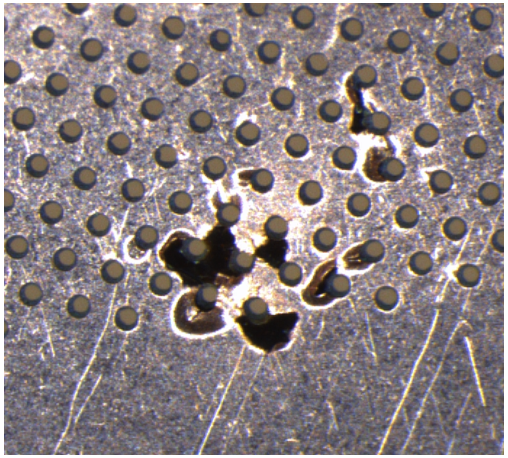
Fighting with shorts

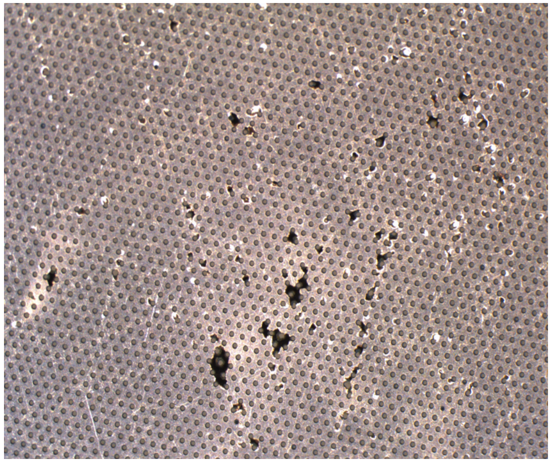
Ultrasonic bath

- 2 foils (2 x 3 shorts) were treated this way
- Holes visibly cleaner
- 3 out of 6 sectors were cured
  - Leakage currents I_{LEAK} < 1 nA at 550 V (R_{LOAD} = 100 MΩ)



- After bathing and drying parts of the foils, which were dipped in liquid, are wrinkled
- Drying (24h in 60 ^{o}C) didn't help
- Effect enhanced by stretching?





- TOP Copper layer was destroyed in many places
- In most of those places one can observe that copper was „different” there: scratches, light reflected differently
- Micro defects in raw material?
- Effect of stretched and framed foil?

Summary

- **First GEM-IROC prototype has been successfully built and commissioned**
- Stability issues occurred during the test at LHC: **23 trips and 7 shorts developed**
- **5 shorts in sectors with problems at QA - HV tests**
- Most of the problems from the first QA check were gone after stretching/gluing/**curing** procedure (curing the glue in 70°C for 24h) **but probably came back later on, causing the problems**
  - One sector had a short which could be burned with several μA current
- Defects in foils seem to be less important for their stability
  - Shorts and discharges found at/near the "proper" holes
  - One discharge found nearby the defect
  - **New foils experience** → discharge by piece of copper sticking out from the foil
- Burning the shorts was not successful: **shorts must be avoided!**
- **Additional cleaning of the foils**
  - Cleaning methods, like ultrasonic bath or CO_2 particles may be effective but dangerous
  - Pieces of light dirt found nearby two shortened holes (pollutant, chemicals?)
  - **New foils**: 7 sectors with HV problems (high I_{LEAK} or tripping) → **send back to CERN for cleaning**
- **HV tests of the foil seem to be crucial**

Outlook

- **QA – HV tests**
  - Precise I_{LEAK} measurements (pA precision, instead of >0.1 nA)
  - Foil training? (leave the foils tripping for 24h) – uncontrolled procedure
- **Discharge propagation:**
  - 6 independent HV channels may not trip simultaneously
  - In present configuration, TRANSFER2 increases after the trip
  - Passive Voltage Divider (resistor chain) → fixed values of fields
  - Active HV Divider is now taken into account
- **New step of QA: tests with highly ionizing particles**

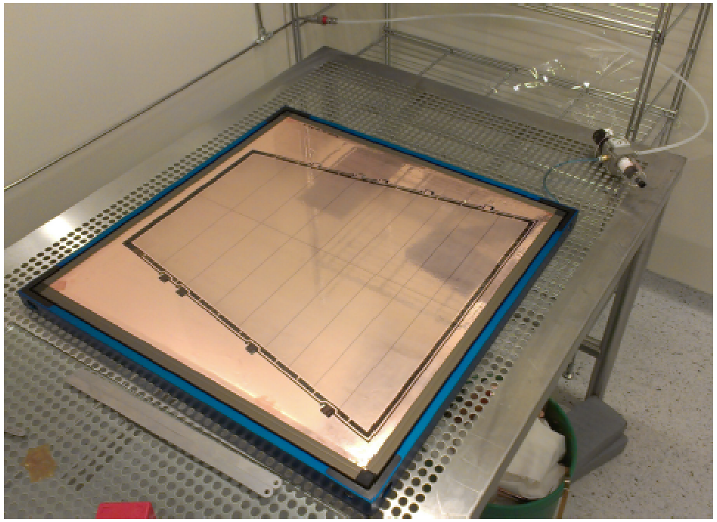
THANK YOU

ALICE TPC Upgrade

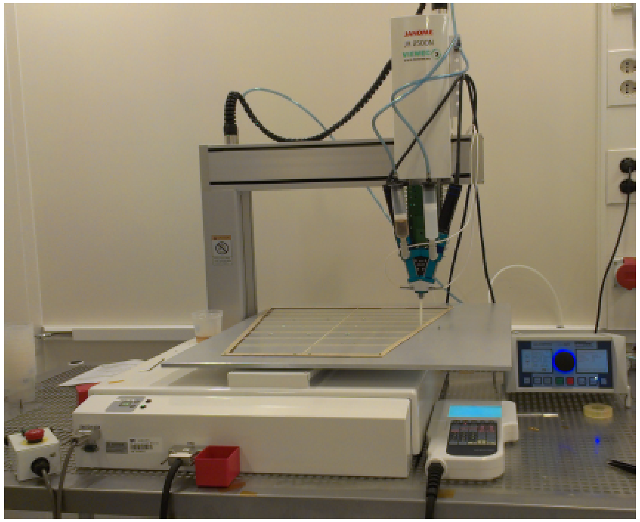
- **ALICE TPC will operate at a factor 100 higher readout rate after LS2**
  - 2 MHz in p-p and 50 – 100 kHz in Pb-Pb collisions
  - No gating and continuous readout
- **GEMs as an alternative for MWPC readout**
  - No issue with rate capability
  - Possibility to efficiently block ions
  - Lower (effective) gain 1k – 2k, 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 and simulations)
  - New electronics (polarity, continuous readout)

Gluing procedure

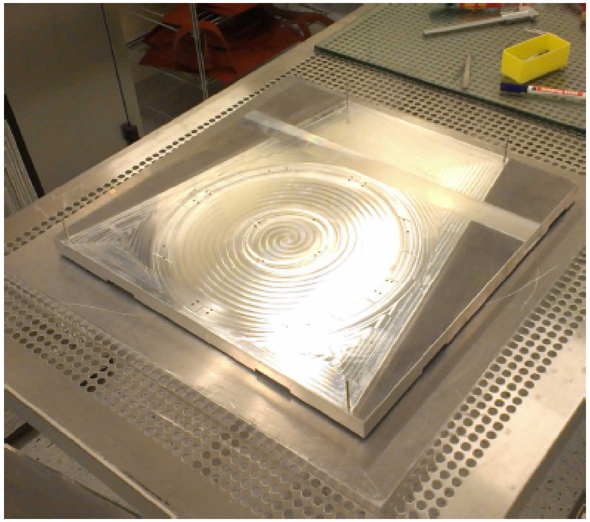
1. Stretching (DEK frame, 10 N/cm)



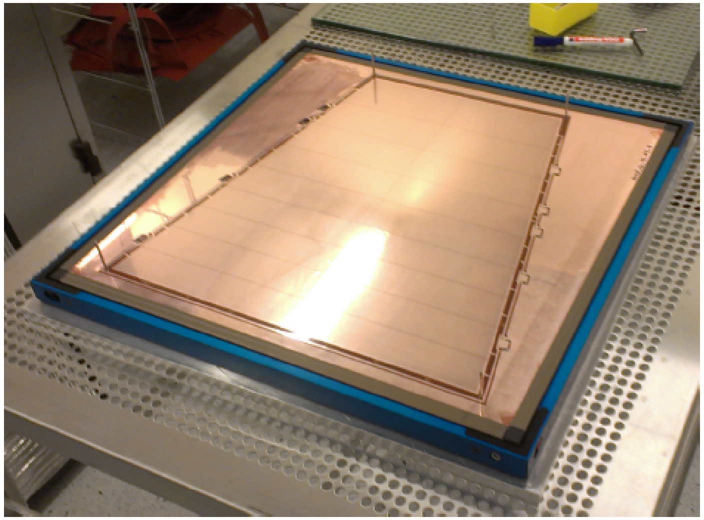
2. Glue dispensing (ARALDIT 2011)



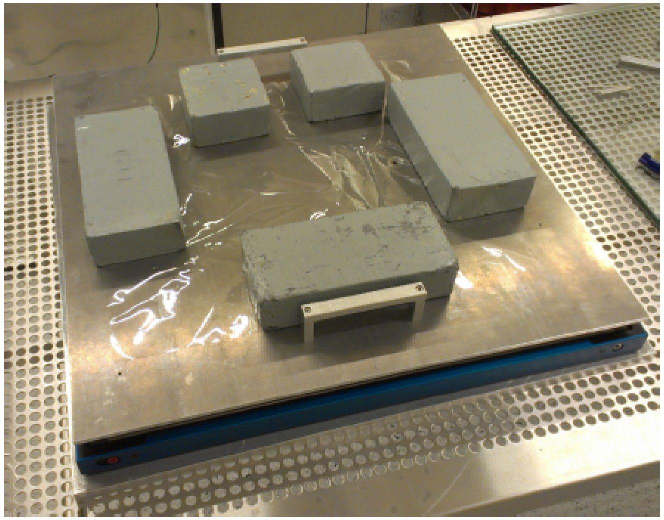
3. Alignment tool



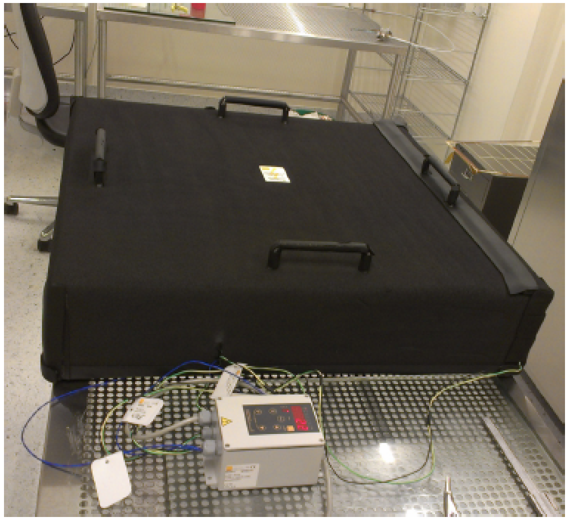
4. Foil glued onto the frame



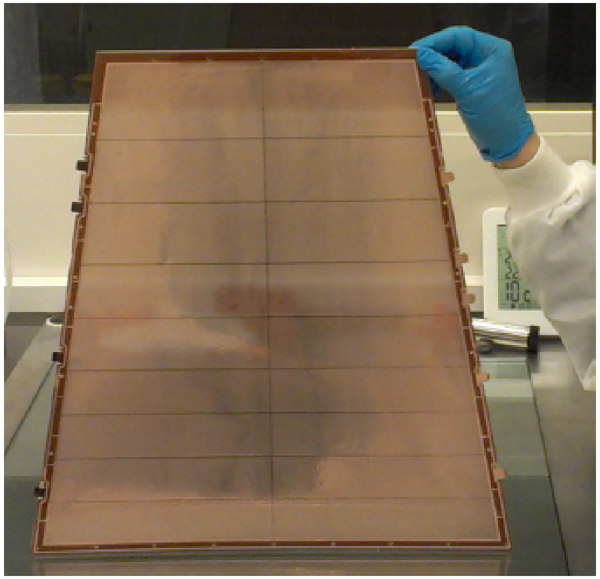
5. Counterweight for gluing

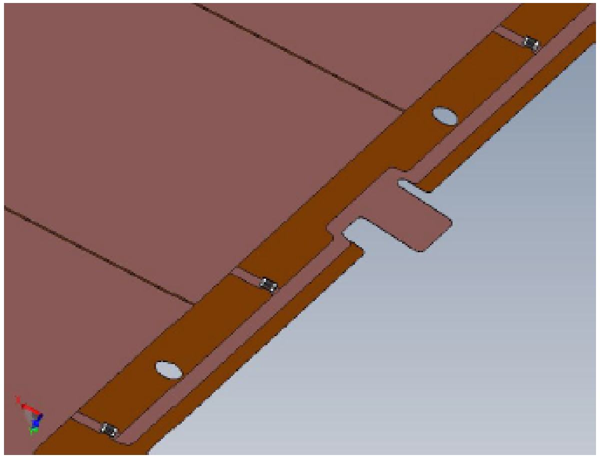


6. Curing the glue (70°C for 20h)



Framed GEM

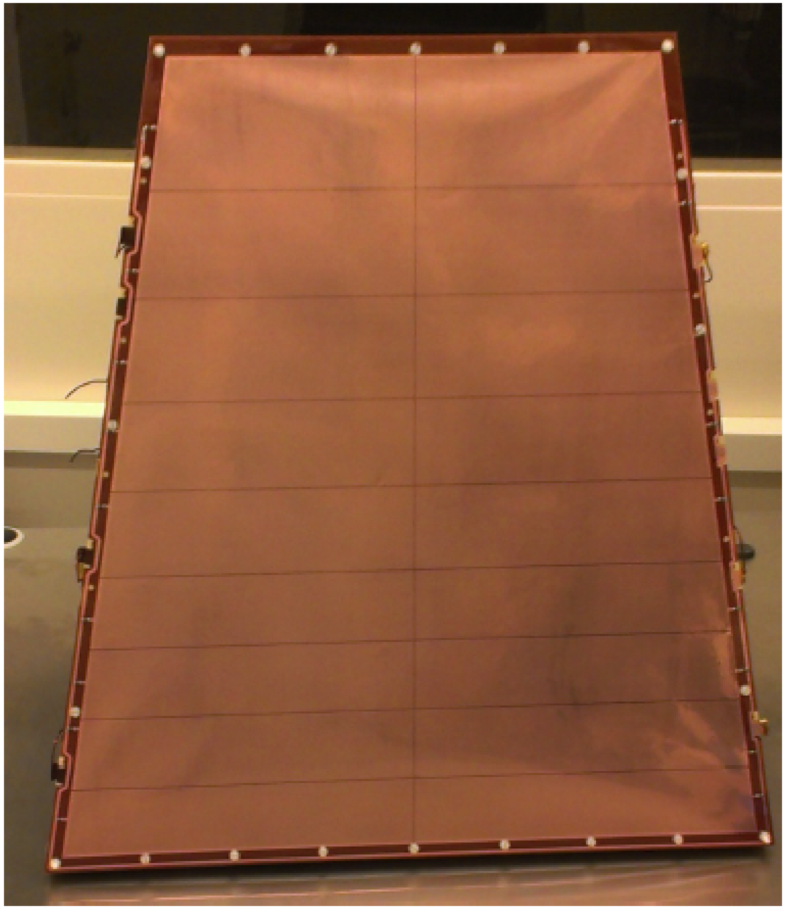




- raw material is cut off
- HV tests → foils are more stable after gluing/heating procedure
- loading resistors (SMD) are soldered
- flaps used for HV connection (with Kapton wires) after mounting GEMs on the Alubody

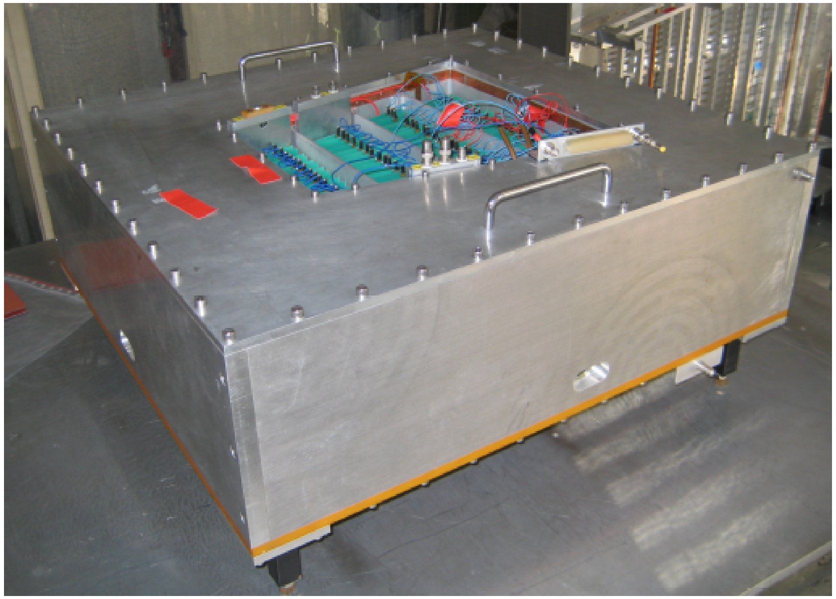
Assembled Prototype

GEM-stack mounted on IROC-Alubody



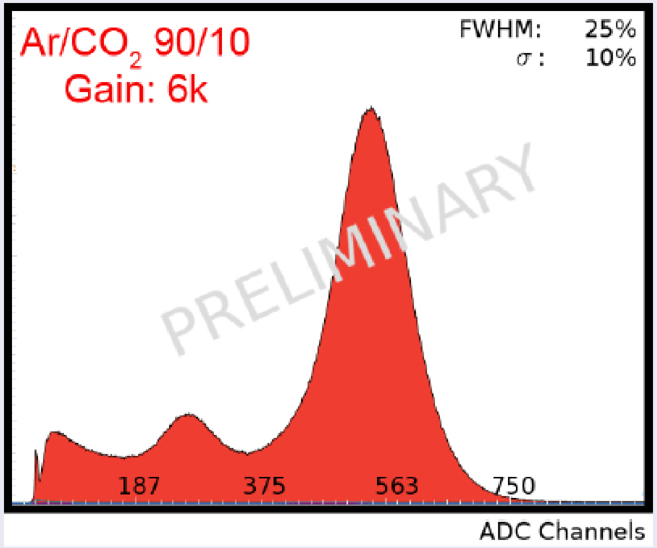
- After mounting, "wrinkles" appeared near parallel edges of trapezoid.
- Wrinkles on the foil may result in inhomogeneities in the gain.
- Current method of fixing the foils seems to be not sufficient and <u>will be improved</u>.

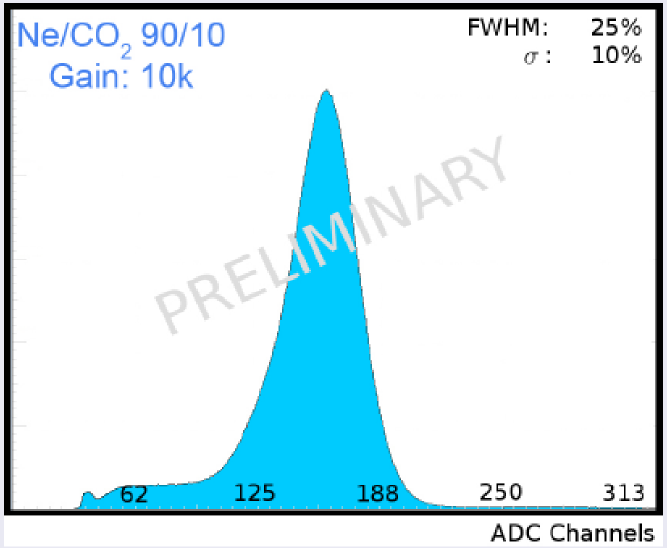
Commissioning in the LAB



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

First ^{55}Fe spectra

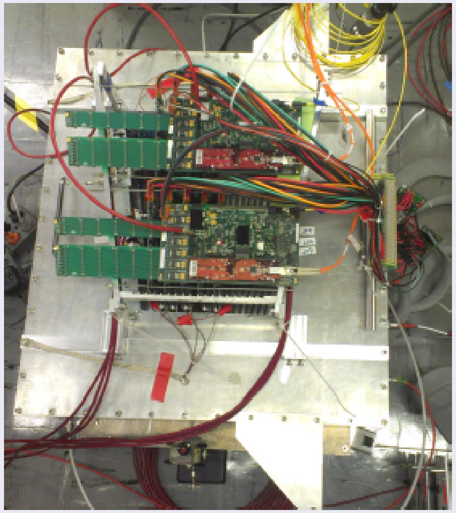


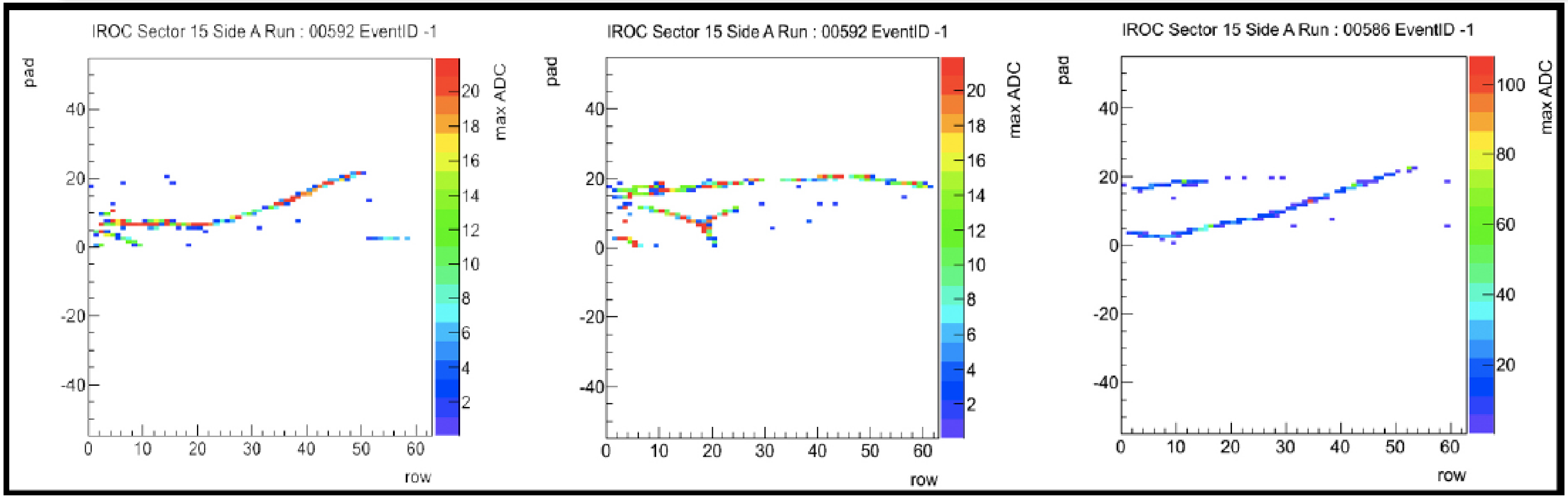


Preparation to the testbeam

Readout

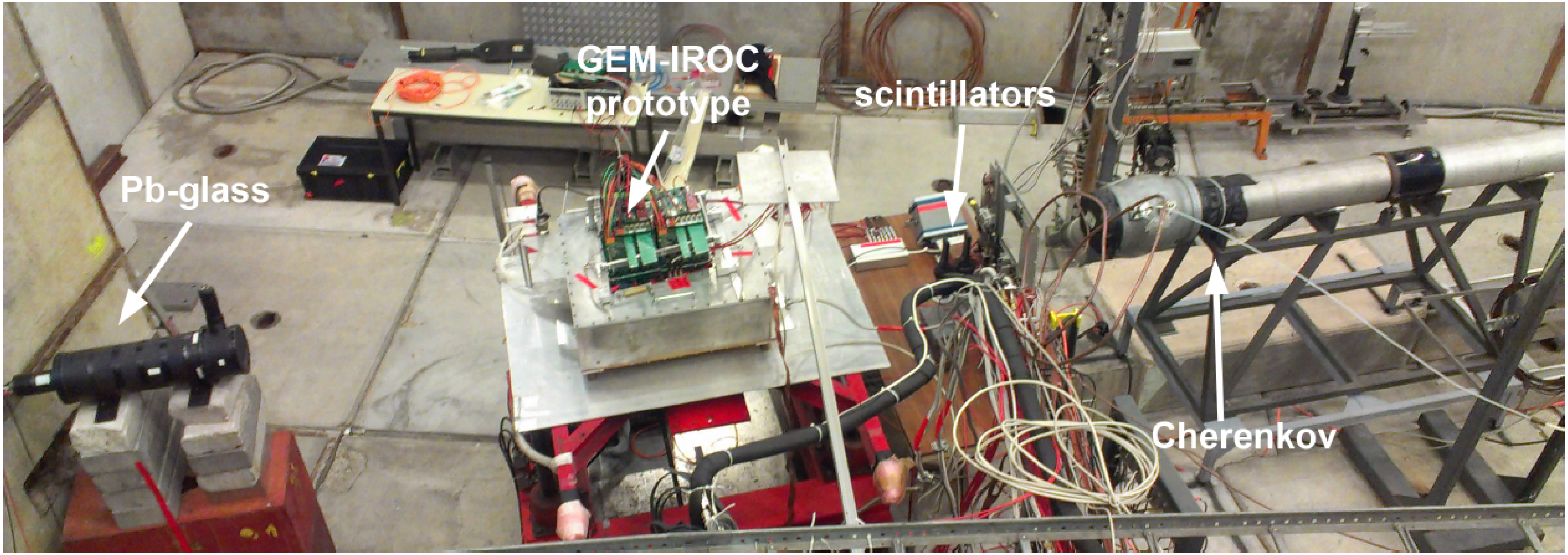
- **10 Front-End Cards** (borrowed from the LCTPC Collaboration via Lund):
  - 16 to 18 pads (size 4×7.5 mm^2, 320 cm^2 in total) on 64 pad rows
  - region covered $\sim$ 6 cm wide
  - average noise (ENC) at the level of 500 – 600 e^-
- **EUDET Front-End Card:**
  - programmable charge preamplifier: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



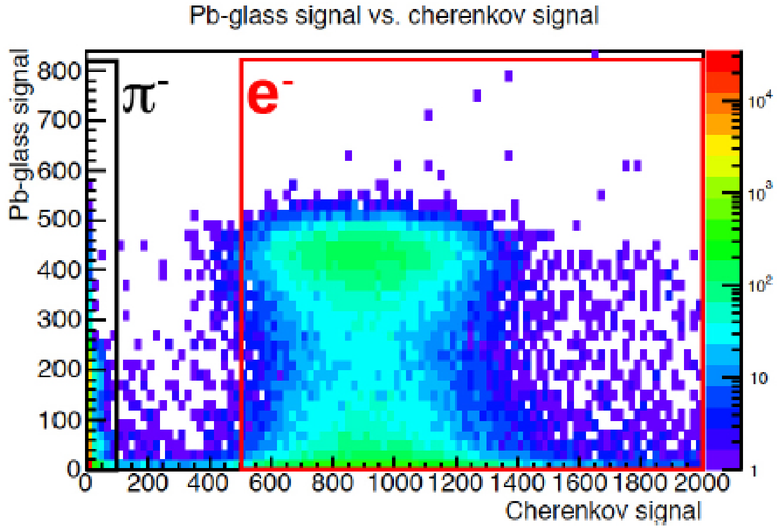


→ First tracks
→ Ne/CO_2 (90/10)
→ ^{90}Sr source

PS TESTBEAM

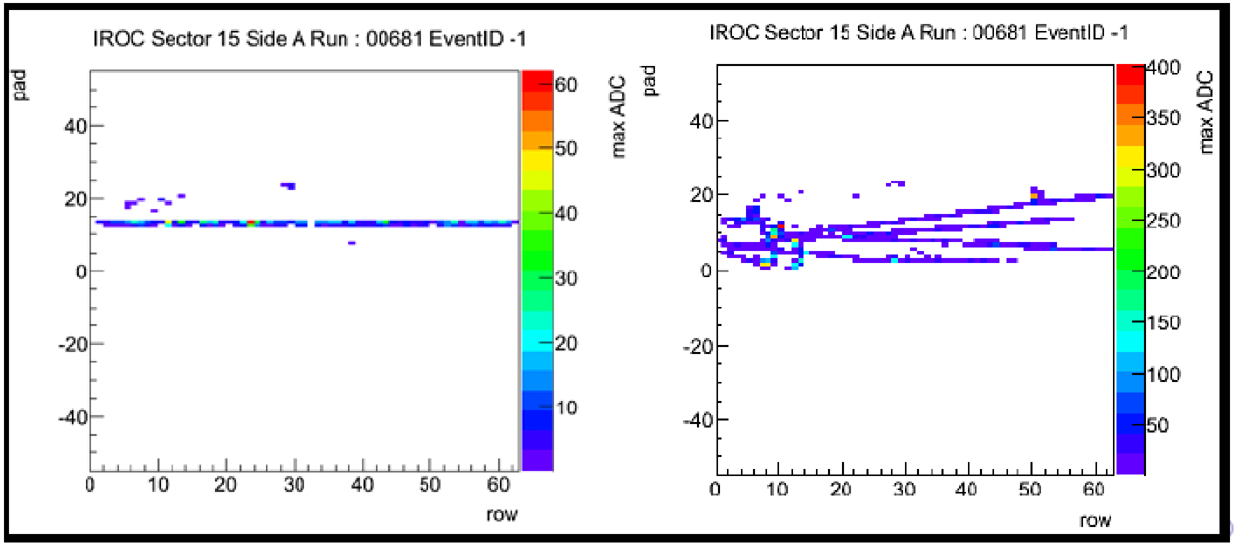


PS TESTBEAM



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

- Beam tracks



TRIPS @ PS

1 GeV/c, negatives

#	Settings	Gain	U_{G1T} (V)	Channel
1	107% IBF, 600 V/cm	5.5 k	3197	G1T
2	107% IBF, 800 V/cm	6.5 k	3237	G1, G2
3	107% IBF, 600 V/cm	5.5 k	3197	G1, G1

2 GeV/c, negatives

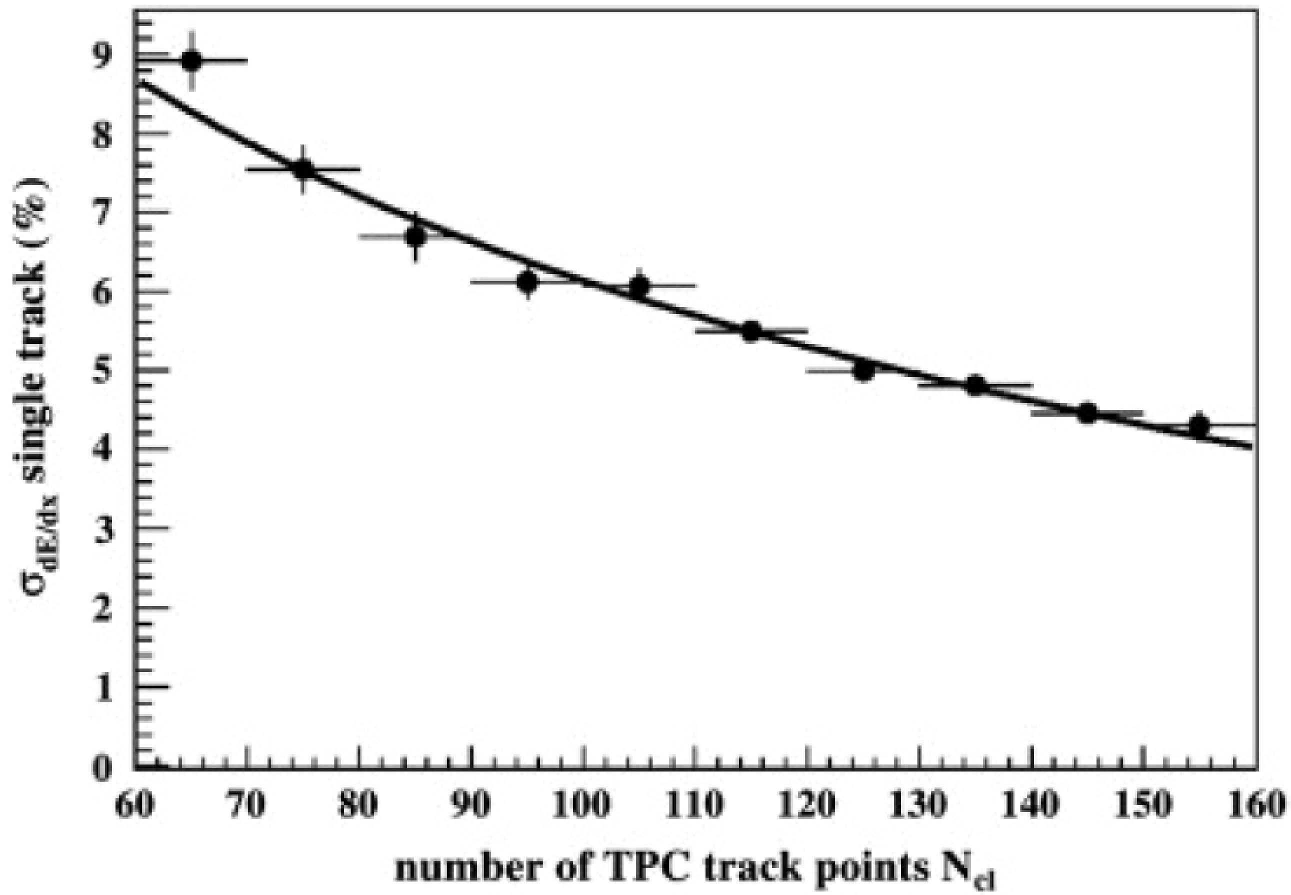
#	Settings	Gain	U_{G1T} (V)	Channel
4	105% IBF, 400 V/cm	2 k	3142	G1T
5	105% IBF, 800 V/cm	3 k	3222	G1
6	107% IBF, 400 V/cm	4 k	3197	G1
7	107% IBF, 400 V/cm	4 k	3157	G1, G2

3 GeV/c, negatives

#	Settings	Gain	U_{G1T} (V)	Channel
8	100% IBF, 600 V/cm	1.8 k	3145	G1

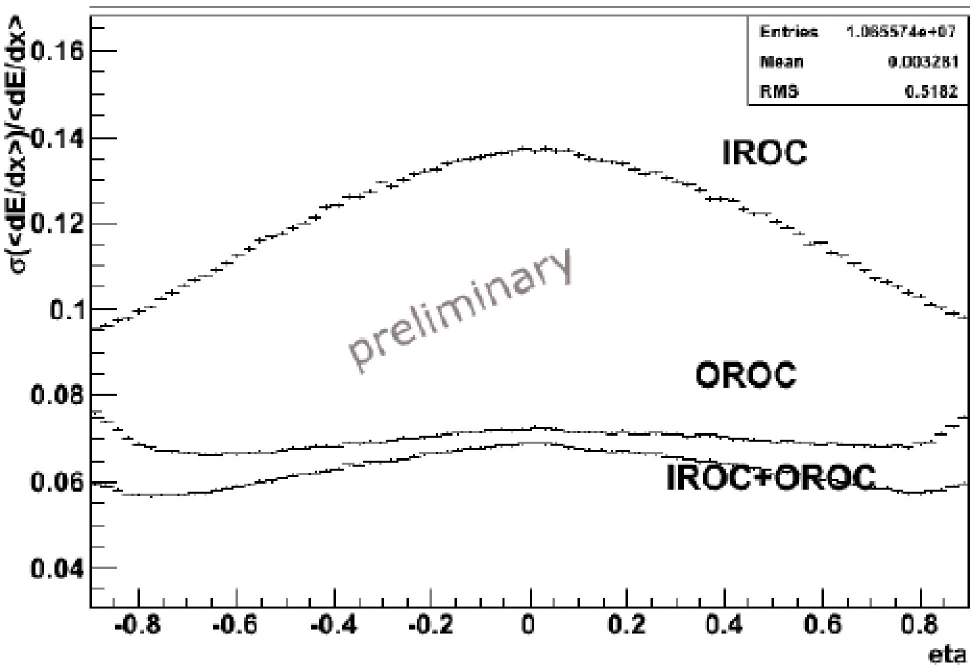
- **8 trips during PS beamtime**
- **No harm to the foils**
- Probably always started from GEM1
- Trips occurred at the highest absolute GEM1 potentials (≈ 3.2 kV)
  (voltage across GEM1 – small, ≈ 235 V)
- Didn't occur at similar gains with "standard" configuration (lower absolute potentials)
- All trips during the beam
- **7 electronic channels damaged (in 3 trips) – no signature on padplane!**

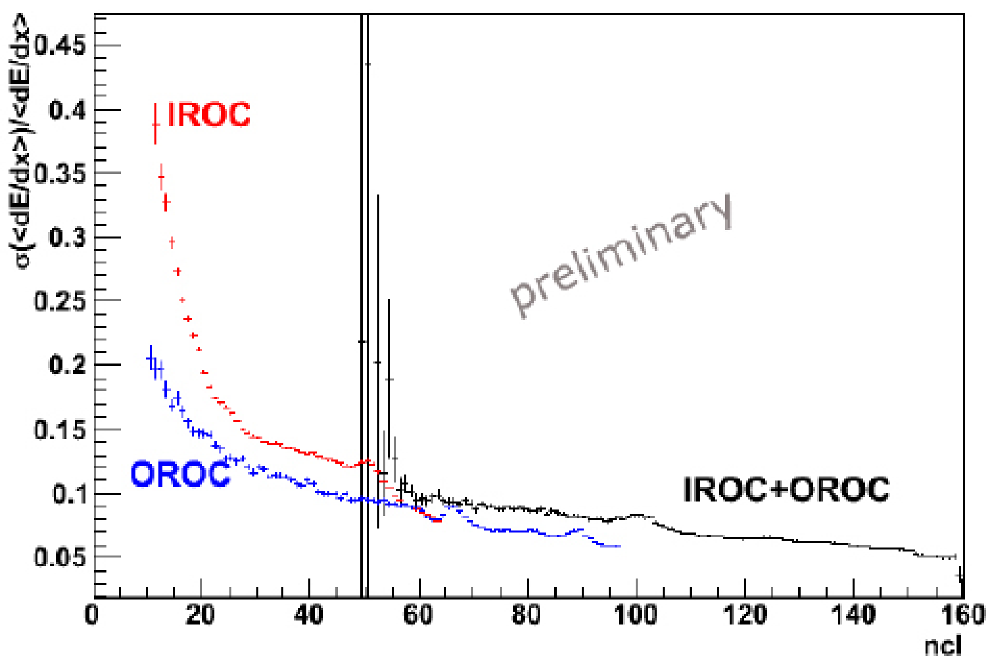
ALICE dE/dx vs. track size



W. Yu, Nuclear Instruments & Methods In Physics Research A (2012), http://dx.doi.org/10.1016/j.nima.2012.05.022

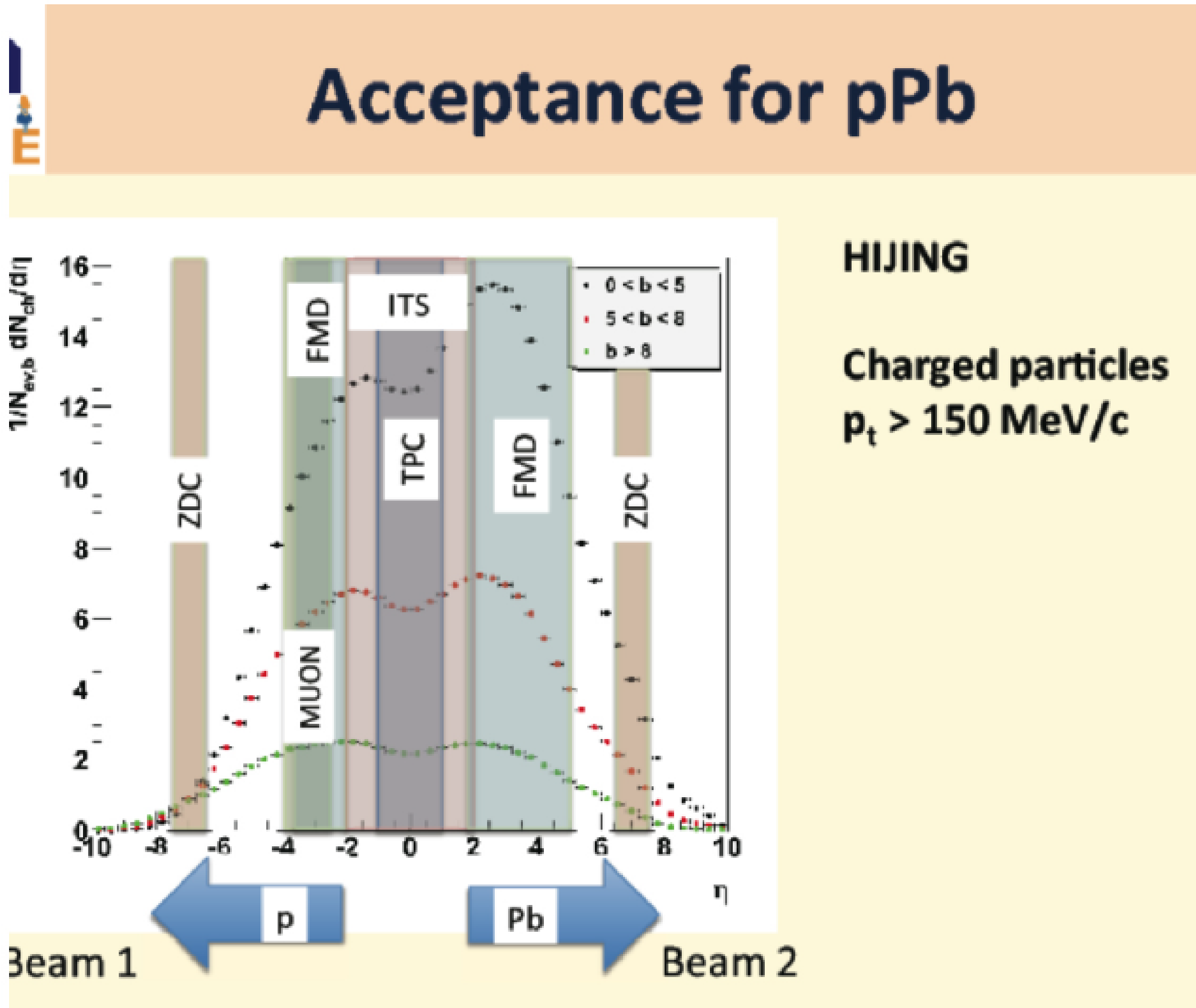
ALICE dE/dx resolution estimation



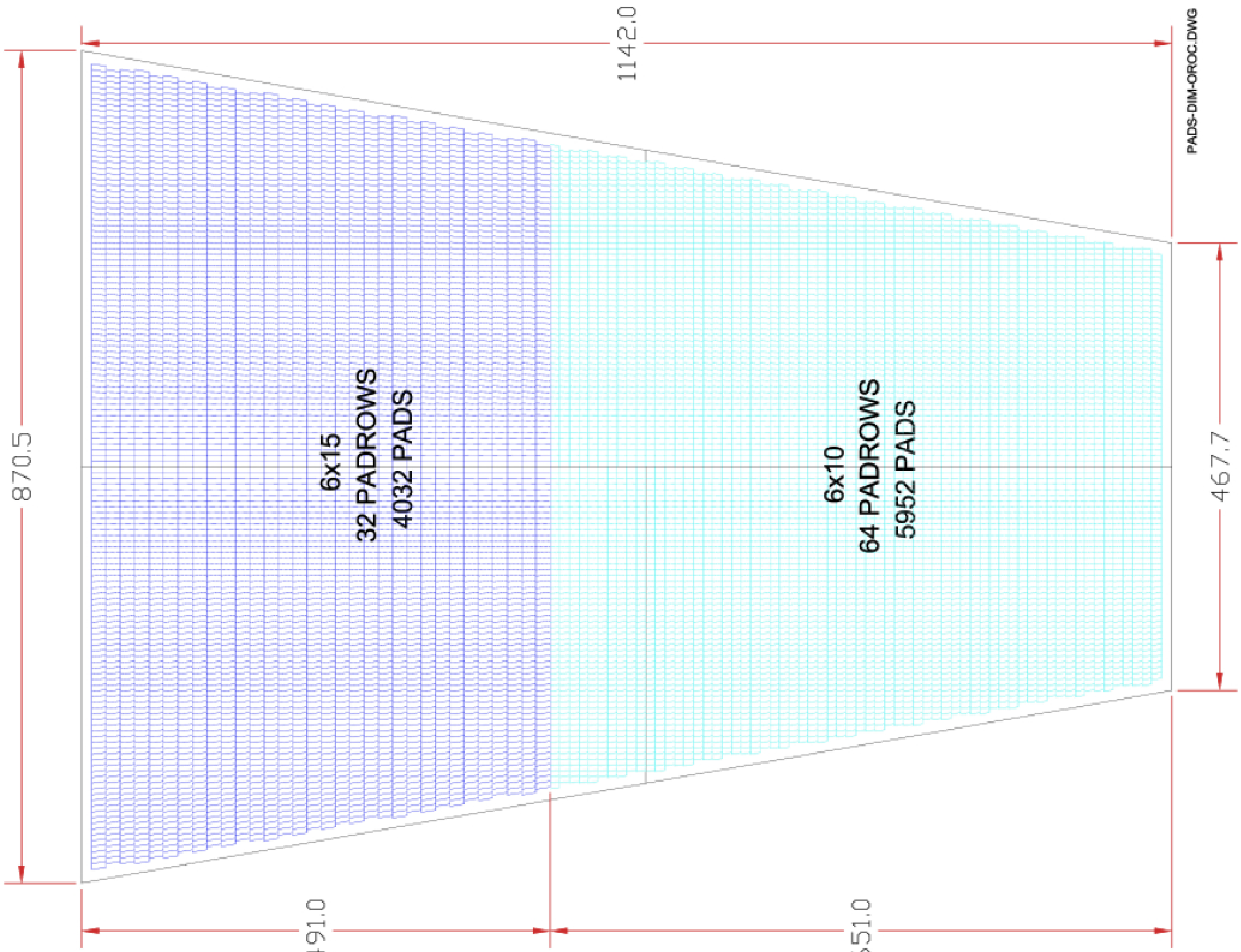


LHC Conditions

- Prototype at rapidity η ~ 2.6 (2.2-3.3)
- Assume multiplicity ~25 for p-Pb, and 200 kHz interaction rate
- Particle rate ~5000 kHz per unit, ~5 cm tracklets per pad row
- 20000 kHz per unit in upgrade scenario, ~1 cm tracklets per pad row
- Comparable!



OROC


1142.0
PADS-DIM-OROC.DWG
870.5
6x15
32 PADROWS
4032 PADS
6x10
64 PADROWS
5952 PADS
467.7
491.0
651.0