The MPGD-based photon detectors for the COMPASS RICH-1 upgrade

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on behalf of ***COMPASS THGEM*** group:

Alessandria, Aveiro, Budapest, Freiburg, Kolkata, Liberec, Prague, Torino, Trieste.

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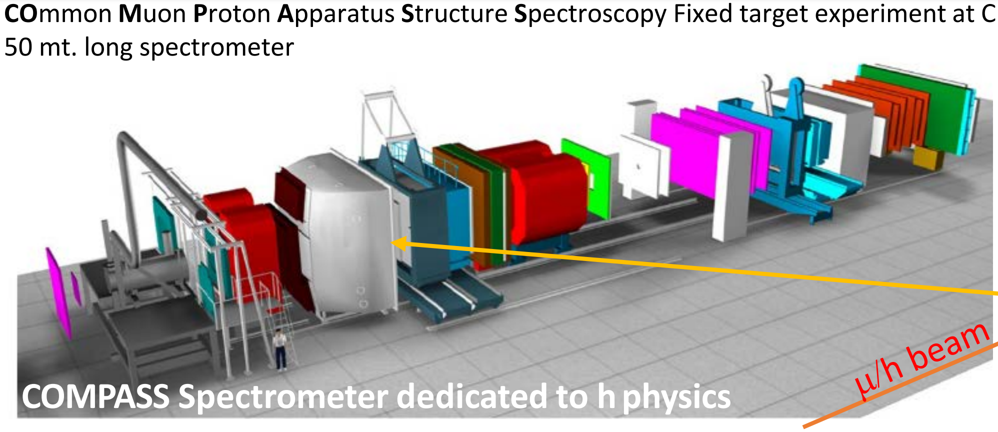
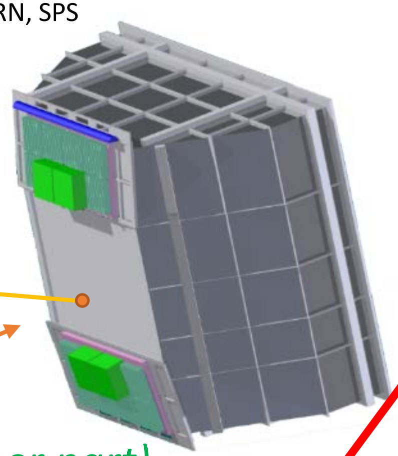
Outline

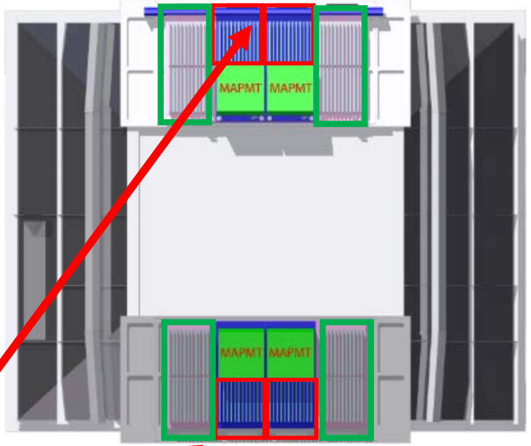
- Introduction: COMPASS RICH-1 @ CERN
- Why MPGD-based photon detectors and a *change* in the Cherenkov *photo detection technology*
- The architecture of the MPGD-based detector
- Construction, quality control and assembly
- Detector commissioning
- Performance hints

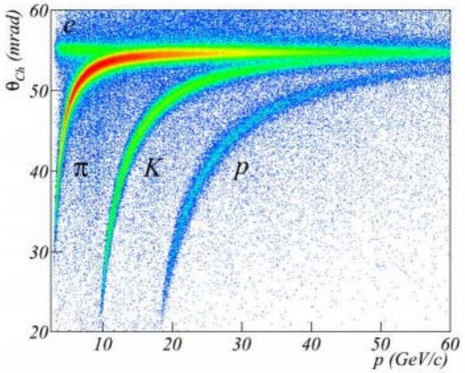
Introduction: COMPASS RICH-1 @ CERN

COmmon **M**uon **P**roton **A**pparatus **S**tructure **S**pectroscopy Fixed target experiment at CERN, SPS
50 mt. long spectrometer

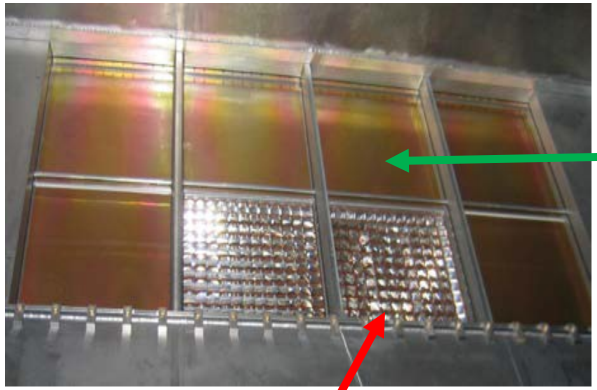






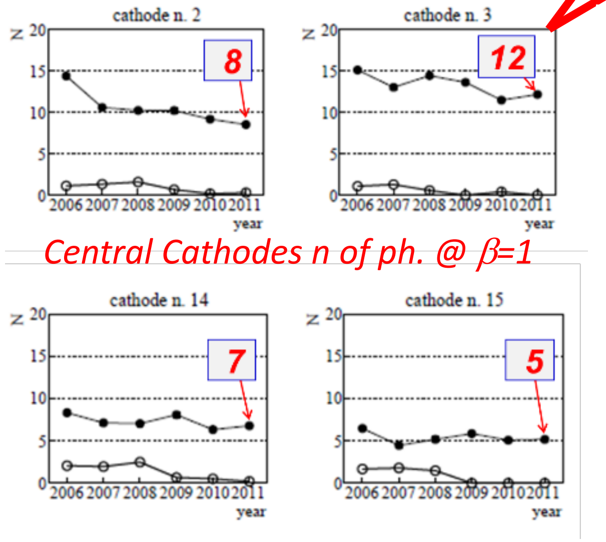


The photo detector system of compass RICH-1 (upper part)



MWPCs+CsI (from RD26): <u>successful</u> but performance limitations, in particular for the 4 central chambers

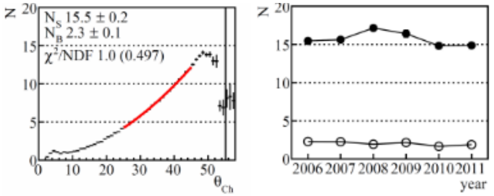
COMPASS RICH-1 upgraded in **2006** with **MAPMT** in the most inner central region **MAPMTs coupled to lens telescopes** 1.4 m^2

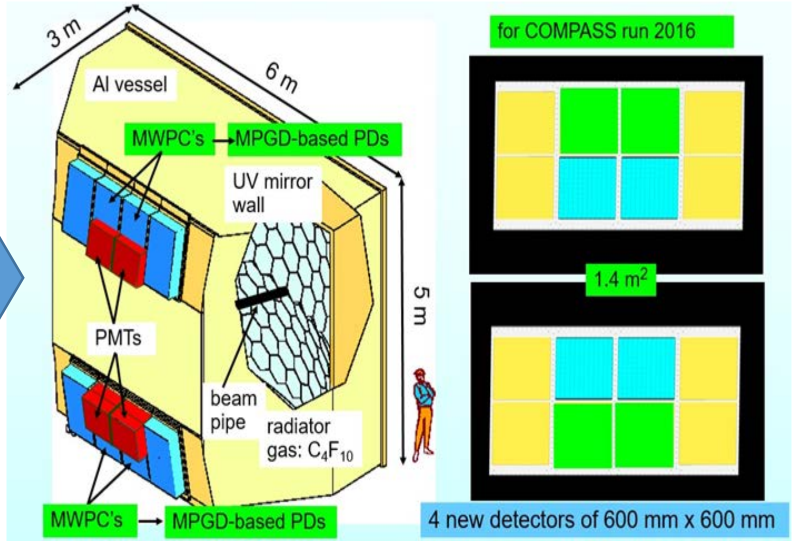


Central Cathodes n of ph. @ β=1

Number of photons for the very top and very bottom 60x60 cm^2 MWPC:

- **On average lower than the other PC $\langle N_{ph} \rangle = 13$**
- **Slow decreasing trend $\langle N_{ph} \rangle$ vs year**





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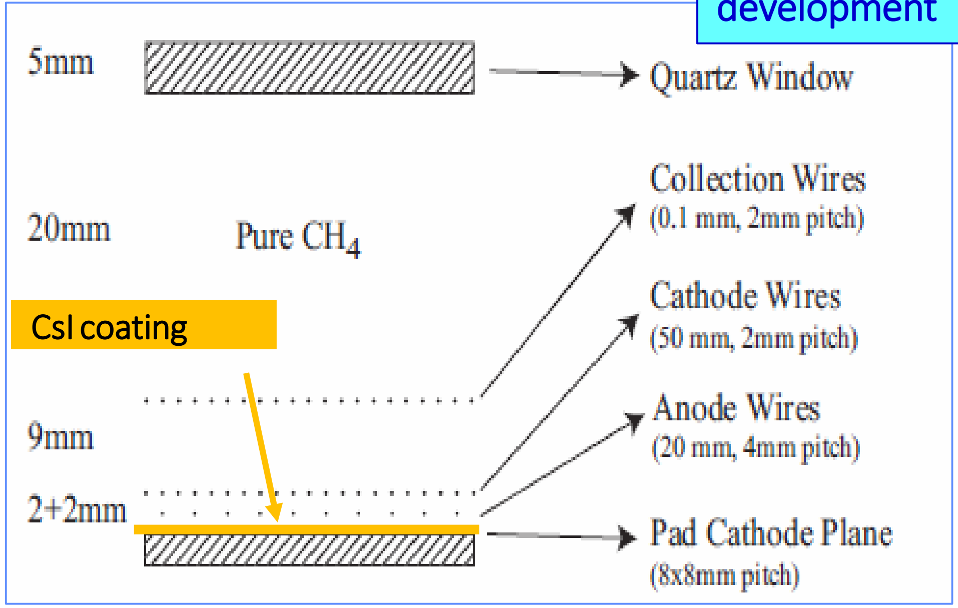
MWPCs + CsI

RD26 development



Reduced wire-cathode gap because of :

Fast RICH (fast ion collection)
Reduced MIP signal
Reduced cluster size
Control photon feedback spread

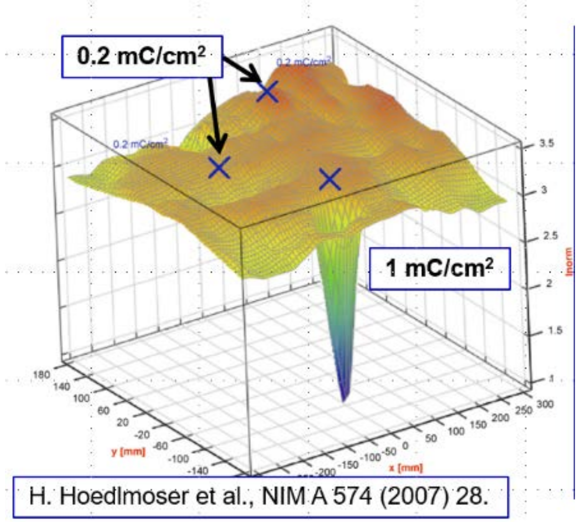
MWPCs with CsI photocathode, the limitations

Severe recovery time (~ 1 d) after a detector discharge
- *Ion accumulation at the* ***photocathode***

Feedback pulses
- *Ion and photons feedback from the multiplication process*

Ageing (QE reduction) after integrating a few mC / cm^2
- *Ion bombardment of the photocathode*

Low gain: a few times 10^4 (effective gain: <1/2) "slow" detector



H. Hoedlmoser et al., NIM A 574 (2007) 28.

To overcome the limitations:

Less critical architecture
suppress the PHOTON & ION feedback
use intrinsically faster detectors

MPGDs

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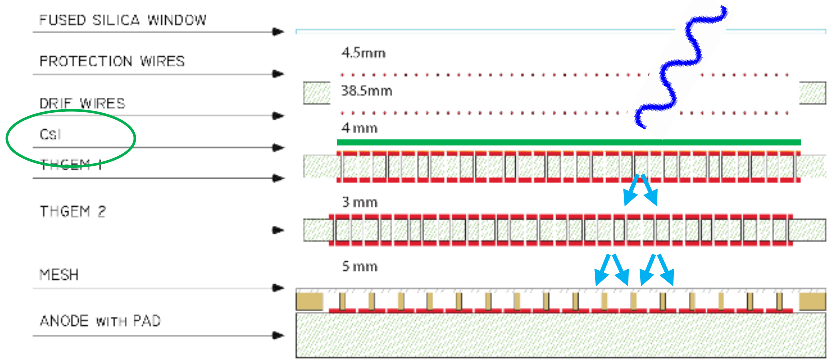
The MPGD hybrid approach: THGEMs and MicroMegas

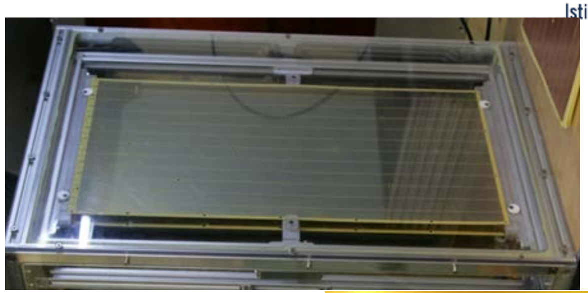


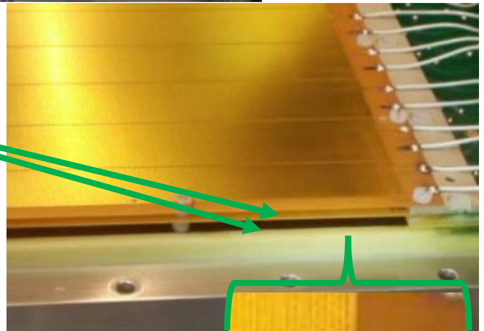
IBF reduction: approx. 3%
Charge splitting processes → Larger Gas Gain

Hybrid detector concept

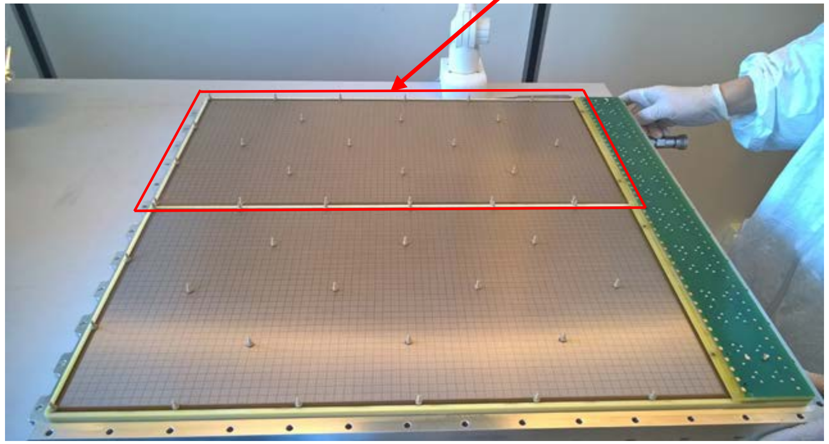
To simplify the construction requirements a modular architecture has been adopted where one "*module*" consists of:

- One 300 mm x 600 mm Bulk Micromegas detector
- Two layers of THGEMs (300 mm x 600 mm) in *staggered* configuration



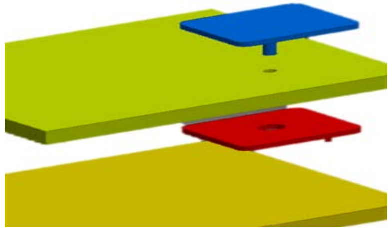


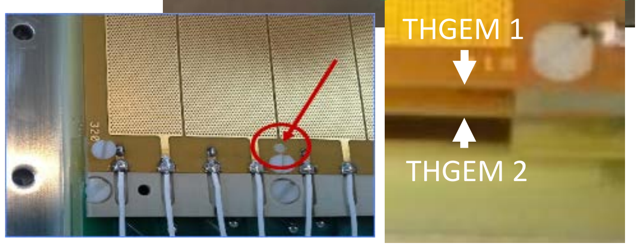
Two modules are put side by side to build a 600 mm x 600 mm detector



Signal read out via capacitive coupling pad readout and APV25 F/E boards

8mmx8mm pad size
0.5 mm pad spacing





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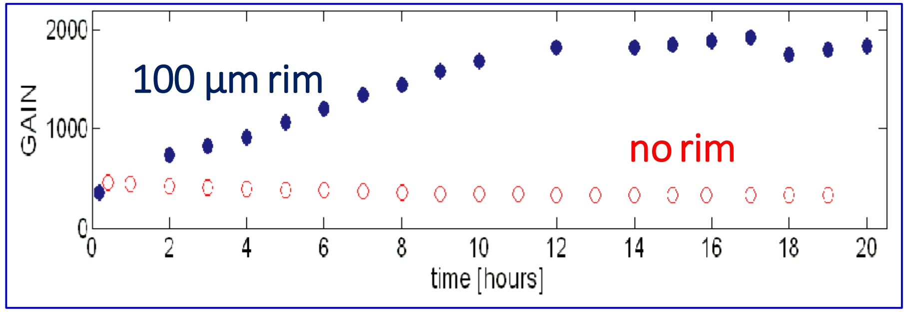
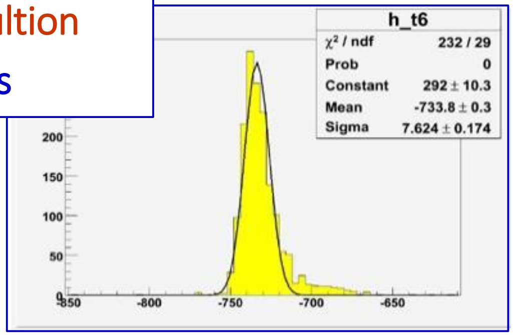
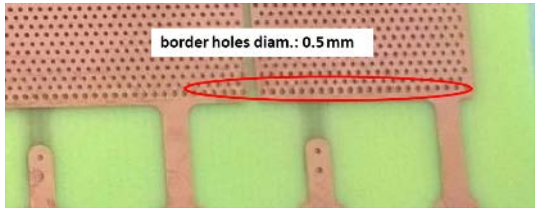
THGEM characterization

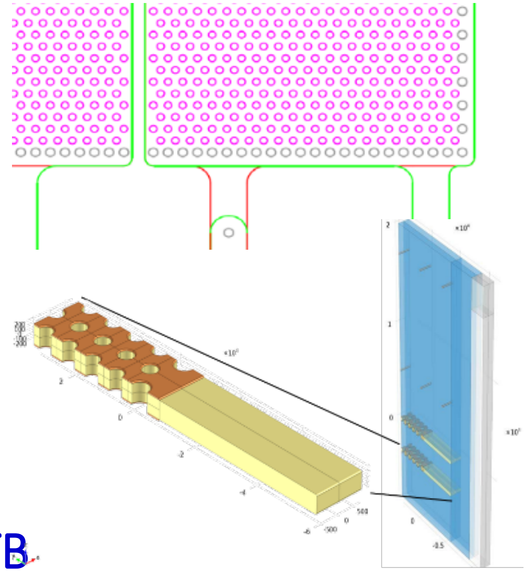


Time resultion

~7 ns

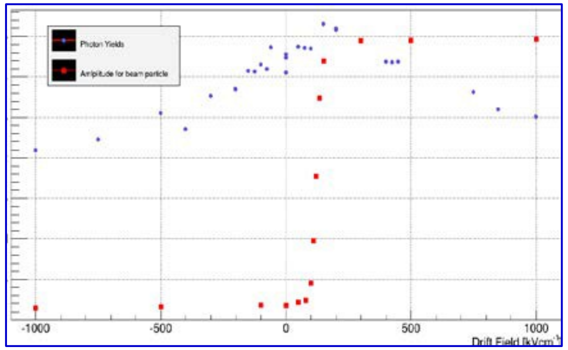


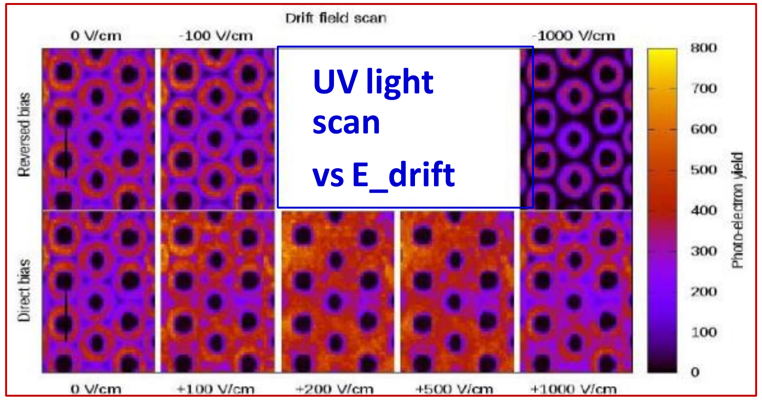




Photoelectron extraction

Photon yield (blue)
& Charged Particles (red)
vs Drift Field





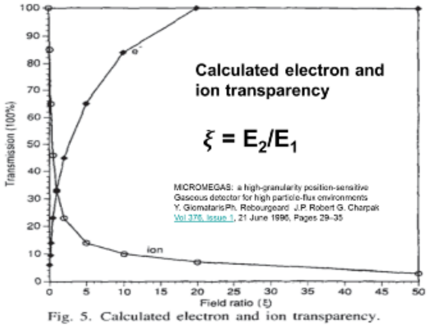
UV light scan

vs E_drift

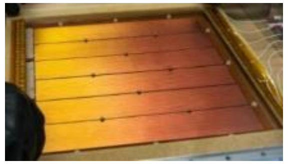
IBF (Ion Back Flow) suppression

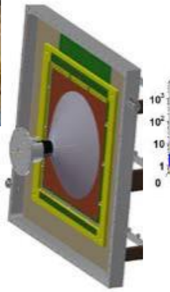
IBF suppression (<3%) introducing a MM stage

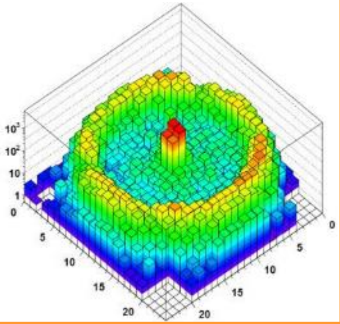
Hybrid architecture

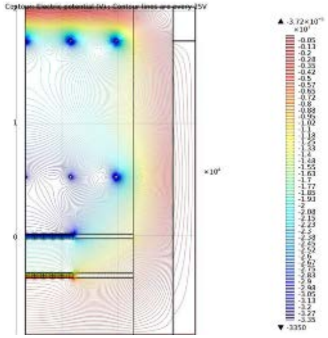


Cherenkov light detection in TB









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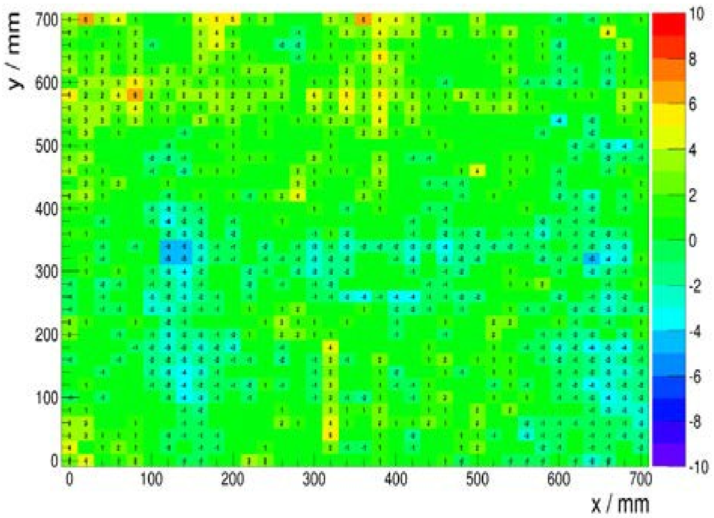
Measurement of the raw material thickness before the THGEM production, accepted:
± 15 μm ↔ gain uniformity σ < 7%



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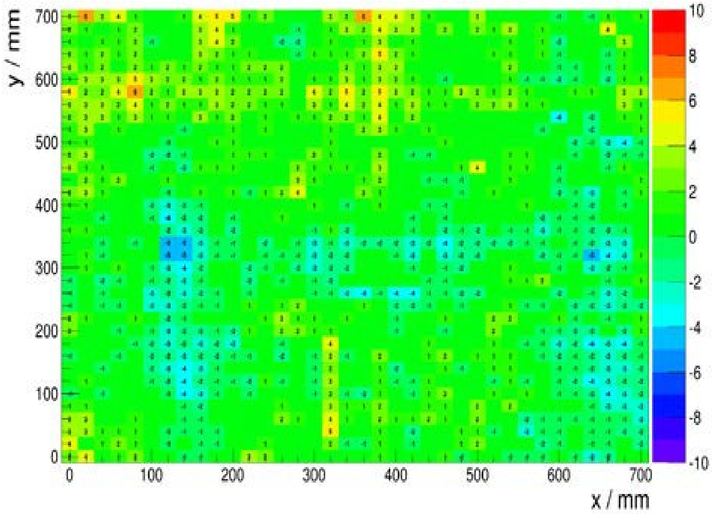
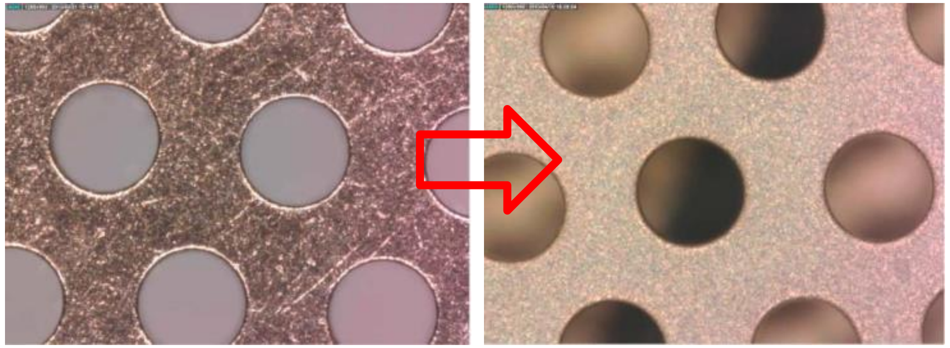


THGEM polishing with an "ad hoc" protocol setup by us *including backing*:
>90% break-down limit obtained



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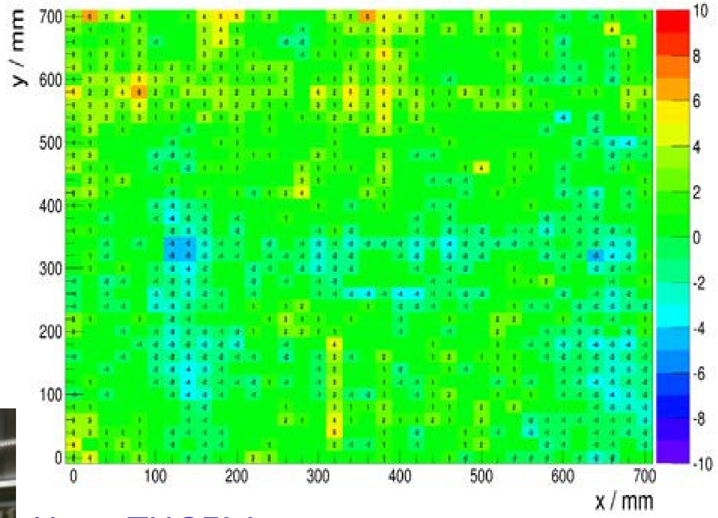
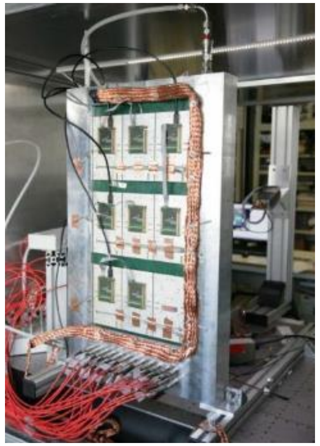
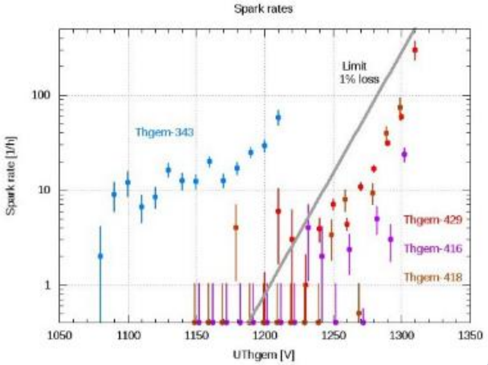




X-ray THGEM test to access gain uniformity (<7%) and spark behaviour



188	202	185	198	206	207
196	207	196	198	199	207
192		193	198	204	204
192		188	199	202	205
199	199	191	195	195	
199	196	199	205	195	199
192	190	194	197	195	194
198	190	195	209	195	199
198	199	195	208	197	201
198	199	195	199	200	199
190	186	185	199	190	199

THGEM polishing with an "ad hoc" protocol setup by us *including backing*:
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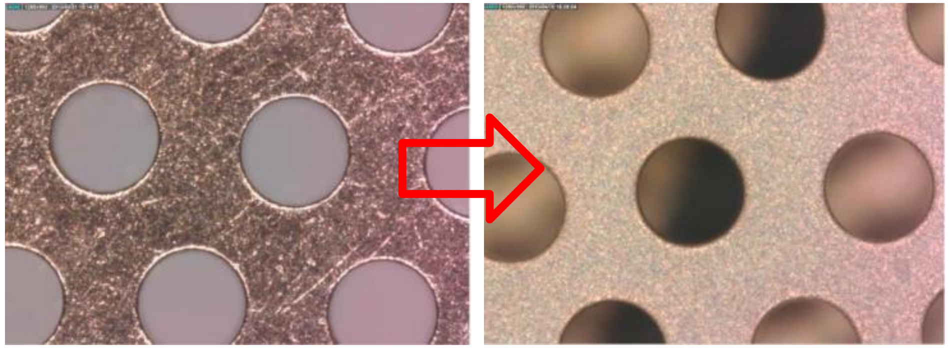
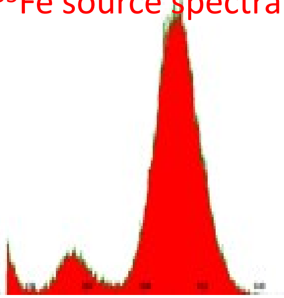
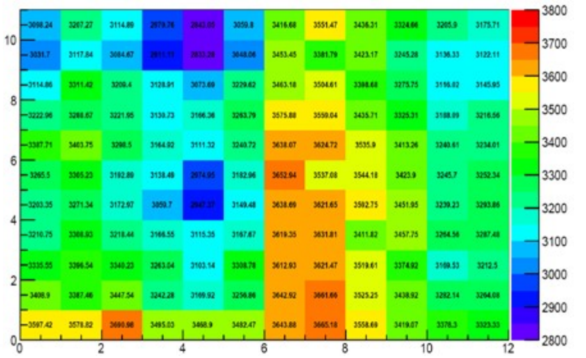


MICROMEGAS

X-ray MM test to access integrity and gain uniformity (<5%)

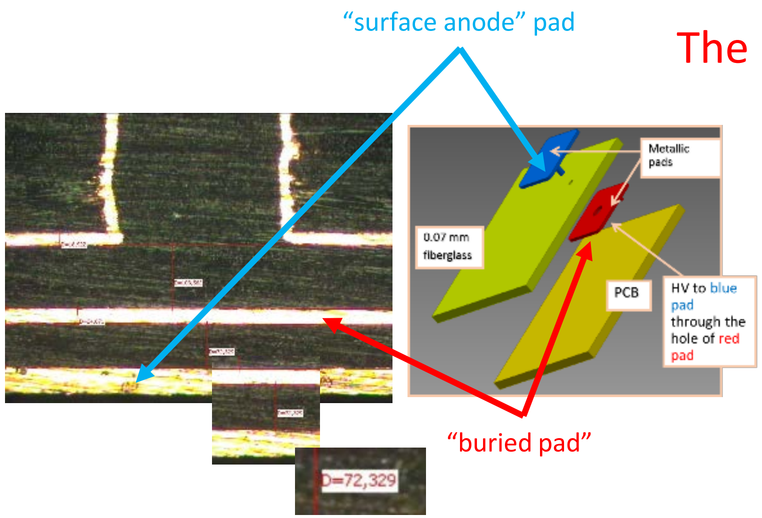
^{55}Fe source spectra





Micromegas: characterization and studies, the discrete element approach

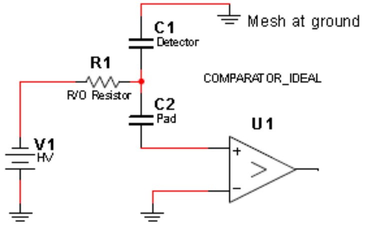
The COMPASS RICH-1 approach



1 Single pad scheme:

Blue pad at HV via individual pad resistor at the PCB rear surface

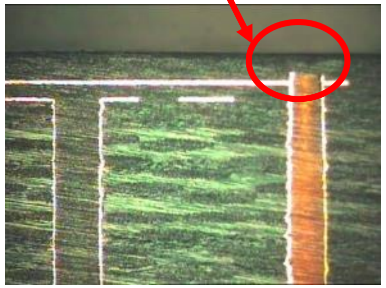
Red pad: signal induced by RC coupling



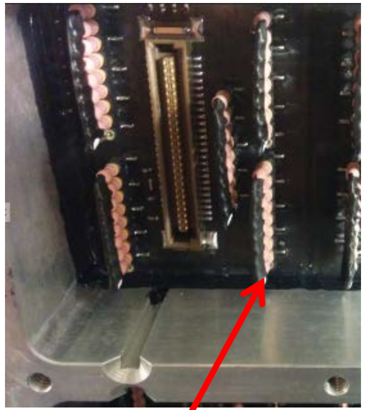
Mesh at Ground

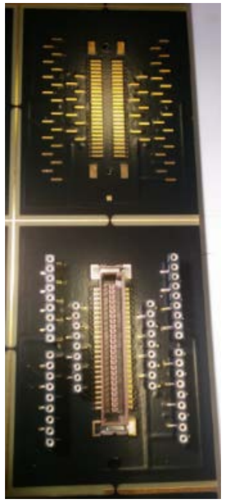
Pads HV segmentation

"Via closure" → leakage issue



"Z drilling controlled via" → planarity issue

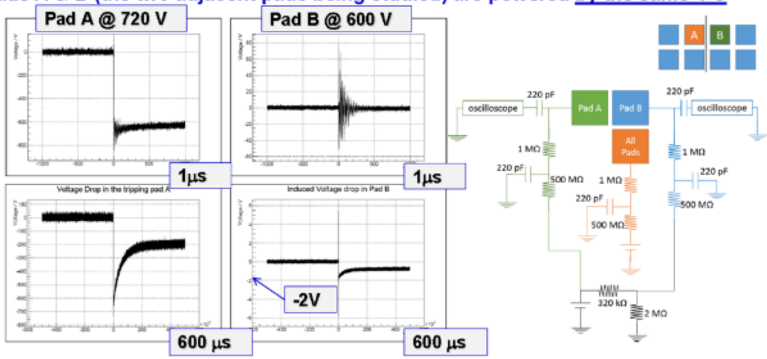




Resistor arrays
Connector 8+1 pin

Test of the (4 x 2) 30 x 60 cm^2 MMs
[in total: 1.4 m^2, 19040 pads]:
-2 pads with shorts
-1 pad: no read-out connection
→ 3 bad pads out of 19040 before installation

Pads A & B (the two adjacent pads being studied) are powered by the same PS



The HV of the non tripping pad is very limited affected:

2V drop → ~4% drop in G

R ~ 0.5 GΩ is preserving the non-tripping pads efficient all the time !

Finale detector: the mounting phase

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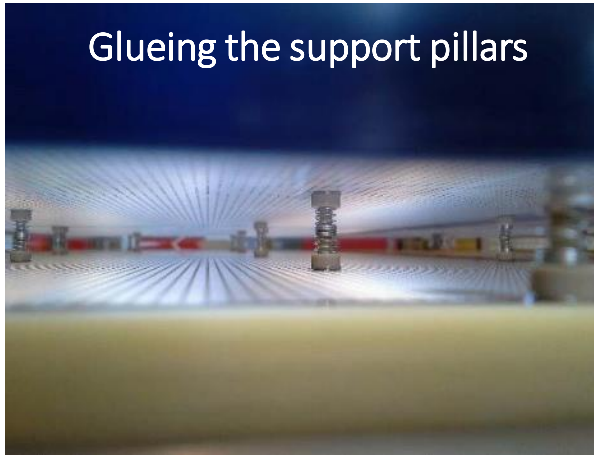
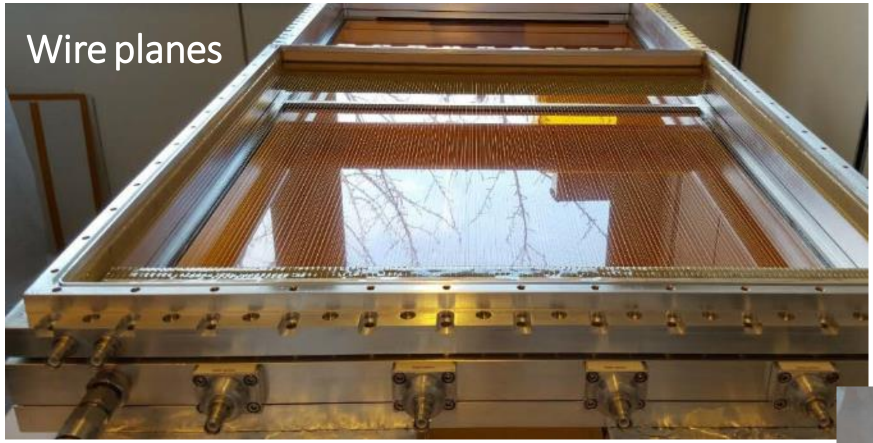
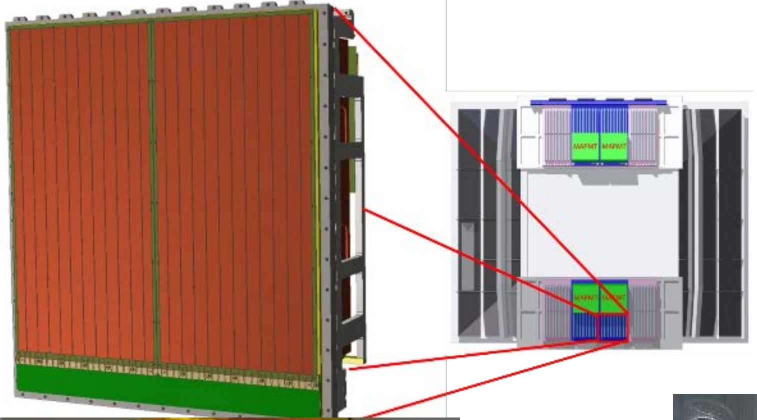
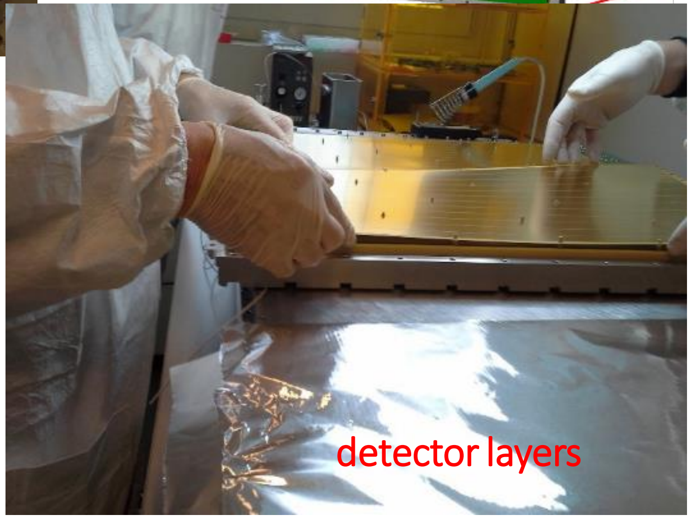
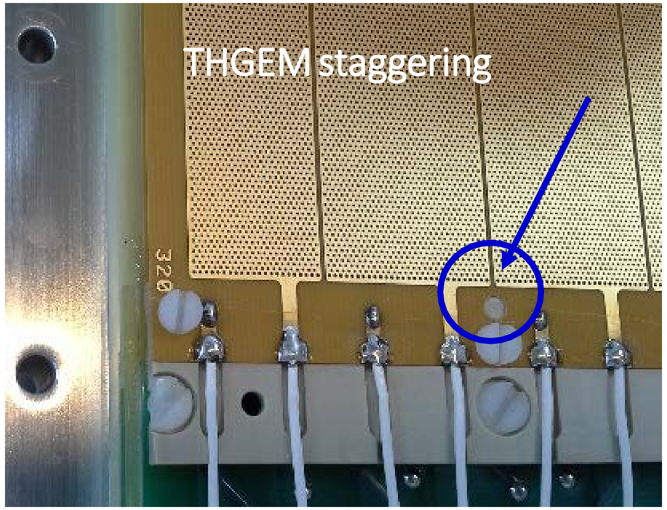


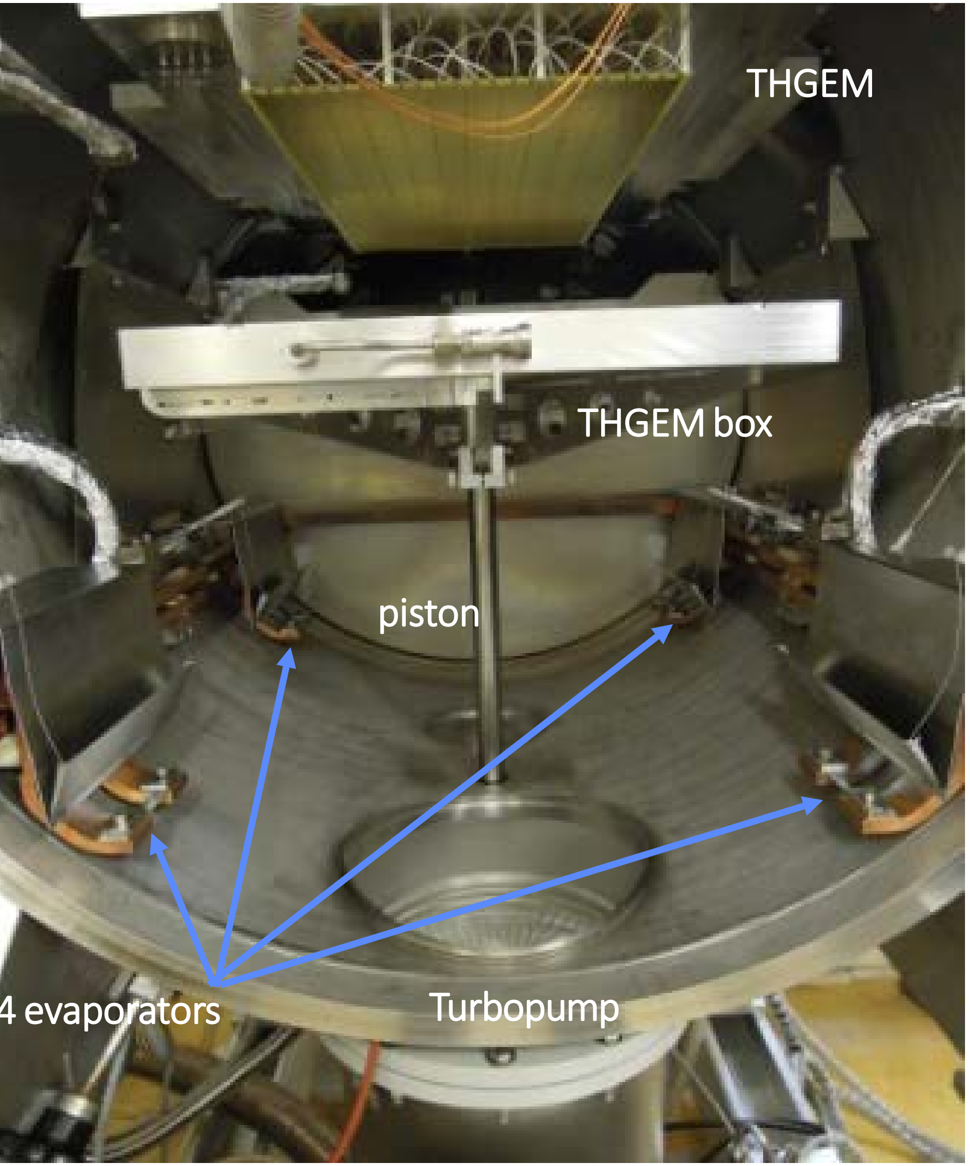


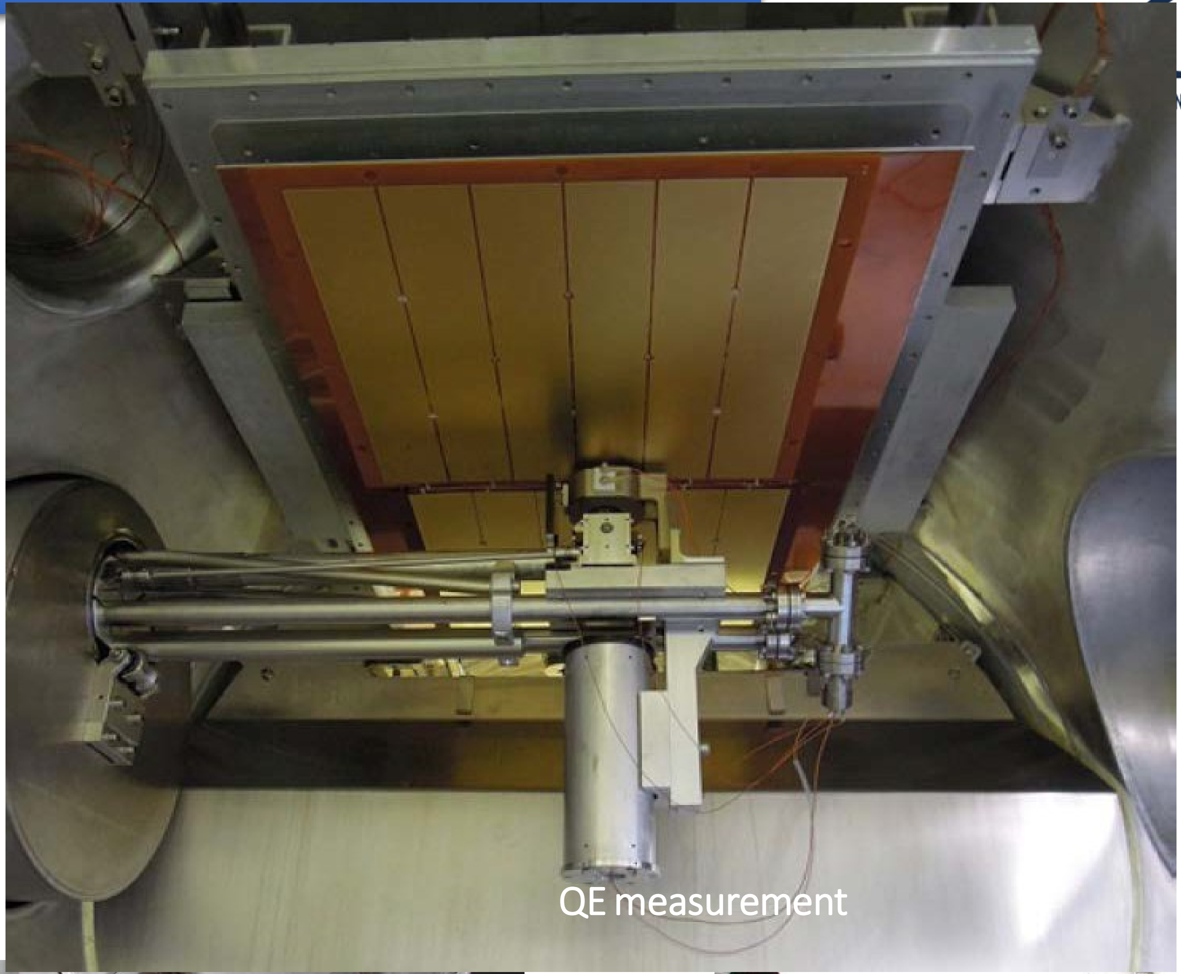


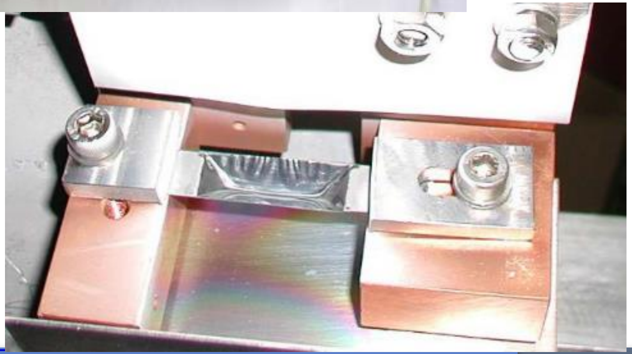




THGEM: CsI coating at CERN







THGEM: CsI coating at CERN, QE measurements

19 CsI evaporations performed in 2015 – 2016 on 15 pieces: 13 THGEMs, 1 dummy THGEM, and 1 reference piece (best from previous coatings) on gold coated substrate

11 coated THGEMs available, 8 used + 3 spares

$$I_{Normalized} = \frac{I_{CsI} - I_{CsI_{Noise}}}{I_{Ref} - I_{Ref_{Noise}}}$$

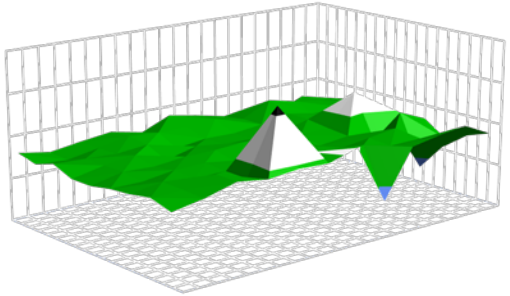
THGEM number	evaporation date	at 60 degrees	at 25 degrees
Thick GEM 319	1/18/2016	2.36	2.44
Thick GEM 307	1/25/2016	2.65	2.47
Thick GEM 407	2/2/2016	2.14	2.47
Thick GEM 418	2/8/2016	2.79	2.98
Thick GEM 410	2/15/2016	2.86	3.14
Thick GEM 429	2/22/2016	2.75	2.74
Thick GEM 334	2/29/2016	2.77	3.00
Thick GEM 421 re-coating	3/10/2016	2.61	2.83
Reference piece	7/4/2016	3.98	3.76

QE measurements indicate

<THGEM QE> =0.73 x Ref. pieceQE

in agreement with expectations

THGEM optical opacity = 0.77



QE is the result of a surface scan (12 x 9 grid, 108 measurements)

Good uniformity, in the example

σ_{QE} / <QE> = 3%

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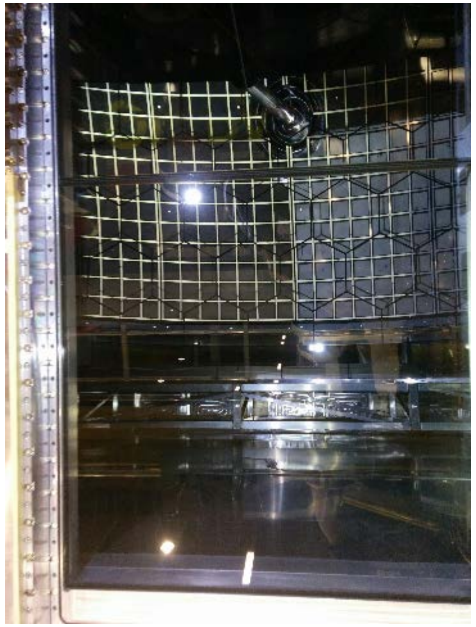
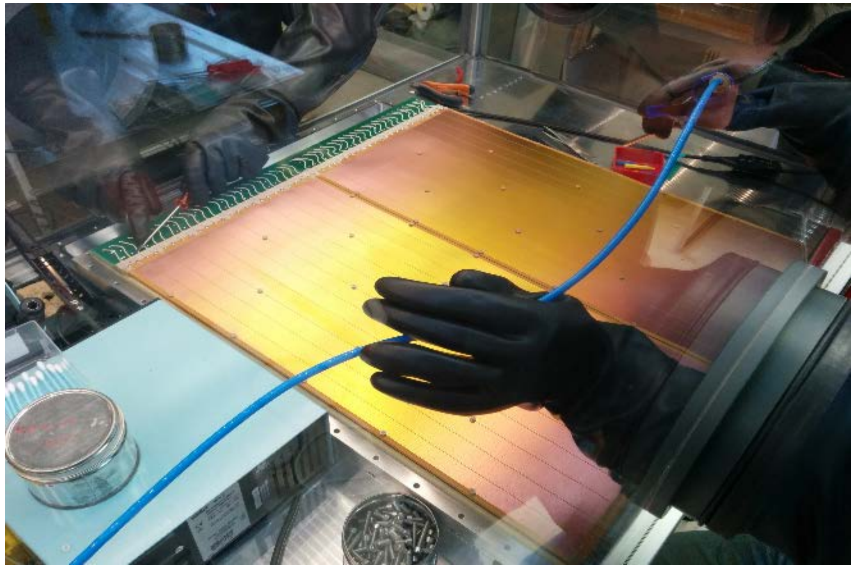
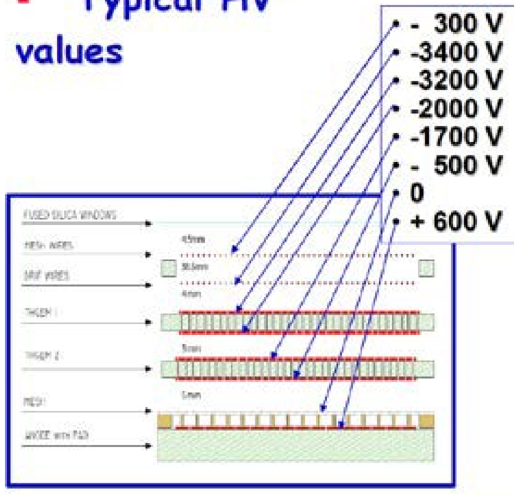
Final mounting on the RICH-1 detector



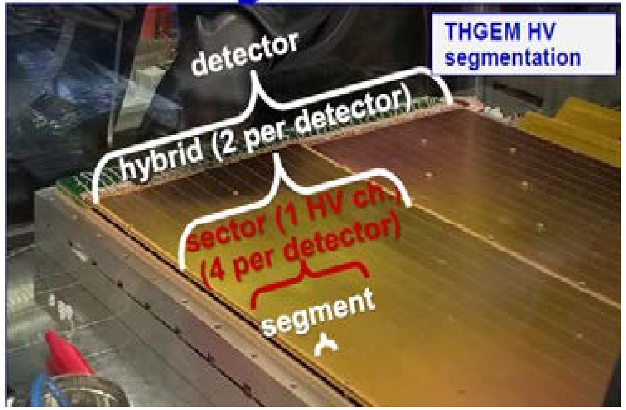


- Typical HV values



- HV segmentation

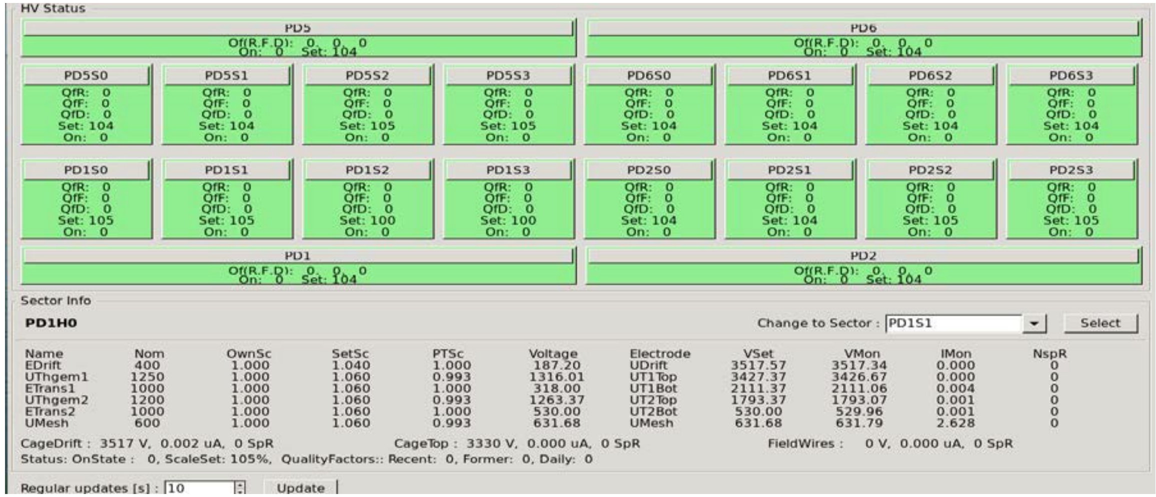


In total 136 HV channels

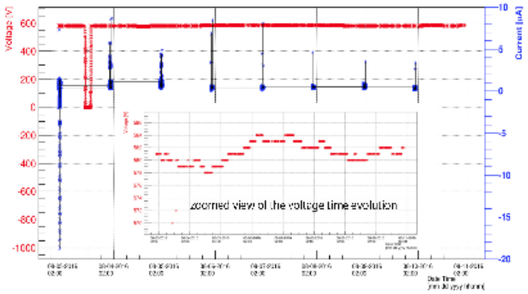
with correlated values

Hardware, commercial by CAEN

Custom HV control system



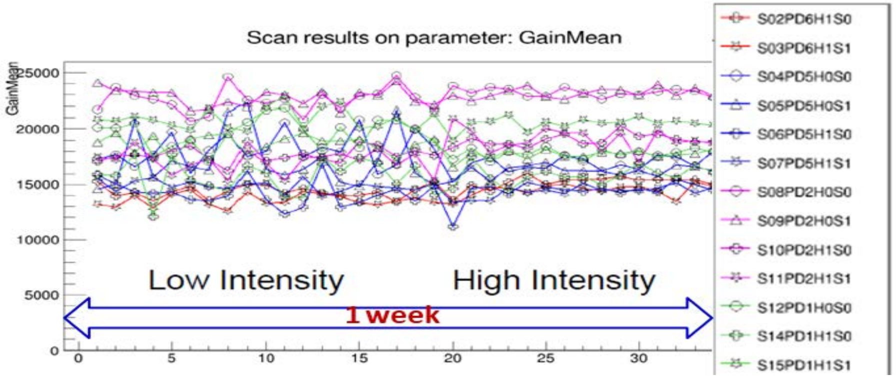
- Gain stability vs P, T:
  - G = G(V, T/P)
  - Enhanced in a multistage detector
  - ΔT = 1°C → ΔG ≈ 12 %
  - ΔP = 5 mbar → ΔG ≈ 18 %



- THE WAY OUT:
  - Compensate T/P variations by V

    Gain stability better than 10%

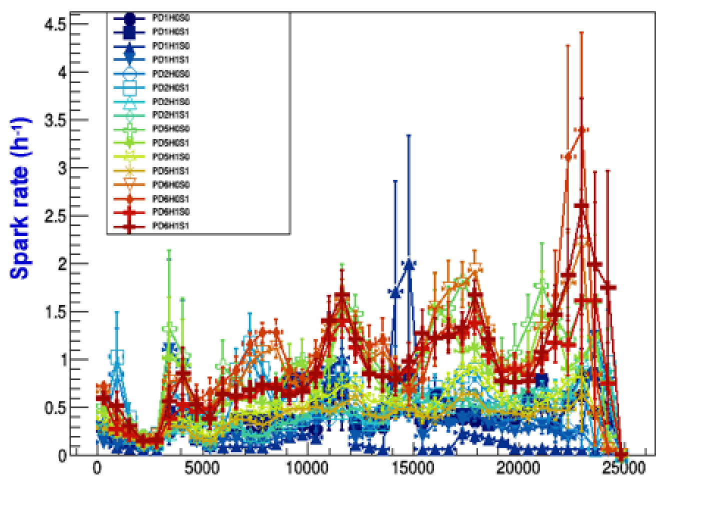
- Custom-made (C++, wxWidgets)
- Compliant with COMPASS DCS (slow control)
- "OwnScale" to fine-tune for gain uniformity
- **V, I measured and logged at 1 Hz**
- **Autodecrease HV if needed (too high spark-rate)**
- User interaction via GUI
- **Correction wrt P/T to preserve gain stability**



THGEMs, lessons

- <u>Full</u> vertical <u>correlation</u> of current sparks THGEM1 & THGEM2
- Recovery time <10 s (our HV arrangement)
- Sparke rates: ~ no dependence on beam intensity and even beam on-off
- <u>Discharge correlation</u> within a THGEM (also non adjacent segments) and among different THGEMs (cosmics ?)

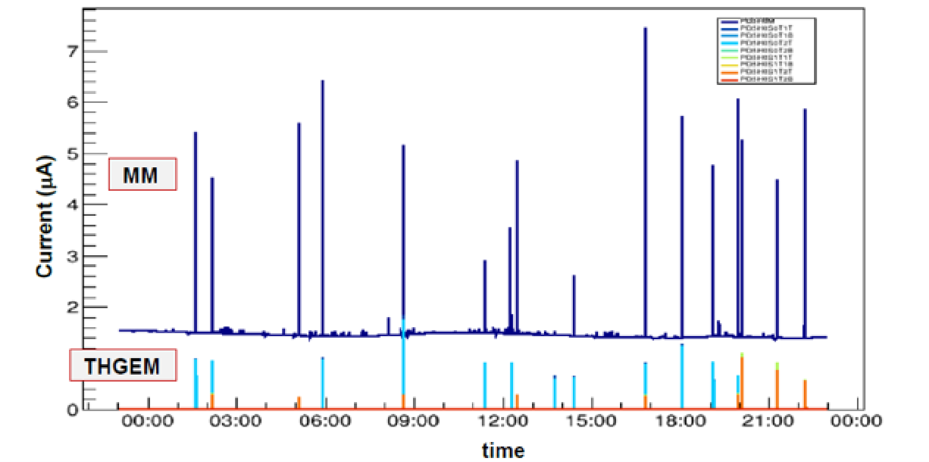
→ Total spark rates (4 detectors): ~10/h



MICROMEGAS, lessons

- MM sparks only when a THGEM spark is observed (not vice versa)
- Recovery time ~1s (our HV arrangement)

- The only real issue: dying channels (pads)
  Local shorts, larger current, no noise issue
  2.5 ‰ developed in 12 months
  Dirty gas / dust from molecular sieves & catalyst?
  Finer mechanical filters added: 7 μm pore



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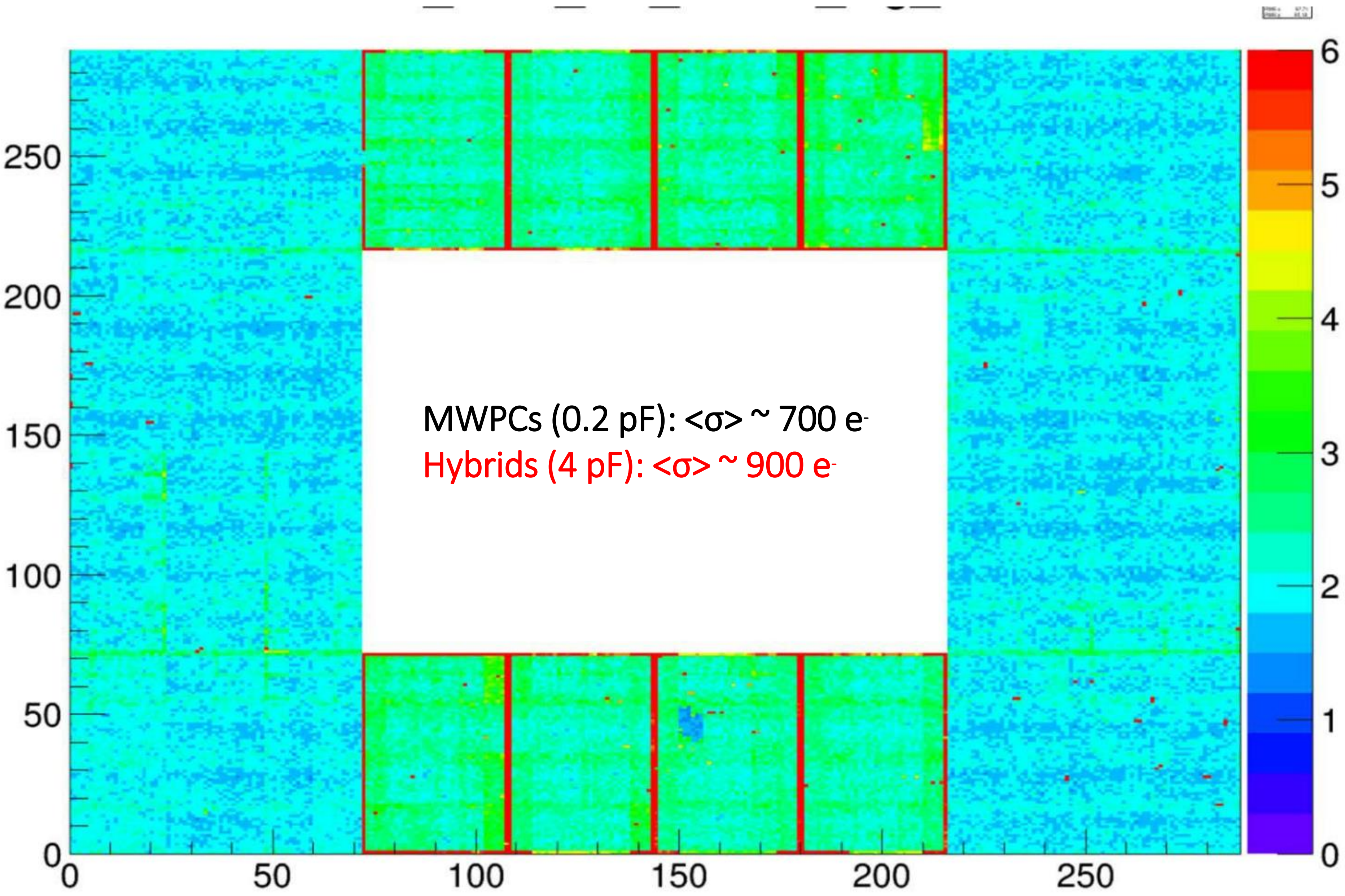
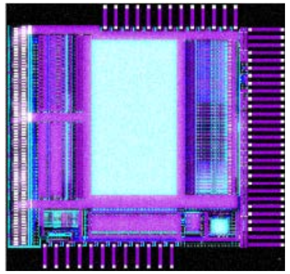


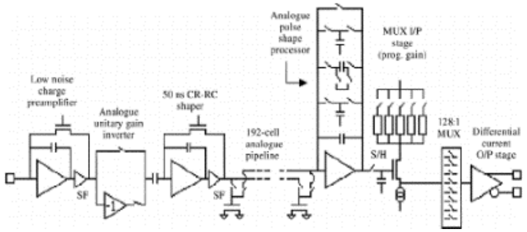
MWPCs (0.2 pF): <σ> ~ 700 e^-

Hybrids (4 pF): <σ> ~ 900 e^-

APV 25 FE chip

Approximately 70 kch.





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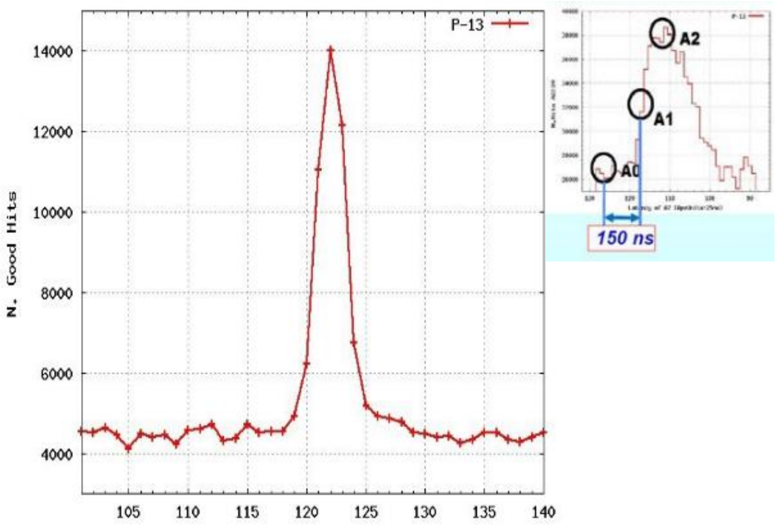
Outline

- Introduction: COMPASS RICH-1 @ CERN
- Why MPGD-based photon detectors and a *change* in the Cherenkov *photo detection technology*
- The architecture of the MPGD-based detector
- Construction, quality control and assembly
- Detector commissioning
- Performance hints

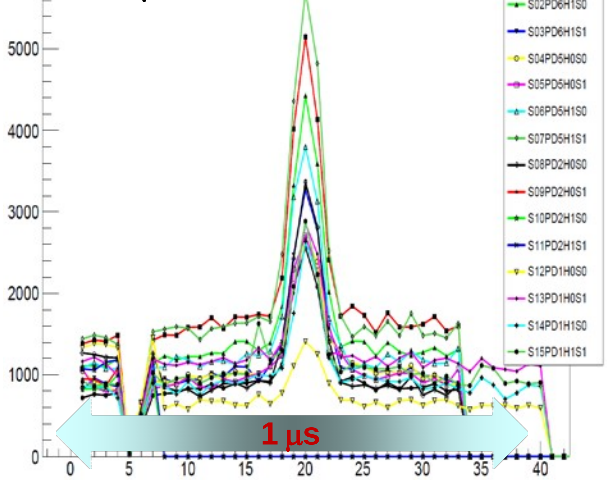
The Cherenkov photon signal detection

Selecting good hit candidates

(A0<5 ADC units, 0.2<A1/A2<0.8)

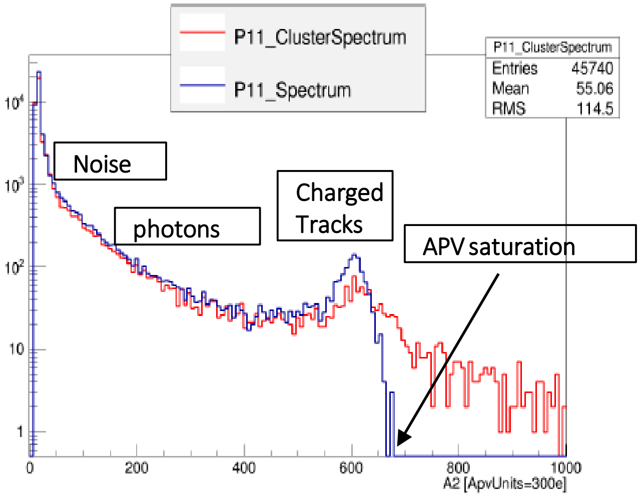


All sectors provide the same time response

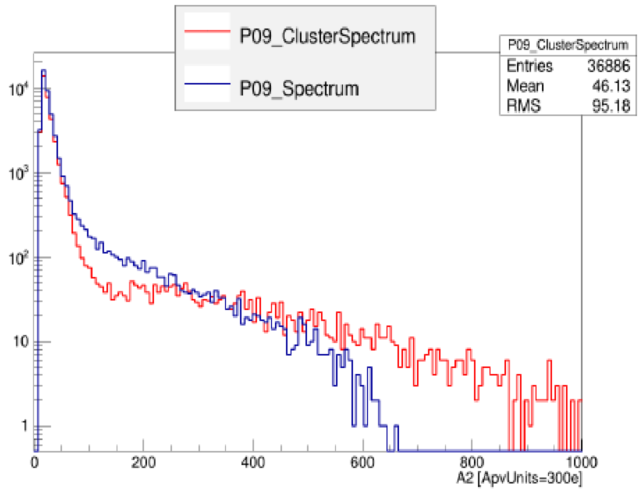


Clusterization to separate charged particle tracks

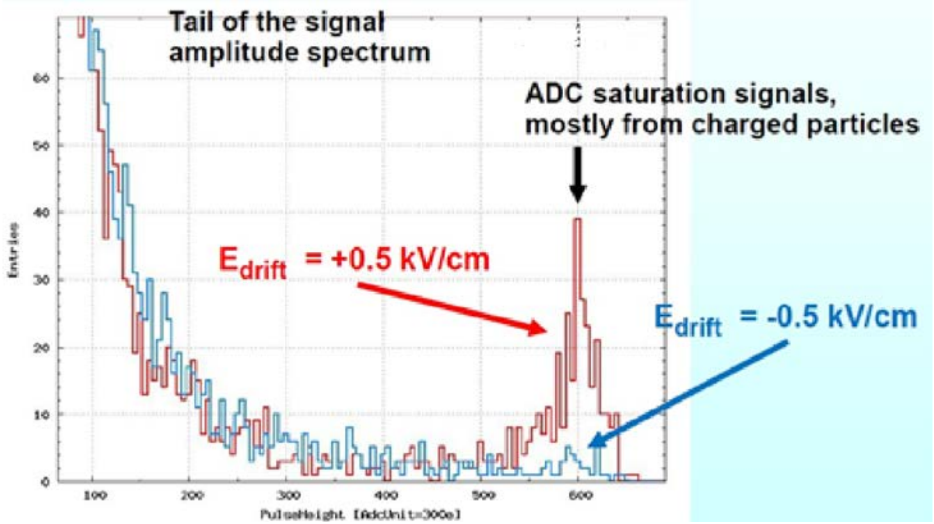
Hybrid MPGD (novel detector)



MWPC (old detector)



Charged particle ionization suppression by strong reversed bias



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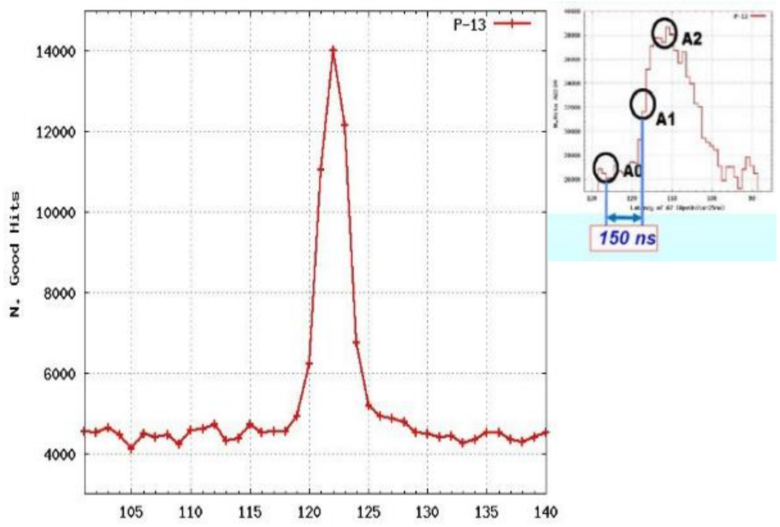
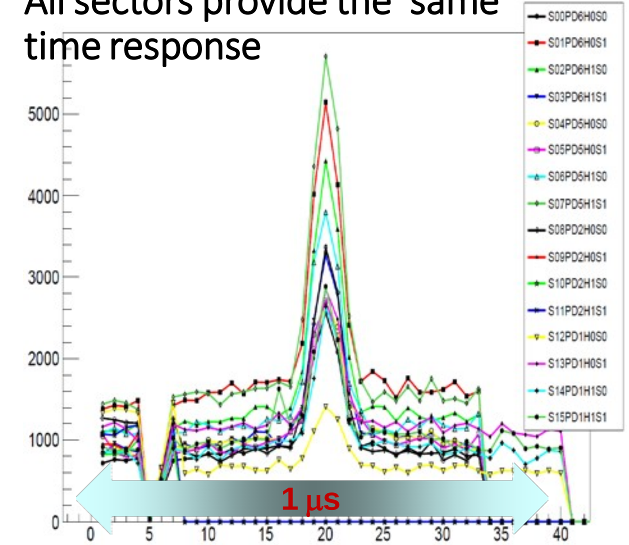
Selecting good hit candidates

(A0<5 ADC units, 0.2<A1/A2<0.8)

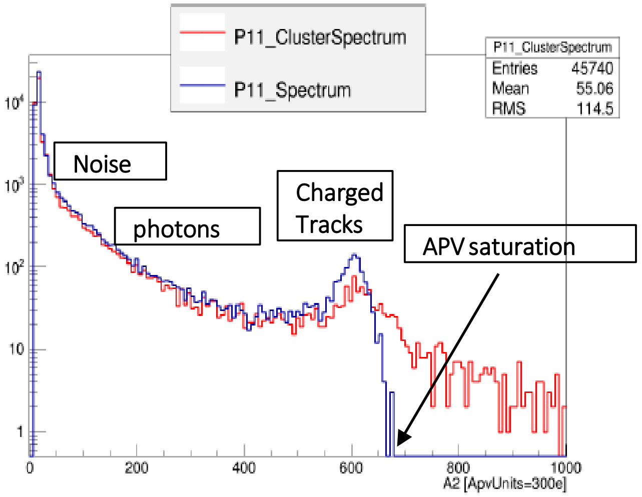


All sectors provide the same time response

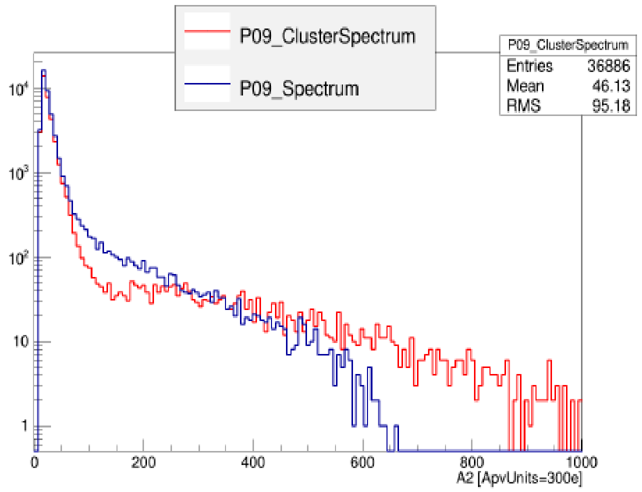


Clusterization to separate charged particle tracks

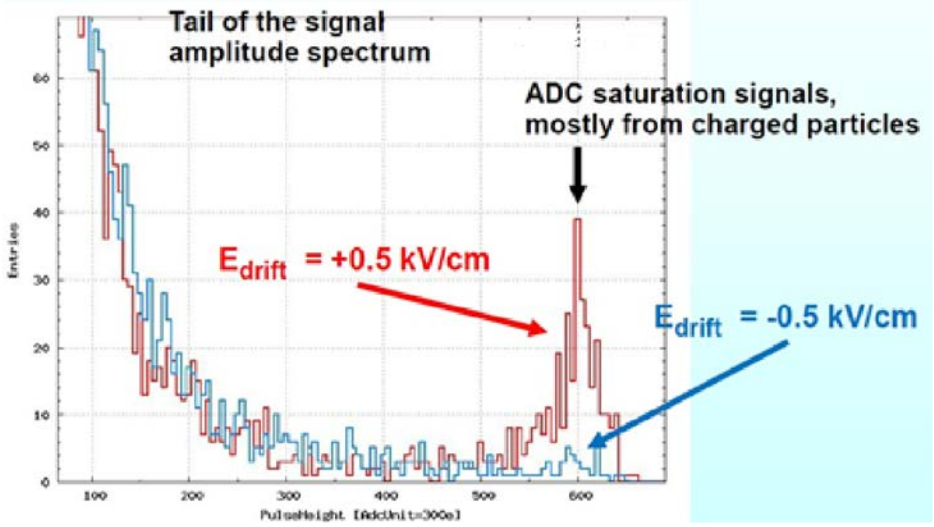
Hybrid MPGD (novel detector)

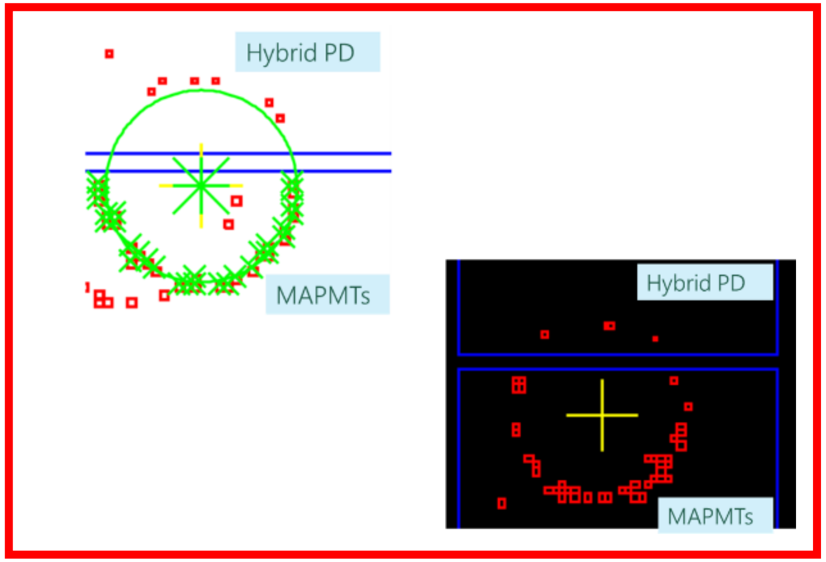


MWPC (old detector)



Charged particle ionization suppression by strong reversed bias





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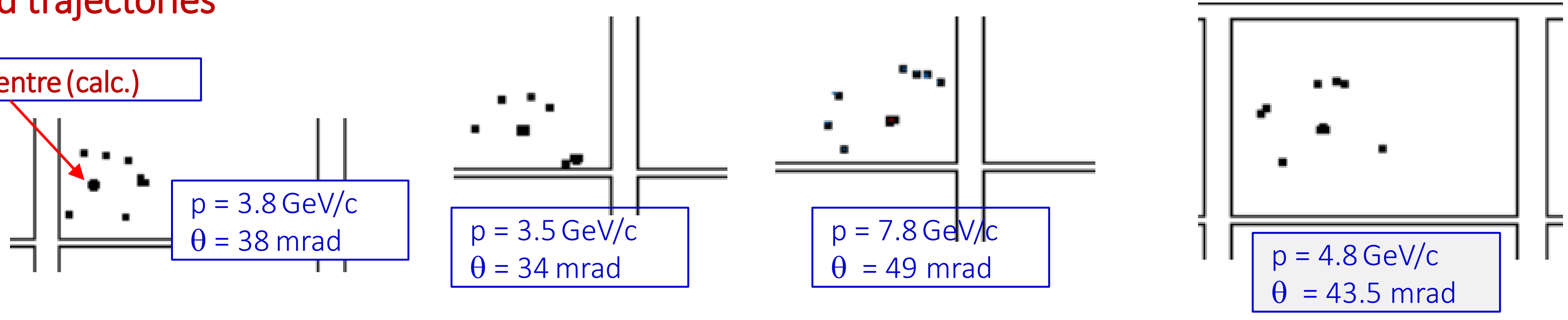
Correlation between photons and trajectories

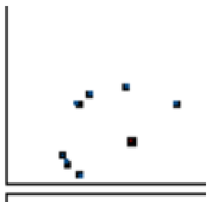
For reference:

θ (β = 1) = 52.5 mrad

Ring centre (calc.)

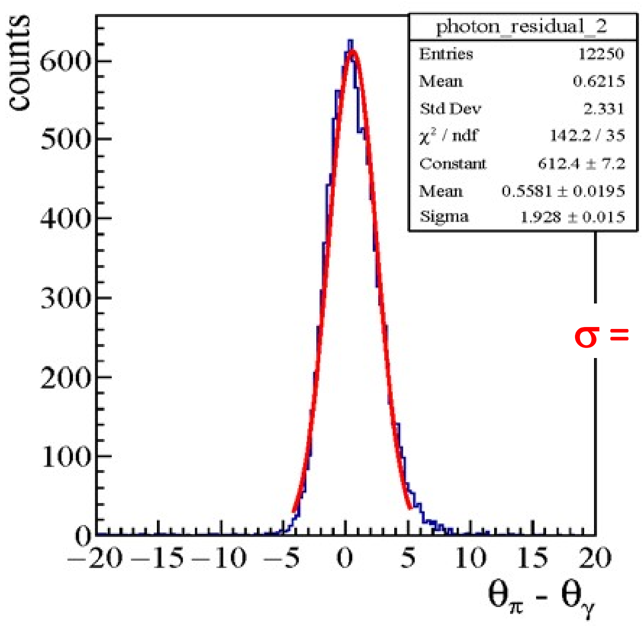


p = 8.4 GeV/c
θ = 49.5 mrad

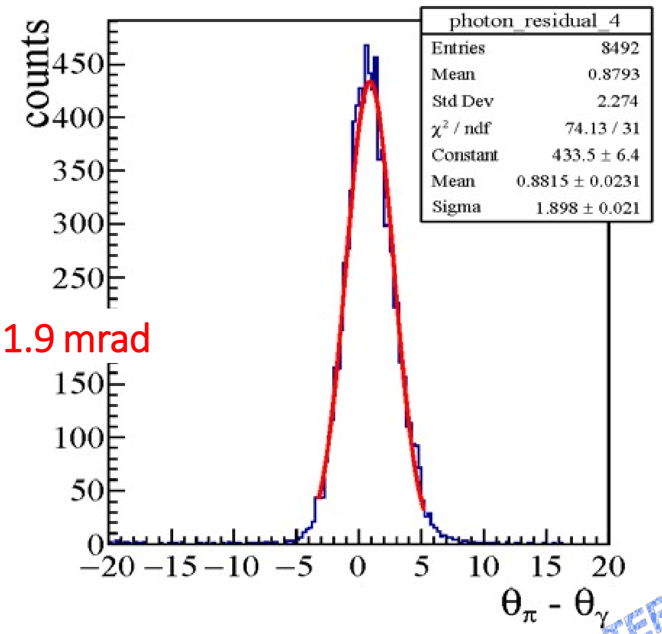


Residual distribution for individual photons (preliminary π-sample):

$$\theta_{\text{calculated}} - \theta_{\text{photon}}$$

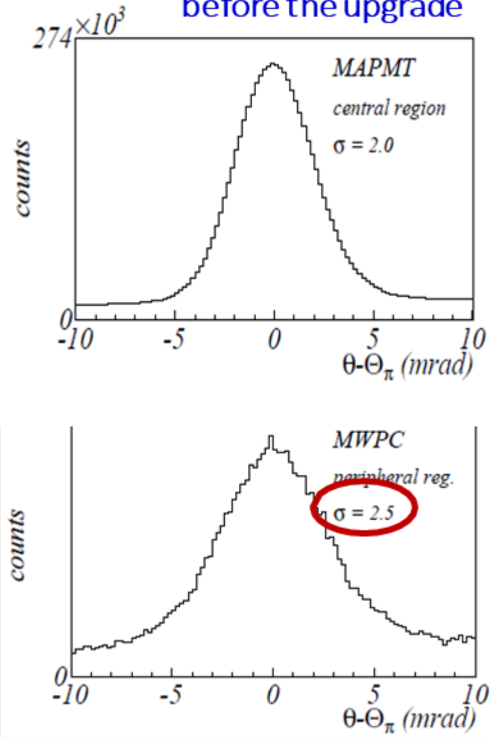


σ = 1.9 mrad



CHARACTERIZATION ON-GOING

before the upgrade



NIM A 631 (2011) 26

Conclusion, remarks

Four hybrid PDs covering 1.4 m^2 were built, tested and mounted on COMPASS RICH and successfully operated during 2016 and 2017 run.

COMPASS RICH-1 is the first RICH where single photon detection is accomplished by MPGDs

Characterization is ongoing!

QUESTIONS ?

Thanks for your attention!

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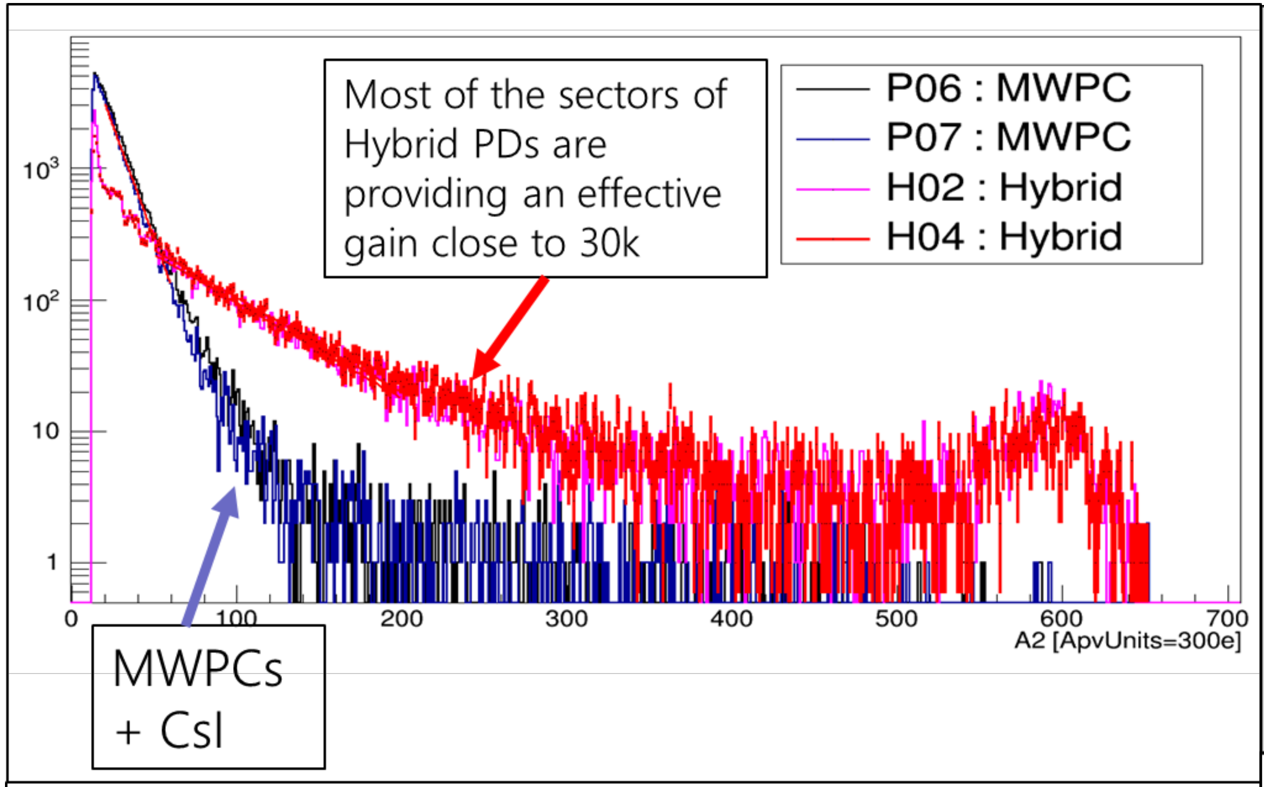
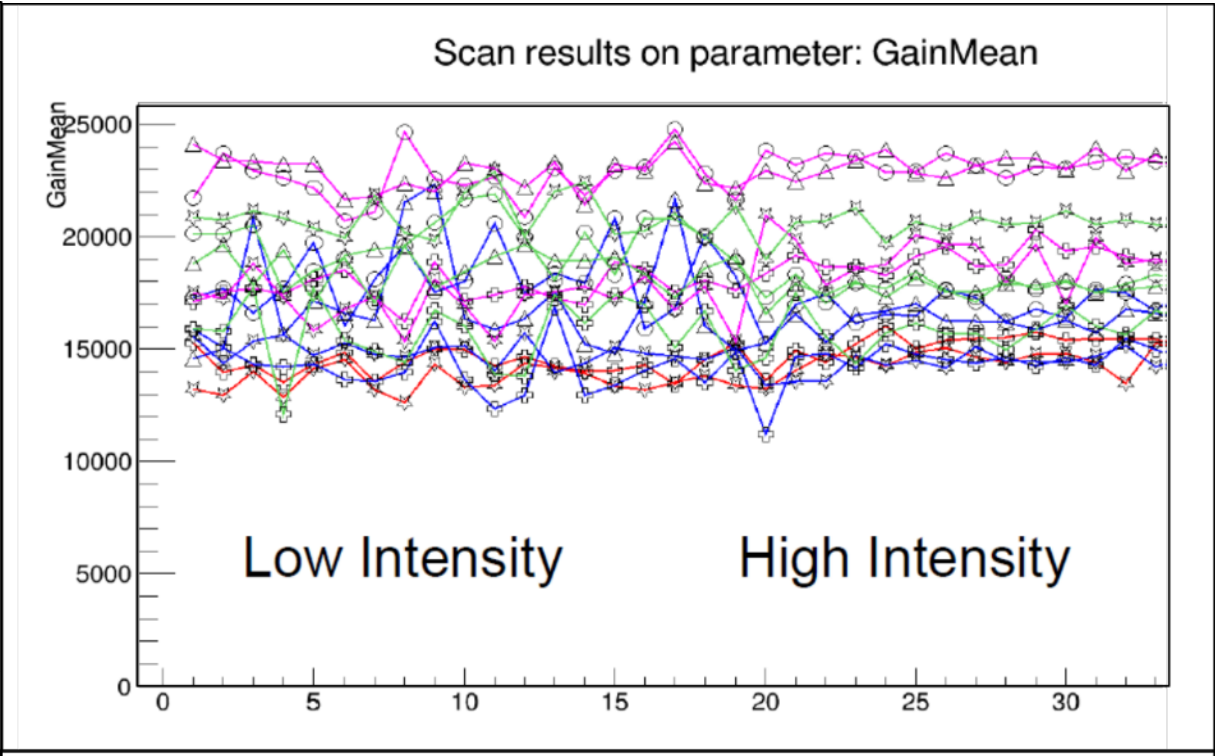
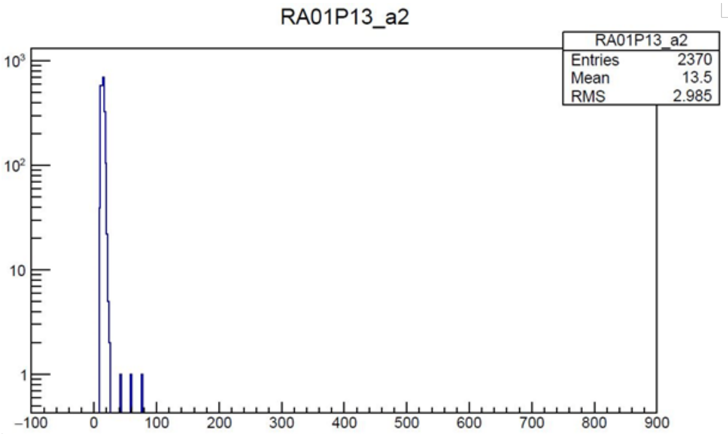
SPARES

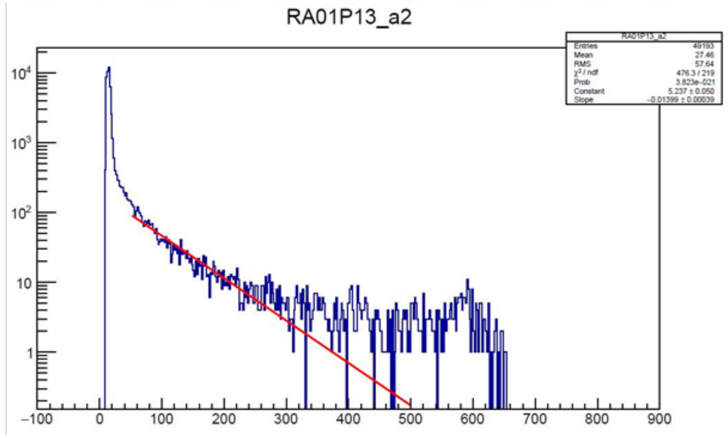


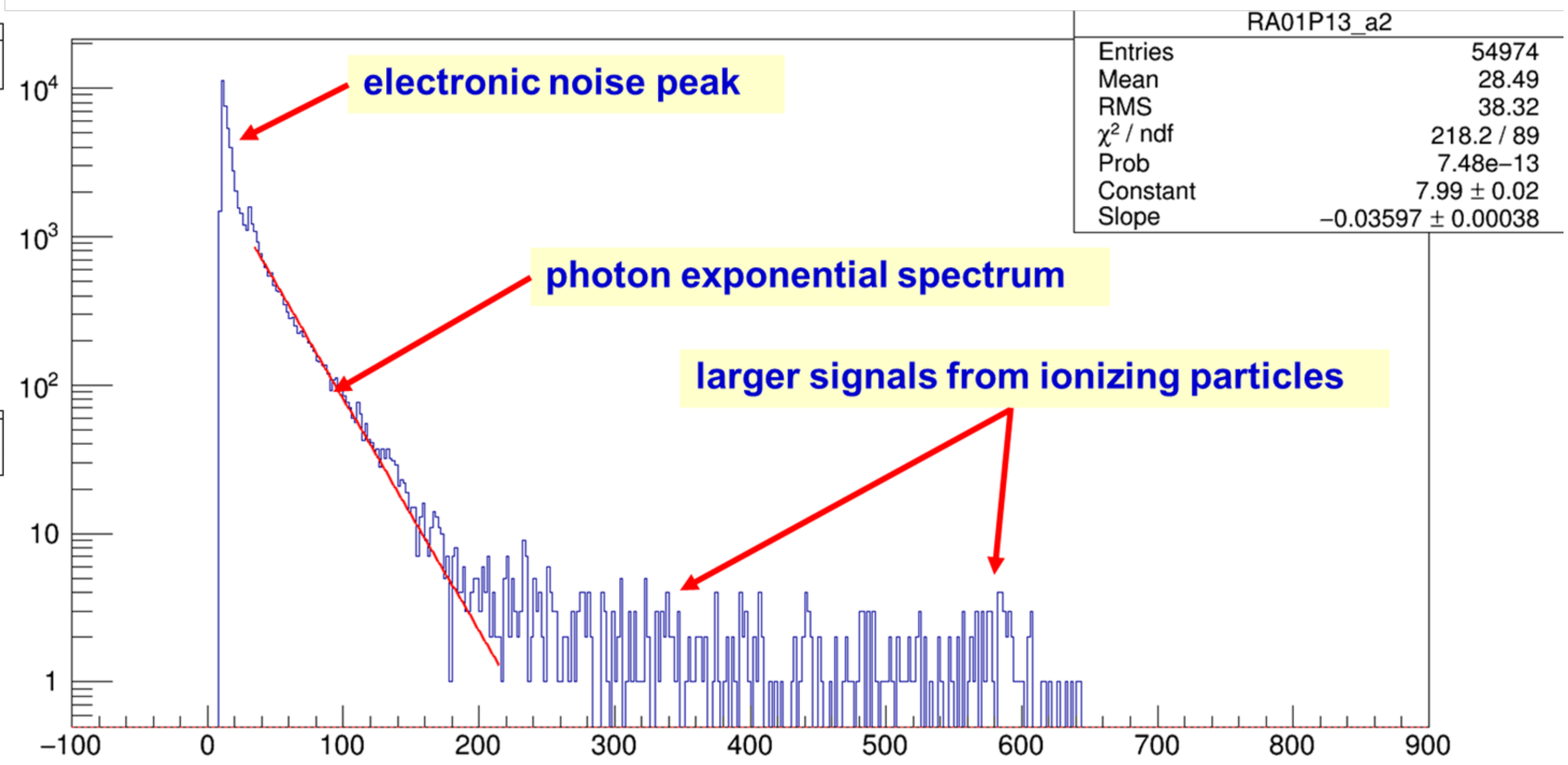
No such a gain in any MPGD in a running experiment.



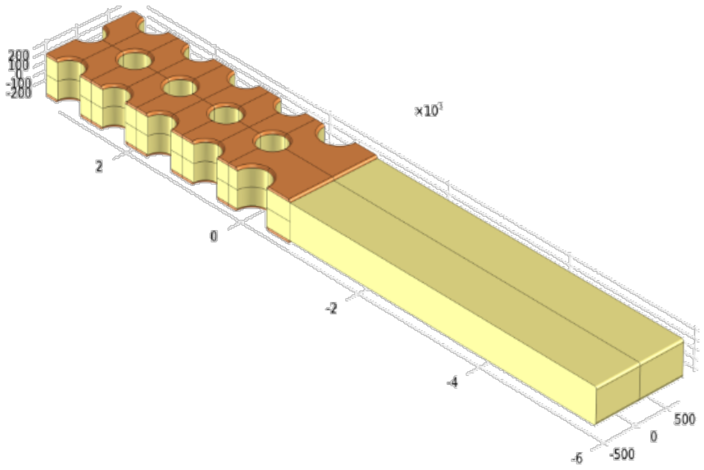
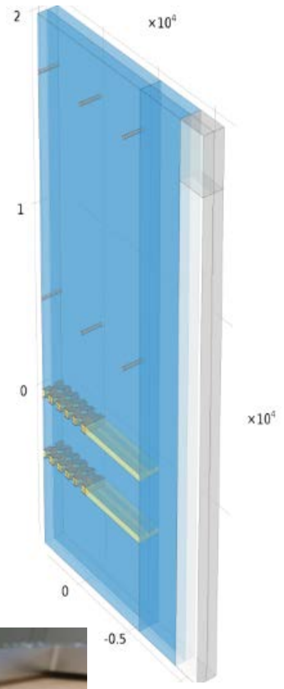
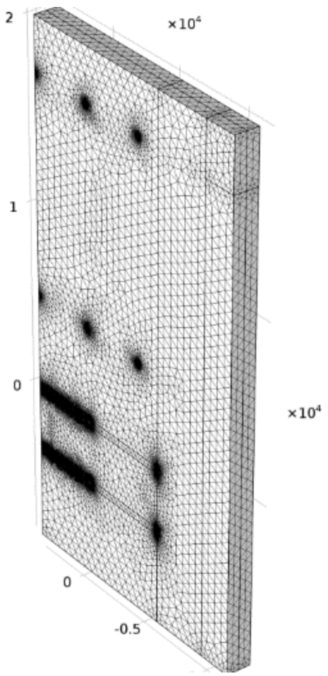
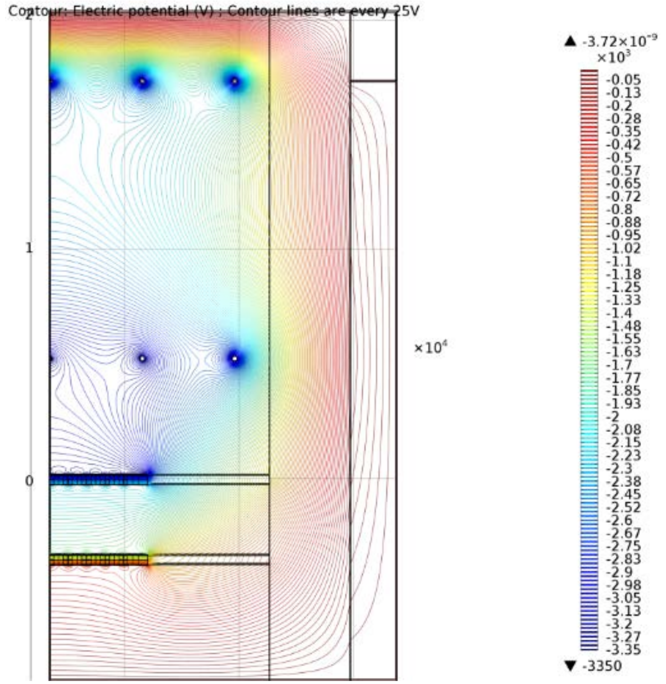
The effective gain does not vary when changing the COMPASS beam intensity by a factor of 2


RA01P13_a2
RA01P13_a2
Entries 2370
Mean 13.5
RMS 2.985
10^3
10^2
10
1
−100 0 100 200 300 400 500 600 700 800 900

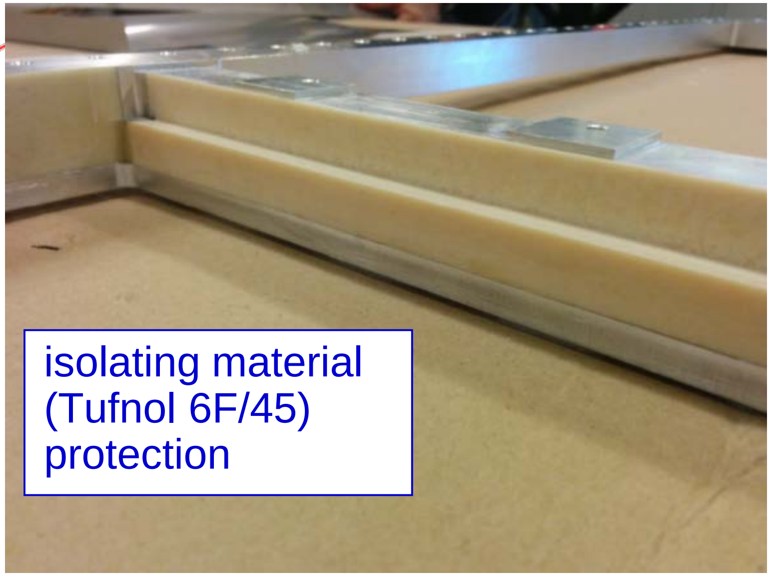

RA01P13_a2
RA01P13_a2
Entries 49193
Mean 27.46
RMS 57.64
χ^2 / ndf 476.3 / 219
Prob 3.823e−021
Constant 5.237 ± 0.050
Slope −0.01399 ± 0.00039
10^4
10^3
10^2
10
1
−100 0 100 200 300 400 500 600 700 800 900


RA01P13_a2
Entries 54974
Mean 28.49
RMS 38.32
χ^2 / ndf 218.2 / 89
Prob 7.48e−13
Constant 7.99 ± 0.02
Slope −0.03597 ± 0.00038
electronic noise peak
photon exponential spectrum
larger signals from ionizing particles
10^4
10^3
10^2
10
1
−100 0 100 200 300 400 500 600 700 800 900

Field shaping near the detector borders

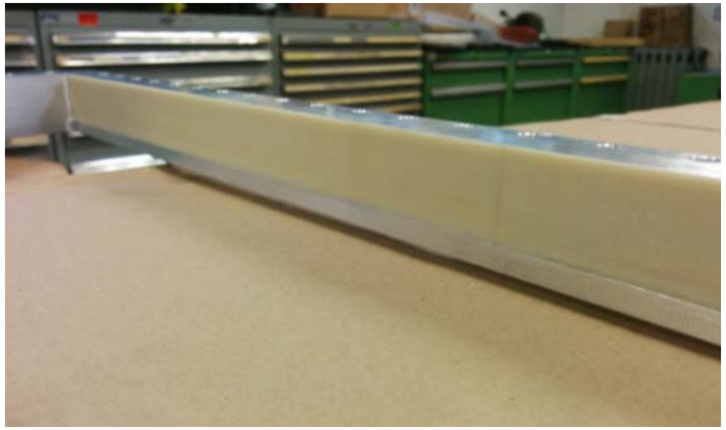





large field values at the chamber edges and on the guard wires

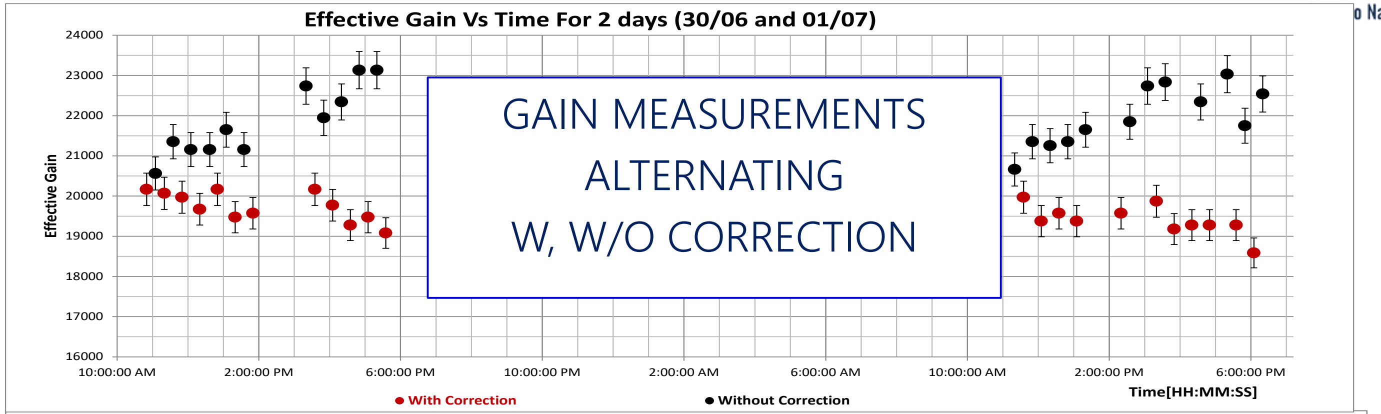


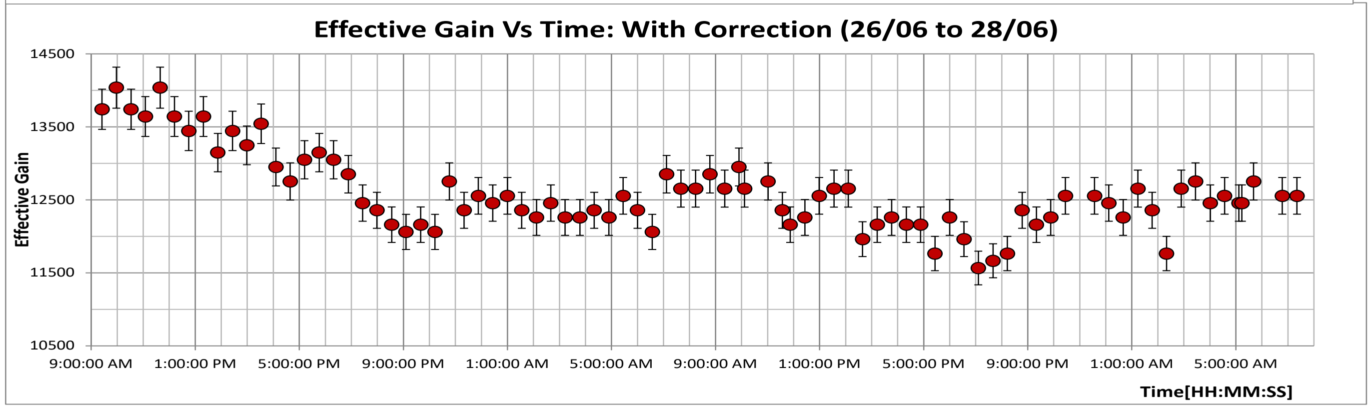
isolating material (Tufnol 6F/45) protection

Field shaping electrodes in the isolating material protections of the chamber frames

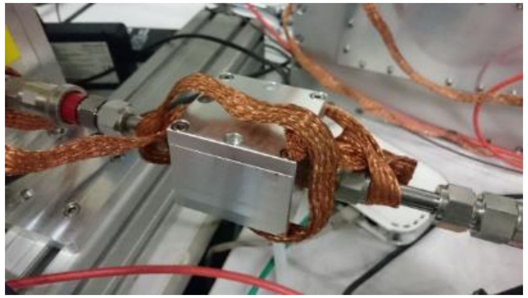


P/T correction, the method



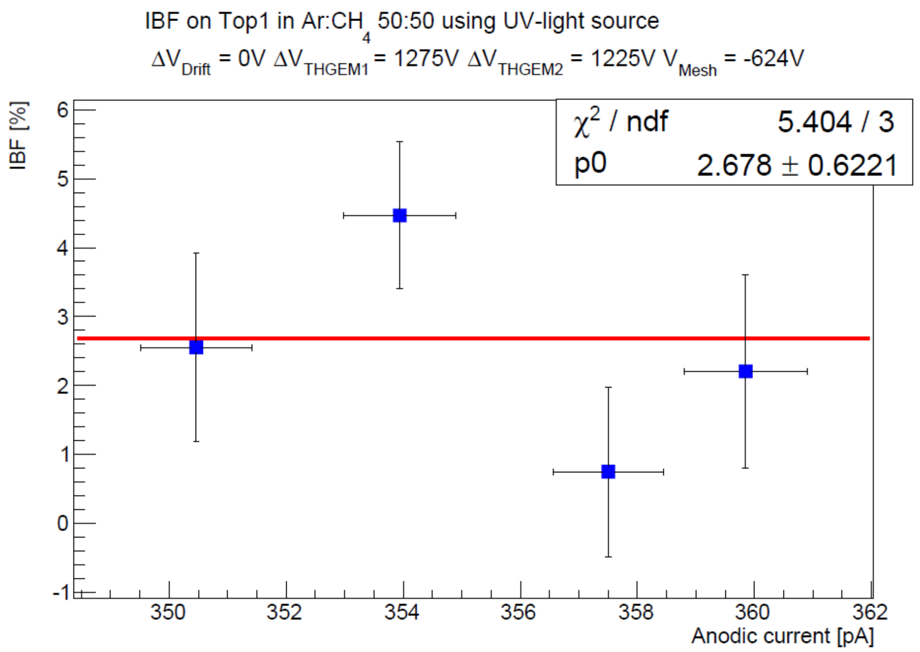


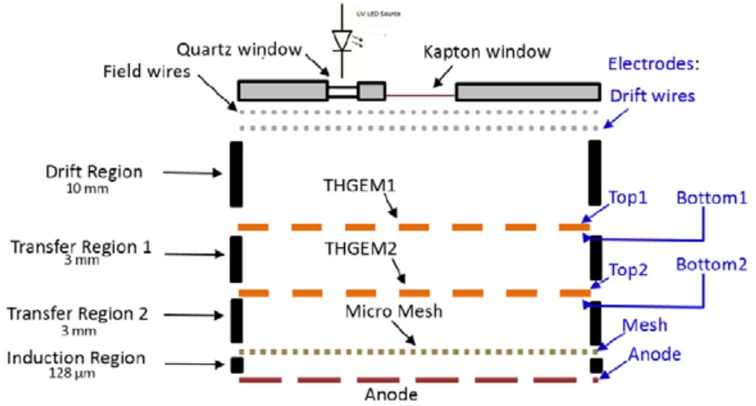
p, T sensor at gas input and output



Correction of Voltage $f(P,T)$ LabVIEW based system fully automated + logging

$$V_{calc} = V_0\left(1 + \alpha\frac{P - P_0}{P_0} - \beta\frac{T - T_0}{T_0}\right)$$

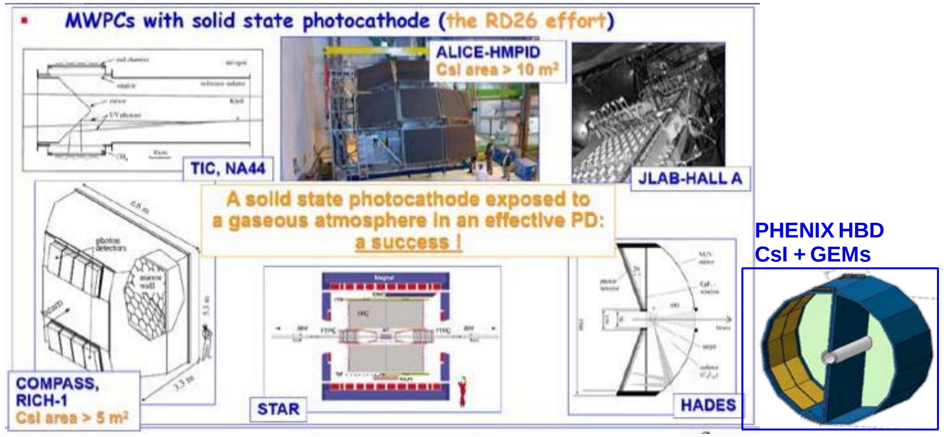




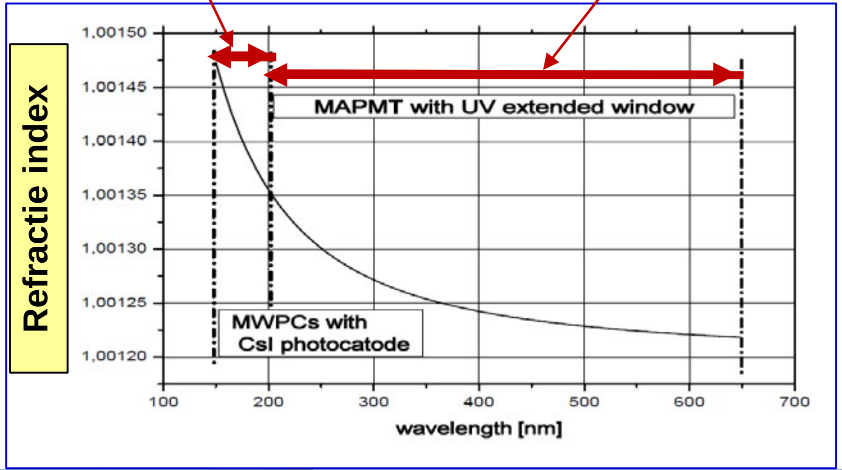
Trieste home-built picoammeters

The result of the direct measurement: 3% nicely matches the expectation

CsI gasous sensors used in several Cherenkov detectors



(n-1) r.m.s (assuming Frank and Tamm):



COMPASS RICH-1, gas transparency

- gas cleaning by on-line filters,
- separate functions:
  - Cu catalyst, ~ 40^0C for O_2
  - 5A molecular sieve, ~ 10^0C for H_2O