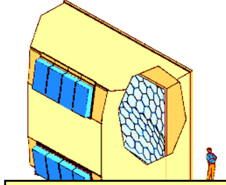
The MPGD-Based Photon Detectors for the upgrade of COMPASS RICH-1 and beyond

S. Dalla Torre

INFN - TRIESTE

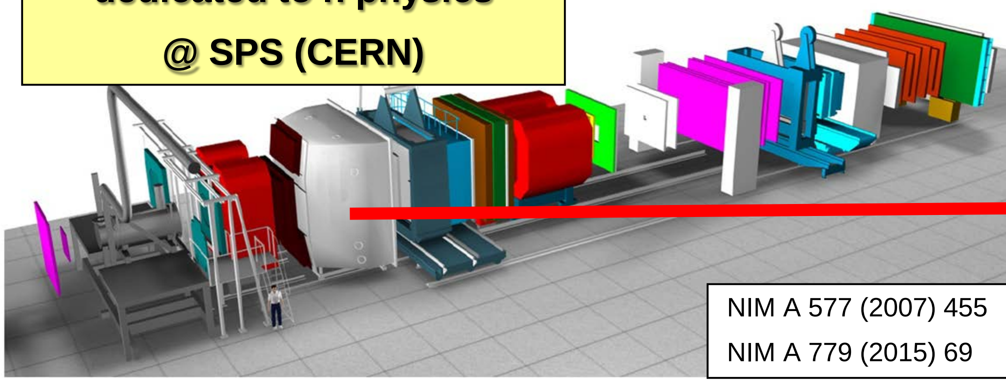
on behalf of the COMPASS RICH group

COMPASS RICH-1

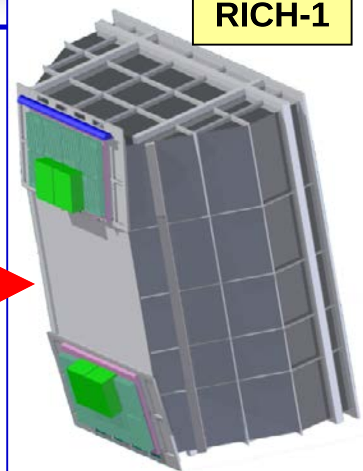


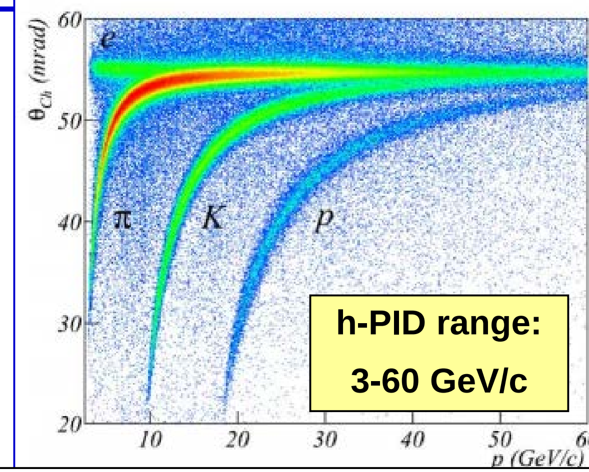
COMPASS Spectrometer dedicated to h physics

@ SPS (CERN)



NIM A 577 (2007) 455
NIM A 779 (2015) 69



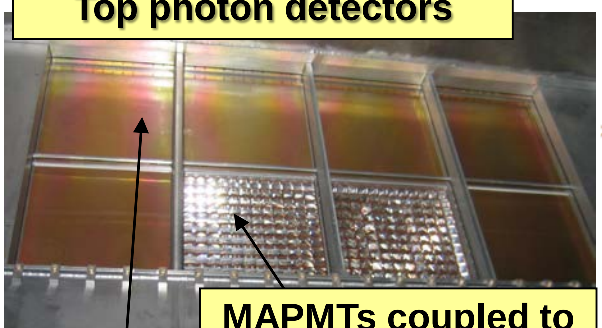


h-PID range:

3-60 GeV/c

NIM A 553 (2005) 215; NIM A(2008) 371; NIM A(616) (2010) 21; NIM A 631 (2011) 26

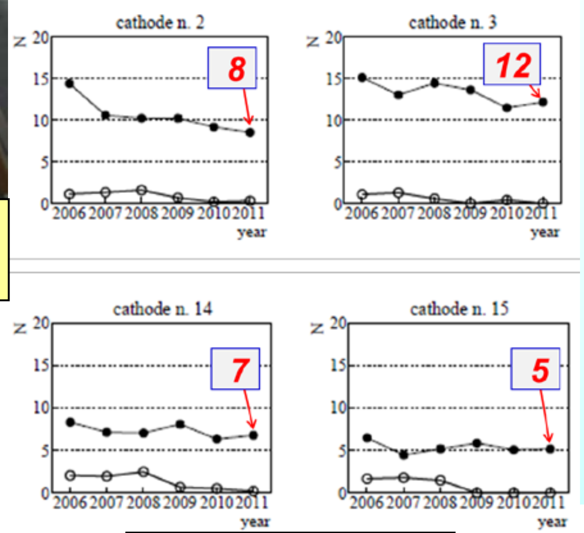
Top photon detectors



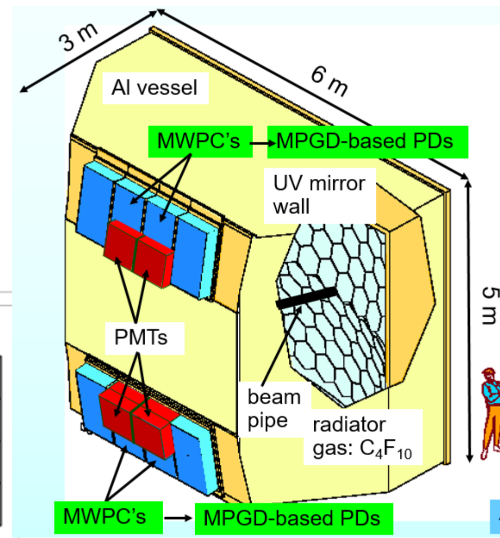
MAPMTs coupled to lens telescopes

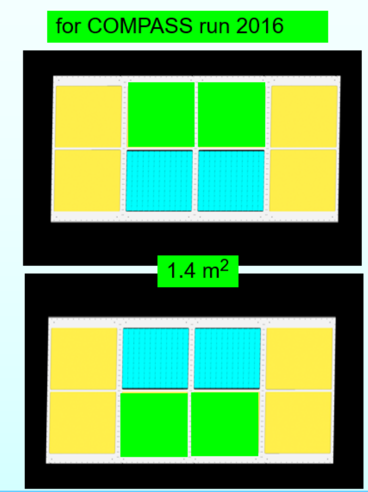
MWPCs+CsI (from RD26): successful but performance limitations, in particular for the 4 central chambers

n. of ph.s @ β = 1

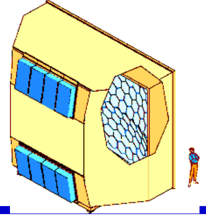


JINST 9 (2014) P01006





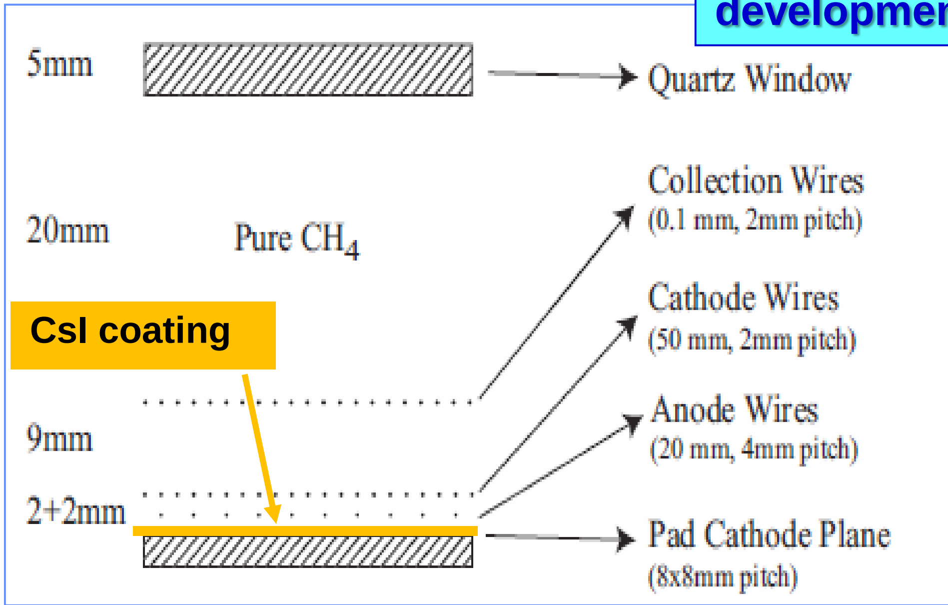
4 new detectors of 600 mm x 600 mm



PHOTON DETECTORS so far

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*

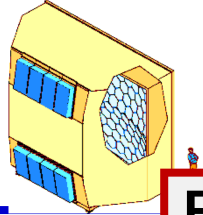
→ Low gain: a few times 10^4 (effective gain: <1/2)

→ "slow" detector

To overcome the limitations:

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

→ MPGDs



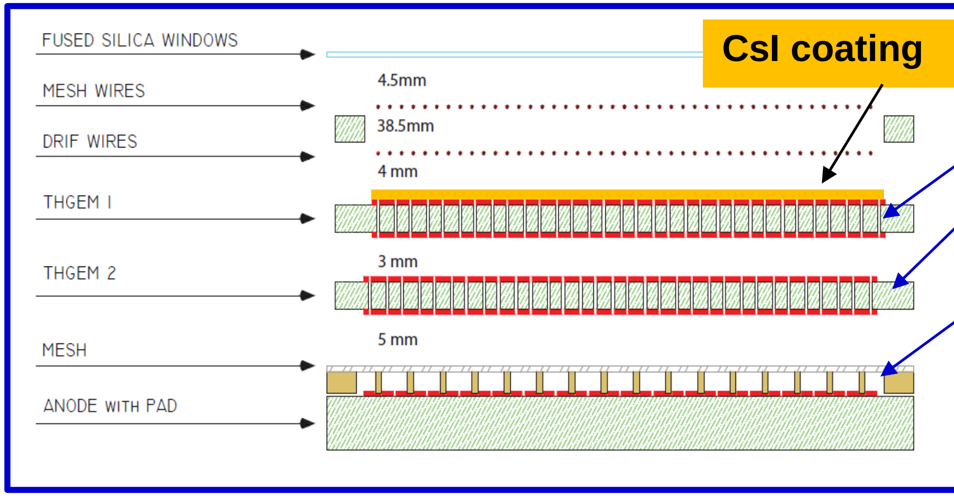
DETECTOR ARCHITECTURE

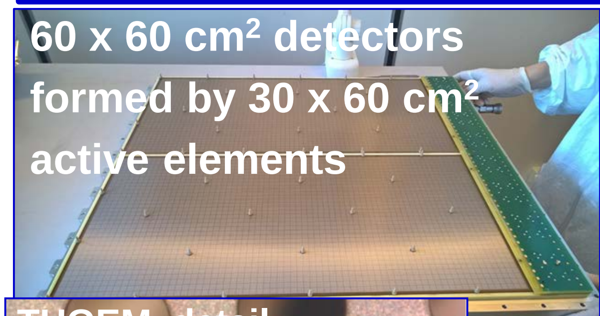
Following a 7-year R&D

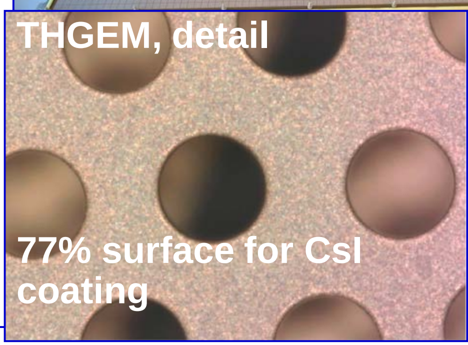
THGEMs bock photon feedback

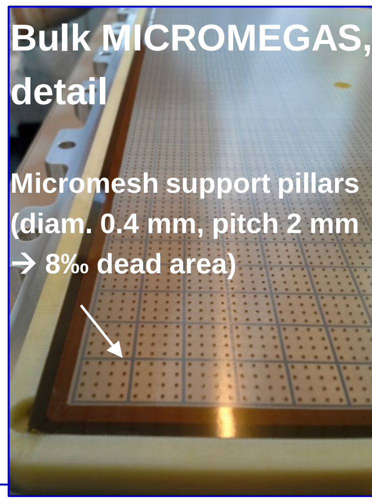
Resistive* MICROMEGAS by *bulk technology

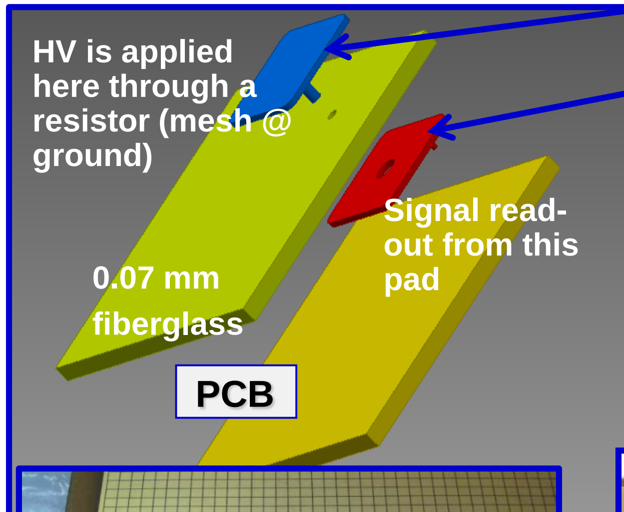
- **traps the ions**
- **~100 ns signal formation**

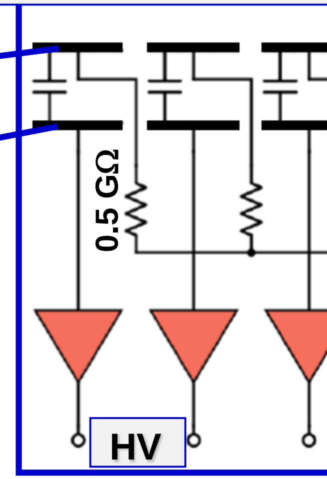


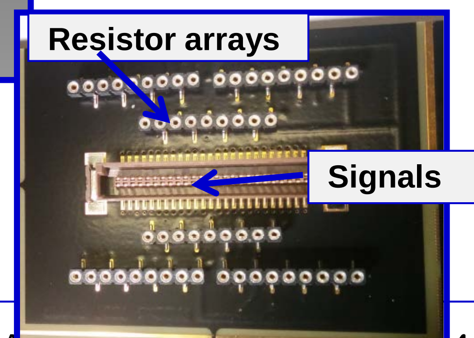


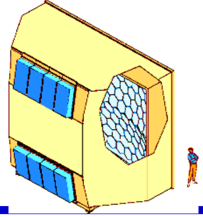






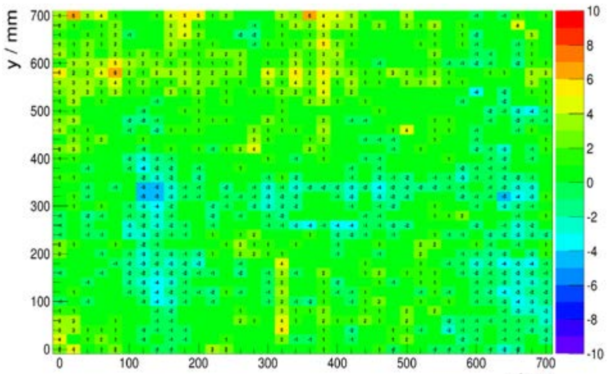




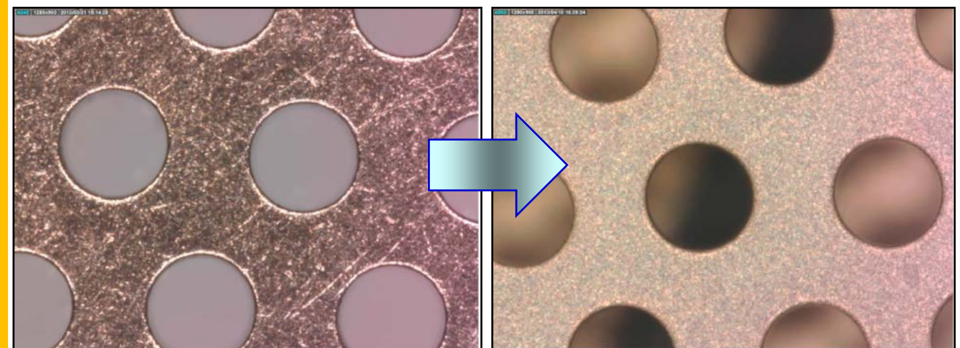


COMPONENT QA in a nutshell

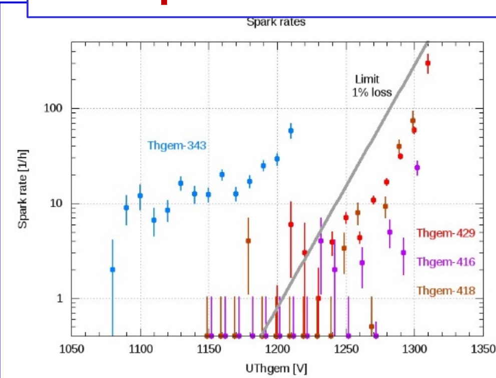
Measurement of the raw material thickness before the THGEM Production, accepted:
± 15 μm ↔ gain uniformity σ < 7%

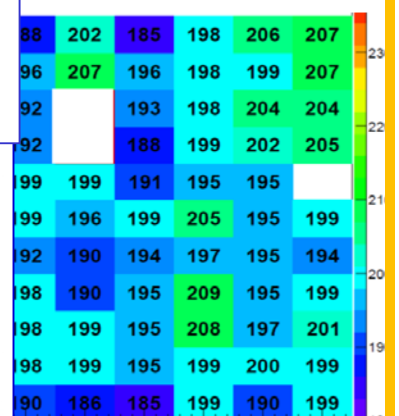


THGEM polishing with an "ad hoc" protocol setup by us:
>90% break-down limit obtained

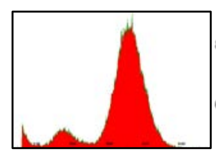


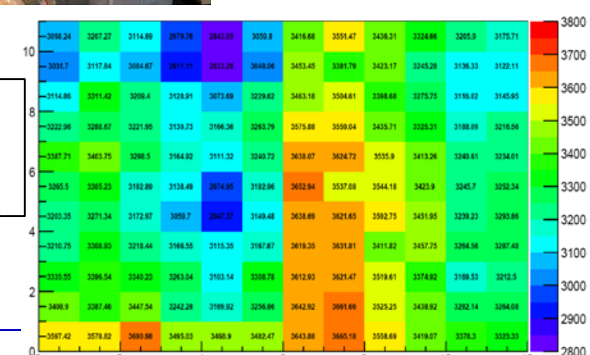
X-ray THGEM test to access gain uniformity (<7%) and spark behaviour



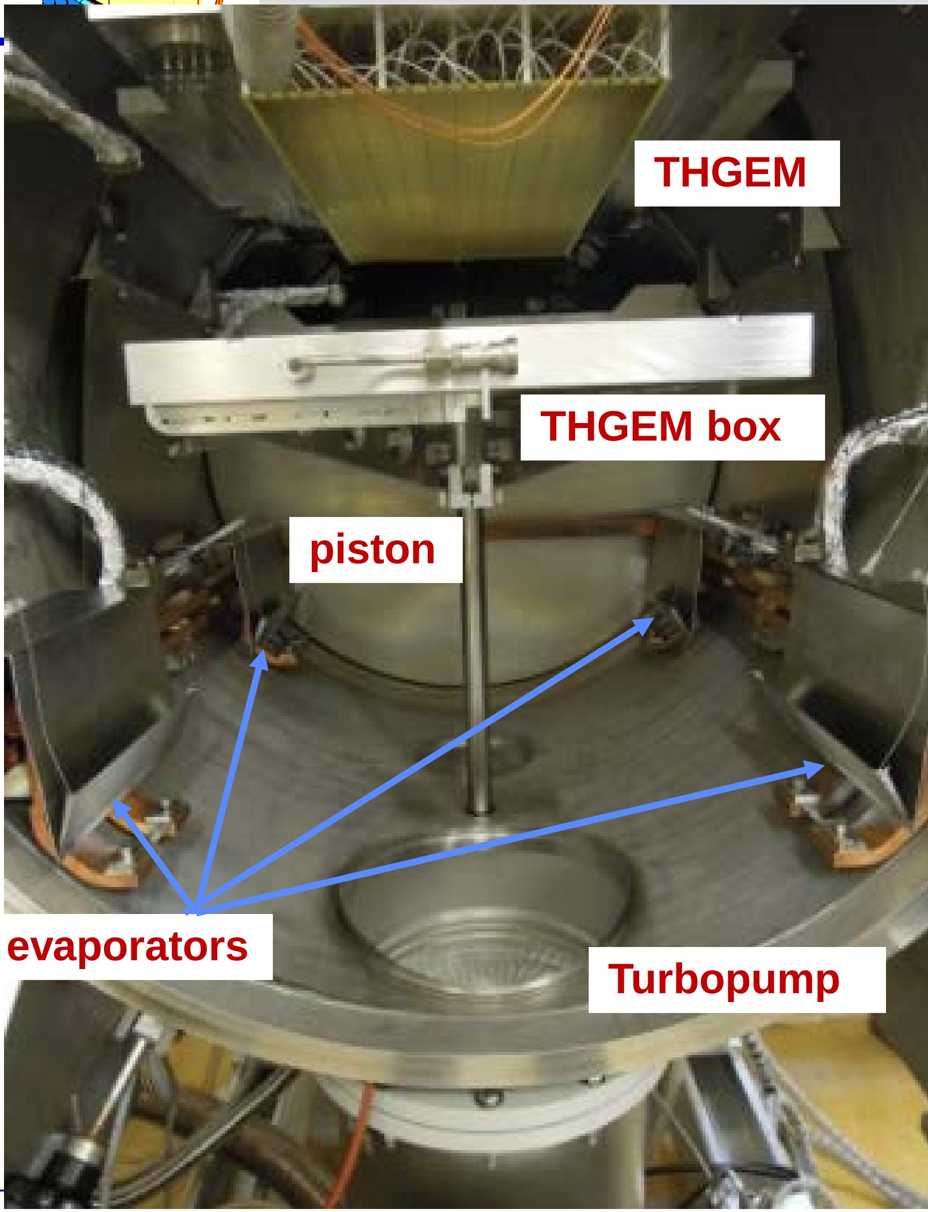


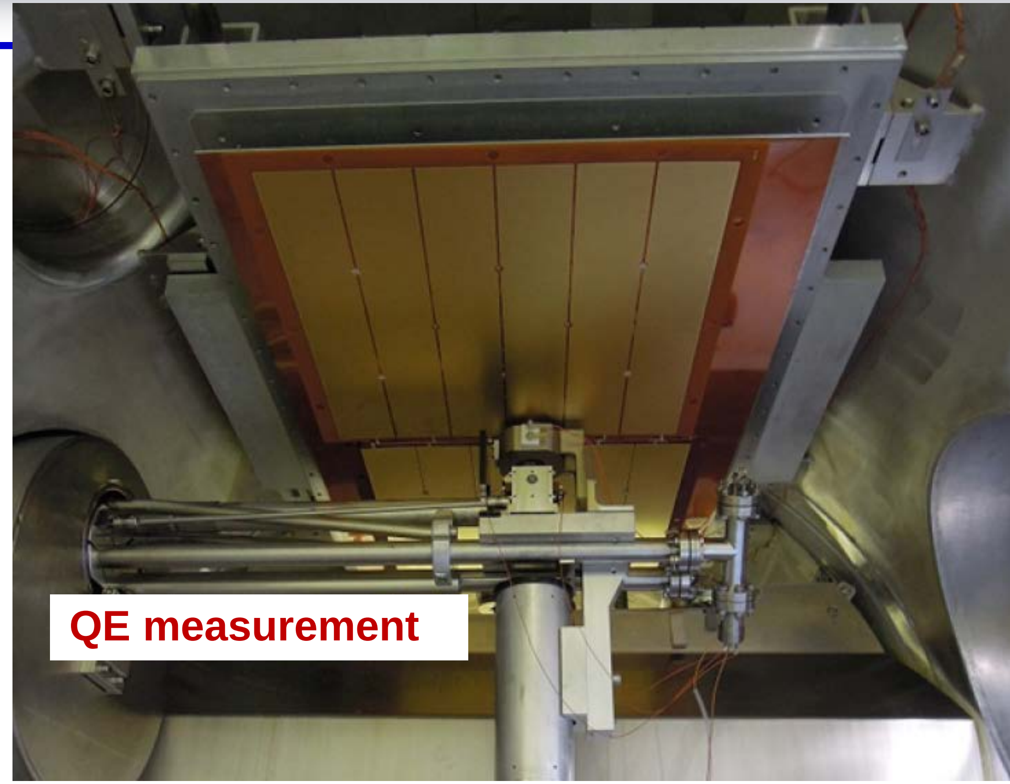
X-ray MM test to access integrity and gain uniformity (<5%)





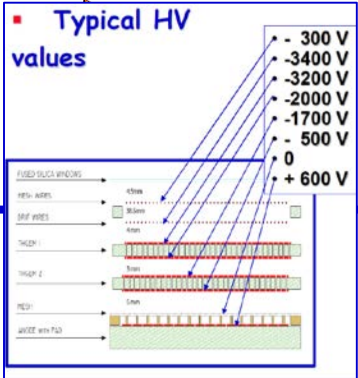
CsI coating for THGEMS



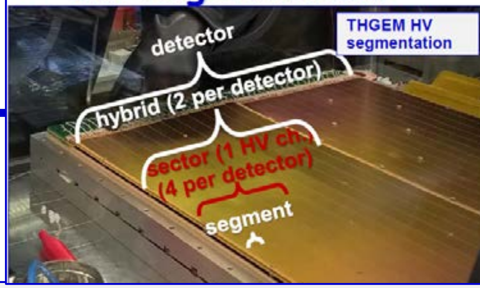


QE uniformity

- 3 % r.m.s. within a photocathode
- 10 % r.m.s. among photocathodes
- mean value: 93% of reference



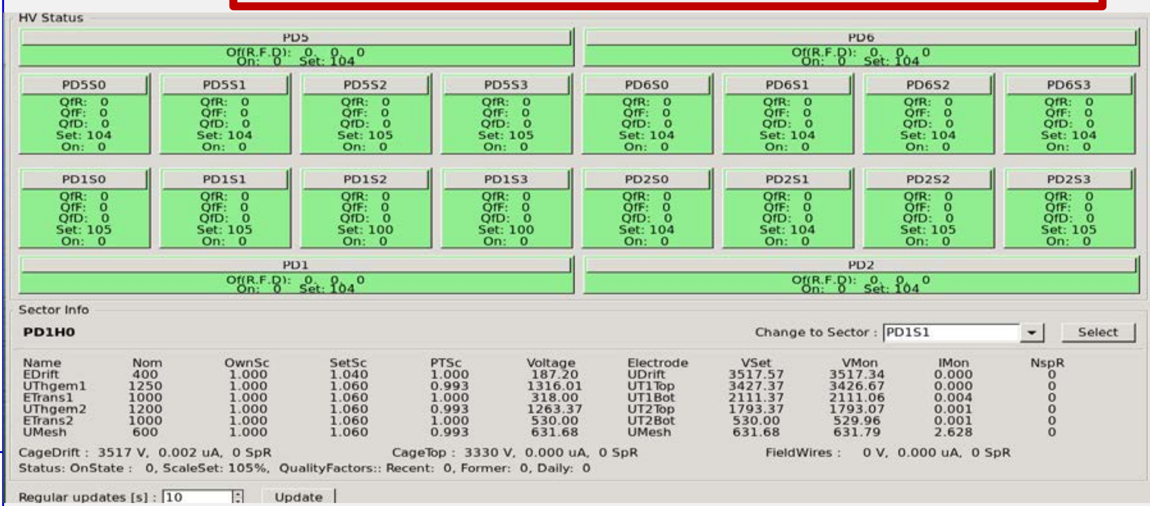
HV segmentation



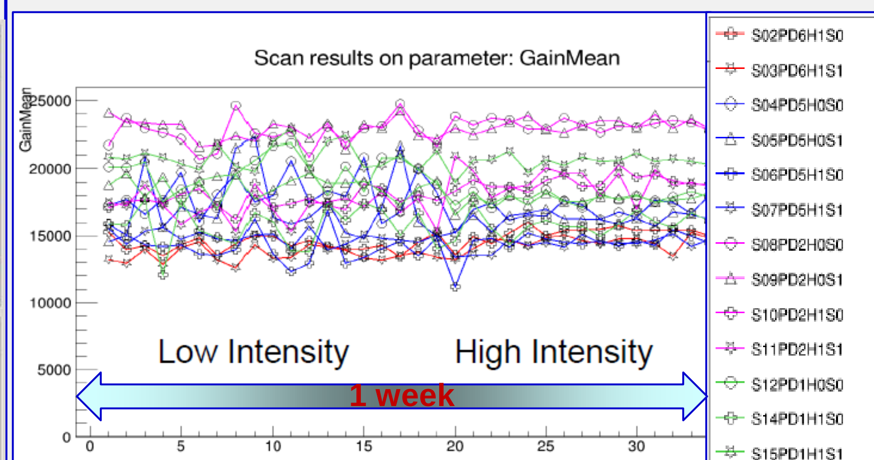
HV CONTROL

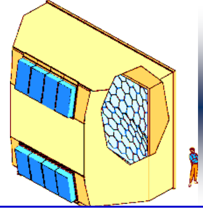
In total 136 HV channels
<u>with correlated values</u>

- **Hardware, commercial by CAEN**
- **HV control**
  - **<u>Custom-made</u> (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**

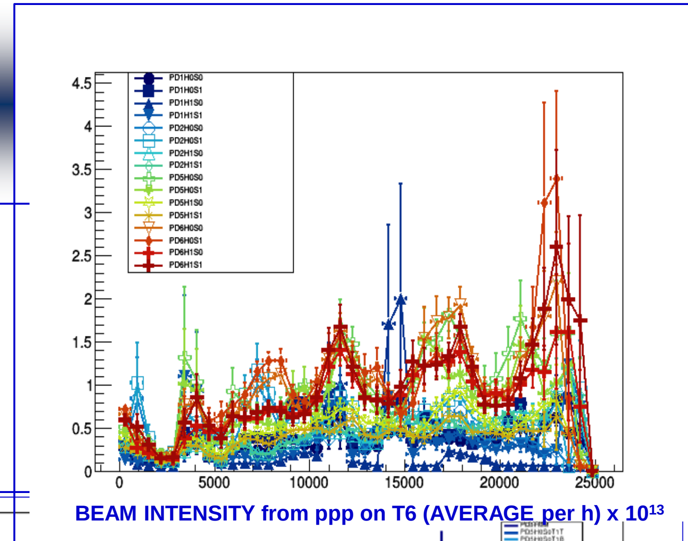


- **Gain stability vs P, T:**
  - **G = G(V, T/P)**
  - **Enhanced in a multistage detector**
  - **ΔT = 1°C → ΔG ≈ 12 %**
  - **ΔP = 5 mbar → ΔG ≈ 18 %**
- **THE WAY OUT:**
  - **Compensate T/P variations by V**
    → Gain stability at 5% level

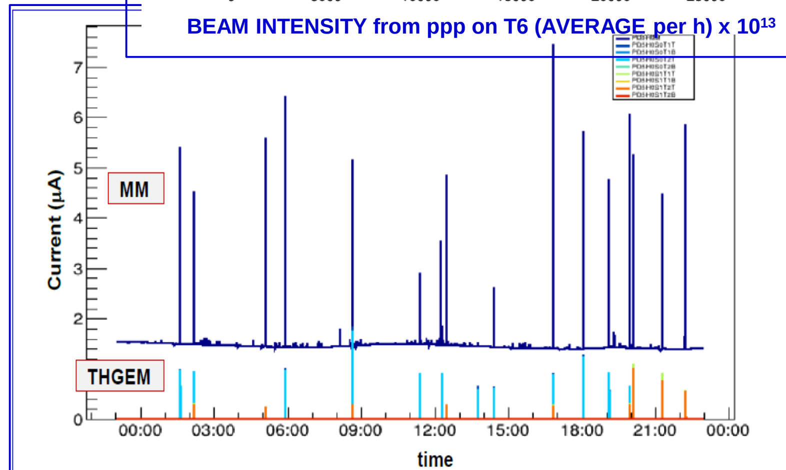




MAIN DETECTOR FIGURES



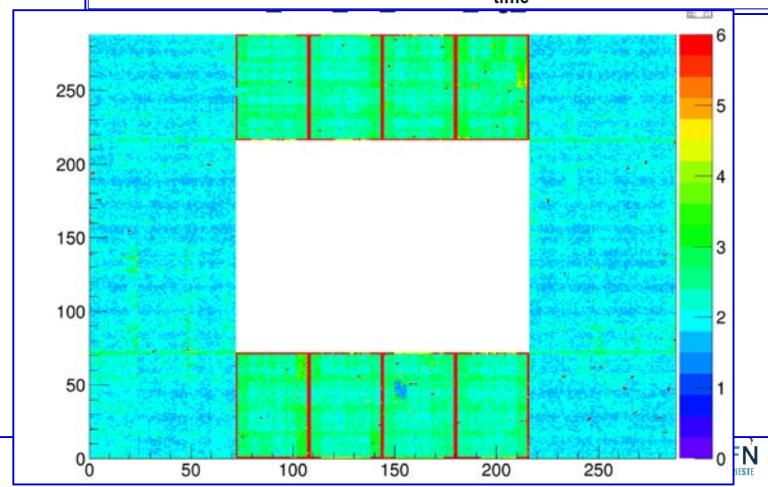
- **Current sparks in THGEMs**
  - **Rate < 1/h per detector**
  - **Recovery time: ~ 10 s**
  - **Fully correlated between the two layers**
  - **Mild dependence on beam intensity**

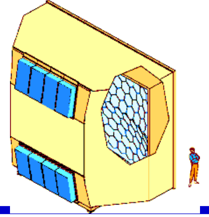


- **Current sparks in MICROMEGAS**
  - **Induced by THGEMs**
  - **Recovery time: ~1 s**

- **Ion backflow: ~ 3% level**

- **Noise: 900 electron equivalent (r.m.s.)**
  - **Channel C : 4pF**





RINGS !!!

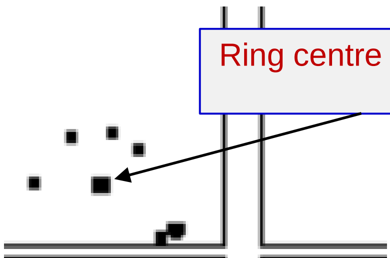
Correlation between photons and trajectories

For reference:

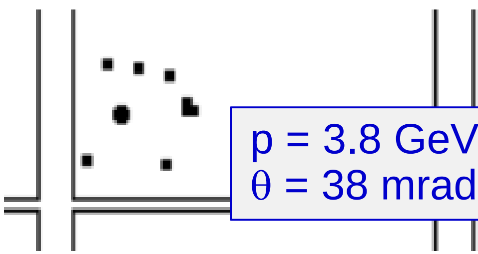
θ (β = 1) = 52.5 mrad

From Event Display

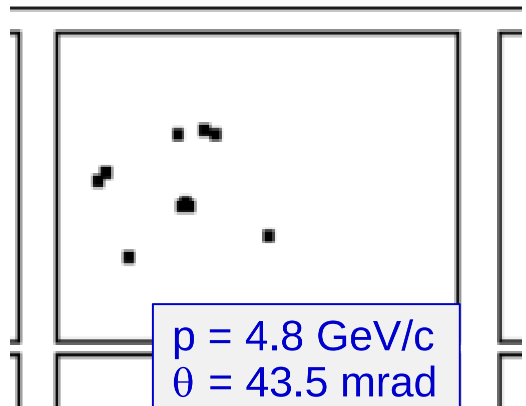
- **Ring centre calculated from particle trajectory**
- **Detected photoelectrons : hits on the sensors**



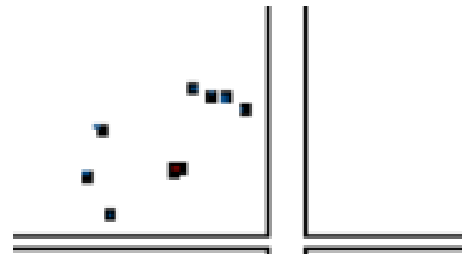
p = 3.5 GeV/c
θ = 34 mrad (π hypothesis)



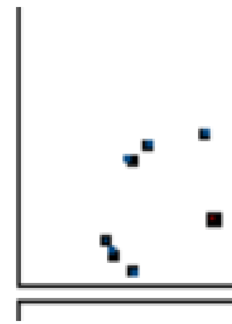
p = 3.8 GeV/c
θ = 38 mrad



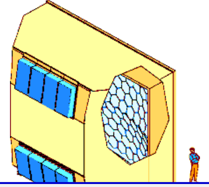
p = 4.8 GeV/c
θ = 43.5 mrad



p = 7.8 GeV/c
θ = 49 mrad

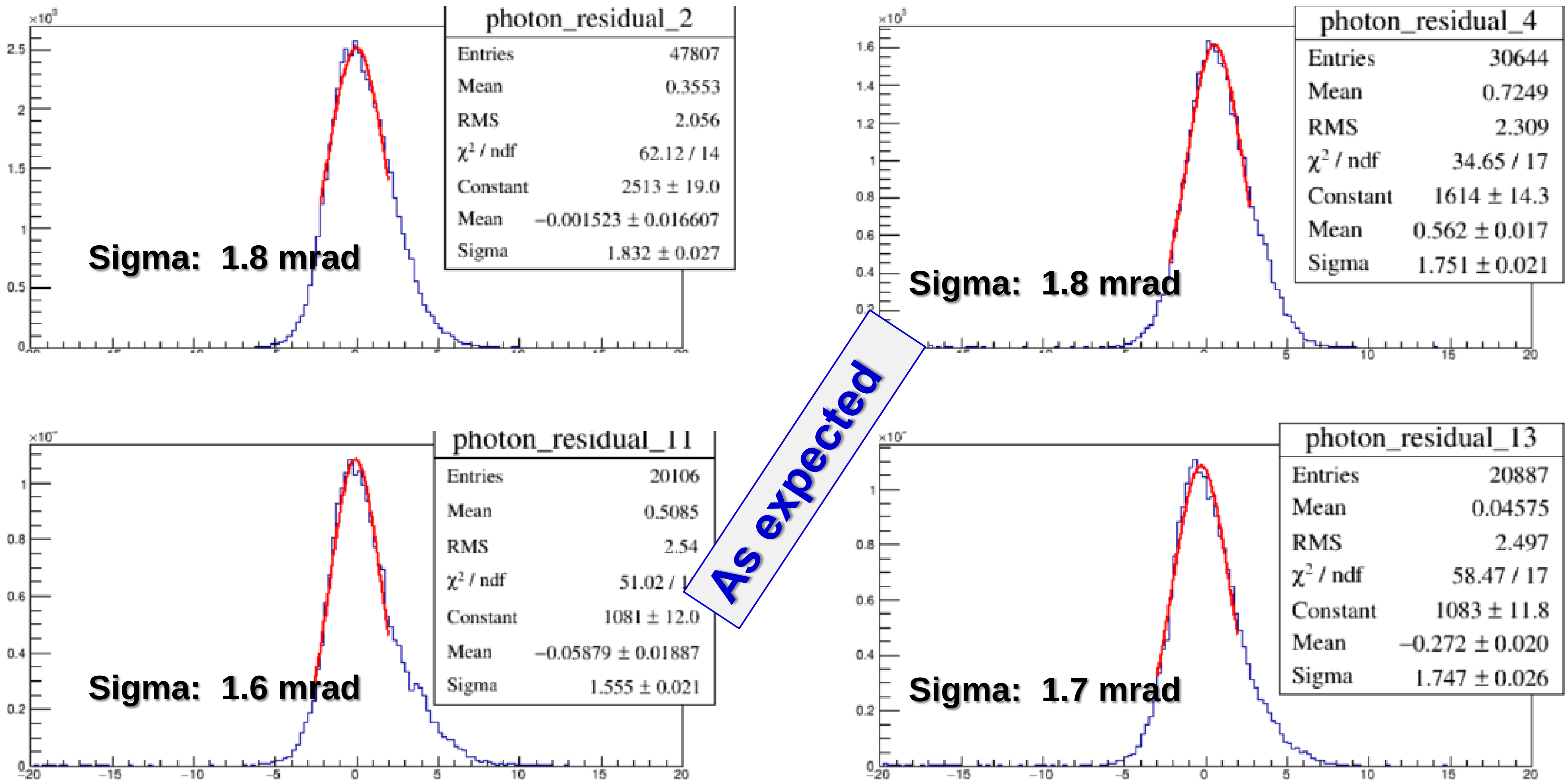


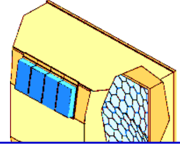
p = 8.4 GeV/c
θ = 49.5 mrad



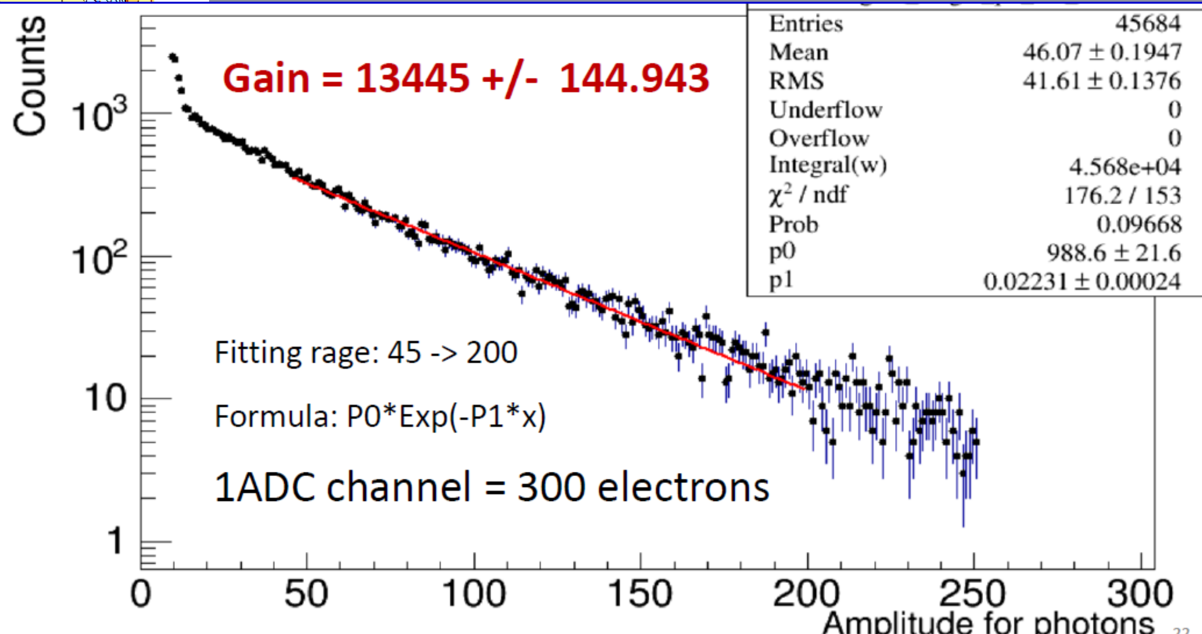
INTRINSIC SPACE RESOLUTION

Residual distribution for individual photons (preliminary π-sample): $\theta_{calculated} - \theta_{photon}$





GAIN FROM A PURE PHOTON SAMPLE



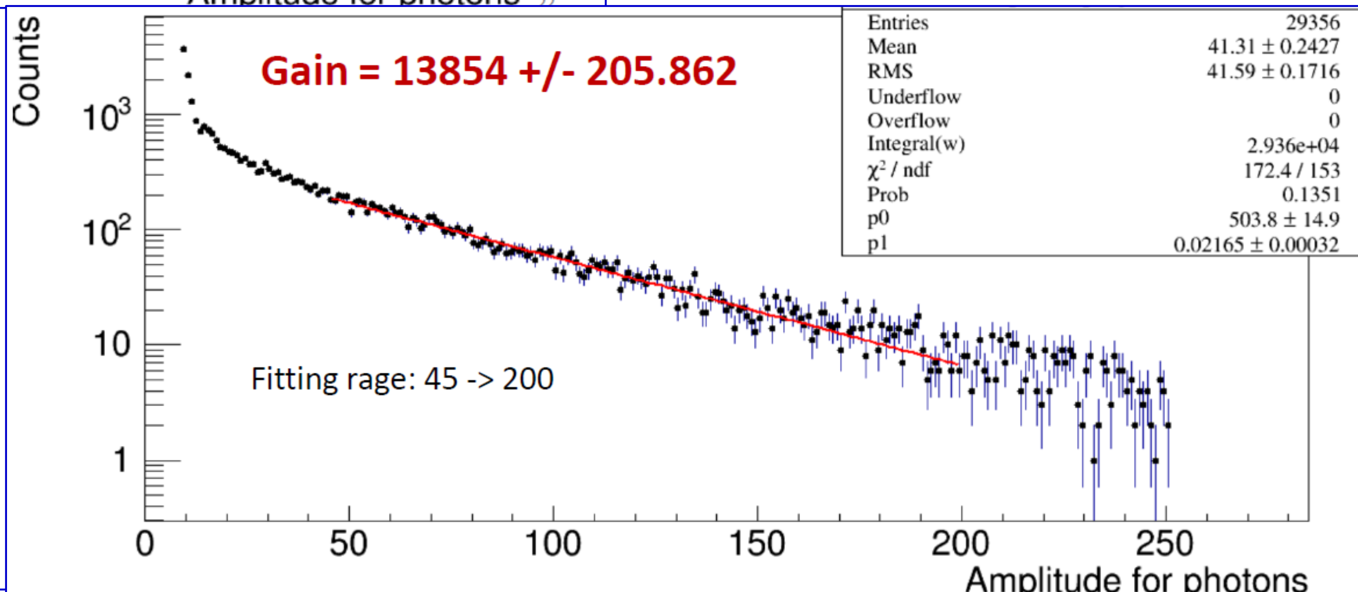
From electronic noise → Threshold

From threshold & gain → **photoelectron detection (effective) efficiency > 80%**

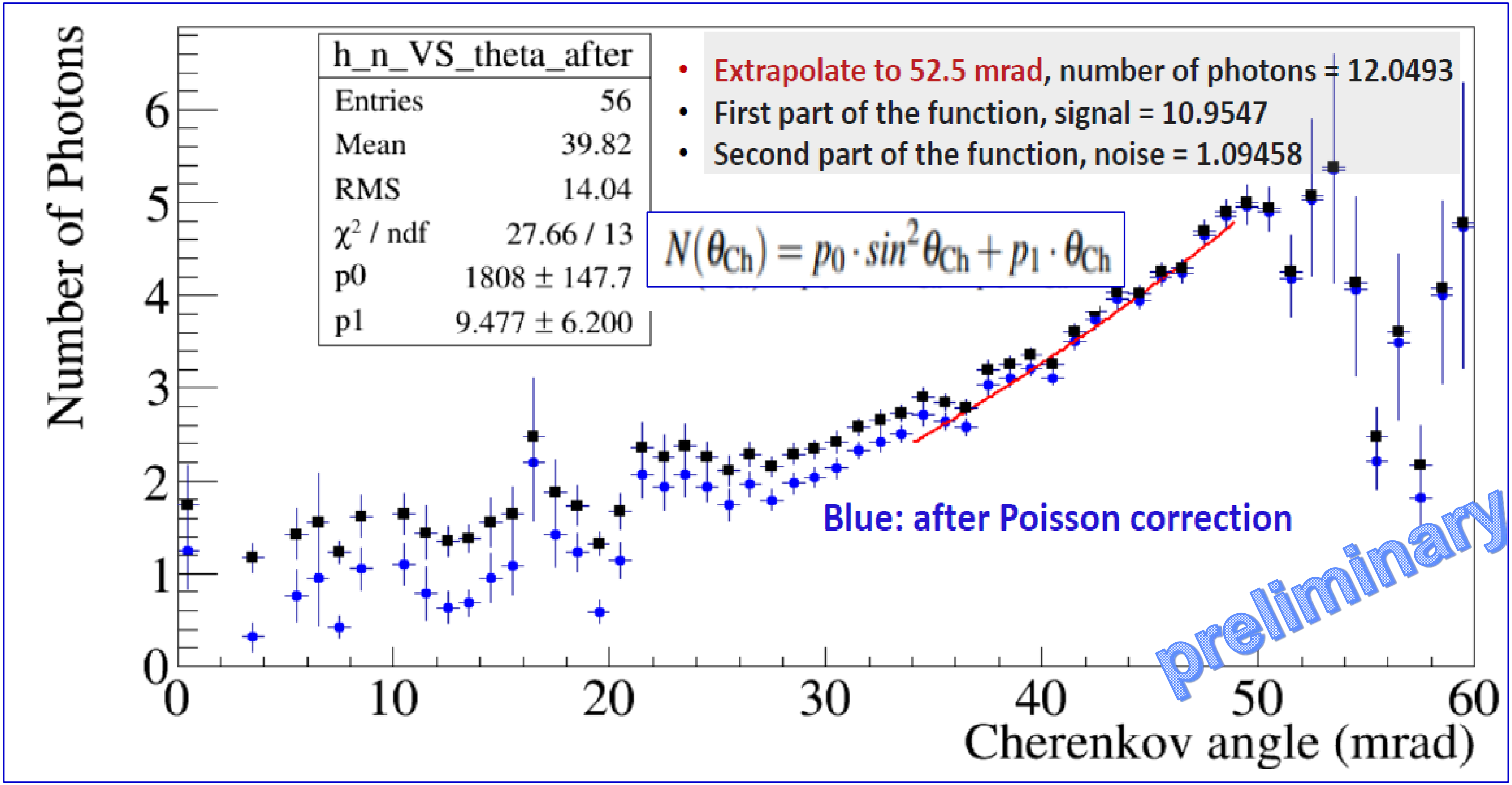
For comparison,
in MWPCs: ~50-60%

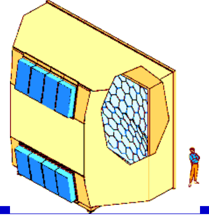
from the extrapolated exponential an estimate of the **noise level under the signal:**

~10%

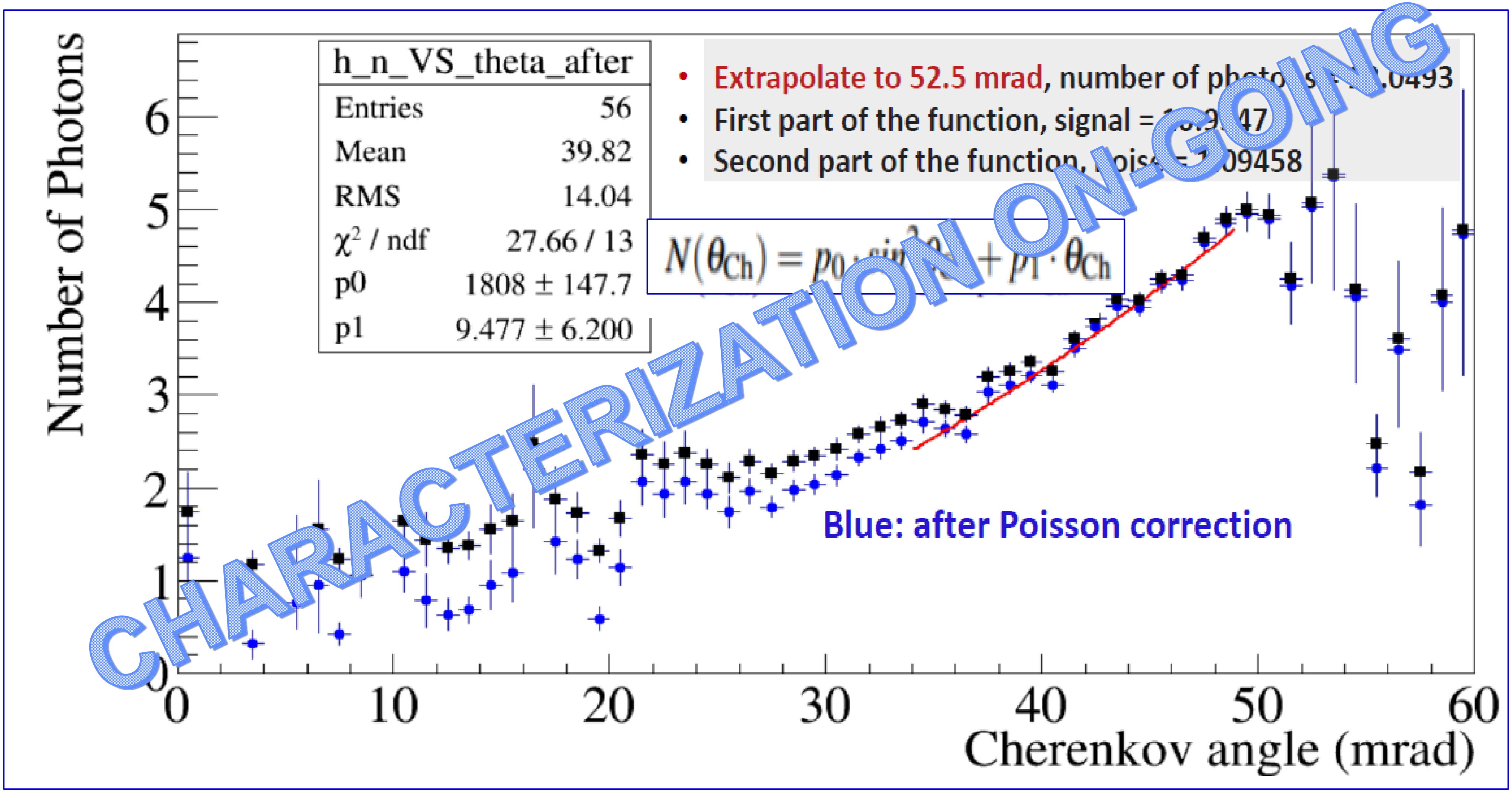


DETECTED PHOTONS per RING





DETECTED PHOTONS per RING



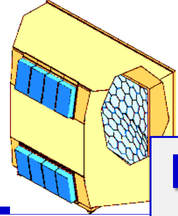
h-PID at high p (> 6-8 GeV/c)

- Required for physics at the future **ELECTRON-ION COLLIDER (EIC)**

- Collider-specific issues
  - shorter radiator to control setup sizes (advantages also for fixed target)
    namely more detected photons per unit radiator length
    → increased resolution
  - Operation in magnetic field

- An interesting option
  - Exploit the extremely far VUV region (~120 nm) with a windowless RICH and gaseous photon detectors, test beam @ Fermilab

IEEE NS 62 (2015) 3256

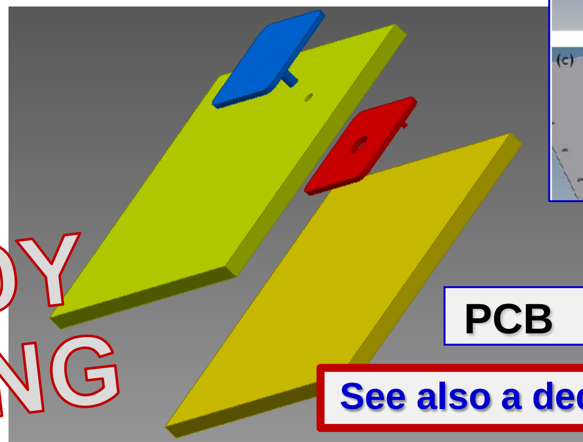


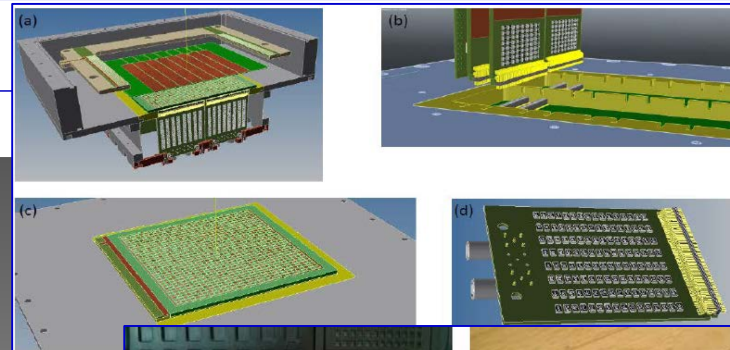
MOVING FURTHER WITH MPGD-based PDs

In the frame of
- **Generic R&D for EIC – eRD6**
- **INFN – RD_FA**

resistive MM
with small
pad size
O(10 mm²)

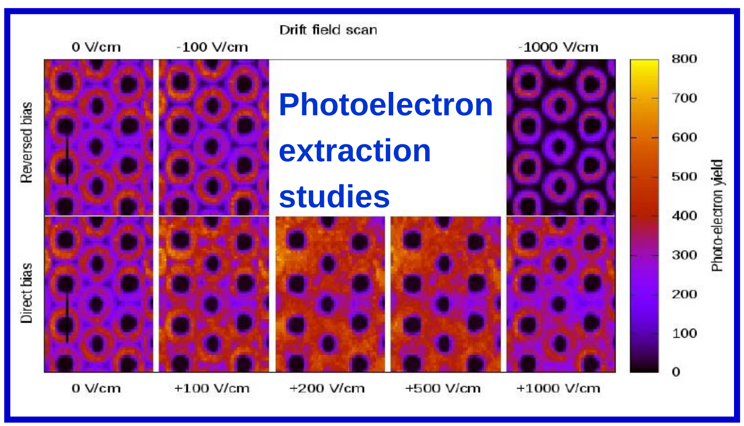
ALREADY ON GOING





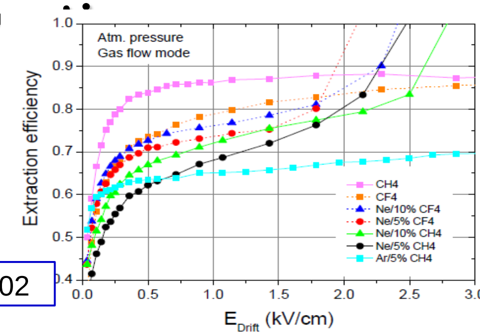
See also a dedicated poster byJ. Agarwala

GEM vs THGEM as photocathodes

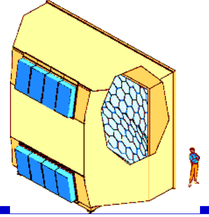


Issues related to hybrid MPGD-based PDs operated in C-F atmosphere:

- photoelectron extr
- detector gain
- ageing



C. D. R. Azevedo et al., 2010 *JINST* 5 P01002



A VERY RECENT NEW OPTION FOR THE R&D

CsI, the only standard photoconverter compatible with gaseous atmospheres, has problematic issues, main ones:

- ***It does not tolerate exposure to air (H_2O vapour, O_2)***
- ***Ageing by ion bombardment***

Antonio Valentini et al. – INFN Bari

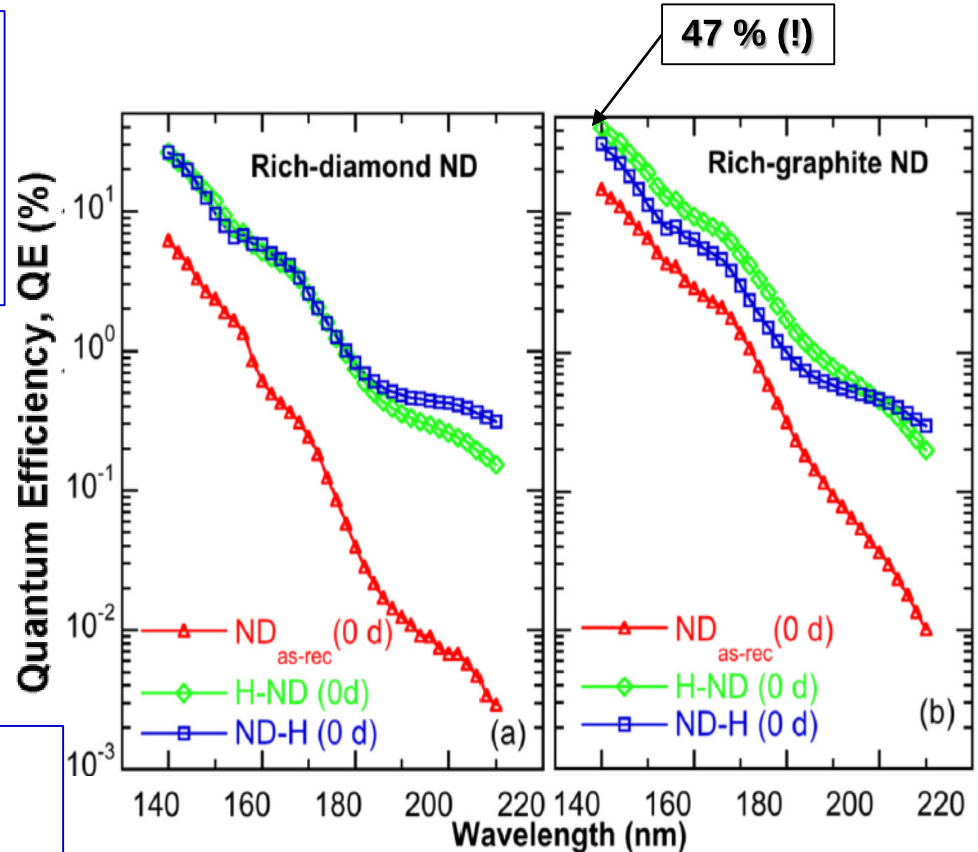
Italian patent application n. 102015000053374

- ***Photocatodes: diamon film obtained with Spray* Technique *making use of hydrogenized ND powder***
  - ***Spray technique: T ~ 120° (instead of >800° as in standard techniques)***

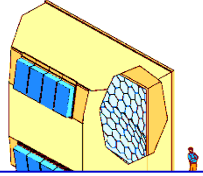
Coupling of ND photoconverter and MPGDs?

an exiting perspective with several open questions

- ***Compatibility, performance with gas ?***
- ***Radiation hardness ?***
- ***Ageing ?***



L.Velardi, A.Valentini, G.Cicala al., Diamond & Related Materials 76 (2017) 1

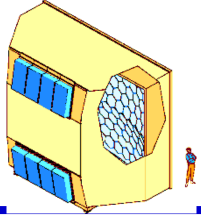


SUMMARIZING …

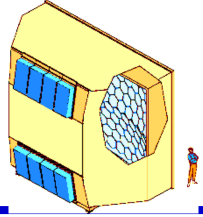
- **MPGD-based photon detectors ACCOMPLISH THEIR MISSION in COMPASS RICH-1**
  - **From preliminary characterization exercises:**
    stable gain, large gain, good number of detected photoelectrons

- **Technological achievement - for the FIRST TIME:**
  - **single photon detection is accomplished by MPGDs**
  - **THGEMs used in an experiment**
  - **MPGD gain > 10k in an experiment**

- **MPGD-based photon detectors have a mission in the future of hadron physics**



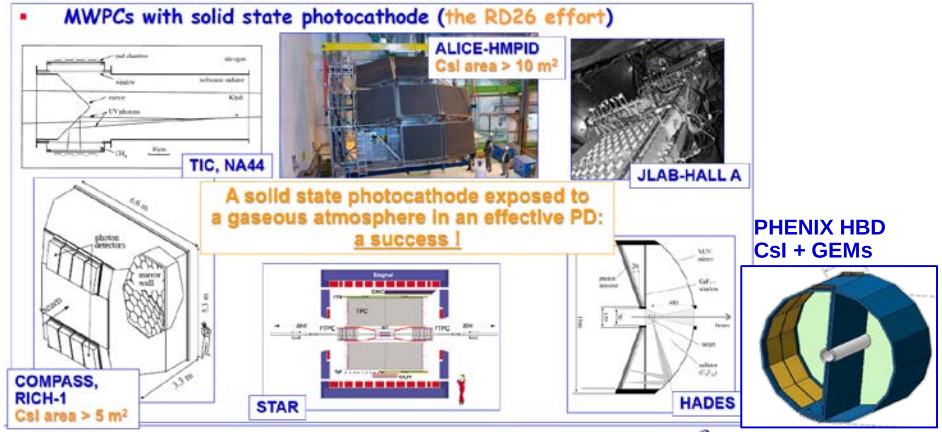
THANK YOU

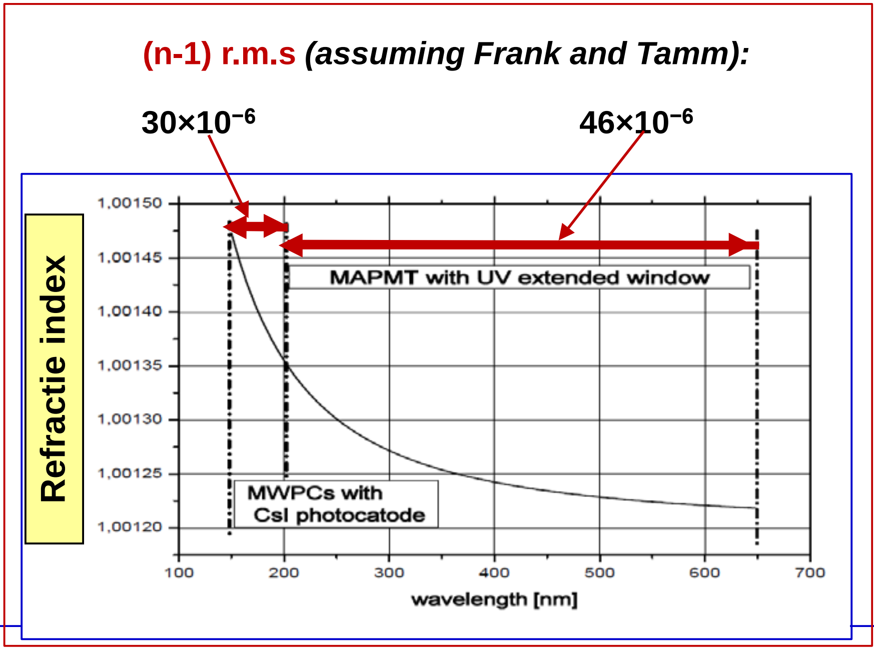


MORE INFORMATION

HANDLING THE VUV DOMAIN

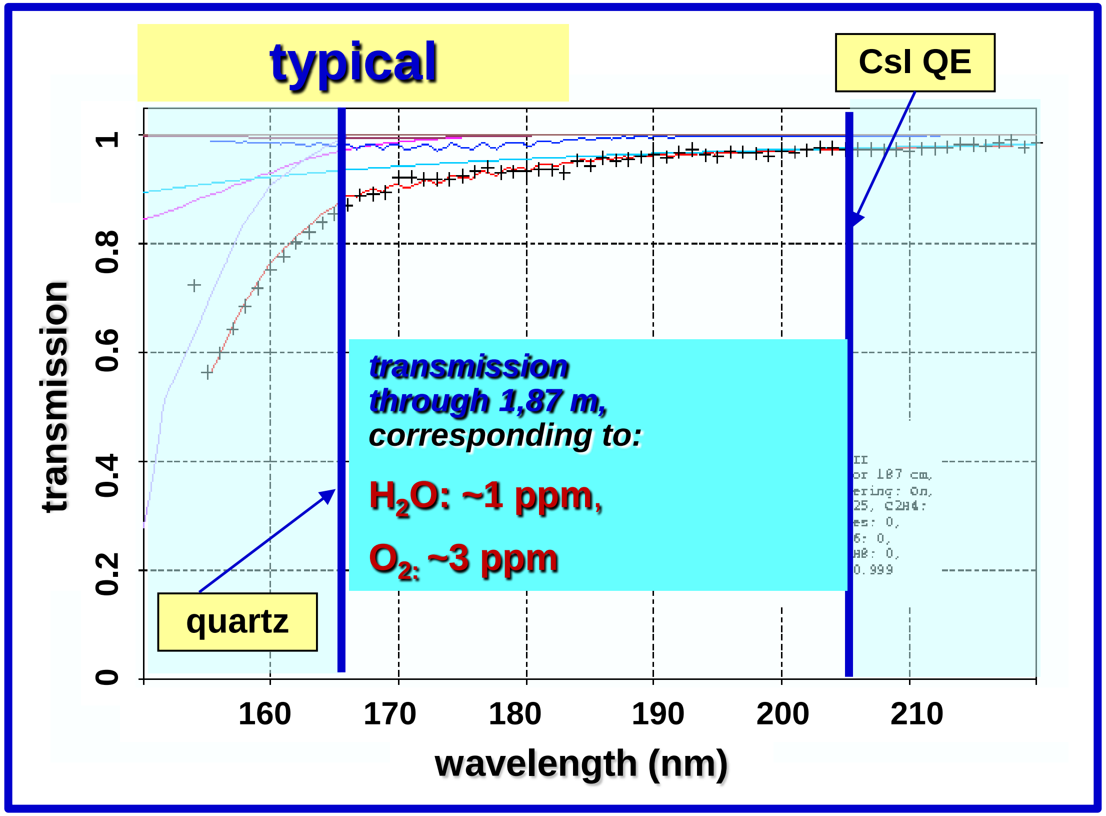
CsI gasous sensors used in several Cherenkov detectors

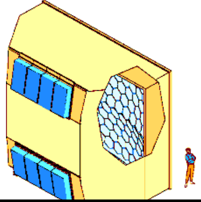




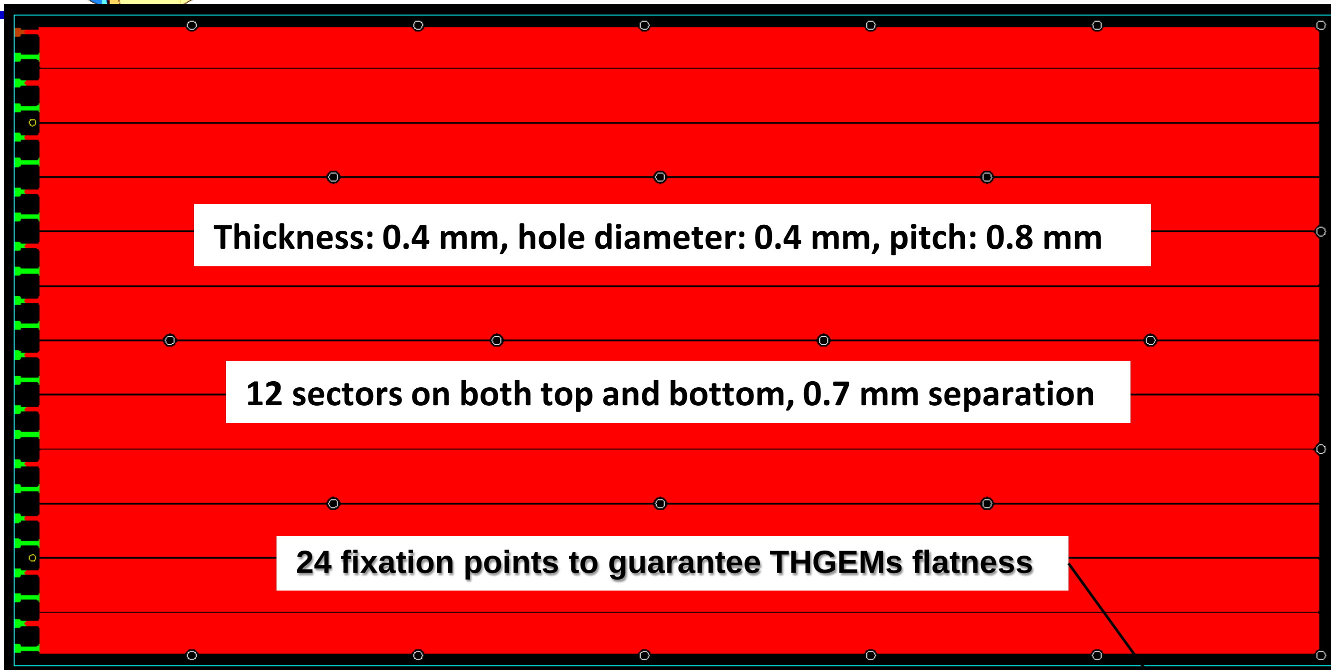
COMPASS RICH-1, gas transparency

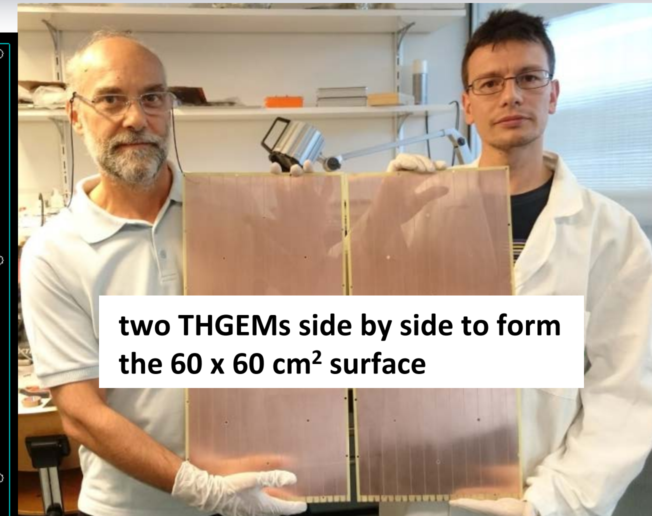
- gas cleaning by on-line filters,
- separate functions:
  - Cu catalyst, ~ 40^0C for O_2
  - 5A molecular sieve, ~ 10^0C for H_2O

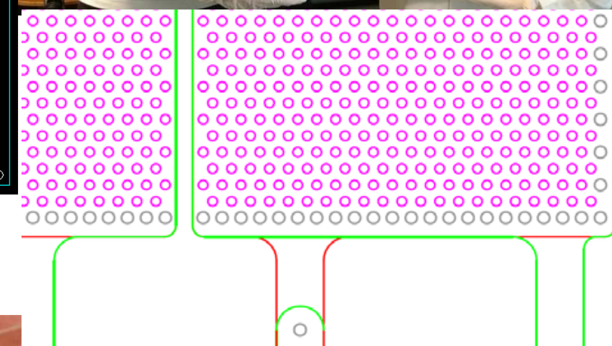


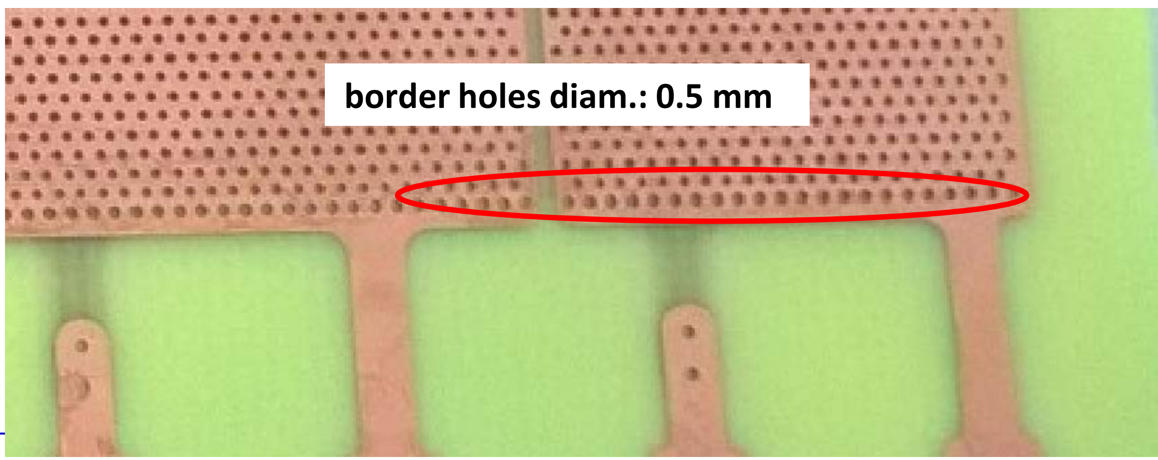


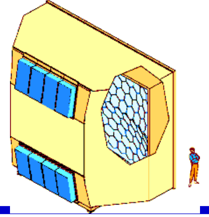
OUR THGEM DESIGN





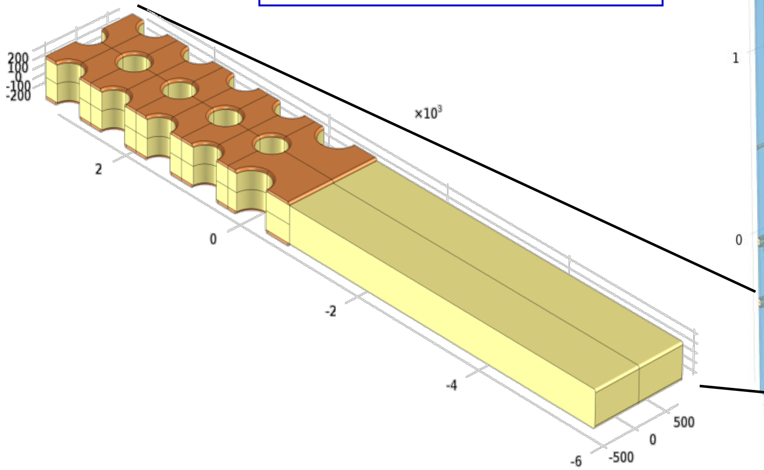


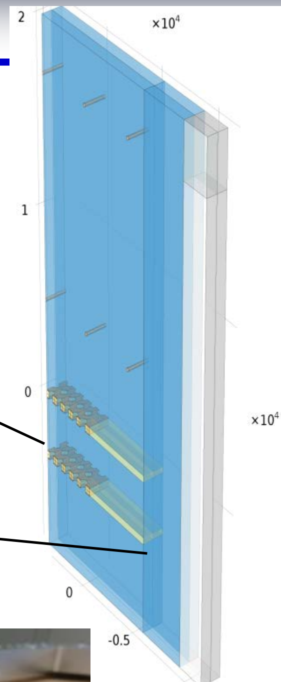


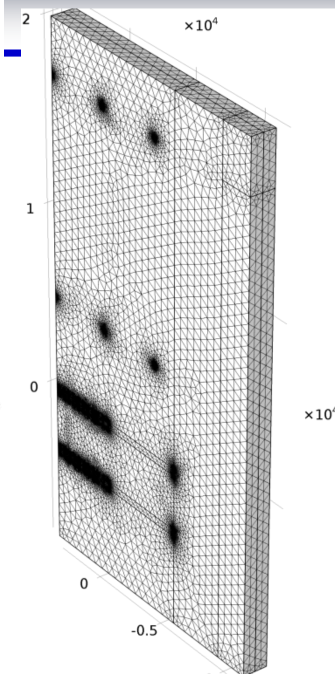


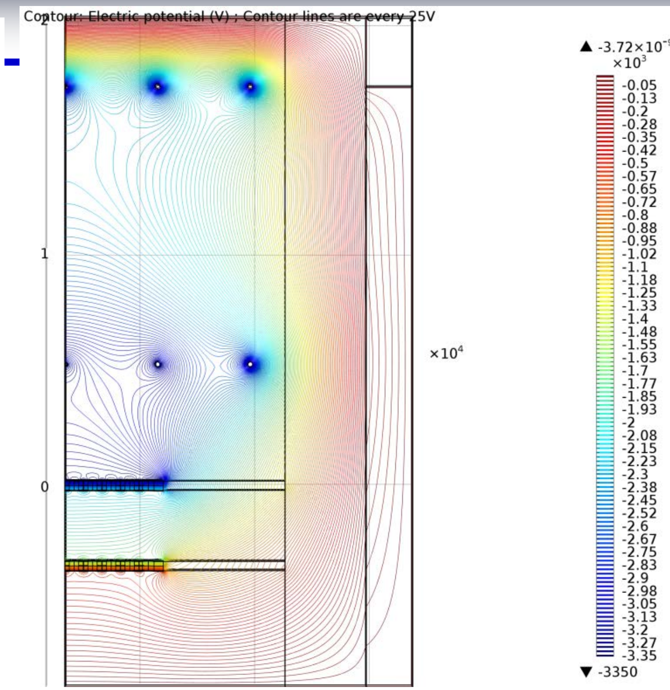
FIELD SHAPING ELECTRODES AT THE EDGES

THGEM border study

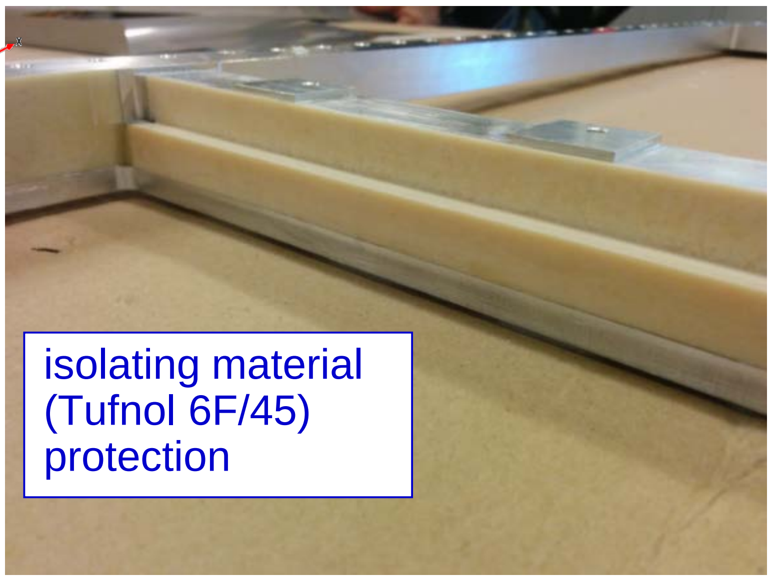






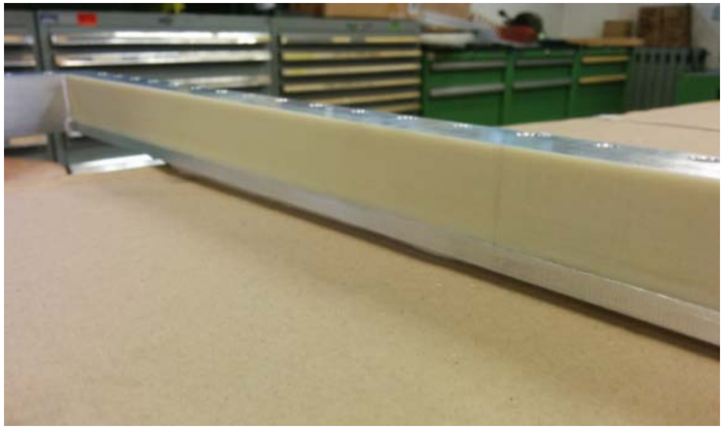


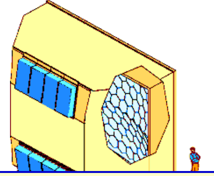
large field values at the chamber edges and on the guard wires



isolating material (Tufnol 6F/45) protection

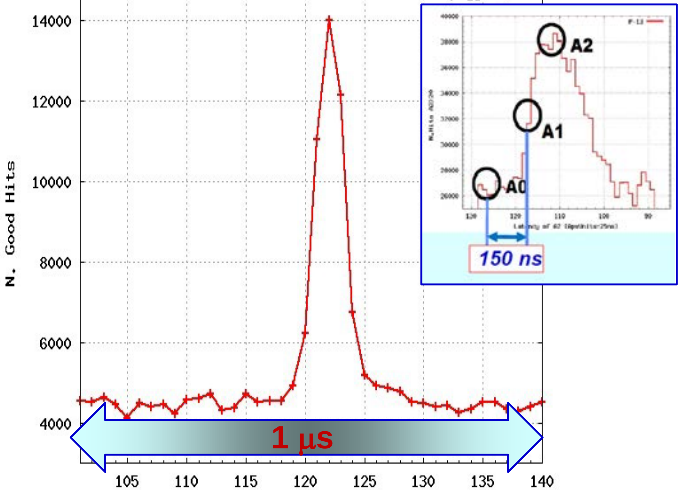
Field shaping electrodes in the isolating material protections of the chamber frames



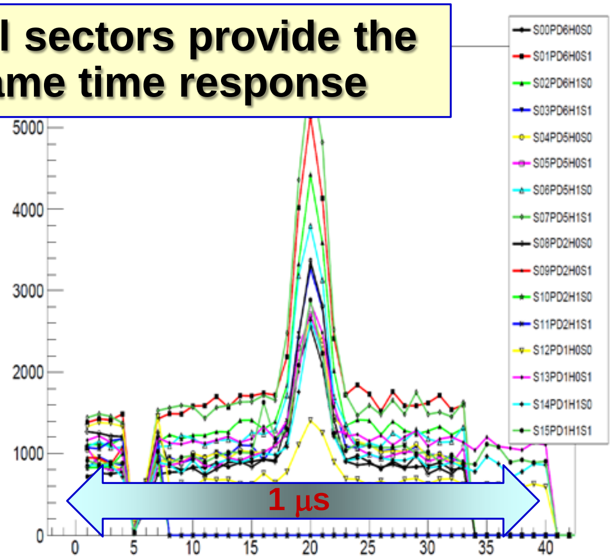


THE PHOTOELECTRON SIGNAL

Selecting good hit candidates (A0<5 ADC units, 0.2<A1/A2<0.8)

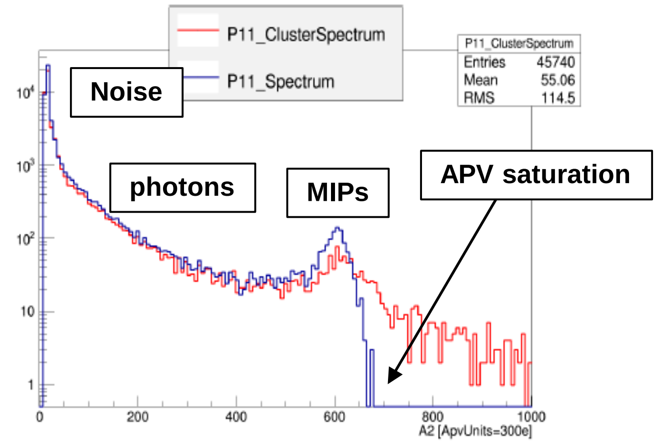


All sectors provide the same time response

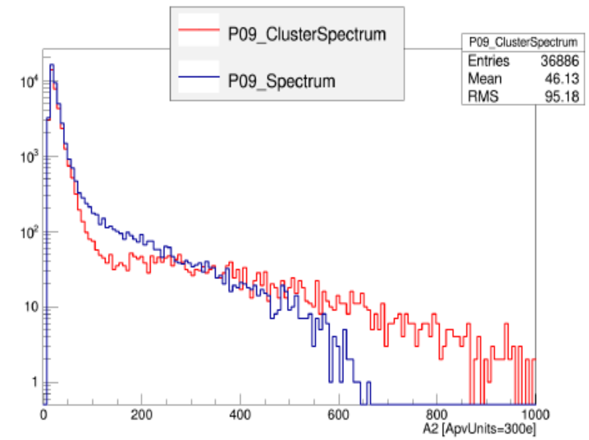


Clusterization to separate MIPs

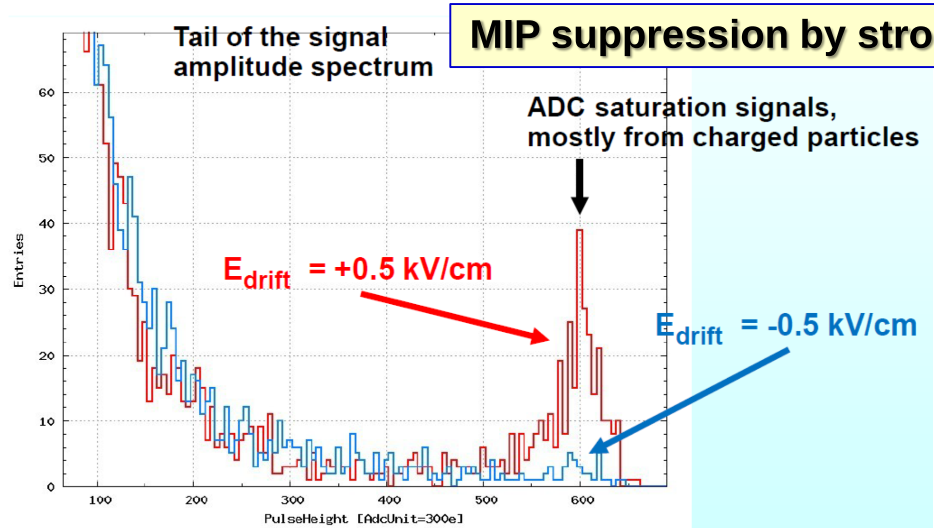
Hybrid MPGD (novel detector)

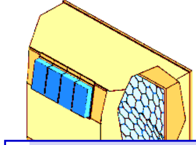


MWPC (old detector)



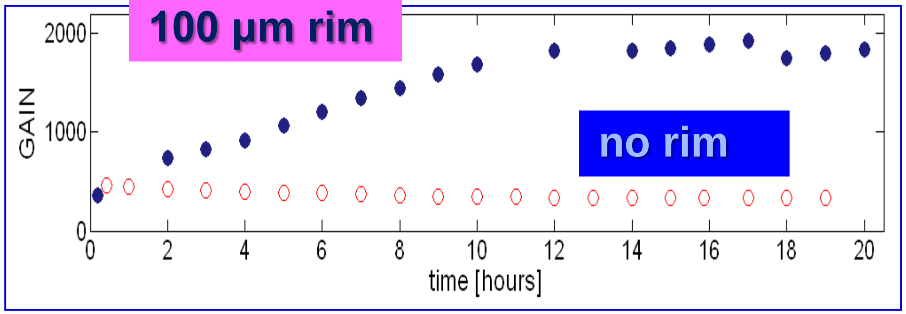
MIP suppression by strong reversed bias



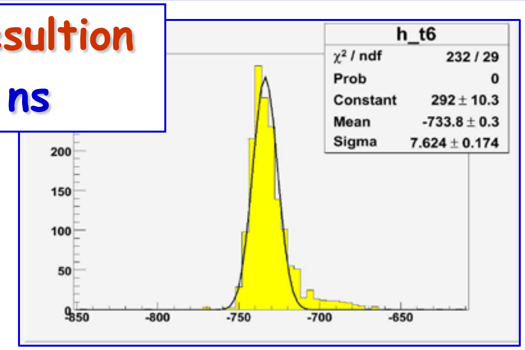


After 7 years of R&D

- ## THGEM characterization, performance

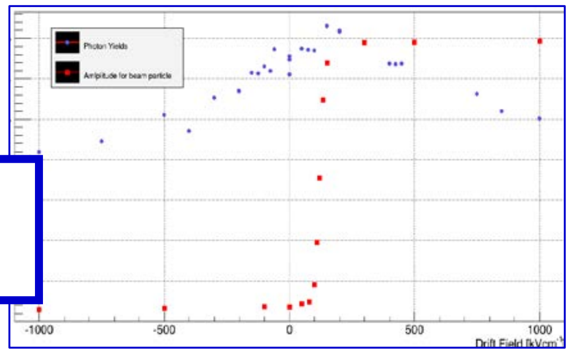


Time resultion ~7 ns

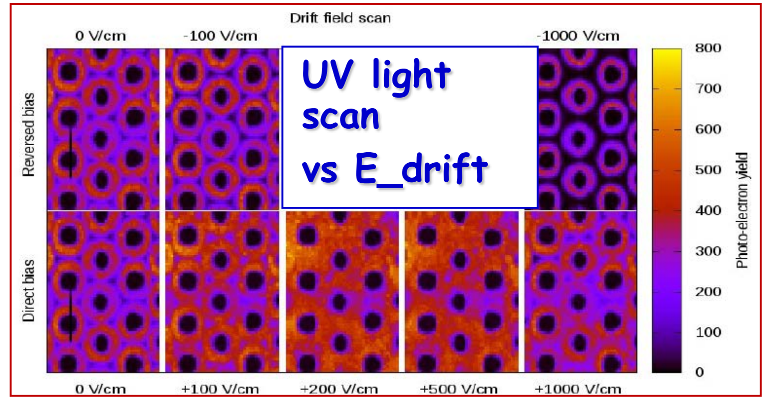


- ## Photoelectron extraction

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

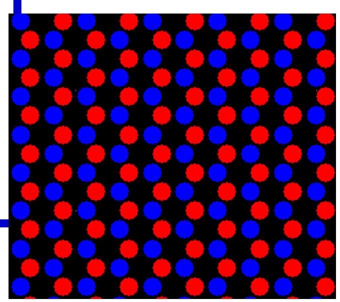


UV light scan vs E_drift



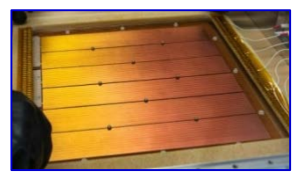
- ## IBF (Ion Back Flow) suppression

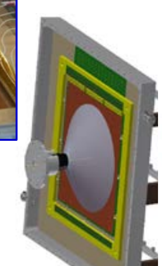
Tripple THGEM: IBF suppression (<5%) by staggering plates

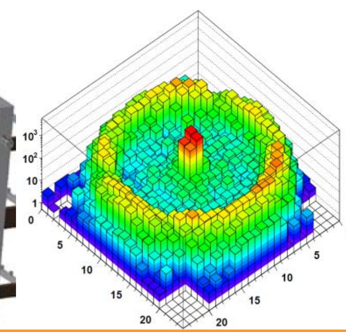


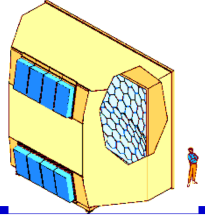
IBF suppression (<3%) introducing a MM stage: no need of high Transfer electric field → **Hybrid architecture**

Cherenkov light detection in TB





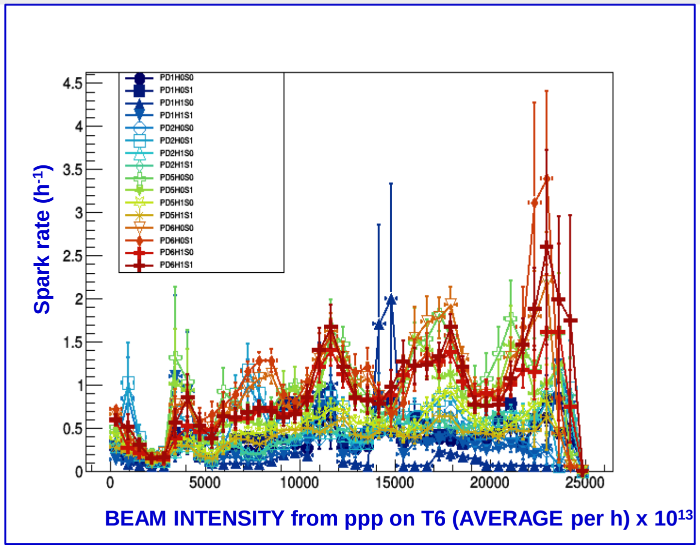




ELECTRICAL STABILITY

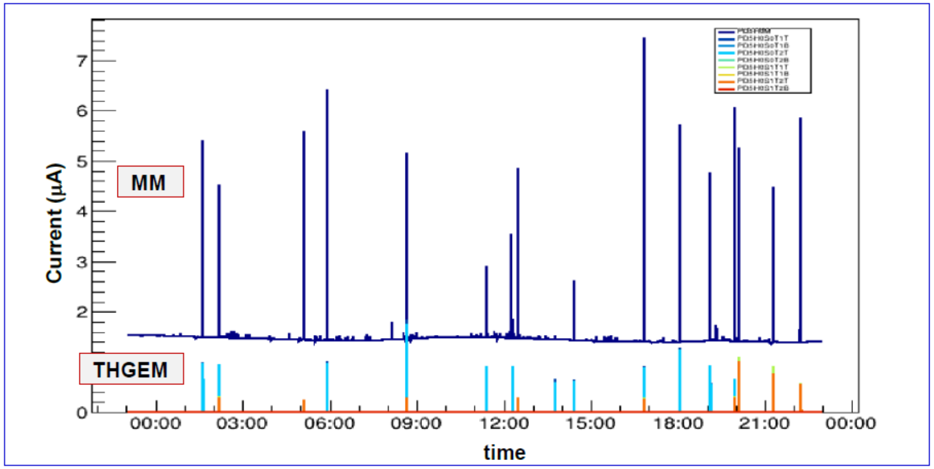
THGEMs, lessons

- **Full vertical correlation of current sparks THGEM1 & THGEM2**
- **Recovery time <10 s (our HV arrangement)**
- **Sparke rates: ~ no dependence on beam intensity and even beam on-off**
- **Discharge correlation within a THGEM (also non adjacent segments) and among different THGEMs (cosmics ?)**
- **Total spark rates (4 detectors): ~10/h**

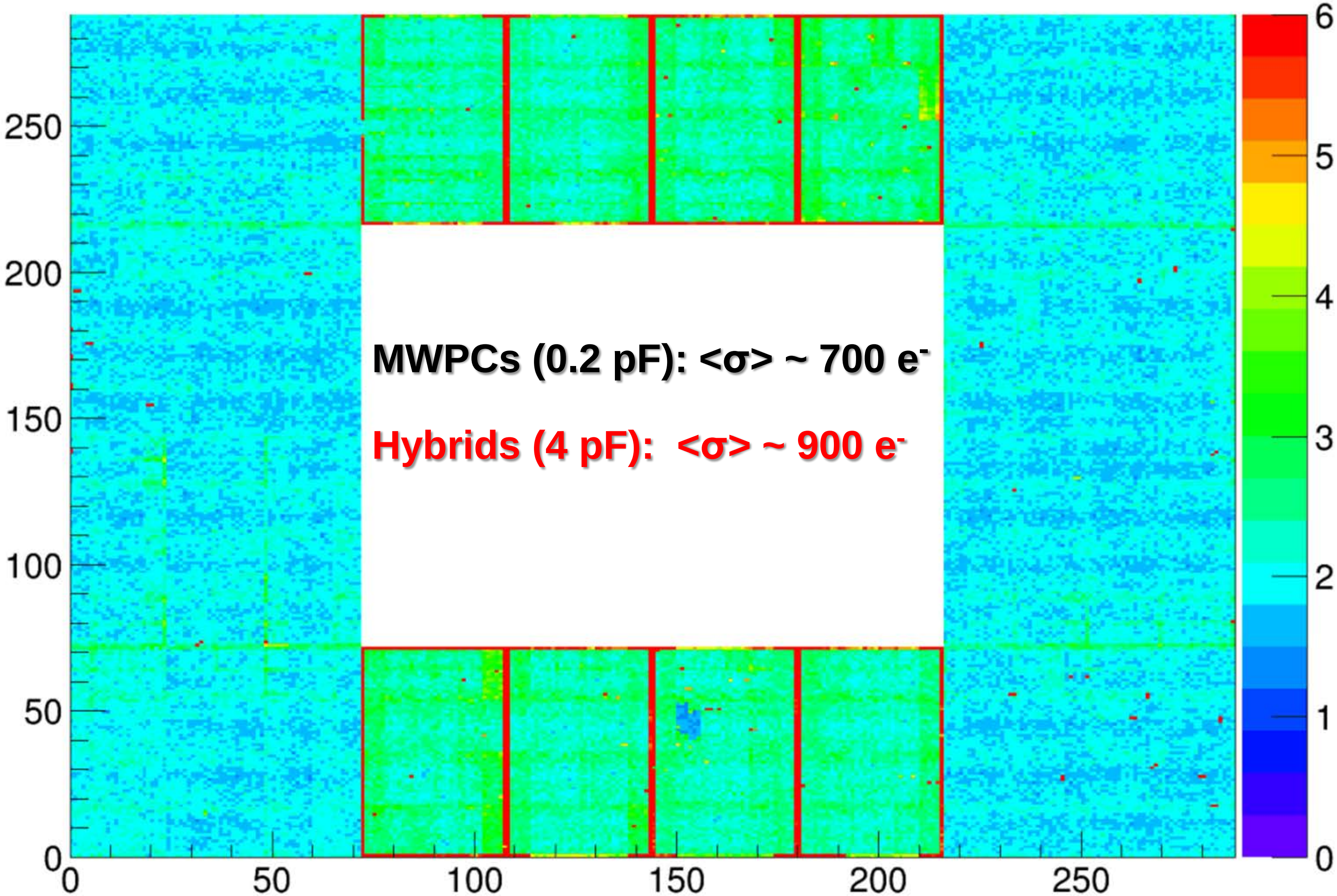


MICROMEGAS, lessons

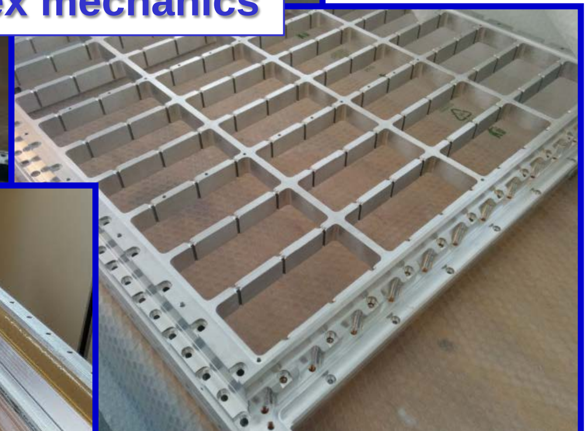
- **MM sparks only when a THGEM spark is observed (not vice versa)**
- **Recovery time ~1s (our HV arrangement)**
- **The only real issue: dying channels (pads)**
  - **Local shorts, larger current, no noise issue**
  - **2.5 ‰ developed in 12 months**
  - **Dirty gas / dust from molecular sieves & catalyst?**



NOISE FIGURES



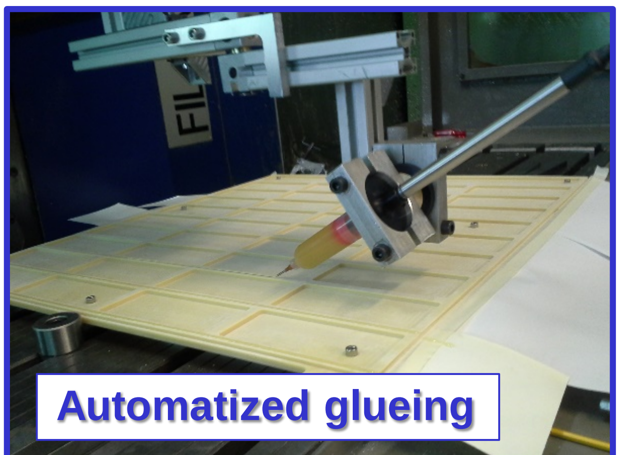
CONSTRUCTION & ASSEMBLY



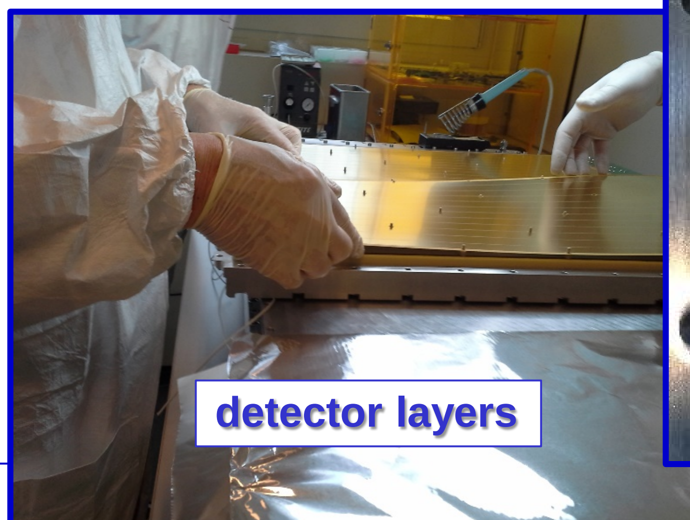
Complex mechanics

Wire planes

Glueing the support pillars

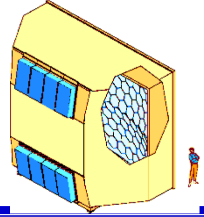


Automatized glueing



detector layers

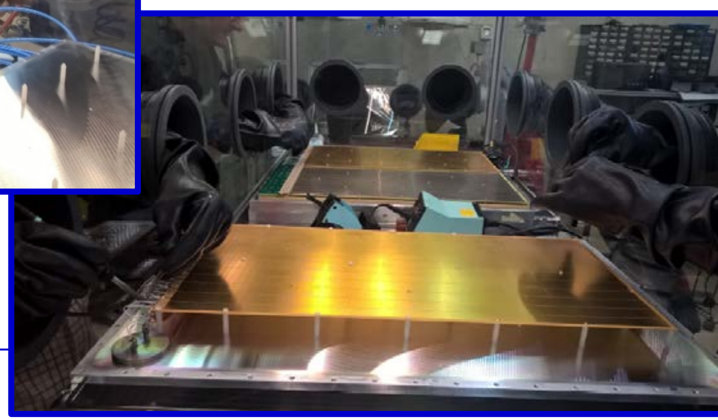
THGEM staggering



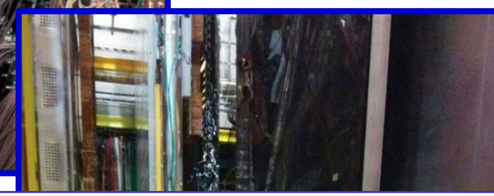
ASSEMBLY in a nutshell

Pre-assembly w/o CsI

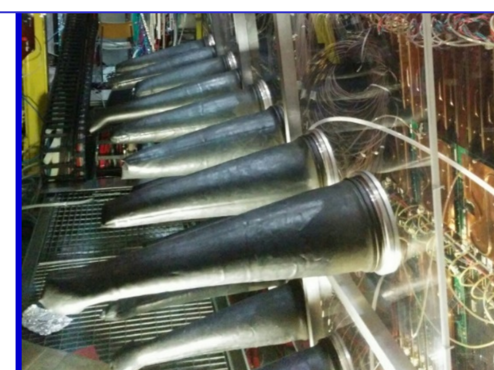
final assembly of the active module assembly with CsI in glovebox

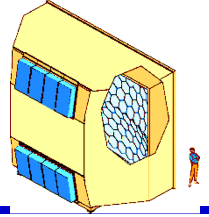


Onto the RICH



glovebox also to mount the active module onto the RICH





CsI QE measurements at coating

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

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

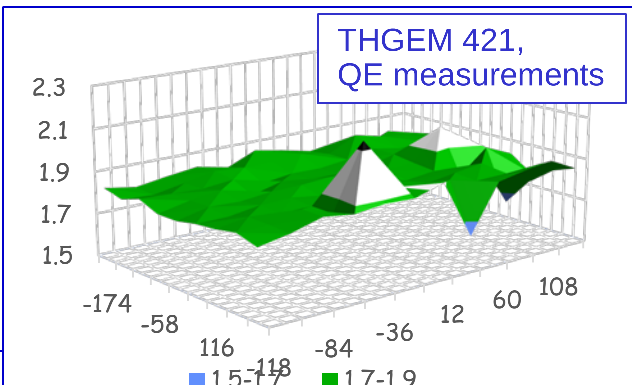
11 coated THGEMs available, 8 used + 3 spares

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
with s.r.m. of 10%

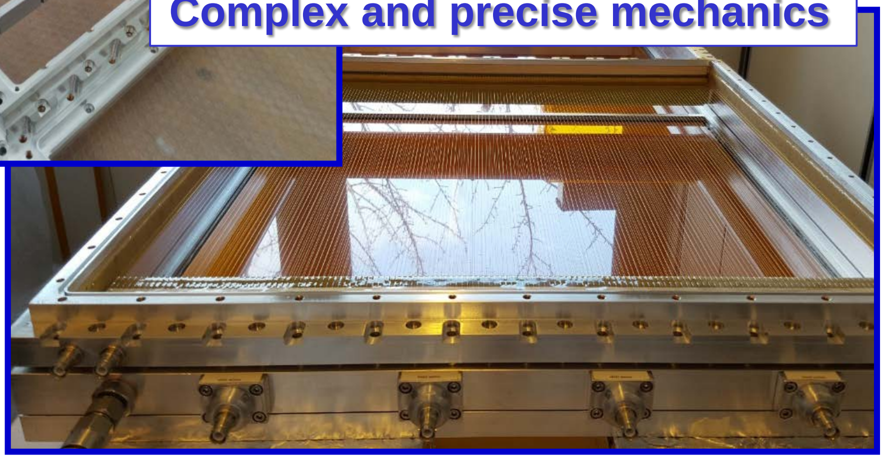
in agreement with expectations
(THGEM optical opacity = 0.78)



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

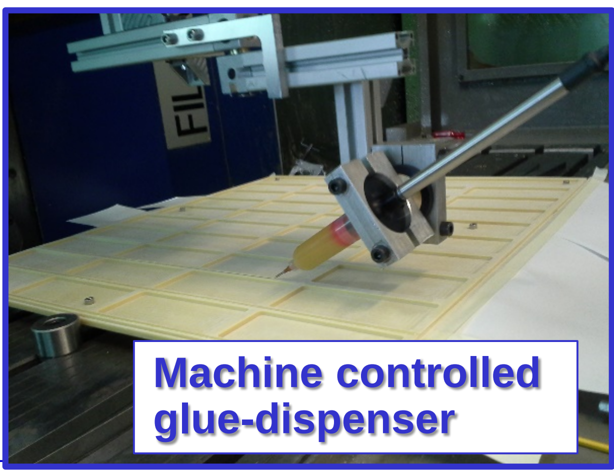
Good uniformity, in the example σ_{QE} / <QE> = 3%

CONSTRUCTION & ASSEMBLY



Complex and precise mechanics

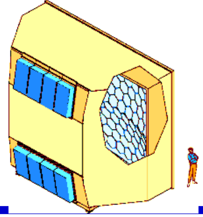
Assembly in clean room



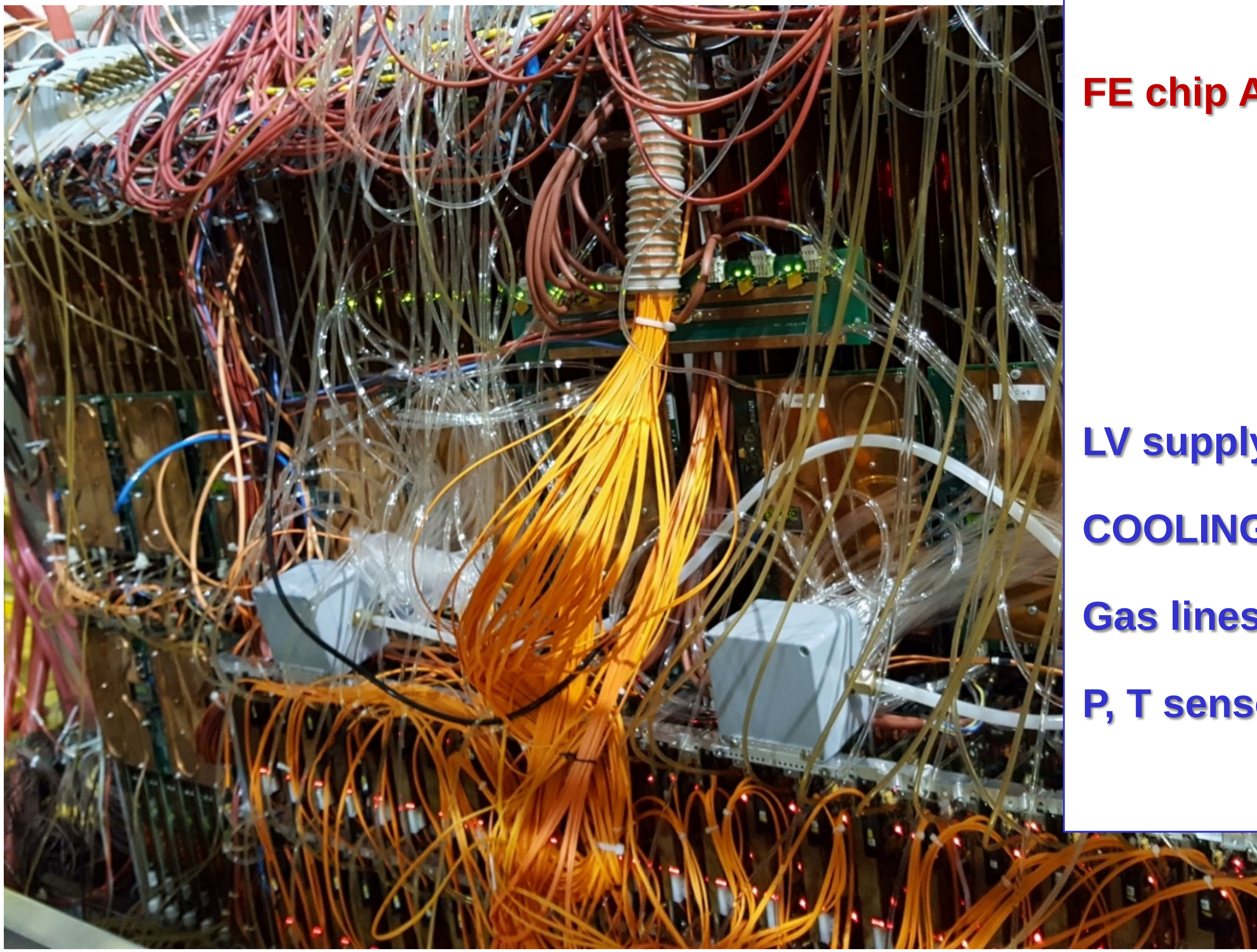
Machine controlled glue-dispenser

Including photocathode in glovebox

glovebox also
to mount the active module
onto the RICH

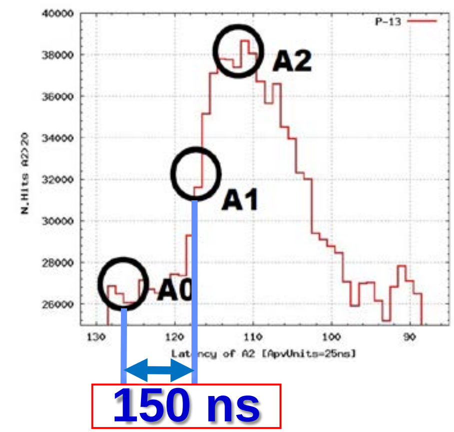


READ-OUT and SERVICES



read-out :
already available for the MWPCs with CsI

FE chip APV25



LV supply

COOLING

Gas lines

P, T sensors