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

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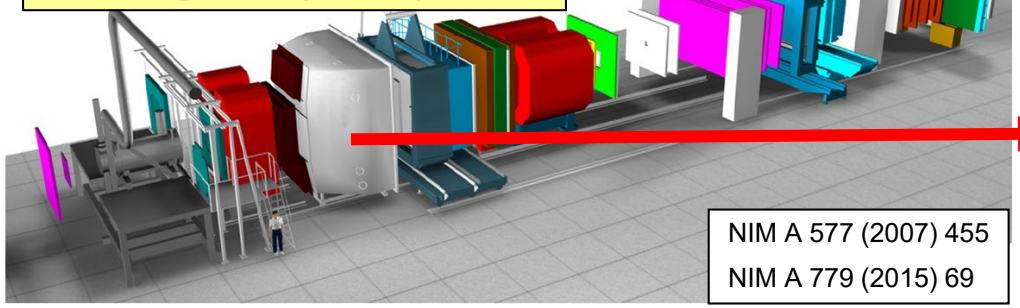
INFN - TRIESTE

on behalf of the COMPASS RICH group

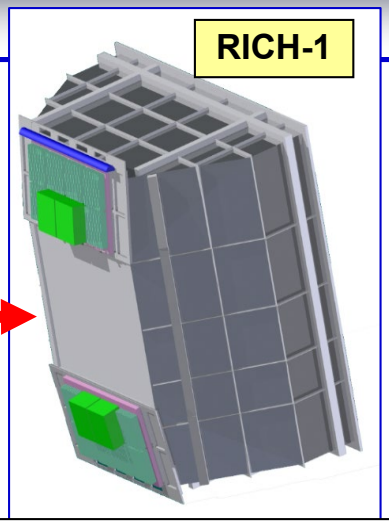
COMPASS RICH-1

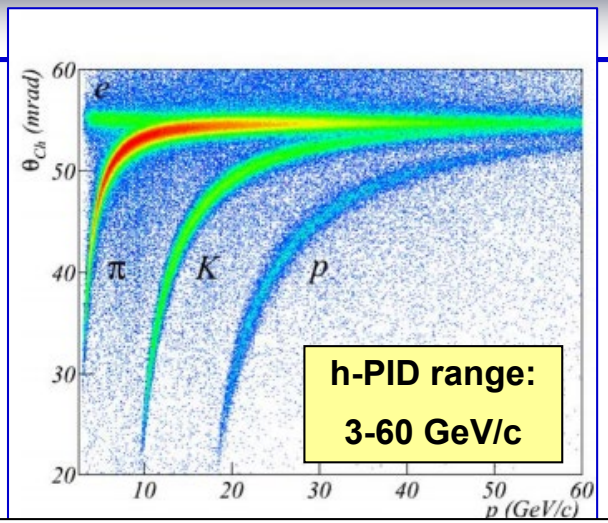
COMPASS Spectrometer dedicated to h physics

@ SPS (CERN)



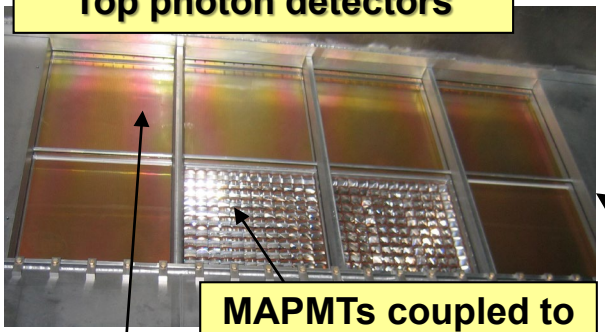
NIM A 577 (2007) 455
NIM A 779 (2015) 69





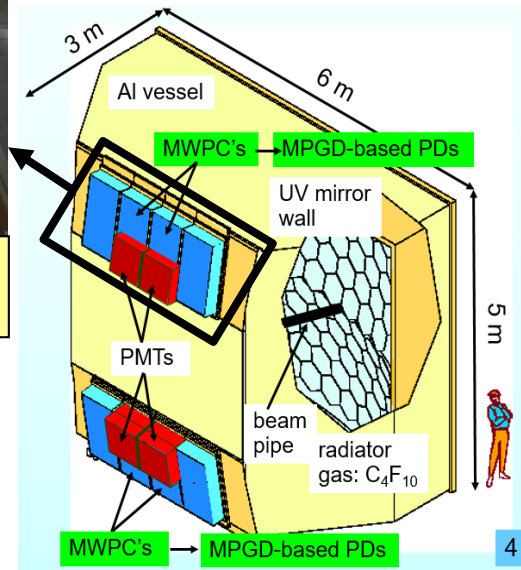
NIM A 553 (2005) 215; NIM A(2008) 371; NIM A(616) (2010) 21; NIM A 631 (2011) 26

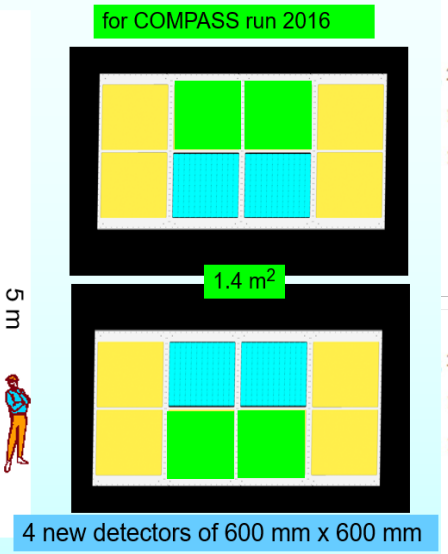
Top photon detectors



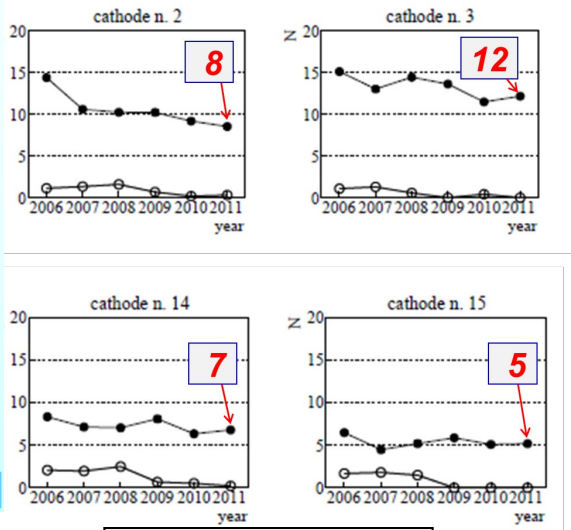
MAPMTs coupled to lens telescopes

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





n. of ph.s @ β = 1

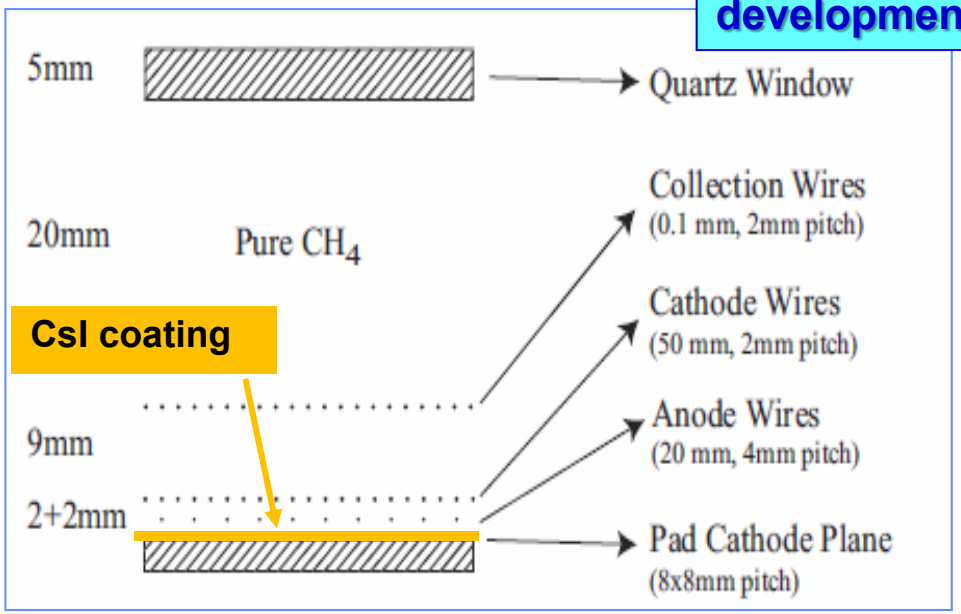


JINST 9 (2014) P01006

GASOUS 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*

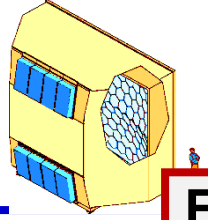
→ Low gain: a few times 10^4 (effective gain: <1/2)

→ "slow" detector

To overcome the limitations:

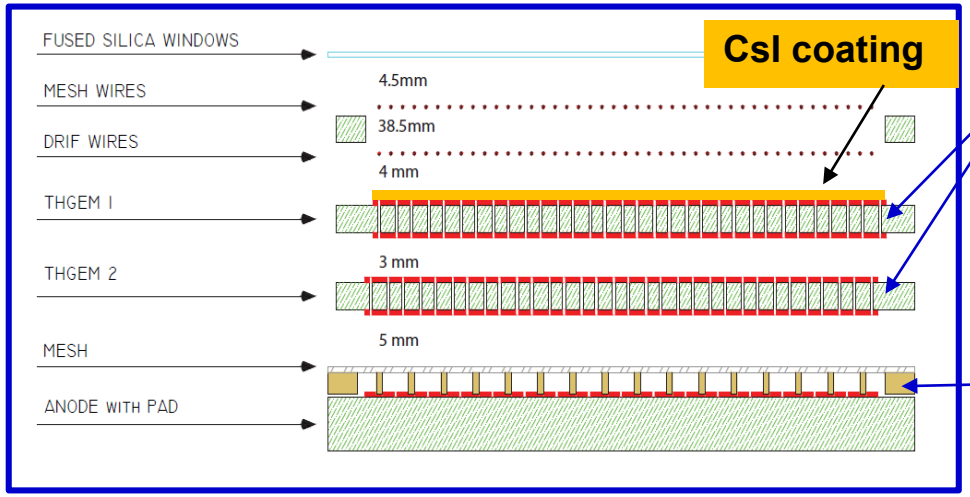
- **Less critical architecture**
- **suppress the PHOTON & ION feedback**
- **use intrinsically faster detectors**

→ MPGDs



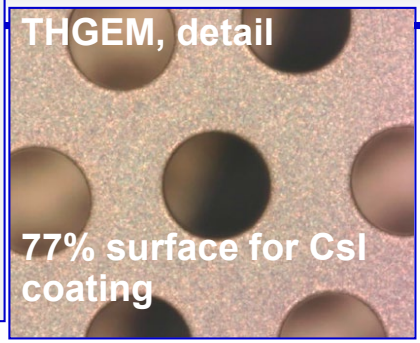
DETECTOR ARCHITECTURE

Following a 7-year R&D



2 layers of staggered THGEMs:

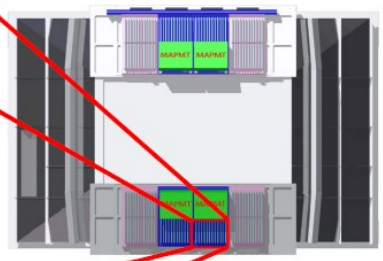
- pre-amplification
- transversally enlarged avalanche

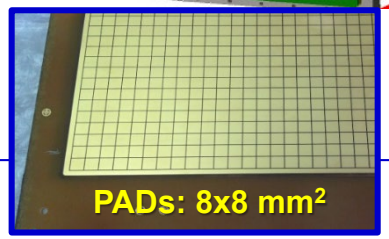


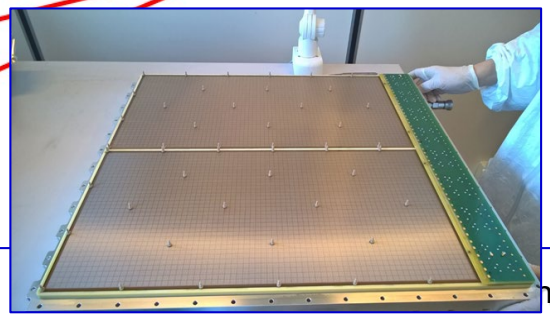
Resistive* MICROMEGAS by *bulk technology

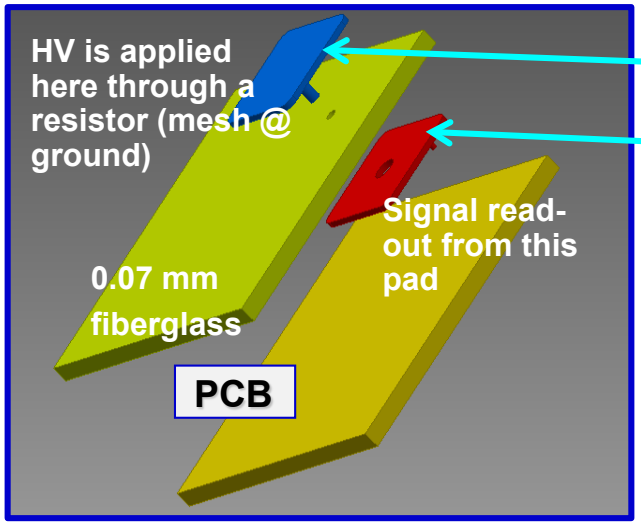
- trapping the ions
- ~100 ns signal formation

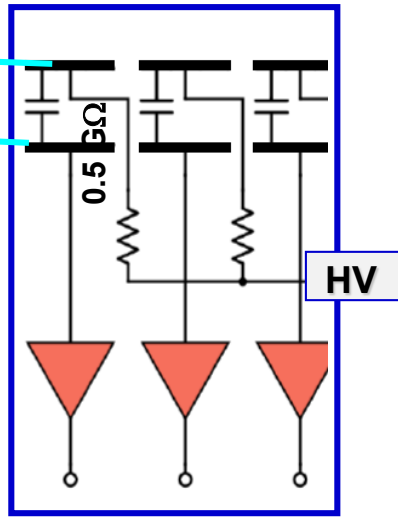
modular structure: one module = 600x300 mm^2

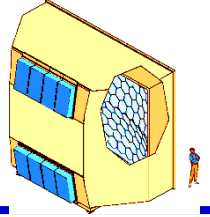






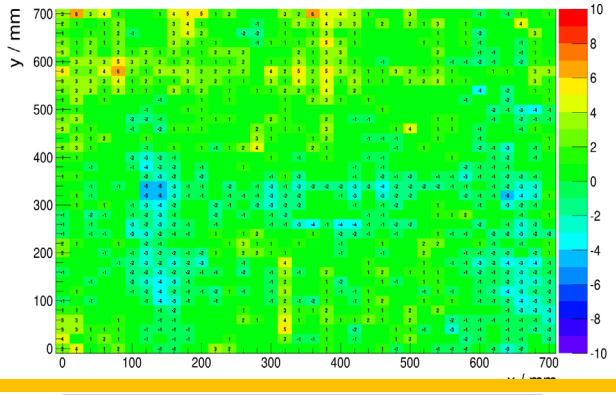




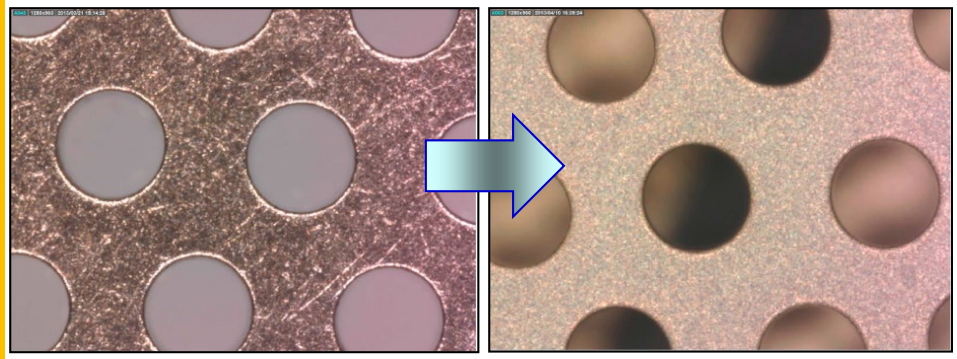


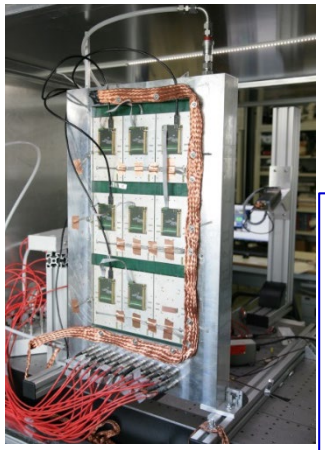
COMPONENT QA in a nutshell

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

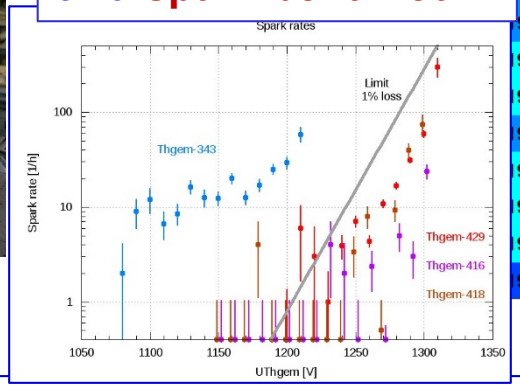


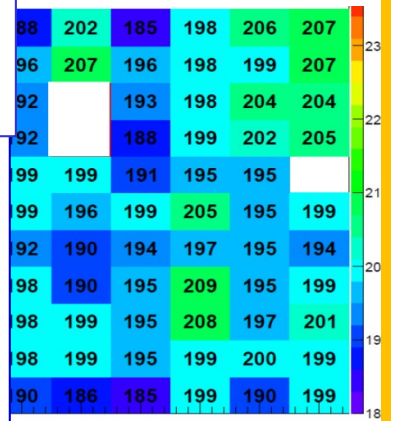
THGEM polishing with an "ad hoc" protocol setup by us:
>90% break-down limit obtained

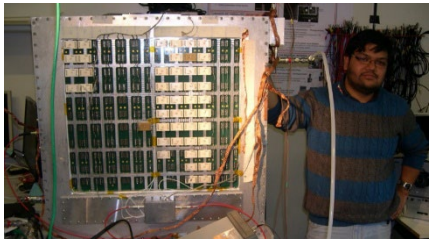




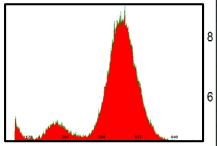
X-ray THGEM test to access gain uniformity (<7%) and spark behaviour

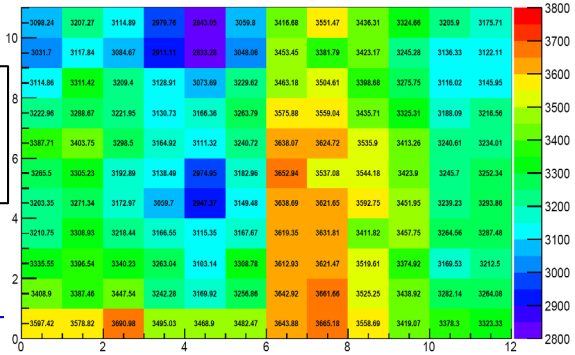




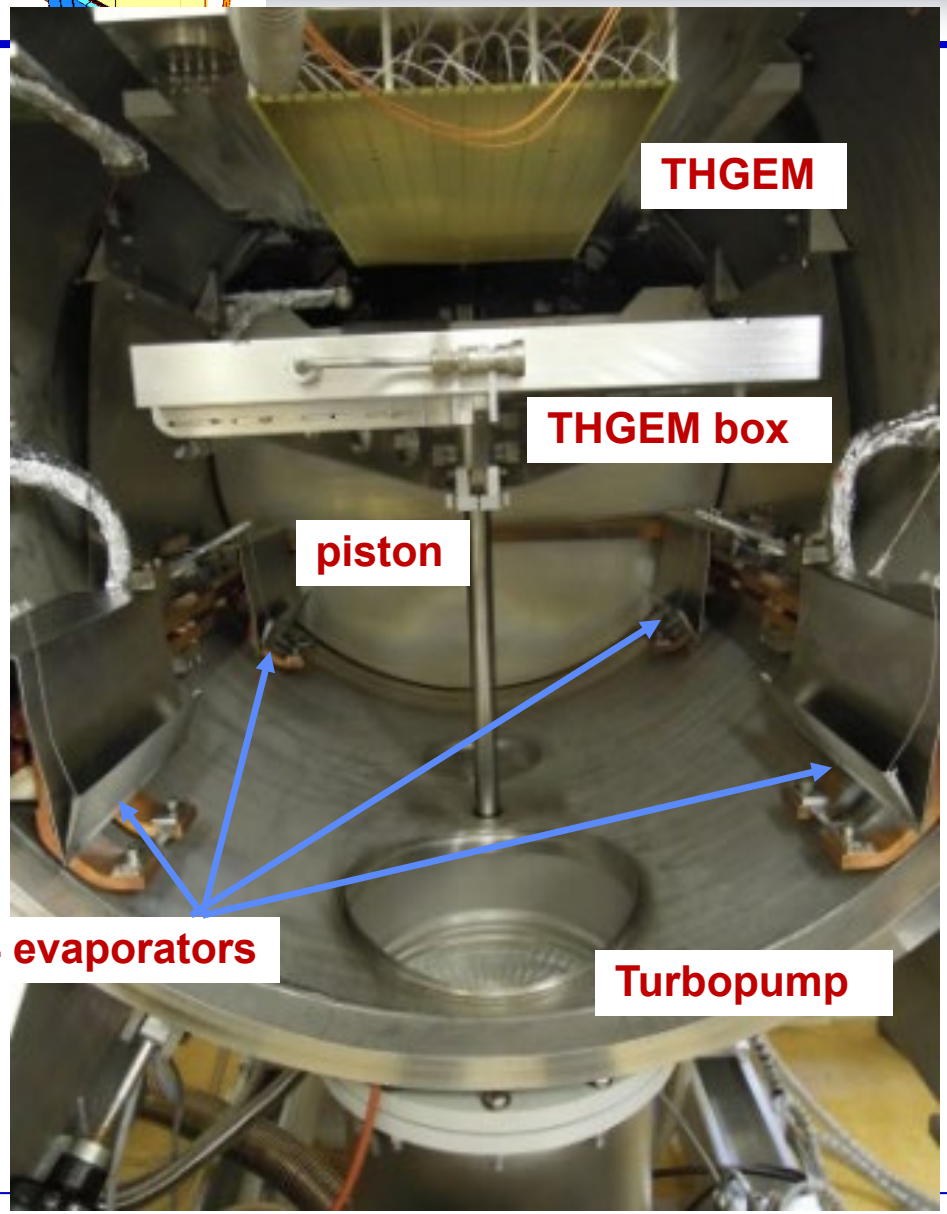


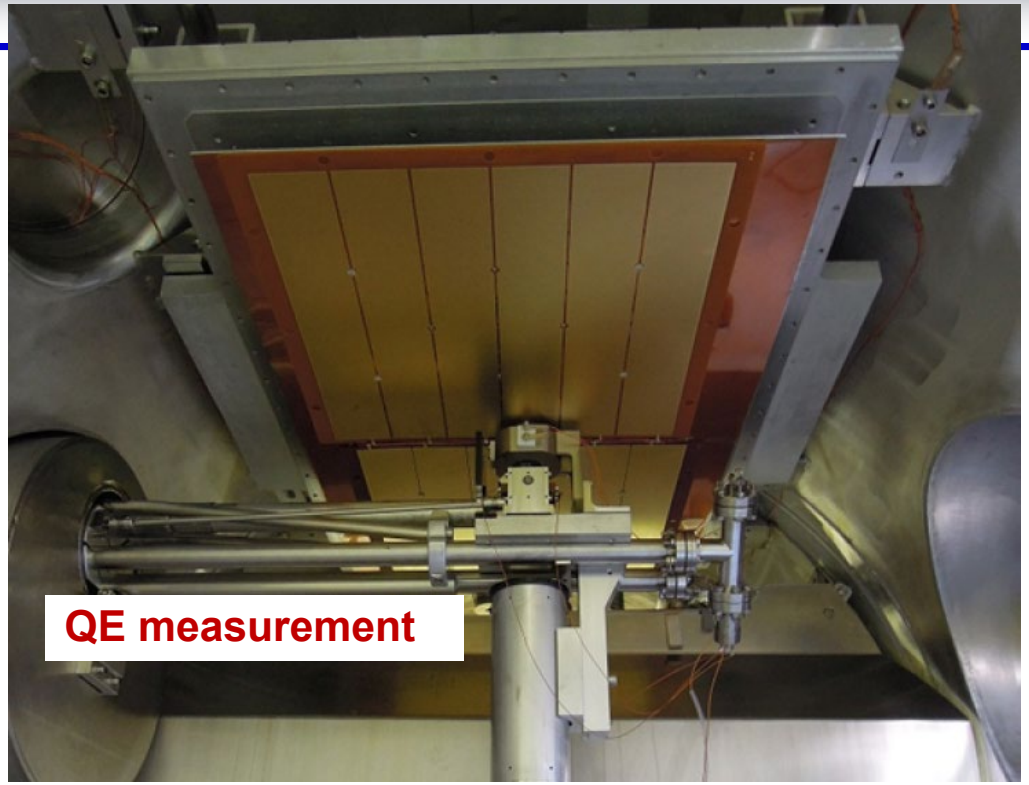
X-ray MM test to access integrity and gain uniformity (<5%)





CsI coating for THGEMS

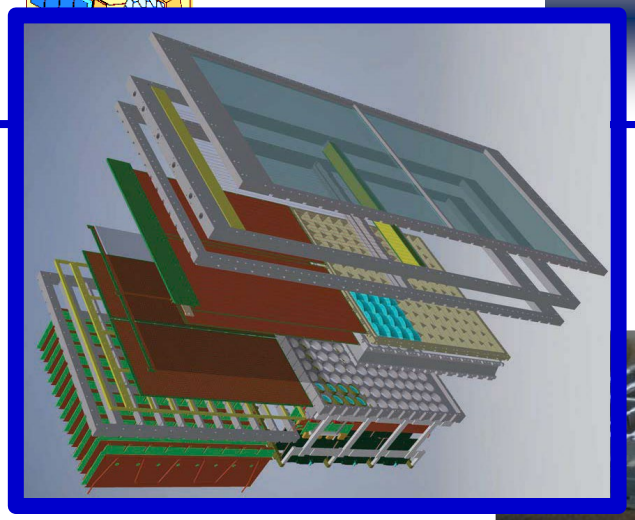


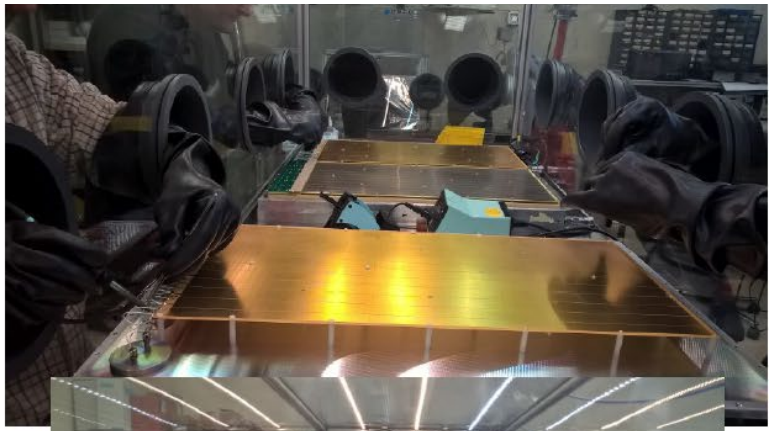


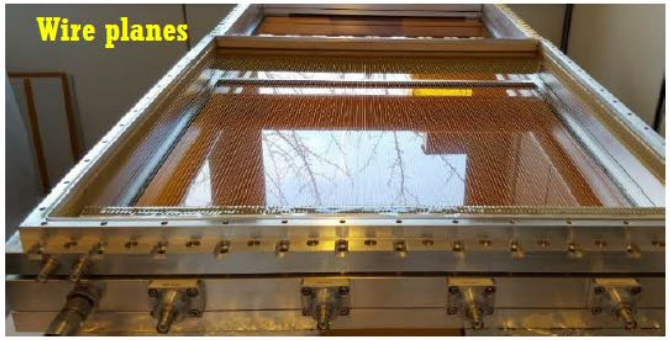
QE uniformity

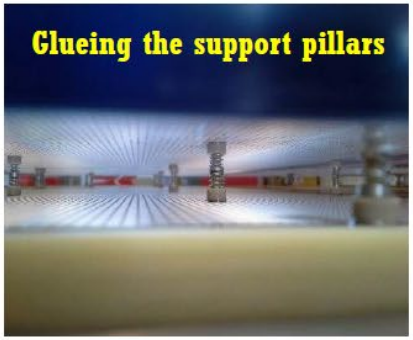
- 3 % r.m.s. within a photocathode
- 10 % r.m.s. among photocathodes
- mean value: 93% of reference

DETECTOR ASSEMBLY

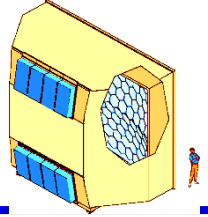






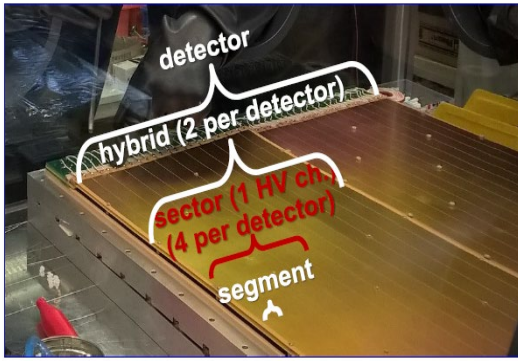


Assembling CsI coated THGEM in a dedicated glove box flushing with N_2



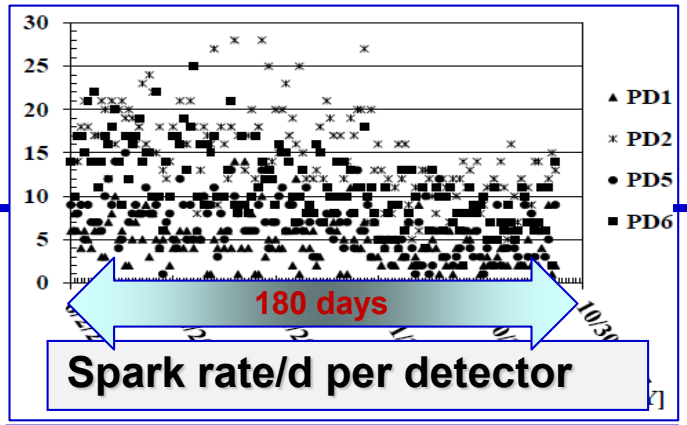
HV CONTROL

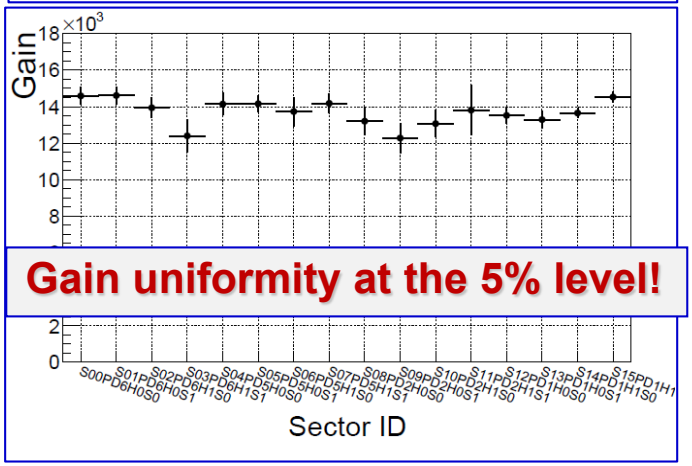
HV segmentation



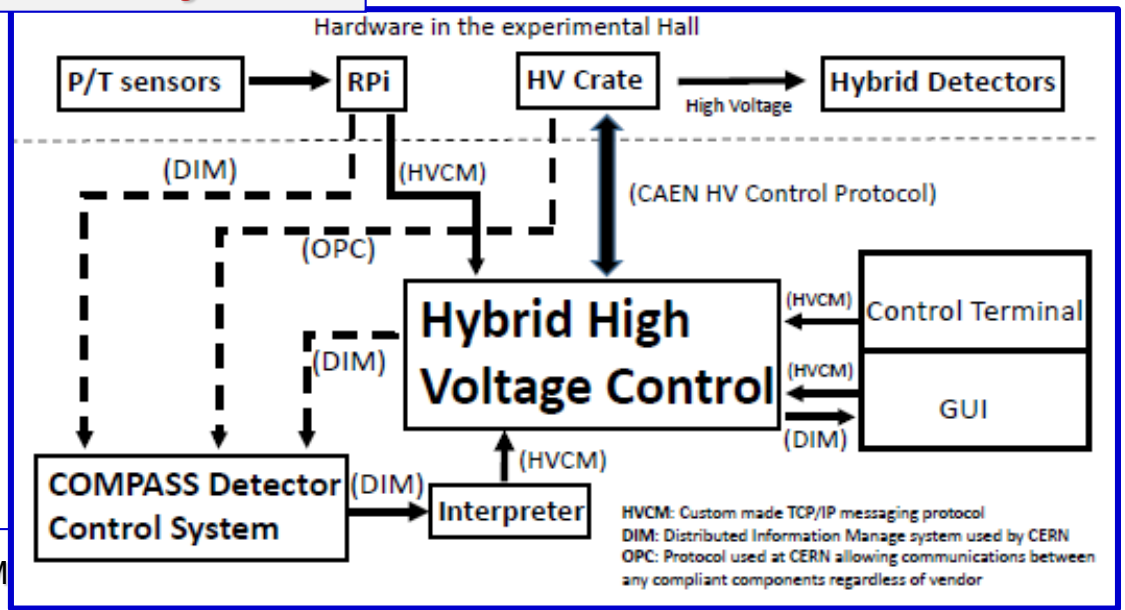
MAIN CHALLENGES

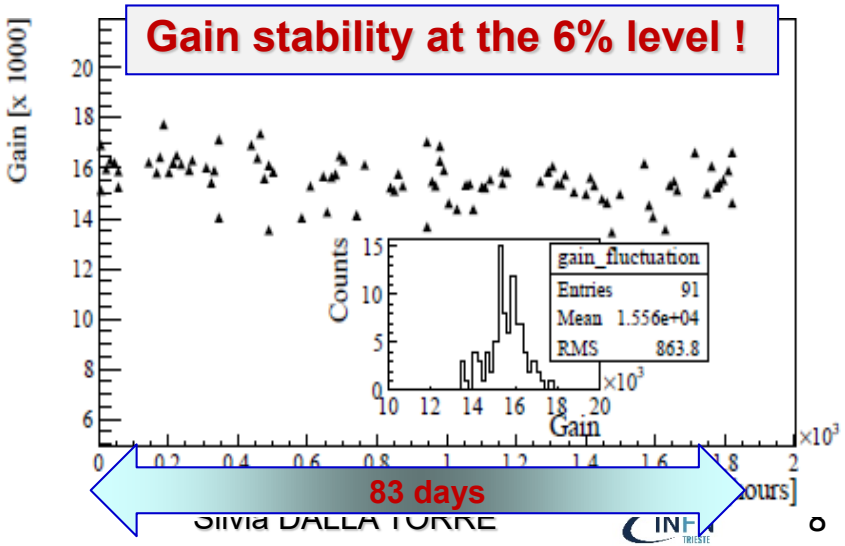
- In total 136 HV channels with highly correlated values
- stabilize and equalize the gain in the 16 sectors
- Gain stability vs P, T:
  - G = G(V, T/P)
  - $\Delta T = 1^{o}C \rightarrow \Delta G \approx 12\ \%$
  - $\Delta P = 10$ mbar $\rightarrow \Delta G \approx 20\ \%$
- THE WAY OUT:
  - Compensate T/P variations by V





The HV system





HV CONTROL

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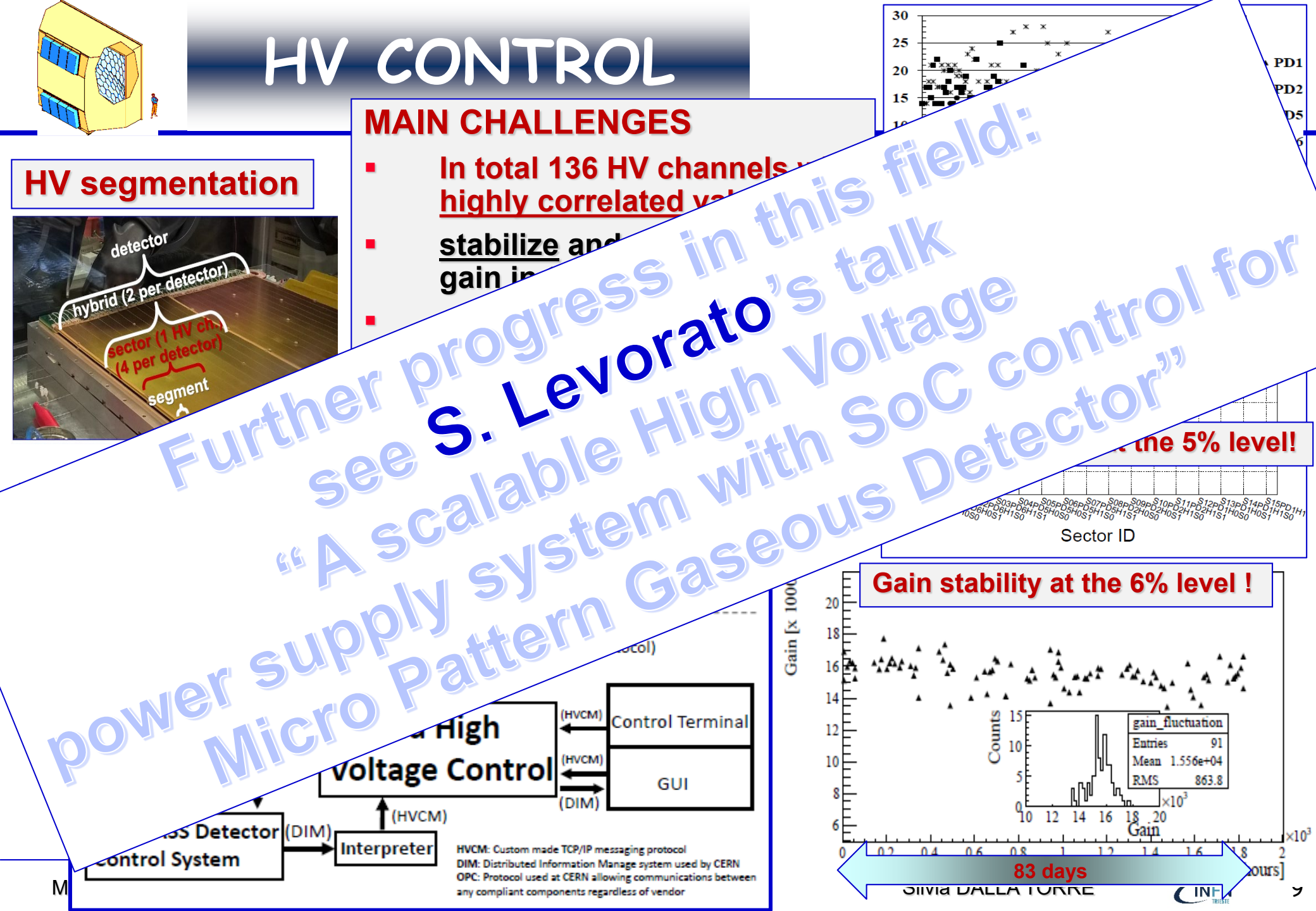
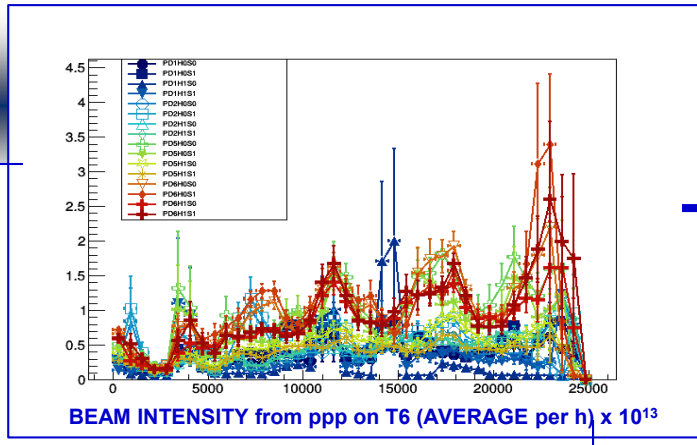
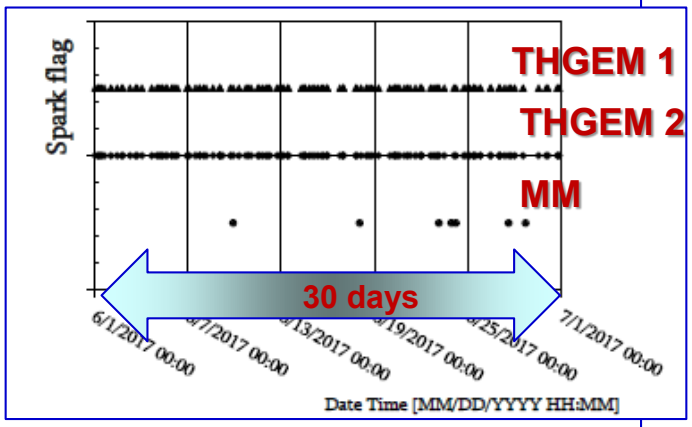


MAIN DETECTOR FIGURES

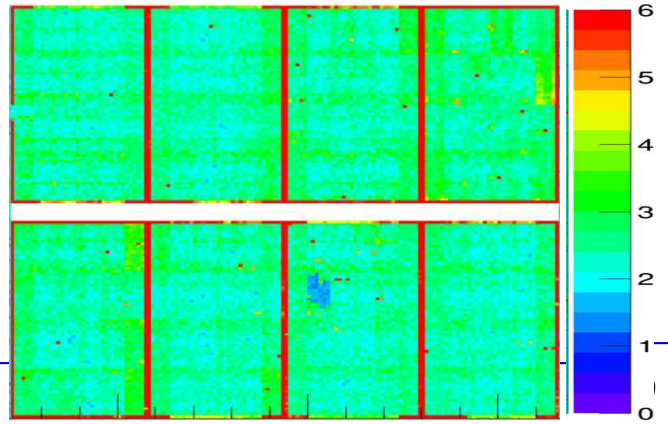
- **Current sparks in THGEMs**
  - Rate < 1/h per detector
  - Recovery time: ~ 10 s
  - Fully correlated between the two layers
  - Mild dependence on beam intensity



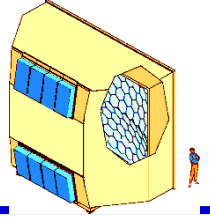


- **Current sparks in MICROMEGAS**
  - Rate < 1/d
  - Correlated with THGEM sparks: 70%
  - Recovery time: ~1 s

Noise distribution in the 19040 r-o ch.s,
Units: ADC ch.s (1 =300 e)



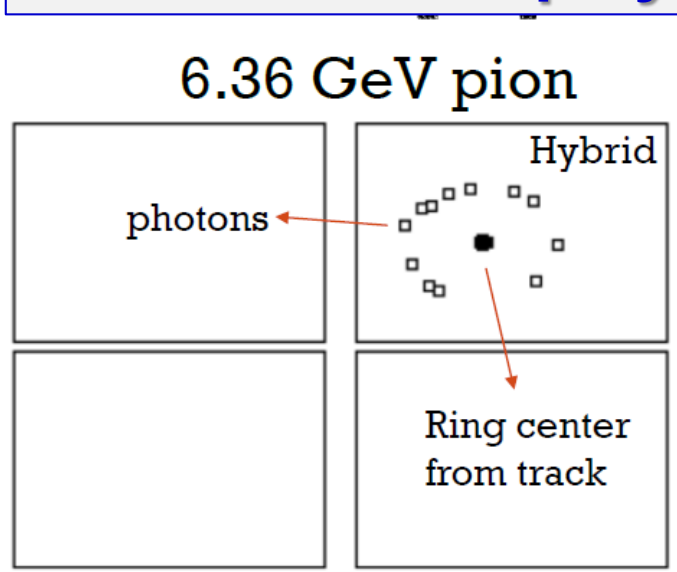
- **Noise (r.m.s.) :**
  - on average 900 electron equivalent
  - Channel C : 4pF
- **Ion backflow: ~ 3% level**

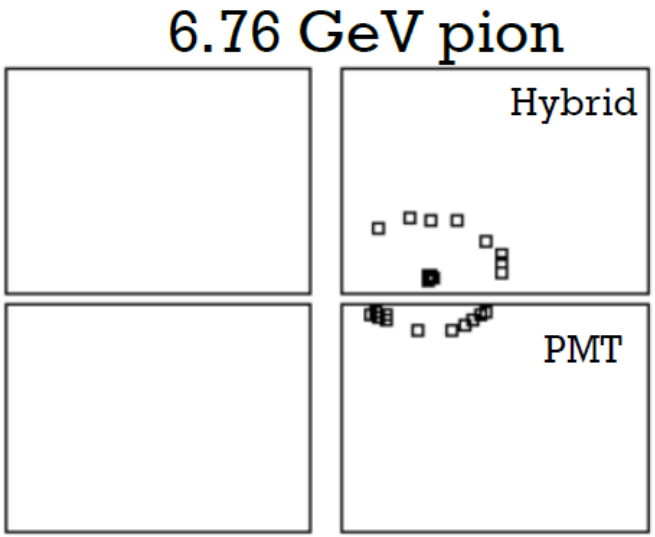


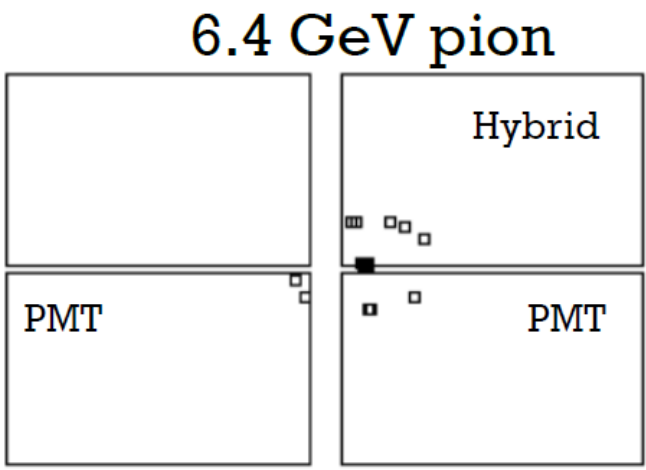
RINGS !!!

Correlation between photons and trajectories

From Event Display

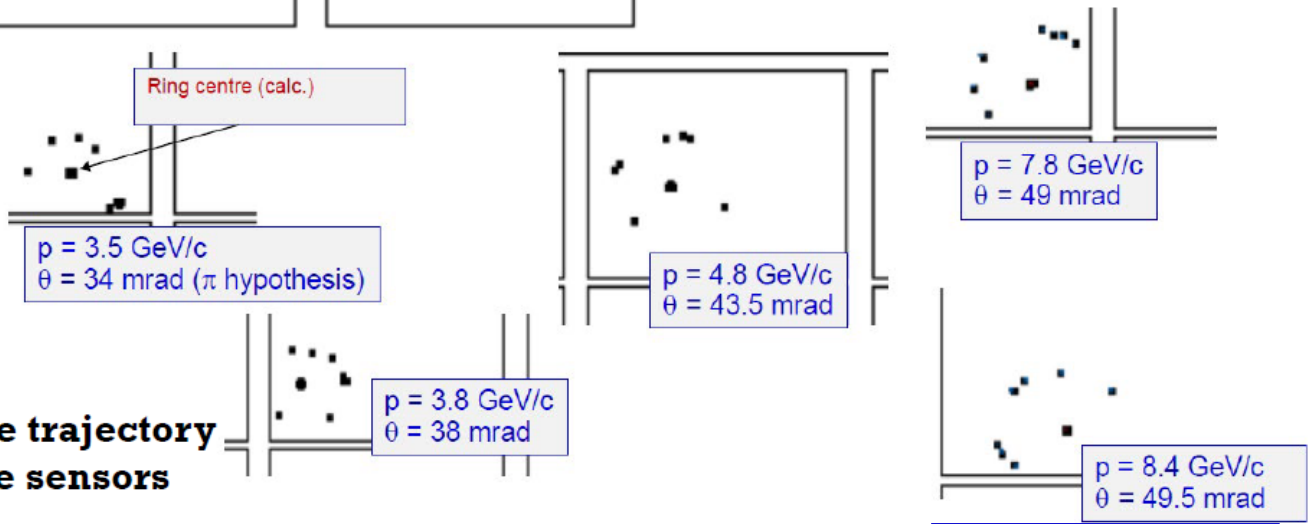






For reference:

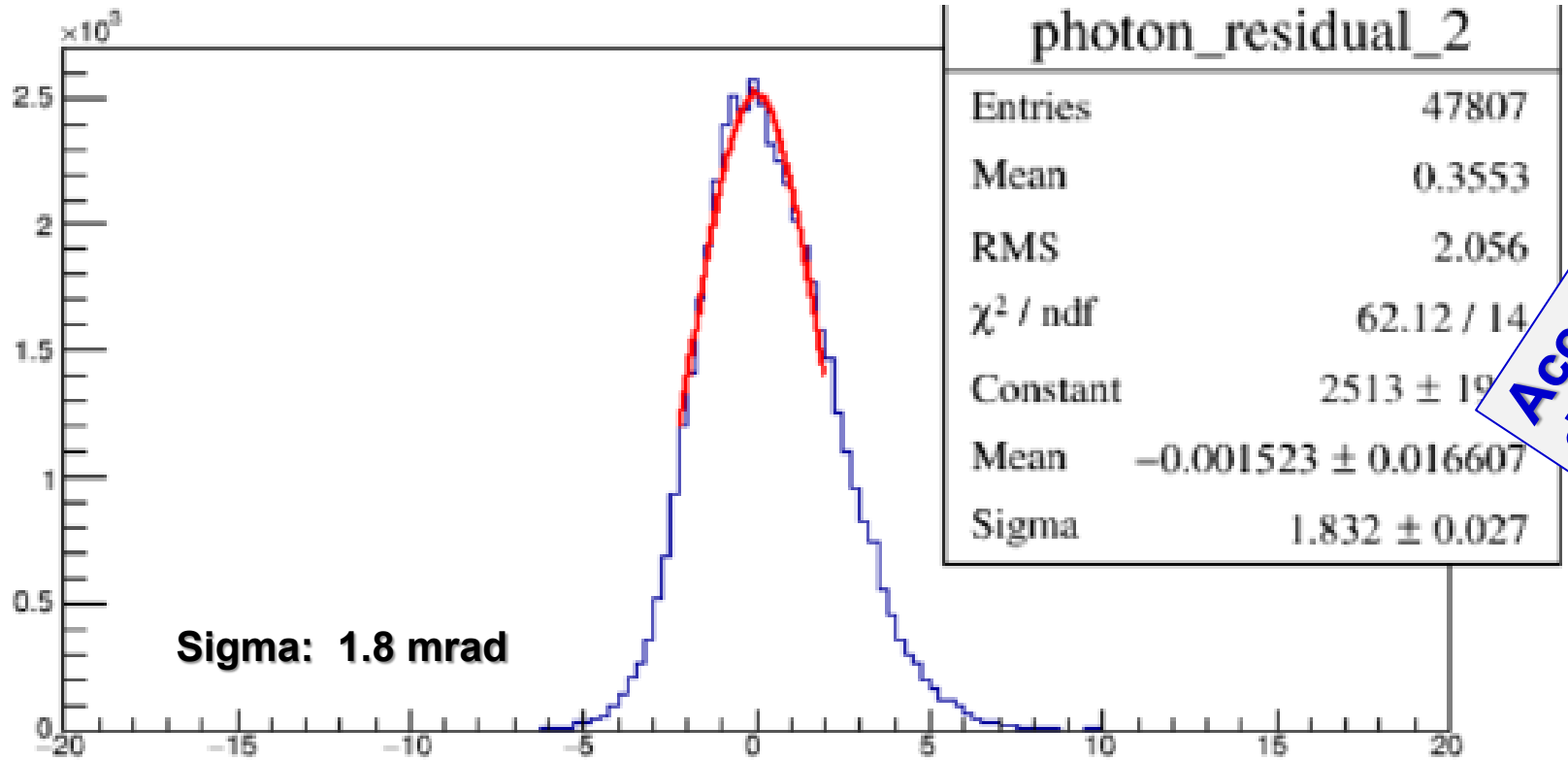
θ (β = 1) = 52.5 mrad



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

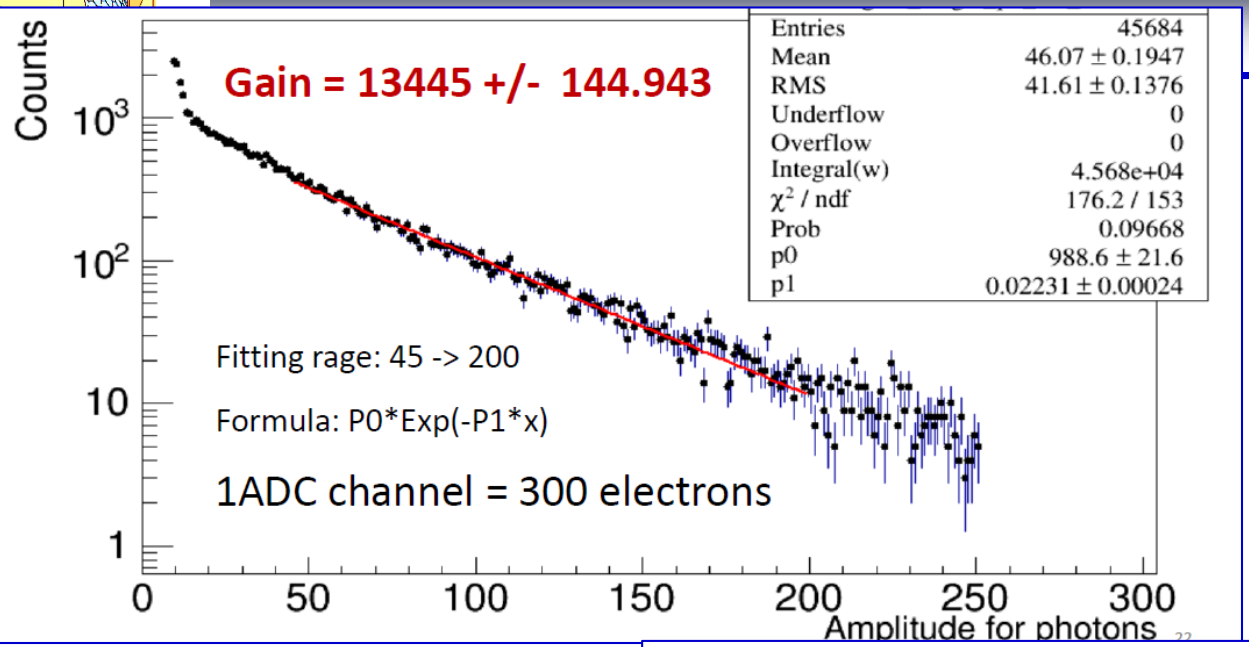
INTRINSIC SPACE RESOLUTION

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



According to design figures

GAIN FROM A PURE PHOTON SAMPLE

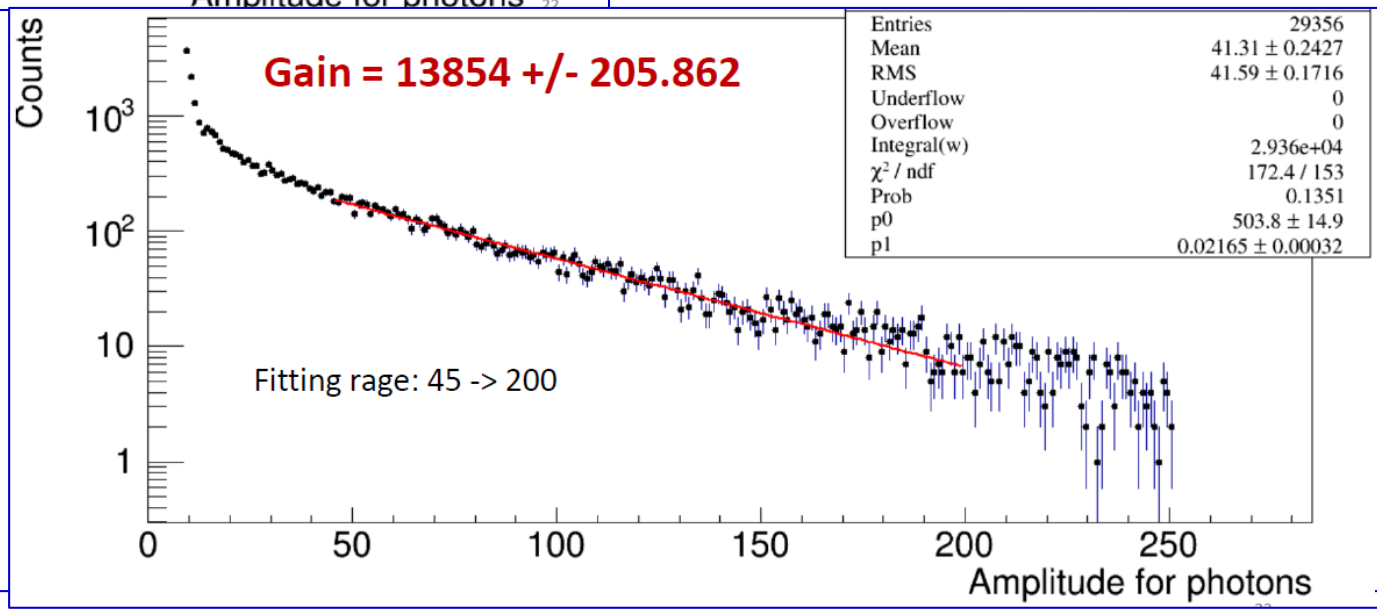


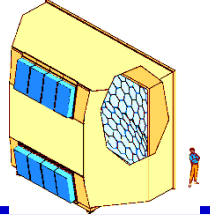
From electronic noise → Threshold

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

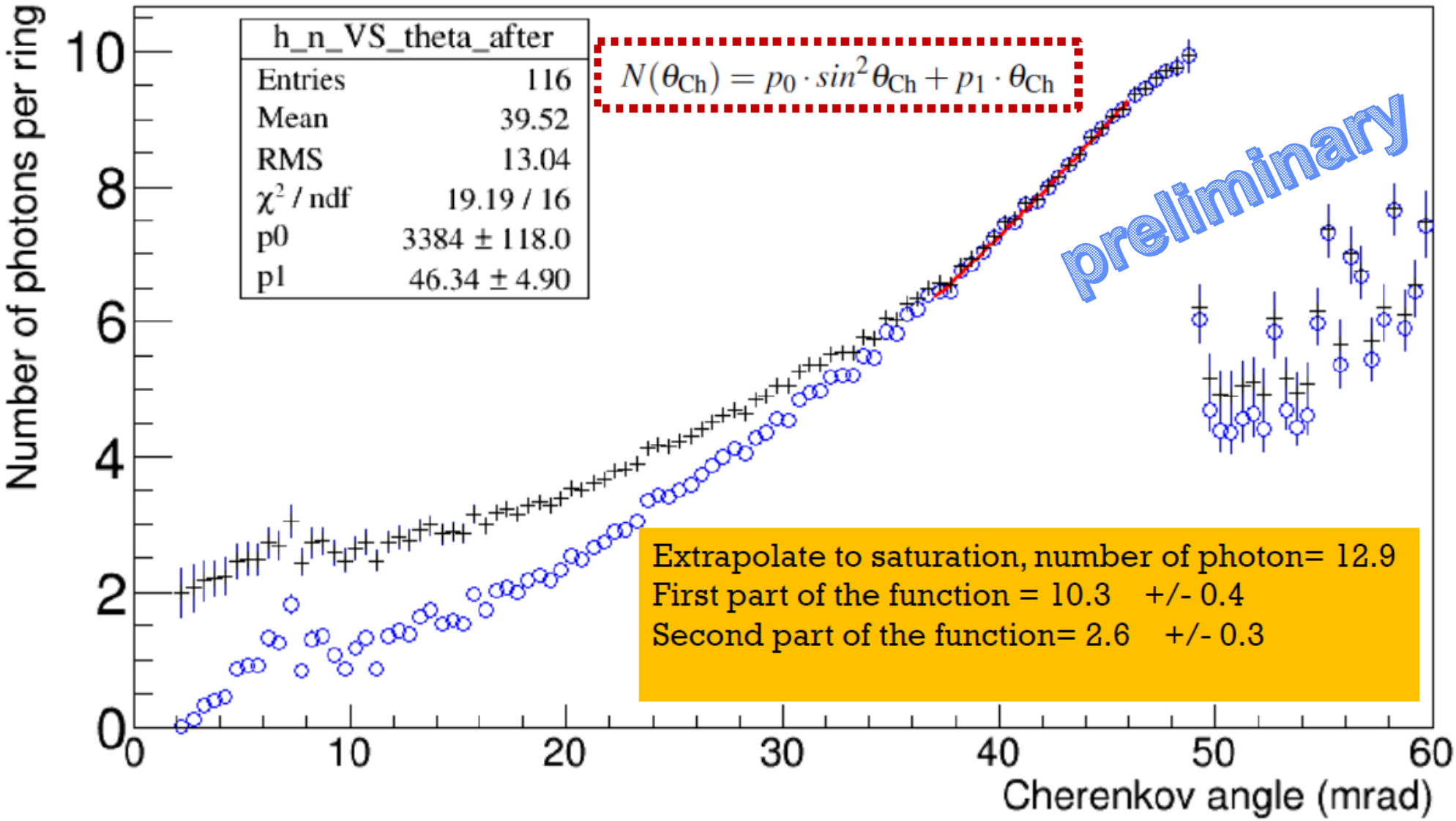
For comparison, in MWPCs: ~50-60%

from the extrapolated exponential an estimate of the **noise level under the signal: ~10%**

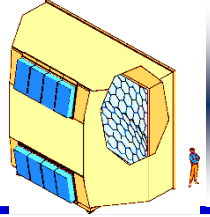




DETECTED PHOTONS per RING

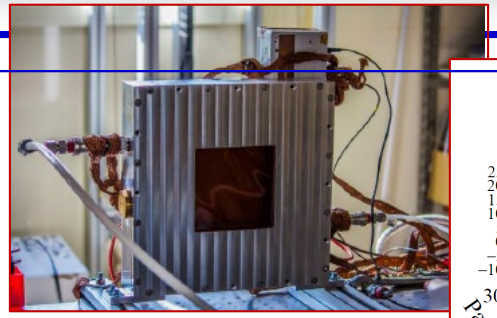


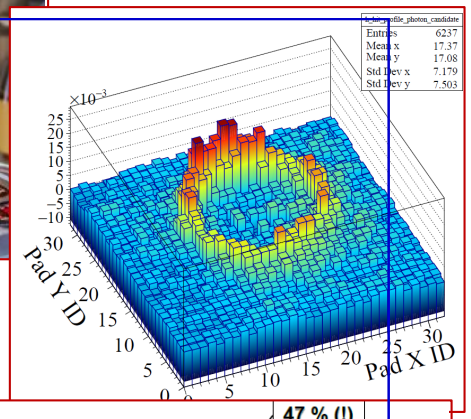
Extrapolate to saturation, number of photon= 12.9
First part of the function = 10.3 +/- 0.4
Second part of the function= 2.6 +/- 0.3



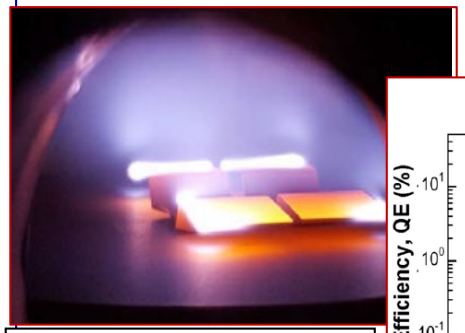
ON-GOING R&D

- Development of an optimized detector for finer spatial resolution based on the hybrid double THGEM + MM and “mini-pads” of size 3mm x 3mm

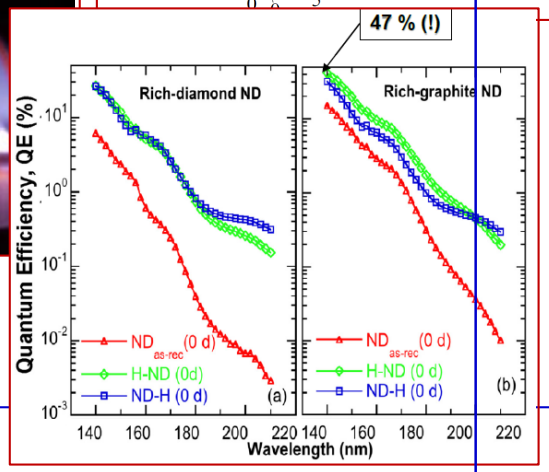




- Exploring the possibility to use a more robust photocathode in the far UV: hydrogenated nano-diamond crystals



Diamond & Related Materials 76 (2017) 1



GOAL

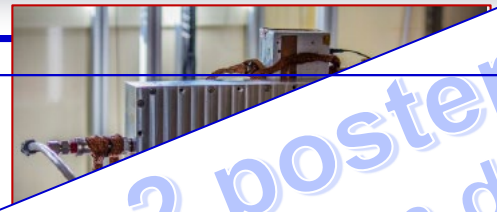
- **Application: h-PID at high p at the future ELECTRON-ION COLLIDER (EIC)**
- **Gaseous PDs exploiting the extremely far VUV region (~120 nm) with a windowless RICH**

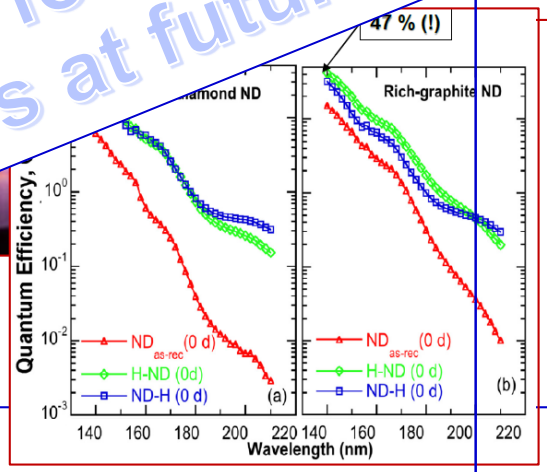
IEEE NS 62 (2015) 3256

ON-GOING R&D

- Development of an optimized detector for finer spatial resolution based on the hybrid THGEM + MM and "mini-pad" size 3mm x 3mm

- E





mond & Related Materials 76 (2017) 1

- D at high p at the future **ELECTRON-ION COLLIDER (EIC)**
- Ds exploiting the extremely far VUV region (~120 nm) with a owless RICH

IEEE NS 62 (2015) 3256

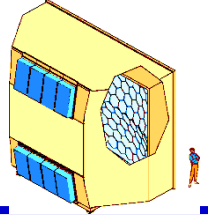
For more information, 2 posters:
S. Dasgupta: "A modular mini-pad photon detector prototype for RICH at the Electron Ion Collider";
Triloki: "Nanodiamond photocathode for MPGD-based single photon detectors at future EIC"

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**
  - **First resistive MM used in an experiment**
  - **For the first time MPGD gain > 10k in an experiment**

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



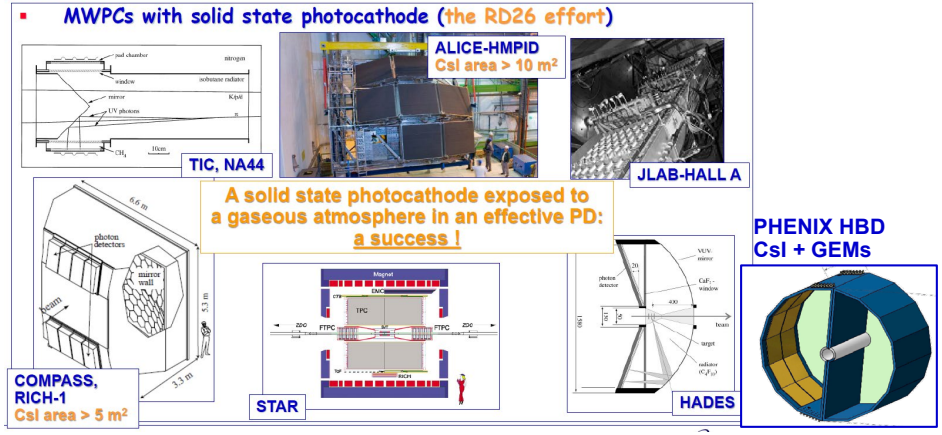
THANK YOU

MORE INFORMATION

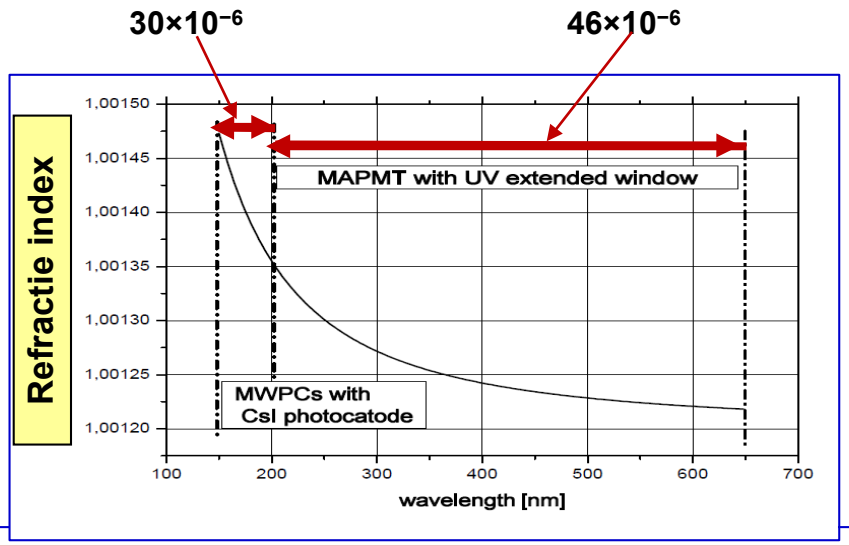
HANDLING THE VUV DOMAIN

CsI gasous sensors used in several Cherenkov detectors

- MWPCs with solid state photocathode (the RD26 effort)

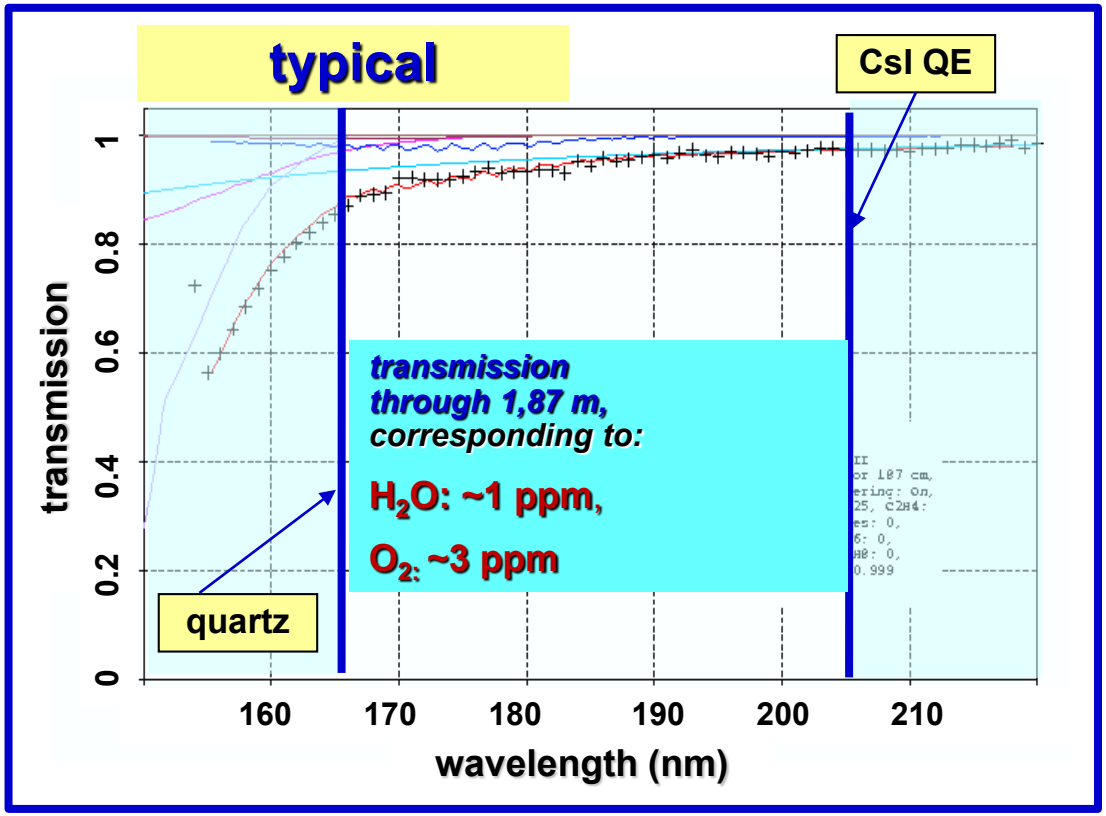


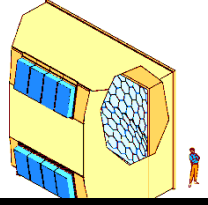
(n-1) r.m.s *(assuming Frank and Tamm):*



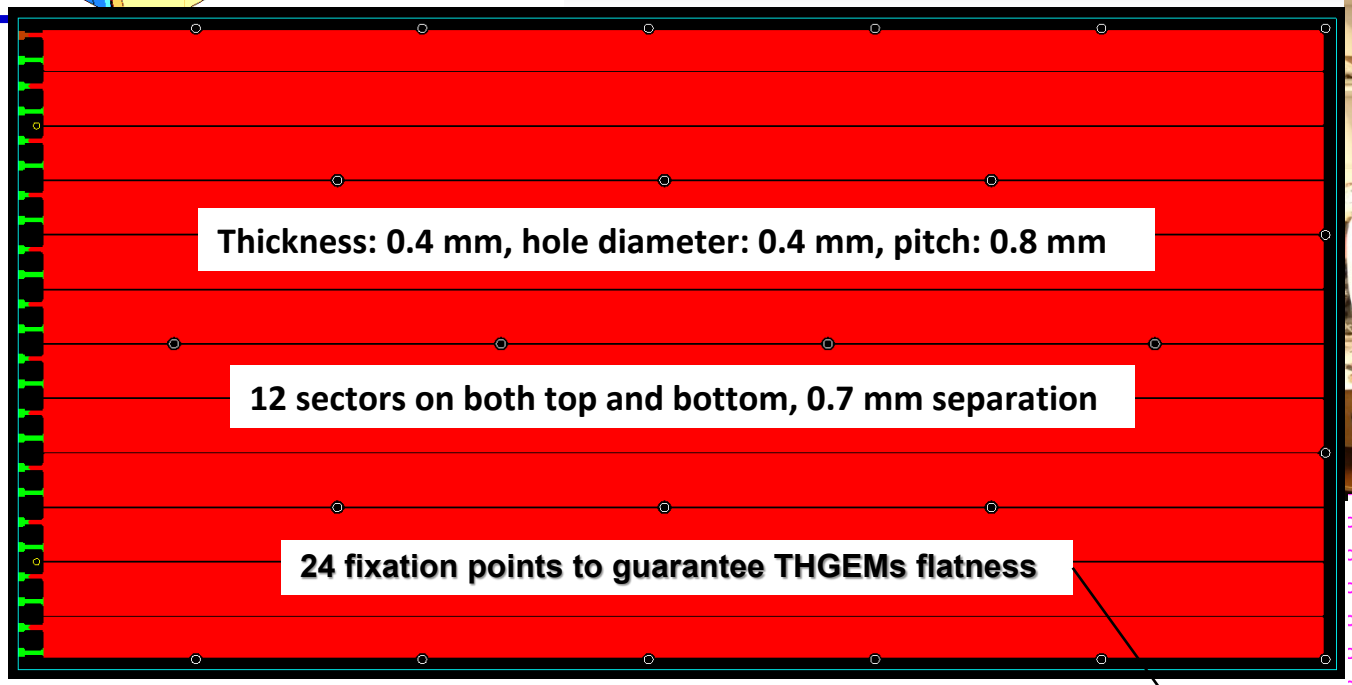
COMPASS RICH-1, gas transparency

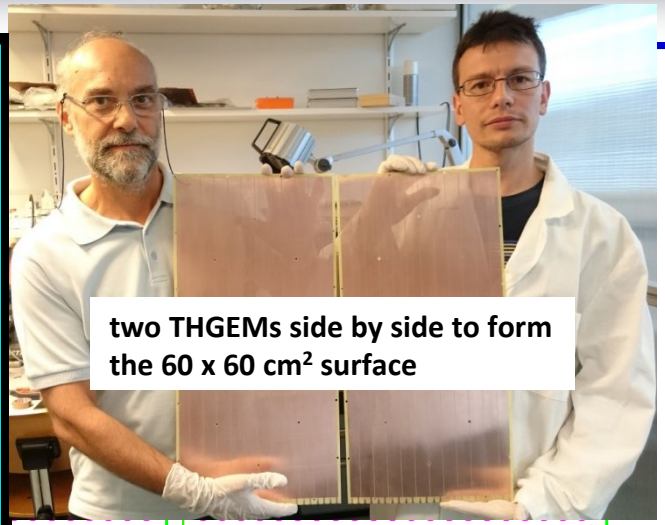
- gas cleaning by on-line filters,
- separate functions:
  - Cu catalyst, ~ 40^0C for O_2
  - 5A molecular sieve, ~ 10^0C for H_2O

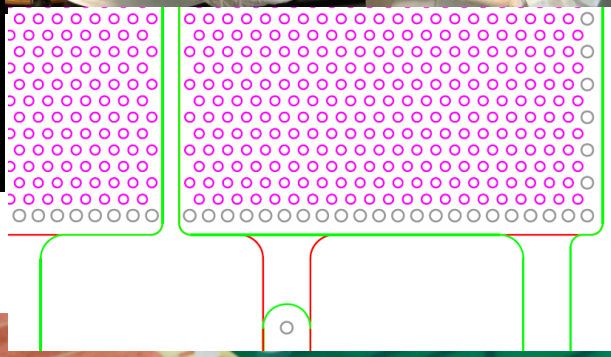


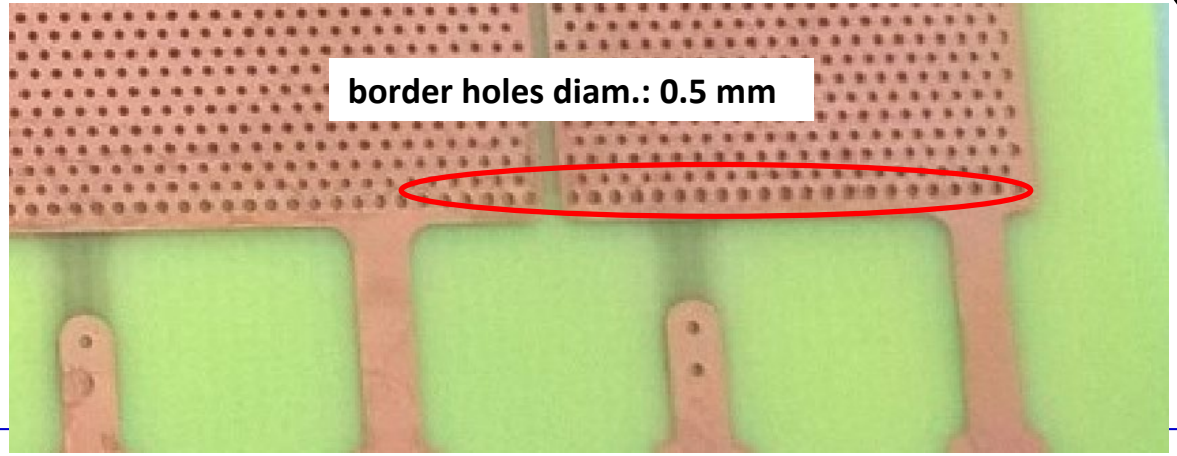


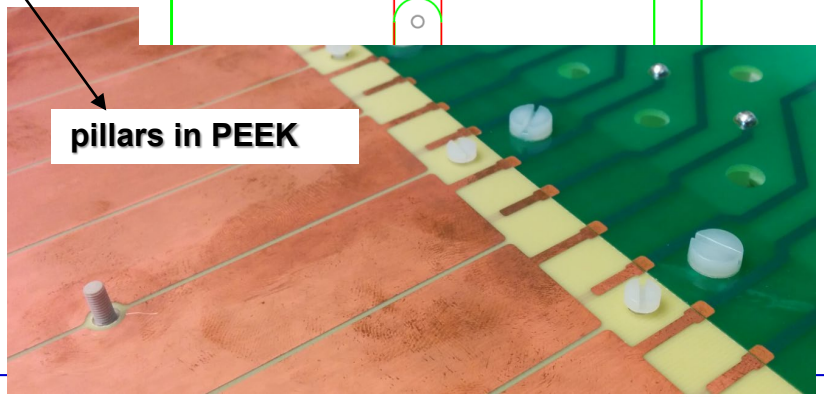
OUR THGEM DESIGN

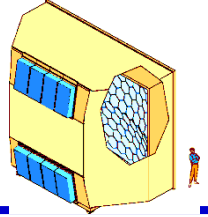






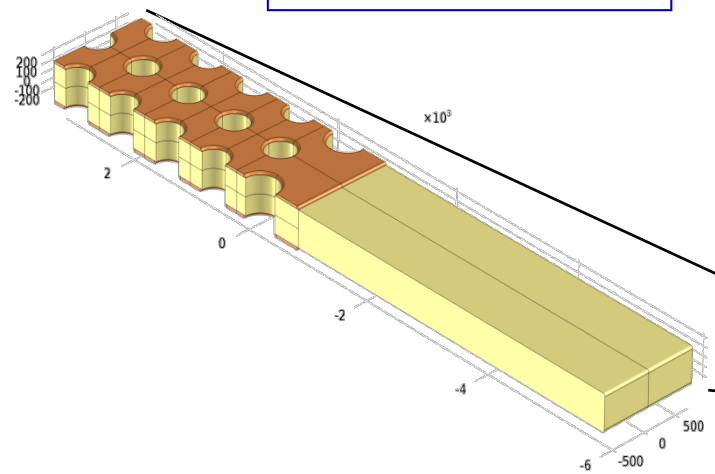


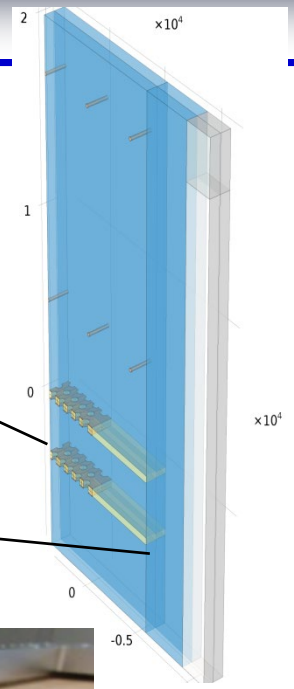


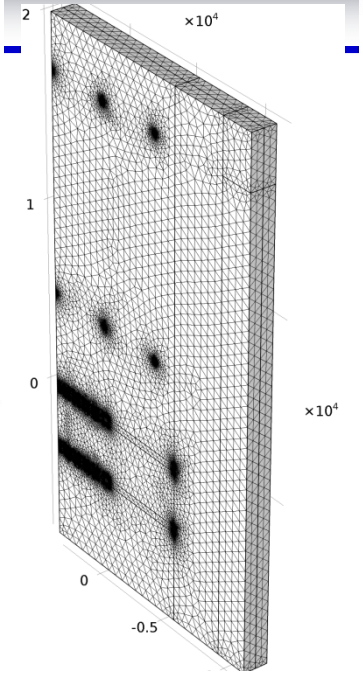


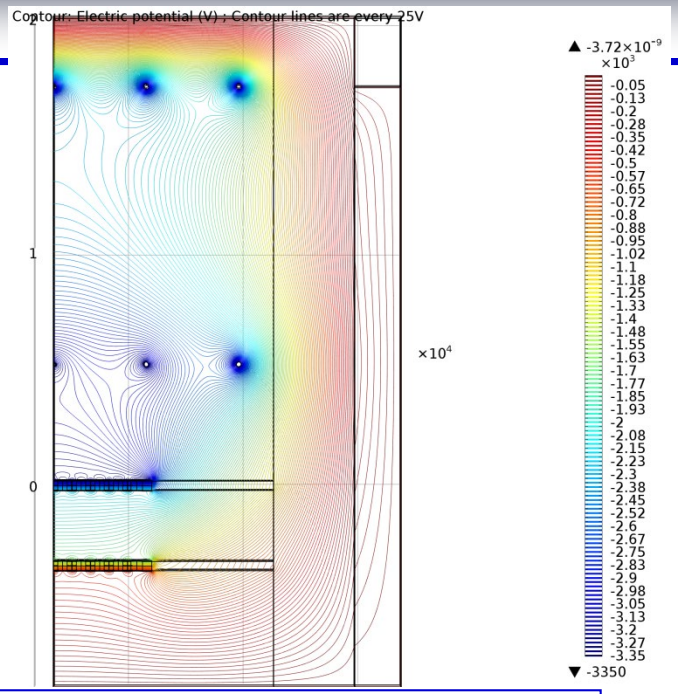
FIELD SHAPING ELECTRODES AT THE EDGES

THGEM border study

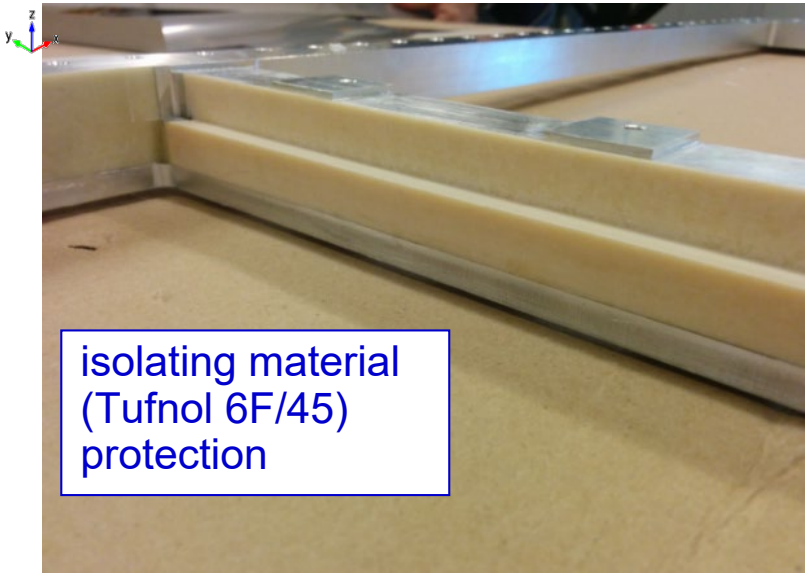






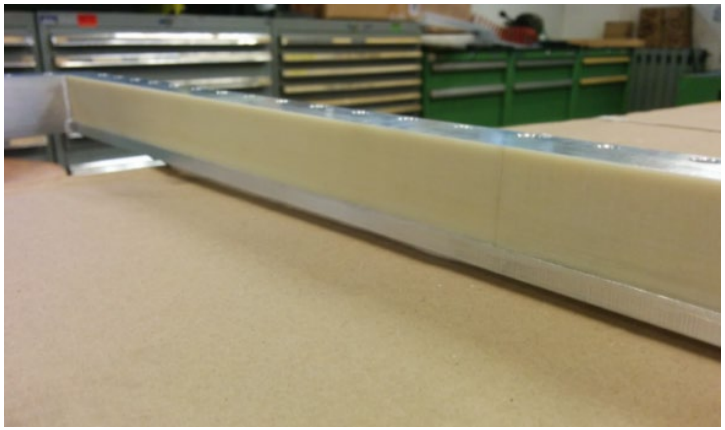


large field values at the chamber edges and on the guard wires



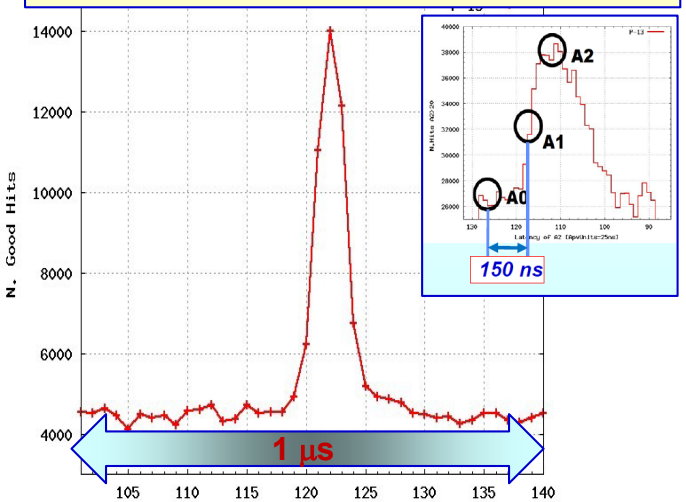
isolating material (Tufnol 6F/45) protection

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

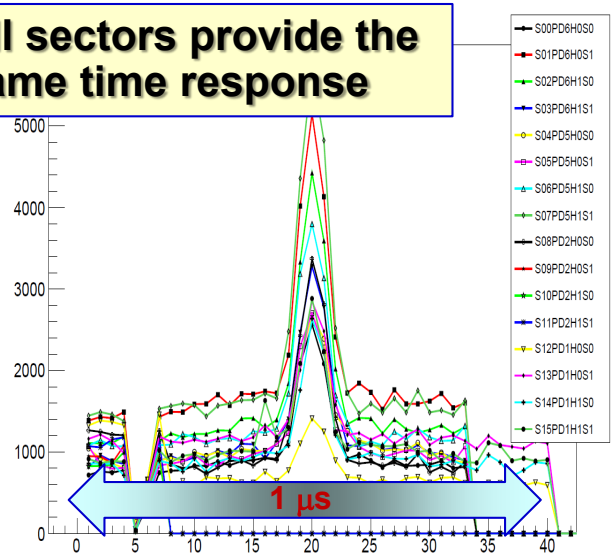


THE PHOTOELECTRON SIGNAL

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

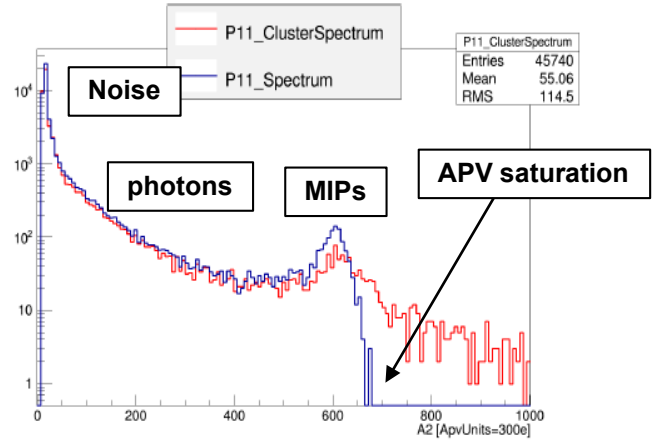


All sectors provide the same time response

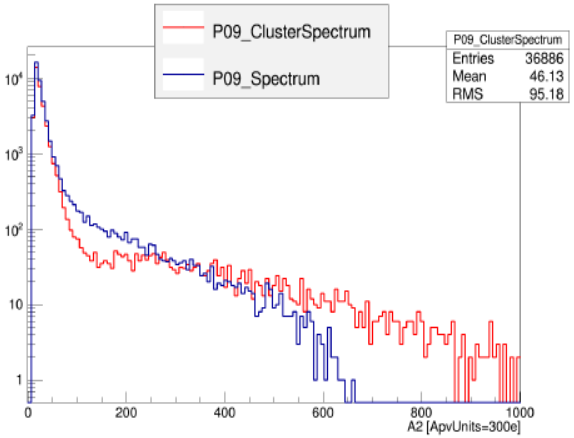


Clusterization to separate MIPs

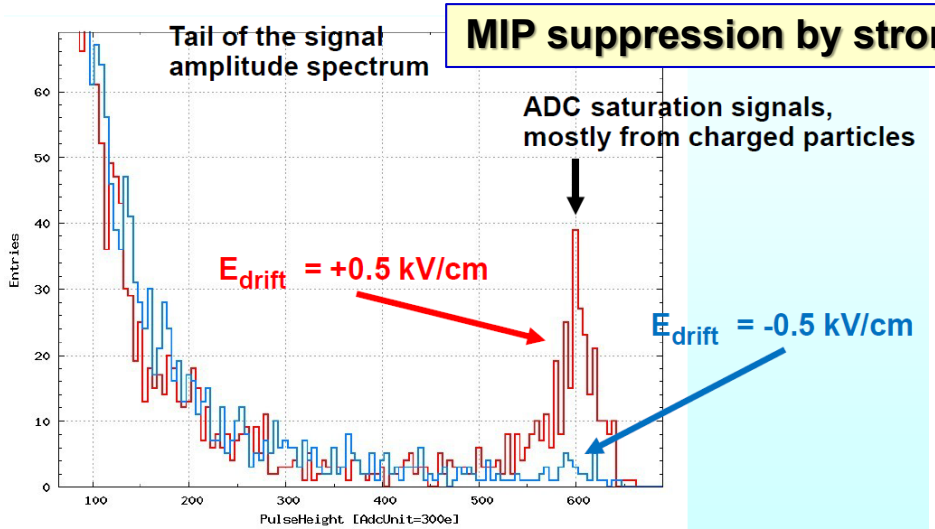
Hybrid MPGD (novel detector)



MWPC (old detector)

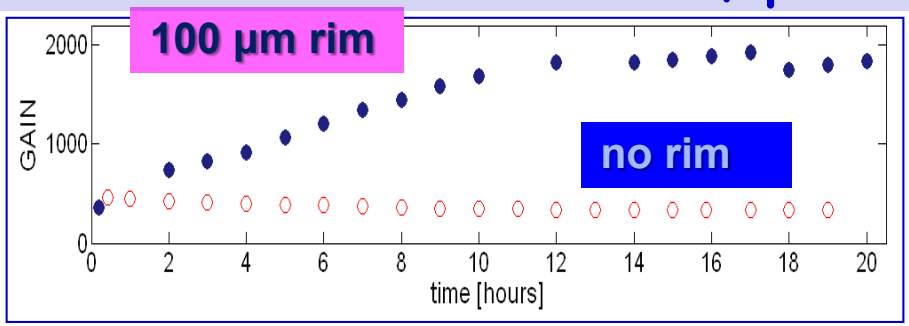


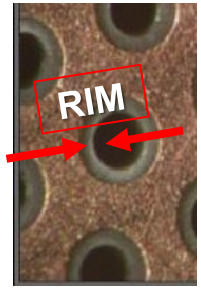
MIP suppression by strong reversed bias



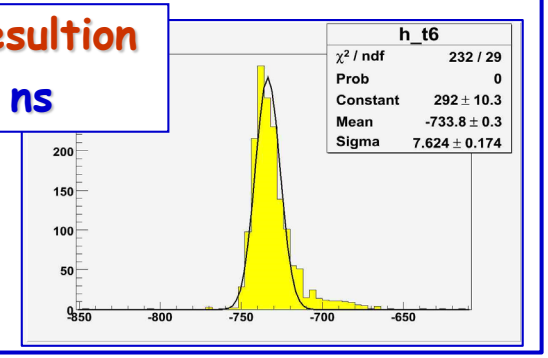
After 7 years of R&D

- **THGEM characterization, performance**



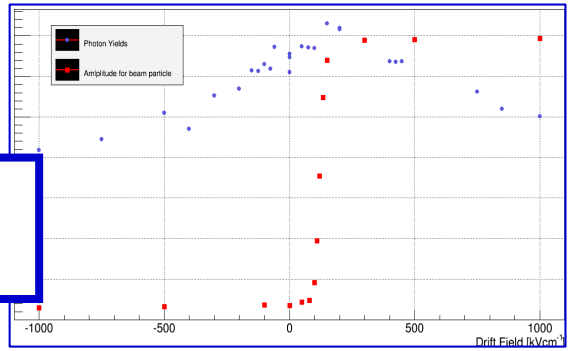


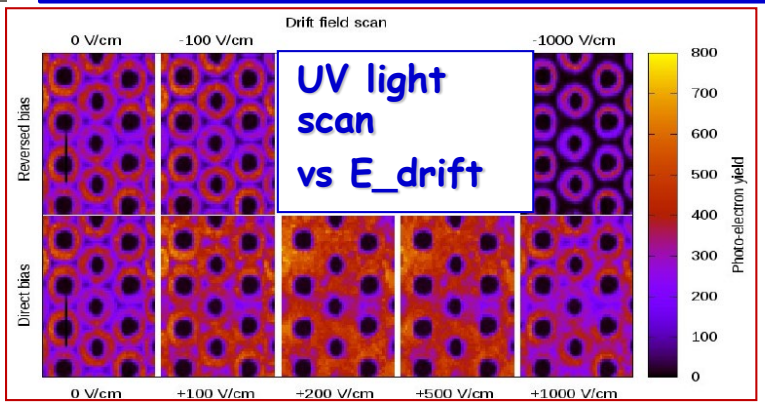
Time resultion ~7 ns



- **Photoelectron extraction**

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

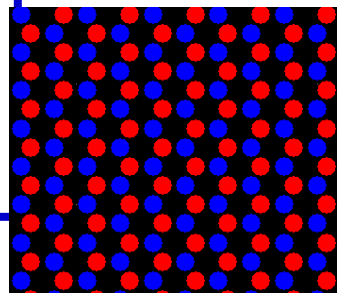




UV light scan vs E_drift

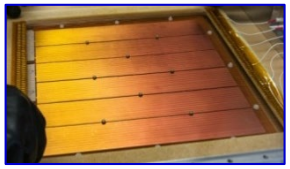
- **IBF (Ion Back Flow) suppression**

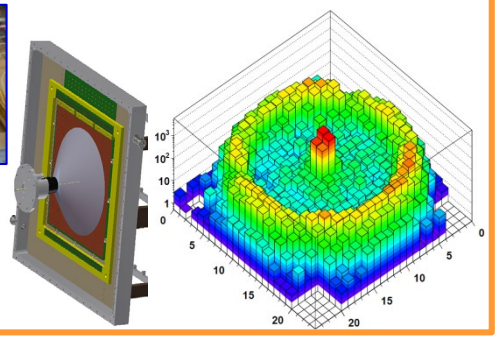
Tripple THGEM: IBF suppression (<5%) by staggering plates

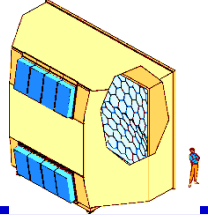


IBF suppression (<3%) introducing a MM stage: no need of high Transfer electric field → **Hybrid architecture**

Cherenkov light detection in TB



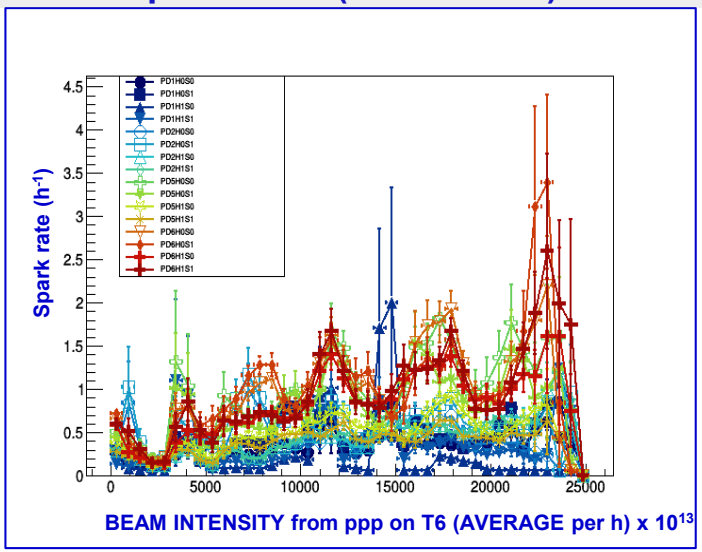




ELECTRICAL STABILITY

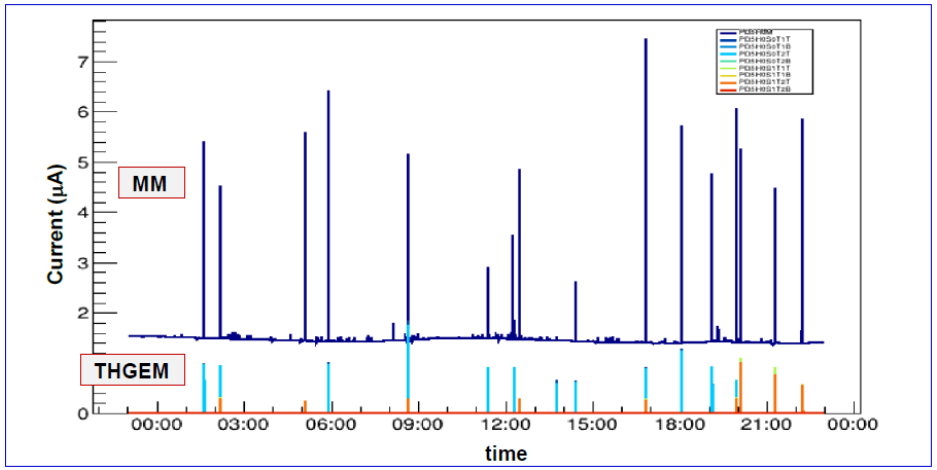
THGEMs, lessons

- 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

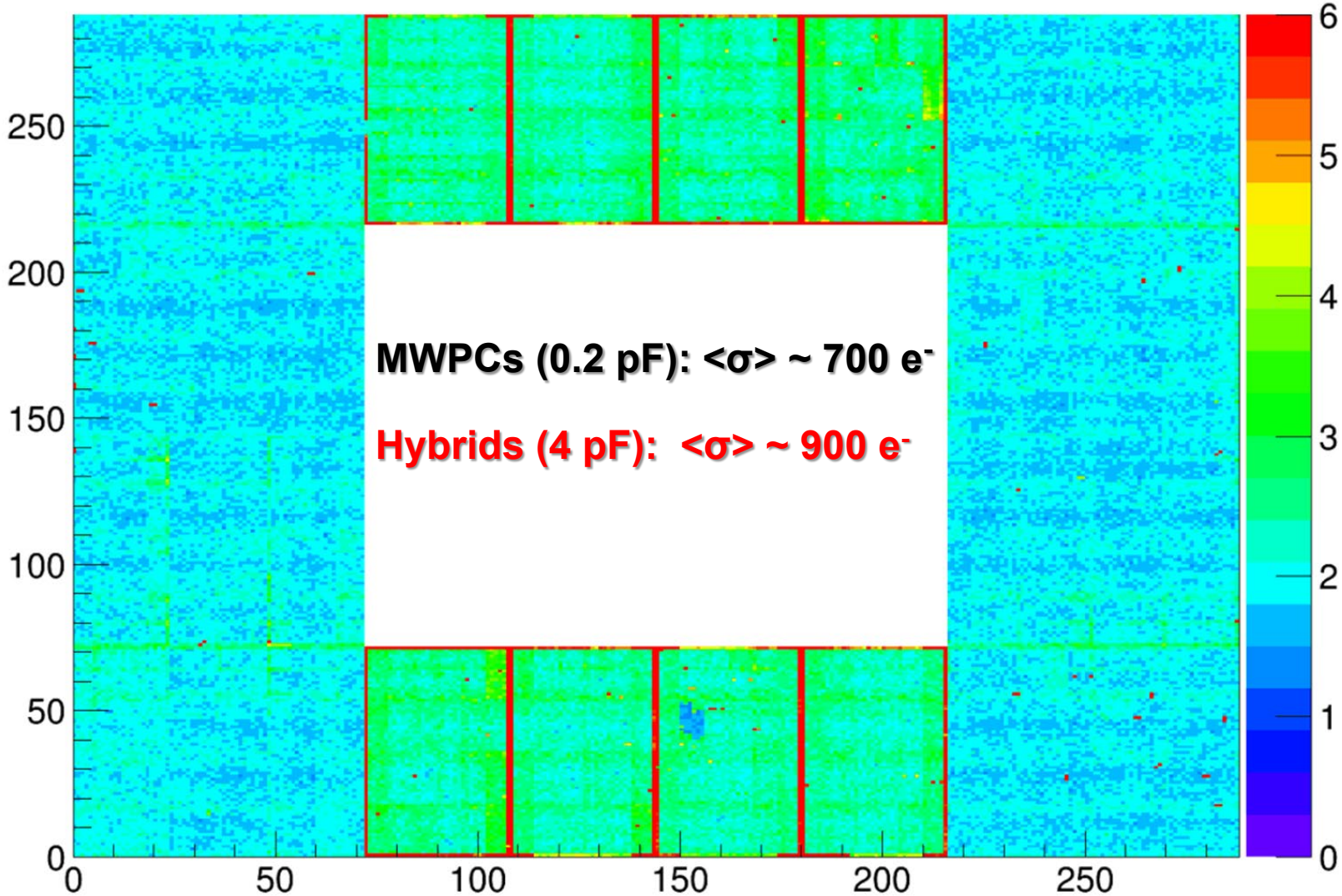


MICROMEGAS, lessons

- 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?

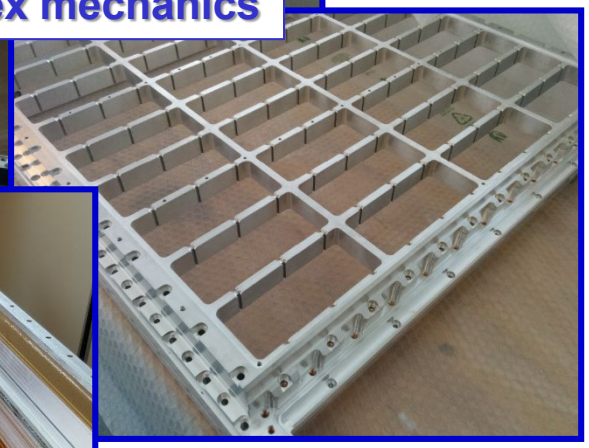


NOISE FIGURES

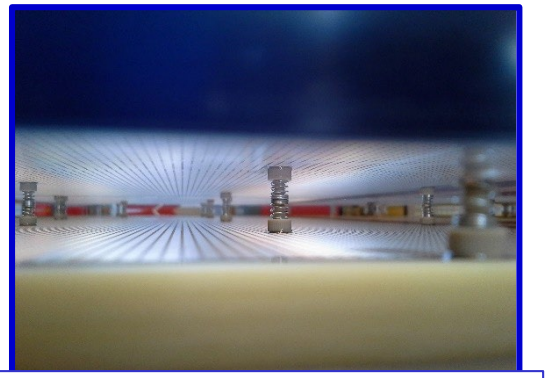


CONSTRUCTION & ASSEMBLY

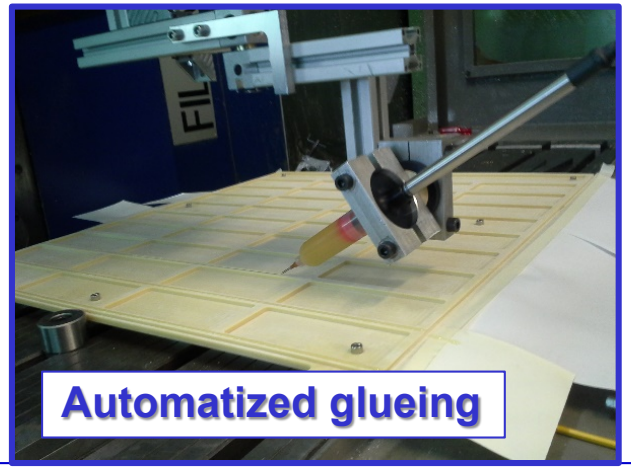
Complex mechanics



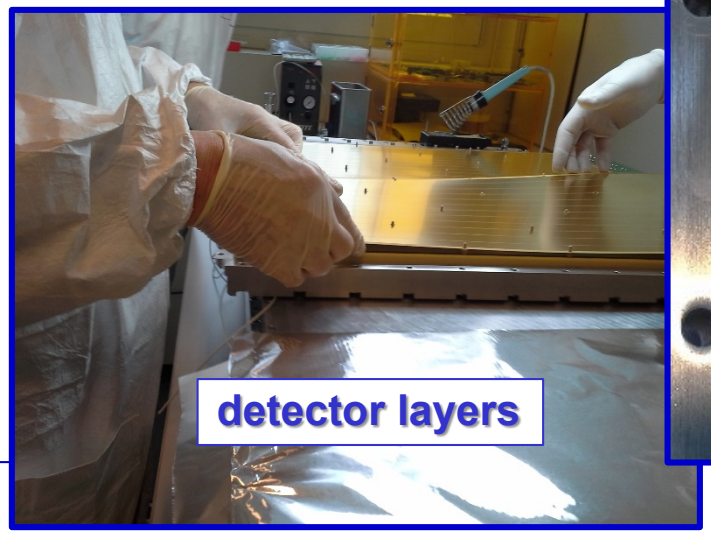
Wire planes



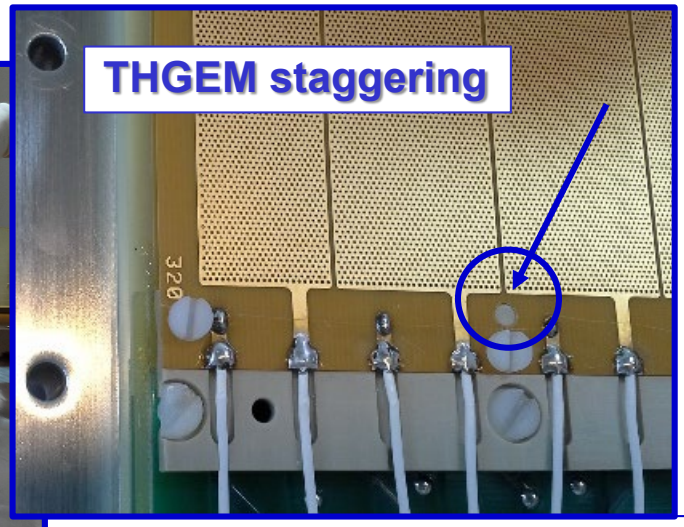
Glueing the support pillars



Automatized glueing



detector layers



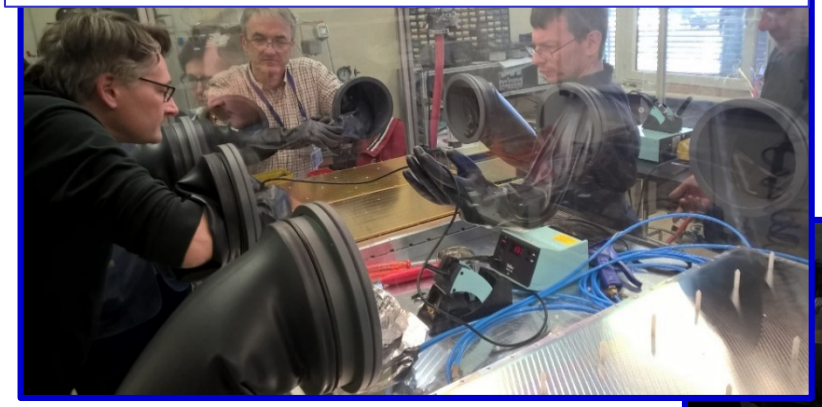
THGEM staggering

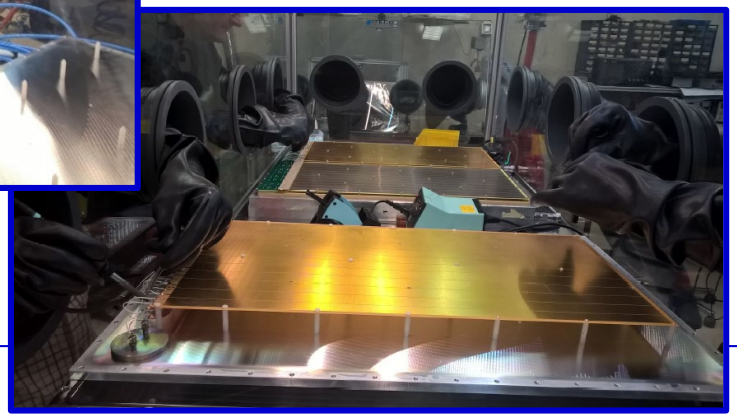
ASSEMBLY in a nutshell

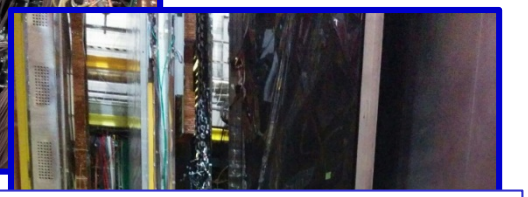
Pre-assembly w/o CsI

Onto the RICH

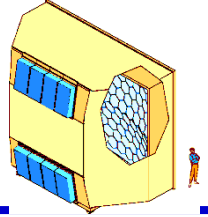
final assembly of the active module assembly with CsI in glovebox







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)

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

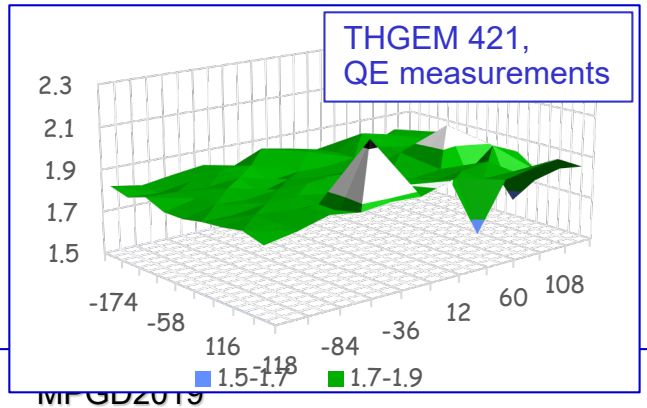
11 coated THGEMs available, 8 used + 3 spares

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%

<u>in agreement with expectations</u> (THGEM optical opacity = 0.78)

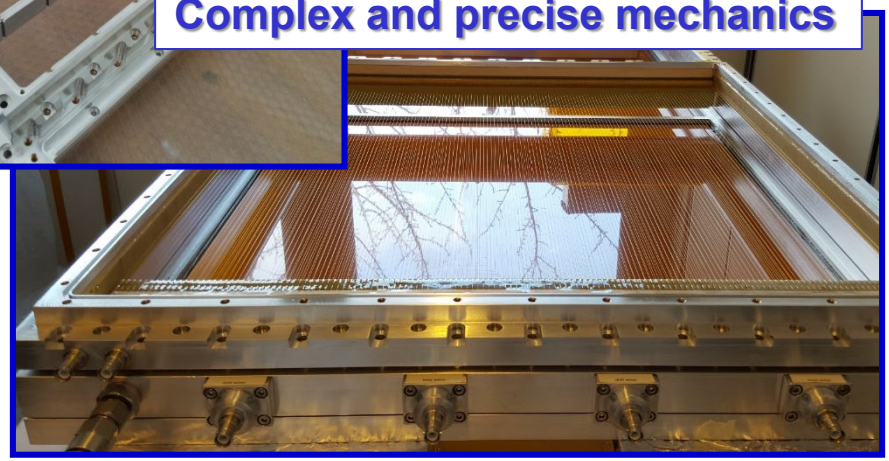


QE is the result of a surface scan (12 x 9 grid, 108 measurements)

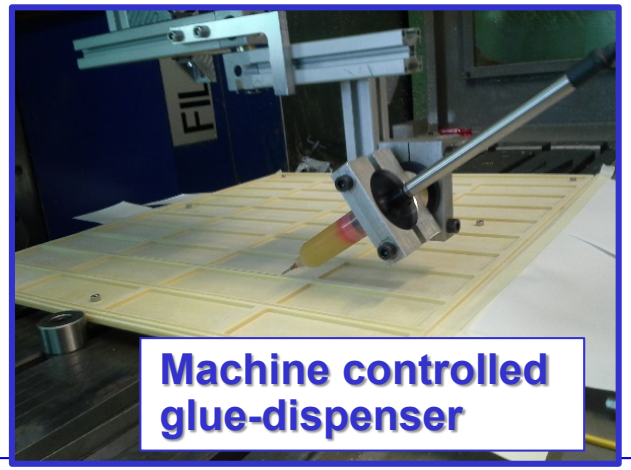
Good uniformity, in the example σ_{QE} / <QE> = 3%

CONSTRUCTION & ASSEMBLY

Complex and precise mechanics



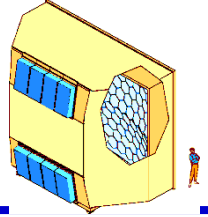
Assembly in clean room



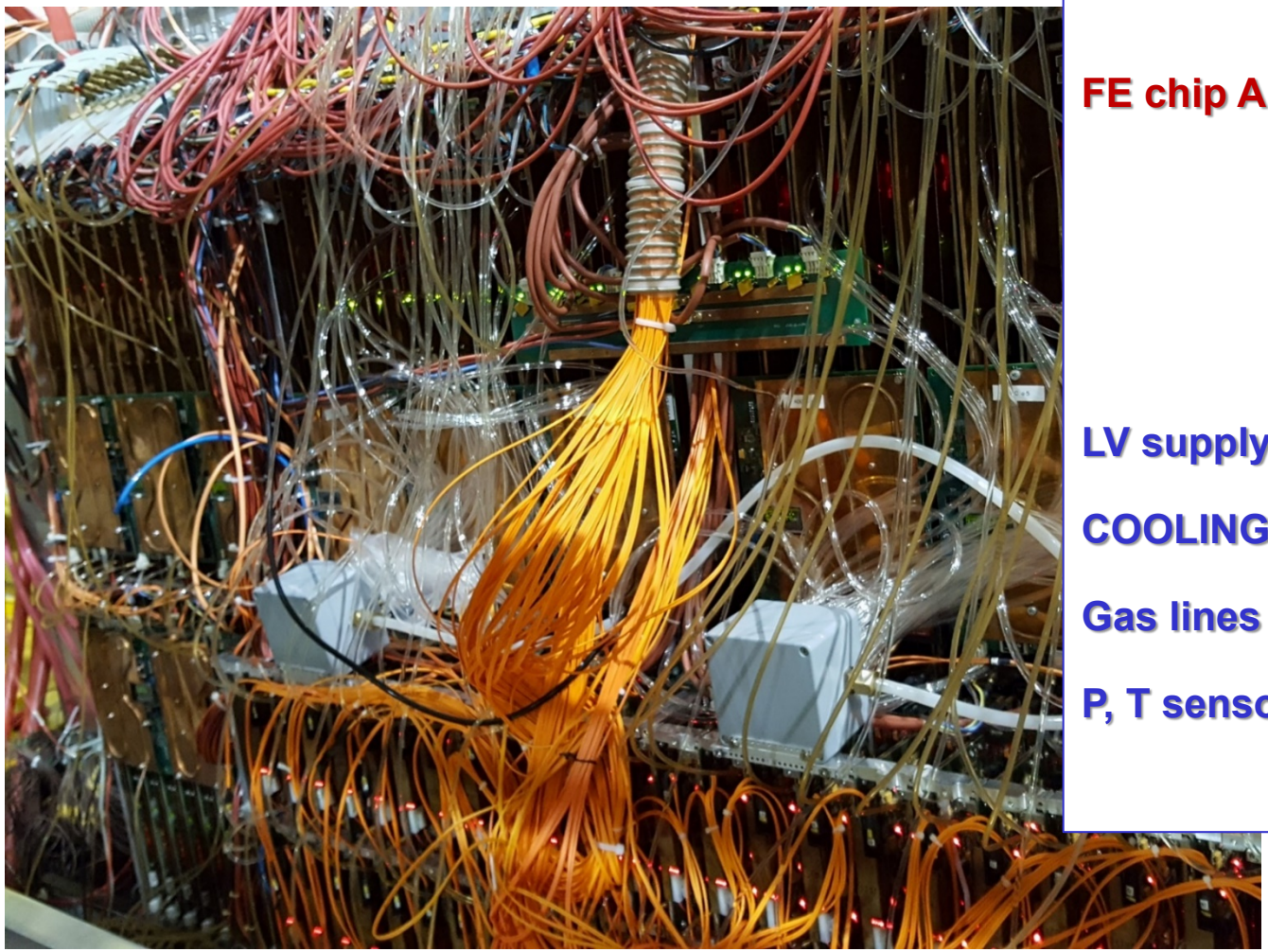
Machine controlled glue-dispenser

Including photocathode in glovebox

glovebox also
to mount the active module
onto the RICH

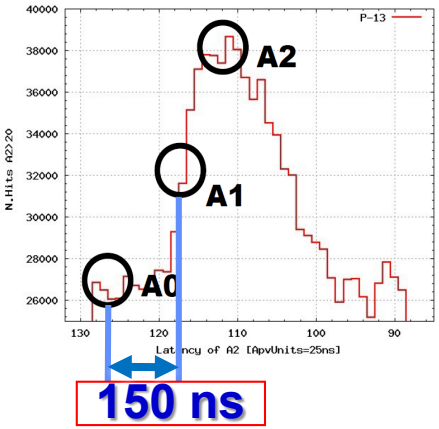


READ-OUT and SERVICES



read-out :
already available for the MWPCs with CsI

FE chip APV25



LV supply

COOLING

Gas lines

P, T sensors