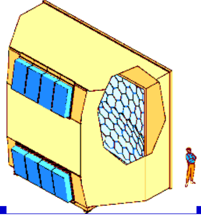
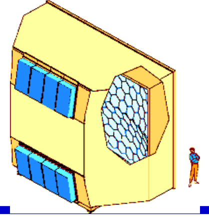


The MPGD-Based Photon Detectors for the upgrade of COMPASS RICH-1 and beyond

S. Dalla Torre

on behalf of the COMPASS RICH group



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- ***The context***
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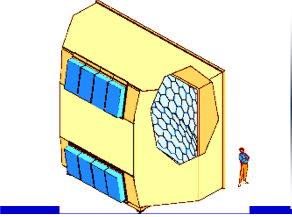
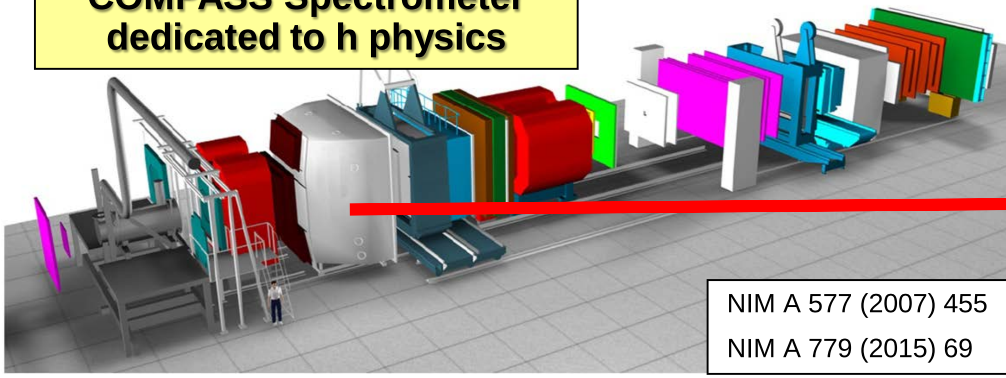
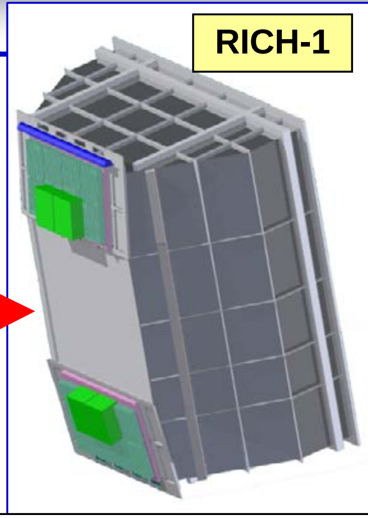
COMPASS RICH-1

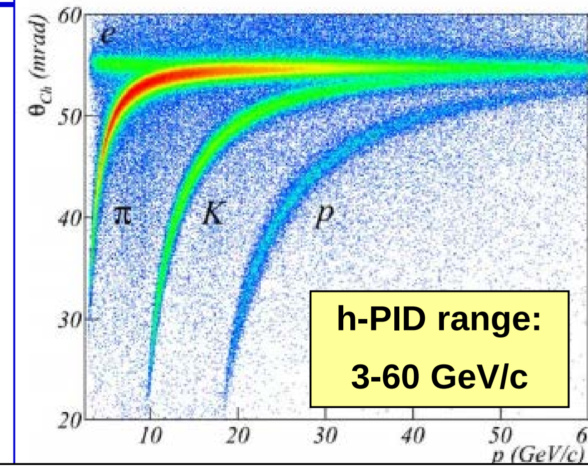


COMPASS Spectrometer dedicated to h physics



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

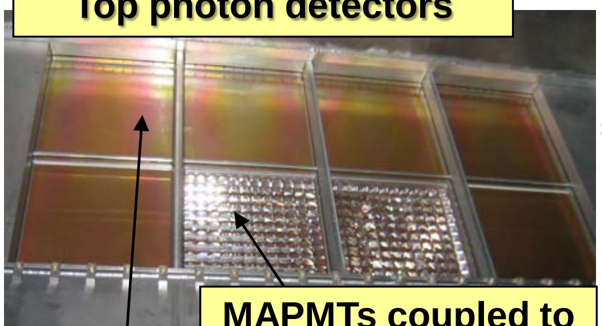




h-PID range: 3-60 GeV/c

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

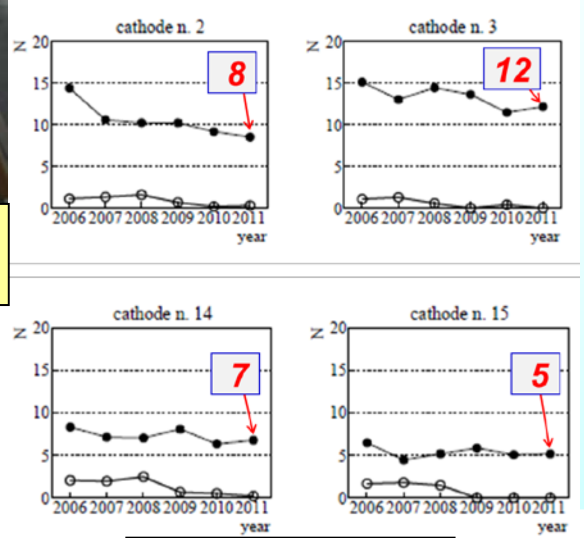
Top photon detectors



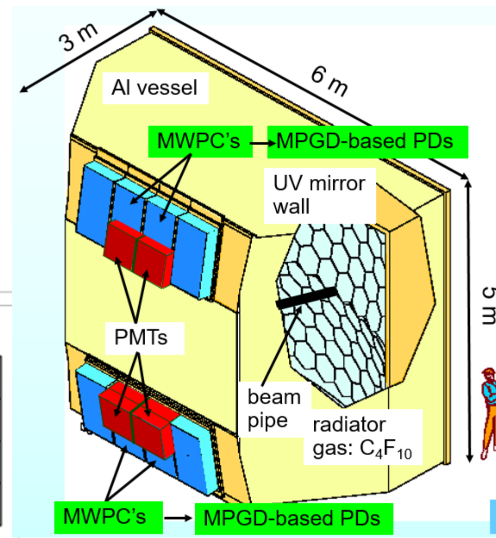
MAPMTs coupled to lens telescopes

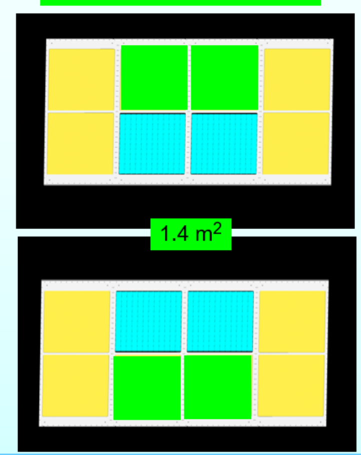
MWPCs+CsI (from RD26):
successful but performance limitations, in particular for the 4 central chambers

n. of ph.s @ β = 1

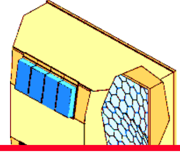


JINST 9 (2014) P01006



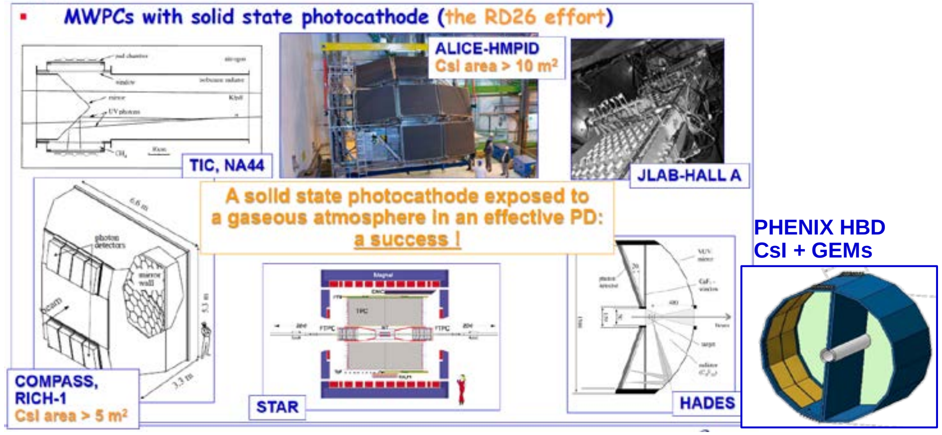


4 new detectors of 600 mm x 600 mm



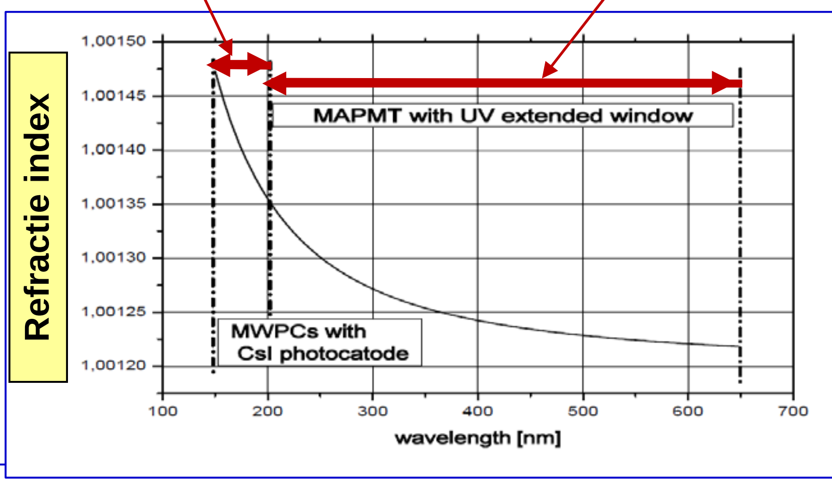
HANDLING THE VUV DOMAIN

CsI gasous sensors used in several Cherenkov detectors



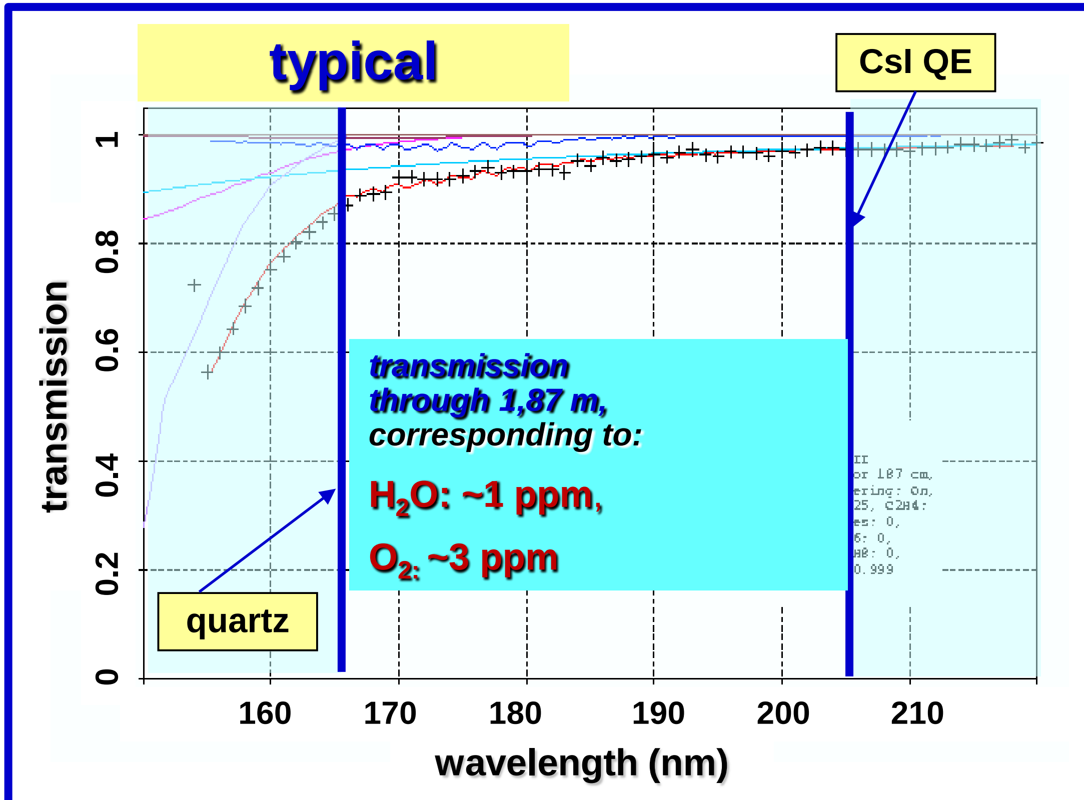
(n-1) r.m.s *(assuming Frank and Tamm):*

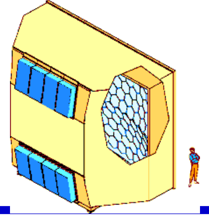
30×10^{-6} 46×10^{-6}



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





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for the upgrade of COMPASS RICH-1 and beyond

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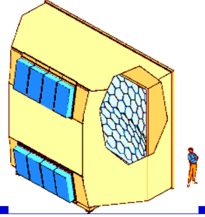
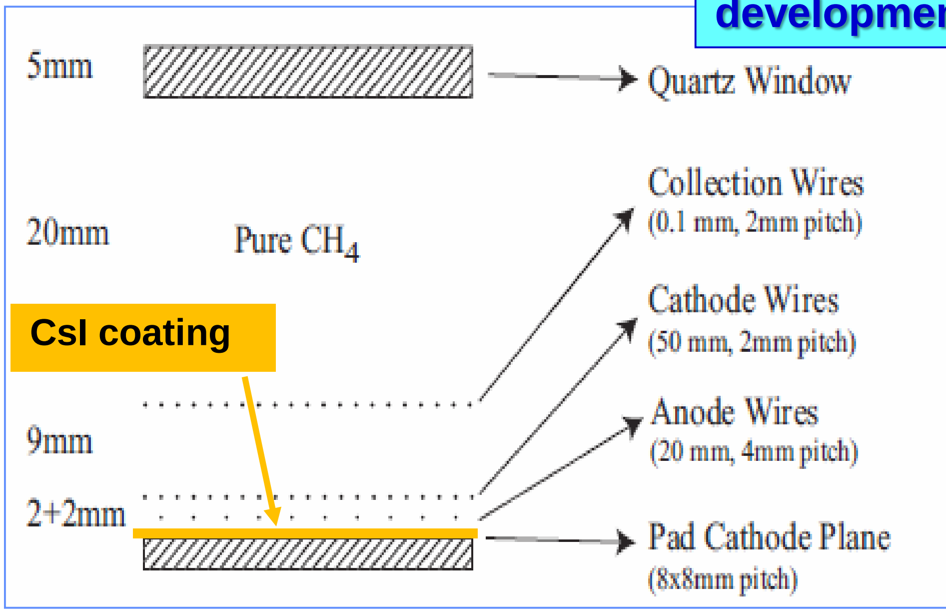


PHOTON DETECTORS so far

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*

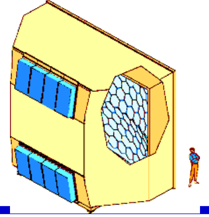
→ Low gain: a few times 10^4 (effective gain: <1/2)

→ "slow" detector

To overcome the limitations:

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

→ MPGDs



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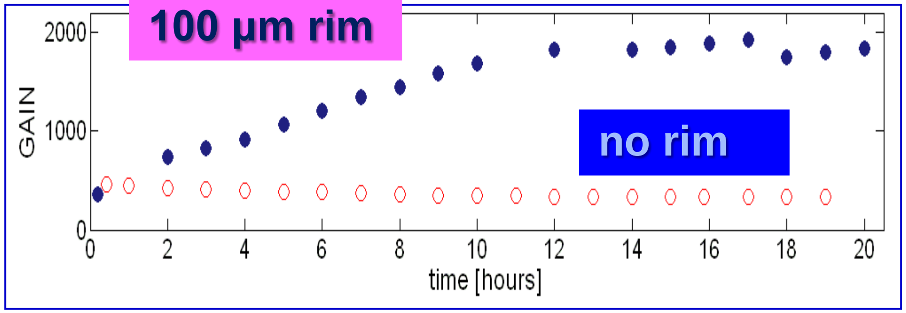
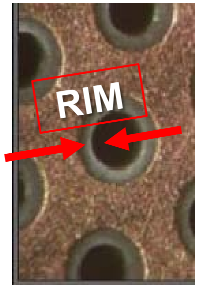
After 7 years of R&D

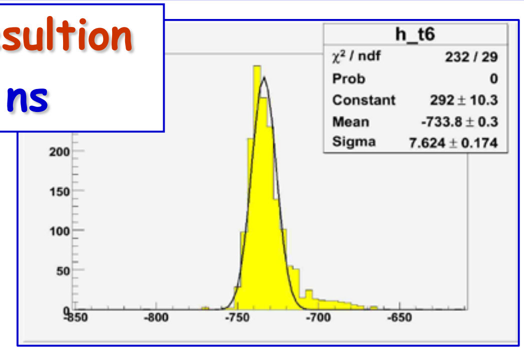
- ## THGEM characterization, performance





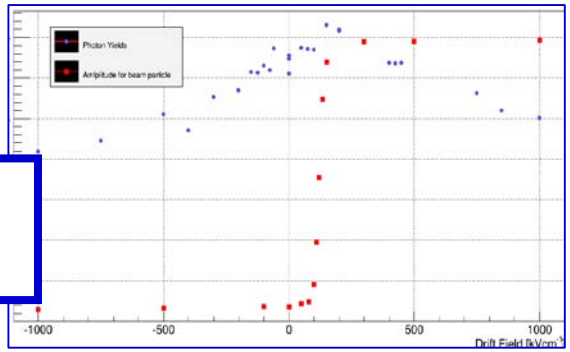
Time resultion

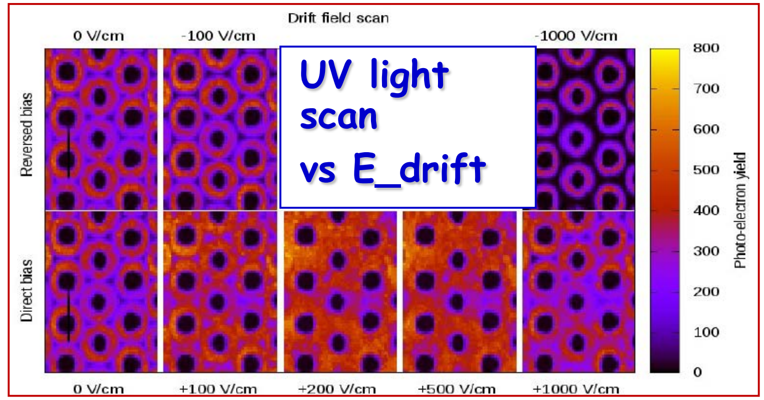
~7 ns



- ## Photoelectron extraction

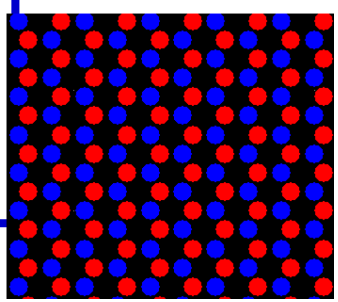
Photon yield (blue)
& Charged Particles (red)
vs Drift Field





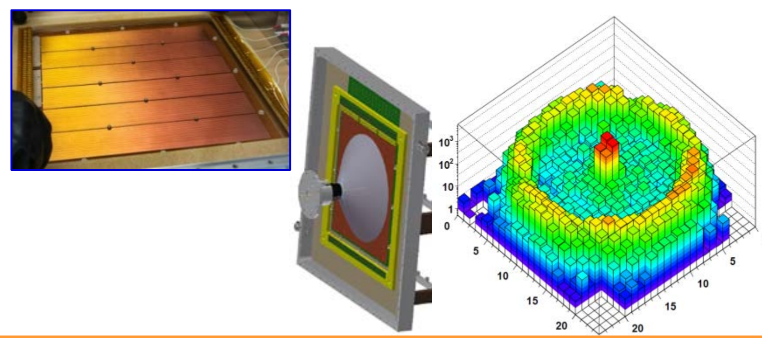
- ## IBF (Ion Back Flow) suppression

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

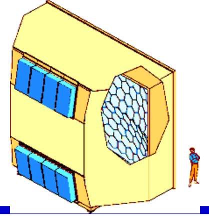


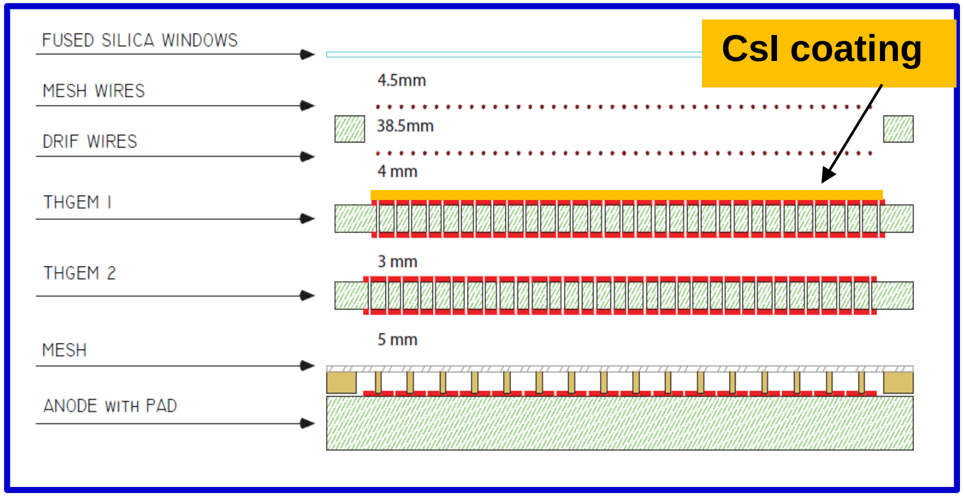
IBF suppression (<3%) introducing a MM stage:
no need of high Transfer electric field
→
Hybrid architecture

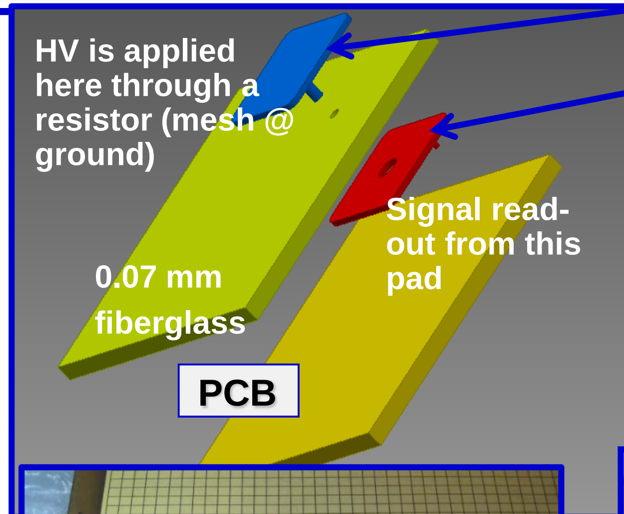
Cherenkov light detection in TB

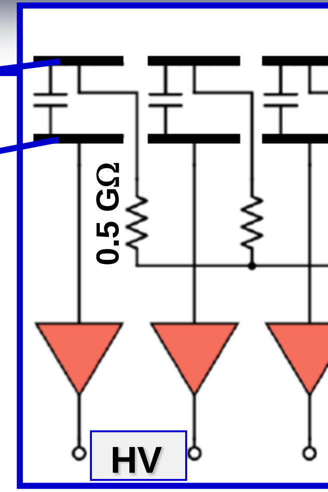


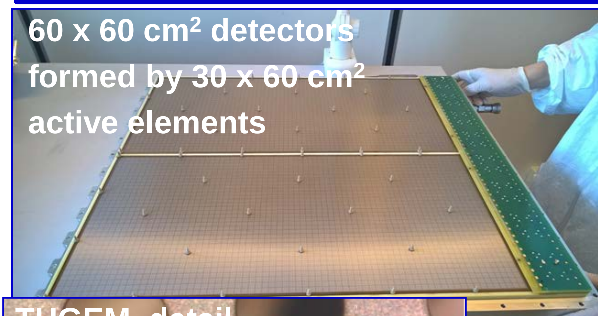
DETECTOR ARCHITECTURE

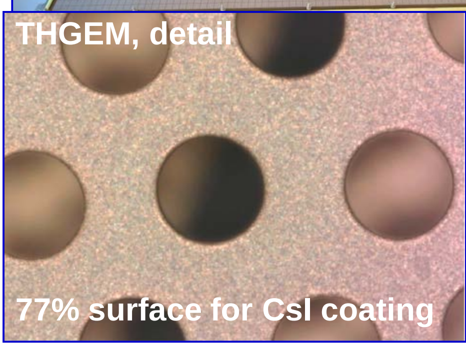


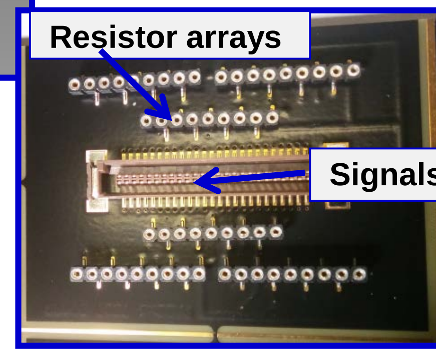


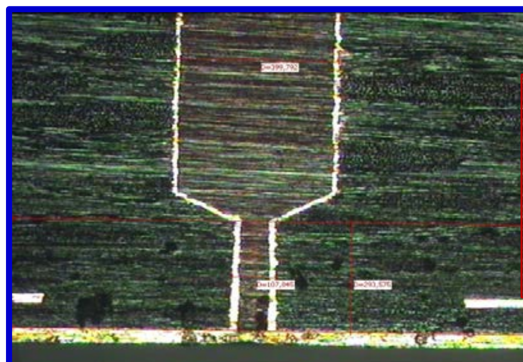






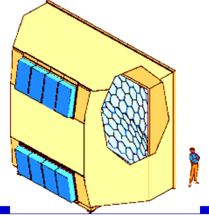






Planar surface issue at the pad:

z drilling controlled via (3D-drilling)



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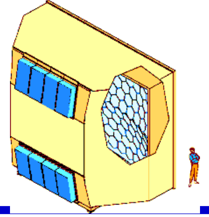
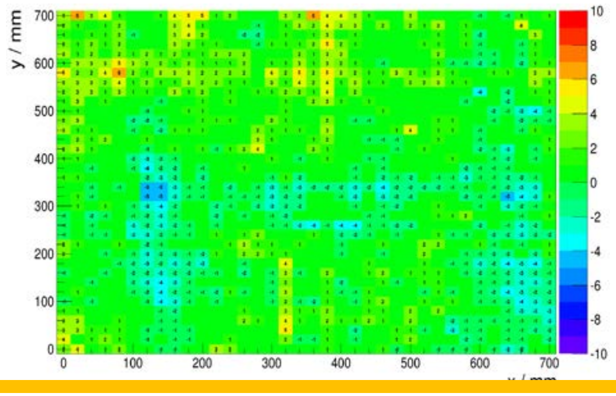
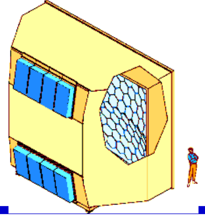


COMPONENT QA in a nutshell

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





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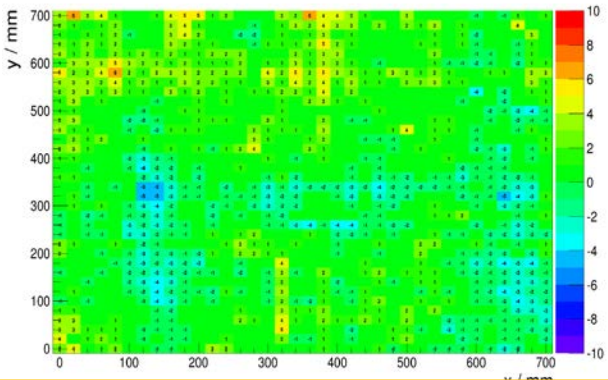
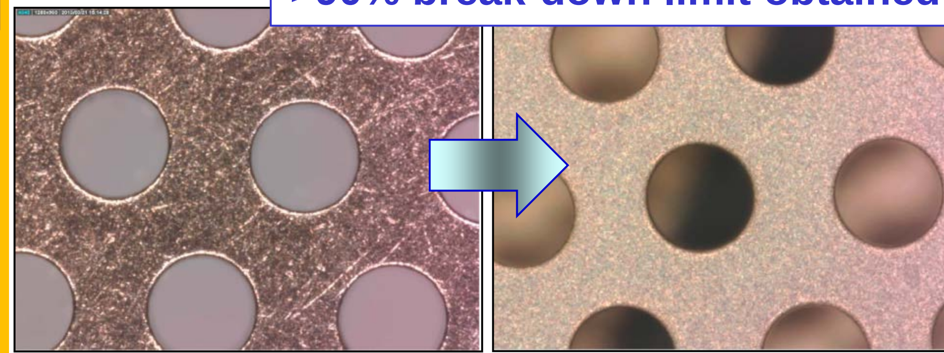
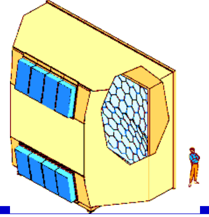


THGEM polishing with an “ad hoc” protocol setup by us *including backing*:
>90% break-down limit obtained





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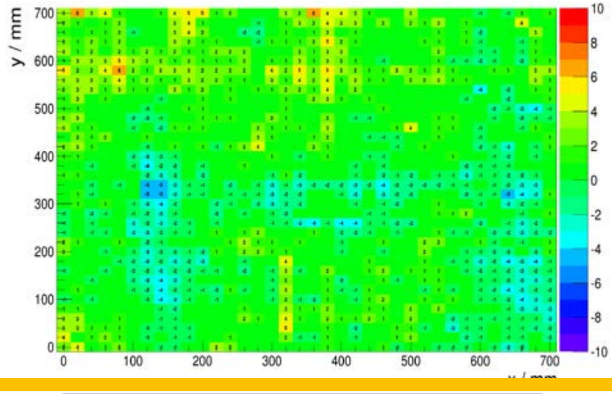
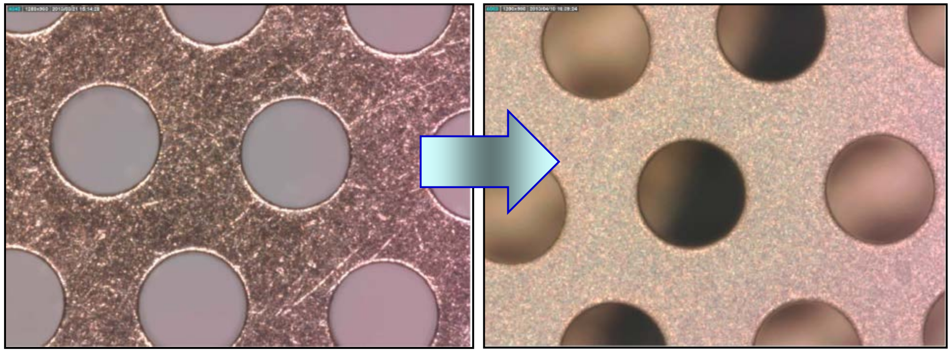
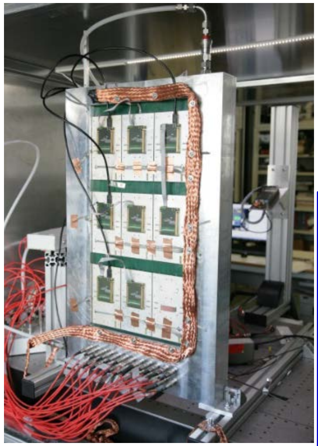
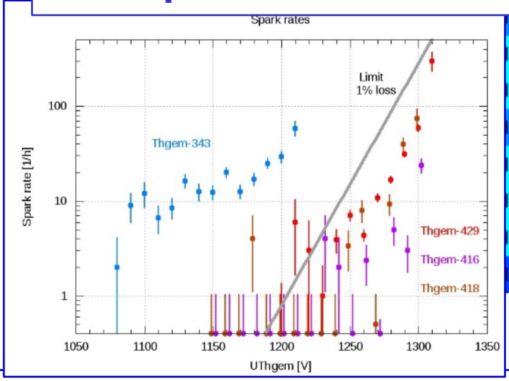


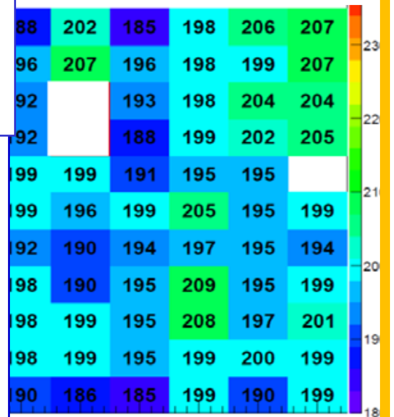
THGEM polishing with an “ad hoc” protocol setup by us: >90% break-down limit obtained

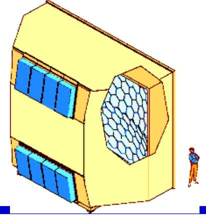




X-ray THGEM test to access gain uniformity (<7%) and spark behaviour







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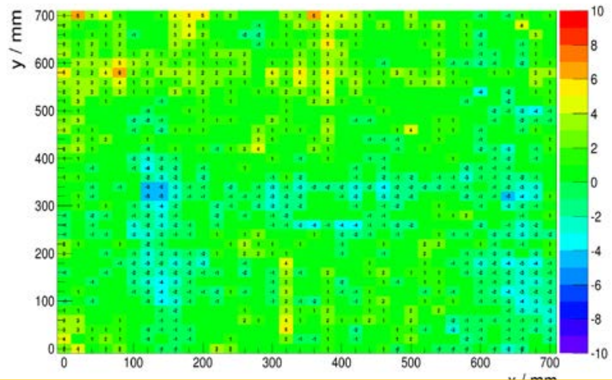

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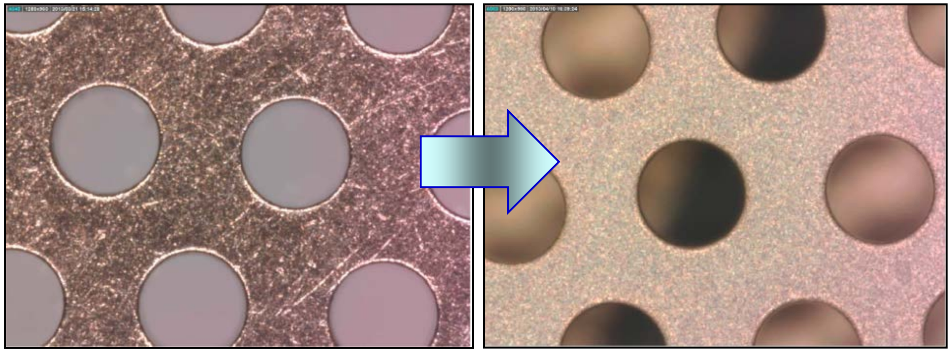

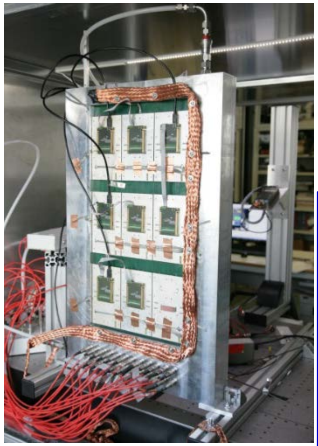

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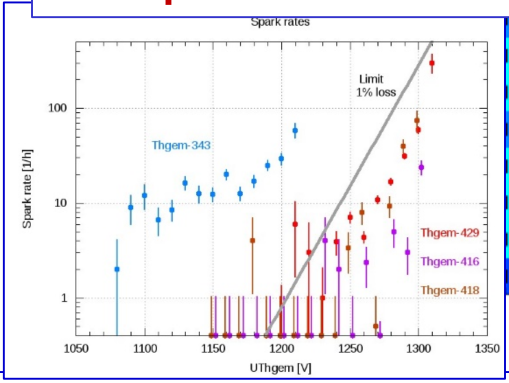
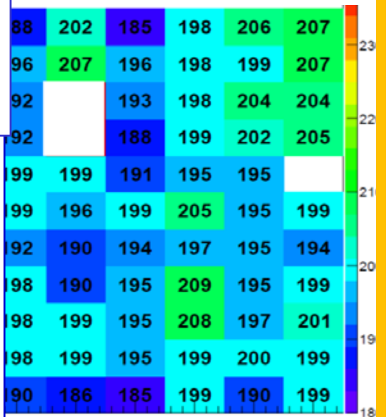
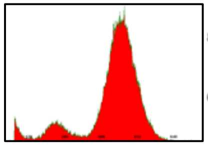
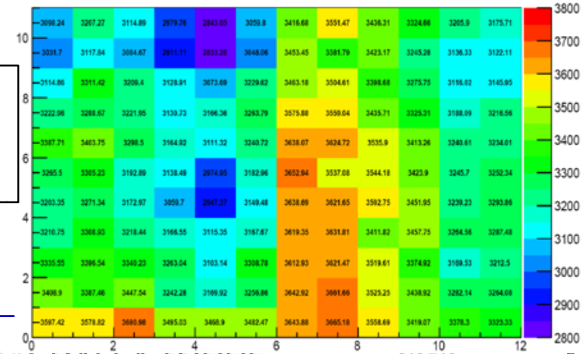
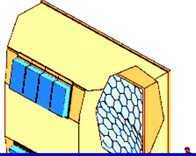




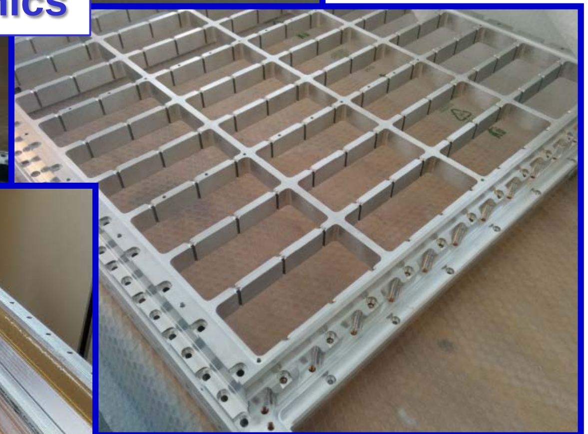
X-ray MM test to access integrity and gain uniformity (<5%)



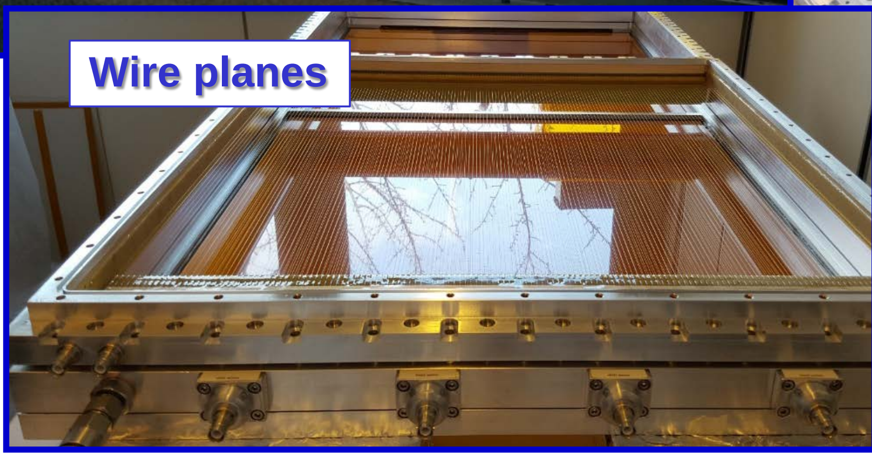




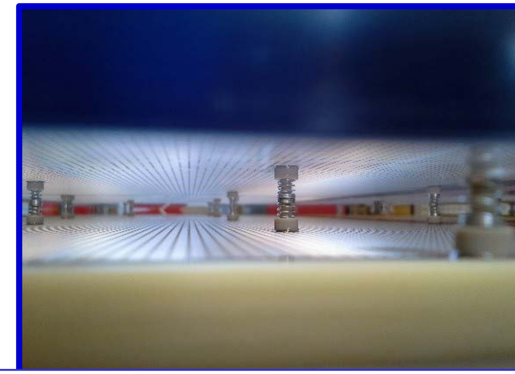
CONSTRUCTION in a nutshell



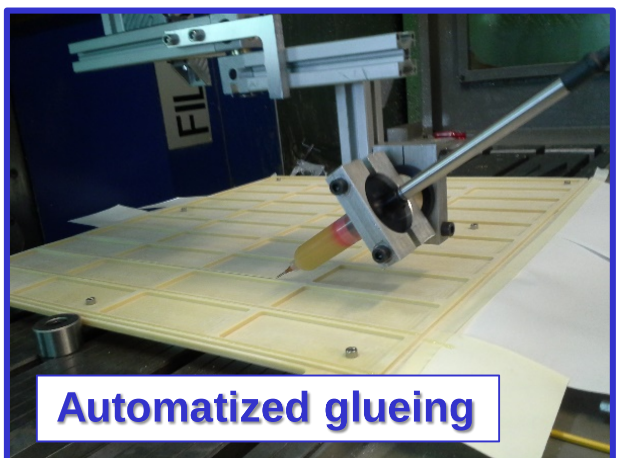
mechanics



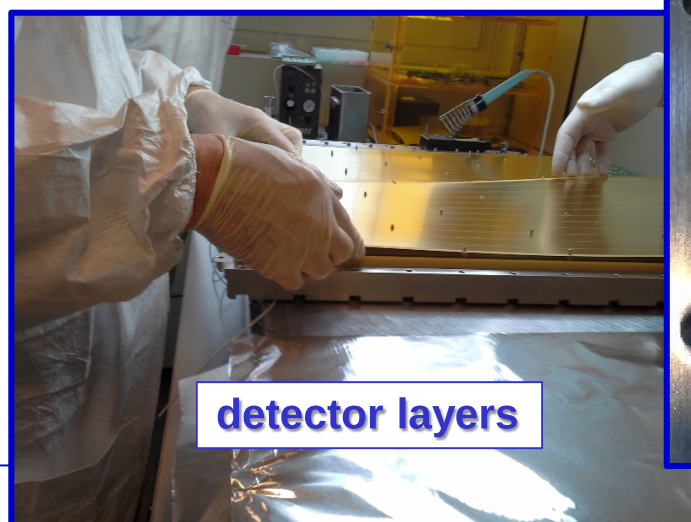
Wire planes



Glueing the support pillars



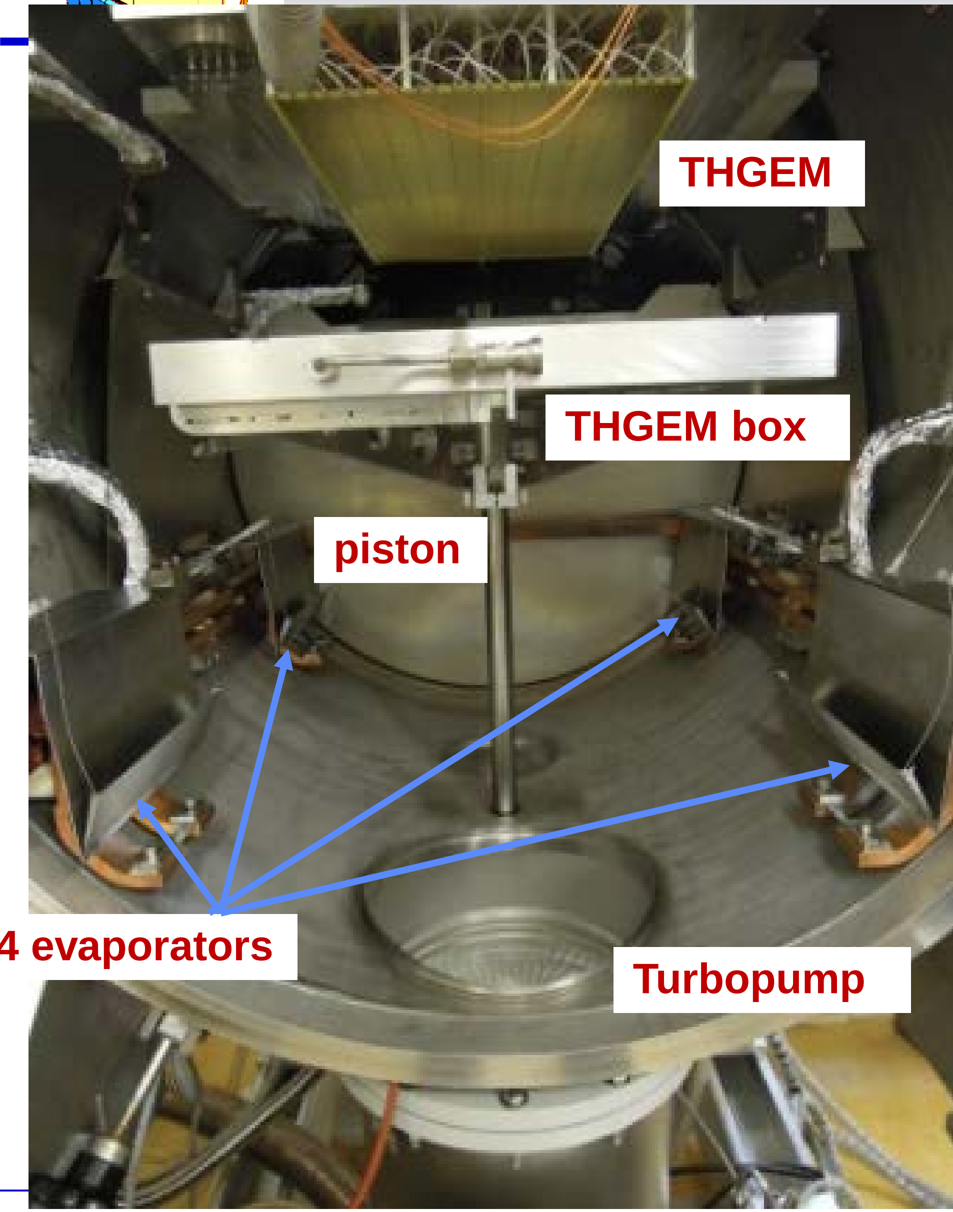
Automatized glueing

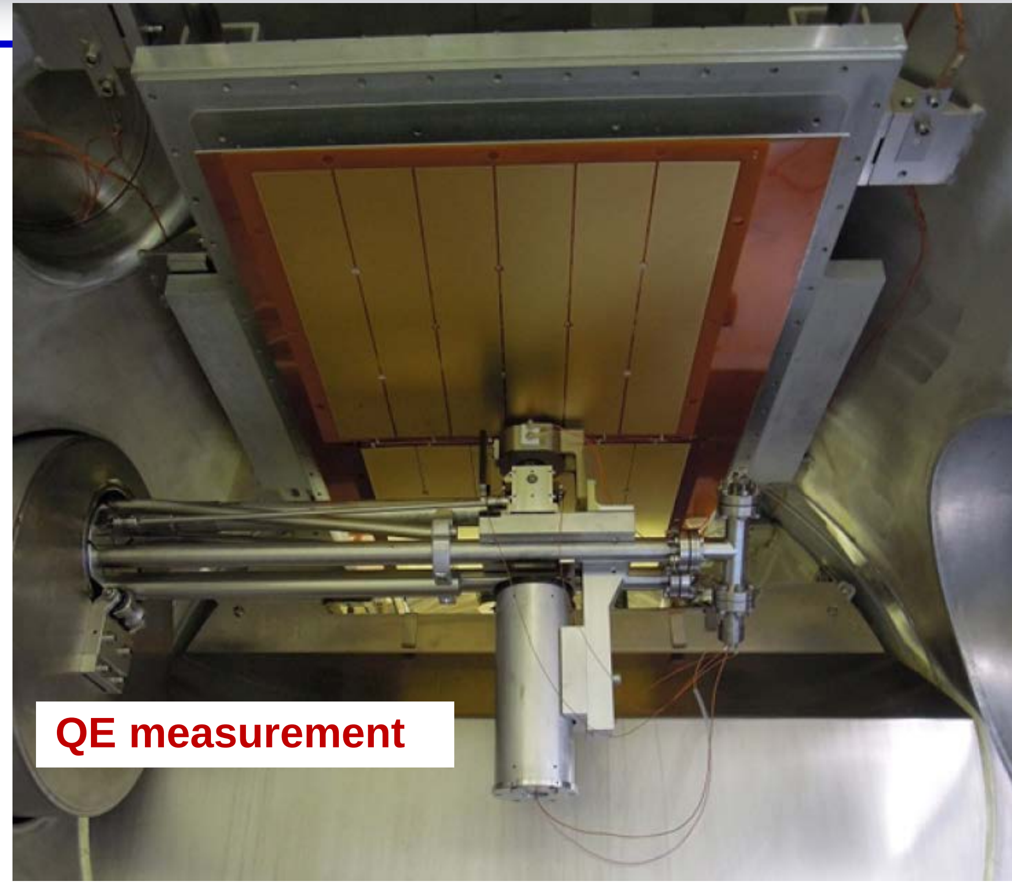


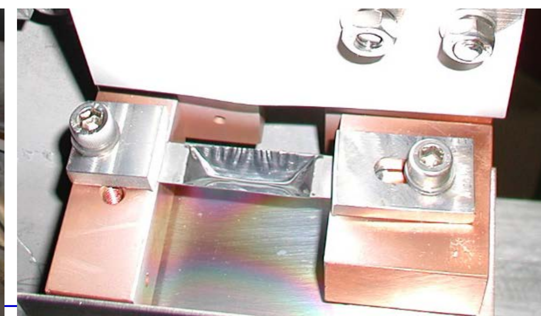
detector layers

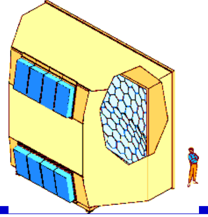
THGEM staggering

CsI coating for THGEMS









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)

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

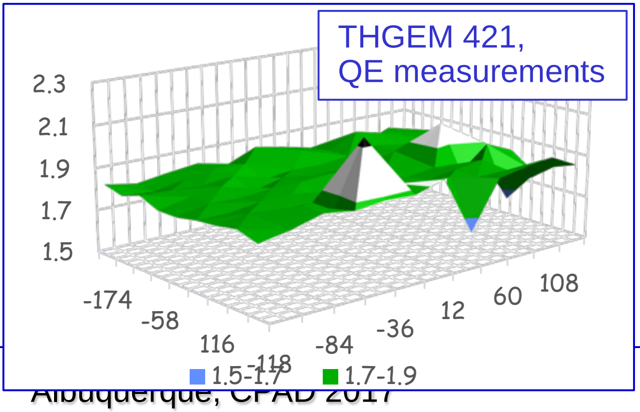
11 coated THGEMs available, 8 used + 3 spares

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

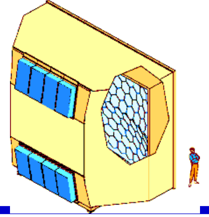
<THGEM QE> = 0.73 x Ref. pieceQE with s.r.m. of 10%

in agreement with expectations (THGEM optical opacity = 0.77)



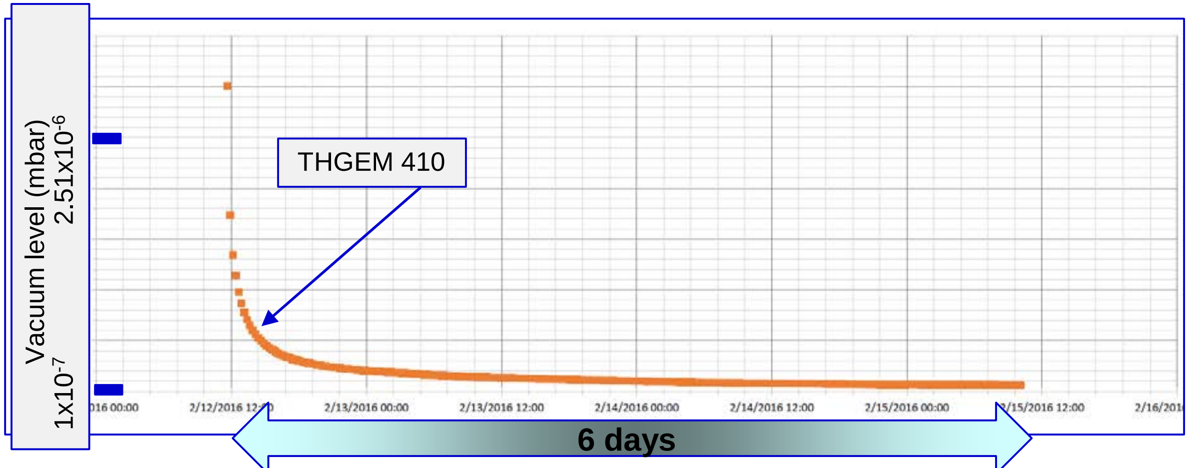
QE is the result of a surface scan (12 x 9 grid, 108 measurements)

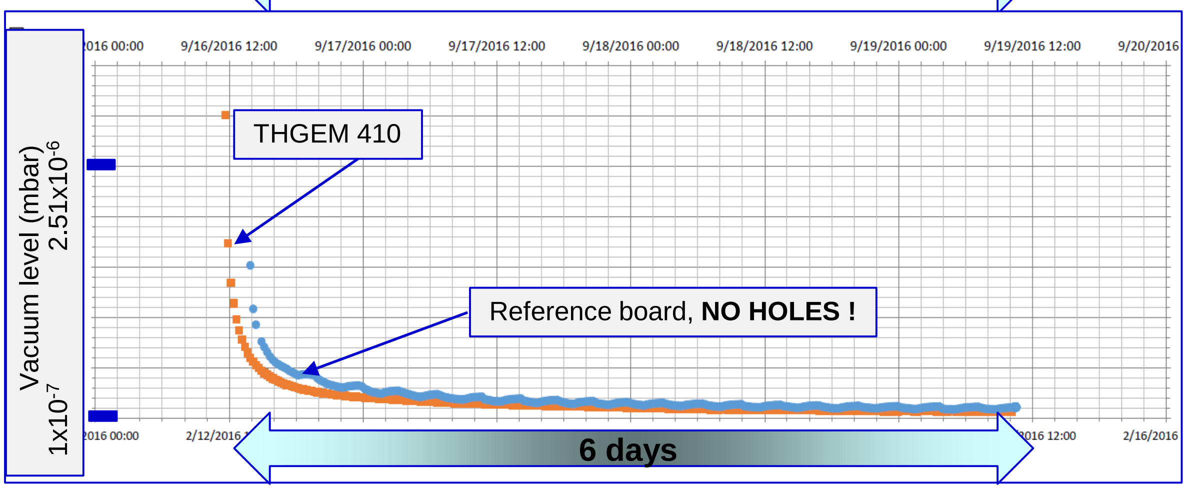
Good uniformity, in the example σ_{QE} / <QE> = 3%



THGEM OUTGASSING: is it an ISSUE ?

Vacuum level while preparing for CsI Coating

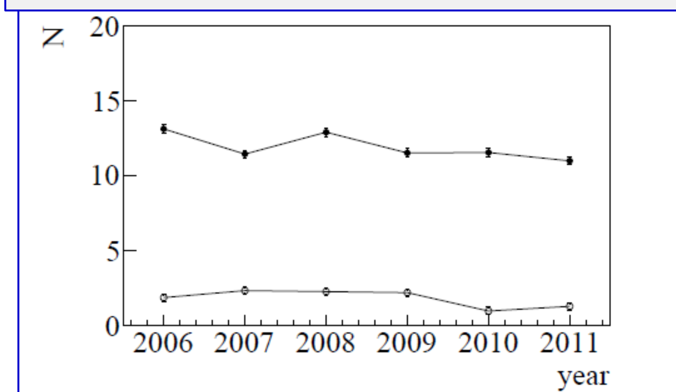


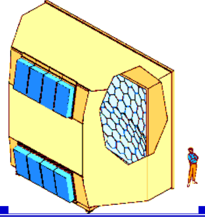


From the experience of CsI-MWPCs

" … The data do not indicate any severe ageing effect: globally they are compatible with the hypothesis of no QE variation and suggest a maximum QE decrease rate of 2.3% per year."

JINST 9 (2014) P01006



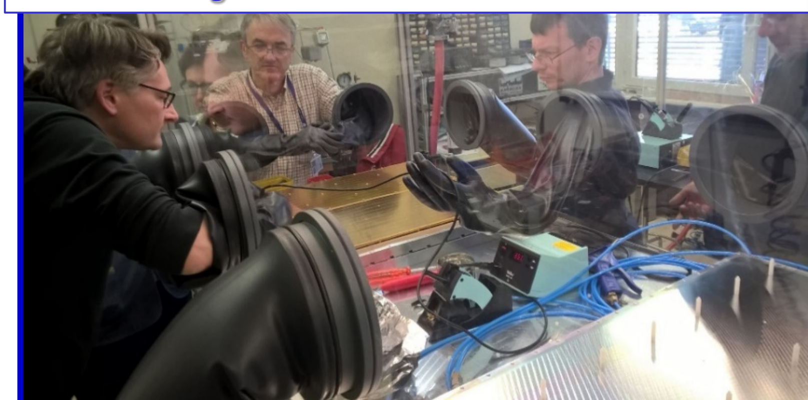


ASSEMBLY in a nutshell

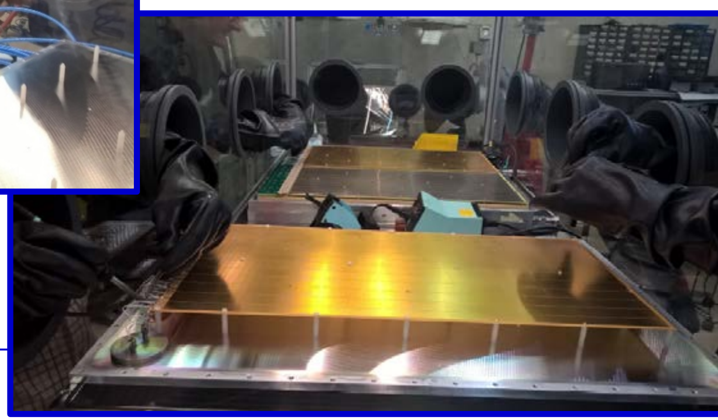
Pre-assembly w/o CsI

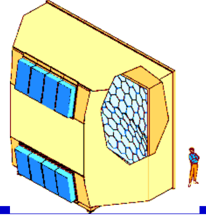
Onto the RICH

final assembly of the active module assembly with CsI in glovebox

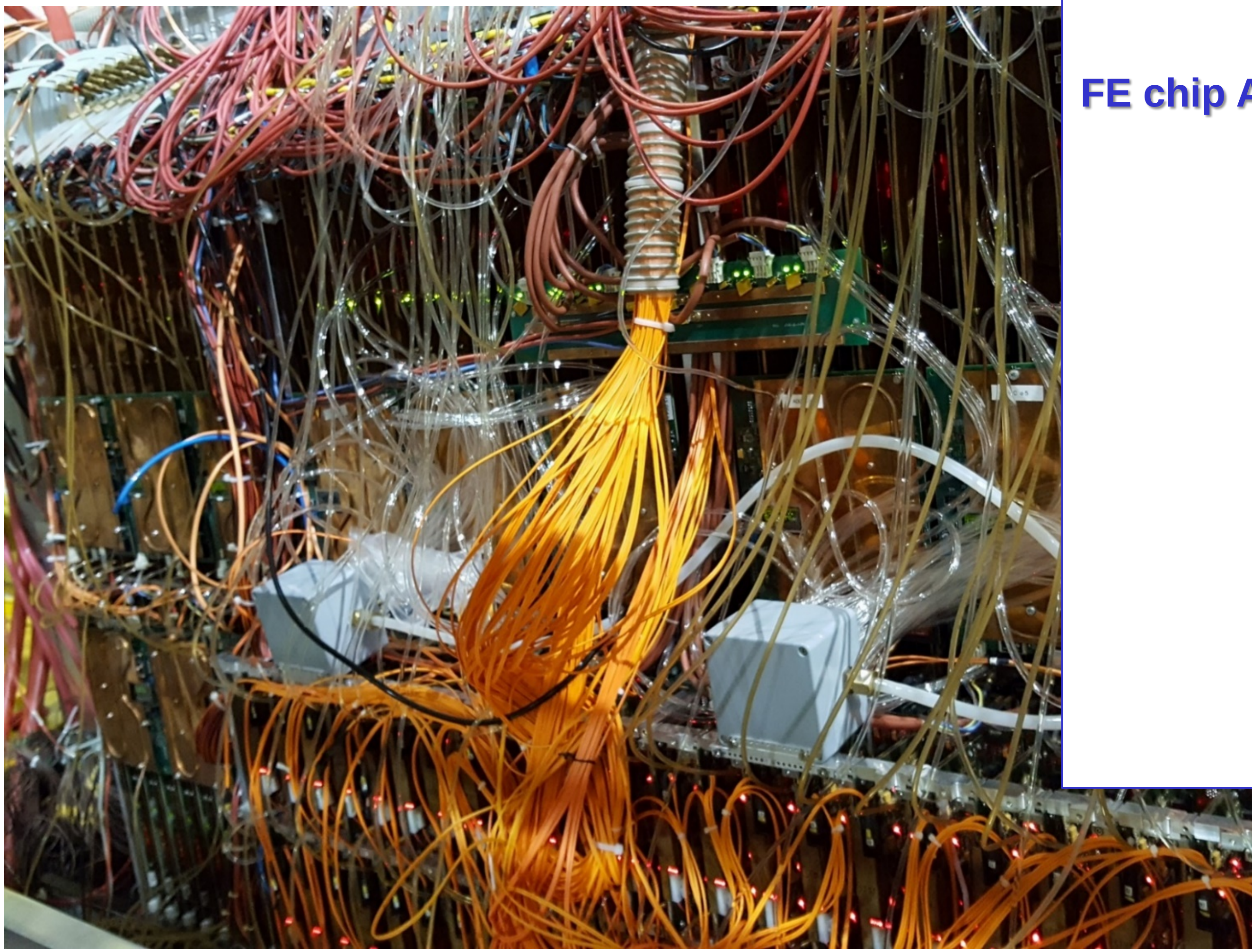


glovebox also to mount the active module onto the RICH



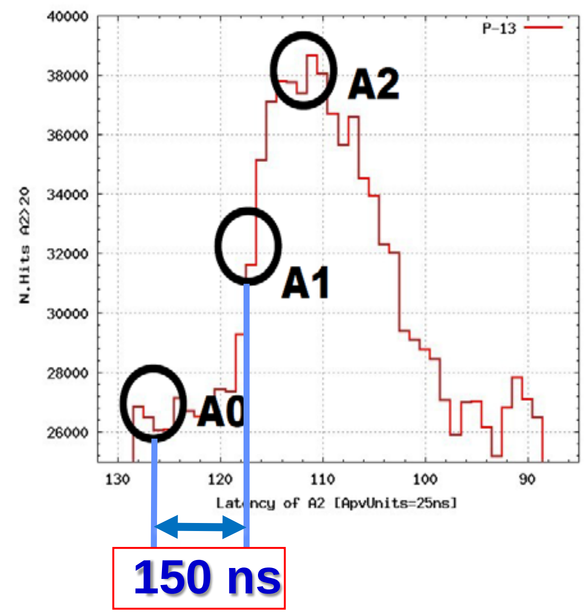


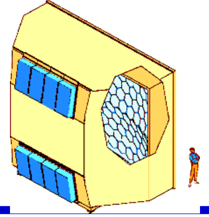
READ-OUT and SERVICES



read-out :
already available for the MWPCs with CsI

FE chip APV25





OUTLINE

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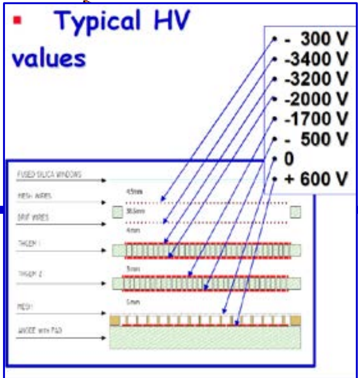
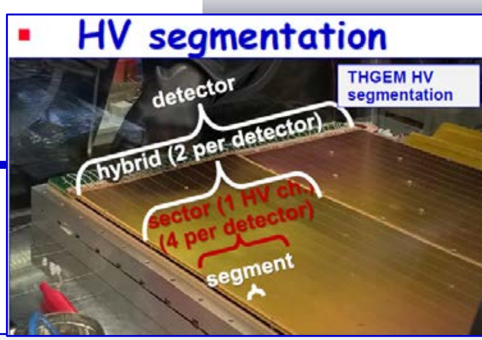
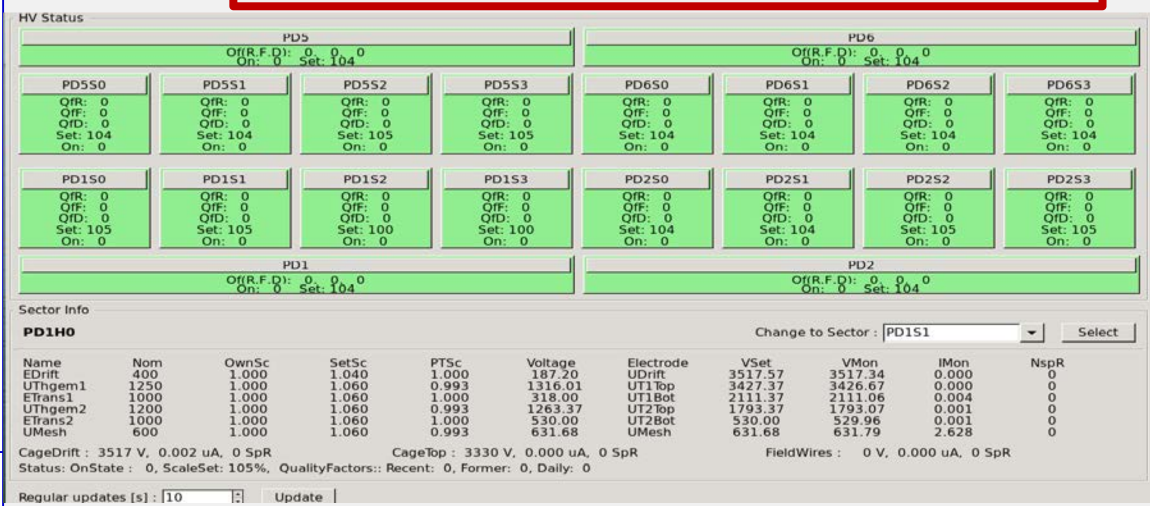




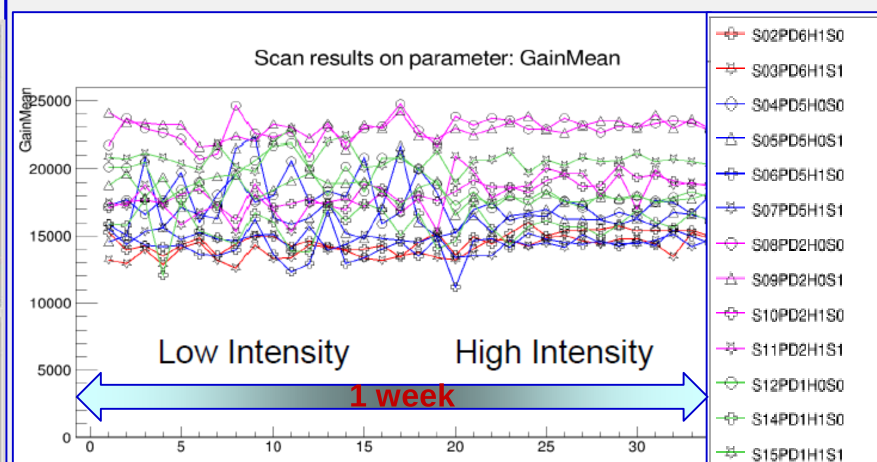
HV CONTROL

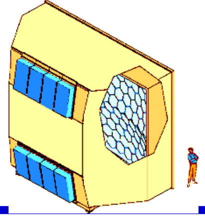
In total 136 HV channels
<u>with correlated values</u>

- **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 better than 10%

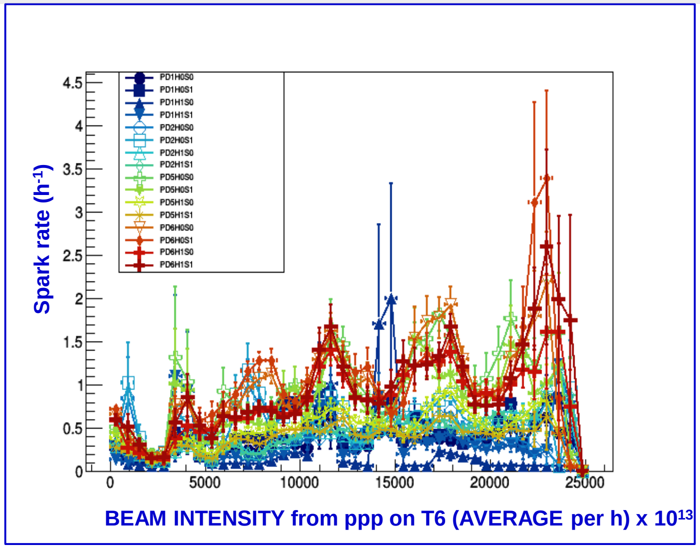




ELECTRICAL STABILITY

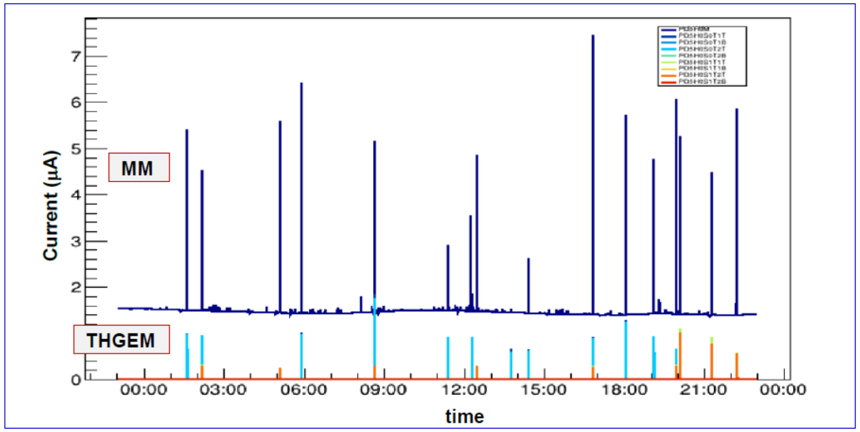
THGEMs, lessons

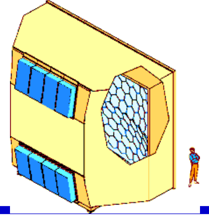
- <u>Full</u> vertical <u>correlation</u> of current sparks THGEM1 & THGEM2
- Recovery time <10 s (our HV arrangement)
- Sparke rates: ~ no dependence on beam intensity and even beam on-off
- <u>Discharge correlation</u> within a THGEM (also non adjacent segments) and among different THGEMs (cosmics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



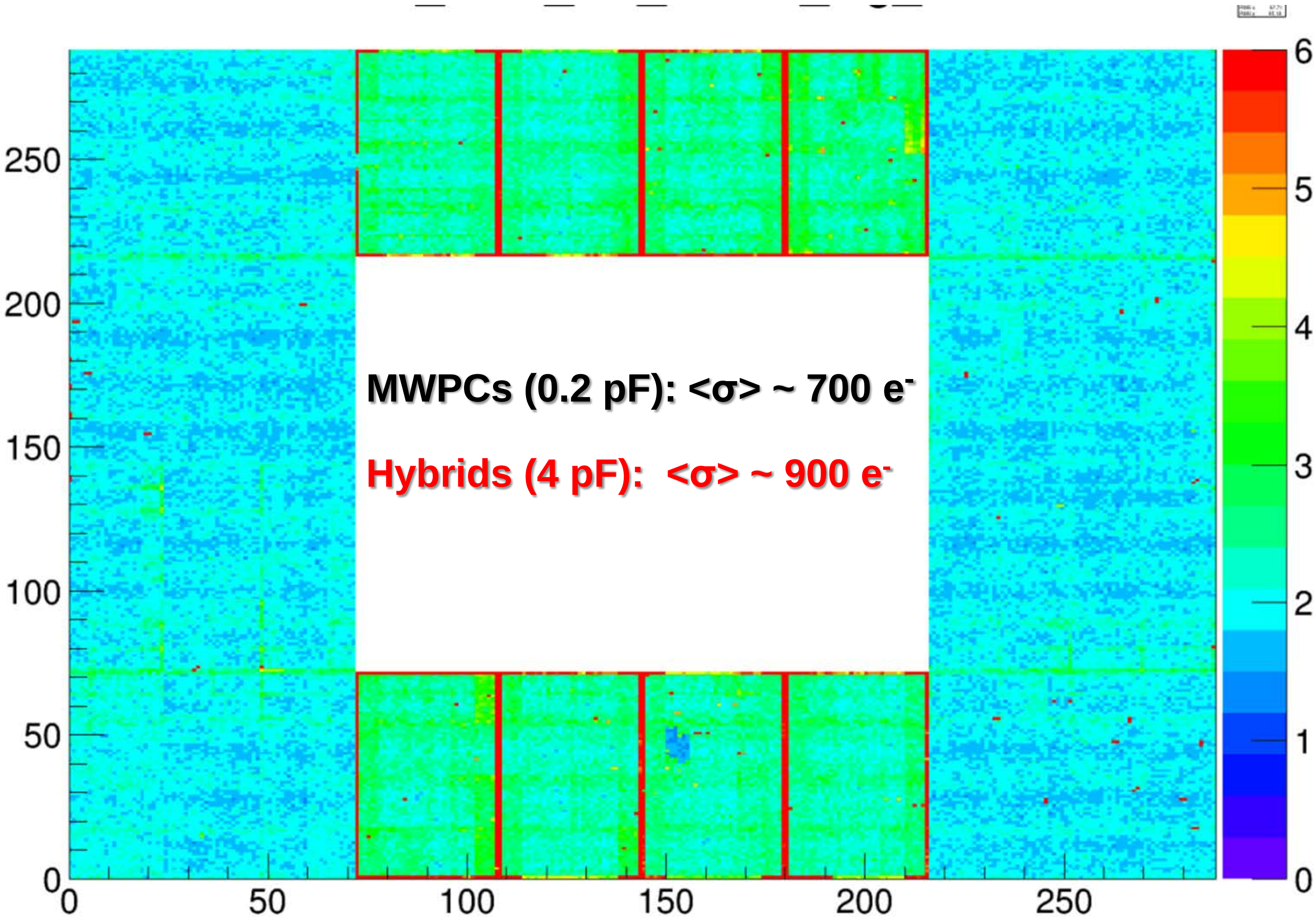
MICROMEGAS, lessons

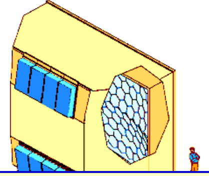
- MM sparks only when a THGEM spark is observed (not vice versa)
- Recovery time ~1s (our HV arrangement)
- The only real issue: dying channels (pads)
  - Local shorts, larger current, no noise issue
  - 2.5 ‰ developed in 12 months
  - Dirty gas / dust from molecular sieves & catalyst?
  - Finer mechanical filters added: 7 µm pore





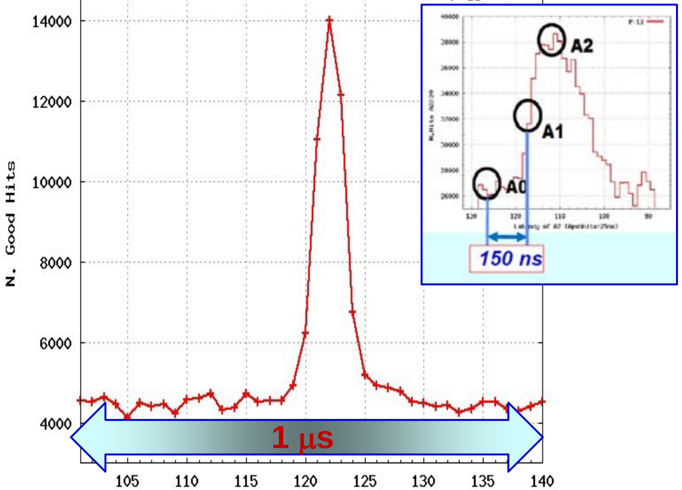
NOISE FIGURES



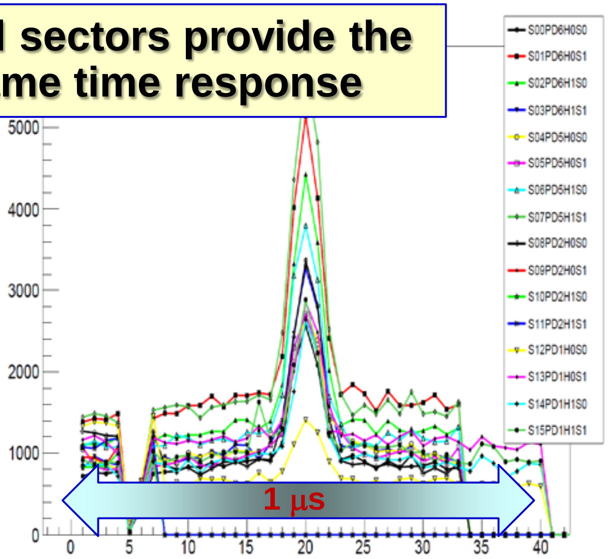


THE PHOTOELECTRON SIGNAL

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

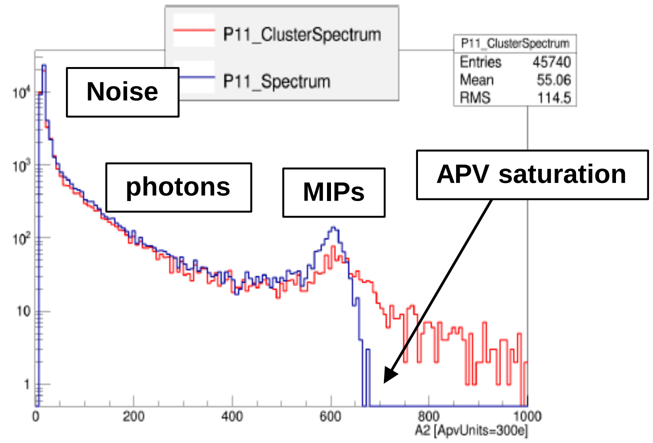


All sectors provide the same time response

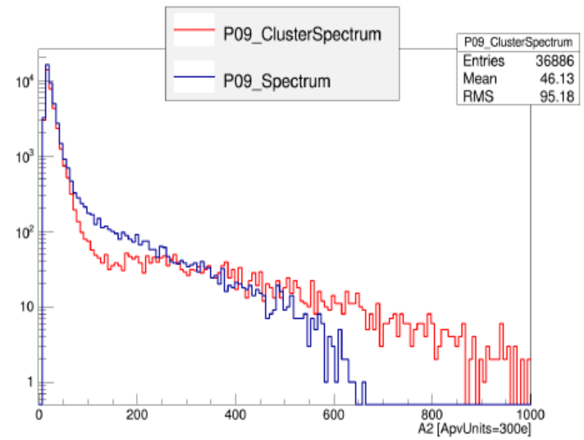


Clusterization to separate MIPs

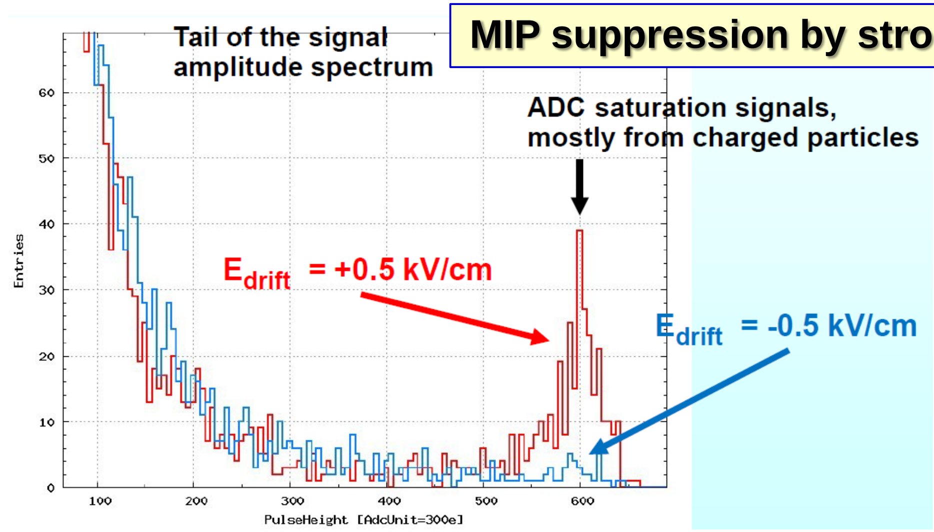
Hybrid MPGD (novel detector)

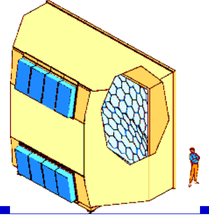


MWPC (old detector)



MIP suppression by strong reversed bias





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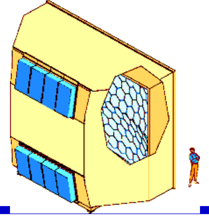
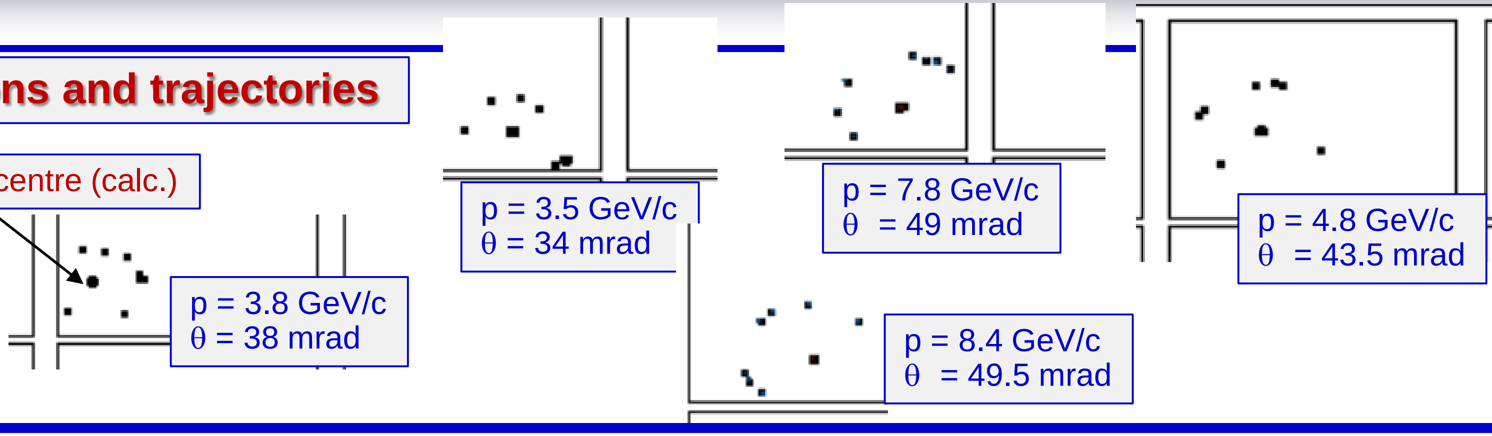


NOVEL PHOTON DETECTOR CHARACTERIZATION ON-GOING

Correlation between photons and trajectories

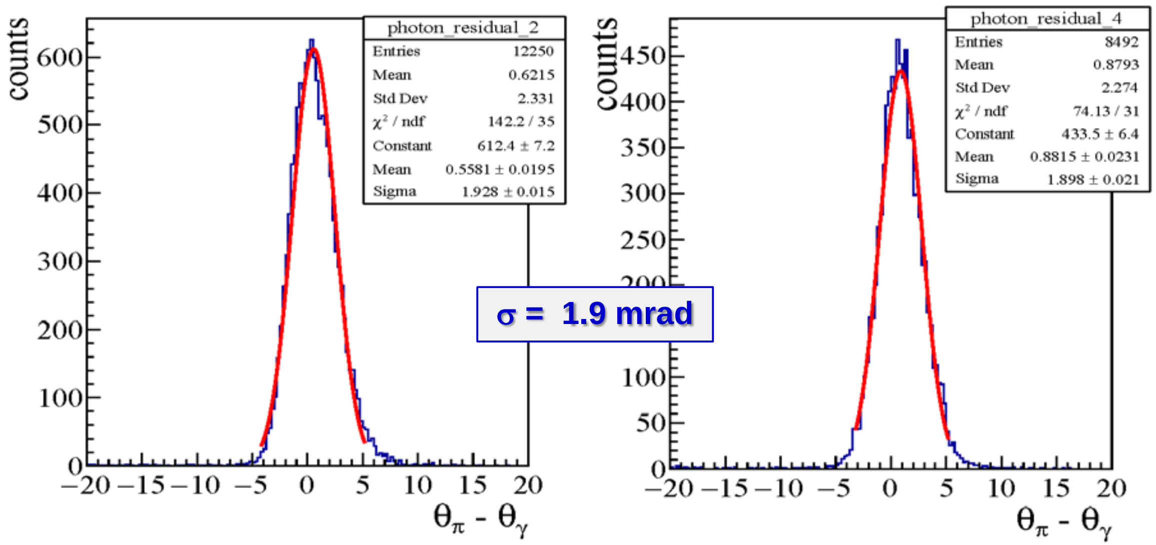
For reference:

θ (β = 1) = 52.5 mrad

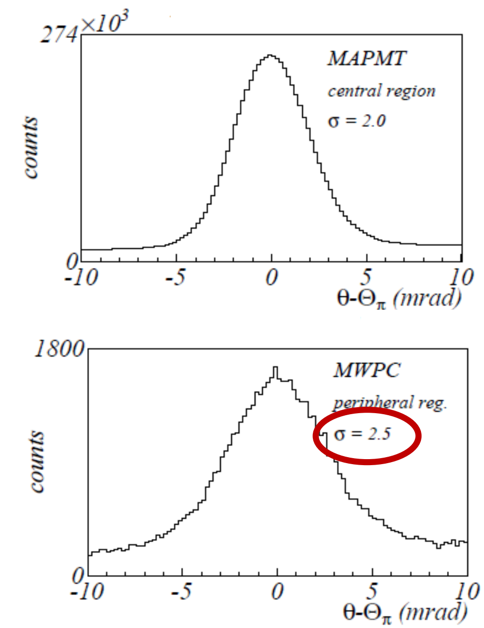


Residual distribution for individual photons (preliminary π-sample):

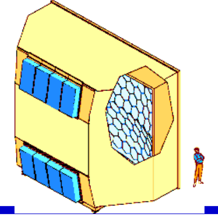
$\theta_{calculated} - \theta_{photon}$



before the upgrade



NIM A 631 (2011) 26



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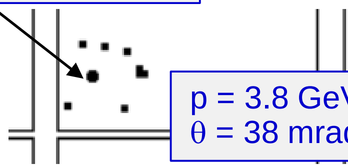

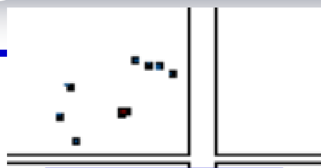

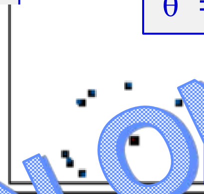

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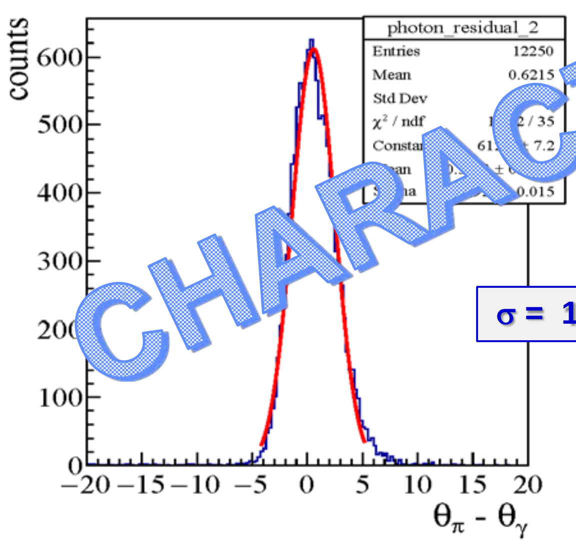
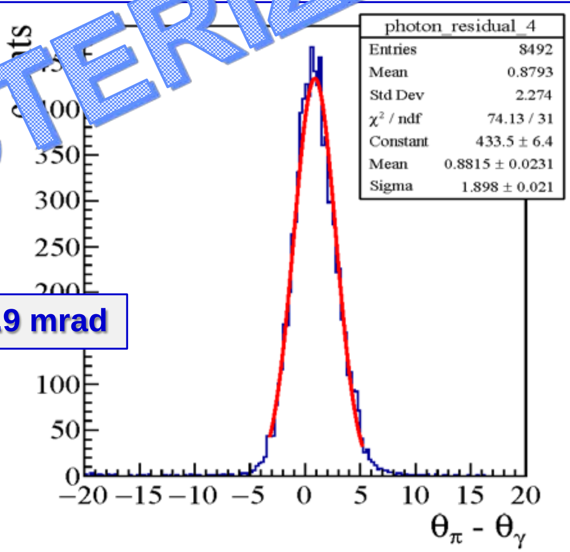
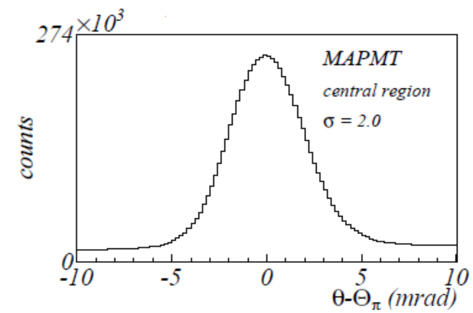
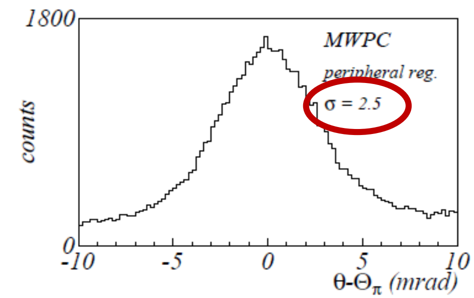


σ = 1.9 mrad

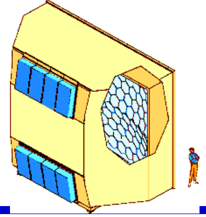


before the upgrade





NIM A 631 (2011) 26



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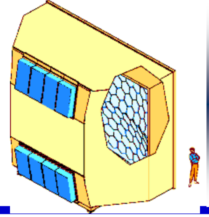


STATUS & PERSPECTIVES OF h-PID

Low p (< 5-6 GeV/c, higher ?)

- **Options**
  - Imaging Cherenkov
  - **Proximity focusing RICHes using**
    - C_6F_{14} **(or analogous)**
    - **aerogel**
  - **DIRC & derived detectors**
    - **FDIRC, TOP, TORCH**
  - **Alternative approaches**
    - t resolution ~O(10ps)
    - **New TOF perspectives**
    - **Improved dE/dx by cluster counting in gas**

- **Progress related to numerous new projects:**
  - **Belle-II barrel**
  - **Belle-II forward**
  - **CLAS12**
  - **GlueX**
  - **Panda barrel**
  - **Panda end-caps**
  - **Panda forward**
  - **LHCb-Torch**

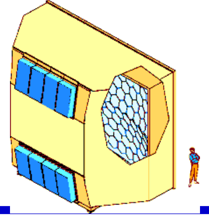
List from RICH2016

High p (> 1-4 GeV/c)

Our focus

- **Option**
  - **Focusing RICHes with extended gaseous radiator**
- **Presently only 3 running high-p RICHes:**
  - **LHCb (2-counter system)**
  - **NA62 (non h-PID!)**
  - **COMPASS, upgraded : novel MPGD-based PDs**
- **Further future projects:**
  - h physics needs
  - **Only EIC**

- **Can the radiator be "thinner" to avoid gigantic sizes: (advantages for colliders, also for fixed target)?**
  namely more detected photons per unit radiator length
- **proposed so far**
  - **P > 1 atm, proposal for ALICE HMPID upgrade, than abandoned**
  - gaseous PDs
  - **Exploit the VUV region with a windowless RICH, testbeam @ Fermilab**
    IEEE NS 62 (2015) 3256
  - **Use vacuum-based (visible light) photon detectors**



MPGD-based PHOTON DETECTOR MISSION IN RICH SECTOR

Sensors used and foreseen in RICH counters in experiments:

- vacuum-based detectors
- gaseous detectors

Time resolution (σ)

- PMTs, MAPMTs >/~ 0.3 ns
- MCP-PMT <50 ps
- MWPCs >/~ 400 ns
- MPGDs ~ 7-10 ns

Effective QE range

- Vacuum-based devices:
  λ > 300, 250, 200 nm
  [also solar-blind]
- Gaseous devices (CsI):
  λ < 205 nm

Operation in magnetic field

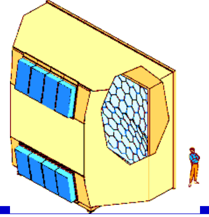
- PMTs, MAPMTs, HPMTs NO
- MCP-PMT, MWPCs, MPGDs YES

COSTS

- Gaseous - $ (0.3-0.6 M / m^2)
- MAPMTs - $$ (0.8-1.2 M / m^2)
- MCP-PMT - $$$ (???)

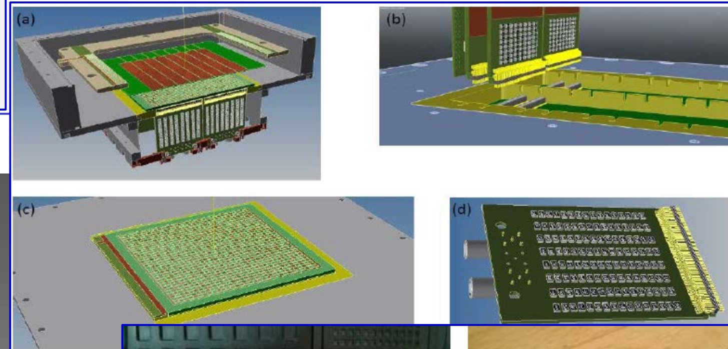
MPGD-based PDs :

match well the requirements of RICHes for **h-PID at high p** (gas radiator, large phase-space acceptance)

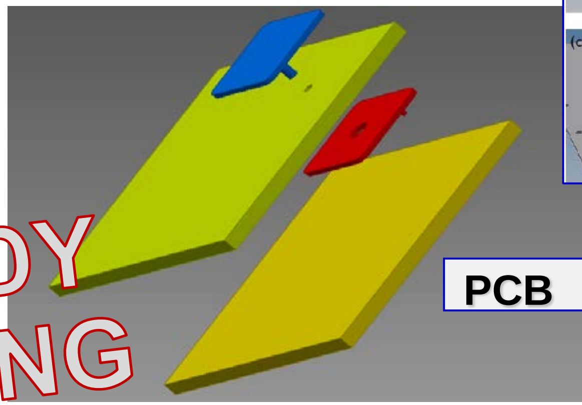


MOVING FURTHER WITH MPGD-based PDs

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

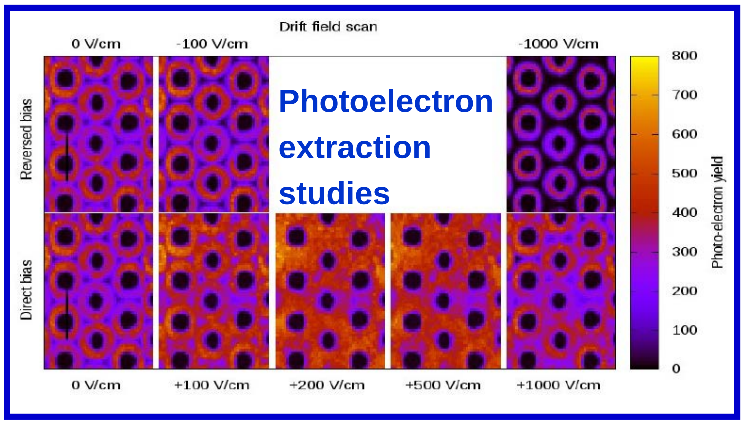


resistive MM with small pad size $O(10\ mm^2)$



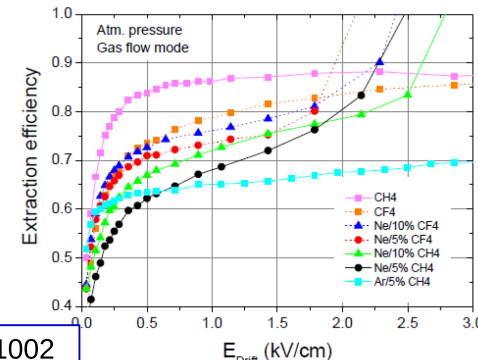
ALREADY ON GOING

GEM vs THGEM as photocathodes



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

- photoelectron extraction
- 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

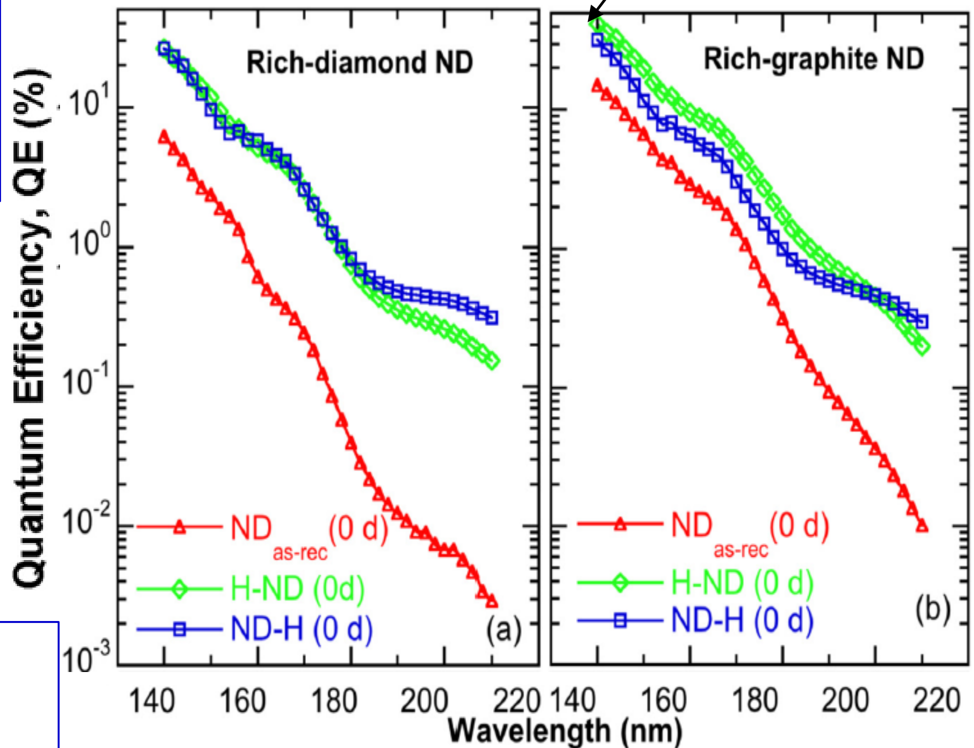
- ***Photocatodes: diamon film obtained with Spray Technique making use of hydrogenized ND powder***
  - ***Spray technique: T ~ 120° (instead of >800° as in standard techniques)***

Coupling of ND photoconverter and MPGDs?

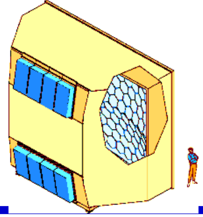
an exiting perspective with several open questions

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

47 % (!)



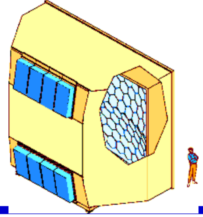
L.Velardi, A.Valentini, G.Cicala al., Diamond & Related Materials 76 (2017) 1



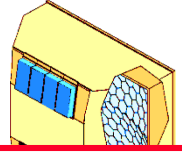
SUMMARIZING …

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

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

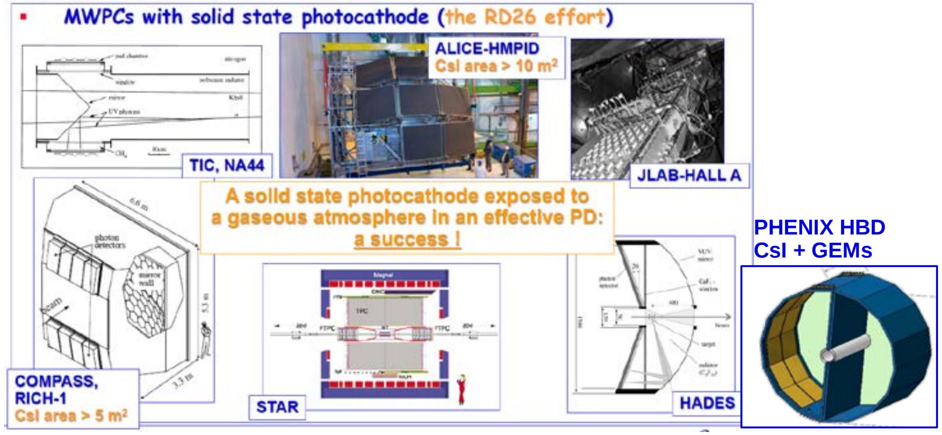


BACK-UP

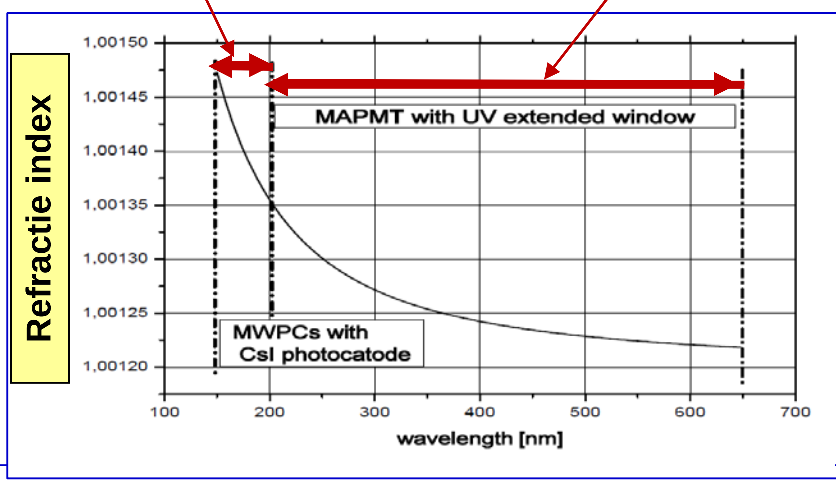


HANDLING THE VUV DOMAIN

CsI gasous sensors used in several Cherenkov detectors

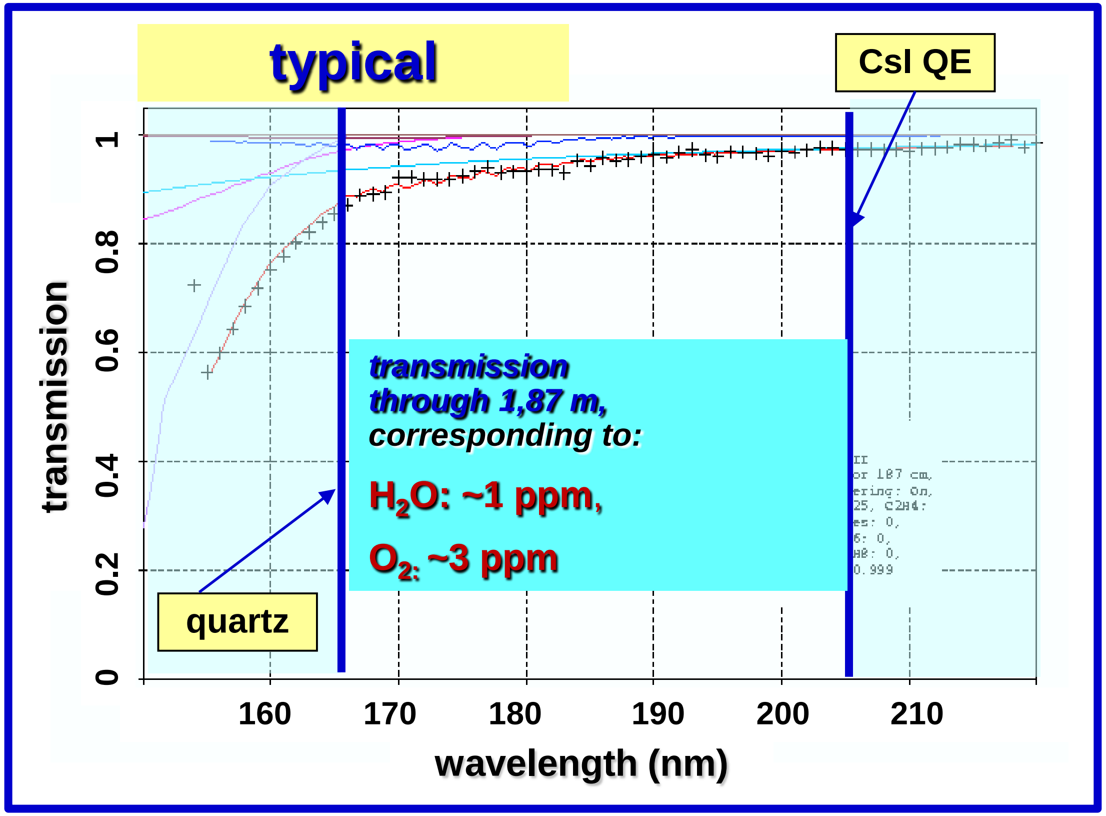


(n-1) r.m.s *(assuming Frank and Tamm):*

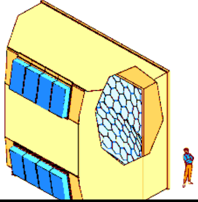


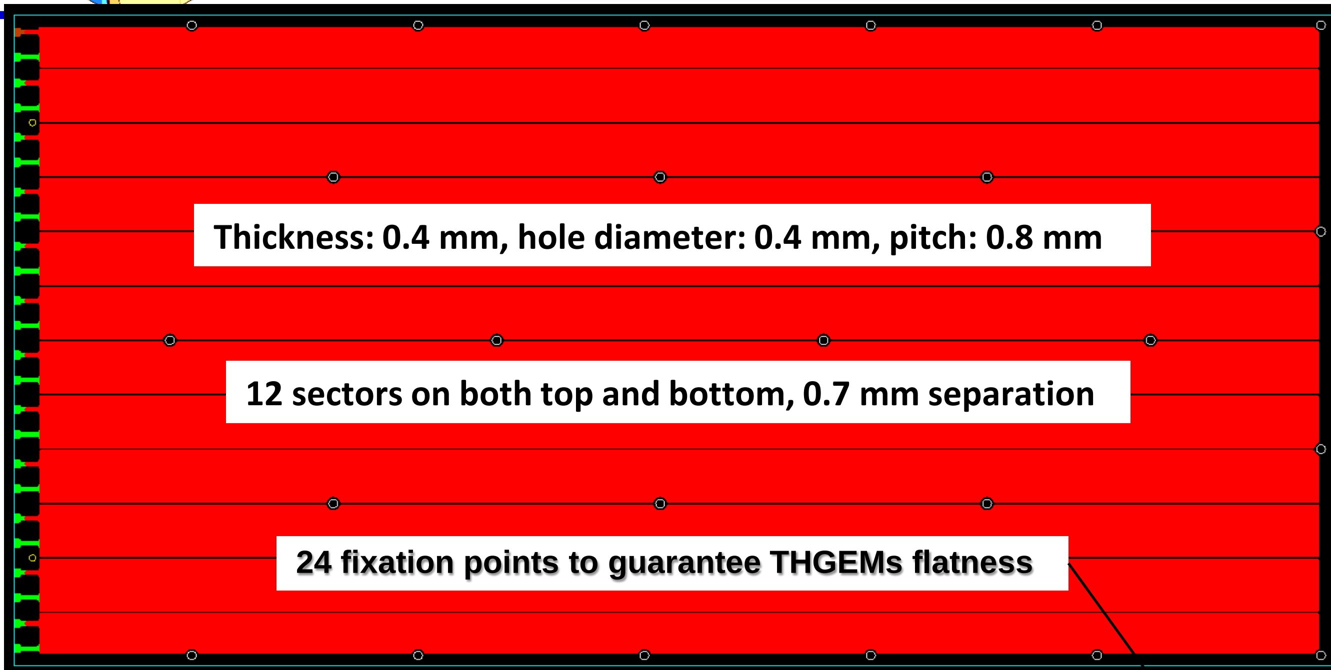
COMPASS RICH-1, gas transparency

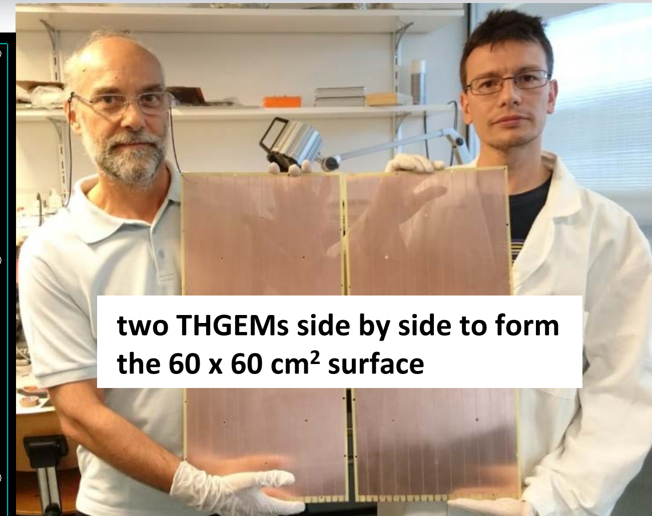
- -gas cleaning by on-line filters,
- -separate functions:
  - -Cu catalyst, ~ 40⁰C for O_2
  - -5A molecular sieve, ~ 10⁰C for H_2O

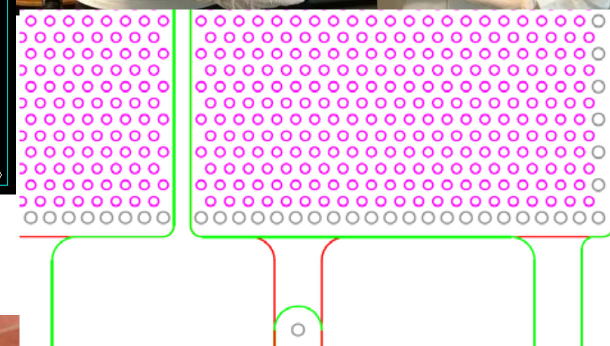


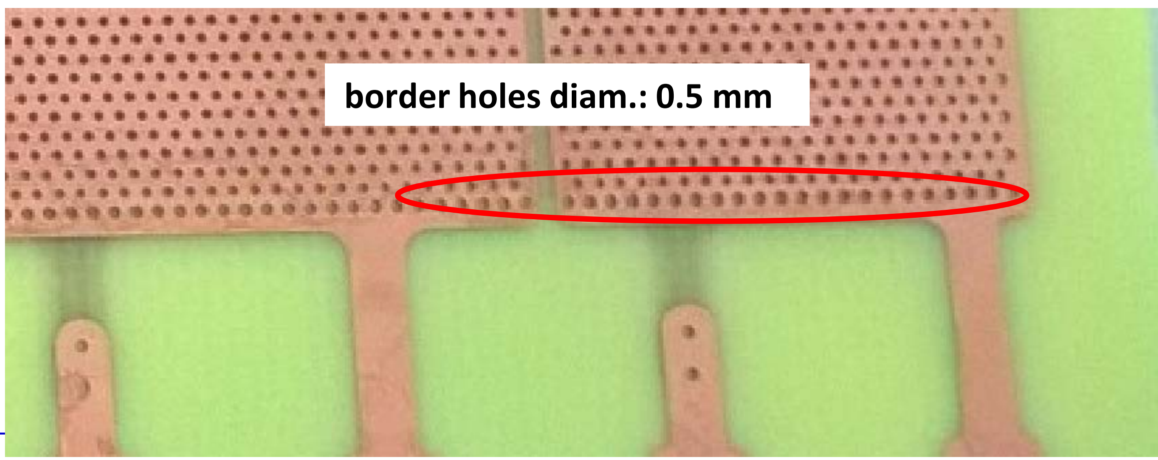
OUR THGEM DESIGN

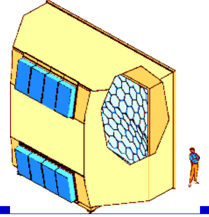






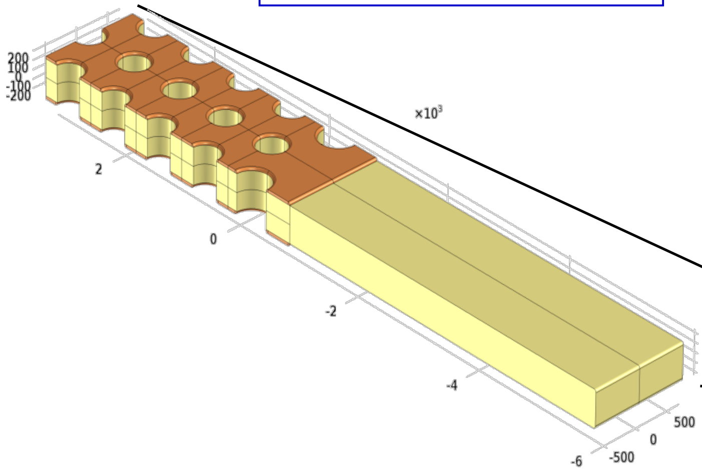


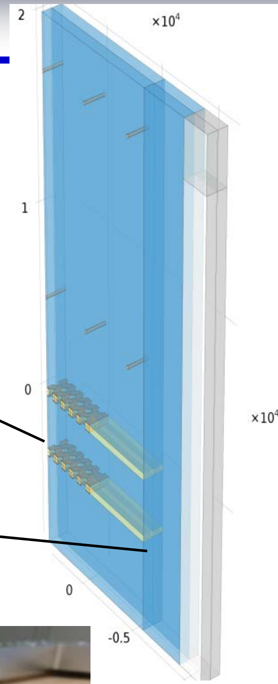


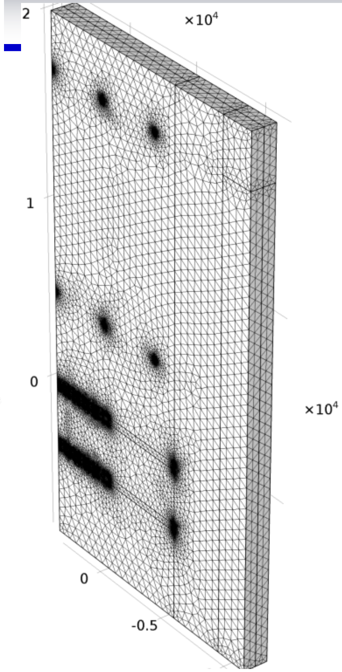


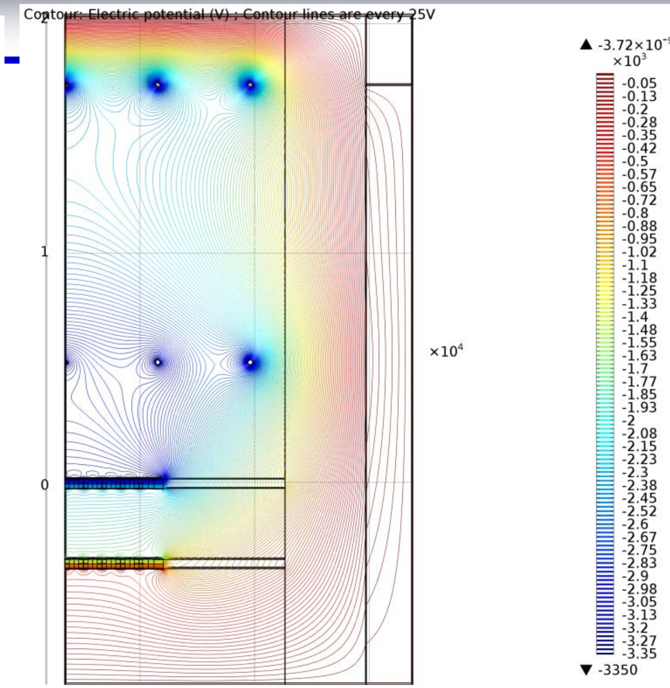
FIELD SHAPING ELECTRODES AT THE EDGES

THGEM border study

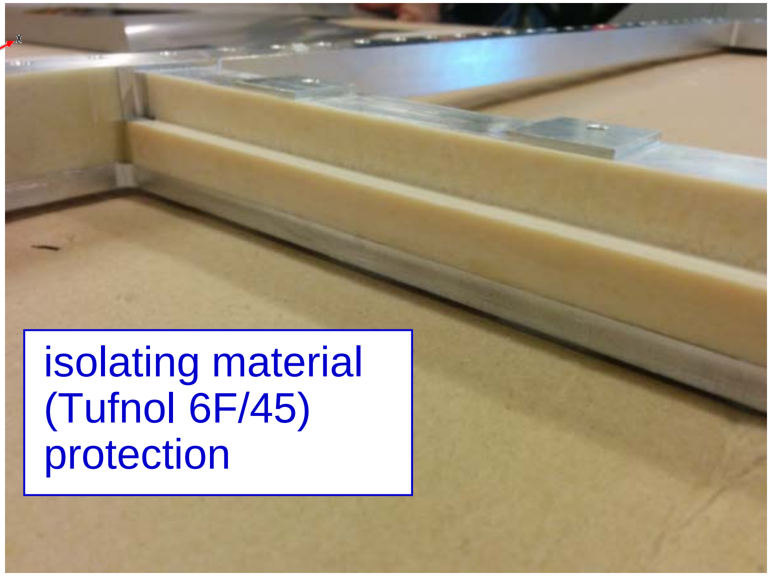








large field values at the chamber edges and on the guard wires



isolating material (Tufnol 6F/45) protection

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