The Hybrid MPGD-based photon detectors of COMPASS RICH-1

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on behalf of the COMPASS RICH Group

The COMPASS RICH-1 upgrade

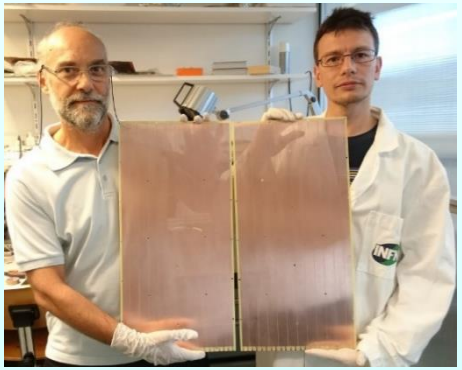
The hybrid PD construction and installation

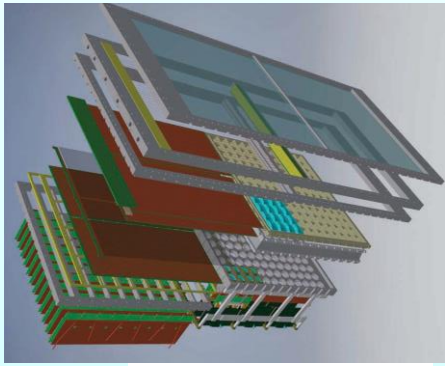
HV control, spark rates, noise level

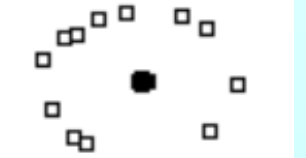
Gain uniformity and stability

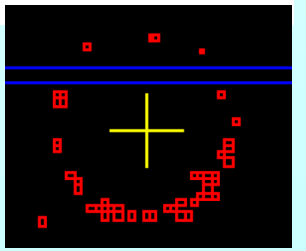
Hybrid PD preliminary characterization

Perspectives and Conclusions



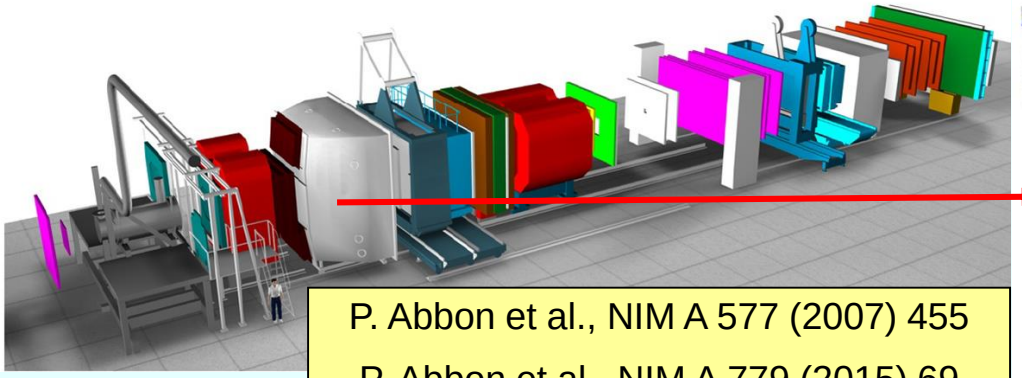






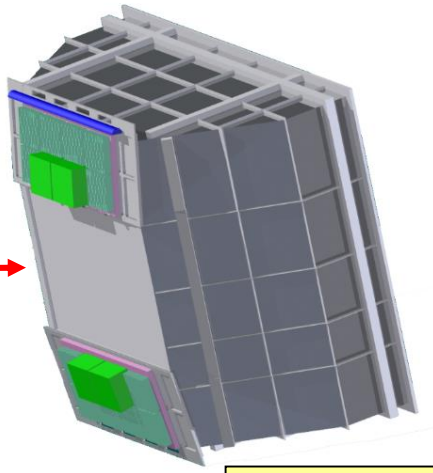
COMPASS RICH-1 upgrade

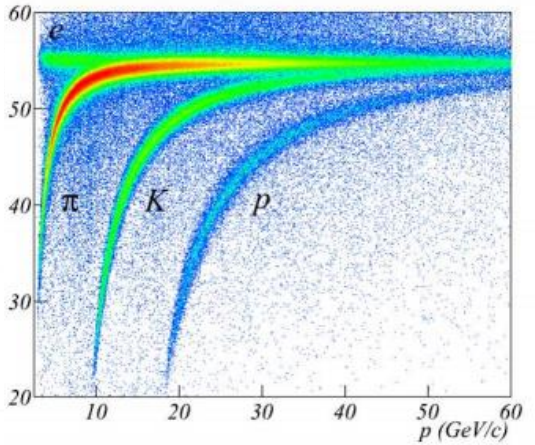
COMPASS Spectrometer



P. Abbon et al., NIM A 577 (2007) 455

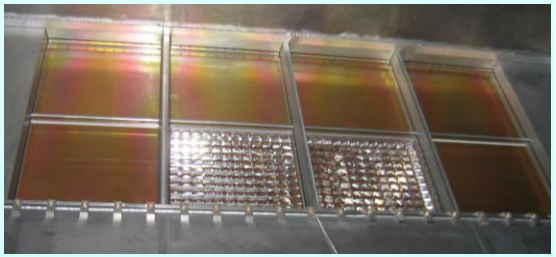
P. Abbon et al., NIM A 779 (2015) 69

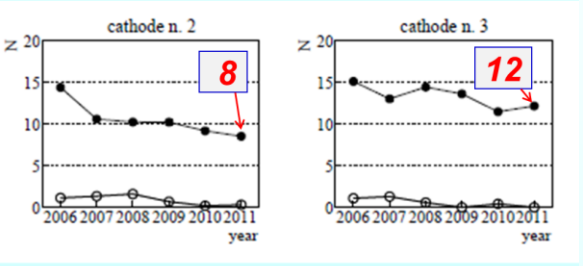




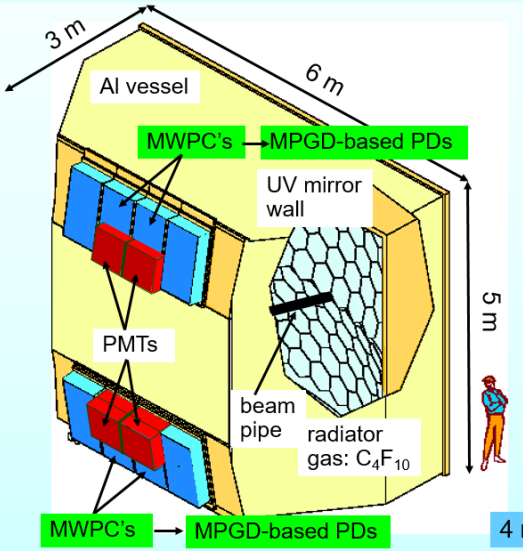
F. Tessarotto et al., JINST 9 (2014) C09011

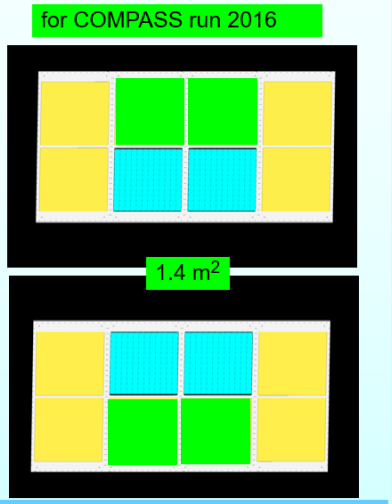
hadron PID from 3 to 60 GeV/c; acceptance: H: 500 mrad V: 400 mrad;
trigger rates: up to ~100 KHz beam rates up to ~10^8 Hz; material: 2.4% Xo (beam region), 22% Xo (acceptance)
80 m^3 C_4F_{10}, 21 m^2 UV mirrors, 1.4 m^2 MAPMTs, 4 m^2 gaseous PDs





MWPCs+CsI: successful but with important performance limitations, in particular in the case of the 4 central chambers

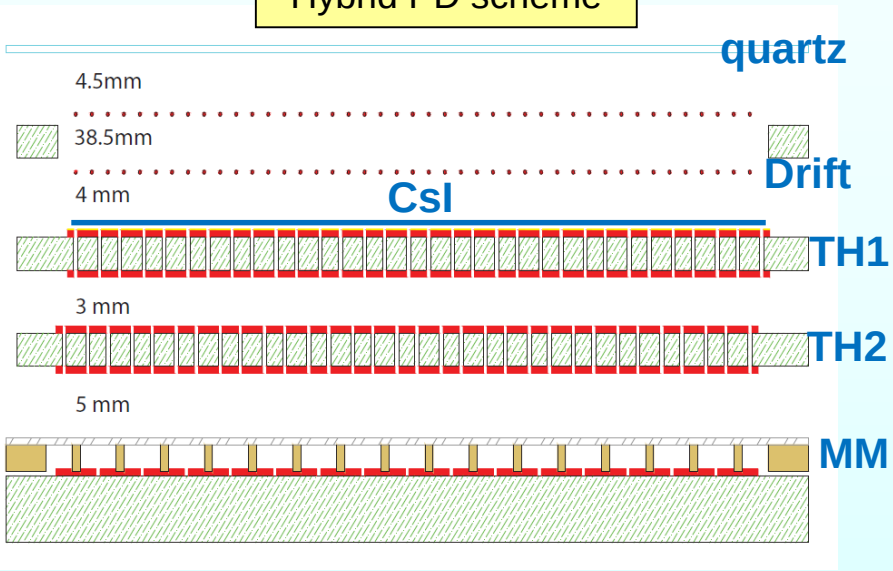




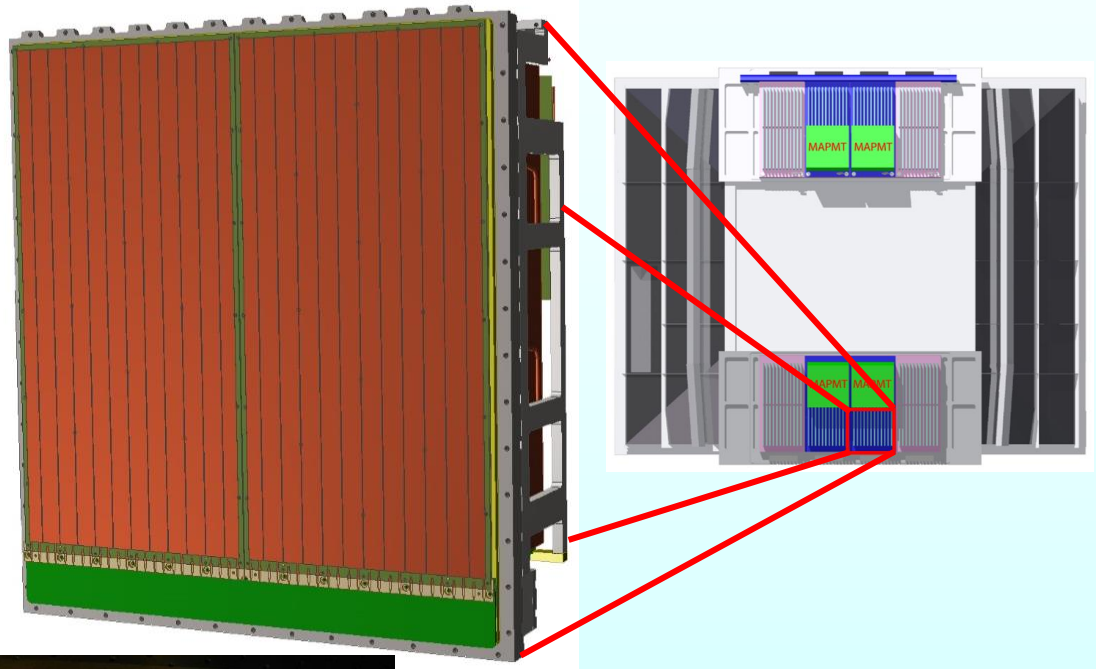
4 new detectors of 600 mm x 600 mm

The hybrid THGEM+Micromegas PDs

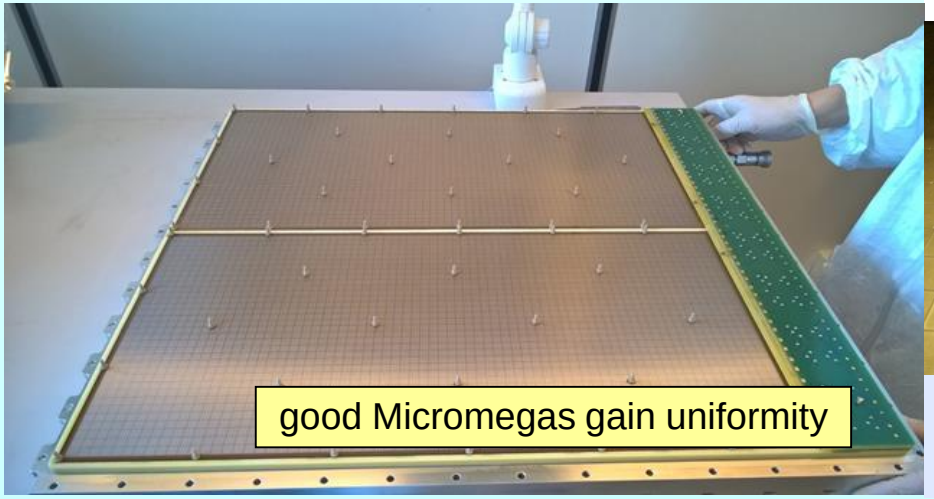
Hybrid PD scheme



modular structure: one module = 600x300 mm^2

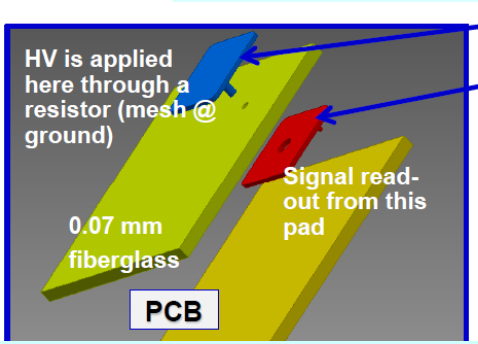


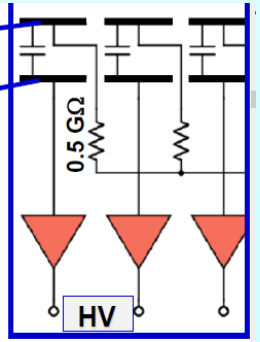
Standard Bulk Micromegas produced at CERN



good Micromegas gain uniformity

8mm X 8mm pads at positive HV

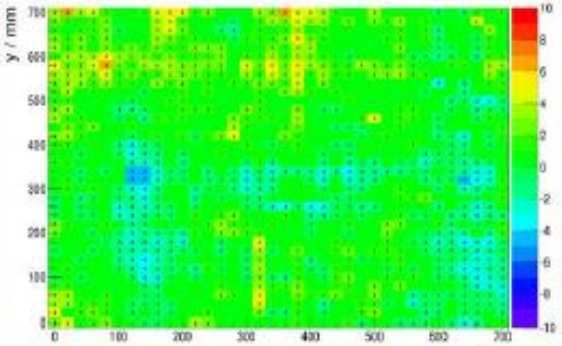




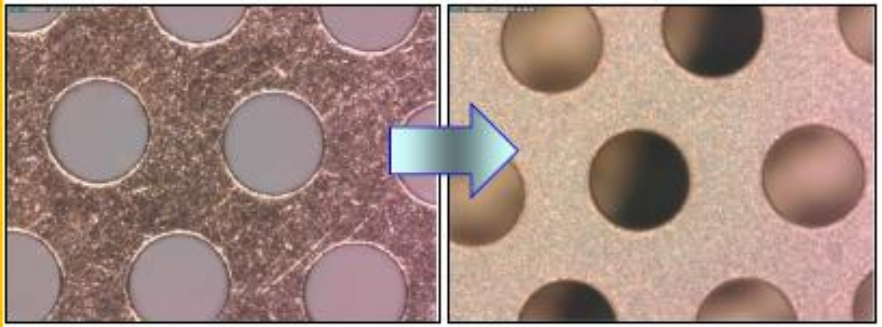
Capacitive coupling → APV25

construction and quality control

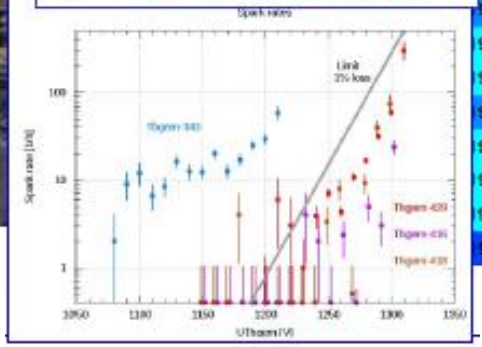
Measurement of the raw material thickness before the THGEM Production, accepted:
± 15 μm ↔ gain uniformity σ < 7%

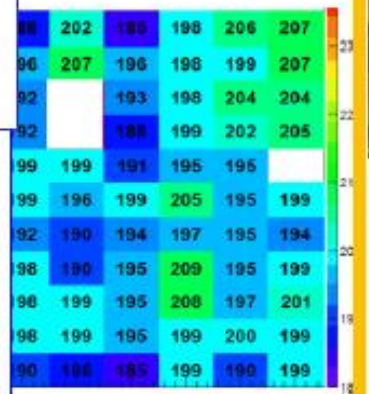


THGEM polishing with an "ad hoc" protocol setup by us:
>90% break-down limit obtained

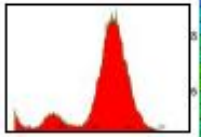


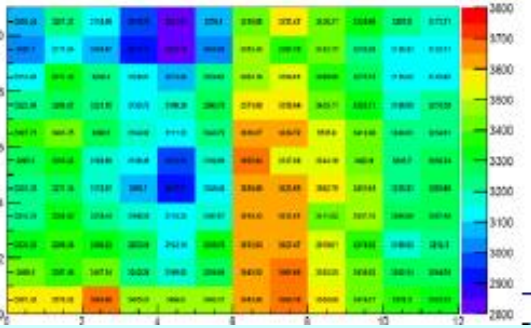
X-ray THGEM test to access gain uniformity (<7%) and spark behaviour



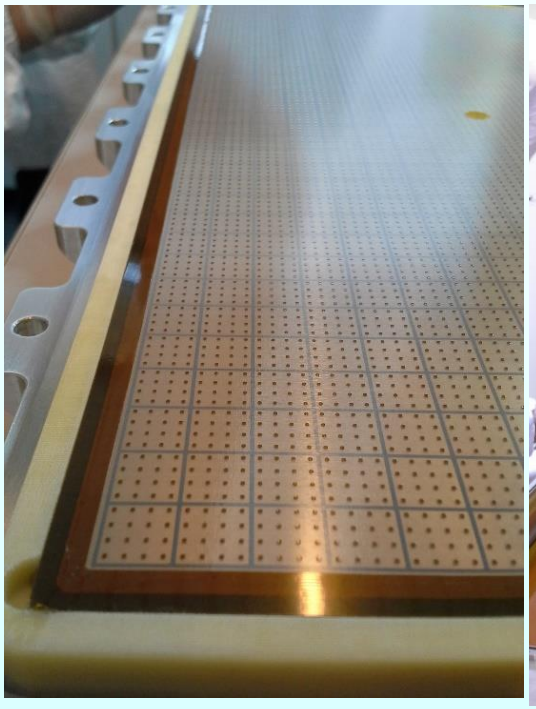


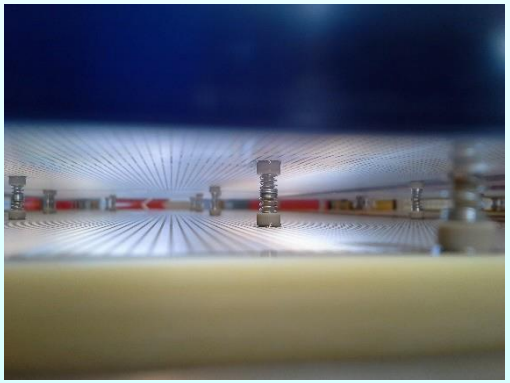
X-ray MM test to access integrity and gain uniformity (<5%)

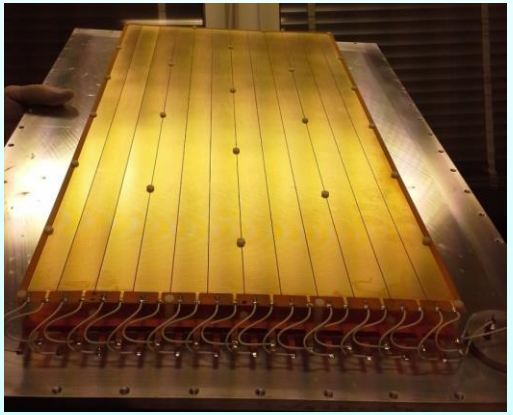


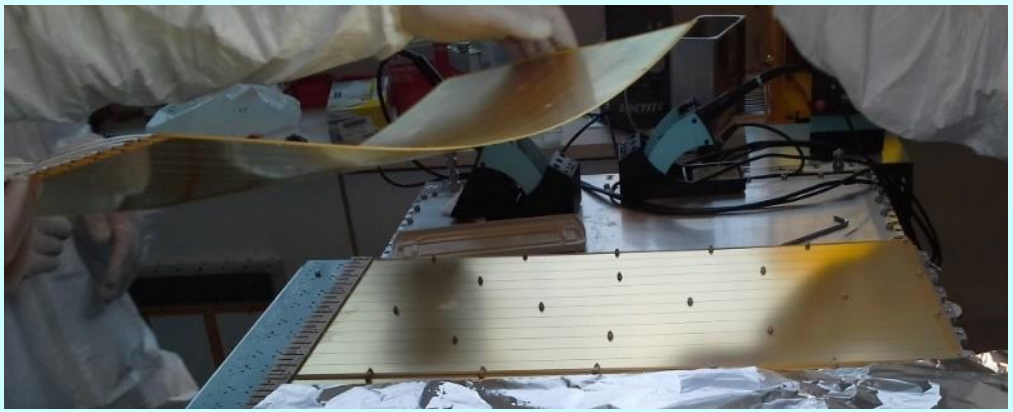


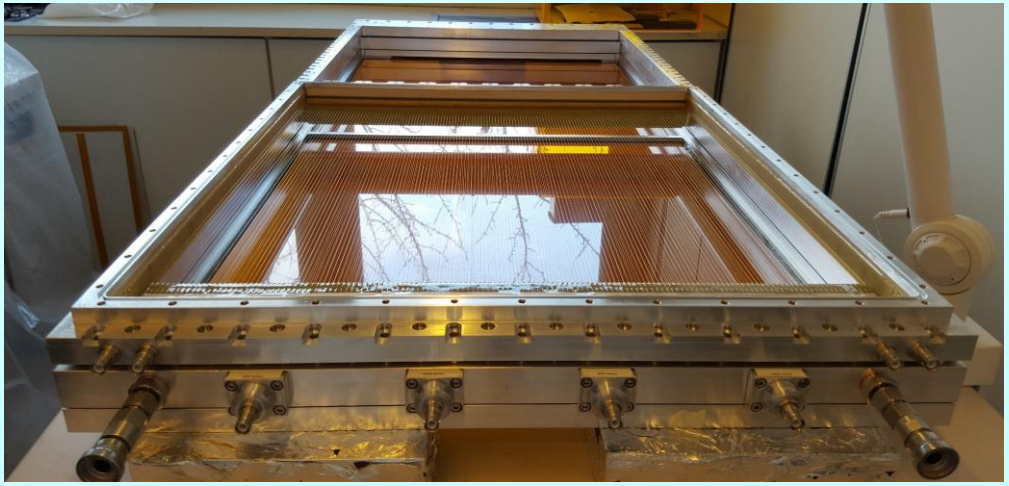
assembling



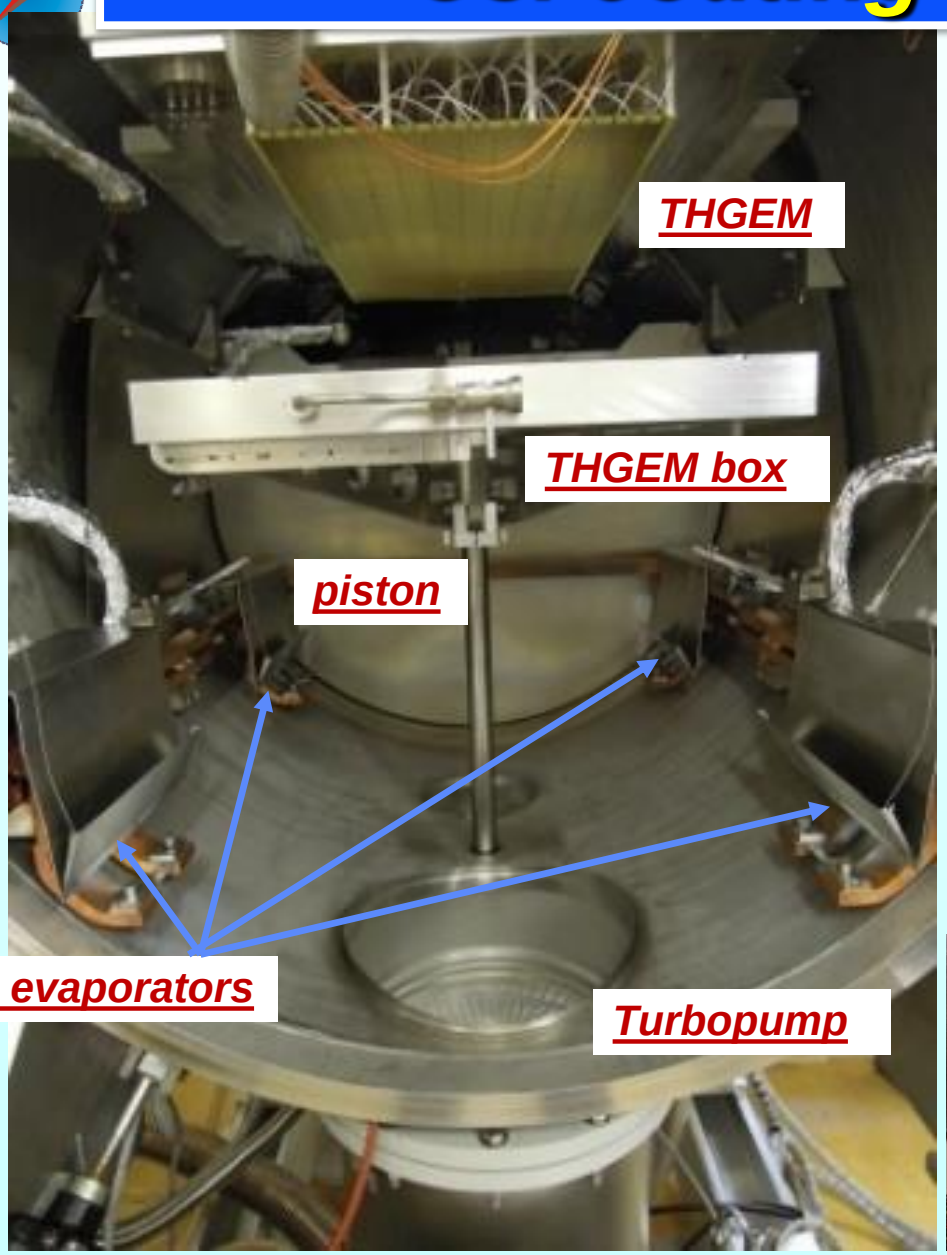


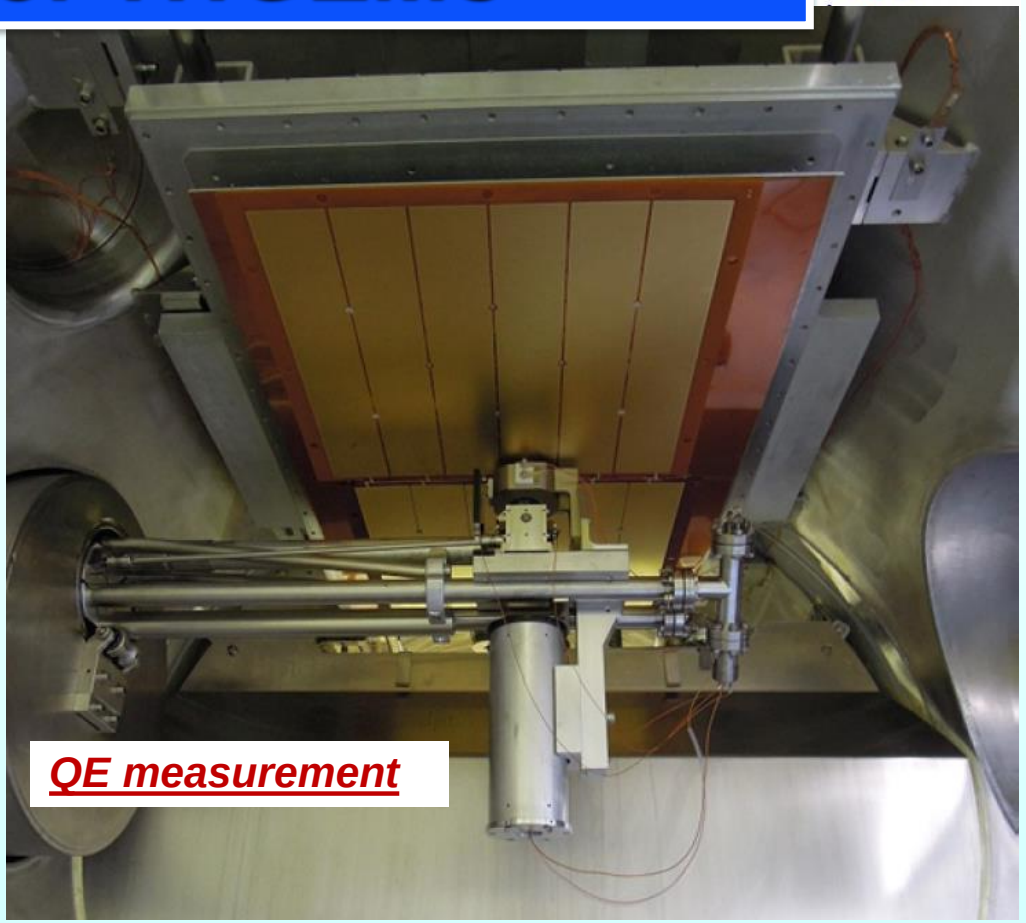


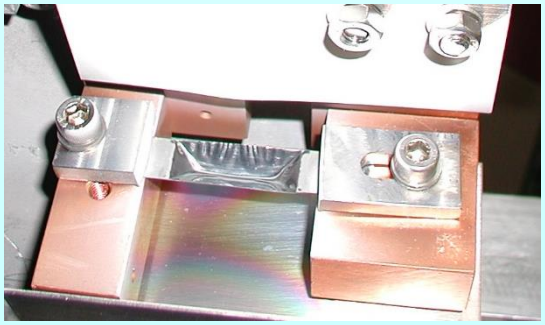




CsI coating of THGEMs



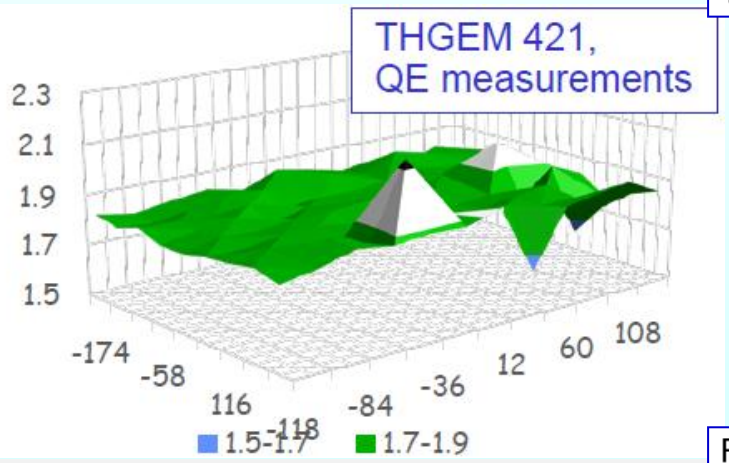




CsI QE measurement

19 CsI evaporations performed at CERN in 2015 - 2016
on 15 pieces: 13 THGEMs, 1 dummy THGEM,
and 1 reference piece (best from previous coatings)
11 coated THGEMs available, 8 used + 3 spares

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



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

QE uniformity

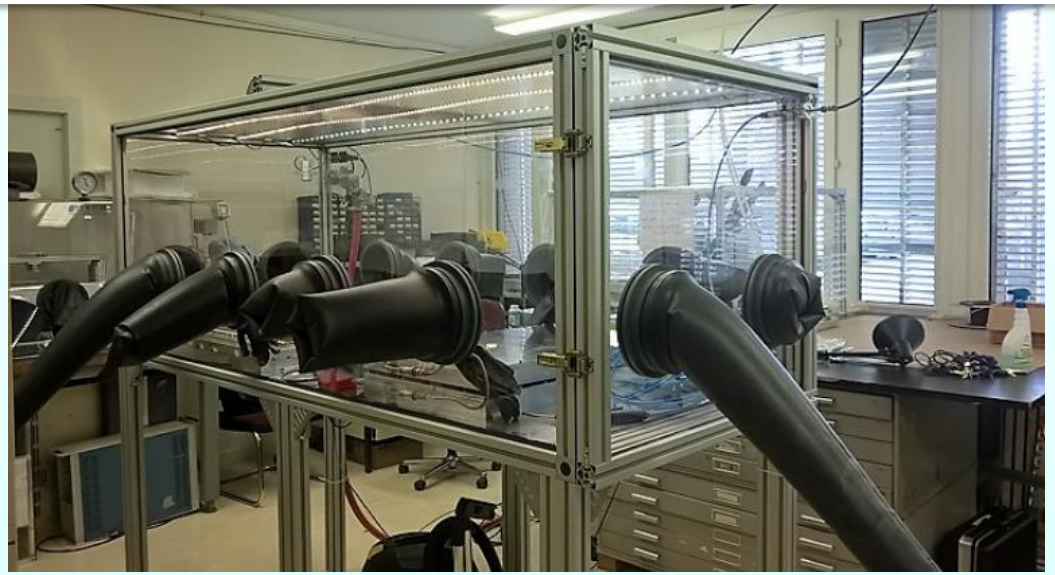
- **3 % r.m.s. within a photocathode**
- **10 % r.m.s. among photocathodes**

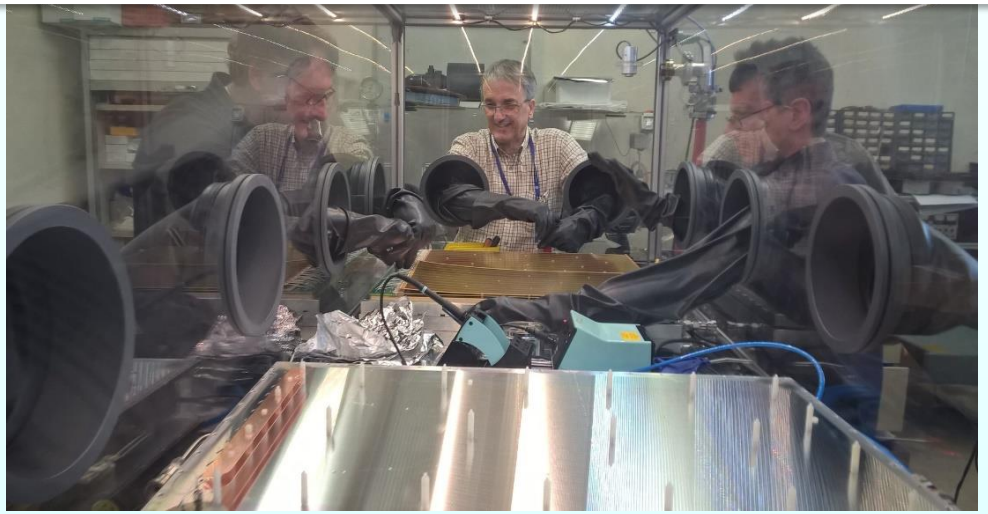
coated by T. Schnider and M. Van Stenis

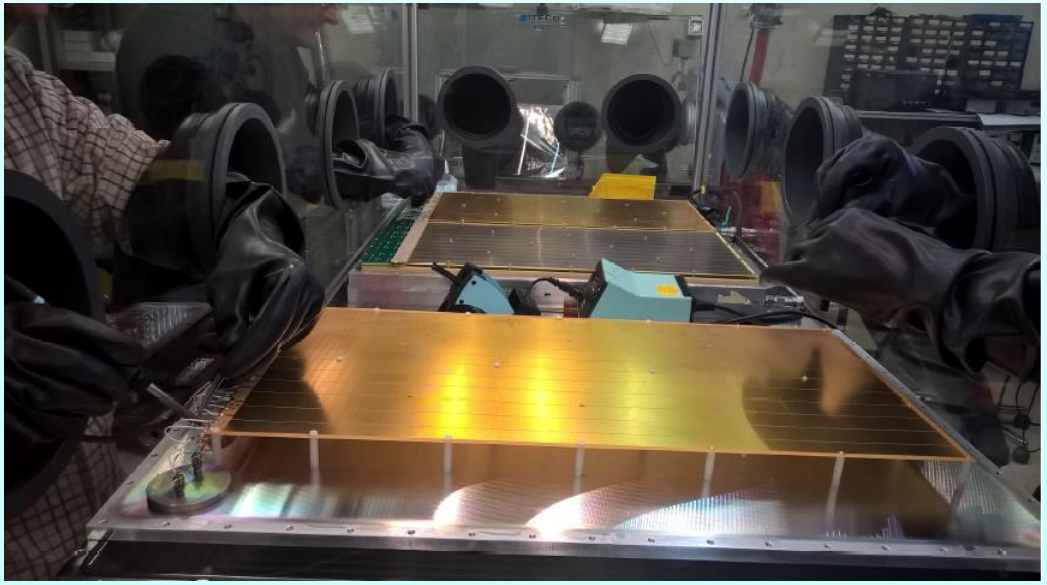
Optical transparency: $\frac{\pi}{2\sqrt{3}}\left(\frac{d}{p}\right)^2$ *~ 0.23*

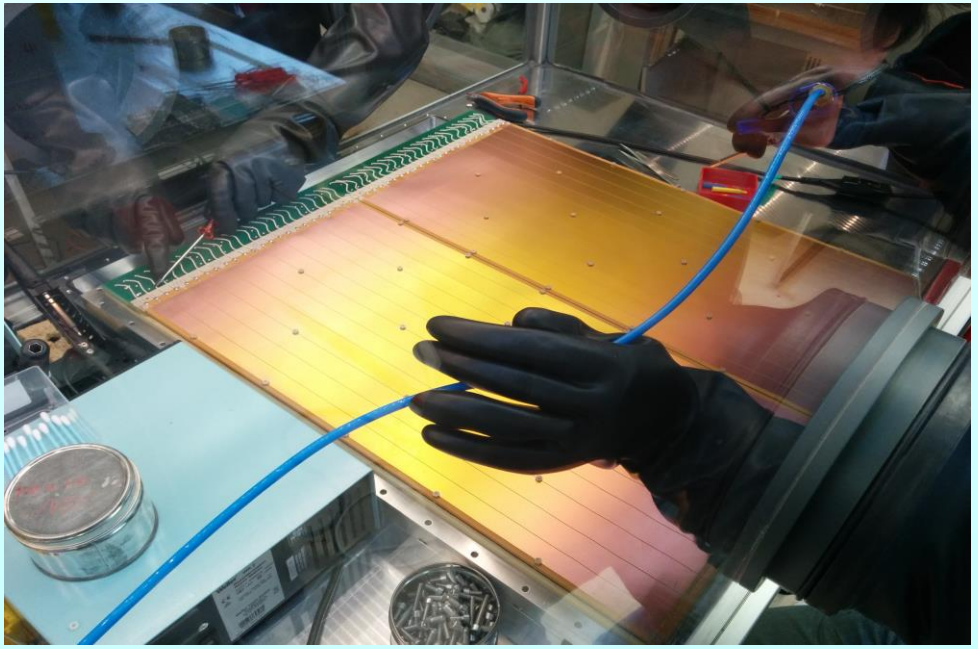
→ ***mean THGEM QE: ~ 93% of reference***

CsI THGEM mounting

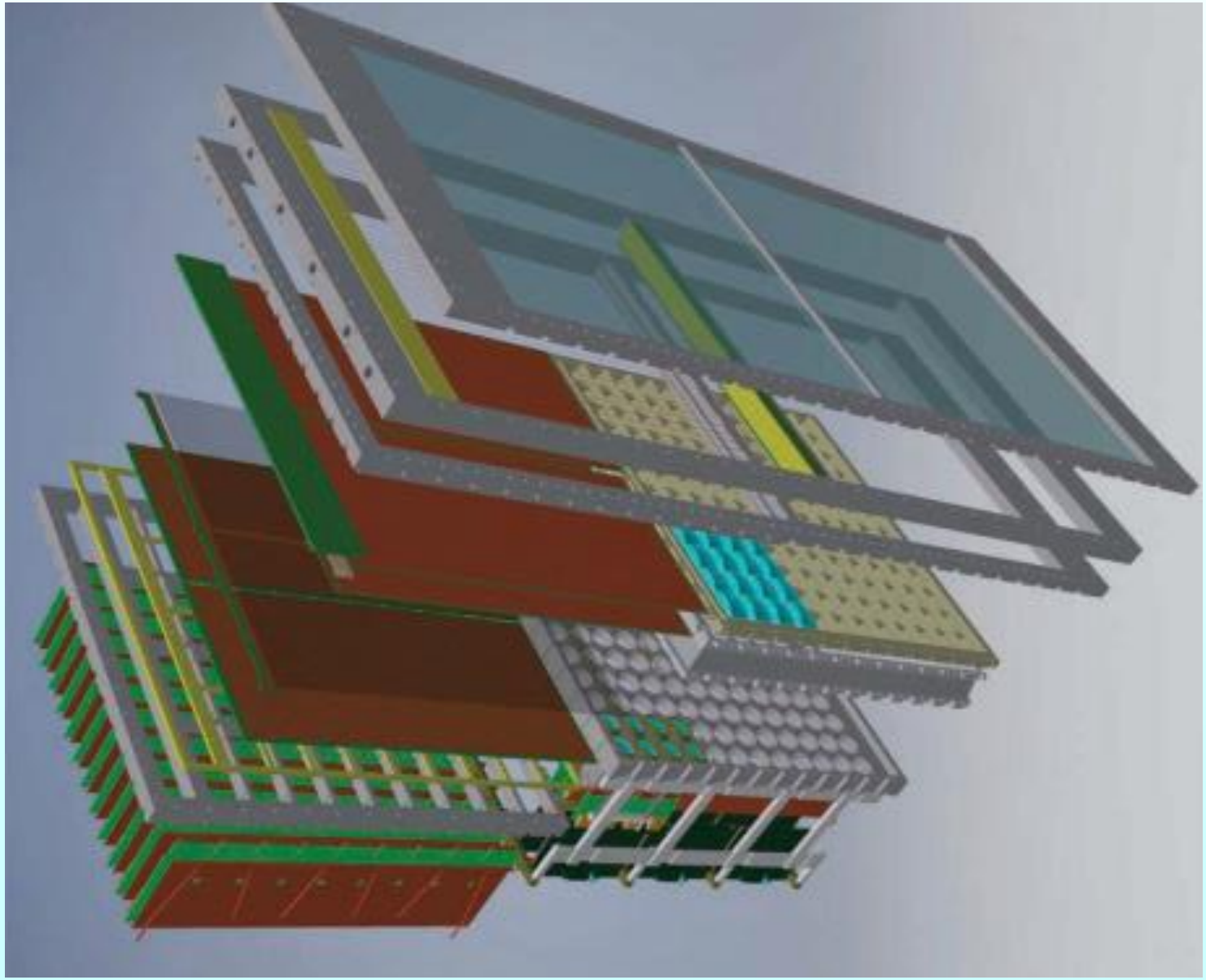




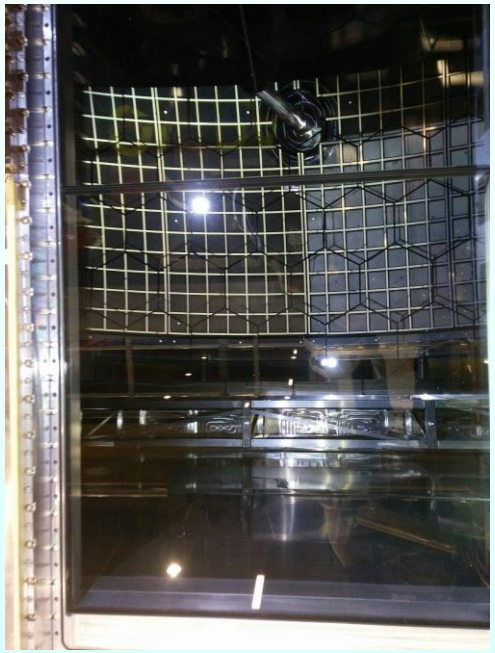
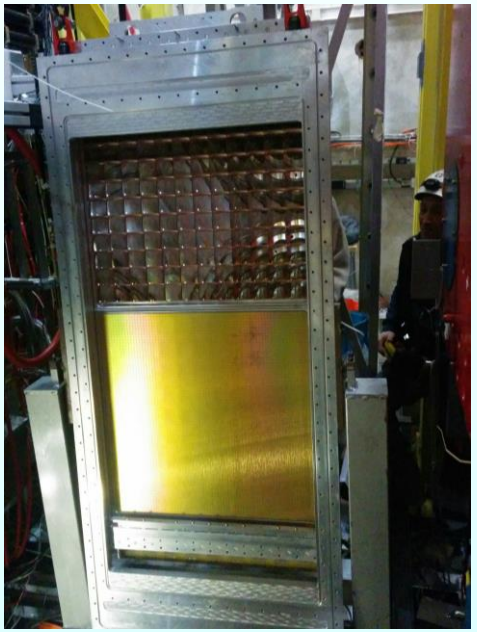


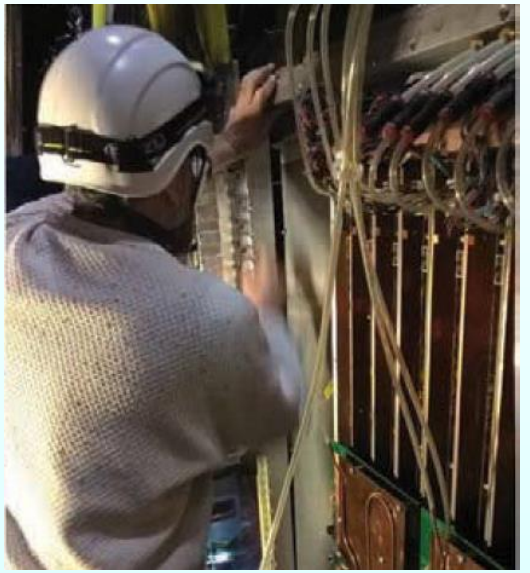


The new COMPASS PDs

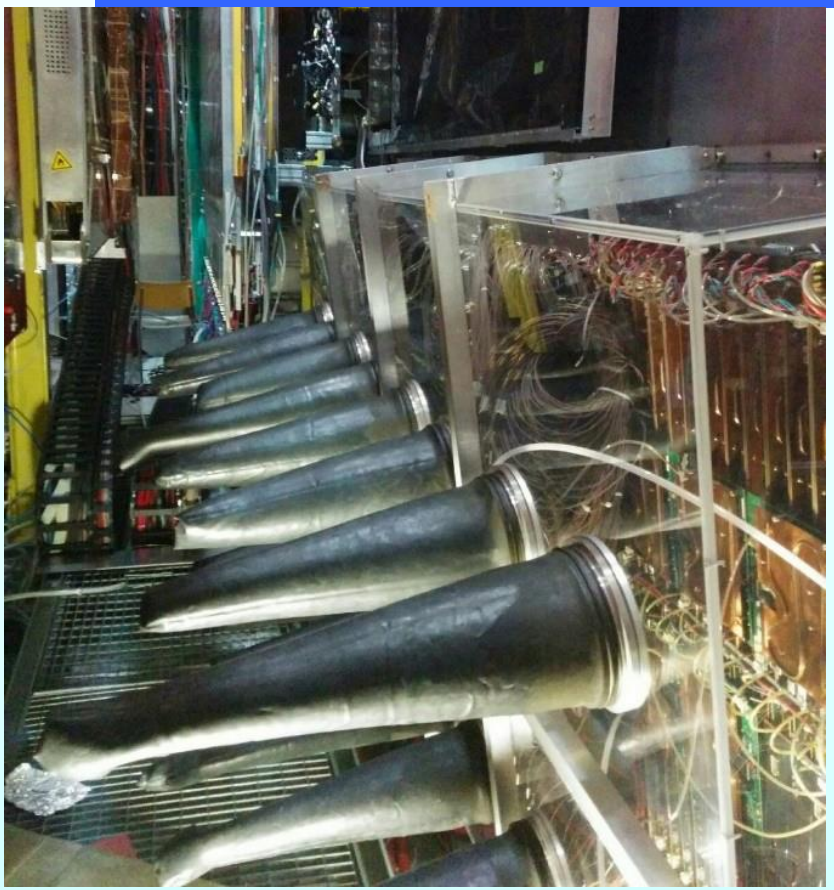


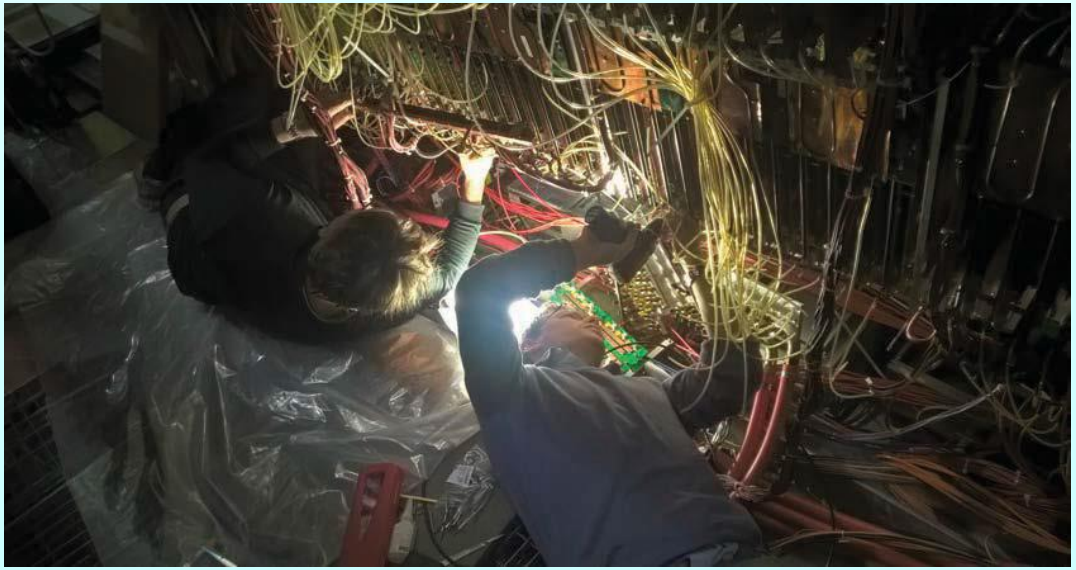
Installation of hybrids on RICH_1

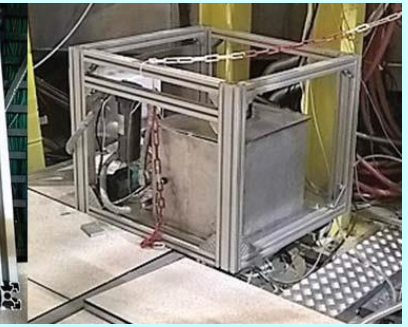





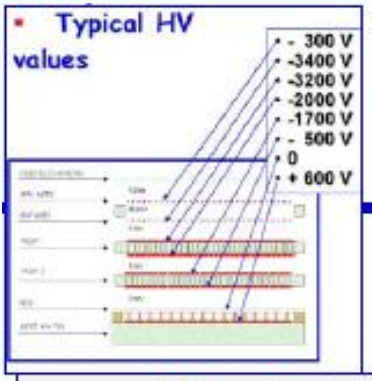

Equipping the hybrids on RICH_1

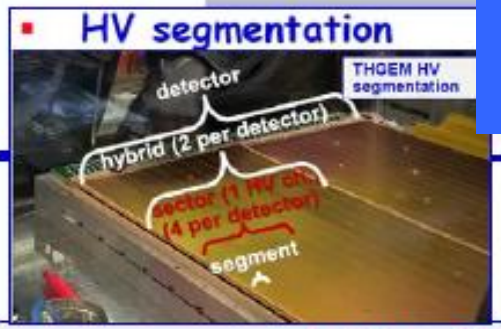






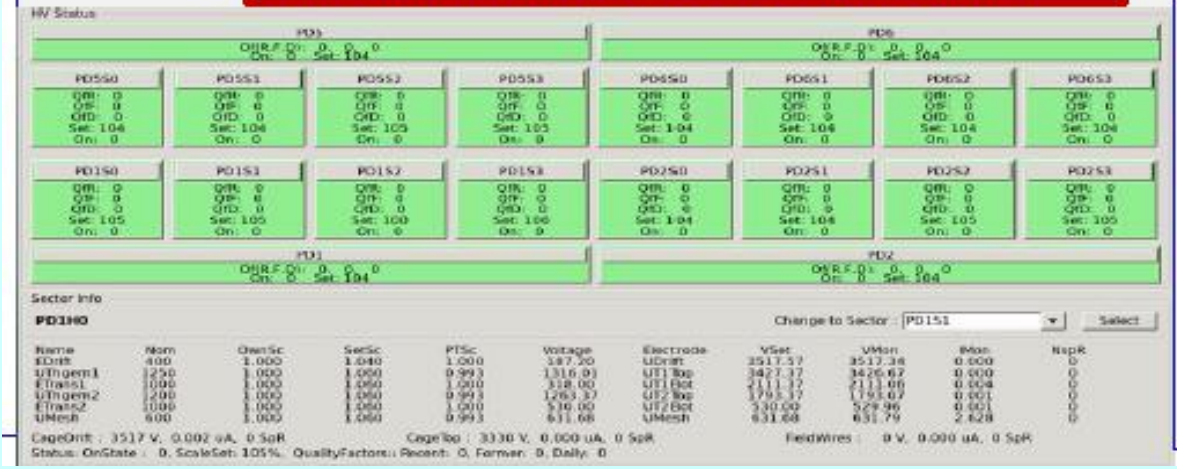
HV CONTROL



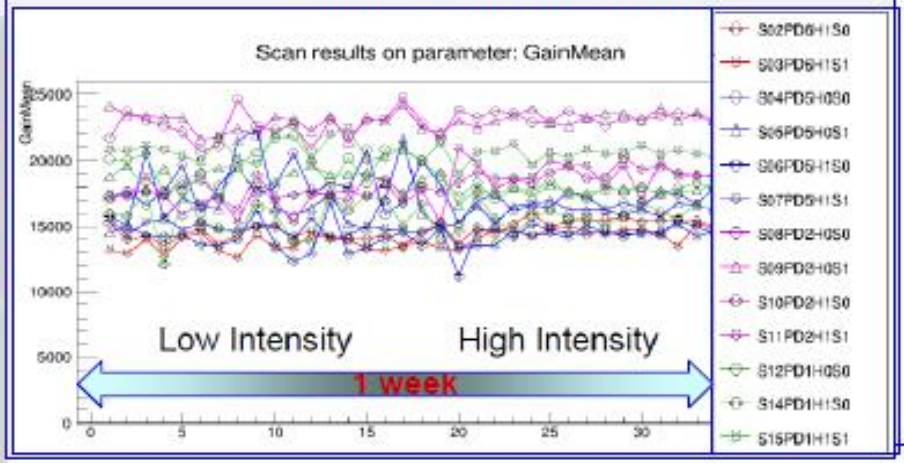


In total 136 HV channels with correlated values

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



- **Gain stability vs P, T:**
  - G = G(V, T/P)
  - Enhanced in a multistage detector
  - $\Delta T = 1^{o}C \rightarrow \Delta G \approx 12\ \%$
  - $\Delta P = 5$ mbar $\rightarrow \Delta G \approx 18\ \%$
- **THE WAY OUT:**
  - Compensate T/P variations by V
    → Gain stability at 5% level



sparks

during 2017 COMPASS run

Spark: event with I > 23 nA

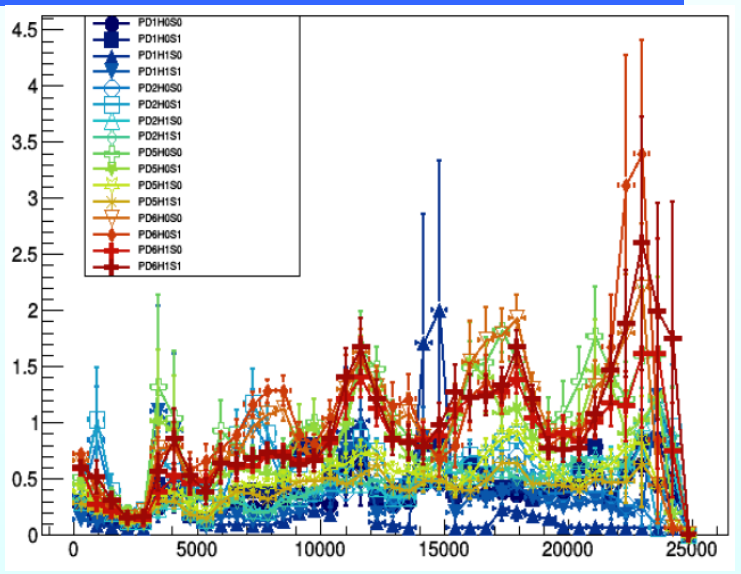
Current sparks in THGEMs

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

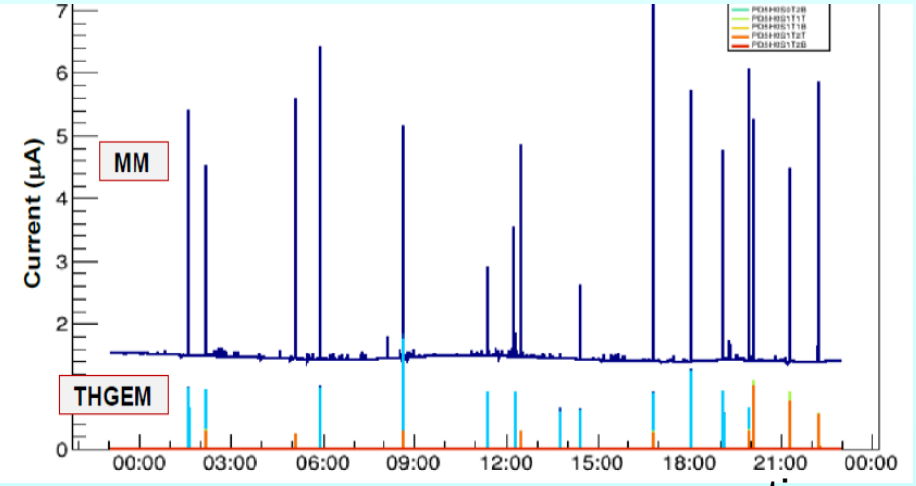
Current sparks in MICROMEGAS

- Induced by THGEMs
- Recovery time: ~1 s

spark rate well under control

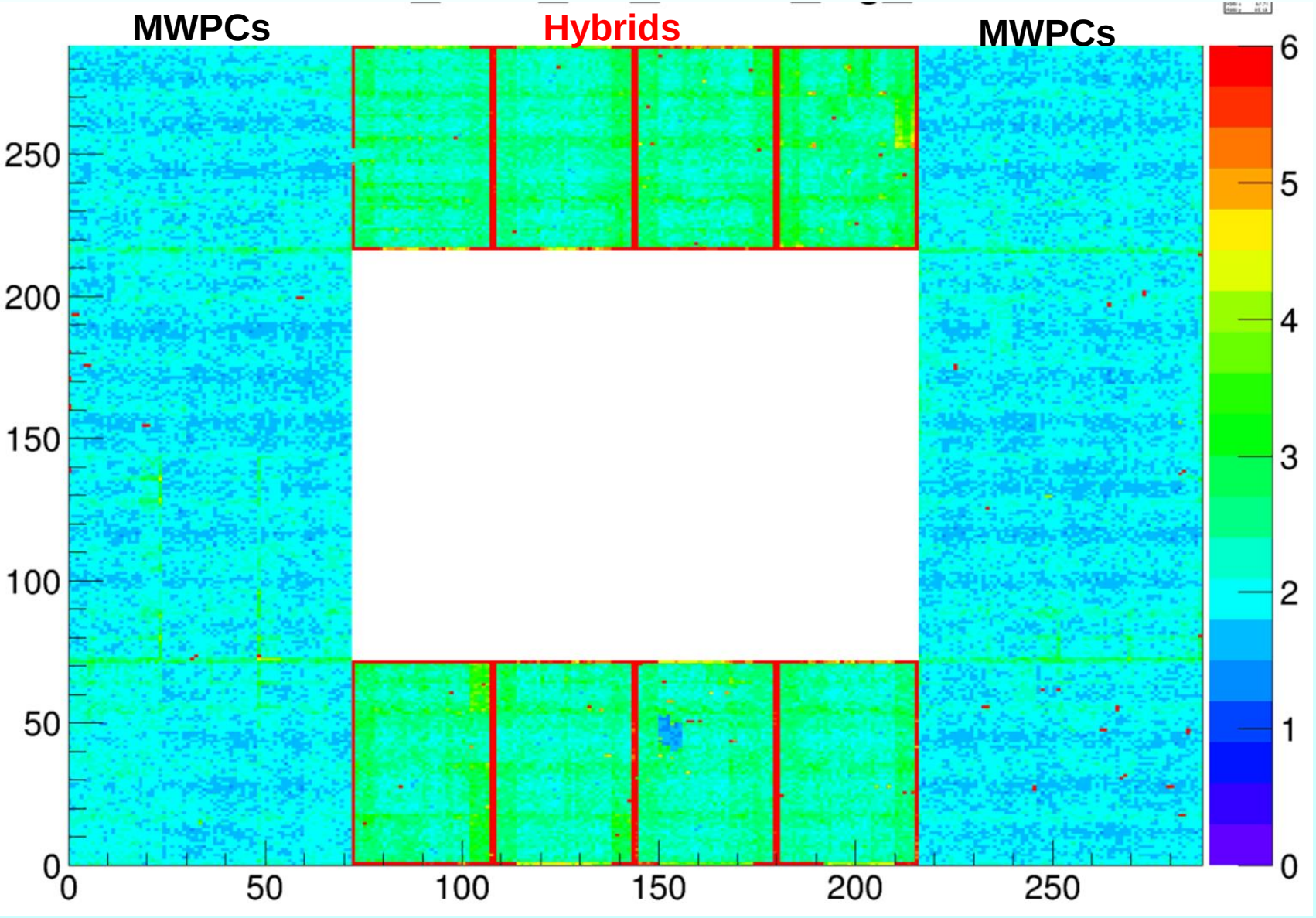


beam intensity ppp on T6 (10^{13} per h)

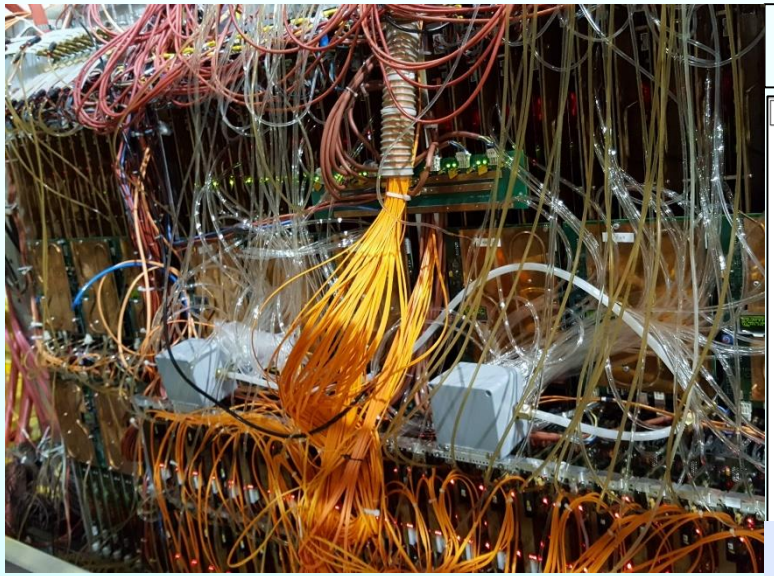


time

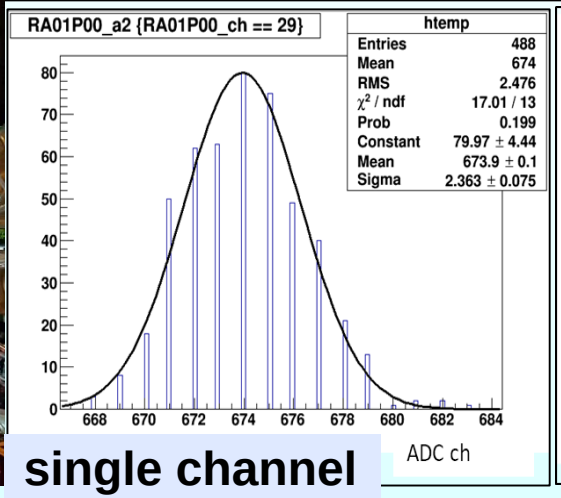
Noise figure for the 62208 ch.



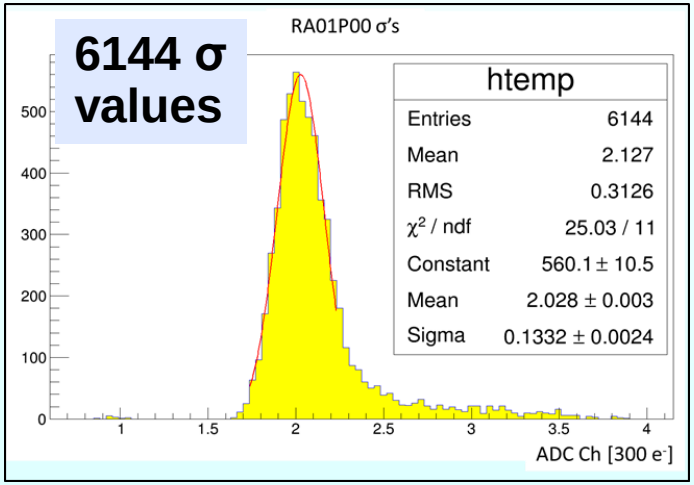
Noise level and pedestal stability



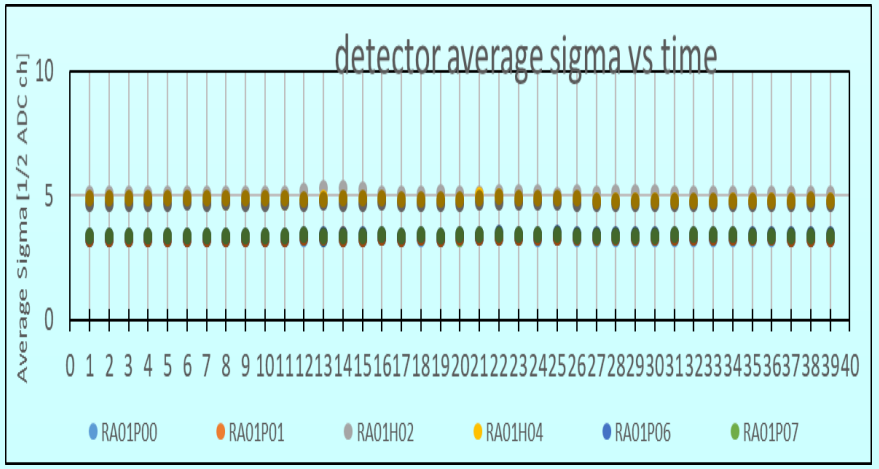
- 12 Detectors, 6144 Ch each.

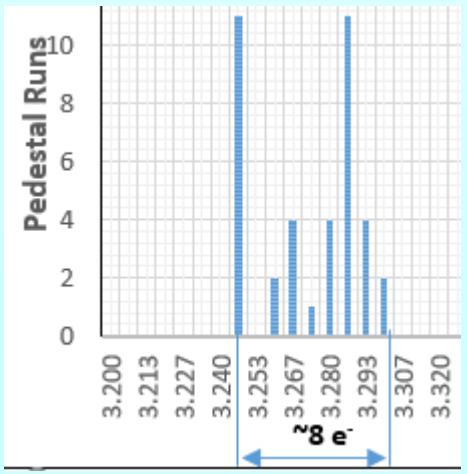


single channel



- 39 APV Pedestal Runs during COMPASS 2017 run.





The APV-based F/E is the same for MWPCs +CsI and Hybrid PD's

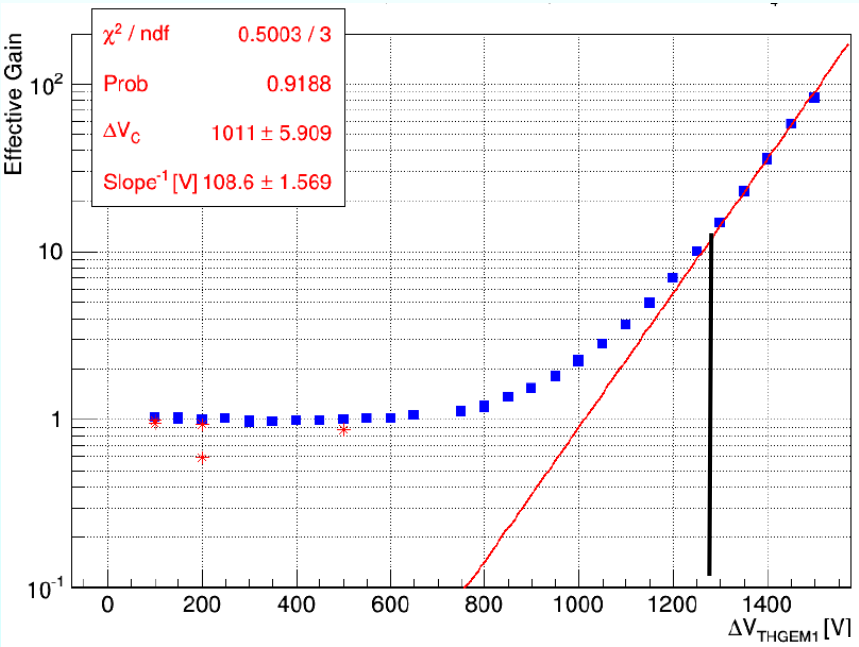
The niose levels are:

- MWPC: ~ 600 e^-
- **Hybrid: ~ 800 e^-**

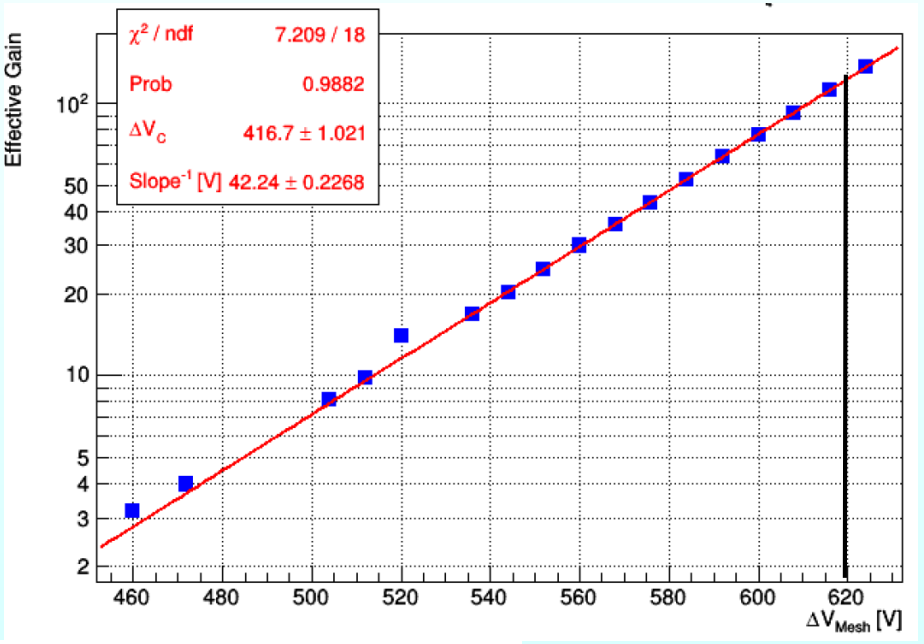
The noise levels are very stable in time

gain shearing among the layers and IBF

Effective gain*transfer of THGEM1 in Ar/CH4, with THGEM2 and MM at nominal voltages



Effective gain of Mcromegas in Ar/CH4, with THGEM1 and THGEM2 at nominal voltages

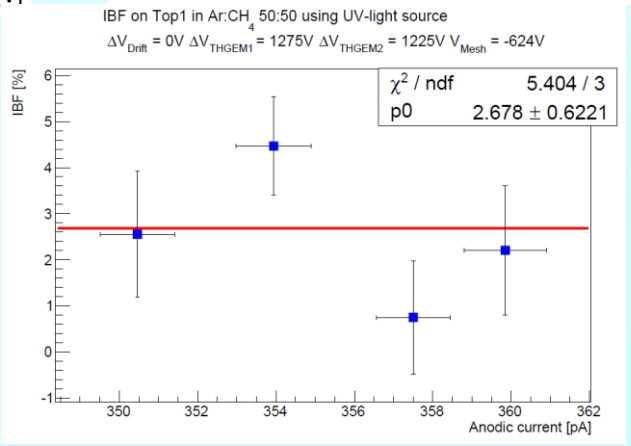


nominal eff. gain: ~17000 with:

THGEM1 gain*transfer1: ~ 13

THGEM2 gain*transfer2: ~ 10

Micromegas gain: ~130

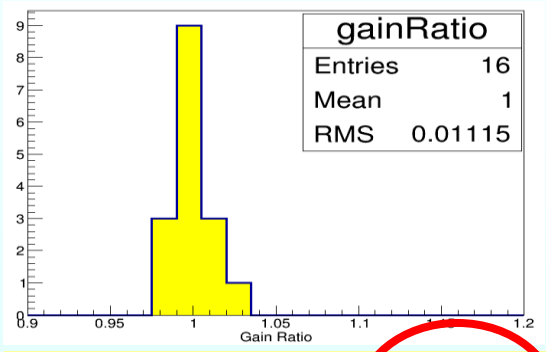


The Ion Back Flow has been measured to be ~ 3% (dedicated exercise)

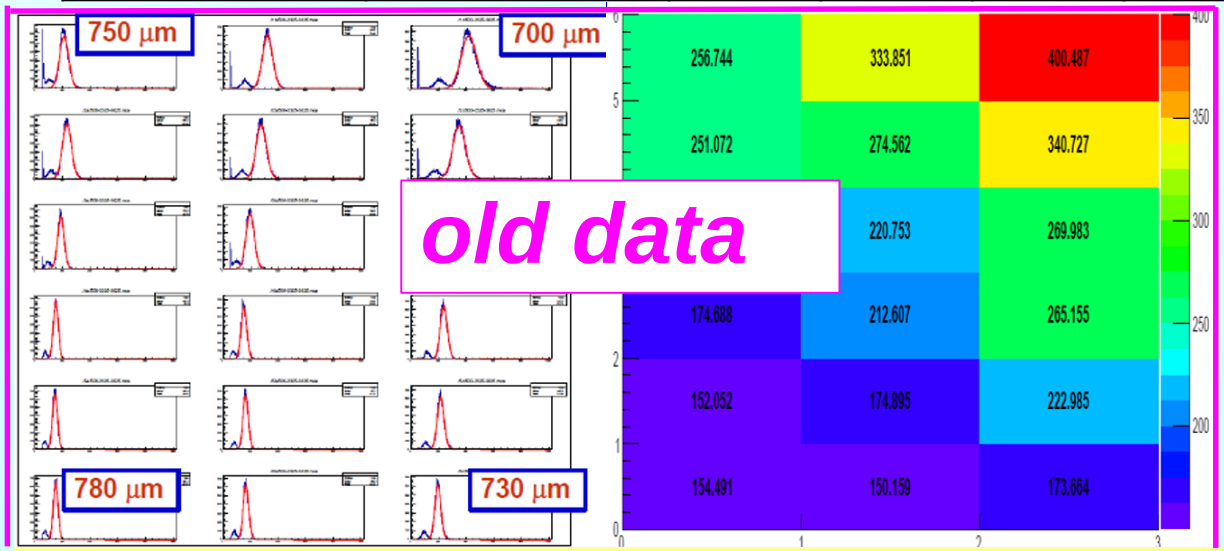
good gain uniformity

A specific gain equalization procedure has been developed and used

Sector	PD6S3	PD6S2	PD6S1	PD6S0	PD5S3	PD5S2	PD5S1	PD5S0
Eff. Gain	14322	14207	14346	14464	14675	14366	14349	14192
Ratio	1.0020	0.9936	1.0037	1.0119	1.0266	1.0051	1.0039	0.9929
Eff. Gain	14322	14024	14255	14073	14470	14291	14213	14099
Ratio	1.0042	0.9811	0.9973	0.9845	1.0123	0.9998	0.9944	0.9863
Sector	PD2S3	PD2S2	PD2S1	PD2S0	PD1S3	PD1S2	PD1S1	PD1S0
Average Eff. Gain		14294		σ	159.40	σ/Avg (%)		1.1



uniform at ~ 1%



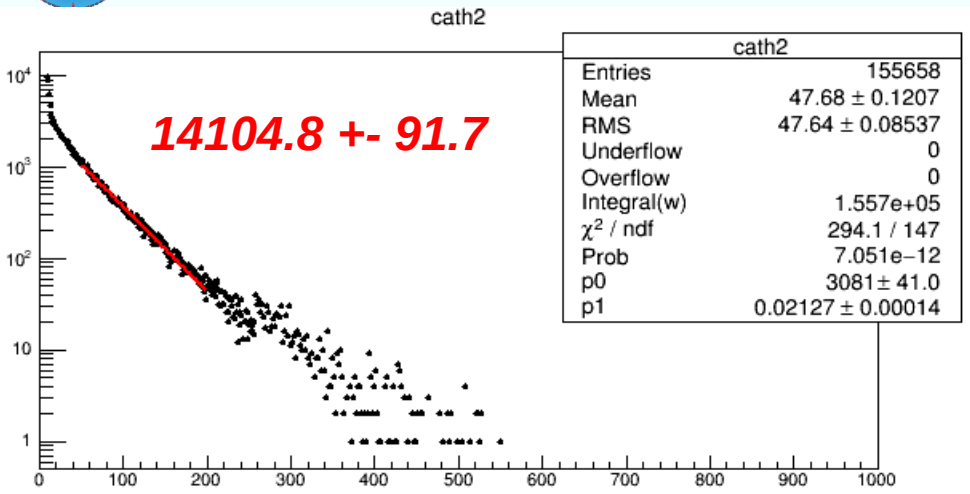
old data

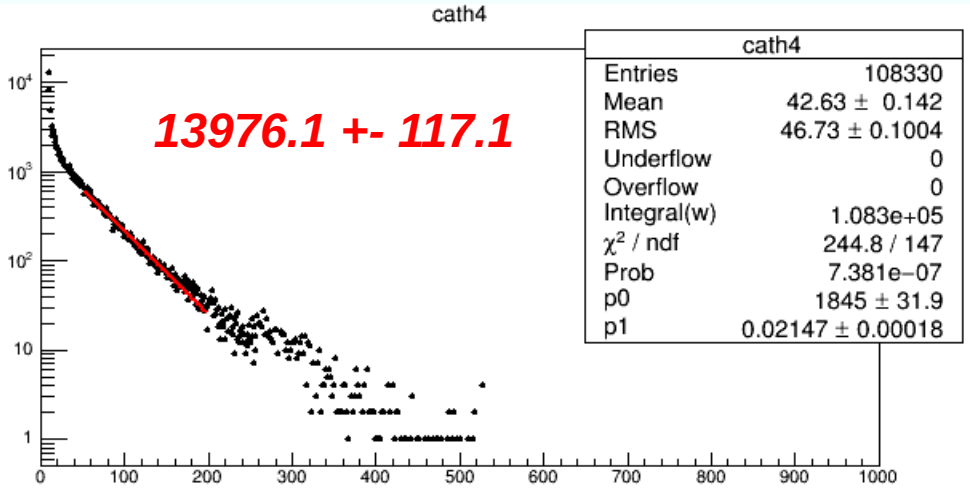
Q.E. uniformity			
1.09	1.14	1.03	0.99
0.90	0.88	0.90	1.08
σ = 9.3%			

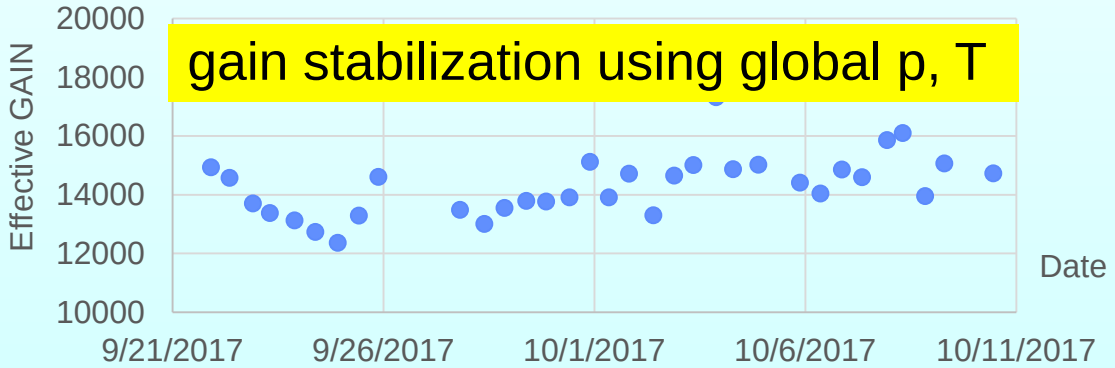
… compared to ~ 30% of old single "raw" PCB THGEMs

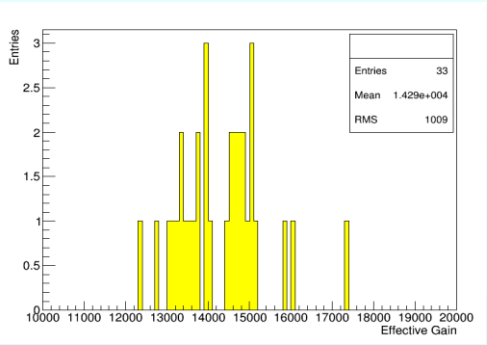
and ~9 % of CsI Q.E. variations

Gain stability in time

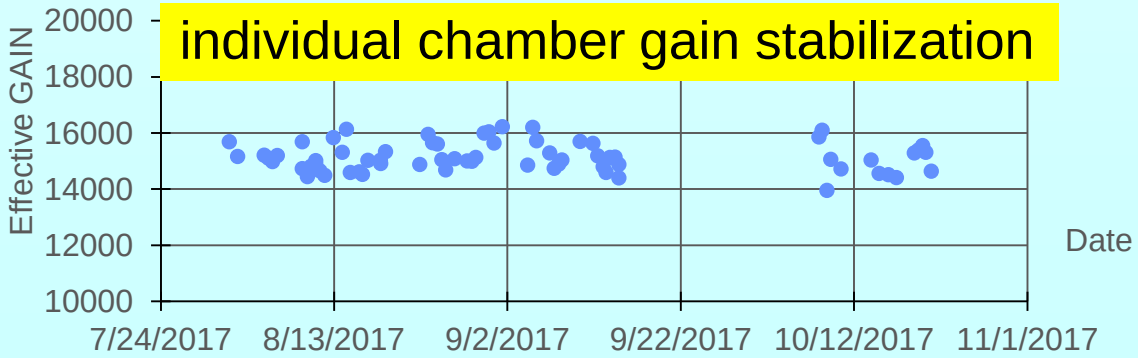


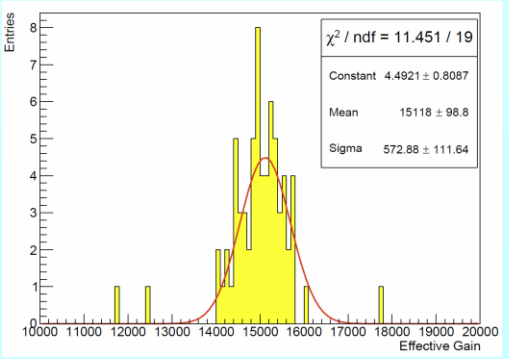






global corrections: **σ/mean ~ 7%**

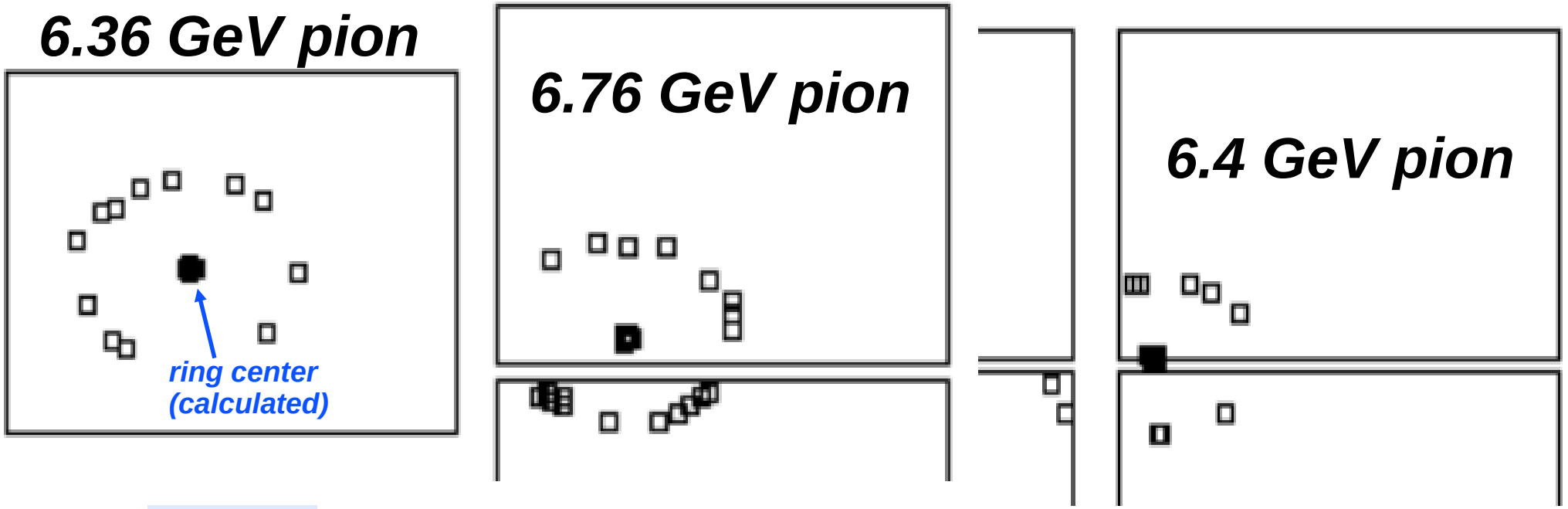


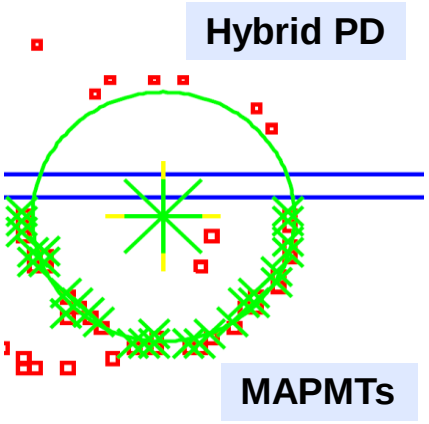


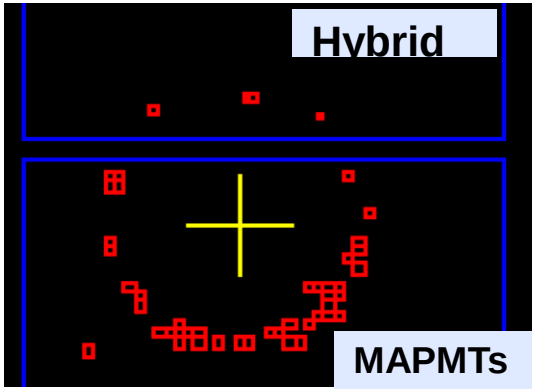
individual corrections: **σ/mean ~ 4%**

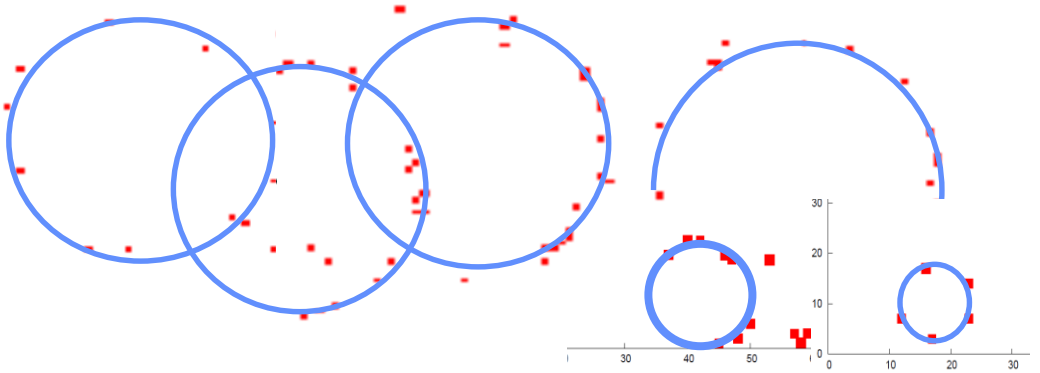
NICE RINGS

(in the 2017 run the Hybrid PDs were receiving Cherenkov photons from low p particles only)

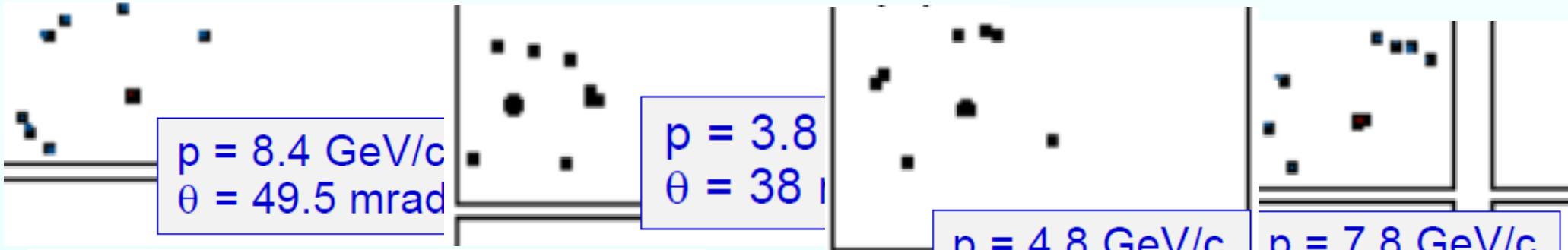


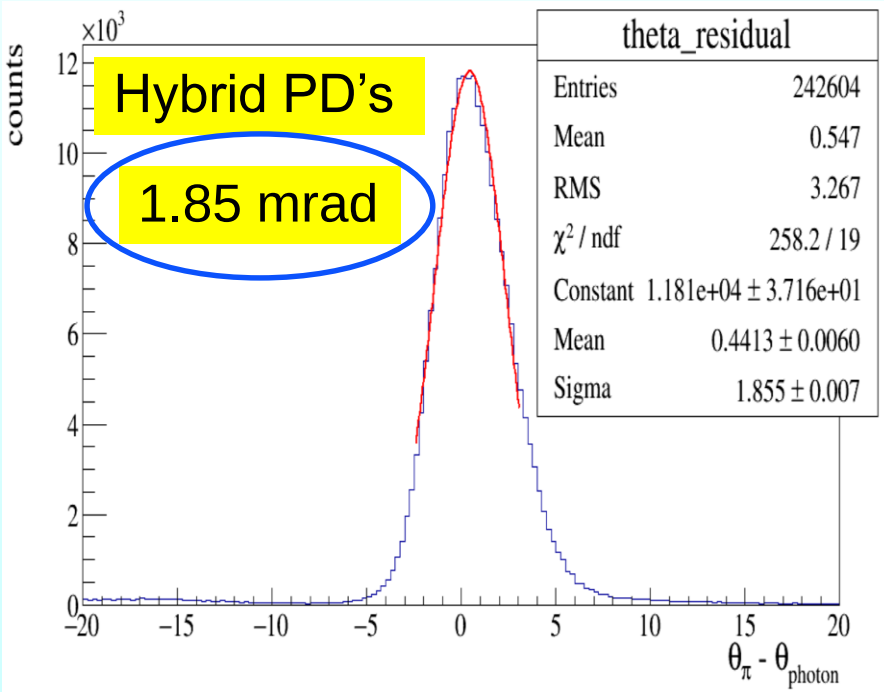


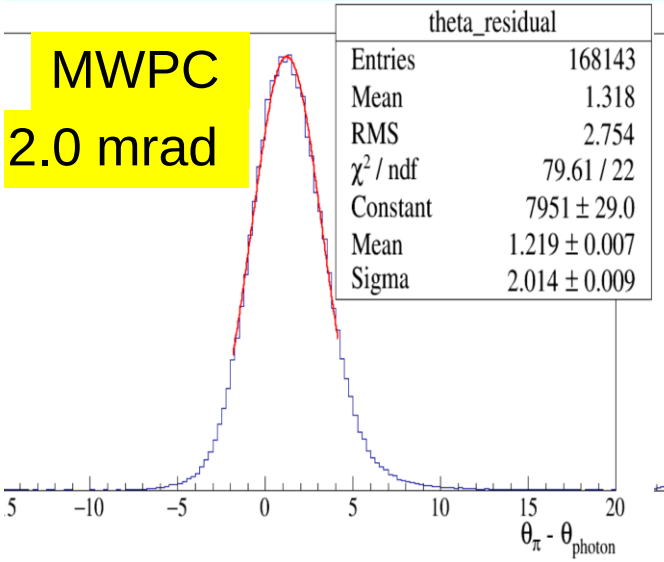


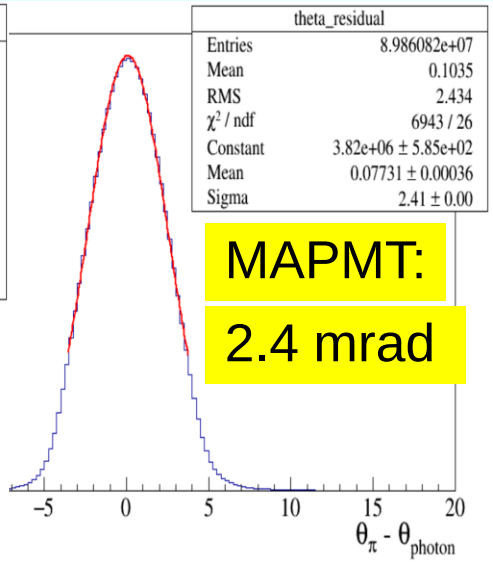


Single photon angular resolution







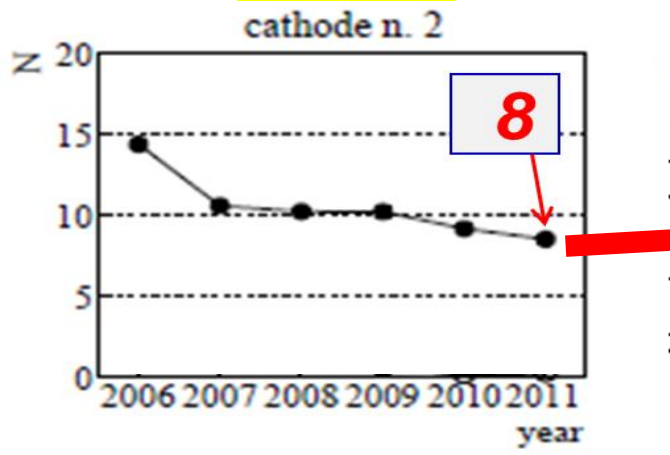


in terms of angular resolution the response of the new Hybrid detectors is similar but slightly superior to the MWPC one. MAPMT's have larger pads

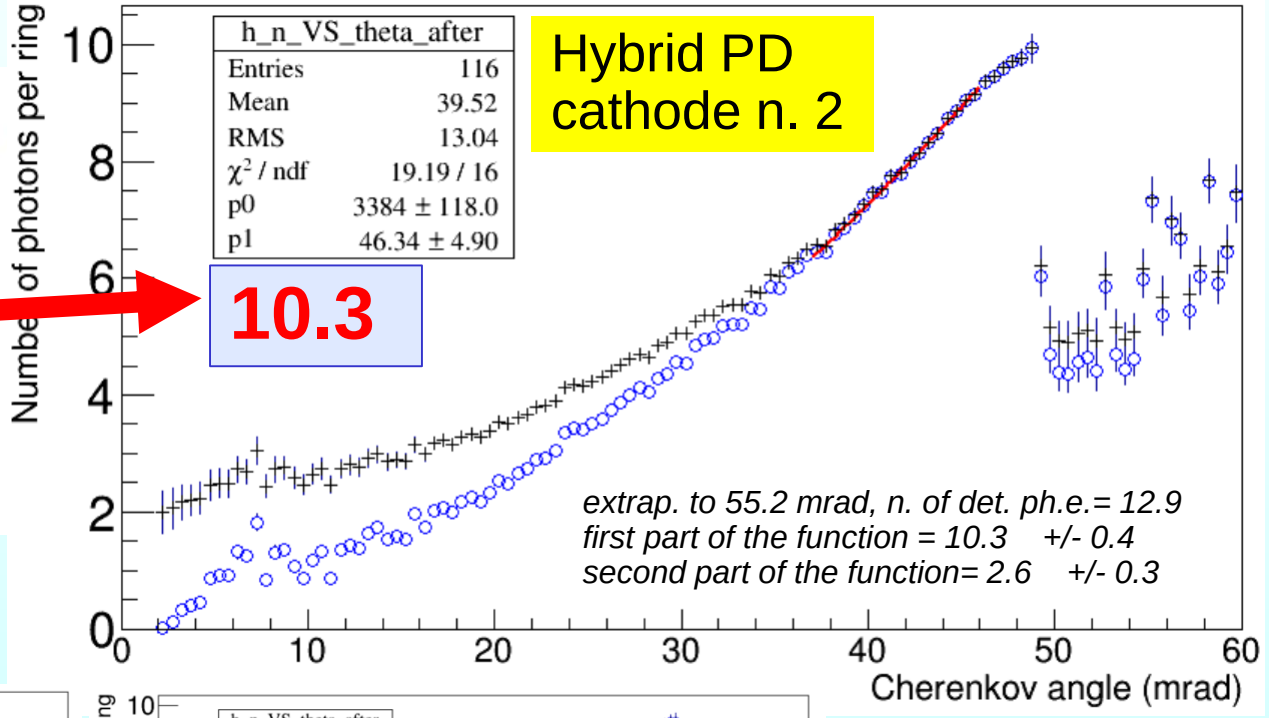
Number of detected photoelectrons per ring

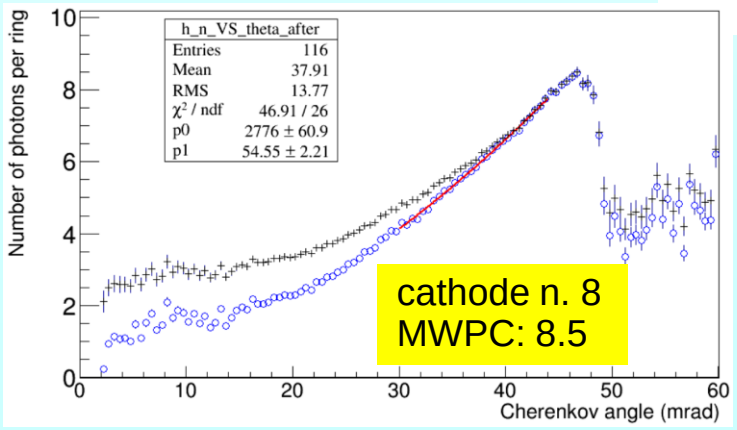
Critical chambers, have been changed from MWPC to Hybrid THGEM + Micromegas

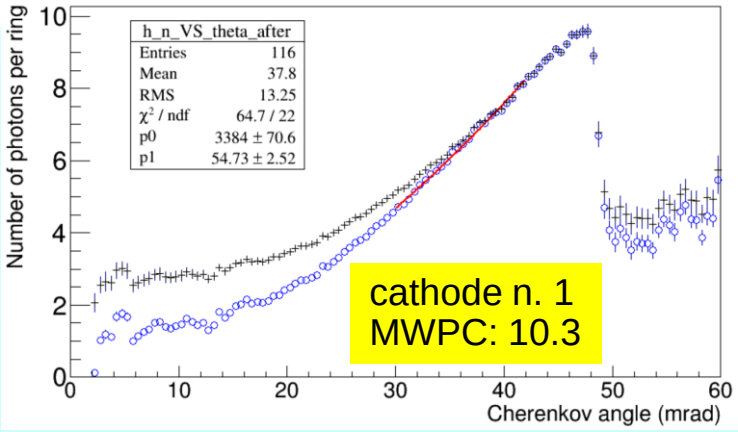
MWPC



the n. of det. ph.e. (55.2 mrad) in cathode n.2 was ~8 → 10.3







The number of detected photons per ring is in line with that of the good MWPC

Perspectives

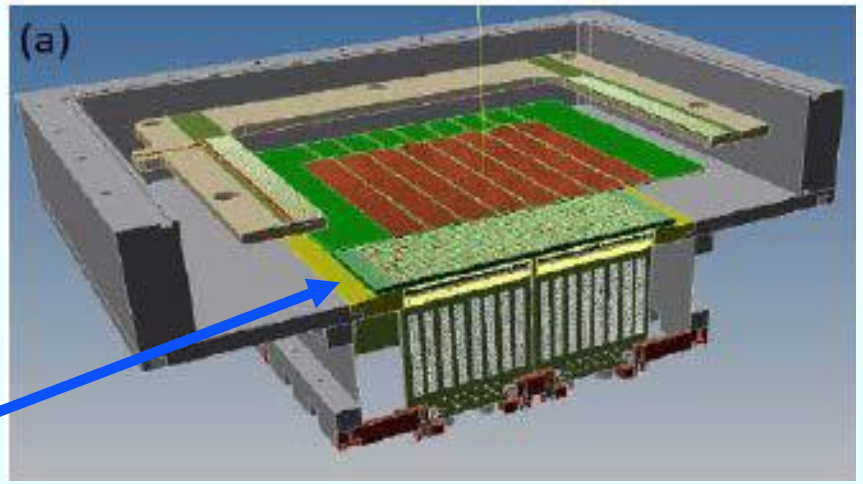
The characterization of the Hybrid PD performance in terms of PID is ongoing

The remaining MWPCs of COMPASS RICH-1 are likely to be replaced for 2021

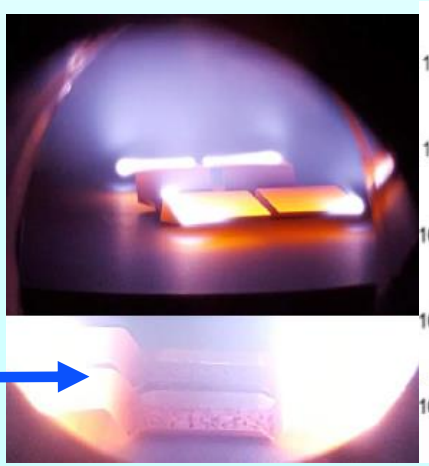
Development of an optimized detector for high space resolution based on the hybrid THGEM + MM and “mini-pads”

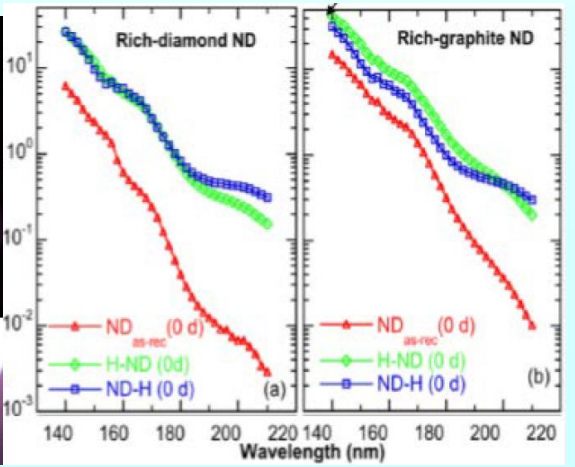
Study the compatibility of these hybrid PDs with CF_4 for a windowless RICH for the Electron Ion Collider

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



Talk by Shuddha Shankar Dasgupta



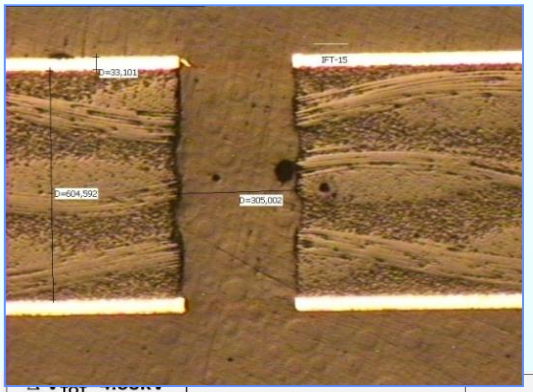


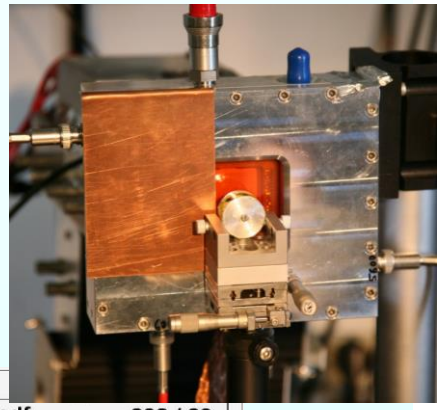
Poster by Chandradoy Chtterjee

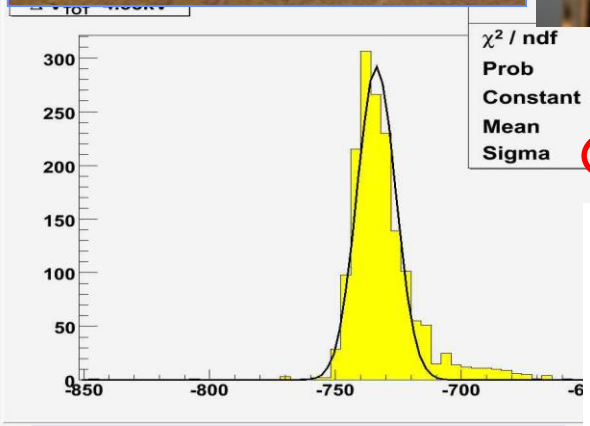
CONCLUSIONS

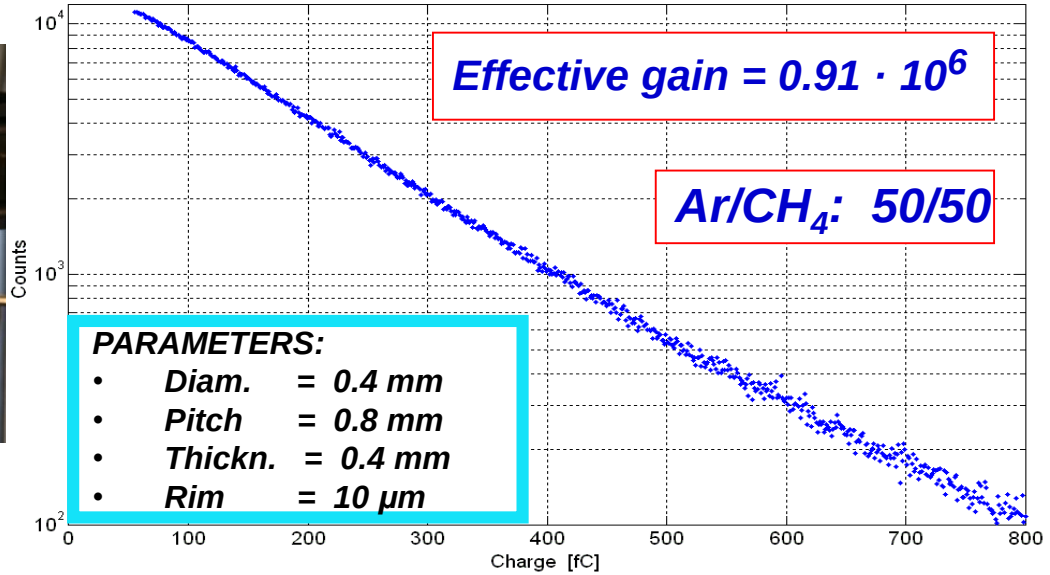
- **COMPASS RICH-1 has been upgraded with 1.4 m^2 of MPGD-based PDs.**
- **The Hybrid PD: 2 THGEMs (1 with CsI) + Micromegas are nicely operating.**
- **They present good gain uniformity and stability, low IBF and clean rings.**
- **1.85 mrad single photon angular resolution, 10 detected photons per ring.**
- **A full characterization of the PID performance is ongoing.**
- **More Hybrid PD's will probably be mounted on RICH-1.**
- **R&D for future RICH projects are considering the use of this technology.**

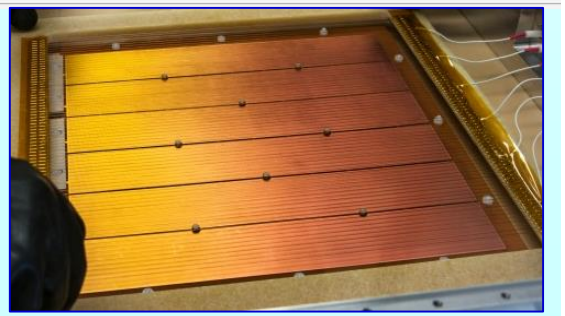
THGEM + CsI: 8 years of dedicated R&D

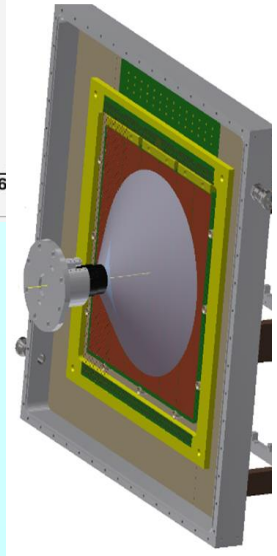


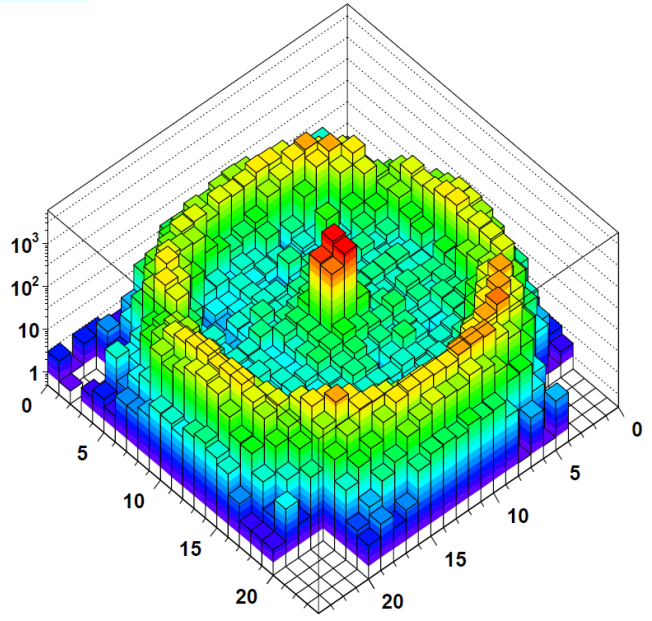




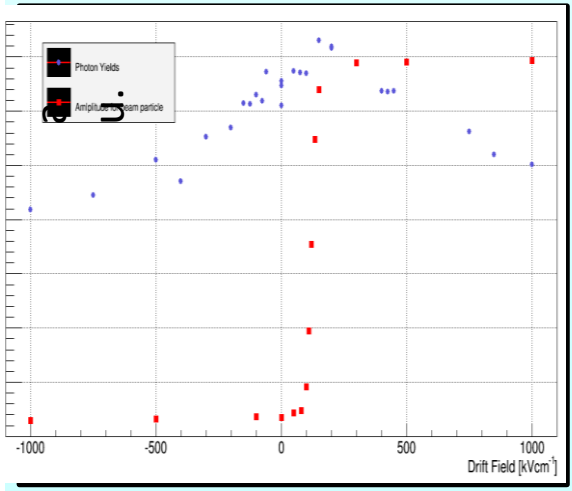






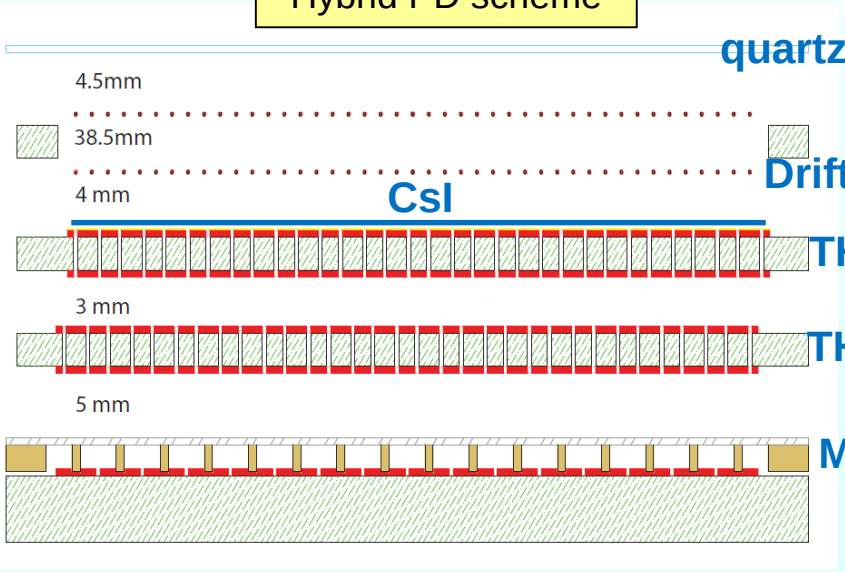


Photon yield & Charged Particles vs Drift Field

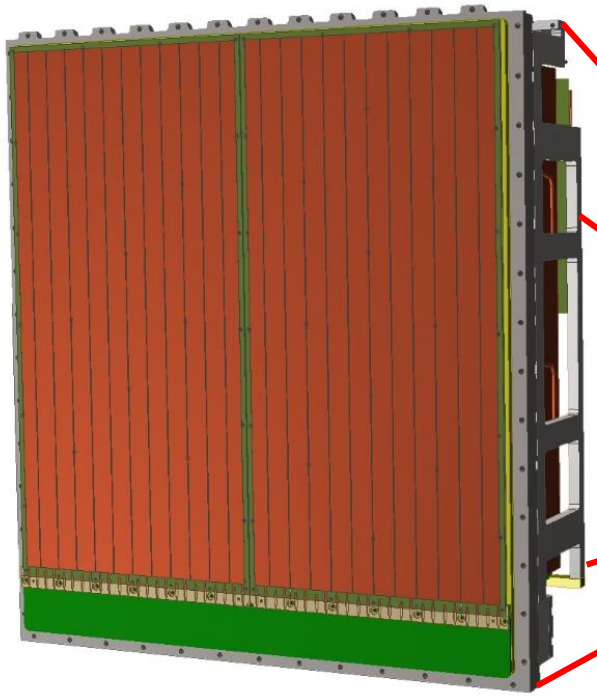


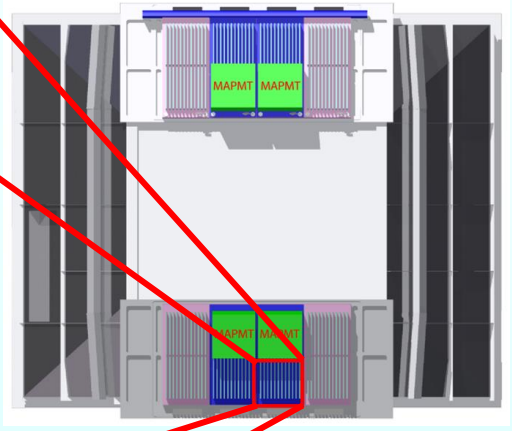
The hybrid THGEM+Micromegas PDs

Hybrid PD scheme

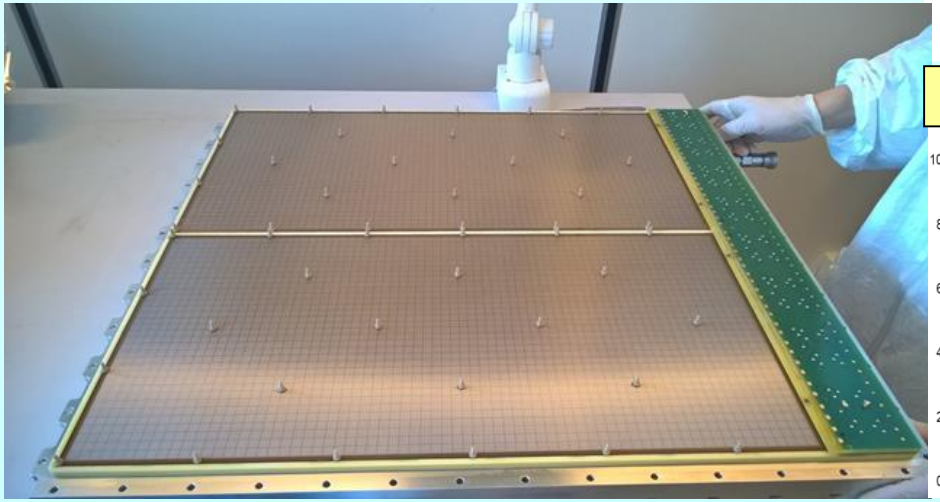


modular structure: one module = 600x300 mm^2

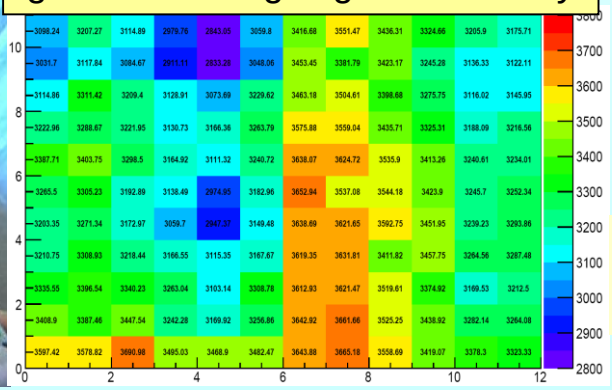


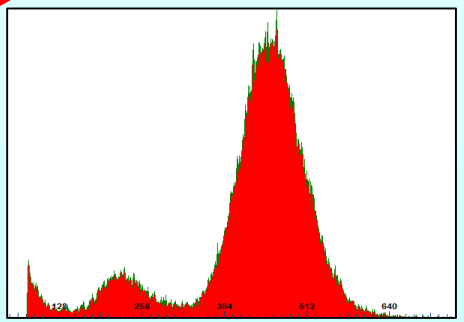


Standard Bulk Micromegas produced at CERN



good Micromegas gain uniformity

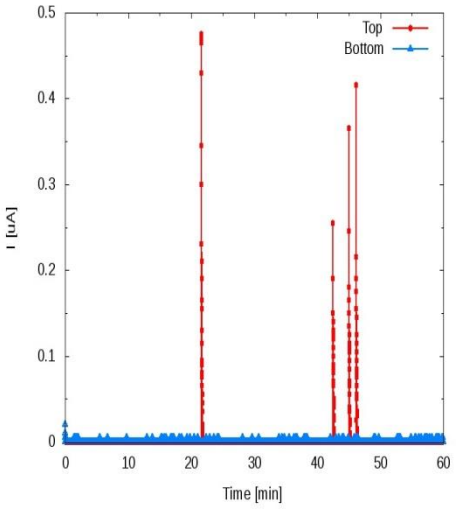




$$\delta_G = \frac{G_{max} - G_{min}}{G_{min}} < 5\ \%$$

THGEM quality assessment

current monitor recording, discharge counting

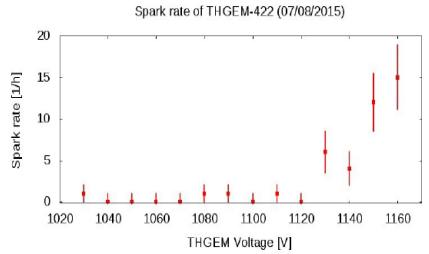


THGEM : 422

- dV=1000V : 4 hours : 0 sparks/h
- dV=1150V : 6 hours : 70 sparks/h

rejected

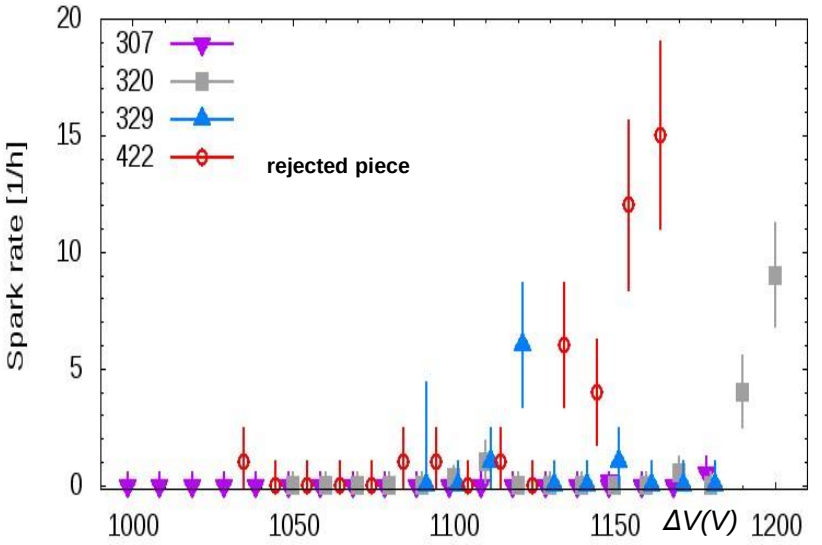
- dV=1030V .. 1160V / 10V steps , 1 hour for all dV



THGEM : 307

- dV=1100V : 74 hours : 0.27 sparks/h
- dV=1150V : 14 hours : 0.29 sparks/h

accepted

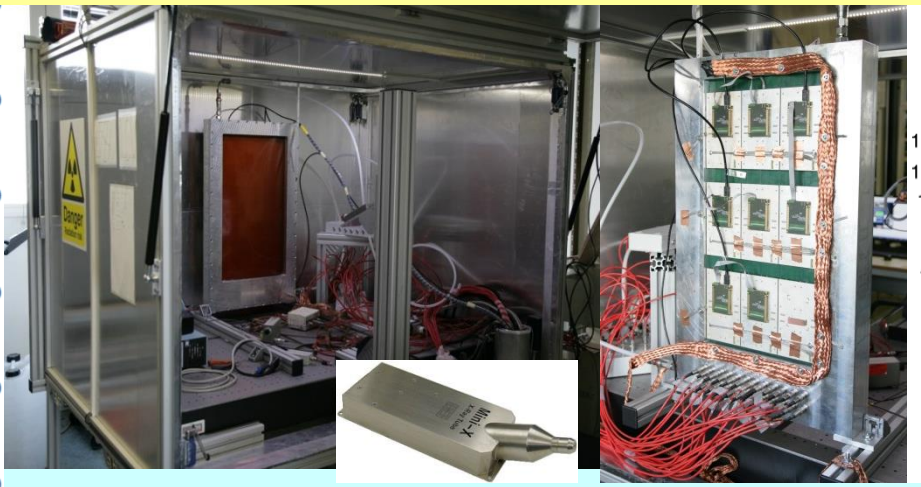


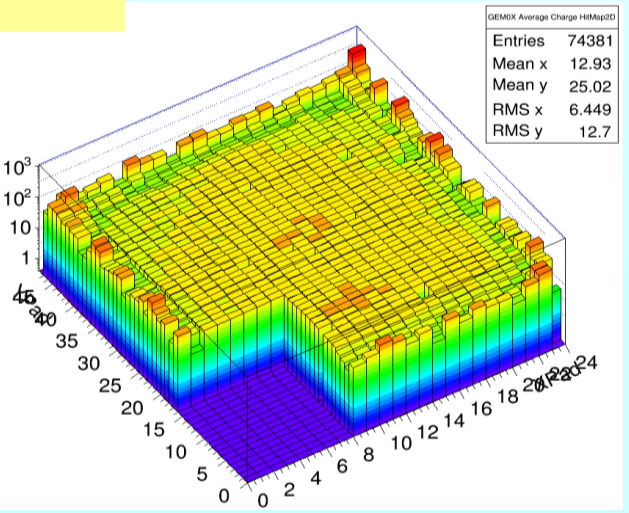
first 4 pieces: 1 rejected. Possibly recovered by repeating the cleaning treatment

Gain uniformity measurement

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

AMPTEK Mini-X Au used at 15 kV, 200μA + Cu foil provides 8 keV X-rays uniform illumination at a rate > 5 kHz cm^{-2} (for 1 cm Ar/CO$_2$ 70/30)



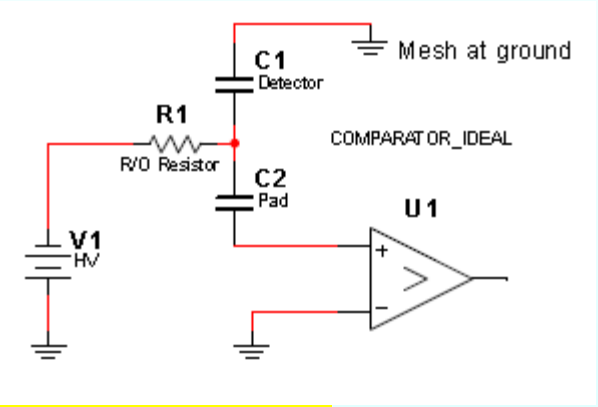


The anodic PCB

anodic pad PCB produced by TVR

8mm X 8mm pads at positive HV

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

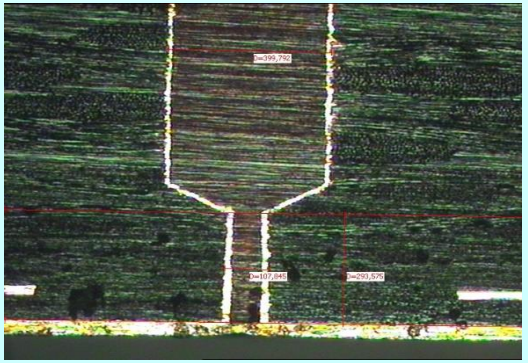


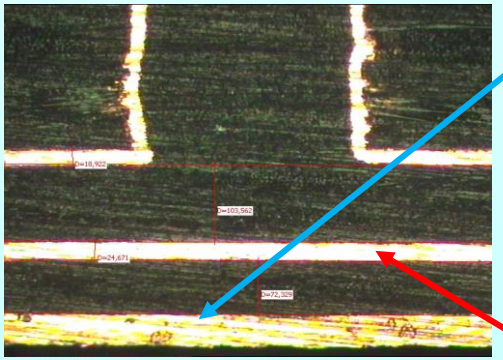
Strong technological effort from TVR Company for the PCB (multilayer 3.2 mm thick) to comply with specific requirements of planarity, surface quality, layer thickness uniformity, surface irregularities (E field).

Tests on 2500 pads: electrical continuity and capacity meas. → 38-42 pF/pad

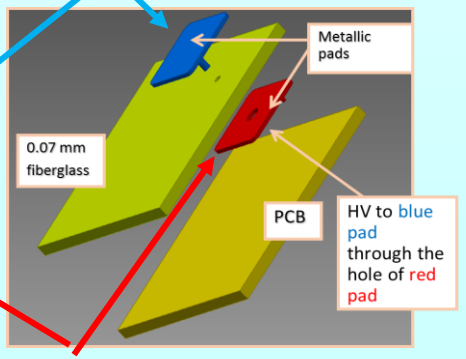
470 MΩ resistor for each anodic pad

"Z drilling controlled via" → planarity issue

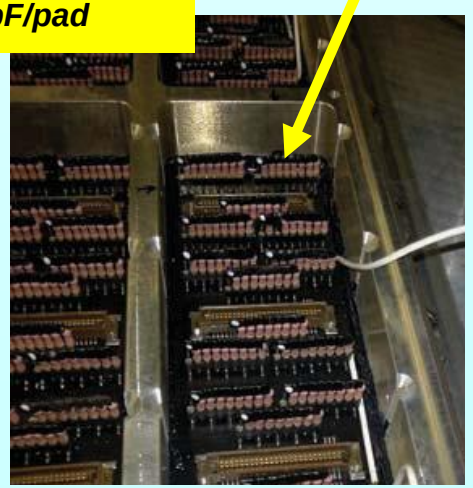




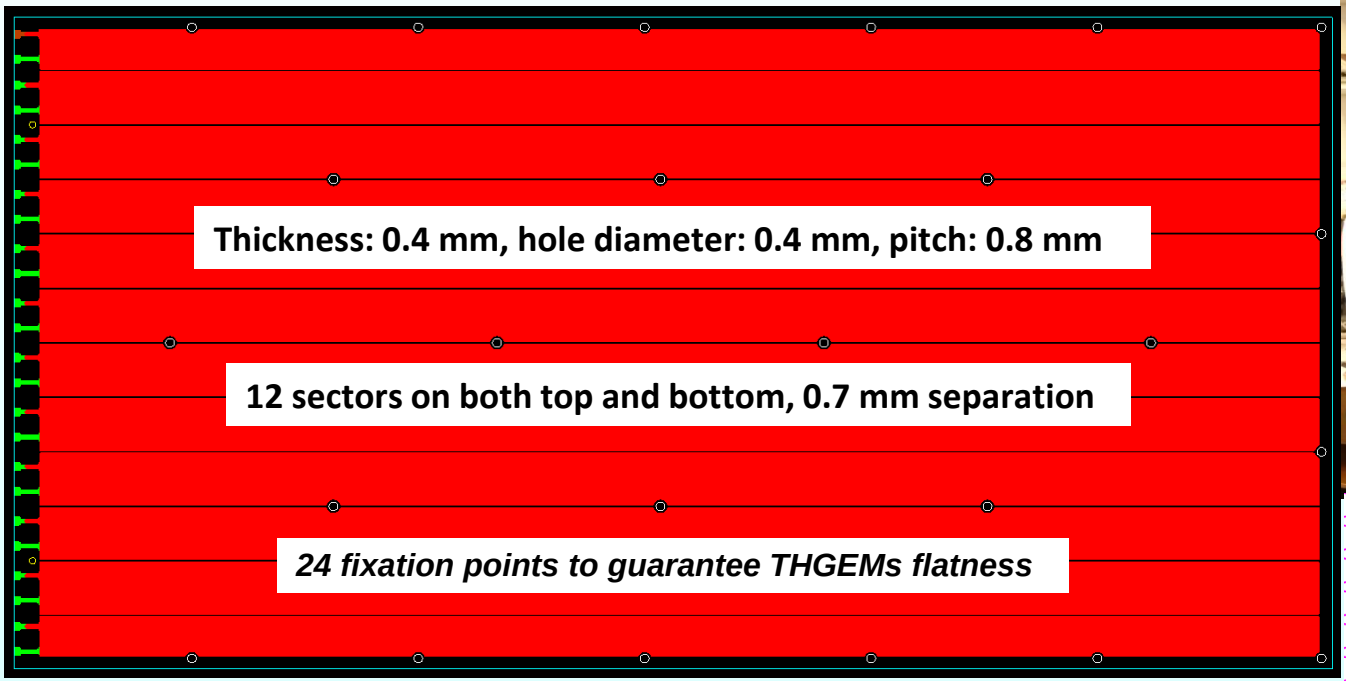
"surface anode" pad

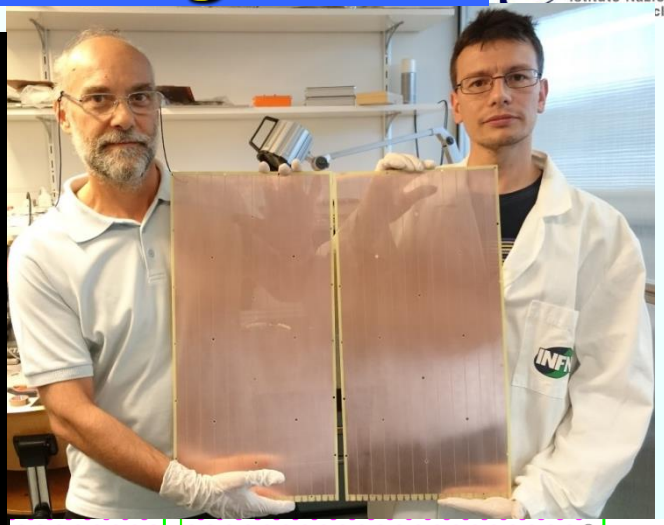


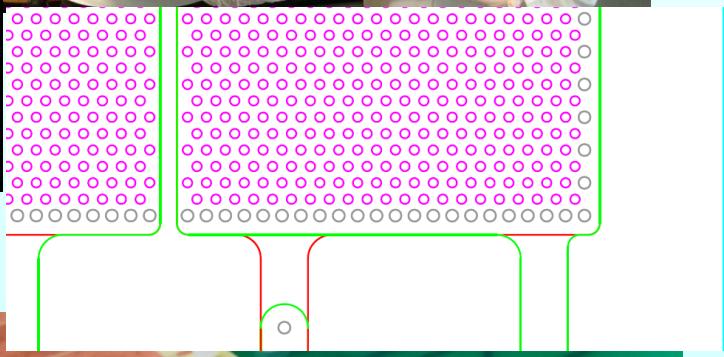
"buried pad"

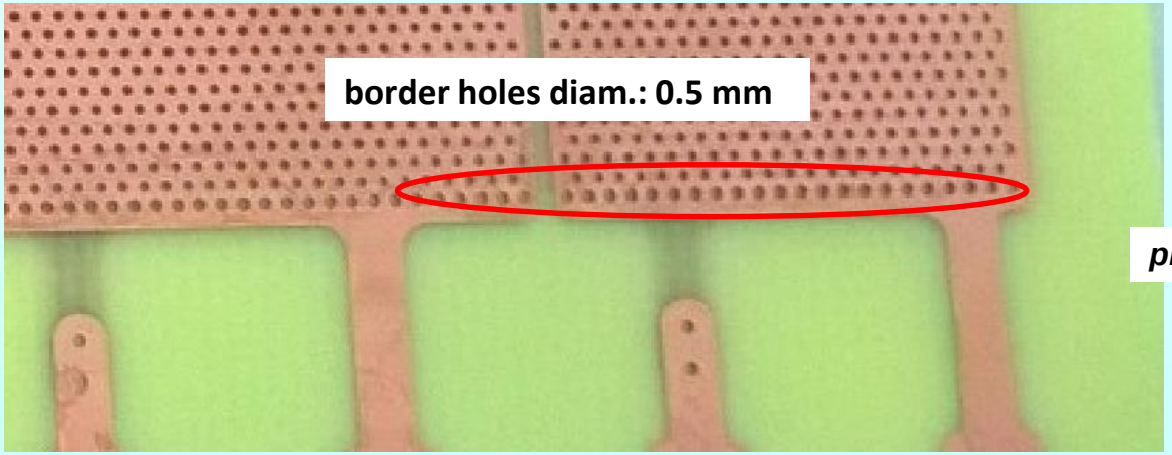


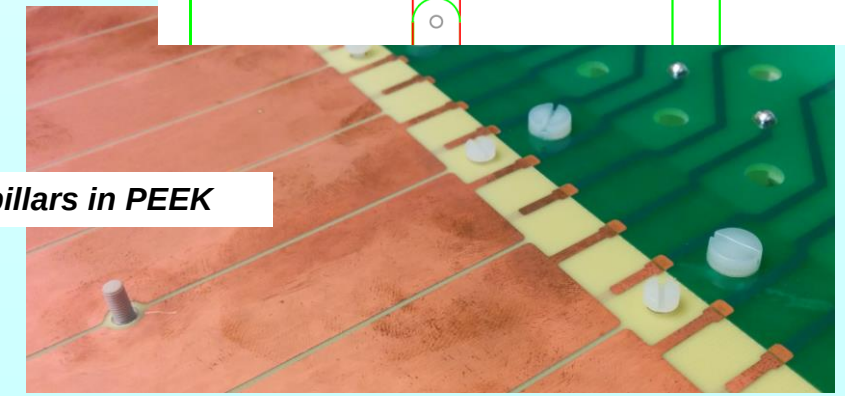
The COMPASS THGEM design











THGEM raw material selection

Our thickness uniformity requirements are stricter than those offered by producers → material selection

50 foils of 1245 mm x 1092 mm → cut out borders → 800 mm x 800 mm → thickness measurement

Elite Material Co., Ltd. Technical Data
http:\\www.emctw.com

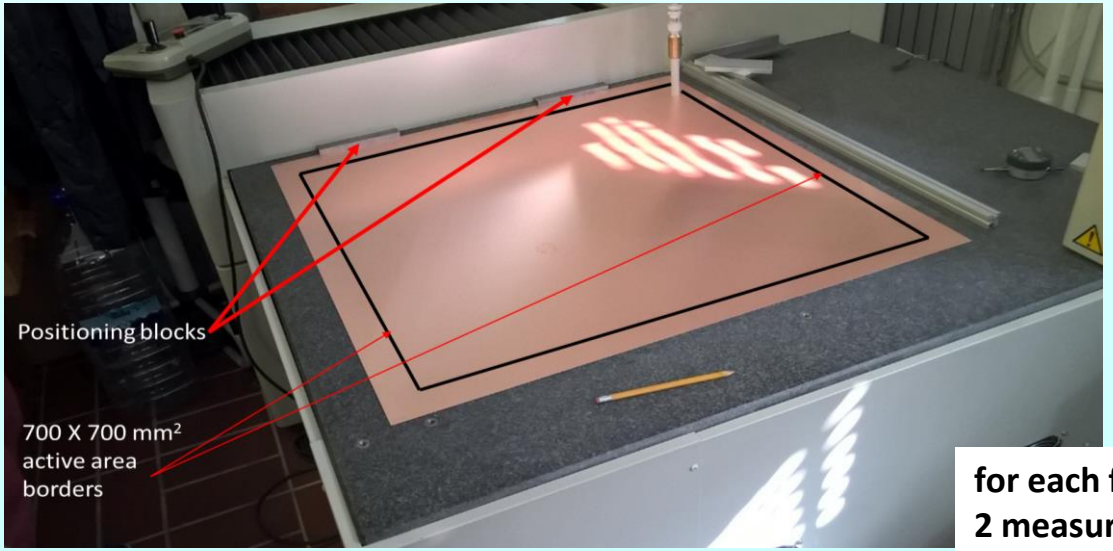
Lead-free , Halogen-free Material

PRODUCT				EM 370-5	
Thickness				0.407 mm	
Copper				35µ / 35µ	
Sheet Size				1 245 x 1 092 mm	
Permittivity (RC 50%)	1 MHz	2.5.5.9	C-24/23/50	–	4.8
	1 GHz			–	4.3
Volume resistivity		2.5.17.1	C-96/35/90	MΩ-cm	$>10^{10}$
Surface resistivity		2.5.17.1	C-96/35/90	MΩ	$>10^{9}$

Mitutoyo EURO CA776

coordinate measuring machine with ruby touch probe,

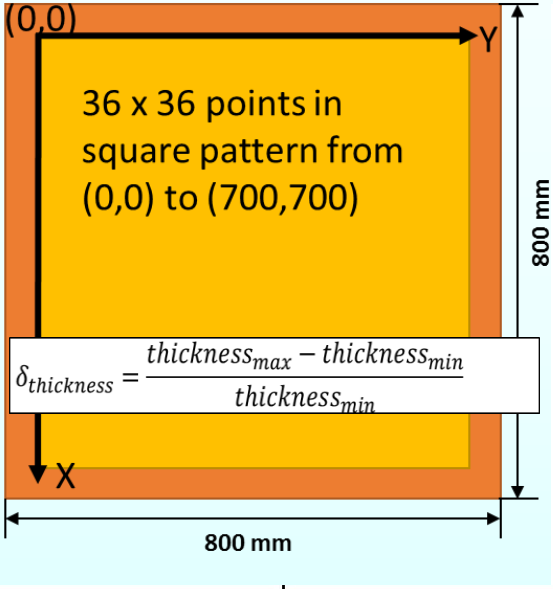
hosted in a thermalized room

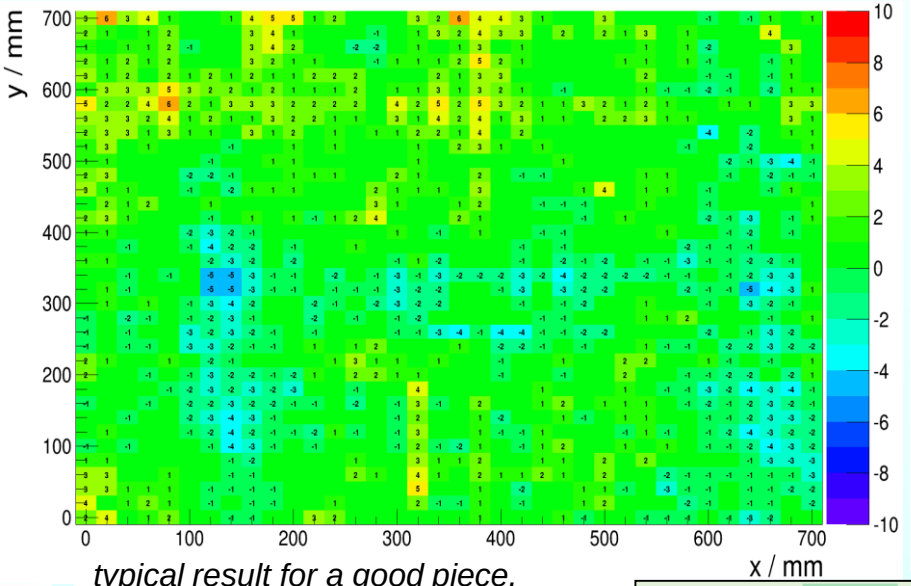


underpressure induced flatness

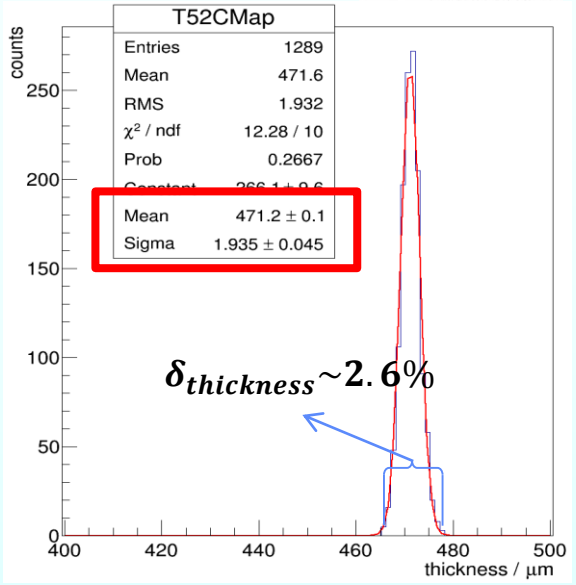
for each foil 36 x 36 points in square pattern are measured
2 measurements (direct and reversed) to allow consistency checks.

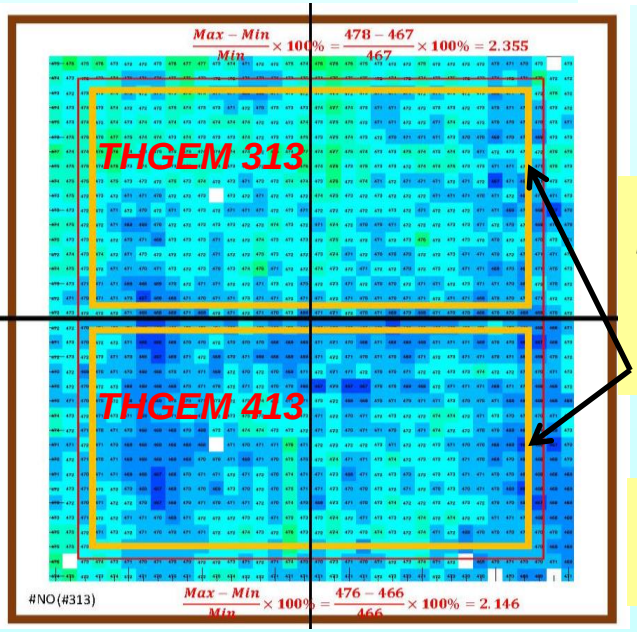
THGEM raw material selection





typical result for a good piece.





all foils have been labelled and measured → database of local thickness of all THGEMS

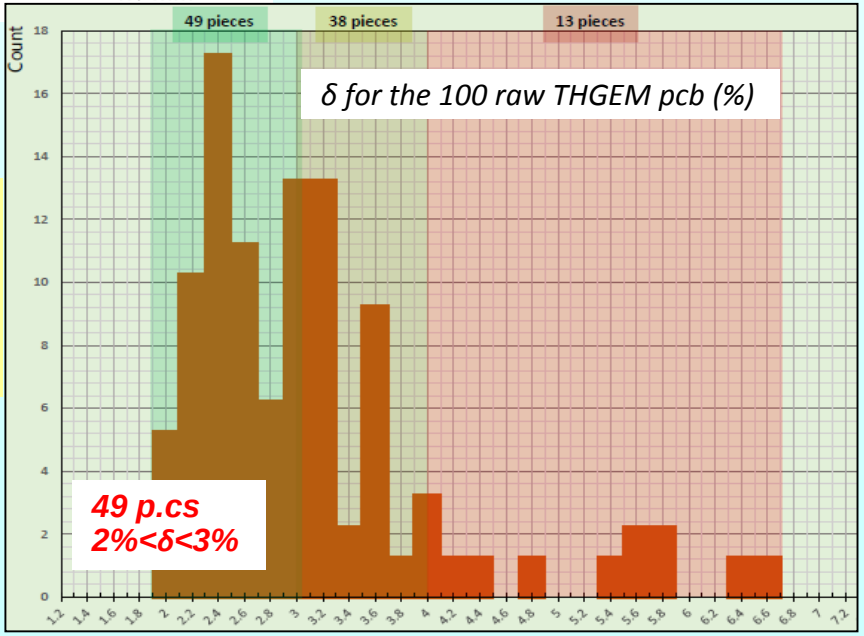
from each foil twoTHGEMS can be produced:

50 foils → 100 raw THGEM pcb

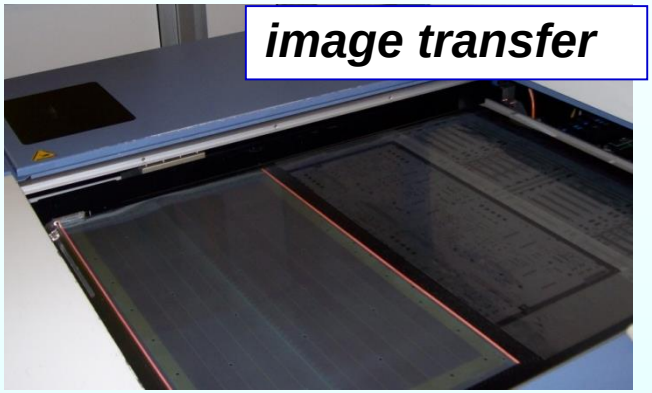
THGEM pcb size = 620 mm x 320 mm,

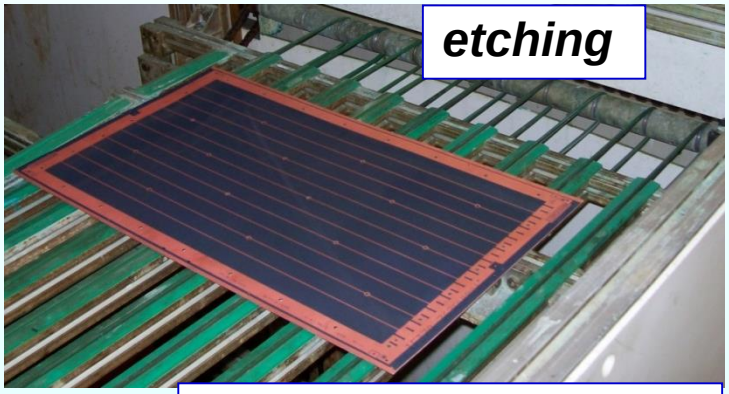
active area = 581 mm x 287 mm

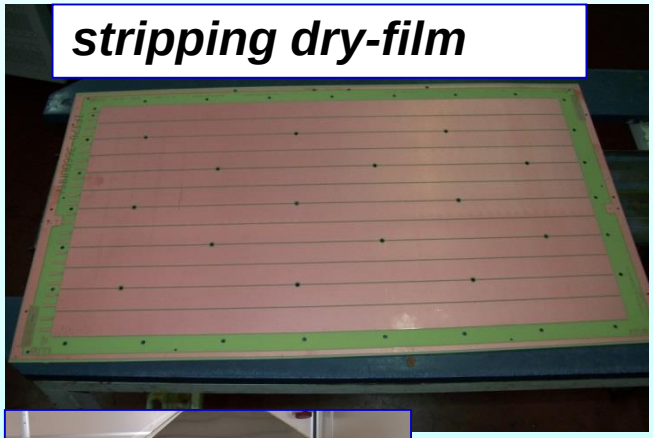
60 THGEMs have been produced by ELTOS

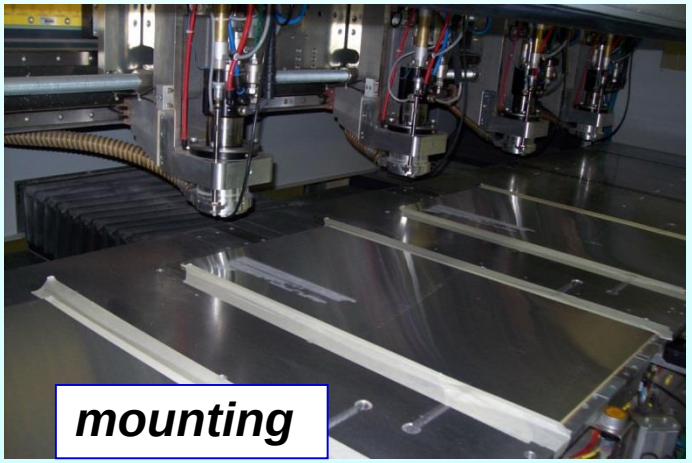


Production of the THGEMs at ELTOS

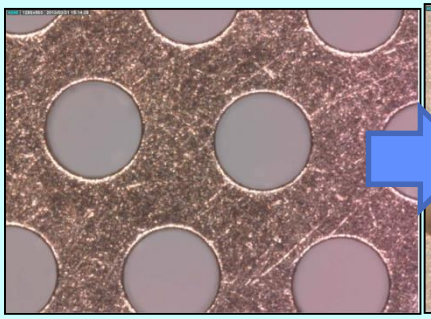


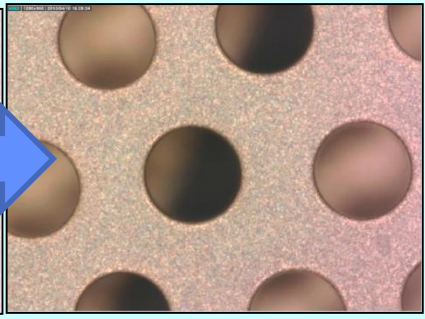






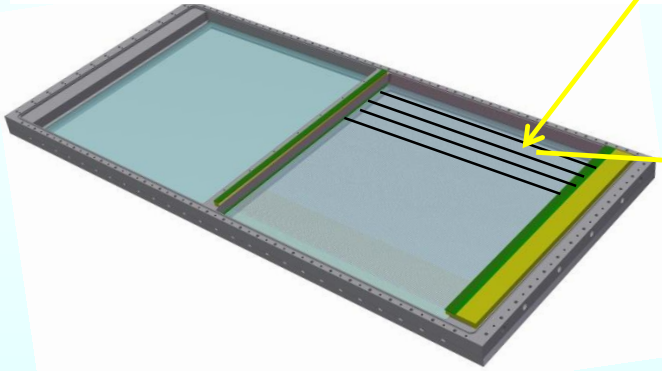
In Trieste a specific cleaning procedure is applied : polish with fine grain pumice powder, pressure water cleaning, ultrasonic Bath with Sonica PCB solution (PH11), distilled water rinsing and oven @ 160 ºC

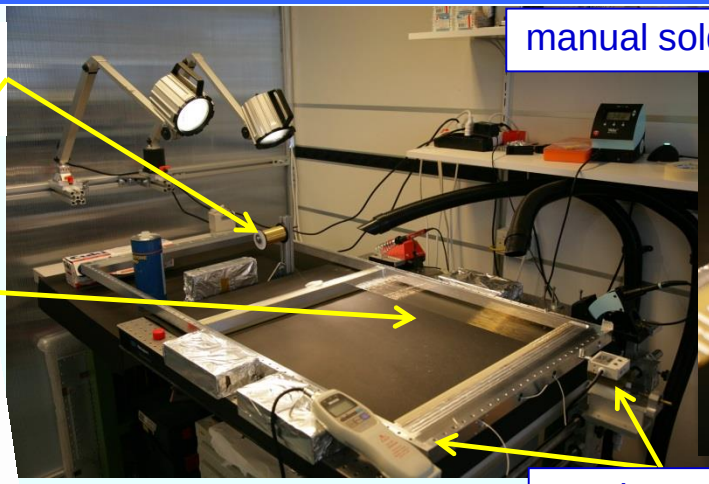




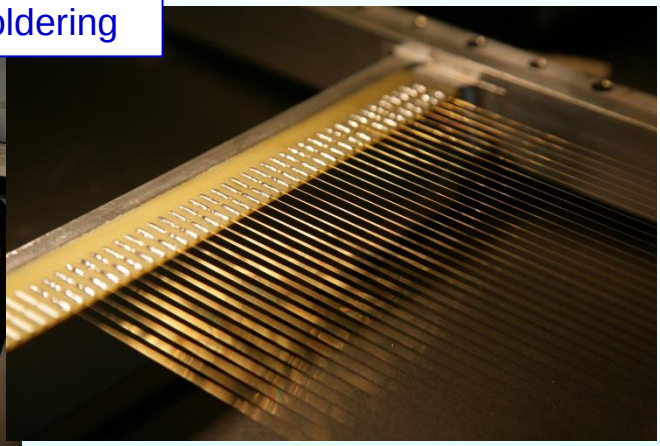
mechanical frames and wires

drift and field wires: Cu-Be, Au coated
4 mm pitch, 100 µm diam.

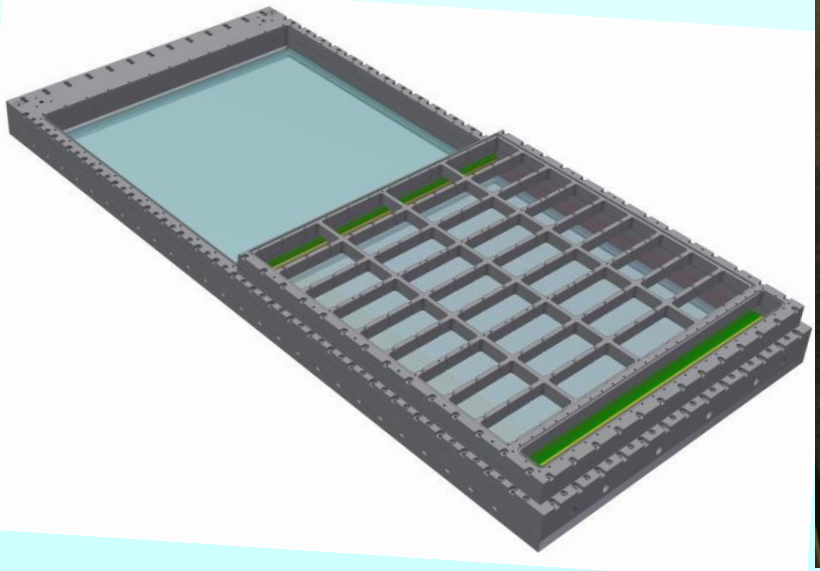


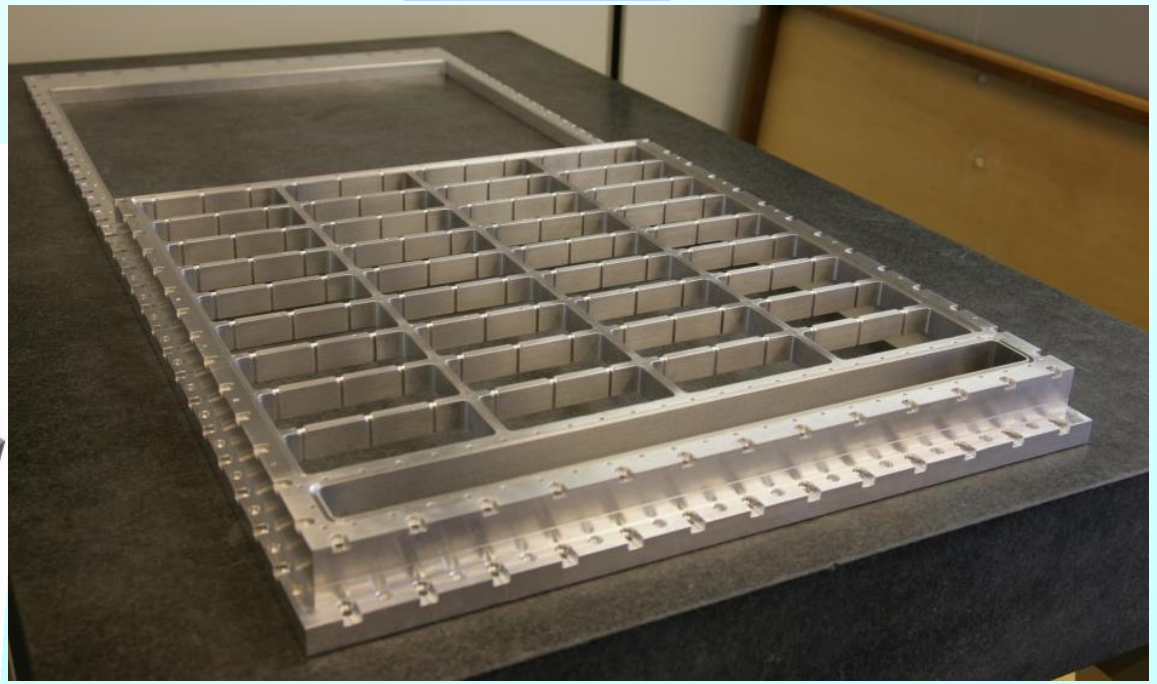


manual soldering



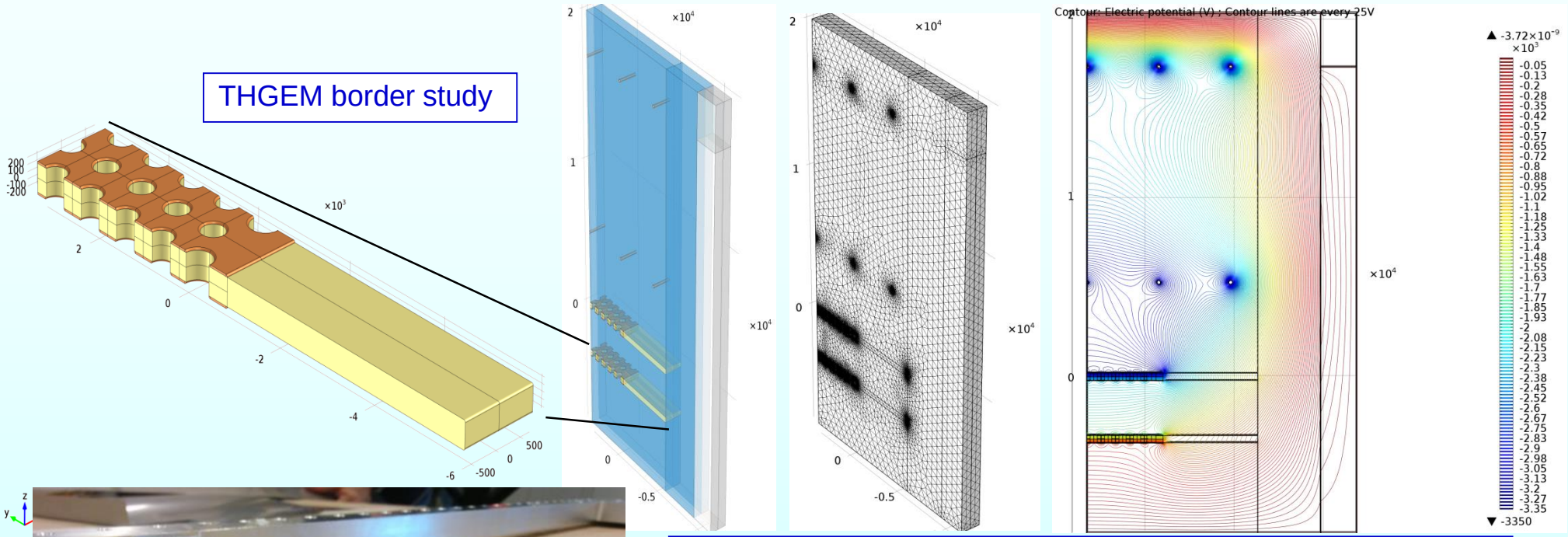
tension meter



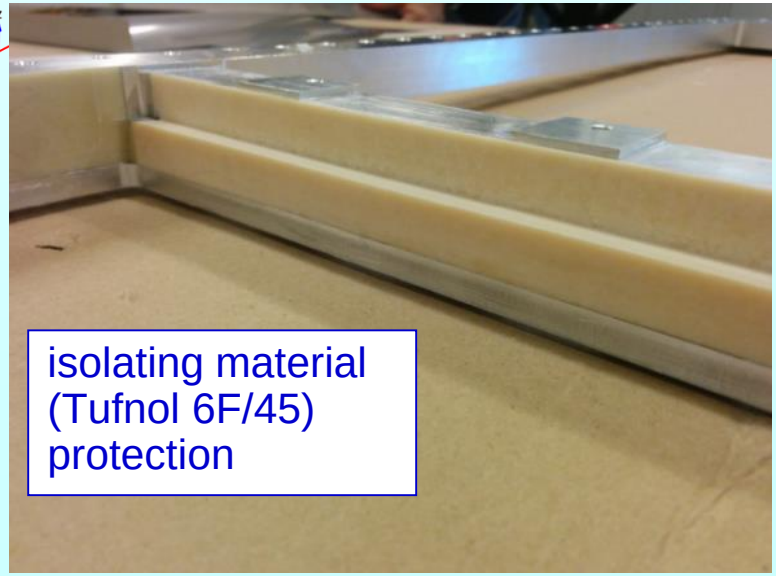


field shaping electrodes

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