Status and progress of the novel photon detectors based on THGEM and hybrid MPGD architectures

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on behalf of the COMPASS THGEM group:

Alessandria, Aveiro, Calcutta, Freiburg, Liberec, Prague, Torino, Trieste

Introduction

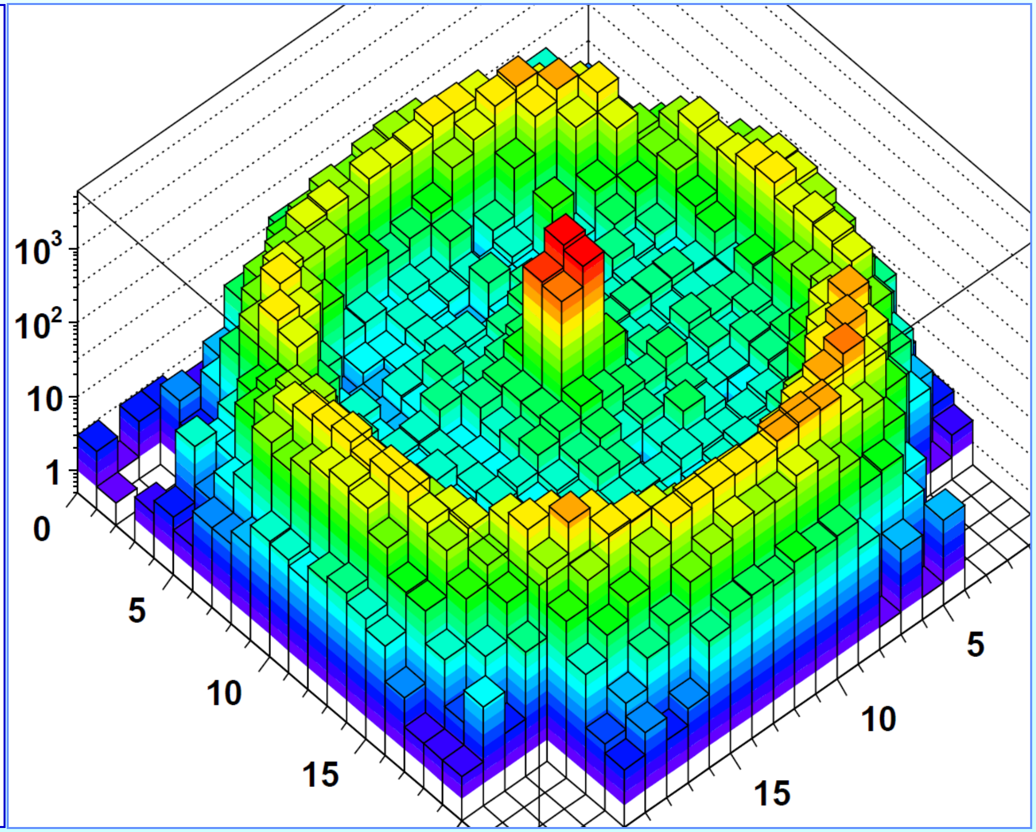
Small prototypes of THGEM-based PD's

The ion backflow reduction

Production issues for large THGEMs

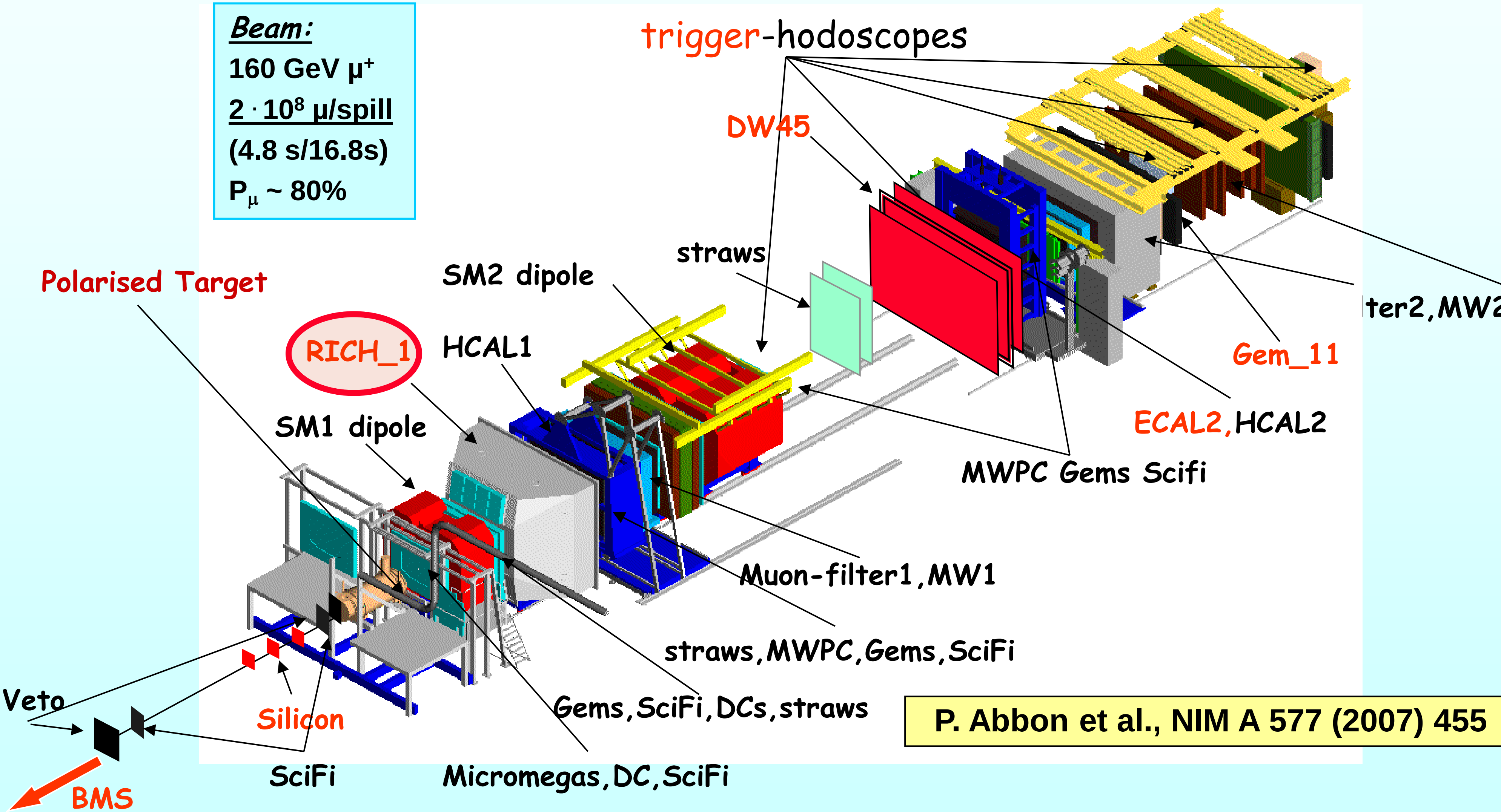
Hybrid THGEM+Micromegas PD's

Conclusions



IN THE COMPASS SPECTROMETER

Beam:
160 GeV μ^+
$2 \cdot 10^8$ μ/spill
(4.8 s/16.8s)
P_μ ~ 80%



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

HADRON PID IS PROVIDED BY RICH-1

COMPASS RICH-1: a large gaseous RICH with two kind of photon detectors providing:

hadron PID from 3 to 60 GeV/c

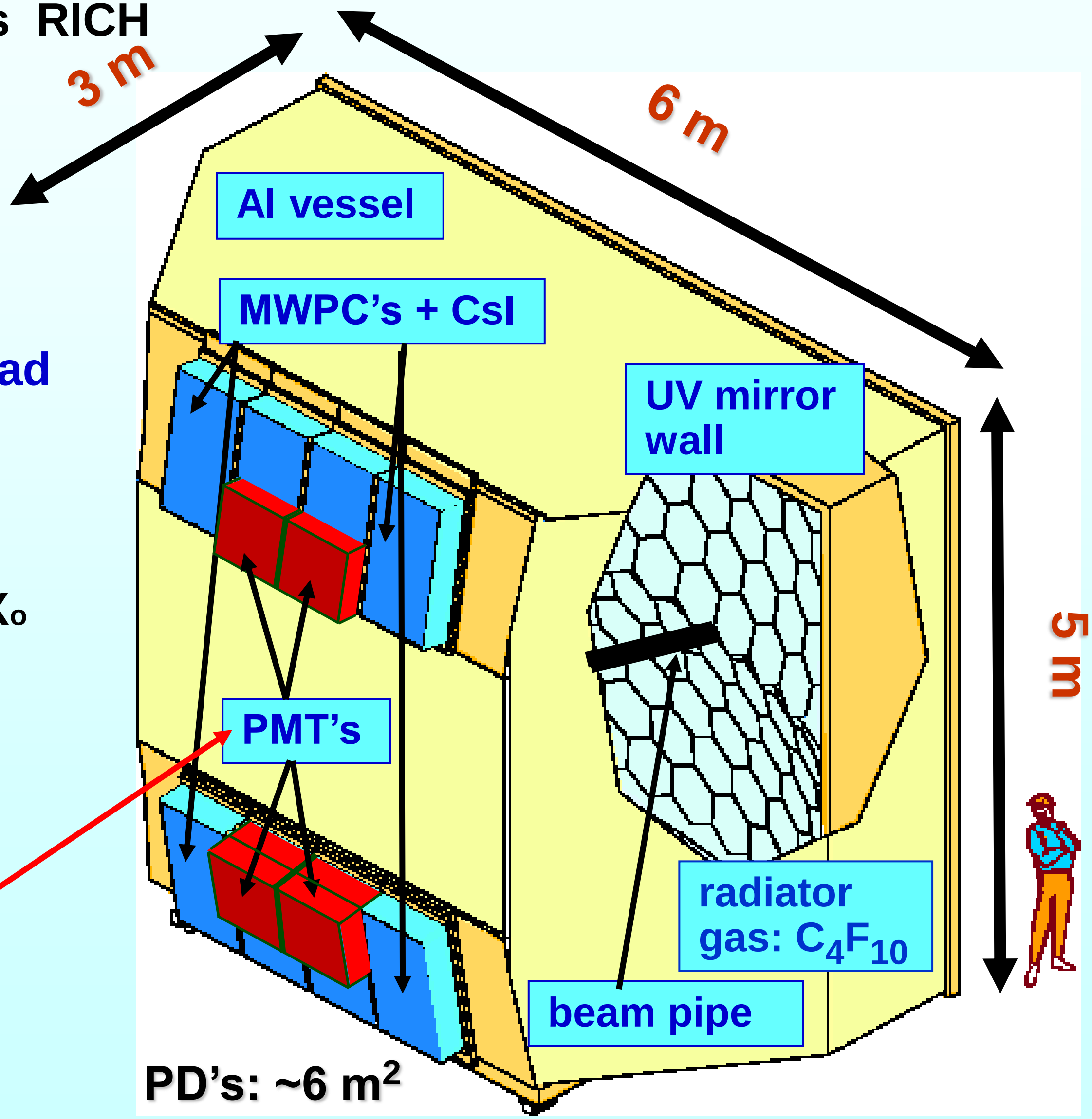
acceptance: H: 500 mrad V: 400 mrad

trigger rates: up to ~100 KHz
beam rates up to ~10^8 Hz

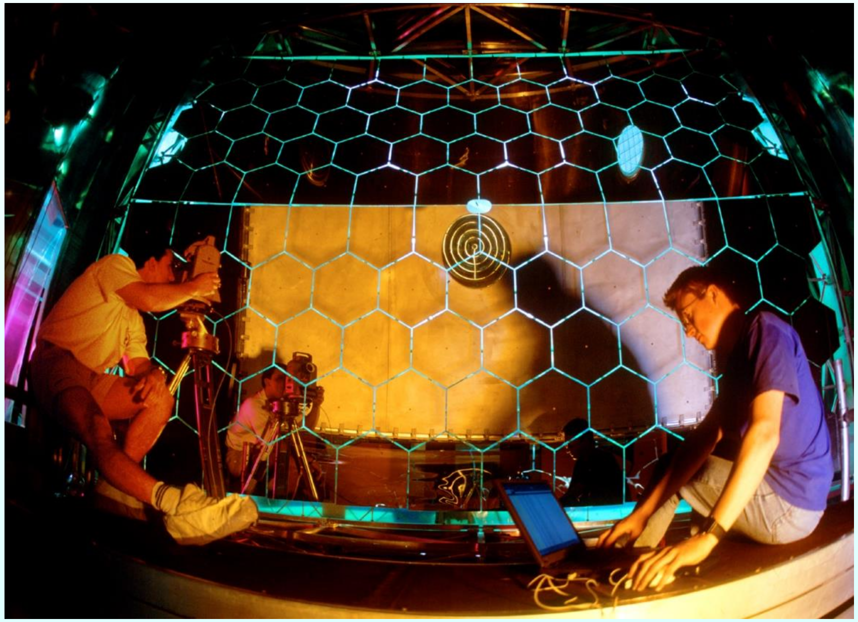
material in the beam region: 2.4% X_o
material in the acceptance: 22% X_o

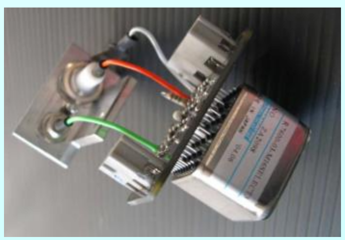
detector designed in 1996
in operation since 2002
first PD upgrade in 2006

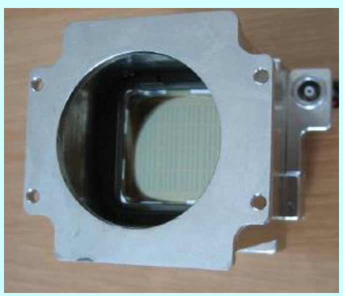
(total investment: ~ 4 M€)

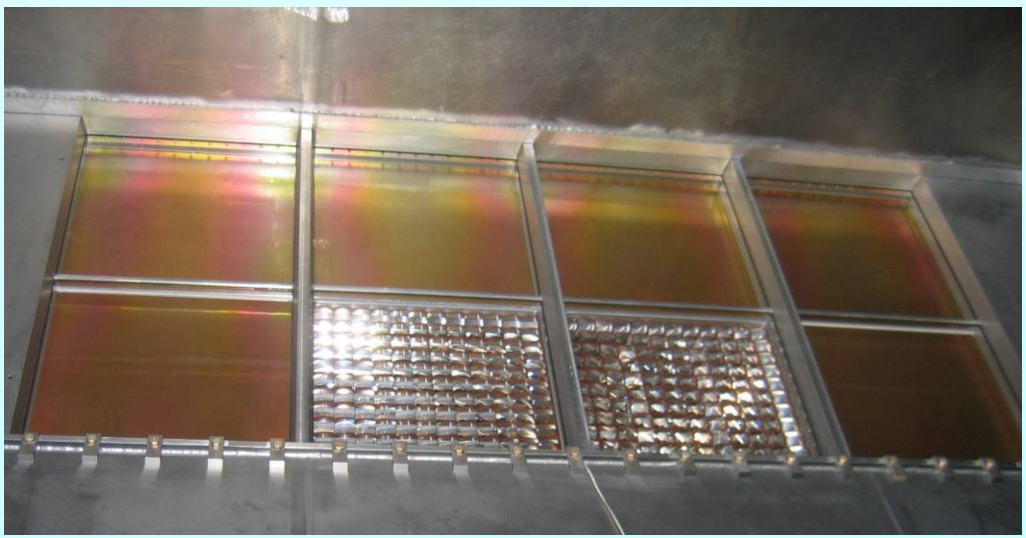


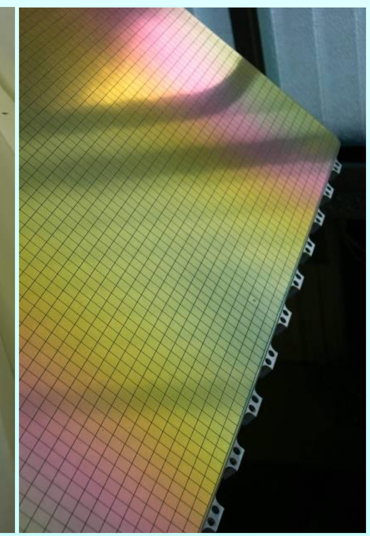
Gas radiator, mirrors, PD's





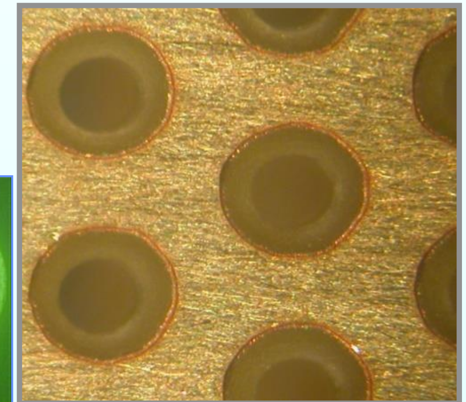


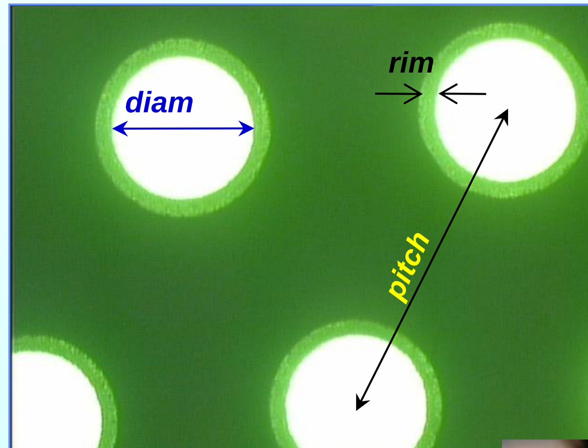




COMPASS THGEM R&D

Five years ago we started an R&D program to develop a large size, cheap, robust, fast, high gain, high rate, magnetic insensitive single photon detector for RICH applications, based on THGEM and reflective CsI photocathode.



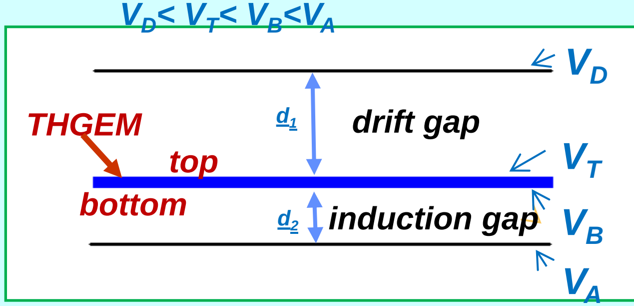


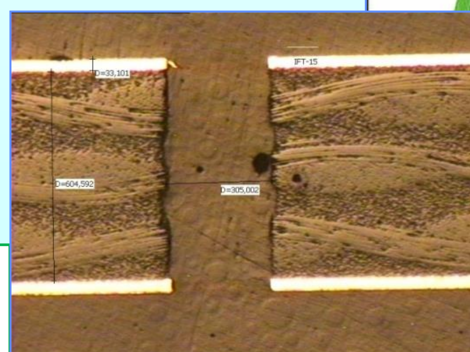
THGEM's with 30 x 30 mm^2 active area

MULTI-DIMENSIONAL SPACE:

- Isolating substrate material
- Thickness
- Hole diameter
- Pitch
- Rim size
- Holes and rim production procedure
- Induction field
- Drift field
- Geometrical arrangement
- Gas mixture

To detect ionizing particle :
$V_D < V_T < V_B < V_A$

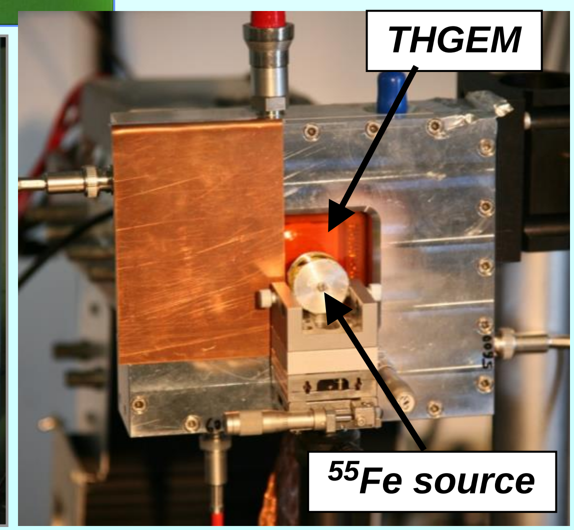




$$E_{drift} = (V_D - V_T)/d_1$$

$$E_{induction} = (V_B - V_A)/d_2$$

$$\Delta V = V_T - V_B$$



THGEM characterization

About 50 different THGEM types have been characterized using X-ray:

- ***optimized drift field (specific for each type)***
- ***large rim → large gain but good gain stability guaranteed for small rim or no rim***
- ***production procedure details are very important***
- ***good rate capability***

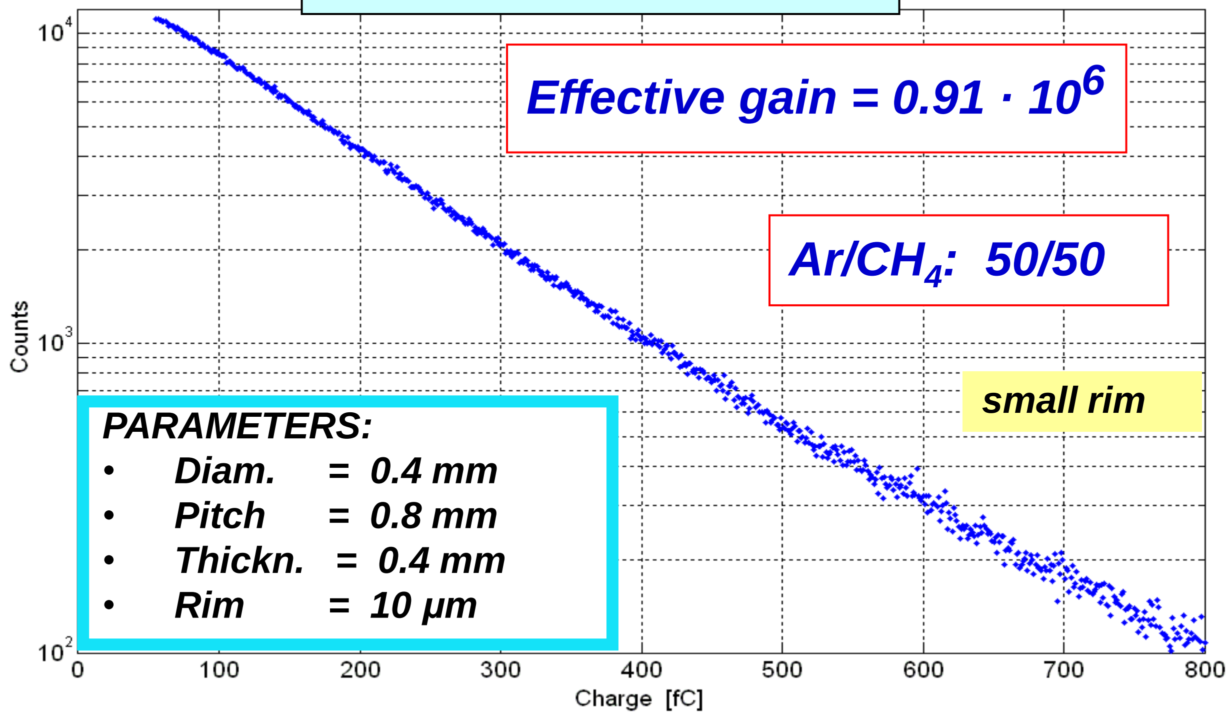
Using UV light sources we investigated:

- ***photoelectron extraction and collection efficiency,***
- ***timing properties of the signal (using 600 ps long light pulses)***
- ***photoelectron detection efficiency with digital r/o***

Several prototypes of small THGEM-based PD's have been built and tested.

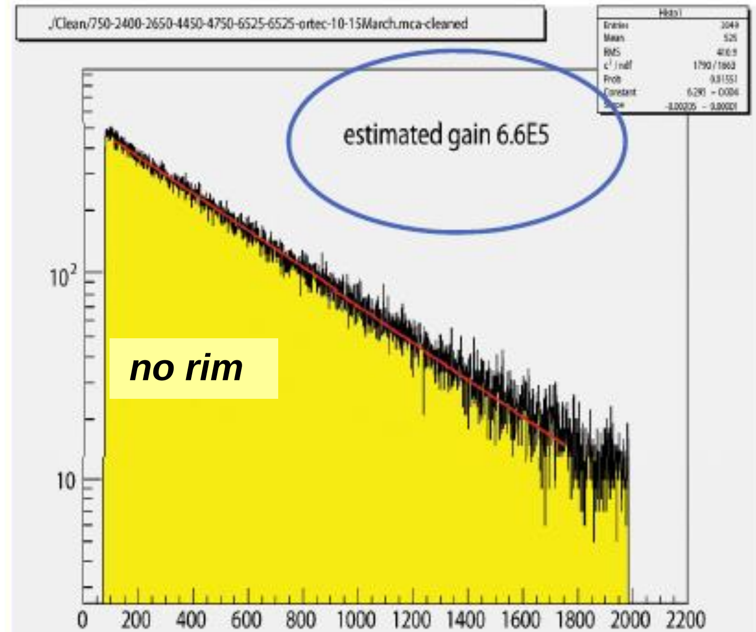
Gain around 1 M, time resolution ~ 8 ns

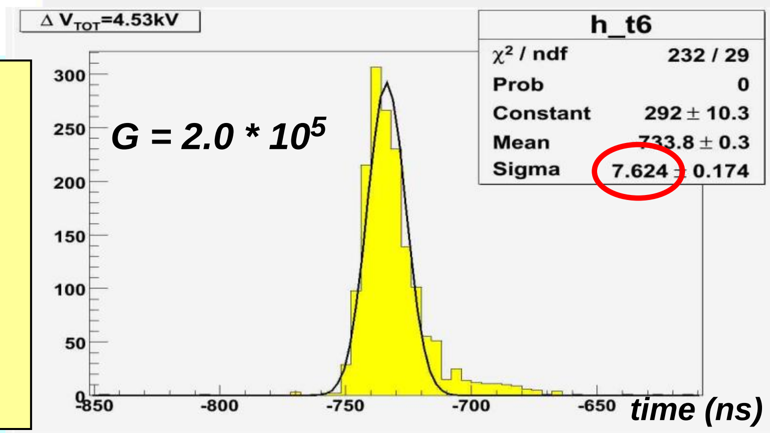
Triple THGEM



■ 3 layers:

hole diameter	0.4 mm
pitch	0.8 mm
thickness	0.8 mm
rim	0





Small size PD's (active area = 30x30 mm^2):

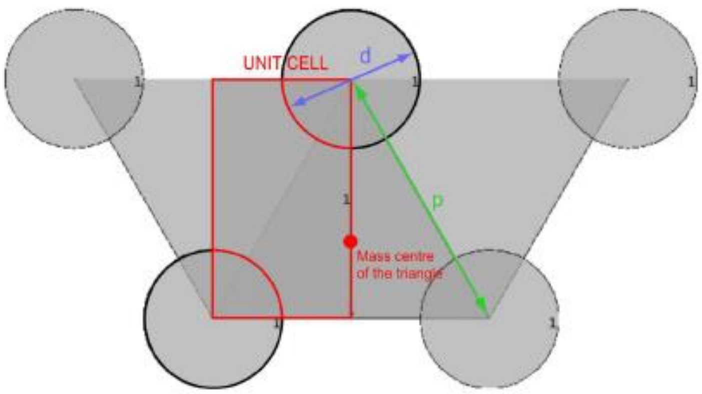
typical max. stable gain: **with UV light in lab: 1 M**
during test beam: 0.2 M

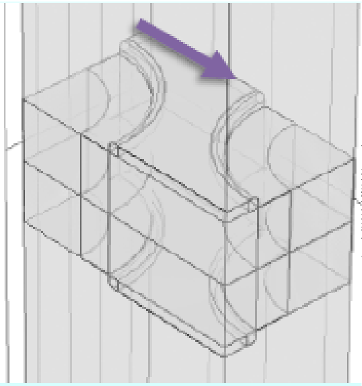
efficient detection of single photons

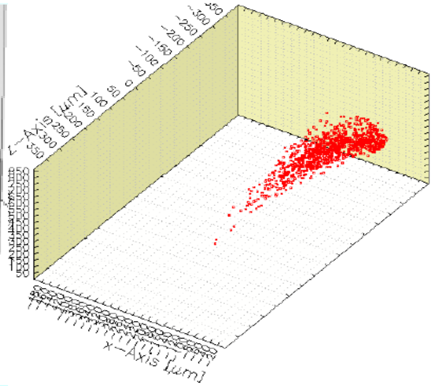
signal formation time ≈ 100 ns, time resolution ≈ 8 ns

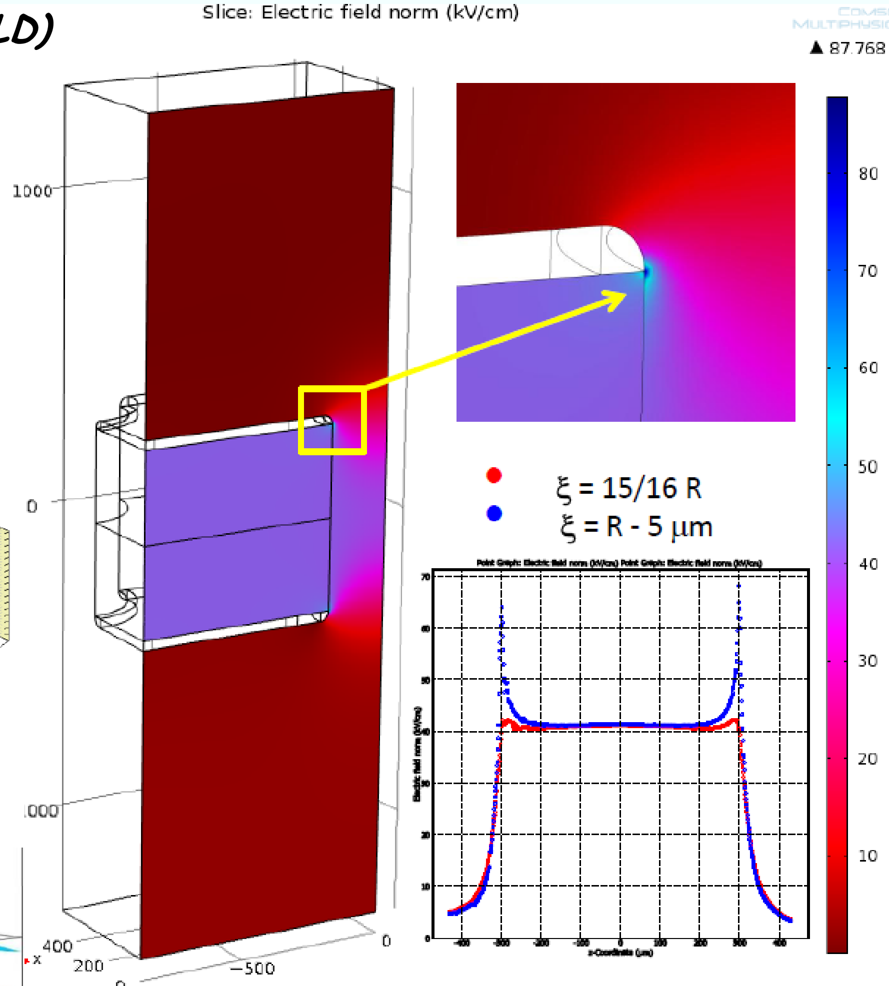
electrostatic calculations (and simulations)

COMSOL and ANSYS (and GARFIELD)

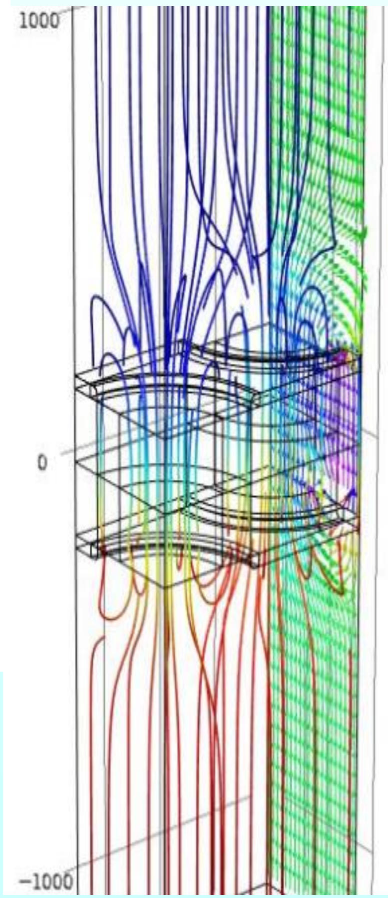


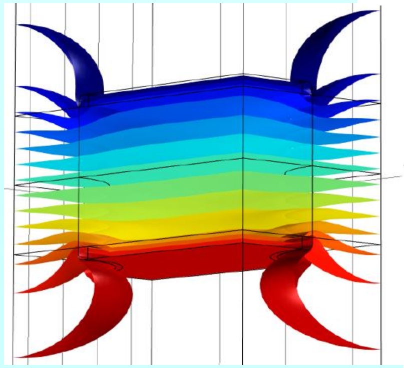


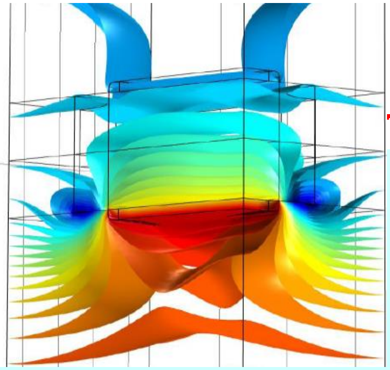




Small "reversed drift bias" provides an inversion of drift field direction: mip suppression.







equipotential surfaces are modified by the presence of a charge on the THGEM rim surface. ***See poster by P.M.M. Correia***

for GEMs, see the nice article by

M. Alfonsi et al, NIM A 671 (2012) 6

We concluded that

In order to achieve a good photoelectron extraction efficiency we need:

- *high value of the electric field at the CsI surface (>1 kV/cm)*
- *a methane-rich gas mixture to reduce backscattering (> 30% CH_4)*

Reasonable geometrical parameters for our application are:

- *THGEM_1 (with CsI): thickn. = 0.4 mm, hole diam. = 0.4 mm, pitch = 0.8 mm*
- *THGEM_2 and THGEM_3: thickn. = 0.8 mm, hole diam. = 0.4 mm, pitch = 0.8 mm*

Predictable detector response is provided by choosing rim size < 10 µm

Practical issues:

- *THGEMs can be produced by industry (ELTOS Company in Italy, for instance)*
- *The price is moderate: 1000 holes/Euro.*

The response may vary a bit from piece to piece, but is stable and reproducible.

The ion backflow to the CsI is an important item

IBF, needs and goals

in the COMPASS RICH-1 environment:

NOW FUTURE

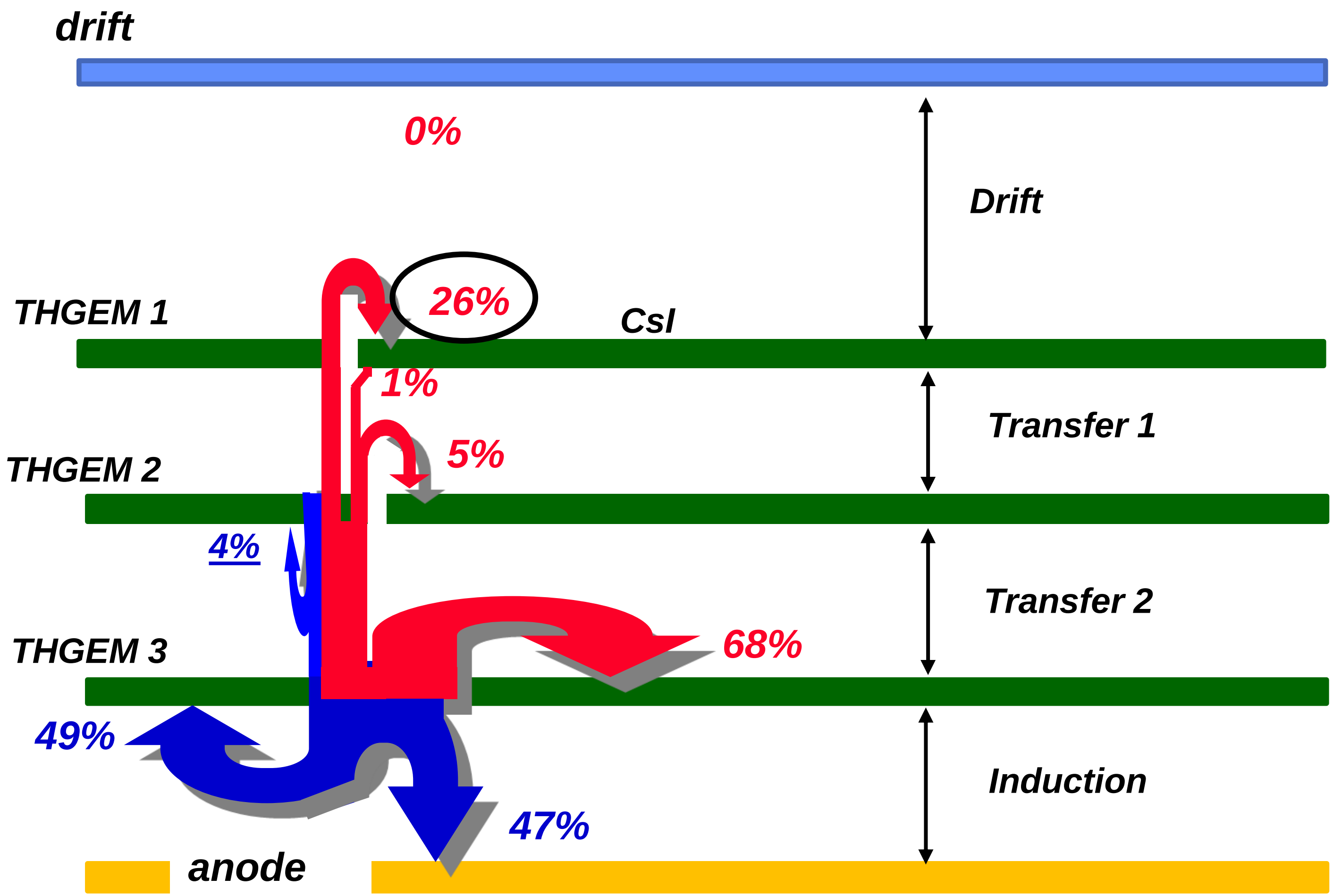
	MWPC	THGEM
photoelectron rate	≈10 Hz/cm^2	≈10 Hz/cm^2
MIP rate	≈10 Hz/cm^2	≈10 Hz/cm^2
gain, i.e. number of ion-electron pairs generated per multiplied electron	4×10^4	4×10^5
collected electrons per MIP	20	≈5
IBFR	≈50%	≈5%
N_i	2×10^4	2×10^4
ion bombardment rate at the photocathode (from MIP and photoelectrons)	4.2×10^6 Hz/cm^2	1.2×10^6 Hz/cm^2

Reverse Bias !!!

GOAL !!!

NOTE: we normalize to the total ionization

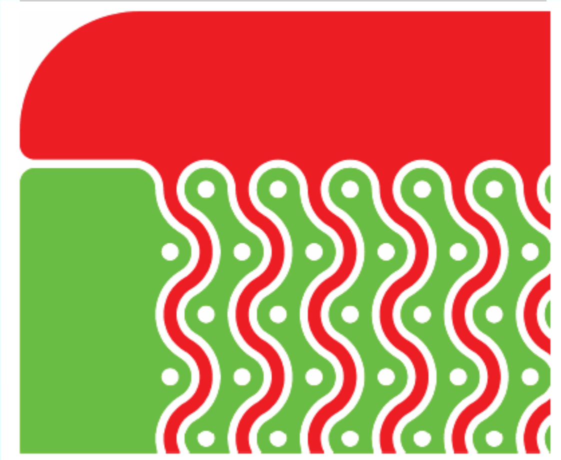
typical charge sharing for THGEM-based PD

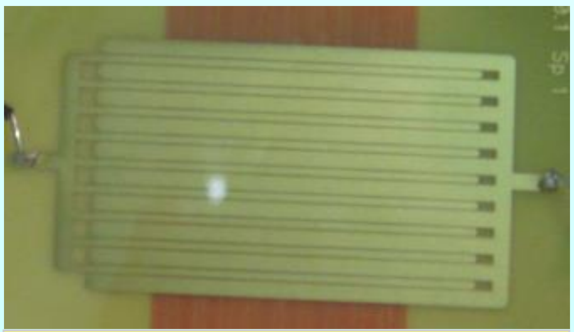


field values optimization could reduce IBF by a factor 2

Several attempts to solve the IBF problem

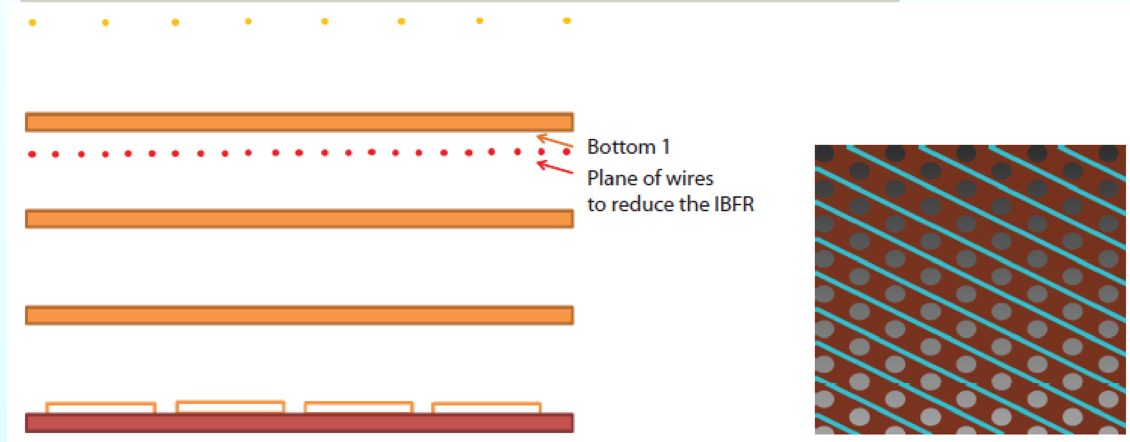
THCOBRA

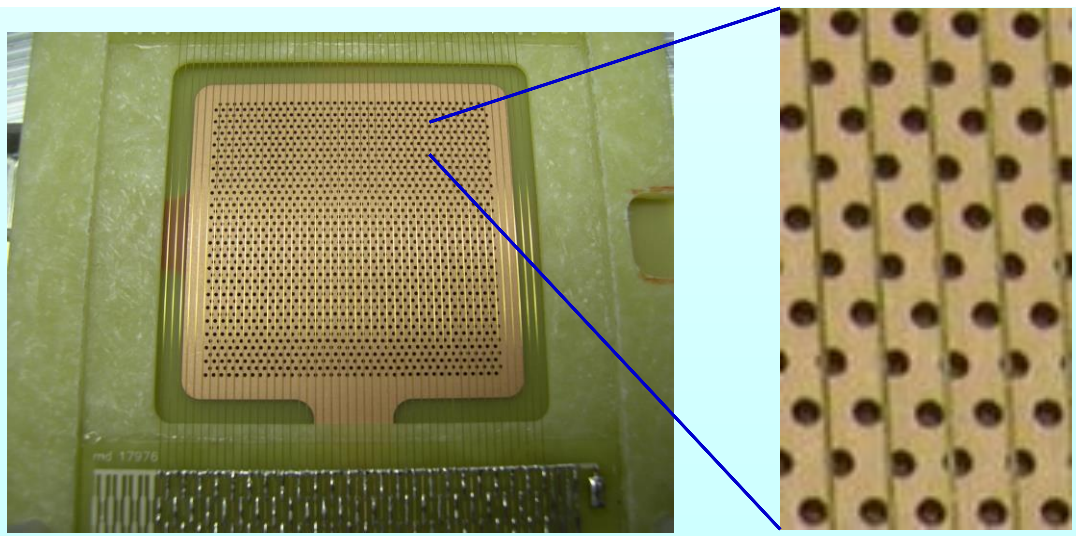




path width < 0.1 mm: may get damaged by sparks

dedicated extra electrode

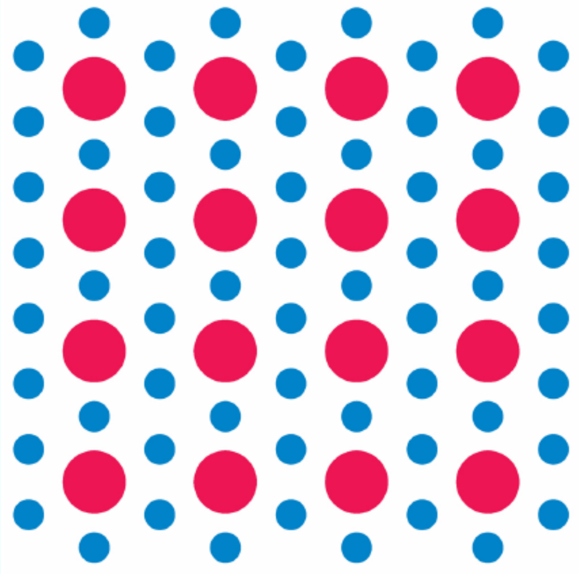


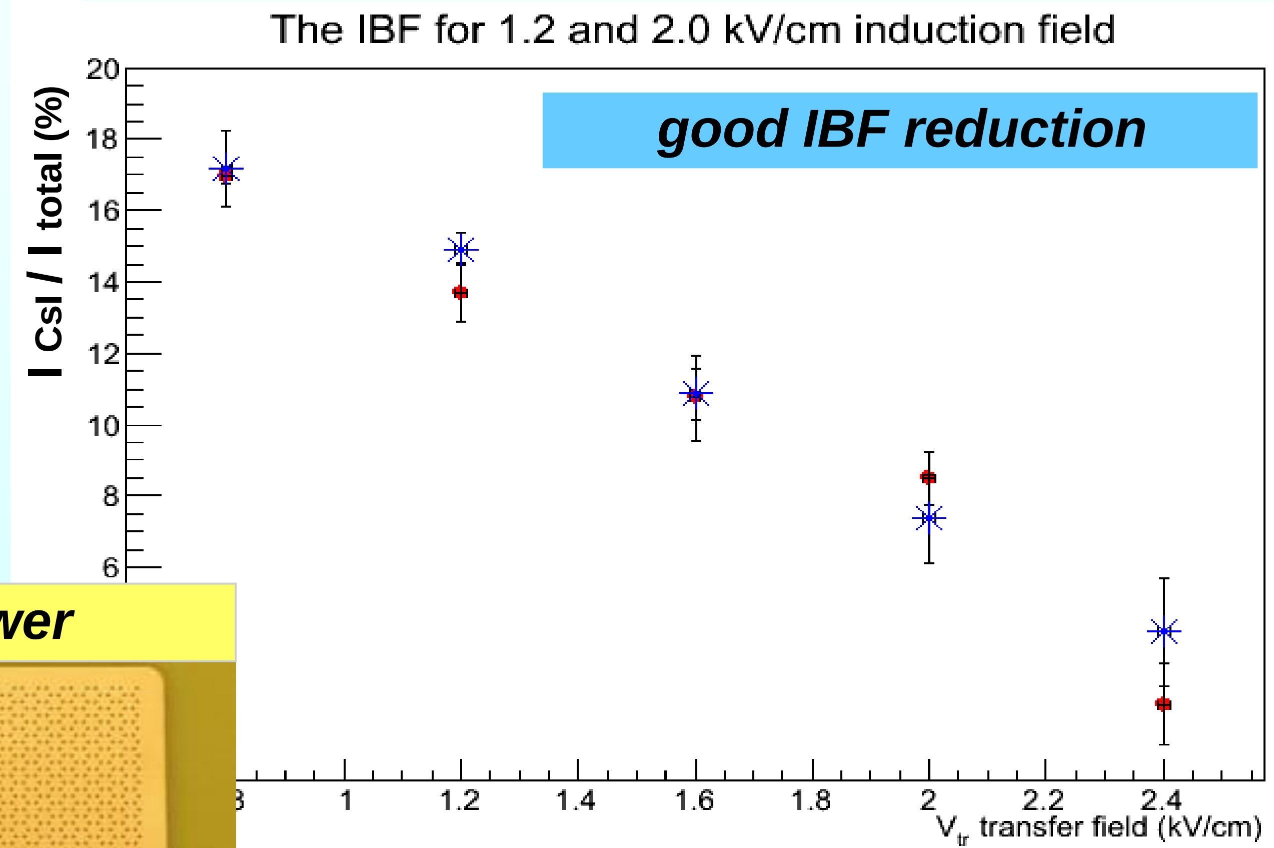


unpractical for large surfaces

The "Flower" THGEM

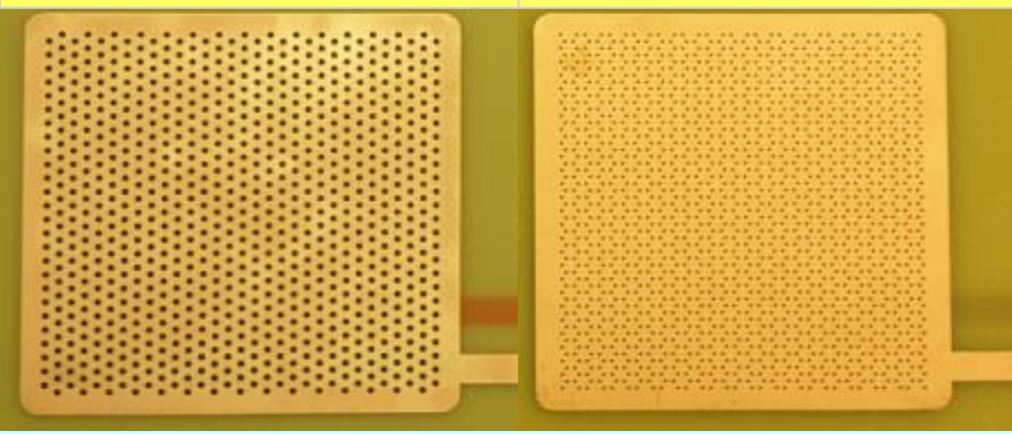
Coupling different geometries: THGEM-1 (red holes) and THGEM-2 (blue holes)





good IBF reduction

THGEM-1 (CsI) | **_Flower_**



unfortunately, the p.e. efficiencies are affected by this geometry

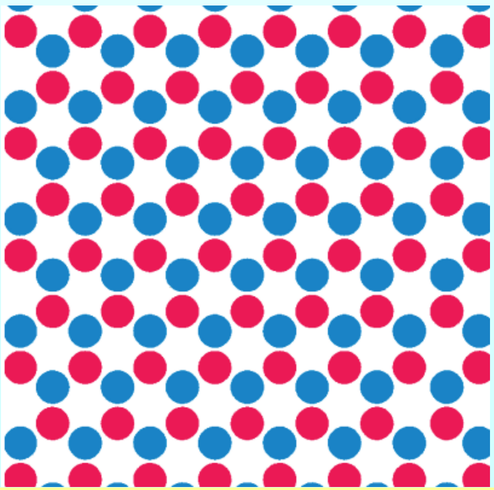
Identical THGEMS: aligned and staggered

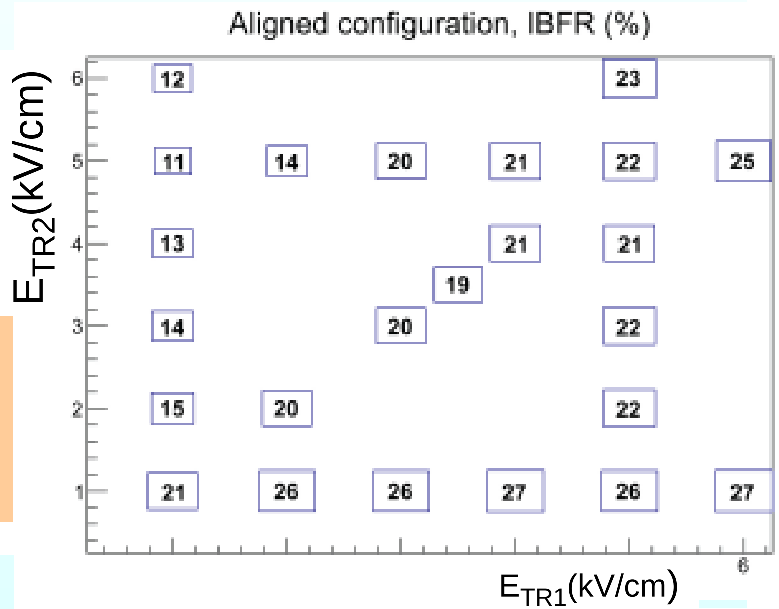
Inspired by:

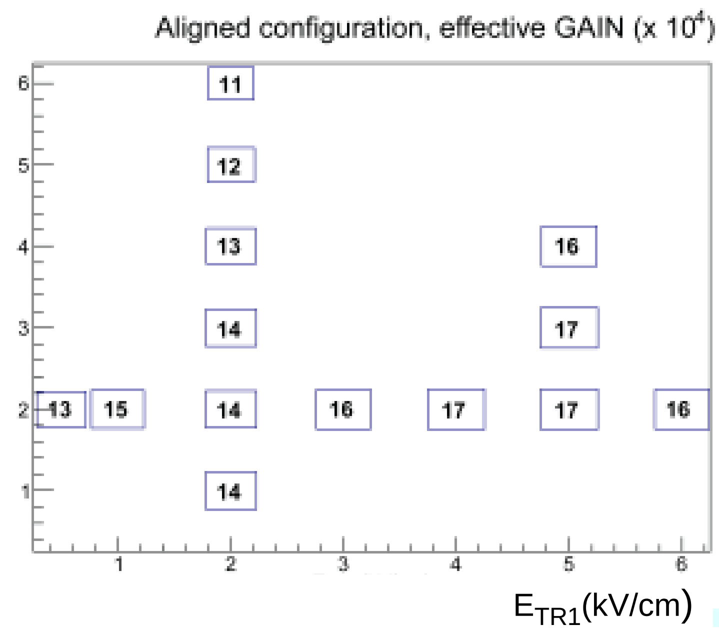
NIM A 260 (2006) 269

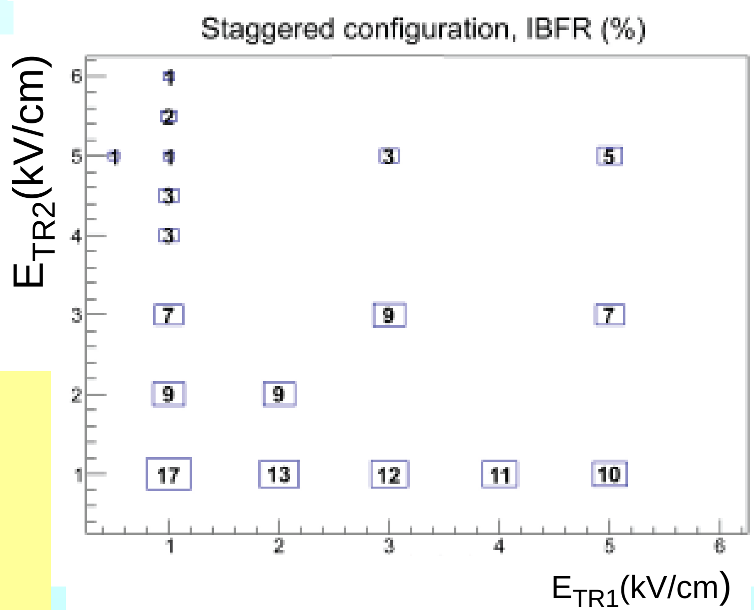
we studied the effect of THGEM hole alignment on IBF.

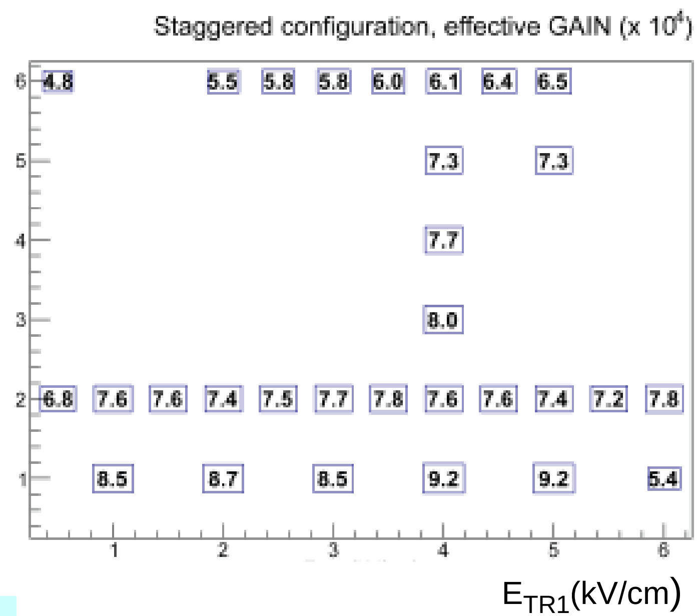
efficient IBF reduction with moderate impact on the effective gain











M. Alexeev et al.

JINST 8 P01021 (2013)

"Ion backflow in thick GEM-based detectors of single photons"

Other progress in the last 12 months

1) *A 300x300 mm2 active area prototype was built and tested at CERN T10 beam*

2) *The effect of the "inverse drift field" on charged particles was verified*

3) *The problem of non uniform gain studied: thickness uniformity improvement*

4) *New production procedure introduced to improve THGEM quality*

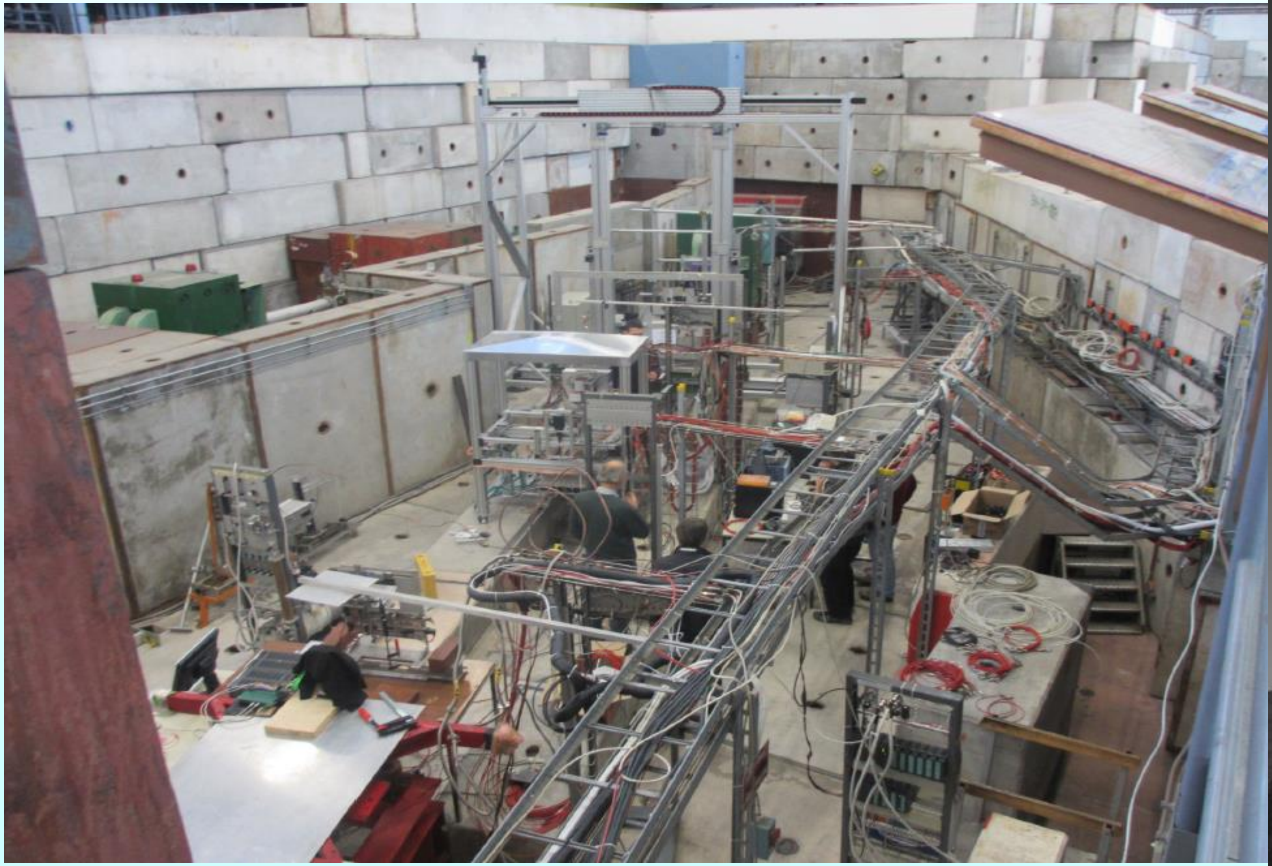
5) *New hybrid THGEM+Micromegas detector architecture investigated*

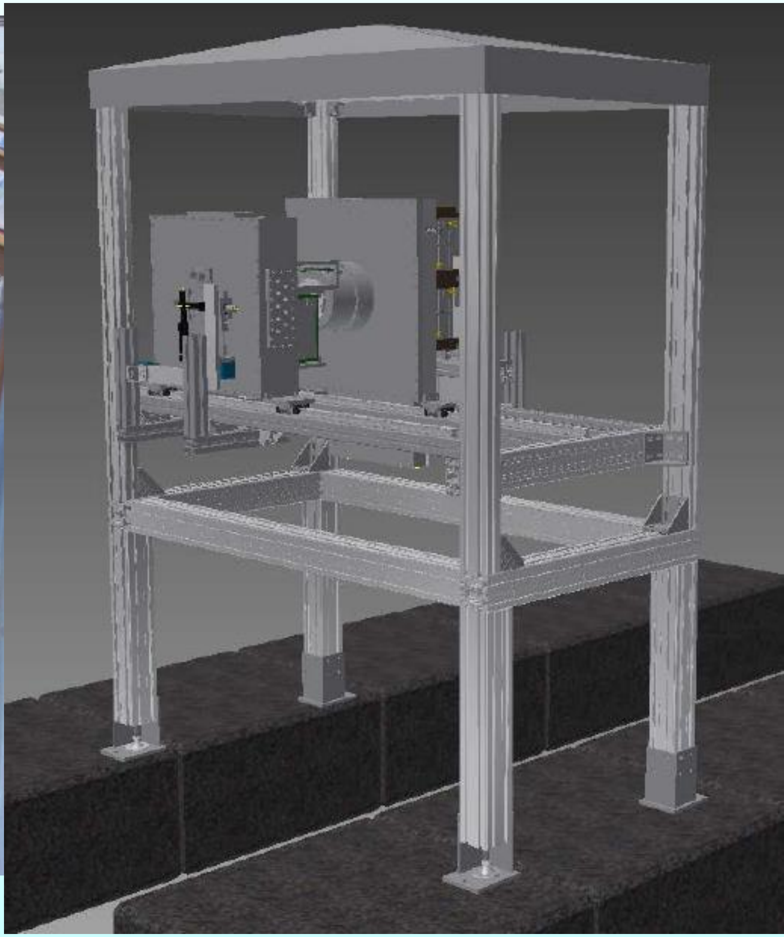
6) *COMPASS RICH-1 upgrade project matured and received approval*

COMP-RICH Test Beam

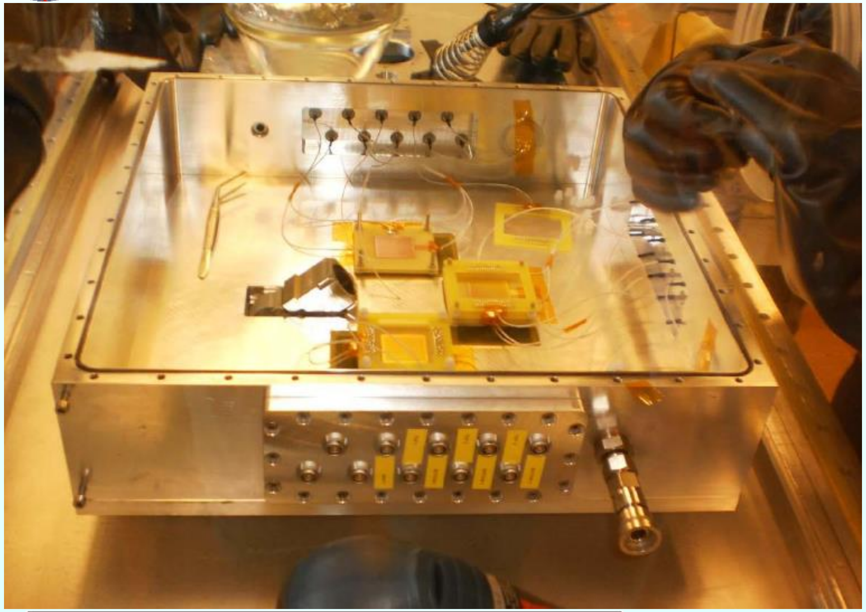
PS T10 beam line   5/11/2012 – 25/11/2012   Single User

Triple THGEM 300x300 (576 pads); 2 Triple 30x30, 1 MWPC, 1 MAPMT
trigger system, Č radiators, Analog & Digital r/o, COMPASS-like DAQ, …





Triple THGEM 30 mm x 30 mm

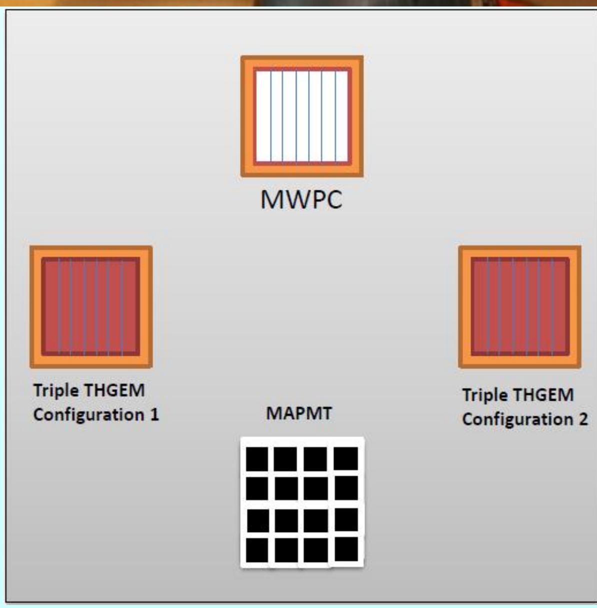


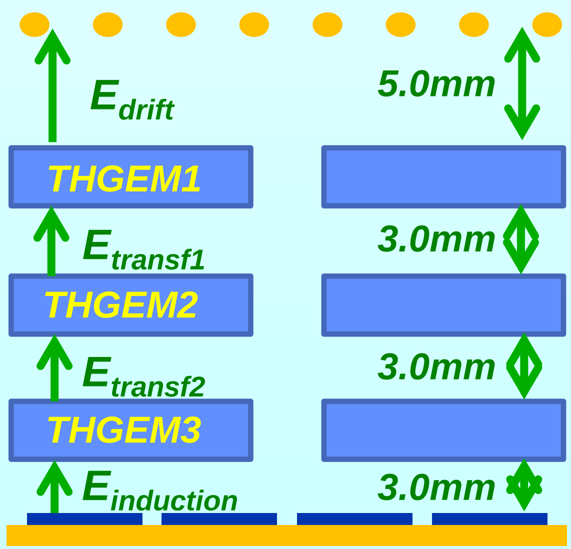
Small prototypes: "studies of principle":

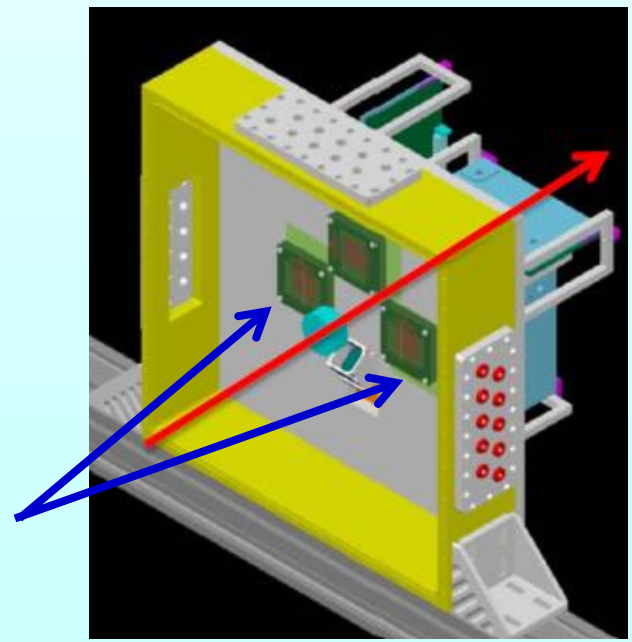
Detector response to ionizing particles (beam mips)

Check the "Reverse Bias effect"

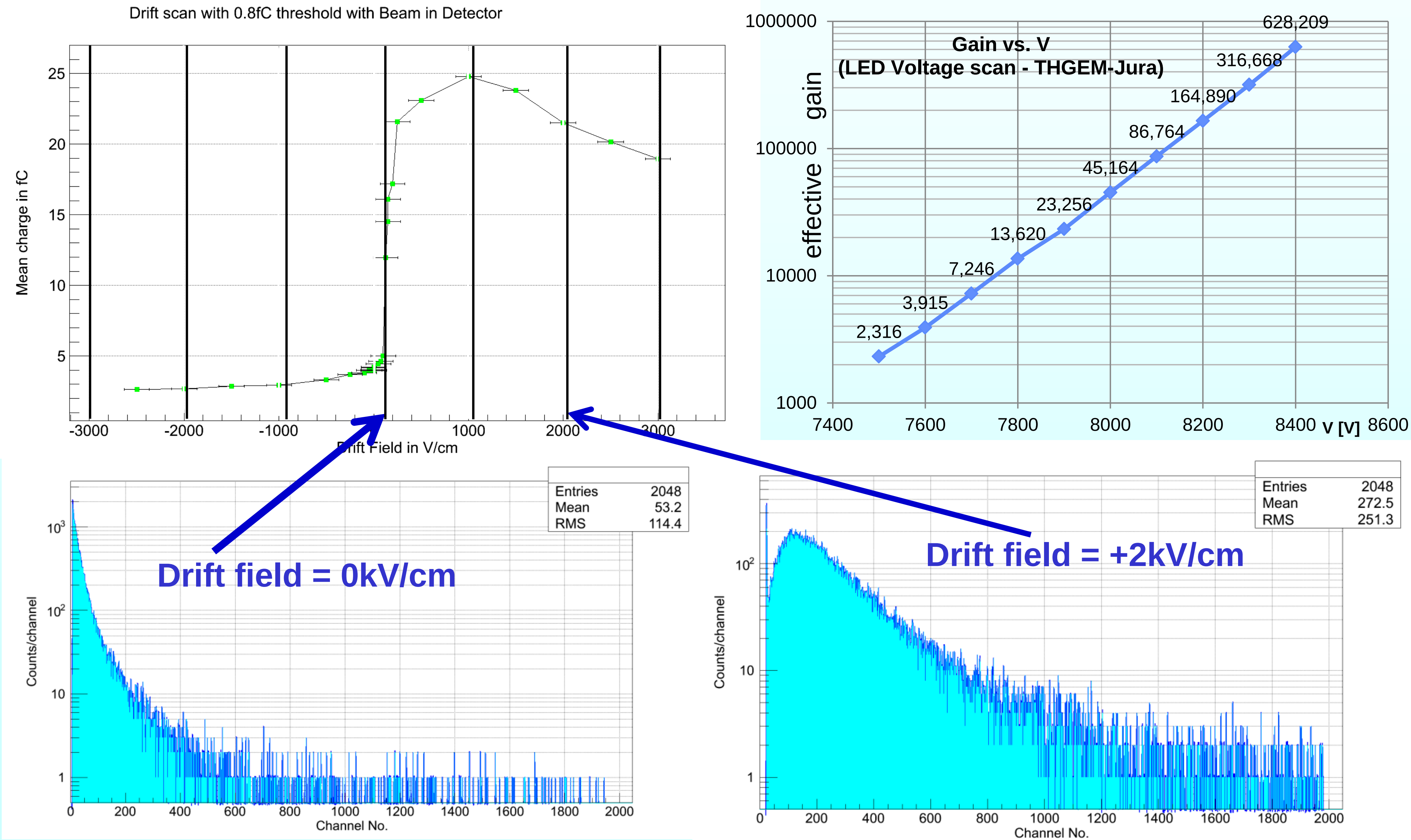
Measure the effective photon detection efficiency as function of the drift field in single photon mode



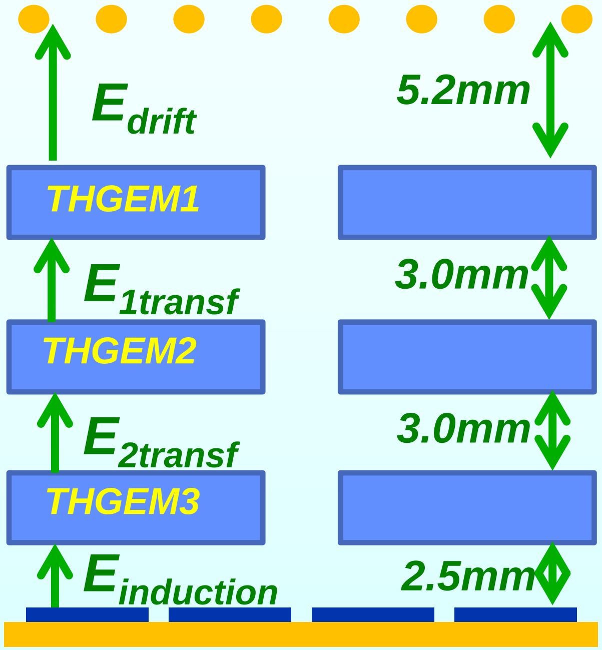




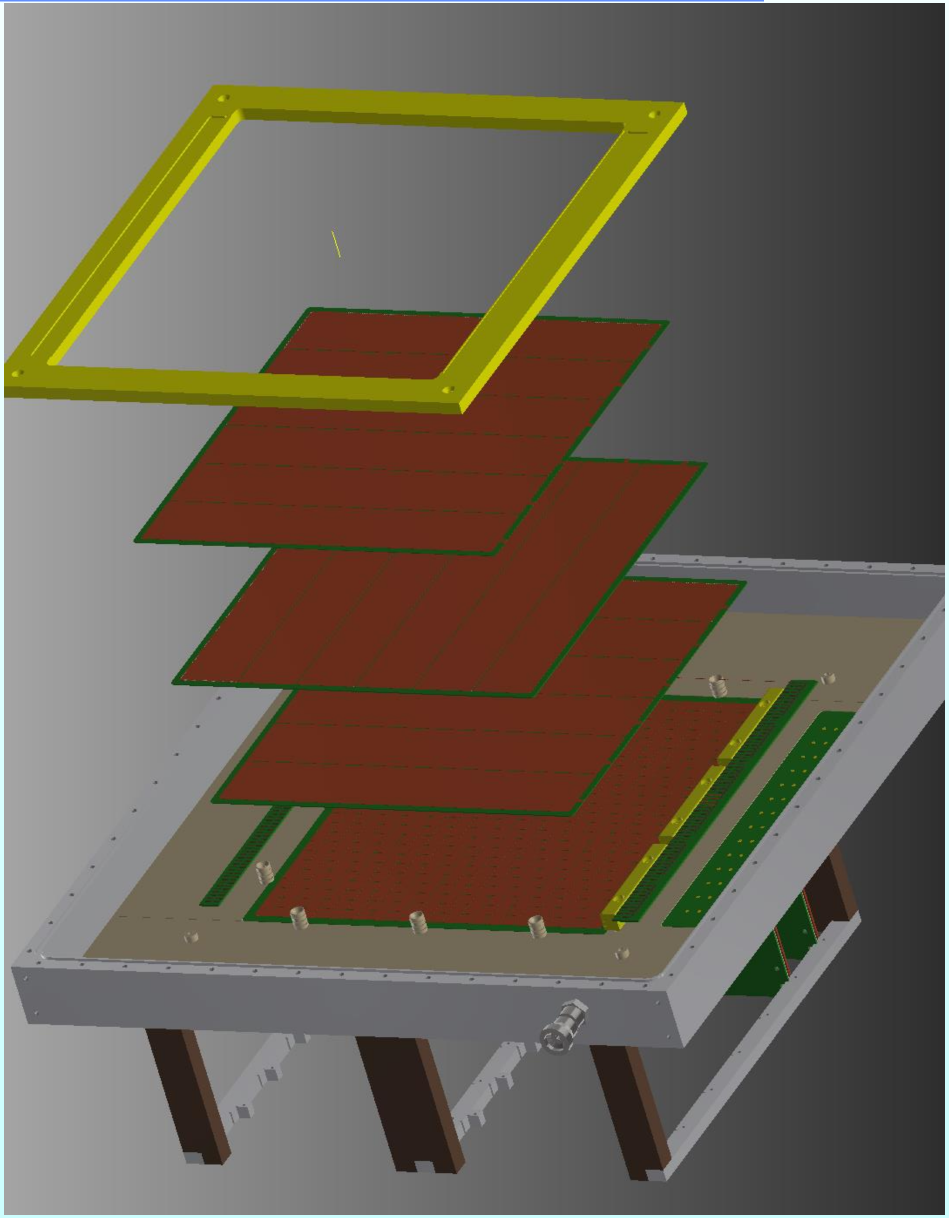
Detector response to mip



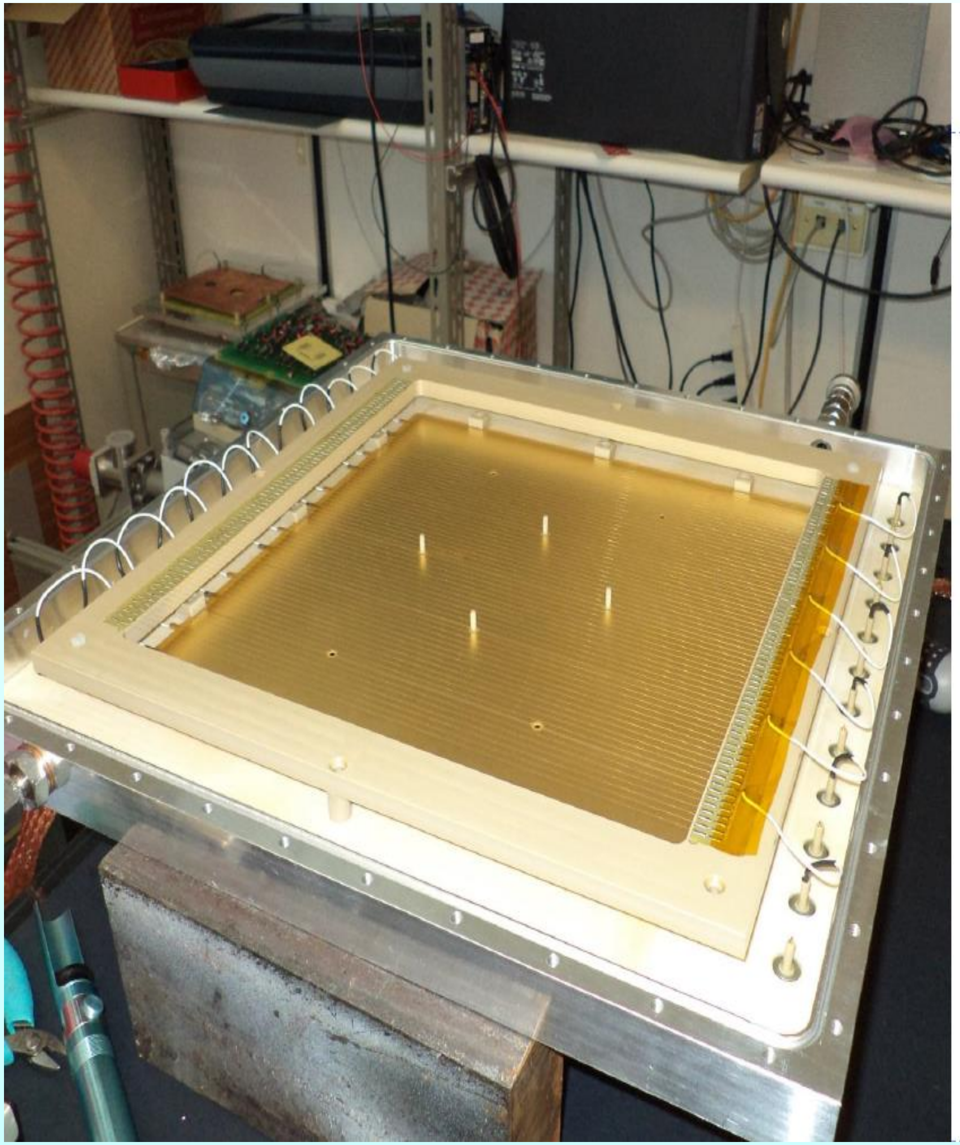
Triple THGEM 300 mm x 300 mm

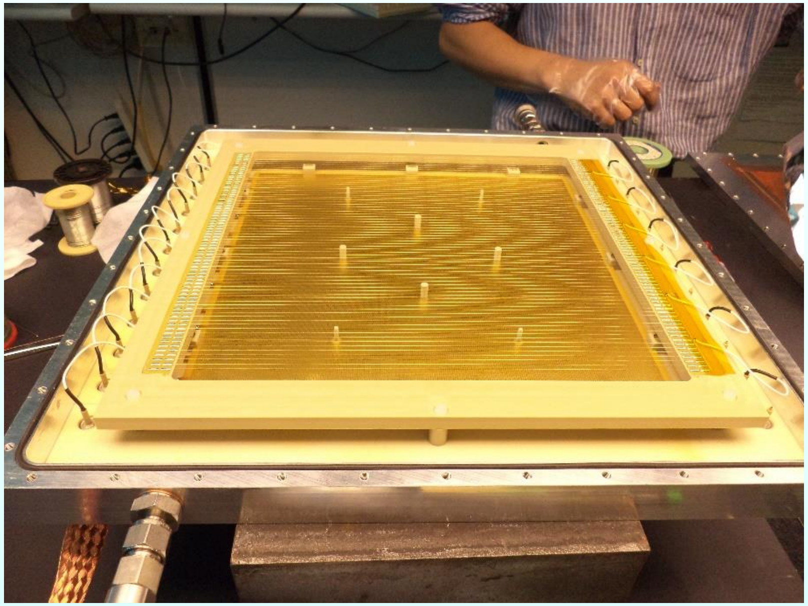


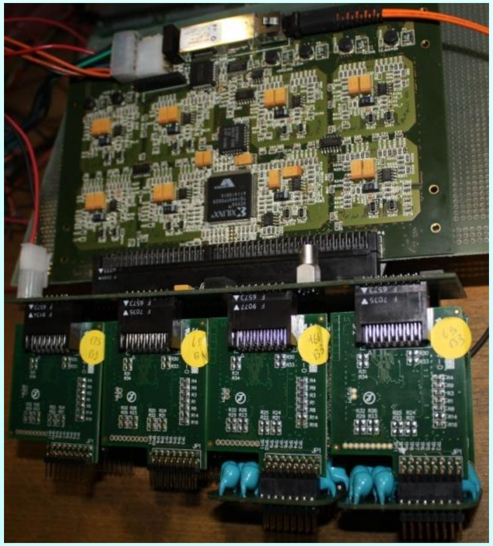
Layer	Pitch / mm	$Ø_{hole}$ / mm	Thickness / mm	RIM / µm
THGEM1	0.8	0.4	0.4	< 5
THGEM2	0.8	0.4	0.8	< 5
THGEM3	0.8	0.4	0.8	< 5



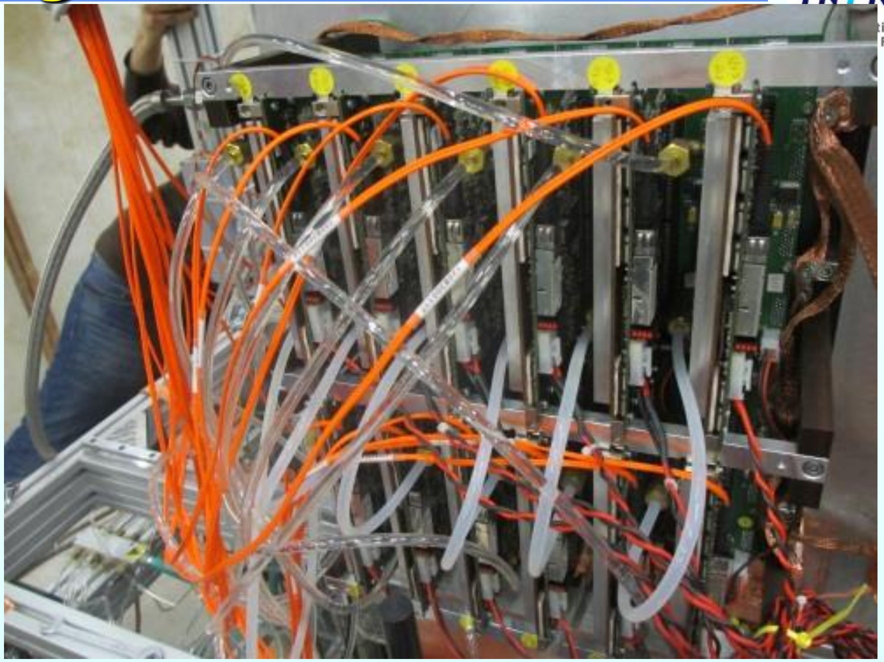
Detector and electronics

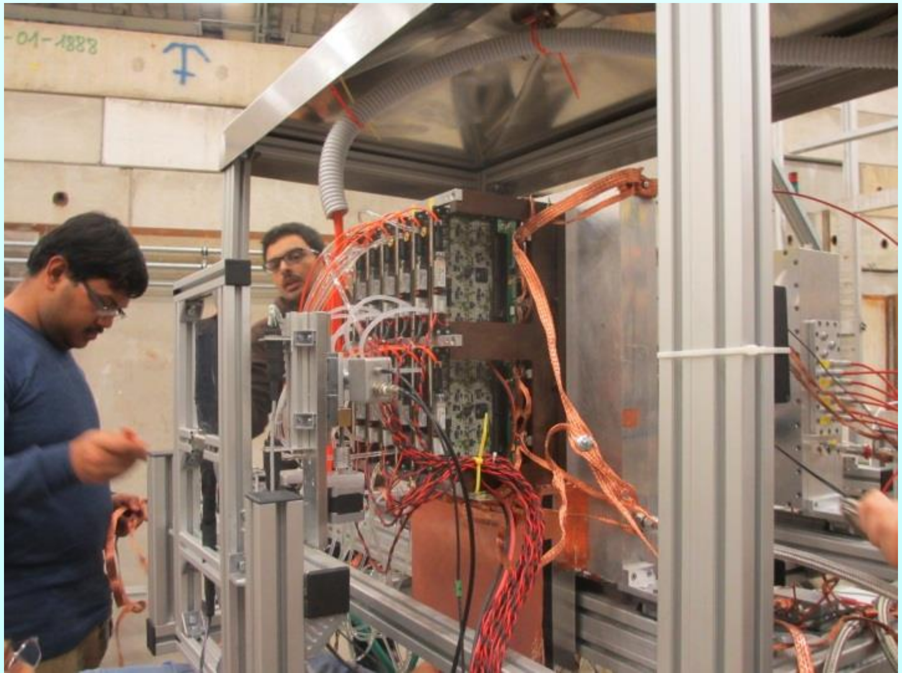




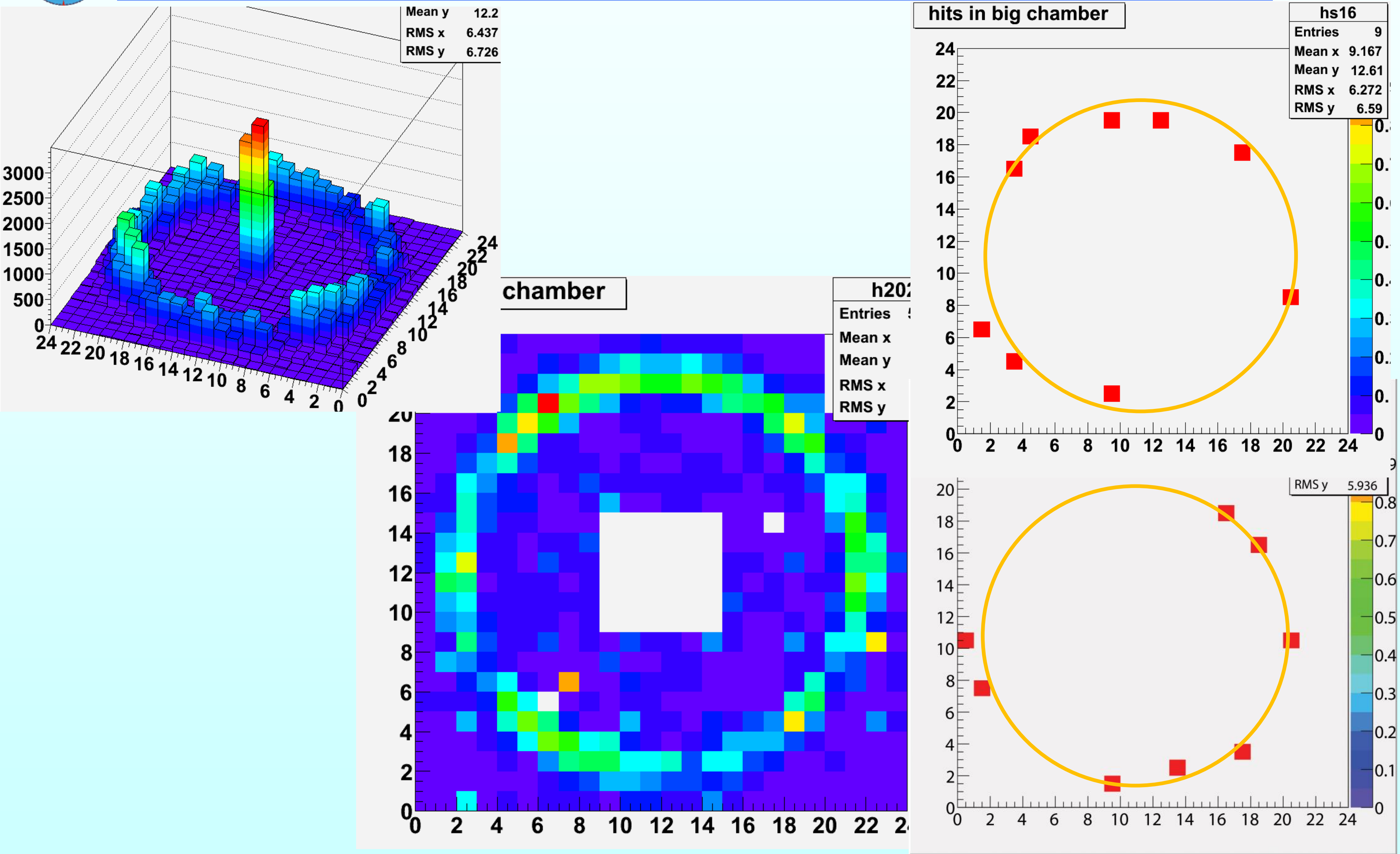


Not always straightforward



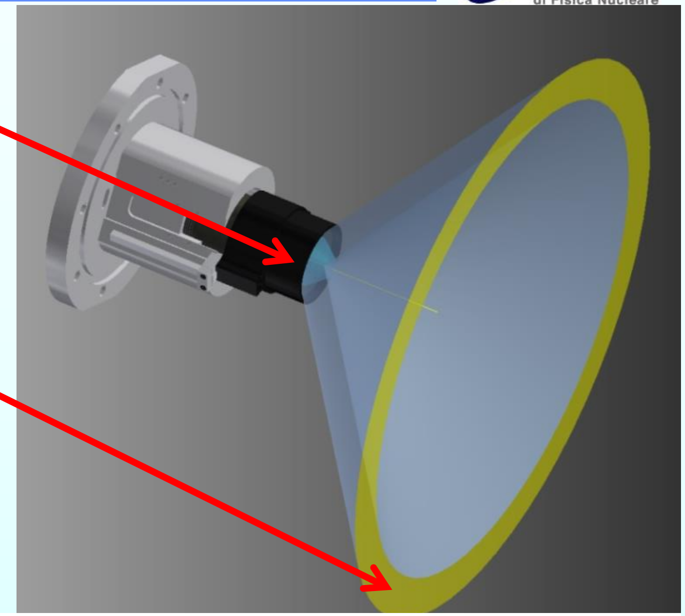


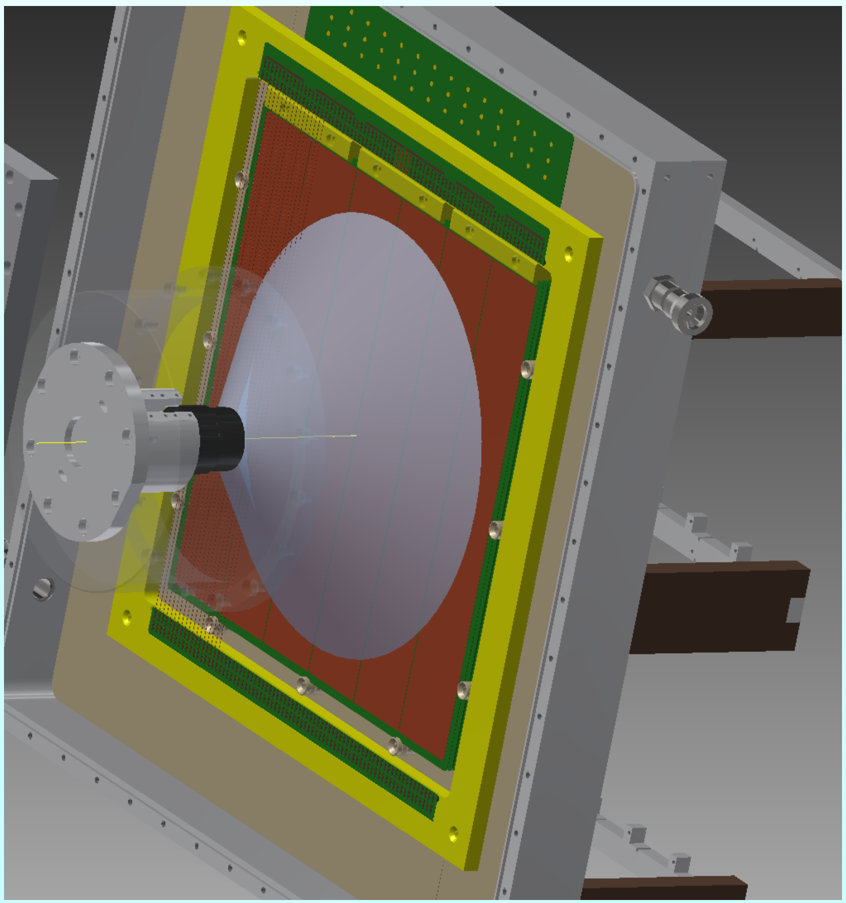
After noise reduction nice single events

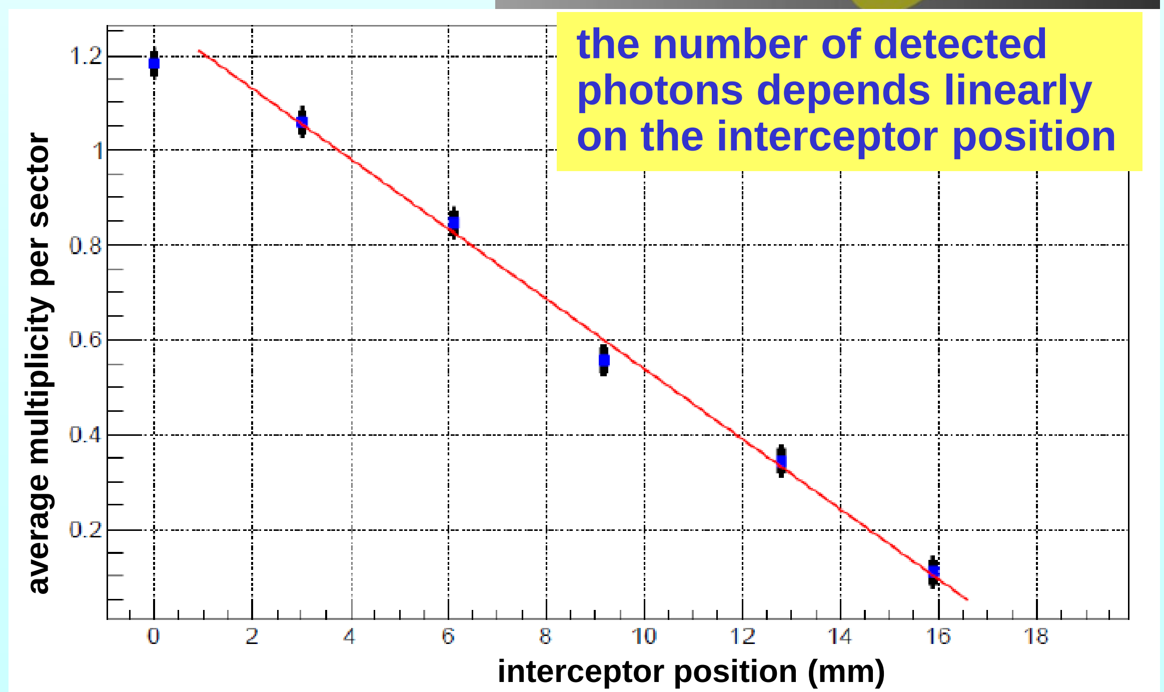


Conical fused silica radiator

A remotely controlled movable interceptor allows for changing the number of photons in the corona

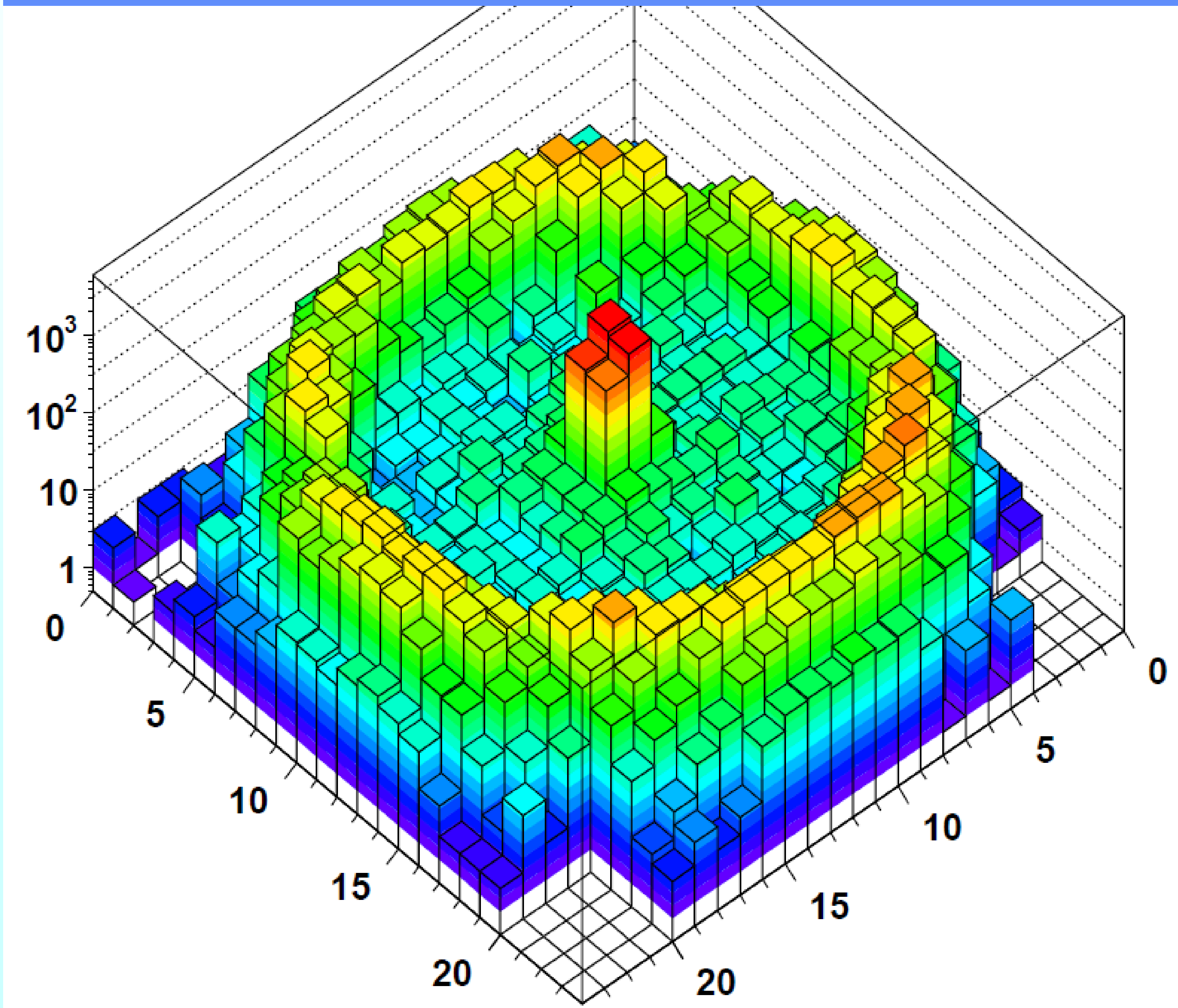




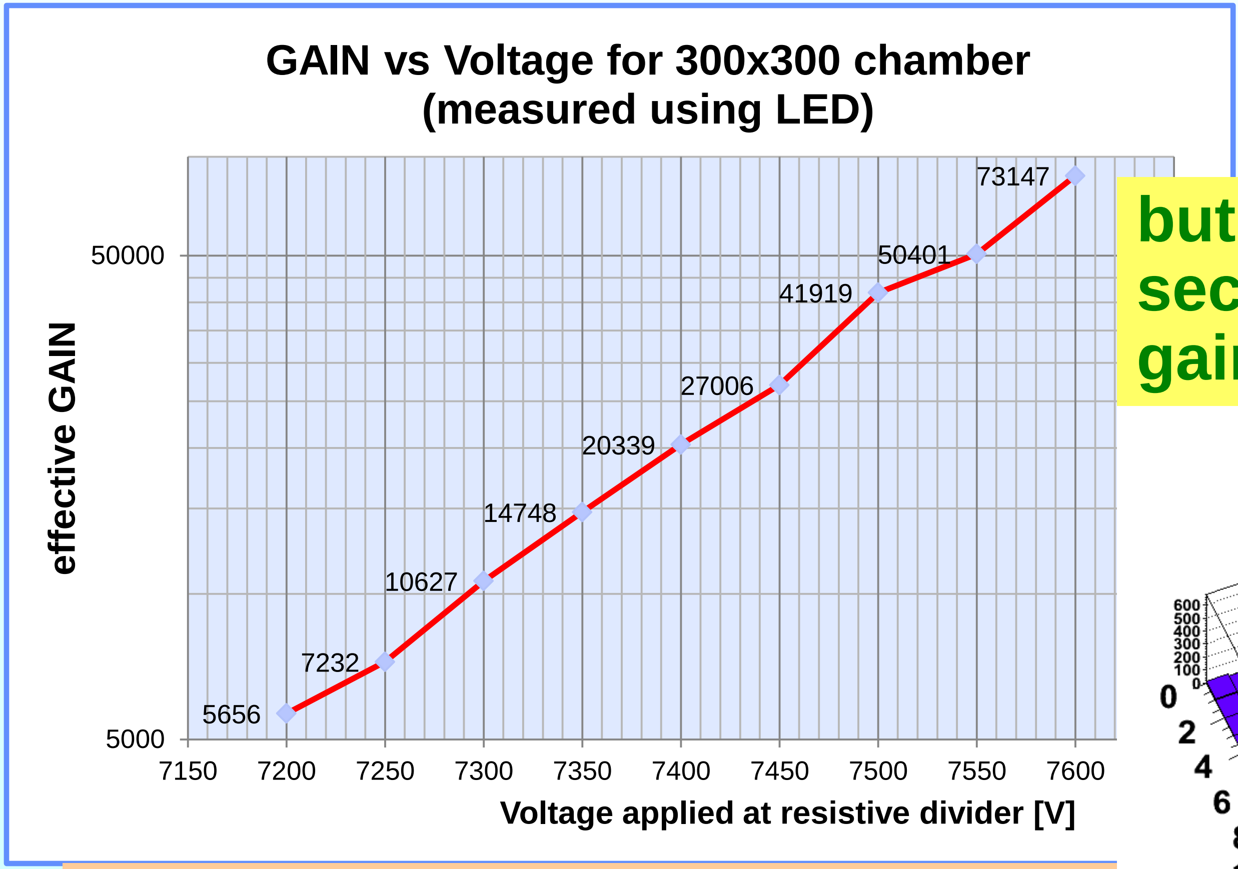


the number of detected photons depends linearly on the interceptor position

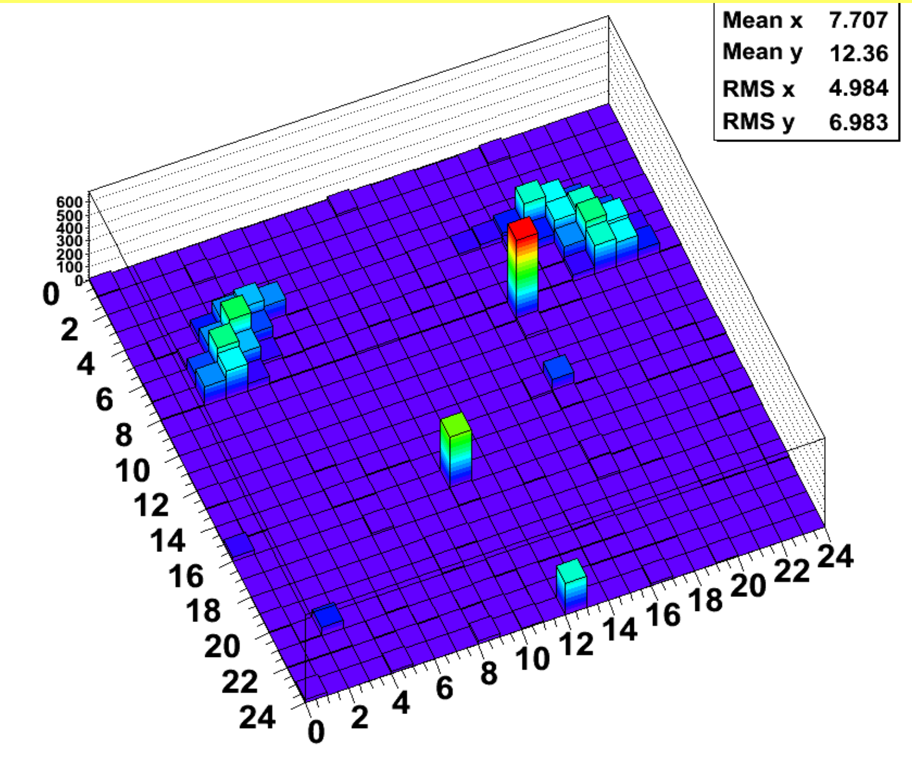
Sum of the events in a run



Gain of the 300x300 at the Test Beam



but when operating a single sector we could achieve a gain of ~0.2 M



➔ Is there a problem of principle or we simply did not put enough attention to the THGEM quality?

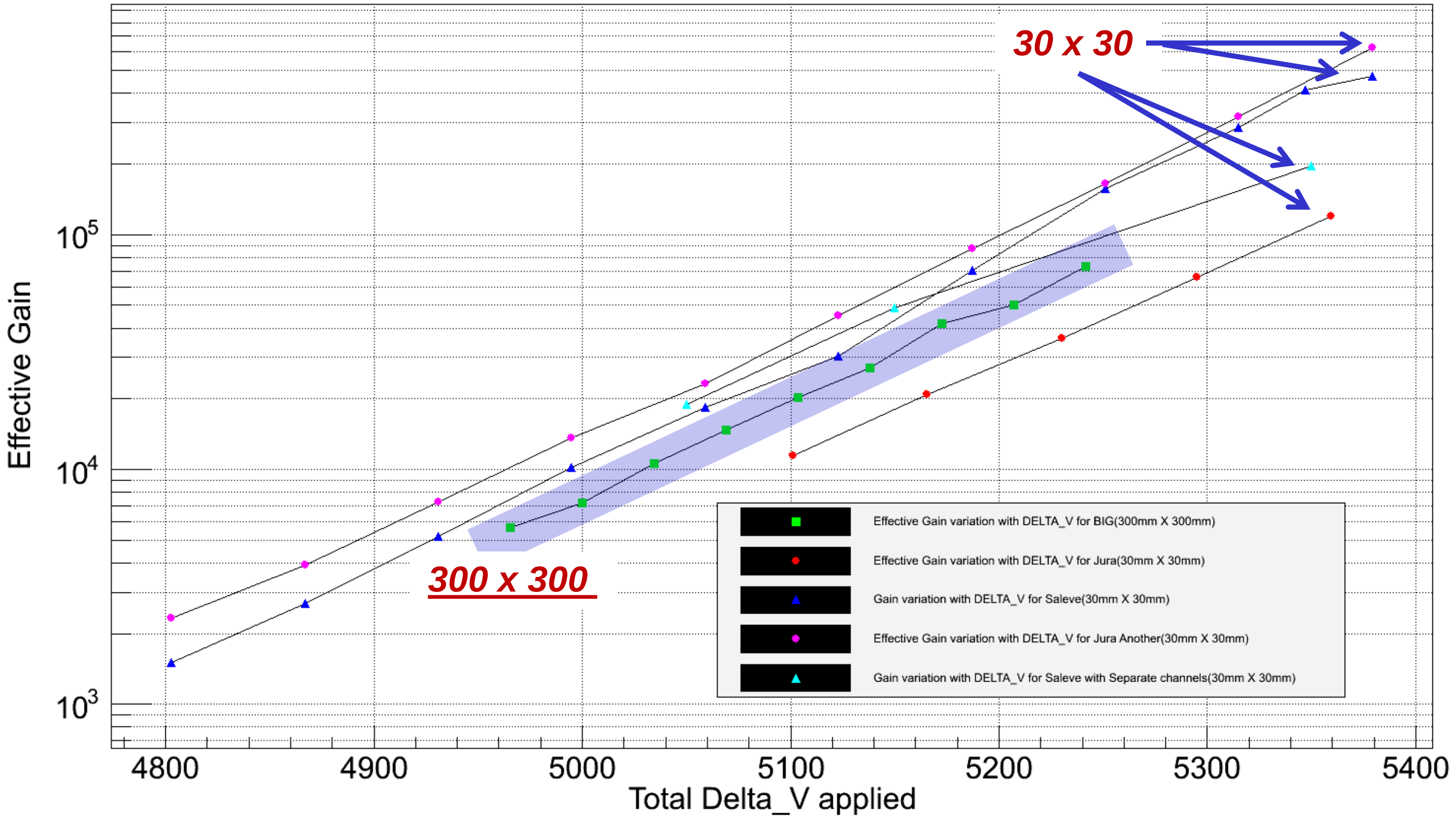
THGEM gain: large versus small

The 300 x 300 mm^2 chamber provided the <u>same response</u> of the small ones (30 x 30 mm^2), but <u>it could not reach the same maximum gain</u>

Max GAIN

small / large = 10

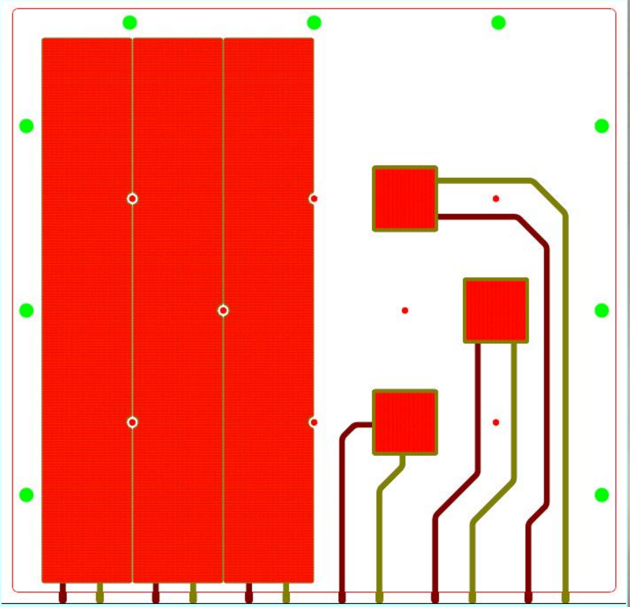
If best small assumed

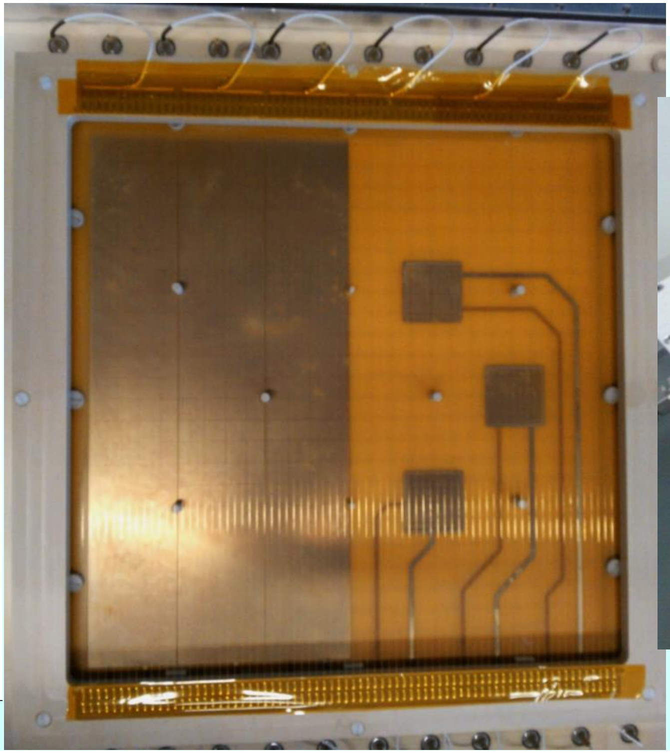


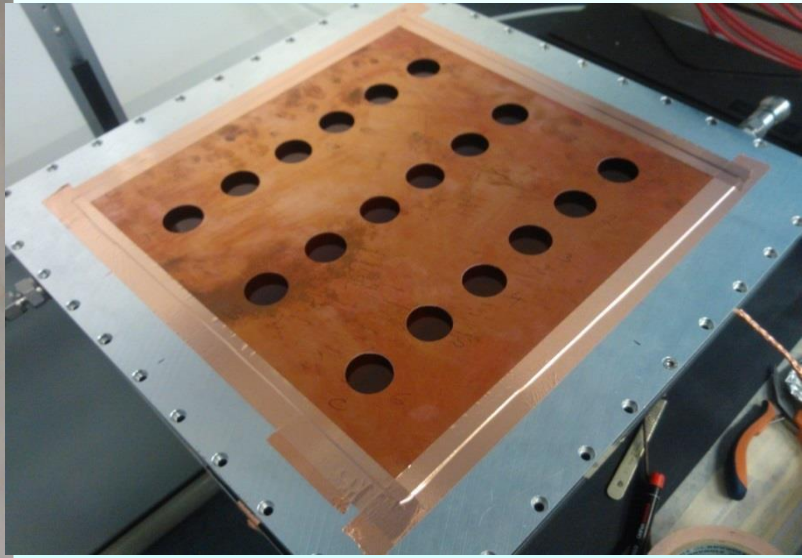
How to investigate the problem?

After the Test beam, we decided to compare "large" and "small" on the same footing:

- produce both on the very same pcb and test them together, under the same conditions.







But …

the new pieces did not stand HV

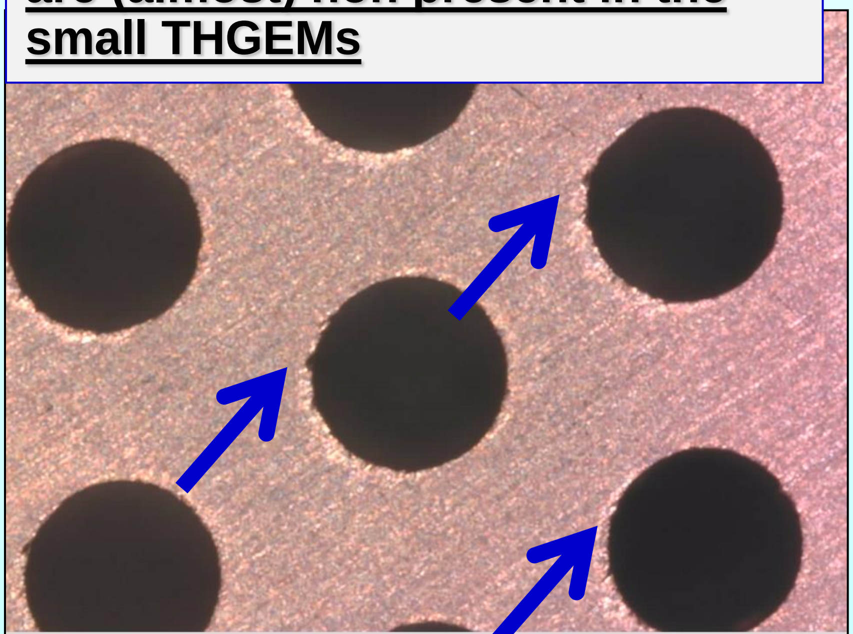
Large THGEM production problem?

THGEM production, after drilling

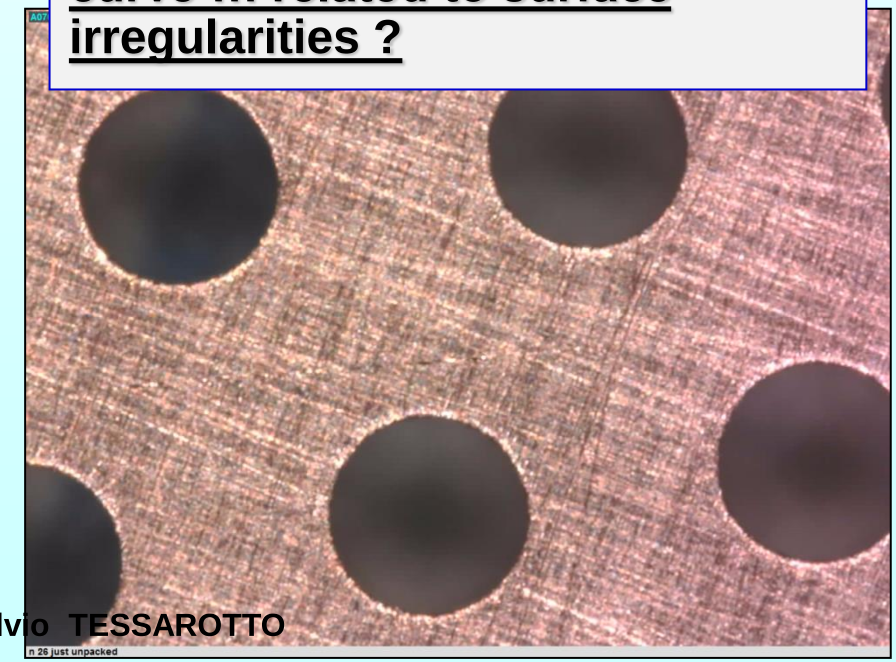
at ELTOS : polishing, brushing (pomice powder), microetching

then, at CERN workshop (Rui), brushing etc.

These defects (due to brushing?) are (almost) non present in the small THGEMs

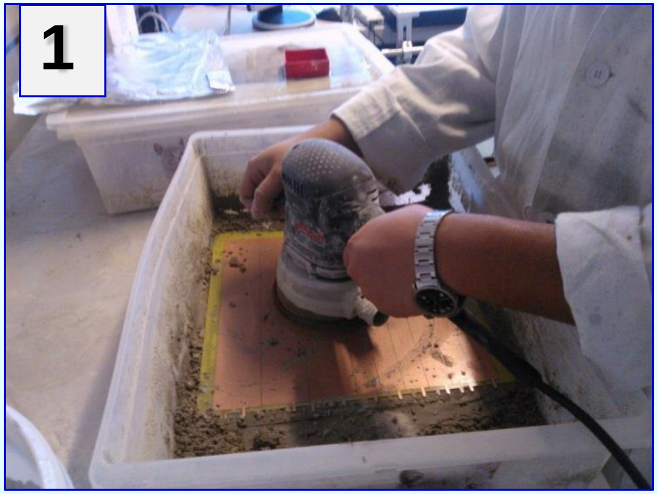


Irregularities are gone, but still the Max V_{bd} is far from Paschen's curve … related to surface irregularities ?

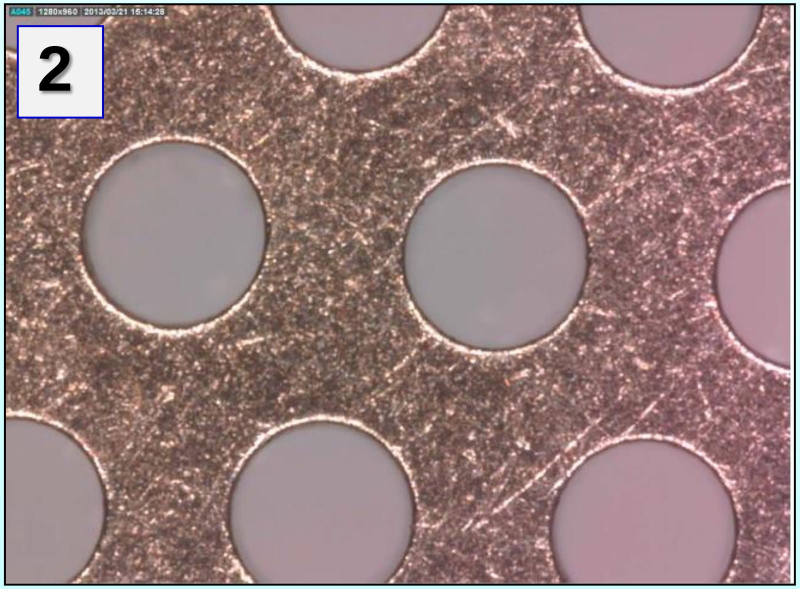


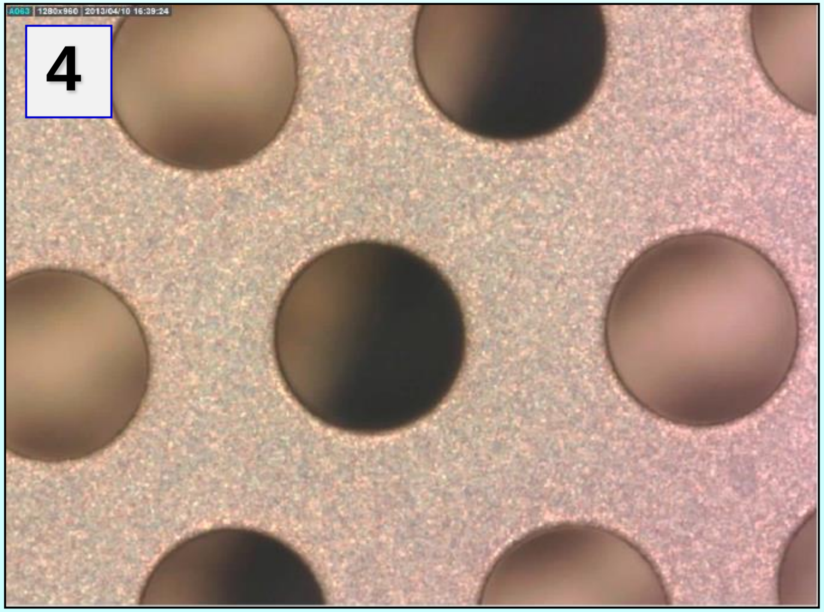
Fulvio TESSAROTTO

New THGEM treatment in Trieste

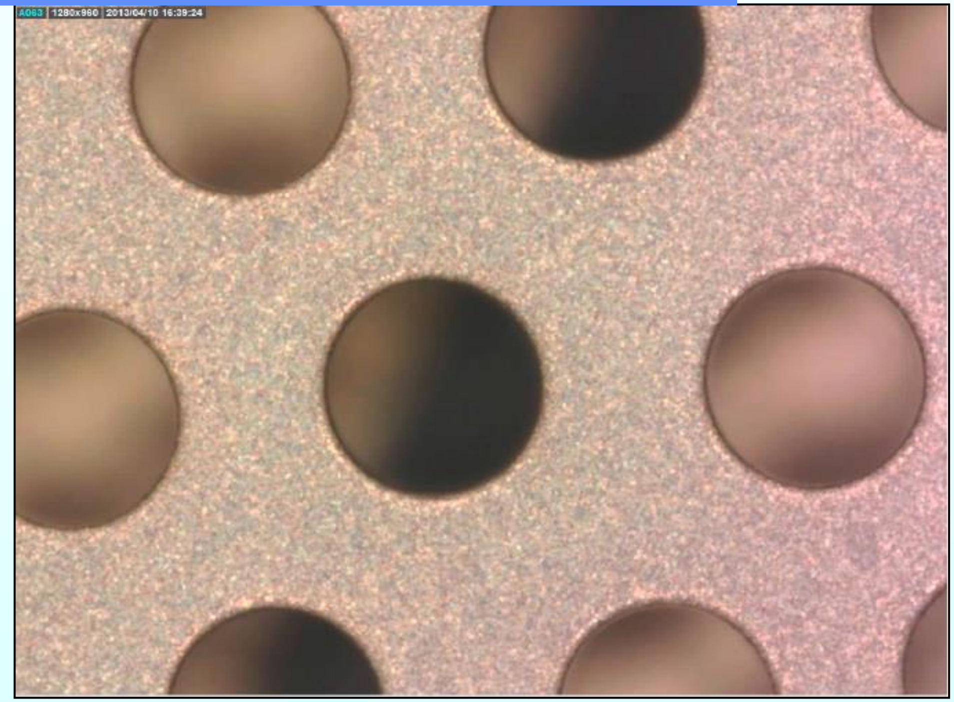


1. polishing (Hinrichs Pumice Powder)
2. cleaning with high pressure water to remove all pumice residuals
3. ultrasonic bath (~1 h) @ 50-60 ^{o}C in Sonica PCB solution (pH11)
4. washing with demineralized water plus oven at 180 ^{o}C for 24 h

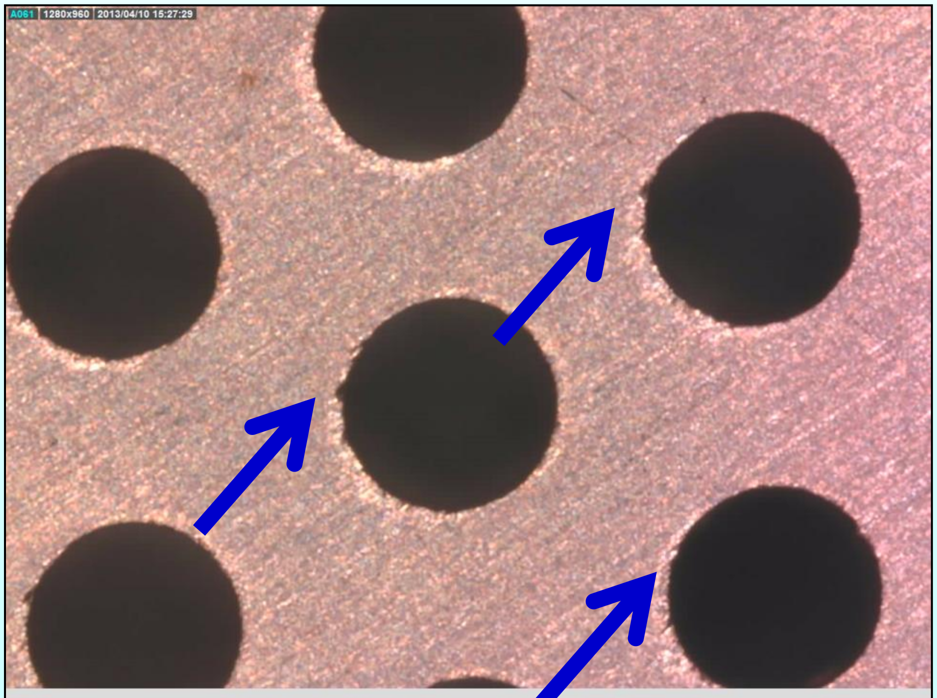




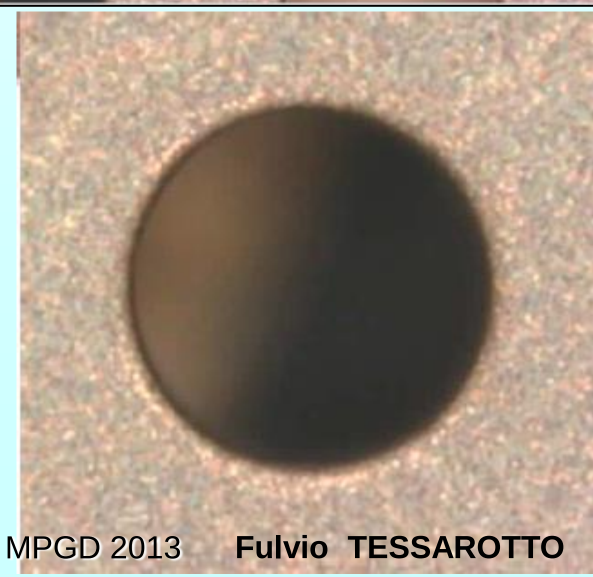
Smoother surface in particular at the hole



initial

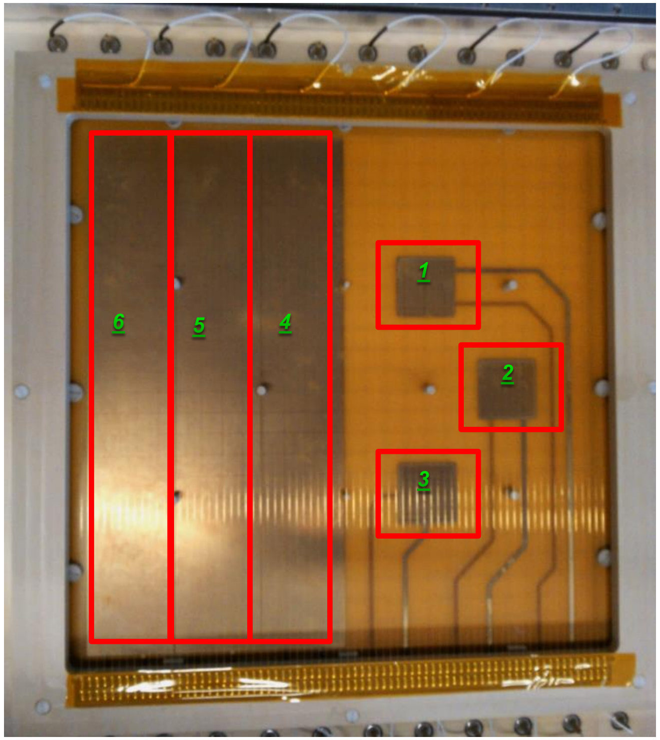


final



Breakdown voltage in air (Pashen V=2400V)

For the THGEM #12, Thickness = 0.4mm, ϕ = 0.4 mm, Pitch = 0.8 mm



Just take out from the package

Sec 1	Sec 2	Sec 3	Sec 4	Sec 5	Sec 6
1820	1650	1660	1630	1570	1330

After first full Treatment

Sec 1	Sec 2	Sec 3	Sec 4	Sec 5	Sec 6
2270	2380	2370	2080	2050	1970

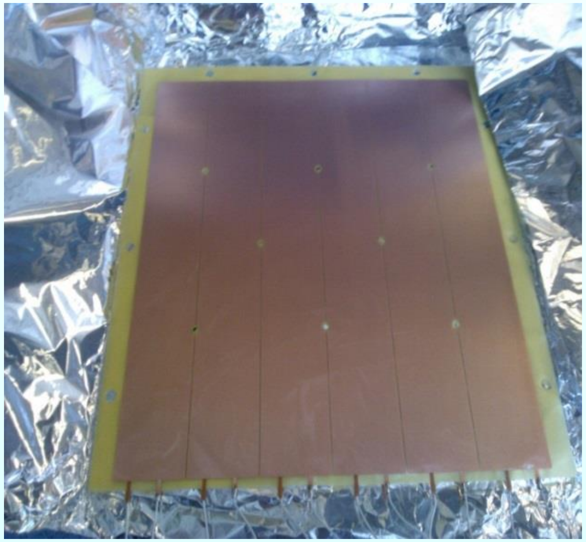
After second full Treatment

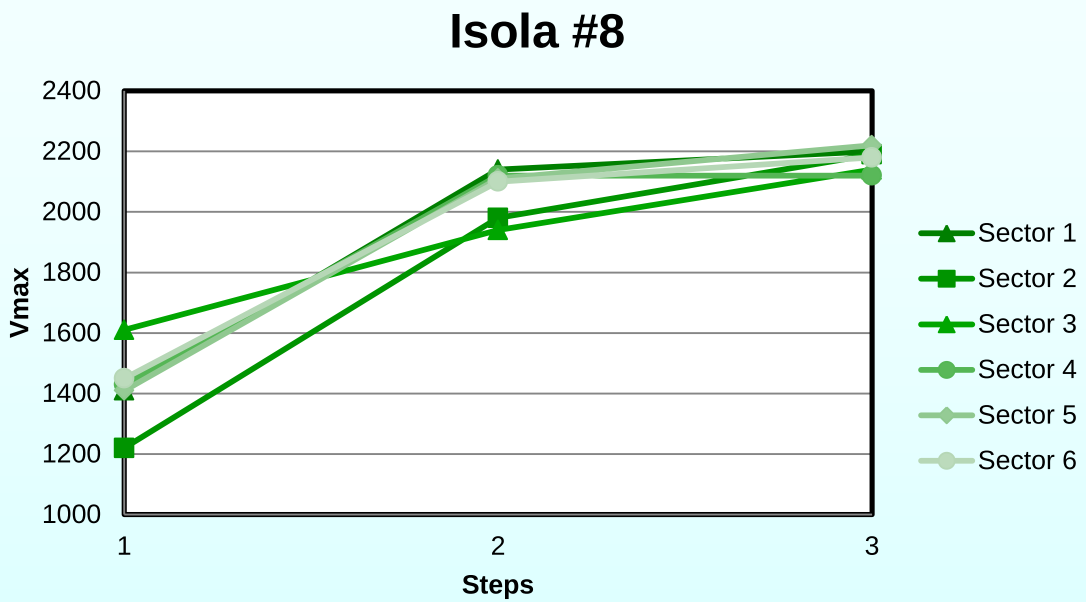
Sec 1	Sec 2	Sec 3	Sec 4	Sec 5	Sec 6
2400	2360	2300	2130	2030	2100

Size effect in the protocol (no trip for 30")?

There is no correction for the surface → under investigation

The procedure works for standard 300





out of the box	1410	1220	1610	1430	1410	1450
After first treatment	2140	1980	1940	2120	2110	2100
After second treatment	2200	2190	2140	2120	2220	2180

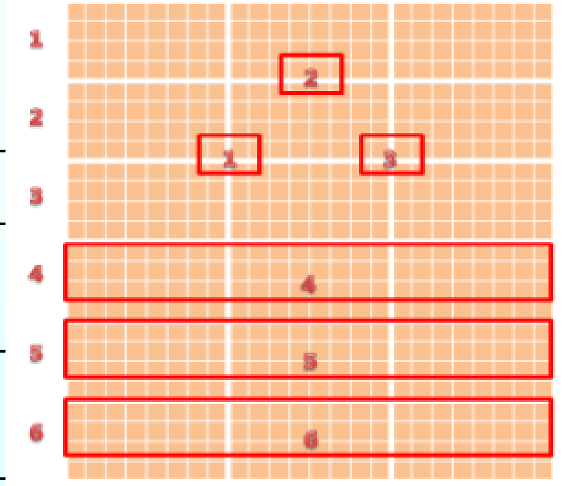
Paschen V ≈ 2240

THGEM gain: large versus small

Maximum ΔV scan with & without source

	A	B	C
1		1690 (1540)	
2		1810 (1610)	
3		1660 (1570)	
4	1470 (1410)	1470 (1410)	1470 (1410)
5	1510 (1490)	1510 (1500)	1510 (1500)
6	1590 (1580)	1590 (1550)	1590 (1500)

Without source
(With Source)



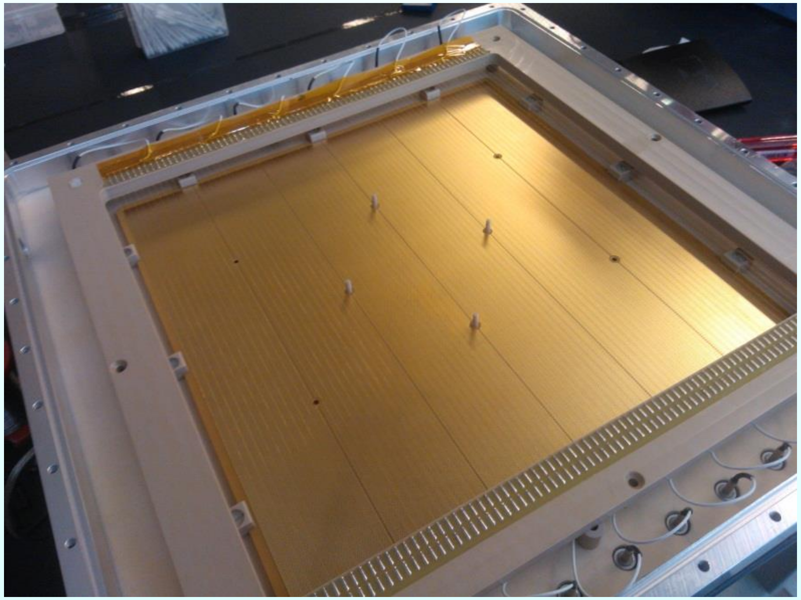
Ar/CO2 : 70-30%

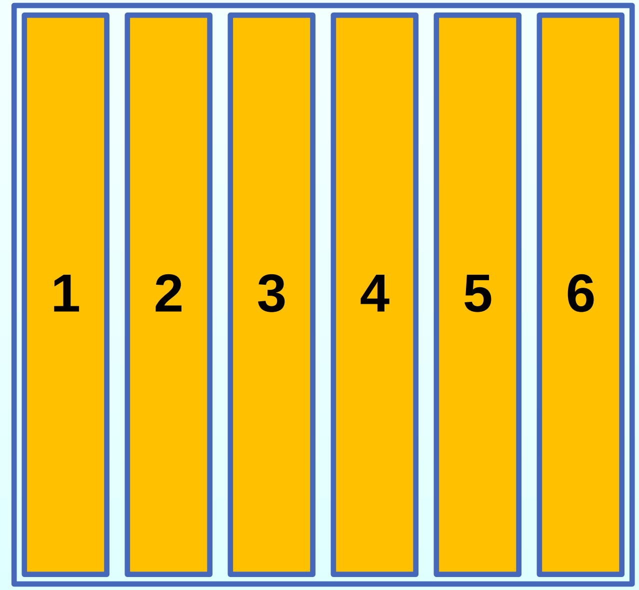
Gain measurement @ highest ΔV of the sectors

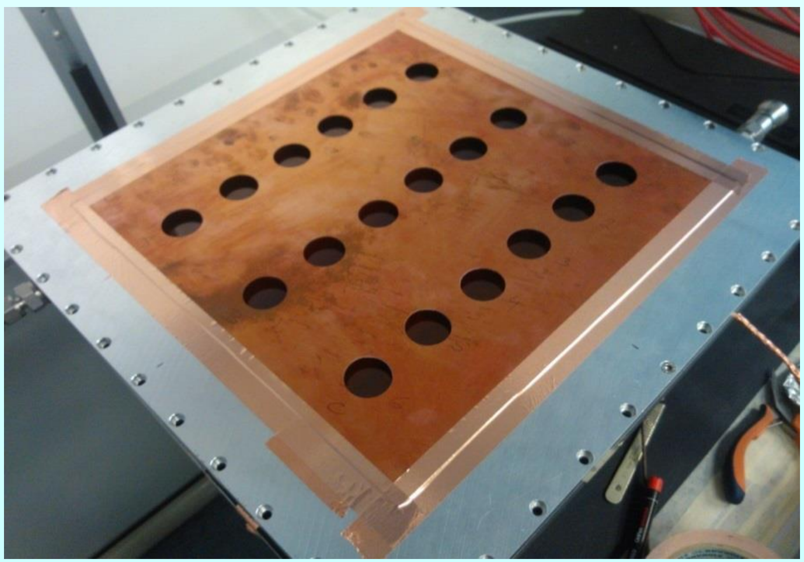
	A	B	C
1			
2		1137	
3			
4			
5	312	335	350
6	581	474	

work in progress

Local characterization of the sectors

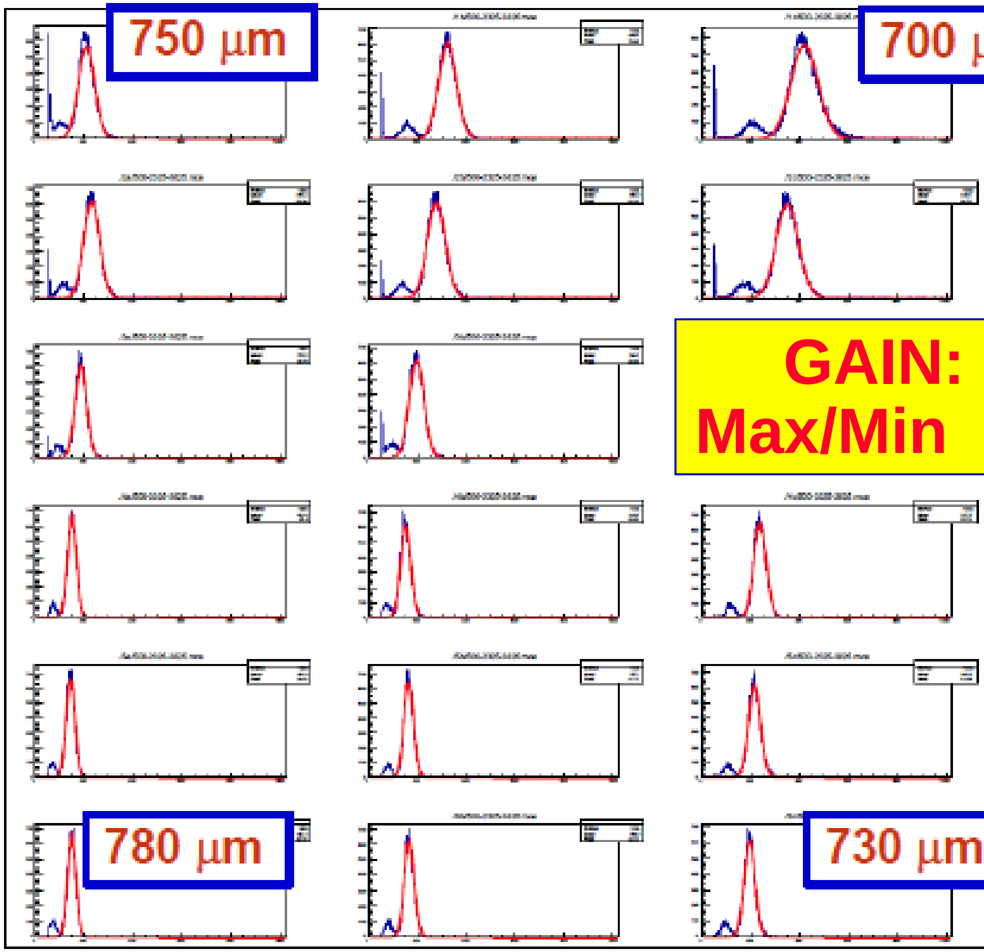




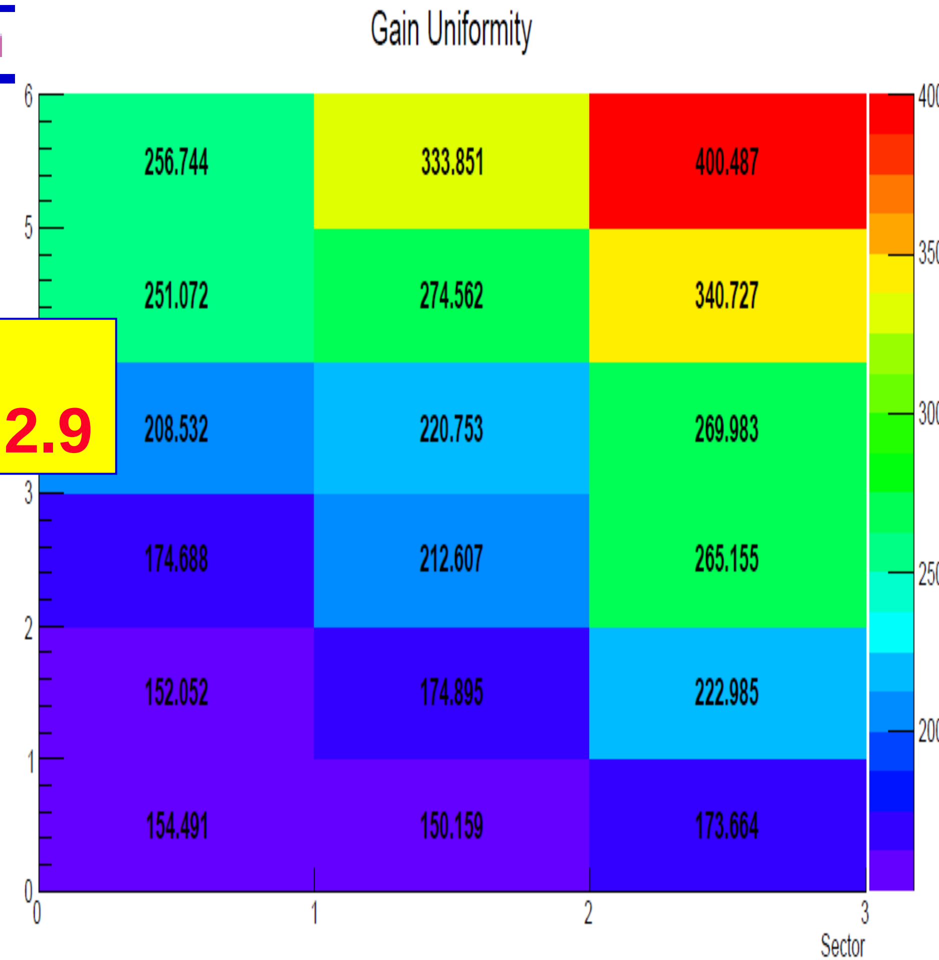


Gain uniformity and thickness uniformity

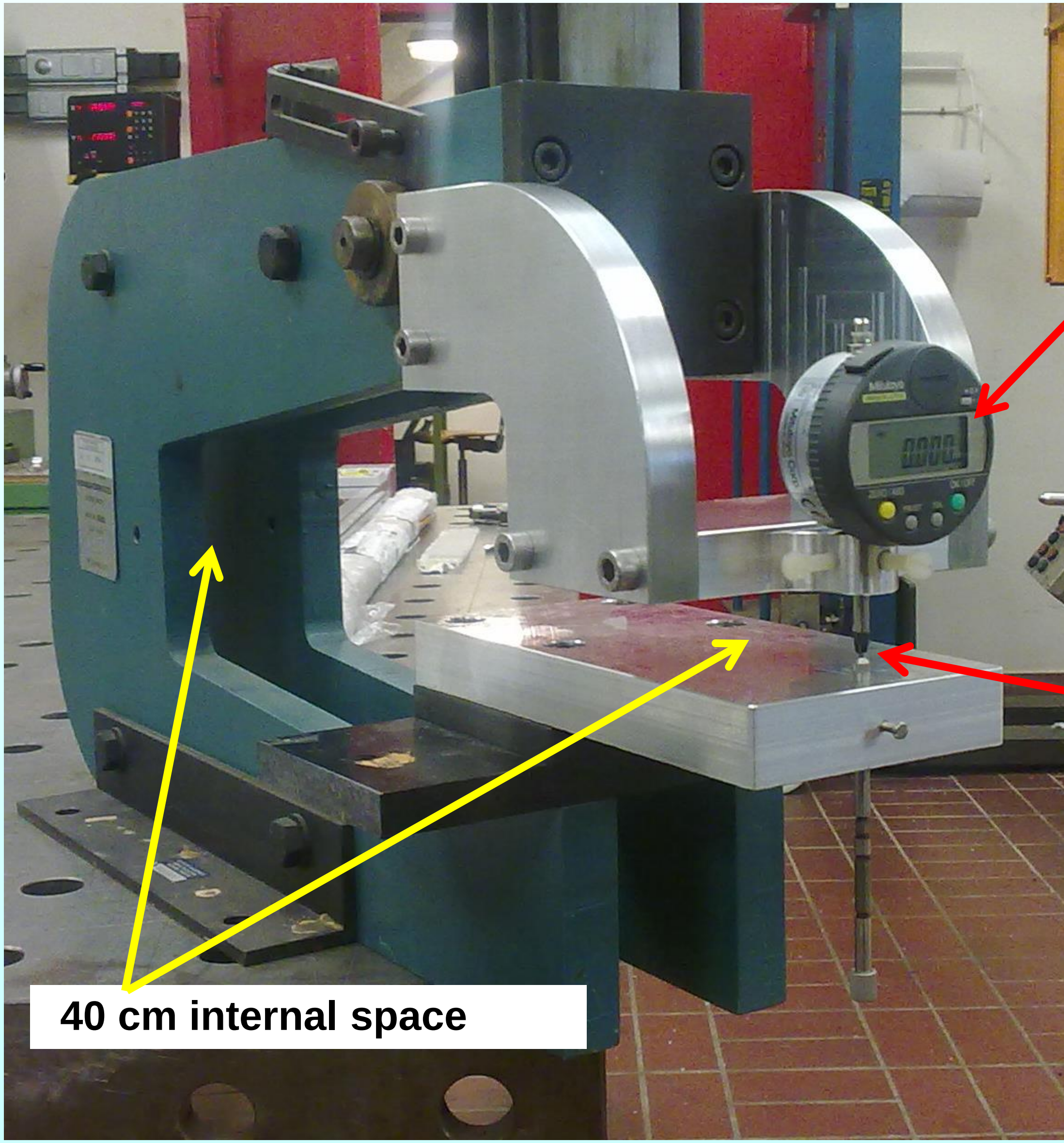
Systematic measurements of 300 x 300 mm² THGEMs (source: ^{55}Fe) :
Gain variations correlated with the thickness



GAIN:
Max/Min = 2.9



We decided to measure pcb thickness

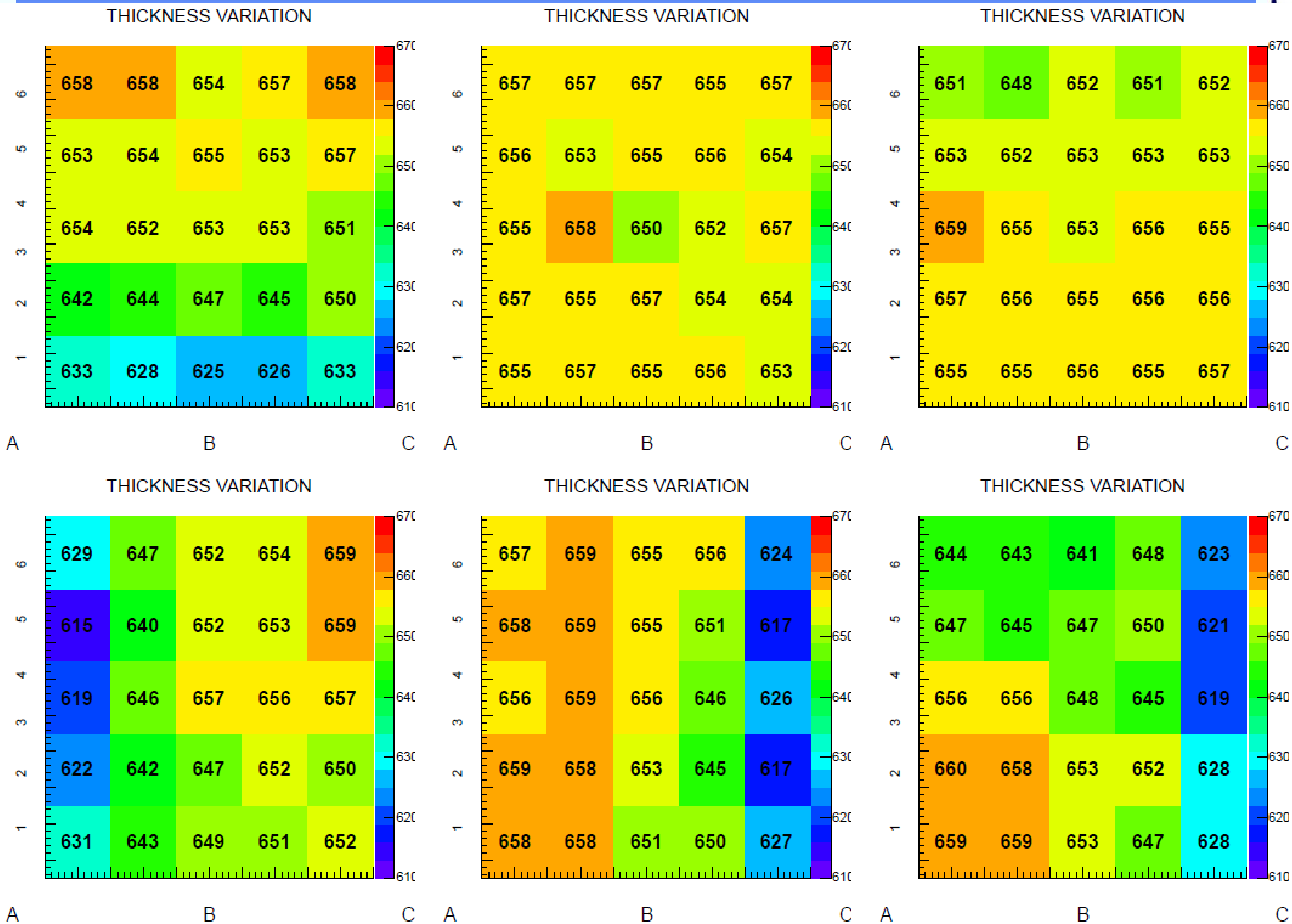


Mitutoyo digital micrometer

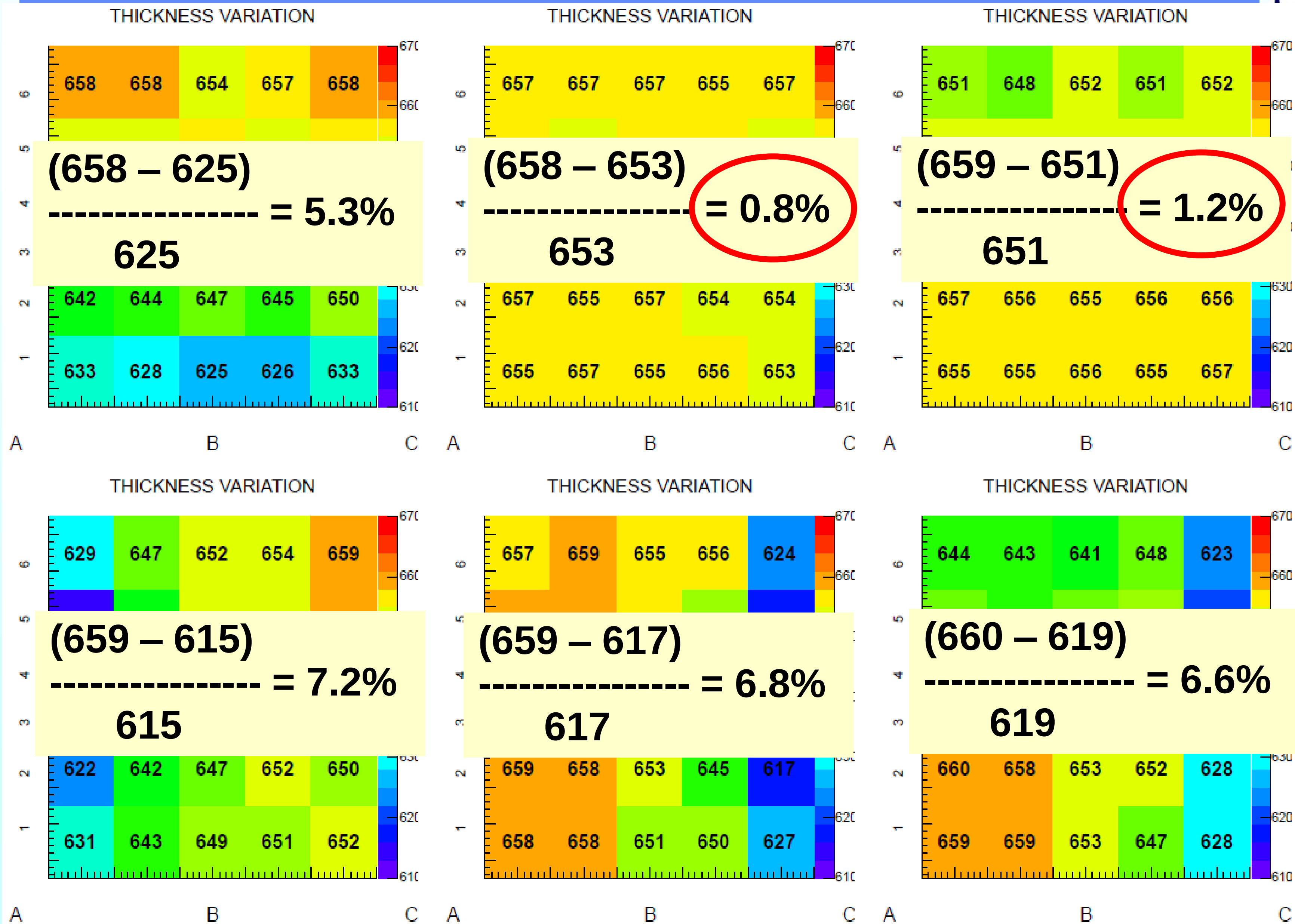
“aligned” sphere to sphere contact: the THGEM is inserted here and the upper sphere is lowered down until it touches the piece.

40 cm internal space

25 points/piece (reading in microns)

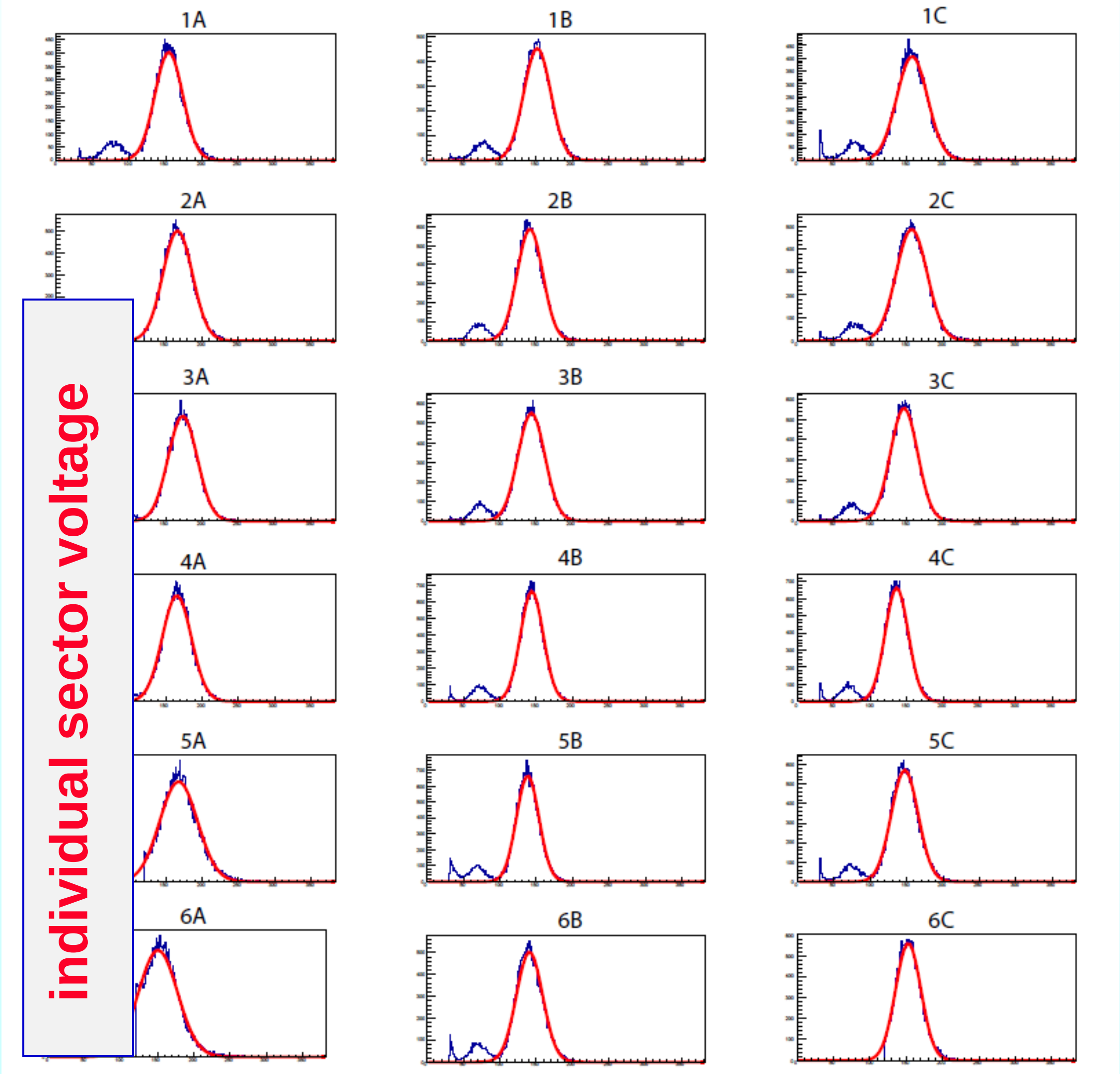


Relative variations are quite different



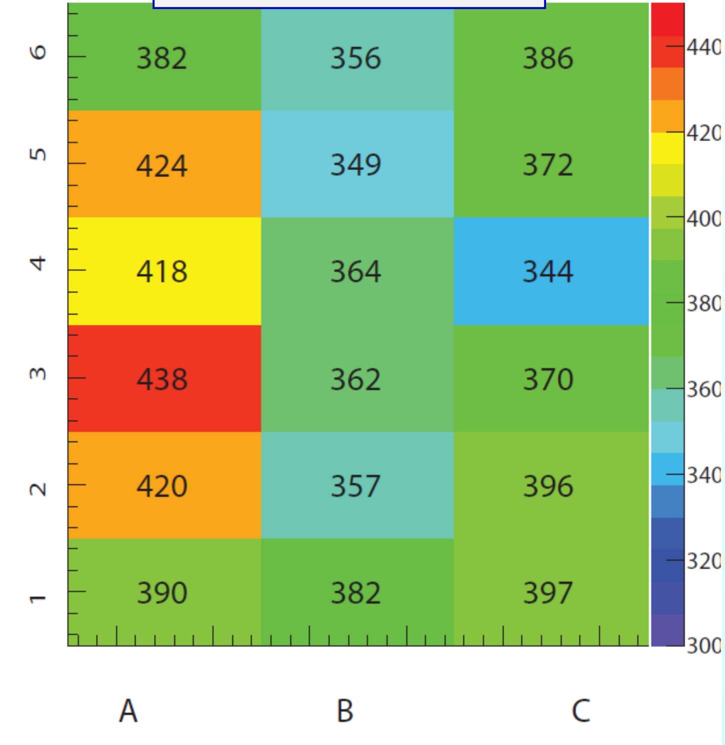
Relative variations are quite different

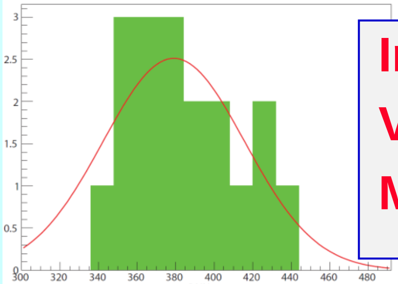
Same voltage on all sectors: GAIN Max/Min = 1.6



individual sector voltage

Effective gain



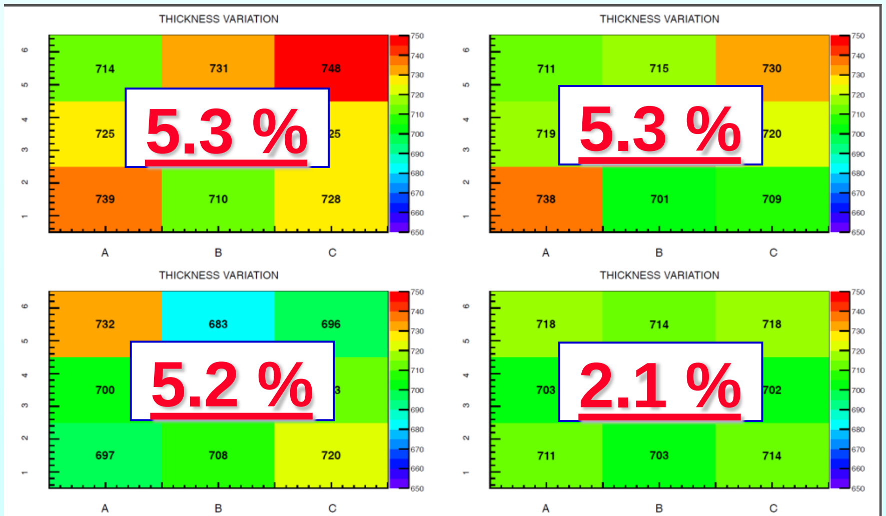


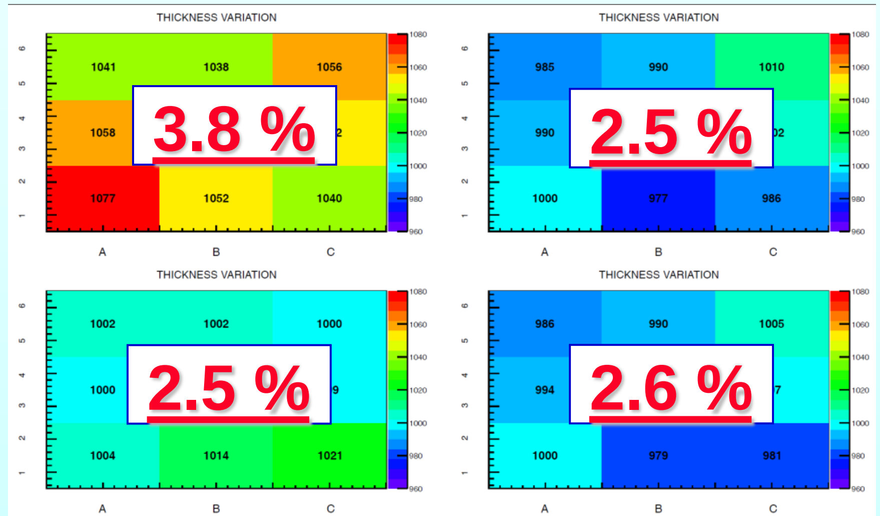
Individual Voltages: GAIN Max/Min = 1.25

THGEM production using non pcb material

- **Different material:**
  - **Permaglas (from RESARM, Belgim), machinable (~ Stesalite)**

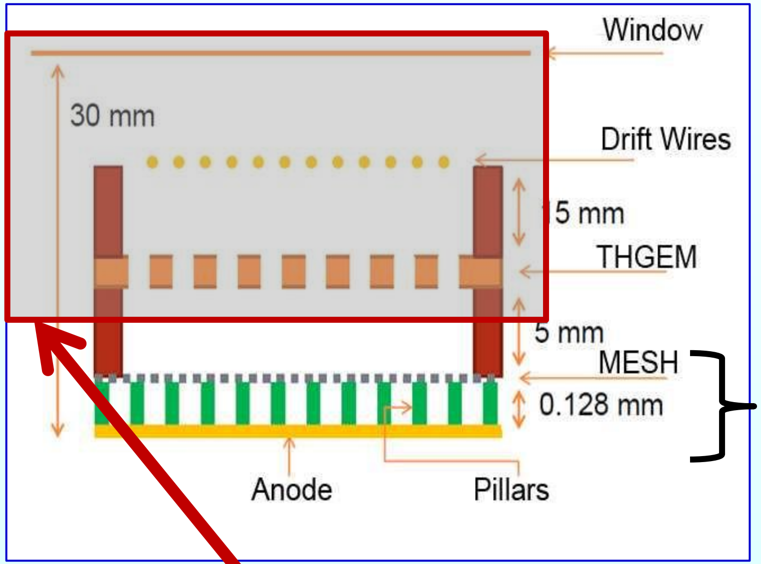
Thickness: 0.8 mm | **Thickness: 1 mm**





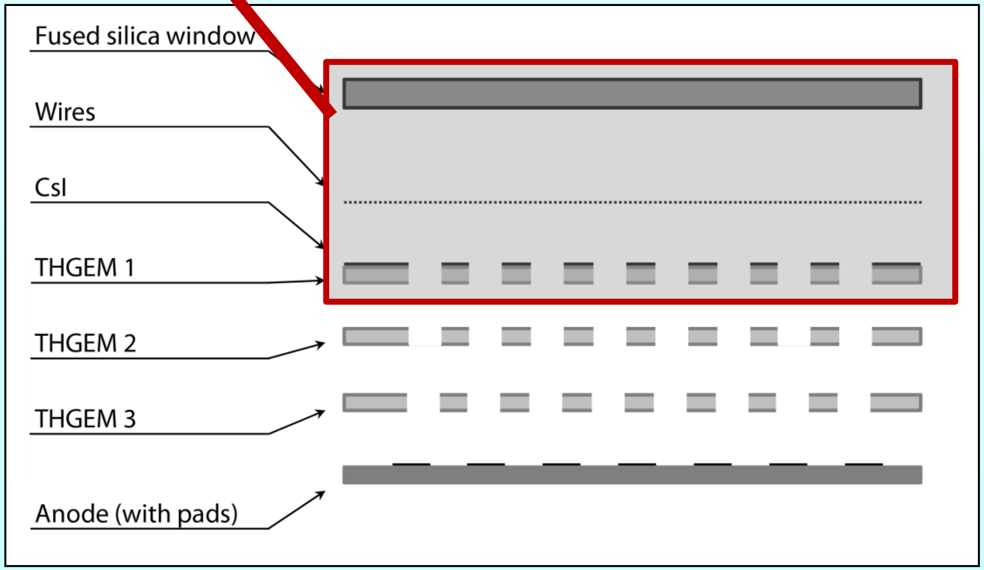
- **Machining foreseen to increase thickness uniformity**
- **Cu layer could not be easily glued with standard pre-preg**
- **Glueing done by Rui de Olivera.**

Hybrid THGEM + Micromegas PD



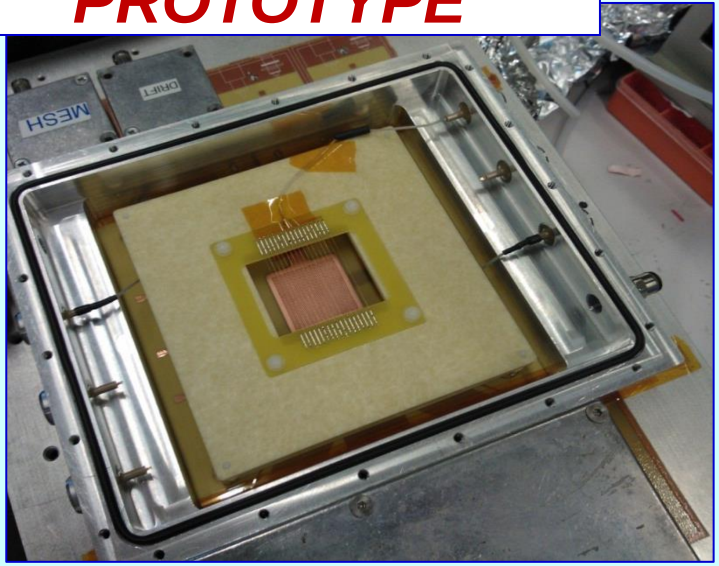
Hybrid detector

MICROMEGAS stage



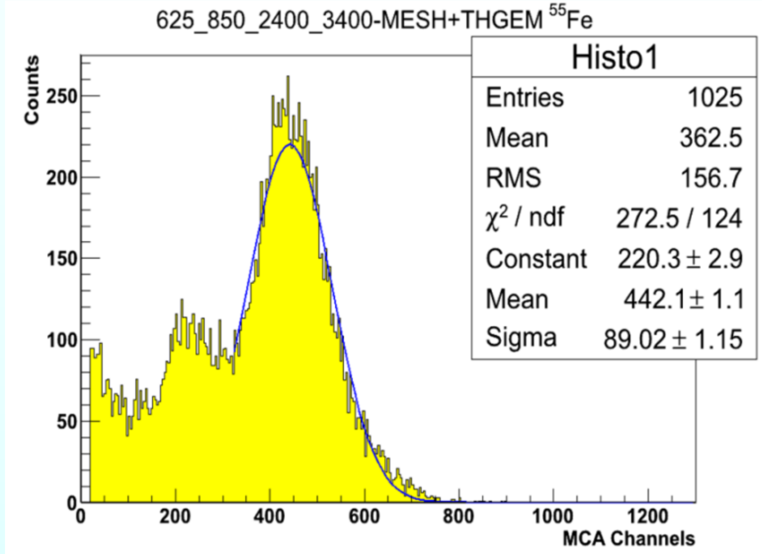

Bulk Micromegas: courtesy of Saclay COMPASS colleagues

PRELIMINARY PROTOTYPE



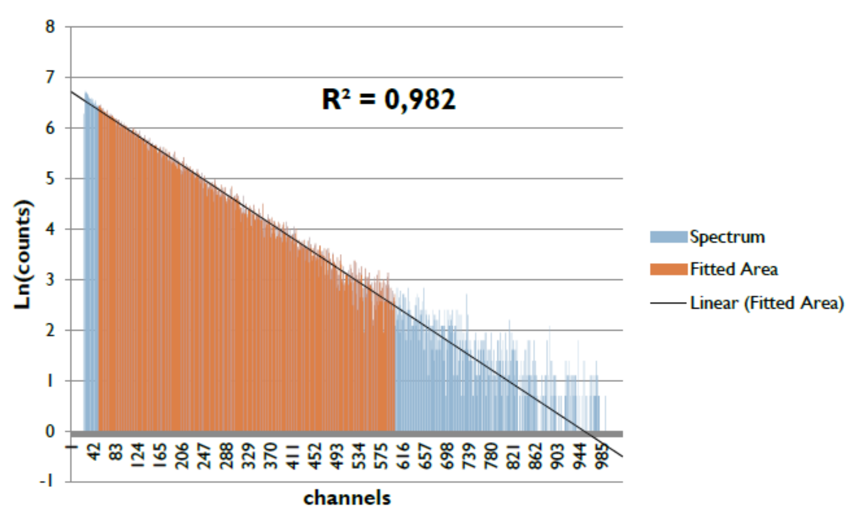
Very promising hints

^{55}Fe source



V_{mesh} = 625 V
E_{trans} = 450 V/cm
ΔV = 1550 V
E_{drift} = 666 V/cm
ER = 47%
Gain = 250 k

Pulsed UV source (single photoelectron mode)



Gain ≈ 1.7E6

V_{mesh} = 600 V
E_{trans2} = 625 V/cm
ΔV_2 = 1450 V
E_{trans1} = 967 V/cm
ΔV_1 = 1410 V
E_{drift} = 0 V/cm

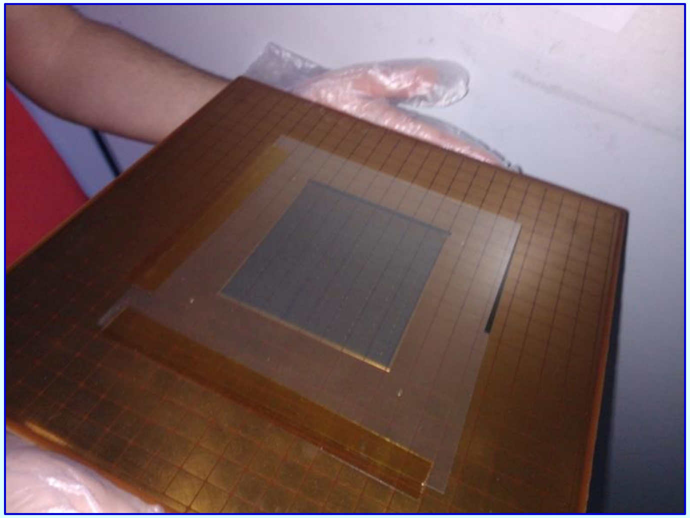
Rate ≈ 771 Hz

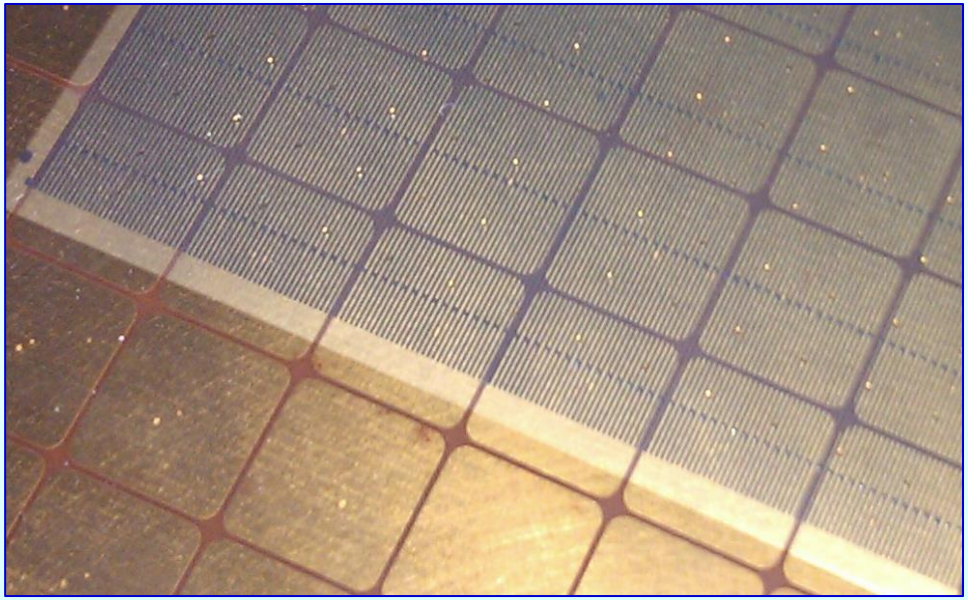
IBF: ~ 4%

Next steps

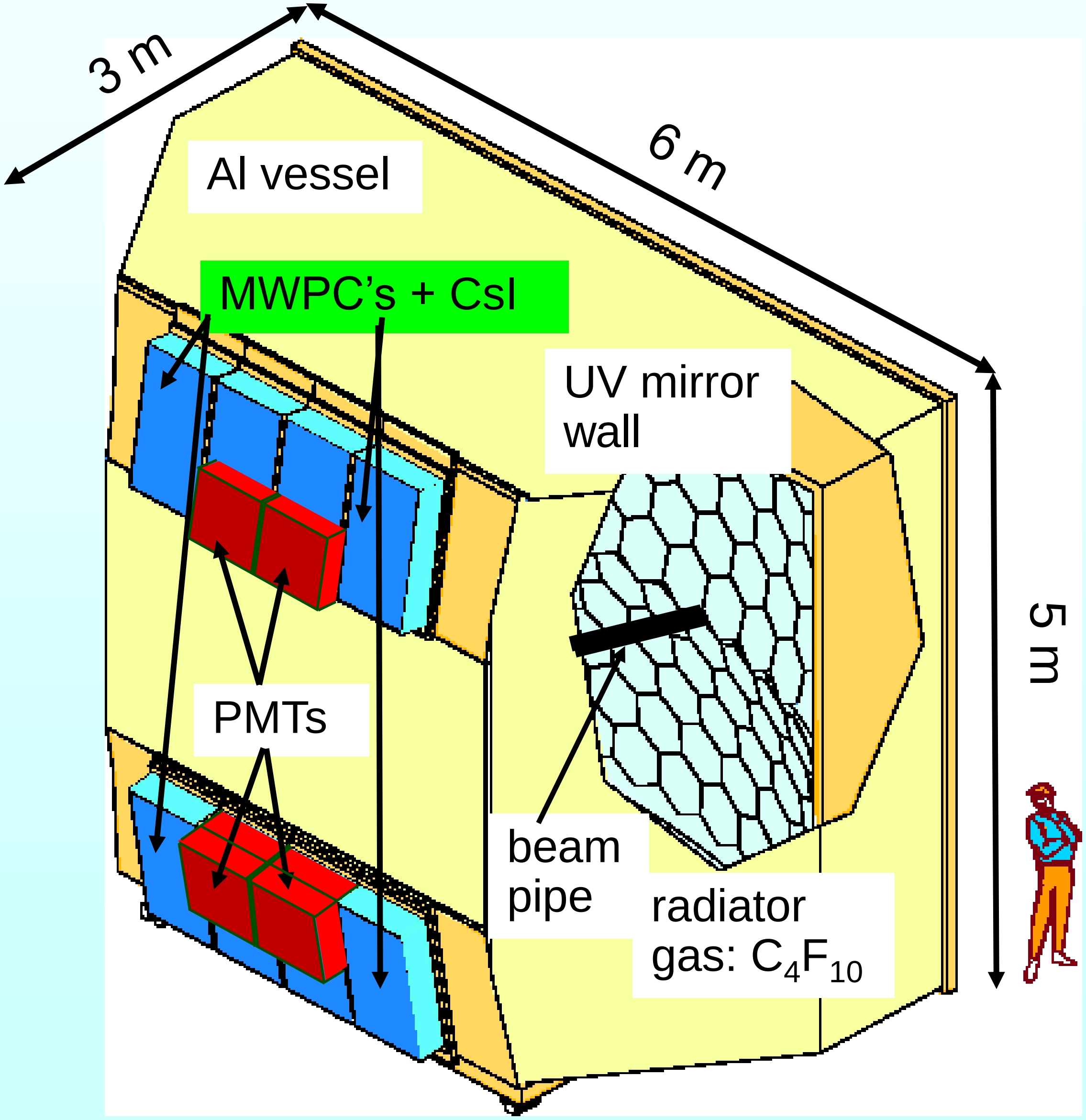
- **A first resistive anode produced by Rui obtained modifying an existing anode and using lithographic masks already available (useful surface: 100 x 100 mm^2)**

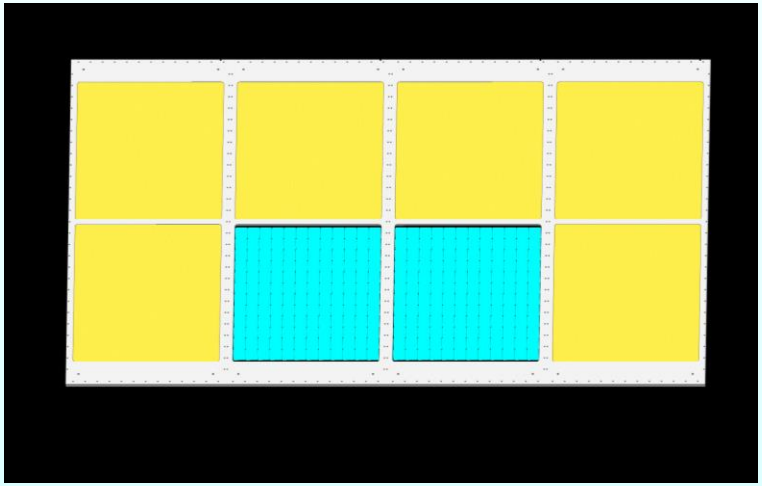
- **Mesh prepared at Seritech**

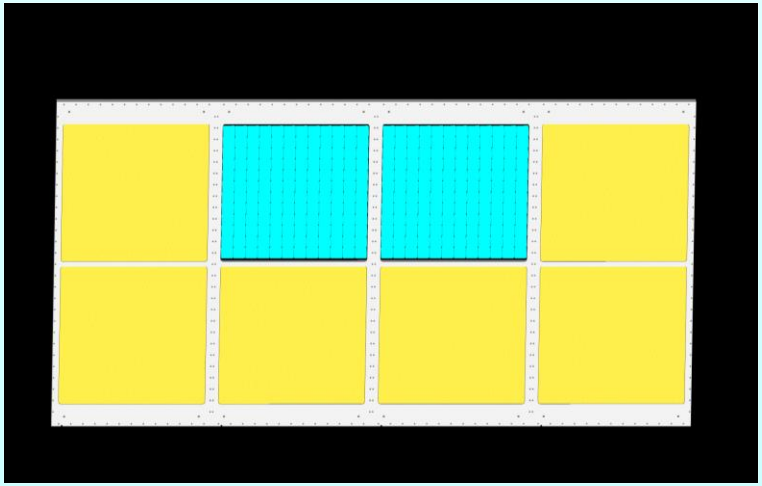




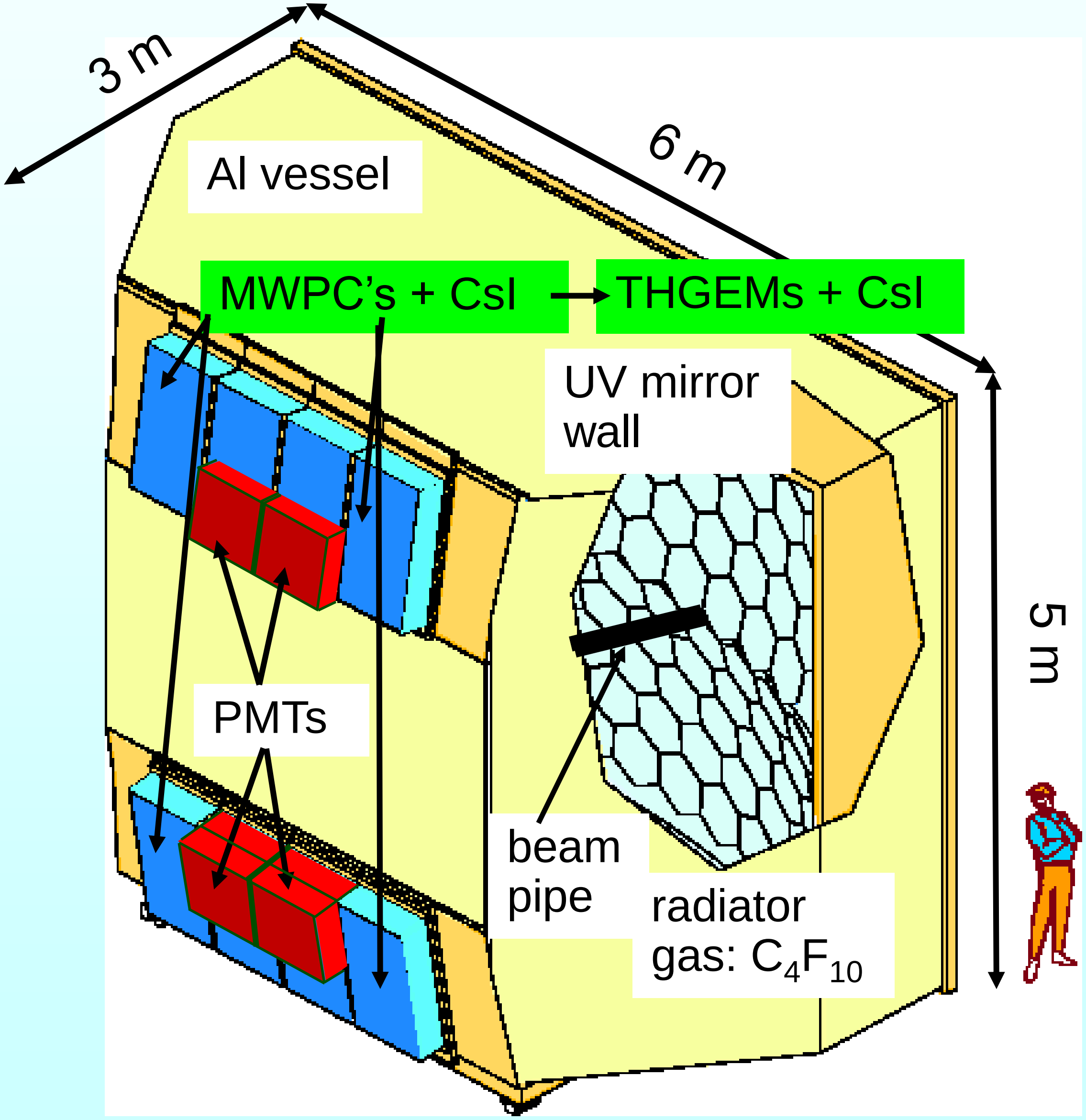
COMPASS RICH-1 PD upgrade



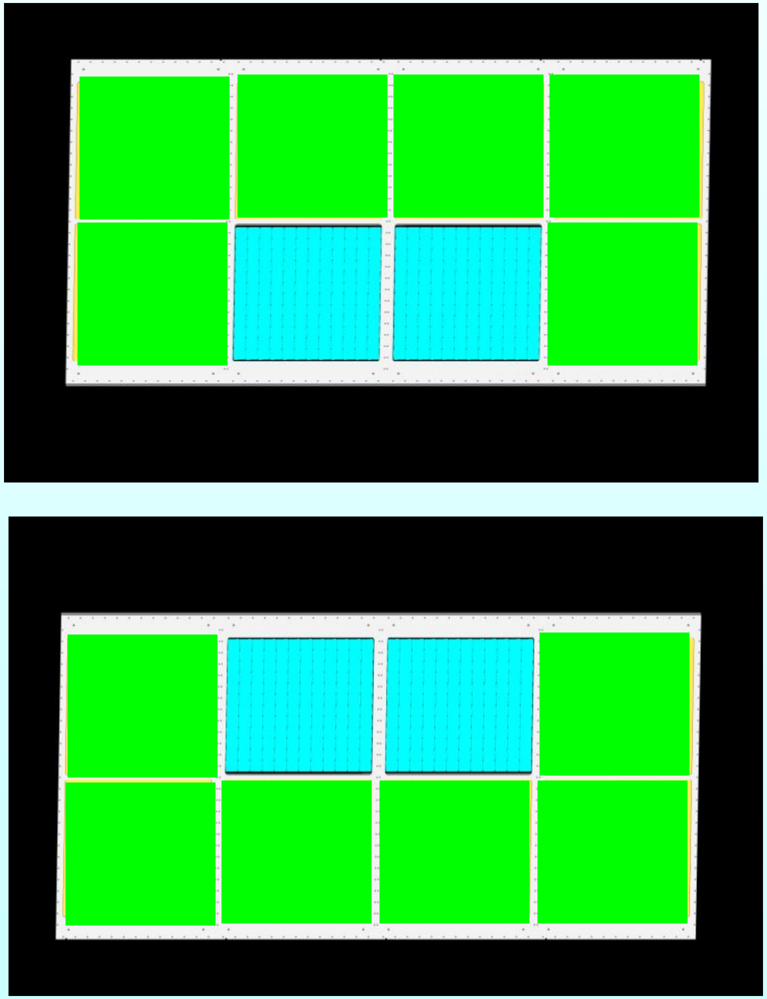




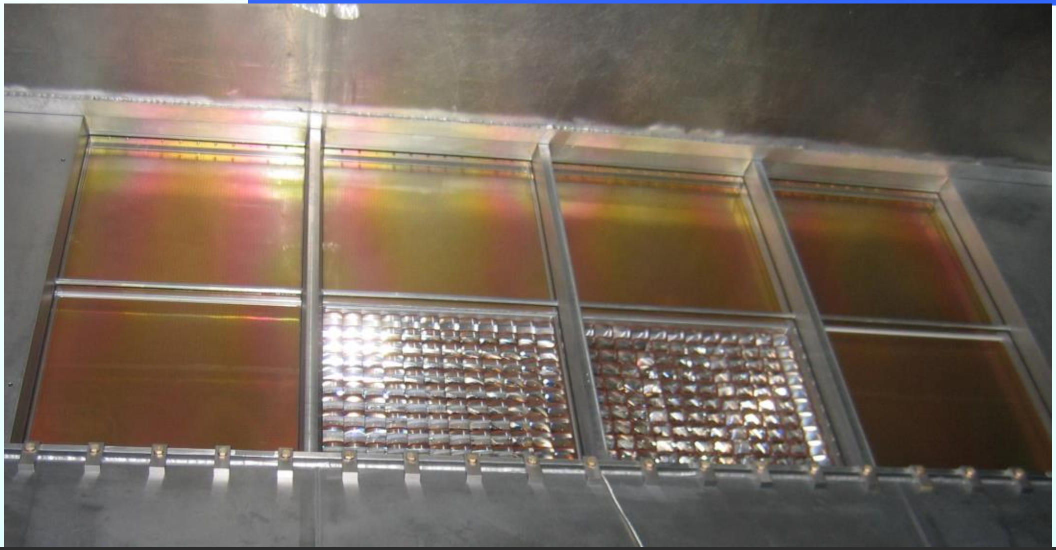
COMPASS RICH-1 PD upgrade

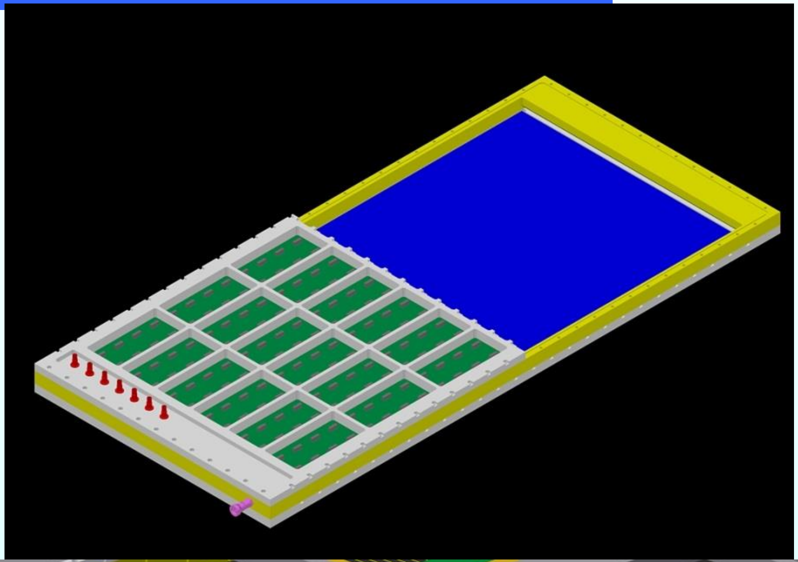


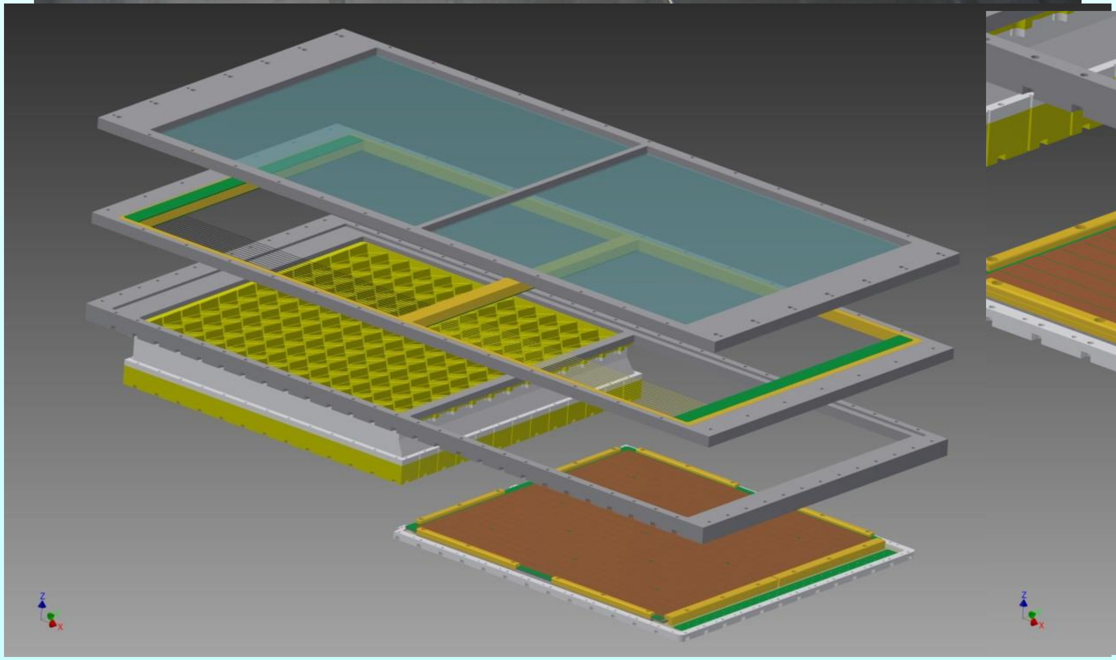
Foreseen for 2016-2017

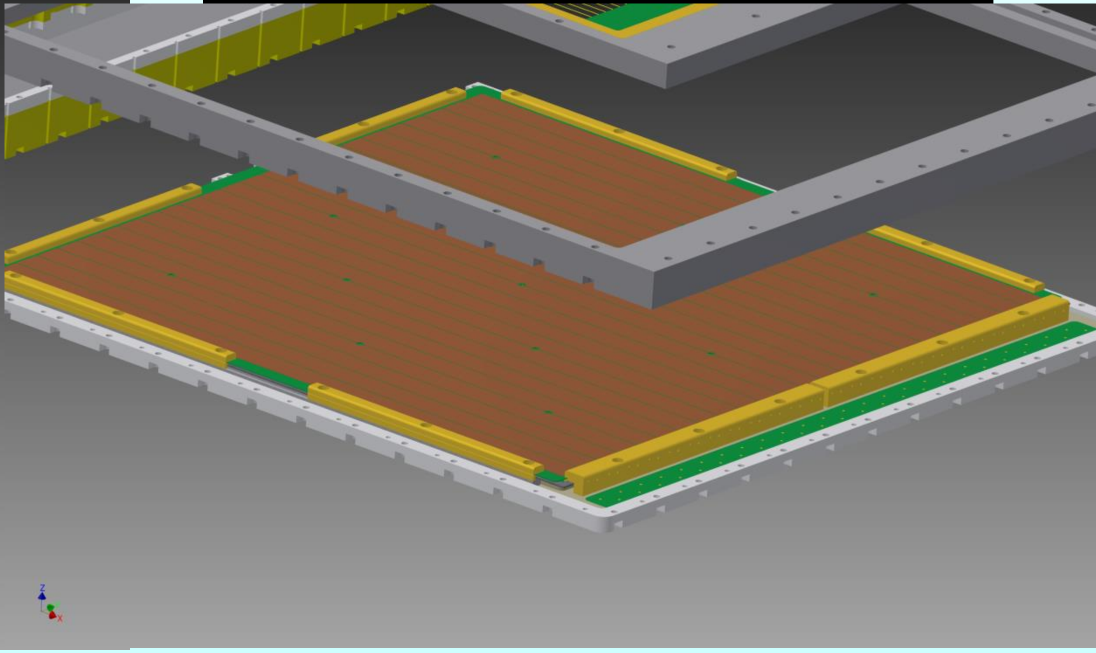


New PD's

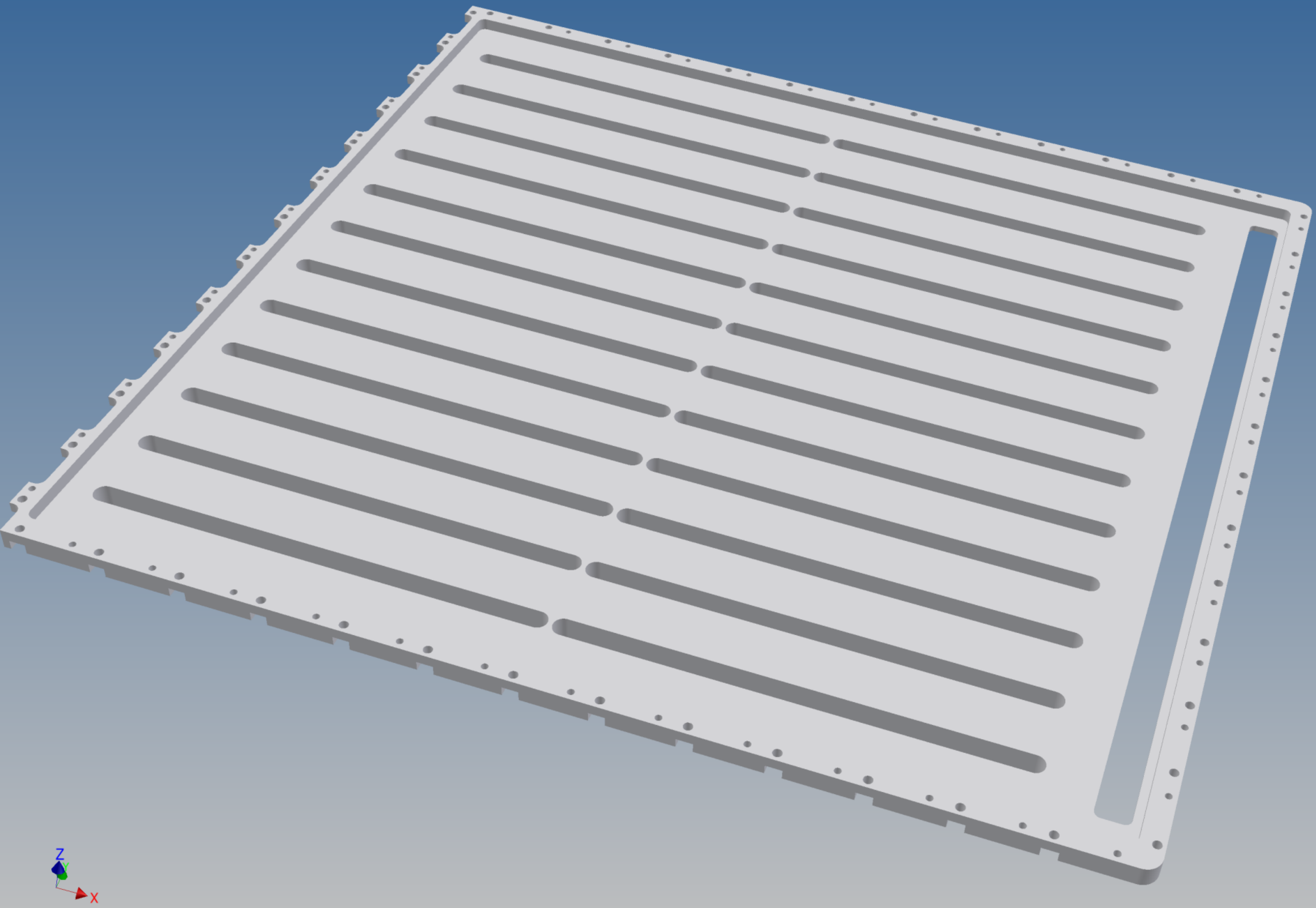




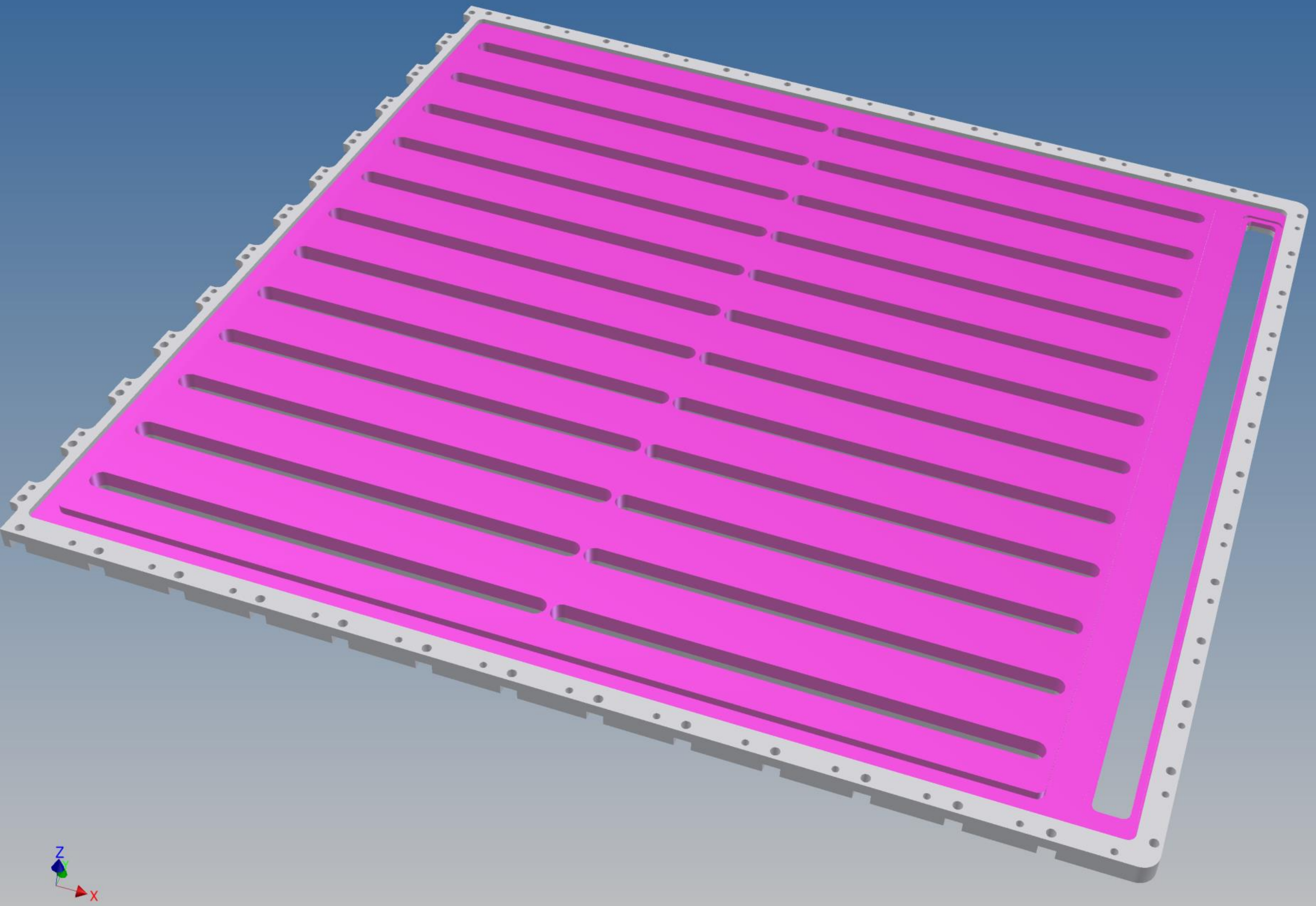




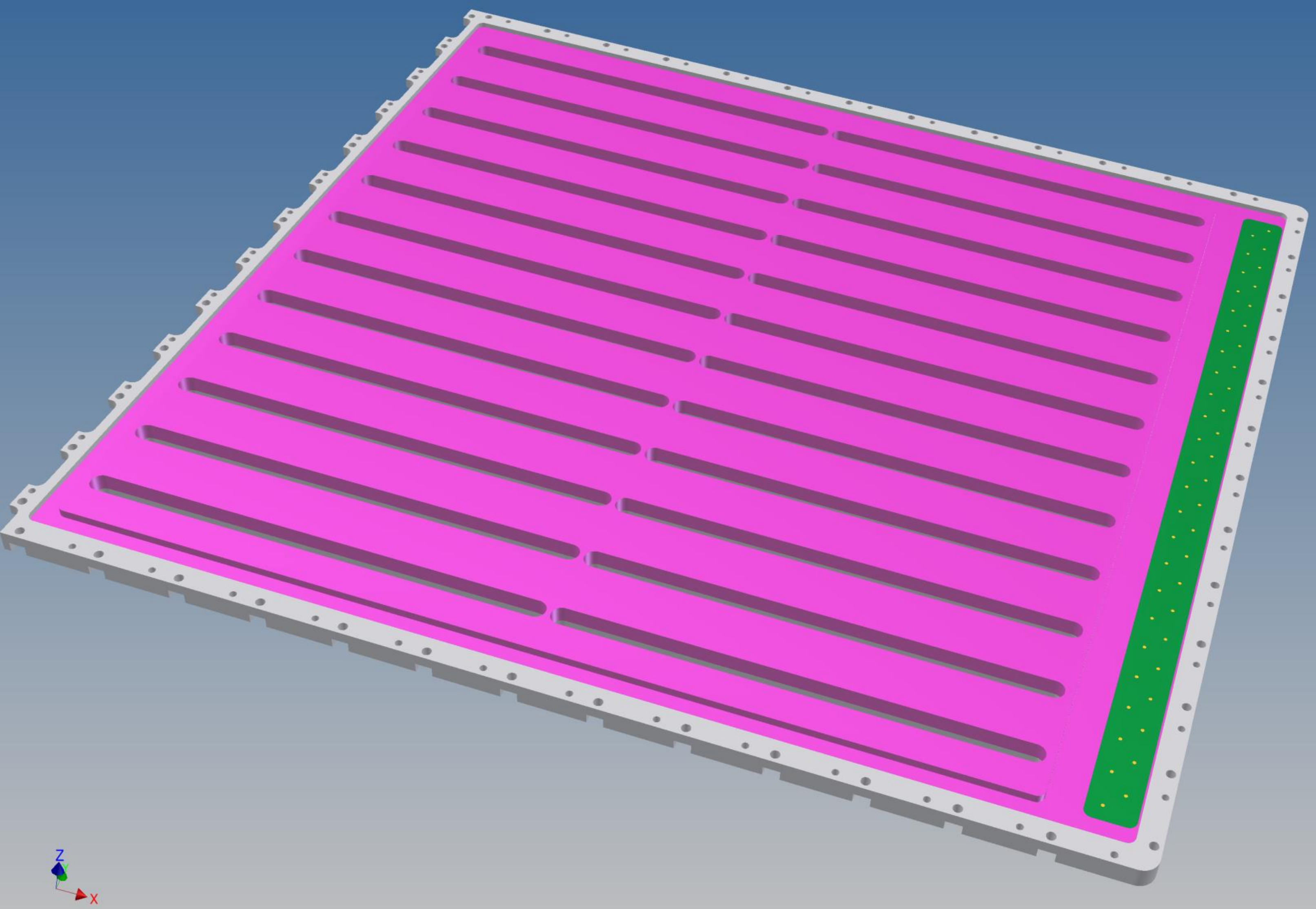
The THGEM+Micromegas version



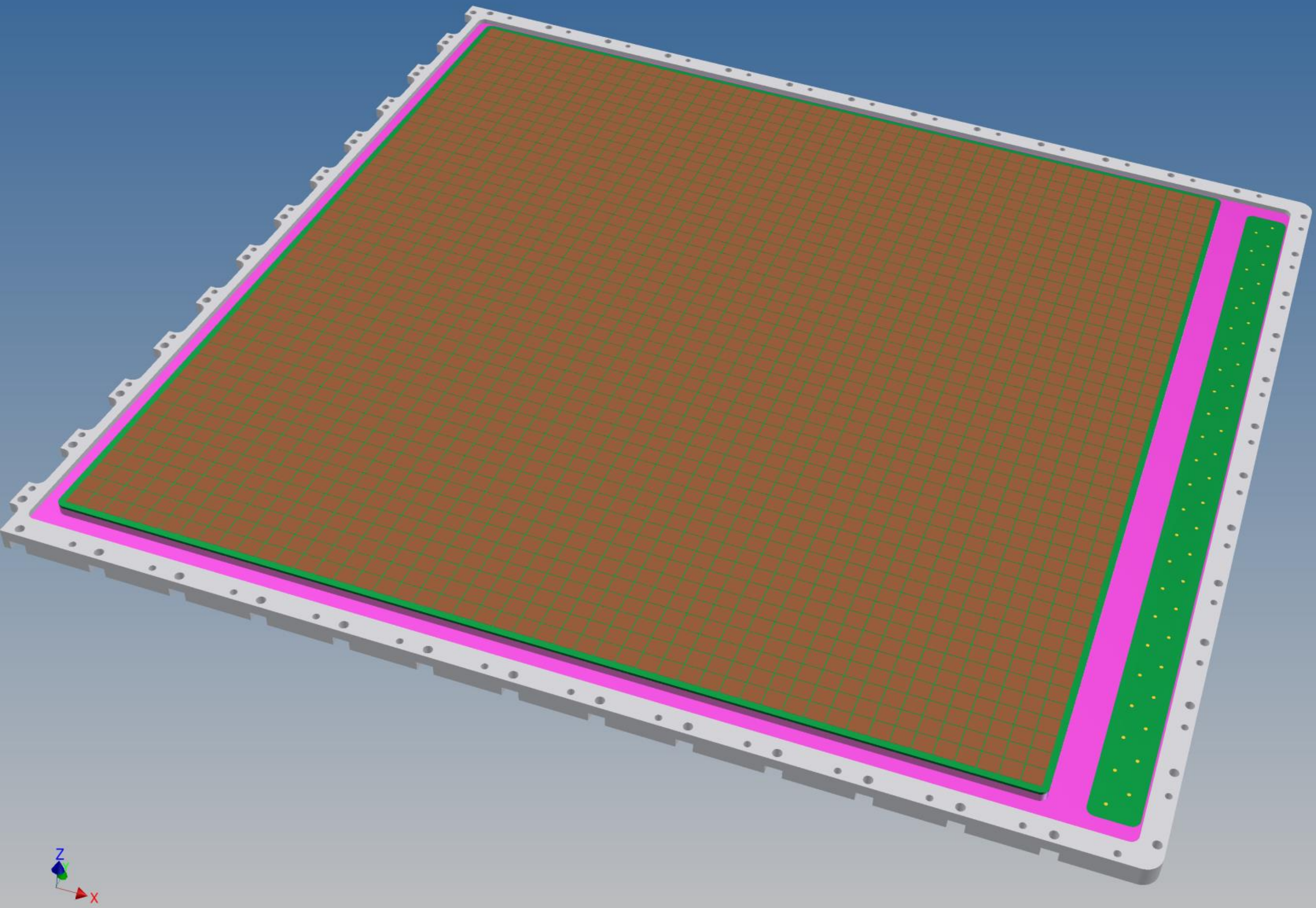
The THGEM+Micromegas version



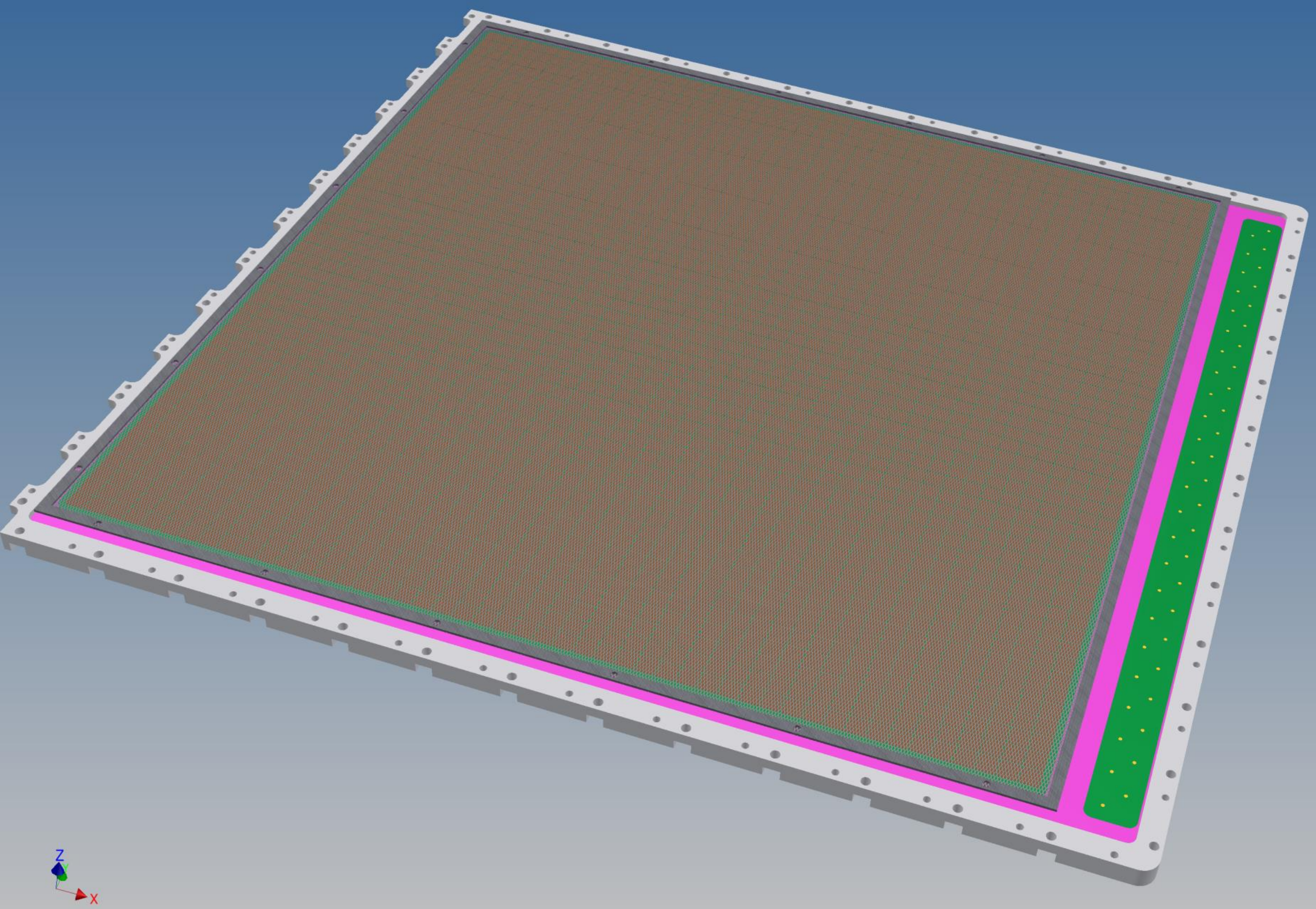
The THGEM+Micromegas version



The THGEM+Micromegas version



The THGEM+Micromegas version



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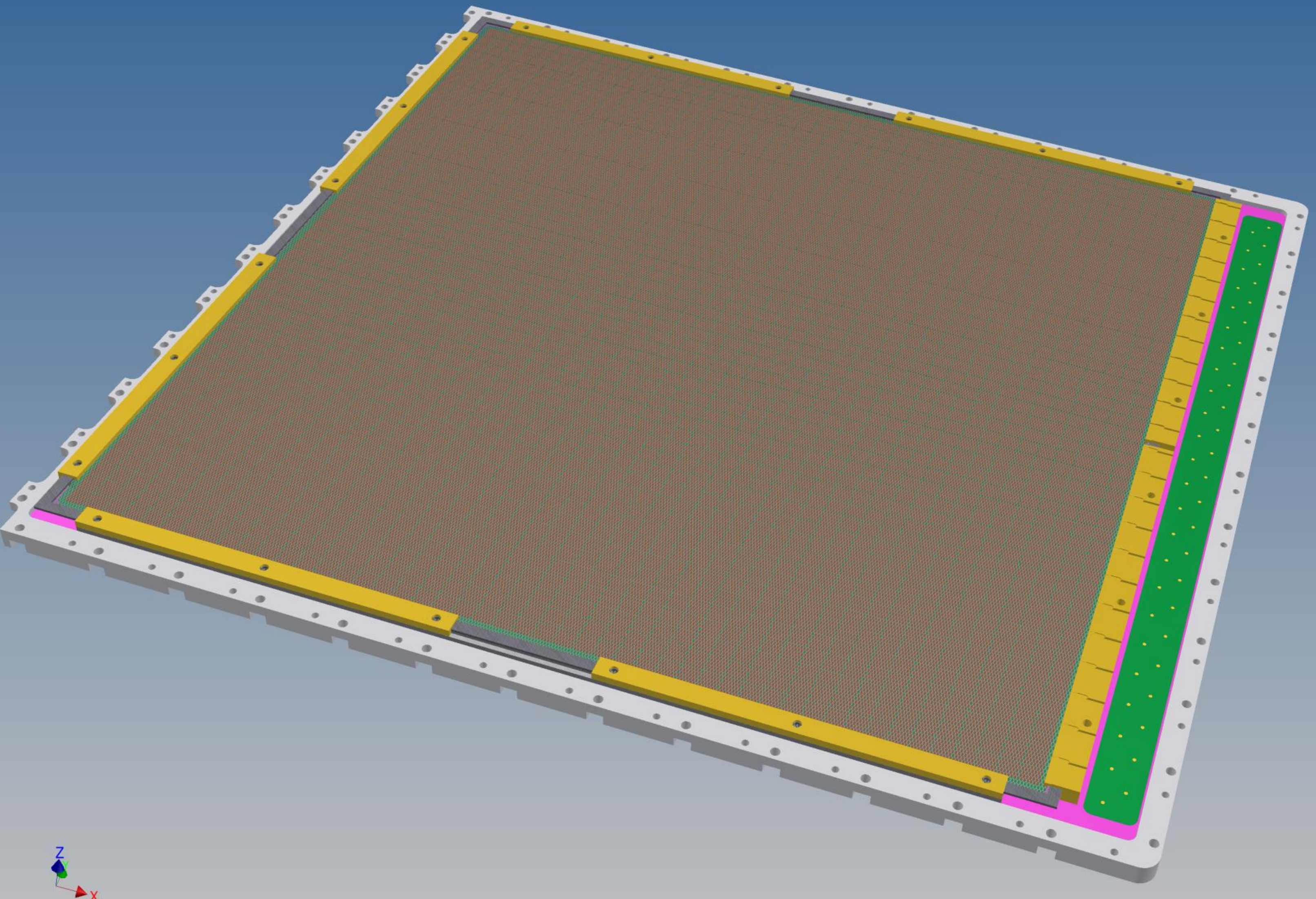
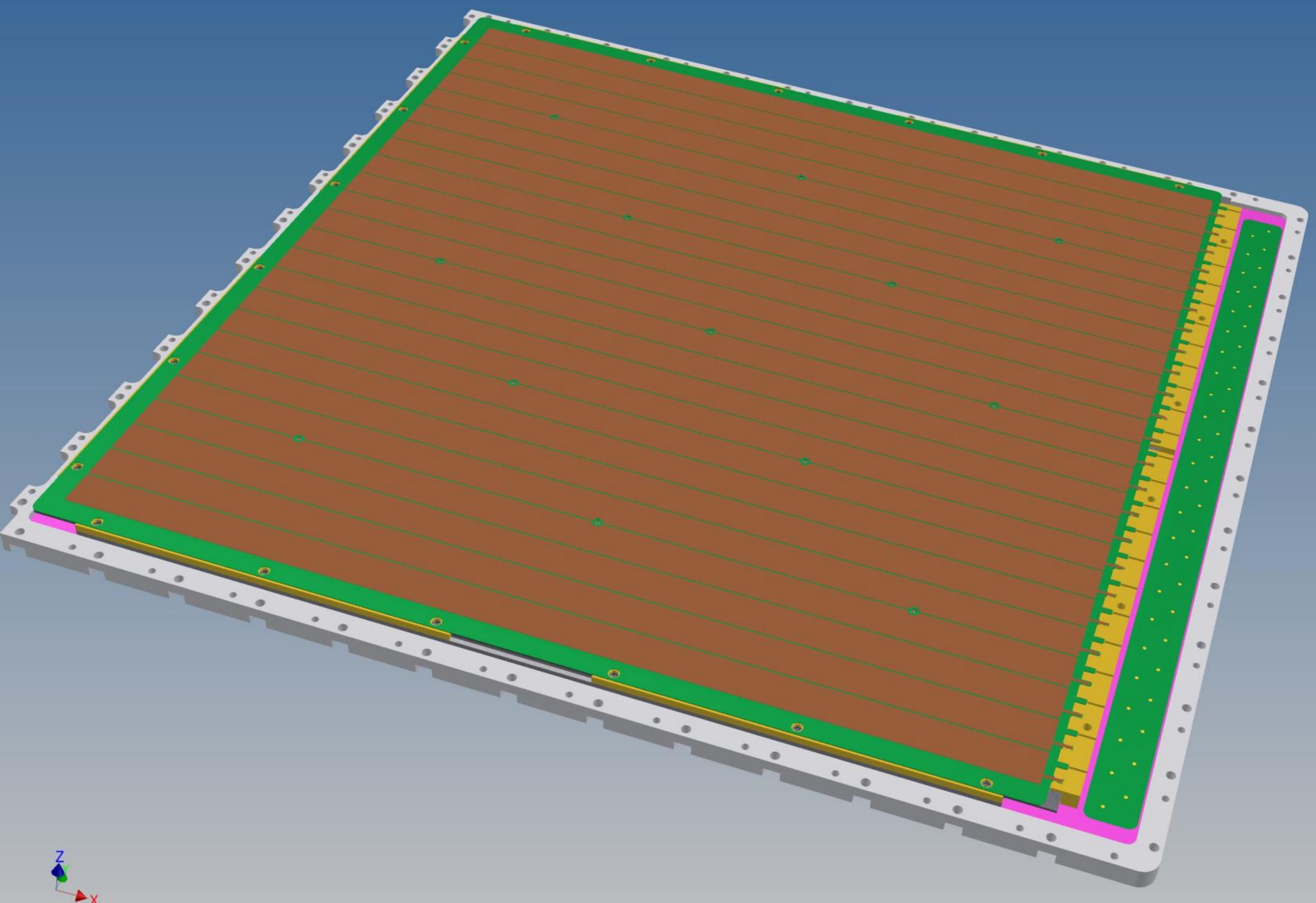
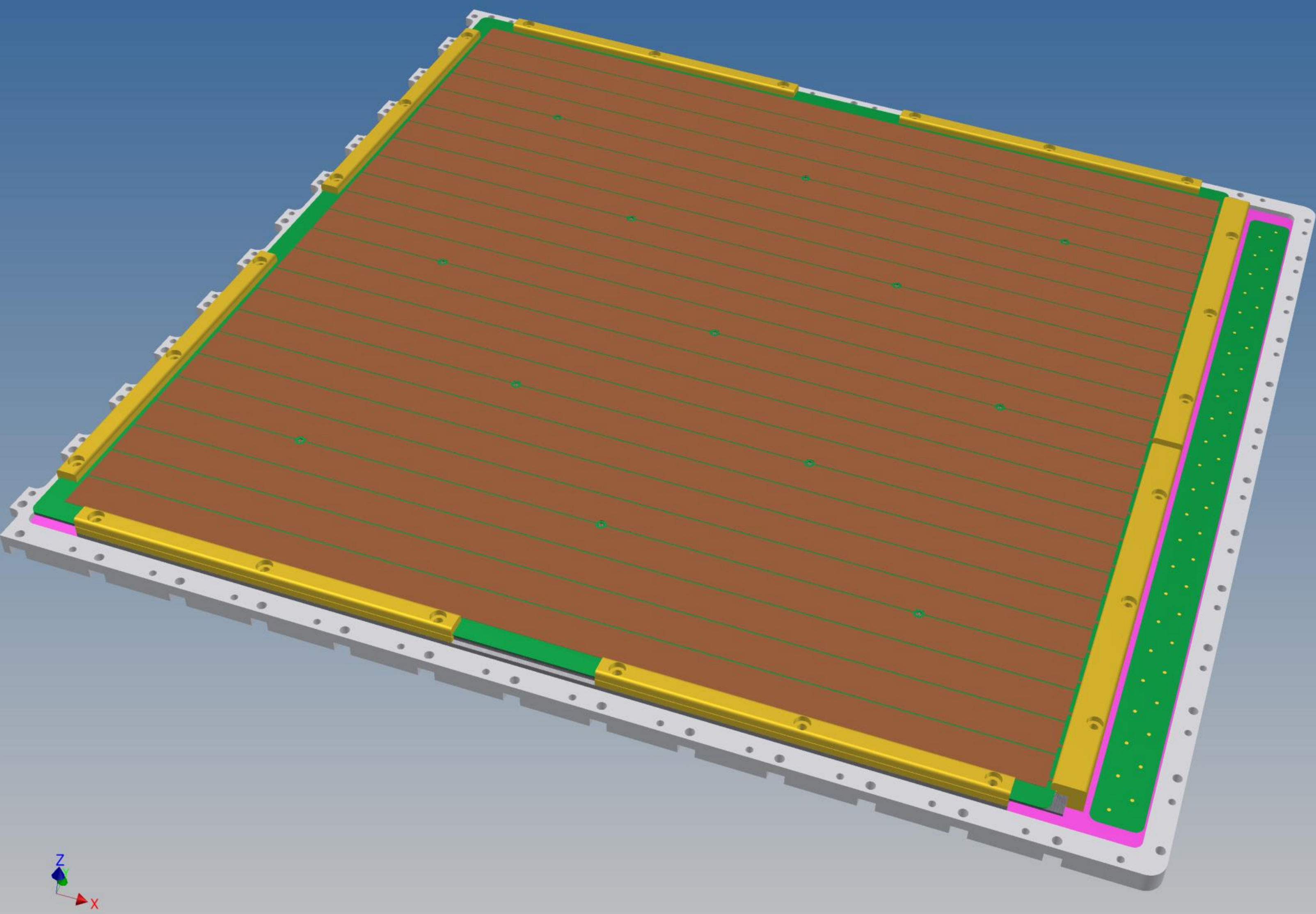


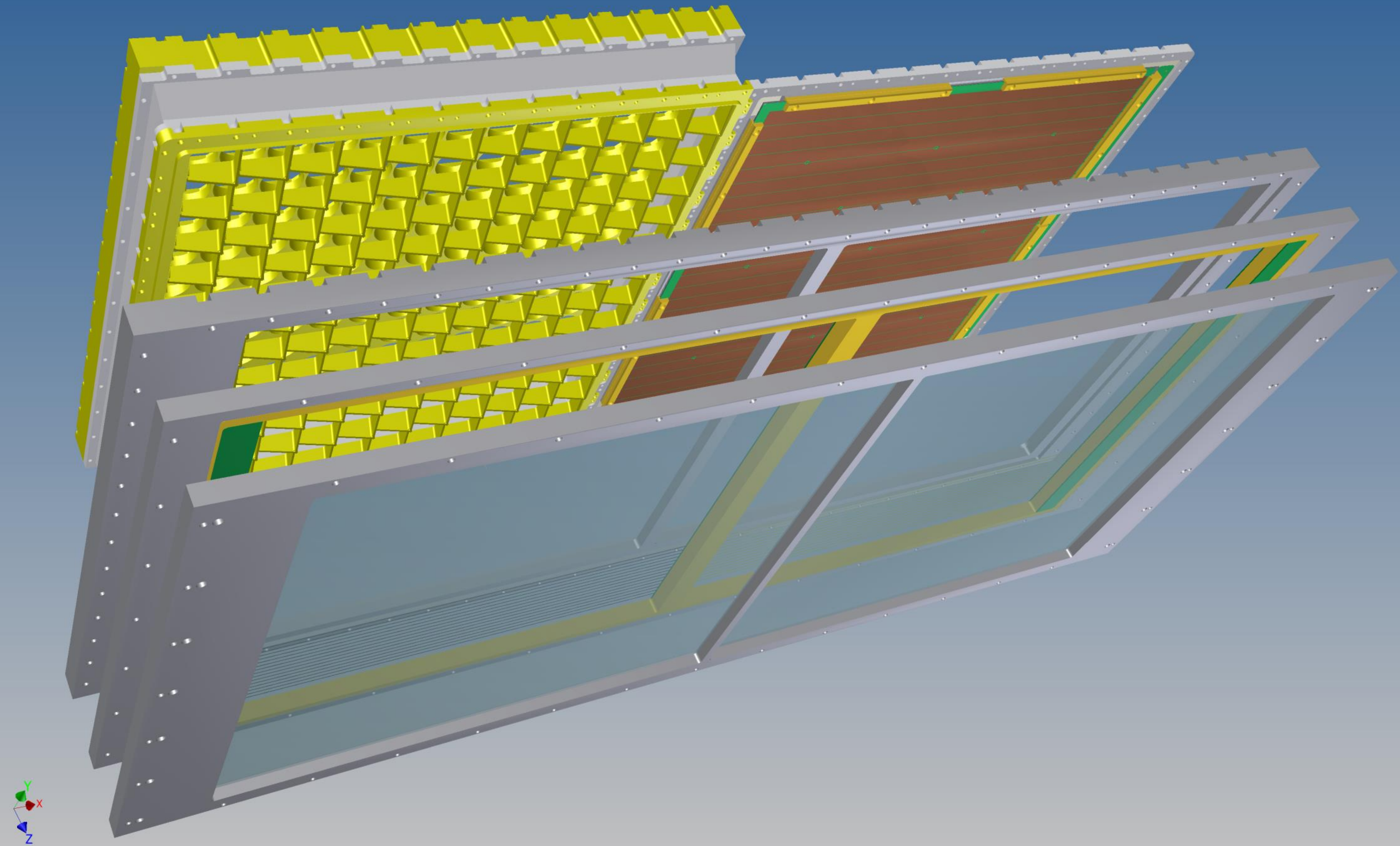
The THGEM+Micromegas version



The THGEM+Micromegas version



The THGEM+Micromegas version



CONCLUSIONS & OUTLOOK

- THGEMs represent a good choice for single UV photon detectors
- Many aspects have been validated and understood using small size prototypes:
- 300x300 mm^2 active area PD built and tested
- Major progress toward a full scale prototype for COMPASS
- Hybrid THGEM + Micromegas PD very promising
- RICH-1 upgrade mature and approved