Development of THGEM-based photon detectors for COMPASS RICH-1

Fulvio Tessarotto (I.N.F.N. – Trieste)

on behalf of an Alessandria, Aveiro, Freiburg, Liberec, Prague, Torino, Trieste Collaboration

COMPASS RICH-1

The choice of new THGEM-based PD's

Characterization and simulations

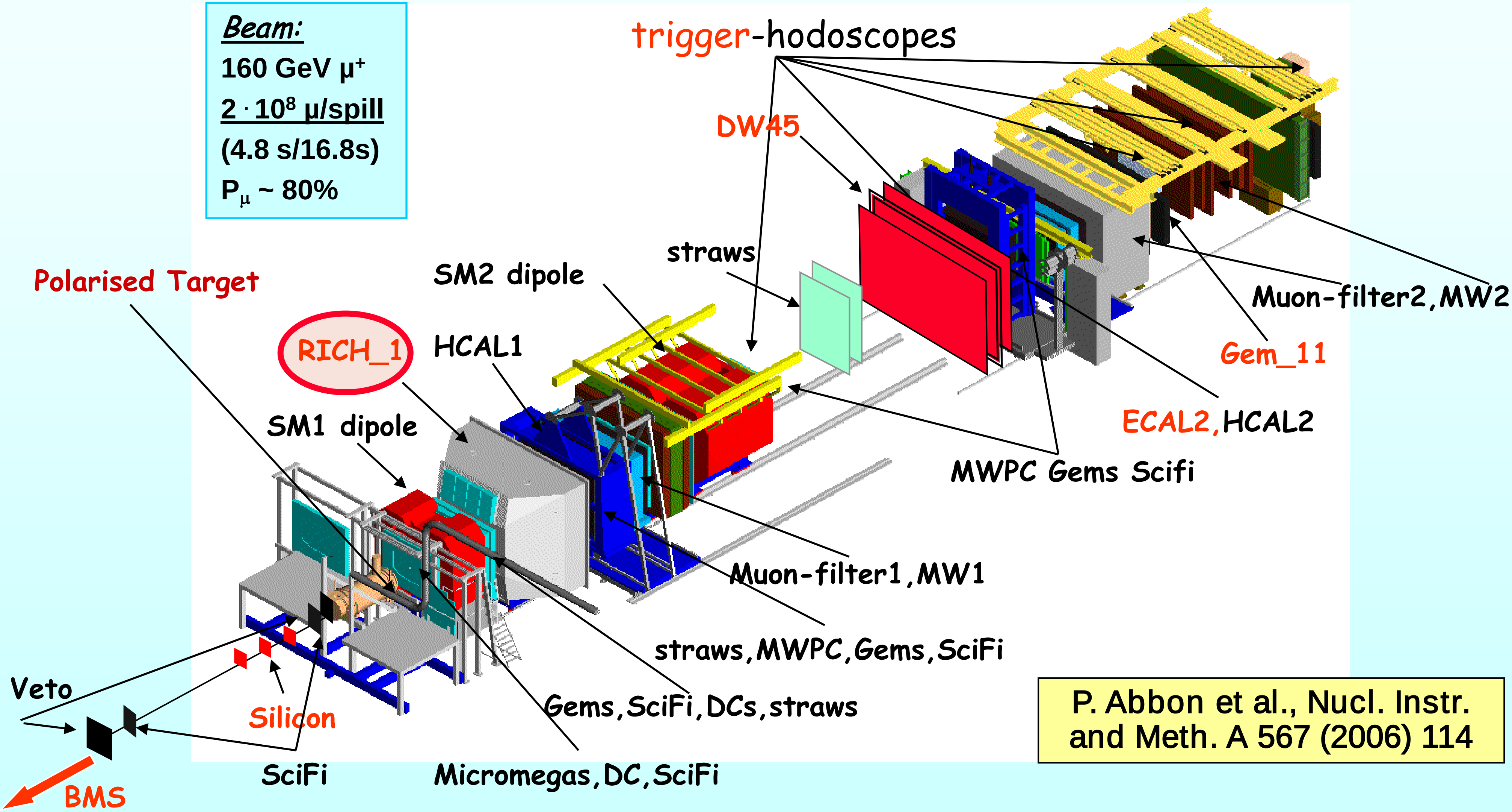
PD prototypes and test-beam results

Engineering problems and large size PD's

Conclusions

IN THE COMPASS SPECTROMETER

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



P. Abbon et al., Nucl. Instr. and Meth. A 567 (2006) 114

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

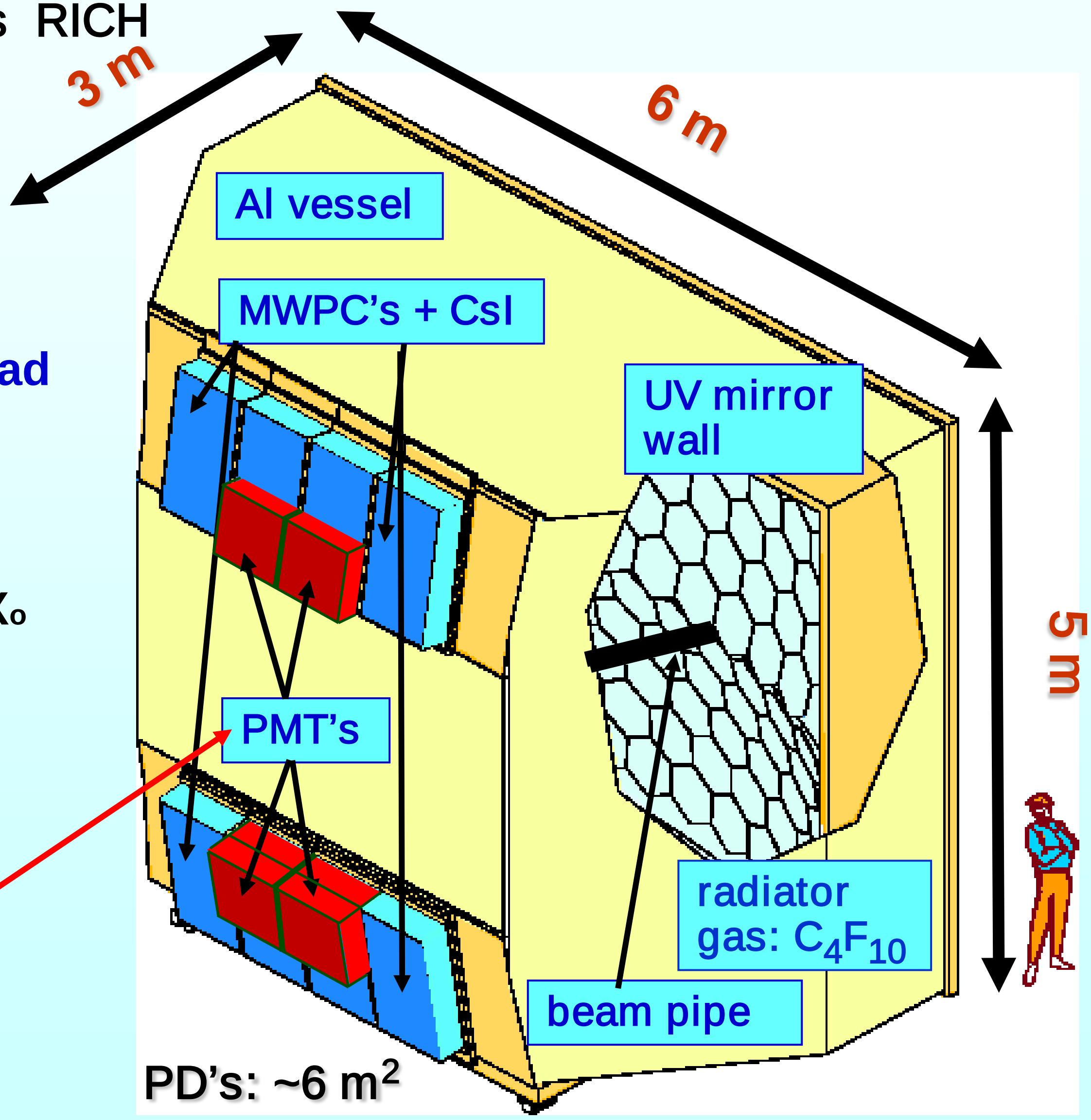
acceptance: H: 500 mrad V: 400 mrad

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

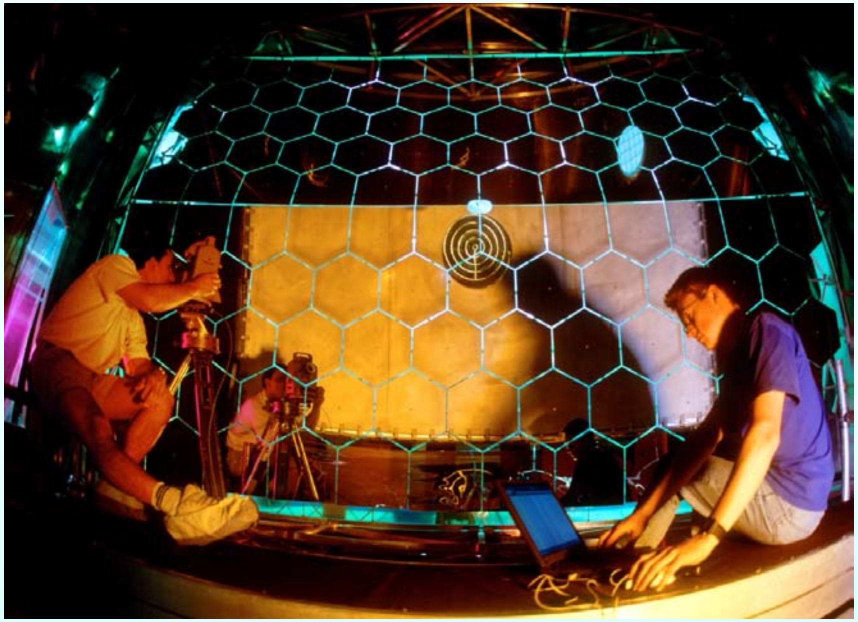
material in the beam region: 2.4% X_o
material in the acceptance: 22% X_o

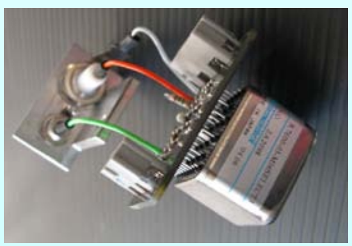
detector designed in 1996
in operation since 2002
first PD upgrade in 2006

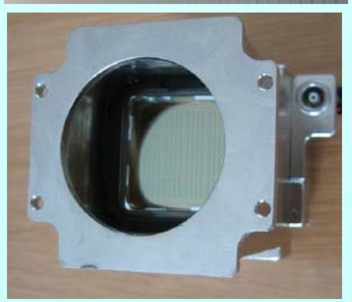
(total investment: ~ 4 M €)

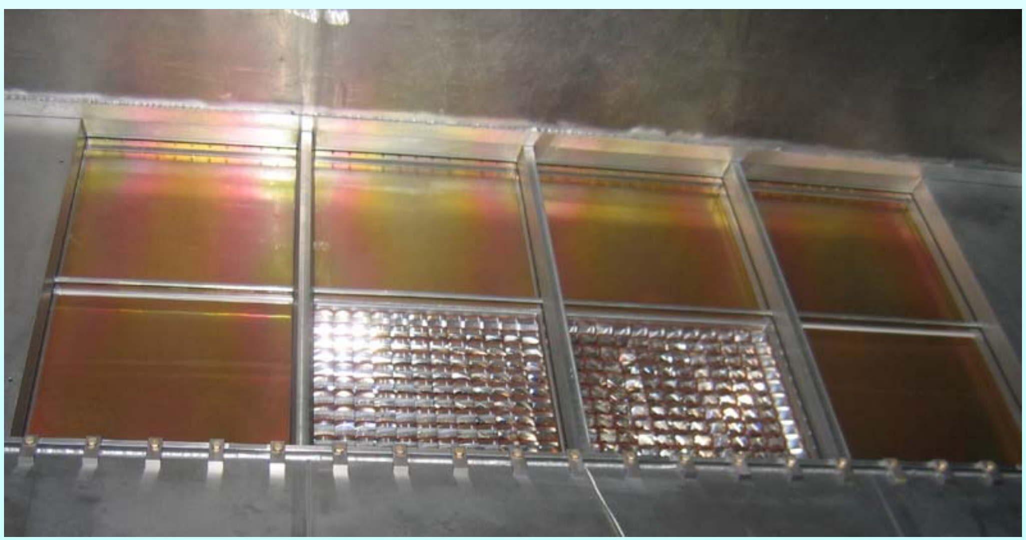


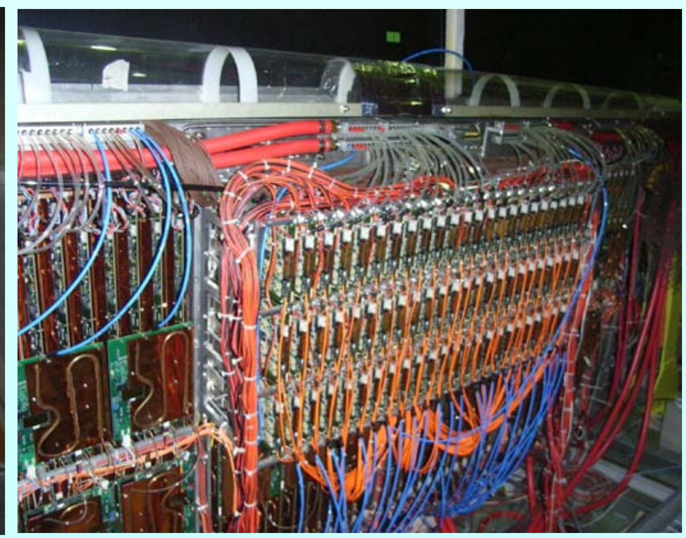
COMPASS RICH-1 elements



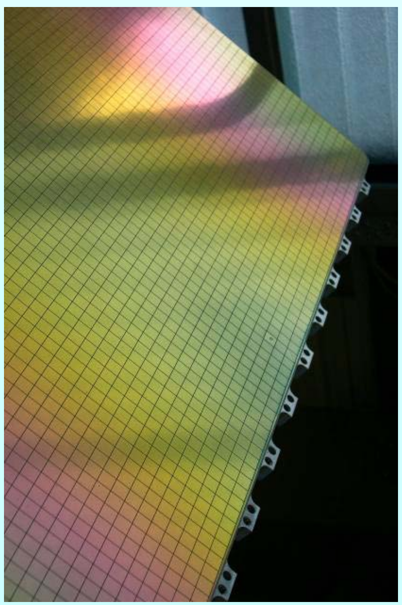








Why changing the peripheral MWPC's too?



MWPC's with CsI are successfully used, but:

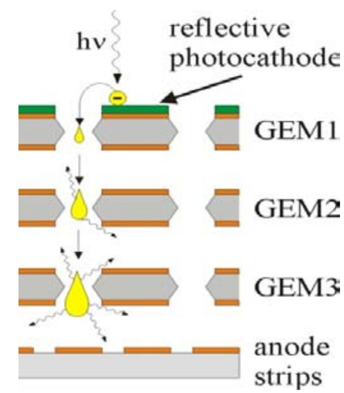
- *the effective gain is moderate (~10,000 → p.e. detection eff. ~70%)*
- *the quantum efficiency is challenged by aging (~1 mC/cm^2)*
- *the signal is slow, coming from the ions drift (~100 ns)*
- *for larger gains the electrical stability in the experimental environment is limited and the recovery time after a detector trip is long (~1 d)*

<u>Performances in terms of rate capability and noise rejection cannot be increased without a change of technology</u>.

At present the only economic way to cover with photon detectors very large surfaces is to use gaseous photon detectors.

The new photon detectors should:

- *use a closed geometry to avoid photon feedback*
- *reduce the ion backflow to the CsI layer*
- *detect signals from electron drift (few ns)*
- *use simple and robust components*



following the experience of PHENIX HBD

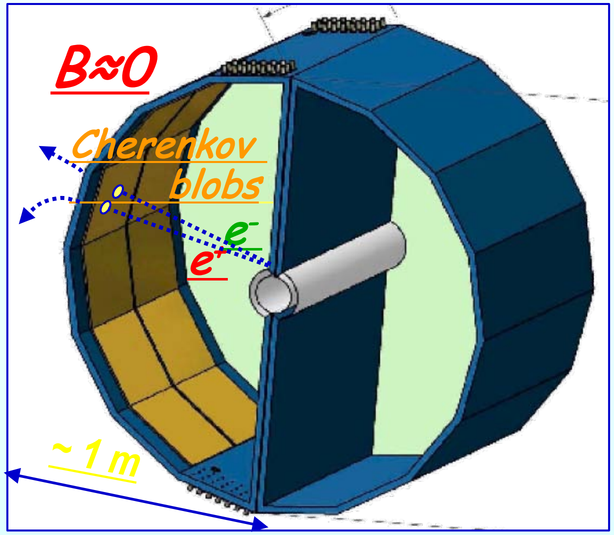
PHENIX HBD,

a threshold Cherenkov counter

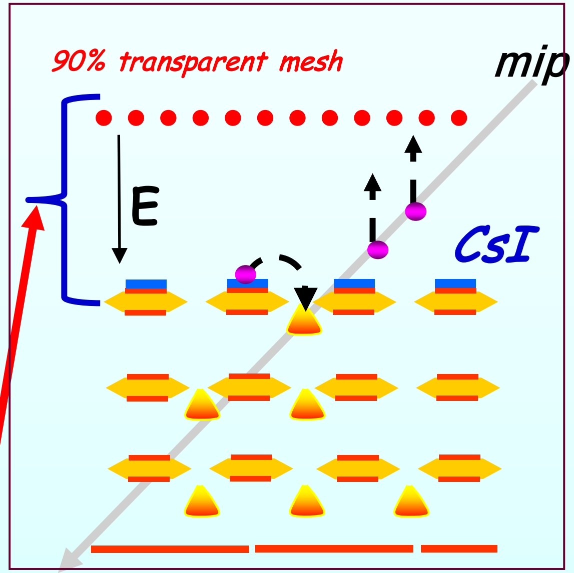
(window-less)

Central message for any similar application

Reversed bias cuts the MIP signal



A. Milov et al. J. Phys. G34, S701 2007

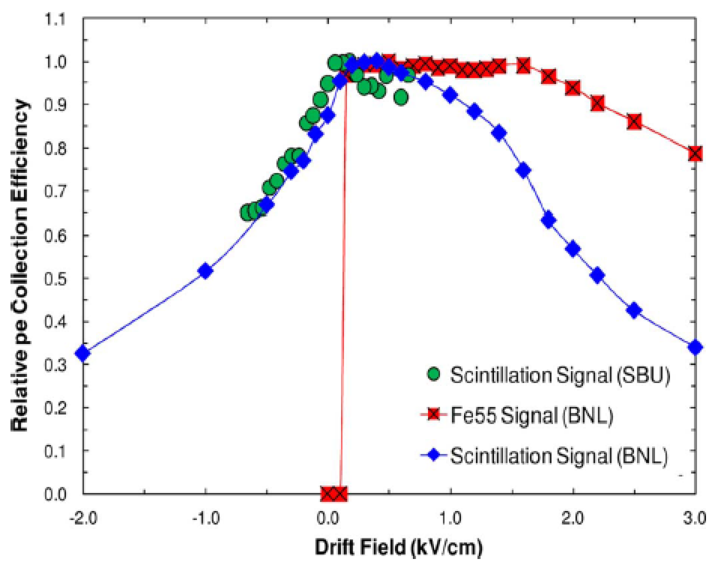


Aspects non exportable to imaging devices:

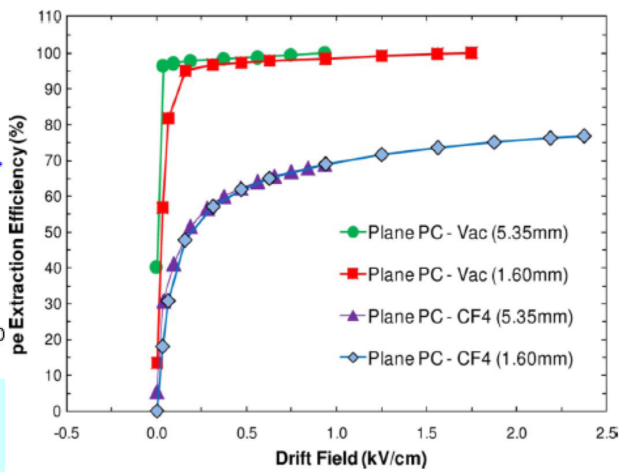
detection of >> 1 photon per pad: low gain (5000)

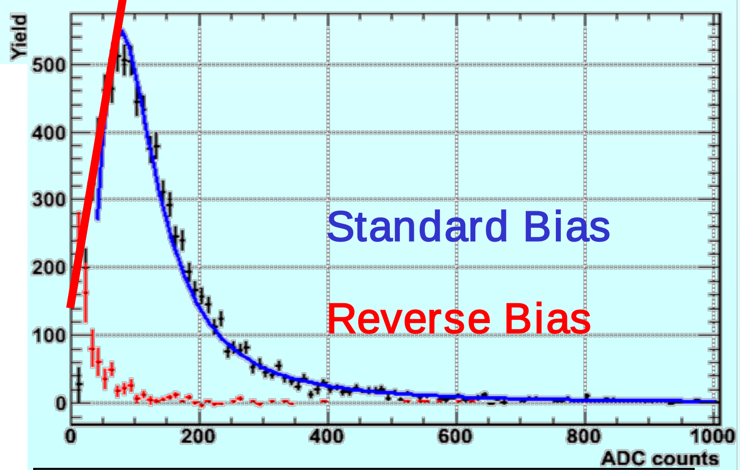
non negligible noise level (~20% single photon signal)

detect photons with λ down to ~110 nm: chromaticity



B. Azmoun et al., IEEE Transactions on Nuclear Science, vol. 56 (2009) 1544





W. Anderson et al,doi:10.1016/j.nima.2011.04.015

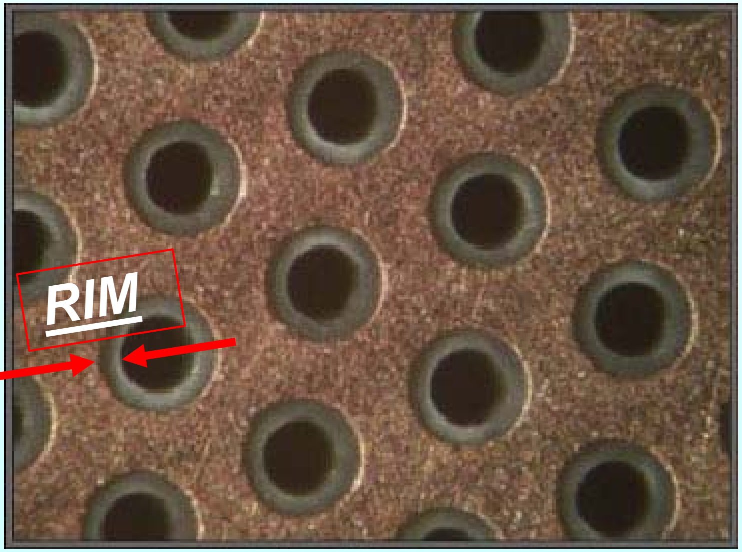
We decided to choose THGEM-based PD's

PCB technology, thus:

- robust
- mechanically self supporting
- industrial production of large size boards
- economic

About PCB geometrical dimensions:

Hole diameter :	*0.2 - 1 mm*
Pitch :	*0.5 - 5 mm*
Thickness :	*0.4 - 3 mm*



Comparing to GEMs

- Geometrical dimensions X ~10
  - But e^- motion/multiplic. properties do not!
  - Larger holes: dipole fields and external fields are strongly coupled

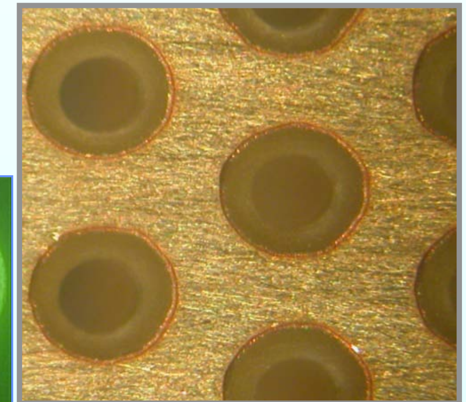
introduced in // by different groups:
L. Periale et al., NIM A478 (2002) 377.
P. Jeanneret, PhD thesis, Neuchatel U., 2001.
P.S. Barbeau et al, IEEE NS50 (2003) 1285
R. Chechik et al, .NIMA 535 (2004) 303

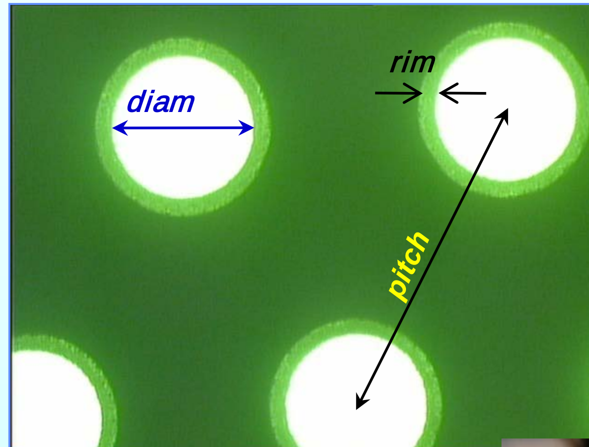
About gain:

- Large gains are easily obtained (rim !)

COMPASS THGEM R&D

Four 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.



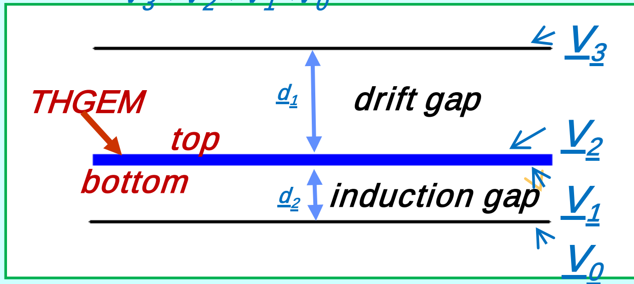


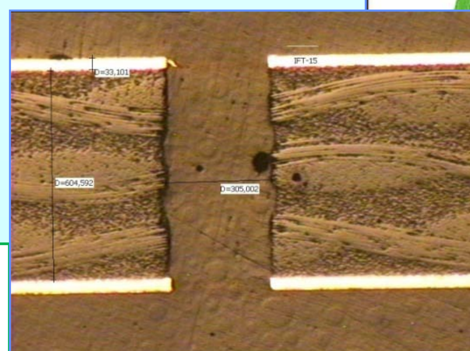
THGEM's with 30 x 30 mm^2 active area

EXPLORING A 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 : $V_3 < V_2 < V_1 < V_0$

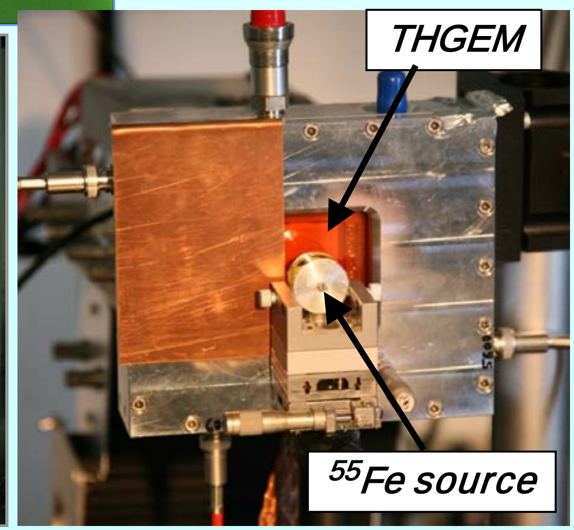




$$E_{drift} = (V_3 - V_2)/d_1$$

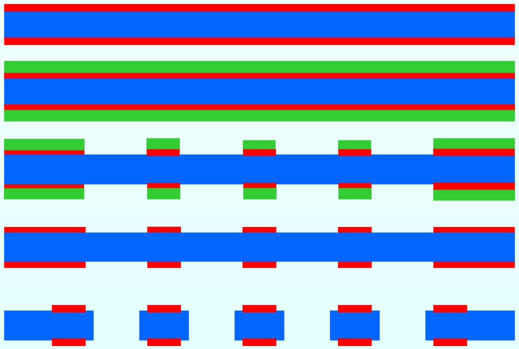
$$E_{induction} = (V_1 - V_0)/d_2$$

$$\Delta V = V_2 - V_1$$

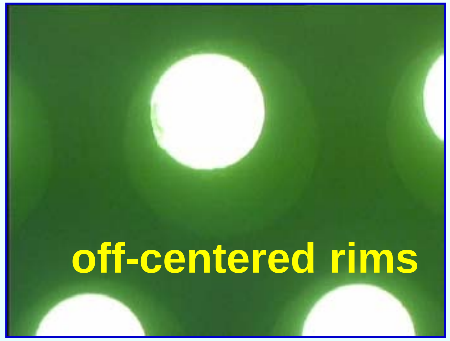


4 rim prodution methodes

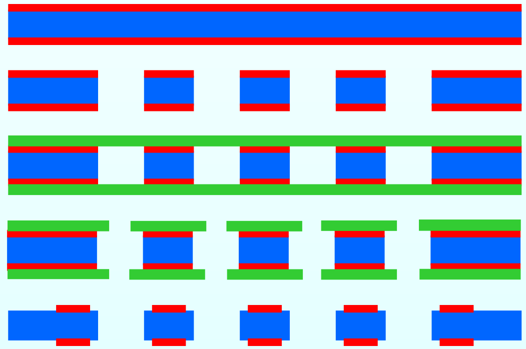
1) traditional



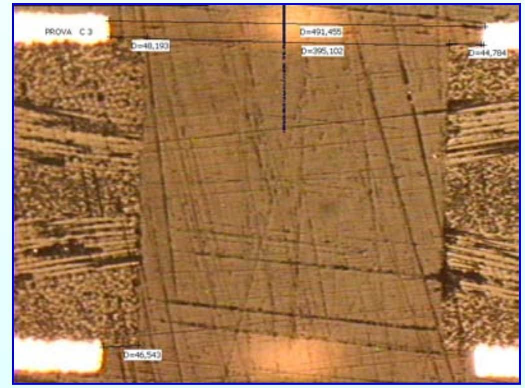
etching before drilling



2) large rim

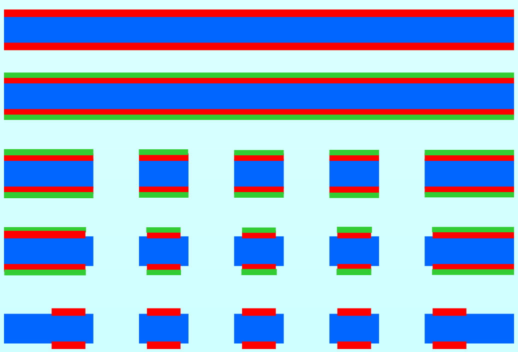


metallographic section

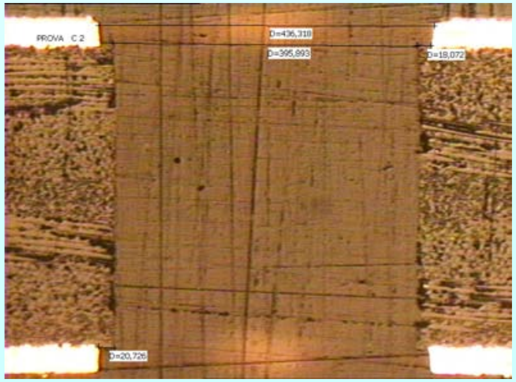


100 μm rim

3) small rim

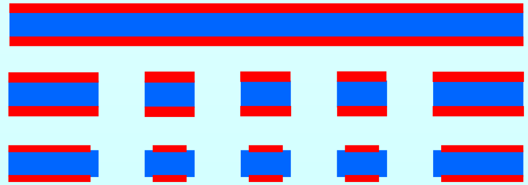


20 μm galvanic tin
instead of photo-resist

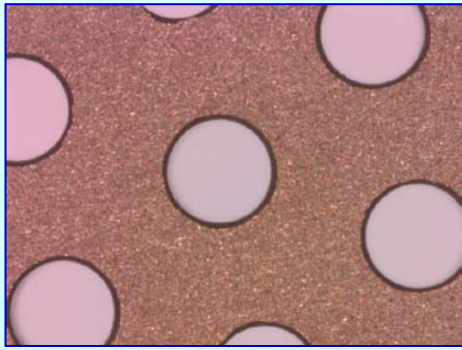


25 μm rim

4) global etching



uniform and smooth



our choice: global micro- etching

THGEM characterization

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

- *best response only with optimized drift field (specific for each type)*
- *the rim plays a fundamental role: large rim → large gain*
- *gain stability guaranteed only for small rim or no rim type*
- *thicker types provide larger gain too*
- *production procedures are very important*
- *good rate capability is guaranteed*

Using UV light sources we investigated (with either CsI coated or metal surfaces):

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

Several prototypes of small size THGEM-based PD's and of 100mm x 100 mm PD's have been built and tested.

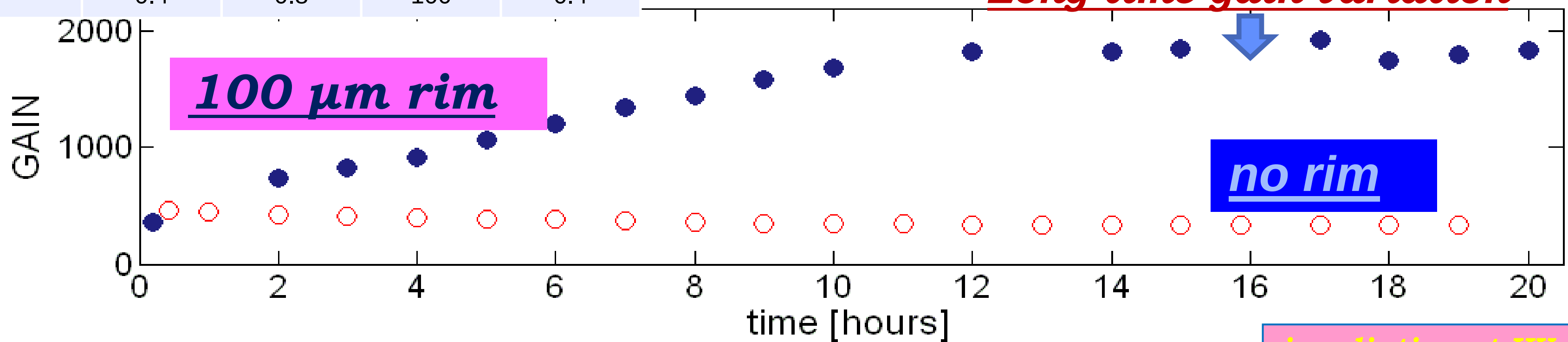
Here only a flavor about the role of the rim

remainder about gain stability and rim (Silvia dalla Torre, TIPP 2009)

Name	Diam (mm)	Pitch (mm)	Rim (µm)	Thick (mm)
M1	0.4	0.8	0	0.4
C4	0.4	0.8	100	0.4

^{55}Fe source; uniform irradiation

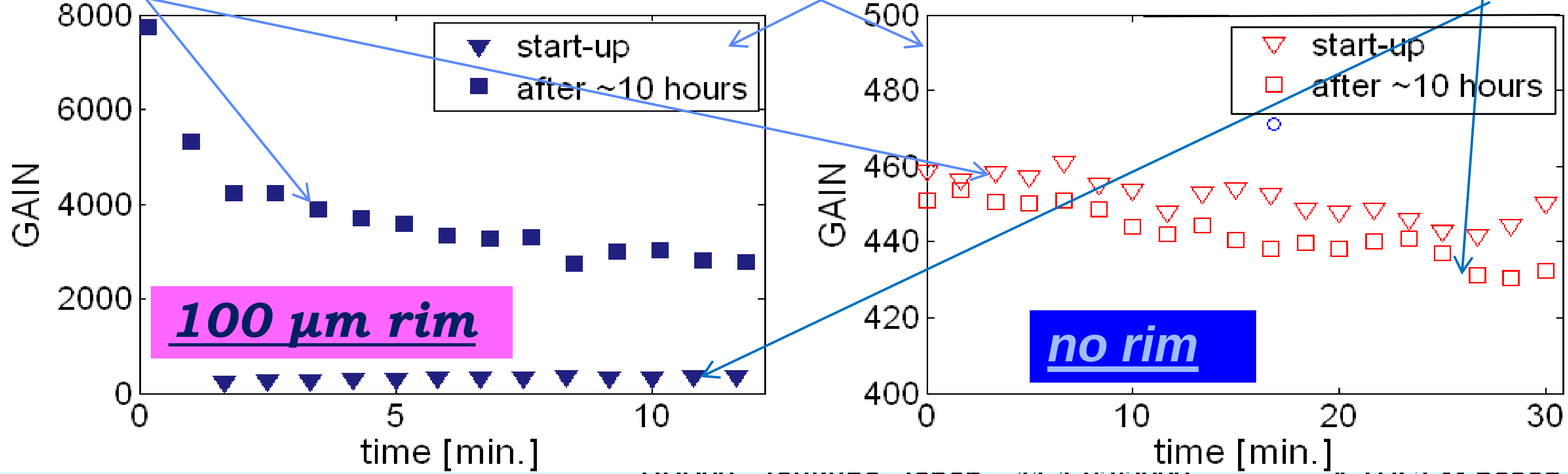
Long time gain variation



START IRRADIATING after ~10 hours at nominal voltage

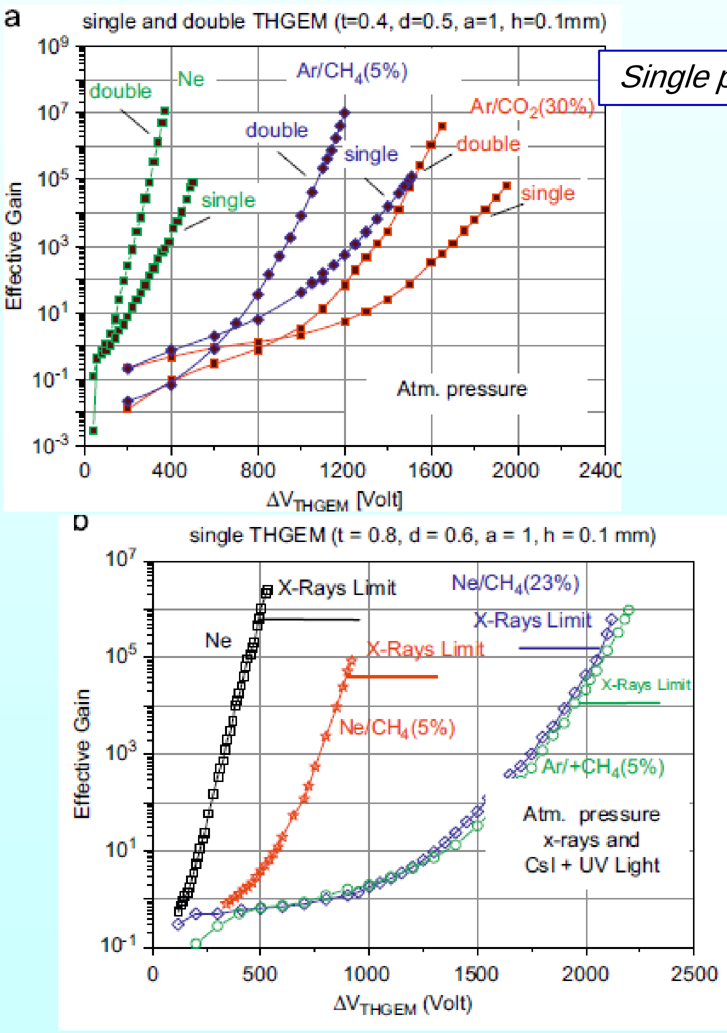
irradiation at HV switch on (after ~1 day with no voltage)

Short time gain variation



the issue of THGEM gain and rim

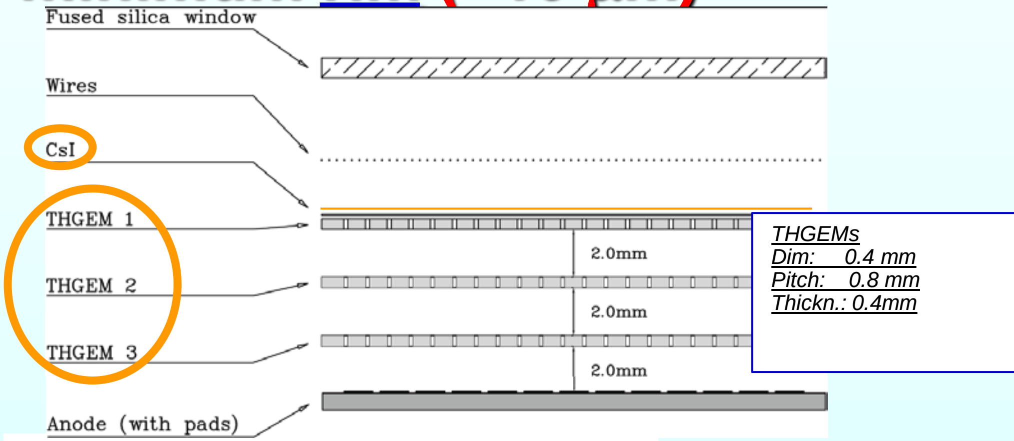
employing large rim (100 μm)

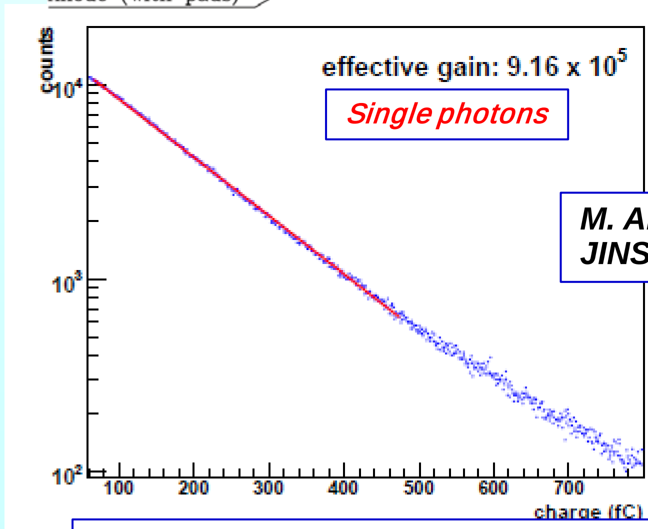


Single photons

A. Breskin et al., NIMA 623 (2010) 132

minimum rim (<10 μm)





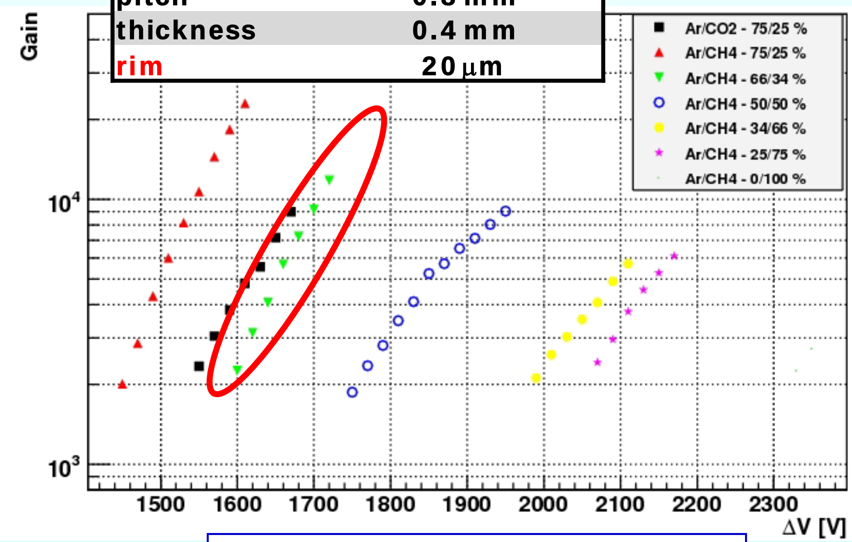
Single photons

M. Alexeev et al., JINST 5 (2010) P08009

Gain limited to ~10^5 in test beam: MORE WORK REQUIRED

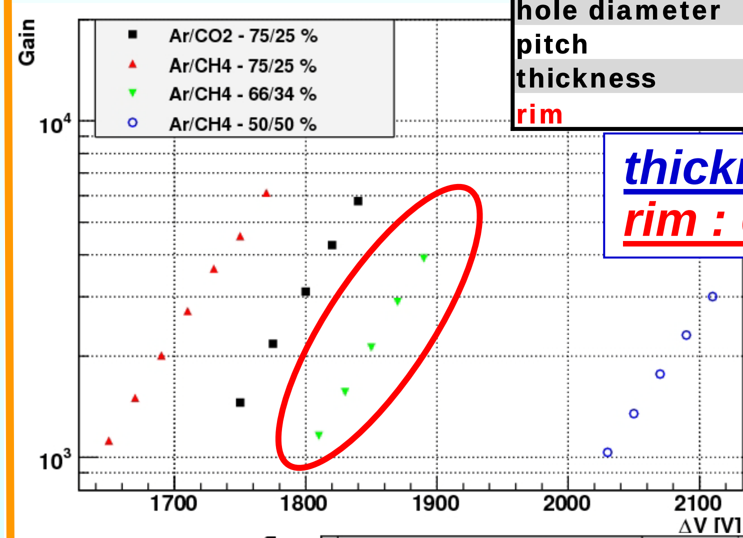
THGEM's with rim and without rim

hole diameter	0.4 mm
pitch	0.8 mm
thickness	0.4 mm
rim	20 µm



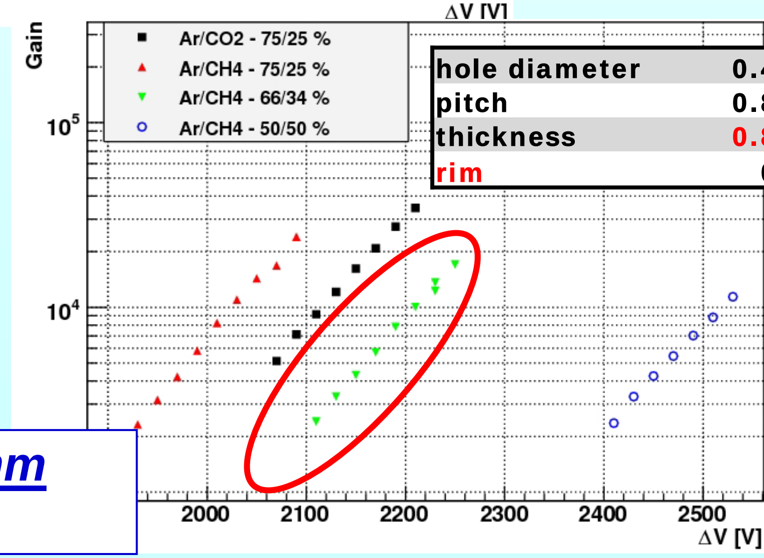
thickness: 0.4 mm
rim : 20 µm

hole diameter	0.4 mm
pitch	0.8 mm
thickness	0.6 mm
rim	0



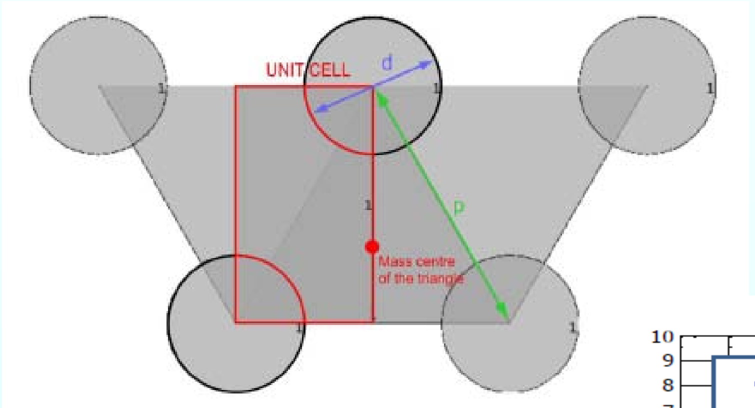
thickness: 0.6 mm
rim : 0

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

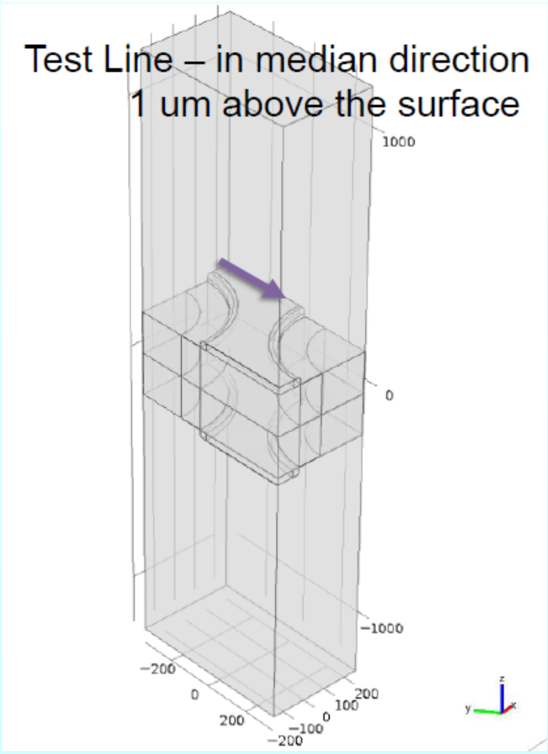


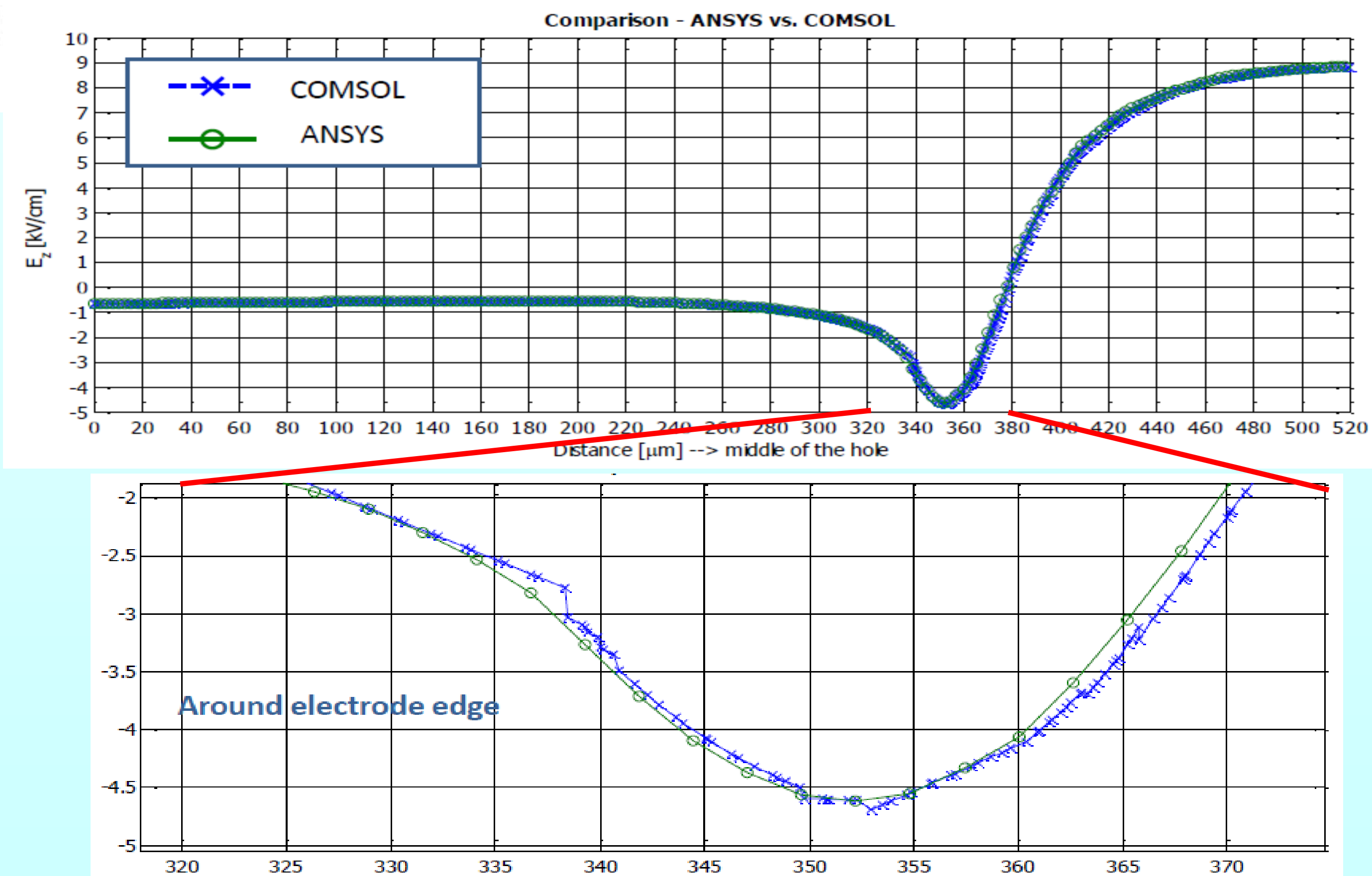
thickness: 0.8 mm
rim : 0

electrostatic calculations

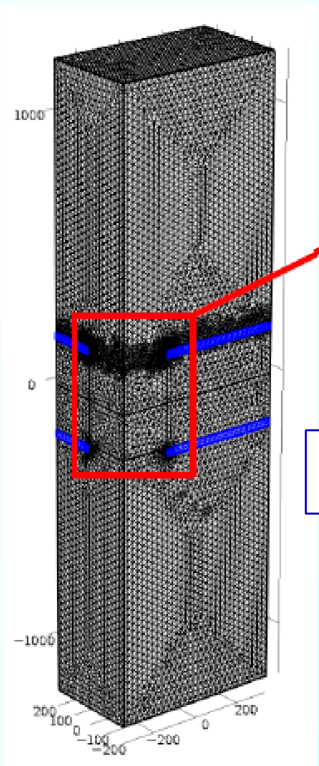


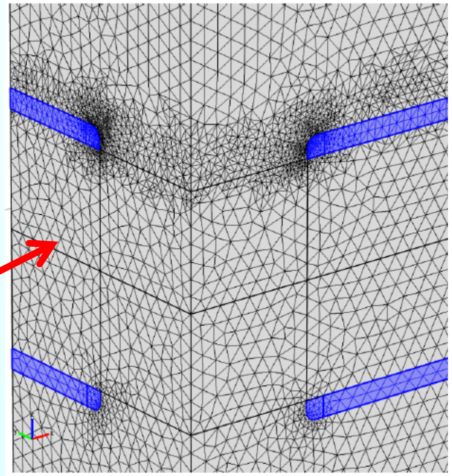
In order to achieve a realistic description of the THGEM electric field configuration a comparative study has been performed: at the beginning the results from ANSYS and COMSOL were not completely consistent; after few bug fixing now the agreement is good.



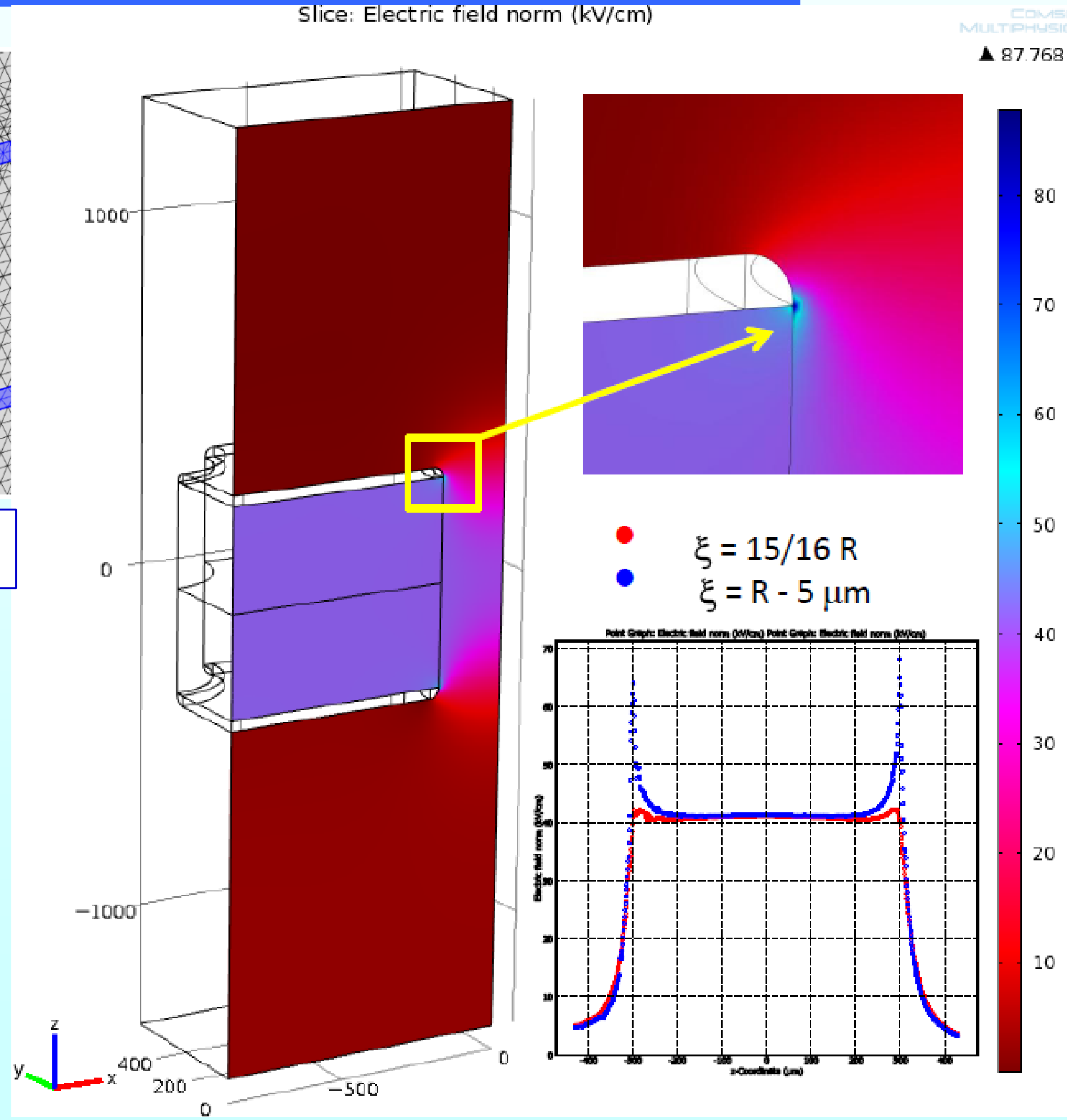


electrostatic calculations





It is important to use an appropriate mesh granularity

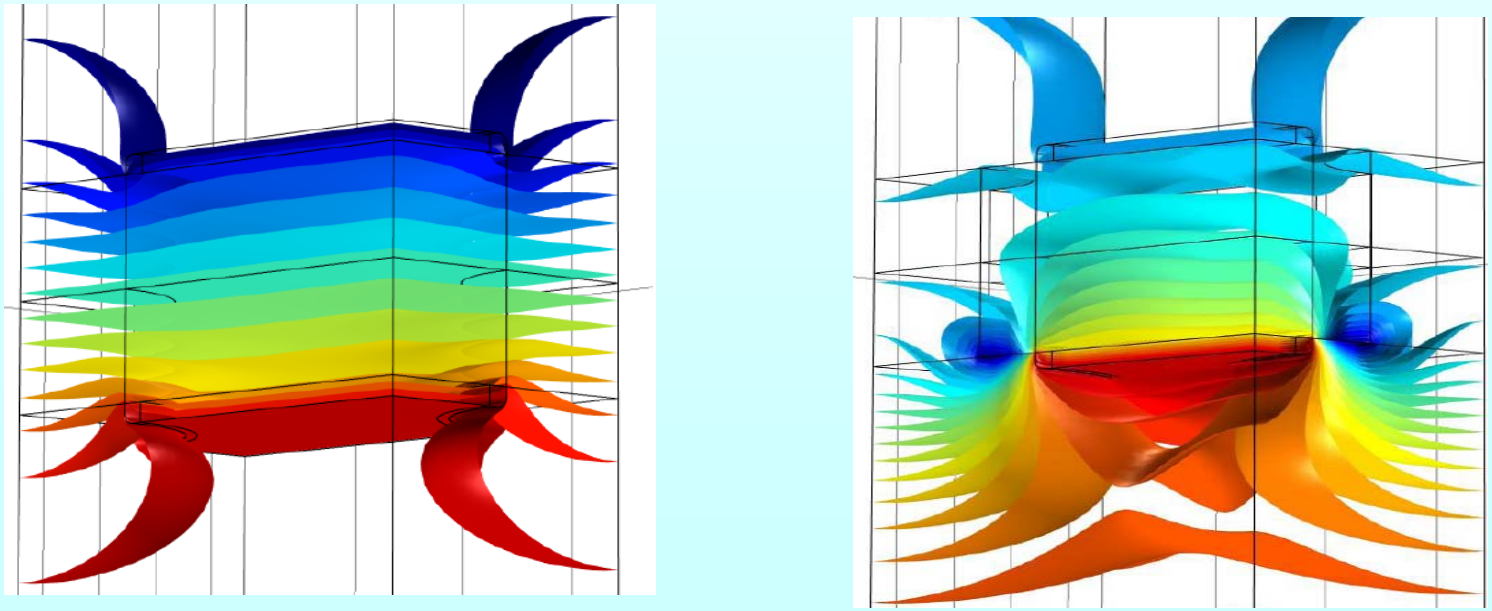


Understanding the charging up

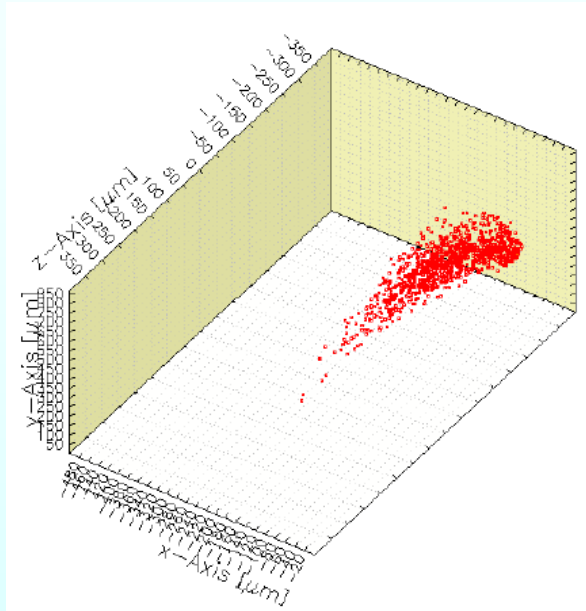
It has been done for standard GEMs: a lengthy iterative procedure to simulate the time dependent process
M Alfonsi, G. Croci, R. Veenhof et al., not yet published

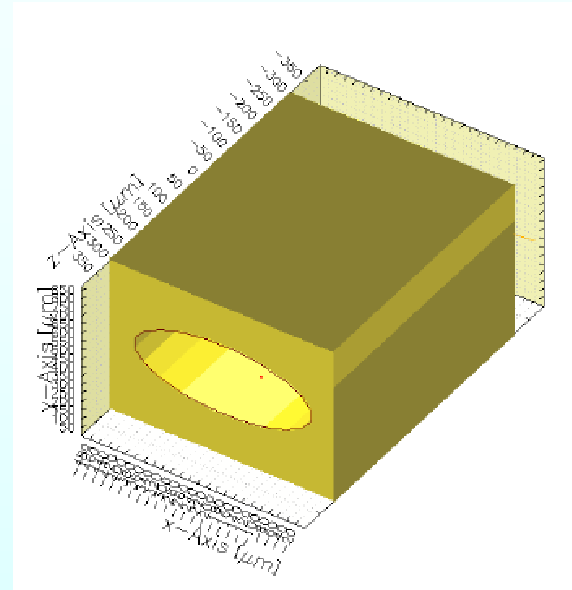
[studies in the context of the RD51 effort to provide adequate simulation tools for MPGDs]

Example of how the equipotential surfaces are modified by the presence of a charge on the THGEM rim surface. This work is just beginning.



Simulations with ANSYS and GARFIELD



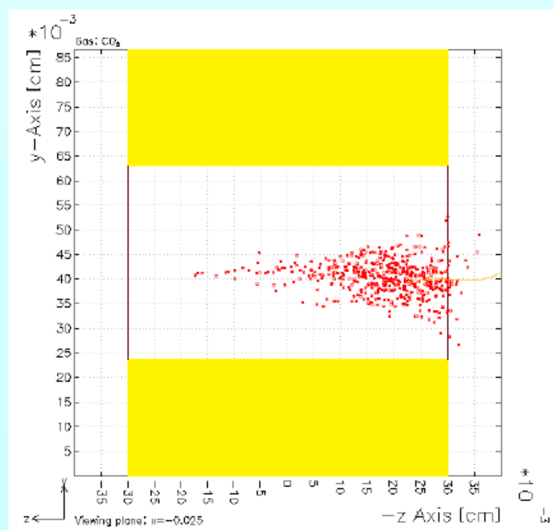


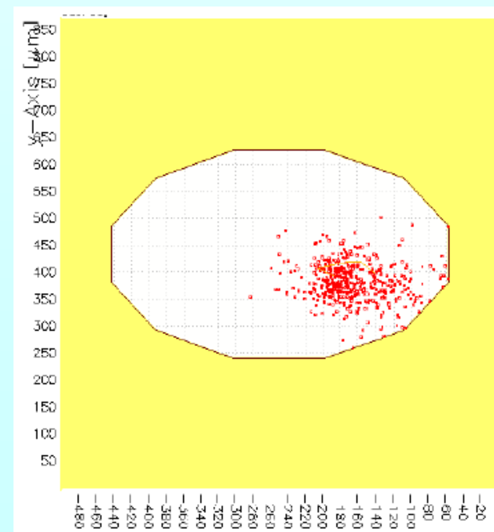
Thickness = 600 μm
Metal = 30 μm
Pitch = 1000 μm
ΔV = 2000 V
Fillet = 30 μm
Drift = 2mm
Induction = 2mm
E_{drift} = 0 V/cm
E_{ind} = 3 kV/cm

$Ø_{hole}$ = 400 μm

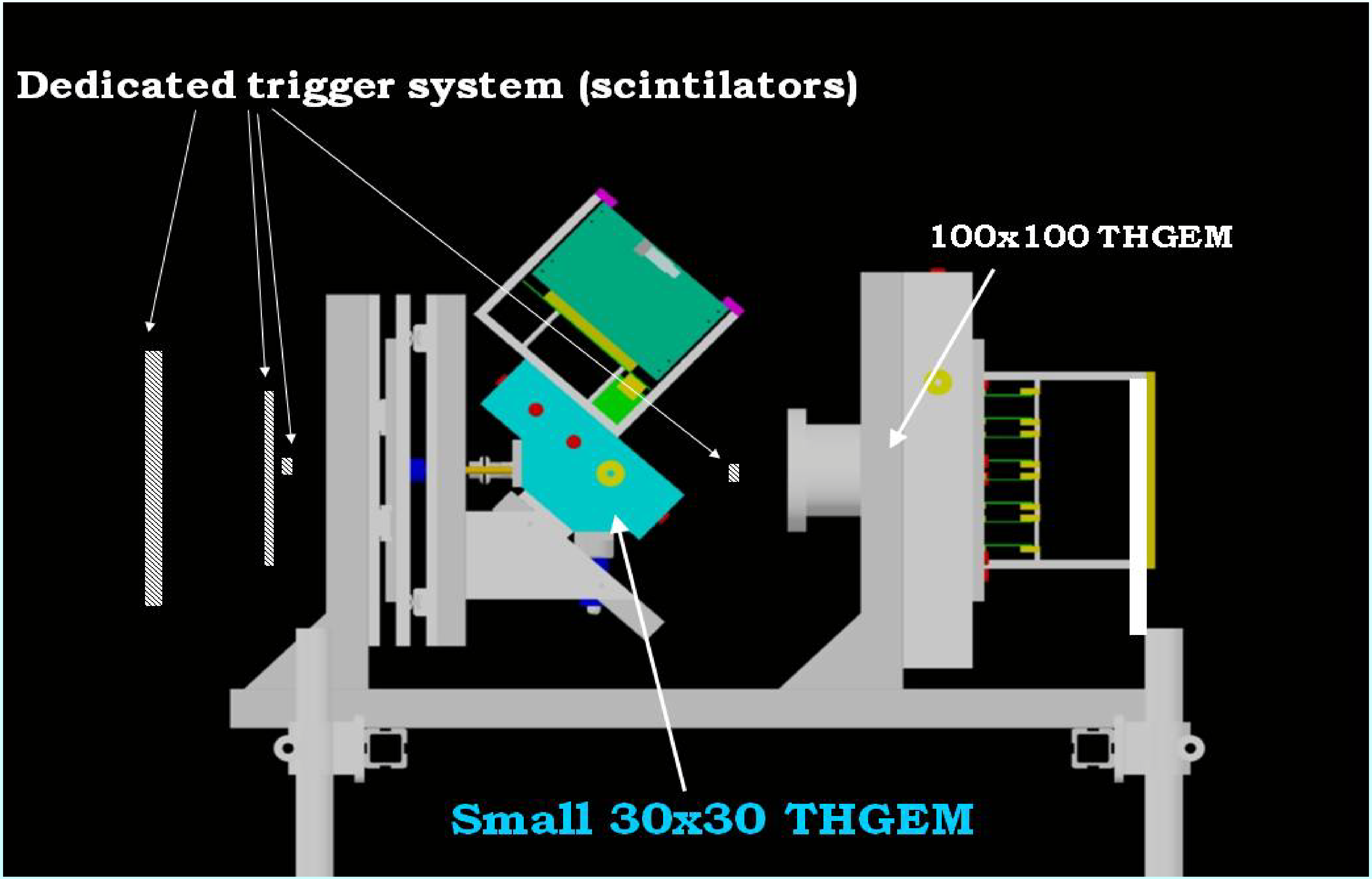
Gas: Argon (50%) / Methane (50%)

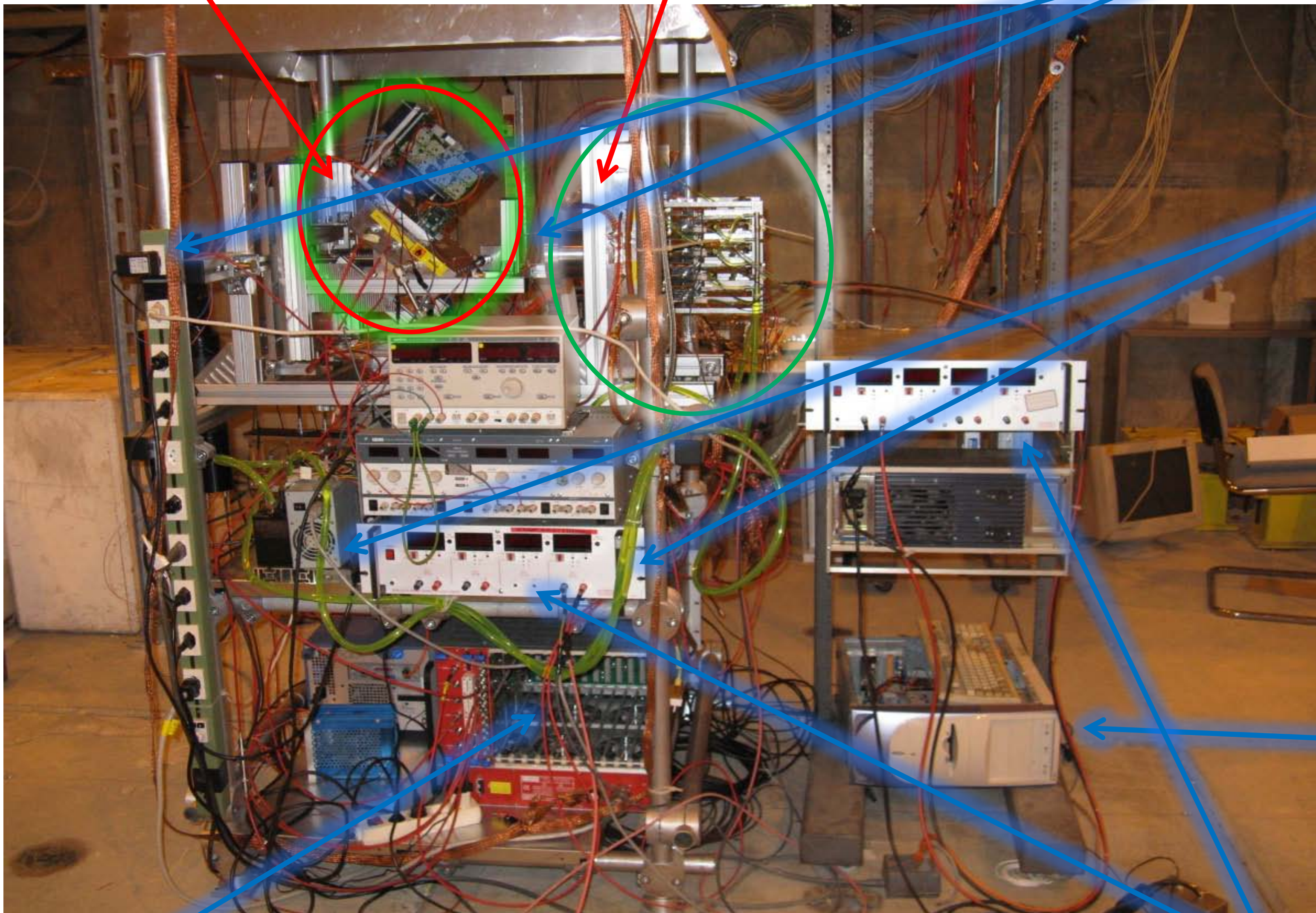
1 event distribution for a single hole in 3D





test beams: oct 2009 and aug 2010




100 mm x 100 mm triple THGEM detector
30 mm x 30 mm triple THGEM detector
Trigger System
Cooling System
Remotely controlled PC
HV Power units
LV front end

2010 test beam

Chamber with 1 MAPMT and 3 triple THGEM
photon detector prototypes installed

CERN SPS T2-H4 beam line (RD51 test beam)
150 Gev/c m+ , beam spot s ~12 mm, rate ~1 kHz

Two identical small PD prototypes: triple THGEMs with 30 mm x 30 mm active area.

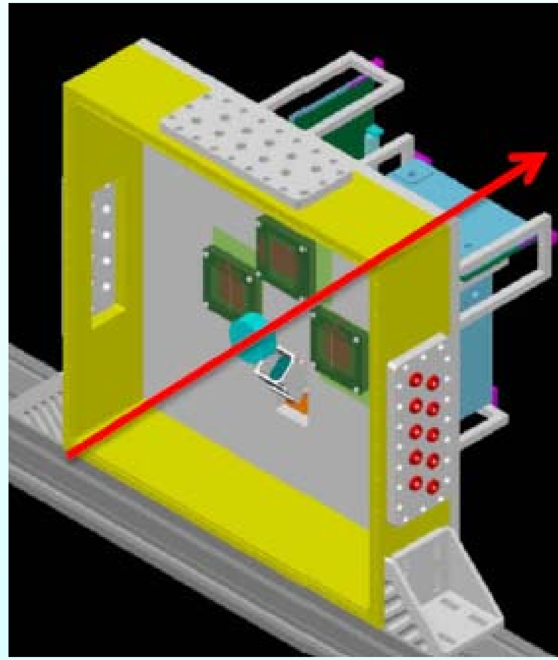
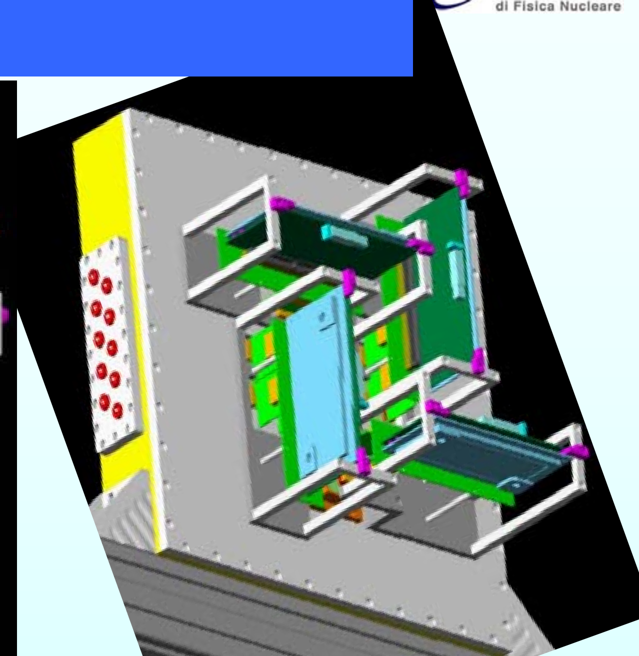
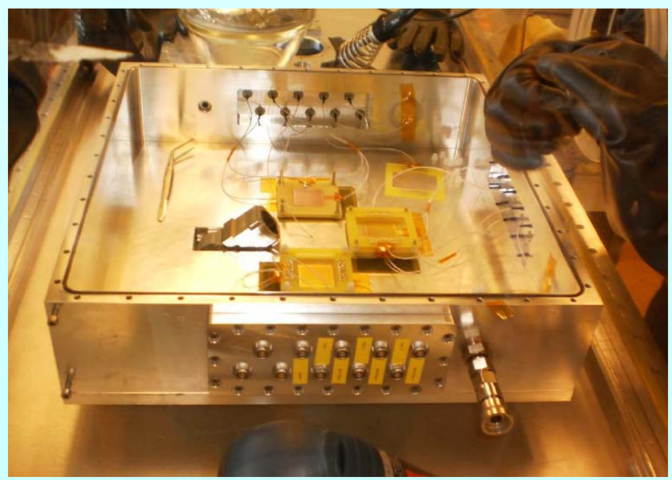
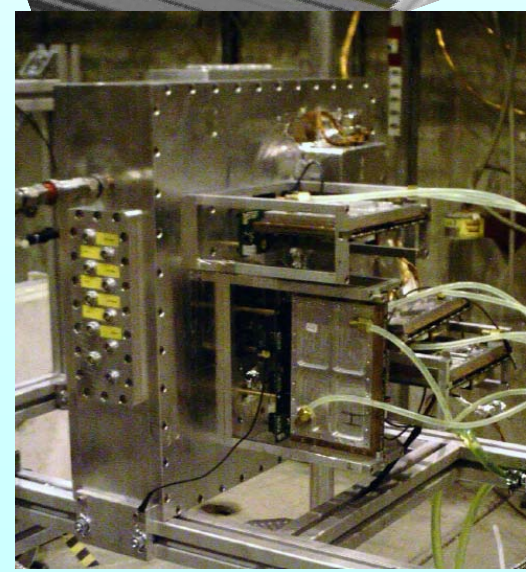
All THGEMs had the same parameters (in mm)
thickn. = 0.4, hole diam. 0.4, pitch 0.8, rim 0.01

Gas mixture: Ar/CH_4 50/50, flow: ~50 l/h

Spherically shaped fused silica radiator focusing Cherenkov light on a thin corona onto the THGEM's

Two possible illuminations: full radiator – partially darkened radiator to avoid multiple photons
A 45 degrees rotation allows to change illumination condition

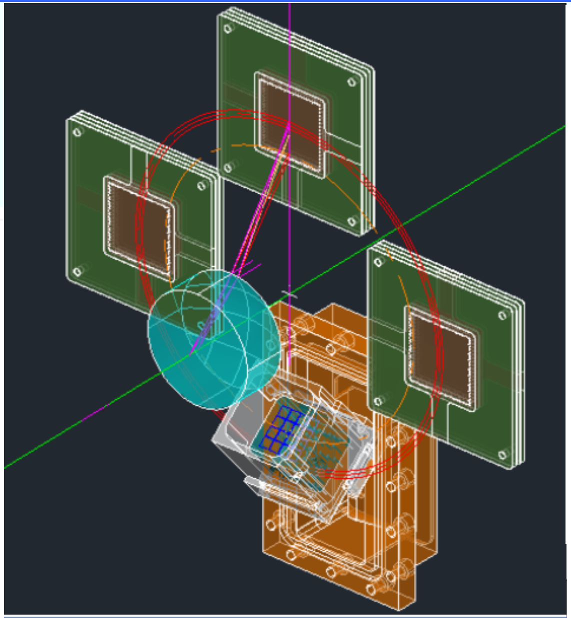
Two readout configurations used:
analog r/o (all channels together, Cremat CR110 preampl., ORTEC amplifier, AMPTEK MCA 8000A)
digital r/o of 32 ch, COMPASS MAPMT r/o (CMAD + ROOF + DREISAM (with F1 TDC) + HOTLINK + CATCH) and standard COMPASS DAQ

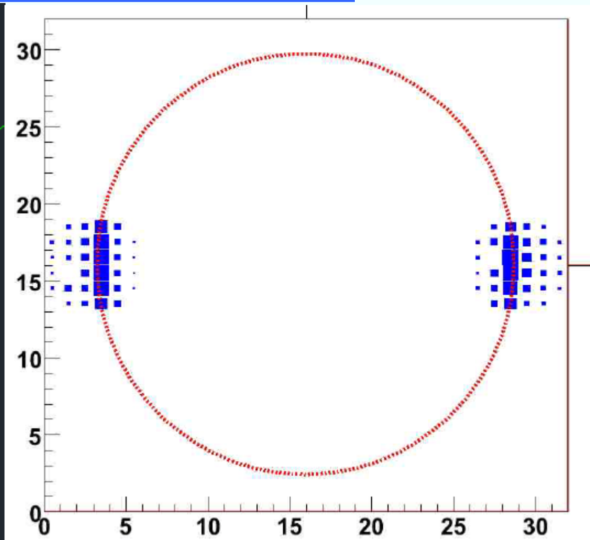





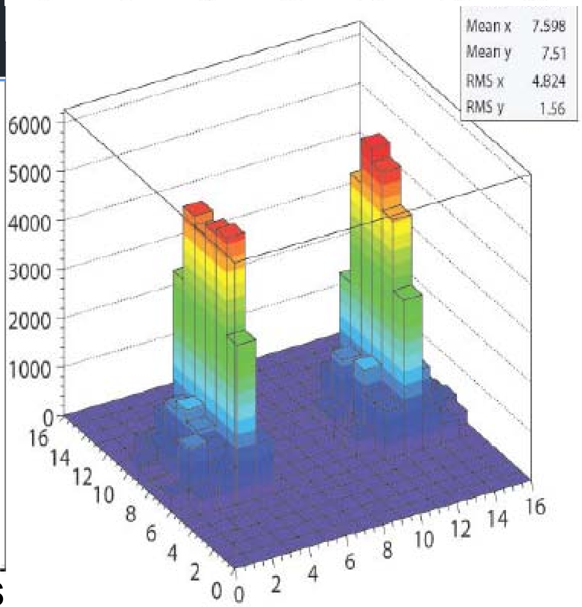
Signal space and time distributions

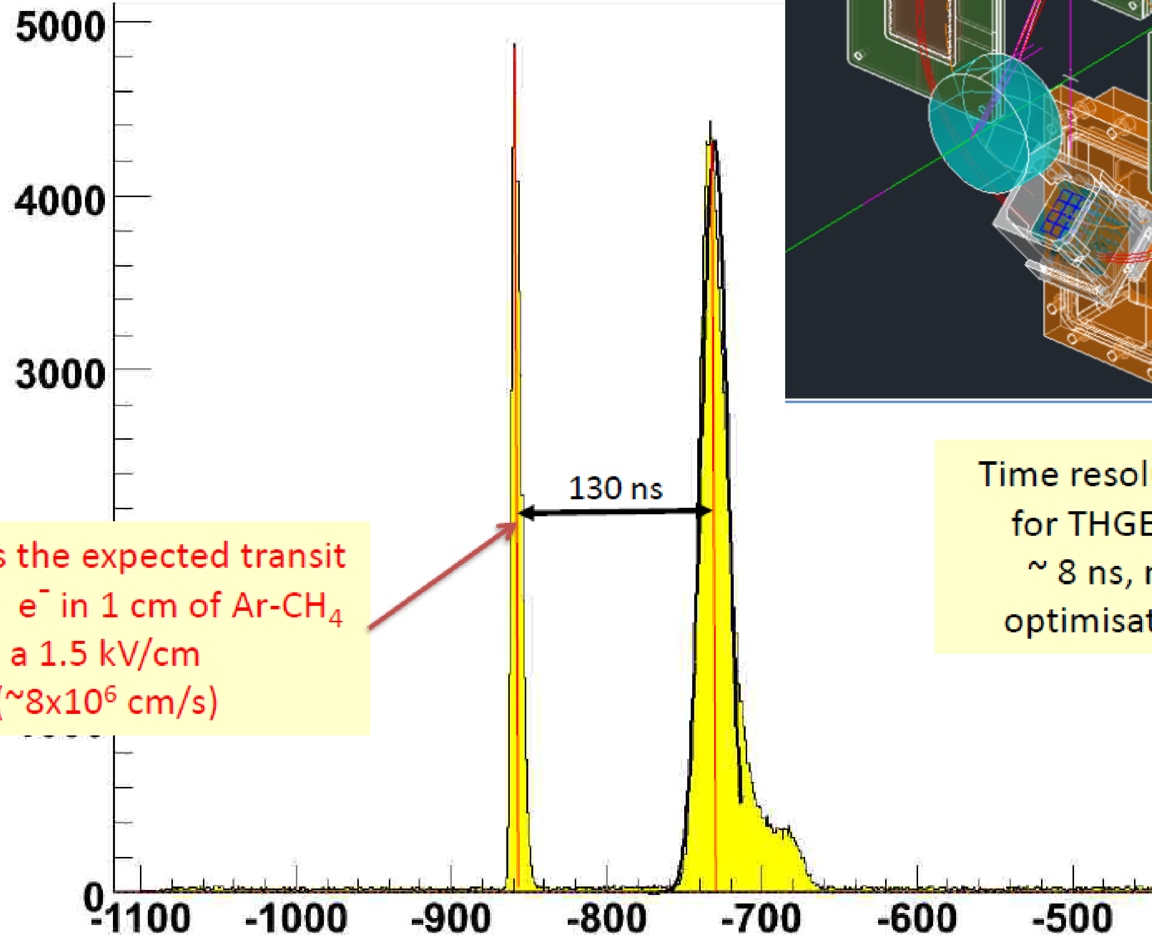
Chamber with 1 MAPMT and 3 triple THGEM photon detector prototypes installed

CERN SPS T2-H4 beam line (RD51 test beam)
150 Gev/c m+ , beam spot s ~12 mm, rate ~1 kHz





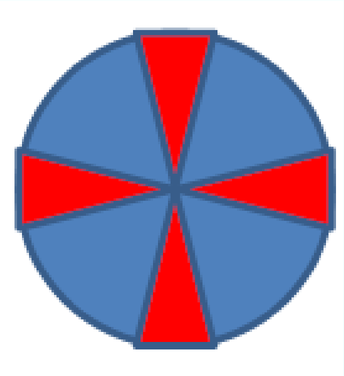




125 ns is the expected transit time for e^- in 1 cm of Ar-CH_4 a 1.5 kV/cm (~8×10^6 cm/s)

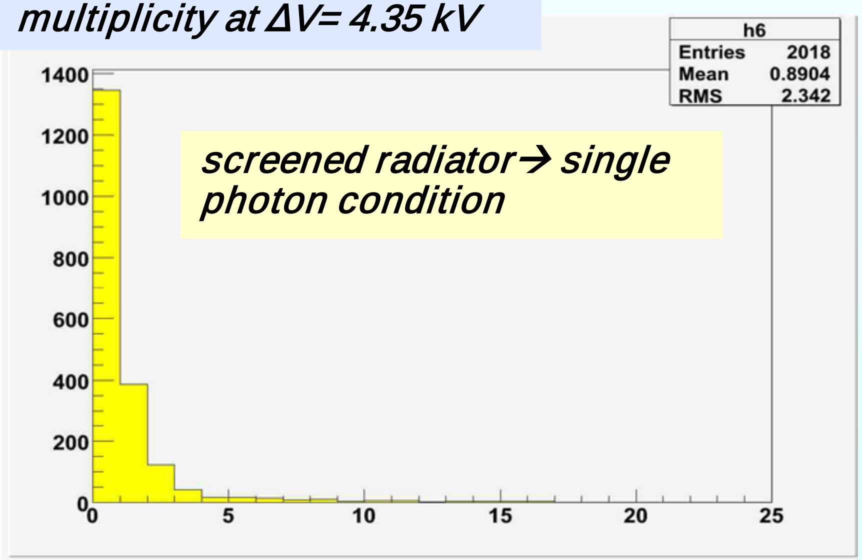
Time resolution for THGEM: ~ 8 ns, no optimisation

Detected photoelectron multiplicity



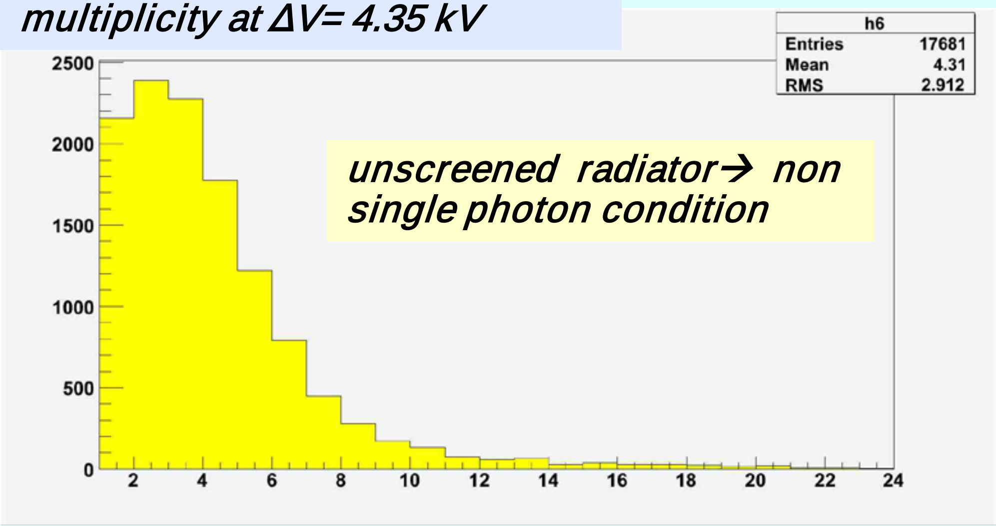
Quartz radiator,
Half of the radiator is darkened at sectors of nearly 40 degrees,
45 degrees rotation allows for non single photon illumination

multiplicity at ΔV= 4.35 kV



screened radiator→ single photon condition

multiplicity at ΔV= 4.35 kV



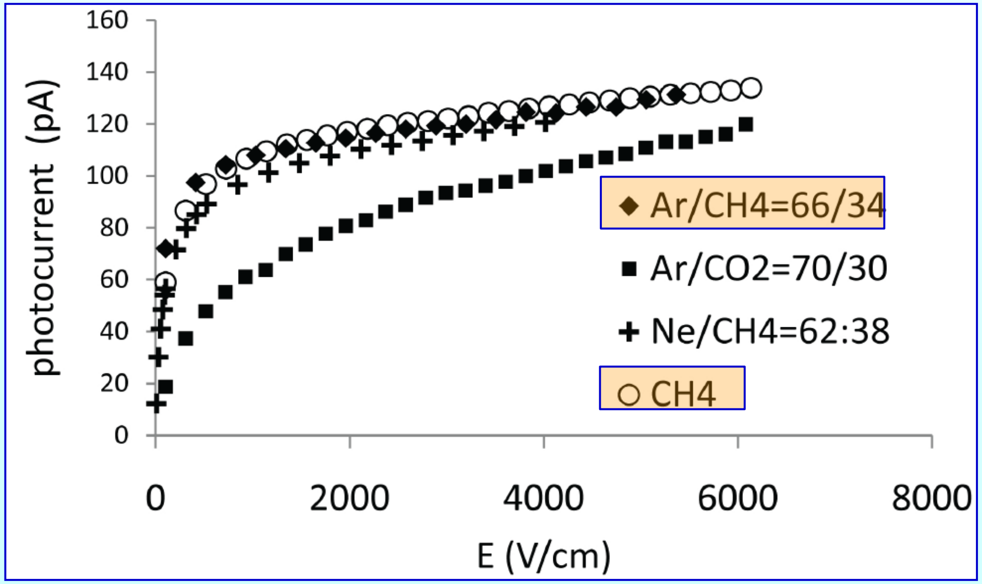
unscreened radiator→ non single photon condition

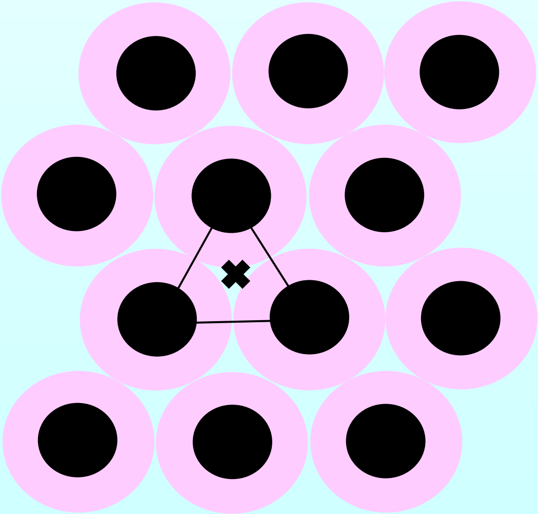
Both multiplicities are compatible with the expected values from Zemax simulation for the generated photons, the geometrical acceptance and the estimated chamber efficiency

Photoelectron extraction from time response

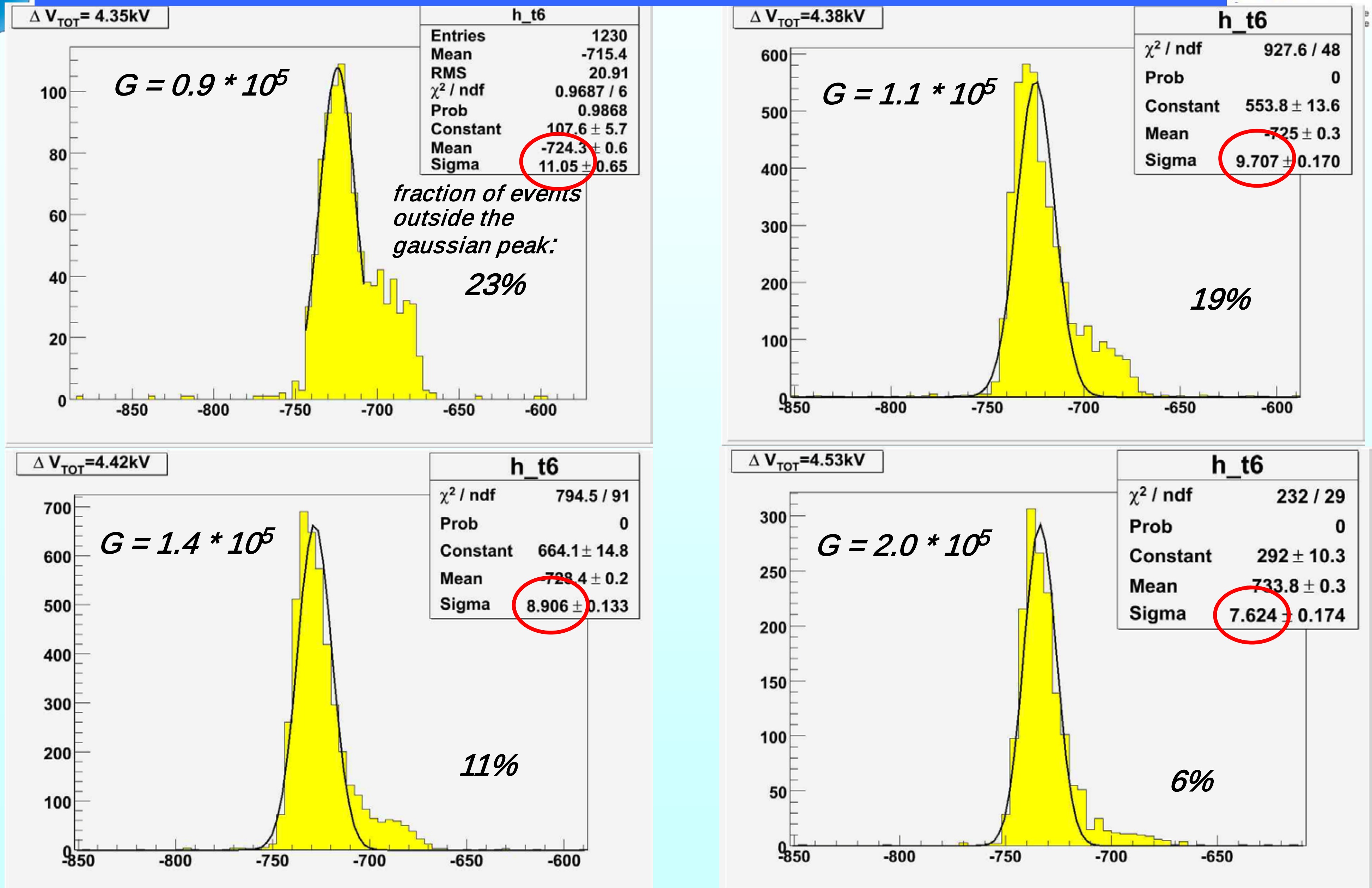
The electric field (horthogonal to the THGEM surface) must be large enough to ensure an effective photoelectron extraction

The most critical point: the centre of the triangle





Photoelectron extraction from time response

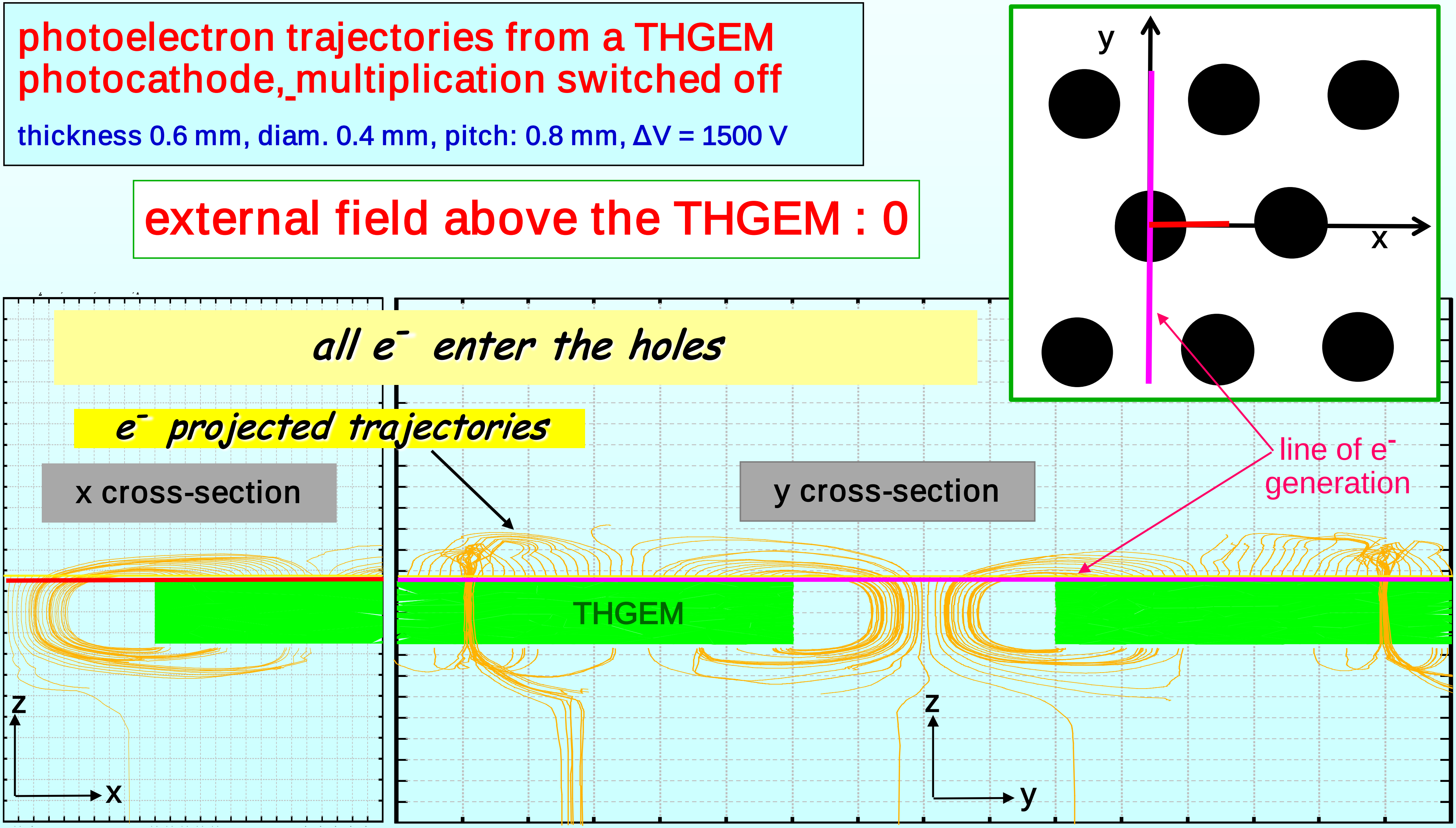


simulation of photoelectron collection

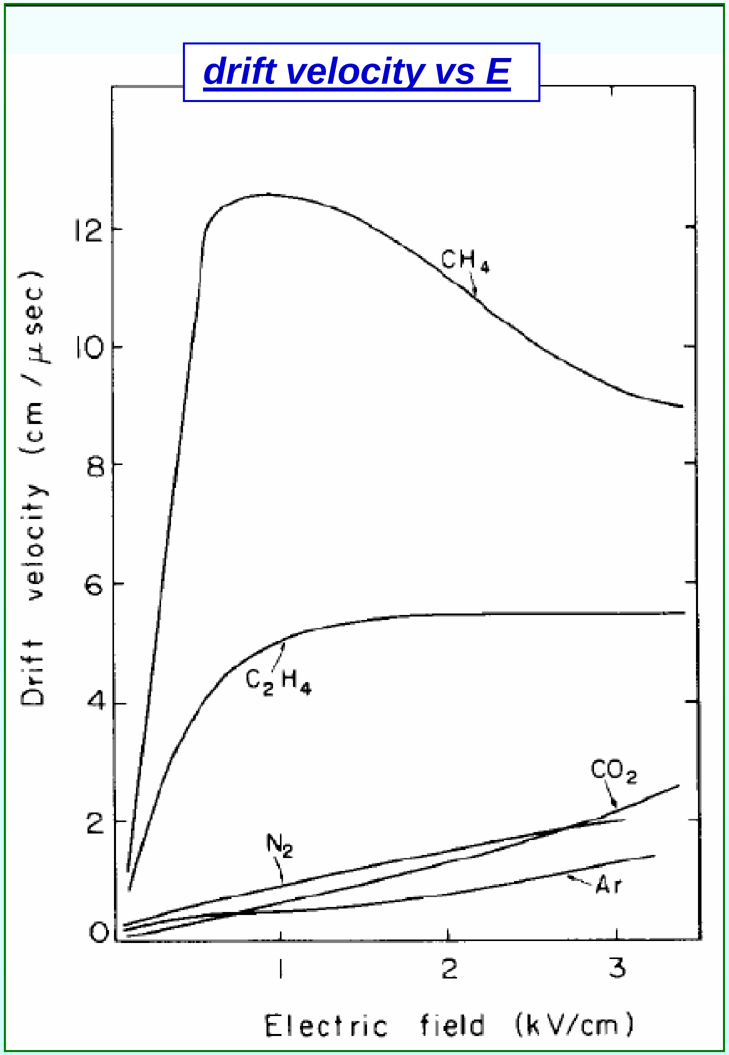
photoelectron trajectories from a THGEM photocathode, multiplication switched off

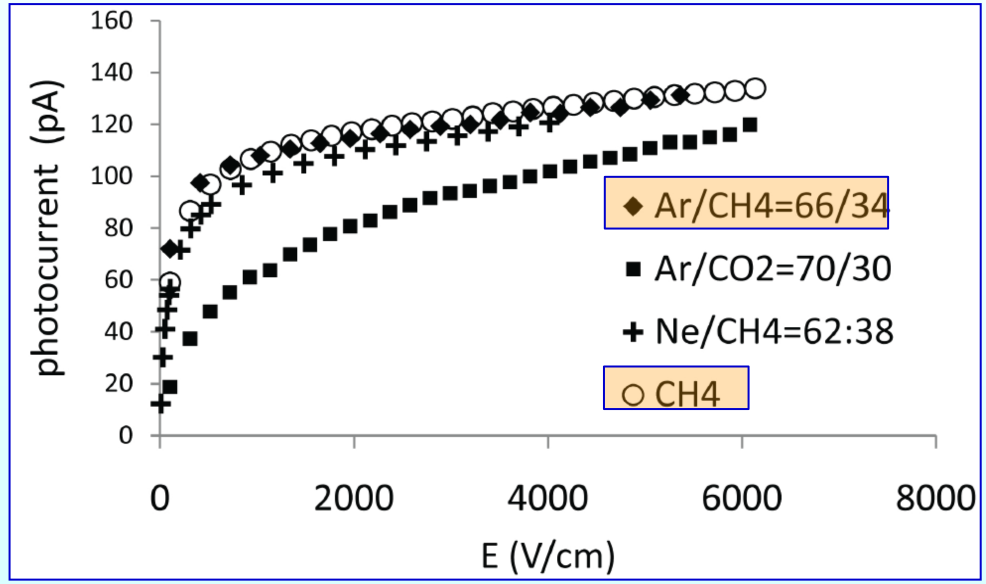
thickness 0.6 mm, diam. 0.4 mm, pitch: 0.8 mm, ΔV = 1500 V

external field above the THGEM : 0



Photoelectron extraction from time response



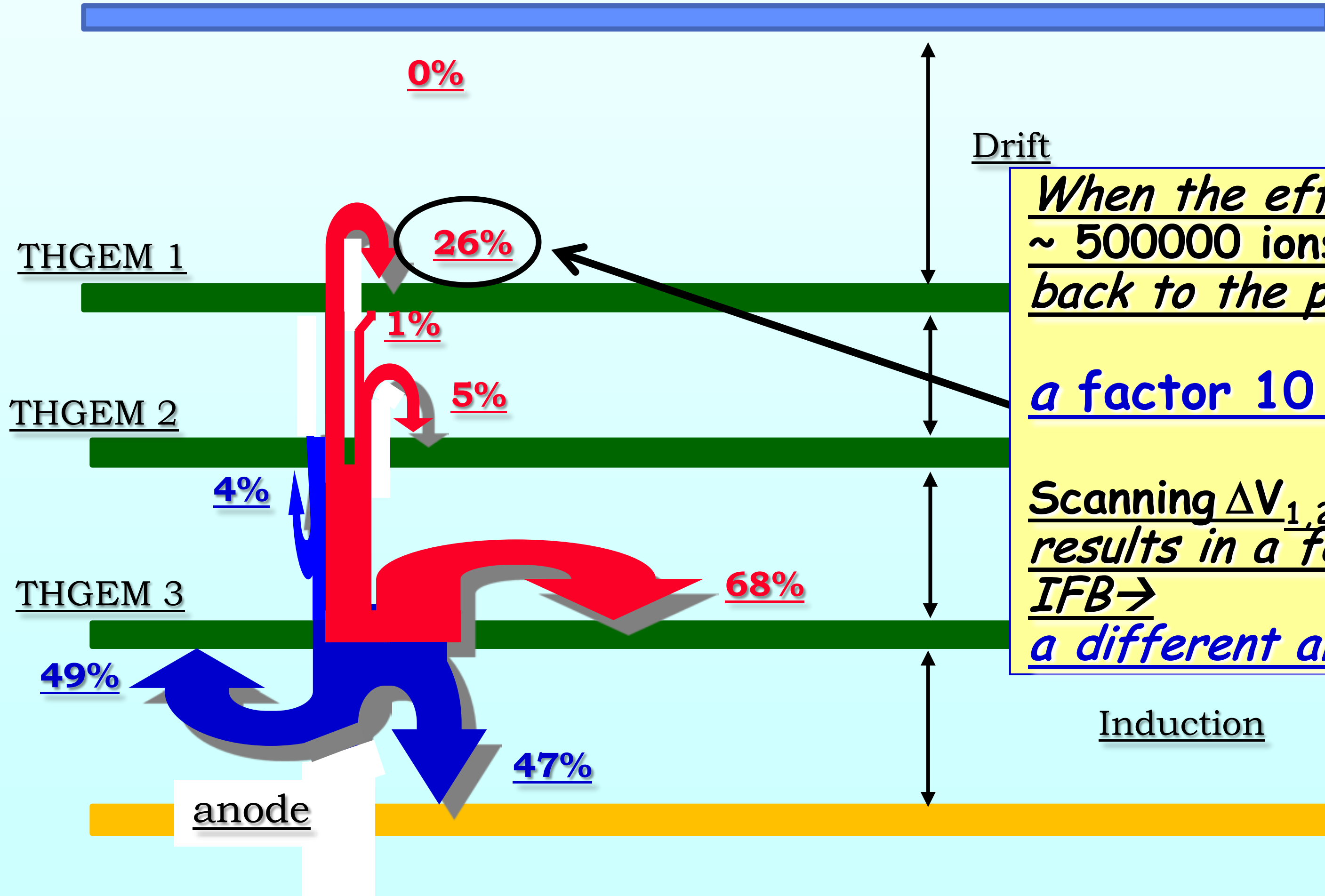


correlation between the tail of the timing peak and the reduced extraction efficiency: an effective method to check the field conditions

Important open problem: reduction of IBF

THGEMs
Dim: 0.4 mm
Pitch: 0.8 mm
Thickn.: 0.4mm

typical charge sharing



When the effective gain is 10^6 →
~ 500000 ions/(detected photon)
back to the photocathode

a factor 10 less is needed

Scanning $\Delta V_{1,2,3}$, $E_{transfer}$, $E_{induction}$
results in a few % variation of the IFB→
a different architecture is needed

Engineering problems

1) Strict THGEM quality test protocol

2) Final segmentation to be optimized

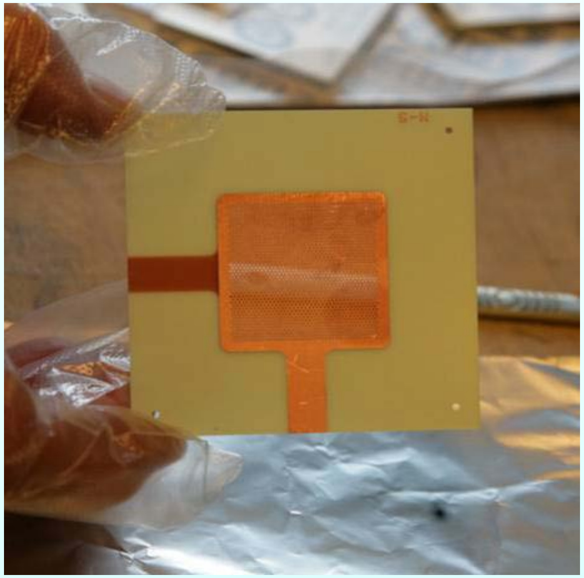
3) Final choice of HV distribution system and power supply

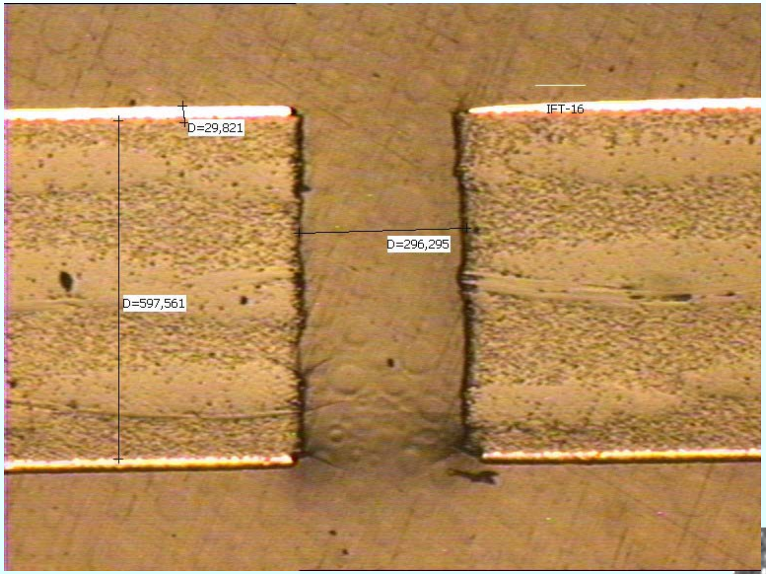
4) THGEM planarity and mechanical/electrical stability to be guaranteed

5) Quality and uniformity of very large THGEM to be demonstrated

6) Chamber border effects and dead areas to be minimized

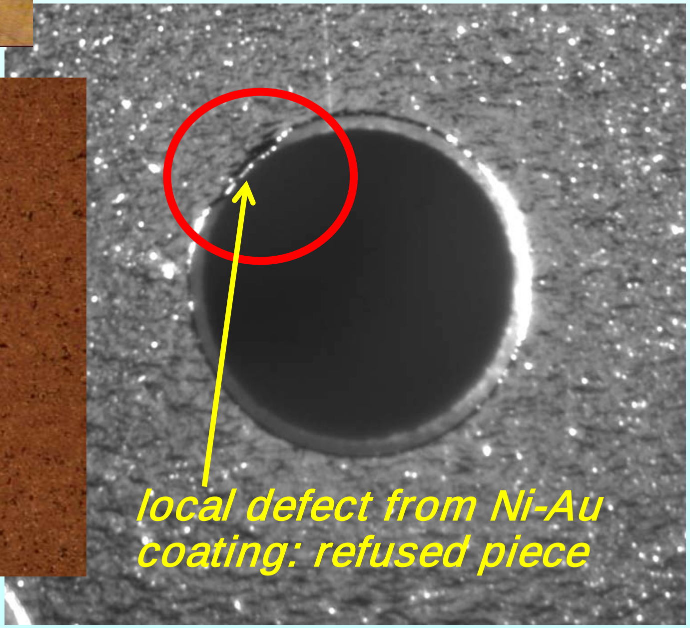
THGEM Quality checks



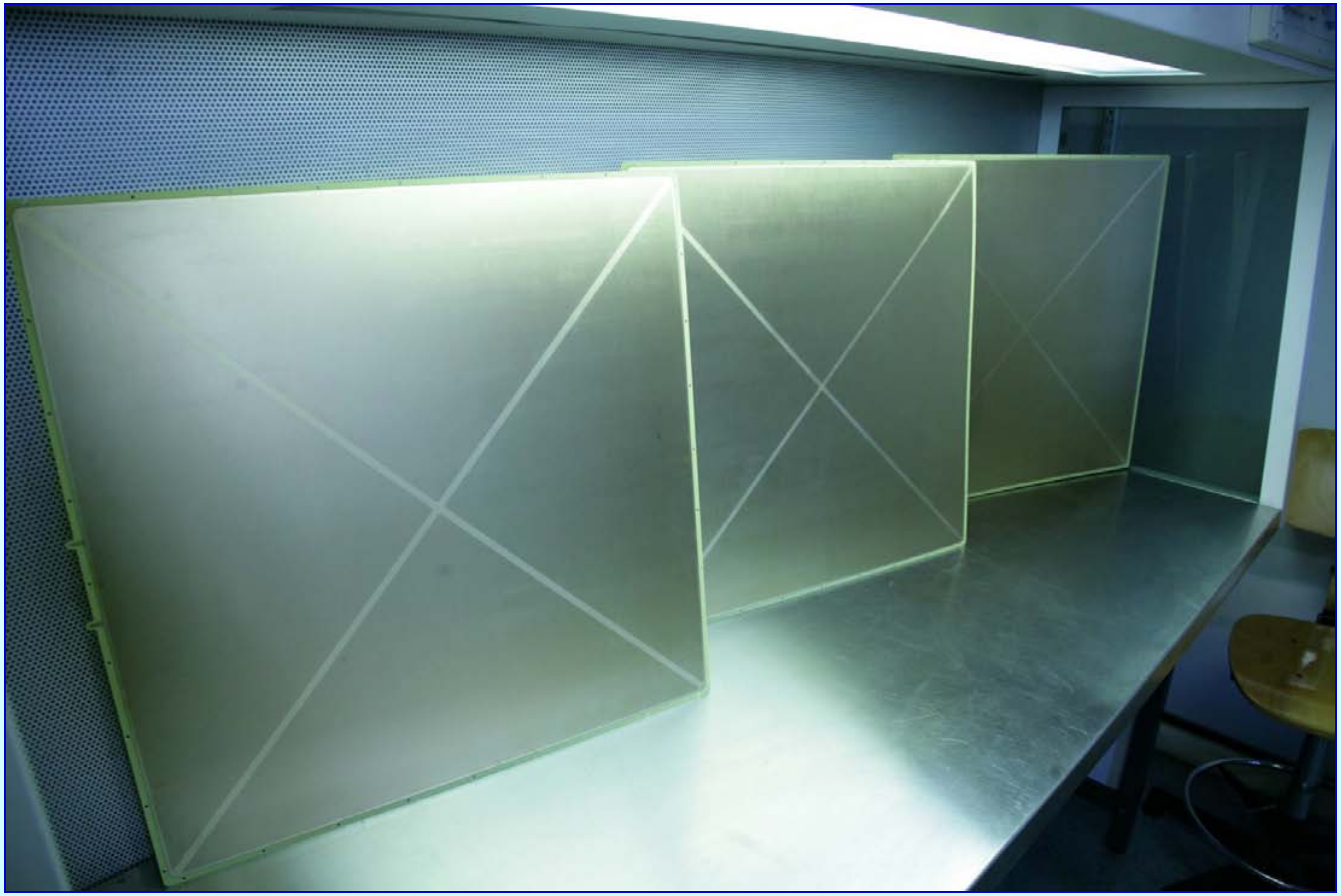


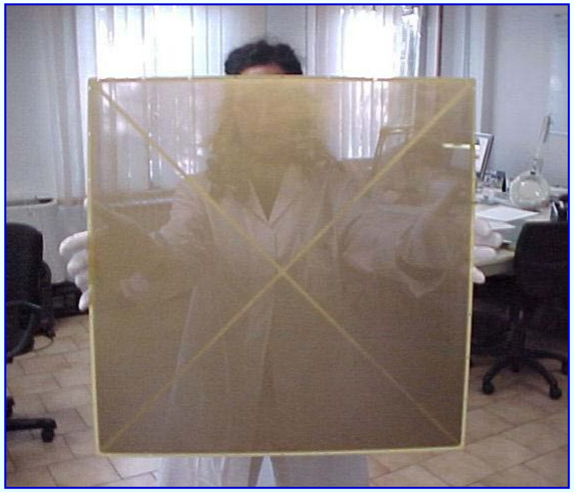
COMPASS THGEM pcb's are produced by an industrial pcb Company: ELTOS S.p.A. (Arezzo - Italy)

<u>Defects are detected by a quality check procedure when</u> THGEMs are received



Test production of large size THGEMs

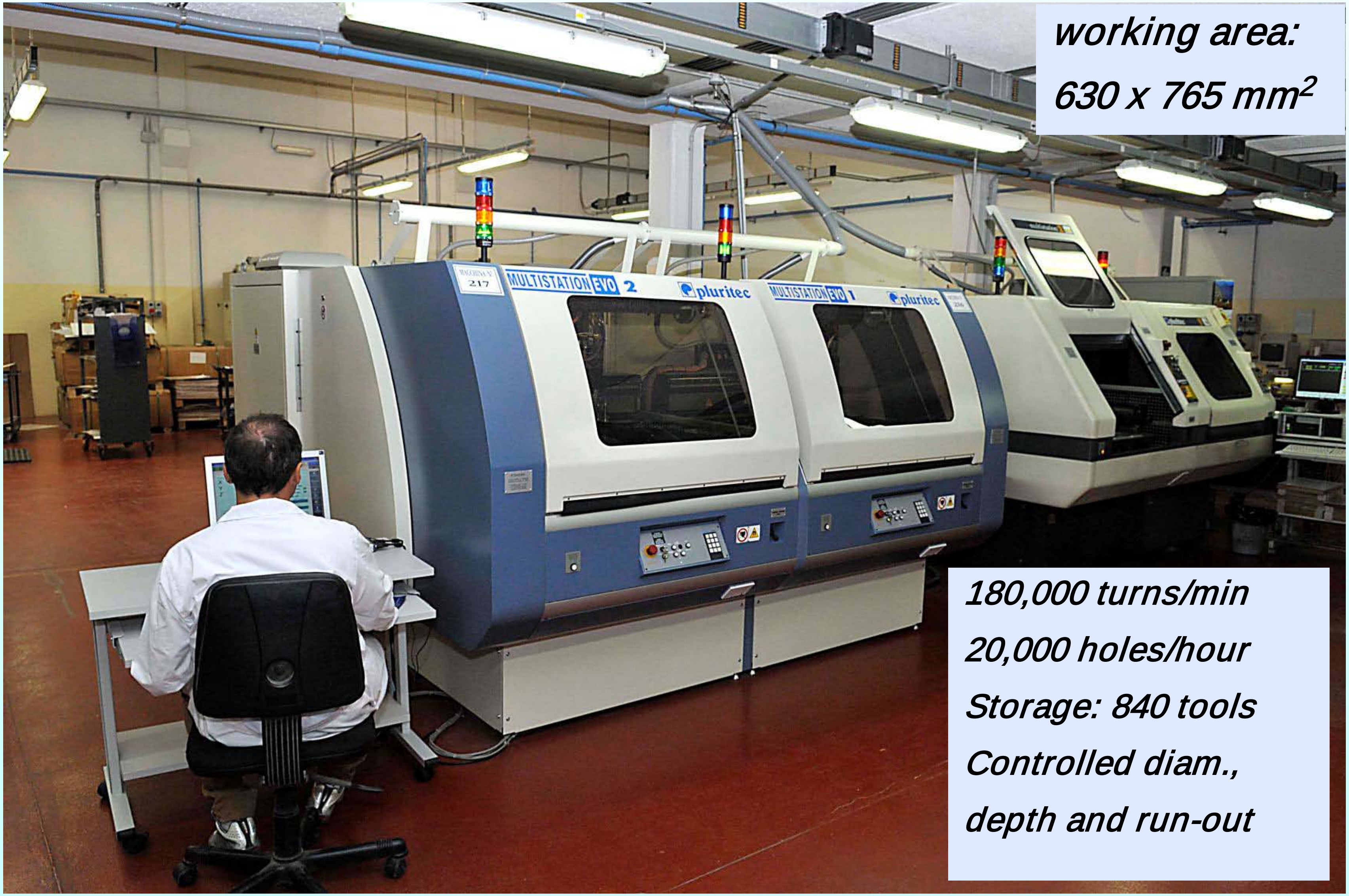




600 x 600 mm² → ~ 600,000 holes/piece (cost: ~0.001 € / hole)

Ø: 0.4, pitch: 0.8, thickness: 0.6 mm, rim: 5 µm (micro-etching), Ni-Au coating

PLURITEC MULTISTATION EVOLUTION



working area:

630 x 765 mm^2

180,000 turns/min

20,000 holes/hour

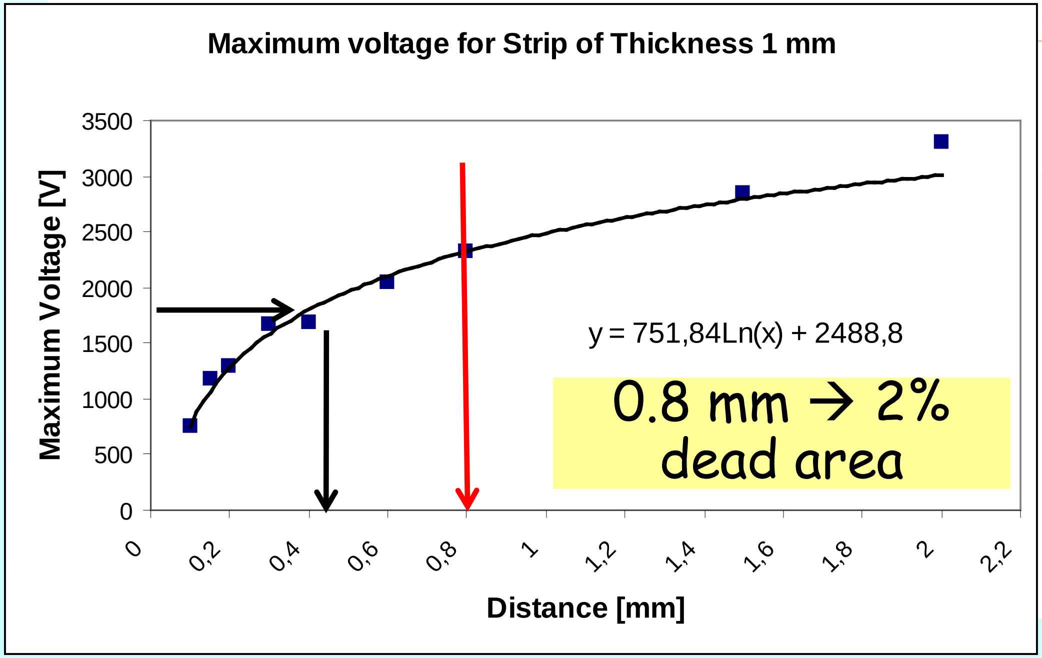
Storage: 840 tools

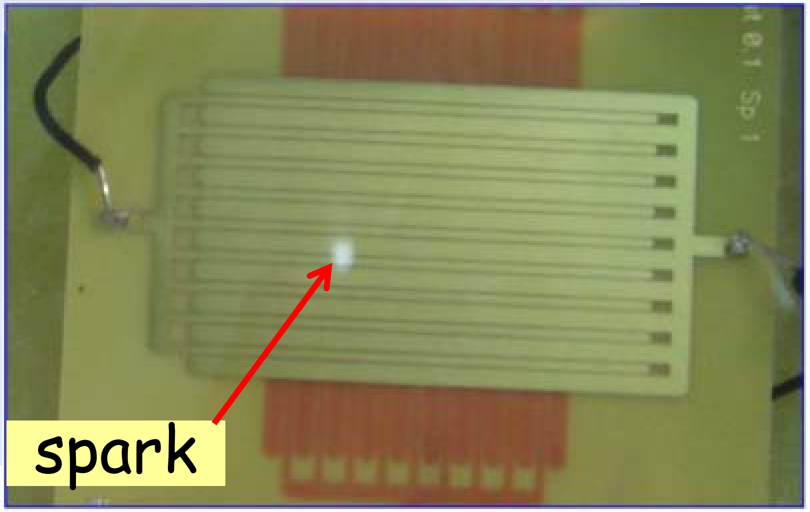
Controlled diam.,

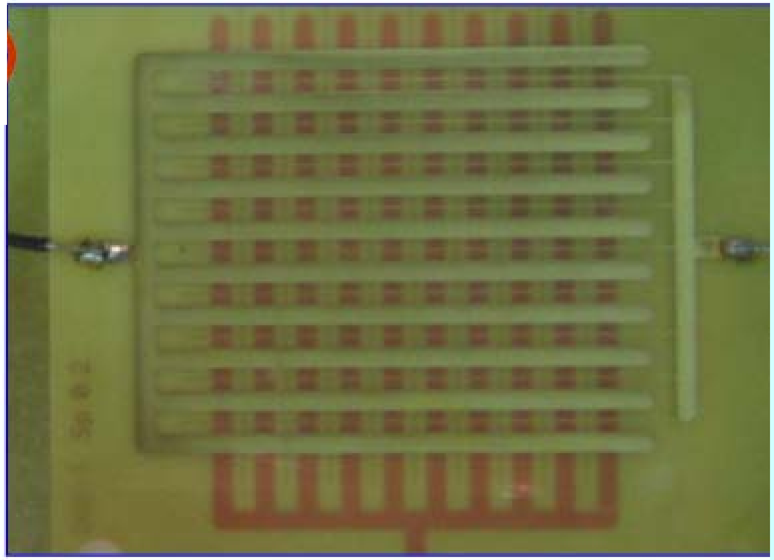
depth and run-out

THGEM segmentation studies

Samples of 20 different types measured to determine the breakdown voltage and study the effect of discharges.
This information is useful to properly define the THGEM segmentation.



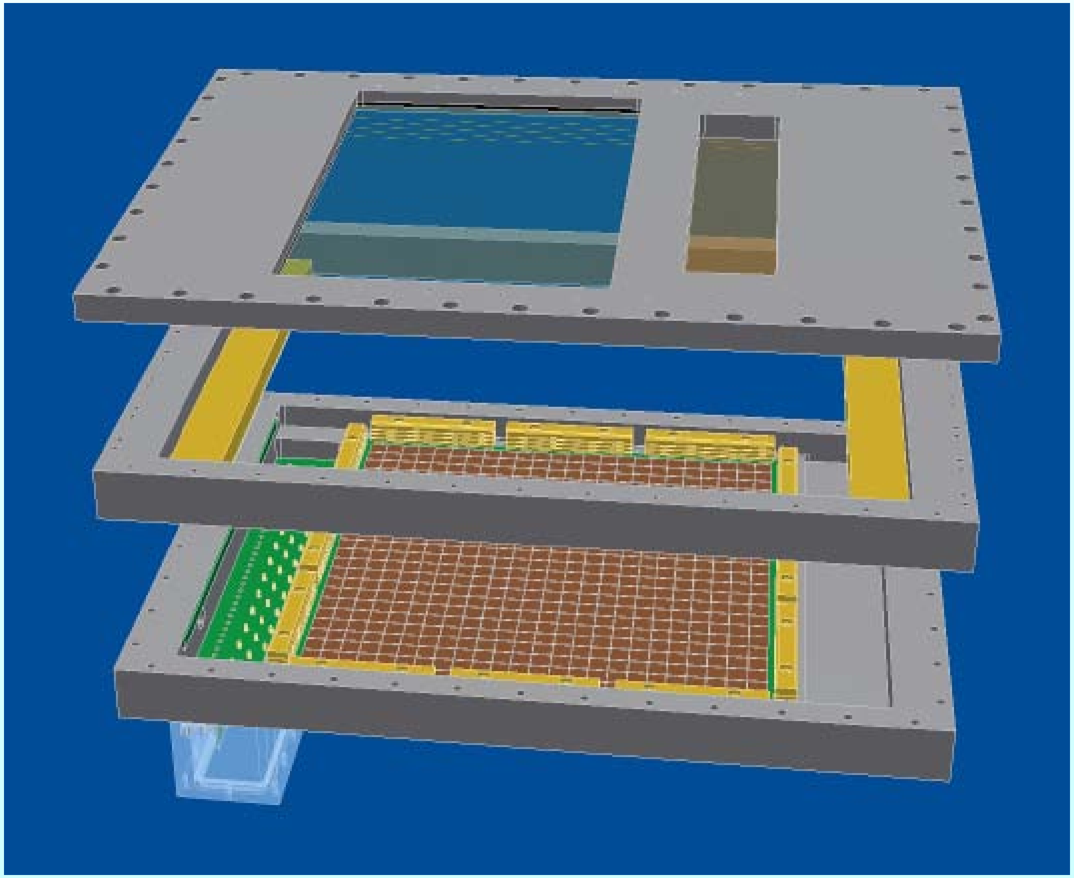




The 300 mm x 300 mm prototype PD

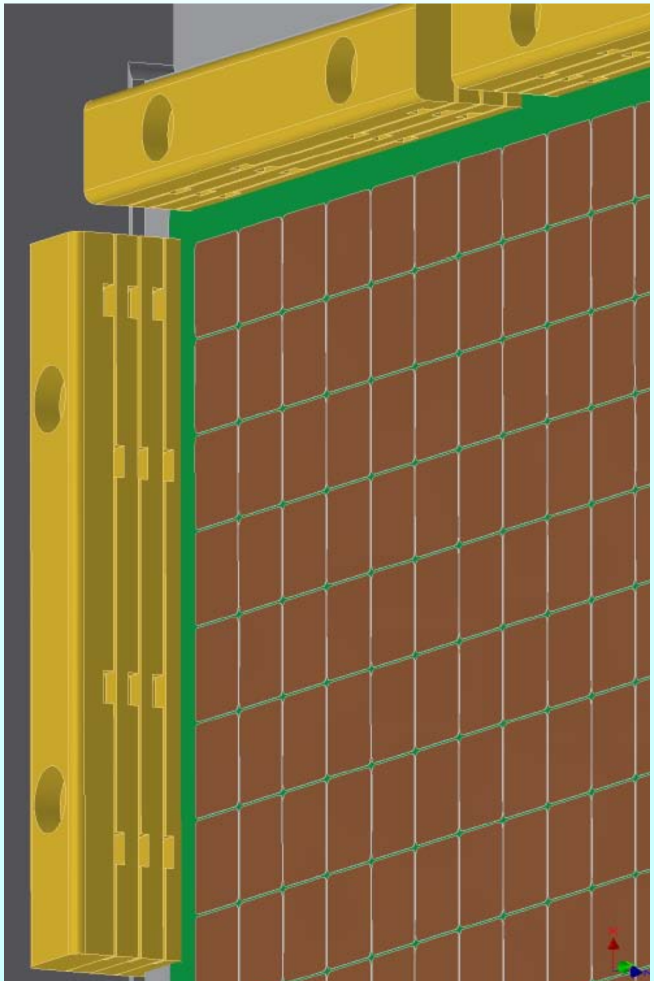
Main goal :

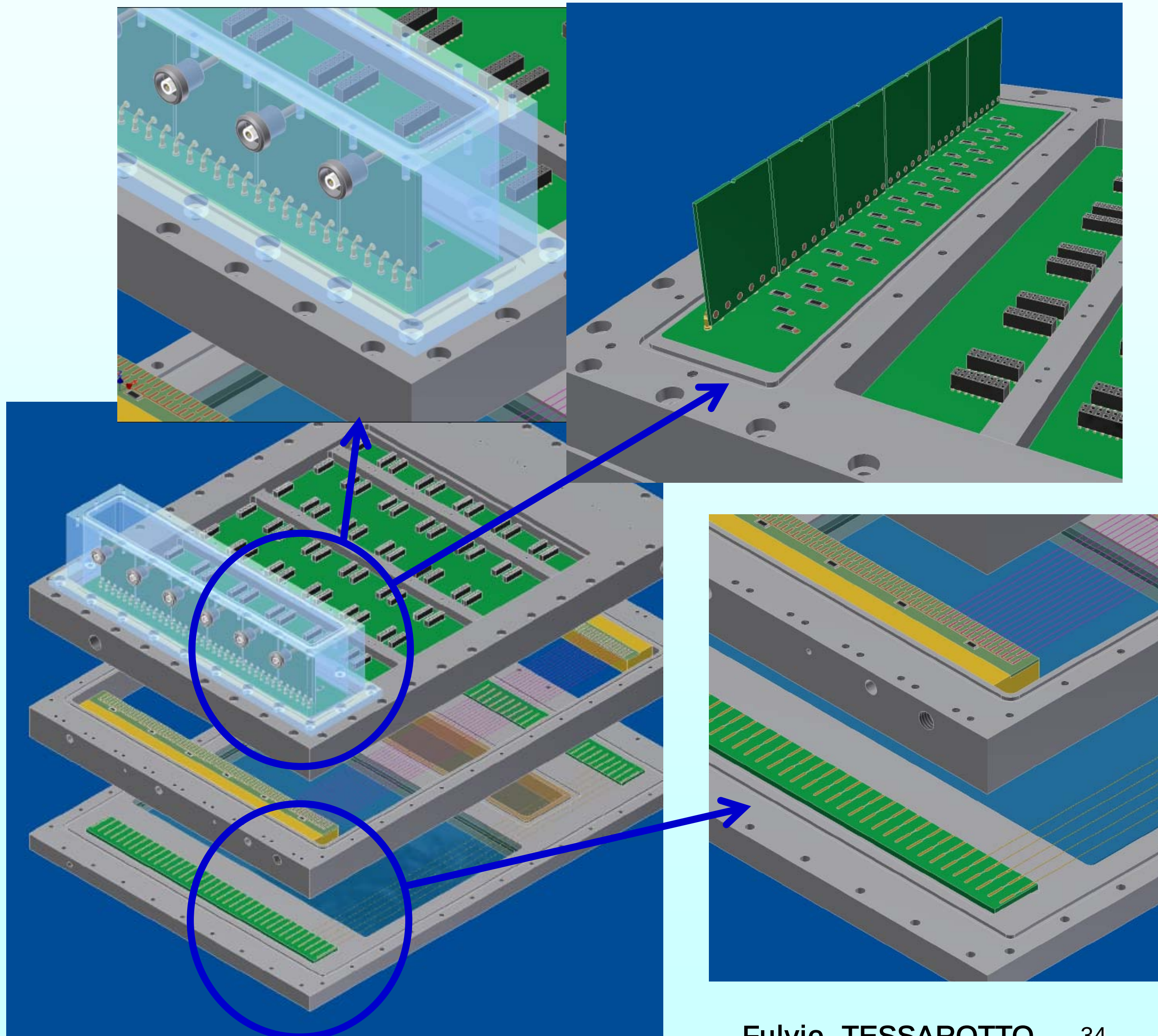
- **an opportunity to approach the large size, reduced dead zone detectors, as required for RICH-1 – <u>engineering effort</u>**



The 300 mm x 300 mm prototype PD

Some details

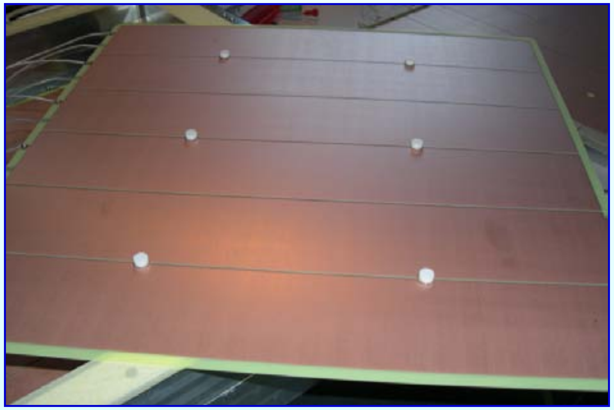
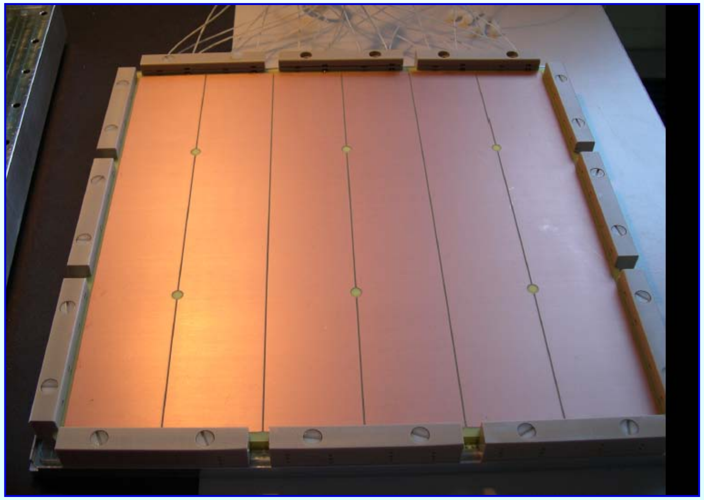
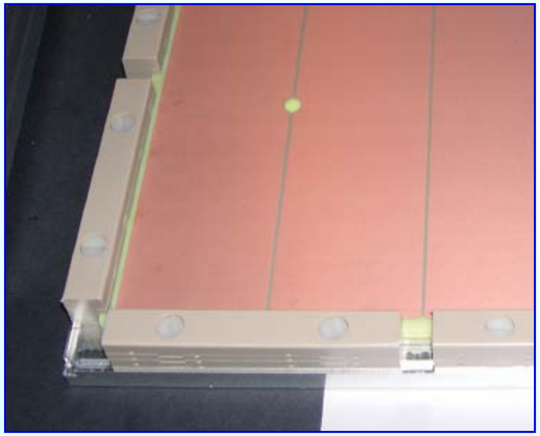
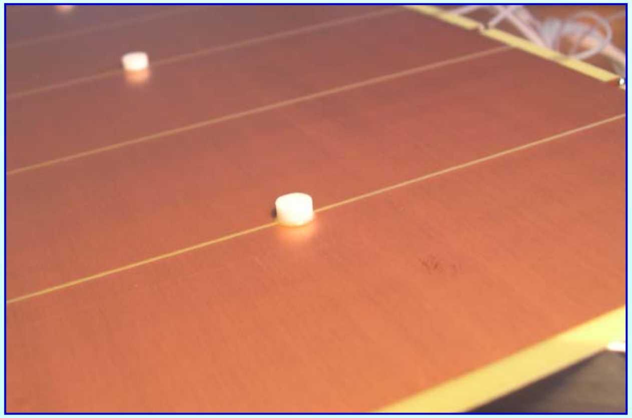
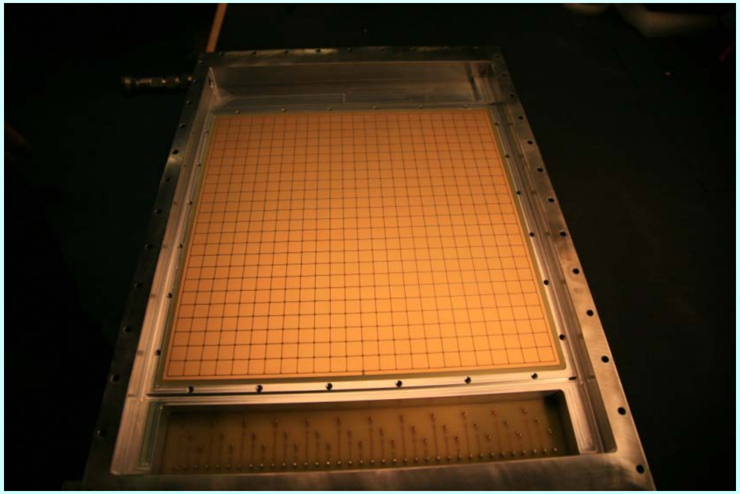
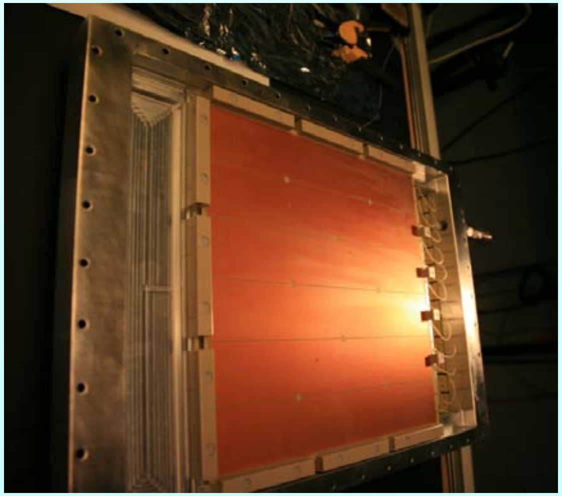




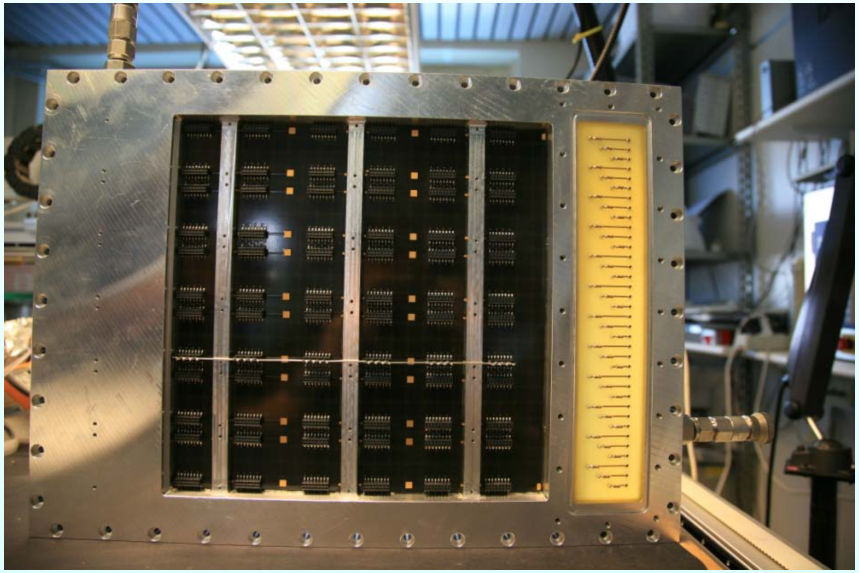
Fulvio TESSAROTTO

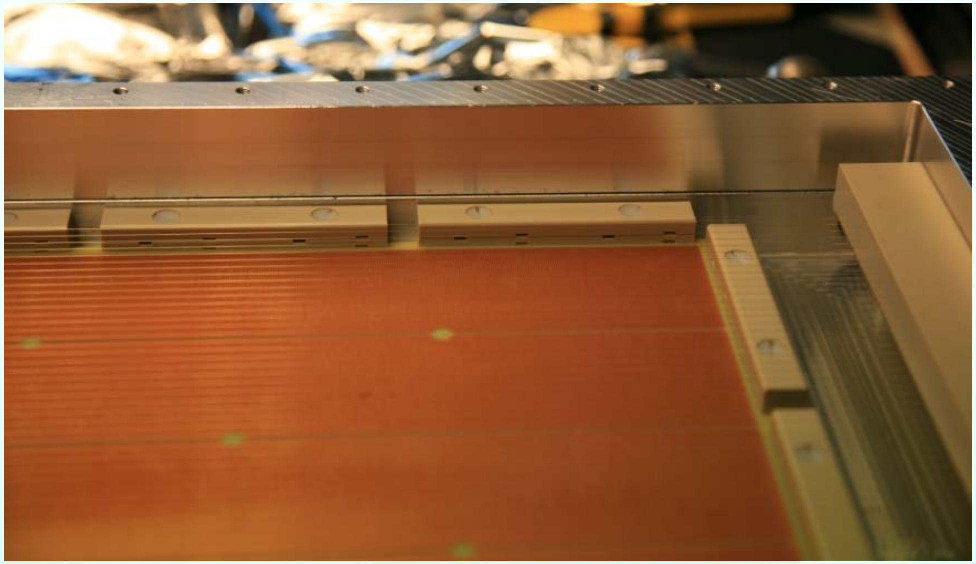
The 300 mm x 300 mm prototype PD

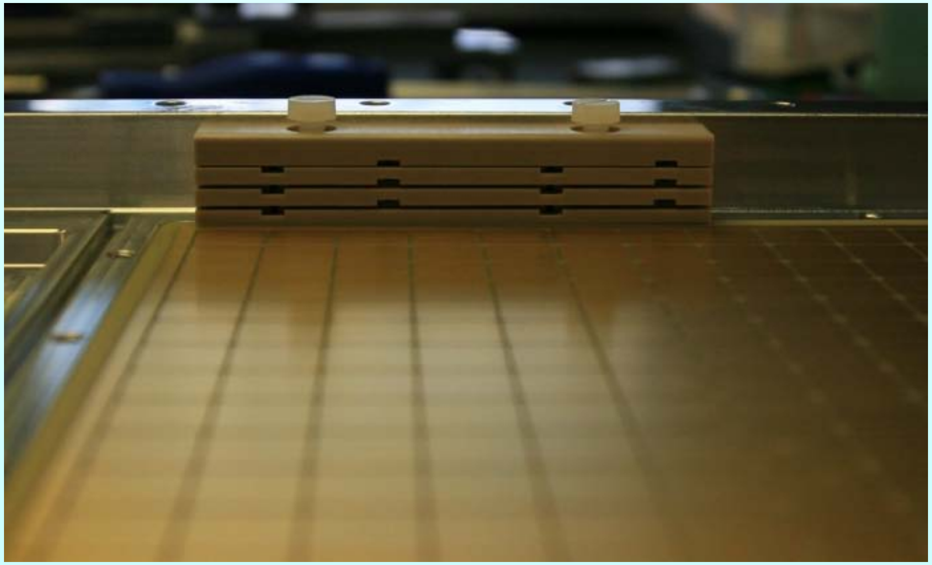
Some pictures

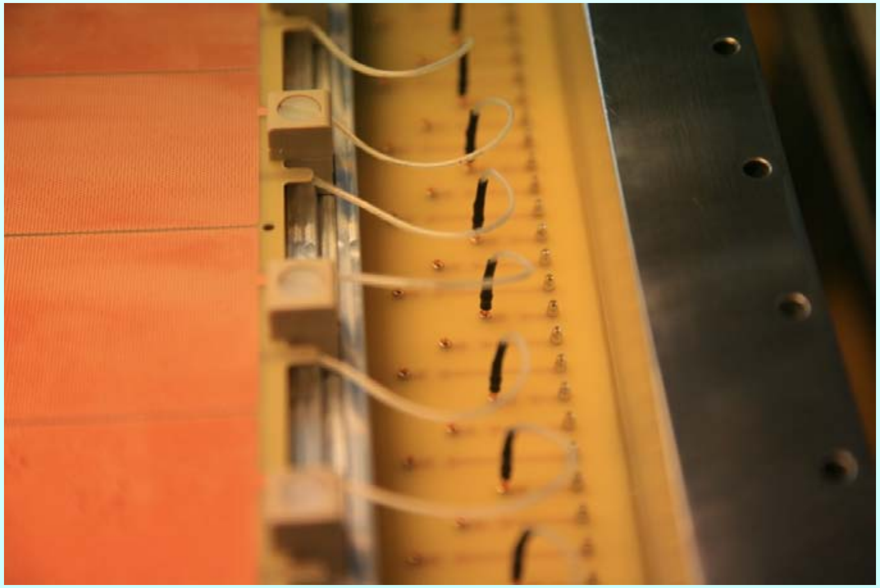







The 300 mm x 300 mm prototype PD

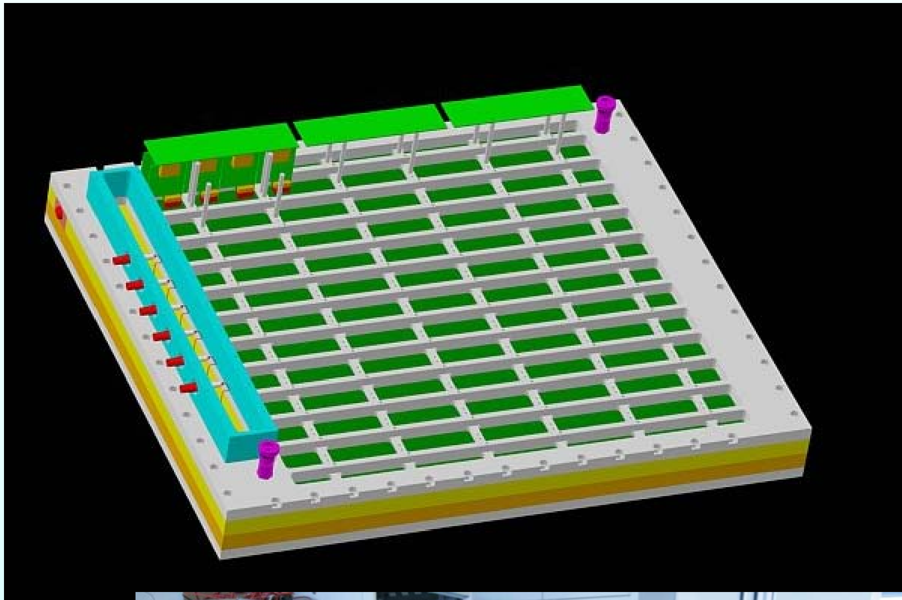


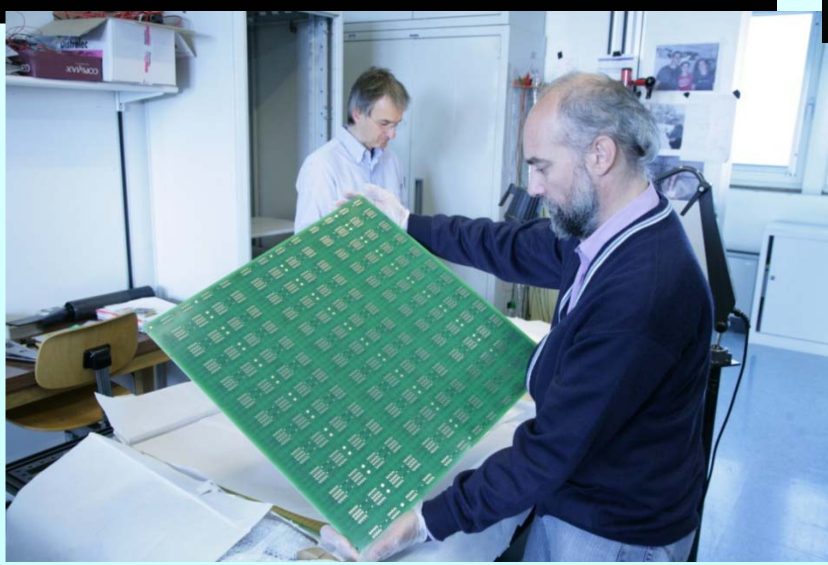




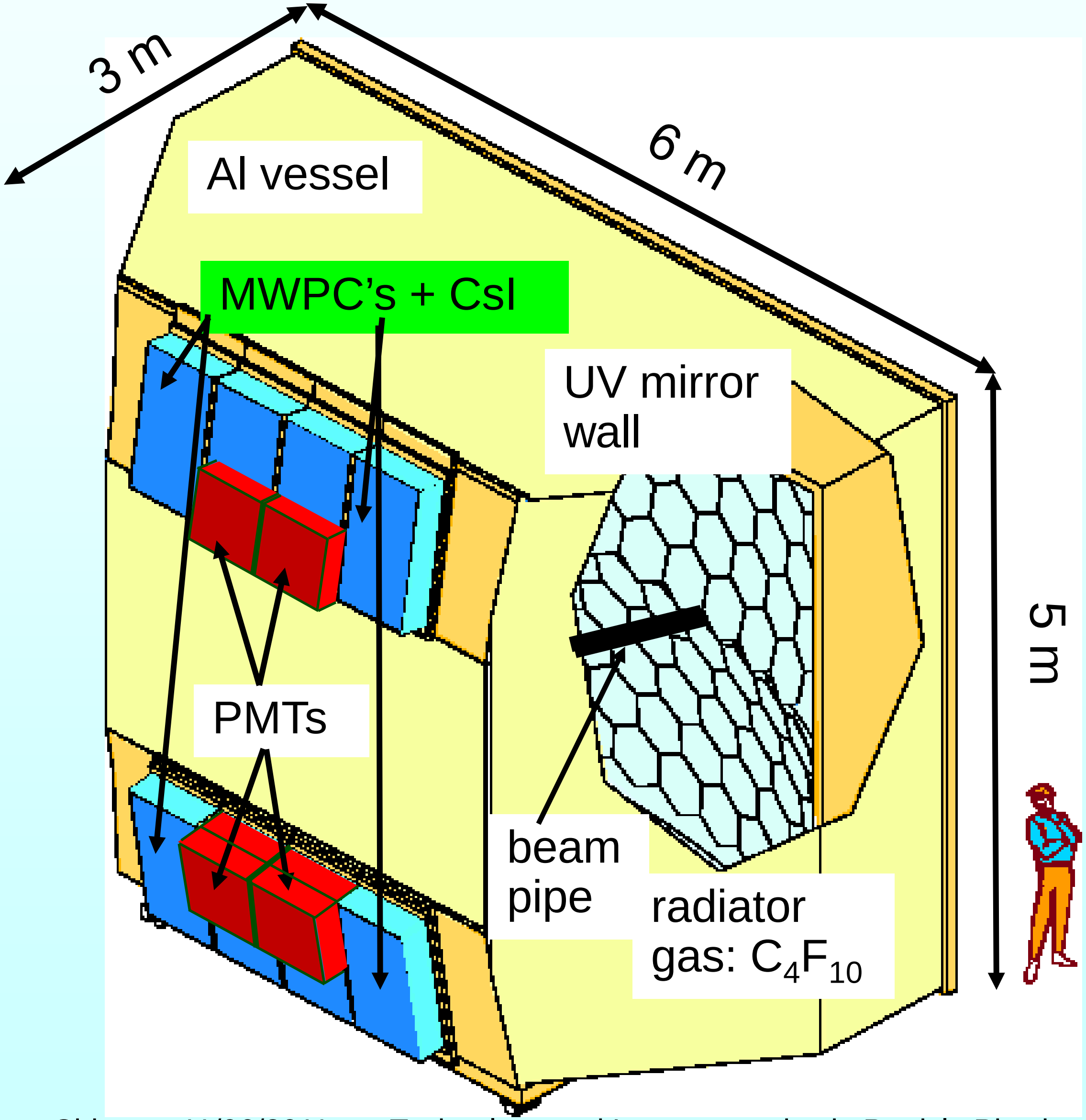


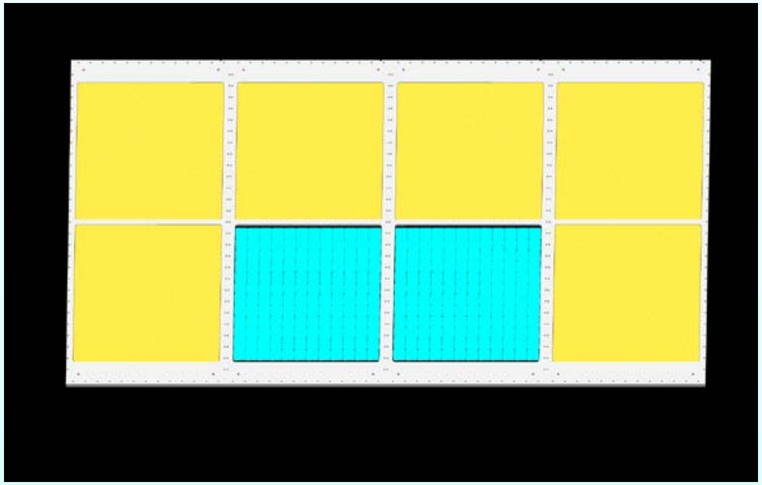
Towards 600 mm x 600 mm PD's

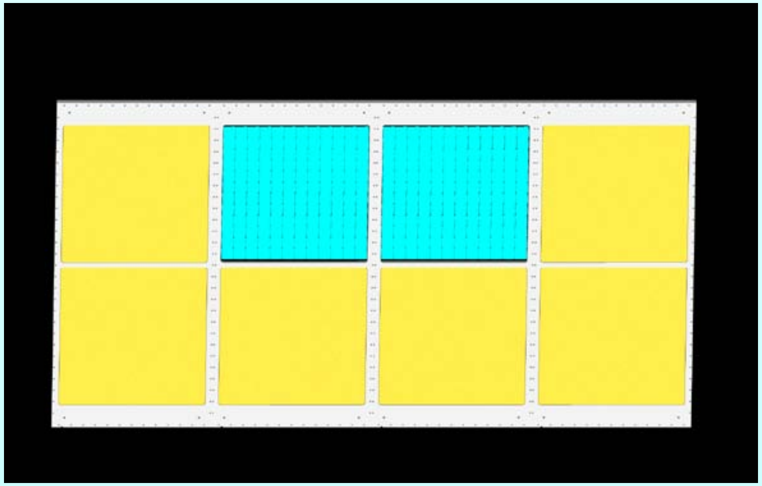




COMPASS RICH-1 PD upgrade

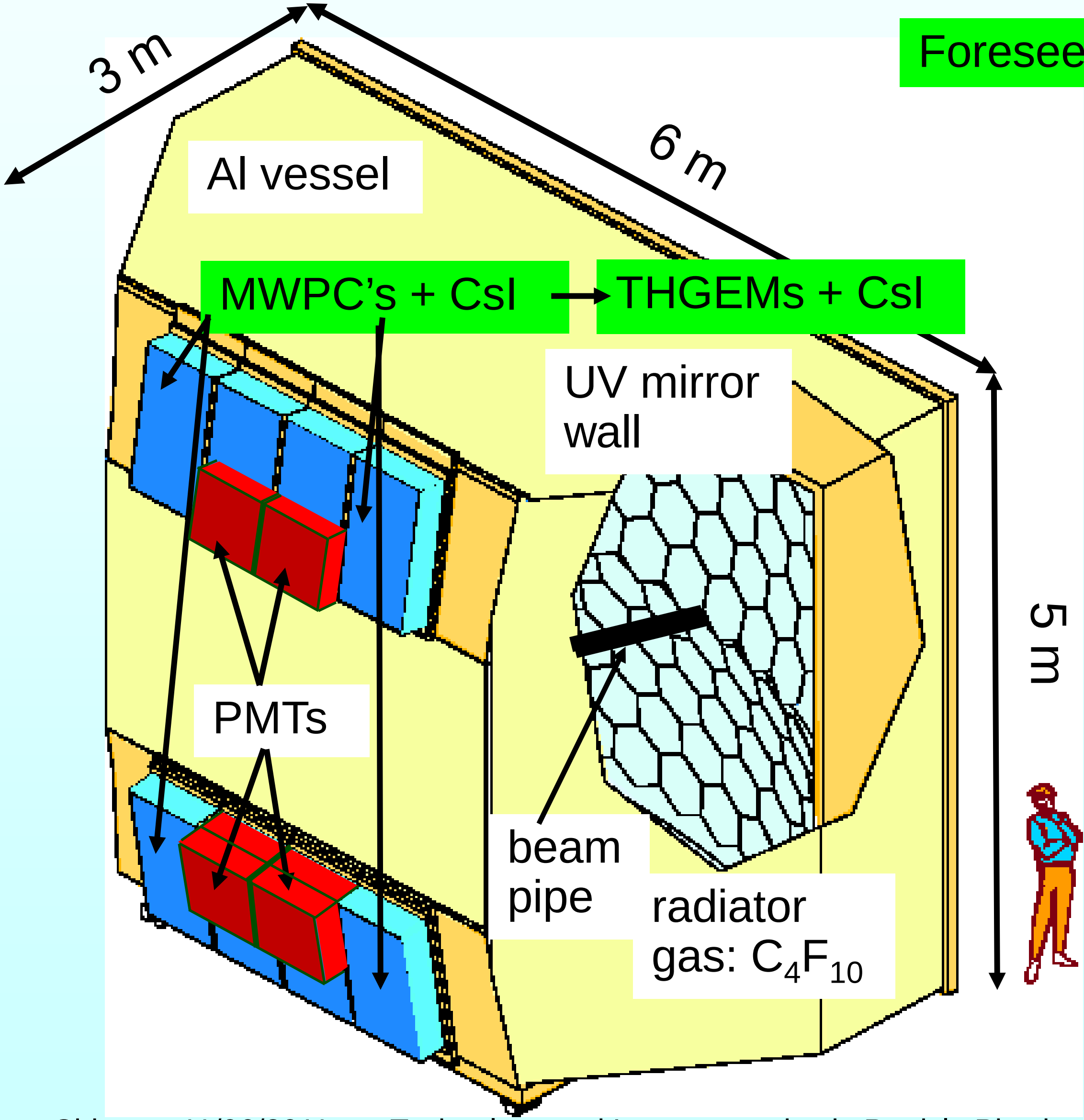


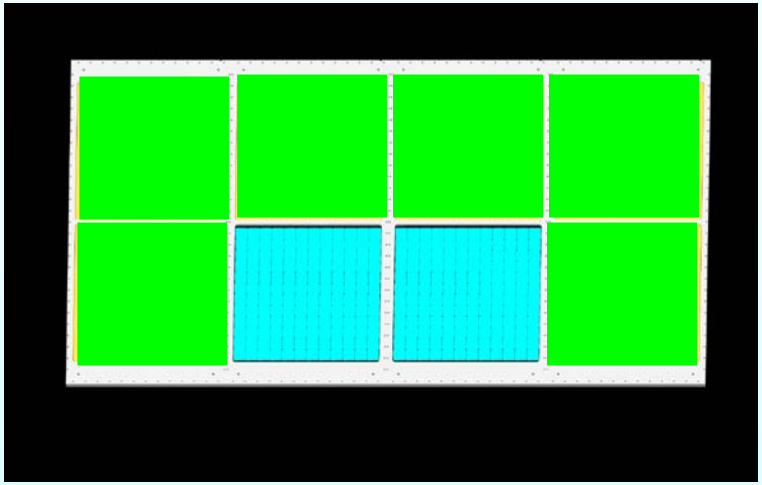


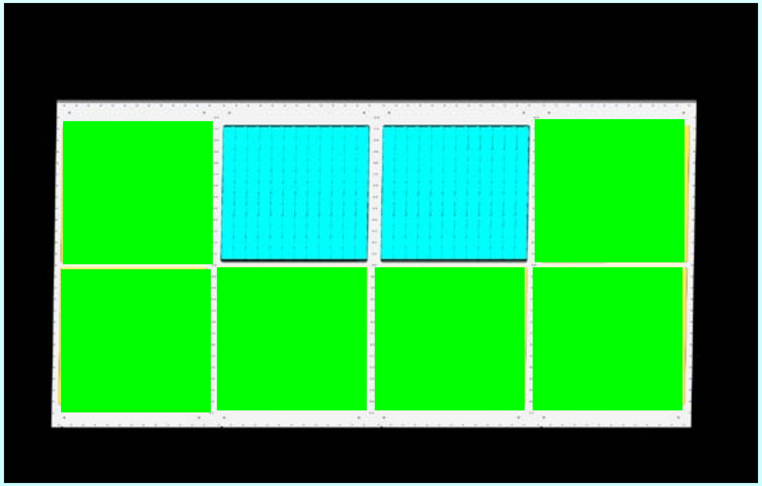


COMPASS RICH-1 PD upgrade

Foreseen during CERN shut-down 2013-14







CONCLUSIONS & OUTLOOK

- **THGEMs represent a good choice for single UV photon detectors:**
  pcb technology is o.k. provided appropriate parameters are chosen

- **Almost all principle aspects have been validated and understood using small size prototypes:**
  effective single photon detection, large and stable gain, fast signals

- **Optimization still to be performed on many details and open points**

- **"All the rest is engineering". Many challenges to overcome before achieving large size, cheap, robust, fast, high gain, high rate, magnetic insensitive single photon detectors, but we are progressing**

- **COMPASS RICH-1 will probably be the first to use THGEM-based PDs**