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New Developments In Photodetection
NDIP2011
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Bruno Mazoyer - LAL Orsay

Detection of single photons with ThickGEM-based counters

- The reasons behind the choice of THGEM-based PD's
- Characterization and simulations
- PD prototypes and test-beam results
- Large size PD's
- Conclusions

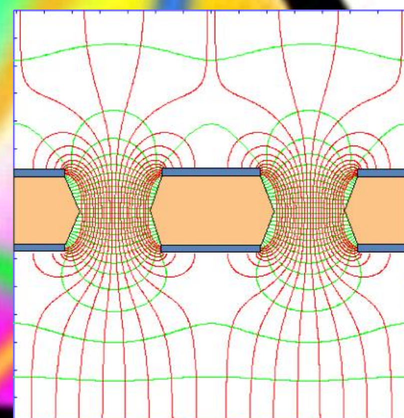
S. Levorato

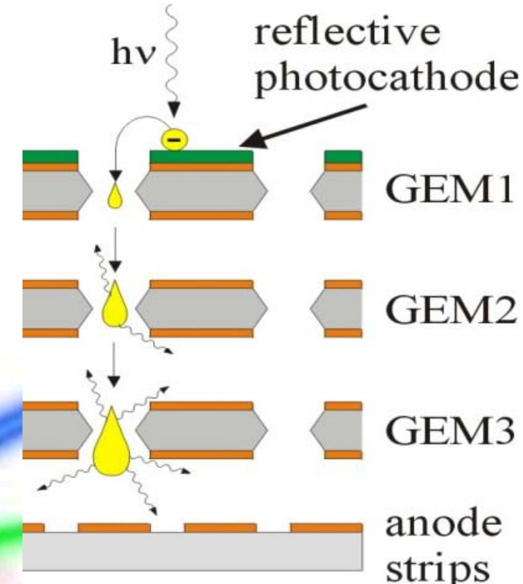
on behalf of Alessandria , Aveiro, Freiburg, Liberec, Prague, Torino, Trieste Collaboration

Why THGEM based counters for single photon detection

THGEM based photodetectors characteristics:

–GEM based
–large surface fraction available for photon converter coating
–production with standard PCB techniques
–closed geometry structure
–high gain device
–fast signal from electron drift (few ns)
–robust and self supporting





THGEM-PD are a possible and economical affordable alternative to overcome the severe limitations of the actual open geometry gaseous single-photon detectors (MWPC + CsI pc) when large are coverage is needed (low gain, rate capabilities, electrical instabilities, long recovery time after detector trips)

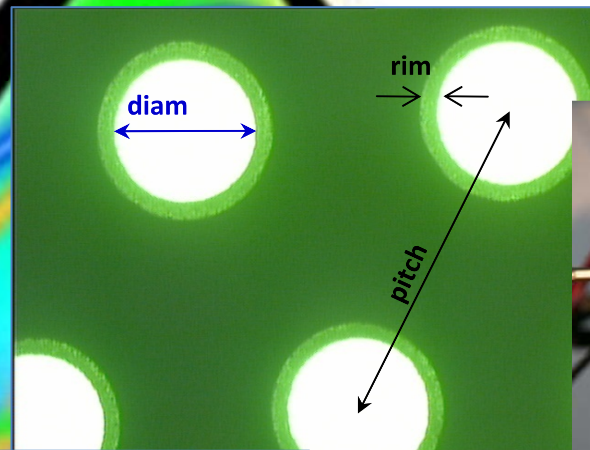
THGEM characterization: parameters

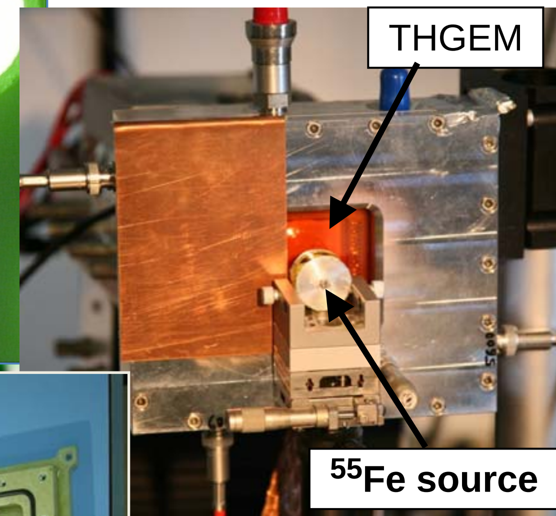
Four years ago an R&D program was started to develop a large size, cheap, robust, fast, high gain, high rate, magnetic insensitive single photon detector for RICH applications based on THGEM and reflective CsI photocathode.

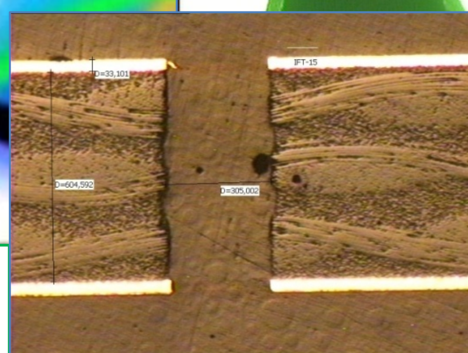
EXPLORING A MULTI-DIMENSIONAL SPACE

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

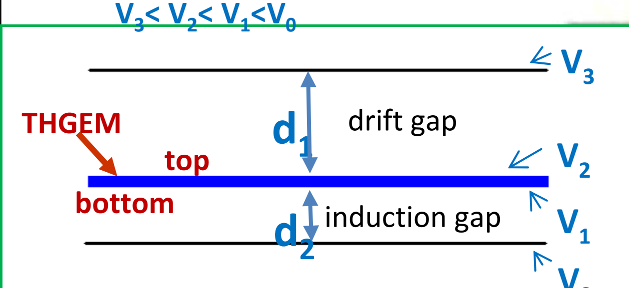
THGEM's with 30 x 30 mm^2 active area







To detect ionizing particle : $V_3 < V_2 < V_1 < V_0$



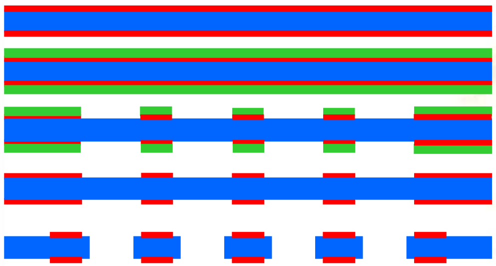
$E_{...ft} = (V_3 ... /d_1$

$E_{...n} = (V ...) /d_2$

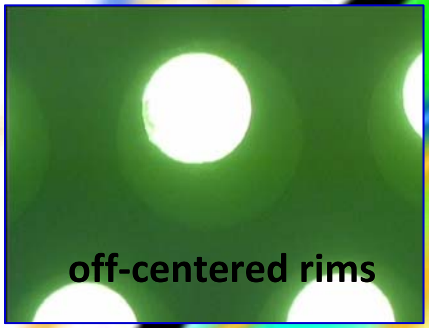
$\Delta V ... = V_2 - V_1$

THGEM characterization: production techniques: an overview

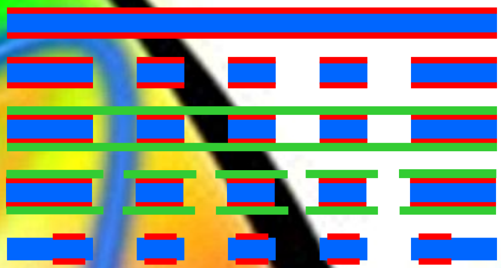
1) traditional



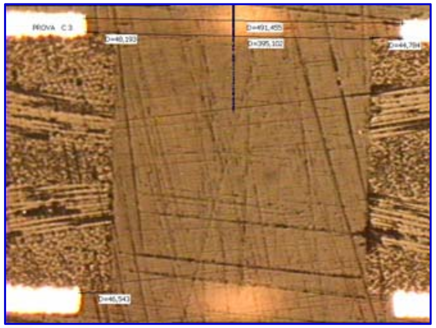
etching before drilling



2) large rim

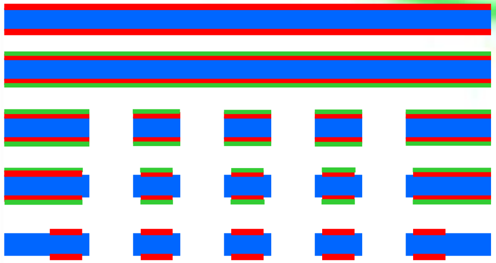


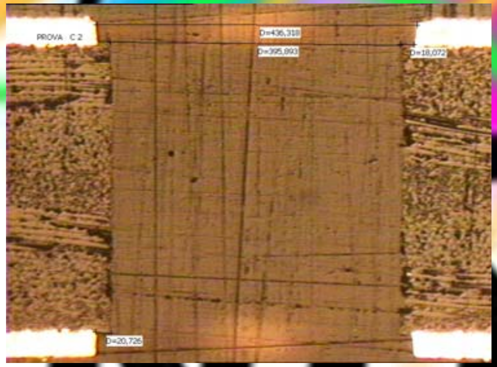
metallographic section



100 μm rim

3) small rim



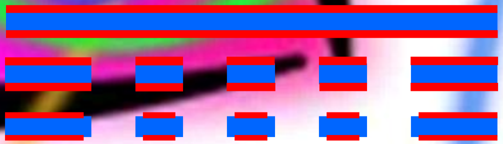


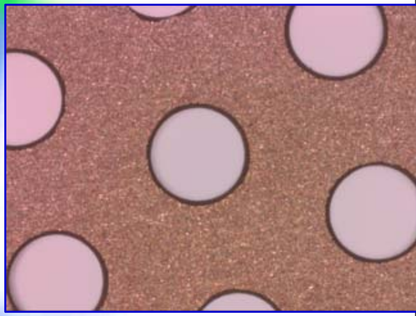
20 μm galvanic tin

instead of photo-resist

25 μ m

4) global etching





u orm oth

our choice: global micro- etching

THGEM characterization tests

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**

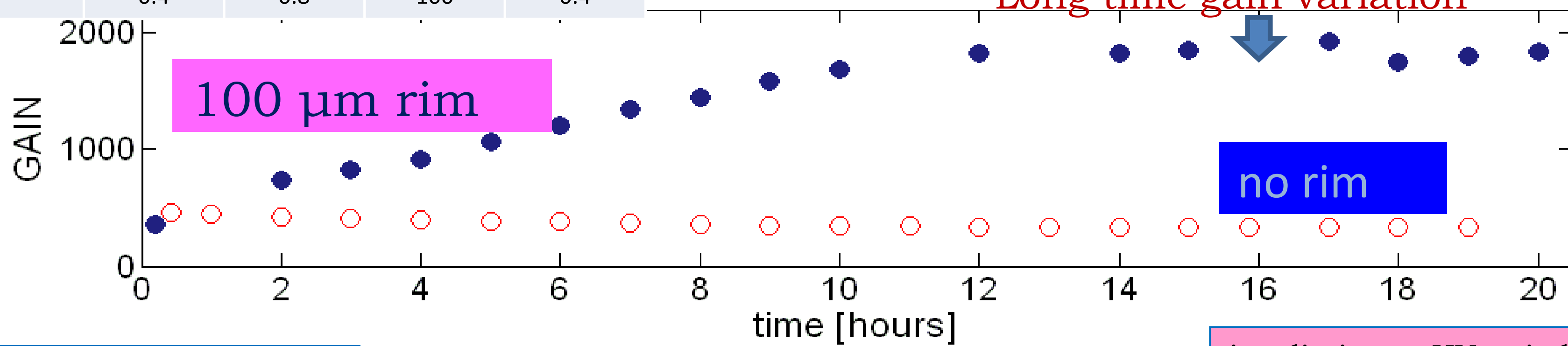
Prototypes of small size THGEM-based PD's and of 100mm x 100 mm PD's have been built and tested. Some of the results are shortly presented in the next slides

RIM role: gain stability

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

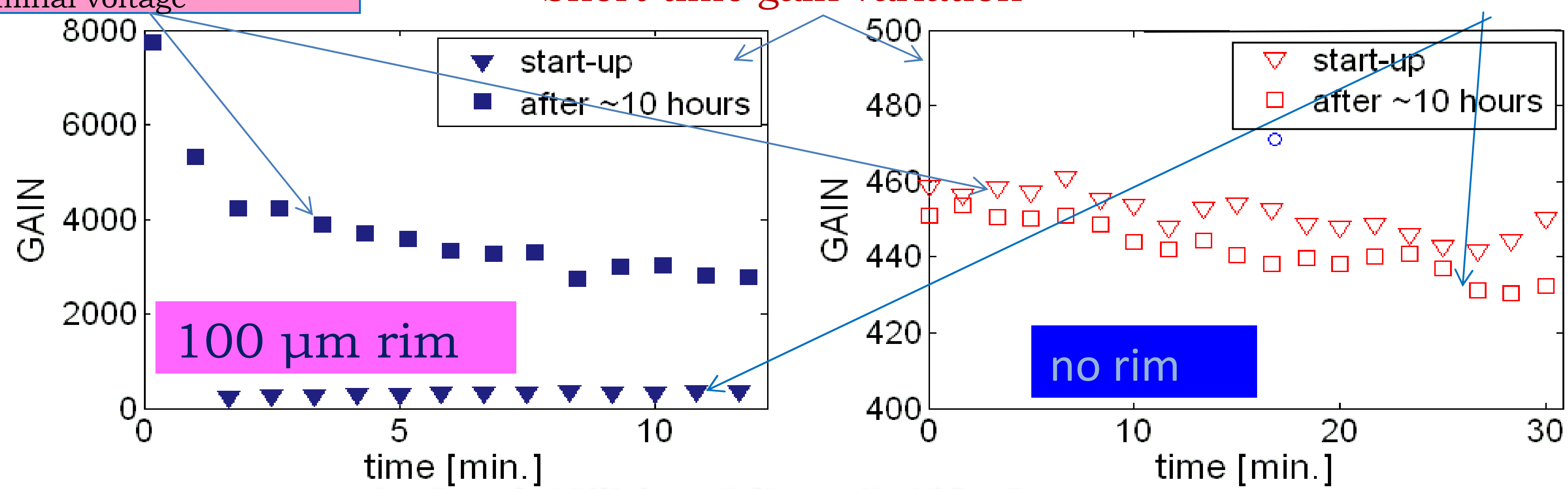
Long time gain variation



START IRRADIATING after ~10 hours at nominal voltage

Short time gain variation

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



Gain stability: dielectric surface effect

this effect is seen in GEM's:

2007 IEEE Nuclear Science Symposium Conference Record MP5-3

gain variations are related to the dielectric surface

Understanding the gain characteristics of GEMs inside the Hadron Blind Detector in PHENIX.

W. Anderson, B. Azmoun, C.-Y. Chi, Z. Citron, A. Dubey, J. M. Durham, Z. Fraenkel, T.Hemmick, J. Kamin, A. Kozlov, A.Milov, M. Naglis, R. Pisani, I. Ravinovich, T. Sakaguchi , D. Sharma, A. Sickles, I. Tserruya, C. Woody

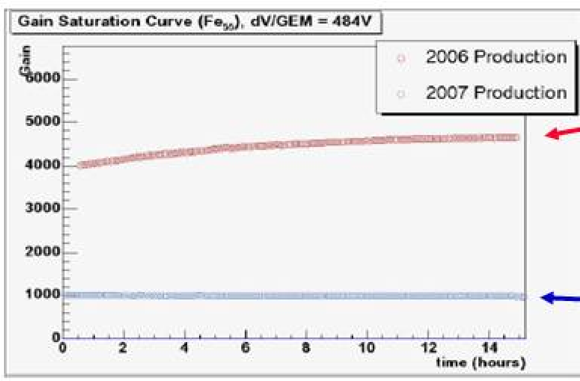


Fig. 11. Gain as a function of time after HV was on for 3 days. Red points are for a GEM stack comprised of GEMs produced in 2006; blue points are for a stack of 2007 GEMs.

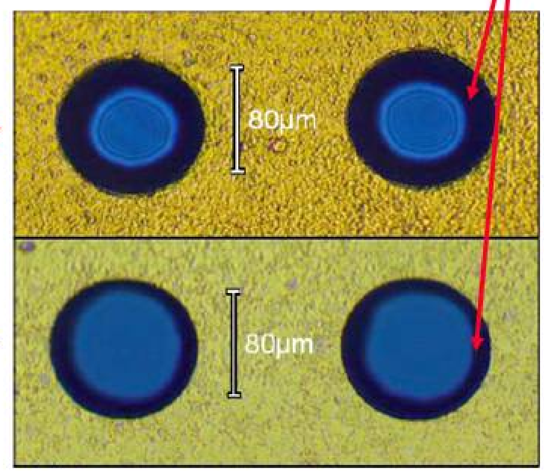
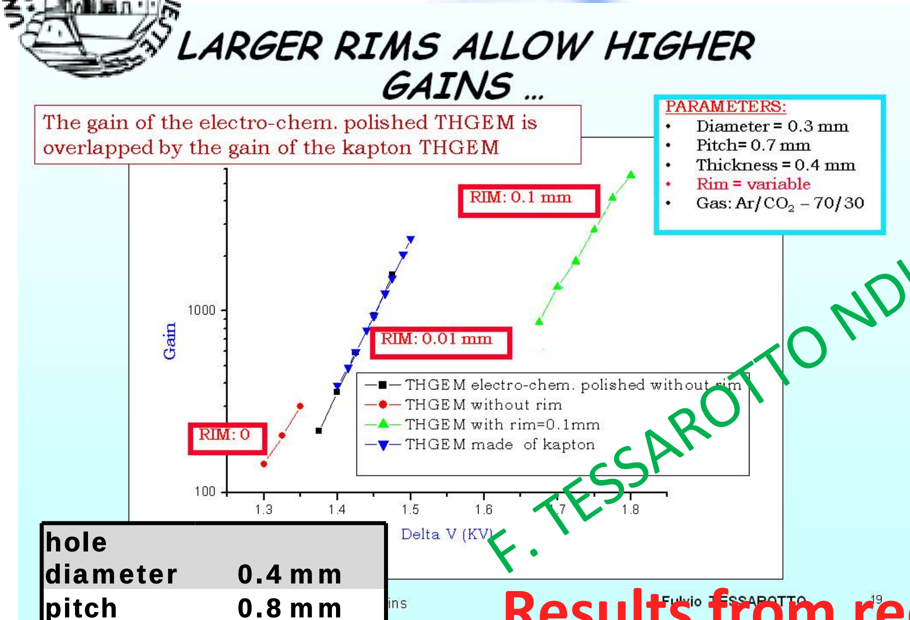
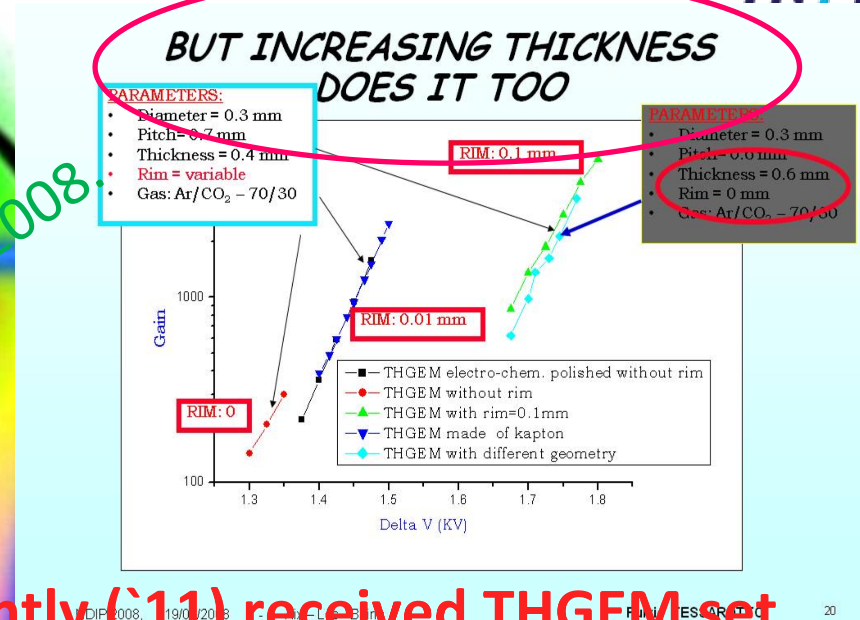


Fig. 12. GEM holes viewed under a microscope. 2006 production GEMs are shown above; 2007 production GEMs are below.

NDIP 2008, 19/06/2008 - Aix – Les - Bains Fulvio TESSAROTTO 18

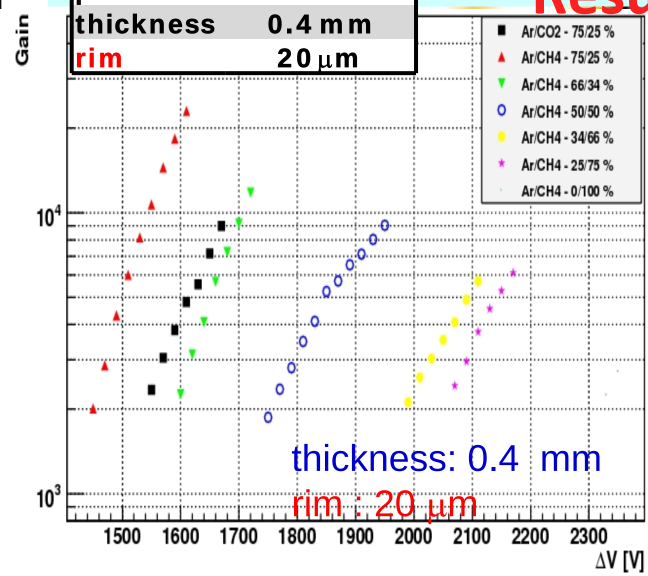
Thickness and rim role



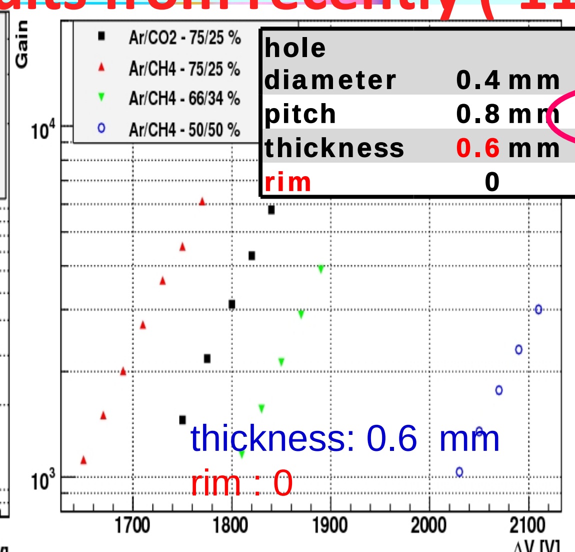


F. TESSAROTTO NDIP 2008.

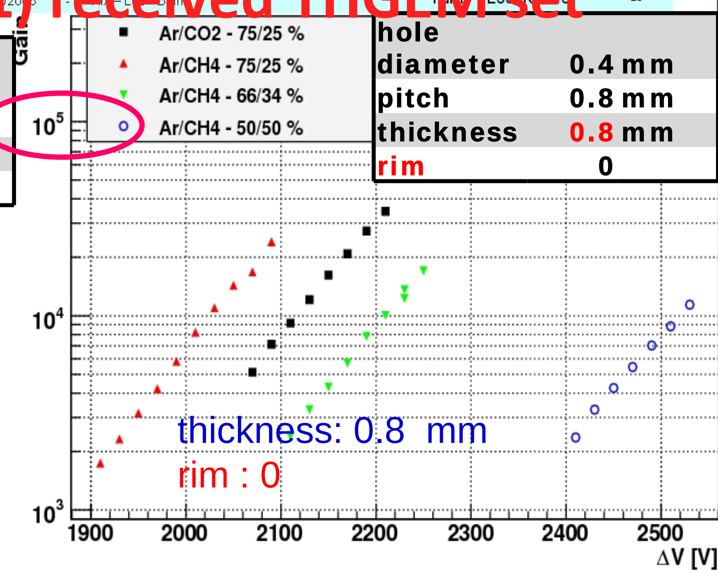
Results from recently (`11) received THGEM set



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



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



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

THGEM 2010 Test Beam: setup

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

CERN SPS T2-H4 beam line (RD51 test beam)
150 Gev/c $\mu/\pi+$, beam spot σ ~12 mm, rate ~1 kHz

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

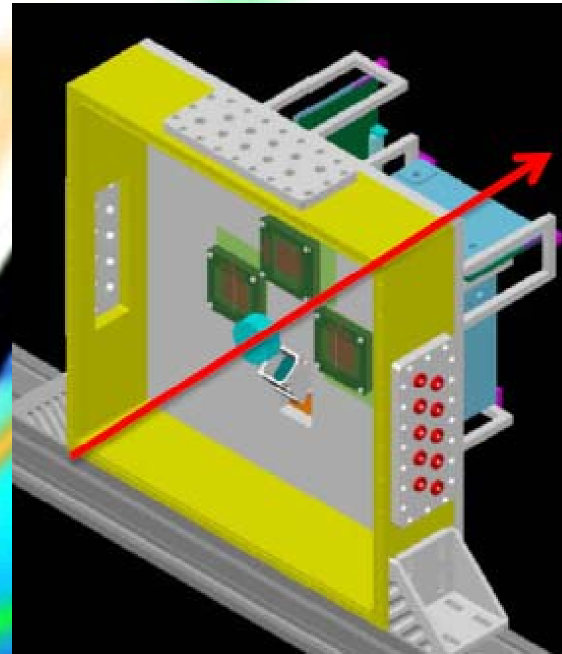
All THGEMs had the same parameters (in mm)
thickn. = 0.4, hole diam. 0.4, pitch 0.8, rim 0.01

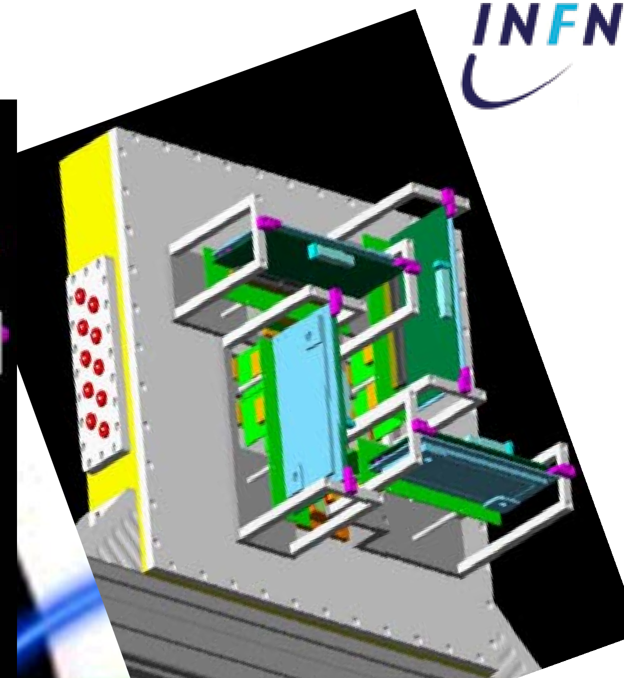
Gas mixture: Ar/CH_4 50/50, flow: ~50 l/h

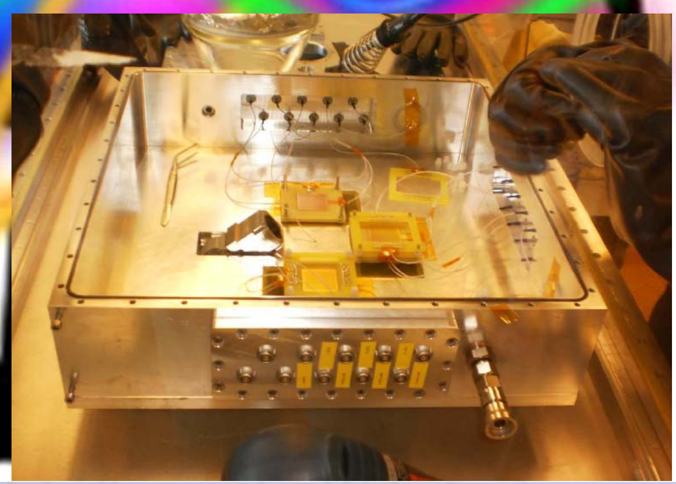
Spherically shaped fused silica radiator focusing Cherenkov light on a thin corona onto the THGEM's

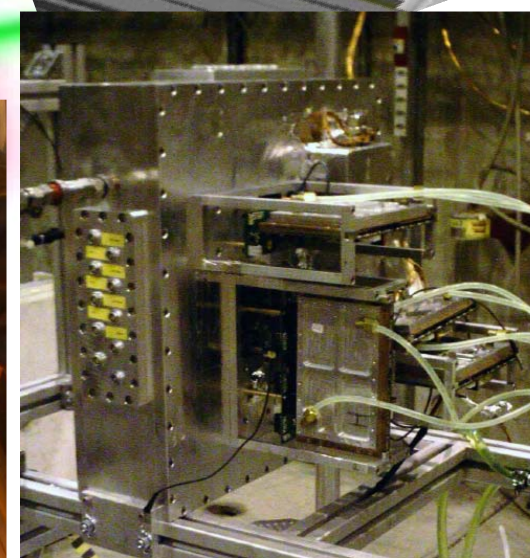
Two possible illuminations: full radiator – partially darkened radiator to avoid multiple photons
A 45 degrees rotation allows to change illumination condition

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



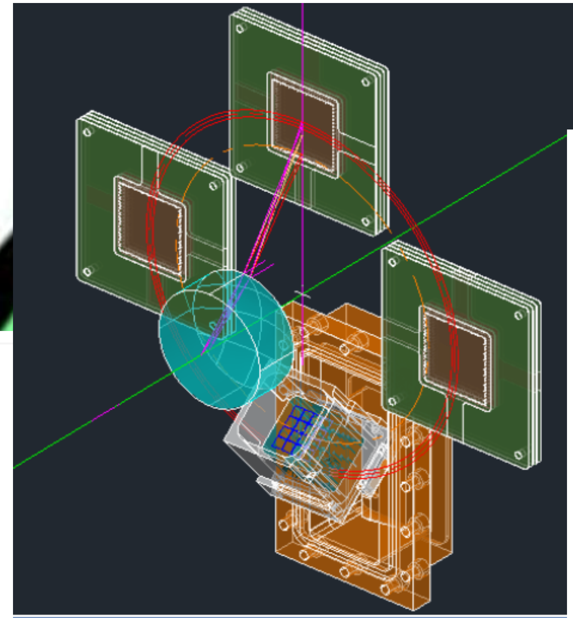


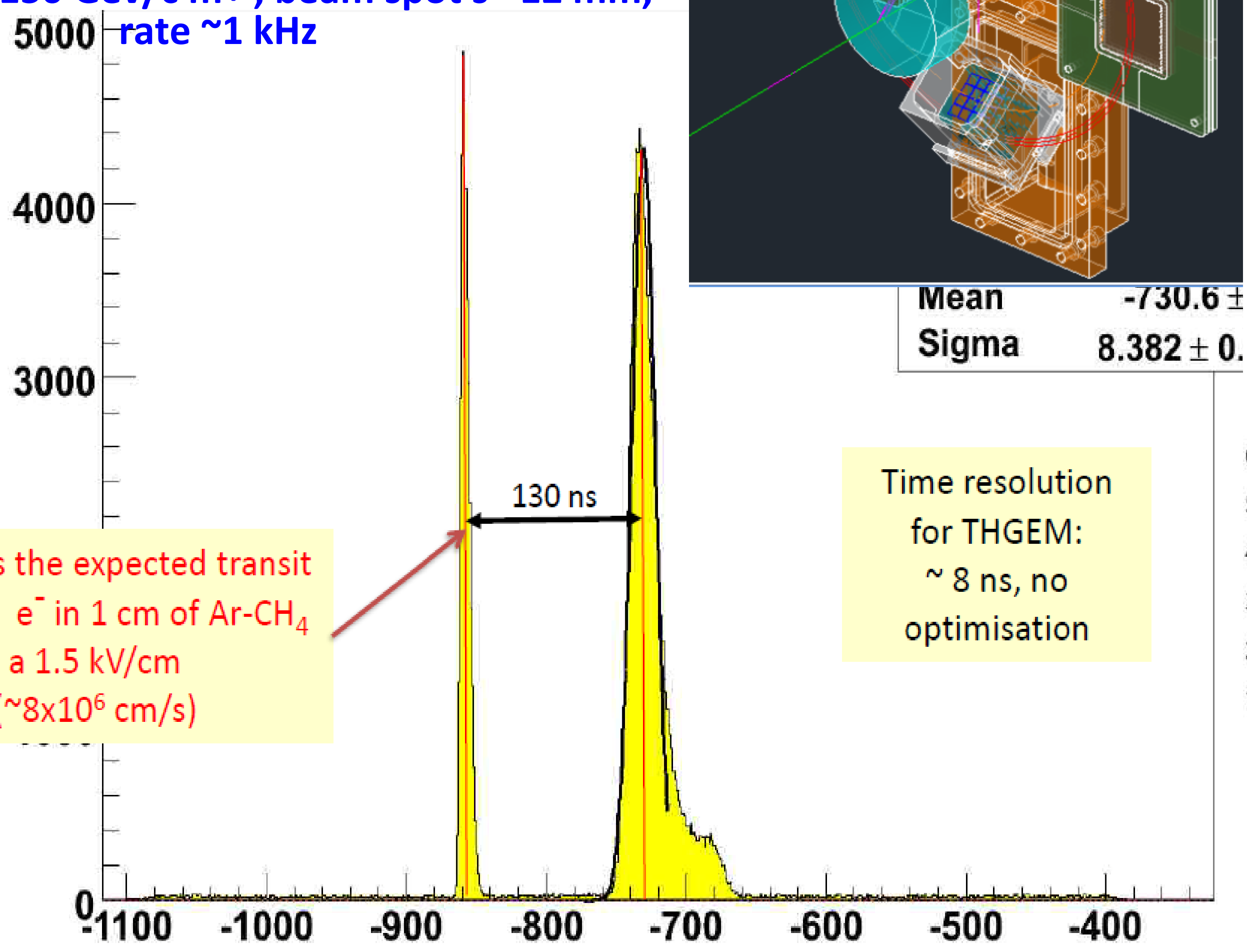




THGEM 2010 Test beam results: time development of the signal/imaging

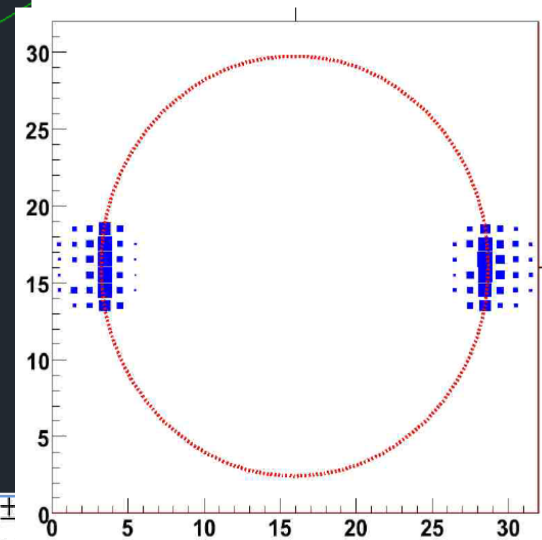
- 1 MAPMT and 3 triple THGEM photon detector prototypes
- CERN SPS T2-H4 beam line (RD51 test beam)
- 150 Gev/c m+ , beam spot s ~12 mm, rate ~1 kHz

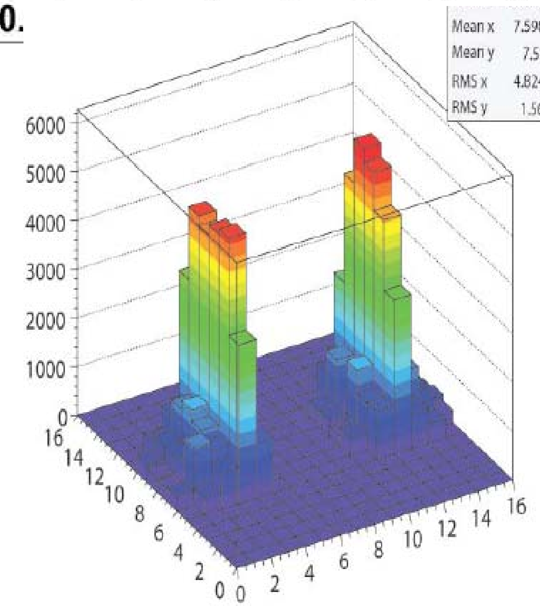




125 ns is the expected transit time for e^- in 1 cm of $Ar\text{-}CH_4$ a 1.5 kV/cm ($\sim 8 \times 10^6$ cm/s)

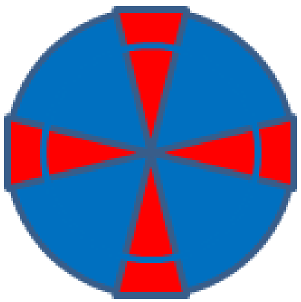
Time resolution for THGEM: ~ 8 ns, no optimisation

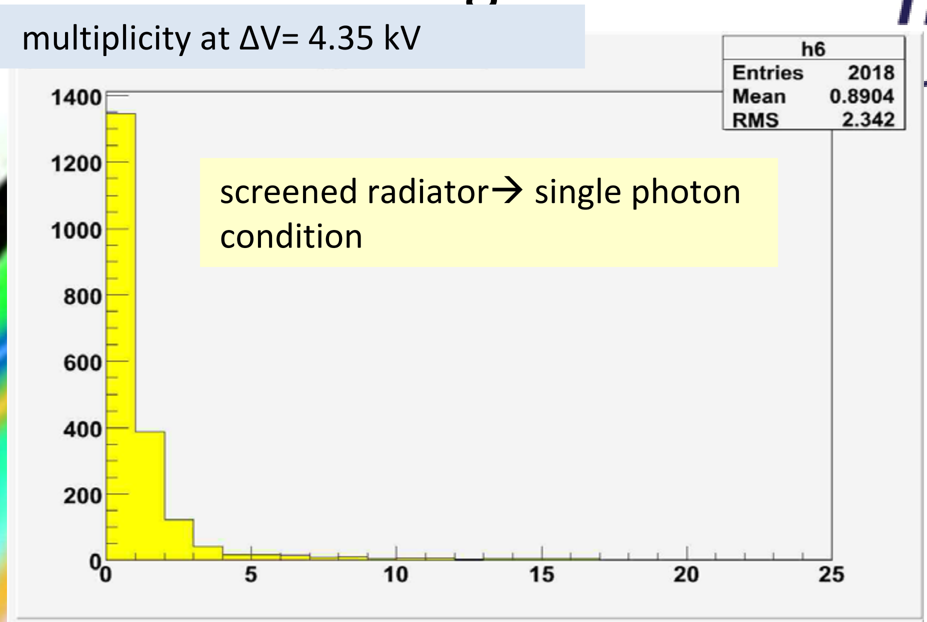


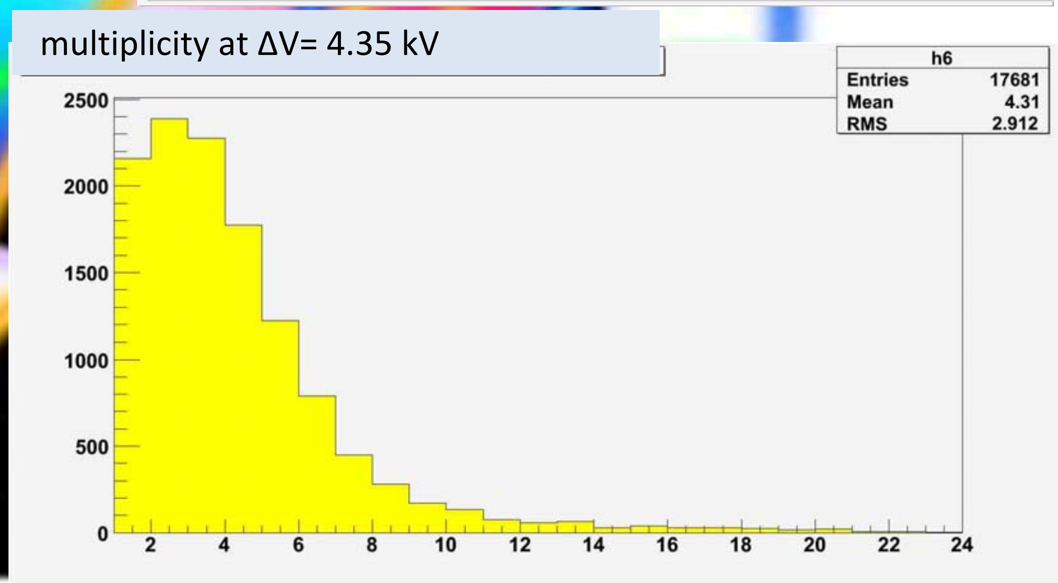


THGEM Test beam: illumination regimes

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





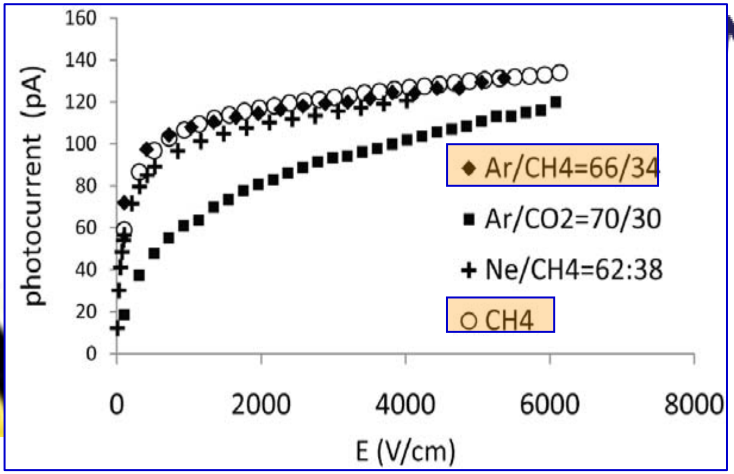


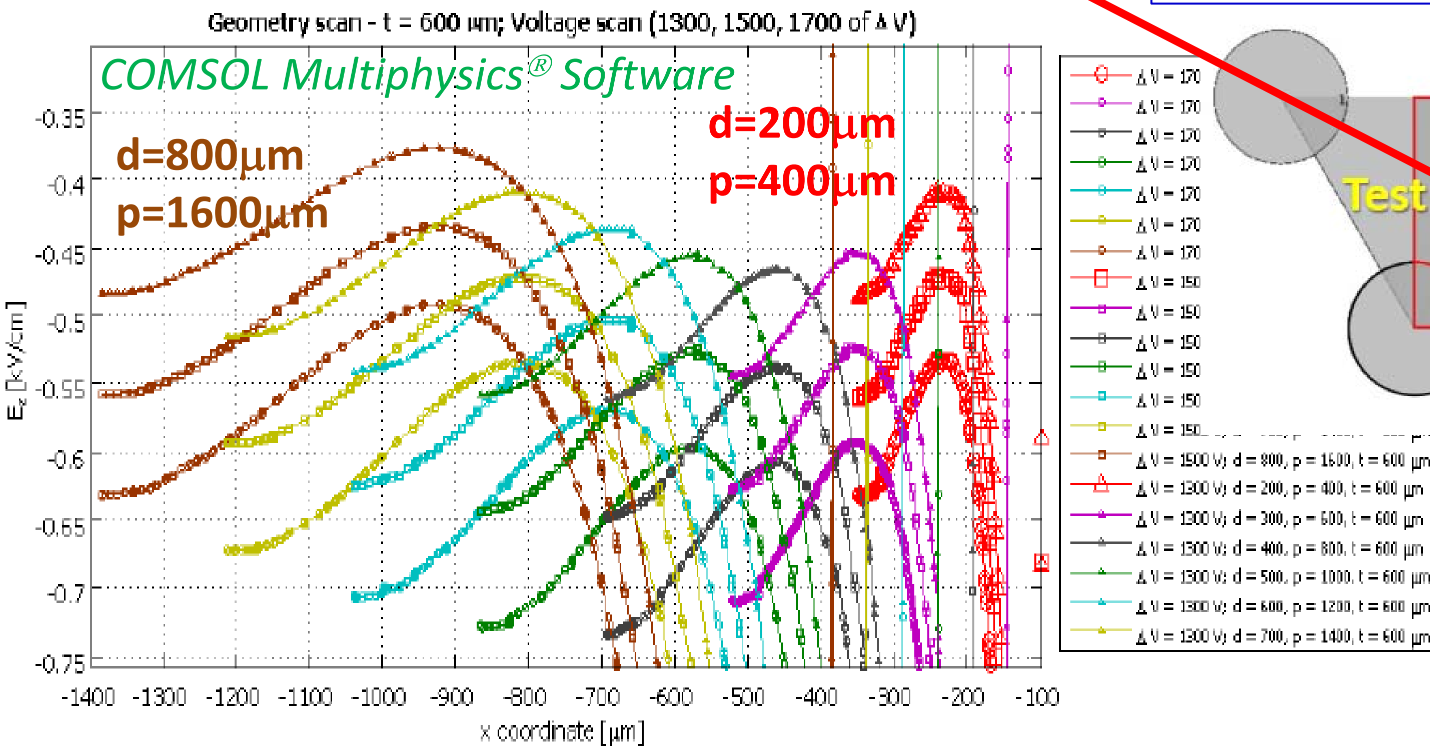
Both multiplicities are compatible with the expected values from Zemax simulation for the generated photons, the geometrical acceptance and the estimated chamber efficiency

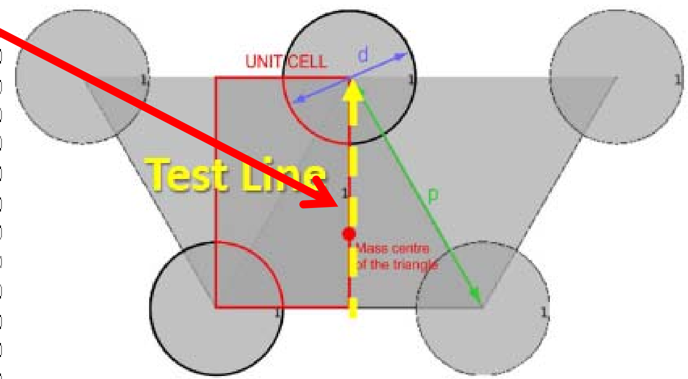
THGEM electrostatic simulation: exploring the ph-*e* extraction fields

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

The most critical point: the centre of the triangle







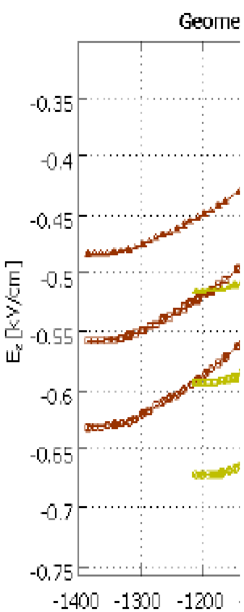
Example of field dependence along the test line for different geometries with d/p=2 and different ΔV

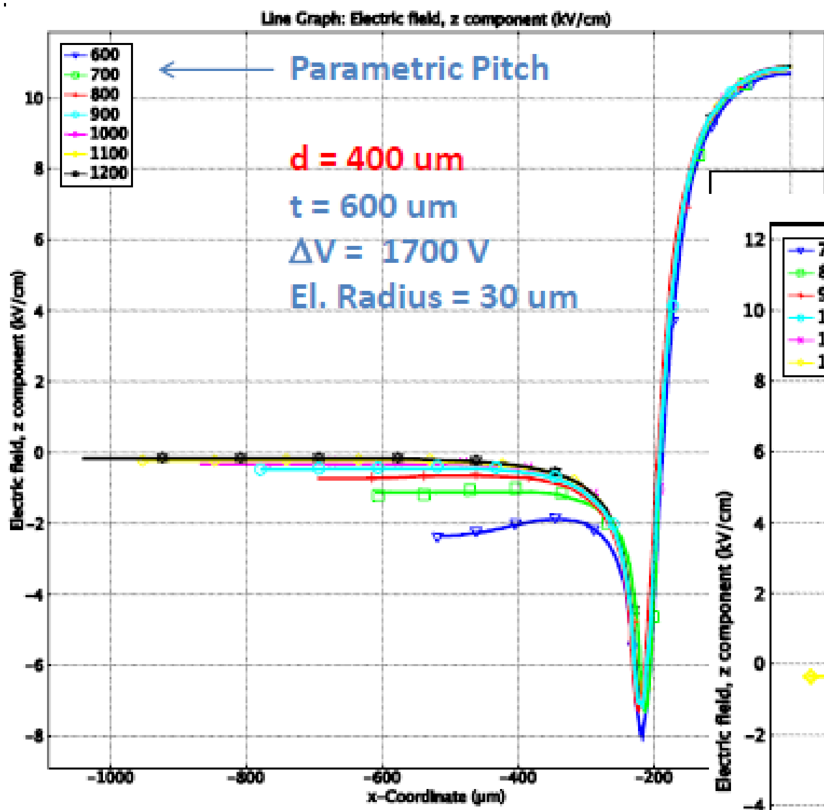
Thickness= 0.6 mm

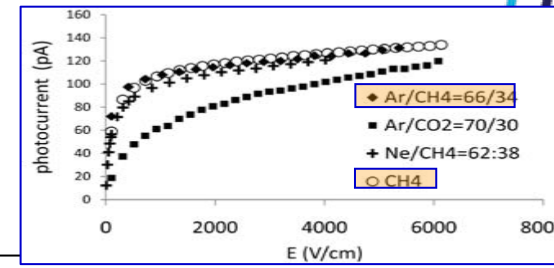
The E field in the critical point: a glimpse to the parameter dependence

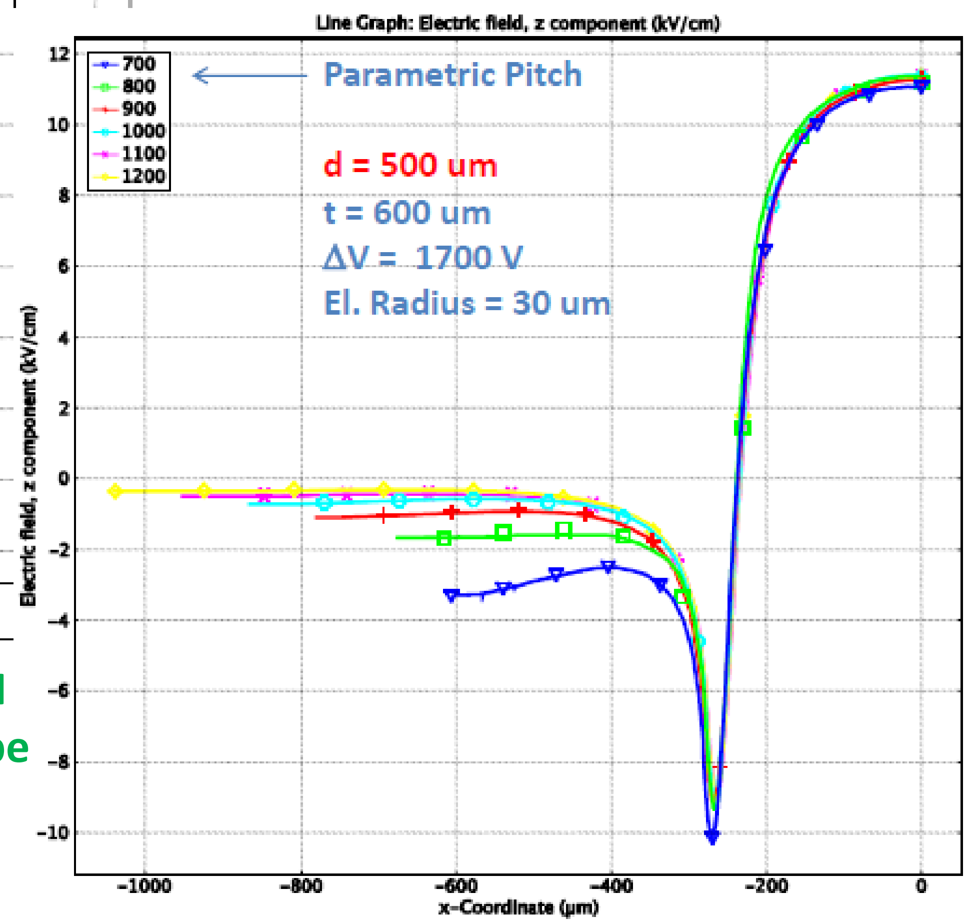
The electric
surface) mu
effective ph

The most cr
triangle



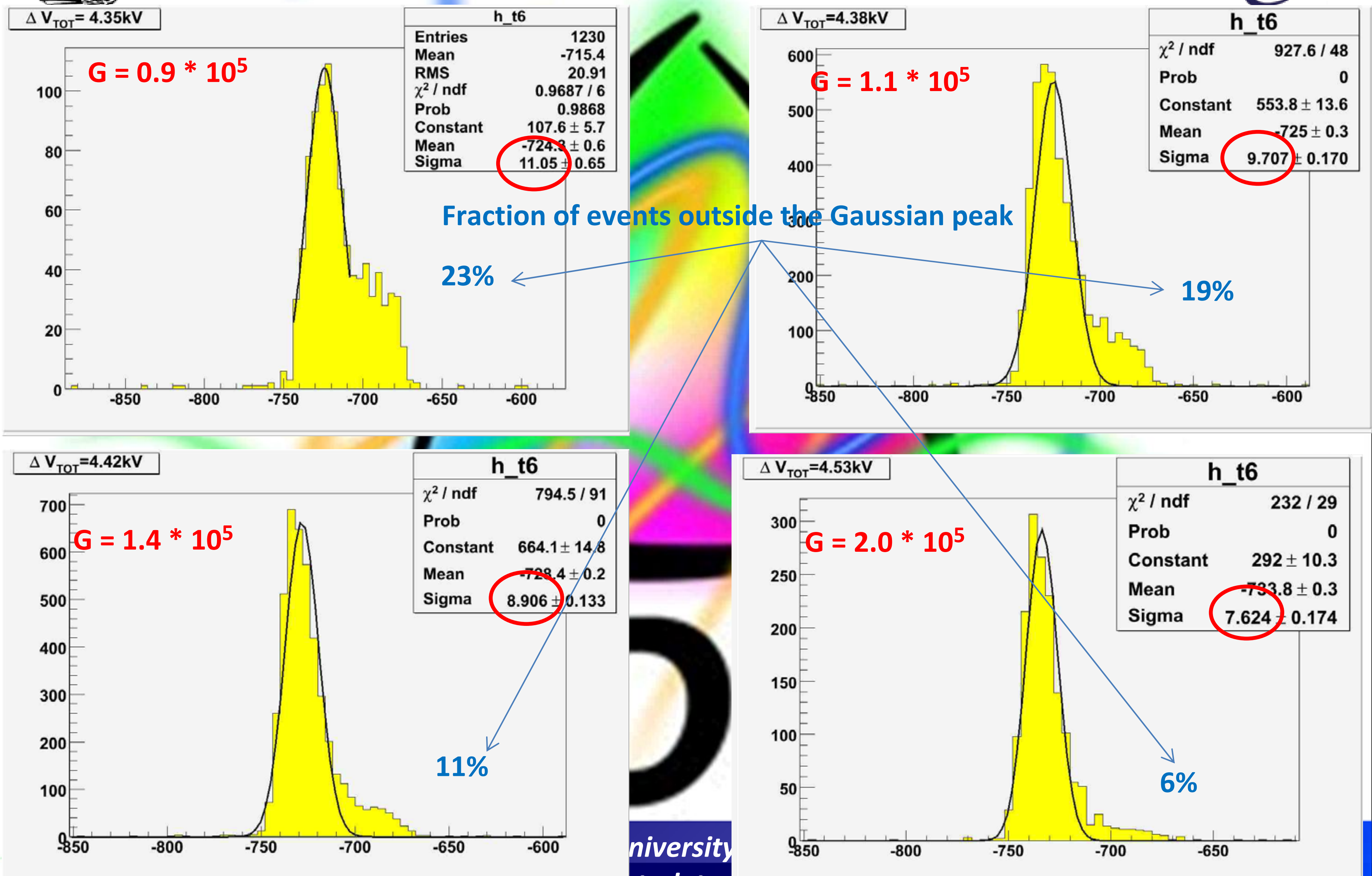




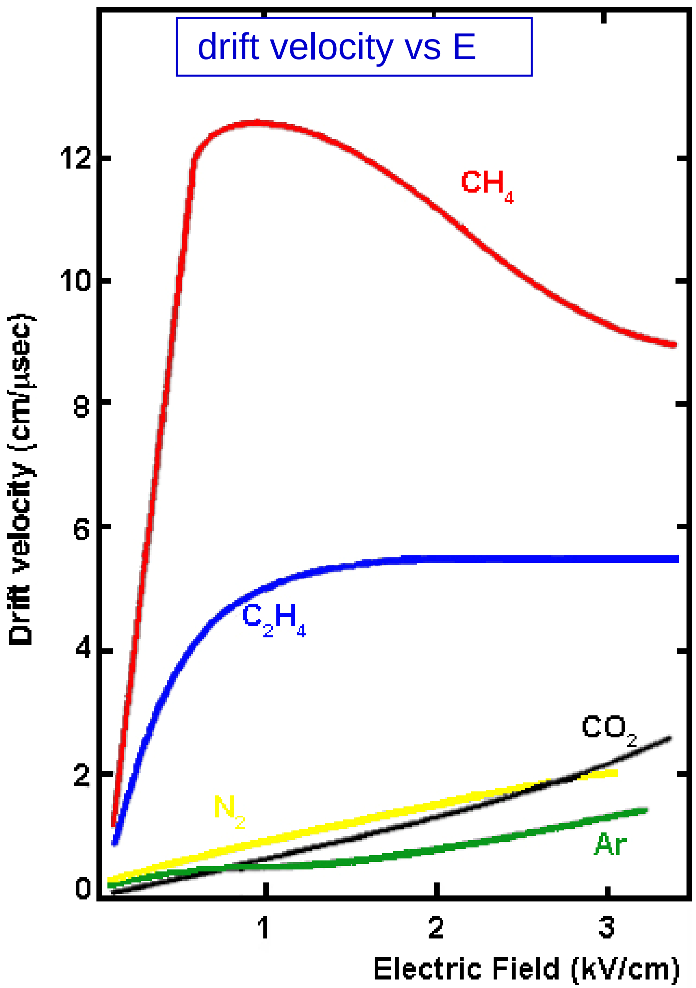


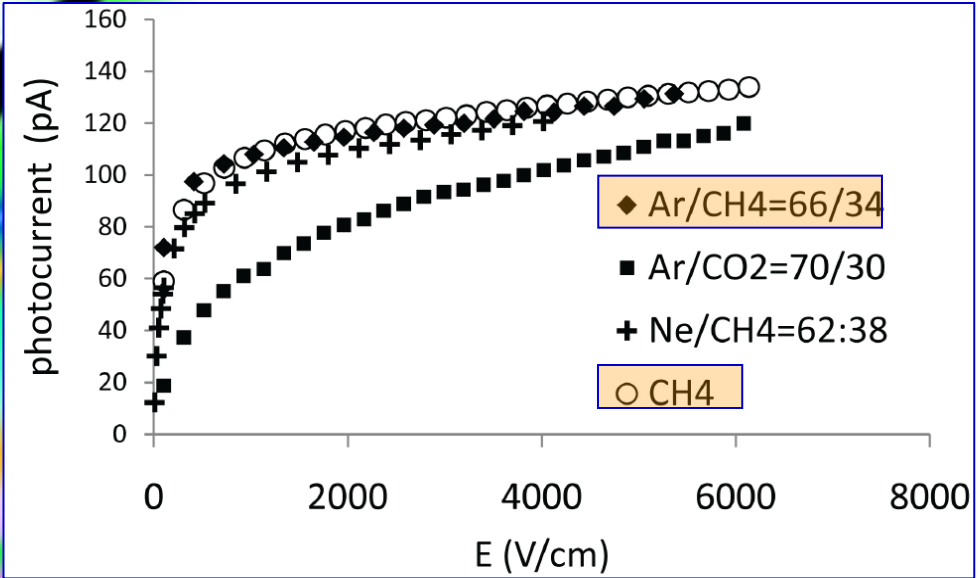
The THGEM parameters where CsI photocathode is deposited must be optimized to have the highest possible values of E_z in the critical point

Timing properties of the signal: dependence on the E field



Timing spectrum: a way to check/monitor the extraction efficiency





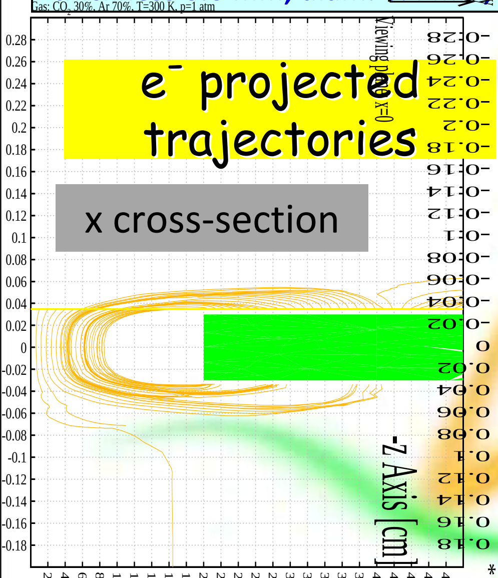
correlation between the tail of the timing peak and the reduced extraction efficiency:

an effective method to check the field conditions

THGEM, field optimization at the photocathode surface

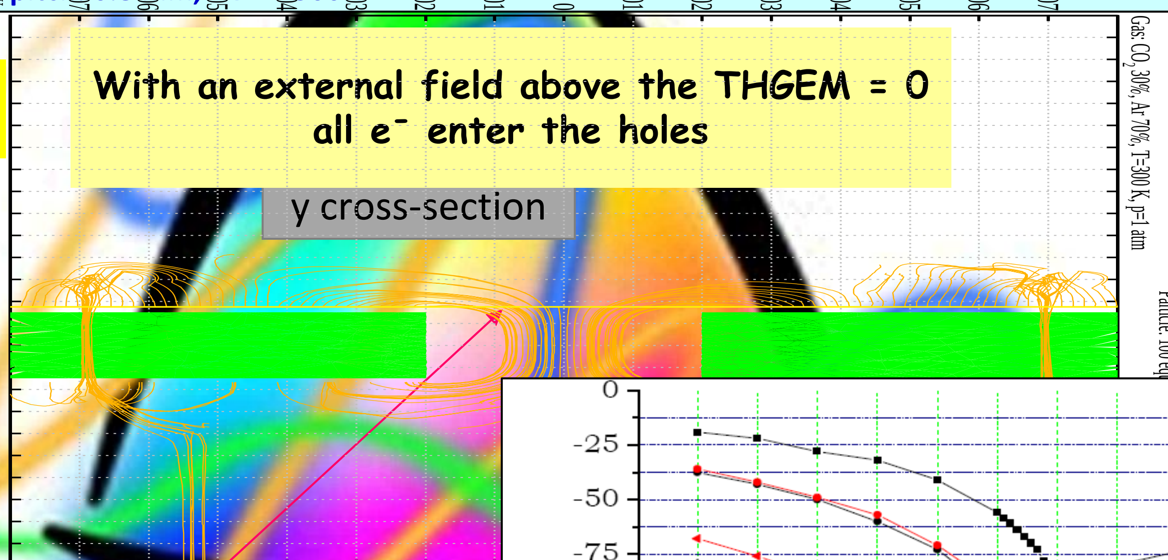
photoelectron trajectories from a THGEM photocathode, multiplication switched off

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



e⁻ projected trajectories

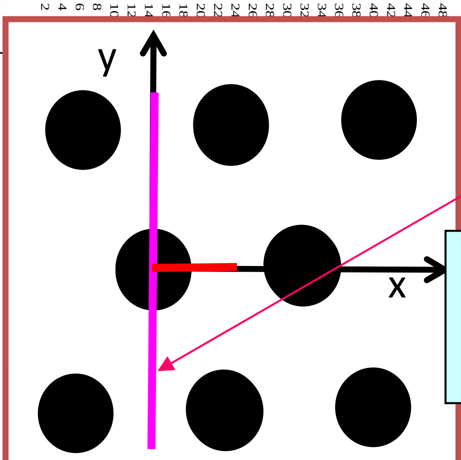
x cross-section

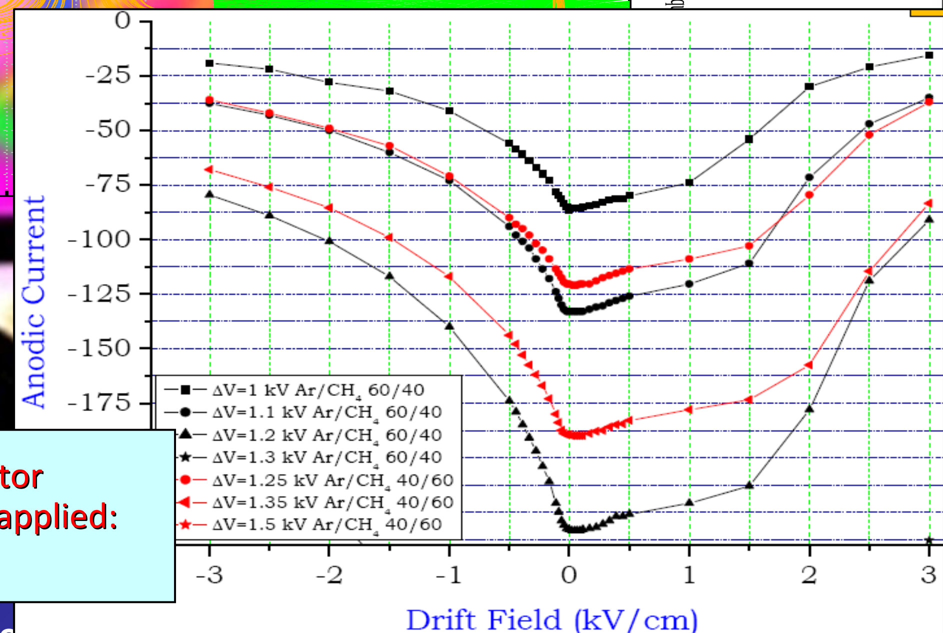


With an external field above the THGEM = 0
all e⁻ enter the holes

y cross-section

line of e⁻ generation

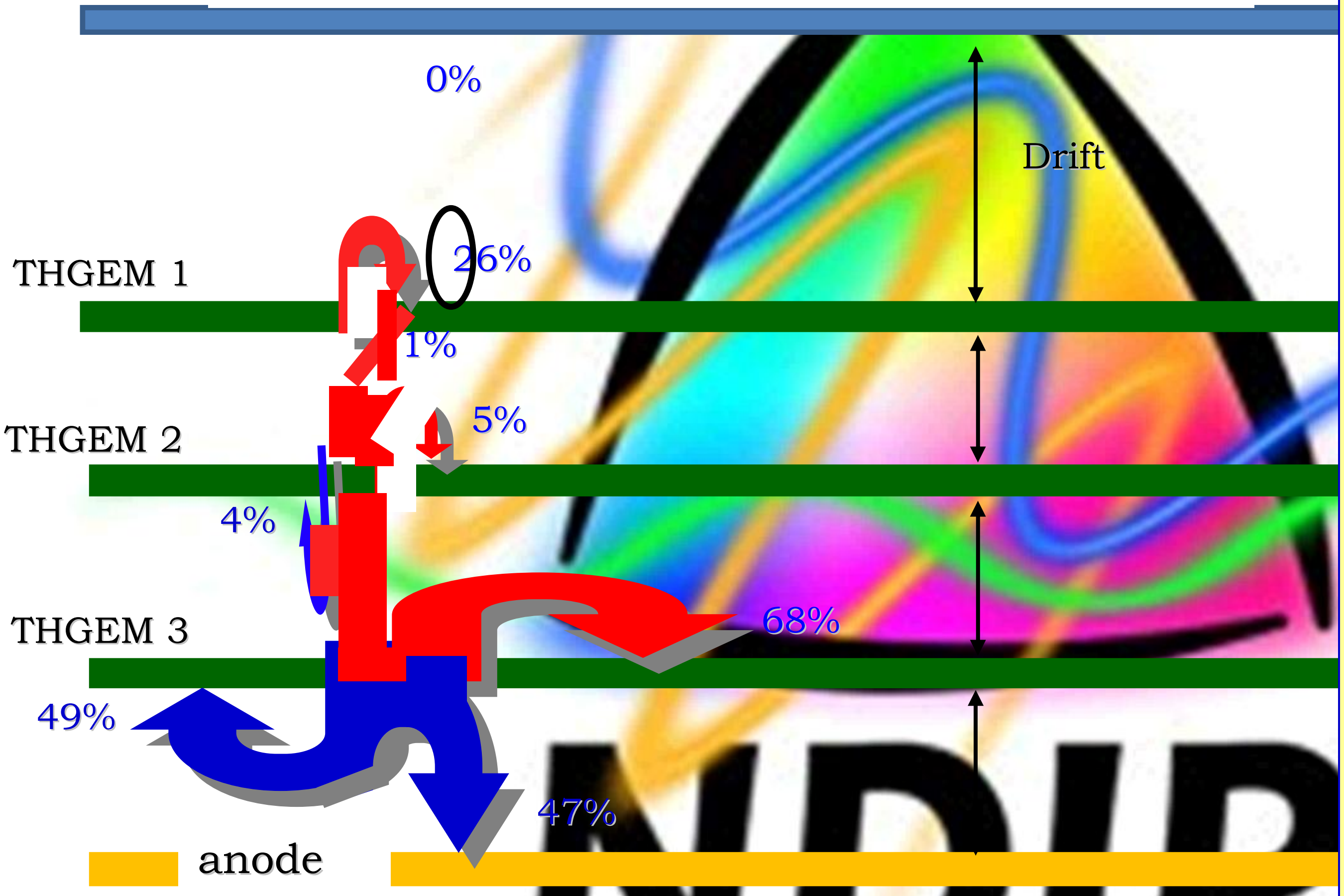




Anodic current in a THGEM detector versus the external electric field applied: a measurement

The Ion Back Flow problem, still an open question

typical charge sharing between electrodes in a triple THGEM detectors



See C. SANTOS poster in session PIV

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**

Different techniques under investigation via simulations and tests.

Open points before going to large size

1)Strict THGEM quality test protocol

2)Final segmentation to be optimized

3)Final choice of HV distribution system and power supply

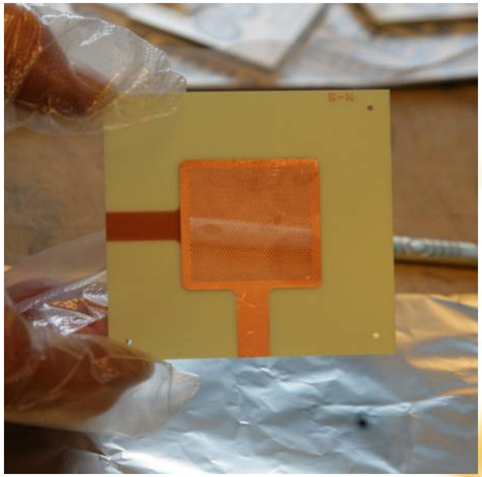
4)THGEM planarity and mechanical/electrical stability to be guaranteed

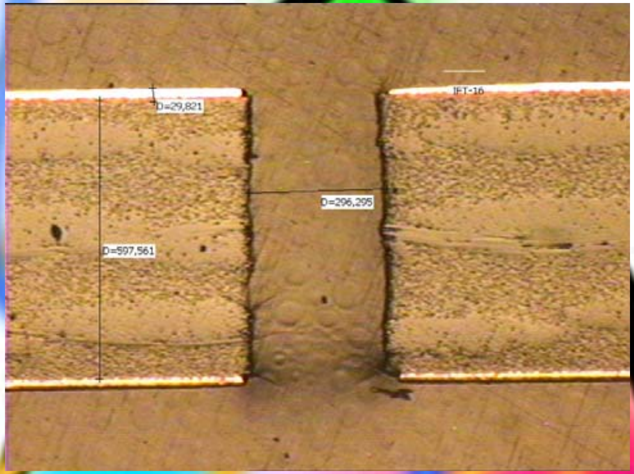
5)Quality and uniformity of very large THGEM to be demonstrated

6)Chamber border effects and dead areas to be minimized

Our effort towards a solution

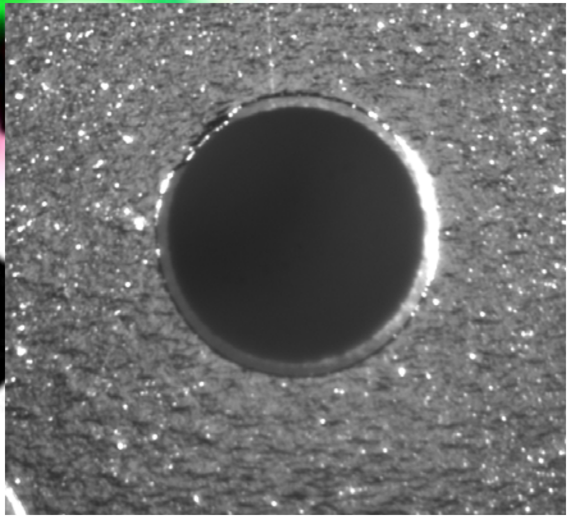
THGEM quality checks





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

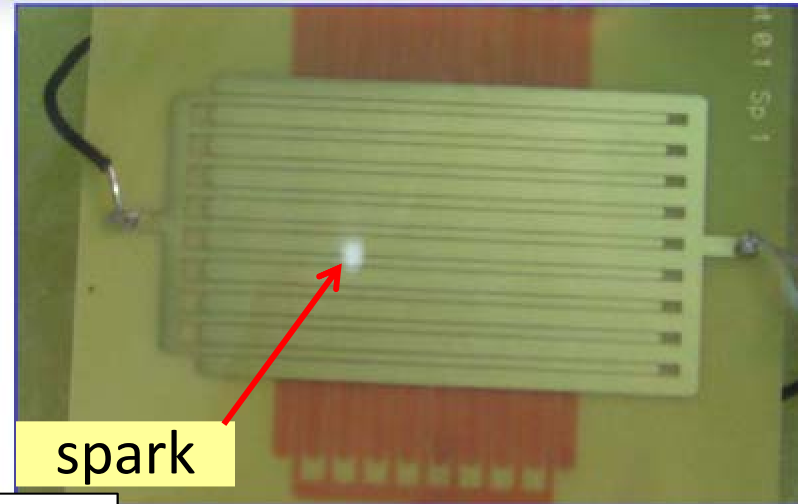
Defects are detected by a quality check procedure when THGEMs are received

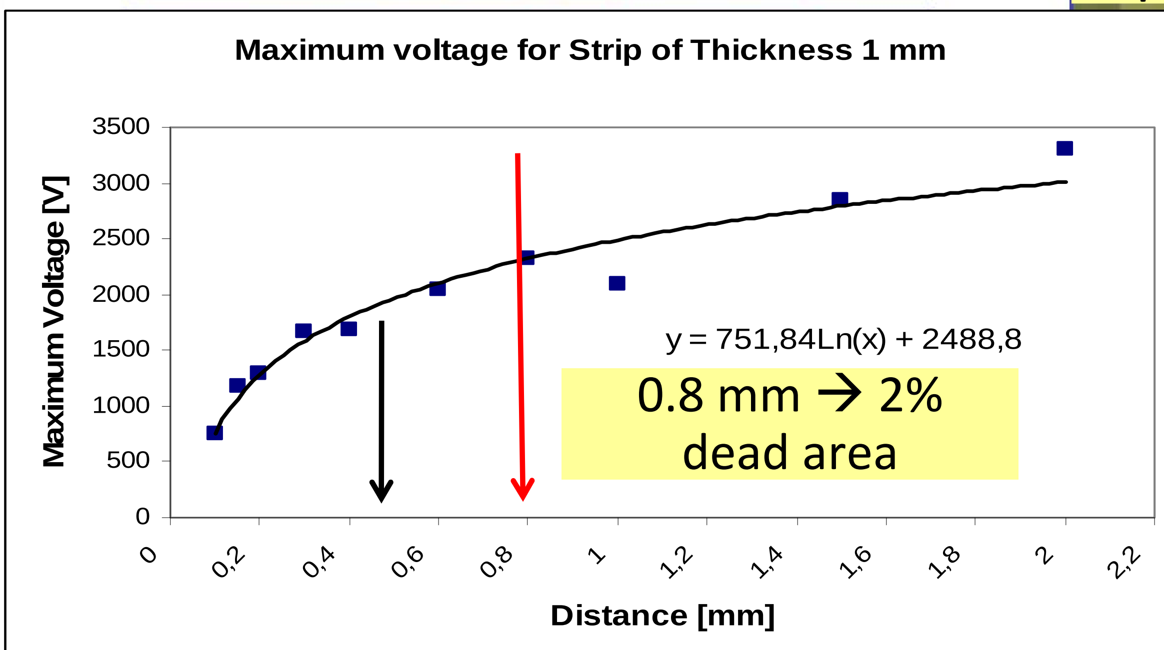


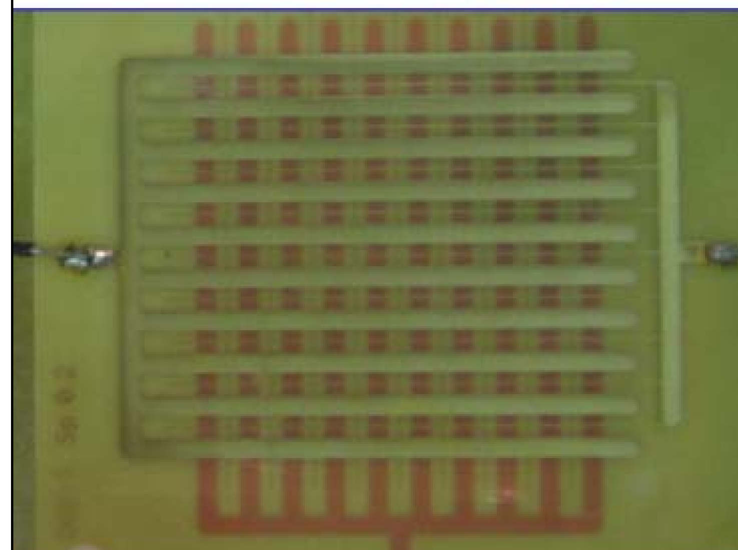
Segmentation optimization tests/results

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.







Towards a large size detector: gain issues and layer specialization

•Stable gain (<20% variation) can be achieved both with small rim or thicker THGEMS.

•For large size detectors the rim uniformity control over a large area is extremely critical already at the level of 100 x 100 mm^2 detector

•High field in the critical point is mandatory to achieve good ph-electron extraction efficiency (gas choice!)

➢Each layer must be "specialized" for a main function

➢To achieve stable high gain it is necessary to go to thicker THGEM instead of THGEM with rim to equip large areas

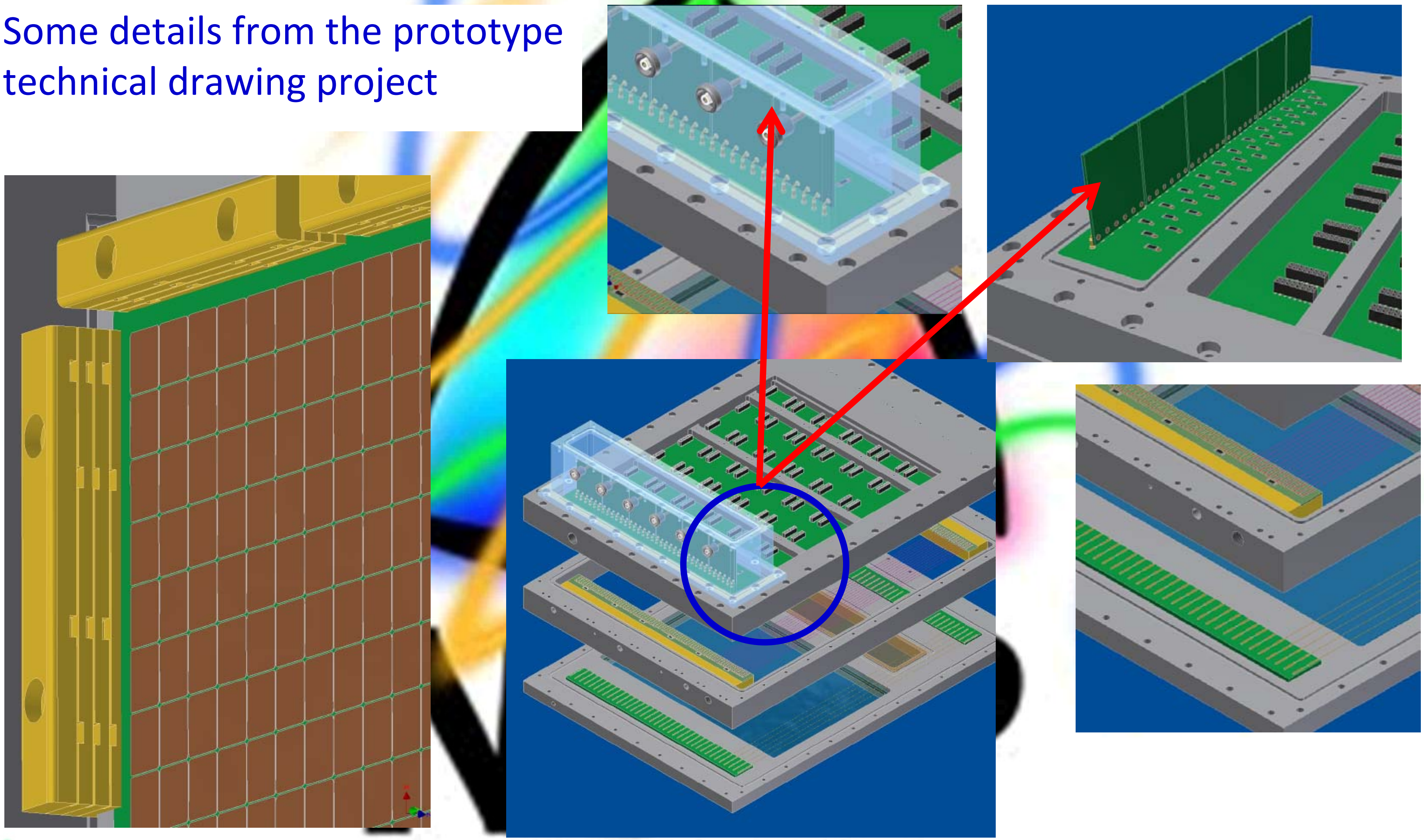
➢The first layer geometrical parameters must be adapted to achieve the highest E_z on the CsI surface with the lowest gain possible (IBF reduction)

➢IBF simulations and study are in progress, probably a dedicated layer is needed

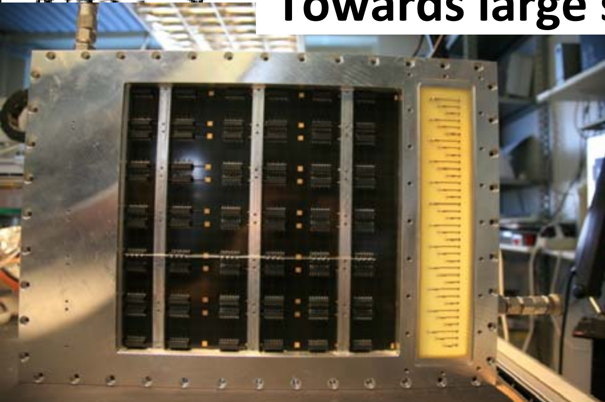
➢Charge splitting may help in achieving higher gains

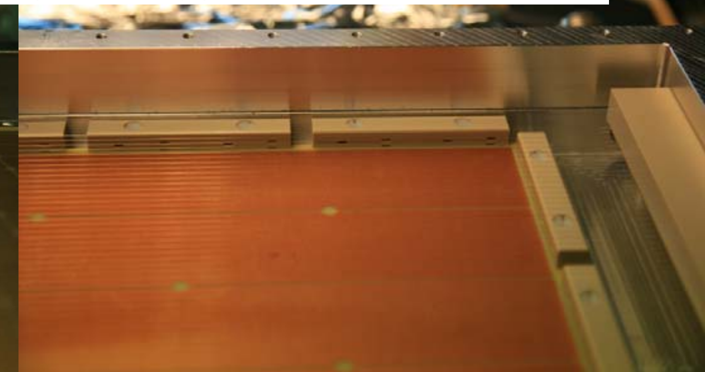
Towards large size detectors, 300x300 mm^2 prototype project

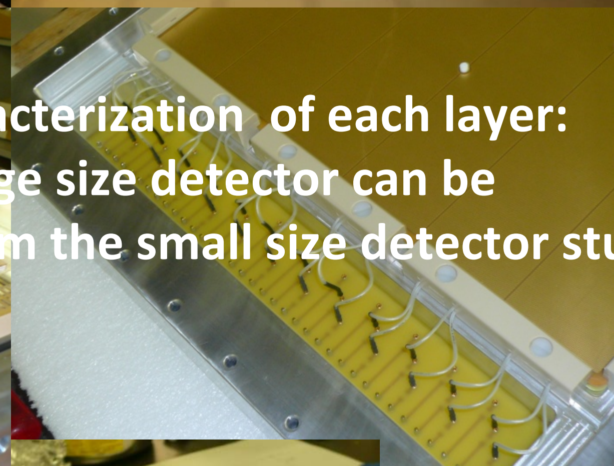
Some details from the prototype technical drawing project



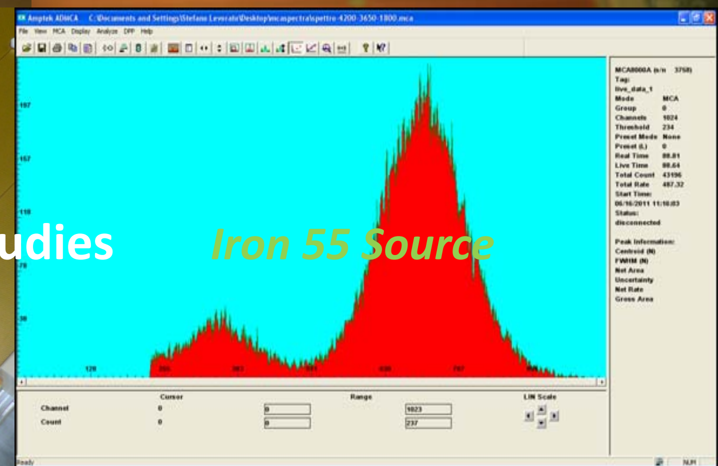
Towards large size detectors, 300x300 mm^2 prototype realization

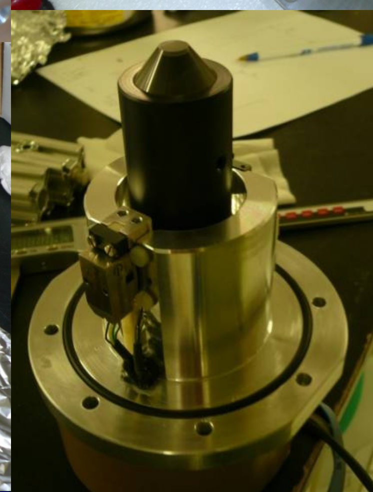




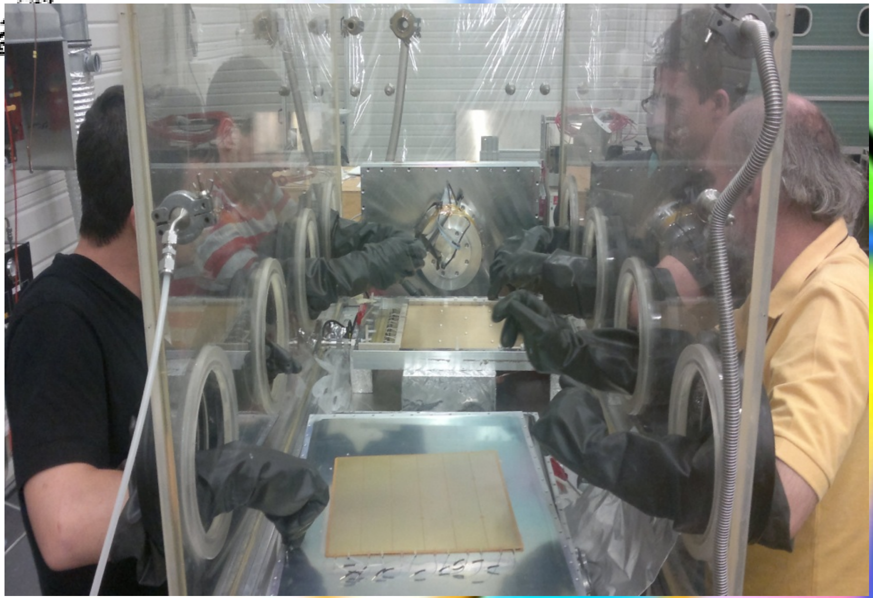


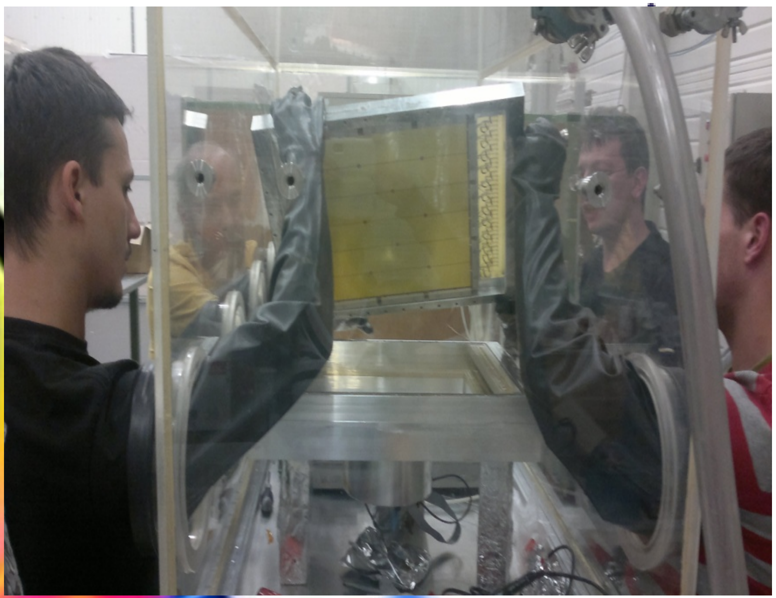
Preliminary test / characterization of each layer:
The behavior of the large size detector can be correctly predicted from the small size detector studies

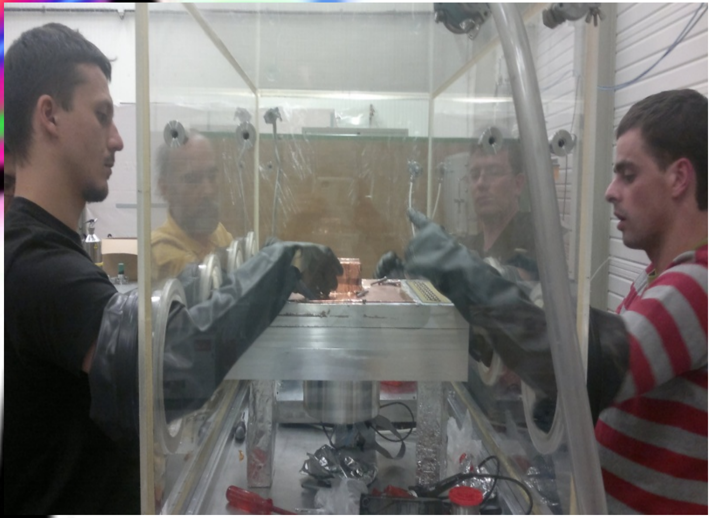


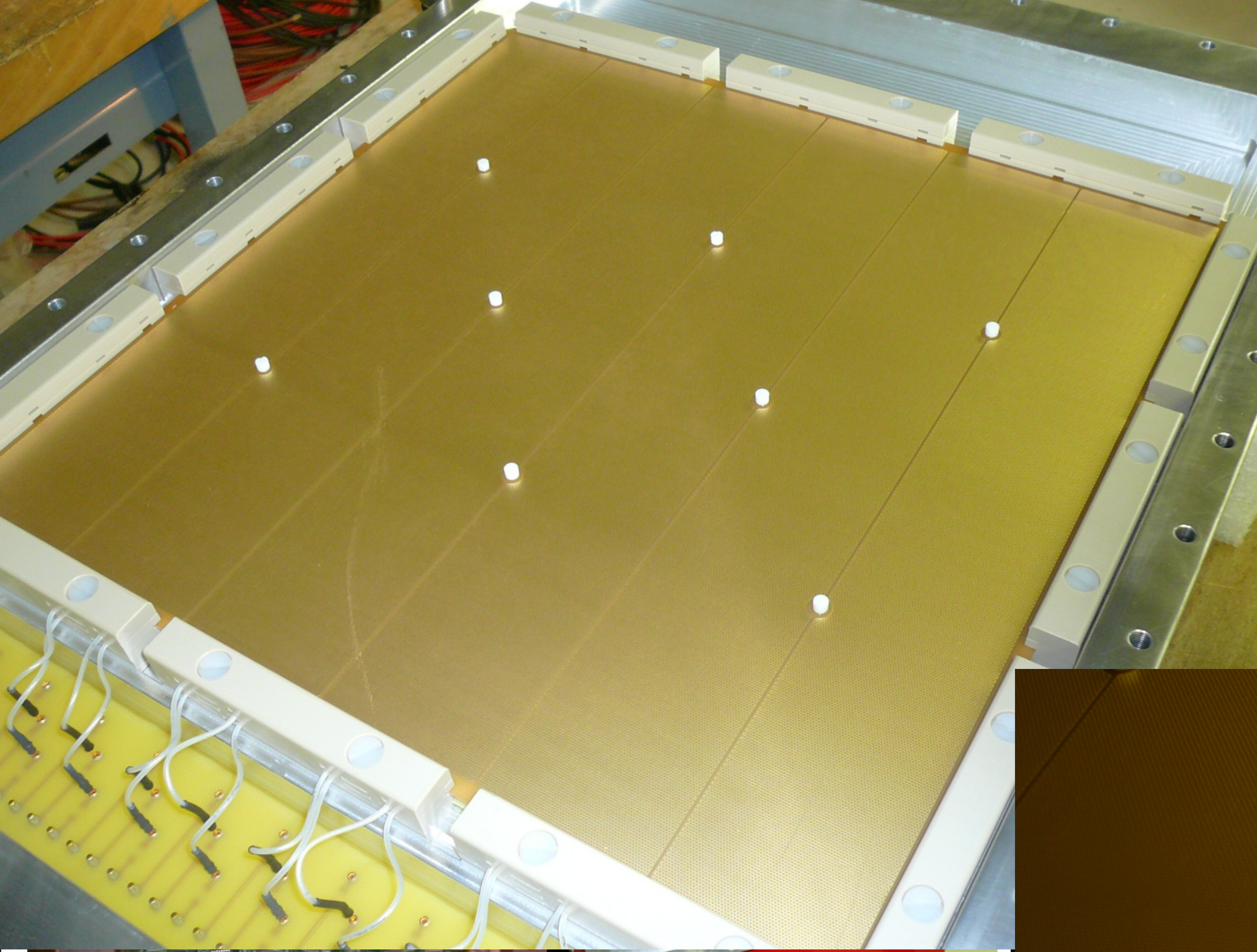




Towards large size detectors, 300x300 mm^2 prototype mounting

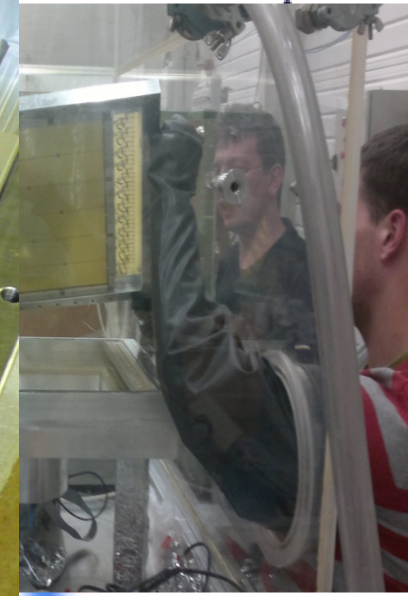


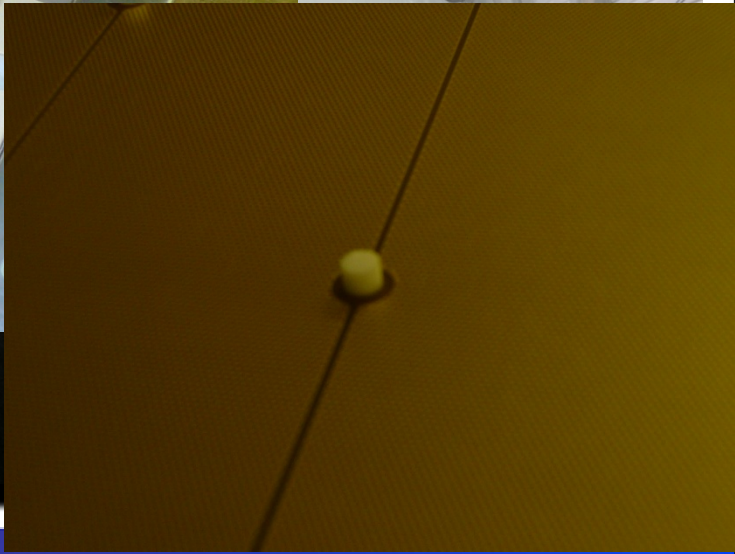






mounting



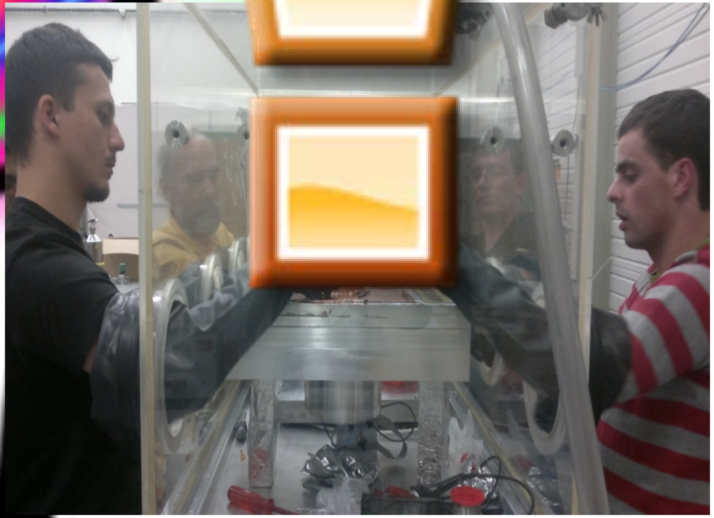


300 x 300 mm2 prototype: mounting


Tests will start soon...

Keep tuned





Conclusions & Outlook

THGEMs represent a good choice for single UV photon detectors:
pcb technology is o.k.

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 but possible solutions are not so far: layer specialization can help in this direction

Still there are many challenges to overcome before achieving *large size, cheap, robust, fast, high gain, high rate, magnetic insensitive* single photon detectors.

Conclusions & Outlook

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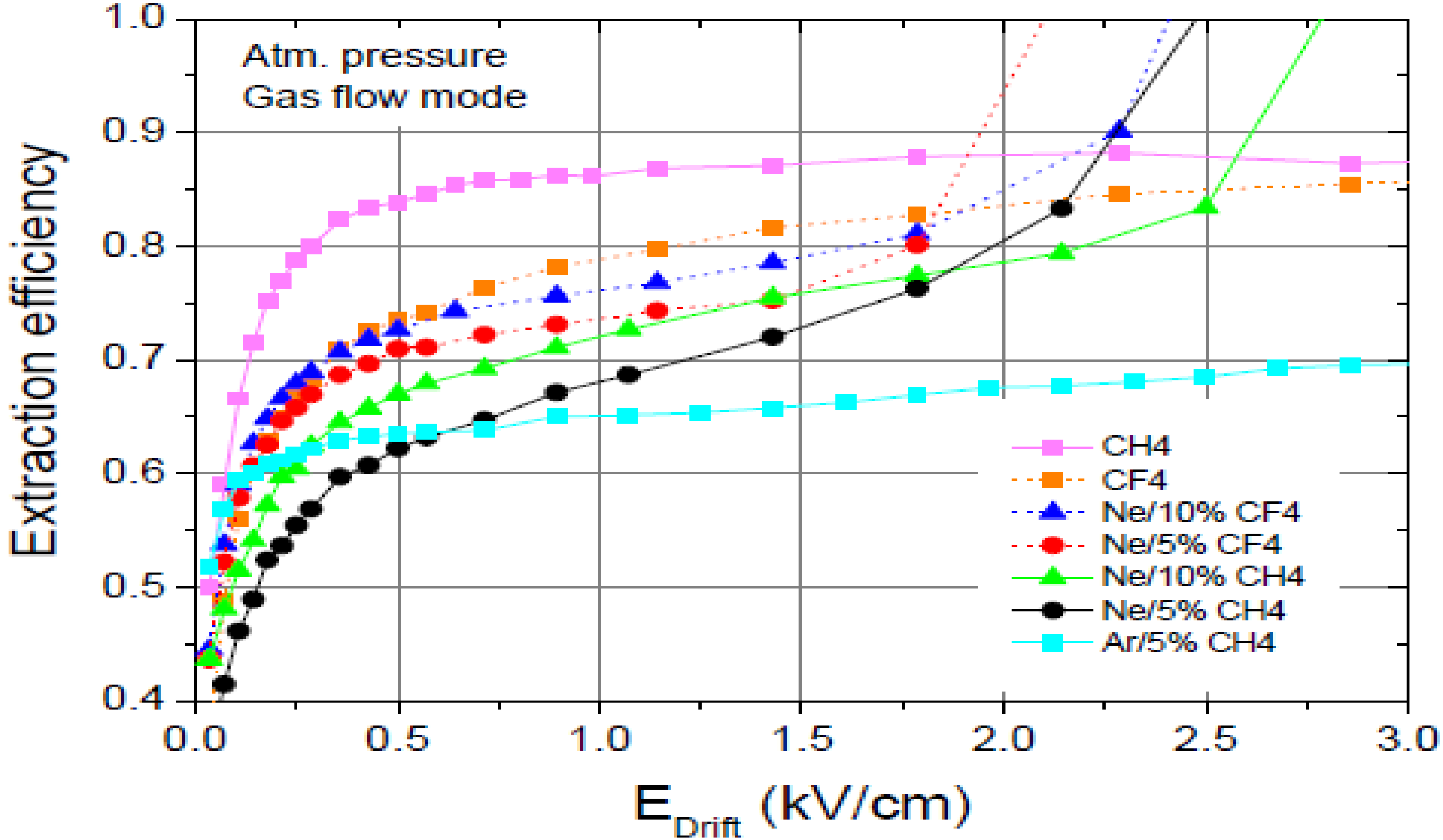
Thank you !

In case of need….extra slides


Atm. pressure
Gas flow mode
Extraction efficiency
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
E Drift (kV/cm)
CH4
CF4
Ne/10% CF4
Ne/5% CF4
Ne/10% CH4
Ne/5% CH4
Ar/5% CH4

Photoelectron extraction

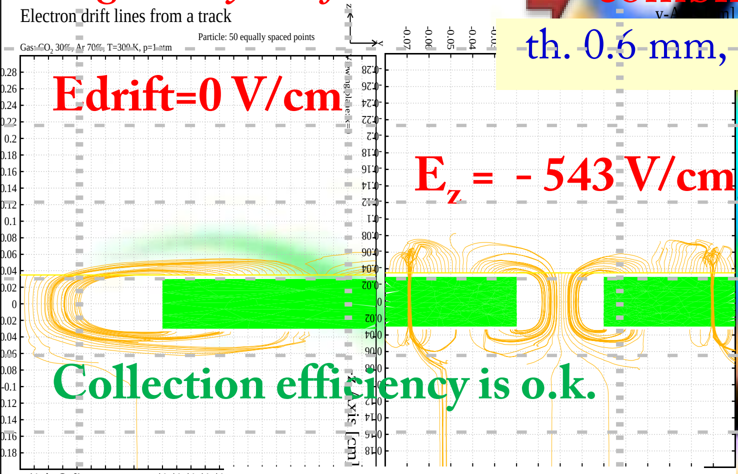
Electrostatic calculations are essential to optimize our THGEMs

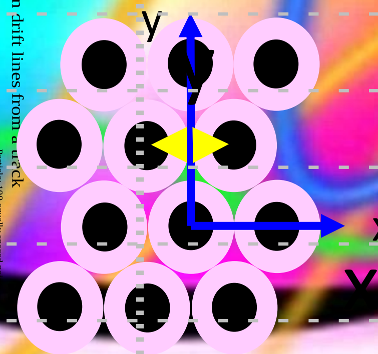
Critical points:

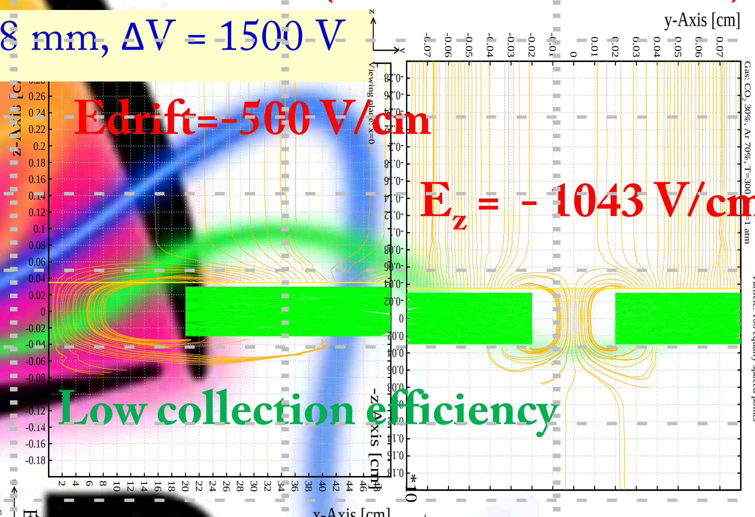
- Effective CsI Q.E. depends on the *electric field at the CsI surface* and *e focusing* is done by dipole field
- The backscattering effect depends on *the gas and on the field too*
- The collection of photoelectrons in the holes for multiplication is difficult to measure and critically *depends on geometry and fields*

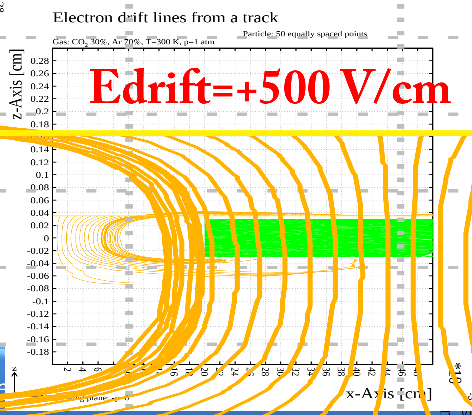
→ combine measurements and simulations (ANSYS+ Garfield)

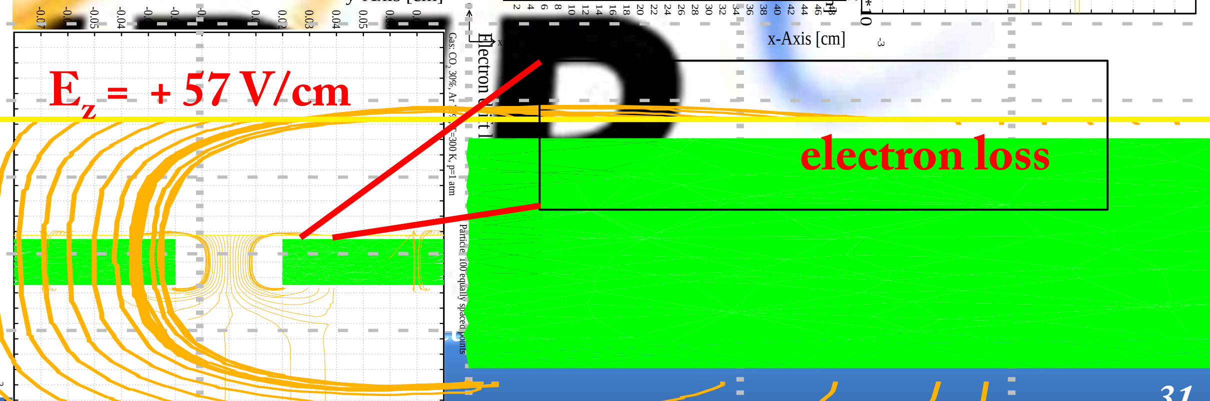
th. 0.6 mm, diam. 0.4 mm, pitch: 0.8 mm, ΔV = 1500 V



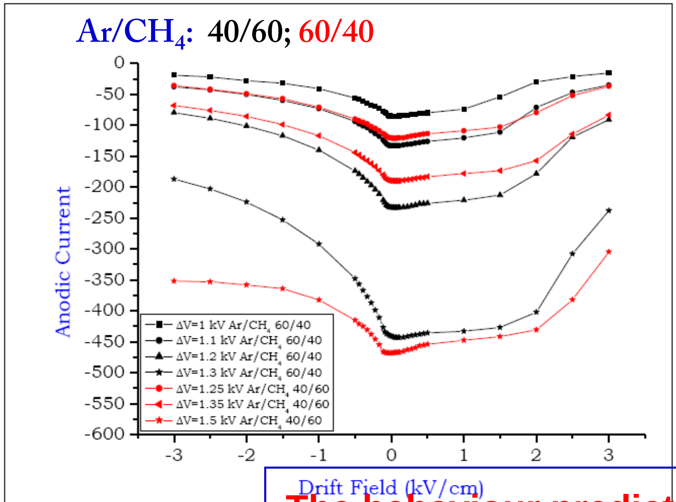




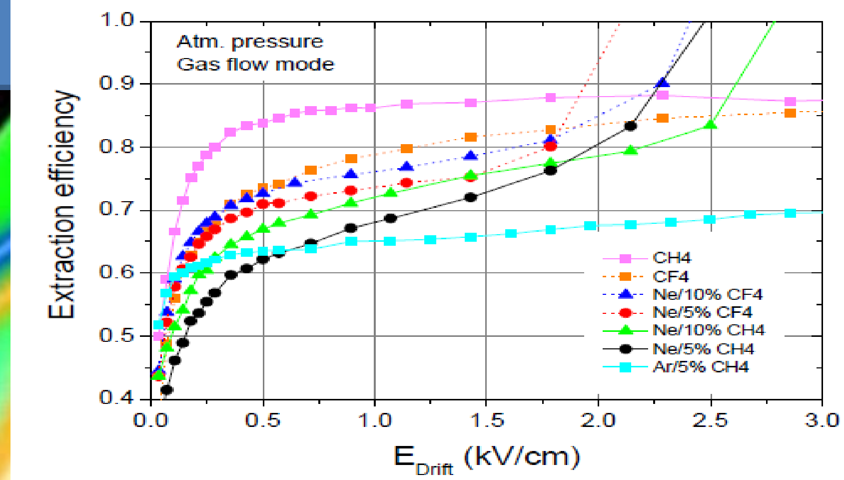




Photoelectron extraction

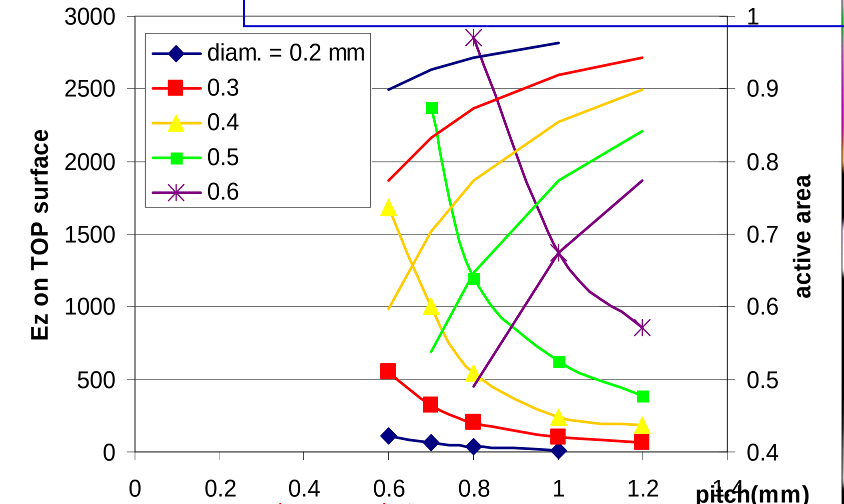


ΔV (kV)
1
1.1,
1.2
1
1.25
1.35
1.5

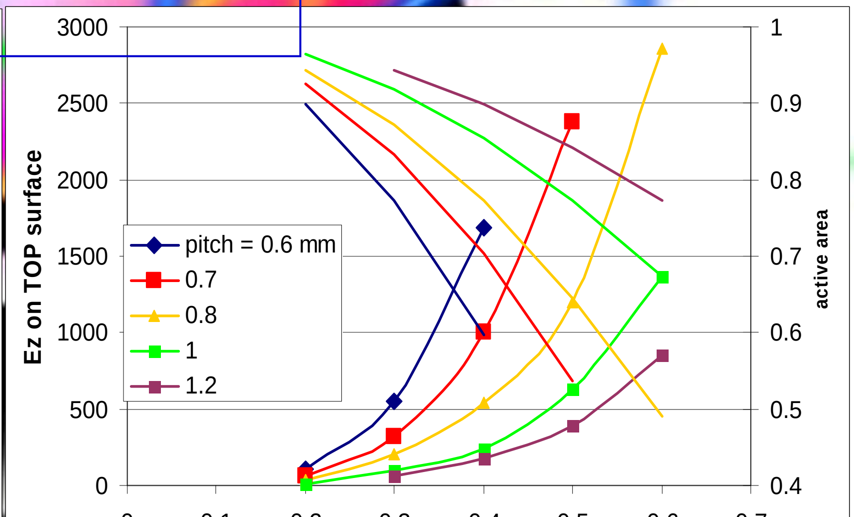


The behaviour predicted by the simulation is confirmed!

C. D. R. Azevedo et al., 2010 *JINST* 5 P01002



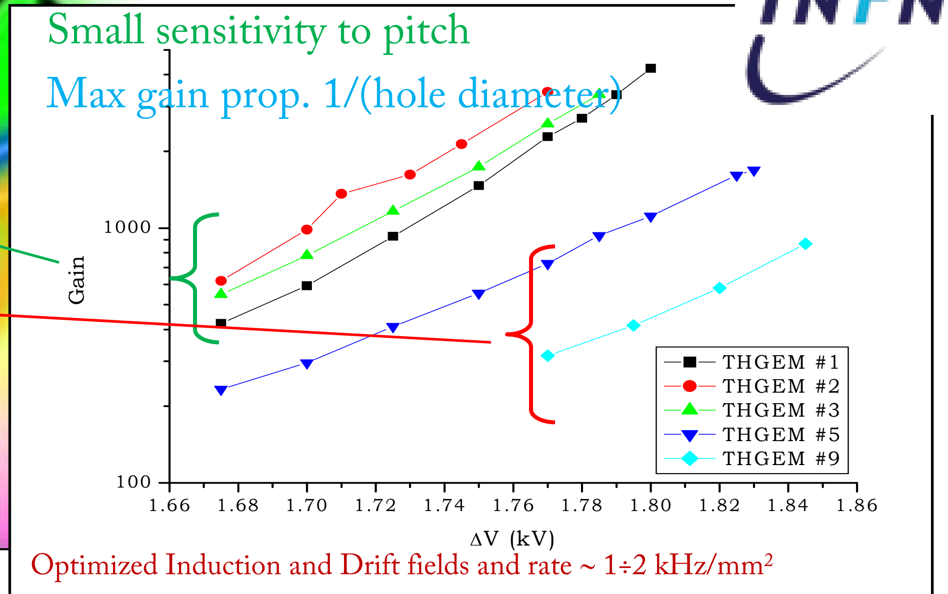
$E_z \sim 1/(\text{pitch})^4$

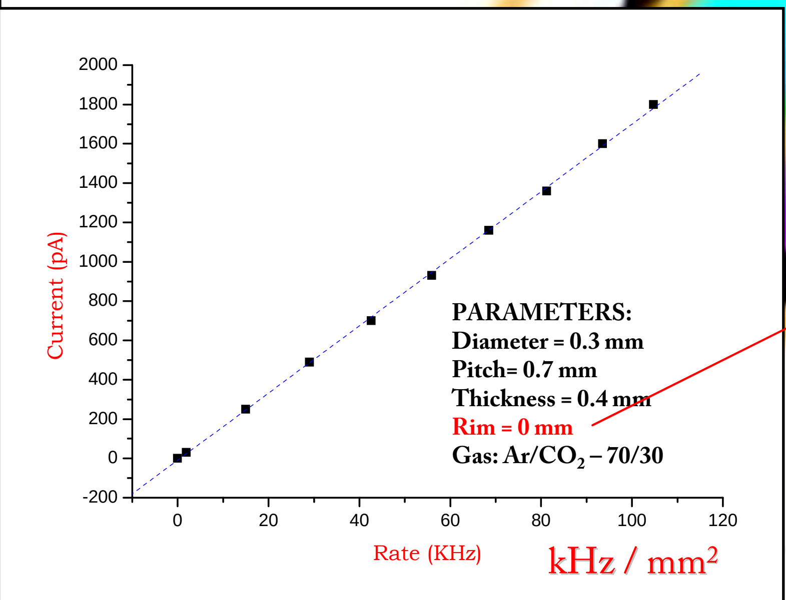


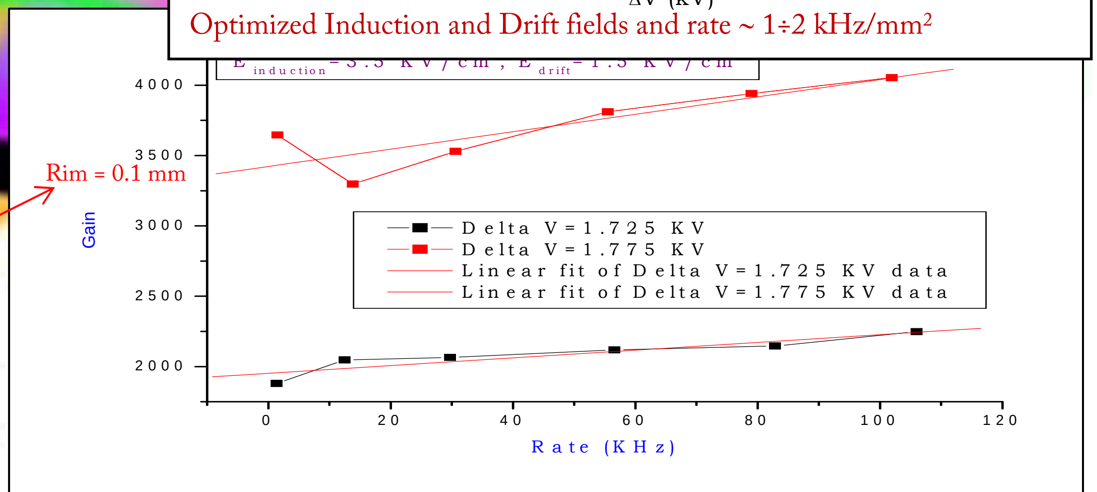
$E_z \sim \exp(\text{diam.})$

Characterization: 1- geometrical and production parameters

Name	Diam (mm)	Pitch (mm)	Rim (μm)	Thick (mm)
THGEM_1	0.3	0.7	0	0.6
THGEM_2	0.3	0.6	0	0.6
THGEM_3	0.3	0.5	0	0.6
THGEM_5	0.4	0.7	0	0.6
THGEM_9	0.5	0.7	0	0.6



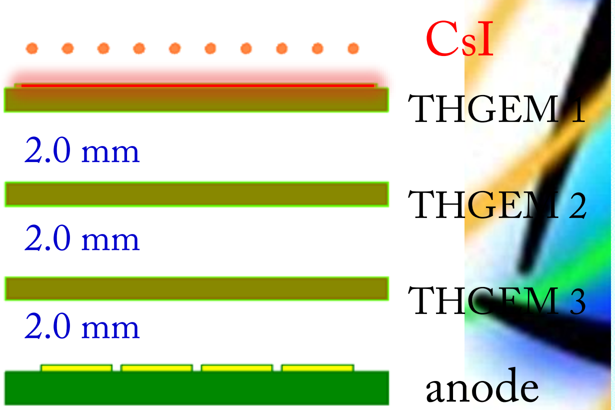


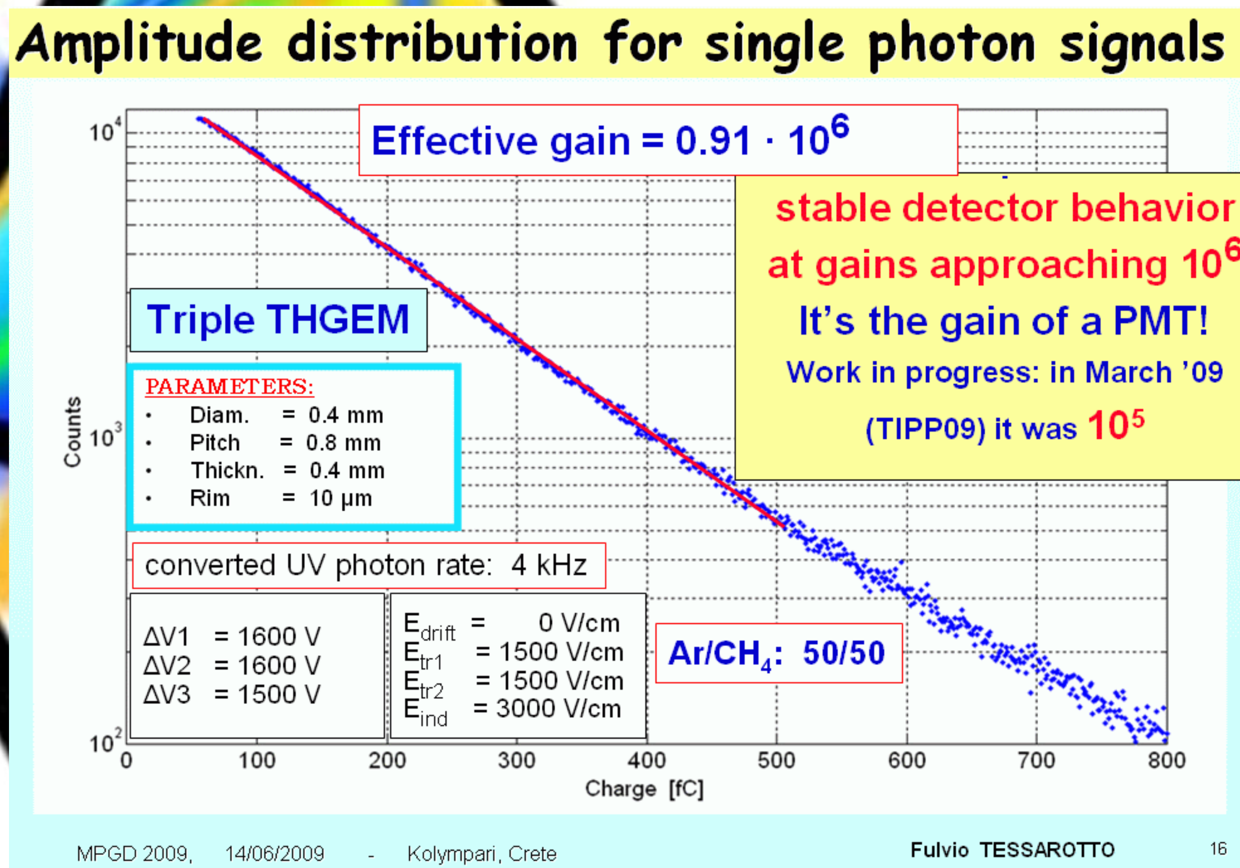


120 kHz/mm² 300 e- → single photoelectron rates of ~35 MHz/ mm² → good rate capability

Single photon detection

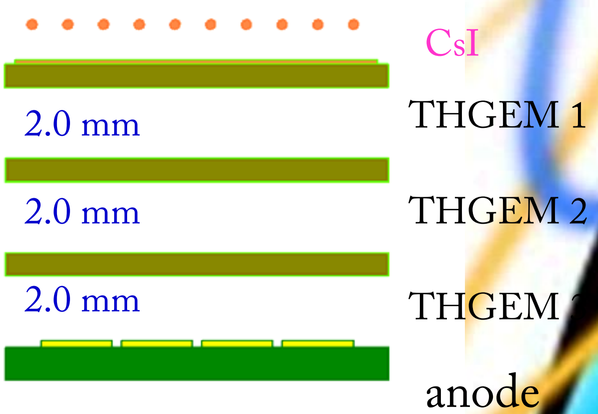
Our goal single photon detection!



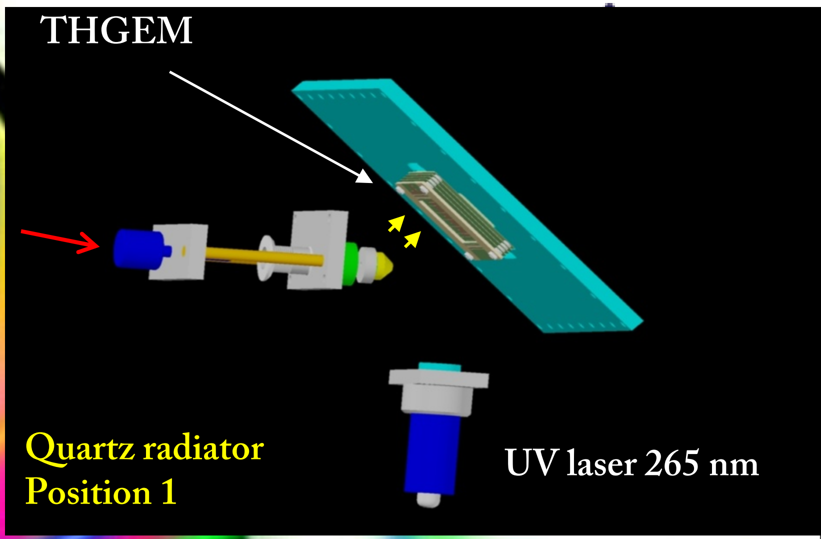


Our first detection of Cherenkov light

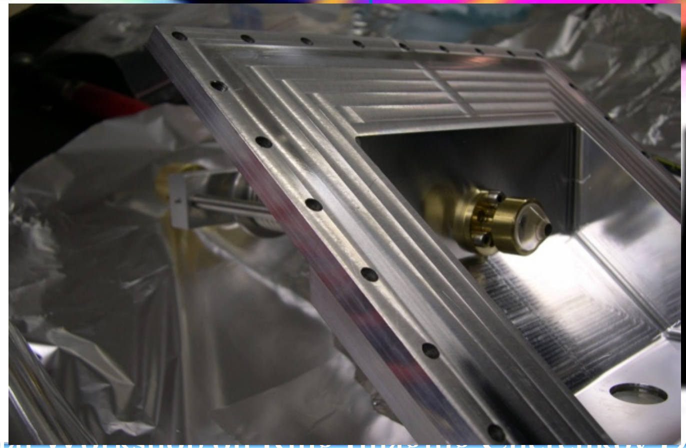
Triple THGEM (CsI) Ar/CH_4 50/50 Diam=0.4 mm, pitch=0.8, Thick=0.4, rim ≤10 μm (GE)

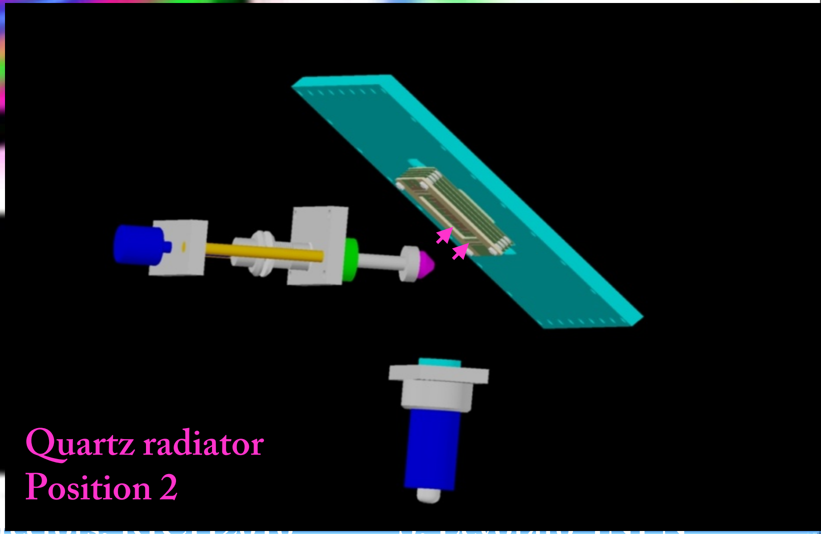


πBeam
p=150 GeV/c
Trigger AND 4 (2+2)
3mm x 3mm scintillators



-External illumination: pulsed UV laser, monitoring currents, analog readout, digital readout in single photon mode
- Adjustable quartz radiator – Cherenkov photons



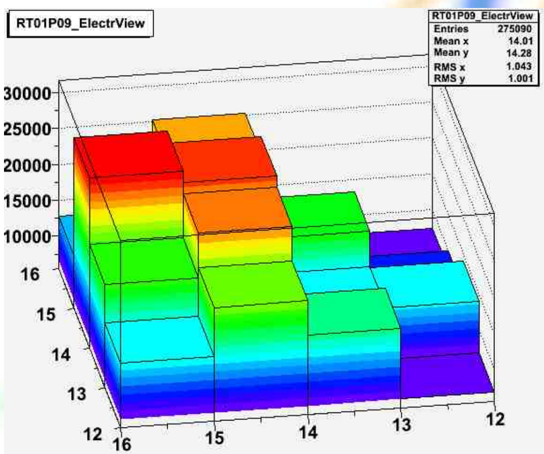


Detector behaves in the same way as in the LAB: Gain up to 10^6, good reproducibility, full control

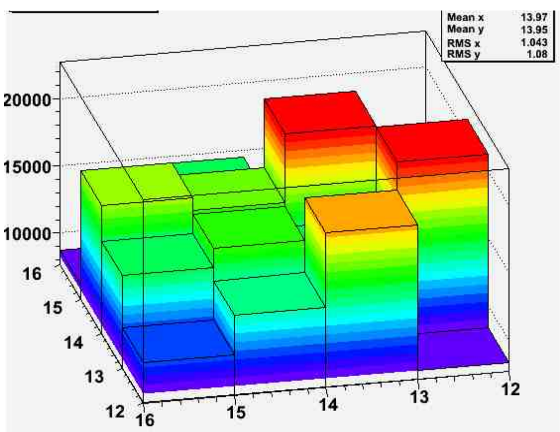
Test beam 2009: result

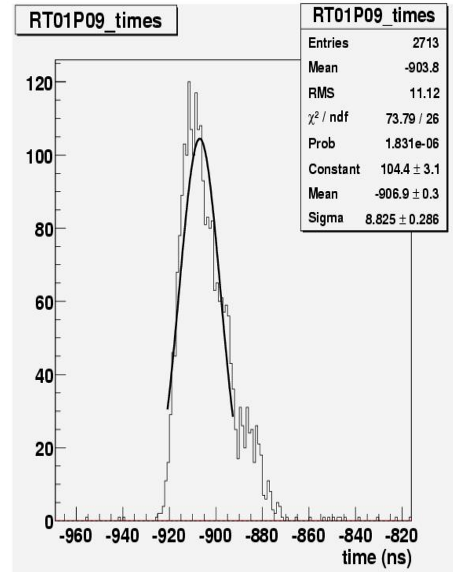
Timing properties

2 different positions of radiator (change of 20mm)

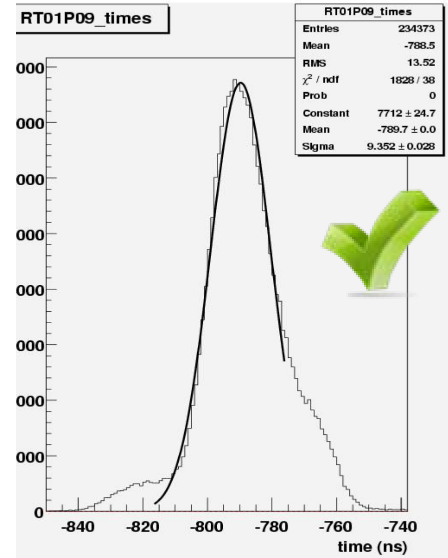


First indication of Cherenkov light





Laser (no beam)
σ=8.8 ns



High intensity beam
σ=9.3 ns

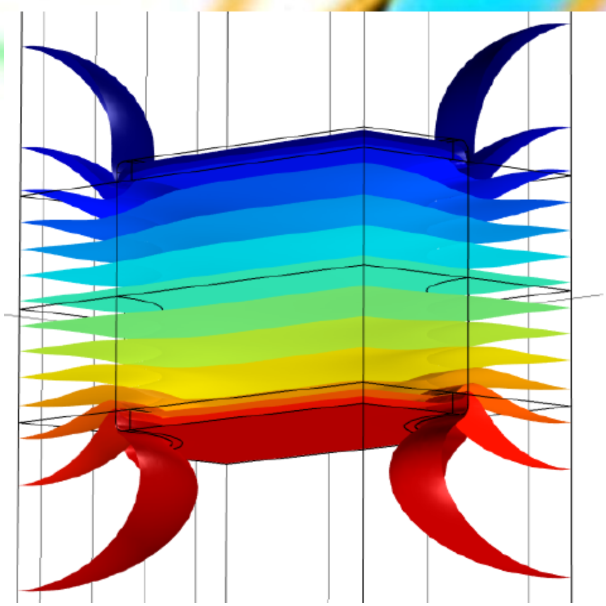
Max. sustainable gain for stable operation: ~ 10^5
More studies are needed in beam conditions
(mip ionization, Ion Back Flow….)

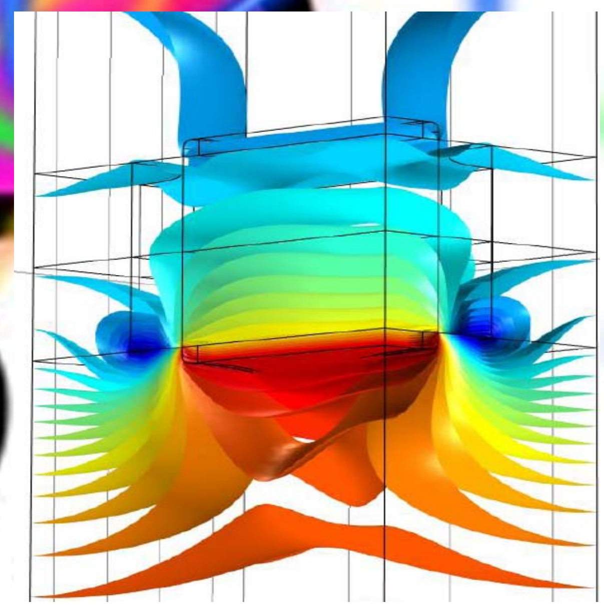
Understanding the charging up

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

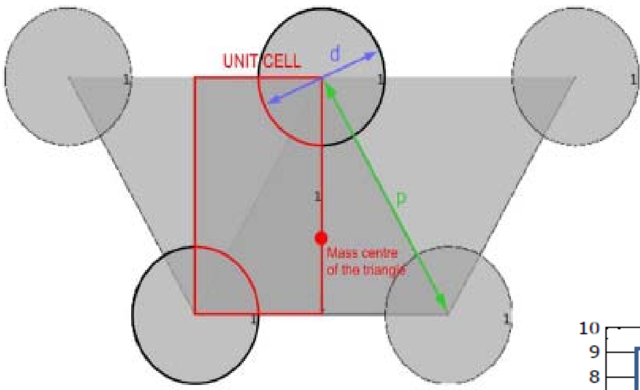
[studies in the context of the RD51 effort to provide adequate simulation tools for MPGDs]

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



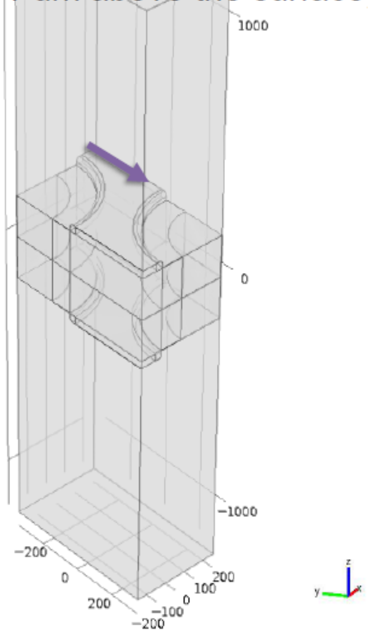


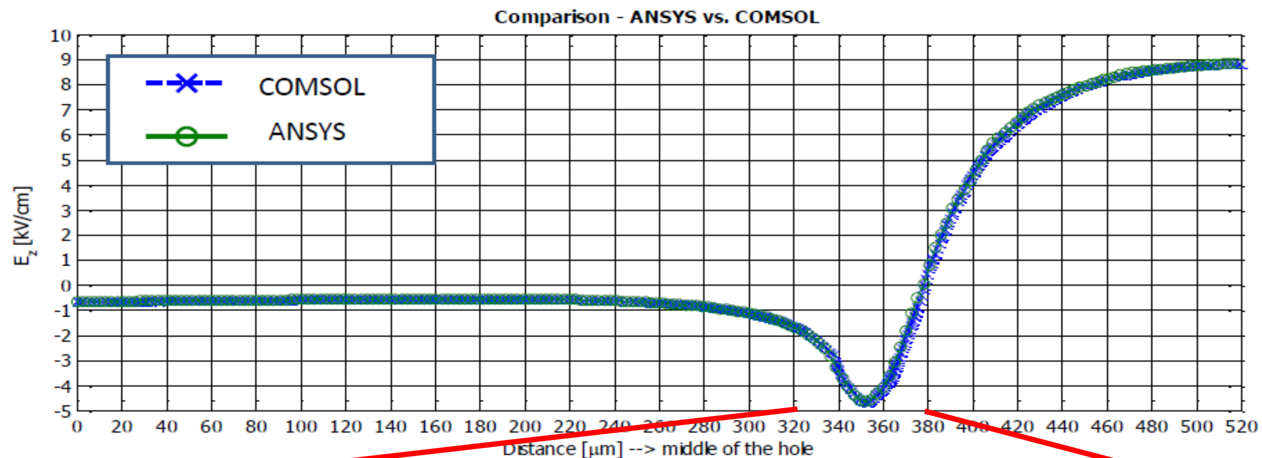
electrostatic calculations

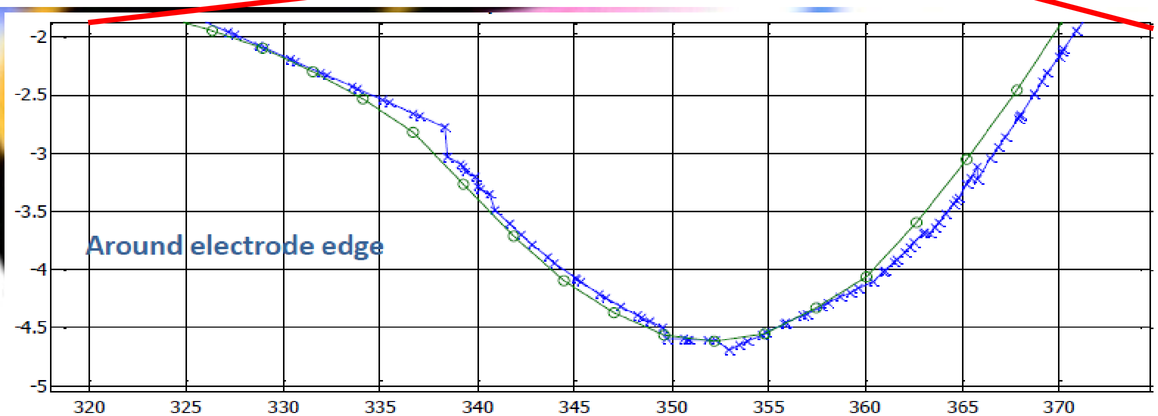


In order to achieve a realistic description of the THGEM electric field configuration a comparative study has been performed: at the beginning the results from ANSYS and COMSOL were not completely consistent; after few bug fixing now the agreement is good.

Test Line – in median direction 1 um above the surface







Performance limitations of MWPC with CsI

1) MWPCs with CsI photocathodes in COMPASS:

beam off: stable operation up to > 2300 V

beam on: stable operation only up to ~2000 V

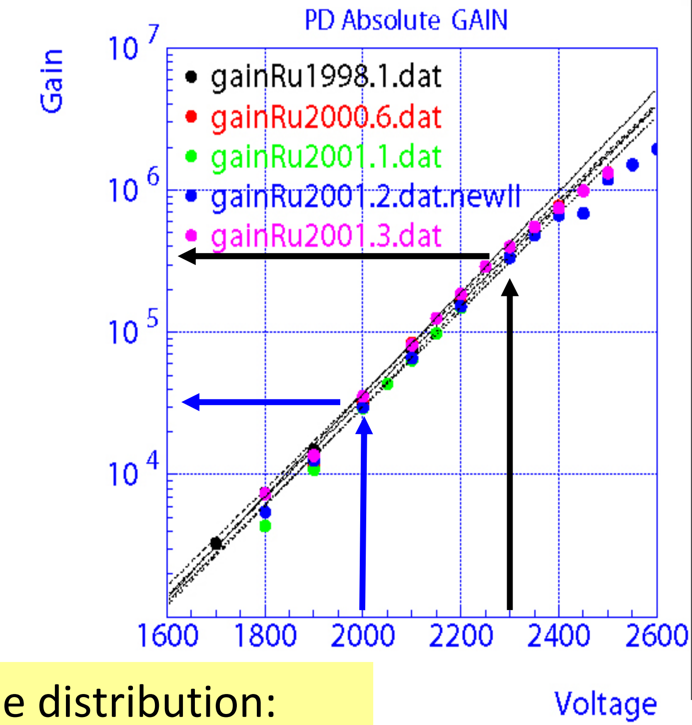
(in spill→ ph. flux: 0 - 50 kHz/cm^2 , mip flux: ~1 kHz/cm^2)

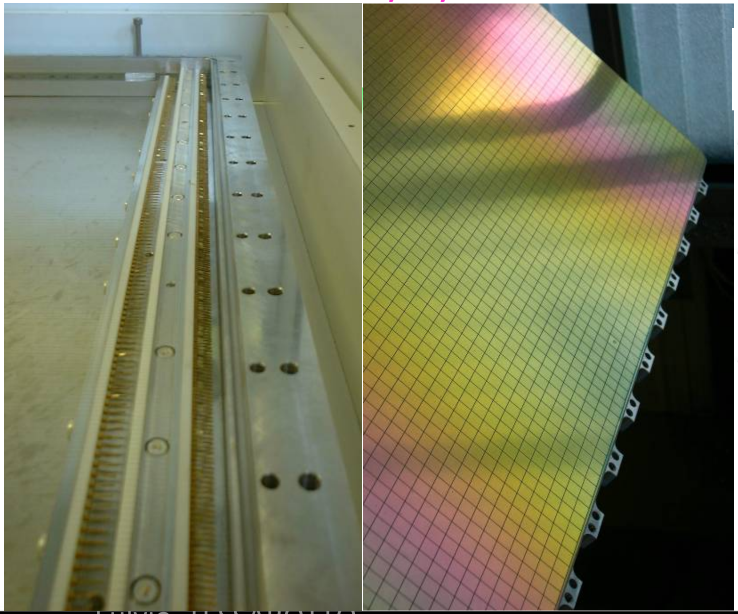
Whenever a severe discharge happens, recovery takes ~1 day.

Similar behavior reported from JLAB Hall-A

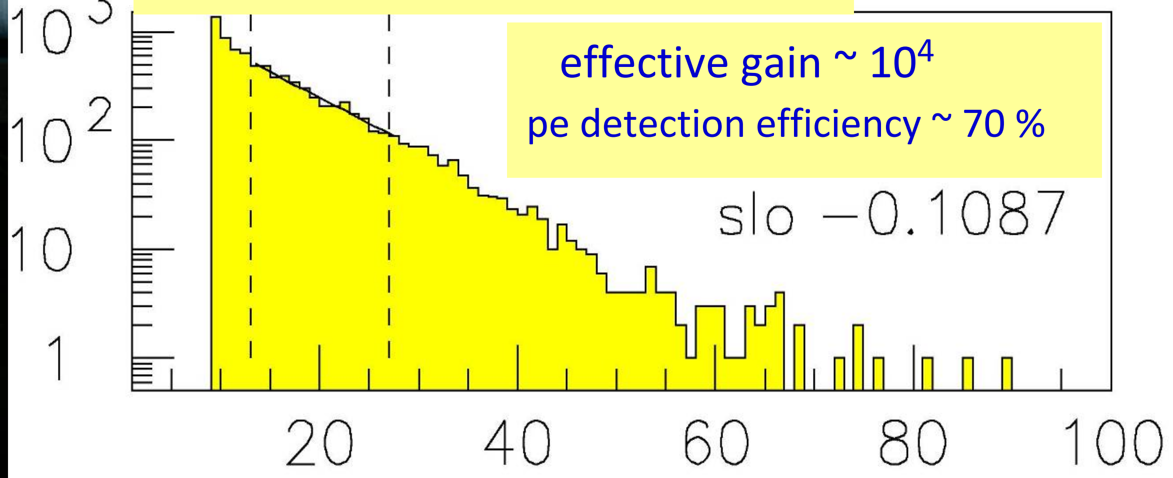
2) Photocathode aging:

- our information from accidental contamination
- detailed study by Alice team

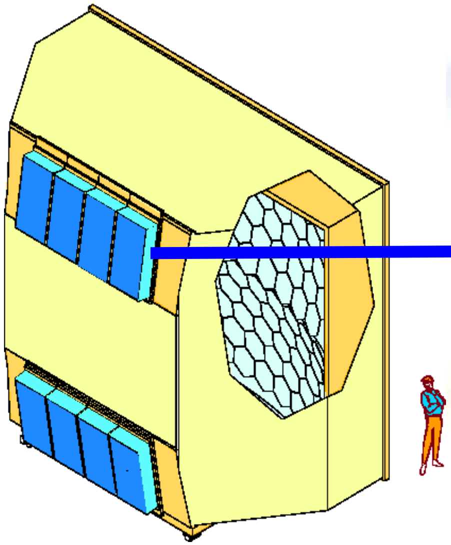


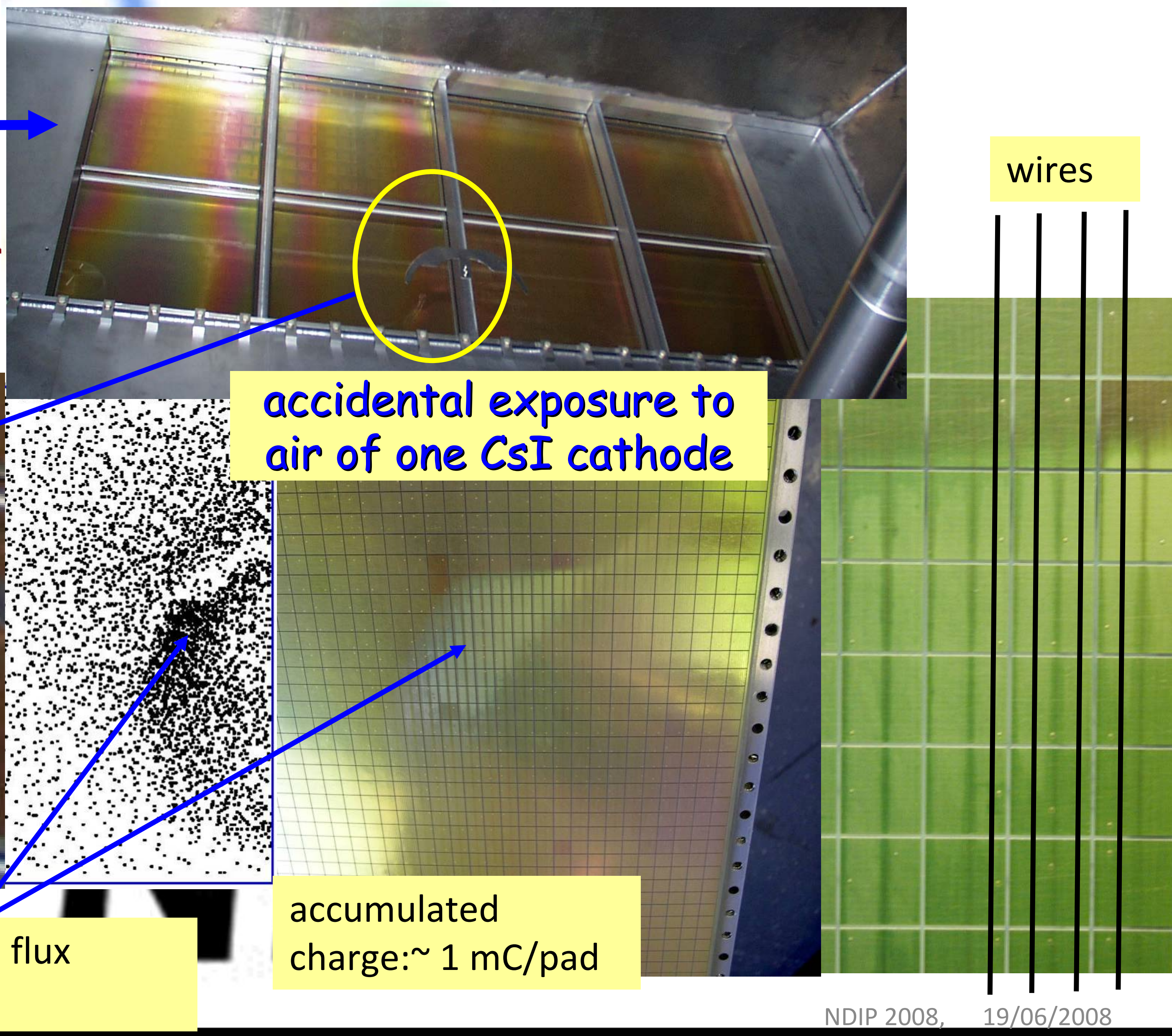


cluster amplitude distribution:



Few months after the end of the run





CsI surface at microscope (x 1000)