Progress towards a THGEM-based detector of single photons

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Outline

- *THGEM* characterization:
  - Rim role
  - Geometrical parameters and E field optimization
  - Our choice of parameters

- Single photon detection
  - Setup of the detector
  - Result for Cherenkov light detection
  - photoelectron extraction
  - IBF

- Towards large size dimensions

- Conclusions

Introduction

The requirements imposed by the *next generation* of Cherenkov detectors

- high sensitivity to single photon → good efficiency, gain and signal to noise ratio
- fast development of the signal → rate capability
- large detection areas coverage @ low production cost → economically affordable
- good electrical stability → no detector trips and/or long detector recovery time
- long term efficiency stability → reduce ageing effect and charge integration
- space resolution → good resolution on $\theta_{Cherenkov}$ / PID

Our answer is in the direction of THGEM MPGDs

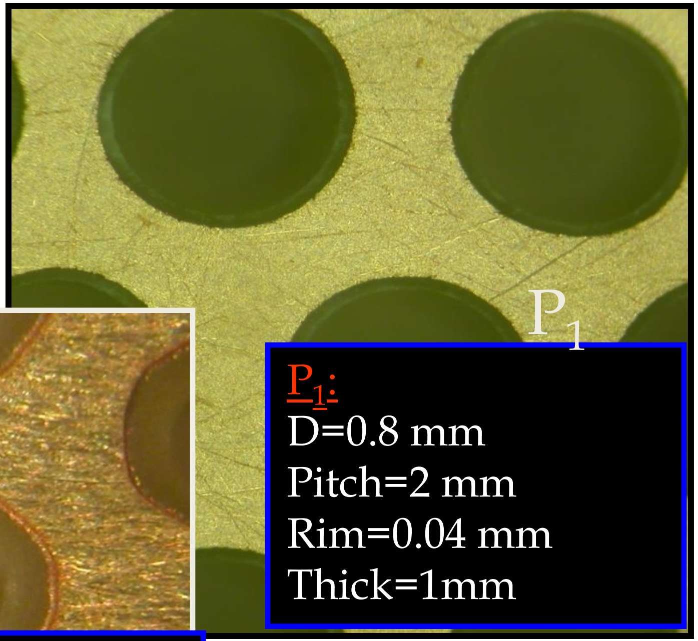
- GEM based
- large surface fraction available for photon converter coating
- production with standard PCB techniques
- closed geometry structure
- high gain device
- fast signal from electron drift (few ns)
- robust and self supporting

Potentially THGEM based detectors match all the requirements provided the proper choice of parameters and production technical solutions (see later)

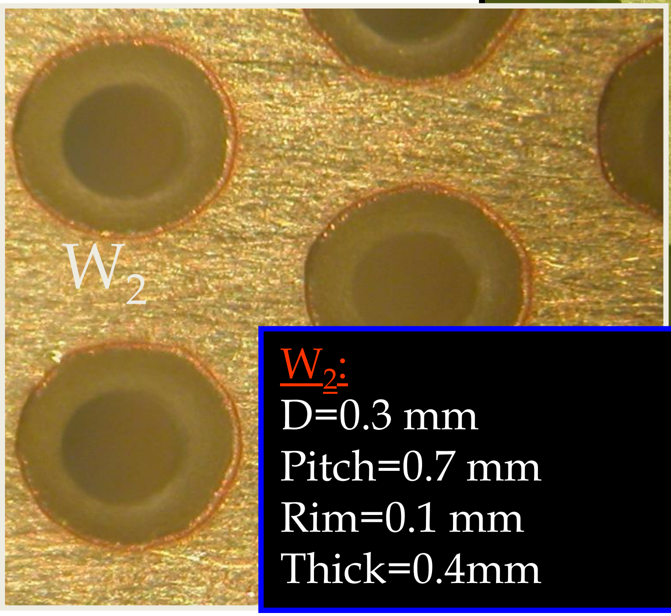
Characterization: 1- geometrical and production parameters

Multi parameter space exploration on **30 different THGEMs** allows to single out the role of

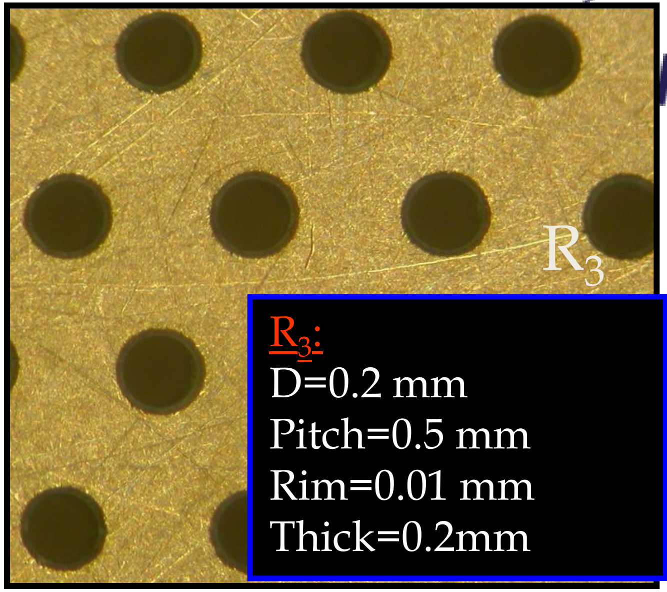
- diameter
- pitch
- rim
- thickness
- material
- production procedure



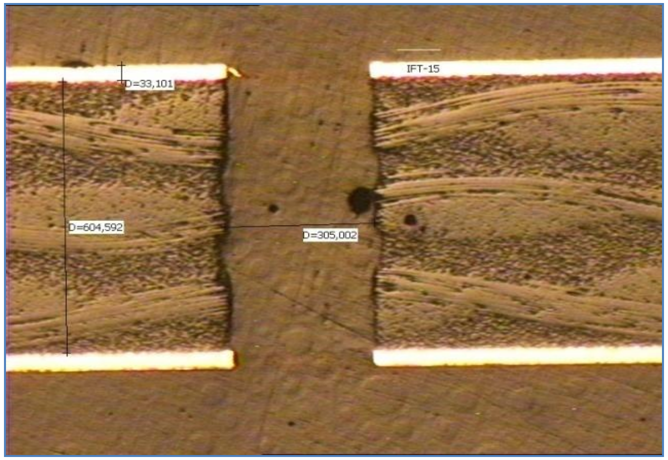
P_1:
D=0.8 mm
Pitch=2 mm
Rim=0.04 mm
Thick=1mm



W_2:
D=0.3 mm
Pitch=0.7 mm
Rim=0.1 mm
Thick=0.4mm



R_3:
D=0.2 mm
Pitch=0.5 mm
Rim=0.01 mm
Thick=0.2mm



Characterization: 1- geometrical and production parameters

Single THGEM layer in the chamber, active surface: 30 x 30 mm^2;

Gas mixture: Argon/CO_2 (70/30)

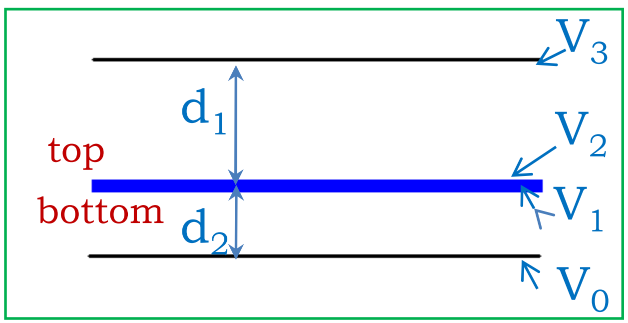
Sources: X-Ray (Cu – collimated source) and ^{55}Fe (uniform irradiation);

Two approaches:

gain from signal *amplitude spectra* and from *current measurements*

SKETCH OFTHE CHAMBER

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

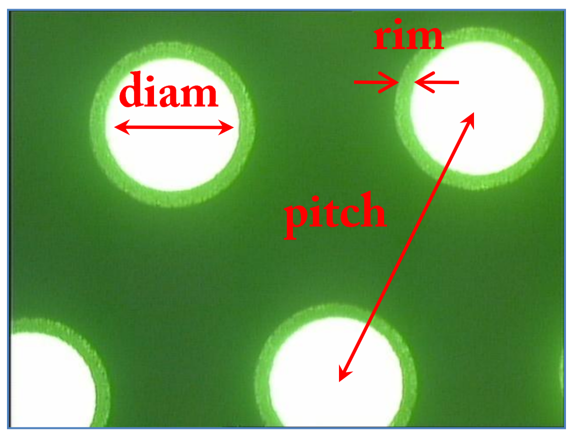


$E_{drift} = (V_3 - V_2)/d_1$

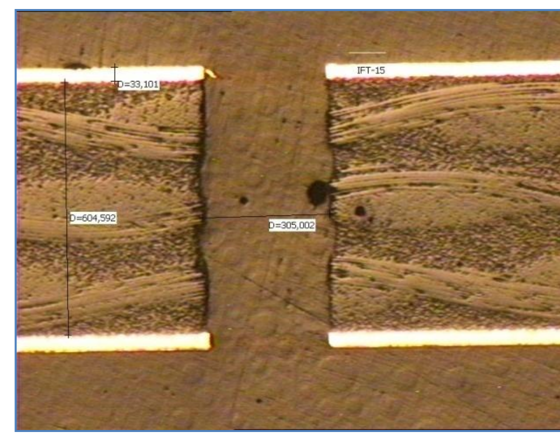
$E_{induction} = (V_1 - V_0)/d_2$

$\Delta V = V_2 - V_1$

Picture at the microscope

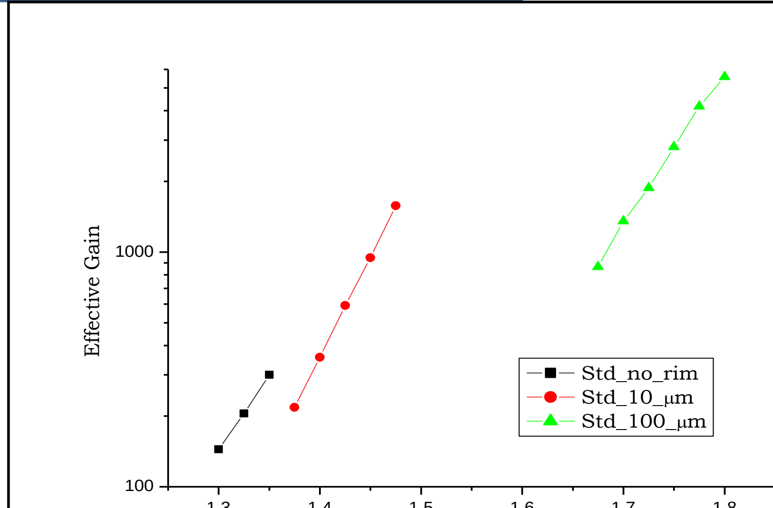


Metallographic section



Characterization: 1- geometrical and production parameters: rim fundamental role

Name	Diam (mm)	Pitch (mm)	Rim (μm)	Thick (mm)
Std_no_rim	0.3	0.7	0	0.4
Std_10_μm	0.3	0.7	10	0.4
Std_100_μm	0.3	0.7	100	0.4

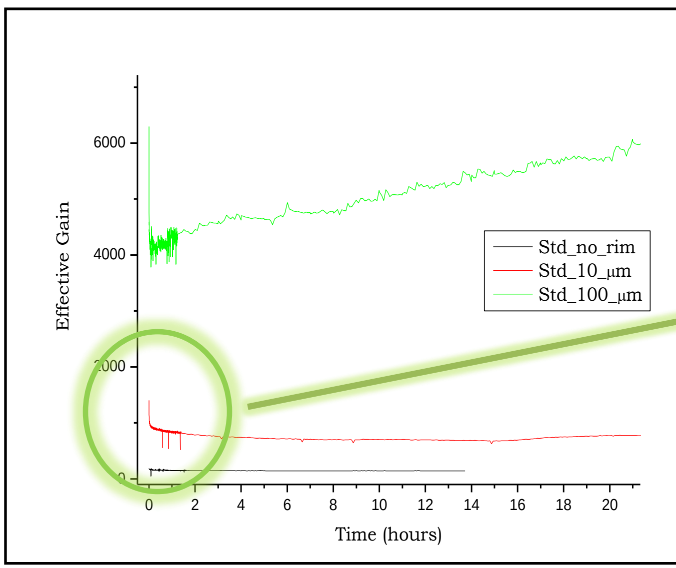


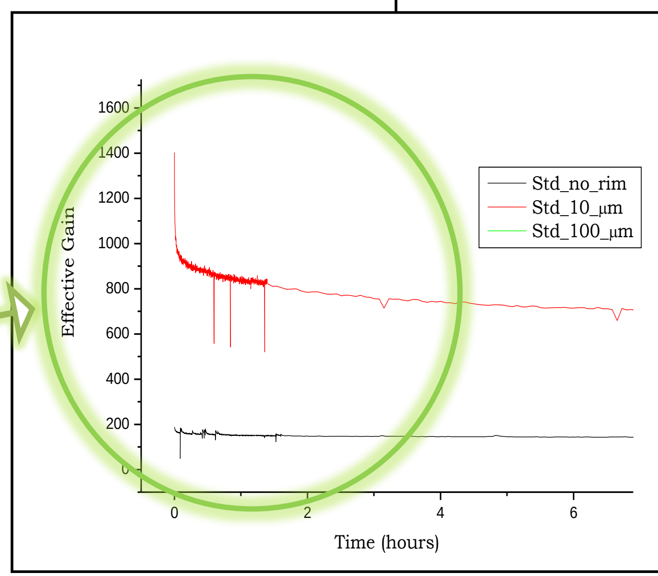
Optimized Induction field and rate ~ 1÷2 kHz/mm^2

Important gain dependence vs. the rim size

Different ΔV applied to the THGEMs, maximizing the gain for stable working conditions

Continuously irradiated with collimated X-Ray source





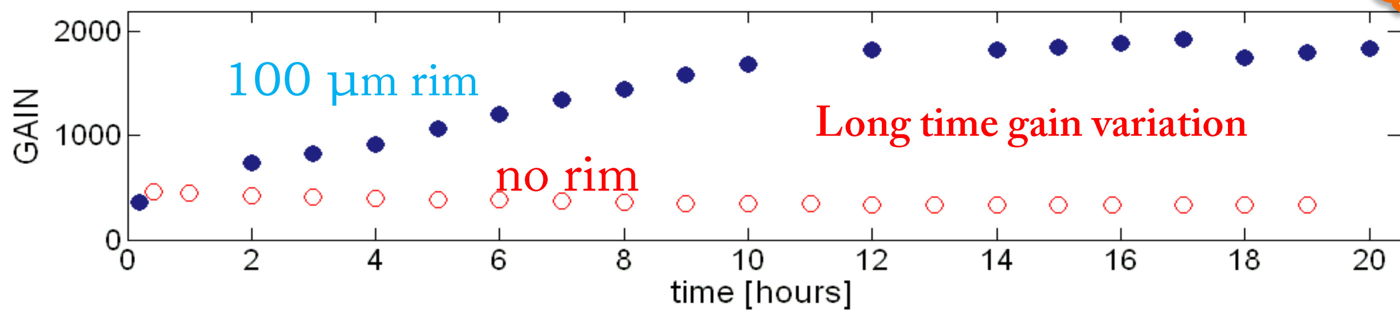
- A factor >>2 in gain variation between the initial drop and the stabilization;
- Different behaviour for THGEMs with and without (or small) rim.
- History dependent gain for THGEMs with rim

Characterization: 1- geometrical and production parameters: rim fundamental role

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

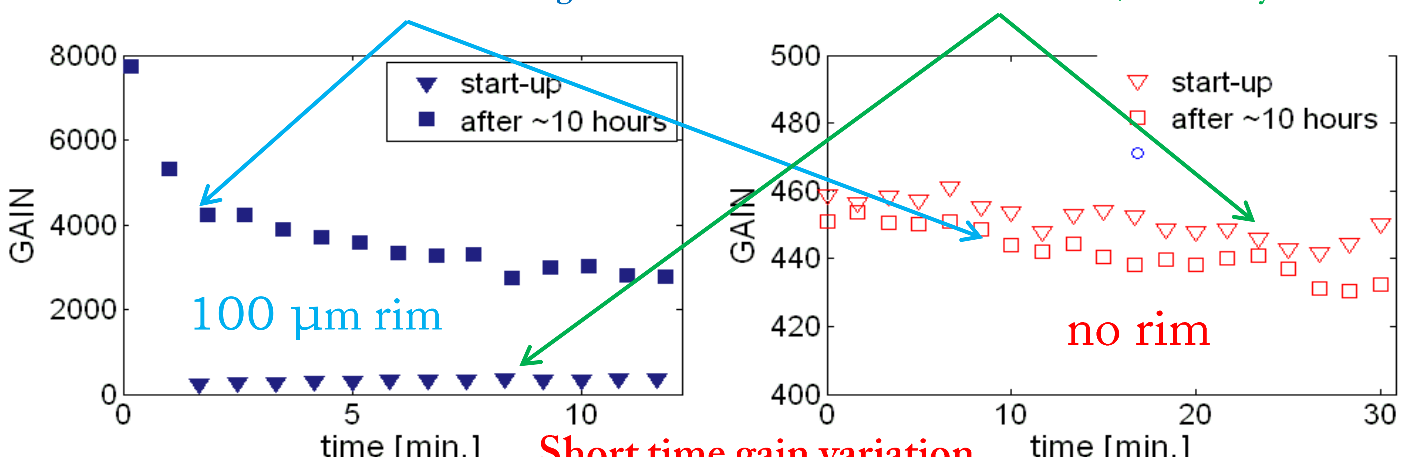
^{55}Fe source; uniform irradiation

Reproducible



START IRRADIATING after ~10 hours at nominal voltage

Irradiation within HV switch on (after ~1 day with no voltage applied)



Short time gain variation

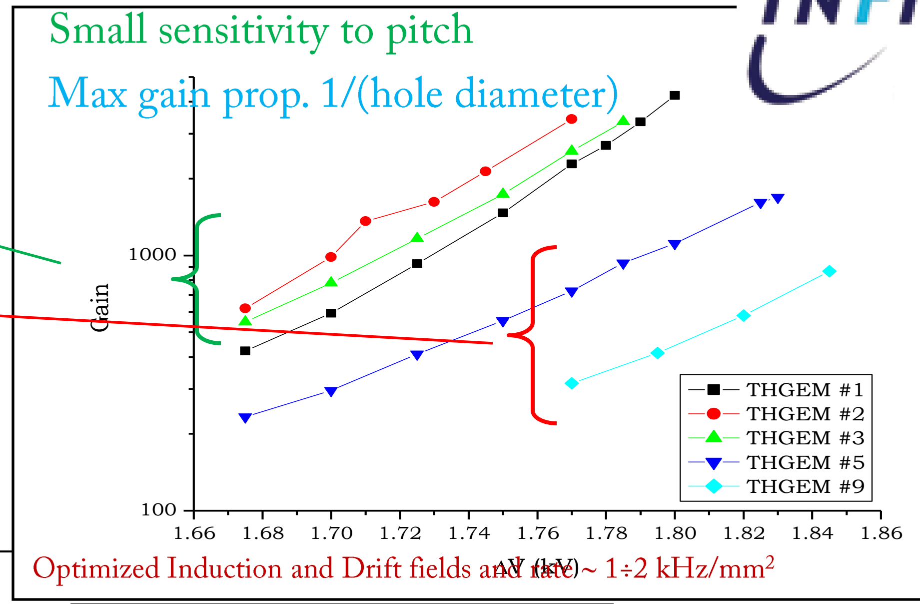
Good gain stability (within ~20-30%) is obtained with small rim (< 20 µm)

Characterization: 1- geometrical and production parameters

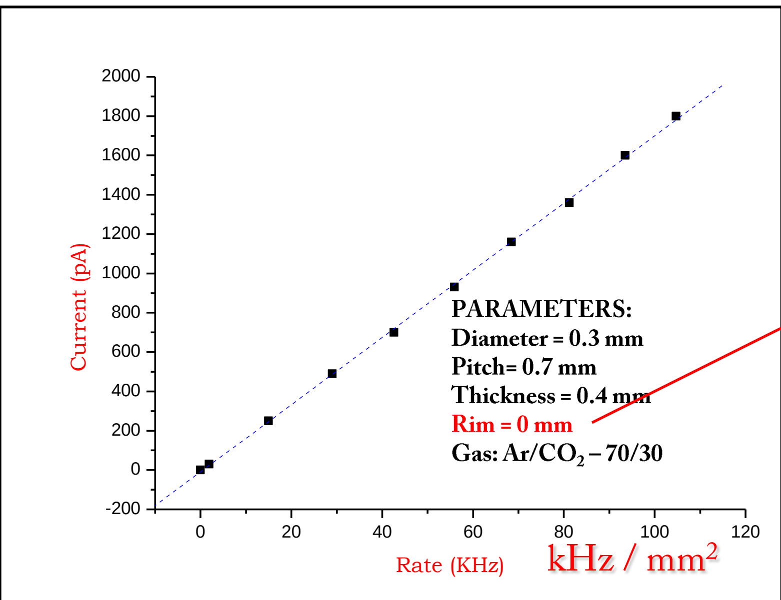
Name	Diam (mm)	Pitch (mm)	Rim (µm)	Thick (mm)
THGEM_1	0.3	0.7	0	0.6
THGEM_2	0.3	0.6	0	0.6
THGEM_3	0.3	0.5	0	0.6
THGEM_5	0.4	0.7	0	0.6
THGEM_9	0.5	0.7	0	0.6

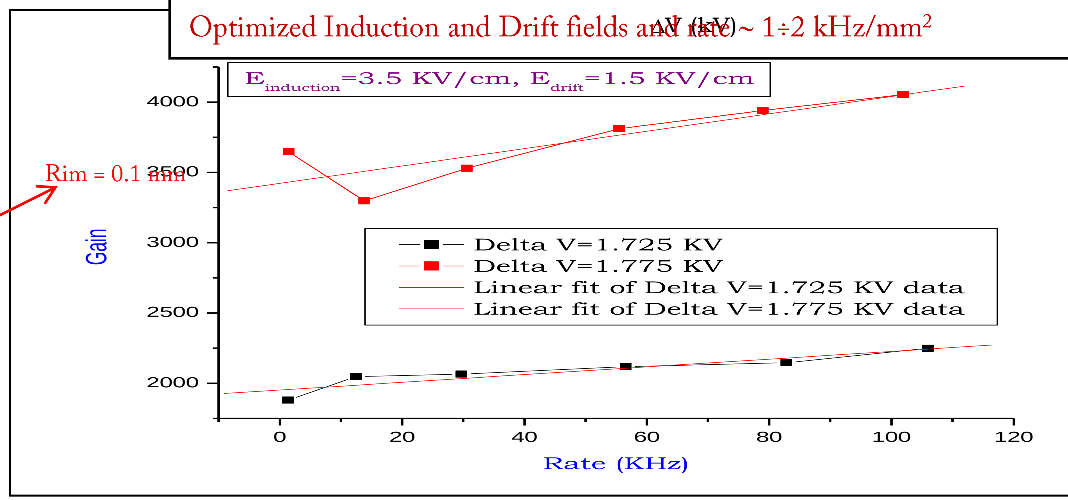
Small sensitivity to pitch

Max gain prop. 1/(hole diameter)



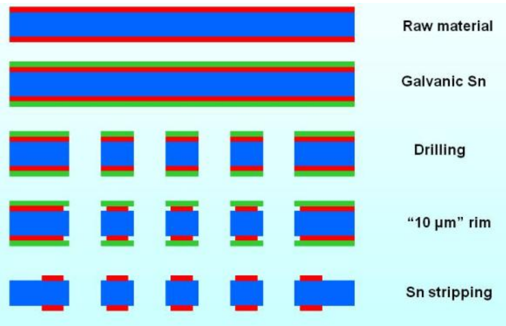
Optimized Induction and Drift fields and rate ~ 1÷2 kHz/mm²

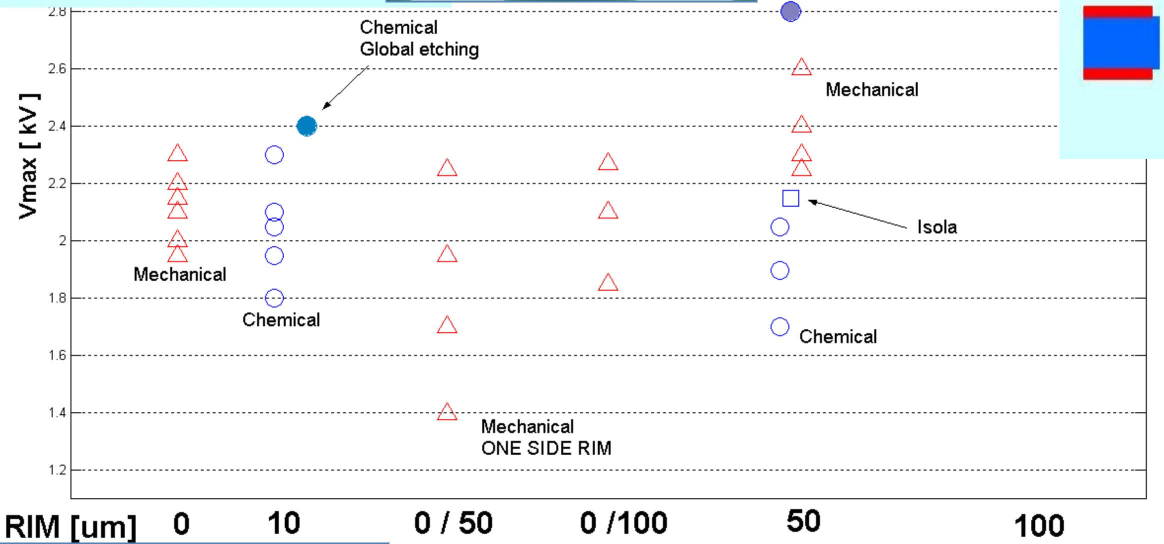


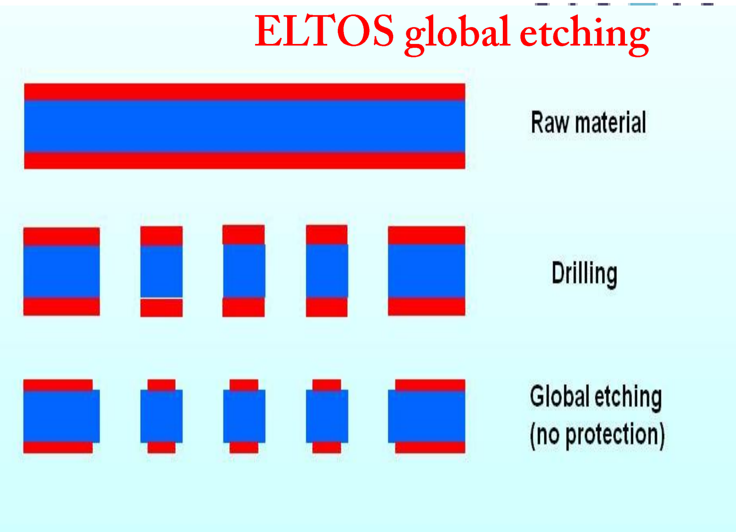


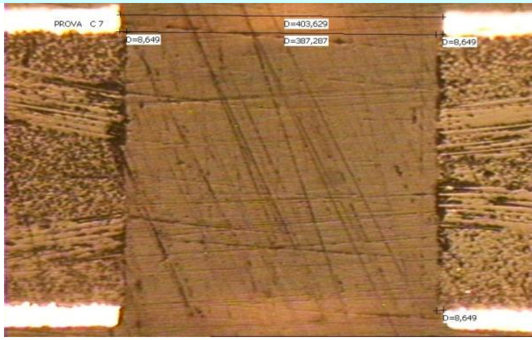
120 kHz/mm² 300 e- → single photoelectron rates of ~35 MHz/ mm² → good rate capability

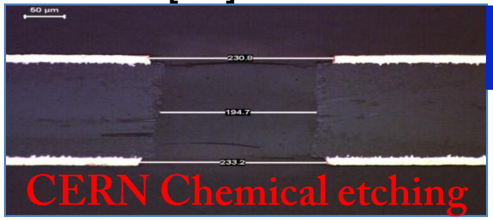
Characterization: 1- geometrical and production parameters: production techniques











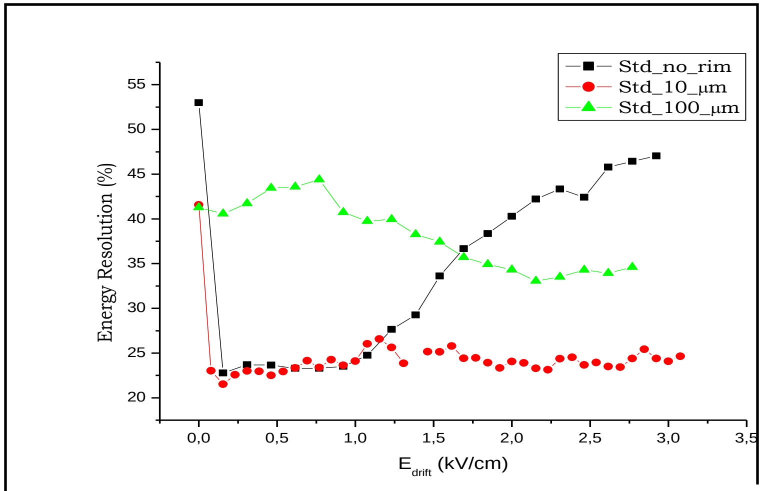
rim production techniques – 5 approaches tested

Different production techniques ➔ different behaviors

E field

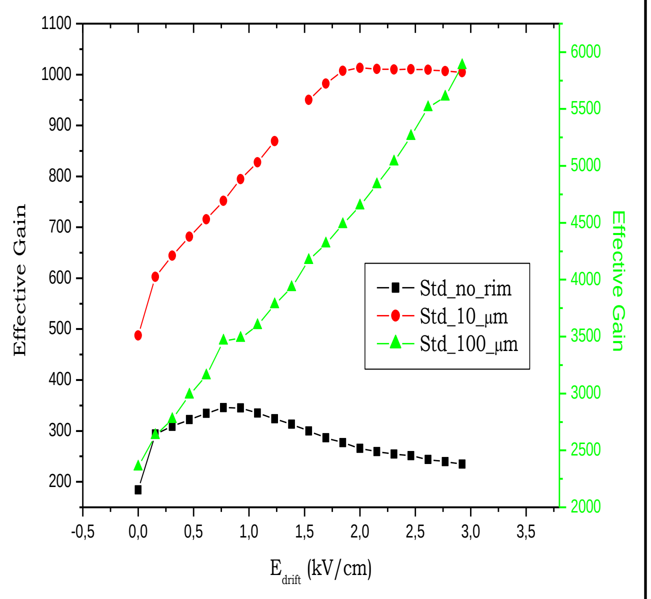
Poor energy resolution → not complete charge collection

Name	Diam (mm)	Pitch (mm)	Rim (µm)	Thick (mm)
Std_no_rim	0.3	0.7	0	0.4
Std_10_µm	0.3	0.7	10	0.4
Std_100_µm	0.3	0.7	100	0.4



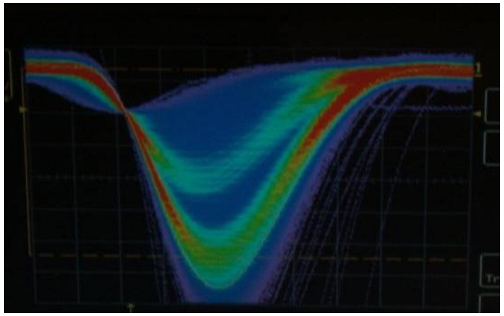
Different ΔV applied to the THGEMs, maximizing the gain for stable working conditions

NOTE: two different scales



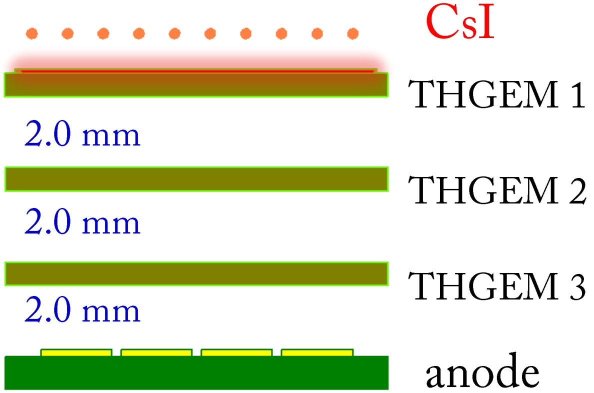
CONCLUSIONS: increasing the rim size the plateau region is displaced at high drift field or never reached for reasonable field values!!!

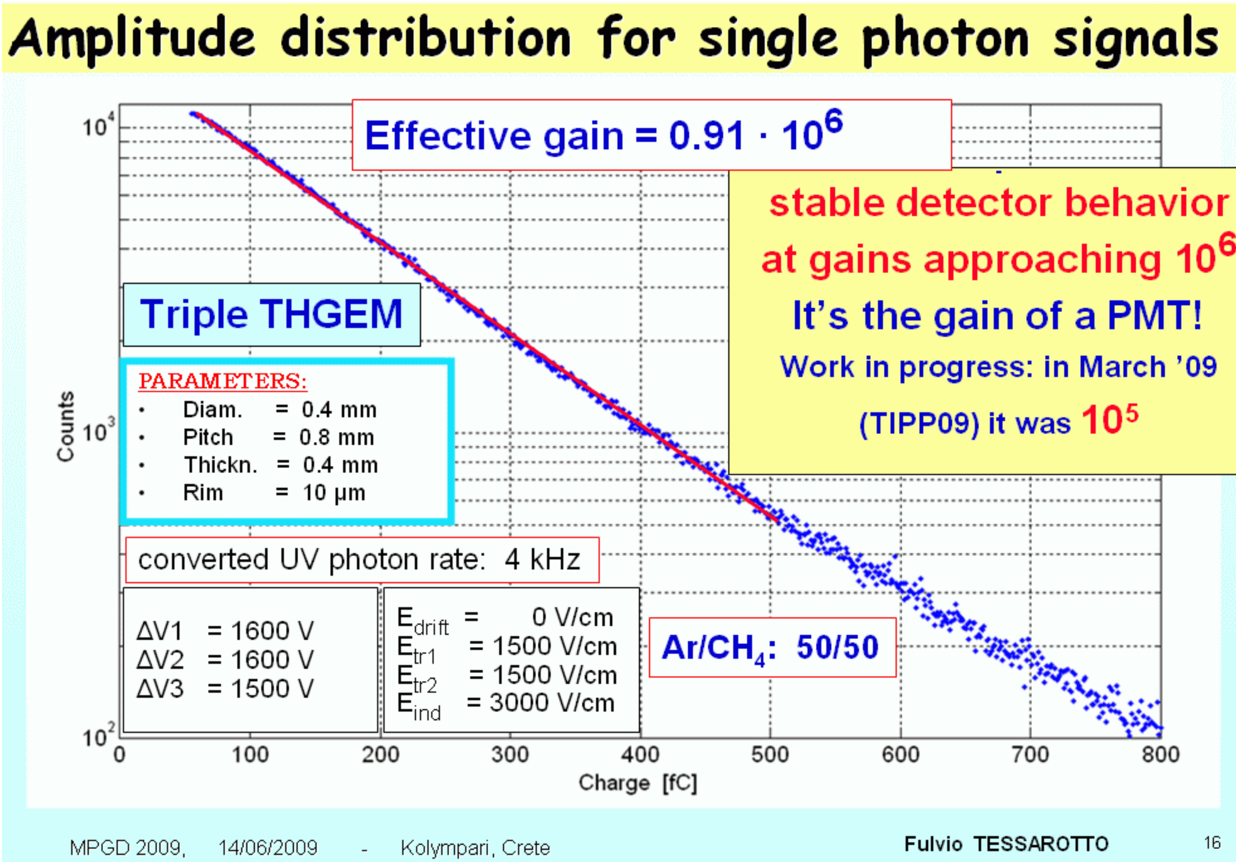
Contrary to the DRIFT scan, in the INDUCTION scan, the energy resolution is pretty constant. The values are included in a range between 22 ÷30 %



Single photon detection

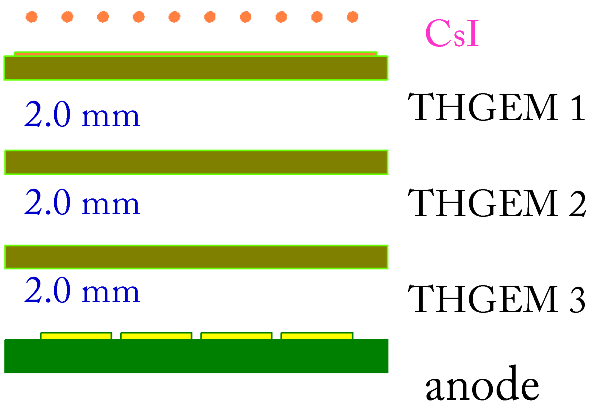
Our goal single photon detection!



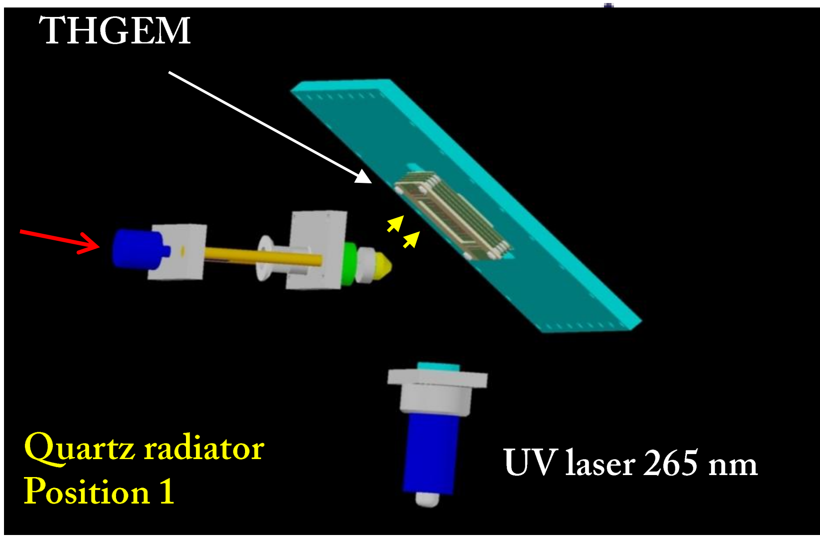


Our first detection of Cherenkov light

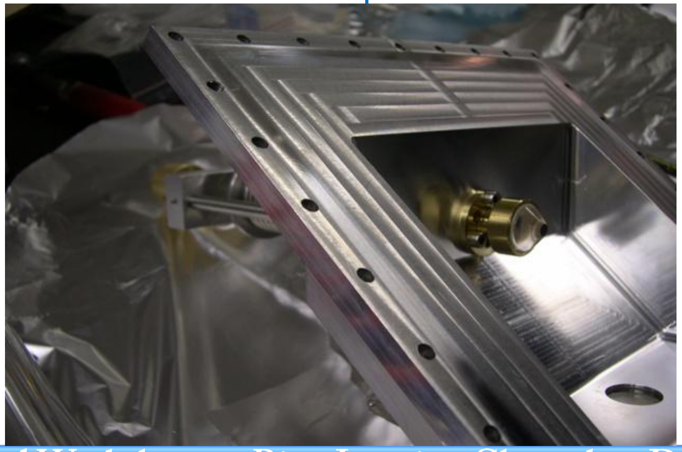
Triple THGEM (CsI) Ar/CH_4 50/50 Diam=0.4 mm, pitch =0.8, Thick=0.4, rim ≤10 μm (GE)

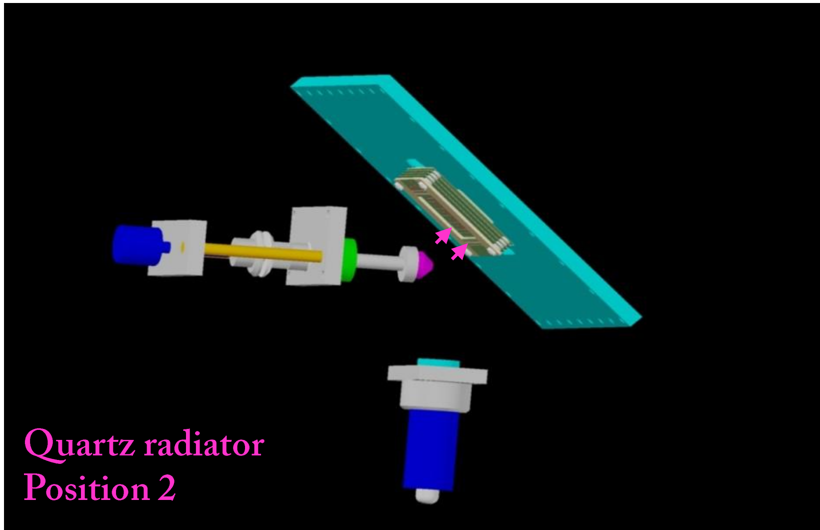


πBeam
p=150 GeV/c
Trigger AND 4 (2+2)
3mm x 3mm scintillators



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



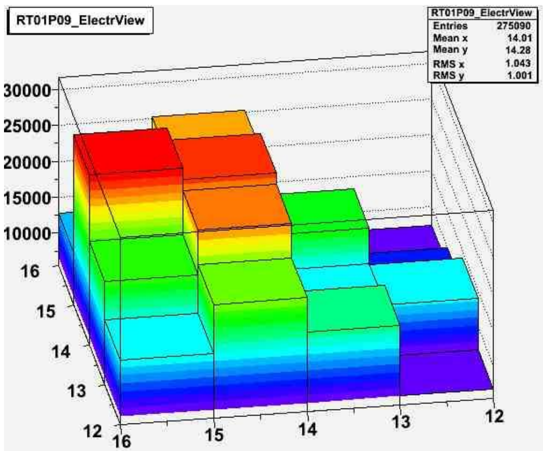


Detector behaves in the same way as in the LAB: Gain up to 10^6, good reproducibility, full control

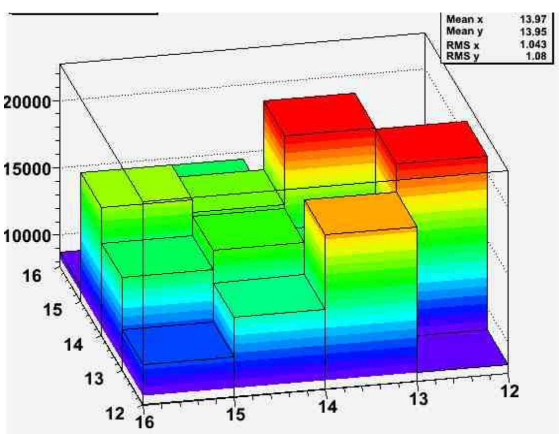
Test beam 2009: result

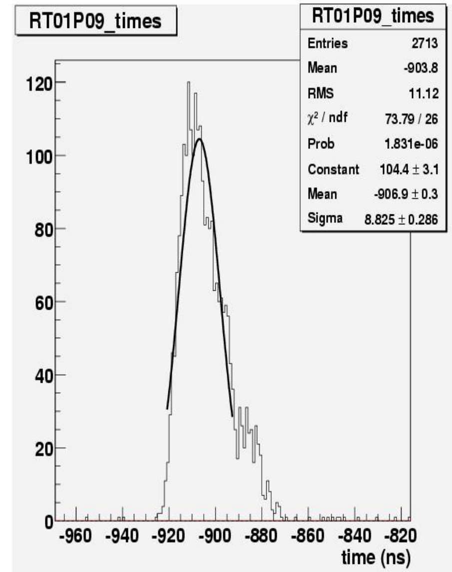
Timing properties

2 different positions of radiator (change of 20mm)

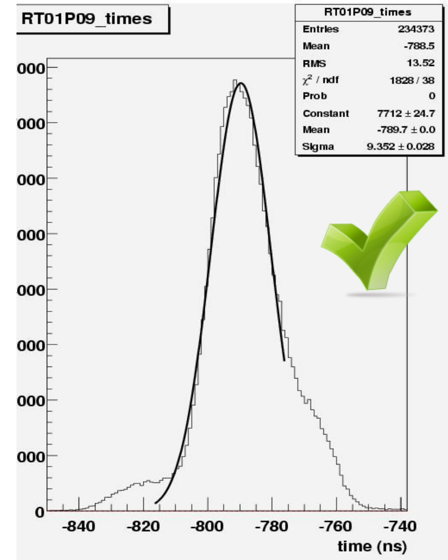


First indication of Cherenkov light





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….)

Photoelectron extraction

Electrostatic calculations are essential to optimize our THGEMs

Critical points:

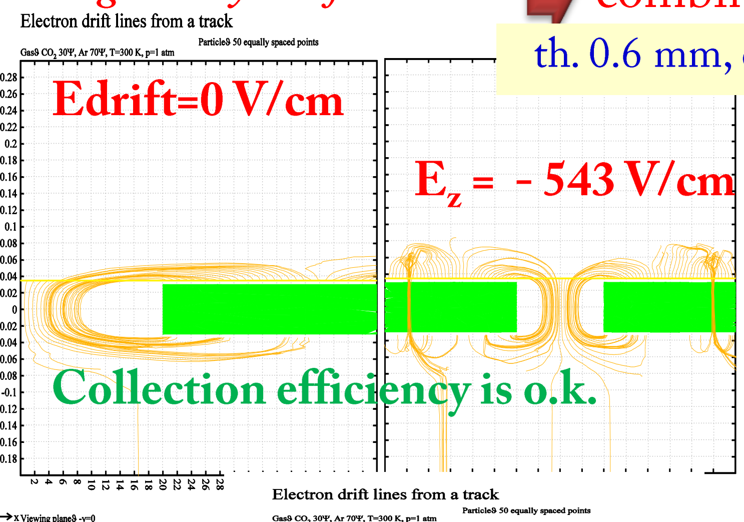
Effective CsI Q.E. depends on the *electric field at the CsI surface* and *e focusing* is done by dipole field

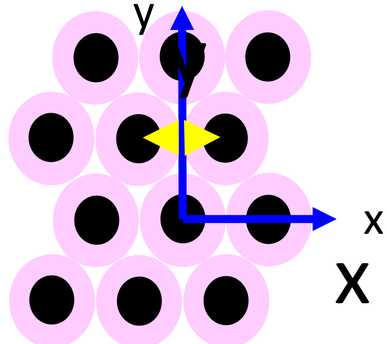
The backscattering effect depends on *the gas and on the field too*

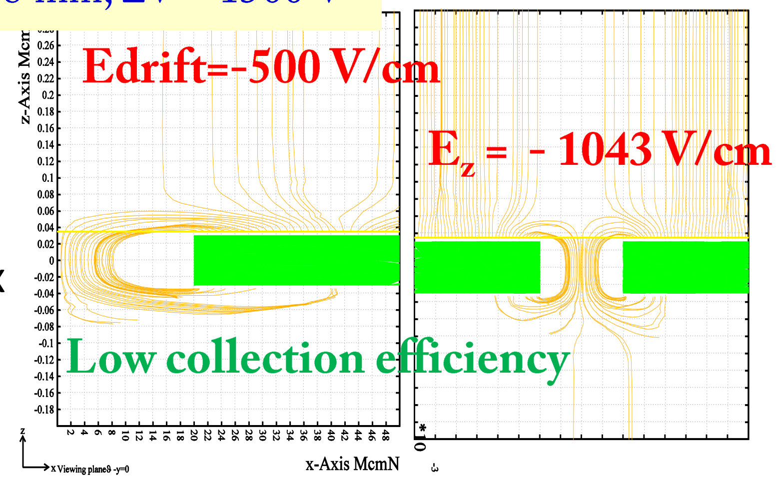
The collection of photoelectrons in the holes for multiplication is difficult to measure and critically *depends on geometry and fields*

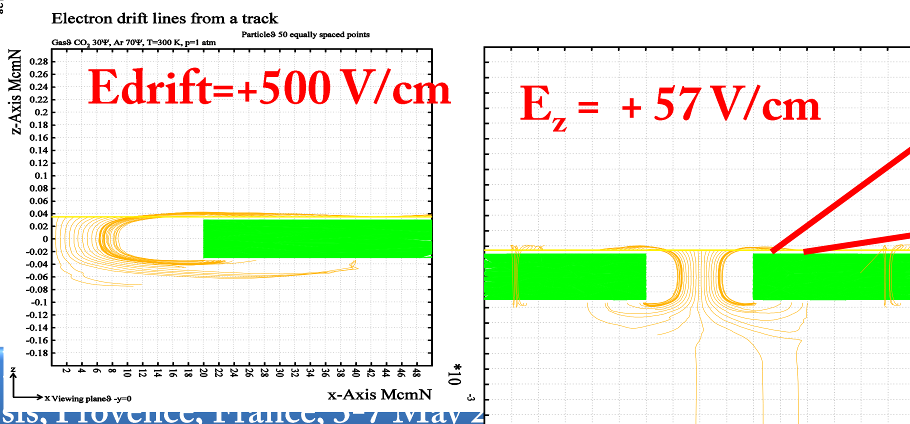
→ combine measurements and simulations (ANSYS+ Garfield)

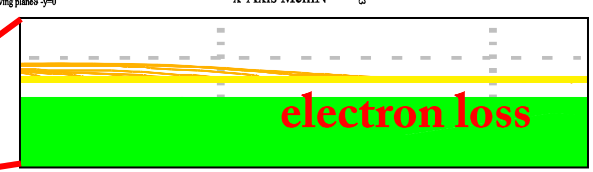
th. 0.6 mm, diam. 0.4 mm, pitch: 0.8 mm, ΔV = 1500 V



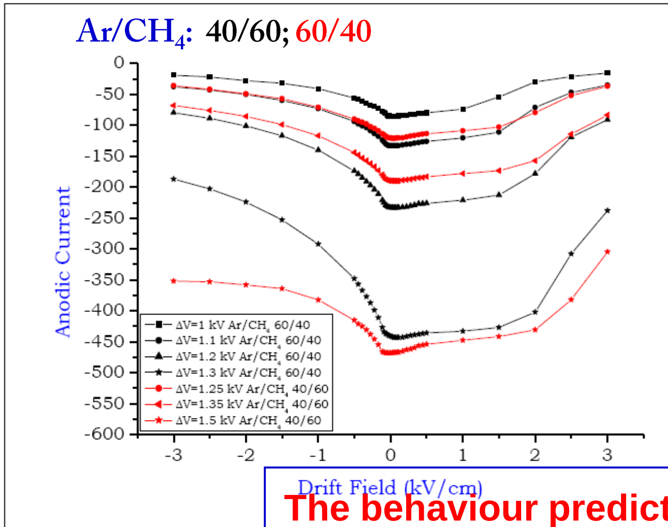




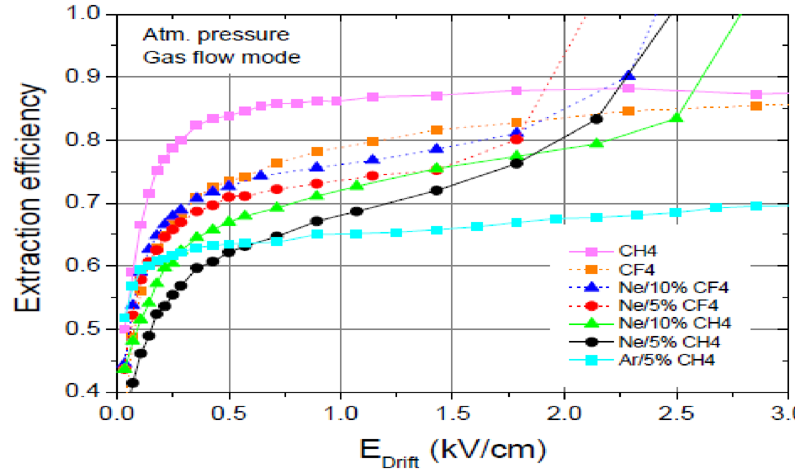




Photoelectron extraction

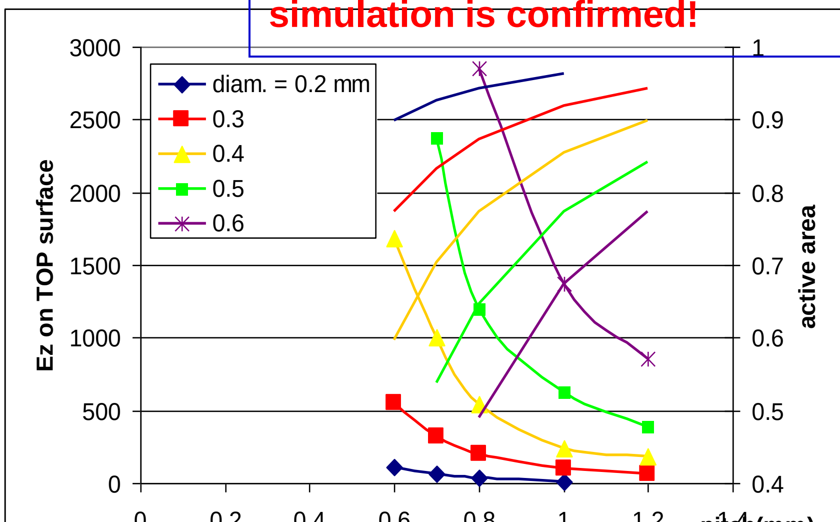


ΔV (kV)
1
1.1,
1.2
1.3
1.25
1.35
1.5

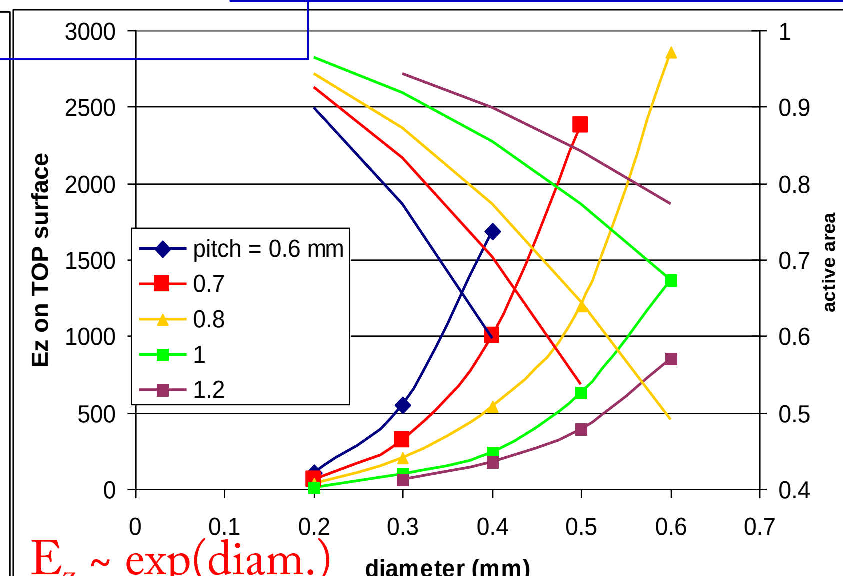


The behaviour predicted by the simulation is confirmed!

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



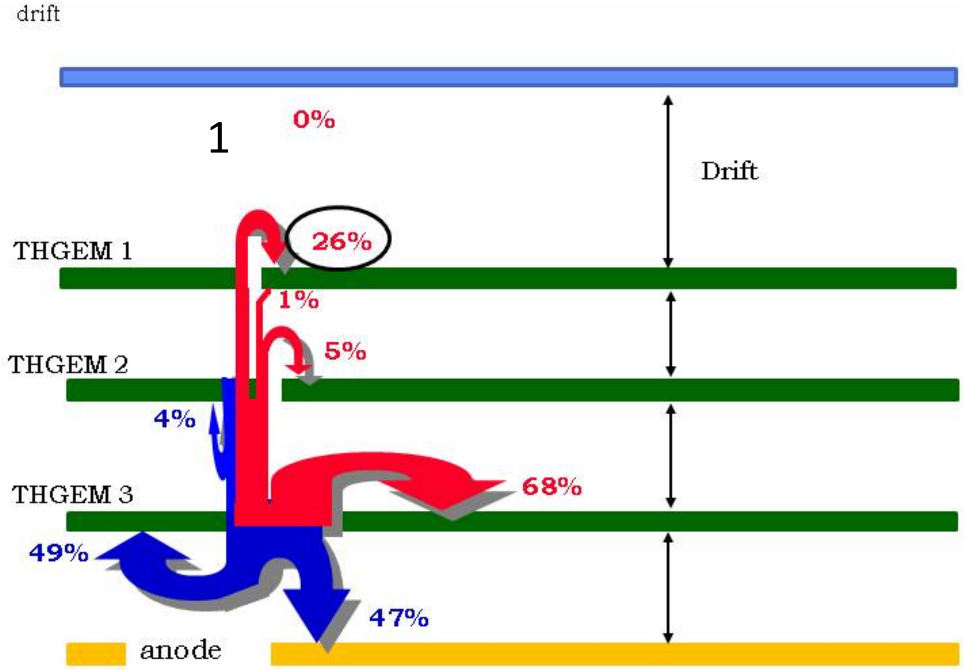
$E_z \sim 1/(\text{pitch})^4$



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

Ion Back Flow:

Main problem: Ions
-secondary *e* emission
-ion feedback
-gain & performance limitations in terms of instabilities /charge accumulation on PC



Ion Back Flow

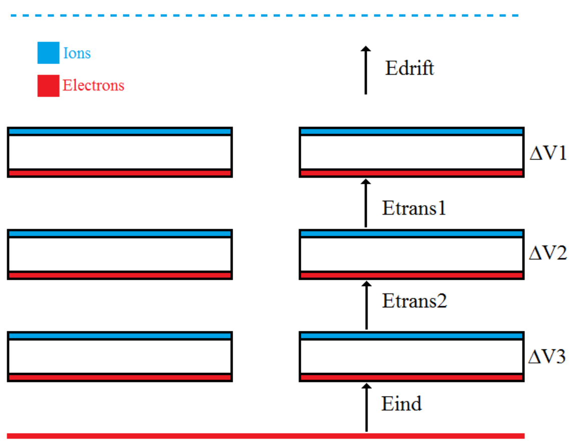
First trial: modify middle THGEM geometry

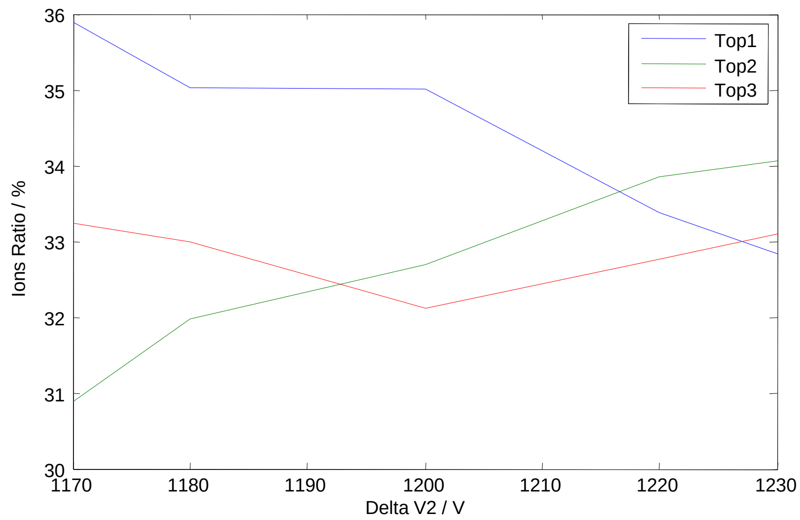
same pitch 0.8 mm and same thickness but holes from 0.4 to 0.2 mm

Induction Scan, Transfer field scan, ΔV scan and multiple combinations → *reduction possible in the order of few percent only*

$E_D = 0$ V/cm
$E_{T1} = 500$ V/cm
$E_{T2} = 750$ V/cm
$E_I = 2500$ V/cm

$\Delta V1 = 1050$ V
$\Delta V2 = 1200$ V
$\Delta V3 = 1000$ V

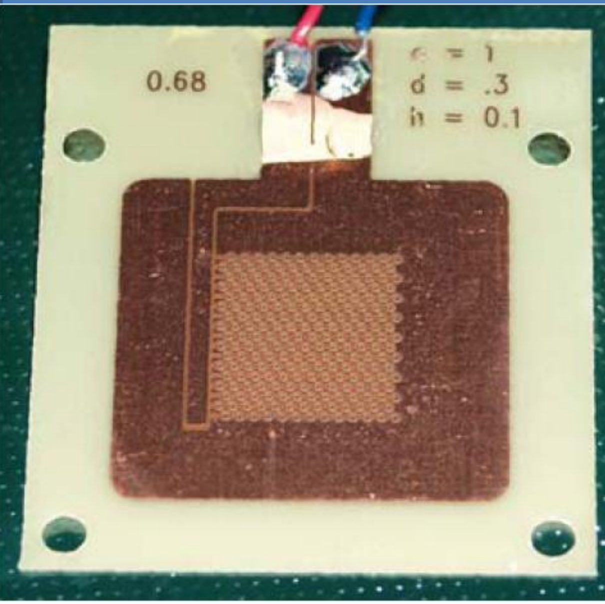


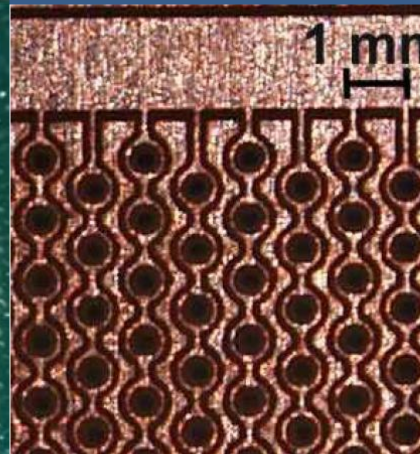


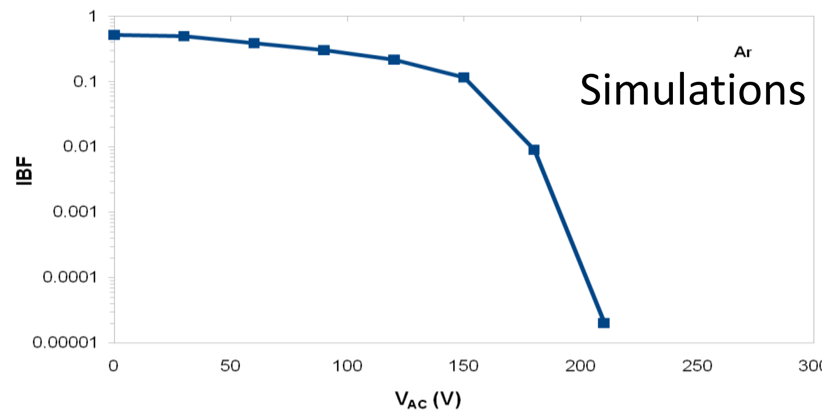
Simple geometrical solutions seem not to be sufficient, different approach needed

Work done in collaboration with Carlos Santos (Thanks!)

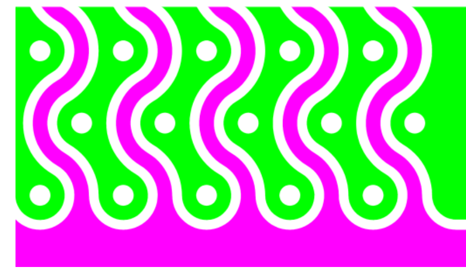
Ion Back Flow reduction







New Thick Hole-Structures for Gaseous Detectors, João Veloso RD51



Single photon detection efficiency strongly affected by

Active area (electrode) / Dead area (holes) → limits on the geometry of 1th THGEM

E field on the surface → geometrical parameters of the 1th THGEM

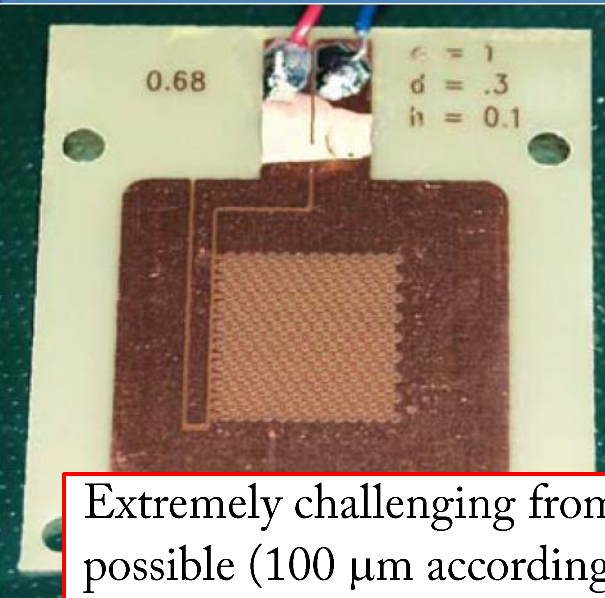
$E_z \sim \exp(\text{diam.})$

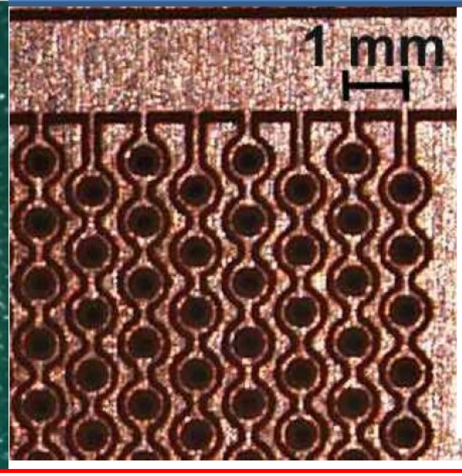
$E_z \sim 1/(\text{pitch})^4$

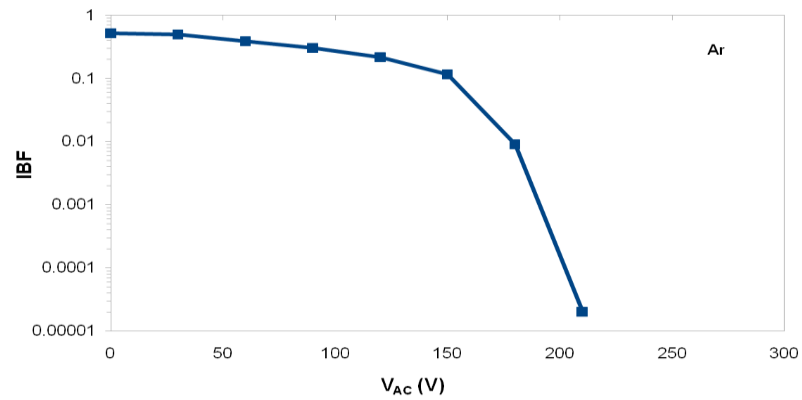
Impose constrains on the maximum space between electrodes for THCOBRA → pitch and hole size

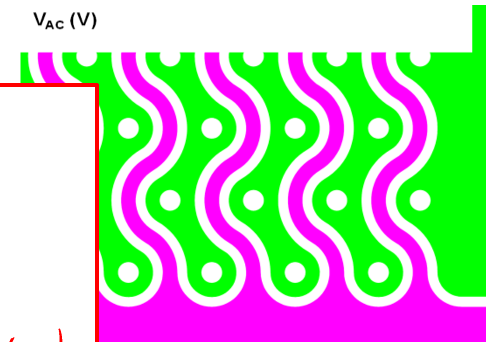
Hole	Ering	Clearance	Cobra Electrode	Pitch
400	2X80	2X80	80	800

Ion Back Flow reduction









Si

THGEM

Extremely challenging from the technological point of view
possible (100 μm according to PCB producers suggestion is feasible)

-expensive

-parameter control for large surfaces is very difficult

-reduction of Cu thickness → detector robustness is affected (discharges see later)

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

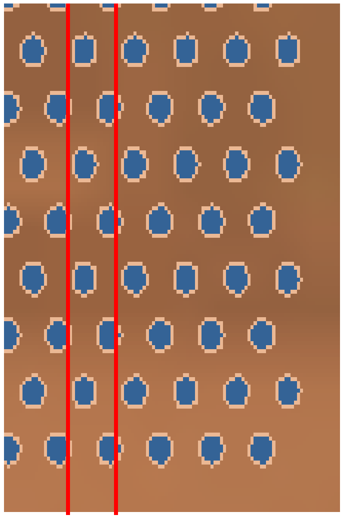
$E_z \sim 1/(\text{pitch})^4$

Impose constrains on the maximum space between electrodes for THCOBRA → pitch and hole size

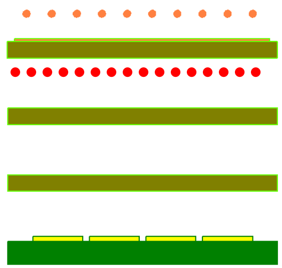
Hole	Ering	Clearance	Cobra Electrode	Pitch
400	2X80	2X80	80	800

Ion Back Flow reduction

To get rid of geometrical constrains -> plane of wires facing the 1th bottom electrode

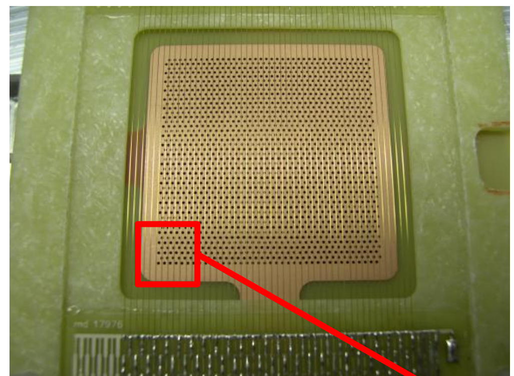


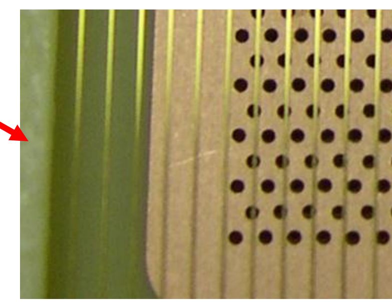
Distance from the bottom plane 500 μm
Wires spacing according to pitch of the THGEM

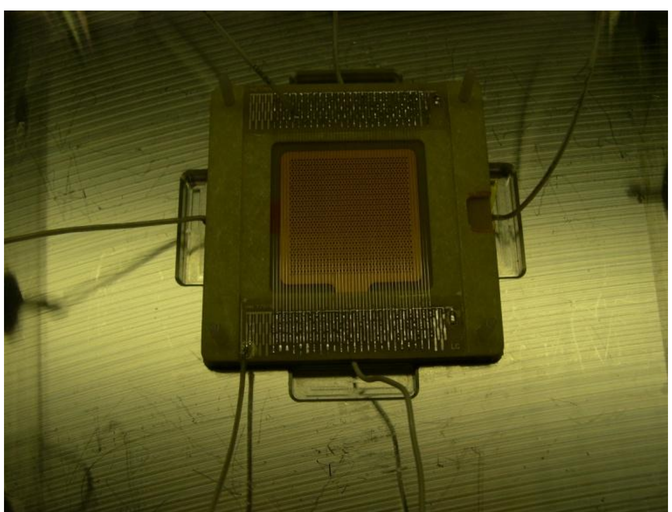


Its realization
100 μm wires

Very firs trial!



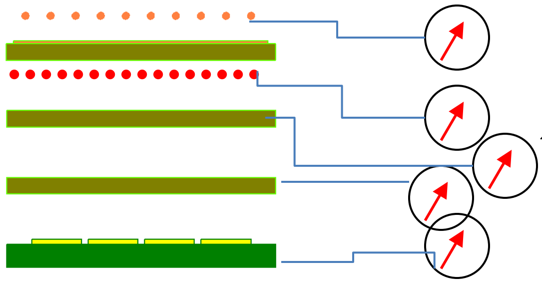




Ion Back Flow reduction

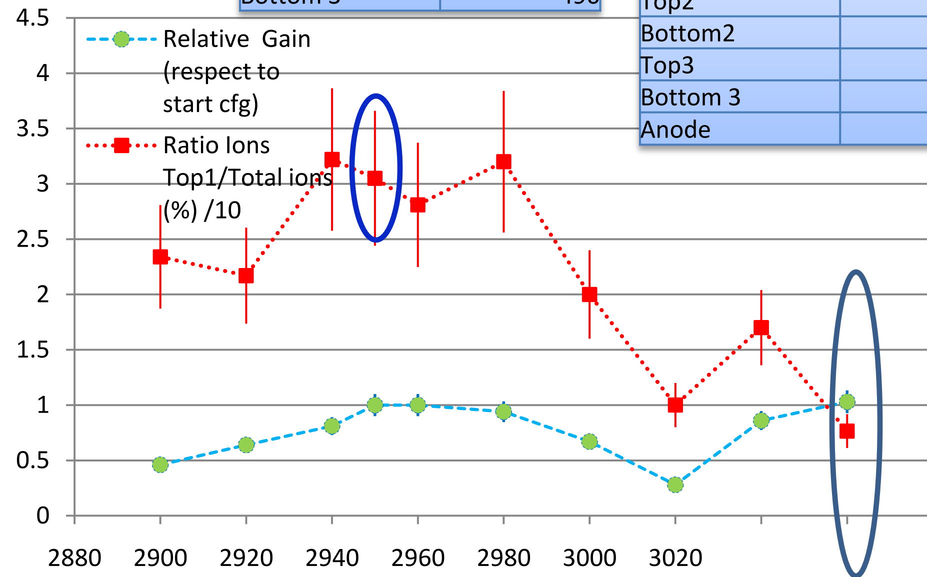
HV	Volt
Drift	4100
Top1	4100
Bottom 1	2956
Cobra wires	3020
Top2	2807
Bottom2	1650
Top3	1510
Bottom 3	490

Anode	0
Drift	4100
Top1	4110
Bottom 1	3150
Cobra wires	3220
Top2	3000
Bottom2	1650
Top3	1510
Bottom 3	500
Anode	0



1 pA for each layer,
2mm spacing

HV	Volt			E (V/cm)	Current measured
Drift	4015	Cfield	0	0	-10
Top1	4015	DV1	1059	2647.5	30
Bottom 1	2956	Edrift	16	40	0
Cobra wires	2940	Trans1	133	886.6667	0
Top2	2807	DV2	1157	2892.5	27
Bottom2	1650	Transf2	140	700	-8
Top3	1510	DV3	1020	2550	46
Bottom 3	490	Induction	490	2450	-35
Anode	0				-63



Increasing Second THGEM ΔV (200V)

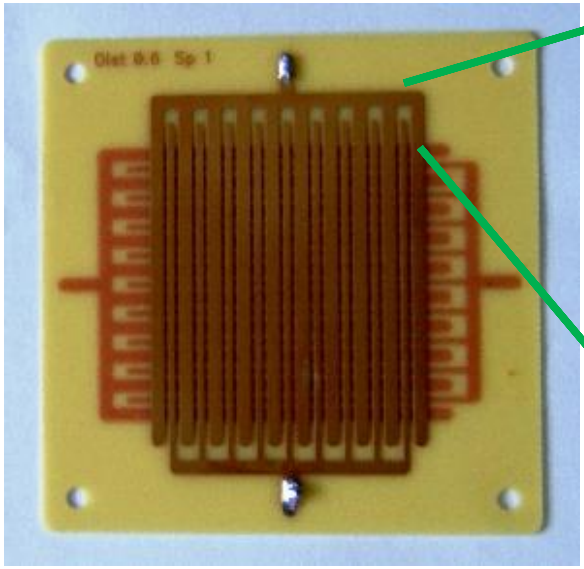
Very first trial!

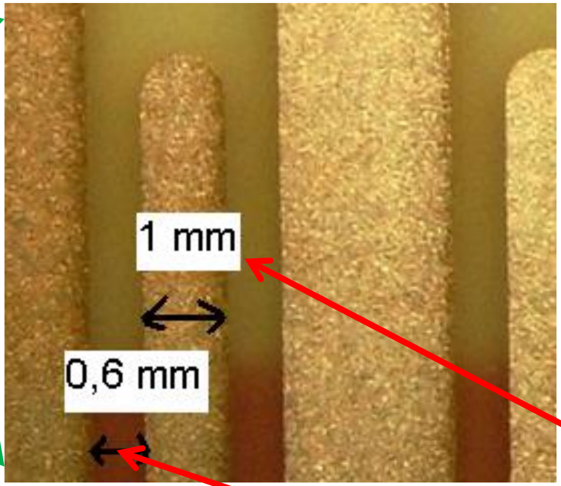
Other implementation possible

Up to a factor 5 in ions reduction wit no gain loss!
To be investigated !!! (simulations are needed)

A small step towards big dimensions

Problem: *large surfaces* to be covered means *high capacity (~1nF for 100 cm^2)* *and accumulated energy :* segmentation is needed .
Test of the minimum space separation requirements
to avoid in case of trip/discharge the involvement of the very next segmented area





10 different distances between strips have been tested
0.1 0.2 0.3 0.4 0.6 0.8
0.15 1 1.5 2 mm
for 3 strip thickness
0.1 0.2 1 mm

Strip thickness

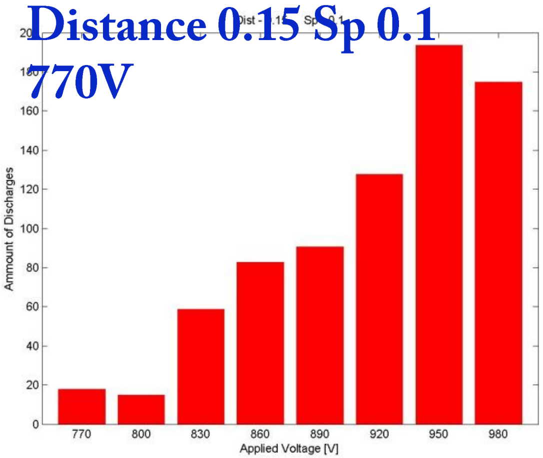
Distance between strips

Nitrogen atmosphere, increasing potential difference applied , discharge counting system implemented

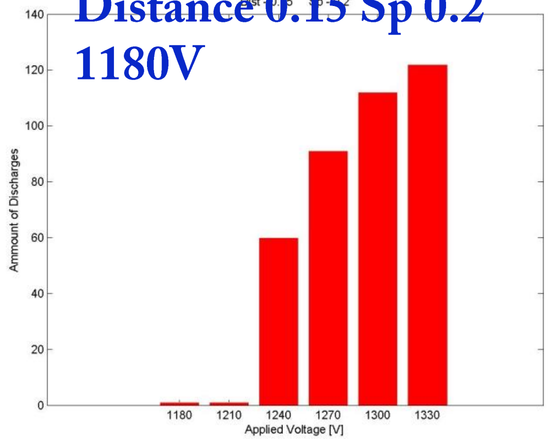
A small step towards big dimensions

INFN

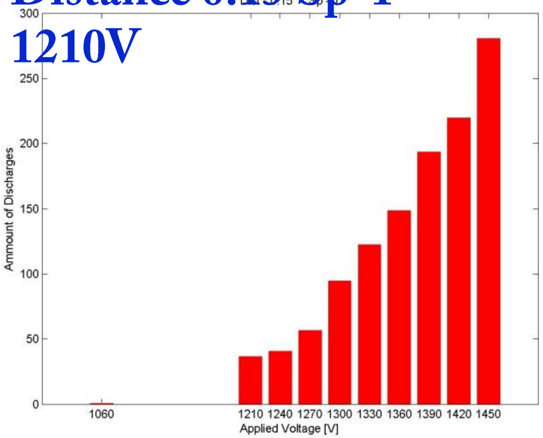
Distance 0.15 Sp 0.1
770V

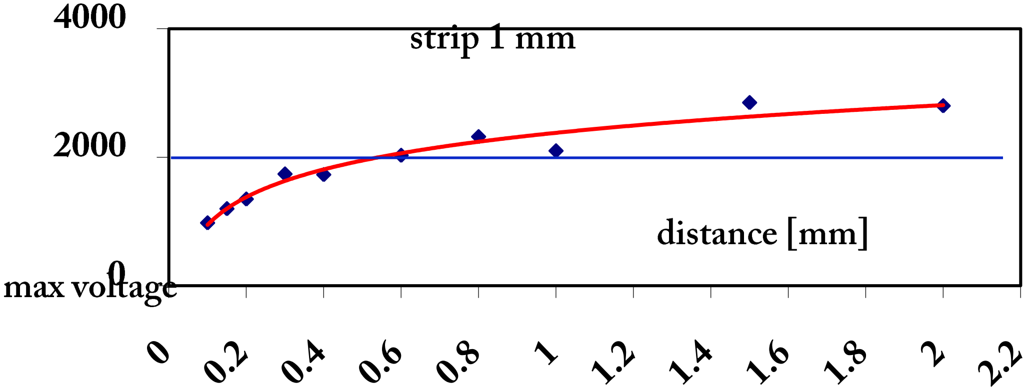


Distance 0.15 Sp 0.2
1180V



Distance 0.15 Sp 1
1210V





Extracted the Maximum ΔV (discharge) for the two parameters:
strip distance and
strip thickness

Can be helpful in large detector parameter modelisation!

CONCLUSIONS

- Characterization of the THGEM has proven to be fundamental in understanding the role of the different parameters and in their choice

Towards THGEM based single photon detector

Achievements

- Cherenkov light has been detected, large stable gain in laboratory (10^6),
- Nice time resolution <10 ns
- Photoelectron extraction understood

Open points

- IBF reduction: first encouraging tests using an ad hoc electrode
- Gain reduction in presence of ionizing particles: to be further studied
- Engineering studies for large size started

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THANK YOU