A case study on a Single Photon Detector System based on MPGD

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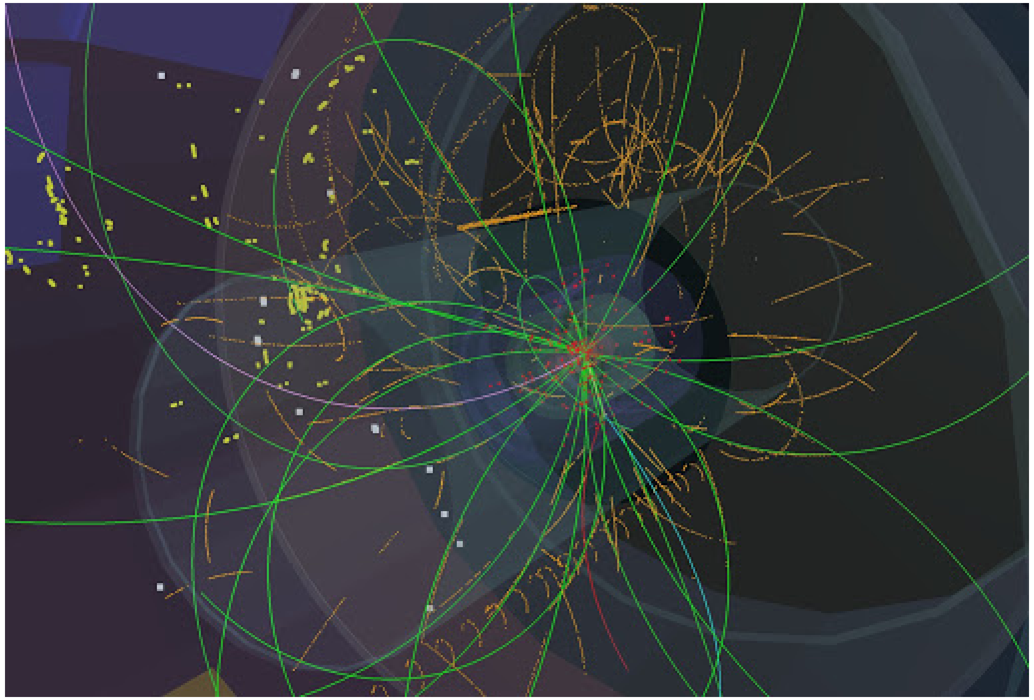
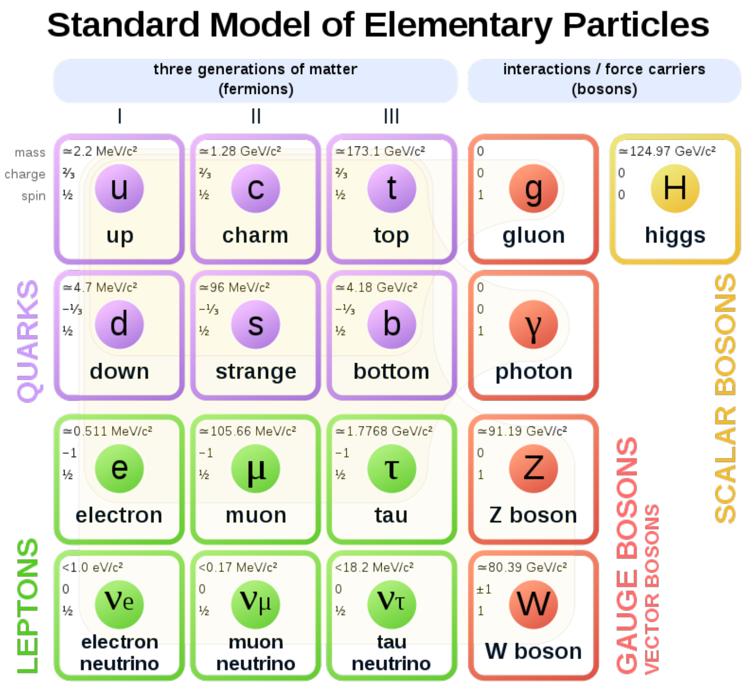
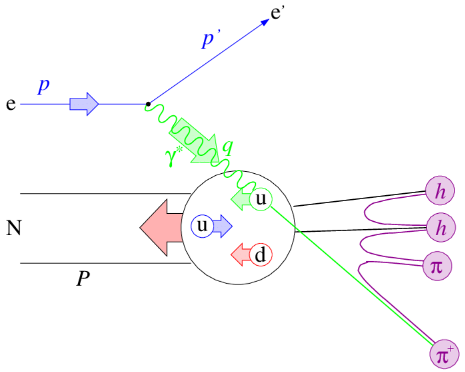
- Introduction
- The need of Particle Identification (PID) in physics
  - Methods of particle identification
- The Cherenkov phenomenon
  - An introduction to its characteristics
- Detecting single photons via gaseous based detector
  - From MWPC to MPGD single photon detectors
- The COMPASS MPGD single photon counter
  - The R&D
  - Its realization, installation
  - A look to the future

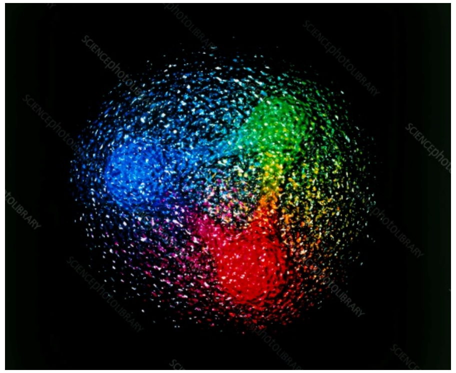
Particle Identification (PID) is a crucial aspect of most High Energy Physics (HEP) experiments

In a typical experiment beams collide within the detectors or a single beam collides with a fixed target. Physicists wish to reconstruct as fully as possible the resulting events, in which many particles emerge from the interaction point









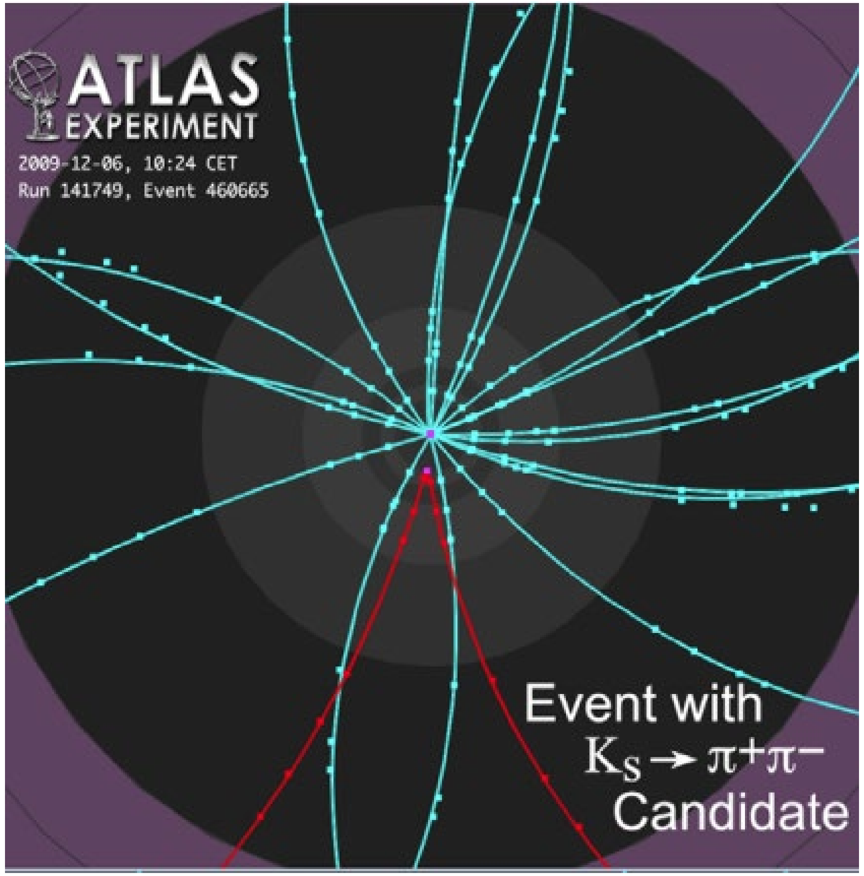
→ an important task for all detectors in particle physics

Introduction: Particle Identification, motivation

To identify long-lived (but still weakly decaying) neutral particles like the hyperons Λ_0 and Ξ_0, short-lived particles (τ, charm, beauty, resonances) the determination of the 4-vector (energy and momentum) of all decay products is necessary to be able to calculate the invariant mass of the final state and identify the original particle.

PID reduces to identify all (nearly) stable particles: p, n, $K^{\pm}$, K_L^0, $\pi^{\pm}$, $e^{\pm}$, $\mu^{\pm}$, γ

Particle	*m* [MeV]	Quarks	Main decay	Lifetime	*c*τ [cm]
π	140	$u\bar{d}$	$\mu\nu_\mu$	2.6×10^{-8} s	780
K	494	$u\bar{s}$	$\mu\nu_\mu$, $\pi\pi^0$	1.2×10^{-8} s	370
K_S^0	498	$d\bar{s}$	ππ	0.9×10^{-10} s	2.7
K_L^0	498	$d\bar{s}$	πππ, π*l*ν	5×10^{-8} s	1550
p	938	uud	stable	> 10^{25} years	∞
n	940	udd	$pe\nu_e$	890 s	2.7×10^{13}
Λ	1116	uds	pπ	2.6×10^{-10} s	7.9



Example of $K_S^0 \rightarrow \pi^- + \pi^+$
Not a “stable particle” but it decays in nearly stable ones

Particle identification techniques are based on the interaction of particles with the matter. The applicable methods depend on the range of momenta of the particle to identify

- Based on the specific features of particle interactions, examples
  - High energy muons, penetration
  - Intermediate energy muons, range
  - e.m. particles vs hadrons: calorimetry (shower development)

- Measurement of the particle mass m
  combining the measurement of p (deflection in magnetic field) and the measurement of E
  - $E^2 = (mc^2)^2 + (pc)^2$ (4 vector)

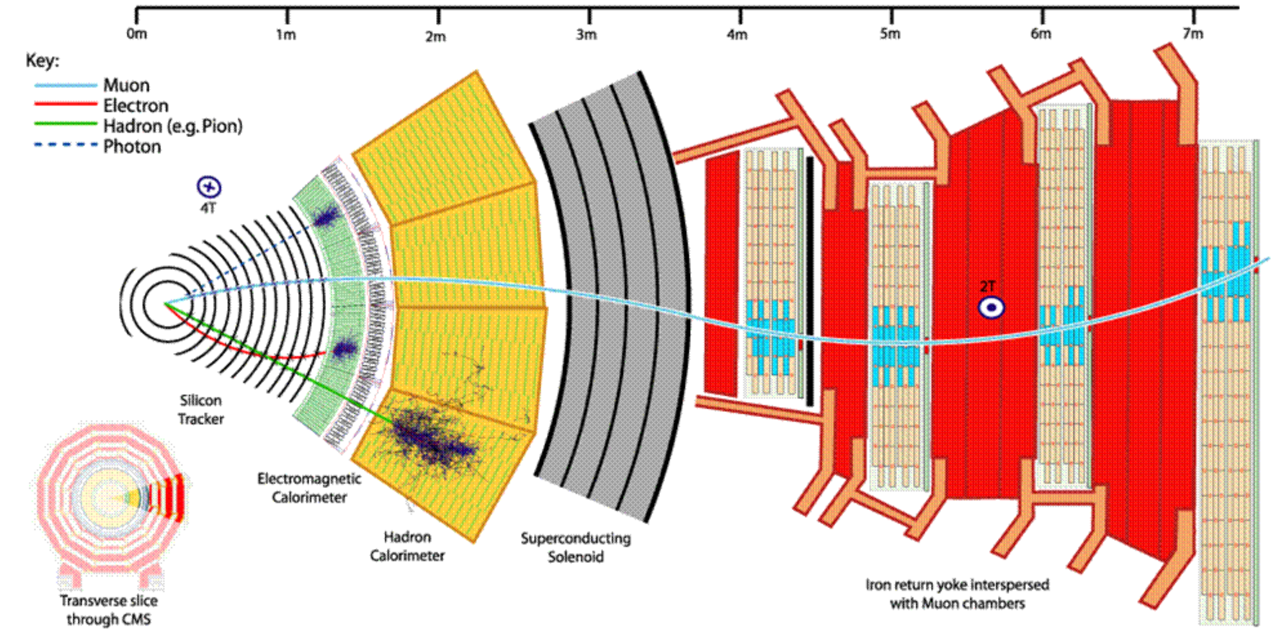
- Time of flight techniques
  - Measurements of the time between taken by a particle to travel between two different detectors at distance L

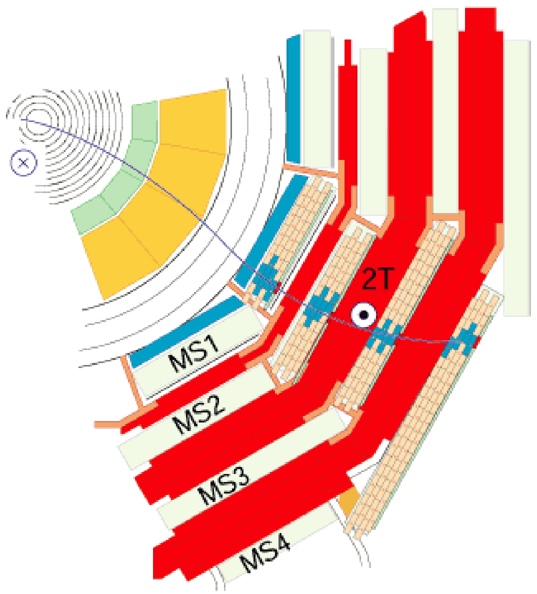
Muons act like heavier versions of the electron, with mass 105.7 MeV
They decay to electrons $\mu^- \rightarrow e^-$ (anti)ν_e ν_μ with (proper) lifetime τ_μ= 2.2 μs

Distance they travel (on average) before decay: d= $\beta\gamma c\tau_\mu$
where velocity β= v/c boost γ= E/m= $1/\sqrt{(1-\beta^2)}$

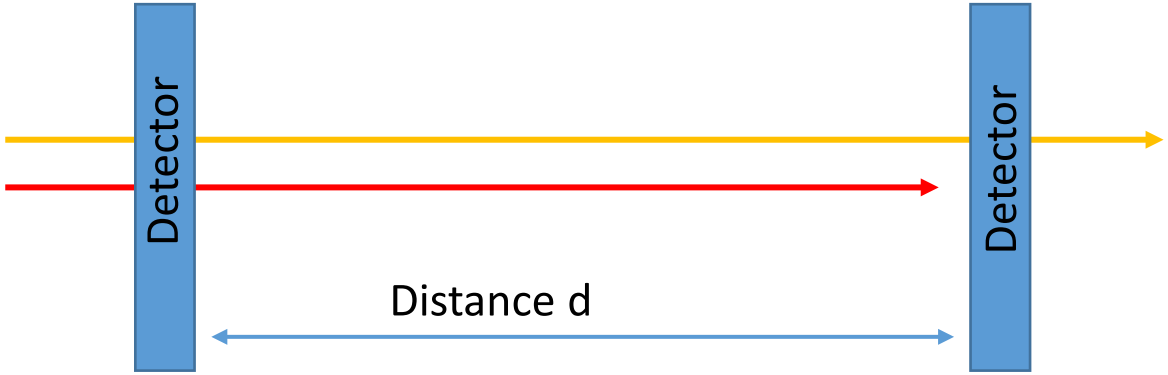
So a 10 GeV muon flies ~ 60 km before decay >> detector size → effectively stable

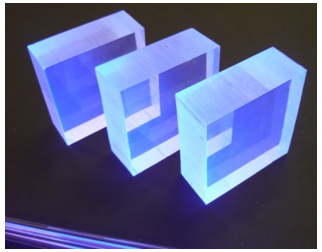
Since mass is large, Bremsstrahlung radiation is small, and as a lepton it does not feel the strong interaction

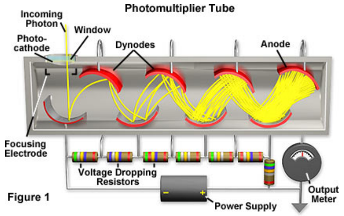


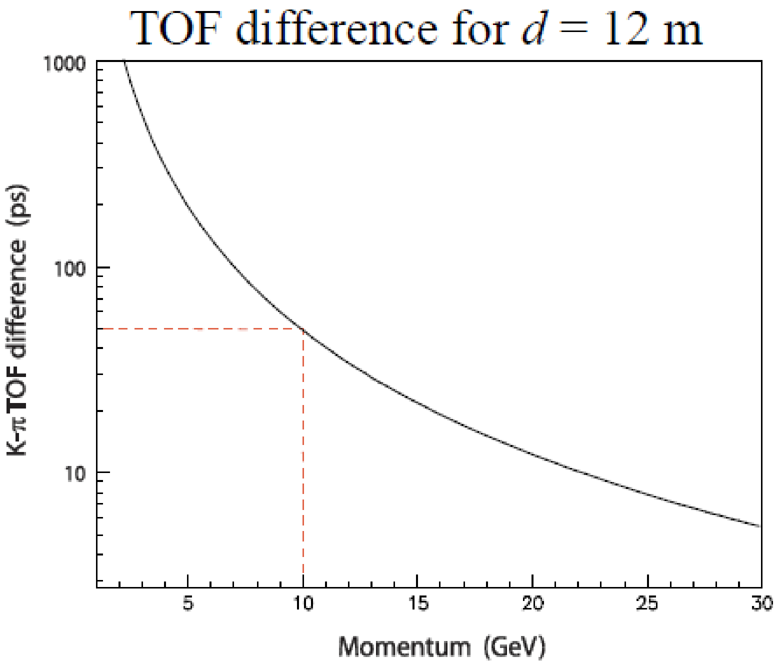


Simple concept: measure the time difference between two detector planes β= d/cΔt



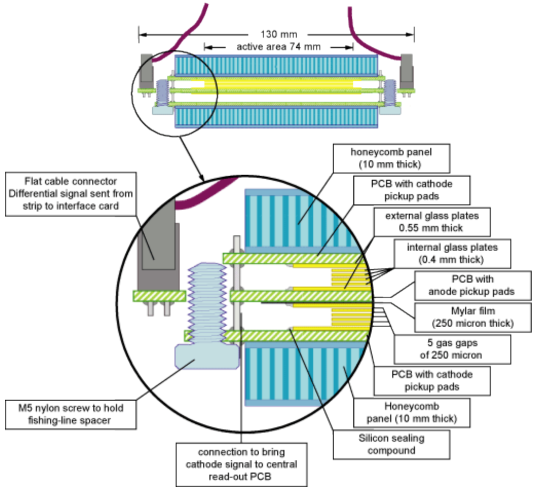


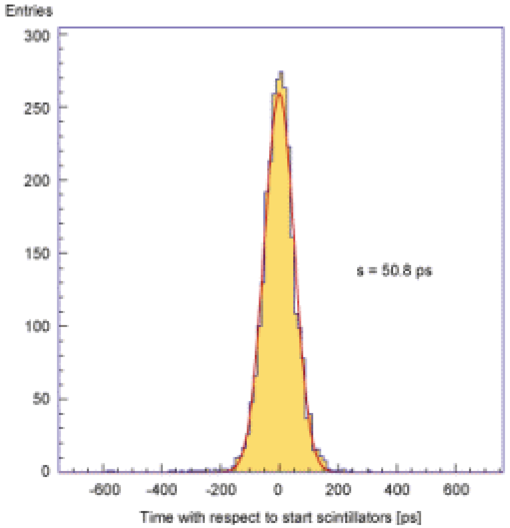




At high energy, particle speeds are relativistic, closely approaching to c
For a 10 GeV K, the time to travel 12 m is 40.05 ns, whereas for a π it would be 40.00 ns, so the difference is only 50 ps

Modern detectors + readout electronics have resolution σ_t~ 1 ns, but need σ_t< 1 ns to do useful TOF
TOF gives good ID at low momentum, very precise timing is required for p> 5 GeV





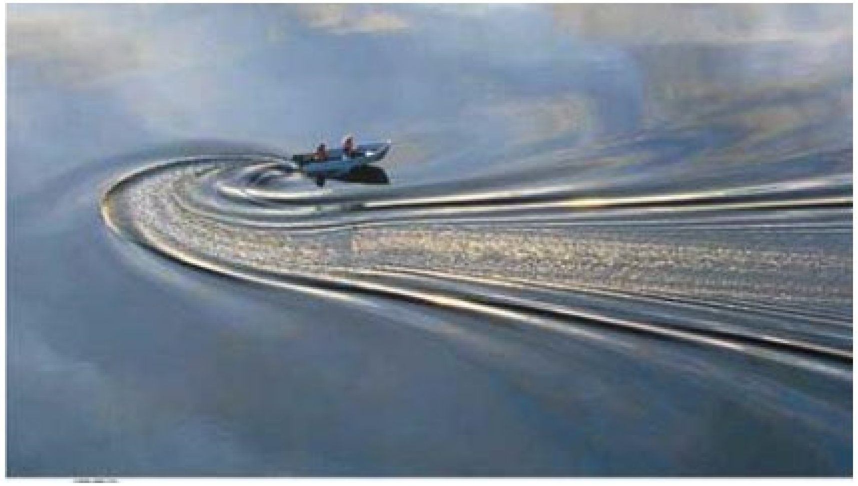
Can not rely on this method at large momenta
Any other method exploiting the measurement of β

Named after the Russian scientist P. Cherenkov who was the first to study the effect in depth (he won the Nobel Prize for it in 1958)

From Relativity, nothing can go faster than the speed of light c (in vacuum)

However, due to the refractive index n of a material, a particle can go faster than the local speed of light in the medium $c_p = c/n$ (For example, the speed of the propagation of light in water is only 0.75c)

This is analogous to the bow wave of a boat travelling over water or the sonic boom of an airplane travelling faster than the speed of sound



Measurement of the speed of the particle an alternative method via the Cherenkov light, propagating waves

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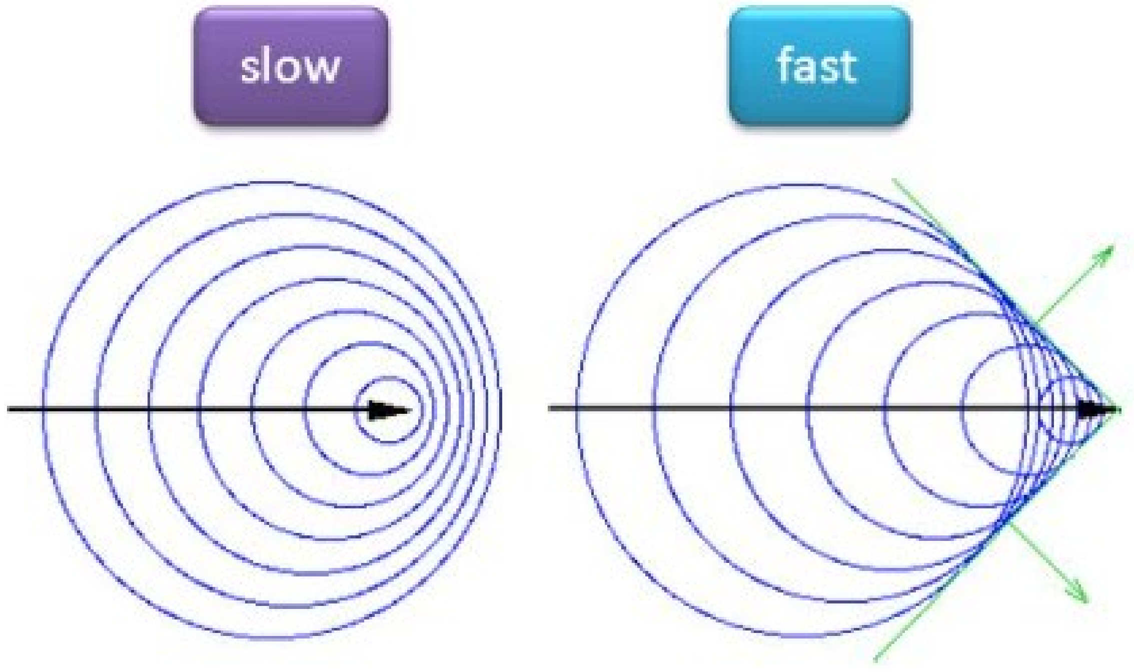
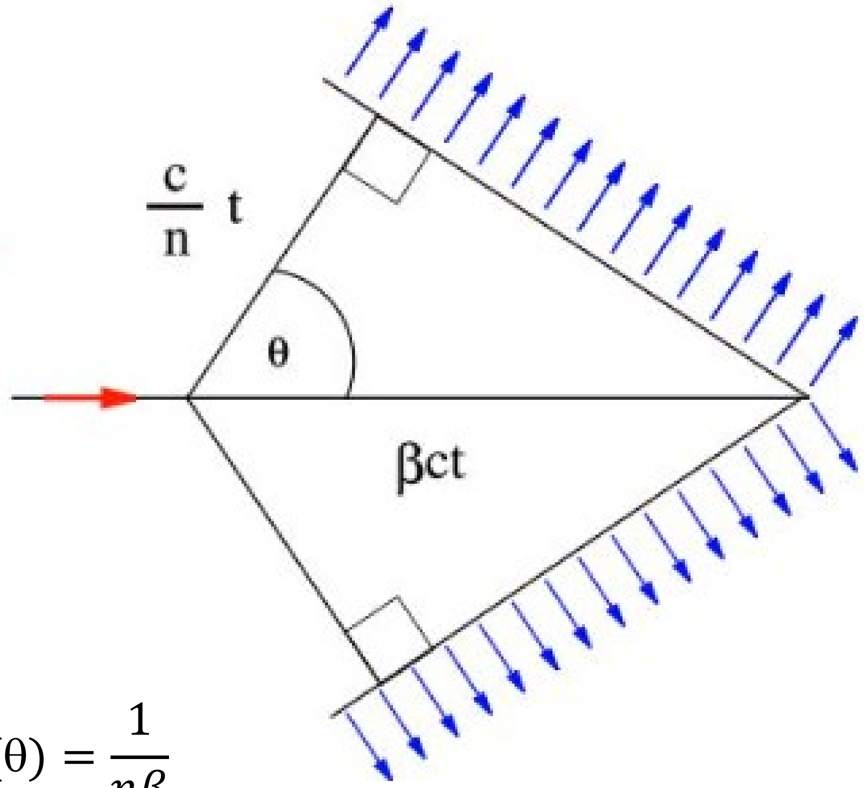
Propagating waves





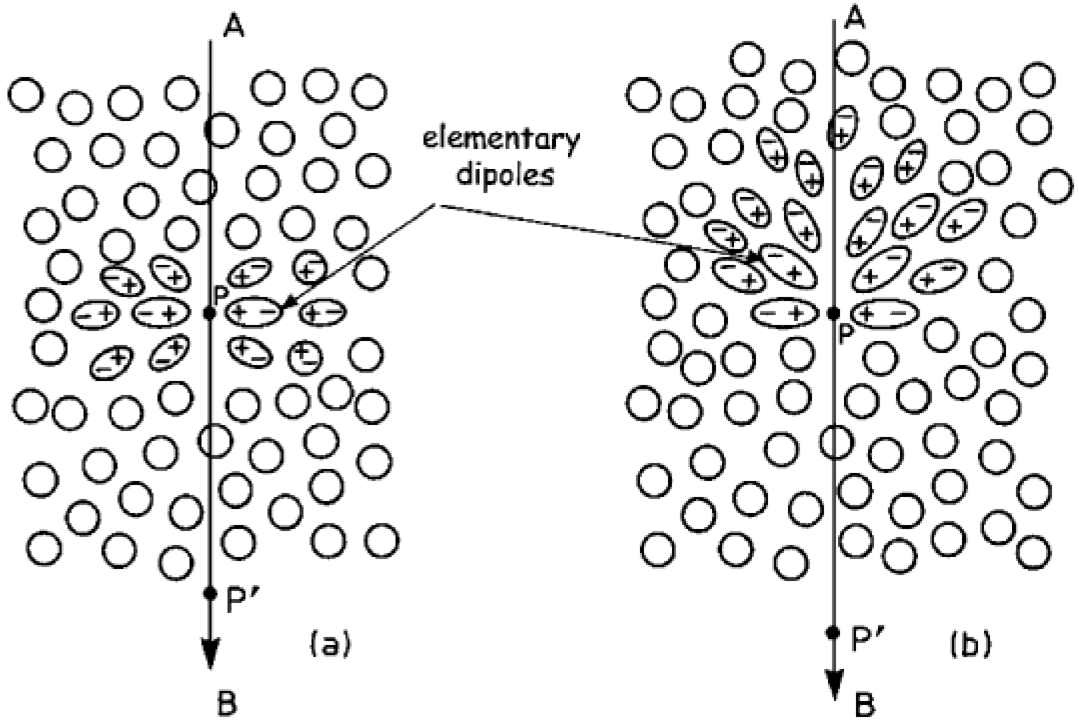
$$\cos(\theta) = \frac{1}{n\beta}$$

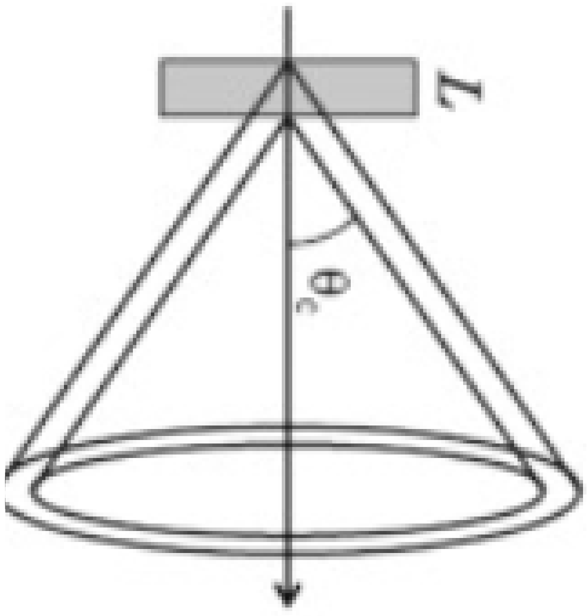
Where blue arrows are photons and $\beta = \frac{v}{c}$

$$v_{th} \geq \frac{c}{n} \Rightarrow \beta_{th} \geq \frac{1}{n}$$

Threshold effect!

phase velocity of the light in the medium : c/n





β_{part}·c < phase velocity of the light in the medium symmetric configuration

→Destructive interference

β_{part}·c > phase velocity of the light in the medium

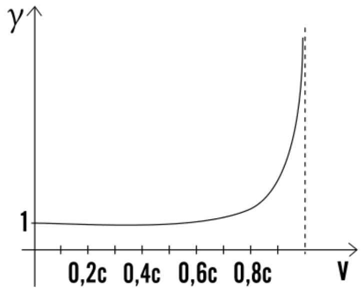
No longer a Symmetric configuration →a coherent interference front is created

Light is emitted symmetrically around the direction of the particle → cone of light

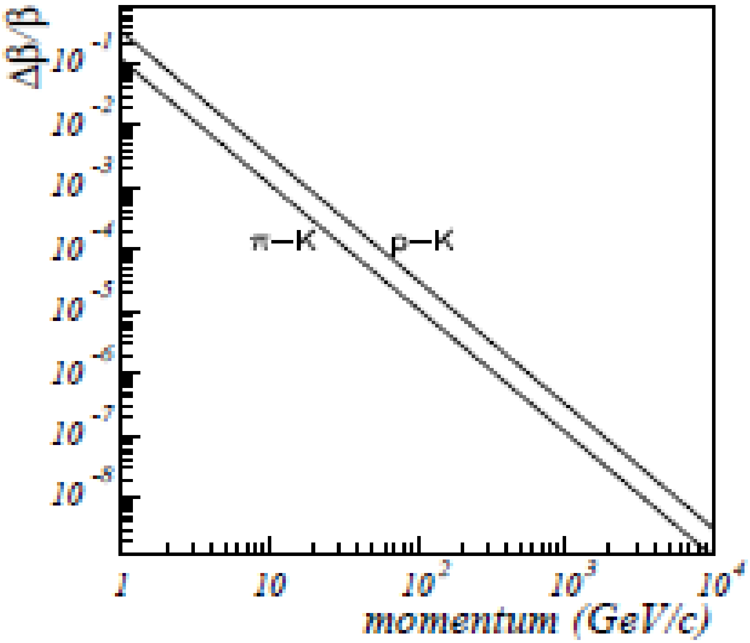
Assuming p is measured with fine resolution, the resolution on m $\frac{\Delta m}{m}$ becomes a specific request concerning the resolution of the β measurement: $p = m_0\gamma\beta c$

Resolution: $$\left(\frac{dm}{m}\right)^2 = \left(\gamma^2\frac{d\beta}{\beta}\right)^2 + \left(\frac{dp}{p}\right)^2$$

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$



$$\frac{\Delta\beta}{\beta} \simeq \frac{m_1^2 - m_2^2}{2p^2}.$$

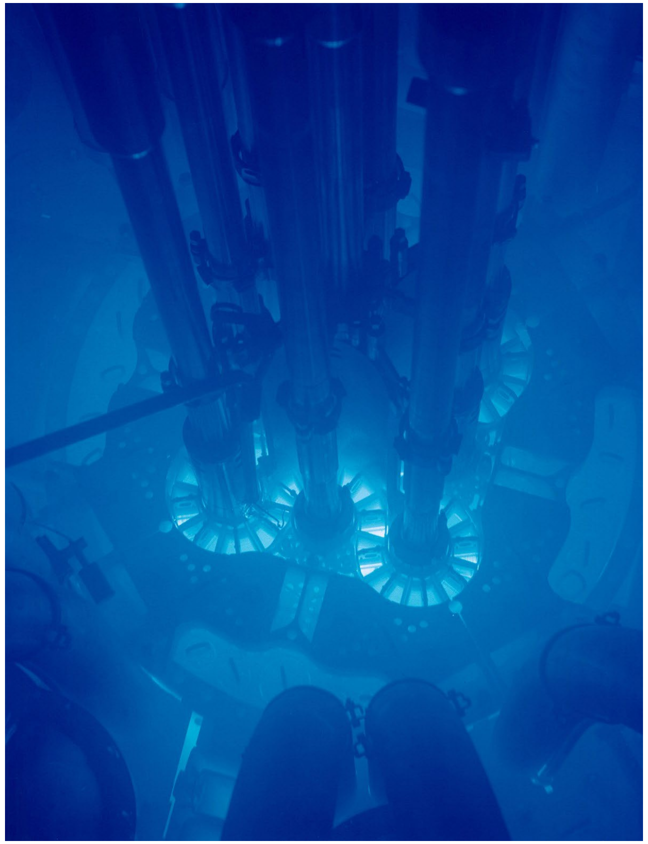


The Frank–Tamm formula yields the amount of Cherenkov radiation emitted on a given frequency as a charged particle moves through a medium at superluminal velocity. It is named for Russian physicists Ilya Frank and Igor Tamm who developed the theory of the Cherenkov effect in 1937, for which they were awarded a Nobel Prize in Physics in 1958.

The energy dE emitted per unit length travelled by the particle per unit of frequency $d\omega$ is:

$$\frac{d^2 E}{dx\, d\omega} = \frac{q^2}{4\pi}\mu(\omega)\omega\left(1 - \frac{c^2}{v^2 n^2(\omega)}\right)$$

Permeability of medium



Cherenkov radiation does not have characteristic spectral peak. The relative intensity of one frequency is approximately proportional to the frequency. That is, higher frequencies (shorter wavelengths) are more intense in Cherenkov radiation → Vacuum ultraviolet domain

Fixing the radiator length L:

$$\frac{dW}{d\omega} = \frac{LZ^2e^2\omega}{c^2}\left(1 - \frac{1}{\beta^2 n^2(\omega)}\right)$$

Integrating the spectrum:

$$\frac{\Delta N}{\Delta E} = \left(\frac{\alpha}{\hbar c}\right) Z^2 L \sin^2\theta = \left(\frac{\alpha}{\hbar c}\right) Z^2 L\left[1 - \left(1 - \frac{n}{\beta}\right)^2\right],$$

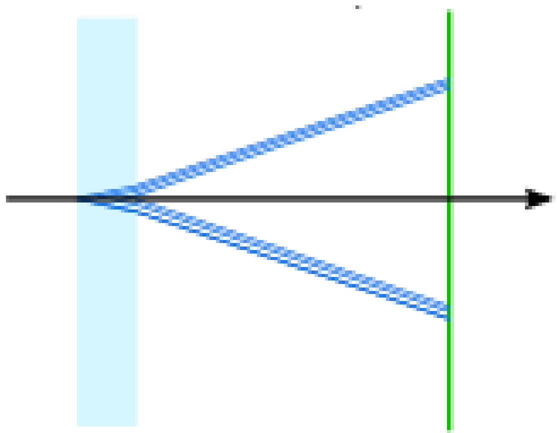
When β = 1, L = 1 and ΔE = 1 :

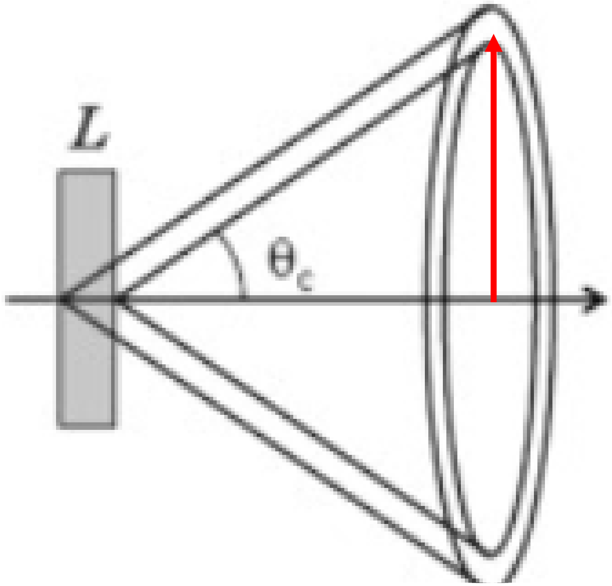
$$N(cm^{-1}eV^{-1}) = 370Z^2\left(1 - \frac{1}{n^2}\right)$$

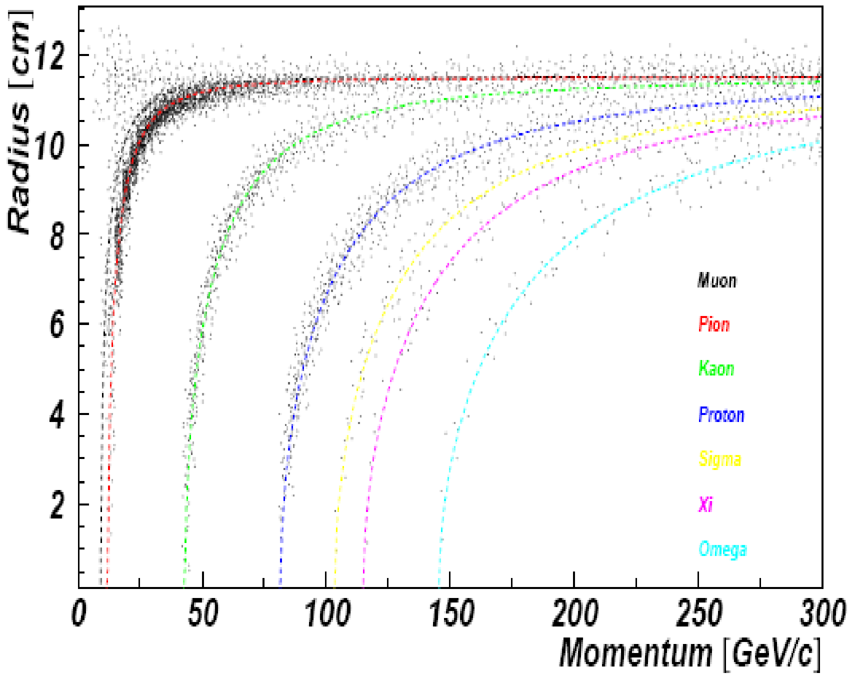
$$N_0 = \frac{1}{137\hbar c}\int_{E_1}^{E_2} \varepsilon_{\mathrm{D}}(E)\varepsilon_{\mathrm{R}}(E)\varepsilon_{\mathrm{T}}(E)\mathrm{d}E.$$

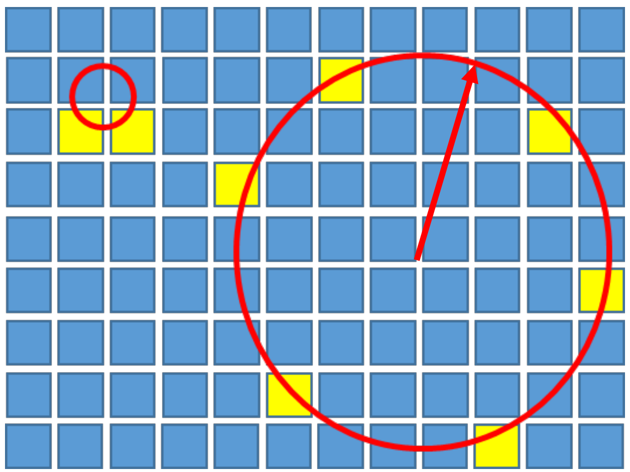
$N \approx 1 - 1/(\beta n)^2 = \sin^2\theta_C$

N is a mean value: poisson statistics → v from a direct measurement of θ_C , not from N !!!, Apart when $Z^2 \neq 1$









$$\theta_{\mathrm{MAX}} = \cos^{-1}\frac{1}{n}.$$

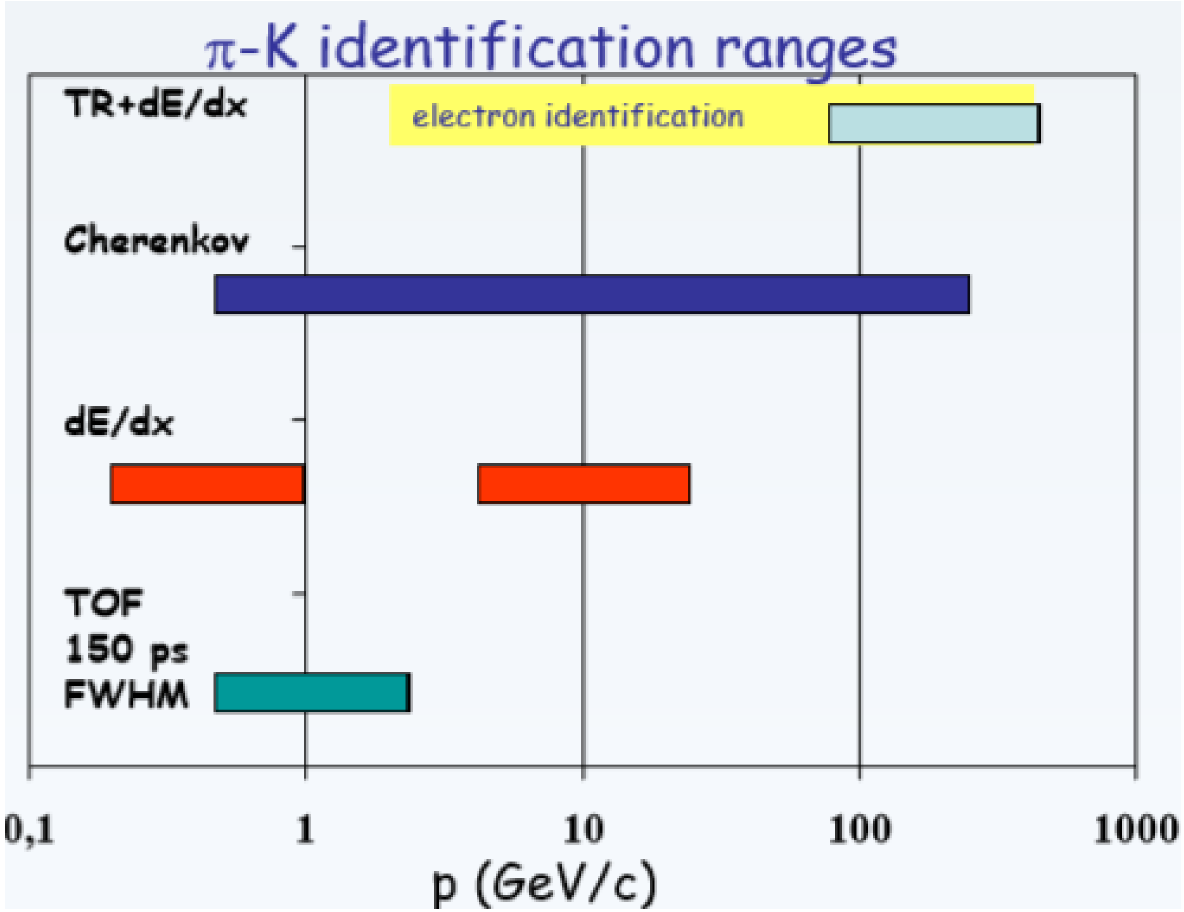
Measure the radius

$$\cos(\theta) = \frac{1}{n\beta}$$

$$\sigma_{\theta_{Cherenkov}} = \frac{\sigma_{\theta_{photon}}}{\sqrt{N}}$$

The refractive index defines the threshold at which the particle can be identified, the angle at saturation, the maximum radius and the resolution needed

Particle identification techniques are based on the interaction of particles with the matter. The applicable methods depend on the range of momenta of the particle to identify



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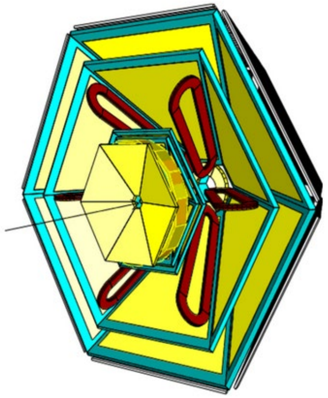
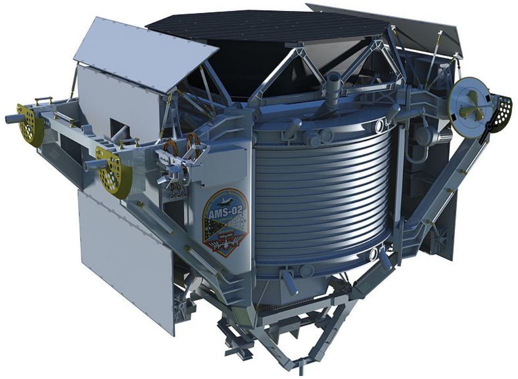
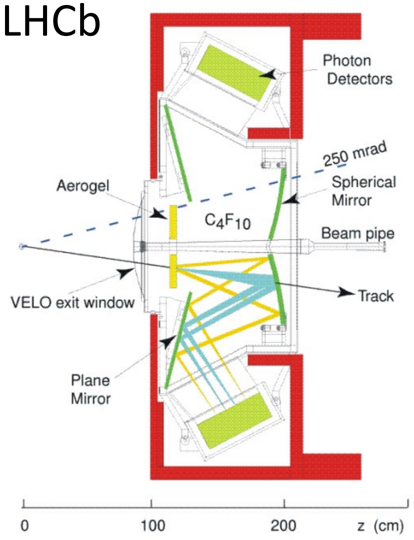


HADES at GSI,

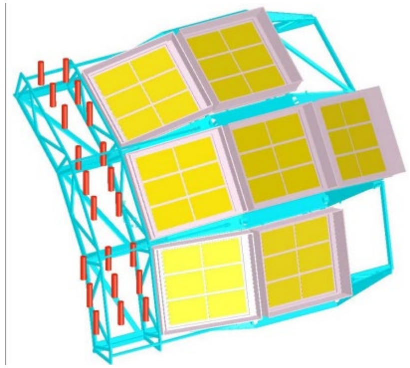


AMS RICH

LHCb

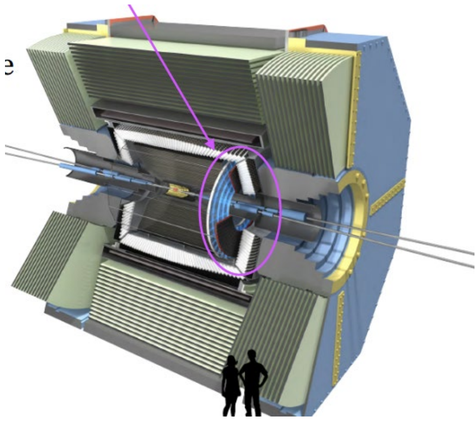


ALICE HMPID

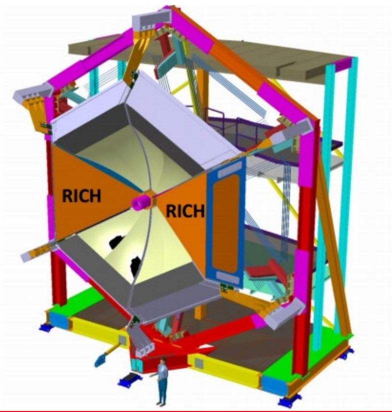


Cherenkov imaging techniques (RICH counters)

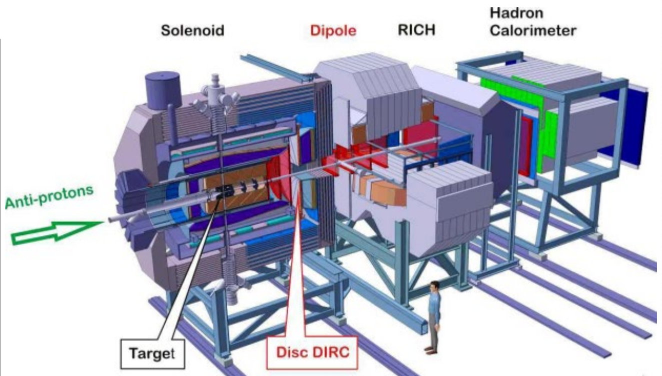
BELLE 2 KEK



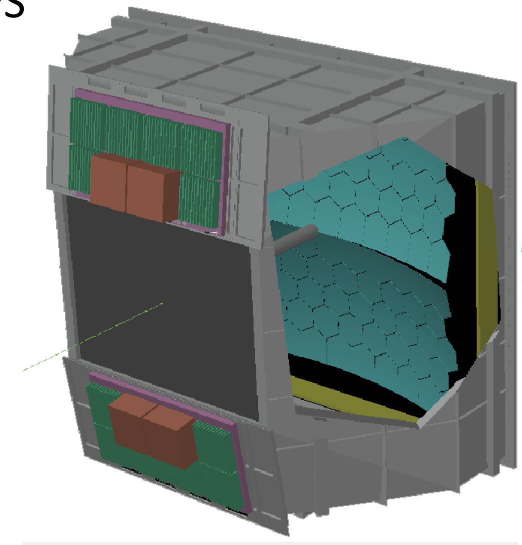
CLAS-12 JLAB



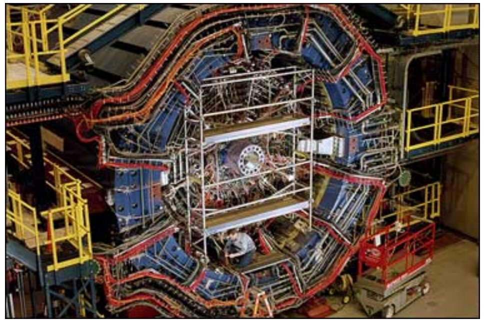
DIRC at PANDA GSI



COMPASS at SPS



STAR-RICH at RHIC



Their performance is
largely based on that of the **single photon detectors employed**.

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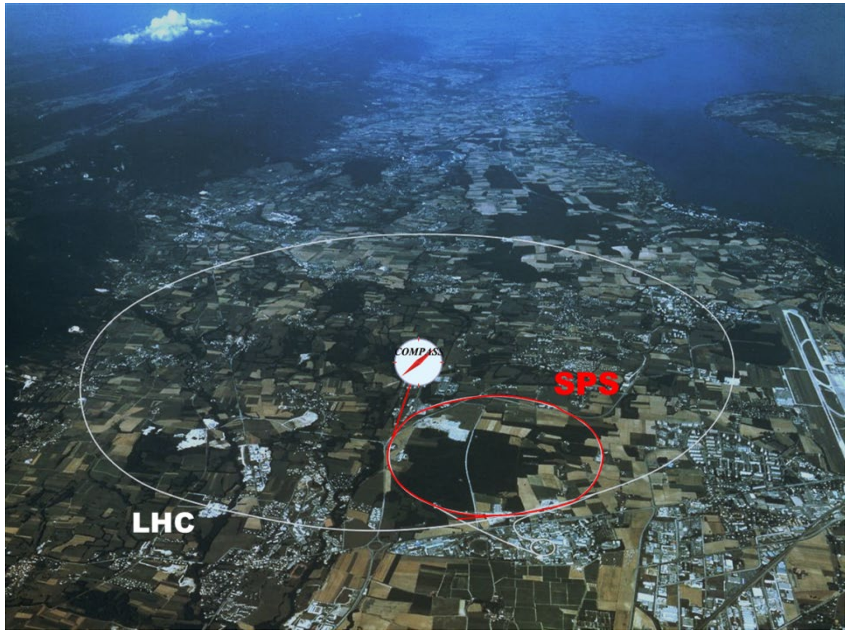


Дубна (LPP and LNP), Москва (INR, LPI, State University), Протвино

Warsawa (NCBJ), Warsawa (TU) Warsawa (U)

Praha (CU/CTU)
Liberec (TU)
Brno (ISI-ASCR)

Calcutta (Matriviani)

Taipei (AS)

CERN

Yamagata

Lisboa/Aveiro

Tel Aviv

Bochum, Bonn (ISKP & PI), Erlangen, Freiburg, Mainz, München TU

USA (UIUC)

Saclay

Torino (University, INFN), Trieste (University, INFN)

Experiments with muon beam:

Experiments with hadron beams:

COMPASS - I (2002 – 2011)

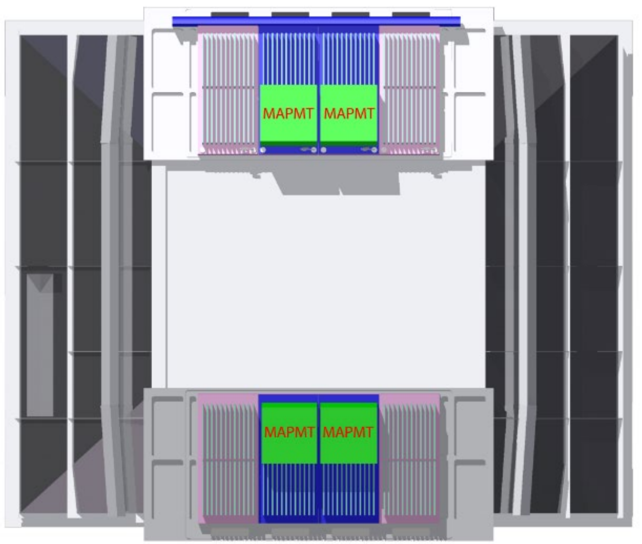
Experiments with muon beam	Experiments with hadron beams
Spin structure, Gluon polarization	Pion polarizability
Flavor decomposition	Diffractive and Central production
Transversity	Light meson spectroscopy
Transverse Momentum-dependent PDF	Baryon spectroscopy

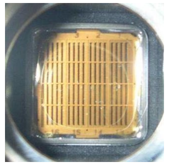
COMPASS - II (2012 – 2021) …

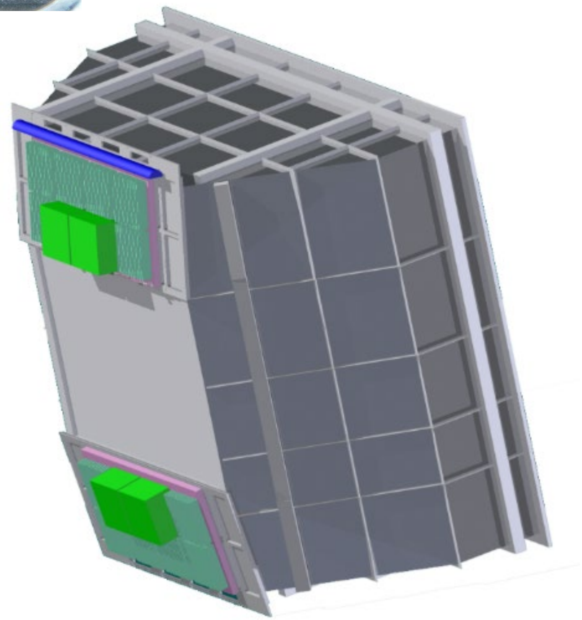
Experiments with muon beam	Experiments with hadron beams
DVCS and HEMP	Pion and Kaon polarizabilities
Unpolarized SIDIS and TMDs	Drell-Yan studies

hadron spectroscopy (p, π, K)
- light mesons, glue-balls, exotic mesons
- polarisability of pion and kaon

nucleon structure (μ)
- longitudinal spin structure
- transverse momentum and transverse spin structure







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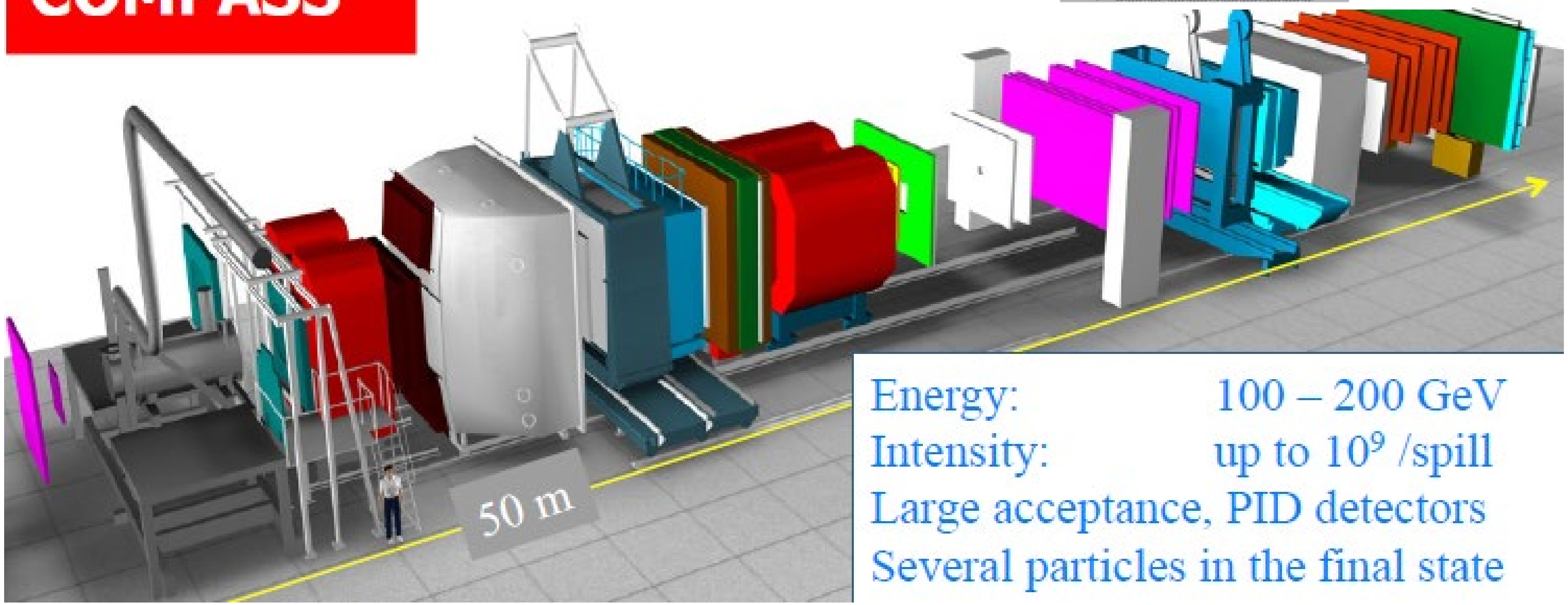
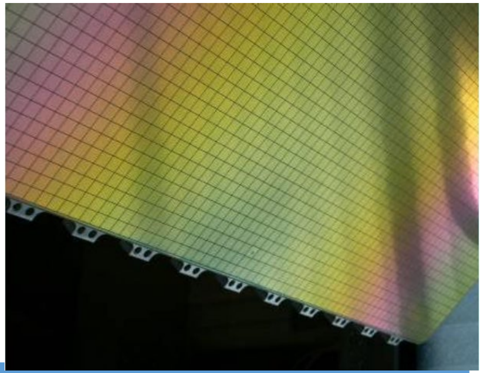
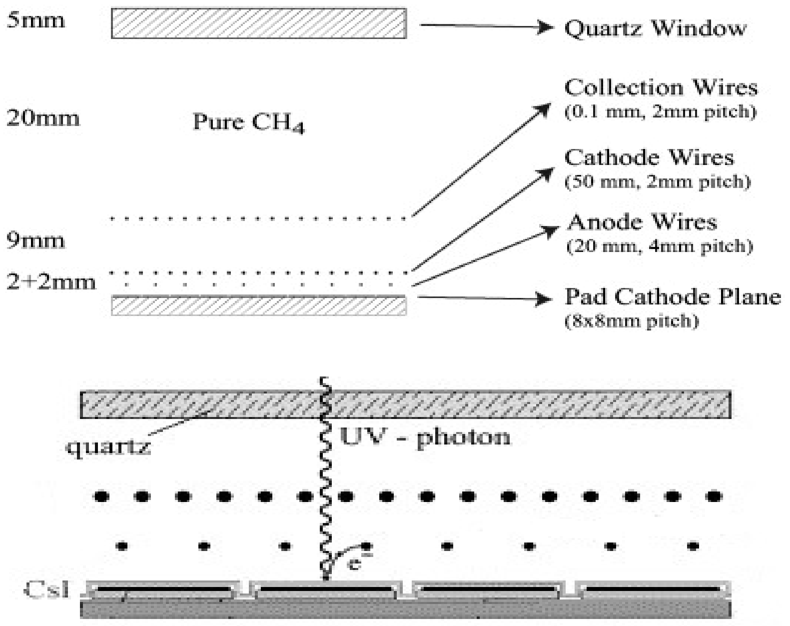


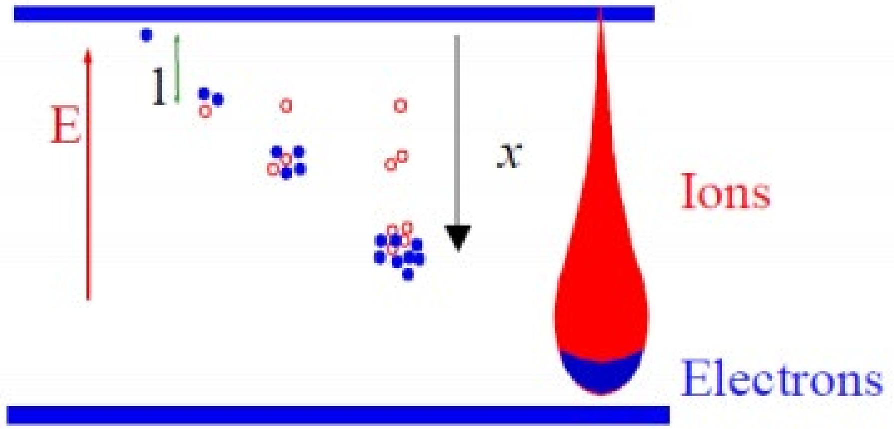
Energy: 100 – 200 GeV
Intensity: up to 10^9 /spill
Large acceptance, PID detectors
Several particles in the final state

~80k electronic channels to read



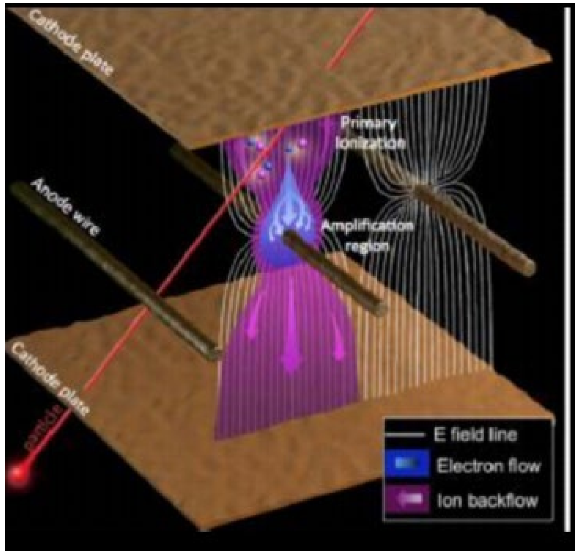
Photon detection via MWPC coupled o CSI





Reduced wire-cathode gap because of :

- Fast RICH (fast ion collection)
- Reduced MIP signal
- Reduced cluster size
- Control photon feedback spread



drift velocity of electrons in this region, it appears that the whole process of multiplication will take place in less than 1 nsec: at that instant, electrons have been collected on the anode and the positive ion sheath will drift towards the cathode at decreasing velocity. The detected signal, negative on the anode and positive on the cathode, is the consequence of the change in energy of the system due to the movement of charges. Simple electrostatic considerations show that if a charge Q is moved by dr, in a system of total capacitance ℓC (ℓ is the length of the counter), the induced signal is

$$dv = \frac{Q}{\ell C V_0} \frac{dV}{dr} dr \quad . \qquad (33)$$

Electrons in the avalanche are produced very close to the anode (half of them in the last mean free path); therefore their contribution to the total signal will be very small: positive ions, instead, drift across the counter and generate most of the signal. Assuming that all charges are produced at a distance λ from the wire, the electron and ion contributions to the signal on the anode will be, respectively,

$$v^- = -\frac{Q}{\ell C V_0} \int_a^{a+\lambda} \frac{dV}{dr} dr = -\frac{Q}{2\pi\varepsilon_0 \ell} \ln \frac{a+\lambda}{a}$$

and

$$v^+ = \frac{Q}{\ell C V_0} \int_{a+\lambda}^{b} \frac{dV}{dr} dr = -\frac{Q}{2\pi\varepsilon_0 \ell} \ln \frac{b}{a+\lambda} \quad .$$

The total maximum signal induced on the anode is seen to be

$$v = v^+ + v^- = -\frac{Q}{2\pi\varepsilon_0 \ell} \ln \frac{b}{a} = -\frac{Q}{\ell C}$$

and the ratio of the two contributions is

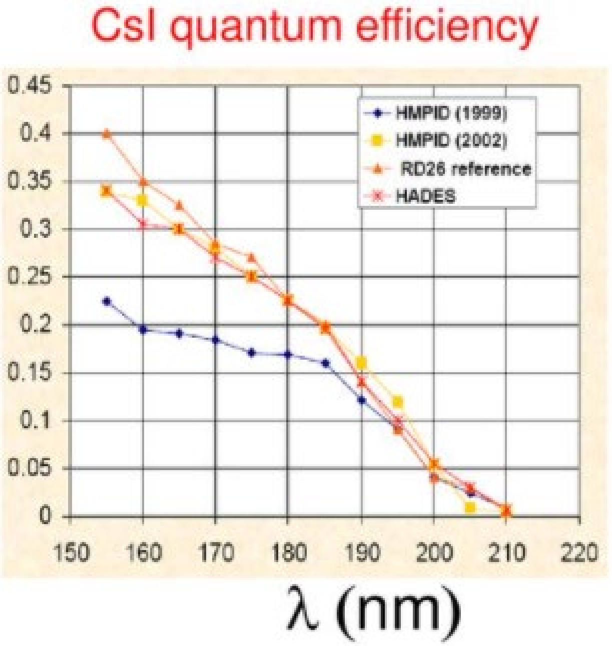
$$\frac{v^-}{v^+} = \frac{\ln(a+\lambda) - \ln a}{\ln b - \ln(a+\lambda)} \quad .$$

Typical values for a counter are a = 10 μm, λ = 1 μm, and b = 10 mm; substituting in the previous expression one finds that the electron contribution to the signal is about 1% of the total. It is therefore, in general, neglected for all practical purposes. The time development of the signal can easily be computed assuming that ions leaving the surface of

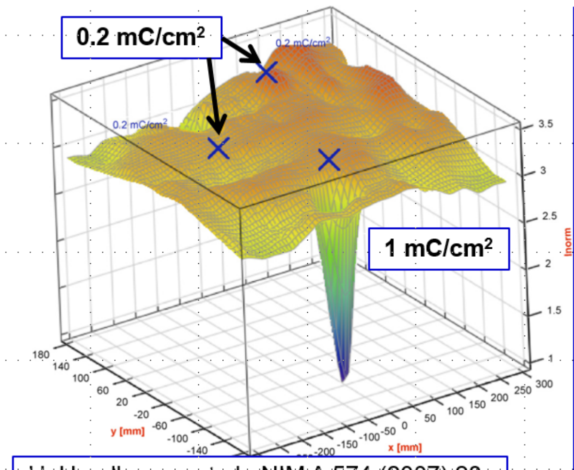
The RD-26 project

Launch of CERN/RD-26 project in 1992, by F. Piuz et al., :

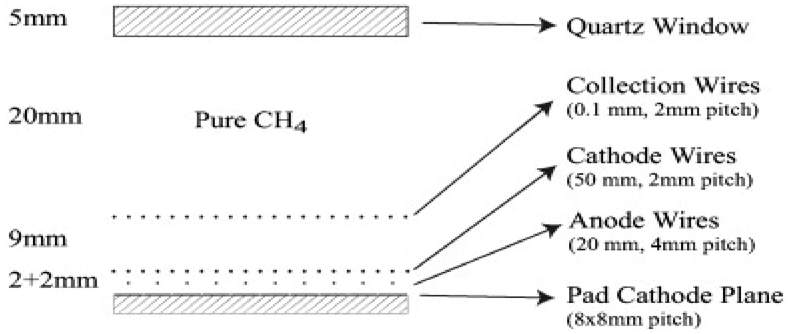
"Development of large area advanced fast-RICH detector for particle identification at the LHC operated with heavy ions"

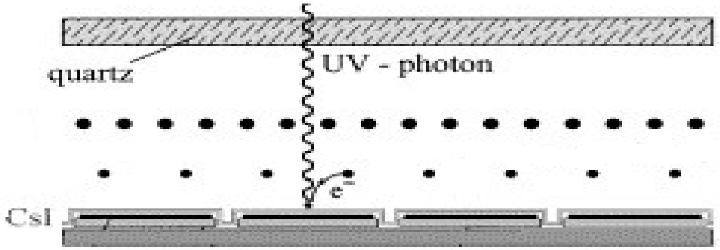


(From L. Molnar – RICH 2007 Trieste)



H. Hoedlmoser et al., NIM A 574 (2007) 28.





Use of the CsI as photon converter:

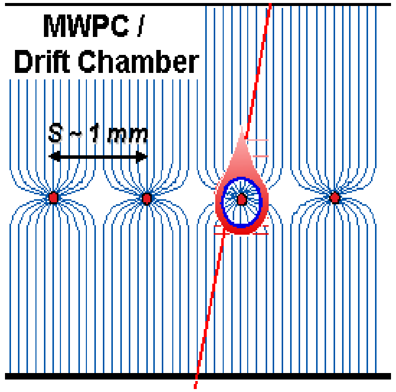
A revolution in the panorama of Cherenkov detectors

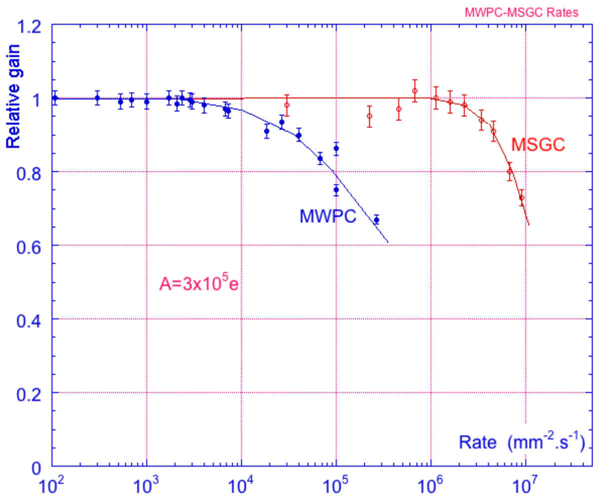
Anyhow this technology suffers from some limitations:

- Long recovery (1 day) time after a discharge occurs
- Ions accumulation at the photocathode: limitation in the maximum gain < 10^5
- Photon and ion feedback from the multiplication avalanche
- «Ageing» few mC / cm^2 reduction in the QE

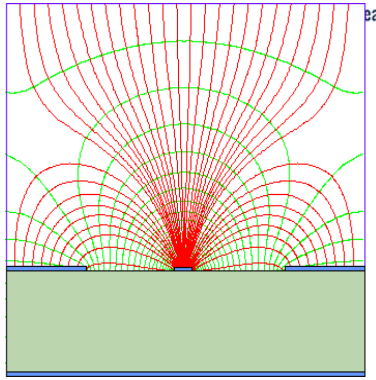
Possible to overcome the limitations of this technology?

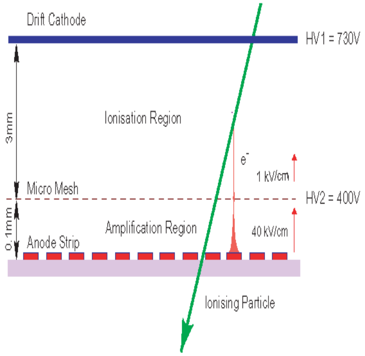
- Able to work and cope with high rate detection
- High gain achievable: gas gain
- Good time/space/E resolution
- Robust: ageing robustness
- Natural Ion Backflow/Photon feedback reduction CG
- Low cost large size detector production possible
- Intrinsically fast: signal is induced by electrons…!

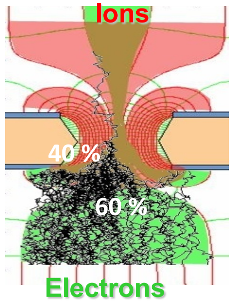


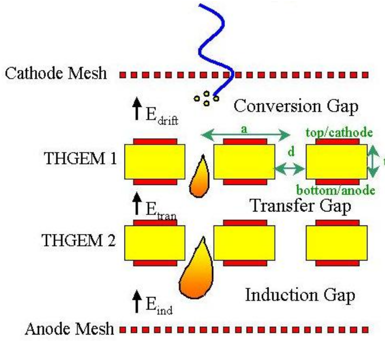


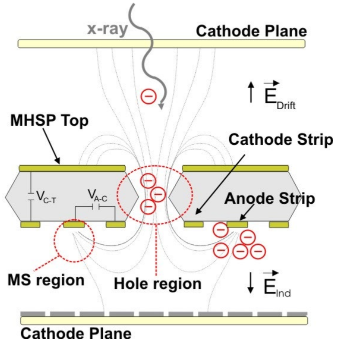
Rate Capability Comparison for MWPC and MSGC

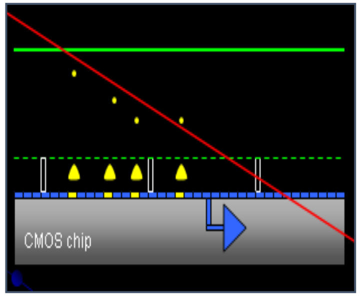


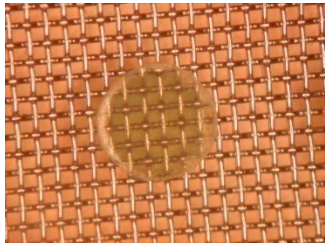


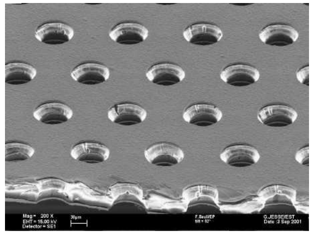


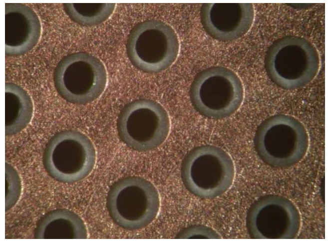


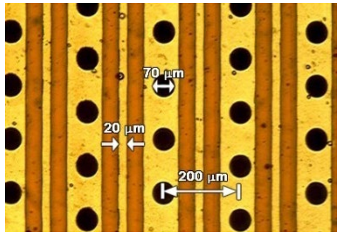


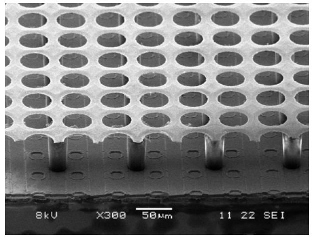


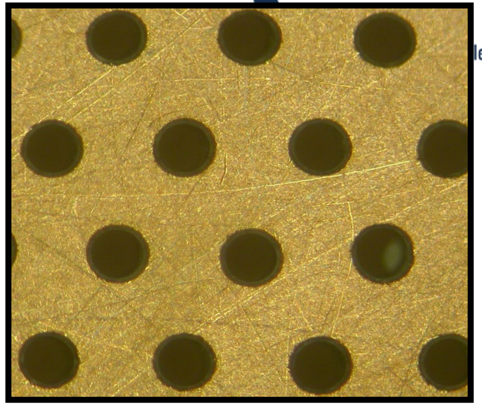






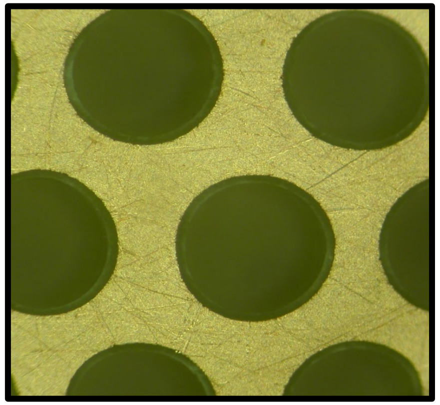


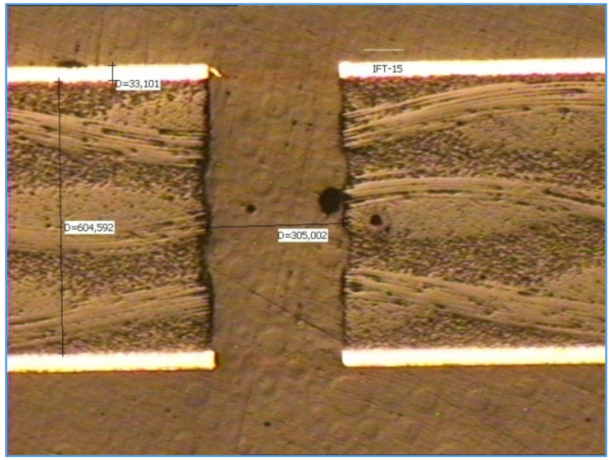




Use of the industrial technology to produce Printed Circuit Boards

- Electrical robustness: no damages induced by discharges
- Mechanical properties: robust and self supporting no stretching is needed
- Possible industrial production of large size @ low cost PCB
- Economic material



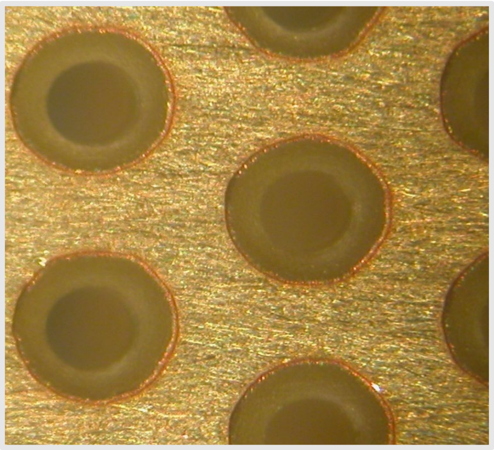


Compared to GEM

- Geometrical dimensions x 10
- *e* motion and multiplication properties do not scale
- Dipolar and external field 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 PCB geometrical dimensions:
Hole diameter : 0.2 – 1 mm
Pitch : 0.5 – 5 mm
Thickness : 0.2 – 3 mm

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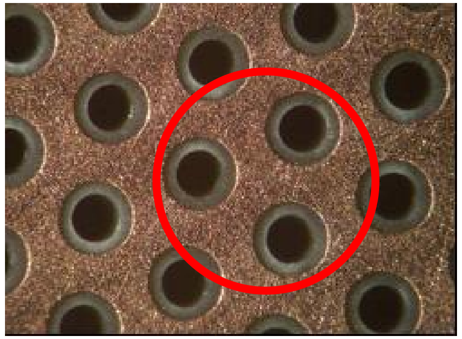
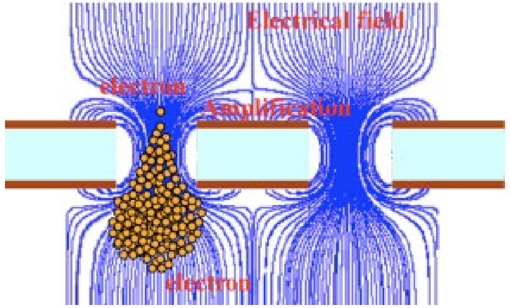
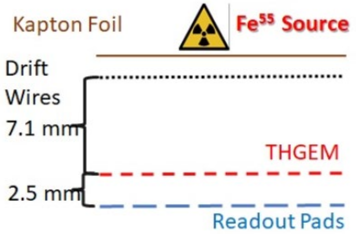
THGEMs are electron multipliers derived from the gem concept changing geometrical dimensions and production technology.

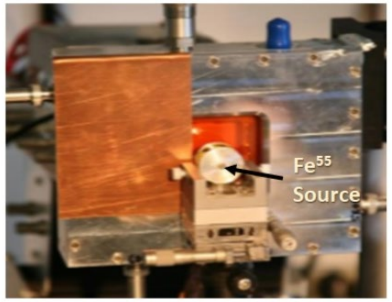
$$\text{Gain} = \frac{\mathit{Charge\ collected}}{\mathit{Initial\ Carge}}$$



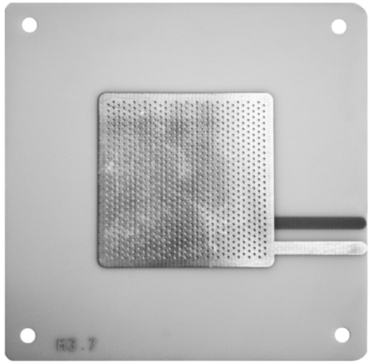




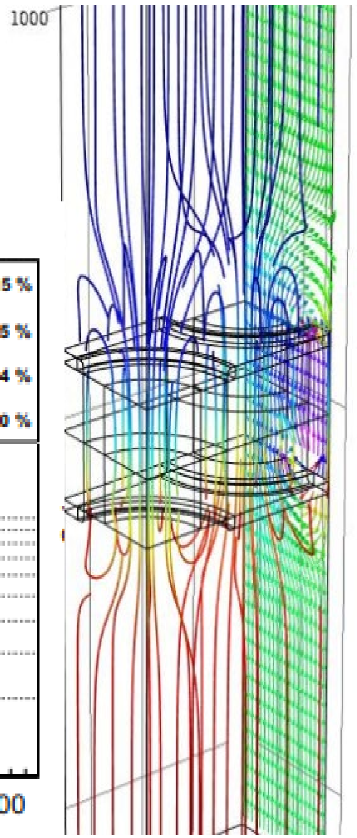
Schematic Diagram of the Chamber



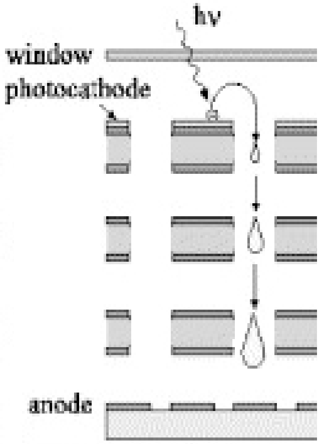
Small size 30x30 mm^2
Built and operated

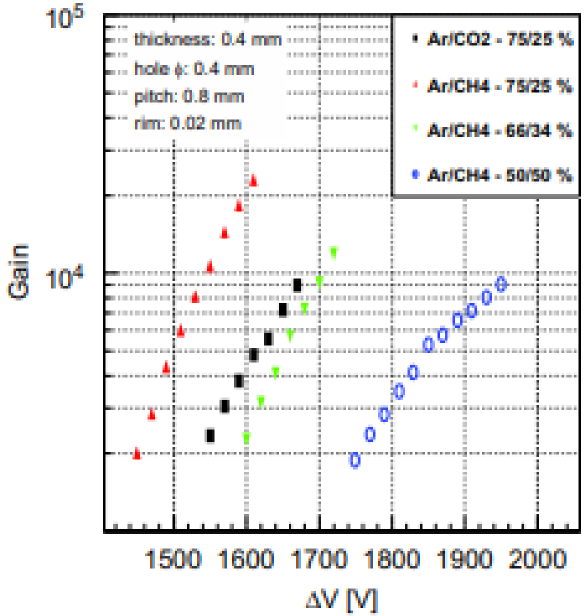


Electrostatic simulations



Characterisation of small 10cm^{2}size THGEM prototypes
- Using X-ray sources
- Using UV light sources
- With Cherenkov light at the test beams
- Analogic read-out, single channel
- Digital read-out, 1 channel per anode pad
- Read-out of the current on the various electrodes

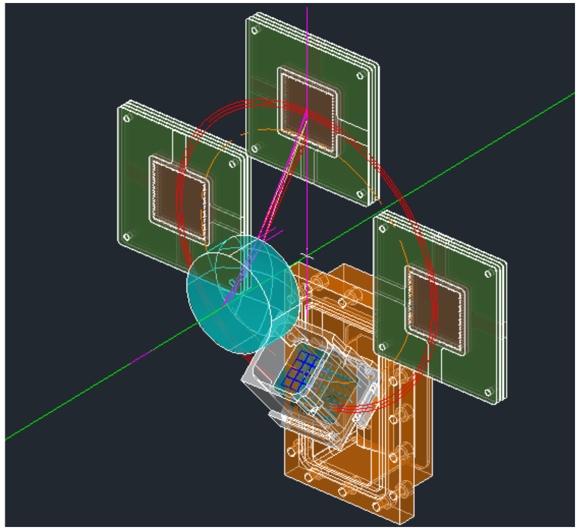


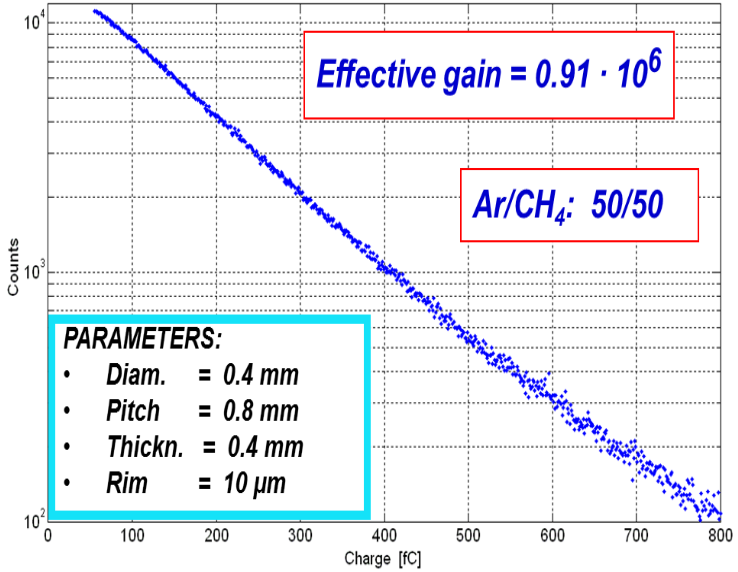


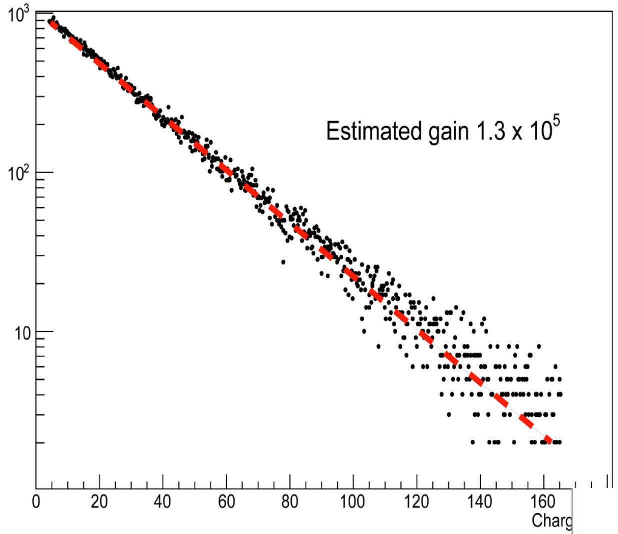
For small prototypes Ar/CH4 60-40%

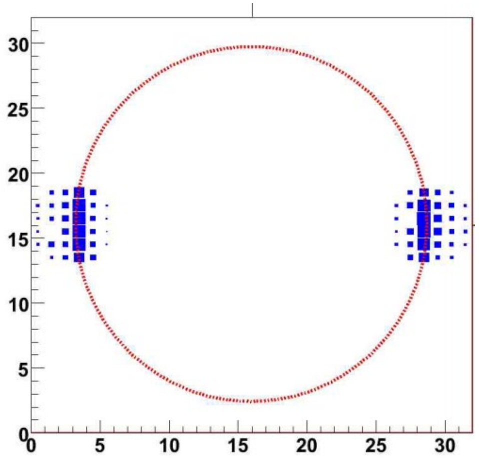
Gain achieved in laboratory with triple THGEM structures (stable condition) and UV light 0.9 10^6

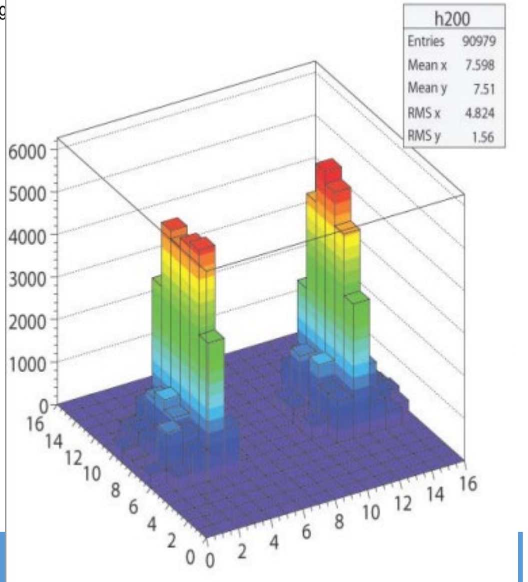
Gain achieved in test beams with triple THGEM structures (stable condition) and Cherenkov light from quartz radiator 1 10^5

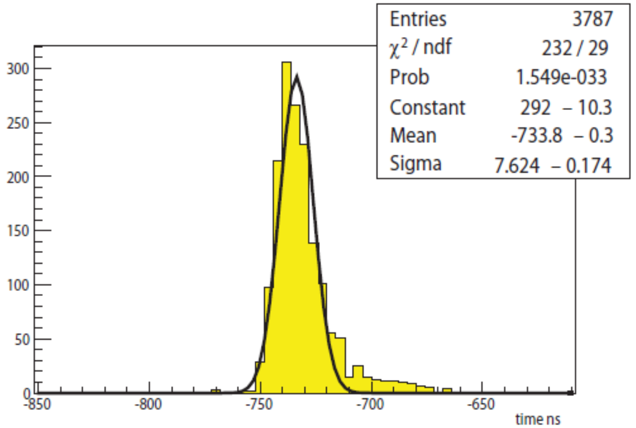












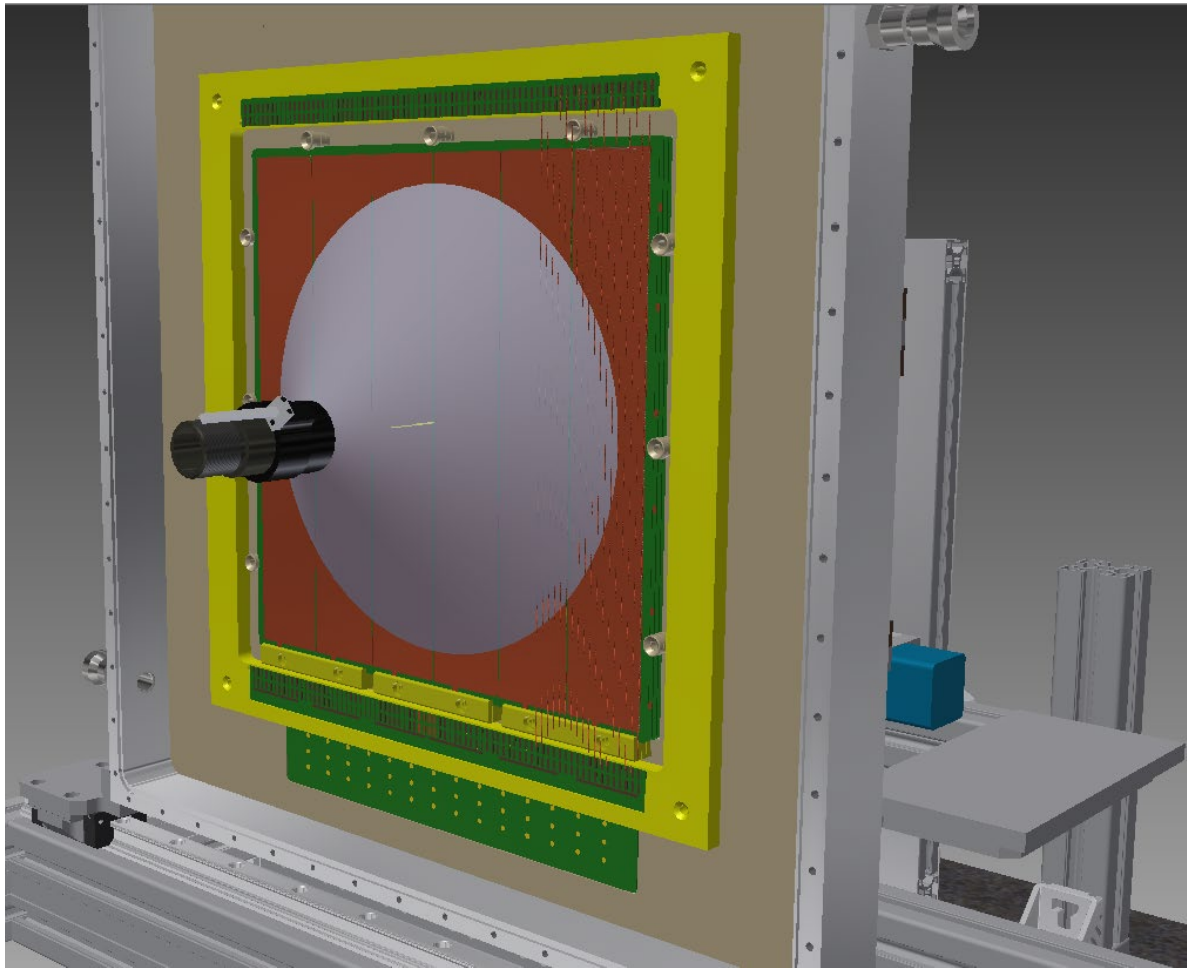
Small size PD's (active area = 30x30 mm2):

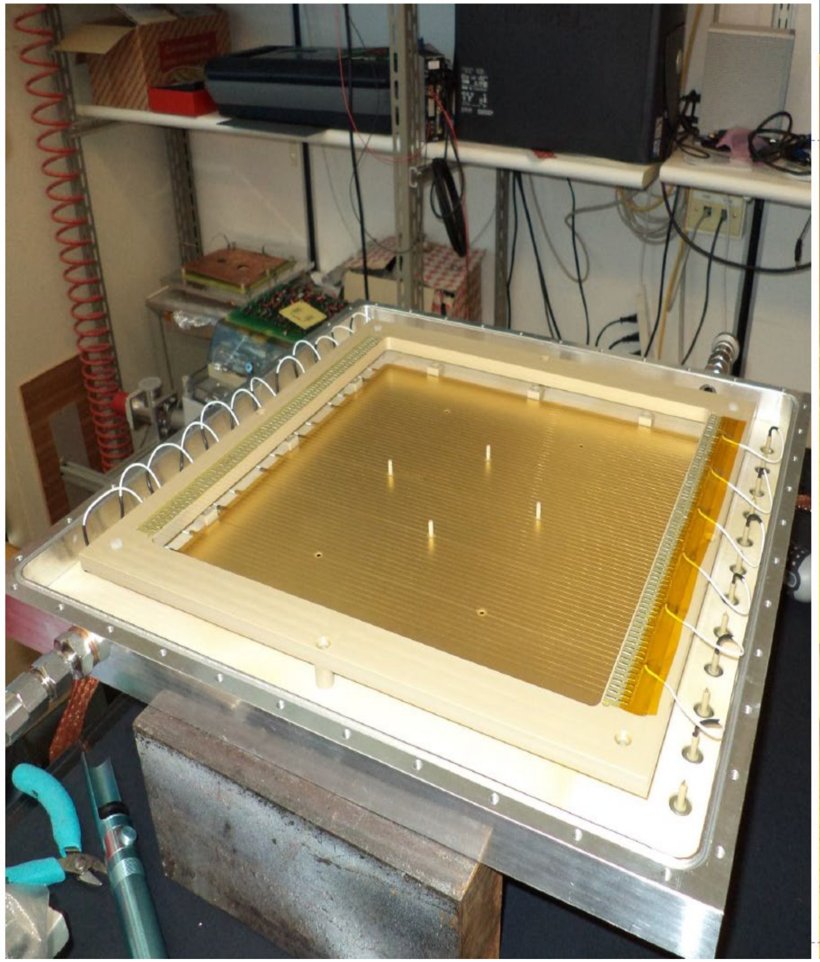
typical max. stable gain: with UV light in lab: 1 M
during test beam: 0.2 M

efficient detection of single photons

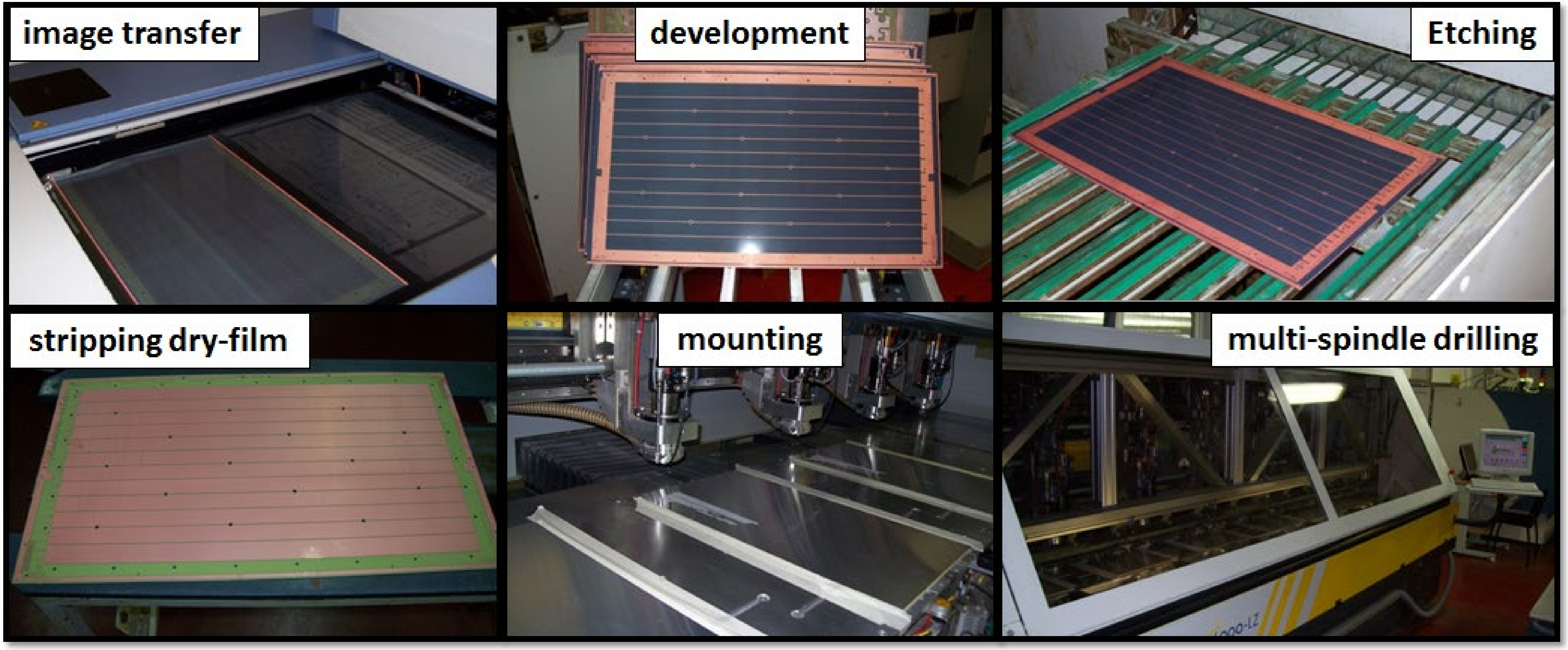
signal formation time ≈ 100 ns, time resolution ≈ 8 ns

The THGEM, Thick Gas Electro Multiplier as photon detector, enlarging the surface





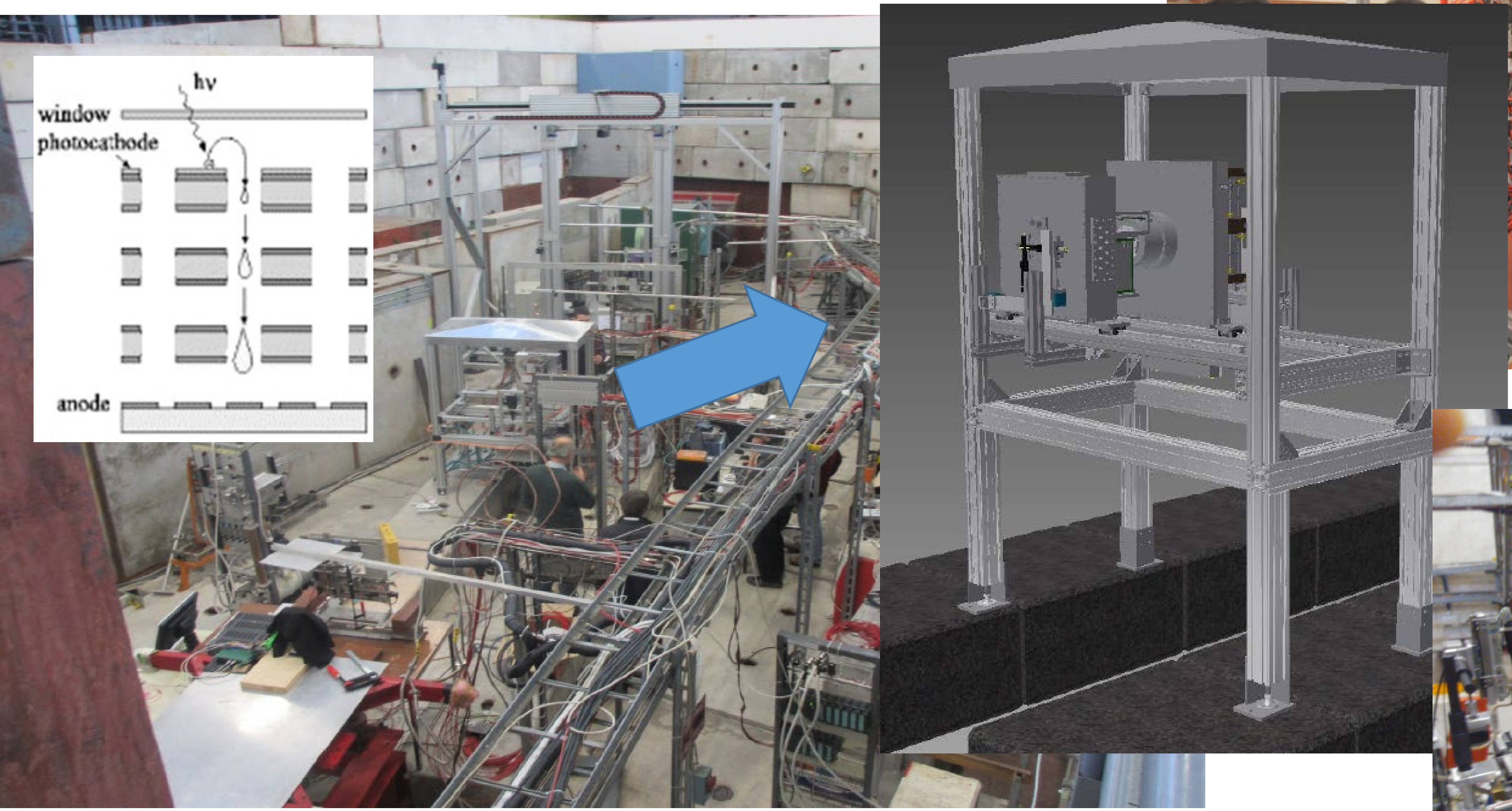
The THGEM, Thick Gas Electro Multiplier as photon detector, large THGEM production

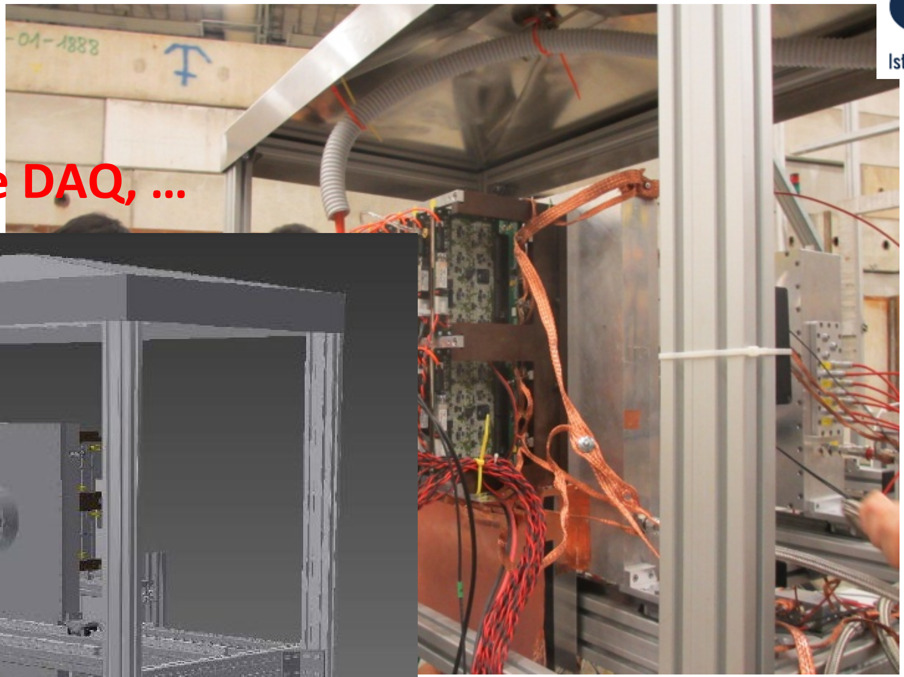


PS T10 beam line 5/11/2012 – 25/11/2012

<u>Triple THGEM 300x300</u> (576 pads); 2 Triple 30x30, 1 MAPMT

trigger system, Č radiators, Analog & Digital r/o, COMPASS-like DAQ, …





The THGEM, Thick Gas Electro Multiplier as photon detector, large size triple THGEM results

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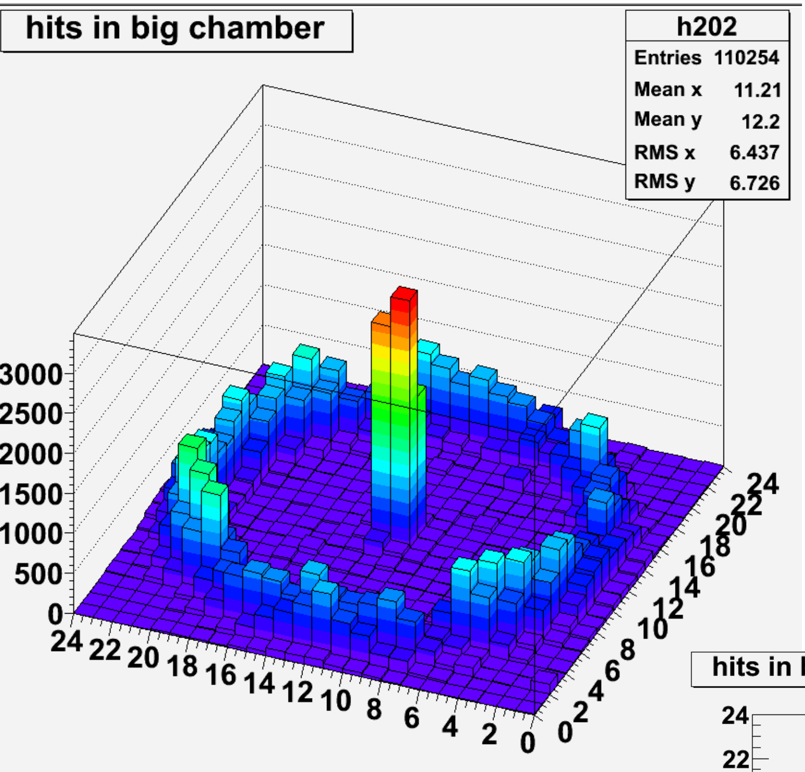
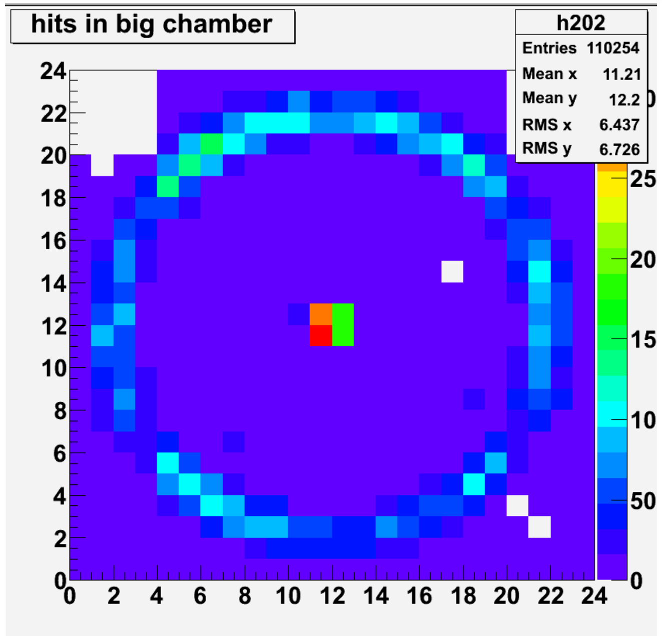
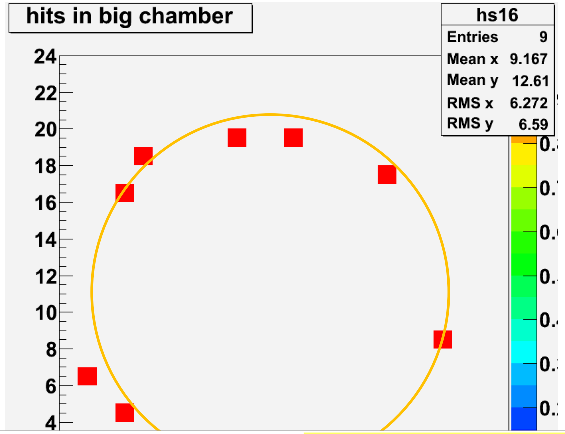
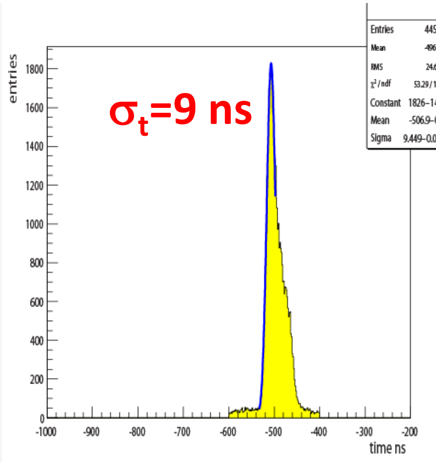
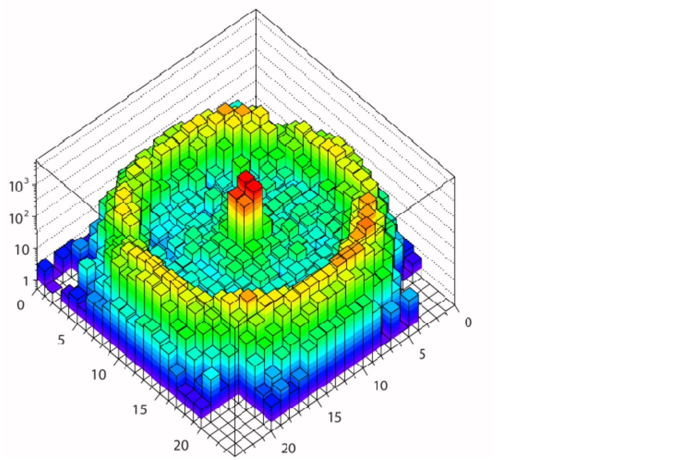


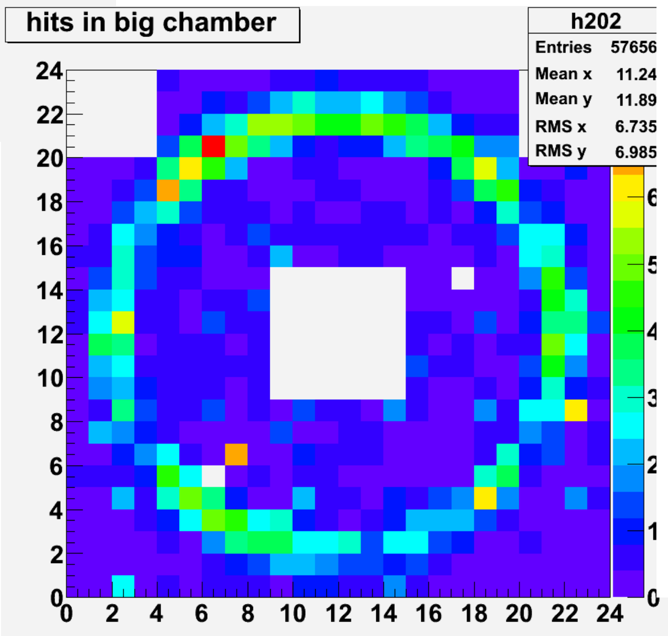


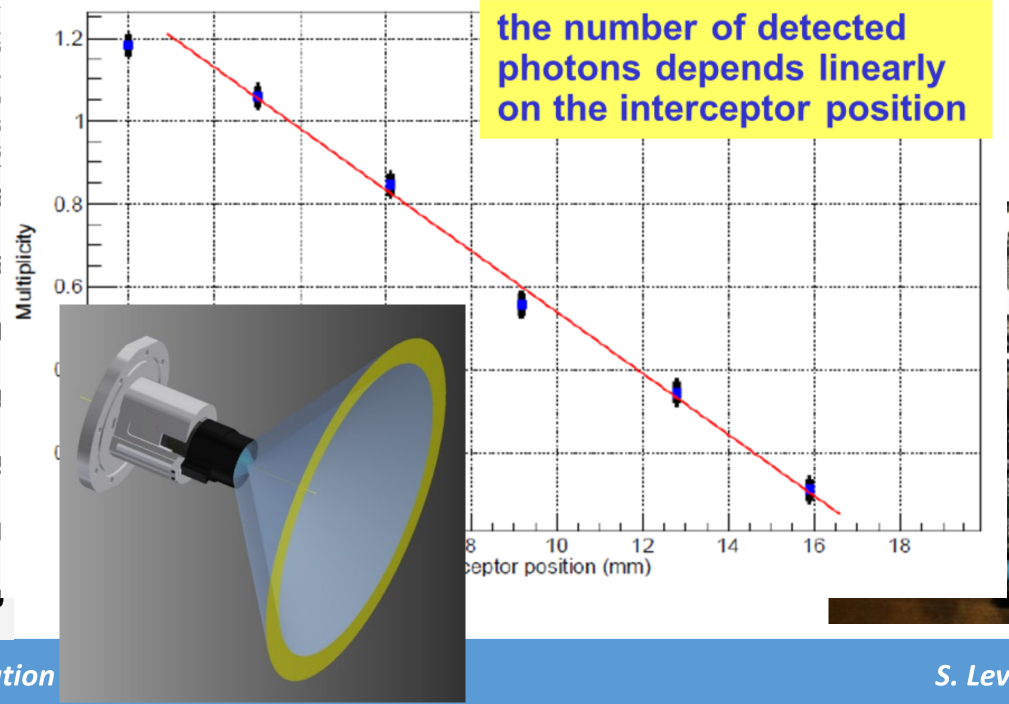
HV Settings
(7400,7520,7450,7400,7400,7350),
Threshold (FE) 2-3 fC



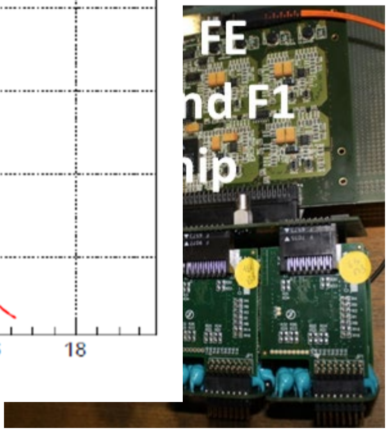




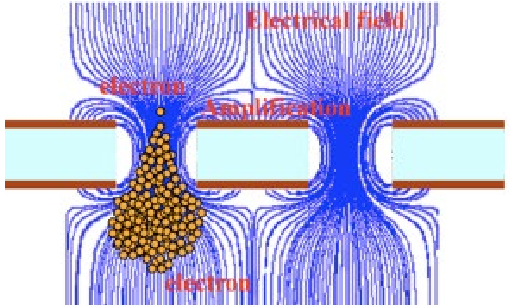


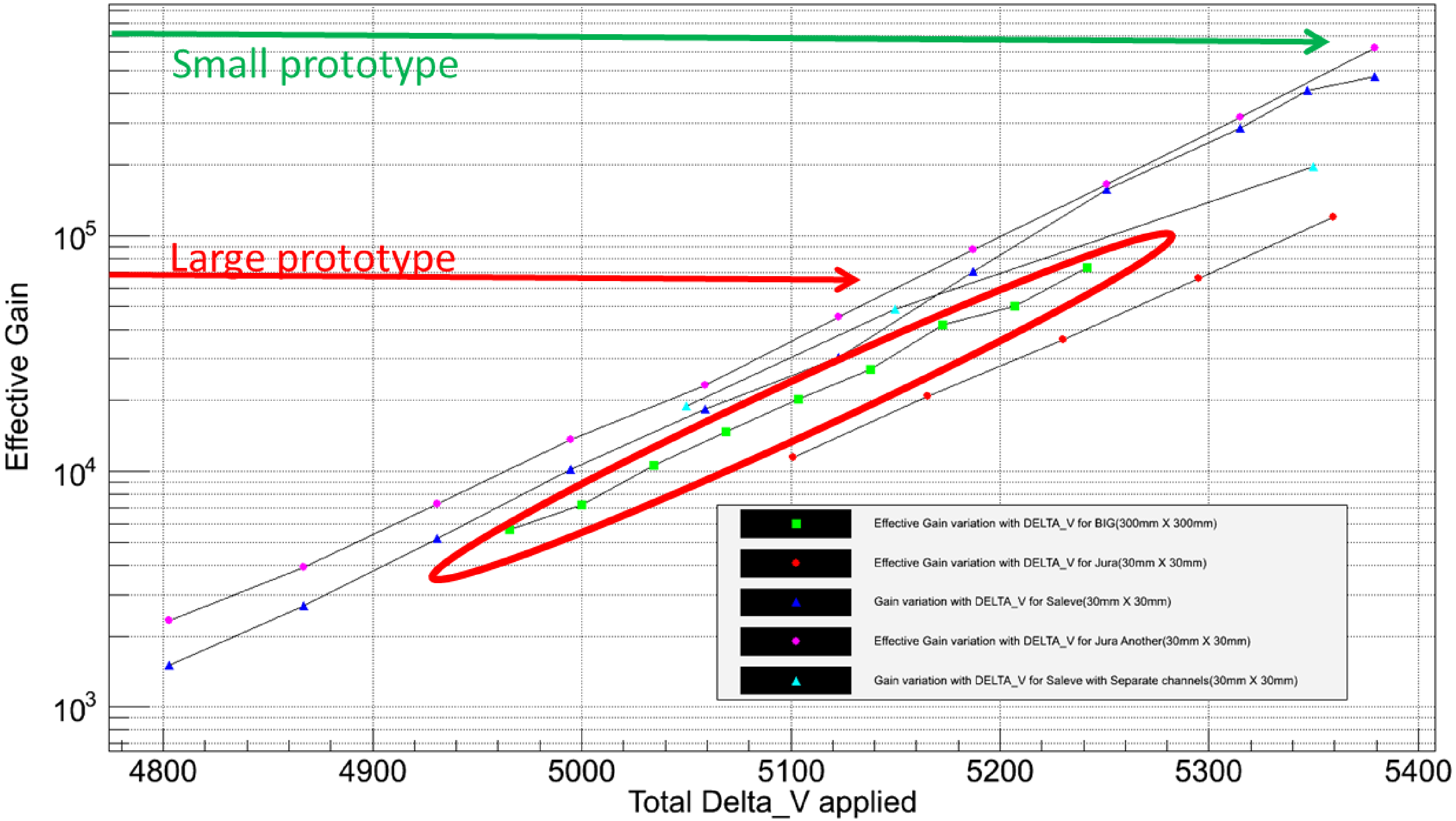


the number of detected photons depends linearly on the interceptor position



For large size prototypes Ar/CH_4 60-40%:
Gain achieved in test beams with triple THGEM structures
Cherenkov light from quartz radiator 2 10^4

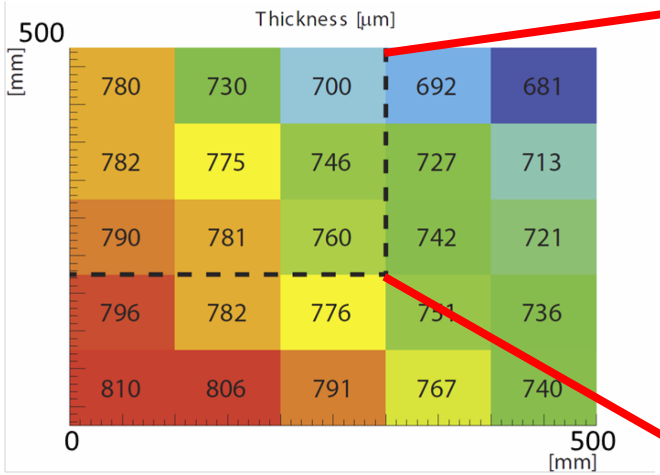


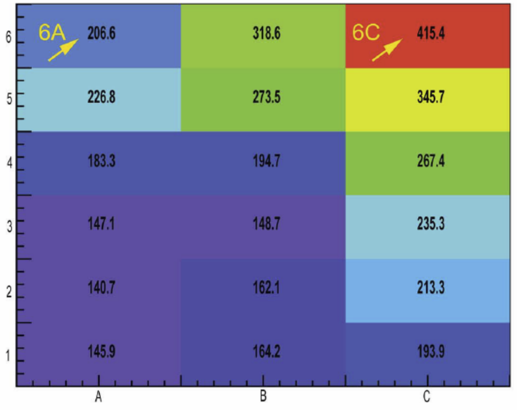


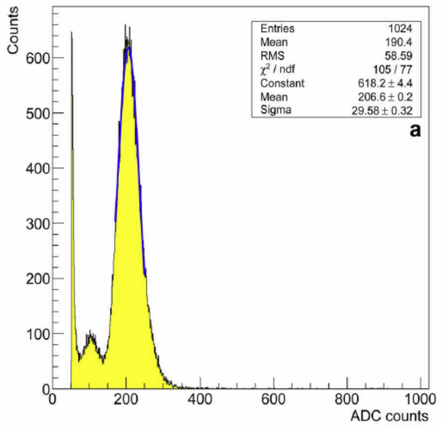
The thickness uniformity plays an essential role in defining the gain achievable

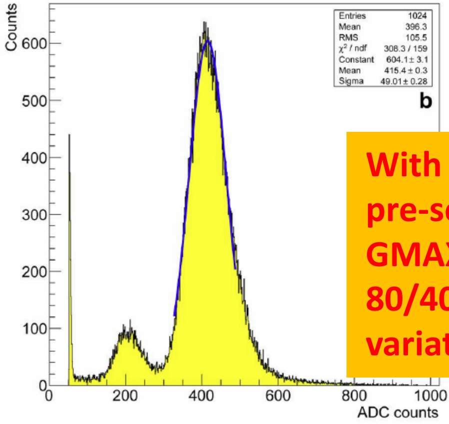
the maximum gain is limited by the thinner area, standard PCB variation 30% , our requirements <2%.

We have implemented a pre selection chain for PCB thickness → tolerances reduced, but material selection is not trivial

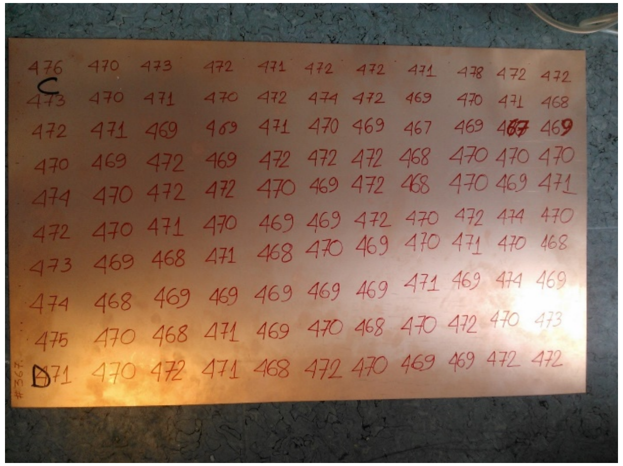




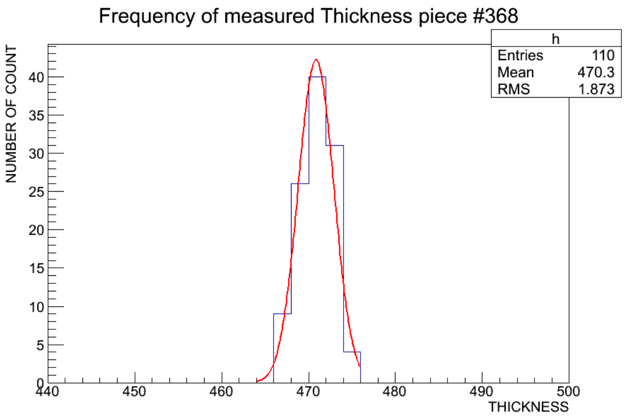


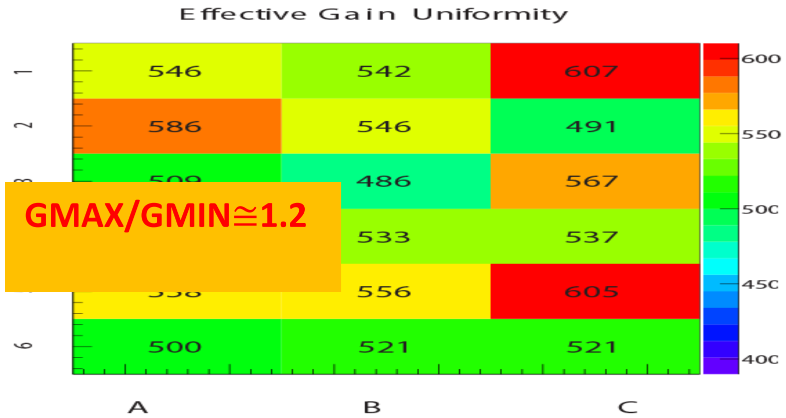


With no material pre-selection GMAX/GMIN≅2.9 80/400 mm variation



With material preselection $\sigma_{thickness}$ ≅2µm

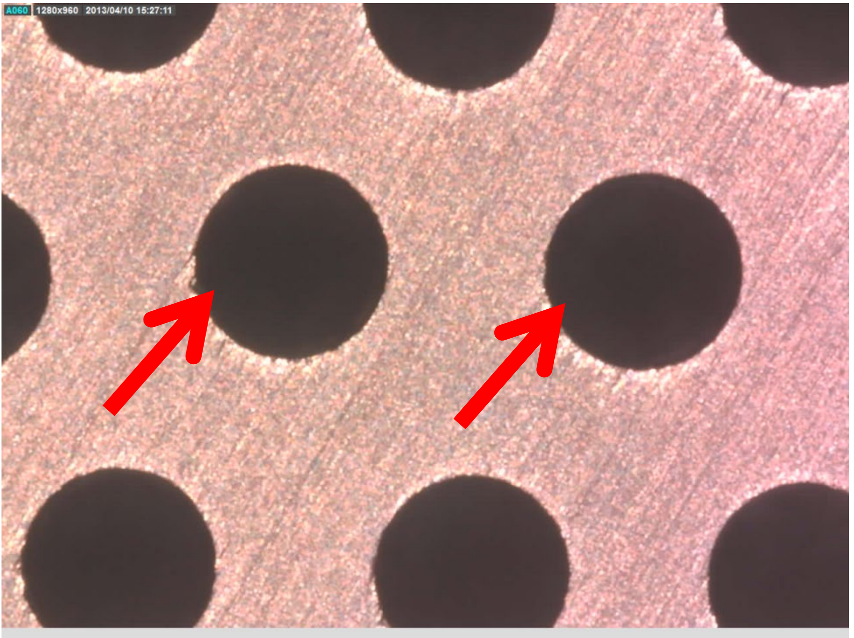


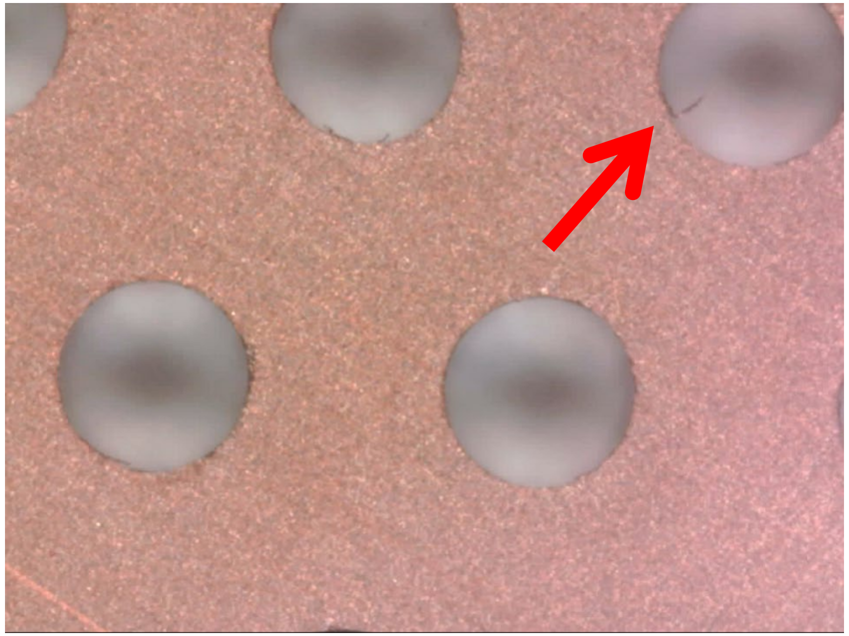


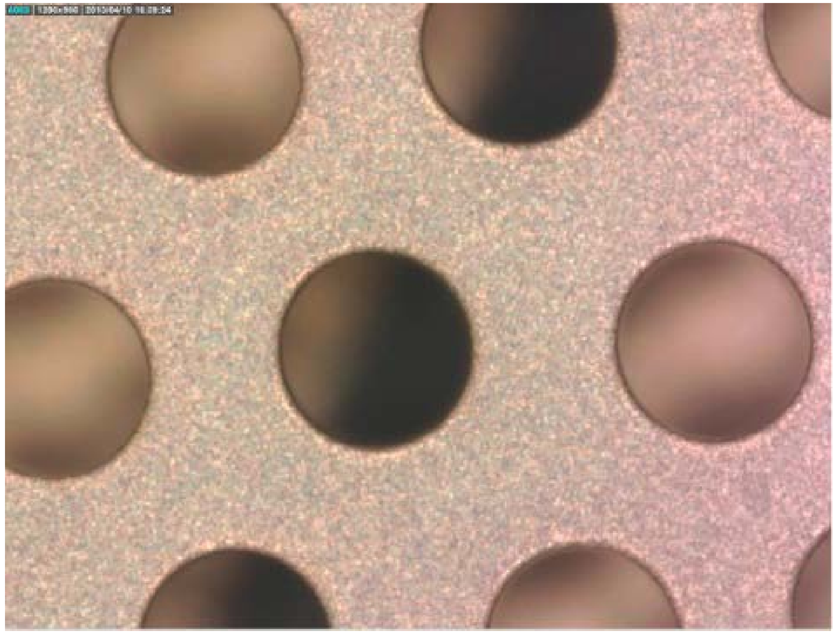
GMAX/GMIN≅1.2

The standard procedure of PCB production has been refined → better smoothened hole edges improve the detector maximum gain achievable, (*developed in Tieste Lab*)
Large number of holes/layers → challenging

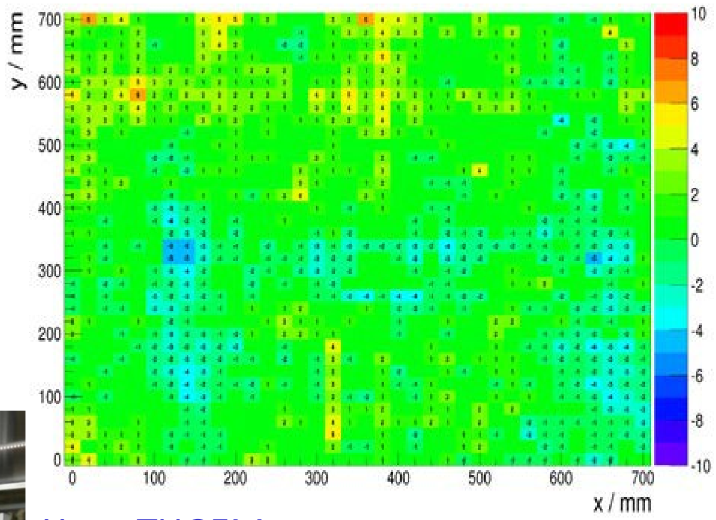
Based on fine pumice grain polishing, high pressure washing and ultrasonic bath in mild commercial etching solution

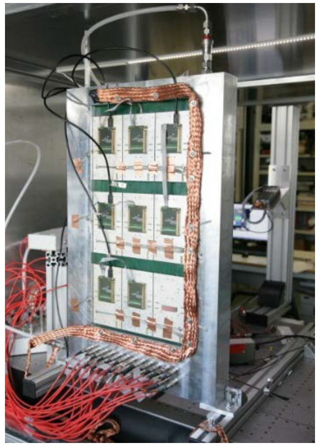




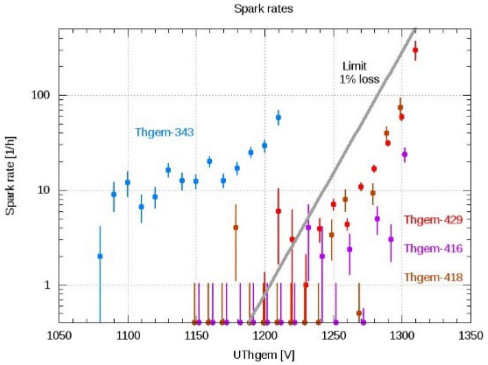


Measurement of the raw material thickness before the THGEM production, accepted:
± 15 μm ↔ gain uniformity σ < 7%

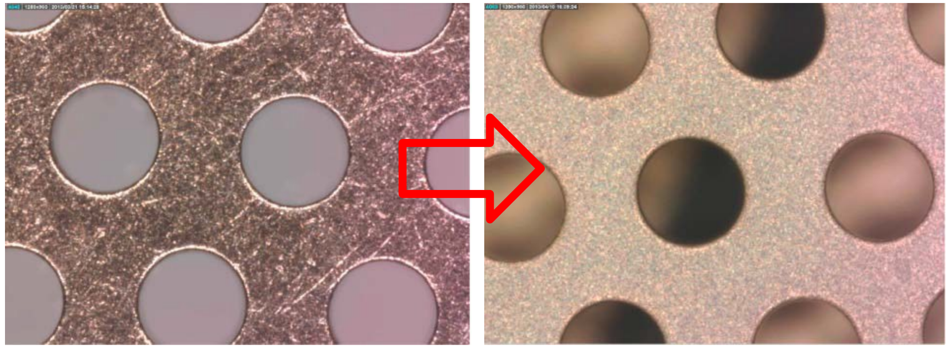




X-ray THGEM test to access
gain uniformity (<7%) and spark behaviour



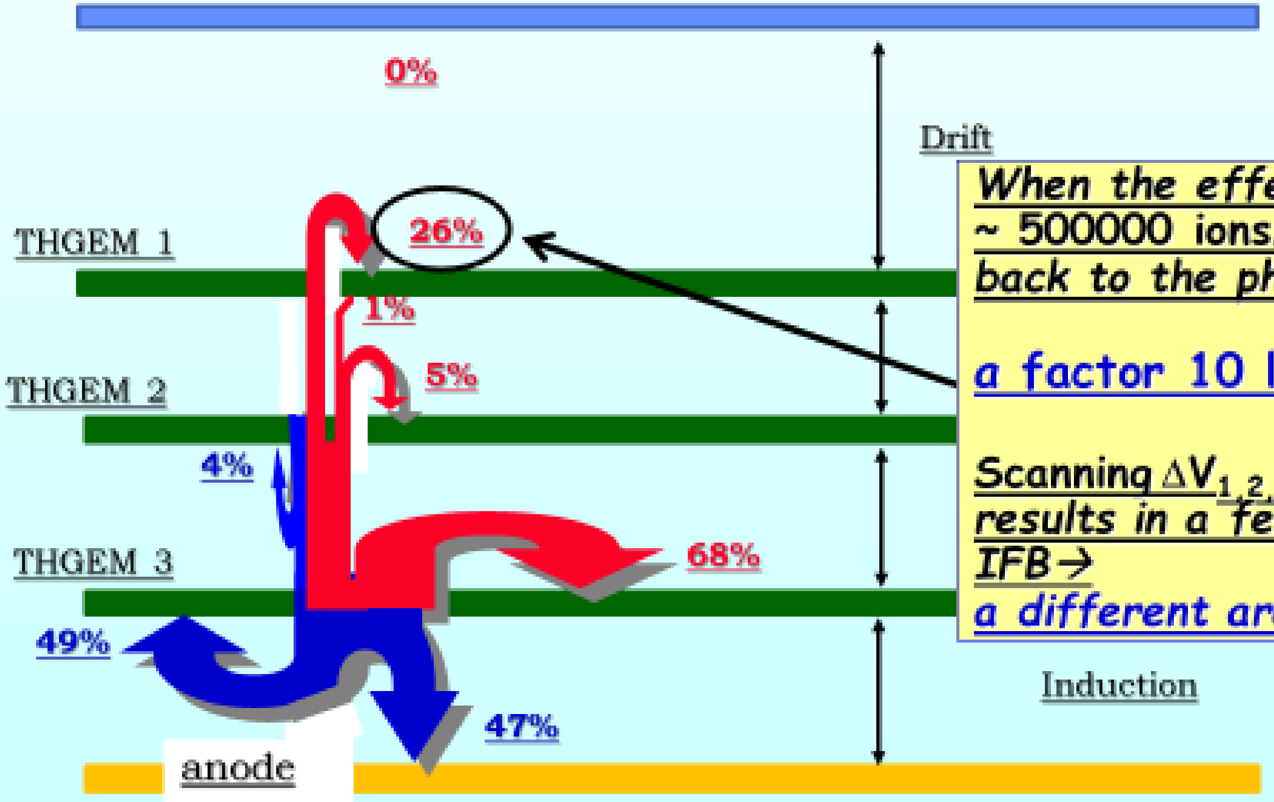
THGEM polishing with an “ad hoc” protocol setup by us *including backing*:
>90% break-down limit obtained



Important open problem: reduction of IBF

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

typical charge sharing

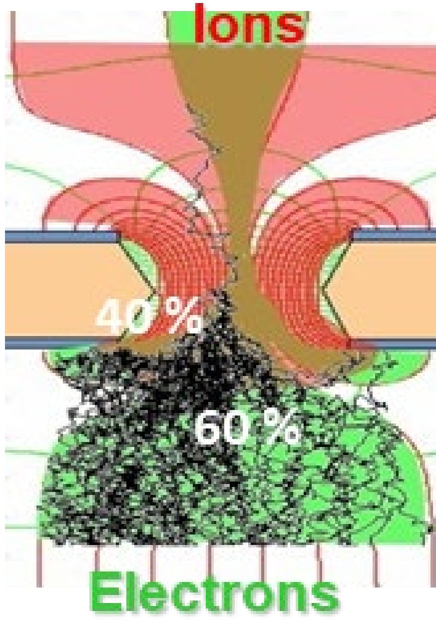


When the effective gain is 10^6 → ~ 500000 ions/(detected photon) back to the photocathode

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

Chicago, 11/06/2011 - Technology and Instrumentation in Particle Physics Conference, TIPP 2011 Fulvio TESSAROTTO 27



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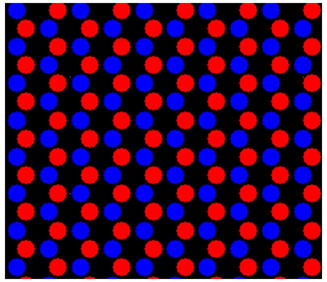
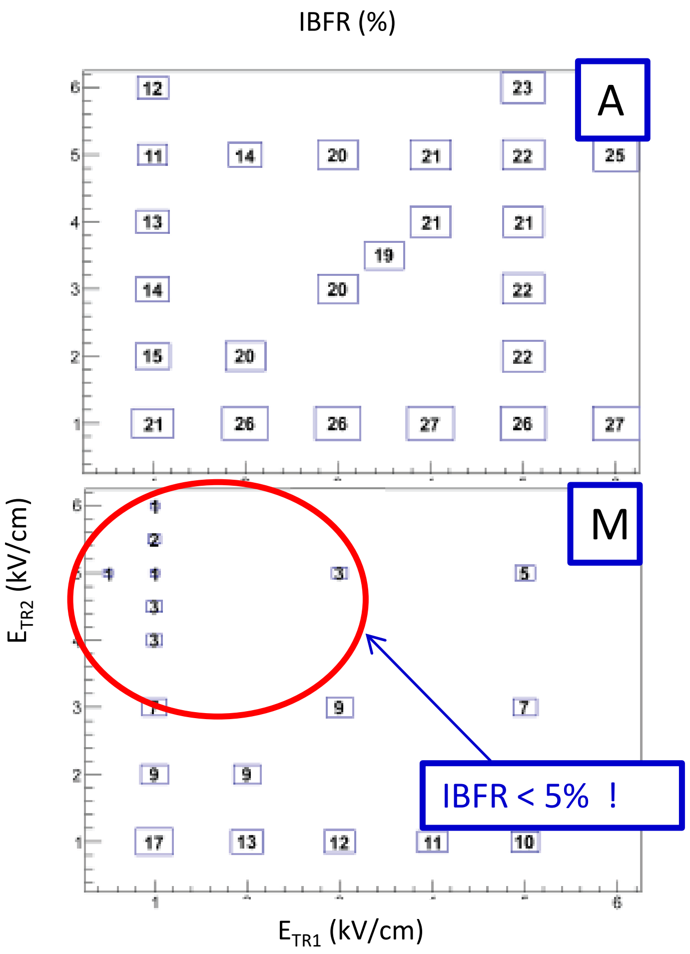
Triple THGEM:
Ion Back Flow
reduction by
staggering plates





M. Alexeev et al., JINST 7 (2012) C002014

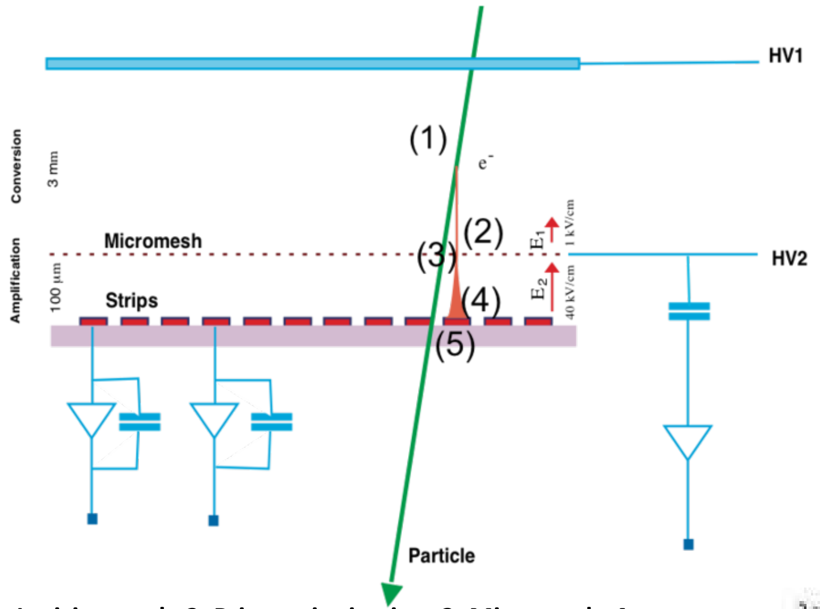
The Misaligned configuration can give a IBF in the order o few percent.

- the misalignment between holes $m = 0.8\frac{\sqrt{3}}{2}$~0,6928
- the use of strong electric field between the THGEM multipliers, results in and increase of the potential values to be applied to the THGEM electrodes, problematic in case of discharge
- Lower gain (~ 50%) : higher V to recover, problematic in case of discharge

Look back in the MPGD world

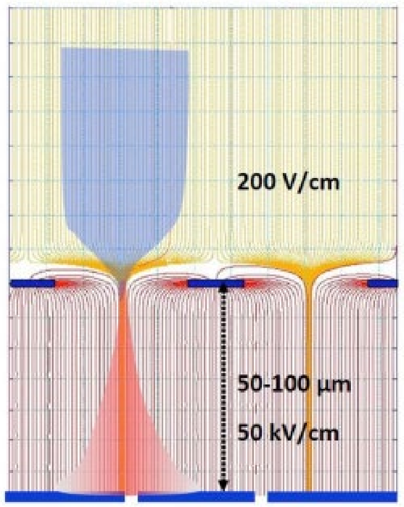
A Micromegas detector consists in an ionization stage + by a parallel plate avalanche chamber with a very narrow amplification gap (~100 μm) defined by the anode plane and by a micromesh.

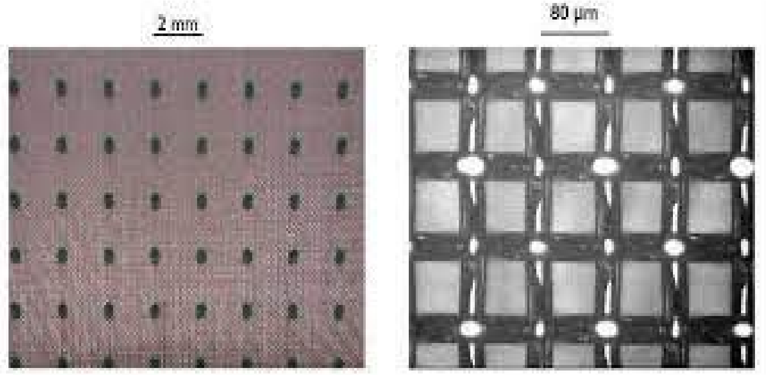
Natural suppression of the Ion Back Flow: Fraction of the ions flowing back from the multiplication volume !!!

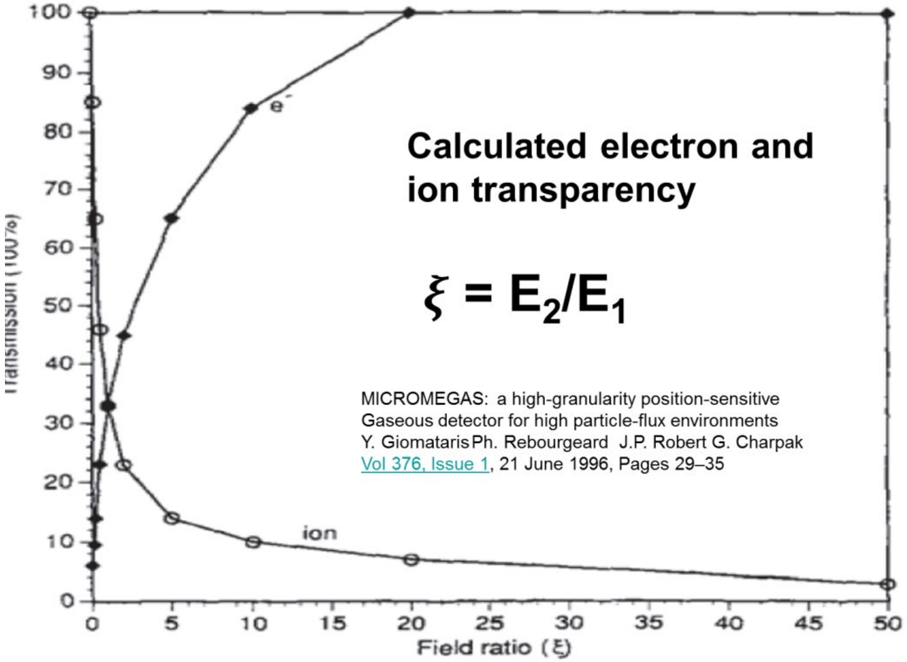


1: Ionizing track, 2: Primary ionization, 3: Micromesh, 4 Charge Avalanche, 5 Readout Pad

MICROMEGAS
Thin (50-100 µm) multiplication gap:

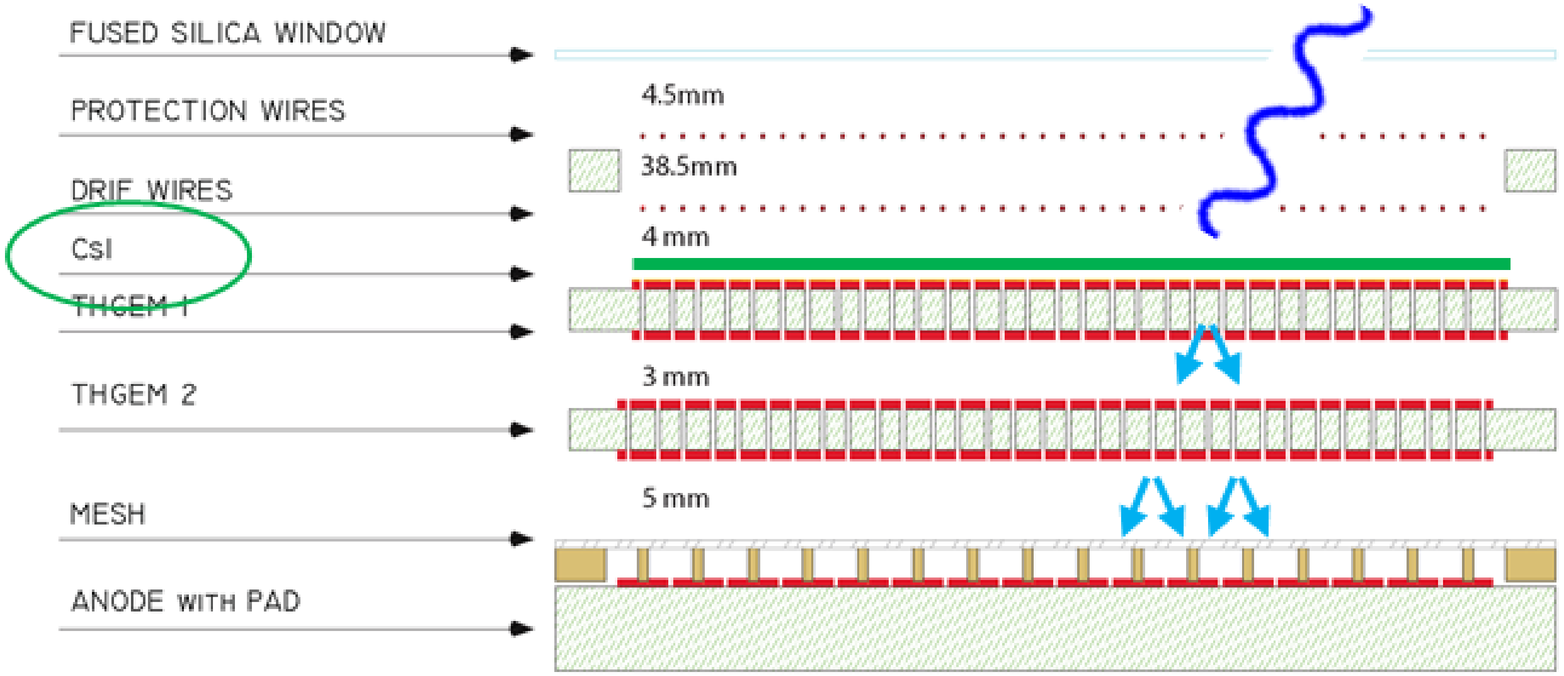






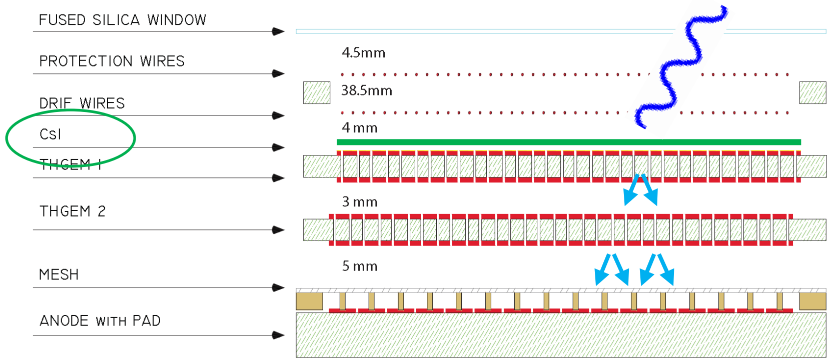
MICROMEGAS: a high-granularity position-sensitive Gaseous detector for high particle-flux environments
Y. Giomataris Ph. Rebourgeard J.P. Robert G. Charpak
Vol 376, Issue 1, 21 June 1996, Pages 29–35

Fig. 5. Calculated electron and ion transparency.


FUSED SILICA WINDOW
PROTECTION WIRES
DRIF WIRES
CsI
THGEM 1
THGEM 2
MESH
ANODE WITH PAD
4.5mm
38.5mm
4 mm
3 mm
5 mm

The Hybrid architecture structure

Istituto Nazionale di Fisica Nucleare

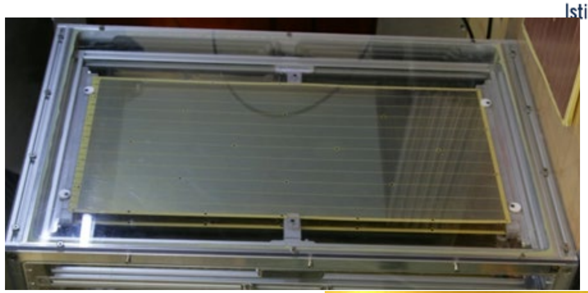


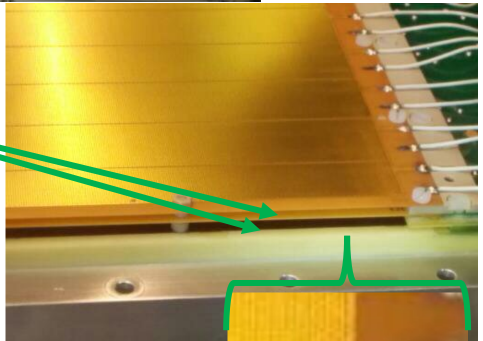
IBF reduction: approx. 3%
Charge splitting processes →Larger Gas Gain

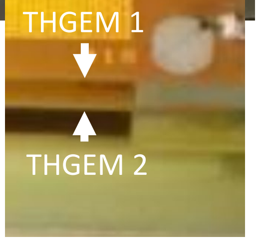
Hybrid detector concept

To simplify the construction requirements a modular architecture has been adopted where one "*module*" consists of:

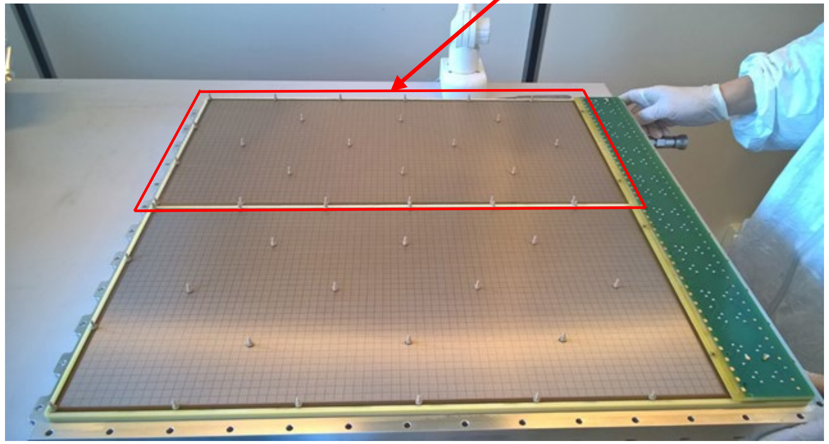
- **One 300 mm x 600 mm Bulk Micromegas detector**
- **Two layers of THGEMs (300 mm x 600 mm) in *staggered* configuration**



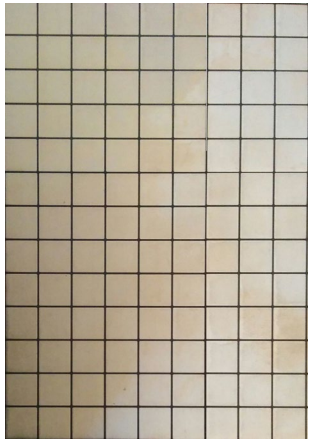


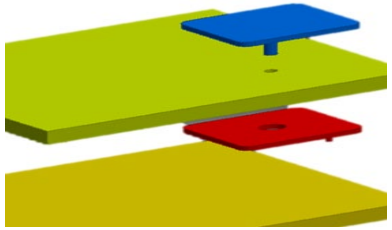


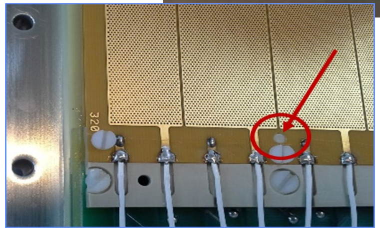
Two modules are put side by side to build a 600 mm x 600 mm detector



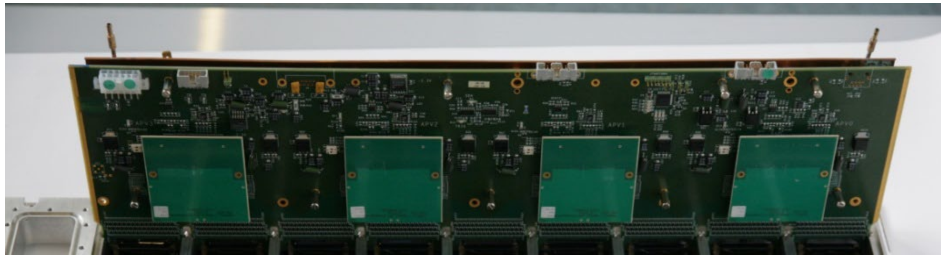
Signal read out via capacitive coupling pad readout and APV25 F/E boards





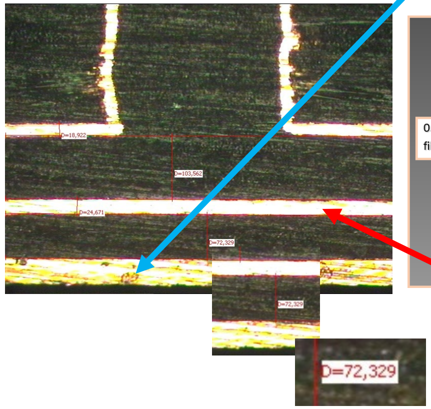


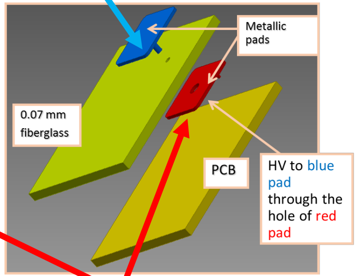
8mmx8mm pad size
0.5 mm pad spacing



The COMPASS RICH-1 approach

"surface anode" pad



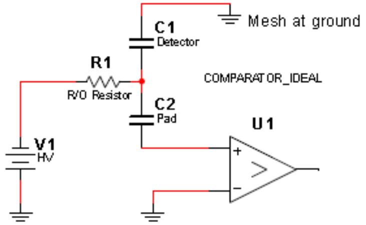


"buried pad"

1 Single pad scheme:

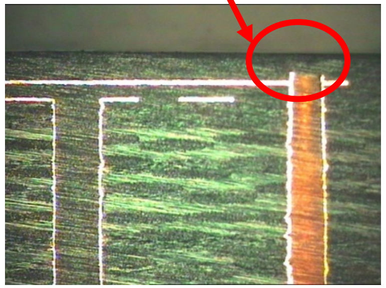
Blue pad at HV via individual pad resistor at the PCB rear surface

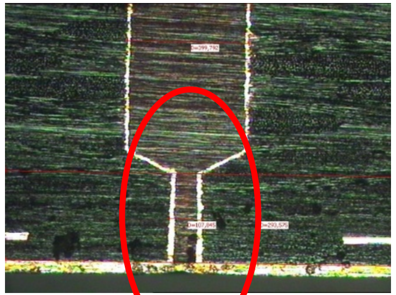
Red pad: signal induced by RC coupling



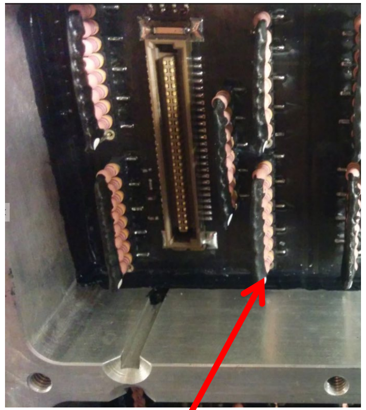
Mesh at Ground
Pads HV segmentation

"Via closure" → leakage issue

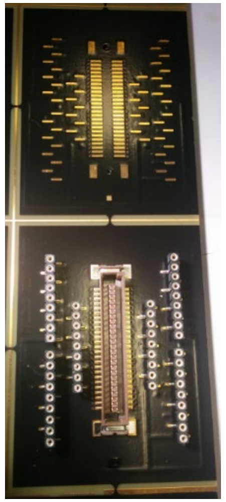




"Z drilling controlled via" → planarity issue

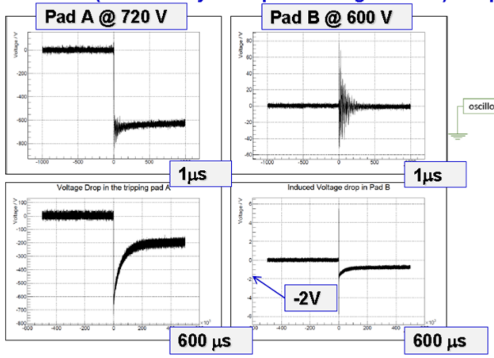


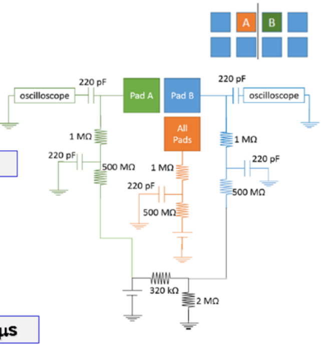
Resistor arrays
Connector 8+1 pin



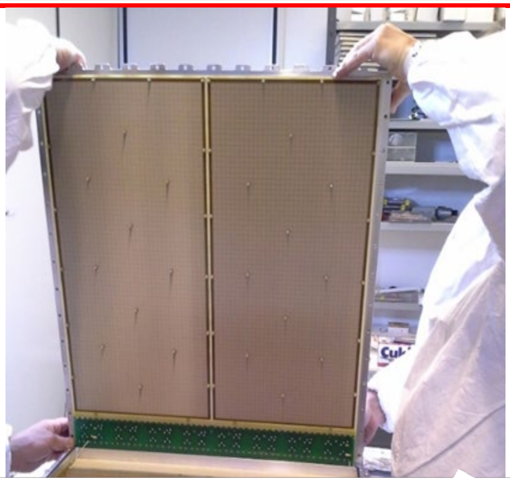
Test of the (4 x 2) 30 x 60 cm^2 MMs
[in total: 1.4 m^2, 19040 pads]:
-2 pads with shorts
-1 pad: no read-out connection
→ 3 bad pads out of 19040 before installation

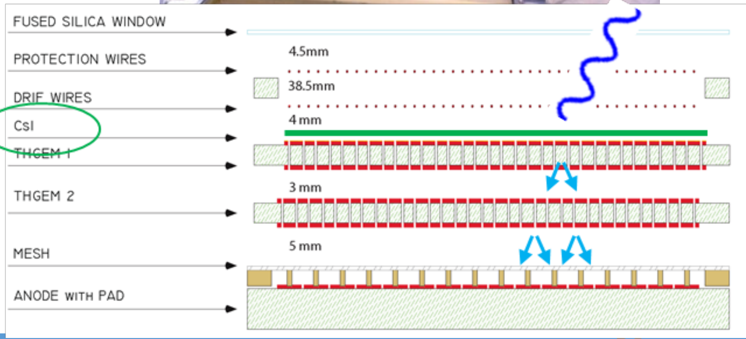
Pads A & B (the two adjacent pads being studied) are powered by the same PS



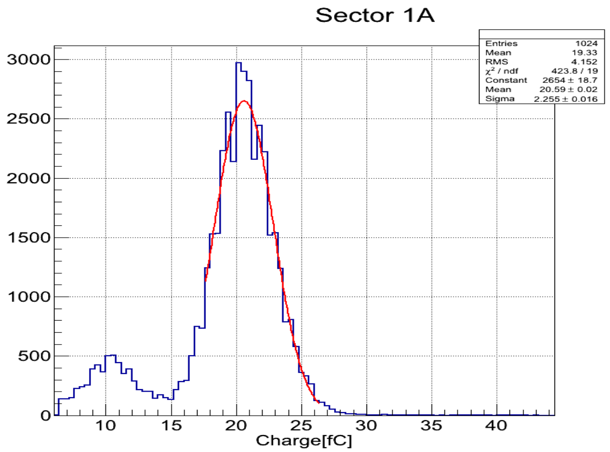


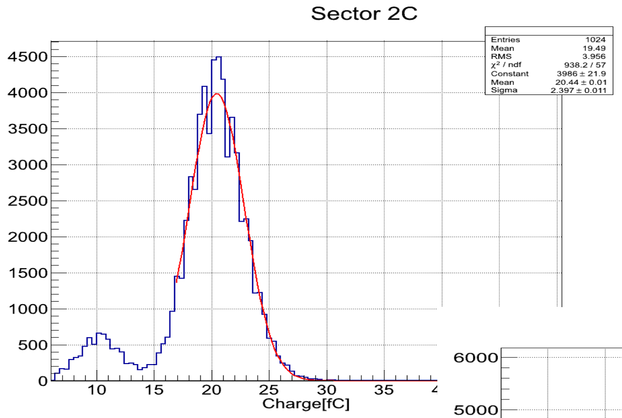
The HV of the non tripping pad is very limited affected:
2V drop → ~4% drop in G
R ~ 0.5 GΩ is preserving the non-tripping pads efficient all the time !

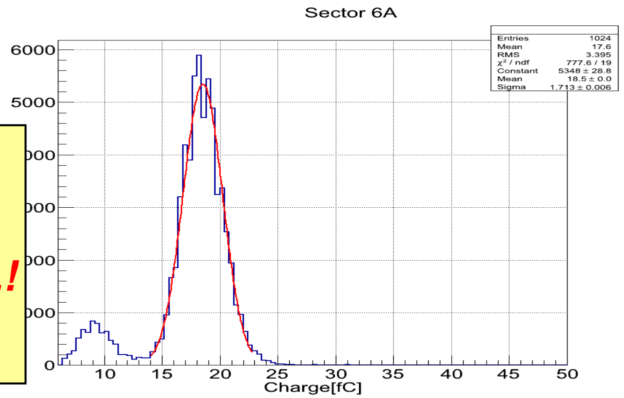


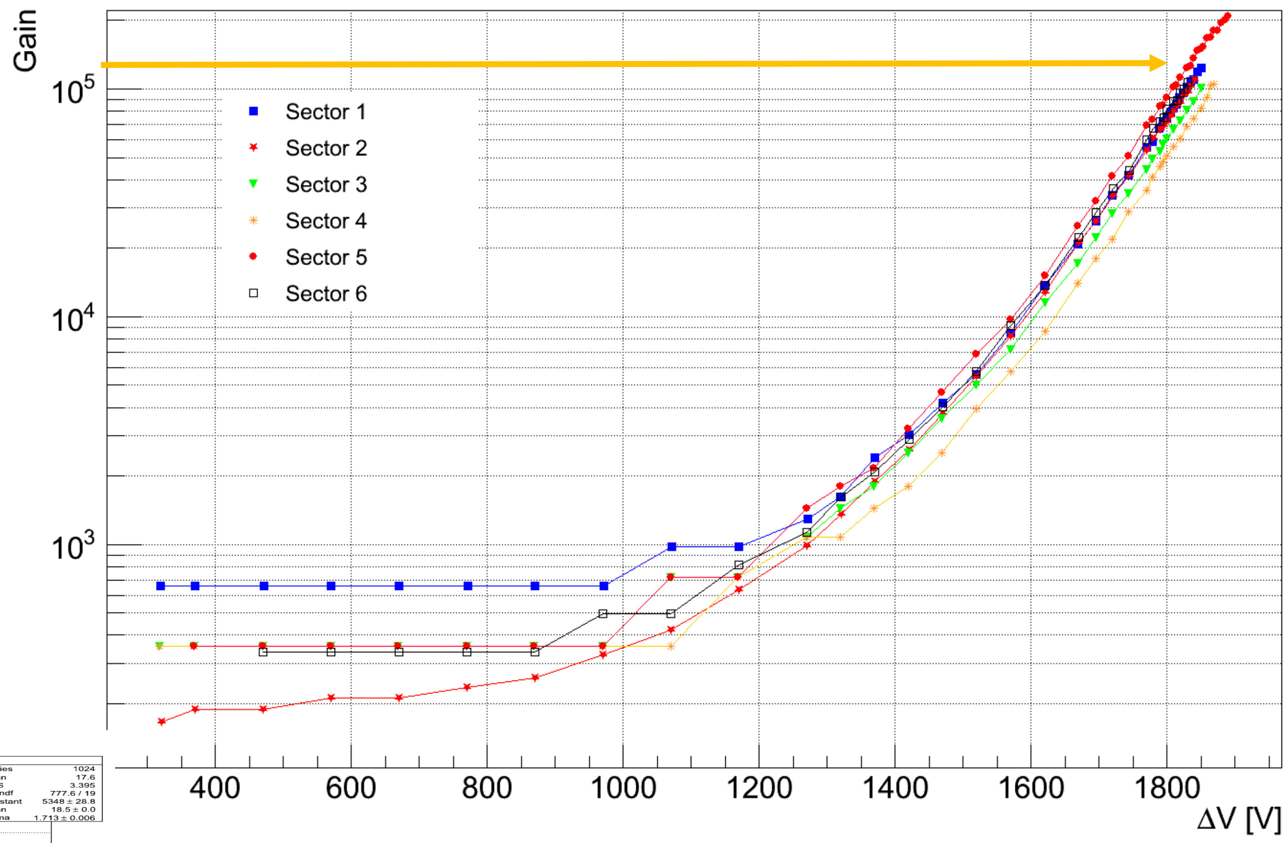


ΔV Scan of Sectors of a large THGEM. VMESH = 640V. Gas used Ar:CH4 30:70.





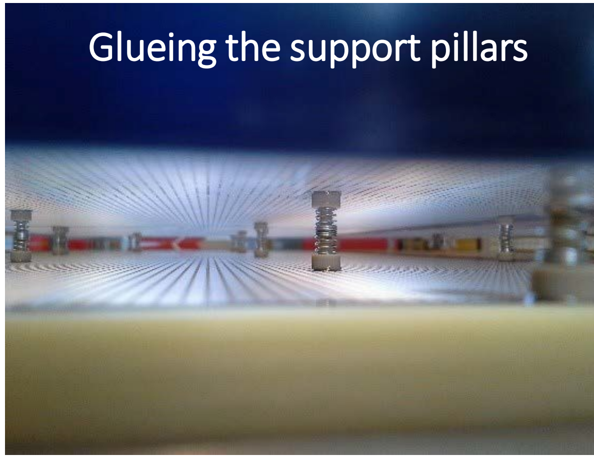


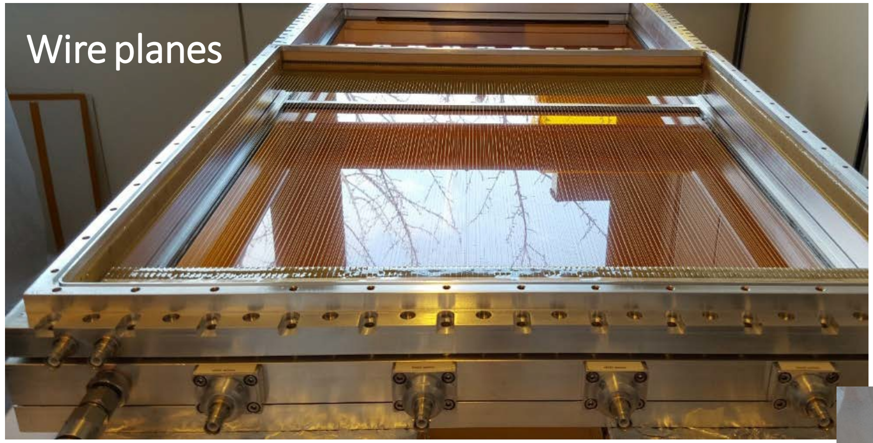


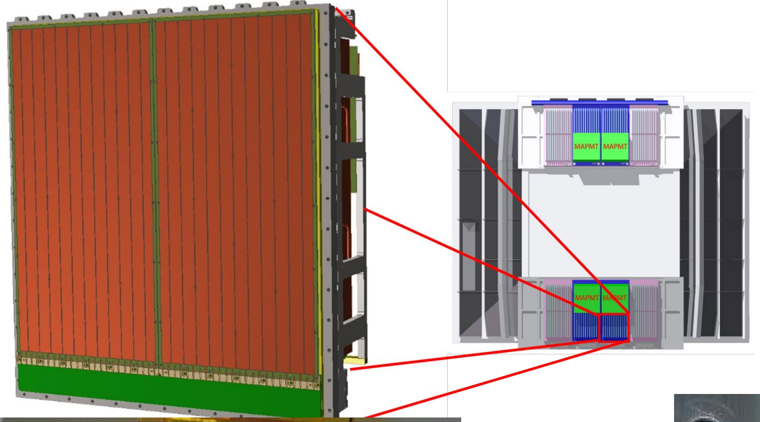
The large prototype works nicely! same performance as the small p.!

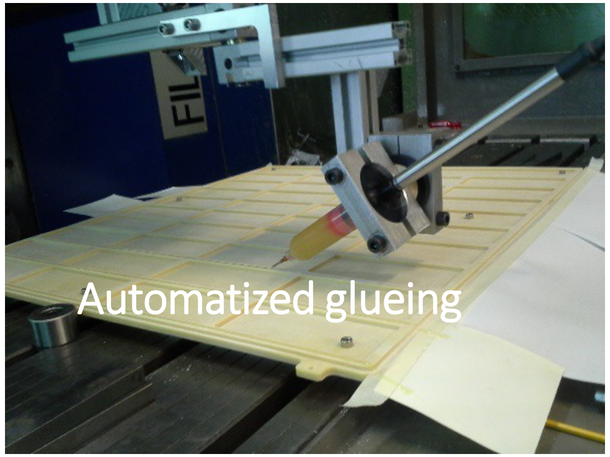
Source ^{55}Fe
Pre-Amplifier stage Cremat CR110 (spark protection circuit installed)+Ortec Amplifier + MCA

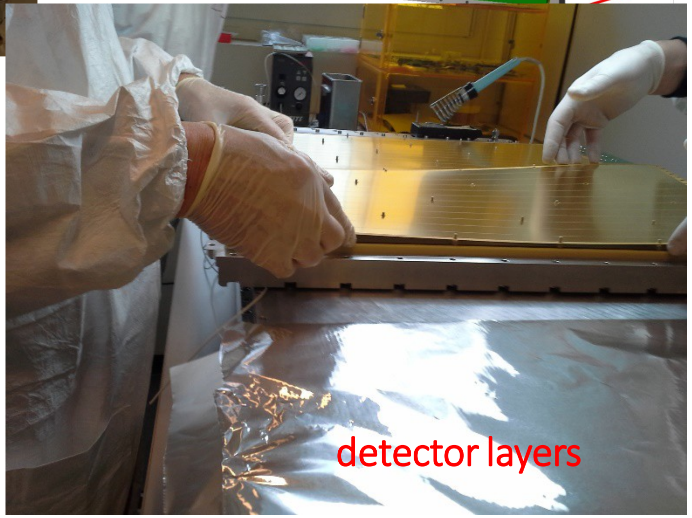
The Construction of the detectors in 2016

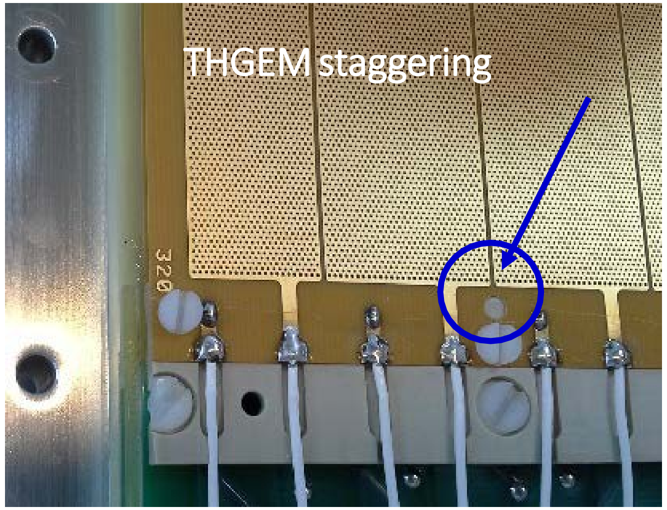




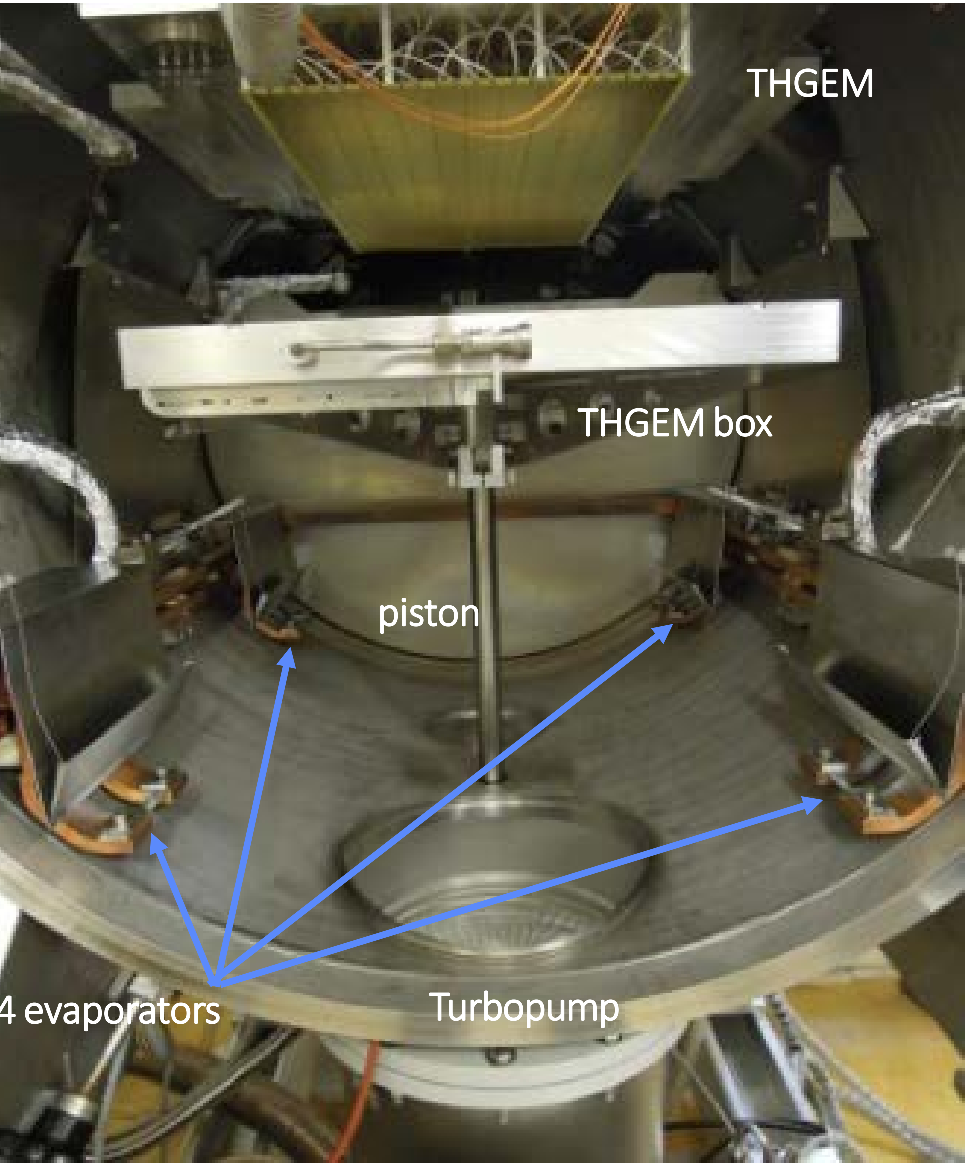


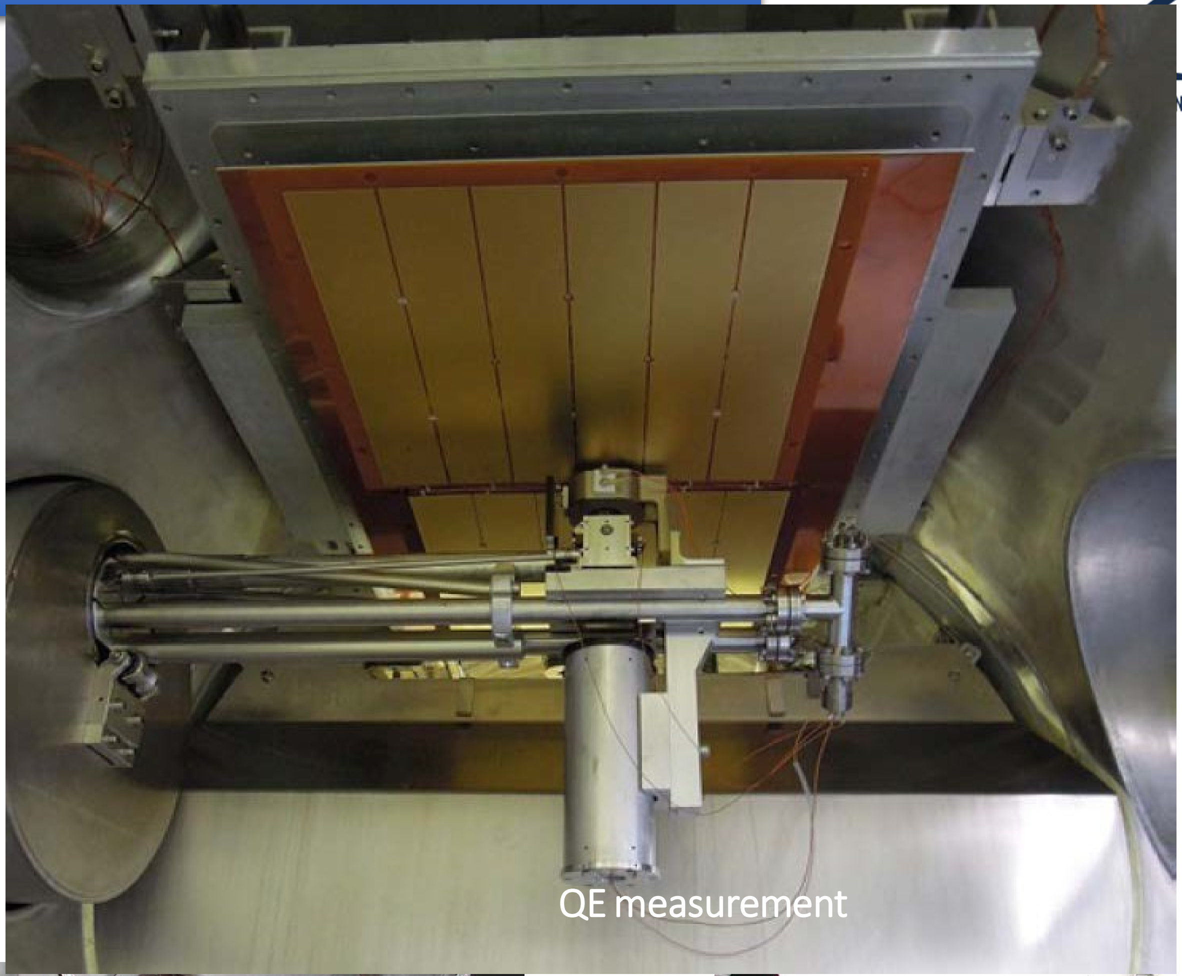


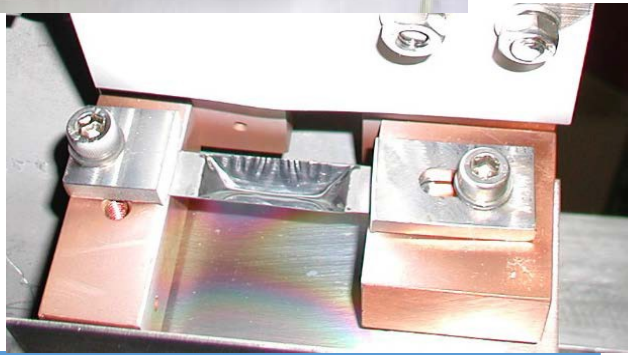




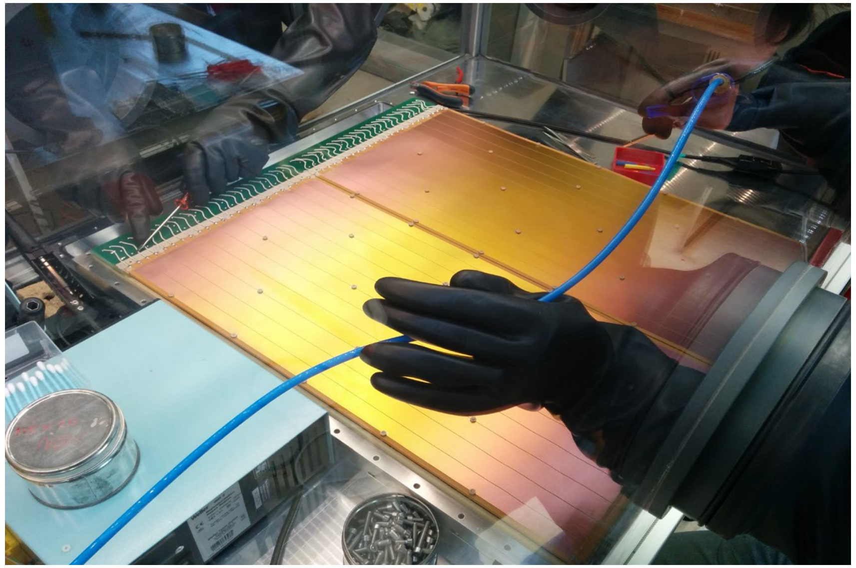
The CsI coating







The Installation of the detectors in 2016



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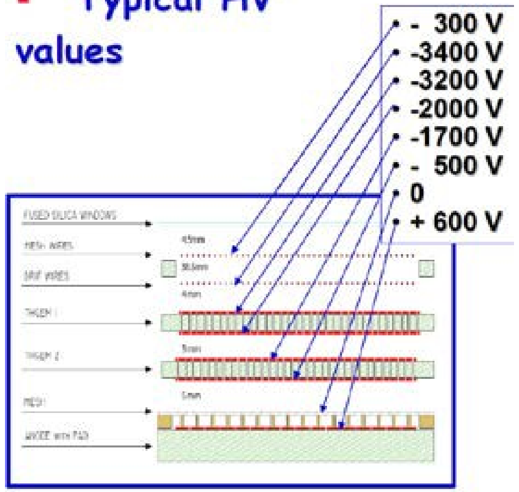
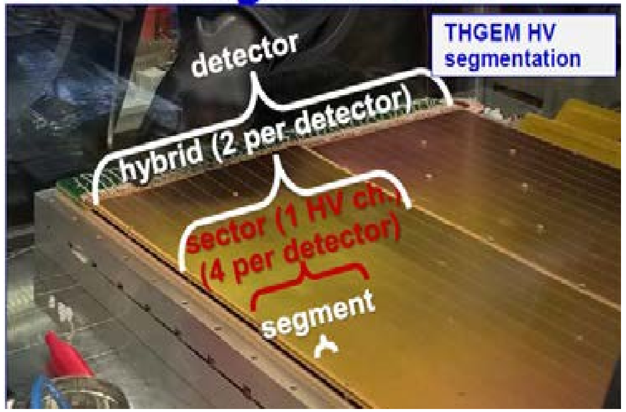
- Typical HV values

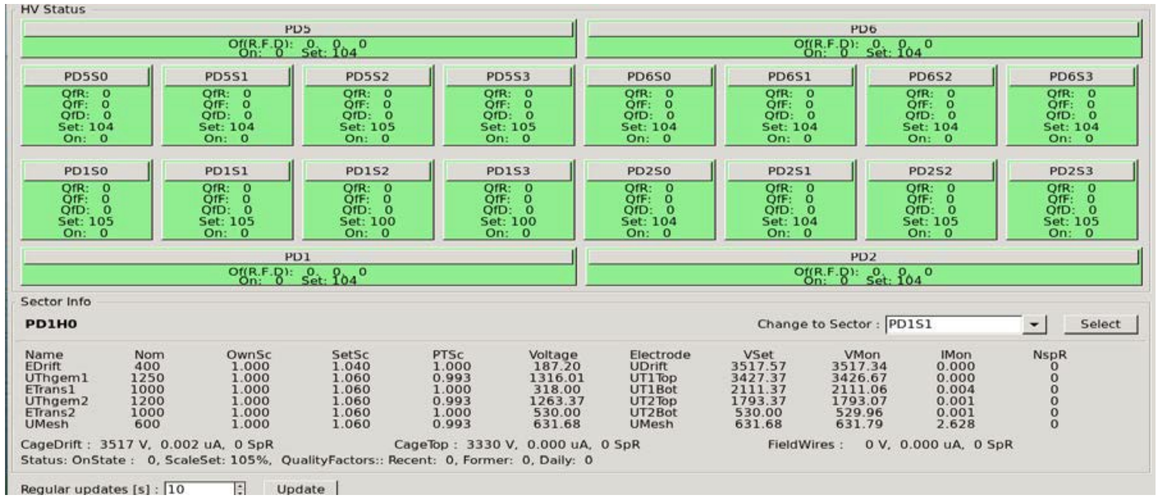


- HV segmentation

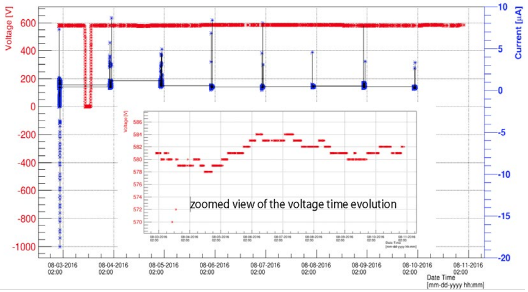


In total 136 HV channels
with correlated values

Hardware, commercial by CAEN
Custom HV control system



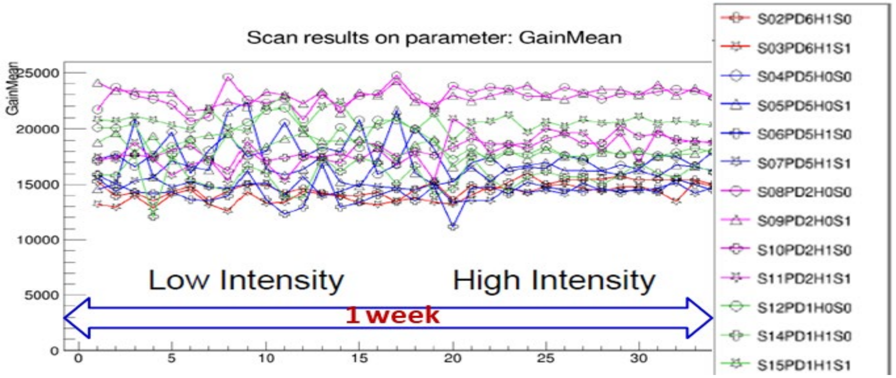
- Gain stability vs P, T:
  - G = G(V, T/P)
  - Enhanced in a multistage detector
  - $\Delta T = 1^{o}C \rightarrow \Delta G \approx 12\%$
  - $\Delta P = 5$ mbar $\rightarrow \Delta G \approx 18\%$



- THE WAY OUT:
  - Compensate T/P variations by V

    Gain stability better than 10%

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



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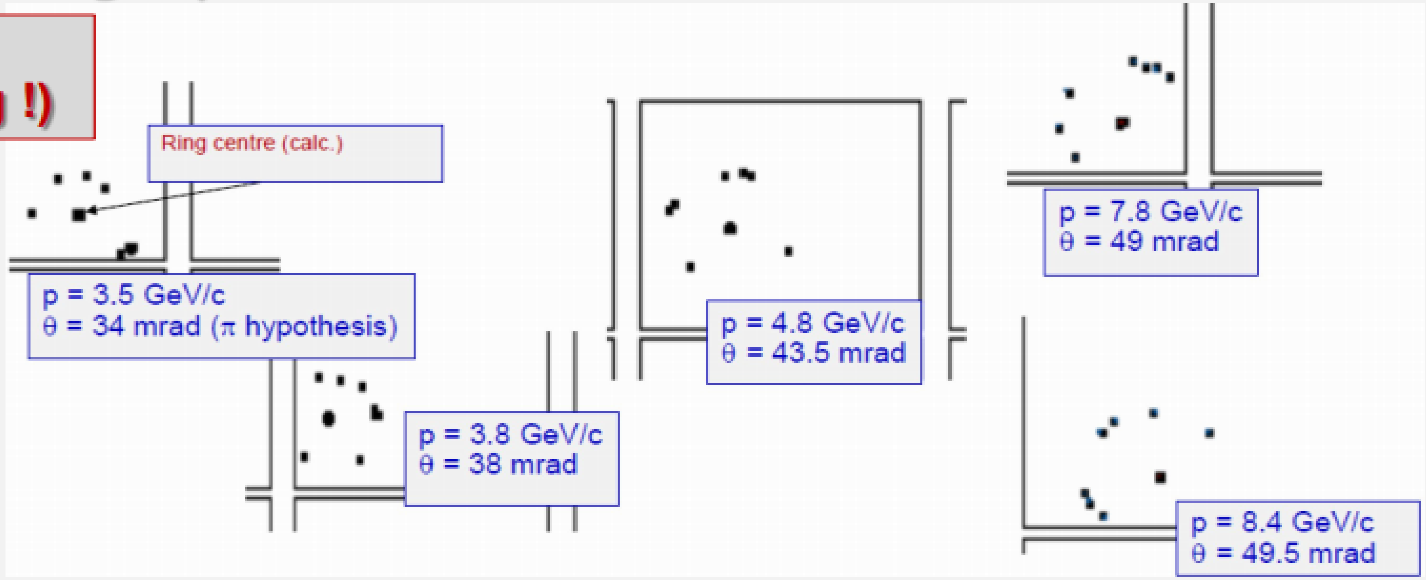
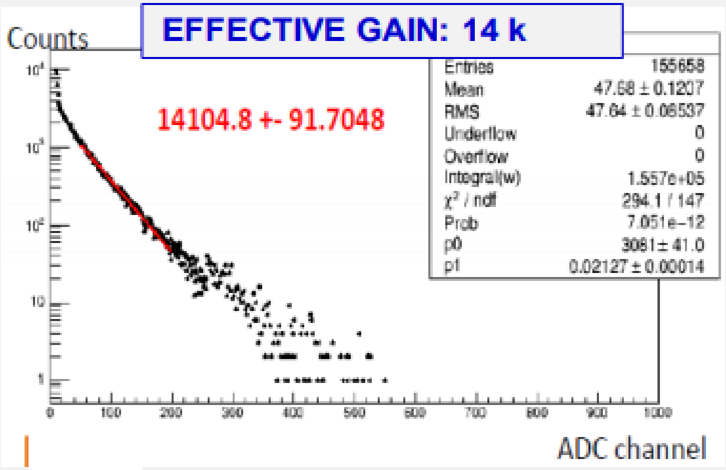
The novel gaseous single photon detectors of COMPASS RICH

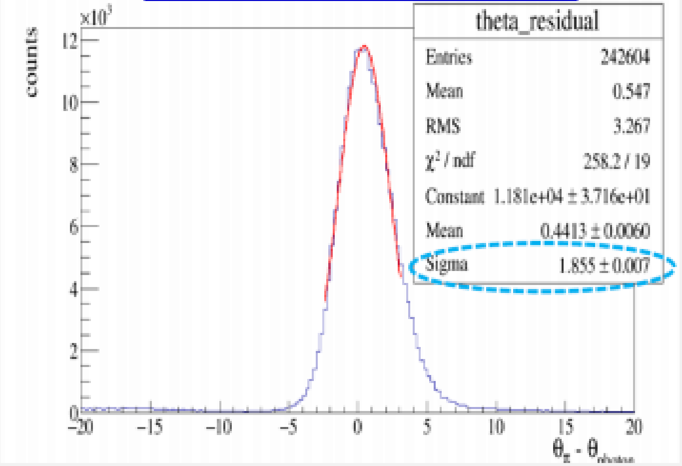
EVENT DISPLAY (no image filtering !)



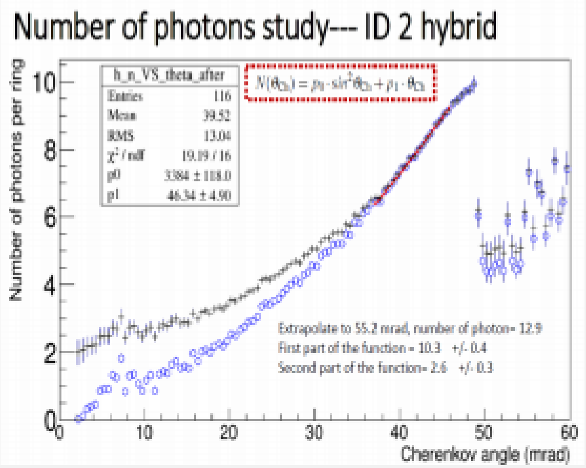
EFFECTIVE GAIN: 14 k



Resolution: 1.8 mrad



n. of photons/ring : 10-12 (β → 1)



The MPGD-based photon detectors has proven to be an alternative to MPWC + CsI

Technological achievement

- single photon detection is accomplished by MPGDs in an experiment
- THGEMs used in an experiment
- resistive MM used in an experiment
- MPGD gain > 10k in an experiment
- gain stable at 6% level over months

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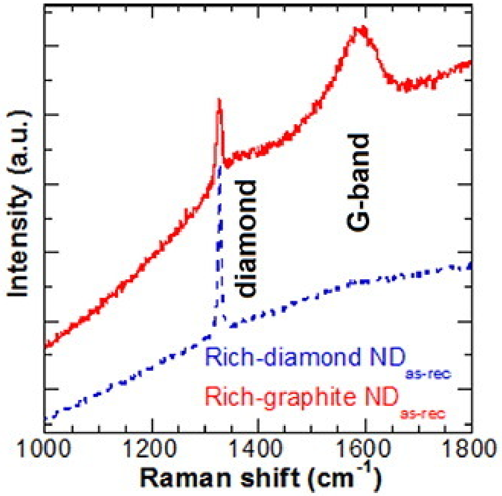

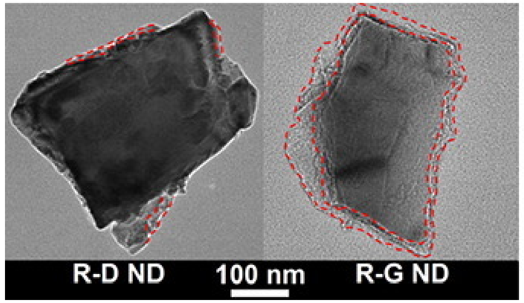

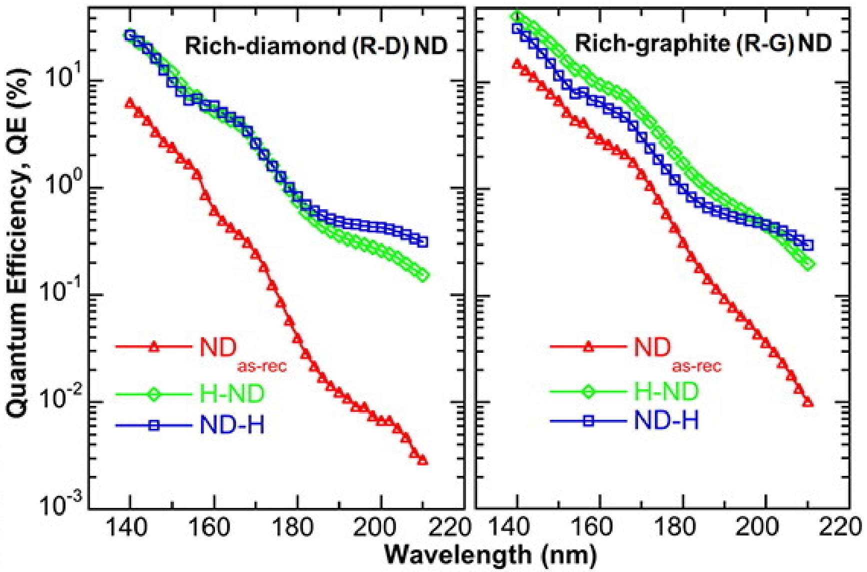

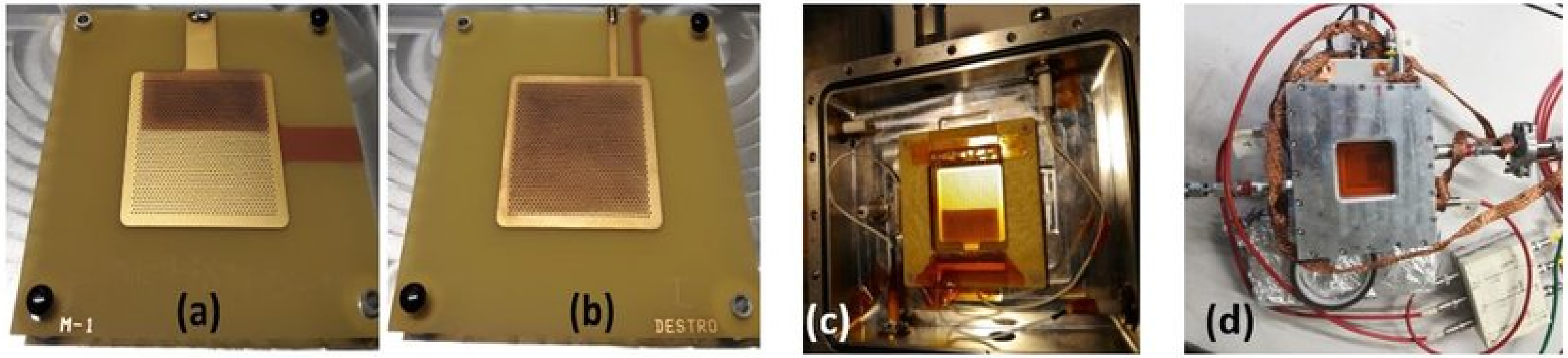

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The MPGD-based photon detectors has proven to be a valid alternative to MPWC + CsI

stable gain and large gain, fine resolution, good number of detected photoelectrons

Technological achievement
- single photon detection is accomplished by MPGDs in an experiment
- THGEMs used in an experiment
- resistive MM used in an experiment
- MPGD gain > 10k in an experiment
- gain stable at 6% level over months

Thanks!