A Single Photon Detector System Based on Micropattern Gaseous Electron Multiplier

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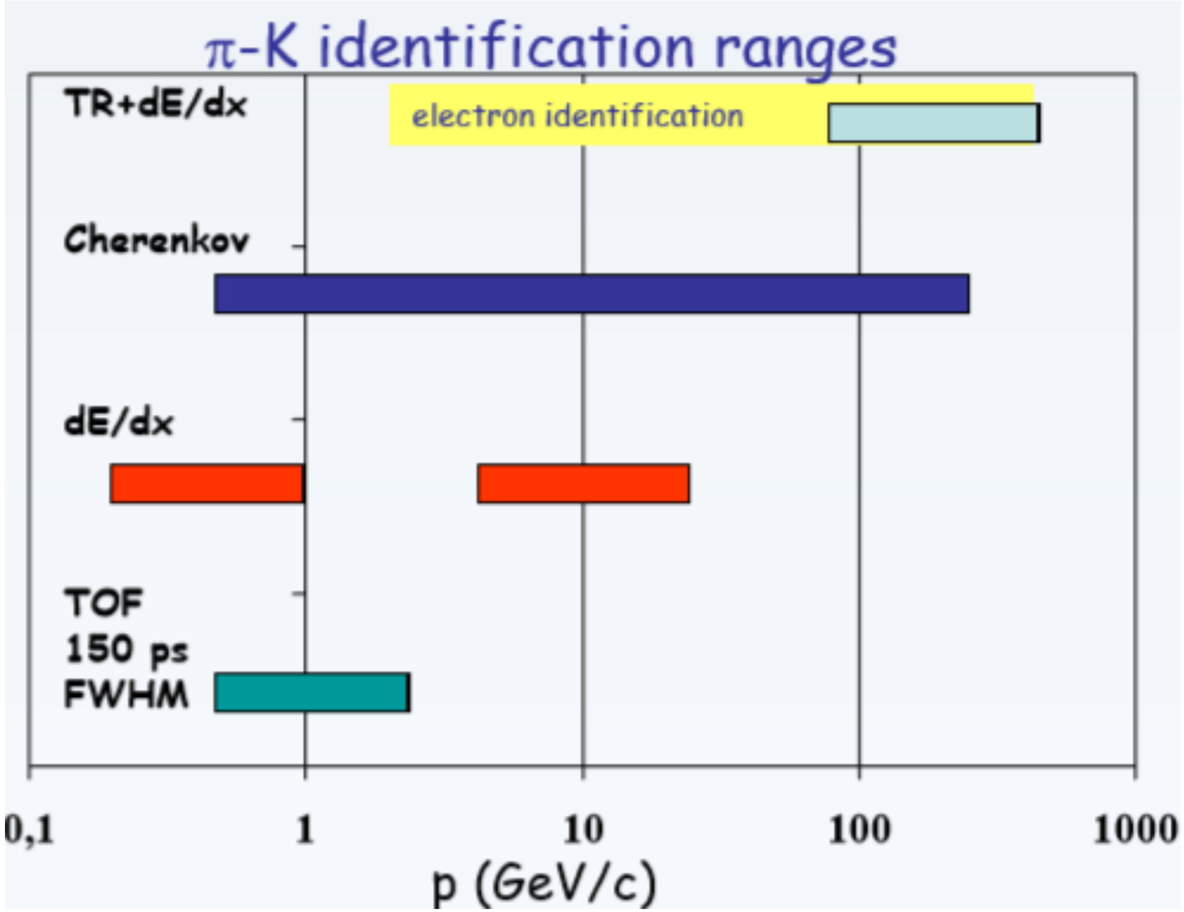
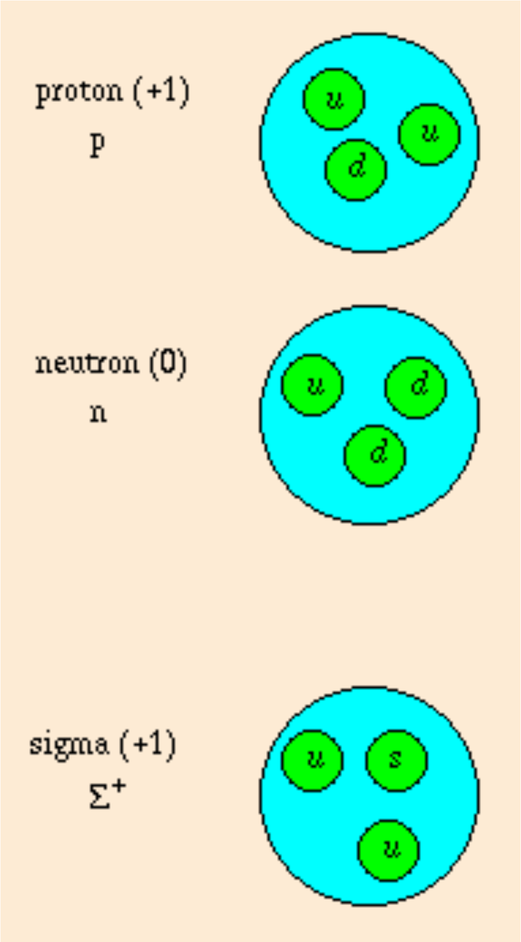
- Introduction
  - A little bit of my “world”
  - Particle identification: what it is
- Gaseous based detector: from MWPC to MPGD
- The single photon counter from small to large size
- What we learned and the tools to improve, a dedicated system to monitor and control the HV
- What you will see in the lab

Particle identification techniques are based on the interaction of particles with the matter
The applicable methods depends 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
  - Low energy p, range
  - e.m. particles vs hadrons: calorimetry (shower development)
  - ...

- Measurement of the particle mass m
  - m from the equation

$$E^2 = (mc^2)^2 + (pc)^2$$

2 measurements have to be combined

p (deflection in magnetic field)

E (range)

p (deflection in magnetic field) p

(deflection in magnetic field) p

(deflection in magnetic field)

v (TOF, Cherenkov) v

(TOF)

dE/dx (for instance in TPCs) E/m

(transition radiation)

E (range)

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

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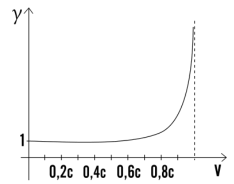
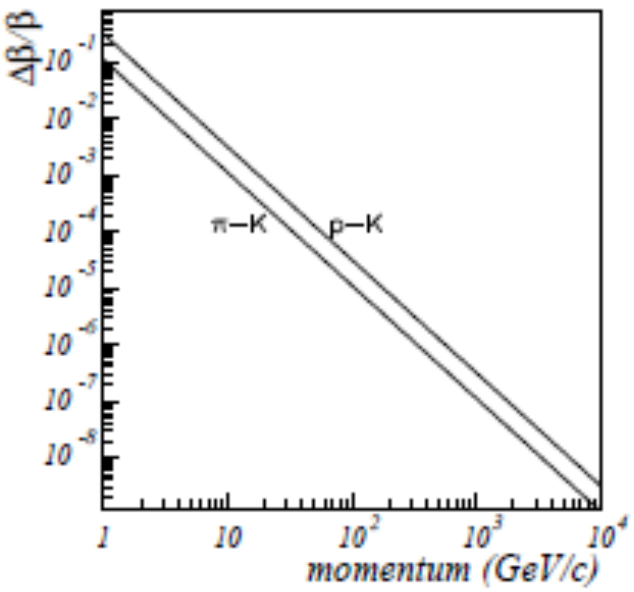
Resolution:

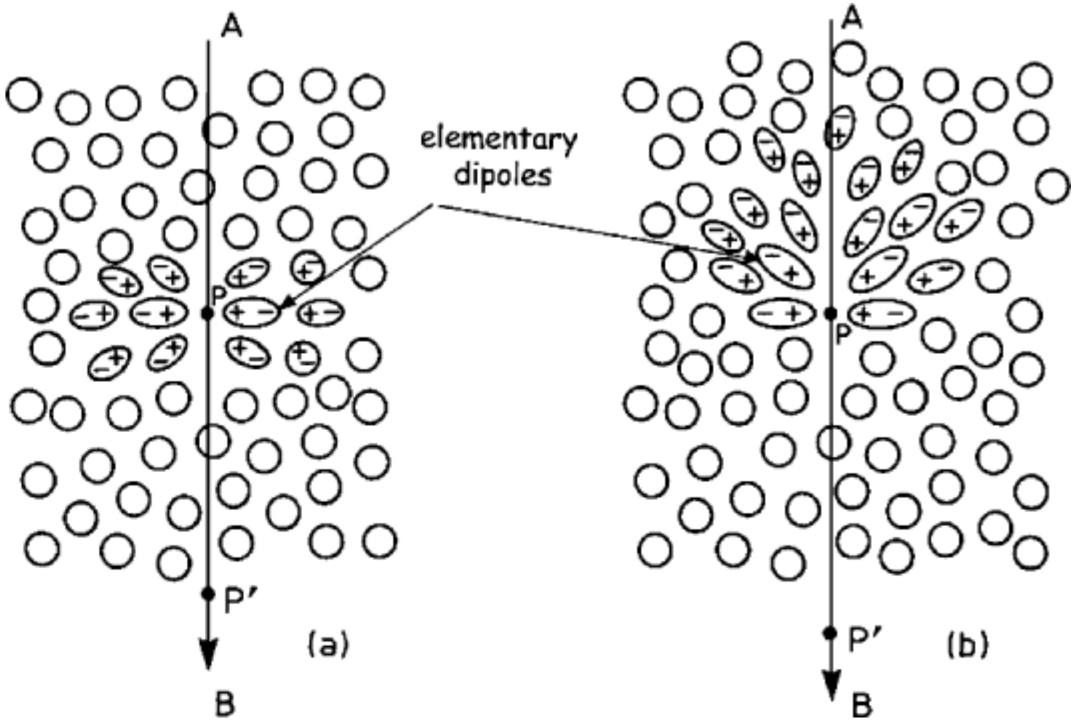
$$\left(\frac{dm}{m}\right)^2 = \left(\gamma^2\frac{d\beta}{\beta}\right)^2 + \left(\frac{dp}{p}\right)^2 \qquad \gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$



Assuming p is measured with fine resolution, the resolution in Δm/m becomes a specific request concerning the resolution of the β measurement:

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





phase velocity of the light in the medium:

$1/n \cdot c$

$\beta_{part} \cdot c$ < phase velocity of the light in the medium

Symmetric configuration

→ *Destructive interference*

$\beta_{part} \cdot c$ > phase velocity of the light in the medium

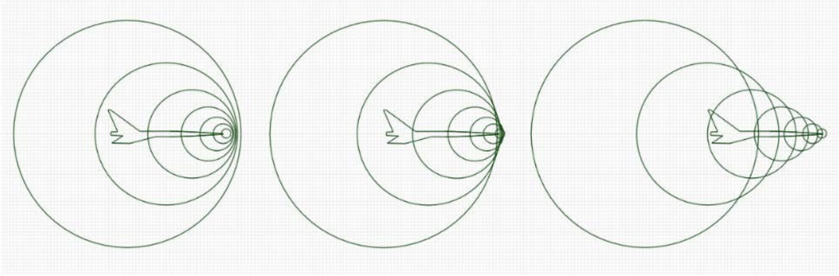
No longer a Symmetric configuration

→ *a coherent interference front is created*

Analogous phenomena (mechanical waves):

- Boat wake

- Supersonic plane



(a)Vs < V Subsonic (b)Vs >= V Slightly supersonic (c)Vs >> V Supersonic

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Frank e Tamm, photon spectrum:

- Photons are in the infrared, visible and UV range

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

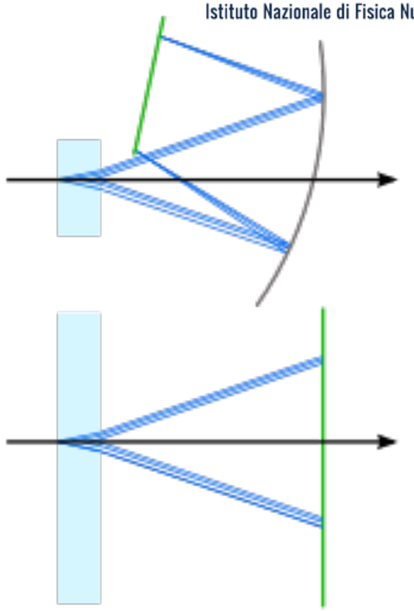
Fixing the radiator length L:

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

Integrating the spectrum:

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

$$N = 2\pi L Z^2\alpha\int_{\beta n>1}\left[1 - \left(\frac{\beta_t(\lambda)}{\beta}\right)^2\right]\frac{d\lambda}{\lambda^2}$$



- When β = 1, L = 1 and ΔE = 1 :

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

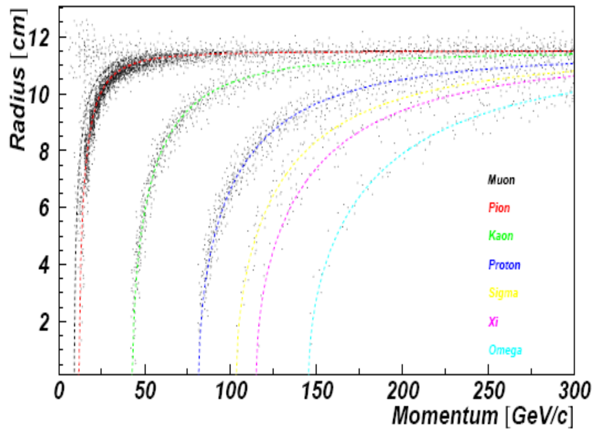
- Always:

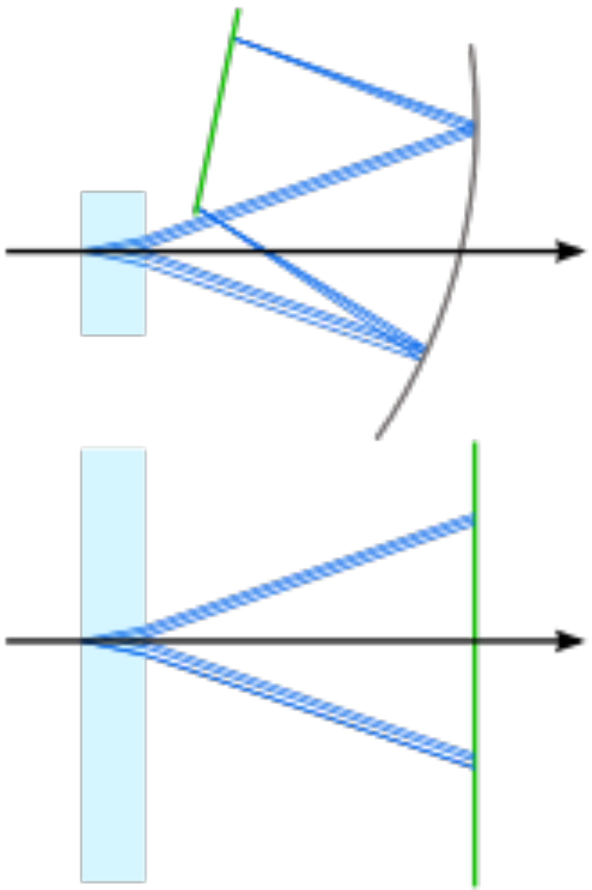
$$N \approx 1-1/(\beta n)^2 = \sin^2\theta_C$$

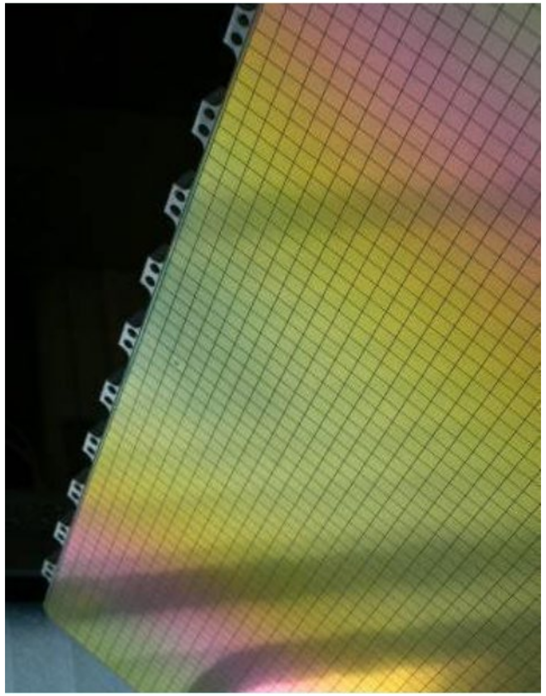
N is a mean value:

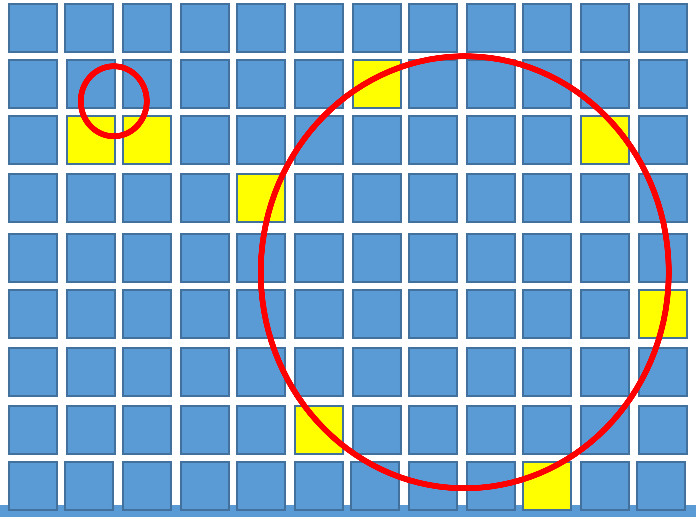
- Poisson statistics → v from a direct measurement of θ_C, not from N !!!
- A part when $Z^2 \neq 1$

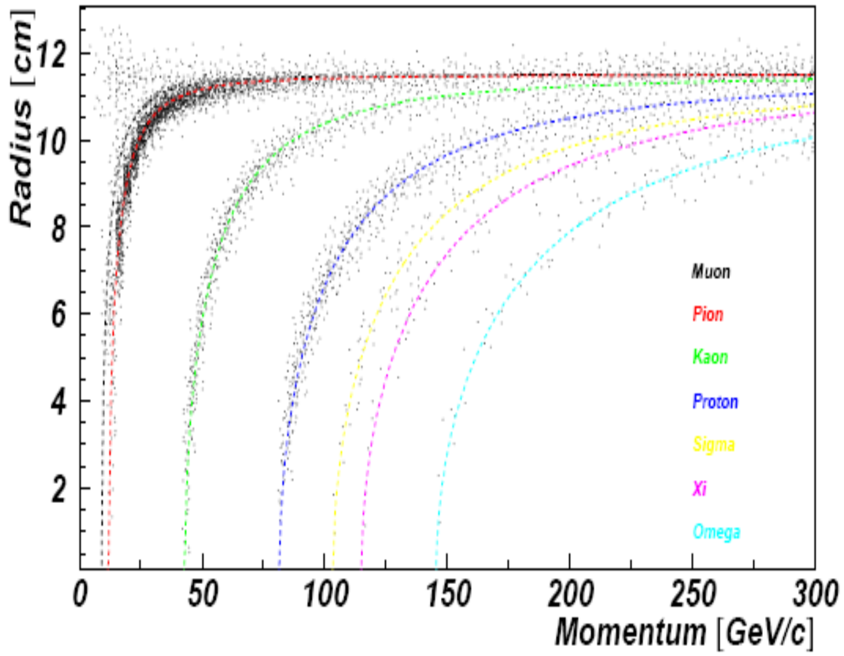
$$\cos(\theta_{Ch}) = \frac{1}{n\beta}$$





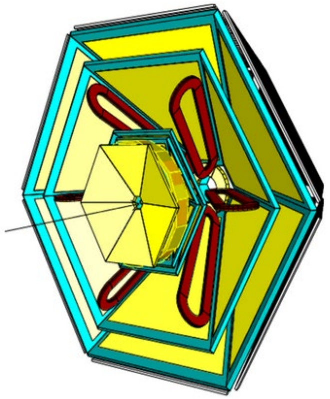




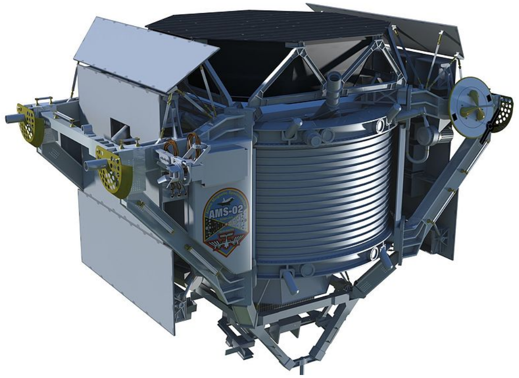


Resolution translates into electronic channel numbers

Single photon detection for Cherenkov imaging counters in HEP

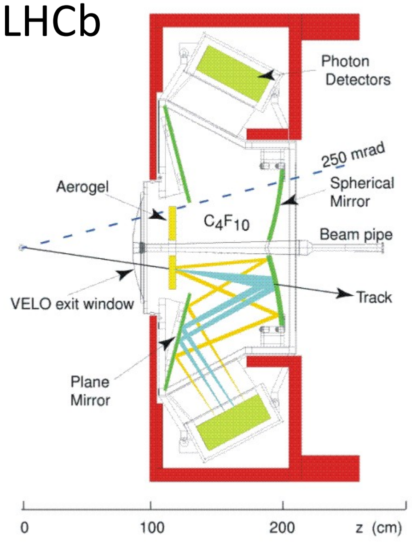


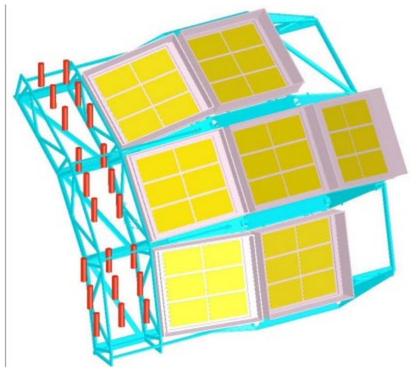
HADES at GSI,



AMS RICH

LHCb





Cherenkov imaging techniques (RICH counters)

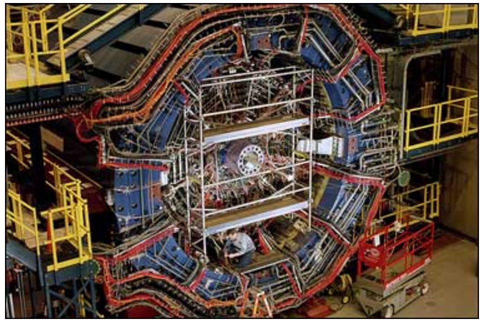
BELLE 2 KEK

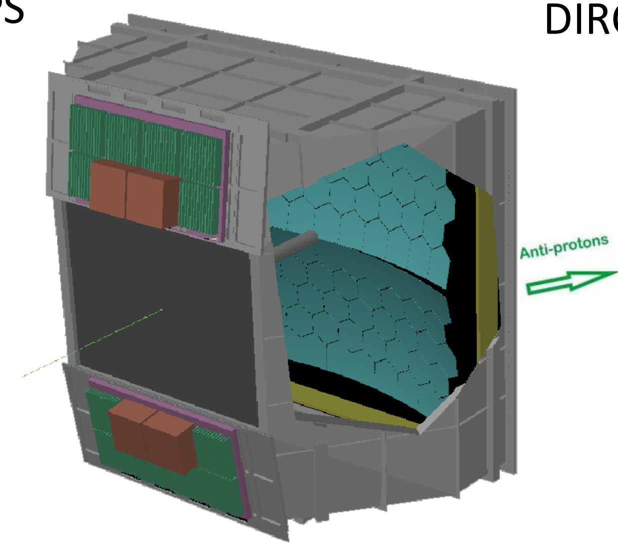
CLAS-12 JLAB

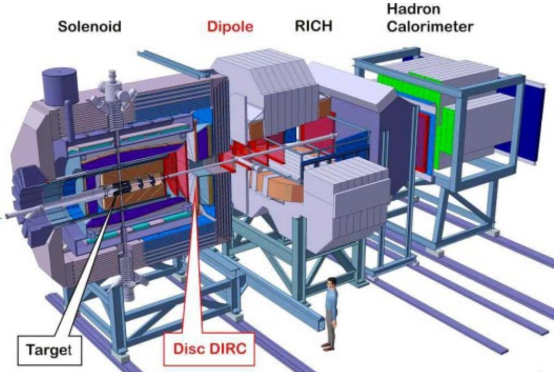
COMPASS at SPS

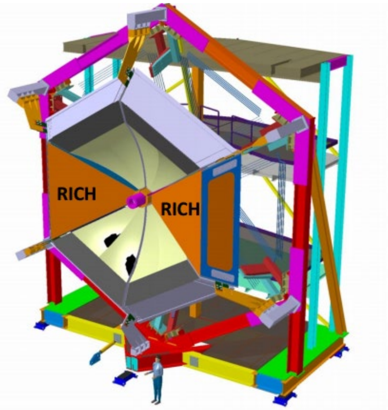
DIRC at PANDA GSI

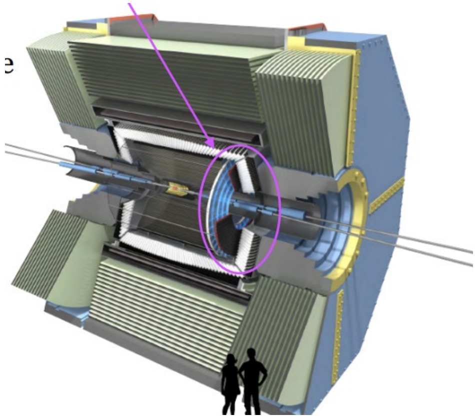
STAR-RICH at RHIC



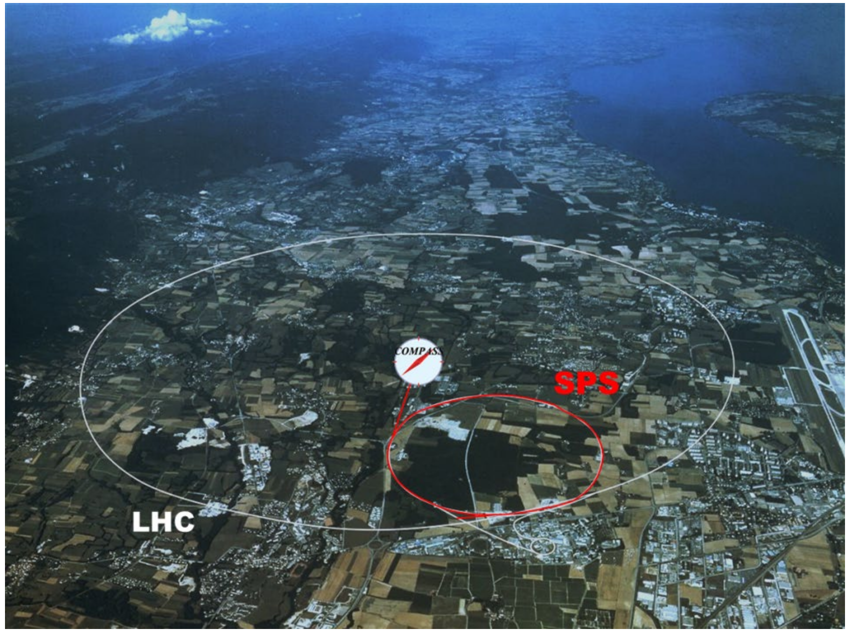








Their performance is **largely based** on that of the **single photon detectors employed**.



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)

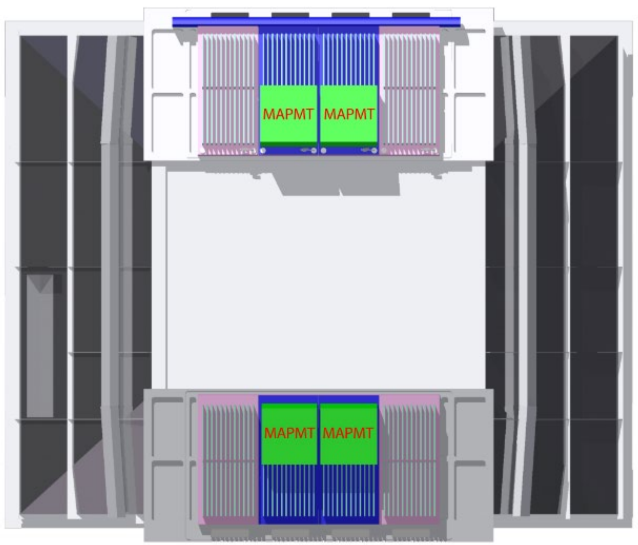
Experiments with muon beam	Experiments with hadron beams
Spin structure, Gluon polarization	Pion polarizability
Flavor decomposition	Diffractive and Central production
Transversity	Light meson spectroscopy
Transverse Momentum-dependent PDF	Baryon spectroscopy

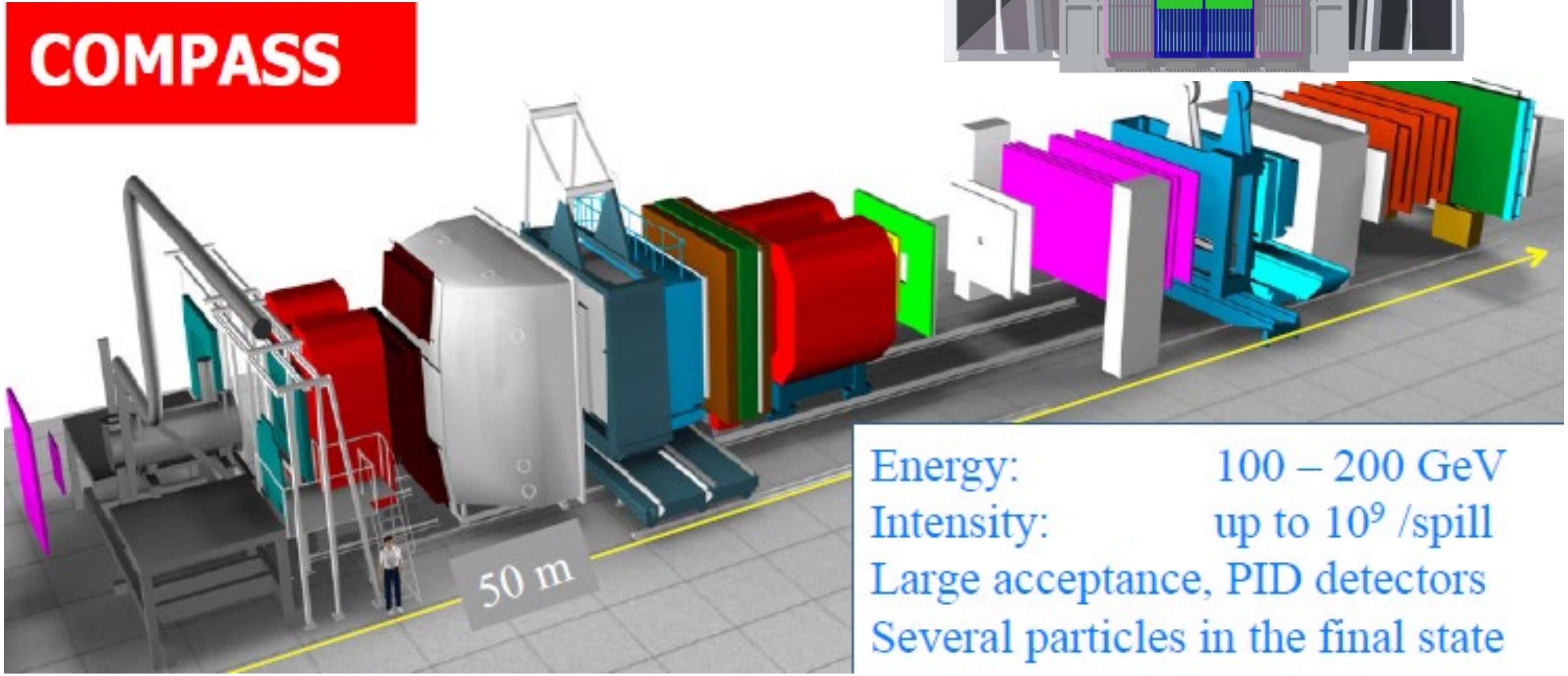
COMPASS - II (2012 – 2021) …

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

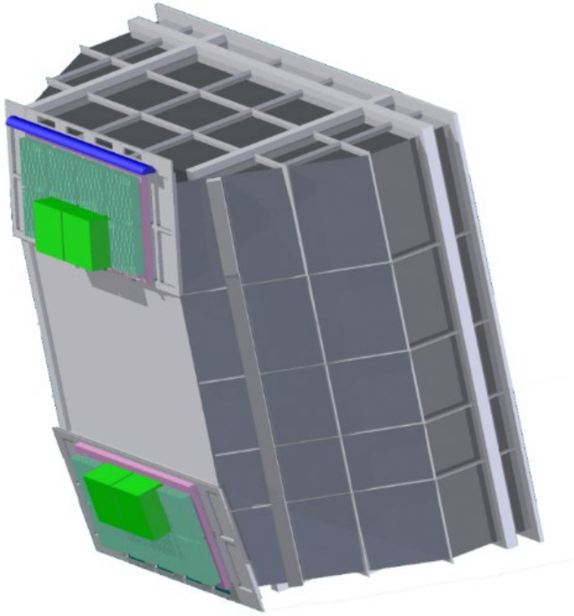
hadron spectroscopy (p, π, K)
- light mesons, glue-balls, exotic mesons
- polarisability of pion and kaon

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





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

Cherenkov light detection, MWPC with CsI photocathode: the nearly worldwide used architecture and its limitation

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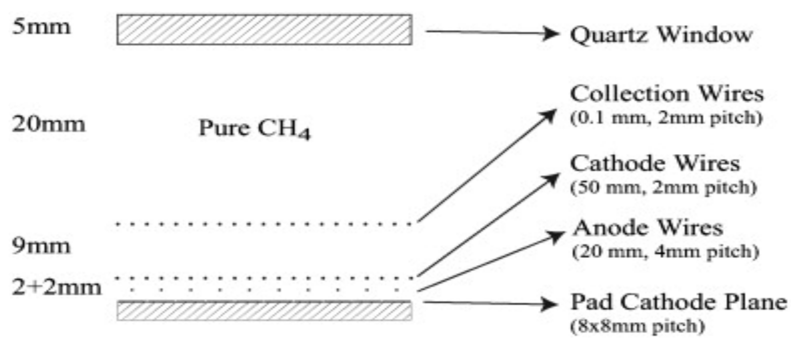
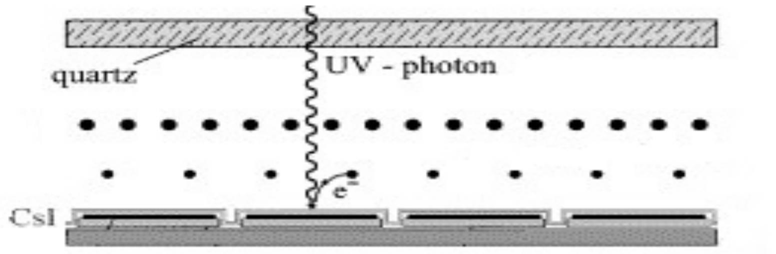
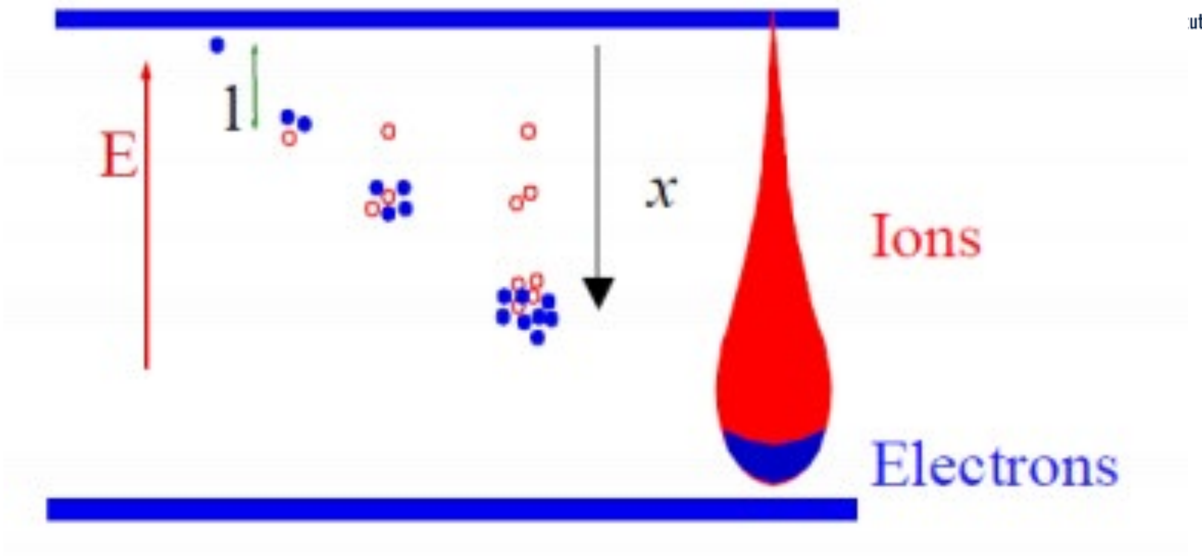
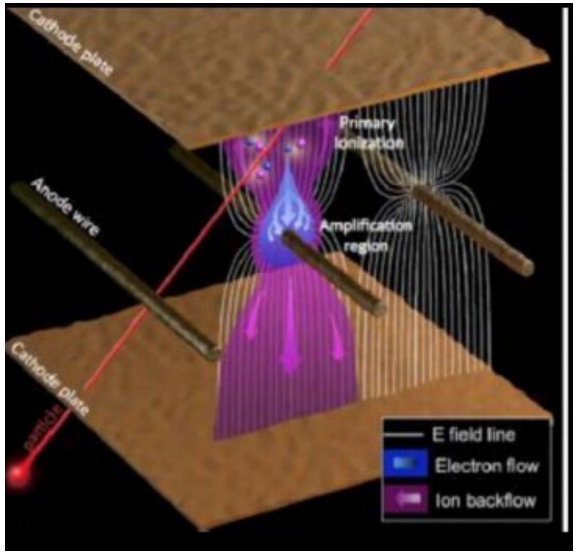








drift velocity of electrons in this region, it appears that the whole process of multiplication will take place in less than 1 nsec: at that instant, electrons have been collected on the anode and the positive ion sheath will drift towards the cathode at decreasing velocity. The detected signal, negative 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

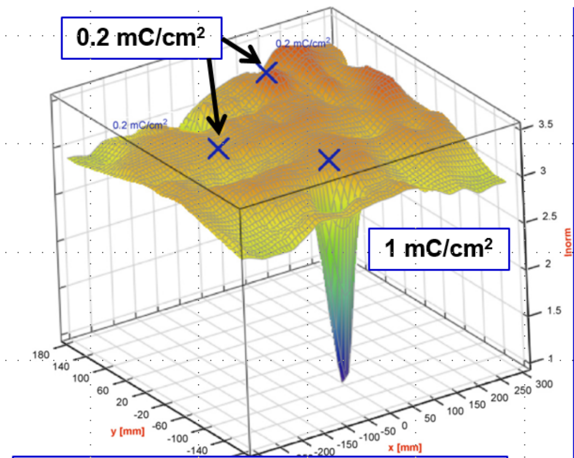
Reduced wire-cathode gap because of :

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

The RD-26 project

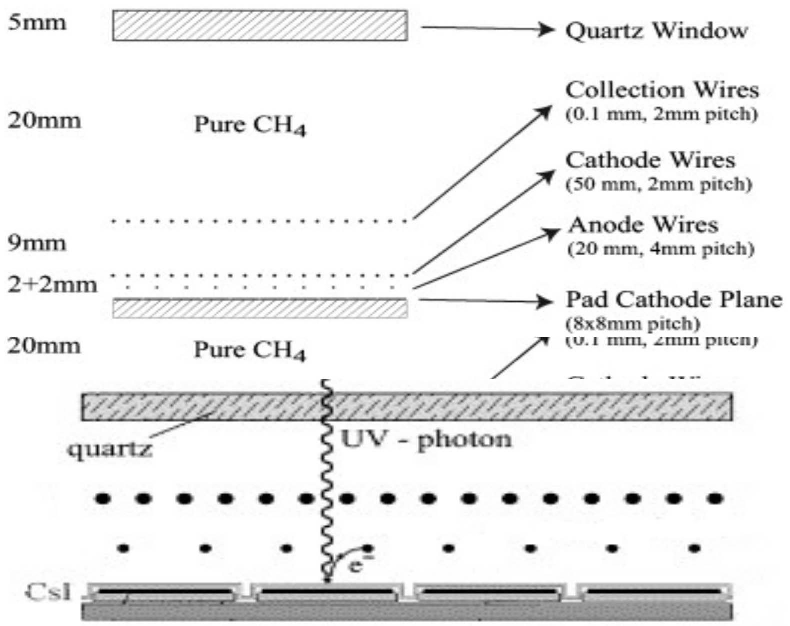
Launch of CERN/RD-26 project in 1992, by F. Piuz et al., :

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



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

Gaseous based



Use of the CsI as photon converter:
A revolution in the panorama of Cherenkov detectors

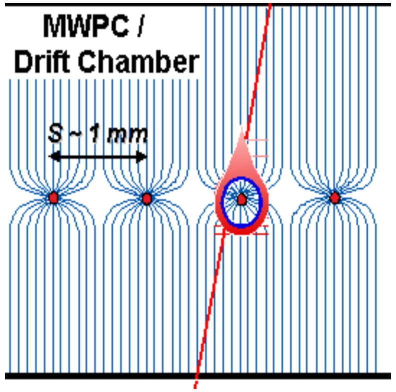
Anyhow this technology suffers from some limitations:

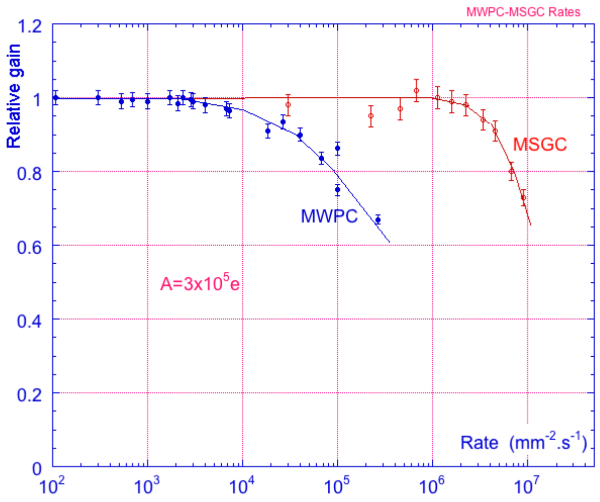
- Long recovery (1 day) time after a discharge occurs
- Ions accumulation at the photocathode: limitation in the maximum gain < 10^5
- Photon and ion feedback from the multiplication avalanche
- «Ageing» few mC / cm^2 reduction in the QE

Possible to overcome the limitations of this technology?

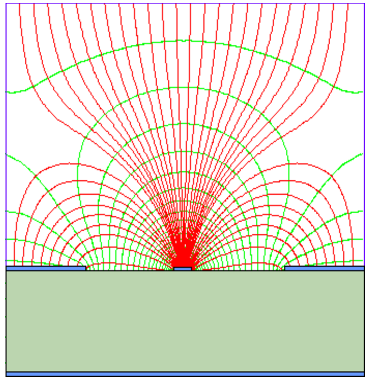
The keystone for the next generation of large single photon detectors: MicroPatternGaseousDetector (MPGD)

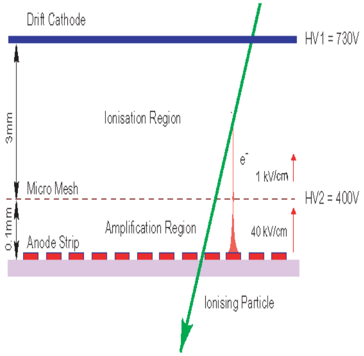
- Able to work and cope with high rate detection
- High gain achievable: gas gain
- Good time/space/E resolution
- Robust: ageing robustness
- Natural Ion Backflow/Photon feedback reduction CG
- Low cost large size detector production possible
- Intrinsically fast: signal is induced by electrons…!

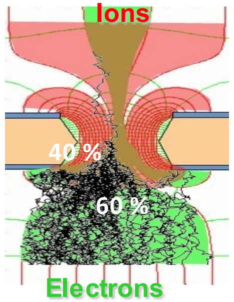


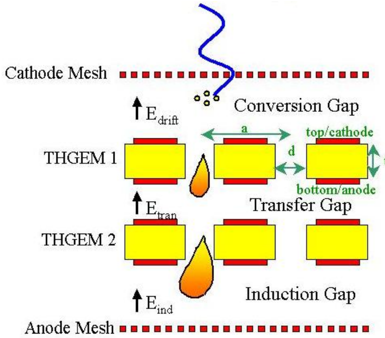


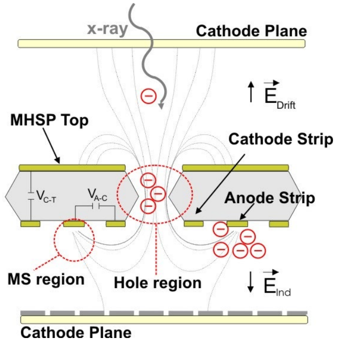
Rate Capability Comparison for MWPC and MSGC

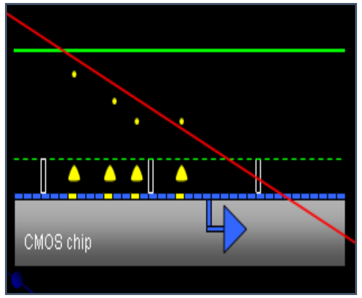


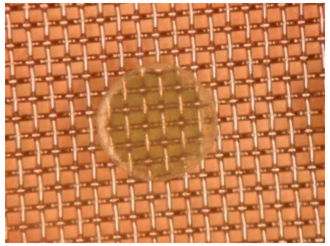




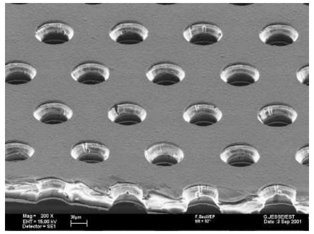


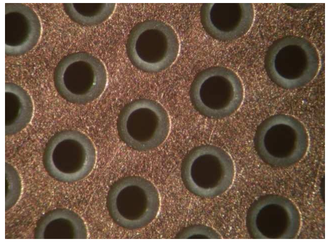


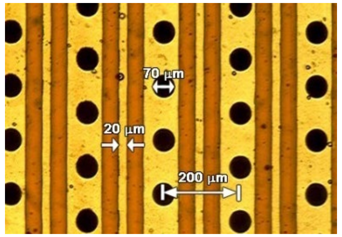




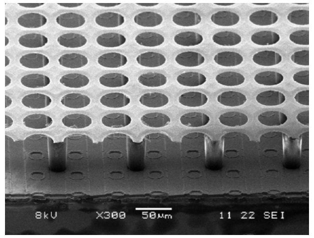
Micromegas



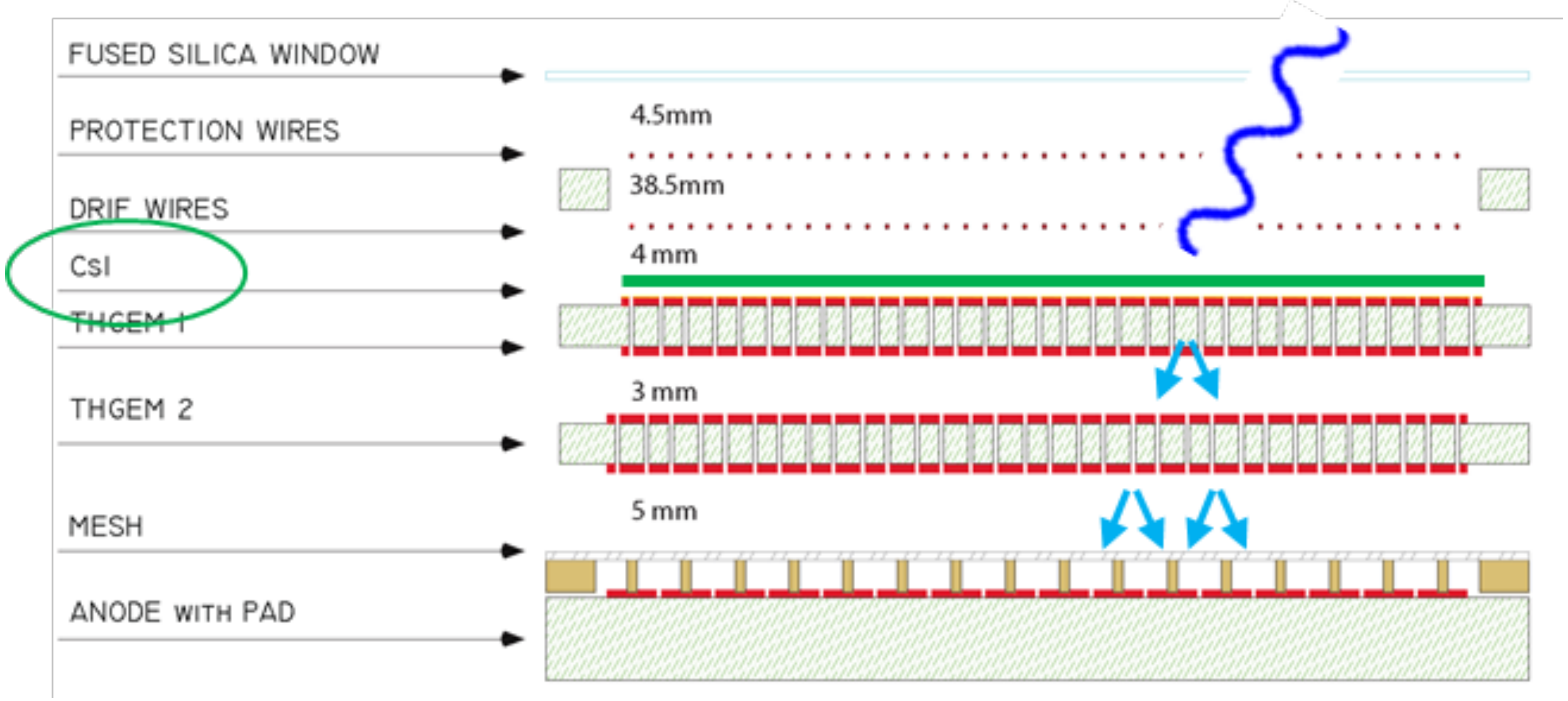


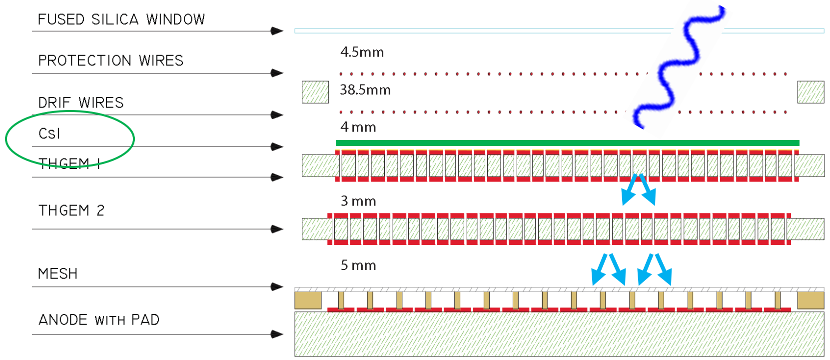


MHSP



Ingrid


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



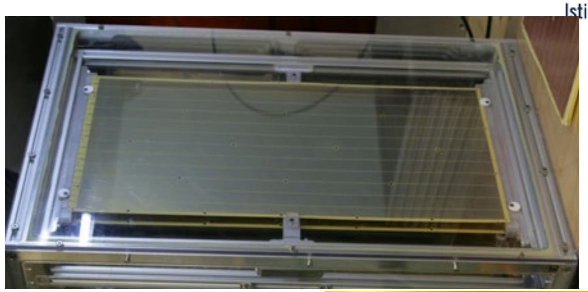
IBF reduction: approx. 3%

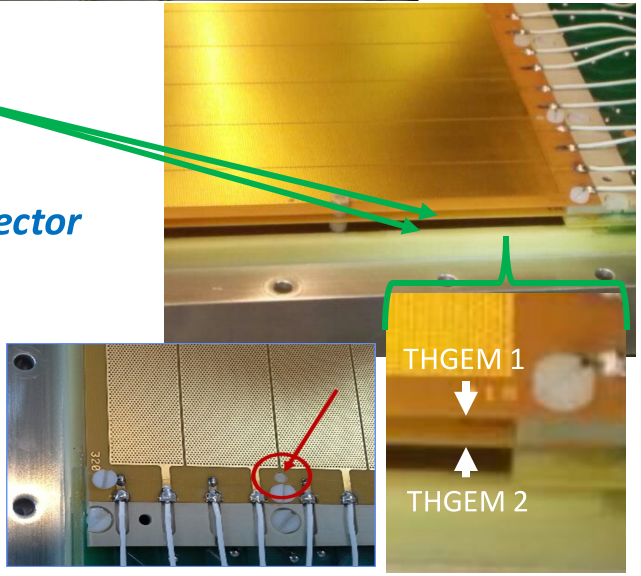
Charge splitting processes → Larger Gas Gain

Hybrid detector concept

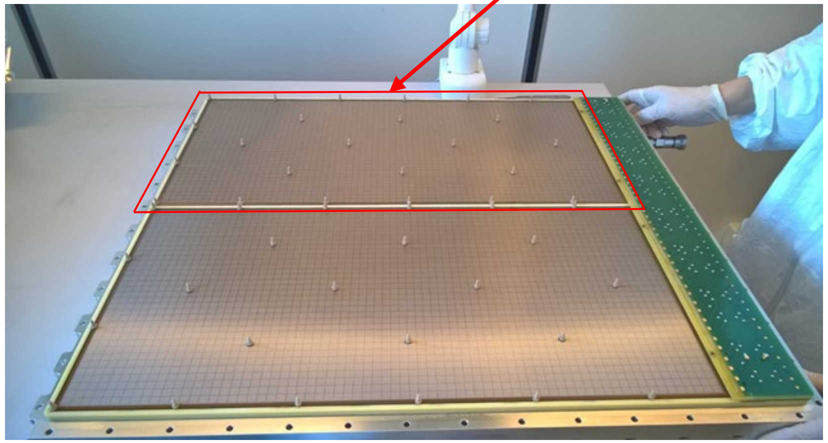
To simplify the construction requirements a modular architecture has been adopted where one "*module*" consists of:

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

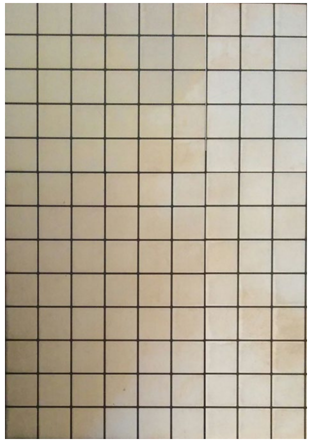


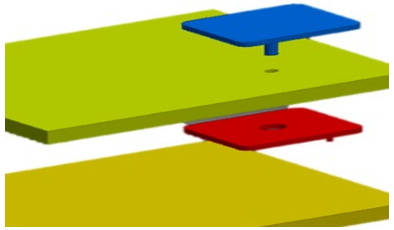


Two modules are put side by side to build a 600 mm x 600 mm detector



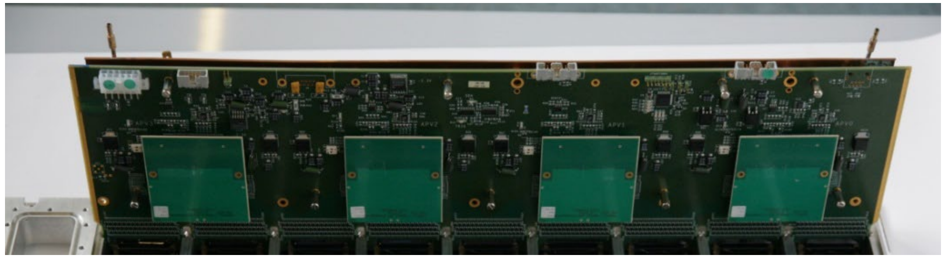
Signal read out via capacitive coupling pad readout and APV25 F/E boards

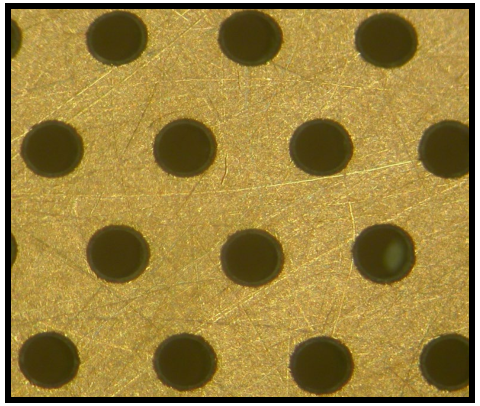




8mmx8mm pad size

0.5 mm pad spacing

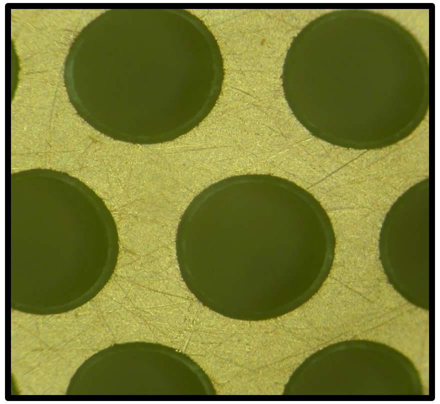


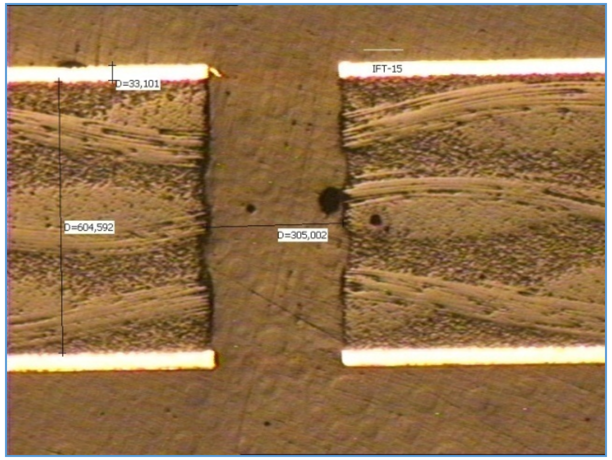


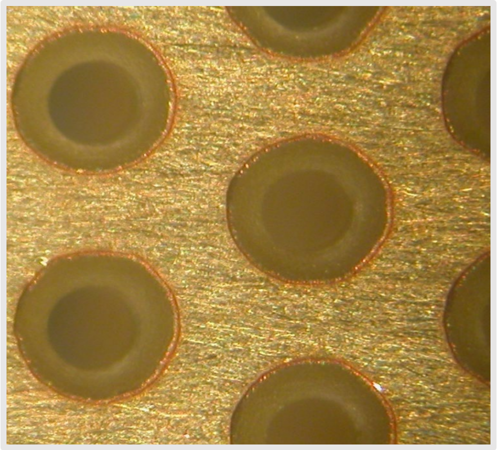
Use of the industrial technology to produce Printed Circuit Boards

- 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





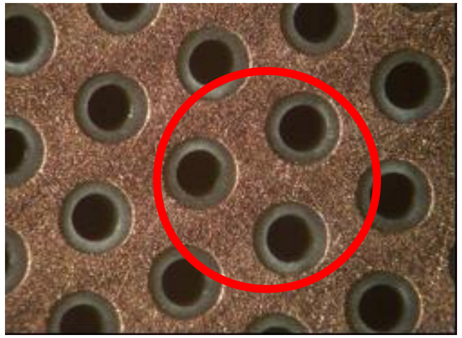


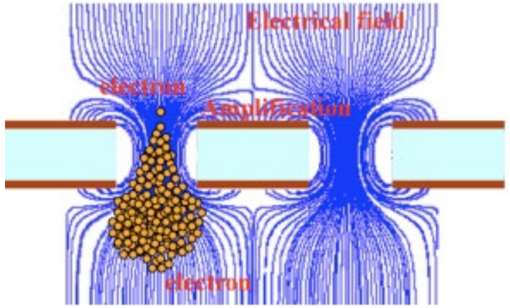
About PCB geometrical dimensions:
Hole diameter : 0.2 – 1 mm
Pitch : 0.5 – 5 mm
Thickness : 0.2 – 3 mm

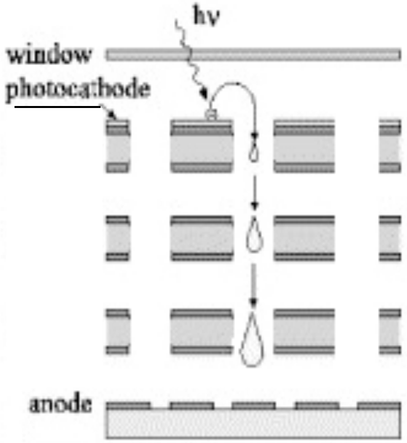
introduced in // by different groups:
L. Periale et al., NIM A478 (2002) 377.
P. Jeanneret, PhD thesis, Neuchatel U., 2001.
P.S. Barbeau et al, IEEE NS50 (2003) 1285
R. Chechik et al, .NIMA 535 (2004) 303

THGEM: characterization campaign

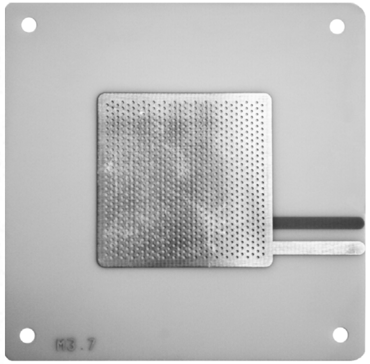
THGEMs are electron multipliers derived from the gem concept changing geometrical dimensions and production technology. (ELTOS Arezzo)

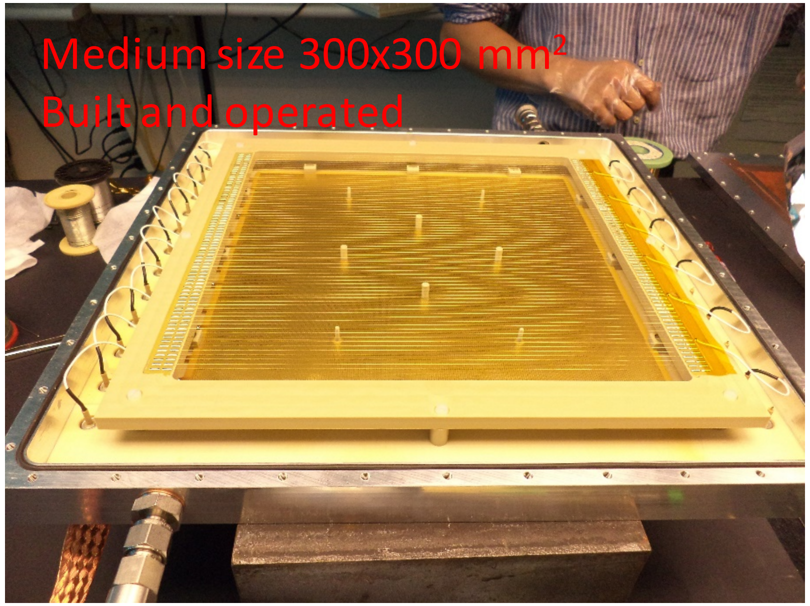




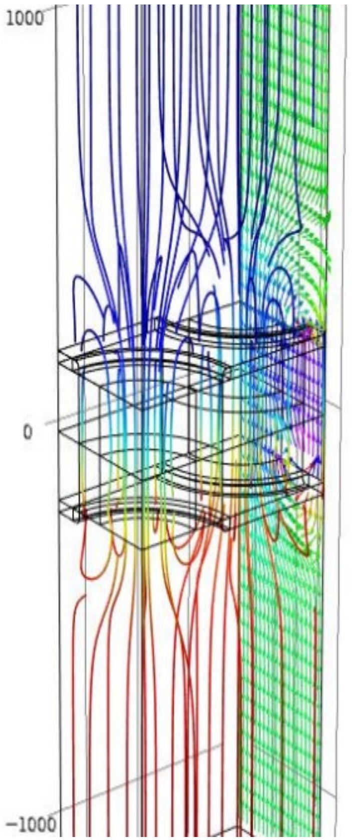


Small size 30x30 mm^2
Built and operated





Electrostatic simulations

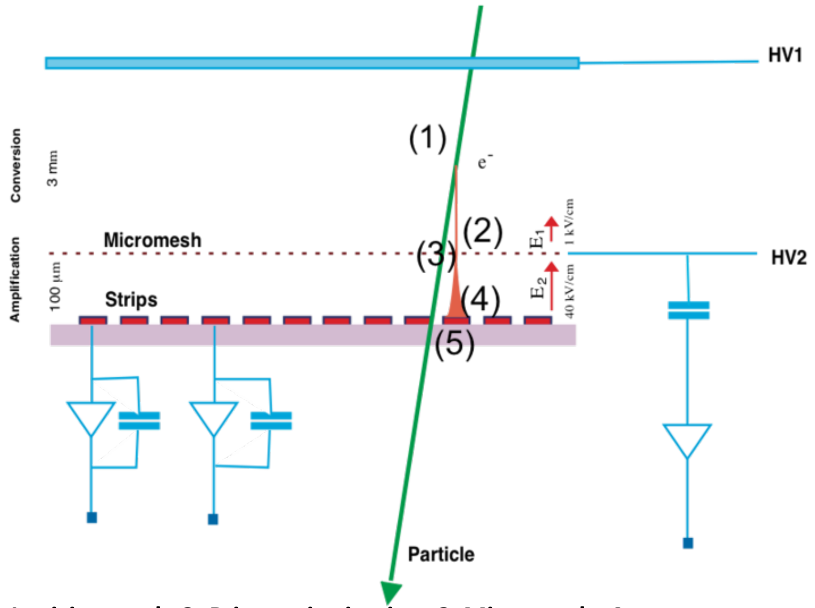


Characterisation of small 10cm^{2}size THGEM prototypes

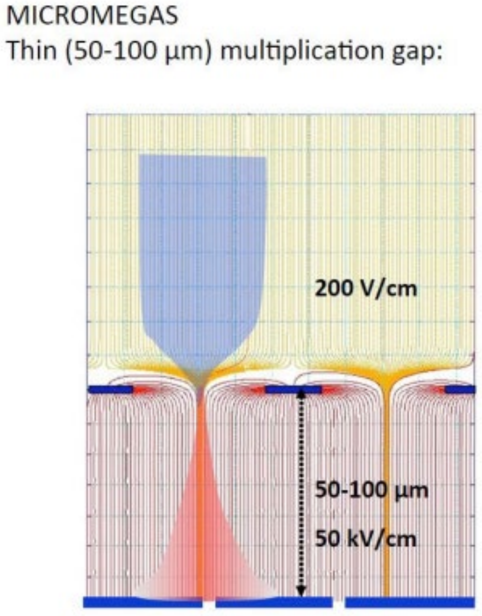
- Using X-ray sources
- Using UV light sources
- With Cherenkov light at the test beams
- Analogic read-out, single channel
- Digital read-out, 1 channel per anode pad
- Read-out of the current on the various electrodes

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



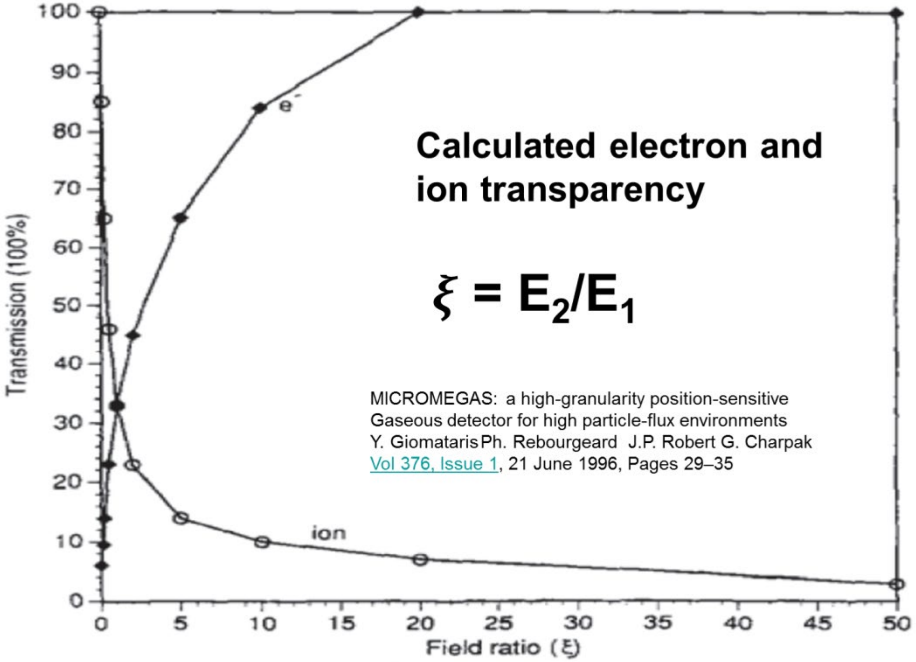
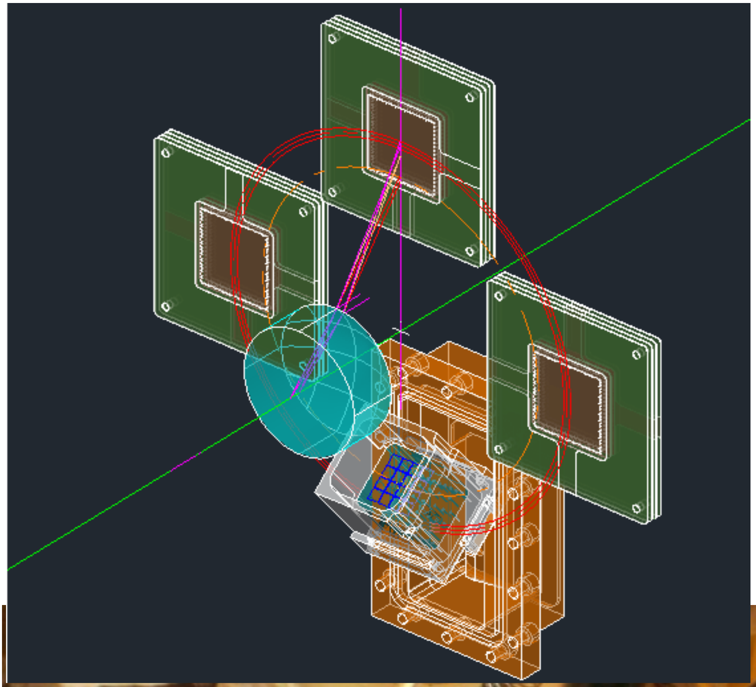
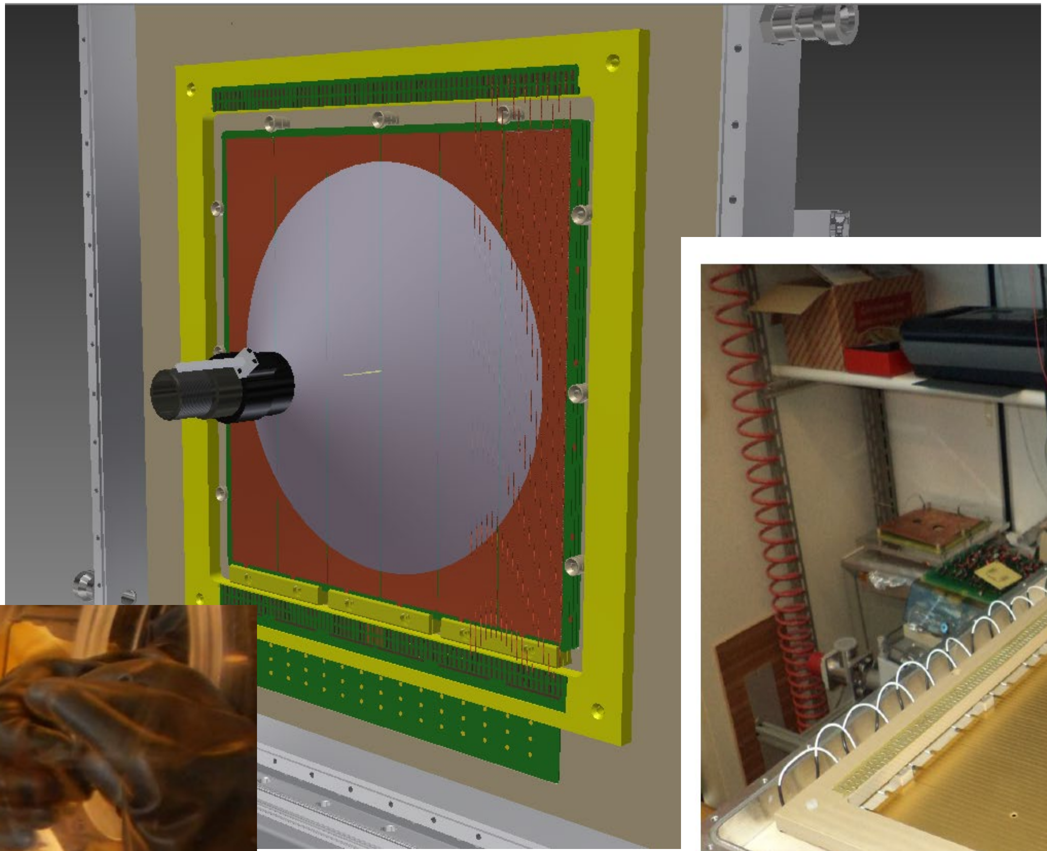
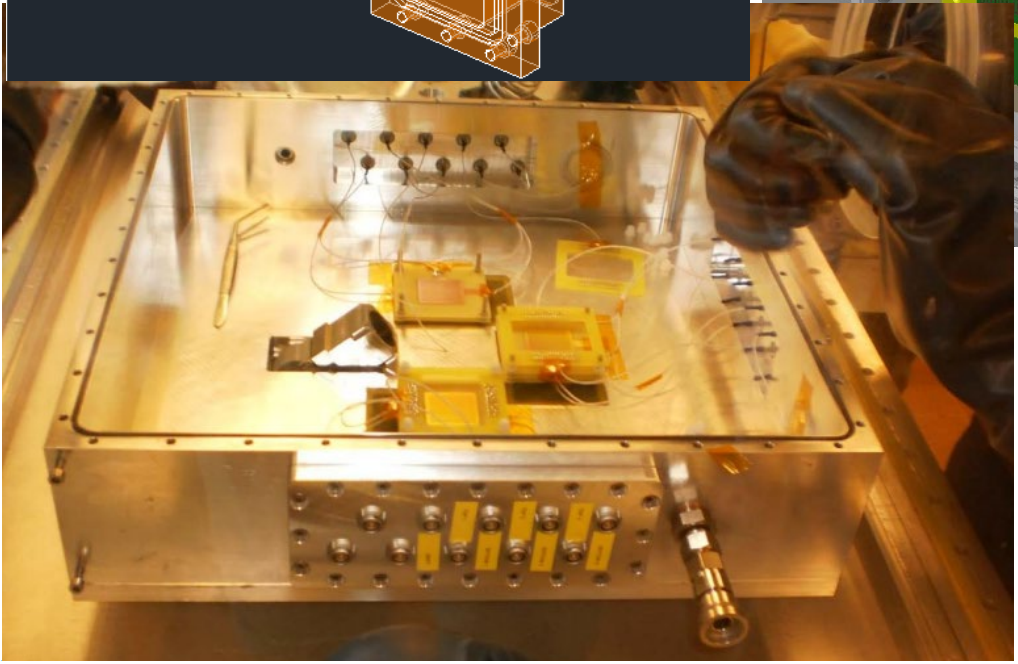


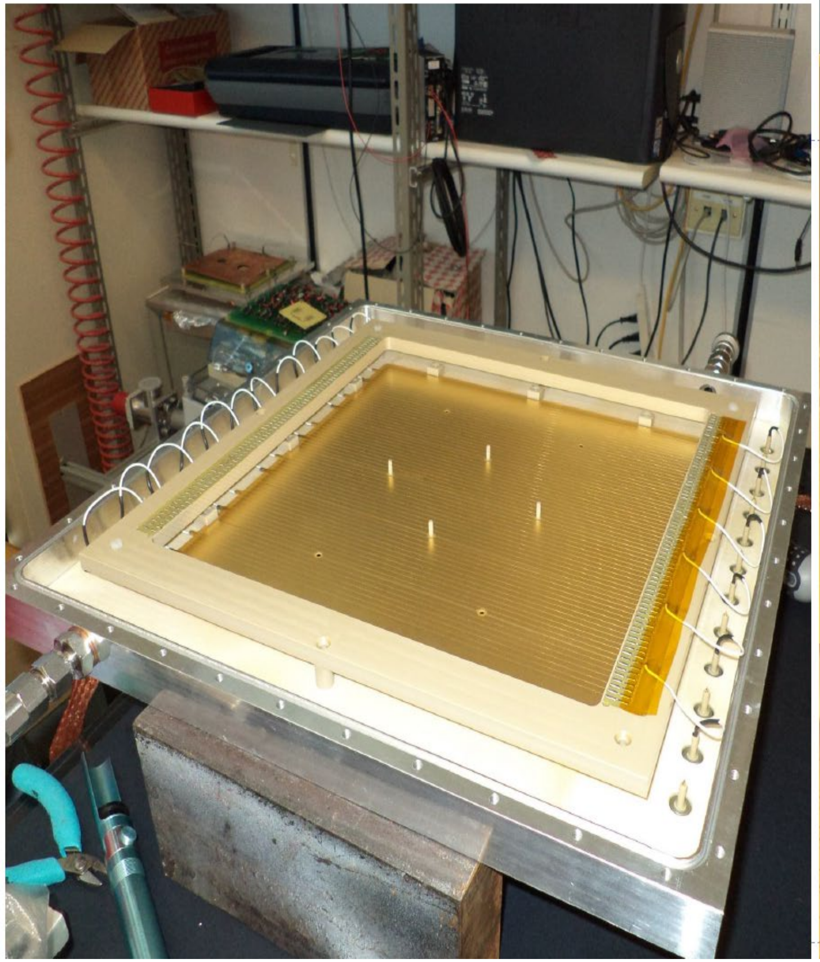
Fig. 5. Calculated electron and ion transparency.

THGEM as single photon detector: test beam campaign







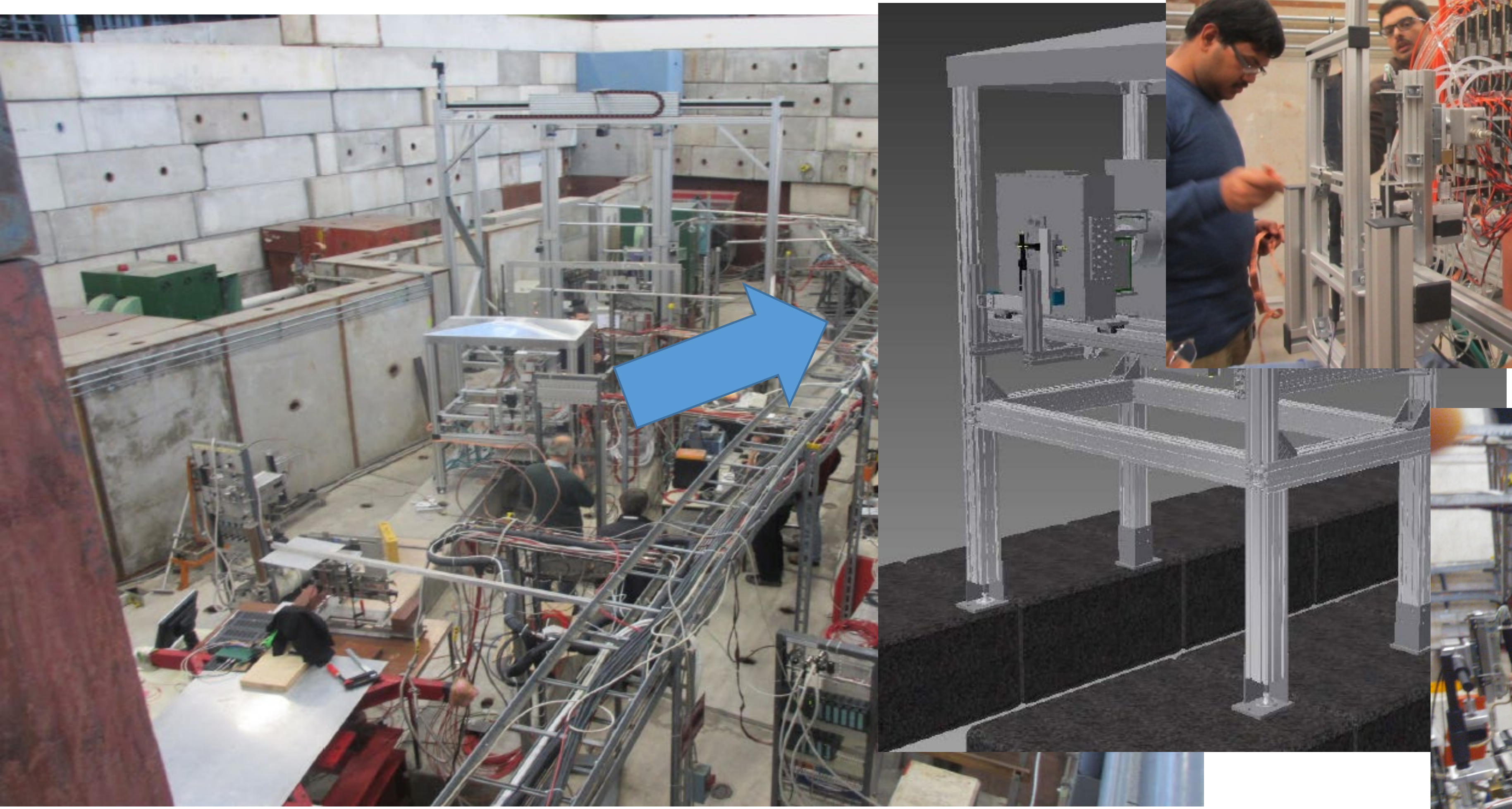


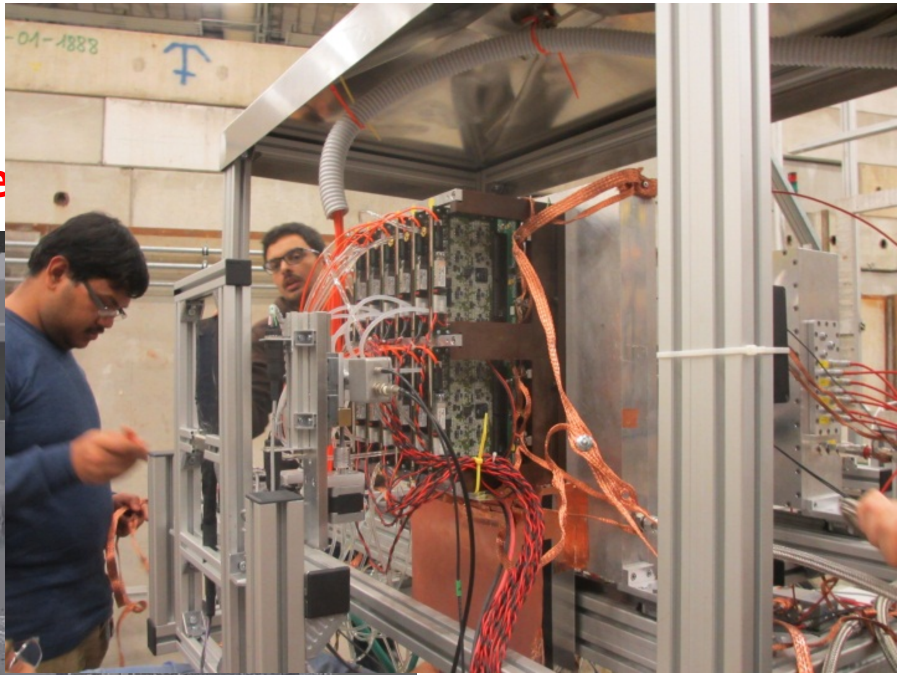
THGEM as single photon detector, test beam

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



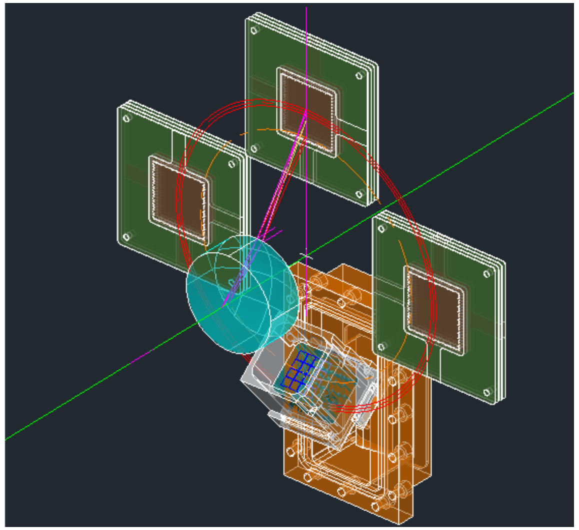


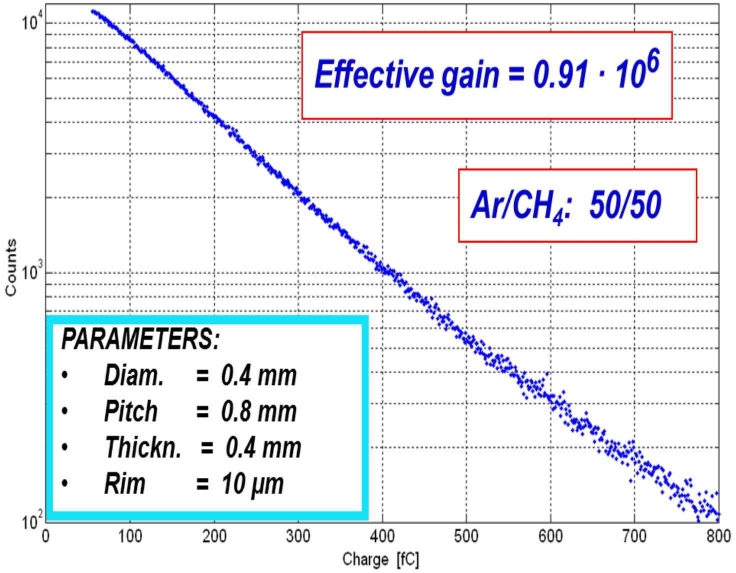
THGEM as single photon detector, test beam

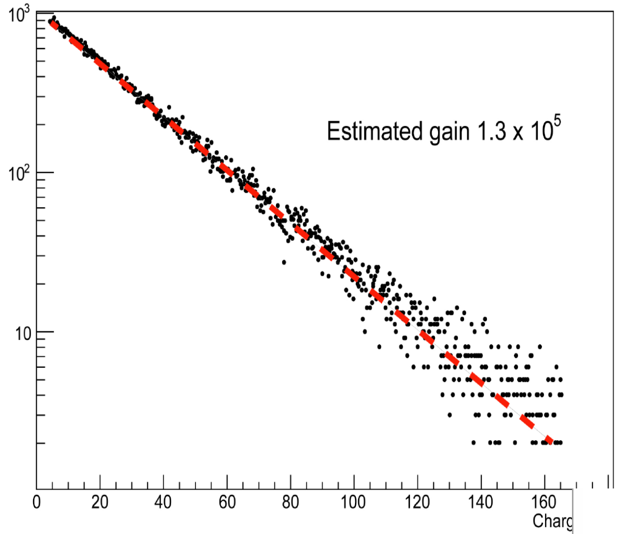
For small prototypes Ar/CH4 60-40%

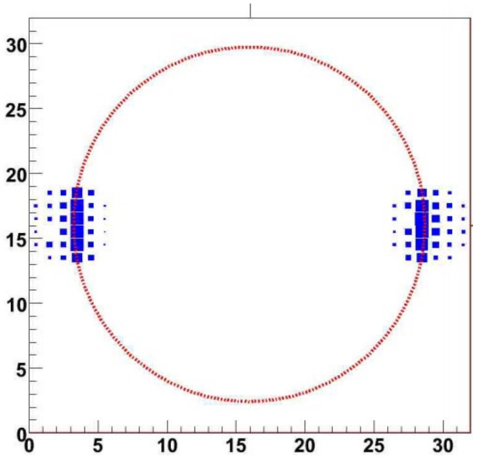
Gain achieved in laboratory with triple THGEM structures (stable condition) and UV light 0.9 10^6

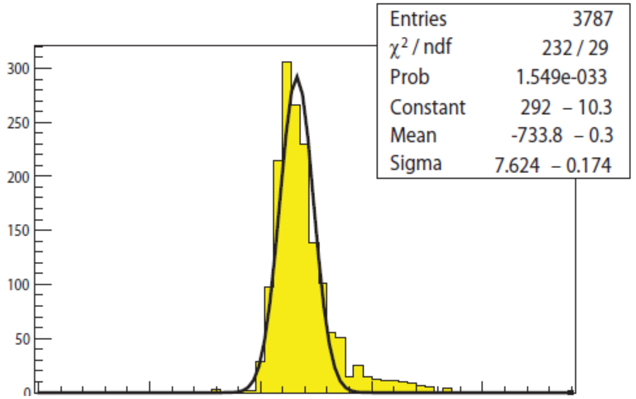
Gain achieved in test beams with triple THGEM structures (stable condition) and Cherenkov light from quartz radiator 1 10^5









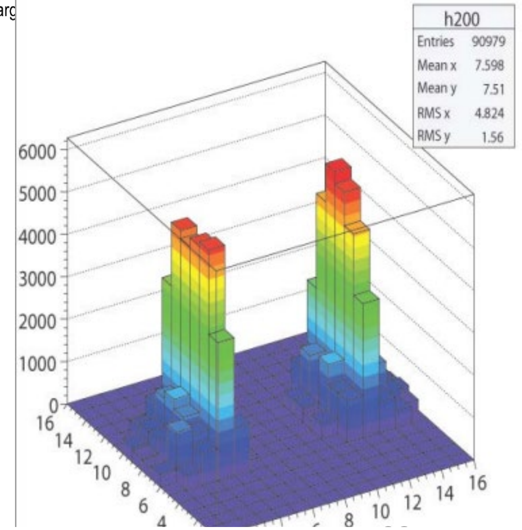


Small size PD's (active area = 30x30 mm2):

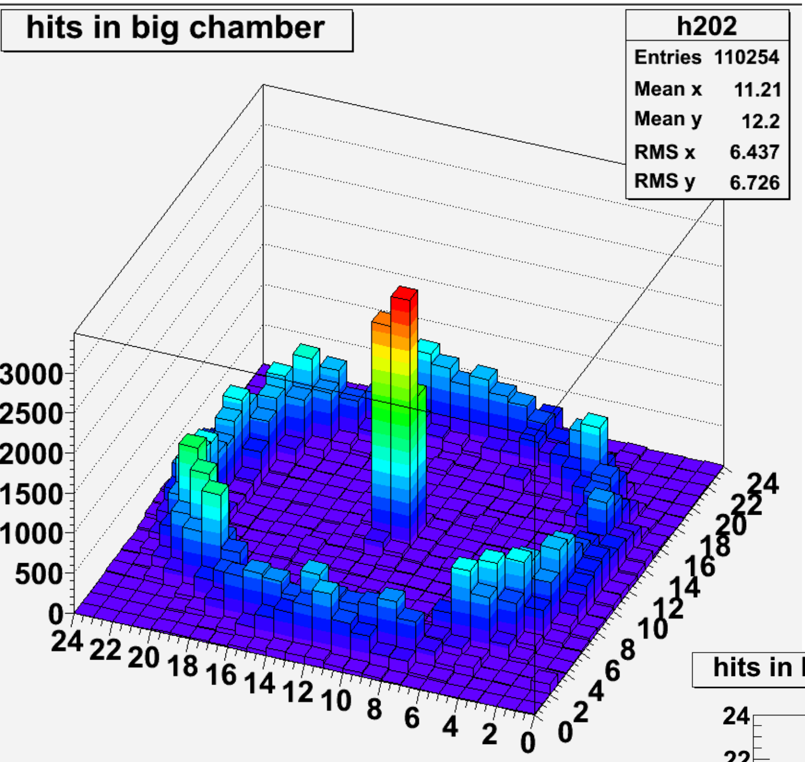
typical max. stable gain: with UV light in lab: 1 M
during test beam: 0.2 M

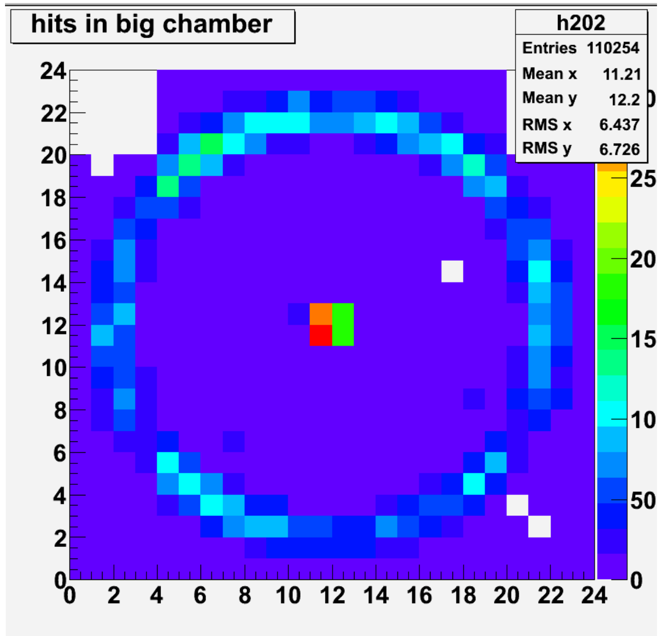
efficient detection of single photons

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

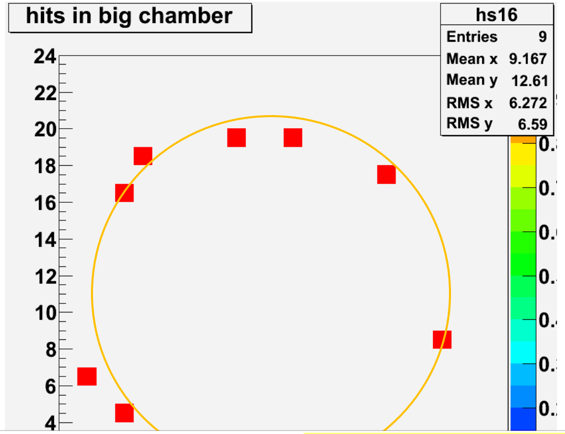


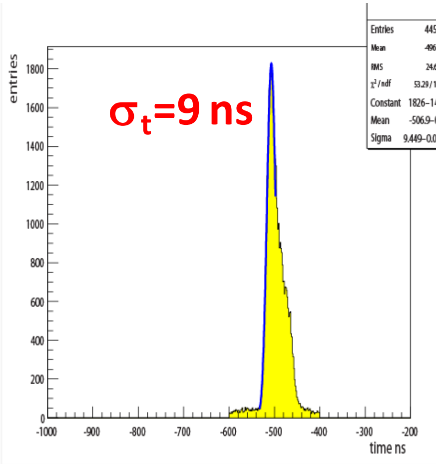
THGEM as single photon detector: large size prototype performance with Cherenkov light from conical radiator

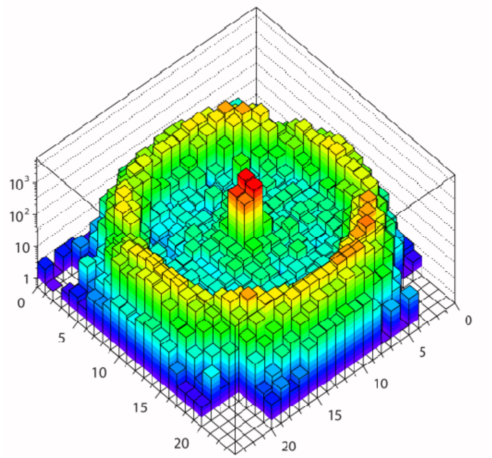


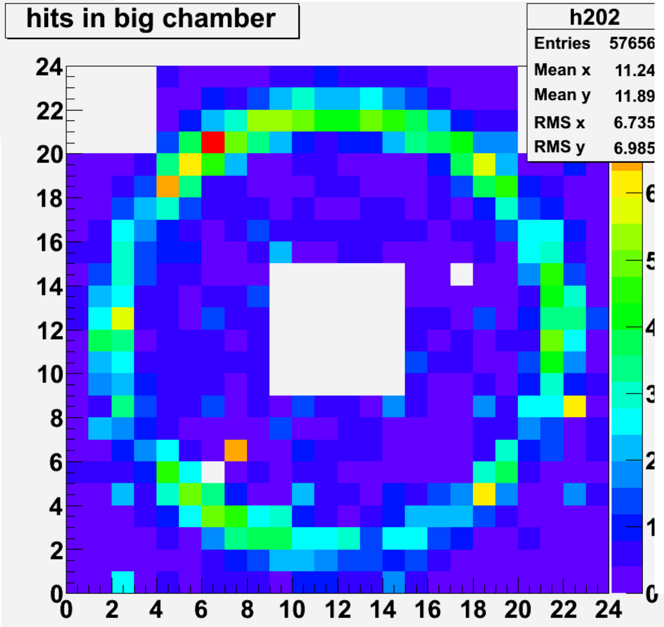


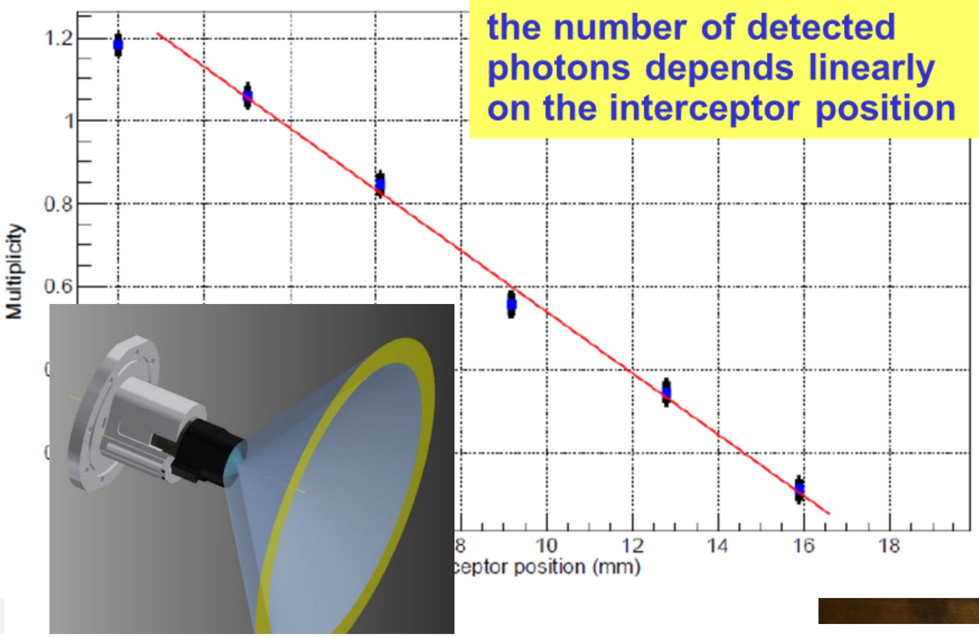
HV Settings
(7400,7520,7450,7400,7400,7350),
Threshold (FE) 2-3 fC



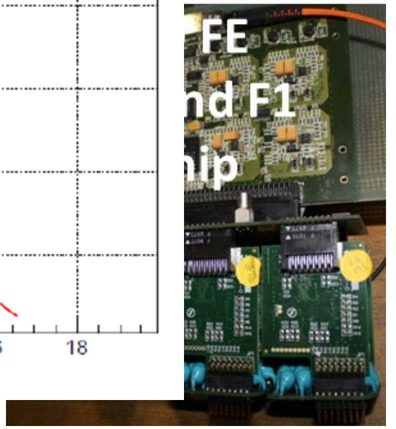






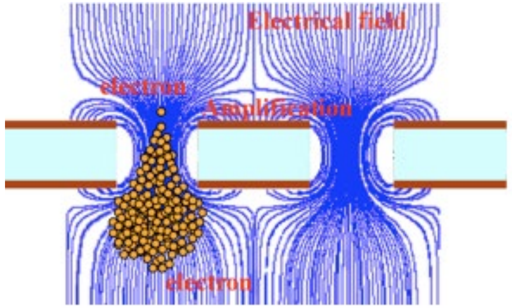


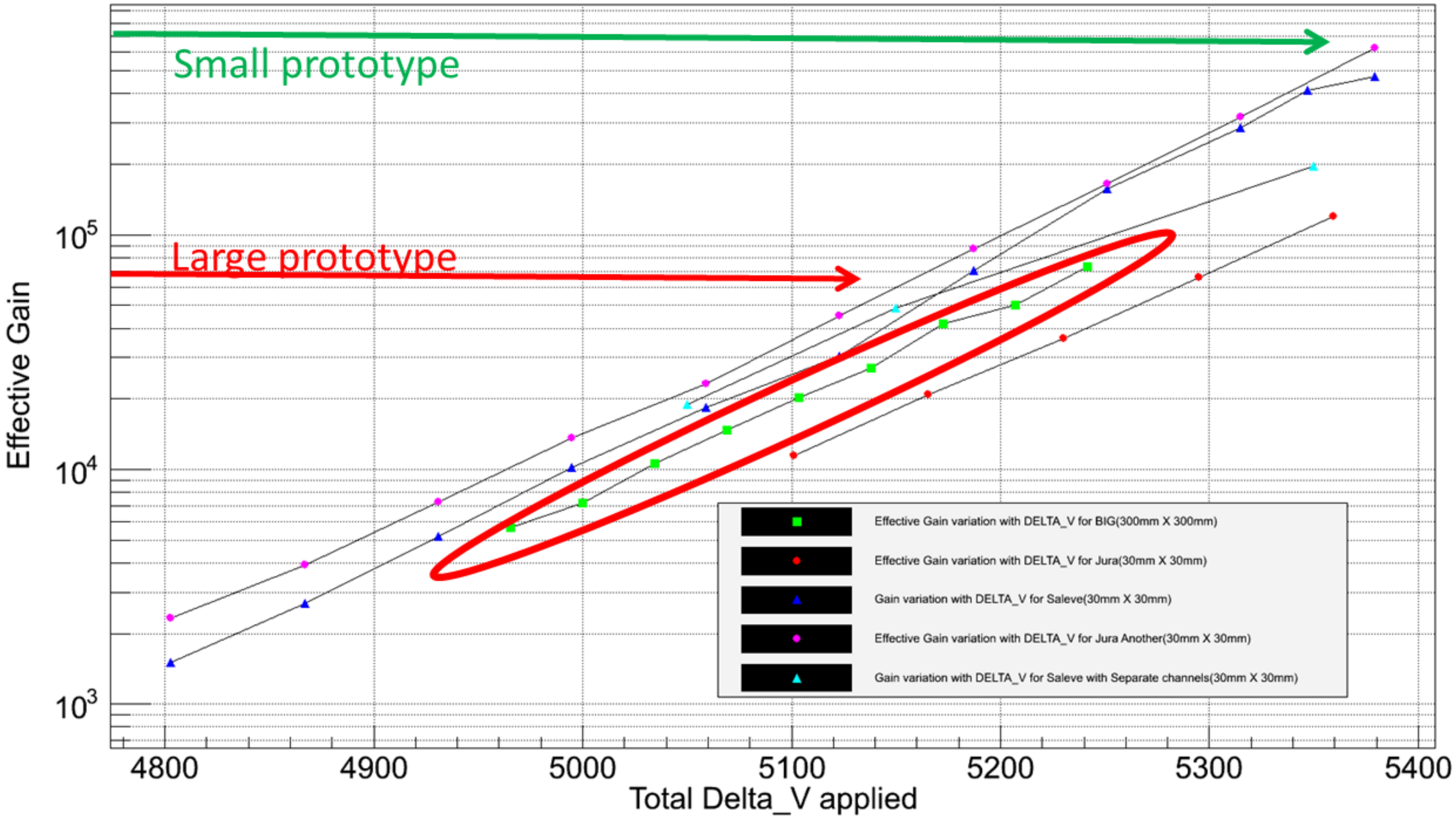
the number of detected photons depends linearly on the interceptor position



THGEM as single photon detector: large size prototype performance

For larger size prototypes (300x300mm^2) Ar/CH4 60-40%:
Gain achieved in test beams with triple THGEM structures
Cherenkov light from quartz radiator 2 10^4

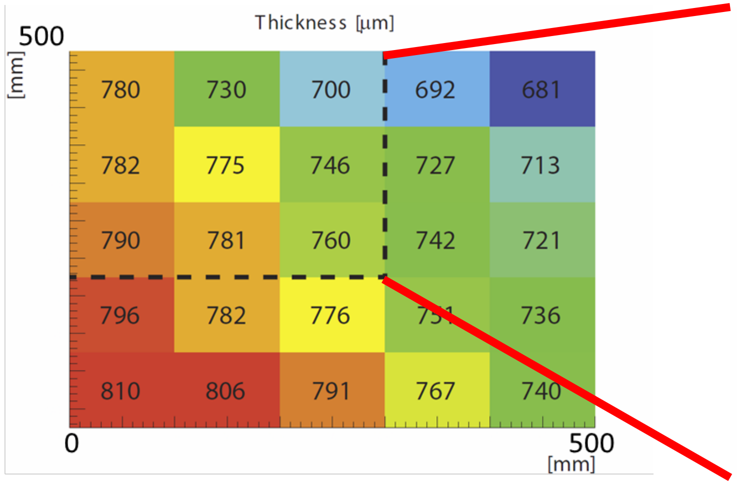


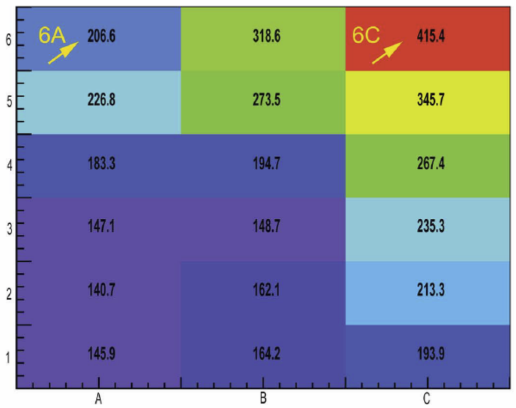


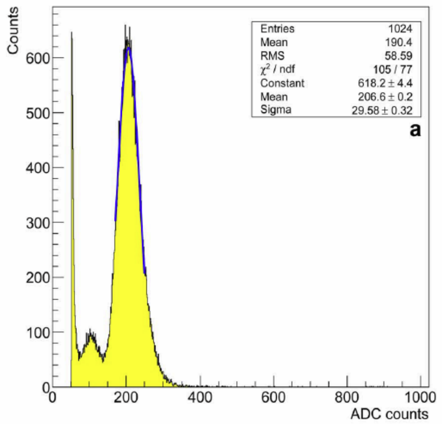
The thickness uniformity plays an essential role in defining the gain achievable

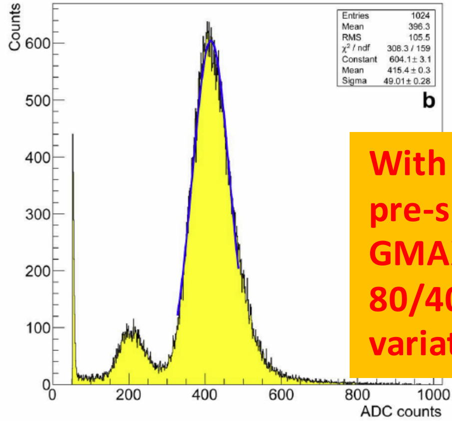
the maximum gain is limited by the thinner area, standard PCB variation 30% , our requirements <2%.

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

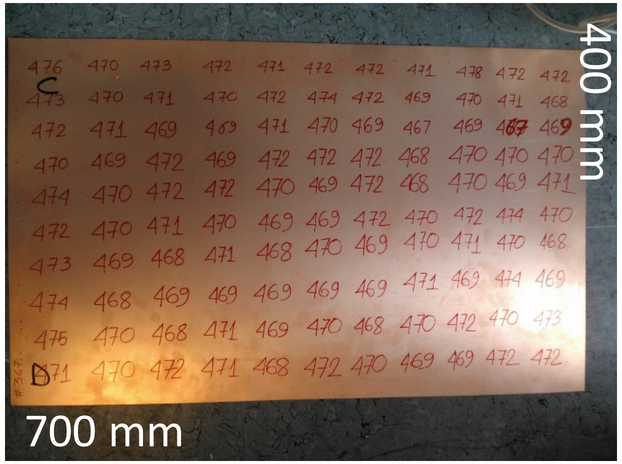




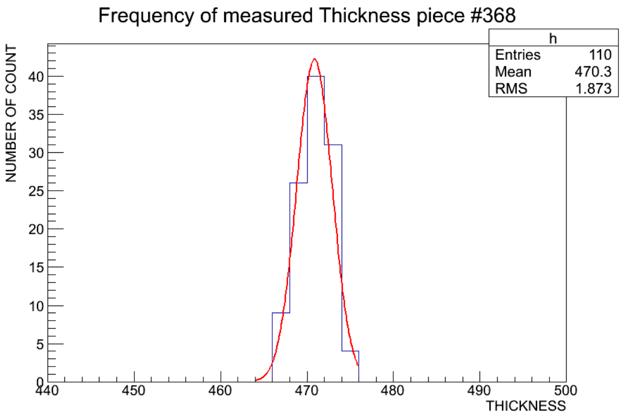


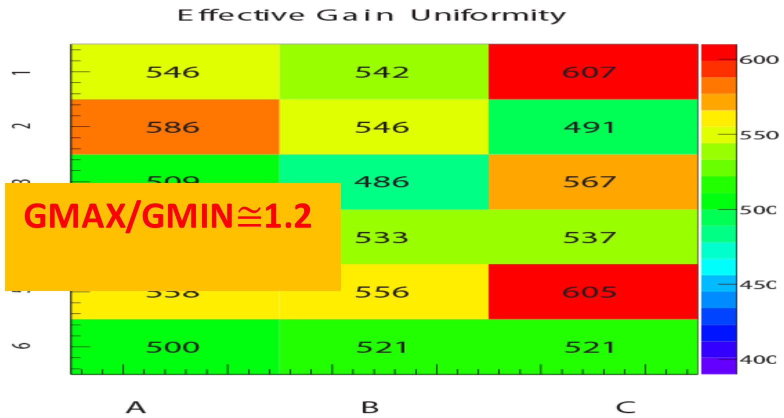


With no material pre-selection GMAX/GMIN≅2.9 80/400 mm variation



<u>With</u> material preselection $\sigma_{thickness}$ ≅2µm

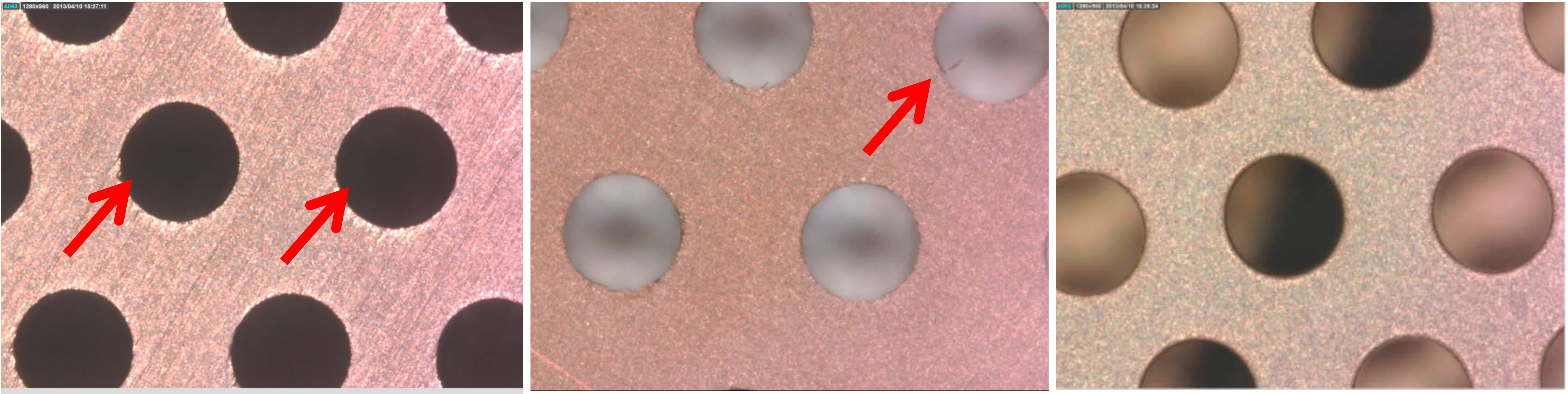




GMAX/GMIN≅1.2

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

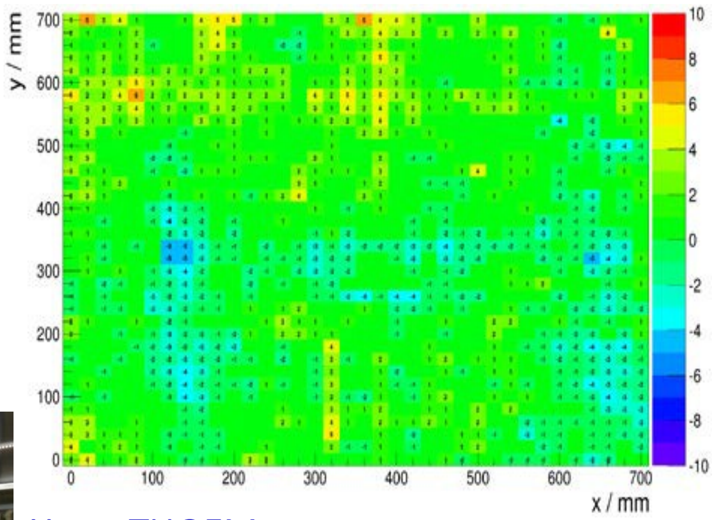
Based on fine pumice grain polishing, high pressure washing and ultrasonic bath in mild commercial etching solution

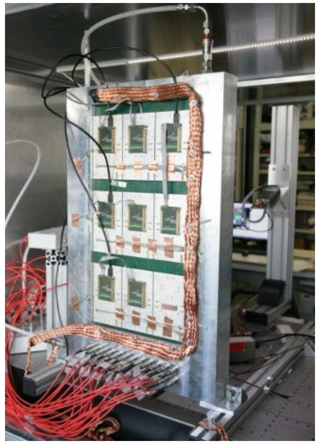


THGEM and Micromegas: quality assessment

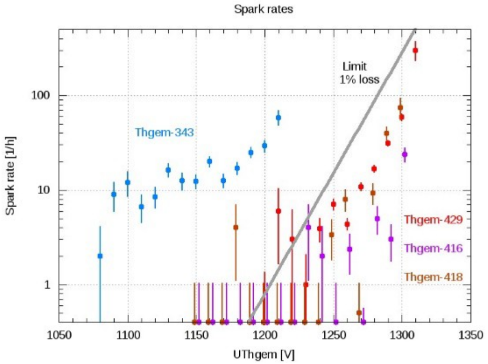
INFN
Istituto Nazionale di Fisica Nucleare

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



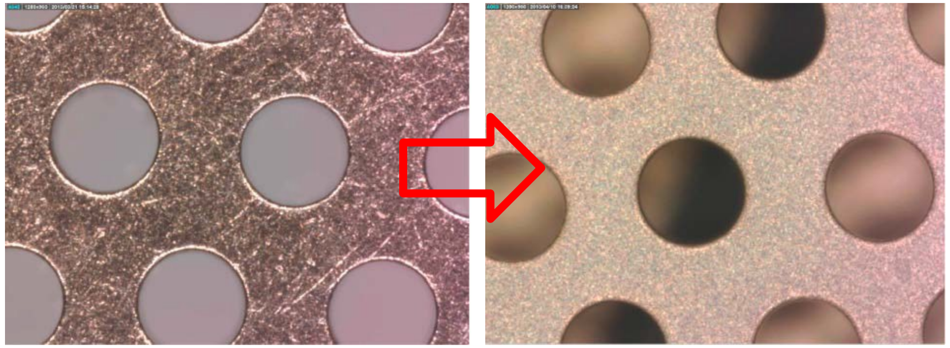


X-ray THGEM test to access gain uniformity (<7%) and spark behaviour



188	202	185	198	206	207
196	207	196	198	199	207
192		193	198	204	204
192		188	199	202	205
199	199	191	195	195	
199	196	199	205	195	199
192	190	194	197	195	194
198	190	195	209	195	199
198	199	195	208	197	201
198	199	195	199	200	199
190	186	185	199	190	199

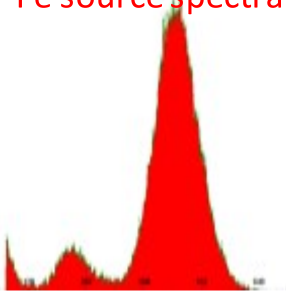
THGEM polishing with an "ad hoc" protocol setup by us *including backing*:
>90% break-down limit obtained

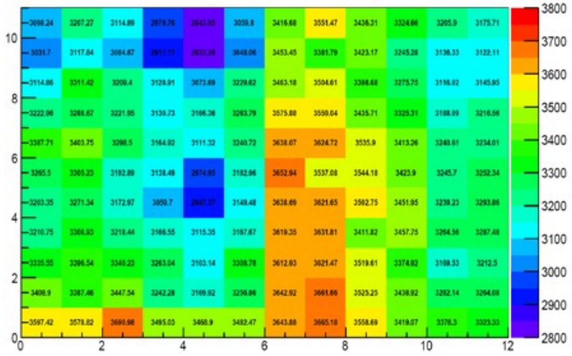


MICROMEGAS

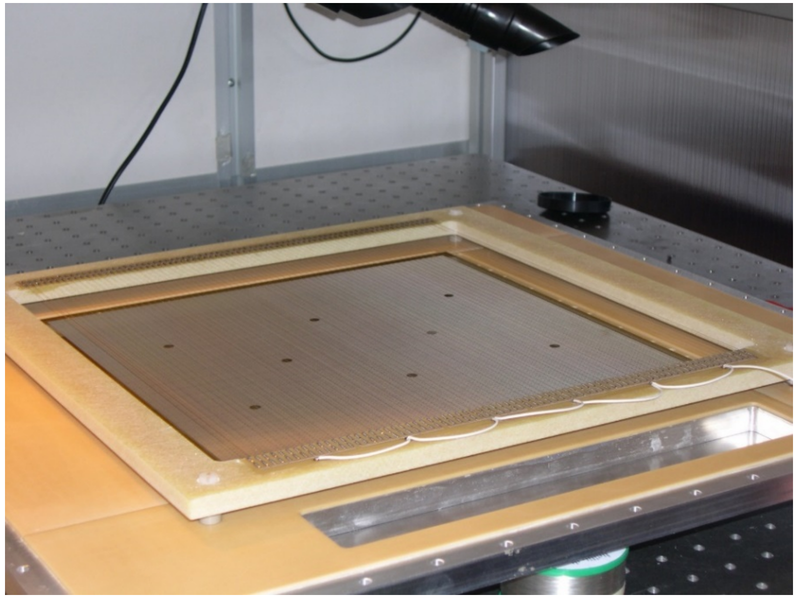
X-ray MM test to access integrity and gain uniformity (<5%)

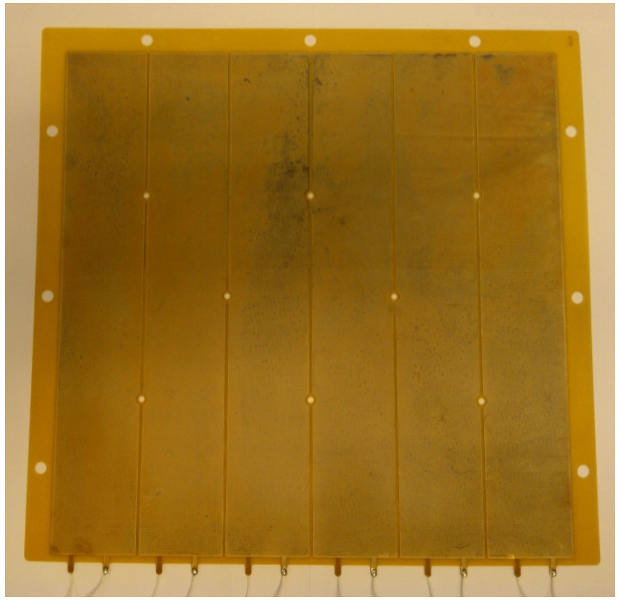
^{55}Fe source spectra

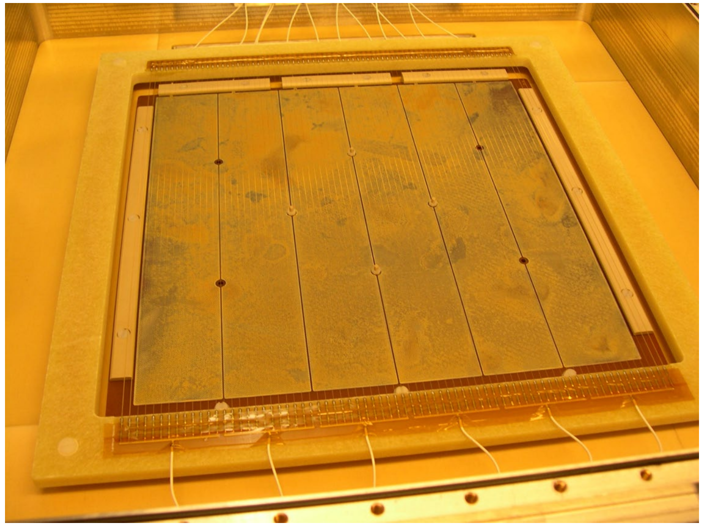


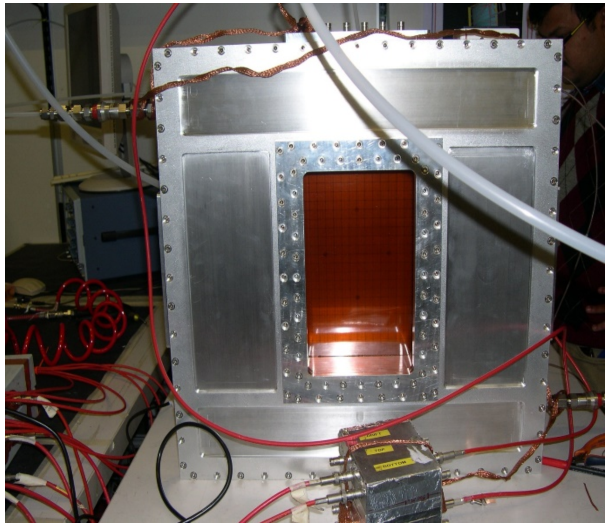


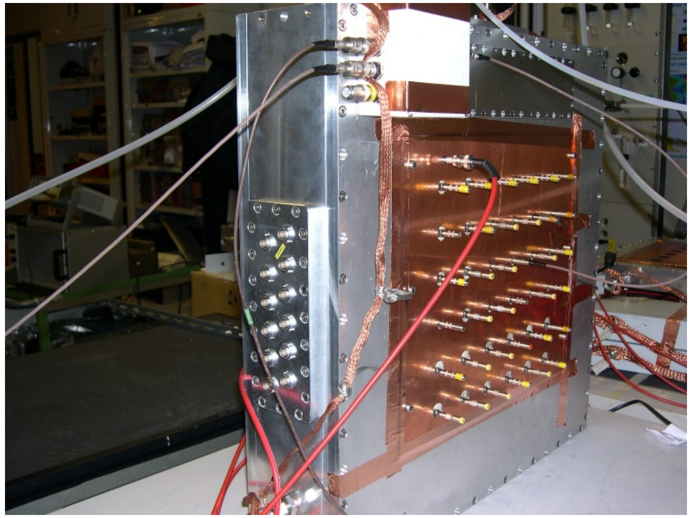
The Hybrid scheme MicroMegas detector and THGEM, performance , large prototype











Segmentation!

Q=CV

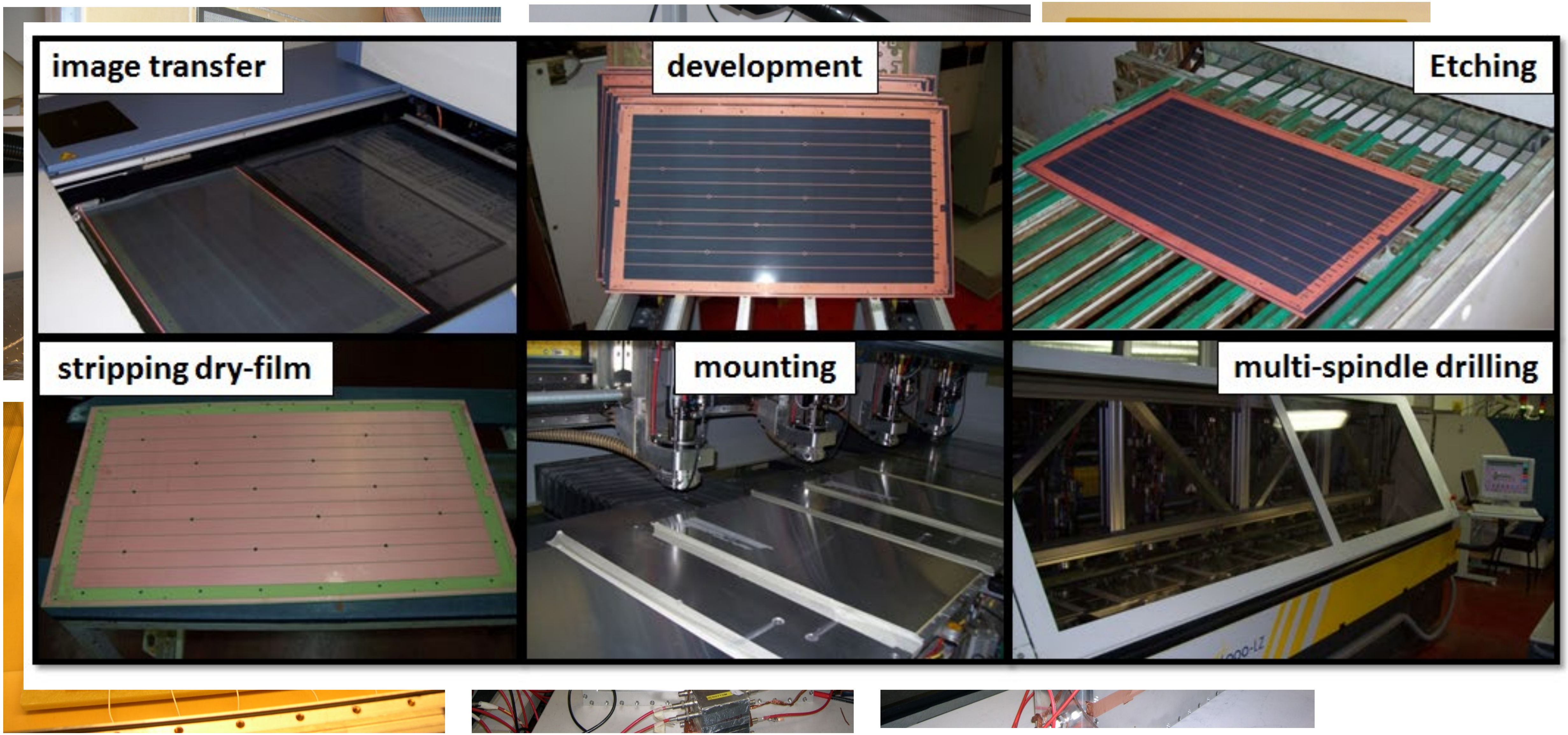
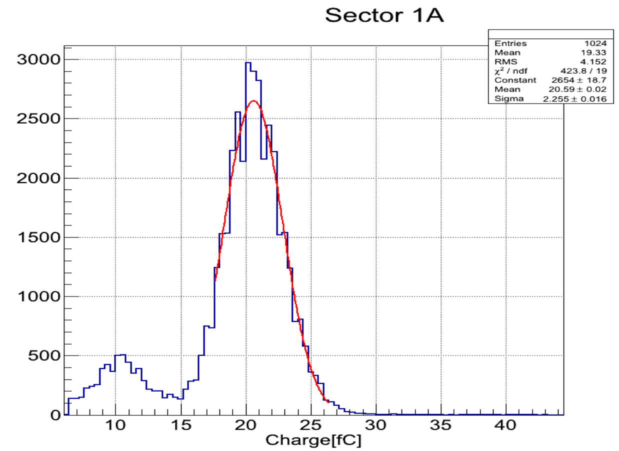
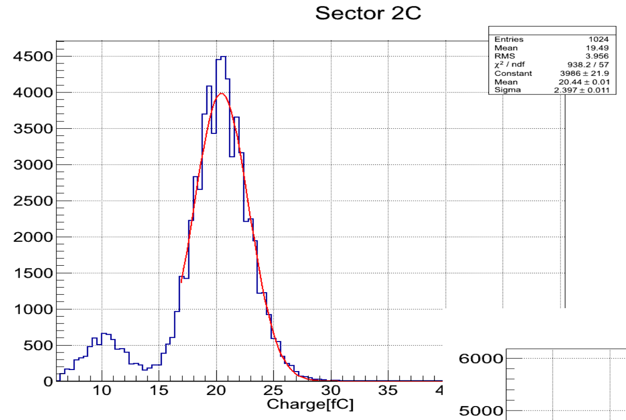


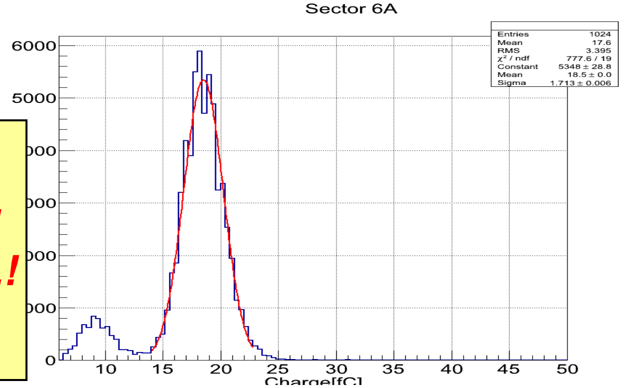
image transfer
development
Etching
stripping dry-film
mounting
multi-spindle drilling

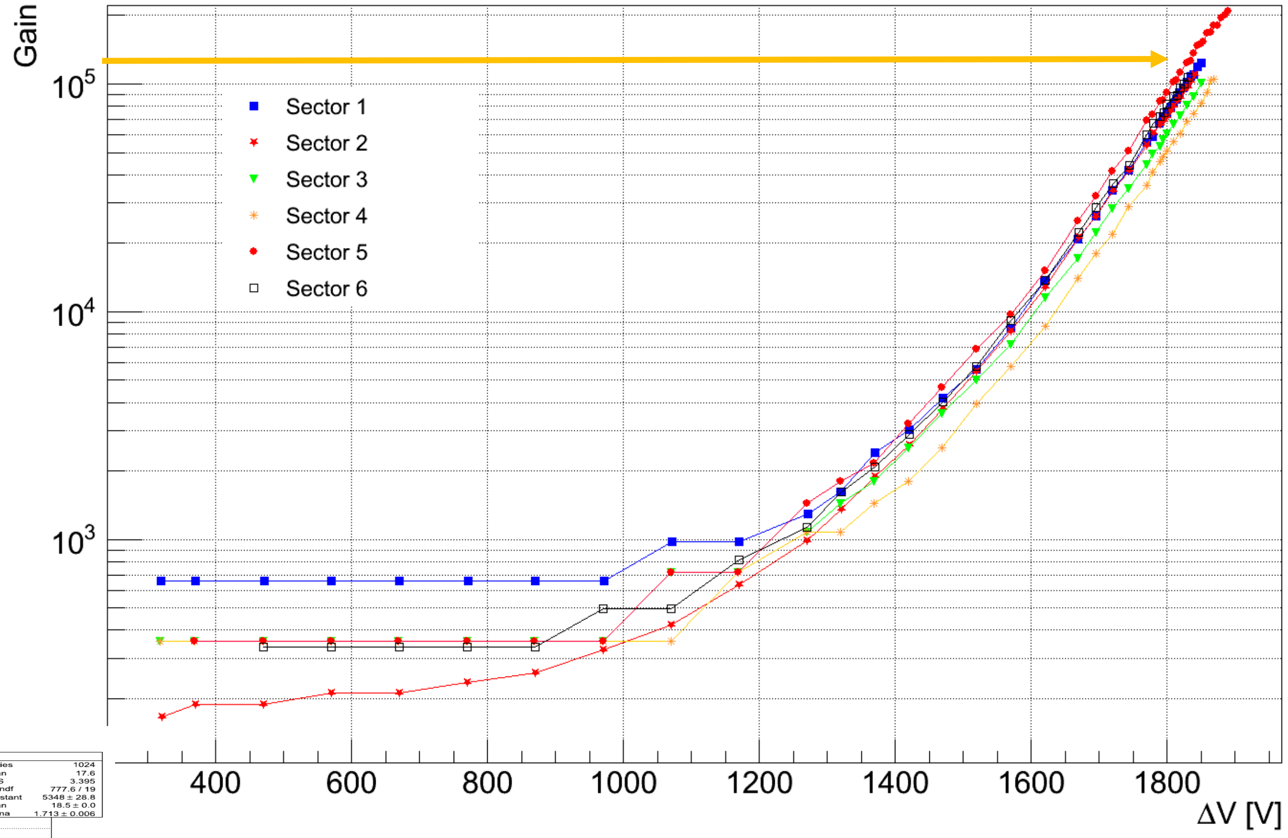
The Hybrid scheme MicroMegas detector and THGEM, medium size performance

ΔV Scan of Sectors of a 300X 300 mm2 THGEM. VMESH = 640V. Gas used Ar:CH4 30:70.





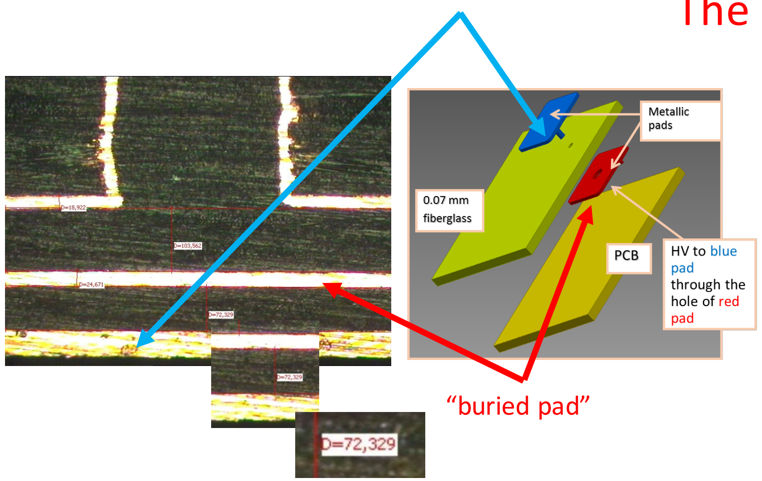




The large prototype works nicely! same performance as the small p.!

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

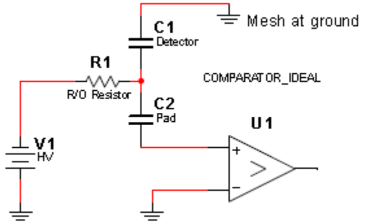
The COMPASS RIICH-1 approach



1 Single pad scheme:

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

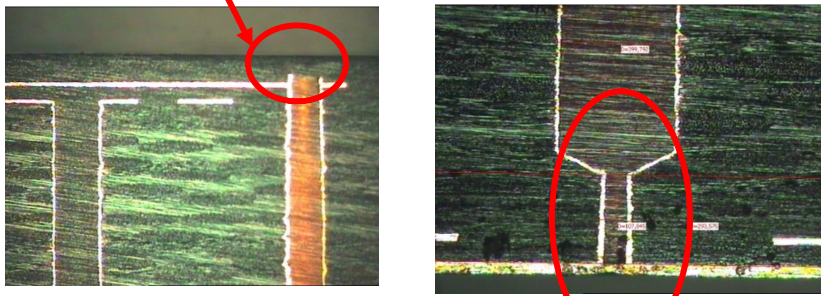
Red pad: signal induced by RC coupling



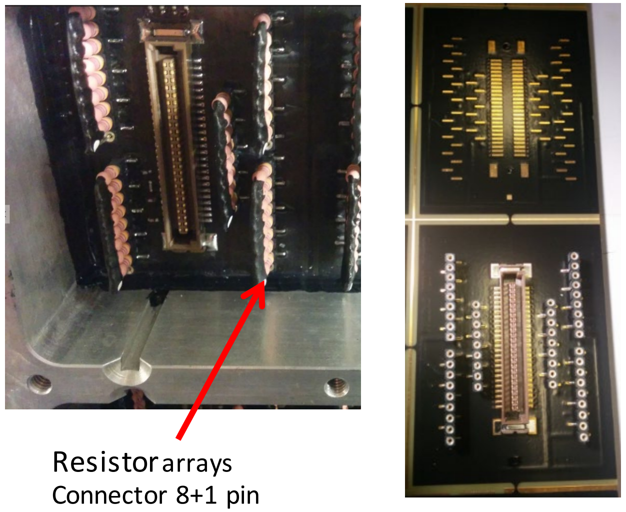
Mesh at Ground

Pads HV segmentation

"Via closure" → leakage issue



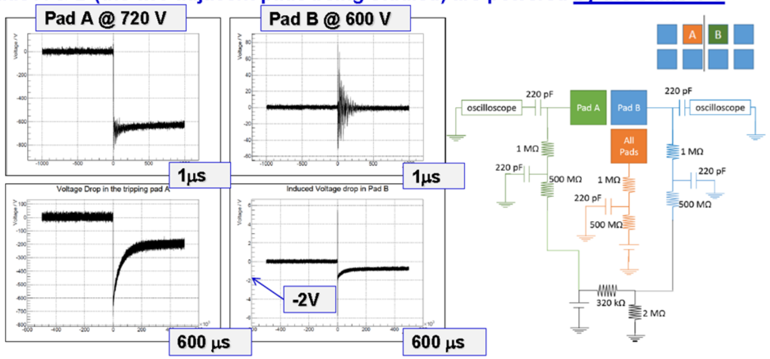
"Z drilling controlled via" → planarity issue



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 !

Finale detector: the mounting phase

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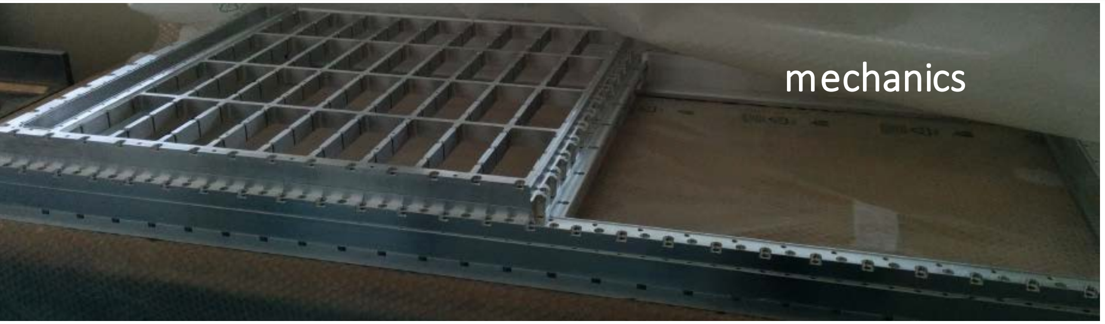
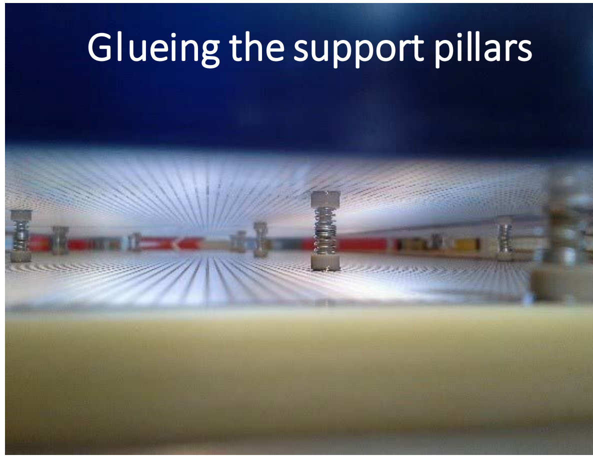
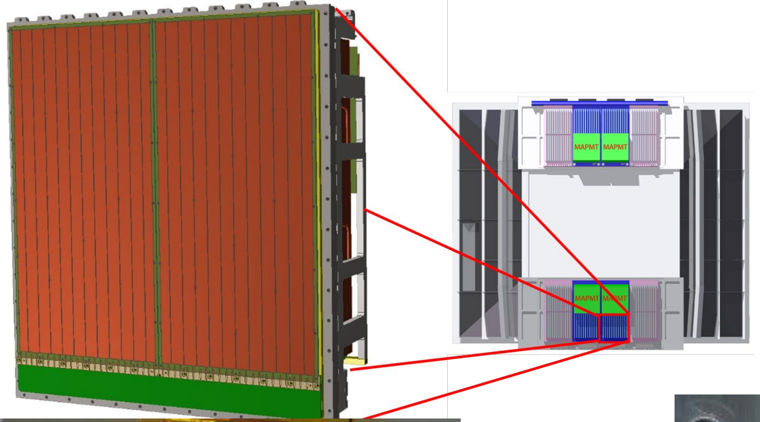
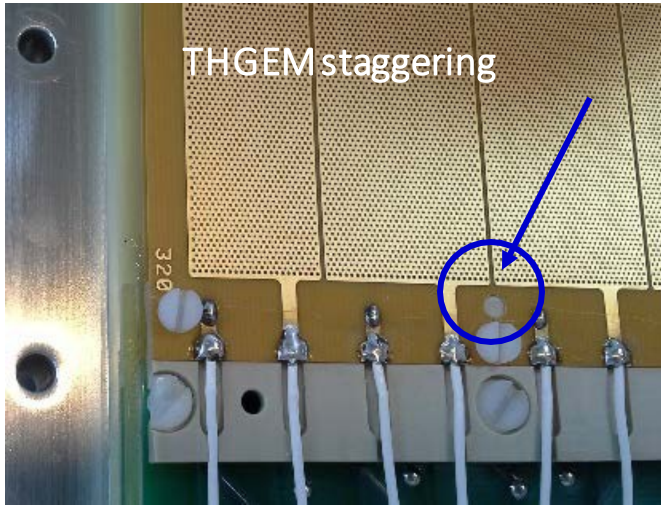
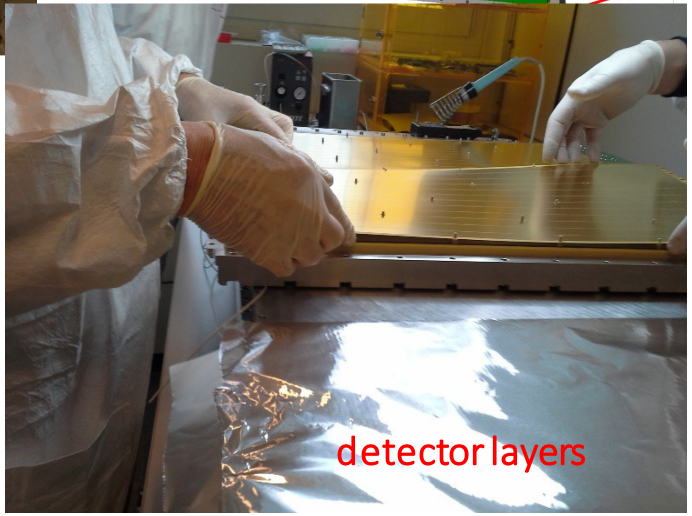


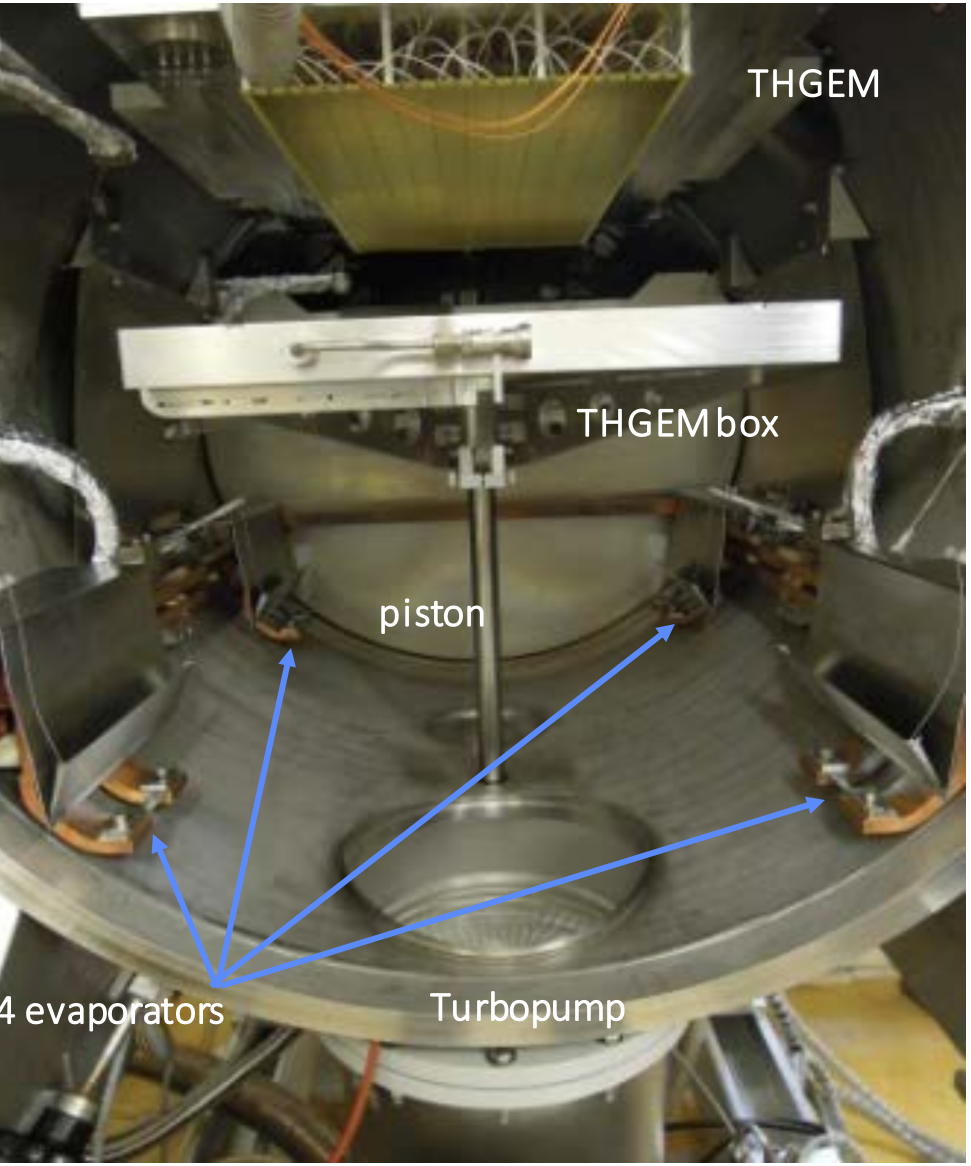


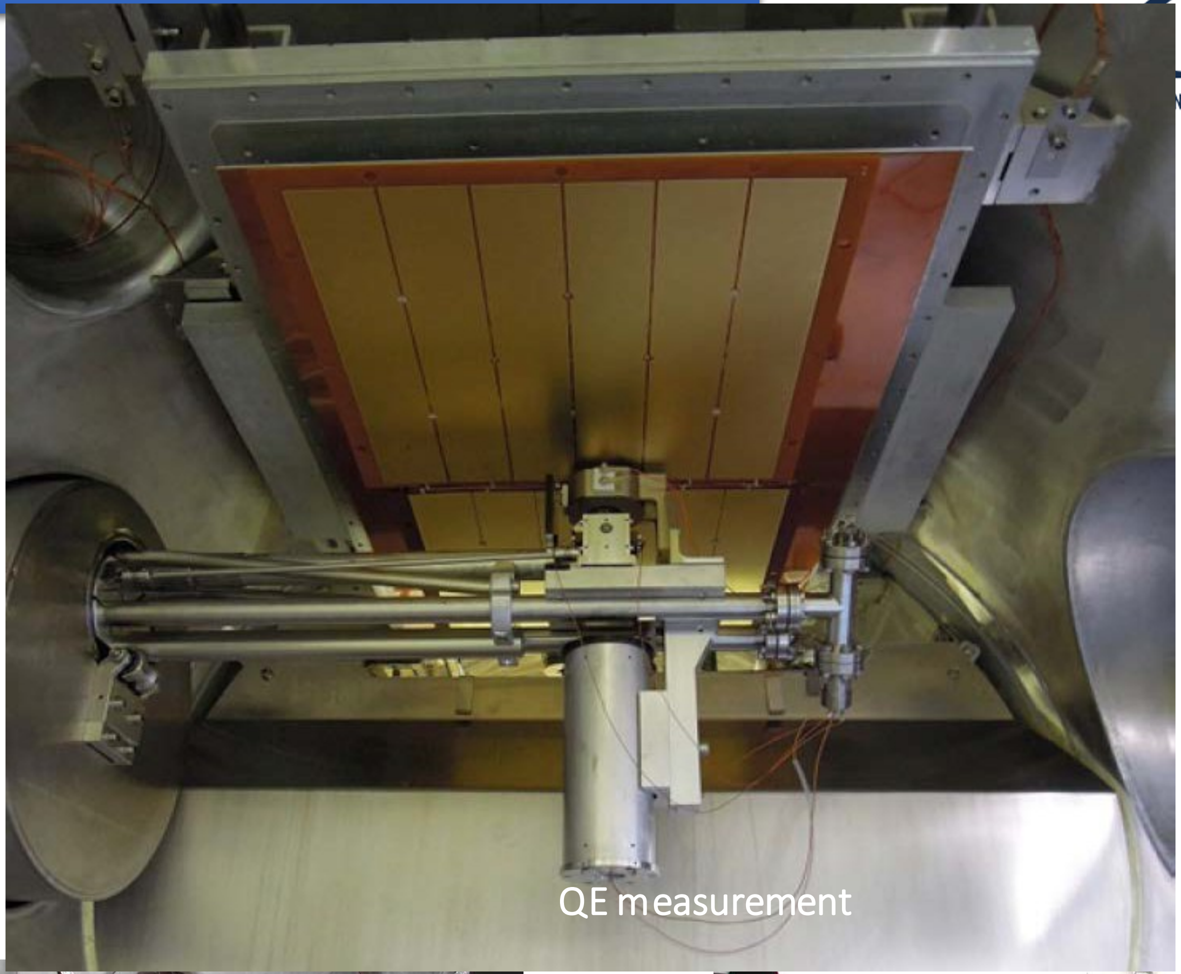


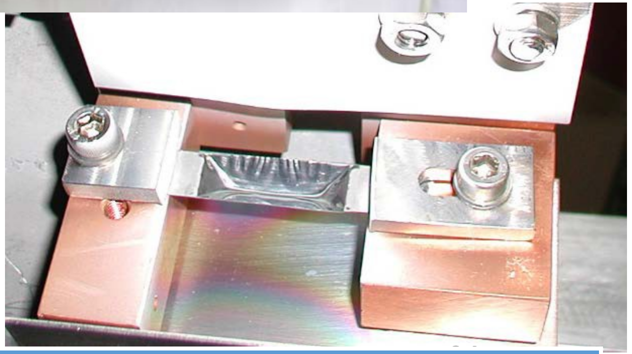




THGEM: CsI coating at CERN



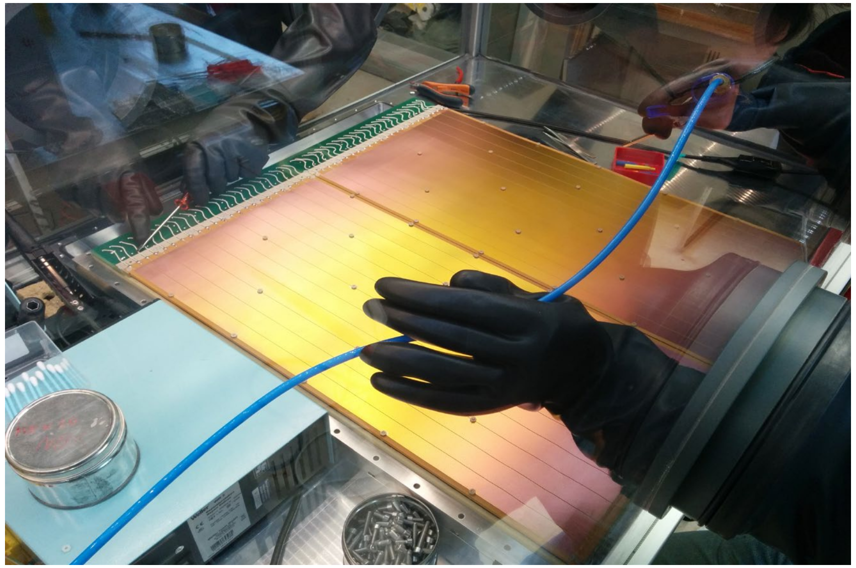




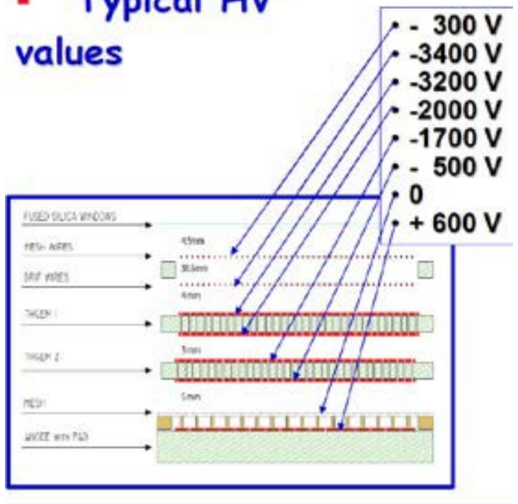
Final mounting on the RICH-1 detector



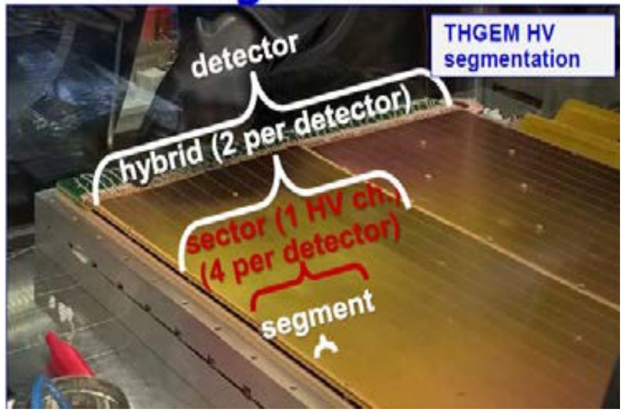


- Typical HV values



- HV segmentation

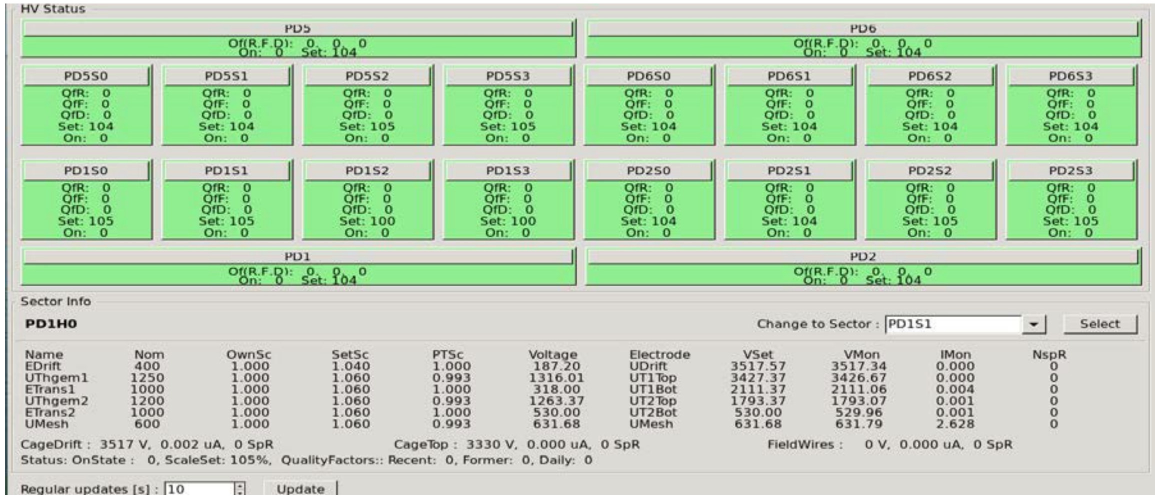


In total 136 HV channels

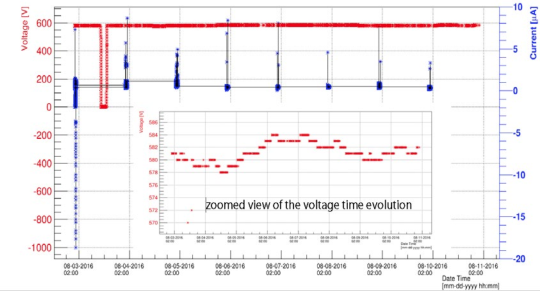
with correlated values

Hardware, commercial by CAEN

Custom HV control system



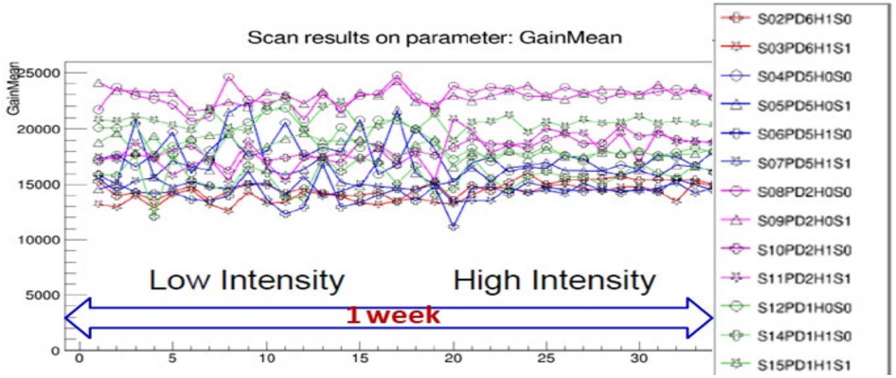
- **Gain stability vs P, T:**
  - G = G(V, T/P)
  - Enhanced in a multistage detector
  - $\Delta T = 1\,^{o}C \rightarrow \Delta G \approx 12\,\%$
  - $\Delta P = 5$ mbar $\rightarrow \Delta G \approx 18\,\%$



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

  Gain stability better than 10%

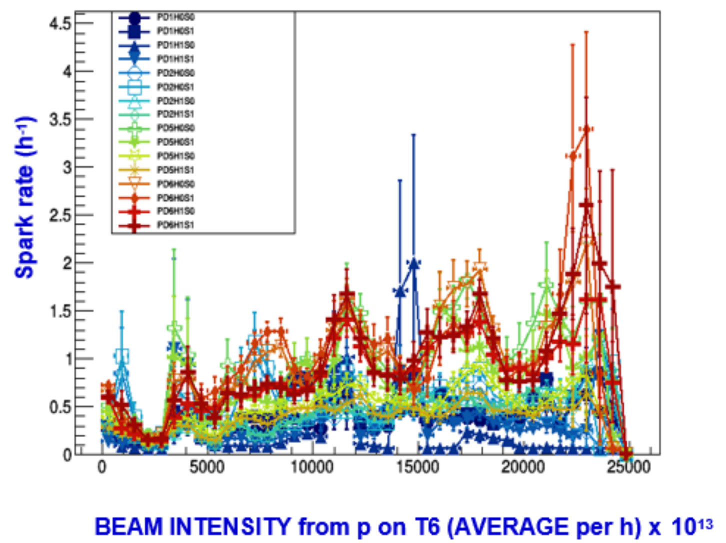
- Custom-made (C++, wxWidgets)
- Compliant with COMPASS DCS (slow control)
- "OwnScale" to fine-tune for gain uniformity
- **V, I measured and logged at 1 Hz**
- **Autodecrease HV if needed (too high spark-rate)**
- User interaction via GUI
- **Correction wrt P/T to preserve gain stability**



THGEMs, lessons

- Full vertical correlation of current sparks THGEM1 & THGEM2
- Recovery time <10 s (our HV arrangement)
- Sparke rates: ~ no dependence on beam intensity and even beam on-off
- Discharge correlation within a THGEM (also non adjacent segments) and among different THGEMs (cosmics ?)

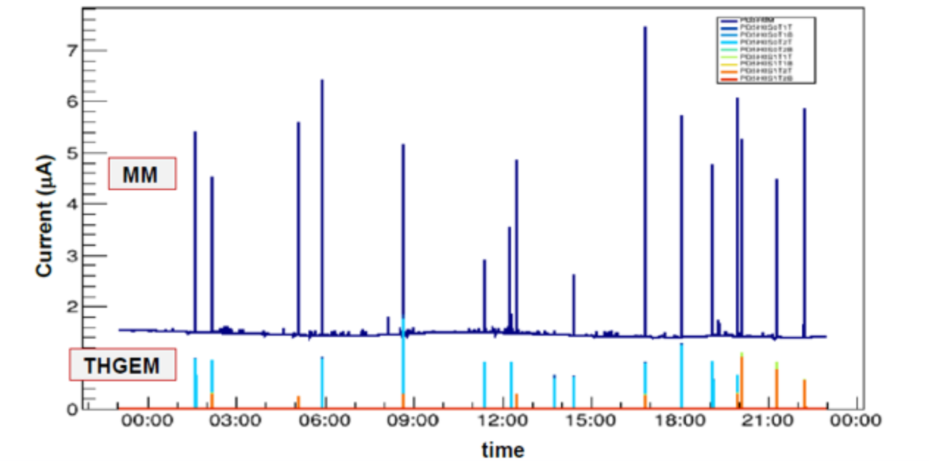
→ Total spark rates (4 detectors): ~10/h



MICROMEGAS, lessons

- MM sparks only when a THGEM spark is observed (not vice versa)
- Recovery time ~1s (our HV arrangement)

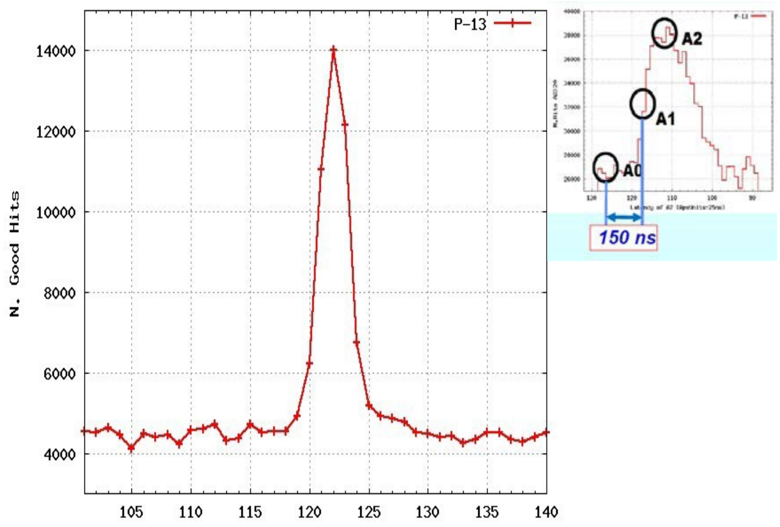
- The only real issue: dying channels (pads)
  Local shorts, larger current, no noise issue
  2.5 ‰ developed in 12 months
  Dirty gas / dust from molecular sieves & catalyst?
  Finer mechanical filters added: 7 μm pore



The Cherenkov photon signal detection

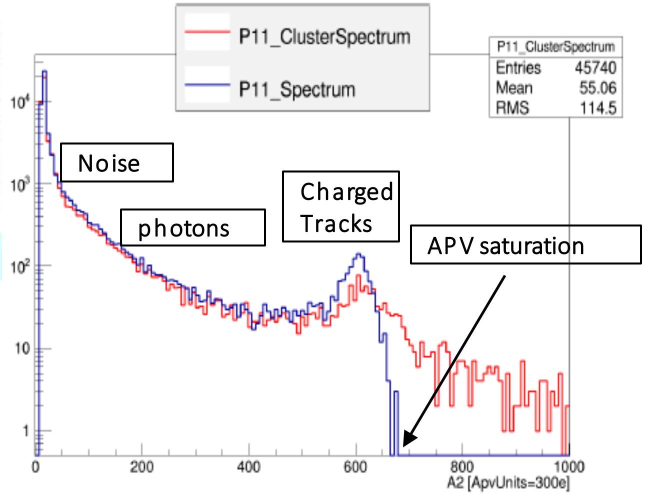
Selecting good hit candidates

(A0<5 ADC units, 0.2<A1/A2<0.8)

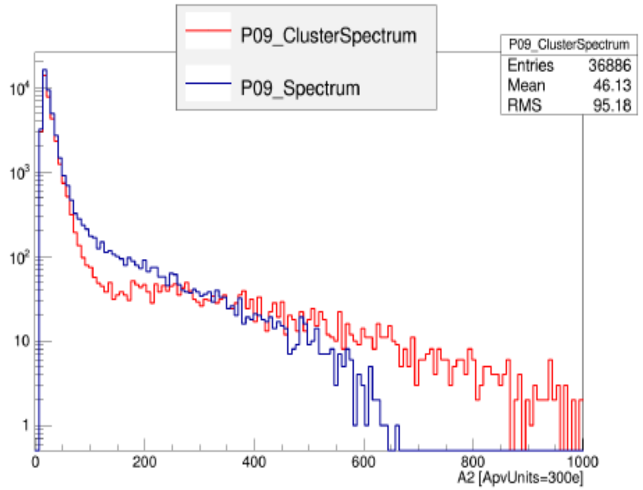


Clusterization to separate charged particle tracks

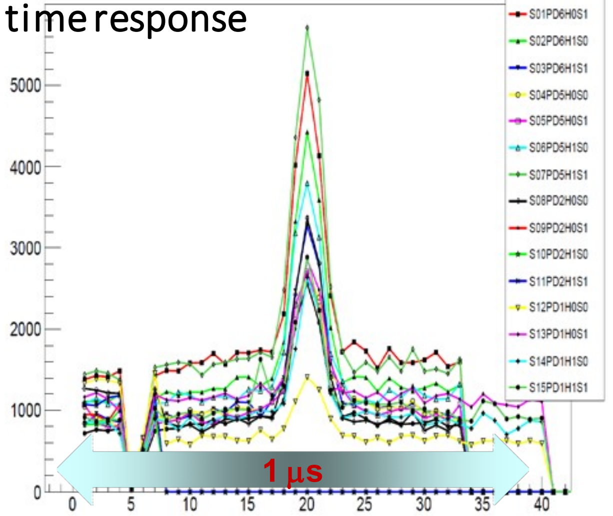
Hybrid MPGD (novel detector)



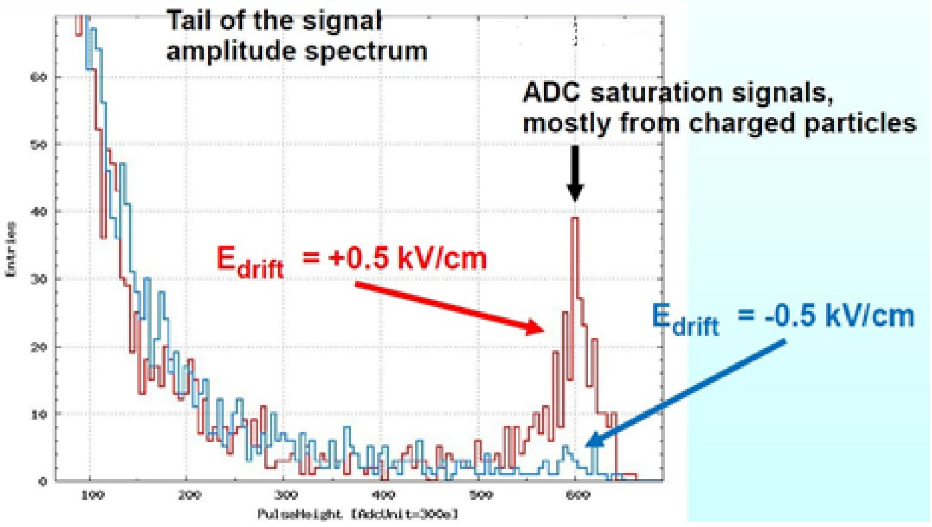
MWPC (old detector)

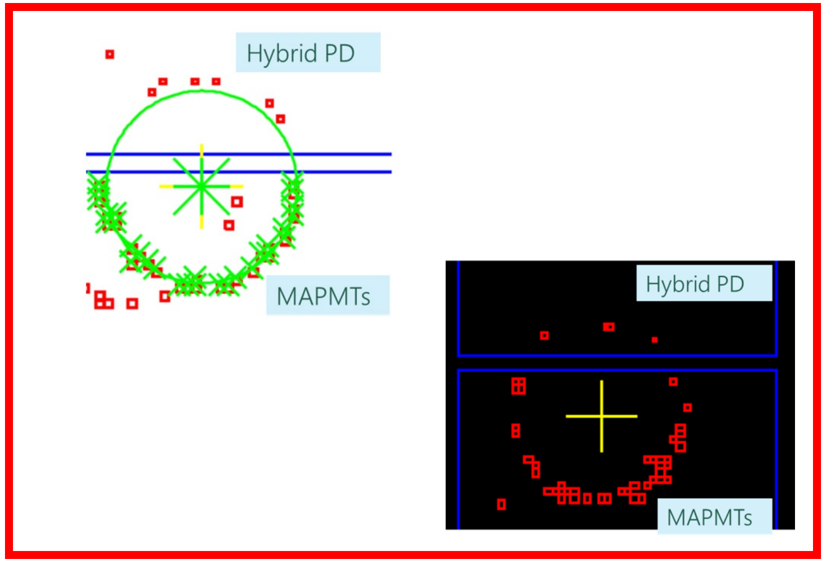


All sectors provide the same time response



Charged particle ionization suppression by strong reversed bias





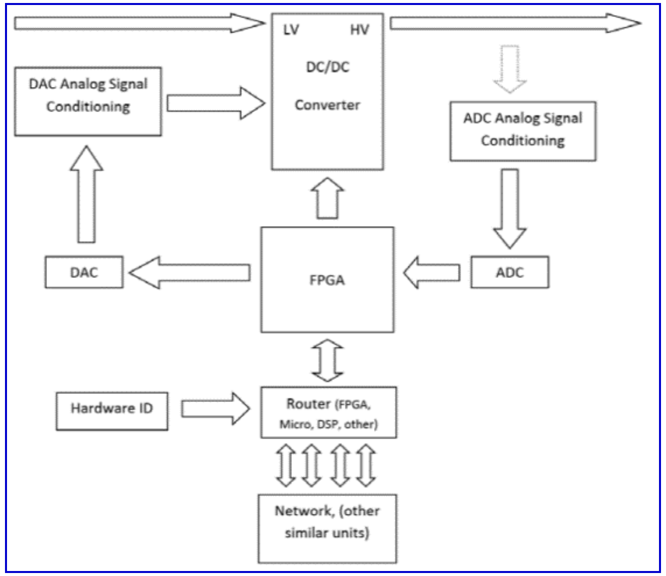
Is he sure he is at the right place ?

Where is my VHDL ???

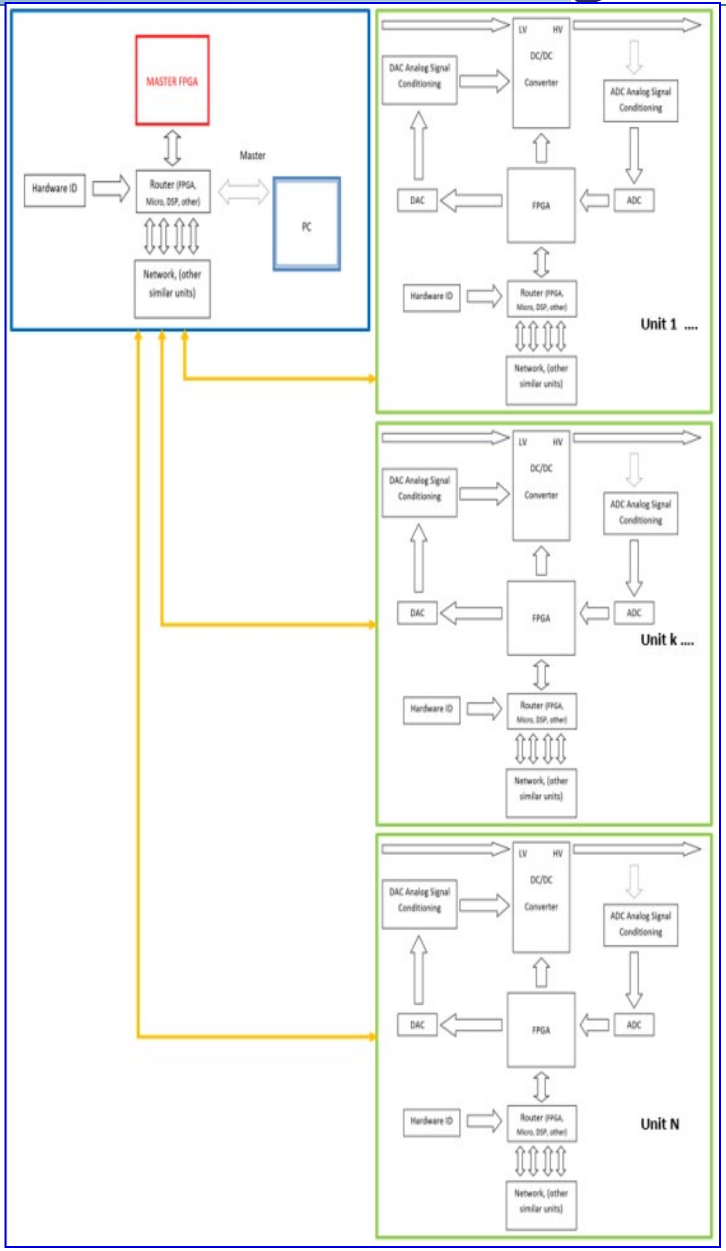
I was supposed to hear something about FPGAs…?

Main goal is to match the HV requirements not commercially available for the MPGD needs

- true real-time monitoring of the main parameters (voltage, current)
- the fast control of the HV channels (related to the next point)
- the use of local intelligence for the application of feedback protocols when pre-breakdown conditions are detected, useful for systems where the large number of HV channels increases the monitor and control complexity of the system
- HV generated at the detector level: HV cabling, connectors, space constrains, cost, accumulated charge issues
- Modularity of the system: large size projects employing MPGDs may use a large number of channels (M/S architecture)
- Compactness



Block diagram of the single HV module.



Block diagram of the architecture of the HV system

By combining commercially available devices as well as custom made the foreseen performance figures to achieve:

- Time stamp resolution for current and voltage monitoring in the order of 10 ns or better
- High resolution voltage monitoring better than 0.5 Volt on several kVolt scale at sampling rate > 100 kHz
- Precise current monitoring at the level of 10 pA at sampling rate > 100 kHz
- On board logic for decisional operation on predefined scheme as well as warning on "interesting" events to the user: two mode systems 1) normal monitoring with *relaxed* separation between consecutive time stamps 2) very fine monitoring info in case of non standard events

The main innovative features are:

1. **true real-time monitoring**
2. **A tool** to perform MPGD R&D: by the detailed time-stamped information, understand **the precise evolution of the break-down events**
3. **HV generated** at the detector level
4. **Reduced size**: each HV unit ~ 30 cm x 20 cm x 5 cm

Applications:

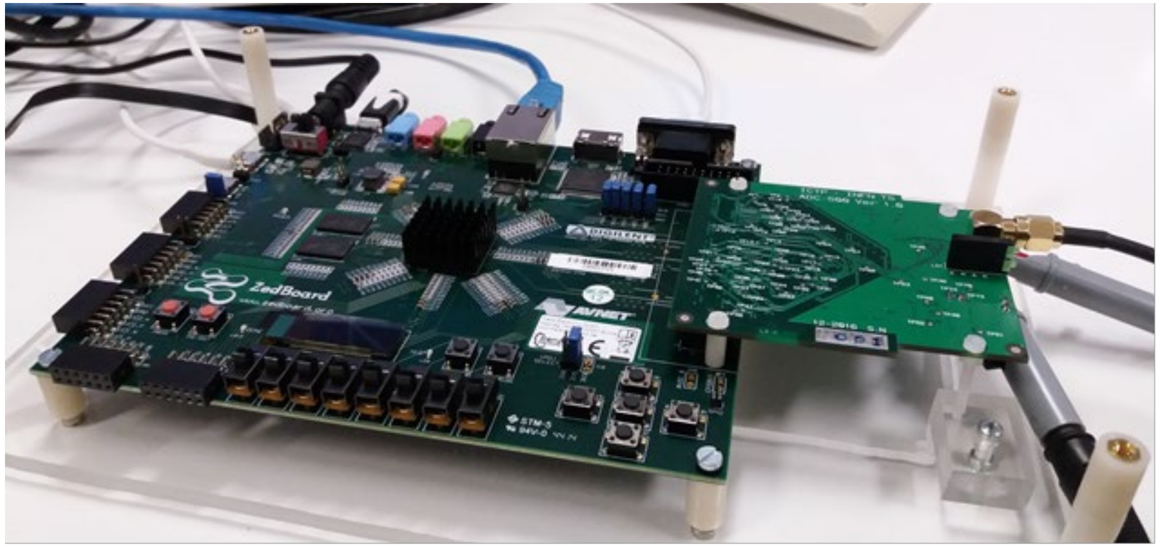
MPGD characterization studies

Powering of large-size MPGD systems

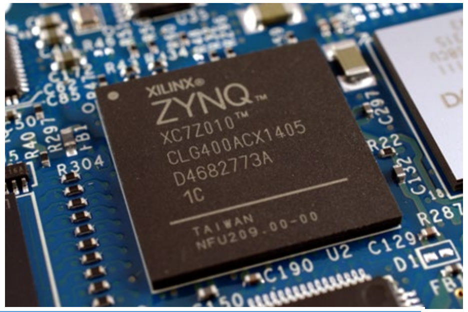
carrier in FMC standard

Zed Board based on hybrid Xilinx Zynq
commercial carrier including high throughput low-pin-count FMC

Fully Programmable System-on-Chip (SoC) device
combining a ‘hard’ dual core ARM processor with an FPGA fabric
dual-core ARM Cortex-A9 processor,
Programmable Logic: FPGA Artix-7 fabric



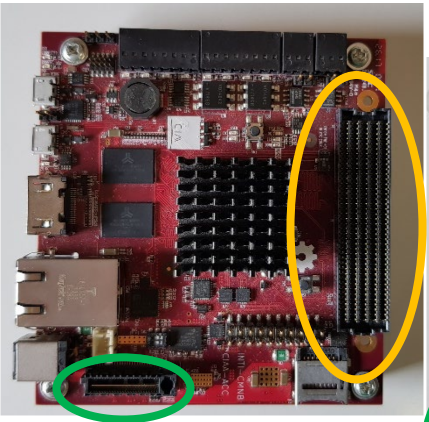
8 bit ADC read at maximum speed of 500 MSPS

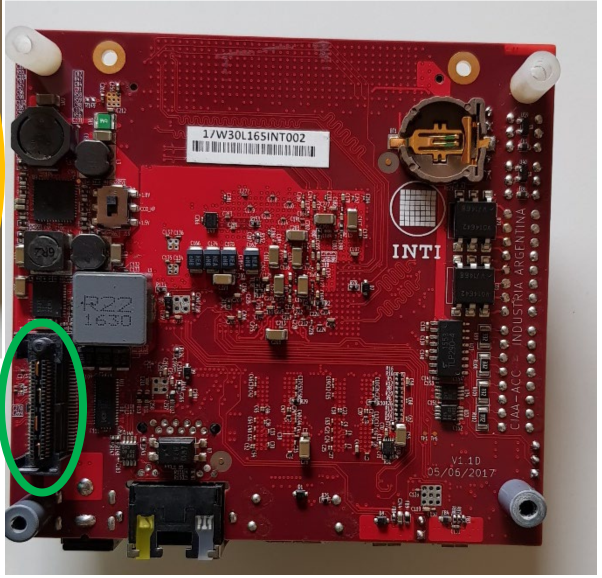


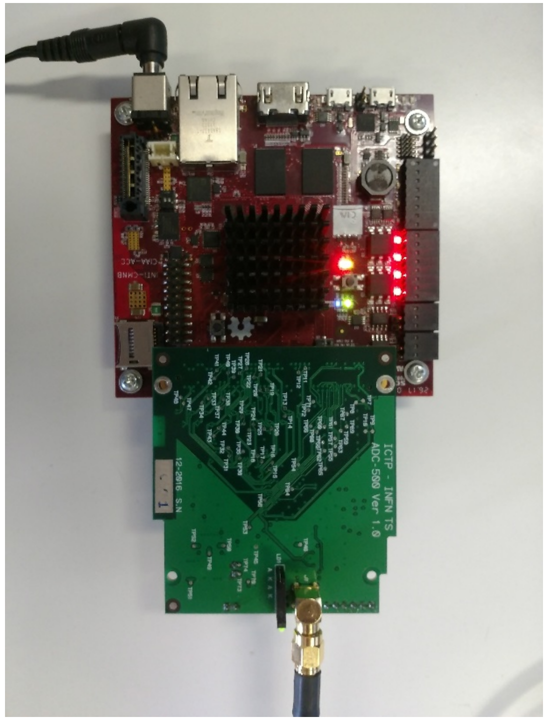
carrier in FMC standard the new board

FPGA: we moved from the commercially demo board to the open hardware FMC carrier based on a Zynq-7030. The CIAA ACC board selected has been developed by the Center of Micro and Nanoelectronics of the Bicentenary (CMNB) of the National Institute of Industrial Technology (INTI). (Collaborators of the ICTP MLAB)

→ Open HW, SW programming under VIVADO Package
→ More compact design well suited for our application: avoids to engineer a new FPGA board
→ PCIe allows for stackable operations







PCB of 12 layers and a size of 90 x 96 mm.

- Main device: Xilinx Zynq-7000 (XC7Z030-2FBG676I, also compatible with a XC7Z045).
- Memories: DDR3 (1GB), QSPI (128MB).
- Peripherals: SD/SDIO, GEth, USB OTG, 2 x I2Cs, SPI, 3 x UARTs (one RS-485), CAN, Real Time Clock, HDMI.
- GPIOs: 2 x LEDs, 8 x GPIOs, 8 x optical isolated digital IOs (for industrial applications).
- One VITA 57.1 FMC-HPC Connector.
- PCIe/104 connectors (to allow stackable applications).

FPGA design: VHDL code for the Programmable Logic of Zynq

The main purposes of the firmware implemented on the PL of the Zynq device are:

a) Hardware control of the HV DC-DC converter (directly and by mean of DAC)

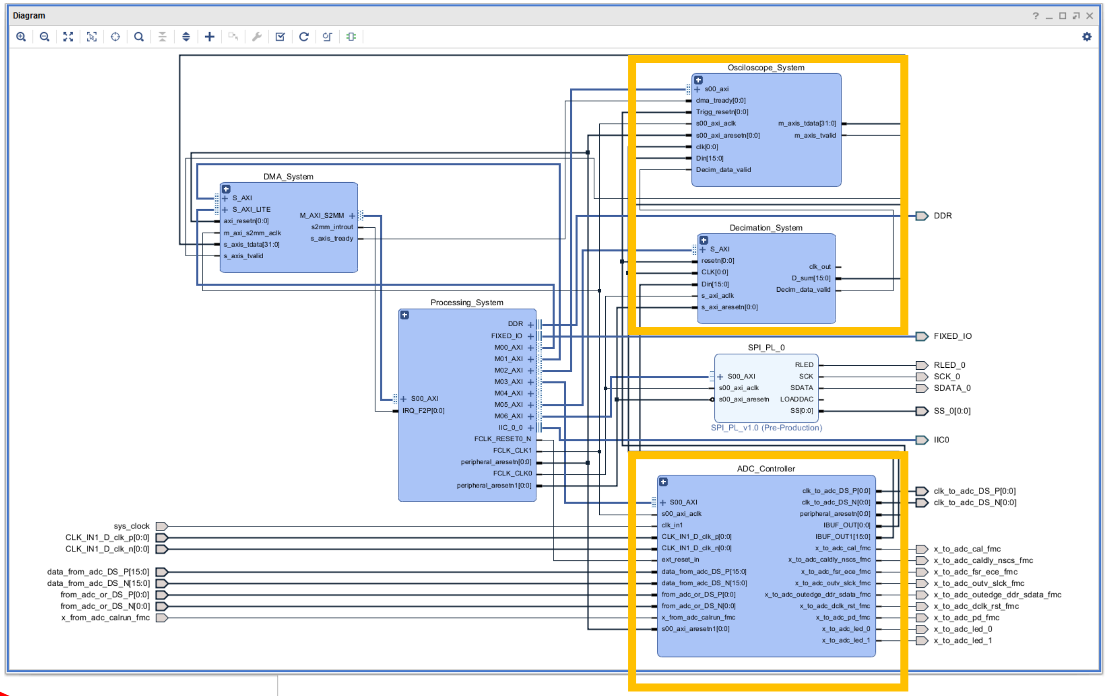
b) Hardware control of the FMC ADC Board through a high data throughput FMC connector

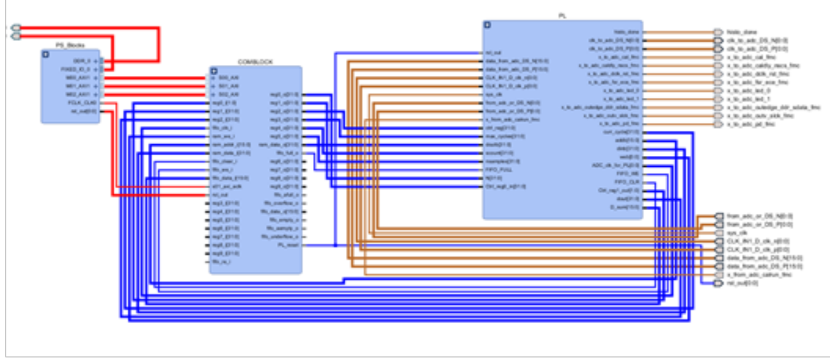
c) Hardware control of PMOD DAC and ADC Modules

d) Communication Protocol with the PS through the Custom Communication Block

e) Hardware histogram generation for probability distribution analysis using the RAM memory available in the Communication Block.

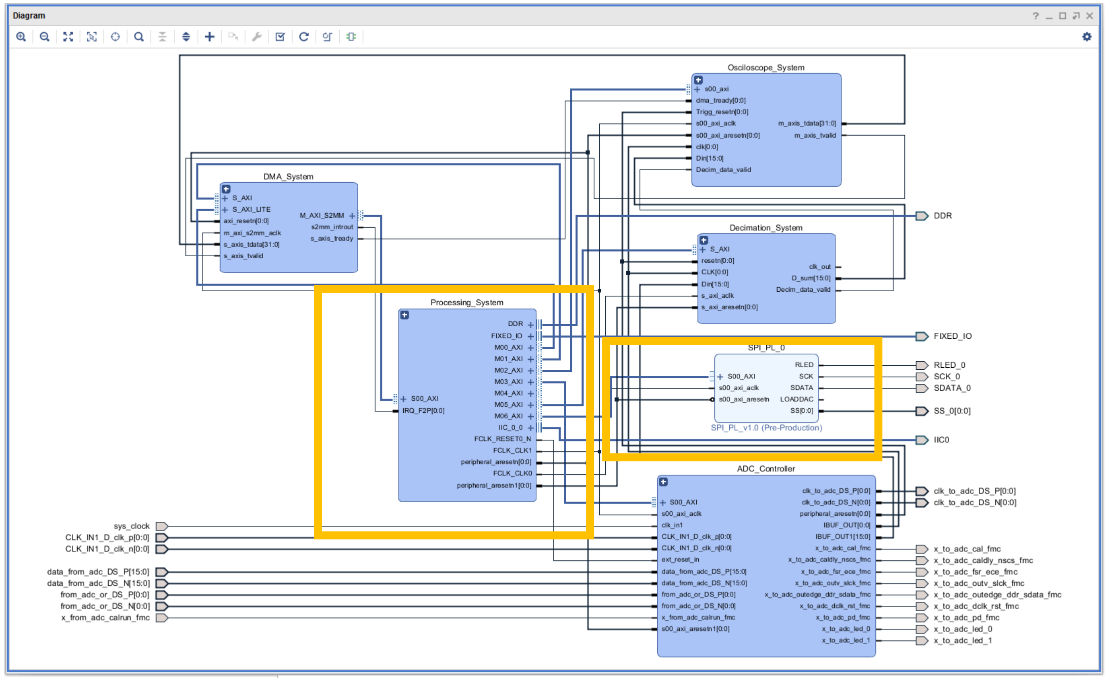
f) Specific data processing blocks/IP: discharges detection, high-resolution time stamping, oversampling, high-resolution amplitude measurements, etc





ARM programming: Embedded C code for the Processing System of Zynq

The PS acts as a server TCP/IP for the exchanging of predefined data packets between the Zynq device and a PC. Basically, the PS awaits and fulfills requests from the PC.



a) Reading data coming from PL (FIFO memory) through DMA configuration for data transmission from FIFO to an external DDR RAM memory

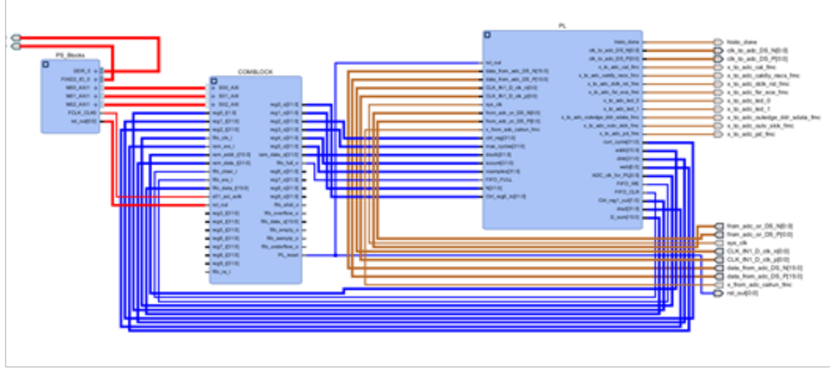
b) Packing data from DDR RAM according to PC-Zynq TCP/IP communication protocol specifications

c) Software for managing I2C temperature and pressure sensors.

d) Creation of Protocol Data Unit (PDU) containing header and data for transmission to PC. Unpacking data and fulfill requests from PC according to the information provided by the header of PDUs coming from PC (Middleware)

e) Read and Write into I/O peripheral interfaces via specific predefined ARM memory addresses

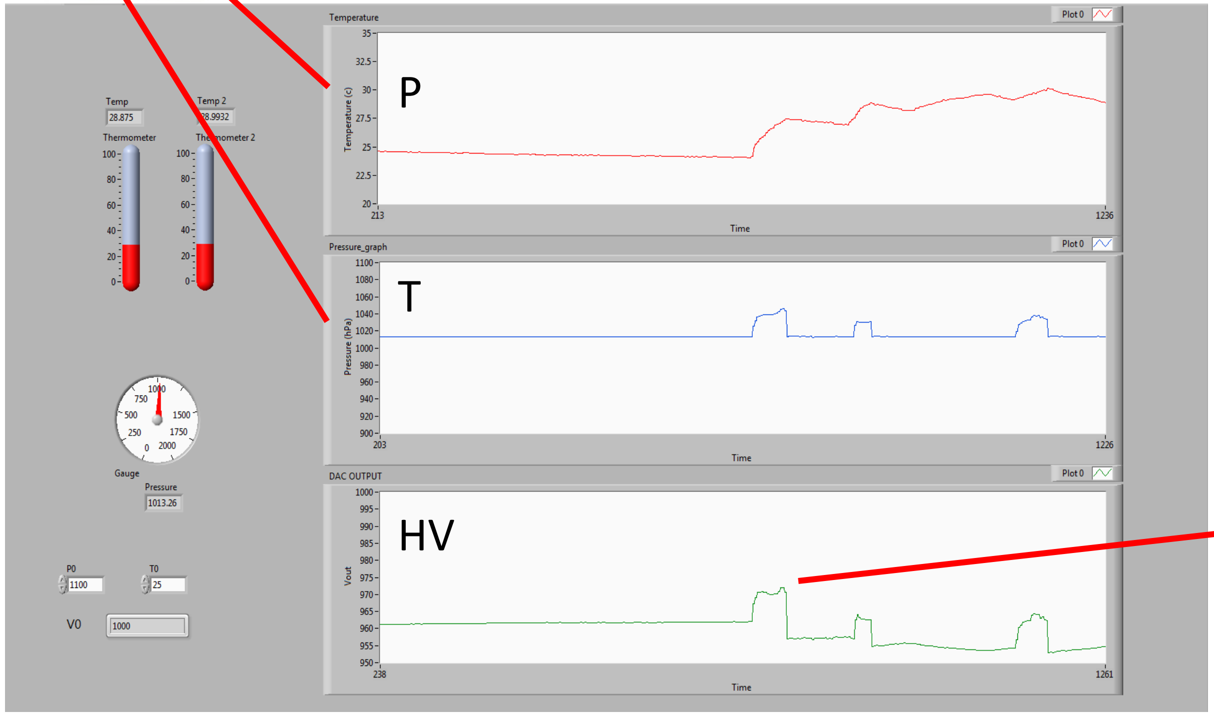
f) Communication Protocol with the Zynq-PL through the Custom Communication Block



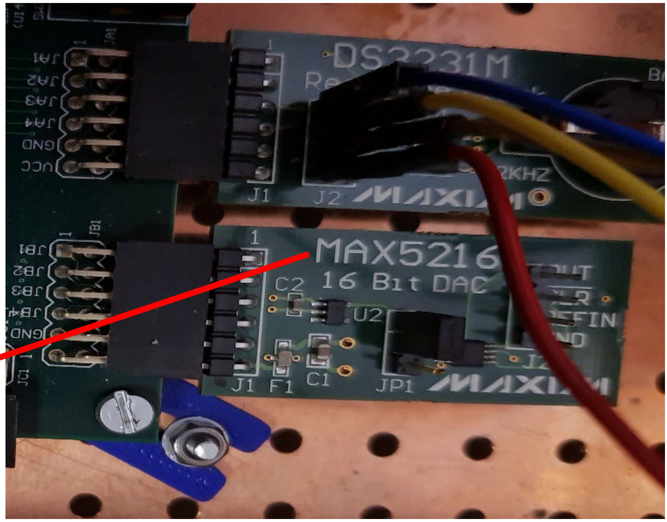
ARM programming: Embedded C code for the Processing System of Zynq

Temperature and pressure monitoring fully implemented via IIC ADT7420 and MS5611 sensors → physically connected to the JA1 PMOD

Automatic voltage adjustment of voltage based on the experimental temperature and pressure dependent equation has been fully implemented→ PMOD 16 bit DAC MAX5216, MAXIM for HV control



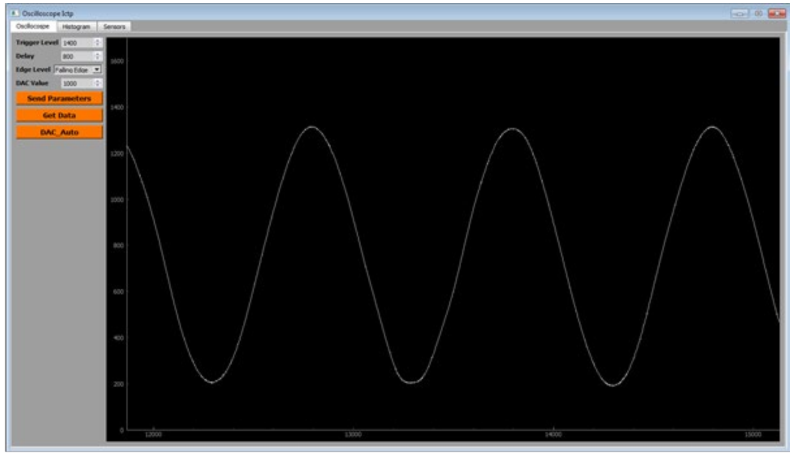
$$V = V_0 * \left(1 + 0.5\left(\left(\frac{P}{P_0}\right)\left(\frac{T_0}{T}\right) - 1\right)\right)$$



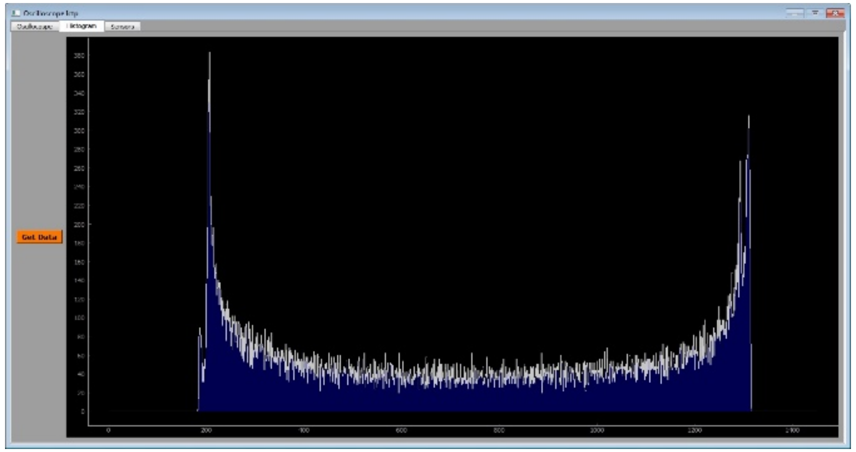
Voltage resolution 16 Bit @ 70 kHz

PC resident software and GUI for remote control

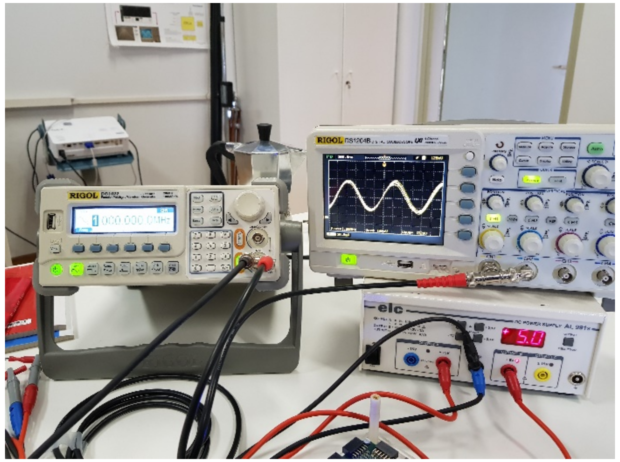
The PC resident software is being developed in PyQT (Python-QT) and QT designer is used to graphically generate the Graphical User Interface (GUI). Free SW



Widget of the 50 kHz sine signal digitized by the ADC at 300 MSPS.

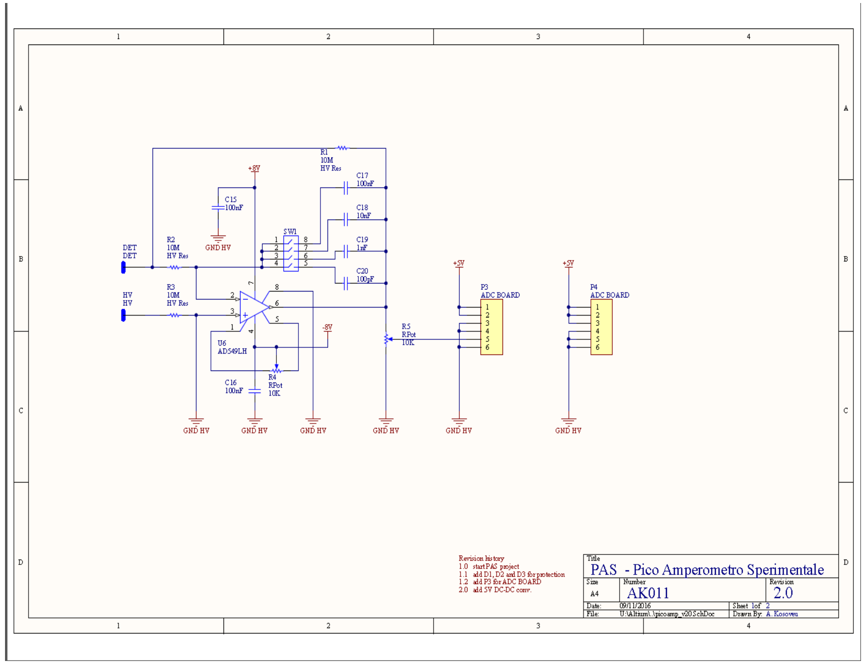


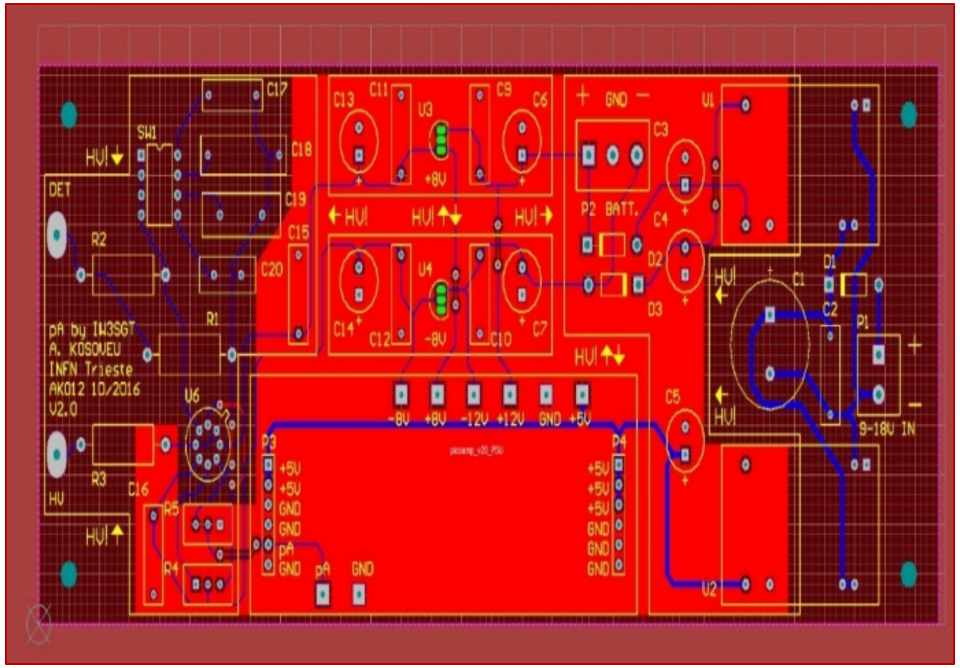
Widget of the histogram of the data received



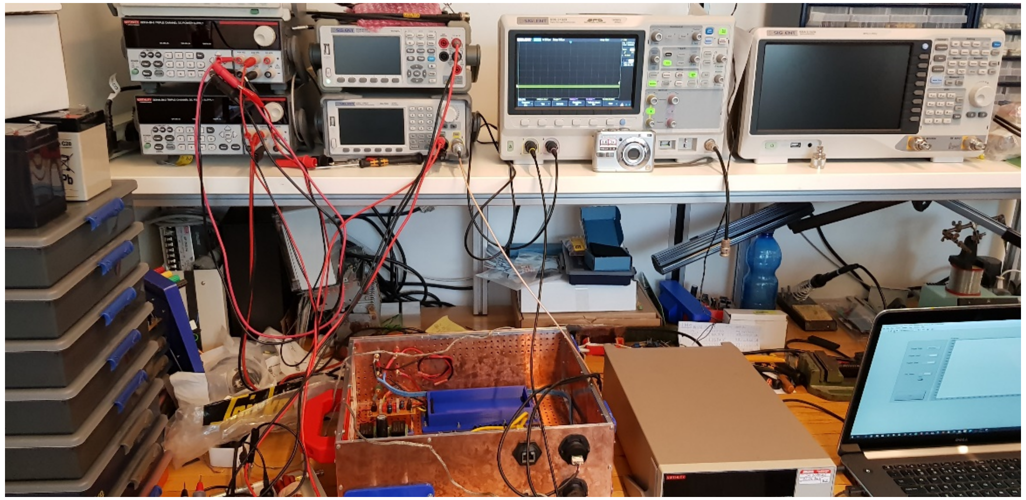
Widget of the values of the temperature and pressure from the sensors

Analog part and its integration … last time

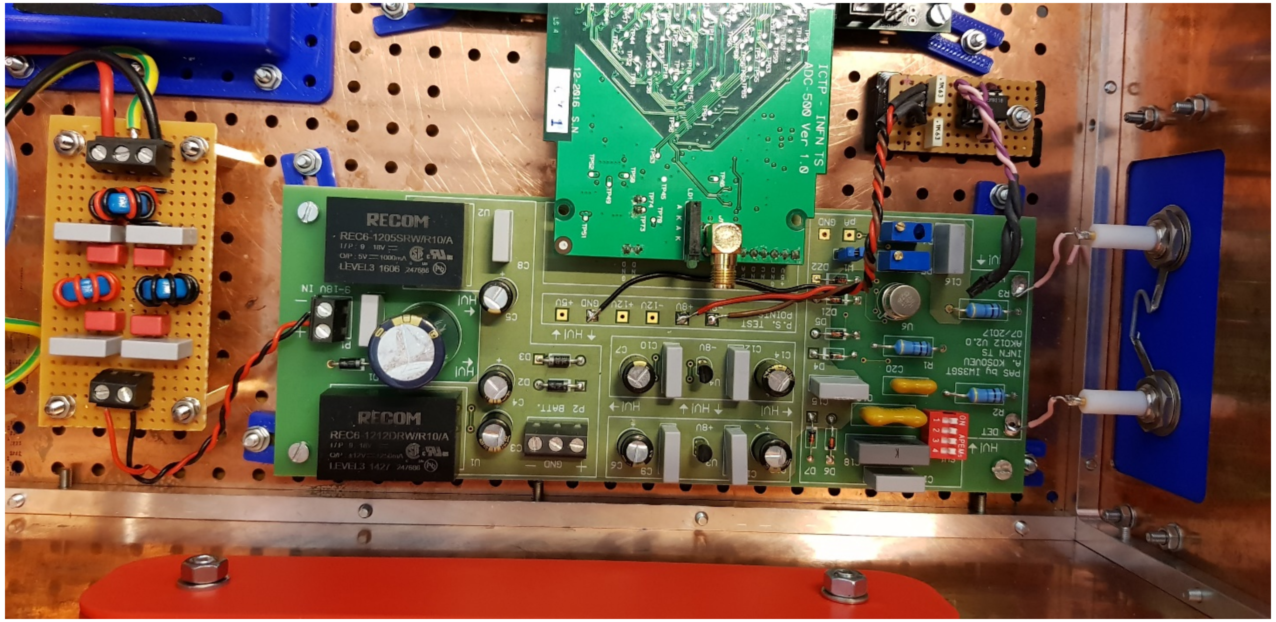




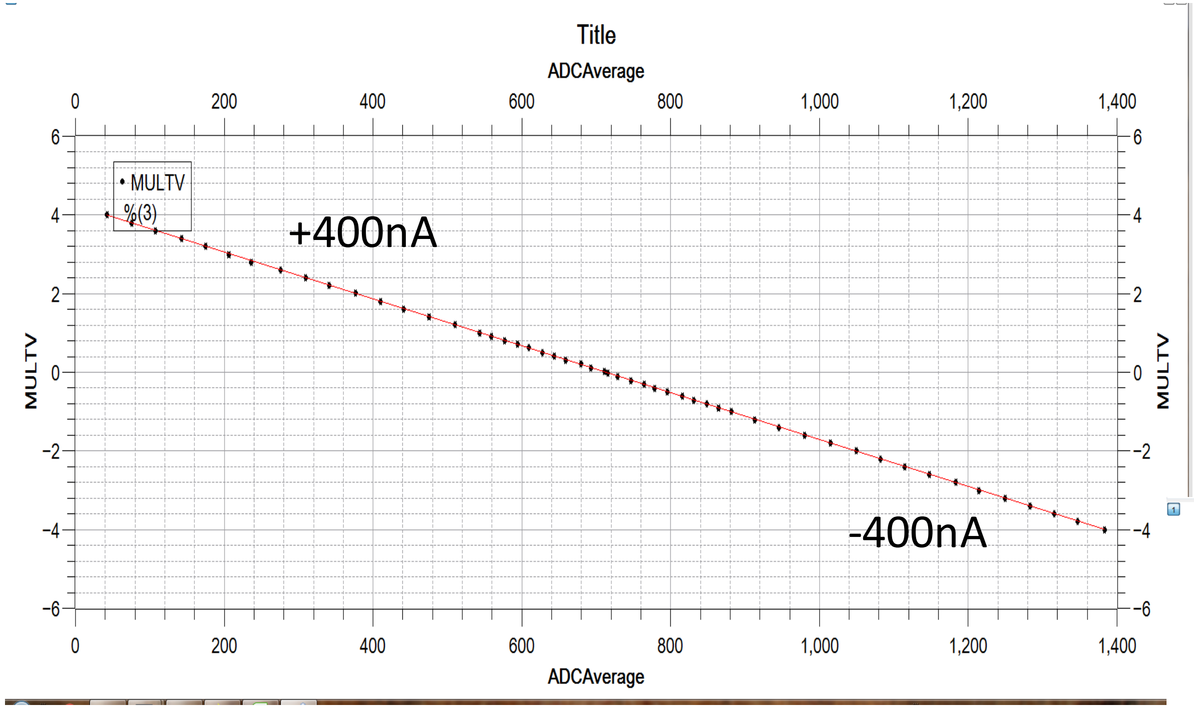
Analog part and its integration



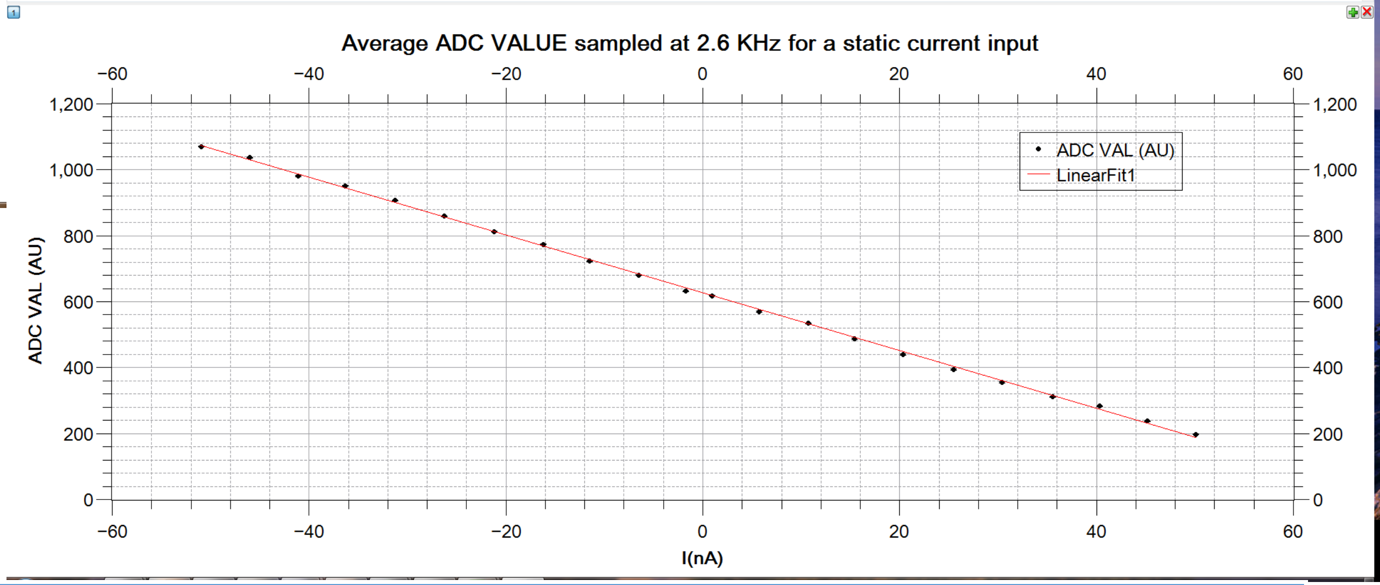
The PA board has been designed, realized, tested and interfaced



Full chain linearity tested over the range of 800 nA, sampling @ 2.6 kHz



Current source -> power supply + resistor
Remarks on I resolution in the next slide



Some remarks:

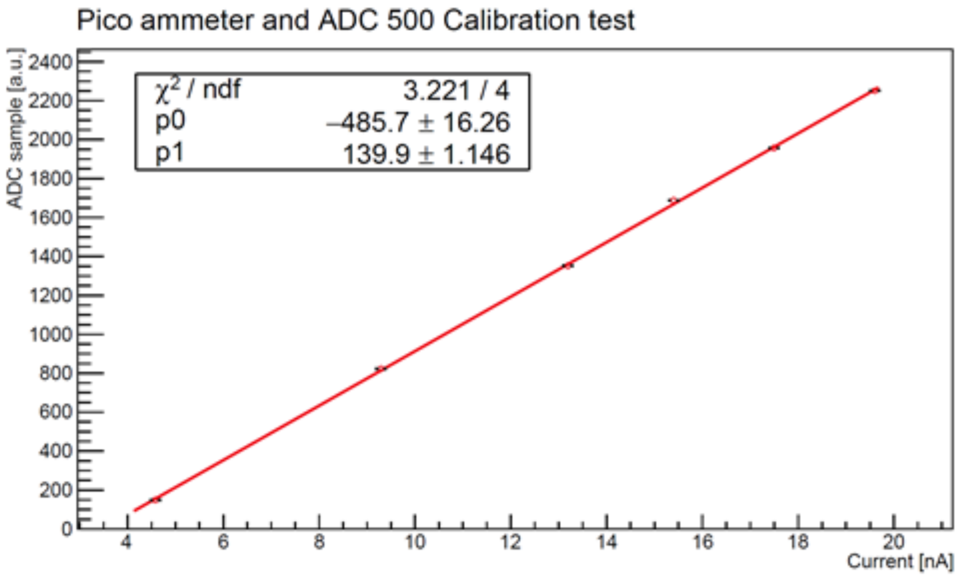
ADC works @ 500 MS/s @ 8 bit Δ_{vin}=1.9V

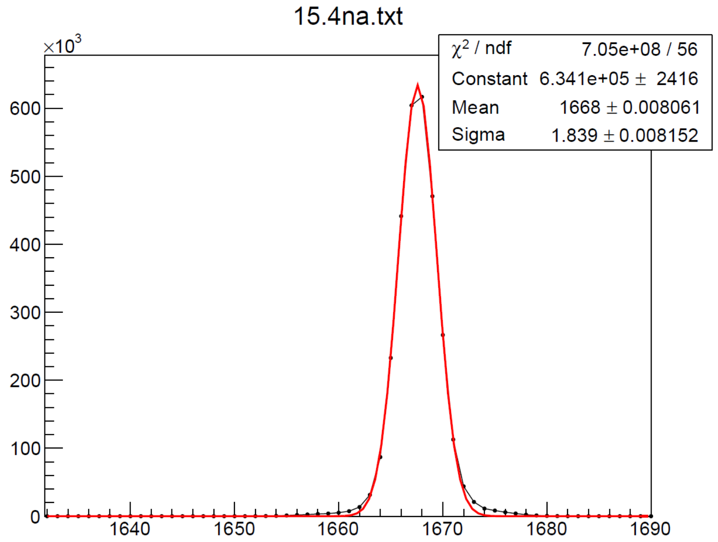
With the scheme implemented the **maximum theoretical** current resolution achievable is 48 pA @ 100 kHz over a *i* range of 800 nA. We wanted to achieve 10pA in the original plan, but

Resolution can be increased by

- Oversampling at the cost of reducing the sampling frequency: to gain N bits to obtain a larger ENOB f_{samp} is scaled by 2^{2N}
- Changing the gain of the OPA in transconductance mode

Measurement performed by connecting a I current source, the PA and the Keitley 6485 calibrated Picoammeter

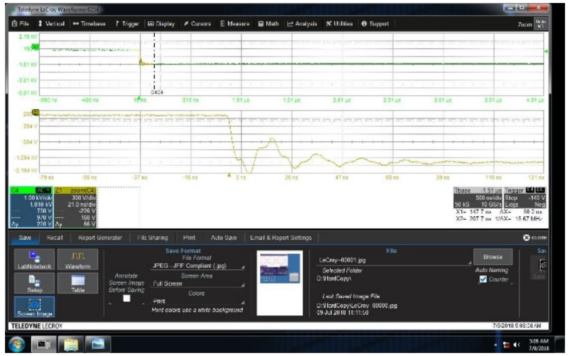


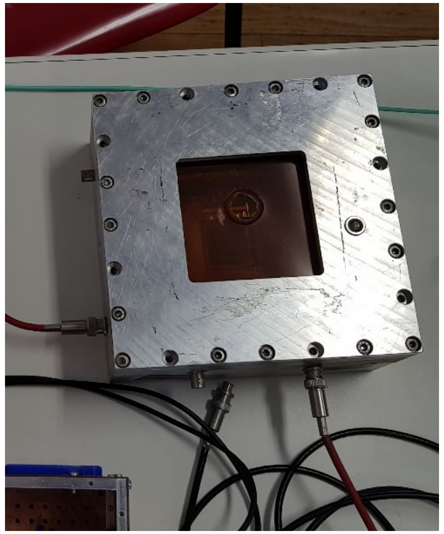


→ **Effective *i* resolution** ~ 25 pA by changing the rate and/or the OPA gain

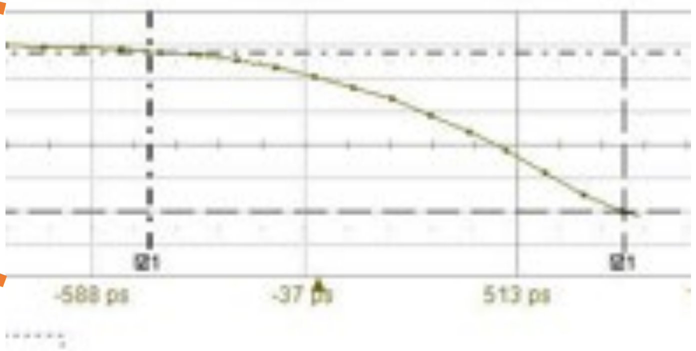
Unfortunately the gain has to be changed hardware wise

Discharge tagging and time stamping





Discharges stimulated by increasing the Voltage across a THGEM detector over the breakdown Voltage.

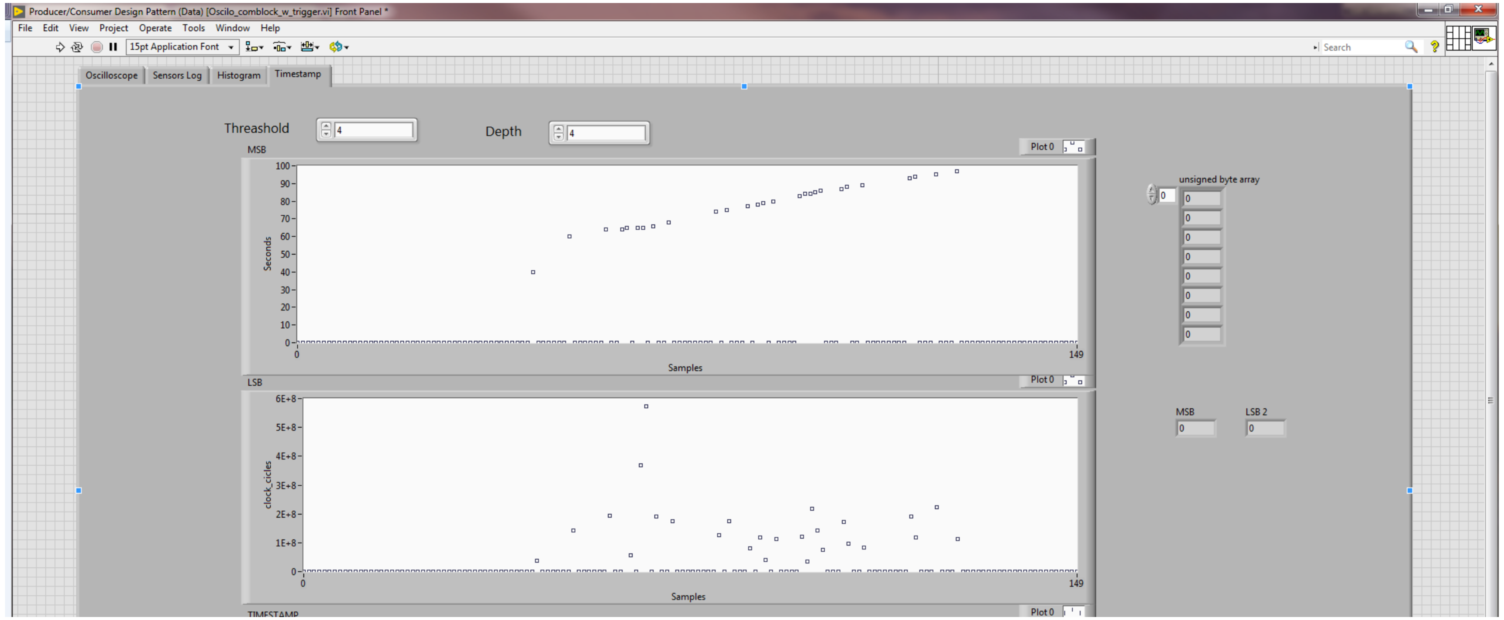


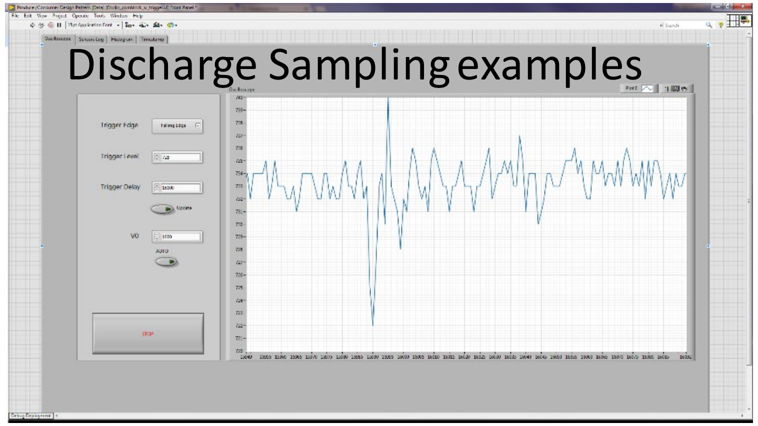
The system underwent several thousand discharges to check it robustness, at the moment we have not damaged any device despite the large current, typical capacitance ~nF → Instantaneous currents ~ A

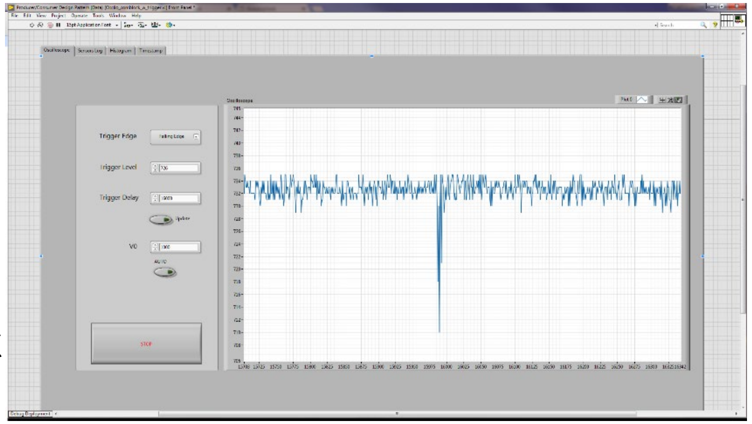
$$\cong i = \frac{Q}{t} \cong C\frac{\Delta V}{t}$$

Discharge tagging and time stamping

Very simple trigger on discharges by sampling @ 500 MS/s and taking the difference between two samples, if the different is above a threshold → triggered event → save both the timestamp with 2ns time resolution within the waveform.

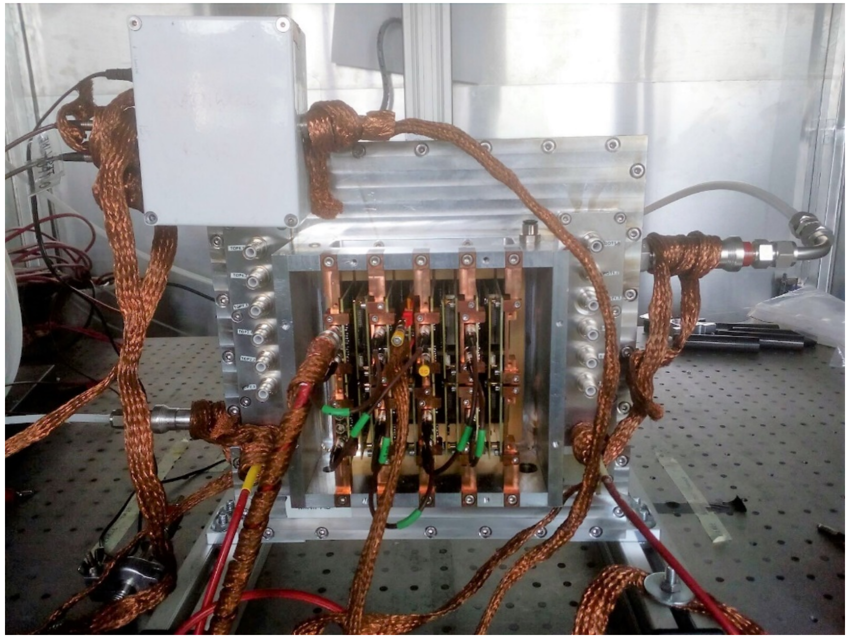


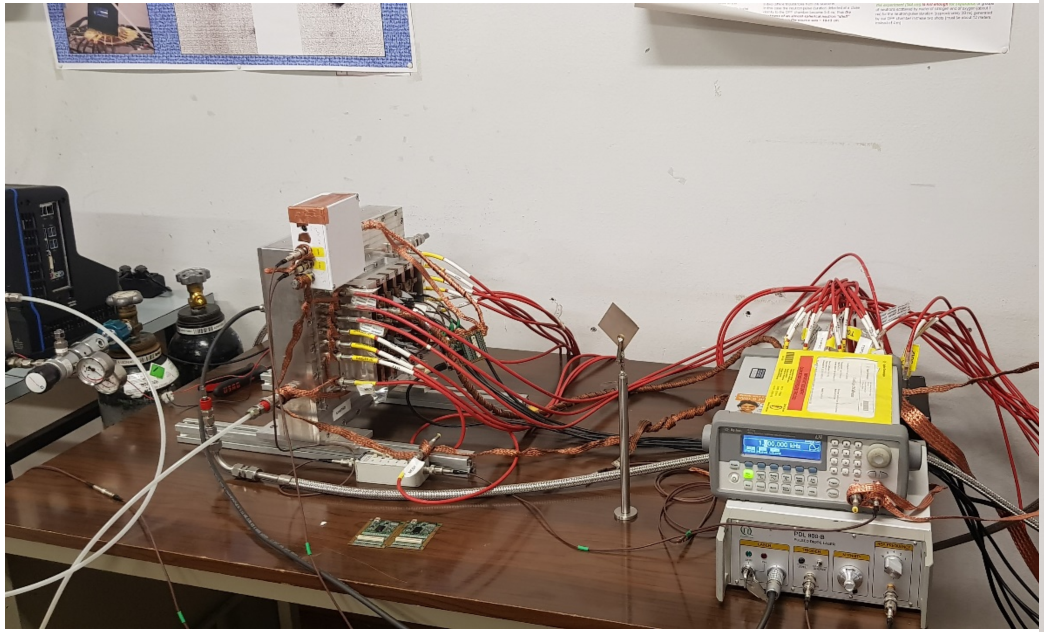


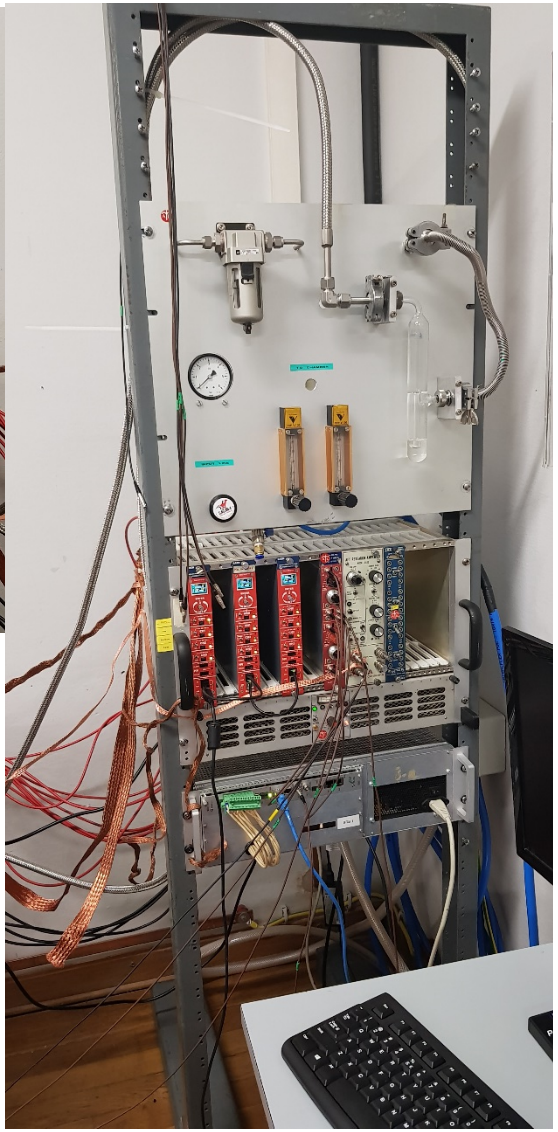


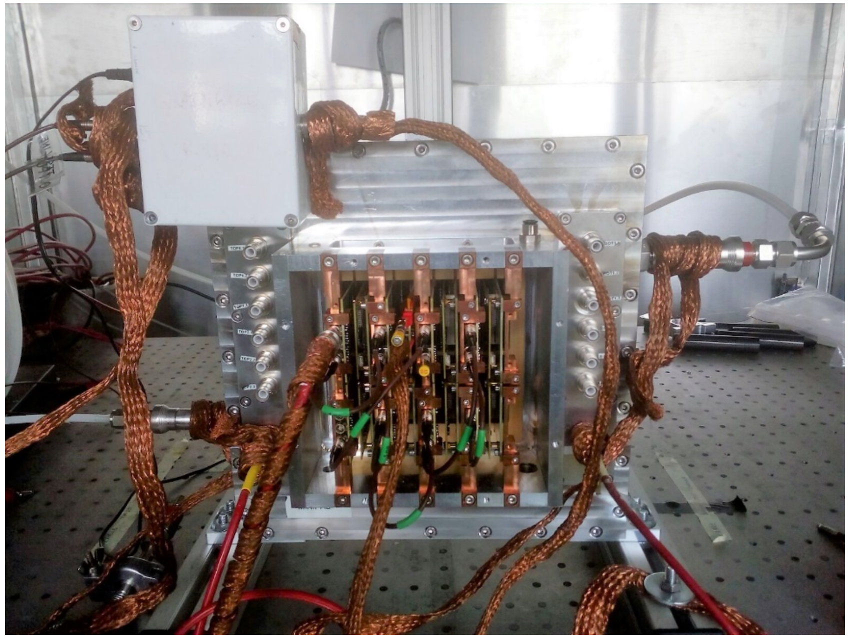
The Absolute time stamp is given by the sum of the timing of a RT slow Clock and of a fast Clock @250 MHz

Communication via TCP/IP protocol with optical fiber to achieve HV insulation is fundamental
With direct connection we bring the Ethernet port of the PC in an unstable state → freeze the communication



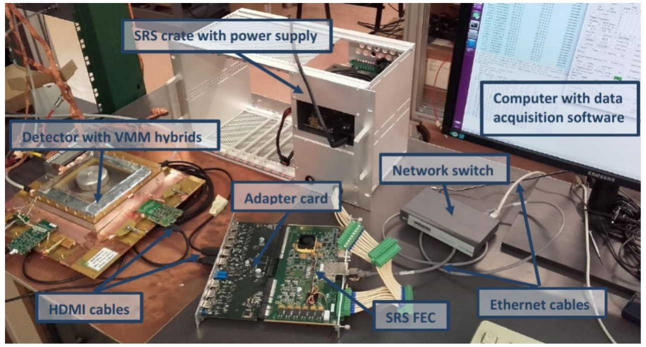






SRS + APV25

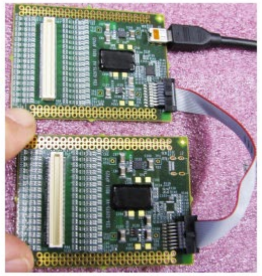
- 16ch 12-bit 50-MHz ADC card



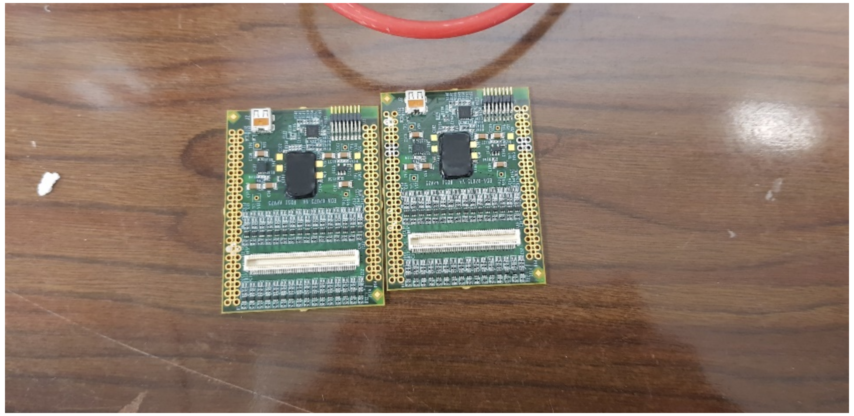
FECv3 with C-Card connects to APV25 hybrids

APV25 ASIC: Readout chip for CMS tracker
- 250 nm CMOS technology
- Delivered: 2001
- Configuration via I2C
- 128 channels with preamp and shaper
- Output: multiplexed analog levels
- 40MHz clock

APV25 hybrid:
- One APV25 ASIC
- PLL
- LDO for power
- Master/Slave
- Protection circuit



Adapter card:
- Mainly ADCs
- Can read up to 16 APV25 hybrids



Thanks!