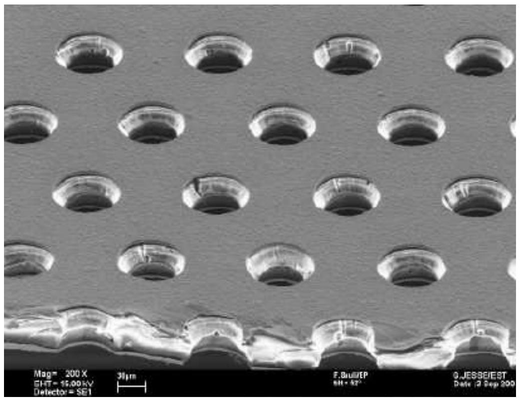
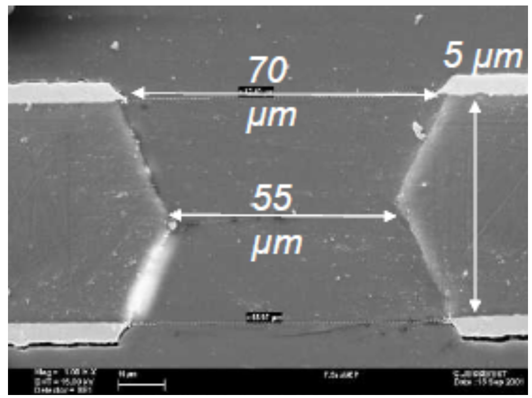
GEM detector construction and characterization

Tutor L. Benussi

GEM (gas electron multiplier) introduced by Sauli in 1997, consists of a thin, metal-clad polymer foil chemically perforated by a high density of holes, typically 100/mm2

GEM: A new concept for electron amplification in gas detectors
F. Sauli, Nucl. Instr. and Meth. A386(1997)531





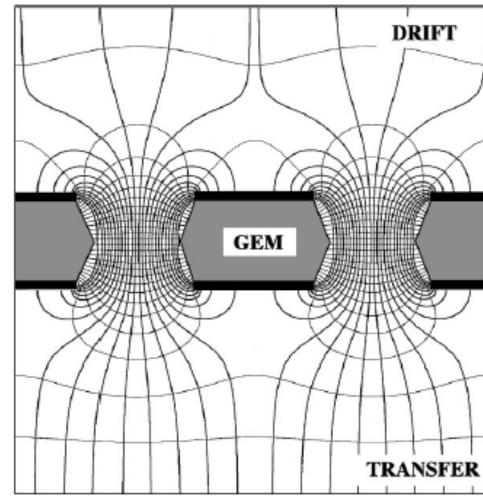


Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

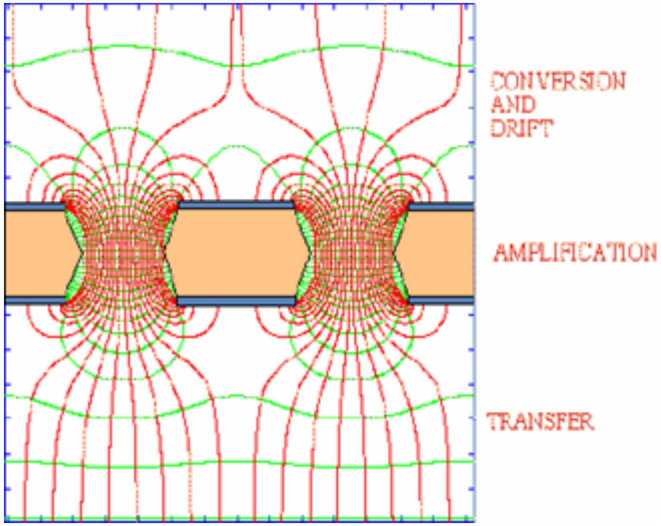
UNIQUE FEATURE

<u>PREAMPLIFICATION AND TRANSFER</u> OF CHARGE PRESERVING THE IONIZATION PATTERN

Sharing of the gain between two or more cascaded amplifiers, each operated at a voltage well below the discharge limit, appears to be a good solution to the problems common to all single-stage micro pattern detectors.

GEM: principle of operation

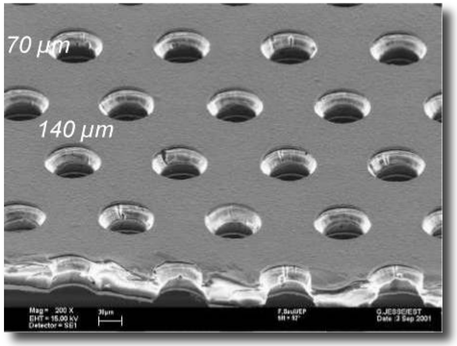
The GEM (Gas Electron Multiplier) [F.Sauli, NIM A386 (1997) 531] is a thin (50 µm) metal coated kapton foil, perforated by a high density of holes (70 µm diameter, pitch of 140 µm) → standard photo-lithographic technology.

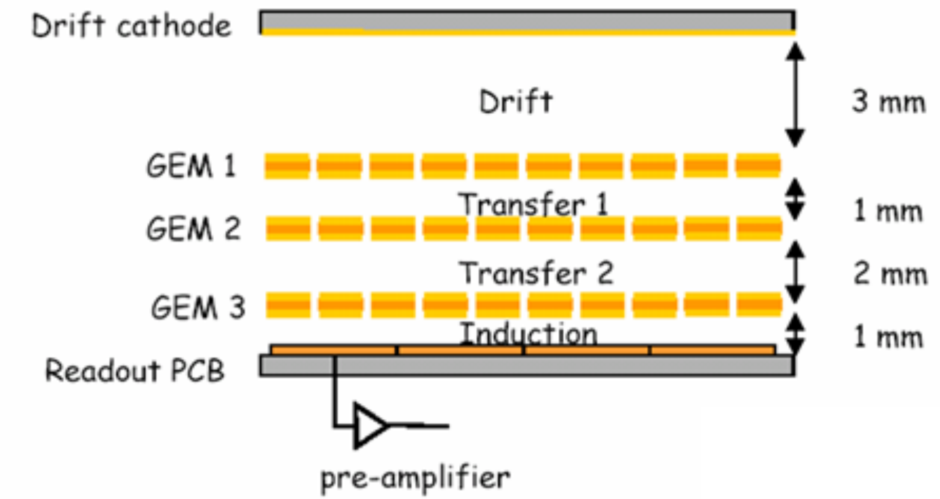


By applying 400-500 V between the two copper sides, an electric field as high as ~100 kV/cm is produced into the holes which act as multiplication channels for electrons produced in the gas by a ionizing particle.

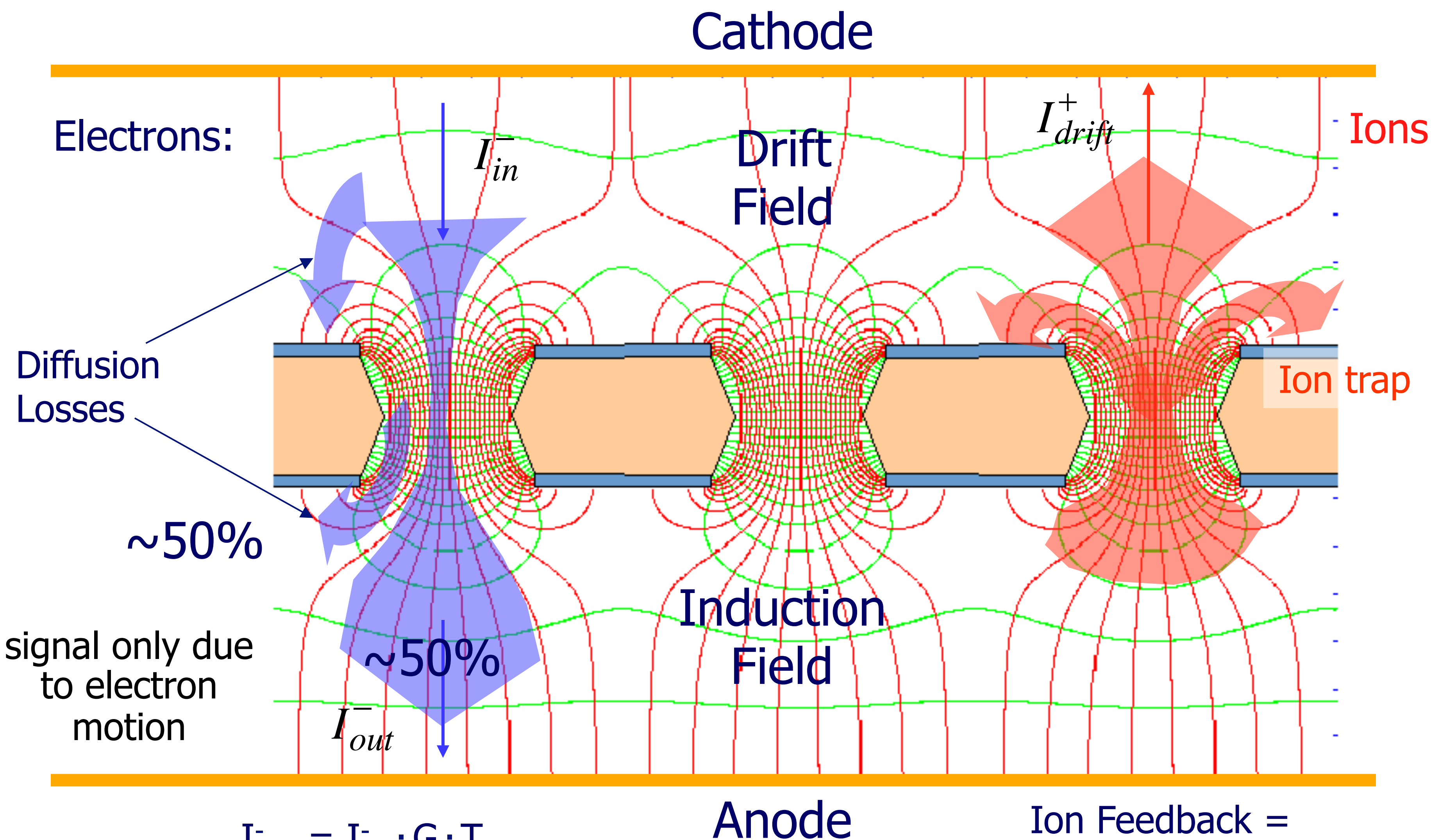
Gains up to 1000 can be easily reached with a single GEM foil. Higher gains (and/or safer working conditions) are usually obtained by cascading two or three GEM foils.

A Triple-GEM detector is built by inserting three GEM foils between two planar electrodes, which act as the cathode and the anode.





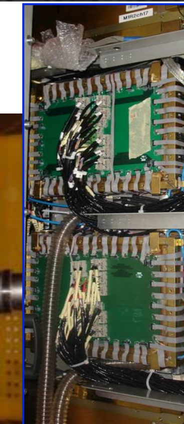
Electron transparency (single-GEM)



$I^{-}_{out} = I^{-}_{in} \cdot G \cdot T$
(gain **x** transparency)

Ion Feedback = $I^{+}_{drift} / I^{-}_{out}$

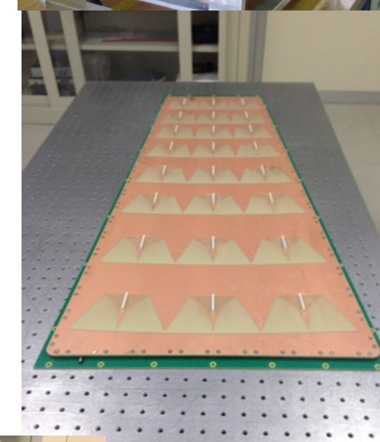
MPGDs @ Frascati (HEP applications)



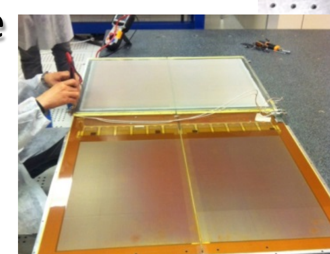
- The LHCb-LNF group (in coll. Cagliari) started a pioneering work on GEM in the 2000. LHCb has been the first LHC experiment to use GEM detectors (24 GEM chambers)

- Cylindrical-GEM Inner Tracker (4 layers) for the KLOE experiment; BESIII- LNF (+ Ferrara & Torino) is developing a similar detector for the upgrade of the IT of their experiment

  more recently:



- The CMS GEM upgrade project: LNF is one GE1/1 assembly site, where 20 large area GEM chambers (~ 130x50 cm^2/chamber) will be produced (the 2nd assembly site is BARI)

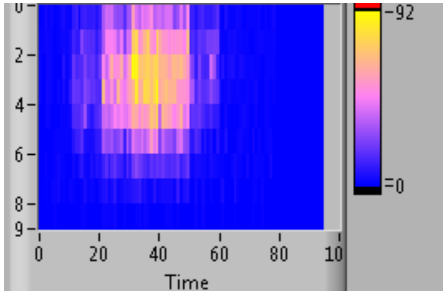


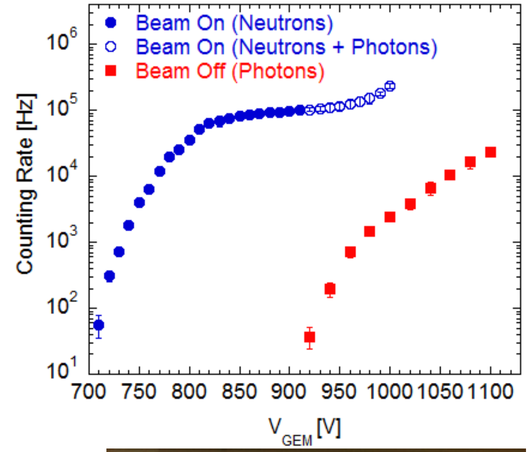
- The ATLAS-LNF is involved in the New Small Wheel upgrade where large area Micromegas (128 chambers, 2 – 2.5m^2) will be installed (@ LNF 30 % of the global production – RM1,RM3, Na, Le, Pv, Cs)

MPGDs @ Frascati (applied research)

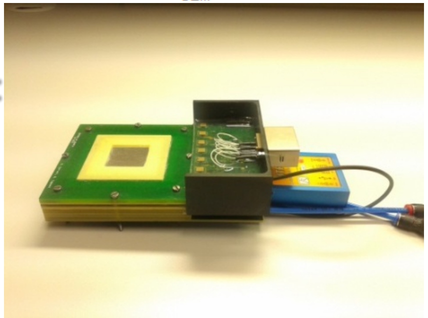
GEM detectors (developed at LNF by F. Murtas - GEMINI, BEAM4FUSION, INFN-E, ARDENT) have been used in several fields of applied research:

- ❑ Neutron detection, conversion on Boron coated cathode (good candidate for He^3 detector replacement):
  - ➢ Imaging capability
  - ➢ good time resolution (5 ns),
  - ➢ high gamma rejection ($>10^5$)
  - ➢ high rate capability O(10 MHz/cm^2)
  - ➢ good spatial resolution O(1mm)

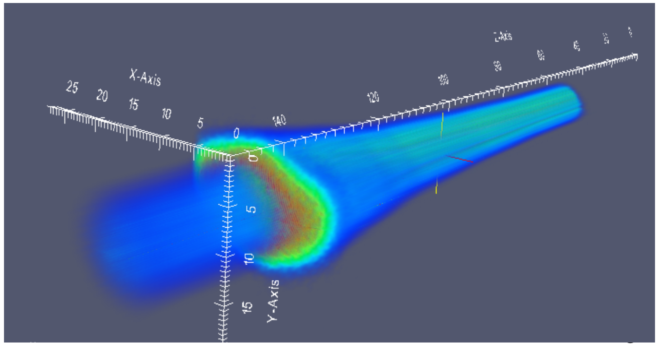




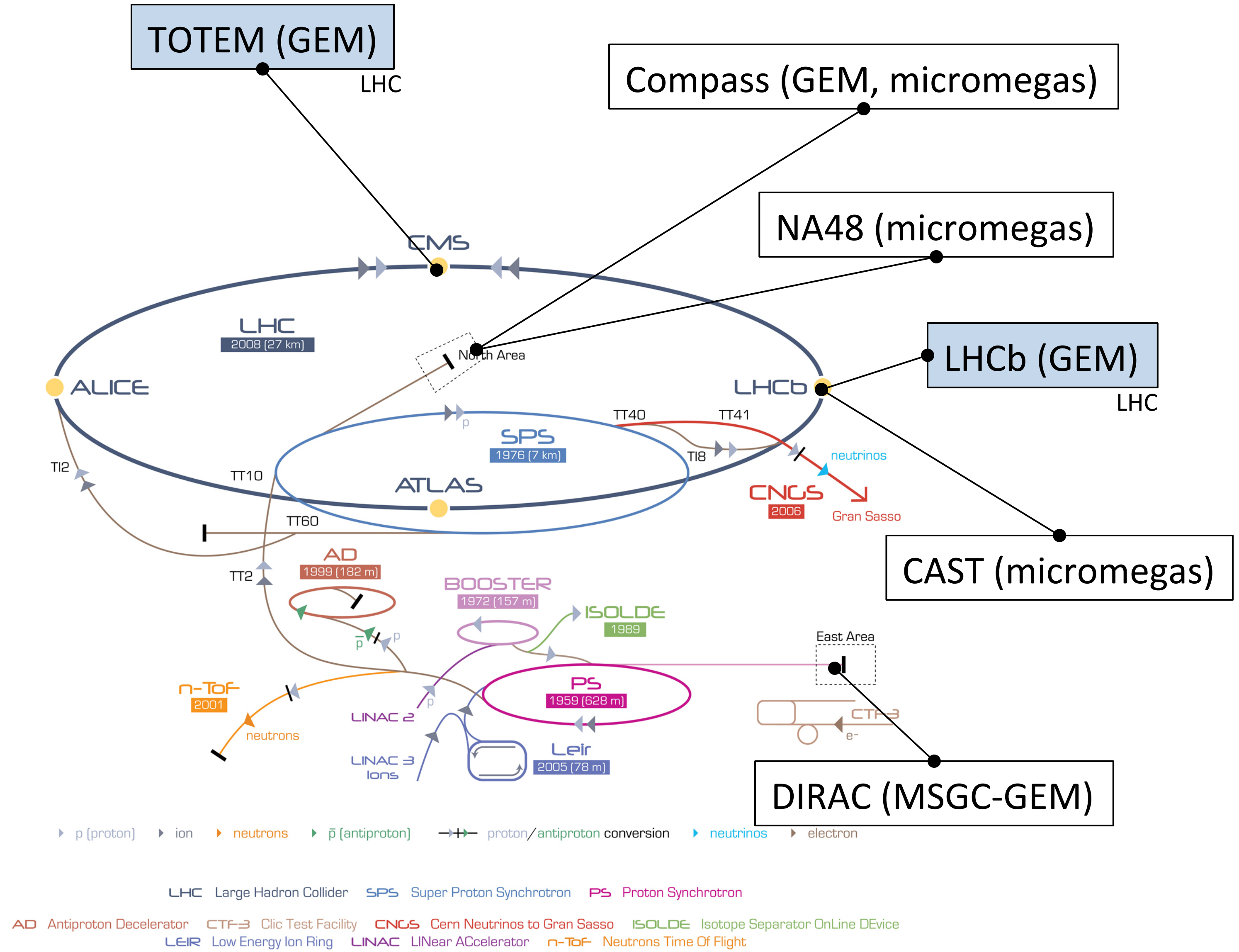
- ❑ GEMPIX, a triple-GEM with Timepix chip (50 x 50 ?m pixels) readout :
  - ➢ 3D particle track reconstruction with O(100 μm) space resolution
  - ➢ Very Low flux : Radioactive waste and microdosimetry
  - ➢ Very High flux : Burning Plasma monitor at Tokamak



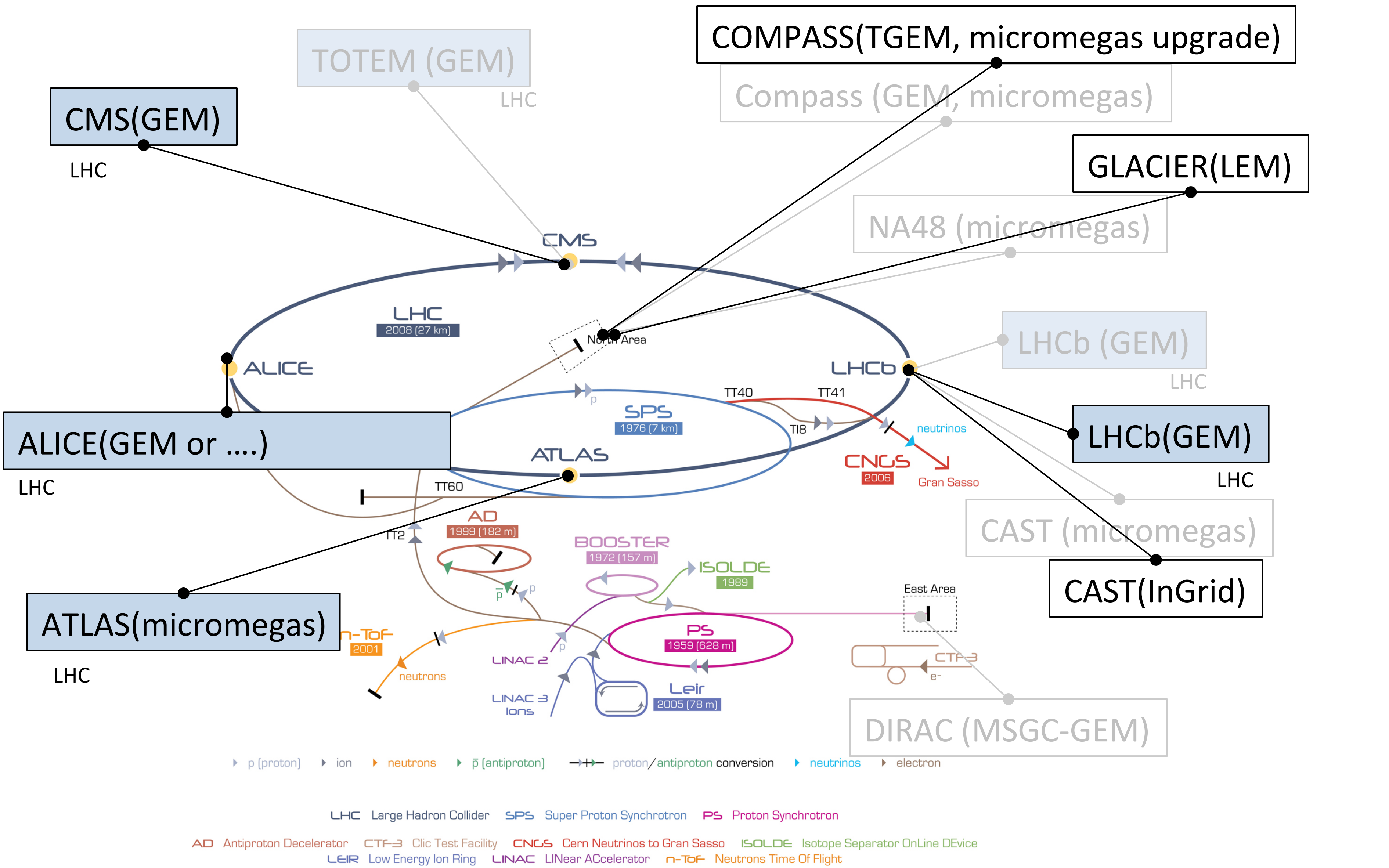
- ❑ Medical applications with triple-GEM and GEMPIX :
  - ➢ 2D Beam monitor for daily quality check at CNAO
  - ➢ 3D energy relased measurement in water phantom (Bragg peak finder)
  - ➢ Beam monitor in radiotherapy at Pol. Tor Vergata



MPGD detectors already running at CERN….



…. and possible upgrades



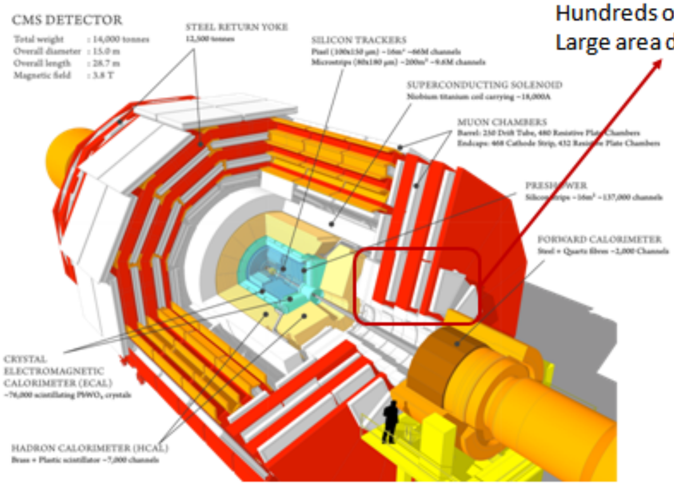
… but I will not talk directly about them

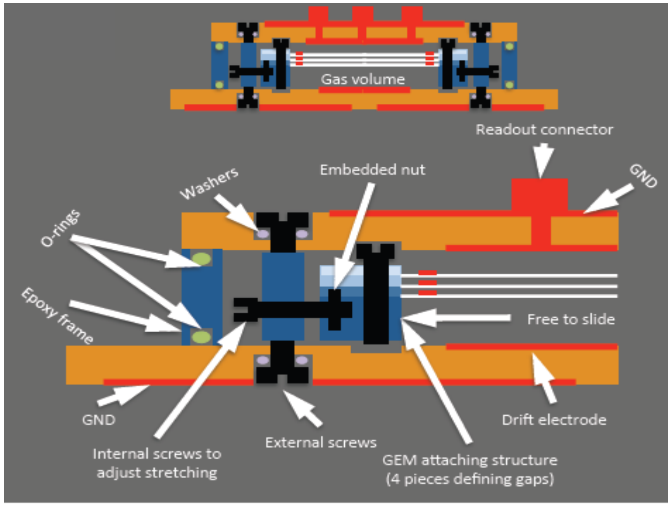
Muons System @ LHC: CMS GEM

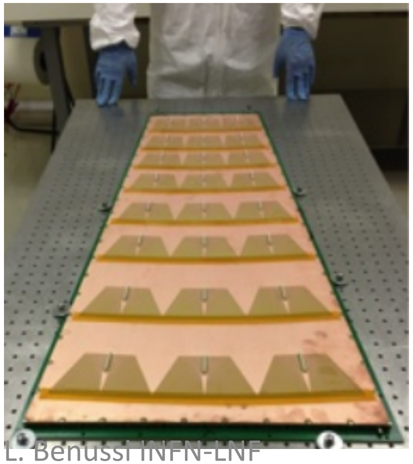
cover large areas with GEM…one example of playing with the production processes

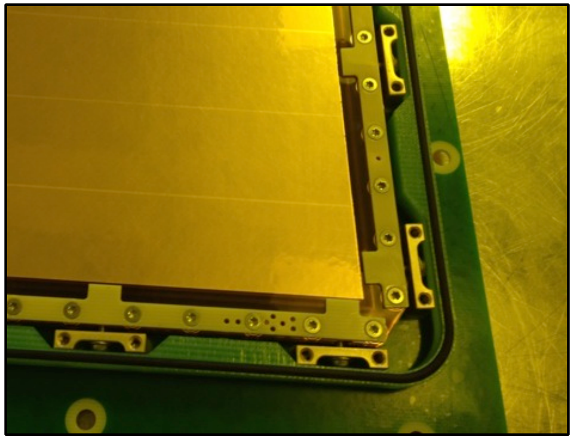
CMS, Large GEM proposal

Hundreds of square meters…
Large area detectors needed









Gain Measurement

The effective detector's gain **G**eff is the ratio between the number of electrons at the end of the triple-GEM amplification process and the number of the primary ones.

Geff =**N**el/**N**p

where
Nel is the amount of the electrons in the induction gap, which generate the outgoing signal
Np is the amount of primary electrons, produced in the drift zone by ionization.

We will use a gas mixture **Argon/CO_2 70/30** and an **Fe55** x-ray source with main peak emission energy of 5.9 keV

Gain Measurement

To measure the triple-GEM prototype's gain, we should estimate the number of primary electrons generated by an interaction in the drift zone and then measure the total amount of electrons which generate the signal. To this aim it is very useful to use an X-ray source like Iron-55, whose energy spectrum is well known. Moreover the source is easy to control, in particular, it can be moved along the full detector sensitive area.

The main emission line for the iron-55 source is at 5.9 keV. In most of the cases the whole photon's energy is absorbed and used to produce primary ionization electrons.

However in the some cases the photon extracts an electron from the inner K-shell of the 63 argon and the vacancy is filled by an outer electron, with the emission of another X-Ray photon of 2.9 keV, seen by the detector and we observe a second peak in the iron-55 spectrum, called escape peak. All tests on the prototype have been performed with the Ar/CO2 - 70/30 % gas mixture, hence we have to calculate an average value for the mixture in use of the mean ionization energy W.

The Ar and CO2 W values are respectively 25eV and 34eV. Now we can compute the average number of primary electrons produced by an X-ray photon of 5.9 keV

$$Np = 5.9keV * (\%(Ar)/W(Ar)) + 5.9keV * (\%(CO2)/W(CO2)) = 207.7$$

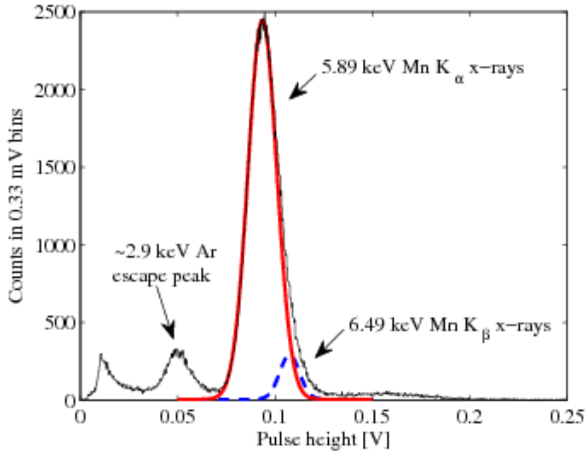
Gain Measurement

Np = 5.9keV * (%(Ar)/W(Ar)) + 5.9keV * (%(CO2)/W(CO2)) = 207.7

Geff =**N**el/**N**p

Nel is determined by measuring the charge of the signal produced by the detector that must be decoupled from the amplification factor of the electronics and the impedance of the circuit.

In our case we will integrate the signal area (ADC method) offline.
The signals will be acquired with a 2 Gs digital oscilloscope and analyzed with a root macro.

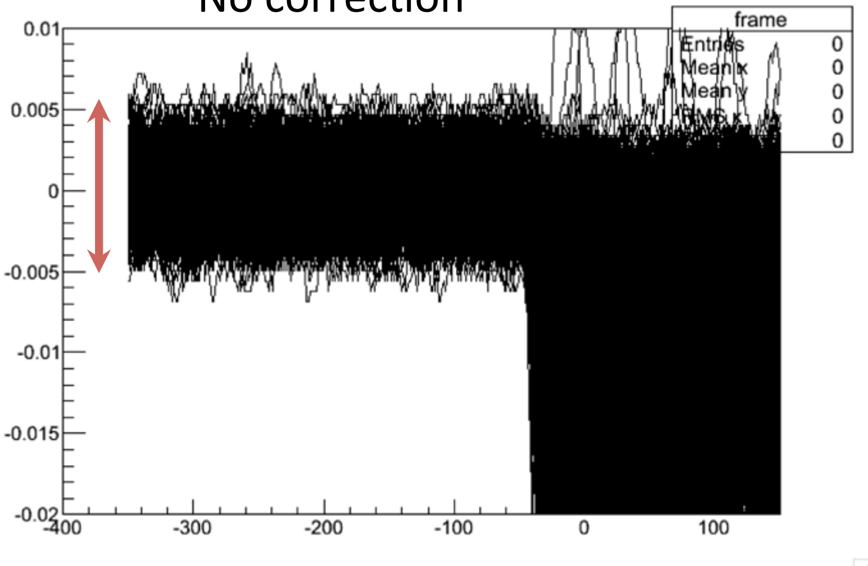


Typical Fe55 spectrum obtained with a MWPC operated with an Argon based gas mixture

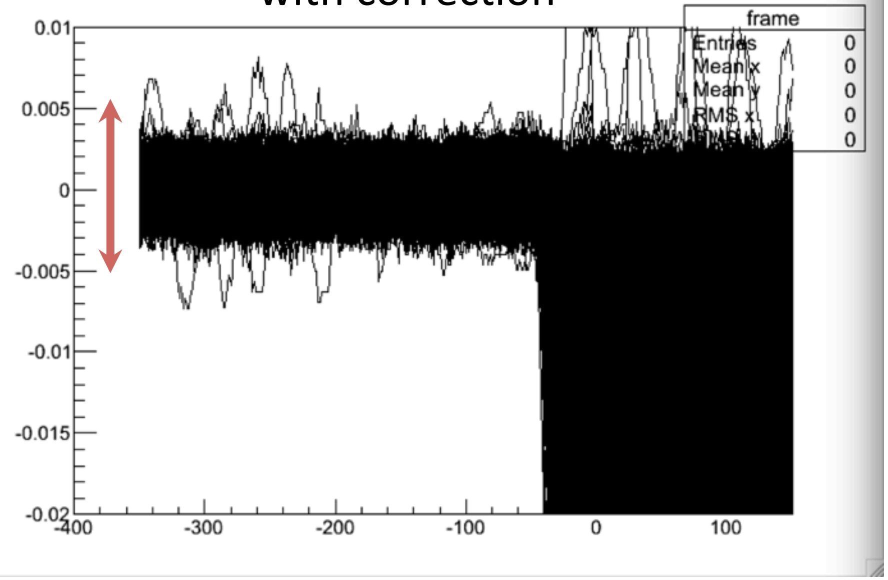
Gain Measurement

In our lab there is a low frequency (few kHz) electromagnetic noise which moves the baseline of the fast GEM signal effecting time resolution.
This effect ("baseline-correction (B-C)") is corrected offline.
VG1, VG2, VG3 = 430, 420, 410

No correction



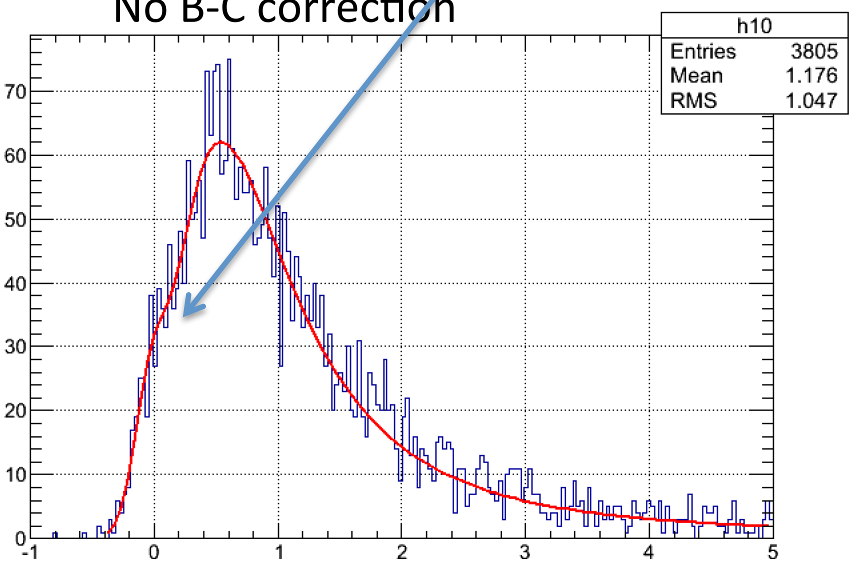
with correction



Gain Measurement

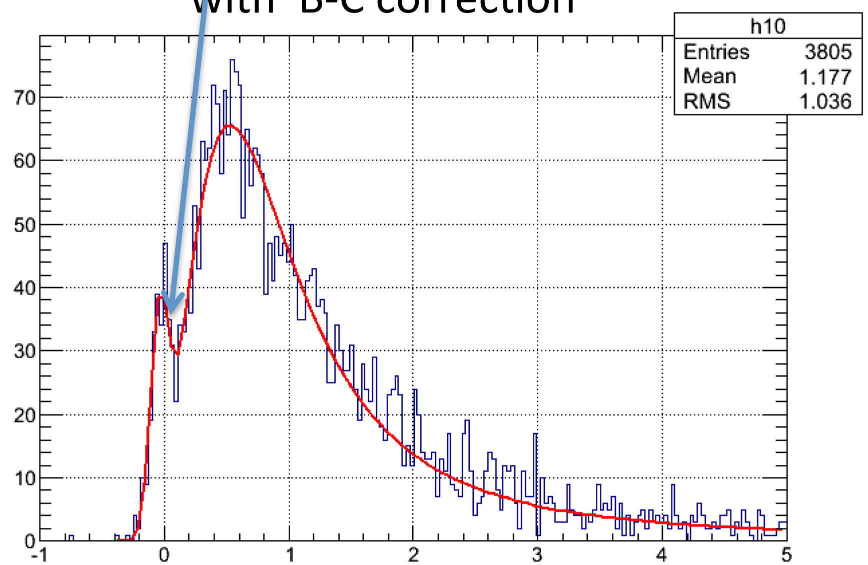
Cosmic ray signals. Much lower than Fe55 without baseline correction the ADC pedestal is not visible, while it shows up once the correction is applied. The pedestal is the zero position in the ADC, meaning the response of the instrument when no signal is produced by the detector. It is very important to know where it is in your measurement.

No B-C correction



ADC channels

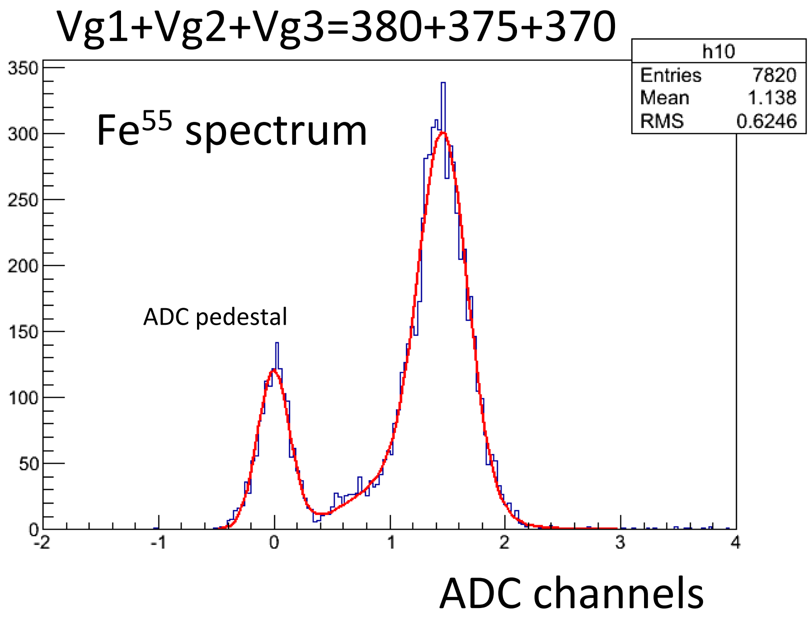
with B-C correction

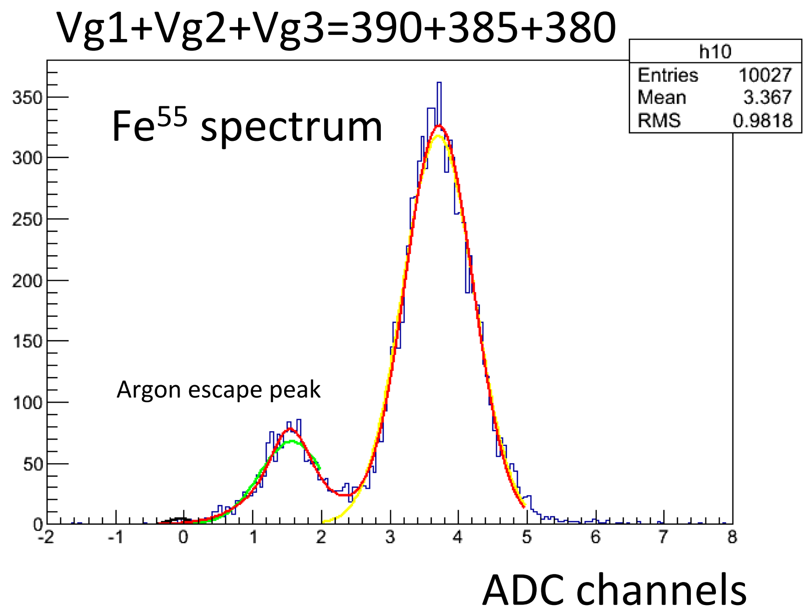


ADC channels

Gain Measurement

Gain measurements done using Fe^{55}
Gas Ar/CO_2 70/30
GEM geometry 3-1.5-2-1





Gain Measurement

Gain is defined as

$G = Peak/(A_g \times Q \times N)$

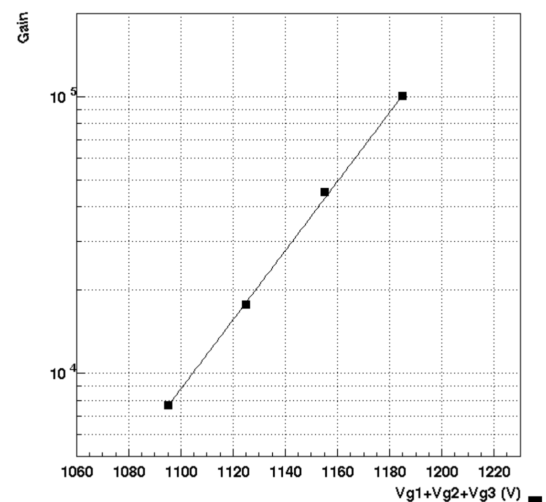
Where Peak is the Fe^{55} main peak position (in fC!), A_g is the NIM amplifier gain (20) Q the electron charge N = (the number of electron produced by the Fe^{55} x-ray).

Consider that I=V x Δt Where V is the signal amplitude and Δt is the signal time duration. From the Ohm’s law:

dQ/dt = V/R where Q is the signal charge and R is the input oscilloscope impendence. *As consequence we can write*

Peak=V/R x ∫dt = V/R x Δ*t = A/R*

You are supposed to reproduce this plot!



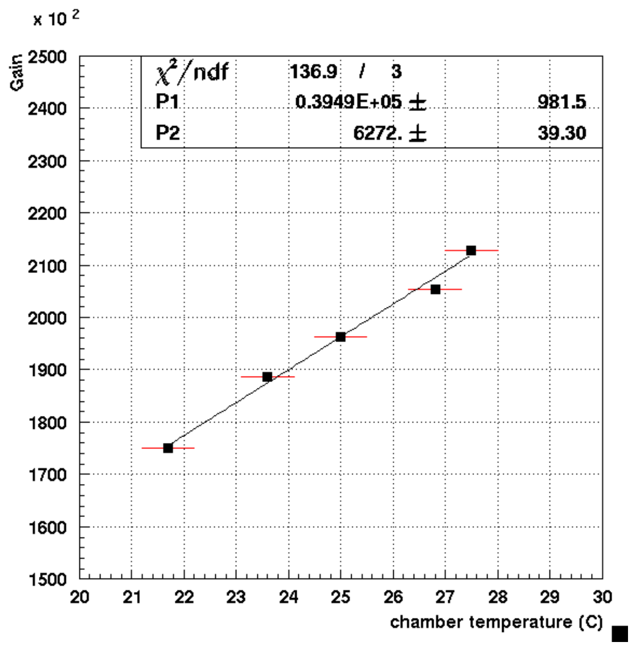
Gain Measurement

Why gain measurement is so important?

- The gain gives you a rough estimation of the S/N you can expect in you detector
- The charged produced in the detector must be controlled....You should know how big it will be
- Charged particles flow are one of the major source of aging. To much gain can be a problem
- Knowing the gain of your detector you can optimize the electronics to better match the signal output

Gain Measurement

- Measure the gain stability as a function of temperature
  - Vg1+Vg2+Vg3= 1140 V
  - P_{atm} = 999 mbar almost stable (within 1 mbar) the whole period of measurement
  - Temperature has been measured both inside and outside the copper box housing the chamber to ensure thermalization.



Please remember

The work in a laboratory can be dangerous

Be careful and do not touch anything you do not know, it can be dangerous for you and for the stuff you are going to touch!

You are not supposed to be experts.
Do no hesitate to make questions. Sometimes I could be able to give you answers

Good Work!