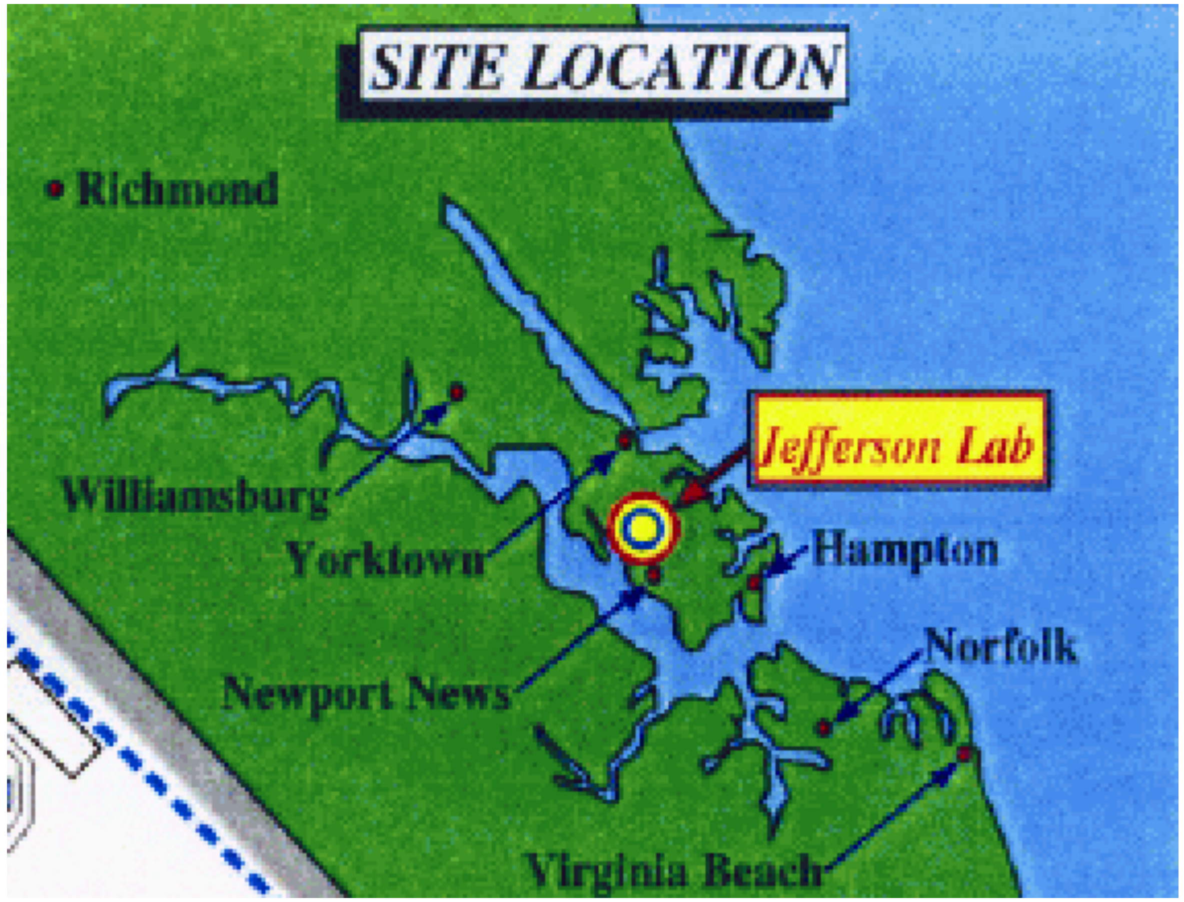
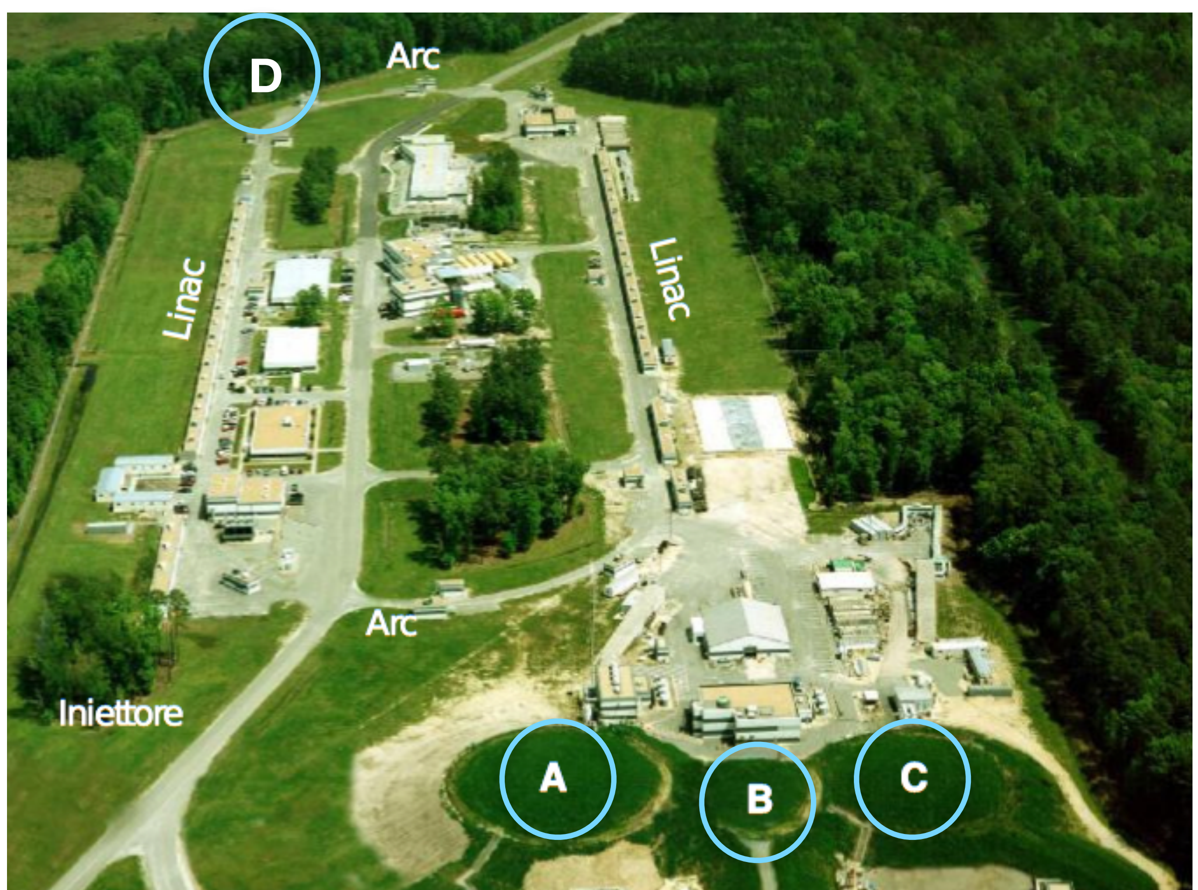
Simulations of Triple-GEM tracker's response for experiments at JLab

Vanessa Brio

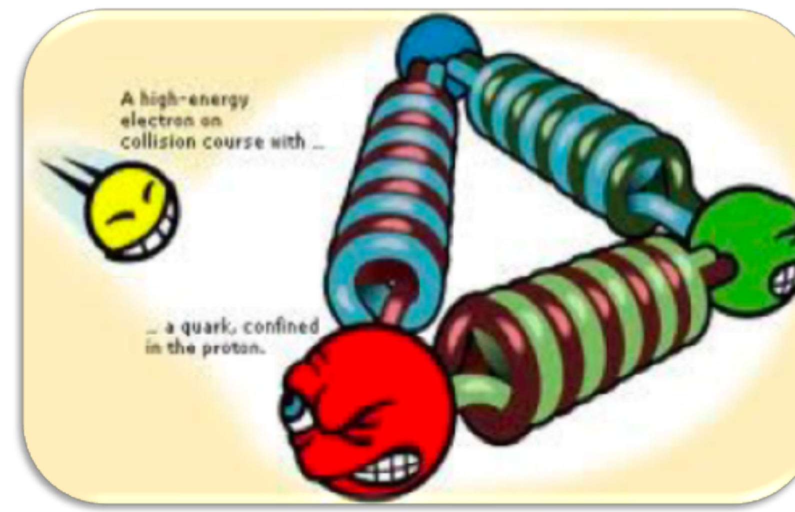
Table of Contents





Jefferson Lab

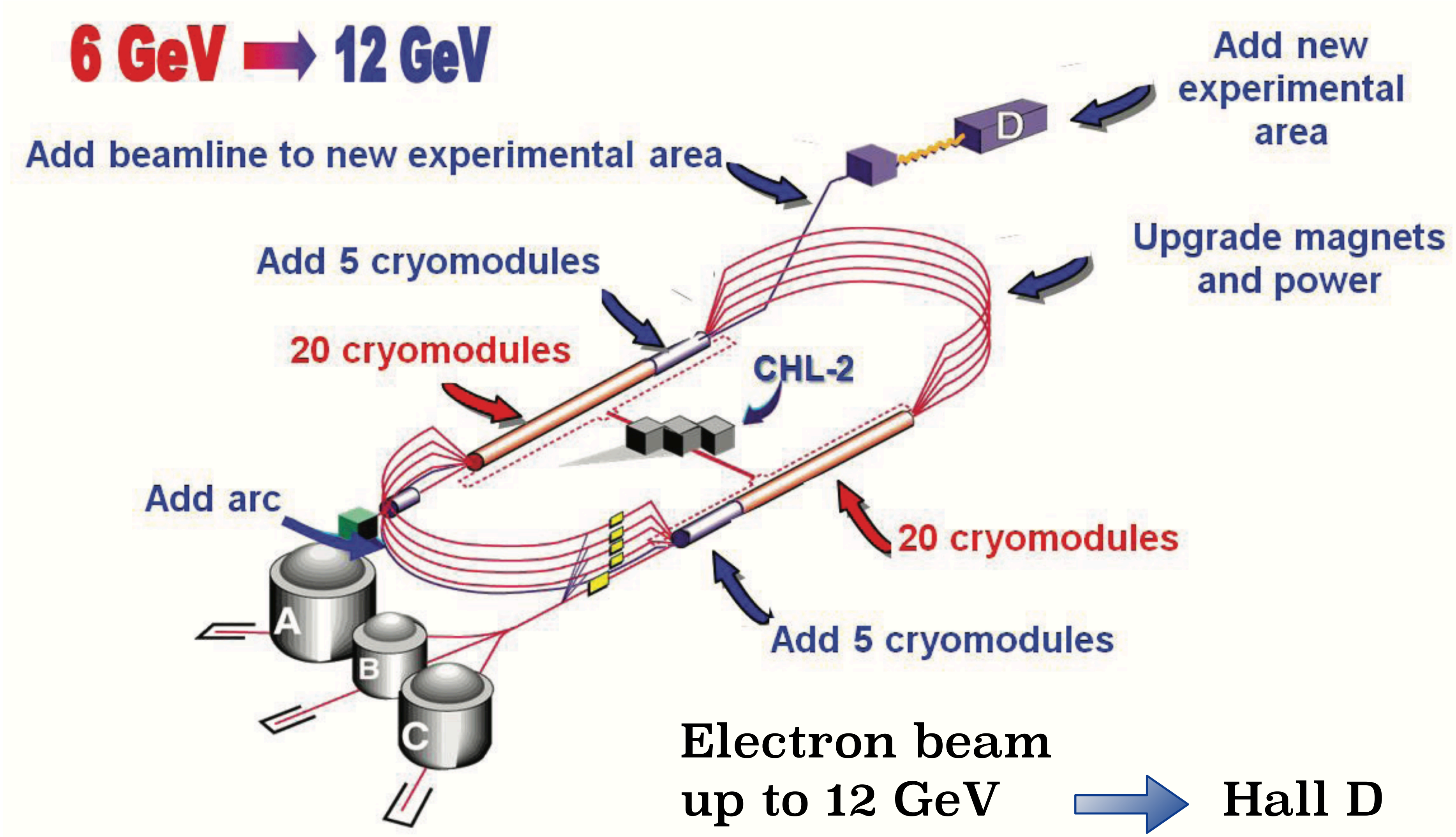
The main purpose is to investigate the fundamental nature of nuclear matter



Nucleon Form Factors

4 different experimental rooms

CEBAF Continuous Electron Beam Accelerator Facility



Electron beam up to 12 GeV → Hall D

Electron beam up to 11 GeV → Halls A, B and C

Max current : 100 µA

Longitudinal Polarization : ~ 85%

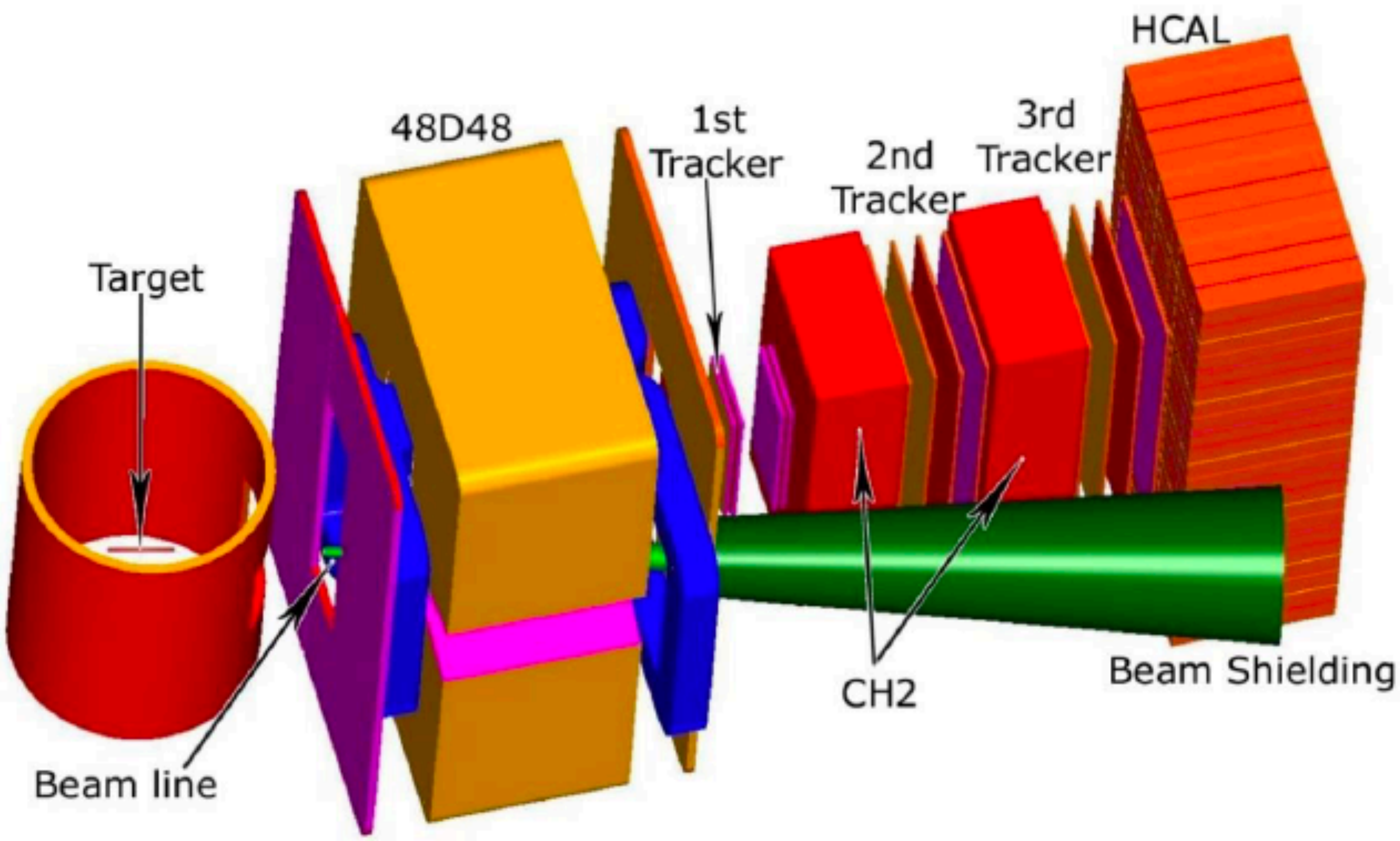
SBS Super Bigbite Spectrometer

JLAB12

University of Catania -Dipartimento di Fisica e Astronomia
INFN - Catania section
INFN Bari
INFN Genova
ISS Roma

GEM Tracker (Gas Electron Multiplier)

Hadronic Calorimeter HCAL-J



To deflect the reaction products

Front, second and third tracker to track the charged particles

To measure the two components of polarization

To evaluate the energy of the particles and distinguish between protons and neutrons

Gas Electron Multiplier (GEM)

↓

Gaseous detector

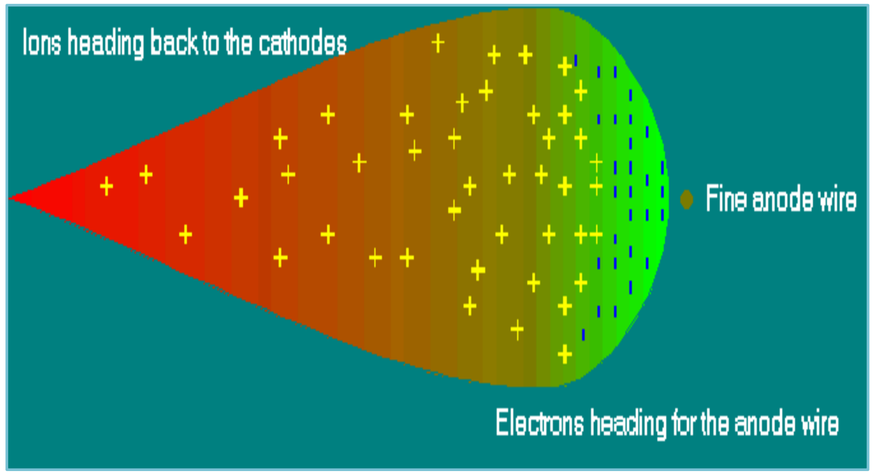
Charged particles pass through the gas, lose their energy and create ion-electron pairs. If we apply an appropriate electric field, we can accelerate these charges towards the electrodes and collect them.

$$n_{pairs} = \frac{E_{primary}}{w_{ionization}}$$

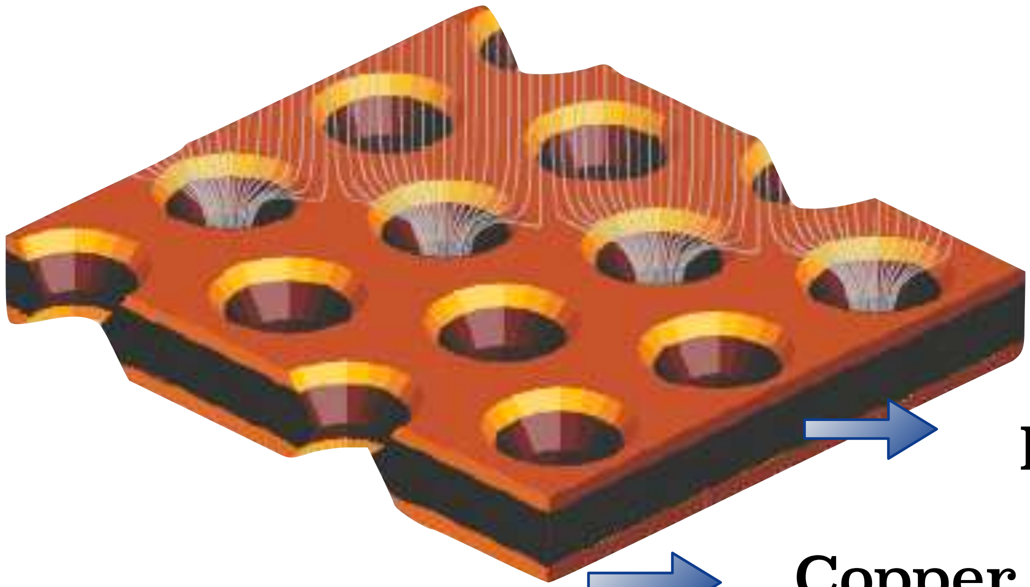
$w_{ionization} \simeq$ 30-35 eV/pairs

ΔV → Electric field → Energy for more ionizations

→ Creation of avalanche



Single GEM foil



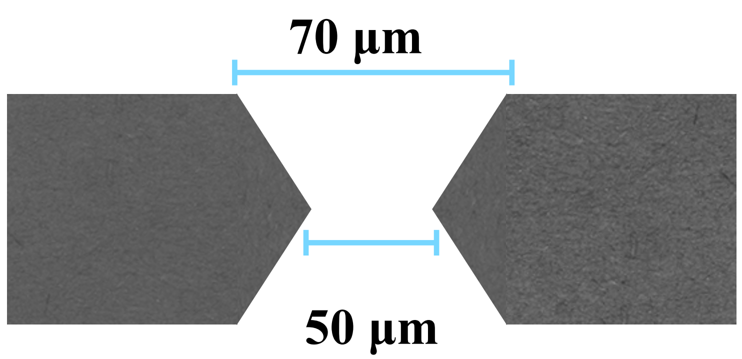
Copper = 5 µm

kapton=50 µm

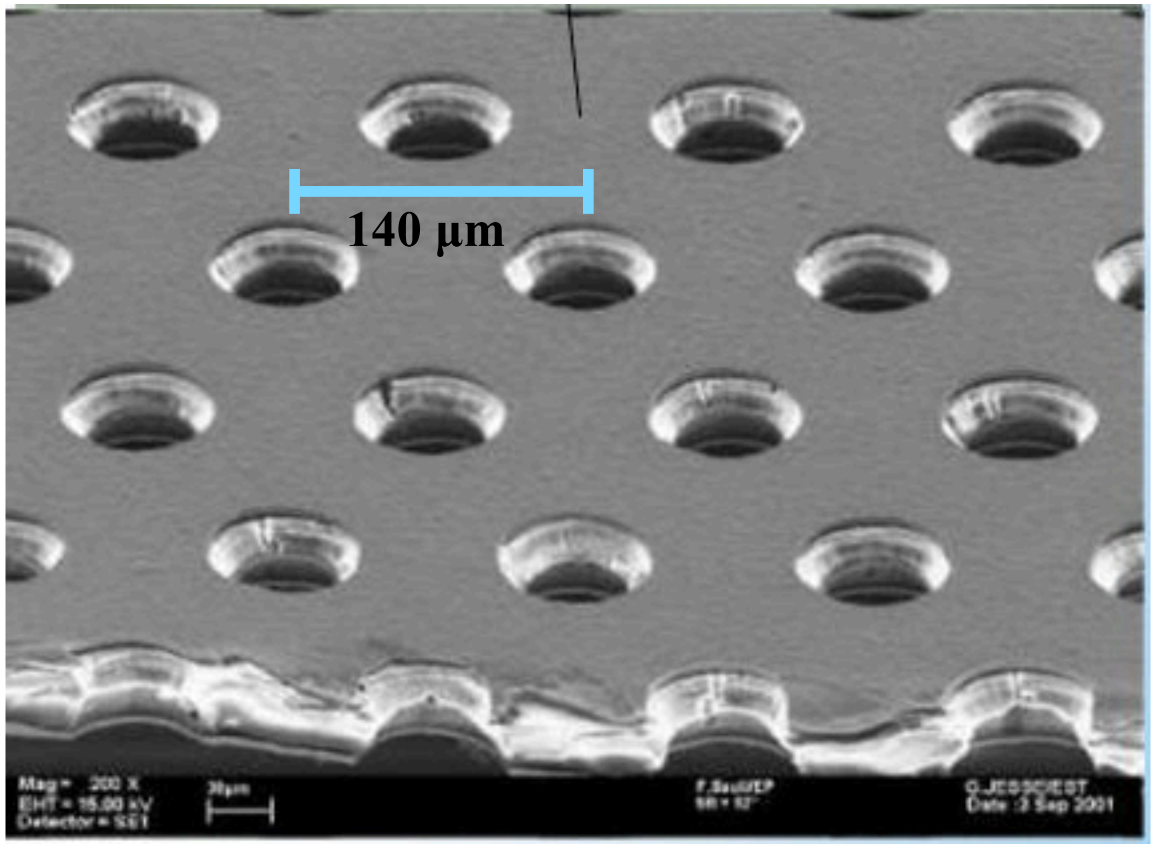
Copper = 5 µm

Biconical holes

D_{ext}= 70 µm
d_{int} = 50 µm

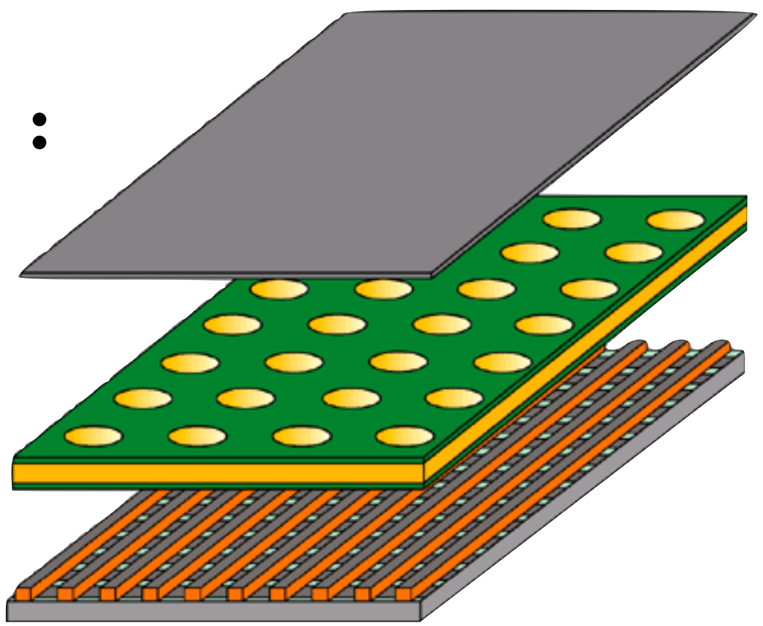


Holes matrix



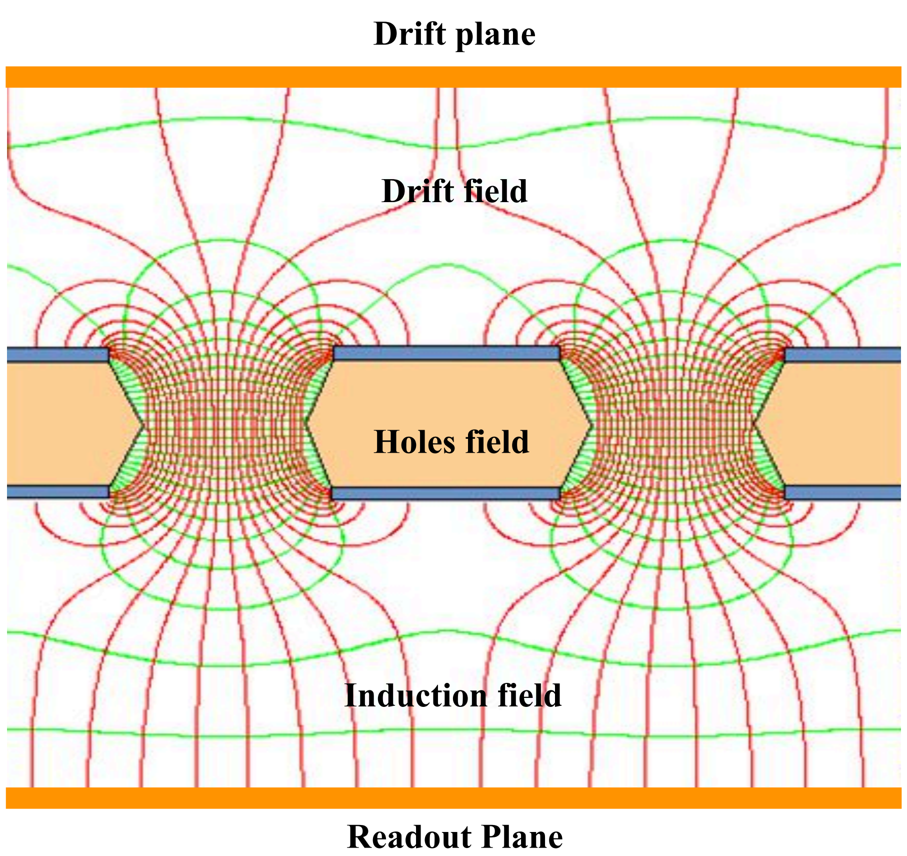
Single GEM foil

Gas mixture :
Ar 70%
CO_2 30%



Drift plane
GEM foil
Readout plane

ΔV = 300-500 Volts → Strong electric field in each hole



Advantages:

- Conversion, amplification and charge collection take place in separate layers;
- Good gain in the final state;
- Flexible geometry;
- Good spatial resolution;
- A GEM foil is not expensive!

Gain in a single GEM

Relative Gain

$$G = \frac{n}{n_0} = e^{\alpha x} \approx 10^3$$

α → **Towsend Coefficient** = ionization number to length unit

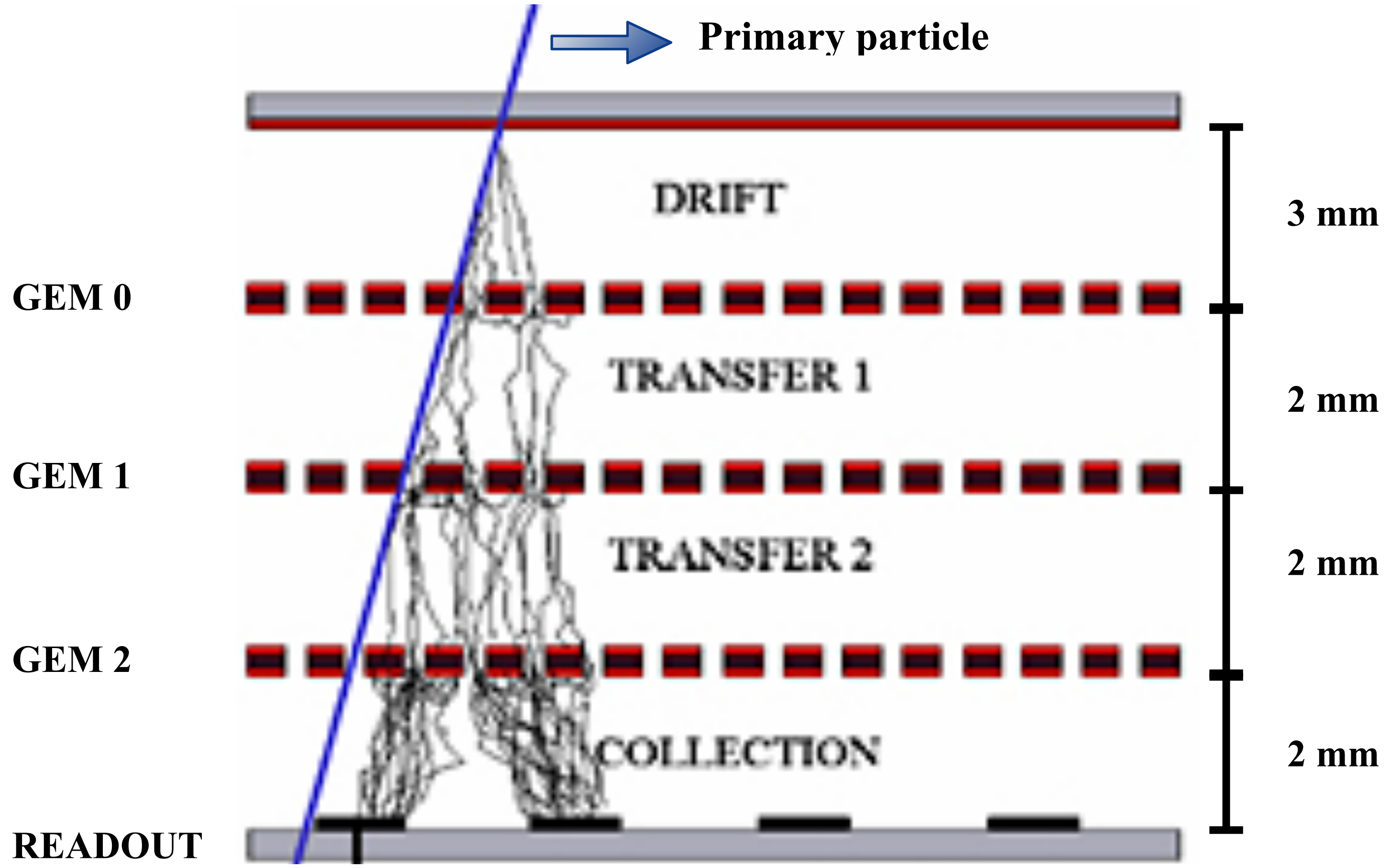
But not all electrons can reach the readout plane !!!

Real Gain depends from:

- Electric field intensity;
- Thickness of the drift region and the induction region;
- Ratio between the number of electrons entering the GEM holes and the number of electrons produced in the drift area;
- Ratio between the number of electrons extracted from the holes and the number of electrons produced inside the holes.

Triple GEM detector

3 GEM foil in cascade between the drift and the readout planes



Gain:

$$G \propto e^{\alpha \sum V_{tot}}$$

Effective Gain ~ 10^5

Advantages:

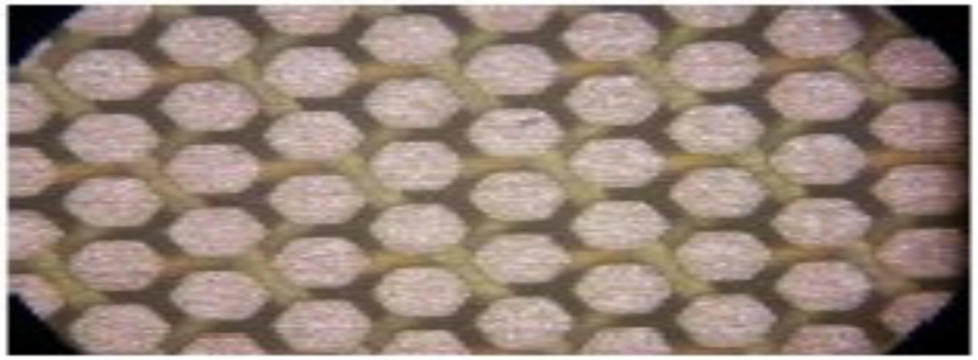
- Better gain but using smaller potential differences;
- Probability of lower discharge phenomena;
- Lower number of ions at the cathode.

Readout plane

Kapton sheet with copper on one side; the geometry for the readout plane can take two different configurations:

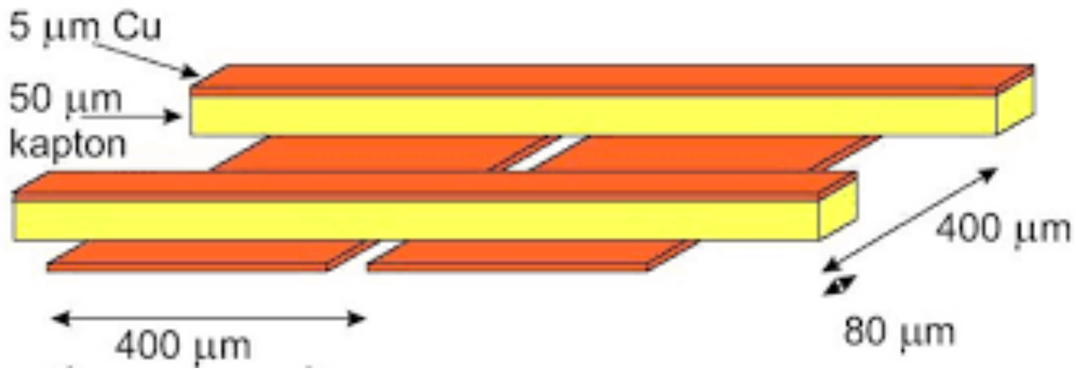
Pad

Double strip with 45° angle



Strip

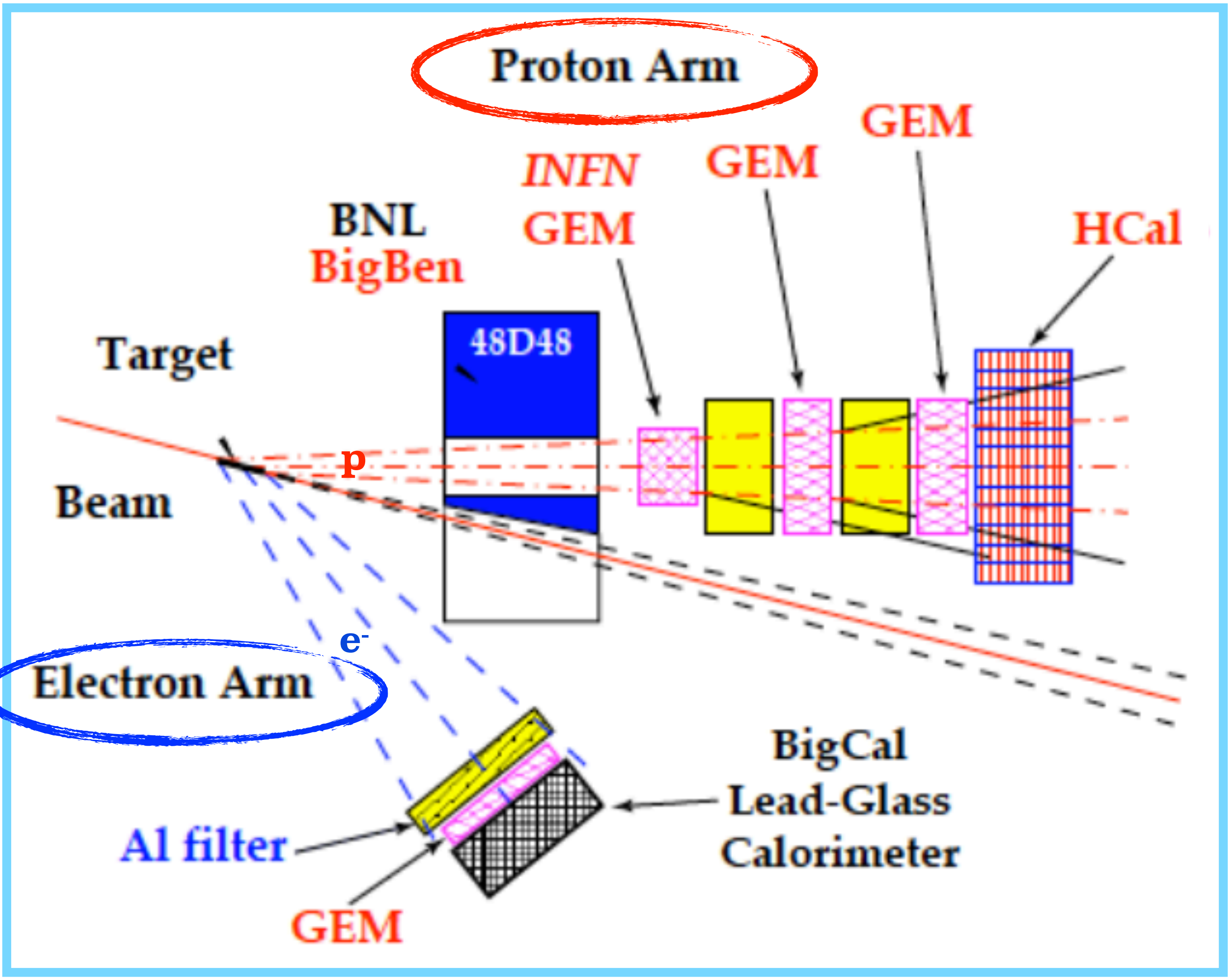
Double strip with 90° angle



The readout plane, for SBS configuration is a Strip plane and allows us reach a good spatial resolution in x and y directions

SBS for GEp5 Experiment

Study of the electric Form Factor of the proton



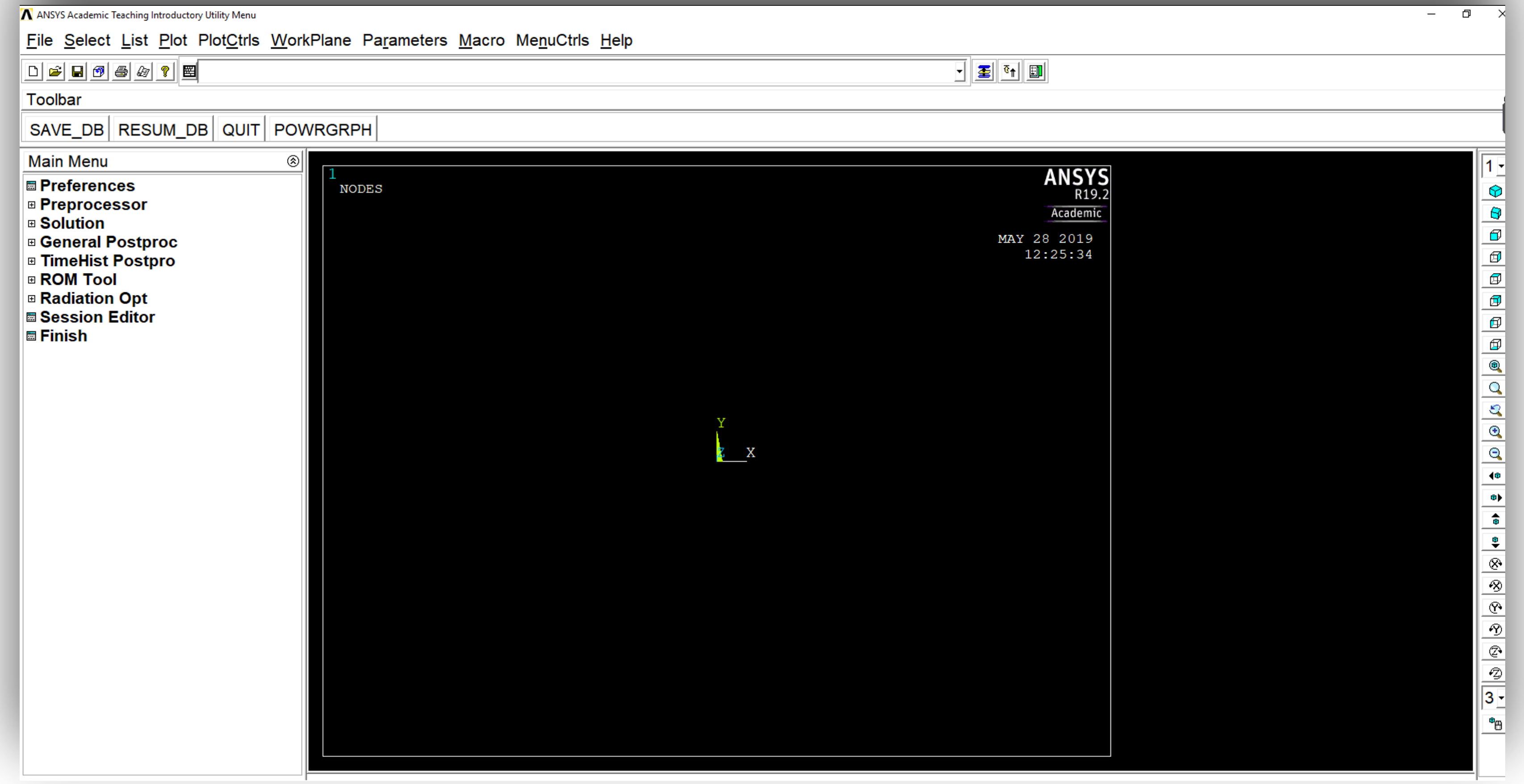
e⁻ Beam	Target	Q^2
11 GeV, 75 μA, 85% pol.	Liquid H_2, 40 cm.	6, 12.5, 15 GeV^2

Proton	Electron
θ = -14° , Ω = 35 msr	θ = 37° , Ω = 180 msr

ANSYS software

ANSYS is an engineering software useful to create complex geometries, assign materials to different volumes and create electrostatic field solutions.

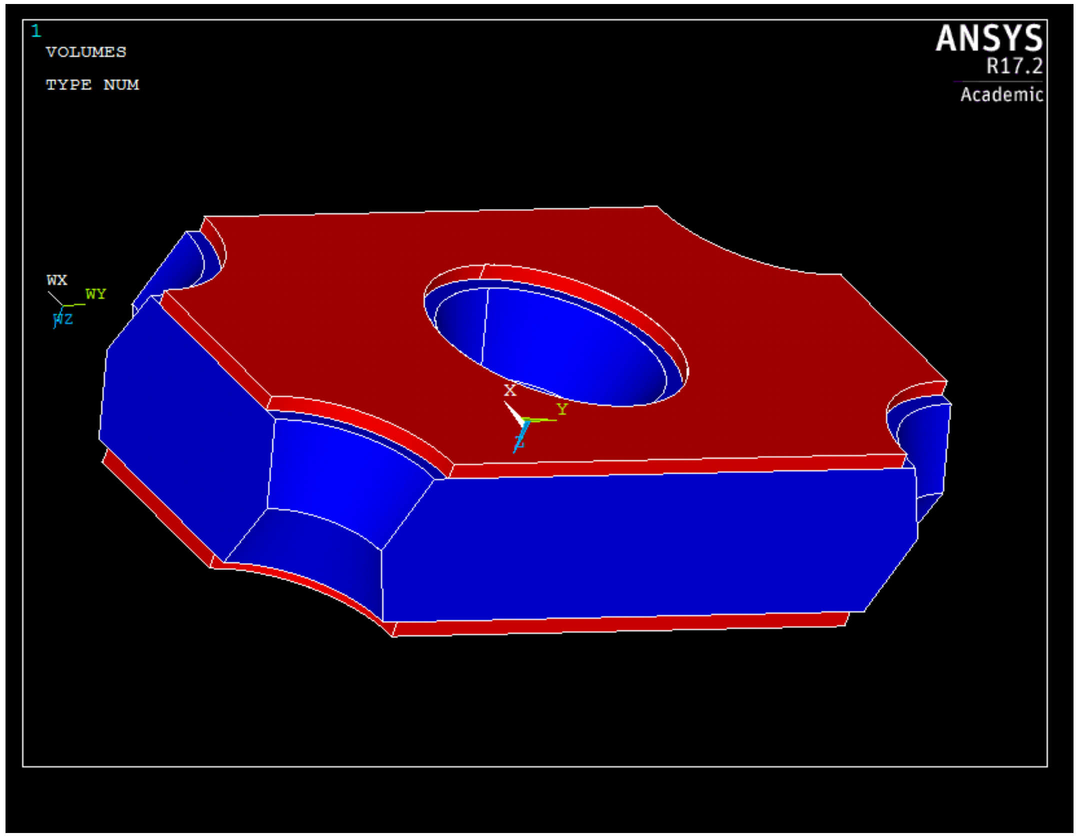
Mechanical APDL (ANSYS Parametric Design Language)



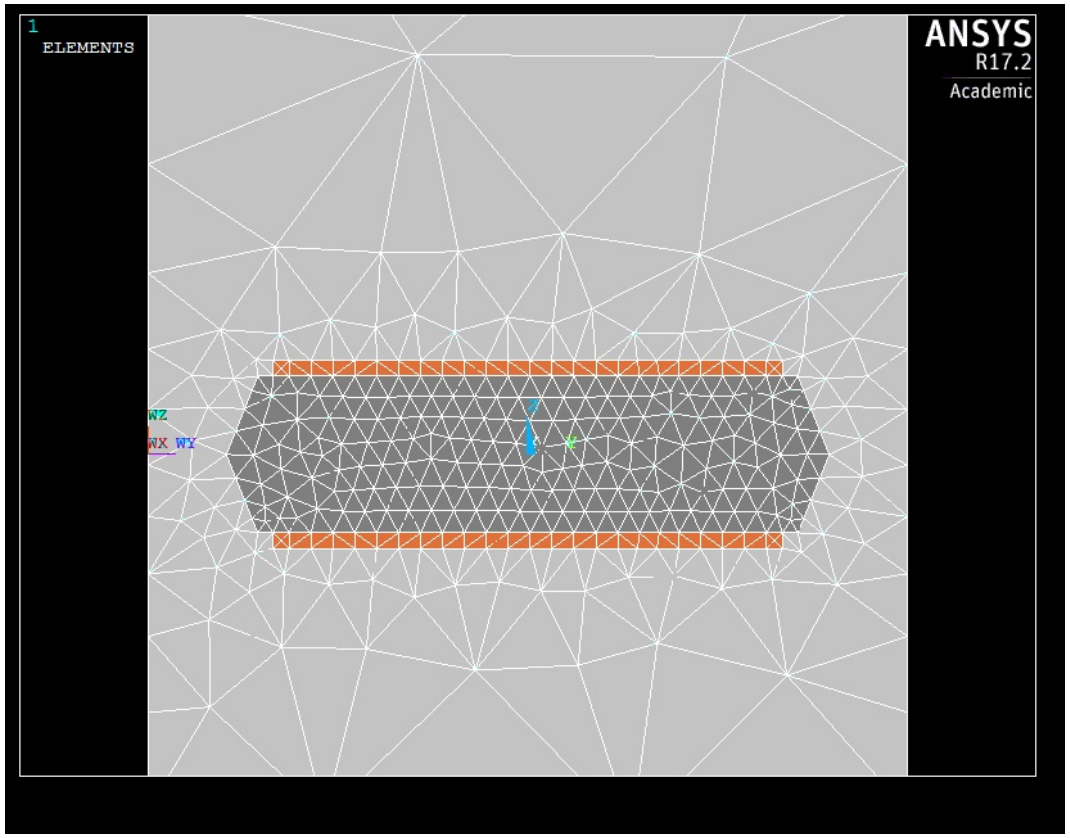
- Preprocessor (Geometry, material and mesh)
- Solution (Potential and field)
- General Post-processor (look the data and save the files)

ANSYS software-preprocessor

Geometry



Mesh

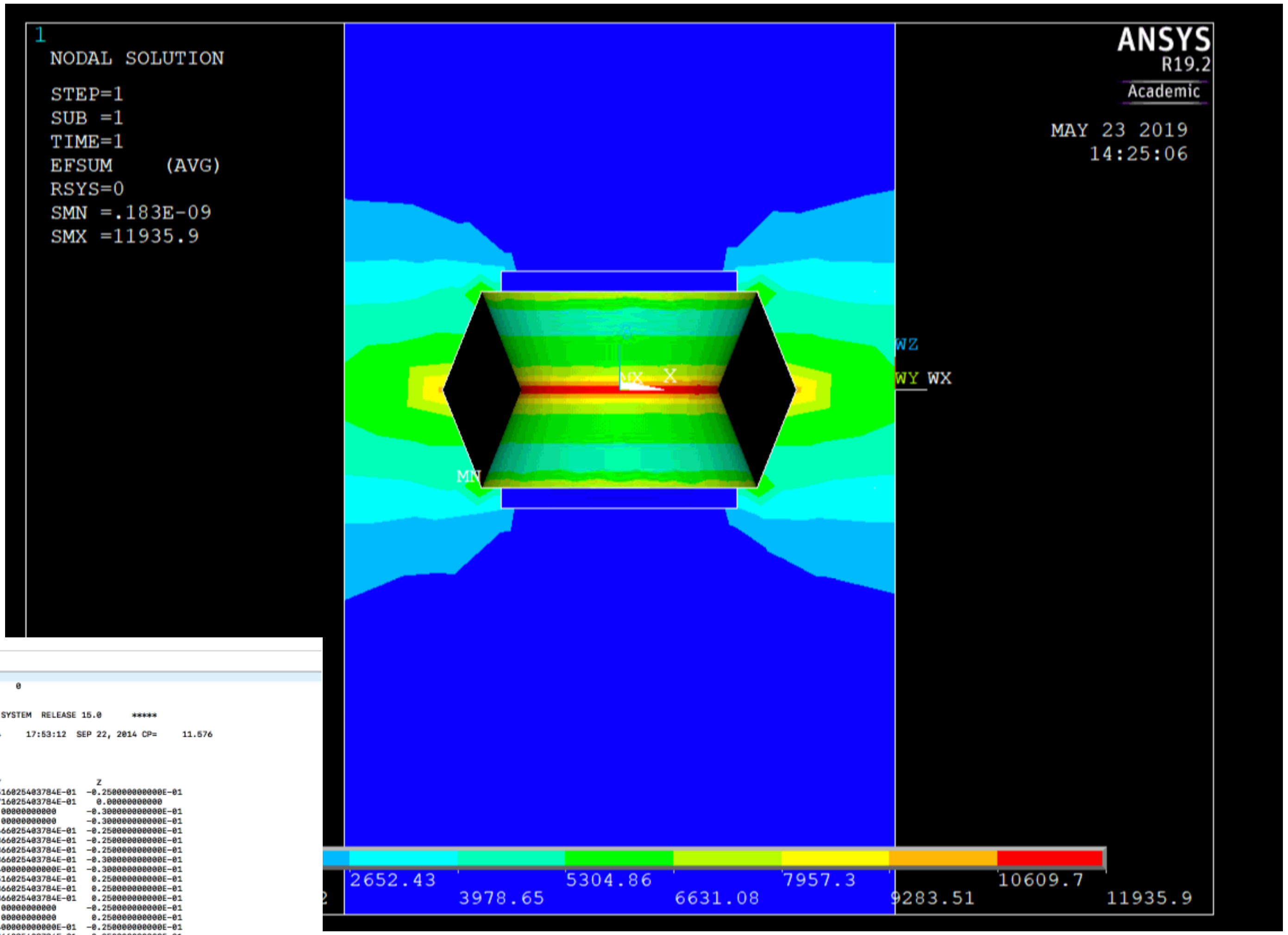


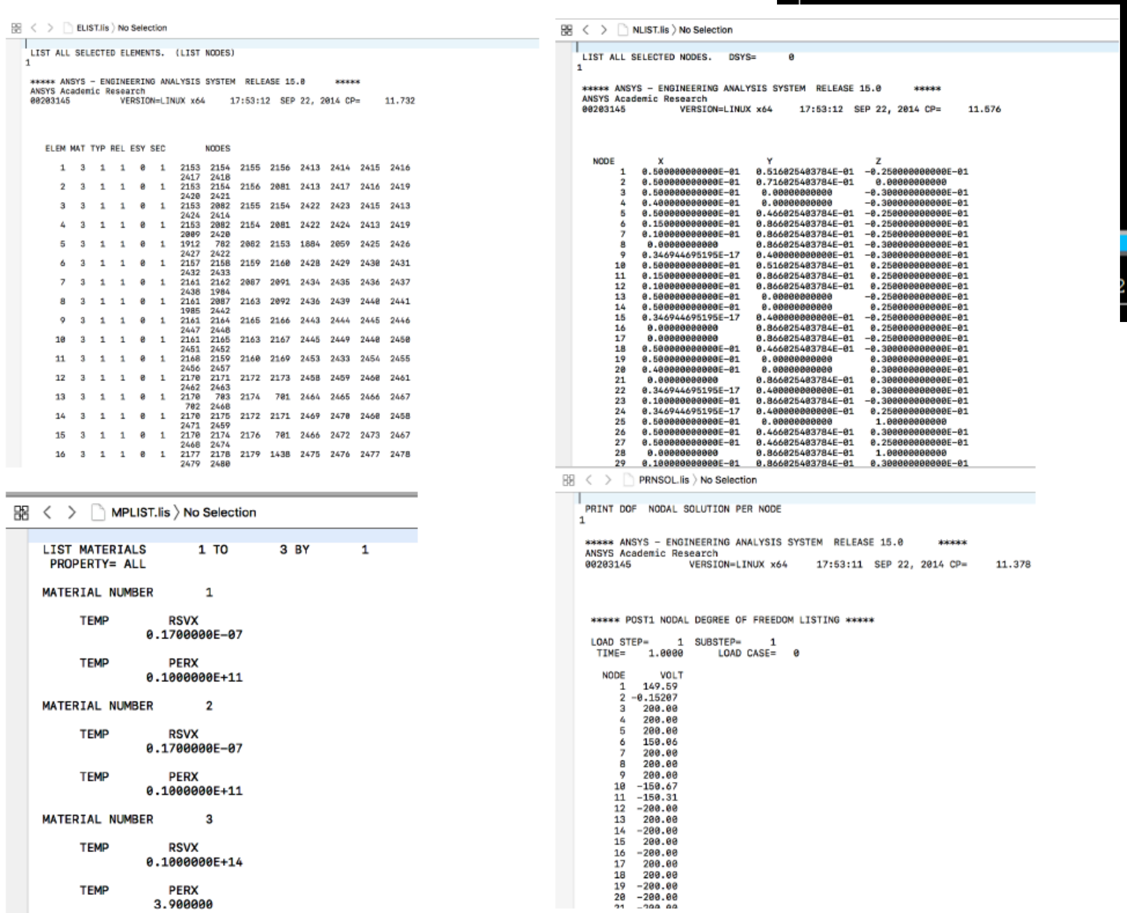
Potential

```
! Voltage boundaries on the drift and induction plane
ASEL, S, LOC, Z, drift
DA, ALL, VOLT, -1857
ASEL, S, LOC, Z, induct
DA, ALL, VOLT, 0

! Voltage boundary conditions on the lower metal
VSEL, S, , , 1
ASLV, S
DA, ALL, VOLT, -729

! Voltage boundary conditions on the upper metal
VSEL, S, , , 2
ASLV, S
DA, ALL, VOLT, -1128
```

ANSYS software - solution and postprocessor

Analysis results





Files useful with Garfield ++:

MPLIST.lis
NLIST.lis
ELIST.lis
PRNSOL.lis

Garfield++ tool

Garfield++ is the best tool to simulate the behavior of gaseous detectors.

Garfield++code read the ANSYS .lis files →

```
// Load the field map.
ComponentAnsys123* fm = new ComponentAnsys123();
//  fm->EnableDebugging();
const std::string efile = Form("%s/ELIST.lis",cla_modeldir);
const std::string nfile = Form("%s/NLIST.lis",cla_modeldir);
const std::string mfile = Form("%s/MPLIST.lis",cla_modeldir);
const std::string sfile = Form("%s/PRNSOL.lis",cla_modeldir);
```

We also use the MAGBOLTZ library to define the atomic and thermodynamic characteristic of the gas (mixture percent, temperature and pressure)

For the simulation we are using:

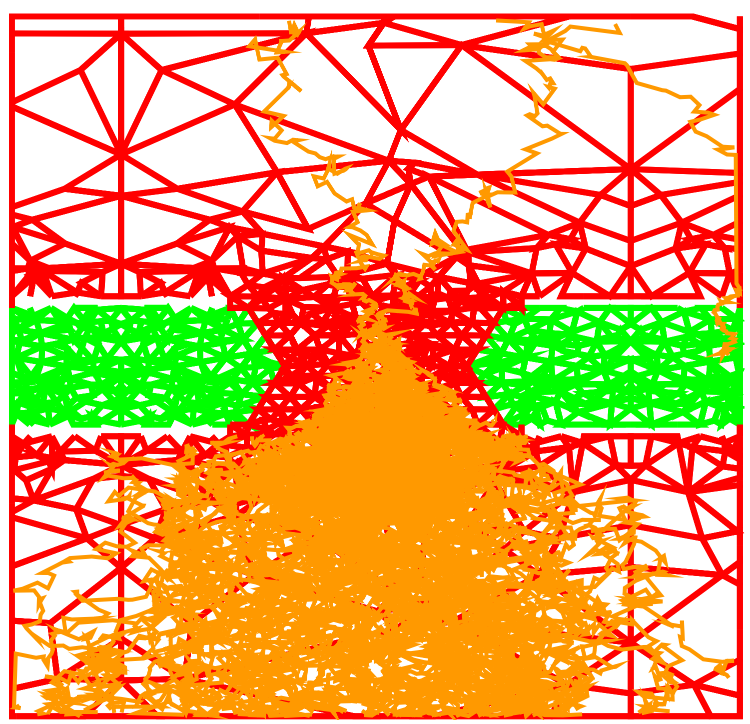
Gas mixture **70% Argon** and **30% CO_2**;
Temperature = 293.15K;
Pressure= 760Torr

Garfield++ tool

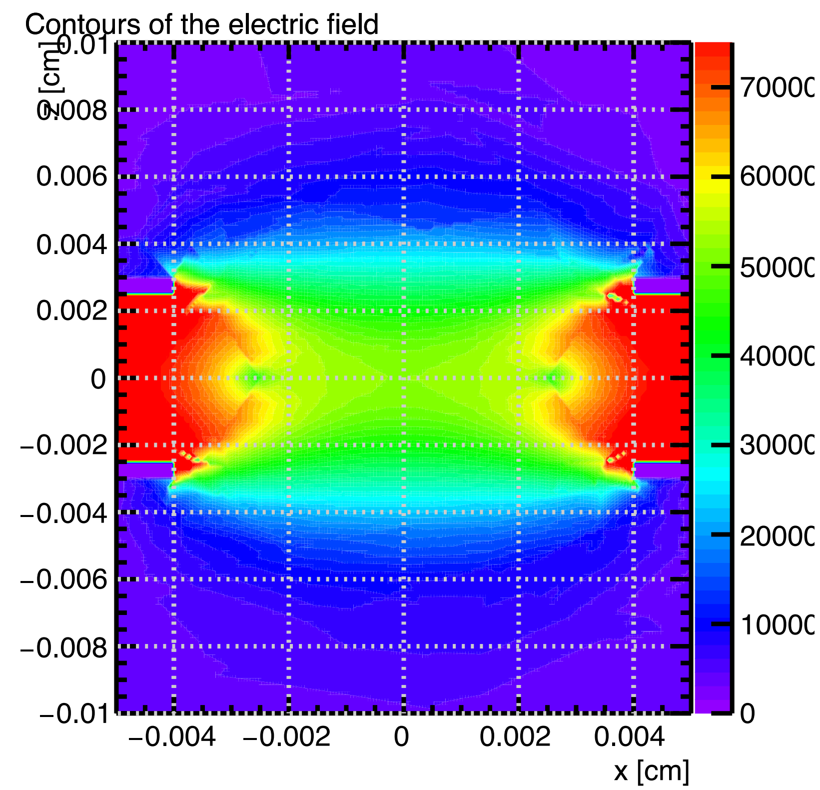
What we can change using Garfield ++:

- The physic volume of the simulation;
- Number of the particles that we want simulate in input and primary particle type (e^-, p, π, etc.);
- Energy (eV), direction and impact point (angle) of the primary particles.

We can visualize the results of the simulation using ROOT libraries:



Avalanche creation and its distribution in the readout plane



Electric Field map

Simulations models

Cascade Triple-GEM Model

3 GEM single foil in cascade and an ideal readout plane.

Microscopic simulations are carried on each layer in a hierarchical way: simulation outcome of the previous layer is sent to the next layer.

It's a flexible multistep model that easily allows to simulate different schemes, imperfections, foil misalignment, by decomposing the 3xGEM+Readout chamber in 4 adjacent layers.

Full 3GEM Model

It is a complete model with drift, readout and 3 GEM foil.

Microscopic simulations are carried from the drift plane, trough the 3 gem foils, to the ideal readout plane.

We can evaluate the simulations results only in the readout plane.
It's a model useful to show that the cascade model is correctly working.

Simulations Conditions

Two different “work environments”:

JLAB Experimental Conditions

4 GeV electron beam.

Simulations when some physical parameters change.

Simulations carried on with both the model: cascade and full.

GEMs size:

40 [cm]x 50[cm]

Julich Experimental Conditions

2.8 GeV proton beam.

Simulations to compare the results with the real data.

The simulations are in progress.

We tested 1 reference module 10 [cm]x 10[cm]

and 5 GEMs foil 40 [cm]x 50[cm]

Simulations in JLAB conditions

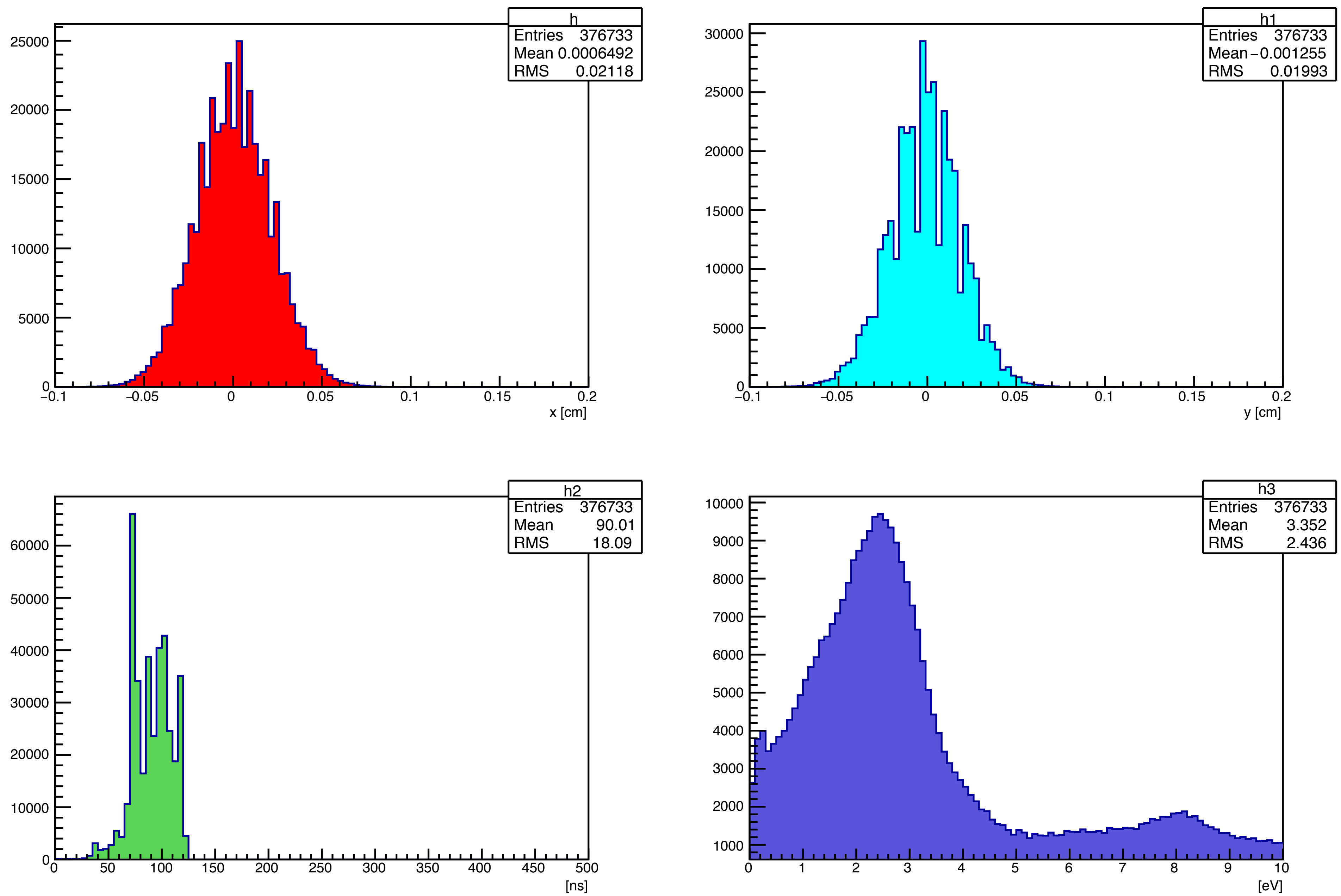
Systematic study to verify the consistency of the simulations:

Number of electrons in the readout plane

Spatial distribution of the avalanche (x and y axes)

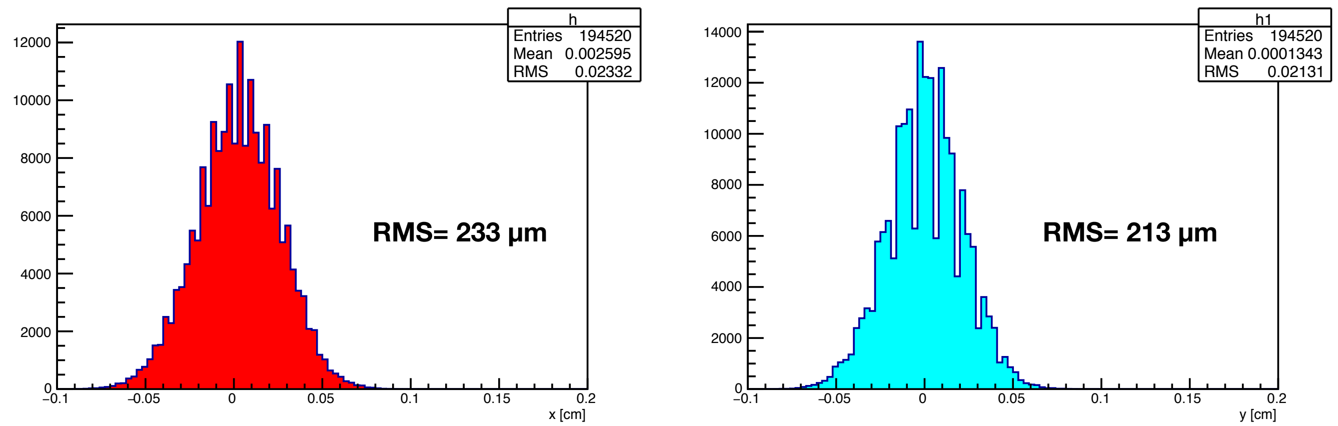
Energy of the particles in the readout plane

Particles arrival time.

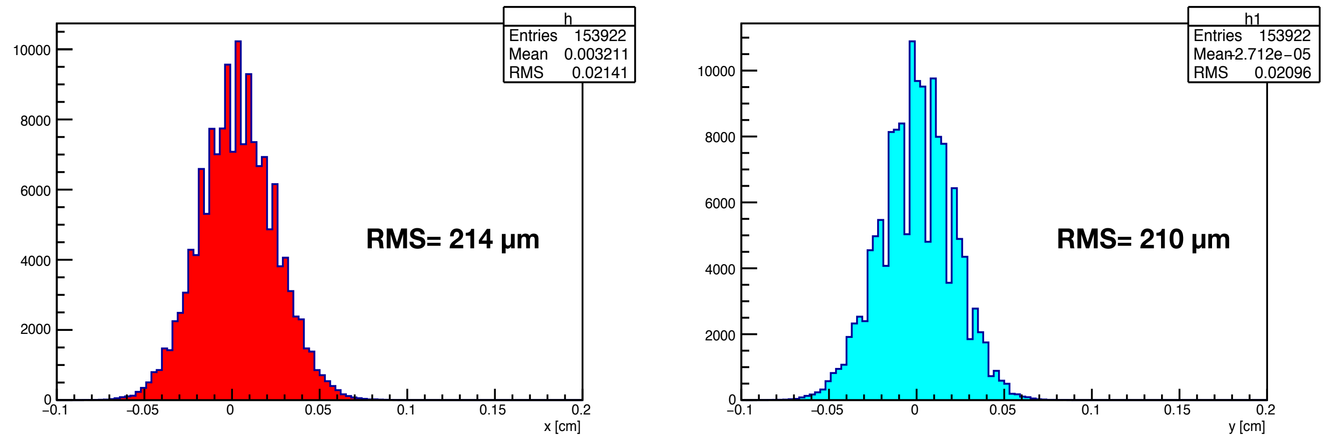


Simulations in JLAB conditions

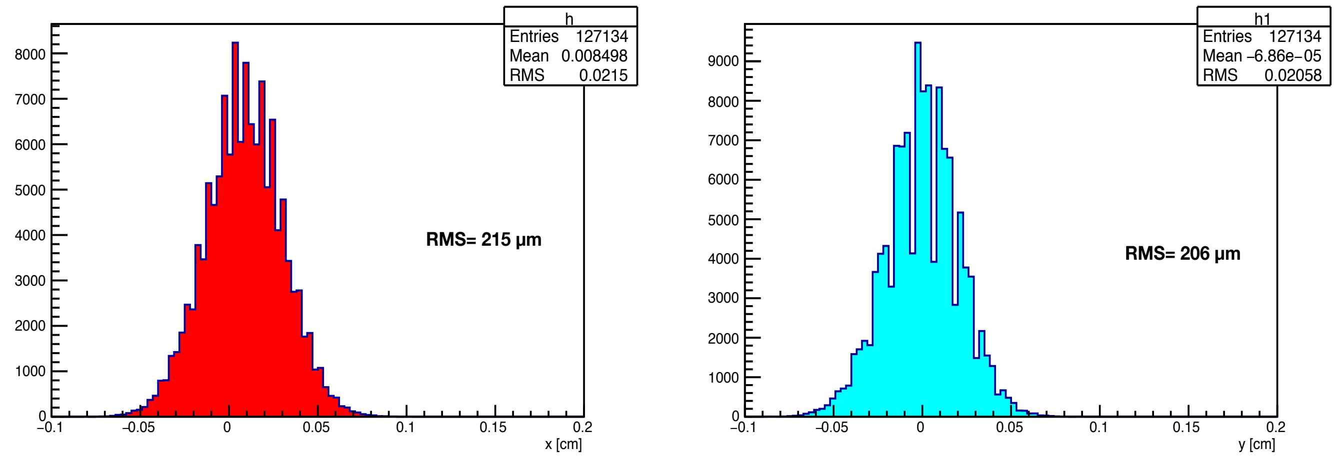
We evaluated the response, in terms of avalanche distribution in the readout plane, when the impact point of the primary particles changes.



X (red) and y (blue) distributions of the charge in the readout plane, when the incident particles **pass through the center of the hole** and perpendicular to the readout plane.



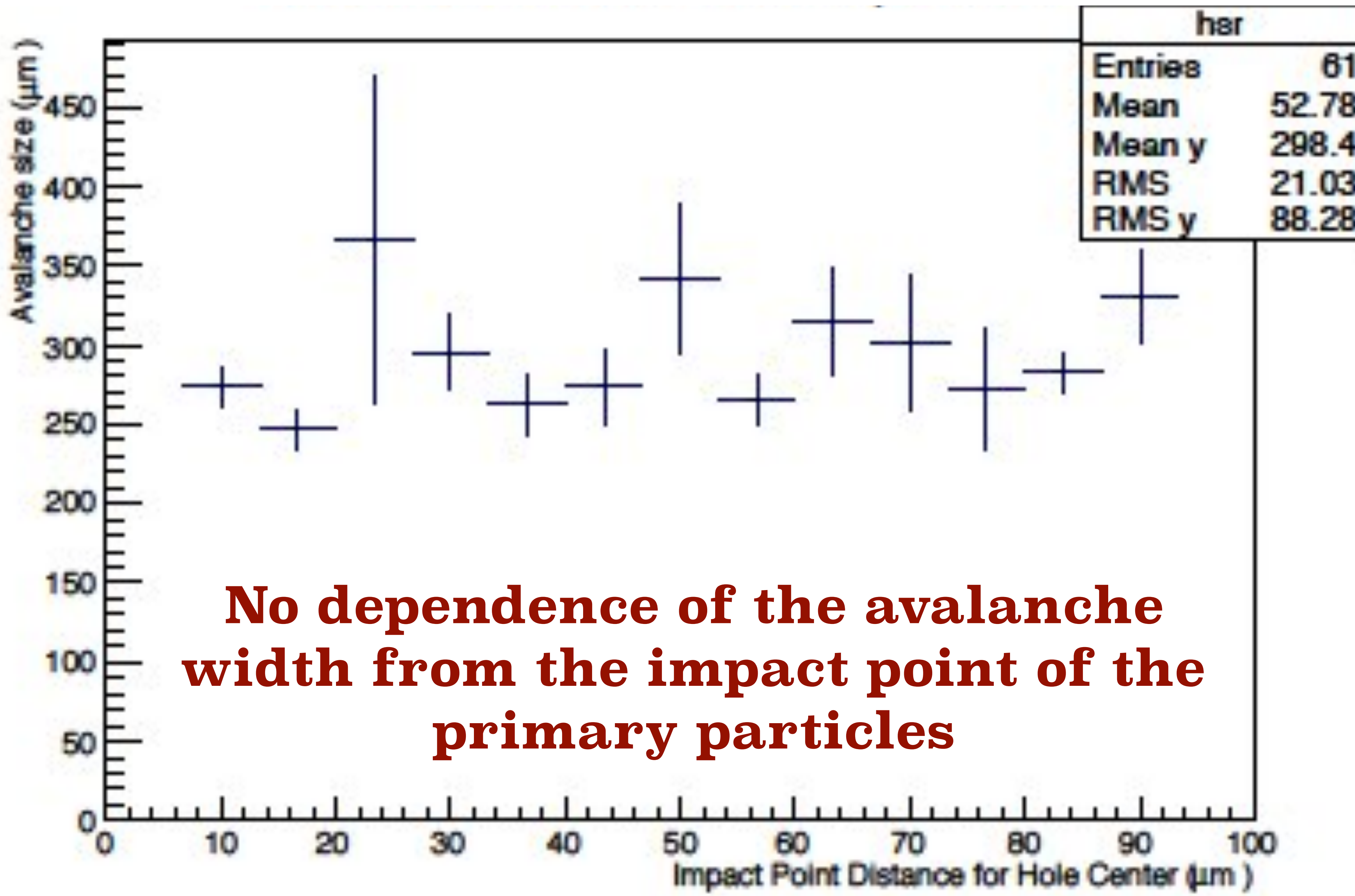
X (red) and y (blue) distributions of the charge in the readout plane, when the particles incise in **x= 0.0035 cm** and perpendicular to the readout plane.



X (red) and y (blue) distributions of the charge in the readout plane, when the particles incise in **x= 0.0070 cm** and perpendicular to the readout plane.

Simulations in JLAB conditions

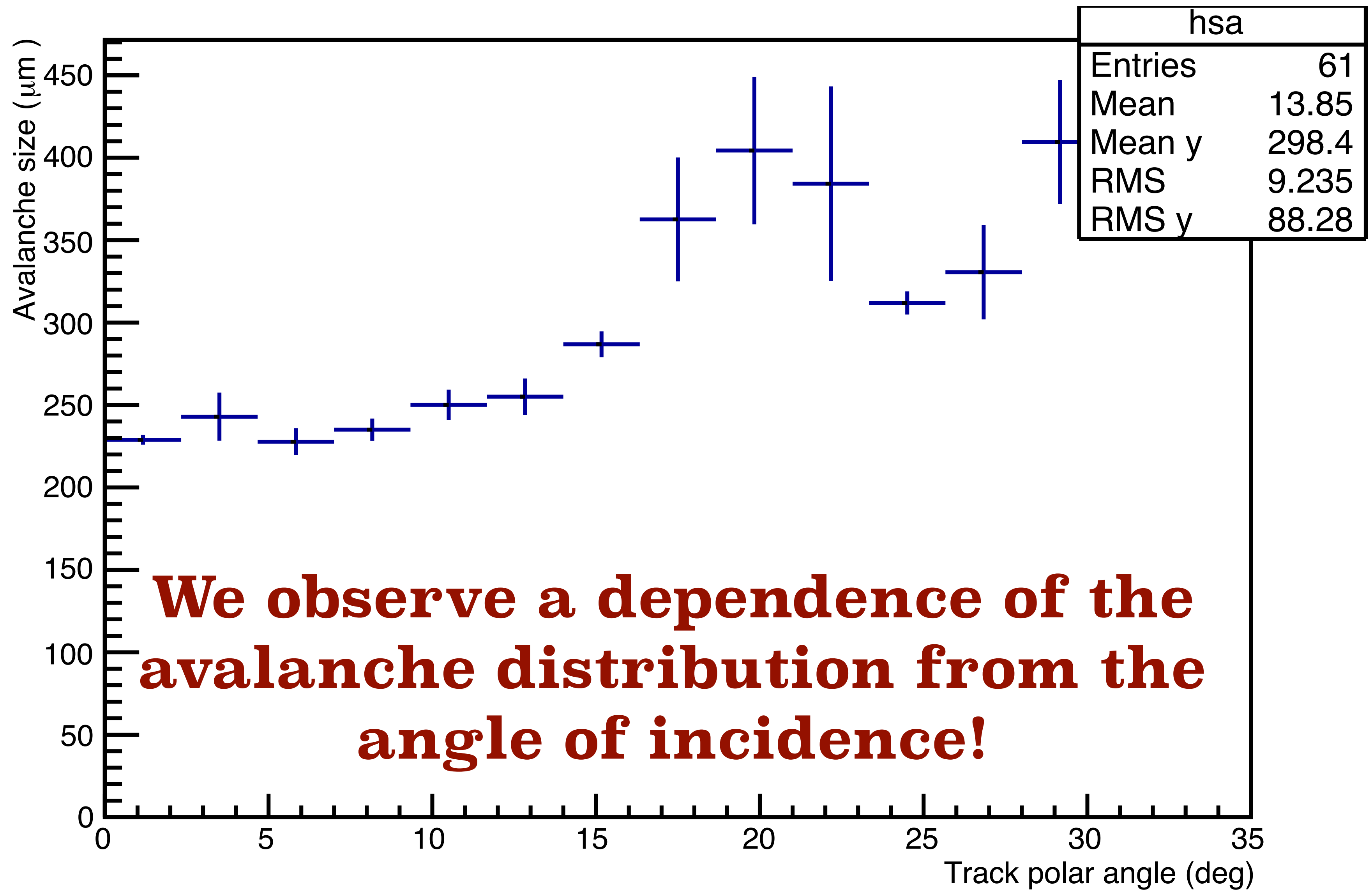
Avalanche width VS impact point of primary particles.



No dependence of the avalanche width from the impact point of the primary particles

Simulations in JLAB conditions

Avalanche width VS impact angle of primary particles.



	0°	10°	30°
RMS	233 µm	295 µm	381 µm

Simulations in JLAB conditions

Comparing the cascade 3GEM model and the full 3GEM model results we can observe that:

- Stable and comparable results for the electric field;
- Good agreement when we change the mesh size or potential values;
- Small but unexpected suppression in gain and efficiency in the full 3GEM model;

Reasonable predictions from cascade model!!!!!

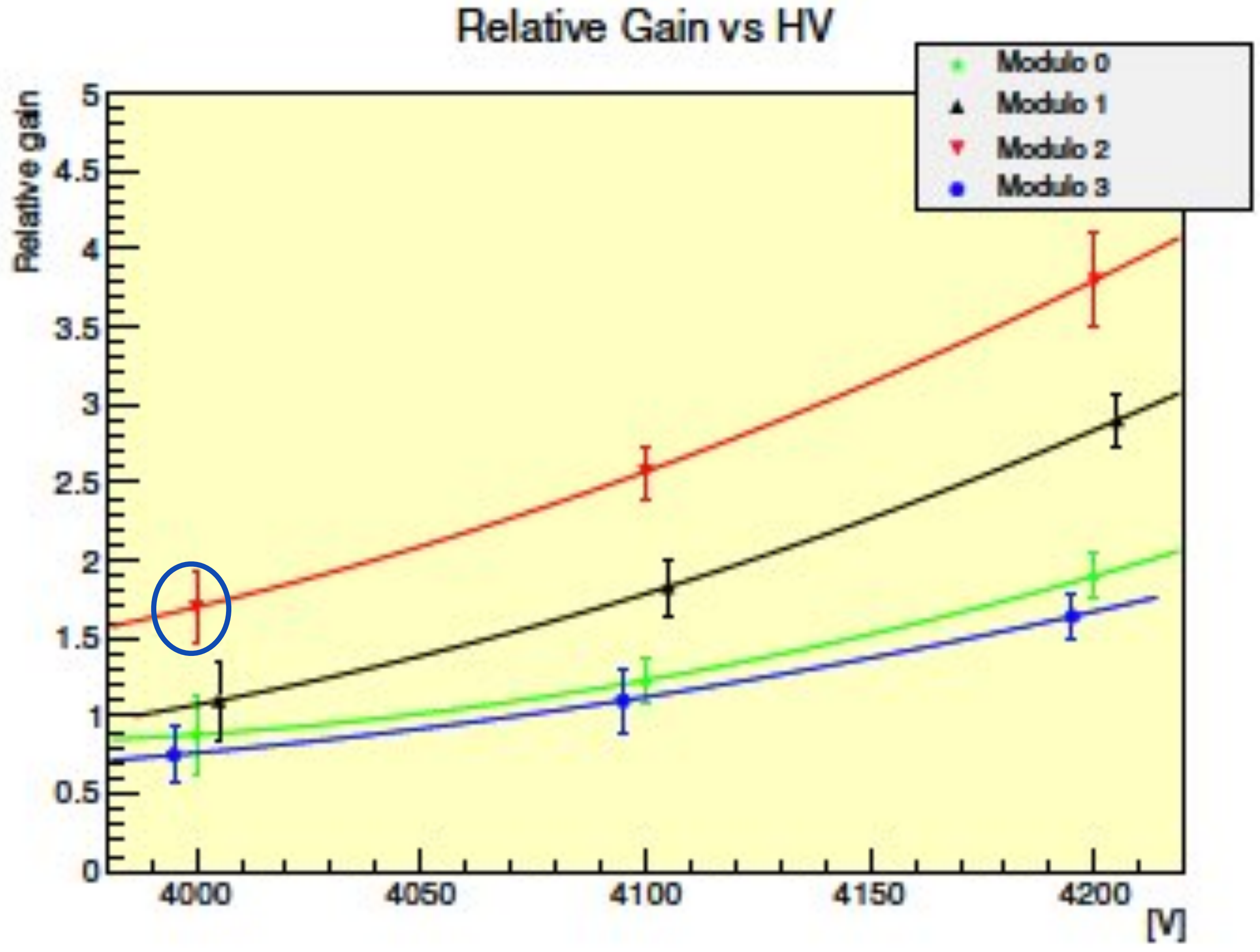
Simulations in Julich conditions

We tested 4 modules and 1 reference module with known gain:

	$R_1[\Omega]$	$R_2[\Omega]$	$R_3[\Omega]$	$R_4[\Omega]$	$R_5[\Omega]$	$R_6[\Omega]$	$R_7[\Omega]$	$R_8[\Omega]$
Modulo 0	441 K	7.2 M	3.76 M	7.2 M	3.63 M	7.2 M	2.98 M	7.2 M
Modulo 1	441 K	7.2 M	3.92 M	7.2 M	3.57 M	7.2 M	3.57 M	7.2 M
Modulo 2	441 K	7.2 M	3.92 M	7.2 M	3.92 M	7.2 M	3.92 M	7.2 M
Modulo 3	441 K	7.2 M	3.76 M	7.2 M	3.66 M	7.2 M	2.98 M	7.2 M
Modulo rif.	441 K	4.8 M	2.66 M	4.8 M	2.66 M	4.8 M	2.27 M	4.8 M

Relative Gain of module 2, tested in Julich is 1.7

$$\text{Relative Gain} = \frac{(n_e)_{mod2}}{(n_e)_{rif}}$$

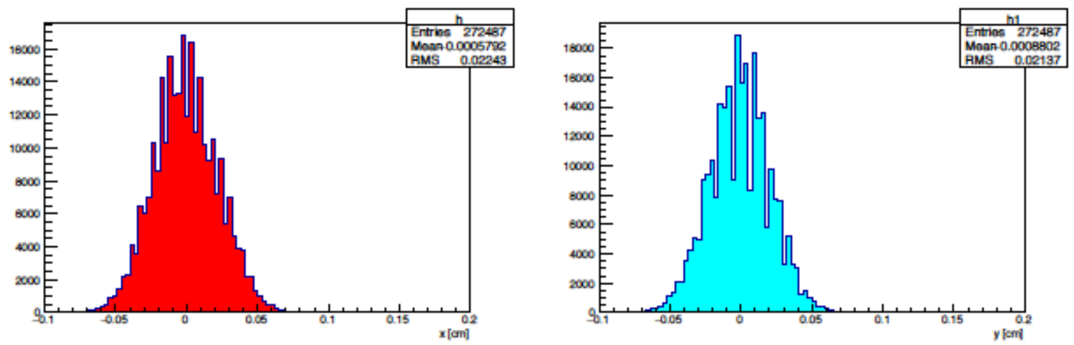


Simulations in Julich conditions

The relative gain of module 2 is :

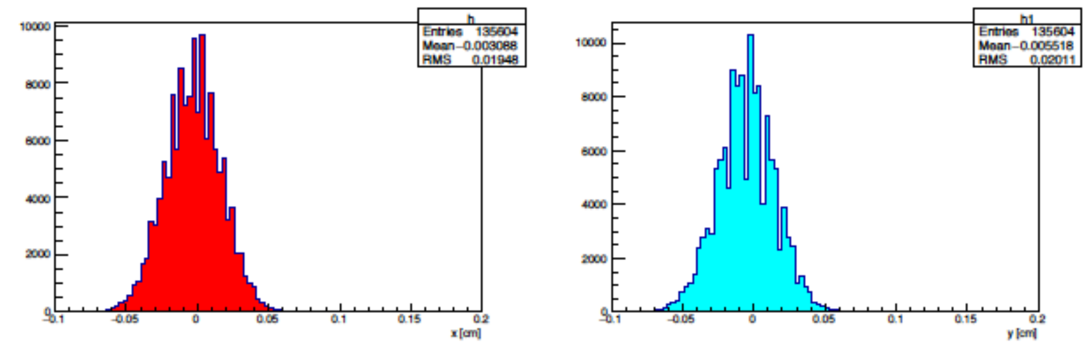
$$G_{rel} = 2.00 \pm 0.013$$

module2

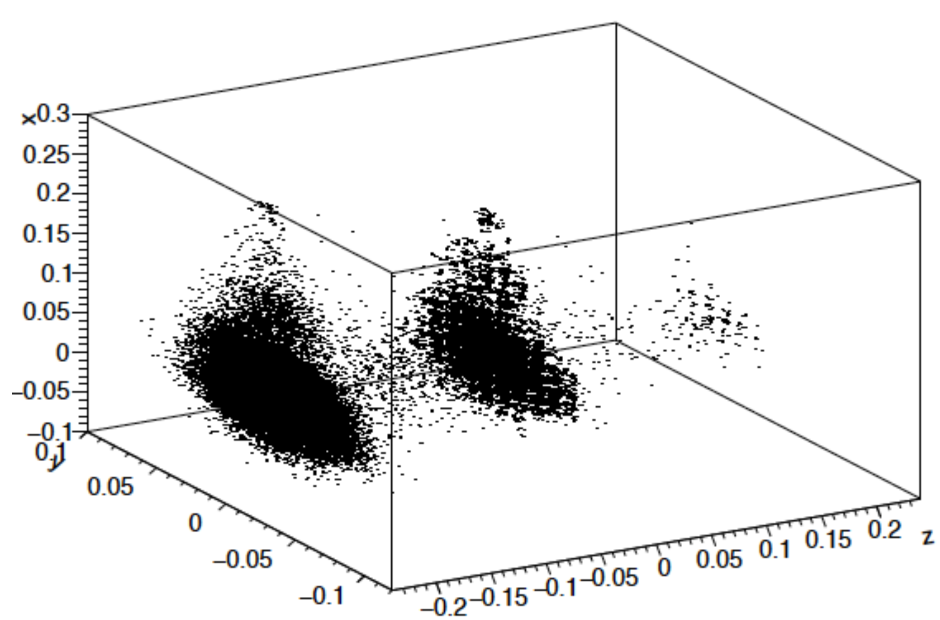


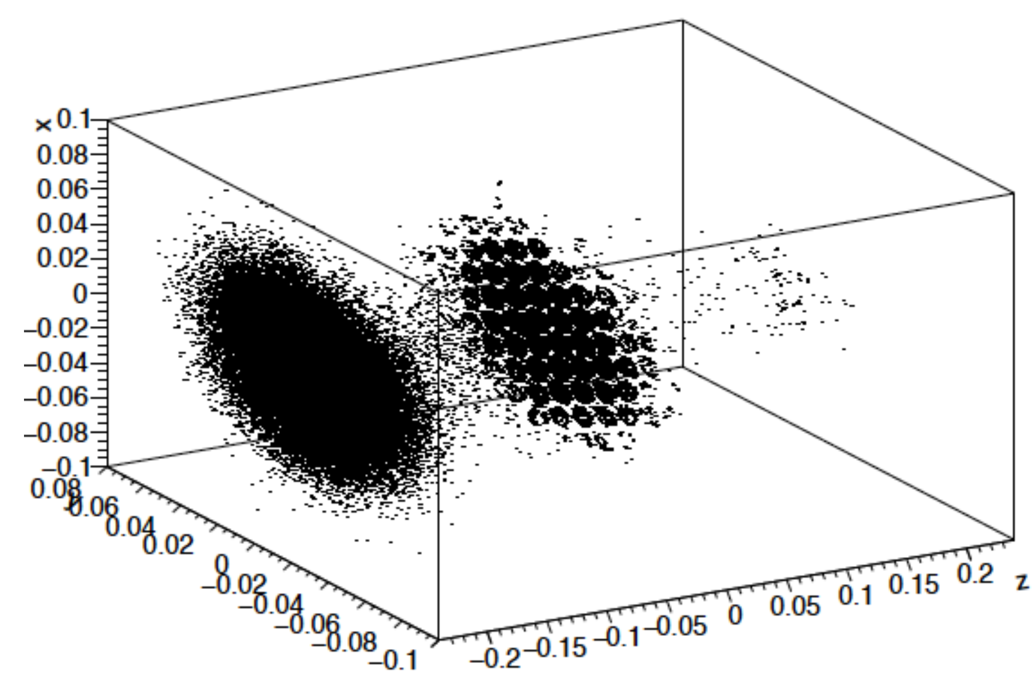
Entries:272487

Ref.module



Entries:135604





Conclusions

- Construction of two different model using ANSYS software and GARFIELD++ tool.
- Study about the charge distribution in the readout plane, avalanche width, electric field value, gain etc.
- Confirmation that the gain and the avalanche width not depend on the impact point of the primary particle but depend on the incidence angle.
- Comparison between cascade and full models and proof that the two model give us the same results.
- Simulations in Julich condition to compare the simulations data and the real data from Julich test.
- Confirmation that the gain obtained with the simulations is in agreement with the real data.

What's next?

- Finish the simulations to compare all the modules tested in Julich
- Create a real readout strip geometry
- Use free program softwares, GMSH and Elmer, and compare the gain results with ANSYS results


Thanks!!!

Backup Slides

Sachs Form Factors

The electromagnetic structure of the nucleus, in the diffusion with an electron can be described through the Sachs Form Factors:

$$G_E(Q^2) = \int d^3\vec{r}\rho_E(\vec{r})e^{\frac{i\vec{q}\cdot\vec{r}}{\hbar}}$$

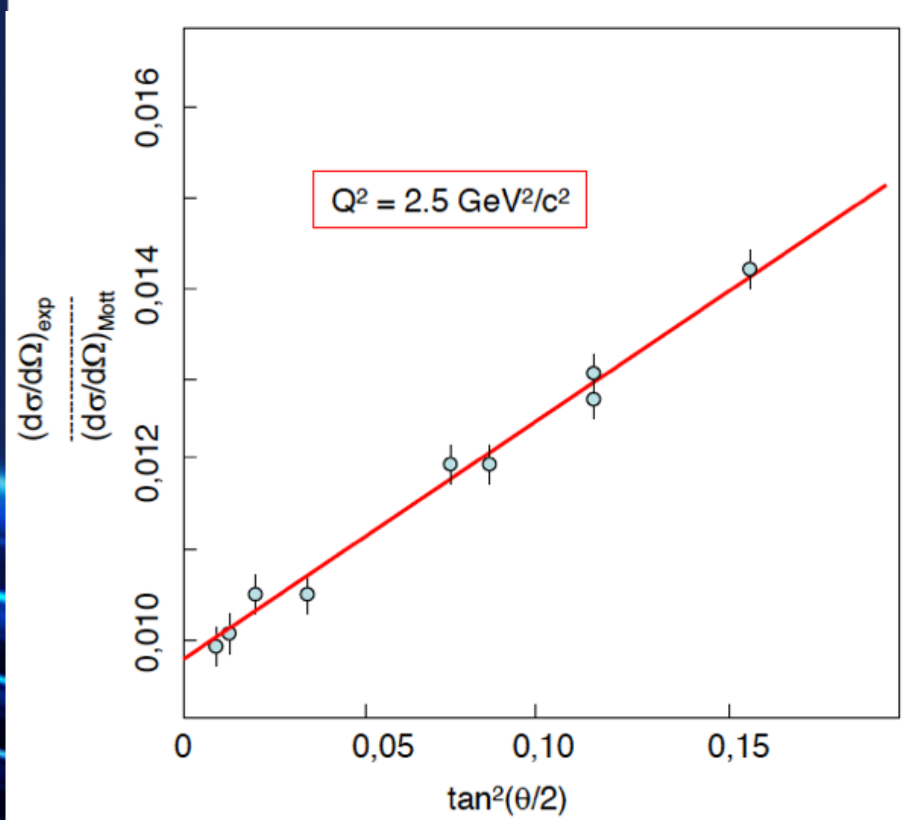
Spatial charge distribution

$$G_M(Q^2) = \int d^3\vec{r}\rho_M(\vec{r})e^{\frac{i\vec{q}\cdot\vec{r}}{\hbar}}$$

Magnetic Density

The Form Factors of the nucleons can be considered as the Fourier transform in 3D of charge distribution and magnetic density

Rosenbluth Formula



$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{Mott}\left[\frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2)tan^2\frac{\theta}{2}\right]$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{Mott} = \frac{Z^2\frac{e^4}{16\pi^2}cos^2\frac{\theta_e}{2}}{4p_0^2 sen^4\frac{\theta_e}{2}(1+\frac{2p_0}{M}sen^2\frac{\theta_e}{2})}$$

$$\tau = \frac{Q^2}{4M^2c^2}$$

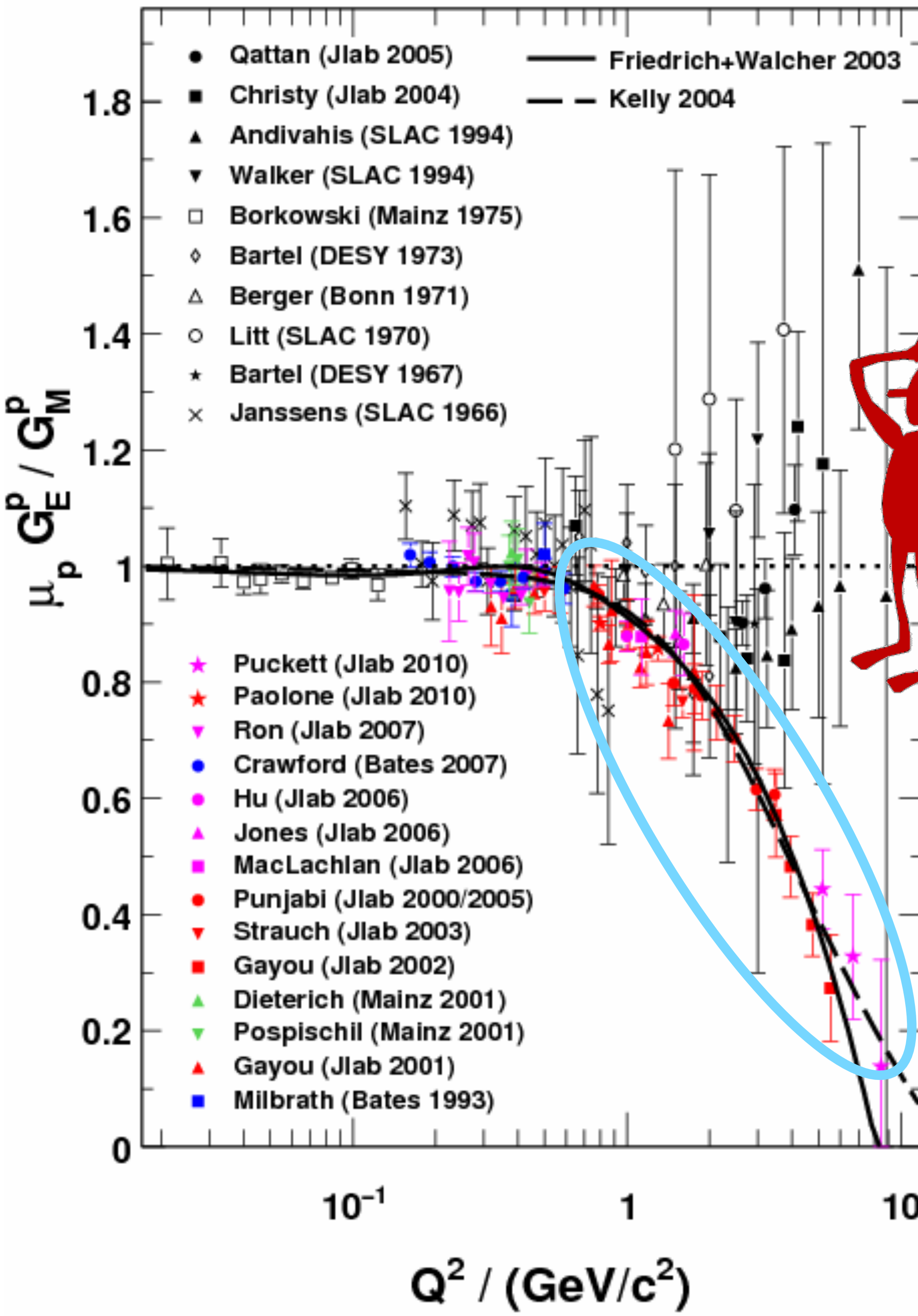
θ scattering angle

M mass of the target

Slope → **G_M**

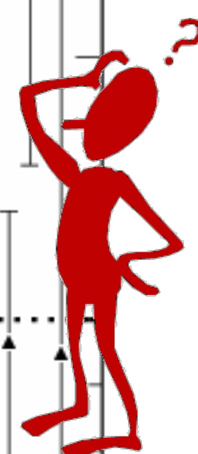
Intercepts → **G_E**

Recoil Polarization Method



Proton G_E/G_M

There is an unexpected discrepancy for high value of Q^2



The ratio between G_E and G_M decreases linearly with Q^2

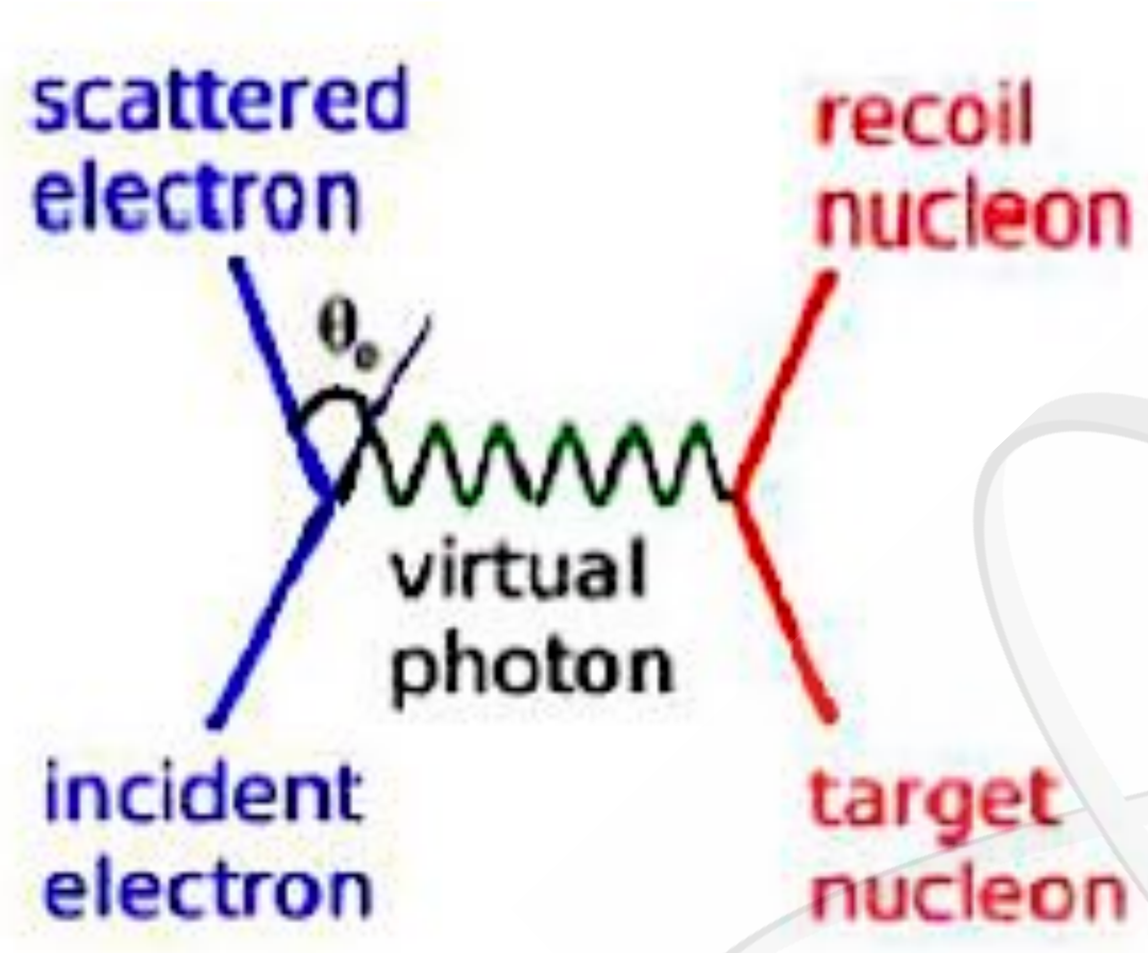
It is possible to measure, at the same time, the transverse and the longitudinal polarization component of the recoil proton to obtain the ratio:

$$\mu \frac{G_{Ep}}{G_{Mp}} = -\mu \frac{P_t}{P_l} \frac{(E_{beam} + E_e)}{2M_p} \tan \frac{\vartheta_e}{2}$$

E_e= scattered electron energy
P_t= transverse polarization of proton
P_l= longitudinal polarization of proton
M_p= proton mass
Θ_e= electron diffusion angle

e^- - nucleon interaction

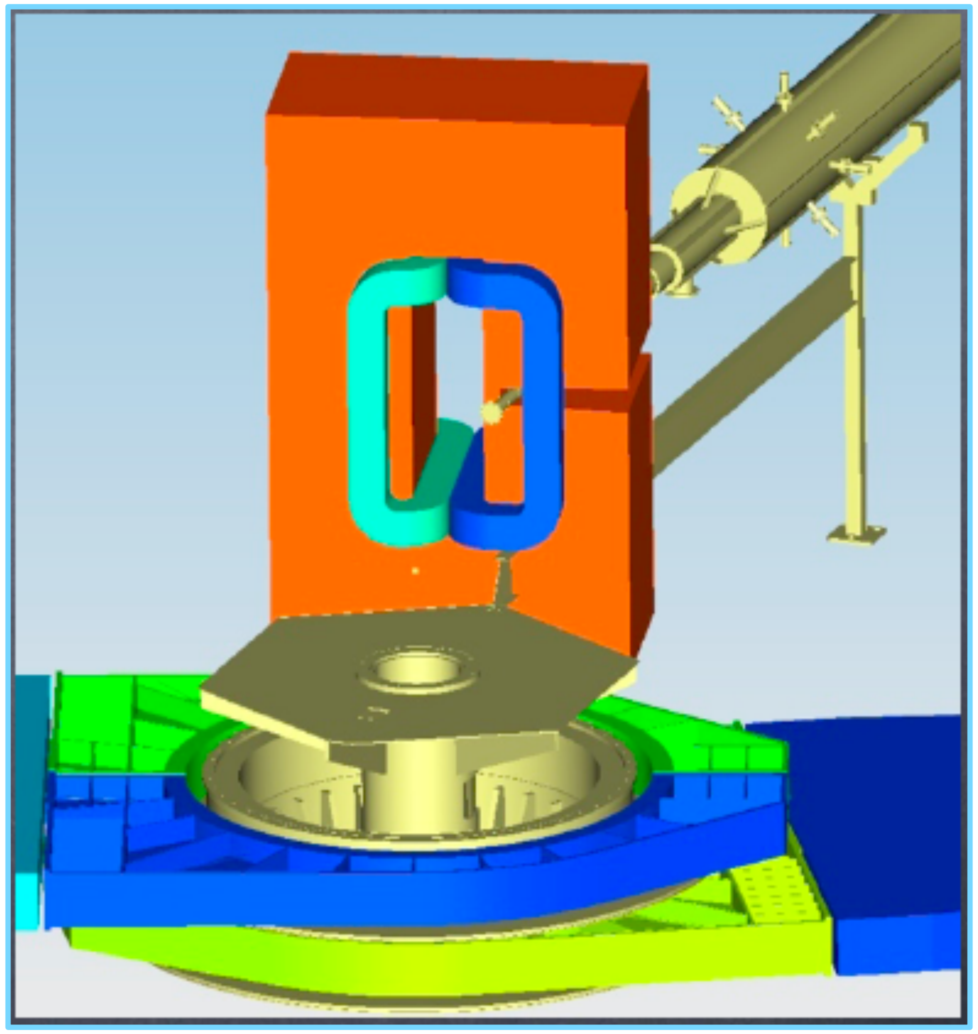
In the elastic scattering between an electron and a nucleon, there is the exchange of a virtual photon



The cross - section of this process was given by Rosenbluth and it is a good method up to $Q^2 < 6\ GeV^2$

SBS main components: 48D48 Dipole Magnet

The Super Bigbite magnet is optimized for Form Factor measurements



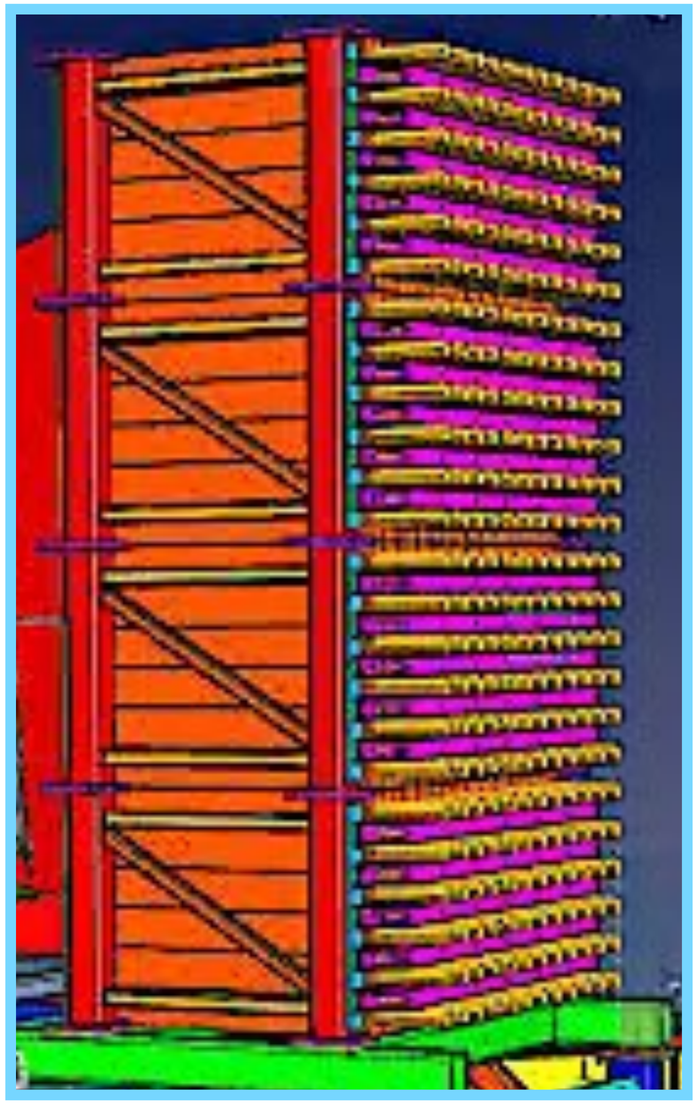
- It provides adequate momentum resolution (~1%) and large solid angle (~70 msr) acceptance.
- Vertical aperture well matched to electron arm while still appropriate for $\Delta Q^2/Q^2 \sim 0.1$.
- Cut in yoke permits operating at small angles where the recoil is going.

The magnet weighs 100 tons total and consists of five iron slabs

Integral field strength ≈ 1.7 - 3 T · m

SBS main components: HCAL-J

It's a sampling calorimeter with a modular structure



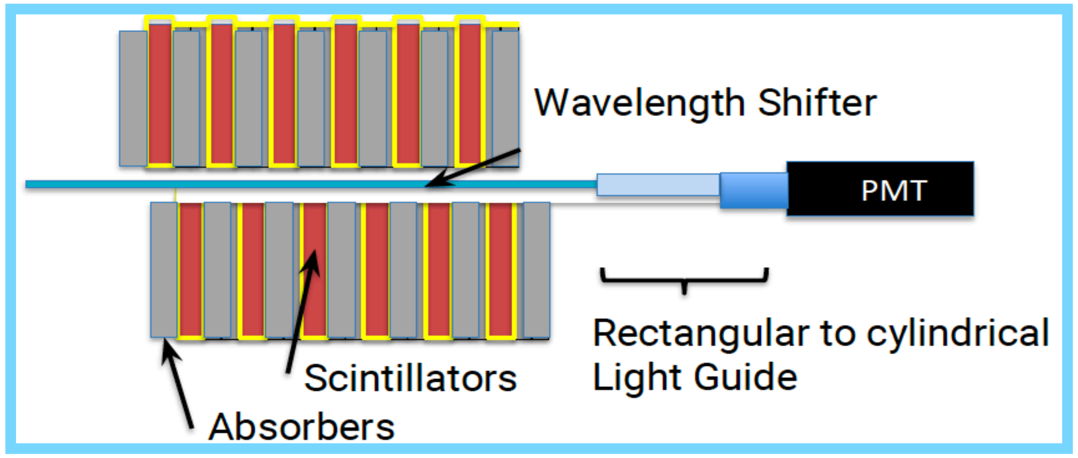
INFN of Catania and CMU

288 modules (each 15x15 cm²) in a matrix of 24 modules in length and 12 in width
Weight ~ 40 tons

Iron thickness: 1.5 cm
Scintillator material PPO-only (2,5–Diphenyloxazole) thickness: 1.0 cm

WLS placed at the center of the each module, carries on the light on the **PMTs**

4 "crane-able" subassemblies and a **Rollable stand** to move gantry + HCAL-J together without need to disconnect cables.



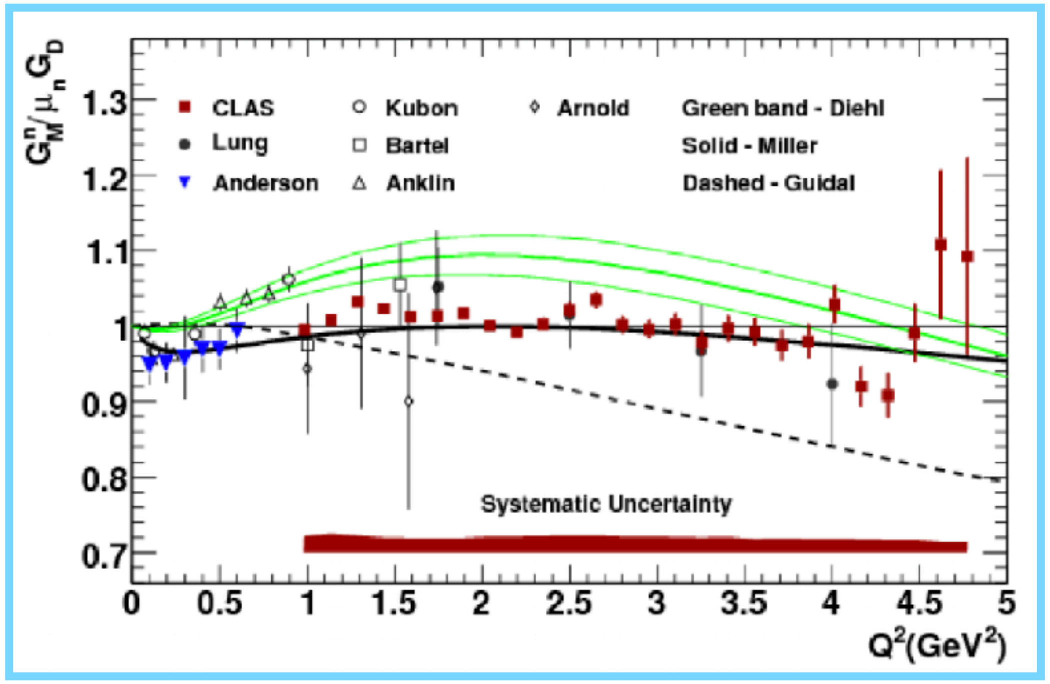
HCAL-J Requirements:

- Linear energy response and good energy resolution,
- 95% efficiency with trigger threshold at 25% peak signal,
- Spatial resolution ~ 5 cm rms,
- Time resolution < 1.0 ns rms,
- Angular resolution 5 mrad.

SBS main components: First and Back GEMs Trackers

	FIRST TRACKER	BACK TRACKER
STRUCTURE	6 GEM chambers	10 GEM chambers
TOTAL AREA	40 x150 cm^2 (3 triple-GEM modules)	60 x 200 cm^2 (4 triple-GEM modules)
AREA of each tracker	40 x 50 cm^2	60 x 50 cm^2

GMn experiment



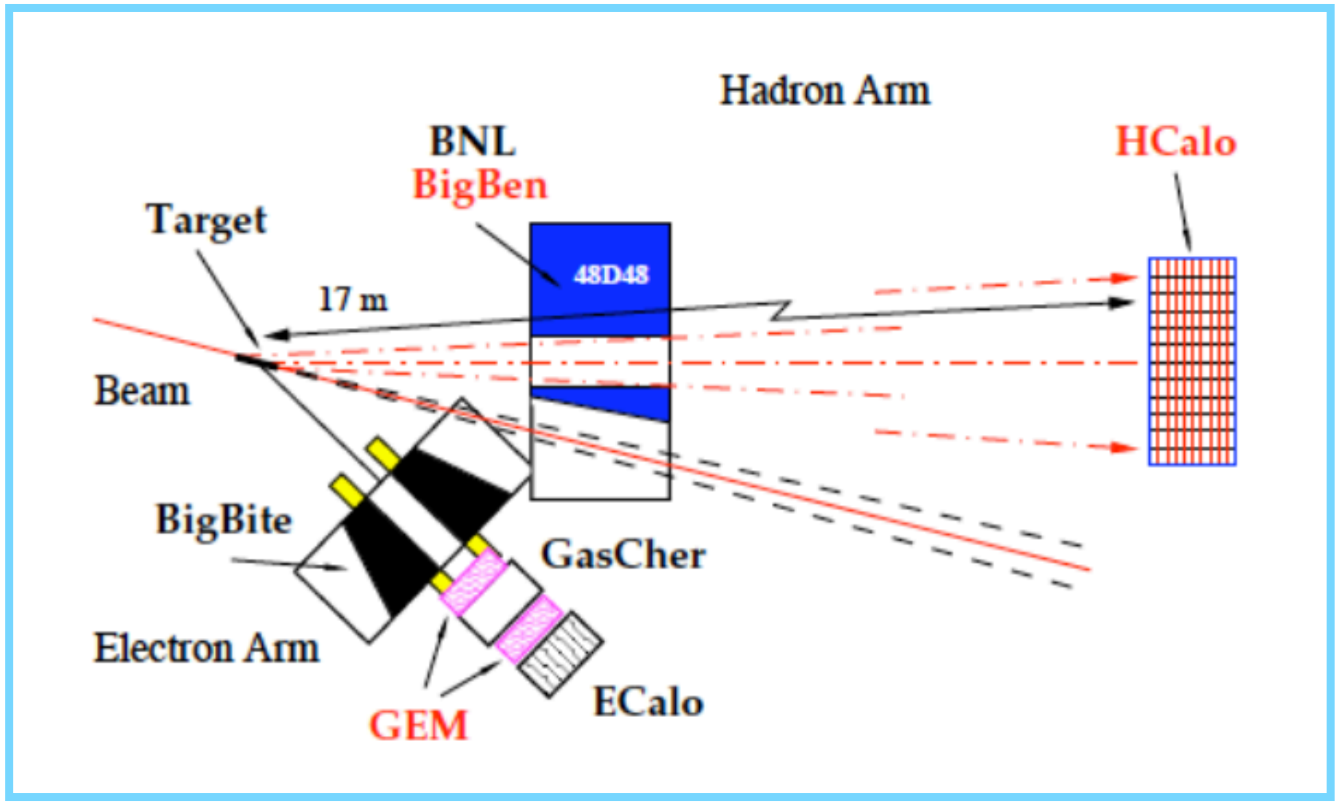
Ratio Method for GMn

Use the ratio method requires the measurement of both neutron-tagged, d(e,e'n), and proton-tagged, d(e,e'p), quasi-elastic scattering from the deuteron.

$$R'' = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))}$$

$$R = \frac{\eta\sigma_{Mott}\left(\frac{\tau/\epsilon}{1+\tau}G_M^n\right)^2}{\frac{d\sigma}{d\Omega}\Big|_{p(e,e')}}$$

Knowing the form factors of the proton we can extract the neutron magnetic form factor from the previously ratio



Study of the magnetic Form Factor of the neutron

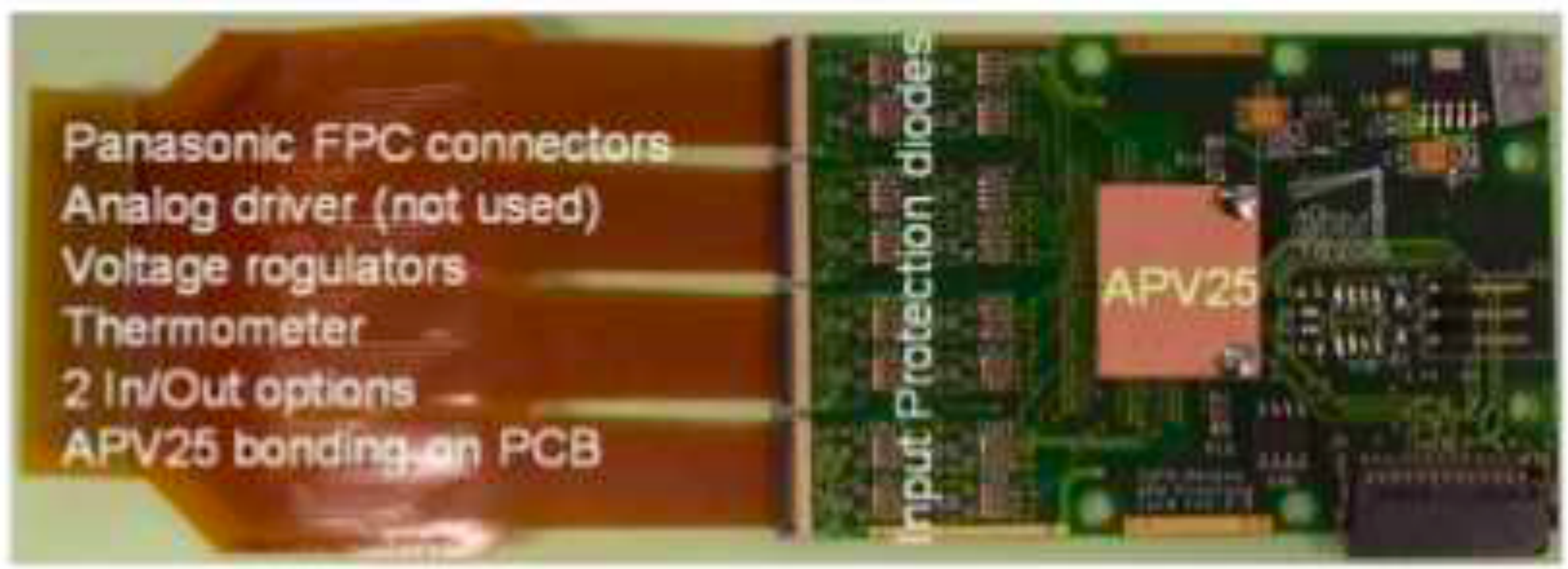
Beam current: 10.5 μA

Target: 10 cm non-polarized liquid deuterium

Q^2 range: $4.5 < Q^2 < 18.0$ (GeV/c)²

Electronics

GEMs system use the flexible electronics developed by INFN around the APV25 chip, compliant with the VME-VXS JLab standard and able to transmit data over optical link.



Le carte di front-end utilizzate sono 18 per modulo e sono distribuite lungo i quattro lati del frame. Ogni carta di front-end (FEC) contiene un chip APV25 (Analogue Pipeline Voltage), sviluppato da Imperial College London e tale chip APV25 è un pipeline ASIC (Application Specific Integral Circuit) analogico con un output seriale. Esso è stato progettato per tollerare alte quantità di radiazioni incidenti.

il coefficiente di diffusione in argon
$D = 200 - 300 cm^2/s$

velocità di deriva tipica degli elettroni secondari ~5−6 cm/µs

un percorso di circa 0.9 cm, i tempi massimi di traversata
dell’intera GEM sono di circa $t \sim 150ns$, mentre la distribuzione
spaziale della valanga si allarga di almeno
$\sqrt{2 * D * t} \sim 90\mu m$