Hadron Calorimeter MPGD-based development for future Muon Collider Experiment.

PhD Candidate: Muhammad Ali

First year Presentation - 39th Cycle

Supervisor:
Prof. Rosamaria Venditti

Co-supervisor:
Prof. Salvatore My

Outline

- Introduction to Muon Collider Experiment:
    i. Challenges for HCal design.
    ii. Strategy for Muon Collider.

- Current research activities:
    i. MPGD setup in Bari.
    ii. Test Beam July-2024.
    iii. GEANT4 HCal.

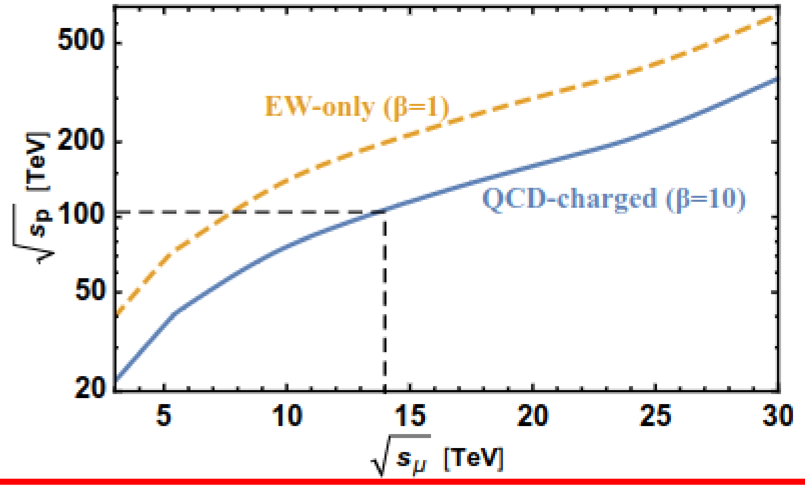
- Future plans.

- PhD Plan for three years.

- Subjects and Schools.

The Multi-TeV Muon Collider Experiment

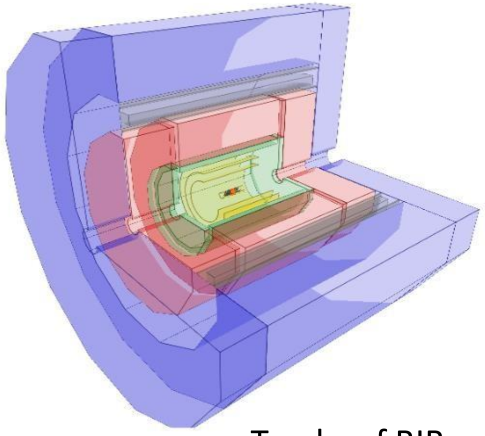
It is a proposal for future colliders after HL-LHC.
Advantages:
- multi-TeV energy range in **compact circular** machines;
- well **defined initial state** and **cleaner final state**;
- all **collision energy available** in the hard-scattering process.



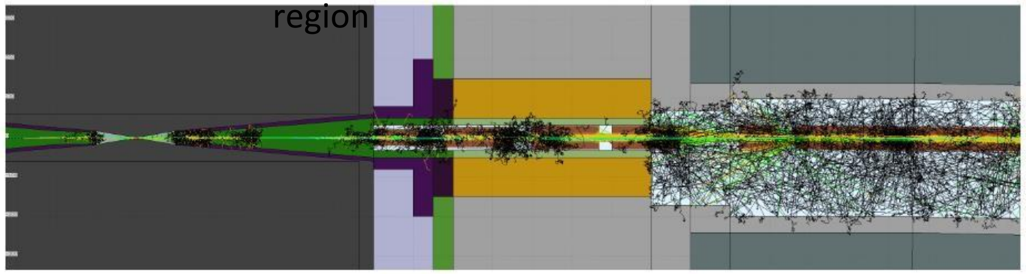
https://doi.org/10.1140/epjc/s10052-023-11889-x

Challenges:
- muon is an **unstable** particle
  intense flux of background particles: **beam-induced background (BIB)**.

Section of the Muon Collider experiment:
- Tracking system
- ECAL
- HCAL
- Magnet return yoke + Muon System



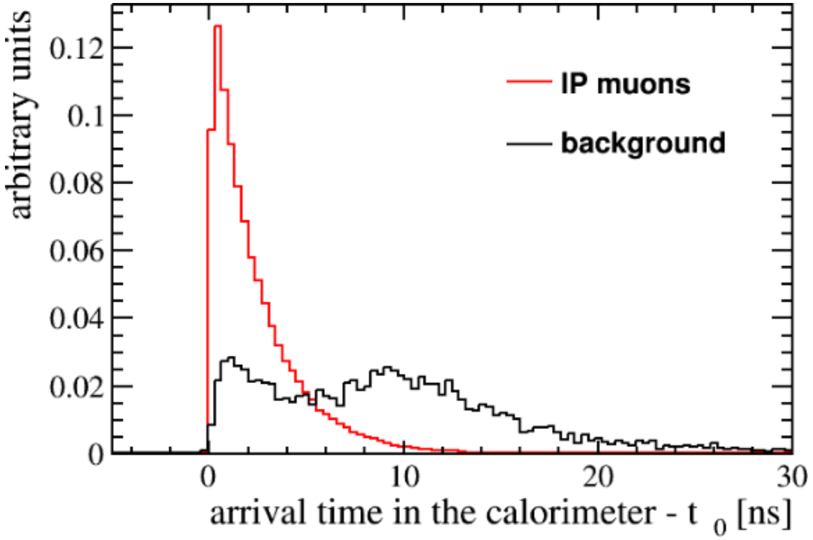
Tracks of BIB particles in interaction region

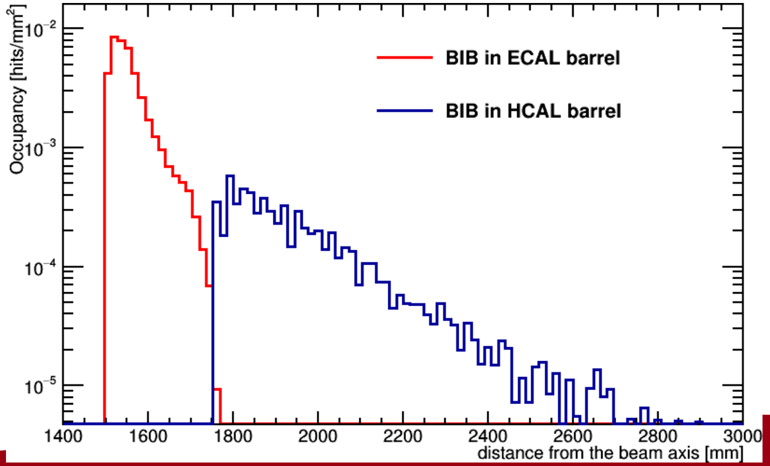


Challenges for HCal design

Beam Induced Background in HCAL:
- Mostly photons (96%) and neutrons (4%)
- Asynchronous time of arrival
- Occupancy ~ 0.06 hit/cm^2 (x10 the one at HL-LHC)

HCAL requirements:
- Radiation hard technology
  - total ionizing dose: 10^5 GRad/year
- Good time resolution (few(ns))
- Good energy resolution
  - ~ 10% / √E for ECAL
  - ~ 55% / √E for HCAL
- Fine granularity (1 – 3 cm^2)
- Longitudinal segmentation
- Good response uniformity for the active layers.





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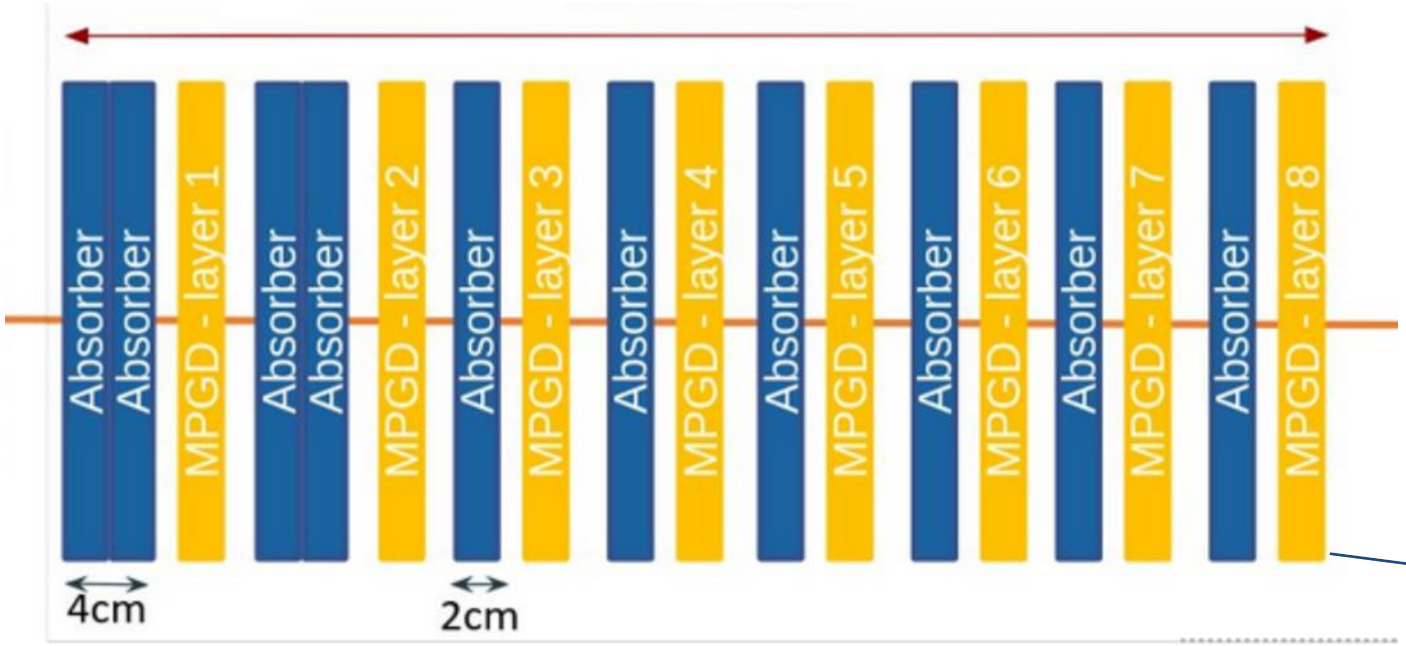
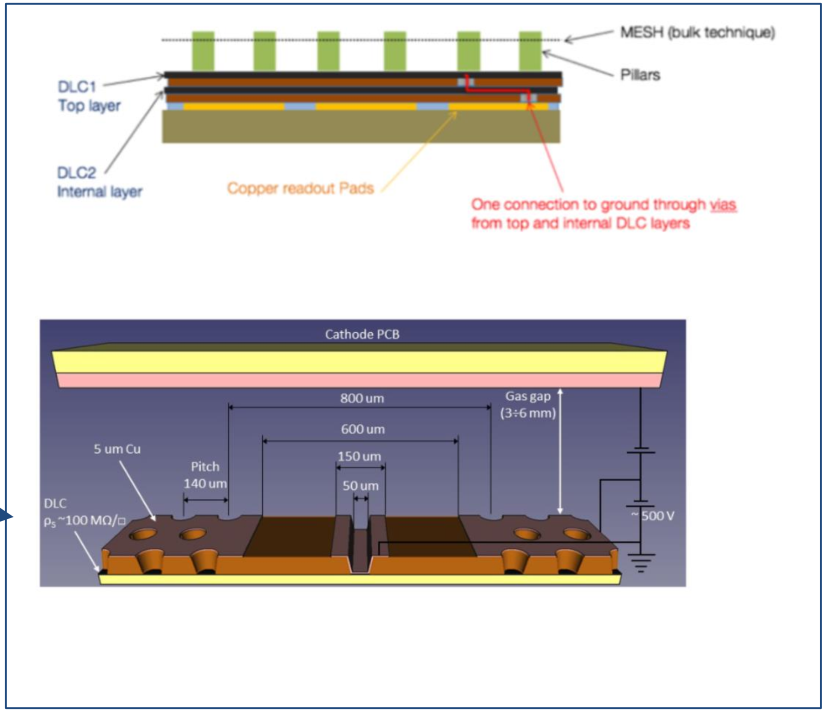
MPGD HCAL Prototype





Absorber:
Stainless steel

Resistive MPGDs technology under test:

- µRWELL
- Micromegas

MPGD-HCAL R&D strategy for Muon Collider

Stand-alone simulation with GEANT4

- Design optimization, provide input parameters for full simulation and experimental data

Test on a MPGD calorimeter prototype

- Assess the performance of an active layer and within calorimeter system

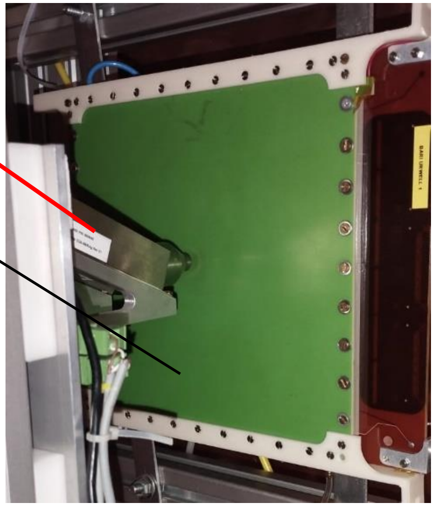
GOAL of my Phd project

1. **Design the MPGD-based HCAL prototype with Geant4**
2. **Characterization of the single MPGD response to MIPs**
3. **Test the performance of resistive MPGD in a calorimeter prototypes.**

MPGD test setup in Bari

Amp Tek X- Ray source

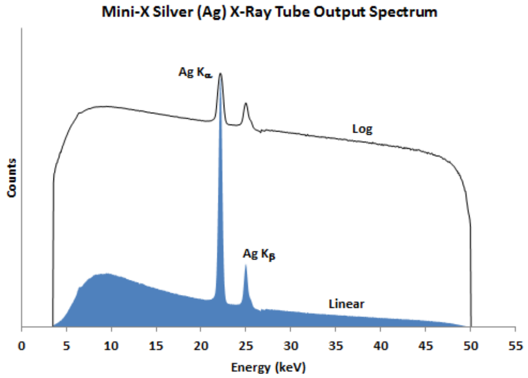
µ-RWELL Detector

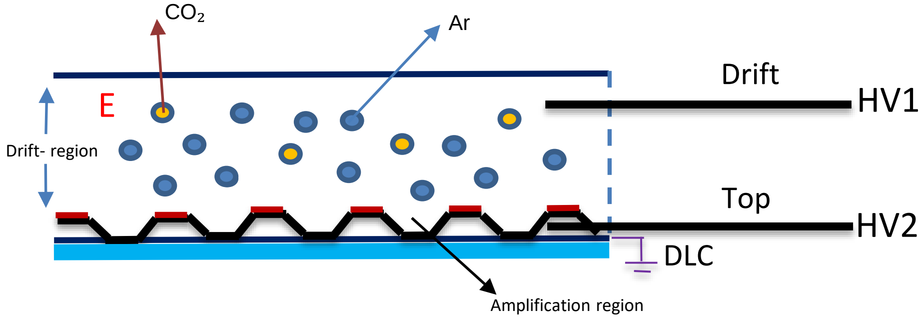


- Our main focus is on µ-RWELL and MicroMegas as a active test layers for HCal.

Measurements are taken for µ-RWELL in Bari Lab:

- Effective Gain (X-ray)
- Response uniformity (X-ray)



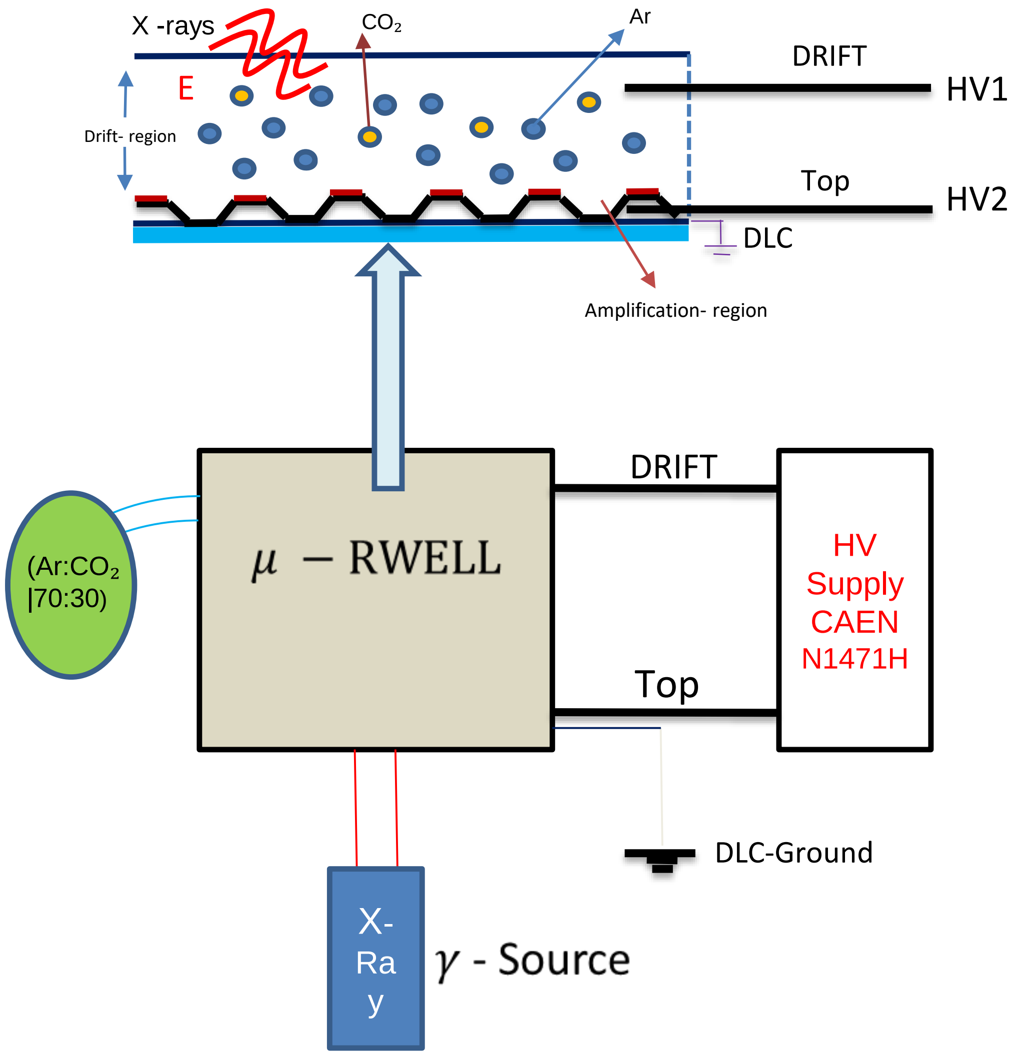


Source:

- Amp Tek X-Rays source is used in these measurements..
- X-Ray interacting with the gas mixture.

DLC ~100 MΩ/□
Drift region ~ 6 mm
Amplification region ~70 µm (50 µm) top (bottom) diameter.

Experimental Setup



PROCEDURE for the measurement:

- The power supply was controlled by a Labview software for setting the voltages and record the currents drawn by each electrode.
- The drift current has been measured from the drift electrode for different values of E_{Drift}, keeping fixed the ΔV_{Amp}.
- The amplification current has been measured from the top for different values of ΔV_{Amp} and fixing E_{Drift}.
- The currents have been measured first with the source off and then with the source on to remove the offset.
- The effective gain is the ratio $\frac{I_{Amp}}{I_{Drift}}$

Effective gas gain measurement

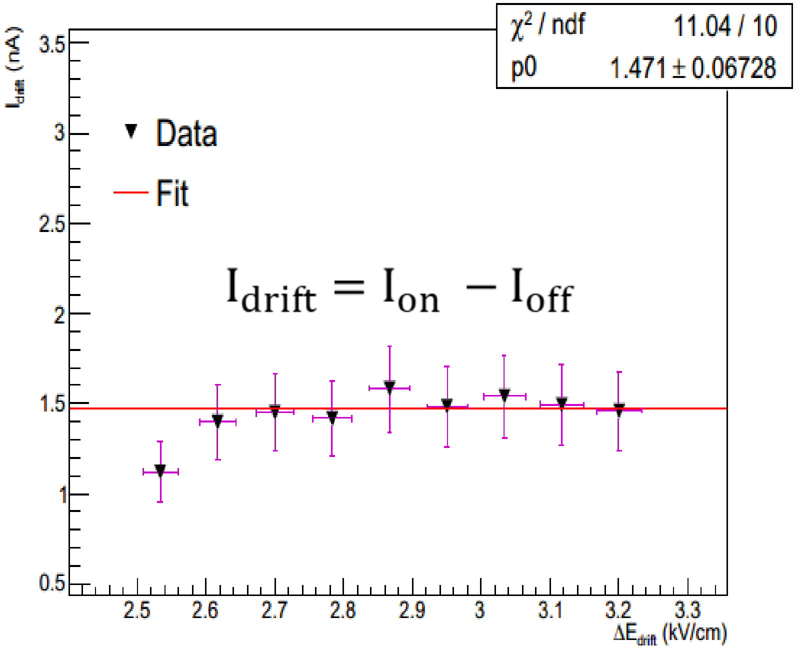


Figure 1

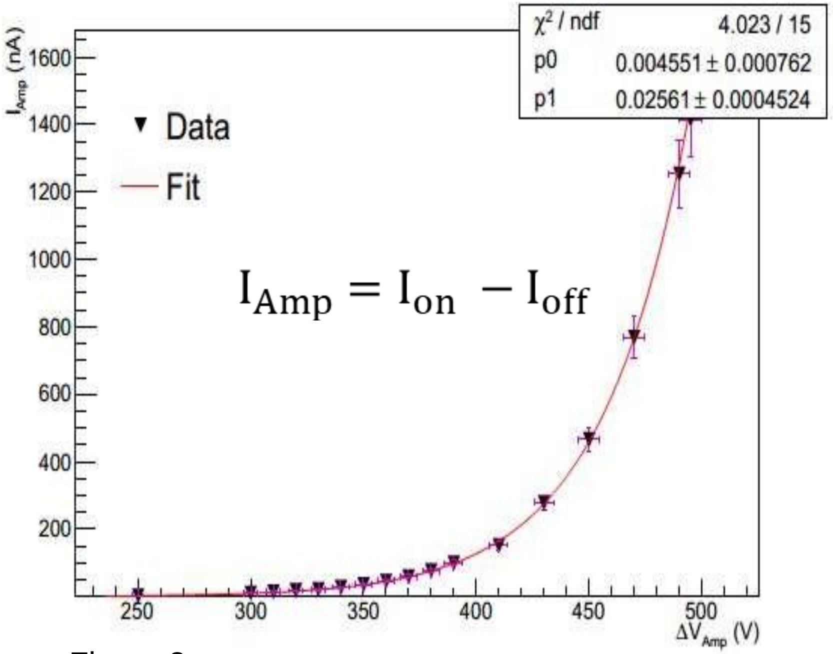


Figure 2

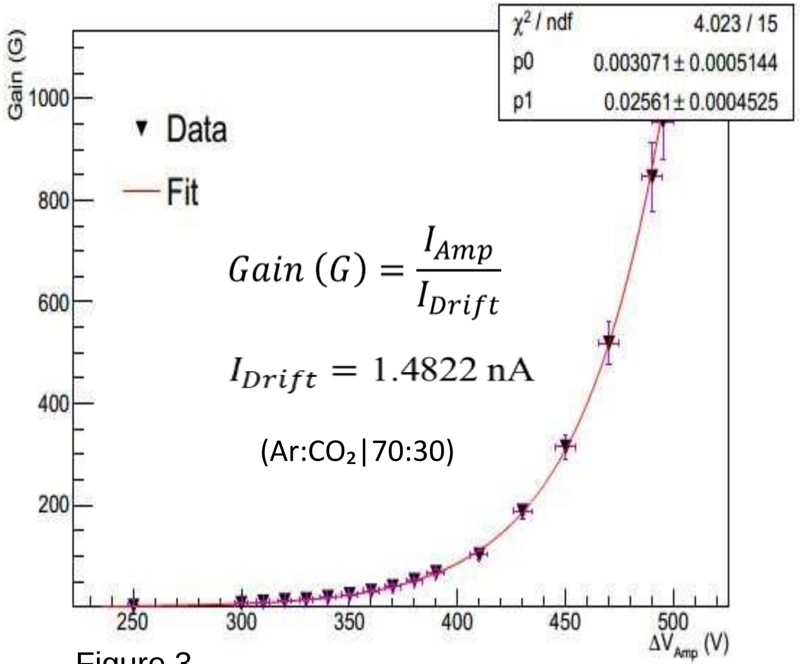
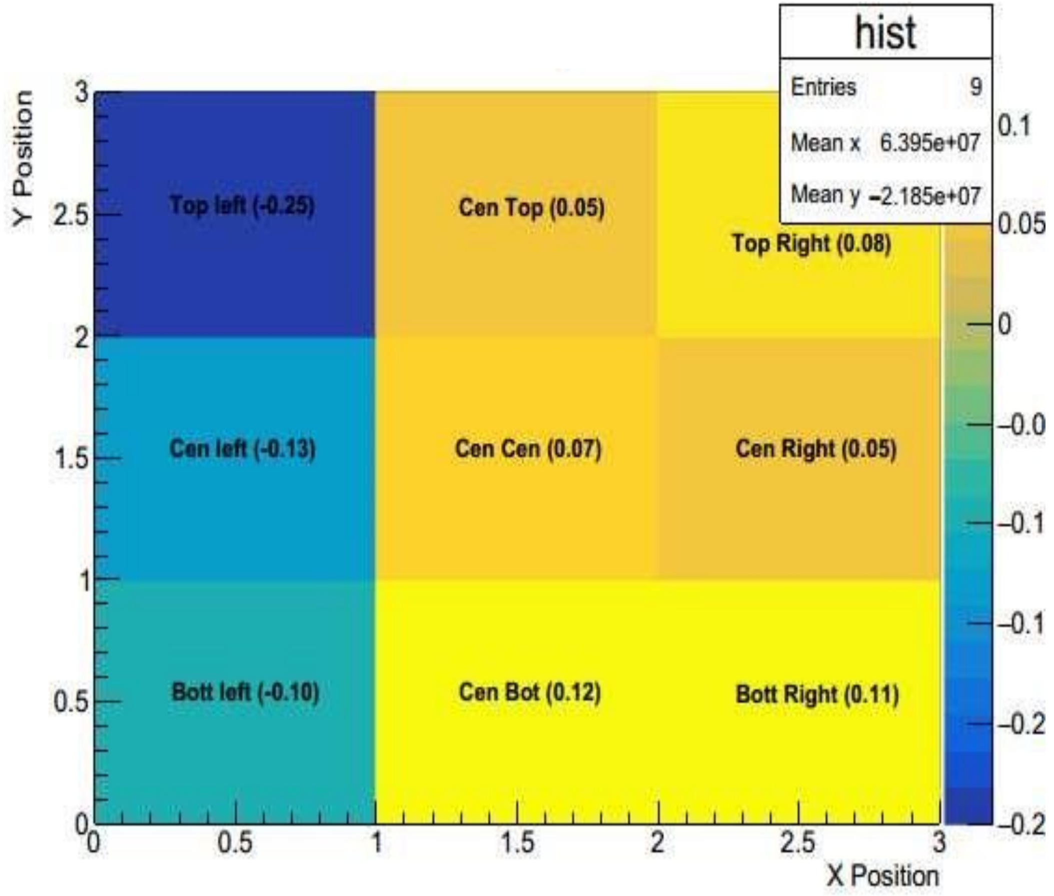


Figure 3

- Drift Current remains constant with increase in drift field E_{Drift} (Figure 1).
- Exponential production of secondary electrons I_{Amp} (nA) in amplification region (Figure 2).
- Exponential increase in Gain (G) is observed (Figure 3).

Gain uniformity measurement



Procedure

I moved the source in 9 positions and measure gain.

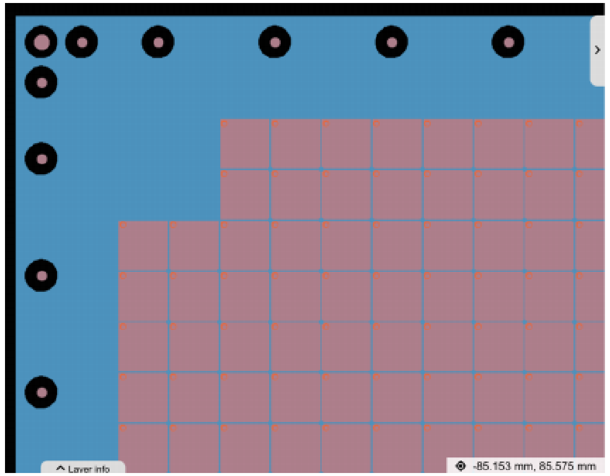
- Gain (G) variation w.r.t mean gain (M.G) across the whole surface (Uniformity).
- $Gain\ (G)\ \% = \frac{G - M.G}{M.G}$
- It is observed that Gain G % is maximum in central region.
- Gain variation is around 25% in top left region

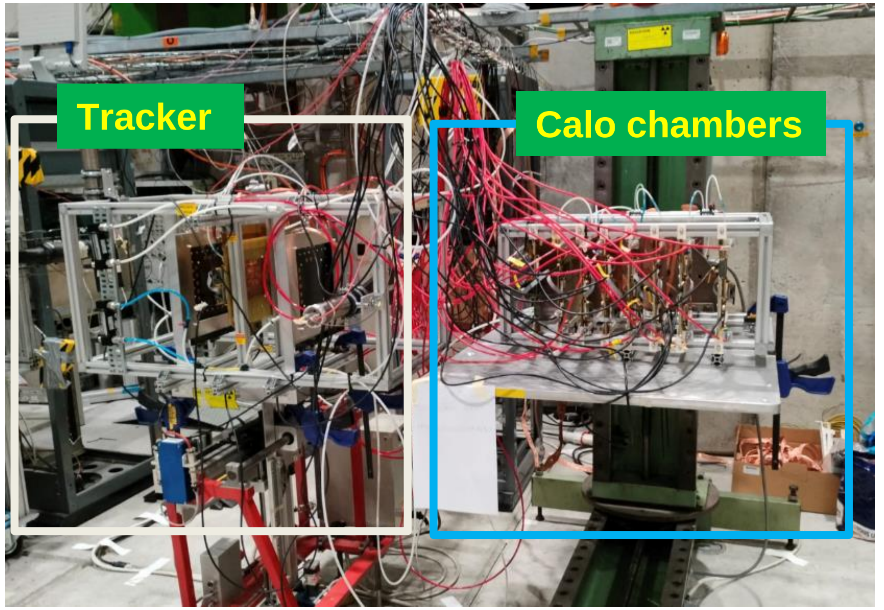
Test Beam July 2024

MPGD-HCAL Prototype – PS (Pion 2-10 GeV and SPS (Muon 80 GeV).

MPGDs technologies:

- 3 MicroMegas.
- 5 μ-rwell.





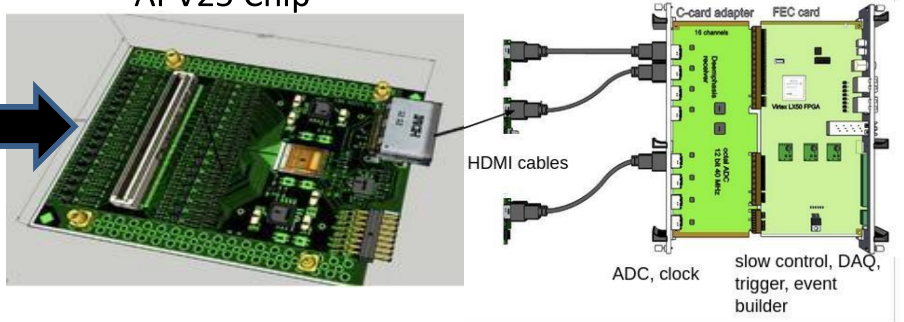
Data Acquisition (DAQ)

<u>Front-End-Electronics</u>

- 3 APV25 Chips for each detectors.

- 128 channels per APV25.
- Analogic readout.
- SRS system (ADC + FEC) for data aggregation and slow control.

APV25 Chip

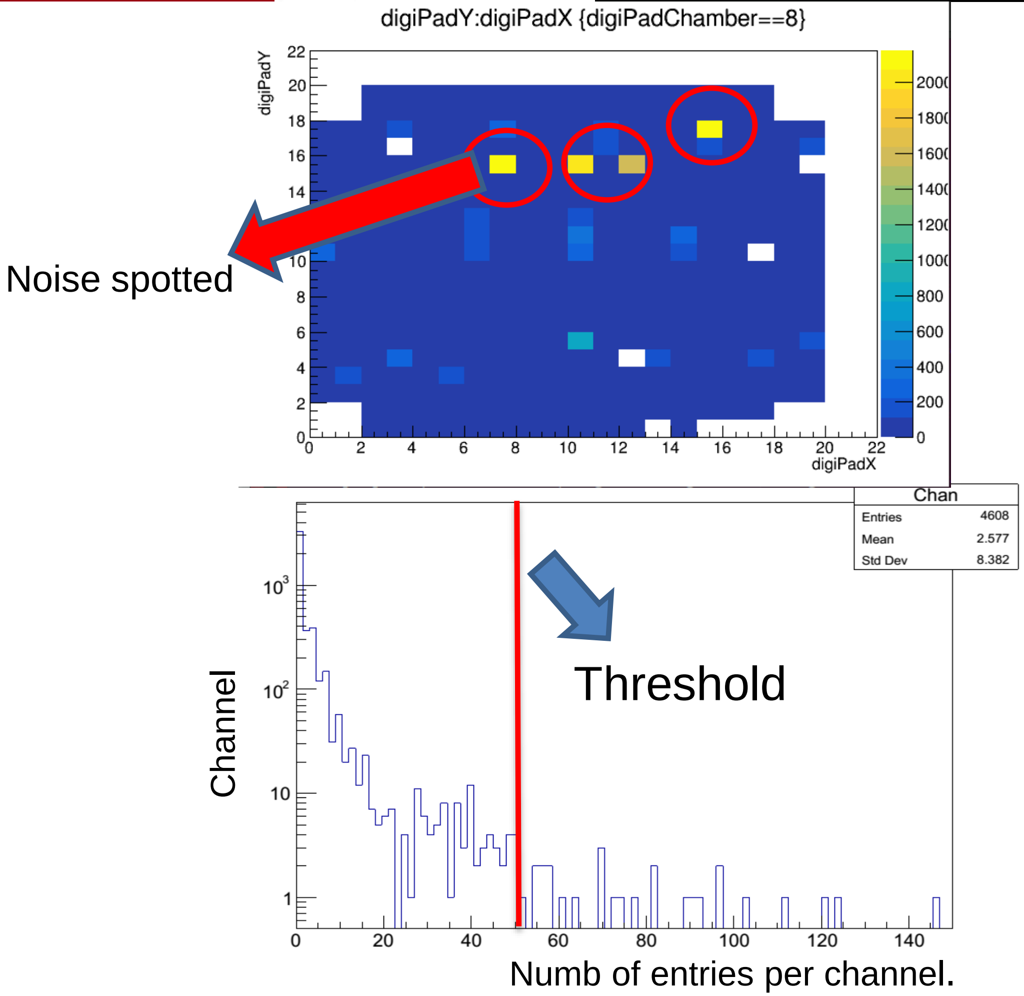


Test Beam July 2024

- Noise Runs: data collected with random trigger without beam
- In this way noise can be analyzed statistically.

Current Activity:

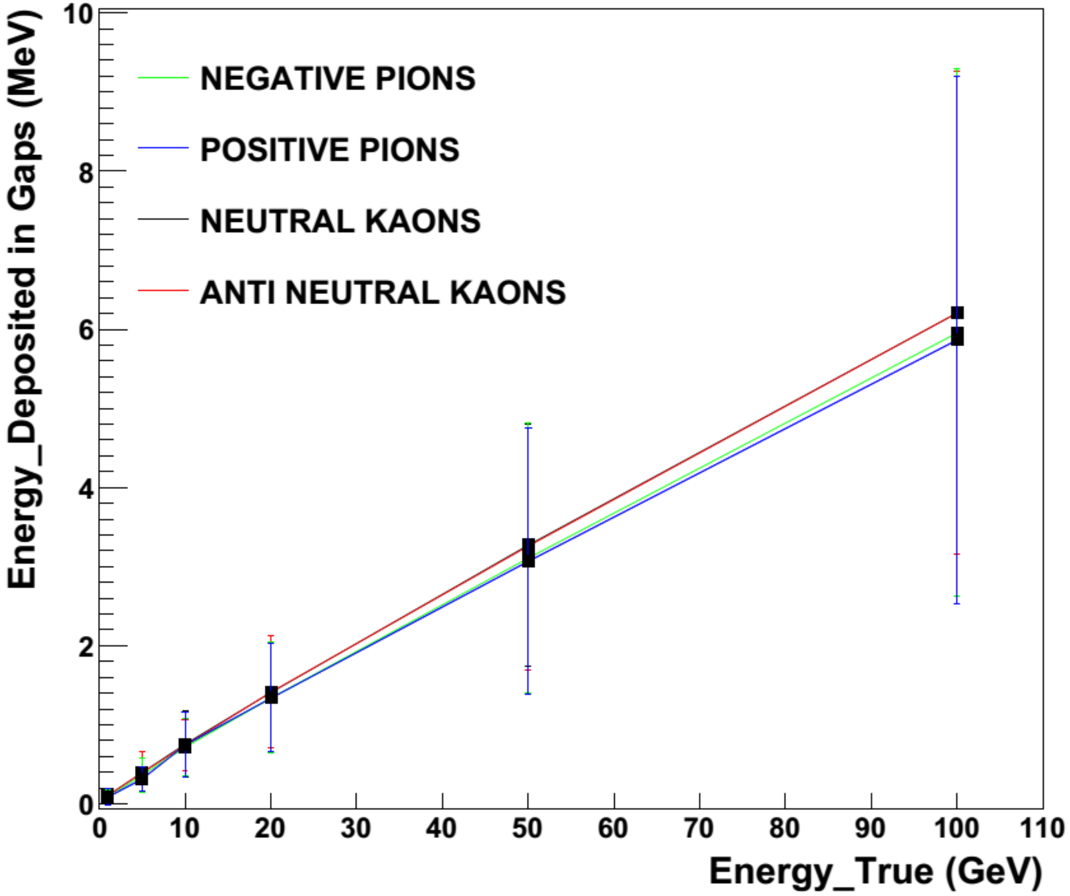
- The goal is to improve the accuracy of measurements by eliminating the influence of noisy channels during the event reconstruction process.
- Comparison of number of entries in each channels to threshold (mean value plus 3 times standard deviation)
- To spot the noisy channel and corresponding APV25 and FEC, if the number of entries in each channel exceed the threshold.



GEANT4-MPGD HCal

a first exercise

- Implementation of the geometry in GEANT4 of the MPGD calorimeter prototype.
    i. Calorimeter Size XY = 100 cm^2 (50 Layers).
- Investigating energy deposition in gaps at energies 1, 5, 10, 20, 50 GeV.
- Pions (π^- ,π^+) and Kaons (K^0 and $\overline{K^0}$) beams are used for energy deposition measurements.



Conclusions

- All hadrons have the same response.

Future Plans

R&D on MPGD:

1. Characterization of 20x20 cm^2 MPGD (GEM, µ-RWELL and Micromegas) prototypes in Bari lab (To measure Gain, Uniformity response with X- Ray source).
2. Efficiency, uniformity response and timing measurements with Muon beams at CERN at SPS accelerator.

R&D on MPGD-based HCAL:

Test of a 10 layer MPGD-HCAL prototype with Pion beams and comparison with GEANT4.

MPGD HCAL simulation with GEANT4

Study the response of MPGD-HCAL to muon and pion Beams with GEANT4 and compare to the real data in order to underwent the PID (particle identification capabilities) of the MPGD-HCAL prototype.

PhD plan for three years

Year 1:
I arrived in Italy in April.

- Geant 4 simulation studies HCal for design optimization.

- μ-RWELL prototype characterizations.
- Test beam 2024 activity.

- Course work.

Year 2:
- MicroMegas, μ-RWELL prototypes characterization for HCAL prototype.

- Studies of hadronic calorimeter response to muon and pion beams with Geant4.
- CMS triple GEM characterization
- Course work

Year 3:

- Test beam Data analysis.
- Comparison of simulation studies with experimental findings.

- Thesis submission.

Subjects and Schools

Subjects

Year 1:

- Gaseous detectors for experimental particle physics.
- Machine learning programming in physics.
- Design of readout integrated circuits for particle physics.

Year 2:

- Fundamentals of system engineering and project management for large scientific project.

Schools

- XXXV Edition of the International School "Francesco Romano" on Nuclear, Subnuclear and Astroparticle Physics - Monopoli (Italy) - 6-13 October 2024. https://agenda.infn.it/event/40753/
- DRD1 Gaseous Detectors School November 27, 2024 to December 6, 2024 CERN, Switzerland. https://indico.cern.ch/event/1384298/

Backup

MPGD working principle

1. Charge particles/photons interaction with gas molecules

2. Ionization.

3. Production of primary electrons.

4. Utilizes etched holes (Electric field).

5. Electrons drift.

6.Amplification.

7. Charge spreading on DLC layer.

8. Readout.

https://arxiv.org/pdf/1903.11017.