MPGD-based HCAL for a future experiment at Muon Collider

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Multi-TeV Muon Collider

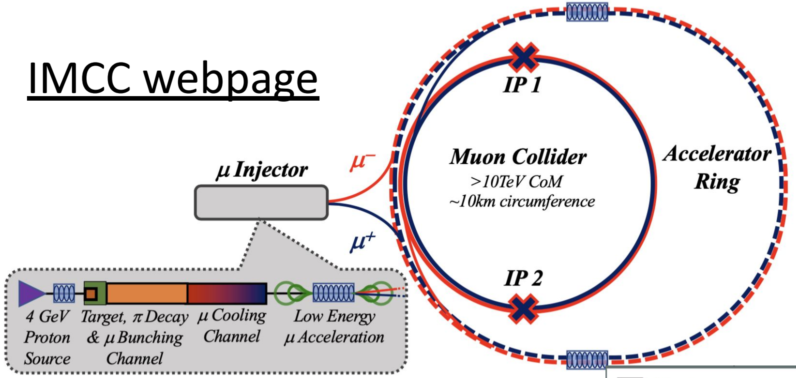
Advantages:

- 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.

Challenges:

- muon is an unstable particle; its decay products interact with the machine elements generating an intense flux O(10^{10}) of background particles: **beam-induced background (BIB)**.
- Two conical tungsten shieldings **(nozzles)**, cladded with borated polyethylene, allow the reduction of background by 2-3 orders of magnitude.

IMCC webpage



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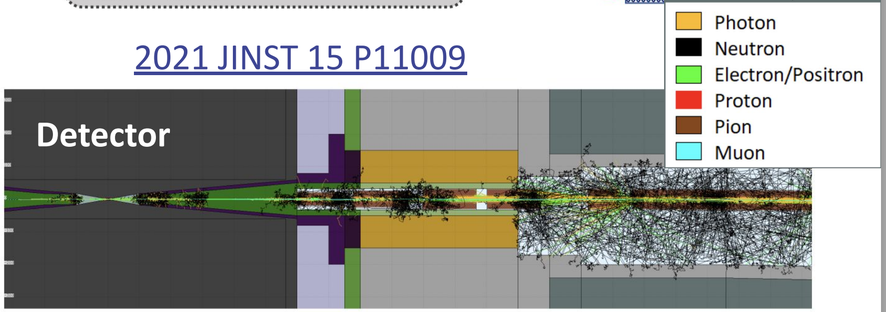
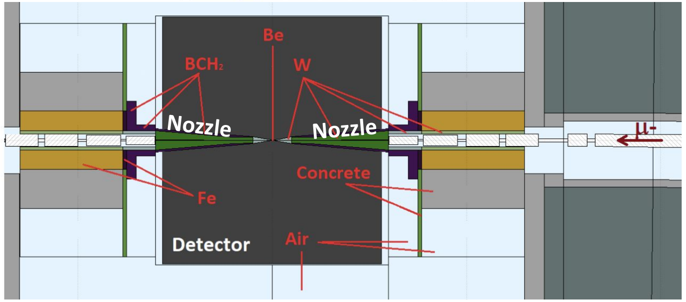


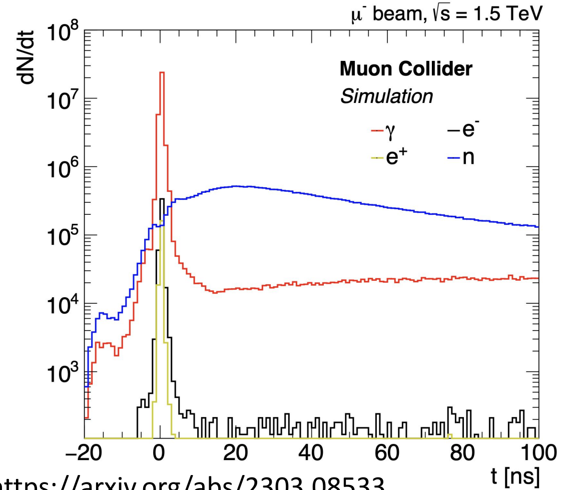


BIB in the detector

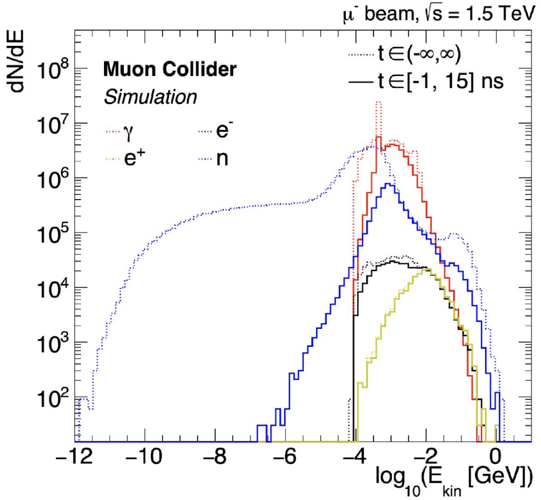
Main BIB components entering the detector per bunch crossing (BX):

- photons (~10^8),
- neutrons (~10^8),
- electrons/positrons (~10^6).

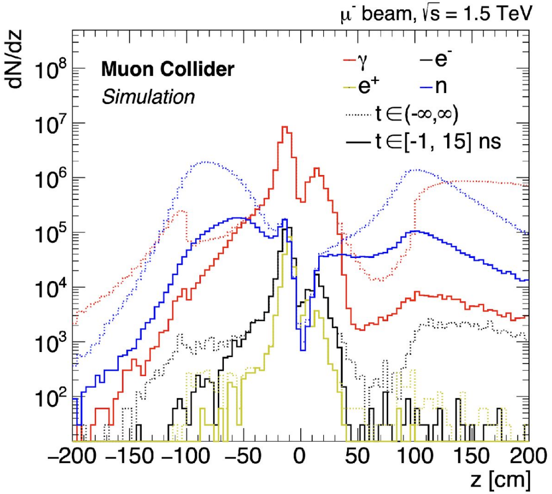
Asynchronous arrival time



Soft energy spectrum



Large displacement



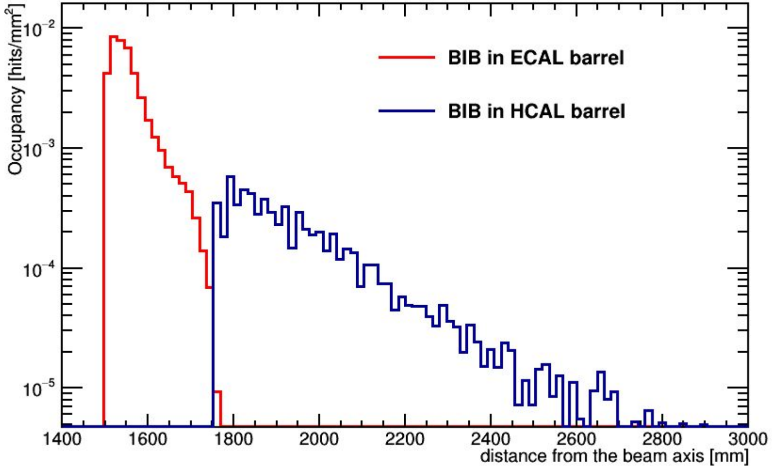
https://arxiv.org/abs/2303.08533

BIB in the calorimeter system

- The **BIB** comes mainly from **photons** (96%) and **neutrons** (4%).
- Occupancy for energy above 0.2 MeV:
  - Electromagnetic Calo (ECAL): 0.9 hits/cm2
  - Hadronic Calo (HCAL): 0.06 hits/cm2

Requirements for a Particle Flow calorimeter at Muon Collider:

- High granularity: O(1cm^2) cell in ECAL, O(3cm^2) cell in HCAL.
- Longitudinal segmentation.
- Good timing (σ_t = 100 ps-1ns).
- Energy resolution to work in Particle Flow approach:
  - ECAL: 10%/√E,
  - HCAL: 30%/√E.
- Radiation hardness.



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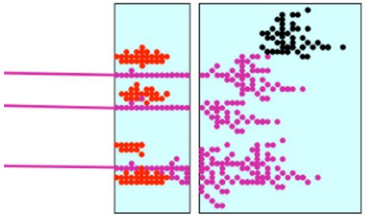
5D calorimeter



$E_{JET} = E_{TRACK} + E_{\gamma} + E_n$

Particle flow

MPGD-HCAL for Muon Collider

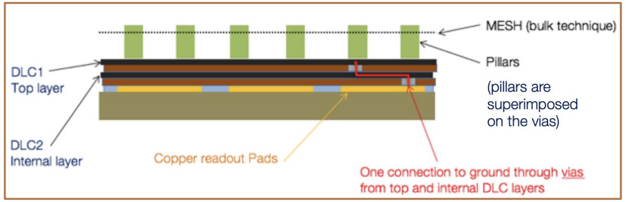
- CALICE collaboration has already proposed **gaseous detectors** for **sampling calorimeter**.
- On going R&D effort on a **Hadronic Calorimeter** based on **Micro Pattern Gaseous Detector (MPGD)**

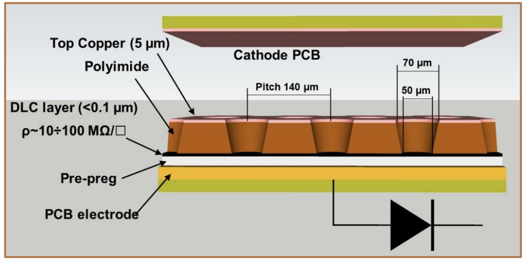
Why MPGD-base HCAL?

- Radiation hardness,
- fine granularity,
- rate capability O(MHz/cm2)
- good space (<100 um) resolution,
- response uniformity,
- cheap for large area instrumentation.

Technologies

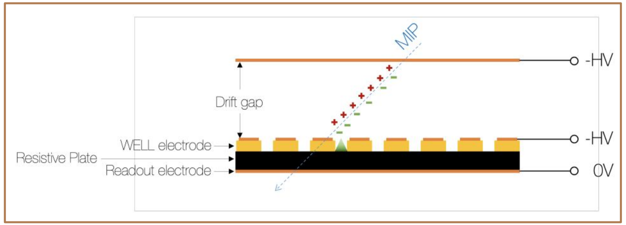
Micromegas (MM)





µRWELL

RPWELL



R&D MPGD-HCAL

Geant4 simulation studies:
- shower containment
- cell dimension (1cm^2 Vs 3cm^2)
- energy resolution

MPGD-HCAL prototype:
- characterization of the various 20x20 cm^2 detectors used as active layers;
- HCAL prototype performance at test beams

Work in progress

GEANT4 simulation studies

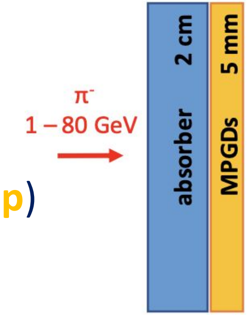
G4 simulation - Shower containment

Preliminary

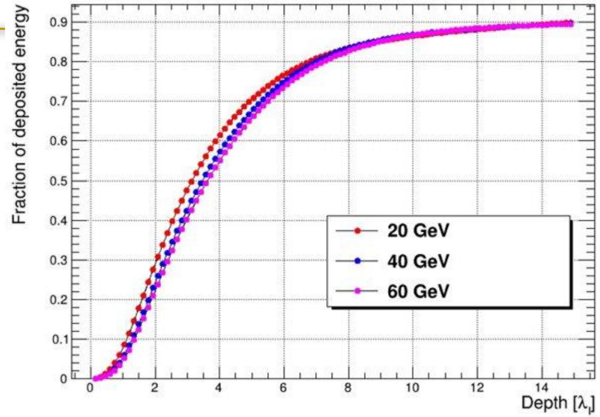
Geometry implemented

- Sampling calorimeter made of
  - 2 cm of Iron (**absorber**)
  - 5 mm of Ar/CO2 (**active gap**)
  - Cell granularity: 1x1 cm2

Source: π gun from 1 to 80 GeV



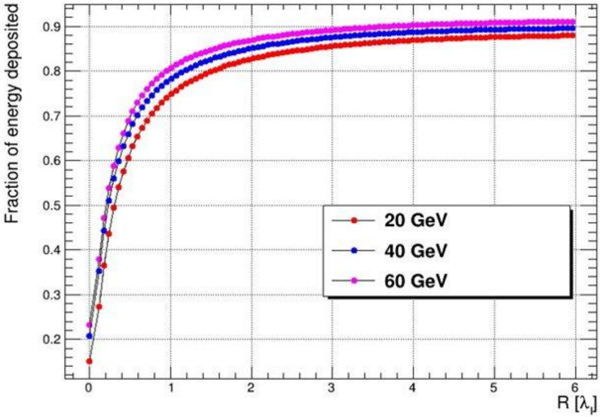
Longitudinal direction



Energy contained at 90%

- 14 $\boldsymbol{\lambda}_N$ in the direction of the incoming π
- 3 $\boldsymbol{\lambda}_N$ in the orthogonal direction

Transverse direction

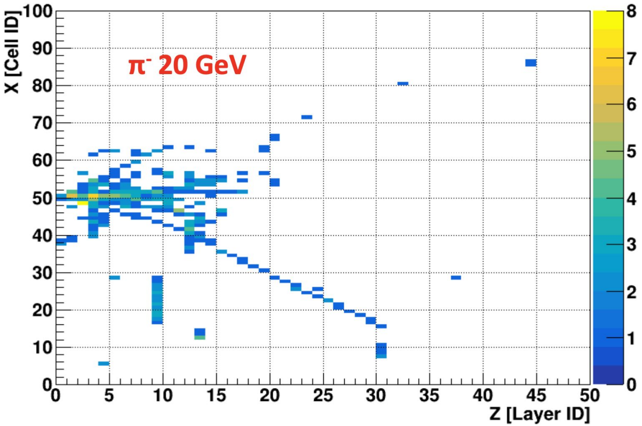


G4 simulation - Digital and Semi-digital HCAL

Preliminary

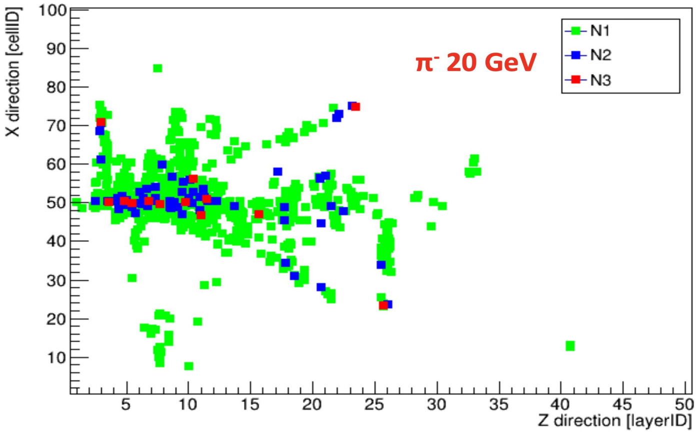
Digital Readout

- **Digitization:** 1 hit=1cell with energy deposit higher than the applied threshold
- **Calorimeter response function:** $<N_{hit}>=f(E_{\pi})$
- **Reconstructed energy:** $E_{\pi}=f^{-1}(<N_{hit}>)$



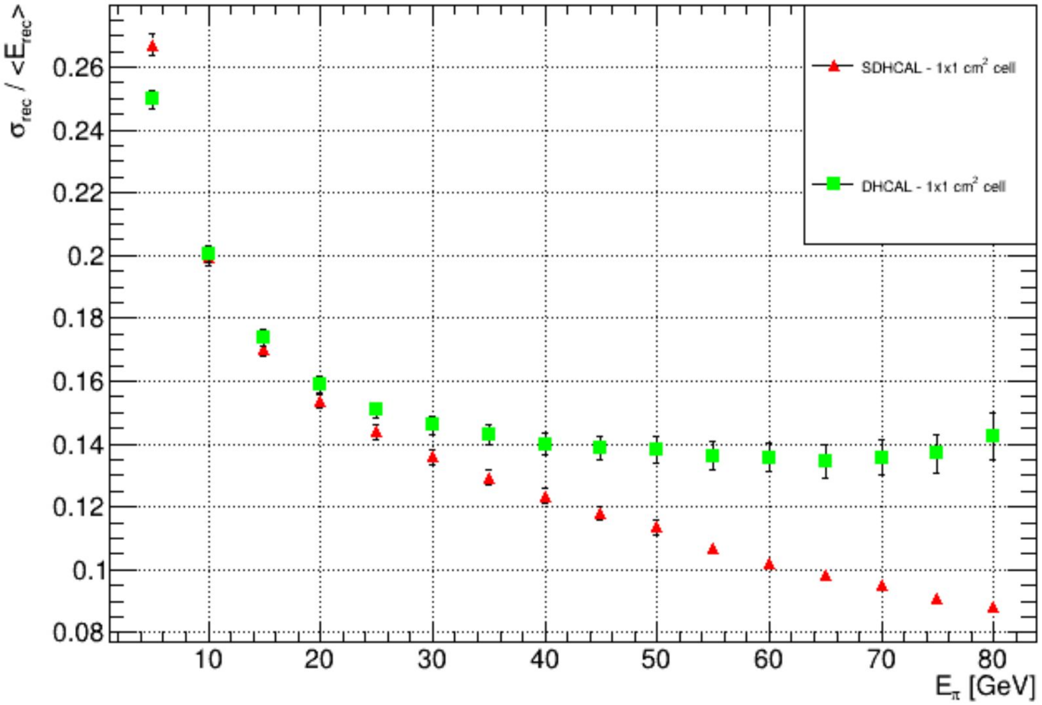
Semi-digital Readout

- **Digitization:** defined multiple thresholds
- **Reconstructed energy:** $E_{\pi}= \alpha N_1+\beta N_2+\gamma N_3$ with:
  - $N_{i=1,2,3}$ number of hits above i-threshold
  - α,β,γ parameters obtained by χ^2 minimization procedure



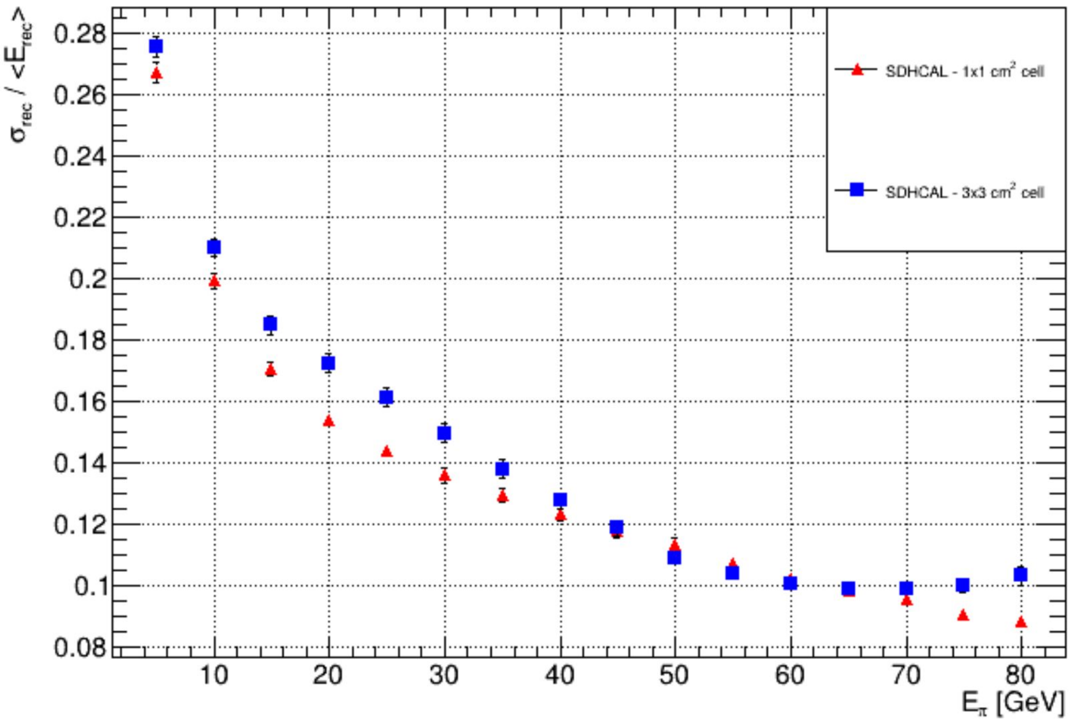
G4 simulation - Digital and Semi-digital HCAL

Preliminary



- **Digital HCAL (DHCAL)** is affected by the **saturation** of the number of hits at energies above 40 GeV
- **Semi-digital HCAL (SDHCAL)** shows an energy resolution of ~8% for a pion of 80 GeV

G4 simulation - Cell size



The increase of cell size (**$1x1cm^2$** $\rightarrow$ **$3x3$ cm^2**) implicates a **saturation effect** at energies above 60 GeV:

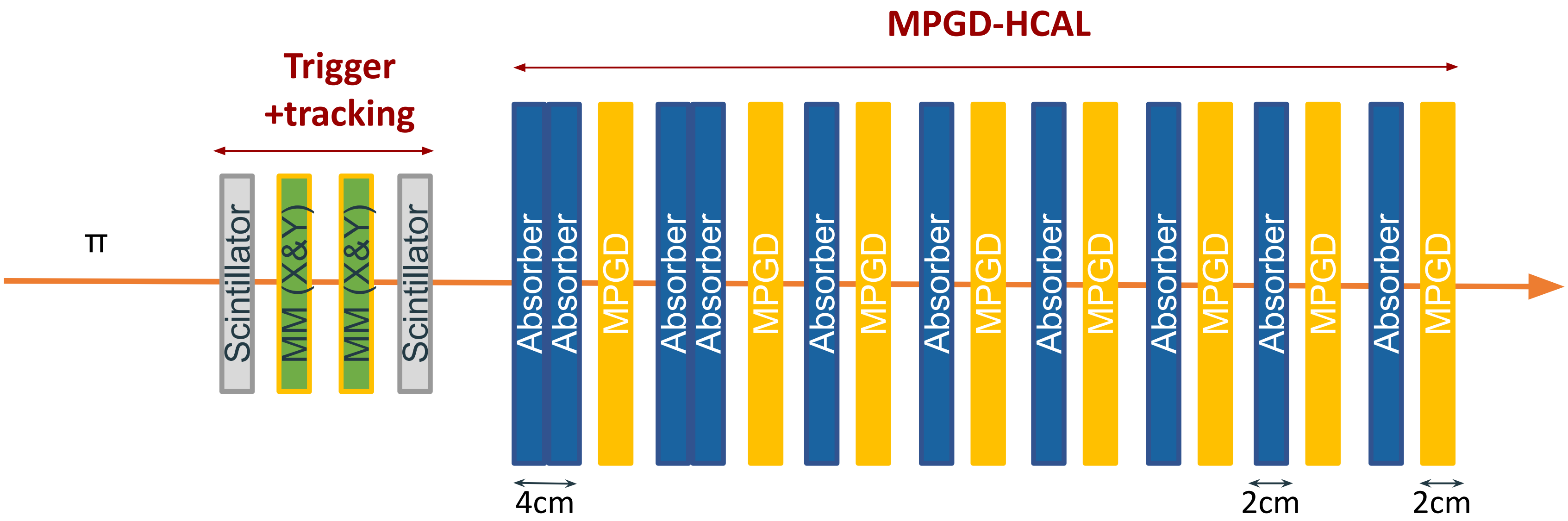
- SDHCAL $1x1cm^2$ resolution of ~ 8%
- SDHCAL $3x3cm^2$ resolution of ~10%

MPGD-HCAL prototype

In collaboration with:

- **INFN - Frascati**
- **INFN - Naples**
- **INFN - Rome3**
- **Weizman Institute of Science**

MPGD-HCAL prototype



8 layers

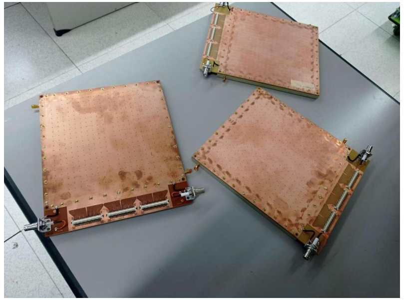
- MPGD: MM, µRWell, RPWELL
- Iron absorber ~ $1\lambda_N$

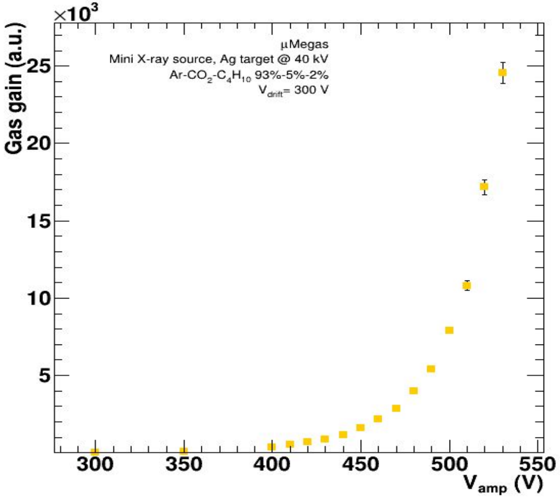
Two test beam campaigns in 2023 to measure:

- **single MPGD performance (5-19 July)**
- **HCAL cell performance (30 August - 6 September)**

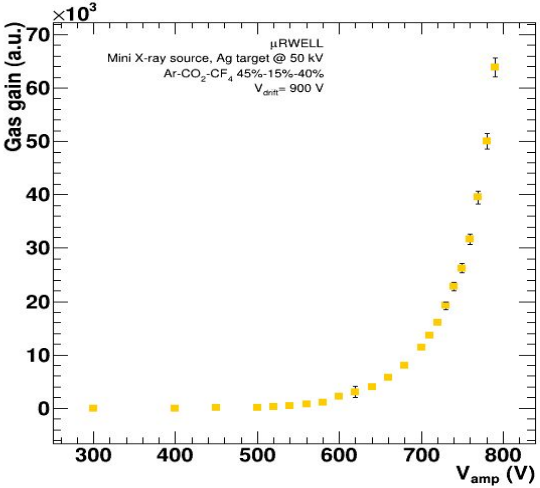
MPGD-HCAL prototype - Detectors

- **MPGD total production batch**:
  - 7 uRWELL
  - 4 MicroMegas
  - 1 RPWELL
- detector size: 20x20 cm^2
- pad size: 1cm^2 pad$\longrightarrow$ 384 pads
- Common readout board





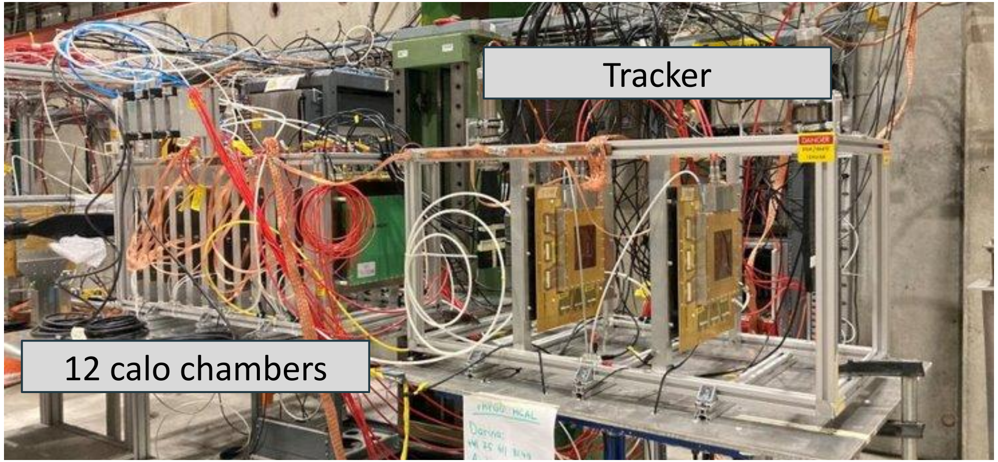
First characterizations (HV stability & effective gain) performed in all the labs involved in the project



MPGD-HCAL prototype - July test beam

July 2023: MPGD test beam campaign at SPS with O(100 GeV) muon beam with the goal to measure

- response uniformity
- efficiency
- spatial resolution



Data taking:

- 12 chambers to be tested in total, read 6 chambers at a time
- HV, XY position scan
- During last days instrumented only central pads to read all the calo-chambers at once

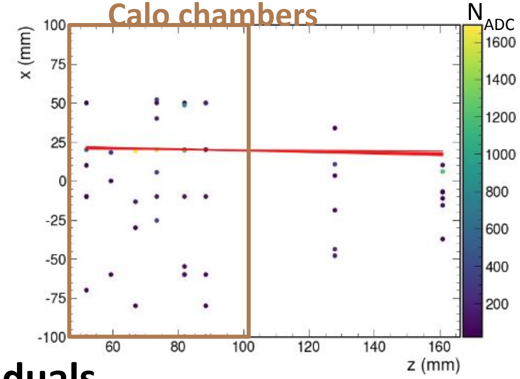
Track reconstruction:

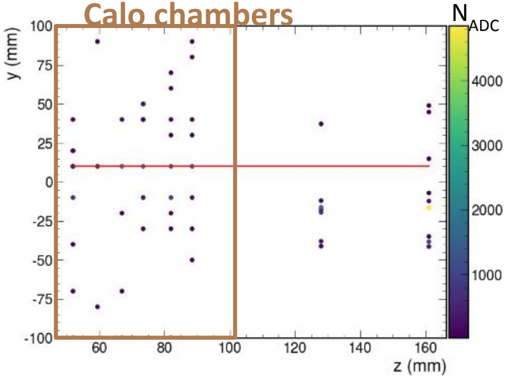
- TMM temporarily excluded
- reconstruct the track using hits from 5 calo detectors, the 6 chamber is the one under test

MPGD-HCAL prototype - July test beam

Preliminary

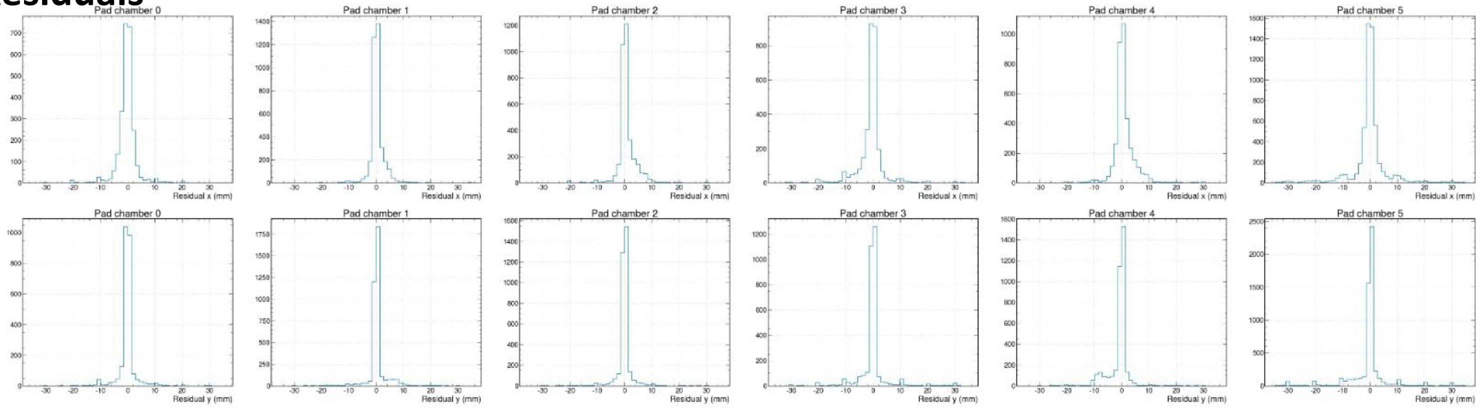
Reconstructed track in X-Z and Y-Z plane





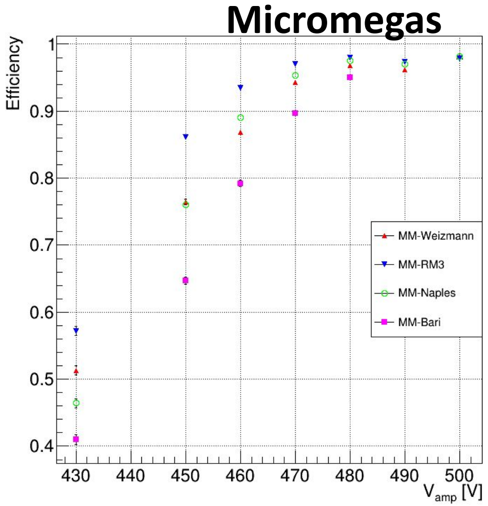
Narrow residuals, in agreement with detector granularity

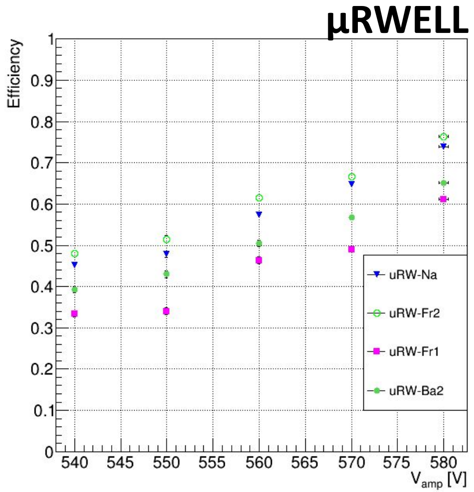
Residuals

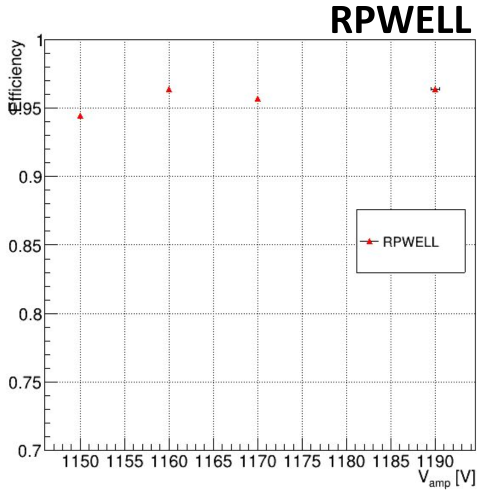


MPGD-HCAL prototype - July test beam

HV scan







- Micromegas and RPWELL show efficiency of above 95%
- µRWELL not in plateau for the scanned values → foreseen a new HV scan

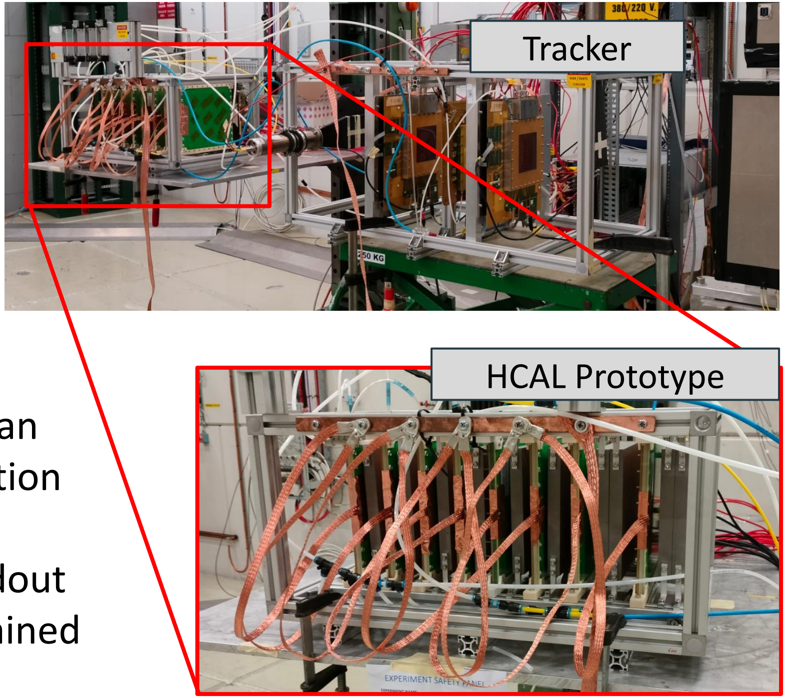
MPGD-HCAL prototype - Aug test beam

Results coming soon

Full prototype test beam campaign at PS

- pure negative pion beams
- beam size of ~1cm^2
- monochromatic E=2, 4, 6,7,9,10 GeV

First operation of the full system!



Scientific program

- without absorbers: response to an X&Y scan
- with absorbers: energy and energy resolution measurement with monochromatic beam
- Define the thresholds for semi-digital readout using the per-pad charge distribution obtained with the analog readout

Conclusions

Conclusions

MPGD-HCal simulation in G4– response to single π:

- Energy resolution better with **semi-digital RO** for cells of 1x1 cm2

Test on MPGD prototype:

- preliminary results show that the single detectors run well but **performance studies are in progress**
- **results from PS test beam to be fully analyzed and compared with a GEANT 4 simulation**