Design and optimization of a MPGD-based HCAL for a future experiment at Muon Collider

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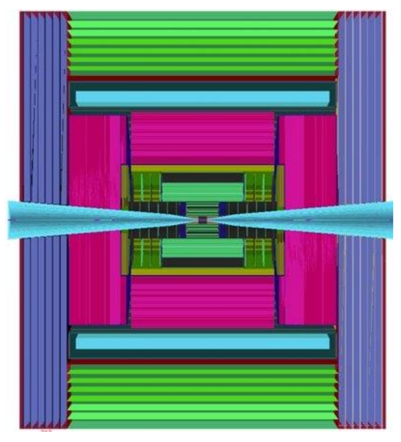
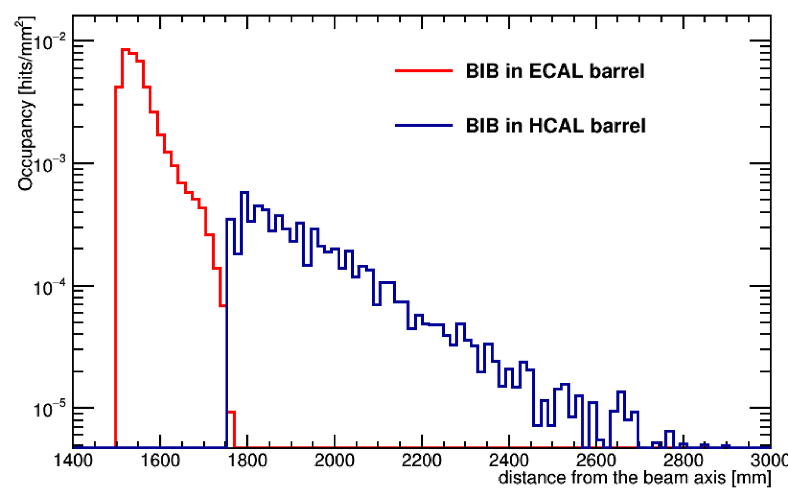
1 Particle-Flow calorimeter for Muon Collider



- A Muon collider [1] combines the best of hadrons (can reach **multi-TeV energy range**) and leptons (all energy available to the collision) colliders
- **Challenge**: the decay of the μ induces a high flux of background particles in the detectors (**BIB**)
  - **coping with BIB as main driver of detector design**

Requirements for HCAL @ Muon Collider:

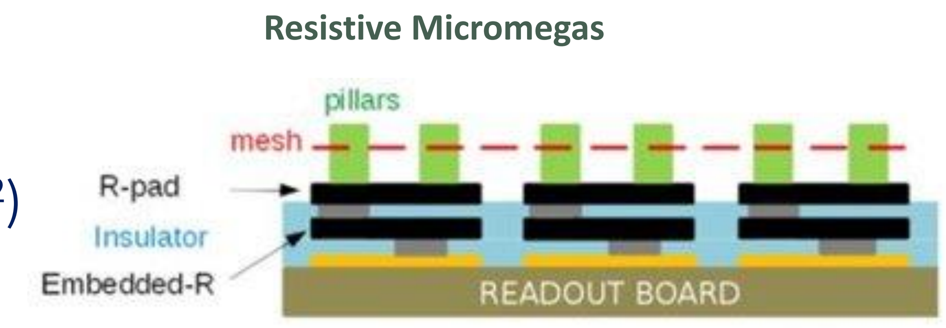
- High granularity: O(3cm²) cell in HCAL
- Good timing (σ_t = 100 ps-1ns)
- Energy resolution to work in Particle Flow approach [2] (HCAL: 30/%√E)

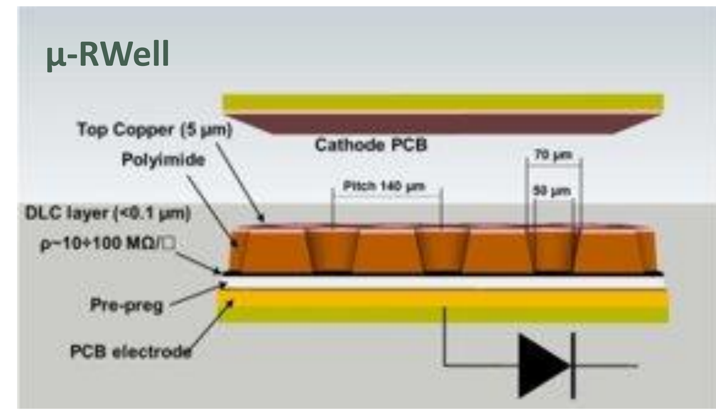


2 Why MPGD-based HCAL?

- ✓ Radiation hardness
- ✓ Fine granularity
- ✓ Rate capability O(MHz/cm²)
- ✓ Good space (<50 um) and time (5-10 ns) resolution
- ✓ Response uniformity
- ✓ Cheap for large area instrumentation
- ✓ Eco-friendly gas mixture

Resistive μMegas [3] **and μRWELL** [4] **for discharge suppression**



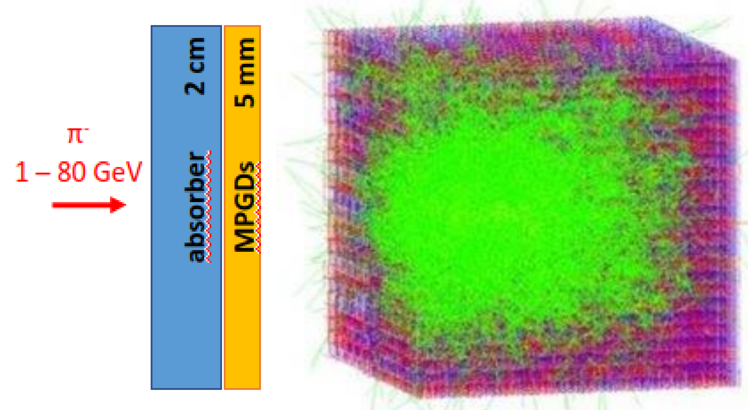


3 Monte Carlo simulation in GEANT4

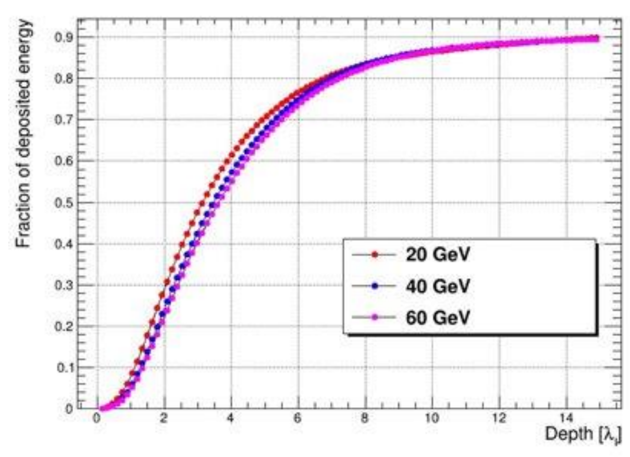
Geometry implemented

- Sampling calorimeter made of
  - 2 cm of Iron (**absorber**)
  - 5 mm of Ar/CO_2 (**active gap**)
  - Cell granularity: 1x1 cm²

Source: π^- gun from 1 to 80 GeV

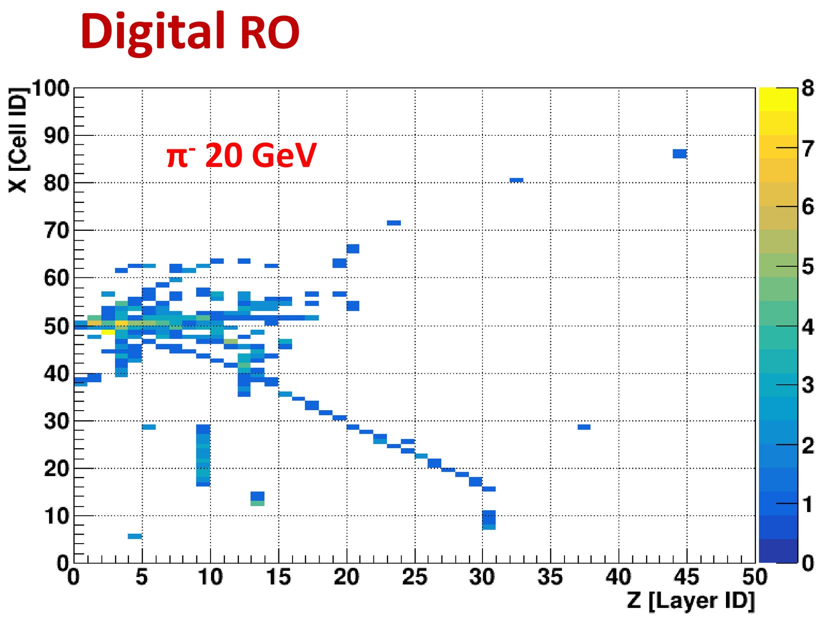


Energy contained at 90%
- 14 λ_N in the direction of the incoming π
- 3 λ_N in the orthogonal direction



Digital and Semi-digital HCal

Digital RO



1. **Digitization**: 1 hit = 1 cell with energy deposit higher than the applied threshold
2. Find the **calorimeter response function**: $\langle N_{hit} \rangle = f(E_\pi)$
3. **Reconstruct the energy** with the inverse response function $E_{rec} = f^{-1}(N_{hit})$

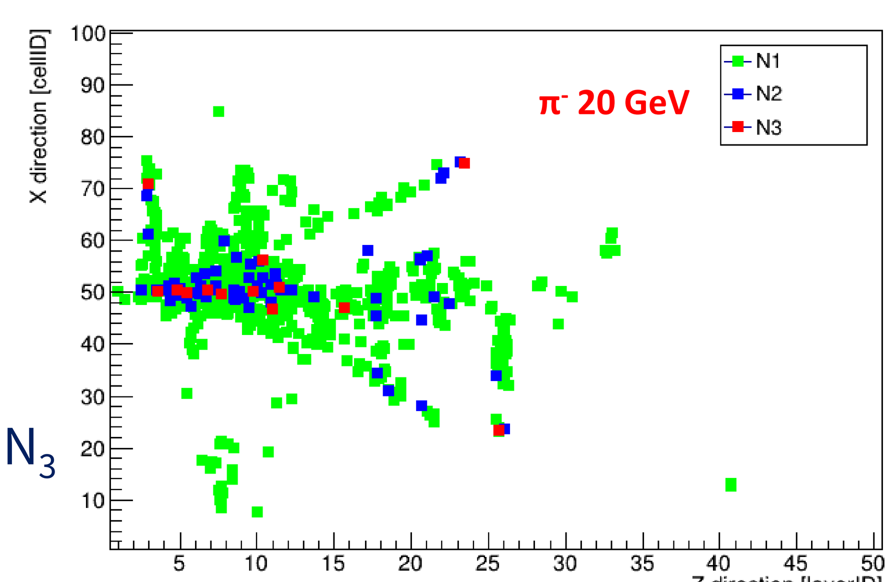
Semidigital RO

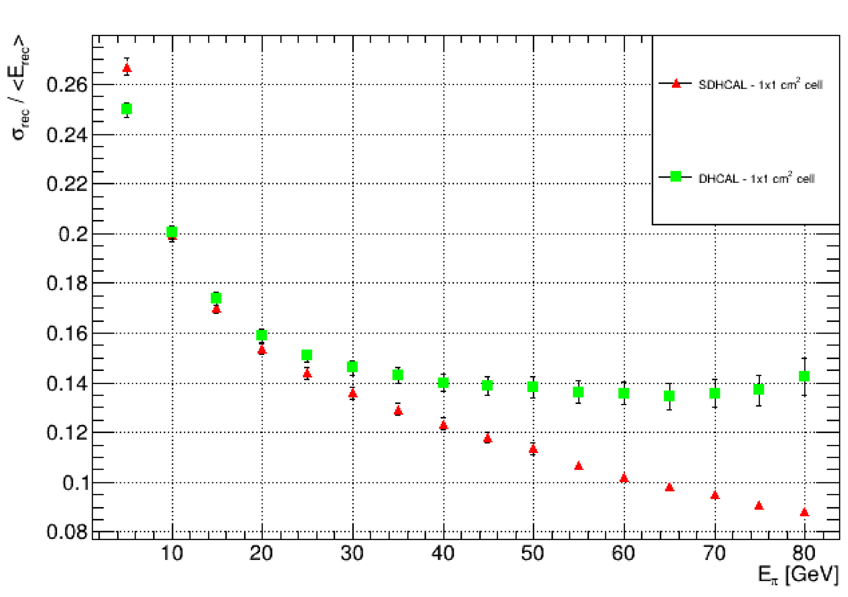
1. **Digitization**: define **multiple threshold** and **weighted hits distributions**
2. **Energy reconstruction** with the formula:

$$E_{rec} = \alpha \cdot N_1 + \beta \cdot N_2 + \gamma \cdot N_3$$

where α, β and γ depends on $N_1 + N_2 + N_3$ and are estimated minimizing

$$\chi^2 = \sum_{i=1}^{N} \frac{\left(E^i_{true} - E^i_{rec}\right)^2}{E^i_{true}}$$



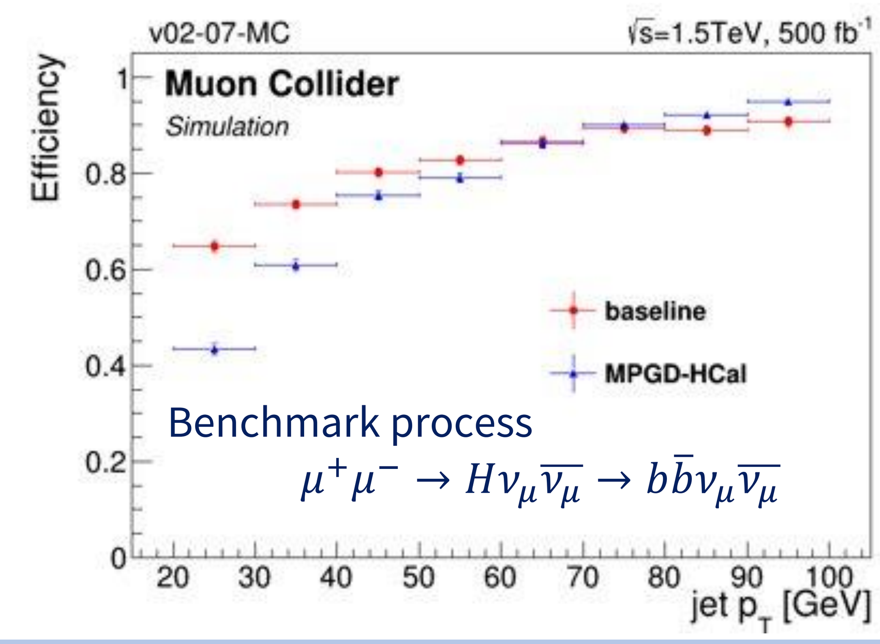


Energy resolution: DHcal vs SDHcal

for E_π = 80 GeV:
- DHcal ~ 14%
- SDHcal ~ 8%

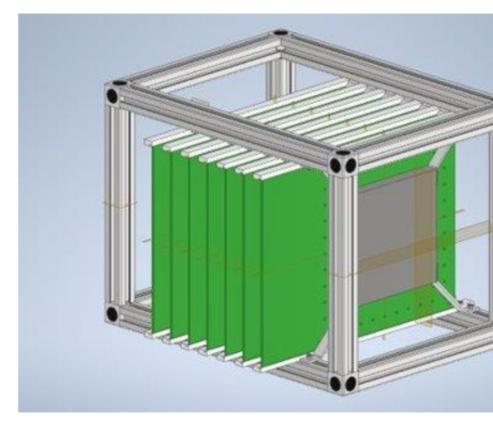
4 MPGDs Hcal in Muon Collider framework

From preliminary studies, jet reconstruction efficiency simulated with the baseline geometry (plastic scintillators as active layers) is **comparable** with the MPGD geometry.

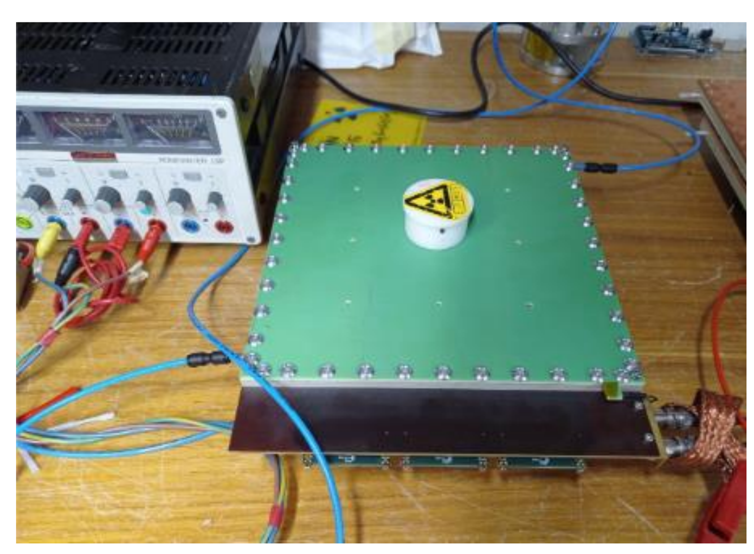


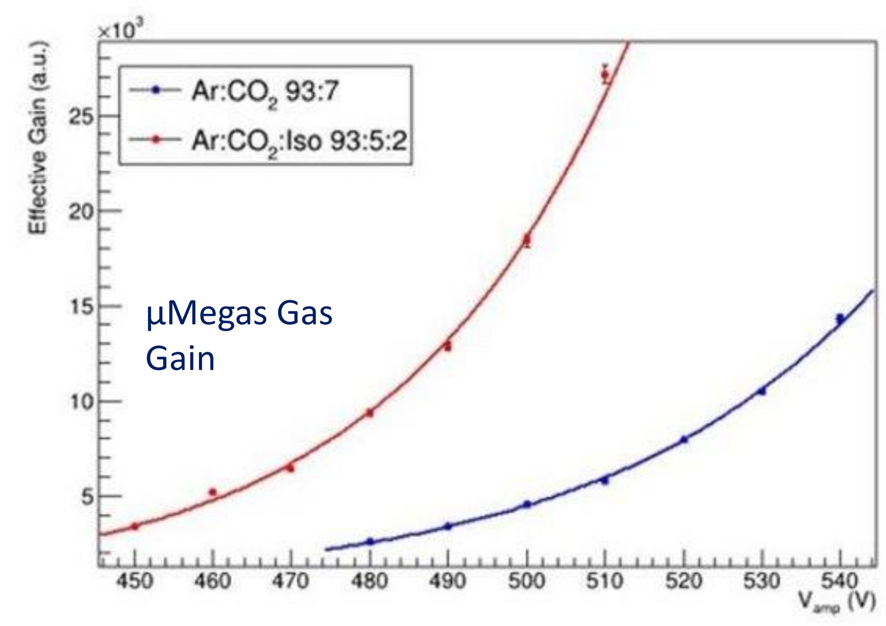
5 Future steps: test on MPGDs Hcal prototype

- **Main goal**: Test Beam with π- (1-6 GeV) on **a MPGD HCAL prototype** (September 2023)
  - ~ 1 λ_N (8 layers) and 20x20 cm² trasversal size, 1 cm² RO pads
  - μRWELL and μMegas for active layers
- Preliminary Test Beam with MIPs on **MPGD alone** (July 2023)
  - test the performance and choose the best detectors to be included in the HCAL prototype



- All the detectors (11 overall) have been tested to assess the working point with INFN sections of Bari, Napoli, Frascati, Roma3 and the Weizmann Institute of Science





CONCLUSIONS

MPGD-HCal simulation in G4– response to single π:
- Energy resolution better with **semi-digital RO** for cells of 1x1 cm²

MPGD-HCal in Muon Collider framework – jet reconstruction
- Comparable performance between baseline and MPGD-Hcal → **geometry optimization** of MPGD-HCal, with RO DHCal and SDHCal

Test on MPGD prototype: 20x20 cm² – 8 layer (~ 1 λ_N)
- Test beam with **MIP** on telescope with the active layers alone + test beam with **π from 1 to 6 GeV** on the calorimeter (absorber + MPGDs)

Bibliography

[1] https://doi.org/10.48550/arXiv.2203.08033
[2] https://doi.org/10.48550/arXiv.1308.4537
[3] https://doi.org/10.1016/j.nima.2022.167310
[4] https://doi.org/10.48550/arXiv.1903.11017

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