16th Pisa meeting on advanced detectors – May 26 - June 1, 2024

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

A. Pellecchia[1], M. Buonsante[1,2], M. Borysova[3], A. Colaleo[1,2], M. T. Camerlingo[1], L. Longo[1], M. Iodice[5], M. Maggi[1], L. Moleri[3], R. Radogna[1,2], G. Sekhniaidze[4], F. M. Simone[1,2], A. Stamerra[1,2], R. Venditti[1,2], P. Verwilligen[1], D. Zavazieva[3], A. Zaza[1,2]

[1] INFN Bari [2] Università degli studi di Bari [3] Weizmann Institute of Science [4] INFN Napoli [5] INFN Roma 3

Calorimeter slice simulation

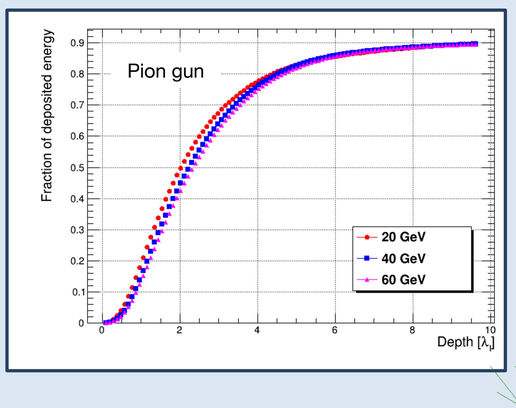
Digital calorimeter	Primary energy is proportional to total number of hits
Semi-digital calorimeter	Hits are weighted based on three thresholds $E_\pi = \alpha N_1 + \beta N_2 + \gamma N_3$ N_x = number of hits overcoming x-th threshold

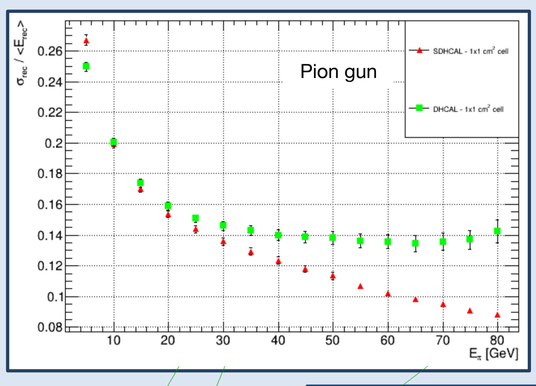
Standalone Geant4 simulation for shower containment calculation

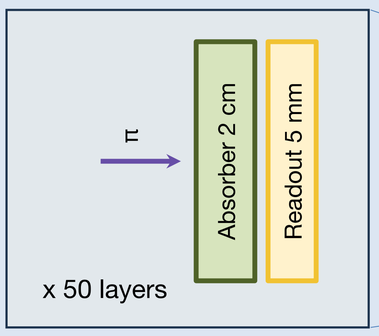
- Geometry: 2 cm iron, 5 mm gas (Ar/CO_2)
- Cross section 1×1 m^2
- Readout pad granularity 1×1 cm^2

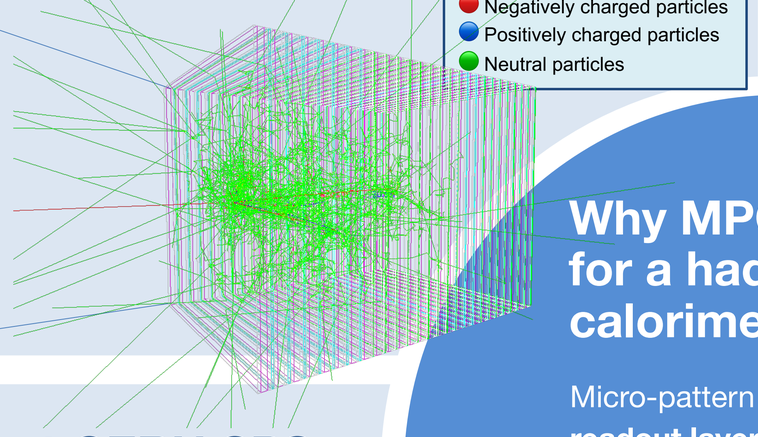
Longitudinal **containment** in 10 λ, transversal in 3 λ

Semi-digital energy resolution:
down to **8% for a 80 GeV** pion
Digital calorimeter **saturates** at 14%

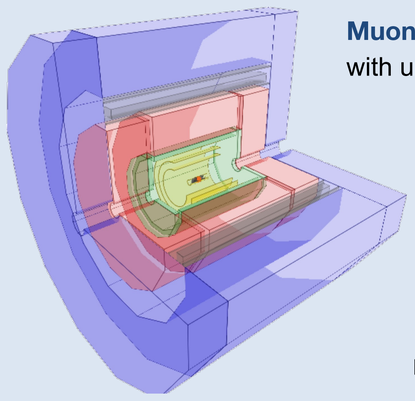








MPGD-HCAL for a Muon Collider experiment



Towards a muon collider. *Eur. Phys. J. C* **83**, 864 (2023)

Muon Collider: powerful probe to investigate the Standard Model with unprecedented precision after HL-LHC

Beam-induced background (due to in-flight muon decay) in hadron calorimeter:

- Mostly **photons** (96%) and **neutrons** (4%)
- Large **asynchronous** component
- Occupancy: 0.06 hits / cm^2

Goals

- 3-4 % jet energy resolution for hadronic Z decays
- How: $30\%/\sqrt{E}$ for HCAL
  Granularity < $3cm^2$, sub-ns timing

Determines physics requirement for → Standalone simulation → Determines design for
Standalone simulation → Simulation in Muon collider framework, Calorimeter cell prototype development
Sets performance for

Why MPGDs for a hadronic calorimeter?

Resistive MPGDs

Micro-pattern **gaseous detectors** as **readout layers** for a sampling **HCAL**

- Cost effectiveness
- **Several C/cm^2** radiation hardness
- **Discharge rate** not impeding operations
- O (**MHz/cm^2**) rate capability
- O (**100 μm**) space resolution
- **Few ns** timing with MIPs

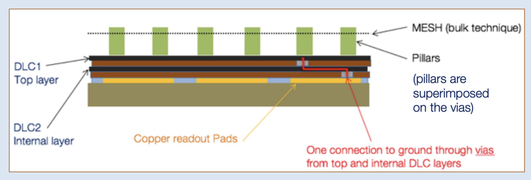
Development of an HCAL cell prototype

12 sampling layer prototypes produced and tested in **RD51 common project**:

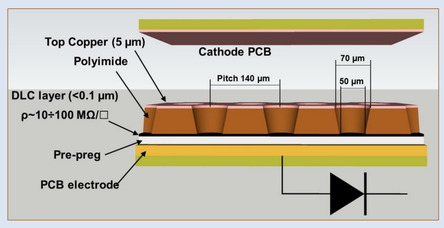
7 μ-RWELL, 4 MicroMegas, 1 RPWELL ← **Common readout** for all three technologies

- Active area **20×20 cm^2**, pad size **1×1 cm^2**
- **Drift gap 6 mm**

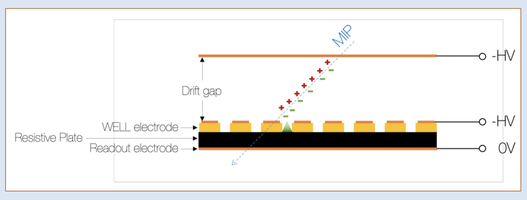
Micromegas



μRWELL

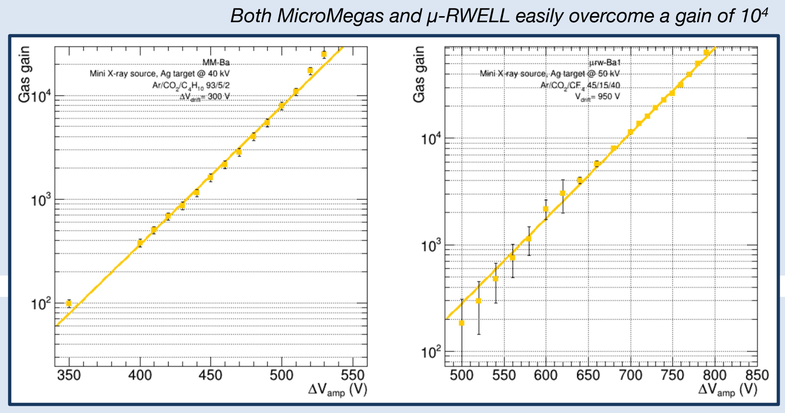


RPWELL

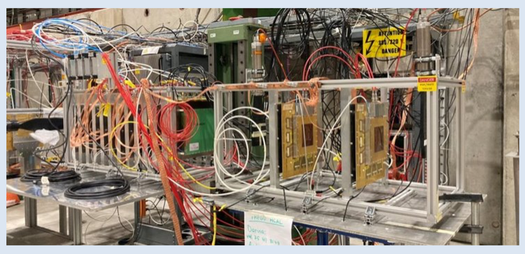


Comparable laboratory performance for all three technologies

Both MicroMegas and μ-RWELL easily overcome a gain of 10^4



MPGD performance at CERN SPS

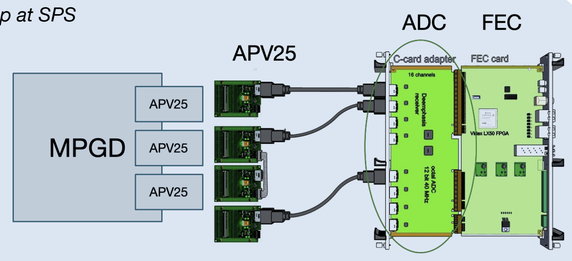


Test beam setup at SPS

Test beam at SPS (July 2023)

Goal: **validating** the readout detectors **with MIPs** and **comparing** the three MPGD technologies

- **Efficiency** higher than 95% throughout all active area
- **Space resolution** smaller than pad size

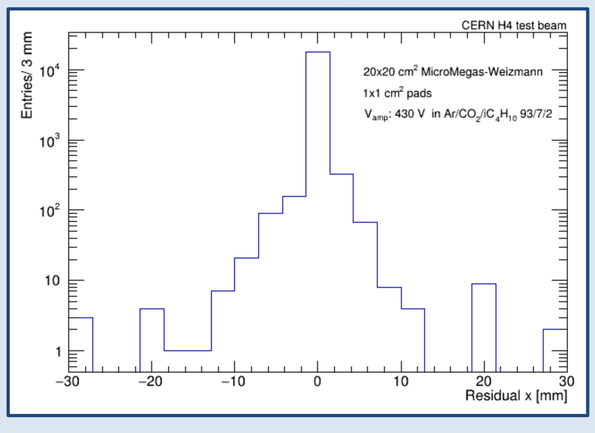


SRS for the test beam setup

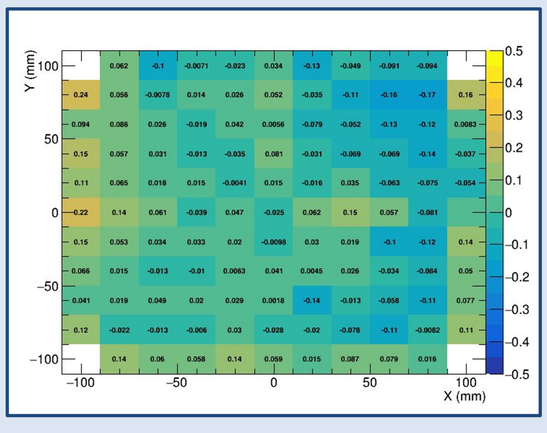
Tracking	MicroMegas (256 μm-strip)
Under test	12 MPGD prototypes
Gas	**Ar:CO_2:C_4H_{10}** 93:5:2 (MicroMegas, RPWELL) **Ar:CO_2:CF_4** 45:15:40 (μ-RWELL)
Particle	80 GeV/c muons
Electronics	APV25 front-end (analog readout + timing) SRS back-end

Detector	Uniformity (%)
MM-RM3	$(12.3 \pm 0.8)\%$
MM-Na	$(11.6 \pm 0.8)\%$
MM-Ba	$(8.0 \pm 0.5)\%$
RPWELL	$(22.6 \pm 4.7)\%$
μrw-Na	$(11.3 \pm 1.0)\%$
μrw-Fr2	$(16.2 \pm 1.7)\%$
μrw-Fr1	$(16.3 \pm 1.1)\%$

MicroMegas residual distribution

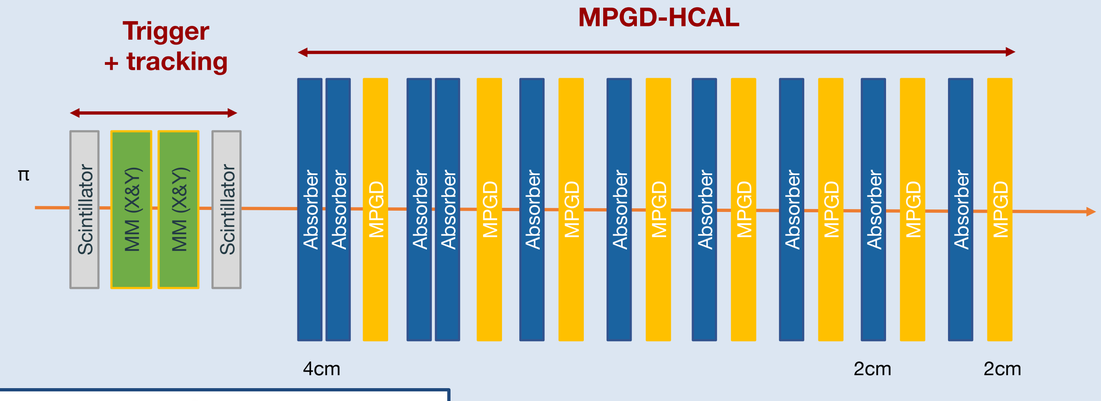


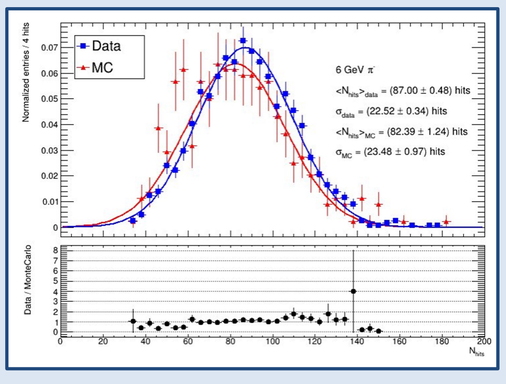
MicroMegas response uniformity



Good uniformity for **MicroMegas**; regions of non-uniformity observed on some **μ-RWELLs** → under investigation in lab

HCAL cell performance at CERN PS





Test beam data to simulation comparison for 6 GeV pion

Test beam at PS with calorimeter prototype (August-September 2023):

- Goal: **measuring** the energy resolution of a 1 λ calorimeter prototype with **1-10 GeV pions beam**
- Compared with **G4 simulation** for the **small prototype**, including problematic electronics effects

Very good data/MC agreement

antonello.pellecchia@cern.ch