MPGD-HCAL

L. Longo on behalf of Bari group

RD_MuCol Italia, Torino

4-6 Dec 2024

A MPGD Hadronic Calorimeter

Bari group proposal: a sampling hadronic calorimeter with micro-pattern gaseous detector as readout layers

MPGD features:

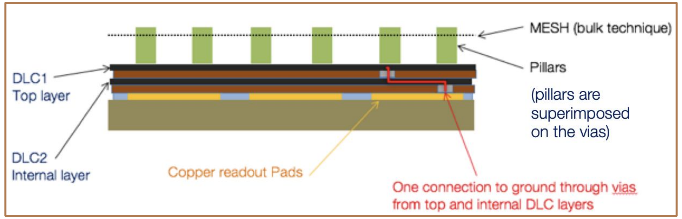
- **cost-effectiveness** for large area instrumentation
- radiation hardness up to several **C/cm^2**
- **discharge rate** not impeding operations
- rate capability O(**MHz/cm^2**)
- high granularity
- time resolution of **few ns**

Past work:

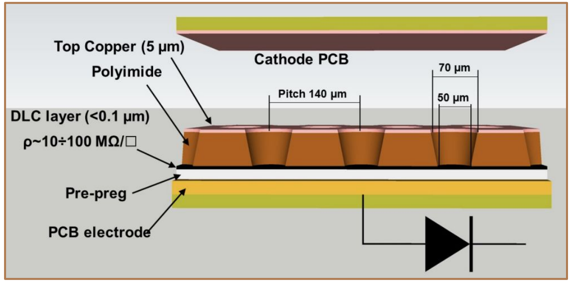
- CALICE collaboration: a sampling calorimeter using **gaseous detectors** (RPC) but also tested MicroMegas
- SCREAM collaboration: a sampling calorimeter combining RPWELL and resistive MicroMegas

Our plan → systematically **compare** three MPGD technologies for hadronic calorimetry: resistive MicroMegas, μRWELL and RPWELL, while also investigating **timing**

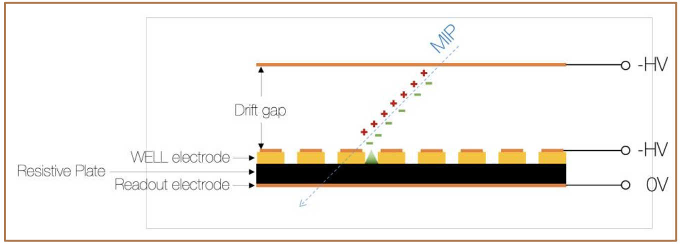
Micromegas (MM)



μRWELL



RPWELL



HCAL R&D well included in DRD1-WP5 (Calorimetry) and DRD6-WG1 (Sampling Calorimeter)

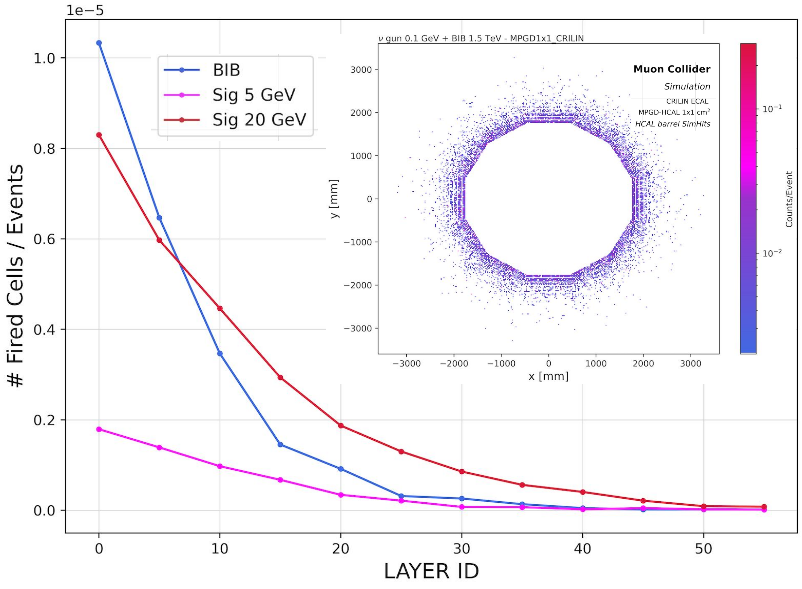
MPGD-HCAL BIB studies

Preliminary

Simulation: 60 layers of Iron (19mm) + Ar (3mm); 3 TeV layout

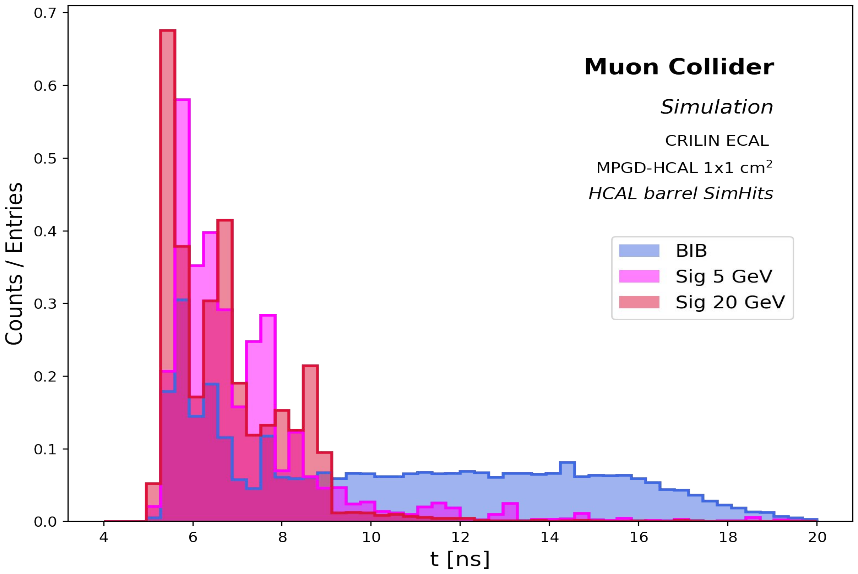
Hit Occupancy:

- **BIB** containment within the **first 20 layers** of HCAL
- Probability of a cell to be fired in the first layer :
  - **BIB** : ~ 1 x 10-5
  - **$\pi^{\pm}$ 5 GeV** : ~ 0.2 x 10-5
  - **$\pi^{\pm}$ 20 GeV** : ~ 0.8 x 10-5
- Challenge for low energy pion reconstruction

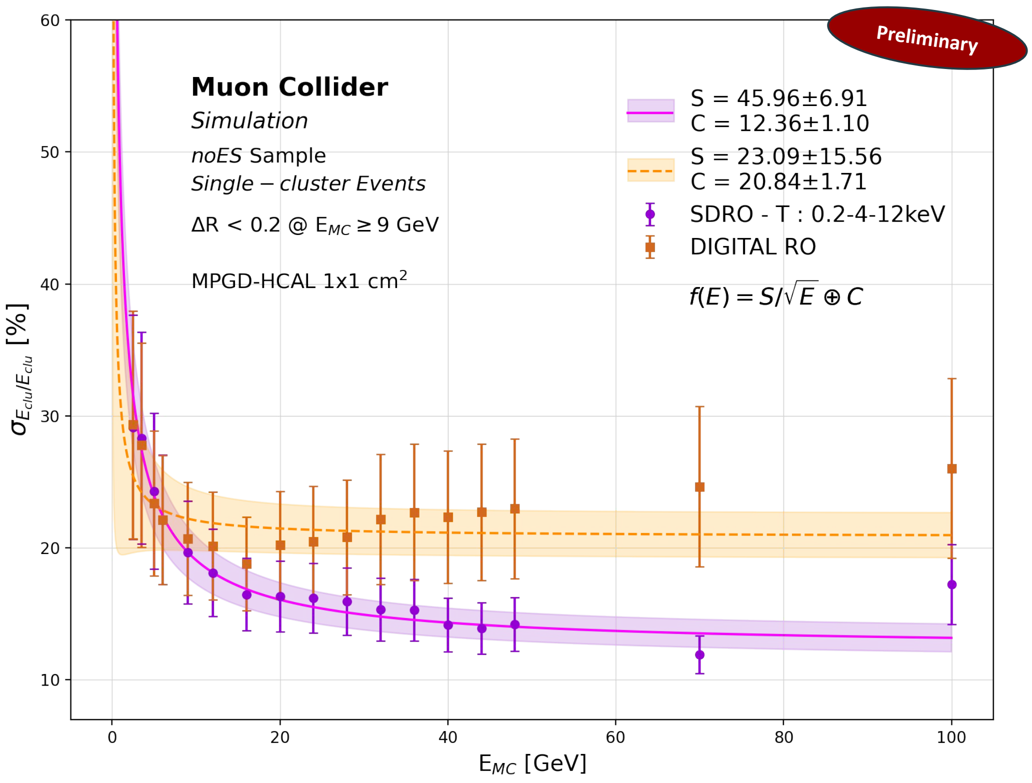


Arrival time:

- **BIB** arrival time distribution uniform in the **range 7-20 ns;**
- **signal** arrival time peaks at **~ 6ns**;
- discrimination possible for ***t>9/10 ns*** → **achievable with MPGD detectors**

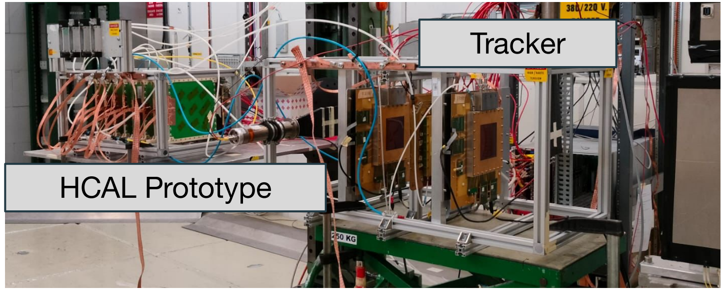


Full simulation: Digital Vs Semi-digital



- $\pi^{\pm}$ guns with energy ranging from 2.5 to 100 GeV;
- MPGD-HCAL with 1x1cm^2 pads
- **only pions not showering in ECAL**;
- reconstruction with Digital ReadOut (RO):
  - $E_\pi = f^{-1}(<Nhit>)$
- reconstruction with SemiDigital RO (SDRO)
  - $E_\pi = \alpha N_1 + \beta N_2 + \gamma N_3$
  - Thresholds considered for SDRO: 0.2, 4, 12 keV
- fit function $f(E) = S/\sqrt{E} \oplus C$;
- comparable performances below 6 GeV between Digital RO and SDRO
- **Digital RO: saturation at high energies**
- **Overall, better performances of the SDRO**
  - $\sigma/E = 45.96\%/\sqrt{E} \oplus 12.36\%$

MPGD-HCAL Test Beam



R&D effort in collaboration with INFN-RM3, INFN-Fr, INFN-Na, Weizmann and CERN

2 test beam campaigns in 2023 and 2024:

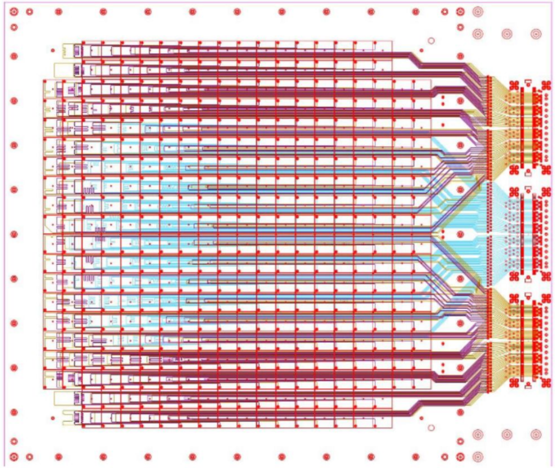
- **without absorbers** for detector characterization,
- **with absorber** for shower studies (~$1\lambda_I$).

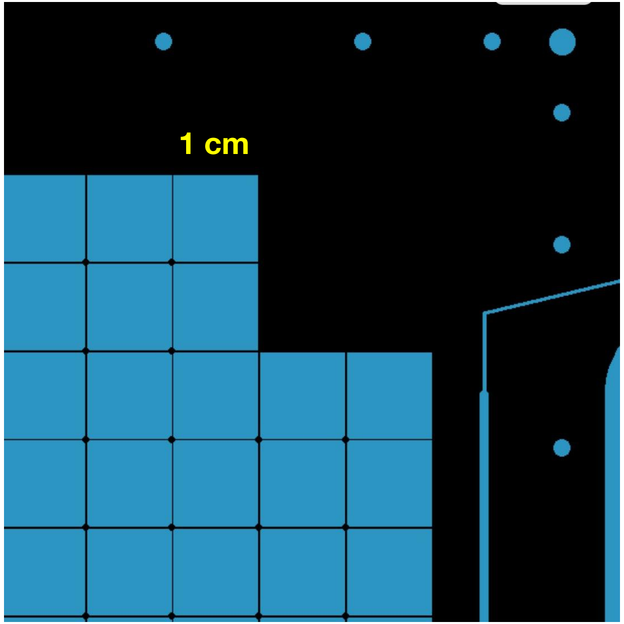
Prototypes produced and tested within **RD51 common project**:

- 7 μ-RWELL
- 4 MicroMegas
- 1 RPWELL

Detector design:

- Active area 20×20 cm^2
- Pad size 1×1 cm^2
- **Common readout** board





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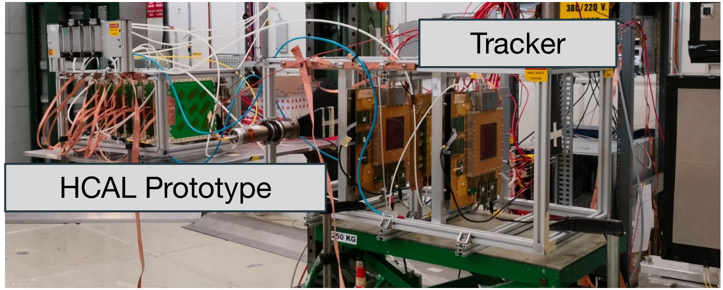
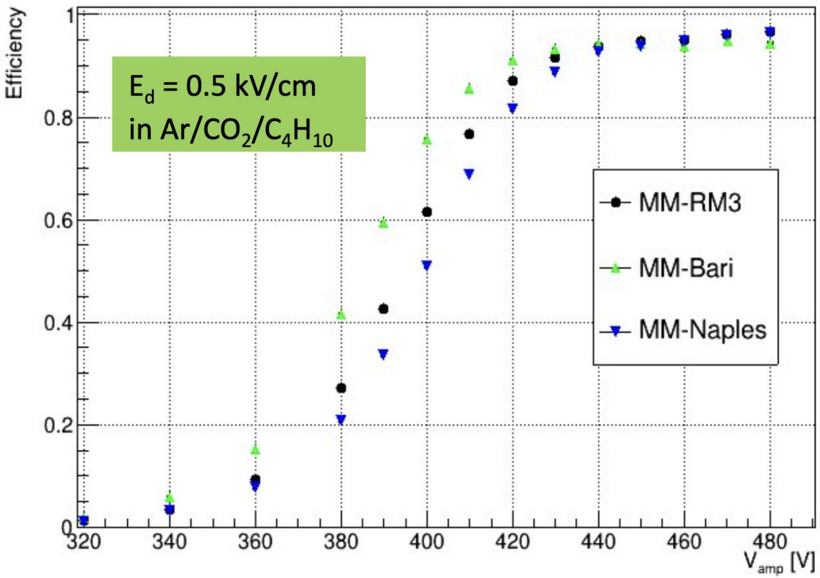
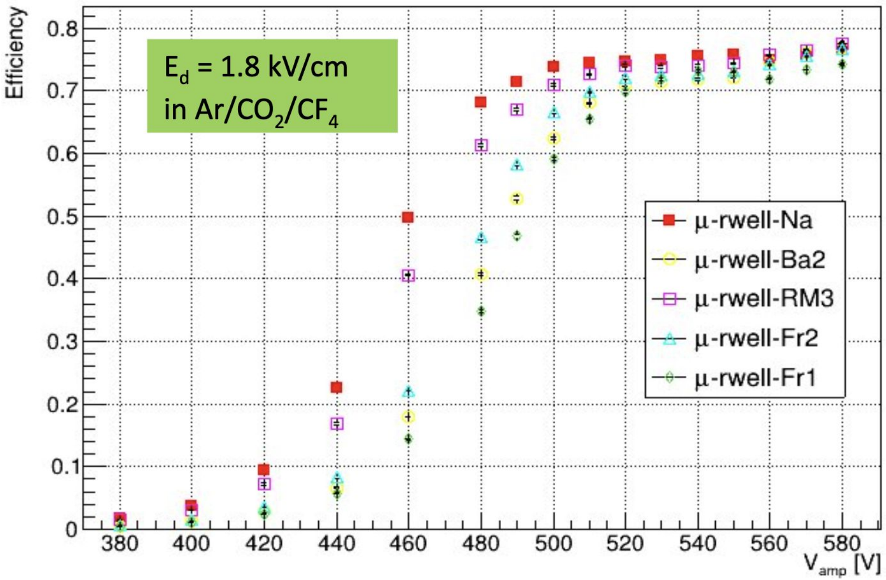


Micromegas efficiency



µRWELL efficiency



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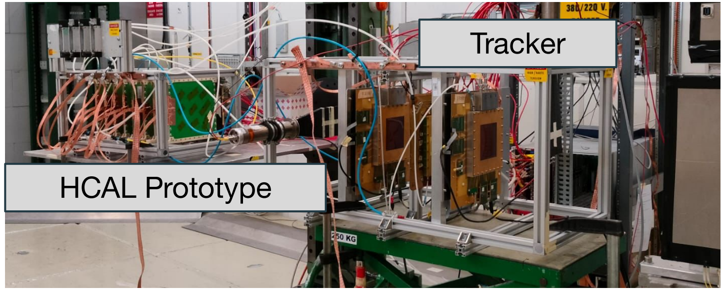

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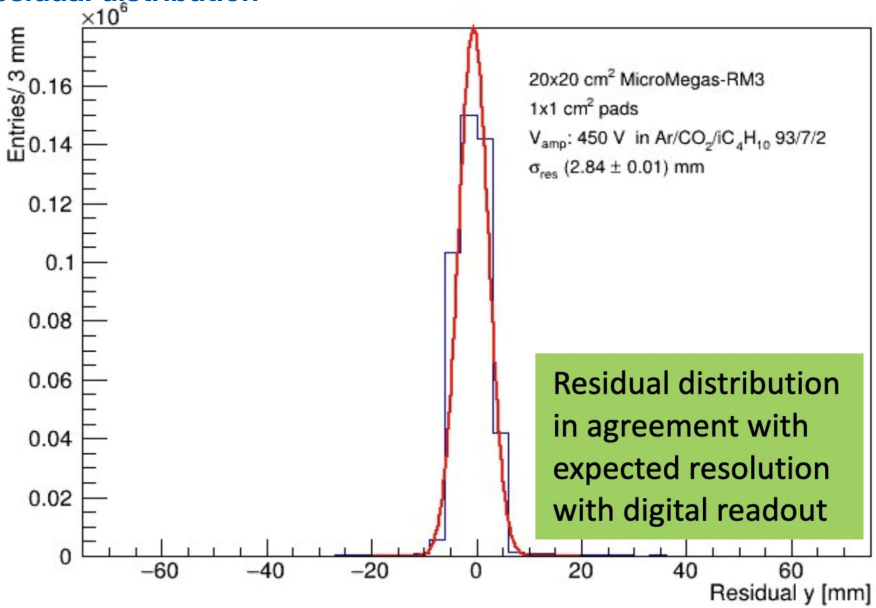
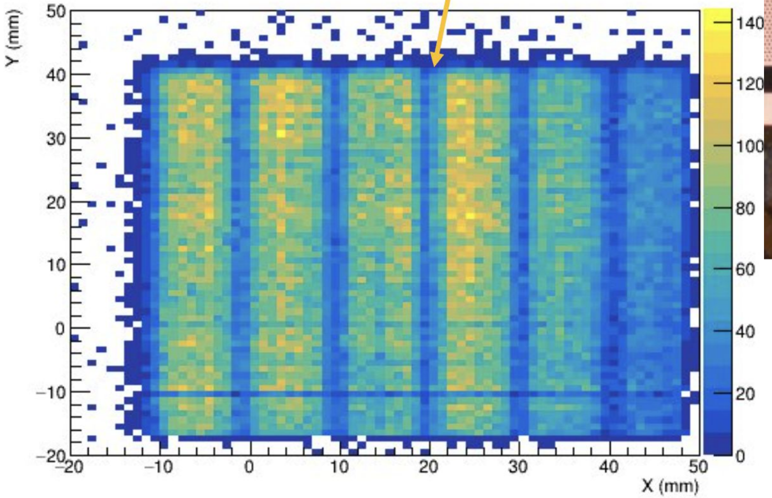
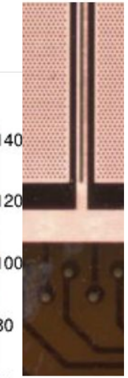
Residual distribution



µRWELL occupancy

Dead areas due to PEP lines in µrwell





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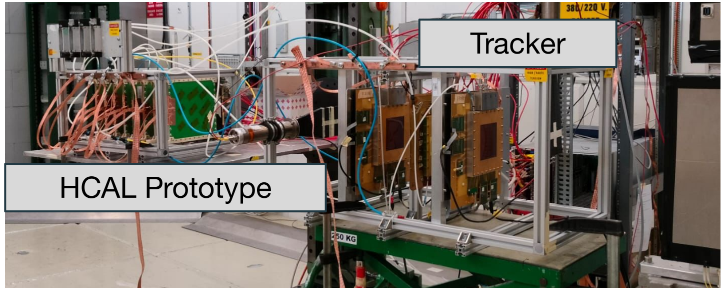

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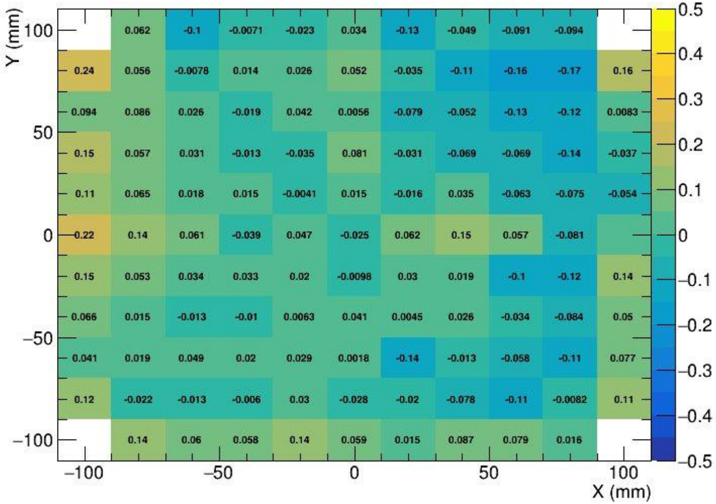
Response uniformity measured using clusters matching muon tracks

- Good uniformity for **MicroMegas** (~10%)
- Regions of non-uniformity observed on some **µ-RWELLs** → under investigation in lab
- Slightly worse uniformity for **RPWELL**

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 ± 1.0) %
μrw-Fr2	$(16.2 \pm 1.7)\%$
μrw-Fr1	$(16.3 \pm 1.1)\%$

2D-MPV variation for MicroMegas-Bari



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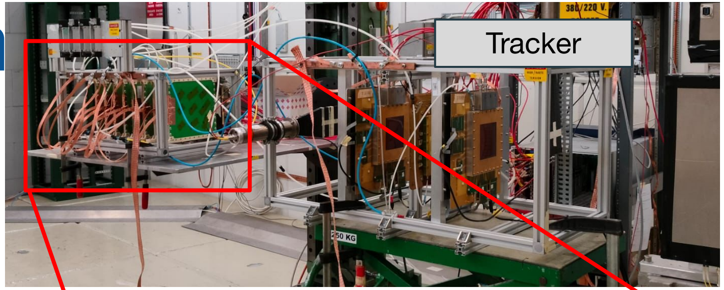
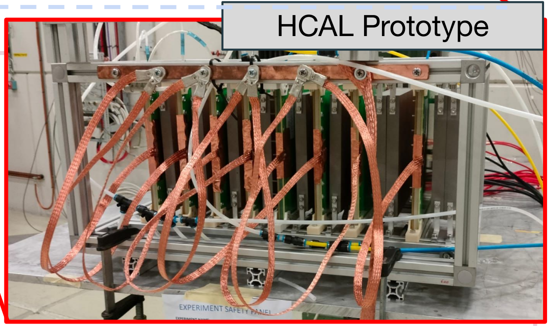


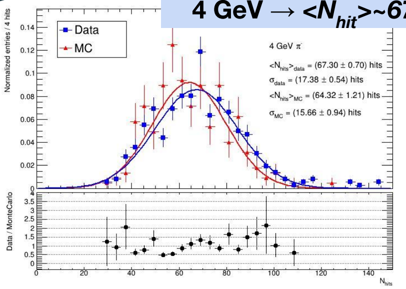


Number of hits distributions for MC and data at different pion energies ($E_\pi = f^{-1}(\langle N_{hit}\rangle)$)

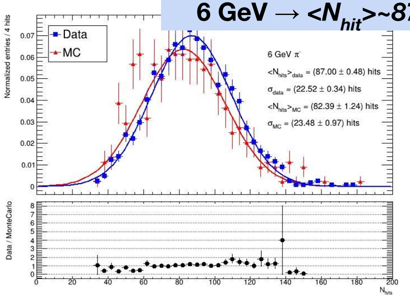
2023 Data

Preliminary

4 GeV → $\langle N_{hit}\rangle$~67



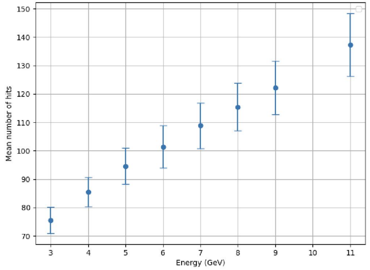
6 GeV → $\langle N_{hit}\rangle$~87

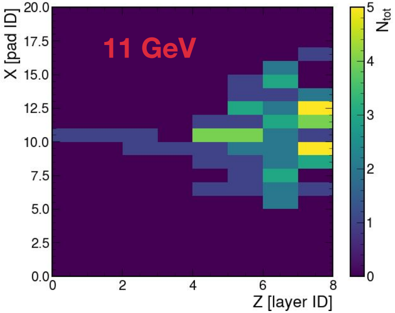


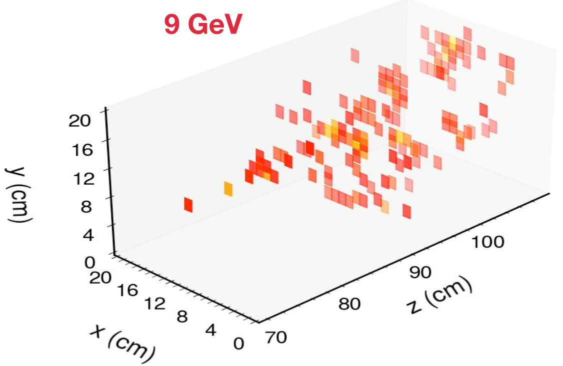
2024 Data

Preliminary

Response function: Total number of hits increases as a function of the energy



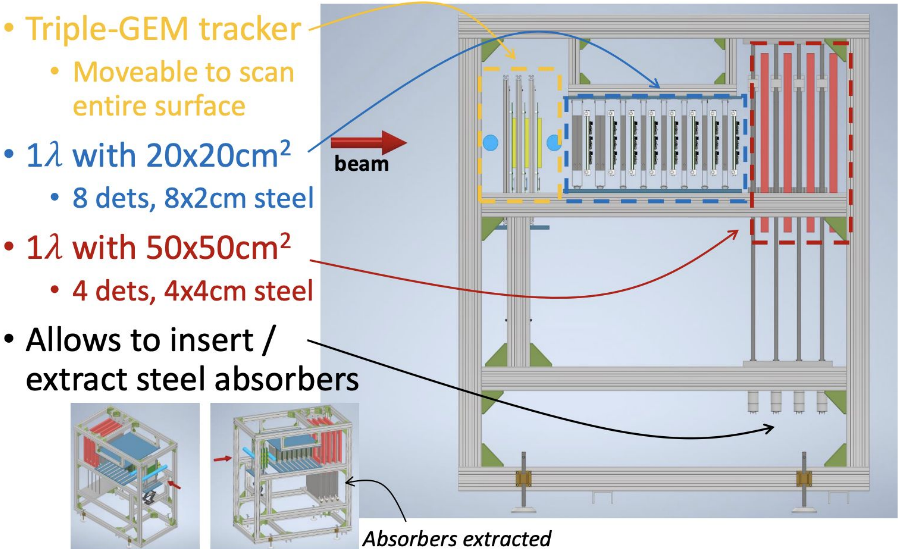


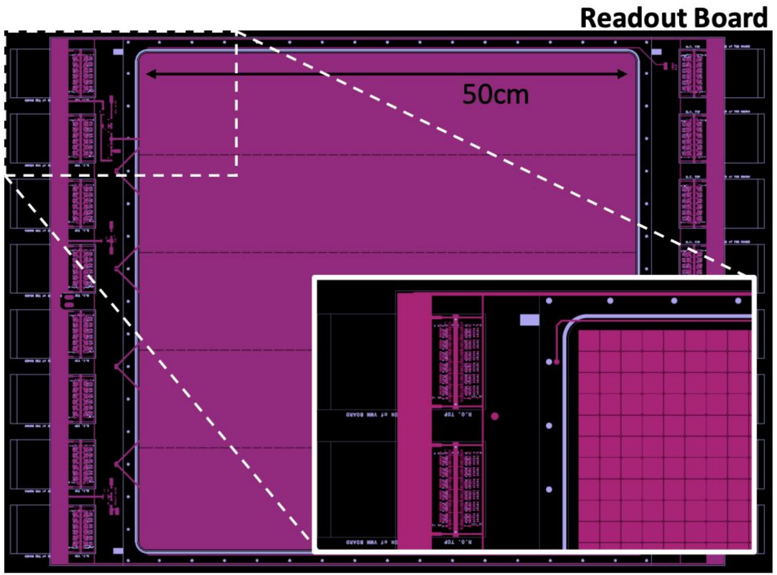


MPGD-HCAL future activities

- Finalize the studies with digital/semi-digital readout for the small prototype:
  - Current semi-digital threshold not optimize for MPGDs
- Development of a new cell prototype of ~$2\lambda_I$, including 8 20x20cm^2 chambers plus 4 50x50cm^2 chambers (2 Micromegas & 2 µRWELL, their production foreseen for beginning of next year):

New cell prototype





MPGD-HCAL future activities

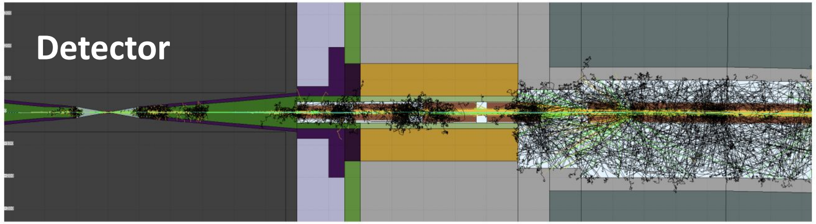
- **2025 plans:**
  - Profiting of DRD1 testbeams to perform 50x50cm2 chambers characterization during summer
  - Asked for PS testbeam slot for Fall 2025:
    - aiming for a combine testbeam with CRILIN (?);
    - if we will not receive any testbeam period for next year, we need to target 2026.
  - Both testbeams can be done next year only if we will receive the new chambers before spring, otherwise we will target only the september DRD1 testbeam
  - understand the best technology between Micromegas and µRWELL, balancing performances and large area production feasibility & cost:
    - µrweel response disunifomity could be a bottleneck for mass production?

- **Electronics:**
  - so far data collected with APV hybrids; too old, not able to sustain high rate and not supported;
  - preliminary tests with VMM hybrids (ATLAS chip) show good results compatible with what observed with APVs;
  - Interest in FAst TIming Integrated Circuit (FATIC) chip developed by our BARI electronics team.

- **Long term plan (>>2026):**
  - development of 50x100cm^2 MPGD detectors with and without embedded electronics;
  - starting thinking about cooling.

Backup

Beam-Induced Background



The **BIB** comes mainly from **photons** (96%) and **neutrons** (4%):

- BIB decreases increasing the distance from the beam axis;
- average deposited energy lower than 1 GeV.

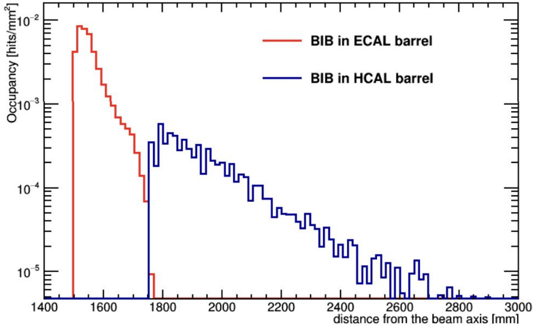


Fig. 25 BIB hit occupancy in the calorimenter barrel region in a single bunch-crossing.

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

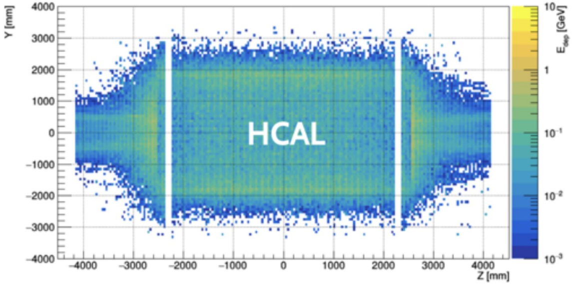


Fig. 28 Energy deposited by the BIB in a single bunch-crossing in the HCAL.

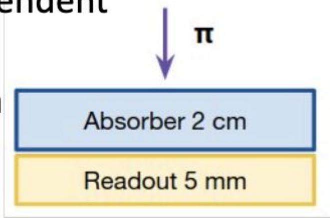
Advanced assessment of beam-induced background at a muon collider [2021 JINST 15 P11009]

G4 simulation: Digital Vs Semi-digital

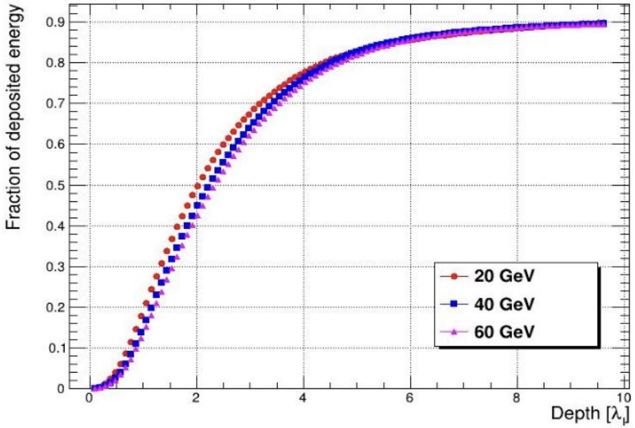
Standalone Geant4 simulation technology-independent

- Geometry of single layer:
  - 2 cm of iron for absorbers
  - 5 mm gas (Ar/CO_2)

  } $\lambda \sim 26$ cm
- Readout granularity 1x1 cm^2

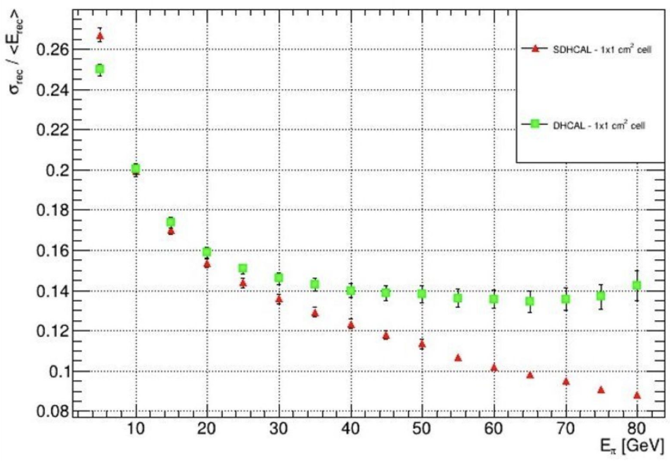


Result: longitudinal containment in 10 λ, transversal in 3 λ



Energy resolution simulated in two scenarios:

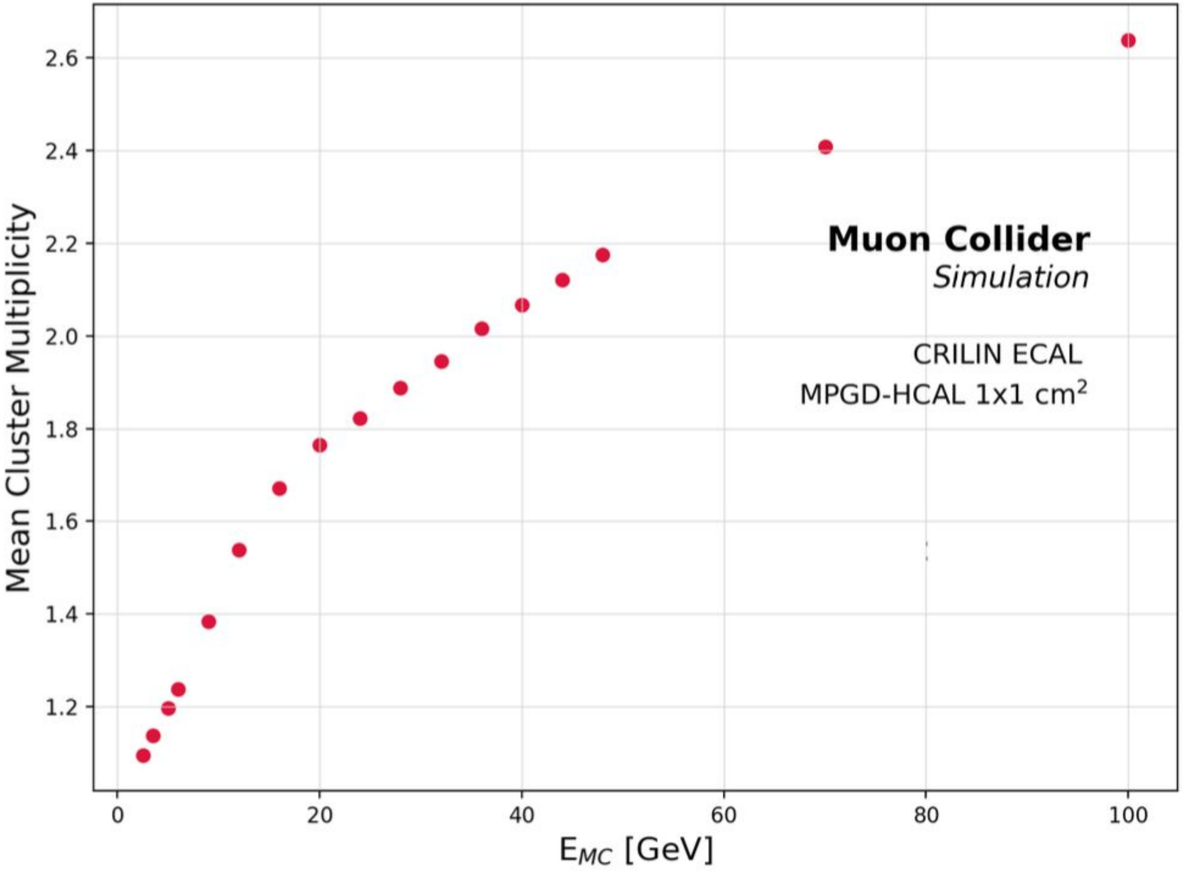
- **Digital** calorimeter: shower energy proportional to total number of hits
- **Semi-digital** calorimeter: hits are weighted based on three thresholds $E_\pi = \alpha N_1 + \beta N_2 + \gamma N_3$



Result:

- resolution at 8% for $E_\pi \sim 80$ GeV with semi-digital readout
- resolution saturates at 14% for $E_\pi \sim 30$ GeV for digital readout

Full simulation: clusterization



PEP lines Vs PEP dots

2022

PEP-Groove:

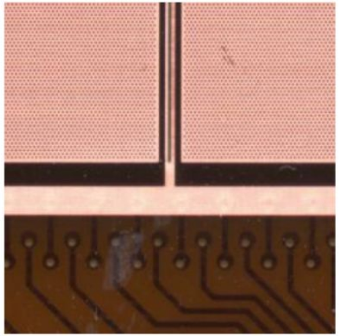
DLC grounding through conductive groove to ground line

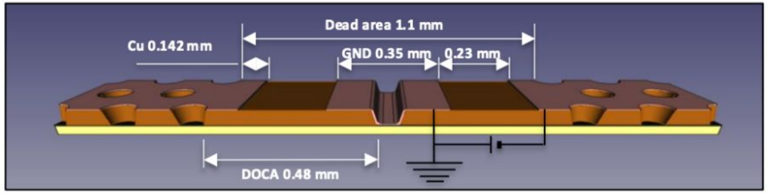
Pad R/O = 9×9mm^2

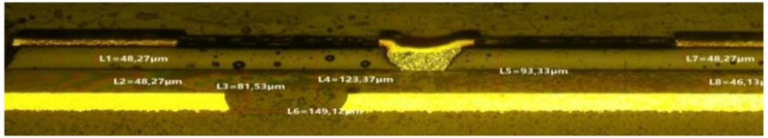
Grounding:

- Groove pitch = 9mm
- width = 1.1mm

→ 84% geometric acceptance







2023

PEP-DOT:

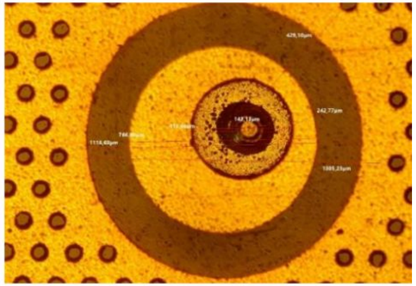
DLC grounding through conductive dots connecting the DLC with pad r/outs

Pad R/O = 9×9mm^2

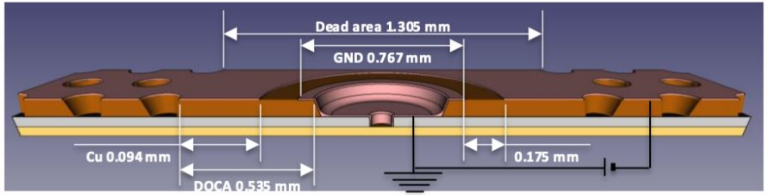
Grounding:

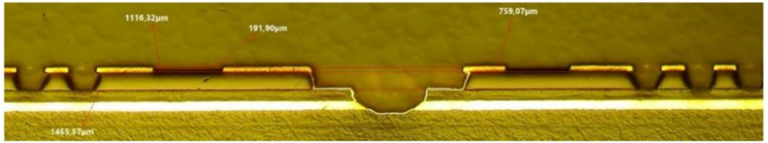
- Dot pitch = 9mm
- dot rim = 1.3mm

→ 97% geometric acceptance



DOT → plated blind vias





https://indico.cern.ch/event/1413681/contributions/6013367/attachments/2881828/5049134/The%20micro-RWELL%20for%20high-rate.pdf

Response uniformity

Preliminary