MPGD-HCAL: Micro Pattern Gaseous Detectors for an hadronic calorimeter

L. Longo on behalf of CERN, INFN Sezione di Bari, INFN Frascati, INFN Sezione di Napoli, INFN Sezione di RM3, Weizmann Institute of Science

DRD6 Collaboration meeting

Apr 9th - 11th, 2024

HCAL readout with MPGD

Proposal: micro-pattern gaseous detectors as readout layers for a sampling hadronic calorimeter

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**

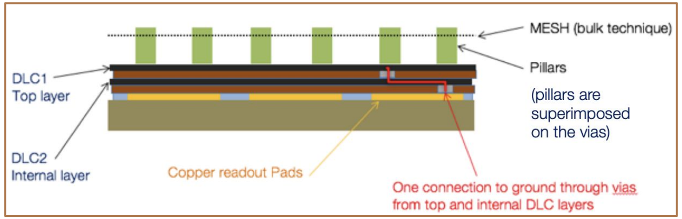
Resistive MPGDs

Past work:

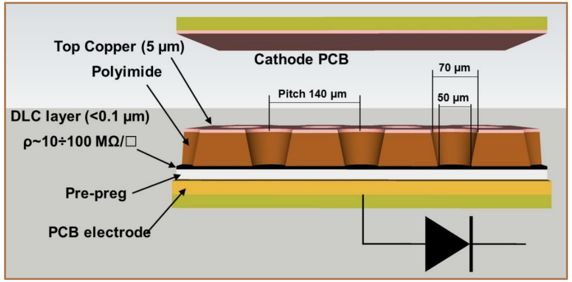
- CALICE collaboration: a sampling calorimeter using **gaseous detectors** (RPC) but also tested MicroMegas
- SCREAM collaboration: a sampling calorimeter combining RPWELL and resistive MicroMegas

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

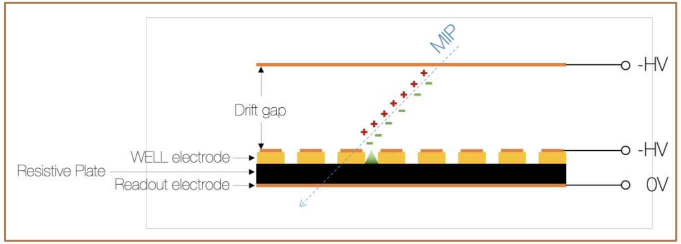
Micromegas (MM)



µRWELL



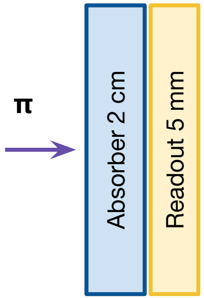
RPWELL

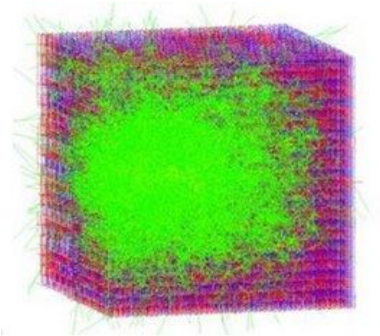


Simulation studies

Simulation: shower containment studies

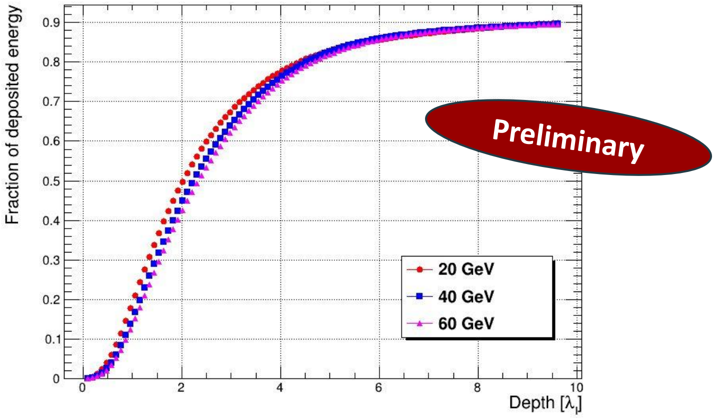
Geant4 simulation of a 100 layers calorimeter



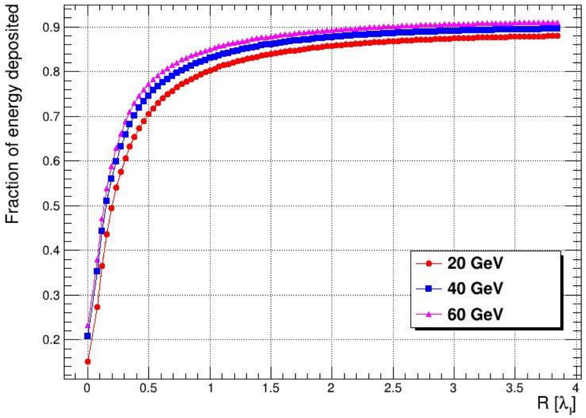


- Geometry: 2 cm iron, 5 mm gas (Ar/CO_2)
- Readout granularity → cell size of
  - 1×1 cm^2
  - 3×3 cm^2
- Pion guns of different energies
- **Result:** longitudinal containment in ~10 λ_I, transversal in ~2 λ_I

Longitudinal shower containment



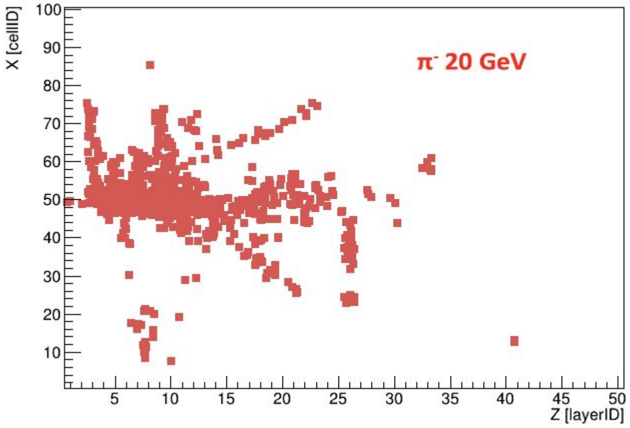
Transversal shower containment



Simulation: Digital and Semi-digital HCAL

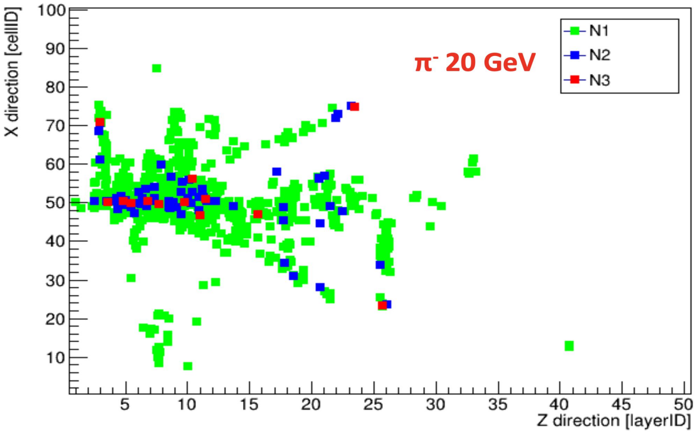
Digital Readout

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

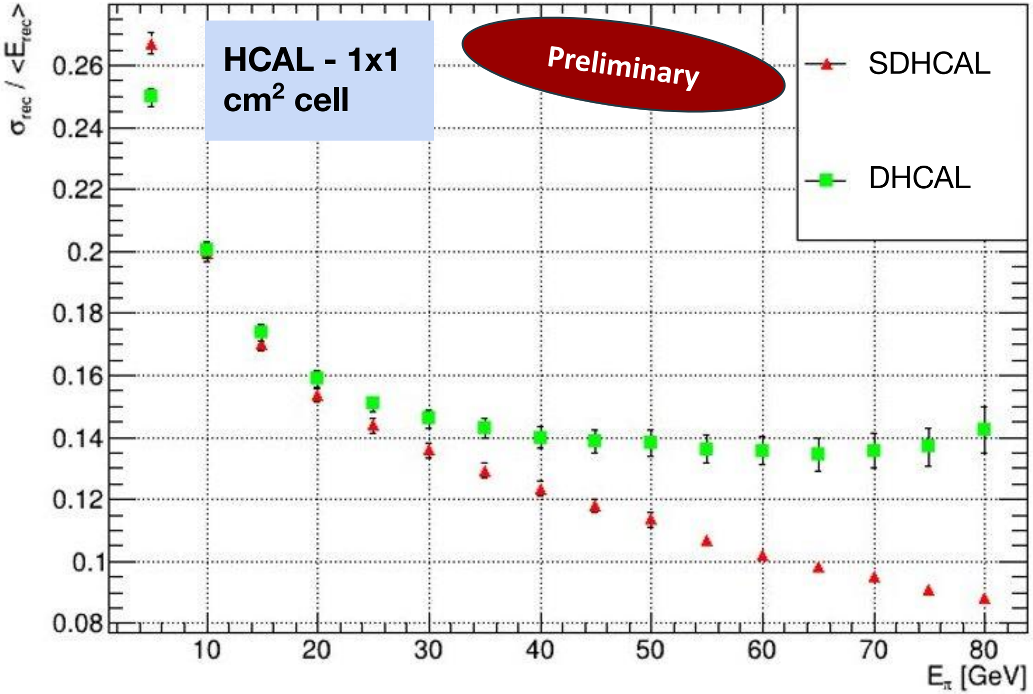


Semi-digital Readout

- **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



Simulation: Digital and Semi-digital HCAL



SDHCAL shows better resolution for E_π > 40 GeV

At E_π= 80 GeV, the resolution

- DHcal ~ 14%
- SDHcal ~ 8%

DHCAL suffers from **saturation effect** for E_π > 40 GeV

Comparable results for granularity of 1x1cm^2 (~9% at 80 GeV) and 3x3 cm^2 (~11% at 80 GeV)

Development of a hadronic calorimeter prototype

MPGD prototypes

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

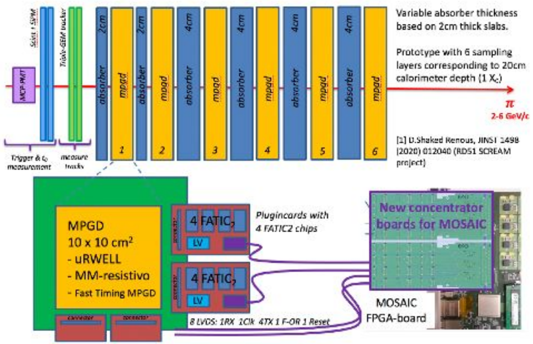
Prototype characterization performed in all the laboratories

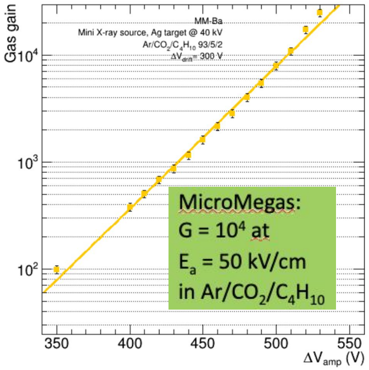
Development of Resistive MPGD Calorimeter with timing measurement (2021-2023)

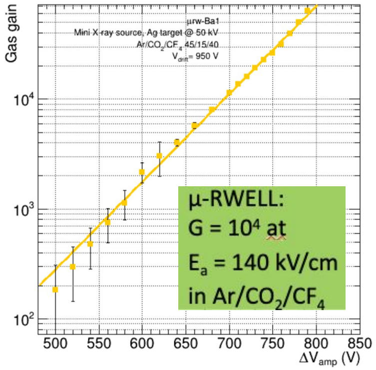
RD51 Institutes:
1. *INFN sez. Bari, contact person: piet.verwilligen@ba.infn.it*
2. *INFN sez. Roma III, contact person: mauro.iodice@roma3.infn.it*
3. *INFN LNF Frascati, contact person: giovanni.bencivenni@lnf.infn.it*
4. *INFN sez. Napoli, contact person: massimo.dellapietra@na.infn.it*

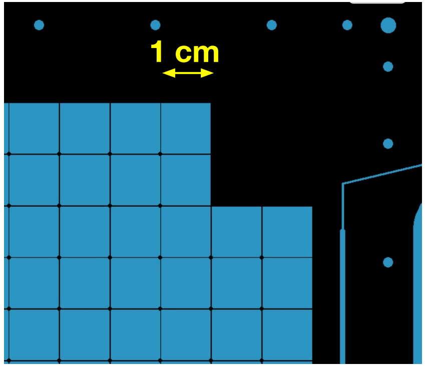
\+ Weizmann Institute of Science

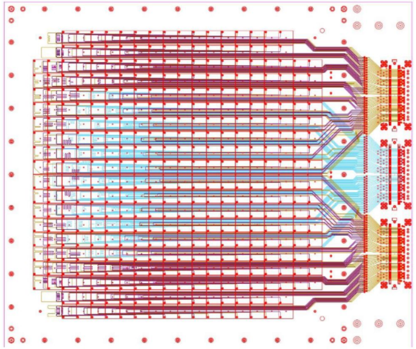
Design of MPGD-based HCAL cell



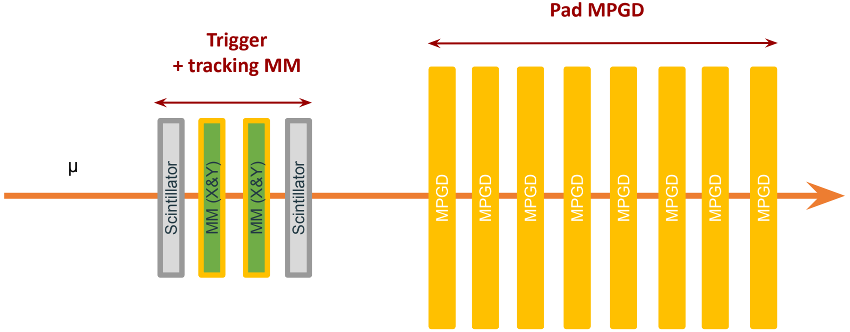




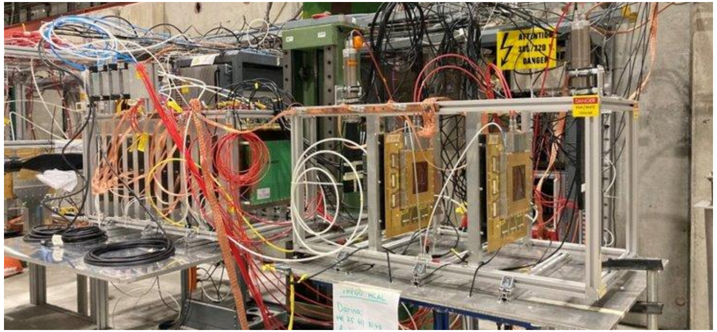




MPGD performance at SPS test beam



Test beam setup at SPS



Readout layers operated in **test beam at SPS** (July 2023):

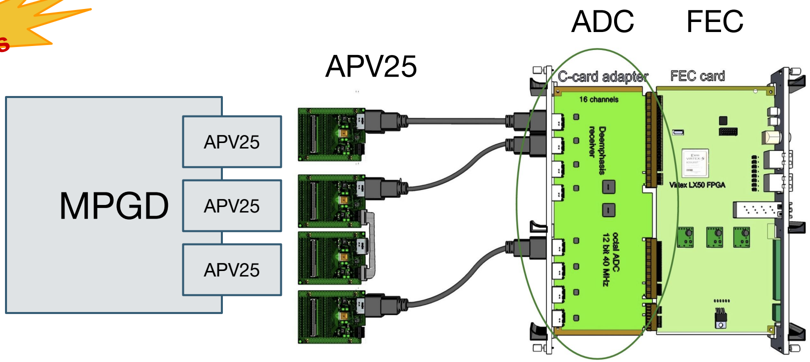
- Tracking: 2 MicroMegas (256 μm-strip)
- Under test: 12 MPGD prototypes

  Gas: **$Ar:CO_2:C_4H_{10}$** (MicroMegas & RPWELL),
  $Ar:CO_2:CF_4$ (μ-RWELL)
- Particle: O(100) GeV/c **muons**

No absorbers

Readout **electronics**:

- **APV25** front-end chip (analog readout + time information)
- **SRS** back-end



Readout electronics based on the APV25 SRS

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

Detector performance

Test beam **analysis workflow**:

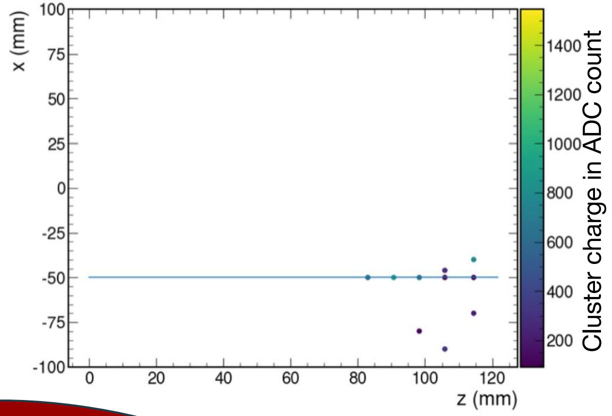
- **Tracking detectors unused** in reconstruction for the moment (high noise → possible to recover the tracker offline, currently ongoing). **Tracks built using MPGDs** under test (5 out of 6 at a time)

Track residuals:

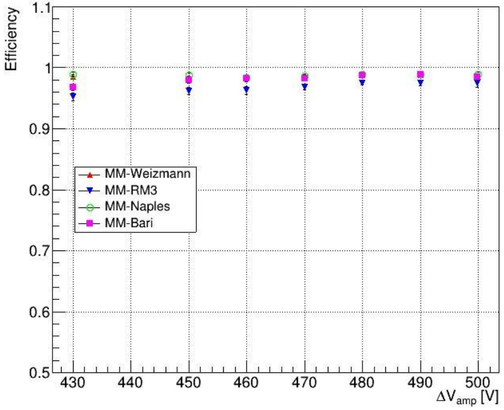
- Observed high probability of **cross-talk** between pads *due to routing of readout vias from pads to front-end*
- Patched **offline** by clustering pads based on charge sharing fraction

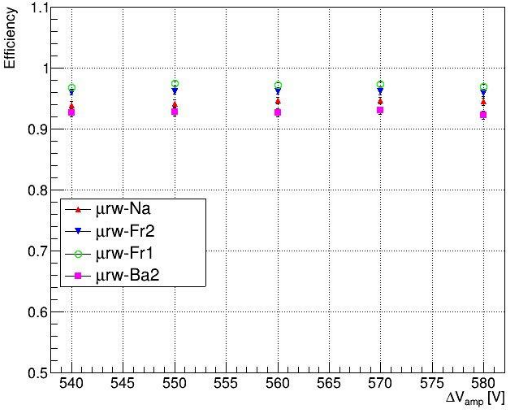
High average **efficiency** (detectors always operated at plateau)

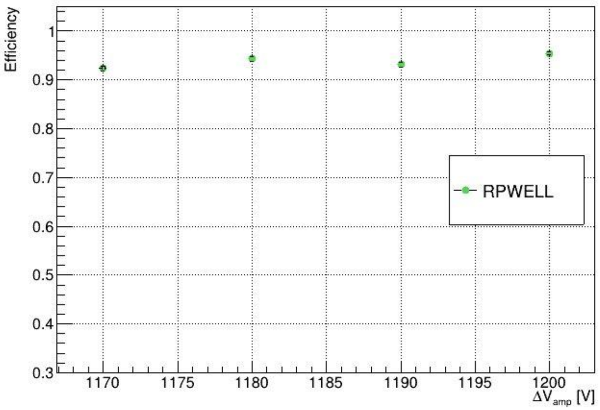
Track reconstructed using 4 detectors out of 5



Preliminary







Detector uniformity

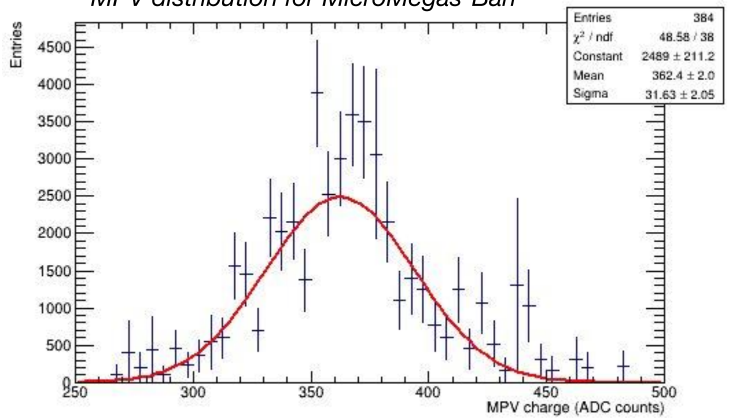
Preliminary

Response uniformity measured using clusters matching muon tracks

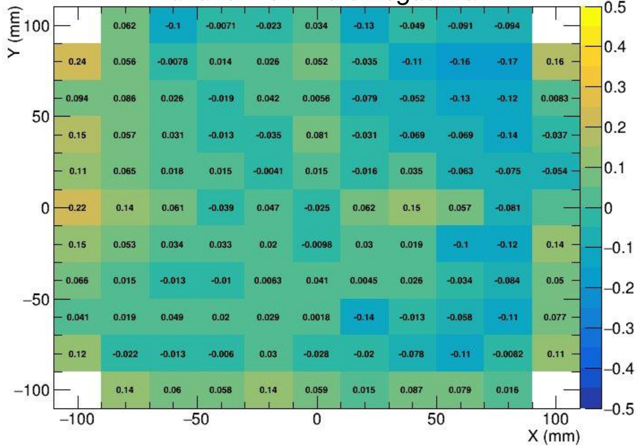
- Good uniformity for **MicroMegas** (~10%)
- Regions of non-uniformity observed on some **μ-RWELLs** → under investigation in lab
- Slightly worse uniformity for **RPWELL**

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	$(11.3 \pm 1.0)\%$
μrw-Fr2	$(16.2 \pm 1.7)\%$
μrw-Fr1	$(16.3 \pm 1.1)\%$

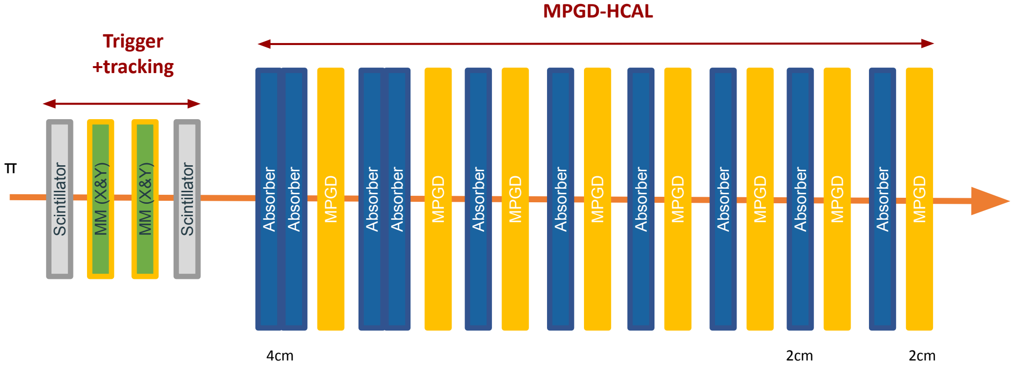
MPV distribution for MicroMegas-Bari

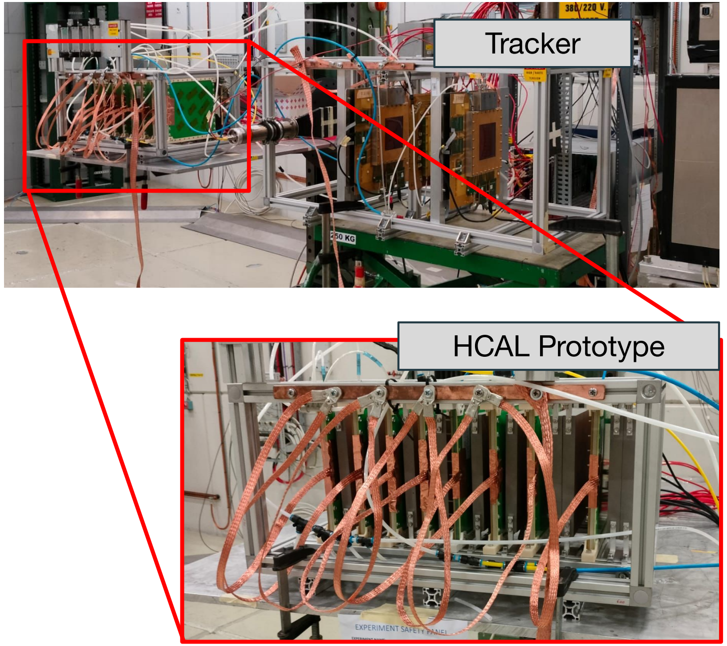


2D-MPV variation for MicroMegas-Bari



Calorimeter prototype at PS test beam





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

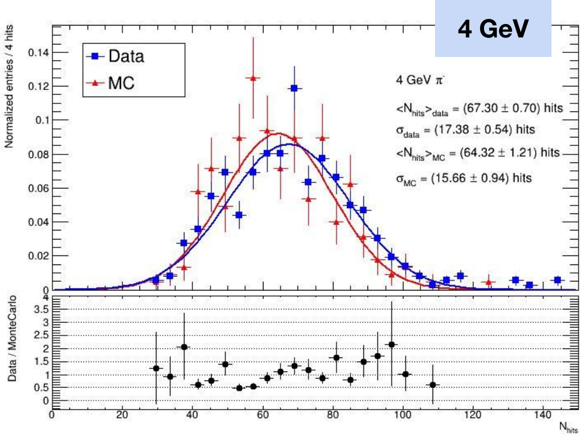
- Goal: **measuring** the energy resolution of a 1 λ calorimeter prototype with 1-10 GeV pions beam
- Developed **G4 simulation** for the **small prototype**, including a **digitization algorithm** to account for charge-sharing among adjacent pads and detector efficiency
- **Issue:** problematic electronics for the first 2 MPGD layers → taken into account for data/MC comparison

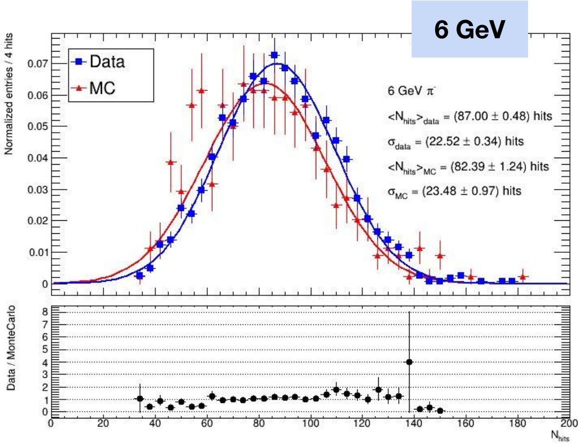
Calorimeter prototype at PS test beam

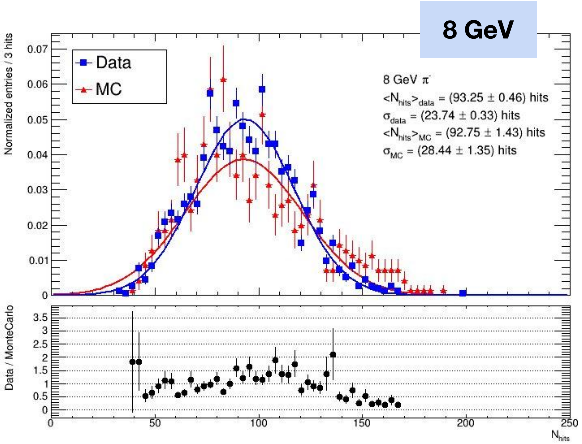
Event selection: events where pions start showering from the third layer

Preliminary

Number of hits distributions for MC and data at different pion energies







- **Good data/MC comparison**
- Ongoing studies to fully exploit all the data collected

Conclusion and next steps

Development of MPGD-HCAL ongoing in **simulations** and **hardware**

- Tested 12 MPGDs and small cell calorimeter within RD51 **common project**

Plans for 2024-2025

- Consolidating results with present prototypes in two test beams in 2024:
  - SPS: full efficiency Vs HV curve, response uniformity
  - PS: test of a fully equipped 8 MPGD layers prototype
- 4 **large detectors** (50×50 cm^2) to be built in 2024:
  - Design **optimization** to exclude cross-talk and simplify manufacturing
- Ongoing work on designing a mechanical structure hosting 8 MPGD layers 20x20cm^2 plus 4 50x50cm^2 MPGD layers

Long term plans: construction of 4 1x1m2 layers, 2 of them with embedded electronics

Bottlenecks:

- the ongoing activity uses APV25 electronics →low rate, not supported: new electronics is needed
- Under evaluation possible to use different electronics for the detector R&D phase as VMM3a or FATIC3:
  - Both are analog electronics and a step forward to digital embedded electronics is due
- R&D on electronics is expensive and need a lot of support non only on the chip but also on backend, firmware,...

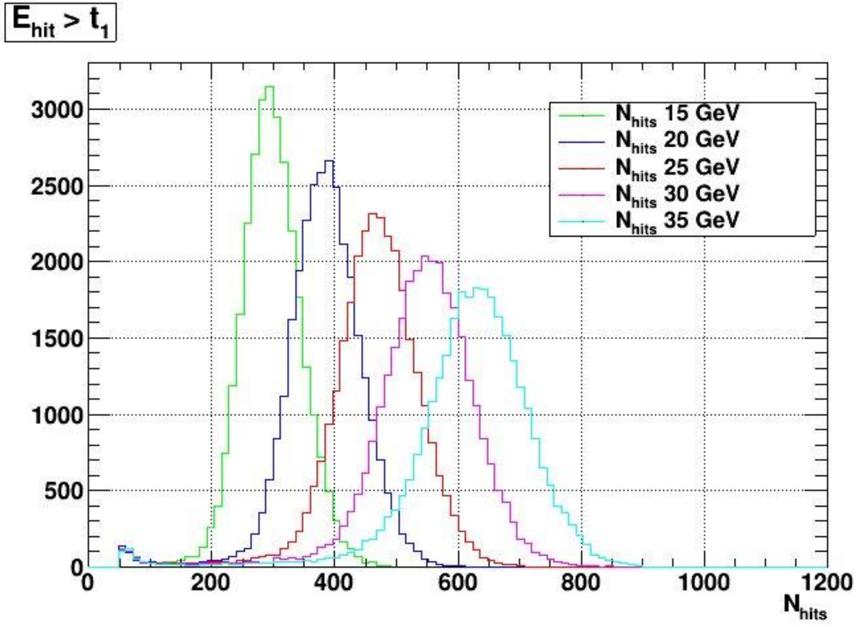
Backup

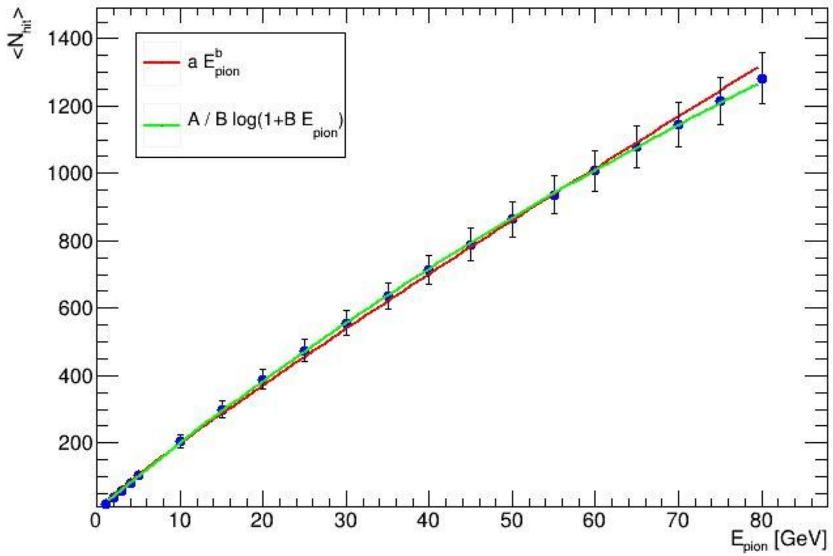
Simulation: Digital readout

Preliminary

- **Digitization:** 1 hit --> 1 cell with energy deposit higher than the applied threshold

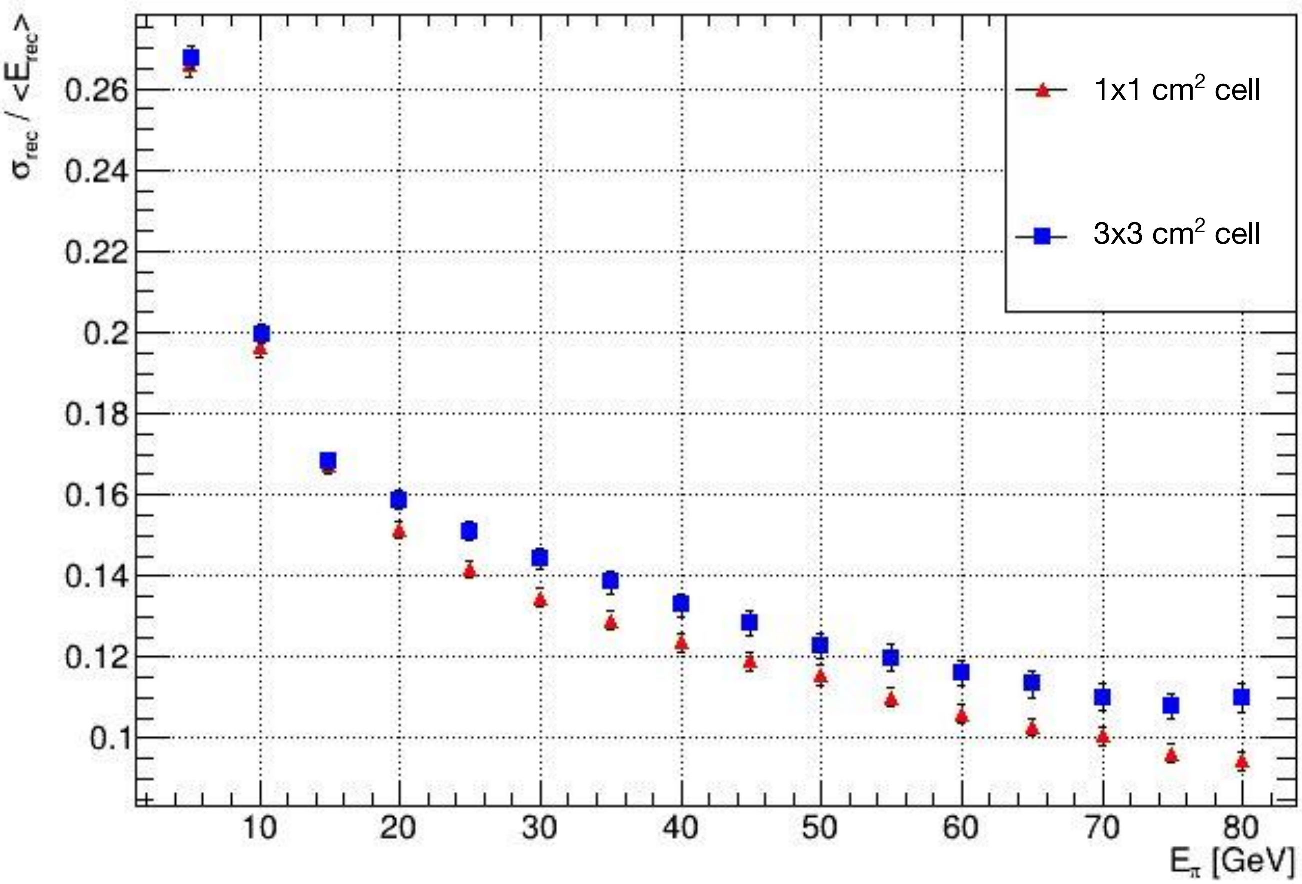
- **Calorimeter response function:** $<N_{hit}>=f(E_\pi)$
- **Reconstructed energy:** $E_\pi=f^{-1}(<N_{hit}>)$





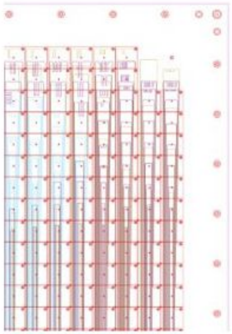
Simulation: Semi-Digital readout

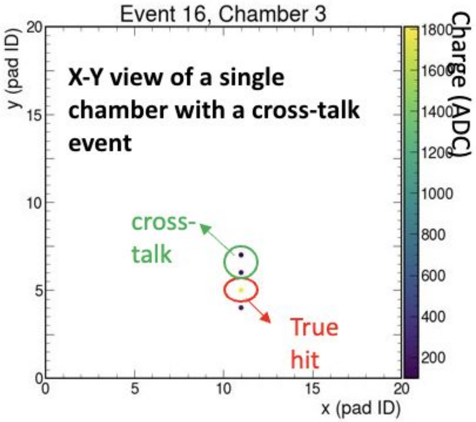
Preliminary



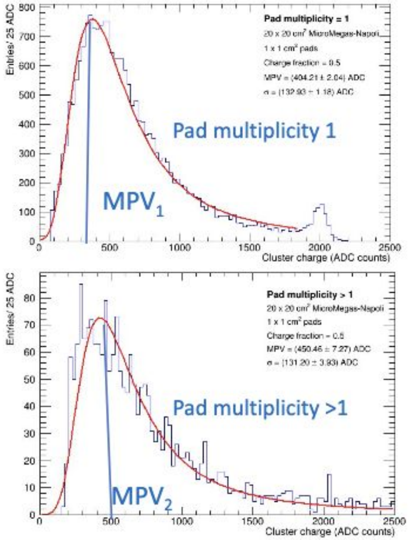
Cluster reconstruction

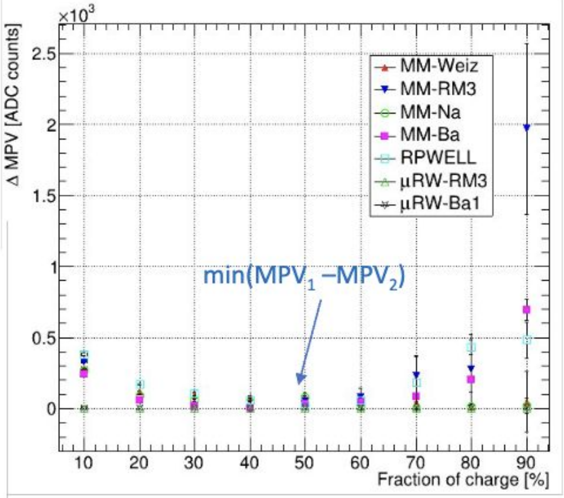
Preliminary





High probability of **cross-talk** effect observed among adjacent pads due to routing of the vias connecting pads to the connectors



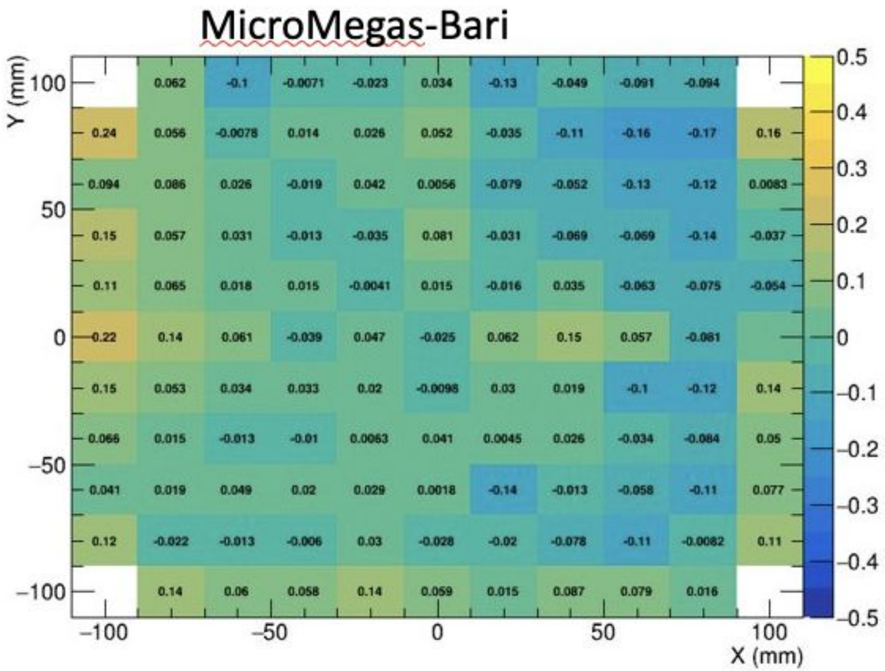


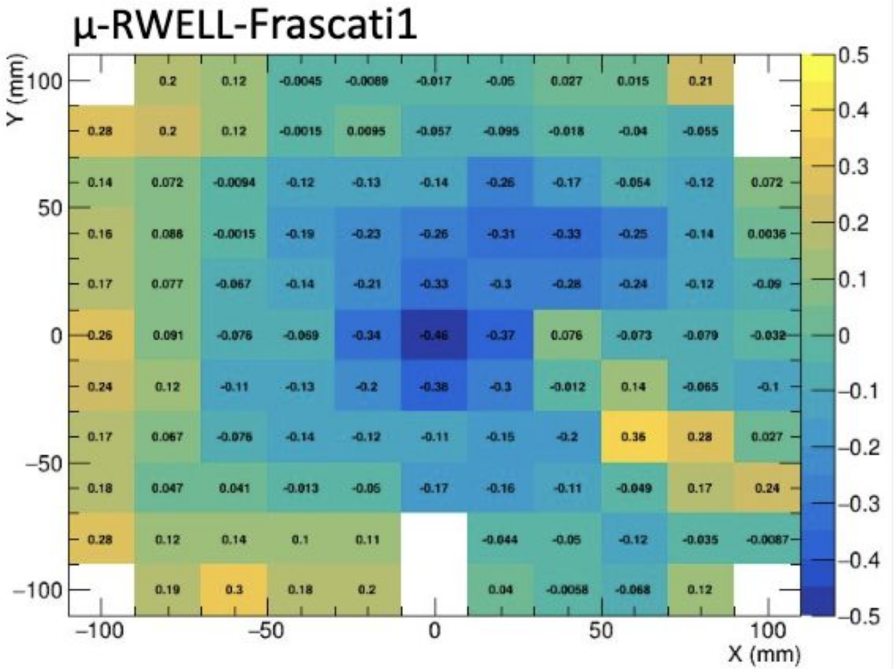
Developed ad-hoc **clustering algorithm** based on charge sharing criterium

- Selected pad with **highest charge** Q_{max}
- Add a second pad if $Q = 50\% \, Q_{max}$

Response uniformity

Preliminary



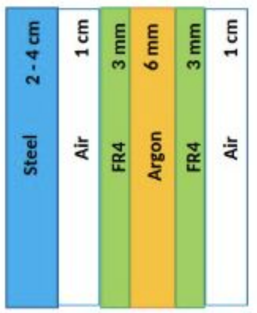


G4 simulation: small prototype

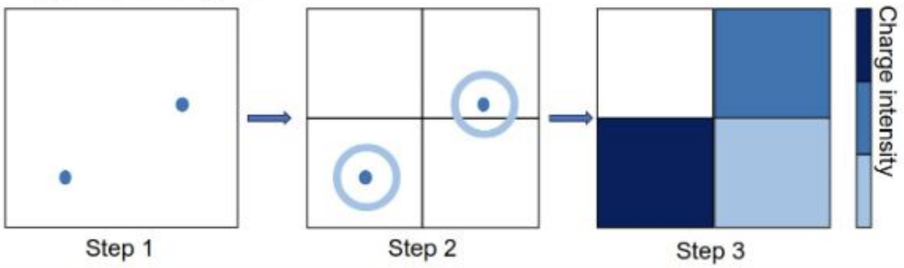
Preliminary

- Small detector geometry implemented
  - 8 layers of alternating of 2 cm stain-less steel absorbers and MPGD
    - First 2 layers with 4 cm absorbers to increase probability of shower development in the first layers
  - 20x20 cm^2 active surface
  - 1x1 cm^2 pad granularity
- Pion gun of energy range available at PS (4 – 8 GeV)

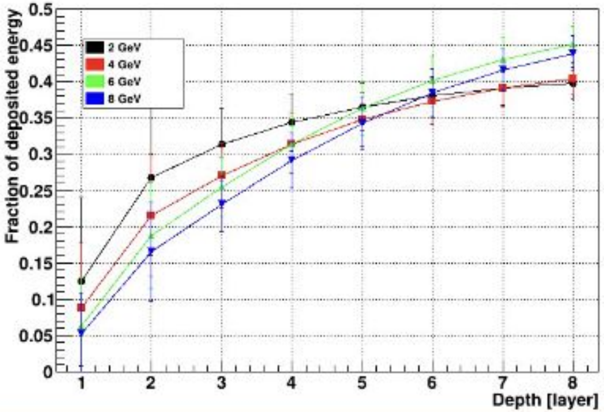
- **Digitization algorithm** implemented to account for charge-sharing among adjacent pads and detector efficiency



Digitization algorithm



Shower containment



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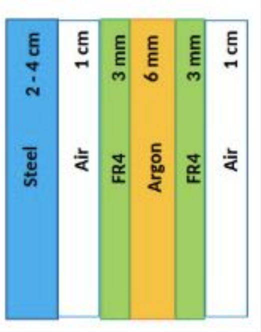
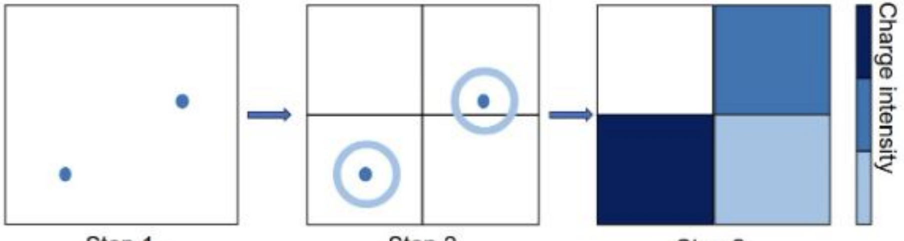
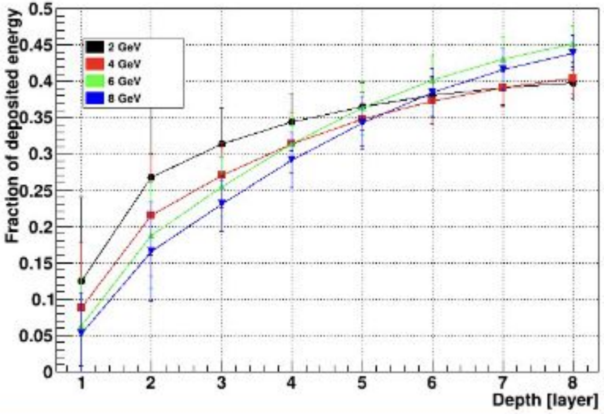


- **Digitization algorithm** implemented to account for charge-sharing among adjacent pads and detector efficiency

Digitization algorithm



Shower containment



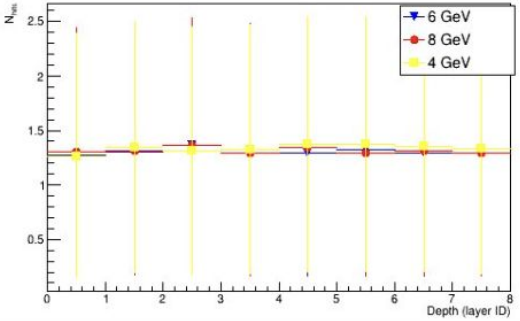
PS data / G4Sim prototype - event selection

Preliminary

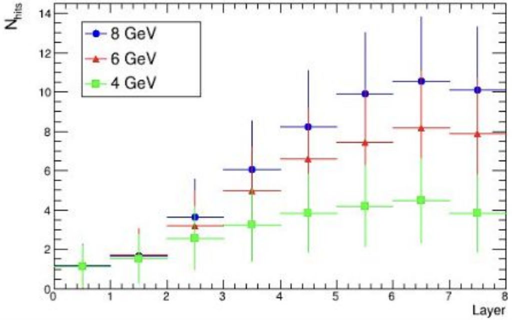
Event **selection criteria** supported by **simulation** using MC truth

- MIP-like events:
  - single hit in each layer
- Shower events:
  - more than 4 hits per layer starting from layer 3

MIP-like events - simulation

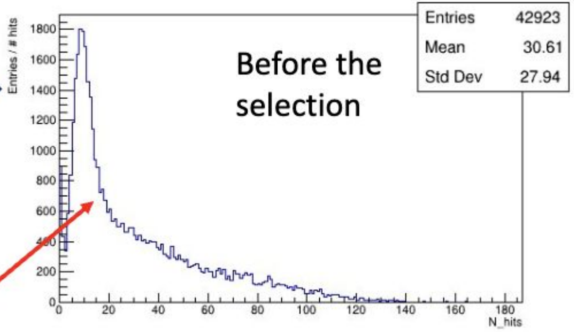


Shower events - simulation



Distribution of the **number of hits** in all active layer from the **experimental data**

Number of hits for all events



Peak at ~ 10 hits
-> MIP-like events

Number of hits for showers event