MPGD-Calo studies

2nd DRD1 Collaboration Meeting

21-06-2024

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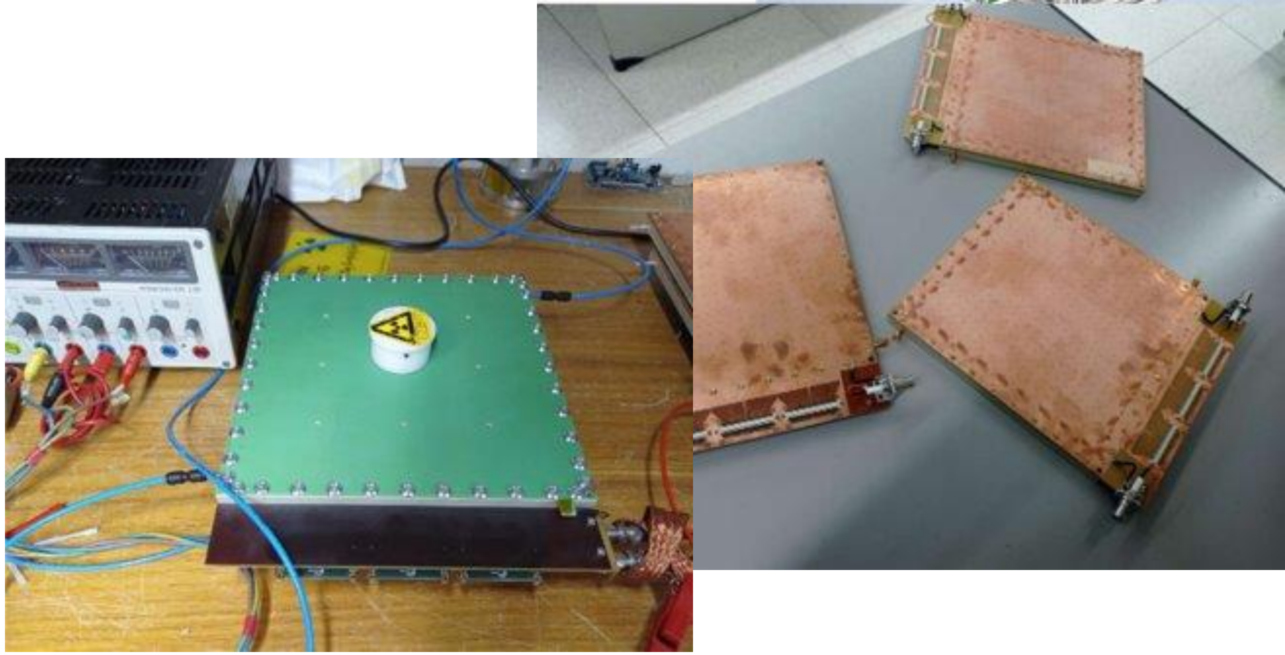
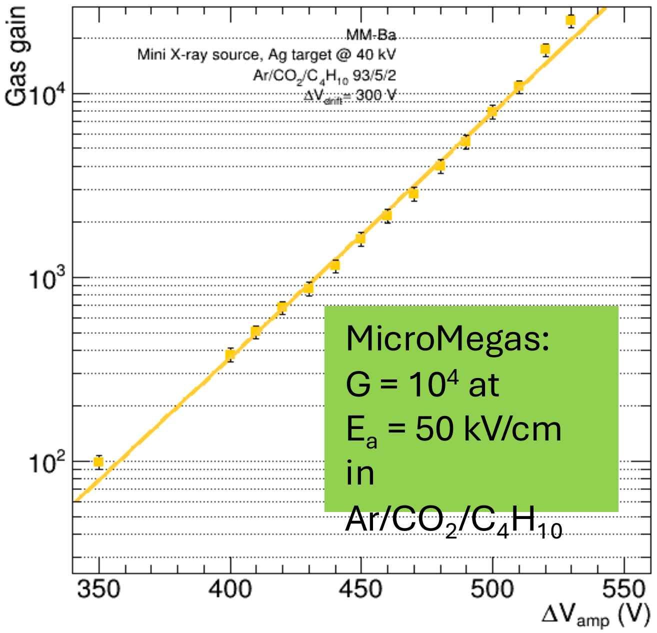
MPGD prototypes

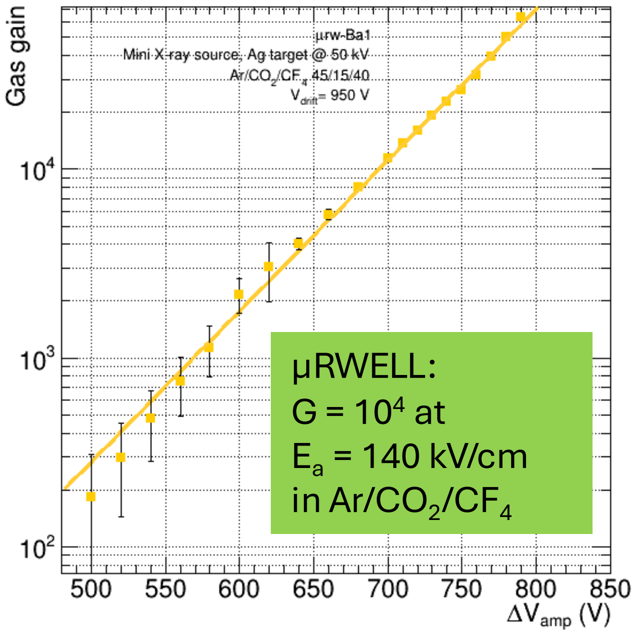
- **MPGD** :
- 7 µRWELL (Ba1, Ba2, Fr1, Fr2, Weiz, RM3, Na)
- 4 resistive MicroMegas (Ba, Weiz, RM3, Na)
- 1 RPWELL (Weiz)

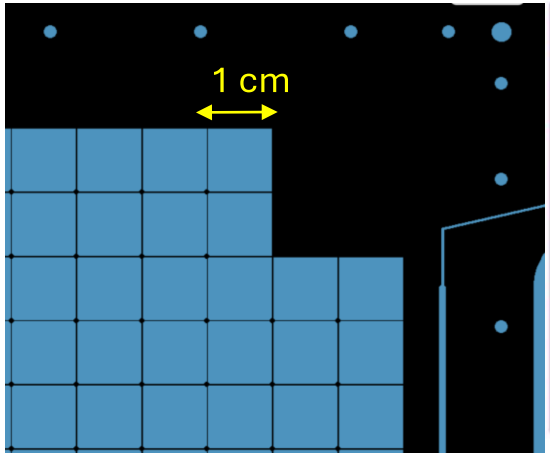
- detector size: 20x20 cm^2
- ~6 mm drift gap
- **Common readout** board: 1x1cm^2 pad→ 384 pads

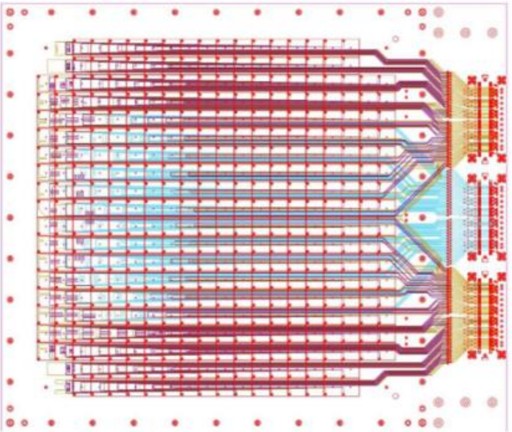
First characterizations in terms of effective gain using X-ray performed in lab in Frascati, Roma3, Bari, Napoli, Weizmann







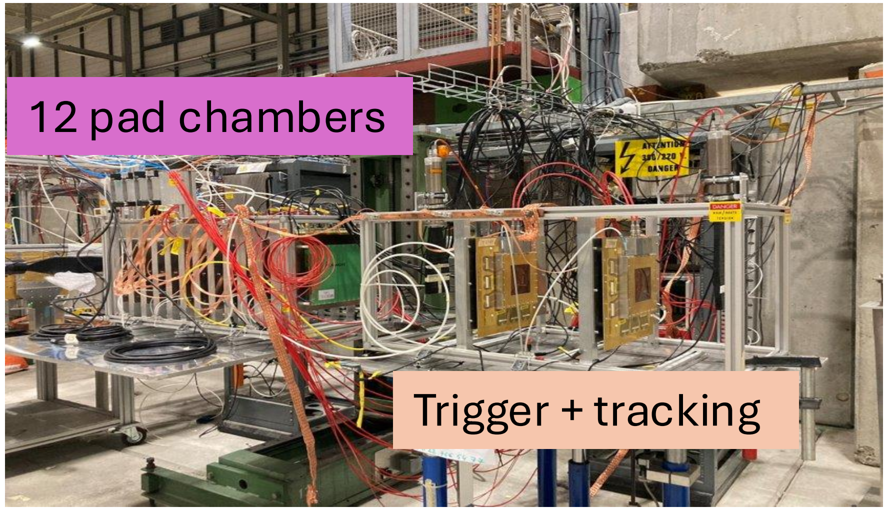


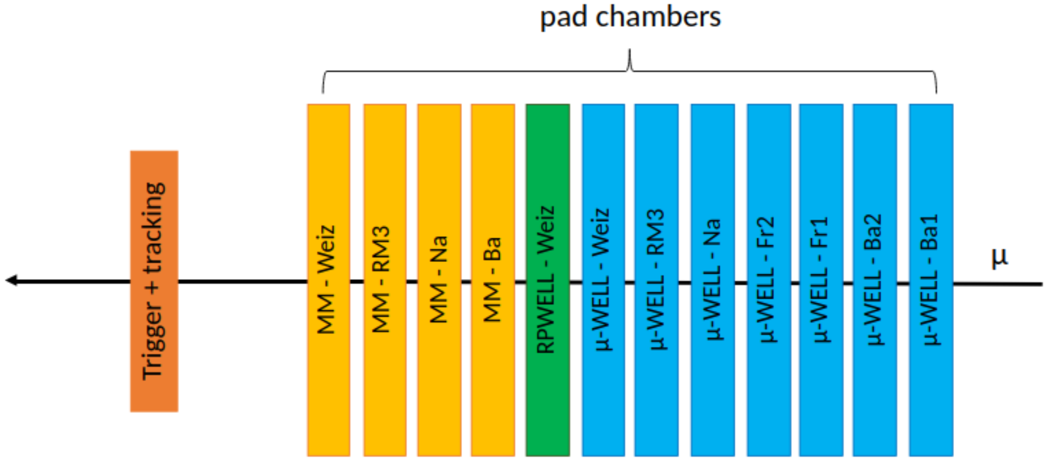


MPGD prototypes - SPS test beam

SPS test beam with μ beam at O(100 GeV) to validate and compare the technologies measuring:

- **Efficiency**
- **Response uniformity**



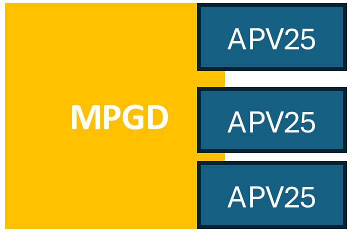


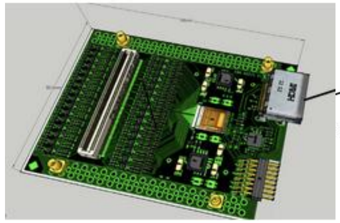
12 *pad chambers* under test flushed with

- **$Ar/CO_2/CF_4$ 45/15/40** for μ-RWELL
- **$Ar/CO_2/C_4H_{10}$ 93/5/2** for MicroMegas and RPWELL

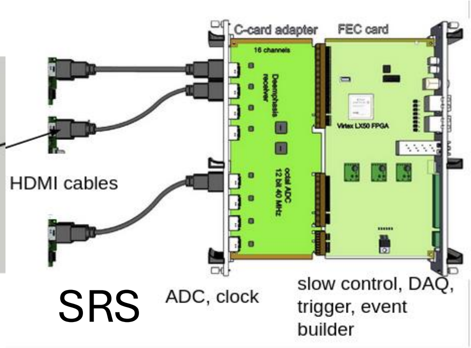
Data taking based on analog FE

- APV25 + SRS backend system for the DAQ
  - Read 6 chambers at a time
- HV efficiency scan, XY position scan





APV25

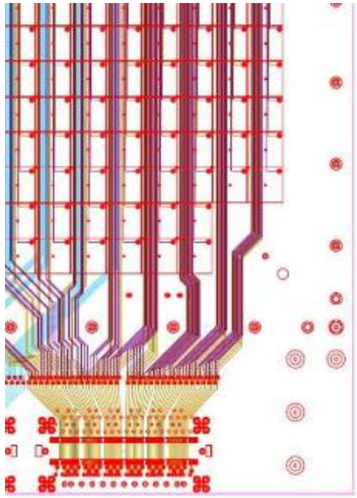


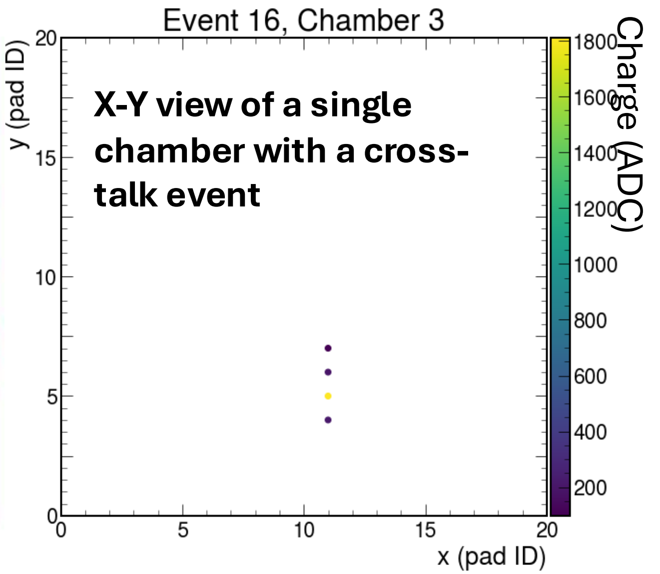
SRS

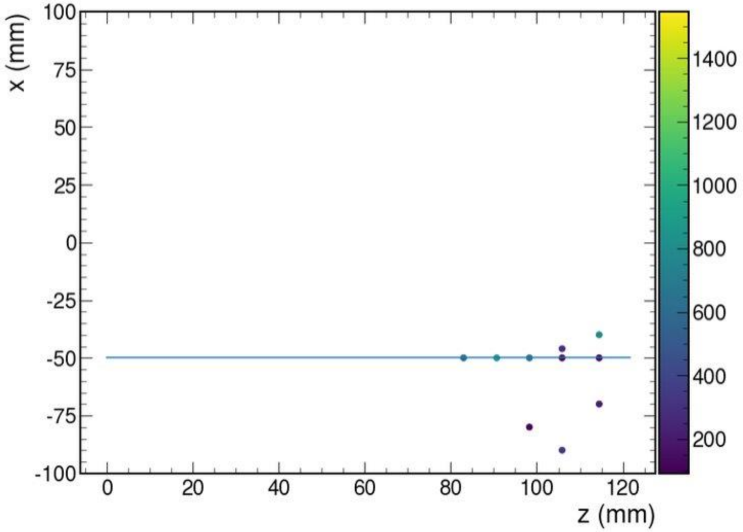
Analysis workflow

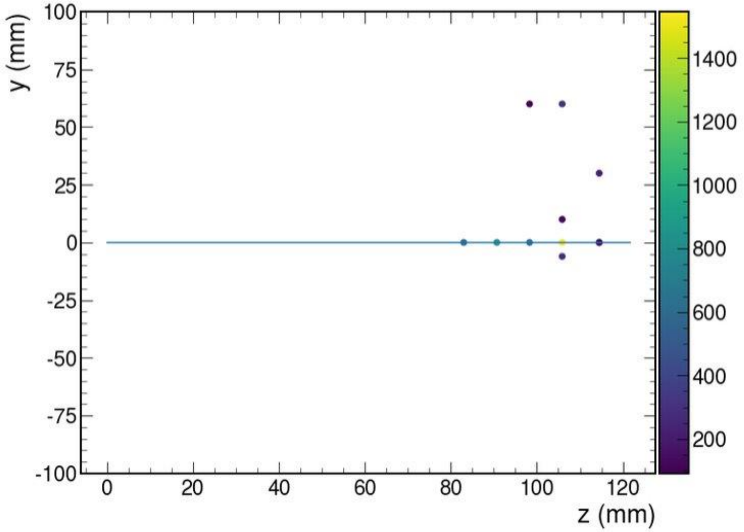
- Observed high probability of **cross-talk** between pads due to routing of readout vias from pads to front-end
  - Patched offline by clustering pads based on *charge sharing fraction* (details in backup)

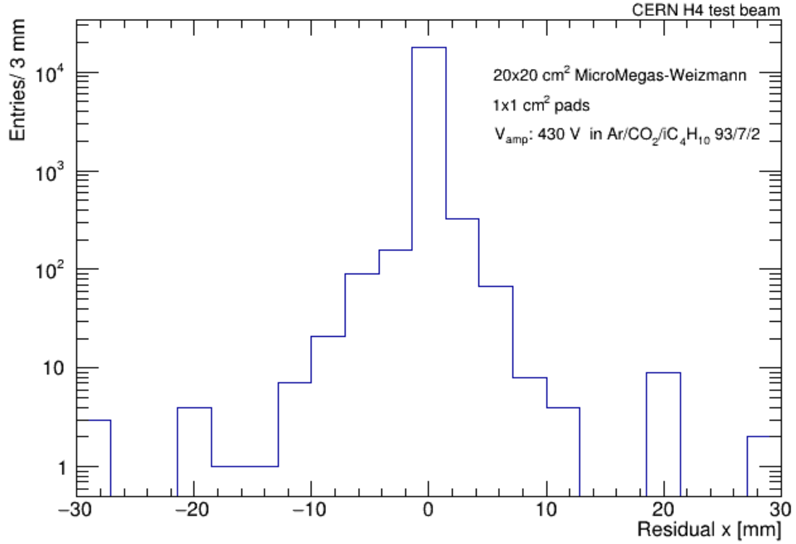
- Tracking detectors unused in reconstruction (high noise and discharge rate) → Track reconstructed with clusters from 5 out of 6 pad chambers, excluding the one under test







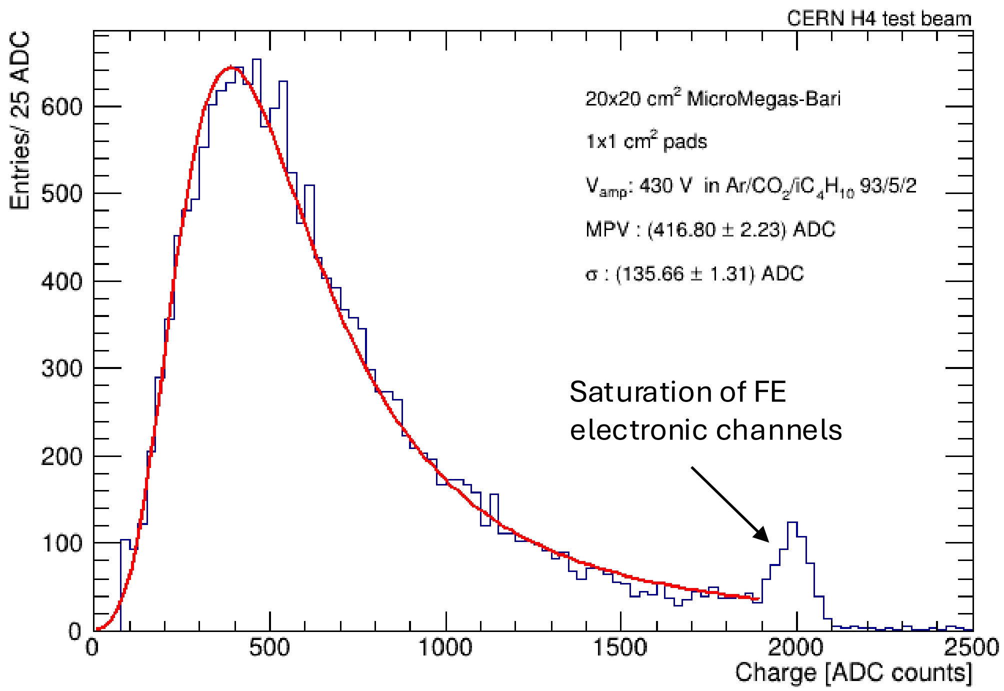




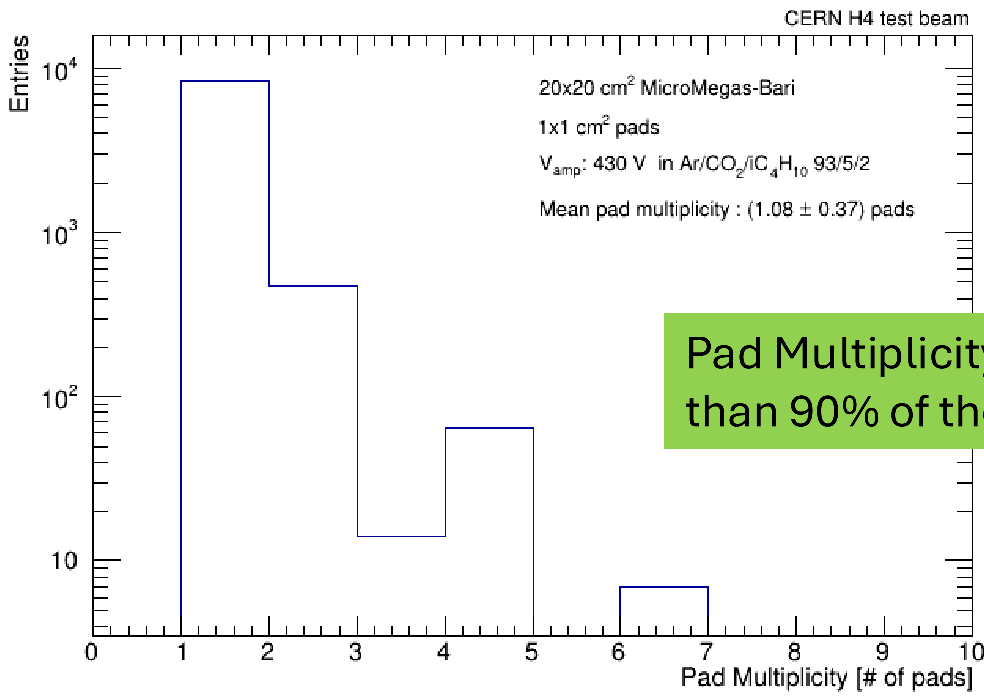
Cluster **matching** with track: $hit_{prop} - hit_{rec} < 9$ mm ~ $3\sigma_s$

SPS test beam – Results

Charge distribution of clusters matched with track



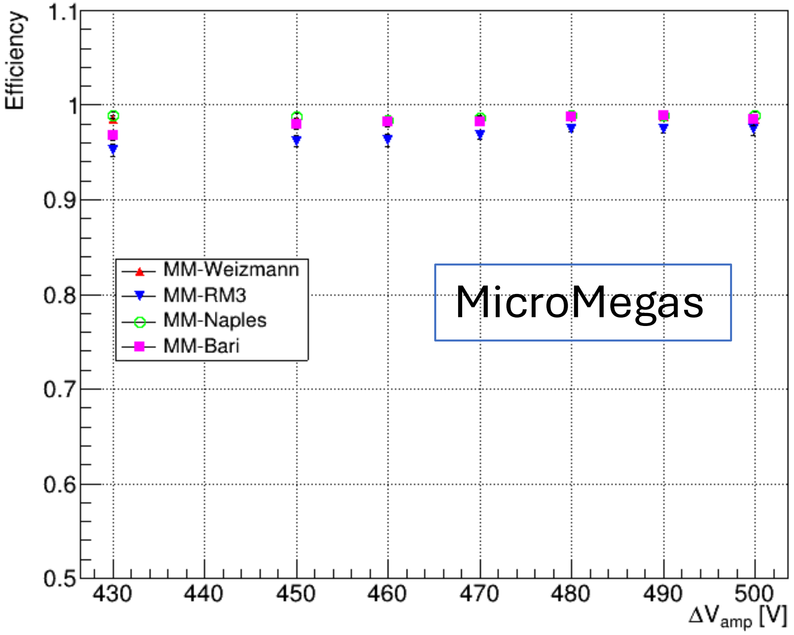
Pad-multiplicity distribution of clusters matched with track

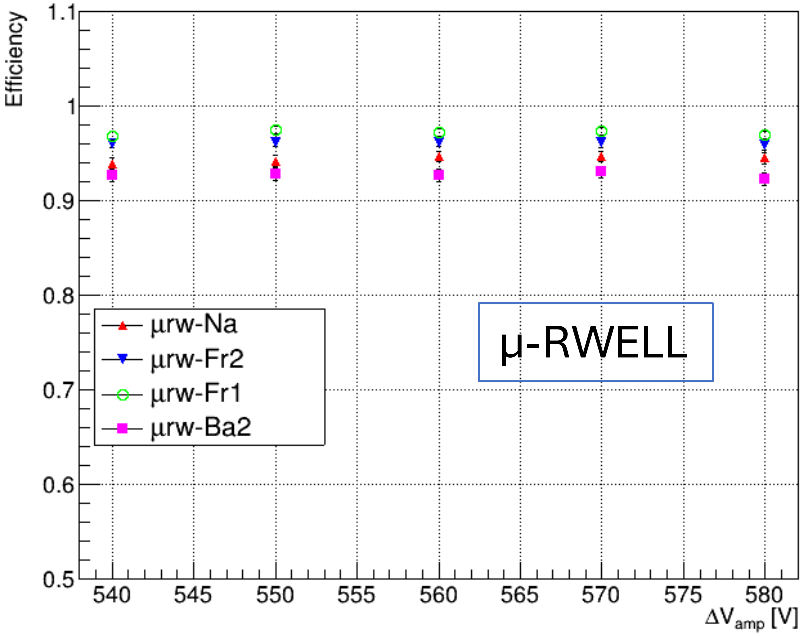


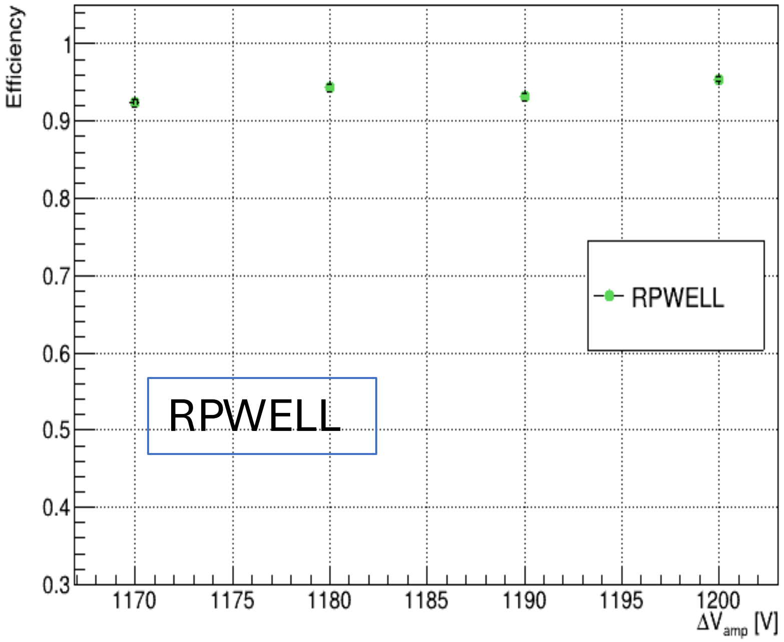
Pad Multiplicity is 1 for more than 90% of the clusters

SPS test beam – Efficiency

- Efficiency = # hits matched with tracks / # tracks
- Measured for each technology as a function of amplification voltages
- Efficiency related to the central region of the detectors







- High MIP detection efficiency – detectors always operated at **plateau** already at gains < 10^3
- Detectors can be operated with lower gain and still be efficient

SPS test beam – Response uniformity

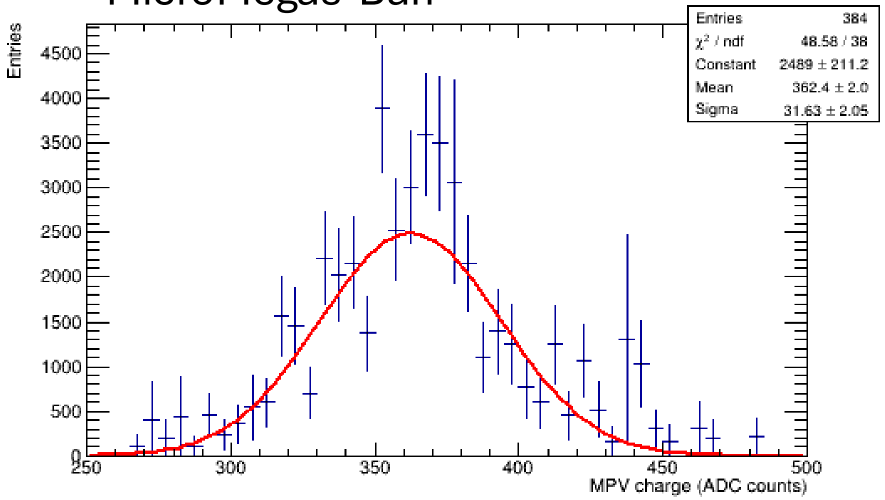
Uniformity measured using hits matching with tracks

- Good uniformity for MicroMegas ($\sigma/\mu \sim 10\%$)
- Slightly worse uniformity for μ-RWELL ($\sigma/\mu \sim 16\%$) and RPWELL ($\sigma/\mu \sim 22\%$)

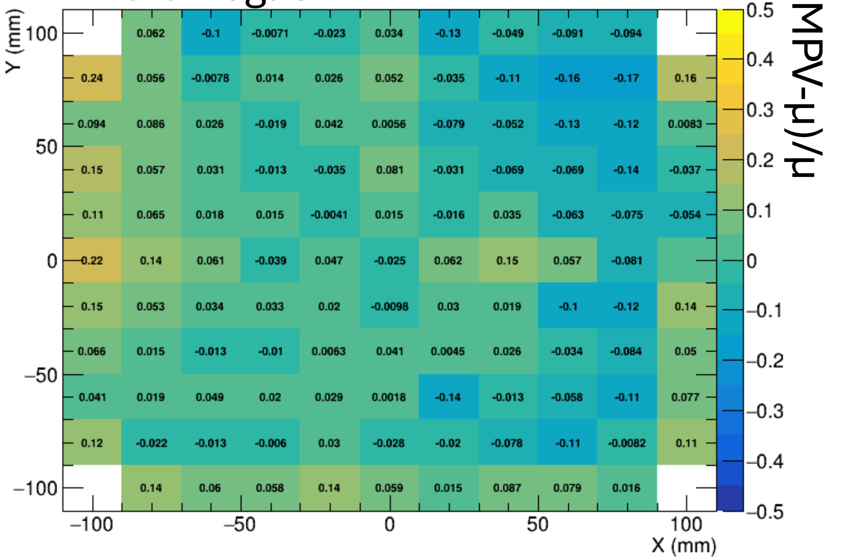
Spotted non-uniformity regions in μRWELL → to be better investigated

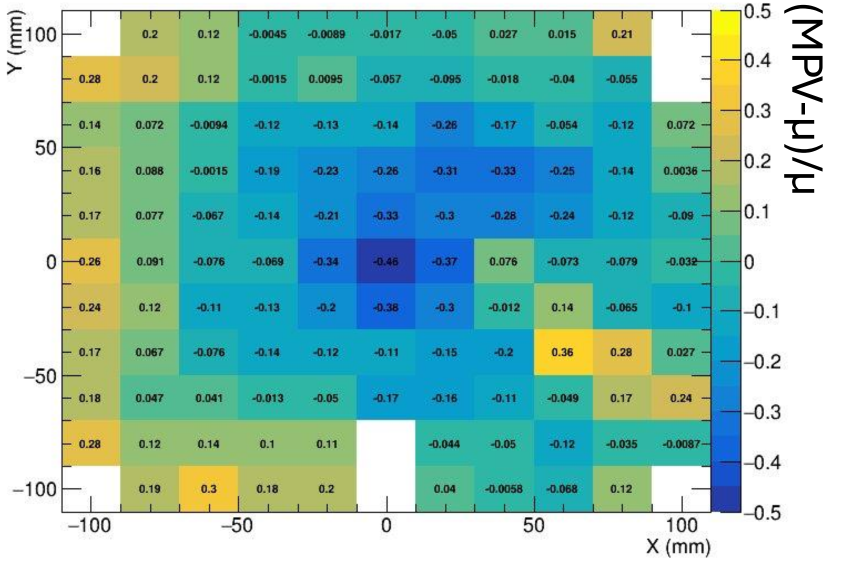
Detector	Uniformity (%)
MM-RM3	$(12.3 \pm 0.8)\%$
MM-Na	$(11.6 \pm 0.8)\%$
MM-Ba	$(8.0 \pm 0.5)\%$
RPWELL	$(22.6 \pm 4.7)\%$
μrw-Na	$(11.3 \pm 1.0)\%$
μrw-Fr2	$(16.2 \pm 1.7)\%$
μrw-Fr1	$(16.3 \pm 1.1)\%$

MicroMegas-Bari



MicroMegas

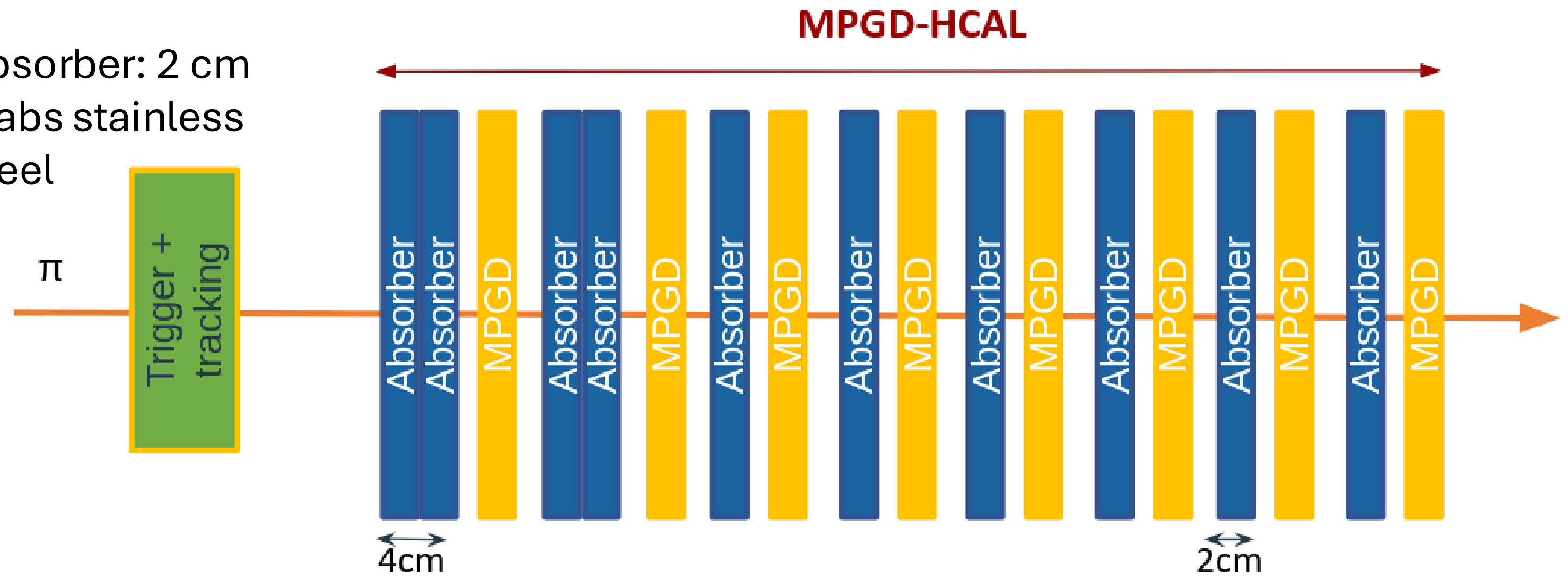


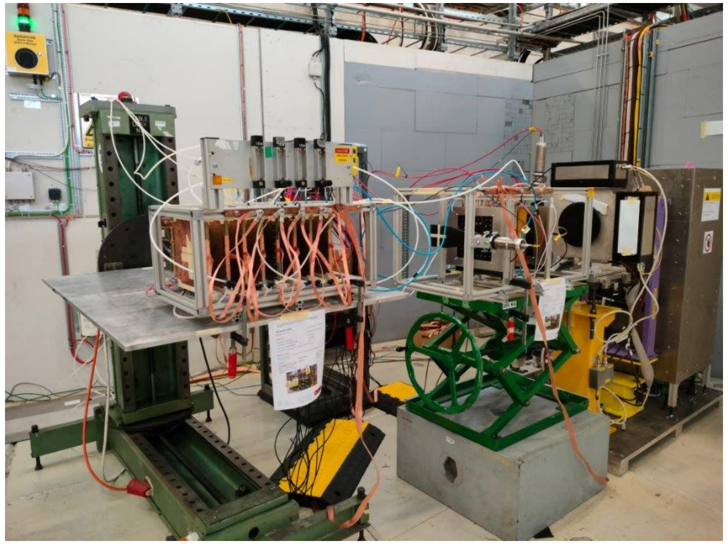


R&D on small-size calorimeter prototype at PS

MPGD-HCAL prototype – PS test beam

Absorber: 2 cm slabs stainless steel



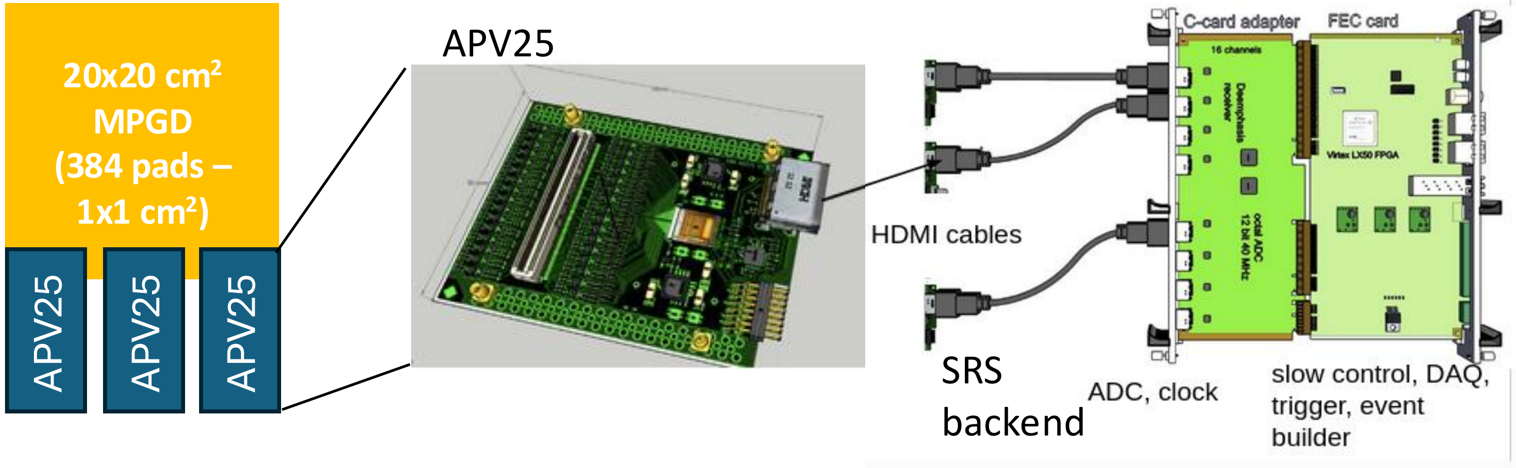


HCAL cell performance ~ 1 λ_I (8 active layers)

Data taking based on analog FE (APV25 + SRS)

Runs at different π^- energy (4 – 8 GeV)

- Cherenkov discriminators used to veto electrons and muons

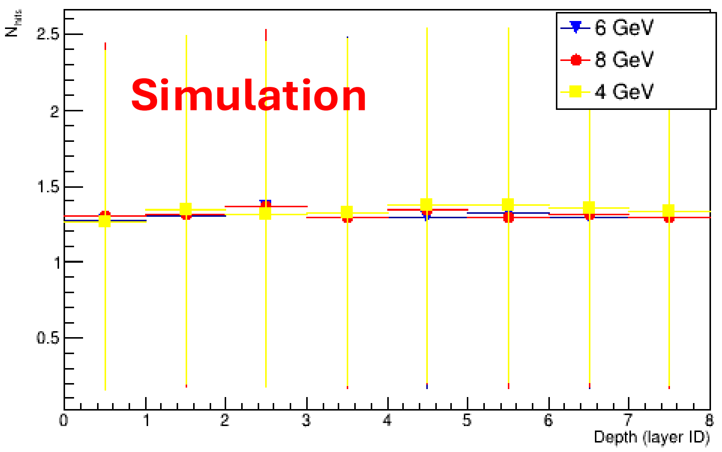


Event selection in Monte Carlo and data

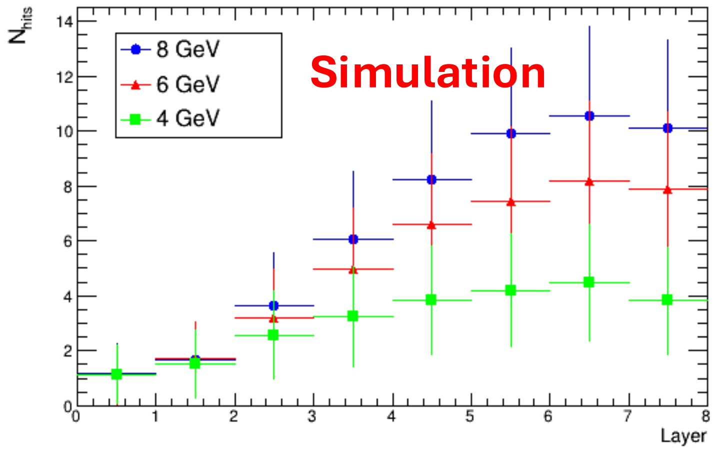
Event **selection criteria** supported by **simulation** using MC truth

- MIP-like events:
  - ~1.3 hit in each layer
- Shower events starting from layer 3:
  - more than 4 hits per layer from layer 3

MIP-like events

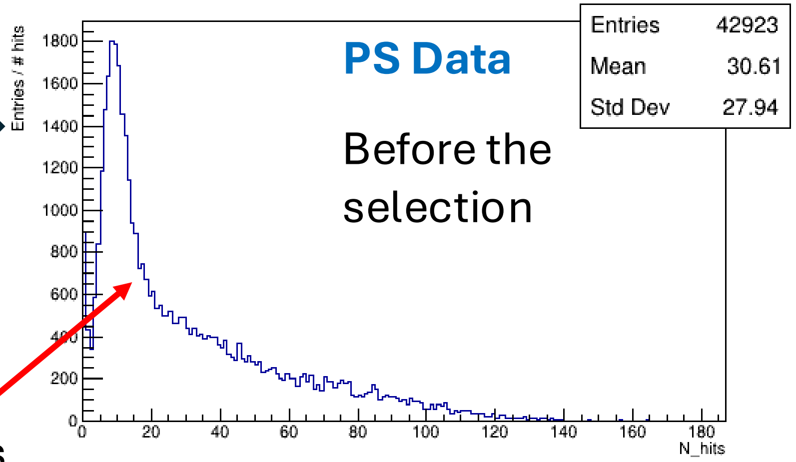


Shower events



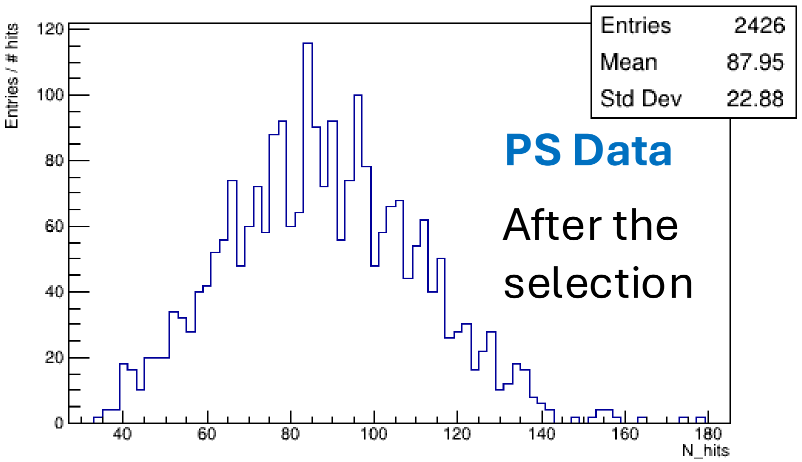
Distribution of the **number of hits** in all active layer from the experimental data

Number of hits for all layers



Peak at ~ 10 hits
-> MIP-like events

Number of hits for all layers

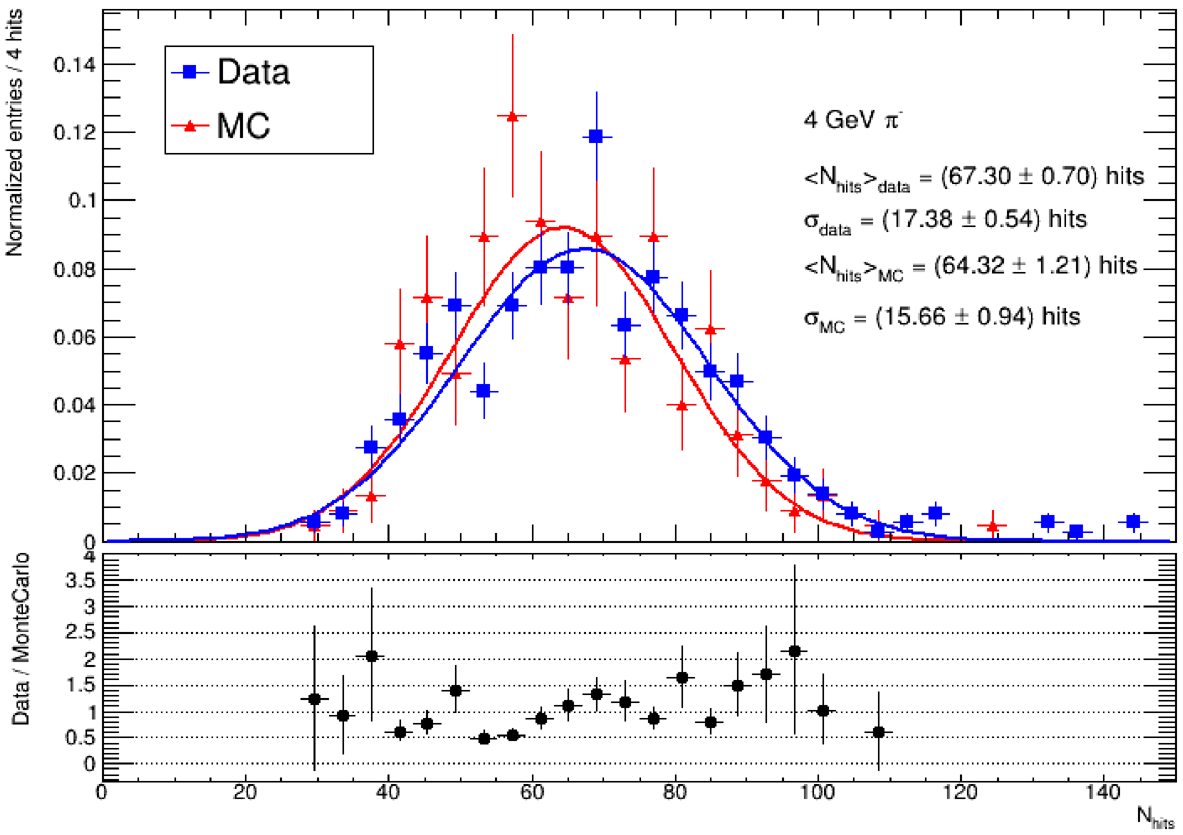


Data-MC comparison

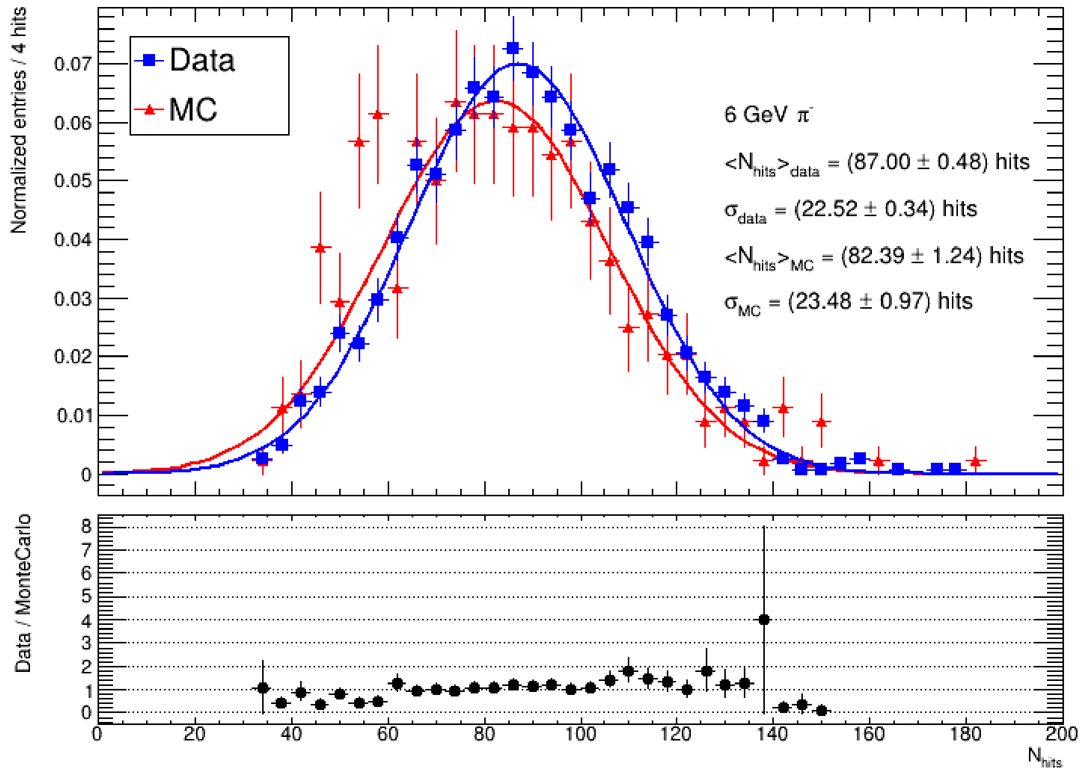
- Distribution of total number of hits for hadronic shower events for experimental data and Monte Carlo simulation
- Distributions fitted with Gaussian to extract mean and sigma

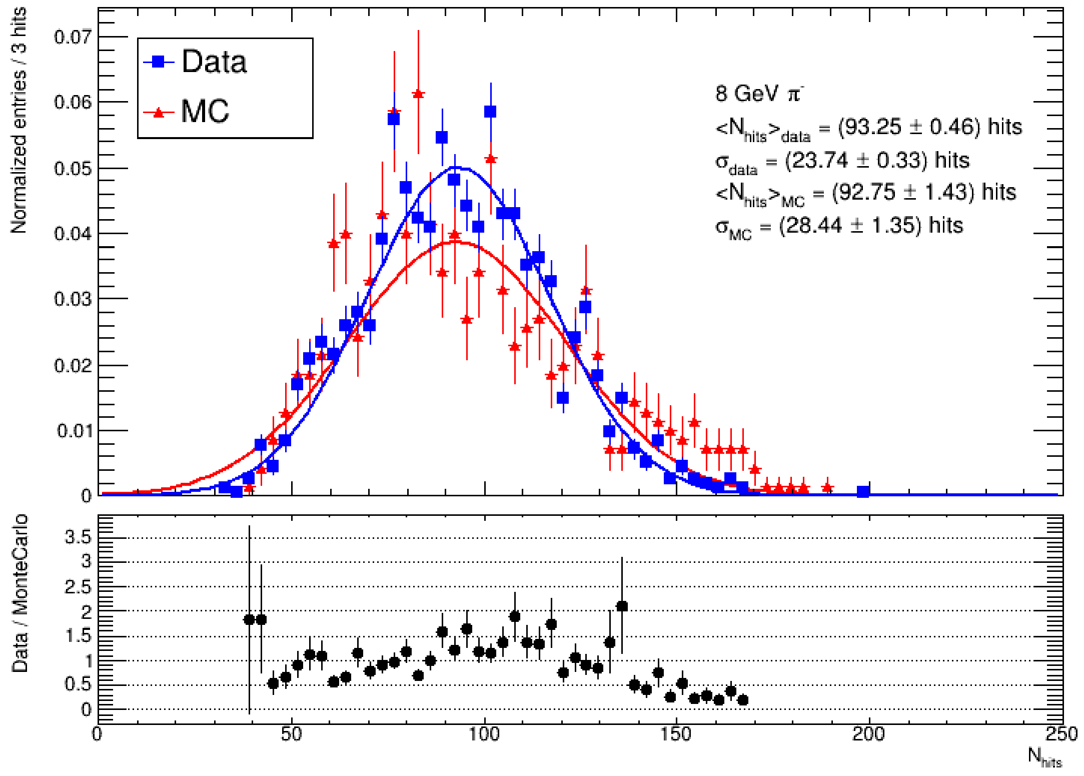
Good agreement between data and Monte Carlo

Successful **validation** of MPGD-HCal prototype with 8 layers of 20x20 cm^2



MPGD-HCAL prototype – Data-MC preliminary comparison





Lessons learnt

Detector design

- **Cross-talk** associated with readout routing → Two possible solutions in next prototype batch:
  - Shielding in R/O PCB
  - Shorten R/O vias at the expense of equalizing signal delays

Operational experience

- Detector under test operated at high gains: MIP efficiency > 90% for all technologies **but** observed electronic saturation both at SPS and PS
  - Working point to be optimized for better energy resolution
- Tracking system issue
  - Triple-GEM detector not efficient
  - TMMs not very well understood: mix of high noise and discharge rate
    - Ongoing debug applying promising ad-hoc cleaning
- Front-end electronics (APVs) issue:
  - many dead/noisy channels
  - few hybrids completely faulty

Plans for upcoming test beam

Next week SPS Test beam

- Test of 8 pad chambers (resistive MicroMegas + µRWELL) with both **muon** and **pion** beam
  - Optimize detector working point with APV (MIP efficiency scan)
  - Consolidate response uniformity results

PS Test beam right after SPS

- Test same setup with pion beam
- Include absorbers and repeat pion energy scan at optimized working point for energy resolution studies

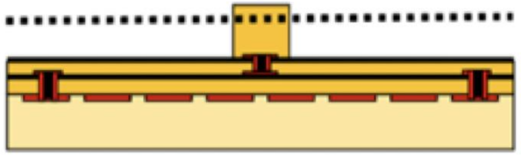
Backup

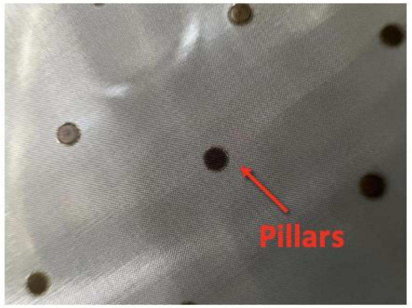
MPGD technologies

Table 3.2: Characteristics of the resistive MPGD prototype tested in this work. The brute value of the resistivity refers to the value of the DLC foil at production; the value after curing is the one measured after the curing procedure of the DLC foil.

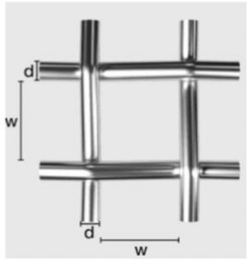
Technology	Amplification gap	Drift gap	Resistivity (brute value)	Resistivity (after curing)
resistive Micromegas	$\approx 100\ \mu m$	≈ 6 mm	(100 ± 30) MΩ/□	≈ 45 MΩ/□
μ-WELL	$\approx 50\ \mu m$	≈ 6 mm	(200 ± 60) MΩ/□	$85 \div 110$ MΩ/□
RPWELL	$\approx 400\ \mu m$	≈ 5 mm	≈ 2 GΩ·cm (bulk)	

Micromegas (MM)

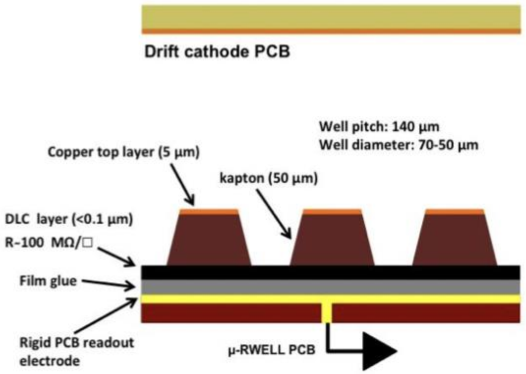




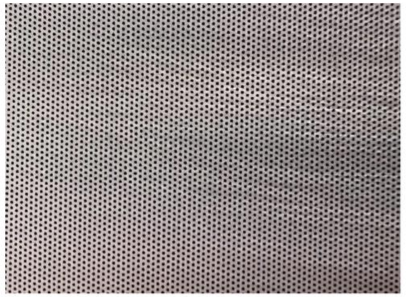
d= 18 µm
w= 45 µm
Pillar size =?



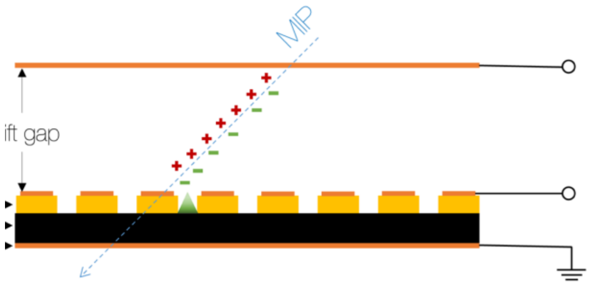
uRWELL

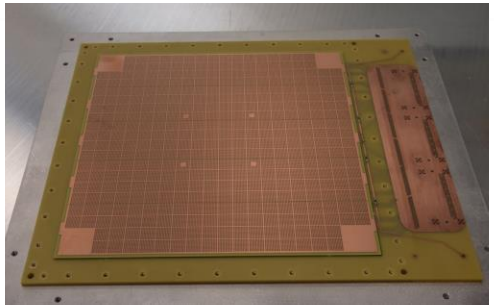


µRWELL seen at the microscope

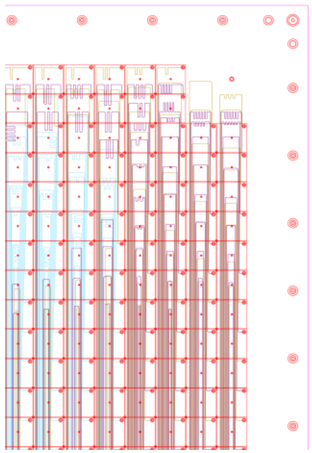


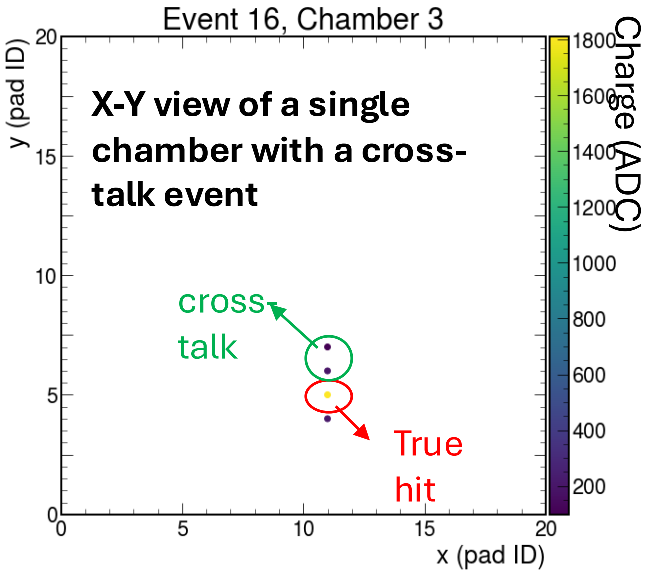
RPWELL



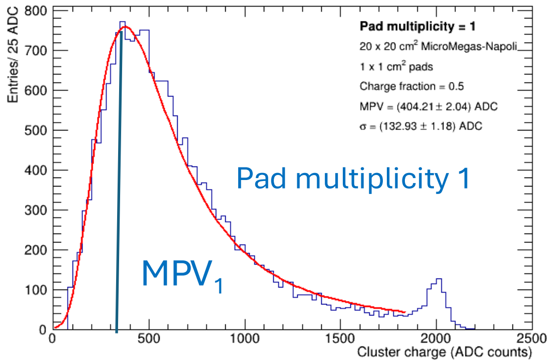


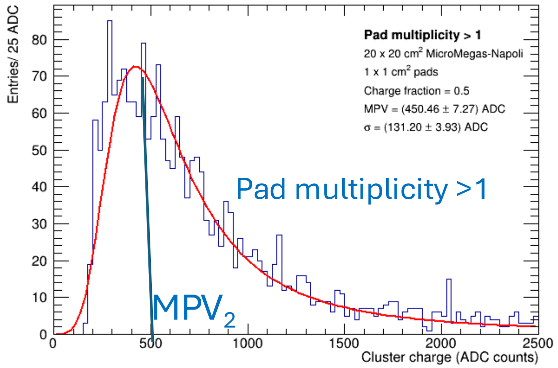
SPS test beam – Cluster reconstruction

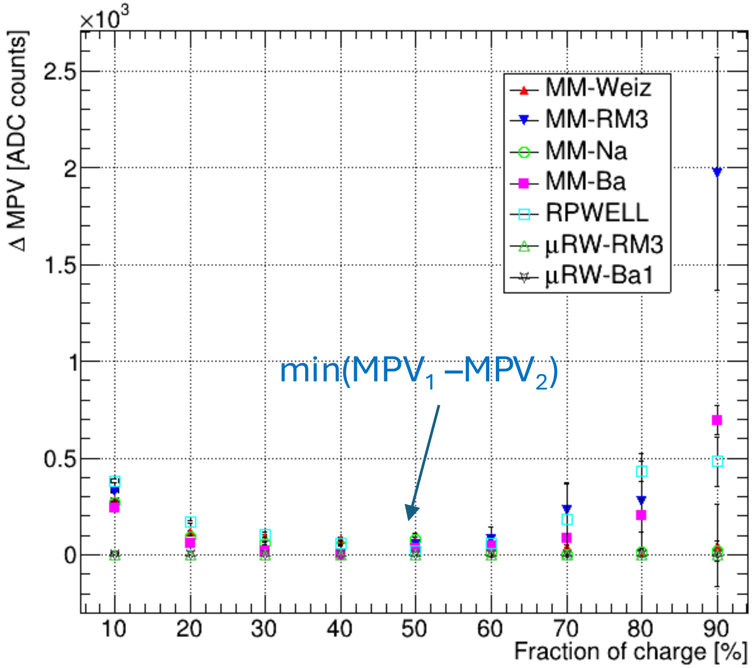




High probability of **cross-talk** effect observed among adjacent pads due to routing of the vias connecting pads to the connectors





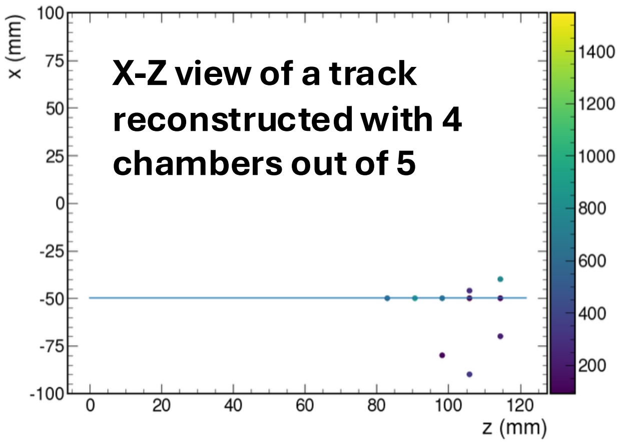


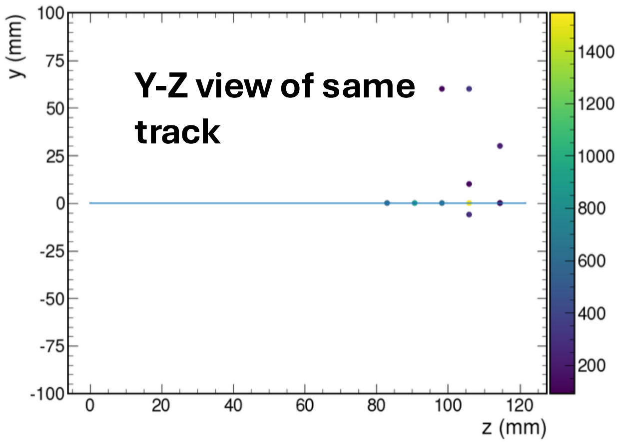
Developed ad-hoc **clustering algorithm** based on charge sharing criterium

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

SPS test beam – Track reconstruction

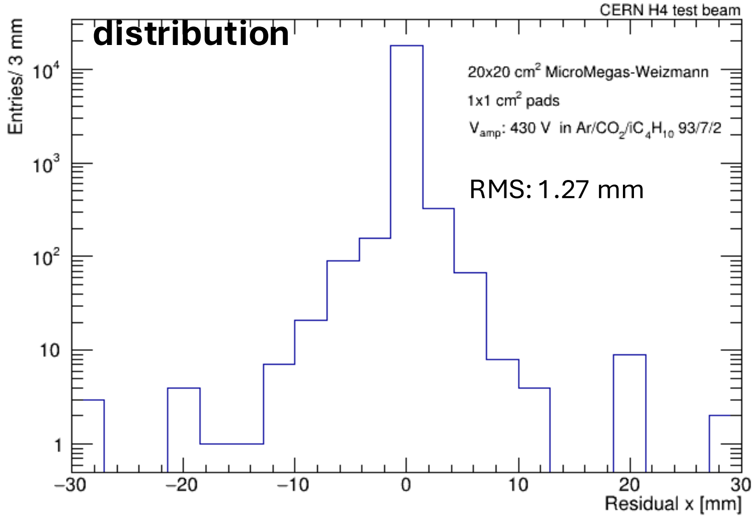
Track reconstructed with clusters from 5 out of 6 pad chambers, excluding the one under test



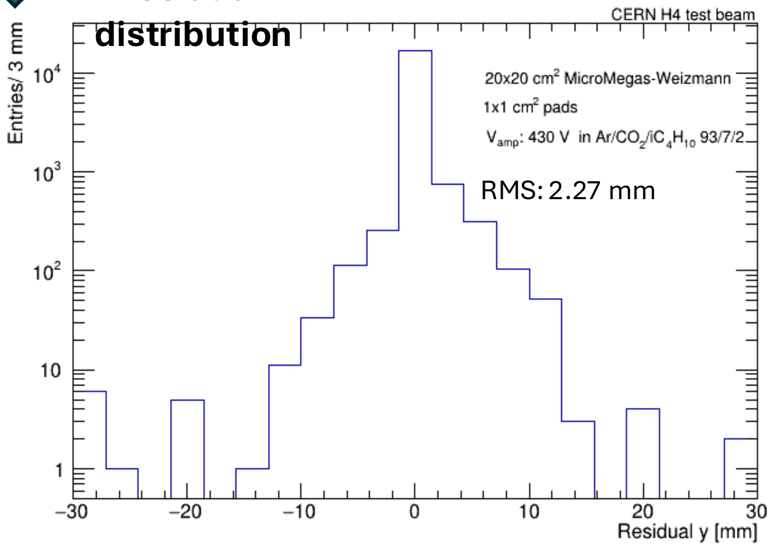


Residual distribution: $hit_{prop} - hit_{rec}$
hit_{pro}: (x,y) on chamber extrapolated from the track
hit_{rec}: (x,y) recostructed on the test chamber

X residual distribution



Y residual distribution

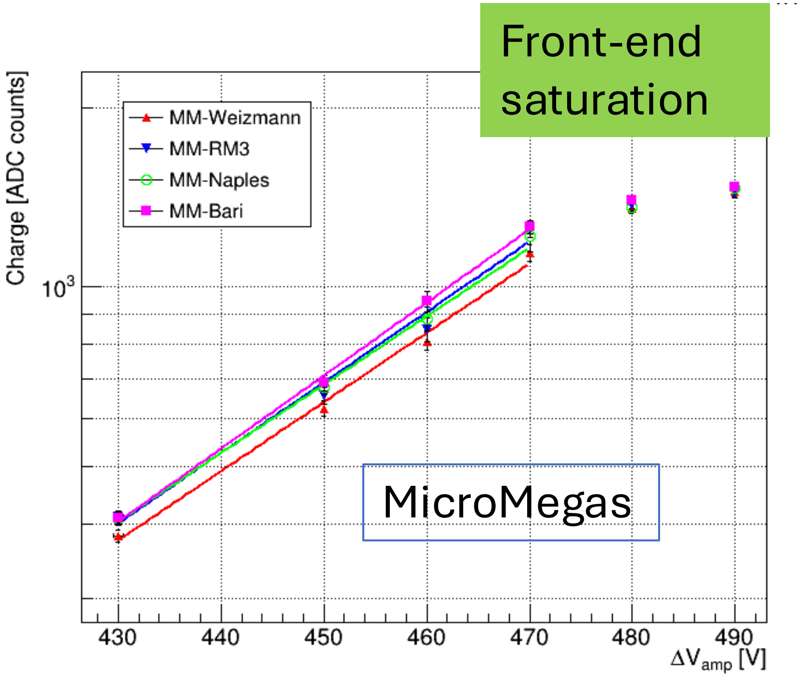


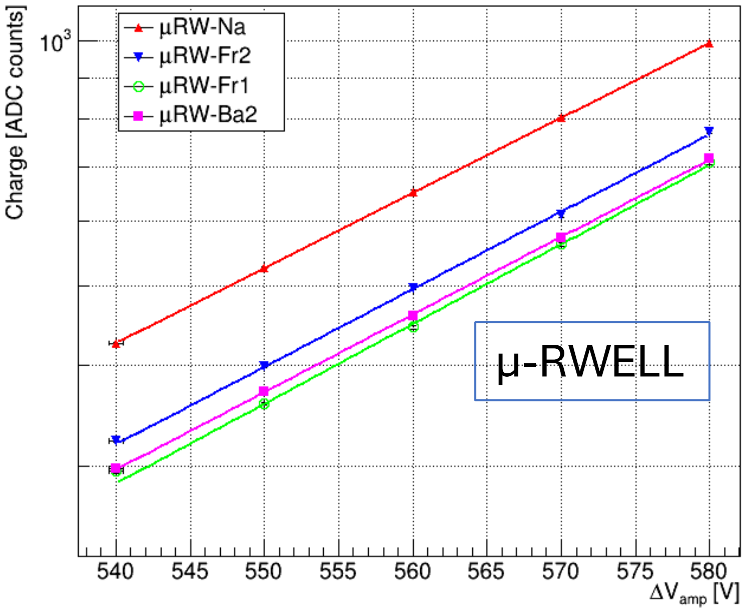
Residual distribution in agreement with detector **granularity**

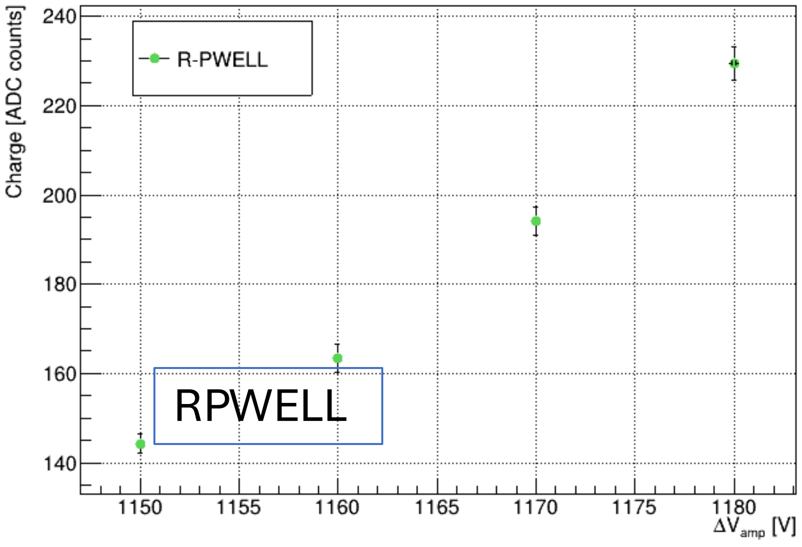
Cluster **matching** with track: $hit_{prop} - hit_{rec} < 9$ mm ~ $3\sigma_s$

SPS test beam – Charge

- Charge value is the MPV of the charge distribution of clusters matching the track

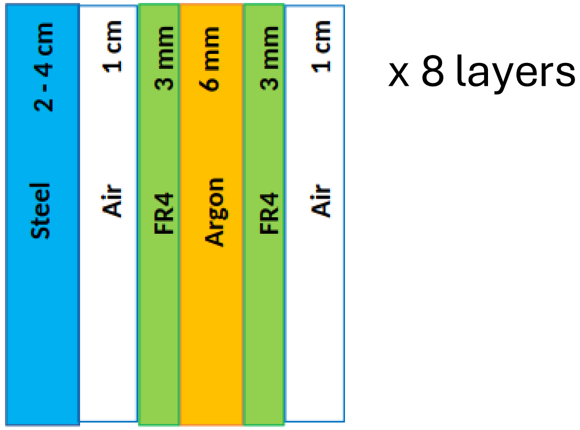






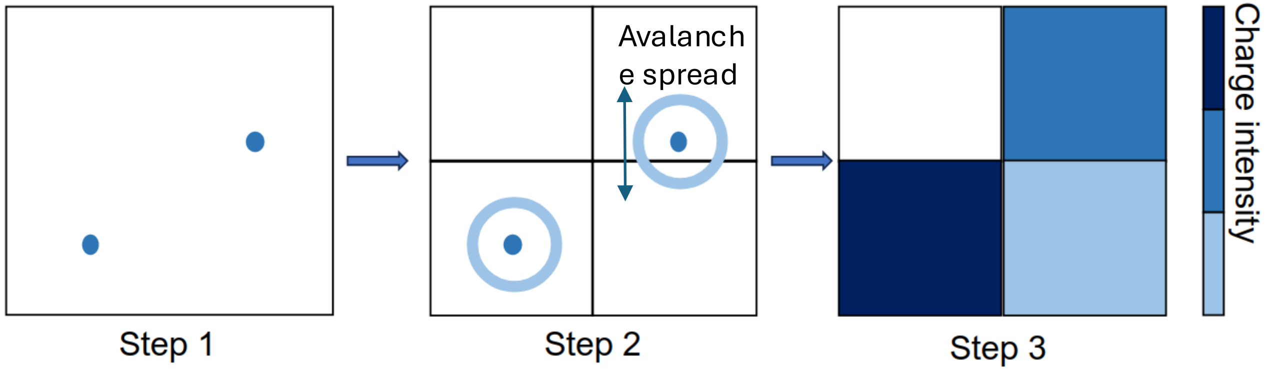
MPGD-HCAL prototype - G4 simulation setup

- Small calorimeter 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)

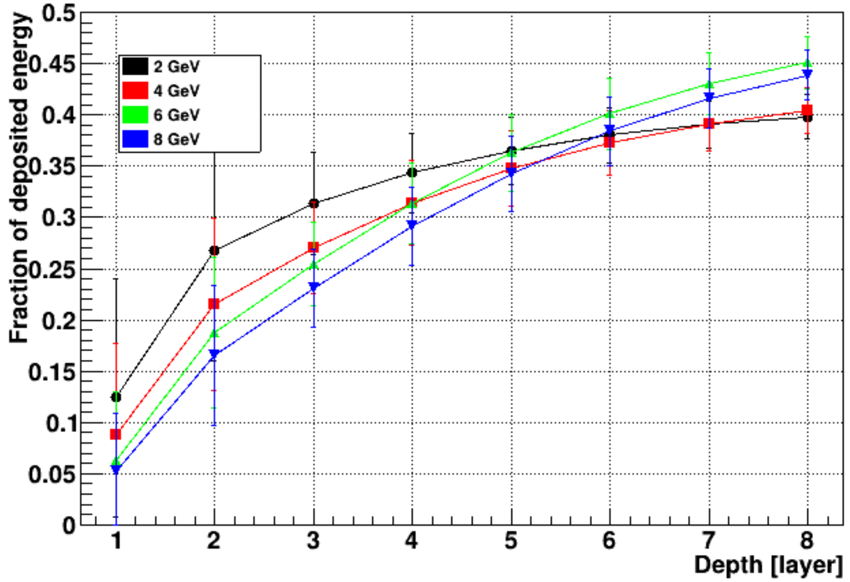


- **Digitization algorithm** implemented to account for charge-sharing among adjacent pads and detector efficiency

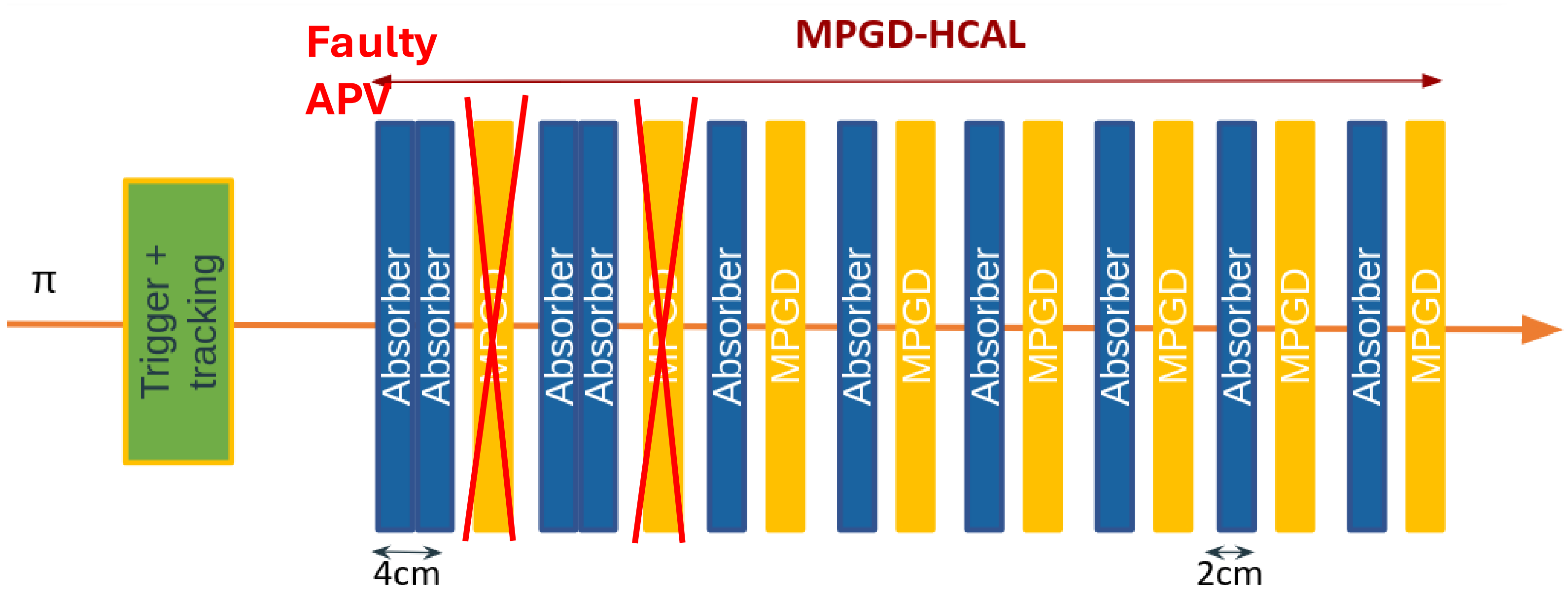
Digitization algorithm

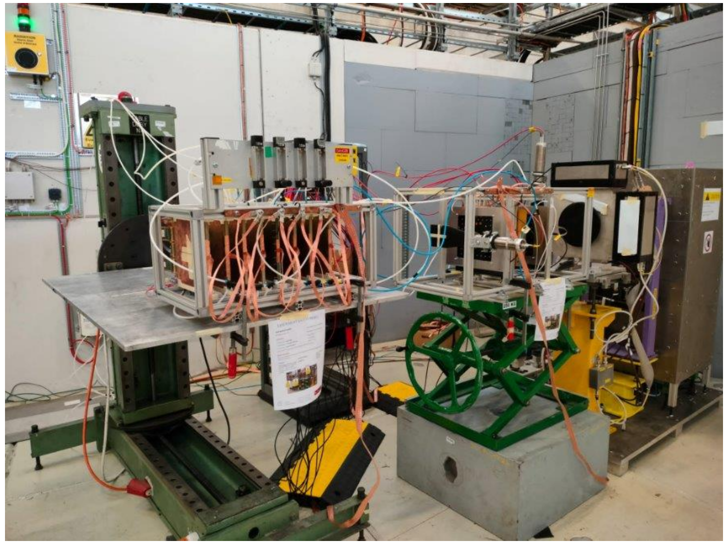


Shower containment



MPGD-HCAL prototype – PS test beam



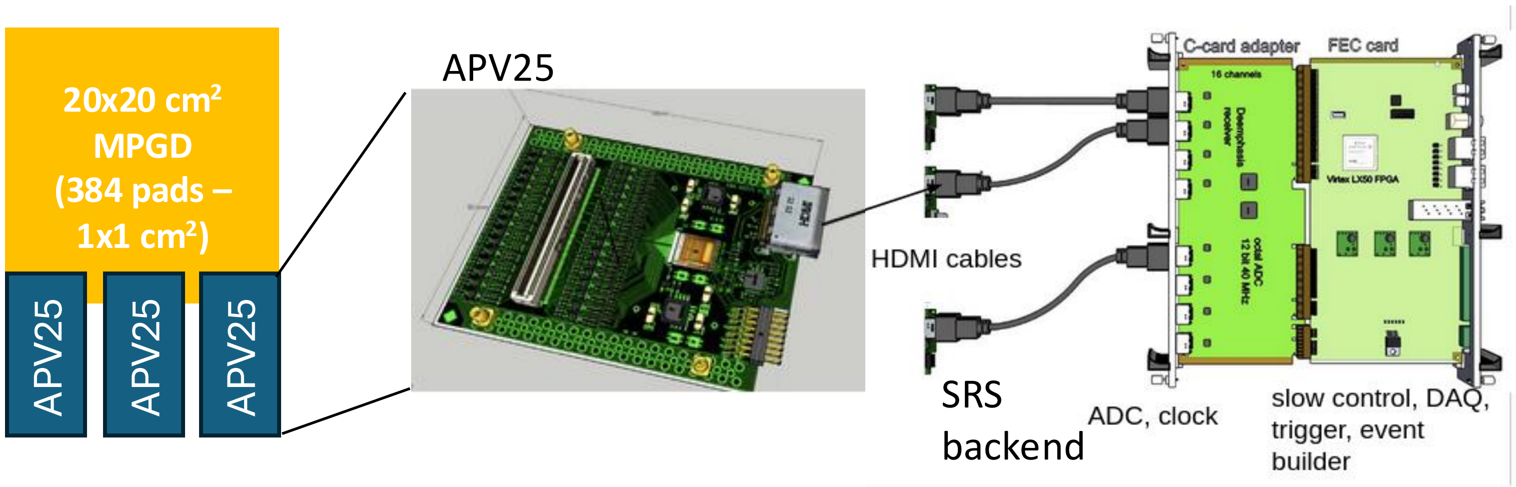


HCAL cell performance ~ 1 λ_I
(8 active layers)

Data taking based on analog FE (APV25 + SRS)

Runs at different π^- energy (4 – 8 GeV)

- Cherenkov discriminators used to veto electrons and muons



MPGD-HCAL prototype – Faulty APVs

Simulation – beam profile per layer

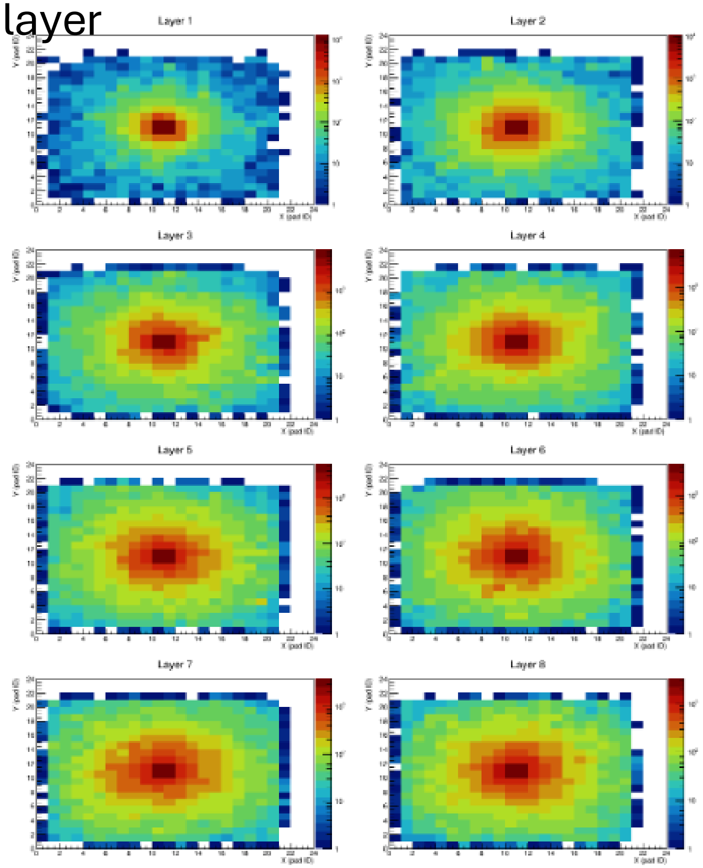


Figure 4.18: X-Y distributions of hits per each active layer after the digitization algorithm. These distributions are obtained with 30 thousand π^- of 6 GeV. The z-axis is the number of fired pads considering the whole set of events.

Experimental data– beam profile per layer

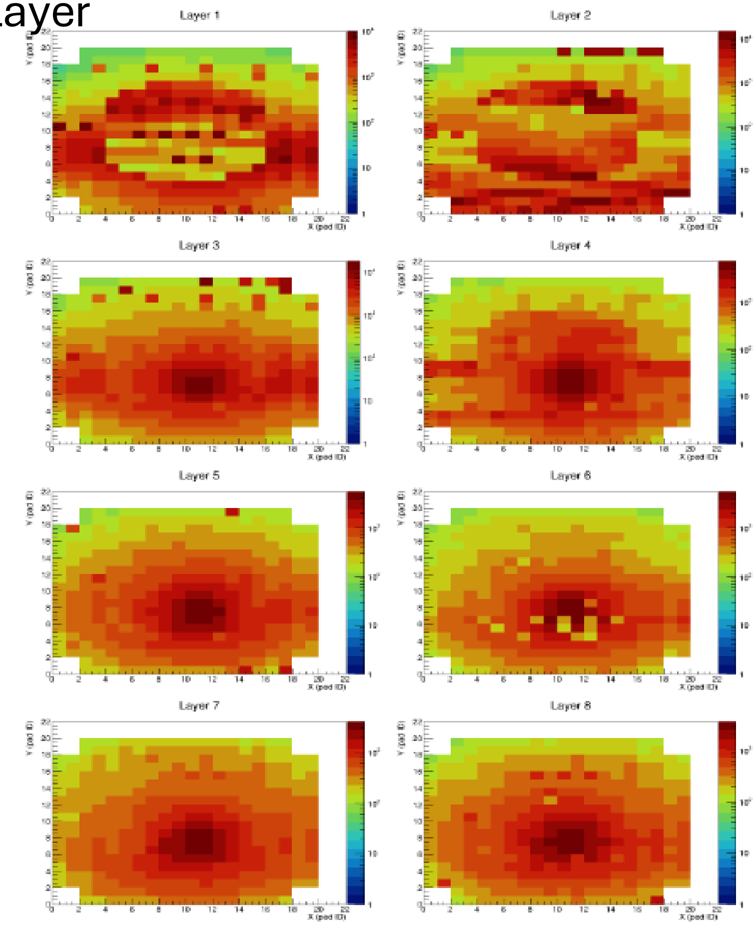


Figure 5.6: X-Y distributions of hits per each MPGD layer obtained for the run with pion energy of 6 GeV. The z-axis is the number of fired pads, in logarithmic scale, considering the whole set of events.