A hadronic calorimeter based on resistive micropattern gaseous detectors

IFD 2025 – INFN Workshop on Future Detectors

Sestri Levante (GE), 18-03-2025

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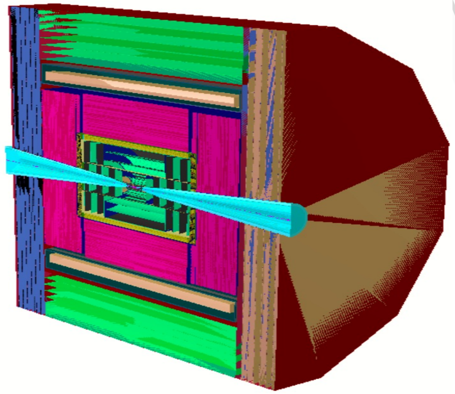
MPGD-HCAL

A hadronic calorimeter based on resistive MPGDs

GOAL at future Higgs factories :
Jet energy resolution for Z/H separation:
$\sigma_E /E< 3\% - 4\%$

PROPOSAL

Project framed within the **DRD6/DRD1 collaborations**



SAMPLING HADRONIC CALORIMETER FOR EXPERIMENTS AT FUTURE CIRCULAR LEPTON COLLIDERS (Muon Collider, FCC-ee …)

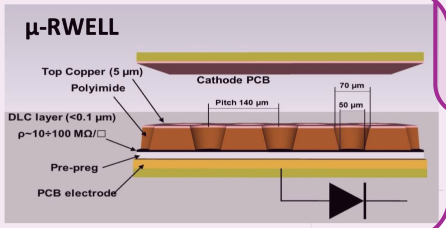
- **Resistive Micro Pattern Gaseous Detectors (MPGDs)** as active layers (with Argon-based gas mixture)
- Iron as absorber

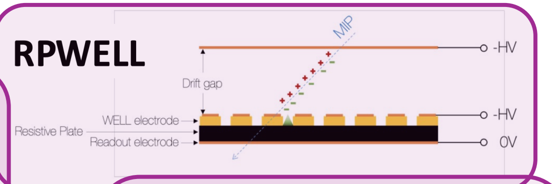
Novel MPGD-based readout

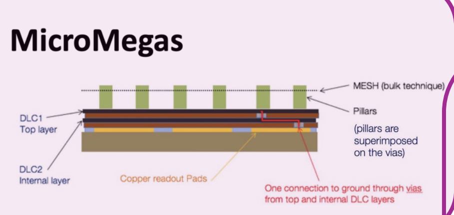
- **Fine granularity** (up to 1x1 cm^2) for **Particle Flow Calorimetry**

+

- Radiation hardness up to several C/cm^2
- Time resolution of O(ns)
- Longitudinal segmentation
- High rate-capability O(MHz/cm^2)
- Cost-effective for large-area instrumentation





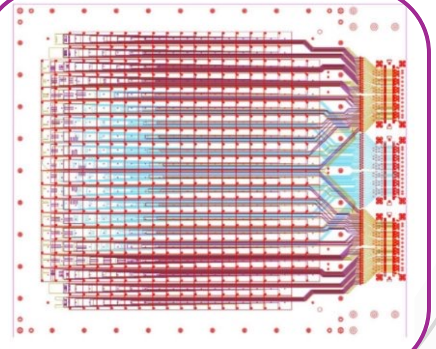


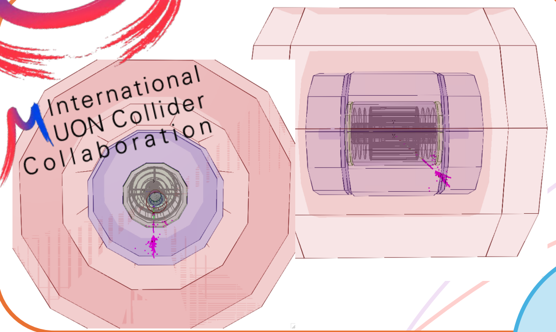
Candidate technologies

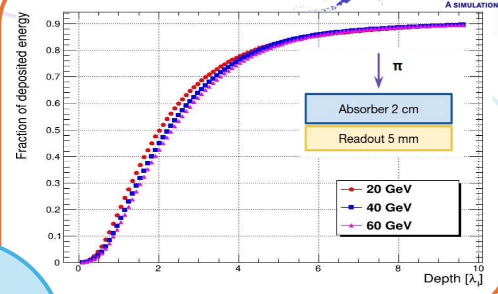
- μRWELL , MicroMegas (MM) , RPWELL

Tested detector layout: 20x20 cm^2

- 384 pads of 1x1cm^2 with a common readout board







MPGD-HCAL R&D Strategy

SIMULATION IN MUON COLLIDER FRAMEWORK

determines physics requirements for

STANDALONE SIMULATION WITH GEANT4

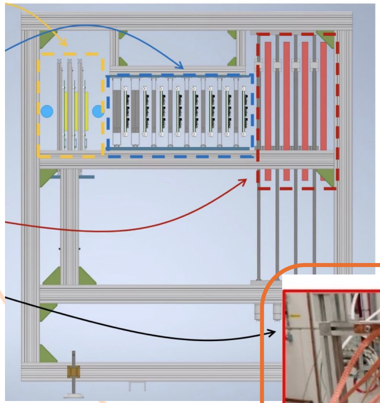
defines the design requirements for

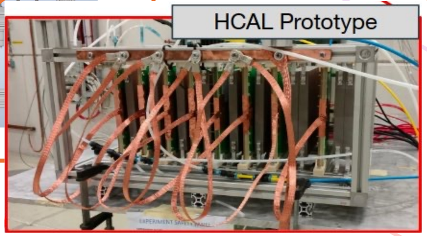
DEVELOPMENT OF MPGD TECHNOLOGIES

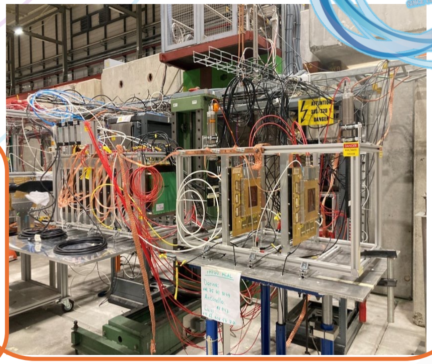
used in

DESIGN AND TEST OF THE CALORIMETER CELL PROTOTYPE

sets the performances for







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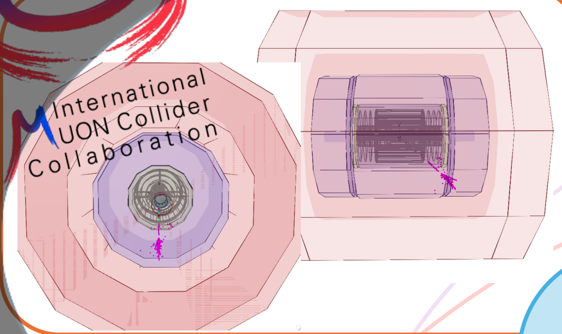

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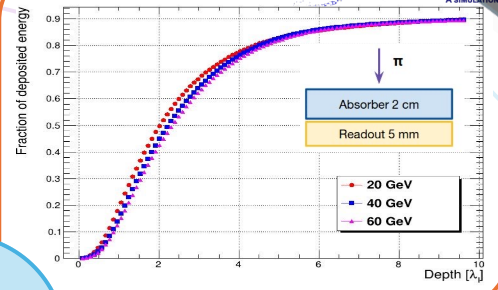

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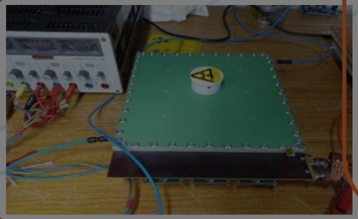

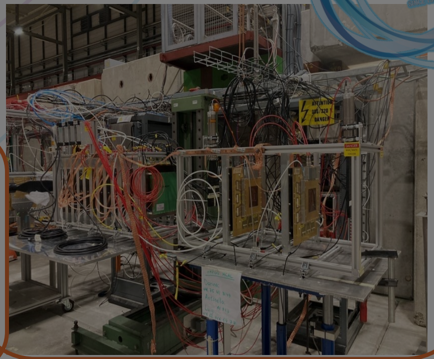

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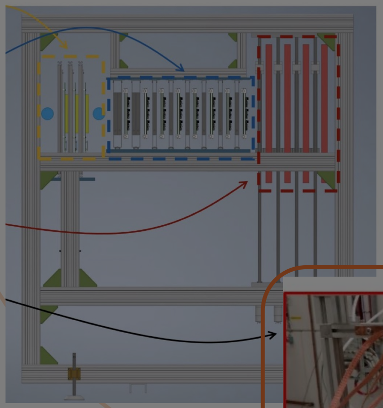
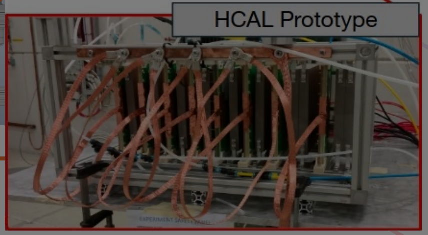




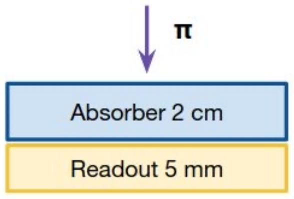
sets the performances for

SIMULATIONS

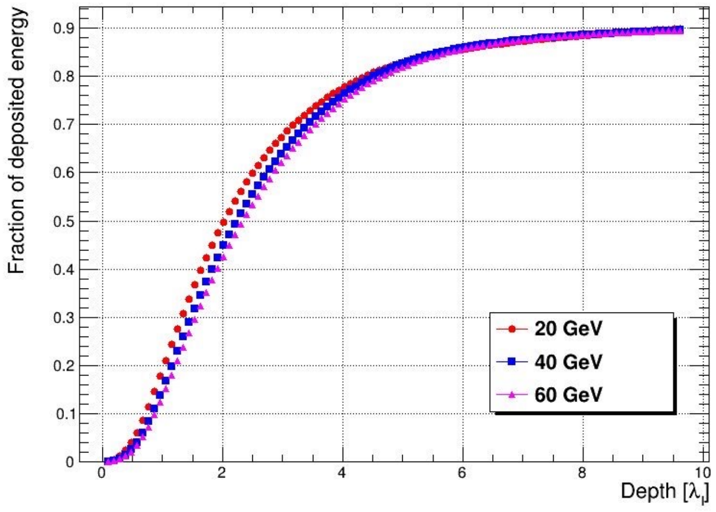
Charged monochromatic pion guns up to 100 GeV

Shower containment in Geant4

- Geometry of single layer:
  - 2 cm of iron for absorbers
  - 5 mm gas (Ar/CO_2)
- Readout granularity 1x1 cm^2



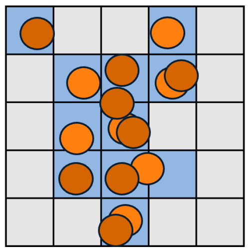
Result: longitudinal containment in 10 λ, transversal in 3 λ



Energy resolution in the 3 TeV Muon Collider framework

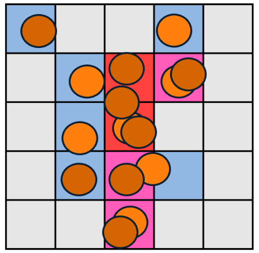
DIGITAL READOUT

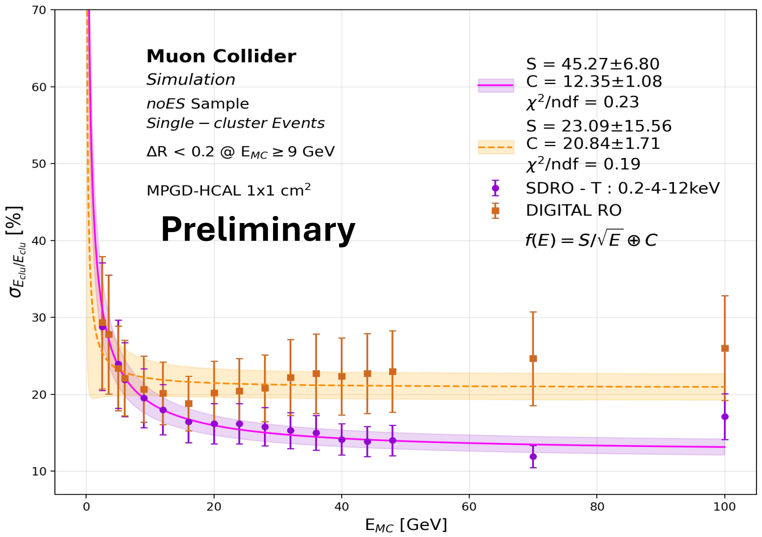
$$E_{cluster} = f(N_{hits})$$



SEMI-DIGITAL READOUT

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

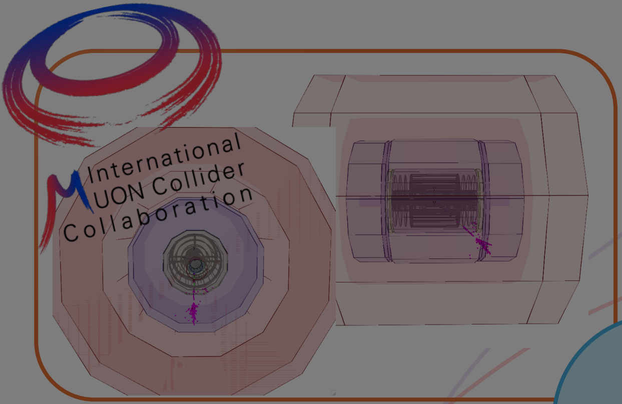


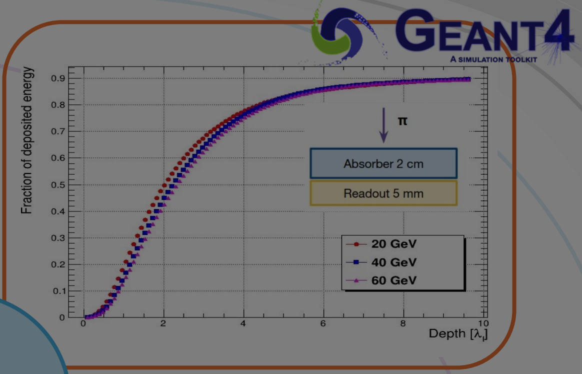


- Energy resolution saturates with digital readout for energies > 40 GeV
- Better performance with semi-digital readout

$$\sigma/E = 46\%/\sqrt{E} \oplus 12\%$$

MPGD-HCAL R&D Strategy





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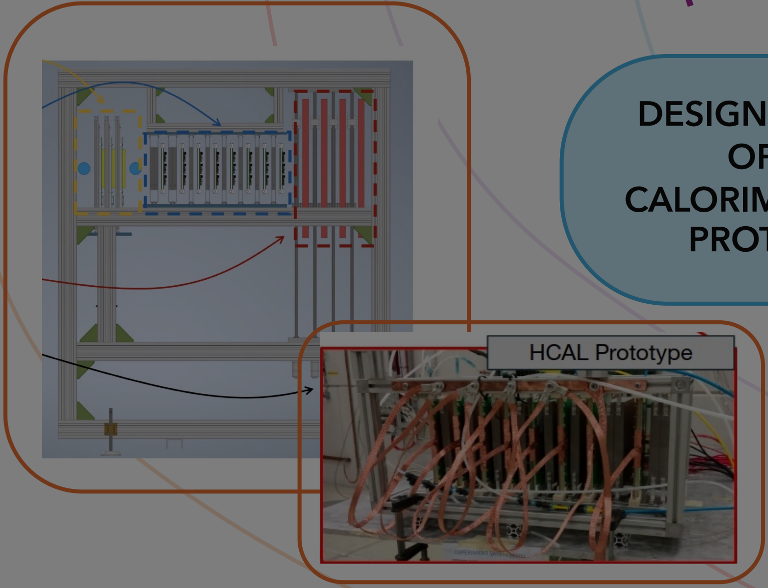
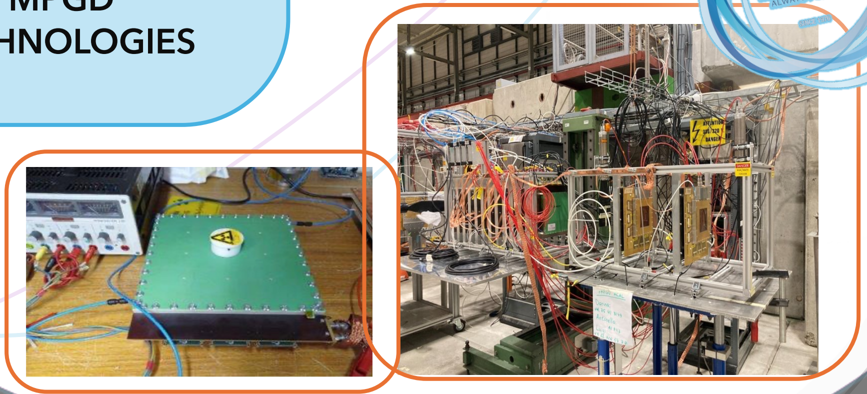




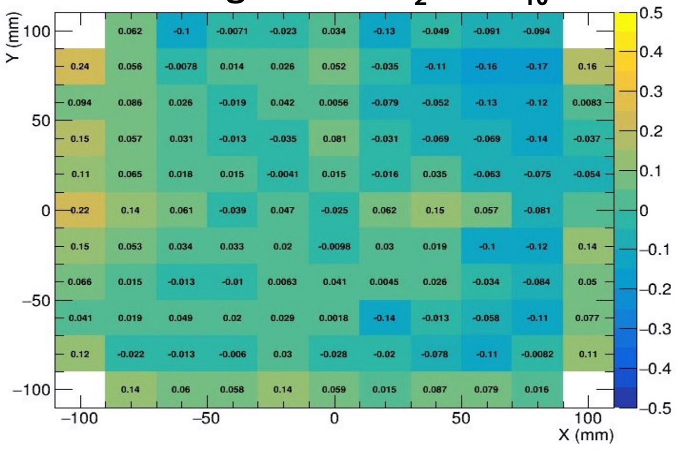
SPS TEST BEAMS 2023 & 2024

MPGD prototyope characterization with MIPs

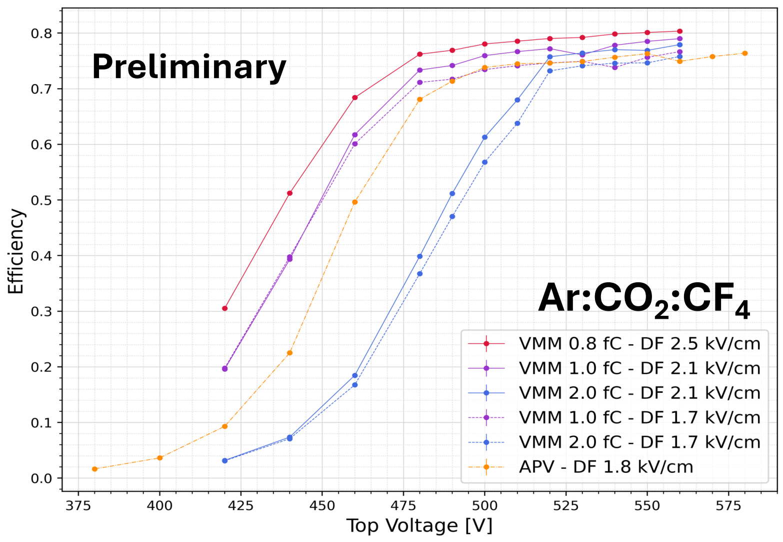
SET UP: external trigger and tracking system + pads chambers under test

- Consistent results for **APV25** and **VMM3a ASIC** as front-end electronics
- **Gain uniformity:** Best values for MM (σ/μ ~ 10%)
- Full turn-on **efficiency vs gain :**
  - Plateau > 90% for MMs, ~ 90% for μ-RWELL s
- **Time resolution:** Best values of **~ 6 ns for μ-RWELLs** in $Ar:CO_2:CF_4$ at a 560 V top voltage and ~5 kV/cm drift field

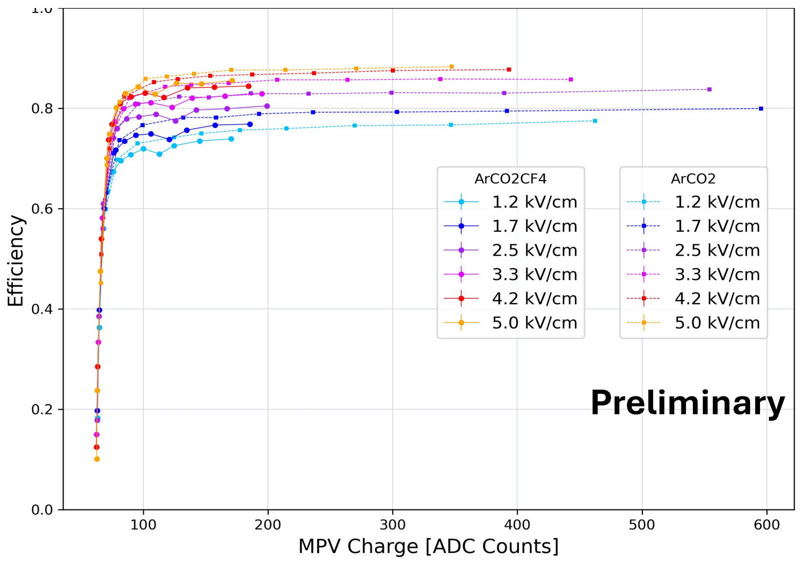
MicroMegas - $Ar:CO_2:iC4H_{10}$



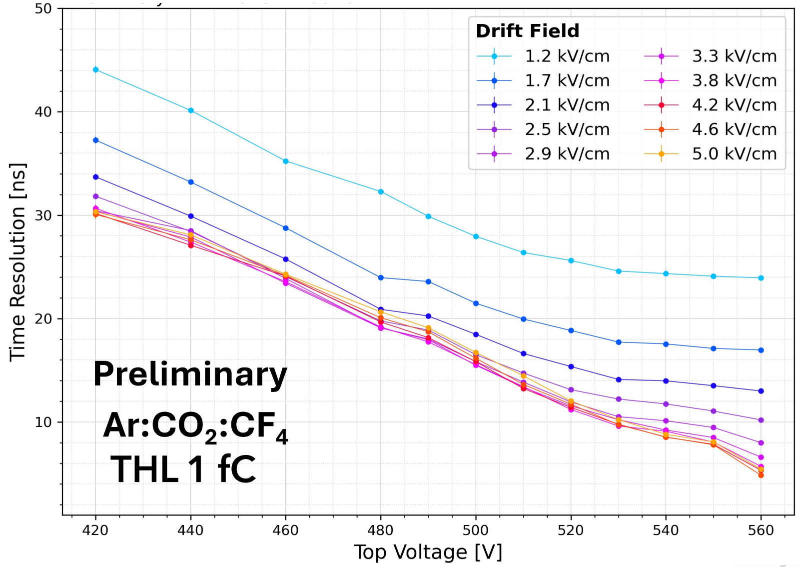
μ-RWELL - electronics comparison



μ-RWELL - gas mixture comparison



μ-RWELL - time resolution



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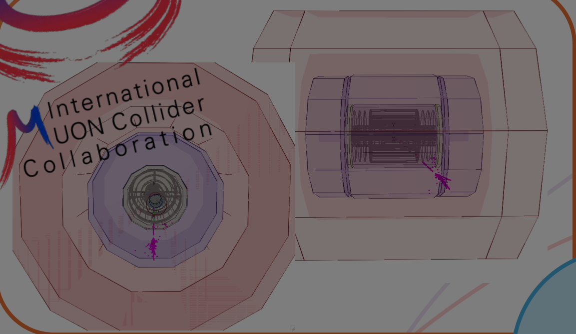

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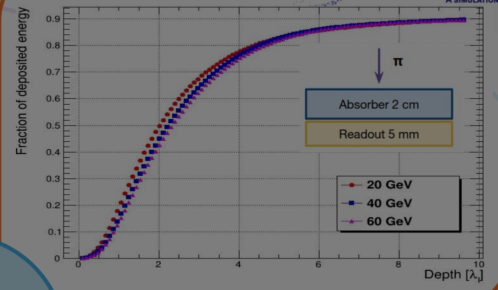

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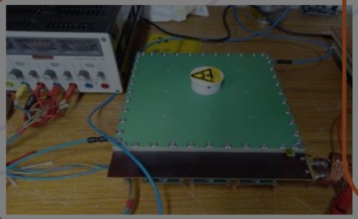

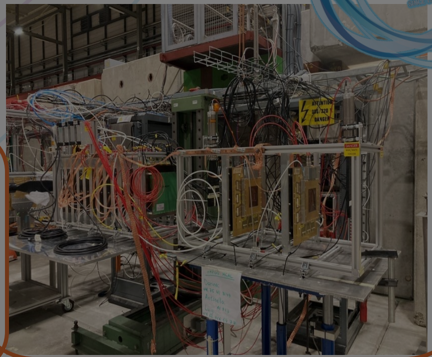

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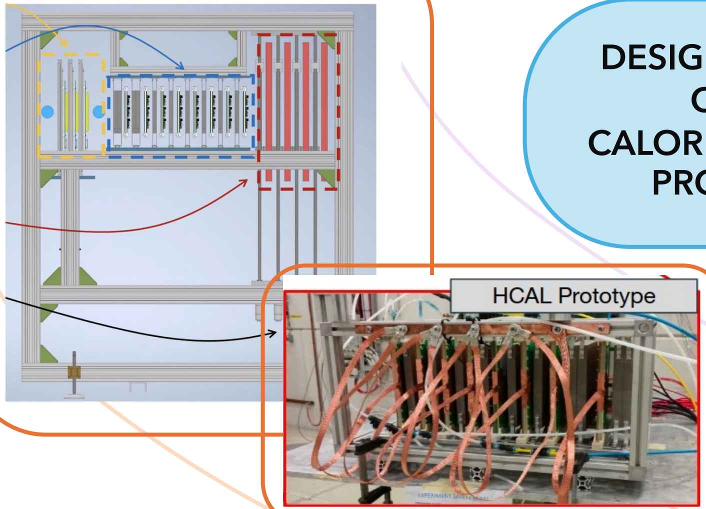
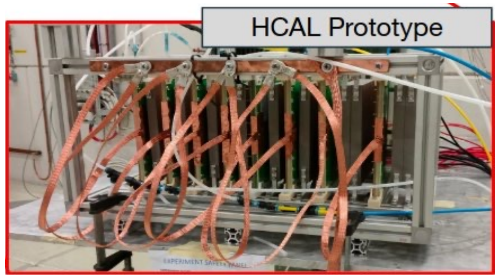


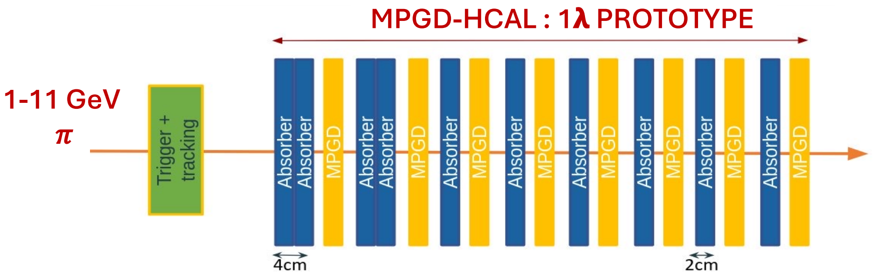
sets the performances for

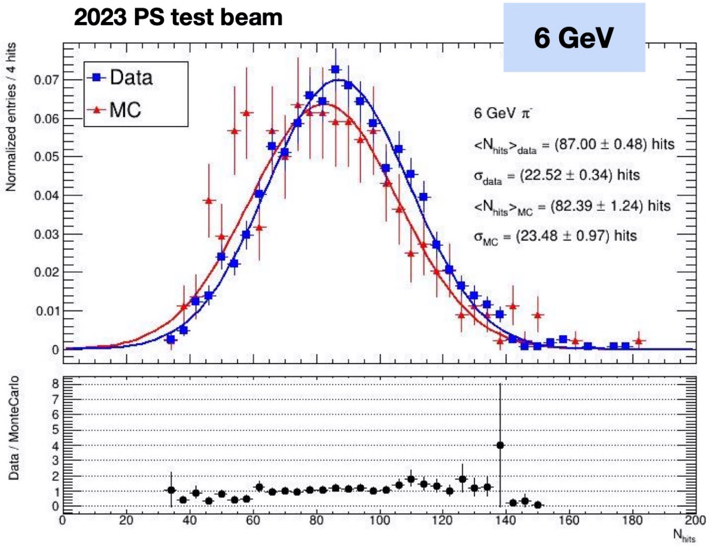
PS TEST BEAMS 2023 & 2024

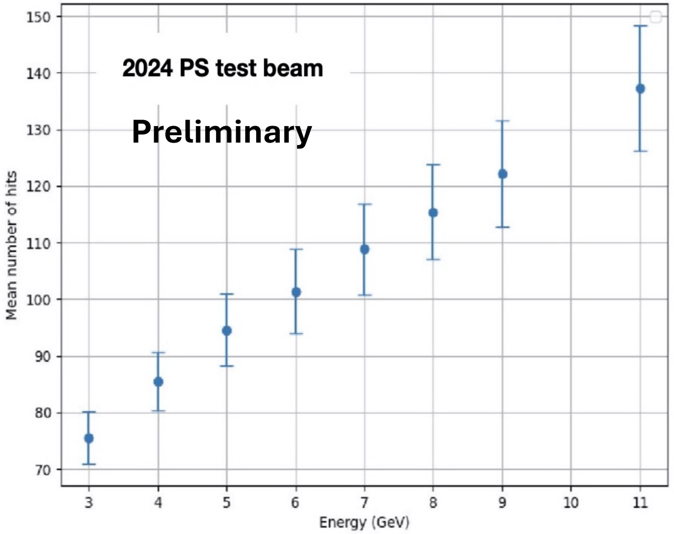
Study of pion showers in a cell HCAL prototype



Goal: Measuring the energy resolution of a 1 nuclear interaction length (λ) calorimeter prototype (8 layers of 20x20cm^2 MPGDs) with 1-10 GeV pion beam







Preliminary results for digital readout:

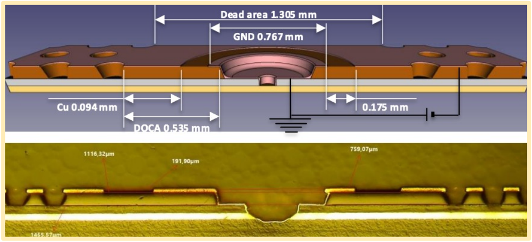
- Good data/MC agreement in the number of hits per shower
- Good linearity in the number of hits with energy
- Saturation at high energy due to shower containment

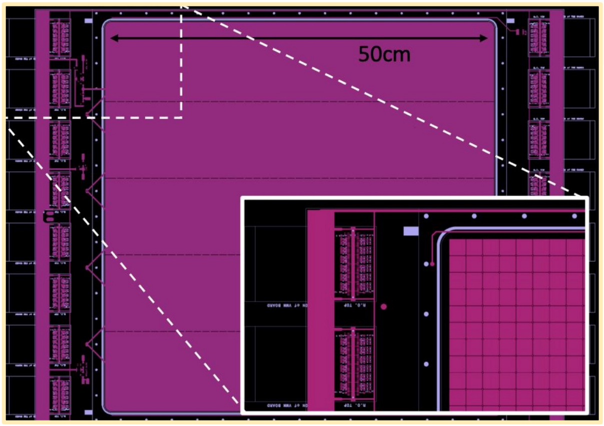
FUTURE PLANS

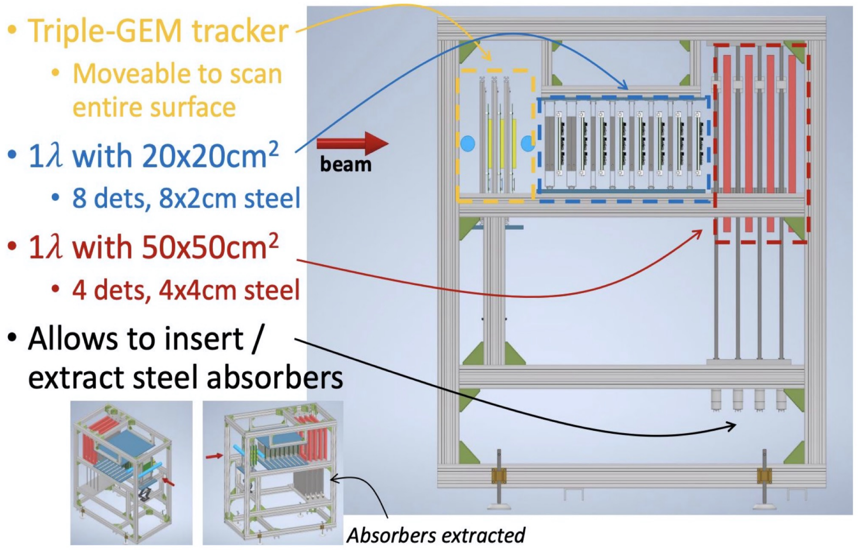
R&D of a new cell prototype

4 new large 50x50 cm² detectors to be produced and tested:

- 121 mm² pads, read out by 16 APV/VMM cards
- For μ-RWELLs : novel <u>PEP-DOT DLC grounding</u>
- Timing studies
- Response uniformity test







Integration with fast, high-rate read-out electronics :

- Continuing studies with VMM3a
- Test with FATIC3 chips

Further studies :

- Energy resolution using the semi-digital approach
- Optimization of the drift gap width for timing and gain
- Alternative gas mixtures

Common project:

- TB with ECAL CRILIN in 2026

THANK YOU

FOR THE ATTENTION

BACKUP SLIDES

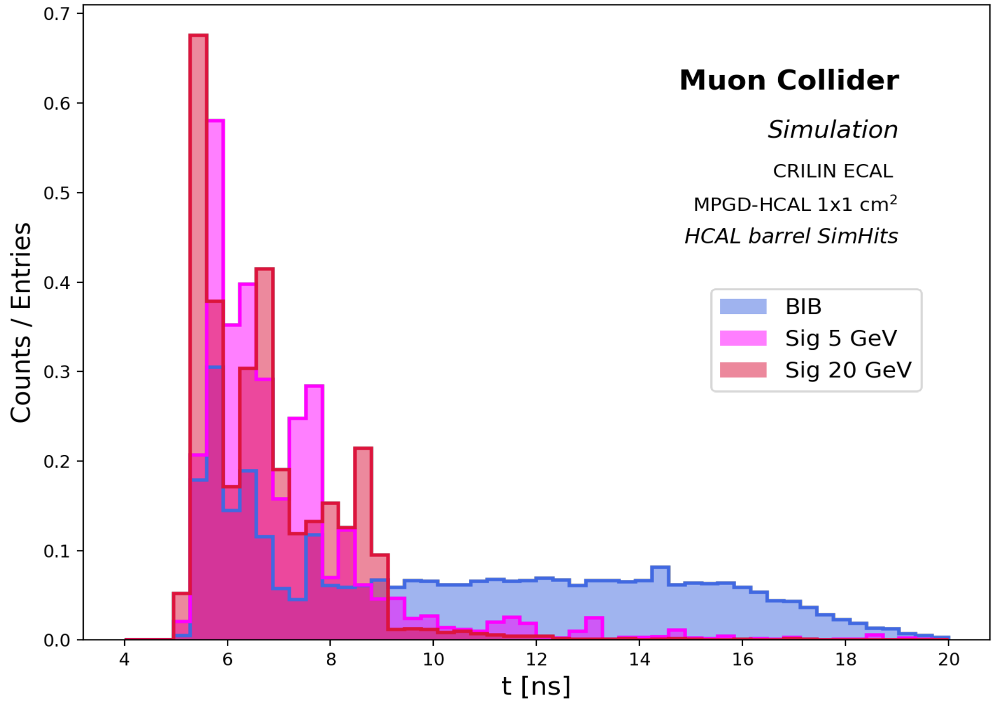
SIMULATIONS

Pion Guns + background in the Muon Collider framework

Simulation of Beam Induced Background (BIB) (at a center of mass energy of 1.5 TeV)

- BIB containment within the first 20 layers
- Uniform distribution of arrival time in the range 7-20 ns

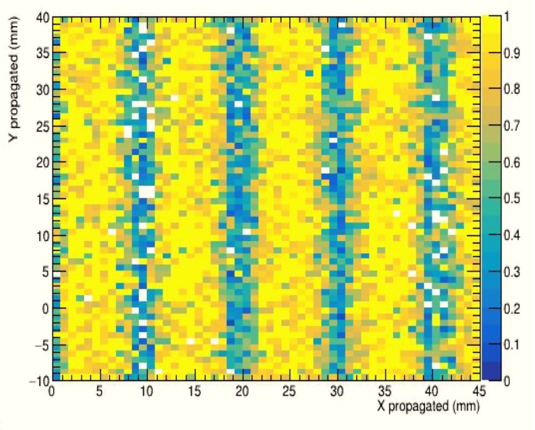
ARRIVAL TIME



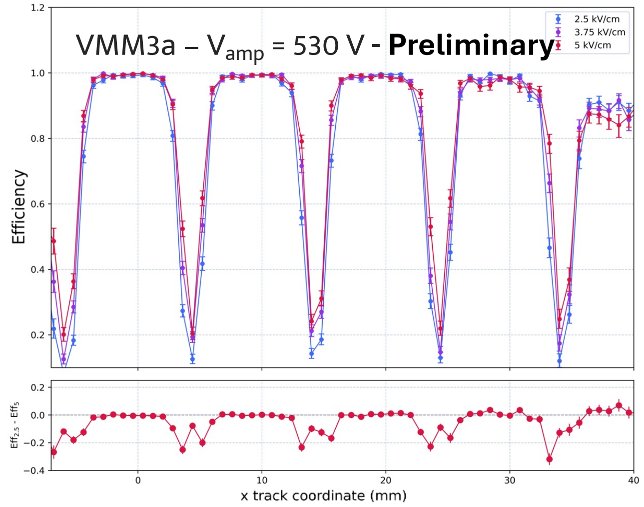
- Signal arrival time peaks at ~ 6ns;
- Discrimination possible for t > 9/10 ns
  → achievable with MPGD detectors

SPS TEST BEAMS 2023 & 2024

μ-RWELL characterization with MIPs

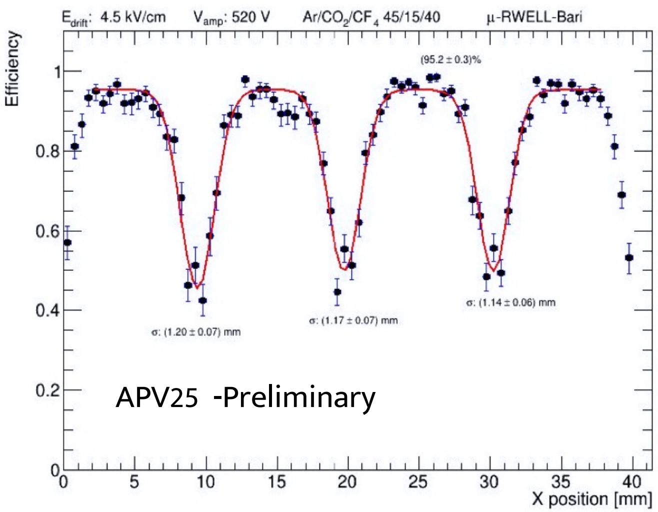


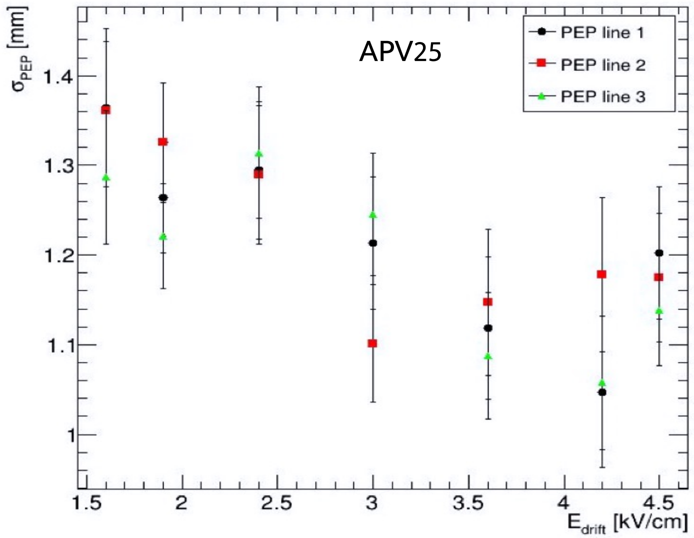
- For a high enough amplification field, the efficiency increases with the drift field despite a drop in the ADC MPV
- Efficiency drop due to PEP lines with dead areas of ~1 mm
- At increasing DF, the efficiency drop region gets thinner and smaller



Interpretation :

- The DF increases the charge collection close to the PEP lines, enhancing the overall efficiency, provided the amplification field is larger than 520 V
- Otherwise, acceptance is reduced by lower collection efficiency in the holes





SPS TEST BEAMS 2023 & 2024

μ-RWELL characterization with MIPs

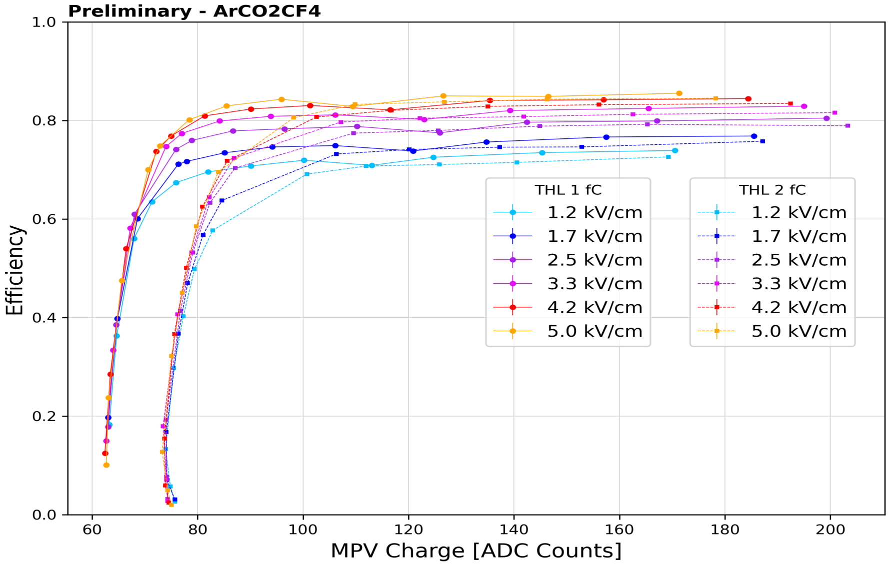
Analog Threshold Comparison

THL 1 fC Vs 2 fC

- Plateau reached almost for the same charge value, independently of the drift field :

  THL 1 fC @ ~80 ADC counts
  THL 2 fC @ ~100 ADC counts

- The lower the THL the larger the saturating efficiency



Charge vs Field Ratio

THL 1 $Ar:CO_2:CF_4$

- Maximum charge at a voltage ratio of ~40