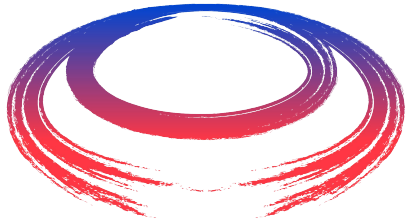


R&D of MPGD-based HCAL for a Muon Collider Experiment

R. Venditti, on behalf of the RD_MuCol HCAL Bari group

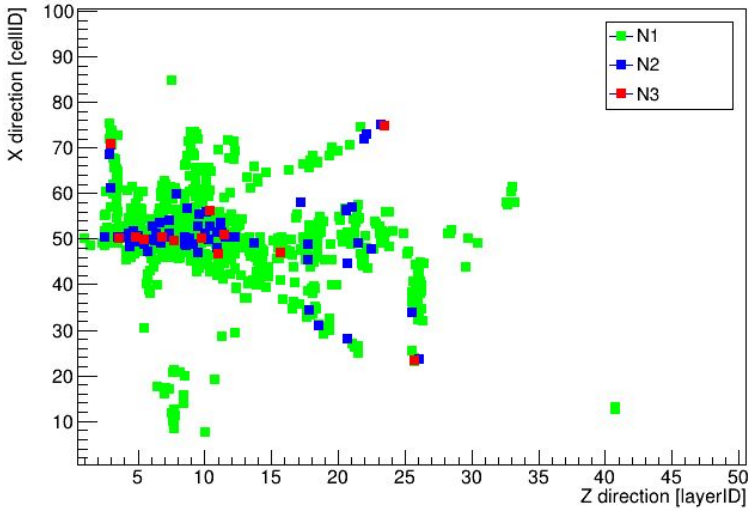
2023 Activity overview

1. MPGD based HCAL for Muon Collider in Geant 4
    - New!! Digital vs Semidigital RO
2. MPGD based HCAL for Muon Collider in Muon Collider Framework
3. MPGD based HCAL Prototype in Geant 4
    - New: First implementation
4. MPGD based HCAL cell Prototype characterization
    - Construction and first measurements

Confronto SDHcal – Dhcal

Risoluzione energetica vs Readout

G4 Simulation 50 ayer MPGD-HCAL



Primi studi sulla elettronica di lettura Semi-Digitale in G4

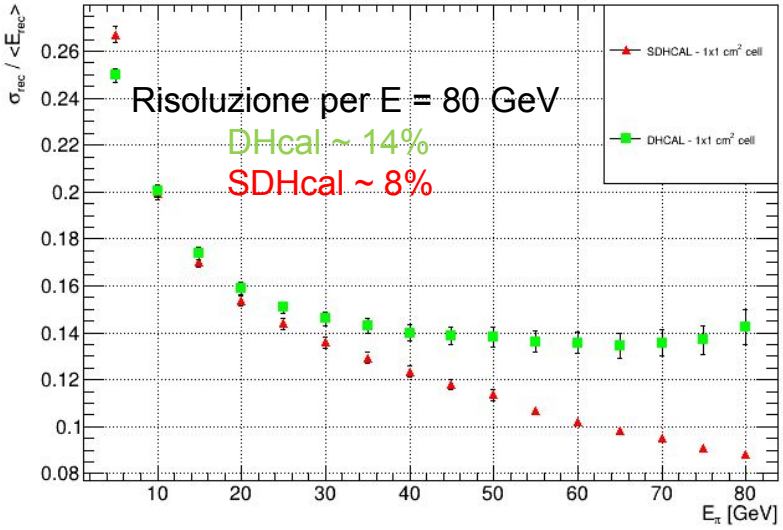
Soglia bassa t_1 $\rightarrow N_1$ hits con $t_1 < E_{hit} < t_2$

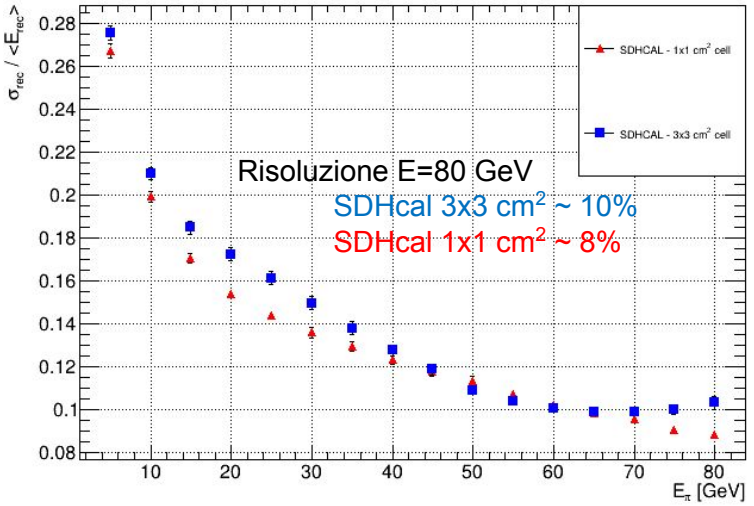
Soglia media t_2 $\rightarrow N_2$ hits con $t_2 < E_{hit} < t_3$

Soglia alta t_3 $\rightarrow N_3$ hits con $E_{hit} > t_3$

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

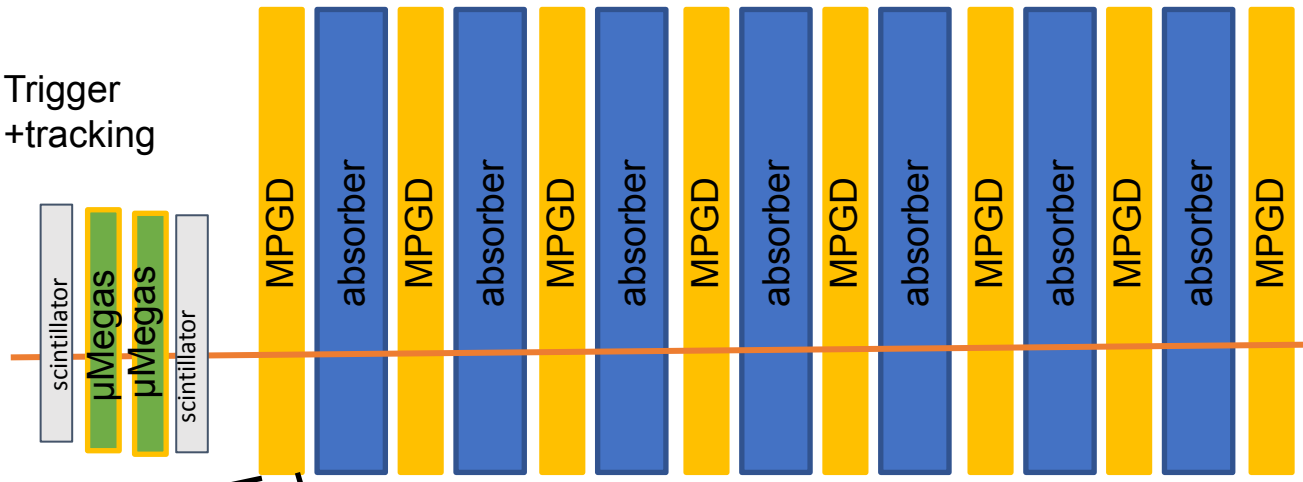
DHcal risente dell'**effetto di saturazione** di N_{hit} ad alte energie (E > 40 GeV):





MPGD-based HCAL cell - Proto 0

Layout

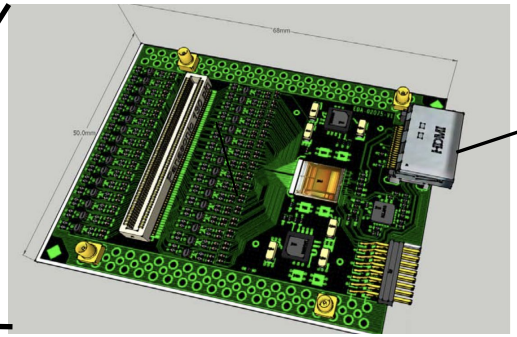


6-8 layers
-MPGD=µRWell, µMEGAS
-2 cm Fe absorber (1 lambda)

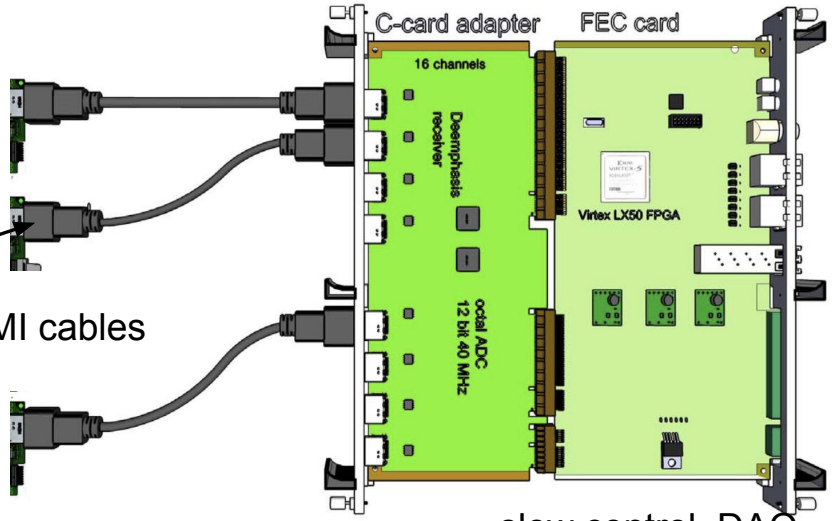
20x20cm^2 MPGD
(384 pads - 1cm^2)
-µRWell
-µMEGAS

APV25
APV25
APV25

APV25 , 128 ch
Analogic readout



HDMI cables



ADC, clock

slow control, DAQ, trigger, event builder

Two test beam campaigns in 2023 to measure:

- **single MPGD performance (1-15 luglio)**
- **HCAL cell performance (29 agosto-7 settembre)**

MPGD-based HCAL cell - Proto 0

G4 Simulations

6 layers of 20x20cm^2 → to be updated with 8 layers

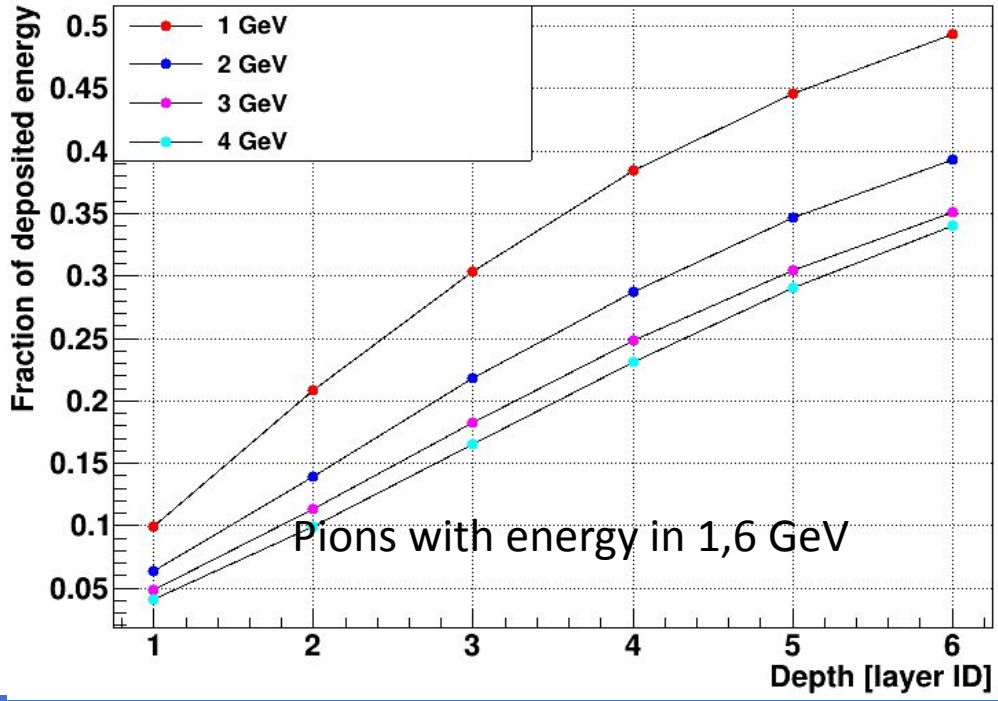
- 4 cm of Steel (**absorber**) → to be updated to 2 cm
- 1 mm of copper (for the cathode)
- 5 mm of Ar/CO2 (**active gap**)
- 1 mm of Fr4 (for the PCB RO board)
- Granularity given by cell of 1x1 cm²

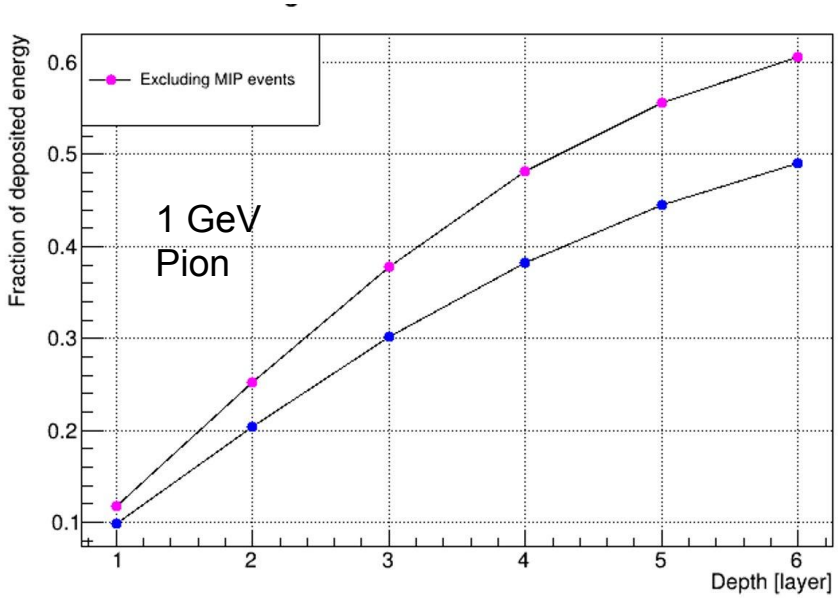
G4 Simulation 6 layer MPGD-HCAL

Idea:

-study the hit distributions for fully contained showers in simulation.

-Use the results to tag fully contained showers in the TB.

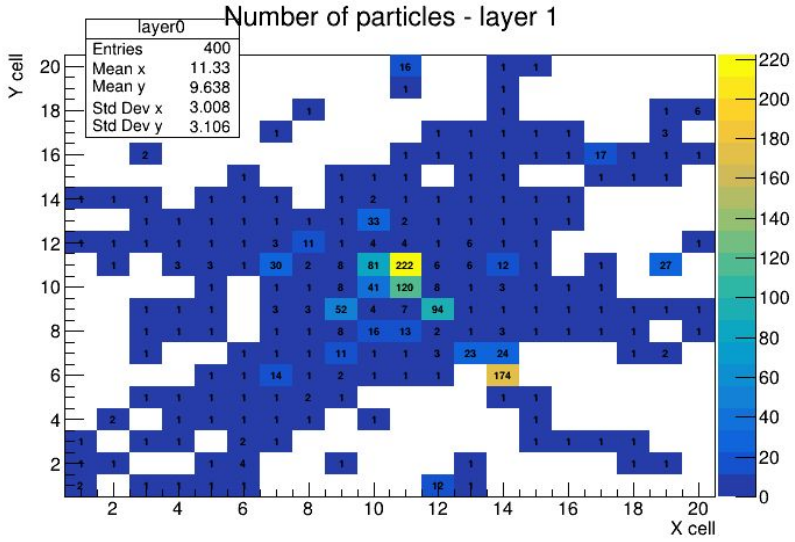




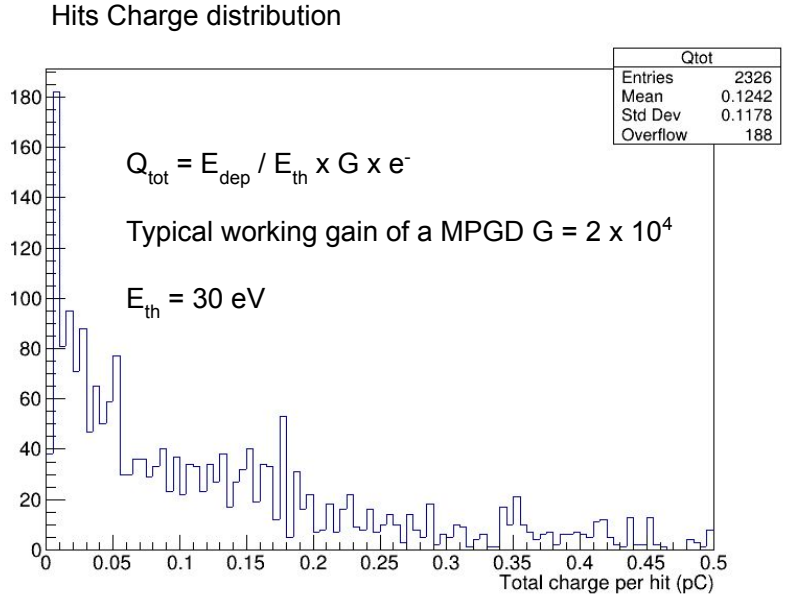
MPGD-based HCAL cell - Proto 0

G4 Simulations

- Semidigital readout would allow to improve the energy resolution → Need to define the optimal thresholds
- Compute the expected electric charge released by the particles in the hadronic shower in a 1x1cm^2 cell in each layer
    - **to be compared with results obtained at TB**

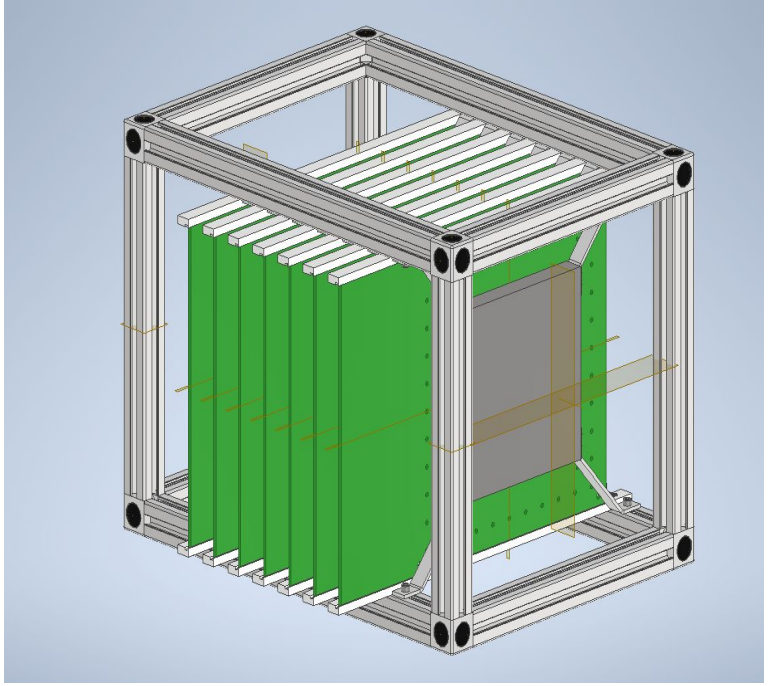


Conversion from E_{dep} into charge arriving to Front End electronics



Extract the energy deposit for the single hit E_{dep}

Proto 0 status



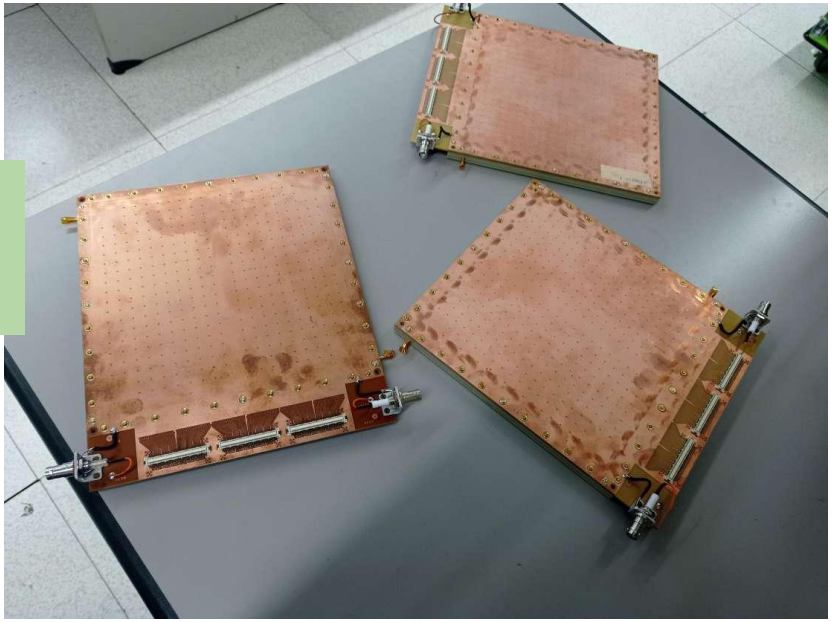
HCAL cell Protoype design:

- 8 MPGD (µrwell, µMegas) active layers
- 2cm x 8 Fe absorber layers ($1\lambda_N$)
- 20x20 cm^2 detectors
- $1cm^2$ pad⟶ 384 pad
- Common Readout board
- (Analogic) readout by SRS system (APV25+ADC+FEC)

MPGD rotal production batch:

- 7 uRWELL
- 4 MicroMegas

one of the goals of such R&D is to choose the best technology for calorimetry @ Muon Collider



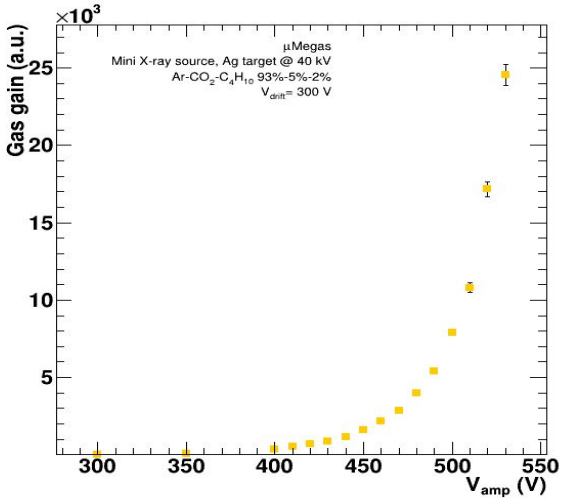
3 detectors shipped to Bari (2µRWell, 1MM), 2 Weizmann, 2 Roma3, 2 Napoli, 2 LNF

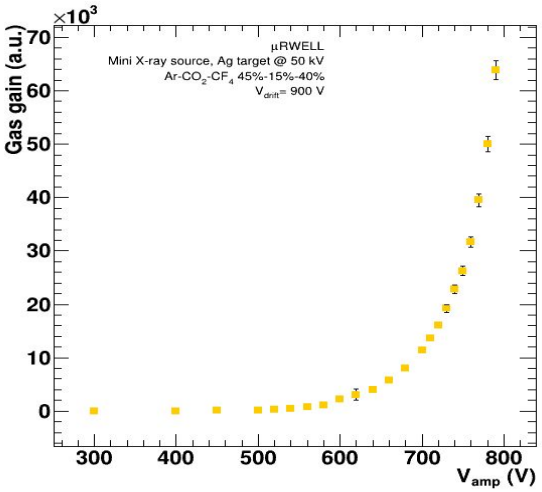
- Preliminary test done at CERN
- First characterization in lab

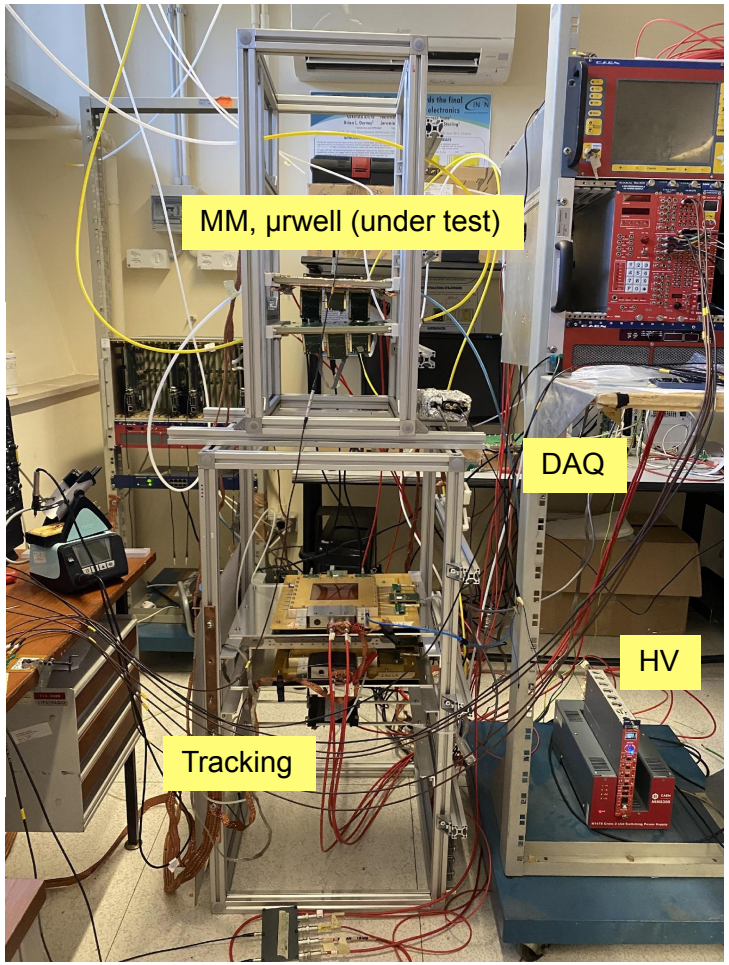
Prototype characterization in lab

Preliminary test in lab in the involved institutes (Ba, LNF, Rome3, Weizmann):

- HV stability
- effective gain and response under X-ray, Fe55





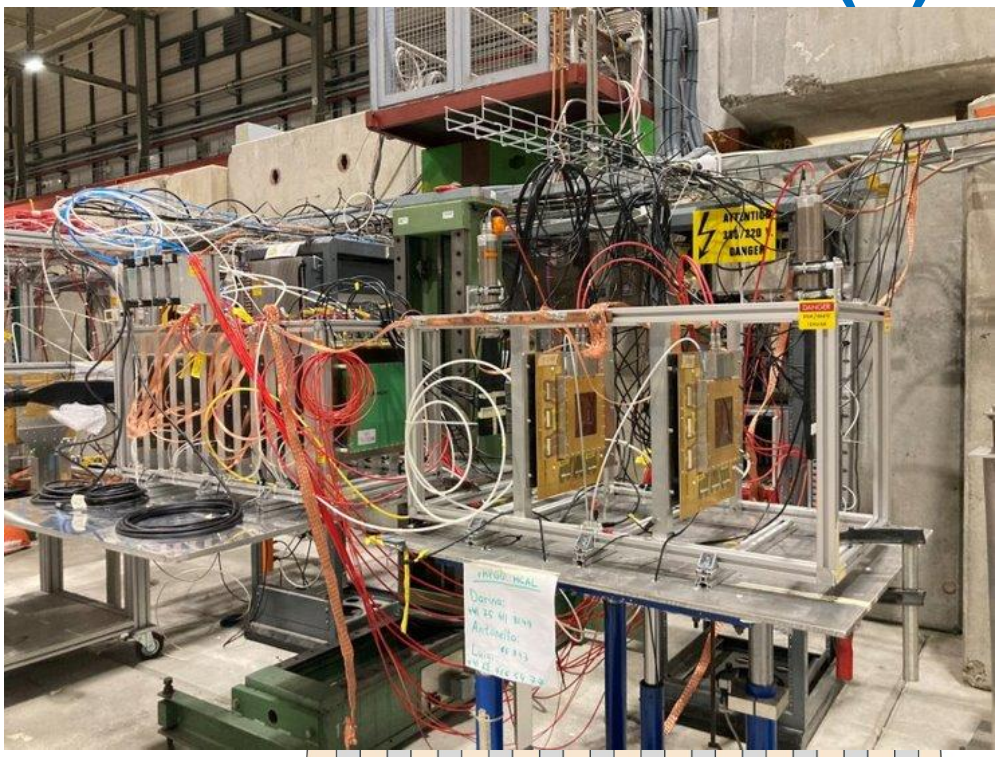


Setup of test stand in Bari

Performance measurement in test beam (1)
MPGD layers

July 2023: MPGD test beam campaign at SPS with O(100 GeV) muon beam with the goal to measure

- response uniformity
- efficiency
- spatial resolution

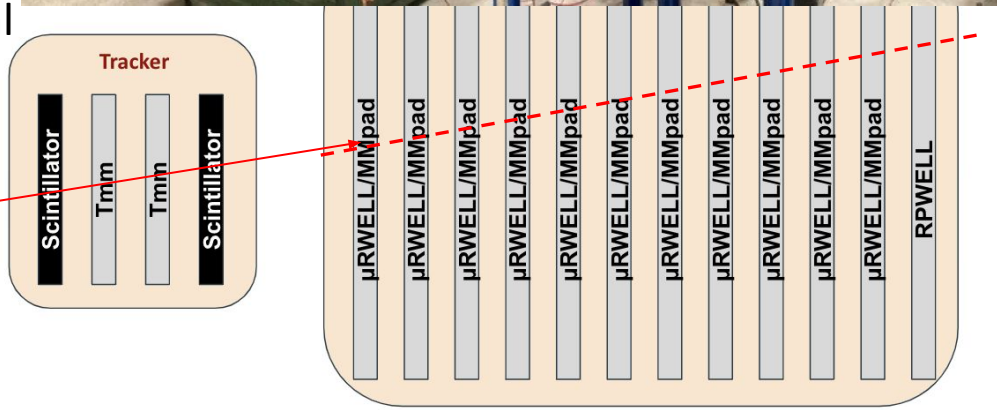


Data taking:

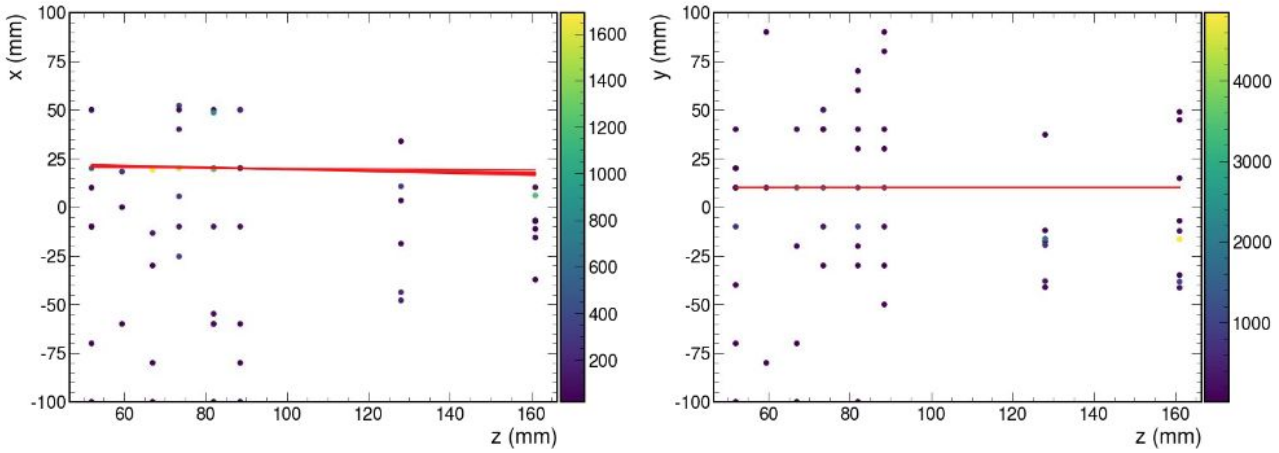
- 12 chambers to be tested in total, read 6 chambers at a time
- HV, Drift field, XY position scan
- During last days we instrumented only central pads to read all the calo-chambers at once

Two methods for track reconstruction:

1) Hits from TMM propagated to the surface of the chamber under test → some problems in correlating hits with chambers under test
2) TMM excluded, reconstruct the track using hits from 5 detectors, the 6 chamber is the one under test

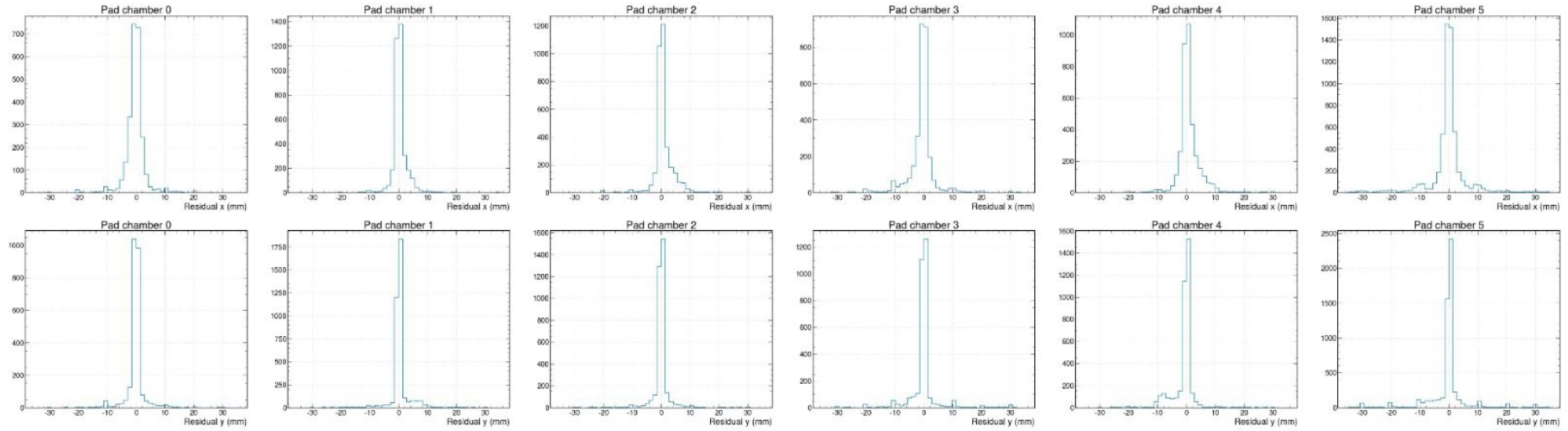


Performance measurement in test beam (1)
Preliminary results

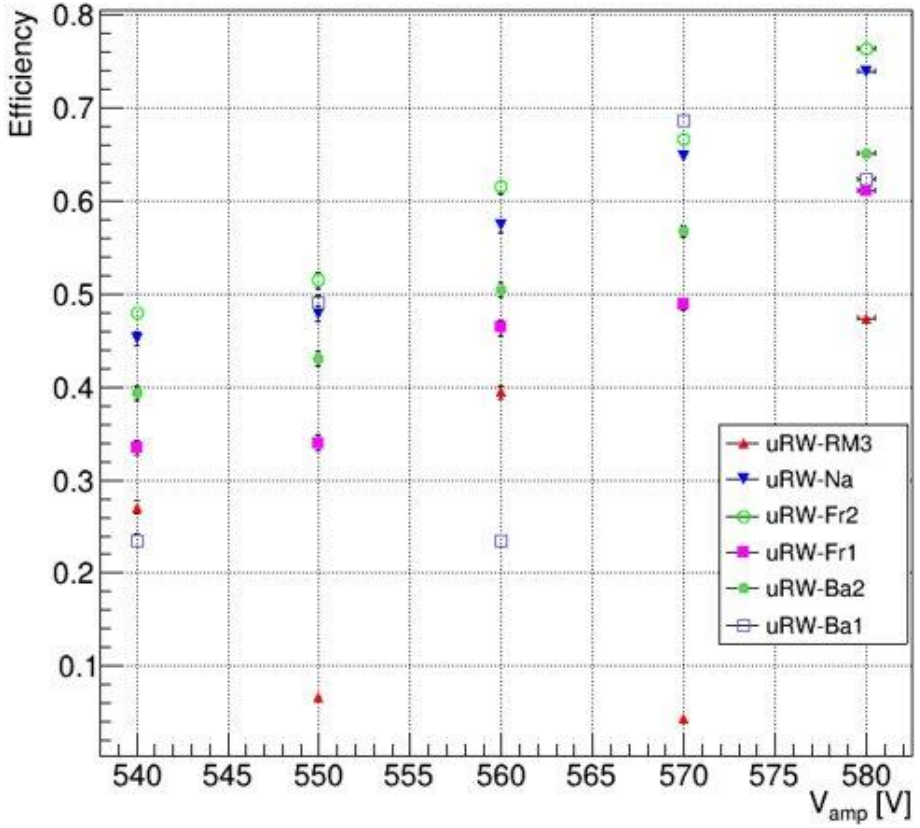


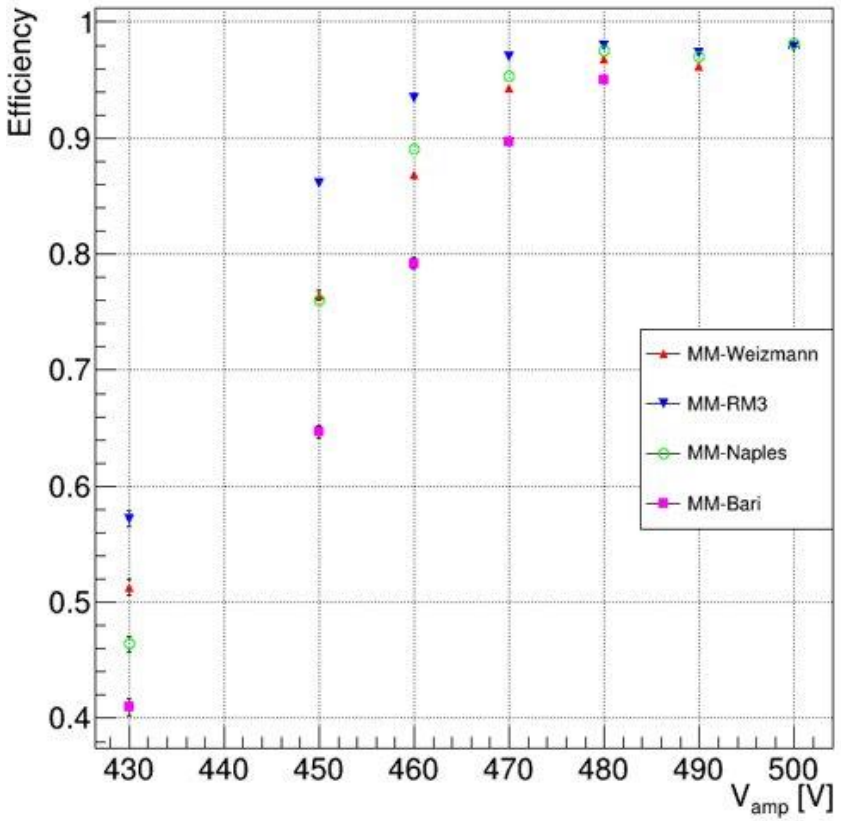
Method 2): iteratively exclude each detector, use the other 5 to reconstruct the track and extrapolate it to the detector under test

Narrow residuals, in agreement with detector granularity



Performance measurement in test beam (1)
Preliminary results



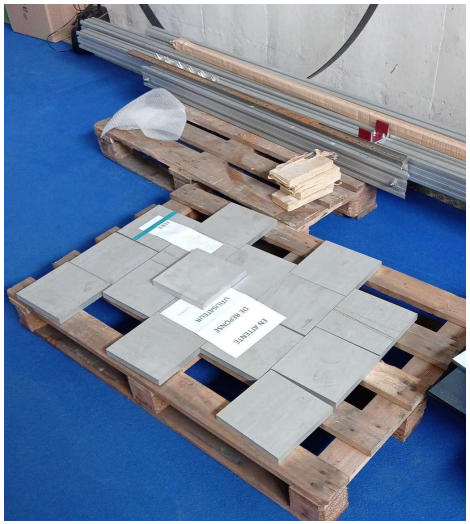


Performance measurement in test beam (2)
HCAL cell

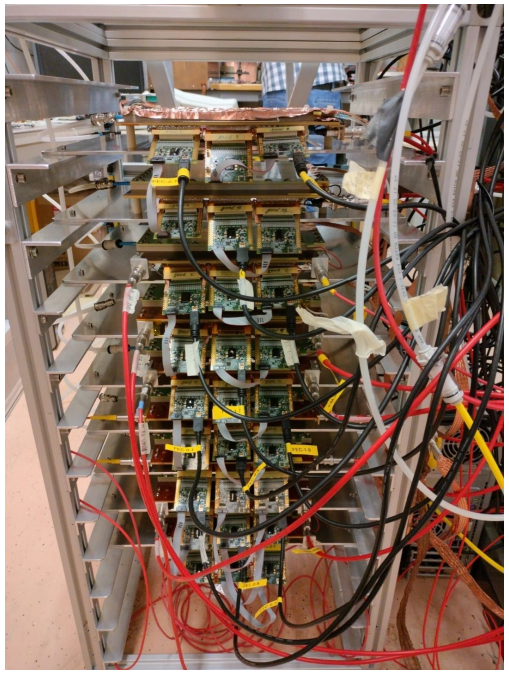
August 2023: Full prototype test beam campaign at PS

- pure pion beams
- few mm collimation
- monochromatic E=1, 3, 5 GeV

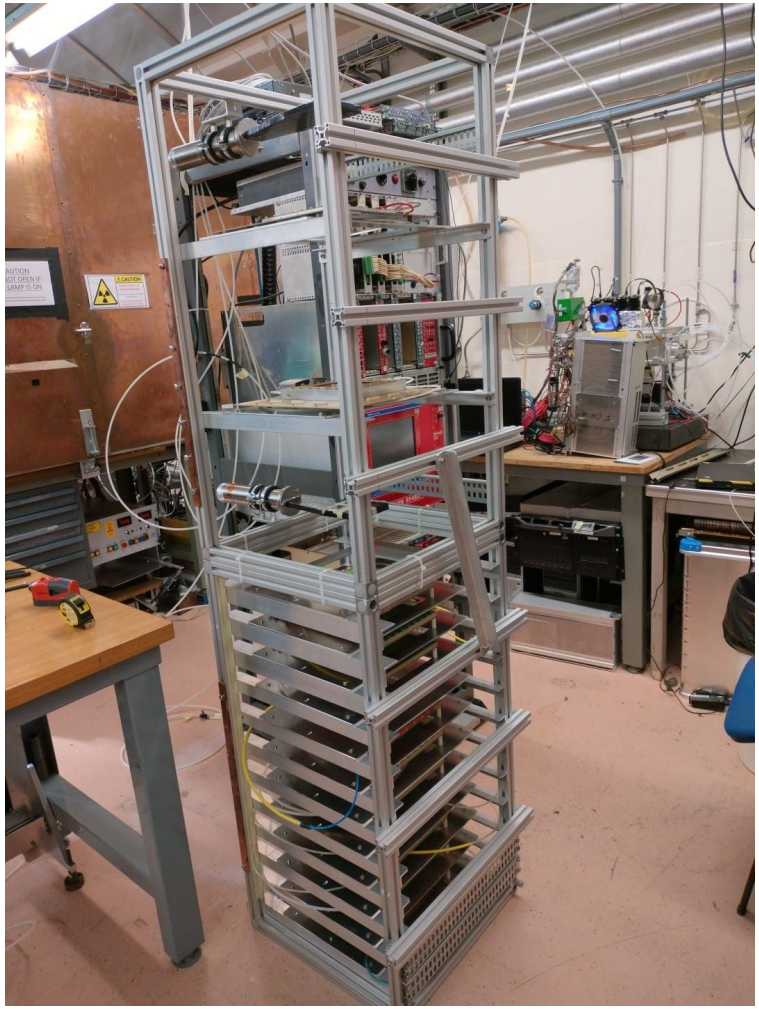
First operation of the full system!



Stainless steel absorber tiles

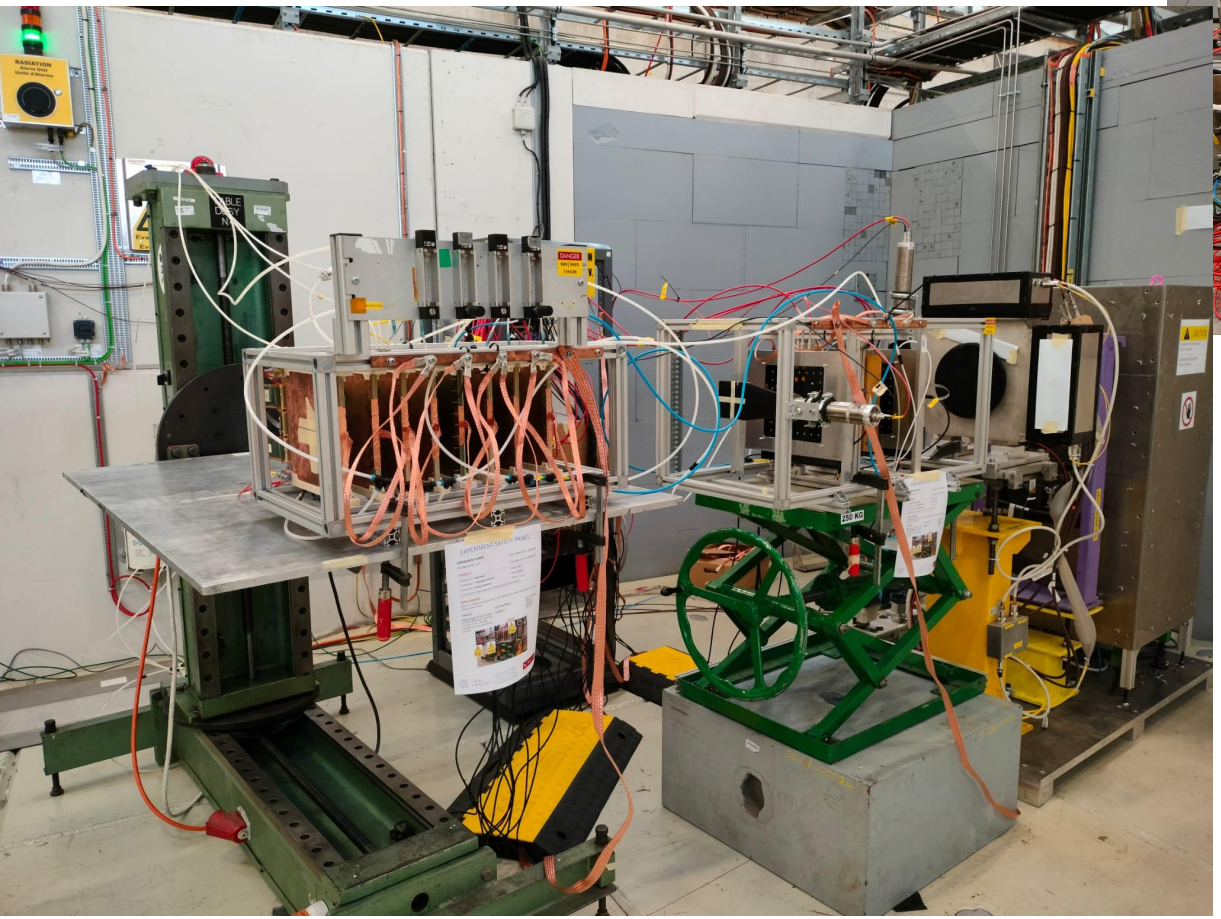


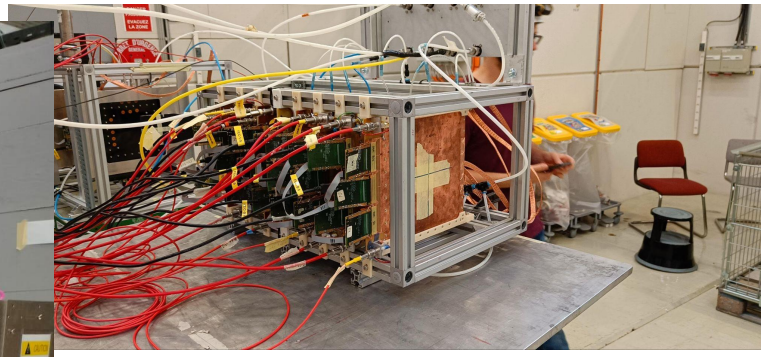
MPGD with APV connected



Setup in GDD lab at CERN (structure for MPGD test)

Performance measurement in test beam (2)
HCAL cell





Scientific program

- without absorbers: further response scan
- with absorbers: energy and energy resolution measurement with monochromatic beam
- Define the thresholds for semidigital readout using the per-pad charge distribution obtained with the analogic readout

Presentazioni a conferenze e programmi di ricerca

- **Phd thesis:** “Development of a MPGD-based hadronic calorimeter for a future Muon Collider Experiment”, A. Stamerra
- **Presentation at conferences:**
  - IFAE 2023
  - IWASI 2023 (Monopoli)
  - IWORID 2023, International Workshop on Radiation Imaging Detectors (Oslo)
- Abstract accepted by:
  - IPRD, Topical Seminar on Innovative Particle and Radiation Detectors, Siena
  - IDTM, Innovative Detector Technologies and Methods, Lisboa
  - PSD13: The 13th International Conference on Position Sensitive Detectors, Oxford
- 1 borsa CERN Summer Student (covered)
- 1 borsa INFN per neolaureati (covered)
- 1 borsa di dottorato nazionale (deadline 4 Sept.)

Partecipazione a progetti

- RD51 Common project [2020-2022], 30k
- Eurolabs 2023, 4k
- PRIN 2022, 90k

Piani e richieste per 2023 e oltre

2023 plans

- **Simulation studies**
  - **G4**: include BIB, repeat energy resolution studies, update Proto-0 geometry
  - **Muon Collider full sim:** implementation of digital and semidigital RO, timing studies (E_{cm}= 1.5,3,10 TeV)
- **Analysis of test beam data**
  - efficiency, response uniformity, spatial resolution
  - shower containment, threshold studies for semidigital RO vs beam energy
- Design and produce a **new MPGD 20x20 (or directly produce 50x50)**
- Plan is to leave the HCAL setup at CERN after August test beam in RD51 lab
  - explore the possibility to test some new RO electronics

Milestone	Description	Expected	Achieved
MS4	Test beam of MPGD active layers at SPS	March 2023	July 2023
MS5	Assemblaggio del prototipo ($1\lambda_N$) di cella calorimetrica	June 2023	August 2023
MS6	Test su fascio del prototipo ($1\lambda_N$) di cella calorimetrica	Oct 23	August 2023
MS7	Realizzazione prototipo con 2 λ_N	Dec 23	
MS1-Sim:	GEANT simulation of MPGD-HCAL	Dec 23: Study the response to multiple MIPs, introduce timing.	
MS2-Sim:	Impact on charged hadrons/jet reconstruction in Muon Collider full simulation	Dec 23: implementation of digital and semidigital RO, timing studies (E_{cm}= 1.5,3, 10 TeV)	

MPGD-HCAL in DRD

- The roadmap **of gaseous detectors for calorimetry at future HEP experiments** is framed in **DRD1-WP5**. We are active part of the proposal. Main points for MPGD-HCAL R&D:
  - T6: study of the detector time resolution, crucial to reduce the BIB.
  - M1: construction of medium size gaseous detector.
  - M2: uniformity study including efficiency and cluster size with medium size detectors.
- The roadmap of **calorimetry at future HEP experiments**, framed in **DRD6-WP1** (sandwich calorimeters with embedded electronics) target the development of proof-of-principle HCAL cell of increasing size.

Name	Calorimeter Section	Sensitive Material/Absorber	Target Application	Current Status
MPGD-HCAL	Hadronic	MPGD (Micromegas, μRWELL)/Steel	$\mu^+\mu^-$ collider central detector	Small prototype for proof-of-principle, Lateral and longitudinal extension envisaged

	Milestone	Deliverable	Description	Due date
MPGD-HCAL	M1.11		Specifications for 50x50 cm^2 prototype	2025
	M1.12		Design of 50x100 , cm^2 layers	2026
		D1.14	Completion of 6 layers 20x20 cm^2 prototype	2024
		D1.15	10 layers prototype (6L:20x20cm^2, 4L:50x50 cm^2)	2026
		D1.16	3x100x100 cm^2 layers	>2026

From DRD6 Proposal document

MPGD HCAL DRD1,6 activities (2024)

Time resolution measurement of µRWell and µMEGAS

- 2023 test beam results analysis
- Setup of the cosmic telescope in Bari
  - 2 plastic scintillators + light guide+ PMT
- Measurement in Test beam

Richieste:
-2 plastic scintillators + light guide+ PMT → **5k**
❖ **Sinergica a DRD1**

Toward $3\lambda_N$ prototype (10 layers)

- 2023 test beam results analysis
- final technology choice (µMEGAS, µRWell)
- **Design and production of 50x50 MPGD**
  - 50x50 Readout board design
  - characterization in lab and with beams

Richieste:
-2 MPGD of 50x50 cm^2 → **15k**
❖ **Sinergica a DRD1**
-8 layer Fe 50x50 cm^2, spessore 2 cm → **1.5 k**
❖ **Sinergica a DRD6**
-materiale test stand MPGD + infrastruttura HCAL →**2k**
❖ **Sinergica a DRD6**

- test beam (time resolution + 50x50 response) → **11k**
❖ **Sinergica a DRD1**

Readout electronics studies (2024)

- **Readout electronics for calorimeters in future HEP experiments** should be able to provide
  - time measurement with O(ns) accuracy
  - large dynamic range to provide precise energy measurement in a wide range
  - operation with small power consumption (huge numbers of channels)
- On the long term: **develop a common electronics in DRD6, DRD1-WP5**
- On the short term: we need r**eliable electronics to commission our prototype**, as close as possible to the current state-of-the art (e.g. semidigital used by CALICE)
- HCAL TB in 2023: APV25 asic + SRS (DAQ)
  - borrowed from with CMS-GEM setup
  - full analog readout
  -
- Possible options:
  - GEMROC; dynamic range in 1-500fC, 3 adjustable thresholds, time jitter ~ few ns
  - FATIC: sensitivity ~ few fC, rise time 7 ns, time jitter 100 ps

Richieste finanziarie: Plugin card per interfaccia detector-ASIC→ **5K (Sinergica a DRD6)**

SJ, per definire specs e una strategia comune con gli R&D in corso per abbattere i costi di produzione futuri

Gli asic saranno finanziati da PRIN 2022

Activity 2024: first characterization of RO electronics on detector

-full simulation and TB results studies to define the specs

-procurement and characterization of chips needed to instrument one 20x20 MPGD

Totale richieste 2024

Capitolo	Descrizione	Parziali (K-EUR)	Parziali SJ (K-EUR)
consumo	DRD6 [MPGD-HCAL] - Materiale per costruzione dell'infrastruttura meccanica della cella calorimetrica (MPGD+assorbitori).	2	
consumo	DRD1-WP5 [MPGD-HCAL]: Materiale per setup di misura di risoluzione temporale di rivelatore MPGD: 2 scintillatori plastici 20x20 cm^2 + 2 PMT con guida di luce	5	
consumo	DRD1-WP5 [MPGD-HCAL] - Costruzione di 2 rivelatori MPGD 50x50 cm^2 (nota: il prezzo quotato si riferisce alla tecnologia micromegas. Qualora l'opzione piu' conveniente risultasse la micro-rwell, costo sarebbe il 30% piu' basso).	15	
consumo	DRD6 [MPGD-HCAL]: Lastra di Ferro (200x100x2 cm^3) per assorbitore per realizzazione di prototipo 50x50 con 1/2 lunghezza di interazione nucleare.	1,5	
consumo	DRD6 [MPGD-HCAL]: schede di acquisizione per la lettura di un MPGD 20x20. Acquisteremo i 6 ASIC necessari (valore stimato circa 5k) con con i fondi PRIN2022. Chiediamo all' INFN di coprire l'acquisto delle schede di plugin necessarie per montare gli ASIC sul rivelatore. Chiediamo SJ perche' intendiamo studiare i risultati dei test beam 2023 e consultare i colleghi di CALICE prima di prendere una decisione sulla tipologia di elettronica da acquistare (nell'ottica di fare un test beam comune con il setup di CALICE).	5	5
Totale consumo		28,5	
Missioni	DRD1-WP5 [MPGD-HCAL] : Test beam per misura della risoluzione temporale dei rivelatori MPGD 20x20 e primo test dei rivelatori 50x50 (3settimane x 3 persone + trasporto materiale). Chiediamo SJ perche' vorremmo studiare i risultati dei test beam del 2023 prima di progettare un test beam per il 2024.	11	11
Totale		39,5	16

2024-2026 project overview

[2024-2025]:**3λ_N prototype**

(2λ_N (6 MPGD 20x20) +1 λ_N (4 MPGD 50x50))

- Design, produce, characterize (lab and test beam) 50x50 MPGD
  - 2024: pre-production of 2 MPGD 50x50
  - 2024: 50x50 MPGD characterization
  - 2025: production of 2 MPGD 50x50
- 2025: procurement of the RO electronics
- 2025: 3λ_N HCAL TB

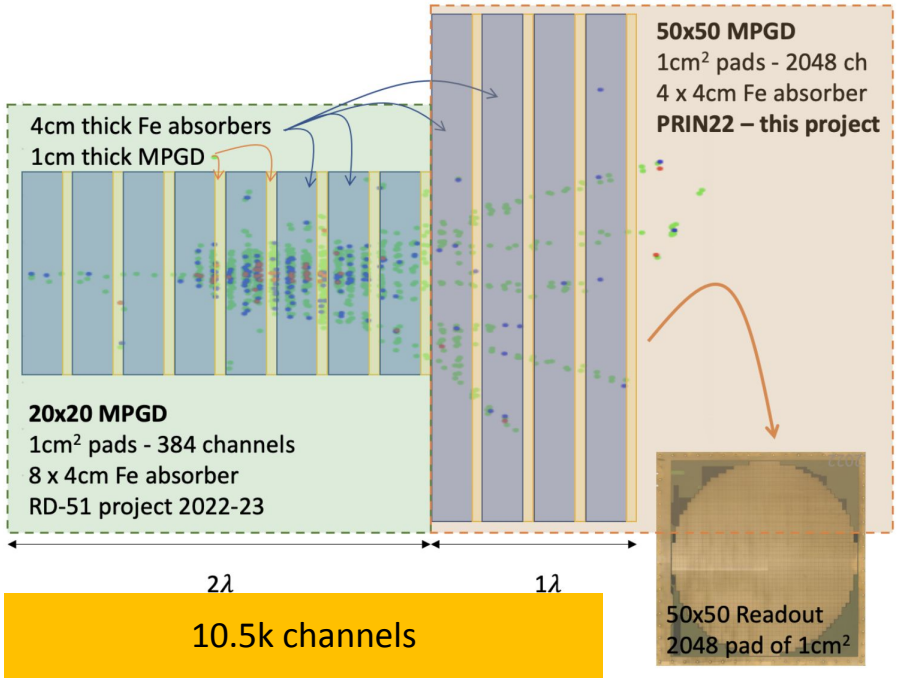


Fig. 2.4: Layout of the HCAL prototype with 3λ depth. The first 2λ is made of the 20x20cm² prototype developed in the RD-51 project in 2022, while the last λ necessary to contain longitudinally (95%) protons and pions of 1-6 GeV is made of 50x50cm² detectors developed in this project.

- [2026-2029] **toward large area**
  - 2026: 2 layers of 50x100 MPGD production + test beam
  - >2027: production of 4 layers of 50x100 MPGD
  - >2027: RO electronics procurement
  - >2027 CALICE Test beam

PRIN 2022 overview

An Innovative and Radiation Hard Calorimeter Proposal for a future Muon Collider Experiment

Simulate, design, construct and test prototype calorimeter for a Muon Collider experiment, optimized for the reconstruction with the Particle Flow algorithm.

- Proposed technology ECAL: CRILIN
  - ⟶ UO2, vice PI: I.Sarra,
- Proposed technology HCAL: MPGD-sampling
  - ⟶ UO1: UniBa, PI: R. Venditti

- Richieste:
  - UO1: UniBa (HCAL) ⟶ 106 k
  - UO2: INFN-LNF (ECAL) ⟶ 142k
- Finanziato
  - UO1: UniBa (HCAL) ⟶ 90k
  - UO2: INFN-LNF (ECAL) ⟶ 120k

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Finanziato dall'Unione europea
NextGenerationEU

Ministero dell'Università e della Ricerca

Segretariato Generale

Direzione Generale della Ricerca

PRIN: PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE – Bando 2022
Prot. 20229TBY8B

PART A

1. Research project title

An Innovative and Radiation Hard Calorimeter proposal for a future Muon Collider experiment: CALORHINO.

Suddivisione dei costi delle Unità

La suddivisione fondi è stata trasmessa il 31/05/2023

N°	Sede dell'Unità	Responsabile Scientifico	Contributo MUR per ricerca	Cofinanziamento Ateneo/Ente	Costo Totale
1	Università degli Studi di BARI ALDO MORO	VENDITTI Rosamaria	89.895	19.827	109.722
2	Istituto Nazionale di Fisica Nucleare	SARRA Ivano	119.939	38.697	158.636
Totale			209.834	58.524	268.358

PRIN 2022: *An Innovative and Radiation Hard Calorimeter Proposal for a future Muon Collider Experiment*

M1: Full implementation of Geant4 model and analysis for ECAL/HCAL

M2: Full implementation of the proposed ECAL+HCAL geometry in Muon Collider simulation framework

M3: ECAL prototype construction and BTF Test Beam

M4: HCAL prototype construction

M5: MPGD Performance measurement

M6: Performance measurement for ECAL+HCAL

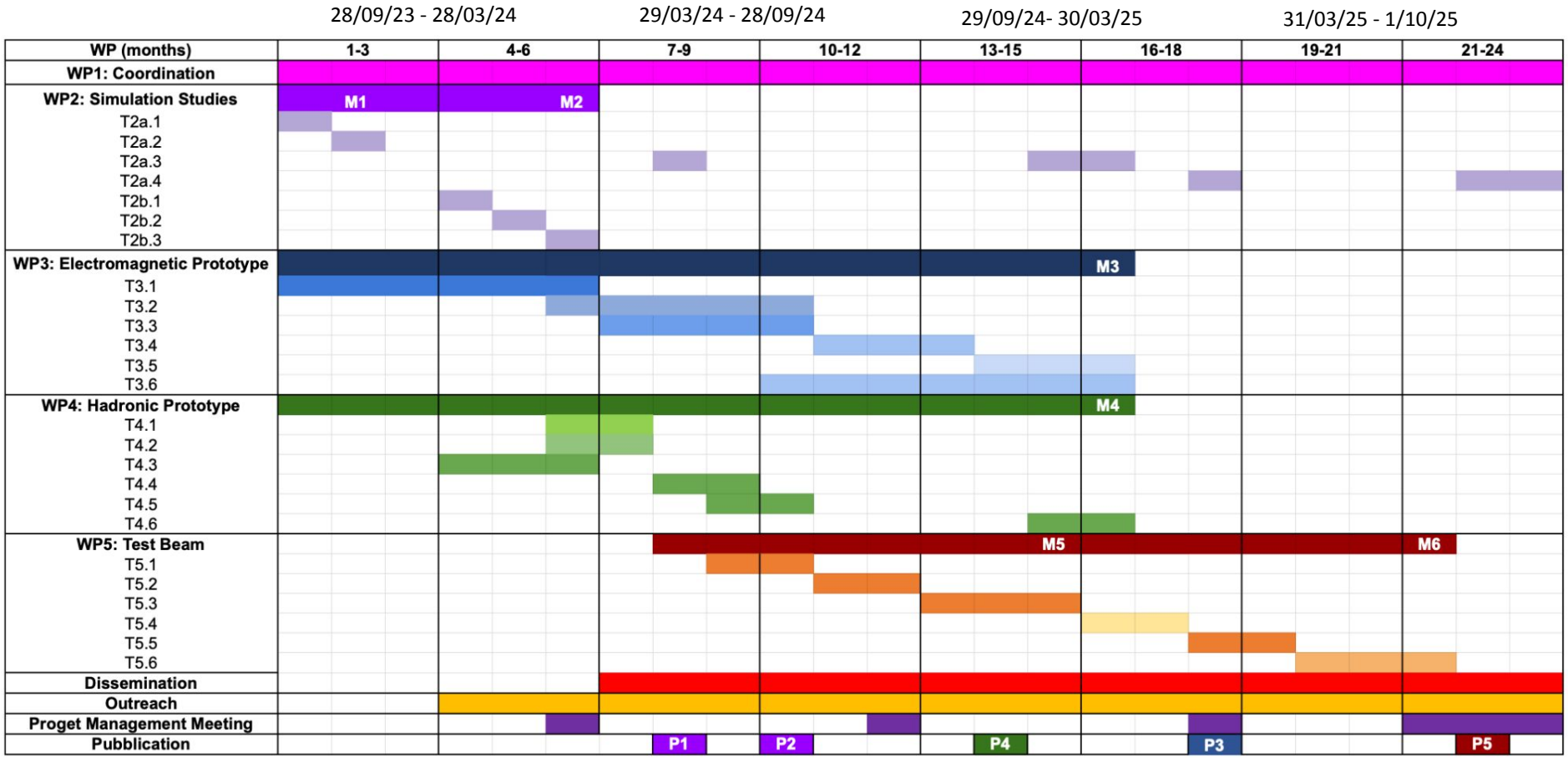


Fig. 3.1: Gantt chart reflecting project work packages (WP), milestones (M) together with tasks (T) and publications (P). Dissemination, outreach activities and collaboration meetings are also shown.

Breakdown dei costi previsti nel PRIN

- 106k richiesti, 90k finanziati
- **Disponibilità effettiva per consumi su PRIN: 90k-25k (AdR)-2k (UniBa) = 63k**
- 16k tagliati dal finanziamento → chiediamo all'INFN di coprire la differenza e quanto é stato sotto-stimato
  - 2 MPGD (2024) → 10-15k con le quotazioni attuali (sottostima del costo nel PRIN!!)
  - 2 MPGD (2025) → 10-15k con le quotazioni attuali
  - produzione di qualche plugin card (2024)→ 5k **[SJ]**
- Vorremmo usare i 63k restanti per l'acquisto dell'elettronica

Detailed cost breakdown HCAL

ITEM	kEUR	QUANTITY	TOTAL
Resistive MPGDs (uRWELL/resMM) 50x50 with ~2000 pixels in circle (-20% of readout channels w.r.t. full instrumented square)	2	5	10
4 Wafers multi-project for in total 400 new FATIC3 asics	28	1	28
Plugin cards housing 4 FATIC3 asics with HRS130 and SAMTEC conn	0.2	70	14
SAMTEC Cables 8 twisted pair, screened	0.08	60	4.8
Concentrator boards sending output 4 plugin cards to MOSAIC	0.225	18	4.05
MOSAIC General Purpose DAQ board 1GB/s	2.4	7	16.8
~~Project Travel Costs for Meetings~~			3
2 year postdoc contract (DETECTOR construction + test + DAQ SW development + operation in testbeam)	25	1	25
TOTAL			**105.65**

5 MPGD foreseen
-2k/MPGD
(under!!!)estimated →5-7k from last quotations
-4 MPGD to be produced

Readout electronics 42k

DAQ: 26k

68k

Saranno utilizzati per coprire la percentuale da dare a UniBa

Attivata procedura per bandire su UniBa

tabella estratta dal progetto sottomesso

2025-2026 cost project estimation

Istituti partecipanti al progetto:

- Bari INFN and University (DRD1,6): 3 FTE
- INFN-Napoli (DRD1): 0.5 FTE
- INFN-Roma3 (DRD1): 0.5 FTE
- Weizmann Institute (DRD1,6): 3 FTE

Richieste all'INFN

2024: 40k

Consumi: 29k (di cui 20k come recupero del PRIN)

Test Beam: 11k

2025: 70k

Consumi:

-10k: 2x50x50cm^2 MPGD (DRD1)

-40k: plugin cards for $3\lambda_N$ prototype (DRD1,6)

-10k: HCAL integration (stand, absorber) (DRD6)

Test Beam: 10k for HCAL (DRD6)

2026: 30k

- Consumi: 20k for 2 MPGD 50x100 (DRD1)
- Test Beam: 10k for test beam 50x100 MPGD (DRD1)

Covered by PRIN

2024: 30k

- 25k: Assegno di ricerca
-Consumi: 5k, ASIC procurement (DRD1,6)

2025: 60k

Consumi:

-20k: DAQ system (DRD1,6)

-40k: ASIC for $3\lambda_N$ prototype (DRD1,6)

Note:

Tutti i consumi indicati tengono conto del costo totale del progetto. Qualora gli altri istituti partecipanti contribuissero, i costi si abbatterebbero del 50%.

Backup

Toward 2 λ_N prototype

- $5\lambda_N$ needed for full shower containment (assuming infinite transverse size)
- In order to improve shower containment and make more reliable energy resolution measurement, we ask to extend the prototype at least to 2 λ_N
- What we need
  - 2 detectors (1 founded by RD51-CP)
    - we are limited by available electronics (we have material to read 2 further detectors)
  - $1\lambda_N$ steel absorber (we can find material for $0.25\lambda_N$)

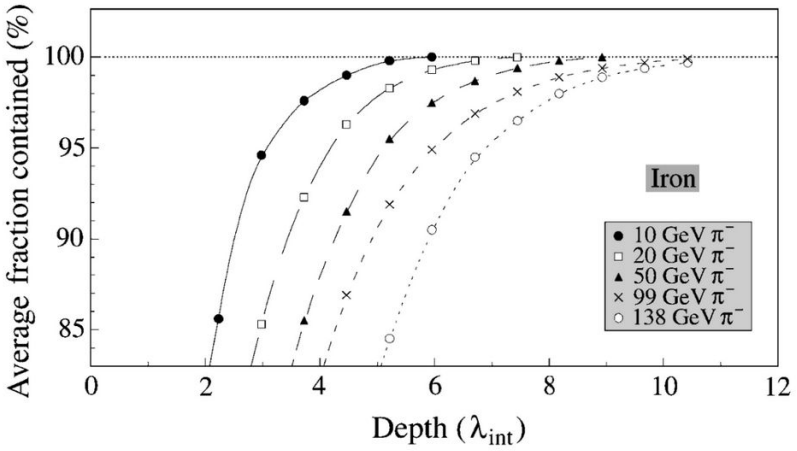
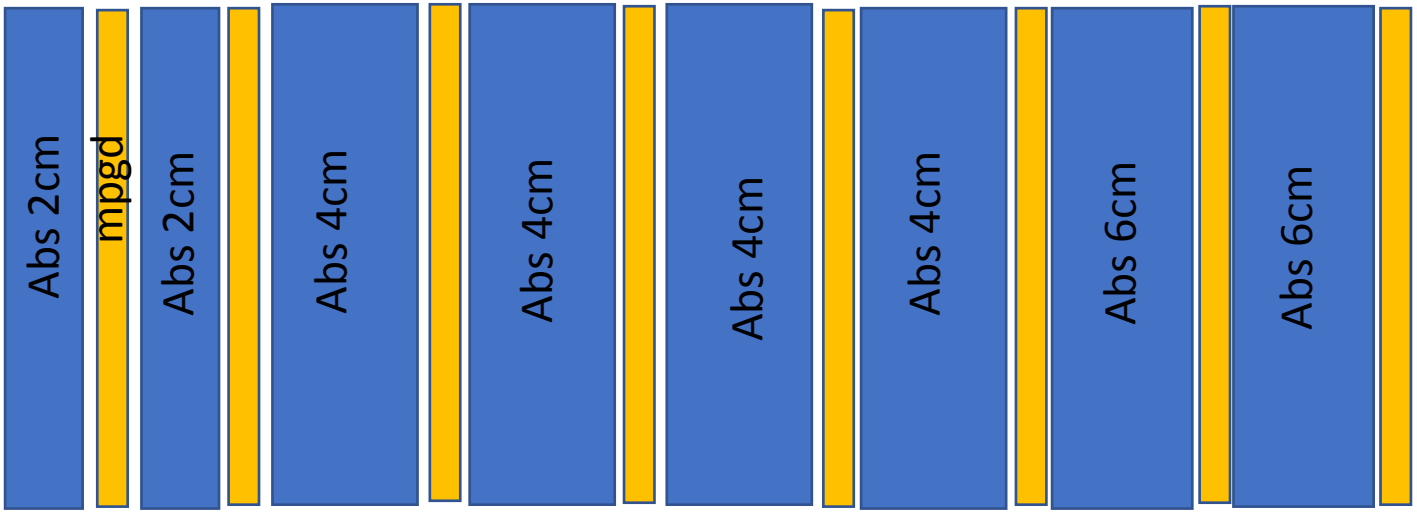
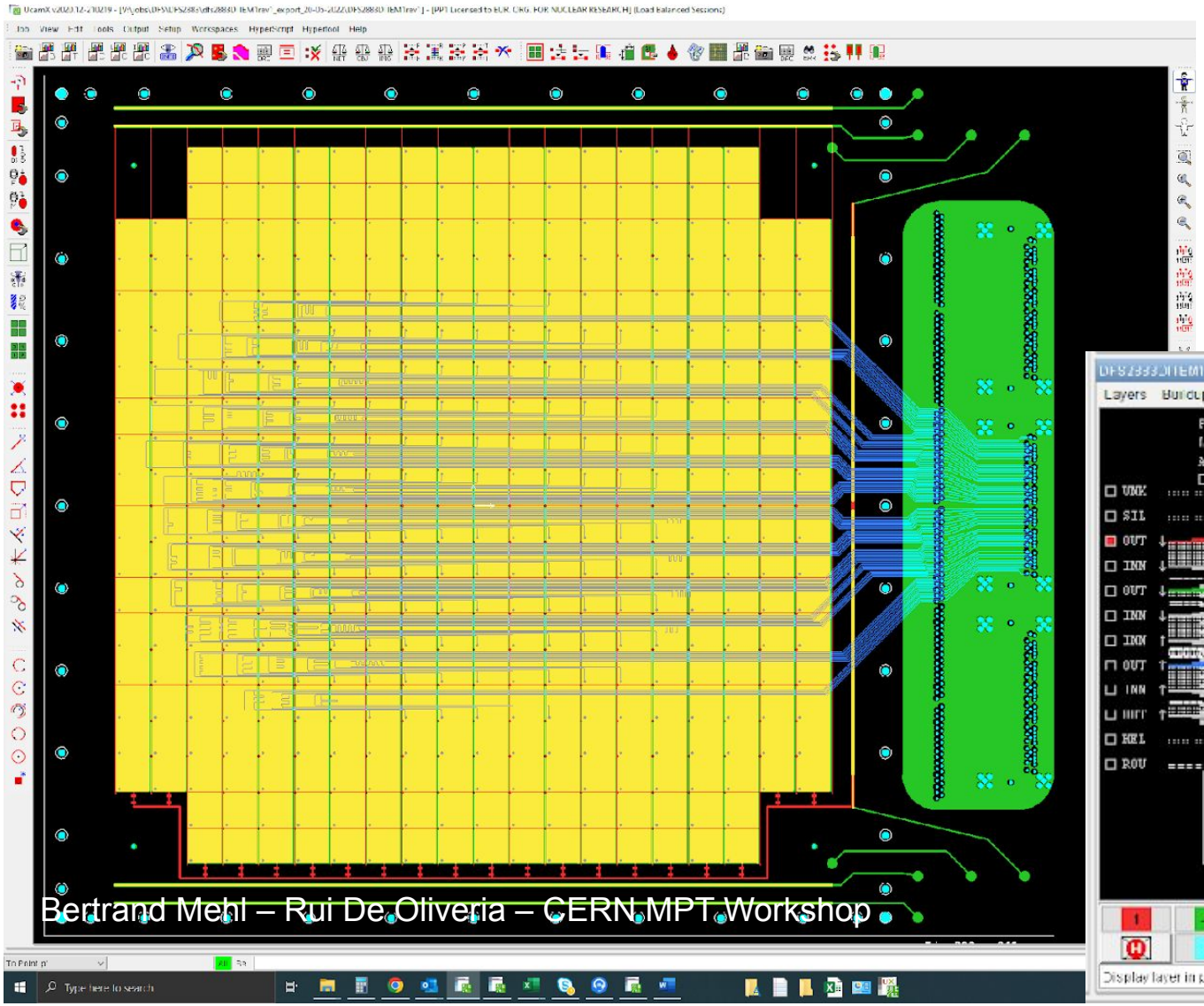
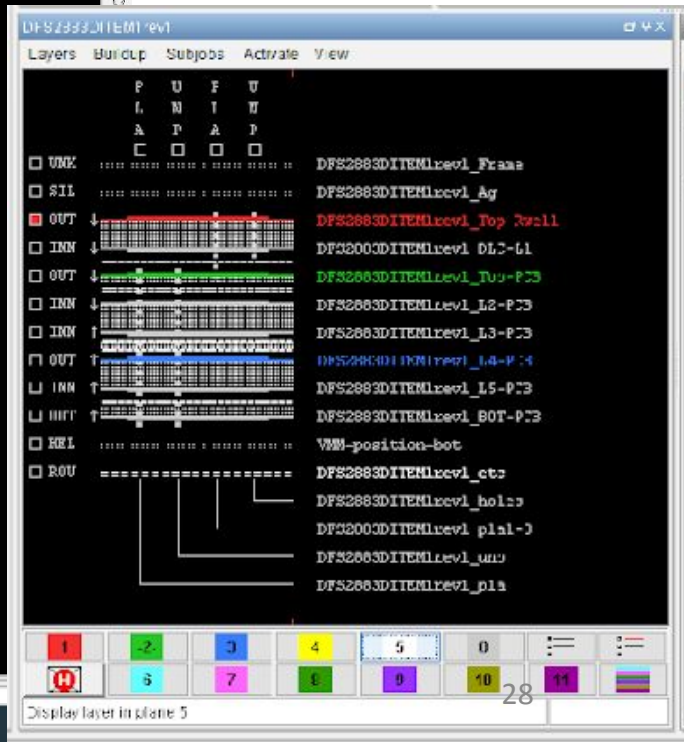


FIG. 2.43. Average energy fraction contained in a block of matter with infinite transverse dimensions, as a function of the thickness of this absorber, expressed in nuclear interaction lengths. Shown are results for showers induced by pions of various energies in iron absorber. Experimental data from [Abr 81].



Design 20x20 Readout Board

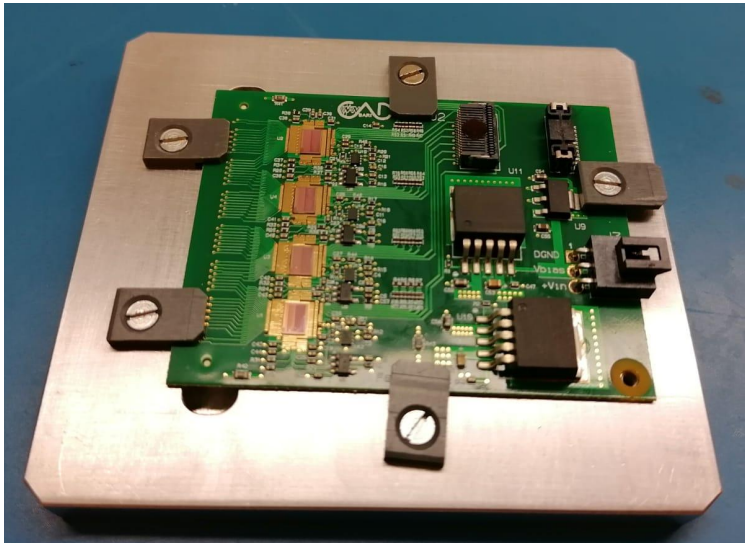


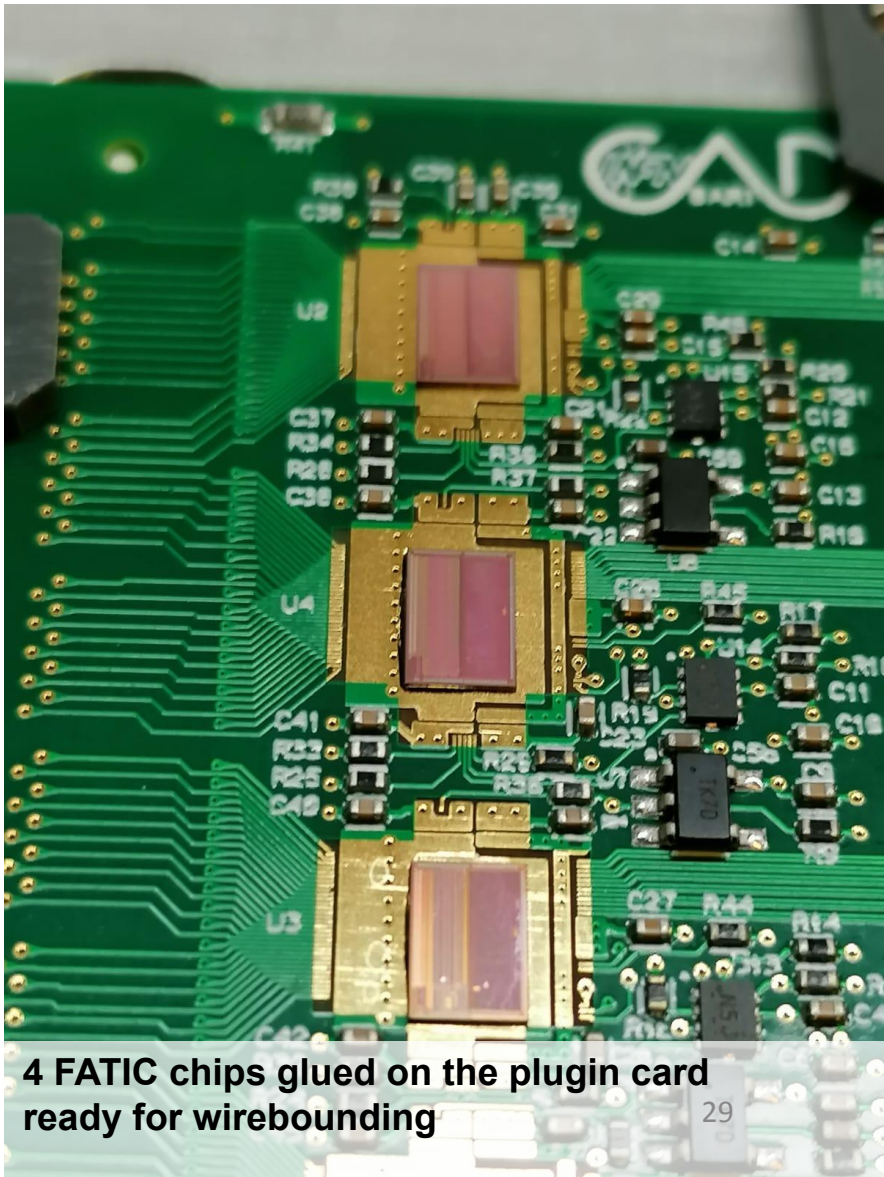


- Common RO board is 6-layer PCB
- 386 pixels – 3 HRS connectors
- Equalized Tracelength

Front-End Electronics: Plugin-Card

- Plugin card with HRS connector processes signals from 128 channels
- 4 FATIC2 asics (32 channels each)
- Plugin-card board designed in 2021
- Order in Febr'22 – PCB produced and components mounted Jun'22
- Currently: chip glueing and wirebounding on 1 card (demonstrator)
- In total 18 cards were produced



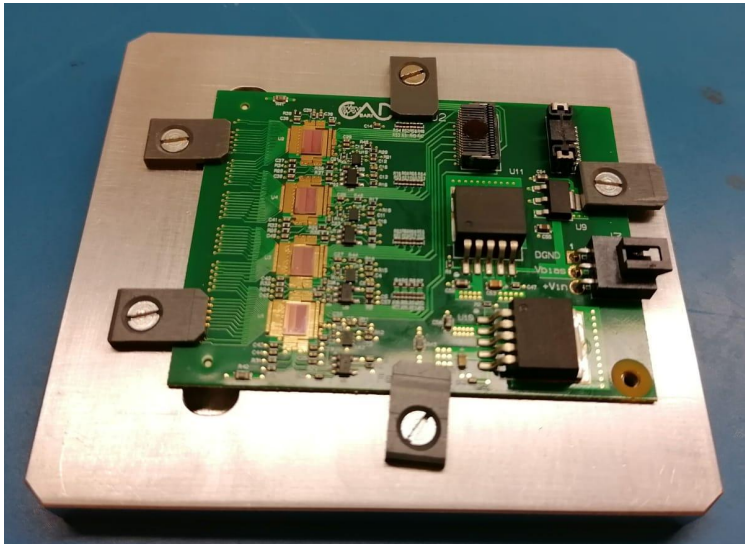


4 FATIC chips glued on the plugin card ready for wirebounding

Front-End Electronics

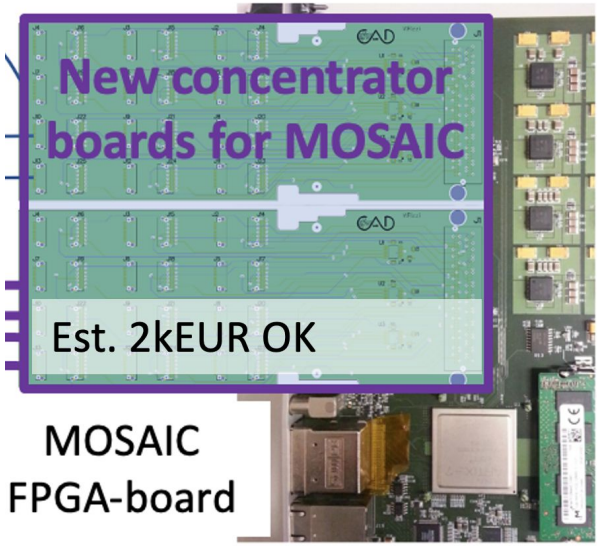
18 Plugin card produced

- HRS connector processes signals from 128 channels
- Will host 3 FATIC2 asics32 channels each
- Currently: chip glueing and wirebounding on 1 card (demonstrator) in Bari

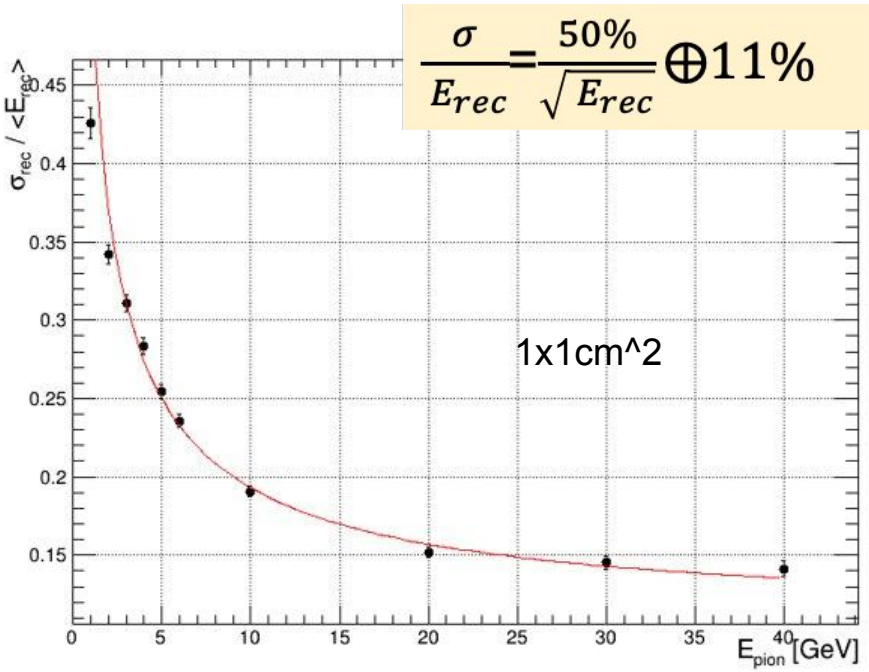


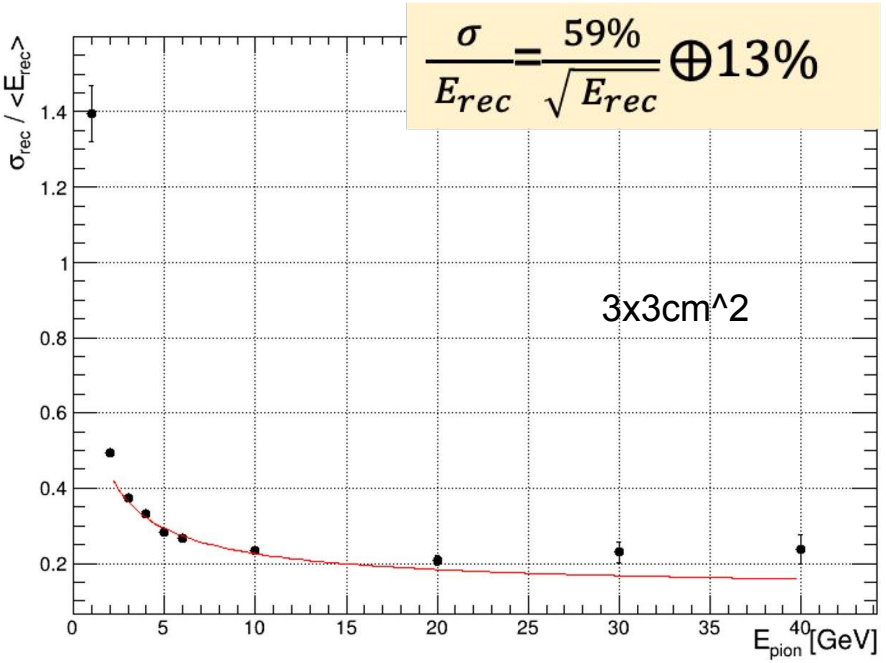
Backend: Concentrator board + MOSAIC

- Each Concentrator board receives signals from 4 plugin-cards (12 asics)
  - 4 boards ordered in Feb'22 – PCB produced and components mounted Jun'22
- Each Mosaic can mount 2 Concentrator boards (32 asics)
  - 2 MOSAIC boards available



Energy resolution vs cell granularity





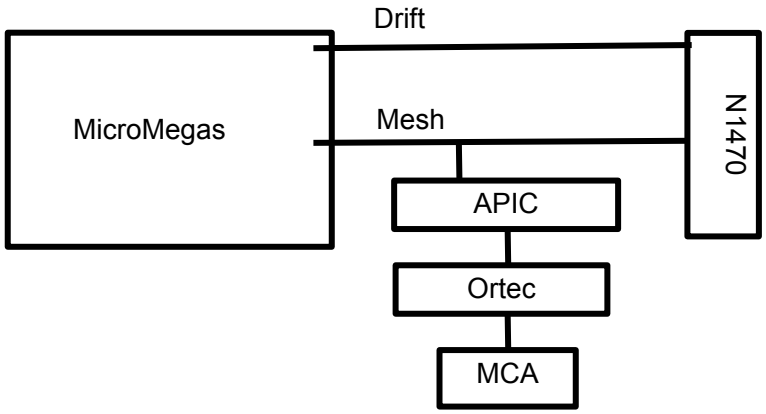
- Energy resolution is computed for single pion impinging the detector
- Slightly worse energy resolution performance with increased cell size
- To be assessed in Muon Collider full simulation with charged hadrons and jet

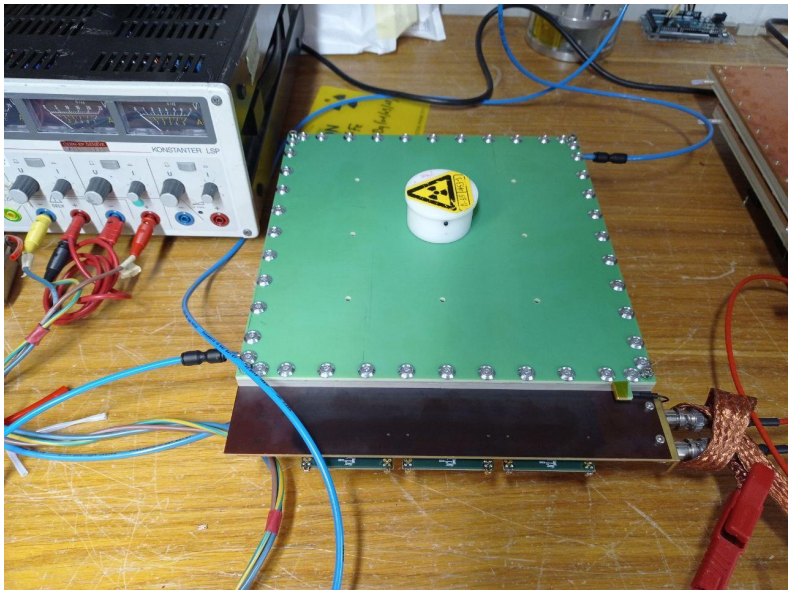
Very preliminary results: µMegas

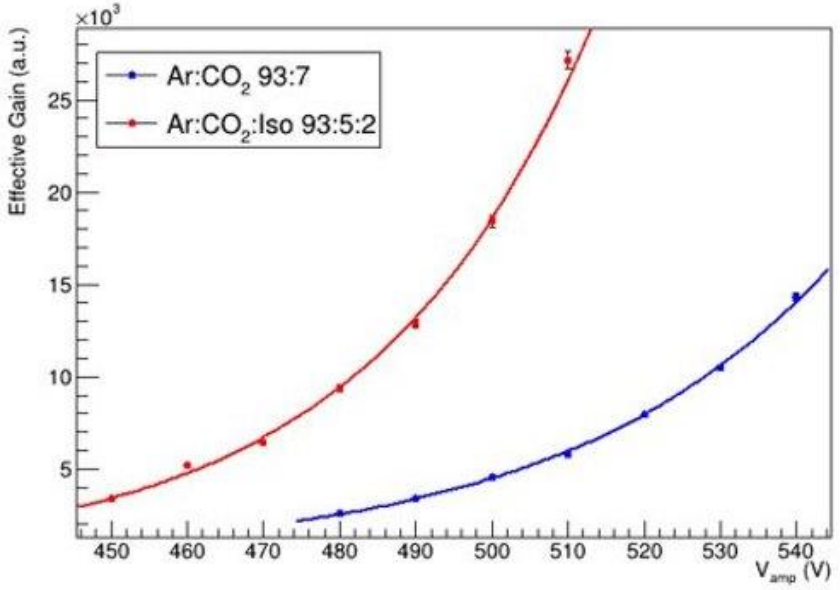
Gas gain measured with X ray source for two different mixtures

- Ar/CO_2 93/7
- Ar/CO_2/Iso 93/5/2

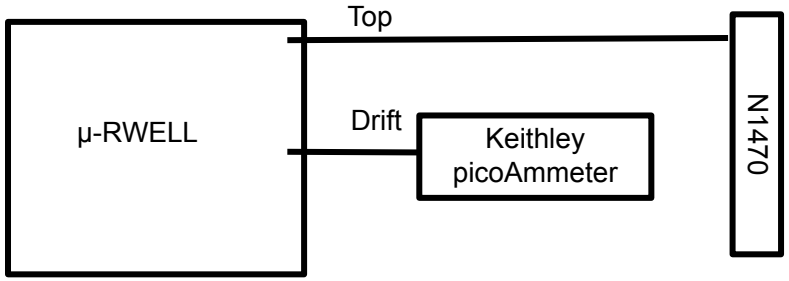
The amplified currents on the mesh is compared with the Xrays interaction rate



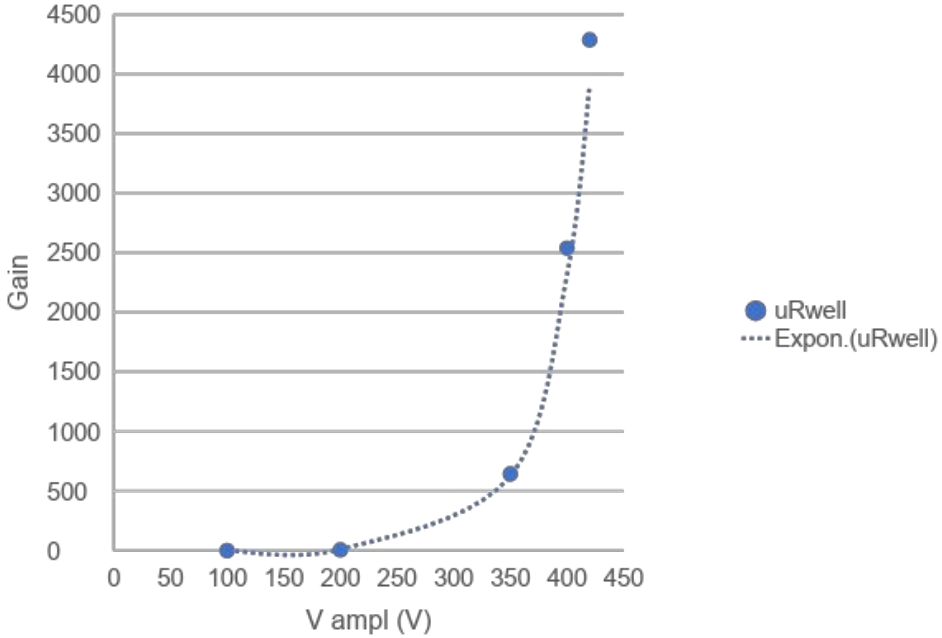


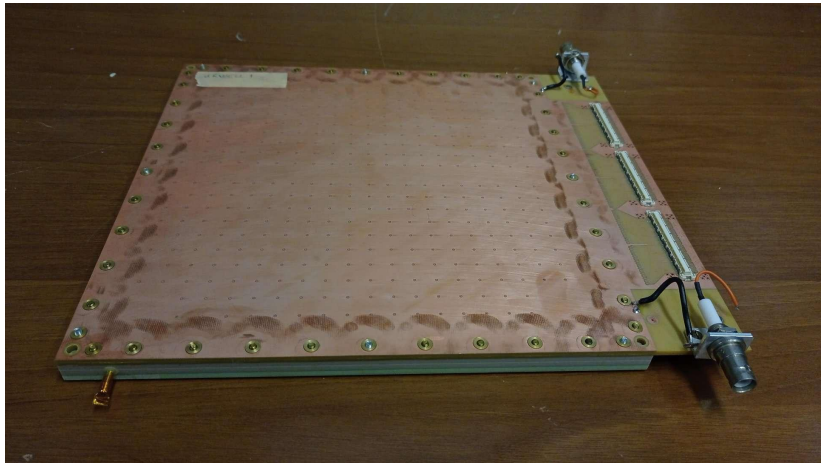


Very preliminary results: µRwell



- Tests with MiniX ray gun with Silver target
- The gain is measured by comparing the amplified currents on the top with the primary current on the cathode





Readout electronics cost estimation

Asic unit price GEMROC	detector	number of channels	Number of chips	Total ASIC GEMROC Cost	GEMROC + plugin card cost
270	20x20	384	3	810	1620
Plugin card	50x50	2048	32	8640	17280
270	6 20x20 + 4 50x50	10496	164	44280	88560
number of channel/asic	50x100	30000	468,75	126562,5	253125
64					
channl unit cost					
8,4375					

Asic unit price VFAT	detector	number of channels	Number of chips	Total ASIC fatic Cost	FATIC+Plugin card cost
70	20x20	384	12	840	1260
plugin	50x50	2048	64	4480	6720
35	6 20x20 + 4 50x50	10496	328	22960	34440
number of channel/asic	50x100	30000	937,5	65625	98437,5
32					
channl unit cost					
3,28125					

Anagrafica 2024

Totale: 2.3 FTE

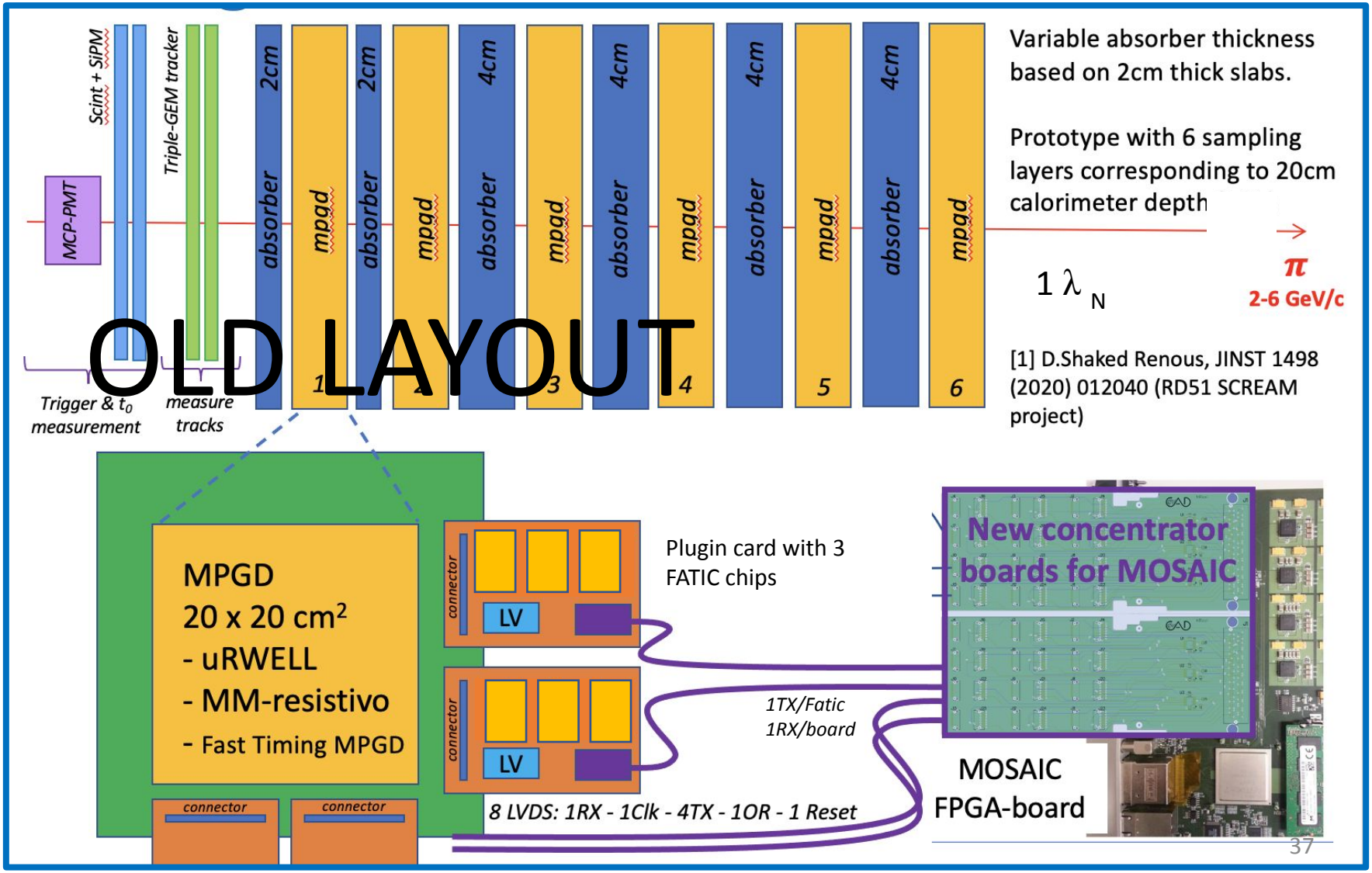
Catanesi	Maria Gabriella	Associazione Senior	0,10
Colaleo	Anna	Incarico di Ricerca scientifica	0,10
Creanza	Donato Maria	Incarico di Ricerca scientifica	0,10
Fiore	Luigi	Primo Ricercatore	0,20
Longo	Luigi	Ricercatore	0,20
Maggi	Marcello	Primo Ricercatore	0,10
Margjeka	Ilirjan	Assegno di Ricerca	0,20
Pellecchia	Antonello	Assegno di Ricerca	0,20
Radicioni	Emilio	Primo Ricercatore	0,05
Silvestris	Lucia	Dirigente di Ricerca	0,05
Stamerra	Anna	Scientifica Dottorandi	0,30
Venditti (RL)	Rosamaria	Scientifica Ricercatori/Professori università	0,30
Verwilligen	Piet Omer J	Ricercatore	0,10
Zaza	Angela	Scientifica Dottorandi	0,30

Richieste di servizi di sezione 2024

Servizio	MP	Motivazione	Stato
Progettazione Meccanica	1	• progettazione dell'infrastruttura meccanica per prototipo di cella calorimetrica (layer attivo: rivelatore MPGD + assorbitore + elettronica di lettura) e dello stand necessario per misurarne le performance.	• Richiesta sottomessa, in attesa di risposta
Officina meccanica	0.5	• costruzione della cassette e dello stand	• Chiesto e accordato
	0.5	• Allestimento test beam al cern	• Richiesta sottomessa, in attesa di risposta
Servizio elettronico	1	• Supporto per progettazione di elettronica di front-end per la lettura dei layer attivi (basati su tecnologia MPGD) del prototipo di un calorimetro adronico per un futuro esperimento al Muon Collider	• Chiesto e accordato

Prototype development: MPGD-based HCAL cell

Common project
Cofounded by RD-51



Simulation studies (2024)

G4 studies: Complete MPGD-HCAL model

- Optimization of semidigital thresholds vs energy resolution
- Multiple MIPs
- Simulation studies for 50x50 proto

Full simulation studies with pion guns (E=10 GeV- few TeV) w/o BIB

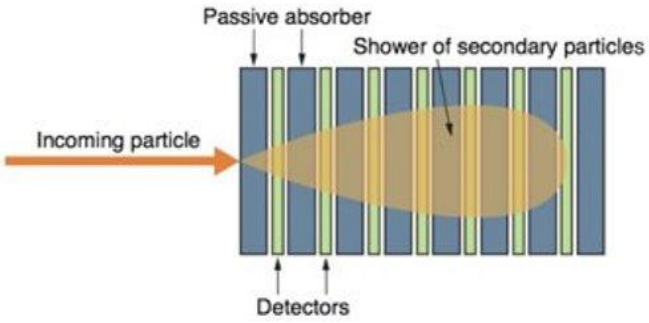
- HCAL response and PF parameters optimization
  - with baseline geometry
  - with MPGD-HCAL geometry

Why MPGD based HCal?

Proposal of a sampling calorimeter with **Micro-Pattern Gas Detector** as active layer

Advantages

- Radiation hardness
- High rate capability (MHz/cm^2)
- Suitable for fine granularity
- Good space ($> 50\mu m$) and time resolution ($5 - 10\ ns$)
- Good response uniformity (~10%)
- Relatively cheap for large area instrumentation



µRWell and resistive **µMEGAS** best MPGD options for reducing discharge effects

MPGD-based HCAL development: the strategy

From simulation to prototype

Simulation in G4 to study the response to hadronic showers
- MuCol setup
- Prototype setup

Implementation of the proposed design in the **muon collider full simulation** and study the impact on the reconstruction

Develop a **HCAL cell prototype** to measure the performance with test beam

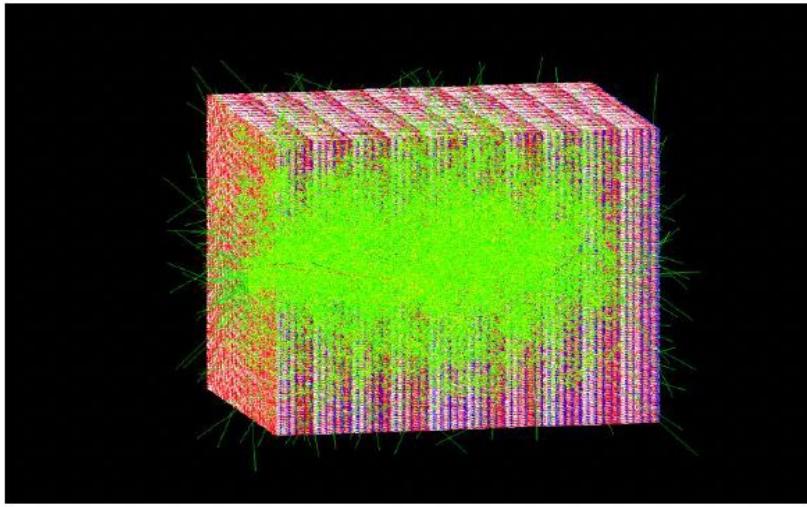
Fund obtained!!!

Additional founding:
- **Obtained in 2021: R&D51 Common project** (15ke/y, 2y) "*Development or resistive MPGD calorimeter with timing measurement*", P. Verwilligen, INFN (Ba, LNF), RM3

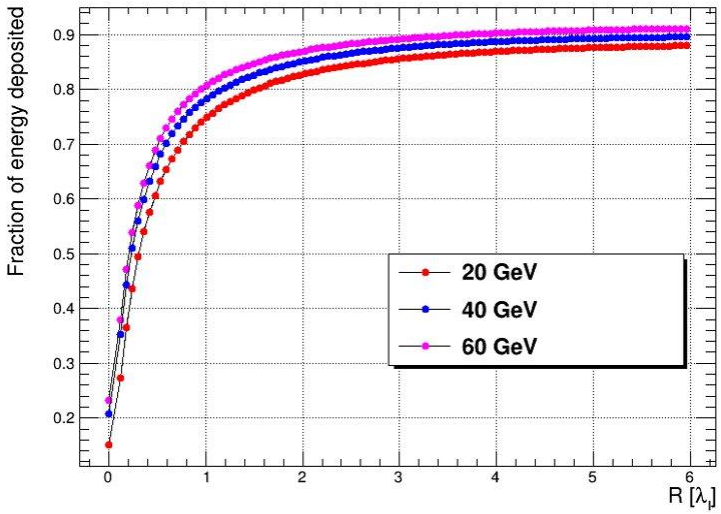
…nitted in 2022, PRIN: «*An innovative and Radiation Hard Calorimeter Proposal for a future Muon Collider Experiment*»,
- Requested: 110k (UniBa) + 140ke INFN
- Obtained: 90k (UniBa) + 120k (INFN-LNF)
- EURO-LABS 2023 for PS & SPS
  4kE (to be used for test beam)
  PI: Luigi Longo (INFN-Ba)

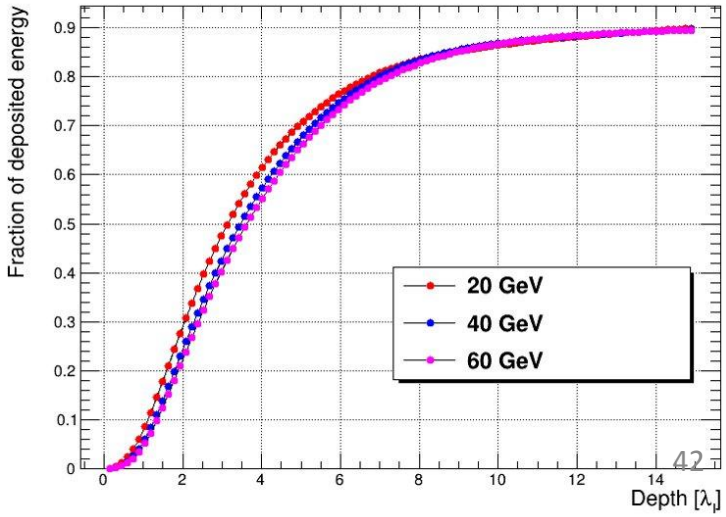
MuCol MPGD-based HCAL in Geant4

G4 simulations: shower containment



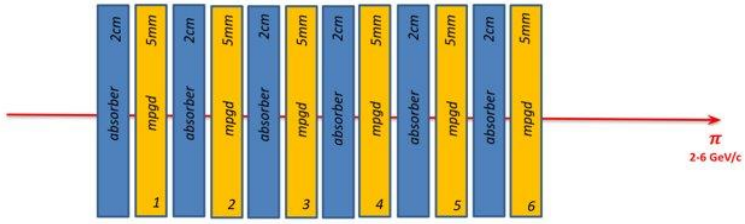
- Implementation of geometry with a sampling
  - 2 cm of Fe (**absorber**)
  - 5 mm of Ar (**active gap**)
- Granularity given by cell of 1x1 cm²
- Geometry optimization for shower containment
  - 3 λ_I for 90% transverse containment
  - 14 λ_I for 90% longitudinal containment



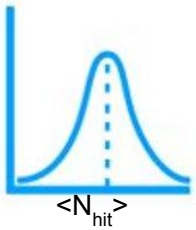


Energy resolution workflow

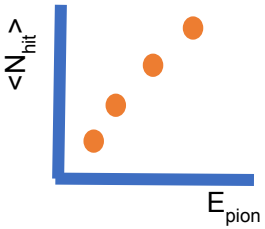
Pion guns with different energies in E=10-100 GeV



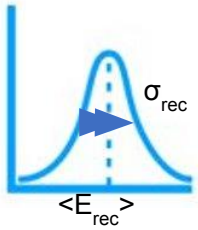
1st step: Get the N_{hit} distribution for each energy value E_{pion} and extract the mean value $<N_{hit}>$



2nd step: Plot $<N_{hit}>$ as a function of E_{pion} to find the calorimeter response function $N = f(E)$



3rd step: Reconstruct the energy distribution through the inverse response function $= f^{-1}(N)$ and extract $<E_{rec}>$ and σ_{rec}

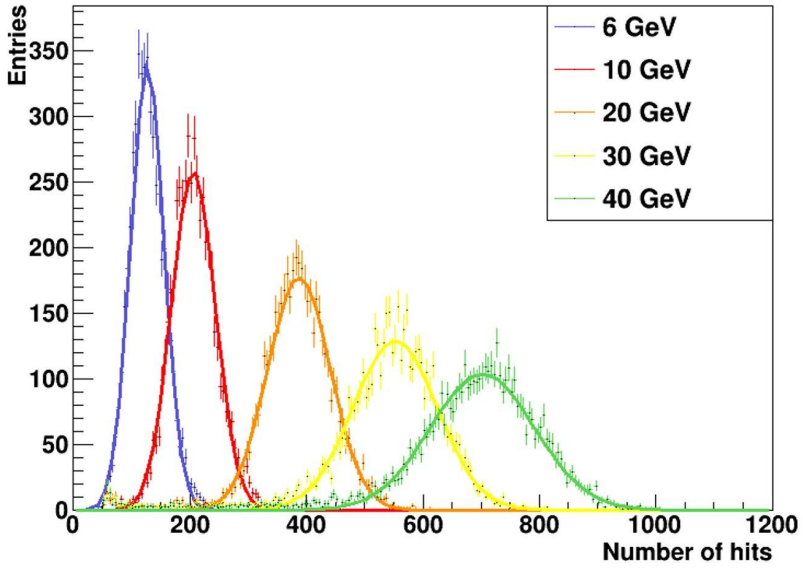


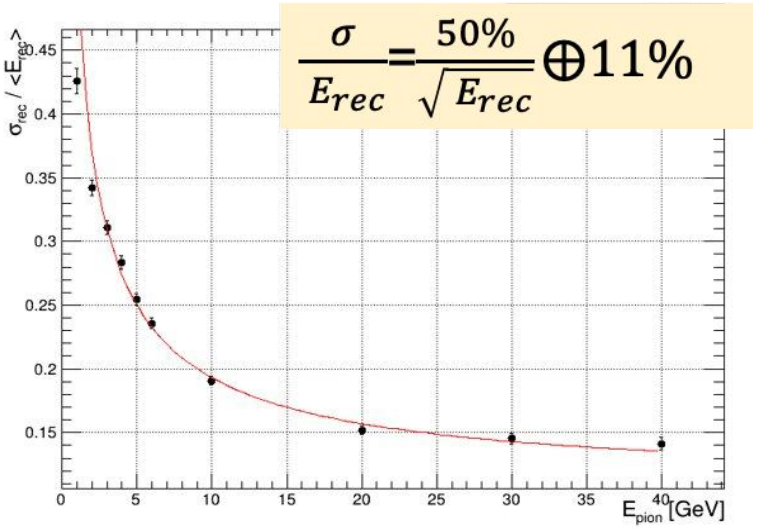
4th step: Get the energy resolution parameters fitting $\frac{\sigma}{E[GeV]} = \frac{S}{\sqrt{E[GeV]}} \oplus C$ to the data

Energy resolution vs Digital RO

- Pion guns with energy in 1-60 GeV
- Detector Geometry:
  - 50 layers, 1x1 m^2
  - 1x1 cm^2 cell vs 3x3 cm^2 cell
- **Digital RO** (single threshold) 1 hit = 1 cell with deposited energy higher than 30 eV
- Response function

$N_{hit} = f(E_{pion}) \rightarrow E_{rec} = f^{-1}(N_{hit})$





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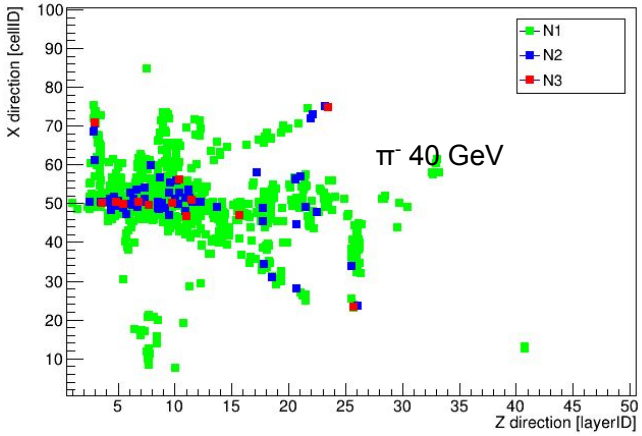
Semi-digital RO

Digitizzazione: **soglie multiple e hit pesate**

- **Soglia bassa t_1** -> N_1 è il numero di hits con $t_1 < E_{hit} < t_2$
- **Soglia media t_2** -> N_2 è il numero di hits con $t_2 < E_{hit} < t_3$
- **Soglia alta t_3** -> N_3 è il numero di hits con $E_{hit} > t_3$



Ricostruzione: Energia ricostruita tramite formula empirica

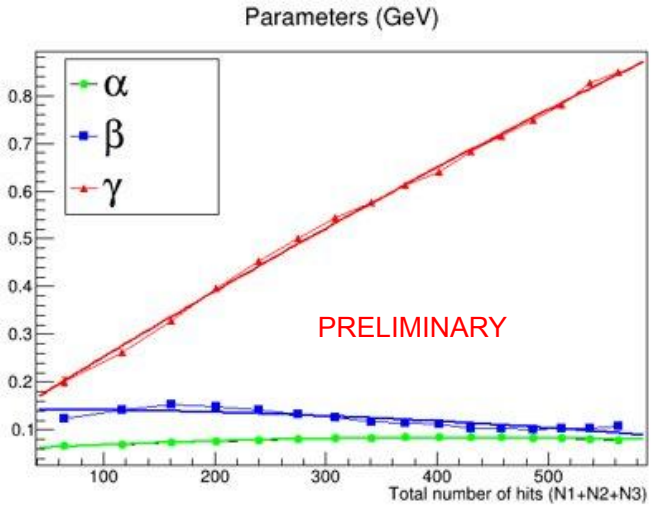
$$E_{rec} = \alpha \cdot N_1 + \beta \cdot N_2 + \gamma \cdot N_3$$

dove i pesi

- dipendono dall'energia (parametrizzati in funzione di $N_{tot} = N_1 + N_2 + N_3$)
- sono calcolati per ogni valore di energia **minimizzando** la funzione

$$\chi^2 = \Sigma_{i=1}^{N} \frac{(E^i_{\text{true}} - E^i_{\text{rec}})^2}{E^i_{\text{true}}}$$

dove N è il numero di eventi



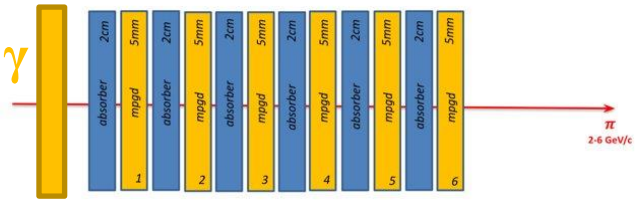
Calorimeter response function – BIB modeling

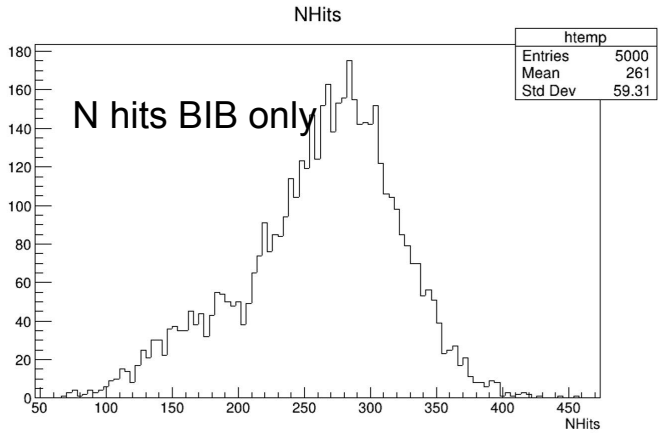
In order to reproduce the Muon Collider conditions of BIB, besides the pion guns a first attempt of BIB model is implemented Just BIB photons considered for now

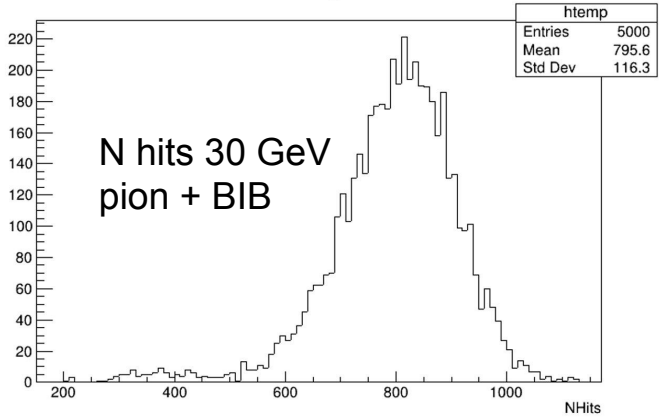
- Pion gun, 1 GeV to 40 GeV
- Plane source of photons
  - **3gamma/cm^2** per event, Eγ =**1.7 MeV**

- The presence of the photon background complicates the energy reconstruction (shifted peak, increased width, tails)

Ongoing:
- study a fit model to perform background subtraction to extract mean number of hits when BIB is included, in order to build the energy response function
- Add neutron bkg
- Implementation of analogic (RO)





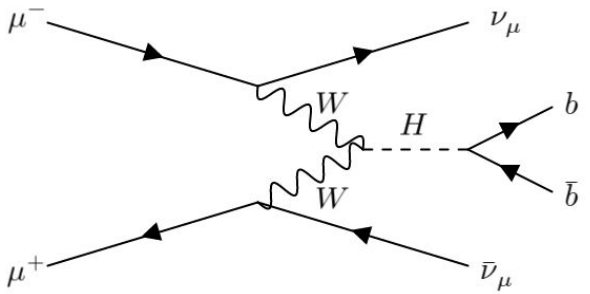


MuCol MPGD-based HCAL in Muon Collider full simulation

MPGD-based HCal for the Muon Collider

Jet reconstruction performance evaluation

- 10k events produced with Pythia
- 100 BIB events
- Signal events simulated within the detector system with the BIB overlayed
- Full event reconstruction performed
- x2 geometries



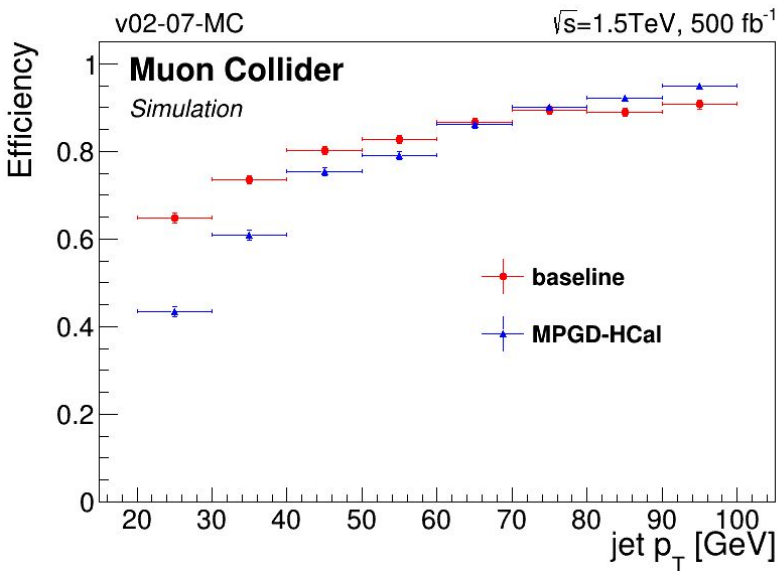
Benchmark process: $\mu^+\mu^- \rightarrow H\nu_\mu\overline{\nu_\mu} \rightarrow b\bar{b}\nu_\mu\overline{\nu_\mu}$

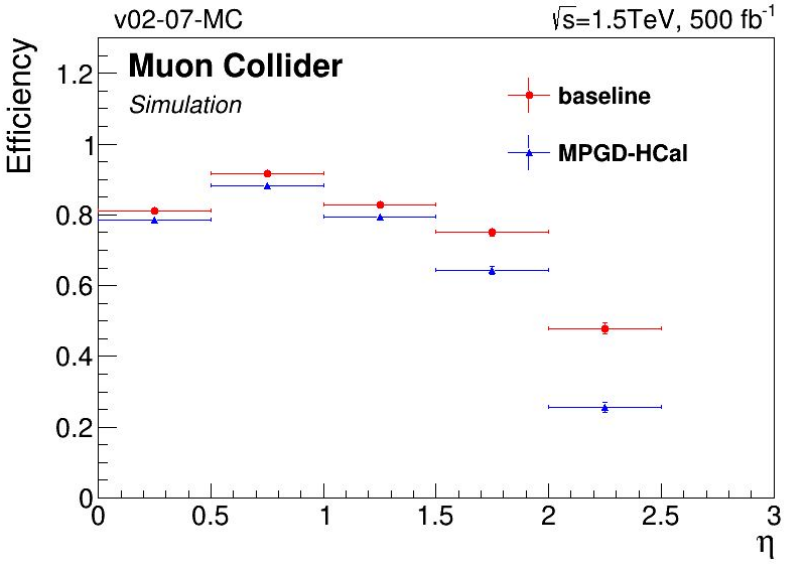
1.5 TeV center-of-mass energy

- HCal geometry in the Muon Collider software
  - Cell granularity: 3x3 cm^2
  - Active layer depth: 3 mm
  - Absorber depth: 20 mm
- Digital readout in both options
- **Baseline HCAL**: scintillators (Polystyrene) + Steel
- **MPGD-Hcal:** Argon + Iron
- Hit digitization: different hit energy smearings due to the different physical process involved in signal formation and different thresholds applied in the two HCal implementations

Jet Reconstruction Efficiency

PRELIMINARY

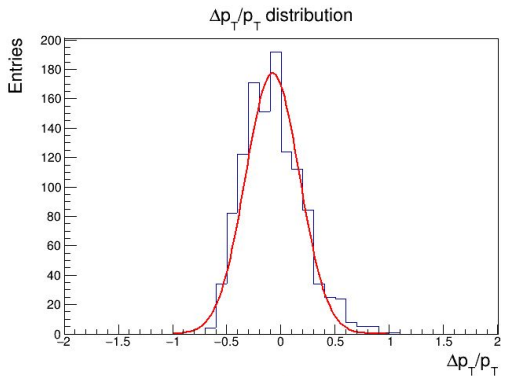




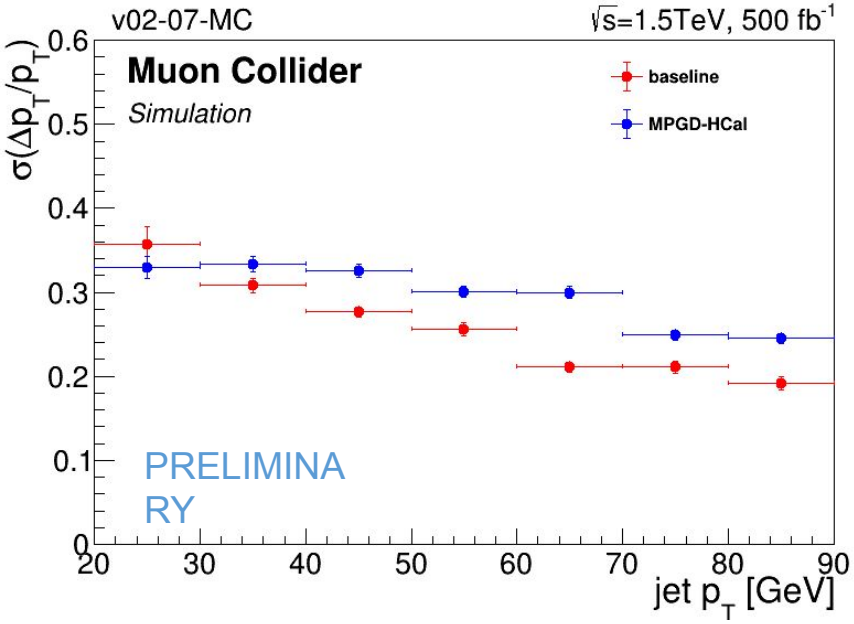
Jet reconstruction efficiency estimated with the MPGD-HCal is comparable to the baseline one.

To be understood:
Drop at low pT, high eta with MPGD based geometry

Jet p_T Resolution



Jet momentum resolution extracted with a gaussian fit on $\Delta p_T / p_T$ (Δp_T = p_T gen - p_T reco). Small sample statistics → suboptimal fit quality



The jet p_T resolution evaluated with the new MPGD-HCal is comparable with the baseline.

Plans:

- Implementation of analogic readout
- Study the reconstrunction performance as a function of cell granularity
- Study response to single pions
- Simulate the process and the BIB at higher center-of-mass energies