RD MuCol Bari

L. Longo

21 Nov 2024

The case for a muon collider

A high-energy lepton collider: combining cutting edge discovery potential with precision measurements

Motivations

- No synchrotron radiation: **higher energy** reachable than e^+e^-
- **Point-like** particles: comparable physics reach at lower centre-of-mass than pp
- Good **luminosity** to beam power ratio: high s-channel cross sections at high energy

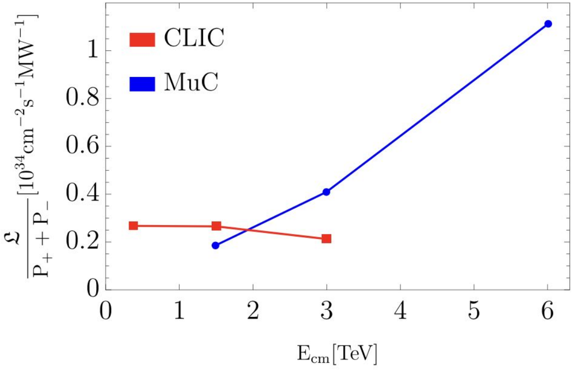
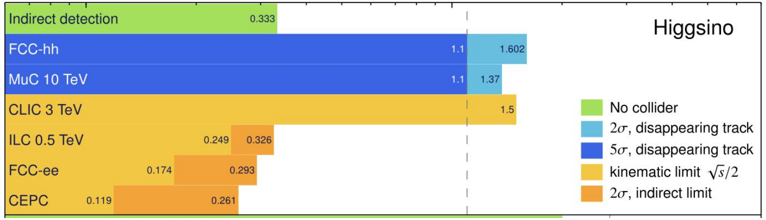


Fig. 10 MuC luminosity normalised to the muon beam power and compared to CLIC, for different beam energies

Towards a muon collider. *Eur. Phys. J. C* **83**, 864 (2023)

Physics reach

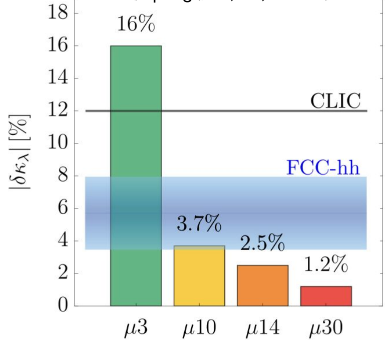
- Potential for new **discoveries**
- Precise **Higgs** studies
- Direct reach for physics coupled to **muons and neutrinos**



	HL-LHC	HL-LHC +10 TeV	HL-LHC +10 TeV + ee
κ_W	1.7	0.1	0.1
κ_Z	1.5	0.4	0.1
κ_g	2.3	0.7	0.6
κ_γ	1.9	0.8	0.8
$\kappa_{Z\gamma}$	10	7.2	7.1
κ_c	-	2.3	1.1
κ_b	3.6	0.4	0.4
κ_μ	4.6	3.4	3.2
κ_τ	1.9	0.6	0.4
κ_t^*	3.3	3.1	3.1

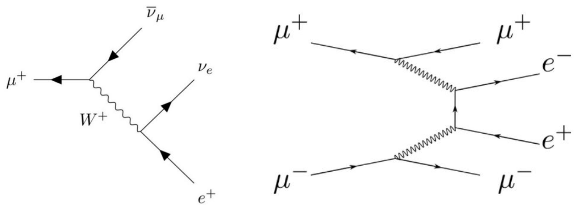
* No input used for the MuC

Trilinear coupling at 3, 10, 14 and 30 TeV



Muon collider challenges

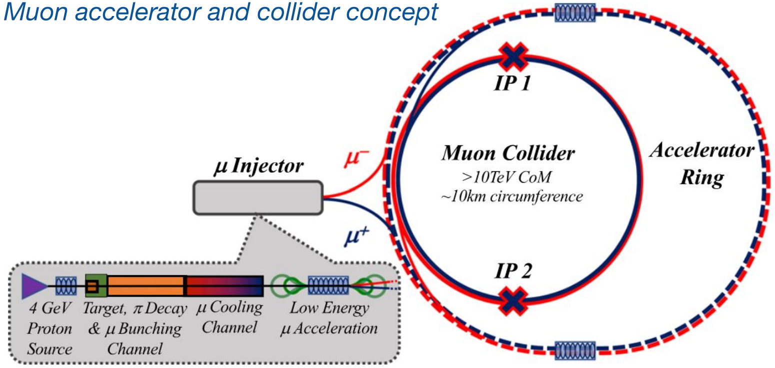
The muon lifetime is 2.2 μs



Short muon lifetime

Requires fast production, cooling (transverse emittance reduction) and acceleration

Muon accelerator and collider concept



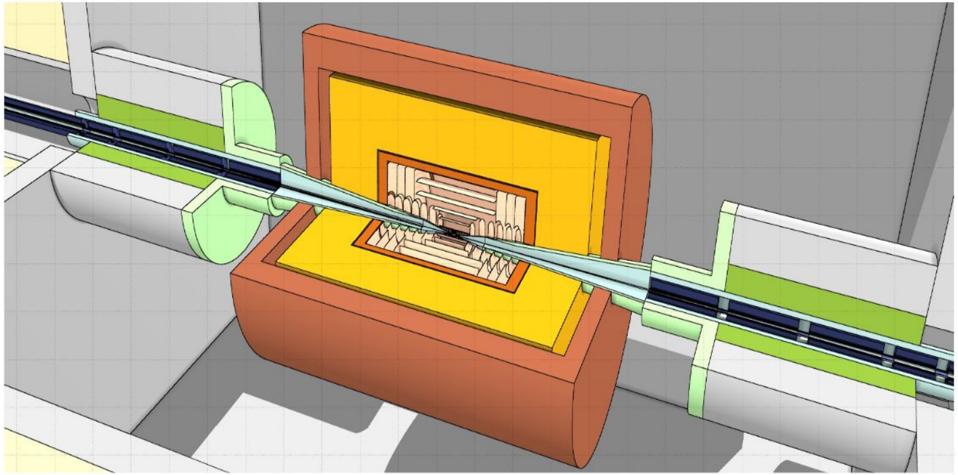
Addressed first by US muon acceleration program (MAP), now by IMCC

Muon decay

Asynchronous **beam-induced background** (BIB) in experiments

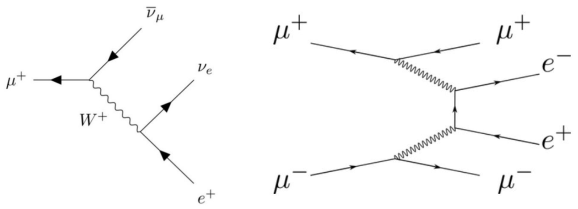
1. Mostly photons, neutrons and electrons
2. Incoherent e^+e^- pairs produced at bunch crossing

Mitigation by **shielding** and choice of **detector** technologies



[arXiv:2105.09116] Advanced assessment of Beam Induced Background at a Muon Collider

Muon collider challenges



The muon lifetime is 2.2 μs

Short muon lifetime

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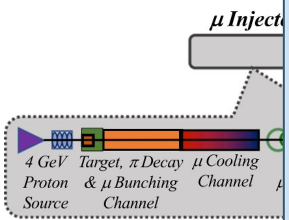
Muon accelerator and co



Addressed first by US muon acceleration program (MAP), now by IMCC

Muon decay

Asynchronous **beam-induced background** (BIB) in experiments

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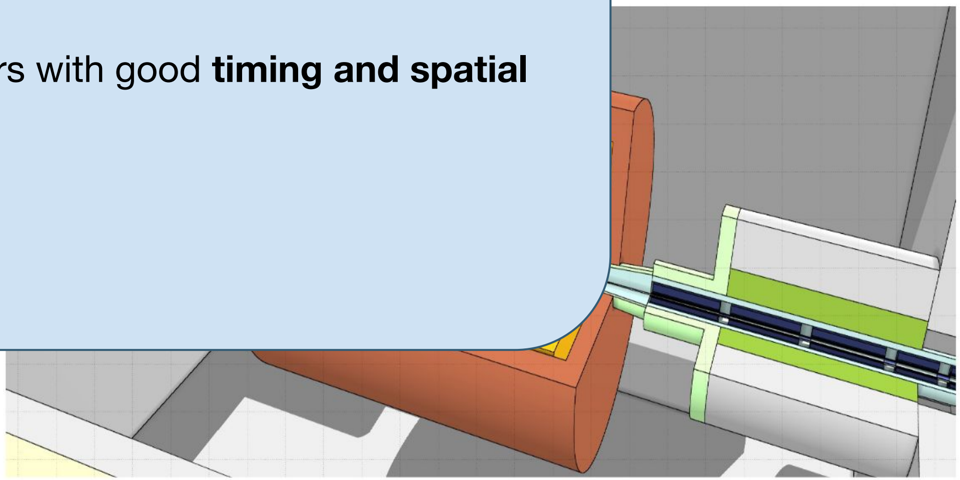
unch crossing

tor technologies

What do we need?

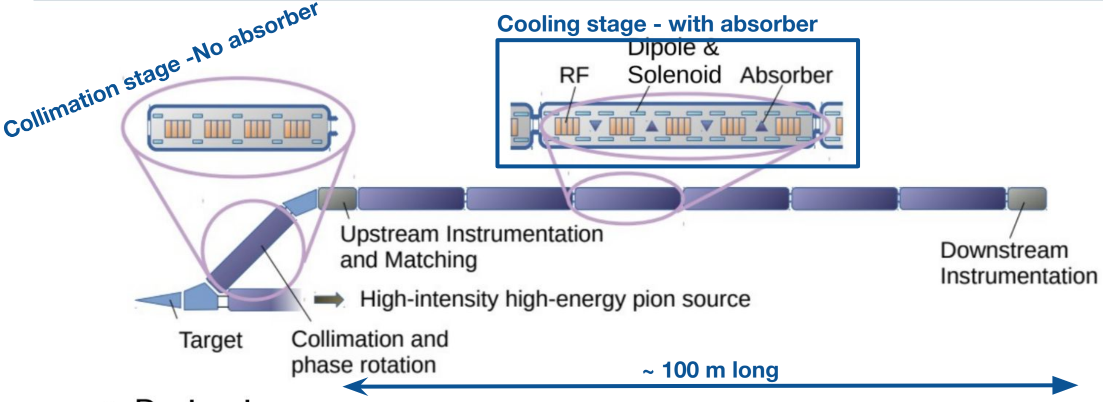
- A **demonstrator** to prove that we are able to reduce the transverse emittance of a muon beam
- **Radiation hard** detectors with good **timing and spatial resolution**



[arXiv:2105.09116] Advanced assessment of Beam Induced Background at a Muon Collider

Demonstrator

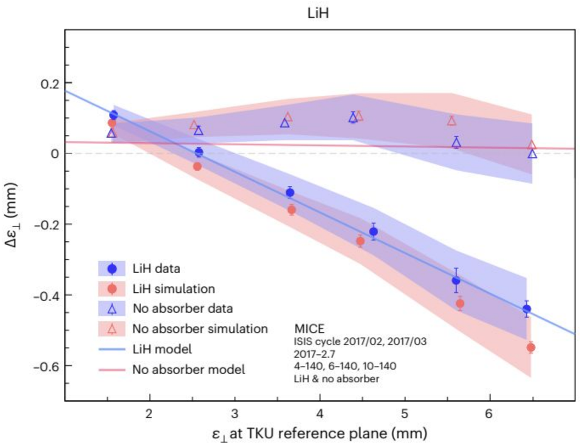
Muon Cooling Demonstrator – Layout



- Design in progress
  - Muon source – target and pion capture
  - Beam transport
    - Pion decay
    - Chicane (momentum selection & beam dump)
    - Muon phase rotation & collimation (beam preparation system)
    - Matching section
  - Cooling channel/lattice
- Design process may be informed by the siting options

P. B. Jurj (ICL) | Cooling Demonstrator Design Update | IMCC Annual Meeting, 14.03.24 | 5 / 27

Muon Ionization Cooling Experiment (MICE) has already demonstrated that transverse emittance can be reduced (link), by means of low-Z absorber

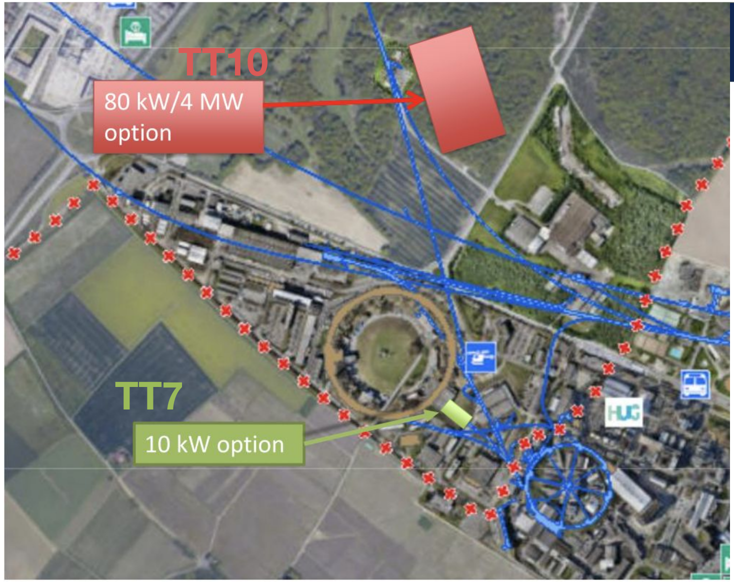


Goal: reach 25 μm of transverse emittance

Cooling Demonstrator Design Update - IMCC Annual meeting 2024

Demonstrator at CERN

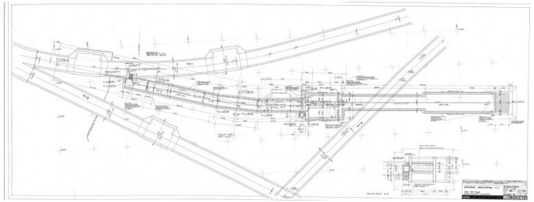
Cooling Demonstrator Design Update - IMCC Annual meeting 2024

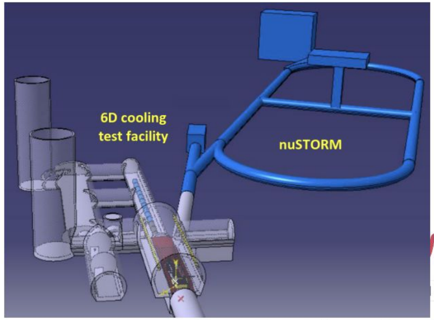


Demonstrator facility siting options at CERN

Two siting options at CERN are currently considered

- Intersection Storage Rings (ISR) complex
  - In the TT7 extraction line
  - Proton beam from the PS
  - Near surface level, lower proton beam power required (10kW), 14 GeV
- TT10
  - Pion production system could be shared with the nuSTORM facility
  - Proton beam from the PS (26 GeV) or SPS (100 GeV)
  - Underground, beam power up to 80 kW (first phase)





Main differences:

- Repetition rate
- Cost

Other sites (ex. Fermilab, RAL) have been expressed interested to host the demonstrator [Demonstrator Workshop 30 Oct-1 Nov 24]

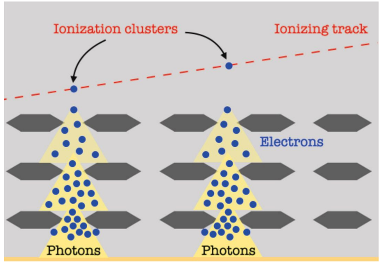
A TPC for the demonstrator?

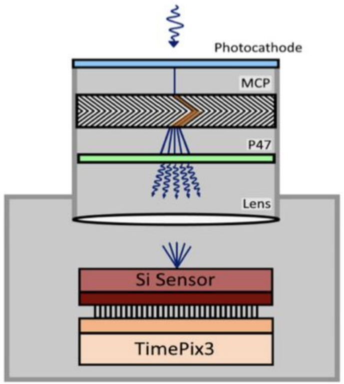
Precision measurement of the muon beam emittance is a crucial aspect for the validation of the demonstrator. A TPC with optical readout represents the ideal detector for this purpose:

- already study for beam monitoring in the past, ex. GEMINI
- full particle parameters (x, p) reconstructed in 3D
- very low material budget
- excellent track resolution
- light structures
- higher rate w.r.t. a traditional pad plane thanks to the optical readout
- NOT required pressurized operation

In 2023 the Bari group proposed to realize a large prototype of a TPC (30 cm diameter, 50 cm drift) with optical readout (TimePix4 or similar) tailored to precise, particle-by-particle muon emittance measurement during beam setup phases

- A field-cage suitable for atmospheric-pressure operation is already available.
- The readout part can be easily replaced with an optical one.
- Once ready, the size allows to insert it in a solenoid (available at CERN) and test it in a muon beam.





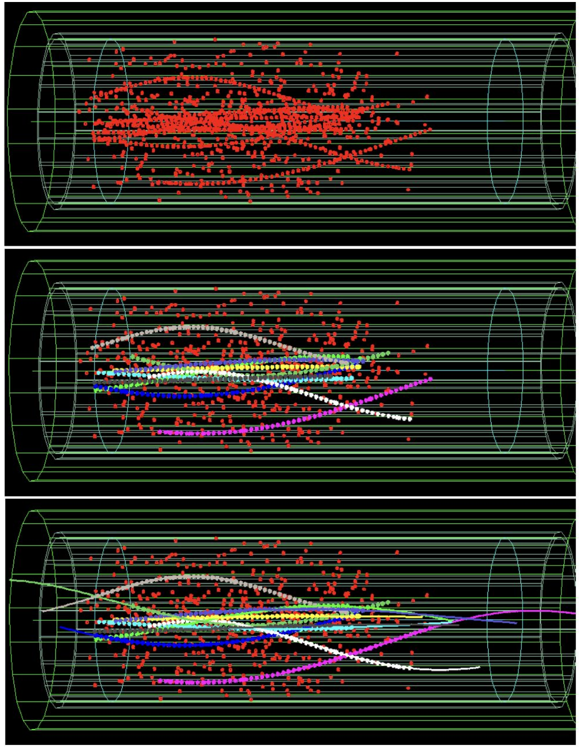


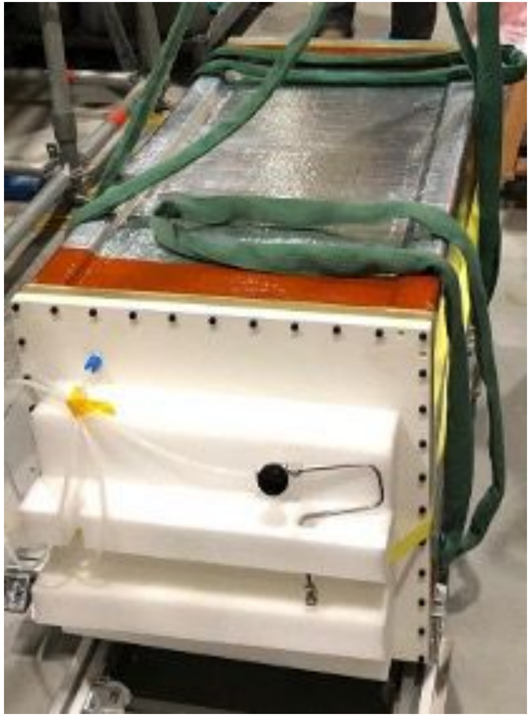
Figure 8.7: top: simulated track and noise hits in the TPG; middle: highlighted hits are those assigned by the pattern recognition to belong to the same track; bottom: track fitted on the selected hits.

TPC Bari activities status

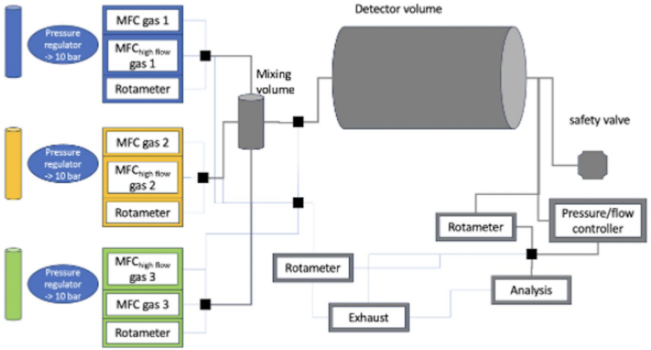
TPC prototype with optical readout will be assembled and characterized in the same Bari lab, where the tests for a high-pressure TPC will be performed (AIDA+DRD1):

- HV system ready;
- Gas:
  - system designed and under construction,
  - flowmeters with all the components of the gas system already tested;
- Field Cage:
  - tables have been designed and built;
  - one of the 2 Field-Cage T2K prototype (50x50x100 cm^3);
- Optical Readout:
  - under procurement.

Field Cage

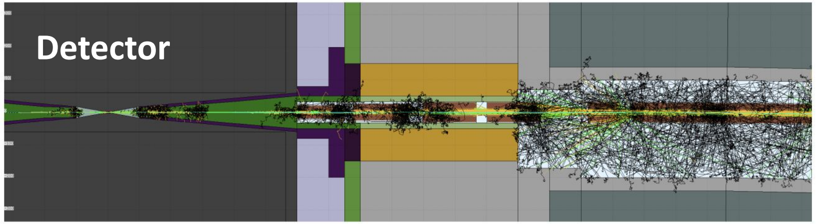


Gas system



The TPC R&D is well included in the DRD1-WP4 program (tracking TCP); moreover all the R&D on optical readout can be re-used for high-pressure TPC, under the hat of DRD1-WP8 (reaction/decay TPC)

Beam-Induced Background



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

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

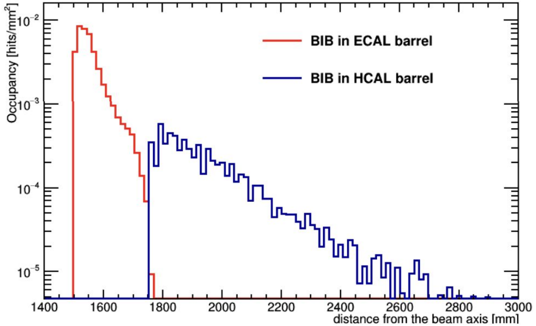
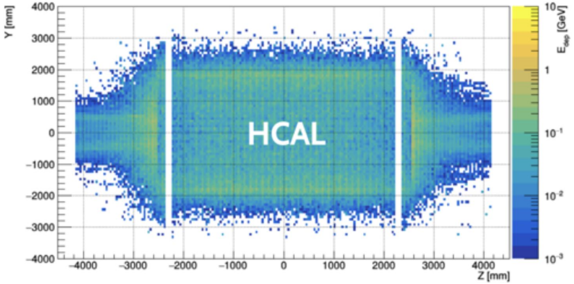


Fig. 25 BIB hit occupancy in the calorimenter barrel region in a single bunch-crossing.

Challenges:

- muon is an **unstable particle**; its decay products interact with the machine elements generating an intense flux $O(10^{10})$ of background particles: **beam-induced background** (BIB).
- Two conical tungsten shieldings (**nozzles**), cladded with borated polyethylene, allow the reduction of background by 2-3 orders of magnitude:
  - photons ($\sim10^8$),
  - neutrons ($\sim10^8$),
  - electrons/positrons ($\sim10^6$)



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

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

A MPGD Hadronic Calorimeter

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

MPGD features:

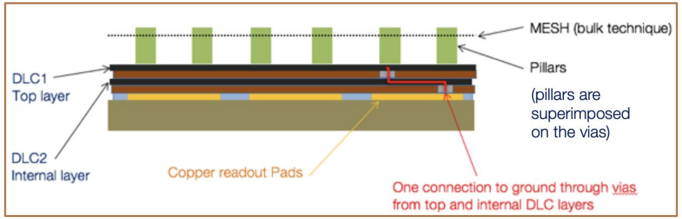
- **cost-effectiveness** for large area instrumentation
- radiation hardness up to several **C/cm^2**
- **discharge rate** not impeding operations
- rate capability O(**MHz/cm^2**)
- high granularity
- time resolution of **few ns**

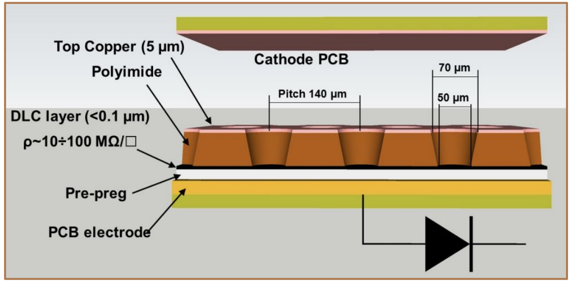
Past work:

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

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

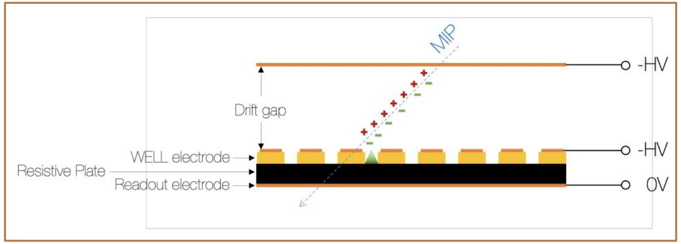
Micromegas (MM)





μRWELL

RPWELL



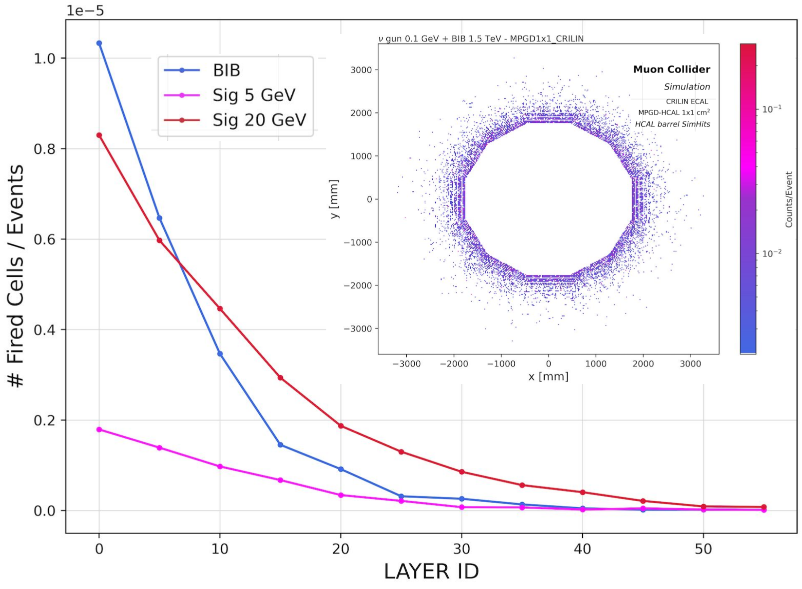
HCAL R&D well included in DRD1-WP5 (Calorimetry) and DRD6-WG1 (Sampling Calorimeter)

MPGD-HCAL BIB studies

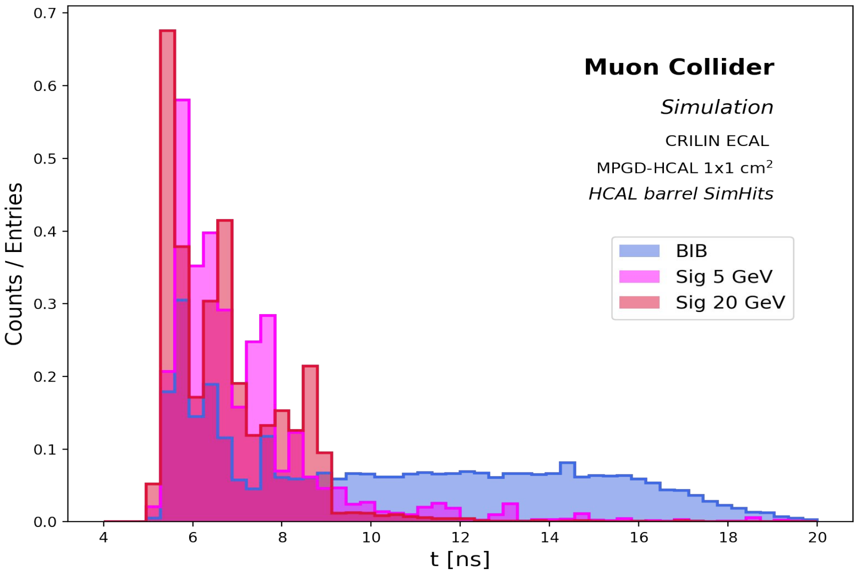
Preliminary

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

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



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



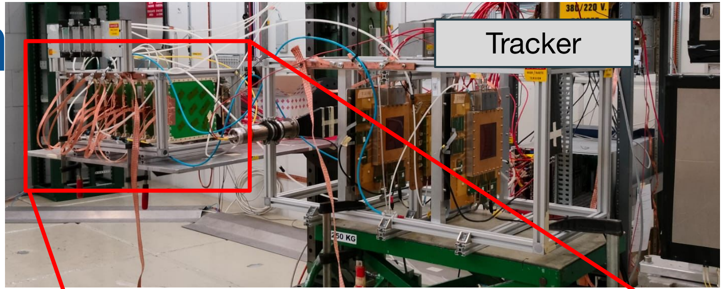
MPGD-HCAL Test Beam

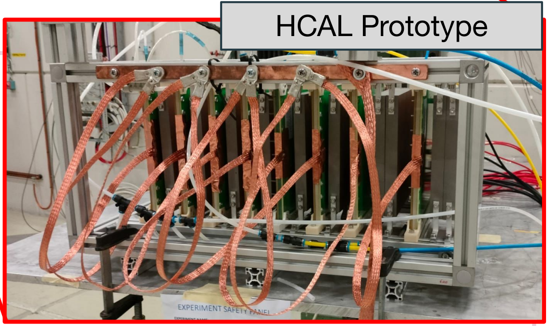
R&D effort in collaboration with INFN-RM3, INFN-Fr, INFN-Na, Weizmann and CERN

2 test beam campaigns in 2023 and 2024:

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

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

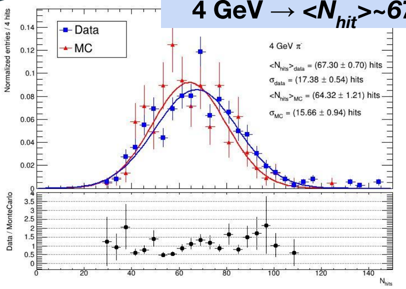




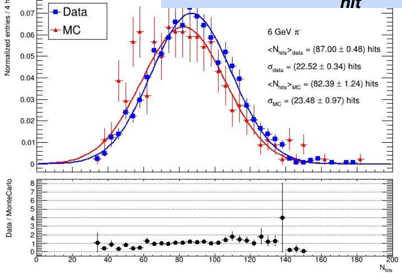
2023 Data

Preliminary

4 GeV → $\langle N_{hit} \rangle$~67



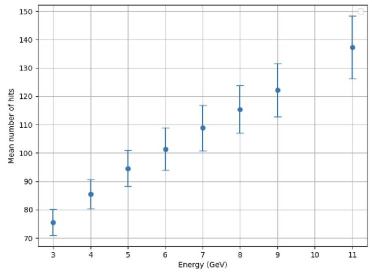
6 GeV → $\langle N_{hit} \rangle$~87

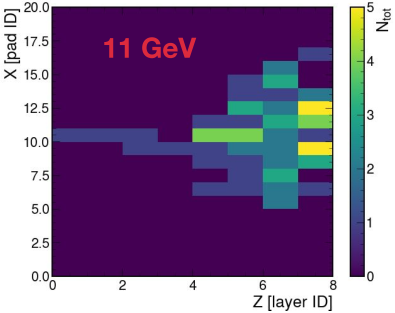


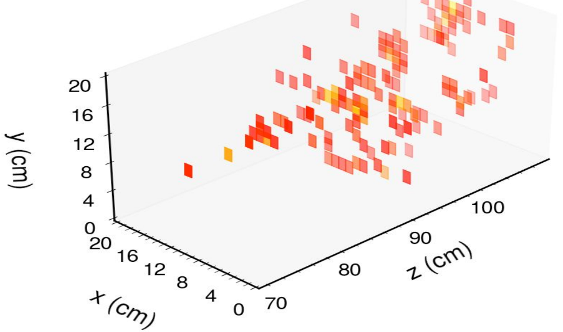
2024 Data

Preliminary

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

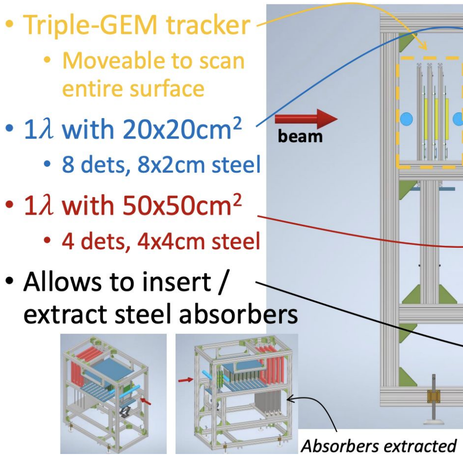


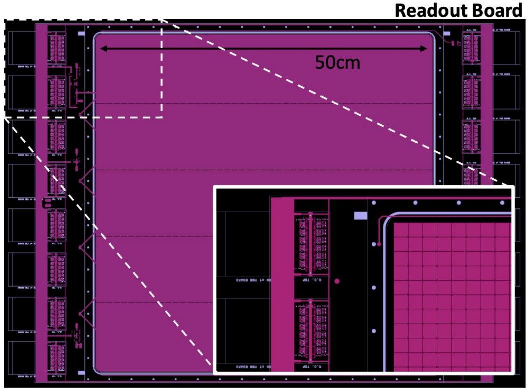




MPGD-HCAL future activities

- Development of a new cell prototype of $\sim 2\lambda_I$, including 8 20x20cm^2 chambers plus 4 50x50cm^2 chambers (2 Micromegas & 2 µRWELL, their production foreseen for beginning of next year):





- Test beam with CRILIN (a Crystal calorImeter with Longitudinal InformatioN) electromagnetic calorimeter and with CALICE.
- Understand the best technology between Micromegas and µRWELL, balancing performances and large area production feasibility & cost.
- Electronics:
  - so far data collected with APV hybrids; too old, not able to sustain high rate and not supported;
  - preliminary tests with VMM hybrids (ATLAS chip) show good results compatible with what observed with APVs;
  - Interest in FAst TIming Integrated Circuit (FATIC) chip developed by our BARI electronics team.
- (>>2026) Development of 50x100cm^2 MPGD detectors with and without embedded electronics, starting thinking about cooling

Inputs for ESPP

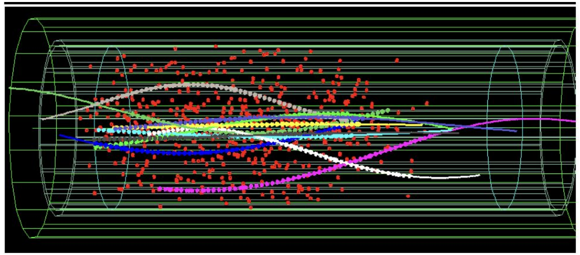
INFN Strategy 6-7 May 2024

Implementation at CERN: a possible roadmap

- 2028-2035
  - FCC is approved:
    - We (already have) convinced the management that the demonstrator is essential
    - We continue on the low power side, at a pace compatible with running HL-LHC and the FCC programme, still aiming at a reasonable facility by 2035.
  - FCC is further delayed or not clearly approved
    - We request the full budget for the high-power option
    - We speed up in order to start installation in TT10 by 2033, first beam 2035.

Ionisation Cooling Demonstrator / R. Losito / CERN

- Next European Strategy Update to get support for the demonstrator
- In all the scenarios (even with a demonstrator at Fermilab), the aim is to have a facility by 2035



Full interest for a TPC with optical readout for beam monitoring

Inputs for ESPP?

MPGD-HCAL is an excellent alternative for a Hadronic Calorimeter

- cost-effectiveness for large area instrumentation
- radiation hardness up to several C/cm^2
- rate capability O (MHz/cm^2)
- high granularity
- different pad size segmentation, being capable to achieve good space resolution (*O*(100μm))→express interest, from colleagues involved into the MAIA experiment concept at MuCol, for a MPGD-HCAL capable to also perform muon tracking
- good timing resolution (*O*(ns))
- easy to cover large areas
- MPGDs:
  - both Micromegas and μRWELL are ones among the main MPGD technologies for detectors at future colliders, thanks to their versatility
  - **Strong synergies with other FCC R&Ds currently on-going**

INFN Strategy 6-7 May 2024

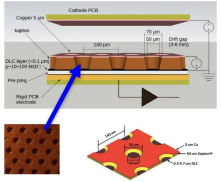
FCC INFN 18

Preshower and Muon detectors

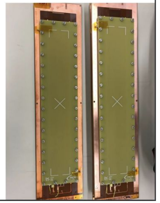
Based on μ-RWELL technology

Preshower:
- High resolution after the magnet to improve $\pi^{\pm}/e^{\pm}$ and 2γ separation
- Space Resolution < 100 μm
- pitch = 0.4 mm
- 1.3 million channels

Muon detector:
- Identify muons and search for LLPs
- Space resolution < 400 μm
- pitch = 1.2 mm
- 5 million channels



Ongoing development
- Mass production
- Optimization of FEE channels/cost
- 50x50 cm^2 2D tiles to cover more than 1650 m^2



New μ-RWELL prototypes with 40 cm long strips

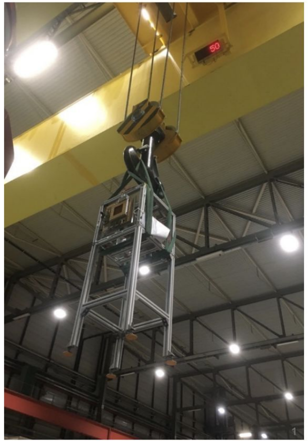
RD_FCC

Resistive Micromegas in RD_FCC

Napoli:
M. Alviggi, R. De Asmundis, M. Della Pietra, C. Di Donato, P. Iengo, G. Sekhniaidze

Roma3:
M. Biglietti, R. Di Nardo, M. Iodice, R. Orlandini, F. Petrucci

Incontro con i Referee 26 Luglio 2024



Synergies and common effort

Bari team: 15 people for 3.6 FTE for 2025 (starting from 2.3 FTE of 2024)

[Inauguration Muon Collider US meeting]