International MUON Collider Collaboration

UNIVERSITÀ DEGLI STUDI DI BERGAMO | Dipartimento di Ingegneria e Scienze Applicate

INFN PAVIA

Detector R&D

Ilaria Vai on behalf of the Muon Collider Physics and Detectors working group*

3rd Muon Collider Community Meeting
October 7th 2021

Muon Collider Detector

Based on CLIC detector: arXiv:1202.5940
ILCSoft: http://ilcsoft.desy.de/portal

hadronic calorimeter

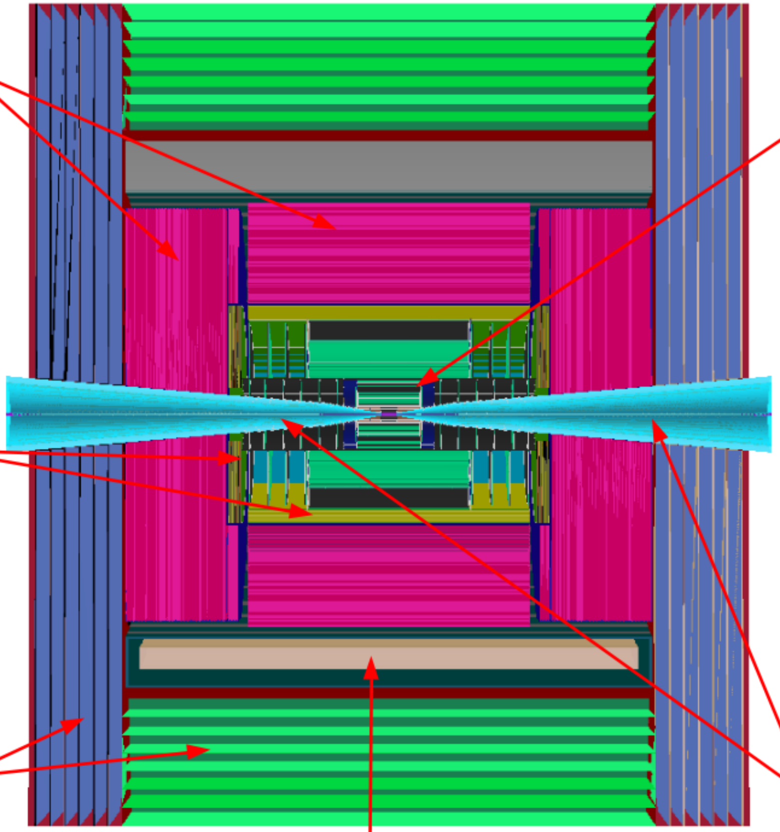
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm^2 cell granularity;
- 22 X_0 + 1 λ_I.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm^2 cell size.



superconducting solenoid (3.57T)

tracking system

- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 μm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 μm x 10 mm micro-strip Si sensors.

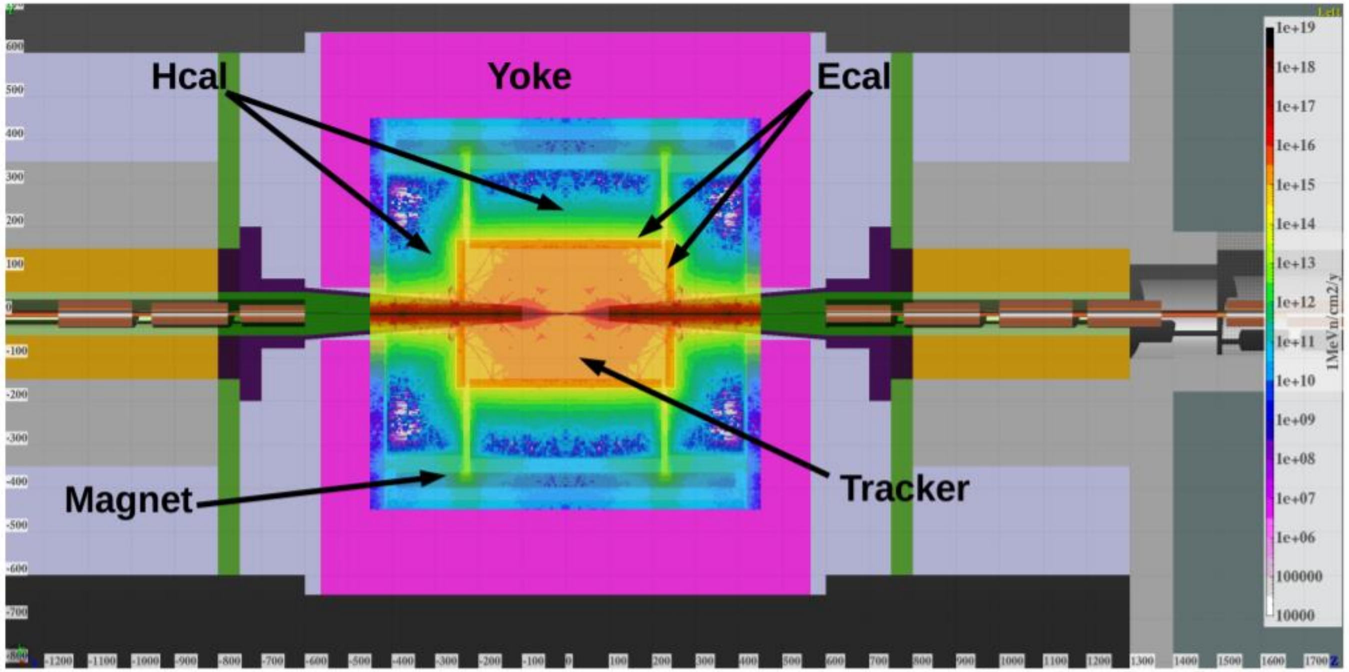
shielding nozzles

- Tungsten cones + borated polyethylene cladding.

Beam-Induced-Background

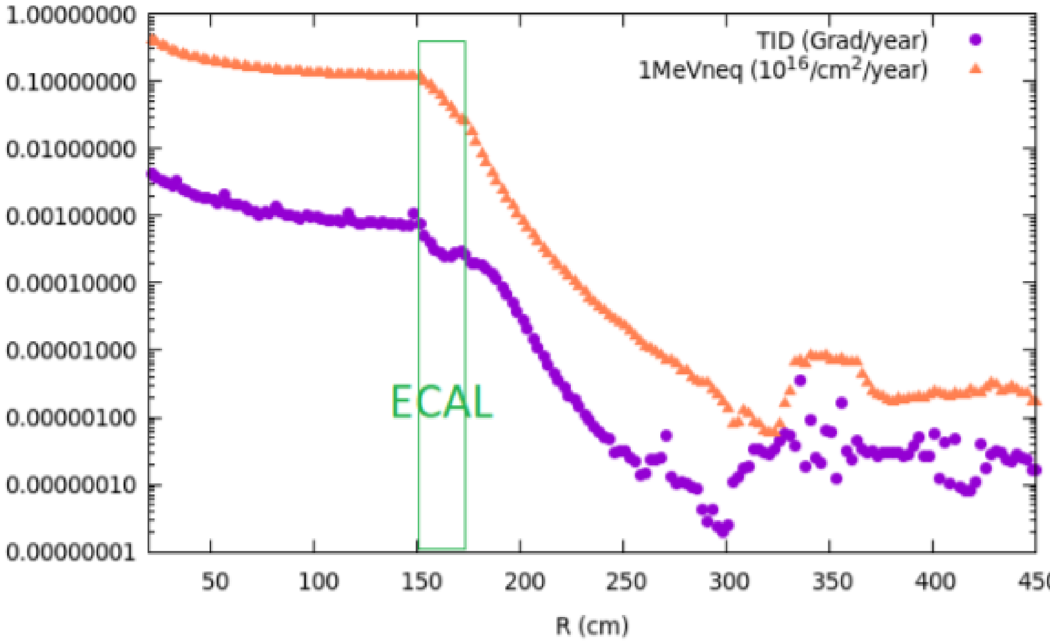
C. Curatolo et al

Beam Induced Background (BIB) is mainly due to the decay of muons → huge background contribution in the inner detectors.



FLUKA @ 1.5 TeV

1 MeV neutron equivalent and Total Ionizing Dose



Proposed detector R&Ds

Activities already on-going:

- ***ECAL → CRILIN***
  → goal is to build a crystals calorimeter, fast, cheap, and with a granularity (both transversal and longitudinal) tuned on MC simulations for BIB subtraction
- ***Muon System → Fast timing MPGDs***
  → current GRPCs are limited both in rate capability and space resolution
  → R&D on a detector able to combine an improved time resolution with an excellent space resolution and rate capability.

Other proposed activities:

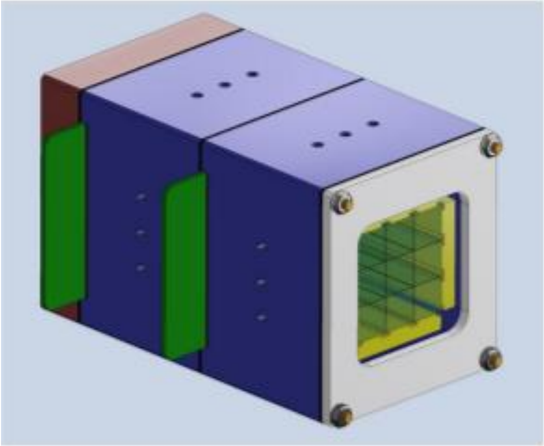
- ***Tracker → Resistive AC-Coupled Silicon Detectors***
  → 4D tracking
- ***HCAL → MPGD-based calorimeter***
  → RadHard HCAL

ECAL

The CRILIN detector

I. Sarra, L. Sestini

CRILIN
the semi-homogeneous crystal calorimeter



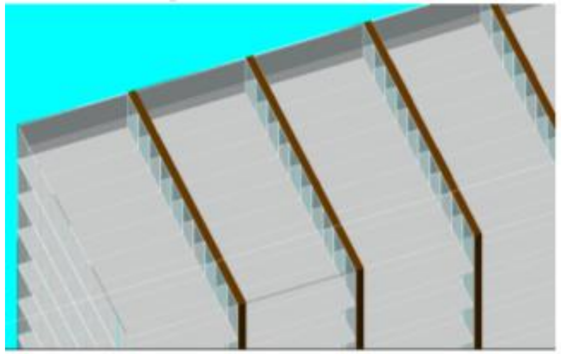
Goal of the R&D: find solutions alternative to the W-Si sampling calorimeter

CRILIN = CRystal calorimeter with Longitudinal Information

It's a semi-homogeneous crystal calorimeter (PbF_2), where Cherenkov light is read by SiPMs. PbF_2 has

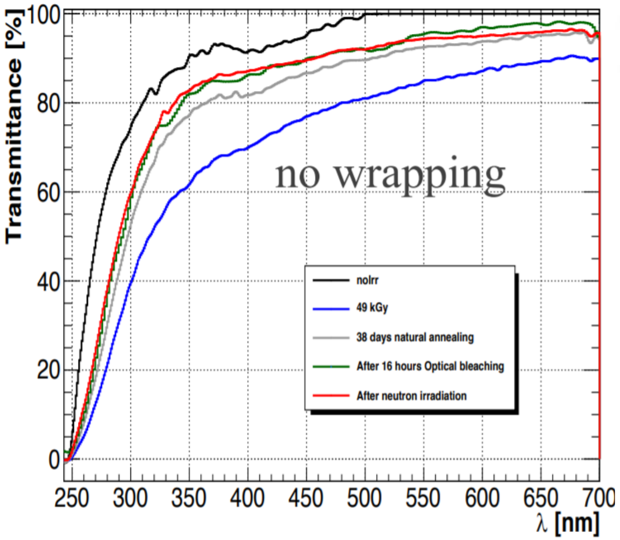
- good light yield (3 pe/MeV)
- fast signal (300 ps for muons, 50 ps for pions)
- radiation hard
- relatively cheap.

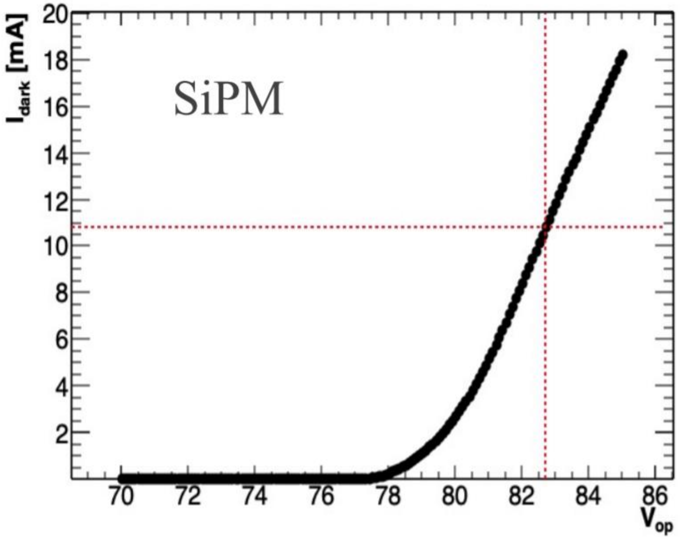
Proposal: five layers (40 mm thick → ~21.5 X_0), 10 x 10 mm^2 of cell area.



Prototypes results

I. Sarra, L. Sestini



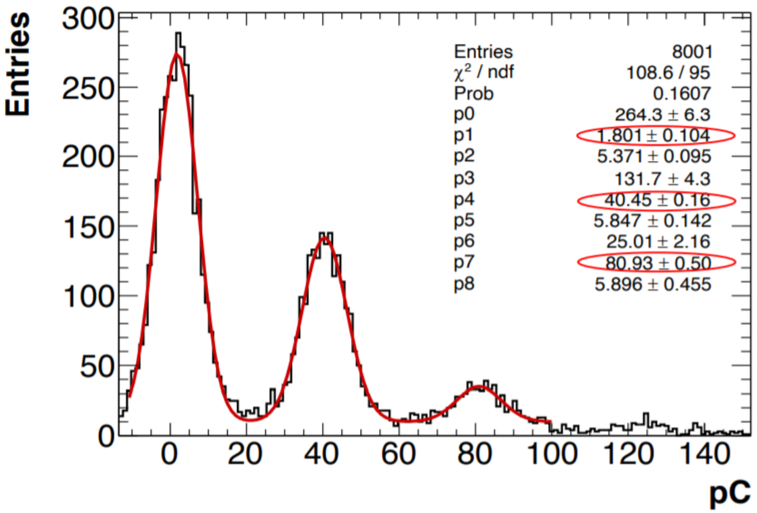


Single components tested for **dose and response to neutrons:**

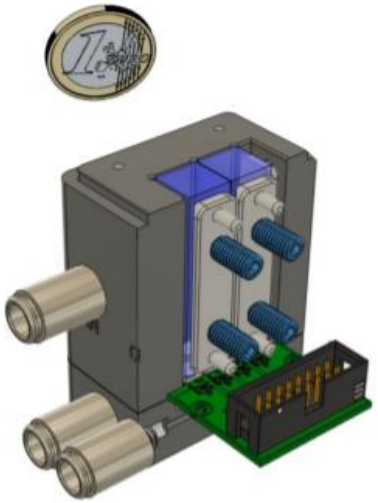
- SiPM tested up to 10^{12} neutrons
- Cristals tested up to 10^{13} neutrons and 4 Mrad.

→ Goal is to reach almost 10^{14} for the next year, reducing the pixel size to 15 μm (now is 50 μm)

Light Yield measured with MIP → 6 p.e/MeV



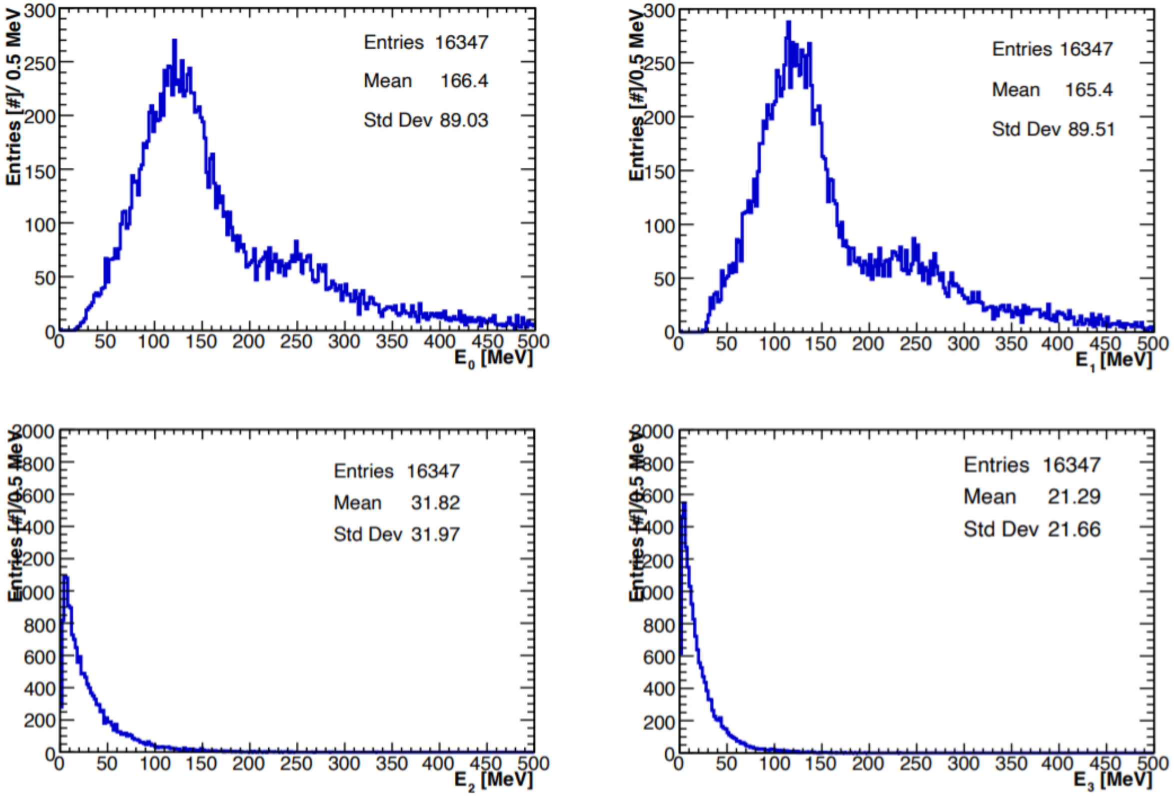
Two 10x10x40 mm^3 PbF_2 crystals enclosed in Mylar/EJ510 → 4 readout channels.



Test beams results - 1

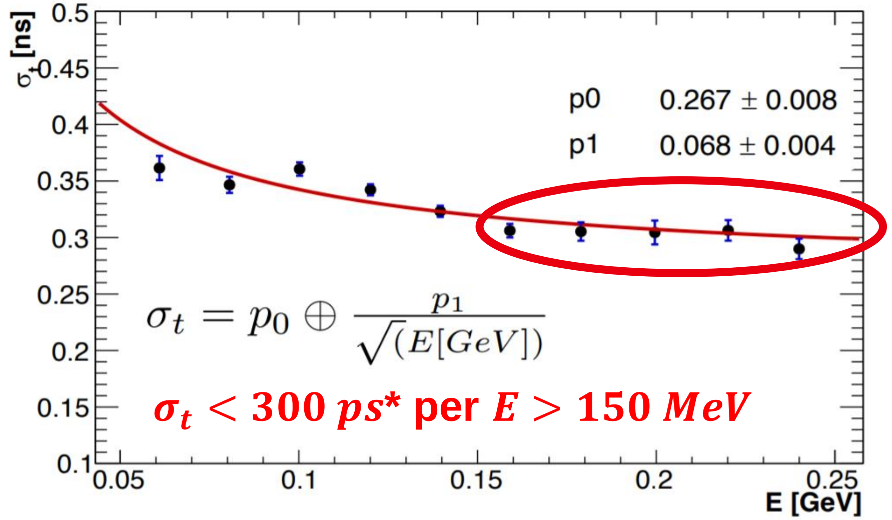
I. Sarra, L. Sestini

Test Beam @ BTF (Frascati):



500 MeV electrons on the two crystals (2 SiPM per crystal)

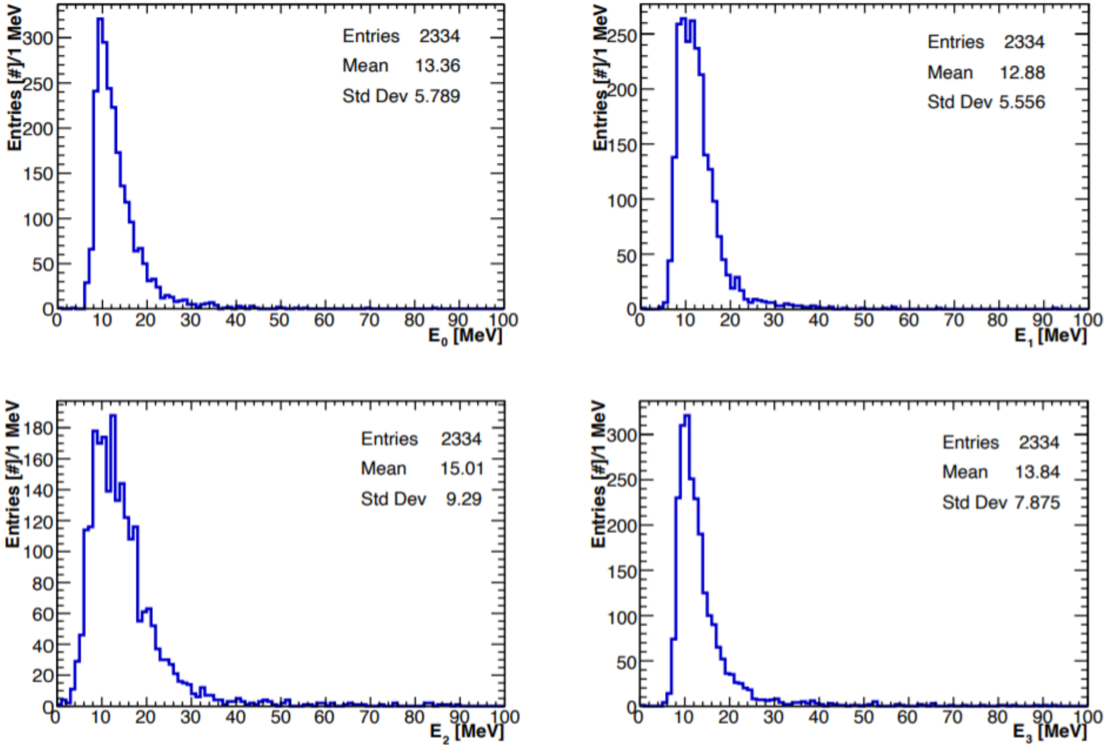
Distribution divided in 10 MeV slices → time resolution measured as time difference between the 2 SiPM in each crystal per each slice



* To be divided by 2 for the 2 photosensors

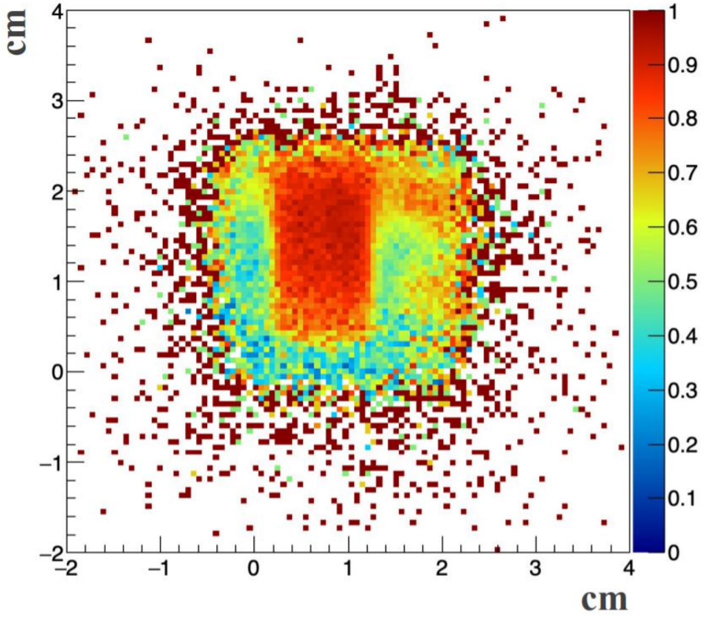
Test beams results - 2

I. Sarra, L. Sestini



Test Beam @ BTF (Frascati):
MIPs transversally crossing the crystals (10 MeV deposits)

Test Beam @ H2 (CERN):
crystals reconstructed with tracker system (required 1 cluster before and > 6 after)

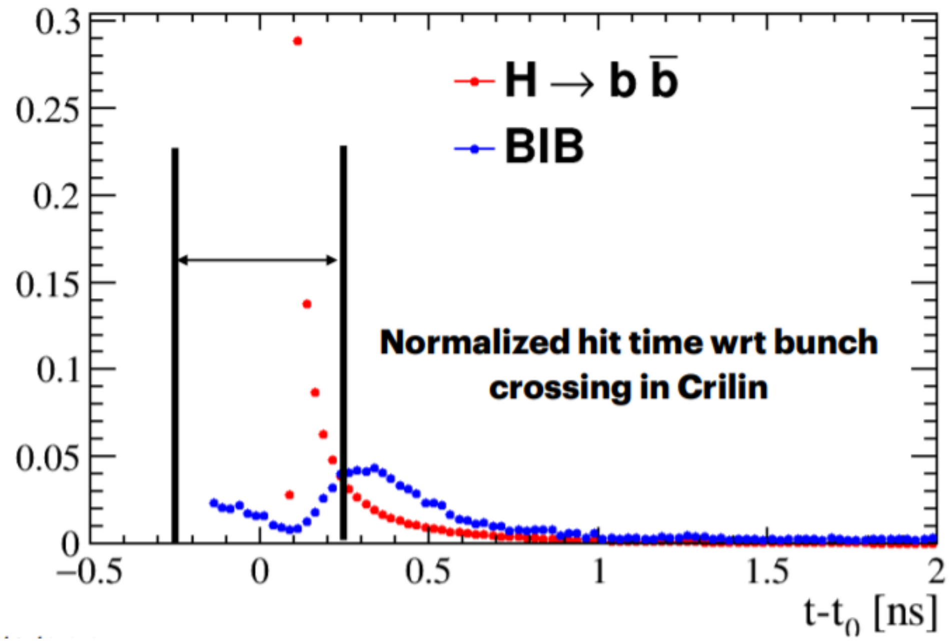


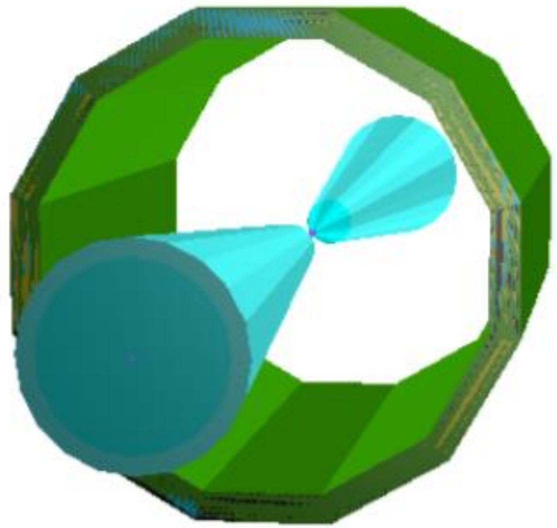
Full analysis still on going, but preliminary results are promising.

CRILIN in the muon collider simulation - 1

I. Sarra, L. Sestini

Full simulation of the **signal** (H→bb) and **BIB** in the detector with Crilin as ECAL barrel has been performed @1.5 TeV.



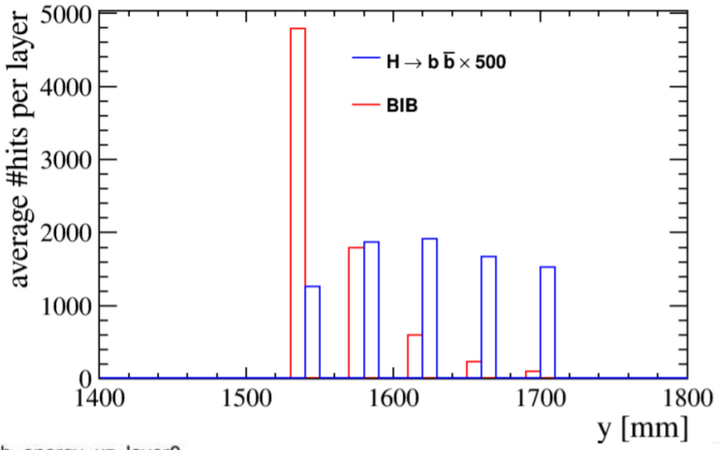


- implementation done with the DD4HEP interface to Geant4
- 5 layers of 40 mm length, 10 X 10 mm^2 cell area
- dodecahedra geometry.

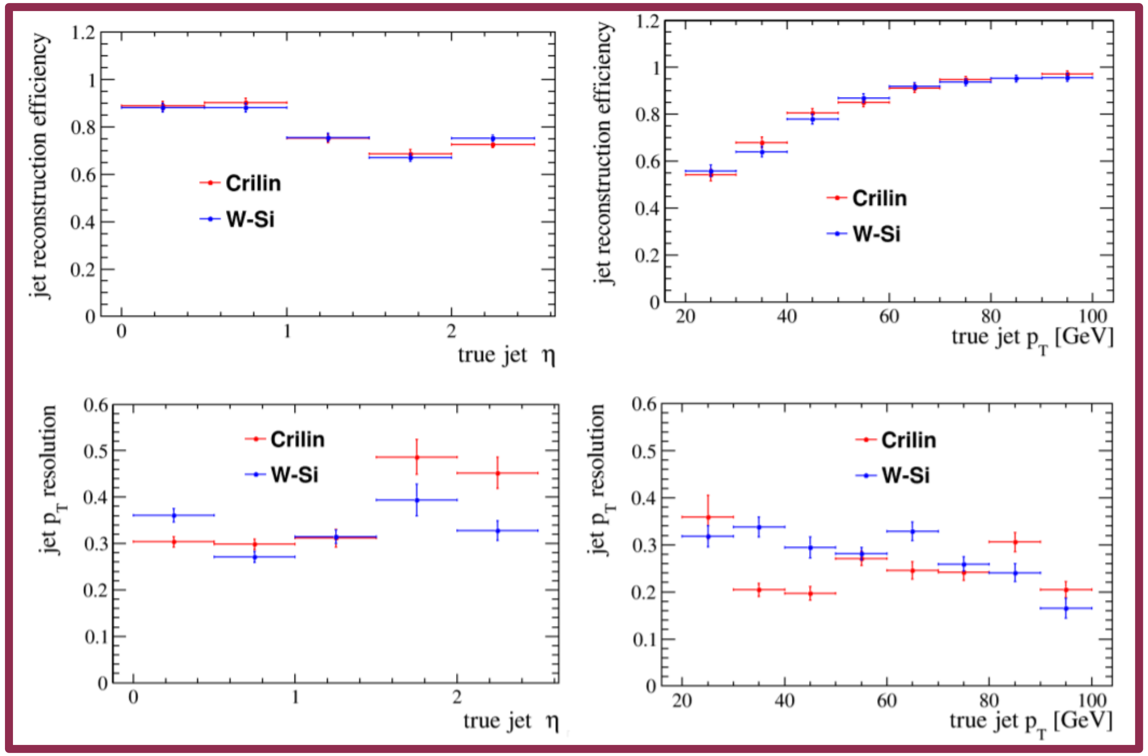
Acquisition time window of [-250,+250] ps wrt bunch crossing applied to separate signal from BIB → ***achievable with a time resolution of about 80 ps*** (window ≈ 3σ).

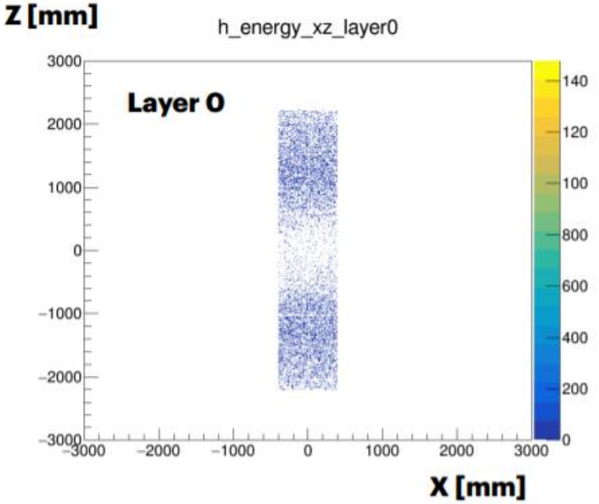
CRILIN in the muon collider simulation - 2

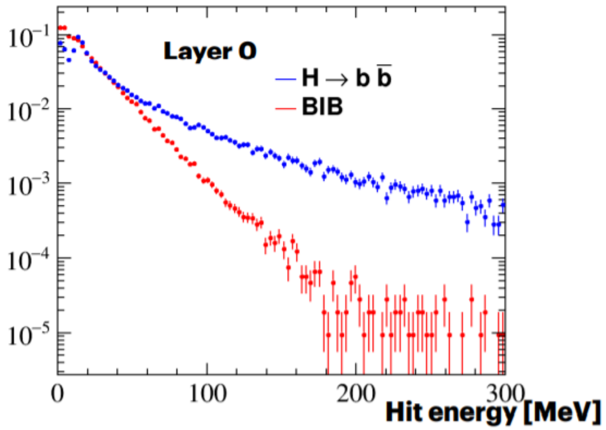
I. Sarra, L. Sestini



The performance obtained with Crilin is at the same level of W-Si.





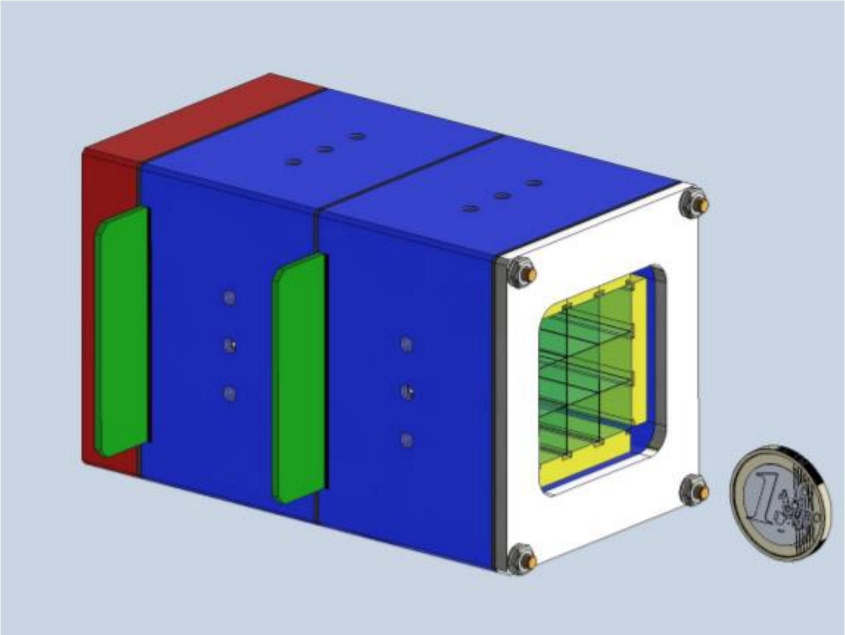


Planned activities

I. Sarra, L. Sestini

- Realization and test of a prototype made of 2 layers of PbF_2 3x3 crystals each

- Improvements on the simulation side:
    - implement the lateral dead material around the cells
    - implement a better digitization model
    - to be repeated when a better version of the reconstruction will be available



Muon System

Technologies for the muon system

Detector	σ_t	σ_x	Rate capability
RPC (HPL o Glass)	1 ns (single-gap) < 100 ps (multi-gap)	~mm	~ 1 kHz/cm^2
Standard MPGD (GEM, Micromegas)	5-10 ns	~100 μm	> 100 kHz/cm^2

R&D Goal: develop a detector able to reach good performance on all the three items → to be used at the muon collider as

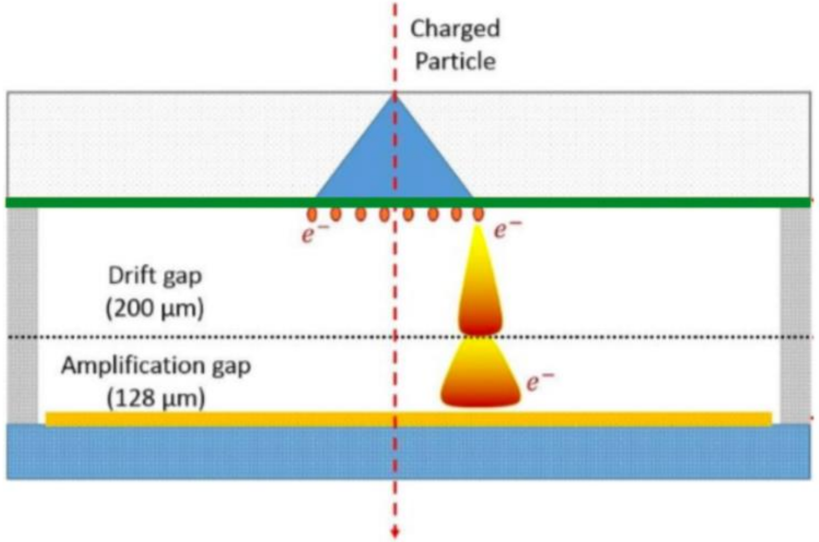
- Standalone detector for the muon system, using σ_t, σ_x and rate capability

or

- Dedicated Timing layer, to be combined with a tracking layer

Picosec detector - 1

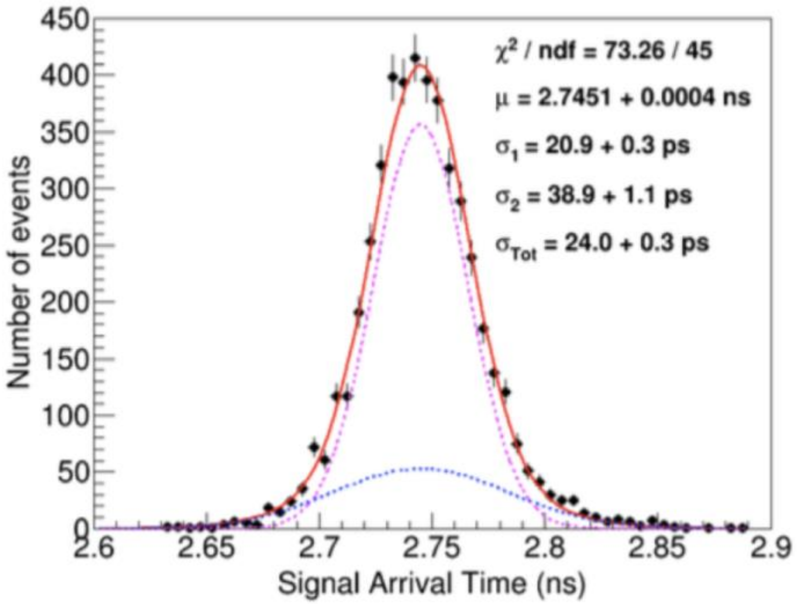
https://gdd.web.cern.ch/activities-picosec



New MPGD composed by:

- MgF_2 Cherenkov radiator (3-4 mm)
- Photocathode (10 nm), currently of CsI
- Standard Micromegas with reduced drift gap

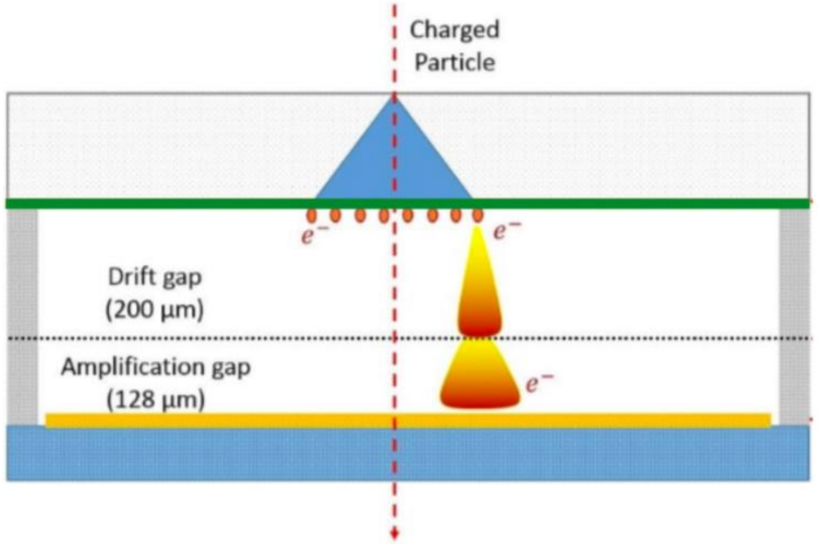
→ Measured time resolution ~ 25 ps ($Ne/C_2H_6/Cf_4$ – 80/10/10)



Picosec detector - 2

Interesting because, as an MPGD, we aim at combining the improved time resolution with an excellent space resolution and rate capability (improvement w.r.t. RPC).

https://gdd.web.cern.ch/activities-picosec



Plans for 2022:

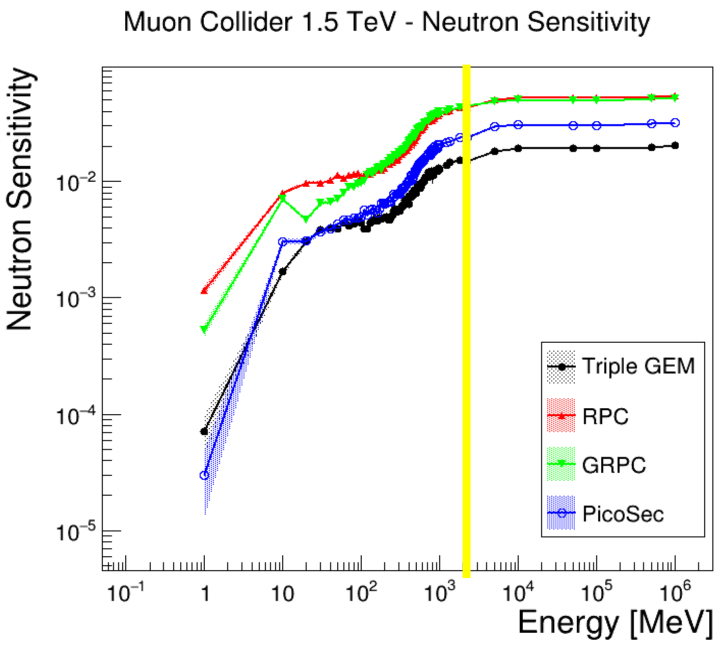
- Design, built and characterize a 10x10 cm^2 prototype
- Begin the study on an eco-friendly gas mixture
- Test possibile new materials for the Cherenkov radiator
- Perform simulations to optimize the detector config

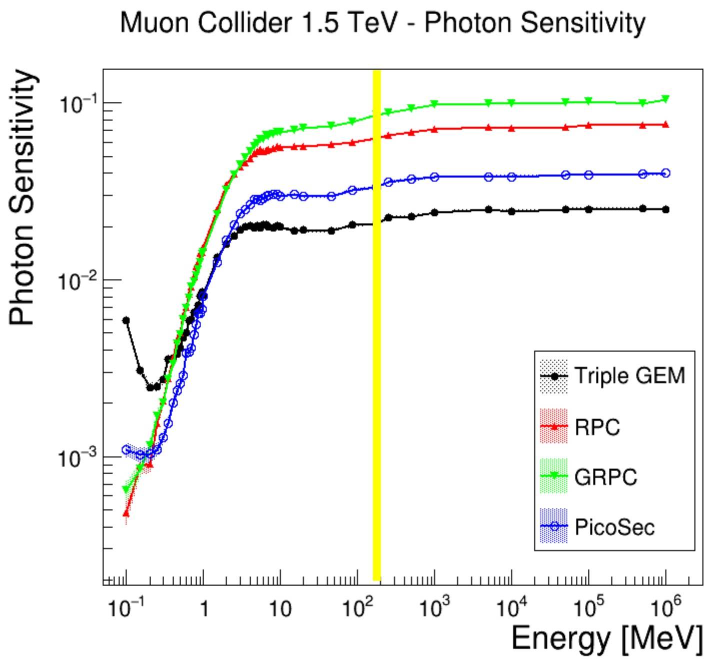
Standalone simulations - 1

Geant4 standalone simulation (*Geant4.10.06 p02*) to study the response of the detectors to BIB @ 1.5 TeV.

Detector sensitivity to BIB simulated for:

- Double-gap Glass RPC
- Double-gap HPL RPC
- Triple-GEM
- Picosec





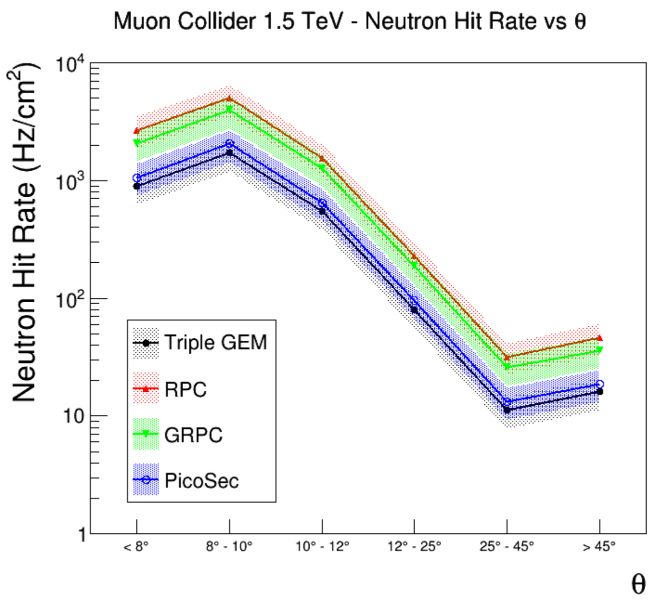
Picosec sensitivity lower than RPC one, because MPGDs have lower material budget.

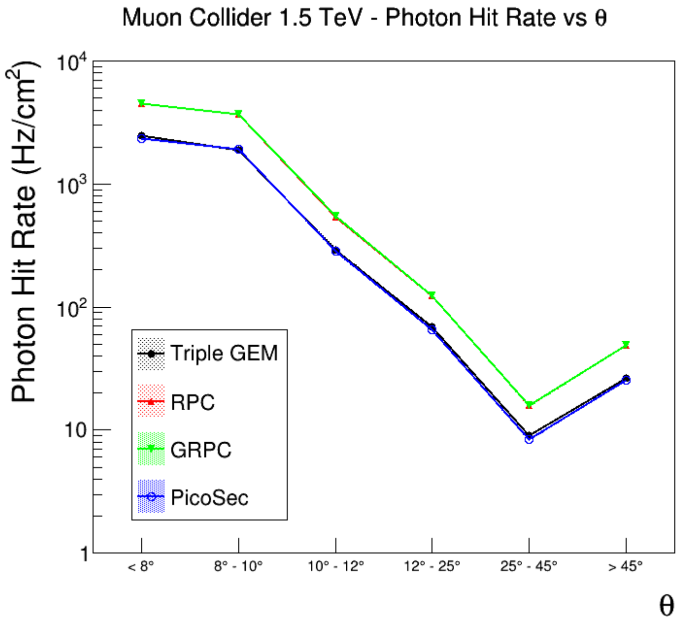
Standalone simulations - 2

Hit Rate = Sensitivity × BIB flux

→ Picosec has lower expected hit rate than RPC (because sensitivity is lower)

→ Expected Hit Rate for RPC already at the limits for current technology

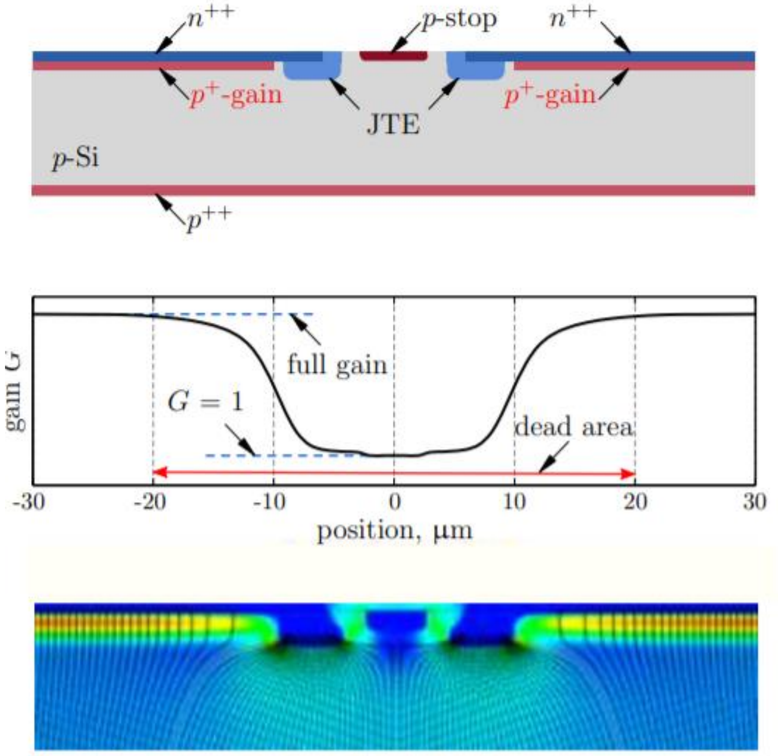




Other proposed R&D - Tracking

M. Mandurrino

4D particle tracking with Resistive AC-Coupled Silicon Detectors (RSD)



http://dx.doi.org/10.1016/j.nima.2020.163479

RSD:

- Analogic readout with bipolar signals
- Benefit from the good timing performances proper of LGADs, + increased capability to track particles in space → **suitable for 4D tracking**
- 100% fill-factor + analogic readout = reconstruct the hit position with a precision ~2 orders of magnitude lower than the pad pitch

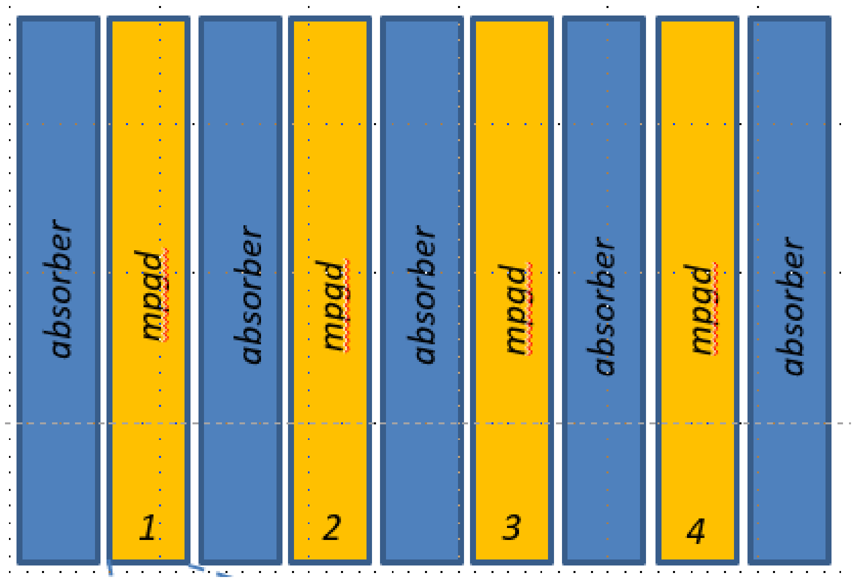
Optimization for a muon collider requires:

- low material budget
- Optimized geometry to match physics requirements
- large-area detectors
- radiation-hardness studies

Other proposed R&D - HCAL

P. Verwilligen

Resistive MPGD-based calorimeter



From FLUKA simulations, HCAL may be subjected to $10^{11} - 10^{15}$ 1MeV n-equiv /cm^2 per year

→ Proposal: RAD-HARD calorimeter, based on absorber + MPGDs:

- High granularity at low cost
- Good energy resolution (from CALICE studies)

+

- Usage of resistive gaseous detectors
- Possibility to exploit also timing information

Plan:

- Simulation studies with Geant4
- Test different MPGD technologies in a small-size stack with stainless steel absorbers

Summary

The **Muon Collider** is a great opportunity for precision physics at high energy and high luminosity. However, its unique environment – in particular the presence of the BIB - requires a careful design of the most suitable detectors.

Interesting R&Ds have already started on the ECAL detector and for the muon system, others have been proposed for the tracker and HCAL.

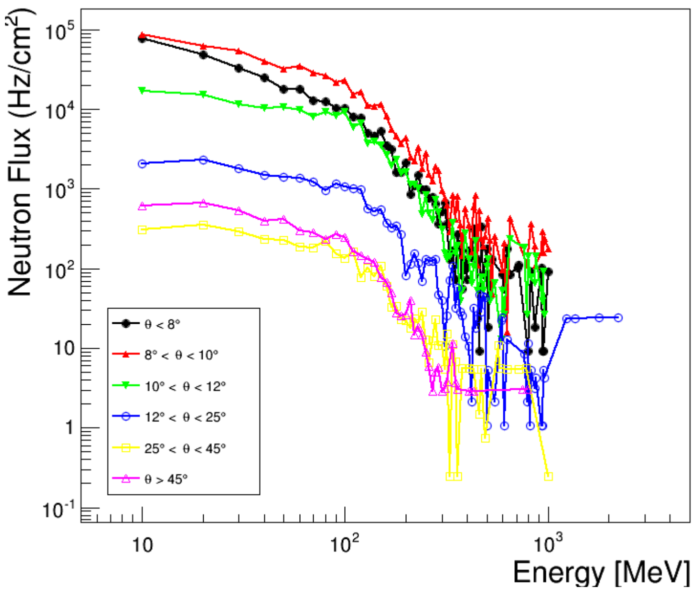
These activities will continue in the next months, together with the definition of the requested performance by simulation.

Thanks!

Backup

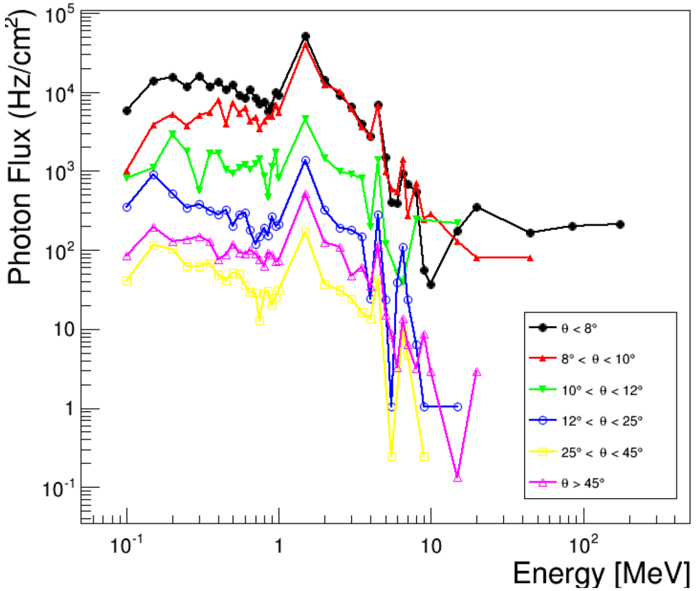
Beam Induced Background

BIB Energy distribution - Neutrons vs θ



The BIB in the muon system is mainly composed by neutrons and photons.
In the inner regions the flux is almost 3 order of magnitudes higher than in the out regions.

BIB Energy distribution - Photons vs θ



At $\sqrt{s} = 1.5\ TeV$:

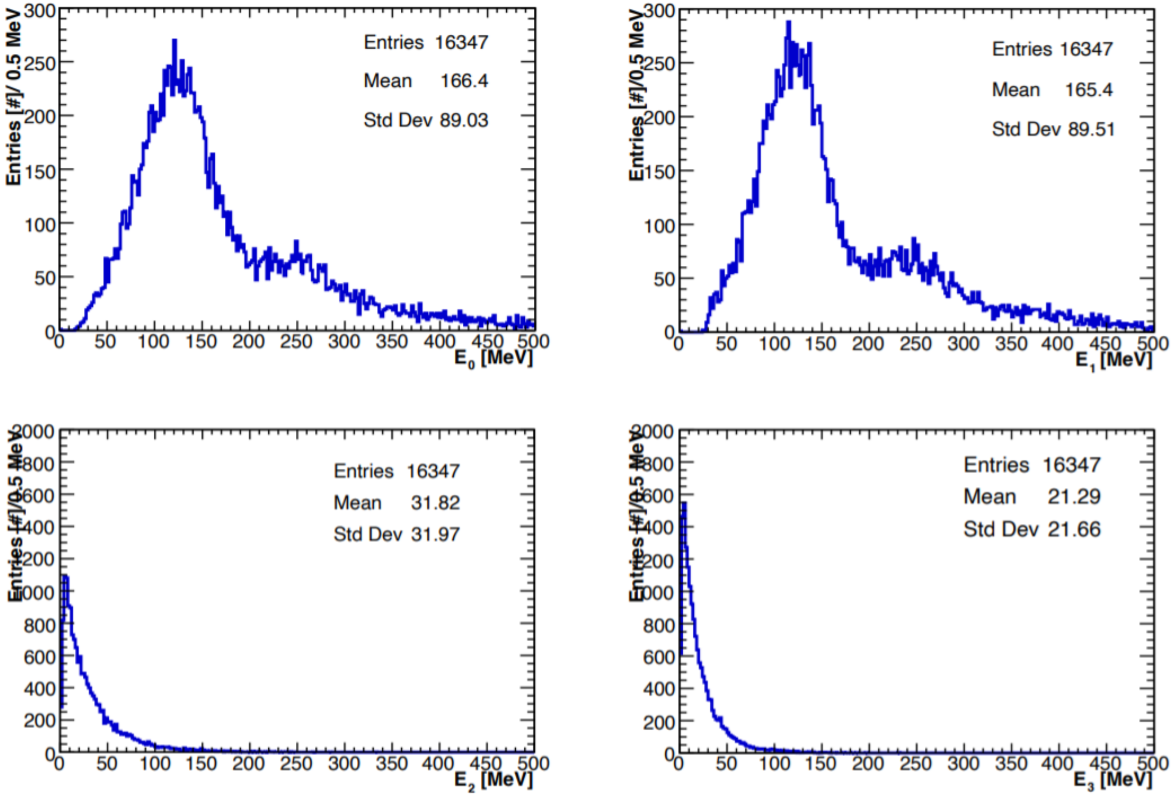
- Neutrons: energies up to 2.5 GeV
- Photons: energies up to 200 MeV

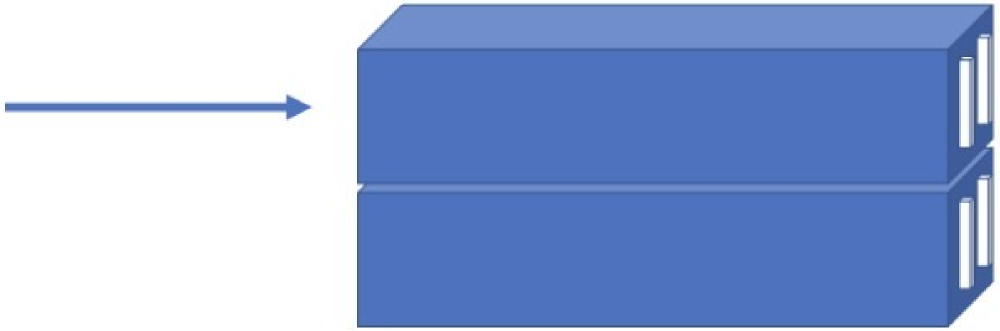
Distributions obtaines from MARS+Geant4+v02-05-MC selecting the particles that arrive at the muon system.

Test beams results - 1

I. Sarra, L. Sestini

Test Beam @ BTF (Frascati):





500 MeV electrons on the two crystals (2 SiPM per crystal)