Detector R&D

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

RD_MUCOL – Riunione di collaborazione @ Padova

International MUON Collider Collaboration

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

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Muon Collider Detector

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

hadronic calorimeter

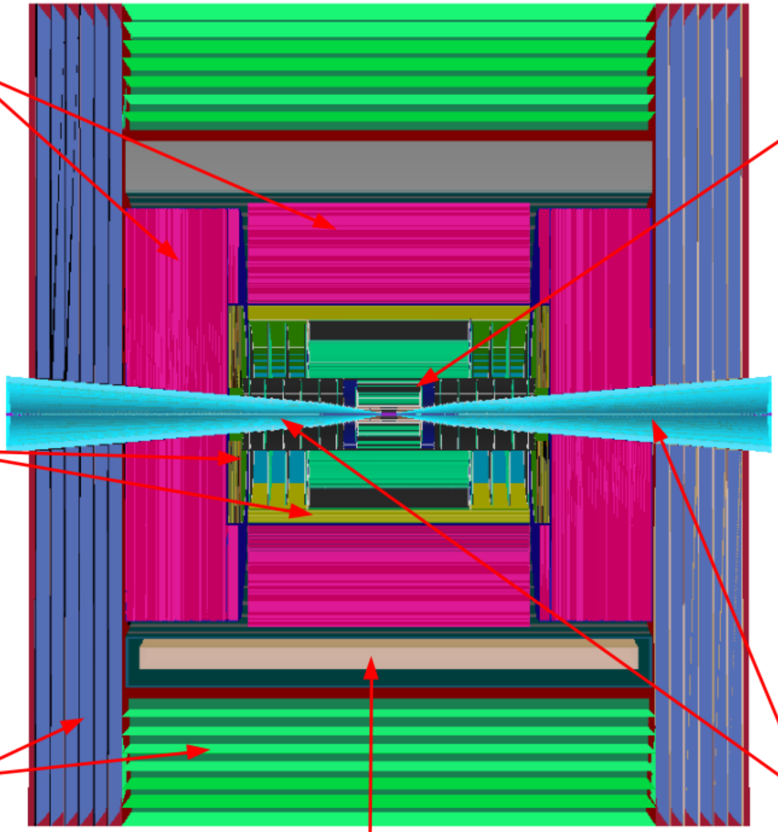
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

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.

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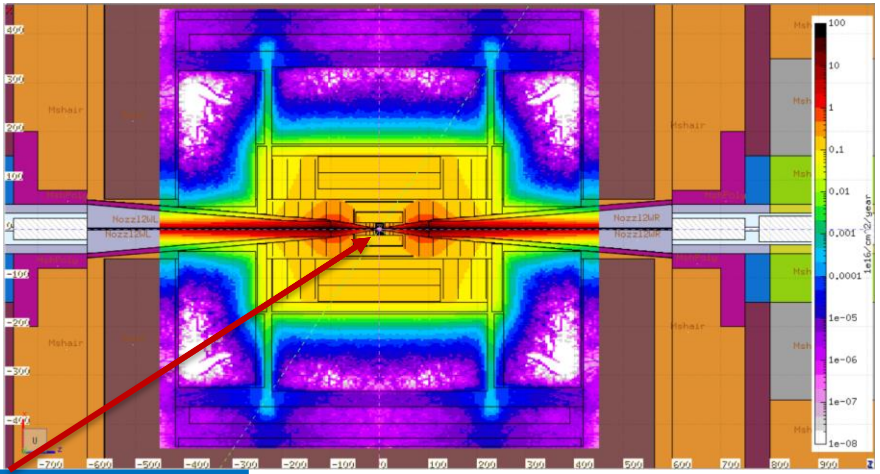
1 MeV n_{eq} fluence/year

P. Sala et al



Color scale: 10^{16}/cm^2/year

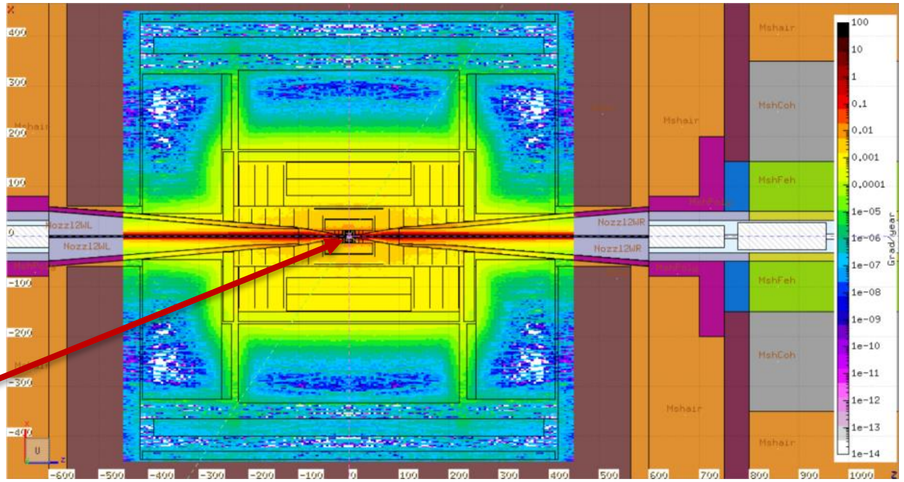
≈ few 10^{15}/cm^2 /y

Normalization:
2 × 10^{12} muons/bunch
200 days/year
100 kHz bunch crossing

Total Ionizing Dose/year

1 Gy = 100 rad
1 Grad = 10 MGy

≈ 10^{-3} -10^{-2} Grad/y



Color scale: Grad/year

Proposed detector R&Ds

Activities already on-going:

- ***ECAL → CRILIN → Slides from Ivano***
  → 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

Muon System
Fast timing MPGD – Picosec

Chiara Aimè, Simone Calzaferri, Davide Fiorina, Cristina Riccardi, Paola Salvini, Ilaria Vai, Nicolò Valle, Paolo Vitulo

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

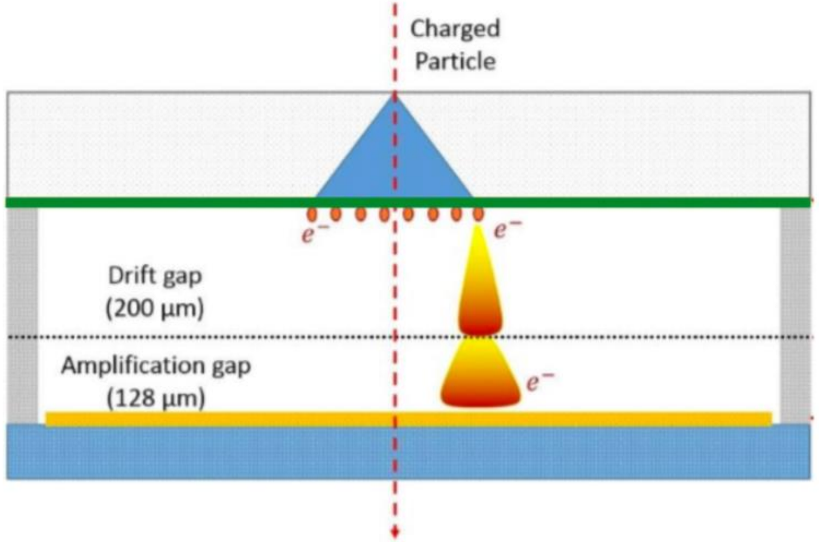
- Dedicated Timing layer, to be combined with a tracking layer

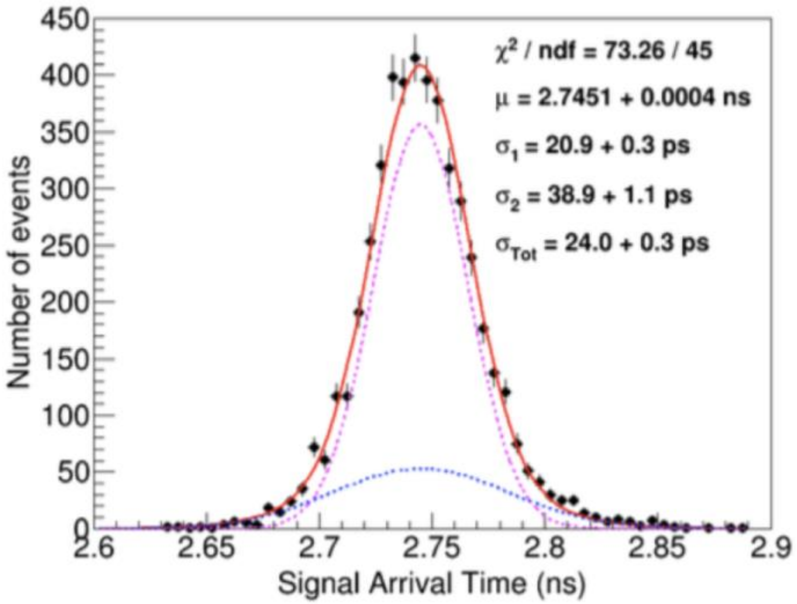
Picosec detector - 1

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



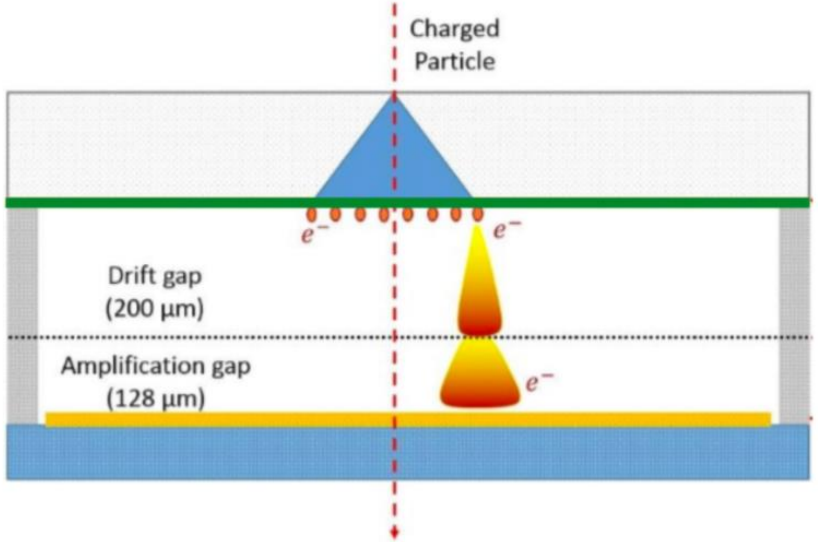


→ Measured time resolution ~ 25 ps
($Ne/C_2H_6/Cf_4$ – 80/10/10)

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:

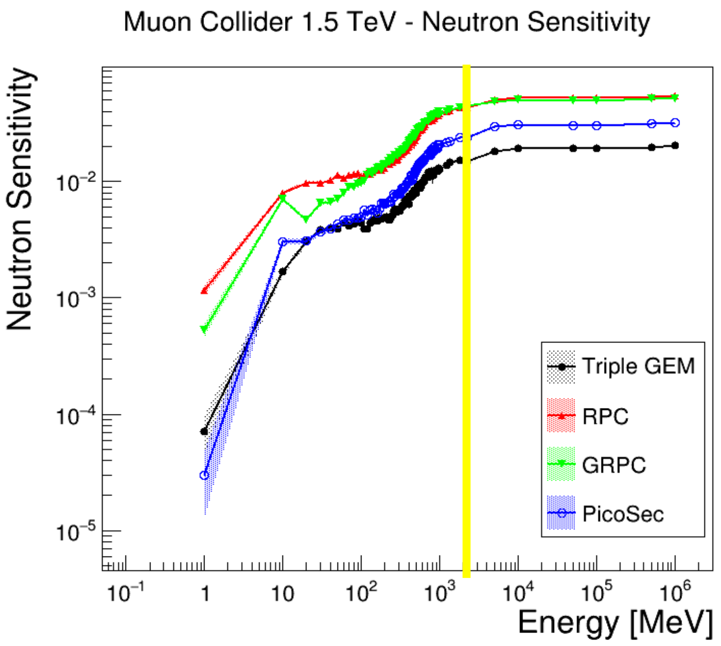
- Design, built and characterize a 10x10 cm^2 prototype
- Begin the study on an eco-friendly gas mixture
- Test possibile new materials for the Cherenkov radiator
- Perform simulations to optimize the detector config

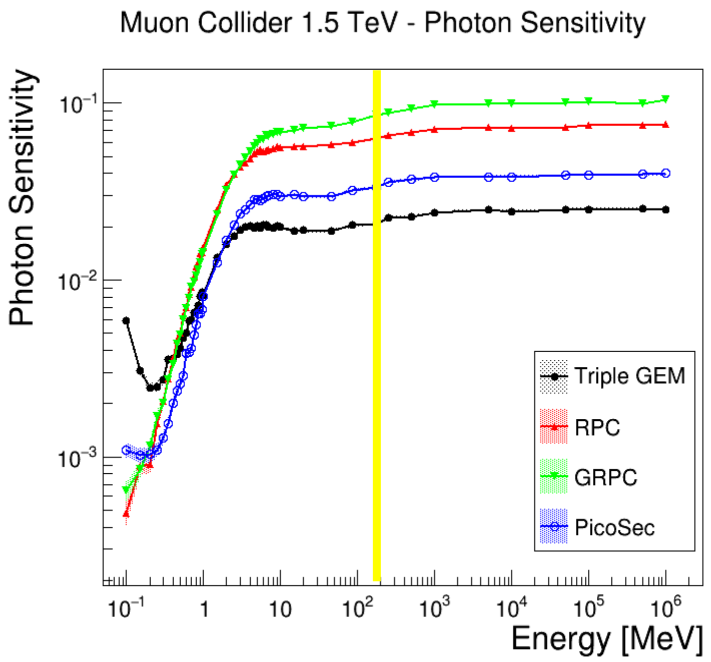
Standalone simulations - 1

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





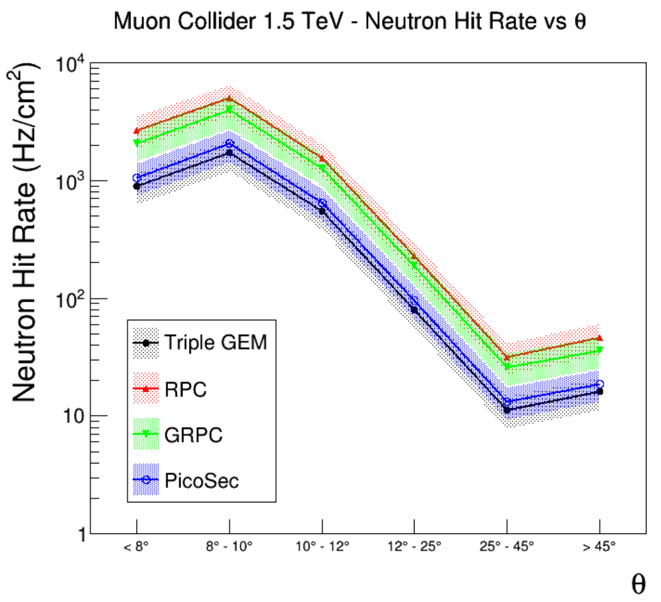
Picosec sensitivity lower than RPC one, because MPGDs have lower material budget.

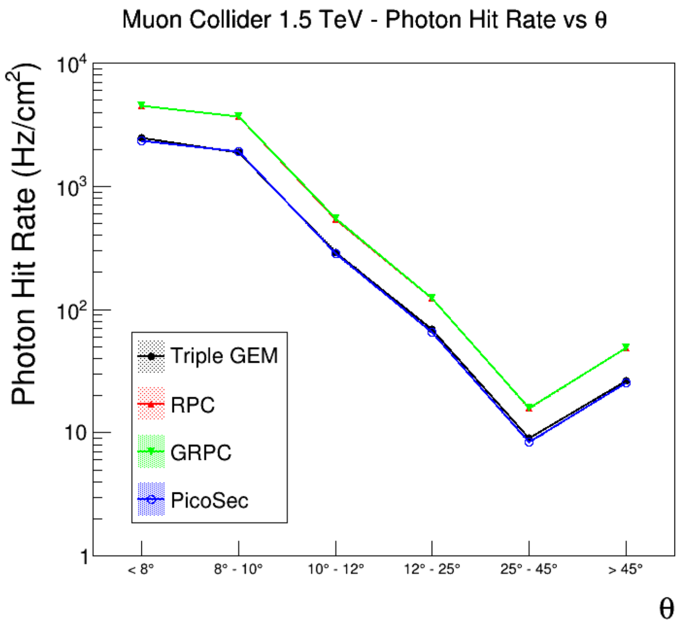
Standalone simulations - 2

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





Plans for 2022

Last week we had a very productive meeting with Eraldo Oliveri (RD51), Beatrice Mandelli and Roberto Guida (CERN Gas Group) and we agreed on the following plan:

First half of 2022:

- 10x10 cm^2 prototype design and production
- Begin work on single channel prototipe to:
  - Acquire operational expertise with the technology
  - Optimize the lab setups needed for the characterization
- Test in lab with small Cherenkov windows
- Start to work on Geant4/Garfield simulations for gas mixture choice

Second half of 2022:

- 10x10 cm^2 prototype:
  - Characterization in lab with LED source
- Small prototype:
  - Test with modified gas mixtures to remove C2H6 and/or CF4

Material needed & Funding requests

Requests made to CSN 1:

- 10 x 10 cm^2 prototype → **12 kE: Sub-judice from CSN1**
- MCP-PMT for timing measurement → **8kE: procurement on-going on Dotazioni 1**

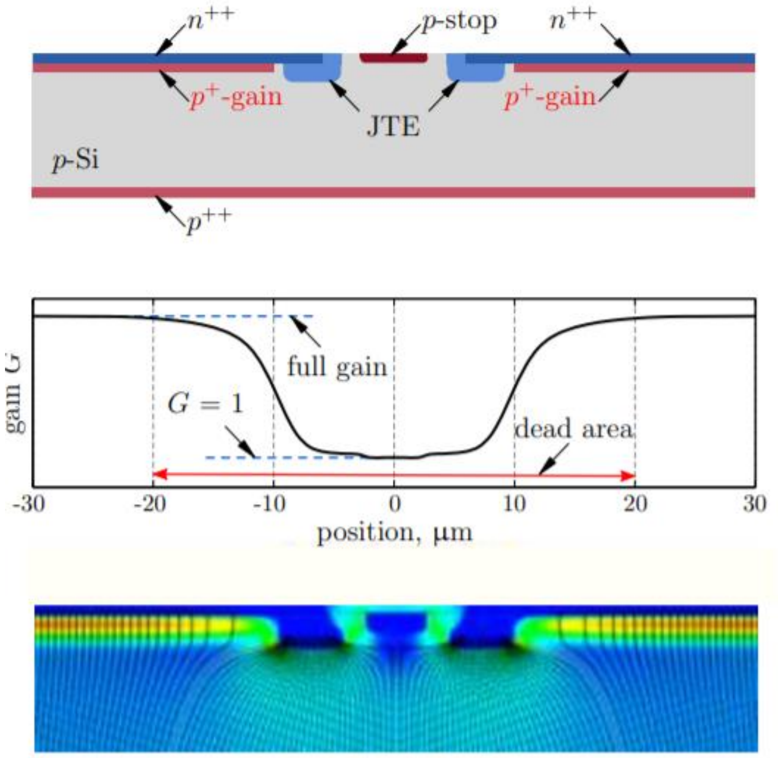
Other instrumentation needed:

- LED + Photodiode + Optic setup + set of Cherenkov windows → **procurement on going on other available funds**
- Basic readout chain (Cividec ampl + oscilloscope) → **Already present in the lab**
- Mixer with different gas bottles available or under procurement
  - Ar, CO2, Ne, Isobutane, R1234-ze (by the end of 2021), premixed Ne/C2H6/CF4 (in 2022) → **procurement on going on other available funds**

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

MPGD-based HCAL

MuColl Meeting

November 2021

Piet Verwilligen

Anna Colaleo, Marcello Maggi, Rosamaria Venditti, Anna Stamerra, Federica Simone, Antonello Pellecchia

International MUON Collider Collaboration

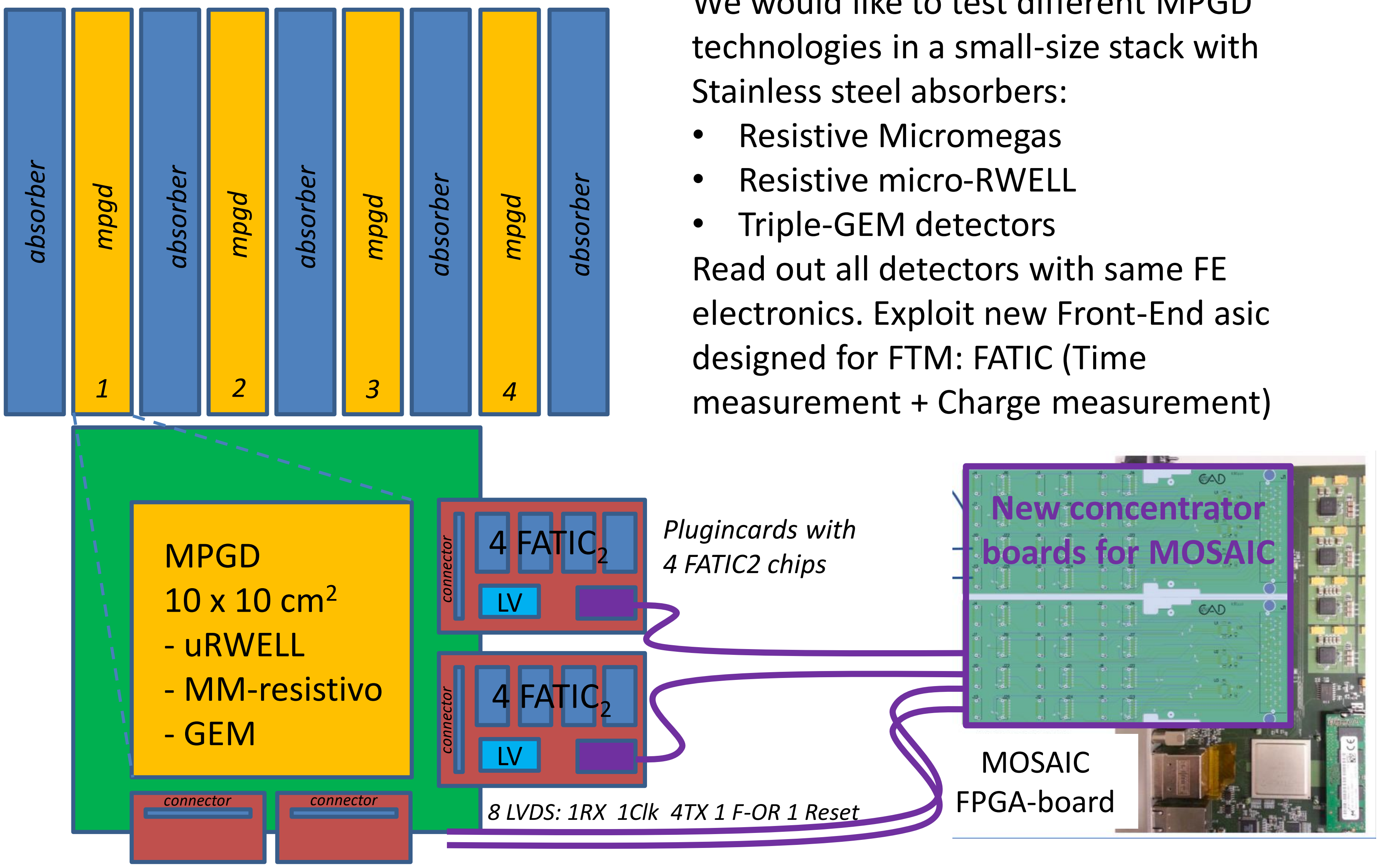
INFN

Online, September 9th 2021

Where does this proposal come from?

- CLIC detector: *(follows mainstream Calice proposal)*
  – ECAL: Si-W
  – HCAL: Fe-Scintillator (AHCAL)
- CALICE:
  – SDHCAL w/ RPC obtains same resolution as AHCAL (for reduced cost)
  – some Micromegas modules built and inserted
    - Show better performance w.r.t. RPC: better rate cap, smaller clustersize, Energy measurement possible, very radiation hard
    - activity not continued … (need to talk to LAPP Annecy)
- CEPC: R&D ongoing for Calorimeter with Resistive MPGD (concentrated on RP-WELL Weissmann (Israel) USTC (China)
- We would like to propose R&D effort on resistive MPGD
  – Unifies various groups in INFN working on resistive MPGDs (Na,LNF,Ba)
  – Submitted Common Project for add. RD51 funding (15kEUR/anno)
    - Na,LNF cannot commit %FTE to Muon Collider, but are interested
- *Not to be discussed with Referees:*
  – *This summer preparation for MuCol detector paper made me realize that there are also other interesting options for ECAL and HCAL that I would not exclude…*
    - *E.g. DR & Timing with Segmented homogeneous ECAL + DR HCAL (C.Tully, Princeton)*
    - *Have impression we did not reach well enough the Calorimeter community in the past…*

Design of MPGD-based HCAL cell



We would like to test different MPGD technologies in a small-size stack with Stainless steel absorbers:

- Resistive Micromegas
- Resistive micro-RWELL
- Triple-GEM detectors

Read out all detectors with same FE electronics. Exploit new Front-End asic designed for FTM: FATIC (Time measurement + Charge measurement)

Backup

Particle-Flow HCAL with MPGD:

what has been done so far …

- Mainly Linear Collider (ep) driven effort (CALICE)
- Digital & Semi-Digital HCAL (DHCAL – SDHCAL)
  - Digital HCAL improves on Analog HCAL because less affected by Landau tails in energy distribution
  - Further improvement by Semi-Digital approach to give different weight to high and low energy deposit with 1bit and 2bit ADCs
  - Readout Pixel size studied so far: $1cm^2$
  - Gaseous detectors considered:
    - Glass RPC & MPGD: GEM, MM, RPWELL
- **We will start from existing knowledge in the field**
  - However not clear wich MPGD is MPGD of choice
    - *Want to test objectively different technologies*
  - *Want to understand the time resolution* achievable for hadronic showers with standard MPGDs
    … and leave some room for MPGD R&D in future … FTM

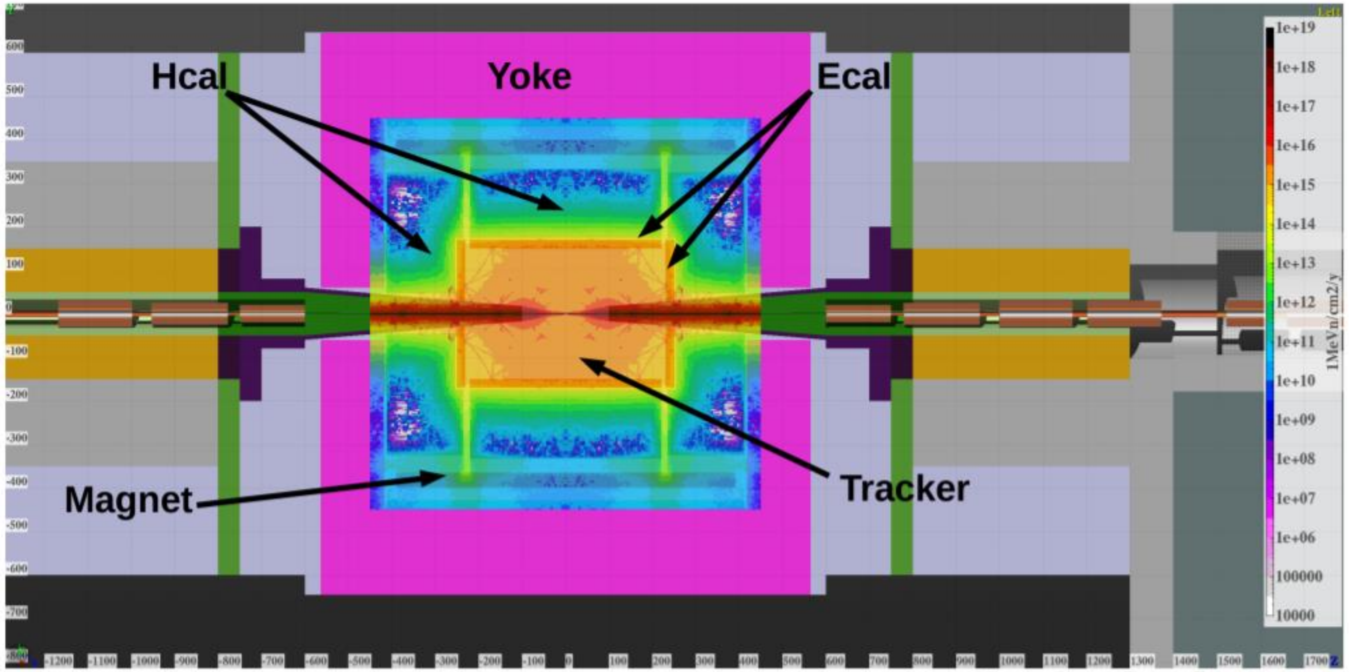
Side Remarks

- **Hadron Calorimeter R&D is expensive task**
  - ECAL: small moliere radius allows for small prototypes
  - HCAL: smallest prototype to contain most of hadronic shower: 50cm x 50cm
    - 2500 pixels – 100 ASICs – 25 Front-end boards …
  - Need several sampling layers
    - Costs for detectors and Electronics explode ….
    - Cannot make demonstrators for each technology
    - Cannot easily test different electronics and compare …
- So far no work was done on time-resolution of (S)DCAL prototypes (not even using the superb time-res of the glass-RPCs in CALICE!)
  - Gain in reduction of "confusion term" of energy resolution
- Even though we cannot contain full hadronic shower, we will be able to contain the (EM) core of the hadronic shower
  - We believe timing is mostly driven by the energetic core
  - We will not concentrate on energy resolution (for this you need to contain full shower)

Beam-Induced-Background

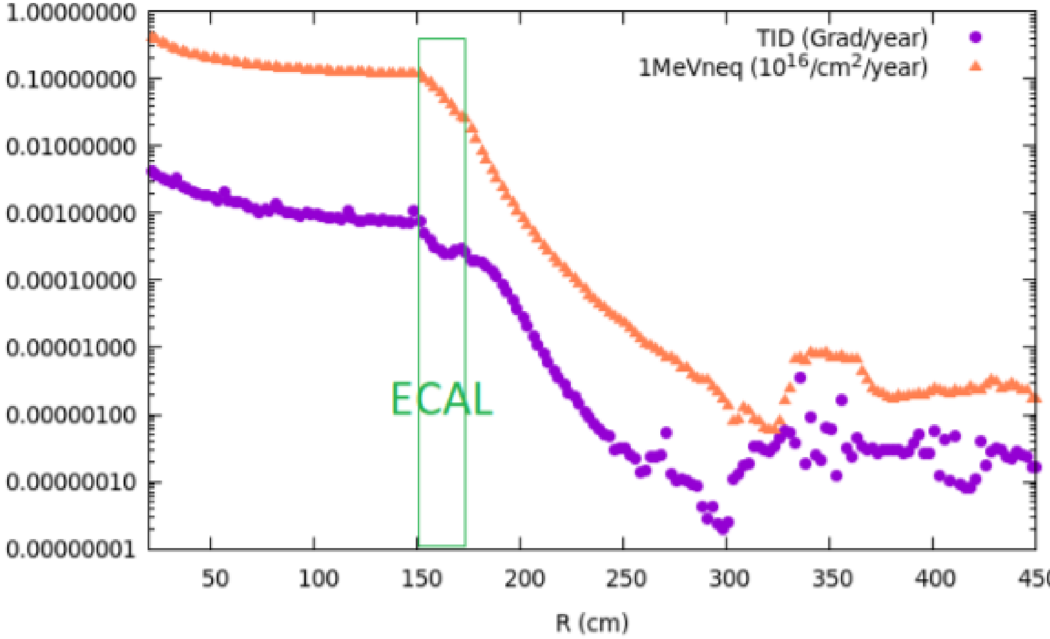
C. Curatolo et al

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



ECAL

The CRILIN detector

I. Sarra, L. Sestini

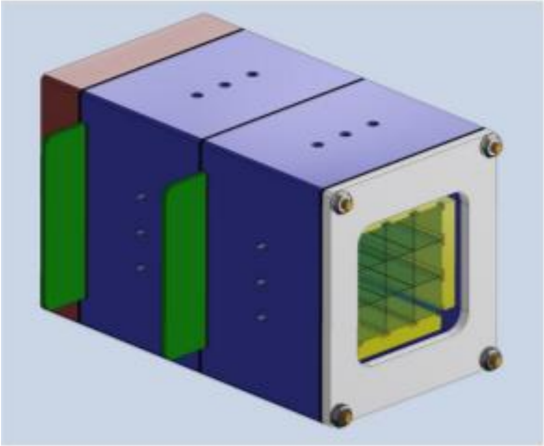
CRILIN
the semi-homogeneous crystal calorimeter

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

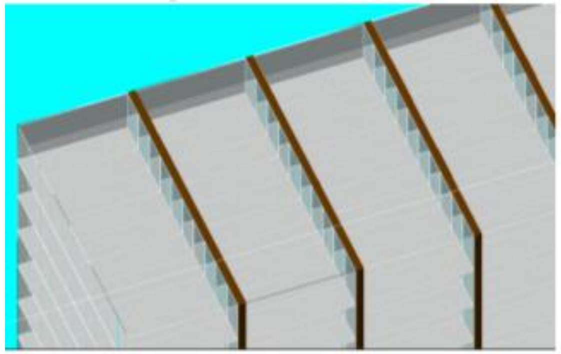
CRILIN = CRystal calorimeter with Longitudinal Information

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.



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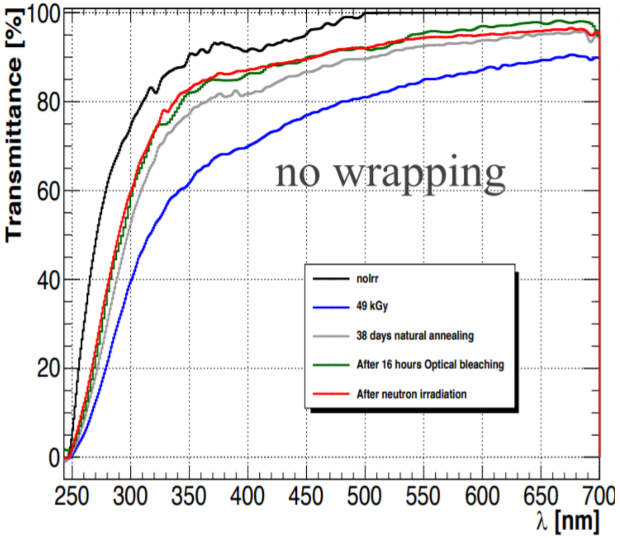
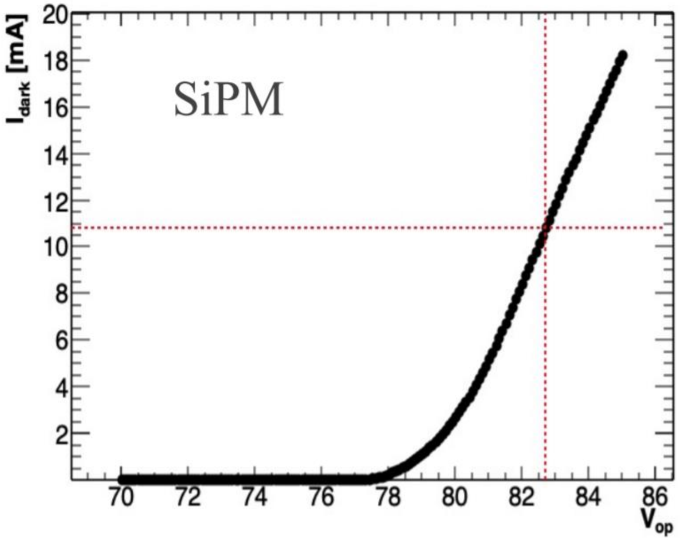
Prototypes results

I. Sarra, L. Sestini

CRILIN
the semi-homogeneous crystal calorimeter



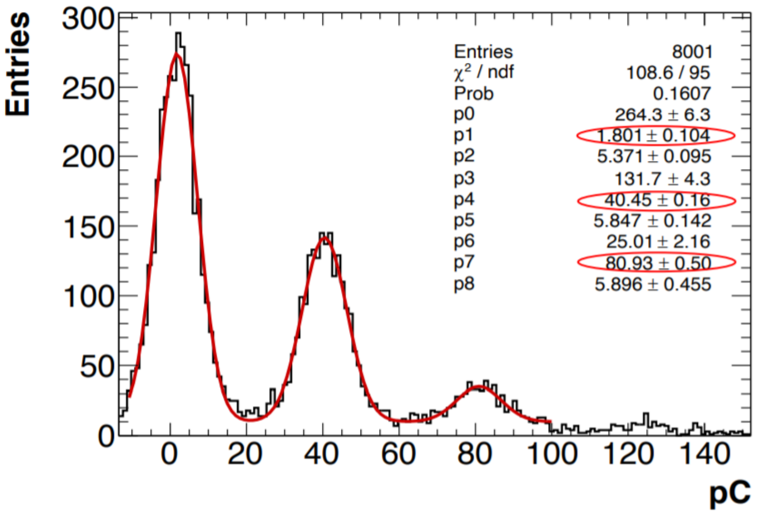


Single components tested for **dose and response to neutrons:**

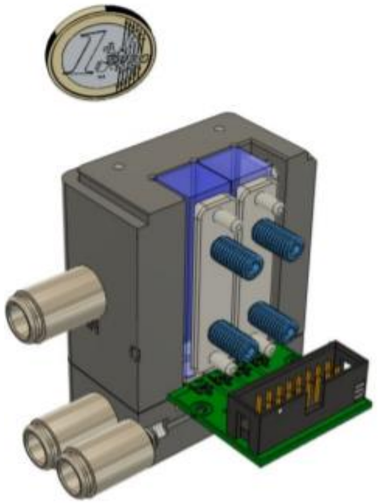
- SiPM tested up to 10^{12} neutrons
- Cristals tested up to 10^{13} neutrons and 4 Mrad.

→ 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



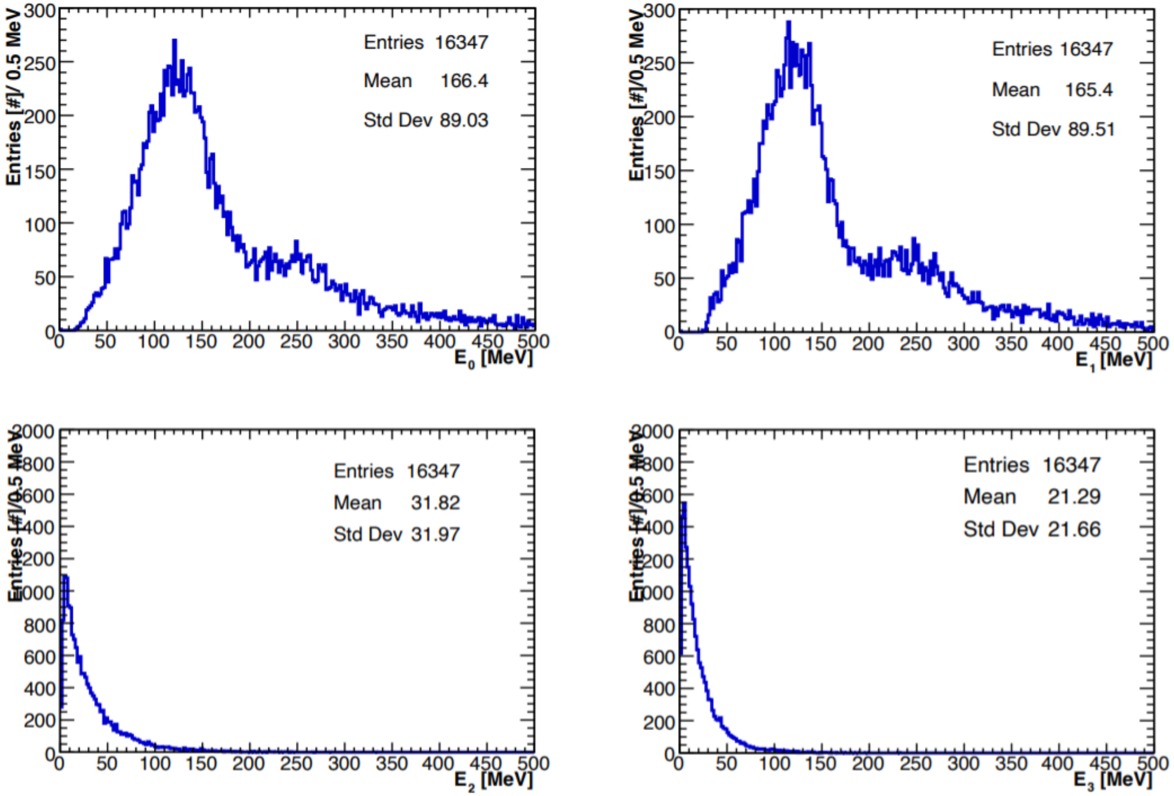
Two 10x10x40 mm^3 PbF_2 crystals enclosed in Mylar/EJ510 → 4 readout channels.



Test beams results - 1

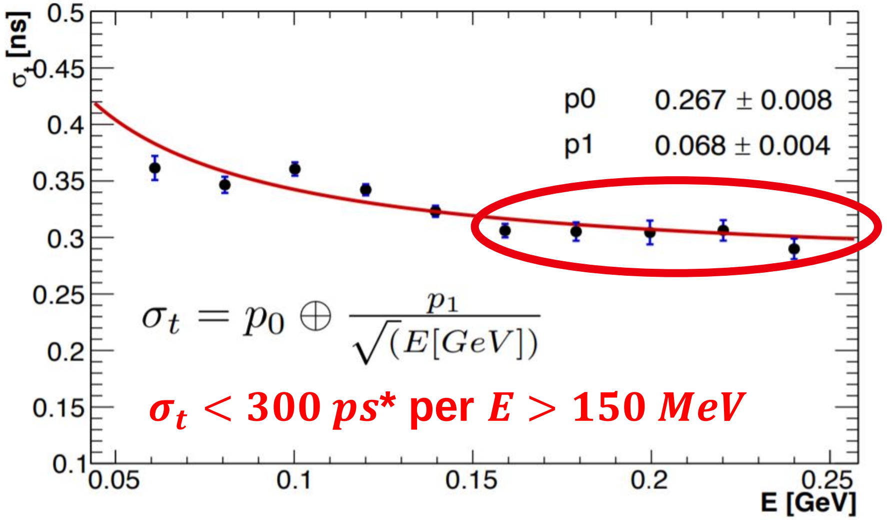
I. Sarra, L. Sestini

Test Beam @ BTF (Frascati):



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

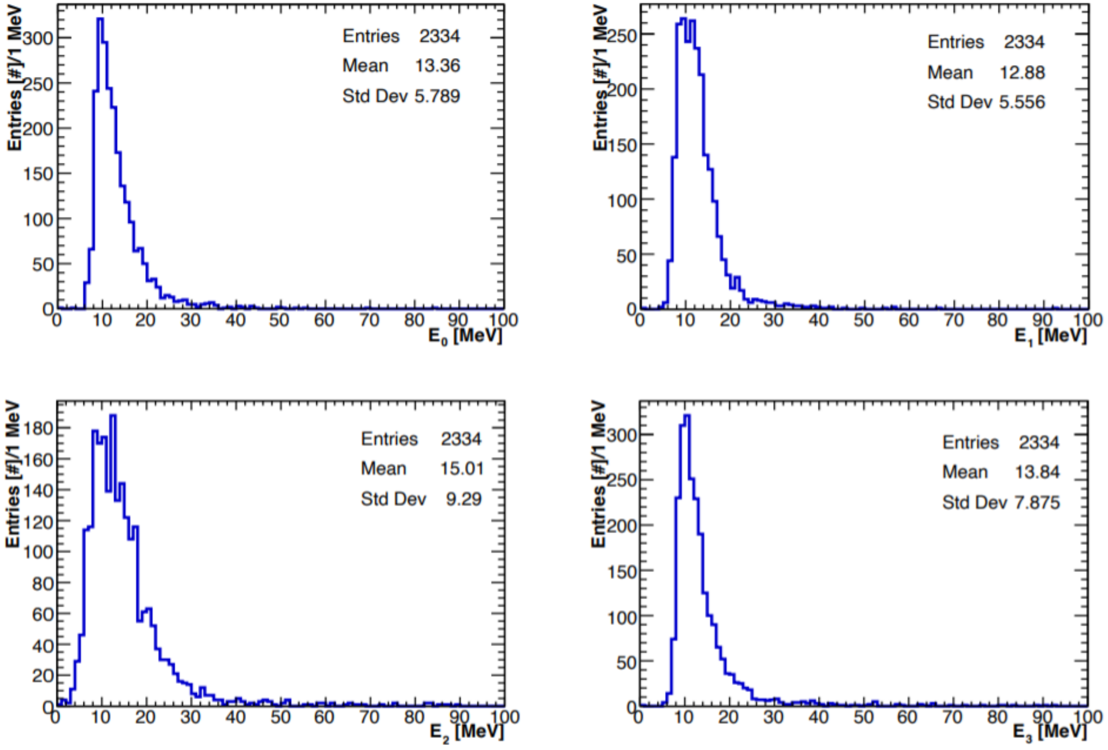
Distribution divided in 10 MeV slices → time resolution measured as time difference between the 2 SiPM in each crystal per each slice



* To be divided by 2 for the 2 photosensors

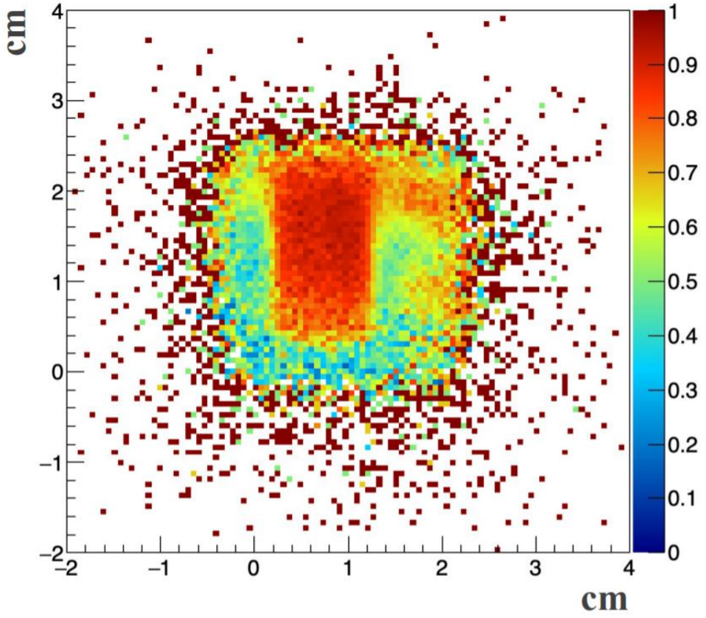
Test beams results - 2

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)

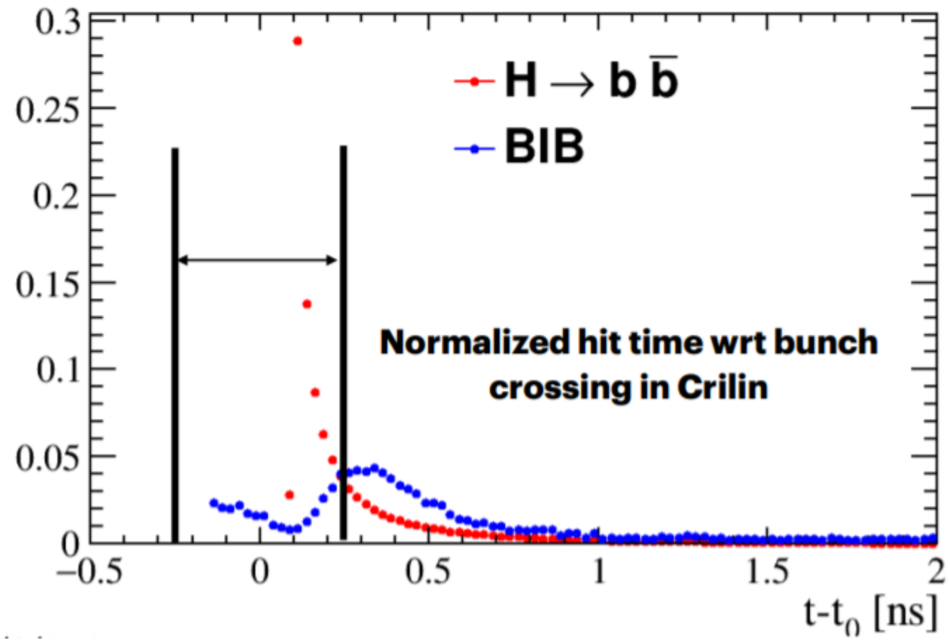


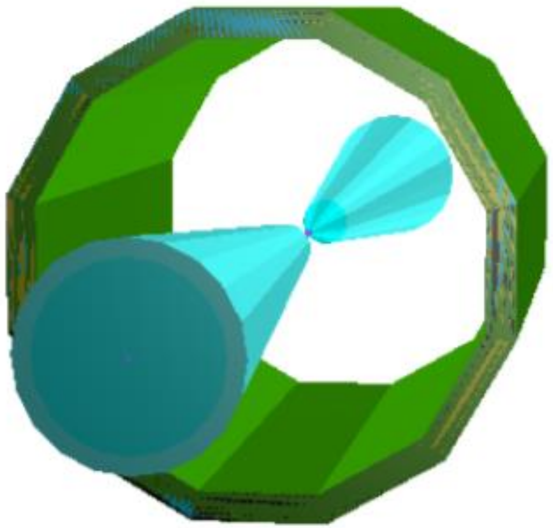
Full analysis still on going, but preliminary results are promising.

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.



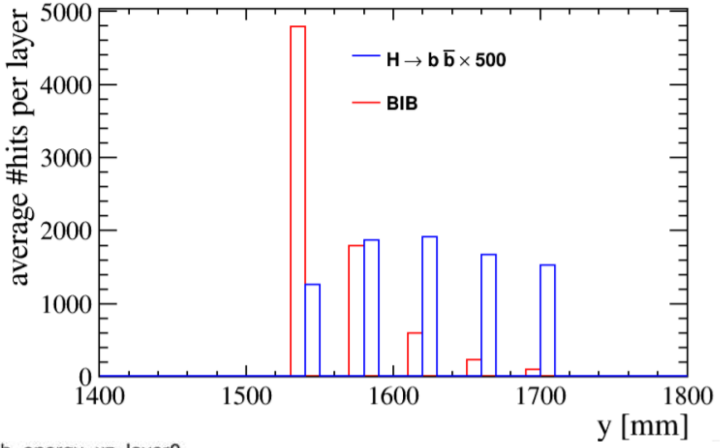


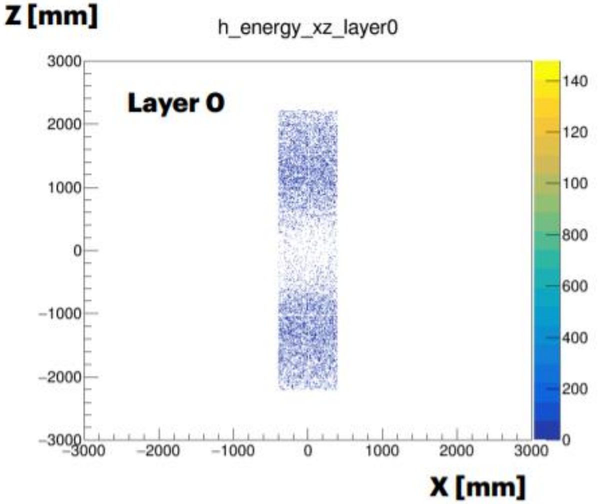
- implementation done with the DD4HEP interface to Geant4
- 5 layers of 40 mm length, 10 X 10 mm^2 cell area
- dodecahedra geometry.

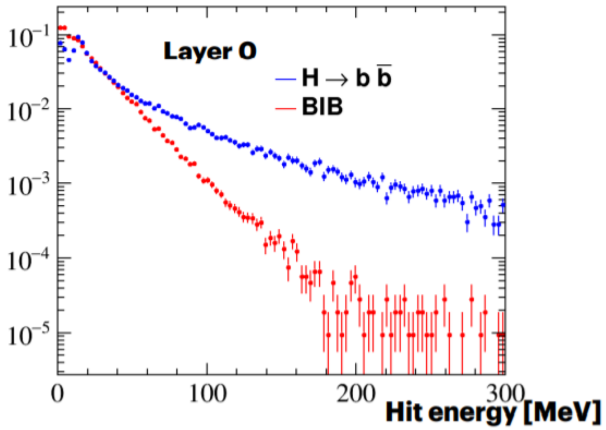
Acquisition time window of [-250,+250] ps wrt bunch crossing applied to separate signal from BIB → ***achievable with a time resolution of about 80 ps*** (window ≈ 3σ).

CRILIN in the muon collider simulation - 2

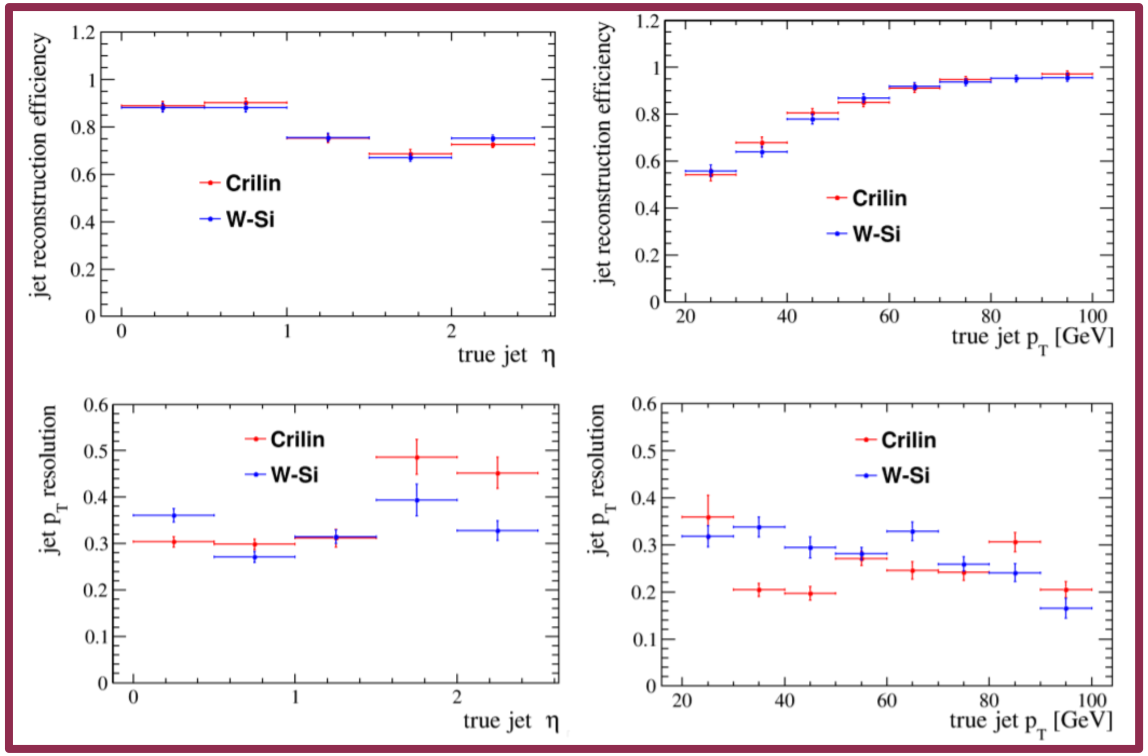
I. Sarra, L. Sestini







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

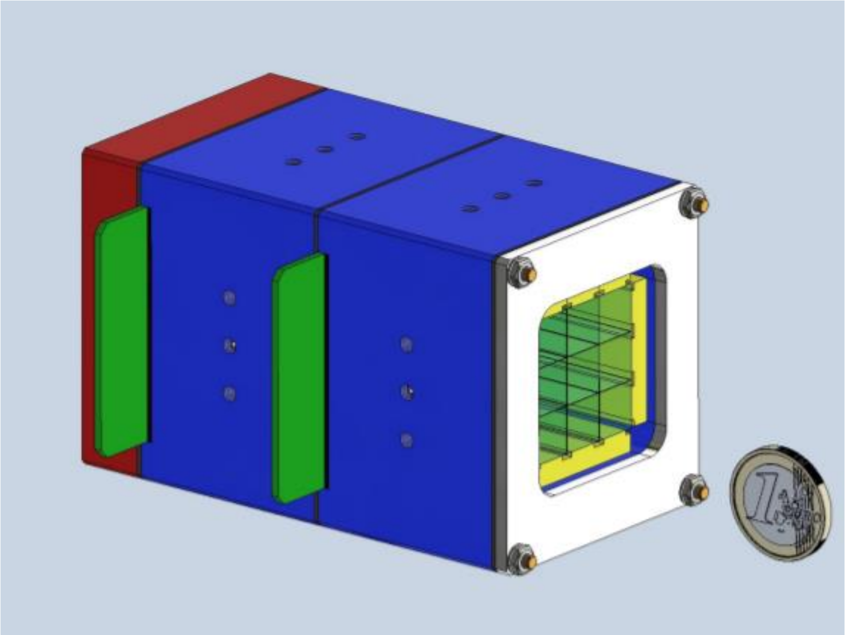


Planned activities

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



Summary

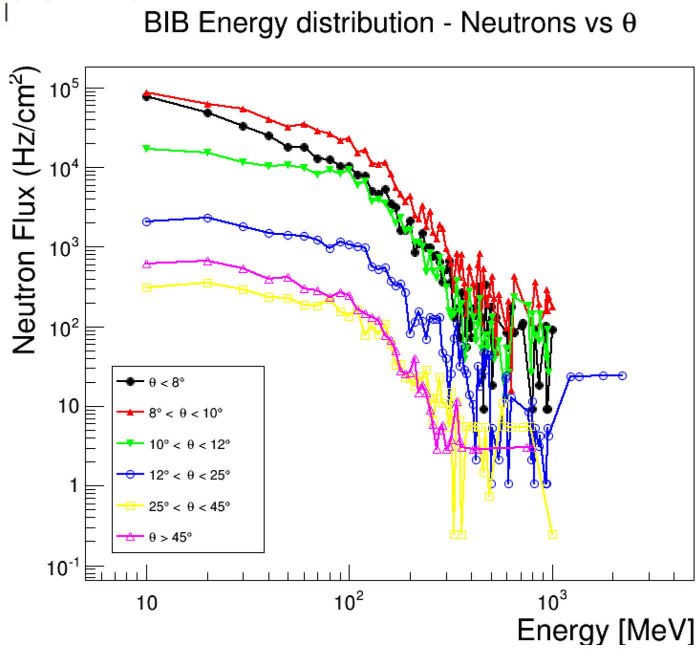
The **Muon Collider** is a great opportunity for precision physics at high energy and high luminosity. However, its unique environment – in particular the presence of the BIB - requires a careful design of the most suitable detectors.

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

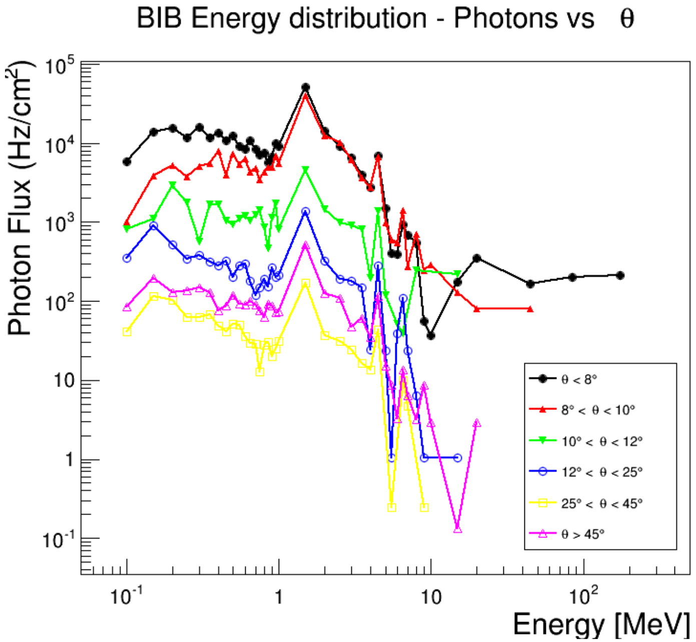
These activities will continue in the next months, together with the definition of the requested performance by simulation.

Thanks!

Beam Induced Background



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.



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

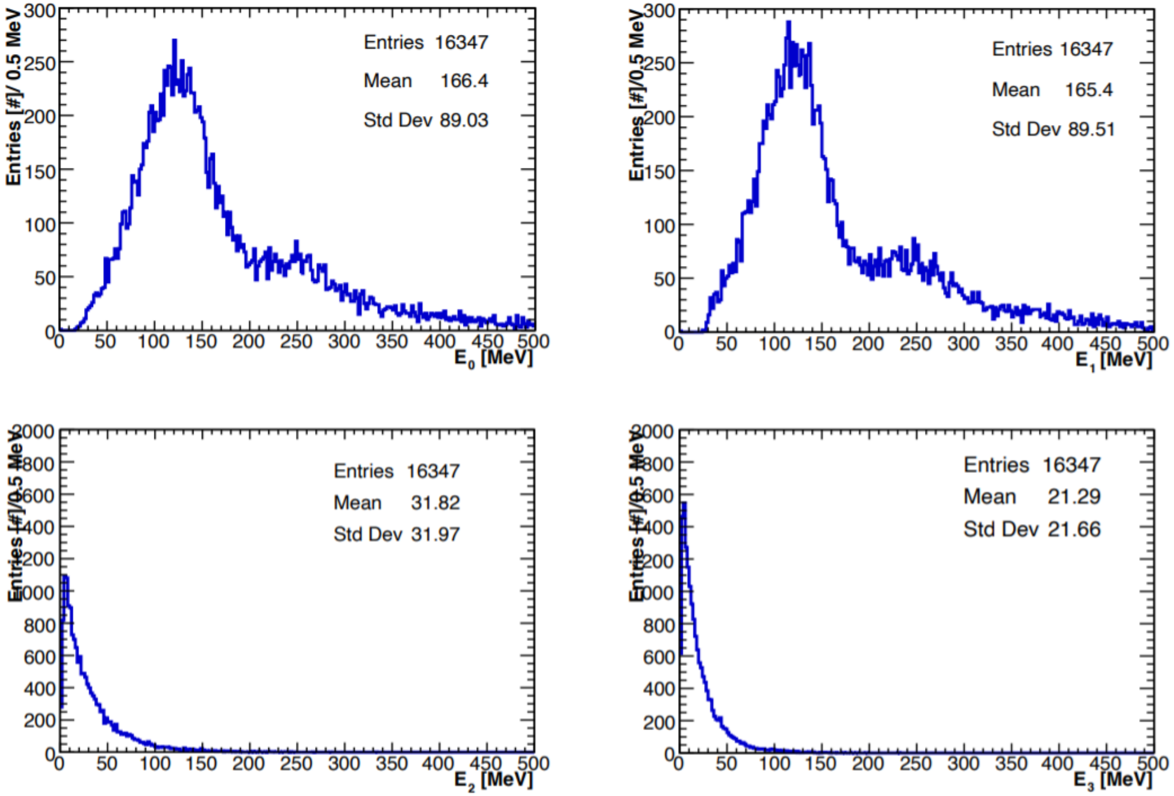
- Neutrons: energies up to 2.5 GeV
- Photons: energies up to 200 MeV

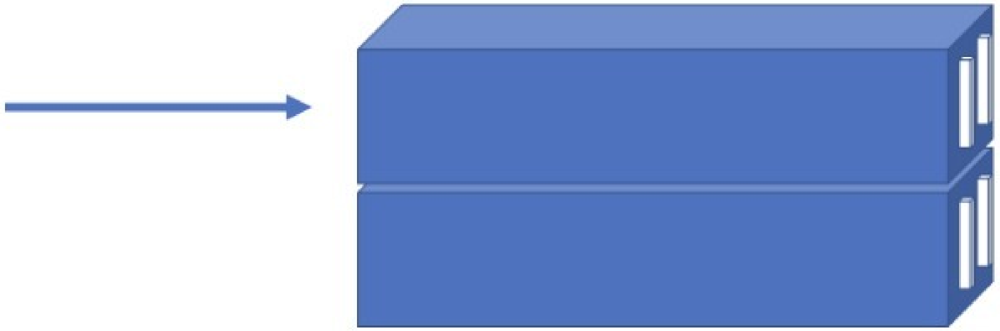
Distributions obtaines from MARS+Geant4+v02-05-MC selecting the particles that arrive at the muon system.

Test beams results - 1

I. Sarra, L. Sestini

Test Beam @ BTF (Frascati):



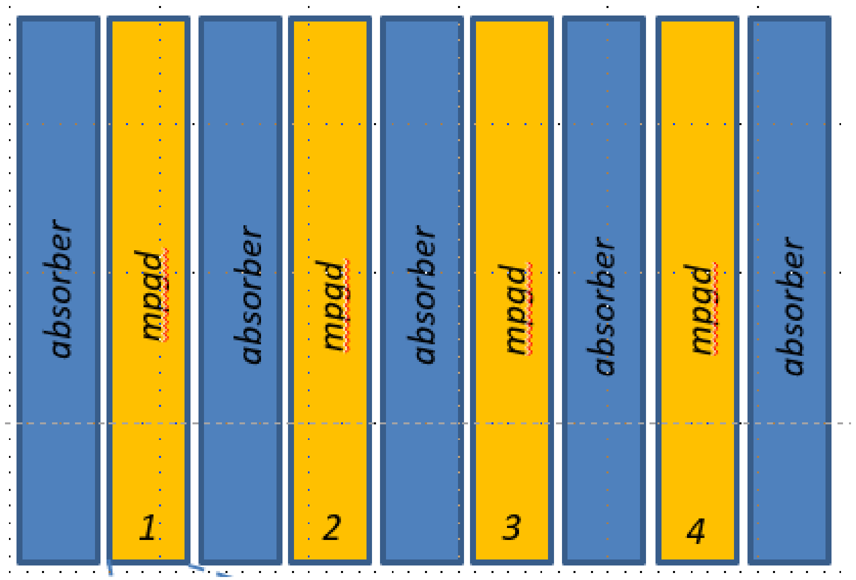


500 MeV electrons on the two crystals (2 SiPM per crystal)

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