



R&D studies on muon detector

Ilaria Vai on behalf of the Physics and Detector working group

Muon Collider detector

Based on CLIC detector: [arXiv:1202.5940](https://arxiv.org/abs/1202.5940)

ILCSOFT: <http://ilcsoft.desy.de/portal>

hadronic calorimeter

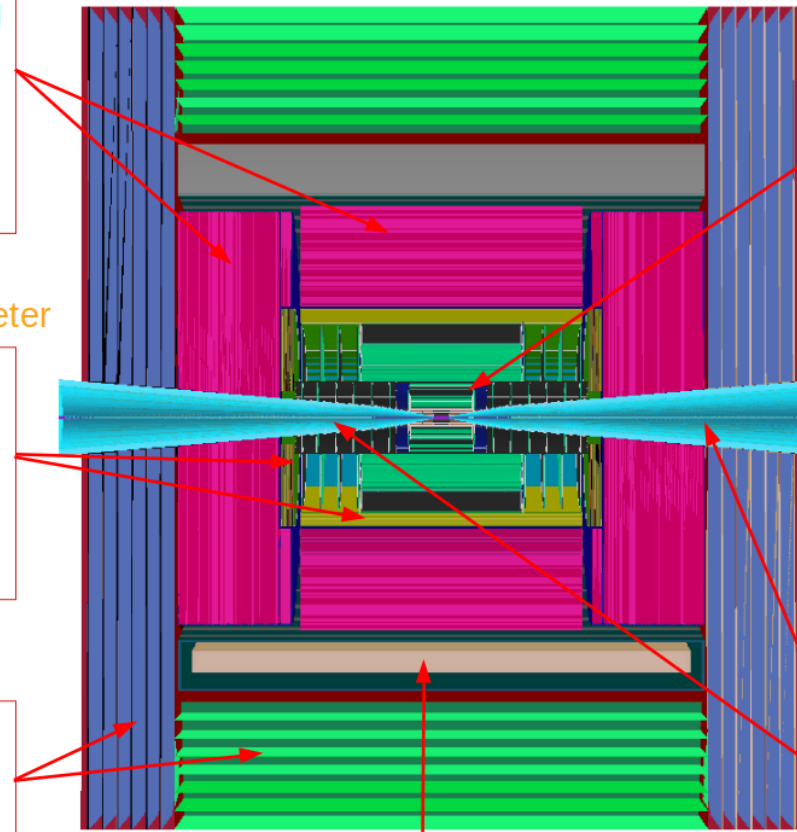
- ◆ 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- ◆ 30x30 mm² cell size;
- ◆ 7.5 λ_I .

electromagnetic calorimeter

- ◆ 40 layers of 1.9-mm W absorber + silicon pad sensors;
- ◆ 5x5 mm² cell granularity;
- ◆ 22 X_0 + 1 λ_I .

muon detectors

- ◆ 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- ◆ 30x30 mm² cell size.



superconducting solenoid (3.57T)

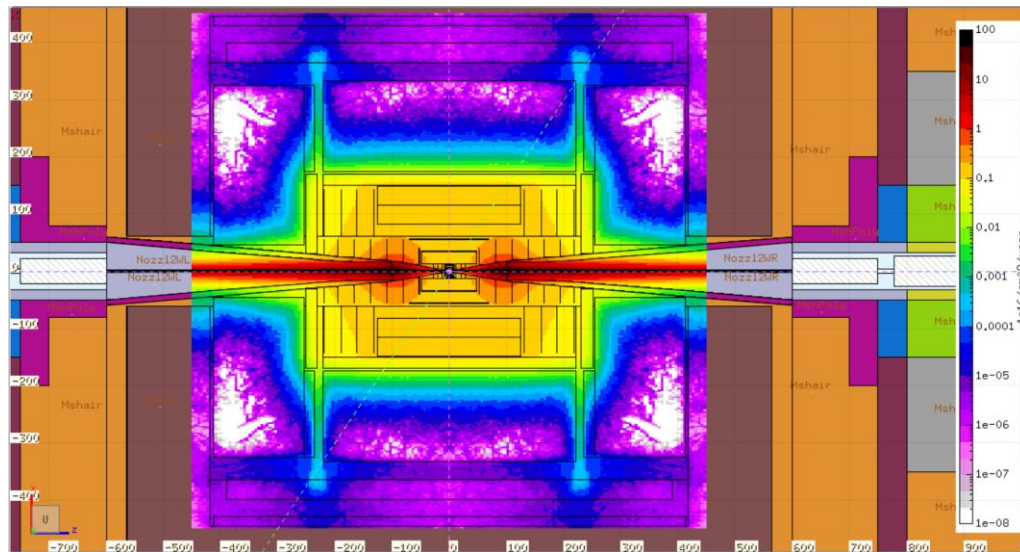
tracking system

- ◆ **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.

1 MeV n_{eq} fluence/year

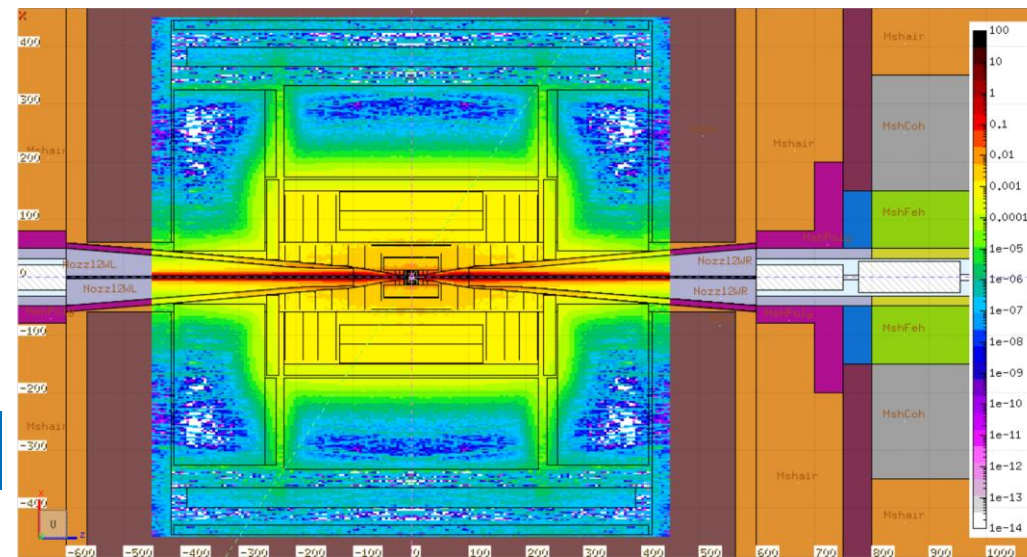


$\approx \text{few } 10^{15}/\text{cm}^2 / \text{y}$

1 Gy = 100 rad
1 Grad = 10 MGy

$\approx 10^{-3} - 10^{-2}$ Grad/y

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



Color scale:
Grad/year

Muon System

Fast timing MPGD – Picosec

Technologies for the muon system

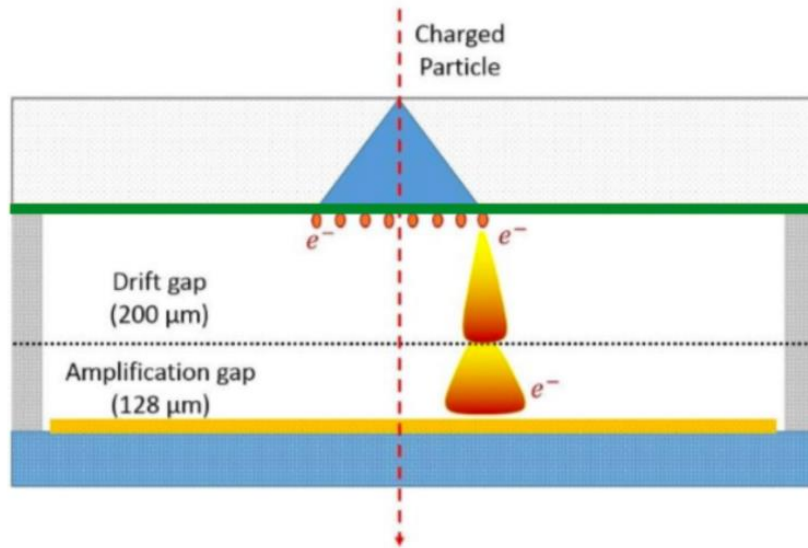
Detector	σ_t	σ_x	Rate capability
RPC (HPL o Glass)	1 ns (single-gap) < 100 ps (multi-gap)	~mm	~ 1 kHz/cm ²
Standard MPGD (GEM, Micromegas)	5-10 ns	~100 μ m	> 100 kHz/cm ²

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

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

Picosec detector

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

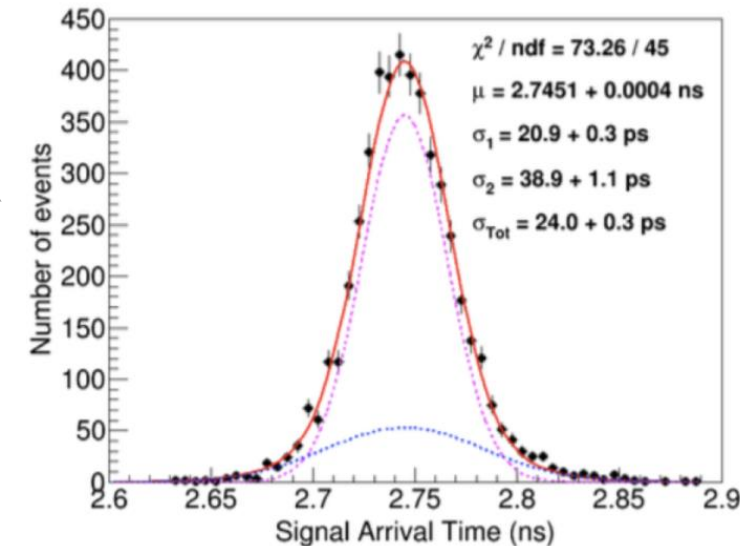
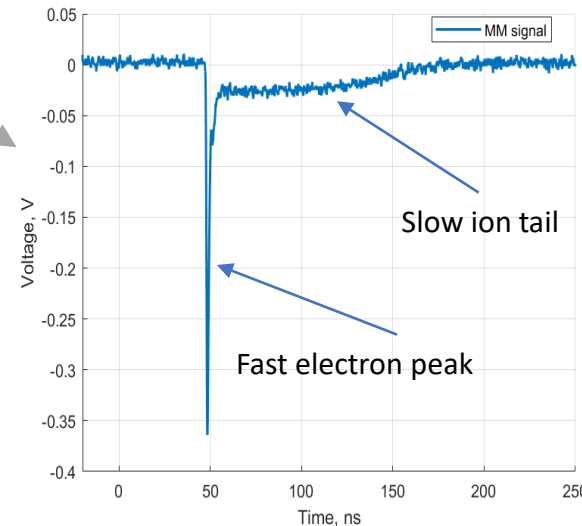


→ Measured time resolution ~ 25 ps
(Ne/C₂H₆/Cf₄ – 80/10/10)

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

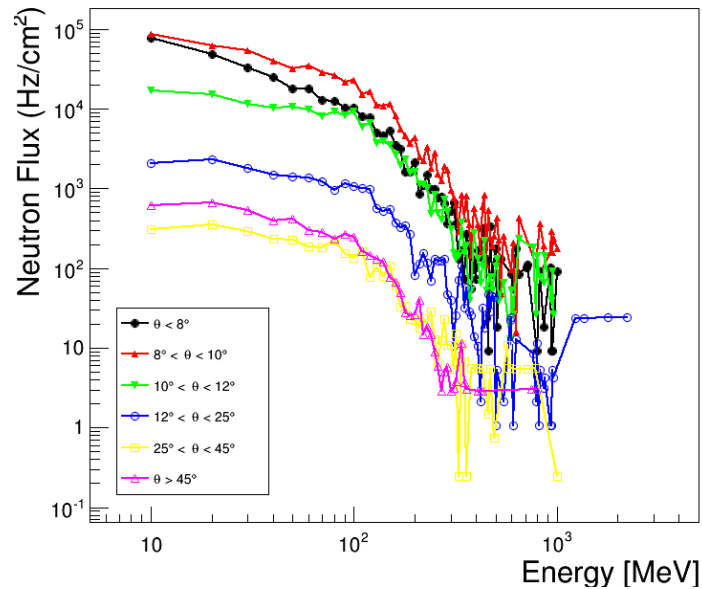
New MPGD composed by:

- MgF₂ Cherenkov radiator (3-4 mm)
- Photocathode (10 nm), currently of CsI
- Standard Micromegas with reduced drift gap



Beam Induced Background

BIB Energy distribution - Neutrons vs θ

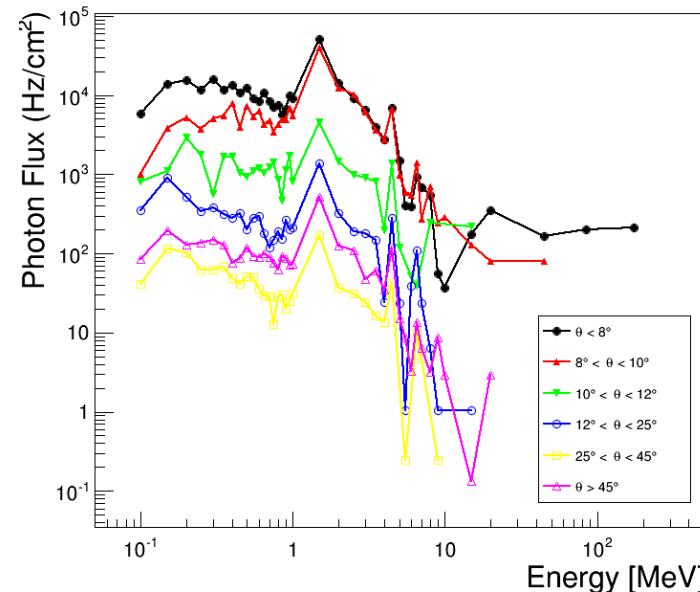


Distributions obtained from MARS+Geant4+[v02-05-MC](#) selecting the particles that arrive at the muon system.

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 outer regions.

BIB Energy distribution - Photons vs θ



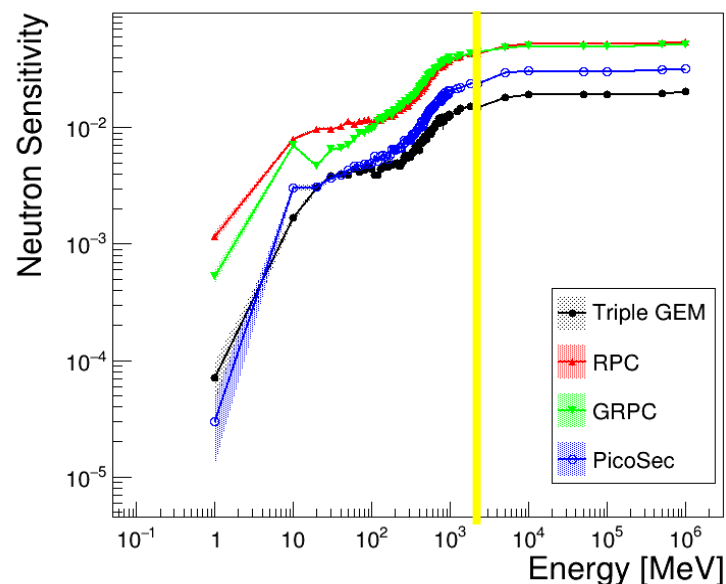
At $\sqrt{s} = 1.5 \text{ TeV}$:

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

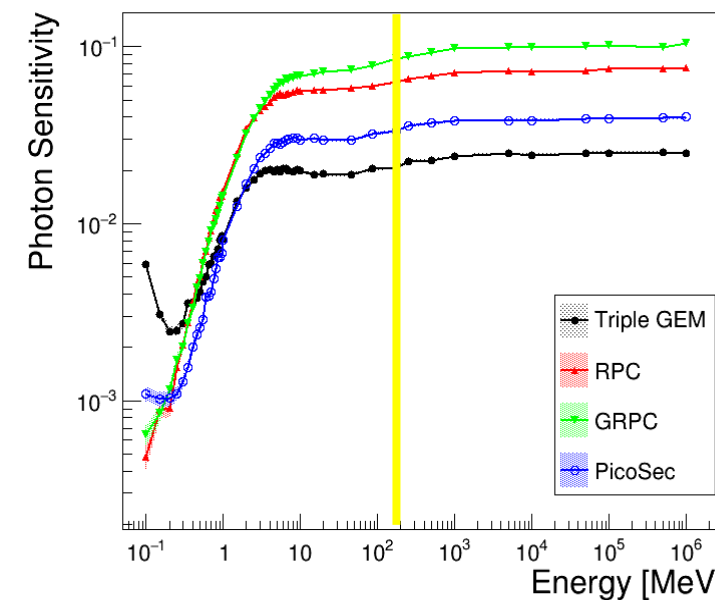
Standalone simulations - 1

- 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

Muon Collider 1.5 TeV - Neutron Sensitivity



Muon Collider 1.5 TeV - Photon Sensitivity



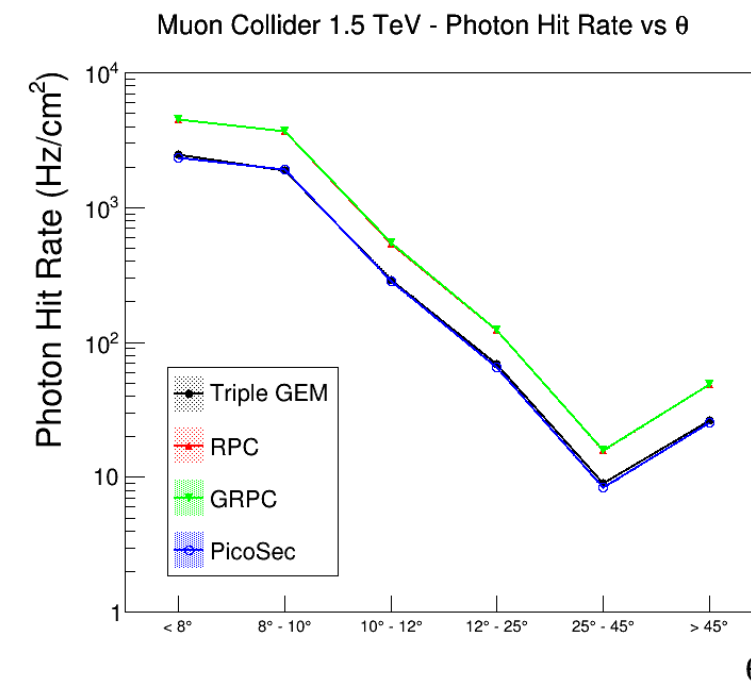
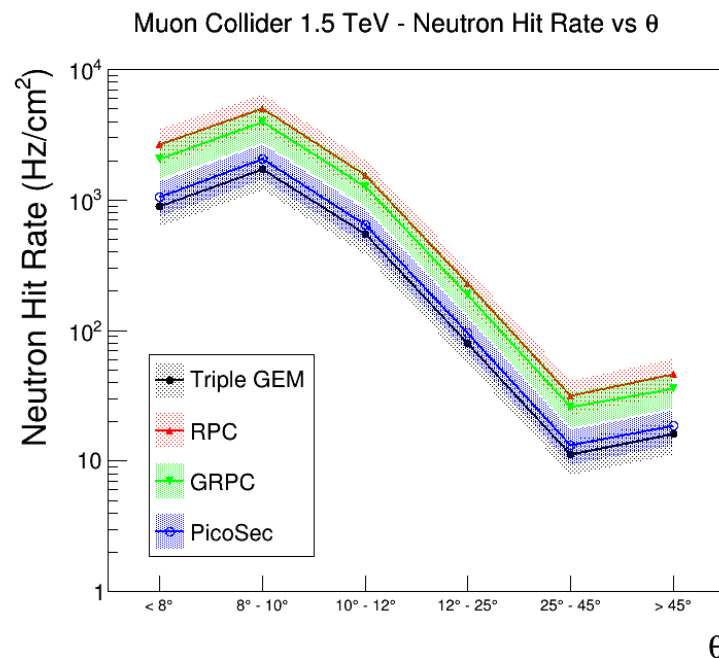
PicoSec sensitivity lower than RPC one, because MPGDs have lower material budget.

Standalone simulations - 2

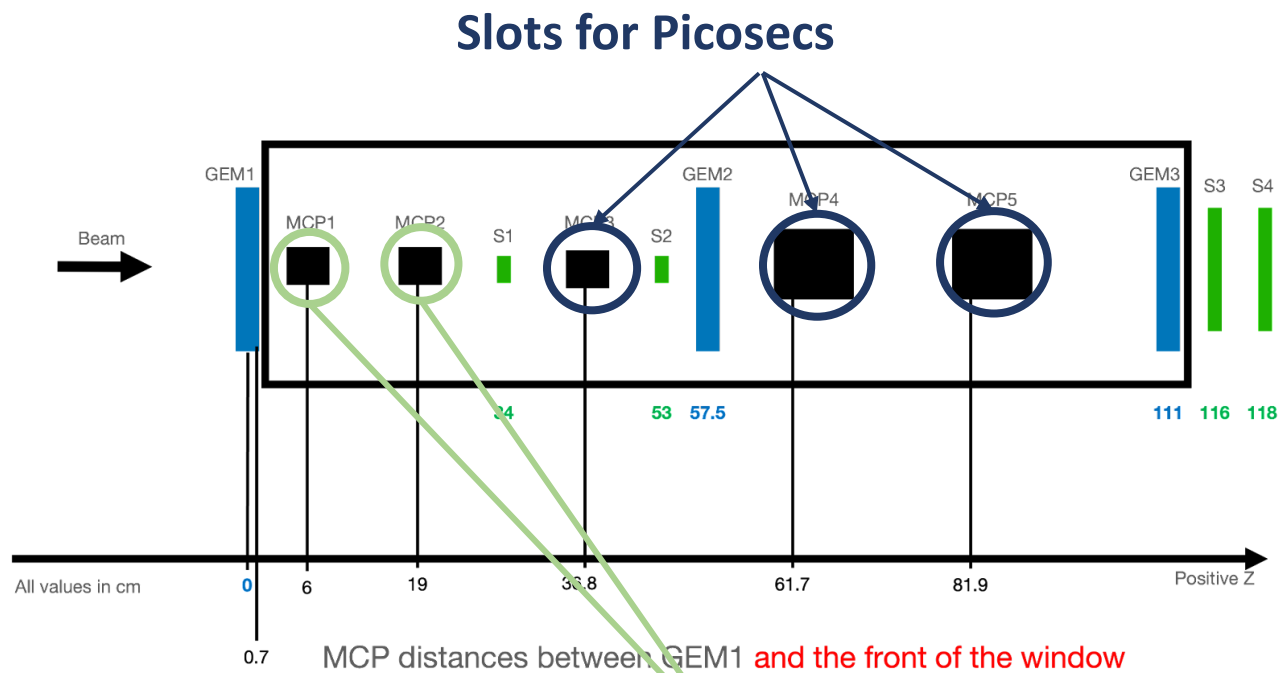
Hit Rate = Sensitivity \times BIB flux

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

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



Participation in RD51 testbeams



Micro Channel Plate PMT (MCP) for time reference ($\sigma_t \approx 5\text{ps}$)

→ 1 MCP from Pavia group (8ps, but not used at 100% HV value)

In 2022, we participated in 3 RD51 testbeams with the following measurement plans:

1. April

- Measure the time response of MCP for the next testbeams

2. May

- Test new photocathode (B4C) – thin mesh/gap – resistive MM
- Test new custom preamplifier
- 10x10 uniformity – SAMPIC digitizer readout (64ch)

3. July

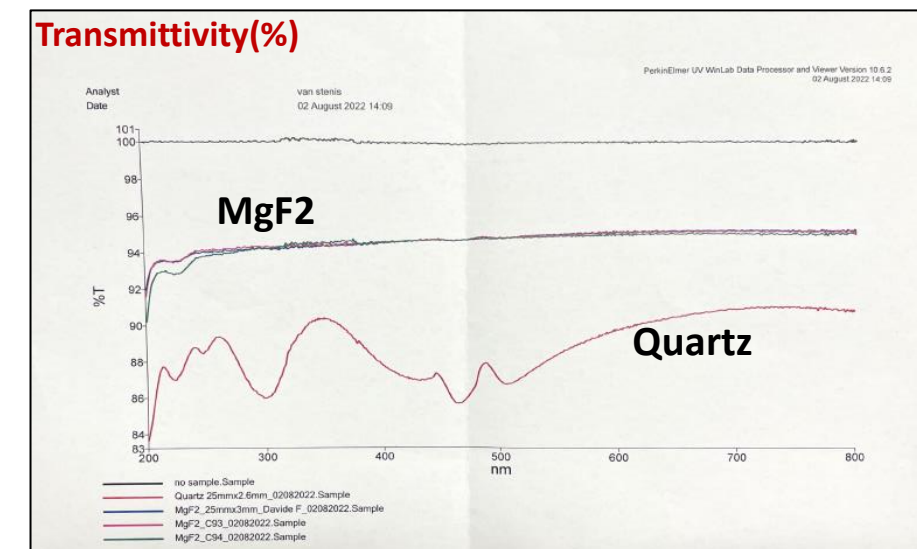
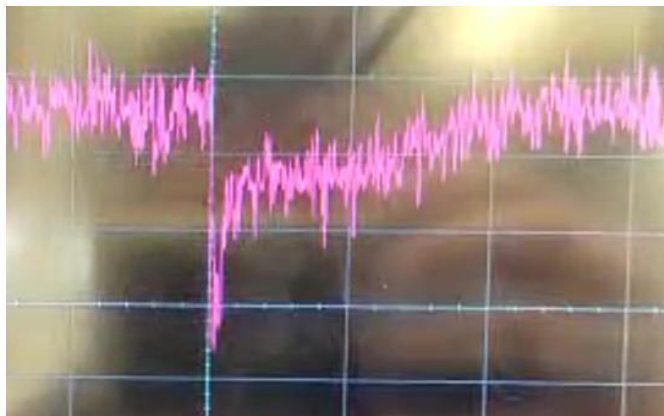
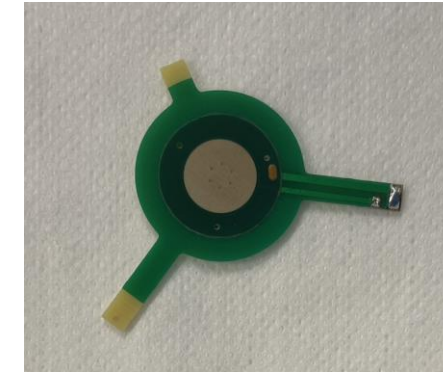
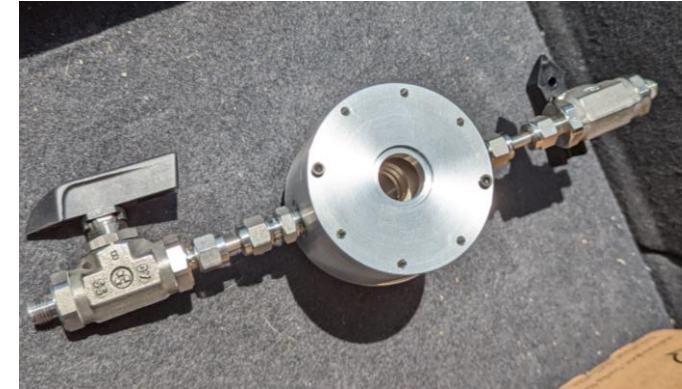
- Test new photocathode (B4C different thickness, DLC without Chromium)
- SAMPIC digitizer 256ch full 10x10 readout
- Picosec for the electromagnetic calorimeter

Procurement of new prototypes

10x10 detector already ordered and production ongoing

Meanwhile, we assembled a **single-channel detector** with:

- micromegas from RD51
- Radiator and mechanics from spare material
- Radiators tested @ CERN dedicated lab (see transmissivity plot)
- Chromium photocathode (calibration configuration)



Plans for single-channel test

New radiators

- **MgF2 is the most UV transparent material but:**
 - High cost, Fragile
 - Non perfectly stable during material deposition (imperfection on half of the samples)
- **Investigate:**
 - CaF2, BaF2, sapphire
 - **Quartz → the most promising for large areas, low cost and robustness (lower transparency)**

New photocathodes

- CsI has the best performance in terms of time resolution, resistive photocathodes are more promising for the long term and robustness
 - B4C and DLC
 - (Graphene and nanodiamonds trials by RD51)

New Gases

- Baseline Ne/C2H6/CF4 80/10/10 – Flammable, High GWP, High cost!
 - Removal of CF4
 - Substitution of C2H6 (ethane) with C4H10 (isobutane) or even better CO2
 - Look for a Neon substitute (very difficult...)

Each of these comes with a price to pay in terms of time resolution and/or stability



Next steps

- Participate in the October test beam (19 Oct-31 Oct) with single-channel:

- MgF2 and Quartz **radiator** comparison (different WP)
- CsI, DLC and B4C, Chromium **photocathodes** comparison (different WP)
- Cividec and RF **amplifier** comparison (different WP)
- Timing resolution at different **sampling rates** (only with scope 1-40 Gs/s)
- Help to develop DAQ for **SAMPIC** (RD51 10x10)
- Only premixed bottles during testbeam → no test on gas

- From November in Pavia, single-channel gas tests:

- Test w/o CF4, change of quencher

- **10x10 detector tests in the RD51 lab start:**

- Time uniformity response test with ultrafast laser
- CsI and DLC test on large areas
- Preparation for next testbeam



Full simulation in muon collider framework
ongoing to assess the muon collider
performance requirements
(see [Chiara Aimè talk](#))



**Thanks for your
attention**