Optimization of the Picosec-MM detector for a Muon Collider experiment

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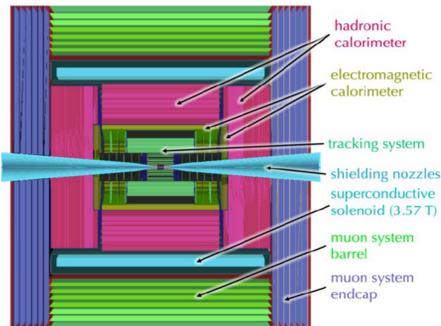*Contact: matteo.brunoldi01@universitadipavia.it*

MUON COLLIDER AND BEAM INDUCED BACKGROUND

Fig. 1. *Initial design of a Muon Collider detector. [1]*

- **Muon Collider (MC)** is a promising future collider, combining the advantages of electron and hadron machines.
- A major challenge is the **Beam-Induced Background (BIB)**, i.e. particles generated directly or indirectly by muon decays.
- A possible design for an experiment at the MC is shown in Fig. 1.
- The **BIB fluence** is shown in Fig. 2, highlighting that the **innermost region of the detector** is the most affected.
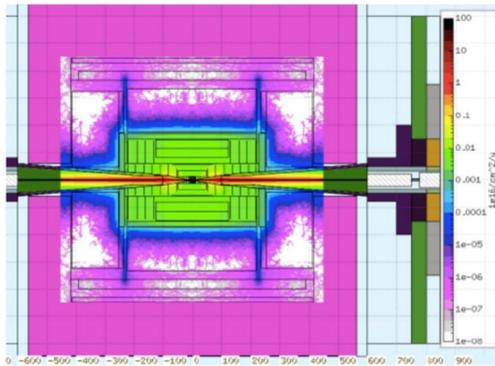
A new approach to muon reconstruction is proposed where muons are reconstructed **from the outside to the inside** of the detector:

- the BIB arrival time is more widely spread than the signal;
- a precise timing detector can help discriminate BIB from the signal;
- muon tracks are reconstructed starting from the outer detectors and propagated back to the tracker.

Fig. 2 *Map of the 1MeV-neq fluence in the detector region, shown as a function of the position along the beam axis and the radius, normalized to 1 year of operation and a collision rate of 100kHz. [2]*
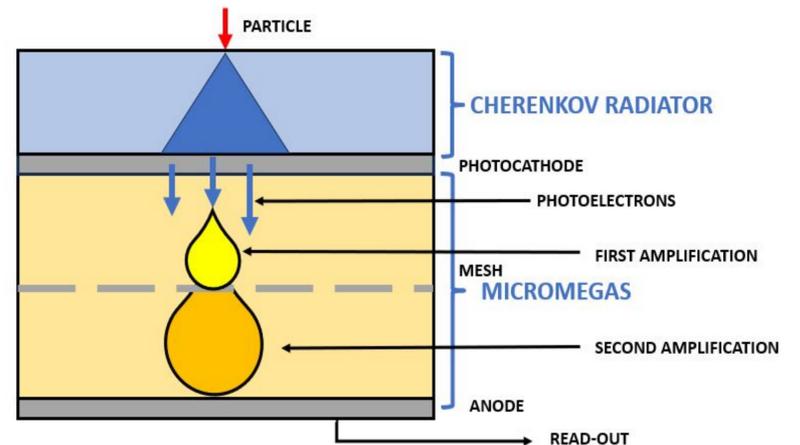
PICOSEC DETECTOR CONCEPT

Fig. 3. *Particle detection with Picosec: the incoming radiation emits Cherenkov light prompt in the radiator. Then, the photocathode converts part of the photons produced above in electrons that undergo two stages of amplification. The resulting signal is induced on the anode. [3]*

- **Picosec** [4] is a precise timing MicroPattern Gaseous Detector (MPGD) based on **MICROMEGAS** technology.
- Time resolution is improved by using **Cherenkov effect** and a **two-stage amplification**.
- Charged particles produce Cherenkov photons in the radiator, which are converted into electrons by a **photocathode**.
- A ~100 µm drift gap ensure immediate amplification, reducing the time jitter and improving the **time resolution** up to **tens of ps.**

OPTIMIZATION OF THE DETECTOR: A NEW GAS MIXTURE

Fluorinated gases

- **Fluorinated gases** are used in high-timing performance detectors but they have a high **Global Warming Potential** (GWP) and are not environmentally friendly.
- **GWP** is the ratio between the **greenhouse power** of a compound and that of the CO_2, over the same time interval (typically 100 years).
- The EU Regulation [6] mandates a **complete ban** on HydroFluoroCarbons (HFCs) by 2050.
- This raises concerns about **supply availability** and rising **costs.**
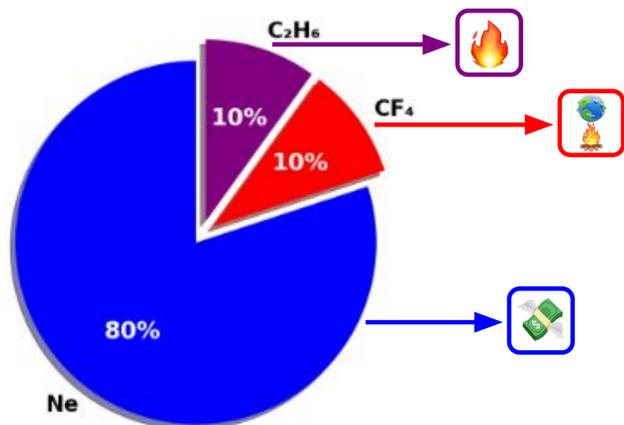
Picosec **standard mixture** consists of Neon (**Ne**), ethane (**C_2H_6**) and Tetrafluoromethane (**CF_4**):

- Neon is **expensive**
- Ethane is **flammable**
- CF_4 has a **high GWP** (about 7500)

Test beam results

Different **alternatives** have been tested during the test beam campaigns:

- mixtures using **isobutane** as a quencher (**GWP < 1**);
- mixtures based on different **noble gases**;
- the goal is to **reduce** the **GWP** and the **cost** of the gas mixture while **maintaining** detector **performance**.
- Different tests to assess the best ratio of the components

Fig. 4. *Comparison between the standard mixture and the Ne/iC4H10 94%/6%. The photocathode was the CsI 18 nm thick. The Micromegas used was resistive (82 MΩ/cm²). [5] Data from the July 2023 test beam.*
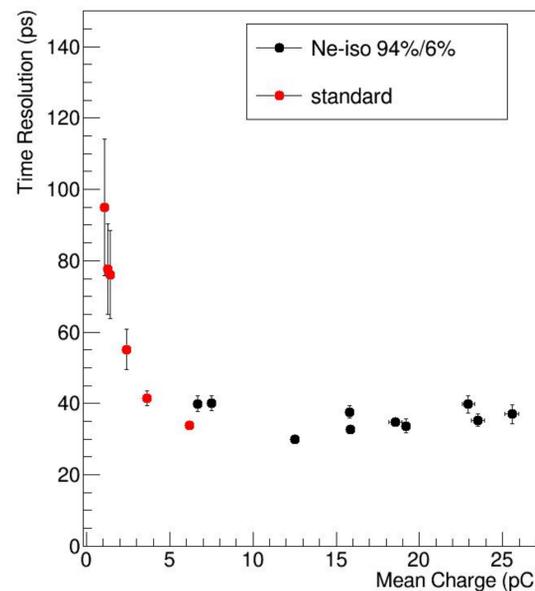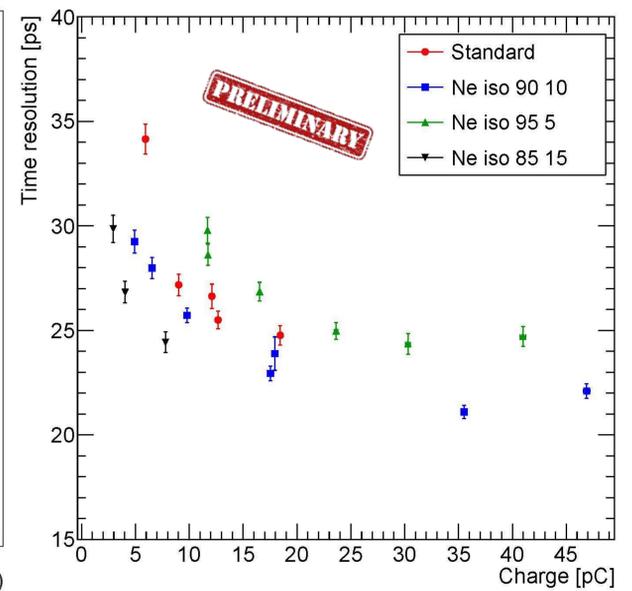
Fig. 5. *Comparison between the standard mixture and the Ne/iC4H10 with different ratios. The photocathode was the CsI 18 nm. The Micromegas used was resistive (20 MΩ/cm²). Data from the July 2025 test beam.*

CONCLUSIONS & FUTURE PERSPECTIVES

- **Picosec** is a **precise timing** MPGD designed to achieve excellent time resolution, at the level of a **few tens of picoseconds**, significantly better than the typical performance of standard MPGD technologies (around few ns)
- The standard Picosec gas mixture is composed of Ne, C_2H_6, and CF_4. This mixture is flammable, expensive, and has a **high GWP** ($\approx$ 450), raising concerns about both environmental impact and supply availability.
- Data collected during test beam campaigns indicate that a **Ne-based mixture using isobutane as a quencher can achieve time resolution performance comparable** to that of the standard mixture.
- Among the different concentrations tested, the mixture with 90% Ne and 10% isobutane showed the best performance.
- Future work will focus on the optimization of other detector components, such as the photocathode and the radiator. In addition, further tuning of the gas mixture ratio is planned, as well as tests of alternative mixtures based on different gases.
- Another key topic of investigation will be the **scalability** of the technology toward the development of a large-area Picosec detector.

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[6] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32024R0573