Picosec R&D towards Muon Collider applications

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Endorsed by the International Muon Collider Collaboration and the Picosec Micromegas Collaboration

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MUON COLLIDER AND BEAM INDUCED BACKGROUND

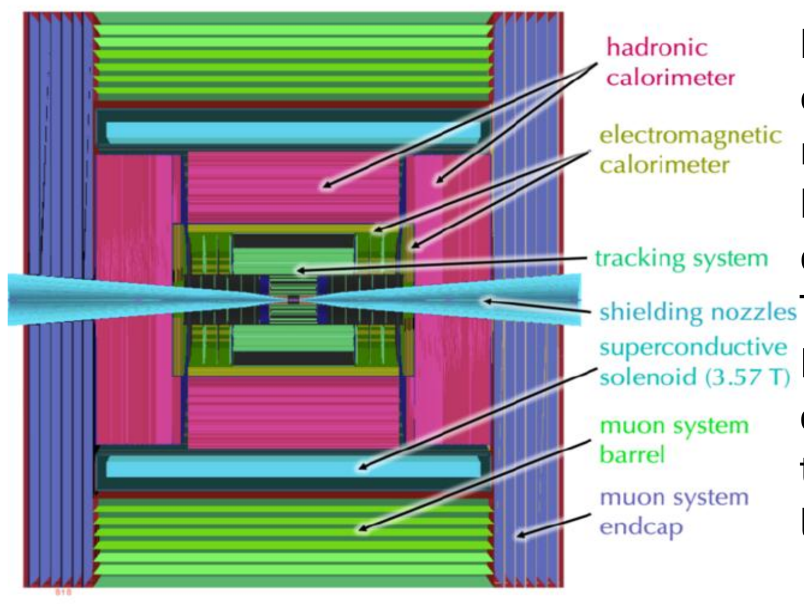

Fig. 1. *Initial design of the Muon Collider experiment detector. [1]*

Muon Collider (MC) is a promising future collider, combining advantages of electron and hadron machines, a major challenge is the **Beam Induced Background** (BIB), originated mainly from muon decay and interaction with surrounding materials. The initial detector design for an experiment at a MC is presented in Fig.1. The **BIB fluence distribution** (Fig.2) shows that innermost region is the most affected, while muon system experiences lower background levels.

A new **"out-to-in" reconstruction** method is being developed to reduce the BIB:
Muon tracks are first reconstructed in the muon system and then propagated back to the tracker.
A **fast timing detector** with tens of picoseconds resolution is required.

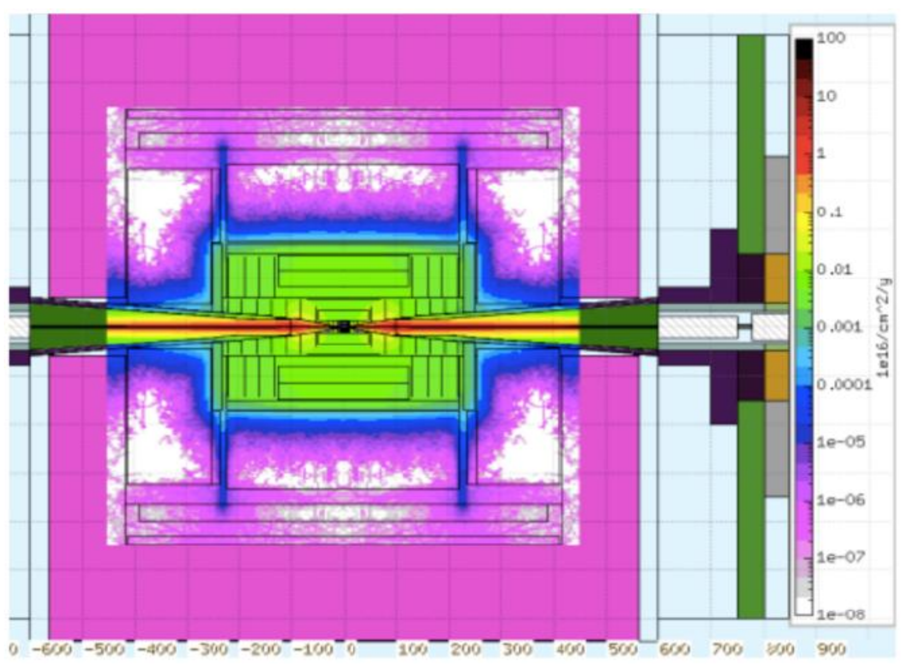

Fig. 2 *Map of the 1MeV-neq fluence in the detector region, shown as a function of the position along the beam axis and the radius, normalized to 1 year of operation and a collision rate of 100kHz. [2]*

PICOSEC DETECTOR CONCEPT

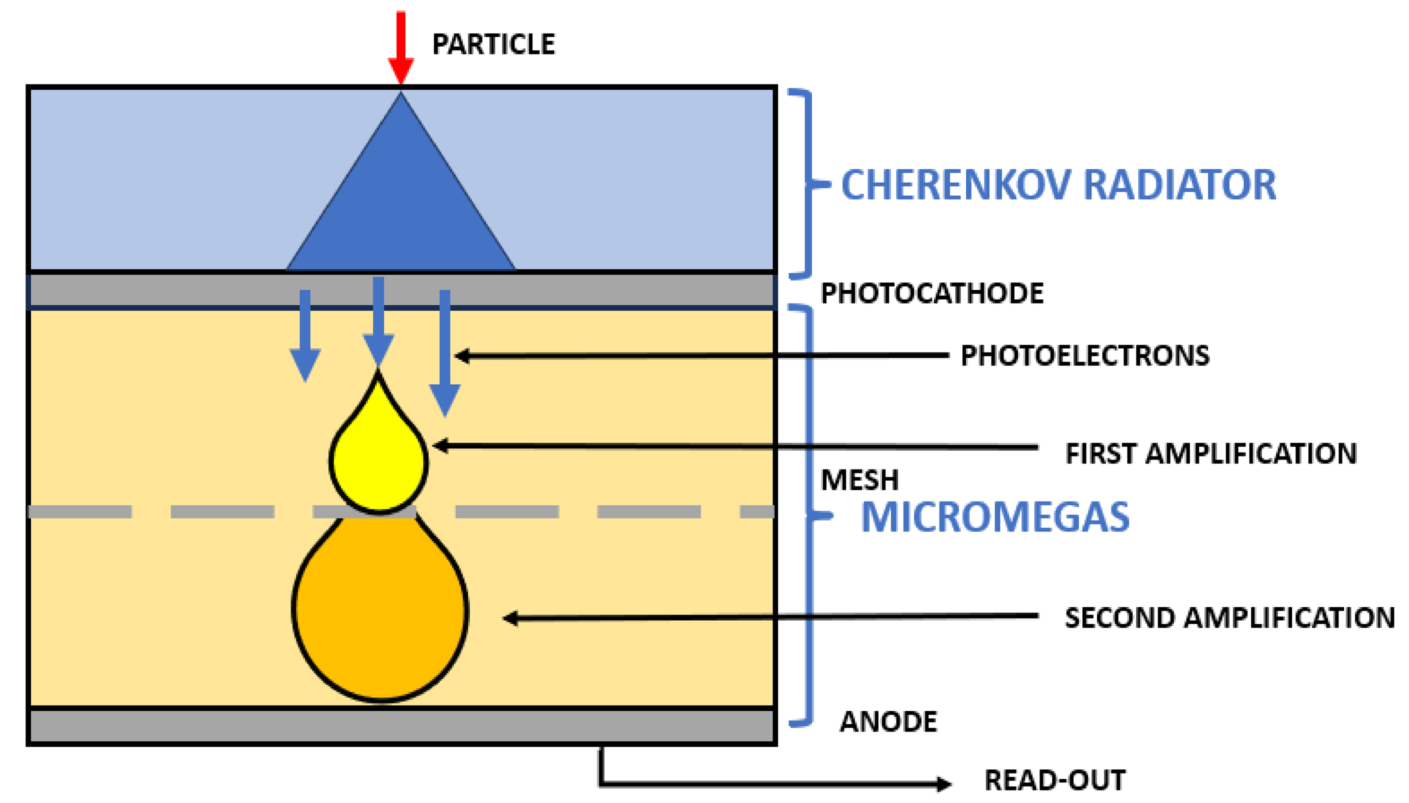

Fig. 3. *Particle detection with Picosec: the incoming radiation emits Cherenkov light prompt in the radiator. Then, the photocathode converts part of the γ produced above in electrons that undergo two stages of avalanche amplification. The resulting signal is induced on the anode. [3]*

- **Picosec** is a fast 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 a 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.**

R&D ON PICOSEC TECHNOLOGY

R&D efforts are needed to optimize Picosec for large-scale experiments like the MC. The **photocathode** is a key component under investigation:
•**Cesium Iodide** (CsI) has high photon conversion **efficiency** but suffers from **hygroscopicity** and **ion backflow**.
•**Diamond-Like Carbon** (DLC) and **Boron Carbide** (B4C) are being evaluated as alternatives.
•Preliminary results (Fig. 4) suggest **DLC** as a **robust** and durable photocathode candidate.

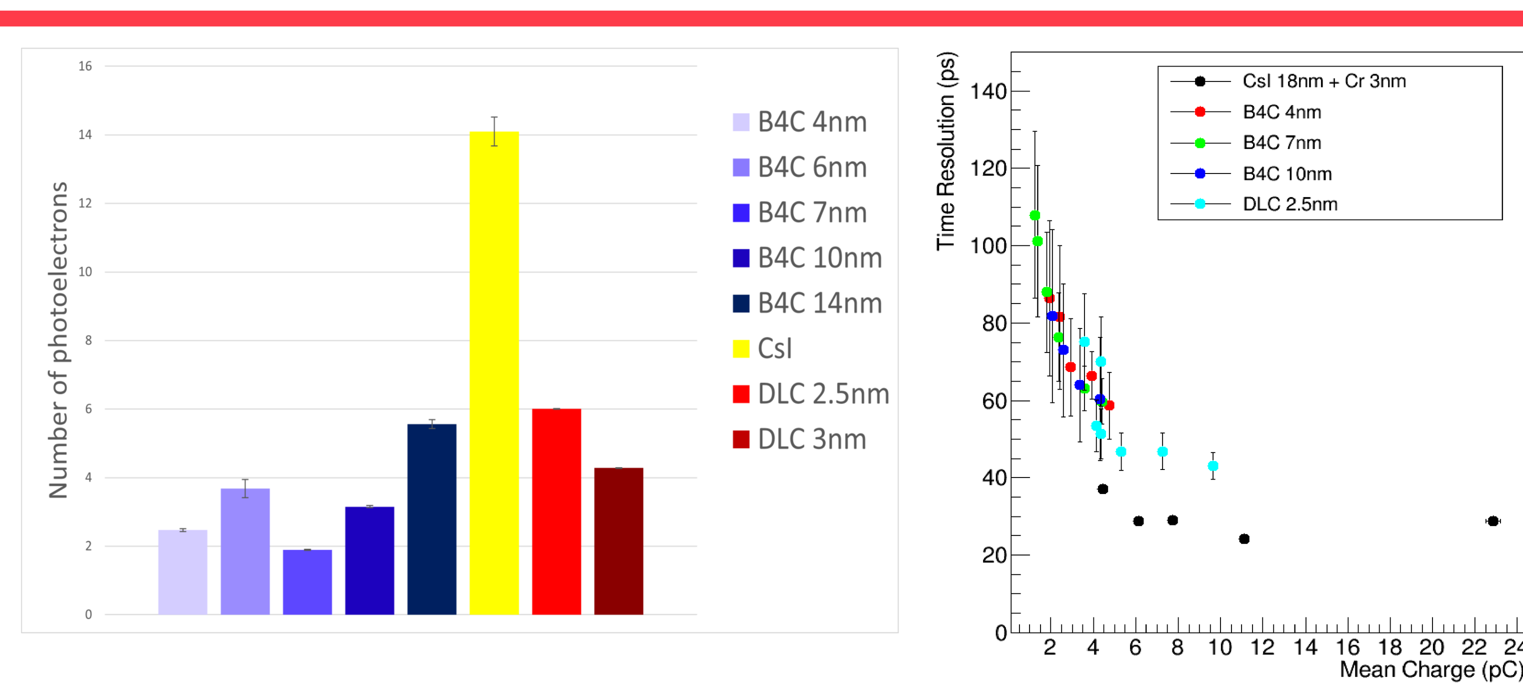

Fig. 4. Left: *comparison of the experimental results obtained by the tested photocathodes concerning the mean number of photoelectrons emitted per MIP. [4]* Right: *comparison between the photocathodes' performance in terms of time resolution as a function of signal mean charge. The gas mixture used is the standard one and the Micromegas was resistive (380 kΩ). [4]*

GAS MIXTURE STUDIES

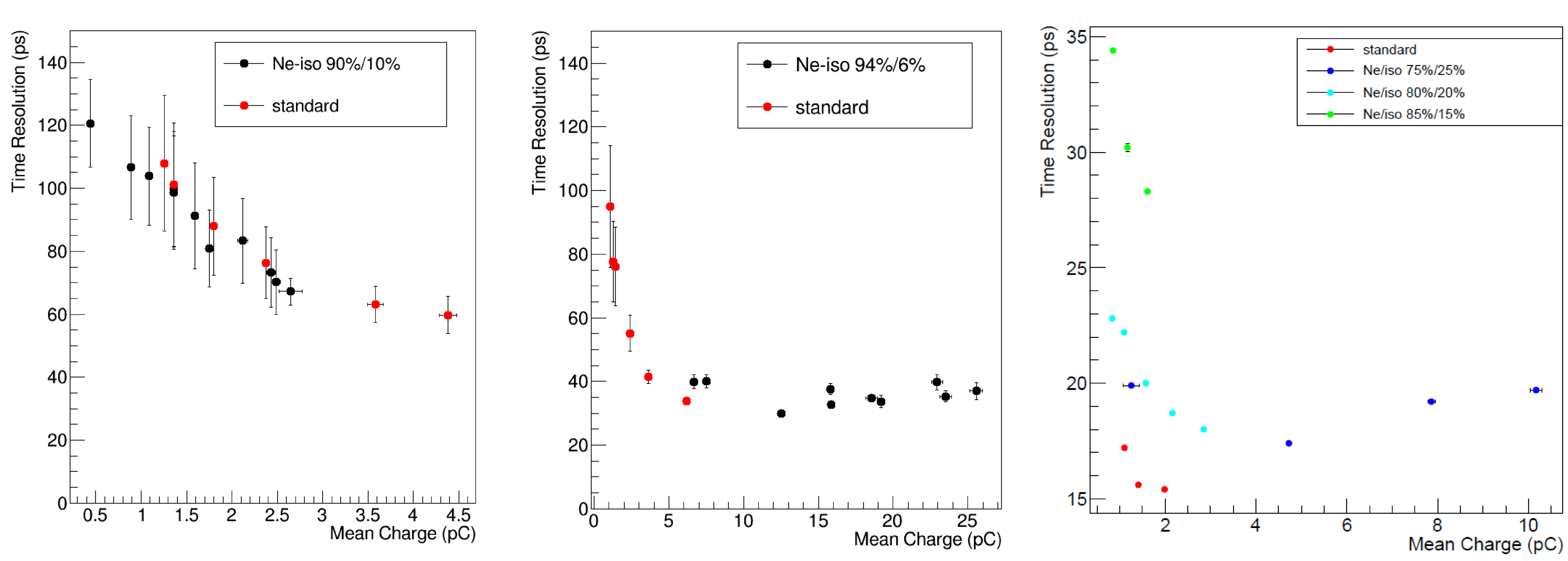

Fig. 5. Left: *comparison between the standard mixture and the Ne/iC$_4$H$_{10}$ 90%/10% one in terms of time resolution as a function of the signal charge. The photocathode used was the B4C 7 nm thick. The Micromegas used was resistive (380 kΩ). [3]* Center: *Comparison between the standard mixture and the Ne/iC4H10 94%/6%. The photocathode was the CsI 18 nm thick with a 3 nm chromium layer. The Micromegas used was resistive (82 MΩ). [3]* Right: *Comparison between the standard mixture and the Ne/iC$_4$H$_{10}$ mixtures with different ratios in terms of time resolution as a function of the amplitude of the signal. The photocathode used was CsI, and the Micromegas was non-resistive. [5]*

•**Fluorinated gases** are used in high-timing performance detectors but have a high **Global Warming Potential** (GWP) and are not environmentally friendly.
•The EU Regulation [6] mandates a **complete ban** on HydroFluoroCarbons (HFCs) by 2050.
•This raises concerns about **supply availability** and rising **costs.**

•The standard gas mixture (**Ne/ethane/CF$_4$**, 80/10/10) is effective but expensive, flammable, and has a **high GWP** (~740).
•Alternative mixtures using Ne and isobutane (iC$_4$H$_{10}$) are being explored for lower environmental impact (GWP < 1).
•Preliminary results (Fig. 5) indicate these mixtures could be viable and sustainable alternatives.

CONCLUSIONS AND FUTURE PERSPECTIVES

- Picosec is a fast-timing MPGD with a time resolution of tens of picoseconds.
- Photocathode tests show promising results for **DLC** as a robust alternatives
- Gas mixture studies indicate **Ne/iC$_4$H$_{10}$** as a potential substitute, but further research is needed to optimize the ratio of the two components, and address flammability and costs concerns.
- Future efforts will focus on scaling the Picosec for **large-area detectors** and testing new Cherenkov radiators materials to balance transparency and crystal size feasibility.

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