Title: Fast timing detectors for the muon system of a muon collider experiment: requirements from simulation and prototype performance.

Content:
The future path of high-energy physics passes through the ability to make collisions at a multi-TeV center-of-mass energy and to measure the products of the collisions with high precision. Achieving these goals would give the chance of exploring new physics and deepening the understanding of possible discoveries made by the LHC at high luminosity. Muon colliders in particular offer incomparable potential for discovery in the multi-TeV energy range: the large mass of muons, compared with that of electrons, implies enormous suppression of synchrotron radiation compared with electron beams of the same energy. Moreover, the leptonic nature of muons poses a cleaner analysis environment, free of the Quantum Chromodinamics effects characteristic of hadron colliders. The technological challenges related to the development of a muon collider arise from the short muon lifetime, 2.2 μs, and from the difficulty of producing large numbers of muons in groups with small emittance. The first one in particular leads to the production of the so-called Beam-induced Background (BIB), which affects the design of the machine and detector. Simulations were performed with FLUKA to characterize such a background, which is mainly composed of neutrons, photons and low-energy electrons/positrons. They deposit energy diffusely throughout the detector volume, with a significant difference of their arrival time with respect to the bunch crossing. All these characteristics must be considered when designing a dedicated detector. The Muon Collider simulation activity was based so far on the usage of the iLCSoft framework, previously adopted by the CLIC Collaboration. In its initial design, the simulation includes a tracking system based on multiple layers of silicon detectors, followed by electromagnetic and hadronic calorimeters. These three components are contained within a solenoidal magnet, which provides a field of 3.57 T. Outside the solenoid extends the muon system, based on multiple layers of gaseous detectors in both the barrel and endcap regions.
The purpose of this contribution is to describe the expected performance of a multipurpose muon collider detector designed to reconstruct the products of multi-TeV collisions with extreme accuracy. The results presented will include the contribution of the BIB particle in order to address the proper operating conditions of the detector. The main focus will be on the muon system, which is currently instrumented in the simulation with glass-RPC technology. We will present results from a standalone simulation showing that the hit rate expected in the endcap regions closest to the beamline are at the limit of the current performance reachable by such a detector. For this reason, we are proposing an alternative design of the muon system fully based on Micropattern Gaseous Detectors (MPGD). The new design foresees the combination of tracking layers based on Triple-GEM detectors, with a timing layer based on a new generation MPGD called Picosec. Picosec was developed in the last few years by the RD51 collaboration, with the aim of obtaining a fast timing (sub ns) MPGD. It consists in a micromegas detector with reduced drift gap (from 4 mm to 200 um) combined with a Cherenkov radiator and a proper photocathode. When the muon crosses the radiator, Cherenkov photons are emitted and then converted in the photocathode: photoelectrons finally enter in the micromegas, generating the signal. In this concept the reachable time resolution is of the order of 25 ps (against the 5-10 ns of classical MPGDs) thanks to the fact that the fluctuation on the position of the first ionization cluster is greatly reduced.
A dedicated R&D is ongoing to optimize such a technology for the application in a muon collider experiment, both from the detector and the mechanics point of views. First of all, the standard gas mixture (Ne/Ethane/CF4) is highly dangerous for the environment, expensive and its procurement may become difficult in the next few years due to bans on the use of high greenhouse gases imposed by the European Union. For this reason, new eco-friendly gas mixtures must be taken in consideration, and the performance of the detector operated with them must be evaluated. Moreover, the photocathode shall be optimized to improve its resistance to high radiation flux, thus maintaining a high Cherenkov photon conversion yield. The photocathode currently used, CsI, is also hygroscopic, which makes it difficult to use in a future experiment. Finally, different materials and thicknesses of the Cherenkov converter must be considered and tuned to the characteristics of the radiation present in the experimental area. Moving to the mechanical aspects, current Picosec prototypes are of the order at most of 10x10 cm2, which assures a reliable high voltage stability of the Micromegas, as well as an appropriate flatness, which is a key element for time resolution. Therefore, for implementation at the muon collider, dedicated mechanics that allow coupling several small detectors until the desired surface area is covered shall be designed and tested.
This contribution will present the results obtained during the R&D of the Picosec technology for the muon collider both from laboratory tests and test beams performed in 2023. Special attention will be given to the performance obtained with different gas mixtures. Moreover, we will discuss the plans for the R&D dedicated to the muon collider also considering the demands given by simulations with dedicated physics channels.

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