Letter of Interest: Machine Detector Interface Studies at a Muon Collider

Abstract

Muon collisions can represent the new frontier for the investigation of the physics beyond the standard model since they can reach multi-TeV center of mass energies. One of the main issues is the beam-induced background caused by the muon decays that can limit the collider functionalities and the detector performance if not mitigated properly. This letter proposes to study the Machine Detector Interface at $\sqrt{s} = 1.5$ TeV and $\sqrt{s} = 3.0$ TeV by using the MAP accelerator design and a new software framework.

Status of the art

Muon beams at a Muon Collider are expected to have the order of $2 \cdot 10^{12}$ muons per bunch to reach the desired instantaneous luminosity. The number of particles produced by the muon decays along the ring is very large, for example two beams of 750 GeV of energy generate about $4.28 \cdot 10^{5}$ decays per meter of the lattice in a single pass.

The primary products of these decays are energetic electrons and neutrinos. Then, the electrons emit synchrotron photons in the presence of the high magnetic field of the accelerator ring magnets. Electrons and photons, in turn, produce electromagnetic showers by hitting the beam pipe and the Interaction Region (IR) elements, hadrons via photo-nuclear interactions and muons via the Bethe-Heitler process. All the particles, in turn, generate additional showers and particles by interacting with the detector components.

The beam-induced background (BIB) has been studied in detail for accelerators with center of mass energies of 1.5 TeV [1] and 126 GeV [2] by the MAP collaboration. Following these studies, the Machine Detector Interface (MDI) was optimized. Two conical-shaped Tungsten structures, called nozzles, are placed around the beam pipe to shield the detector from the high particles flux. The material, the angles close to the interaction point and far from it, and the length of the nozzles are determined by studying the level of the background on the detector surface by varying the optics of the final focus region. Therefore, it is essential that results from the MDI studies are taken in account when designing the IR lattice and vice-versa.

During the last year, a software framework and the relevant code to produce the beam-induced background starting from the MAP IR design has been developed [3], and, currently, is being validated by reproducing the previous results published by the MAP collaboration. The Fluka line builder is used to automatically build the accelerator geometry starting from the machine optics. Then, with the Fluka Monte Carlo, muon beams and their products are generated and tracked on the relevant region. Finally, the density of particles on the nominal detector volume is produced. The same simulation framework will be used also to track the neutrino fluxes along the ring and at the IR to study neutrino interaction with the matter and the environment.

Proposed activities

The MAP collaboration has already made available the IR lattice description for $\sqrt{s} = 1.5$ TeV and they are planning to recover the files for $\sqrt{s} = 3.0$ TeV as part of the Snowmass activities. With these two IR descriptions and by using the new software framework, we propose the following activities:

- Reproduce the beam-induced background studies inside the nominal detector volume by using the IR and the MDI designed by MAP at $\sqrt{s} = 1.5$ TeV. The results will be compared with the published ones to benchmark the code.
- Study the MDI at $\sqrt{s} = 3.0$ TeV by using the MAP IR design with the following steps:
    1. evaluate the BIB characteristics with no detector shielding in order to identify the origin of the background and to be able to understand how one can mitigate it with improved machine design.;
    2. assess the backgrounds inside the nominal detector volume by assuming the $\sqrt{s} = 1.5$ TeV detector nozzles and shielding;
    3. optimize the nozzles and the shielding by iterating the evaluation of the BIB inside the nominal detector volume at $\sqrt{s} = 3.0$ TeV.

Outcome

- Detailed comparison between the BIB studies performed by MAP and those obtained with the new software framework at the center of mass energy of 1.5 TeV.
- BIB characteristics and behaviors at $\sqrt{s} = 1.5$ TeV and $\sqrt{s} = 3.0$ TeV. These studies will lay the foundation for a new collider and detector design that minimizes the impact of background at other center of mass energies like the 10 TeV or more.
- Information on the requirements for high center of mass energy detector to mitigate BIB.

References:

[1] N.V. Mokhov and S.I. Striganov, "Detector Backgrounds at Muon Colliders", Phys. Procedia 37 (2011)[arXiv:1204.6721].

[2] N.V. Mokhov, S.I. Striganov, and I.S. Tropin, "Reducing backgrounds in the Higgs factory muon collider detector",arXiv:1409.1939 (2014).

[3] F. Collamati et al., "A flexible tool for Beam Induced Background Simulations at a Muon Collider", ICHEP2020 presentation Talk