Solving Critical Problems of the Energy Frontier Muon Collider: Optics, Magnets and their Protection, Detector Backgrounds and Neutrino Hazard

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High-energy high-luminosity Muon Collider (MC) is considered as a discovery machine. Since the muon energy is not divided between the constituents like in the case of protons, the energy reach of a MC is an order of magnitude higher than that of a *pp* collider with nominally the same collision energy [1]. Based on more than 20 years of the author's experience in design studies of lattice, magnets, their protection, detector backgrounds and radiation issues for muon colliders with c.o.m. energy ranging from 125 GeV to 4 TeV [2-8], we propose a MC study for the particular c.o.m. energy of 6 TeV. Its energy reach noticeably exceeds the $\sqrt{s}$ = 27 TeV goal of the LHC energy upgrade making the 6 TeV MC a competitive option to explore this energy scale. There is also a good understanding of challenges that such a machine may present [5-7] as well as a preliminary design of the Interaction Region (IR) for $\sqrt{s}$ = 6 TeV MC [3, 9].

We will not consider here problems of muon generation, cooling and acceleration and take for granted the muon beam parameters established by the Muon Accelerator Program (MAP). The following issues will be addressed:

- MC lattice design which provides the average luminosity of up to 10^{35}/cm^2/s at the top c.o.m. energy of 6 TeV. The lattice allows a wide range of β* and muon energy variation necessary for the energy scan, provides an adequate protection of magnets and detectors from muon decay products [5, 6, 8], and minimizes the severity of neutrino production in the arcs and IR [7] and consequently in places where the neutrino approaches or exits the ground surface. The latter includes mitigation measures introduced in [7].
- High-field / high-gradient superconducting (SC) magnets with the coil apertures as large as 24 cm in IR and 15 cm in the arcs. These large magnet apertures are determined by the large muon beam emittance and beta functions as well as by the necessity of using protective liners inside apertures to reduce energy deposition by muon decay products in the cold mass.
- Design of the machine-detector interface (MDI) which permits radical suppression of the detector backgrounds generated by muon decays [2, 5, 6].

Protection of SC magnets and detector from radiation imposes strict limitations on the lattice choice hence the design of the collider optics, magnets and MDI is closely intertwined. As the first approximation we will use the IR design with β*=3 mm [3], while for the arcs we will rescale the arc cell design of the 3 TeV collider. For chromaticity correction, two options will be evaluated: the three-sextupole scheme [3] and the four-sextupole scheme [9] which promises a better dynamic aperture.

The high level of operating fields and large apertures of the SC magnets, needed for such machine, require using hybrid multilayer coils made of high-temperature and low-temperature superconductors (HTS and LTS). The major issue to address is the stress management in the coil to avoid substantial degradation or even damage of brittle HTS and LTS coils. Stress management concepts for shell-type coils have been recently proposed and are being experimentally studied for high-field accelerator magnets based on HTS (Bi2212 and ReBCO) and LTS (Nb_3Sn) cables [4, 10]. Both concepts use metallic structures with radial shells and azimuthal bars to intercept and transfer Lorentz forces inside the coil. Although the experimental studies and optimization of these concepts are still at a very early stage, the stress management elements are included in the described MC magnet designs. The magnet coils are designed to provide realistic field maps for the analysis and optimization of the arc lattice and IR design, as well as for studies of beam dynamics and magnet protection from radiation [5, 8]. Stress management elements will be further optimized once the magnet and machine designs mature.

In the assumed IR design, the dipoles close to the IP and tungsten masks in each interconnect region (needed to protect magnets) help reducing background particle fluxes in the detector by a substantial factor. The tungsten nozzles in the 6 to 600 cm region from the IP (as proposed in the very early days of MC [2] and optimized later [6]), assisted by the detector solenoid field, trap most of the decay electrons created close to the IP as well as most of incoherent $e+e-$ pairs generated in the IP. With sophisticated tungsten, iron, concrete and borated polyethylene shielding in the MDI region [8], the total reduction of background loads by more than three orders of magnitude can be achieved.

Note, that all the beam induced deleterious effects in the MC– radiation loads and peak energy deposition in SC magnets, MDI design and background particle loads on detectors and neutrino-induced hazard for TeV-range MC [7] – and their mitigation were studied over many years with the continuously upgraded MARS Monte Carlo [11].

The proposed white paper will summarize in a coherent form the results of our previous studies on Muon Collider and present design concepts of the 6 TeV MC optics and SC magnets, and a preliminary analysis of the protection system to reduce radiation loads on the MC magnets as well as particle backgrounds in the collider detector. It will also refine further the problem of neutrino induced radiation and methods of its mitigation. The realistically achievable MC energy with the proposed concept and the required R&D effort will be presented and discussed.

References

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