Solving Critical Problems of the Muon Collider Higgs Factory: Optics, Magnets and their Protection, and Detector Backgrounds

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Precision measurements of the Higgs boson decay channels with possible Higgs Factory options under discussion present high interest for HEP. We propose a detailed study of a low-energy medium-luminosity Muon Collider Higgs Factory (MCHF) for this purpose as already has been discussed in [1]. A significant advantage of MCHF over e^+e^- machines is low spread of the collision energy which permits direct precise measurements of the Higgs boson mass and width. Besides the Higgs boson study, a low-energy MCHF has also a unique discovery potential being able to produce in $\mu^+\mu^-$ collisions the unknown particles whose decay into $\mu^+\mu^-$ pairs was already observed in some experiments [2]. There is also a synergy of the MCHF with the next generation muon experiments and Neutrino Factory which will use its front end and the accelerator chain. Unlike a high energy MC, the MCHF is less costly and easier to build since it does not require the final muon cooling stage with yet-to-be-developed ≥30 T solenoids nor very fast ramping synchrotrons for acceleration. On the other hand, some of its frontend systems could become in the future a part of the Energy Frontier Muon Collider.

In this study we are not discussing the problems of muon production, cooling and acceleration. They will be addressed in separate LOI's. We are focusing on the problems related to the MCHF collider ring (CR) which includes the arc and the interaction region (IR), in particular on

(1) a versatile CR design that permits two operation modes (high luminosity or low energy spread),

(2) large-aperture high-field superconducting (SC) magnets and their protection against muon decay products, and

(3) reduction of background particle fluxes in the MCHF detector to the tolerable levels.

A preliminary design of MCHF with the 125 GeV c.o.m. energy and an average luminosity up to 10^{32}/cm^2/s and a 6 MeV collision energy spread was described in [3-6]. In those papers the MCHF CR layout, the design concepts of SC magnets and the first results of the MARS15 [7] energy deposition simulations in these magnets were presented and discussed. At the 62.5 GeV muon energy and $2 \cdot 10^{12}$ muons per bunch intensity, the electrons from muon decays deposit more than 300 kW in the SC magnets of the MCHF CR. This heat deposition corresponds to an unprecedented level of average dynamic heat load of 1 kW/m around the 300-m long CR, which corresponds to a multi-MW room temperature equivalent if the heat is deposited in magnet cold masses at liquid helium temperature. It was shown that a thorough optimization of the multi-component protection system [6] would allow reducing the dynamic heat load on the SC magnet cold components below 15 W/m which is still large but seems acceptable for the modern cryogenic systems.

The large normalized emittance and the large β_{max} of the muon beams as well as the large transverse size of the protection absorbers (liners) needed to protect SC magnets and detector from showers generated by muon decay products, require SC magnets with very large apertures in the CR. A preliminary design of the MCHF storage ring is based on Nb_3Sn SC magnets with the coil aperture ranging from 16 cm in the arc to 50 cm in the interaction region [5]. The coil cross-sections were designed to provide appropriate magnet operating fields and margins, field quality and magnet quench protection conditions as well as adequate spaces for the beam pipe, helium channel and inner absorber (liner).

The high level of Lorentz forces in large-aperture coils, operating at relatively high fields, requires stress management in the coil to avoid large degradation or even damage of brittle Nb_3Sn superconductor. Several stress management concepts for shell-type coils have been recently proposed for high field accelerator magnets based on the Nb_3Sn superconductor [8, 9]. All the concepts use special metallic structure with radial shells and azimuthal bars to intercept and transfer Lorentz forces inside the coil to the external mechanical structure. Although the experimental studies and optimization of these concepts are still at a very early stage, the stress management elements are being now included in the described MCHF magnet design concepts. Preliminary designs of the described SC magnets with stress management elements for MCHF CR were produced and used to provide realistic field maps for the analysis and optimization of the CR design, as well as for studies of beam dynamics and magnet protection against radiation [3, 5, 6, 10]. Mechanical and magnetic optimization of SC magnets with stress management will be performed and included in the energy deposition simulations once the magnet and machine designs mature.

The proposed white paper will address the specifics of the SC magnet designs for the MCHF, beam dynamics with realistic magnetic field quality, as well as thorough optimization of protection systems for both the SC magnets and the collider detector. The important magnet and material R&D steps towards practical realization of the MCHF will be also presented and discussed.

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