International Muon Collider Collaboration

On behalf of the forming international muon collider collaboration[1]

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1 Motivation

Circular muon colliders have the potential to reach centre-of-mass energies of tens of TeV with high luminosity. Muons are point-like particles, so the entire nominal energy is available to produce short-distance reactions, which allows direct searches for new particles in particular to be carried out over a wide range of unexplored masses. A muon collider also allows accurate tests of the Standard Model to be performed at extremely high energy, offering great opportunities to detect new physics indirectly and/or to confirm and to characterise direct discoveries. Furthermore, by exploiting the copious rate for Vector Boson Fusion and Vector Boson Scattering processes, the muon collider provides the opportunity to probe the most intimate nature of the Electroweak Symmetry Breaking mechanism.

The MAP collaboration[5] has developed the muon collider concept and technologies; the efforts have been reduced several years ago. The concept is based on a proton-driven muon source and requires muon beam cooling, which has been tested in the UK by the MICE collaboration[6]; results were recently published. The LEMMA team[7] has proposed to use positrons for muon beam production. With innovations this could become an important alternative solution and simplifiy a number of design issues.

The European Strategy for Particle Physics therefore recommended to form a new international muon collider study as a part of the accelerator R&D roadmap[2]. In Europe, the European Large National Laboratories Directors Group (LDG) has subsequently initiated an international muon collider collaboration[3], which covers the physics, detector and collider facility.

2 Scope

The study aims to establish whether a muon collider is feasible and, if so, to develop the concept and technology to a level of maturity that allows committing to its construction supported by a validation of the physics reach. This full conceptual design is expected to demand a very important effort, similar to other large projects. In particular, the technology challenges motivate further R&D, prototype construction and performance demonstrations.

The study will focus on high energies, in particular 3 TeV and 10 TeV or more. The tentative goal for the integrated luminosity target, which will be refined later, would be

$$\int \mathcal{L} = 10\ \mathrm{ab}^{-1} \left(\frac{\sqrt{s}}{10\ \mathrm{TeV}} \right)^2$$

The 3 TeV case, with a luminosity of $\mathcal{L} \approx O(10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1})$, would substantially extend the energy reach of superconducting linear colliders and allows the study to benefit from the work on the machine that has been performed in the US and elsewhere as well as from the physics and detector studies performed for CLIC.

The case of 10 TeV or more, with a luminosity of the order of $\mathcal{L} \approx O(10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1})$, would extend lepton collider to an energy range inaccessible to normal conducting linear colliders. A muon collider operating in this energy range will open entirely new physics opportunities in the domains of Higgs/Electroweak and Beyond the SM physics.

3 Plan

A muon collider, in particular at an energy of 10 TeV or above, is uncharted teritory. Therefore the study has to explore the full physics reach and develop a concept of the detector that can realise the physics potential and mitigate background effects. An integrated collider concept has to be devised that can deliver the required luminosity and background conditions. It has to have acceptable impact on the environnement and be cost and power efficient. The study will profit from the substantial progress has been made in the design of the muon collider and in the development of its technologies[4, 5, 7].

In the first period, in time for the next European Strategy for Particle Physics Update, the study aims to establish whether the investment into a full CDR is justified. It will provide a baseline concept, well-supported performance expectations and assess the associated key risk as well as cost and power consumption drivers. It will also identify an R&D path toward a full CDR for the machine and the associated experiments.

Depending on the strategic decision, this could be followed by a period of about six years to develop an optimised conceptual collider design with cost and power consumption estimate. This period focuses on the construction and operation of a key prototypes for performance validation and on the construction and operation of the required test facility infrastructre to demonstrate the concept. The conceptual design will be the technical basis for a decision on whether to commit to the project. In the this case a technical design can be developed over a period of about four years. This would require a continuation of the technology development and more integrated tests with beam.

4 Initial Workplan

The work until the next European Stratgy Update will be split in two phases, the exploratory phase, which will last about two years, and the definition phase.

In the exploratory phase, the collaboration will define goals for the muon collider performances and develop a prioritised list of key challenges that have to be addressed in the definition phase. The physics reach and its dependence on luminosity and detector performances will be studied. The potential detector performances with existing and novel technologies will be established and the potential impact of background will be considered. The potential performance of the machine will be explored. Based on these initial studies, ambitious and achievable goals will be defined for the definition phase.

Associated to the goals, a list of key challenges to achieve them will be identified. Its prioritisation will serve as the basis to define the work programme in the definition phase. Starting from a tentative list, an initial list of key issues is expected to be ready in time for the Snowmass Process and a refined one at the end of the exploratory phase. The exploration of the detector and the whole collider complex, the development of key concepts and the definition of critical parameters will be essential to identify issues and in particular to prioritise them.

In the definition phase, the workprogrammes developed in the exploratory phase will be implemented for the physics, experiment and facility and might require an increase in resources as more detailed studies might be needed. The effort will consist of studies to support the ability of reaching the performance goals and to refine these goals where required. Identification and conceptual design of the key demonstration facilities and components will define the R&D path for the CDR phase and allow to assess its cost and timeline. The construction of models for key hardware might be required during this phase.

More details can be found in other Letters of Interest, see[8, 15].

Contact

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References

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[3] European Large National Laboratories Directors Group (LDG), Minutes of the LDG meeting on July 2, 2020.

[4] J. P. Delahaye, M. Diemoz, K. Long, B. Mansouli, N. Pastrone, L. Rivkin, D. Schulte, A. Skrinsky, and A. Wulzer, Muon Colliders, arXiv:1901.06150.

[5] https://map.fnal.gov/

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[7] LEMMA Team, Positron driven muon source for a muon collider, arXiv:1905.05747v2 [physics.acc-ph]

[8] Lettre of Interest for Snowmass 2020: "Muon Collider Accelerator Facility", AF-4.

[9] Lettre of Interest for Snowmass 2020: "Muon Collider Physics Potential", EF.

[10] Lettre of Interest for Snowmass 2020: "Muon Collider Experiment", EF.

[11] Lettre of Interest for Snowmass 2020: "Machine Detector Interface Studies at a Muon Collider", EF.

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[14] Lettre of Interest for Snowmass 2020: "LEMMA: a positron driven muon source for a muon collider", AF-4.

[15] Lettre of Interest for Snowmass 2020: "Multi-TeV Collider and AF2: Accelerator for Neutrino Physics", AF-4.