Muon Collider Collaboration

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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 European Strategy for Particle Physics therefore recommended to form an international muon collider study as a part of the accelerator R&D roadmap[]. In Europe the Laboratory Directors Board has subsequently initiated an international muon collider collaboration[], which covers the physics, detector and collider facility.

2 Scope

In the past, substantial progress has been made in the design of the muon collider and in the development of its technologies[]. Further development and innovation is now required to bring it to a maturity level that will allow reliable predictions of the feasibility, risk, performance, cost, and power consumption of the facility to be made.

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 two main energy ranges. The first is in the range of 3 TeV centre-of-mass energy, with a luminosity of $\mathcal{L} \approx O(10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1})$. This energy 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 second energy range would be around 10 TeV or more with a luminosity of the order of $\mathcal{L} \approx O(10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1})$. This 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

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 key prototypes for performance validation and on the generation of the test infrastructure. 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 Key R&D

The production of bright muon beam is instrumental for a collider. The more developed and studied proton-driven option still requires a final demonstrator and further optimisation. The appealing positron driven source, at present missing a feasible design to produce high luminosity, demands dedicated R&D studies and tests also in synergy with other ongoing projects.

The high-energy acceleration complex and the colldier ring contain important performance, cost and power consumption challenges that can ultimately define the energy reach of the collider. A wide range of cutting edge technologies, detailed studies and R&D is required. In particular:

- Advanced detector concepts and technologies, requiring excellent timing, granularity and resolution, able to reject the background induced by the muon beams.
- Advanced accelerator design and beam dynamics for high luminosity and power efficiency.
- Robust targets and shielding for muon production and cooling as well as collider and detector component shielding and possibly beam collimation.
- High field, robust and cost-effective superconducting magnets for the muon production, cooling, acceleration and collision. High-temperature super-conductors would be an ideal option.
- High-gradient and robust normal-conducting RF to minimise muon losses during cooling.
- High rate positron production source and high current positron ring.
- Fast ramping normal-conducting, superferric or superconducting magnets that can be used in a rapid cycling synchrotron to accelerate the muons.
- Efficient, high-gradient superconducting RF to minimise power consumption and muon losses during acceleration.
- Efficient cryogenics systems to minimise the power consumption of the superconducting components and minimise the impact of beam losses.
- Other accelerator technologies including high-performance, compact vacuum systems to minimise magnet aperture and cost as well as fast, robust, high-resolution instrumentation.

The goal of the collaboration will be to address these challenges.