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IPAC-2025: International Particle Accelerator Conference 2025 (Taipei, 1-6 June 2025)

Collider ring magnet design for a Muon Collider

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The Muon Collider represents a promising candidate for a post-LHC accelerator, offering a unique opportunity to probe the frontiers of high-energy physics in a more cost-effective and energy-efficient manner compared to traditional hadronic colliders. The International Muon Collider Collaboration (IMCC) is currently conducting an extensive feasibility study for a cutting-edge facility designed to achieve 10 TeV center-of-mass energy within a compact 10 km circumference ring. This ambitious project faces a variety of technical and scientific challenges, requiring breakthroughs in multiple areas of accelerator technology. A key focus of this endeavor is the development of advanced superconducting magnets for the collider ring, which are critical components due to their demanding specifications. These magnets must deliver very high magnetic fields, accommodate large bore sizes, and maintain low energy consumption. Also the magnets of the interaction region present a significant technological challenge due to the demanding high gradients required to achieve the necessary emittance and luminosity, as well as the extremely high levels of radiation expected. This contribution will discuss the challenges associated with such magnets, presenting the status of the preliminary conceptual designs under investigation and the required R&D necessary for such configurations.

Progress on the design of solenoids for the 6D cooling channel of a muon collider

Siara S. Fabbri, Luca Bottura, Marco Statera

In the current and most evolved design concept of a muon collider, there exists two long (~ 1 km) channels for cooling newly created muons and anti-muons, termed the `6D cooling channels'. There the beam is cooled in momentum and position space using a series of alternating polarity solenoids, which create an oscillating field in the beam direction, through absorbers and radio-frequency cavities. In total there are around 3000 solenoids per channel, contributing to a significant portion of the cost and engineering demands of the entire machine. The integration of the requirements of the field profile with feasible solenoid configurations is a difficult and unique problem, without analytic descriptions to readily relate these. Our approach addresses this problem in two steps: in the first we constrain the beam optics optimization studies by setting engineering limits on solenoid parameters; in the second we have developed a numerical optimization routine to find the best configuration given a desired field profile, in terms of cost and engineering complexity. The following paper reviews this approach and key features, and presents optimization results on the latest optics solution.

New developments in the design of the muon production target area of a multi-TeV muon collider

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As the International Muon Collider Collaboration advances the conceptual design for a multi-TeV muon collider facility, new technical constraints continue to arise in the muon production stage, where a high-power proton beam interacts with a target. Achieving the required muon bunch intensity may necessitate increasing the primary beam power up to 4 MW. Consequently, the shielding design must address sustained radiation exposure, particularly on critical components such as superconducting solenoids, which generate strong magnetic fields essential for capturing both pions and decay muons. Additionally, the portion of the proton beam that passes through the target without undergoing inelastic interaction leads to a very high power density in the chicane area and an intense ionising dose on the insulation material of the normal-conducting chicane magnets, which are used to separate the muon component. A robust method to safely extract these spent protons is crucial. This study presents the latest results from FLUKA Monte Carlo simulations, modelling the radiation load on solenoids and the extraction channel across varying beam power and target designs.

A Muon Beam Facility at CERN to Demonstrate Muon Ionisation Cooling.

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The International Muon Collider Collaboration (IMCC) has been formed following the 2020 European Strategy for Particle Physics Update, with the goal of studying the feasibility of a muon collider at a centre of mass energy of around 10 TeV. One of the most challenging sections of a muon collider is the initial cooling before acceleration, due to the necessity to apply intense magnetic and electric fields to reduce the 6D emittance of the muon beam by 5 orders of magnitude in a very short time, to cope with the limited lifetime of muons (2.2 µs at rest). The IMCC proposes to build a Demonstrator to prove that all the involved technologies (RF, magnets, absorbers, beam instrumentation) can be built at the required specifications, and integrated in order to limit the length of the cooling sections to an acceptable value. Several options are being considered in different laboratories within the collaboration. This paper describes a possible implementation at CERN, in the existing TT7 tunnel.

Magnet R&D for the Muon Collider: Proposed R&D Plans

L. Bottura, B. Bordini, S. Fabbri, M. Statera, F. Boattini, S. Mariotto, B. Caiffi, S. Gourlay

The muon collider represents a transformative approach in particle physics, offering a pathway to achieve high energy and luminosity with reduced environmental impact compared to other collider technologies. Central to its feasibility is the development of advanced magnet systems capable of supporting the stringent requirements of muon production, acceleration, and collision. The key targets for magnet R&D include achieving field levels up to 40 T, magnets with stored energies up to 300 MJ, managing heat loads from muon decay at the level of several W/m, and ensuring radiation resistance well above 50 MGy. Given such extraordinary challenges, research presently focuses on integrating high-temperature superconductors (HTS), tailored for efficient cooling at cryogenic temperature, and striving for compact magnets to reduce the capital expenditure. In the past years we have progressed in the conceptual design, and in some cases we have initiated engineering design, as well as materials and small-size coil testing. This has allowed to outline an R&D plan that we describe in this paper. The proposal plan involves staged milestones, includes the development of small- and full-scale magnet prototypes, up to the validation under collider-relevant conditions.

Transient finite-element simulations of fast-ramping normal-conducting magnets for a 10TeV muon collider

Dominik Moll, Laura A.M. D'Angelo, Herbert De Gersem, Fulvio Boattini, Luca Bottura, Marco Breschi

Ongoing conceptual studies for a 10TeV muon collider identified rapid cycling synchrotrons as major engineering challenge. Due to the muon’s short lifetime of only 2.2µs at rest, normal-conducting bending magnets with field rise rates of well beyond 1kT/s are indispensable to support accordingly fast acceleration cycles. Energies of 100MJ will be interchanged between magnets and capacitor banks within few milliseconds. Accurate models of the magnets are thus required to evaluate and optimize the overall system performance. The non-uniform temperature distribution in the magnet strongly affects material properties like the electrical conductivity of copper and must therefore be considered in the electromagnetic field problem posed by Maxwell’s equations. This contribution presents recent advancements in addressing this multi-physical problem by using problem-specific finite-element tools allowing to describe the inherently transient behavior. The ferromagnetic yoke is accurately resolved by using a novel combination of a Bergqvist hysteresis and a homogenized eddy current model. Finally, different magnet design concepts are compared in terms of material costs, magnetic energy, losses, field quality and temperature buildup.

Design, Integration and Technology R&D of a Muon Ionisation Cooling Cell.

L. Rossi, R. Losito, D. Giove, M. Statera, D. Schulte, C. Rogers, A. Grudiev, C. Barbagallo, L. Bottura, S.S. Fabbri, G. Scarantino,… more EU and US colleagues

The International Muon Collider Collaboration (IMCC) was established following the 2020 European Strategy for Particle Physics Update, with the goal of investigating the feasibility of a muon collider with a center-of-mass energy of approximately 10 TeV. The initial muon cooling section, prior to acceleration, is a critical component, as it necessitates the application of intense solenoidal magnetic fields overlapping with high radio frequency (RF) electric fields. This process aims to reduce the 6D emittance of the muon beam by five orders of magnitude in a very short time to accommodate the limited lifetime of muons (2.2 µs at rest). Building on the previous US-led Muon Accelerator Program (MAP), the IMCC team has developed a series of very high field (20-30 T peak), medium bore (100-1000 mm) high-temperature superconducting (HTS) solenoids, along with RF cavities that have gradients exceeding 30 MV/m at 352/704 MHz. Following several iterations, the first complete cooling cell has been fully designed, integrating various components, including magnets with a 20 K cooling circuit, RF cavities with power couplers and windows, and solid absorbers in a dispersive field. This integration has been accomplished with a satisfactory assembly procedure. Numerous research and development (R&D) and technology validation steps are currently underway in various laboratories, contributing to the ongoing optimization of beam cooling performance.

MT-29: International Conference on Magnet Technology 2025 (Boston, July 1-6 2025)

EUCAS-2025: European Conference on Applied Superconductivity (Porto, 21-25 September 2025)