Final list of IMCC-related abstracts approved by IMCC-PSC to be submitted to IPAC24 (as of 11/12/2023)

1) Radiation shielding studies for superconducting magnets in multi-TeV muon colliders

Authors: A. Lechner, D. Calzolari, J. Mańczak, G. Lerner, F. Salvat Pujol, C. Carli, K. Skoufaris, P. Borges de Sousa, R. van Weelderen, J. Ferreira Somoza, D. Schulte, L. Bottura, D. Amorim

Abstract: Circular muon colliders provide the potential to explore center-of-mass energies at the multi-TeV scale within a relatively compact footprint. Because of the short muon lifetime, only a small fraction of stored beam particles will contribute to the physics output, while most of the muons will decay in the collider ring. The resulting power carried by decay electrons and positrons can amount to hundreds of Watt per meter. Dedicated shielding configurations are needed for protecting the superconducting magnets against the decay-induced heat and radiation damage. In this paper, we present generic shielding studies for two different collider options (3 TeV and 10 TeV), which are presently being explored by the International Muon Collider Collaboration. We show that the key parameter for the shielding design is the heat deposition in the magnet cold mass, which will be an important cost factor for facility operation due to the associated power consumption.

2) Radiation load studies for the proton target area of a multi-TeV muon collider

Authors: Jerzy Mańczak, Daniele Calzolari, Anton Lechner, Claudia Ahdida, Chris Rogers, Rui Franqueira Ximenes, Francisco Javier Saura Esteban, Daniel Schulte, Alfredo Portone, Luca Bottura

Abstract: Muon production in the multi-TeV muon collider studied by the International Muon Collider Collaboration is planned to be performed with a high-power proton beam interacting with a fixed target. The design of the target area comes with a set of challenges related to the radiation load to front-end equipment. The confinement of the emerging pions and muons requires very strong magnetic fields achievable only by superconducting solenoids, which are sensitive to heat load and long-term radiation damage. The latter concerns the ionizing dose in organic materials such as insulation, as well as the displacement damage in the superconductor. Therefore, the magnet shielding design has to limit the heat deposition and must ensure that the induced radiation damage is compatible with the operational lifetime of the muon production complex. Finally, the fraction of the primary beam passing through the target without performing inelastic collisions poses a need for an extraction channel. The design of this channel must ensure the extraction of the spent proton beam without compromising the emittance of the muons intended for the subsequent cooling stage. In this study, we use the FLUKA Monte Carlo code to assess the radiation load to the production and capture solenoids, and we explore the feasibility of the possible spent proton beam extraction scenarios taking into account the constraints stemming from the power and spot size of the spent beam and the required magnetic field strength. **Abstract > 1200 characters => To be reduced!**

3) FLUKA simulations of neutrino-induced effective dose at a Muon Collider

Authors: Giuseppe Lerner, Jerzy Mańczak, Claudia Ahdida, Anton Lechner, Christian Carli

Abstract: The International Muon Collider Collaboration (IMCC) is conducting a feasibility study to confirm the realistic performance and feasibility of a circular accelerator colliding TeV-scale muon beams. During the operation of a muon collider in an underground tunnel, most circulating muons decay into an electron (or positron) and a neutrino-antineutrino pair, resulting in a narrow disk of high-energy neutrinos emitted radially in the collider plane and emerging on the Earth's surface at distances of several km. The goal is to ensure that this effect does not entail any

noticeable addition to natural radioactivity and that the environmental impact of the muon collider is negligible. Dedicated studies of the expected neutrino and secondary-particle fluxes are therefore required to assess the environmental impact. This work presents a set of FLUKA Monte Carlo simulations aimed at characterizing the radiation showers generated by the interactions of high-energy neutrinos from TeV-scale muon decays in a reference sample of soil. The results are expressed in terms of effective dose in soil at different distances from the muon decay, quantifying the peak dose and the width of the radiation cone, for beam energies of 1.5 TeV and 5 TeV. The implications of these results for realistic muon collider scenarios are discussed, along with possible methods to mitigate the local neutrino flux. **Abstract > 1200 characters => To be reduced!**

4) Conceptual RF Design and Modelling of a 704 MHz Pillbox Cavity for the Muon Cooling Complex

Authors: C. Barbagallo and A. Grudiev

Abstract: The Muon Cooling Complex (MCC) is a prospective facility to develop technology essential for ionization cooling for a future high energy Muon Collider at CERN. This cooling technique necessitates the utilization of normal conducting, RF accelerating cavities operating within a multi-Tesla magnetic field. This study illustrates the conceptual RF design of a 704 MHz cavity equipped with beryllium windows for the muon cooling demonstrator. Based on the specifications from the beam dynamics, frequency-domain eigenmode simulations have been conducted to calculate the primary RF figure of merits for the cavity. Several materials were simulated for the cavity walls, including copper, beryllium and aluminum. In selected cases, more advanced engineering analyses, including thermo-mechanical simulations and design of the cooling channels, have been performed to enable operation at gradients up to 44 MV/m within strong solenoidal magnetic fields up to 13 T. Furthermore, the impact of the beam loading on the muon energy spread is investigated, and appropriate mitigation techniques are proposed.

5) Update of the code PLACET2 for the low-energy acceleration stages of the Muon Collider

Authors: Paula Desiré Valdor, Andrea Latina (perhaps also Raul Costa, still in discussion with Andrea) => Paula will finally not be able to go to IPAC24 and Bernd Stechauner accepted to present her work if he gets the grant

Abstract: This work describes the updates performed to the tracking code PLACET2 to make it feasible for the simulation of the acceleration from 200 MeV to 63 GeV in the proposed? future muon collider. The election of this software lays in its ability to simulate recirculating linacs, which are part of the proposed layout for this initial acceleration stage. PLACET2 has been updated to simulate non-ultra relativistic particles and to consider particle beams of different species, charges and masses. The main changes were introduced in the longitudinal dynamics, but it also affects synchrotron radiation and wakefields descriptions. In addition, the decay of particles has been added as a new feature. The performed changes were benchmarked in different tests against RF-Track, a code able to simulate low energy muon beams and their decay. Finally, the lattice of the 17 GeV droplet arc in the initial acceleration stage of the muon collider was simulated with both PLACET2 and RF-Track, providing another test. All the results showed excellence accordance between both codes, verifying the performed implementation in PLACET2.

6) Introducing a Semi-Gaussian Mixture Model for Simulating Multiple Coulomb Scattering in RF-Track

Authors: Bernd Stechauner, Andrea Latina, Daniel Schulte, Rudolf Frühwirth, Jochen Schieck
=> Bernd applied for a student's grant, so it's not sure if he will be able to go

Abstract: The deflection of charged particles in matter can be characterized by multiple-Coulomb scattering. Simulating the interaction of each particle with the Coulomb forces of the material is prohibitively time-consuming from a computational perspective. To address this, scientists have developed a scattering probability model, such as the Moliere model, which has seen refinements and contributions from various researchers over the past decades. In the context of the design study of the LINAC for ionization cooling, RF-Track has recently incorporated particle interactions with matter. This inclusion enables simulations for applications like ionization cooling channels for muon colliders and the design of machines for medical purposes. Within RF-Track, a novel Semi-Gaussian mixture model has been introduced to describe the deflection of charged particles. This innovative model comprises a Gaussian core and a non-Gaussian tail function to account for the effects of hard scattering. To validate the accuracy of our results, we conducted a benchmark against other particle tracking codes, and the outcomes demonstrated a high level of agreement.

7) Optimizing Initial Beam Parameters for Efficient Muon Ionization Cooling
Authors: Bernd Stechauner, Co-Authors: Elena Fol, Chris Rogers, Daniel Schulte, Jochen Schieck
=> Bernd applied for a student's grant, so it's not sure if he will be able to go
Abstract: Ionization cooling stands as the only cooling technique capable of efficiently reducing the phase space of a muon beam within a short timeframe. The ultimate cooling stage of a muon collider will minimize transverse emittance while simultaneously curbing longitudinal emittance growth, resulting in the highest luminosity within the collider ring. This study shows that achieving efficient cooling performance requires selection of the best initial muon beam parameters. We present a technique that enables the determination of these optimal initial parameters through simulations and compare them with analytical models.

8) Transient finite-element simulations of fast-ramping muon-collider magnets
Authors: Dominik Moll, Jan-Magnus Christmann, Laura A.M. D'Angelo, Herbert De Gersem, Marco Breschi, Luca Bottura, Fulvio Boattini
Abstract: Conceptual studies for a muon collider identify fast-ramping magnets as a major design challenge. Rise times of more than 1 T/ms are only attainable with normal-conducting magnets, incorporating iron yokes to make sure that stored magnetic energies and inductances stay below reasonable thresholds. Moreover, for energy efficiency, the magnets need to exchange energy with capacitors, such that the electric grid only needs to compensate for the losses. The design of such magnet systems is based on two- and three-dimensional finite-element models of the magnets coupled to circuit models of the power-electronics equipment. The occurring phenomena necessitate nonlinear and transient simulation schemes. This contribution will discuss a two-dimensional transient nonlinear field-circuit coupled simulation of a bending magnet submitted to a 1 ms cycle generated by a switched capacitor bank. The magnet's yoke is represented by a homogenized material refraining from the spatial discretization of the individual laminates, but nevertheless representing the true eddy-current losses. The hysteresis losses are estimated in a post-processing step.

9) Cooling Demonstrator Target and Pion Capture Study
Authors: P. B. Jurj and C. Rogers (maybe others, under discussion)
Abstract: The muon collider has great potential to facilitate multi-TeV lepton-antilepton collisions. Reaching a suitably high luminosity requires low-emittance high-intensity muon beams. Ionisation cooling is the technique proposed to reduce the emittance of muon beams. The Muon Ionisation Cooling Experiment (MICE) has demonstrated transverse emittance reduction through ionisation cooling by passing the beams with relatively large emittance through a single absorber, without

reacceleration. The international Muon Collider Collaboration aims to demonstrate 6-D ionisation cooling at low emittance using beam reacceleration. Two siting options are currently considered for a Cooling Demonstrator facility at CERN, with proton-driven pion production facilitated by the Proton Synchrotron or the Super Proton Synchrotron. In this work, we use FLUKA-based Monte Carlo simulations to optimise the number of pions produced in the proton-target interactions and subsequently captured by a magnetic horn or solenoid-based system. We explore the feasibility of different target and capture system designs for 14, 26 and 100 GeV proton beam energies.

10) Simulating a Rectilinear Cooling Channel using BDSIM for the 6D Muon Cooling Demonstrator

Authors: K. Rohan and C. Rogers

Abstract: Muon colliders hold promise for high luminosity multi-TeV collisions, without synchrotron radiation challenges. However, this involves investigation into novel methods of muon production, acceleration, cooling, storage, and detection. Thus, a cooling demonstrator has been proposed to investigate 6D muon ionization cooling. The MICE experiment validated ionisation cooling to reduce transverse emittance. The demonstrator will extend this to also cool longitudinal emittance. It would also use bunched beams instead of single particles from a muon source. The 6D cooling lattice comprises successive cells which consist of: solenoids for tight focusing, dipoles to introduce dispersion in the beam, wedge-shaped absorbers for differential beam absorption, and RF cavities for reacceleration. In this paper, the simulation and further optimization of the rectilinear cooling channel is discussed. This analysis extends existing theoretical and numerical work using BDSIM, a Geant4-based accelerator framework built to simulate the transport and interaction of particles. The study also incorporates beams from existing proton drivers, using output from targetry and capture designs for the same.

11) Initial design of a proton complex for the Muon Collider

Authors: Isabela Vojskovic, Simone Gilardoni, Vitaliy Goryashko, Emanuele Laface, Alessandra Lombardi, Natalia Milas

Abstract: The proton complex is the first piece in the Muon Collider, it comprises a high power acceleration section, a compressor and a target delivery system. For the International Muon Collider Collaboration we are investigating the possibility of having a full energy 5-GeV linac followed by an accumulator and a compressor ring and finally a target delivery system. In this paper we present the initial studies for the complex and derived initial beam parameters at each interface.

12) Innovative bulge test setup to characterize thin beam vacuum windows

Authors: V. Giovinco, M. Morrone, J.A.F. Somoza, C. Garion

Abstract: As part of the International Muon Collider study ~~at CERN~~, a beam vacuum window, a few hundred nm thin, is being developed at CERN. It is required for the final cooling, where the charged particles travel from the vacuum chamber to the absorber; here, the beam loses momentum to cross a second window entering in a RF cavity that increases the longitudinal momentum. The best absorber for the final cooling is hydrogen. As the absorber should be installed inside a high field focusing solenoid, the hydrogen density should be as high as possible, ideally liquid or high pressure gas, to have a reasonable solenoid length. To evaluate the performance of the window, it is necessary to study the tightness at cryogenic temperatures, resistance to burst, high temperature and beam-induced damage. The main objective of the proposed work is to design and validate a versatile bulge test setup for the mechanical characterization of thin windows at different pressures and temperatures to cover all operating conditions, from 77 K to 293.15 K and ideally above. Due to the low thicknesses, a non-contact measuring technique based on a confocal chromatic sensor is proposed. The setup consists of a stainless steel vacuum enclosure connected to a bulk copper rod where a pressurized channel is obtained to load the window. Measurements at different temperatures are made by cooling or potentially heating the copper rod on which the window is mounted. **Abstract > 1200 characters => To be reduced!**

13) Optical matching procedure employing multi-objective optimization with efficient beam dynamics computation

Authors: Isabela Vojskovic and Emanuele Laface

Abstract: The conceptual design of the Muon Collider aims to achieve muon beam collisions at approximately 10 TeV. Challenges, such as the imperative for a short pulse and an intense beam to prevent muon decay, necessitate an investigation into crucial design parameters. This study specifically addresses the transfer line lattice, which includes FODO-cells and a triplet, situated between the muon-proton compressor and the target. The aim is to determine the optimal lattice design for effective matching. In addressing this objective, we introduce multi-objective optimization techniques for obtaining design variables tailored to the requirements of the final focusing parameters in the presence of space charge. Additionally, we present an optimized numerical computing technique enabling parallelization and GPU acceleration, specialized for simulating the beam dynamics in the transfer line. By comparing its performance and accuracy trade-off with a physics-constrained neural network surrogate model, our goal is to establish a time-effective tool for optimizing the muon transfer-line lattice across various input beam parameters. This research contributes to enhancing the efficiency and precision of muon collider design. **Abstract > 1200 characters => To be reduced!**

14) Progress in the Design of the Magnets for a Muon Collider

Authors: Luca Bottura, Siara Sandra Fabbri and the whole magnets working group

Abstract: Magnets have been identified as one of the critical technologies for a proton-driven Muon Collider. Within the scope of the International Muon Collider Collaboration we have progressed in the review of requirements, and the development of concepts towards the initial engineering of several of the most critical magnets identified from our previous work. In this paper we present an update of the accelerator magnet configuration for all the parts of the Muon Collider complex, from muon production to collision. We then give details on the specific technologies that have been selected as baseline. Overall, it is clear that a Muon Collider requires very significant innovation in accelerator magnet technology, mostly relying on the success of HTS magnet development. We include in our description a list of options and development staging steps intended to mitigate technical, cost and schedule risk.