International Muon Collider Design Study

Accelerator Design meeting

Monday 06/02/2023, 16:00 – 17:30
(https://indico.cern.ch/event/1250083/)

Chair:	Daniel Schulte
Speakers:	Daniel Schulte, Antoine Chancé
Participants (zoom): 39	*Alexej Grudiev, Antoine Chancé, Akira Yamamoto, Alex Bogacz, Anton Lechner, Bernd Stechauner, Carlo Carrelli, Chris Rogers, Claude Marchand, Claudia Ahdida, Daniel Schulte, Daniele Calzolari, Daniele Sertore, David Amorim, David Kelliher, Elena Fol, Elias Métral, Fabian Batsch, Heiko Damerau, Ivan Karpov, Jean-Pierre Delahaye, John Hauptman, Jose Antonio Ferreira Somoza, Luca Bottura, Massimo Casarsa, Max Topp-Mugglestone, Nazar Bartosik, Nadia Pastrone, Peter Sievers, Roger Ruber, Shufang Su, Siara Sandra Fabbri, Simon Albright, Scott Berg, Ursula Van Rienen, Vladimir Shiltsev, Yasar, Yuhu Zhai.*

MEETING ACTIONS

1: David Amorim	Do a similar study for the RCSs as the one he did for the collider to evaluate the minimum required aperture.
2: Antoine Chancé	Following the question from Roger Ruber, check with MaxTM by how much the beam position will change in an FFA and what the effects would thus be.

1. NEWS (DANIEL SCHULTE)

- EU project MuCol is back (approved for the 2nd time) and the (zoom) kick-off meeting will take place on 28/03/23 (see https://muoncollider.web.cern.ch/events-calendar) => Please note that, due to some migration to Drupal 10, I do not have the edit rights anymore on the

IMCC webpage and therefore modifications take more time and the website might not be always up-to-date. Daniel mentioned that we will try and improve our webpage by putting a real calendar to gather all the events and that a dedicated space will be created to gather all the US events to try and keep track of all the activities linked to muon colliders.

- The 2nd annual meeting, coordinated by L. Bottura and C. Carli, will take place on 19-23/06/23 in Paris-Orsay (see https://muoncollider.web.cern.ch/events-calendar).
- The Muon4Future workshop will take place on 29-31/05/23 in Venice (see https://muoncollider.web.cern.ch/events-calendar).
- The Synergy workshop was initially foreseen to take place back-to-back to the Muon4Future in Venice but it will now be linked to the 2nd annual meeting in Paris => To be discussed tomorrow during the IMCC Coordination Committee.
- Reminder about the workshop from 27/02/23 to 10/03/23 (2023 KITP - Kavli Institute for Theoretical Physics - Muon Collider Workshop, UC Santa Barbara, USA: see https://muoncollider.web.cern.ch/events-calendar).
- Daniel mentioned that the presentation he gave on 13/12/22 (at the Committee on Elementary Particle Physics – Progress and Promise Meeting No. 4, National Academies of Sciences, Engineering, and Medicine) went well (see last minutes).

2. Report from WG on Muon Acceleration (Antoine Chancé)

- Antoine reminded the goal and associated challenges of the fast acceleration (after recirculating linacs) to collision energy, i.e. from ~ 63 GeV to ~ 5 TeV. He reminded also that the IMCC Muon Acceleration Working Group (WG) is covered by some Tasks of the EU MuCol project within the High-Energy Complex Work Package (WP). This WP is focused on parameter optimisation, optics design and lattice integration. Some activities are in close interaction with other IMCC WGs: Magnetic Systems (pulsed magnets), RF systems, Beam-matter interaction, Collective effects, Matching conditions with the Collider WG.
- At the beginning of last year, it was decided to discuss the related issues within a dedicated meeting called HEMAC (for High-Energy Muon Acceleration Chain) chaired by H. Damerau. The kick-off meeting took place on 22/02/22 and 14 meetings took place so far (see https://indico.cern.ch/category/14979/).
- The current scheme is based on a chain of Rapid Cycling Synchrotrons (RCS) with 2 counter-rotating muon bunches (mu+ and mu-) => See https://cernbox.cern.ch/index.php/s/I9VpITncUeCBtiz:
    - RC1 from 63 GeV to 0.31 TeV
    - RC2 from 0.31 TeV to 0.75 TeV
    - RC3 from 0.75 TeV to 1.5 TeV
    - RC4 from 1.5 TeV to 5 TeV

- RC1 and RC2 would be in the same tunnel (with a circumference of ~ 6 km, i.e. slightly smaller than the CERN SPS of ~ 7 km), with the first as a normal conducting RCS and the second one as a hybrid one (hybrid in the sense of having both normal- and super-conducting magnets). RC3 and RC4 would be hybrid RCS as well in other tunnels (circumference of RCS3 ~ 11 km and circumference of RCS4 ~ 35 km). It should be noted that as the circumference of the RCS4 is close to the circumference of the LHC, the possibility to have it inside the LHC tunnel was also studied (with both a parametric study and first test of genetic algorithms for accelerator parameters optimisation) leading to a slightly smaller final energy (at ~ 4.5 TeV instead of 5 TeV).
- Many constraints need to be taken into account
    - Fast muons decay => We should accelerate as fast as possible
    - To decrease the cost, we should
        - ⇨ Minimise the total voltage and thus energy gain per turn, i.e. we should have RCS as small as possible
        - ⇨ Consider hybrid RCS, with a higher average field, which leads to a small synchrotron (but then different path lengths and orbits, which was studied in detail)
        - ⇨ Optimise the dipole ramp to minimise the power consumption
    - Find the best extraction/injection ratio between the different acceleration stages
- Antoine reminded first the work done on the variation of the path length in RCS2 (up to ~ 1 cm) and associated variation of the synchronous phase (up to ~ 10 degrees).
- Antoine reminded then the work done on the general stability criteria for RCS1 in the presence of the HOMs of the ILC-type RF cavities (which is close to the limit when all the HOMs are taken into account and for which a correction of the chromaticity might be needed) and the HOM power, which is quite challenging. Indeed, 10 kW HOM power per bunch is a current concern, as it is extremely challenging to handle. HOM power coupler for 3-4 kW are under development (and up to 20 kW). The present parameter tables are based on the ILC cavity (1.3GHz), but a lower frequency, e.g. 800MHz, might be required if the power cannot be handled.
- Antoine also reminded the work done on the 10 TeV collider to determine the minimum chamber radius depending on the material used: ~ 17 mm radius required for Copper at 300 K and ~ 25 mm for Tungsten at 300 K.
- Antoine then reminded the work done on the accelerator magnets and related powering system
    - It is important to optimise the design of the accelerating magnets and the power system together, in order to find an optimal solution with an acceptable cost
    - Due to the considerable level of peak power required by the acceleration stage, the best approach is to use LC discharge circuits

    - The total power must be divided into several sectors (~100). So many LC circuits will probably all resonate differently due to differences in the LC parameters (and temperature effects)
    - The active filter role would then be to correct the differences among all circuits which boils down to defining the required control accuracy
    - Resistive magnets have been studied and compared (different dipole designs with different steel materials) => Integrated design of magnets and power systems requires magnetic models that consider saturation of magnetic materials and hysteresis
    - Superconductive magnet concepts have been also studied and compared for which the decay loss is an important input (average 3 W/m?)
- An alternative to RCSs is to use FFAs due to the time-independent magnetic fields, which means that the rate of acceleration is limited only by the RF (and not by the ramp time). This mitigates engineering challenges of designing and powering fast-ramping dipoles and all magnets can be superconducting DC magnets
    - hFFA
    - vFFA => Quasi-isochronous (fixed RF frequency), which is an advantage for the RF. But the drawback is that it is new and therefore we have very little experience with the optics (unique coupling behaviour - dominated by skew quadrupole focussing and solenoid components in fringe fields - , nonplanar orbits) and challenging optimisation. The current research field is to develop the understanding of vFFA and to optimise the lattice for muon acceleration (reducing the ring size and the excursion and maximising the dynamic aperture). Max Topp-Mugglestone is working on this for his PHD and he developed already an analytic model of a vFFA optics for larger-ring FODO lattices. The next steps are
        - ⇨ Numerical benchmarking of this analytical model
        - ⇨ Use this analytical model to optimise vFFA lattices for muon acceleration
        - ⇨ Physical prototype of vFFA magnet for construction
- Summary and next steps
    - The main goal of this WG is to gather information (from other WGs) to get a coherent parameter table for a chain of pulsed synchrotrons or FFA. We get regular meetings in this aim.
    - A parameter table is regularly updated here: https://cernbox.cern.ch/index.php/s/I9VpITncUeCBtiz
        - ⇨ The current baseline has 4 RCS to go up to 5 TeV with possible reuse of LHC tunnel
        - ⇨ Genetic algorithms are considered also to optimise the different stages (already a good agreement with current table)

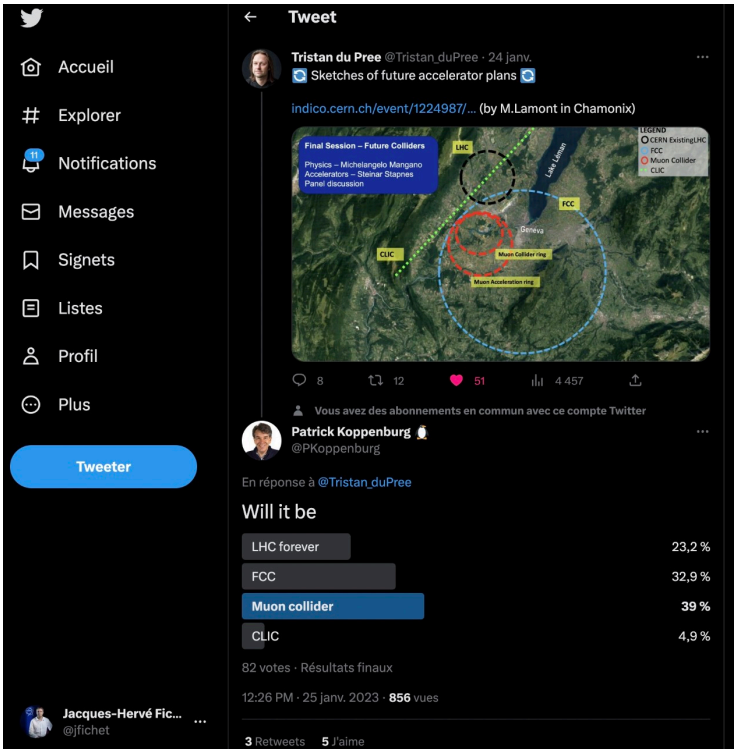
- We have a margin of 8 on stability due to (ILC-like) cavity impedance (when only the most critical mode is considered and it is ~ fine when all the HOMs are considered)
    - ⇨ Nevertheless, the HOM power is huge: 10 kW
    - ⇨ We will consider another frequency like 800 MHz to see the improvement
- Stability studies show that we should correct the chromaticity in RCS1 (to be confirmed with the final impedance model)
- For the collider, resistive wall impedances require a beam screen radius of 17 mm with Copper at 300 K against 25 mm with Tungsten at 300 K. The studies need to be updated for the acceleration chain (**see Action 1**)
- Dual harmonics discharge circuits can provide close to linear Bref shapes during the acceleration
- We have first design of the resistive and SC magnets. The work is on-going
- Analytic model of vFFA optics for large-ring has been developed. The next steps are numerical benchmarking, lattice optimisation and magnet prototype construction

- Discussion
    - Following a question from Alex Bogacz, Antoine clarified that this study of fast muon acceleration concerns the energies between ~ 60 GeV and ~ 5 TeV (following the past work from MAP).
    - Concerning the energy swing, ScottB mentioned that a factor of 5 can only come from a non-hybrid synchrotron. There is a choice to be made between the cost or having to performed more turns (as there will be less RF). For 3 TeV, a non-hybrid synchrotron inside the LHC tunnel should work according to DanielS, but it requires more RF as the RF/unit length has to remain the same for survival rate considerations.
    - Concerning the FFA, Roger Ruber asked by how much the beam position will change and what the effects would thus be. Antoine will like to ask Max (**See Action 2**).
    - ScottB mentioned that when he looked at some FFA designs, the 3 things which always came back were: i) how long the quads can be?; ii) what about the aperture?; iii) what about the impedance? The shielding will have some thickness and some studies have been done for the collider ring. Would be good to have some studies on this for the RCS as well (see Action 1). Can we use collimators? If we use HTS, DanielS mentioned that we can suppress by a factor ~ 10 the losses. Would be great to localise the losses => This is the next iteration and AntonL said that we need a dedicated meeting for that.
    - VladimirS asked if the beam was tracked longitudinally and what happened? FabianB answered positively and that we did the full simulations. FabianB mentioned also that he studied the linear and nonlinear ramp. On slide 8 for instance, we see the synchronous phase changing. And we changed the phase instead of the RF voltage due to the filling time of the cavities (blue line is linear and

orange is slower). See also https://indico.cern.ch/event/1175126/contributions/5025431/.

3. AOB (EVERYBODY)

- DanielS mentioned that as concerns the EPJC paper on muon collider, largely based on what was done for Snowmass, all the comments have been submitted and it should be released soon. Please remember that DanielS also sent an email to everybody in case some people should appear in the co-authors list.
- Elias mentioned that he was recently informed about a short survey on Twitter ;-)



- Next meeting next week: Beam-matter interaction / target systems (Anton Lechner) => See https://indico.cern.ch/event/1252027/.

Reported by E. Métral and D. Schulte