International Muon Collider Design Study

International MUON Collider Collaboration

Accelerator Design meeting

Monday 15/05/2023, 16:00 – 17:30
(https://indico.cern.ch/event/1272154/)

Chair:	Daniel Schulte (who was finally absent) => I took over from the CERN CCC (as I was LHC coordinator)
Speakers:	Siara Sandra Fabbri
Participants (zoom): 32	*Alexej Grudiev, Alex Bogacz, Andrea Wulzer, Antoine Chancé, Anton Lechner, Bernd Stechauner, Cary Yoshikawa, Chris Densham, Chris Rogers, Daniele Calzolari, David Amorim, Donatella Lucchesi, Elena Fol, Elias Métral, Fabian Batsch, Fulvio Boattini, Hans S-M, Jaap Kosse, Ji Qiang, Liang Zhang, Lorenzo Sestini, Luca Bottura, Mark Palmer, Nazar Bartosik, Paula Desire Valdor, Roberto Losito, Roger Barlow, Roger Ruber, Scott Berg, Sergio Calatroni, Siara Sandra Fabbri, Yifeng Yang.*

Meeting Actions: None

1. News

- Daniel was not present
- ChrisR asked about the SLAC meeting and MarkP gave a short report
    - P5 received interesting input on all potential accelerator paths => Lots of discussions
    - There will be some additional meetings and the P5 report should be ready for distribution in October
    - ChrisR mentioned that he heard that there were some very positive, interesting and productive discussions about the muon collider

2. Siara Sandra Fabbri (Initial Evaluations of the Cooling Solenoids for the Rectilinear 6D Cooling Channel)

- Work in collaboration with Jonathan Pavan
- DISCLAIMER: These are tentative results based on the geometries and parameters from the US MAP original design => See Stratakis, Diktys, and Robert B. Palmer. "Rectilinear six-dimensional ionization cooling channel for a muon collider: A theoretical and numerical study." *Physical Review Special Topics-Accelerators and Beams* 18.3 (2015): 031003
- **Reminder about the goal of the study: simulate and characterize the cooling solenoid magnets based on geometries and initial parameters from the US MAP study**
- **Reminder about the goal of the Rectilinear 6D cooling channel: reduce the emittance of the muon beam by several orders of magnitude**
  - o 12 unique stages (with each stage having a repeating series of a cell type)
    - ⇨ 4 cooling stages before bunch recombination (A1-A4)
    - ⇨ 8 cooling stages after bunch recombination (B1-B8)
  - o Some figures
    - ⇨ Fields on axis: 2 (A1) to 14 T (B8)
    - ⇨ Cell Lengths: 0.8 (B8) to 2.7 m (B1)
    - ⇨ Total length of all stages: ~ 1 km
    - ⇨ Total number of solenoids: 2432
- Simulation study
  - o Magnetic properties => Bz, Br, |B|, Bmax in coils, L and Em, stray fields
  - o Mechanical properties => Stresses (hoop sigma_theta, radial sigma_r and longitudinal sigma_z), peak stress, force densities and coil parameters
  - o Simulations done in COMSOL but continuously validated against analytical formulas (see slide 14 => with an excel coil calculator discussed on slide 17. ChrisR asked if the excelsheet could be made available and Siara answered positively) and supplied G4beamline fieldmaps
- Results are shown from slides 22 to 25, from 27 to 34, from 36 to 41
- Summary of the initial evaluations
  - o From the results, it is obvious that the magnet parameters will need to be optimised from an energy/cost and engineering perspective
    - ⇨ Potentially large self inductance and large stored magnetic energy
    - ⇨ Hoop stresses > 150 MPa

        - ⇨ Tensile radial stresses
        - ⇨ Longitudinal forces on coils up to 37 MN
        - ⇨ Large stray fields
    - o Reminder of what was not included in this study
        - ⇨ A more complete mechanical structure
        - ⇨ Matching sections between stages
        - ⇨ Deeper engineering considerations
            - Iron
            - Realistic space requirements (e.g. B8 is super tight)
            - …
        - ⇨ Dipole magnets
- Questions going forward / some next steps
    - o Beam dynamics vs. field quality and magnet alignment (as the magnet configurations are iterated on)
    - o Options to change towards optimized magnet configurations: higher current density (practical limits), number of magnets, magnet size (radius), etc.
- Understanding the magnetic field requirements: present physics approach focuses on fields along the axis – a sinusoidal wave with defined harmonics. Beam physicists care about just the first 'few' harmonics (what does it really mean? => To be further discussed with ChrisR)
    - o How do we define field quality based on the on-axis field?
    - o How do the beam dynamics depend on the ratios of the first few harmonics?
    - o How accurately can we achieve a certain field profile?
    - o What happens to the field off-axis, especially when introducing errors?
- Study on a single cell field (B1 initial focus for this study)
    - o Approach: use a numerical simulation code based on semi-analytic equations for approximating the field inside of a solenoid (validated against COMSOL)
    - o Goals
        - ⇨ Establish different solenoid geometries: evaluate the change in the harmonics on and off axis for changes in solenoid geometries.
        - ⇨ Error analysis: evaluate the change in the field for introduced 'errors' to the solenoid geometries/setup
    - o => To be further discussed with ChrisR et al.

- Discussion
    - ScottB said that within MAP they looked at the peak field at the coils and Hoop stress but not to this extent
    - MarkP reminded us that it was indeed a physics design and prior to that they looked also at HTS but only optimised in a reasonable way. They wanted to do the same but then MAP was terminated and Siara continued exactly where MAP stopped, which is perfect. More advances have been done in RF and **now it is the time to redo the same analysis but more self-consistently to have more realistic designs for both the magnets and RF: it is one of the most important priorities for the collaboration**
    - LucaB thanked very much MarkP, ScottB and DiktysS as they shared everything. Looking for instance at slide 36, the red line (of 17 T) should be carefully taken into account as there are technological and cost issues… and it is now the time to go through all this in detail
    - AlexejG:
        - ⇨ Why COMSOL: is it a personal choice or are there only things available in COMSOL (OPERA is usually used)? => Was done with COMSOL but could indeed be studied with other codes
        - ⇨ Geometry of the coil: why is the coil so big around the RF? ScottB said that if you bring the coil closer, the field will be more peaked. We could maybe have the same field pattern with several coils, if we want to minimise the stored energy. To be further studied. Linked to this subject, RobertoL mentioned that the optimisation needs to respect the shape of a real cavity, with its coupler, etc.
    - ScottB: how critical the 2 parameters, of large self-inductance and stored energy, are? => LucaB answered that they play an important role during a quench. Following another question from ScottB, LucaB answered that there is no need for a long chain of computations and some guidelines can be provided
    - Chris
        - ⇨ Slide 36 is very encouraging
        - ⇨ Future work: we could work for the not yet designed B9 and B10 cells

3. AOB (EVERYBODY)

- Next meeting will take place on Monday 22/05/23: https://indico.cern.ch/event/1271455/.

Reported by E. Métral and D. Schulte