International Muon Collider Design Study

Accelerator Design meeting

Monday 12/12/2022, 16:00 – 17:30

(https://indico.cern.ch/event/1219424/)

Chair:	Daniel Schulte
Speakers:	Daniel Schulte, Luca Bottura
Participants (zoom): 36	*Alexej Grudiev, Antoine Chancé, Anton Lechner, Arjan Verweij, Barbara Caiffi, Bernardo Bordini, Bernd Stechauner, Chris Rogers, Christian Carli, Claude Marchand, Daniel Schulte, Daniele Calzolari, Daniele Sertore, David Neuffer, Donatella Lucchesi, Elena Fol, Elias Métral, Fabian Batsch, Francisco Javier Saura Esteban, Fulvio Boattini, Ivan Karpov, John Hauptman, Jose Antonio Ferreira Somoza, KarioAU, Kyriacos Skoufaris, Lionel Quettier, Mariusz Wozniak, Mark Palmer, Nadia Pastrone, Patricia Tavares Coutinho, Peter Sievers, Rob Van Weelderen, Scott Berg, Ursula Van Rienen, Xavier Chaud.*

MEETING ACTIONS

1: Daniel and LucaB	Plan a meeting at the beginning of 2023, with all the relevant people, to discuss the recommendations from LucaB et al. to use 9 T (for NbTi) and 14 T (for Nb3Sn) instead of the 10 T and 16 T, which we are currently considering in our studies.

1. NEWS (DANIEL SCHULTE)

- No news from EU, no idea of what is happening. Still plan to have the kick-off on March 28th, 2023 (tbc, see https://muoncollider.web.cern.ch/events-calendar).
- 2nd Collaboration meeting in Paris: week starting on 19th June (preferred option) or 3rd of July (tbc, https://muoncollider.web.cern.ch/events-calendar).

- Daniel is finishing his presentation for tomorrow at the Committee on Elementary Particle Physics – Progress and Promise Meeting No. 4, National Academies of Sciences, Engineering, and Medicine (see https://www.nationalacademies.org/documents/embed/link/LF2255DA3DD1C41C0A42D3BEF0989ACAECE30533A6A9B/file/D19B3D617BFE68767AD0FC2F907DC59E80320B15D7FB?noSaveAs=1).
- NadiaP and DonatellaL mentioned that there will be a workshop in FNAL this week, from Wednesday to Friday => See https://indico.fnal.gov/event/56615/timetable/.
- Finally, Daniel proposed to have a drink at the beginning of 2023 to celebrate the new year.

2. Report from WG7: Magnets (Luca Bottura)

- LucaB mentioned that he will report about the work performed during the last 12 months (still work in progress of course), with the following plan
    - Guidelines for the upcoming (magnet) work
    - The 4 challenges => Technical advances
    - Work organization
    - AOB
    - Summary and plans
- The general guidelines
    - Main power consumption for SC magnets = cryogenic system
    - Main power consumption for Resistive magnets = resistive losses (active power, needs to be cooled away) + inductive voltages (reactive power, can be partly retrieved)
    - Quite expensive: Costly materials + complex technology + large mass
    - Seek for practical solutions to minimise the capital investment (CAPEX) and operation cost (OPEX)
    - A large dose of innovation will be required
    - Technology is a mean, not the end of this work
    - Important to identify the relevant KPIs (Key Performance Indicators)
- The 4 challenges
    - **1) Capture solenoid + decay channel: 20 T, 200 mm**
        - ⇨ Large stored energy
        - ⇨ Considerable RT and cryo heat load
        - ⇨ Radiation dose and radiation damage

- **2) Final cooling solenoid: > 40 T, 60 mm (~ 1/2 m length)**
  - ⇨ Total 1 km, > 1000 units
  - ⇨ Compact windings and careful cost optimisation
  - ⇨ UHF solenoids, with field beyond state-of-the-art: calls for novel HTS technology
- **3) Acceleration: NC +-1.8 T, 400 Hz, 100 mm * 30 mm and SC < 10 T, ~ 100 mm**
  - ⇨ Energy storage and power management (how to send and retrieve it)
  - ⇨ Ramp linearity control, requirement (tbd)
- **4) Collider: 16 T peak, 150 mm**
  - ⇨ Large bore and high field result is large EM stress and require novel stress management concepts
  - ⇨ Significant energy deposition and dose

- What was done? => Some technical advances
  - 1)
    - ⇨ If mass is very high, cost will be very high => Attempt to reduce the mass (CAPEX) of the system, and increase operating temperature to improve cryogenic CoP (OPEX)
    - ⇨ But still many questions: Space for beam dump? Vacuum requirements? Maintenance? Cooling? etc.
  - 2)
    - ⇨ Probe the limits of UHF solenoid magnets for the final cooling (performance)
      - 1st option: LTS and HTS
    - ⇨ Make the windings compact to reduce the mass (CAPEX)
      - **2nd option: All-HTS => Allow to reach very high field with very promising recent results**. Reminder: HTS have properties which depend on angle
      - **Final cooling at 40 T => Bmax ~ 55 T**. On the right of slide 19, we see the field disappearing by itself during a quench
      - On the rest of the cooling path, not much work => Important piece of work which remains to be done (to be started in 2023) and we should profit from the previous discussion about compactness. We need also not only the field on axis but we would like also the field profile as certainly it will be several T more far from axis
  - 3)

⇨ NC pulsed dipoles

- Started from MAP. Powered by 2 harmonics with an active filter. Price to be paid still to be quantified
- We cannot power them in series => Have to be split in several circuits like in the LHC (to limit the stored energy, power and voltage)
- Next step: they need numbers for the specification on the field tracking
- Magnets work together with uni of Bologna: LucaB mentioned brilliant work there. The hourglass magnet (due to its shape) is better than H-magnet but the windowframe seems the best as concerns the reactive power. Aperture for these magnets is really critical
- The magnet stored energy is directly proportional to iron gap and pole width: keep them as small as possible
- **Fe-Co seems the only practical way to reach fields in the range 1.8 T but may pose RP issues (to be quantified)**

⇨ SC magnets

- **10 T is an "unfortunate" number for Nb-Ti => Recommendation to set the Nb-Ti design dipole field to 8-9 T**
- **16 T is similarly un "unfortunate" number for Nb3Sn => Recommendation to set the Nb3Sb design dipole field to 13-14 T**

o 4)

⇨ **The combination of 10 T (for on-axis field) + 300 T/m (for on-axis gradient) + 150 mm (for bore diameter) cannot be done** => We are a factor 3 off according to LucaB

⇨ Work is in progress to provide analytical expression for the magnet design limits

⇨ From slide 26 (reminder: it is beginning of work so we should not take this for granted): **proposal to take provisionally 9 T for NbTi and 14 T for Nb3Sn**

⇨ Slide 27 is a first attempt to compile a physical radial build for the various components in the collider bore and magnet: to be continued

- Work organisation

o The organization of the tasks overlaps with the EU MuCol study but the scope of the work extends beyond

    - As concerns the participants, SF is a fellow who will work with LucaB (LQ is for Lionel Quettier, etc.)
    - Conventions in slide 31 (and following): black is for the beneficiaries of MuCol; Blue is for the associated and purple is for the contributors

- Muons Magnets WG
    - 21 meetings to date
    - Site: https://indico.cern.ch/category/13958/
    - Mailing list: muoncollider-magnets@cern.ch

- AOB
    - Papers
        - ⇨ 1 paper submitted to IPAC-23 (Magnets for a Muon Collider)
        - ⇨ Plan to submit specific contributions to MT-28 and EUCAS -2023
    - 1st material order issued
        - ⇨ 414 m of 4 mm REBCO tape for initial tests on high-J solenoids
    - In preparation (collaboration with INFN) a HTS tape performance specification for muon collider magnets

- Summary and plans
    - 4 grand challenges have been identified, they represent well the envelope of design and performance issues. Work has started to see what are the limits, propose technical solutions and associated R&D
    - The challenges are aligned with the structure of MuCol (Tasks 7.2, 7.3 and 7.4). This simplifies the forming and coordination work with the team. We plan to continue along these lines
    - The interaction with the other ”specialties” has started, to discuss specifications, give and receive feedback on feasibility:
        - ⇨ Beam optics
        - ⇨ Impedance limitations
        - ⇨ Radiation heat loads, dose and damage
        - ⇨ Vacuum and cryogenics
    - This is largely integration/configuration work, and would probably deserve its own life at the level of the project
    - It looks like HTS can make a huge difference towards a compact, energy efficient and sustainable collider. Priority will be devoted to this R&D

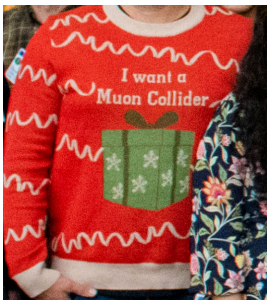
- Discussion
    - AntonL
        - ⇨ Shares the need for a kind of a forum to discuss all this. But there are already a lot of meetings and it is difficult to follow everything. Would be great to have a forum where we could bring all this together. Daniel answered that in principle, today's meeting is the proper place. Anton said that maybe this meeting is too big for such discussions. To be seen in the future if we need another meeting
        - ⇨ Discussion about the magnet design limits from p.26: AntonL mentioned that we need 8 cm of shielding (4 cm on each side) and this would exclude Nb3Sn. But LucaB said that it is for a certain configuration and it is still work in progress, so we still do not exclude Nb3Sn. DanielS mentioned that the stress management might not be consistent with 9 and 14 T for NbTi and Nb3Sn. What would be the impact? The lines are without stress management. To be continued
    - ScottB
        - ⇨ 1st: was surprised from results of slide 23 as he would have thought that the windowframe design would not have the proper field
        - ⇨ 2nd: are you going to study HTS for accelerator magnets and/or collider magnets? LucaB said that we need to find a way out from the limits from slide 26 and one way out is HTS
        - ⇨ 3rd: for the pulsed magnets, is it within your scope to start to look at what a test stand might be? LucaB said that it would be great but it might cost a lot of money. ScottB said not necessarily by building something but at least putting everything together
    - ChrisR => 2 questions on slide 21
        - ⇨ If you use the iron saturation, how can you tune it? LucaB said that the main effect is then done while entering into saturation. But how accurate should be the field? AntoineC said that we have to pay attention about the reproducibility: we need to provide this information to LucaB
        - ⇨ Even without active filter, you need a very good efficiency: do you have a number for this energy loss? FulvioB said that it will come in 2023 and as usual in accelerators, efficiency will be driven by the magnets. Daniel asked about the power loss in the magnets? Fulvio said he does not know. LucaB will check and come back
    - Daniel
        - ⇨ On slide 19, it was mentioned that Bmax ~ 55 T: is it really the max? This is for a uniform cylinder and it does not mean that we are limited there as we never have a uniform cylinder. There is a limit by nature with the formula as

this is coming from the stress and it should be around 55 T. 60 T is certainly a stretched number, 40 T seems feasible and the reality should be in between

- FabianB
  - ⇨ On slide 24, you recommended to use 9 T (for NbTi) and 14 T (for Nb3Sn) instead of the 10 T and 16 T which we are currently considering for our studies: does this mean that one should now consider these numbers for our simulations? LucaB said that we should indeed update our tables with these new numbers as the others are not possible but Daniel and ChristianC (see below) suggested not to make these changes now
  - ⇨ Daniel was expecting ~ + 1-2 T more every decade, which was confirmed by LucaB. LucaB said that today we are at ~ 12 T for dipoles and quadrupoles and the values he mentioned above are consistent with that. Daniel said that we really need to have an idea of the stress management and LucaB replied that this is exactly what HFM is supposed to do, therefore we will fully rely on them for this
- ChristianC
  - ⇨ Linked to field limits discussed just above, ChristianC would propose to keep the same numbers as now and once we have something working we will apply the scaling, adjust and iterate. Daniel agreed and indeed said that we need first to consolidate these numbers and then we will see. LucaB agreed that we need of course to figure out what we can do, but if we want to progress now we need to have a list which is feasible, which is not the case at the moment => LucaB stressed that we should plan for a dedicated discussion on this to decide: this could be planned for the beginning of 2023 (**see Action 1**)

3. AOB (EVERYBODY)

- Merry Christmas everybody and see you in 2023! => For some people who attended the FNAL workshop (https://indico.fnal.gov/event/56615/timetable/), their preferred Christmas present is clear ;-)



Reported by E. Métral and D. Schulte