Accelerator Design

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Proposed Plan

• A start-to-end collider design in particular in the view that this would be the first facility of its kind.

• A machine detector interface that protects the detector from collider background while allowing good machine performance.

• A physics and detector study to assess the physics reach of the collider.

• The design of a demonstrator to be built in the second half of the decade.
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Focus on key parts for now, enough to convince European Strategy
Proposed Plan

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Need much more detail so we can start with next European Strategy Update.
Proton-driven Muon Collider Concept (MAP)

From the MAP collaboration: Proton-driven source (M. Palmer et al.)

Short, intense proton bunches to produce hadronic showers

Pions decay into muons that can be captured

Muon are captured, bunched and then cooled

No CDR exists, no fully integrated baseline
No cost estimate
Need to extend to higher energies (10+ TeV)
But did not find something that does not work
The LEMMA Scheme

45 GeV positrons to produce muon pairs
Accumulate muons from several passages

Low-emittance muon beam can reduce radiation

Less mature than proton-driven scheme
(less resources invested)
Need more work to make this a viable option
Key Challenges

High-energy:

• The neutrino radiation requires mitigation strategy. Requires also site studies.

• The impact of machine induced background on the detector, as it might limit the physics reach.

• Acceleration and collider rings demand advanced technology and accelerator design and drives cost and power consumption.

General:

• Production of a quality muon beam
  — assumed to be the same at all energies
  — source has impact on high-energy challenges

All need to be addressed to show it is worthwhile to do a collider
Demonstrator will be mainly muon beam production but some key high-energy components are needed
Urgent Tasks: Collider Ring Design

Background conditions in detector are important

• Evaluation can only start if have a experimental insertion design
• Also the collider ring has an impact on background
• Physics needs the input
• **Have to launch this activity soon**
• Ring is also the most important ingredients for neutrino radiation
• And an important cost driver
• And has some beamdynamics challenges

- Experimental insertion design
- Exploration of injection, extraction and RF insertion concept
- Collider ring design
- Optics design
- Parametric superconducting magnet study with different technologies for cost
- RF design
- Shielding design (machine and detector)
- Cooling design (6 MW, 400 W/m)
- Beam dynamics (beam-beam, beam stability)
Urgent Tasks: Demonstrator

Demonstrator facility to produce useful muon beam

Demonstrator needs
• to be **based on muon collider source concept**
• a more detailed design than the collider source
• to be based on technologies available in 5 years
• to be affordable (0.5 GCHF?)

Hence we need to
• Need to confirm choice of muon source concept
• Have to have concept of full muon source
• Identify use exiting infrastructure (e.g. proton beams)
• Scale design to funding and available technology
• Explore if it serve some physics

Develop source concept over the first two years
Then design demonstrator, preferably the same people
Urgent Tasks: Source Development

- Two muon source options give very different beams and very different demonstrators
- Currently proton-driven source baseline, positron-driven source alternative
  - Allows to go on with full facility design
  - Gives time to develop the positron option
- Exploit synergies

- At which timescale positron-driven source can be considered as baseline?
  - What are the key efforts required?
  - Can it be ready in two years for consideration?
  - Or is it long-term alternative?
  - Need task force

Important list of R&D exists
Urgent Tasks: Proton Source and Front-end Design

**Proton complex**
- Optics
- Efficient RF
- Magnets

**Front-end**
- High power target
- Capture solenoid (20 T, 1.2 m aperture)
- Radiation from target
- Buncher
- Phase rotator
- Optics

- Based on MAP design, optimise complex
- Choice of target (solid/liquid, ...)

- Identify suitable existing proton installations for demonstrator
  - Design required modifications
- Design front end for demonstrator

Need dedicated procedure for knowledge transfer from MAP MICE and LEMMA experts will become members of the study
Urgent Tasks: Cooling Design

MAP design almost achieves target performance on paper.
Final stage needs to be improved.

Hardware performances were better than assumed in design.

Additional options proposed (parametric cooling):

- Considering MAP design and MICE experience, develop overall concept.
- Design of cooling for demonstrator.

Highly integrated, compact cells.

- Highest-field solenoids for final cooling (> 30 T)
- High-field superconducting magnets for 6D cooling
- 50+ MV/m, normal conducting RF in magnetic field
- Targets
- Optics design
- Safety, instrumentation, vacuum, ...

D. Schulte
Muon Collider Facility Design, CERN, July 3, 2020
Important Tasks: Accelerator Design

Important for performance, cost and power consumption

Two main options

• Right with fixed lattice and very large energy acceptance (FFAG)
• Ring with fast-ramping magnets (Rapid cycling synchrotron, RCS)
• MAP identified RCS as cheaper, to be reviewed

Collider ring independent of this choice

• so can explore both if resources permit

Source of neutrino radiation
Significant beam losses $O(30 \text{ W/m})$
Trade-off, cost, power, muon survival, ..

**RCS requires high-field, fast-ramping magnets and efficient energy recovery**
  • @14 TeV: stored energy $O(0.2 \text{ GJ})$
  • $O(40 \text{ km long if normal-conducting})$
Optics is challenging

“Low-energy” acceleration is still a very important RF installation

• Explore RCS design
• Fast ramping magnets
• Efficient power converters
• Explore FFAG design
• Static magnets (RCS and FFAG)
• Efficient superconducting RF
• Shielding

• Develop “Low-energy” acceleration
Key Technologies

- Advanced detector concepts and technologies, requiring excellent timing, granularity and resolution, able to reject the background induced by the muon beams.

- **Advanced accelerator design** and **beam dynamics** for high luminosity and power efficiency

- Robust **targets** and **shielding** for muon production and cooling as well as collider and detector component shielding and possibly beam collimation.

- High field, robust and cost-effective **superconducting magnets** for the muon production, cooling, acceleration and collision. High-temperature superconductors would be an ideal option

- High-gradient and robust **normal-conducting RF** to minimise muon losses during cooling.

- High rate **positron production source** and high current positron ring.

- **Fast ramping** normal-conducting, superferric or superconducting **magnets** that can be used in a rapid cycling synchrotron to accelerate the muons and **efficient power converters**.
Key Technologies, cont.

- Efficient, high-gradient **superconducting RF** to minimise power consumption and muon losses during acceleration.
- **Efficient cryogenics** systems to minimise the power consumption of the superconducting components and minimise the impact of beam losses.
- **Other accelerator technologies** including high-performance, compact vacuum systems to minimise magnet aperture and cost as well as fast, robust, high-resolution instrumentation.

- Some technologies might still need to be identified (e.g. radiation mitigation)
- And all the technologies required for the demonstrator need to be addressed

- There is some detail behind items such as “advanced accelerator design” or “high-field superconducting magnets”

- Site and reuse of existing infrastructure is of great importance
Homework

Need to start defining workpackages
• for the technological components
• and for collider parts
• tentative “shopping list” will be on our web page http://muoncollider.web.cern.ch

Start putting the experts together
• collect your interest and expertise today
• see who wants to be partner
• start to see how work can be split
• iterative process will take some time
  – everyone needs to find resources
  – in particular US labs might need time
  – fair sharing of tasks
  – optimising synergies

Start with meetings to define reasonable choices and targets
• focuses on specific areas of the facility, e.g. collider ring
• and on the technologies, e.g. magnets

Everybody in this collaboration needs to start taking ownership
Conclusion

We have an ambitious charge from the European Strategy and LDG

The demonstrator and R&D programme will allow to do hardware development in the near future

Let us start!

Regular meetings from early September
- Mondays 15:00 Geneva time
- First subject: MDI
- Then: Muon sources

Subscribe to the mailing list muoncollider_facility@cern.ch
Reserve
Example: Fast Ramping Magnet Systems

If we use RCS, need fast ramping magnets

Longest of all systems
• depends on final energy
• cost driver
• important for power consumption

\[ L = 10.5 km \frac{E}{B} \frac{T}{TeV} \]

3 TeV collider
• **7.9 km** at ±2 T magnets
• Assumed aperture 80x40 mm
• Stored energy in aperture \( O(40 \text{ MJ}) \)
• Ramping from -2 T to 2 T in 2.1 ms
• 38 GW during ramp

14 TeV collider
• **37 km** at ±2 T magnets
• Stored energy in aperture \( O(200 \text{ MJ}) \)

• high-field fast ramping magnets for cost reduction
• normal conducting option
• should explore superferric/superconducting option
• need efficient energy recovery of magnetic energy
Example: Losses, Shielding, Cooling

Collider ring is worst place
400 W/m electrons/positrons from muon decay
30 W/m in accelerator ring

MAP design N. Mokhov et al.:
Tungsten shielding of 50/30 mm on each side
Dipole aperture 150 mm

Or consider open midplane dipole design?

- Collider ring shielding
- Experiment shielding
- Neutrino radiation calculation
- Exploration of accelerator shielding

- Magnet cooling
- Shielding cooling
Example: Neutrino Radiation Mitigation

Radiation from arcs is known problem at 14 TeV with no mitigation

Need simple model, lattice design, civil engineering, mitigation technologies

“Wiggling” the beam requires $O(14 \text{ mm})$ for a small factor i.e. 100 RMS beam sizes (assuming 100m betafunction)

Maybe consider “less conservative” solutions
Moving beam and beamline $O(100 \text{ mm})$ to reduce radiation by factor $O(100)$???
Fields of Expertise

- Physics Motivation
- Experiment and Physics Simulation
- Detector Design and R&D
- Machine Detector Interface
- High-energy Collider Design
- Proton-based Muon Source
- Positron-based Muon Source
- Magnets
- Radio Frequency Technology
- Radiation, Shielding, Losses, Targets, Collimation, Materials
- Other Technologies
  - cooling, vacuum, instrumentation, machine protection and more
- Civil engineering and Infrastructure
- Synergies with other projects