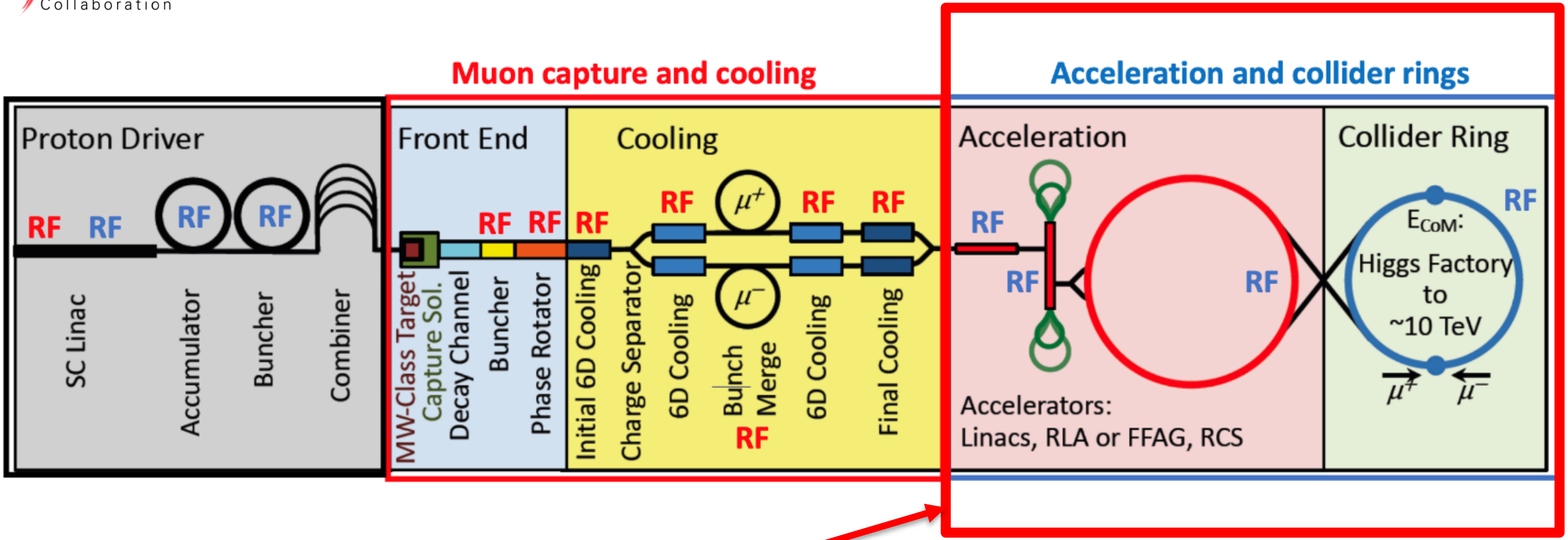
International
MUON Collider
Collaboration

Summary of High-energy Complex

by Antoine CHANCE (CEA)
On behalf of HEC WG
Friday 21 May 2021

Scope of the HEC WG



Objective of this WG

Courtesy of A. Grudiev et al.

Programme HEC 20/05/2021

(https://indico.cern.ch/event/1030726/timetable/#all.detailed)

- Joined session with magnet people in HEC room 20/05/2021 14:00
  - Overview of magnet needs for a vFFA for a skew collider ring (Shinji Machida, STFC/RAL)
  - Overview of magnet needs for a RCS (J. Scott Berg, BNL)
  - Overview of magnet needs for a muon collider (Christian Carli, CERN)
- Joined session with RF and BD in RF room 20/05/2021 16:10
  - Low Energy acceleration: Linac & RLA (Alex Bogacz, JLAB)
  - High Energy acceleration (J. Scott Berg, BNL)
- Joined with MDI and RPOT in MDI room 17:15
  - Neutrino hazard & mitigation (Nikolai Mokhov)
  - Mitigation methods from machine side (Christian Carli)
  - Movers in the arcs (Helene Mainaud Durand)
- Joined with BD in HEC room 18:20
  - Needs in simulation tools for a vFFA (Jean-Baptiste Lagrange, STFC)

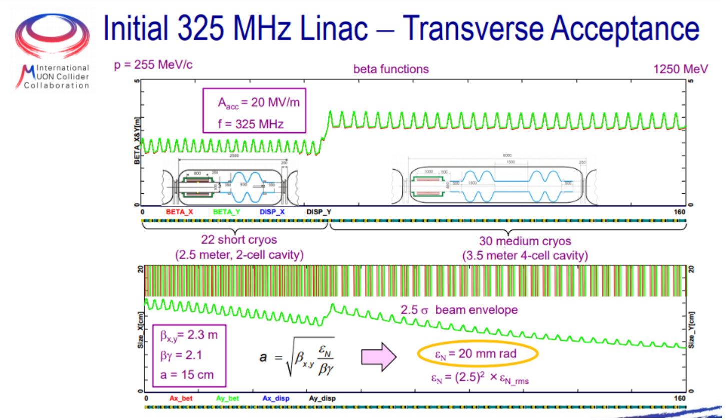
Programme 21/05/2021

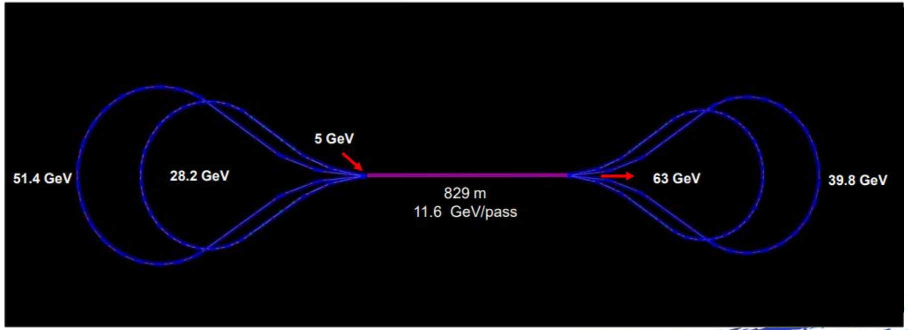
(https://indico.cern.ch/event/1030726/timetable/#all.detailed)

- Session HEC 09h30 in HEC room
  - Lattice design for the collider and critical aspects (Christian Carli, CERN)
  - Exotic option for the HE complex: vFFA and collider lattice with skew QPs (Shinji Machida, STFC/RAL)
  - Preparation of the HEC summary + R&D list

Low energy acceleration
Status: Linac + RLA

- Included in the MAP design.
- **Mature design exists for the Linac + RLA**. Needs for smaller RF frequency in the linac because of longer pulse (compression during acceleration)
- Next step: optimization of the design (injection energy into the RCS).
- Coherent design: 5 passes using Tesla technology. May push to 7 passes.





R&D for the linac + RLA
RF cavities

- Why is it important? This is the key component to accelerate the muons as fast and efficiently as possible.
- What are the key issues? Beam loading, wakefields.high-gradients
- What do we need before next ESPPU:
  - What others will do: development of SRF cavity technology and cavity/coupler efficiency
  - What we need to do:
    - To optimize the design (optimum injection energy into the RCS/vFFA for the operating cost).
    - Deep study of the longitudinal and transverse beam loading and coherent wake field effects, BBU, and so on.
- Which resources are needed
  - RF people to evaluate, optics + beam dynamics experts

Rapid Cycling Synchrotron

- Included in MAP studies.
- 2 concepts: « conventional » RCS and/or hybrid RCS (alternating dipoles of 1.5 T + fixed SC dipole).

Sample scenario (courtesy: J. Scott Berg)

Injection Energy (GeV)	63	303	750
Extraction Energy (GeV)	303	750	1500
Circumference (m)	5210	5210	9361
Fixed Dipole Length (m)	—	1103	2358
Ramped Dipole Length (m)	4229	3126	5240
Turns	13	25	23
Time (ms)	0.23	0.43	0.72
Cavity Power (kW)	950	950	530

Rapid Cycling Synchrotron

- Included in MAP studies.
- 2 concepts: « conventional » RCS and/or hybrid RCS (alternating dipoles of 1.5 T + fixed SC dipole).
- Several challenges:
  - **Magnets**. Very short cycling time. Needs very stable power converters + high efficiency: can be a cost killer on operating (up to 1 GW peak power to be delivered).
  - **RF**. High peak current. High beam loading.
  - **Beam dynamics**. longitudinal emittance preservation + chromaticity to be corrected?
- Good compromise to be found on the cycling: low decay but high voltage and higher Eddy currents.

Rapid Cycling Synchrotron
Magnets and power supplies

- Why is it important? The shorter the cycling is, the more muons we can keep. High efficiency is of the utmost importance to keep the operating cost at a reasonable level.
- What are the key issues? Efficiency + power supply reproducibility and stability.
- What do we need before next ESPPU:
  - What others will do: development of HTS pulsed magnets, stable and efficient power supplies
  - What we need to do: to complete a parametric model of the RCS including magnet consumption (cycling for instance), to make a lattice design, to check if sextupoles are required, to give a tolerance table on the power supplies and field quality, magnet protection from decay
- Which resources are needed
  - Magnet people to evaluate, optics people (first lattice design)
- RCS is in fact a RC **pulsed** Synchrotron

Rapid Cycling Synchrotron
RF

- Same thing as for the linac + RLA
  - We need high efficiency and high gradient cavities.
  - Beam loading issues.
  - Can benefit from other developments on other machines.

vFFA

- New concept. Not included in MAP studies.
- **Big advantage: fixed field + isochronicity (revolution period undependent on energy).**
- Promising alternative to the RCS, especially at low energy when we are the most demanding in cycling.
- Needs:
  - **Large aperture in the magnets** (100 mm x 700 mm) + special 3D maps ($B \propto \exp(n\,y)$).
  - **Special simulation issues**: orbit finding tools (some codes are already functioning), fully coupled optics, space charge issues (short arcs + long pulses), time-dependant wakefields.
  - **Theoretical developments**
  - **Realistic design/feasibily studies before next ESPPU + timeline**
- **Possible synergy with other projets (short synchrotrons or spallation source).**

vFFA
Demonstration path

- First demonstation with n.c. dipole under studies.
- Possible synergy with ISIS spallation source programme

	1st n.c. prototype	12 MeV proton	1.2 GeV proton	1.5 TeV muon
Aperture (H) x (D)	600 mm x 220 mm	700 mm x 300 mm	700 mm x 300 mm	700 mm x 200 mm
Length	1.0 m	0.5 ~ 1.0 m	2 ~ 3 m	10 ~ 20 m
Max field	~ 0.01 T	~ 3 T	~ 6 T	~ 9 T
Gradient, *m*	1.3 /m	1.3 /m +/- 25%	1.3 /m +/- 25%	6.8 /m
High/low field ratio	2	2	2	~ 30

International UON Collider Collaboration

Collider

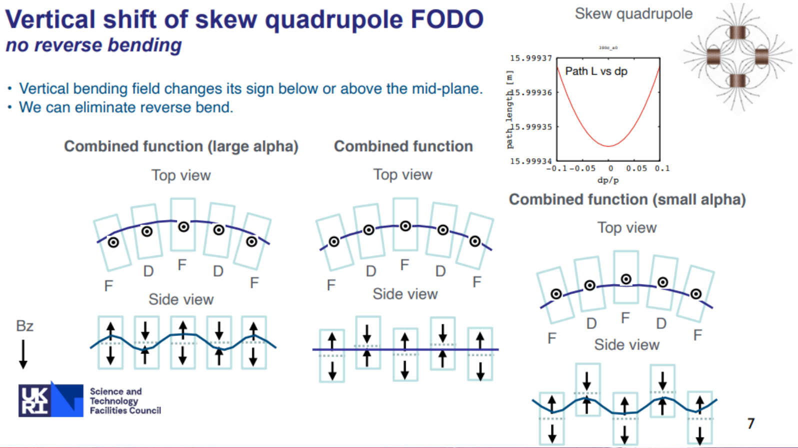
- Consistent lattice exists, from MAP project (3 TeV c.m). On the repository.
- A lot of challenges: neutrino hasard, MDI, magnet protection from decays, global lattice (instrumentation, injection/extraction, absorbers, RF, interaction region, correction systems…).
- New first lattice is ongoing a study (zero momentum compaction, smaller betatron function) in a racetrack configuration.
- MDI/radioprotection needs:
  - Inner triplet. Needs large apertures to insert shielding.
  - To absorb the decayed particles in the arcs. Vacuum compatibility. Cryogenics efficiency.
  - Tools to integrate deposited power (FLUKA support + new materials for absorbing)
  - Non linearities, non linear effects of momentum compaction, chromaticty correction (local or global?)

Collider

- To mitigate the neutrino hasard in the arcs :
  - The distance between dipoles (zero dipole field region) should be as short as possible. **Combined function magnets (like MAP) would be a great help**: Higher dipole component + smaller Qpole component. Some design exists with a quadrupole inside a dipole..
  - Open midplane dipoles do not seem to be the solution (Qpole kick near the gap does not help and deflects some decayed particles to the coils).
  - « wobbling » option. Interesting proposal by slowly moving the magnets to modify the emission angles of the neutrino beam. But several challenges: magnet stability, cryogenics, alignment and stability, other components as beam pipes and vacuum components, reproducibility, vertical dispersion
  - Other idea?

Collider
alternative with skew quadrupole

- Alternative proposal for the arcs: using skew quadrupole component.
  - Enable wobbling of the orbit.
- Needs:
  - combined magnets (skew quadrupoles against normal component before)
  - **Realistic design/feasibily studies before next ESPPU + timeline**



Collider
R&D needs

- **Lattice design**:
  - To add multipole errors to give tolerance table for the magnets including power supplies
  - Integrated lattice (with insertions) and beam dynamics studies including collective effects (see BD group)
- **Combined functions magnets:**
  - Should be able to tune independently the different multipole components
  - Needs a scaled prototype.
- **Mechanical wobbling option:**
  - Needs a demonstrator to test the stability and reproducibility.
- Needs **alignment and stability tolerance**
- **Testbench** for full remote alignment system.

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Thank you for attention