The muon collider

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Advantages

- Because of its heavier mass compared with the electron, the muon

couples strongly to the Higgs sector.

- The muon emits almost no synchrotron radiation, which makes possible a circular collider that uses the expensive RF equipment efficiently and can fit on the site of an existing laboratory.
- A muon accelerator could also explore the neutrino sector. The high-energy neutrino beam derived from the decay of stored muons in a ring has well-understood properties, with minimal hadronic uncertainties in the spectrum and flux.
- This channel can be observed with low background, giving the neutrino factory unmatched sensitivity for studies of CP violation, the mass hierarchy, and unitarity in the neutrino sector.

Challenges

- Because muons are created as a tertiary beam, the production rate is low. The production process also results in a beam with very large transverse phase space and energy spread.
- The short muon lifetime is also challenging from an accelerator perspective. All beam manipulations must be very rapid, requiring high-gradient RF cavities that operate in a magnetic field (for the cooling channel), use of the presently untested ionization cooling technique, and a fast acceleration system.
- The decaying muons produce an intense beam of decay electrons in the mid-plane of the collider ring or neutrino factory decay ring. These electrons produce a substantial heat load for the superconducting magnets and potentially create backgrounds in the collider detectors.

Question from Liu Kai

- Oscillations from electron to muon neutrinos give rise to easily detectable “wrong-sign” muons, that is, muons whose sign is opposite to that of the stored muon beam.
- How does this reaction happen ?

Muon Collider Systems

A proton driver that produces the primary beam

A target, capture, and decay region where the pions are created, captured, and decay into muons

A bunching and phase rotation section where the muons are rotated in longitudinal phase space to reduce their energy spread

A cooling section

An acceleration section

A collider ring where the beam is stored

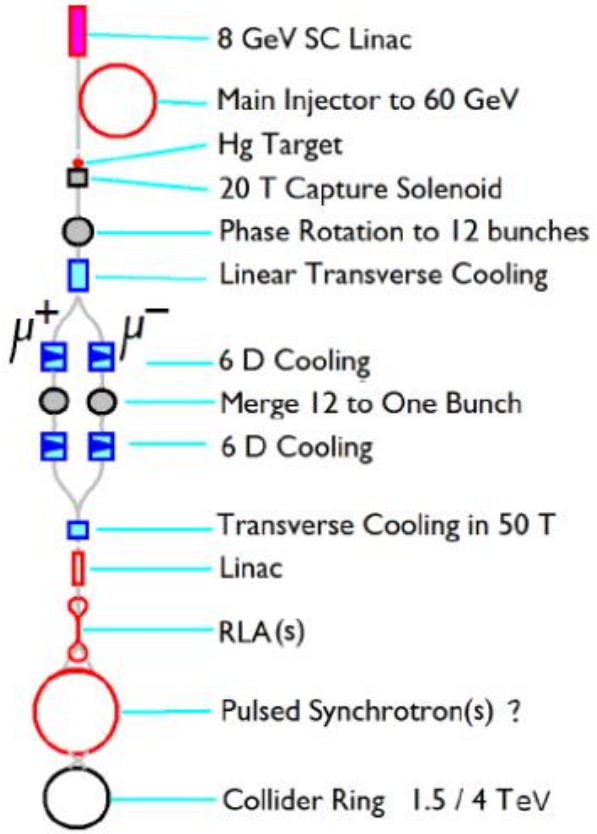


Figure 2. Schematic layout for muon collider.

Subsystems

- The target, capture, and decay channel makes use of a free Hg jet contained within a tapered solenoid field, as shown in fig. 4. At the target, the solenoidal field is 20 T, falling to 1.75 T at the end of the decay channel. The channel captures low energy pions, with kinetic energies between 100 and 300 MeV.

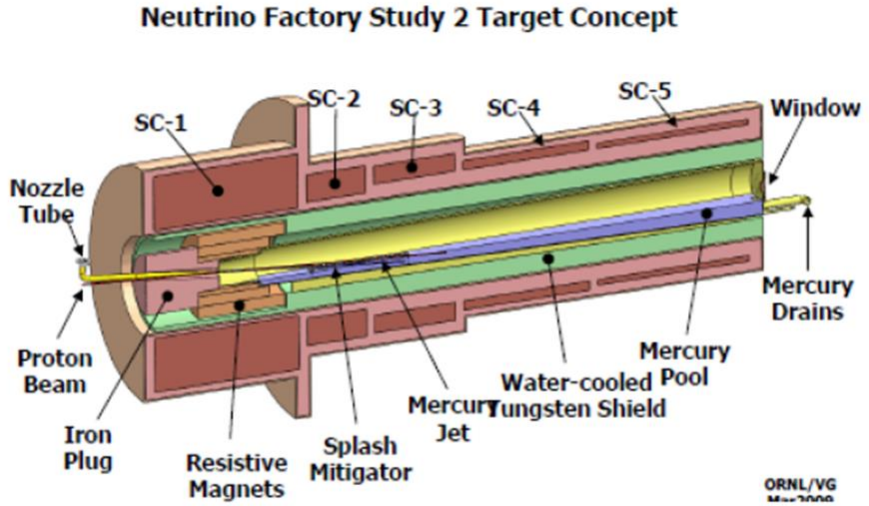


Figure 4. Diagram of target area showing initial portion of field taper.

- Ionization Cooling Section. A number of cooling channel implementations have been investigated during the past 10 years. The current baseline design is the so-called Study 2a channel, illustrated in fig. 6. This channel is able to transmit muons of both signs, interleaved at opposite phases of the RF cavities.

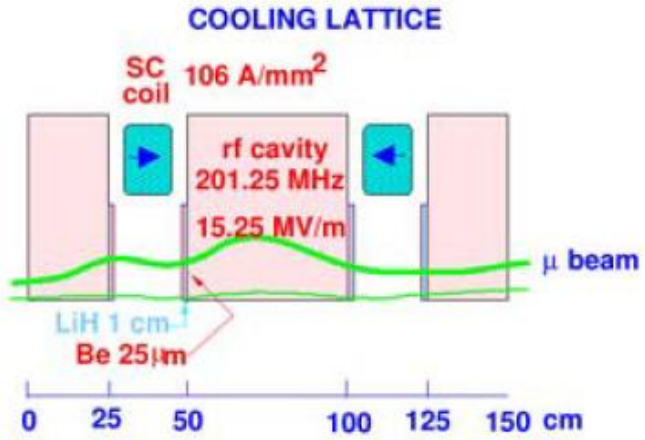
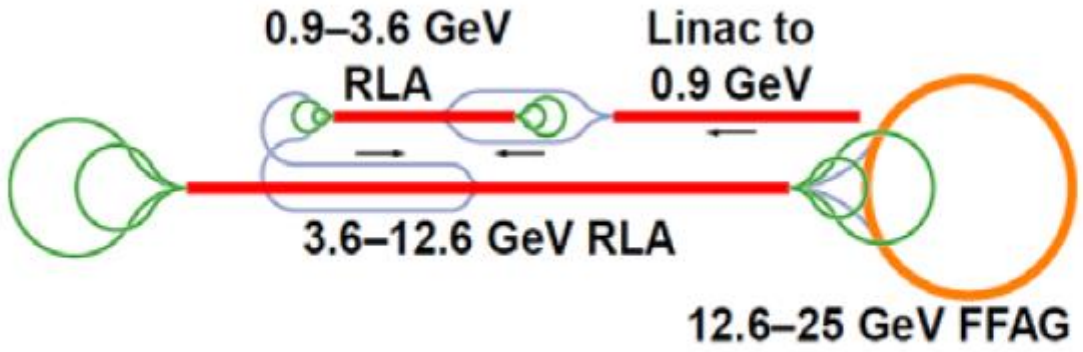


Figure 6. Layout of Study 2a transverse cooling channel.

Question from Ryuta

- What is "6D Cooling" in Figure 2 ?
- Ionization cooling is provided by high pressure hydrogen gas which removes both transverse and longitudinal momentum. Lost longitudinal momentum is replaced using radio frequency (RF) cavities, giving a net transverse emittance reduction. The longer path length in the hydrogen of higher momentum muons decreases longitudinal emittance at the expense of transverse emittance. Thus emittance exchange allows these rings to cool in all six dimensions and not just transversely.

- Acceleration Section. The low energy acceleration section includes a linac followed by a pair of dog-boneshaped recirculating linear accelerators. At higher energies, a different scheme is employed. The baseline design makes use of a pair of rapid cycling synchrotrons. To achieve the fast cycling rate in the lower energy RCS, the magnets must be fabricated from grain-oriented silicon steel. For the higher energy RCS, superconducting magnets are needed, but these cannot cycle rapidly. A hybrid ring has been designed with fixed-field superconducting magnets interleaved with silicon steel magnets in order to maintain an orbit with acceptable excursions.



. Low-energy acceleration system suitable for neutrino factory or muon collider.

- R&D toward a muon collider is making steady progress. The MERIT experiment has been completed and MICE is well under way, with all components in production. The muon collider design is also progressing well, with a promising lattice and all of the main subsystems simulated at least partially. Finalizing the system matching details and end-to-end simulations remain to be done. Development of muon based accelerator facilities offers great scientific promise and is a worthy—and challenging—goal to pursue.

THANKS