Muon Acceleration for a $\sqrt{s} = 10$ TeV $\mu^+\mu^-$ Collider

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A single pass linac with 650 MHz superconducting RF (SRF) is used to accelerate muons to 1.95 GeV. High-gradient normal conducting RF cavities at these frequencies require extremely high peak-power RF sources. Hence SRF cavities are preferred. The 650 MHz SRF linac is configured using 25 MV/m RF cavities with a 7.5 cm aperture radius. The initial phase-space of the beam, as delivered by the muon front-end, is characterized by significant energy spread; the linac has been designed so that it first confines the muon bunches in longitudinal phase-space, then adiabatically superimposes acceleration over the confinement motion, and finally boosts the confined bunches to 1.95 GeV. In the initial part of the linac, when the beam is still not relativistic, the far-off-crest acceleration induces rapid synchrotron motion (1.5 periods along the linac), which allows bunch 'head' and 'tail' to switch places within the RF bucket three times during the course of acceleration. This process[1] is essential for averaging energy spread within the bunch, which ultimately yields desired bunch compression in both bunch-length and momentum spread. The large acceptance of the linac requires large apertures and tight focusing. This, combined with moderate beam energies, favors solenoidal rather than quadrupole focusing for the entire linac [2].

The linac is followed by a Recirculating Linear Accelerator (RLA) configured with 2.9 GeV/pass, 650 MHz superconducting linac based on quadrupole focusing, completed with four 'droplet' arcs, where the beam reaches 15 GeV in 4.5 recirculation passes. This configuration is illustrated in Fig. 1. The arcs use 1.6 T dipoles. The configuration was chosen so that a tolerable level of RF phase slippage along the multi-pass linac, with RF cavities phased for the speed-of-light particle, could be maintained (∼20 degrees in RF phase).

The main thrust of the multi-pass RLA is its very efficient usage of the expensive superconducting linac. The 'dogbone' topology further boosts the efficiency of linac usage (close to a factor of 2 higher than a corresponding racetrack RLA), because the beam is being accelerated while traversing the linac in both directions. Finally, the 'dogbone' topology is inherently suited for simultaneous acceleration of both μ^+ and μ^- charge species; they follow the same direction through the linac, while moving in opposite directions through the 'droplet' arcs. RLA acceleration from 1.95 GeV to 15 GeV further compresses and shapes the longitudinal and transverse phase-space [3]. The beam is injected from the single-pass linac via a double chicane [4]. The

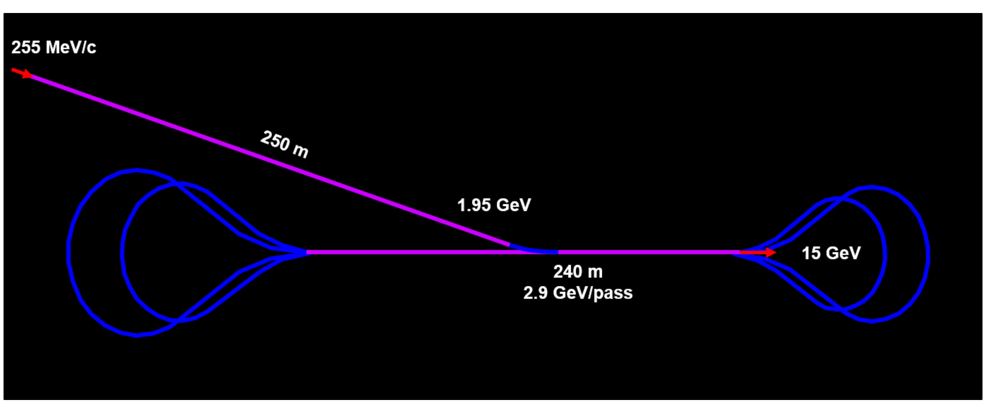

Figure 1: Linac plus 4.5 pass dogbone acceleration to 15 GeV.

injection point into the 'dogbone' RLA coincides with the middle of the multi-pass linac to minimize the effect of initial phase slippage.

The quadrupole focusing profile along the RLA linac was chosen so that beams traversing linac in both directions could be effectively confined in the transverse dimensions. Here, the quadrupole gradients scale up with momentum to maintain 90^0 phase advance per cell for the first half of the linac and then they are mirror reflected in the second half; so called 'bisected' linac optics. The virtue of the optics for higher passes is the appearance of distinct nodes in the beta beat-wave at the ends of each pass (where the arcs begin), which limits growth of initial betas at the beginning of subsequent droplet arcs, hence it eases linac-to-arc matching.

Muons are accelerated from 15 GeV to 5 TeV using fast ramping synchrotron rings.

In the muon collider collaboration initially green field sites will be considered and reuse of existing sites will come once the designs are mature enough. However, to give an appreciation of the tunnel sizes, one could consider accelerating the beam in the ISR(63 GeV), SpS(1.2 TeV), and LHC(5 TeV) tunnels at CERN. Sixteen Tesla Nb_3Sn fixed superconducting dipoles are interleaved with ± 1.8 T fast ramping dipoles to give a wide magnetic field range. A small ± 1.8 T dipole has been constructed and run at 1410 Hz [5]. A total of 50 GV of superconducting RF is required. Overall muon survival during acceleration is 60%. A $\sqrt{s} = 8$ TeV collider ring using 16T dipoles would fit in the SpS tunnel with a dipole packing fraction of 76%. Neutrino radiation considerations will be an important factor in evaluating if these scenarios would actually be possible.

To expand beyond the current goals of the muon collider collaboration, one could consider a scenario, where the FCC tunnel would be built. In this case muon acceleration to 25 TeV may be possible in this tunnel. The muon lifetime at 25 TeV is 0.52 seconds and the longitudinal synchrotron damping time in the LHC tunnel is 0.19 seconds. Trickle charge injection for improved luminosity is being explored. Further studies could also explore whether muon acceleration using very high gradient plasma wakefield accelerators could improve the performance of a muon collider.

References

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