A Proton-Based Muon Source for a Collider at CERN

Muon Collider Collaboration

1 Introduction

Authors:I would prefer individual author signatures I think - good to collect list of people directly interested in this effort

TODO: references, proof read for english, collect signatures

The muon collider collaboration was formed following the European Strategy update recommendation to invest in research for muon colliders. The collaboration is investigating two options for producing muons at CERN; either by firing protons onto a target to produce pions and other mesons, which decay into muons; or to fire high energy positrons onto a target near to the threshold for muon pair production. In this document we discuss plans for the proton-based source.

2 Proton Source

TODO: Need help here...

3 MAP Muon Source

Too long... would more on target, less on cooling, be useful? The muon collider collaboration plans to adopt the proton source concept that was developed by the US Department of Energy funded Muon Accelerator Programme (MAP). The proton-based muon source is described below.

Pions, muons and other particles are produced by firing protons onto a liquid mercury target. The target is contained in a 20 T magnet which serves both to confine the mercury jet and to confine the resultant secondary particles. The field is tapered to a 1.5 T constant solenoid field.

High momentum impurities are removed from the beam by means of a chicane. The chicane is created using a bent solenoid field, which introduces vertical dispersion. High momentum particles get proportionately more dispersion and are removed on scrapers. A reverse bend returns the surviving particles with remarkably little emittance growth despite the large transverse emittance and huge momentum spread.

Low momentum protons are removed by a thick Beryllium window. The window is designed to remove protons while leaving the muon beam relatively unperturbed, as low momentum protons lose much more energy than muons and electrons. The window marks the end of the active handling area.

Muons are first captured longitudinally. The muon beam contains all momenta up to the limit of the chicane. Fast muons migrate to the front of the bunch while slow muons migrate to the end of the bunch. RF cavities are placed successively with gradually increasing voltage to adiabatically introduce microbunches into the beam. Frequency of successive cavities is selected to match the increasing time spread in the beam. Once the microbunches are established, further RF cavities are placed that are dephased such that the earlier, faster bunches experience a decelerating gradient and the later, slower bunches experience an accelerating gradient. This is repeated until the energy of the later bunches matches the energy of the earlier bunches.

An initial ionization cooling channel, capable of cooling both muon charges, reduces the 6D emittance of the muon beam. In this scheme, the transverse field is alternated so that the beam passes through focusses. Dipole fields introduce dispersion, with oppositely charged muons having opposite dispersion. By carefully selecting position and size of wedge-shaped absorbers, the beam is cooled in all six dimensions.

The beam is separated into positive and negative beams by means of another solenoid chicane. Positive muons take an opposite dispersion to negative muons.

A series of combined dipole and solenoids with wedges cools the beam in 6D. Because the charge is separated, more dispersion and tighter focussing can be introduced with consequently more cooling.

21 microbunches are merged longitudinally into 7 microbunches by means of a phase rotation scheme using slightly dephased RF cavities. The bunch at the front of each set of 3 bunches undergoes a lower accelerating gradient and is slowed, while the bunch at the back experiences a higher accelerating gradient and is accelerated.

7 microbunches are merged transversely into 1 bunch by means of a series of transfer lines. Each microbunch is kicked transversely into a different transfer line, introducing a different time delay so that the microbunches emerge from the transfer lines synchronously. The microbunches are brought together and stacked transversely into one bunch.

The beam then goes through another solenoid-dipole 6D cooling channel to further reduce its emittance.

A sequence of high field solenoids is used to introduce tight focussing to further reduce the transverse emittance. In order to reach very low emittances cooling is performed at low momentum. At these momenta muons with lower energy tend to collide more readily with atomic electrons and lose more energy, resulting in longitudinal emittance growth. In order to maintain a small momentum spread in the beam and suppress chromatic aberrations, RF frequencies as low as 20 MHz are used.

4 Acceleration

The MAP scheme proposed acceleration to 5-10 GeV using a linac, followed by a linac with multiple dogbone arcs to recirculate the muon beam for reuse of the accelerating equipment for acceleration to higher energies (so-called ‘dogbone RLA’). This scheme was optimal for acceleration of a higher emittance neutrino factory beam and later upgrade to a muon collider. It may be fruitful to re-examine the optimisation in the light of the lower emittances required for a muon collider.

Further acceleration will be designed suitable for both the LEMMA source and the proton-based source; the proton-based source, being higher emittance and higher current, is likely to be more challenging.

5 Plans

The muon collider collaboration will continue to investigate the issues surrounding the muon source.

Technical risk in the target area may be avoided by adopting a solid target scheme. Such schemes have been considered previously, for example for the neutrino factory. The high instantaneous beam power makes solid targets challenging. Rotating targets, fluidised powder targets and similar concepts may all be considered.

The final cooling is a priority, where further design work is required to meet the baseline cooling performance. Improvements to the cooling lattice will be considered, along with novel ideas such as parametric ionisation cooling or emittance exchange schemes.

The collaboration will seek improvements to the initial acceleration scheme, for example optimising for lower emittances suitable in a muon collider.