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Muon Storage Ring Neutrino Source: The Path to a Muon Collider ?

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Abstract

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14.60.Pq, 13.15.+g, 13.35.Bv, 07.77Ka

1 Introduction

Recent results from atmospheric neutrino, solar neutrino, and short–baseline accelerator neutrino experiments indicate that neutrino oscillations may occur at rates that are within reach of the next generation of accelerator based experiments. If this is the case, we can anticipate a new generation of neutrino experiments designed to precisely measure the oscillation parameters, determine neutrino masses and mixing angles, establish how many neutrino types are involved in the oscillations, and search for CP violation within the neutrino system. This experimental program would benefit from higher intensity neutrino beams than currently available. It has been pointed out [1] that a new type of intense neutrino source could be constructed by exploiting the very intense muon beams needed for a high–luminosity muon collider [2]. Taking as an example the accelerator scenario and beam parameters being considered in ongoing muon collider feasibility studies [3], and assuming all of the muons from a muon collider muon source are accelerated and injected into a storage ring containing long straight sections [4] pointing in the desired direction, neutrino beams containing O(10^{20}) neutrinos and antineutrinos per year seem possible [1].

In this paper we explore the idea that a muon storage ring neutrino source could be constructed as a step towards developing the first muon collider. In particular, a muon production, cooling, acceleration, and storage ring scenario is described, and the physics potential of the resulting neutrino beams discussed. The paper is organized as follows. Section 2 describes the muon production scenario being considered in muon collider feasibility studies. A scheme to accelerate a muon beam occupying a large six-dimensional phase-space is discussed in Section 3. The lattice for a muon storage ring neutrino source is described in Section 4. The muon acceleration scheme and the storage ring lattice place requirements on the beam transverse and longitudinal phase–space, and hence on the minimum amount of beam cooling required for a muon storage ring neutrino source. The muon cooling channel requirements are discussed in Section 5. Calculated neutrino fluxes from the neutrino source are presented in Section 6, and the minimal requirements for the accelerator complex feeding the first muon storage ring neutrino source are discussed. Conclusions are summarized in Section 7.

2 Muon production scenario

The muon source that has been considered in muon collider feasibility studies [2] consists of a proton accelerator, charged pion production target and collection system, pion decay channel, and muon cooling channel. In the muon collider front-end design that we are taking as an example [3], the muon source receives protons from an accelerator complex [5] that accelerates bunches containing 5×10^{13} particles to energies of 16 GeV. The protons interact in a target to produce approximately 3×10^{13} charged pions of each sign per proton bunch. These pions are produced with only a very limited component of momentum transverse to the incident proton direction. The charged pions can therefore be confined within a beam channel using, for example, a 20 Tesla co-axial solenoid with an inner radius of 7.5 cm. To collect as many pions as possible within a useful energy interval, it is proposed to use rf cavities to accelerate the lower energy particles and decelerate the higher energy particles. Muons are produced by allowing the pions to decay. At the end of a 20 m long decay channel, consisting of a 7 Tesla solenoid with a radius of 25 cm, on average 0.2 muons of each charge would be produced for each proton incident on the pion production target. With two proton bunches every accelerator cycle, the first used to make and collect positive muons and the second to make and collect negative muons, there would be about 1×10^{13} muons of each charge available at the end of the decay channel per accelerator cycle. During dedicated muon storage ring neutrino source running, both proton bunches could be used to produce muons of the desired sign, and there would be about 2×10^{13} muons available at the end of the decay channel per accelerator cycle. If the proton accelerator is cycling at 15 Hz, in an operational year (10^7 secs) about 3×10^{21} muons would have been produced in the decay channel and collected. The muons exiting the decay channel populate a very diffuse phase space. The next step is to "cool" the muon bunch, i.e. to turn the diffuse muon cloud into a very bright bunch with small dimensions in six-dimensional phase-space, suitable for accelerating and injecting into a muon storage ring. The proposed method of cooling the muons is to use ionization cooling [6]. At the end of the ionization cooling channel each muon bunch is expected to contain about 5×10^{12} muons with a momentum of order 100 MeV/c. We will assume that the losses in accelerating the muons to modest energies (up to a few $\times$ 10 GeV or less) are small, and therefore that O(10^{21}) muons of the desired charge are injected into the storage ring each operational year.

3 Acceleration

Dave Neuffer will draft this section

4 Storage ring

Bruno will draft this section

5 Muon cooling requirements

Steve + Dave will construct this section

6 The first muon storage ring neutrino source and neutrino fluxes

Steve will write this

7 Summary

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Figure captions

Fig. 1: bla