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Using high-pressure gas in the front end of a muon source

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High-gradient, pressurized RF cavities are investigated as a means to improve the performance of low-frequency phase-rotation schemes for neutrino factories and muon colliders. We consider placing high-gradient, low-frequency, pressured RF cavities close to the pion production target to facilitate early phase rotation and capture of the pion-muon beam. We also consider the transverse cooling effects that the high-pressure gas has on the beam.

1. INTRODUCTION

Conventional sources for intense muon beams involve pion production from proton interactions within a target. The resulting muon beams require phase rotation to achieve the desired flux of muons into the momentum acceptance of realistic downstream devices, such as an ionization cooling channel [1].

The current techniques for phase rotation [2,3] are limited by the applicable gradient of the RF cavities. High-pressure, gas-filled RF cavities may provide a possible means of overcoming these limits [4], which then may make low-frequency, high-gradient phase rotation possible. The gas may even act as an absorber for ionization cooling. We explore the possibility of designing a low-frequency phase rotation scheme using high-pressure, gas-filled RF cavities.

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2. PION PRODUCTION & CAPTURE

The initial beam has been generated using MARS [5]. We simulated a 1 MW, 25 GeV, 1 ns proton pulse incident on a carbon rod target. The target is 80 cm long and 1.5 cm in diameter, tilted at an angle of 100 mrad with respect to the central axis of the channel in order to reduce pion recapture in the target. Aligned with the central axis of the channel is a 20 T capture solenoid spanning the length of the target. A tapered solenoid follows to adiabatically reduce the field to 5 T over 15 m, simultaneously increasing the aperture from 15 cm to 30 cm. Such a target region, and the pion beam produced in such a region, has been discussed in great detail in the first and second Neutrino Factory feasibility studies [1,6].

3. PHASE ROTATION & COOLING

The lattice following the taper consists of 10-cm long solenoids spaced by 15 cm gaps. The mean field is approximately uniform at 5 T. Gas-

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filled, 100 atm RF cavities with 10-cm long active lengths are placed in the gaps. The first 80 cavities (20 m) are 25 MHz, 25 MV/m, zero synchronous phase cavities meant to phase rotate the beam. The next 120 cavities (30 m) are 400 MHz, 30 MV/m, 6.3° synchronous phase cavities meant to adiabatically capture the beam into higher frequency. This lattice was simulated in G4Beamline, a beamline simulation program based on the GEANT4 Toolkit [7].

We attempt to achieve a beam that can be injected into a helical cooling channel (HCC) with an aperture of 30 cm and momentum acceptance of ±25%, similar to those simulated by Muons, Inc. [8,9]. Thus, we examine the ability of the 20 m phase rotation channel to rotate positively charged pions and muons into the 250-420 MeV/c momentum band acceptance of the HCC.

Figure 1 shows the transmission of positively charged muons in the 250-420 MeV/c acceptable momentum band at various distances downstream from the 15 m tapered solenoid. For comparison, we show the transmission for the same beam in a normal decay channel without gas-filled RF (only 5 T solenoids). The muon yield of 0.24 μ^+ / proton-on-target (POT) is similar to that found in recent neutrino factory studies [10] assuming a similar carbon target.

The transverse emittance of the positive muons has been calculated down the 80 m channel using ECALC9, a tool developed for muon ionization cooling simulations and a part of the ICOOL simulation package [11]. At the end of the channel, the transverse emittance with (without) the gas-filled RF is 13.6 mm-rad (16.5 mm-rad), demonstrating an 18% cooling effect in the transverse plane when gas-filled RF is used.

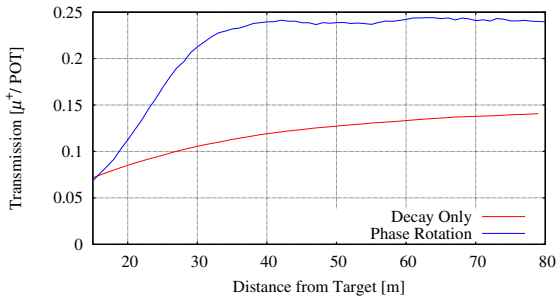

Figure 1. Transmission of positive muons in the 250-420 MeV/c momentum range from 15 m to 80 m downstream from the target. The blue curve shows the transmission with phase rotation and matching into 400 MHz RF. The red curve shows the transmission of a similar beam without RF.

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