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MUON PHASE ROTATION AND COOLING: SIMULATION WORK AT CERN

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Abstract

We present simulation work performed at CERN and collaborating institutes concerning the muon front-end of a neutrino factory and a possible muon cooling experiment. The front-end in the CERN scheme of a neutrino factory has been revised, eliminating the 44 MHz cavities and starting directly with 88 MHz. Two options for a muon cooling experiment have been studied, one based on the 88 MHz CERN cooling channel, one based on the 200 MHz super FOFO channel of the US study II design. A figure of merit for the cooling efficiency is discussed.

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1. Introduction

The front-end of the CERN scheme for a neutrino factory, which was based on using both 44 MHz and 88 MHz cavities, has now been re-designed with the goal of eliminating the 44 MHz cavities. The main part of this paper will be dedicated to the new front-end. Furthermore, we present simulations of a muon cooling experiment.

2. New 88 MHz Front-End

The CERN reference scenario [1] used 44 MHz cavities to perform the phase rotation and the first stage of cooling. The cavities were assumed to provide an average gradient of 2 MV/m and had a 2 T solenoid housed around the beam pipe [2]. For 4 MW beam power on target, the reference scenario could provide some 10^{21} muons/year in the recirculator acceptance. The engineering study for the cooling experiment revealed that a 4 T average field was within the reach of a superconducting solenoid with the required dimensions to fit around a 88 MHz cavity [2]. This triggered a review of the whole front-end. In particular the goal was to design a system with the same efficiency (10^{21} muons in the recirculator acceptance) but without using the bulky 44 MHz cavities. The bottleneck of the longitudinal acceptance is the high rf frequency of the recirculator: the 200 MHz recirculator of the CERN reference scenario offers an acceptance of the order of 0.1 eV s and as longitudinal cooling is not foreseen at this stage, the number of particles that can be potentially accepted must already lie within this acceptance before transverse cooling. Several competing factors came into the trade-off between starting with either a 44 MHz or a 88 MHz system. A 44 MHz system allows for a more efficient RF gymnastics to concentrate particles from the target into the wanted acceptance. A 44 MHz system is also effective at a distance of 30 meters from the target where most of the pions have decayed into muons, thus allowing operation at a very modest gradient. On the other hand, an 88 MHz system, placed closer to the target (about 15 meters) mitigates the semi-relativistic effects which spoil the longitudinal emittance. Also, due to the higher gradient (4 MV/m), fewer cavities are needed. Assuming that it is possible to produce a number of 88 MHz cavities with 40 cm aperture, a system employing only 88 MHz has been proved to perform as well as the CERN reference scenario. The phase rotation is performed by 8 RF cavities and the fundamental cooling cell consists of 6 cavities, half a meter of hydrogen and a half meter long matching solenoid. The parameters are reported in Table 1.

	decay	rotation	cooling	acceleration I	acceleration II
length [m]	15	8	90	≈10	≈450
aperture [cm]	40	40	40	30	20
B-field [T]	4	4	4	4	quadrupoles
frequency [MHz]		88	88	88	88-200
gradient [MV/m]		4	4	4	4-10
E_{kin} [MeV]		200	200	300	2000

Table 1. Parameters of the 88 MHz front-end.

3. Cooling Experiment Simulations

We have studied in detail a Muon Cooling Experiment based on the 88 MHz CERN cooling channel. The simulations have been performed using field maps obtained from an engineering design of the solenoids and cavities. The detailed set-up and beam dynamics of this channel are discussed in [3]. For nominal settings and input beam parameters, the transmission is 100% and the transverse emittance at the exit of the cooling channel is reduced by about 3.7% per plane. As an alternative to the experiment based on 88 MHz cavities, a set-up using the 200 MHz cavities from the US study II [4] was also simulated [5]. This cooling experiment is based on a total of 4 pillbox cavities at 200 MHz with absorbers at the entry and exit as in the case of the 88 MHz set-up. The main difference is the arrangement of the magnetic coils: at 200 MHz, they cannot be integrated in the cavity but must be outside the cavities at a large radius. This drastically changes the beam dynamics of the system, as there is much stronger inter-plane coupling than in the case of the 88 MHz system. However, the overall cooling efficiency of both systems is comparable. In order to diagnose the cooling efficiency in the presence of coupling, an algorithm was developed to measure 4D and 6D cooling rather than the 2D projections. The orientation of the hyper-ellipsoid is adapted to the rms muon distribution. Figure 1 shows the number of muons inside a normalized 4D volume of $(0.015\ \pi\text{m rad})^2$ along the z-position of the cooling experiment. The left plot corresponds to the 88 MHz cooling experiment, the right plot to the 200 MHz scenario. The upper curves are the number of muons in a 4D ellipsoid, the lower ones in the 2D projections.
The beam dynamics simulations reported in this section were performed using the

tracking code PATH. The results of this code were cross-checked and found to be consistent with the code GEANT IV [6].

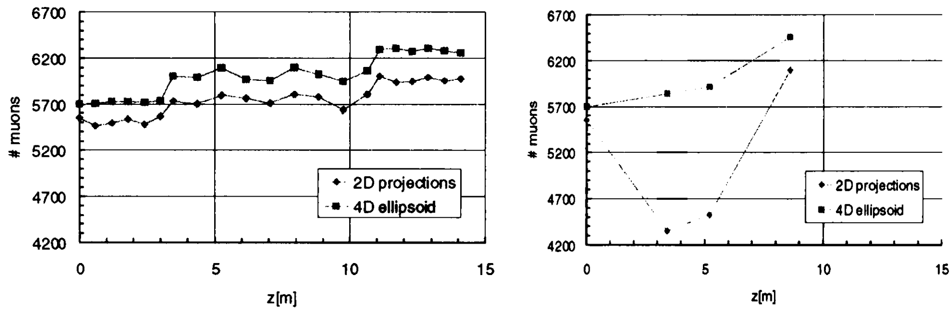

Figure 1. Number of muons along the 88 MHz cooling experiment (left plot) and along the 200 MHz cooling experiment (right plot). The upper curves correspond to a 4D ellipsoid, the lower curves to a 2D ellipsoid.

4. Conclusions

We have successfully designed a new front-end for the CERN neutrino factory scheme using only 88 MHz cavities, which shows the same performance as the previously proposed scheme working at both 44 MHz and 88 MHz. For the cooling experiment, we have completed a study of two options: one based on the 88 MHz CERN cooling channel, the other one based on the 200 MHz US study II super FOFO channel. We find comparable cooling efficiency for both set-ups, even though the beam dynamics (coupling) is very different.

5. References

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