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Muon collection in an alternating gradient channel

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Abstract. The target system of a neutrino factory is more robust when the proton beam is distributed over several targets. The pion beams have then to be merged into a single beam using a "funneling" method. The recombination involves alternating gradient (AG) magnets. The decay channel may be either a single long solenoid or an AG line. The two schemes are compared.

1. Introduction

The very first problems to be solved in a neutrino factory concern the robustness of a target submitted to a multi-MW beam and the lifetime of the pion collector. A system of solid stationary target [1] fully integrated into a magnetic horn has been proposed at this workshop and is assumed to be the pion source in the present paper. The lifetime of a 300 kA magnetic horn working at a 50 Hz repetition frequency is estimated to be of the order of six weeks [2]. The lifetime should reach one year to ensure a high integrated production rate of the neutrinos and the maintenance of the target area at a reasonable cost. Splitting the proton beam into four or more beams paves the way towards a realistic pion production system. Downstream of the source, the pion beams are merged into a single beam using a "funneling" method [3]. The decay channel may be a long solenoid [4] or an alternating gradient beam line. The muon collection in given transverse and longitudinal acceptances is evaluated for the full AG scheme and for a single 30 m long solenoid located after the magnetic horn.

2. Lattice

The alternating gradient structures are well adapted to injection schemes but the optical β value is rather high as compared to the one in a solenoid and must be reduced to its minimum value over the shortest distance. Each channel is made of a horn-target system followed by a doublet which connects the waist at the exit of the horn to a cross-over of the horizontal and vertical β functions at 3 m about from the origin. Then the beam envelope is quickly squeezed into the FODO lattice of the decay channel using a quarter wavelength transformer [5]. Such a transformer consists of a $\pi/2$ phase advance FODO cell with an extra quadrupole at each end to adjust the β and α values at the input of the decay channel. The lattice is calculated in MAD [6] for a global matching of the injection trajectory, the orbit dispersion and the β and α functions (Fig. 1) with the edge effect in the quadrupoles taken into account. The decay channel consists of 14 packed FODO cells. The quadrupole parameters are determined by their aperture: length and spacing are about equal to their radius

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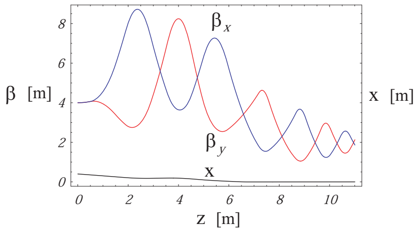

Figure 1. Trajectory and β variations in the funnel.

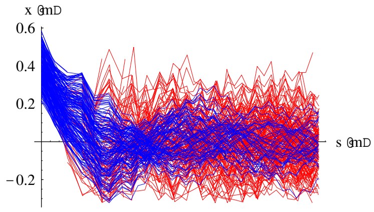

Figure 2. π (dark grey) and μ (light grey) trajectories.

(40 cm). The field on the pole tip is of the order of 1.2 T. The detail design of the magnets is under way assuming a *cos* 2θ and a *cos* θ distribution of the conductors for the quadrupoles and dipoles respectively. They may be pulsed to save energy.

3. Transmission

In contrast with the previous study [4], the transmission is no longer limited to the transverse acceptance of 1 π *cm* which avoids any cooling. Moreover, the longitudinal acceptance is also considered. Ideal distributions have been used to simplify the analysis of the behaviour of pion and muon beams in different systems. The pion beam is uniformly distributed in momentum between 200 and 400 MeV/c. Its transverse emittance at the exit of the horn is 1 π *cm* in agreement with a horn radius of 20 cm and a β value of 4 m. To treat beams with so big emittances and momentum spread, the trajectories are numerically integrated and the pion decay into muons is simulated in ZGOUBI [7]. The pion beam remains well focused all along the decay channel within a radius of 20 cm about. The muons have a roughly triangular spectrum between 105 and 205 MeV/c with a peak at 220 MeV/c. The best muon transmission is actually obtained by tuning the quadrupoles at 220 MeV/c. The trajectories (Fig. 2) are much more distorted than for pions as expected. Particles of low momentum are overfocused and the maximum transverse momentum, of the order of 10 MeV/c for the pions, may reach 40 MeV/c for the muons. A fraction of the muons is thus lost and most of the surviving particles are contained within a radius of 40 cm, hence the aperture chosen for the quadrupoles. The phase portraits of the muons at the output of the decay channel are shown together with 1, 2, 4 and 6 π *cm* acceptance ellipses in Fig. 3. For the solenoid, the horizontal and vertical portraits are the same whereas they are symmetric with respect to the vertical axis for the AG line. The transmission Y in the transverse phase space is the number of particles contained in an acceptance ellipse of given area ϵ_T normalized to the number of pions in an ellipse of 1 π *cm* area at the exit of the horn. It is plotted as a function of ϵ_T in Fig. 4 with the radius of the pipe r_{AG} or r_S as a parameter. Then cuts in the longitudinal space are introduced fpr acceptance ellipses of 0.1, 0.5 and 1 π $eV.s$ (Fig. 5). In Fig. 6, the variations of the transmission are given by pairs of curves for each value of ϵ_T; the upper and lower curves correspond to the solenoid and to the AG line respectively. Only FFAG's have a longitudinal acceptance higher than 1π $eV.s$; for the other systems, longitudinal cooling would improve the muon intensity.

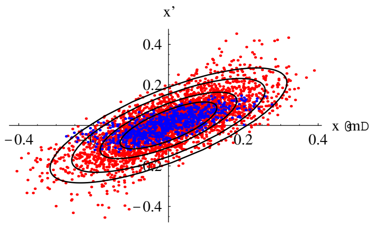

Figure 3. Horizontal portrait at the end of AG line.

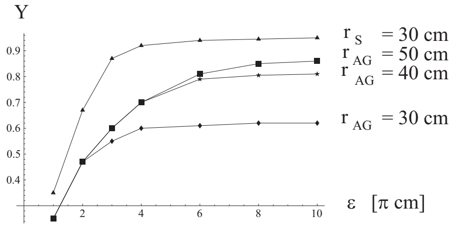

Figure 4. Transmission versus transverse acceptance.

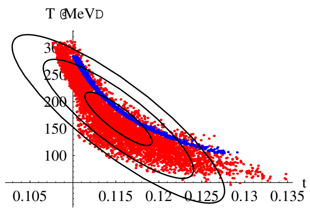

Figure 5. Longitudinal portrait at the end of AG line.

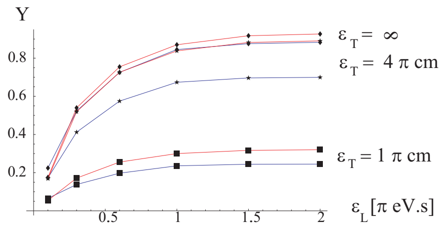

Figure 6. Transmission versus longitudinal acceptance.

Table 1. Acceptances and transmissions.

Scheme	Cooling	ϵ_T $[\pi\ cm]$	ϵ_L $[\pi\ eV.s]$	Y $[\mu/\pi]$
Single target and solenoid	No	1	1	0.3
Single target and solenoid	Yes	4	1	0.84
Multiple targets and AG channel	No	1	1	0.24
Multiple targets and AG channel	Yes	6	1	0.77

4. Conclusion

The properties of a muon beam at the exit of two different decay channels have been compared using a simplified pion distribution at the input. The results are summarized in Table 1. The multiple target system associated with AG beam line has a sufficiently good transmission to be considered, at least presently, as the best scheme for the highest beam powers and development work can start immediately.

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