A NEW PION COLLECTION SYSTEM FOR THE CERN NEUTRINO FACTORY

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Abstract

A new pion collection system has been proposed for the CERN neutrino factory. It consists of an AG channel which matches several horns, with one target per horn, to a solenoid decay channel. The effect of pion decay in this channel has been investigated by means of a ray-tracing code which includes Monte Carlo simulation of pion decay into muons. The method is used in particular for investigating in detail pion and muon acceptances accounting for the strong fringe fields of the short, large aperture optical elements, and for computing muon losses due to this collection system inside a global normalised acceptance of 0.03 m.

1 INTRODUCTION

A new pion collection system has been proposed for the CERN neutrino factory [1]. It features an ensemble of four horns placed close to each other and an alternating gradient matching section which delivers the four beams into the pion decay channel.

Replacing a single target-collector system by n identical systems divides both power and repetition rate per system by n. In our case the horn repetition rate becomes 12.5 Hz, which alleviates considerably the mechanical strain on the horn. The power per target becomes 1 MW, which becomes feasible according to studies on spallation sources [2]. Bending the pion beam has also the advantage of preventing the protons and neutrons outgoing from the target to propagate along the muon line. This might help to solve the beam dump problem which is not yet done satisfactorily for the present project with the 4 MW single target [3].

Thus, if this new system does not lead to unacceptable pion losses, it would make the project go from “challenging” to realistic. This is why the loss problem is addressed in this paper.

The funneling section is shortly described first. All details concerning its optics properties can be found in ref [1]. Then its efficiency is defined in a way somewhat different from that used in [3] so that the funneling and single channel systems can be compared more simply.

2 FUNNELING SECTION

The four pion beams are steered and focused in the same channel. As two beams lie in the horizontal plane and the other two in the vertical plane, the quadrupoles are pulsed to be alternatively focusing and defocusing at half the repetition frequency f of the proton driver. The horizontal dipoles are pulsed at f/4; the vertical dipoles are also pulsed at f/4 but phase shifted by 90 degrees with respect to the horizontal dipoles. The lattice matches a waist at the exit from the horn to another waist at the input of the solenoid of the decay channel in which the four beams are aligned on the axis of the solenoid. The betatron matching is performed with an anti-symmetric quadruplet made of two doublets as described in reference [4]. For orbit and orbit dispersion matching, four quantities have to be cancelled at the entrance to the solenoid: the orbit position and dispersion and their longitudinal derivatives. The four variables to be determined are the strengths of the two dipoles, the angle of the trajectory at the exit from the horn and the spacing between the doublets. The position of the orbit at the exit from the horn is fixed by the geometry of the four horns. The matching [5] is exact only for a reference momentum of 250 MeV/c (fig. 1). The horn radius is 20 cm. The quadrupoles have a 0.4 m radius and a 1.3 T/m gradient and the dipoles a 0.5 T field. All the emittances quoted in the paper are mormalized to 250 MeV/c The lattice can accept a pion beam of 0.03 π m emittance and a momentum range of 200-400 MeV/c.

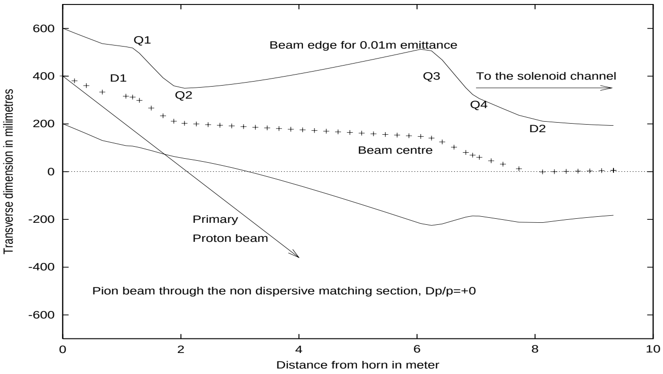

Figure 1: Pion beam in the horizontal plane of the composite decay channel. The horn centre is 400 mm far from the quadrupole axis. The labels D and Q show the location of dipoles and quadrupoles respectively.

3 DECAY CHANNEL WITH A FOUR TARGET SOURCE

The passage of a decaying pion beam has been simulated using Zgoubi [6]. This programs performs a numerical integration of the trajectories including the decay of the magnetic field at the ends of the magnets. It has shown that the geometric aberrations of the funneling section are less important than its chromatic aberrations. The pion decay is included and makes it possible to generate a realistic muon beam. This feature has been tested for the spectrometer SPES3 and the analysis of a beam delivered by the synchrotron SATURNE [7].

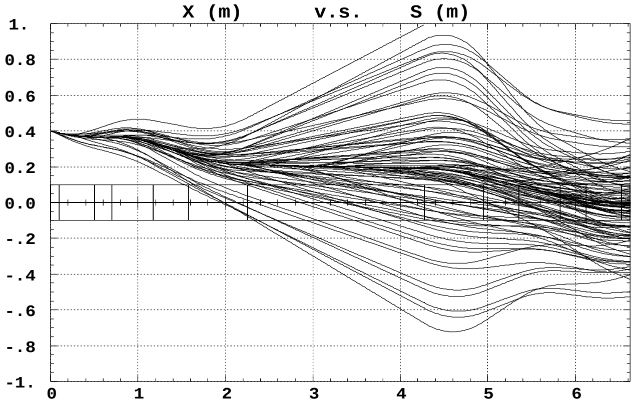

Figure 2: Muon beam originating from a pencil pion beam with no energy spread, in the horizontal plane in the composite decay channel. The horn centre is 400 mm from the quadrupole axis.

The muon emittance build-up due to pion decay in the funneling section is illustrated in figure 2. A beam with a zero emittance and zero energy spread is launched at the beginning of the channel. From the dimension of the beam measured at the exit, the maximum emittance created by the decay looks of the same order of magnitude as the emittance of 0.017 m (figure 3). A substantial muon loss is thus expected.

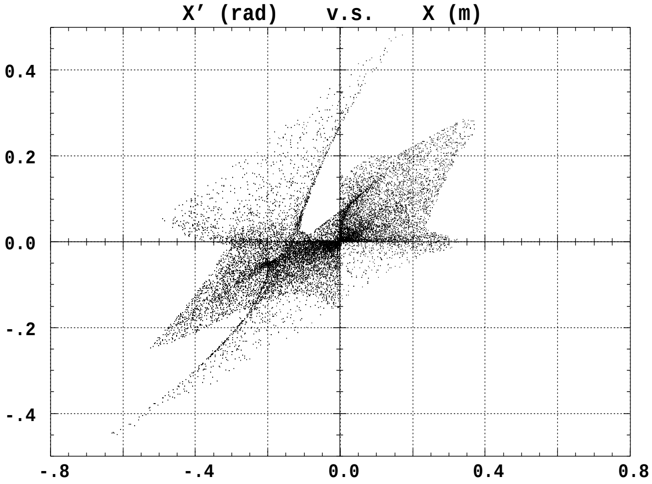

Figure 3: Phase-space plot at the end of the funneling section of the muon beam produced by a pencil pion beam.

The transmission of a beam of 10^4 pions has been simulated for a given emittance, identical in both planes, a central momentum of 250 MeV/c and a uniform momentum spread (-50, +150) MeV/c. The lattice is composed of the funneling section (7 m) and of a 24 m long solenoid. It has been checked that the position of the solenoid with respect to the funneling section is not critical. The effect of the solenoidal field is shown in table 1.

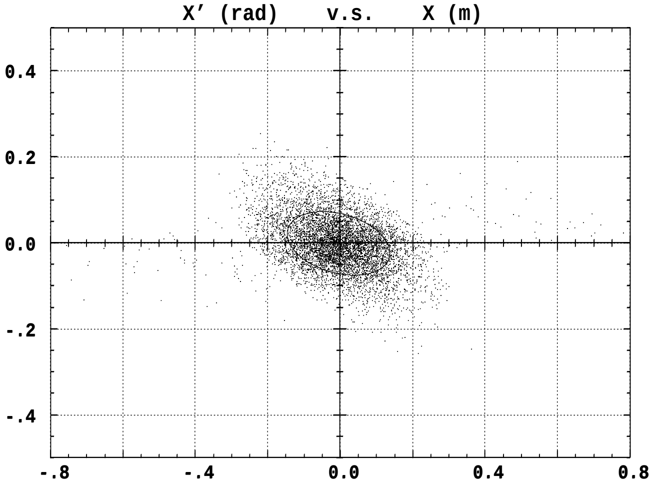

Figure 4: Portrait of the muon+pion beam at the end of the composite decay channel, $\epsilon_{x,z}/\pi = 0.017$, $200 \leq p \leq 400$ MeV/c.

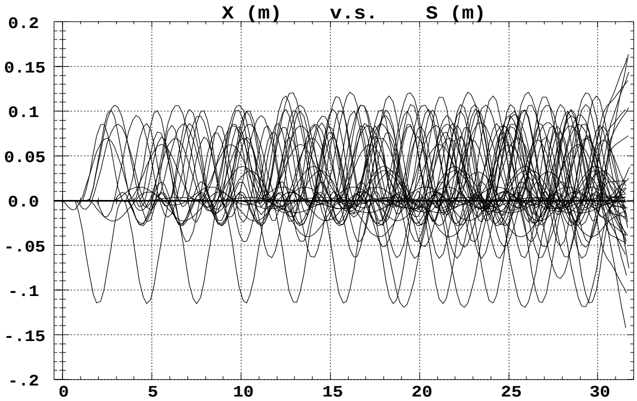

Figure 5: Muon trajectories produced by a pencil pion beam in the 30 m solenoid.

Table 1: Percentage of surviving particles in specified emittances at the end of the decay channel.

Emittance/πm	B/Tesla		
	1	1.3	1.5
0.017	21.5	22.5	21
0.03	22.9	23.3	26.2

The number of particles at the exit of the solenoid in the input emittance is about 2300 in the best case. The associated phase space plot is shown in figure 4 where the smearing of the trajectories appears clearly. The muon momentum is comprised between 100 MeV/c and 260 MeV/c.

4 SOLENOIDAL DECAY CHANNEL

The decay channel of the present CERN neutrino factory project consists of a 30 m long 1.8 T solenoid separated from the horn by a free space of 0.5 m length [3]. Typical trajectories of the muons are shown in figure 5. The emittance build-up due to the decay of a 250 MeV/c pion pencil beam is illustrated in figure 6. The matching ellipse has an area of 0.017 π m.

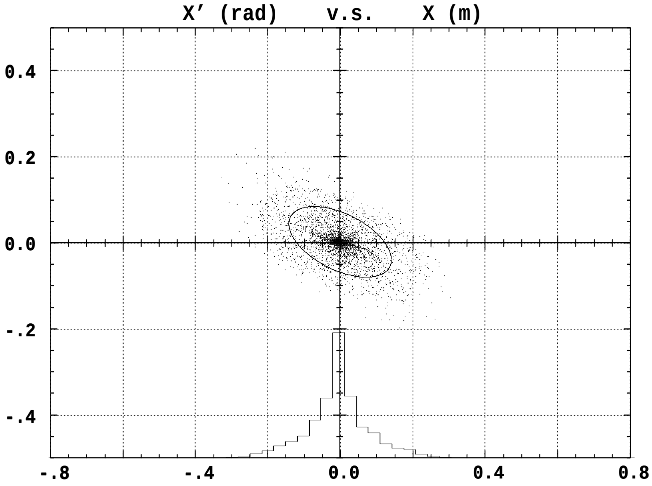

Figure 6: Muon portrait and histogram of the distribution projected in the horizontal plane at the end of the solenoidal decay channel.

The transmission depends little on the solenoidal field, solenoid position with respect to the horn and beam emittance. The effect of the solenoidal field is shown in table 2. The surviving muons and pions amount to 3300 in the best case.

Table 2: Percentage of surviving particles in specified emittances at the end of the solenoidal decay channel.

Emittance/π m	B/Tesla		
	1	1.3	1.5
0.017	30.3	28.2	23.6
0.03	33.3	32.3	26.2

The distribution of the muons in the phase space is shown in figure 7. The muon momentum varies from 100 MeV/c to 260 MeV/c as in the previous case. The absence of the chromatic aberrations introduced by the funneling section explains the larger efficiency obtained for this case.

5 CONCLUSION

The transmission of a funneling scheme is about two third of the transmission of a single solenoidal channel. Funneling four beams can thus be useful when high power beams become available and if the technology of multi MW target is not yet operational. Moreover, further studies can improve the funneling scheme. The value of the β-function is too large and can be reduced by minimizing the quadruplet length and using an additional dipole to match the orbit dispersion. Last, since the chromatic aberrations are the main source of muon losses, a fully quadrupolar decay channel will be investigated.

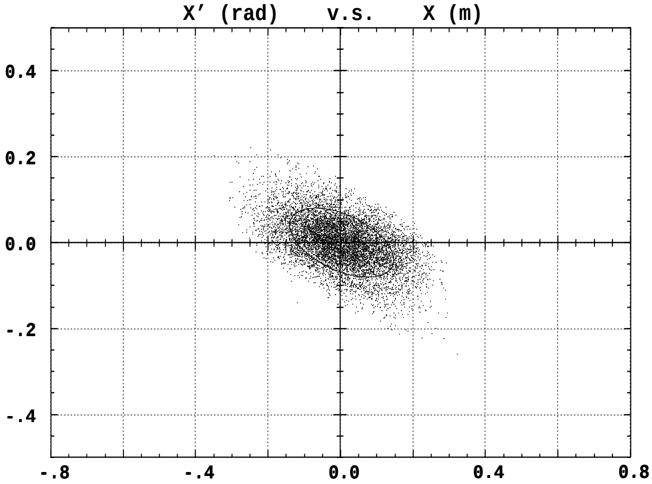

Figure 7: Portrait of the muon and pion beams at the end of the solenoidal decay channel, B = 1 T, $\epsilon_{x,z}/\pi = 0.017$, $200 \leq p \leq 400$ MeV/c.

6 REFERENCES

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