OPTIMIZATION OF PARTICLE PRODUCTION FOR A STAGED NEUTRINO FACTORY*

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Abstract

A first stage of a Neutrino Factory based on muon beams might use a pulsed 3-GeV proton beam with 1-MW average power. We report on optimization of particle production by a carbon target inside a solenoid magnet for this scenario.

INTRODUCTION

The ultimate option for the final stage of a Neutrino Factory (NF) in the Muon Accelerator Program [1] is to use a 8-GeV (or more) proton beam of 4-MW average power interacting with a free-flowing mercury jet to create copious amounts of pions that are captured in a high-field solenoid magnet system. Two capture systems, referred to as IDS120h and IDS120j, as sketched in Fig. 1 have been used for the present study. Figure 2 shows that the axial magnetic field for both the IDS120h tapers adiabatically from 20 T and the IDS120j tapers from 15 T around the target to 1.5 T at the end of the target system. The inner radius of superconducting coils (SC) in the region surrounding the mercury jet target region is 120 cm to permit sufficient internal tungsten shielding for a 10-year operational lifetime of the SC coils against radiation damage [2].
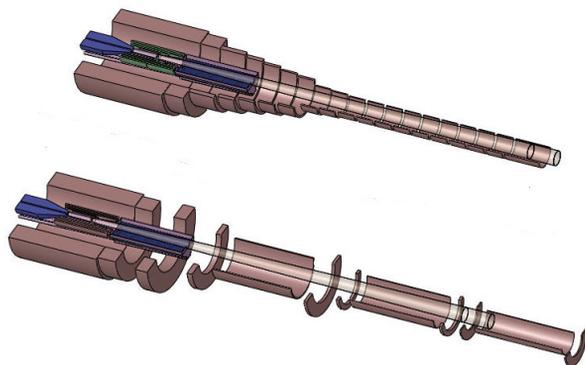

Figure 1: Lower half of the IDS120h (top) and IDS120j (bottom) target system.

A key feature in the staging scenarios [1] for a Neutrino Factory is initial operation of the proton driver at 3-GeV beam energy and 1-MW average beam power. As was noted in previous study, a radiation-cooled graphite target is a viable option for a 1-MW proton beam [3].

The particle production at the target depends on the target geometry as shown in Fig. 3, which illustrates the

length and radius of the target, the radius of the proton beam, the orientation of the proton beam relative to the magnetic field, and the angle of the beam and target relative to each other (both of which lie in a vertical plane).
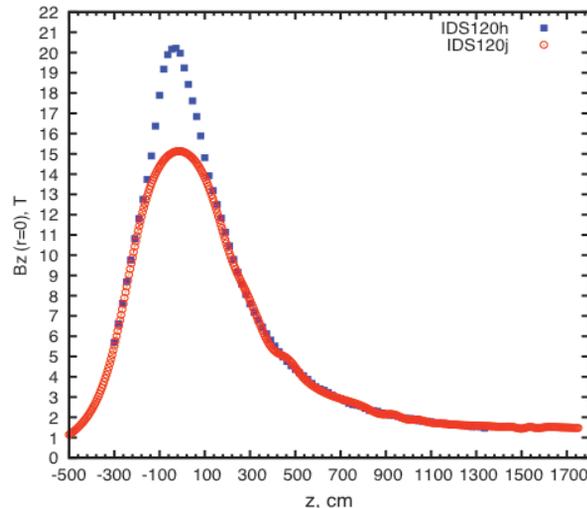

Figure 2: Longitudinal magnetic field along the solenoid axis of SC coils in the IDS120h (dashed line) and IDS120j (solid line) front-end channel.
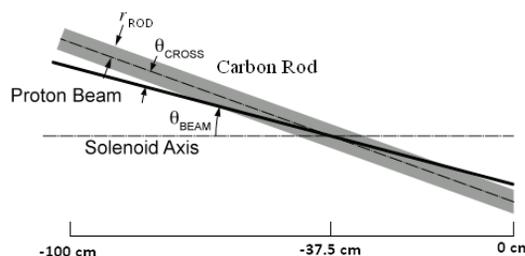

Figure 3: The carbon-target geometry. The proton beam and carbon target cross at $z = -37.5$ cm. The proton beam is launched at $z = -100$ cm.

In this paper, we report on the optimization of particle production (pion and muon yields) by a carbon target inside a solenoid magnet of IDS120h or IDS120j configuration. The pions and muons of interest for a Neutrino Factory are those with kinetic energies between 40 and 180 MeV, and we report rates of these at the transverse planes $z = 0$ m (downstream end of the beam/target interaction region) and $z = 50$ m.

We used four modes of the MARS15(2012) code [4] (denoted MARS15 below), as well as the FLUKA code [5]. The MARS15 modes used in this study were

Mode 1: MARS15 default mode (without either LAQGSM or the MCNP tables);

Mode 2: MARS15 with MCNPDATA (with the MCNP tables but without the LAQGSM mode);

Mode 3: MARS15 in LAQGSM mode (with the LAQGSM mode but without the MCNP tables);

Mode 4: MARS15 in LAQGSM mode with MCNPDATA (with both the LAQGSM mode and the MCNP tables).

OPTIMIZED TARGET PARAMETERS AND PARTICLE PRODUCTION OF IDS120H CONFIGURATION

Using the MARS15 default mode (Mode 1), our optimization started with a 3-GeV proton beam impinging on a carbon target with IDS120h configuration. The initial target radius was chosen as 0.75 cm and the target angle as 50 mrad to the solenoid axis of the SC coils [3]. The target and beam were tilted by the same angle with respect to the solenoid axis, while the beam radius (RMS spot size) was fixed to be either ¼, 1/3.5 or 1/2.5 of the target radius. Several runs were performed during each optimization cycle. In run 1 we varied the target length while keeping initial target radius, target angle fixed; in run 2 we varied the target radius using the new target length while keeping the target angle fixed; and in run 3 we varied the target angle with the new target radius. We repeated the above until convergence was achieved.

Figure 4 depicts the particle production as a function of target length, which shows that the target length corresponding to the peak of production is at 72 cm.
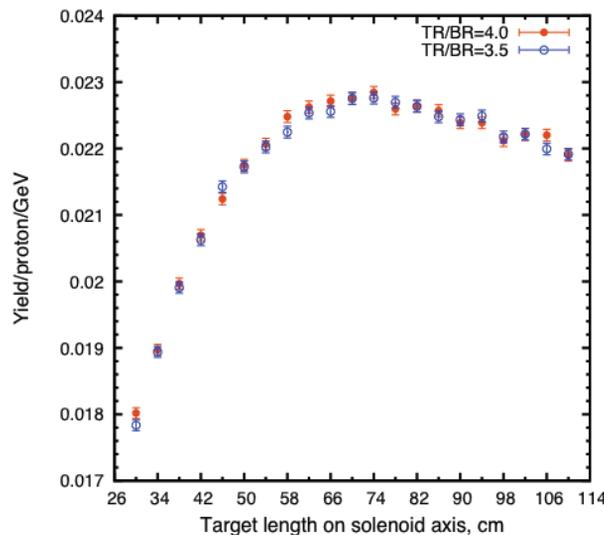
Figure 4: Particle production yields as a function of target length (TR/BR = target radius / beam radius).

Figure 5 shows the variation of particle production with target radius. The production is maximized when the target has a radius of 0.346 cm for a beam radius equal to 1/4 of this.

Figure 6 shows the particle production as a function of beam angle, with a peak around 42 mrad, when the beam radius is 0.0865 cm and the target has a length and radius

of 72 cm and 0.346 cm, respectively. In comparison with the results of our initial setting in Fig. 4, the optimization has given a 15% increase in the peak of particle production (from 0.0228 to 0.0262 per proton per GeV).
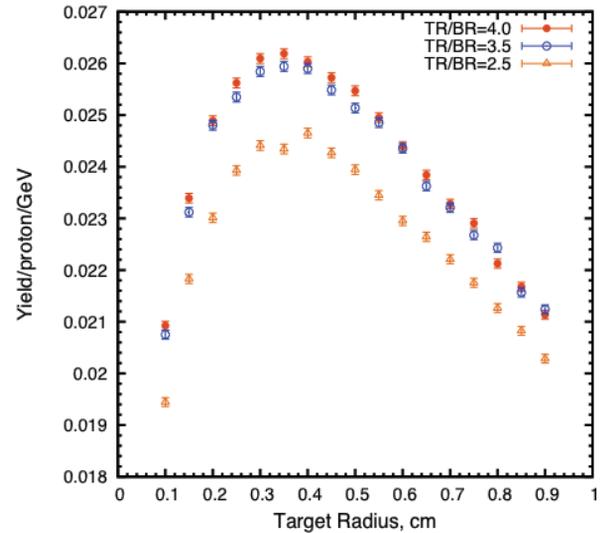
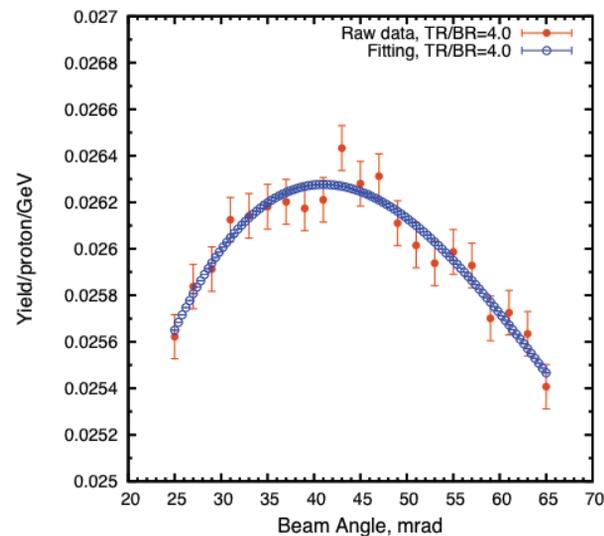Figure 5: Particle production yields as a function of target radius.

Figure 6: Particle production yields as a function of beam angle.

PARTICLE PRODUCTION AND ENERGY SPECTRA OF IDS120J CONFIGURATION

The above optimization of the carbon target in the IDS120h configuration for a 3 GeV proton beam was used as a starting point for studying particle production and energy spectra for the IDS120h configuration. Table 1 shows the particle production results using 10^5 incoming 3-GeV protons. The results using MARS 15 Modes 1 and 2 are similar, as are also those of Modes 3 and 4, which indicates that use of the optional MCNP mode in MARS15 does not play an important role in the particle production study.

Figures 7 and 8 show secondary-particle energy spectra from MARS15 Modes 1 and 4, respectively, and their

06 Accelerator Systems

T20 - Targetry

comparison with FLUKA. A strange shape with both a peak and shoulder of soft pions at $z = 0$ m was observed using MARS15 Mode 1. However, this was not present when MARS15 was used in the LAQGSM mode, for which the results were more compatible with those from FLUKA.

Table 1: Particle Production Yields for the IDS120j Configuration using MARS15 and FLUKA

Running	Yield/proton/GeV $z = 0$ m	Yield/proton/GeV $z = 50$ m
MARS15 Mode 1	0.0341	0.0261
MARS15 Mode 2	0.0335	0.0254
MARS15 Mode 3	0.0299	0.0279
MARS15 Mode 4	0.0296	0.0273
FLUKA	0.0334	0.0298

Factory, which implies that there would be twice as many $\overline{\nu}_\mu$ (ν_e) as ν_μ ($\overline{\nu}_e$) from a Neutrino Factory with these parameters.
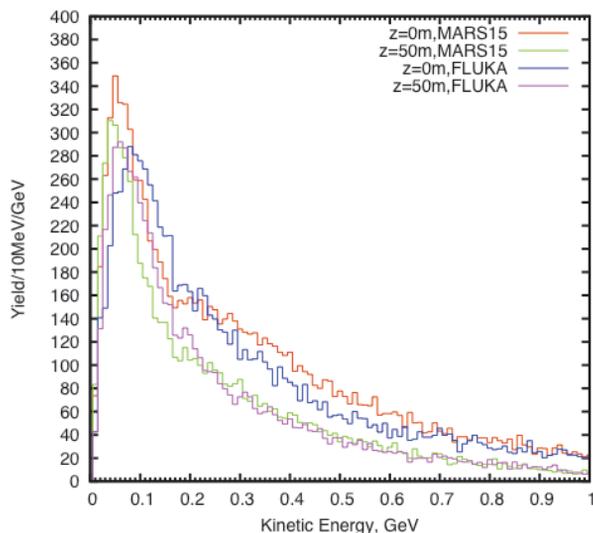

Figure 8: Energy spectra of all positive and negative pions and muons for 3 GeV protons at $z = 0$ m and $z = 50$ m for a carbon target from both MARS15 Mode 4 and FLUKA. Energy spectra of positive or negative pions and muons at $z = 50$ m from MARS15 Mode 4 are also shown.
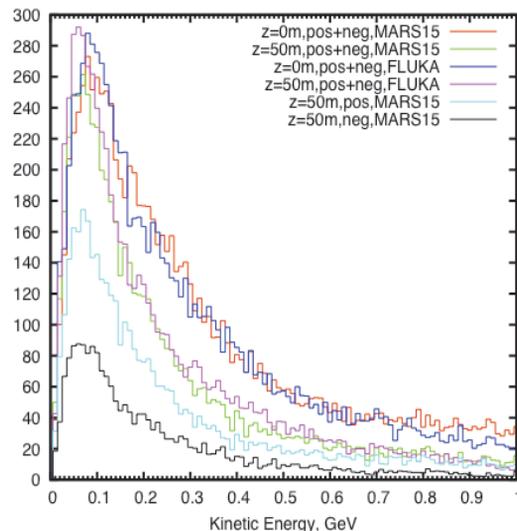

Figure 7: Energy spectra of all positive and negative pions and muons for 3 GeV protons at $z = 0$ m and $z = 50$ m for a carbon target from MARS15 Mode 1 and FLUKA.

CONCLUSIONS

With optimization of the geometric parameters for a carbon target impinged by a 3 GeV proton beam, particle production is around 0.0262 per proton per GeV when the target length is set at 72 cm, target radius at 0.346 cm, beam radius at 0.0865 cm and beam angle at 42 mrad for the IDS120h configuration. With these target parameters, we also studied four running modes of MARS15 for the IDS120j configuration and found energy spectra are comparable with those of FLUKA when the MARS15(2102) in LAQGSM mode with MCNPDATA was used. Production of negative pions from a carbon target with a 3-GeV proton beam is only about half that for positives in the energy range useful for a Neutrino

ACKNOWLEDGMENT

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