GALLIUM AS A POSSIBLE TARGET MATERIAL FOR A MUON COLLIDER OR NEUTRINO FACTORY*

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Abstract

We consider the potential for a free-gallium-jet as an option for the pion-production target at a Muon Collider or Neutrino Factory. Advantages of such a target choice are its liquid state at relatively low temperature, its relatively efficient meson production, and its lower activation (compared to mercury). Using the MARS15 code, we have simulated particle production initiated by incoming protons with kinetic energies (KE) between 2 and 16 GeV. For each proton beam energy, we optimized the geometric parameters of the target: the radius of the liquid jet, the incoming proton beam angle, and the crossing angle between the jet and the proton beam. We compare the quantity of generated muons using a Ga target to that from a mercury jet target.

INTRODUCTION

The baseline option for a possible future Muon Collider (MC) or Neutrino Factory (NF) [1] is to use a 4-MW proton beam interacting with a free-flowing mercury jet to create copious amounts of pions that are captured in a 20-T solenoid magnet system. The pions are then transported into a tapered solenoid decay channel in which decay muons will be captured, cooled and stored in a storage ring, either to provide for $\mu^+\mu^-$ collisions or to produce intense neutrino beams.

In previous work [2, 3, 4] based on MARS [5] simulations, we optimized a mercury jet target utilizing the Neutrino Factory Study 2 target configuration [6]. We simulated particle production initiated by incoming protons with kinetic energies between 2 and 100 GeV. The pions and muons of interest for a Muon Collider/Neutrino Factory are those with kinetic energy $40 < \mathrm{KE} < 180$ MeV at the transverse plane $z = 50$ m (with $z = 0$ being the downstream end of the beam/jet interaction region).

For each proton beam kinetic energy, we maximized meson production by varying the geometric parameters of the target: the mercury jet radius, the incoming proton beam angle, and the crossing angle between the mercury jet and the proton beam (both of which lie in a vertical plane). With an 8-GeV proton beam, we studied the variation of meson production with the entry direction of the proton beam relative to the jet. We also examined the influence on meson production by the focusing of the proton beam. The number of muons surviving through the neutrino factory front end channel was determined as a function of the proton beam kinetic energy.

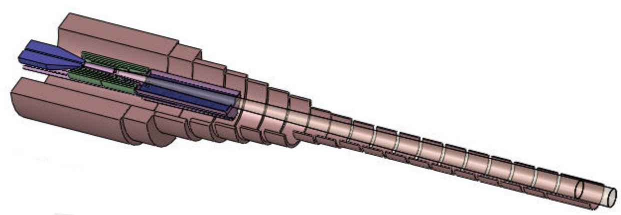

Figure 1: Lower half of the IDS120h target system.

The capture system used for the present study is referred to as IDS120h, as sketched in Fig. 1. The inner radius of superconducting coils (SC) in the region surrounding the mercury jet target region is 120 cm (up from 60 cm in [1]) to permit sufficient internal tungsten shielding for a 10-year operational lifetime of the SC coils against radiation damage. The axial magnetic field tapers adiabatically from 20 T around the target to 1.5 T at the end of the target system. The baseline target is a free mercury jet, ≈ 8 mm in diameter, flowing at 20 m/s to present a fresh region of two interaction lengths to the proton beam every pulse at 50 Hz. Here, we also consider the option of a gallium jet target, which becomes liquid at 29.8° C, and report on particle production optimization similar to that previously done for a mercury target [3, 4].

OPTIMIZATION METHOD

Figure 2 shows a schematic of the mercury-jet target geometry. The center of the beam/jet interaction region is at (0,0,-37.5. The launch point for the proton beam in the MARS simulations is at $z = -200$ cm, well upstream of the interaction region.

For our optimization method, we performed 3 runs in each of several cycles. In run 1 we varied the jet radius with initial beam angle and beam/jet crossing angle fixed; in run 2 we varied the beam/jet crossing angle with the new target radius while keeping the beam angle fixed; and in run 3 we varied the beam angle with the new target radius while ad-

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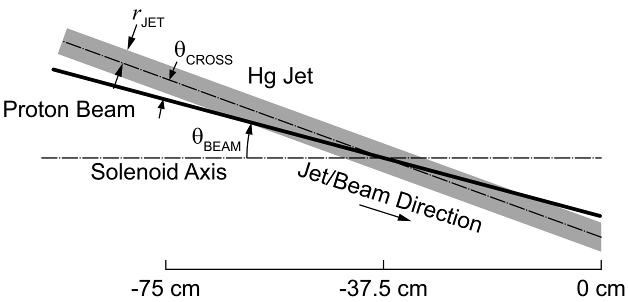

Figure 2: The mercury-jet-target geometry. The proton beam and mercury jet trajectories intersect at $z = -37.5$ cm.

justing the jet angle to maintain a constant beam/jet crossing angle. Then, we repeated the above cycle until convergence is achieved.

OPTIMIZED TARGET PARAMETERS AND MESON PRODUCTION

We first report simulations at a proton kinetic energy of 8 GeV. With initial target parameters from our previous studies [4, 3], we performed 4 cycles for a Hg jet and 6 cycles for a Ga jet to achieve convergence. After optimization, the Hg jet radius is at 4.04 mm, the beam/jet crossing angle is 20.6 mrad and beam angle is 117 mrad. For the Ga jet the final target radius is 4.4 mm, the beam/jet crossing angle is 13 mrad and beam angle is 88 mrad. Figure 3 depicts the meson production as a function of the run number in our optimization process. The meson production approached its convergent value after several cycles. After optimization, we see that at 8 GeV, the meson production for Ga is 13% less than for Hg.

We then used the target parameters obtained at 8 GeV as initial values for further optimizations at proton kinetic energies in the range of 2-16 GeV. The optimized target radius, beam/jet crossing angle and beam angles are plotted as functions of KE in Figs. 4, 5, 6, respectively. In Fig. 7, we plot meson production *vs.* proton KE, which shows that the production from Ga peaks near KE = 5 GeV and is comparable to that from Hg at this energy.

We have also compared meson production in Fig. 8 between the IDS120h configurations and those considered in

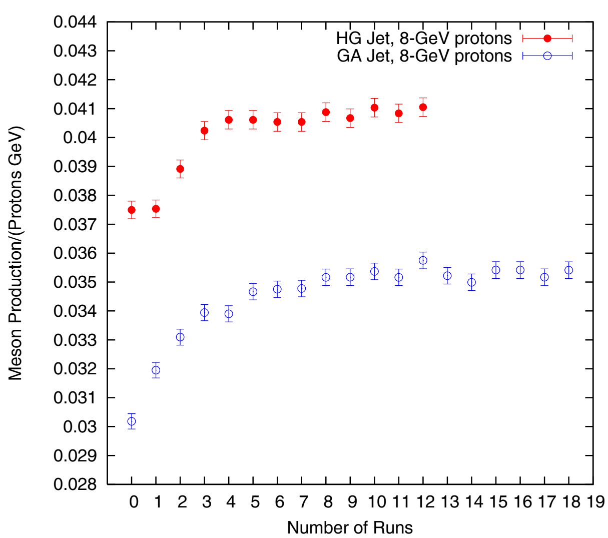

Figure 3: Meson production as a function of run number at 8 GeV for Hg and Ga targets.

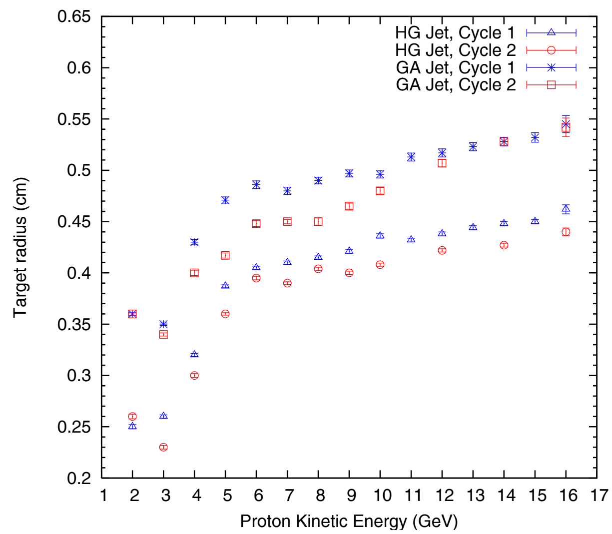

Figure 4: Optimized target radius as a function of proton kinetic energy.

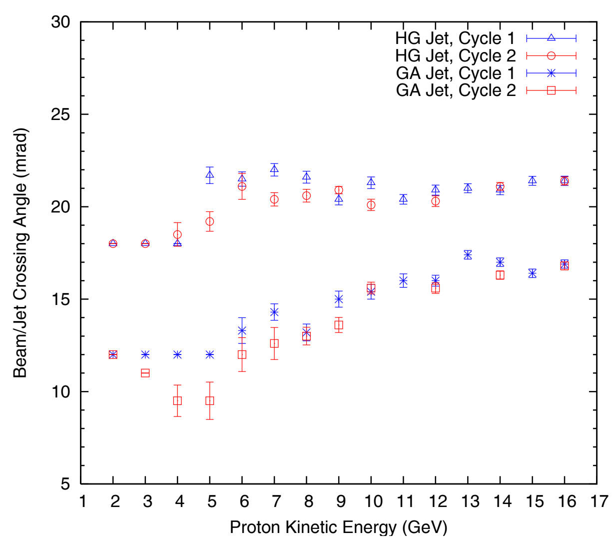

Figure 5: Optimized beam/jet crossing angle as a function of proton kinetic energy.

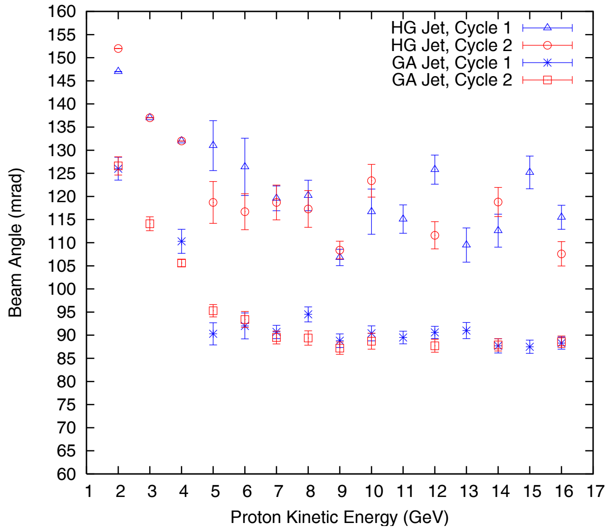

Figure 6: Optimized beam angle as a function of proton kinetic energy.

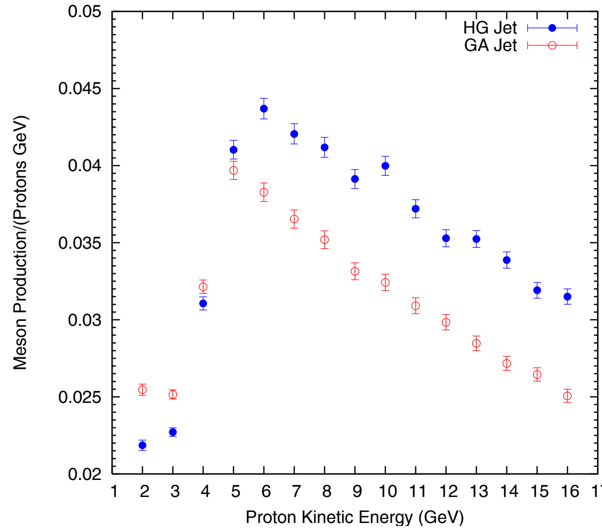

Figure 7: Meson production as a function of proton kinetic energy.

[2, 7]. Compared with the previous studies, we observed a 13% increase in meson production with the IDS120h configuration after the present optimization, due to the final field in the π/μ transport channel being 1.5 rather than 1.25 T. For example, increasing the final field from 1.5 to 1.66 T would increase the useful particle production by another 8% at 8 GeV beam energy [8].

CONCLUSIONS

We have simulated the IDS120h target configuration using gallium and mercury as candidate target materials. With optimization for incident protons at 8 GeV, the Hg jet has a target radius of 4.04 mm, a beam/jet crossing angle of 20.6 mrad and a beam angle of 117 mrad. For Ga, the optimized jet target radius is 4.4 mm, the beam/jet crossing angle is 13 mrad and the beam angle is 88 mrad. In addition, we find that the production from Ga peaks near KE = 5 GeV and is comparable to that from Hg at this kinetic energy.

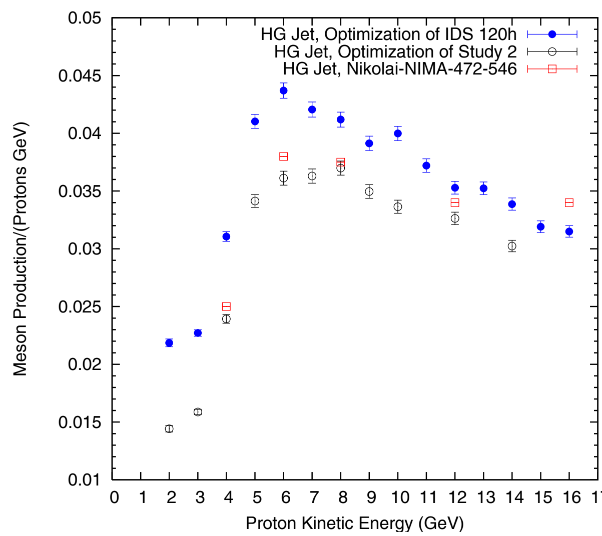

Figure 8: Comparison of meson production by mercury targets in IDS120h, Study 2 [2, 6], and [7], as a function of proton kinetic energy.

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