

## OPTIMIZED PARAMETERS FOR A MERCURY JET TARGET\*

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### Abstract

A study of target parameters for a high-power, liquid mercury jet target system for a neutrino factory or muon collider is presented. Using the MARS code [1], we simulate particle production initiated by incoming protons with kinetic energies between 2 and 100 GeV. For each proton beam energy, we maximize 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. The number of muons surviving through an ionization cooling channel is determined as a function of the proton beam energy.

### INTRODUCTION

A neutrino factory or muon collider [2] needs a large number of muons to achieve acceptable performance. These muons are first produced by focusing a proton beam on to a target, where pions are produced. The pions are captured in a high-field solenoid [3] and then transported into a decay channel where the muon into which they decay are collected. An intense proton beam with energies in the MW range could damage or destroy a target, hence a moving target is considered.

The proposed target material is a liquid mercury jet which can be replenished after each interaction with the proton beam. Solenoid fields of 15-20 T will be adequate to capture most pions with transverse momentum up to 220 MeV/c. These pions are then transported along a tapered solenoid channel in which the muon decay products of the pions are contained and further transported into phase space shaping systems such as phase rotation in longitudinal phase space and cooling channels in which the transverse emittance of the muons is reduced. Figure 1 shows a schematic of the target concept. The validity of the liquid target concept has been demonstrated in the MERIT high intensity liquid mercury target experiment [4].

The production of pions at the target depends on the size of the target, the orientation of the proton beam relative to the magnetic field, and the angle of the beam and jet relative to each other. In order to maximize number of muons produced, we perform an optimization study of these geometric target parameters for this liquid mercury jet target system.

### OPTIMIZATION METHOD

The low-energy pions are produced when an intense proton beam impinges on a mercury jet target. The geometry shown in Figure 1 together with material and

magnetic field distributions have been described in MARS version 15 [1], a Monte Carlo code capable of simulating particle interactions and transport. We run MARS and count all the mesons (pions and muons of both signs) that cross a transverse plane 50 meters downstream from the beam/jet interaction. We then select all the mesons whose kinetic energies are in the range of 40 to 180 MeV. This is done because we find that the number of muons in this kinetic energy band is proportional to the number of muons which eventually survive the subsequent phase rotation and transverse cooling sections, independent of other parameters such as the proton beam energy and target geometry.

To find the optimal values for the geometric parameters, we first make a number of runs with different values for a single parameter. We then fit a curve (using the method of least squares) through the data for meson production (with uncertainties, which can be computed from the MARS results since each proton is independent) as a function of the parameter in question. We take the parameter value at the maximum in the fitted curve to be the optimal value for the parameter. We repeat this process for each parameter, and then cycle through the parameters again until the parameter values have converged. As a result of the least squares fitting process, we are able to obtain uncertainties in the optimal

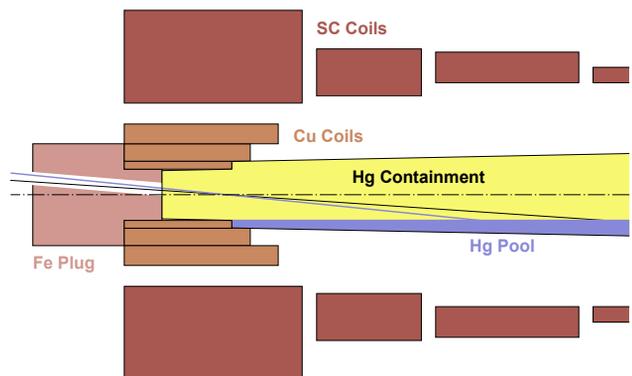


Figure 1: Concept of a continuous mercury jet target for an intense proton beam. Here the jet and beam are tilted by 100 mrad and 67 mrad, respectively, with respect to a 20-T solenoid magnet that conducts low-momentum pions into a decay channel.

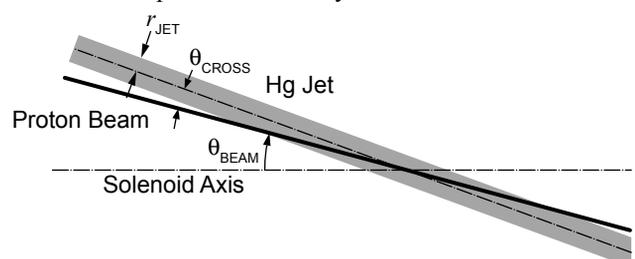


Figure 2: The mercury jet target geometry.

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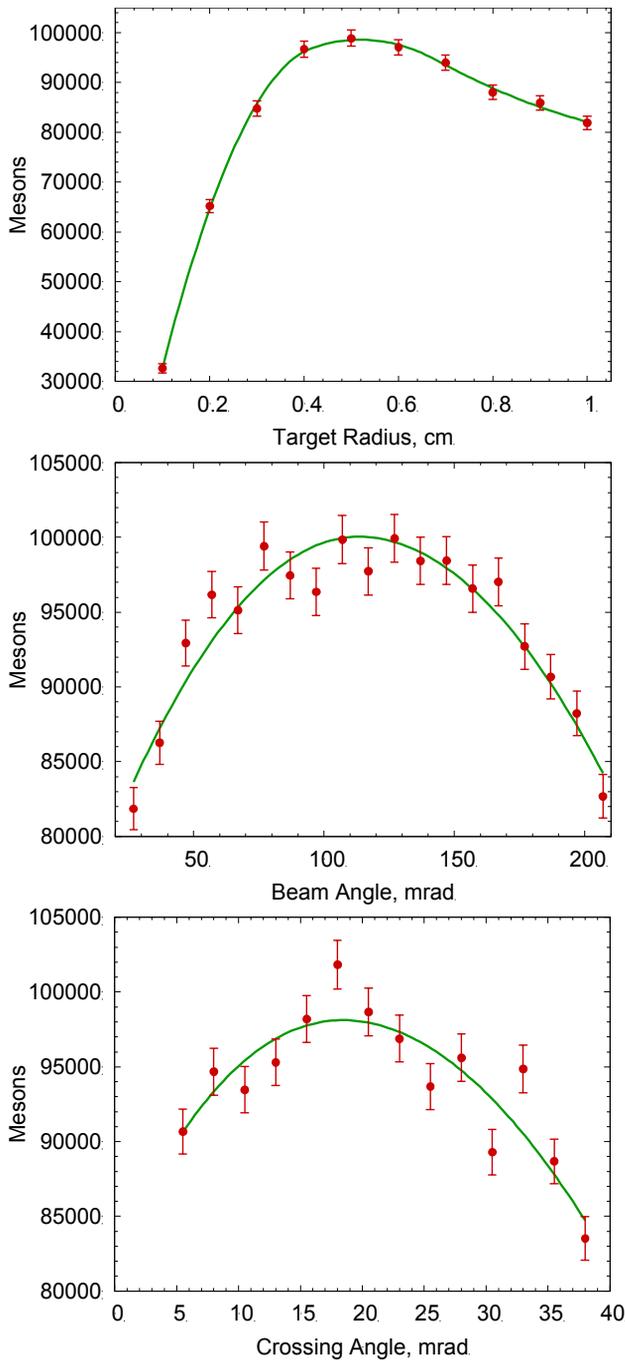


Figure 3: Meson production as a function of target radius (top), proton beam angle (middle), and beam-target crossing angle (bottom). Data points represent mesons generated from  $10^5$  incoming 50GeV protons. Curves are least-squares fits to this data.

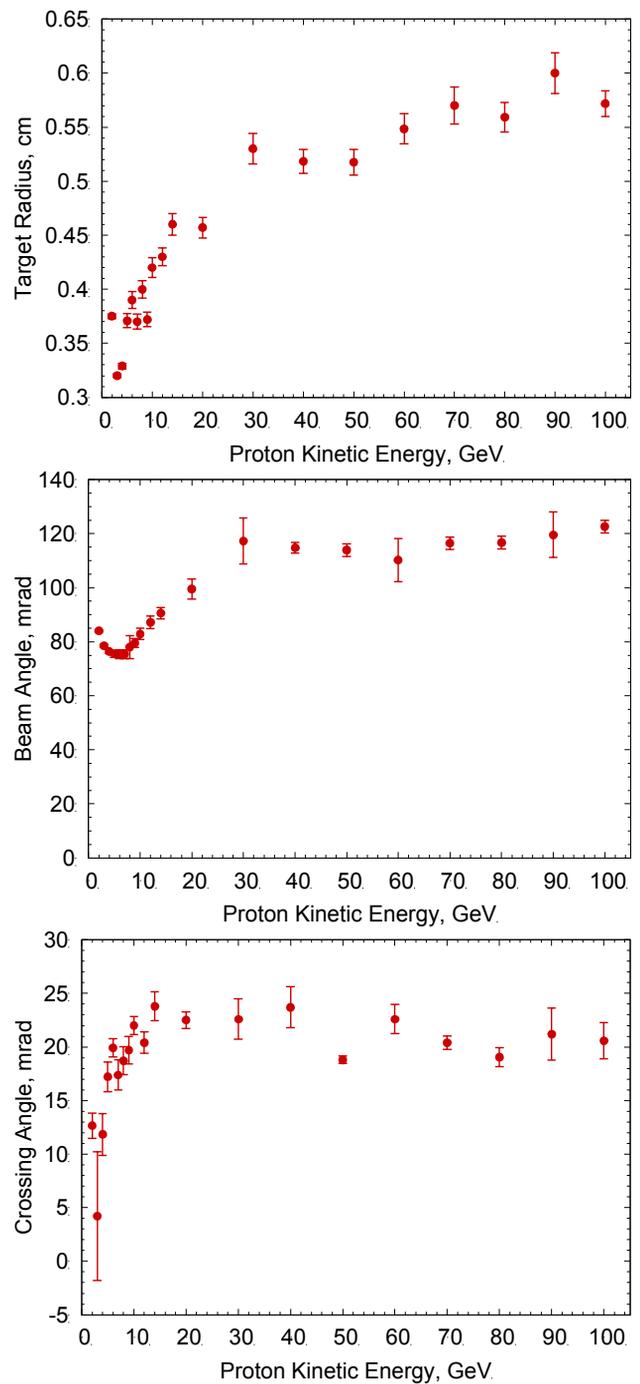


Figure 4: Optimized target parameters as a function of proton energy.

parameter values and the production values.

The parameters we vary are shown in Figure 2. They are the jet radius, the angle between the proton beam and the magnetic field, and the angle between the jet and the proton beam. The magnetic axis, the jet, and the proton beam all lie within the same plane. The proton beam is Gaussian, with an RMS radius set to 0.3 times the target radius. For each energy, we start with the proton beam at an angle of 67 mrad with respect to the magnetic field, a

crossing angle of 33 mrad between the jet and the proton beam, and a target radius of 5 mm. Figure 3 shows examples of the process of fitting curves to the individual parameters.

## RESULTS

Using the described optimization method, we get the optimal values and the uncertainties for target radius, beam angle, and crossing angle for various proton kinetic

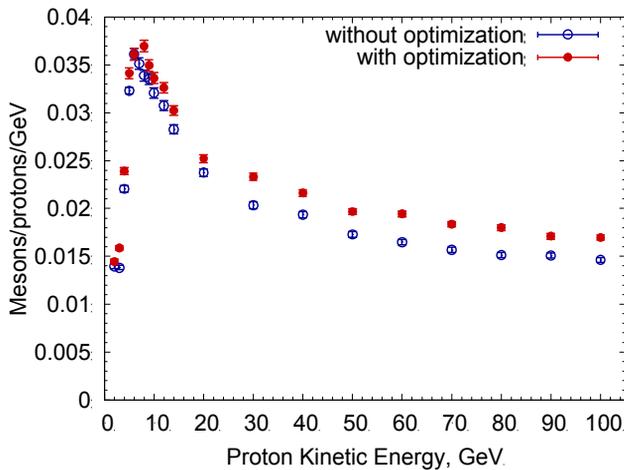


Figure 5: Production with original geometry and with optimized geometry.

energies between 2 and 100GeV. These results are shown in Figure 4.

Figure 5 shows meson production before and after optimization for proton energies between 2 and 100GeV. Each curve has been normalized to beam power.

We also compute the number of muons surviving the subsequent phase shaping system using the code ICOOL [5]. In figure 6 we show the number of muons surviving as a function of the proton beam energy. For this figure the entries are normalized by setting the maximum production efficiency to unity.

## CONCLUSION

We optimize the mercury jet target parameters: the mercury jet radius, the incoming proton beam angle and the crossing angle between the mercury jet and the proton beam for each proton beam energy. The optimized target radius varies from about 0.4 cm to 0.6 cm as the proton beam energy increases. The optimized beam angle varies from 75 mrad to 120 mrad. The optimized crossing angle is near 20 mrad for energies above 5 GeV. These values differ from earlier choices of 67 mrad for the beam angle and 33 mrad for the crossing angle. These new choices for the beam parameters increase the meson production by about 20% compared to the earlier parameters. Our study demonstrates that the maximum meson production efficiency per unit proton beam power occurs when the proton kinetic energy is in the range of 5–15 GeV.

Finally, the dependence on energy of the number of muons at the end of the cooling channel is nearly identical to the dependence on energy of the meson production 50 m from the target. This demonstrates that the target

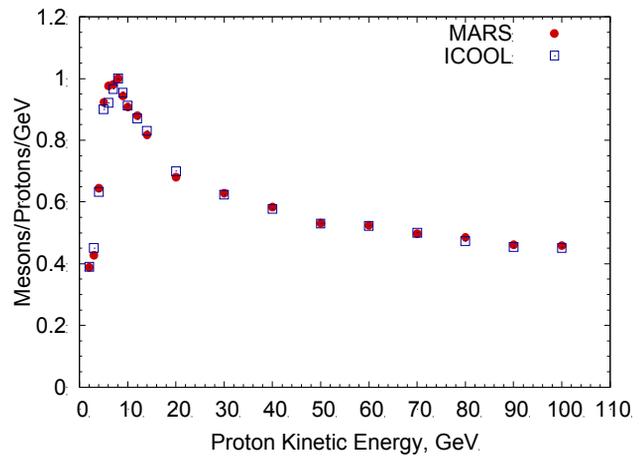


Figure 6: Mesons 50 m from interaction point as computed by MARS, and mesons at the end of cooling channel as computed by ICOOL, starting from distribution at end of target.

parameters can be optimized without the additional step of running the distribution through a code such as ICOOL that simulates the bunching, phase rotation, and cooling.

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