A PION PRODUCTION AND CAPTURE SYSTEM FOR A 4 MW TARGET STATION

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Abstract

A study of a pion production and capture system for a 4 MW target station for a neutrino factory or muon collider is presented. Using the MARS code [1], we simulate the pion production produced by the interaction of a free liquid mercury jet with an intense proton beam. We study the variation of meson production with the direction of the proton beam relative to the target. We also examine the influence on the meson production by the focusing of the proton beam. The energy deposition in the capture system is determined and the shielding required in order to avoid radiation damage is discussed.

INTRODUCTION

The scenarios for a neutrino factory [2] or muon collider [3] require a targeting solution that can convert a 4-MW-class proton beam into an intense muon beam. A concept of utilizing a free-flowing mercury jet has been proposed to accomplish this task and the validity of the liquid target concept has been successfully demonstrated in the MERIT high intensity liquid mercury target experiment [4].

Figure 1 shows a schematic of the target concept. These muons are first produced by focusing a proton beam on to a liquid mercury target, where low-energy pions are produced. These pions are captured in a high-field (~20T) solenoid and then transported into a decay channel where the muon decay products are collected.

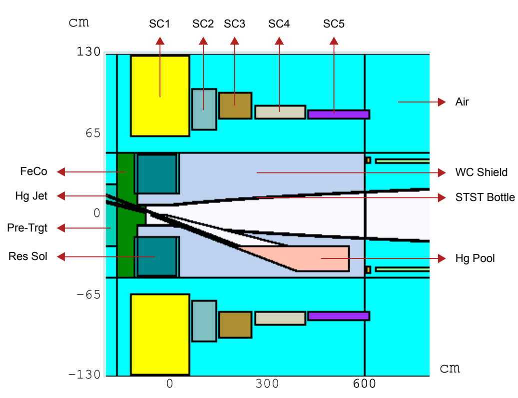

Figure 1: Concept of a continuous mercury jet target for an intense proton beam. The mercury jet is tilted by 100mrad with respect to a 20-T solenoid magnet which captures and conducts low-momentum pions into a decay channel.

The purpose of our simulation efforts is to advance the target concept from a proof-of-principle demonstration to a viable functioning target system. Initial results analysing pion production induced by the interaction of the free liquid mercury jet with an intense proton beam have been published [5]. In addition, the correlation between pion production and multiple beam entry points for the proton beam onto the jet has been examined [6]. In this paper we present the relation between the beta function of the incoming proton beam and mesons (pions and muons) generated. Finally, we investigate the energy deposition in the target system to determine the extent of shielding required to protect the superconducting coils which generate the 20-T field at the target.

MULTIPLE PROTON BEAM ENTRY DIRECTIONS

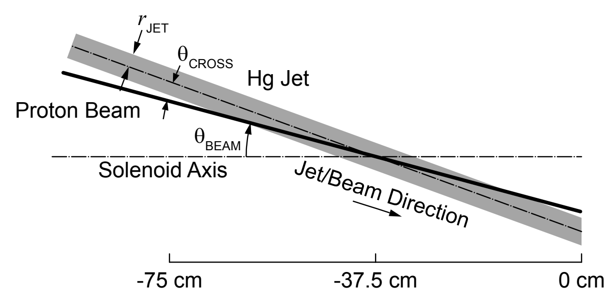

Figure 2: The mercury jet target geometry. The proton beam and mercury jet cross at z=-37.5 cm.

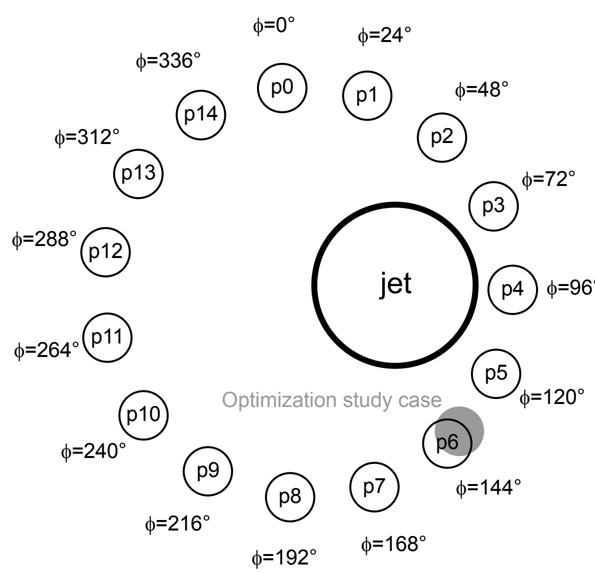

Figure 3: The layout of multiple proton beam entry directions relative to mercury jet at z=-75 cm.

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Figure 2 shows the mercury jet target geometry. The centers of the proton beam and mercury jet intersect at z=-37.5cm. Alternative proton beam entry points for the proton beam onto the jet are also explored. Figure 3 depicts the calculated beam positions of an 8GeV proton beam at z=-75 cm. Fifteen cases, each of which retain the optimal crossing angle of 27mrad at z=-37.5cm [6] are depicted. We note that the pion production rate can vary by as much as 8%.

FOCUSED INCIDENT PROTON BEAM

So far, all of our simulations are based on a simple Gaussian incident proton beam. We consider now a focused 8 GeV proton beam and study the correlation between the beta function of the proton beam and the generated mesons.

In Figure 4 we show the transverse dimensions of the proton beam at three longitudinal positions for the case of horizontal and vertical beta functions of 10cm. We can clearly see the beam is focused and the beam waist is at z=-37.5 cm. Figure 5 shows the meson production as a function of beta function of the proton beam.

We see that the meson production loss is negligible (<1%) for beta functions of 0.3m or greater.

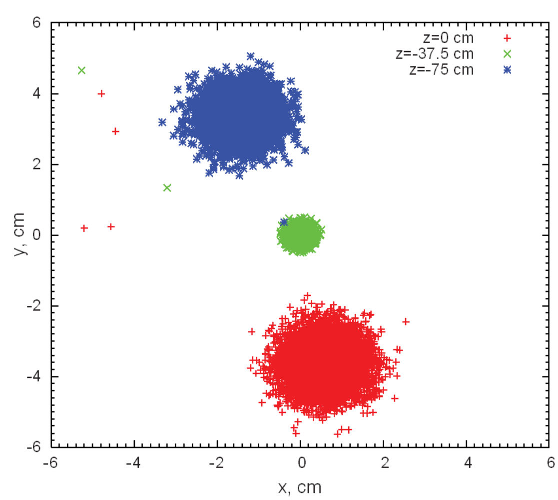

Figure 4: The x-y plot at betax=10 cm and betay= 10cm.

ENERGY DEPOSITION

Energy deposition in the mercury jet target which is associated with a 4-MW proton beam is investigated utilizing the MARS code. We use the geometry and magnetic field map from Ref [2]. The kinetic energy of proton beam is 10GeV and the corresponding number of particles for a 4MW proton beam is 2.5×10^{15} per second. Table 1 lists the energy deposition by component (See Figure 1). We can see that about half of the total power is deposited in the water cooled tungsten carbide (WC) shielding, 10% of total power deposited in the mercury and another 10% in the capture beam pipe.

The power deposition in the superconducting coil which surrounds the target (SC1) is 22.1 kW. Figure 6

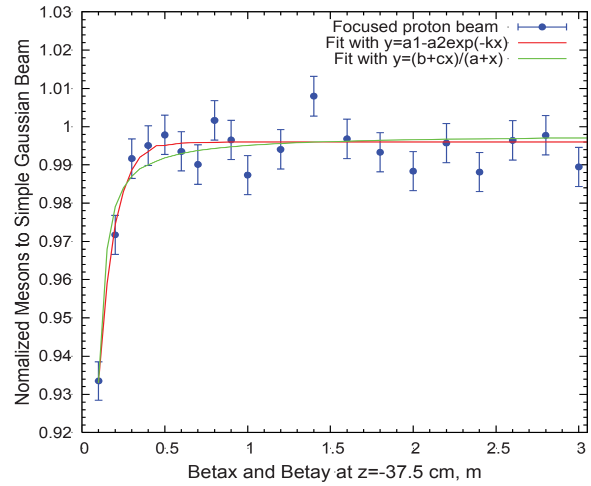

Figure 5: Meson productions as a function of beta function at z=-37.5 cm.

shows the distribution of the energy deposition in the target region surrounding the intersection of the mercury jet and the proton beam. The maximum energy deposition in the SC1 coil is about 10^{-8}GeV/g per incident proton or 4 W/kg. Table 2 gives a comparison with a previous study [7] in which a 24GeV and 1MW incoming proton beam was assumed. We can see a serious radiation issue for SC1 coil and enhanced shielding is necessary to lower the energy deposition in SC1 coil in order to increase its operational lifetime. Our simulation shows the power deposition in SC1 coil can be decreased from 22.1 kW to 4.8 kW if we extend the WC & water shielding region in radius from 50 cm to 63 cm. The power deposition can be decreased further to 1.3 kW if the resistive inner coils are replaced by the WC shield. This would, however, result in a substantial reduction of the capture field strength to 14T which will impact the capture efficiency of the target system.

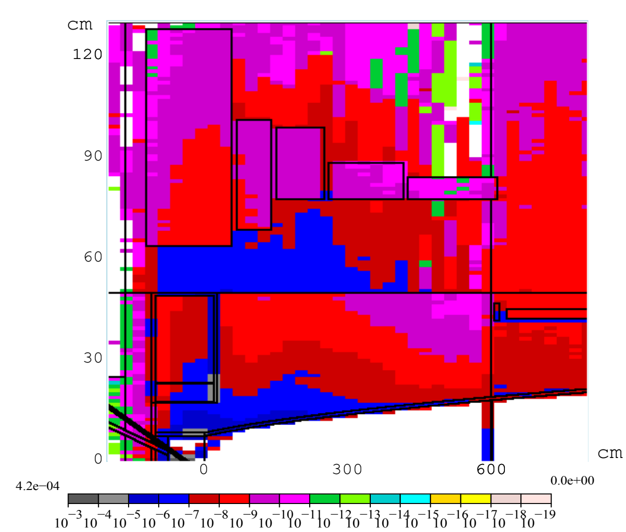

Figure 6: The energy deposition in units of GeV/g per incident proton in the mercury target system.

Table 1: Energy Deposition (ED) of 4 MW Beam in the Target System

Component	ED	Power	P/P_{beam}
WC Shield	4.60 GeV	1838 kW	46.0 %
Hg Jet	1.07 GeV	426 kW	10.7 %
STST Bottle	1.17 GeV	468 kW	11.7 %
Res Sol	0.26 GeV	105 kW	2.6 %
Hg Pool	4.89×10^{-2} GeV	19.5 kW	0.5 %
FeCo	2.25×10^{-2} GeV	9 kW	0.23 %
Be Window	6.22×10^{-3} GeV	2.5 kW	0.06 %
SC1	5.52×10^{-2} GeV	22.1 kW	0.55 %
SC2	5.99×10^{-3} GeV	2.4 kW	0.06 %
SC3	3.30×10^{-3} GeV	1.3 kW	0.03 %
SC4	1.19×10^{-3} GeV	0.5 kW	0.01 %
SC5	$<10^{-3}$ GeV		
Pre-Trgt	$<10^{-3}$ GeV		
Air	$<10^{-3}$ GeV		

Table 2: Radiation Dose and Life Time of Superconducting Coil

Component	Dose/yr	Max allowed Dose	4 MW life
Superconducting coil (Ref. 7)	6×10^{6} Gy/yr	10^{8} Gy	4 yr
SC1 (This study)	8×10^{7} Gy/yr	10^{8} Gy	1.25 yr

John Black of the University of Warwick used the FLUKA code to simulate the same target geometry and obtained similar results [8]. By comparison, the energy deposition in the SC1 coil is 52.7 kW while it is 400.9 kW in the mercury jet. His simulation of simple target geometries found that the energy showers are more penetrating in FLUKA than in MARS.

CONCLUSIONS

The exploration for the multiple proton beam entry directions relative to mercury jet in the 8GeV proton beam case demonstrates that an asymmetric layout is required in order to achieve the same beam/jet crossing angle at the jet axis. We find a correlation between the distance of beam relative to the jet and the meson production. The peak meson production is 8% higher than for the lowest case.

The examination of the influence on the meson production by the focusing of the proton beam shows the meson production loss is negligible (<1%) for a beta function to be 0.3m or higher for the proton beam.

By investigating the energy deposition in the target/capture system, we see that the bulk of 4-MW proton beam power is deposited in the water cooled tungsten-carbide (WC) shielding, the mercury jet and the capture beam pipe. In addition, high power deposition in the first superconducting coil causes an issue for its operation and life time. Enhanced shielding is necessary to lower the radiation damage.

ACKNOWLEDGMENTS

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