A Pion Production and Capture System for a 4 MW Target Station

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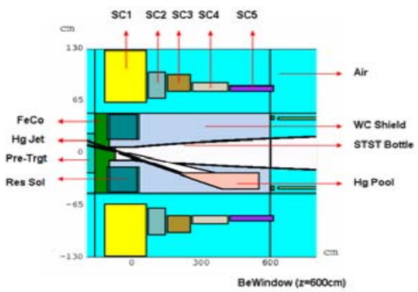
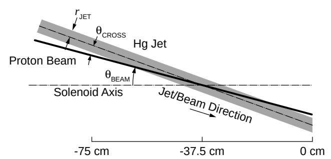
A study of a pion production and capture system for a 4MW target station for a neutrino factory or muon collider is presented. Using the MARS code, we simulate the pion production produced by the interaction of a free liquid mercury jet with an intense proton beam. We study the variation of meson production 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.

1. Schematic of the Target System



2. Pion Production

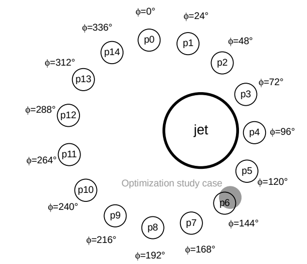


The mercury jet target geometry.

- **Target parameters is optimized to maximize the pion production.**
- **The pion production and the pion-production efficiencies as a function of the primary proton of KE between 2 and 100 GeV are calculated.**

  X. Ding et al., "Optimized Parameters for a Mercury Jet Target," in Proceedings of PAC09, Vancouver, Canada, May 2009, paper WE6PFP102.

3. Multiple Proton Beam Entry Directions

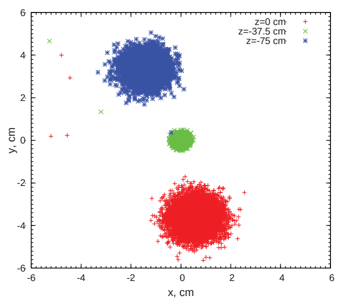


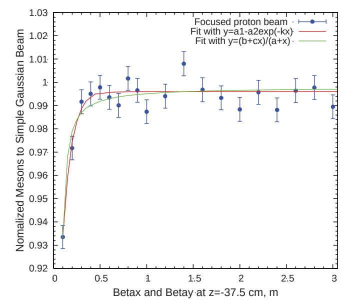
The layout of multiple proton beam entry directions relative to mercury jet at z=-75cm.

- **An asymmetry layout in the 8GeV proton beam case at z=-75cm is required to achieve the same beam/jet crossing angle at z=-37.5 cm.**
- **We found a correlation between the distance of beam relative to the jet and the meson production. The peak meson production is about 8% higher than for the lowest case.**

  X. Ding et al., "Meson Production Simulations for a Mercury Jet Target," in Proceedings of NuFact09, Chicago (2009), AIP Conference Proceedings 1222 (2010), p.323.

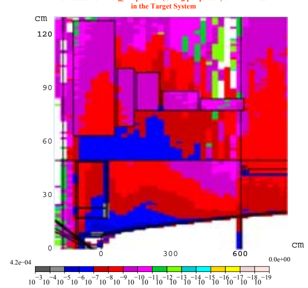
4. Focused Incident Proton Beam





5. Energy Deposition

Distribution of Energy Deposition (GeV/g per proton) of 4 MW Beam in the Target System



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 %
Pre-Trgt	$<10^{-3}$ GeV		
Air	$<10^{-3}$ GeV		

Radiation Dose and Life Time of Superconducting Coil

Component	Dose/yr	Max allowed Dose	4 MW life
Superconducting coil (Study II) (24GeV, 1MW proton beam)	$6*10^{6}$ Gy/yr	10^{8} Gy	4 yr
SC1 (10GeV, 4MW proton beam)	$8*10^{7}$ Gy/yr	10^{8} Gy	1.25 yr

Comparison of Calculated Energy Deposition between MARS and FLUKA Code

Region	P [kW]	% (MARS15)	P [kW] (FLUKA)	%
Hg Jet	426.0	10.7	400.9	10.0
Hg Pool inside WC shield	19.5	0.5	12.5	0.3
WC shield (z < 27 cm)	1838 (WC shield)	46.0	1845.5	46.1
WC shield (z ⩾ 27 cm)	468 (STST Bottle)	11.7	848.3	21.1
Outer Fe yoke (z < −165 cm)	9.0	0.2	-----	-----
Inner Fe yoke (z ⩾ −165 cm)	(FeCo)		15.2	0.4
Inner Cu coil (18 ⩽ r ⩽ 23 cm)	105	2.6	142.0	3.6
Outer Cu coil (23 < r ⩽ 49 cm)	(Res Sol)		90.3	2.3
SC Coil 1	22.1	0.6	52.7	1.3
SC Coil 2	2.4	0.1	5.5	0.1
SC Coil 3	1.3	-----	1.2	-----
SC Coil 4	0.5	-----	0.4	-----
SC Coil 5	0.1	-----	0.1	-----
SC Coil 6	<0.1	-----	<0.1	-----
SC Coil 7	3.5	-----	1.1	-----
SC Coil 8	1.5	-----	0.5	-----
SC Coil 9	0.9	-----	0.2	-----
SC Coil 10	0.7	-----	0.1	-----
SC Coil 11	0.5	-----	0.1	-----
SC Coil 12	0.4	-----	0.1	-----
SC Coil 13	2.6	-----	0.7	-----
Be window at 6m	2.5	-----	1.7	-----

- **According to J. Back's simulation, the energy showers are more "Penetrating" in FLUKA than in MARS .**

  J. Back, Private Communication.

Enhanced Shielding for SC1 Coil

- **Power deposition in SC1 coil could be decreased from 22.1 kW to 4.8 kW if WC & water shield region is extended from 50 to 63 cm in radius.**
- **Power deposition in SC1 coil could be further decreased to 1.3 kW if Resistive inner copper coils are replaced by WC & water shield.**

Conclusion

1. *Based on the study of meson production efficiency per unit proton beam power as a function of the primary proton energy, we favor the energy range of 5~15 GeV for the incoming protons.*
2. *Modeling has explored a range of proton beam entry angles with a view to optimizing the production efficiency of the pions as well as offering an opportunity to explore the possibility of multiple beam entry points for the proton beam onto the jet.*
3. *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 the beta function to be 0.3 m or higher.*
4. *The energy deposition of incoming 4 MW proton beam in the target is investigated. It shows that the bulk of power is deposited in the tungsten-carbide & water (WC) shield, the mercury jet and the stainless steel bottle. Also, we found the power deposition in the first superconducting coil (SC1) is high and enhanced shielding is required to lower the radiation dose and increase the lifetime of SC1.*

Operated by Brookhaven Science Associates for the U.S. Department of Energy