

**The Primary Target Facility for a Neutrino Factory
Based on Muon Beams**

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THE PRIMARY TARGET FACILITY FOR A NEUTRINO FACTORY BASED ON MUON BEAMS

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Abstract

Neutrino beams from the decay of muons in a storage ring offer the prospect of very high flux, well-understood spectra, and equal numbers of electron and muon neutrinos, as desirable for detailed exploration of neutrino oscillations via long baseline detectors [1]. Such beams require large numbers of muons, and hence a high performance target station at which a 1-4 MW proton beam of 16-24 GeV impinges on a compact target, all inside a high field solenoid channel to capture as much of the phase volume of soft pions as possible. A first concept was based on a carbon target, as reported in 2000 the Neutrino Factory Study-I [2]. A higher performance option based on a free mercury jet has been studied in 2001 as part of the Neutrino Factory Feasibility Study-II [3, 4]. An overview of a mercury jet target facility is presented here, including requirements, design concept and summaries of simulated performance. Further details are presented in related papers at this conference.

1 THE TARGET FACILITY

A muon collider [18] or a neutrino factory based on a muon storage ring [1, 2, 3, 4] require intense beams of muons, which are obtained from the decay of pions produced in proton-nucleus collisions. To maximize the yield, pions of momentum near 300 MeV/c should be captured, as illustrated in Fig. 1. For proton energies above 10 GeV, the pion yield per unit of proton beam energy is larger for a high- Z target [5]. For proton beam energies in the MW range, beam heating would melt/boil a stationary high- Z target, so a moving target must be used. A mercury jet target is the main option considered here, although several alternatives remain under active study [6, 7]. For greater detail, consult Chap. 3 of [3]. See also [8].

The low-energy pions are produced with relatively large

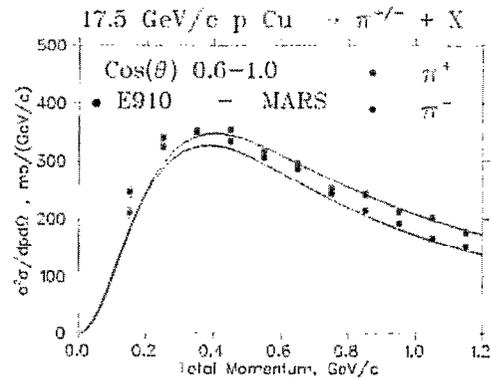


Figure 1: Comparison of pion yield measured in BNL E910 with a MARS calculation.

angles to the proton beam, and efficient capture into a decay and phase rotation channel [9] is obtained by surrounding the target with a 20-T solenoid magnet, whose field tapers down to 1.25 T over several meters, as sketched in Fig. 2. Pion yield is maximized with a mercury target in the form a 1-cm-diameter cylinder, tilted by about 100 mrad with respect to the magnetic axis. To permit the proton beam to interact with the target over 2 interaction lengths, the proton beam is tilted by 33 mrad with respect to the mercury jet axis. See also Fig. 3.

A mercury pool inside the capture solenoid intercepts the mercury jet and the unscattered proton beam, as shown in Fig. 4. The mercury pool, surrounding tungsten carbide/water shielding, and the resistive insert of the 20-T capture magnet [10] are isolated from upstream and downstream beamline elements by a pair of double-walled Be windows. This entire unit can be replaced by remote manipulation should failure occur. The absorbed radiation dose on components near the target is quite large [5], as illustrated in Fig. 5, such that in a 4 Mw proton beam, their

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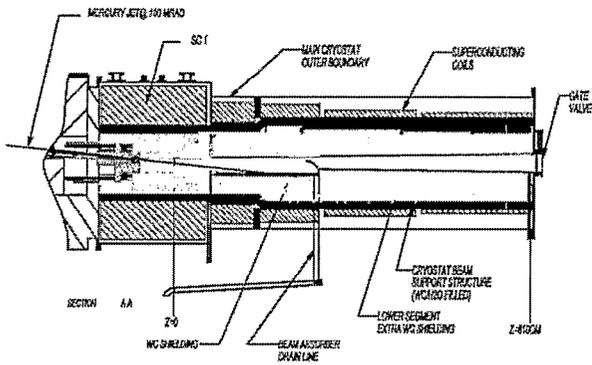


Figure 2: Sketch of the target and capture system based on a mercury jet inside a 20-T solenoid magnet.

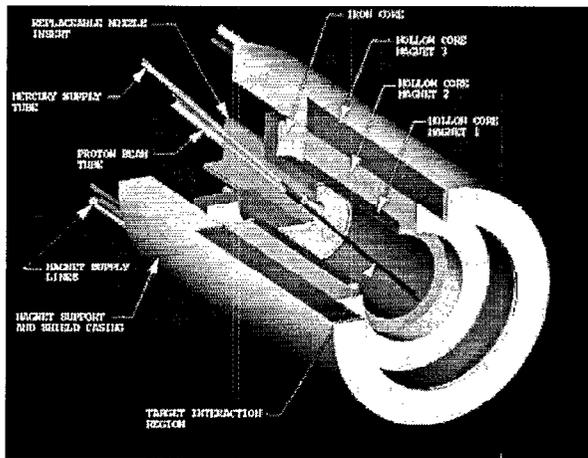


Figure 3: The inner region of the 20-T capture magnet along with the tilted mercury jet target and proton beam.

lifetime against radiation damage may only be 5 years.

The capture solenoid is encased in thick concrete shielding as part of the target facility that includes an overhead crane, hot cells with remote manipulation capability, and a mercury pumping and purification loop [11], as sketched in Fig. 6.

The use of a mercury jet target raises several novel issues. The rapid energy deposition in the mercury target by the proton beam leads to intense pressure waves that can disperse the mercury [12, 13, 14]. Further, as the mercury enters the strong magnetic field eddy currents are induced in the mercury, and the Lorentz force on these currents could lead to distortion of the jet [15, 16]. On the other hand, the magnetic pressure on the mercury once inside the solenoid will damp mechanical perturbation of the jet.

An R&D program is underway to assess these critical issues [17].

2 REFERENCES

[1] C. Albright *et al.*, *Physics at a Neutrino Factory*, hep-ex/0008064.
 [2] N. Holtkamp, D. Finley, eds., *A Feasibility Study of a Neu-*

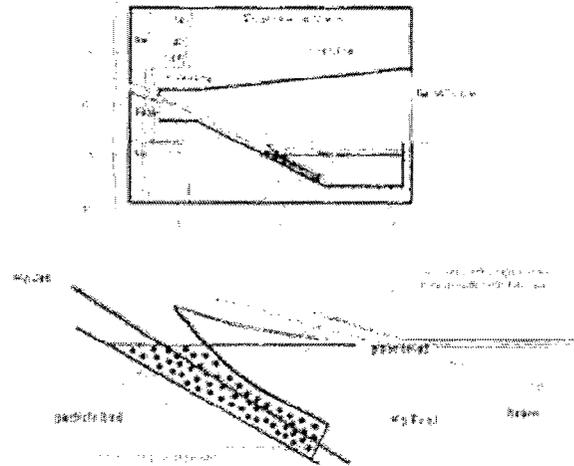


Figure 4: A mercury pool inside the capture solenoid intercepts the mercury jet and the unscattered proton beam.

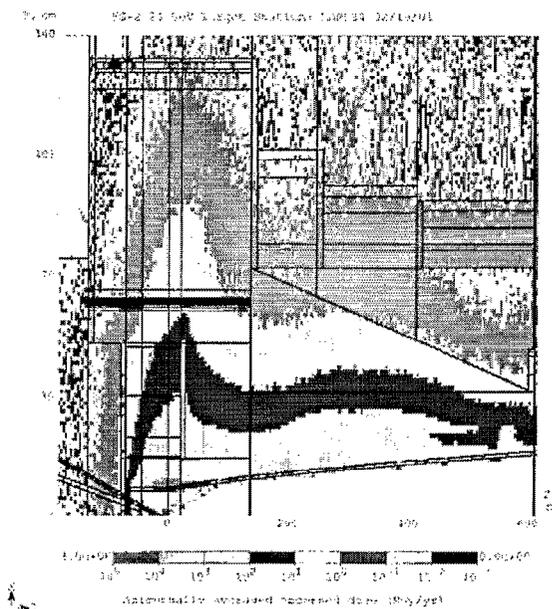


Figure 5: Absorber radiation dose in the pion capture system per 2×10^7 s of a 1-MW, 24-GeV proton beam on a mercury target.

trino Source Based on A Muon Storage Ring,
http://www.fnal.gov/projects/muon_collider/nu-factory/

[3] S. Ozaki *et al.*, eds., *Feasibility Study-II of a Muon-Based Neutrino Source*,
<http://www.cap.bnl.gov/mumu/studyii/FS2-report.html>
 [4] R. Palmer *et al.*, *A Second Feasibility Study of a Muon Storage Ring Neutrino Factory*, PAC2001, FOAC007.
 [5] N. Mokhov, *Particle Production and Radiation Environment at a Neutrino Factory Target Station*, PAC2001, FOAC10.
 [6] B. King *et al.*, *An Inconel Rotating Band Pion Production Target for Neutrino Factories and Muon Colliders*, PAC2001, TPAH136.

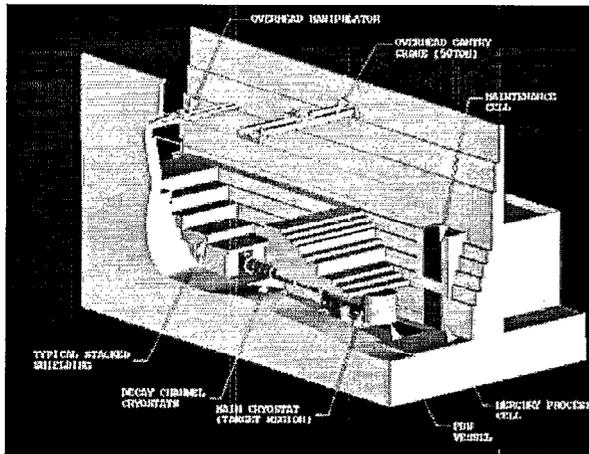


Figure 6: Sketch of the target facility.

- [7] V. Balbekov and N. Mokhov, *Low-Budget Muon Source*, PAC2001, TPAH144.
- [8] T. Gabriel *et al.*, *Targets for High-Intensity Particle Production*, PAC2001, FOAC008.
- [9] H. Kirk *et al.*, *Phase Rotation at the Front End of a Neutrino Factory*, PAC2001, TPPH161.
- [10] R. Weggel *et al.*, *Design Study for 20 T, 15 cm Bore Hybrid Magnet with Radiation-Resistant Insert for Pion Capture*, PAC2001, RPPH074.
- [11] P. Spampinato *et al.*, *Target Enclosure/System Design for a Mercury-Target Neutrino Producing Facility*, PAC2001, TPAH154.
- [12] N. Simos *et al.*, *Thermodynamic Interaction of the Primary Proton Beam with a Mercury Jet Target at a Neutrino Factory Source*, PAC2001, RPAH076.
- [13] A. Hassanein and I. Konkashbaev, *Thermoelastic Response of Suddenly Heated Liquid and Solid Targets for High Power Colliders*, PAC2001, RPAH071.
- [14] R. Samulyak and W. Oh, *Global Numerical Modeling of the Muon Collider Target*, PAC2001, TPAH139.
- [15] S. Kahn *et al.*, *Calculations for a Mercury Jet Target in a Solenoid Magnet Capture System*, PAC2001, ROPB010.
- [16] A. Hassanein and I. Konkashbaev, *Dynamics of Liquid Metal Jets Penetrating a Strong Magnetic Field*, PAC2001, ROPB009.
- [17] K. Brown *et al.*, *The R&D Program for Targetry at a Neutrino Factory*, PAC2001, TPAH156.
- [18] C.M. Ankenbrandt *et al.* (The Muon Collider Collaboration), *Status of muon collider research and development and future plans*, *Phys. Rev. ST Accel. Beams* **2**, 081001 (1999), <http://prst-ab.aps.org/abstract/PRSTAB/V2/i8/E081001/>