Carbon and Mercury Targets for Neutrino Beams and a Muon Collider Source

(BNL E951)

K.T. McDonald
Princeton U.

ICFA Workshop, Fermilab, Apr. 9, 2002

http://puhep1.princeton.edu/mumu/target/
Challenges

- Maximal production of soft pions $\rightarrow$ muons in a megawatt proton beam.
- Capture pions in a 20-T solenoid, followed by a 1.25-T decay channel.
- A carbon target is feasible for 1.5-MW proton beam power.
- For $E_p \gtrsim 16$ GeV, factor of 2 advantage with high-$Z$ target.
- Static high-$Z$ target would melt, $\Rightarrow$ Moving target.
- A free mercury jet target is feasible for beam power of 4 MW (and more).
The Neutrino Horn Issue

- A precursor to a Neutrino Factory is a Neutrino Superbeam based on decay of pions from a multimegawatt proton target station.
- 4 MW proton beams are achieved in both the BNL and FNAL (and CERN) scenarios via high rep rates: $\approx 10^6$/day.
- Classic neutrino horns based on high currents in conductors that intercept much of the secondary pions will have lifetimes of only a few days in this environment.
- Consider instead a solenoid horn with conductors at larger radii than the pions of interest – similar to the Neutrino Factory capture solenoid.
- Adiabatic reduction of the solenoid field along the axis, $\Rightarrow$ Adiabatic reduction of pion transverse momentum, $\Rightarrow$ Focusing.

A carbon-carbon composite with near-zero thermal expansion is largely immune to beam-induced pressure waves.

Sublimation of carbon is negligible in a helium atmosphere.

Radiation damage is limiting factor: $\approx 12$ weeks at 1 MW.

A rotating band target is another option:
Pion/Muon Yield

For $E_p \gtrsim 10$ GeV, more yield with high-Z target.

Mercury target radius should be $\approx 5$ mm, with target axis tilted by $\approx 100$ mrad to the magnetic axis.

Can capture $\approx 0.3$ pion per proton with $50 < P_\pi < 400$ MeV/c.
Mercury jet target inside a magnetic bottle: 20-T around target, dropping to 1.25 T in the pion decay channel.

Mercury jet tilted by 100 mrad, proton beam by 67 mrad.
Lifetime of Components in the High Radiation Environment

<table>
<thead>
<tr>
<th>Component</th>
<th>Radius (cm)</th>
<th>Dose/yr (Grays/2 × 10^7 s)</th>
<th>Max allowed Dose (Grays)</th>
<th>1 MW Life (years)</th>
<th>4 MW Life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner shielding</td>
<td>7.5</td>
<td>5 × 10^{10}</td>
<td>10^{12}</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Hg containment</td>
<td>18</td>
<td>10^9</td>
<td>10^{11}</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Hollow conductor</td>
<td>18</td>
<td>10^9</td>
<td>10^{11}</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Superconducting</td>
<td>65</td>
<td>5 × 10^6</td>
<td>10^8</td>
<td>20</td>
<td>5</td>
</tr>
</tbody>
</table>

Some components must be replaceable.

Kirk T. McDonald

April 9, 2002
Viability of Targetry and Capture For a Single Pulse

- Beam energy deposition may disperse the jet.

- Eddy currents may distort the jet as it traverses the magnet.
Overall Goal: Test key components of the front-end of a neutrino factory in realistic single-pulse beam conditions.

Near Term (1-2 years): Explore viability of a liquid metal jet target in intense, short proton pulses and (separately) in strong magnetic fields.

Mid Term (3-4 years): Add 20-T magnet to beam tests; Test 70-MHz rf cavity (+ 1.25-T magnet) 3 m from target; Characterize pion yield.
The Neutrino Factory and Muon Collider Collaboration

The E951 Collaboration


a Argonne National Laboratory, Argonne, IL 60439
b Brookhaven National Laboratory, Upton, NY 11973
c University of California, Los Angeles, CA 90095
d CERN, 1211 Geneva, Switzerland
e Fermi National Laboratory, Batavia, IL 60510
f Grenoble High Magnetic Field Laboratory, 38042 Grenoble, France
g Lawrence Berkeley National Laboratory, Berkeley, CA 94720
h Michigan State University, East Lansing, MI 48824
i Oak Ridge National Laboratory, Oak Ridge, TN 37831
j Princeton University, Princeton, NJ 08544

1 Project Manager. Email: kirk@electron.cap.bnl.gov
2 Spokesperson. Email: mcdonald@puphep.princeton.edu

Kirk T. McDonald April 9, 2002
Solid Target Tests (5e12 ppp, 24 GeV, 100 ns)

Carbon, aluminum, Ti90Al6V4, Inconel 708, Havar, instrumented with fiberoptic strain sensors.
Passive Mercury Target Tests

Exposures of 25 µs at $t = 0, 0.5, 1.6, 3.4$ msec,
⇒ $v_{\text{splash}} \approx 20 - 40$ m/s:

Two pulses of $\approx 250$ ns give larger dispersal velocity only if separated by less than 3 µs.
Studies of Proton Beam + Mercury Jet

1-cm-diameter Hg jet in 2e12 protons at t = 0, 0.75, 2, 7, 18 ms.

Model: \[ v_{\text{dispersal}} = \frac{\Delta r}{\Delta t} = \frac{r \alpha \Delta T}{r/v_{\text{sound}}} = \frac{\alpha U}{C} v_{\text{sound}} \approx 50 \text{ m/s} \]

for \( U \approx 100 \text{ J/g} \).

Data: \( v_{\text{dispersal}} \approx 10 \text{ m/s} \) for \( U \approx 25 \text{ J/g} \).

\( v_{\text{dispersal}} \) appears to scale with proton intensity.

The dispersal is not destructive.
Tests of a Mercury Jet in a 13 T Magnetic Field
(CERN/Grenoble High Magnetic Field Laboratory)

Eddy currents may distort the jet as it traverses the magnet.

Analytic model suggests little effect if jet nozzle inside field.

4 mm diam. jet, \( v = 4.6 \text{ m/s}, B = 0 \text{ T}; v = 4.0 \text{ m/s}, B = 13 \text{ T}: \)

⇒ Damping of surface tension waves (Rayleigh instability).
20-T Capture Magnet System

Inner, hollow-conductor copper coils generate 6 T @ 12 MW:

Bitter-coil option less costly, but marginally feasible.

Outer, superconducting coils generate 14 T @ 600 MJ:

Cable-in-conduit construction similar to ITER central solenoid.

Both coils shielded by tungsten-carbide/water.
Target System Support Facility

Extensive shielding; remote handling capability.
Summary of Targetry Activities Through FY01

- A target system based on a mercury jet in a 20-T capture solenoid is feasible at 1-4 MW beam power.
- Solid target alternatives include graphite rods or a rotating nickel band.
- An early upgrade to 4-MW may be the quickest path to higher neutrino fluxes.
- Continued R&D is needed. The next step is a combined test of a mercury jet in a proton beam and in a 20-T pulsed magnet (BNL E951 phase 2).
A 15-T Liquid-Nitrogen-Precooled Pulsed Magnet + 2.2 MW Power Supply

- Reduce field by 2 ⇒ forces, costs drops by ≈ 4.
- Preliminary Design by MIT Plasma Science Div. (Titus).
- Can build PS from existing BNL supplies for ≈ $250k (Marneris).
- Cool to 30 K via He gas flow + LH$_2$ head exchanger (Iarocci).