The Target System and Support Facility
at a Muon-Based Neutrino Source

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Neutrino Factory Feasibility Study-II Closeout

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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).
Feasibility Issues

- Pion/muon yield.
- Lifetime of components in high radiation environment.
- Mercury jet interaction with beam and magnet.
- Design of the 20-T capture magnet.
- Beam entrance and exit windows.
- Proton beam absorber.
- Mercury flow loop.
- Target system support facility.
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>coil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superconducting coil</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.
The Neutrino Factory and Muon Collider Collaboration

Proton Beam Will Disperse the Mercury Jet

FronTier simulation, 0 - 30 $\mu$s:

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 $U \approx 100$ J/g.

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

The dispersal is not destructive.
Eddy currents may distort the jet as it traverses the magnet.

Analytic model suggests little effect if jet nozzle inside field.

1 cm 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.
Double Beryllium Foil Beam Windows

Upstream window stressed by beam heating; must be replaceable.

60-cm-diam. downstream window stressed by pressure; must be removable. Double-curved profile favored.
The unscattered proton beam is absorbed in a “windowless” pool of mercury.

Baffles mitigate splashing of mercury due to entry of both the proton beam and the mercury jet.

The proton absorber is replacable.
110 l of mercury flow in a closed loop at 2 cycles/min.

Activation products can be distilled off in a hot cell.
Target System Support Facility

Extensive shielding; remote handling capability.
Summary

- 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).