The R&D Program for Targetry and Capture at a Neutrino Factory and Muon Collider Source

(BNL E951)

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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.
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.
Some components must be replacable.

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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


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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,
\[ \Rightarrow v_{\text{splash}} \approx 20 - 40 \text{ m/s} \]
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.
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, $v = 4.6 \text{ m/s, } B = 0 \text{ T}; v = 4.0 \text{ m/s, } B = 13 \text{ T}$:

$\Rightarrow$ 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.
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**Mercury Flow Loop**

110 l of mercury flow in a closed loop at 2 cycles/min.

Activation products can be distilled off in a hot cell.
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).