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

(K.T. McDonald)

MUTAC, Berkeley, CA, Oct. 19, 2001

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

- Maximal production of soft pions → 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, ⇒ 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 \( E_p \gtrsim 10 \text{ GeV} \), more yield with high-\( Z \) target.

Mercury target radius should be \( \approx 5 \text{ mm} \), with target axis tilted by \( \approx 100 \text{ mrad} \) to the magnetic axis.

Can capture \( \approx 0.3 \) pion per proton with \( 50 < P_\pi < 400 \text{ MeV/c} \).
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 replaceable.

Kirk T. McDonald  
October 19, 2001
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


Argonne National Laboratory, Argonne, IL 60439
Brookhaven National Laboratory, Upton, NY 11973
University of California, Los Angeles, CA 90095
CERN, 1211 Geneva, Switzerland
Fermi National Laboratory, Batavia, IL 60510
Grenoble High Magnetic Field Laboratory, 38042 Grenoble, France
Lawrence Berkeley National Laboratory, Berkeley, CA 94720
Michigan State University, East Lansing, MI 48824
Oak Ridge National Laboratory, Oak Ridge, TN 37831
Princeton University, Princeton, NJ 08544
Solid Target Tests ($5 \times 10^{12}$ ppp, 24 GeV, 100 ns)

Carbon, aluminum, Ti90Al6V4, Inconel 708, Havar, instrumented with fiberoptic strain sensors.

\[\text{Incoming optical fiber} \quad \text{Gauge length} \quad \text{Fabry-Perot cavity length}\]

\[\text{Measured strain (500 KHz) in the 10-mil Aluminum Window} \quad \text{Beam Intensity} = 2.5 \text{ TP}\]

\[\text{Predicted strain in the 10-mil Aluminum Window} \quad \text{Beam Intensity} = 2.5 \text{ TP with 1mm RMS sigma}\]
Passive Mercury Target Tests

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

Exposures of 150 ns at $t = 0, 0.2, 0.4, 0.6$ and 0.8 msec,
$4 \times 10^{12}$ protons, $\Rightarrow v_{\text{splash}} \approx 75$ m/s (then slowed by air drag):
1-cm-diameter Hg jet in $2\times10^{12}$ protons at $t = 0, 0.75, 2, 7, 18$ ms.

Model: $v_{\text{dispersal}} = \frac{\Delta r}{\Delta t} = \frac{r\alpha\Delta T}{r/v_{\text{sound}}} = \frac{\alpha U}{C}v_{\text{sound}} \approx 50$ m/s for $U \approx 100$ J/g.

Data: $v_{\text{dispersal}} \approx 10$ m/s for $U \approx 25$ 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, $v = 4.6 \text{ m/s}, B = 0 \text{ T}; v = 4.0 \text{ m/s}, B = 13 \text{ T}$:

⇒ Damping of surface tension waves (Rayleigh instability).
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.
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).
Targetry R&D Activities in FY02

1. Continued studies with AGS beam in the A3 line.

2. Engineering design studies of the proposed 10-T pulsed magnet.

3. Studies of production of mercury jets up to 20 m/s.

4. Continued simulations of target interactions with beams and magnetic fields.
Continued Studies with AGS Beam in the A3 Line

• Primary goal: study interaction of mercury jet with a pulse of $1.6 \times 10^{13}$ protons. (Achieved only $4 \times 10^{12}$ in FY01.)

• Secondary goal: study interaction of a Wood’s metal jet with a proton beam.

Estimated Budget for AGS Operations

<table>
<thead>
<tr>
<th>Study Type</th>
<th>No. of Shifts</th>
<th>Ops (k)</th>
<th>Hardware (k)</th>
<th>Install (k)</th>
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<tbody>
<tr>
<td>A. Increase intensity of AGS</td>
<td>7</td>
<td>$70k$</td>
<td>$150k$</td>
<td>$10k$</td>
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<td>B. Extraction into dump</td>
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<td>$95k$</td>
<td>$40k$</td>
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<td>C. Extraction into A line</td>
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<td>$60-110k$</td>
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<td>D. Mercury target studies</td>
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<td>$25k$</td>
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<td><strong>Totals</strong></td>
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<td><strong>$300-350k</strong></td>
<td><strong>$220k</strong></td>
<td><strong>$40k</strong></td>
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Grand Total = $560-610k

Items A and B are generic AGS machine studies.

Kirk T. McDonald

October 19, 2001
Your request was for:
1) 5 shifts of SEB parasitic running;
2) 8 shifts of extraction and beam transport studies that are not parasitic on the SEB program.

The first goal of increasing AGS intensity is one that has general benefit to the AGS program and we can expect to provide this as requested. The second goal will have a significant impact on the SEB program and will depend both on the details of next year’s HEP budget and on the importance attached to this work by the MUTAC and MCOG. The MUTAC should be encouraged to comment on the value of the targeting experiment. Certainly, from the viewpoint of BNL, these studies will have general benefit for contemplated future AGS experiments as well as specific benefit for the Muon Storage Ring and Collider R&D program.

Therefore, I intend to provide the parasitic studies as soon as they can be organized (increasing the AGS intensity is going ahead right now with decent success) and will provide the remaining studies as best we can, perhaps developing a “stolen cycle” approach that is nearly parasitic to the SEB program. We have accomplished desirable studies in this mode before, but I can’t fully commit to this goal until I have consulted with the C-AD experts.
20-T Liquid-Nitrogen-Precooled Pulsed Magnet

5.0 MVA Magnet System to Generate 19-20 T throughout 0.15 m dia. by 0.6 m target region, ramping to 1.25 T at z = 3 m; bore ~ 1 / B^0.5

25 MVA Magnet System to Generate 19-20 T throughout 0.15 m dia. by 0.6 m target region, ramping to 1.25 T at z = 3 m; bore ~ 1 / B^0.5
## 20-T Pulsed Magnet Preliminary Budget Estimates

**I. Marneris, R. Weggel, 8/23/01**

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
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<td><strong>Substation</strong></td>
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<td>30 MVA rectifier</td>
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<td><strong>HV buswork</strong></td>
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<td>Transformer</td>
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<td><strong>LV buswork</strong></td>
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<td><strong>Total</strong></td>
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<td>Total</td>
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</tbody>
</table>

**Kirk T. McDonald**

**October 19, 2001**
A 10-T Magnet + 2.2 MW Power Supply

- Reduce field by 2 $\Rightarrow$ forces, costs drops by $\approx 4$.

- Preliminary Design by MIT Plasma Science Div. (Minervini).

- Can build PS from existing BNL supplies for $\approx \$250k$ (Marneris).

Preliminary estimate for new supply from Danfysik = $\$350k$. 

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The rectifier module shall be used to convert ORNL supplied, three phase, 60 Hz power into 400 VDC, 5000 amp, 2 MW, highly regulated, fully controllable power for the Spallation Neutron Source (SNS) Accumulator Ring main dipole magnet string.

Vendor list:
- Alpha Scientific Electronics
- Bruker Analytische Messtechnik, GmbH
- Danfysik A/S
- Dynapower Corporation
- F.u.G. Elektronik GmbH
- GE Industrial Systems
- IE Power
- Inverpower Controls, Ltd
- Neeltran, Inc.
- Siemens Energy & Automation
- Transtechnik Corp
**10-T Pulsed Magnet Preliminary Budget Estimates**

I. Marneris, J. Minervini, J. Scaduto, R. Weggel, 10/12/01

<table>
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<th>Scenario 3</th>
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