Neutrino Factory Feasibility Study 2: Parameters and Tasks for Targetry and Capture

K.T. McDonald

Princeton U.

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http://puhep1.princeton.edu/mumu/target/
From Initial Parameters for Study 2

2.1 Proton Driver

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy protons per bunch</td>
<td>24 GeV</td>
</tr>
<tr>
<td>bunches per fill</td>
<td>( \approx 1.7 \times 10^{13} )</td>
</tr>
<tr>
<td>time between extracted bunches</td>
<td>( \approx 20 ) ms</td>
</tr>
<tr>
<td>repetition rate</td>
<td>2.5 Hz</td>
</tr>
<tr>
<td>rms bunch length</td>
<td>( \leq 3 ) ns</td>
</tr>
<tr>
<td>beam power</td>
<td>( \geq 1 ) MW</td>
</tr>
</tbody>
</table>

Finite time between bunches is required for a number of reasons:

- To allow time to refill the RF cavities in the accelerating systems and avoid excessive beam loading;
- To avoid the need for multi pulsing of the induction linacs; and
- To allow the liquid target to be re-established after its assumed dispersal by the previous bunch. It is this requirement that sets the minimum spacing: The time required depends on the jet velocity and other parameters, and is not yet known. The number of 20 ms is a reasonable starting assumption. An even separation of bunches at 15 Hz would also be even better, but would require an accumulator ring.

The possibility of an average power greater than 1 MW, up to 1.5 MW should also be considered. This would correspond to the average power assumed in Feasibility Study 1.
Proposed Proton Driver Cycle

[75 ms]

6 extracted bunches
1.7e13 protons each

[475 ms]

[Based on possible AGS performance.]
From Initial Parameters for Study 2, cont’d.

2.2 Target

<table>
<thead>
<tr>
<th>material</th>
<th>mercury</th>
</tr>
</thead>
<tbody>
<tr>
<td>velocity</td>
<td>$\approx 20$ m/sec</td>
</tr>
<tr>
<td>length</td>
<td>30 cm</td>
</tr>
<tr>
<td>diameter</td>
<td>1 cm</td>
</tr>
<tr>
<td>angle to muon axis</td>
<td>100 mrad</td>
</tr>
<tr>
<td>displacement of front from axis</td>
<td>$\approx 1$ cm</td>
</tr>
</tbody>
</table>

A single proton bunch will heat the liquid to a temperature above its boiling point and generate substantial shock pressures. It is not believed that these will have significant adverse consequences, but, if it did, liquid lead/tin eutectic could be used. A graphite target (as used in study 1) could also be considered as a backup, but would reduce the neutrino intensity by a factor of 1.9 (see section 3.5).

To Be Done:

- Deflections and shape distortions of the liquid jet as it enters the magnetic field should be estimated (and later calculated when the programs became available), and the interaction of the proton beam with this distorted shape simulated.
- Production with lead/tin should be calculated and the optimum angle, length and radius determined for this case.
2.3 Capture and Matching Solenoids

The 20 T capture solenoid would be a hybrid, with copper (insert) and superconducting (outsert), magnet similar to that discussed in Feasibility Study 1. However, it is proposed here to use hollow copper conductor for the insert, rather than a Bitter style magnet in Study 1. The choice is aimed at achieving longer magnet life and avoiding any problems with highly irradiated water insulation. It is understood that the initial cost will be higher.

After the 20 T magnet, coils are designed to taper the axial field down slowly to 1.25 T over a distance of approximately 18 m. The form of the tapered field is approximately \( B(z) \approx 20/(1 + k \cdot z) \). The final design will have to include space for the beam dump and shielding.

To Be Done:

- Design Beam dump and shielding, and modify coil designs to allow for them.
3.5.3 Target Material & Proton Energy

For comparison with Feasibility Study 1, we have run MARS/ICOOL with a carbon target (80 cm long, at 50 mrad) and 16 GeV proton energy. These are given below together with the Study 1 values.

<table>
<thead>
<tr>
<th>Target</th>
<th>p energy</th>
<th>rms bunch length</th>
<th>( \mu/p )</th>
<th>( \mu/p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>24</td>
<td>3</td>
<td>0.20</td>
<td>0.164</td>
</tr>
<tr>
<td>Carbon</td>
<td>16</td>
<td>3</td>
<td>0.069</td>
<td>0.057</td>
</tr>
<tr>
<td>Carbon (Study 1)</td>
<td>16</td>
<td>3</td>
<td>0.018</td>
<td></td>
</tr>
</tbody>
</table>

So the gain over Study 1 from the capture and cooling design improvements is 3.2 \( \times \); the gain from the use of the mercury target is 1.9 \( \times \); and from the use of a larger accelerator acceptance is 1.2 \( \times \); for a total gain of 7.4 \( \times \). It should be noted that other authors have also reported cooling schemes with efficiencies substantially greater than those in the Feasibility Study 1. It is believed, nevertheless, that the scheme proposed here has significant advantages.
Engineering and Simulation Tasks

Four Topics:

1. The target itself.
   
   - Baseline design: Study 2 Parameters document
   
   - Critical issue: Will the first of 6 beam pulses disrupt the whole mercury jet?
   
   - Engineering: ORNL (?)
   
   - Simulation:
     
     - Pion production: H. Kirk, N. Mokhov
     
     - Thermal hydraulics of beam-jet interaction:
       
       R. Samulyak, N. Simos
     
     - Magnetohydrodynamics of beam-magnet interaction:
       
       S. Kahn, R. Samulyak
The center of the proton beam enters the mercury jet at the upstream end of the nominal 30 cm long interaction region:

Mars Simulation Results of Hg Target
L=30cm; r=5mm; Beam Tilt= 100mrad

Pion/Proton crossing downstream plane of target

<table>
<thead>
<tr>
<th>Target Tilt</th>
<th>133</th>
<th>100</th>
<th>67</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^-$</td>
<td>1.098</td>
<td>1.134</td>
<td>1.091</td>
</tr>
<tr>
<td>$\pi^+$</td>
<td>1.106</td>
<td>1.151</td>
<td>1.117</td>
</tr>
</tbody>
</table>
Thermal Hydraulics

R. Samulyak, using the FRONTIER code:

Beam + Hg jet (no magnetic field), $t = 0$:

Beam + Hg jet (no magnetic field), $t = 6 \text{ µs}$:

Magnetohydrodynamics being added to the code.
2. Beam Dump and Shielding

- Baseline design: I. Stumer

- Critical issues: Personnel safety;
  
  Radiation damage;

  Radionuclide activation.

- Engineering: ORNL (?)

- Simulation: H. Ludewig, N. Mokhov, I. Stumer

The proton beam is dumped, and the mercury jet collected, several meters downstream of the interaction region:
3. Mercury Handling

- Baseline design: SNS (ORNL) [+ ISOLDE (CERN)]
- Critical issues: 25 Atmosphere mercury loop; Radioactive byproducts
- Engineering: ORNL (?)
- Simulation: H. Ludewig, P. Spampinato
Mercuric Handling at the SNS

Fig. 5.3-1. Target system diagram.

Fig. 5.3-2. Target system configuration.
Engineering and Simulation Tasks, cont’d.

4. Capture Solenoid

- Baseline design: Study 2 Parameters document
- Critical issue: Hollow conductor vs. Bitter coils in resistive magnet
- Engineering: NHMFL, B. Weggel
- Simulation: Y. Eyssa, B. Weggel

![Diagram of a solenoid with labels for Copper Sheath, Copper Conductor, Insulator (MgO), and Water Cooling Passage.]

Development of Radiation-Resistant Magnets for the JHF Project