Target Options for a Neutrino Factory

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Objectives for Target Station

- Target Station is an engineering task
  - With scientific objectives
- Focus on NF (and MC?)
- Objective: maximise useful pion yield per $10^7$ s year of operation, over 10 (20?) year lifetime
- Yield = instantaneous yield $\times$ reliability
  - Instantaneous yield is most fun to study
    - has received (almost) all attention so far
  - Reliability includes:
    - Mean time between failure
    - Speed of target, (shield, solenoid etc) changeover
    - Difficult (and less fun) to assess
<table>
<thead>
<tr>
<th>Key target station issues</th>
<th>Candidate/required technologies</th>
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</thead>
</table>
| 1. Target                                    | 1a. Liquid Hg jet  
1b. Fluidised W powder  
1c. Solid W bars  
1d. Low Z targets                                   |
| 2. Beam window                               | Thin low Z windows (beryllium)                                                                     |
| 3. NC inner solenoid                         | Conventional copper                                                                               |
| 4. SC outer solenoid                         | 4a. Nb3Sn  
4b. HTS                                                                                         |
| 5. Solenoid shield                           | WC                                                                                                |
| 6. Target station engineering                | Target integration  
Remote maintenance  
Shielding                                              |
| 7. Beam dump                                 | 7a Liquid Hg  
7b For W bars?  
7c W powder?                                           |
| 8. Horn back-up? (2 drivers for 2 signs!)    | Conventional neutrino beam horn                                                                  |
| 9. Safety / environmental                    | !                                                                                                 |
NF vs MC?

- Muon Collider requires point-like source
- High Z target material strongly favoured
  - Liquid mercury jet is baseline
  - See Kirk MacDonald plenary talk tomorrow for latest news
- Convenient to regard Neutrino Factory target station as prototype for Muon Collider
- If one decouples NF from MC, does one end up with same answer?
- For a NF, are other options possible/preferable?
- Can the beam size be increased (from 1.2 mm (rms) baseline)?
Heat loads in baseline Target Station (J. Back)

Liquid mercury jet target
Baseline solenoid system: Two factors lead to significant technical challenges

1. Demanding Magnet Parameters - *High field (14 Tesla) in a large bore (1.3 m)*
   - Huge magnetic forces (10,000 Ton)
   - Large stored energy (~600 MJ)
   - Low temperature margin of superconductor
   - Pushing at the limits of present superconductor technology

2. Harsh Radiation Environment - *Heating and material damage Issues*
   - Heat load from 4 MW pulsed proton beam
     • Total Heat load into the cold mass
     • Local Power Density
     • Instantaneous pulsed heating effects
   - Radiation damage to materials
     • Superconductor
     • Stabiliser
     • Turn-to-turn insulation
     • Load Bearing Elements
Plus one or 2 liquid mercury jet challenges

Disruption of beam dump by mercury jet

Disruption of beam dump by non-disrupted proton beam

Tristan Davenne
Alternatives to liquid mercury jet?

A few personal comments:

• A neutrino factory will not be built any time soon
• The target station is likely to be the limiting factor in the performance of the facility
• Worth spending time looking at as wide a range of alternatives as possible
Fluidised tungsten powder: broadly compatible with baseline

- Rig contains 100 kg Tungsten
- Particle size < 250 microns
- Discharge pipe length c.1 m
- Pipe diameter = 2 cm
- Typ. 2-4 bar (net) pneumatic driving pressure (max 10 bar)

1. Suction / Lift
2. Load Hopper
3. Pressurise Hopper
4. Powder Ejection and Observation
Pneumatic Conveying Regimes Explored so Far

A. Solid Dense Phase
   - Pipeline full of material, 50% v/v
   - Low velocity
   - Not yet achieved in our rig – further work

B. Discontinuous Dense Phase
   - Low fraction of solid material
   - High velocity = erosion!
   - Used in vacuum recirculation line

C. Continuous Dense Phase

D. Lean Phase
   - Low fraction of solid material
   - High velocity = erosion!
   - Used in vacuum recirculation line
Schematic of implementation as a Neutrino Factory target

NB Alternative configurations possible
Pion+muon production for variable length 50% material fraction W vs 100% Hg

Dotted line is Hg jet yield for 10 GeV beam using Study II optimum tilt, beam & target radii

Acceptance criteria uses probability map to estimate acceptance through the cooling channel in (pT, pL) space.

MARS calculation by John Back, Warwick University

$r_{\text{beam}} = r_{\text{target}} = 0.5 \text{ cm}$

NB increasing target radius is another knob to tweak
## Meson Production at 8GeV (X.Ding)

<table>
<thead>
<tr>
<th>Target</th>
<th>50% W (9.65 g/cm³) with optimization*</th>
<th>Hg (13.54 g/cm³) with optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meson</td>
<td>29069 (pos: 14099, neg: 14970)</td>
<td>28819 (pos: 13613, neg: 15206)</td>
</tr>
</tbody>
</table>

*Target radius: 0.47 cm, target angle: 80mrad, target length: 45cm
Powder 'thimble' test is scheduled to be first ever experiment on HiRadMat this autumn
Re-circulating solid tungsten bar ideas

J. R. J. Bennett\textsuperscript{1}, G. P. Škoro\textsuperscript{2}, J. J. Back\textsuperscript{3}, D. W. J. Bellenger\textsuperscript{1}, C. N. Booth\textsuperscript{2}, T. R. Edgcock\textsuperscript{1,4}, S. A. Gray\textsuperscript{1}, D. M. Jenkins\textsuperscript{1}, L. G. Jones\textsuperscript{1}, A. J. McFarland\textsuperscript{1}, K. J. Rogers\textsuperscript{1}.

Helmholtz Coil Geometry

Target bars
That’s enough about heavy metals

- Is a low Z target an attractive option for a Neutrino Factory?
Target material & heat loads (A. Longhin)

Released power (MW) vs Ep. 4 MW input.

Power release (MW)

- Mercury L=30cm diam.=1.5cm
- Graphite L=78cm diam.=1.5cm

200 kW heat load in graphite = 10 x T2K heat load at 750 kW
Particle production vs target material

- Proton kinetic energy = 2-10 GeV
- Integrated pion yields comparable for carbon and mercury targets
- Neutron flux for Hg reduced by ~ x15 with C !!

(lower neutron flux => lower heating and radiation damage to solenoid system)

(A. Longhin)
Useful pion/muon yields for different Z’s and beam energies (J. Back)

- Study 2 NF geometry and B-map
- Acceptance probability histogram used at z=6m (based on ICOOL)
Packed bed ideas: more attractive for lower Z

Relevant papers:
- A helium gas cooled stationary granular target (Pugnat & Sievers) 2002 [considered for a neutrino factory target with 4MW beam]
- Conceptual Designs for a Spallation Neutron Target Constructed of a Helium-Cooled, Packed Bed of Tungsten Particles (Ammerman et al.) [ATW, 15MW power deposited, 36cm diameter]
Packed bed cannister in symmetrical transverse flow configuration

Cannister perforated with elliptical holes graded in size along length

Model Parameters
Proton Beam Energy = 4.5GeV
Beam sigma = 4mm
Packed Bed radius = 12mm
Packed Bed Length = 780mm
Packed Bed sphere diameter = 3mm
Packed Bed sphere material: Titanium Alloy
Coolant = Helium at 10 bar pressure
And let’s not forget about beam windows

- T2K beam window (M Rooney)
- Double-skinned titanium alloy window, cooled by helium gas
- Installed October 2009
- Designed for 30 GeV, 0.75 MW beam power
Yield strength of beryllium @ 260°C is around 200 MPa. This leaves a small safety factor for a beryllium window with these beam parameters.
A few comments on future programme

• Target technology
  - main focus of NF/MC target station work since Study II (ie last 10 years)
  - at least 1 ‘champion’ of each of 3/4 target technologies
  - Good to have alternatives (provided does not distract from other work that needs to be done – see below)

• Solenoid System
  - Most critical technological issue for NF/MC Target Station?
  - Study 2 baseline appears far from feasible
  - NB ‘Brute force’ solution with extra shielding:
    • Stored energy $\propto r^2$
    • Only very recently receiving any attention

• Activation/handling/safety/environmental issues
  - The other most serious feasibility issue?
  - Nobody working on it?
Cost / Design Issues

- Cost ⇔ technical risk
- Build costs ⇔ running costs?
- Integrated yield ⇔ integrated costs?
- Target Station Design choices depend on grasp of these issues
- May be worth revisiting:
  - Beam energy
  - Target Z
  - Beam size
  - Solenoids vs horns (and 2 proton drivers...)?