Targetry Concept for a Neutrino Factory

EMCOG Meeting

CERN

November 18, 2003
World wide interest in the development of new proton drivers
New physics opportunities are presenting themselves

- Neutron Sources
  - European Spallation Source
  - US Spallation Neutron Source
  - Japanese Neutron Source
- Kaons
  - RSVP at BNL
  - KAMI at FNAL
- Muons
  - MECO and g-2 at BNL
  - SINDRUM at PSI
  - EDM at JPARC
  - Muon Collider
- Neutrinos
  - Superbeams
  - Neutrino Factories
Multi-MW New Proton Machines

SNS at 1.2 MW → 2.0 MW
JPARC 0.7 MW → 4.0 MW
FNAL 0.4 MW → 1.2 MW → 2.0 MW
BNL 0.14 MW → 1.0 MW → 4.0 MW

AGS Upgrade to 1 MW

High Intensity Source plus RFQ
200 MeV Drift Tube Linac
200 MeV
400 MeV
800 MeV
1.2 GeV

BOOSTER

AGS
1.2 GeV → 28 GeV
0.4 s cycle time (2.5 Hz)

0.2 s

To Target Station
To RHIC

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High-power Targetry Challenges

High-average power and High-peak power issues

- Thermal management
  - Target melting
  - Target vaporization
- Thermal shock
  - Beam-induced pressure waves
- Radiation
  - Material properties
  - Radioactivity inventory
  - Remote handling

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New physics opportunities are demanding more intense proton drivers.

1 MW machines are almost here! 4 MW machines are planned.

Targets for 1 MW machines exist but are unproven.

But no convincing solution exists yet for the 4 MW class machines.

Worldwide R&D efforts to develop targets for these new machines.

A key workshop concern was the lack of worldwide support facilities where promising new ideas can be tested.
Neutrino Factory

- Key parameter is neutrino flux
- Source strength is pre-eminent issue
- Maximize protons-on-target in order to maximize pions/muons collected

Muon collider

\[ L = \frac{N_1 N_2 f}{A} \text{cm}^{-2} \text{s}^{-1} \]

- Gain in luminosity proportional to the square of source strength
- Small beam cross-sectional area (beam cooling) is also important

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Neutrino Factory Targetry Concept

Capture low $P_T$ pions in high-field solenoid
Use Hg jet tilted with respect to solenoid axis
Use Hg pool as beam dump

Engineered solution--P. Spampinato, ORNL
Achieving Intense Muon Beams

Maximize Pion/Muon Production

- Soft Pion Production
  - Higher Z material
    - High energy deposition
    - Mechanical disruption
  - High Magnetic Field

\[ \text{Meson Production - 16 GeV } p + W \]

\[ dN/dKE \ (1/\text{GeV}/\text{interacting proton}) \]

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High-Z Materials

Key Properties

- Maximal soft-pion production
- High pion absorption
- High peak energy deposition
- Potential for extension beyond 4 MW (liquids)

Key Issues

- Jet dynamics in a high-field solenoid
- Target disruption
- Achievement of near-laminar flow for a 20 m/s jet
E951 Hg Jet Tests

- 1cm diameter Hg Jet
- 24 GeV 4 TP Proton Beam
- **No** Magnetic Field

![Diagram of proton beam and mercury jet](image)

- $t = 0 \text{ ms}$
- $t = 0.75 \text{ ms}$
- $t = 2 \text{ ms}$
- $t = 7 \text{ ms}$
- $t = 18 \text{ ms}$
CERN Passive Hg Thimble Test

Exposures to a BNL AGS 24 GeV 2 TP beam. T=0, 0.5, 1.6 and 3.4 ms.

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CERN Hg Thimble Results

Simulations—Prykarpatskyy, BNL

Bulk ejection velocity as a function Of beam spot size. ISOLDE data is 17 TP at 1.4 GeV.
Key E951 Results

- Hg jet dispersal proportional to beam intensity
- Hg jet dispersal $\sim 10$ m/s for 4 TP 24 GeV beam
- Hg jet dispersal velocities $\sim \frac{1}{2}$ times that of “confined thimble” target
- Hg dispersal is largely transverse to the jet axis -- longitudinal propagation of pressure waves is suppressed
- Visible manifestation of jet dispersal delayed 40 $\mu$s
CERN/Grenoble Hg Jet Tests

- 4 mm diameter Hg Jet
- \( v = 12 \text{ m/s} \)
- 0, 10, 20T Magnetic Field
- No Proton Beam

A. Fabich, J. Lettry
NuFact’02

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Key Jet/Magnetic Field Results

- The Hg jet is stabilized by the 20 T magnetic field
- Minimal jet deflection for 100 mrad angle of entry
- Jet velocity reduced upon entry to the magnetic field
Simulations at BNL (Samulyak)

Gaussian energy deposition profile
Peaked at 100 J/g. Times run from 0 to 124 μs.

Jet dispersal at t=100 μs with magnetic Field varying from B=0 to 10T
Bringing it all Together

We wish to perform a proof-of-principle test which will include:

- A high-power intense proton beam (16 to 32 TP per pulse)
- A high (> 15T) solenoidal field
- A high (> 10m/s) velocity Hg jet
- A ~1cm diameter Hg jet

Experimental goals include:

- Studies of 1cm diameter jet entering a 15T solenoid magnet
- Studies of the Hg jet dispersal provoked by an intense pulse of a proton beam in a high solenoidal field
- Studies of the influence of entry angle on jet performance
- Confirm Neutrino factory/Muon Collider Targetry concept
70° K Operation
15 T with 4.5 MW Pulsed Power
15 cm warm bore
1 m long beam pipe

Peter Titus, MIT

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Pulsed Solenoid Performance

Pulse Coil Cooled to 70 K and Charged to 7200 A at 600 V, then -600 V

- 5T Peak Field with 2 inner coils; 540 KVA; 80° K
- 10T Peak Field with 2 inner coils; 2.2 MVA PS; 72° K
- 15T Peak Field with 3 coils; 2.2 MVA PS; 30° K
- 15T Peak Field with 3 coils; 4.4 MVA PS; 70° K

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## Possible Target Test Station Sites

### Accelerator Complex Parameters:

<table>
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<tr>
<th>Parameter</th>
<th>BNL AGS</th>
<th>CERN PS</th>
<th>RAL ISIS</th>
<th>LANCE WNR</th>
<th>JPARC RCS</th>
<th>JPARC MR</th>
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<td>28</td>
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<td>300</td>
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<td>06</td>
<td>Now</td>
<td>08</td>
<td>09</td>
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Possible Targetry Test at JPARC

Target Test Site at CERN
Possible Experiment Location at CERN


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A Letter of Intent to
the ISOLDE and Neutron Time-of-Flight
Experiments Committee

Studies of a Target System for
a 4-MW, 24-GeV Proton Beam

J. Roger J. Bennett\textsuperscript{1}, Luca Bruno\textsuperscript{2}, Chris J. Densham\textsuperscript{1}, Paul V. Drumm\textsuperscript{1},
T. Robert Edgecock\textsuperscript{1}, Helmut Haseroth\textsuperscript{2}, Yoshinari Hayato\textsuperscript{3}, Steven J. Kahn\textsuperscript{4},
Jacques Lettry\textsuperscript{2}, Changguo Lu\textsuperscript{5}, Hans Ludewig\textsuperscript{4}, Harold G. Kirk\textsuperscript{4},
Kirk T. McDonald\textsuperscript{5}, Robert B. Palmer\textsuperscript{4}, Yarema Prykarpatsky\textsuperscript{4},
Nicholas Simos\textsuperscript{4}, Roman V. Samulyak\textsuperscript{4}, Peter H. Thieberger\textsuperscript{4},
Koji Yoshimura\textsuperscript{3}

Spokespersons: H.G. Kirk, K.T. McDonald
Local Contact: H. Haseroth

Participating Institutions

1) RAL
2) CERN
3) KEK
4) BNL
5) Princeton University

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We propose running without longitudinal bunch compression allowing for a reduced beam spot size of ~2mm rms radius.
Original Cryogenic Concept at BNL

- BNL specific solution
- Heat exchanger
- LH₂ or LN₂ primary cooling
- Circulating gaseous He secondary cooling
Simplified Cryogenic System
Battery Power Supply R&D

Battery/Charger
12V  1400A

Mech. Switch
1500V 1600 A

IGCT 600V 4000A

Load
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Battery Power Supply (Cont)

Mechanical Switch capable of 4.4 MW Pulsed System
Pulsed Solenoid Project Cost Profile

Magnet
- Fabrication $410 K
- Monitoring $80 K
- Testing $90 K
- Shipping $15 K

Cryogenic System (LN$_2$ without Heat Exchanger)
- Cryo $300 K

PS (Battery array with switching/charging/bussing)
- PS System $460 K

Total Project Cost $1355 K