Targetry and Capture Issues at a Neutrino-Factory/Muon-Collider Source

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November 17, 1999

ACCAPP’99, Long Beach, CA

http://puhep1.princeton.edu/mumu/target/
Muon Requirements

• $\approx 10^{14} \mu^\pm/s$ for either a muon collider or a neutrino factory.

• The muons come from the decay of soft pions produced in $p$-nucleus collisions.

• **Our strategy is to maximize the ratio of captured muons per proton.**

  *i.e.*, to minimize the proton requirements.

• Goal: $0.1\mu/p$ delivered for physics use.

The Source

• The muons come from the decay of soft pions produced in $p$-nucleus collisions.

• Need at least $1.5 \times 10^{15} \ p/s$ at 16-24 GeV

  $\Leftrightarrow$ 4 MW beam power.

• Initial muon emittance is about $10^6$ larger than desired

  $\Rightarrow$ Need fast cooling.

• [Our muon beam is $10^6$ times hotter than existing beams.]
The Muon Source

- Pion production peaks at $P_{\parallel} \approx 350 \text{ MeV}/c$; $P_{\perp} \lesssim 200 \text{ MeV}/c$.

- Capture the soft pions in a solenoid magnet channel.

- Capture efficiency improved with a stronger (20 T) field on the target than in the main channel (1.25 T). [Adiabatic invariance reduces the pion $P_{\perp}$ when going from high to low $B$.]

- High-$Z$ target without nearby cooling structure that would absorb pions.

- Liquid mercury jet target.

- Soft pions have $v/c < 1$, ⇒ Disperse while drifting
  ⇒ Begin RF manipulation as soon as possible to form a bunch with reduced energy spread (Phase Rotation).
Overview of Targetry and Capture

- $1.2 \times 10^{14} \mu^+/s$ via $\pi$-decay from a 4-MW proton beam.
- Proton pulse $\approx 1$ ns rms.
- Mercury jet target.
- 20-T capture solenoid followed by a 1.25-T $\pi$-decay channel with phase-rotation via rf (to compress energy of the muon bunch).
Targetry and Capture Issues

• Is a liquid jet target viable?

  – 1-ns beam pulse $\Rightarrow$ shock heating of target.
  – Resulting pressure wave may disperse liquid (or crack solid).
  – Damage to target chamber walls?
  – Magnetic field will damp effects of pressure wave.
  – Eddy currents arise as metal jet enters the capture magnet.
  – Jet is retarded and distorted, possibly dispersed.
  – Hg jet studied at CERN, but not in beam or magnetic field:

  ![High-speed photographs of mercury jet target for CERN-PS-AA (laboratory tests)
  4,000 frames per second, Jet speed: 20 ms$^{-1}$, diameter: 3 mm, Reynold's Number:$>$100,000
  A. Poncet](image-url)
• Is the first rf cavity viable?
  
  – High-gradient (5 MeV/m), low-frequency ($\approx 70$ MHz) rf cavity only 3 m downstream of target.
  
  – $> 10^{14}$ particles traverse the cavity each proton pulse; many hit the cavity wall.
  
  – Cavities tested against breakdown from beam-induced showers only up to $\approx 10^{12}$ particles/pulse.

• Is the 20-T Solenoid viable?
  
  – Even with water-cooled tungsten inserts, this hybrid (copper/superconductor) magnet will experience a very high radiation dose.
  
  – LANL, MSU have experience with superconducting magnets in high radiation areas.

• Other Radiological Issues
  
  – A 4-MW beam leads to activation issues characteristic of neutron spallation sources.
  
  – Remote handling of activated liquid target material is under study at CERN ISOLDE, the ORNL NSNS, ...
R&D Goals

**Long Term:** Provide a facility to test key components of the front-end of a neutrino factory/muon collider in realistic 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. (Change target technology if encounter severe difficulties.)

**Mid Term (3-4 years):** Add 20-T magnet to AGS beam tests; Test 70-MHz rf cavity (+ 1.25-T magnet) downstream of target; Characterize pion yield.
An R&D Program for Targetry and Capture
at a Muon Collider Source

A Proposal to the BNL AGS Division

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(Submitted Sept. 28, 1998; approved as BNL E951 Oct. 1, 1999)

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The 8 Steps in the R&D Program

1. Simple tests of liquid (Ga-Sn, Hg) and solid (Ni) targets with AGS Fast Extracted Beam (FEB).

2. Test of liquid jet entering a 20-T magnet (20-MW cw Bitter magnet at the National High Magnetic Field Laboratory).

3. Test of liquid jet with $10^{14}$ ppp via full turn FEB (without magnet).

4. Add 20-T pulsed magnet (4-MW peak) to liquid jet test with AGS FEB.

5. Add 70-MHz rf cavity downstream of target in FEB.

6. Surround rf cavity with 1.25-T magnet. At this step we have all essential features of the source.

7. Characterize pion yield from target + magnet system with slow extracted beam (SEB).

8. Ongoing simulation of the thermal hydraulics of the liquid-metal target system.
Step 1: Initial Tests with FEB

- Site presently under consideration: A3 line.

- First test: liquid metal in a trough, a pipe and in free flow.
- Instrumentation: high-speed camera, fiberoptic strain sensors (Duncan Earl, ORNL).
Step 2: Pulsed Liquid Jet

- Inspiration:

- Hg jet under construction at CERN (Colin Johnson, Helge Ravn), and at Princeton.
Step 3: Full Turn Extraction

- G10 kicker can deliver beam to A-C lines as well as to U line.
- Present power supply sufficient to kick out only 1 bunch.
- Upgrade to kick out all 6 bunches requires $\approx 18$ months.
- Initiate design work in FY00 to complete upgrade in FY01.
Step 4: Pulsed 20-T Magnet

- The copper magnet will be cooled by LN$_2$, and can be pulsed once every 10 minutes. Pulse duration $\approx 1$ s.

- Engineers: Bob Weggel, Bill Sands, designer: Bob Duffin.

- 4 MW (peak) power to be bussed from the MPS power supply house to the A3 line (Andy Soukas).

- 100 liters of LN$_2$ boiled off each pulse; vent outside of cave.

- A DC magnet is required as a transition between the pulsed magnet and the DC superconducting magnet around the rf cavity. This will require $\approx 1$ MW average power.
Step 5: 70-MHz RF Cavity

- Cavity has 60-cm-diameter iris, 2-m outer diameter.
  (Jim Rose, BNL, Werner Pirkl, CERN)

- 4-6 MW peak power to be supplied by four 8973 tubes recommissioned from the LBL Hilac.
  (Vince LoDestro, BNL; Don Howard, LBL)

- We are also embarking on an R&D program with industry to develop a 50-MW peak power, 70-MHz power supply
  (EEV, Eimac, Litton, Thomson).
Step 6: 1.25-T Solenoid Around RF Cavity

- Present plan: use PEP-4 TPC superconducting solenoid (Mike Green, LBL).
Step 7: Characterization of Pion Yield

- The final measure of system performance is the capture of soft pions that later decay to muons.
- Add bent solenoid spectrometer downstream of TPC magnet.
- Instrument with low-pressure TPC’s and aerogel Čerenkov counters.
- Collect data with slow beam, $< 10^6$ ppp.
- Compare with extrapolations from data of E-910.
Step 8: Simulation of Beam-Jet-Magnet

- ANSYS simulation (Changguo Lu, Princeton):

![Simulation Diagram](image)

- HEIGHTS simulation (Ahmed Hassanein, ANL):

Mercury Jet with 4 mm Beam and B-field Diffused in
Schedule of Targetry & Capture R&D

• FY99:
  Begin preparations of BNL A3 area; begin work on liquid jets.

• FY00:
  Initial beam tests in A3 line. Liquid jet test at NHMFL.
  (600 hours of AGS beamtime);
  Begin work on extraction upgrade, magnet systems,
  and rf systems.

• FY01:
  Complete extraction upgrade; test of liquid jet + beam.
  (600 hours).

• FY02:
  Complete magnet and rf systems; test with 2 ns beam.
  (600 hours).

• FY03:
  Complete pion detectors; test with low intensity SEB.
  (600 hours).