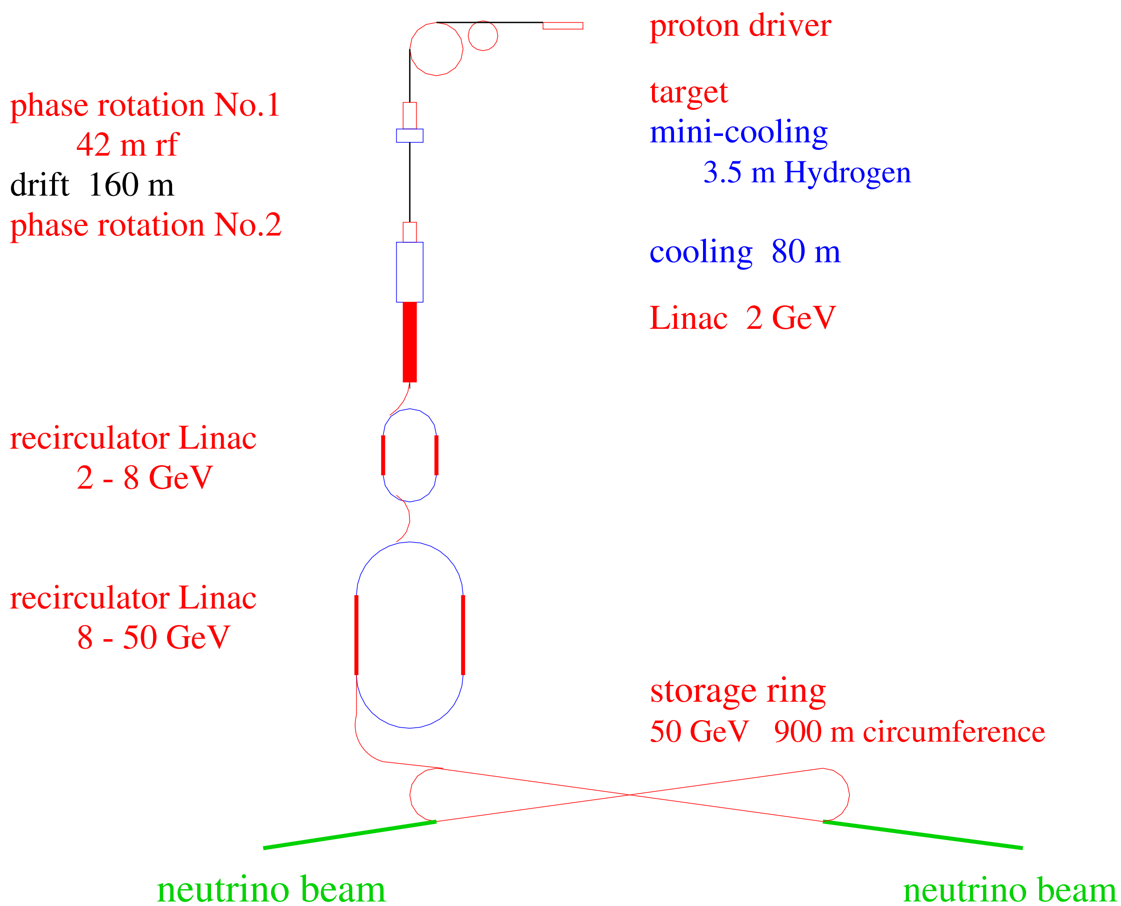
The R&D Program for Targetry and Capture at a Neutrino Factory/Muon-Collider Source



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Neutrino Factory/Muon Collider Collaboration Meeting

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

The Opportunity of a Neutrino Factory

- The next generation of neutrino experiments will firm up present indications of couplings of pairs of neutrinos – but will not explore simultaneous effects of 3 neutrinos.
- Many of the neutrino oscillation solutions permit complete study of the couplings between 3 (4?) neutrinos at a neutrino factory.
- But, $> 10^{21}$ ν's/year are needed for this!
- A neutrino factory is a path to a muon collider.

However, there are at present too many explanations of neutrino oscillation data to define an optimal parameter set for a neutrino factory: energy, distance to remote detectors....

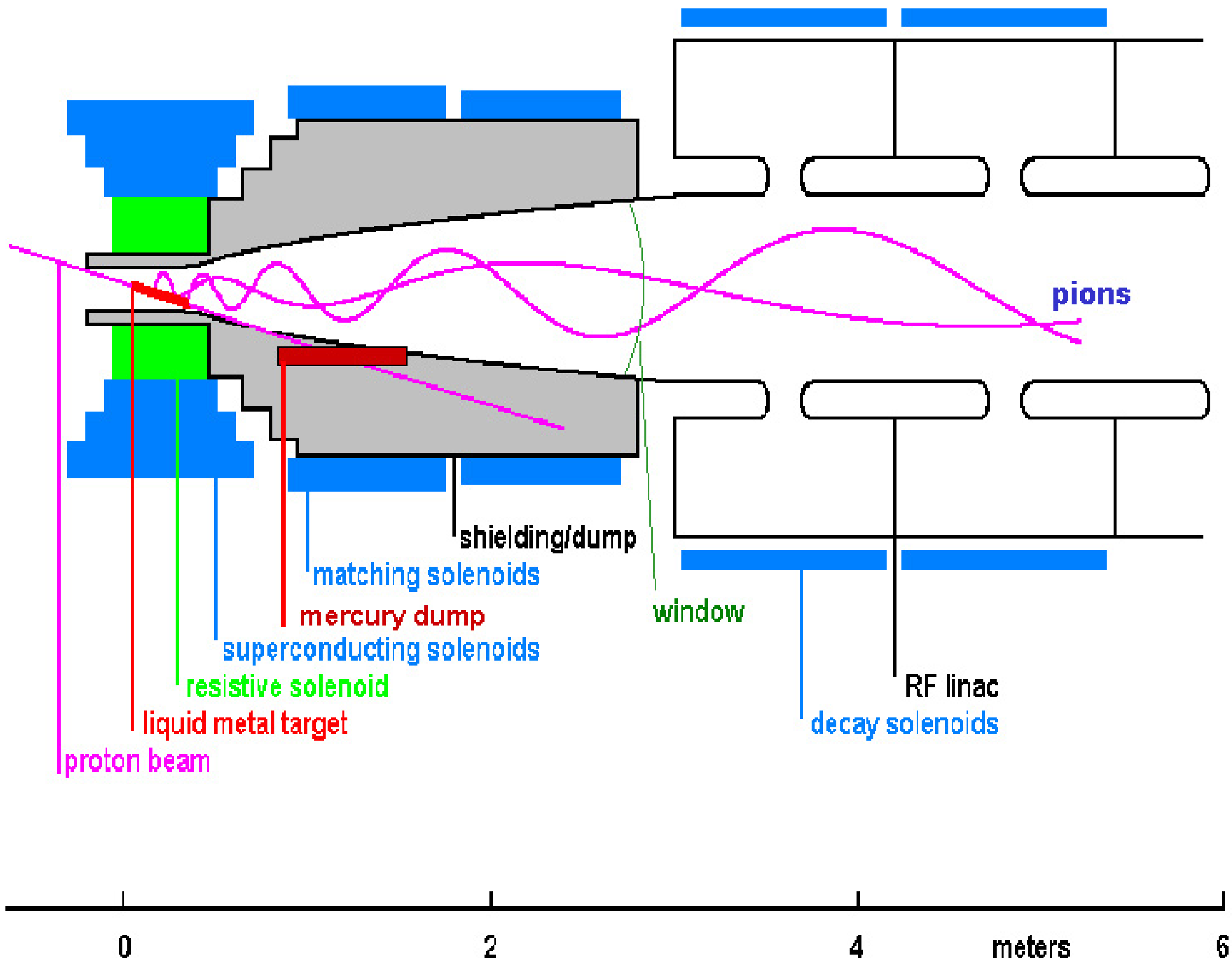
It will take several years for the physics to be clarified enough to make a wise choice of parameters for an initial neutrino factory.

These facts afford both an opportunity and a need for an ambitious R&D program.

We Need a High Performance Source

- We need lots of protons: several megawatts desired, perhaps only 1 MW initially.
- We need to maximize the yield of ν's, and hence μ's per proton.
- For advanced neutrino studies (ν_e in final state), and for a muon collider, we desire controlled muon polarization.
- High yield seems best accomplished in a solenoidal capture system with a dense target and little support structure.
- Solid targets extremely marginal in multimegawatt beams with 10^8 cycles/year.
- A "disposable" target may be preferable; use once and throw away.
- $\Rightarrow$ Mercury jet target.
- Maximal capture + polarization control
  $\Rightarrow$ High-gradient, low-frequency rf close to target.

The Baseline Targetry/Capture Scenario



Choices:

- Liquid or solid target?
- Phase rotation or drift after target?

High performance neutrino factory and muon collider favor the first choices.

May be expedient to start with the second choices.

Two Classes of Issues

1. Viability of targetry and capture for a single pulse.

   - Effect of pressure wave induced in target by the proton pulse.
   - Interaction of a moving metal target with the solenoid field.
   - Operation of the first rf cavity in a magnetic field and in large particle flux.

2. Long-term viability of the system in a high radiation area.

   [Issues for solid target & magnet coils are of the second type.]

The most novel issues (1) are addressable in studies with low rep. rate but a large number of protons/pulse (BNL).

These issues would NOT be readily addressed at a 0.5-1 MW source for an entry-level neutrino factory, due to high radiation levels.

Long-term issues, including solid targets, are better studied in a high-rep.-rate, high-average-power beam (Los Alamos).

R&D Goals

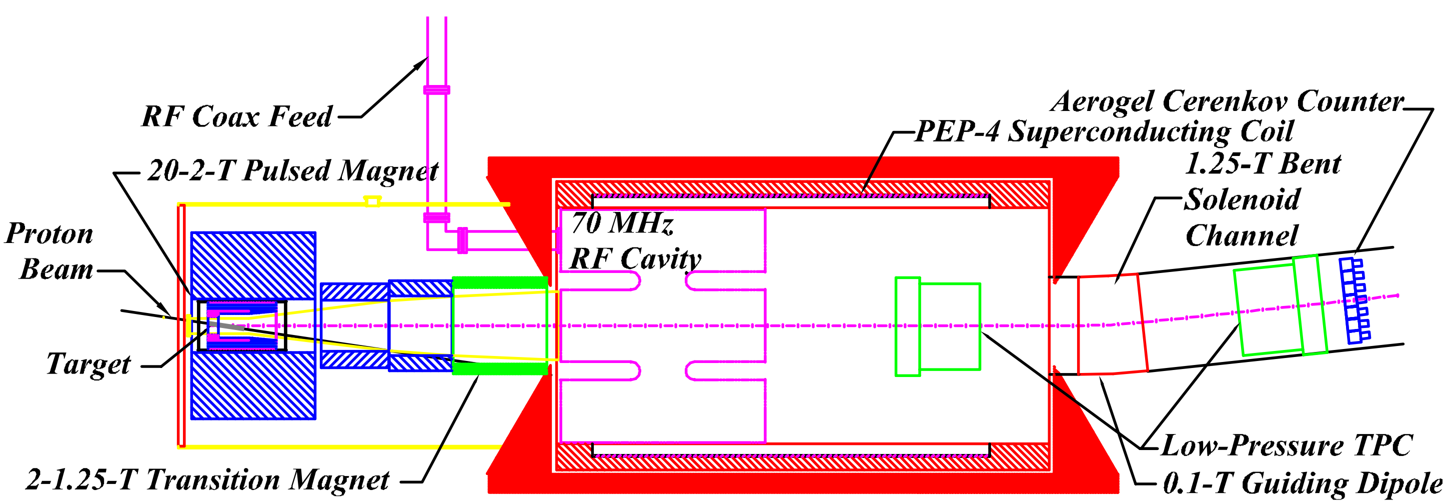
1. Single pulse studies (BNL E951).

   Overall: 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.

   (Change target technology if encounter severe difficulties.)

   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.



2. Long Term Survivability

Define needed R&D program during 2nd half of FY00.

Example: survival of a carbon target:

- Cylindrical geometry focuses reflected pressure wave to very high values on axis, even for diffuse energy deposition.
- 10-100 J/gm/pulse, $> 10^8$ pulse/year, $\Rightarrow > 10^5$ eV/atom/yr.
- $\Rightarrow$ every interatomic bond broken 10^5 times/year.
- Nuclear reaction for every 100 MeV deposited.
- $\Rightarrow$ 1/1000 of all nuclei transmuted/year.

90% of beam energy deposited in the liner of the superconducting magnets.

Is a solid liner viable; should the beam hit a mercury pool?

Are the superconducting coils viable?

An R&D Program for Targetry and Capture at a Muon Collider Source

A Proposal to the BNL AGS Division

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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.

Schedule

- FY99:

  Prepare A3 area; begin work on liquid jets, extraction upgrade, magnet systems, and rf systems.

- FY00:

  Initial beam tests in A3 line. Liquid jet test at NHMFL.

  (300 hours of AGS beamtime).

- 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).

AGS Operations Issues

- In FY00/01, HEP operation of AGS is only for the $g-2$ experiment, with fast extraction. E951 is very compatible with parasitic running in this condition, but must pay incremental costs of operating the A3 line: $\approx$ \$35k/week.
- After FY01, no DOE approved HEP operation of the AGS.
- The AGS2000 program proposes running slow extracted proton beam 30-35 weeks/yr, for 16-20 hours/day during RHIC operation.
- E951 requires fast extracted beam, so cannot parasite off the AGS2000 program; we must interleave running with AGS2000, but seek $\lesssim$ 6 weeks/yr.
- If there is no other HEP operation of the AGS after FY01, E951 would then bear the full incremental cost of proton beam running; $\approx$ \$70k/week.

Targetry and Capture Budgets, I

Yearly Projections

Category	FY99	FY00	FY01	FY02	FY03	Total
Program as proposed in 1998	\$0.5M	\$1.5M	\$2M	\$2M	\$1M	\$7M
AGS Operations		\$0.2M	\$0.2M	\$0.4M	\$0.4M	\$1M
RF Power Source	\$0.05M	\$0.5M	\$1M	\$1M	\$1M	\$3.5M

FY99, Allocated

Task	ANL	BNL	LBL	Princeton	Industry	Total
Initial Target Studies		50		85		105
AGS Beamline Upgrades		100				100
Pulsed Solenoid Design		50				50
RF Systems		165	25			190
Simulation Studies	75			5		80
Total	75	365	25	90		**\$555k**

FY99, Expended

Task	ANL	BNL	LBL	Princeton	Industry	Total
Initial Target Studies		15		45		60
AGS Beamline Upgrades		95				95
Pulsed Solenoid Design		40				40
RF Systems		50	75		60	185
Simulation Studies	75			5		80
Total	75	200	75	50	60	**\$460k**

Targetry and Capture FY99 Expended: Details

1. **Initial Target Studies** **$45k**
   - Powder, Ga-Sn, Hg targets $25k
   - Travel $20k
2. **AGS A3 Beamline Cleanup** **$95k**
3. **Pulsed Solenoid Design (Bob Duffin)** **$40k**
4. **RF Systems** **$185k**
   - RF design (Zhao) $50k
   - 8973 RF tube recomissioning (LBL) $75k
   - RF tube design proposals (EEV, Litton) $60k
5. **Simulation Studies** **$80k**
   - Heights simulation (Hassanein) $75k
   - ANSYS license (Lu) $5k

Targetry and Capture Budgets, II

Total FY00, Allocated

Task	ANL	BNL	LBL	ORNL	Princeton	Industry	Total
Initial Target Studies		50			50		100
AGS Beamline Upgrades		1400					1400
AGS Operations		0					0
Magnet Systems		70			40		110
RF Systems		100	75			0	175
Simulation Studies	80			0	10		90
Engineer Salaries		345					345
Carryover		−100					−100
Total	80	1865	75	0	100	0	**$2120k**

Targetry and Capture FY00 Allocation: Details

1. **Initial Target Studies** **$100k**
   - Remote postioner for target box (BNL) $50k
   - Target box, targets, cameras (Princeton) $50k
2. **AGS Beamline Upgrades** **$1400k**
   - Labor (11,000 hours, BNL) $1100k
   - Materials (BNL) $200k
   - Radiation Safety (BNL) $20k
   - 6-Bunch kicker design (BNL) $80k
3. **Magnet Systems** **$110k**
   - 1/4 mech. engineer (Princeton) $40k
   - Design of 5 MW magnet power supply (BNL) $60k
   - Radiation damage study (MSU) $10k

4. **RF Systems** **$175k**

- Recommissioning of the 8973 power supplies (LBL) . $75k
- Shipment of rf gear from LBL to BNL $20k
- 1/2 RF engineer (BNL) $80k

5. **Simulation Studies** **$90k**

- (ANL) $80k
- (Princeton) $10k

6. **Engineer Salaries (BNL)** **$345k**

Targetry and Capture Budgets, III

Total FY01, Projected

Task	ANL	BNL	ORNL	Princeton	Total
Initial Target Studies		50		50	100
AGS Kicker Upgrade		1000			1000
AGS Operations		200			200
Magnet Systems		400		40	400
RF Systems		300			300
Simulation Studies	150		100	10	260
Engineer Salaries		345			345
Total	150	2295	100	100	**$2645k**

Total FY02, Projected

Task	ANL	BNL	ORNL	Princeton	Total
Target Studies		200		50	250
AGS Operations		400			400
Magnet Systems		600		40	640
RF Systems		600			600
Yield Instrumentation		100		100	200
Simulation Studies	150		100	10	260
Engineer Salaries		345			345
Total	150	2245	100	200	**$2695k**

Targetry and Capture Budgets, IV

Total FY03, Projected

Task	ANL	BNL	ORNL	Princeton	Total
Target Studies		300		50	350
AGS Operations		400			400
RF Systems		300			300
Yield Instrumentation		300		300	600
Simulation Studies	150		100	10	260
Engineer Salaries		350			350
Total	150	1650	100	360	**$2260k**

Note: We trust that more institutions will become involved in the later phases of the program, and the funds listed above will be more widely distributed.

The item "Target Studies" includes some reserve for increased work on long-term issues.