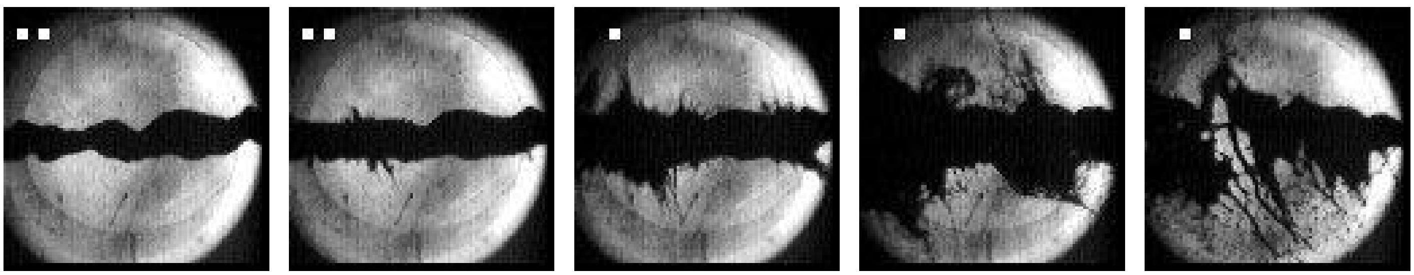
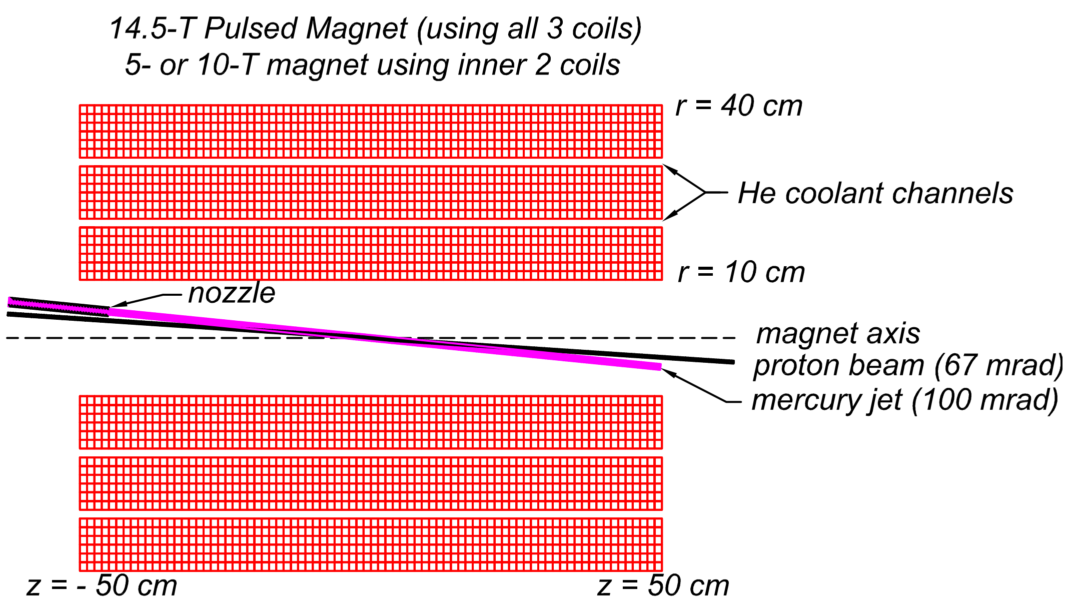
The R&D Program for a 4 MW Target Station for a Neutrino Factory and Muon Collider Source

(BNL E951)





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Muon Collaboration Technical Board, Feb. 9, 2002

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

Overview

- Why do targetry R&D?
- What have we done so far?
- What more should we do?

Technical Presentations

Harold Kirk: Overview of Beam Studies.

Thomas Roser: AGS Intensity Upgrades.

Roman Samulyak: Simulations of MHD and beam effects.

Robert Weggel: Pulsed Magnet Design Issues.

Peter Titus: Magnet Engineering.

Michael Iarocci: Cryogenic Issues.

Ioannis Marneris: Power Supply Issues.

Harold Kirk: Overview of the Pulsed Magnet Project.

KTM: Summary.

Why Do Targetry R&D?

- More π's, μ's and ν's are needed to expand the frontiers of high energy physics.
- Proton drivers are foreseen with beam power up to 4 MW, $>$ 10 times that of present HEP drivers.
- It appears most cost effective to maximize yield at the source (confirmed by Neutrino Factory Feasibility Studies 1 and 2).
- At 4-MW beam power, targets must survive intense heating, intense mechanical shock, and severe radiation damage.
- A disposable (moving) target suggests itself.
- For beam energy above $\approx$ 6 GeV, yield is enhanced for a high-Z target, $\Rightarrow$ Liquid metal target: mercury, Pb-Bi, ...
- Secondary particle yield peaks at low momentum, $\Rightarrow$ **Capture in tapered high-field solenoid magnet**.
- Although "feasible", these target concepts are beyond the state of the art.

What Priority Should Targetry R&D Have?

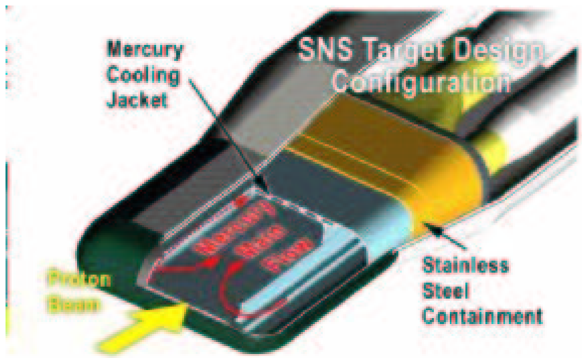
- High-power targetry will be the first topic of R&D efforts of the Muon Collaboration to be implemented in any scenario aimed at physics results: superbeam, neutrino factory, muon collider, ...
- Hence, targetry R&D should be completed in advance of that on other topics.
- Whether or not this implies "top" priority, targetry R&D should continue in a timely fashion.

When Has the Muon Collaboration Done Enough Targetry R&D?

- If high-power targets are established to be so feasible that they can be adopted as the baseline option in a CDR for a future accelerator (with further targetry R&D being low-risk, production prototyping).
- If the Muon Collaboration decides that targetry R&D is outside its mission (because, like proton drivers, it is so relevant to non-muon applications) – but then targetry R&D should be continued under other auspices.
- If high-power targets prove to be unfeasible.

Example 1: The SNS Target

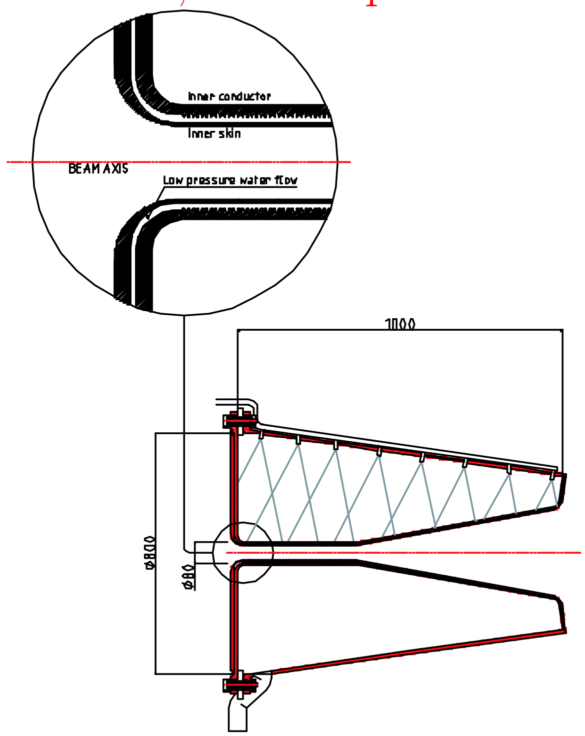
- The SNS CDR baseline target is flowing mercury in a stainless-steel jacket.



- No R&D was done on this concept prior to project approval.
- Beam-induced cavitation in the stainless-steel entrance window was recently confirmed as a serious problem.
- The baseline target design is probably untenable.
  [Similar problems observed years ago at ISOLDE.]

Example 2: The CERN SPL Neutrino Horn

- A proposed SPL neutrino horn surrounds a mercury jet target that intercepts a 4-MW, 2-GeV proton beam at 50 Hz.



- R&D at CERN on electromechanical effects of pulsing this horn ends as of ≈ today.

- The extremely serious issue of radiation damage degradation of the horn integrity has yet to be studied.

- Without further R&D, use of this design in a production facility would be very risky.

Summary of Targetry Activities Through FY01

- Liquid metal targets in vessels show beam-induced cavitation damage to entrance window (ISOLDE, 1995, LANL, 2001).
- Beam tests of large passive mercury target for SNS (BNL 1998, LANL 2000) suggest velocity of sound may be reduced temporarily by beam-induced microcavitation).
- MARS simulations of beam-target interactions ⇒ advantage of high-Z target, of high-field capture solenoid, of tilted beam and target, and disadvantages of high radiation dose (Mokhov).
- Analytic simulations of beam-induced pressure waves in target (Sievers), and of MHD effects of mercury jet entering magnet (KTM, Palmer, Weggel) indicate "feasibility", but need for R&D.
- Numerical simulations (Hassanein, Samulyak) tend to confirm these analytic estimates.

- Beam tests of high-strength solid targets show good agreement between strain-sensor data and ANSYS simulation, and suggest that they can survive single-pulse stresses up to Study-2 design intensity, = 16 TP / 8 mm^2 (BNL, March '01).

- Calculation and experiment indicate that a carbon target could survive against sublimation in a He atmosphere in a 4 MW beam (Thieberger, ORNL).

- Beam tests of active and passive mercury targets indicate dispersal velocities of manageable size, proportional to proton pulse energy (BNL, April '01; ISOLDE, Aug. '01).

- Tests of mercury jets entering a high-field solenoid not yet definitive (CERN, Grenoble, 2001).

Issues for Further Targetry R&D

- Continue numerical simulations of MHD + beam-induced effects [Samulyak].
- Continue tests of mercury jet entering magnet [CERN, Grenoble].
- For solid targets, study radiation damage – and issues of heat removal from solid metal targets (bands, chains, *etc.*).
- Confirm manageable mercury-jet dispersal in beams up to full Study-2 intensity – for which single-pulse vaporization may also occur. Test Pb-Bi alloy jet.
- Study issues when combine intense proton beam with mercury jet inside a high-field magnet.

  1. MHD effects in prototype target configuration.
  2. Magnetic damping of mercury-jet dispersal.
  3. Beam-induced damage to jet nozzle – in the magnetic field.

Further Beam Studies without High-Field Magnet

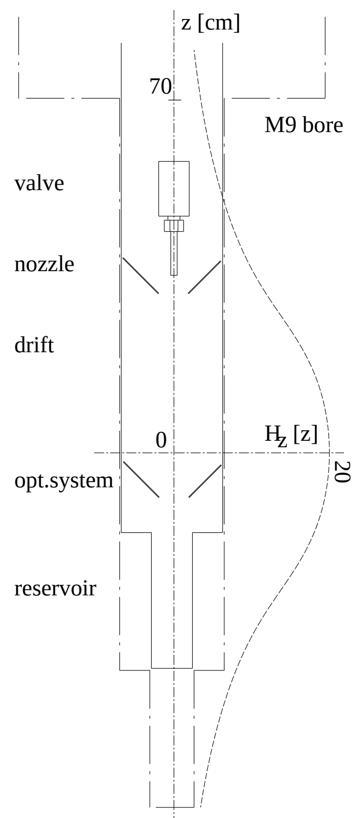
- Studies of production of mercury jets up to 20 m/s. Jet quality is the issue.
- Construction of new liquid metal jet targets with continuous flow: mercury and Wood's metal.
- Upgrade AGS to 8/16 TP single pulses [Roser].
  1. Improve control of fast extraction with bipolar power supply for a key vertical sextupole.
  2. Improve control of chromaticity of bunches during transition with heftier power supply for main ring horizontal sextupoles.
  3. Explore schemes for 2:1 bunch merging at 24 GeV via rf manipulation.
- Test the continuous-flow targets in beam once at least 8 TP per pulse are available.
- [Radiation damage studies of solid targets at BNL booster.]

Further Beam Studies with a High-Field Magnet

- Study jet dispersal, and possible damage to nozzle, as a function of beam intensity, magnetic field strength, and nozzle position.

- Online diagnostics will primarily be optical (+ possible use of fiberoptic strain sensors).

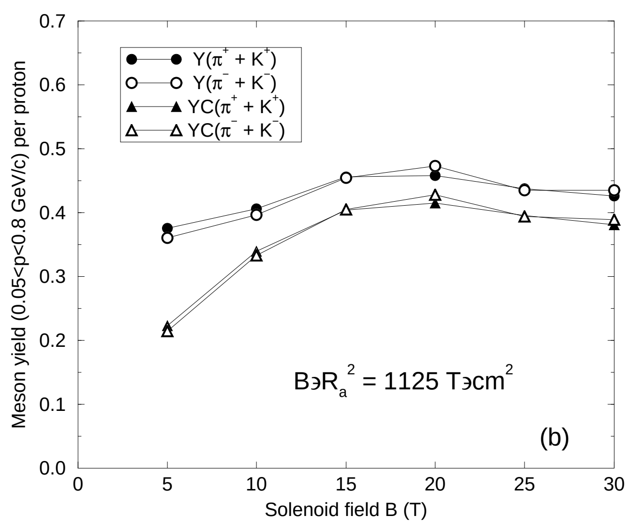
CERN/Grenoble optical system that fits in 20-cm magnet bore:



- To be affordable, construct a 15-T pulsed solenoid magnet.

What Magnetic Field Strength is Appropriate?

- Our muon collider and neutrino factory designs have long called for a 20-T capture solenoid.



A 20-T magnet must be a hybrid: 6-T copper "insert" + 14-T superconducting "outsert".

The small gain in performance from 14 to 20 T may not warrant the cost and complexity of the hybrid magnet.

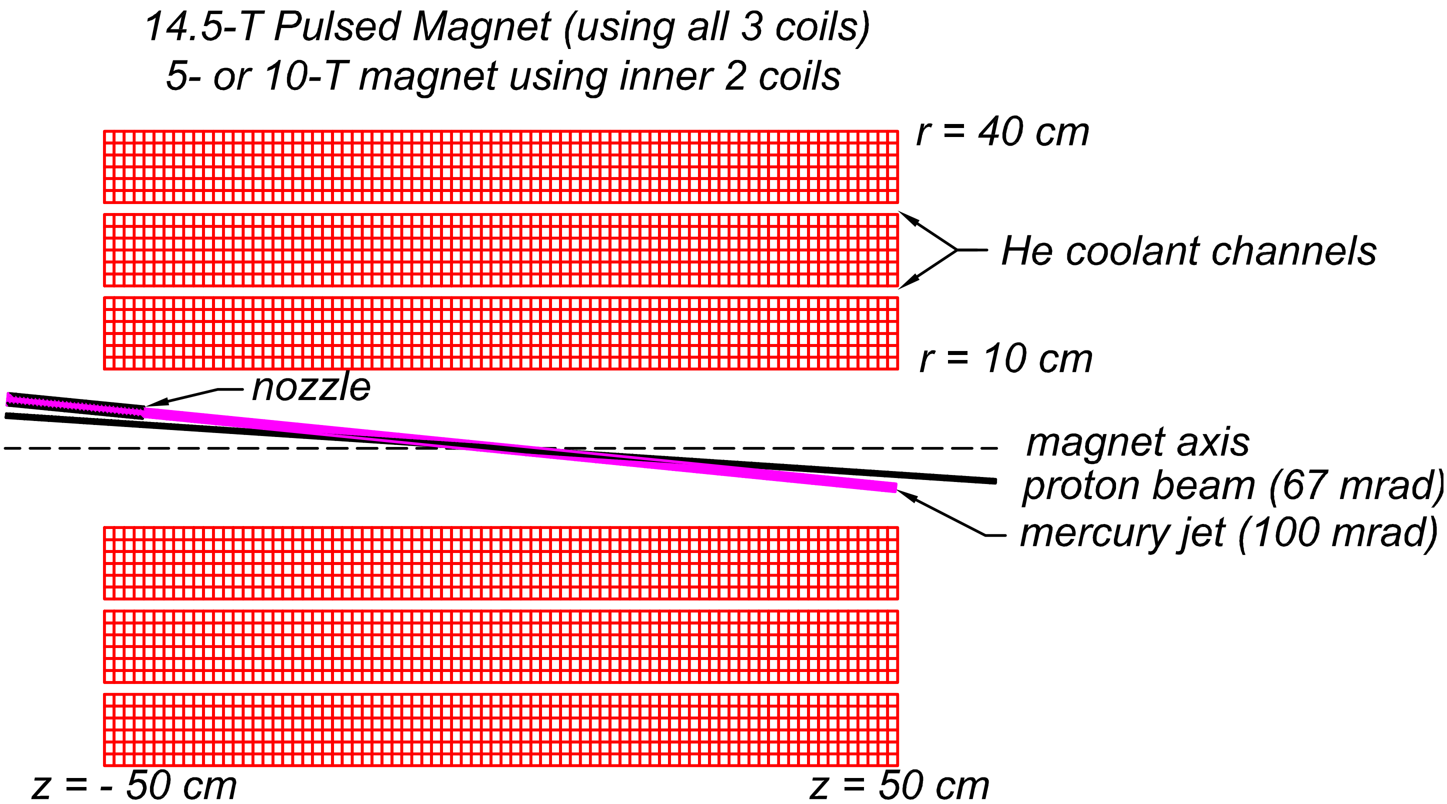
A capture solenoid for a superbeam needs a larger bore to trap higher $P_\perp$ pions, for which 14 T is then sufficient.

$\Rightarrow$ Our physics goals are well satisfied by a 14-T capture solenoid.

Should the Pulsed R&D Magnet have Lower Field?

- Most magnetic-field effects on the mercury jet scale as the magnetic pressure $B^2/8\pi$ (for a fixed geometry).
- Thus, a study using a 5-T magnet would require a factor of 8 extrapolation to the desired performance at 14 T.
- Present cost estimates indicate that we can build a 14-T pulsed magnet for about twice the cost of a 5-T pulsed magnet.
- $\Rightarrow$ We propose to construct a 14.5-T pulsed magnet, that can be staged as a 5-T and 10-T magnet.

A 14.5-T Pulsed Magnet with 5- and 10-T Phased Options

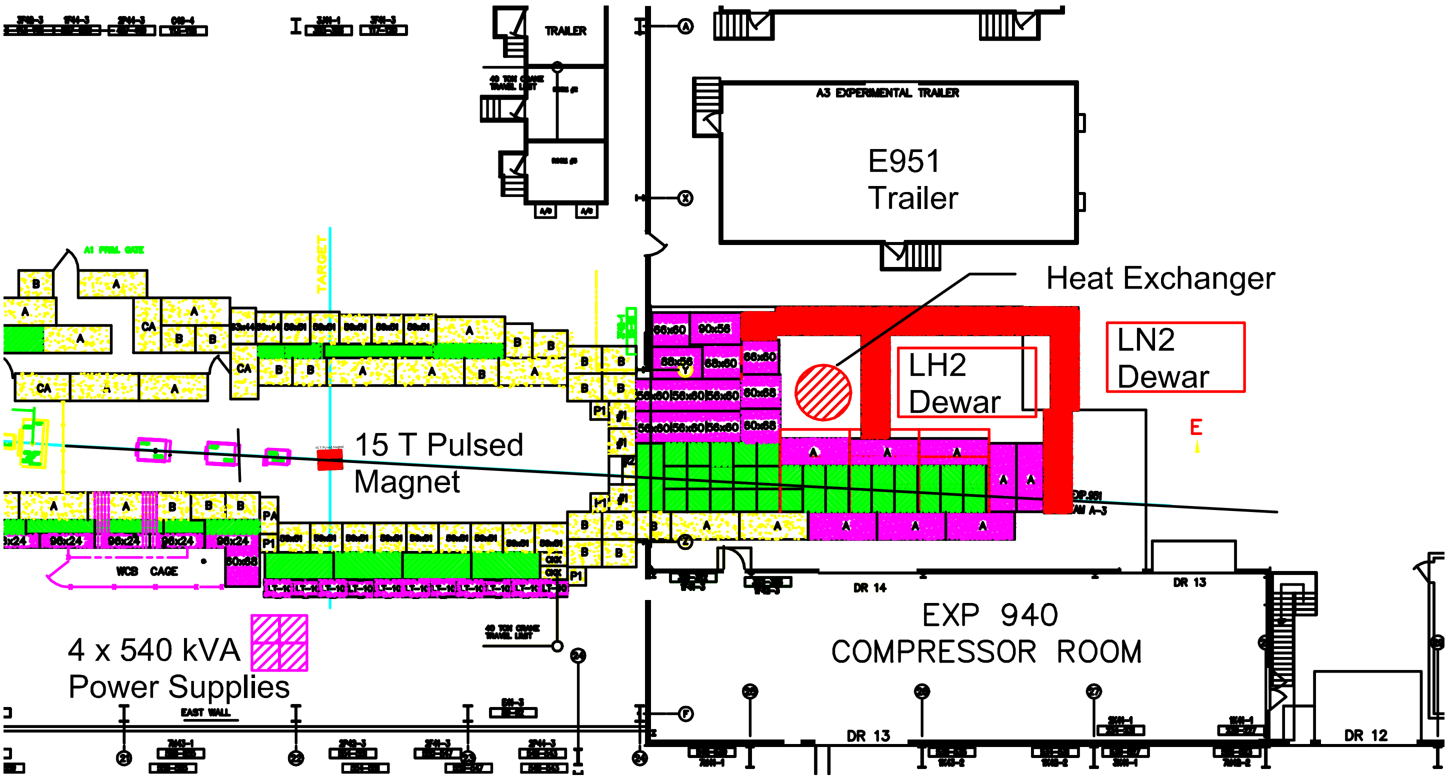


Phase	No. of PS	Coolant	Temp.	Field
1	1	N_2	84 K	5 T
2	4	N_2	74 K	10 T
3	4	H_2	30 K	14.5 T

Keeping Costs Low

- Simple solenoid geometry with rectangular coil cross section and smooth bore (of 20 cm diameter) [Weggel, Titus].
- Power supply built out of 4 existing 540 kVA supplies that can be fed by a single, existing substation [Marneris].
- Cryogenic system reduces coil resistance to give high field at relatively low current [Iarocci].
  - Circulating coolant is gaseous He to minimize activation, and to avoid need to purge coolant before pulsing magnet.
  - Heat exchanger recycled from the SSC.
  - Phase 1 & 2 cooling via N_2 boiloff; Phase 3 via H_2.

Pulsed Magnet System Layout at the AGS



- Locate the 4 x 540 kVA power supplies on the east side of the A3 cave, feed power in via the trench.
- If satisfactory to Safety Committee, locate the heat exchanger and LH_2 dewar in a concrete enclosure that extends the present A3 beam stop.

Budget Request for Continued Beam Studies

FY02:

1/2 of cost of bipolar power supply for vertical sextupole . . . $50k

1/4 of cost of power supply for horizontal sextupoles $50k

3 shifts of dedicated beam studies: rf bunch merging $75k

Technician support for jet targets (BNL) $50k

Fabrication of new jet targets (Princeton) $75k

Total FY02 . . . . $300k

FY03:

20 shifts of parasitic beam studies $100k

Technician support for beam studies (BNL) $50k

Princeton effort on beam studies $50k

Total FY03 . . . .$200

FY04 (If pulsed magnet ready for beam tests:

20 shifts of parasitic beam studies $100k

Technician support for beam studies (BNL) $100k

Diagnostics for beam test with pulsed magnet (Princeton) $100k

Total FY04 . . . . $300k

Budget Request for Pulsed Magnet System

FY02:

BNL magnet engineering $200k

MIT magnet design study $100k

BNL cryo system design study $100k

BNL power supply $125k

Total FY02 .... $525k

FY03:

Coil + cryostat fabrication (industry) $400k

BNL power supply (1 x 540 kVA) $225k

BNL cryo system (to LN_2 operation) $225k

Total FY03 .... $850k

FY04:

Magnet commissioning $50k

BNL power supply (to 4 x 540 kVA) $75k

BNL cryo system (to LH_2 operation) $200k

Total FY04 .... $325k

Targetry Budget Request by Fiscal Year

FY02:

Beam studies $300k

Pulsed magnet system $525k

BNL simulations $75k

Total FY02 . . . . $900k

FY03:

Beam studies $200k

Pulsed magnet system $850k

BNL simulations $50k

Total FY03 . . . . $1100k

FY04:

Beam studies $300k

Pulsed magnet system $325k

BNL simulations $50k

Total FY04 . . . . $675k

3-Year and 4-Year Project Scenarios

Phase 1 = end FY03, 2 = mid FY04, 3 = end FY04.

Item	FY02	FY03	FY04	Total
Coil	\$100k	\$400k	\$50k	\$550k
Cryo	\$100k	\$225k	\$200k	\$525k
P.S.	\$125k	\$225k	\$75k	\$425k
Total	\$325k	\$850k	\$325k	\$1500k

Phase 1 = mid FY04, skip 2, 3 = end FY05.

Item	FY02	FY03	FY04	FY05	Total
Coil	\$100k	\$225k	\$50k	\$225k	\$600k
Cryo	\$100k	\$100k	\$225k	\$100k	\$525k
P.S.	\$125k	\$100k	\$125k	\$75k	\$425k
Total	\$325k	\$425k	\$375k	\$400k	\$1550k

Scenarios that Stop at the End of Phase 1, 2, or 3

Item	Phase 1	Phase 2	Phase 3
Field	5 T	10 T	14.5 T
Coil	$400k	$400k	$550k
Cryo	$100k	$325k	$525k
P.S.	$300k	$425k	$425k
Total	$800k	$1150k	$1500k

Radical Rebudgeting of BNL/Princeton R&D

- Complete E951 phase 1 with beam studies to 16 TP.
- Complete pulsed magnet project design study.
- Expand targetry and cooling simulations.

FY02:

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Technician support for jet targets (BNL) $75k
Fabrication of new jet targets (Princeton) $75k
BNL magnet engineering $200k
MIT magnet design study $100k
BNL cryo system design study $50k
BNL power supply $50k
BNL targetry and cooling simulations $175k

Total FY02 .... $900k

FY03:

Beam studies $100k
Technician support for beam studies (BNL) $50k
Princeton effort on beam studies $50k
BNL targetry and cooling simulations $200k

Total FY03 .... $400k