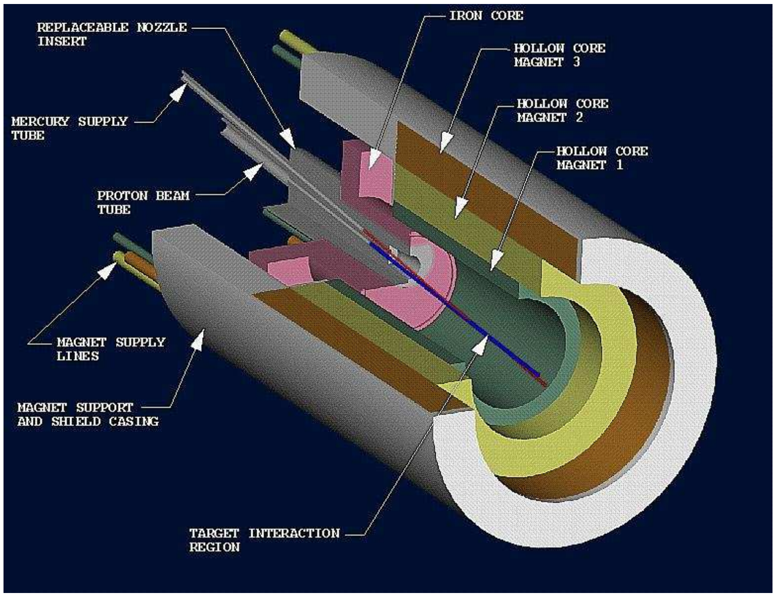
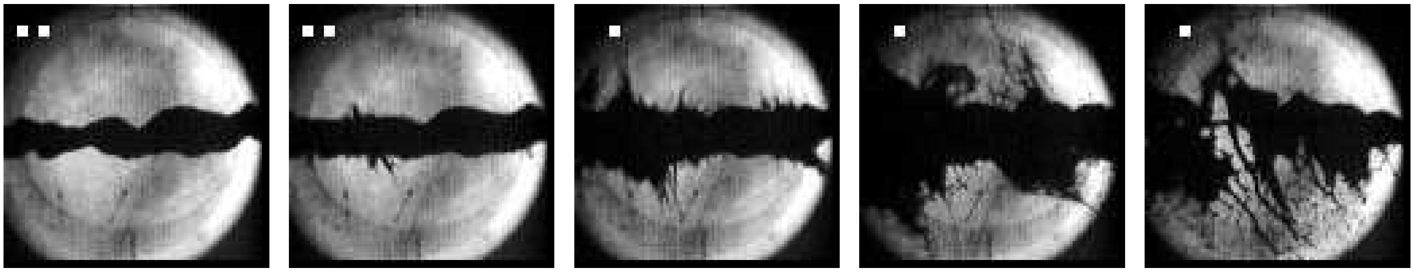
The R&D Program for Targetry and Capture at a Neutrino Factory and Muon Collider Source

(BNL E951)





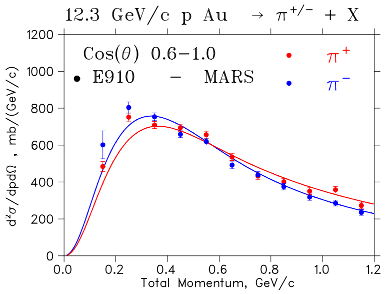
K.T. McDonald
Princeton U.

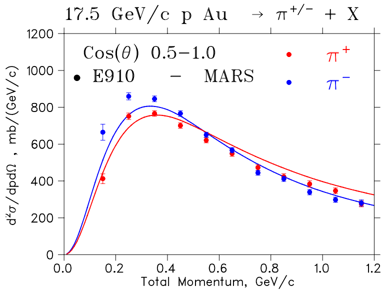
MUTAC, Berkeley, CA, Oct. 19, 2001

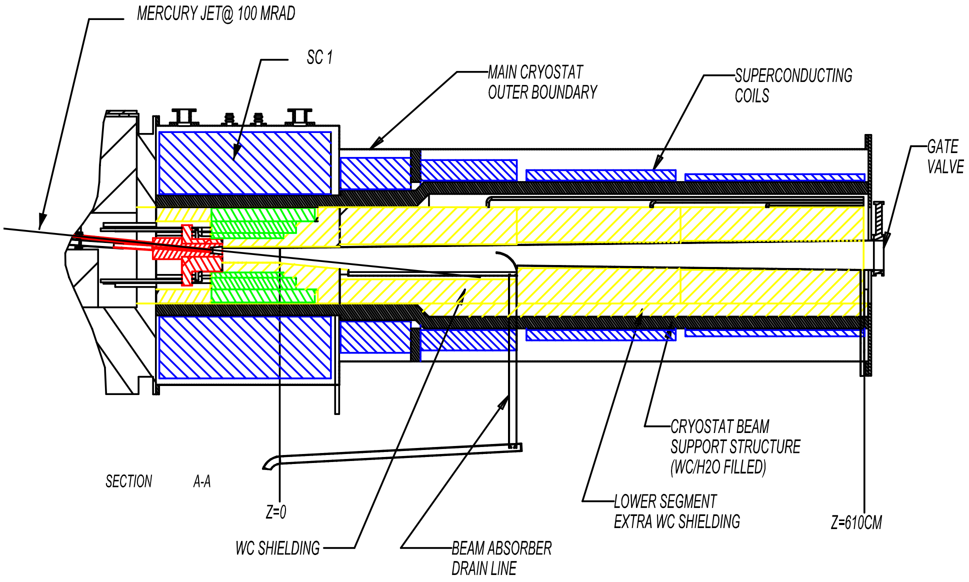
`http://puhep1.princeton.edu/mumu/target/`

Challenges

- Maximal production of soft pions → muons in a megawatt proton beam.
- Capture pions in a 20-T solenoid, followed by a 1.25-T decay channel.





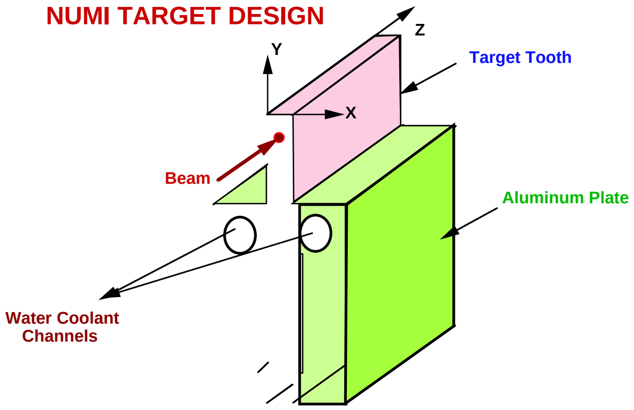


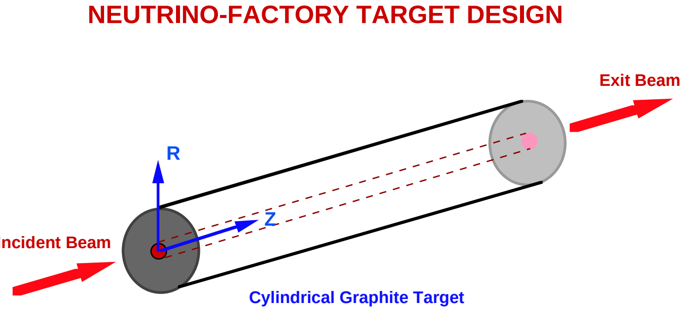
- A carbon target is feasible for 1.5-MW proton beam power.
- For $E_p \gtrsim 16$ GeV, factor of 2 advantage with high-Z target.
- Static high-Z target would melt, ⇒ Moving target.
- A free mercury jet target is feasible for beam power of 4 MW (and more).

The Neutrino Horn Issue

- A precursor to a Neutrino Factory is a Neutrino Superbeam based on decay of pions from a multimegawatt proton target station.
- 4 MW proton beams are achieved in both the BNL and FNAL (and CERN) scenarios via high rep rates: $\approx 10^6$/day.
- Classic neutrino horns based on high currents in conductors that intercept much of the secondary pions will have lifetimes of only a few days in this environment.
- Consider instead a solenoid horn with conductors at larger radii than the pions of interest – similar to the Neutrino Factory capture solenoid.
- Adiabatic reduction of the solenoid field along the axis,
  $\Rightarrow$ Adiabatic reduction of pion transverse momentum,
  $\Rightarrow$ Focusing.

A Carbon Target is Feasible at 1-MW Beam Power





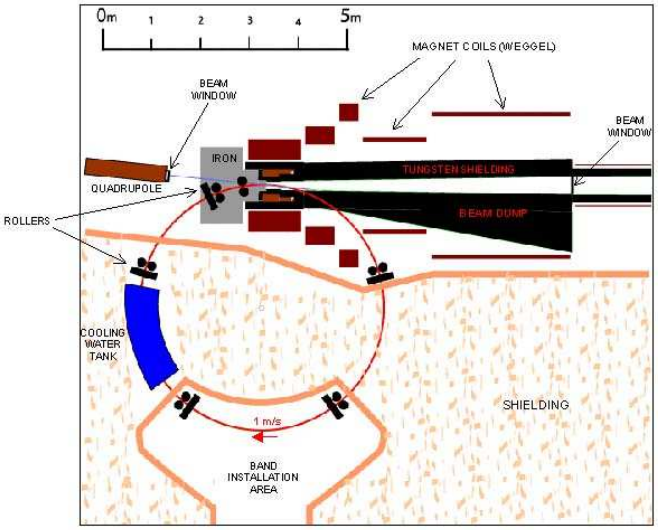
HASSANEIN (ANL)

A carbon-carbon composite with near-zero thermal expansion is largely immune to beam-induced pressure waves.

Sublimation of carbon is negligible in a helium atmosphere.

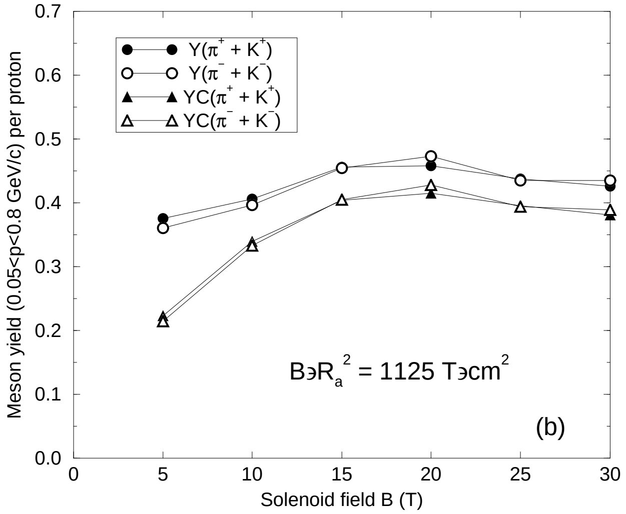
Radiation damage is limiting factor: ≈ 12 weeks at 1 MW.

A rotating band target is another option:



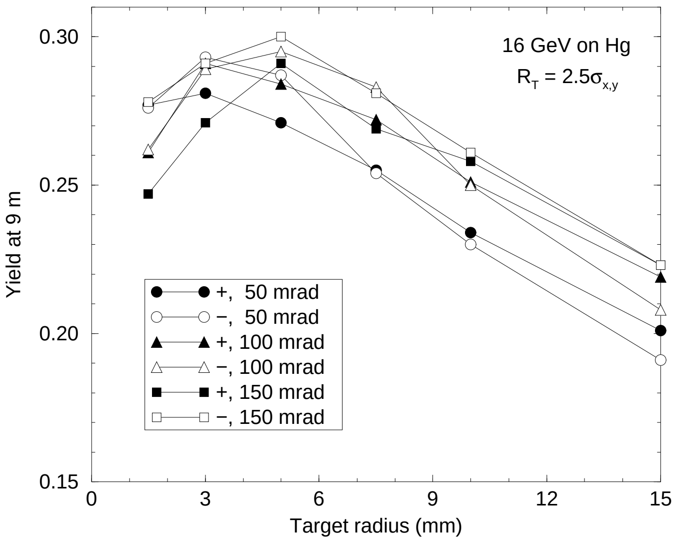
Pion/Muon Yield

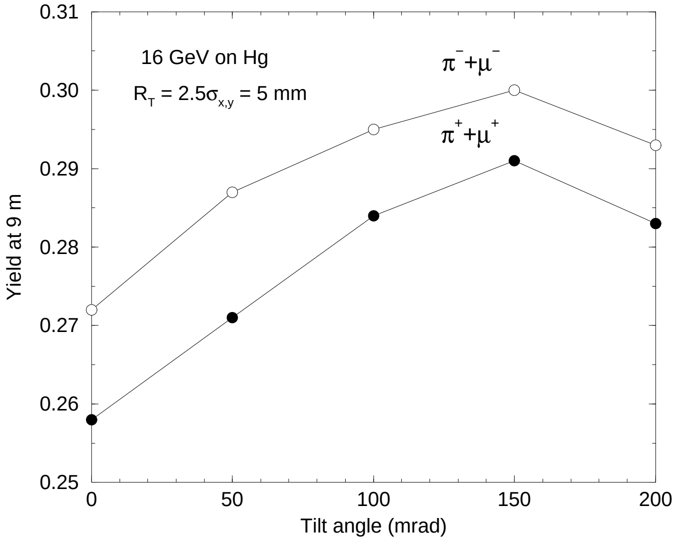
For $E_p \gtrsim 10$ GeV, more yield with high-Z target.



Mercury target radius should be ≈ 5 mm,

with target axis tilted by ≈ 100 mrad to the magnetic axis.

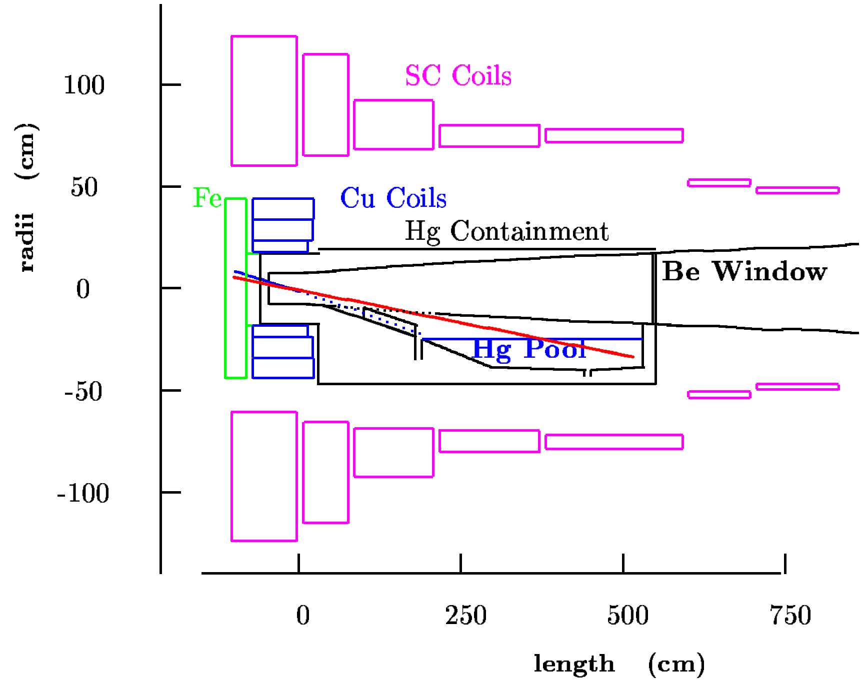




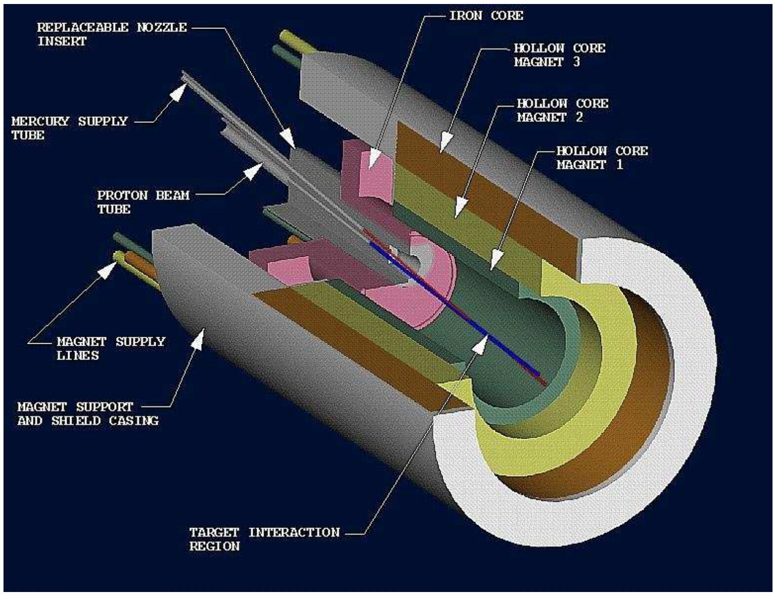
Can capture ≈ 0.3 pion per proton with $50 < P_\pi < 400$ MeV/c.

Target System Layout

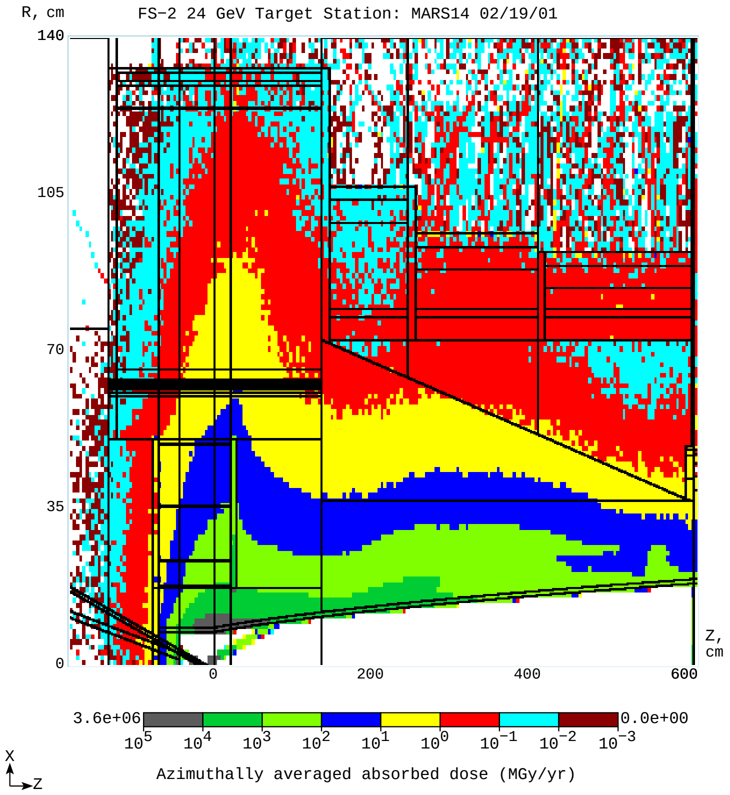
Mercury jet target inside a magnetic bottle: 20-T around target, dropping to 1.25 T in the pion decay channel.



Mercury jet tilted by 100 mrad, proton beam by 67 mrad.



Lifetime of Components in the High Radiation Environment

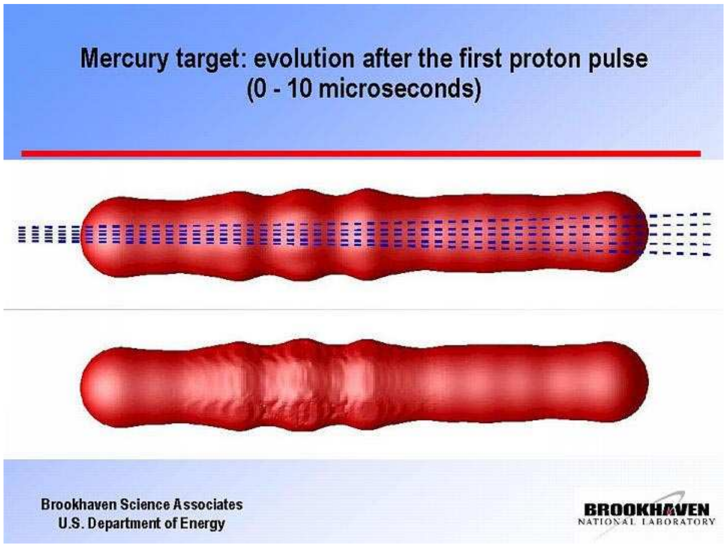


Component	Radius (cm)	Dose/yr (Grays/2×10^7 s)	Max allowed Dose (Grays)	1 MW Life (years)	4 MW life (years)
Inner shielding	7.5	5×10^{10}	10^{12}	20	5
Hg containment	18	10^9	10^{11}	100	25
Hollow conductor coil	18	10^9	10^{11}	100	25
Superconducting coil	65	5×10^6	10^8	20	5

Some components must be replaceable.

Viability of Targetry and Capture For a Single Pulse

- Beam energy deposition may disperse the jet.



Mercury target: evolution after the first proton pulse
(0 - 10 microseconds)

Brookhaven Science Associates
U.S. Department of Energy

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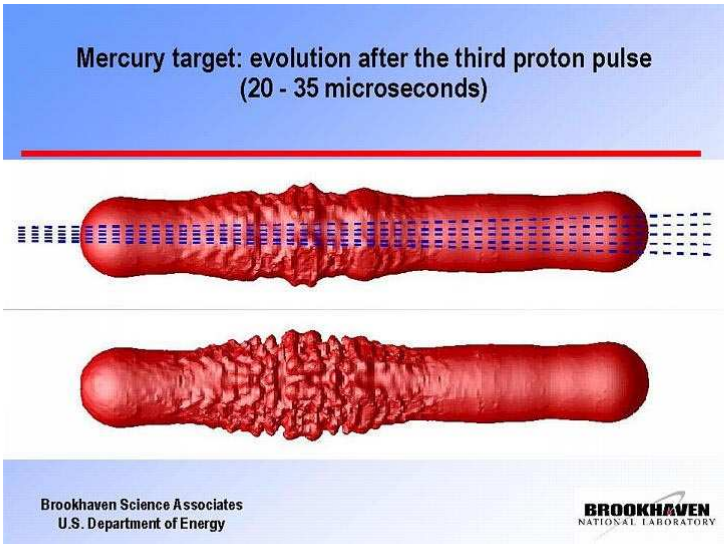
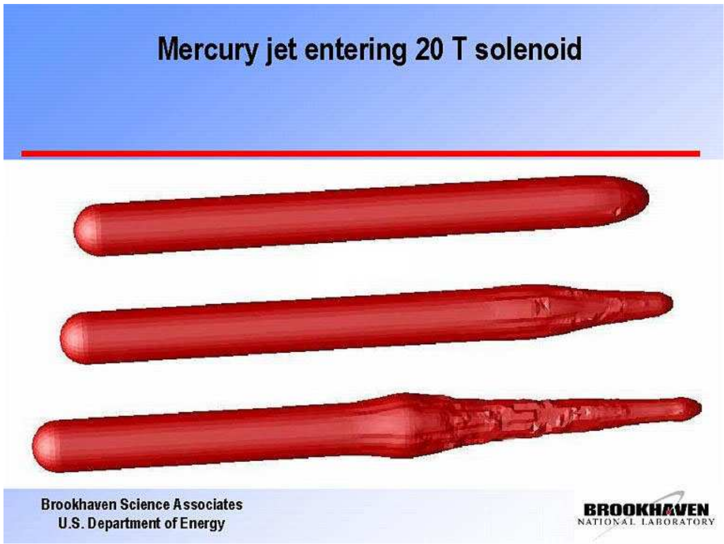


Mercury target: evolution after the third proton pulse
(20 - 35 microseconds)

Brookhaven Science Associates
U.S. Department of Energy

BROOKHAVEN NATIONAL LABORATORY

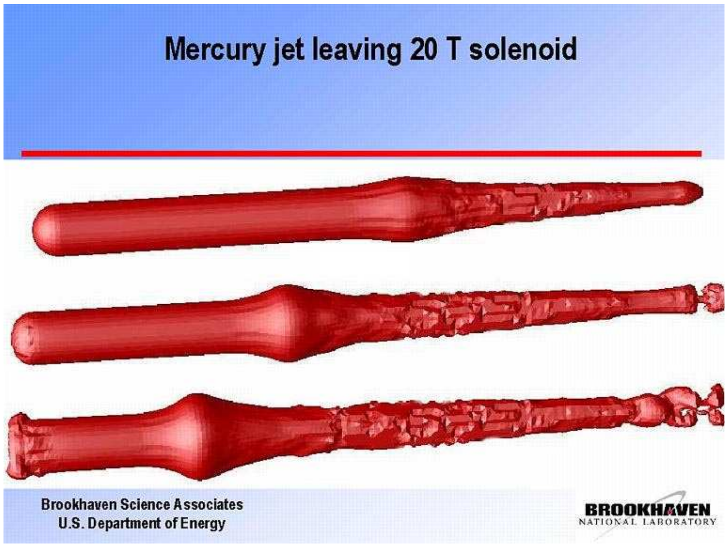
- Eddy currents may distort the jet as it traverses the magnet.



Mercury jet entering 20 T solenoid

Brookhaven Science Associates
U.S. Department of Energy

BROOKHAVEN NATIONAL LABORATORY



Mercury jet leaving 20 T solenoid

Brookhaven Science Associates
U.S. Department of Energy

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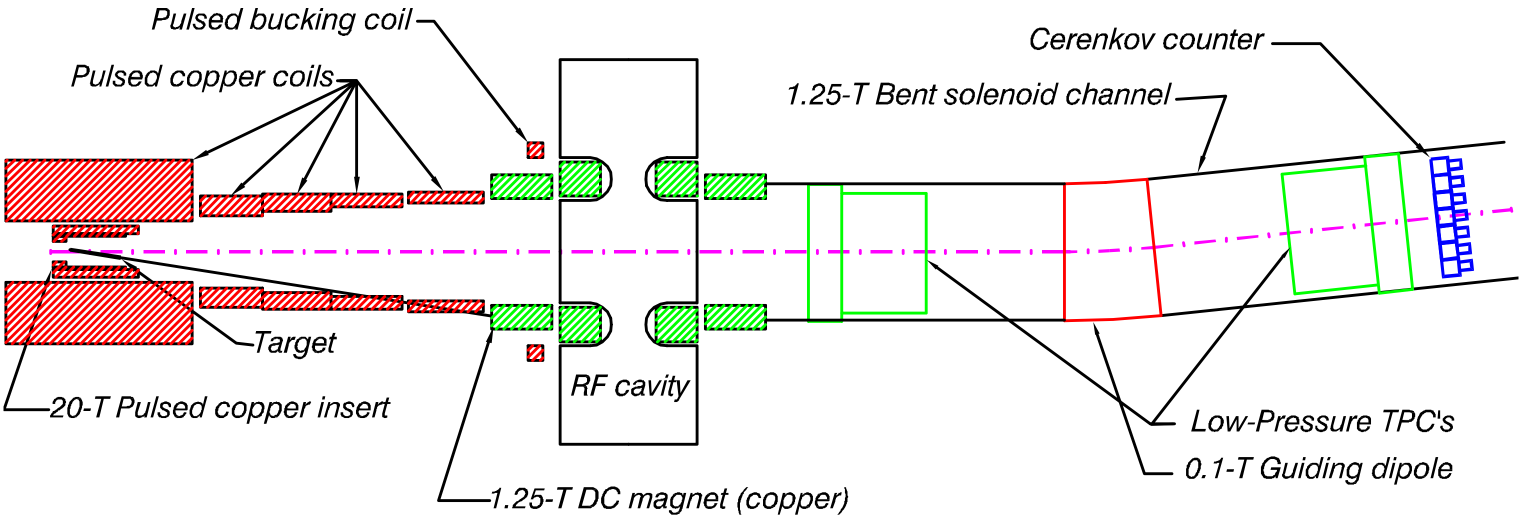
E951 Studies the Single Pulse Issues

Overall Goal: 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.

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.



The E951 Collaboration

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John Corlett,[g] F Debray,[f] Adrian Fabich,[d] Richard C. Fernow,[b] Charles Finfrock,[b]
Yasuo Fukui,[c] Tony A. Gabriel,[i] Juan C. Gallardo,[b] Michael A. Green,[g] George A. Gre
John R. Haines,[i] Jerry Hastings,[b] Ahmed Hassanein,[a] Michael Iarocci,[b] Colin Johnson
Stephen A. Kahn,[b] Bruce J. King,[b] Harold G. Kirk,[b] Jacques Lettry,[d] Vincent LoDestro,[b] Changguo Lu,[j] **Kirk T. McDonald**,[j] Nikolai V. Mokhov,[e] Alfred Moretti,[e] James H. Norem,[a] Robert B. Palmer,[b] Ralf Prigl,[b] Helge Ravn,[d] Bernard Riemer,[i] James Rose,[b] Thomas Roser,[b] Roman Samulyak,[b] Joseph Scaduto,[b] Peter Sievers,[d] Nicholas Simos,[b] Philip Spampinato,[i] Iuliu Stumer,[b] Peter Thieberger,[b] James Tsai,[i] Thomas Tsang,[b] Haipeng Wang,[b] Robert Weggel,[b] Albert F. Zeller,[h] Yongxiang Zhao[b]

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[h] *Michigan State University, East Lansing, MI 48824*
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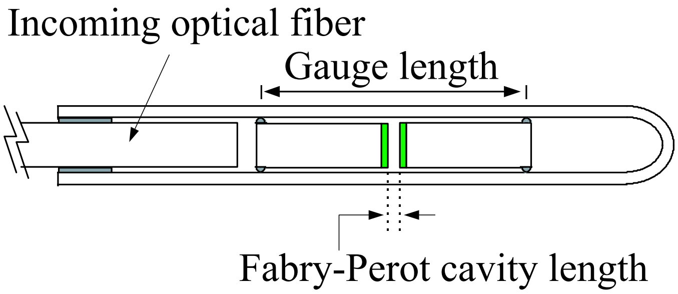
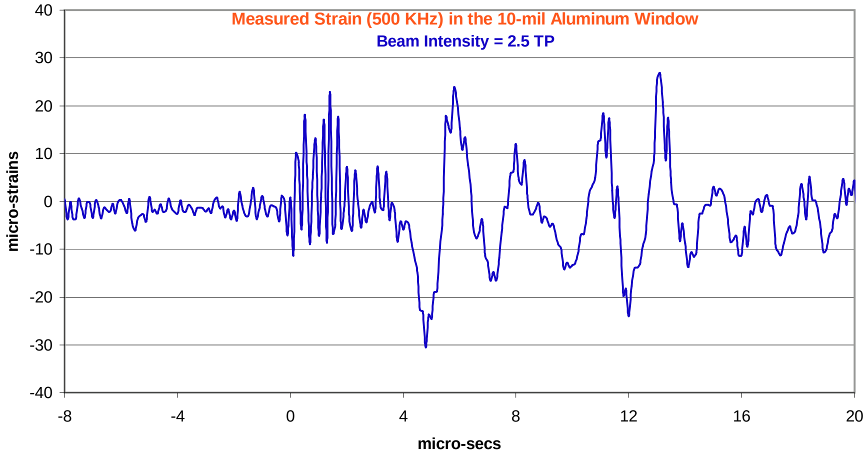
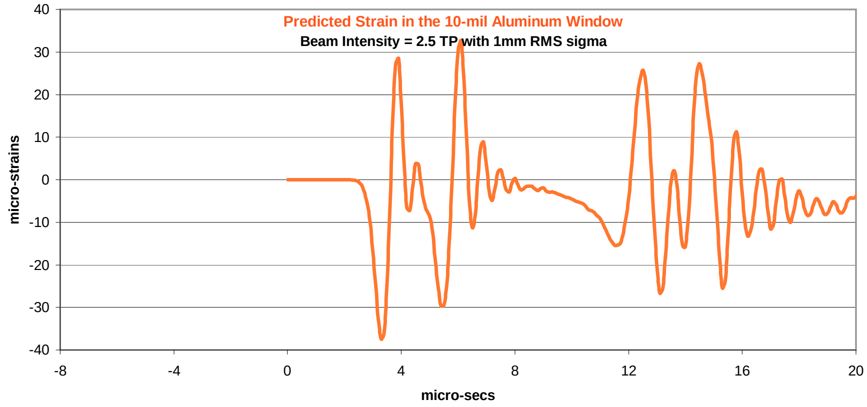
Solid Target Tests (5e12 *ppp*, 24 GeV, 100 ns)

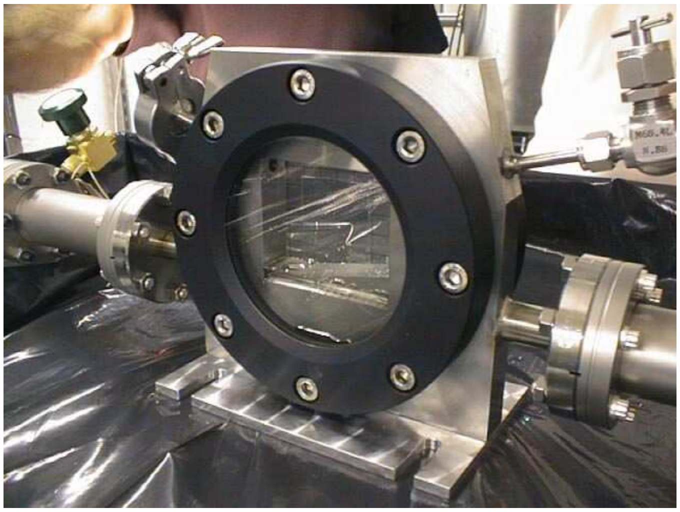
Carbon, aluminum, Ti90Al6V4, Inconel 708, Havar, instrumented with fiberoptic strain sensors.



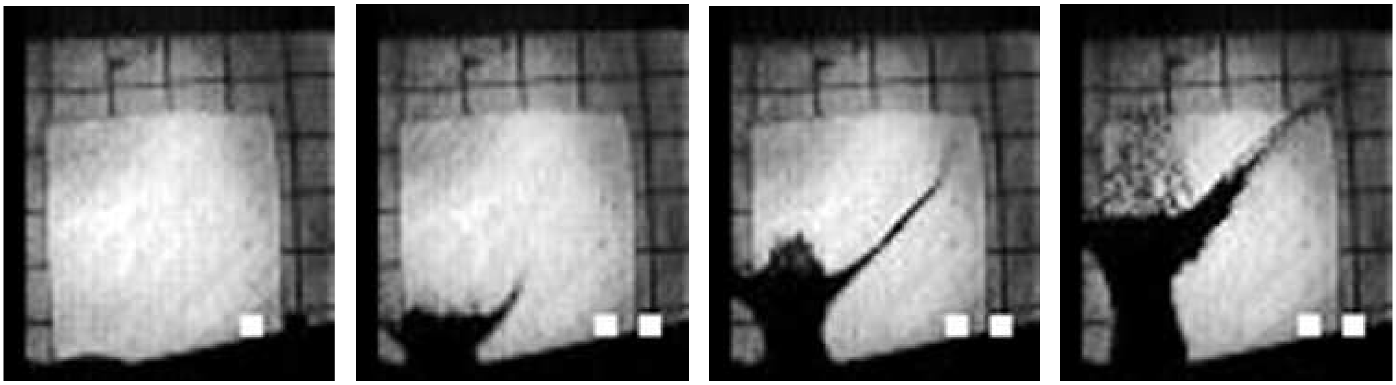




Passive Mercury Target Tests

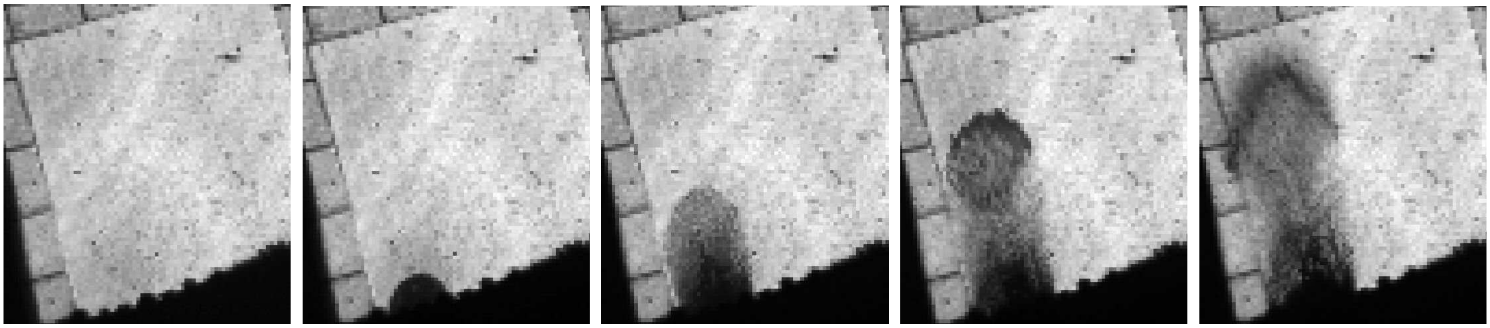


Exposures of 25 μs at
$t = 0, 0.5, 1.6, 3.4$ msec,
$\Rightarrow v_{\rm splash} \approx 20 - 40$ m/s:

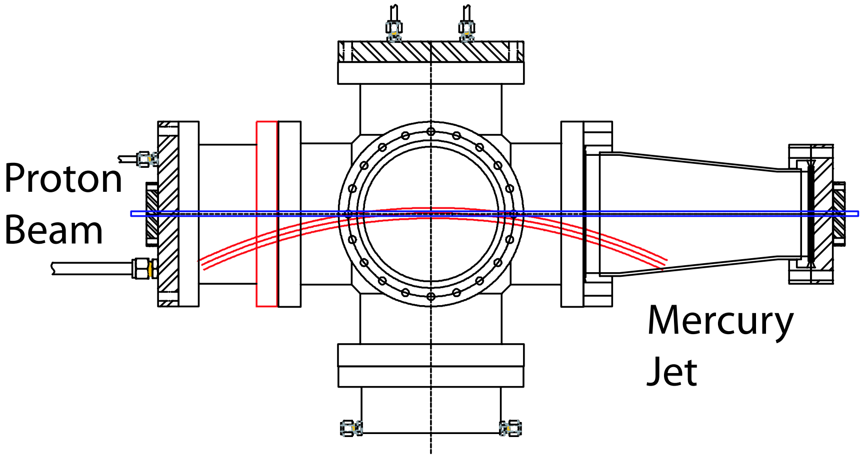


Exposures of 150 ns at $t = 0$, 0,2, 0,4, 0,6 and 0.8 msec,

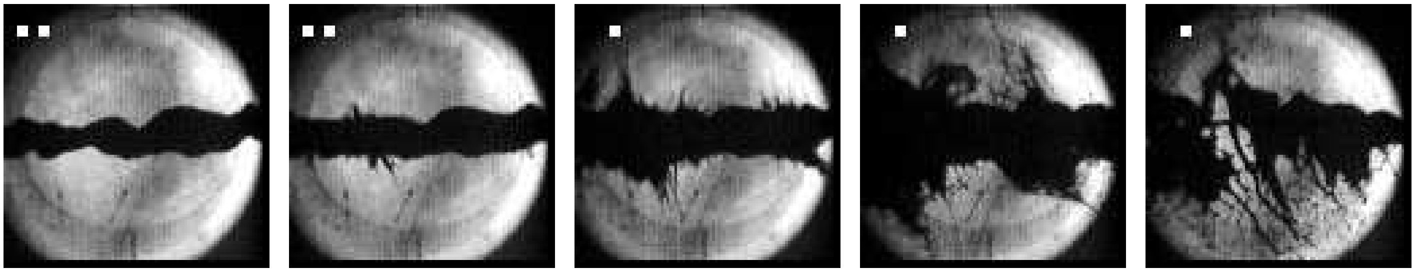
4e12 protons, $\Rightarrow v_{\rm splash} \approx 75$ m/s (then slowed by air drag):



Studies of Proton Beam + Mercury Jet



1-cm-diameter Hg jet in 2e12 protons at $t = 0, 0.75, 2, 7, 18$ ms.



$$\text{Model:} \quad v_{\text{dispersal}} = \frac{\Delta r}{\Delta t} = \frac{r\alpha\Delta T}{r/v_{\text{sound}}} = \frac{\alpha U}{C} v_{\text{sound}} \approx 50 \text{ m/s}$$

for $U \approx 100$ J/g.

Data: $v_{\text{dispersal}} \approx 10$ m/s for $U \approx 25$ J/g.

$v_{\text{dispersal}}$ appears to scale with proton intensity.

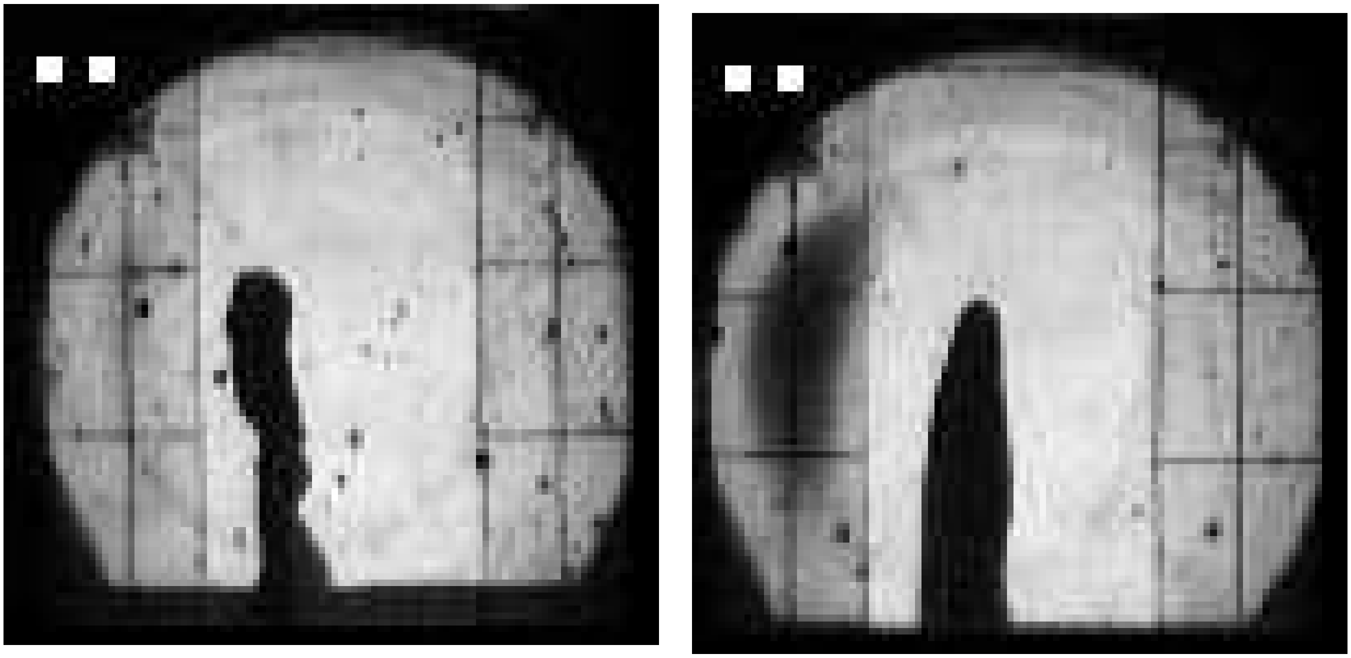
The dispersal is not destructive.

Tests of a Mercury Jet in a 13 T Magnetic Field
(CERN/Grenoble High Magnetic Field Laboratory)

Eddy currents may distort the jet as it traverses the magnet.

Analytic model suggests little effect if jet nozzle inside field.

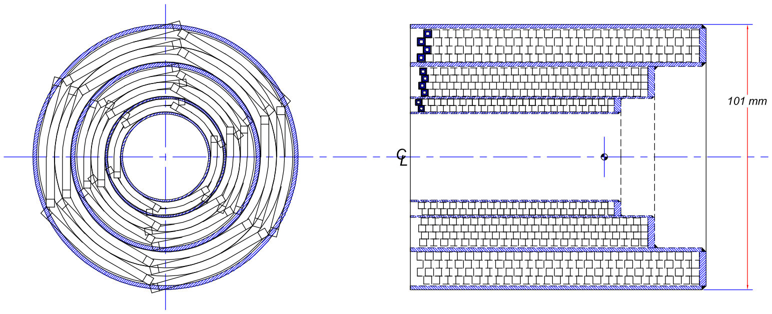
4 mm diam. jet, $v = 4.6$ m/s, $B = 0$ T; $v = 4.0$ m/s, $B = 13$ T:



⇒ Damping of surface tension waves (Rayleigh instability).

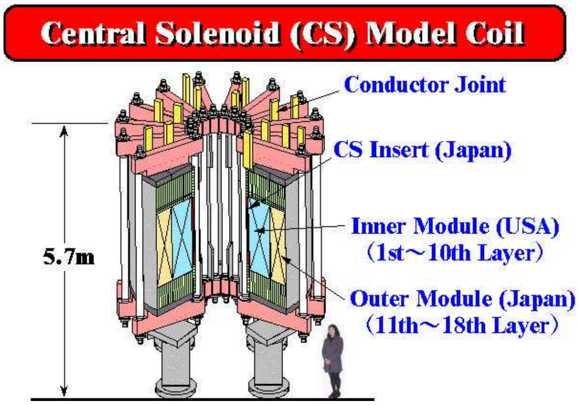
20-T Capture Magnet System

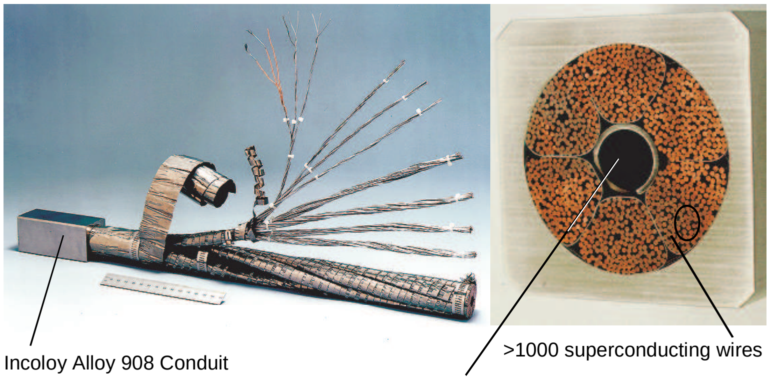
Inner, hollow-conductor copper coils generate 6 T @ 12 MW:



Bitter-coil option less costly, but marginally feasible.

Outer, superconducting coils generate 14 T @ 600 MJ:





Incoloy Alloy 908 Conduit

>1000 superconducting wires

Supercritical helium flows in interstices

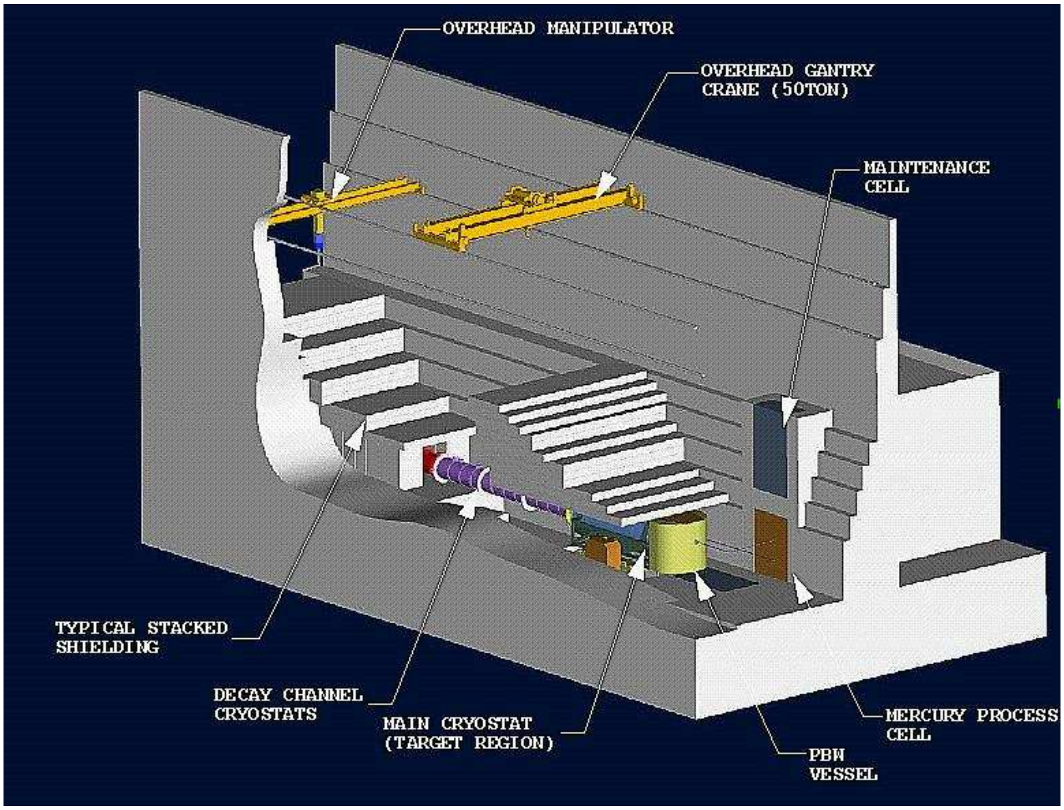
and central channel

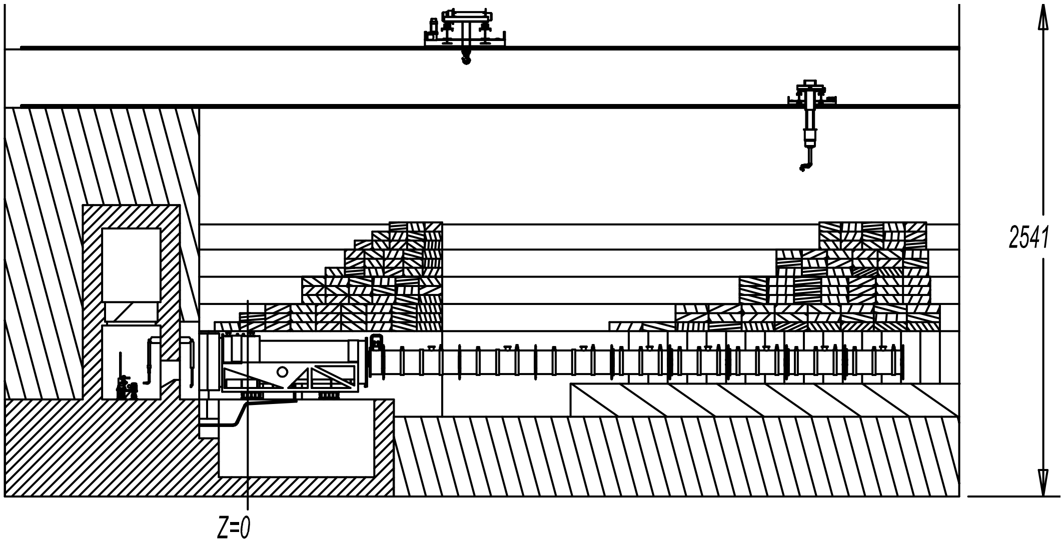
Cable-in-conduit construction similar to ITER central solenoid.

Both coils shielded by tungsten-carbide/water.

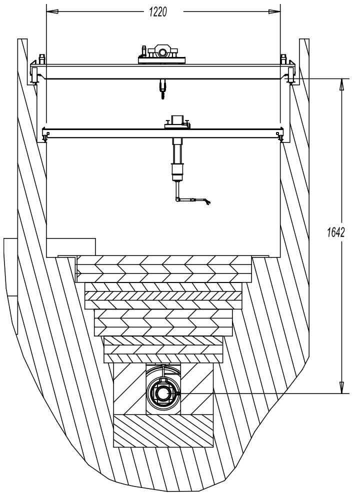
Target System Support Facility

Extensive shielding; remote handling capability.





SECTION C-C



SECTION B-B
DECAY CHANNEL SHIELDING

Summary of Targetry Activities Through FY01

- A target system based on a mercury jet in a 20-T capture solenoid is feasible at 1-4 MW beam power.
- Solid target alternatives include graphite rods or a rotating nickel band.
- An early upgrade to 4-MW may be the quickest path to higher neutrino fluxes.
- Continued R&D is needed. The next step is a combined test of a mercury jet in a proton beam and in a 20-T pulsed magnet (BNL E951 phase 2).

Targetry R&D Activities in FY02

1. Continued studies with AGS beam in the A3 line.
2. Engineering design studies of the proposed 10-T pulsed magnet.
3. Studies of production of mercury jets up to 20 m/s.
4. Continued simulations of target interactions with beams and magnetic fields.

Continued Studies with AGS Beam in the A3 Line

- Primary goal: study interaction of mercury jet with a pulse of 1.6×10^{13} protons. (Achieved only 4×10^{12} in FY01.)
- Secondary goal: study interaction of a Wood's metal jet with a proton beam.

Estimated Budget for AGS Operations

Study Type	No. of Shifts	Ops	Hardware	Install
A. Increase intensity of AGS	7	\$70k	\$150k	\$10k
B. Extraction into dump	6	\$95k	\$40k	\$10k
C. Extraction into A line	4-6	\$60-110k	\$30k	\$20k
D. Mercury target studies	2	\$50k		
E. Wood's metal studies	1	\$25k		
Totals	20-22	\$300-350k	\$220k	\$40k

Grand Total = \$560-610k

Items A and B are generic AGS machine studies.

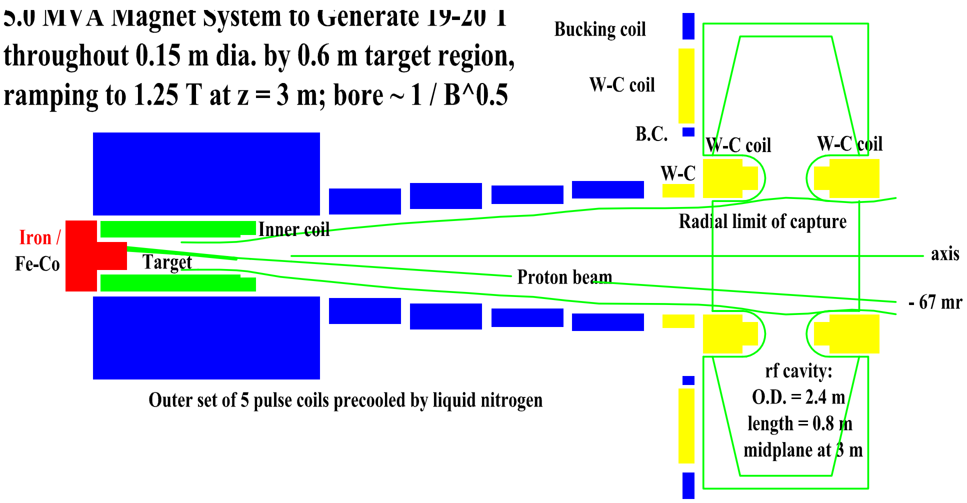
E-Mail to KTM from T.W.B. Kirk, 10/12/01

Your request was for:
1) 5 shifts of SEB parasitic running;
2) 8 shifts of extraction and beam transport studies that are not parasitic on the SEB program.

The first goal of increasing AGS intensity is one that has general benefit to the AGS program and we can expect to provide this as requested. The second goal will have a significant impact on the SEB program and will depend both on the details of next year's HEP budget and on the importance attached to this work by the MUTAC and MCOG. The MUTAC should be encouraged to comment on the value of the targeting experiment. Certainly, from the viewpoint of BNL, these studies will have general benefit for contemplated future AGS experiments as well as specific benefit for the Muon Storage Ring and Collider R&D program.

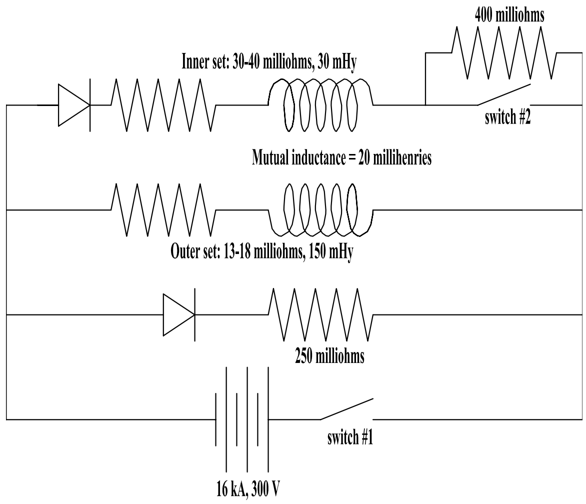
Therefore, I intend to provide the parasitic studies as soon as they can be organized (increasing the AGS intensity is going ahead right now with decent success) and will provide the remaining studies as best we can, perhaps developing a "stolen cycle" approach that is nearly parasitic to the SEB program. We have accomplished desirable studies in this mode before, but I can't fully commit to this goal until I have consulted with the C-AD experts.

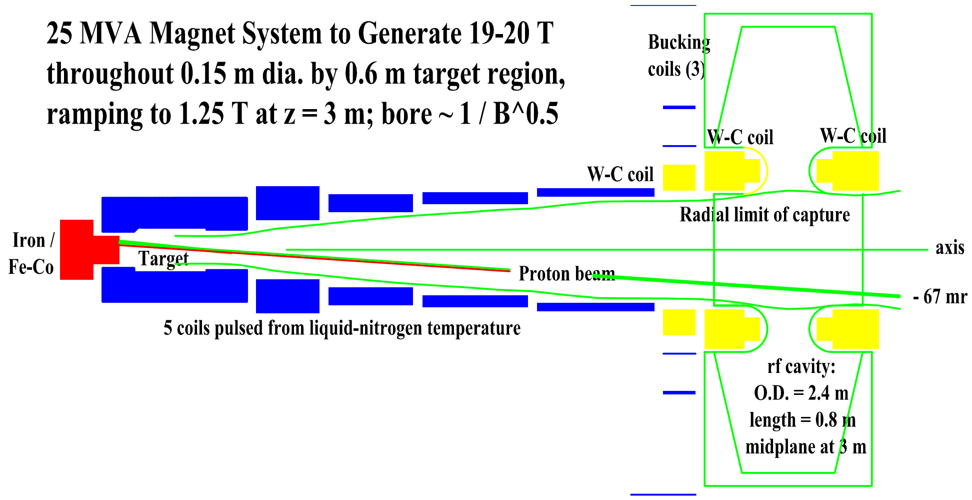
20-T Liquid-Nitrogen-Precooled Pulsed Magnet



5.0 MVA Magnet System to Generate 19-20 T
throughout 0.15 m dia. by 0.6 m target region,
ramping to 1.25 T at z = 3 m; bore ~ 1 / B^0.5

Outer set of 5 pulse coils precooled by liquid nitrogen





25 MVA Magnet System to Generate 19-20 T
throughout 0.15 m dia. by 0.6 m target region,
ramping to 1.25 T at z = 3 m; bore ~ 1 / B^0.5

5 coils pulsed from liquid-nitrogen temperature

20-T Pulsed Magnet Preliminary Budget Estimates

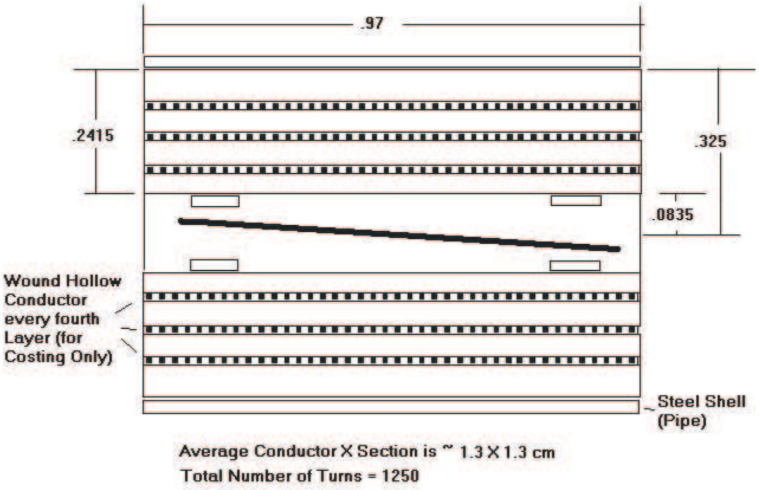
I. Marneris, R. Weggel, 8/23/01

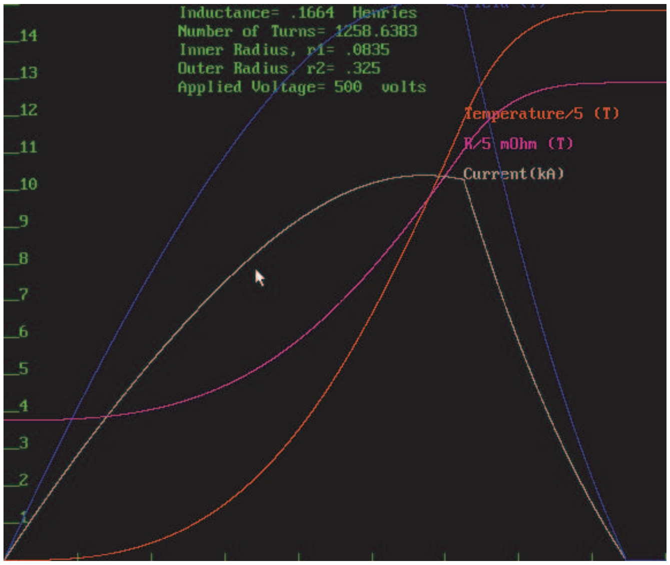
Scenario 1		Scenario 2	
5 MW power supply	\$700k	30 MW Westinghouse P.S.	Exists
Substation	\$300k	30 MVA rectifier	\$600k
HV buswork	\$100k	Transformer	\$600k
LV buswork	\$100k	Substation	\$300k
Switchgear	\$300k	Passive filter	\$300k
Outer Cu coil set (12T)	\$600k	HV buswork	\$180k
Inner Cu coil set (1T)	\$50k	Switchgear	\$60k
Cryostat	\$100k	Resistive energy dump	\$60k
		Cu coil set (4T)	\$200k
		Cryostat	\$50k
Subtotal	\$2250k	Subtotal	\$2350k
Engineering (30%)	\$675k	Engineering (30%)	\$700k
Contingency (25%)	\$550k	Contingency (25%)	\$575k
Total	\$3475k	Total	\$3625k

A 10-T Magnet + 2.2 MW Power Supply

- Reduce field by 2 ⇒ forces, costs drops by ≈ 4.

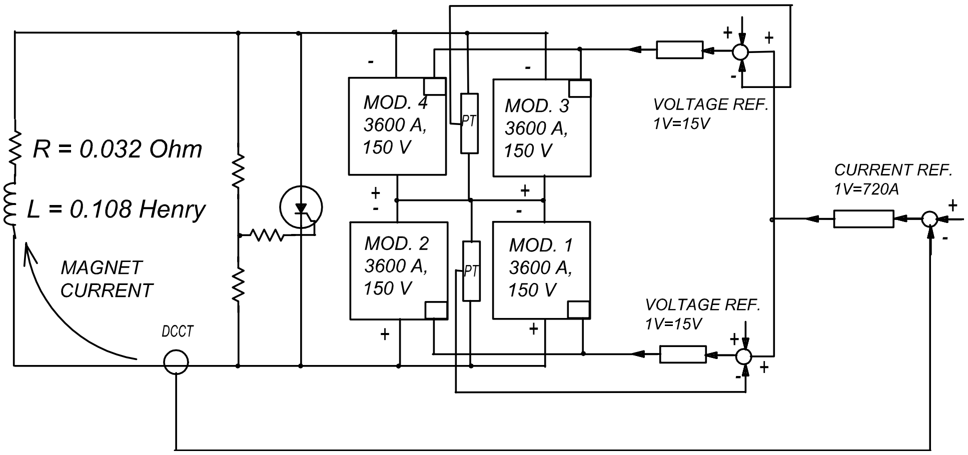
- Preliminary Design by MIT Plasma Science Div. (Minervini).





- Can build PS from existing BNL supplies for ≈ $250k (Marneris).

E951 PULSED MAGNET POWER SUPPLY
7200 A, +- 300 V



Preliminary estimate for new supply from Danfysik = $350k.

A 2-MW PS for the SNS Accumulator Ring

Collider-Accelerator Department / SNS Power Supply Systems
BROOKHAVEN NATIONAL LABORATORY

Spec. No.: SNS-0033 Issue Date: November 15, 2001

Title: SNS Accumulator Ring Main Dipole Power Supply

Cognizant Engineer: Jon Sandberg, AGS Power Supply Group

Approved by: M. Van Essendeleft, Quality Assurance

SNS Power Supply Group Leader: R. Lambiase

The rectifier module shall be used to convert ORNL supplied, three phase, 60 Hz power into 400 VDC, 5000 amp, 2 MW, highly regulated, fully controllable power for the Spallation Neutron Source (SNS) Accumulator Ring main dipole magnet string.

Vendor list:
Alpha Scientific Electronics
Bruker Analytische Messtechnik, GmbH
Danfysik A/S
Dynapower Corporation
F.u.G. Elektronik Gmbh
GE Industrial Systems
IE Power
Inverpower Controls, Ltd
Neeltran, Inc.
Siemens Energy & Automation
Transtechnik Corp

10-T Pulsed Magnet Preliminary Budget Estimates

I. Marneris, J. Minervini, J. Scaduto, R. Weggel, 10/12/01

Scenario 3

2.2 MW power supply	$300k
HV buswork	$100k
LV buswork	$100k
Cu coil set (1T)	$300k
Cryogenics	$100k
Subtotal	$900k
Contingency (22%)	$200k
Total	$1100k