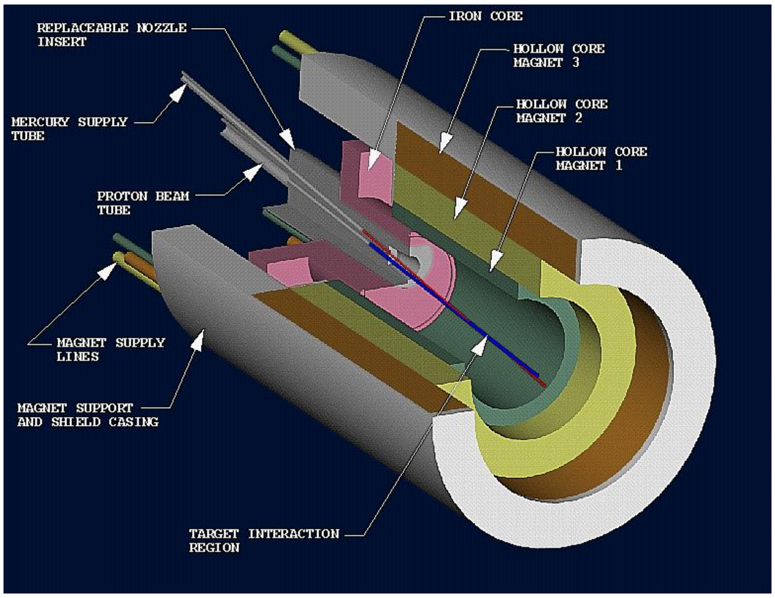
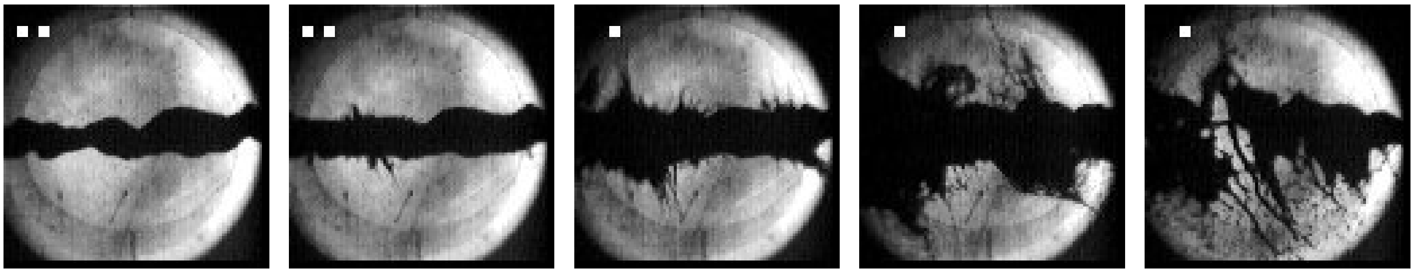
Carbon and Mercury Targets for Neutrino Beams and a Muon Collider Source

(BNL E951)





K.T. McDonald

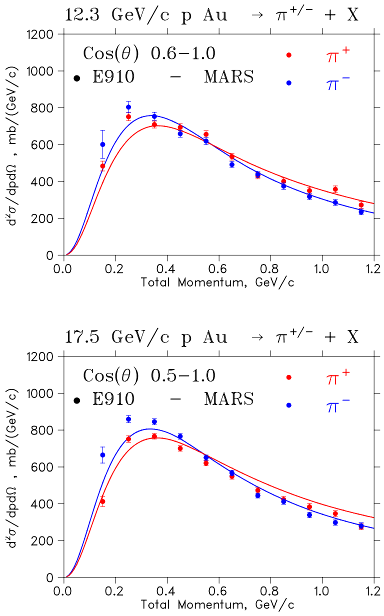
Princeton U.

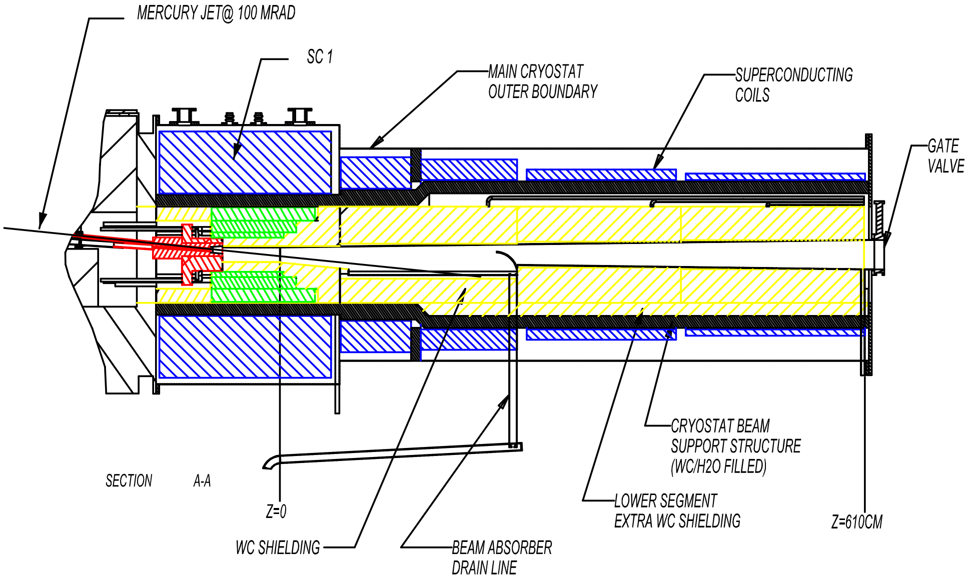
ICFA Workshop, Fermilab, Apr. 9, 2002

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.





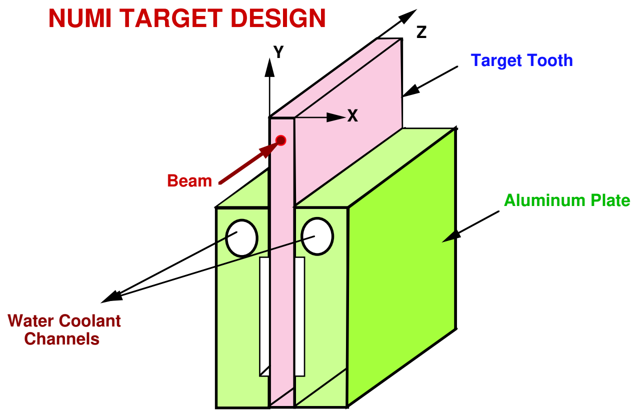
- A carbon target is feasible for 1.5-MW proton beam power.
- For $E_p \gtrsim 16$ GeV, factor of 2 advantage with high-Z target.
- Static high-Z target would melt, ⇒ Moving target.
- A free mercury jet target is feasible for beam power of 4 MW (and more).

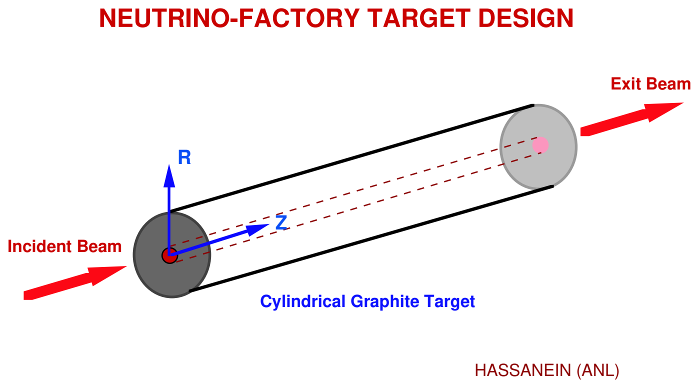
The Neutrino Horn Issue

- 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.

  See, http://pubweb.bnl.gov/users/kahn/www/talks/Homestake.pdf

A Carbon Target is Feasible at 1-MW Beam Power



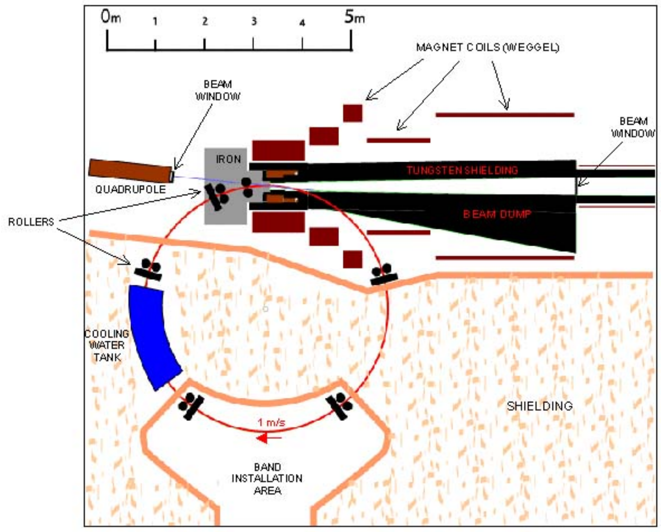


A carbon-carbon composite with near-zero thermal expansion is largely immune to beam-induced pressure waves.

Sublimation of carbon is negligible in a helium atmosphere.

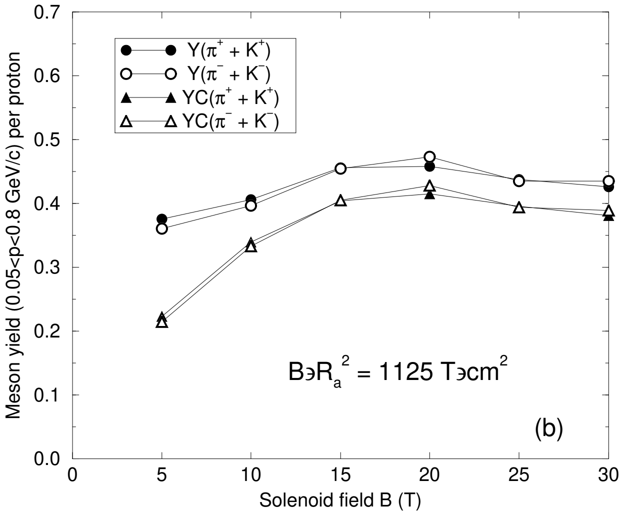
Radiation damage is limiting factor: $\approx$ 12 weeks at 1 MW.

A rotating band target is another option:



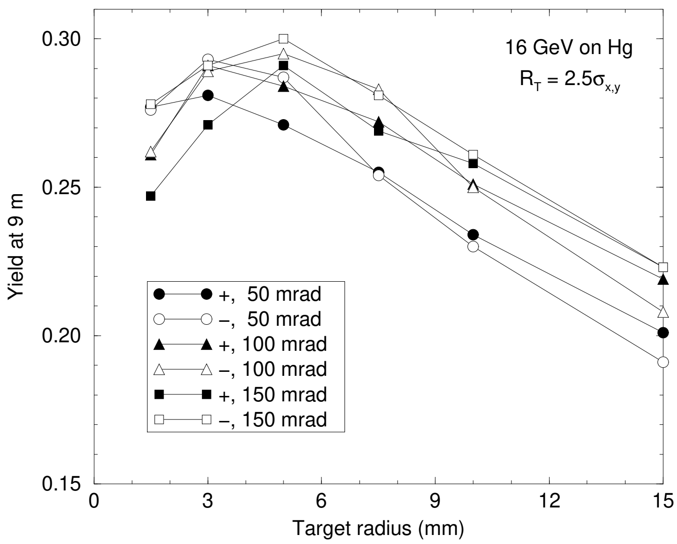
Pion/Muon Yield

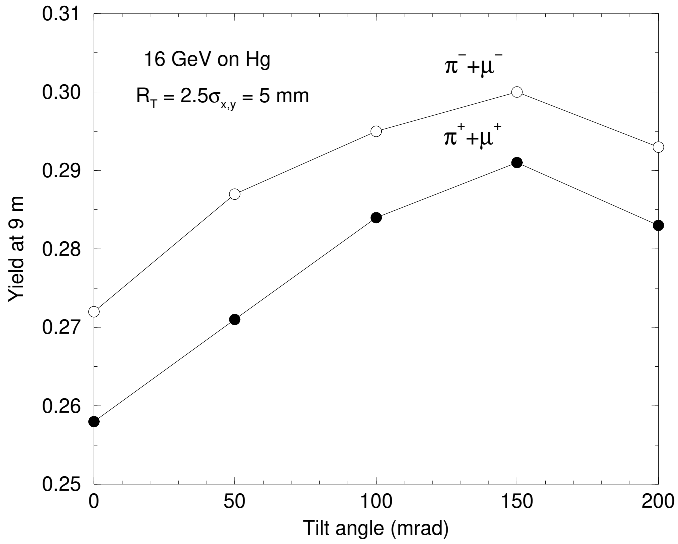
For $E_p \gtrsim 10$ GeV, more yield with high-Z target.



Mercury target radius should be ≈ 5 mm,

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

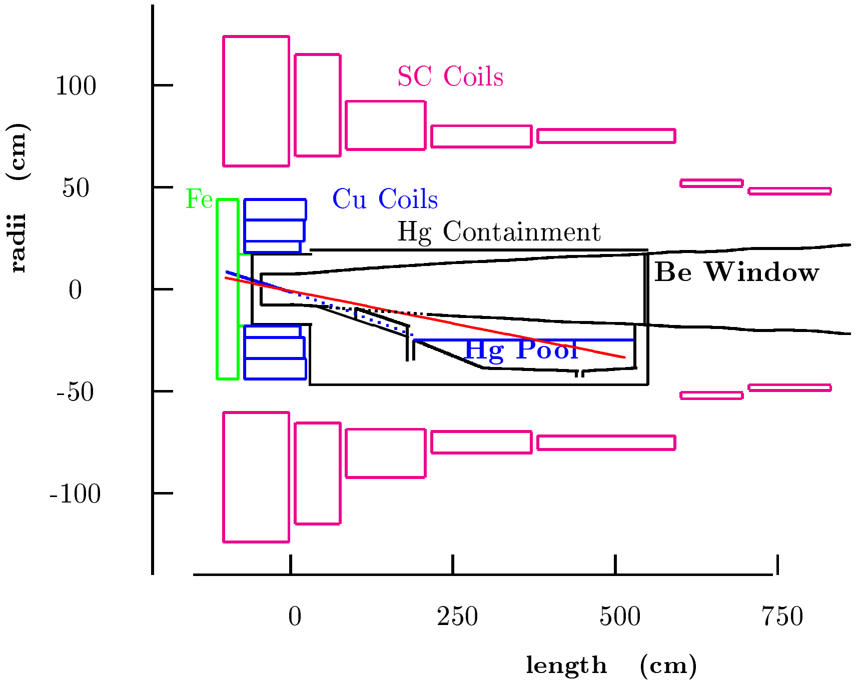




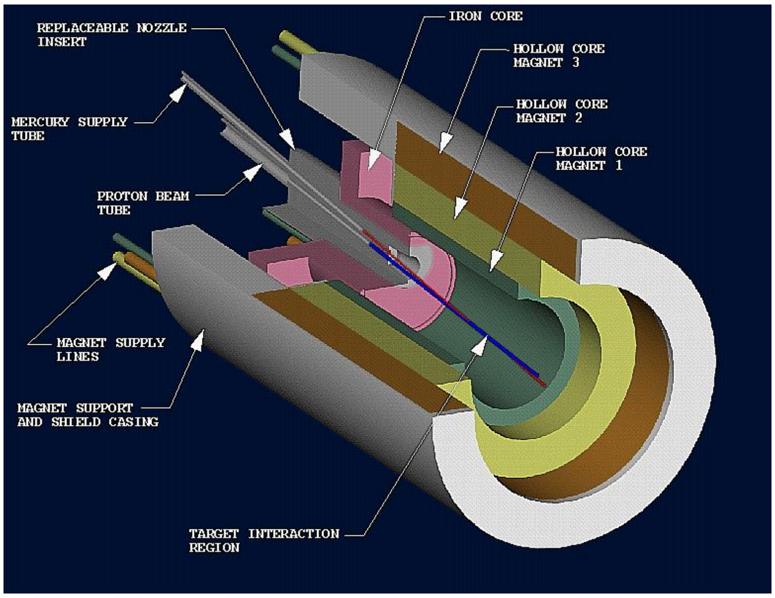
Can capture ≈ 0.3 pion per proton with $50 < P_\pi < 400$ MeV$/c$.

Target System Layout

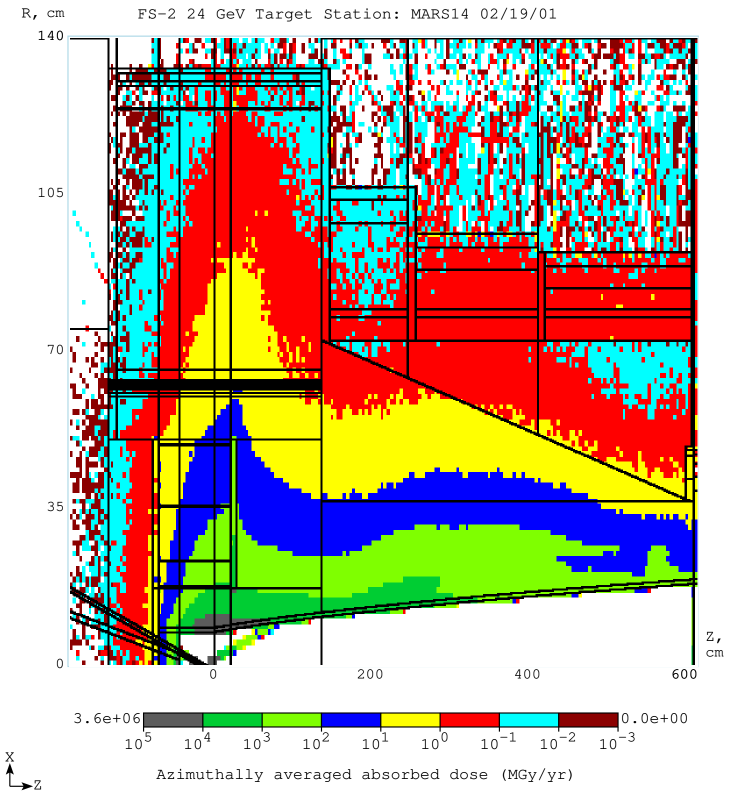
Mercury jet target inside a magnetic bottle: 20-T around target, dropping to 1.25 T in the pion decay channel.



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



Lifetime of Components in the High Radiation Environment

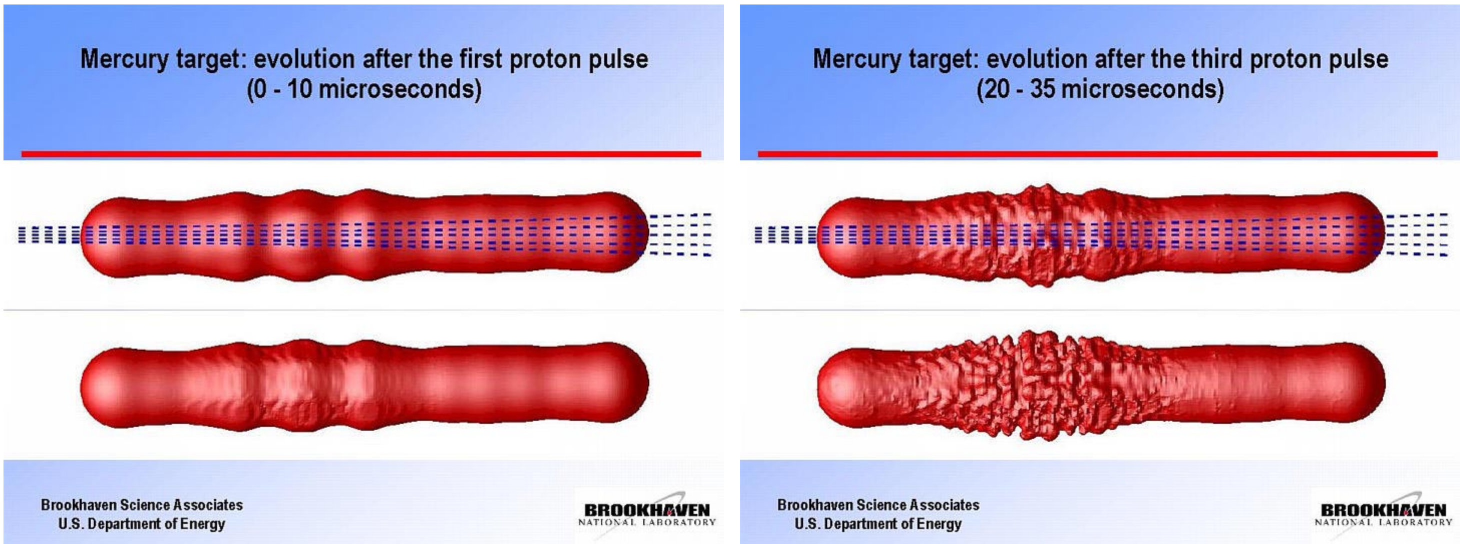


Component	Radius (cm)	Dose/yr (Grays/2×10^7 s)	Max allowed Dose (Grays)	1 MW Life (years)	4 MW life (years)
Inner shielding	7.5	5×10^{10}	10^{12}	20	5
Hg containment	18	10^9	10^{11}	100	25
Hollow conductor coil	18	10^9	10^{11}	100	25
Superconducting coil	65	5×10^6	10^8	20	5

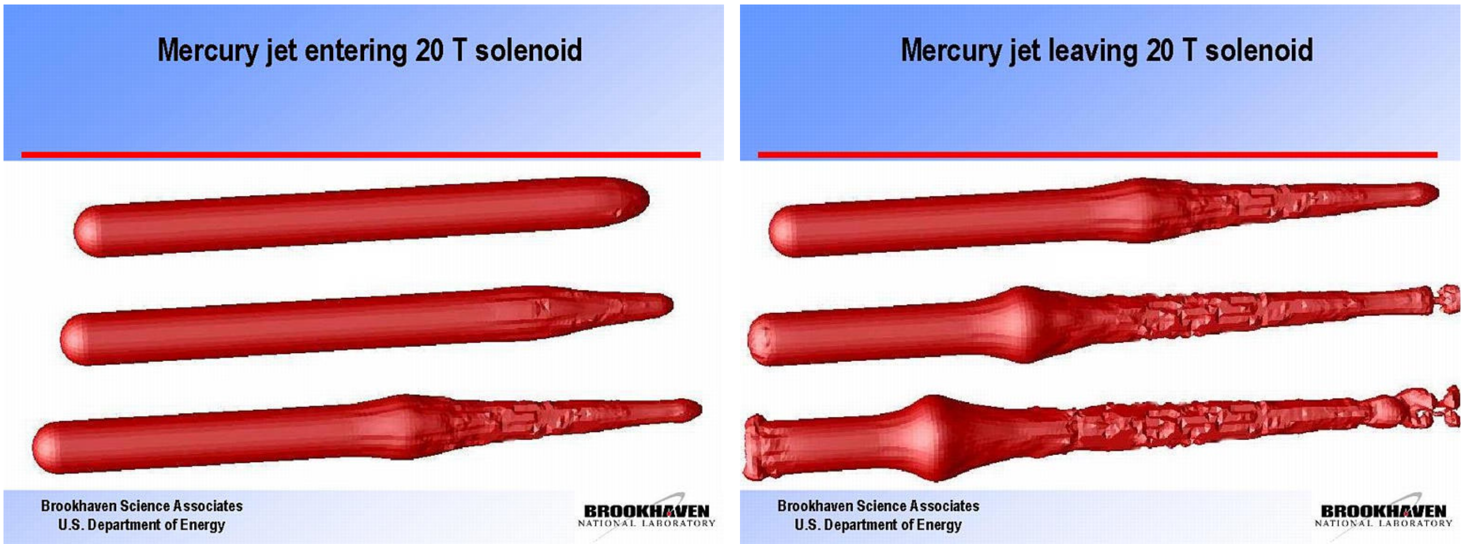
Some components must be replaceable.

Viability of Targetry and Capture For a Single Pulse

- Beam energy deposition may disperse the jet.



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

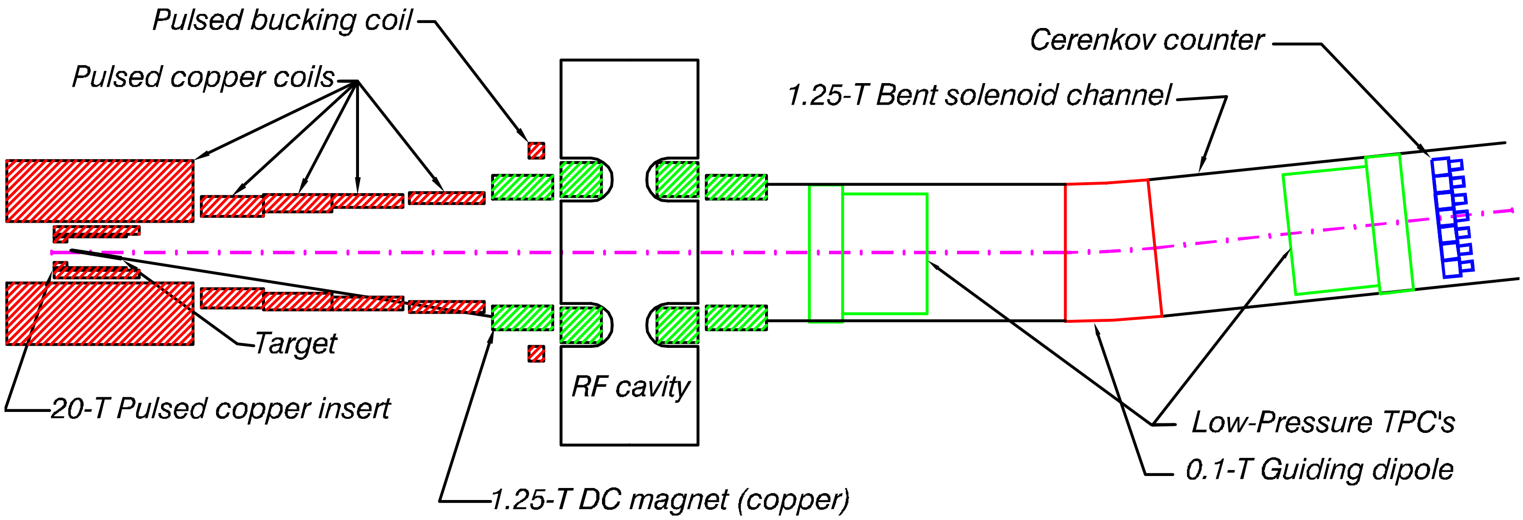


E951 Studies the Single Pulse Issues

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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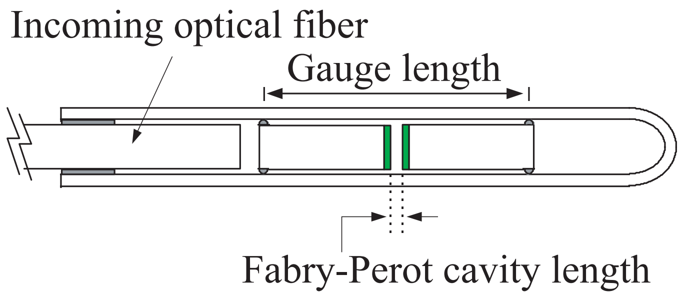
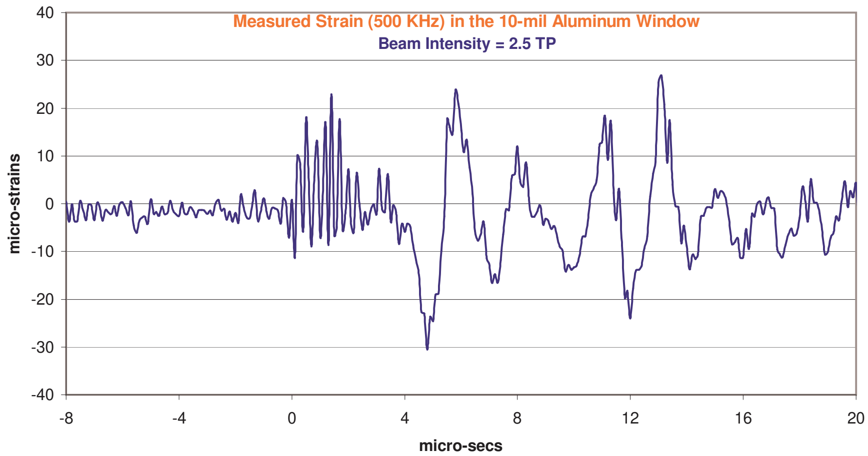
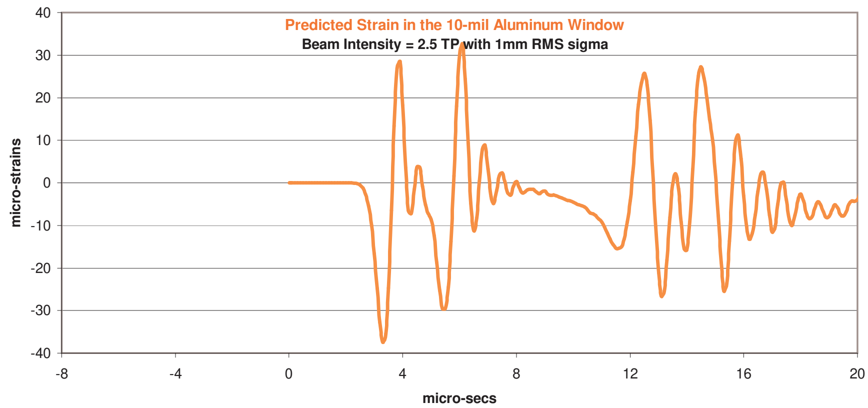
Solid Target Tests (5e12 *p*pp, 24 GeV, 100 ns)

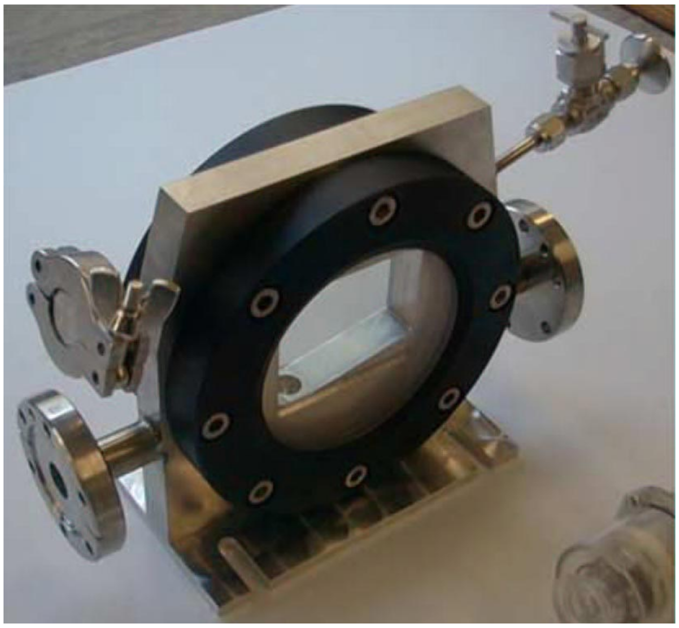
Carbon, aluminum, Ti90Al6V4, Inconel 708, Havar, instrumented with fiberoptic strain sensors.



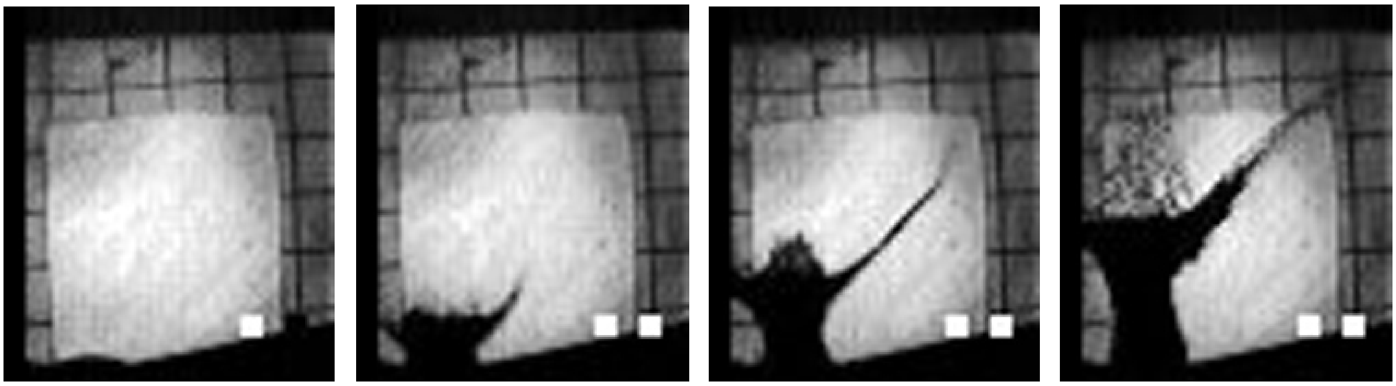




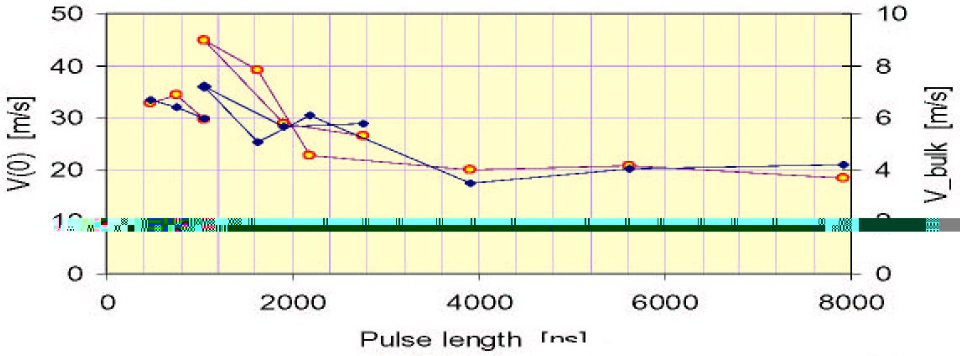
Passive Mercury Target Tests



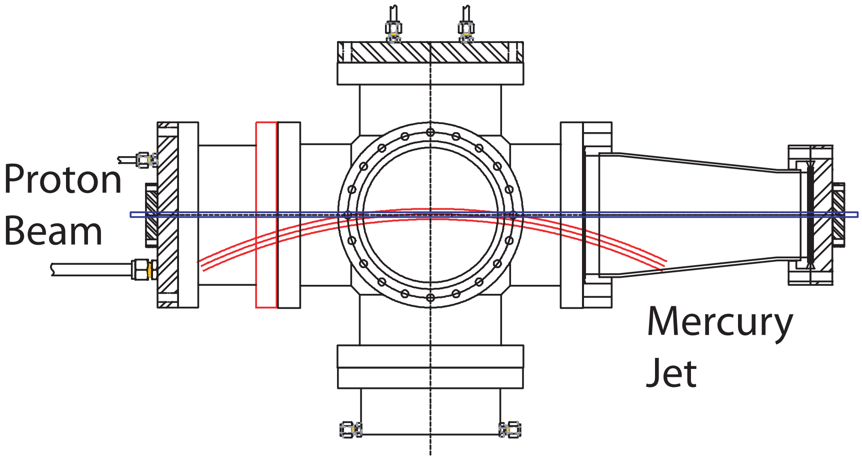
Exposures of 25 μs at
$t = 0,\ 0.5,\ 1.6,\ 3.4$ msec,
$\Rightarrow v_{\text{splash}} \approx 20 - 40$ m/s:



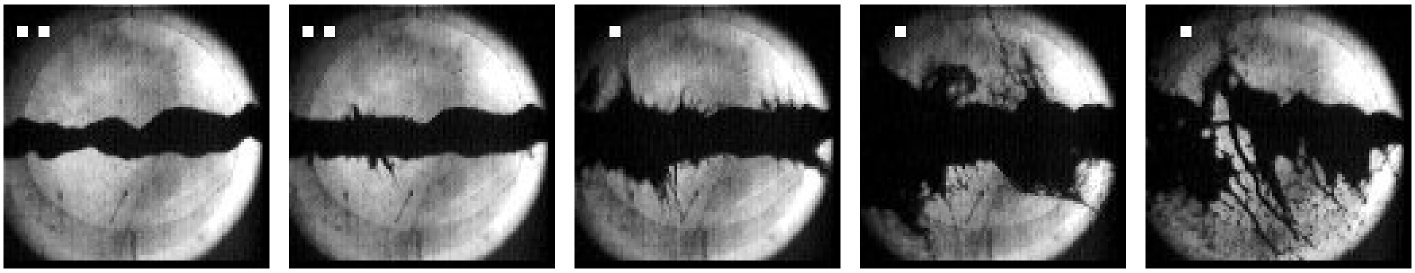
Two pulses of ≈ 250 ns give larger dispersal velocity only if separated by less than 3 μs.



Studies of Proton Beam + Mercury Jet



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



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

for $U \approx 100$ J/g.

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

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

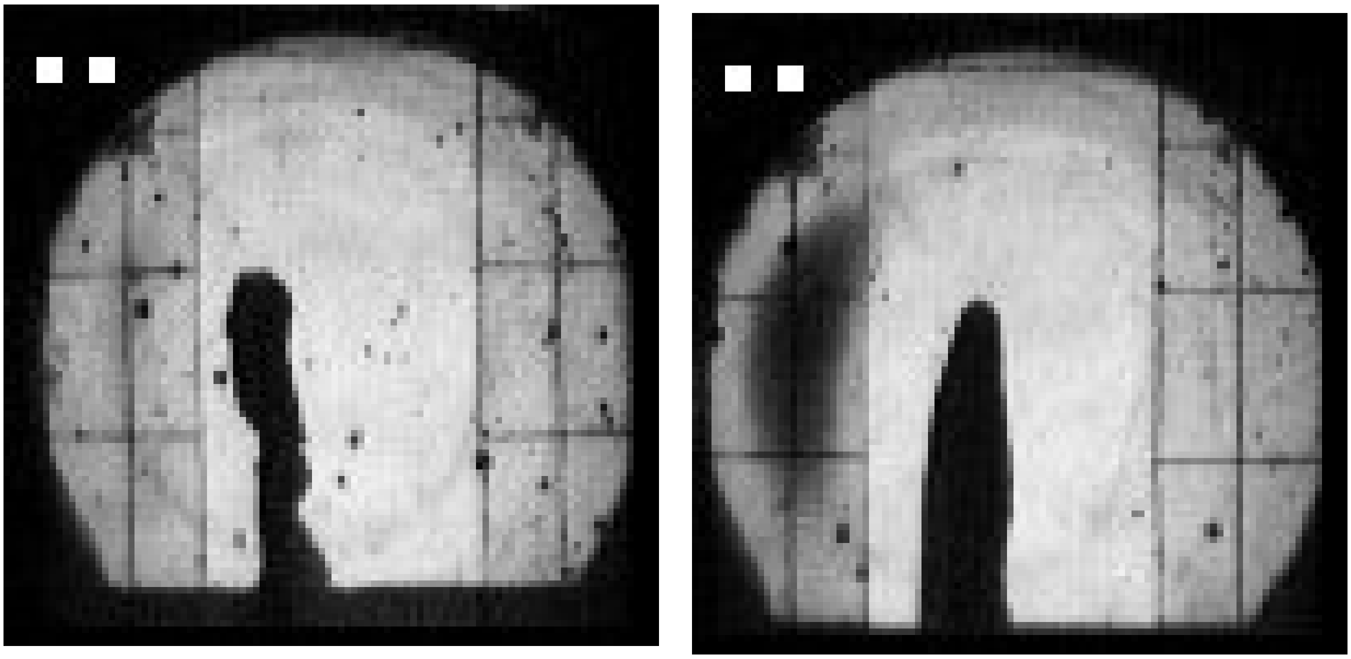
The dispersal is not destructive.

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.

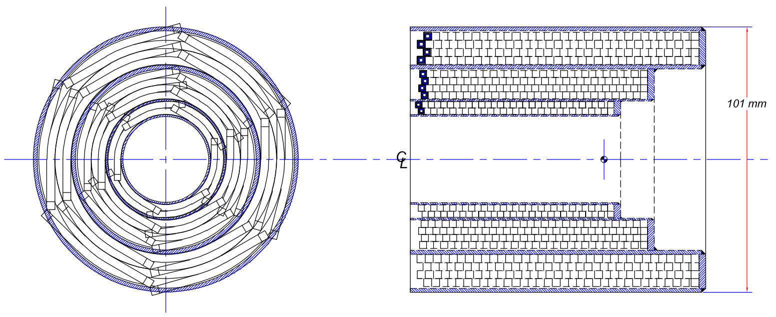
4 mm diam. jet, $v = 4.6$ m/s, $B = 0$ T; $v = 4.0$ m/s, $B = 13$ T:



$\Rightarrow$ Damping of surface tension waves (Rayleigh instability).

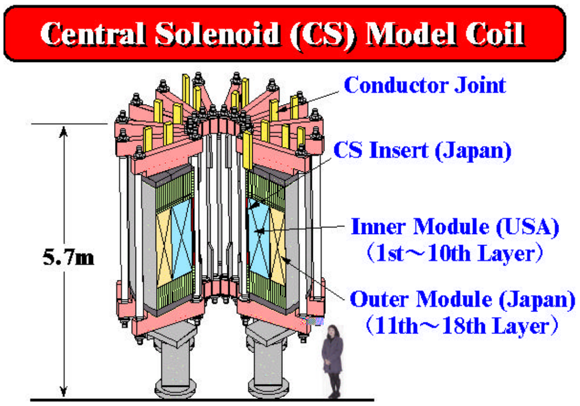
20-T Capture Magnet System

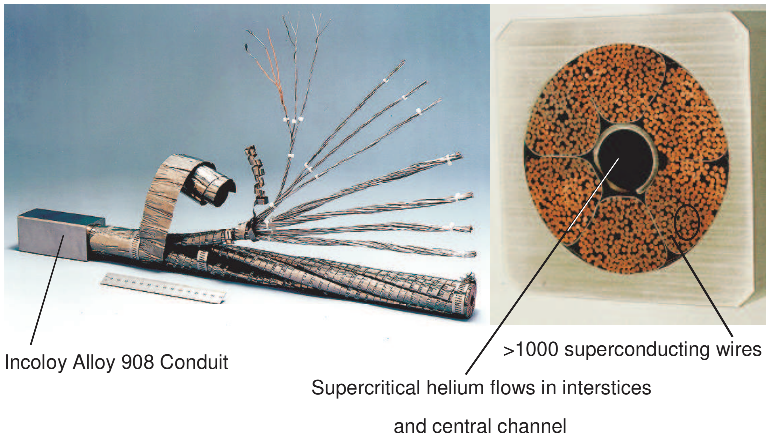
Inner, hollow-conductor copper coils generate 6 T @ 12 MW:



Bitter-coil option less costly, but marginally feasible.

Outer, superconducting coils generate 14 T @ 600 MJ:



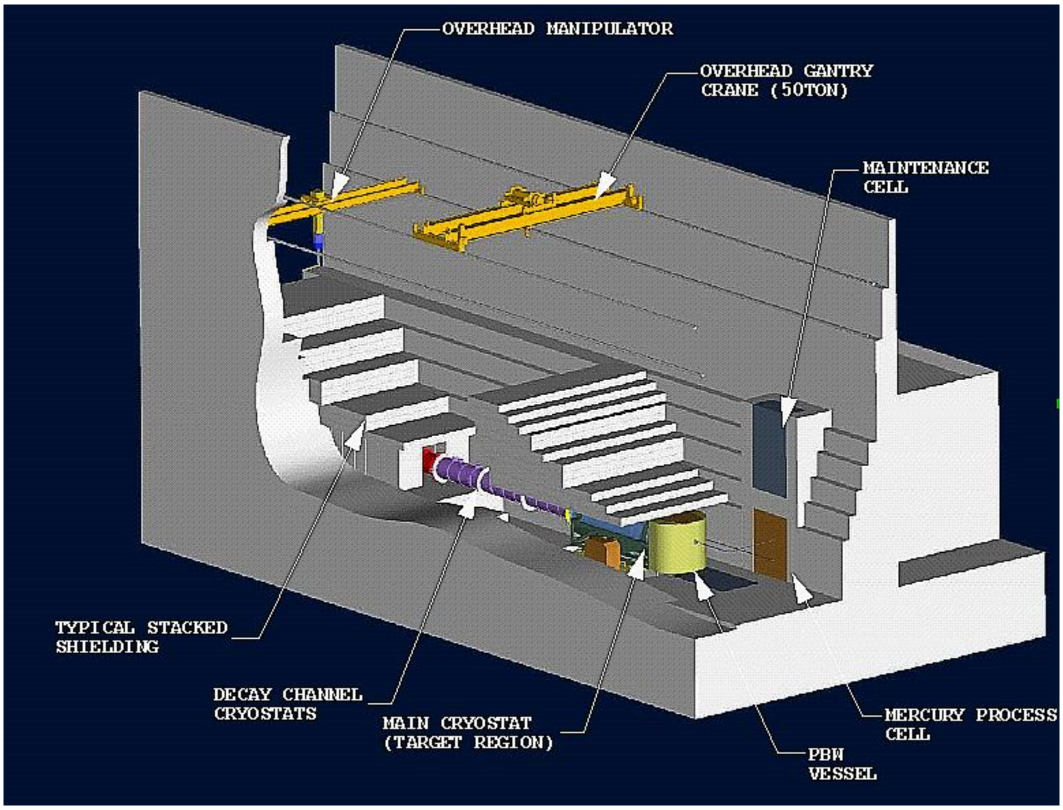


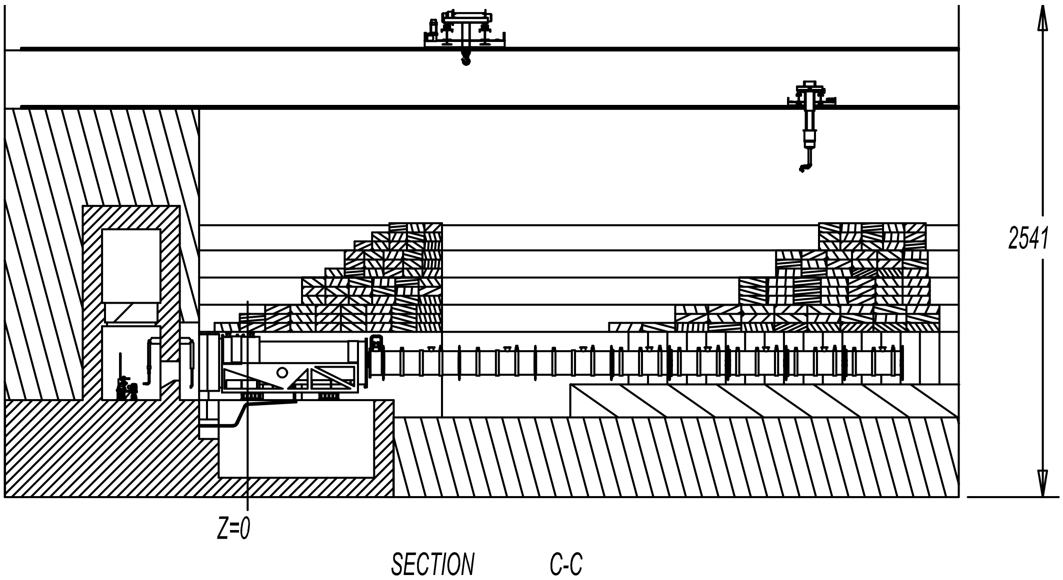
Cable-in-conduit construction similar to ITER central solenoid.

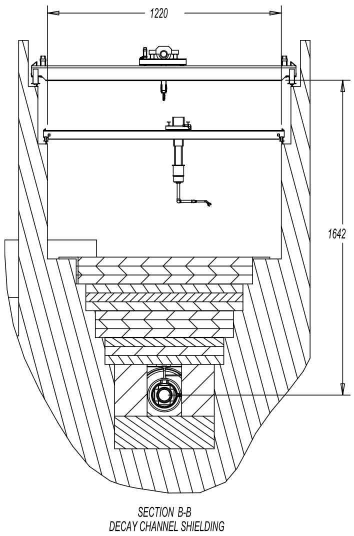
Both coils shielded by tungsten-carbide/water.

Target System Support Facility

Extensive shielding; remote handling capability.





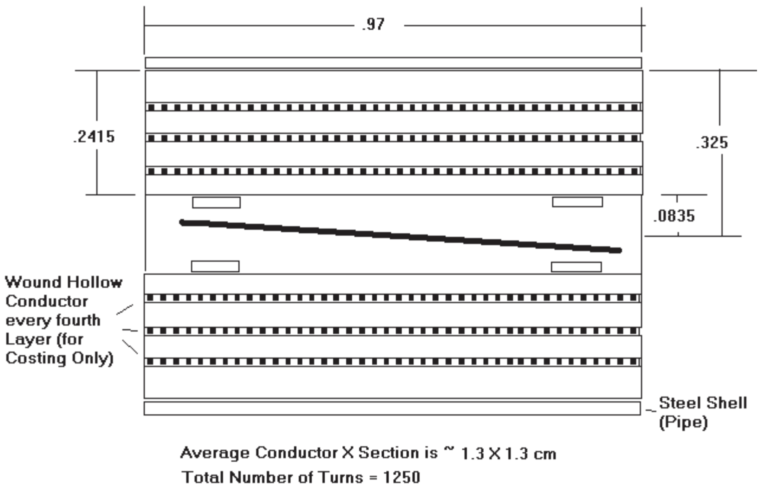


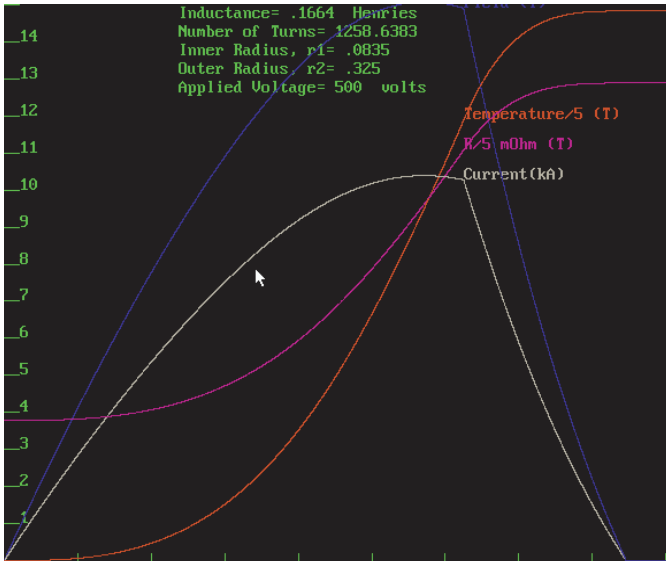
Summary of Targetry Activities Through FY01

- 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).

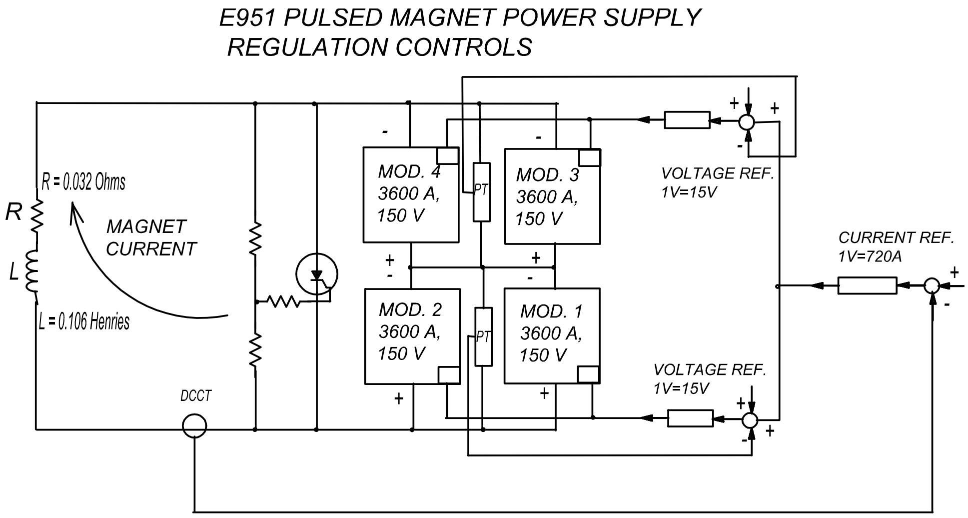
A 15-T Liquid-Nitrogen-Precooled Pulsed Magnet + 2.2 MW Power Supply

- Reduce field by 2 $\Rightarrow$ forces, costs drops by $\approx$ 4.
- Preliminary Design by MIT Plasma Science Div. (Titus).





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



- Cool to 30 K via He gas flow + LH_2 head exchanger (Iarocci).