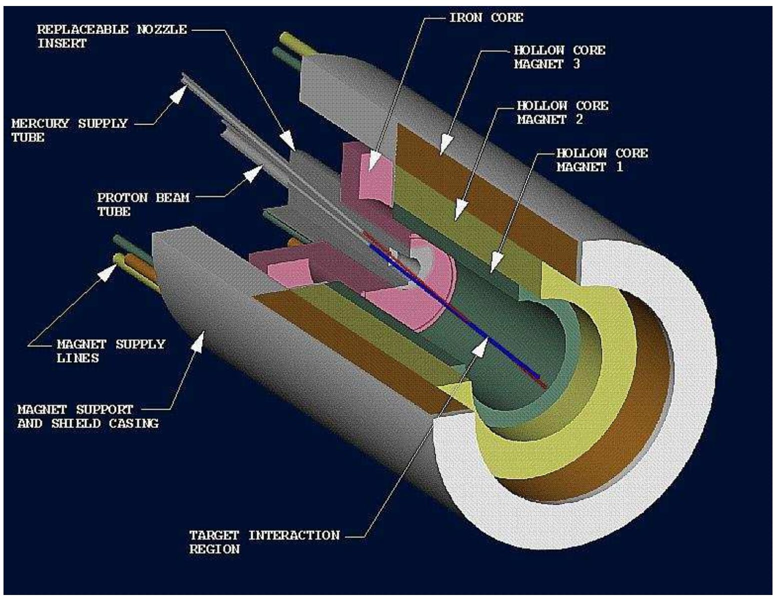
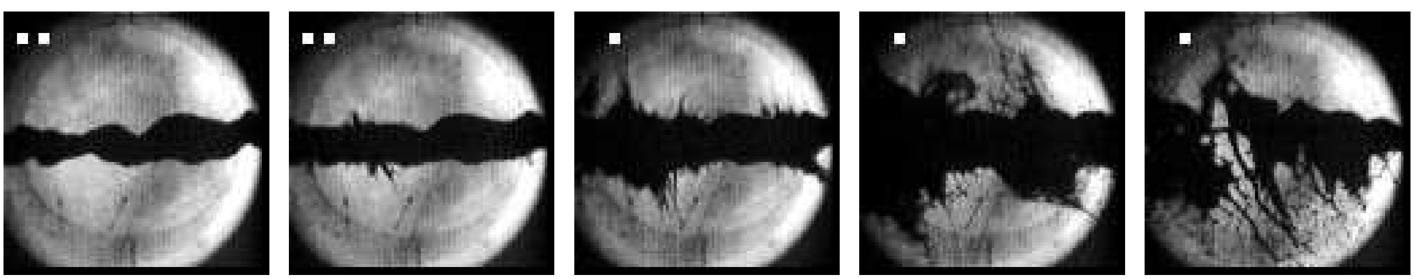
The R&D Program for Targetry and Capture at a Neutrino Factory and Muon Collider Source

(BNL E951)





K.T. McDonald
Princeton U.

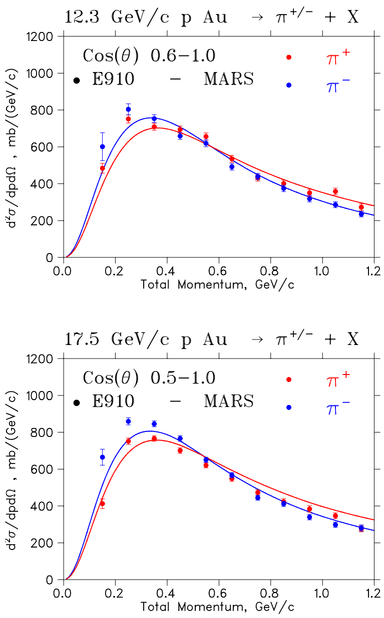
NuFACT'01, Tsukuba, Japan, May 26, 2001

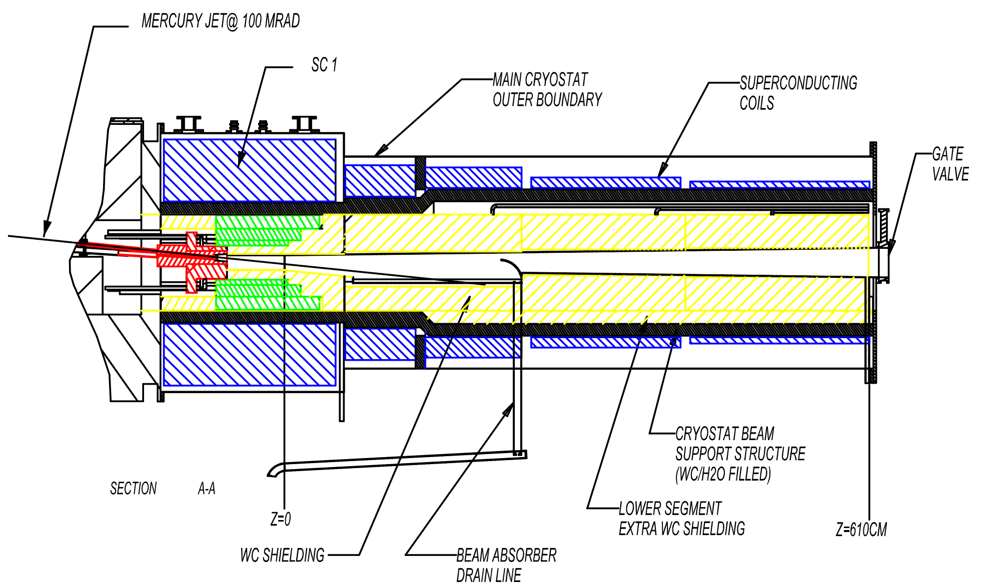
http://puhep1.princeton.edu/mumu/target/

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.

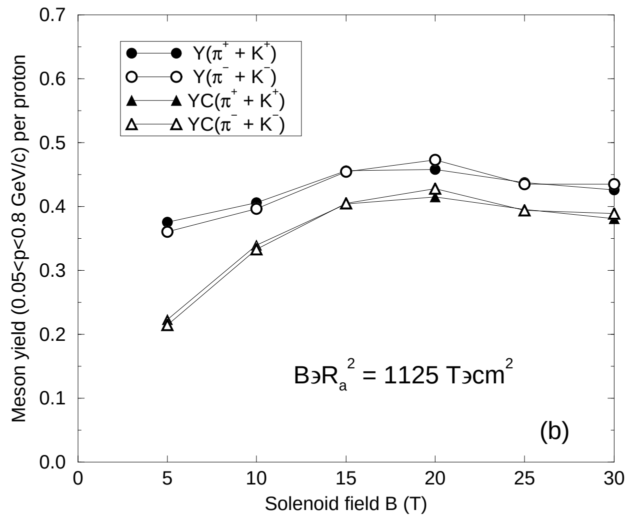
- A free mercury jet target is feasible for beam power of 4 MW (and more).

Feasibility Issues

- Pion/muon yield.
- Lifetime of components in high radiation environment.
- Mercury jet interaction with beam and magnet.
- Design of the 20-T capture magnet.
- Beam entrance and exit windows.
- Proton beam absorber.
- Mercury flow loop.
- Target system support facility.

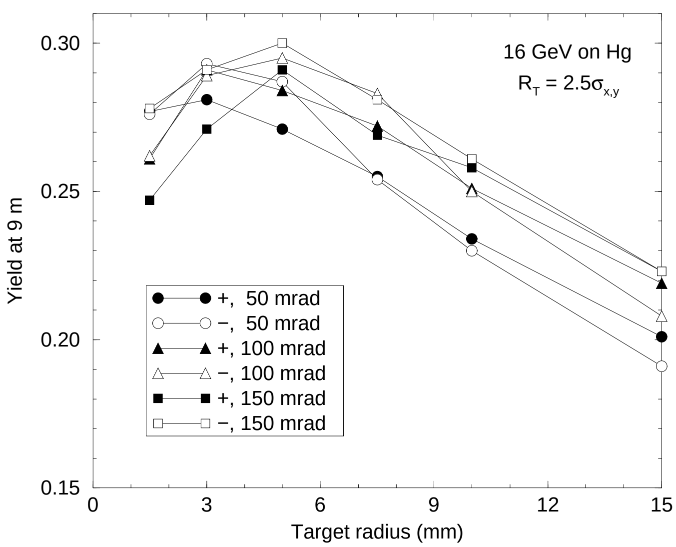
Pion/Muon Yield

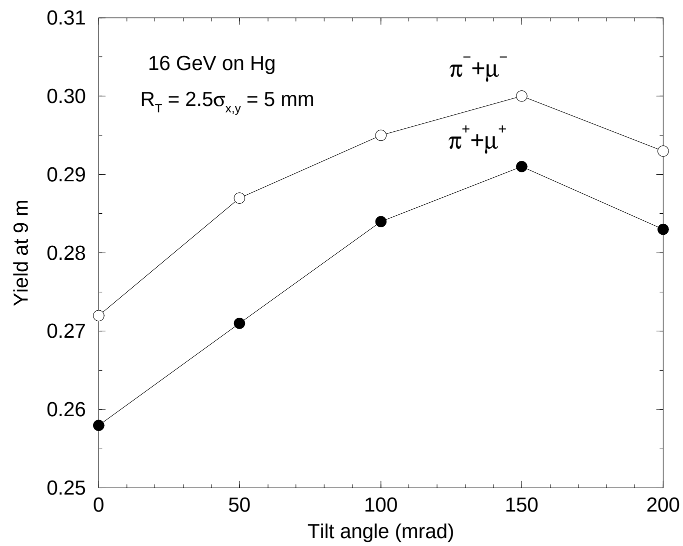
For $E_p \gtrsim 10$ GeV, more yield with high-Z target.



Mercury target radius should be ≈ 5 mm,

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

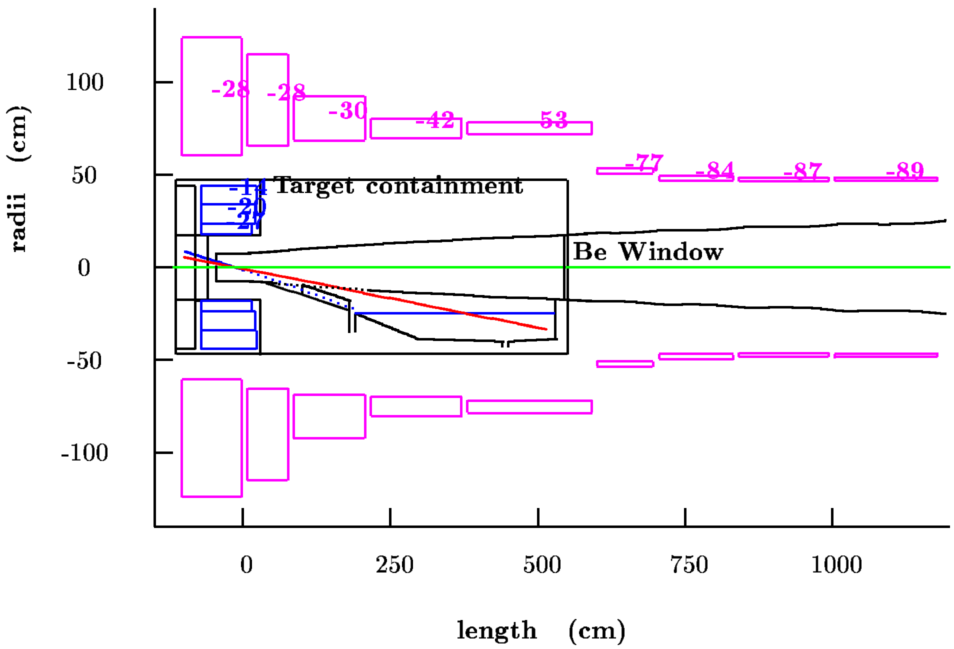




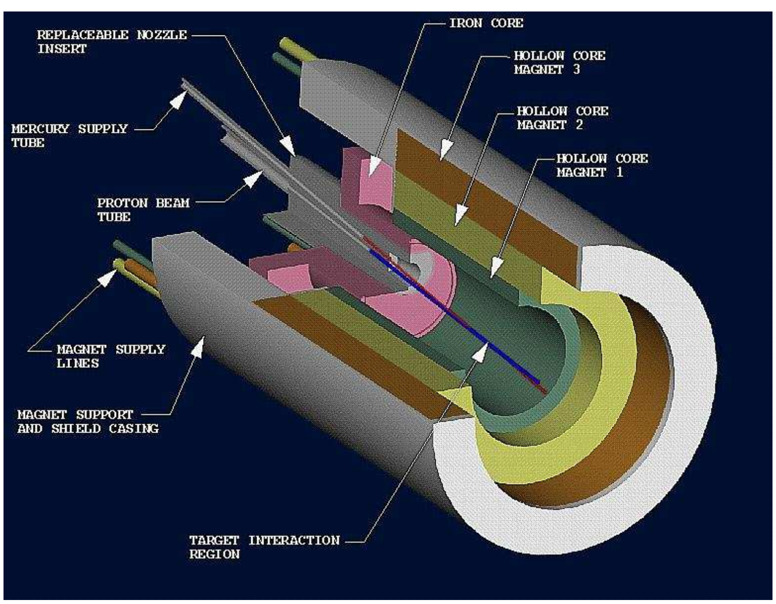
Can capture ≈ 0.3 pion per proton with $50 < P_\pi < 400$ MeV/c.

Target System Layout

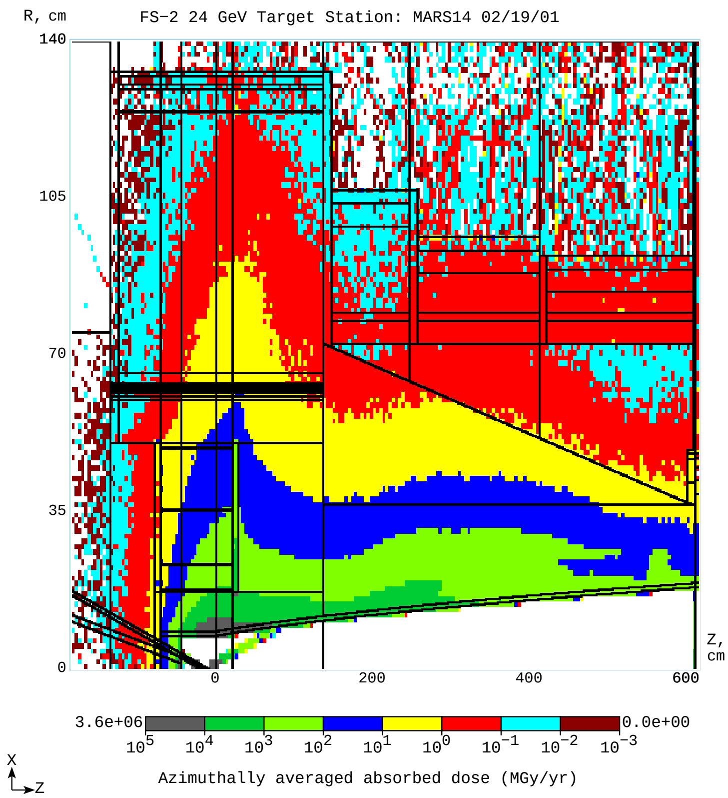
Mercury jet target inside a magnetic bottle: 20-T around target, dropping to 1.25 T in the pion decay channel.



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



Lifetime of Components in the High Radiation Environment

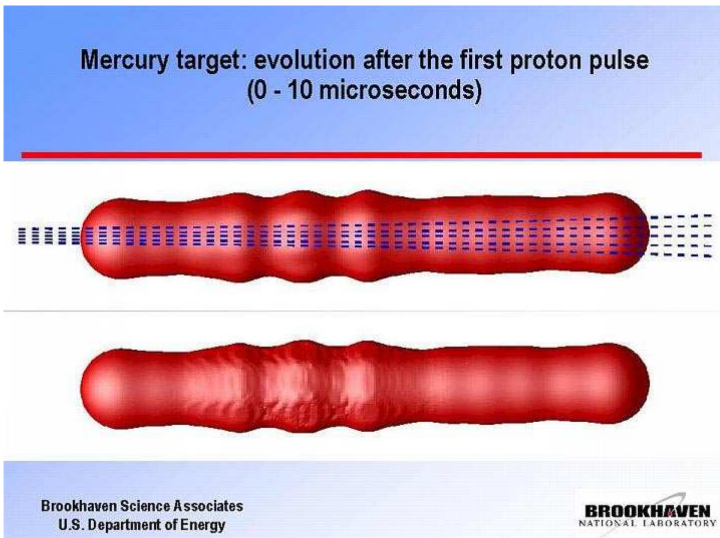


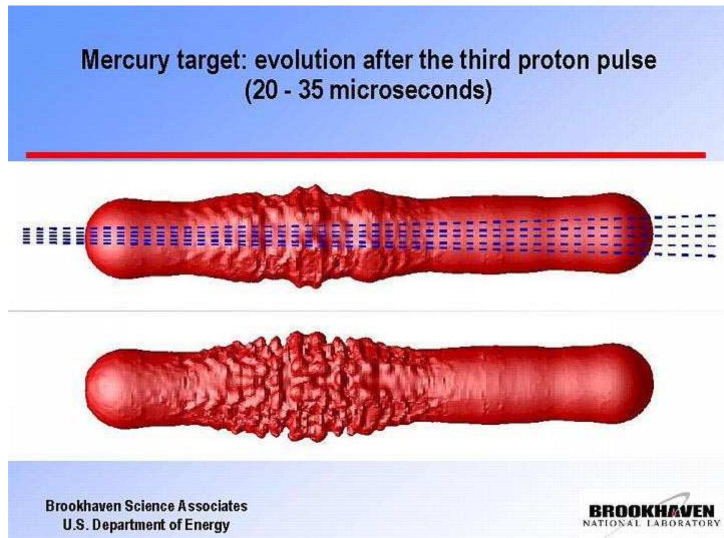
Component	Radius (cm)	Dose/yr (Grays/2×10^7 s)	Max allowed Dose (Grays)	1 MW Life (years)	4 MW life (years)
Inner shielding	7.5	5×10^{10}	10^{12}	20	5
Hg containment	18	10^9	10^{11}	100	25
Hollow conductor coil	18	10^9	10^{11}	100	25
Superconducting coil	65	5×10^6	10^8	20	5

Some components must be replacable.

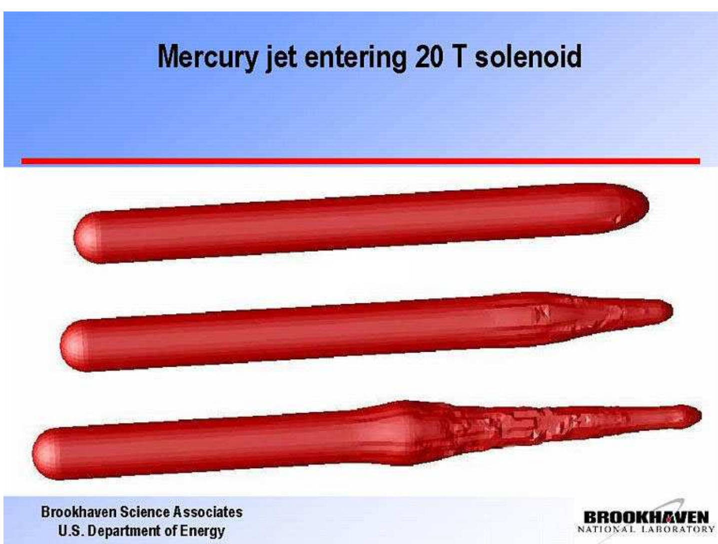
Viability of Targetry and Capture For a Single Pulse

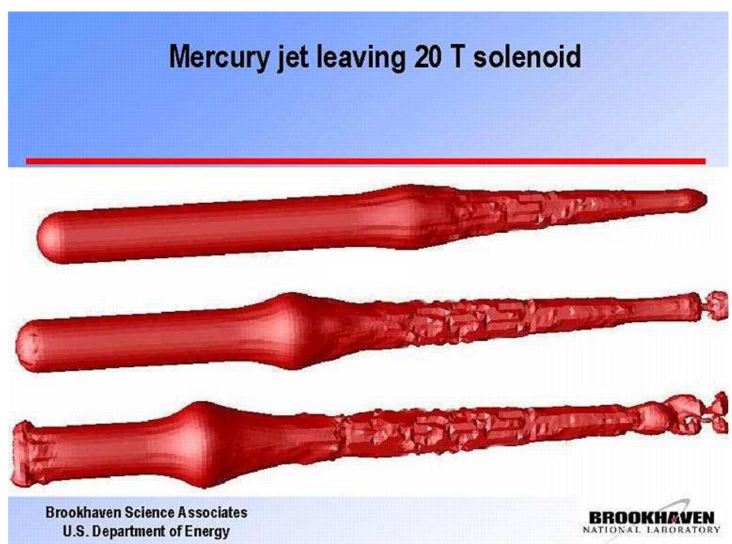
- Beam energy deposition may disperse the jet.





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



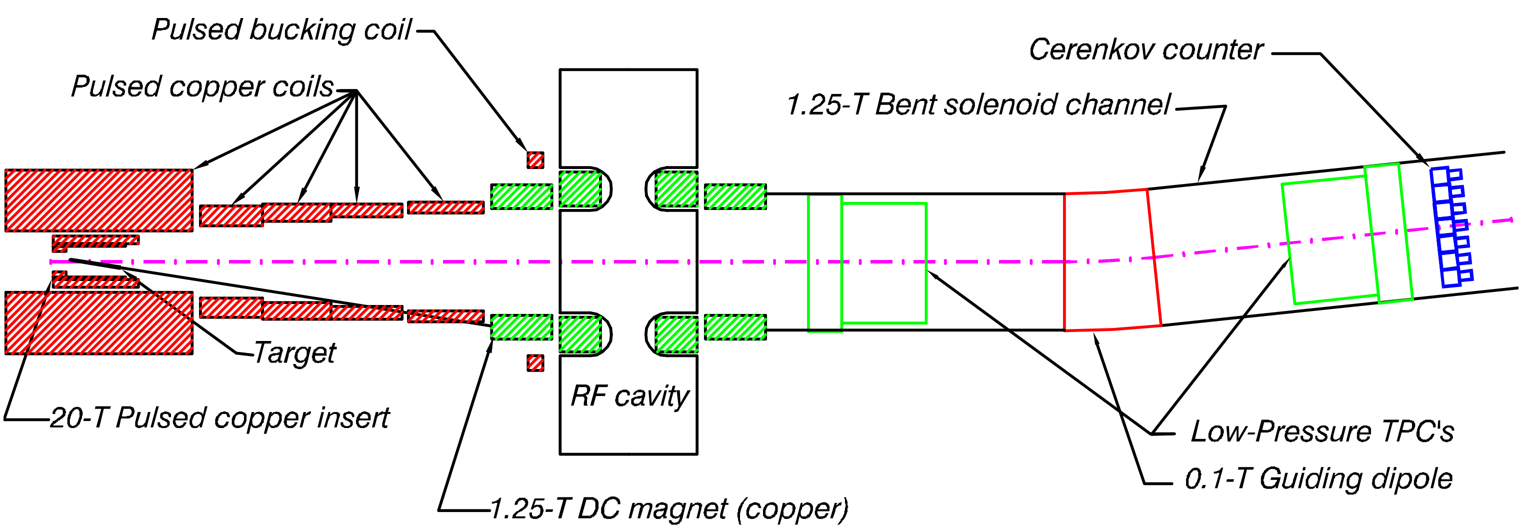


E951 Studies the Single Pulse Issues

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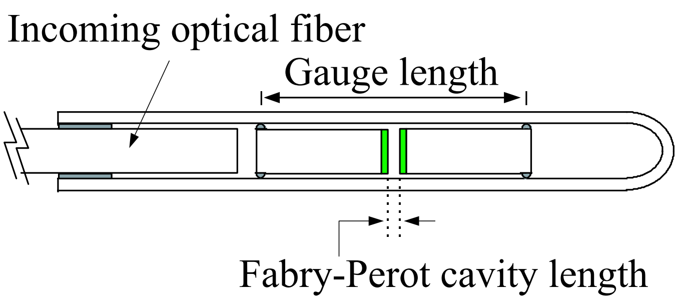
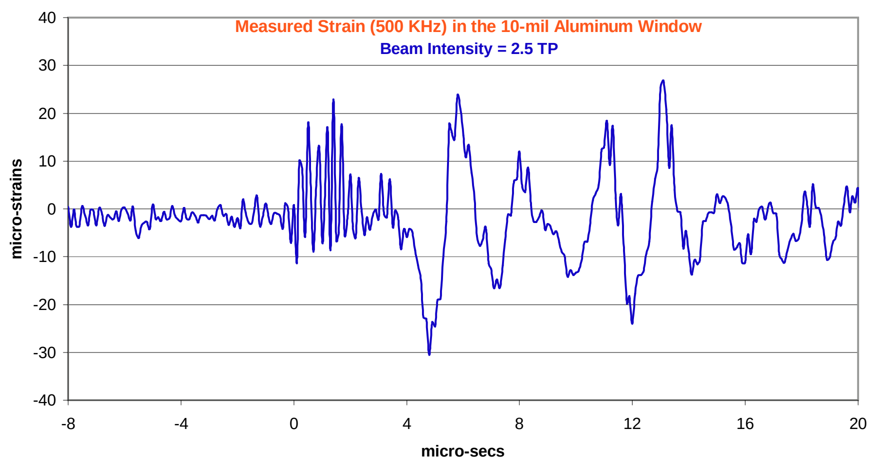
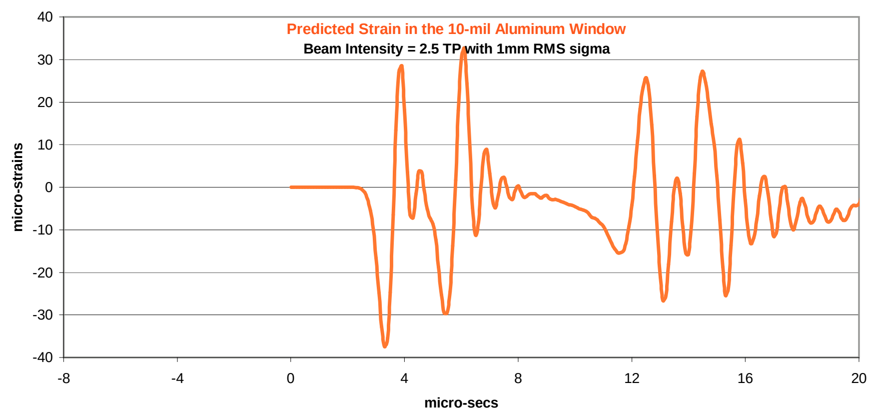
Solid Target Tests (5e12 *p*pp, 24 GeV, 100 ns)

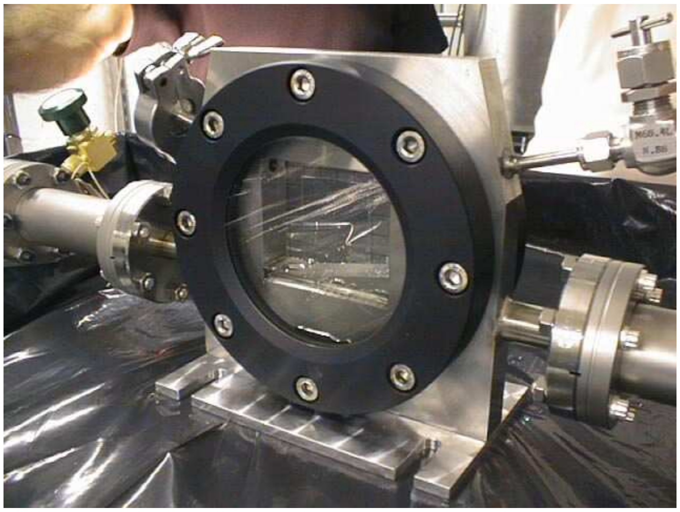
Carbon, aluminum, Ti90Al6V4, Inconel 708, Havar, instrumented with fiberoptic strain sensors.



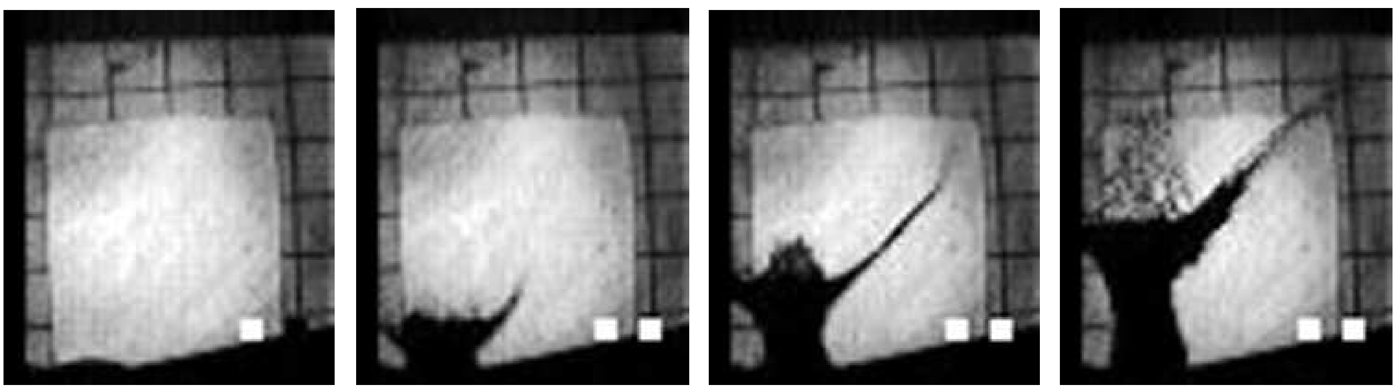




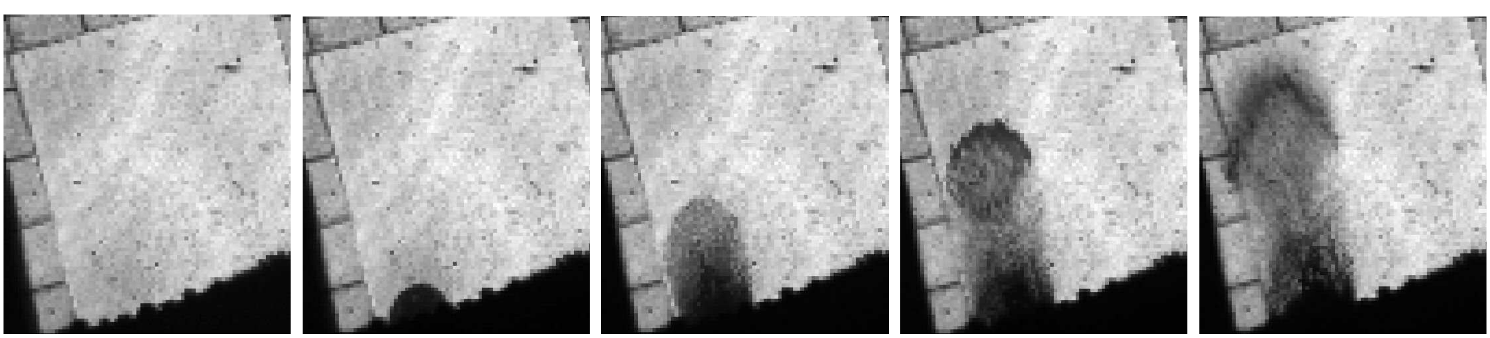
Passive Mercury Target Tests



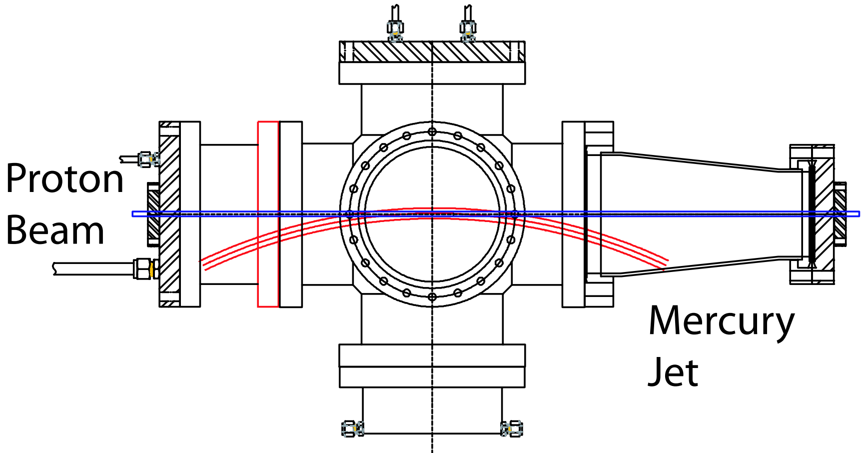
Exposures of 25 μs at $t = 0, 0.5, 1.6, 3.4$ msec, $\Rightarrow v_{\text{splash}} \approx 20 - 40$ m/s:



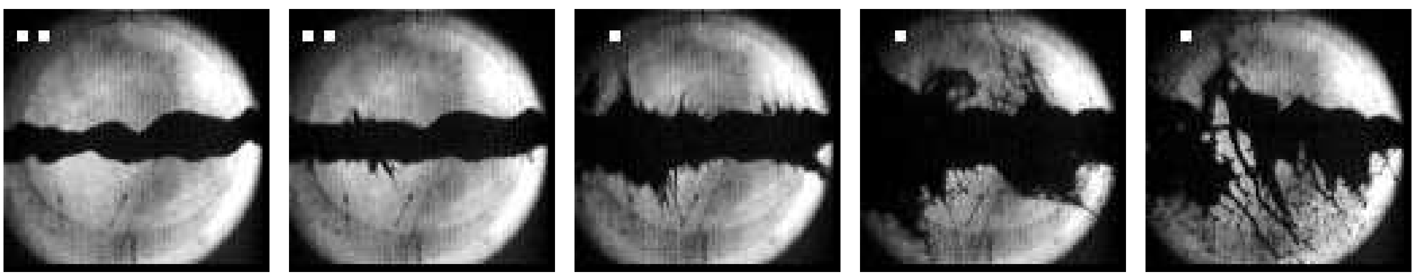
Exposures of 150 ns at $t = 0$, 0,2, 0,4, 0,6 and 0.8 msec, 4e12 protons, $\Rightarrow v_{\text{splash}} \approx 75$ m/s (then slowed by air drag):



Studies of Proton Beam + Mercury Jet



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



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

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.

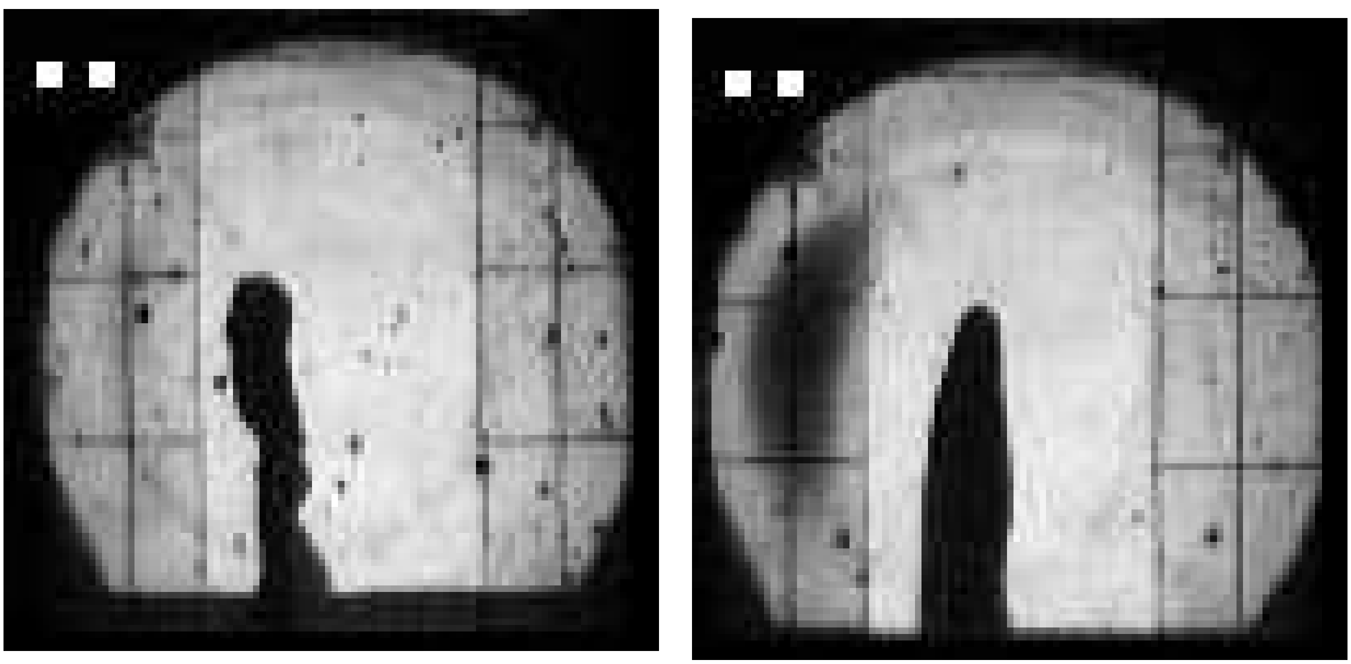
Tests of a Mercury Jet in a 13 T Magnetic Field

(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.

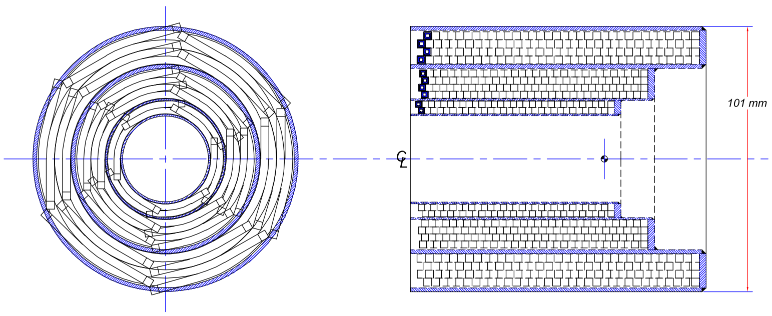
4 mm diam. jet, $v = 4.6$ m/s, $B = 0$ T; $v = 4.0$ m/s, $B = 13$ T:



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

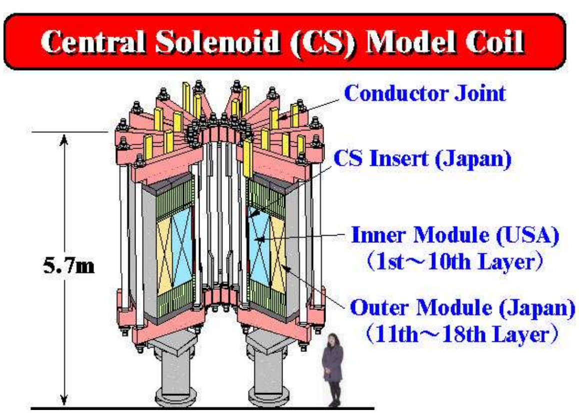
20-T Capture Magnet System

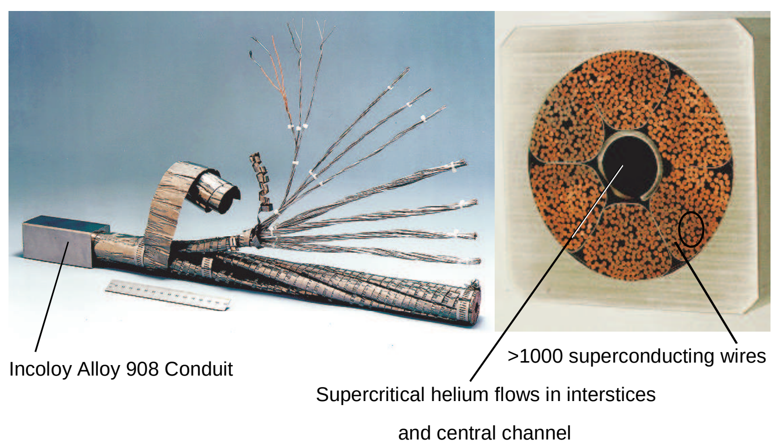
Inner, hollow-conductor copper coils generate 6 T @ 12 MW:



Bitter-coil option less costly, but marginally feasible.

Outer, superconducting coils generate 14 T @ 600 MJ:



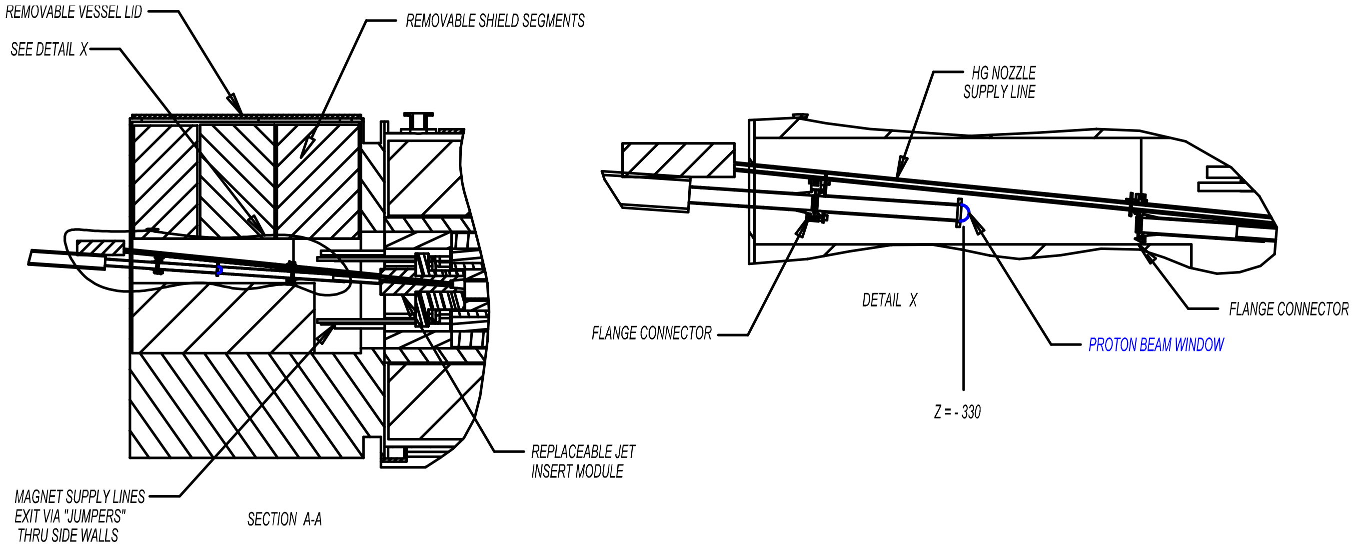


Cable-in-conduit construction similar to ITER central solenoid.

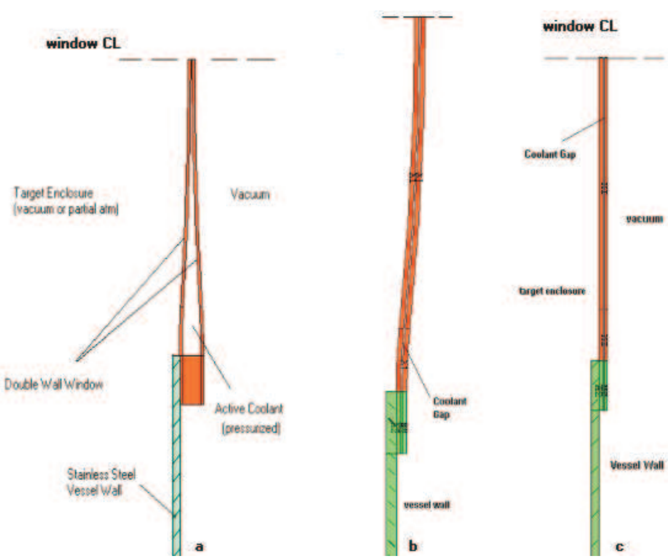
Both coils shielded by tungsten-carbide/water.

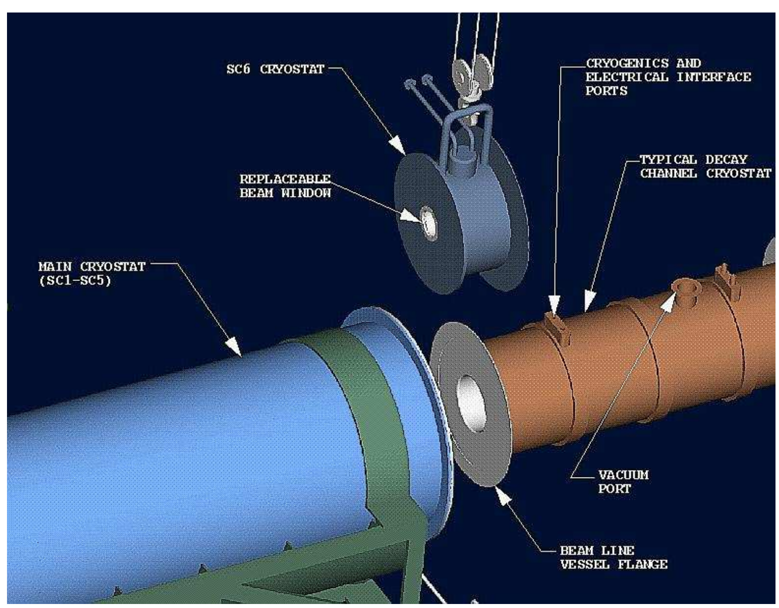
Double Beryllium Foil Beam Windows

Upstream window stressed by beam heating; must be replaceable.



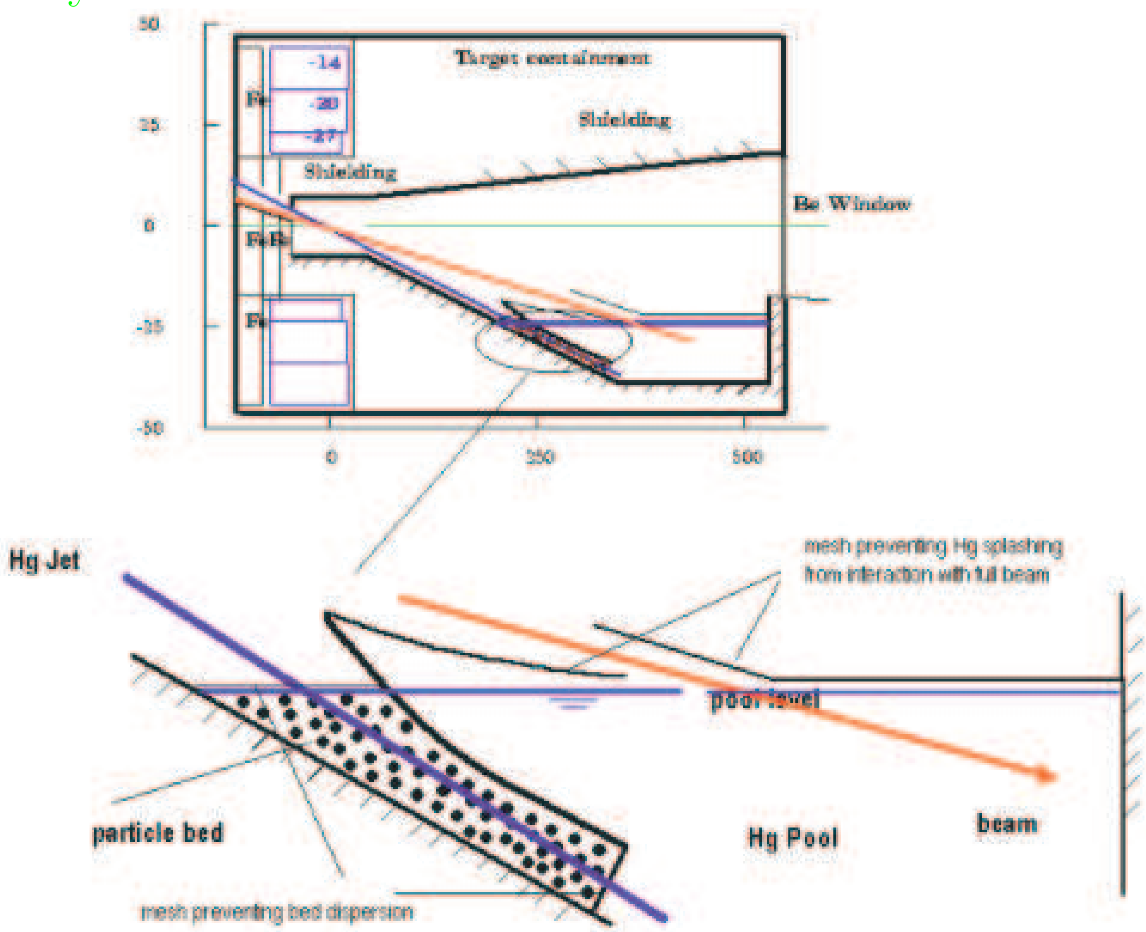
60-cm-diam. downstream window stressed by pressure; must be removable. Double-curved profile favored.





Mercury Pool Proton Beam Absorber

The unscattered proton beam is absorbed in a "windowless" pool of mercury.

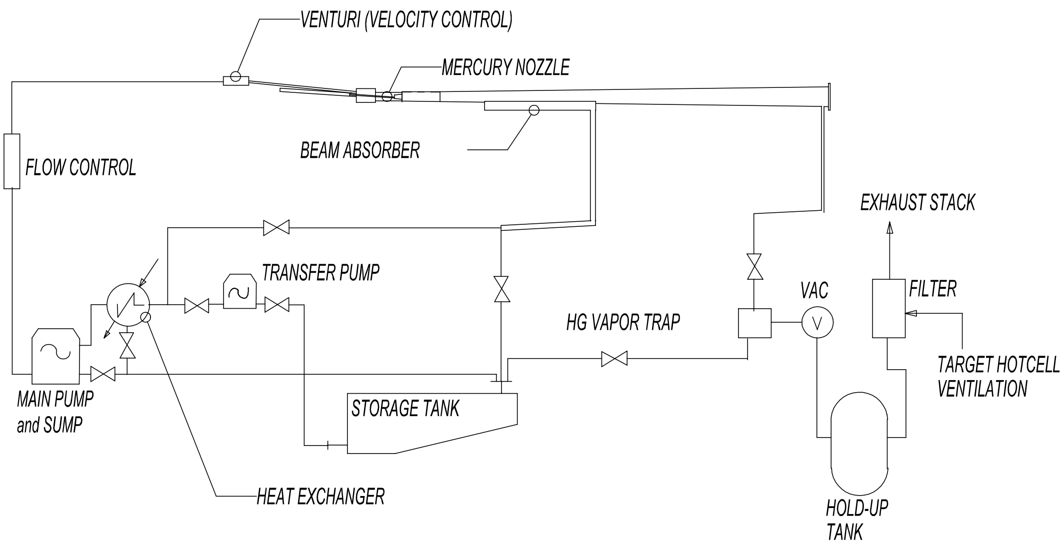


Baffles mitigate splashing of mercury due to entry of both the proton beam and the mercury jet.

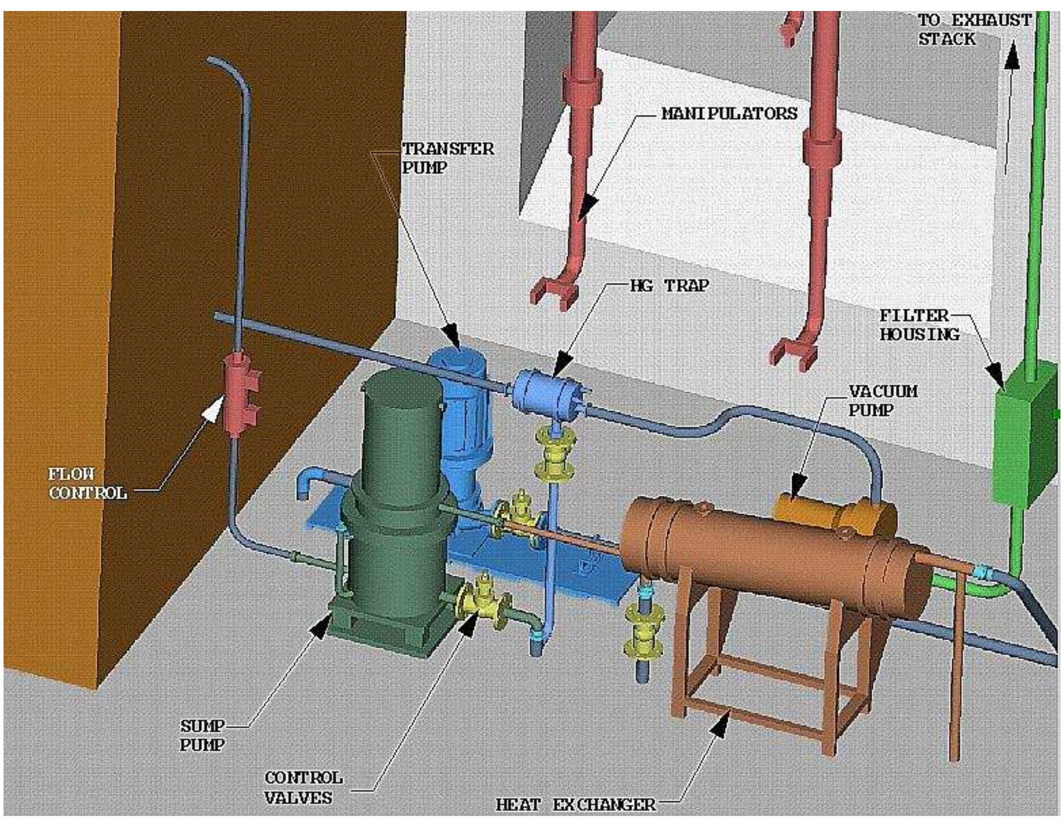
The proton absorber is replacable.

Mercury Flow Loop

110 l of mercury flow in a closed loop at 2 cyles/min.

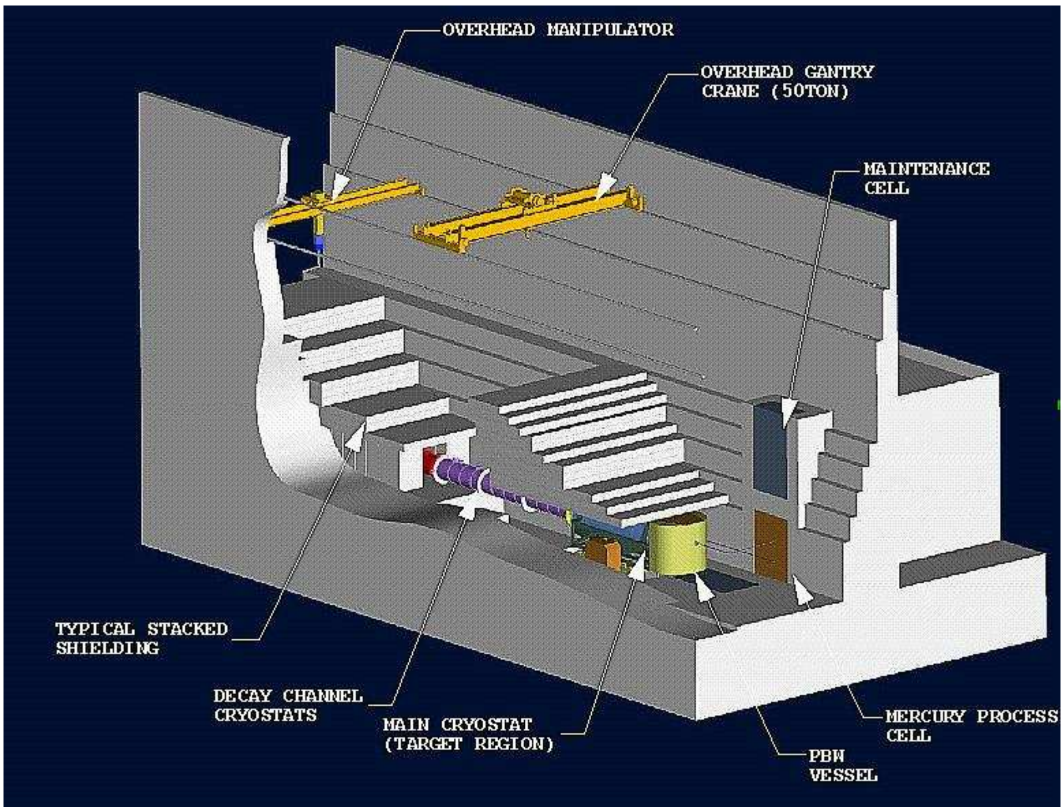


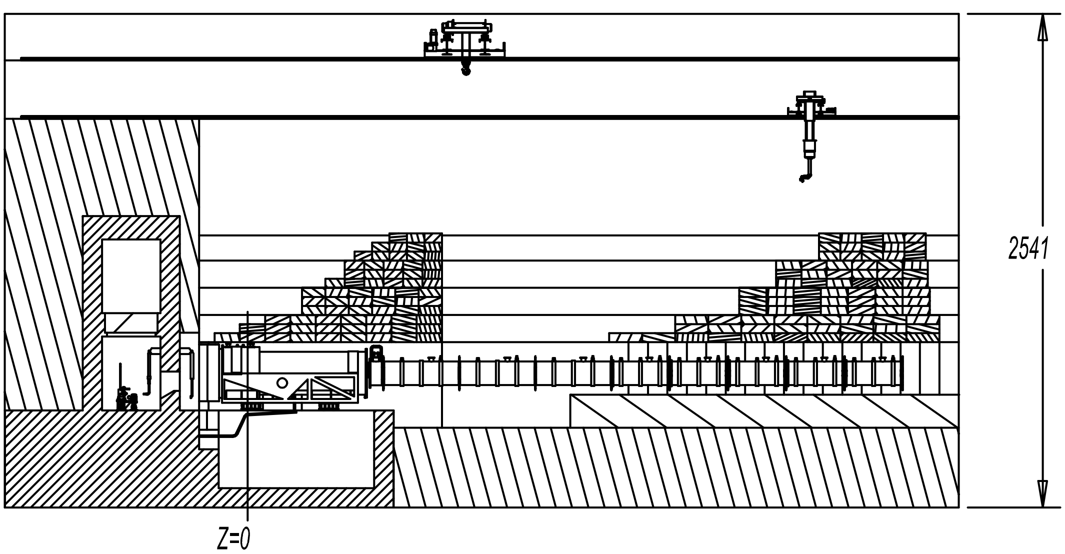
Activation products can be distilled off in a hot cell.

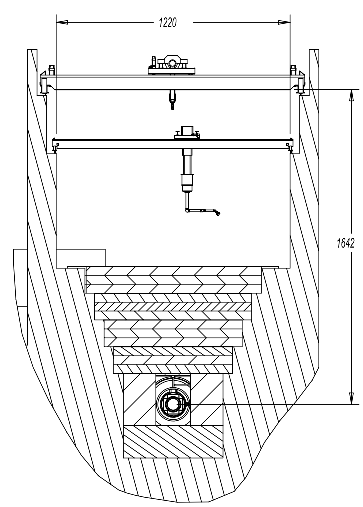


Target System Support Facility

Extensive shielding; remote handling capability.







Summary

- A target sytem 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).