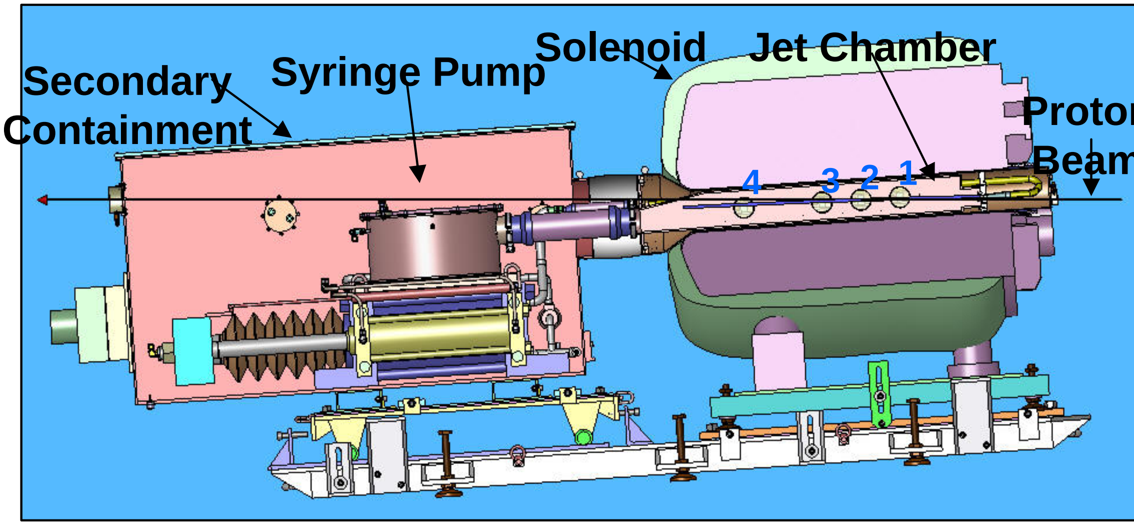
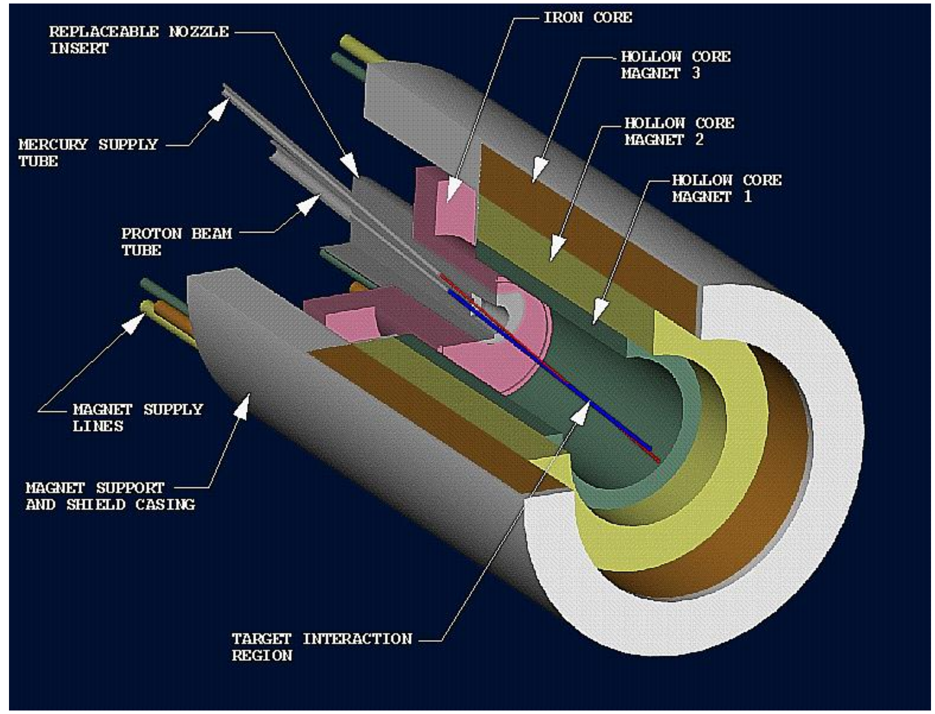
From MERIT to a Muon Collider (Front End)





K.T. McDonald

Princeton U.

Low Emittance Muon Collider Workshop

Fermilab, April 22, 2008

Targetry Web Page:

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

Targetry Challenges of a Muon Collider

Desire $\approx 10^{14}$ μ/s from $\approx 10^{15}$ p/s ($\approx$ 4 MW proton beam).

Highest rate μ^+ beam to date: PSI μE4 with $\approx 10^9$ μ/s from $\approx 10^{16}$ p/s at 600 MeV.

$\Rightarrow$ Some R&D needed!

Palmer (1994) proposed a solenoidal capture system.

Low-energy π's collected from side of long, thin cylindrical target.

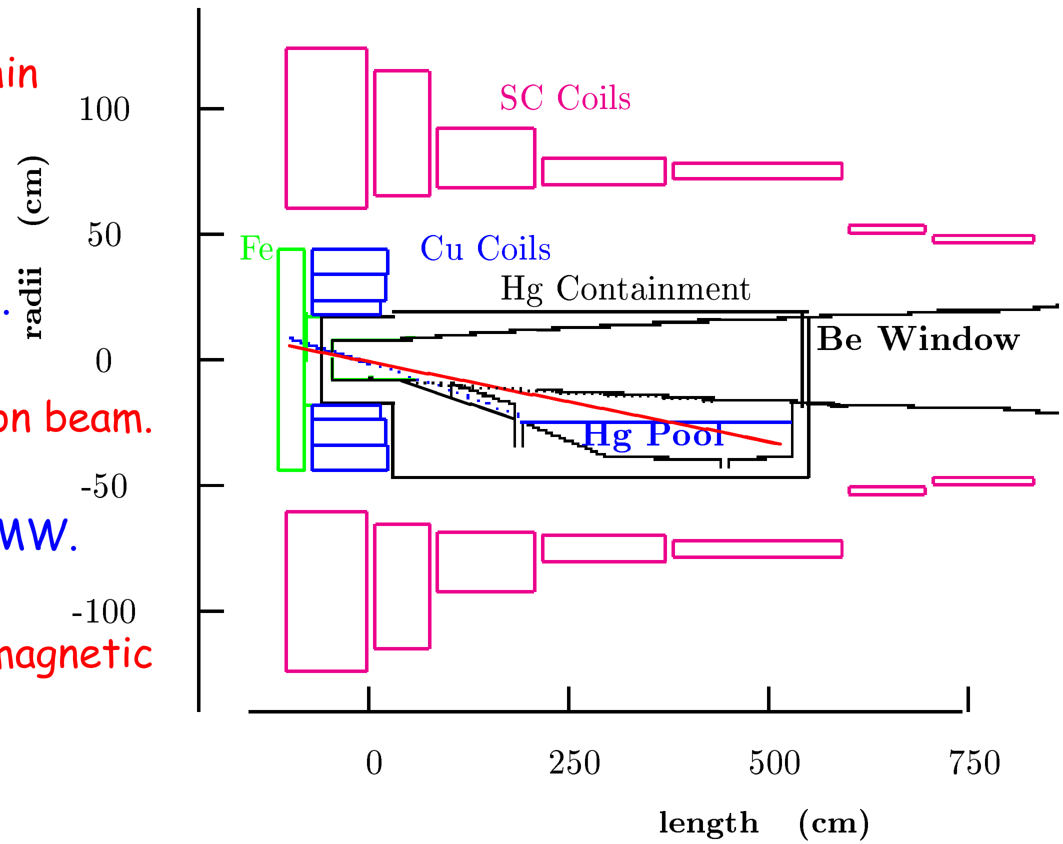
Collects both signs of π's and μ's,
$\Rightarrow$ Shorter data runs (with magnetic detector).

Solenoid coils can be some distance from proton beam.

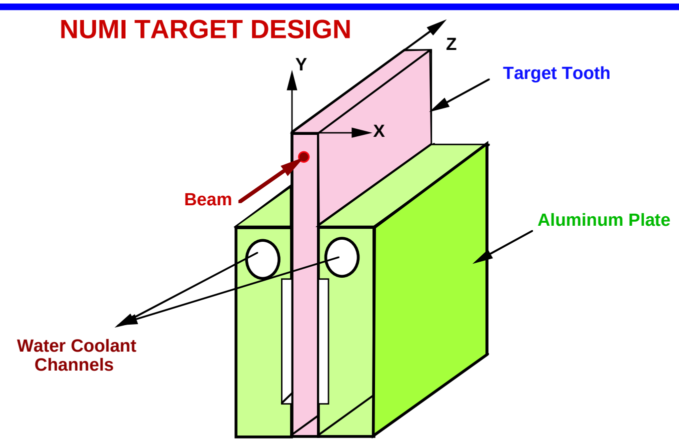
$\Rightarrow \geq$ 4-year life against radiation damage at 4 MW.

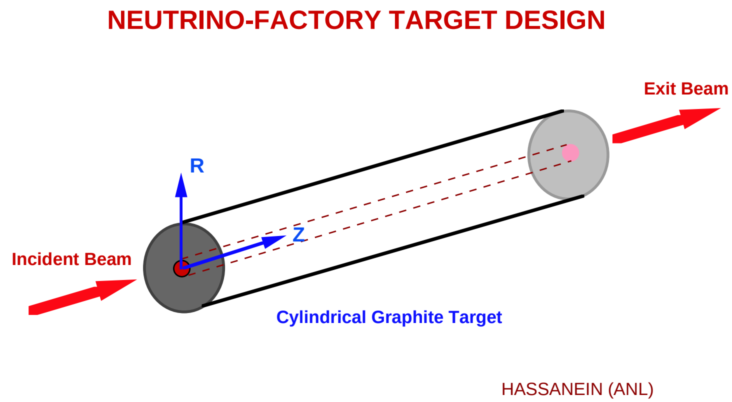
$\Rightarrow$ Proton beam readily tilted with respect to magnetic axis.

$\Rightarrow$Beam dump (mercury pool) out of the way of secondary π's and μ's.



A Carbon Target is Feasible at 1-2 MW Beam Power





Low energy deposition per gram and low thermal-expansion coefficient reduce thermal "shock" in carbon.

Operating temperature > 2000 C if use only radiation cooling.

A carbon target in vacuum would sublimate away in 1 day at 4 MW, but sublimation of carbon is negligible in a helium atmosphere.

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

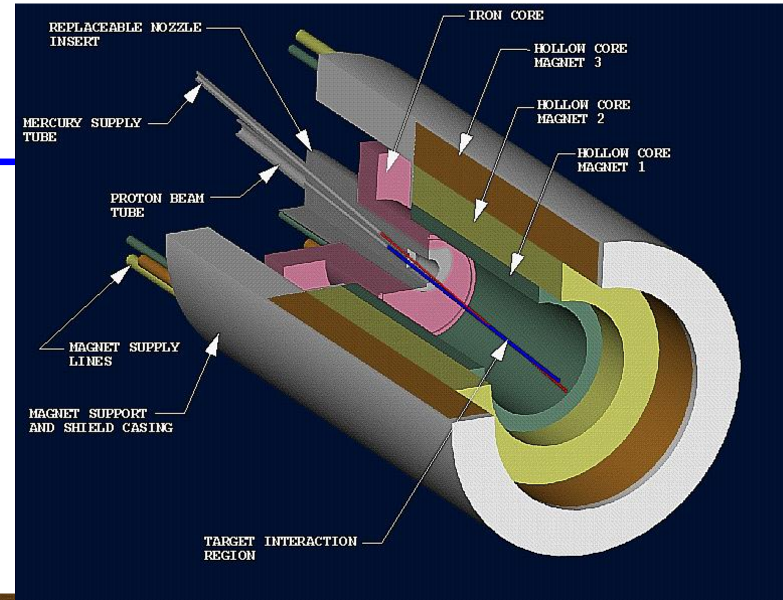
⇒ Carbon target is baseline design for most neutrino superbeams.}

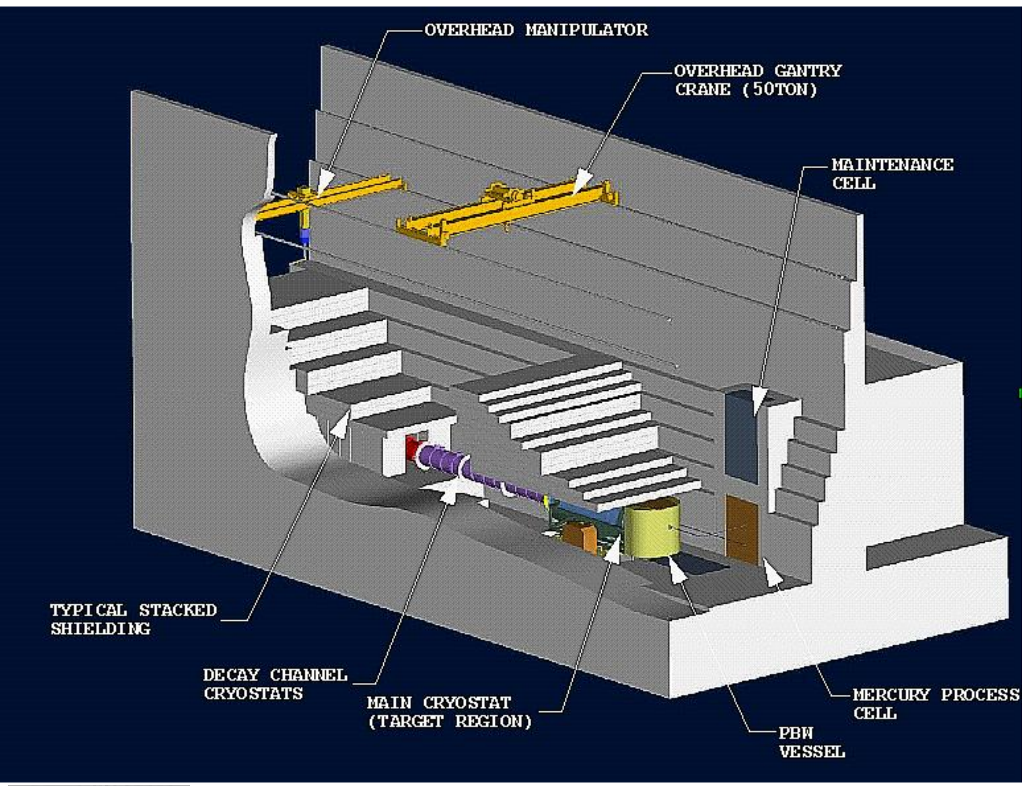
Useful pion capture increased by compact, high-Z target, ⇒ Continued R&D on solid targets.

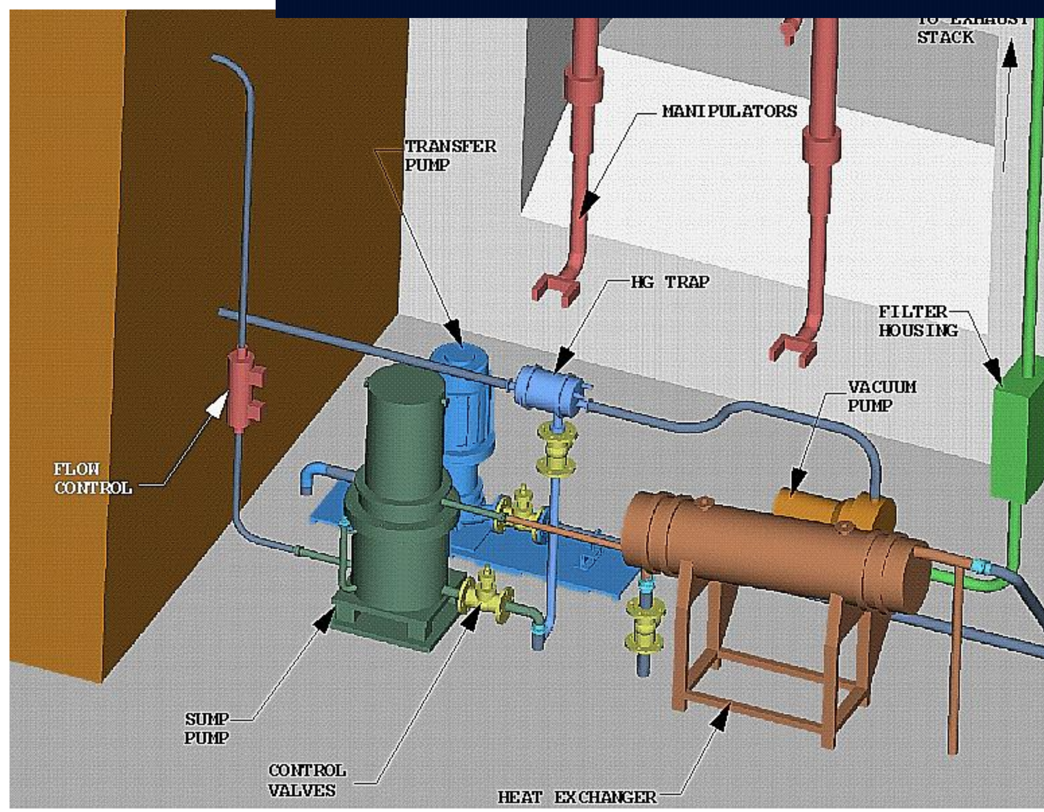
Neutrino Factory Feasibility Study 2

Infrastructure studies based on SNS mercury target experience.
Should be extended during the Muon Collider Feasibility Study.
Considerable engineering support needed to go beyond Study 2.

ORNL/TM-2001/124, P. Spampinato et al.
http://www.hep.princeton.edu/~mcdonald/mumu/target/tm-2001-124.pdf







Features of the Study 2 Target Design

Mercury jet with 1-cm diameter, 20 m/s velocity, at 100 mrad to magnetic axis.

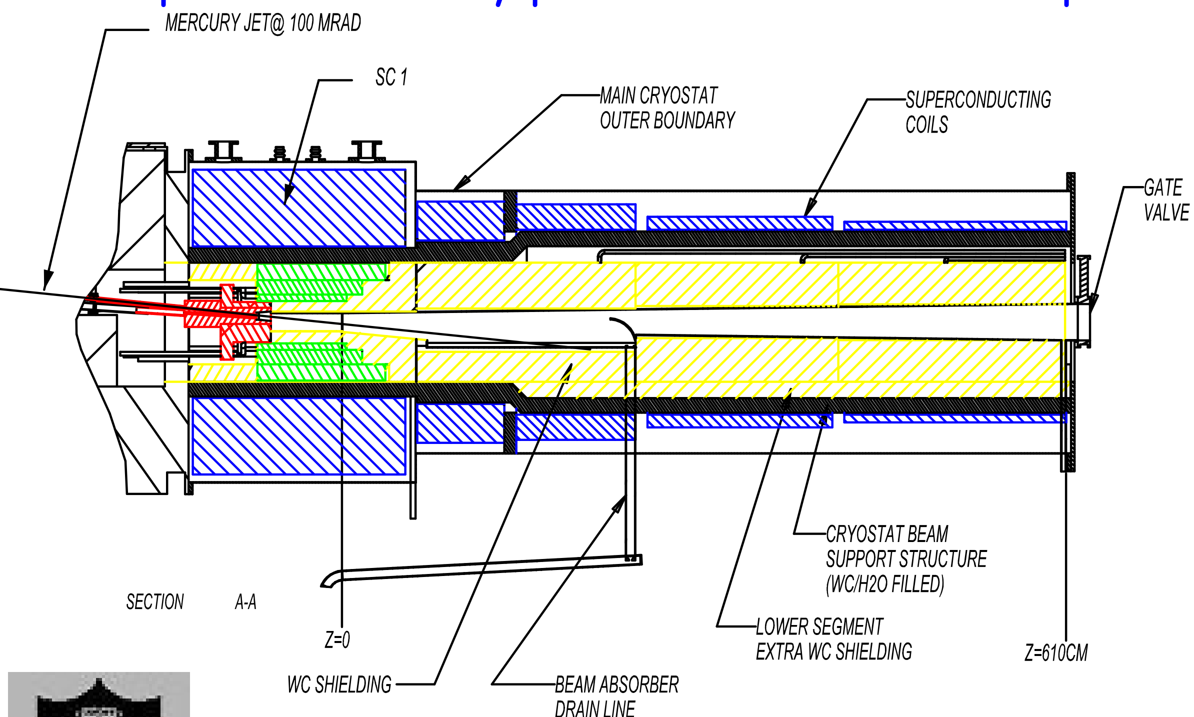
Proton beam at 67 mrad to magnetic axis.

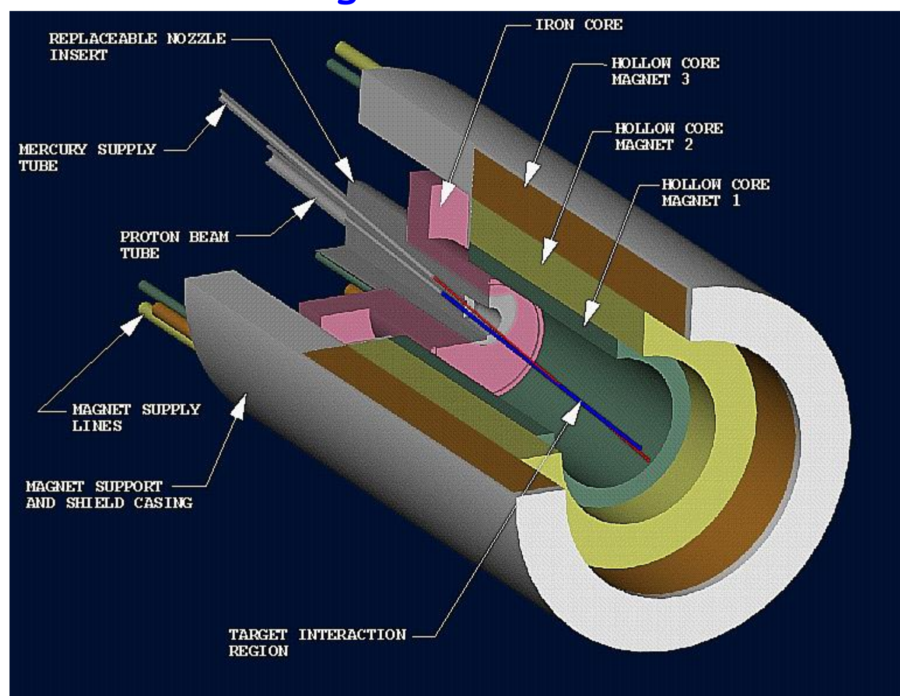
Iron plug at upstream end of capture solenoid to reduce fringe-field effect on shape of free jet.

Mercury collected in a pool in ~ 4 T magnetic field.

Issues:

- Jet quality after emerging from long cylindrical nozzle in iron plug.
- Splash in mercury pool should not extend up into nominal beam region.





CERN nToF11 Experiment (MERIT)

The MERIT experiment was a proof-of-principle demonstration of a free mercury jet target for a 4-megawatt proton beam, contained in a 15-T solenoid for maximal collection of soft secondary pions.

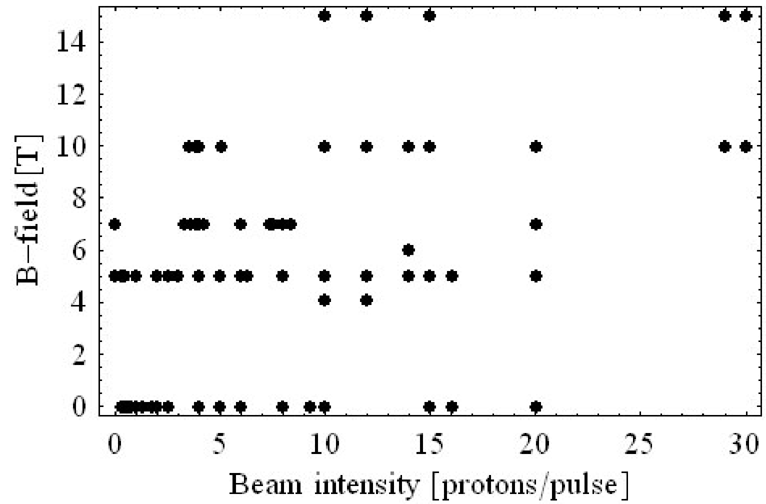
MERIT = MERcury Intense Target.

Key parameters:

- 24-GeV Proton beam pulses, up to 16 bunches/pulse, up to 2×10^{12} p/bunch.
- σ_r of proton bunch = 1.2 mm, proton beam axis at 67 mrad to magnet axis.
- Mercury jet of 1 cm diameter, v = 20 m/s, jet axis at 33 mrad to magnet axis.
- $\Rightarrow$ Each proton intercepted the Hg jet over 30 cm = 2 interaction lengths.

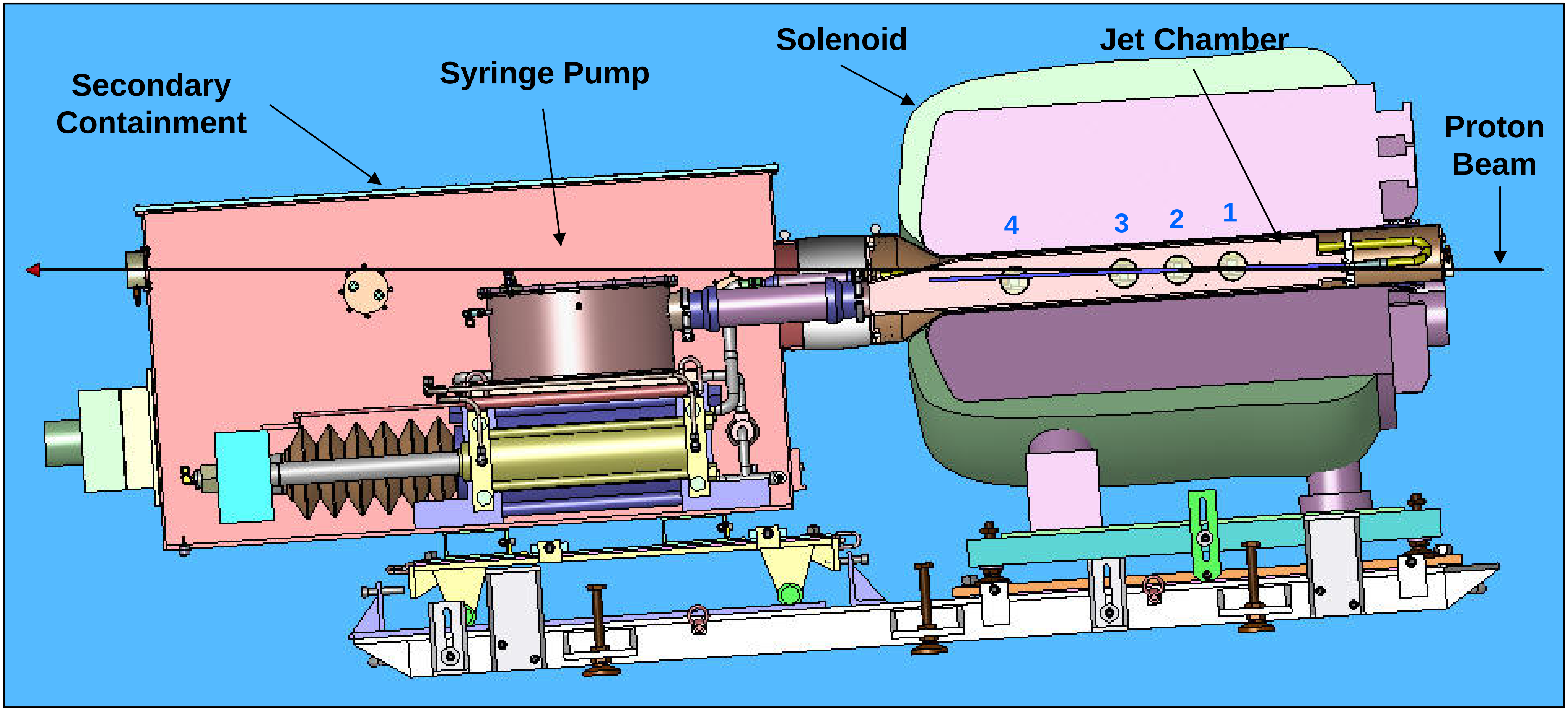
Every beam pulse was a separate experiment.

- $\approx$ 360 Beam pulses in total.
- Varied bunch intensity, bunch spacing, no. of bunches.
- Varied magnetic field strength.
- Varied beam-jet alignment, beam spot size.



MERIT @ CERN was Proof of Principle not Prototype

MERIT @ CERN used a 180° bend in the mercury delivery path because CERN would not permit any mercury-wetted connections to be made onsite.



CERN nToF11 Experiment (MERIT), II

Data taken Oct.22 -- Nov.12, 2007 with mercury jet velocities of 15 & 20 m/s, magnetic fields up to 15 T, and pulses of up to 3 $\times 10^{13}$ protons in 2.5 μs.

As expected, beam-induced jet breakup is relatively benign, and somewhat suppressed at high magnetic field.

"Pump-Probe" studies with bunches separated by up to 700 μs indicated that the jet would hold together during, say, a 1-ms-long 8-GeV linac pulse.

$\Rightarrow$ Good success as proof-of-principle of liquid metal jet target in strong magnetic fields for use with intense pulsed proton beams.

Post-MERIT Liquid Target Issues

MHD simulations

Optimize performance of nozzle in Fe plug

Eliminate 180^0 bend

Splash in liquid pool beam dump

Particle production

Rep-rate delay limits

Use of a Pb-Bi alloy rather than Hg

Target station engineering

Study these issues in context of IDS/MCFS

Issues from MERIT: Jet Quality, Vertical Height

Jet quality poor in zero magnetic field, and improves (as expected) with increasing field.

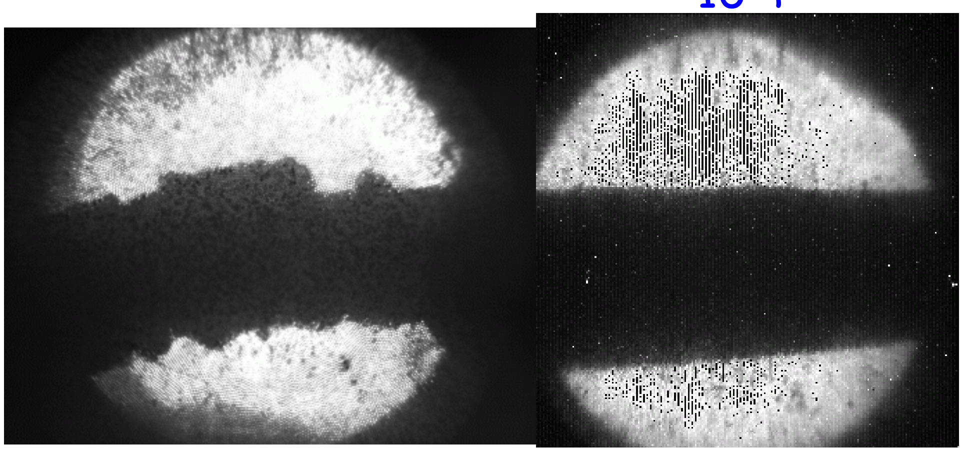
Jet vertical height 1.5-2.4 times nozzle diameter, and little affected by magnetic field.

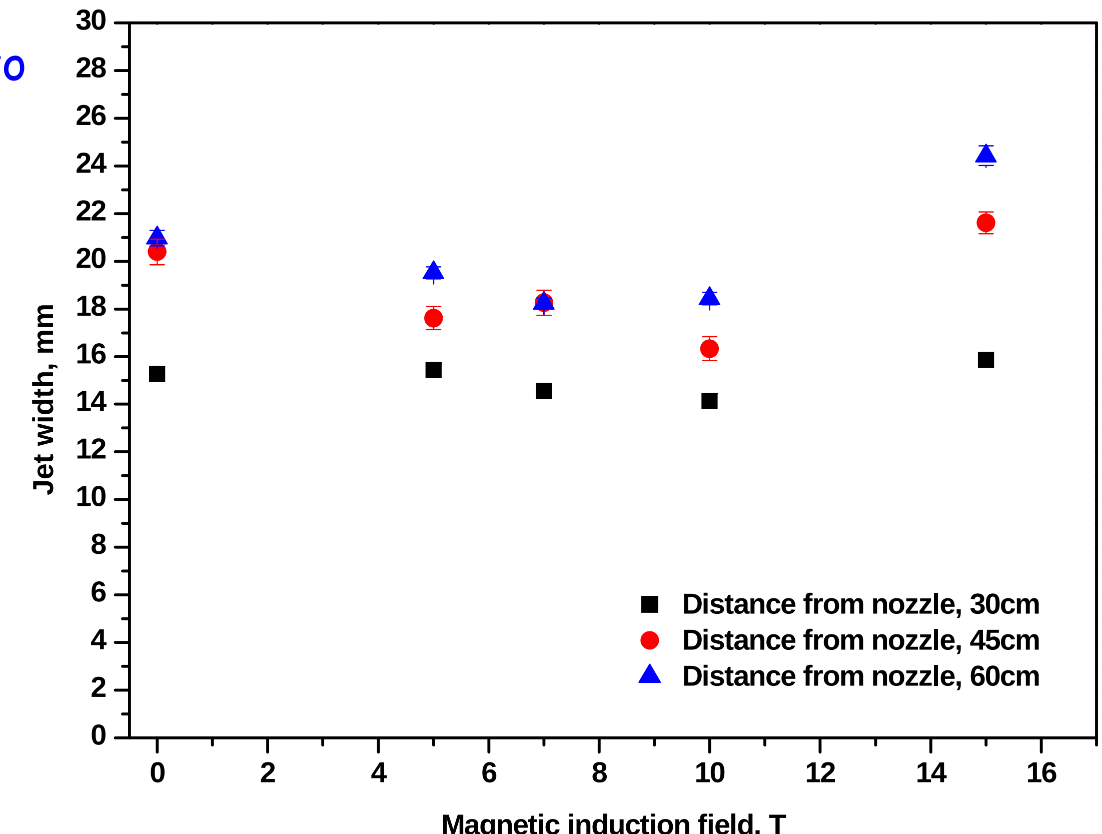
Simulations predict that vertical expansion of jet would be small, and would vary as B^2.

Suggests that 180° bend before nozzle leads to vertical expansion of jet.

Interesting hydrodynamic issues, but may be best to focus of aspects relevant to ν Factory/Muon Collider – where no 180° bend is contemplated.

0 T 10 T





Could Reuse MERIT Equipment to Study Jet Issues without Beam

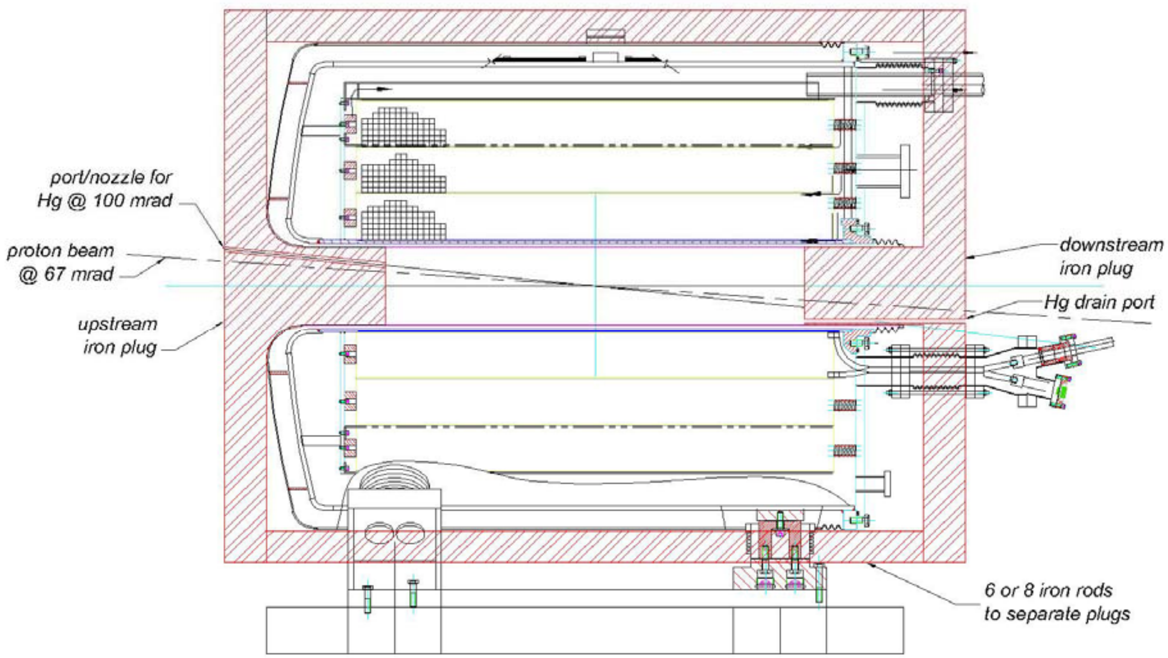
At a facility suitable for more general handling of mercury, could connect the mercury test volume to the mercury pump by hoses so that mercury enters at one end of magnet and exits at the other.

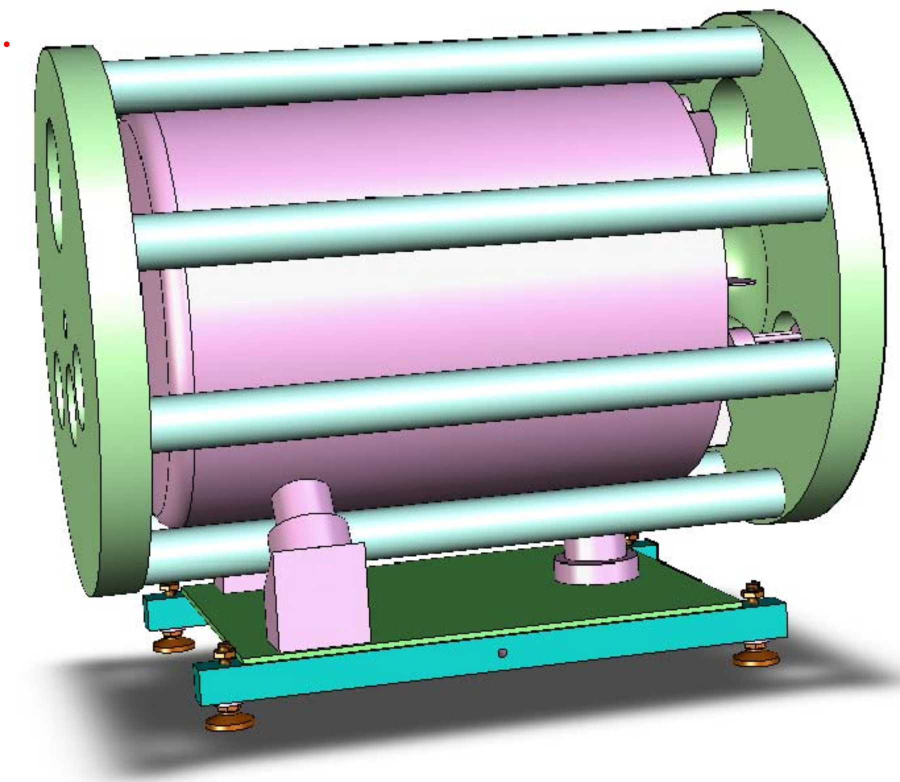
Could study jet quality in nozzles with no sharp bends.

Could use optical diagnostics with both side and top views.

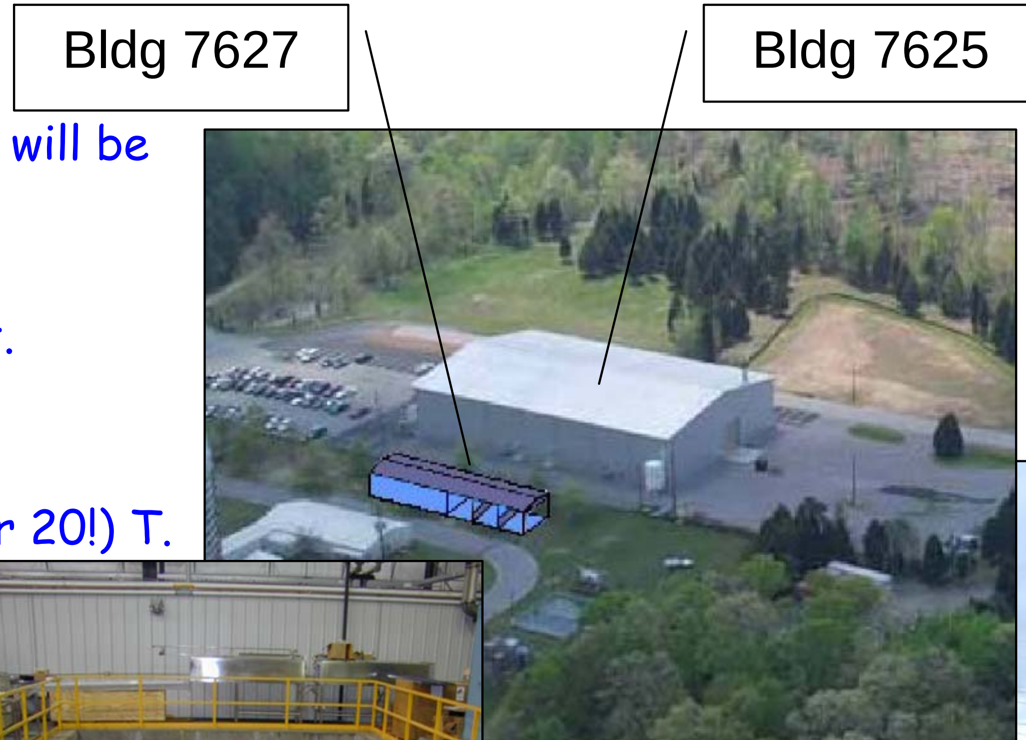
Could add iron plugs to the MERIT magnet to study effect of field on a jet at 100 mrad (instead of 33 mrad as in MERIT @ CERN).

Could also study collection of the jet in a mercury pool.

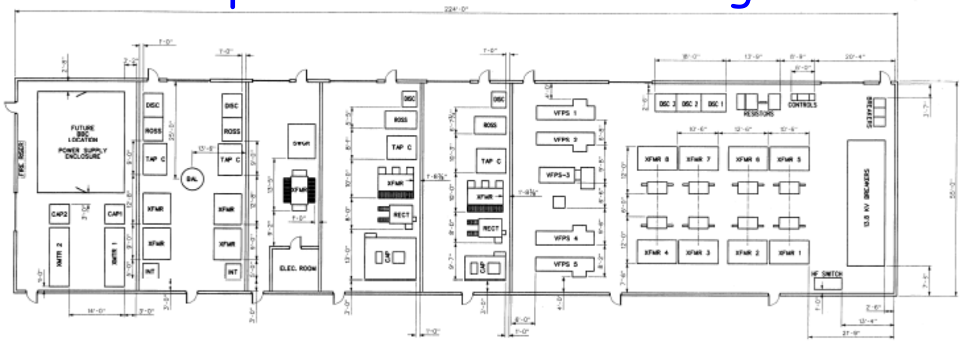




Option for Follow-On Studies at ORNL



- A new fusion test facility in bldgs 7625, 7627 will be completed in late 2008.
- Several 10-MW power supplies available.
- LN_2 dewar 20-t overhead crane, equipment pit.
- Could begin with zero field studies (nozzle optimatization, Hg splash in pool,….)
- Eventual option to use MERIT magnet at 15 (or 20!) T.



Vertical field power supplies (capability of each)
650V peak
15,000 A pulsed > 5 sec
Voltage and/or current can be controlled by SCR gate waveform control

Lead-Bismuth Alloys

Lead-bismuth alloys are solid are room temperature, but liquefy at 70-125°C.

Easier to contain a target "spill" if material solidifies at room temperature.

More radioisotope production with Pb-Bi than with Hg (but "trivial" compared to a reactor).

Boiling of liquid target by proton beam (> 4 MW) less of an issue than with mercury.

Design studies for MERIT-like tests mandated by the NFMCC.

Some Pb-Bi alloys wet quartz, so difficult to use with optical diagnostics.

Woods metal (Low 158) does not wet glass (Palmer), but contains cadmium.

Pb-Bi-Sn alloys melt as low as 95°C.

Lab tests will be done soon on wetting of quartz by several low melting alloys.

Type/ Approx Temp	Antimony	Bismuth	Cadmium	Lead	Tin	1-9 lb	10-49 lb	50 + lb
Low 158	0 %	50%	10%	26.7%	13.3%	17.99	16.19	14.39
Low 158-190	0 %	42.5%	8.5%	37.7%	11.3%	17.99	16.19	14.39
Low 203	0%	52.5%	0%	32%	15.5%	17.99	16.19	14.39
Low 212	0%	39.4%	0%	29.8%	30.8%	17.99	16.19	14.39
Low 217-440	9%	48%	0%	28.5%	14.5%	17.99	16.19	14.39
Low 255	0%	55.5%	0%	44.5%	0%	17.99	16.19	14.39
Low 281	0%	58%	0%	0%	42%	17.99	16.19	14.39
Low 281-338	0%	40%	0%	0%	60%	17.99	16.19	14.39

Summary

Liquid-target MHD simulations are ongoing and should continue to be supported.

Studies of radiation damage of solid-target candidates are ongoing, largely without NFMCC support.

Systems engineering of a 4 MW target facility should be supported in the context of the IDS and/or Muon Collider Feasibility Study.

Hardware studies of jet (and splash) quality in configurations close to those of Feasibility Study 2 could be performed with MERIT equipment at ORNL.

Preliminary studies for use of a liquid Pb-Bi alloy are underway.

Next Targetry Workshop: 1-2 May, 2008, Oxford, UK

http://www.physics.ox.ac.uk/users/peachk/HPT/