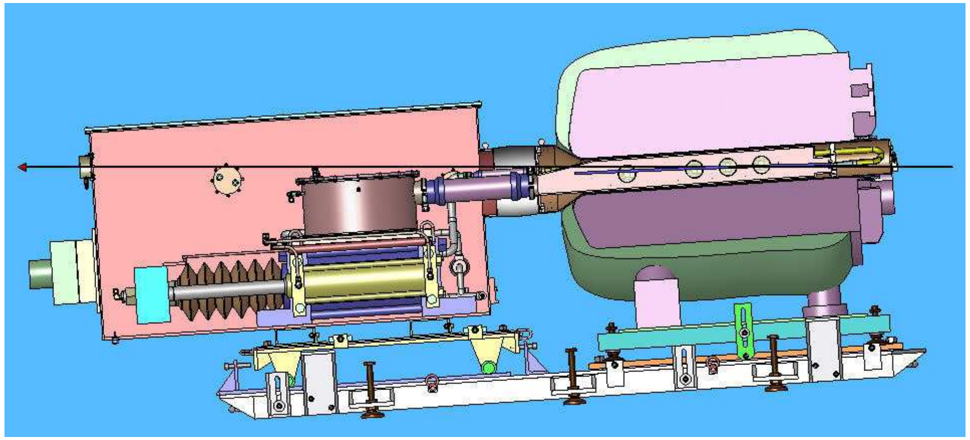
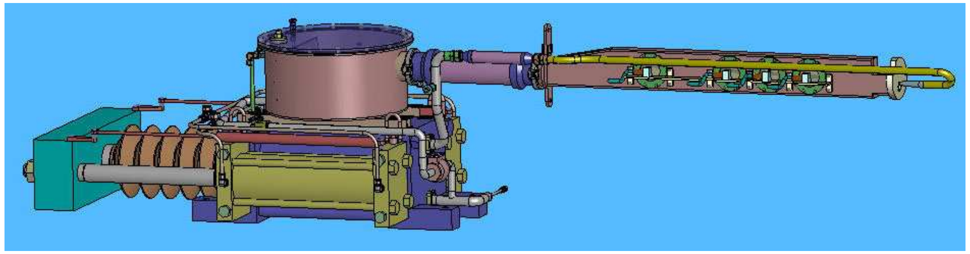
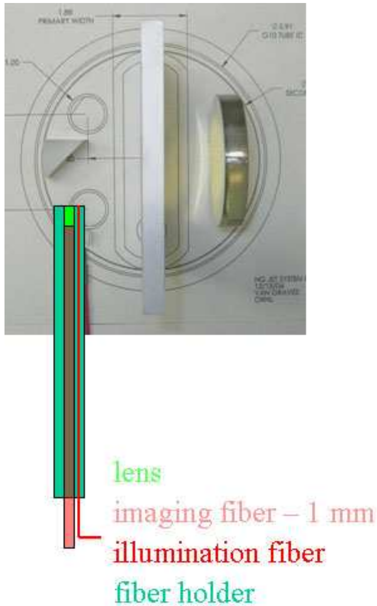
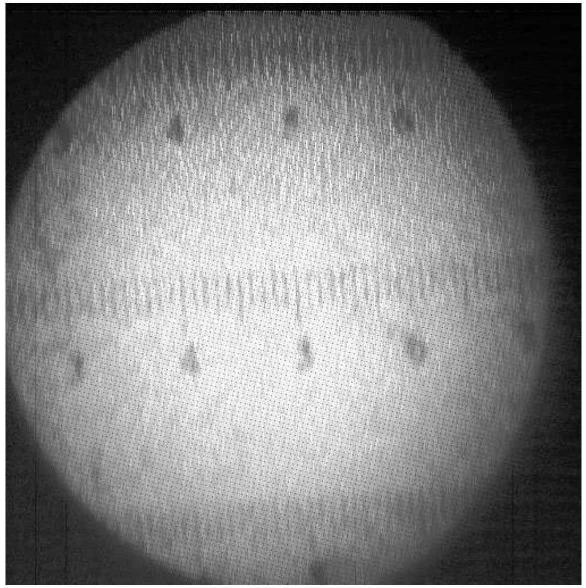
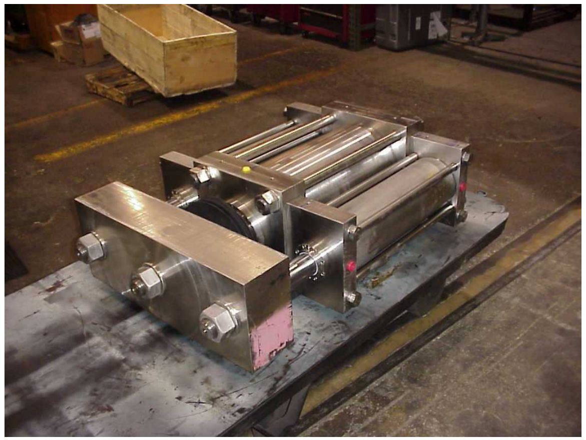
MERIT Experiment Mercury Delivery System and Diagnostics











K.T. McDonald
Princeton U.

MuTAC Meeting, Fermilab

Mar 17, 2006

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

CERN nToF11 Experiment (MERIT)

- The MERIT experiment is 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 2.5×10^{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 intercepts the Hg jet over 30 cm = 2 interaction lengths.
- Every beam pulse is a separate experiment.
  - ~ 100 Beam pulses in total.
  - Vary bunch intensity, bunch spacing, number of bunches.
  - Vary magnetic field strength.
  - Vary beam-jet alignment, beam spot size.

MERIT Experiment Subsystems

- Simulations.
- The 15-T pulsed solenoid magnet.
- The 5.5-MVA power supply.
- The liquid nitrogen cryogenic system.
- The mercury delivery system.
- The optical diagnostic system.

Mercury Delivery System Based on a "Syringe" Pump

$v = 20$ m/s for Hg jet
$\Rightarrow \approx 1000$ psi.

$\Rightarrow$ Use hydraulic "syringe" pump rather than centrifugal pump (V. Graves).

1.6 l/s for 10 sec
$\Rightarrow$ Hg inventory = 16 l.

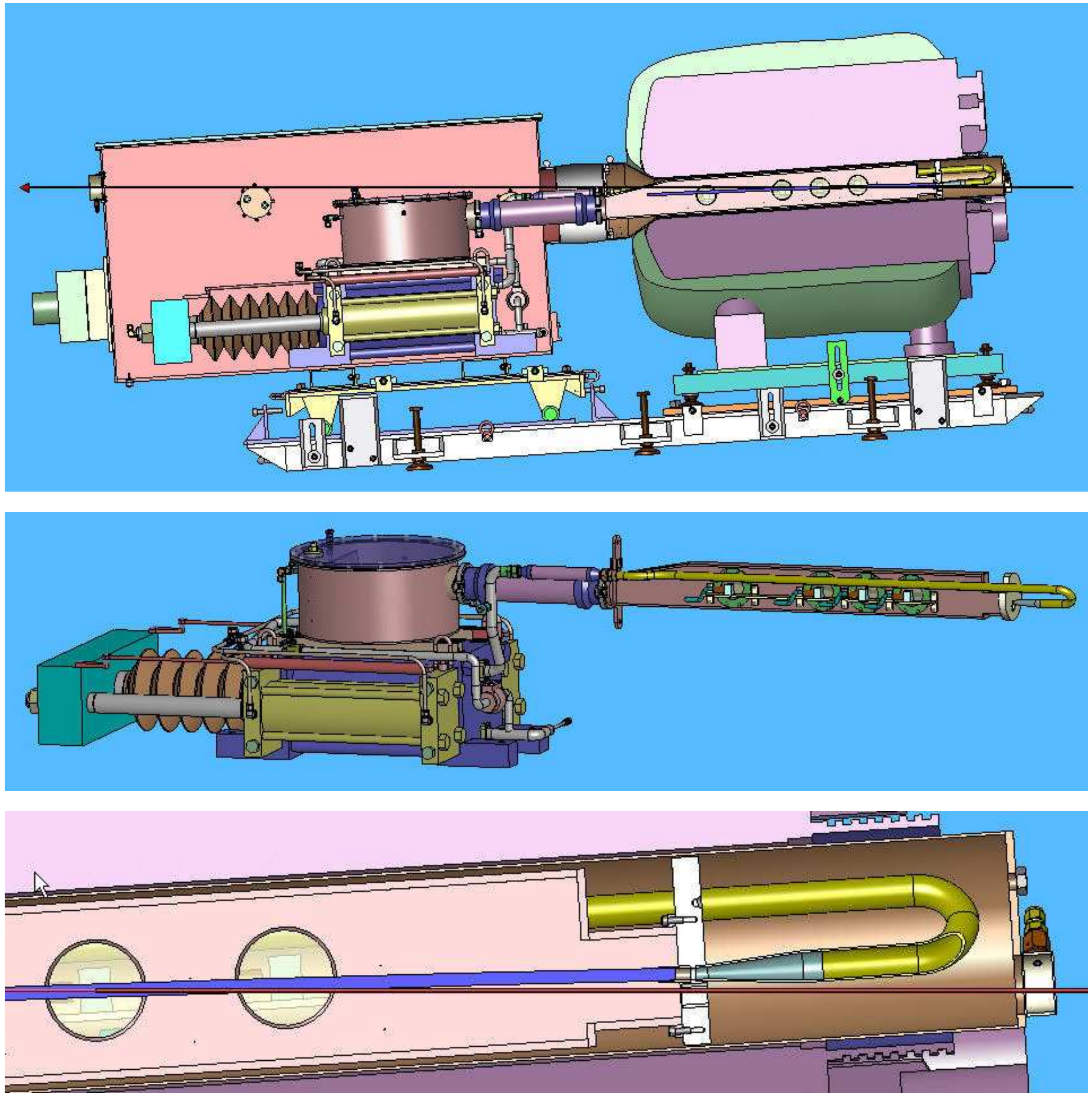
Mercury handling procedures based on SNS experience.

Nonmagnetic double containment system with a $6''$-diameter "snout" that inserts into the 15-T magnet.

Hg nozzle above proton beam at upstream end of magnet; fed by a $1''$-diameter pipe that passes through the magnet.

Issues:

- Nozzle design.
- Integrity of windows.



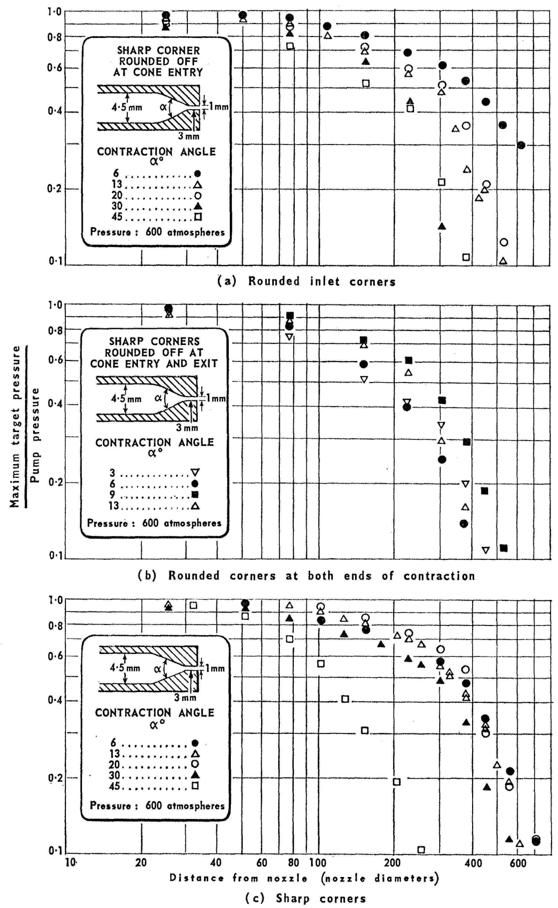
Nozzle Lore

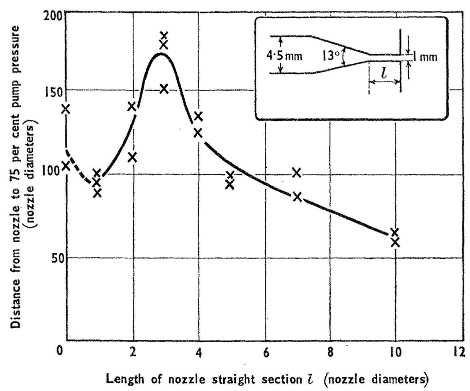
MERIT experiment:
$v = 20$ m/s, $d = 1$ cm for Hg jet
$\Rightarrow$ Turbulent flow.

Lore:

- Should be able to make a 1-cm-diameter Hg jet go 1-2 m before breakup.
- Area of feed should be $\gtrsim 10\times$ area of nozzle.
- $\approx 15^\circ$ nozzle taper is good.
- Nozzle tip should be straight, with $\approx 3:1$ aspect ratio.
- High-speed jets will have a halo of spray around a denser core.
- Low/zero surrounding gas pressure is better.

Leach & Walker (1966):





McCarthy & Molloy (1974):

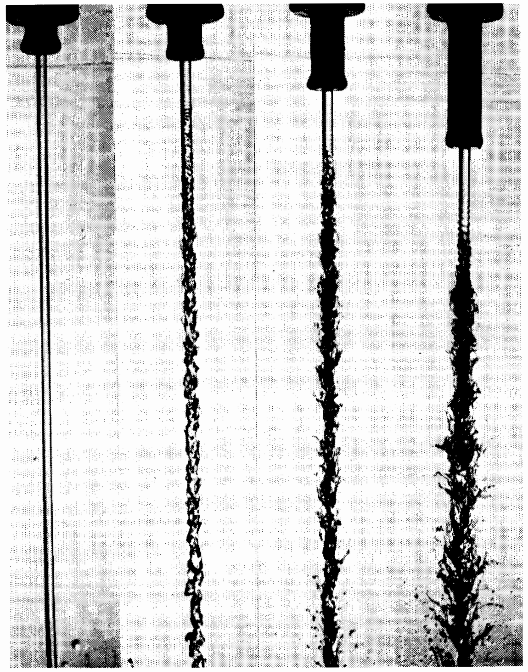
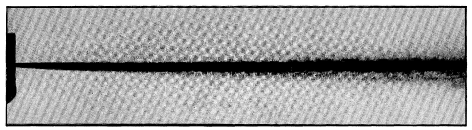


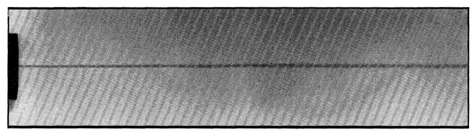
Fig. 5. Effect of nozzle design on the stability of glycerol–water jets.

Jet viscosity	11 cP
Jet velocity	20 m s^{-1} (approx.)
Nozzle diameter	2.54 mm
Jet Reynolds no.	4750
Jet Ohnesorge no.	0.026
Exposure	30 μsec
Nozzle aspect ratio	$AR = L/d$ (see Fig. 7) = 0, 1, 5, 10 L to R.

Leach & Walker:



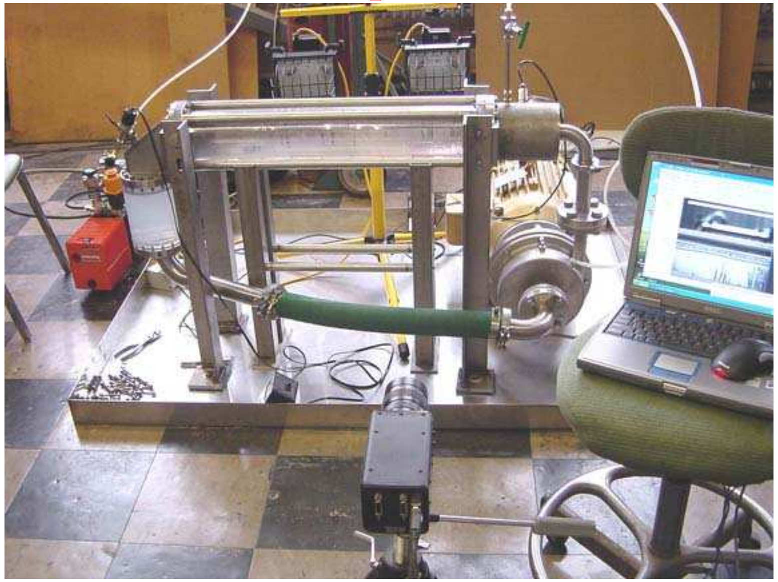
(*d*) Spark source; parallel transmitted light ($\frac{1}{2}$ μs exposure); pressure 130 atm.



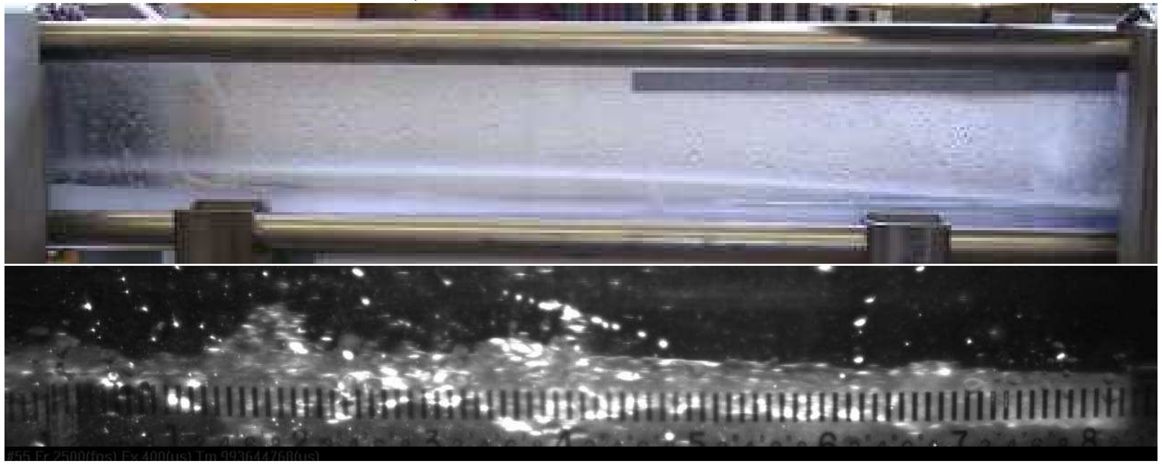
(*e*) X-ray source (5 min exposure); pressure 130 atm.

Nozzle R&D

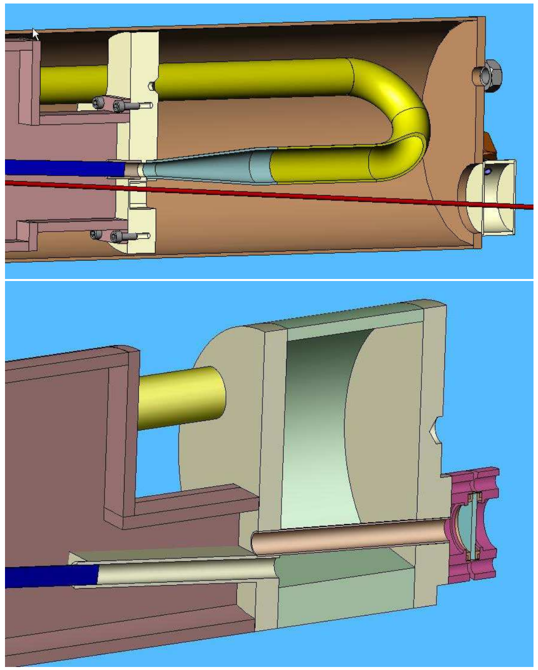
Nozzle test setup at Princeton U:



Water jet at 15 m/s:



- **Jet from a tapered nozzle is better than from a "plenum".**
- **All jets that we have made at ≈ 15 m/s show spray.**
- **Low gas pressure reduces the spray.**
- **Use of a tapered jet $\Rightarrow$ pressure $P \approx \rho v^2 \approx 800$ psi for $v = 20$ m/s (rather than $P = \rho v^2/2$ as for a "plenum").**



MHD effects not yet studied in the lab.

- **Expect suppression of spray.**
- **MHD pressure drop in the 180° bend may be several hundred psi (N. Morley).**

Window Qualification

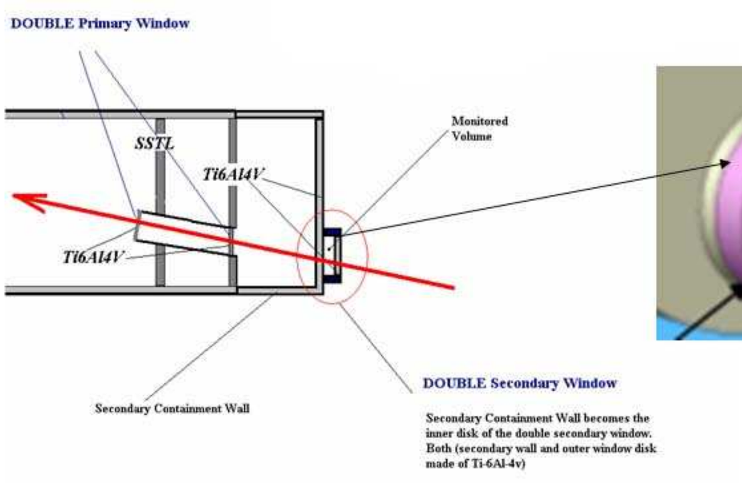
Hg containment system needs proton beam windows.

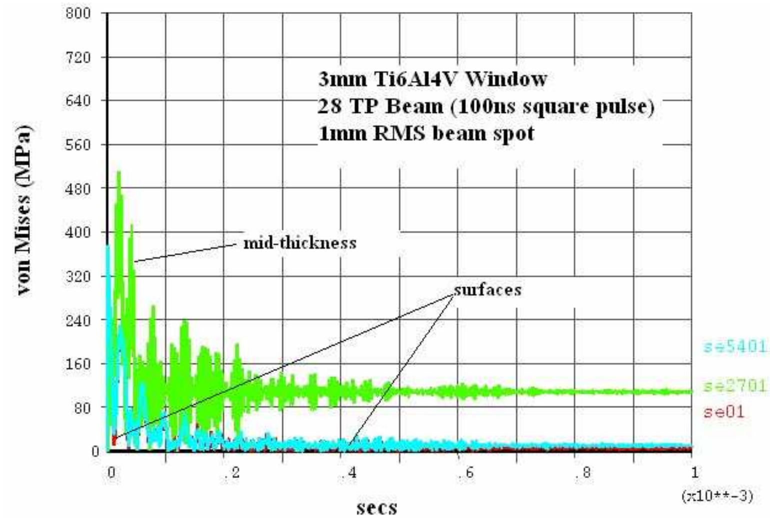
Will these windows survive our intense proton pulses?

Our efforts on window qualification began in 2001 with AGS E-951.

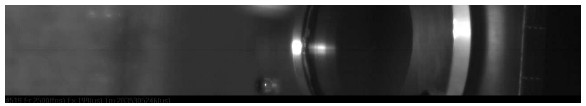
⇒ Good agreement between experiments and ANSYS simulations (N. Simos).

⇒ Ti/Al/V beam windows are well qualified for use in the MERIT experiment.



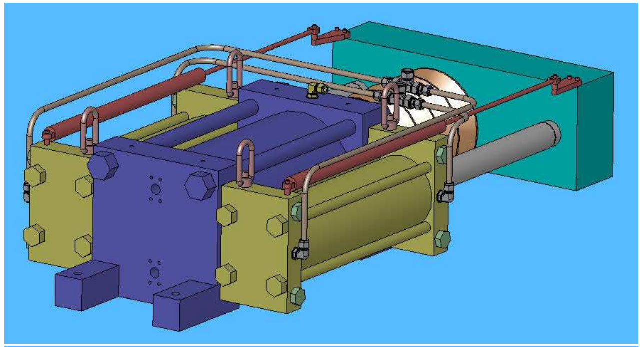


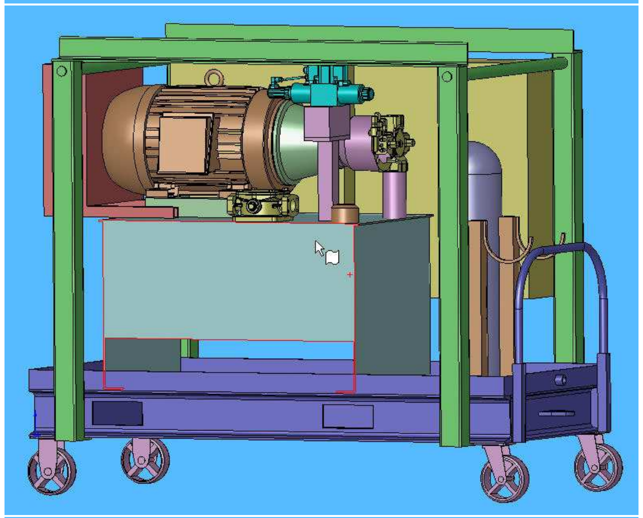
Higher-velocity Hg droplets expected in MERIT than in E-951, ⇒ Use sapphire rather than quartz optical windows.

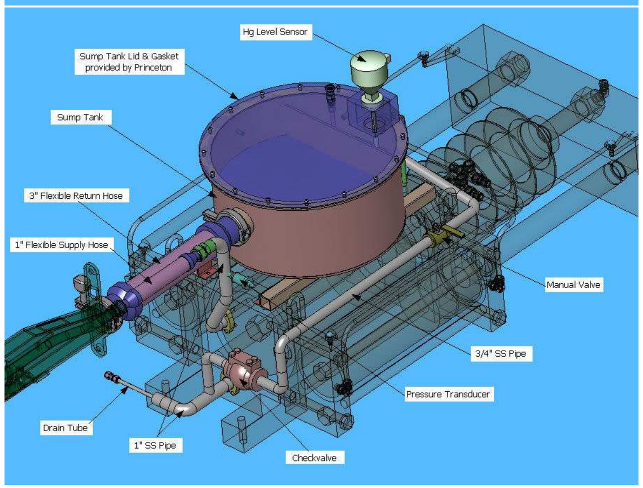


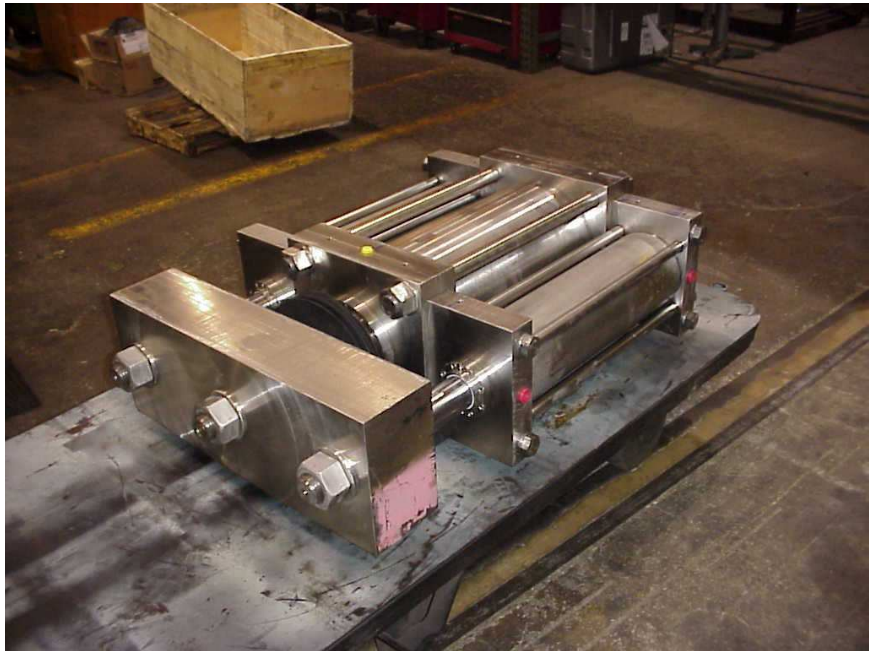
A 6-mm thick sapphire window survived being hit by a “paintball” (equivalent to a 7-mm-diameter drop of mercury) at 95 m/s.

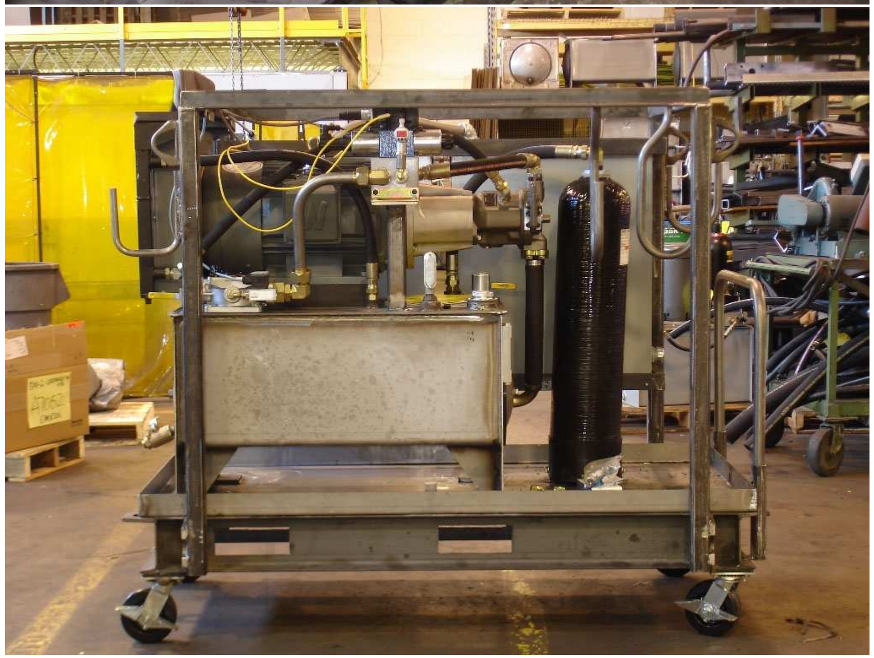
Mercury Syringe Fabrication







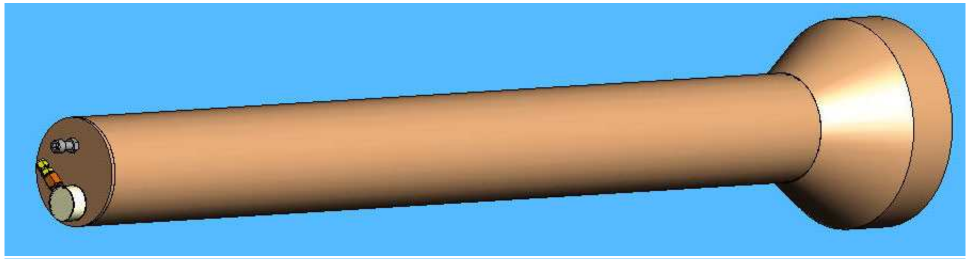


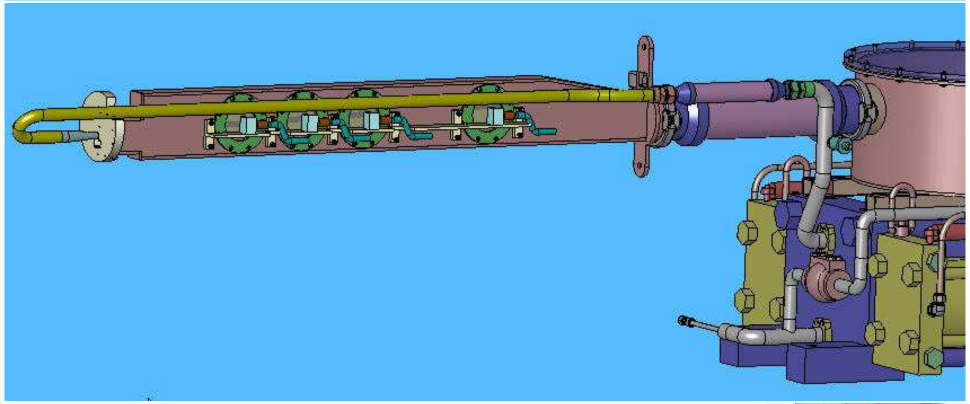


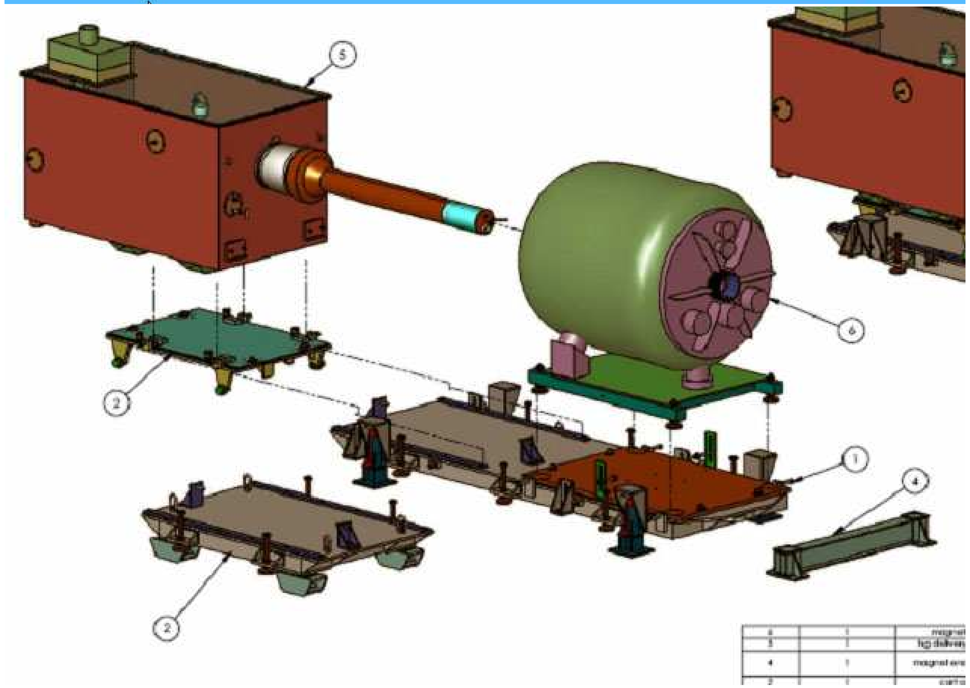
Fabrication of cylinders and hydraulic system to be completed ≈ 1 April by Airline Hydraulics Co. (PA).

Mercury reservoir and piping to be completed ≈ 1 May.

Fabrication of Remaining Components







The secondary containment "snout" and the associated primary containment vessel will be built from titanium if affordable.

High preliminary bids may require us to revert to stainless steel + titanium windows. Issue then is brazing of Ti to SS.

Goal: Complete fabrication by 1 June.

Stainless-steel secondary containment box now being fabricated at Princeton U. Completion ≈ 1 May.

Baseplates now being fabricated at U. Miss. Completion ≈ 1 May.

Integrity of the Primary and Secondary Containment Volumes

The secondary containment volume is observed continuously by one (or more) mercury vapor monitors, to validate the integrity of the primary containment volume.

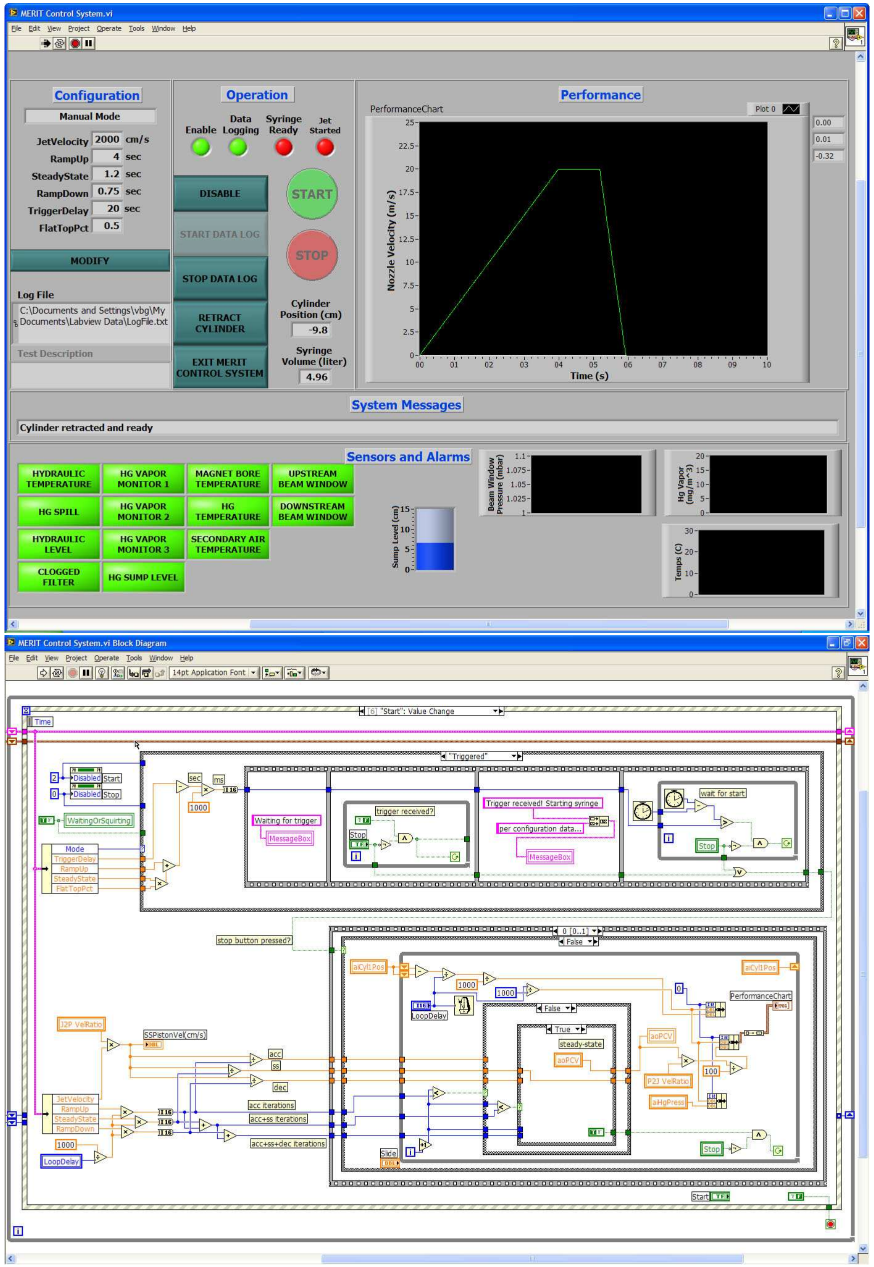
The beam windows of the secondary containment volume are constructed in pairs that enclose a small volume whose pressure is monitored.

The beam windows of the primary containment volume are single layer, and their integrity is validated by the mercury vapor monitor of the secondary containment volume.

We do not plan to open the primary containment volume at CERN.

LabView Control System is Under Development

Control hydraulic pressure *vs.* time to deliver a jet of constant velocity during changing magnetic field.



Sensors:

- Cylinder positions.
- Hydraulic fluid pressure, temperature.
- Hg pressure, temperature.
- Hg vapor in secondary volume.
- Pressure between pairs of beam windows.
- Various hydraulic system status indicators.

Optical Diagnostics

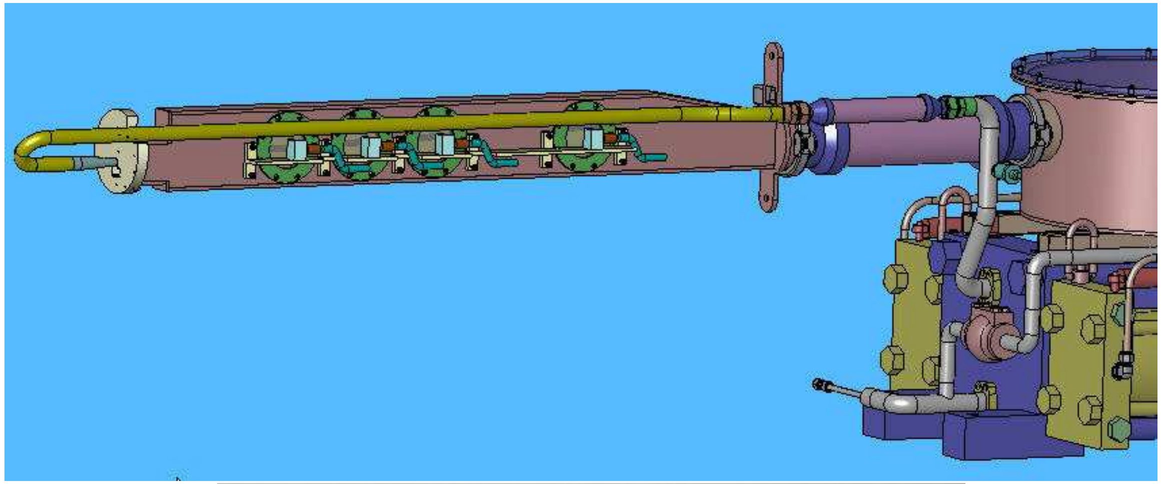
Variant of E-951 optics (T. Tsang).

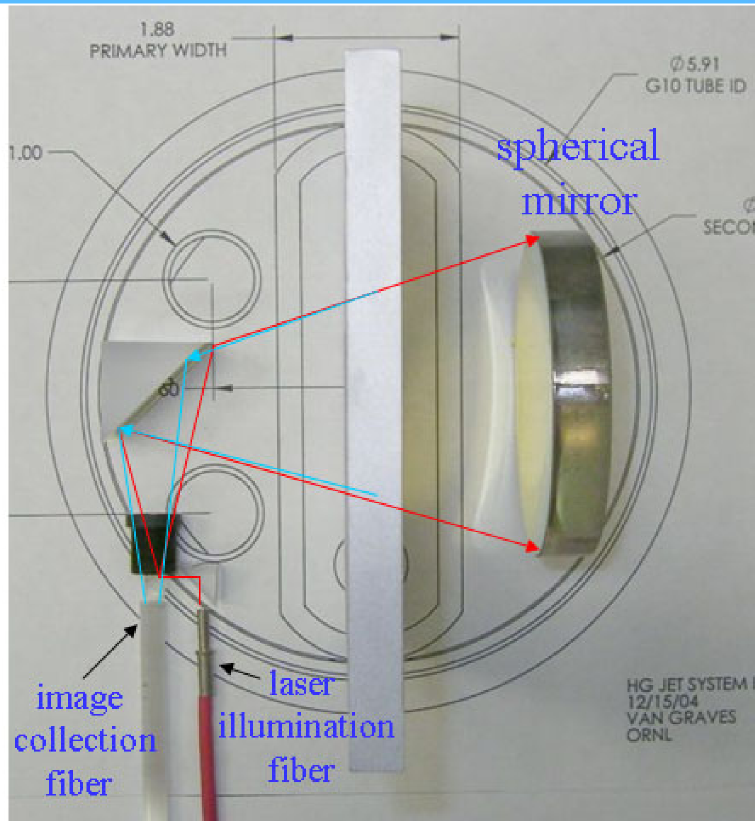
Four views along the Hg jet.

For each viewport:

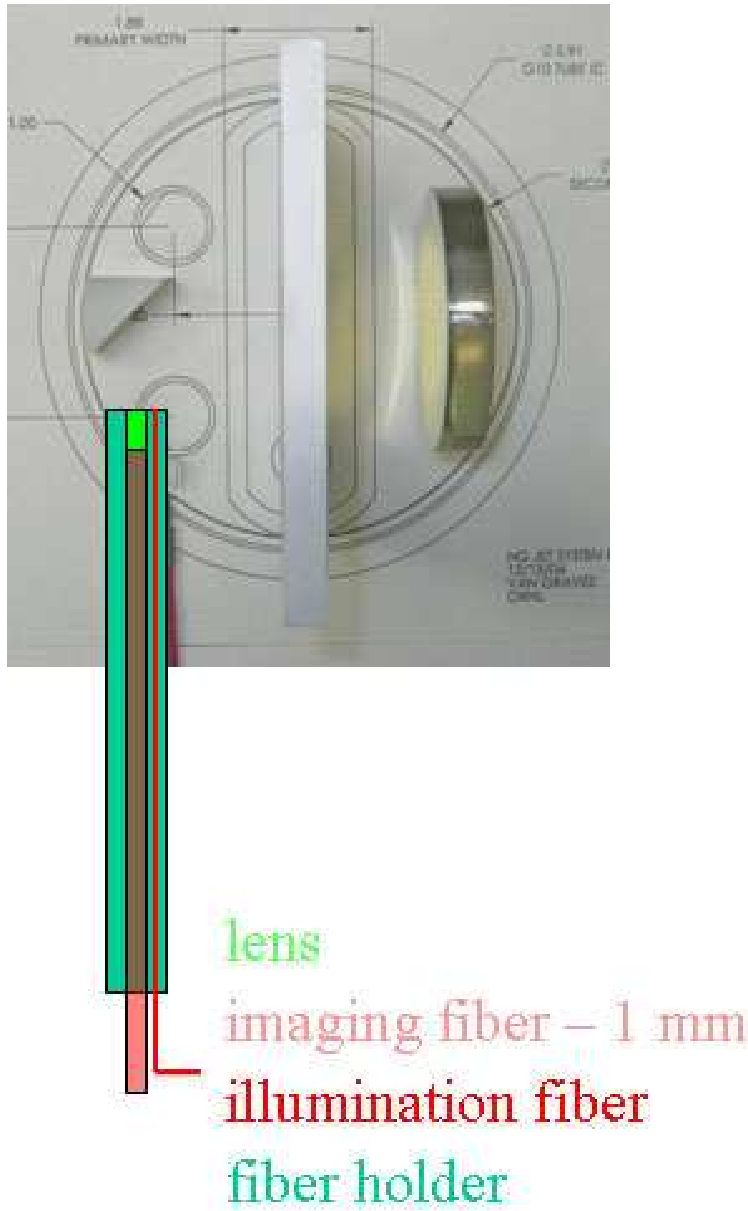
- Single fiber delivers laser light to 45° mirror (after beam splitter).
- Light is retroreflected by spherical mirror.
- Fiber bundle carries shadow image (after beam splitter) to remote camera.

Use of beam splitter twice throws away 3/4 of photons.





Simplified Optical Layout



No beamsplitter.

Illumination fiber and collection fiber bundle offset by ≈ 2 mm.

Spherical mirror rotated to image the illumination fiber onto the collection fiber bundle.

Requires tiny, high-index coupling lens at end of collection fiber. This is only available in "plastic".

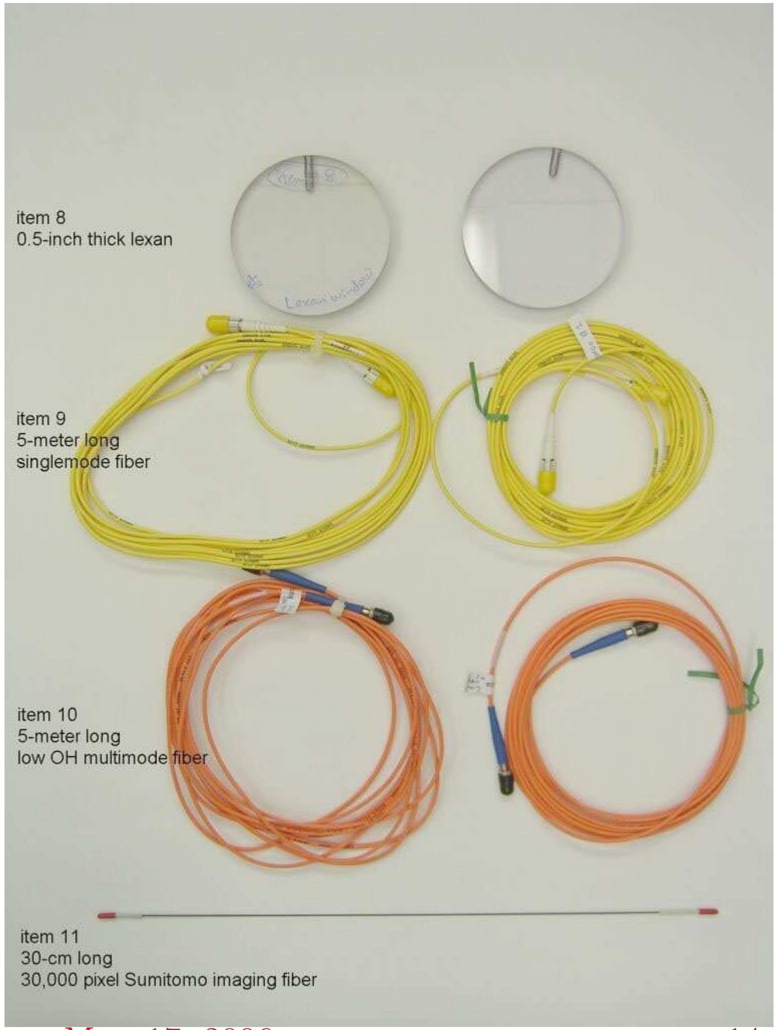
$\Rightarrow$ Must verify radiation hardness (up to ≈ 1 Mrad).

Irradiation Studies of Optical Components

Two irradiations at CERN with $\approx 5 \times 10^{15}$ 1.4-GeV protons each.

$\Rightarrow$ Glass fibers are bad; fused-silica fibers, lens, prisms are good.

Irradiation of tiny lenses in progress.



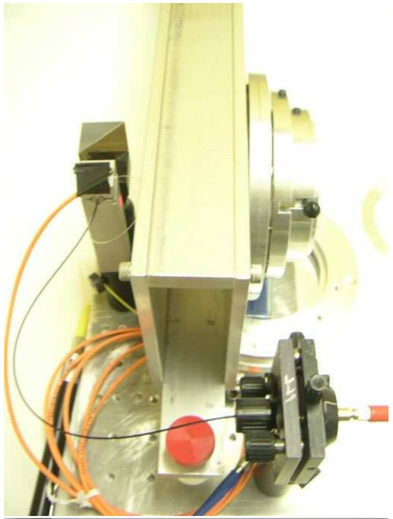
30,000 Imaging Fibers Are "Good Enough"

Images collected with an optics mockup the implements the simplified layout.

Camera frames are 200×200 pixels. (One camera with 10^6 fps, others with 2500 fps.)

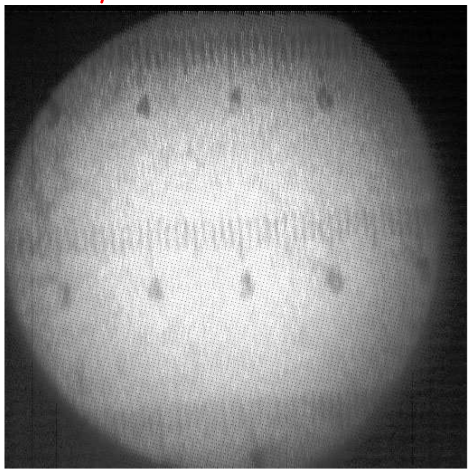
Field of view is 50 mm, $\Rightarrow$ 0.25 mm/pixel.

Fiber-bundle image resolution is consistent with the camera pixel resolution.

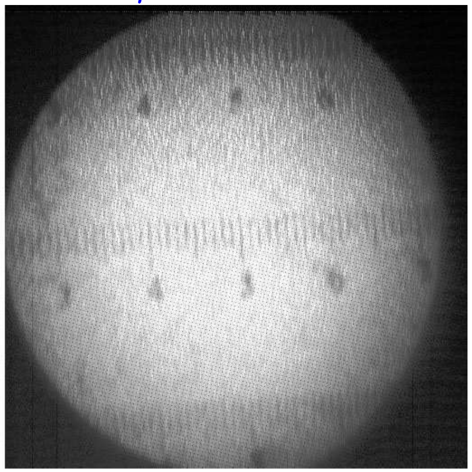


Sumitomo IGN-08/30:
30,000 fibers
\$260/m:
(20 m purchased)

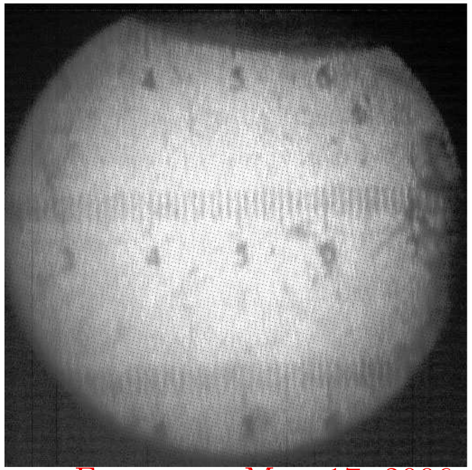
100 μs

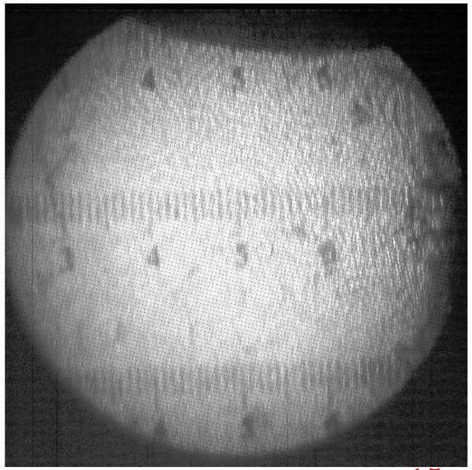


10 μs



Fujikura
FIGH-30-850N:
30,000 fibers
\$700/m





Diagnostics of Secondary-Particle Flux

The MERIT beam pulses will include multiple bunches of up to 20 ms separation.

To monitor possible reduction in particle production during later bunches, we need one or more secondary-particle-flux diagnostics.

Options include a set of scintillators + photodiodes outside the beam, and a pair of beam toroids before and after the target.

New members of the MERIT Collaboration (D. Jensen, M. Haguenauer, N. Mokhov, S. Striganov) will address this issue.

Summary

Design of the mercury delivery system and optical diagnostics is complete.

Fabrication of the mercury delivery system is underway; the time-critical component is the titanium/SS "snout".

Prototype components for the optical diagnostic system will be completed in $\approx$ 1 week.

An effort is underway by new collaborators to build a set of secondary-particle-flux monitors.