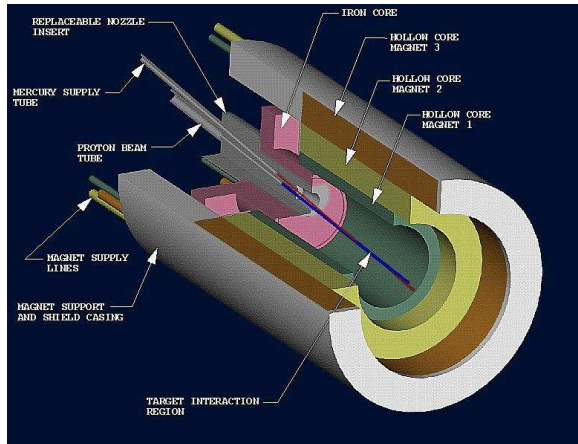
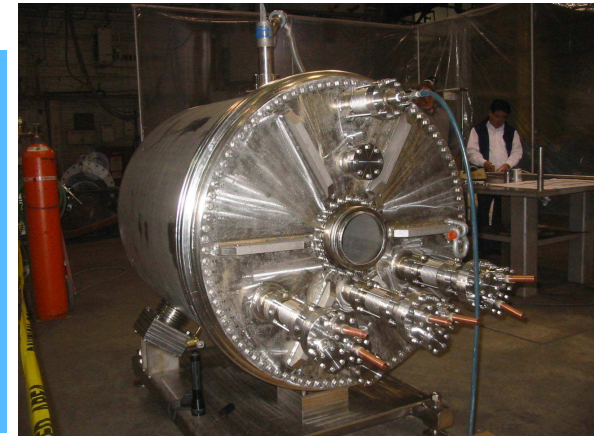
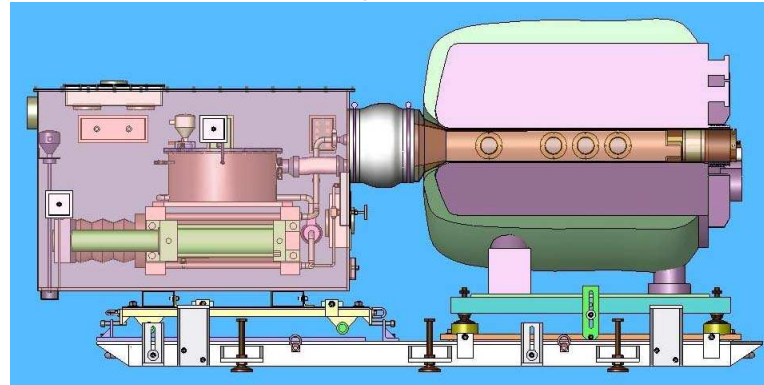


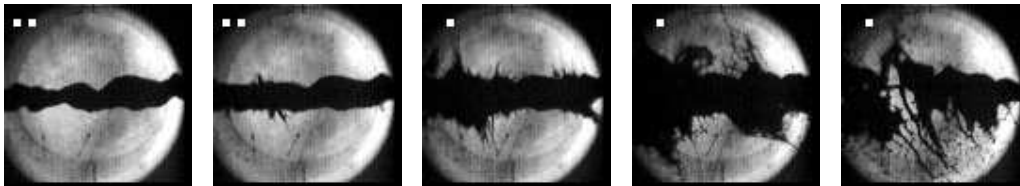
The MERIT Targetry Experiment at CERN



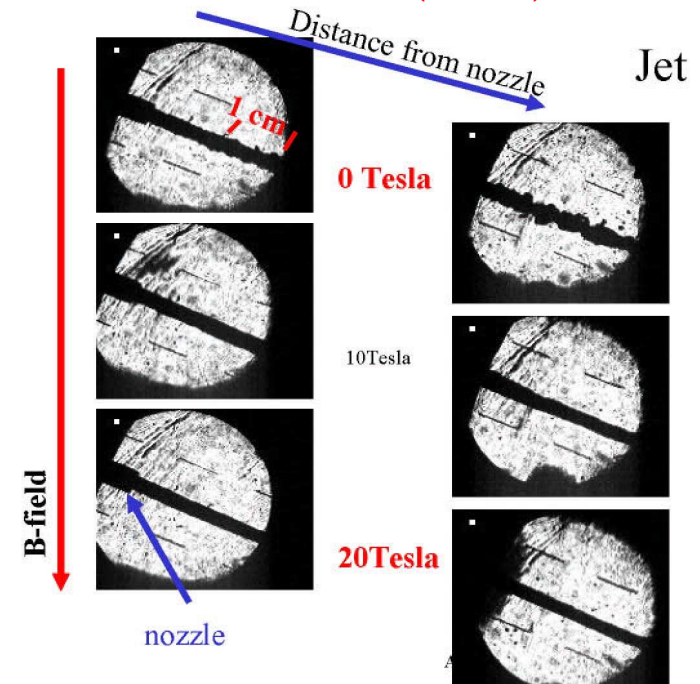
MERIT cutaway view:



BNL E-951 (2001):



CERN-Grenoble (2002):



K.T. McDonald ((MERIT Co-Spokesperson)

Princeton U.

ISS Plenary Meeting, KEK

Jan 24, 2006

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

(Presented by M. Zisman)

What?

- 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 4(8) bunches/pulse, up to 7×10^{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.

Why?

- The quest for high intensity neutrino beams, and high luminosity muon colliders, leads to the need for multimegawatt proton beam and target systems.
- Solid targets are not viable for pulsed beams of greater than 1-2 MW.
- \Rightarrow Explore liquid metal (Hg, Ga, Pb-Bi) targets with free surfaces.
- Previous R&D:
 - Benign dispersal of a free mercury jet by a proton beam in zero field.
 - Stabilization of a mercury jet in a 20-T magnetic field (no proton beam).
- The MERIT experiment combines all features of a multimegawatt target station for a proof-of-principle systems test,
 - \Rightarrow Validation of magnetothermohydrodynamic simulations.
- The MERIT experiment uses parameters of particular relevance to a muon collider: collection of soft π^\pm from a high- Z (mercury) target.
 - Neutrino Factory Study 2: 24-GeV proton beam, 20-T solenoid magnet.
 - CERN concept: 3.5-GeV proton beam, toroidal horn (no field on target).

Who?

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Adrian Fabich³, Richard C. Fernow⁴, Tony A. Gabriel⁵, Van B. Graves⁵,
John R. Haines⁵, Helmut Haseroth³, Friedrich Haug³, Yoshinari Hayato⁶, Yury
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Kirk T. McDonald⁸, Robert B. Palmer⁴, Hee Jin Park², Nicholas Simos⁴,
Roman V. Samulyak⁴, Philip T. Spampinato⁵, Koji Yoshimura⁴

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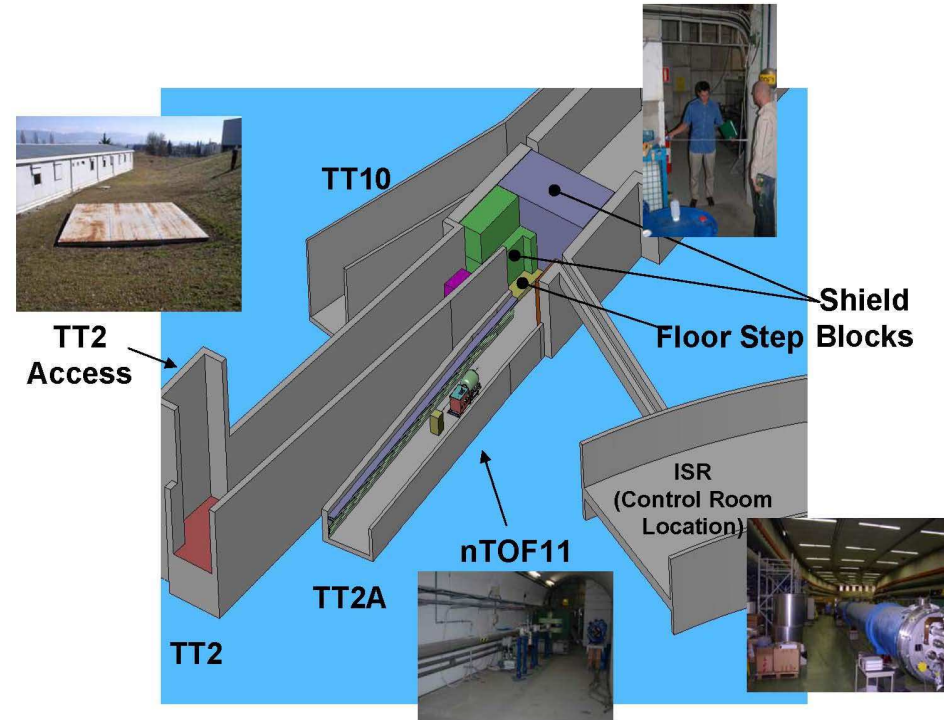
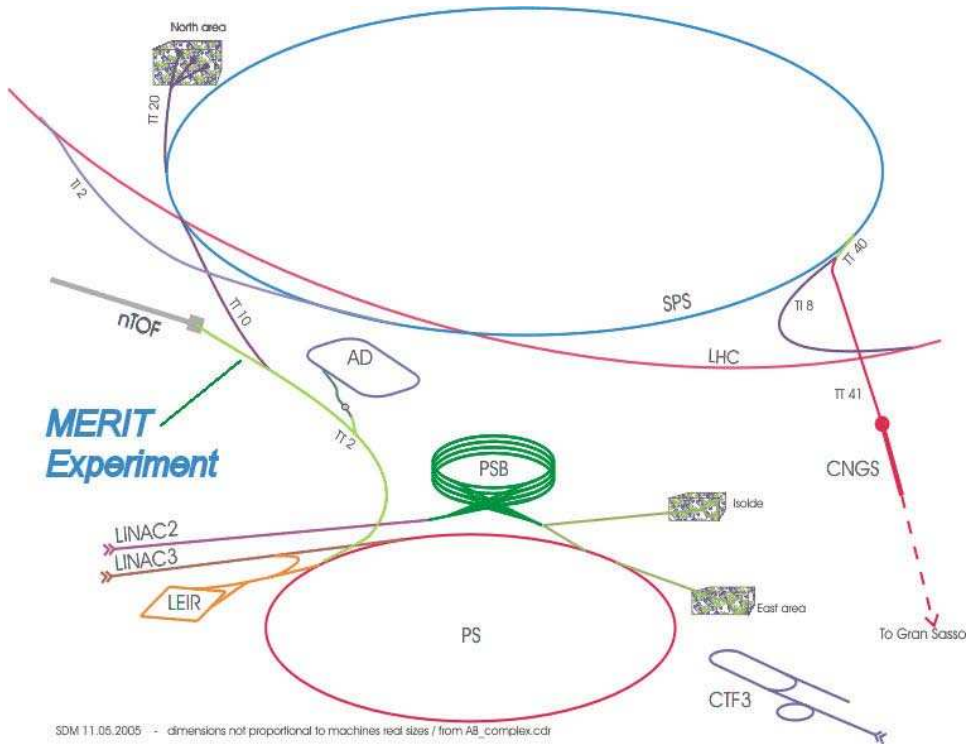
⁶KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801 Japan

⁷Muons, Inc., Batavia, IL 60510, USA

⁸Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544 USA

Where?

The MERIT experiment will be performed in the TT2A tunnel (= old ISR transfer line) at CERN.



When?

The MERIT experiment is tentatively scheduled for a 2-week run sometime during April-June, 2007 (C. Rembser, CERN PS Physics Coordinator).

- 1997: High-power targetry R&D initiated by the Muon Collider Collaboration.
- 2001-02: Studies of jet + beam (AGS, ISOLDE) and jet + magnet (Grenoble).
[Solid-target studies in parallel.] (Photos on slide 1.)

- 2003: LOI's to CERN and JPARC (as BNL beams no longer available for HEP).

- 2004: Proposal to CERN.

Let contract to CVIP to fabricate the 15-T magnet.

- 2005: MERIT experiment approved at CERN.

Rebaseline to use an old CERN 8 MVA power supply.

Simplify cryogenic to operate at 80 K rather than 70 K.

- 2006: Commission magnet at MIT.

Fabricate mercury delivery system and test with magnet at MIT.

Fabricate cryogenic system.

- 2007: Install experiment at CERN and run.

How?

The MERIT experiment is comprised of several subsystems that will be introduced in the following slides:

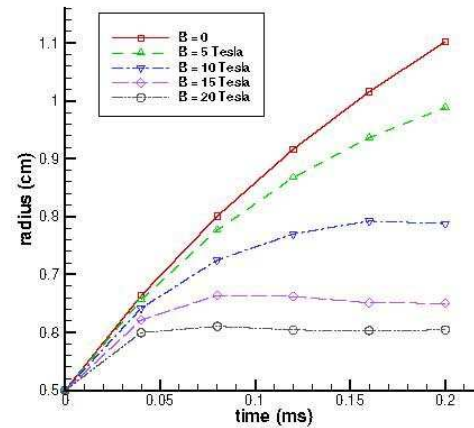
- **Simulations.**
- The 15-T pulsed solenoid magnet.
- The 8 MVA power supply.
- The liquid nitrogen cryogenic system.
- The mercury delivery system.
- The optical diagnostic system.

Simulations

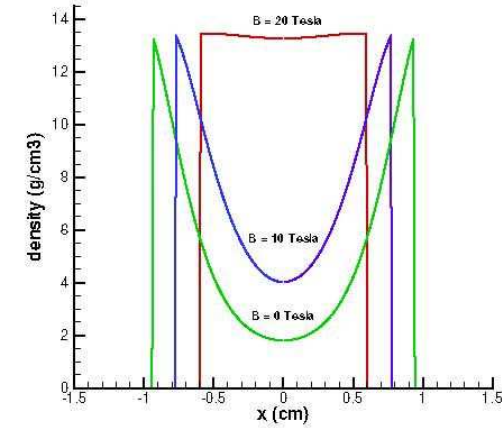
Pushing the state of the art: magnetothermohydrodynamic code with free liquid jets and cavitation.

(J. Du, R. Samulyak; FronTier).

Predicts partial suppression of beam-induced cavitation in strong magnetic fields.



(a) Evolution of the mercury jet radius.

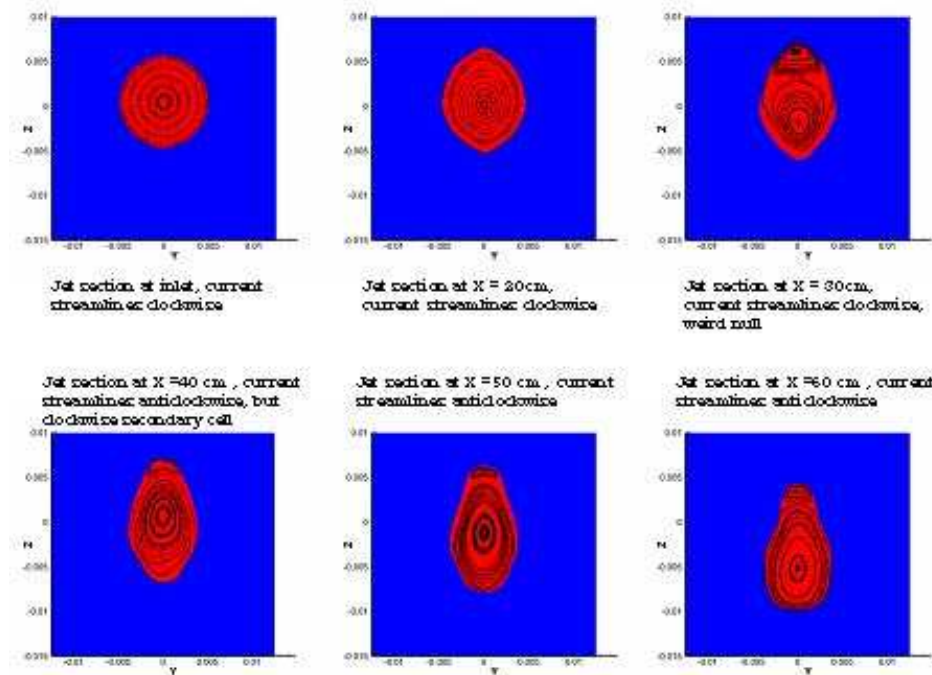


(b) Density profile in the jet cross-section at $t = 130$ microseconds

Incompressible code with free liquid surface confirms predictions of shape distortion of a liquid mercury jet that crosses magnetic field lines.

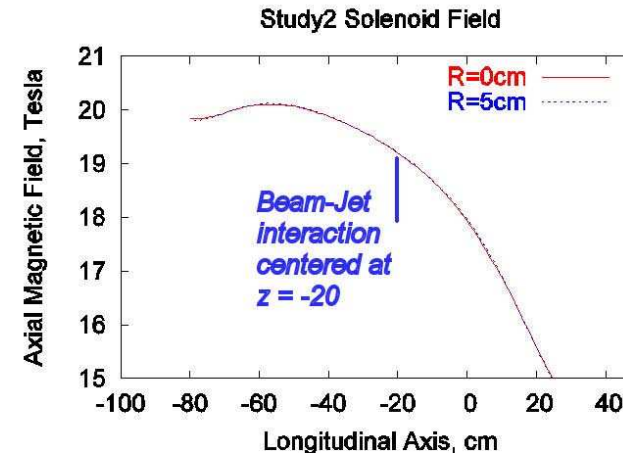
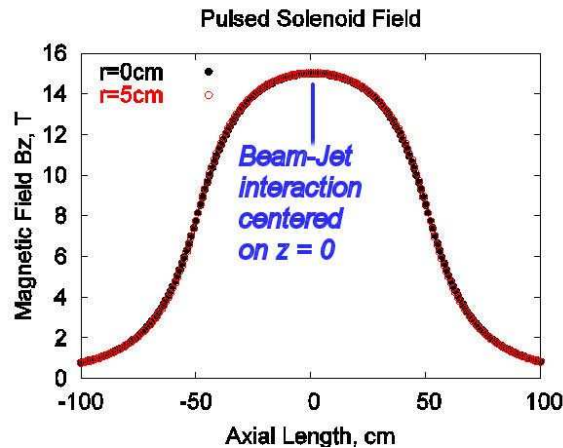
(N. Morley, M. Narula; HIMAG).

Not studied: MHD pressure drops in the mercury delivery pipe, but may be 100's of psi.



New Baseline Angle of Mercury Jet is 33 Mrad to Magnetic Axis

Magnetic field gradients are stronger in the MERIT solenoid than in that considered for Neutrino Factory Study 2.



⇒ Much larger distortion of shape of jet in the MERIT magnet.

100 mrad jet angle in the 15-T magnet

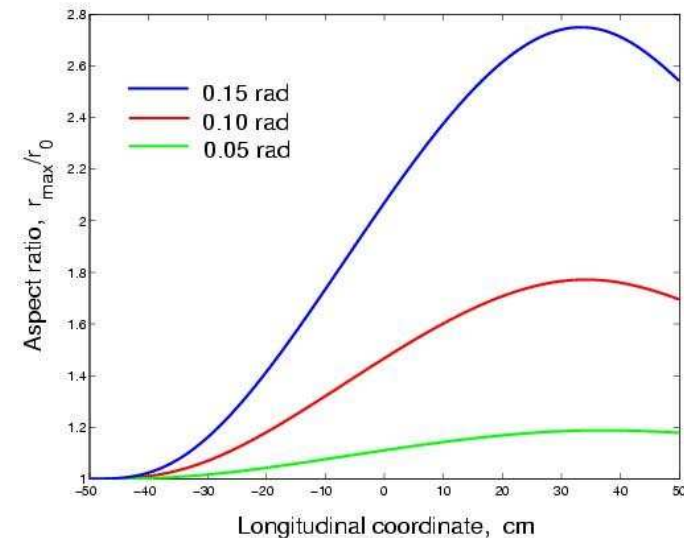
⇒ 2:1 aspect ratio of jet at center of magnet!

33 mrad jet angle in the 15-T magnet

⇒ 1.1:1 aspect ratio of jet at center of magnet

= aspect ratio of 100 mrad jet in Study 2 magnet.

⇒ Change baseline jet angle in MERIT experiment to 33 mrad.



15-T Magnet Commissioning

The magnet was fabricated by CVIP (+ Everson-Tesla).
 Delivered to MIT 10 Jan 2006.

Commissioning at MIT in 2 phases (P. Titus):

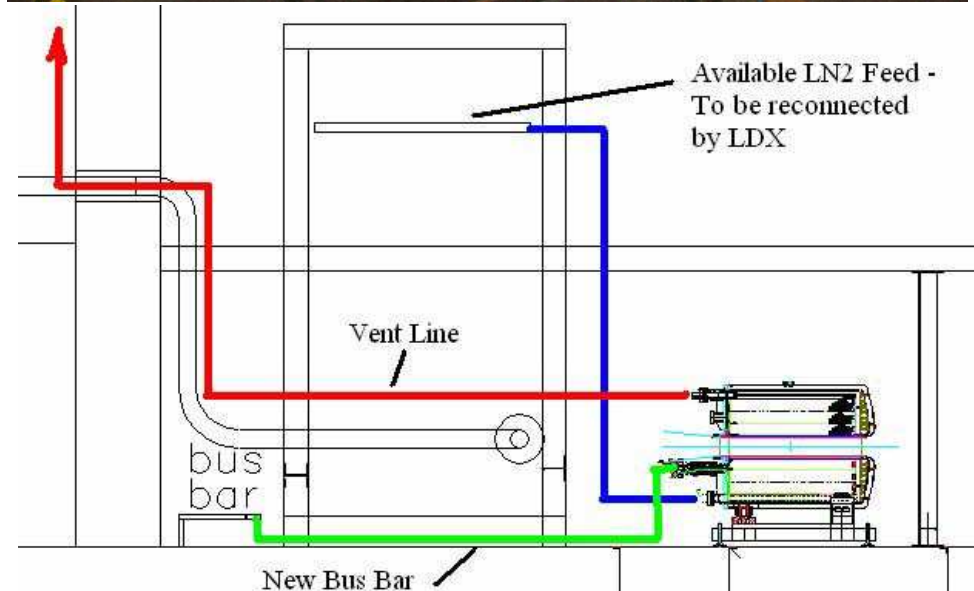
- Cooldown and magnetic excitation (Jan 2006).
- Operation with the mercury jet system (Sept 2006).



30 MW power string:



Test pit layout at MIT:



New Baseline is an 8 MVA CERN Power Supply

Original plan was to use a 4 MVA power supply, and operate magnet at 70 K.

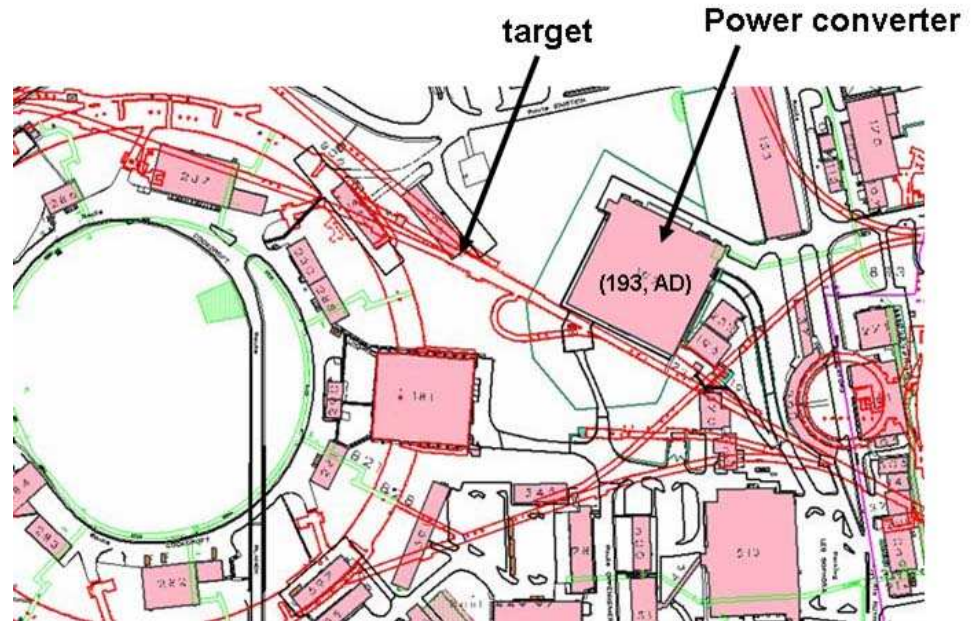
An 8 MVA power supply became available at CERN in Nov 2004 (C.A. Martins).

Lower cost to refurbish than to buy new.

Use of 5 MVA permits magnet to be operated at 80 K.

The power supply will be relocated to Bldg 193 (18 kVA substation) and DC bus run to the TT2A tunnel. (I. Efthymiopoulos, A. Fabich)

[Lights will dim slightly all over CERN when we pulse this supply.]



New Baseline is Operation of the Magnet at 80 K

Cryogenic Cu magnet

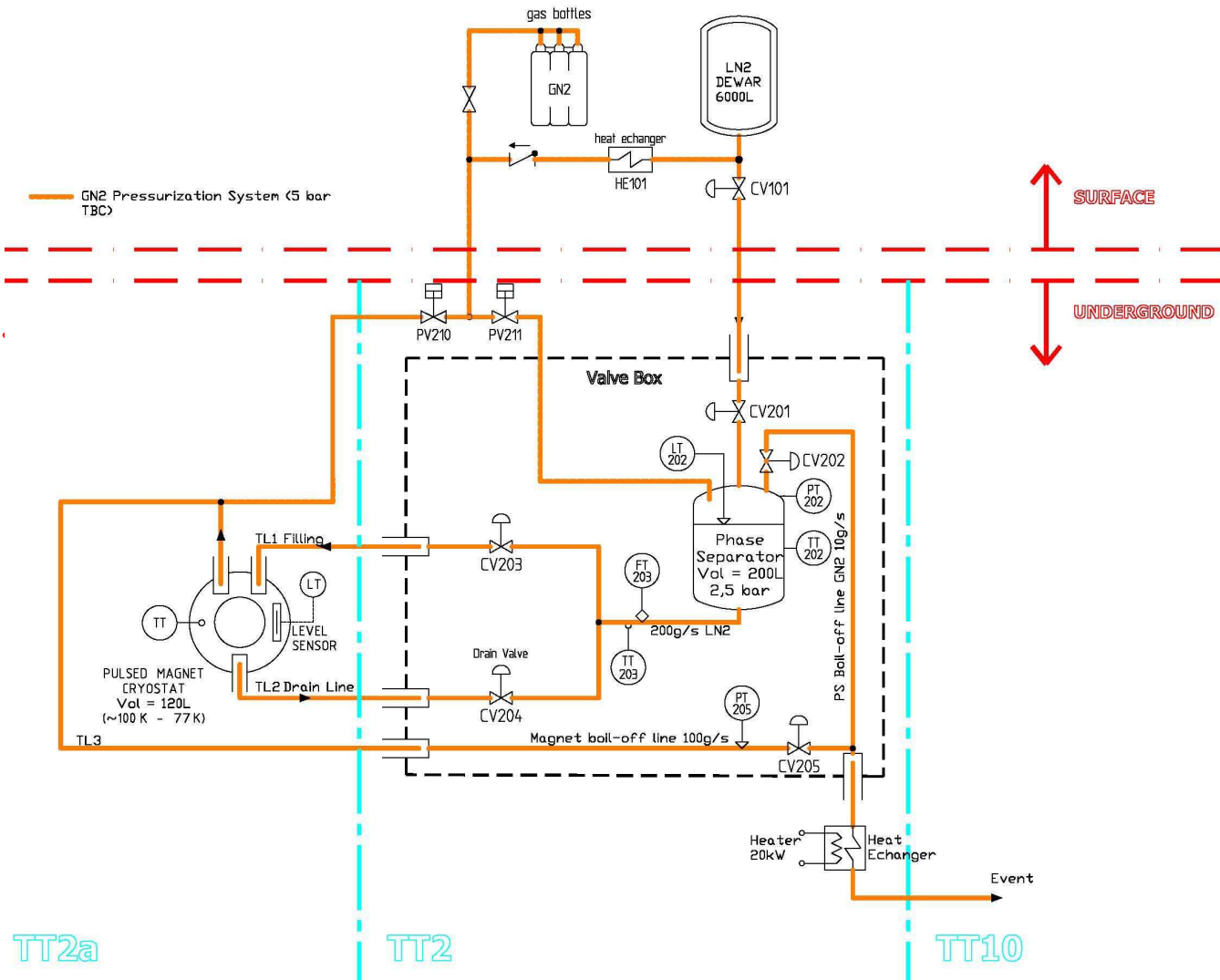
- ⇒ Lower resistance,
- ⇒ Lower power.

Original plan: run at 70K via LN₂ subcooling.

5 MVA power supply permits operation at 80 K.

⇒ Cost reduction of cryogenic system (F. Haug).

- LN₂ supply dewar on surface.
- Control valves in TT2 tunnel.
- Exhaust activated N₂ gas to TT10 tunnel.
- Cool magnet from 110 K to 80 K in 20 min.
- Excess LN₂ returned to valve box in 10 min.



Valve box design/procurement is a joint project of CERN and RAL (R. Bennett, Y. Ivanushenkov).

Mercury Delivery System Based on a “Syringe” Pump

$v = 20 \text{ m/s}$ for Hg jet

$\Rightarrow \approx 1000 \text{ psi}$.

\Rightarrow Use hydraulic “syringe” pump rather than centrifugal pump (V. Graves).

1.6 l/s for 10 sec

\Rightarrow Hg inventory = 16 l.

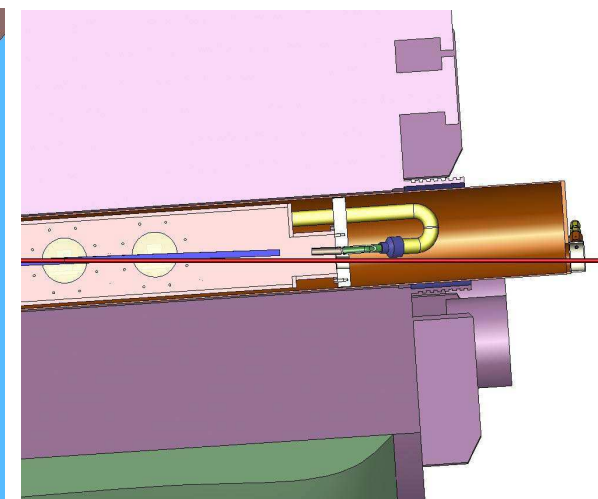
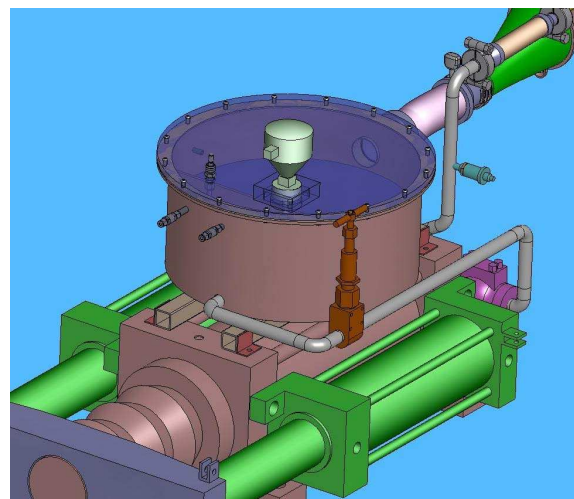
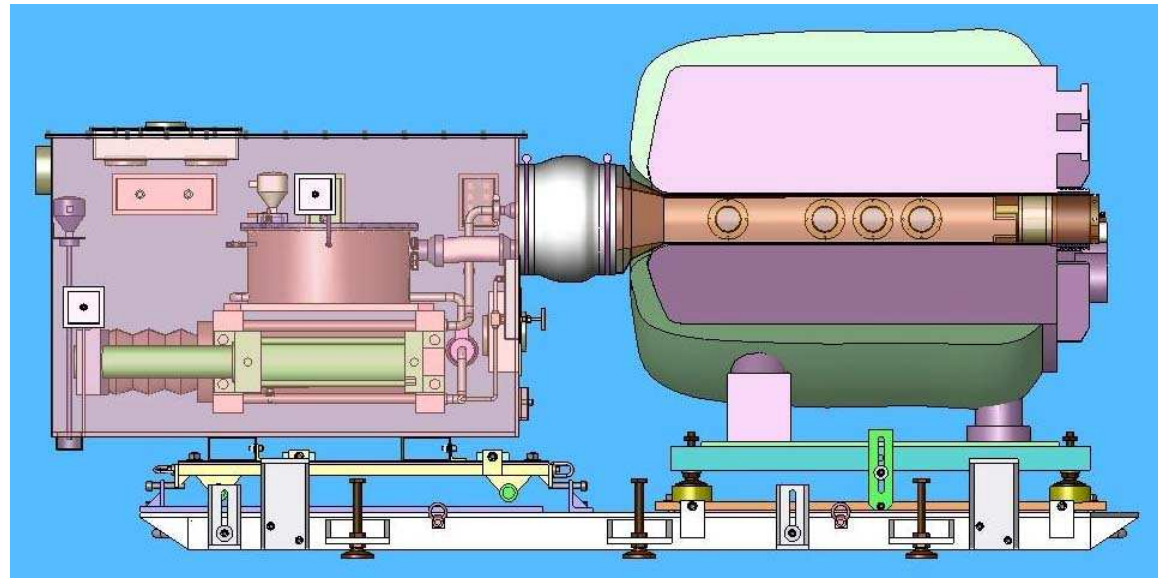
Mercury handling procedures based on SNS experience (P. Spampinato).

Double containment system include 6"-diameter “snout” that inserts into magnet.

Hg nozzle just above proton beam at upstream end of magnet;

fed by a 1"-diameter pipe that passes through the magnet.

Nozzle design still an important issue (H.-J. Park).



Integrity of proton beam windows and optical view-ports is another important issue (N. Simos).

Nozzle R&D

McCarthy & Molloy (1974):

$v = 20 \text{ m/s}$ for Hg jet
 \Rightarrow Turbulent flow.

Nozzle lore:

- Shorter nozzle is better.
- Low/zero surrounding gas pressure is better.
- Should be able to make a 1-cm-diameter Hg jet go 1-2 m before breakup.

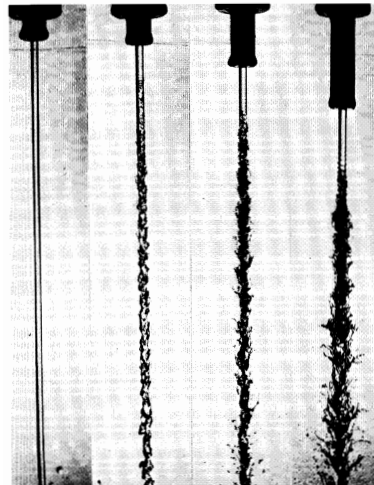


Fig. 5. Effect of nozzle design on the stability of glycerol-water jets.
 Jet viscosity 11 cP
 Jet velocity 20 m s^{-1} (approx.)
 Nozzle diameter 2.54 mm
 Jet Reynolds no. 4750
 Jet Ohnesorge no. 0.026
 Exposure 30 μsec
 Nozzle aspect ratio $AR = L/d$ (see Fig. 7) = 0, 1, 5, 10 L to R.

Nozzle test setup at Princeton U:

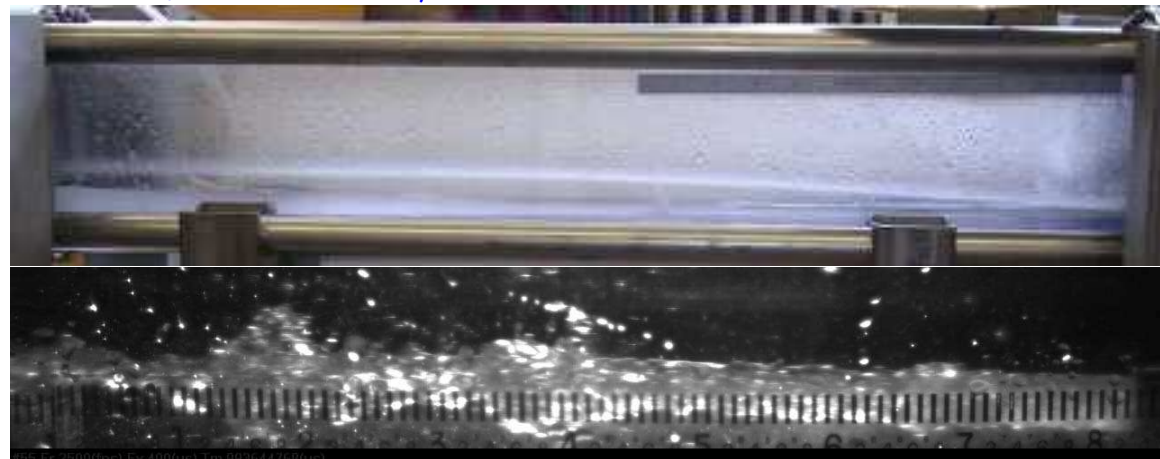


We're still working on this!
 (H.-J. Park)

MHD effects will only be studied in lab during Sep 06 MIT test. Surprises at that late date would be awkward.

\Rightarrow More simulations now would be very helpful.

Water jet at 15 m/s:



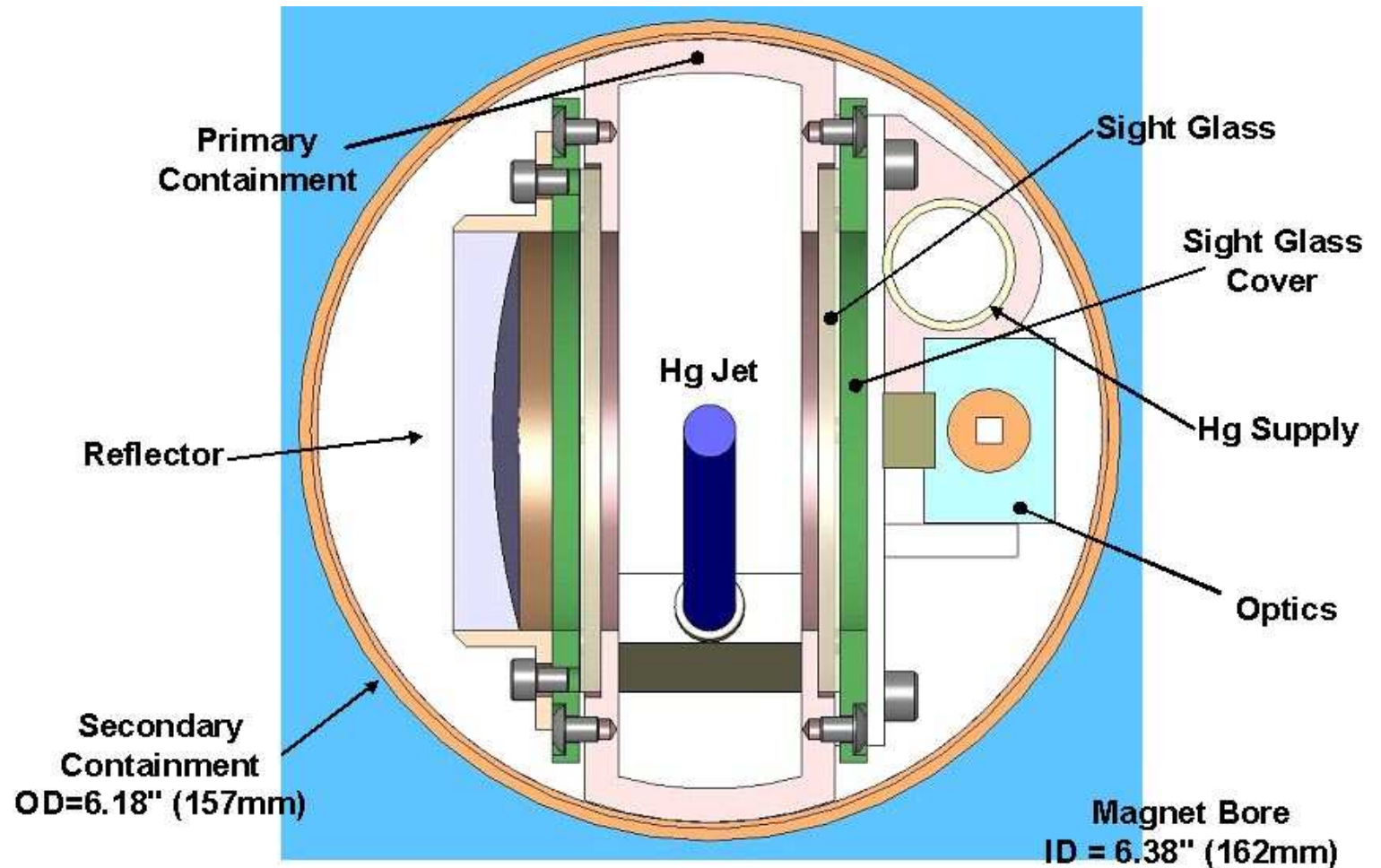
Optical Diagnostics

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

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.



Sumitomo optical fibers tested to be rad hard. 30,000 fiber bundle now baseline.

Sapphire optical windows must withstand the mercury “splash”.

Window Qualification

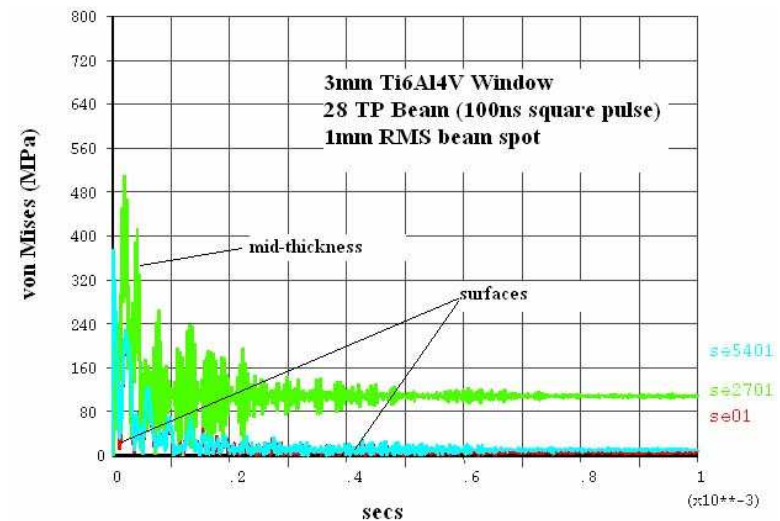
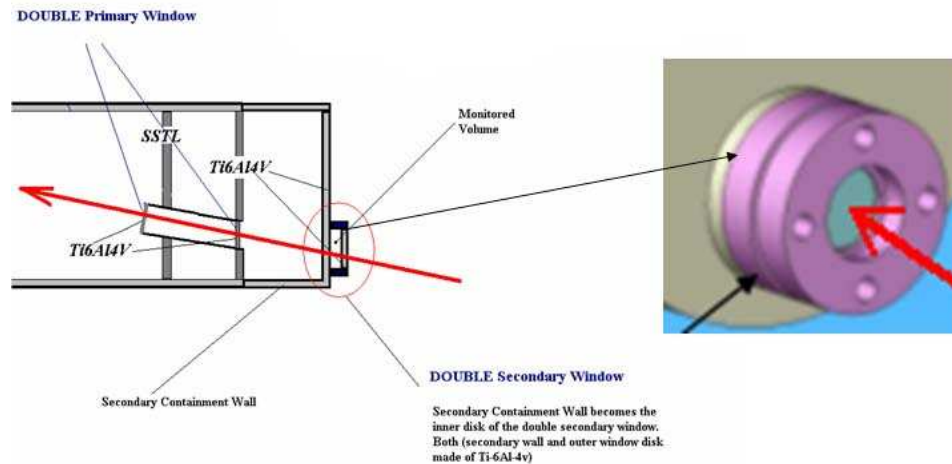
Hg containment system needs proton beam windows.

Will these windows survive our intense proton pulses?

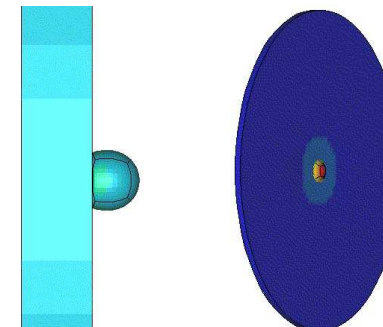
Our efforts on window qualification began in 2001 with AGS E-951.

⇒ 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.



Summary

- The MERIT experiment will be performed in a 24-GeV primary proton beam at CERN in Spring '07 as a proof-of principle of a free mercury jet target + solenoid capture of secondary pions.
- Fabrication of the 15-T pulsed solenoid is complete. Other fabrications are under way.
- Using full-turn extraction at the CERN PS, conditions equivalent to a single pulse of a 4-MW Neutrino Factory source will be studied.