Hg System Design

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MERIT Hg System Safety Review

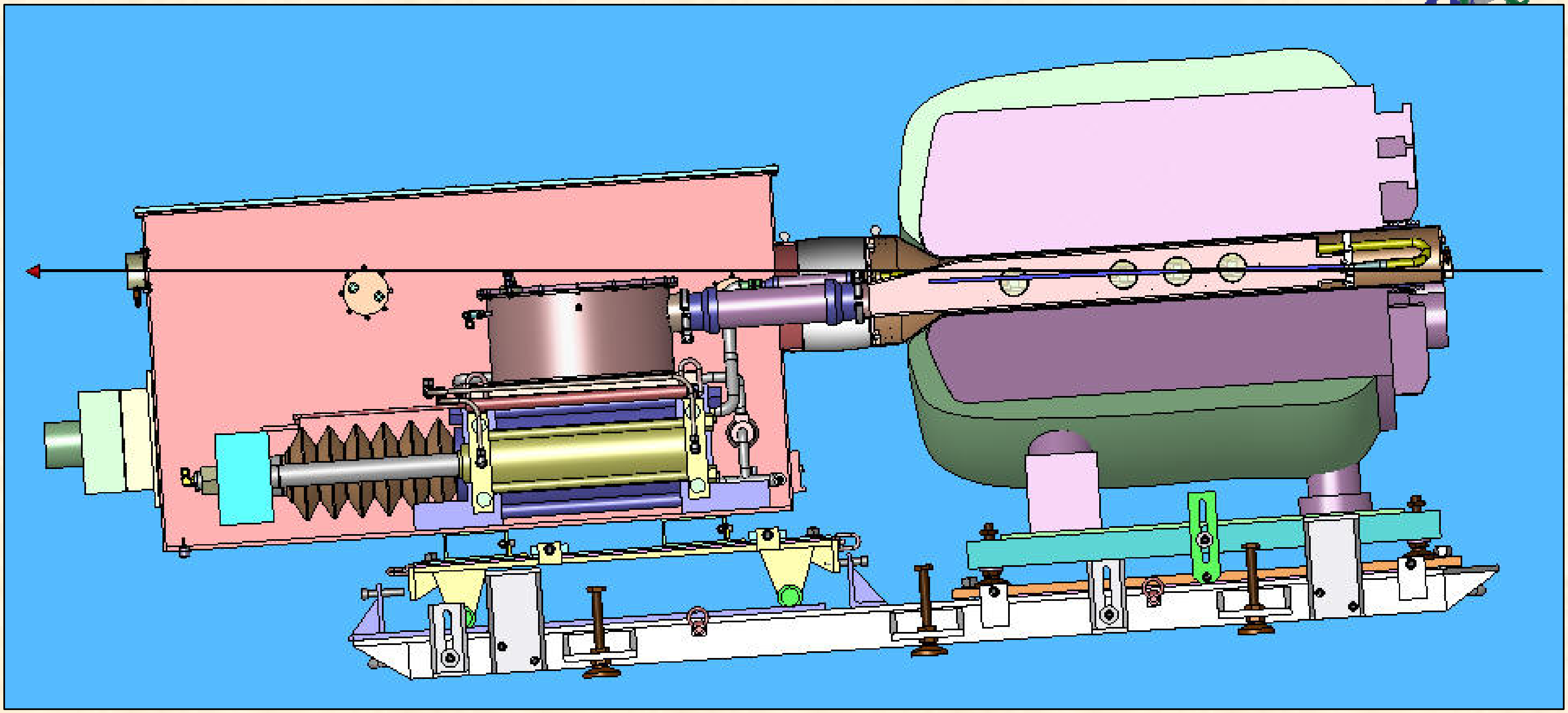
CERN

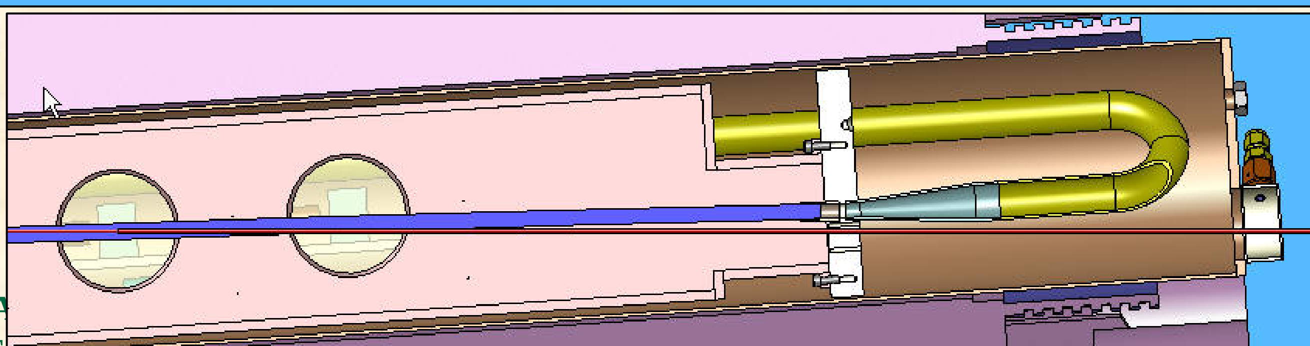
June 19-20, 2006

Outline

- **Requirements & environment**
- **System design overview**
- **Component descriptions**
- **Facility interfaces**
- **System safety design features**

MERIT Side View





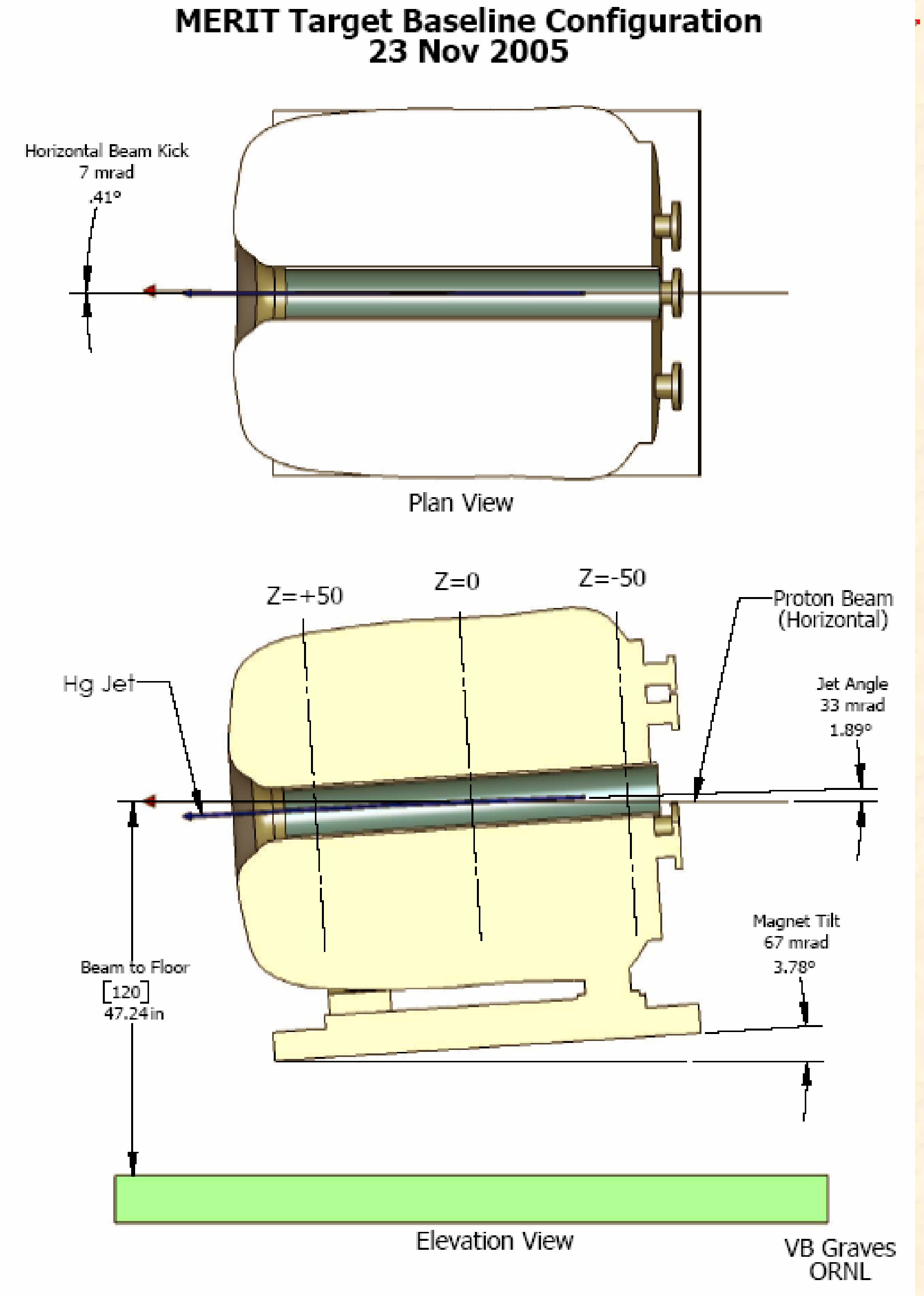
Requirements and Operating Conditions

Target system must deliver a stable, unconstrained jet of Hg into a 15 Tesla field

- **1-cm diameter jet at 20 m/s delivered every 30 minutes**
  - **Q=1.6liter/s, Re~10^6**
- **~1-sec steady state jet during the magnet peak field**
- **Baseline Hg environment is 1-atm air**
- **24 GeV and 14 GeV beam configurations**
- **Up to 100 pulses for the CERN test, >500 operating cycles for system testing**
- **Primary diagnostic is high-speed shadow photography**

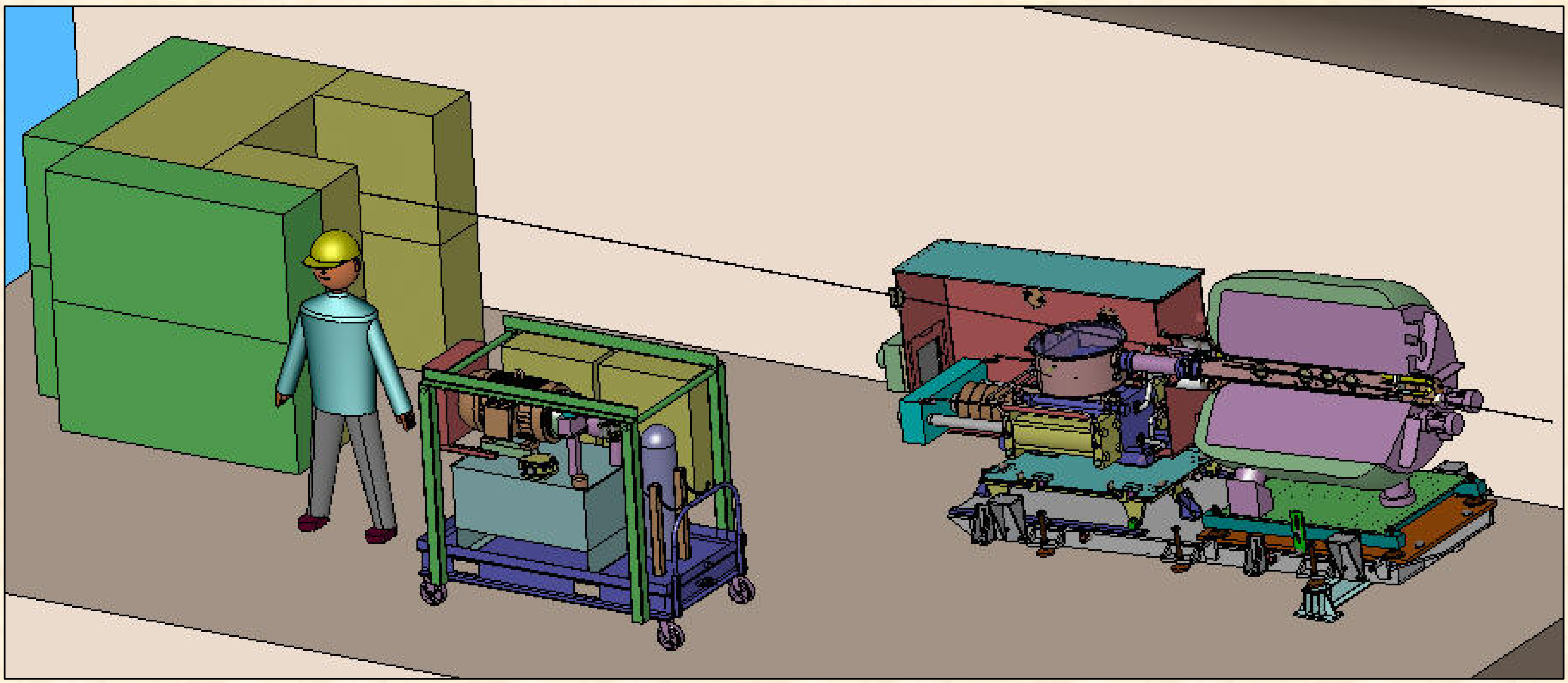
Geometry of the Interaction Region

- **Jet-beam interaction length is 30-cm**
- **Horizontal proton beam**
- **Magnet axis to beam angle 67 milliradians**
- **Jet crosses beam at 33 milliradians**
  - **Jet starts above beam**
  - **Jet & beam in same direction**
- **The jet centerline crosses the beam center at Z=0 (center of the solenoid)**
- **7 milliradian horizontal beam kick in 24 GeV configuration; 12 milliradian kick in 14 GeV configuration**

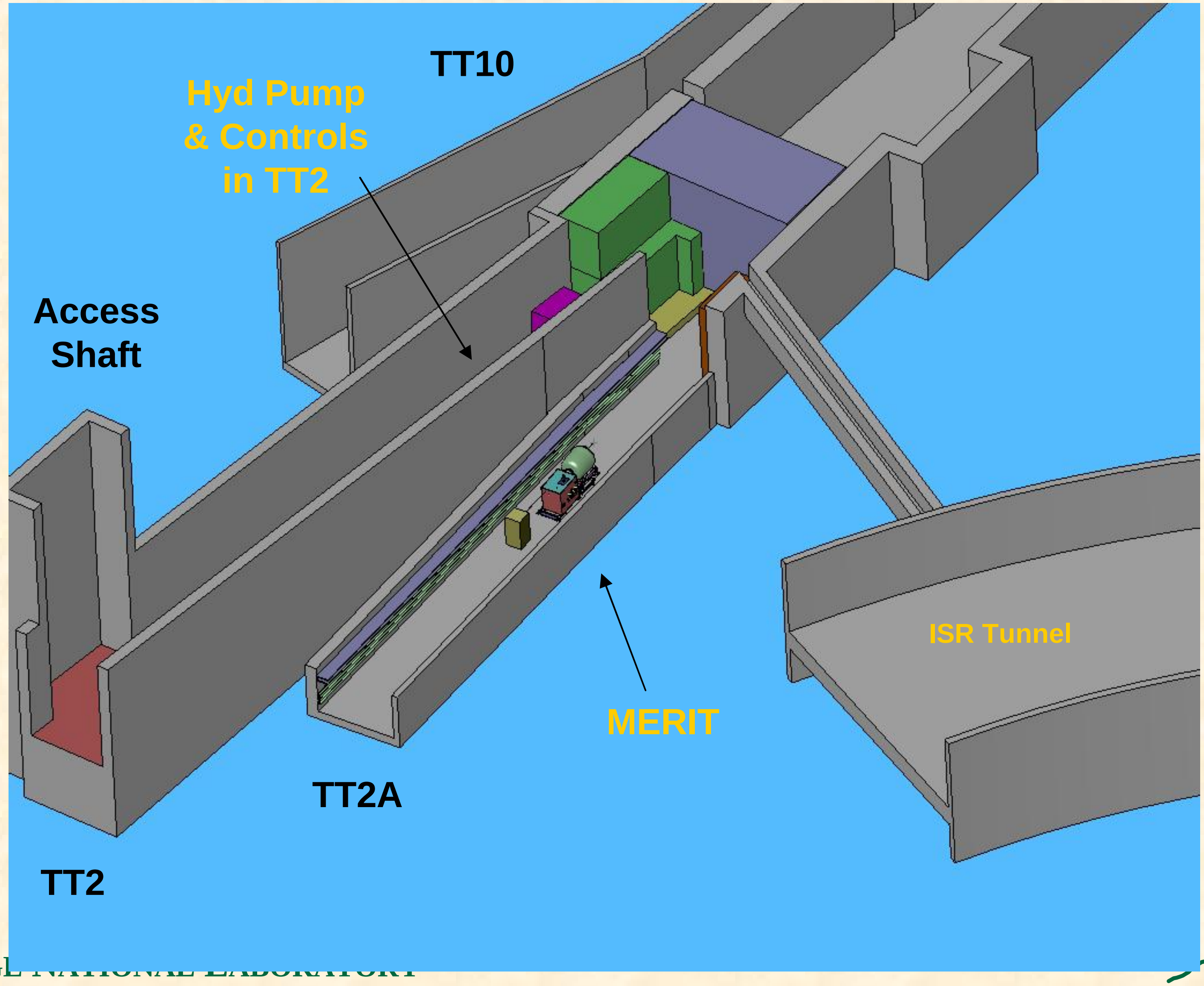


Experiment Layout

- **Hg target is a self-contained module inserted into the magnet bore**
- **Two containment barriers between the Hg and the TT2A tunnel environment**

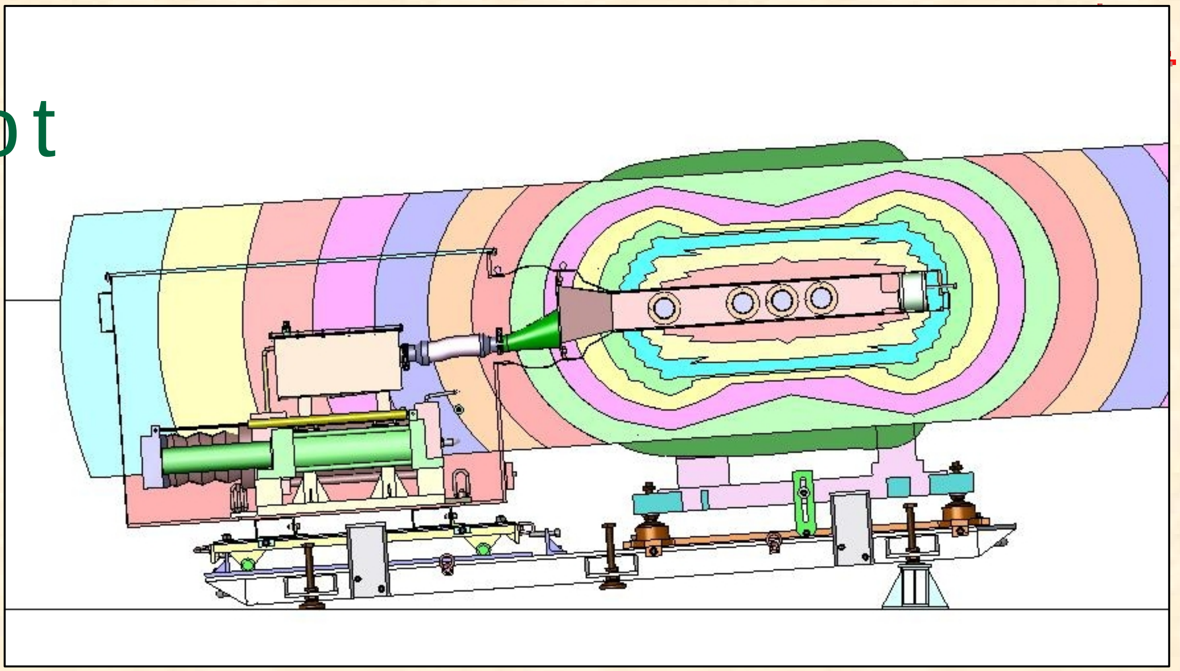


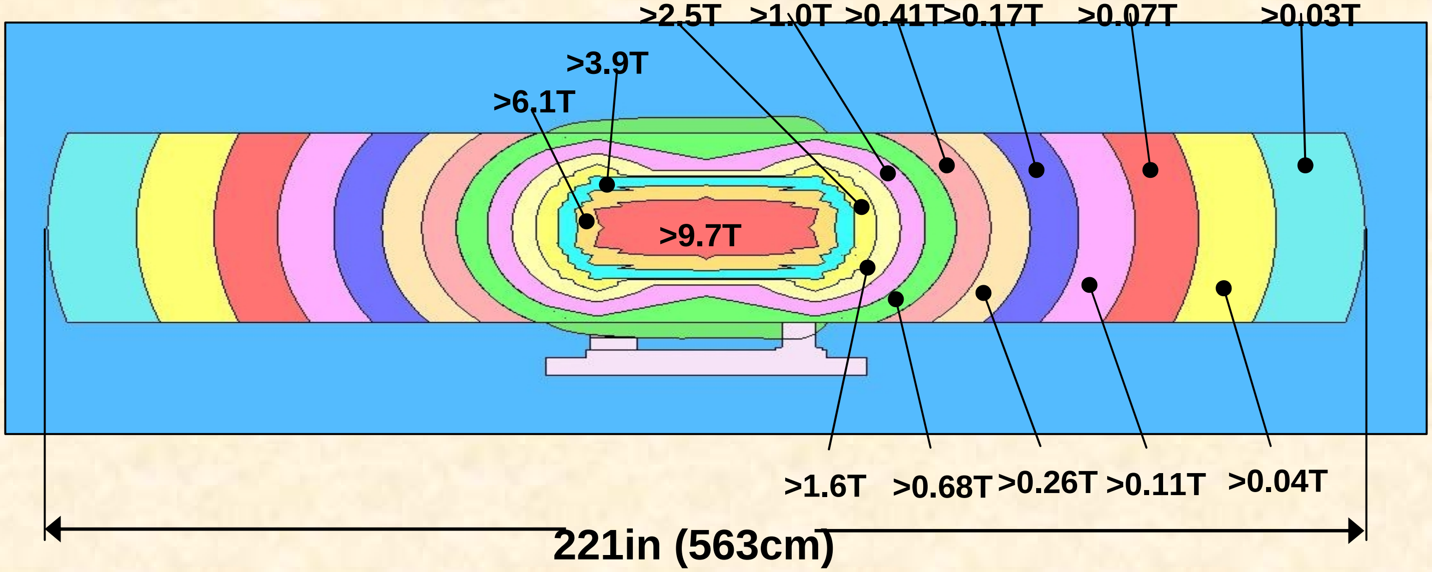
Experiment at CERN



Stray Field Plot

- **The pump equipment operates in a range of 3000 Gauss to 300 Gauss (*1 Tesla = 10^4 Gauss)***
- **Nozzle located in 6-9 Tesla field**





Design Specifications and Requirements

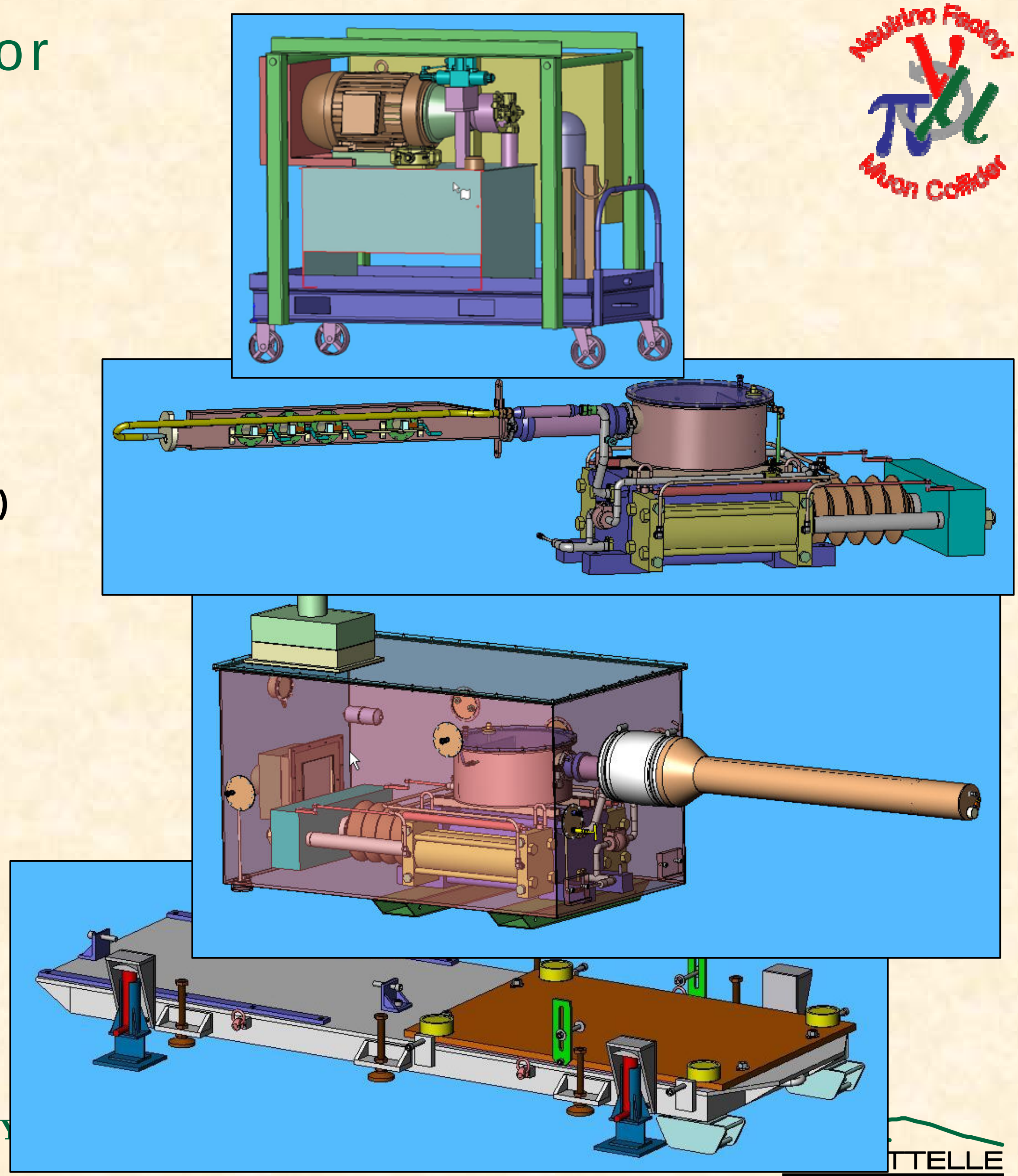
- **ISO 2919, Table 2 "Classification of Sealed Source Performance" suggested by CERN Safety Commission as starting point for design criteria**
  - **Temperature: met by component selection**
  - **External pressure: not applicable**
  - **Impact: sapphire viewports tested**
  - **Vibration: system can be anchored to floor**
  - **Puncture: met by inference**
- **Specific Hg system components designed and fabricated according to appropriate US standards**

Materials of Construction

- **Issues: compatibility with Hg, transparency to magnetic fields**
  - **Total radiation dose ~10^4 rads, within limits of wide variety of materials**
- **Major materials of construction**
  - **Hydraulic cylinders: SS316, Nitronic-50**
  - **Primary containment: SS304L/316L, Ti alloys, sapphire, buna-N (gaskets)**
  - **Secondary containment: SS304L/316L, Lexan**
  - **Baseplates: AL6061-T6**

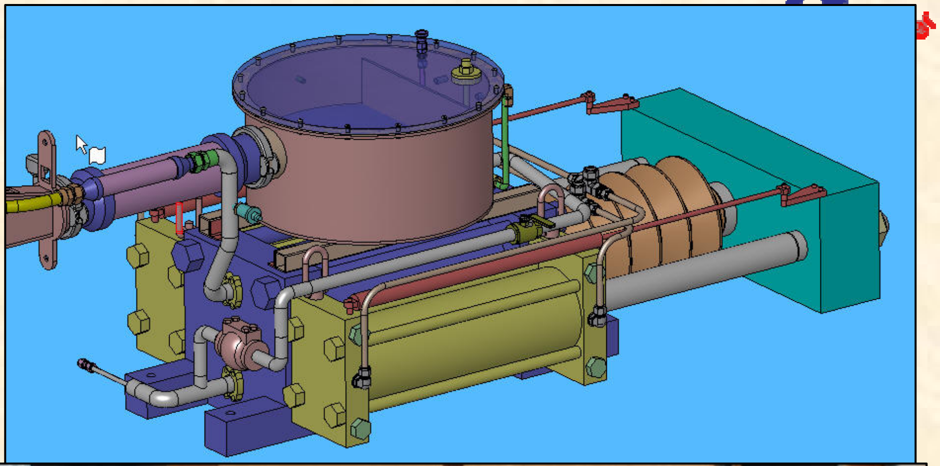
Target Module Major Subsystems

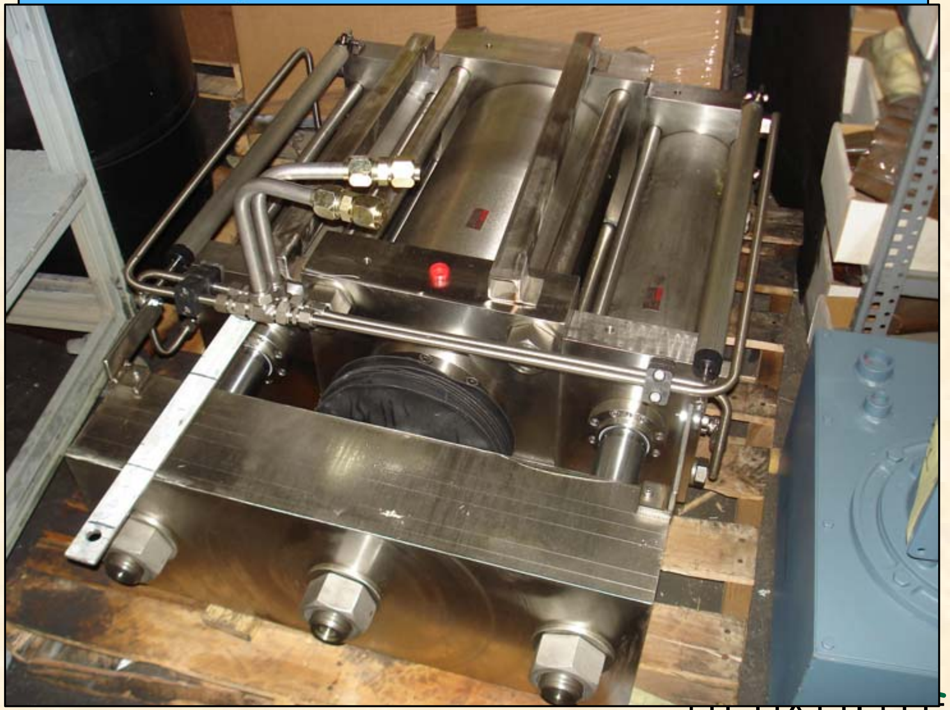
- **Syringe hydraulic power unit (HPU)**
  - **Hydraulic pump & motor**
  - **40 gal fluid reservoir**
  - **Electrical control**
- **Primary containment**
  - **Hg-wetted components**
  - **Capacity 23 liters Hg (~760 lbs)**
  - **Jet duration up to 12 sec**
- **Secondary containment**
  - **Hg leak/vapor containment**
  - **Ports for instruments, Hg fill/drain, hydraulics**
- **Support structures**
  - **Provides mobility and stationary equipment support as well as alignment features**
- **Control system**
  - **Provides remote control capability**



Hg Syringe Cylinders

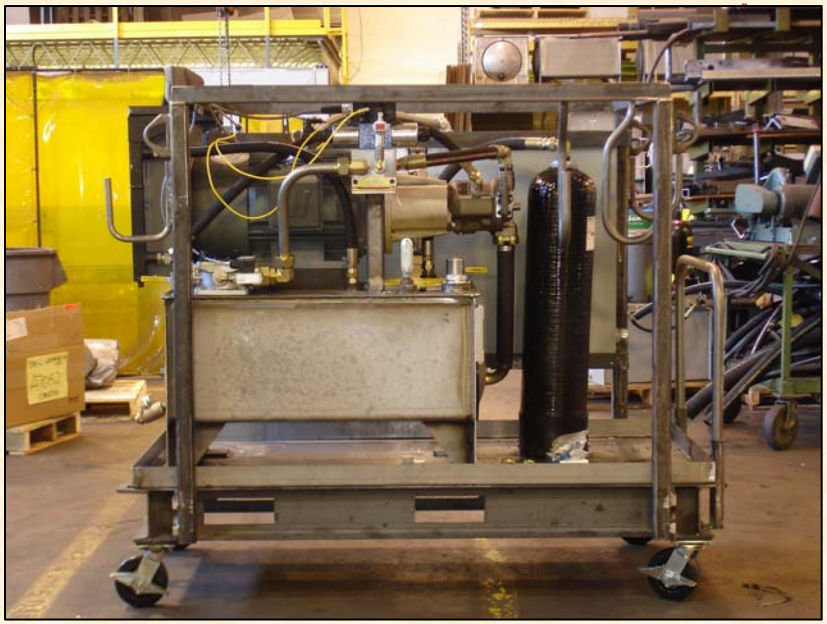
- **Jet 1 cm dia, 20 m/s**
  - **Hg flow rate 95 liter/min (25 gpm)**
  - **Piston velocity 3.0 cm/s (1.2 in/sec)**
- **Hg cylinder force 525 kN (120 kip)**
- **Design standard**
  - **ANSI/B93.10, *Static Pressure Rating Methods of Square Head Fluid Power Cylinders***
- **Pressure ratings**
  - **Hg cylinder 100 bar (1500 psi)**
  - **Drive cylinders 200 bar (3000 psi)**
  - **All cylinders pressure tested to 150% rated capacity**
- **Primary containment volume includes both sides of Hg piston**





Hydraulic Power Unit

- **Actuates syringe drive cylinders**
- **Connected to secondary containment through non-magnetic hoses**
- **Proportional control valve provides precise hydraulic flow based on command signal from control system**
- **200 bar (3000 psi) nominal operating pressure**
- **Incorporates relief valve to prevent over-pressure condition**
- **Breather-vent filter isolates reservoir air from tunnel**
- **Drip pan for small fluid leaks**

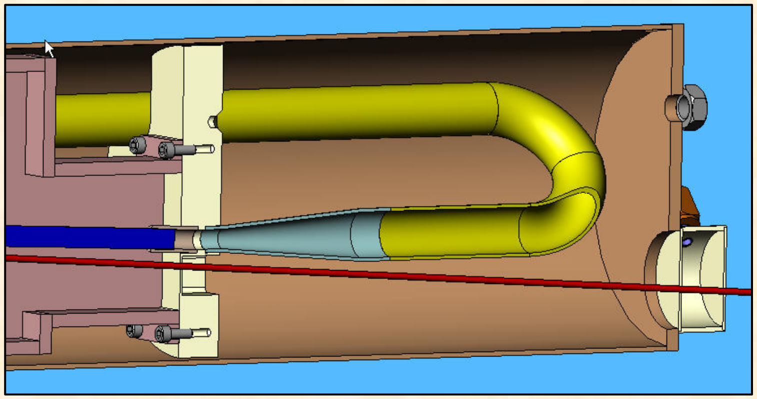


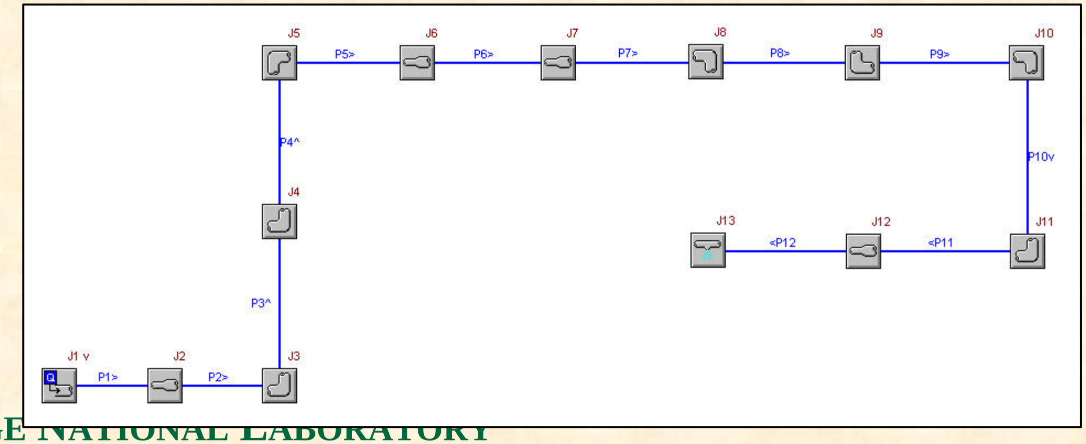
Hydraulic Fluid Containment

- **Hydraulic fluid: Quintolubric-888, low-flammability, vegetable-oil based fluid**
- **Hydraulic fluid will be slightly activated and moving between syringe cylinders and HPU in TT2**
- **Most likely source of fluid leakage at connectors**
  - **Wrap connectors during installation**
  - **Drip pan under secondary containment connectors**
- **Reservoir leak would require additional container with 40-50gal capacity**
  - **Large pan could be added if deemed to be necessary**

Flow Simulation Using AFT Fathom

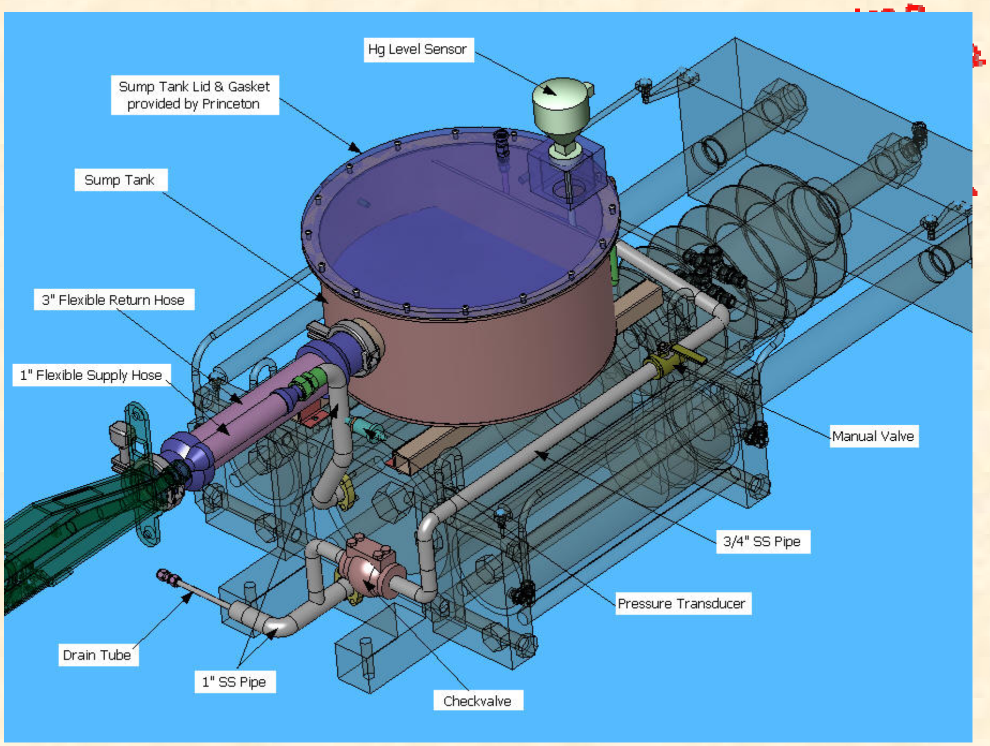
- **Simulates mechanical piping/flow losses**
  - **Does not include MHD effects**
- **Current nozzle configuration predicts cylinder pressure of ~45 bar (650 psi)**
- **Syringe design pressure 100 bar (1500 psi)**
  - **Significant excess pressure capacity to accommodate losses due to field effects**
  - **Can't quantify until MIT testing**
- **Highest Hg pressure occurs in cylinder**
  - **Monitoring cylinder discharge pressure will provide mechanism to protect downstream components**

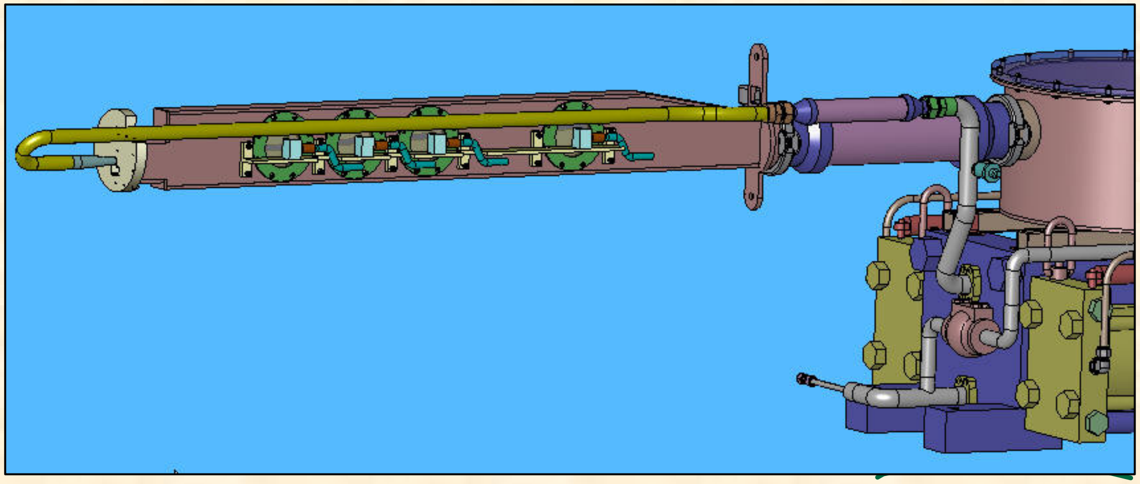




Additional Primary Containment

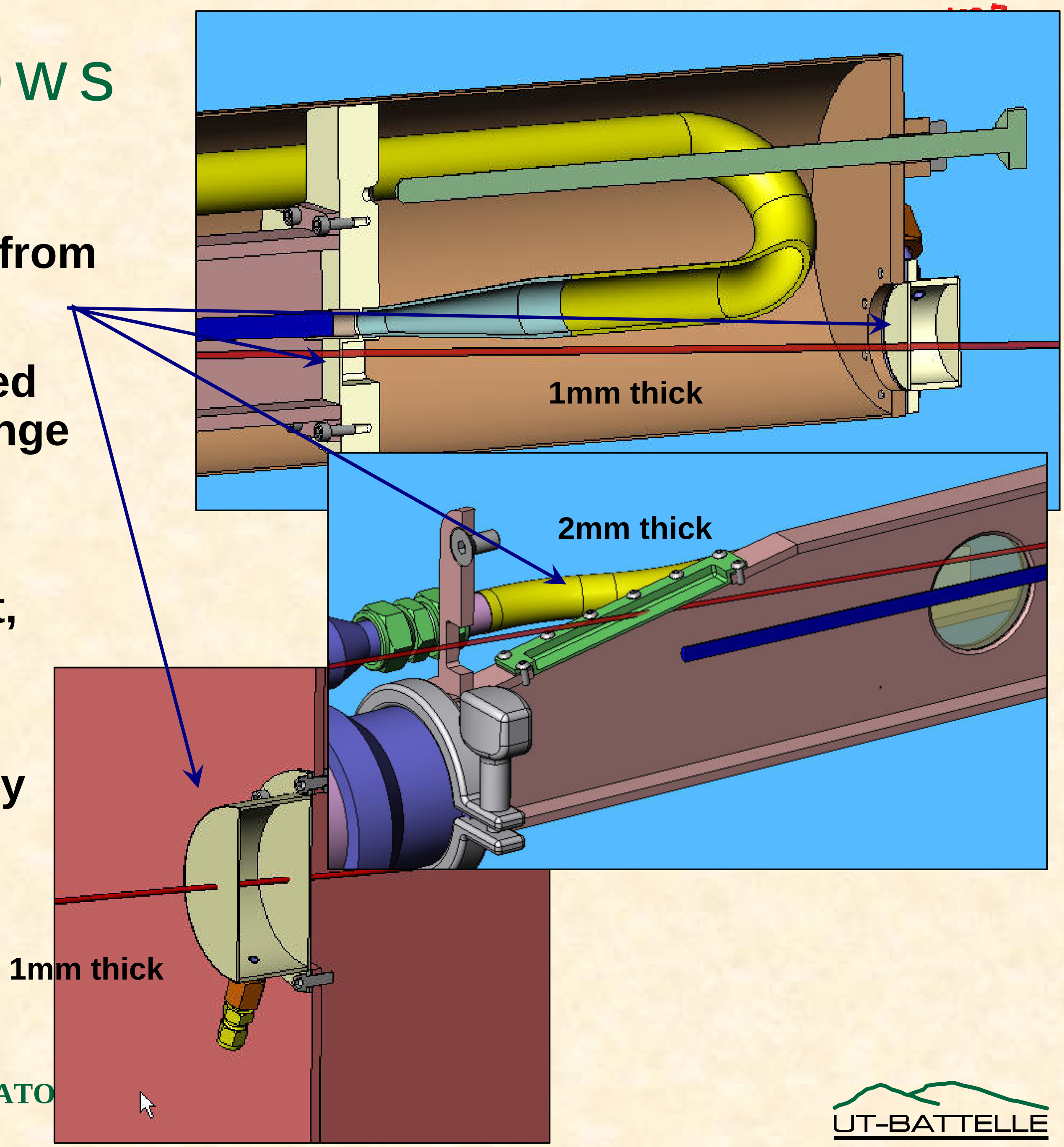
- **High Hg pressures are only in primary containment between cylinder and nozzle**
  - **Jet chamber and sump tank piping are at 1 atm during operations**
- **Flexible hoses in Hg supply and return lines accommodate solenoid movement**
- **Pressure piping rated for full cylinder pressure**
  - **See Table 5 in design document**
- **Pressure piping fabricated to ASME IX code**



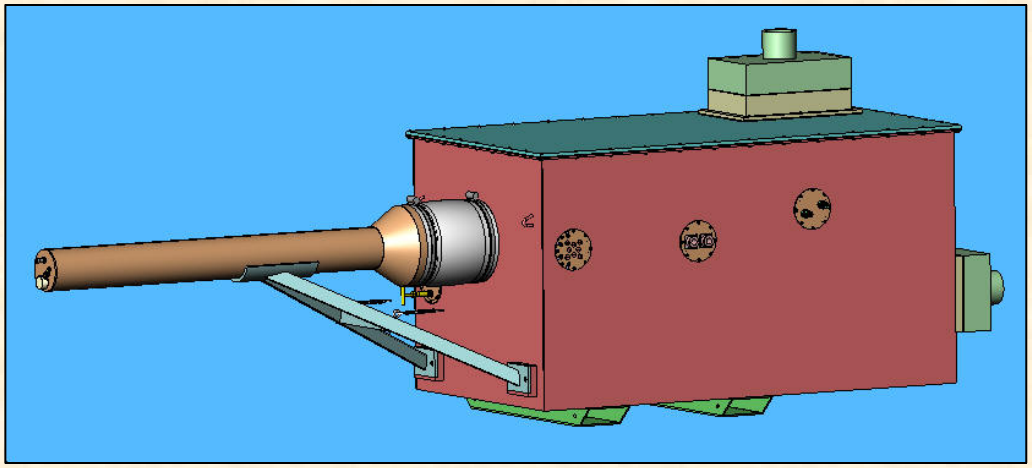


Beam Windows

- **Windows fabricated from Ti6Al4V alloy**
- **Mechanically attached except for nozzle flange (fabricated from Ti)**
- **Single windows for primary containment, double windows for secondary**
- **Pressurize secondary windows, monitor to detect failure**



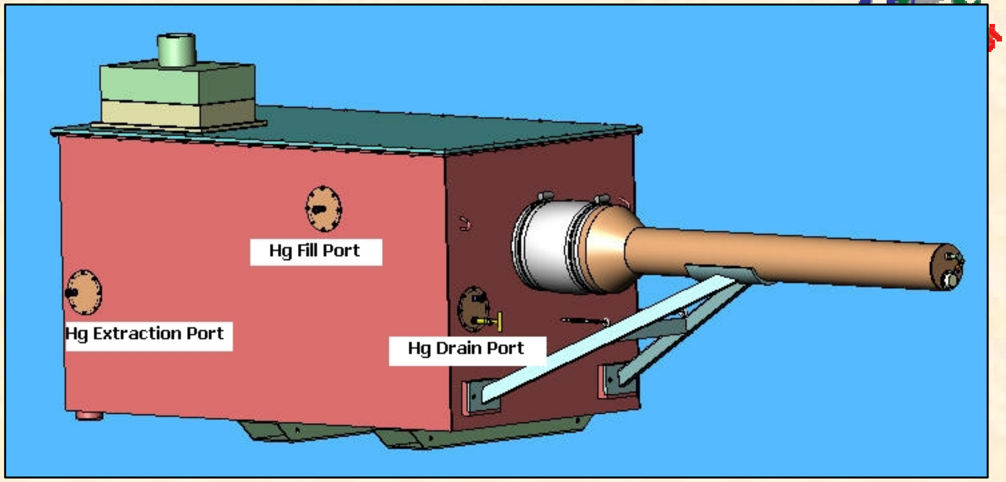
Secondary Containment

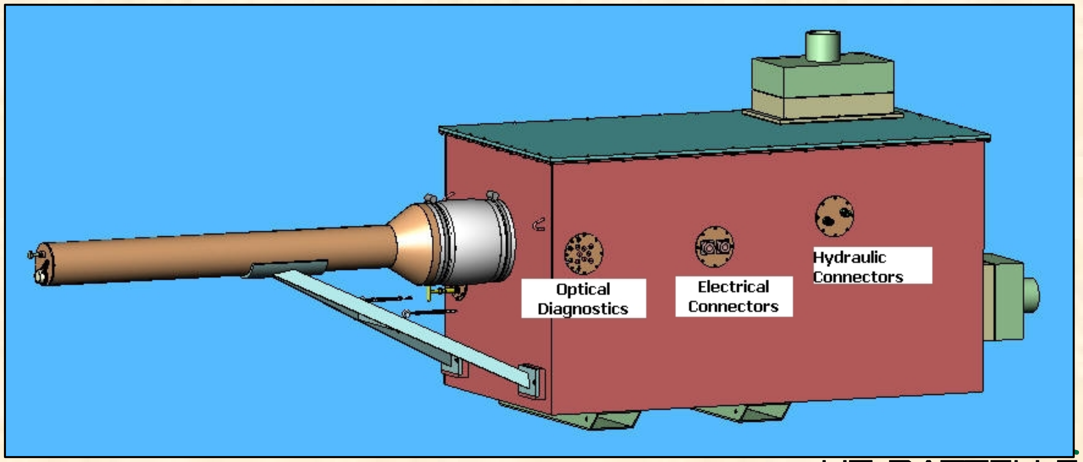


- **Contains liquid Hg leaks and Hg vapors from primary containment**
- **SS304/316 box, flexible metal duct, and cylindrical sleeve**
- **Lexan top allows visual inspection**
- **Passive Hg vapor filtration**
- **Incorporates handling & shipping features**

Ports

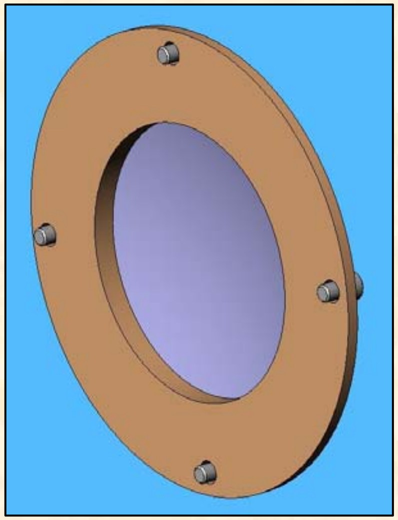
- Hydraulics
- Instrumentation
- Optical diagnostics
- Hg drain & fill (without opening secondary)
- Hg extraction (in event of major leak in primary containment)
- Passive filtration

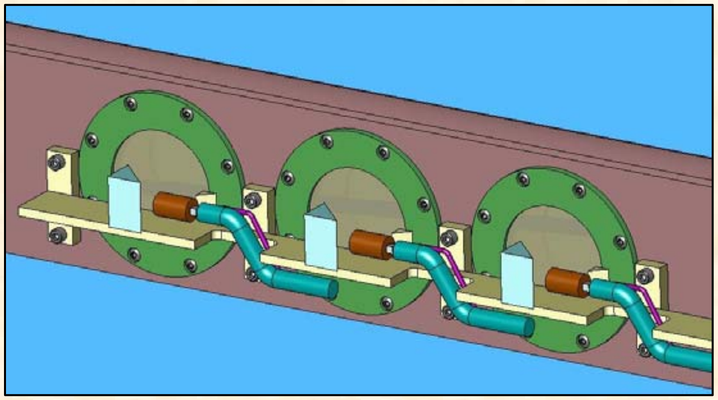


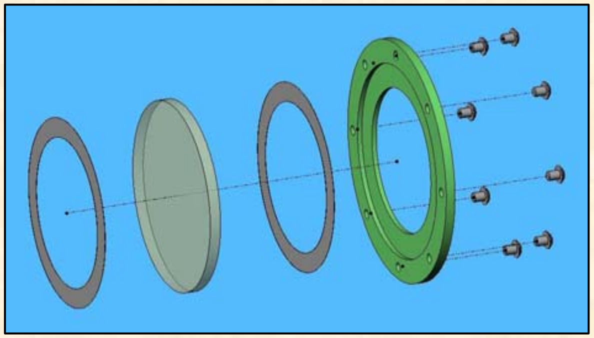


Optical Diagnostics

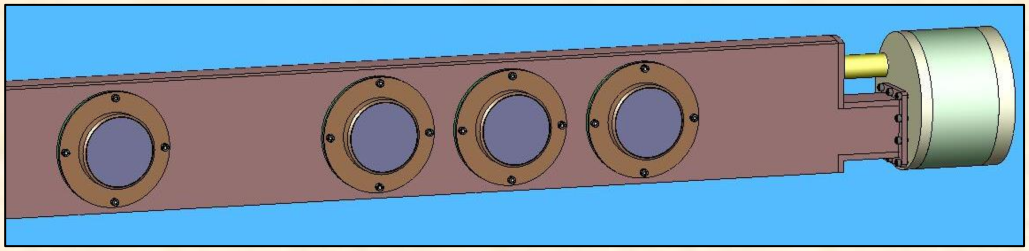
- **8X 100 mm-dia, 6mm-thick sapphire windows with cover plates mechanically attached to jet chamber**
  - **Window has been impact-tested at Princeton**
- **One set of windows configured for reflector assemblies**
- **BNL to provide splitters, prisms, lenses, bracket, mounting hardware, adjustment mechanisms, & installation**





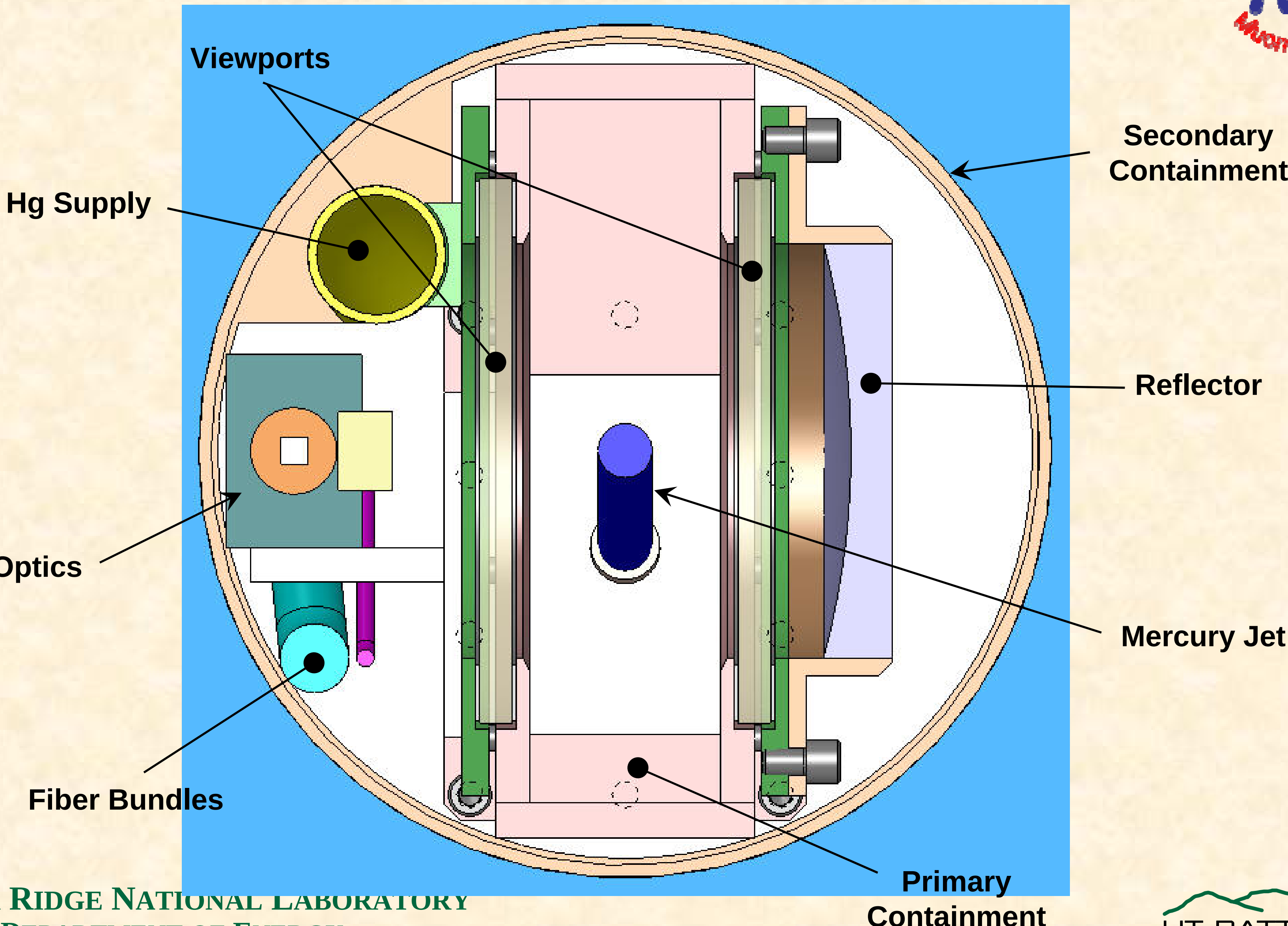


Viewport Assemblies



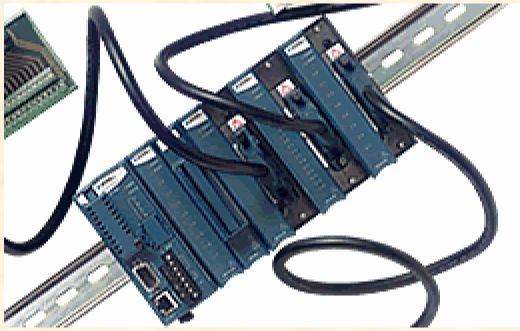
Reflector Assemblies Mounted on Viewports

Z=0 Section Cut



LabView-Based Control System

- **LabView on laptop computer was chosen as system controller**
  - **CompactFieldPoint I/O modules at syringe pump control station**
  - **Communicates to laptop via EtherNet cable**
  - **Should allow straightforward integration with other MERIT control systems**



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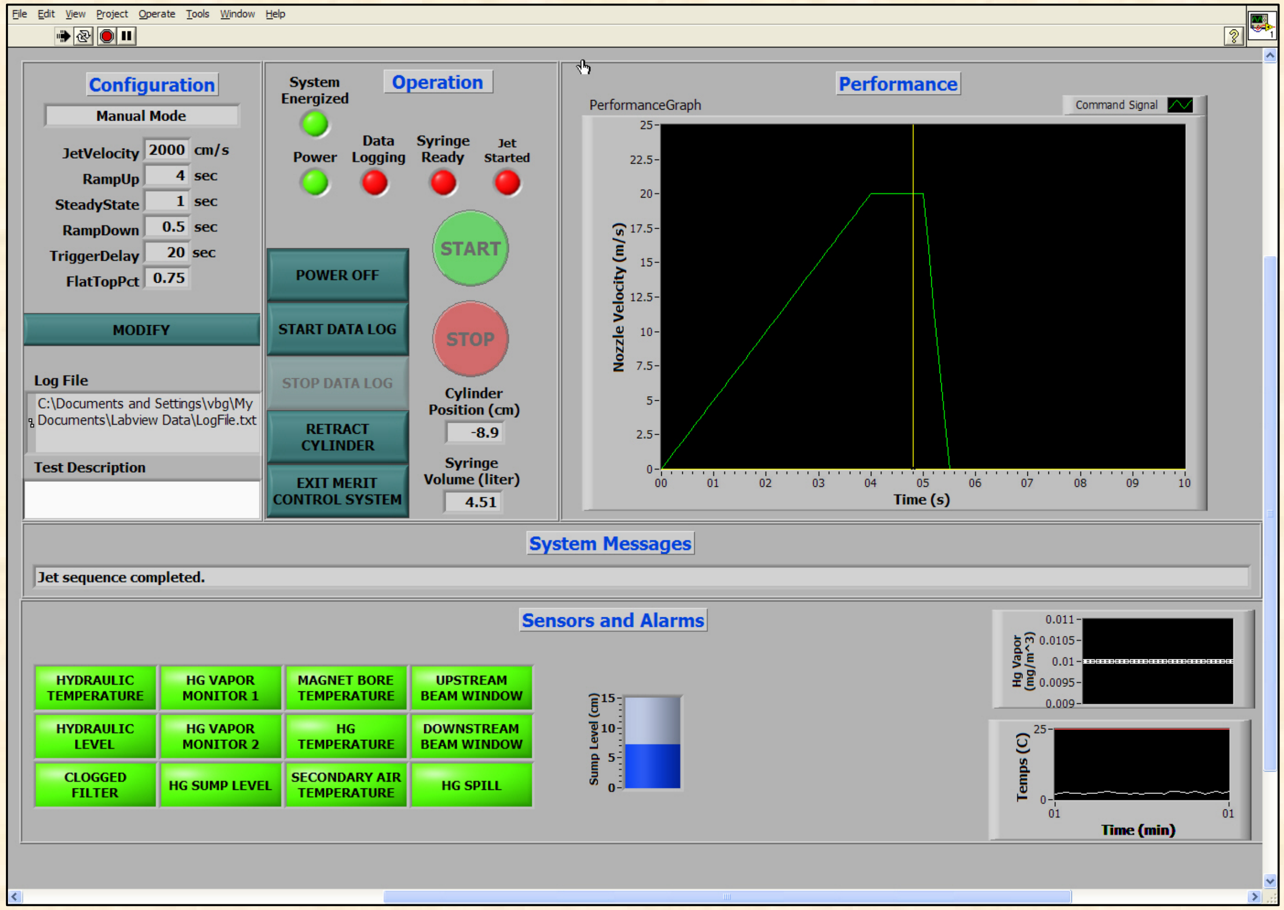
Instrumentation & Sensors

Controlled Components			
Hydraulic pump	Proportional control valve*	Heater foil	
Analog Sensor Inputs			
Hg discharge pressure	Hg level	Hg sump thermocouple	Secondary containment thermocouple
Cylinder 1 position*	Cylinder 2 position	Hg vapor 1*	Hg vapor 2*
Hydraulic fluid high pressure	Hydraulic fluid low pressure	Beam window 1 pressure*	Beam window 2 pressure*
Digital Sensor Inputs			
Hydraulic filter dirty switch	Hydraulic low level switch	Conductivity probe	

* Critical for system operation or safety

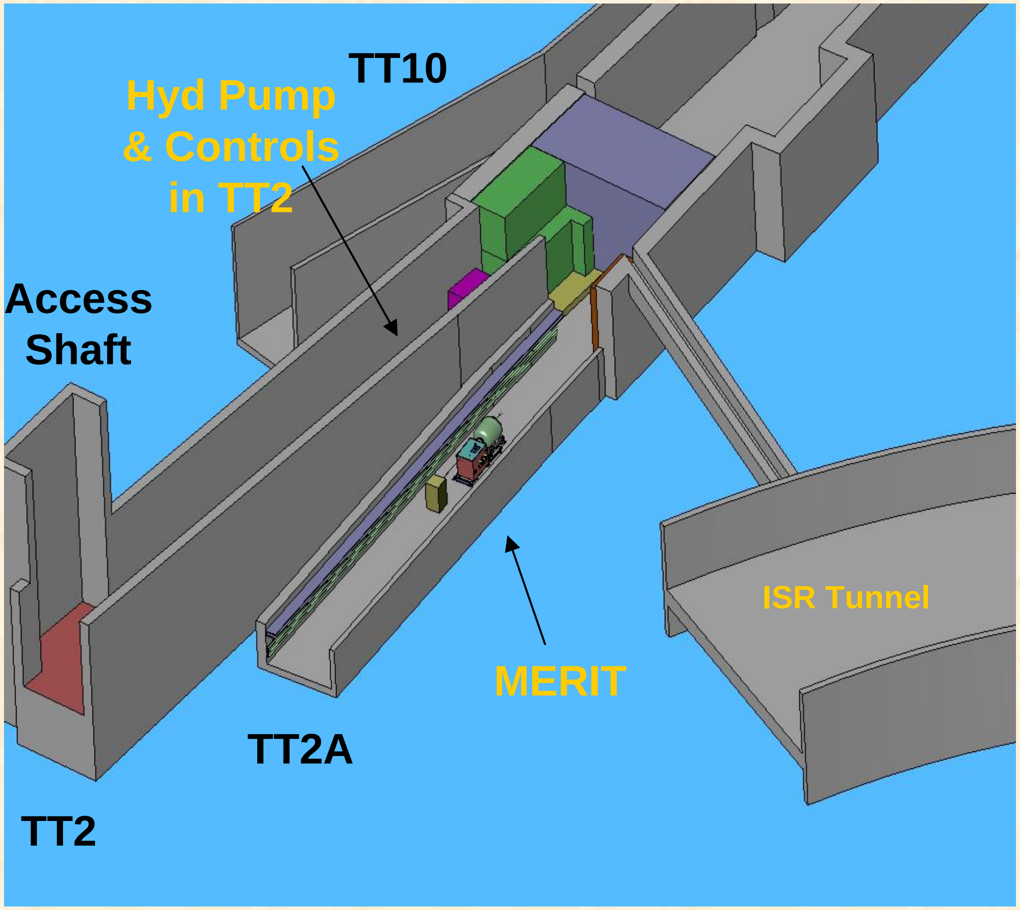
Hg Syringe Control Operator Interface

- Jet velocity profile
- Syringe control
- Performance feedback
- Data logging
- Operator messages
- Status & alarm indicators



Facility Interfaces

- **Electrical**
  - **System requires 30 kW power supply, 380V/3ph/50Hz (460V/3ph/60Hz for MIT)**
  - **HPU has on-board transformer to provide 120 VAC, 24 VDC for other Hg system components and instruments**
  - **Means of de-energizing power source from remote control room required**
- **Network**
  - **System control requires ethernet wiring between control room and TT2**



Off-Normal Conditions

- **Actually controlling a hydraulic pump and proportional valve, not a syringe**
  - **Losing power will shut down pump & stop pistons**
  - **At worst, software malfunction could drive piston at full speed to cylinder end-stop**
  - **Hydraulic system has over-pressure protection to limit pressure induced in Hg & protect cylinders**
- **Secondary containment always closed during operations**
  - **All openings gasketed, any Hg vapors should remain trapped**
- **Only viable means noted for over-pressurizing the secondary containment is temperature rise of hydraulic fluid**
  - **Air temperature inside secondary monitored**

Off-Normal Conditions (cont.)

- **Primary containment pressure should not exceed design limits under any off-normal circumstances**
- **Any Hg leaks due to seal or gasket failure will be contained within the secondary**
  - **Instrumentation should allow diagnosis of condition**
  - **Visual inspection possible after several hour cool-down**
  - **Provisions made in design to allow Hg removal from closed secondary should a catastrophic leak occur**
- **Hydraulic fluid also activated, so precautions needed for leaks and drips**

Conclusions

- **MERIT Hg system designed for pressures greater than anticipated during operations**
- **Secondary containment will contain any Hg liquid or vapors should a primary containment failure occur**
- **System has features to allow Hg fill/drain without opening secondary containment**
- **System operating characteristics will be quantified during ORNL and MIT testing**