Magnet

Achim Franz, BNL

collaboration of SMD, CAD, Physics

arrived at BNL Febr. 2015

tests performed

- electrical tests on warm magnet, fits specs from SLAC
- pressure tests, found small leaks, fixed

ongoing

- field and force calculations
- mechanical modifications, chimney, mounting
- preparations for low and high field tests

sPHENIX SC Magnet - Valve Box Extension, Mechanical Design Review
Thursday, May 14, 2015 from 13:15 to 15:20 (US/Eastern)
at Universe (Building 510 Room 2-160)

Magnet review

SC-Magnet Review Recommendations

1) Continue with plan for the 100A test (or as high current as possible with the same instrumentation) at a site suitable for 1000A or full field test with a strong recommendation to perform full field test prior to DOE review

2) Conduct a study of requirements for a full field test; simple return yoke design, power supply and quench protection.

3) Perform a full field test, if possible, in bldg. 912 before the magnet is moved to 1008.

4) Perform a full field test as soon as possible

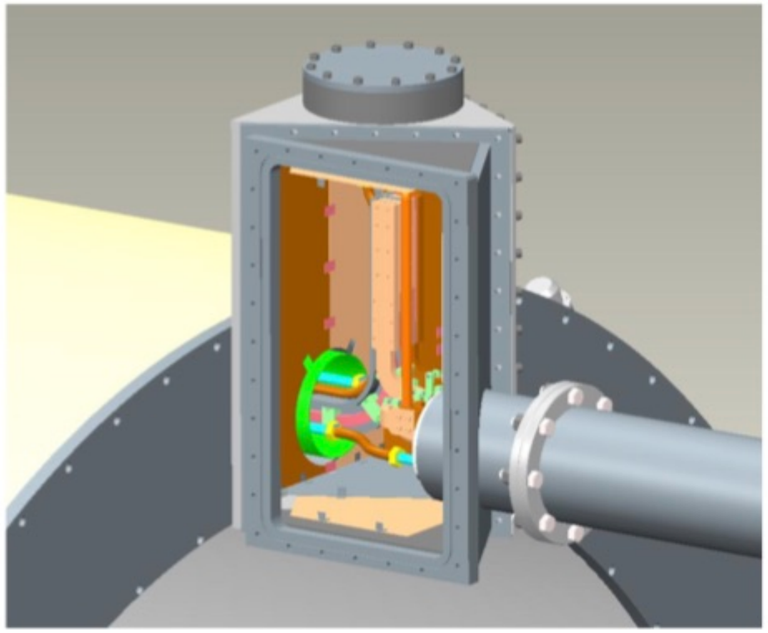
5) [A management team for RHIC 1008 facility has not been identified but names (C-AD) were suggested.]

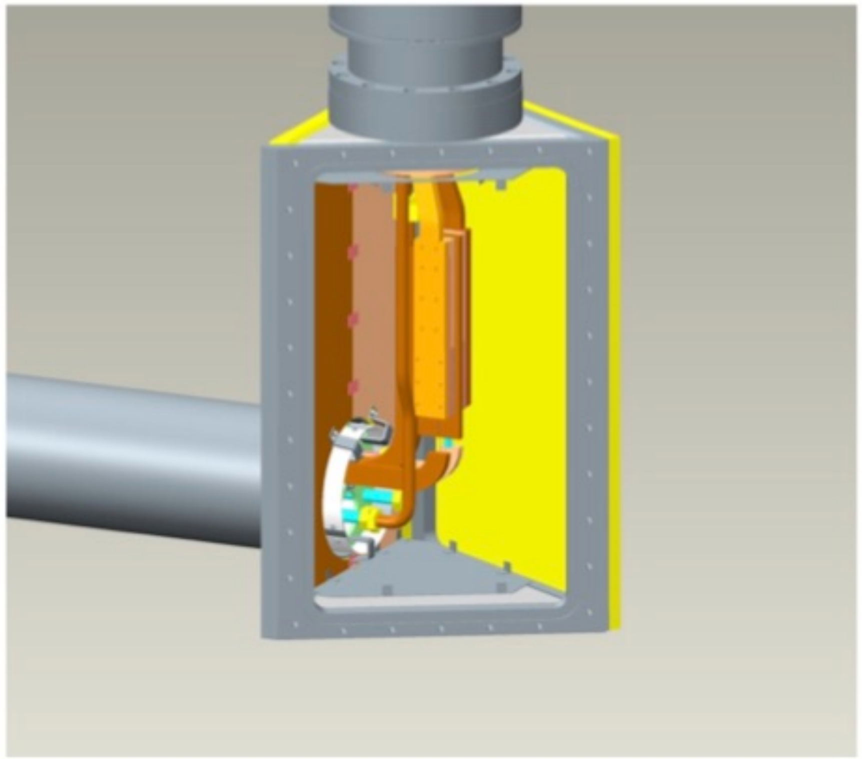
   Work with the ALD and C-AD management to identify the SC-Magnet management team ASAP.

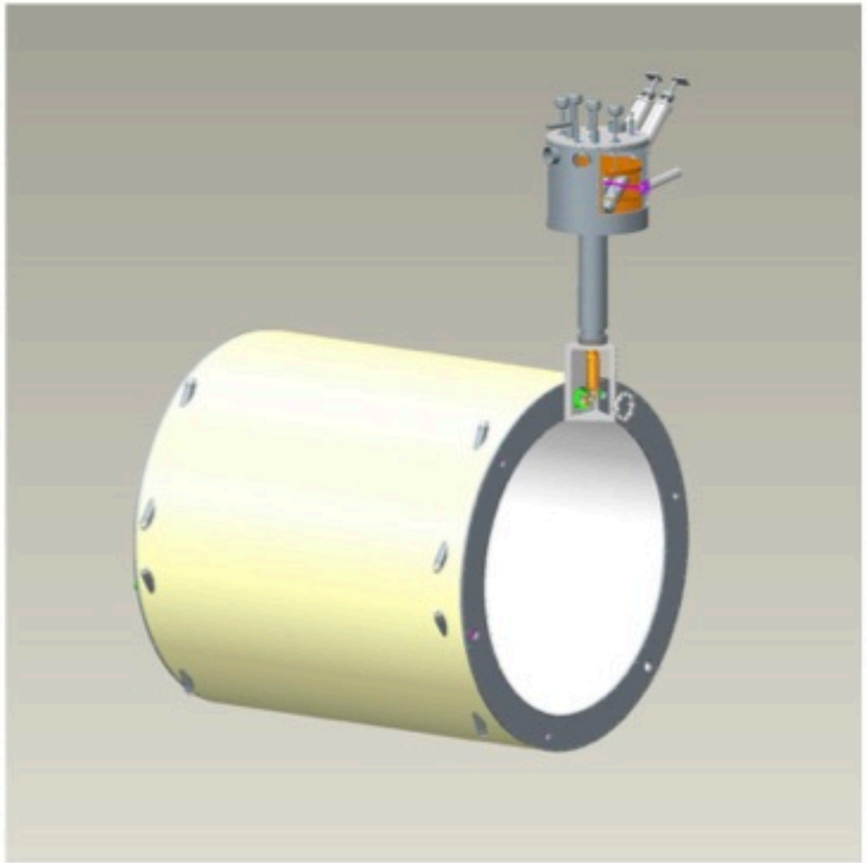
6) Complete a more detailed 1008 installation schedule that incorporates magnet testing in 1008.

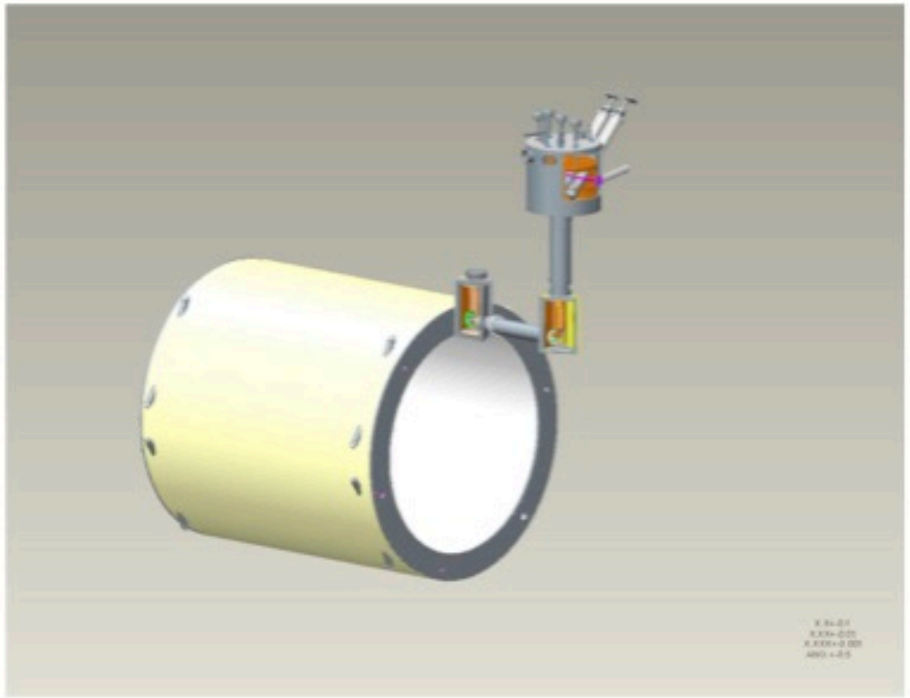
mechanical and electrical modifications

chimney modifications









necessary to allow full calorimeter coverage, parts are being manufactured

electrical modifications

voltage tabs verified
cable extensions are being fabricated

power supplies are being modified to match current CAD controls

quench monitoring and control is being updated

quench resistor is being verified and if needed updated

low field test

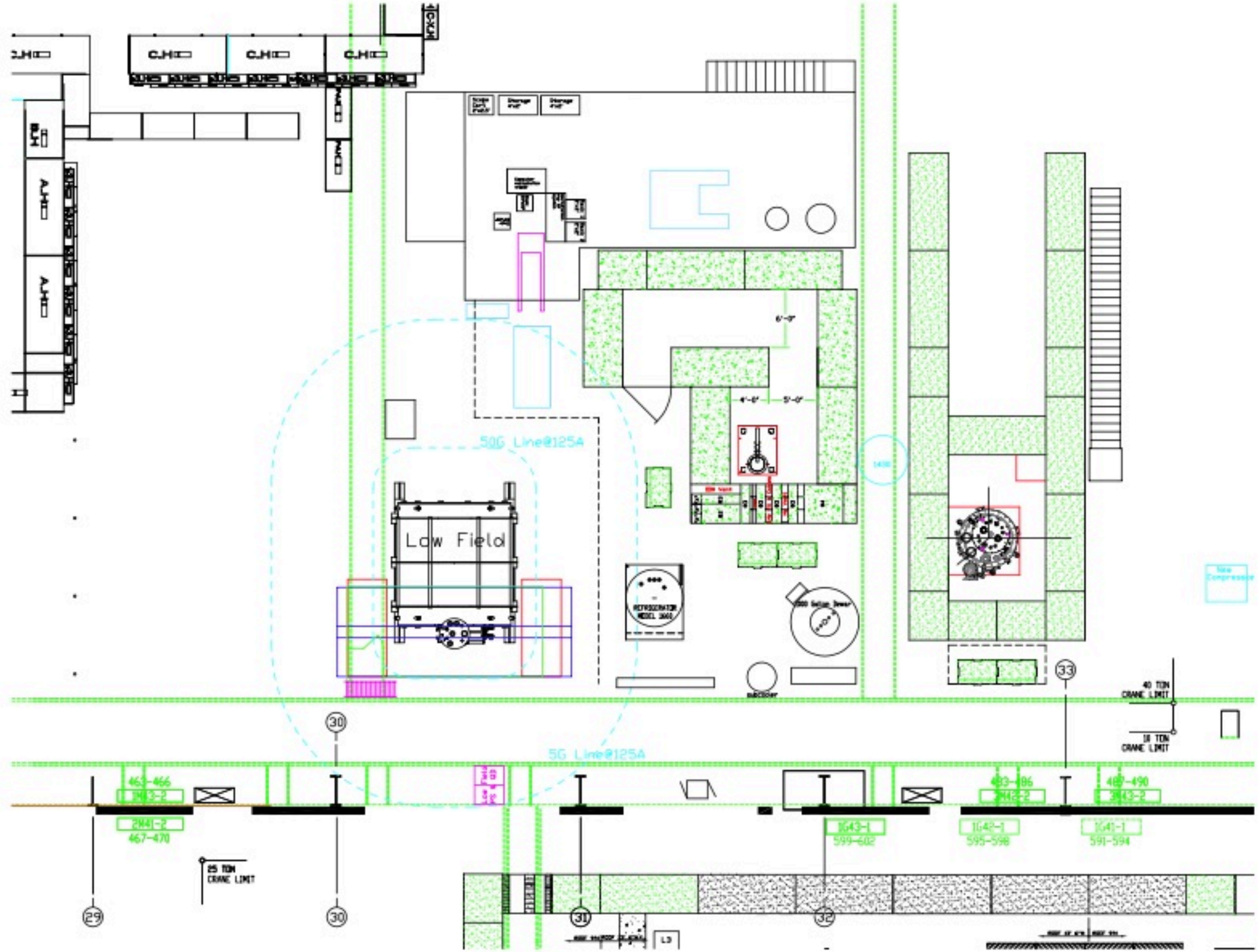
Roles and Responsibilities – Low Field Test

sPHENIX Superconducting Magnet Project Management, Low Field Test		
Project Manager		Kin Yip
Subsystem Lead Engineer		Dave Phillips
Subsystem for Magnet		Technical Manager
Cryogenics		
	Cryo System	Roberto Than
	Cryo Controls	Tom Tallerico
	Cryo Safety	Roberto Than
Internal Mechanical Equipment		
	Radial and Axial Supports	Paul Kovach
	Strain Gage and Potentiometers	Paul Kovach
	Mechanical connections to coil (electromechanical and mechanical)	Paul Kovach
Power Supply		
	Power Supply	Piyush Joshi
	Controls	Piyush Joshi
	Support Instrumentation (strain gage/potentiometer output)	Piyush Joshi
	Safety System (current limiting device)	Piyush Joshi
	Installation of AC Power	Dave Phillips
	DC Distribution Cabling and Installation	Dave Phillips
Infrastructure Support		
	Hall Safety	Dave Phillips
	Overall Coordination of Magnet testing	Dave Phillips
	Convention Systems Support (AC Power, work platform, access ladder)	Dave Phillips
Field Measurement		
	Measure Field	Achim Franz

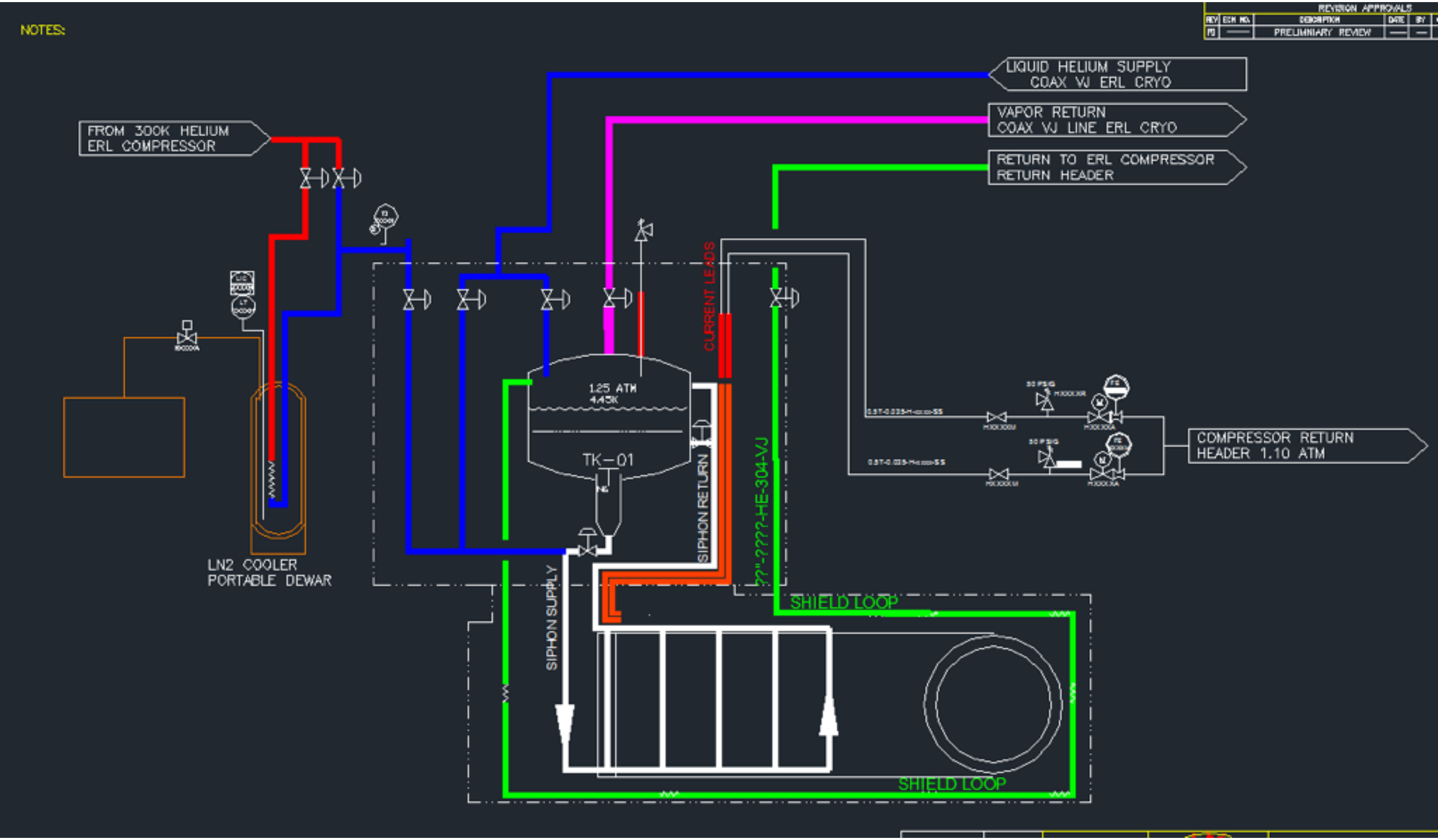
low field test

- Use existing CAD power supply
- Updated power and quench monitoring
- Use ERL Cryogenic Plant
- Operate in thermo-siphon mode
- Add Tie-in on VTF side of ERL distribution lines
  - Isolation valves and Bayonets
- Re-use Co-axial cryogenic transfer line from SLAC
  - Modifications to shorten and get matching bayonets on ERL interface end of this cryogenic transfer line.
- Independent (from ERL) pre-cool using Small LN_2 pre-cooling system for controlled cool down of solenoid using some helium flow from ERL compressor
  - 240 Liter LN_2 Dewar with sub-cooler coil exchanger
  - Control valves for mixing 300K and 85K helium gas
- field strength monitoring with existing Hall Probe(s)

low field test location in 912

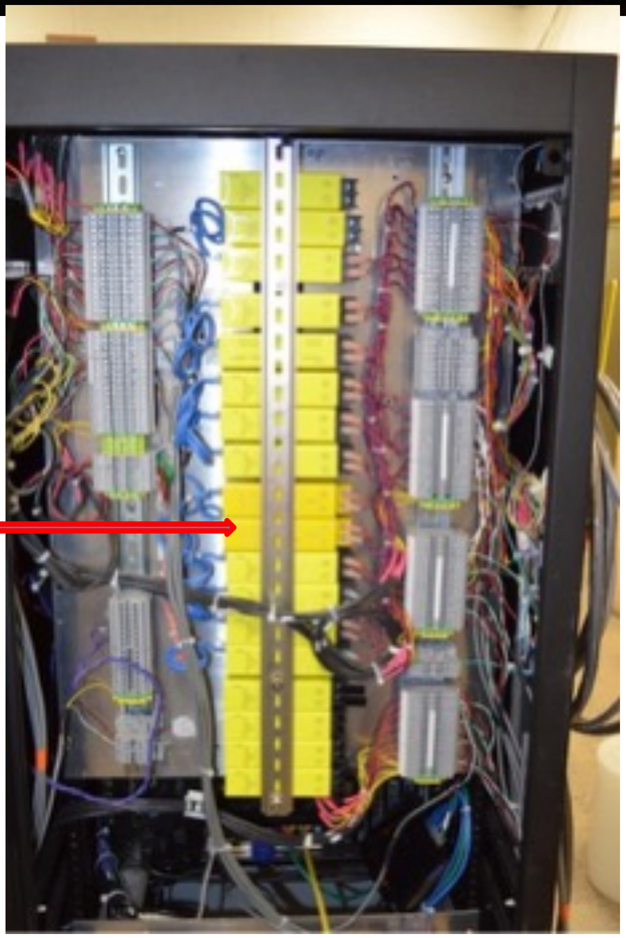


4.5K Low Power Test in Bldg 912



Test Setup Components

100A, 16V PS



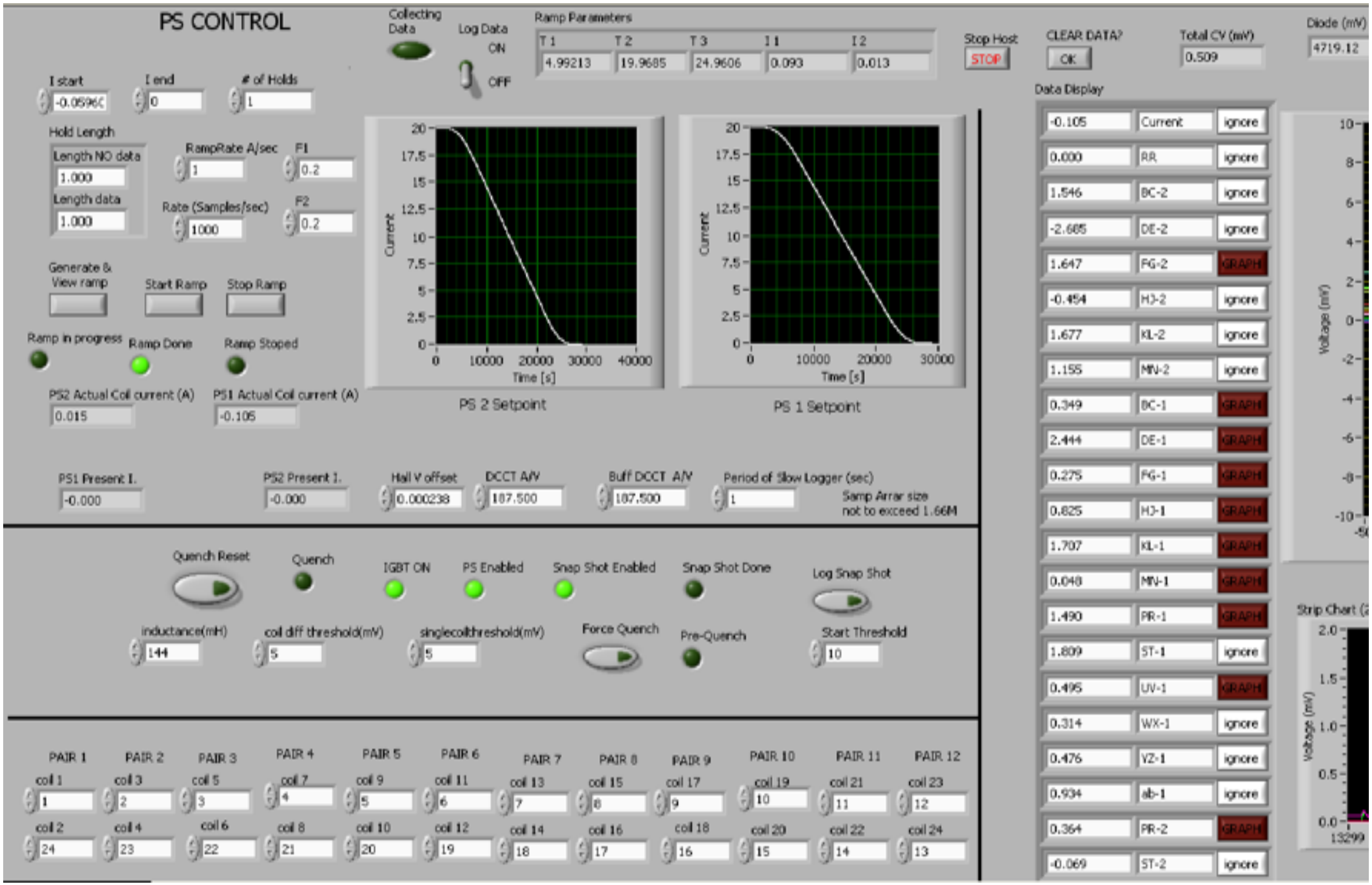
Isolators

Quench Detector

Slow Data Logger

Fast Data Logger

LabView based program to control power supply and capture data



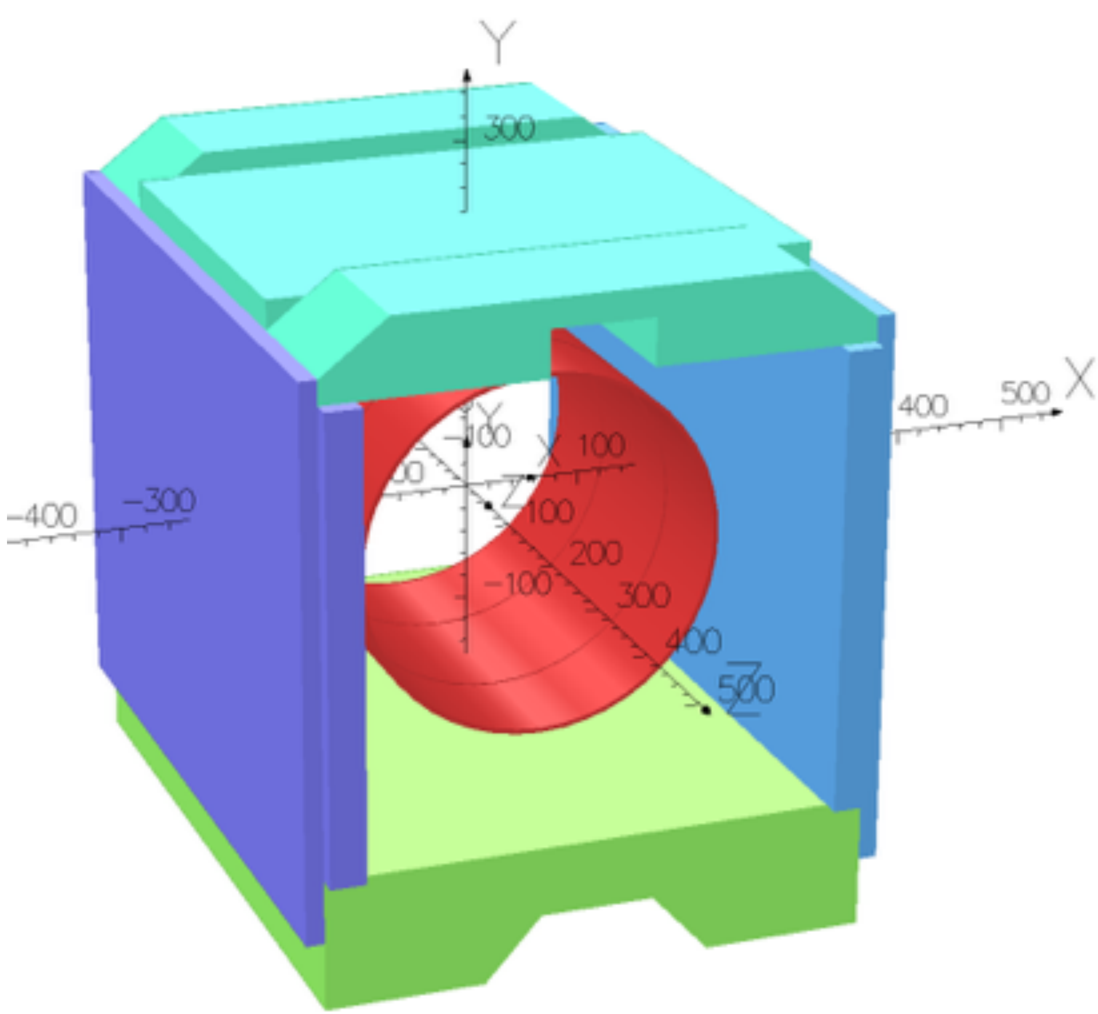
high field test

Roles and Responsibilities – High Field Test

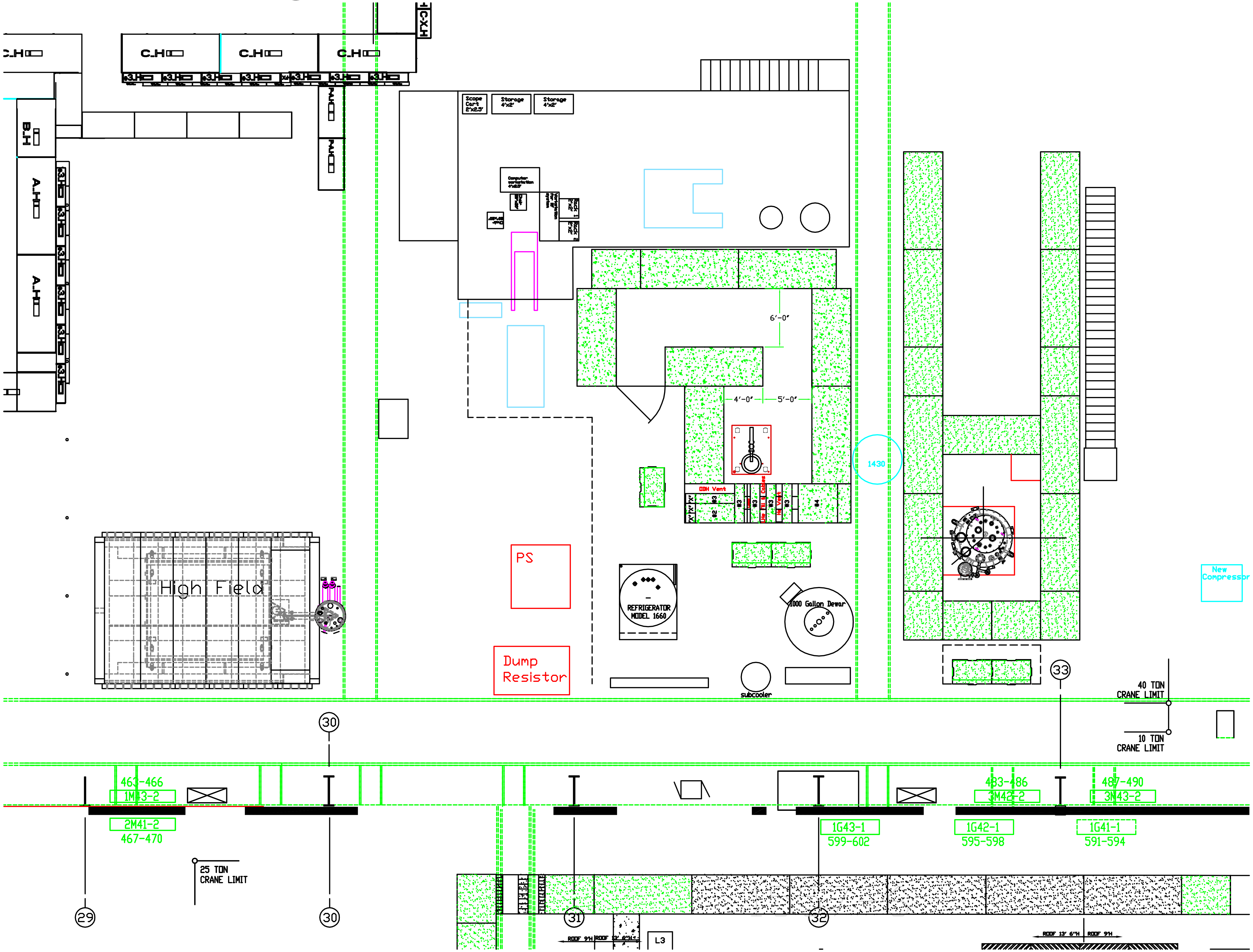
High Field Coil Test with Temporary Flux Return and Pole Tips		
Cryogenics		
	Cryo System	Roberto Than
	Cryo Controls	Tom Tallerico
	Cryo Safety	Roberto Than
Internal Mechanical Equipment		
	Radial and Axial Supports	Paul Kovach
	Strain Gage and Potentiometers	Paul Kovach
	Mechanical connections to coil	Paul Kovach
Power Supply		
	Power Supply	Pablo Rosas (Bob Lambiase, Ioannis Marneris)
	Controls/Communication/Signal	Charlie Theisen
	Safety System (current limiting device)	Bob Lambiase
	Quench Detection	Piyush Joshi
	Dump Resistor	Pablo Rosas (Bob Lambiase, Ioannis Marneris)
	Installation of AC Power	Dave Phillips/PK Feng
	DC Distribution Cabling and Installation	Dave Phillips
Infrastructure Support		
	Hall Safety	Dave Phillips
	Overall Coordination of Magnet testing	Dave Phillips
	Convention Systems Support (AC Power, work platform, access ladder)	Dave Phillips
Magnet Flux Return Steel		
	Backleg Steel	Jon Hock
	Cryostat Alignment and Support	Jon Hock
	Pole Tips	Jon Hock
Field Measurement		
	Measure Field	Achim Franz

high field test

- cool-down magnet and operate up to full field, 4695A max
- temporary shield wall from previous AGS projects
- cryogenics from ERL project, see low field test
- use updated SLAC power supply
- updated power and quench monitoring
- field strength monitoring with existing Hall Probe(s)



high field test location in 912



power supply modifications

1. Evaluation of existing equipment: The power supply will be tested without modification to establish a baseline of functionality and performance. The quench switch and energy dump resistor will be examined to determine what refurbishment is required.

2. Power supply upgrade design:
   a. The existing PLC and its software will be replaced with a more modern model, which is in general usage at BNL.
   b. Controls interface: The existing SLAC controls interface will be replaced by a standard BNL power supply interface (PSI).
   c. A new card to control the triggers to the SCRs will be installed to improve performance.

3. Quench detector design:
   a. A new, modern, quench detector will be designed.
   b. Interfaces between the power supply, quench detector, and energy dump resistor will be defined.
   c. Communication between the quench detector and the BNL accelerator controls will be designed.

4. Interface design:
   a. AC power to the power supply
   b. DC high power (water cooled bus) from PS to magnet
   c. Signal cables and fibers for controls and interlocks.

high field test

Magnetic Forces on each Wall (at full current/field)

	Fx (Lbf)	Fy (Lbf)	Fz (Lbf)	Est. Weight (Lbm)
Bottom	4	148,551 (up)	23 (towards cut direction)	450,560
Top	-67	-142,436 (down)	3709 (towards cut direction)	237,600
Left	135,171 (pointing coil)	-342 (down)	42 (towards cut direction)	204,424
Right	-135,071 (pointing coil)	-341 (down)	42 (towards cut direction)	204,424

1008 operations

Roles and Responsibilities – Installation B1008

sPHENIX Installation Major Facility Hall

Cryogenics		
	Cryo System	Roberto Than
	Cryo Controls	Tom Tallerico
	Cryo Safety	Roberto Than
Internal Mechanical Equipment		
	Radial and Axial Supports	Paul Kovach
	Strain Gage and Potentiometers	Paul Kovach
	Mechanical connections to coil	Paul Kovach
Power Supply		
	Power Supply	Pablo Rosas (Bob Lambiase, Ioannis Marneris)
	Controls	Charlie Theisen
	Safety System (current limiting device)	Bob Lambiase
	Quench Detection	Piyush Joshi
	Dump Resistor	Pablo Rosas (Bob Lambiase, Ioannis Marneris)
	AC/DC Distribution Cabling and Installation	Dave Phillips
Infrastructure Support		
	Hall Safety	Paul Giannotti
	Overall Coordination of Magnet Construction	Kin Yip
	Convention Systems Support (AC Power, work platform, access ladder)	Dave Phillips/PK Feng
	Magnet Testing Coordination	Kin Yip
	Field Testing and Mapping	Achim Franz
Magnet Flux Return Steel		
	Backleg Steel	Anatoli Gordeev (Outer Hcal Steel)
	Cryostat Alignment and Support	Jon Hock
	Pole Tips	Jim Mills
	Magnet/Detector Support Structure	Jim Mills
Field Measurement		
	Field Mapper	Achim Franz
	Field Measurements	Achim Franz
Detector Integration/Installation Design		
	Integration and Installation Overall Detector	D. Lynch, R. Ruggiero

operation in 1008

- final return yoke
- operate up to full field, 4695A
- two cryogenic options, RHIC based or stand-alone
- use updated power supply controlled by CAD systems, see high field test
- final power and quench monitoring, see high field test
- field mapping and monitoring

1008 cryogenic options

<u>Tie-in RHIC Option: A</u>

Interface to RHIC cryogenic system

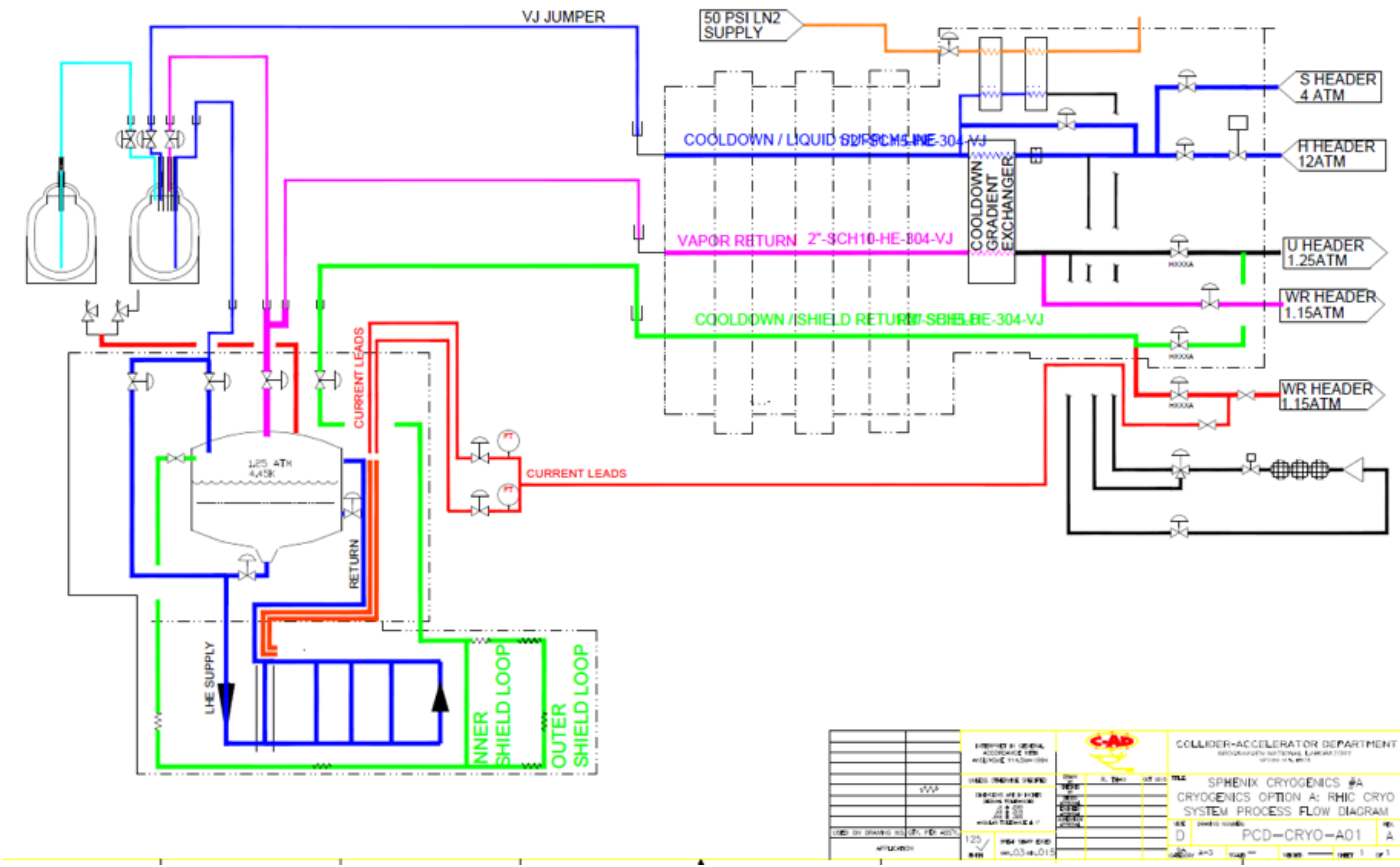
- 80K summer shutdown LN2 keep cool system
  - 5 g/s Helium compressor
- RHIC interface valve-box
  - S header: 4.8K, 3.5 bar
  - H header: 45-80K, 12 bar
  - U header: 4.5K, 1.25 bar
  - WR header: 293K, 1.25 bar
  - Isolation valves to RHIC
  - cooldown gradient control Heat exchanger
  - LN2/He exchanger
- 500L Interface and Hold up reservoir dewar
  - Transfer bayonet for portable 500L
- Cryogenic Transfer VJ jumpers between supply bundle and valvebox/dewar

<u>Stand Alone Plant Option: B</u>

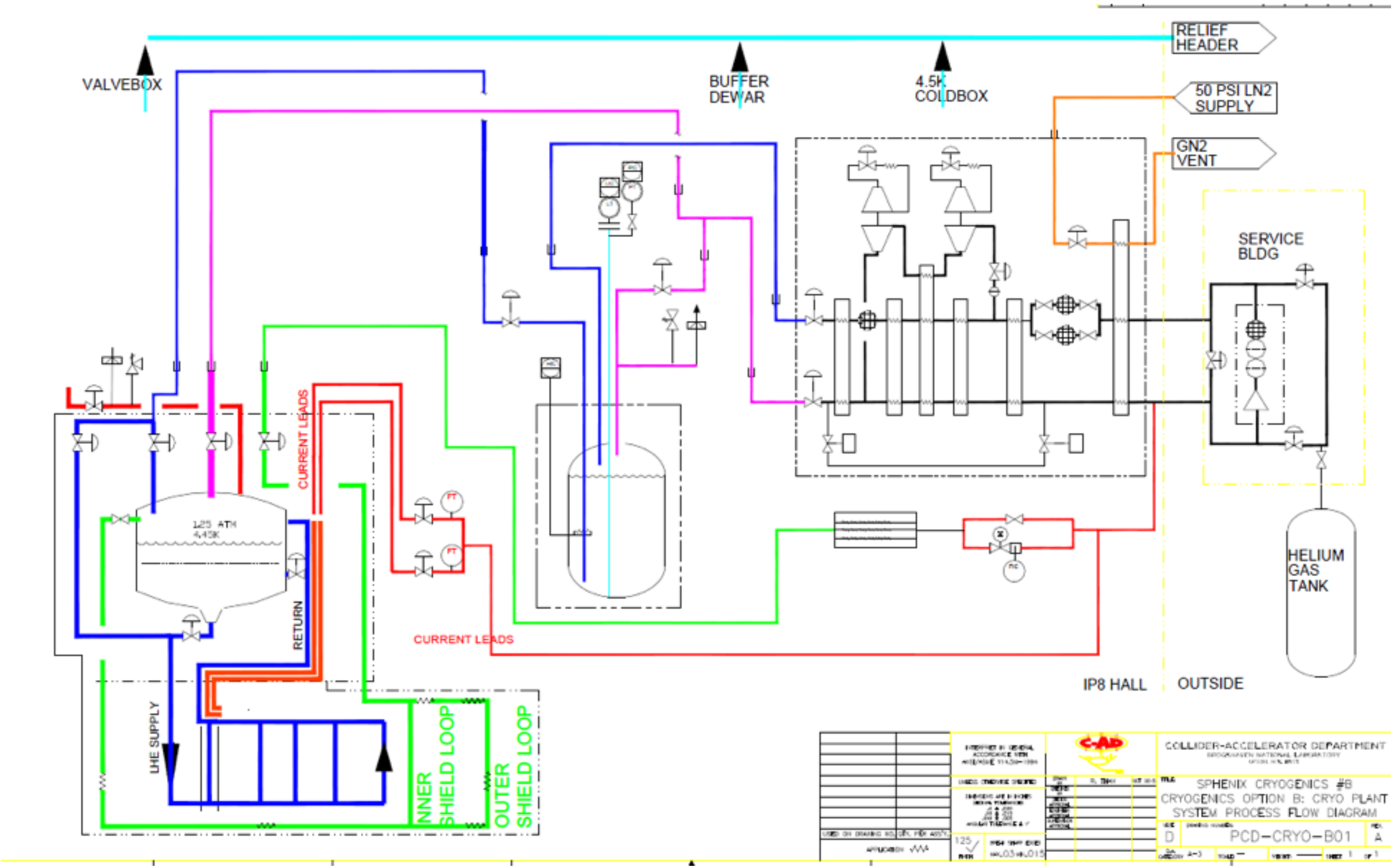
300W Helium Plant

4.5K Coldbox
  - located on detector superstructure platform
- Compressor
  - Service building or Heated shack
- 500L Hold up reservoir dewar
- Gas storage tanks
- Cryogenic lines
- Warm-piping
- LN2 supply Line to coldbox
- UTILITIES
  - Compressor
    - 150 kW, 480VAC
    - Tower water: 50 GPM
    - Air cooling to compressor cabinet: 1400 CFM
    - Instrument Air: 5 CFM
    - Space: 300 ft^2
  - Cold box
    - 3 kW, 120VAC
    - Air 10 CFM
    - Small chiller for turbines: 3 kW
    - Space: 400 ft^2.
  - Return heater shield flow: 5 kW/480VAC

sPHENIX: Cryogenics
RHIC Interface, Option A



sPHENIX: Cryogenics
Independent plant, Option B

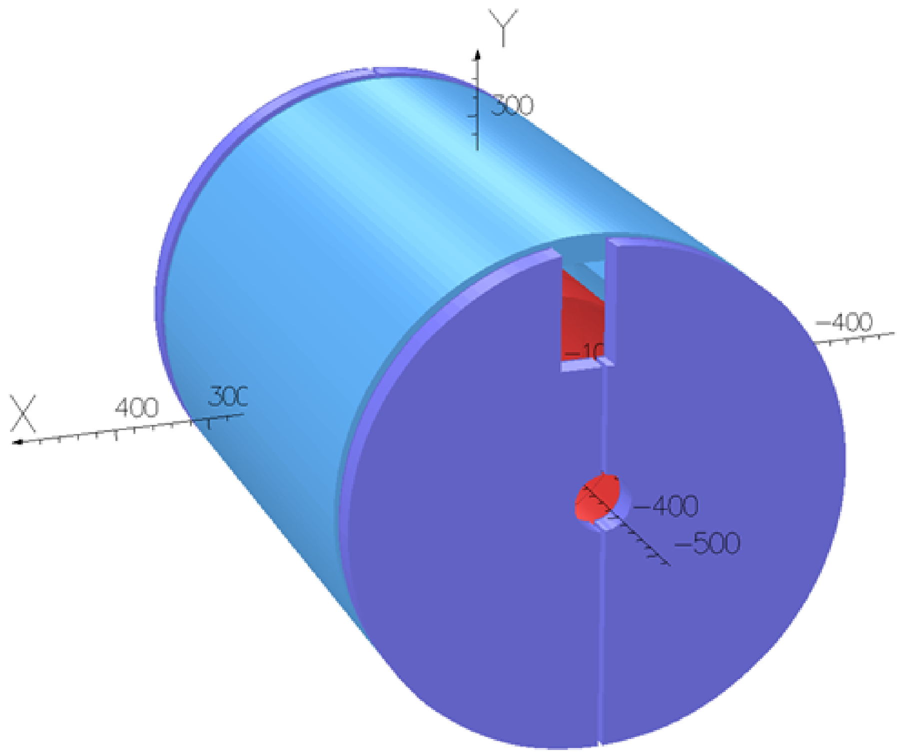


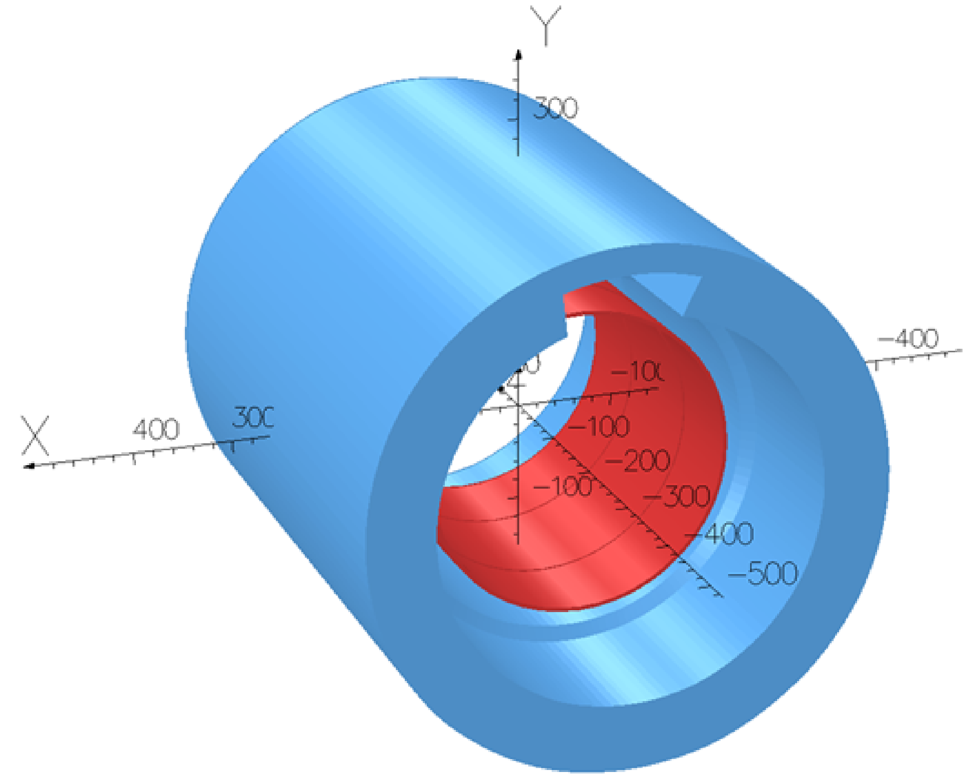
simulations

Field Simulations

- initial Opera2D simulations for Geant4 detector simulations
- 3D simulations to calculate forces on coil
- 3D simulations for the high current test and final setup
- ANSYS mechanical force calculations during cool down
- combined mechanical and magnetic force calculations in preparation

Field Simulations





From the simulations of this model, the magnetic forces and torques at the yoke center due to the coils being misaligned are shown in Table 3.1.

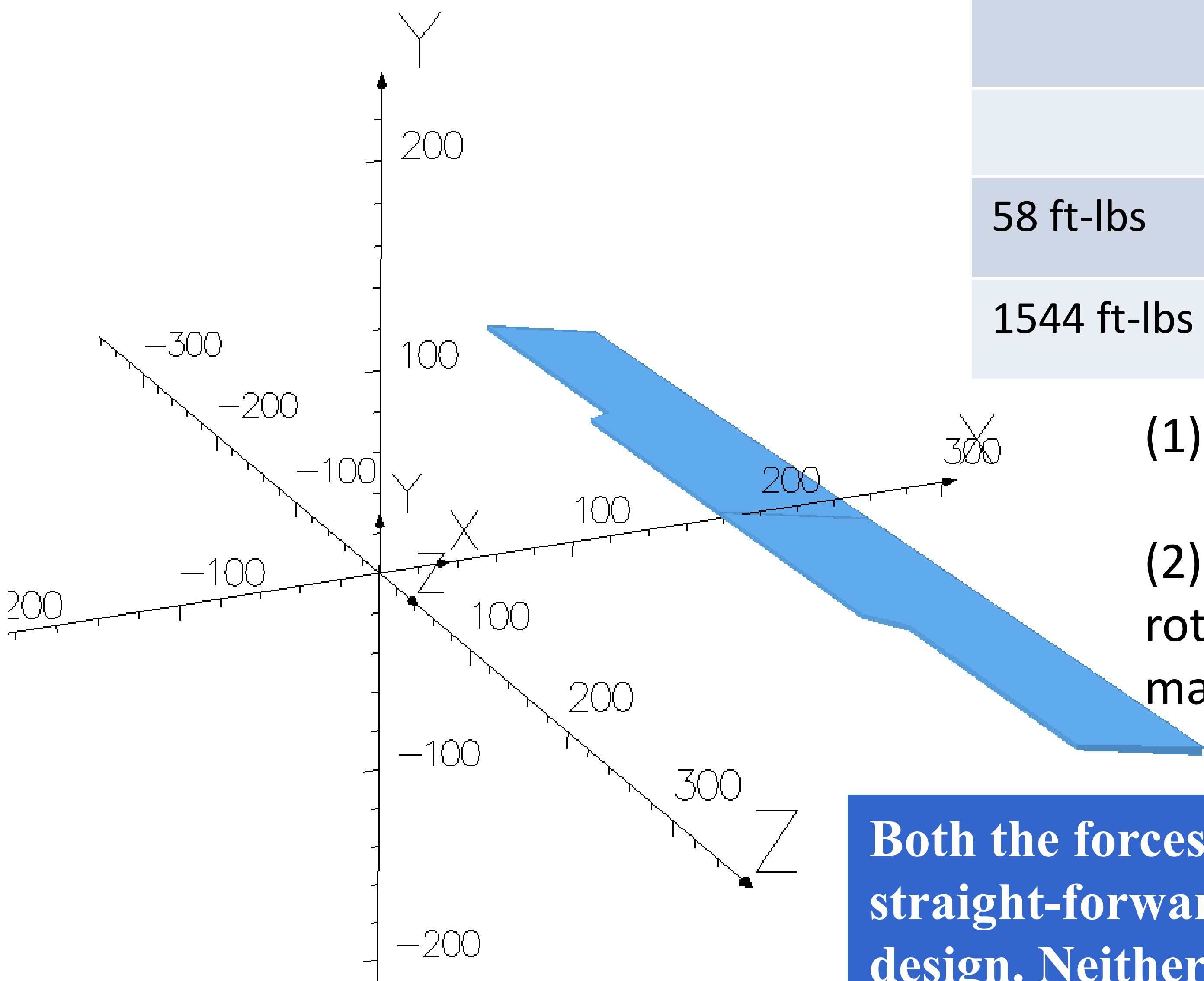
	Fx	Fy	Fz	Tx	Ty	Tz
No misalignments	-1043 N	-14072 N	15640 N	335007 N-cm	160904 N-cm	0 N-cm
Coils shift, dx=2 mm	9412 N	-14077N	15647N	335345 N-cm	157079 N-cm	-2815 N-cm
Coils shift, dz=3 mm	-1033 N	-13903 N	21207N	354464 N-cm	159326 N-cm	0 N-cm

Table 3.1: Magnetic forces (Fx, Fy, Fz) and torques Tx,Ty,Tz in the non-symmetric model.

Field Simulations

Forces and Torques on Each Steel Plate are Calculated by Integrating Maxwell Stress around its Surfaces (4596 A):

Without End-caps		Without End-caps	With End-caps
1607 lbs	Fx (N)	-7157.5	-6342.0
232 lbs	Fy (N)	-1032.2	-824.2
	Fz (N)	-2.6	-2.1
	Tx (N-cm)	-169.0	-139.8
58 ft-lbs	Ty (N-cm)	7886.0	6445.1
1544 ft-lbs	Tz (N-cm)	-209287.2	-166852.6



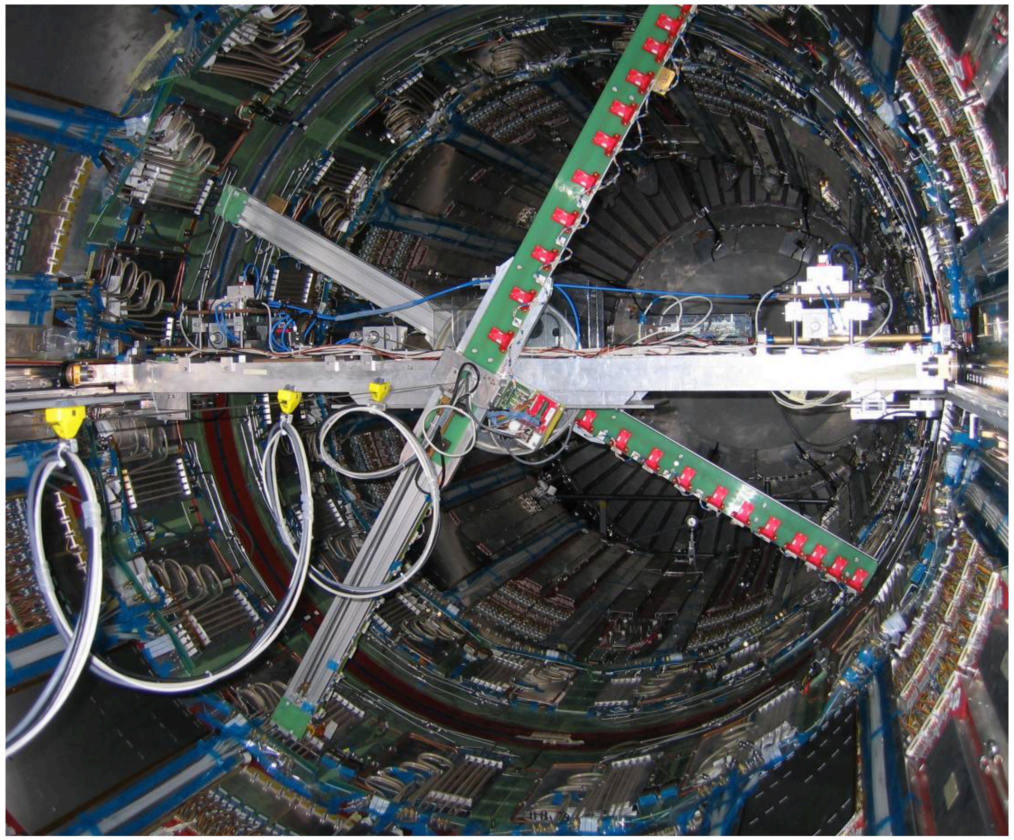
(1) The plate essentially sees a radial inward force;

(2) Tz indicates it has the tendency to rotate (with respect to the center of magnet).

Both the forces and torques on the HCal plates are straight-forward to deal with in the mechanical design. Neither are particularly challenging

field monitoring and mapping

Field Mapping



use existing probes for the low and high field tests, 2015/16
read out separately or together with voltage tabs, …

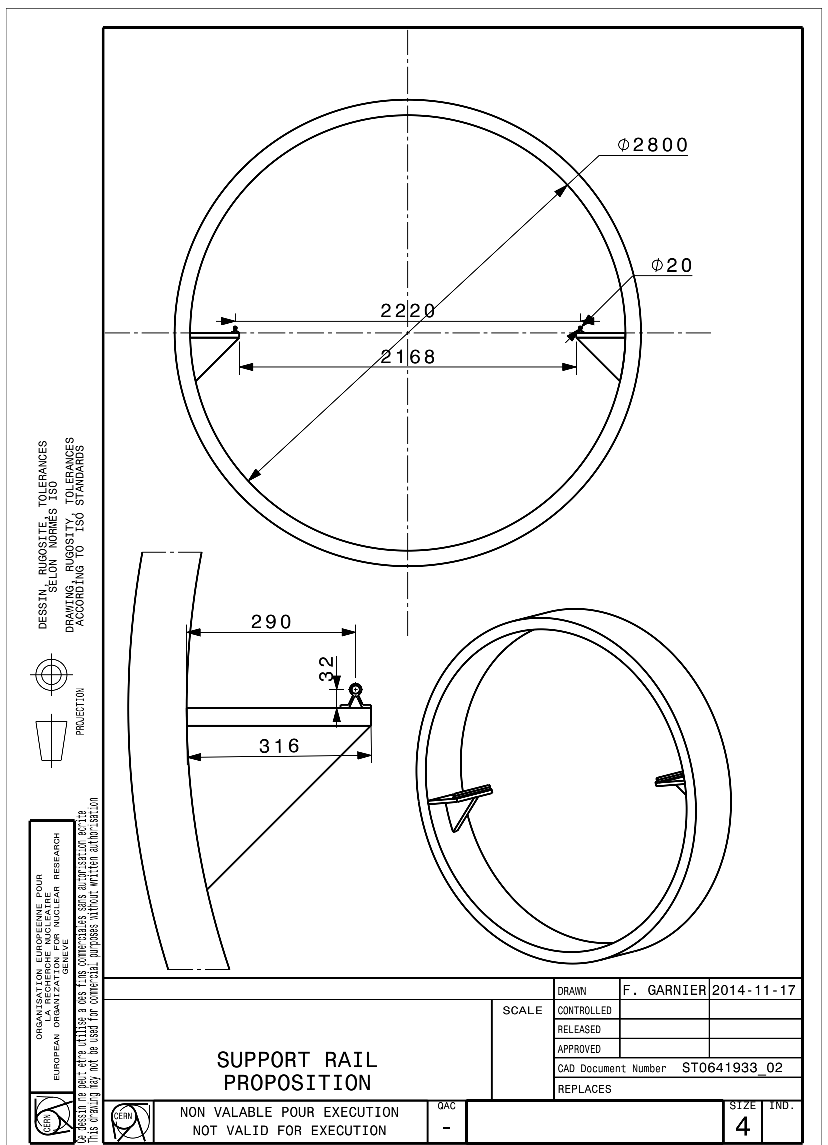
final mapping done by CERN mapping group, F.Bergsma

Magnet mapping using the existing CERN mapper that was used for STAR and recently ATLAS

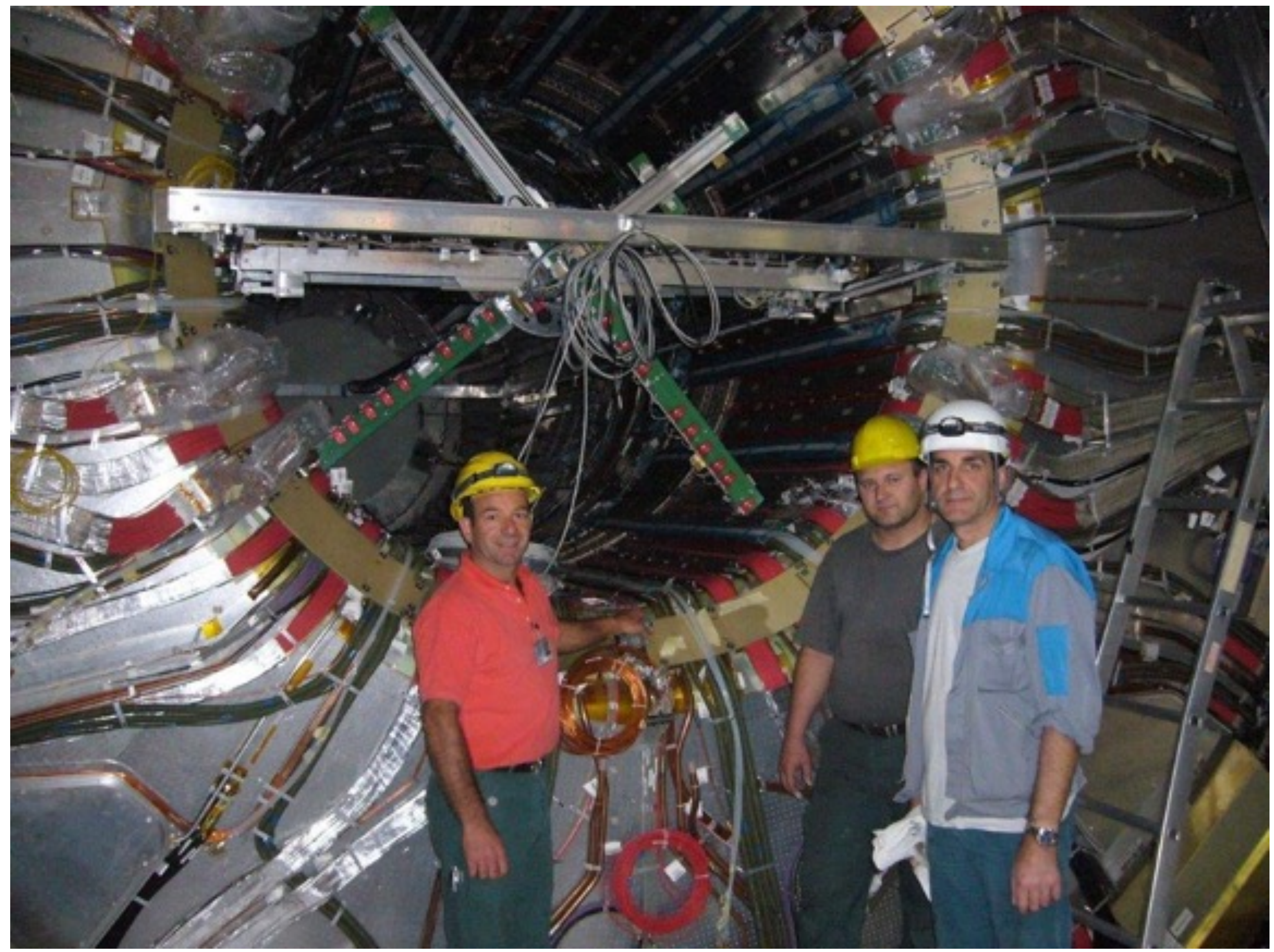
Contacts at CERN:

Pierre-Ange Giudici

Felix Bergsma



suggested supports



Backup Slides

magnet cryogenics summary

SPHENIX: MAGNET: Cryogenics

Support Cylinder MASS	
Outer Diameter, m	3.205
Inner diameter, m	3.1
Length, m	3.59
Mass, kg	3,750

COIL MASS	
Outer Diameter, m	3.1
Inner diameter, m	3.02
Length, m	3.59
Mass, kg	3,940

THERMAL ENERGY [MJ]	
Mass KG	7,700
Specific Heat Integral, J/kg	172,800
Thermal energy 293K to 90K, MJ	1,328
Cooldown time, 2kW, DT=20K	7.5 day
Thermal energy 90K to 4.5K, MJ	102
Cooldown time, 400W	3 days

SPHENIX: MAGNET: Cryogenics

SOLENOID & VALVEBOX LOADS ITEM	Original Design / Nominal Load Operation / Test	Forced 2 phase flow operation And Design Load
Magnet load and valvebox	35W @ 4.5K [siphon mode]	7.5 g/s, 145W [with Valvebox separator loading heaters]
Shield	0.35 g/s, From 4.5K to 50K, 110W	0.5 g/s, From 4.5K to 50K
Vapor cooled leads	0.51 g/s, 4.5K to 300K,	0.6 g/s, 4.5K to 300K,
TOTAL, 4.5K Ref equivalent	129 W	255 W

EXTERNAL EQUIPMENT / TRANSFER LINES LOADS: OPTION A, RHIC INTERFACE ITEM	Nominal Load
500 L Reservoir Dewar. Transfill valve + bayonet	9W @ 4.5K
Transfer line jumper: Vapor return from 500 L Reservoir	7 W @4.5K
Transfer line: Liquid supply from RHIC 120ft, 3 cryogenics valves, 2 bayonets	10+10 = 20 W @4.5K
Transfer line: Vapor return to RHIC 120ft 3 cryogenics valves, 4 bayonets	15+15 = 30 W @4.5K
Transfer line: Shield return to RHIC 120ft 2 cryogenics valves, 2 bayonets	150 + 8 = 158 W 0.5 g/s Liq load
RHIC CRYO PLANT LOAD REFRIGERATION @ 4.5K	321 W [118 kW]
RHIC CRYO PLANT LOAD LIQUEFACTION	1.6 g/s [55 kW]

SPHENIX: MAGNET: Cryogenics

SOLENOID & VALVEBOX LOADS ITEM	Original Design / Nominal Load Operation / Test	Forced 2 phase flow operation And Design Load
Magnet load and valvebox	35W @ 4.5K [siphon mode]	7.5 g/s, 145W [with Valvebox separator loading heaters]
Shield	0.35 g/s, From 4.5K to 50K, 110W	0.5 g/s, From 4.5K to 50K
Vapor cooled leads	0.51 g/s, 4.5K to 300K,	0.6 g/s, 4.5K to 300K,
TOTAL, 4.5K Ref equivalent	129 W	255 W

EXTERNAL EQUIPMENT / TRANSFER LINES LOADS: OPTION B, INDEPENDENT CRYO PLANT	Nominal Load	Design Load
500 L Reservoir Dewar	5W @ 4.5K	10 W
Transfer line jumper: Vapor return from 500 L Reservoir	7 W @4.5K	10 W
Transfer line jumper: Liquid helium from 500L to valvebox 1 cryogenics valve, 2 bayonets	13 W @4.5K	[20 W] included in above table
Transfer line jumper: Vapor return to 500L / Solenoid Valvebox to cryo plant. 1 cryogenics valves, 4 bayonets	17 W @4.5K	20 W
Transfer line: Shield	Budget with solenoid/valvebox load Accounted as 0.35 g/s liquefaction load	Budget with solenoid/valvebox load Accounted as 0.5 g/s liquefaction load
		285 W 320 W plant

leak tests

2.2E-7 at room temperature and 35 psia: Gas density: about 0.4 kg/m3
At liquid density: 120 kg/m3
Factor of 300 increase in leak, if opening stays the same.
6.6E-5 Torr-L/s leak cold
Net pumping speed of 100 L/s
6.6E-7 Torr
Good for insulating vacuum

If leak opens up 10x larger
6.6E-6 Torr
Just sufficient for MLI performance.

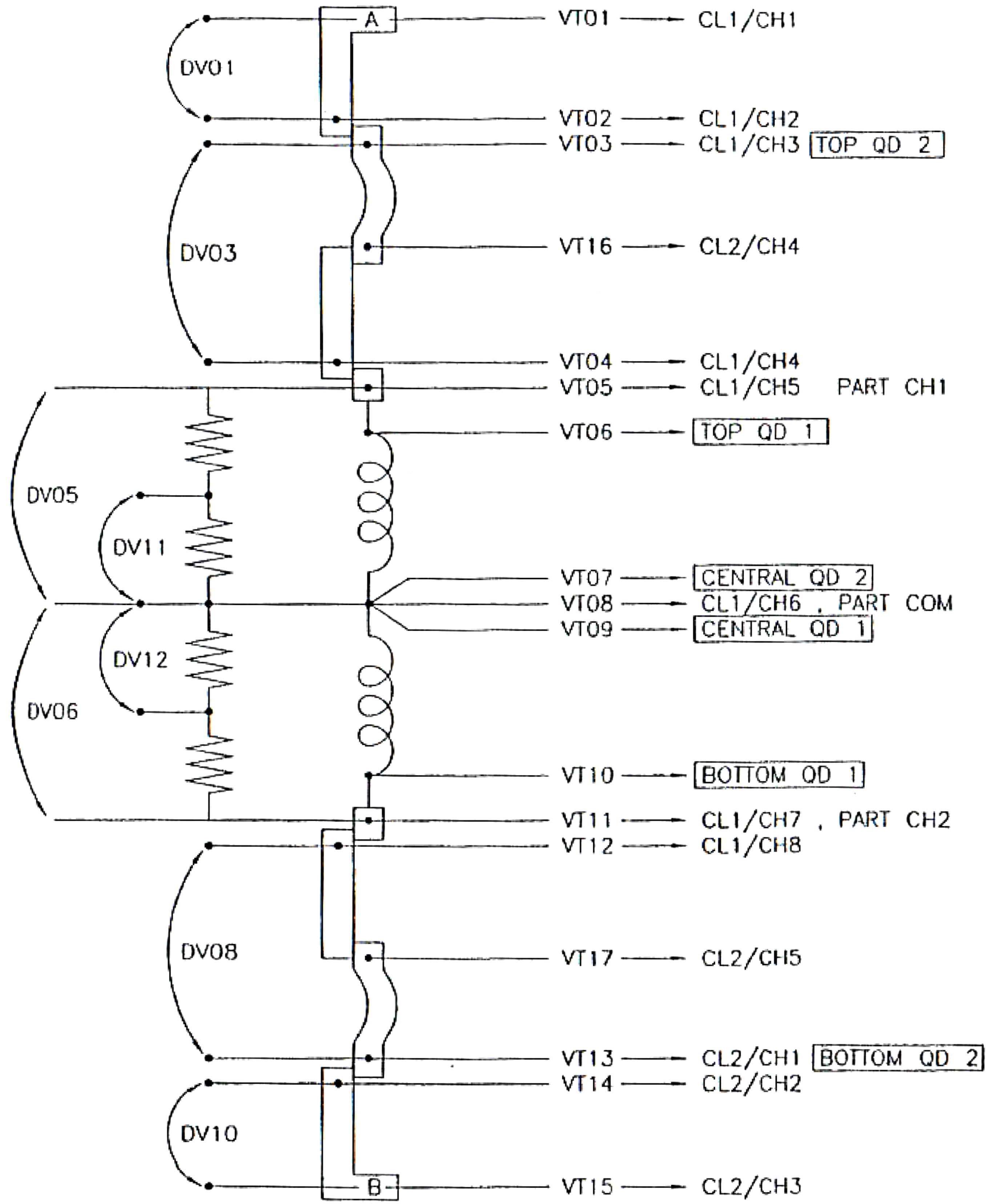
Ray Ceruti reported on the pressure test and the leak rates that he's found in different scenarios. Roberto calculated and seemed to conclude that if the leak doesn't become bigger more than 10 times during cool-down, we should be OK. It's decided to go ahead with the low-field test and see what happen to the leak during the low-field test before we think about whether we want to try to fix this leak --- which might take a few months (as Ray commented).

quench protection and controls, 912 and 1008

The quench detector should be sensitive to a voltage rise of about 100 mV. This is simple when the current in the solenoid is constant. But, when the current is ramping up or down, the induced voltage, V = L di/dt, is much greater than 100 mV. With a ramp rate of 2.5 Amps/sec, V = 6.25 V.

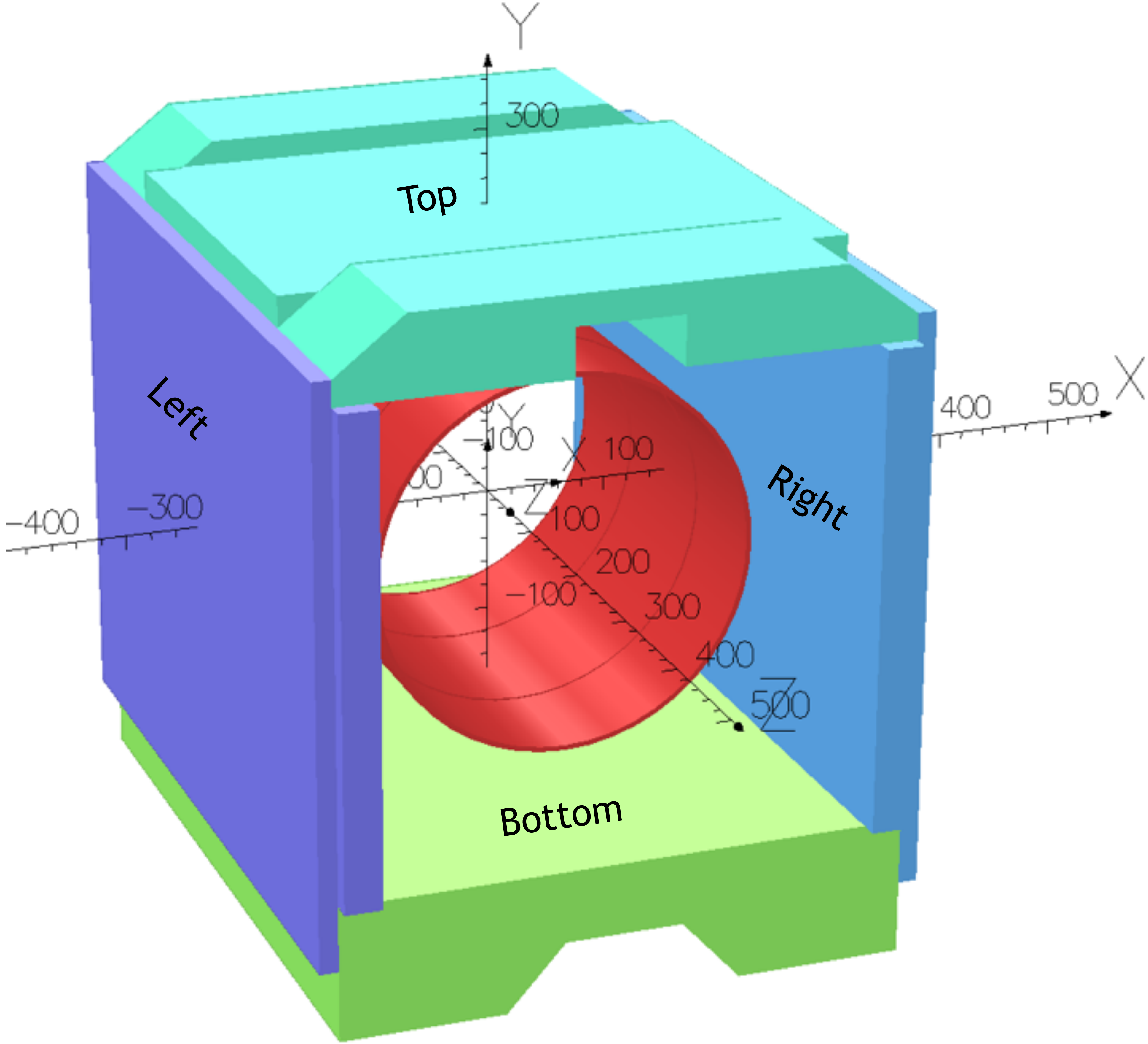
There is a voltage tap at the connection between the inner and outer solenoid windings. During ramping, if the inductance of these windings were identical, the voltage across the top coil (VT05 with respect to VT07) would be exactly negative of the voltage across the bottom coil with respect to the same point (VT10 with respect to VT09).

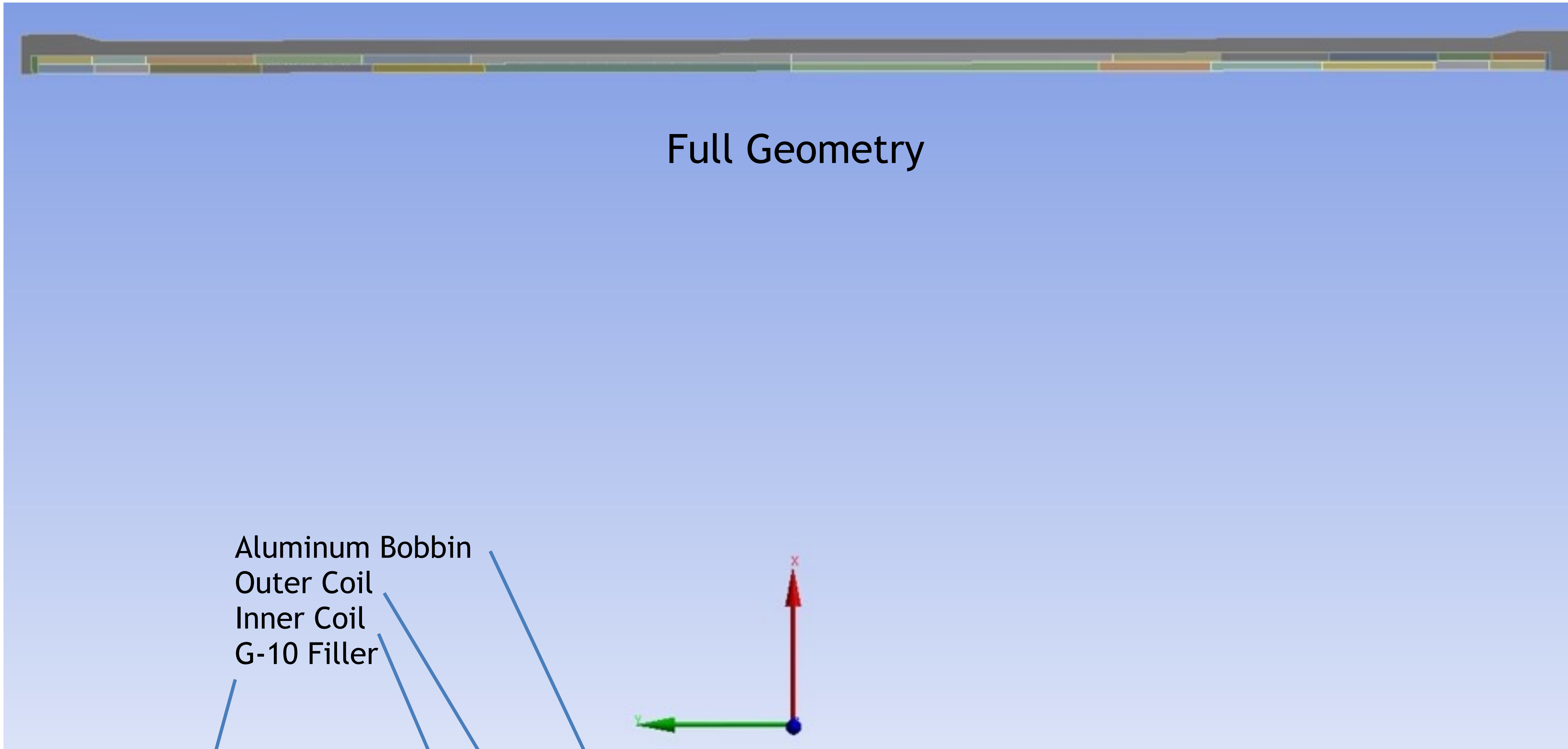
The sum of these two voltages would add to zero. An imbalance caused by a 100 mV quench voltage can then be detected in the sum.

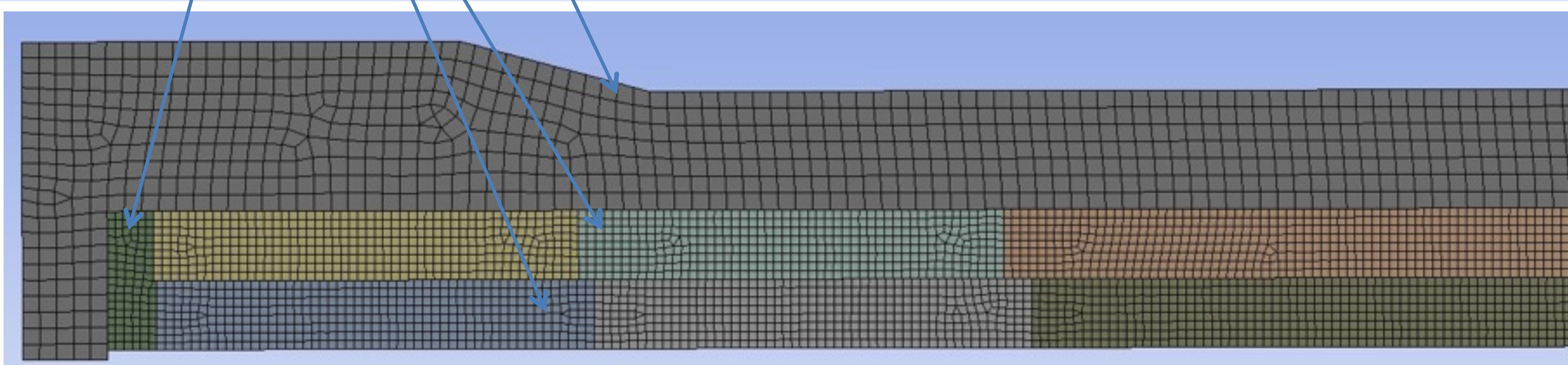


Fifteen years have passed since the original quench detection system in the BaBar experiment has been designed and implemented. In the future implementation which will be done by the cooperation of Superconducting Magnet Division and the Collider-Accelerator Department, new hardware and software will make more accurate and reliable quench detection possible for this Magnet.

high field test shield wall simulations

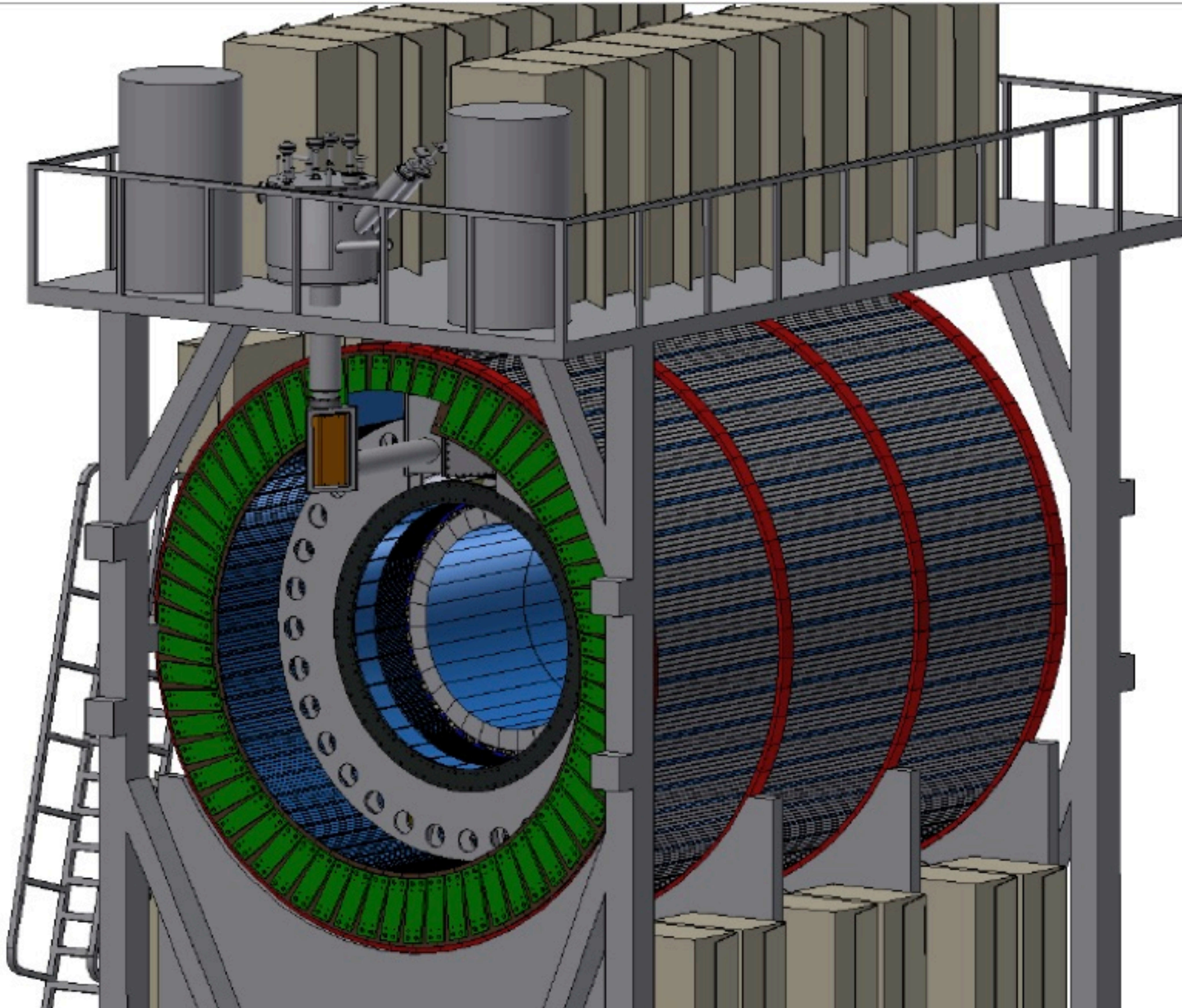






FE Mesh (Lead End)

sPHENIX South side



sPHENIX South side, detail