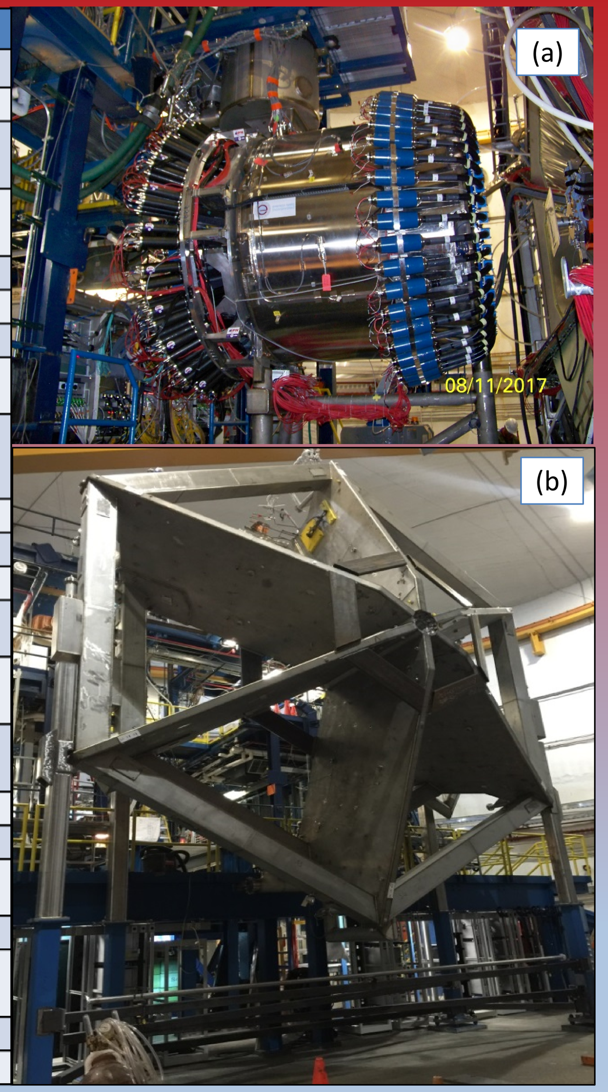
Interactions observed between Torus and Solenoid Superconducting magnets at JLab

D. Kashy, R. Fair, P. K. Ghoshal, R. Rajput-Ghoshal

Abstract - The Jefferson Lab 12 GeV Upgrade of Experimental End Station Hall B required a new detector system that would be more sensitive to forward going particles and able to handle higher luminosity. This new detector is CLAS12 and includes two superconducting iron-free magnets – a torus and an actively-shielded solenoid. The torus magnet consists of 6-trapezoidal racetrack-type coils while the solenoid is an actively shielded 5 T magnet. The torus and the solenoid are located in close proximity to one another and are surrounded by sensitive particle detectors. The torus and solenoid, operating at 3770 A and 2416 A respectively, were commissioned successfully and are operating normally. This paper presents observed electromagnetic interactions which include induced static mechanical loads and inductive coupling as well as a summary of some of the cryogenic interactions and how they are mitigated.

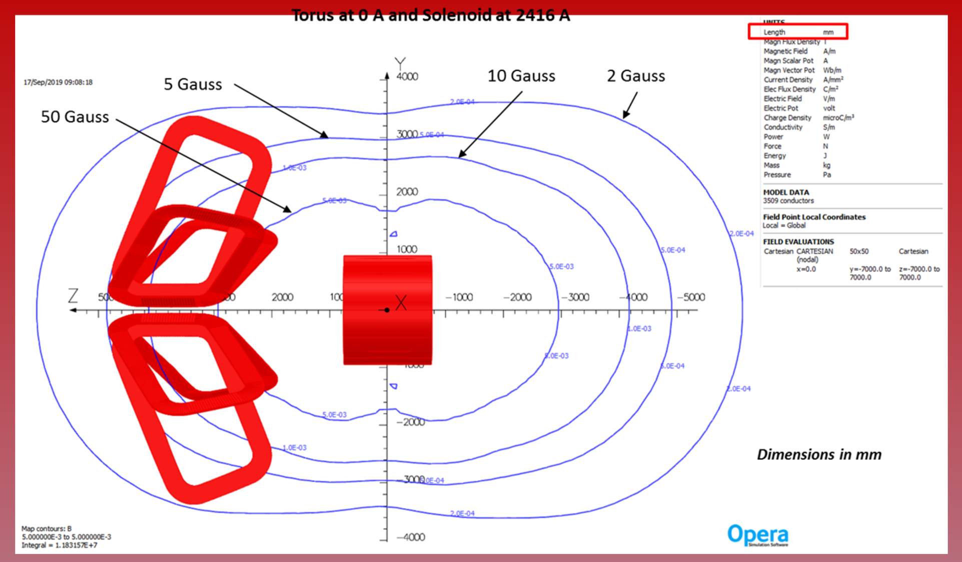
Solenoid and Torus Magnets

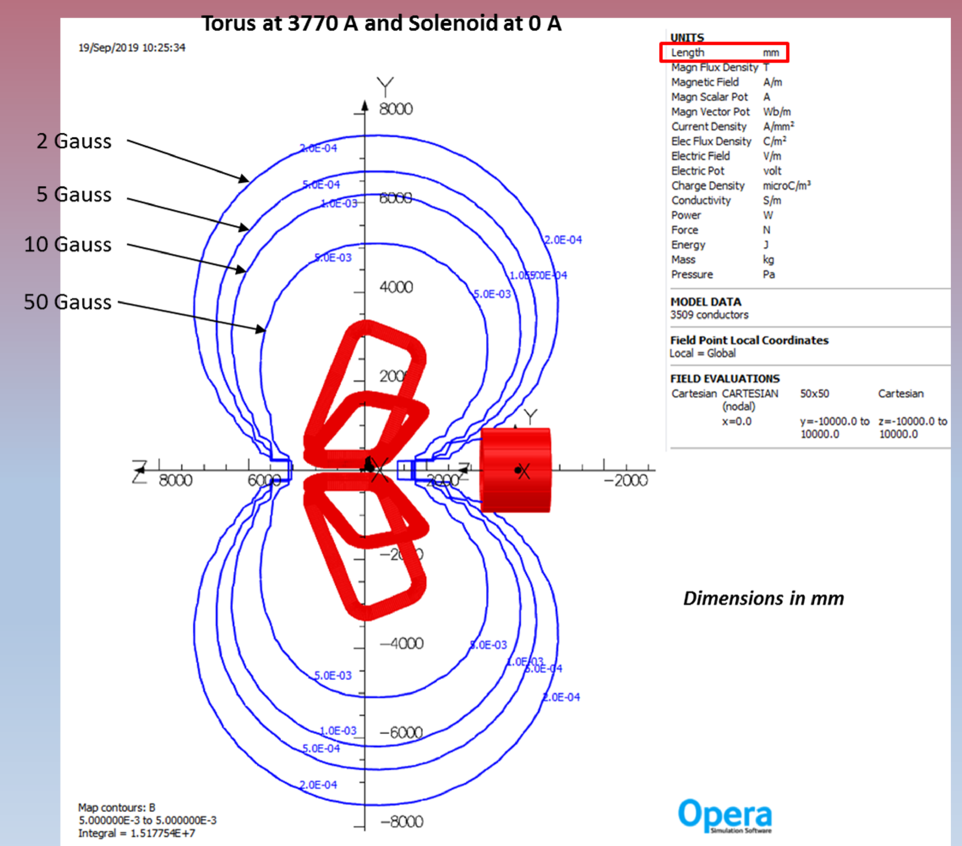
PARAMETER	DESIGN VALUE	
	SOLENOID	TORUS
Number of Coils	4 + 1	6
Coil structure	Layer wound	Double pancake potted in aluminum case
Total number of turns	5096 (2 x 840 + 2 x 1012+1392	1404 (117 x 2 x 6)
NbTi Rutherford cable	SSC 36 strands	SSC 36 strands
Nominal current (A)	2416	3770
Central field (T)	5	N/A
Conductor peak field (T)	6.56	3.6
Field homogeneity in ϕ25mm x L40 mm cylinder	1×10^{-4}	N/A
Inductance (H)	5.89	2
Stored energy (MJ)	17	14
Warm bore (mm)	780	124
Outer diameter x length	2.16 m x1.8 m	8.5m x 3m
Inner bore length /opening angle	0.897 m/41^0	N/A
Coil case thickness	-	Originally 100mm changed to 125mm
Total weight (KG)	18800	25500
Cooling mode	Conduction cooled	Conduction cooled
Supply temperature (K)	4.5	4.5
Temperature margin	1.5	1.5
Stabilized conductor	W17 mm x T2.5 mm copper channel	W20 mm x T2.5 mm copper channel
Turn to turn insulation	0.004" glass tape ½ Lap	0.003" glass tape ½ lap
Heat shield cooling	**Helium boil-off**	**LN2 thermo-siphon**



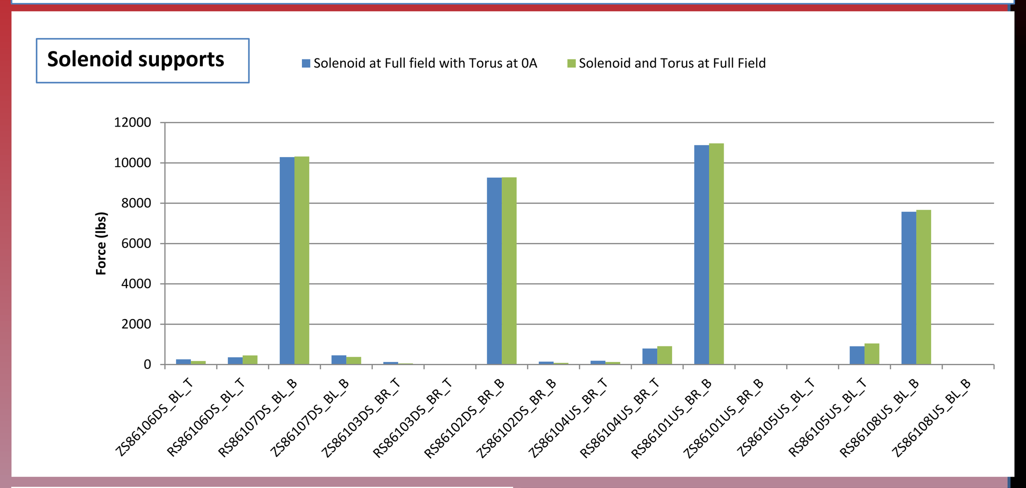
CLAS12 – (a) Solenoid and (b) Torus in Jefferson Labs Experimental Hall B

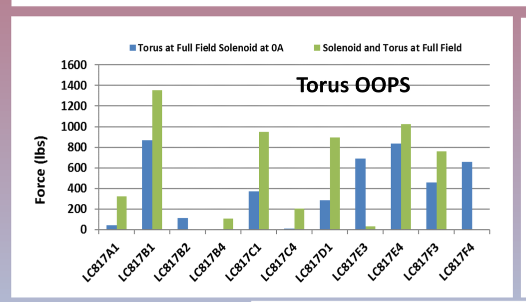
Force Interaction

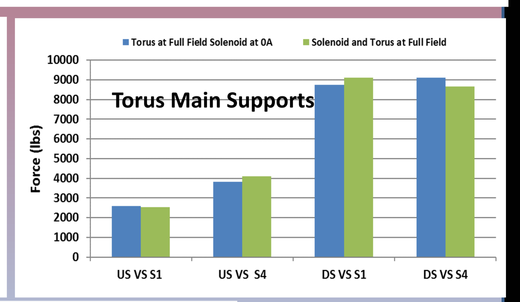


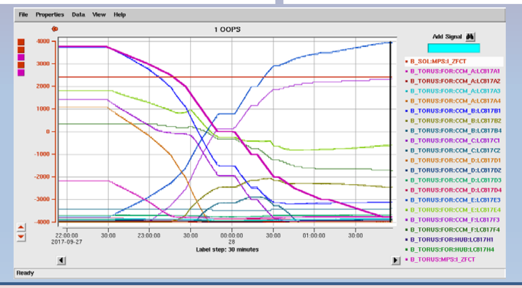


Solenoid at 2416A with Torus varying between 3770A and -3770 A. Many Torus OOPS change load.





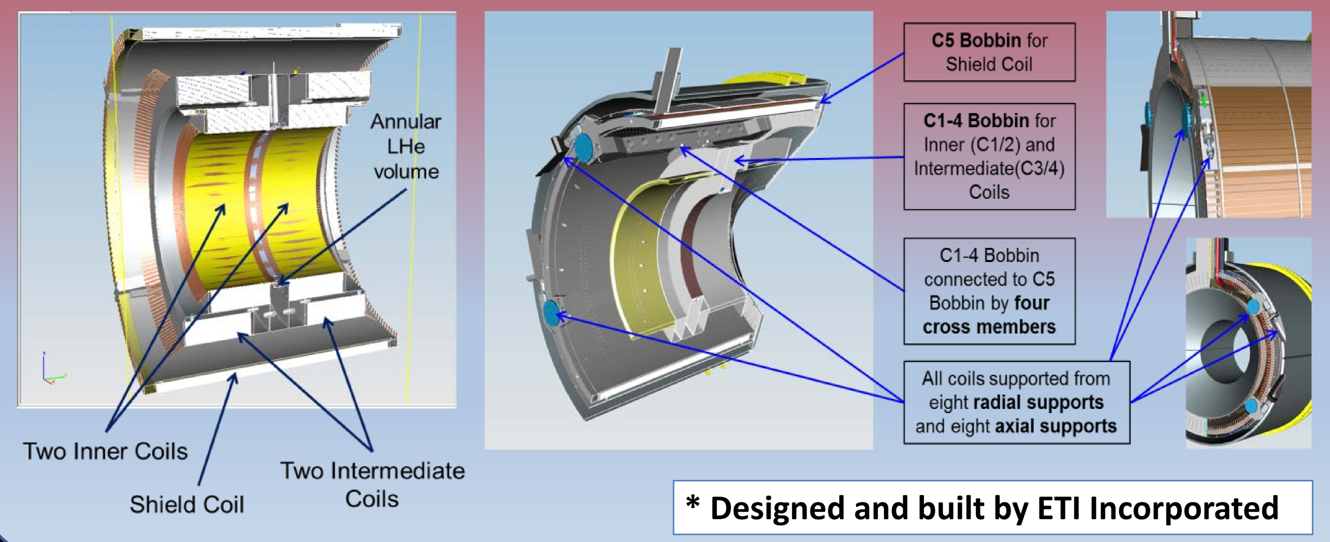




Due to the large stray field of the Solenoid the Torus is exposed to fields between 2 and 50 gauss Torus OOPS load changes of up to 2.9 kN were recorded between 0 and full field in solenoid while one solenoid load cell indicated 640N change

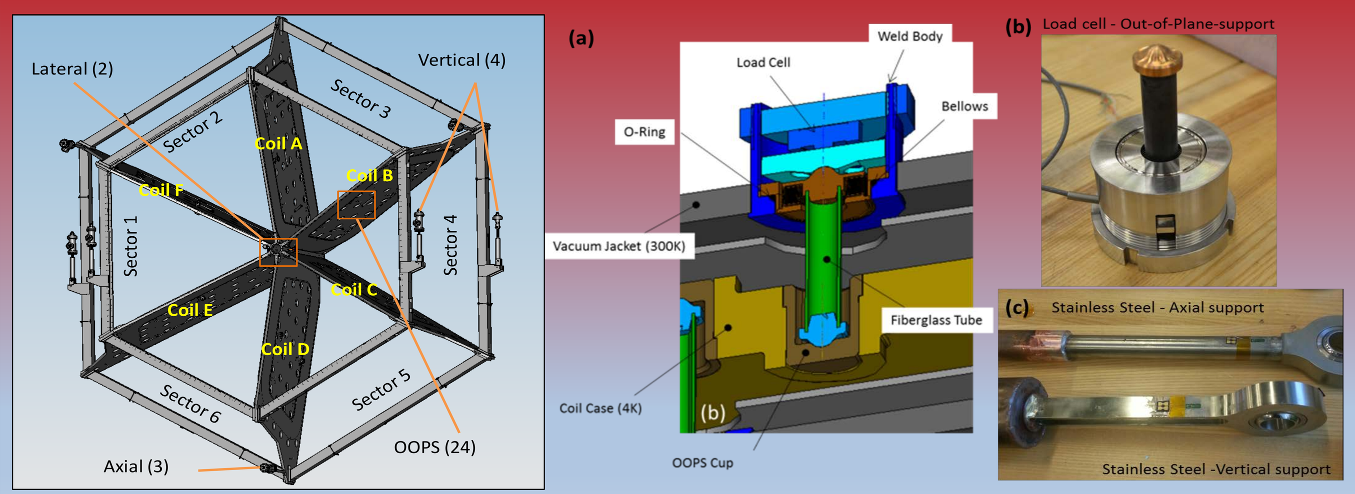
Solenoid Supports

The solenoid has 8 high load radial supports and 8 low load axial supports



*** Designed and built by ETI Incorporated**

Torus Supports



Torus is supported by 8 main supports and 24 OOPS

Summary

Electromagnetic interactions between the two magnets were predicted, studied, and observed during commissioning and operation of both magnets. The stray fields from the solenoid magnet induce forces on the energized torus but not vice versa. These forces are in the direction predicted by modeling and demonstrate the Laplace Force. As a result of the modest inductive coupling between the torus magnet and the shield coil of the solenoid, a quench or fast dump of the torus magnet produces a voltage rise across the shield coil of the solenoid. If the amplitude of this voltage peak exceeds the magnet safety system (MSS) threshold this can result in a MSS fast dump of the magnet. The cryogenic coupling through the distribution box has been limited by check valves in the supply and return U-tubes with all the relief valves venting into the Hall to limit the effect of one magnet fast dumping causing the other to also dump. To date, quenches or fast dumps in one magnet have not resulted in an event that causes a quench or a fast dump in the other magnet due to cryogenic coupling.

Key references

R. Fair and G. Young, "Superconducting Magnets for the 12 GeV Upgrade at Jefferson Laboratory," *IEEE Trans. Appl. Supercond.*, Jun. 2015, V25(3):4500205. DOI 10.1109/TASC.2014.2365737

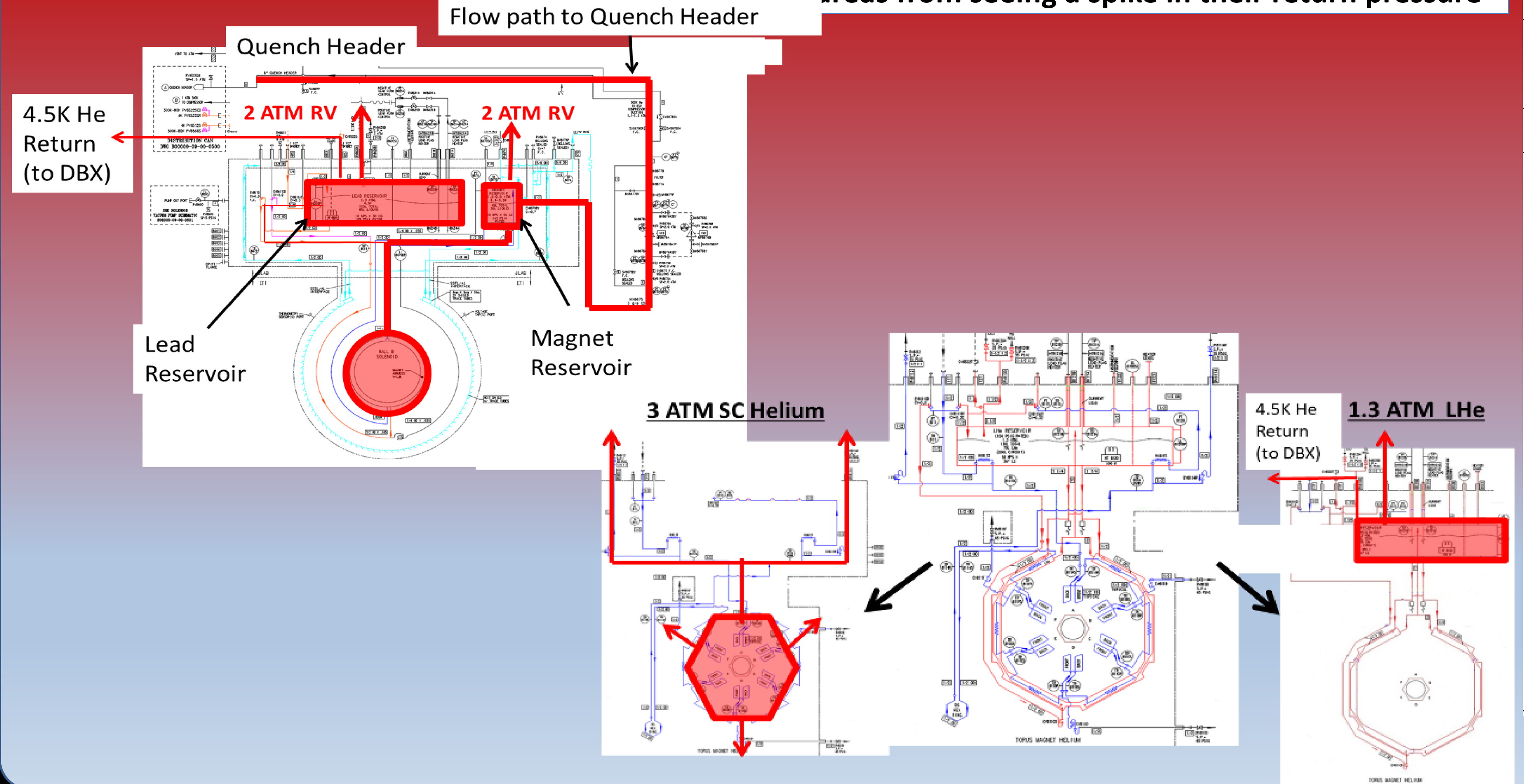
R. Rajput-Ghoshal, R., et al., "An investigation into the electromagnetic interactions between a superconducting torus and solenoid for the Jefferson Lab 12 GeV Upgrade", IEEE Transactions on Applied Superconductivity, V25 (3), June 2015, DOI - 10.1109/TASC. 2014.2372049.

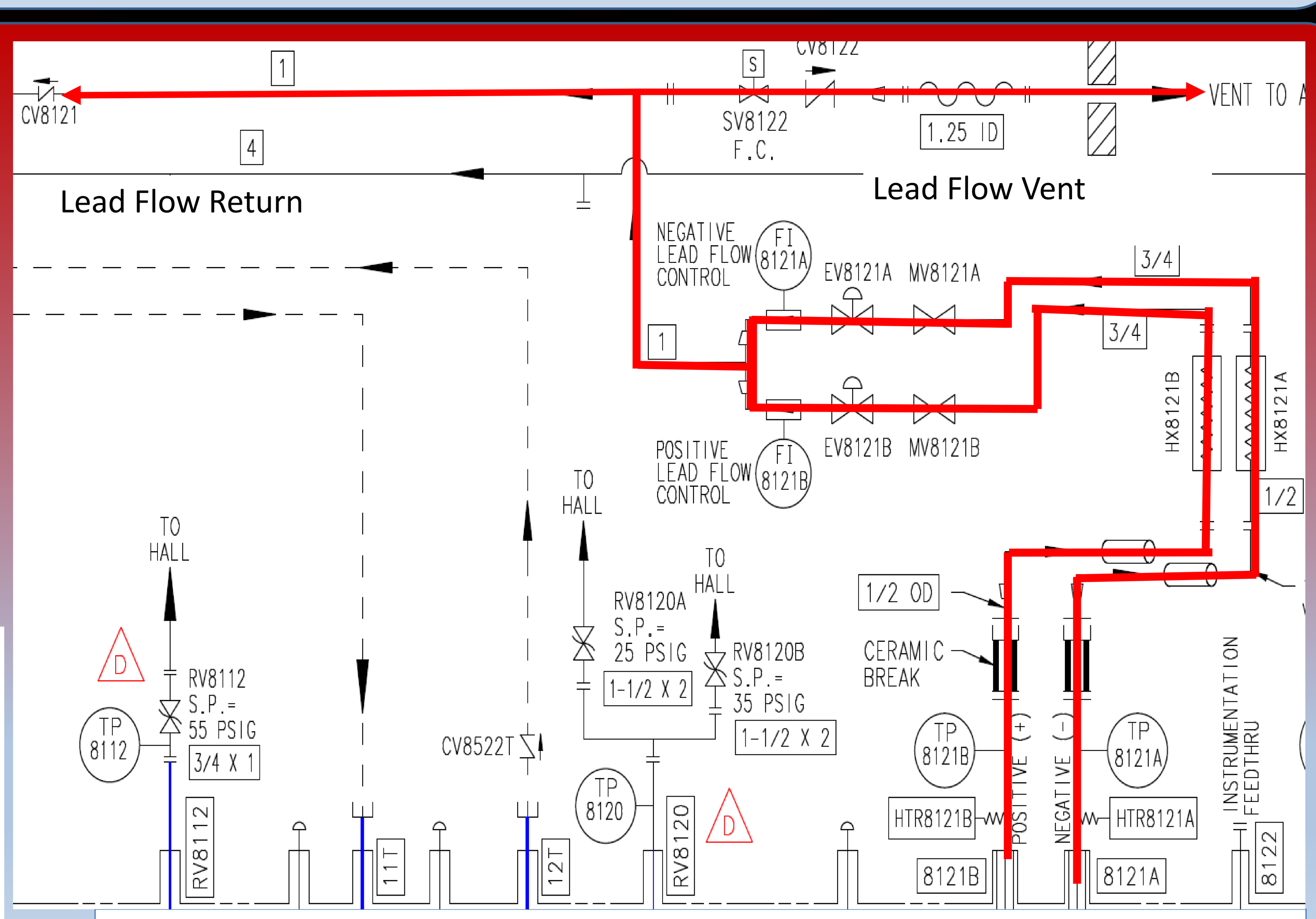
Acknowledgement

This material is based upon work supported by the U.S. Department of Energy, Office of Science, and Office of Nuclear Physics under contract DE-AC05-06OR23177

Cryogenic De-coupling

Relief Valves not piped into the quench header, This protects 15 other magnets in 3 experimental areas from seeing a spike in their return pressure





Lead flows auto-vent upon high return pressure require magnets to slow rundown

Inductive Coupling

We observed that a fast dump of the torus induced a voltage rise above 300mV in C5 of the solenoid for sufficient time to cause the solenoid MSS to trip the breaker and force a fast dump