SNS nEDM Magnet Design

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A. Brinson, D. Molina

Outline

- Goals and Schematic
- Prototype (1/3-scale)
  - Construction
  - Results
    - Magnetic Fields
    - AC Heating
- Full-scale Design and Construction

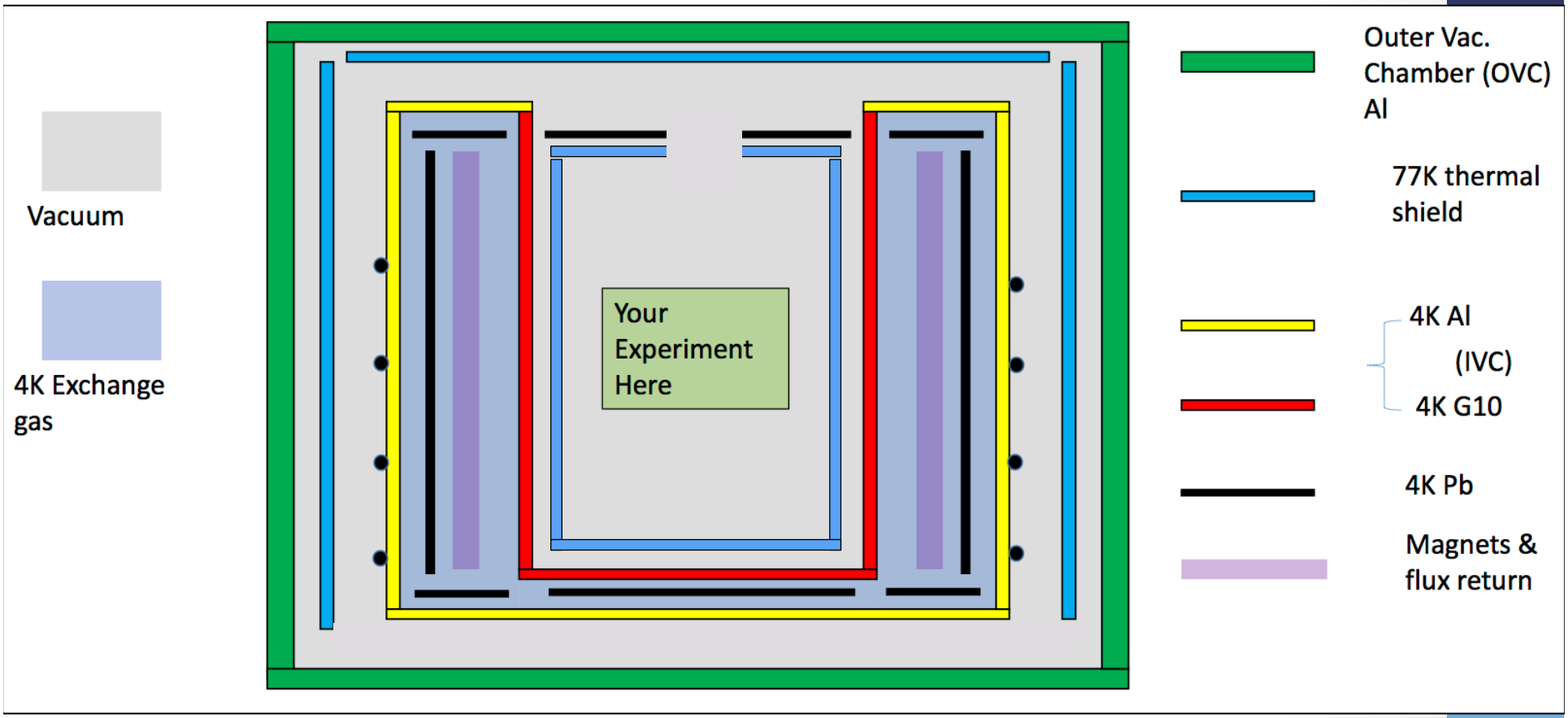
nEDM @ SNS Experiment

- Goal: Measure nEDM to level of $2*10^{-28}$ e-cm
- Magnetic requirement (T2, Geometric Phase):

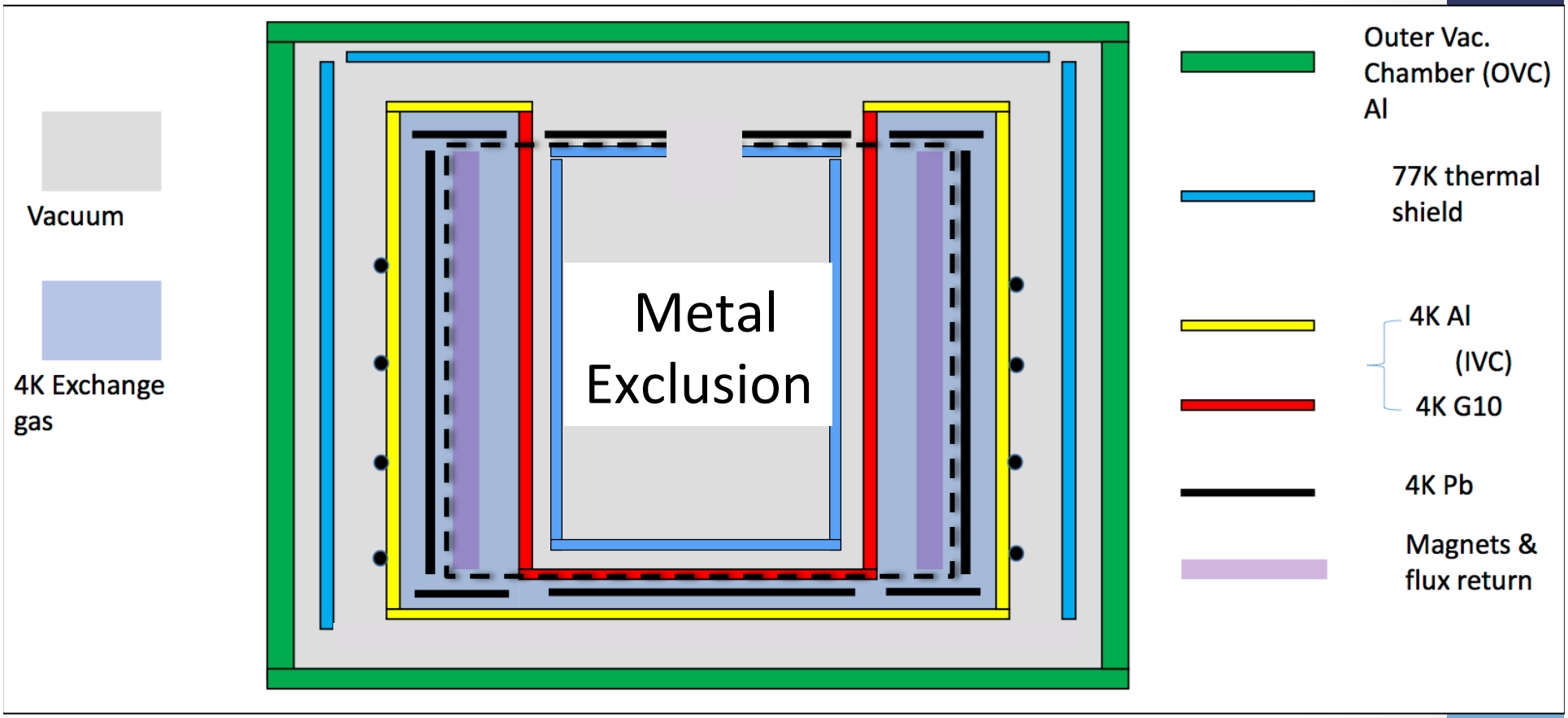
$$\left\langle \frac{\partial B_x}{\partial x} \right\rangle_{vol} / B_0 < 3 \bullet 10^{-6} / cm$$

- Cryogenic Experiment
  - Produce UCN directly in superfluid He-4 at 450 mK
- Metal Exclusion
  - He-3 co-magnetometer - spin-dependent neutron capture on He-3 measures neutron precession frequency
  - Apply RF to match He-3 and neutron spins -> measure deviations from 0
  - Eddy current heating

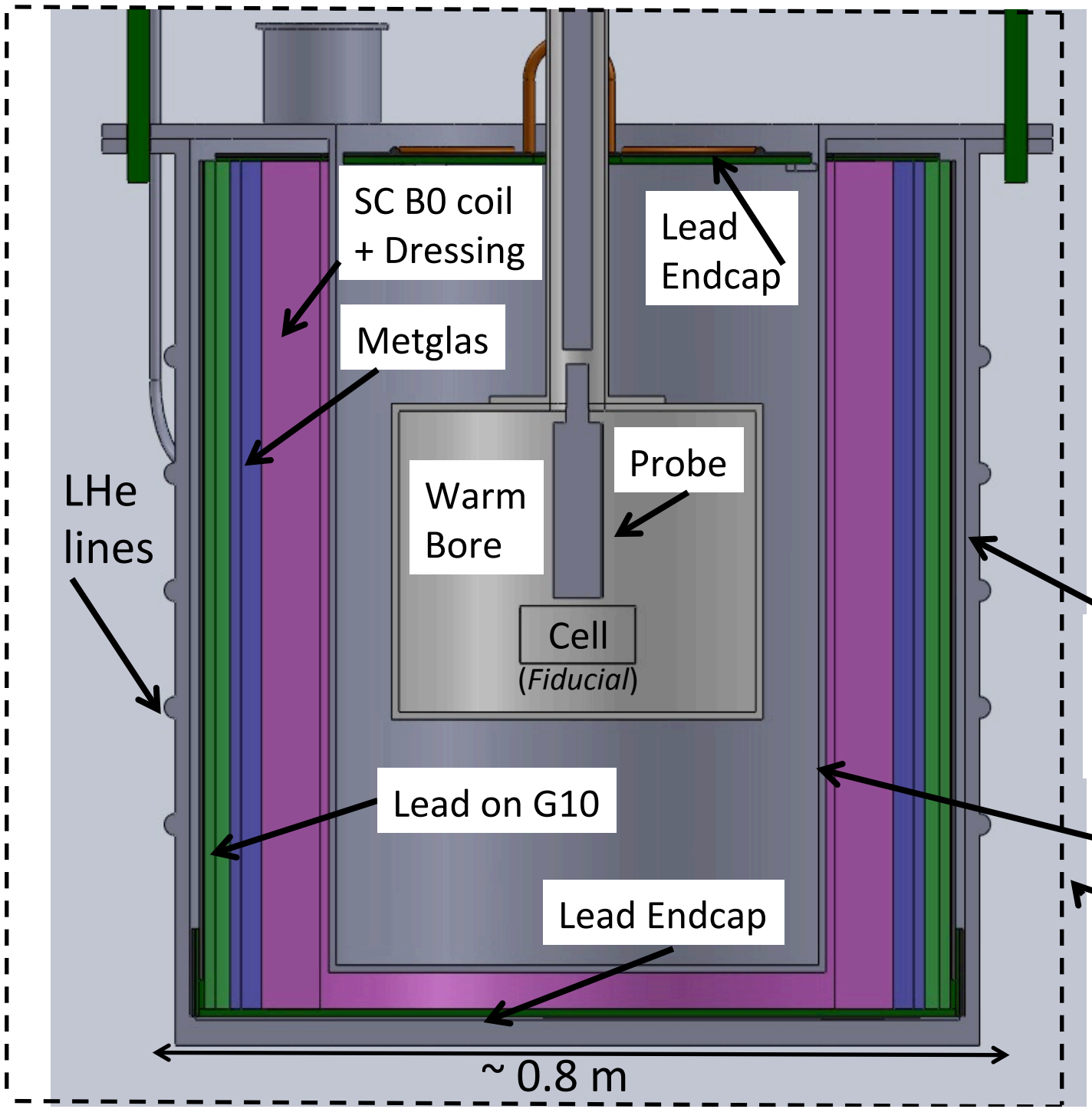
Magnet Package Cartoon



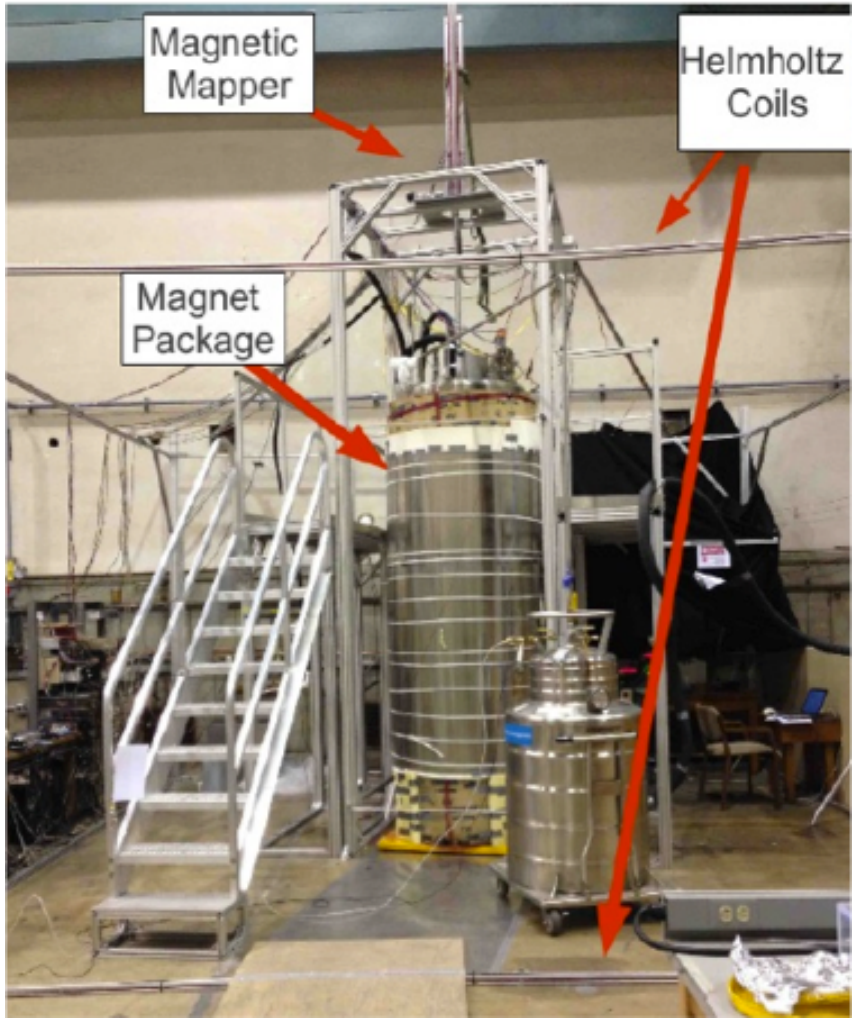
Magnet Package Cartoon



1/3-scale Proto-type



Prototype Magnet System



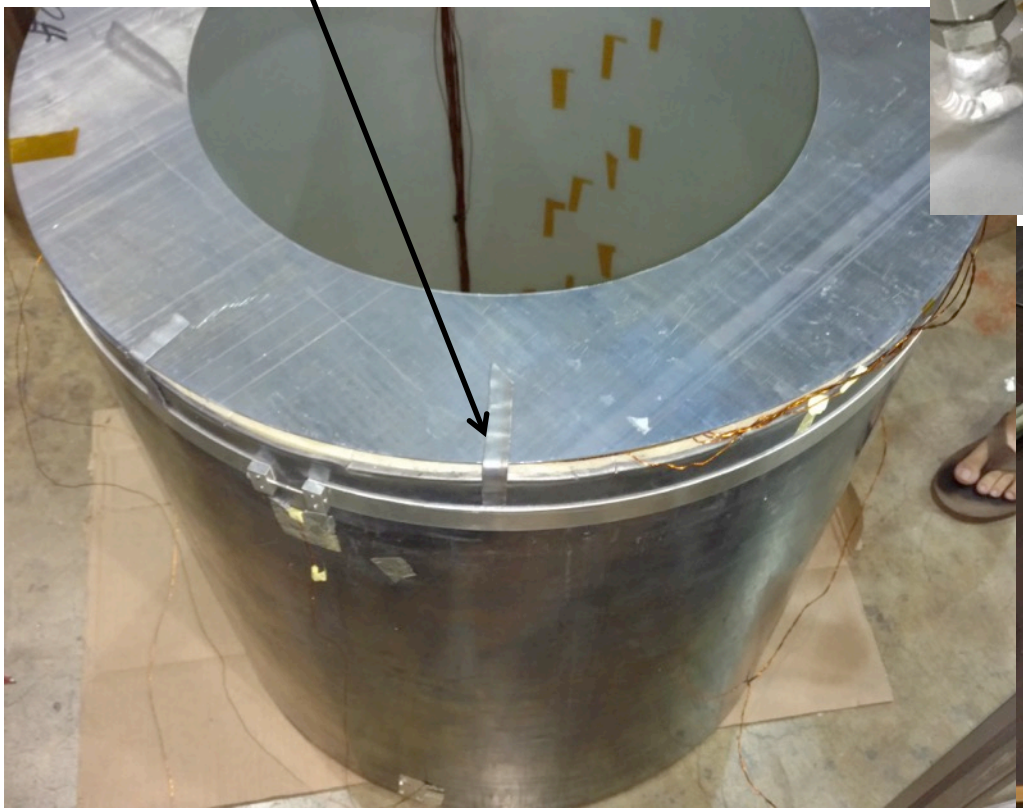
Cryostat holds 1/3-scale models of nEDM @ SNS

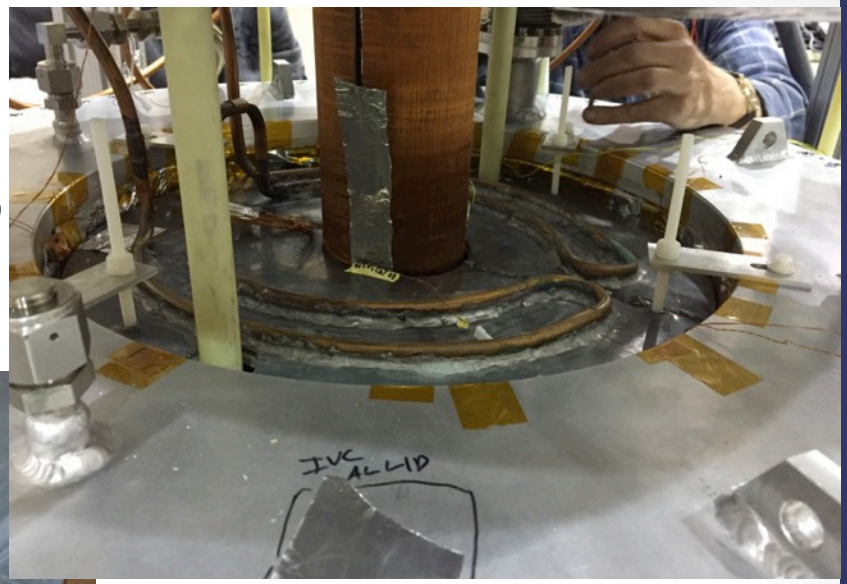
Magnetic mapping with 3-axis low-noise fluxgate magneto-meter

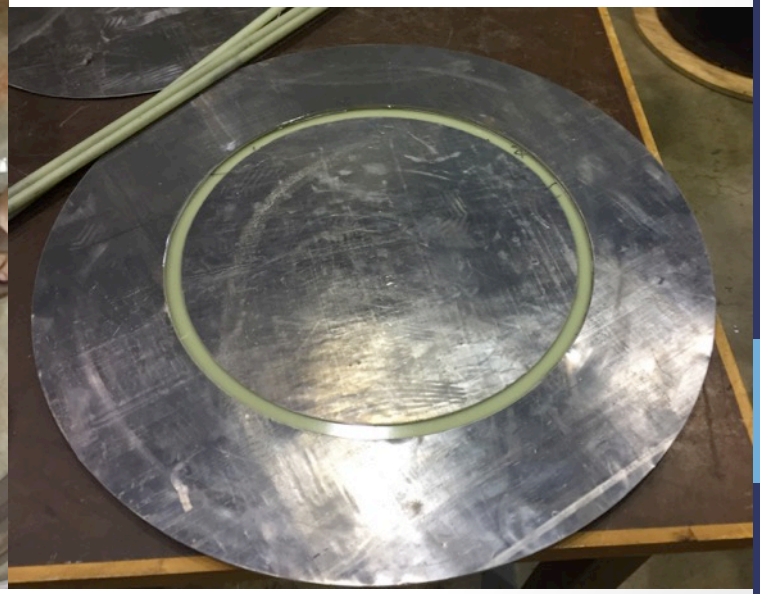
Magnet Vessel (4K)

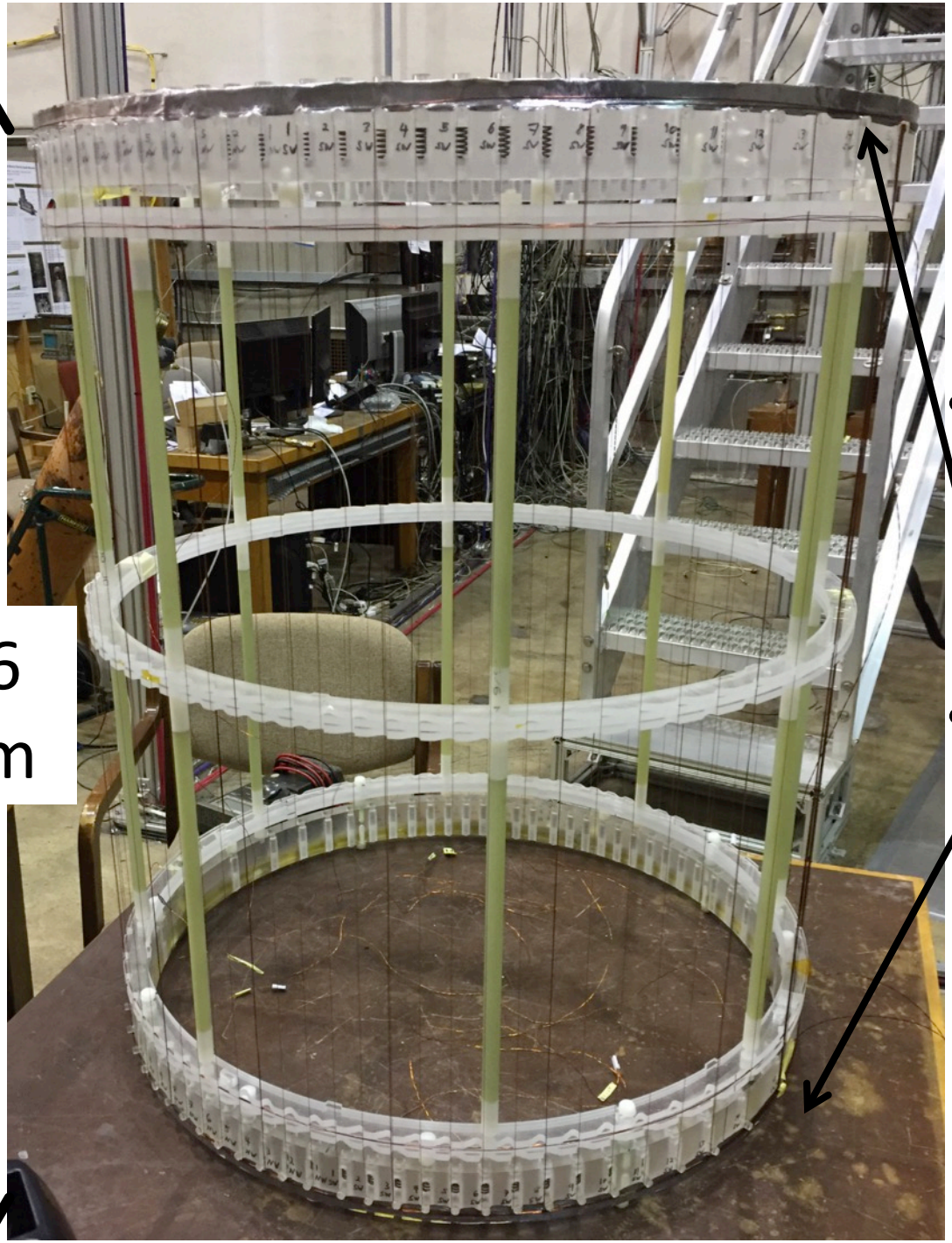
Superconducting Shield

- 0.8 mm of Lead
- Hermetic as possible
- Difficulties cooling upper endcap
  -> Solder to the sides





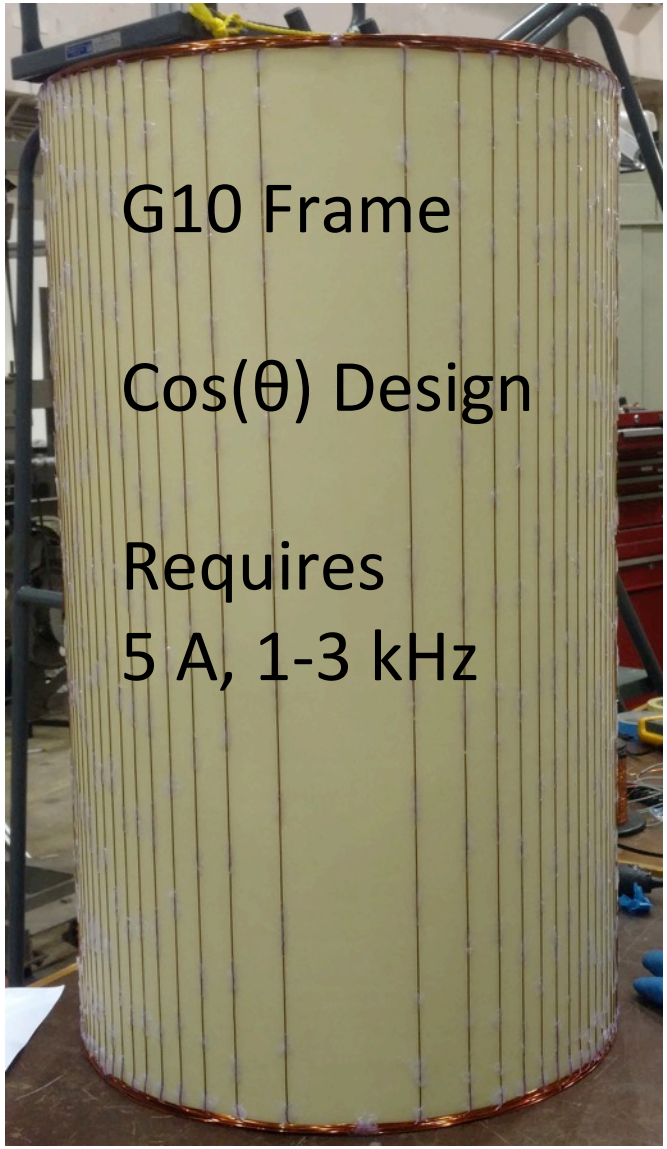




B0 (4K) Cos(θ) coil

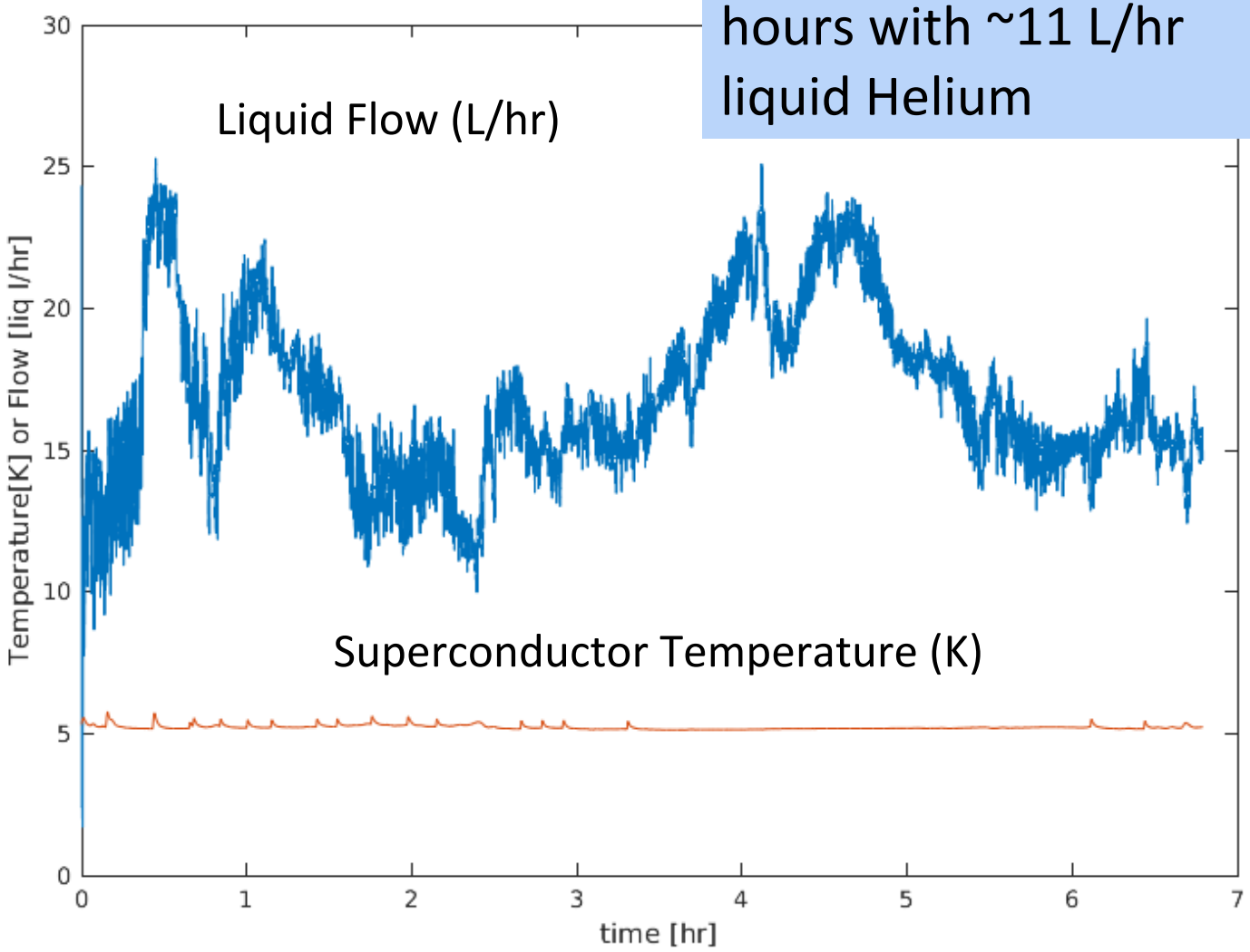
- Cu Wire
  - (NbTi SC for full scale)
- Pb Tape on saddle/return coils for extra shielding

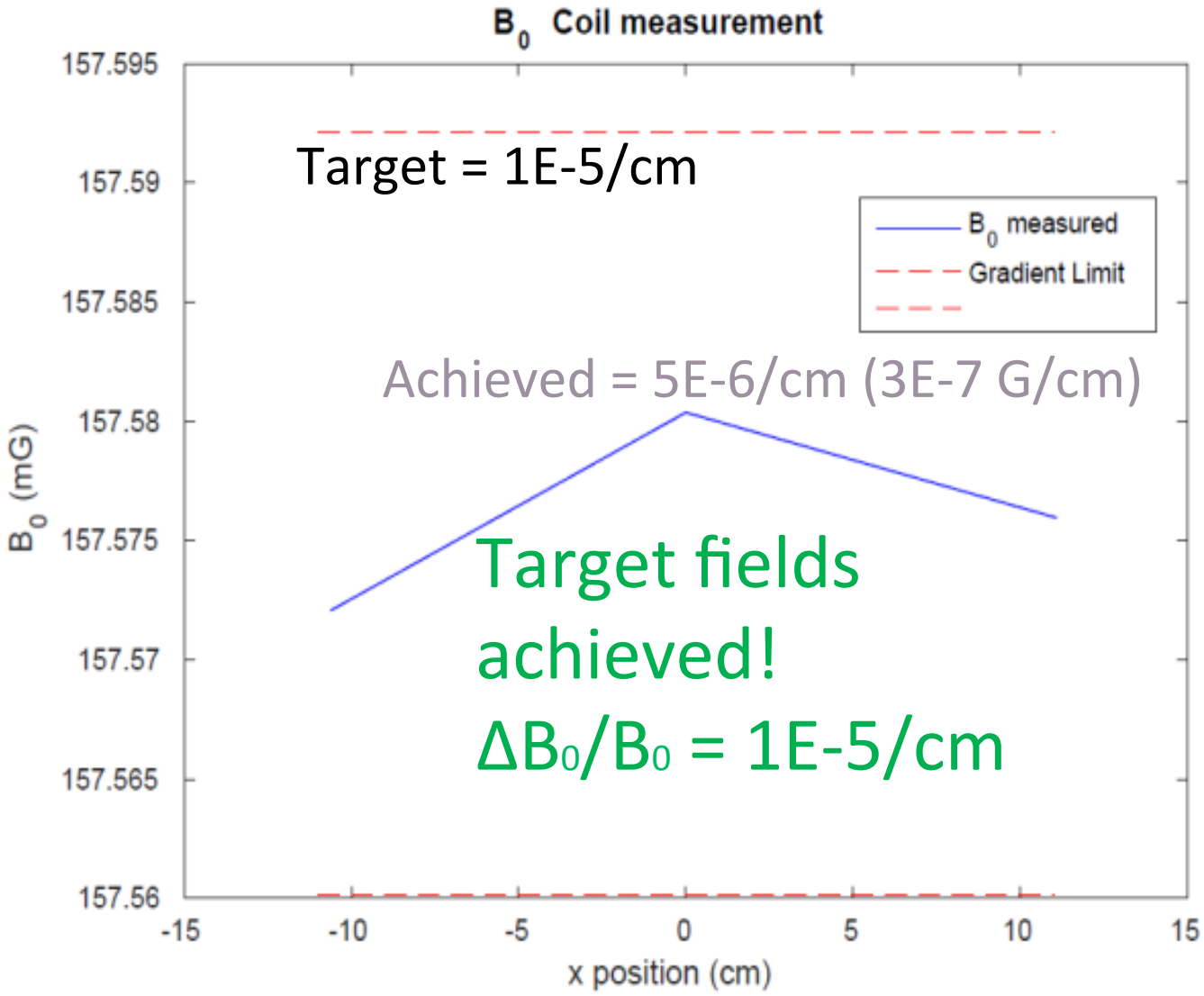
Dressing Coil and Flux Return



Cryogenics

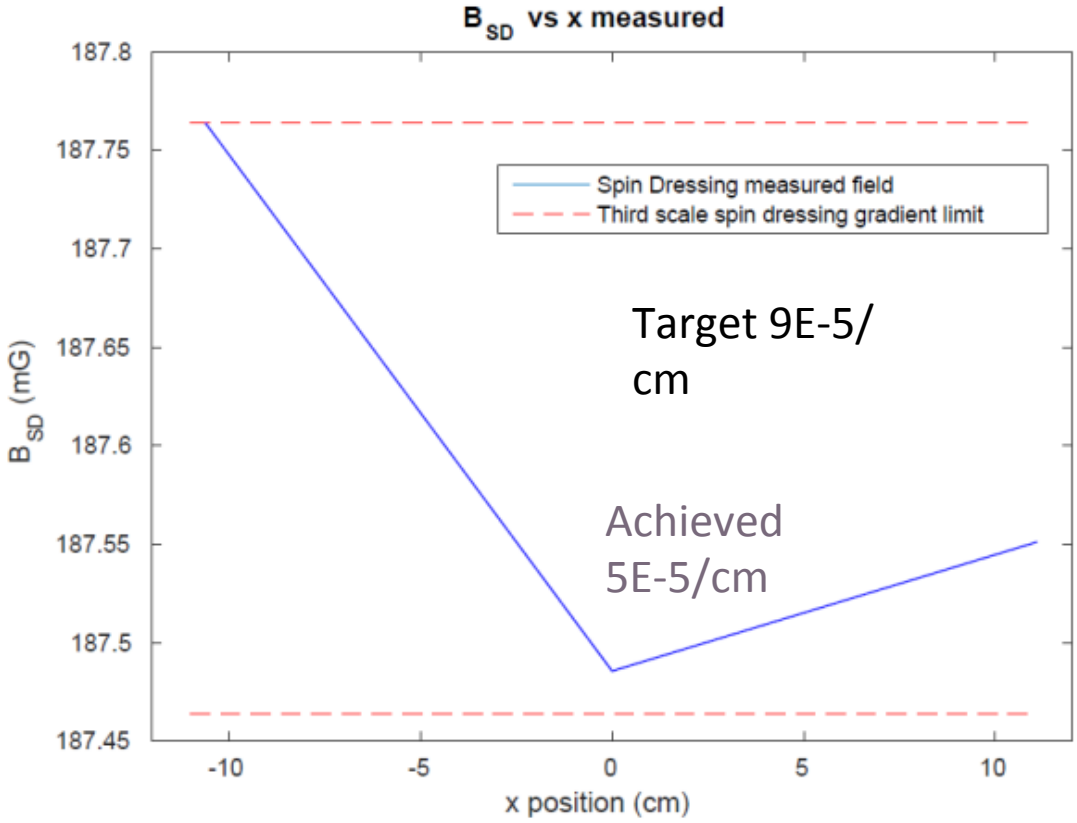
Maintained SC temps for hours with ~11 L/hr liquid Helium





Limited by straightness of probe arm to 3 points

Spin-Dressing Coil



DC uniformity verified

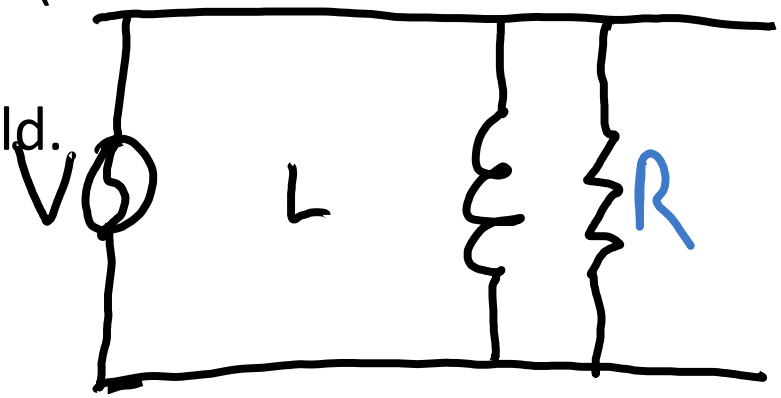
Spin Dressing/Metglas Heating

Metglas Heating

- Eddy current heating from ~1-3 kHz, 5.5 Amp spin dressing B field on Metglas.
- Requires shielding
  - Active Shield (Cos theta coil)
  - Passive Shield.

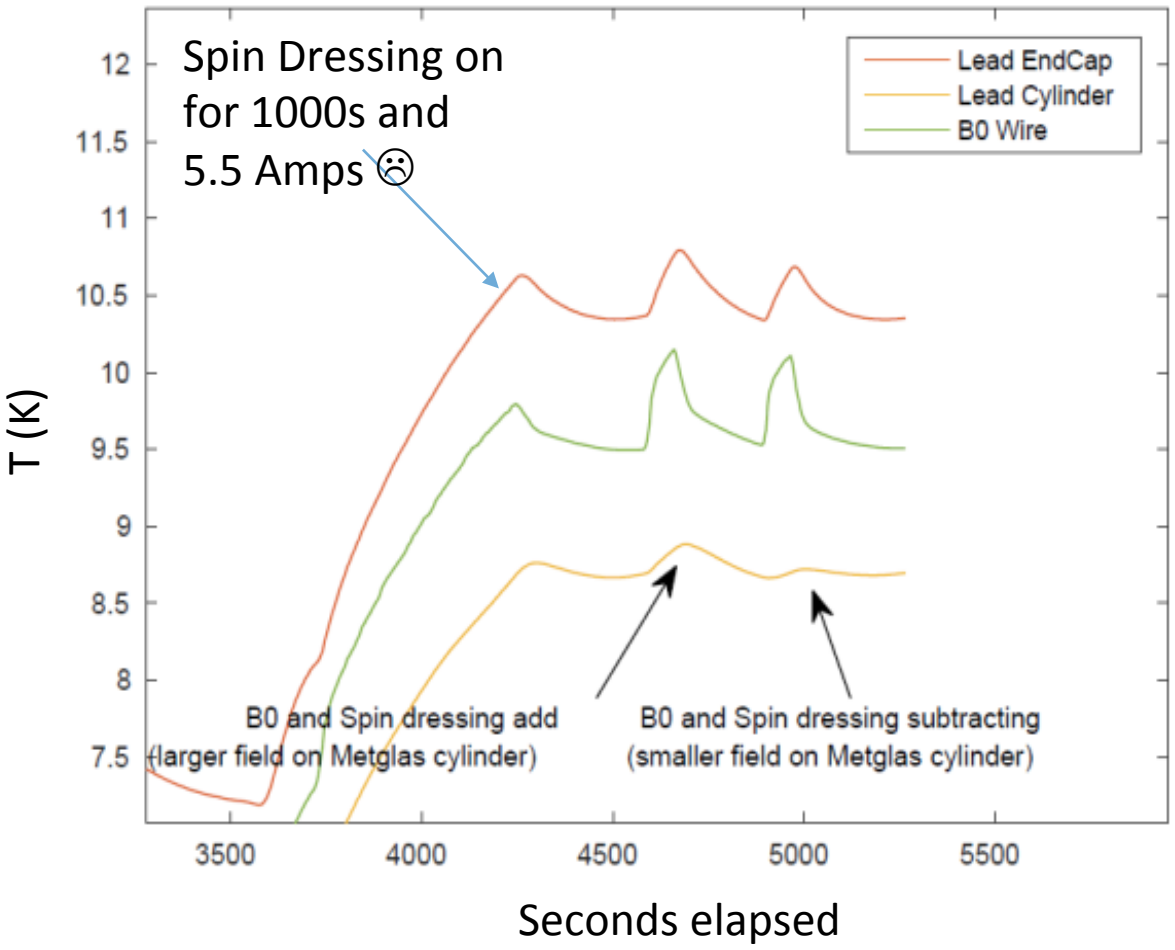
Wire Heating

- Copper cladding on typical NbTi SC wire heats inductively with RF



R from cladding

Dressing Coil Heating - Copper Wire



B0 used as a test for active shield.

A small and unsatisfactory reduction in RF heating is observed (smaller than expected).

Design Constraints for active shield
(~ 1um precision over 1 m) require us to look for alternative solutions.

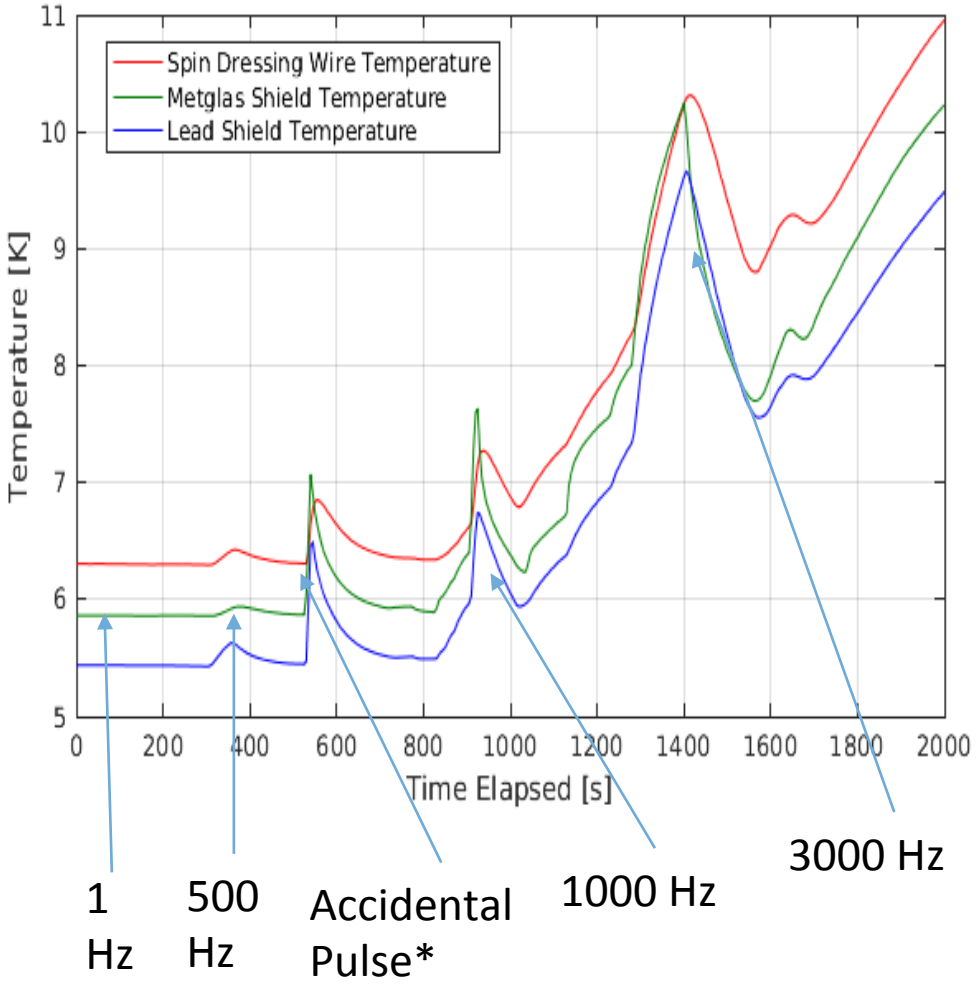
Dressing Coil Alternate Materials

- Wound Coil 50/50 Pb/Sn Solder.
  - Good type 1 superconducting properties. T_C=7.8 K, B_C=0.8 T
- Coated with Teflon. (wirenetics.com)

Dressing Coil Heating – Pb/Sn Wire

Heating of Metglas is visible due to rapid T increase at higher frequencies.

Heating with 15 amps peak to peak



Wire heating is solved

Metglas heating is still large

*unplugged function generator from power supply while supply was active.

Advanced Probe design is nearly completed

Probe extends allowing entry into the warm bore.

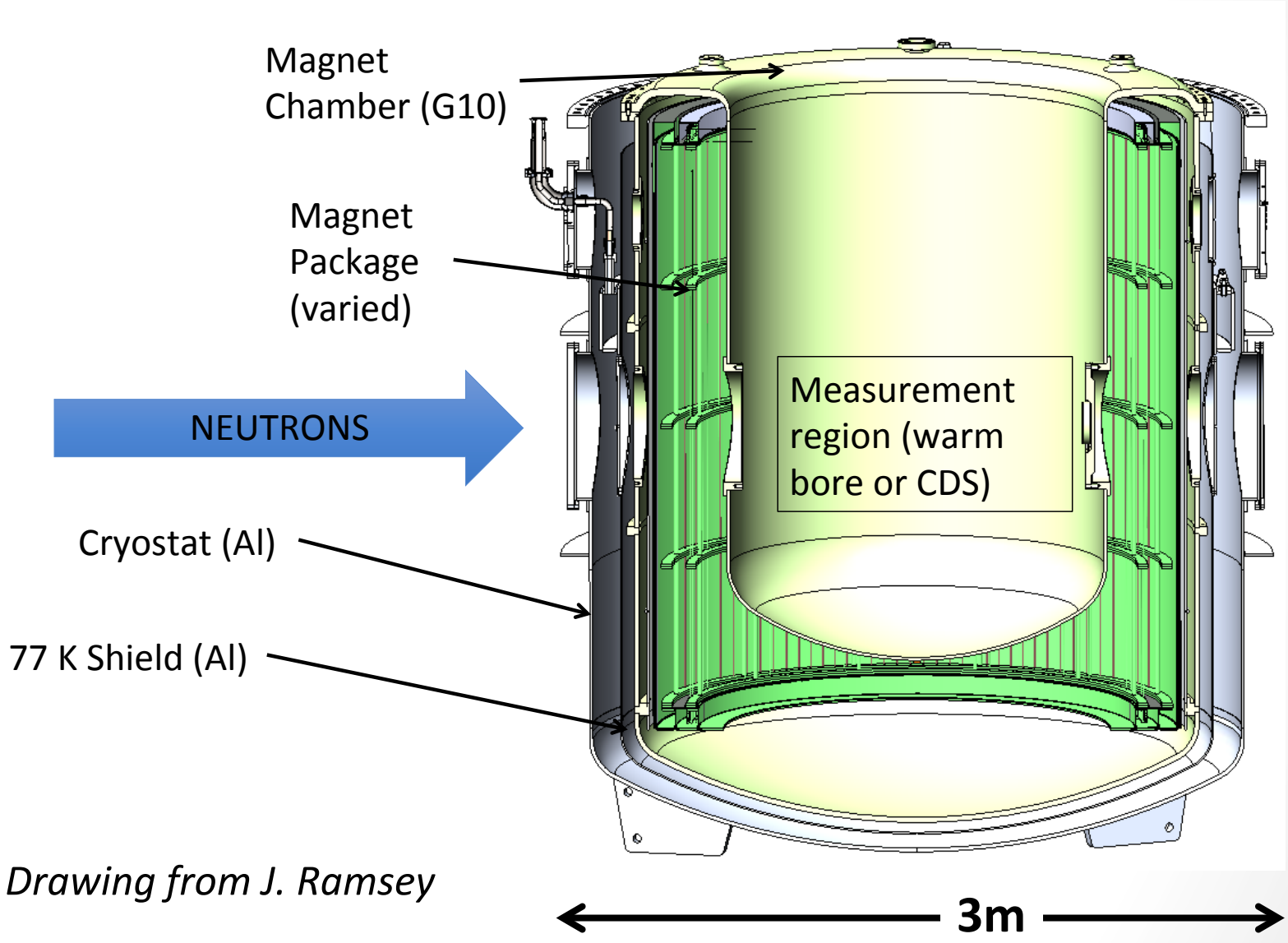
Probe locks in place, allowing:
Rotation
Vertical translation
Translation of the probe on its track.

Verify initial measurements and prepare for full-scale

Future Plans for Prototype

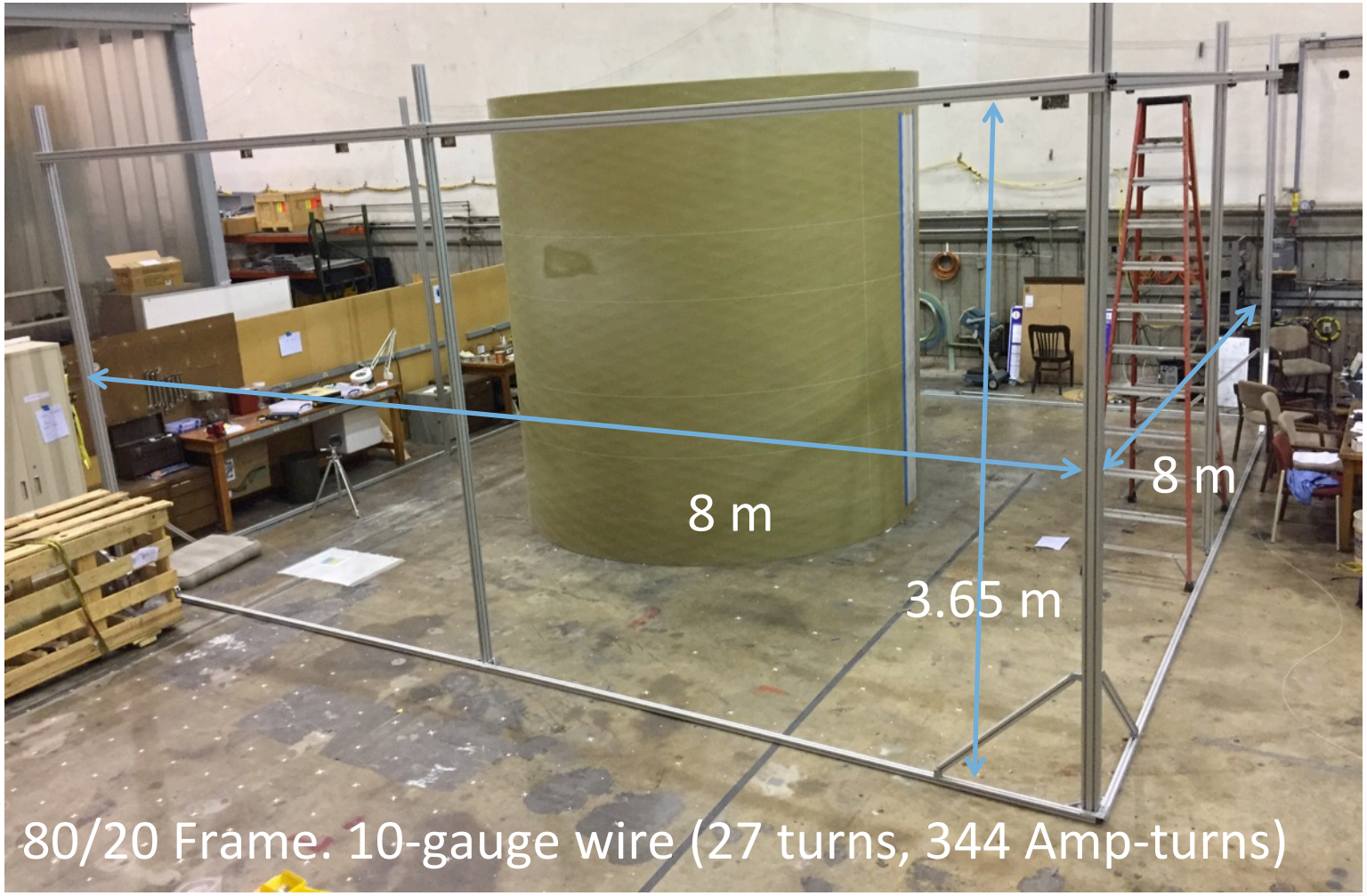
- Test Metglas heating with a copper shield.
- Demonstrate the second generation probe is an adequate design for the full scale magnet.
  - Verify demonstrated fields with the second generation probe.

Full-scale Magnet Construction



Drawing from J. Ramsey

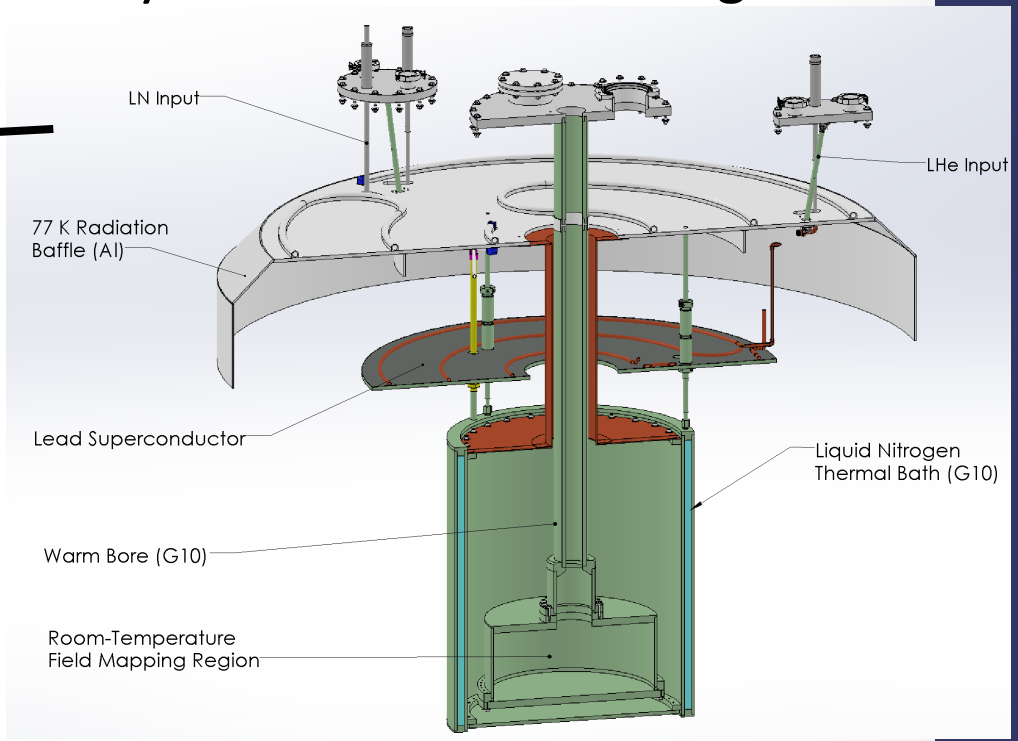
Field Compensation System



80/20 Frame. 10-gauge wire (27 turns, 344 Amp-turns)

Full-scale CIT Test Cryostat

- Dedicated test lid
- Warm bore for mapper – scan cryostat and IMV for magnetism



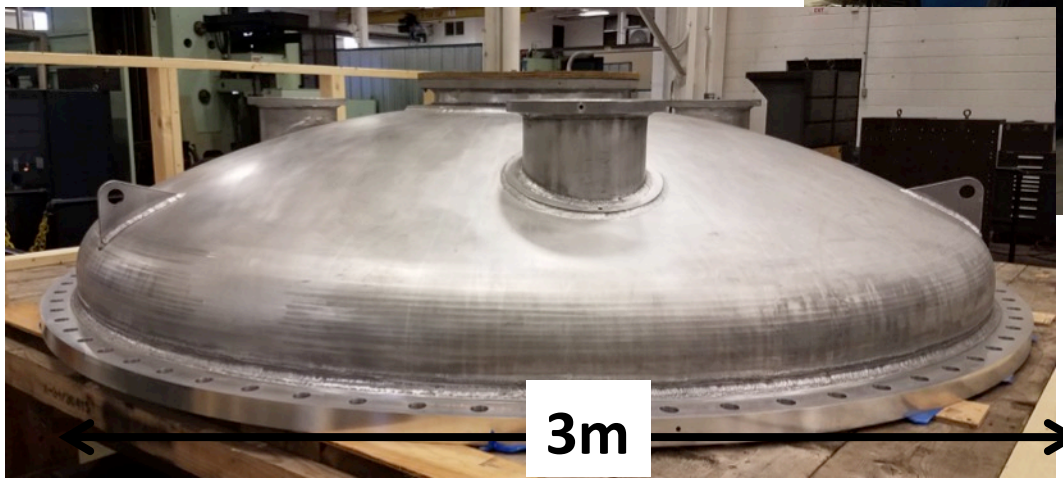
Drawing from J. Ramsey

CIT Test Cryostat

All aluminum

Nearing completion

Keller Technology Corp.

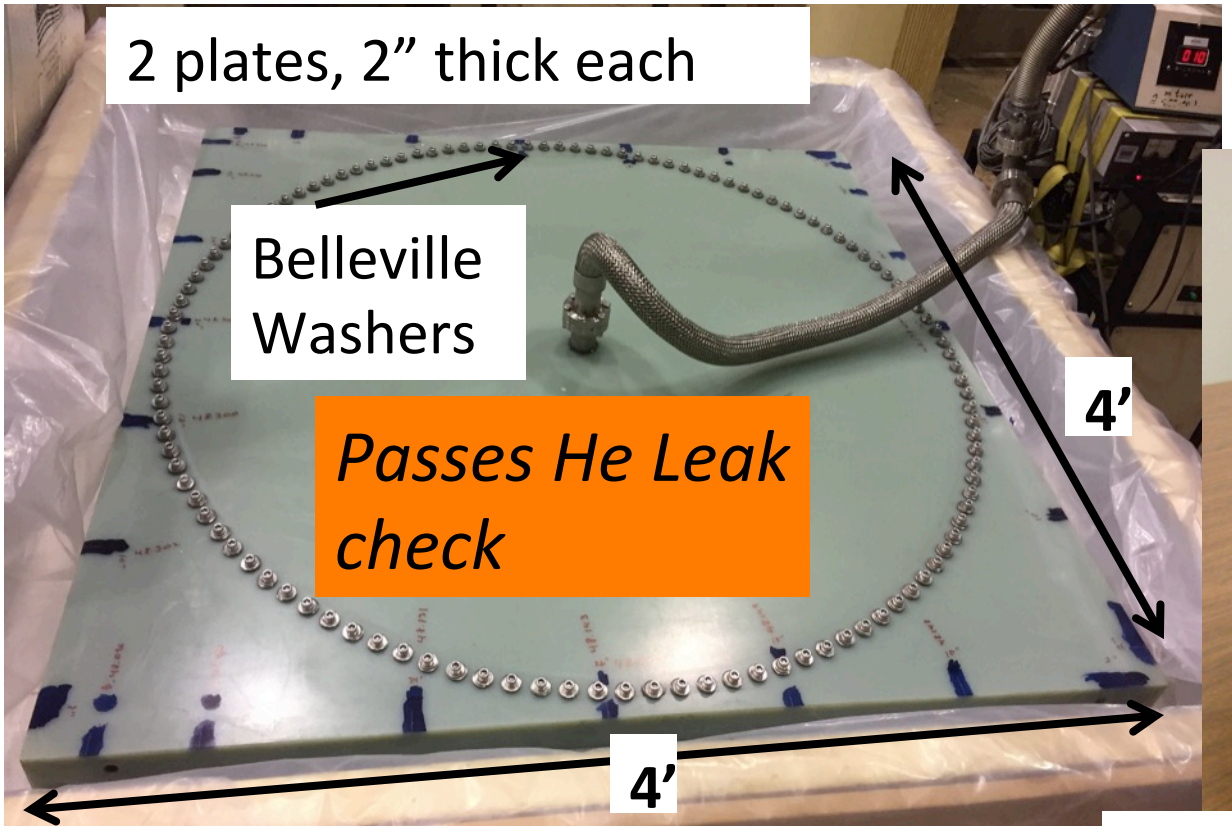


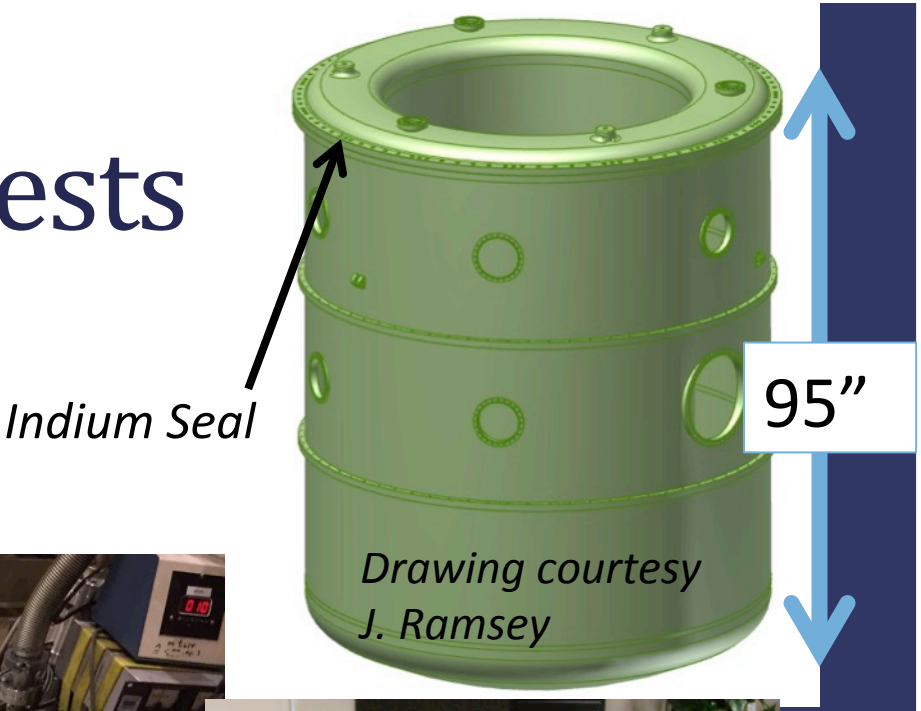
Warm Bore

- All G10 (almost)
- In hand
- Vacuum-tested (at overpressure)

Magnet Volume Tests

- **Entirely G10/FRP**
  - 4'x4' test indium seal on G10 plate





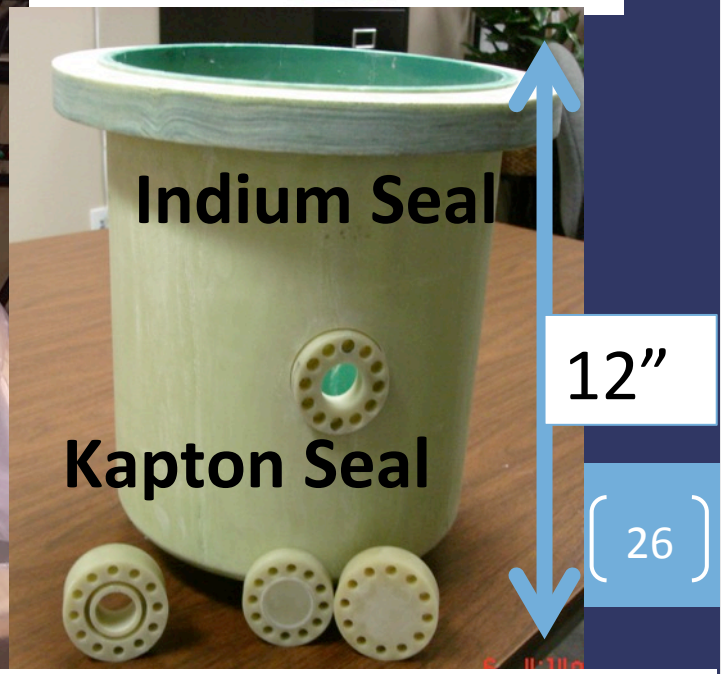
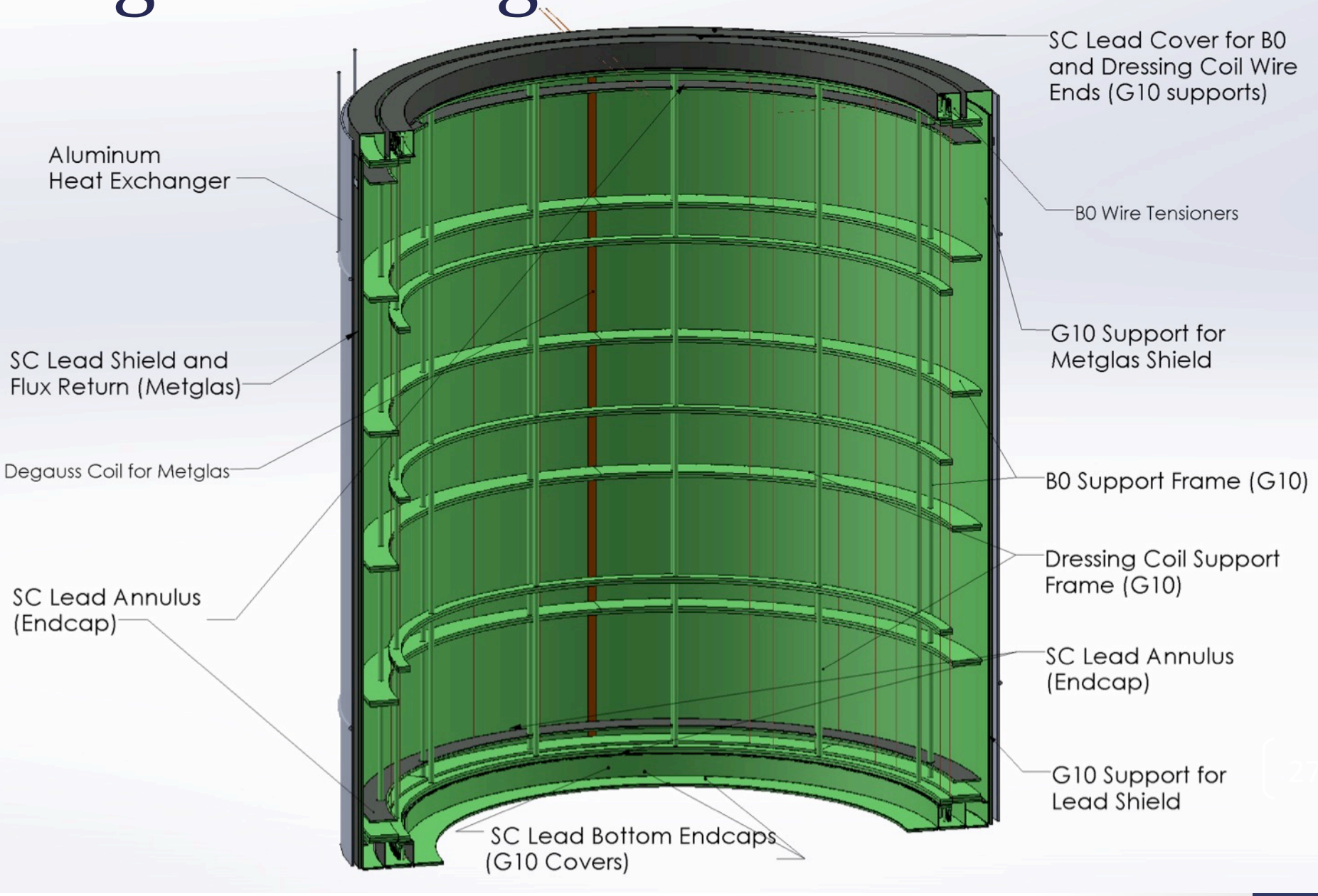


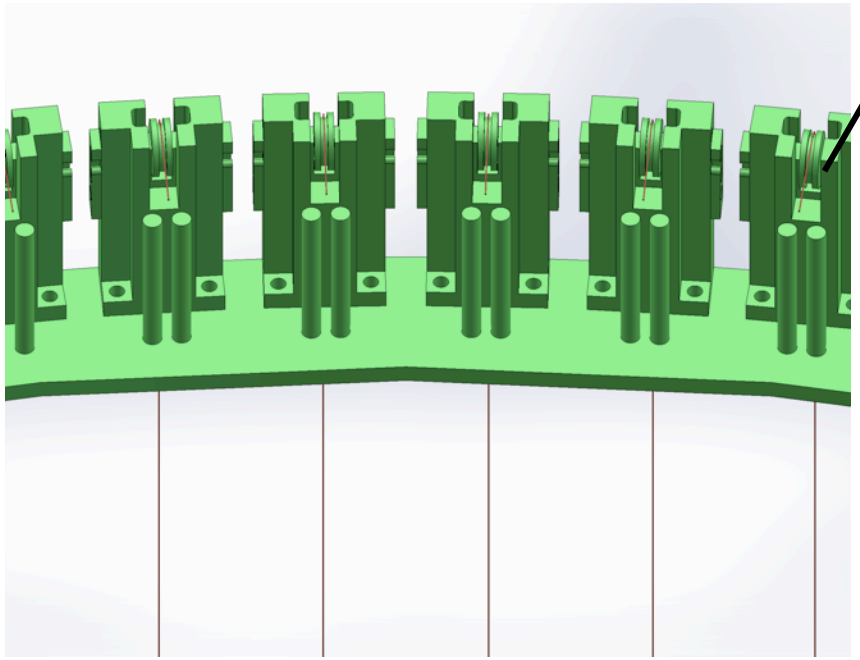
Image from Spencer Composites, Corp.

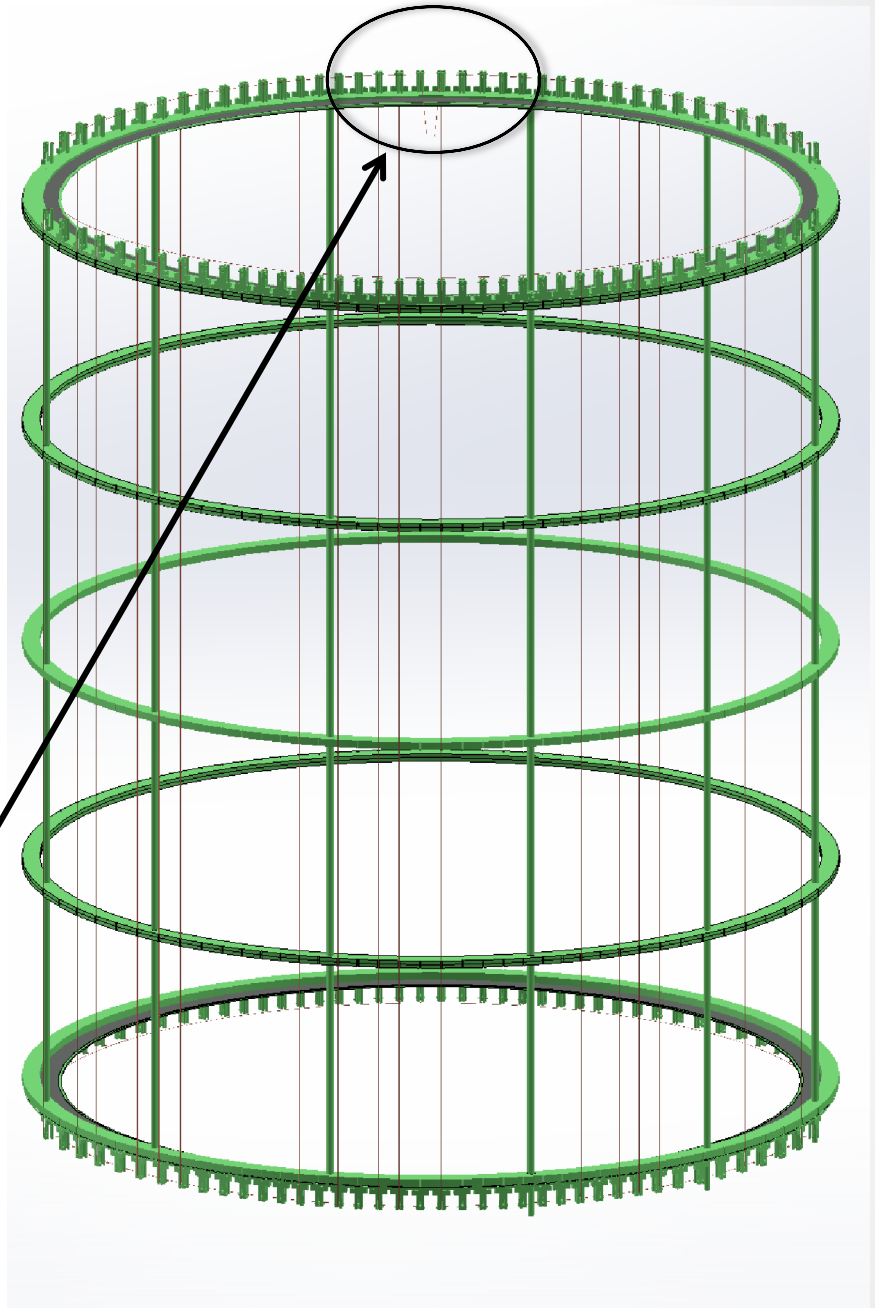
Magnet Package



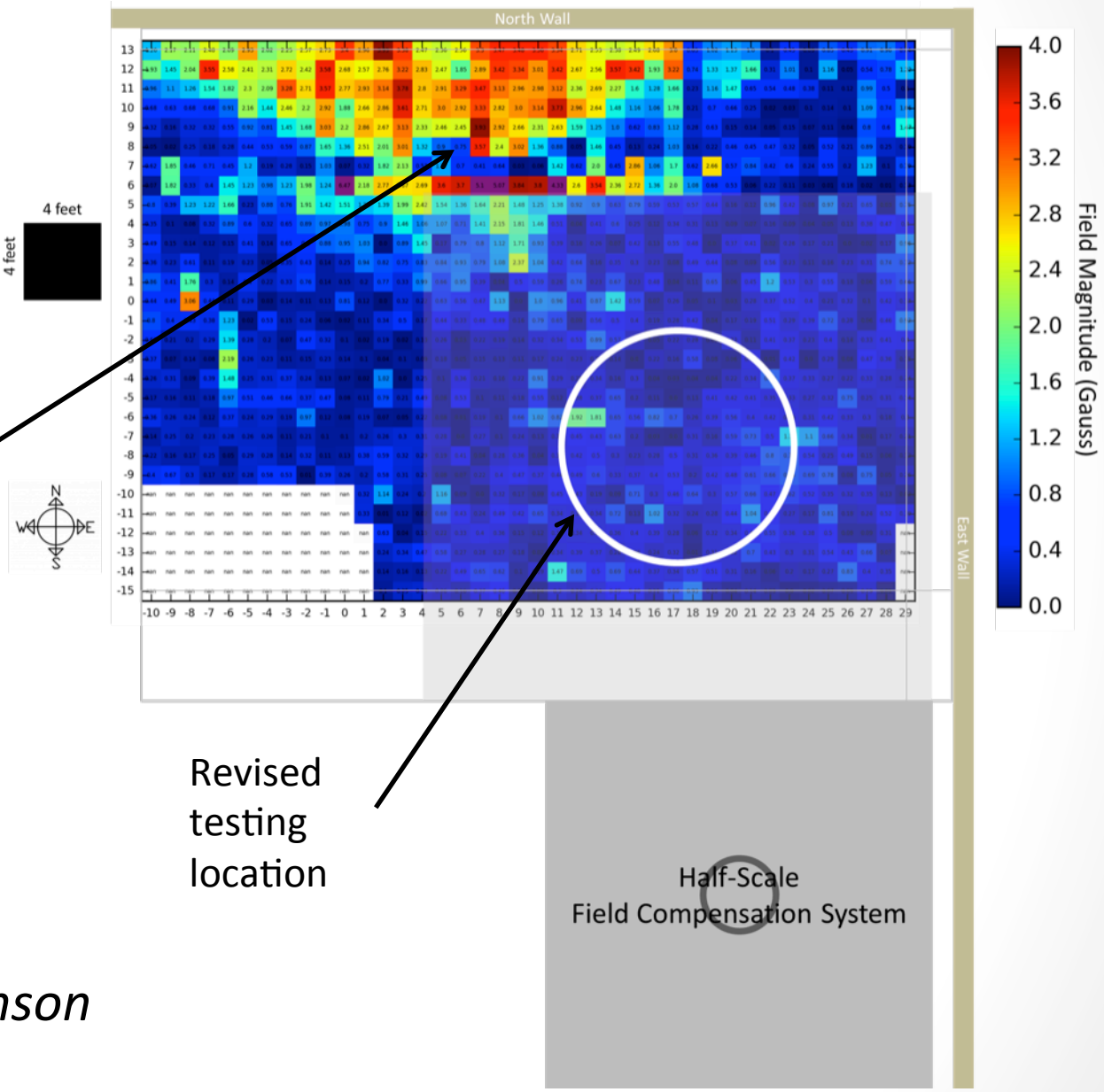
Coil Design

- G10 Frame/Rings
- SC Wire (NbTi)
- Spring loaded with PEEK Springs
- In contact with vendors
- B0 and Dressing coil similar (likely different wire)



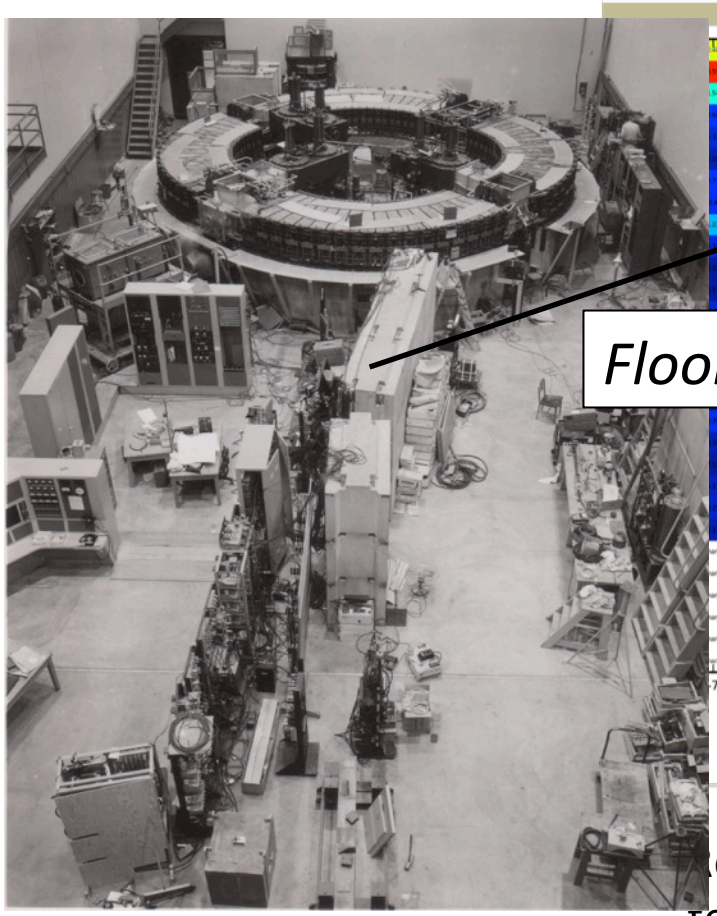


Magnetic Environment at CIT

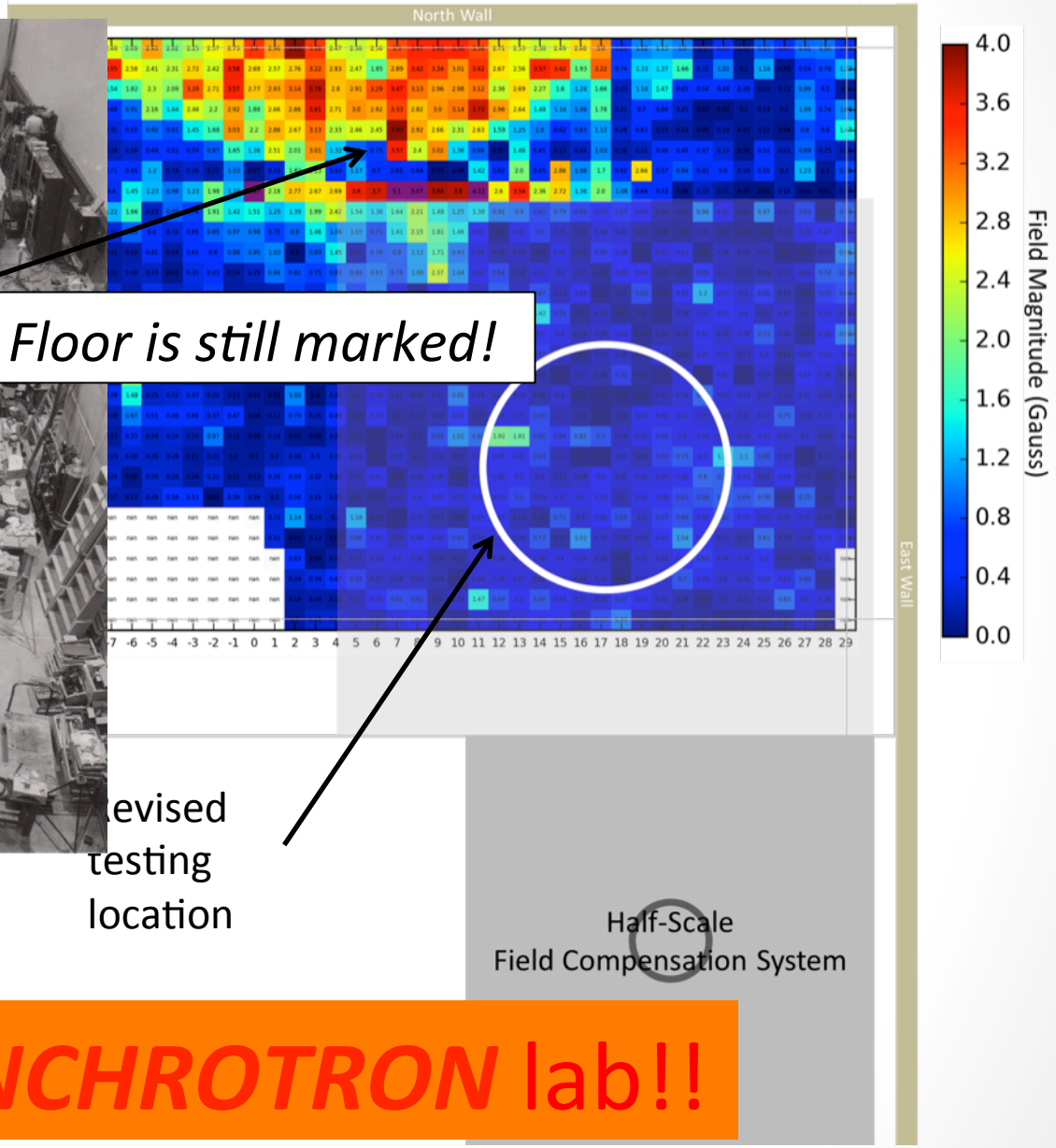


From A. Brinson

Magnetic Environment at CIT



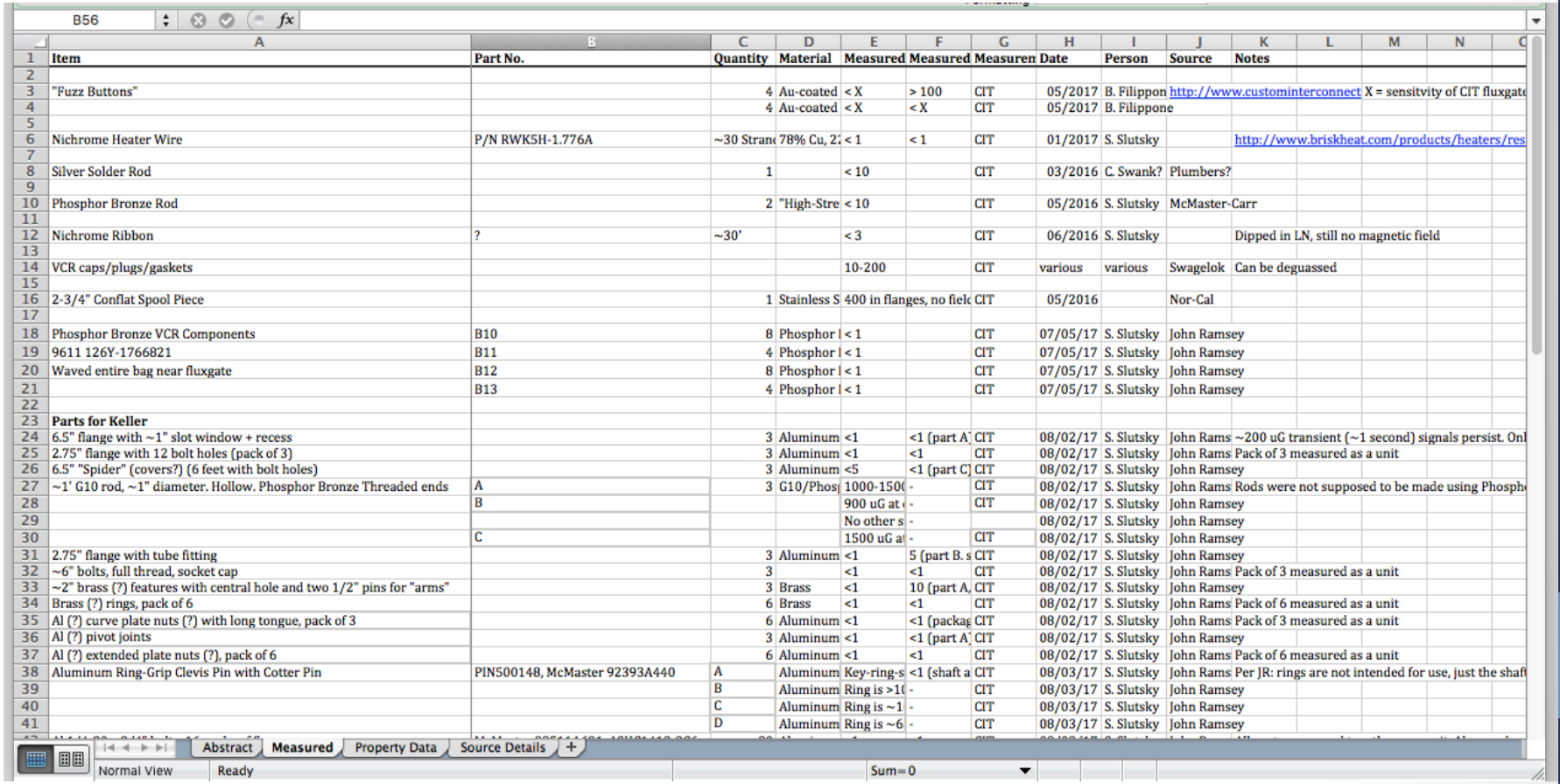
Courtesy Alan Rice



It's the ***SYNCHROTRON*** lab!!

Magnetic Screening

- Carefully pass materials near a fluxgate magnetometer. Noise ~< 1 nanoTesla
- Re-measure after contact with a horseshoe magnet to check magnetizability
- Materials on or inside Cryovessel: **< 100 nanoTesla**



Item	Part No.	Quantity	Material	Measured	Measured	Measuren	Date	Person	Source	Notes
"Fuzz Buttons"		4	Au-coated	< X	> 100	CIT	05/2017	B. Filippon	http://www.custominterconnect	X = sensitvity of CIT fluxgat
		4	Au-coated	< X	< X	CIT	05/2017	B. Filippone		
Nichrome Heater Wire	P/N RWK5H-1.776A	~30 Strar	78% Cu, 2	< 1	< 1	CIT	01/2017	S. Slutsky		http://www.briskheat.com/products/heaters/res
Silver Solder Rod		1		< 10		CIT	03/2016	C. Swank?	Plumbers?	
Phosphor Bronze Rod		2	"High-Stre	< 10		CIT	05/2016	S. Slutsky	McMaster-Carr	
Nichrome Ribbon	?	~30'		< 3		CIT	06/2016	S. Slutsky		Dipped in LN, still no magnetic field
VCR caps/plugs/gaskets				10-200		CIT	various	various	Swagelok	Can be deguassed
2-3/4" Conflat Spool Piece		1	Stainless S	400 in flanges, no fiel		CIT	05/2016		Nor-Cal	
Phosphor Bronze VCR Components	B10	8	Phosphor I	< 1		CIT	07/05/17	S. Slutsky	John Ramsey	
9611 126Y-1766821	B11	4	Phosphor I	< 1		CIT	07/05/17	S. Slutsky	John Ramsey	
Waved entire bag near fluxgate	B12	8	Phosphor I	< 1		CIT	07/05/17	S. Slutsky	John Ramsey	
	B13	4	Phosphor I	< 1		CIT	07/05/17	S. Slutsky	John Ramsey	
Parts for Keller										
6.5" flange with ~1" slot window + recess		3	Aluminum	<1	<1 (part A	CIT	08/02/17	S. Slutsky	John Rams	~200 uG transient (~1 second) signals persist. Onl
2.75" flange with 12 bolt holes (pack of 3)		3	Aluminum	<1	<1	CIT	08/02/17	S. Slutsky	John Rams	Pack of 3 measured as a unit
6.5" "Spider" (covers?) (6 feet with bolt holes)		3	Aluminum	<5	<1 (part C	CIT	08/02/17	S. Slutsky	John Ramsey	
~1' G10 rod, ~1" diameter. Hollow. Phosphor Bronze Threaded ends	A	3	G10/Phos	1000-1500	-	CIT	08/02/17	S. Slutsky	John Rams	Rods were not supposed to be made using Phosph
	B			900 uG at	-	CIT	08/02/17	S. Slutsky	John Ramsey	
				No other s	-		08/02/17	S. Slutsky	John Ramsey	
	C			1500 uG at	-	CIT	08/02/17	S. Slutsky	John Ramsey	
2.75" flange with tube fitting		3	Aluminum	<1	5 (part B. s	CIT	08/02/17	S. Slutsky	John Ramsey	
~6" bolts, full thread, socket cap		3		<1	<1	CIT	08/02/17	S. Slutsky	John Rams	Pack of 3 measured as a unit
~2" brass (?) features with central hole and two 1/2" pins for "arms"		3	Brass	<1	10 (part A,	CIT	08/02/17	S. Slutsky	John Ramsey	
Brass (?) rings, pack of 6		6	Brass	<1	<1	CIT	08/02/17	S. Slutsky	John Rams	Pack of 6 measured as a unit
Al (?) curve plate nuts (?) with long tongue, pack of 3		6	Aluminum	<1	<1 (packag	CIT	08/02/17	S. Slutsky	John Rams	Pack of 3 measured as a unit
Al (?) pivot joints		3	Aluminum	<1	<1 (part A	CIT	08/02/17	S. Slutsky	John Ramsey	
Al (?) extended plate nuts (?), pack of 6		6	Aluminum	<1	<1	CIT	08/02/17	S. Slutsky	John Rams	Pack of 6 measured as a unit
Aluminum Ring-Grip Clevis Pin with Cotter Pin	PIN500148, McMaster 92393A440	A	Aluminum	Key-ring-s	<1 (shaft a	CIT	08/03/17	S. Slutsky	John Rams	Per JR: rings are not intended for use, just the shaf
		B	Aluminum	Ring is >1	-	CIT	08/03/17	S. Slutsky	John Ramsey	
		C	Aluminum	Ring is ~1	-	CIT	08/03/17	S. Slutsky	John Ramsey	
		D	Aluminum	Ring is ~6	-	CIT	08/03/17	S. Slutsky	John Ramsey	

Future Plans

- Continue design and fab of magnet package components
- Aluminum Cryostat/77 K Shield @ CIT
  - Receive and inspect
  - Vacuum Test
  - Evaluate Magnetically
- Prototype G10/FRP Magnet Chambers: vacuum and cryo test at NCSU
- Begin construction of magnet components informed by 1/3-scale prototype studies
- Select vendor and build full-scale Magnet Chamber

SNS nEDM

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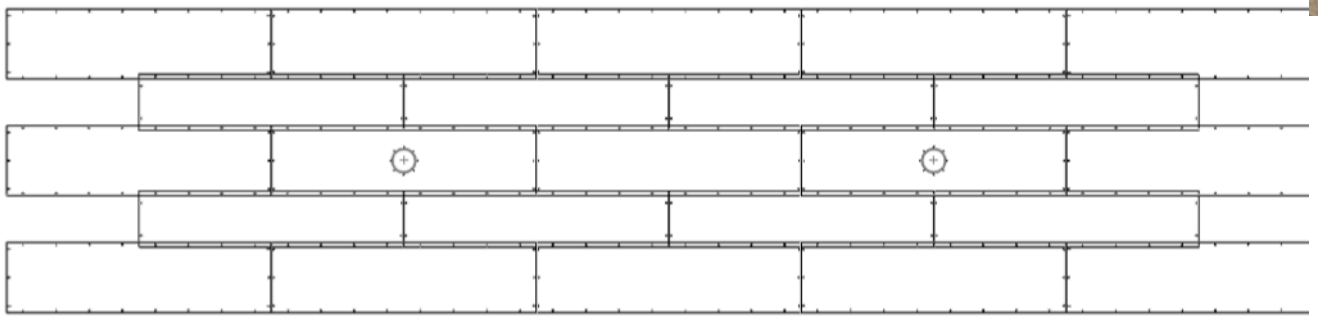
Backup Slide

External Magnetic Shielding

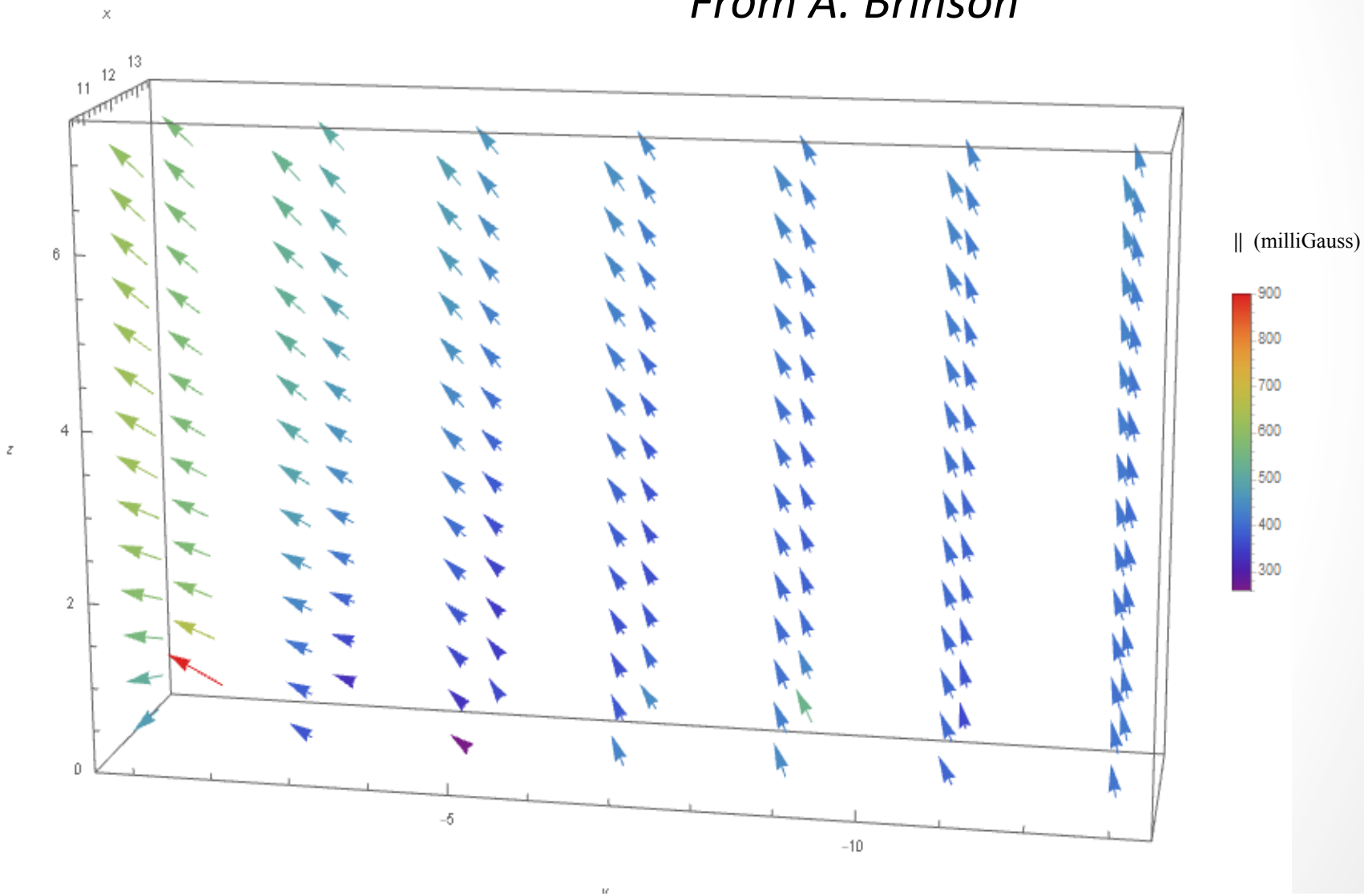
- Mu-Metal/Metglas on FRP form
- Mu-Metal plates wrapped in 5 offset rows
- Mu-Metal Sheets on order



Drawing from W. Wei

Magnetic Environment at CIT

From A. Brinson



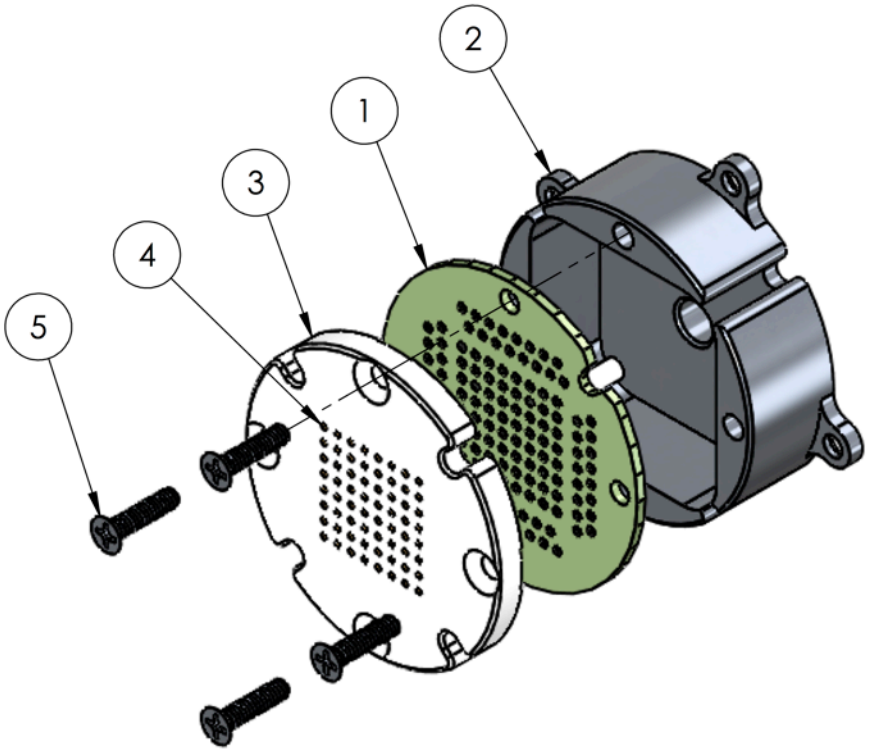
Full-Scale Magnet Package

- Circles Picture

1/3-Scale Magnetic Mapper

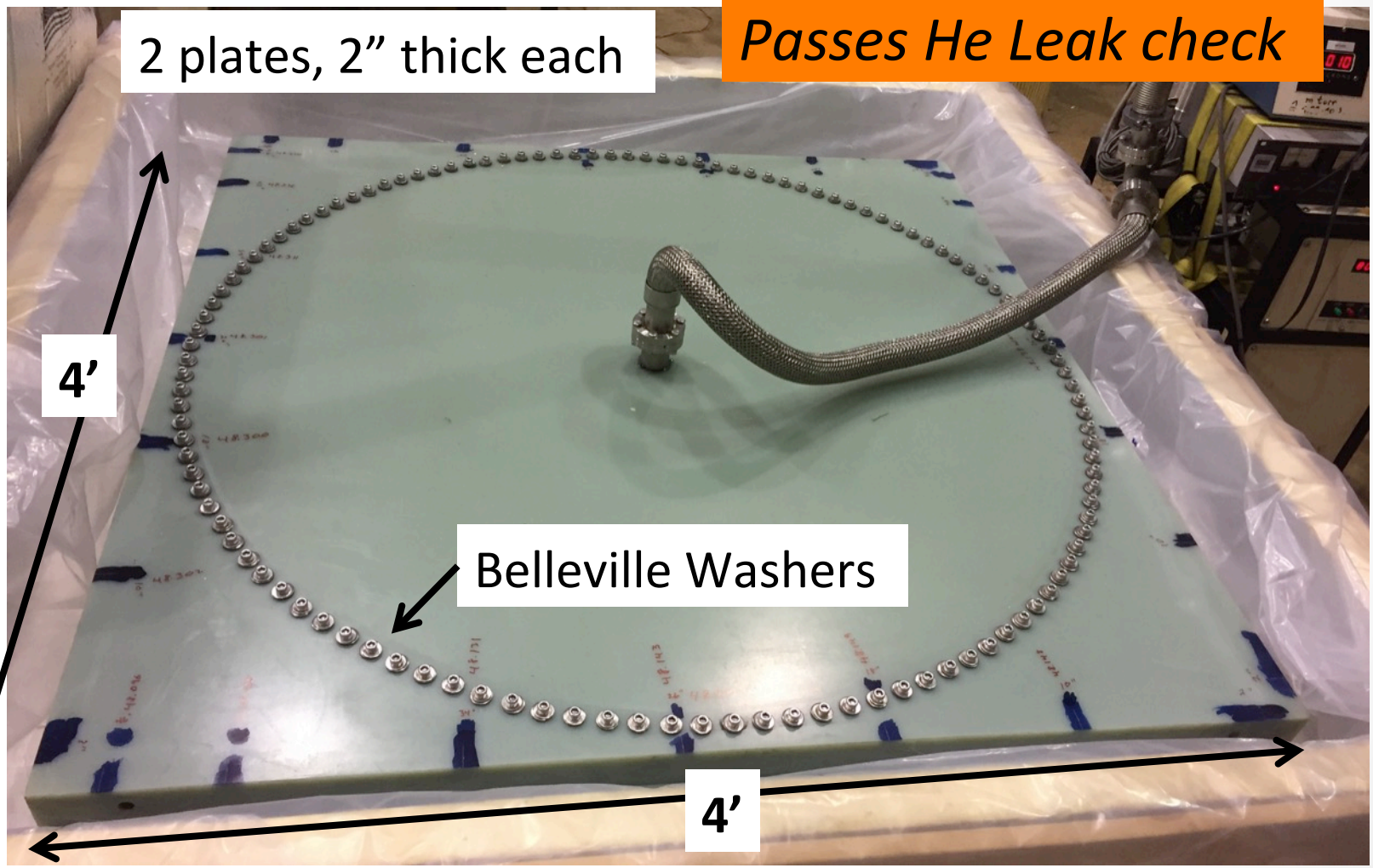
- Linear Travel in the warm bore – can be calibrated
- Smoother motion
- Less out of tolerance
- Prepares for full-scale
- (Picture)

Non-Magnetic Cryo Feedthroughs



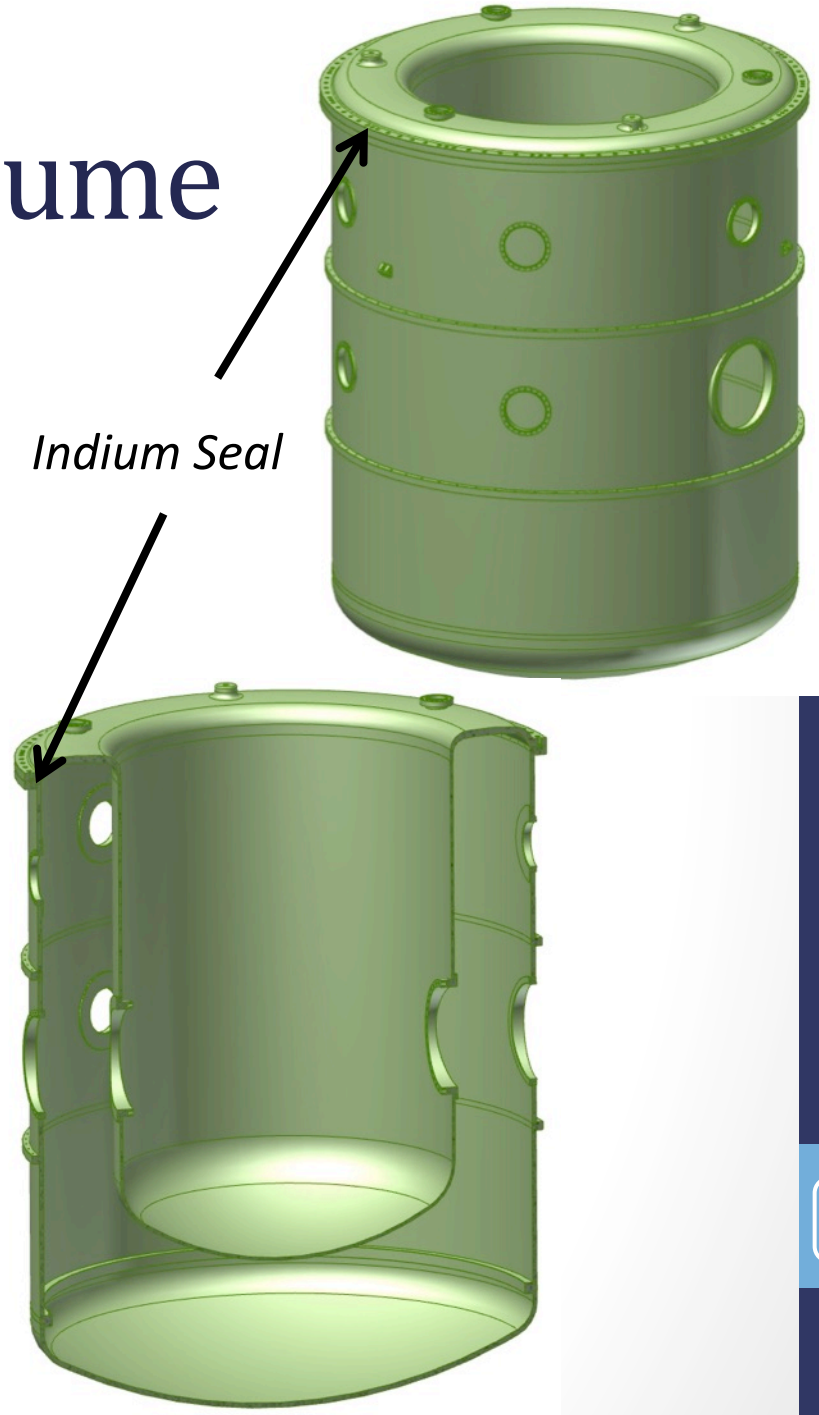
ITEM NO.	PART NUMBER	PartNo	QTY.
1	Feedthrough Test Cable End Backing Plate	N-NEDM-3.01-001-5	1
	edthrough Test ser_Grooved Venting	N-NEDM-3.01-001-6	1
	Fuzz Button	CUSTOM INTERCONNECT STOCK COMPONENTS (.030 DIAMETER X .220 LONG, NO NICKEL FLASH)	64
	97124A139	4-40 x .5 82° ALUMINUM FLAT HEAD MACHINE SCREW (MCMASTER 97124A139 OR EQUIVALENT)	4
	rough Test Mating PC oard_Vac Side	N-NEDM-3.01-001-12	1

G10 Indium Seal Test

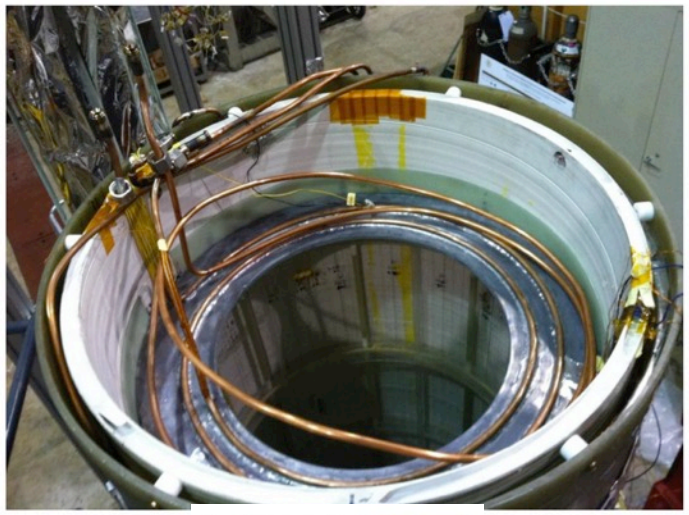


Inner Magnet Volume

- **Entirely G10/FRP**
  - Encouraged by 4'x4' Indium seal on G10 plate (next slide)
- 2 competing vendors
  - Spencer: G10, experienced making scientific components
  - Ershigs: non-G10 FRP, no cryogenic experience (but potential for substantial cost-savings)
- Both companies fab test volumes for cryo/vacuum testing
  - Allows testing sealing technologies (Kapton/Indium) with these materials



½-Scale Protoype Publication



ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

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Cryogenic magnetic coil and superconducting magnetic shield for neutron electric dipole moment searches

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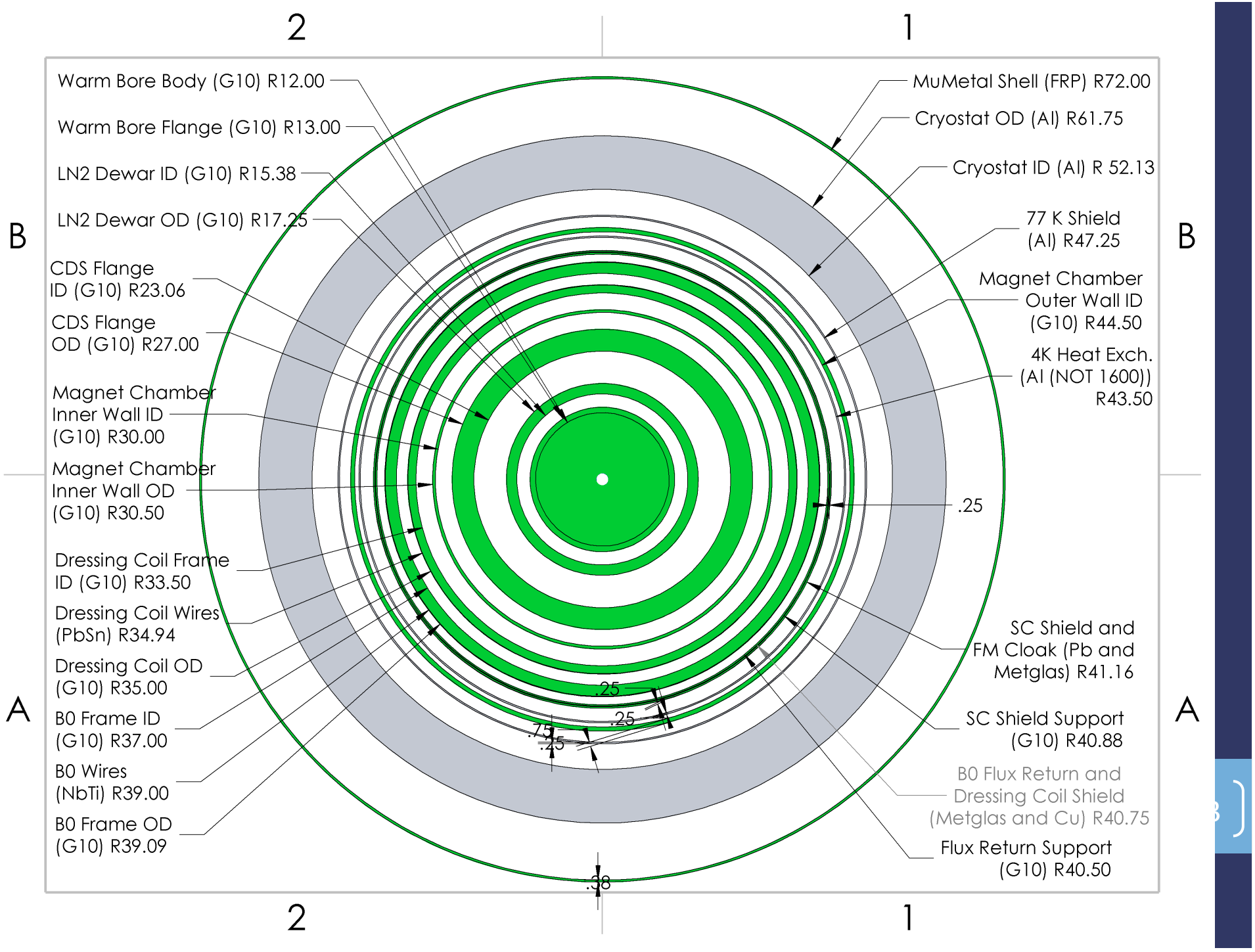
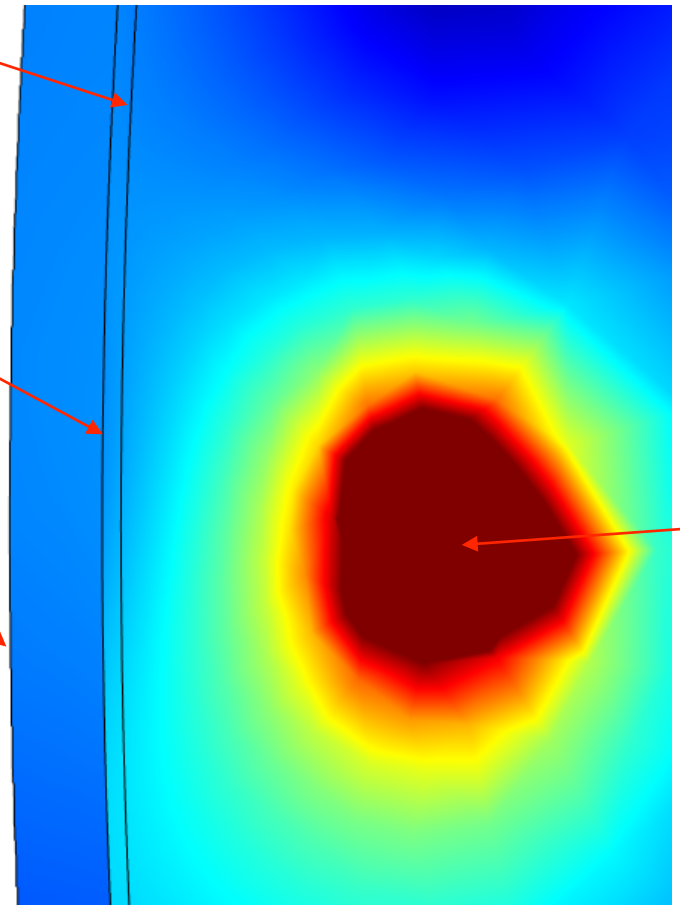
Abstract


2
1
B
B
A
A
2
1
Warm Bore Body (G10) R12.00
Warm Bore Flange (G10) R13.00
LN2 Dewar ID (G10) R15.38
LN2 Dewar OD (G10) R17.25
CDS Flange ID (G10) R23.06
CDS Flange OD (G10) R27.00
Magnet Chamber Inner Wall ID (G10) R30.00
Magnet Chamber Inner Wall OD (G10) R30.50
Dressing Coil Frame ID (G10) R33.50
Dressing Coil Wires (PbSn) R34.94
Dressing Coil OD (G10) R35.00
B0 Frame ID (G10) R37.00
B0 Wires (NbTi) R39.00
B0 Frame OD (G10) R39.09
MuMetal Shell (FRP) R72.00
Cryostat OD (Al) R61.75
Cryostat ID (Al) R 52.13
77 K Shield (Al) R47.25
Magnet Chamber Outer Wall ID (G10) R44.50
4K Heat Exch. (Al (NOT 1600)) R43.50
.25
SC Shield and FM Cloak (Pb and Metglas) R41.16
SC Shield Support (G10) R40.88
B0 Flux Return and Dressing Coil Shield (Metglas and Cu) R40.75
Flux Return Support (G10) R40.50
.25
.25
.75
.25
.38

Spin Dressing/Metglas Heating Simulations (COMSOL)

Location to add a copper shield (PLACE HOLDER)



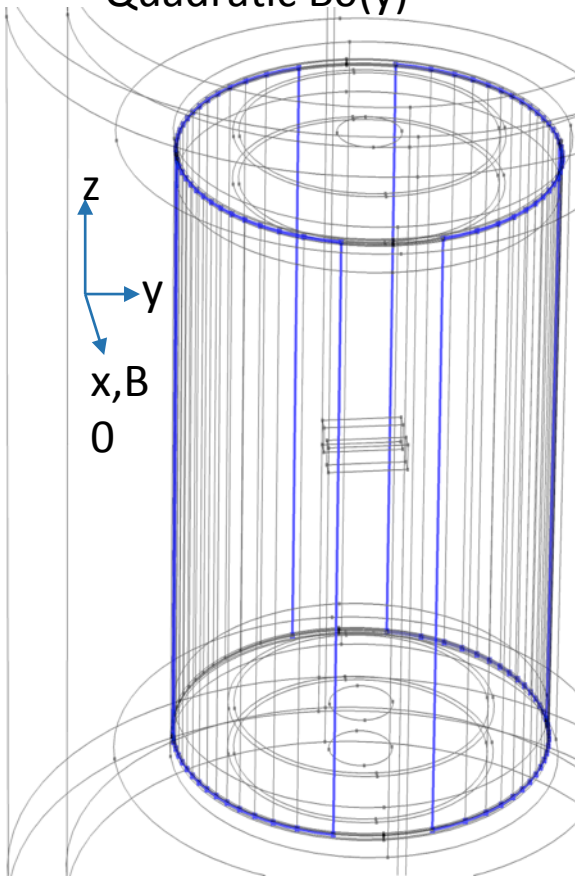
Metglas Shield

Lead Shield

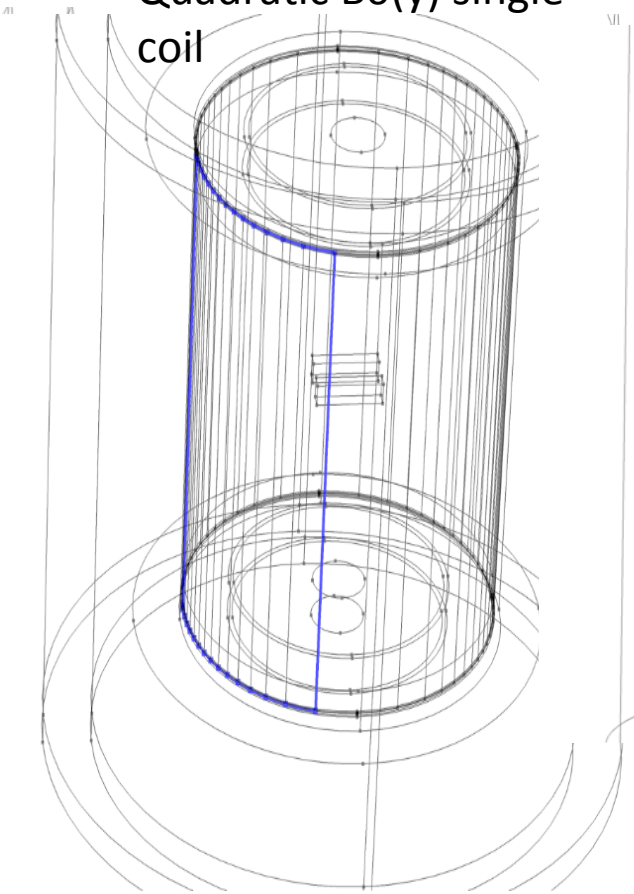
A wire position

B0 shim coils

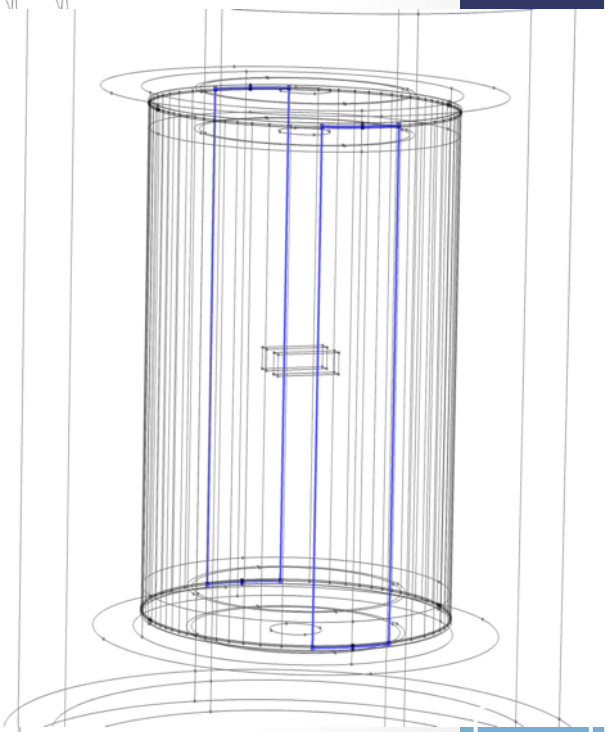
Gradient and Quadratic B0(y)



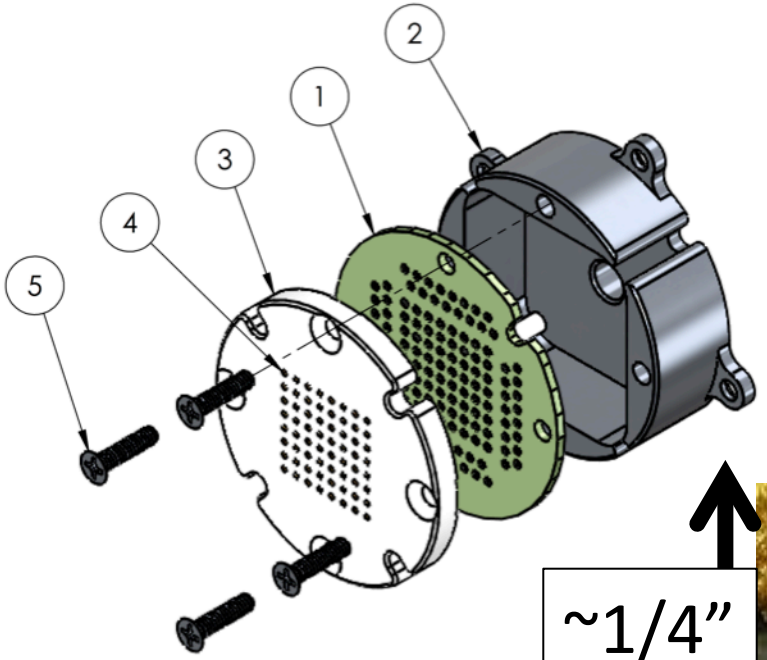
Gradient and Quadratic B0(y) single coil



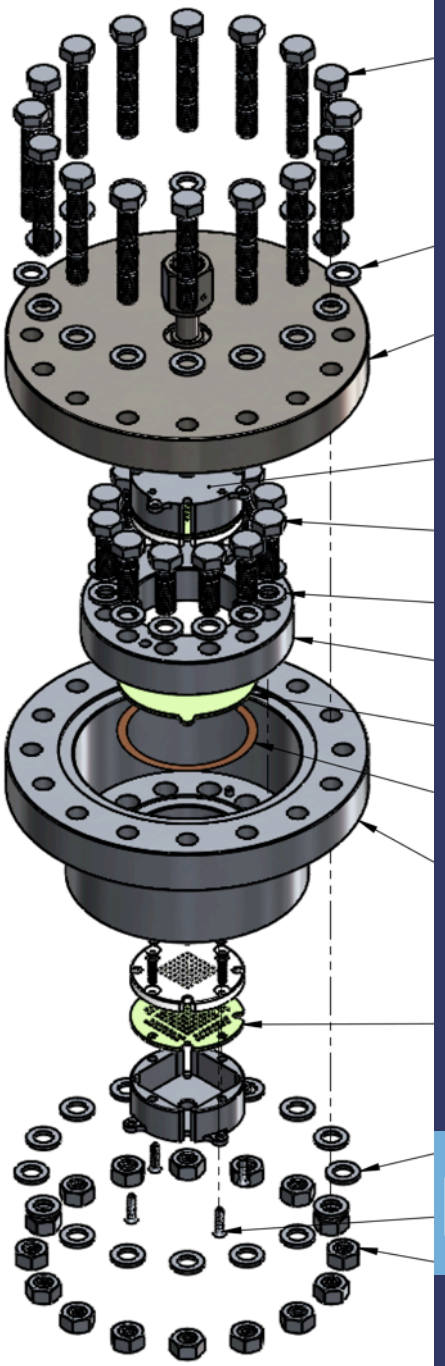
B0(x) Shim



From C. Swank



Drawings courtesy J. Ramsey

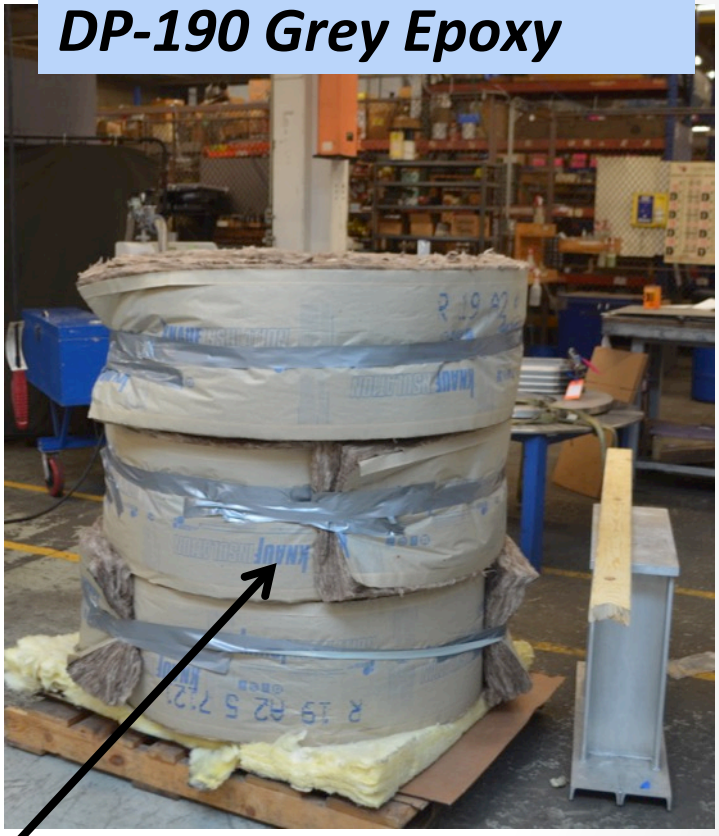


Non-Magnetic Cryo Feedthroughs

- “Fuzz Buttons” (*Custom Interconnects, LLC)*
- Au-coated BeCu, tested non-magnetic
- In-house G10 Connector plate, cabling

77 K Shield for Warm Bore

Drawing Courtesy L. Bartoszek



LN bath (G10) in Fabrication at *Meyer Tool*

Magnet Volume Test

- Fab test volumes for cryo/ vacuum/superfluid leak testing of
  - Material Integrity
  - Indium Seal
  - Kapton Seals (not for IMV but informs CDS design)
- 2 competing vendors
  - ***Spencer***: G10, experienced making scientific components
  - ***Ershigs***: non-G10 FRP, no cryogenic experience (but potential for substantial cost-savings)

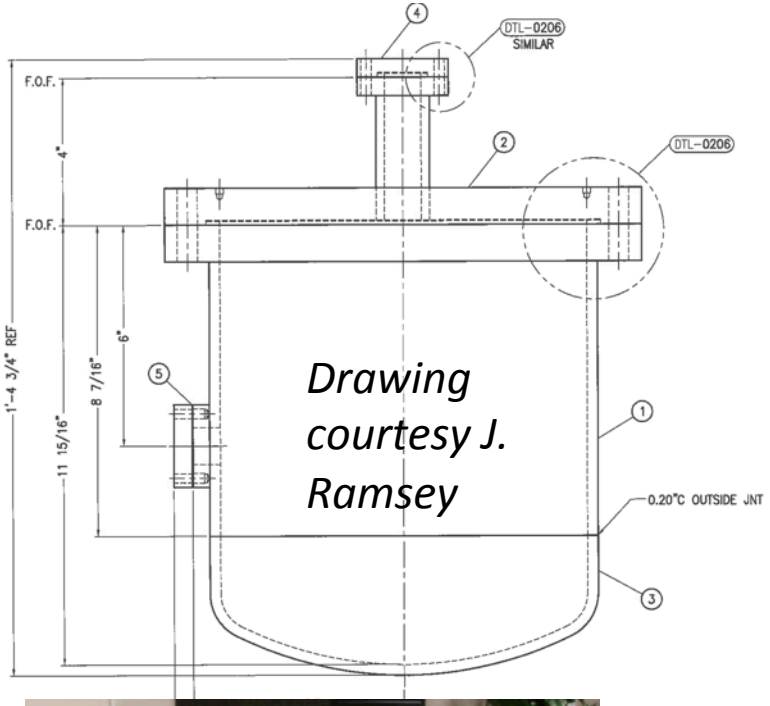


Image from Spencer Composites, Corp.