Critical Current Probe

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NHMFL

Applied Superconductivity Center

Overview

- Introduction
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  - YBCO/BSCCO
- Project Overview
  - Objective
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- Design
  - Possible solutions
  - Selected solutions
- Final Design
  - 3D model
  - Manufacturing and assembly
- Results
  - Economics
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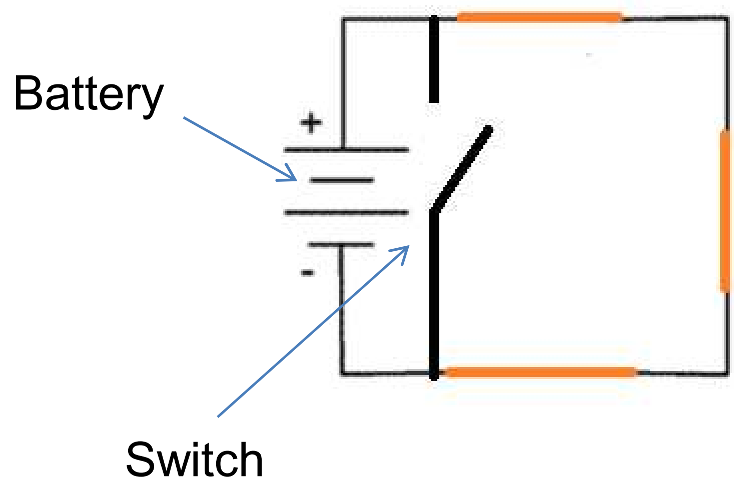
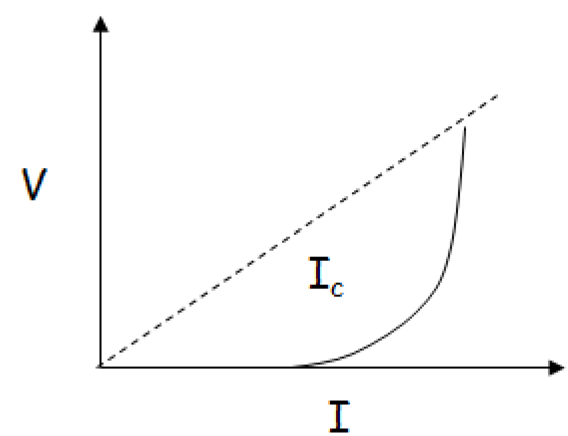
- Conclusions

Superconductivity/Critical Current

- **Superconductivity allows current to flow indefinitely because of negligible or zero resistance.**

- **Critical current probes measure how much current a sample can take before it transitions to the normal state**
  - **Criteria**
    - **Temperature**
      - **4.2 Kelvin, 77 Kelvin**
    - **Magnetic Field**
      - **For test constant field**





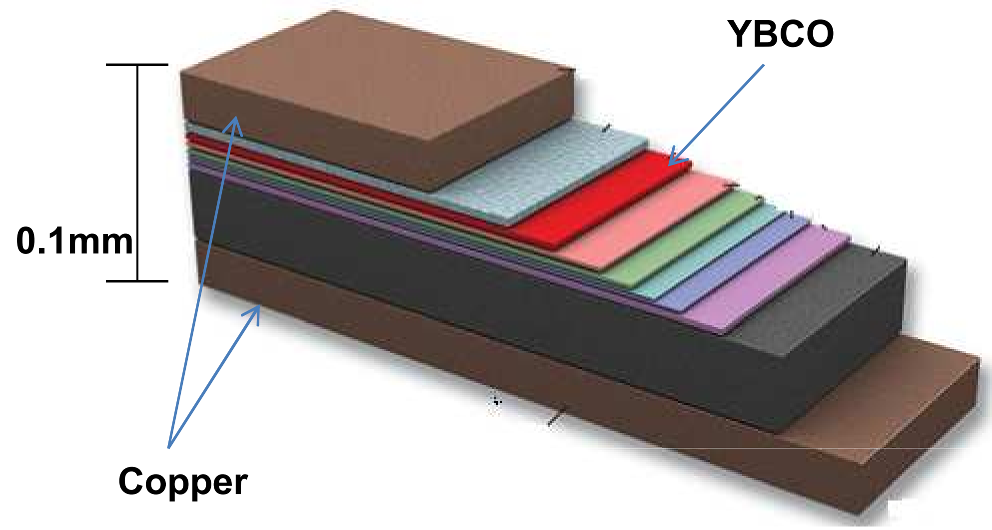
Superconducting Materials

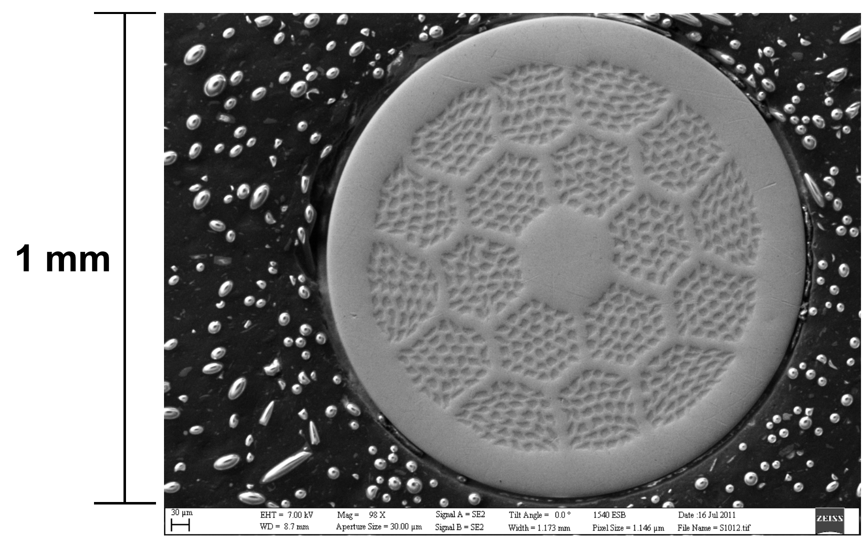
- **YBCO is used in project**
  - **Yttrium Barium Copper Oxide**
  - **HTS (High Temperature Superconductor, 77K)**
  - **Tape**

- **Samples made of BSCCO**
  - **(Bismuth Strontium Calcium Copper Oxygen)**
  - **HTS**
  - **Wire**

- **Samples are mounted at the base of two current leads that run the length of the probe**

- **Submerged in cryogenic liquid**

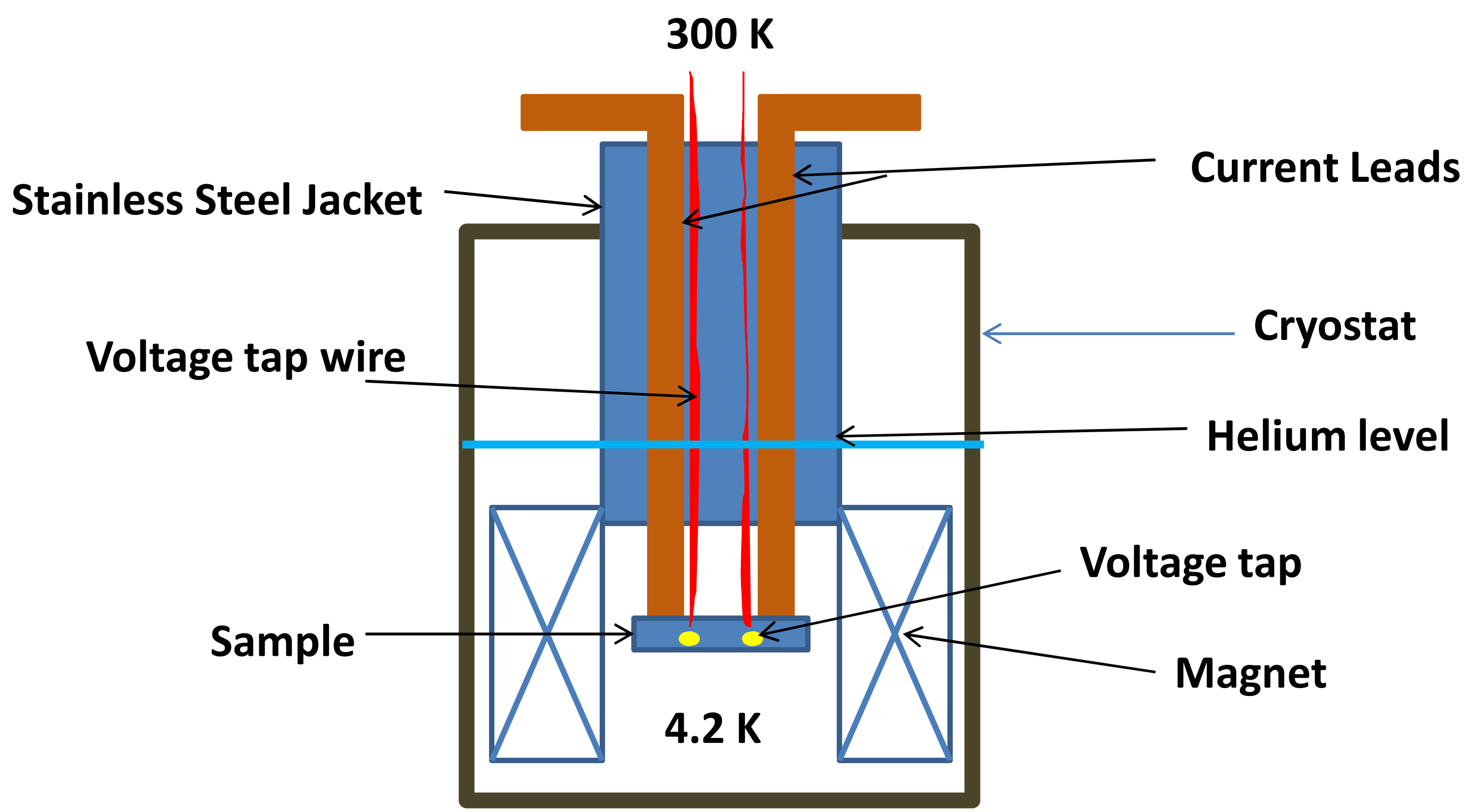




http://www.magnet.fsu.edu/

The Project

- Design a critical current probe to test superconducting samples at cryogenic temperatures.

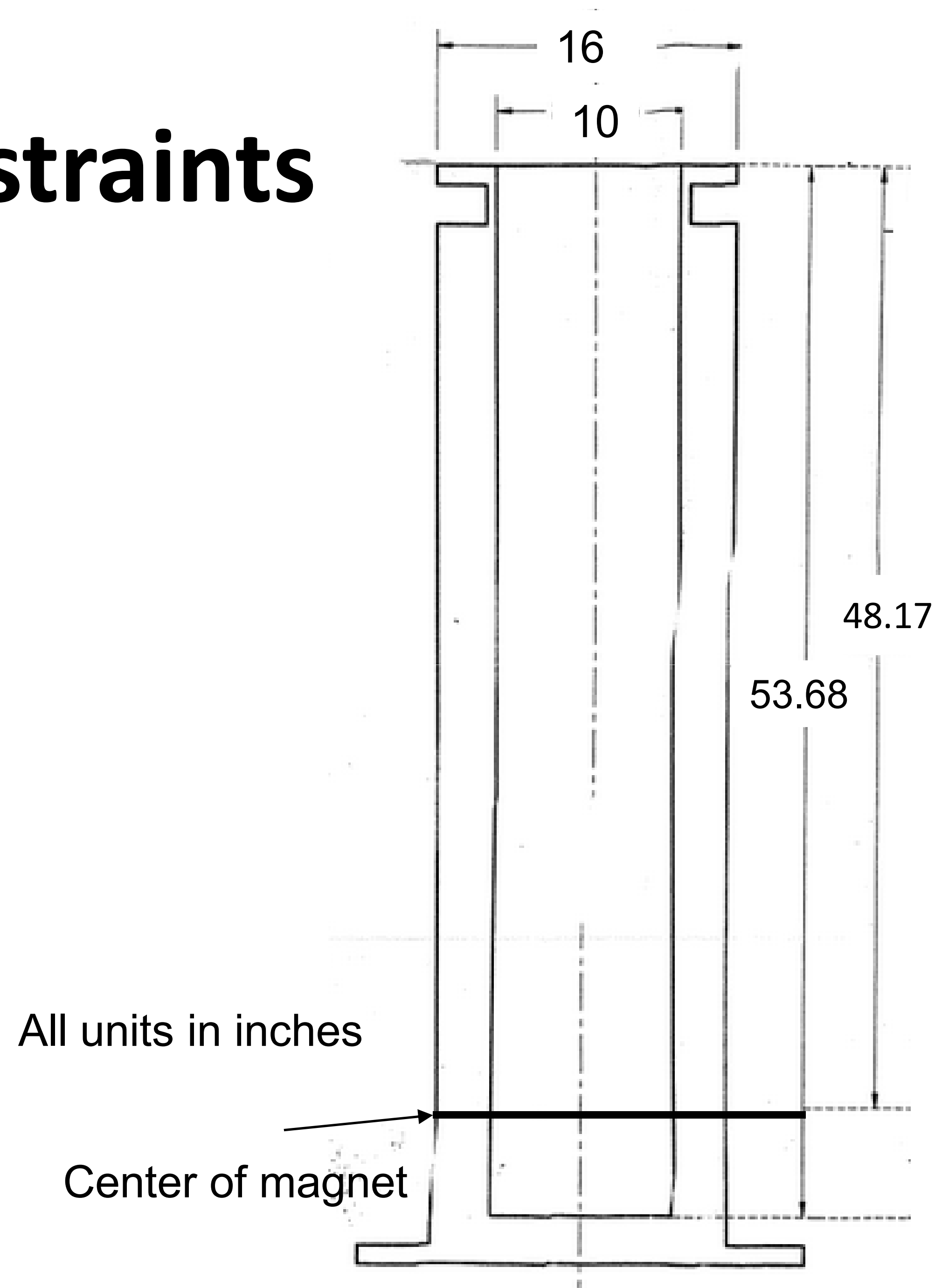


Objectives

- Save Helium
  - $5 per liter
  - Currently uses 100-120 liters a run
  - Weekly tests = $26,000
- Durability
  - Used weekly over many years
- Test 6-8 short samples per test
  - Reduce number of tests
- Able to test one spiral sample per run
- Deliver 1000 A to the samples
- Reduce Weight

Constraints

- **Cryostat**
  - Probe must properly fit inside the cryostat
  - Entrance diameter (2.5in)
  - Length to center of magnet
- **Customer**
  - Test 6-8 samples
  - Budget of $4000



Possible Solutions

Ways to Reduce Helium Consumption

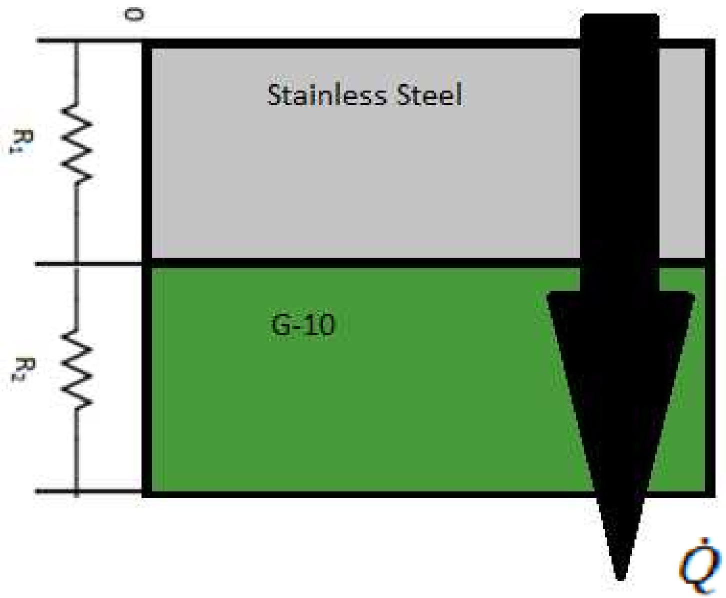
- **Heat Exchanger**
  - **Using He Vapor to cool top of leads**
- **HTS Leads and support**
  - **Remove copper leads from He bath**
- **Number of Leads**
  - **optimization**
- **Fins**
  - **Over length of vapor cooled leads**
- **Gas Insulation**
- **Jacket Design**

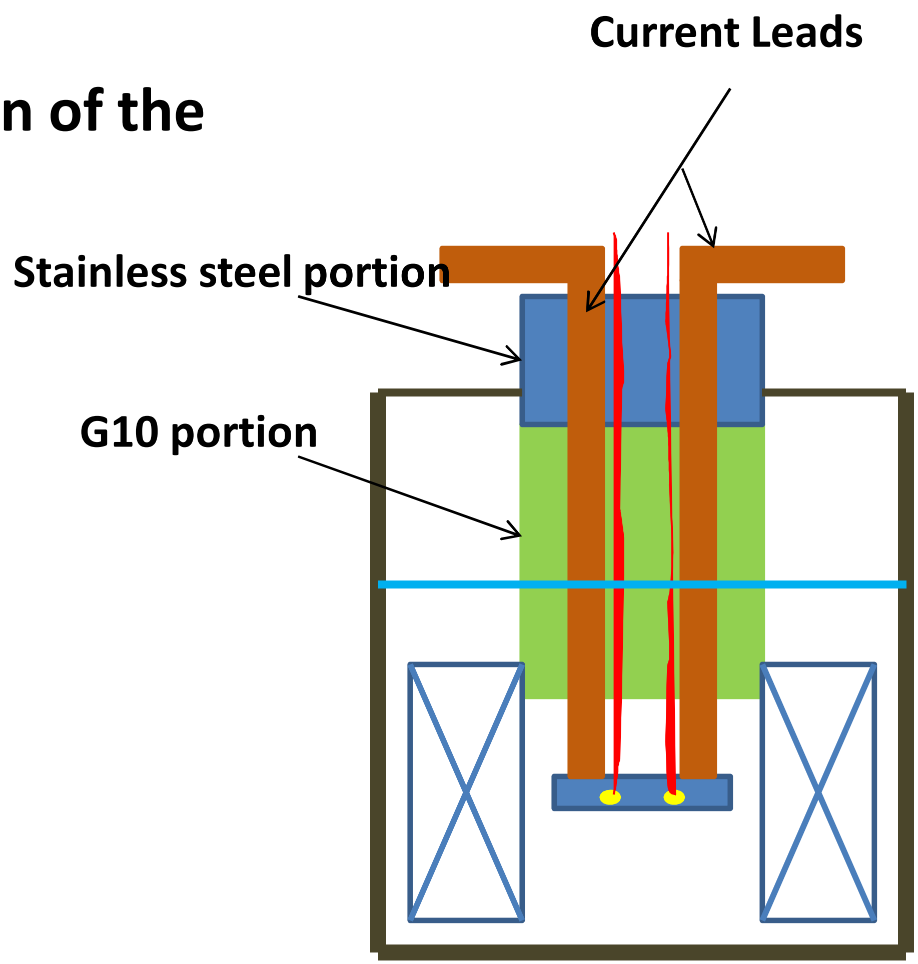
Concepts	He Savings per test (L)	Practical	Accepted
Heat Exchanger	---	Impractical	no
HTS Lead and Support	≤ 26%	Modified	yes
Number of Leads	≤ 22%	Yes	Yes
Fins	9%	Impractical	no
Gas Insulation	---	Impractical	no
Jacket Design	.2%	Modified	yes

Jacket Design

- G-10 fibrous glass epoxy
- Reduces thermal conduction of the stainless steel tube

$$\dot{Q} = -kA\frac{dT}{dx}$$

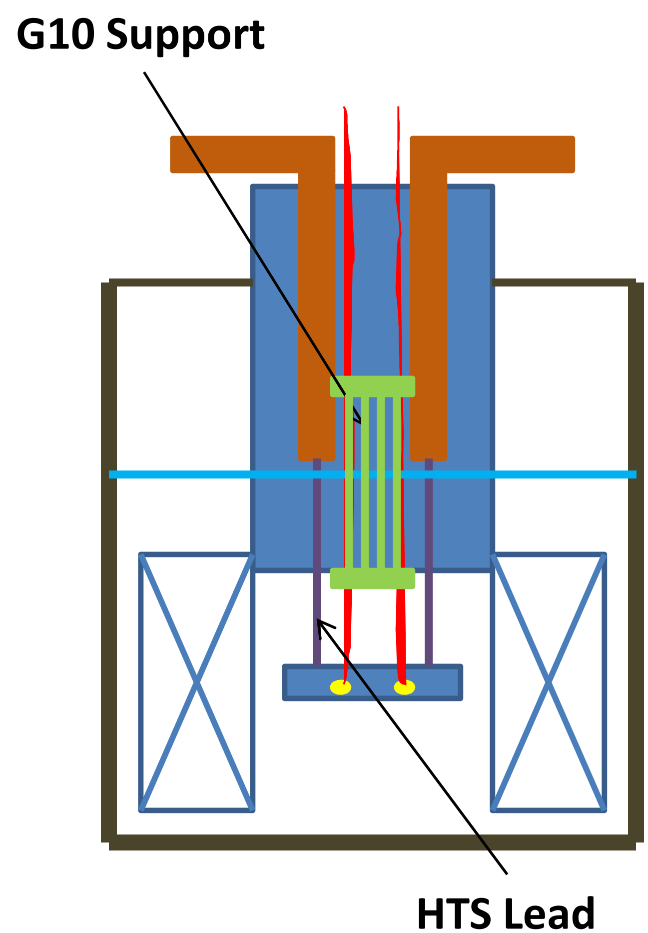




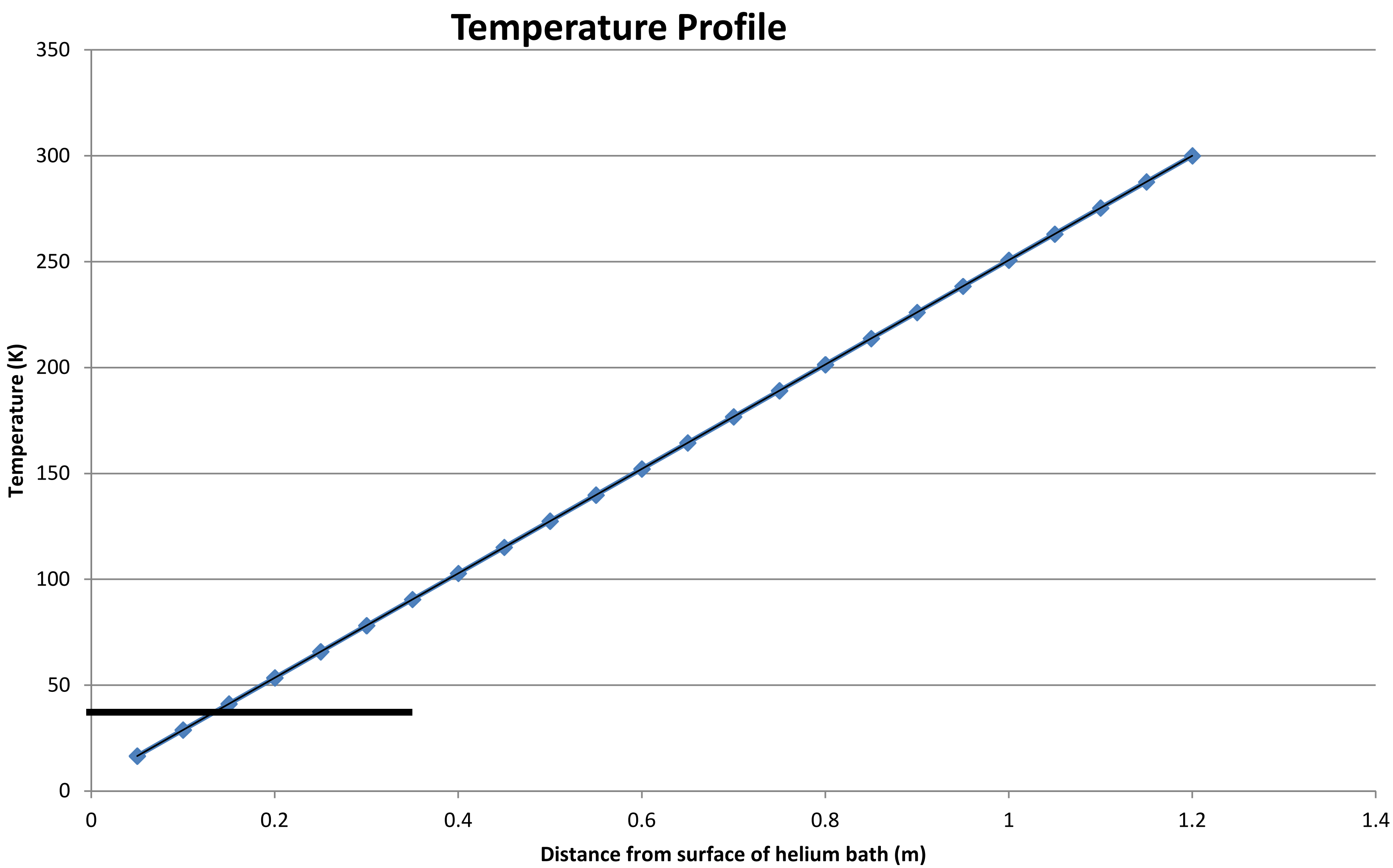
HTS Leads and support

- YBCO <u>Low thermal conductivity</u> with <u>high electrical conductivity</u>
- Prevents copper leads from entering liquid helium bath
- Used standard heat conduction equation for temperature profile

$$Q_{cond} = \frac{A}{L}\int_{4K}^{T} k(T)dT$$

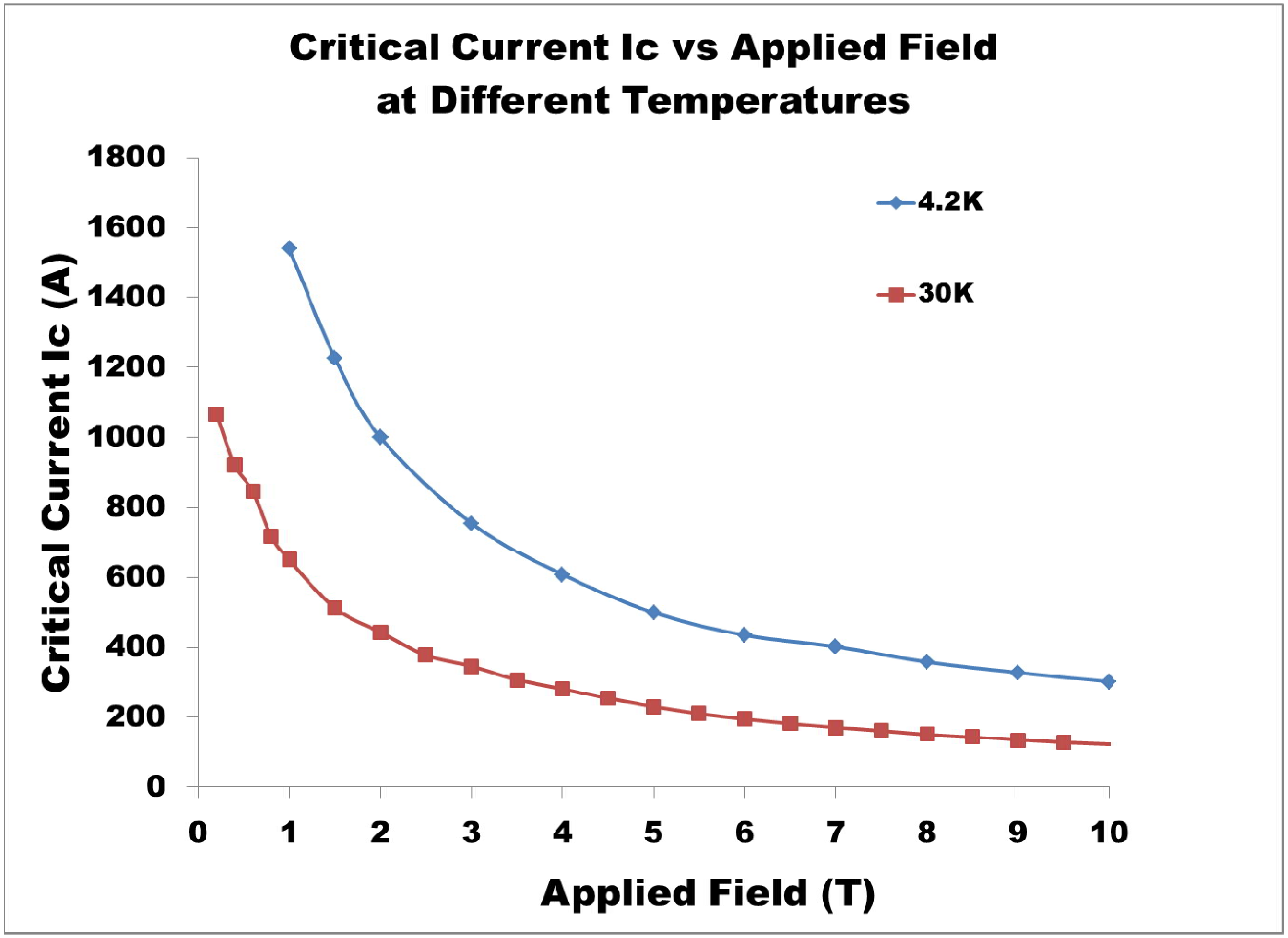


HTS Leads and support



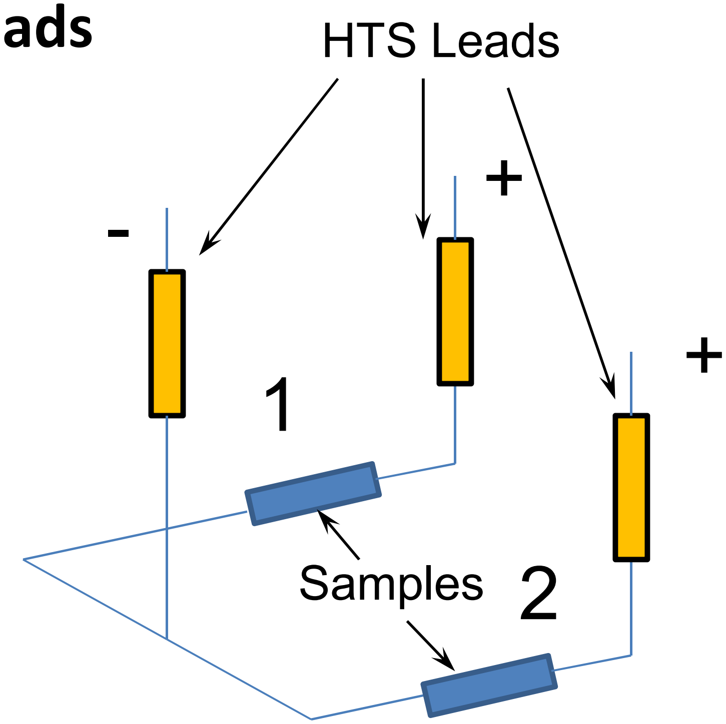
How many strips of YBCO are needed to make a lead?

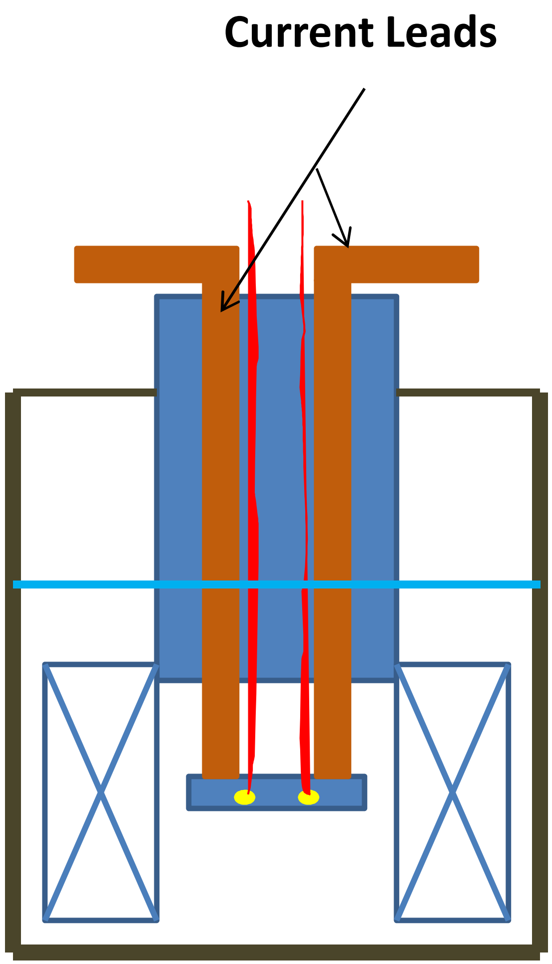
- HTS lead needs to carry 1kA
- I_C dependent on temperature and applied field
- 5 strips needed to conduct 1kA at 9T and 30K
- For factor of safety, 1kA needs to be 60% of I_C
- 8 leads are needed to make one lead



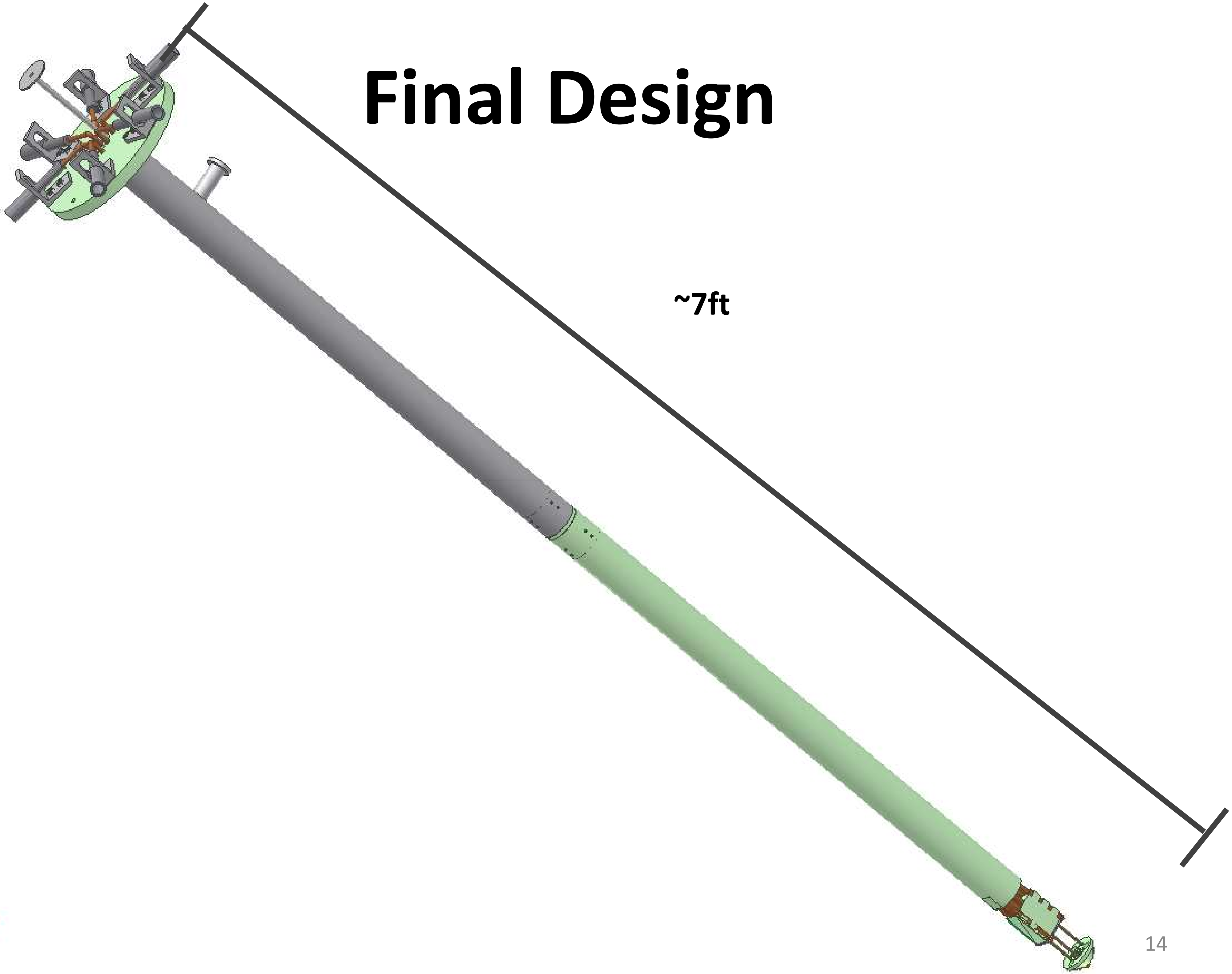
Optimization of leads

- Leads are major heat leak
  - Static heat load from high thermal conductivity
  - Previous probe needed 10 leads for 8 samples
- Able to test 8 samples with 6 leads

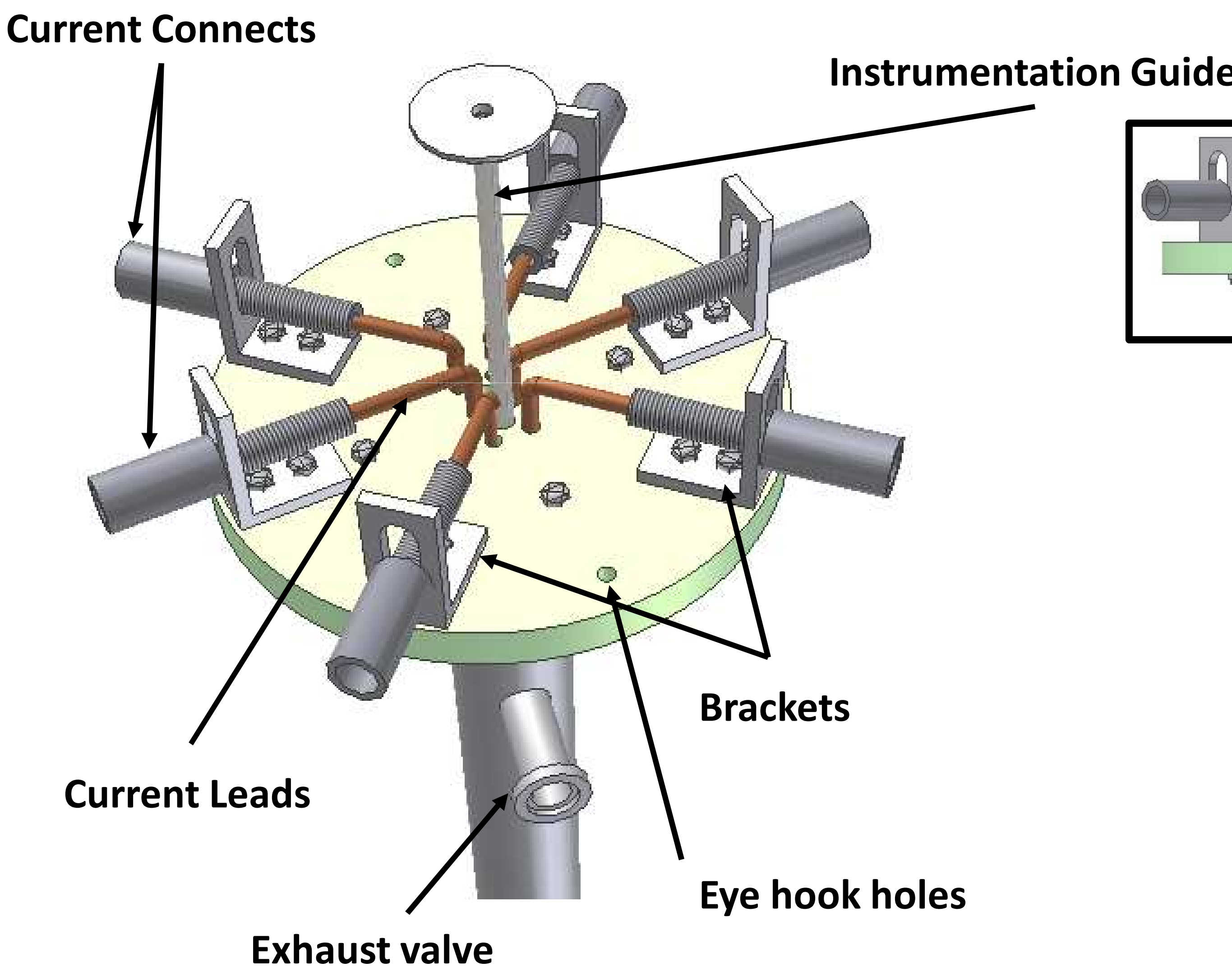


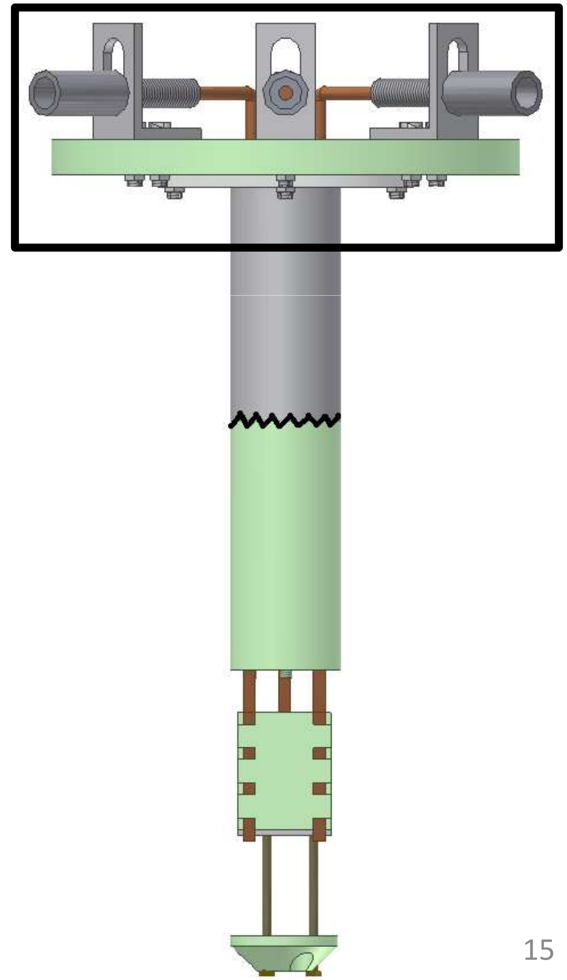


Final Design

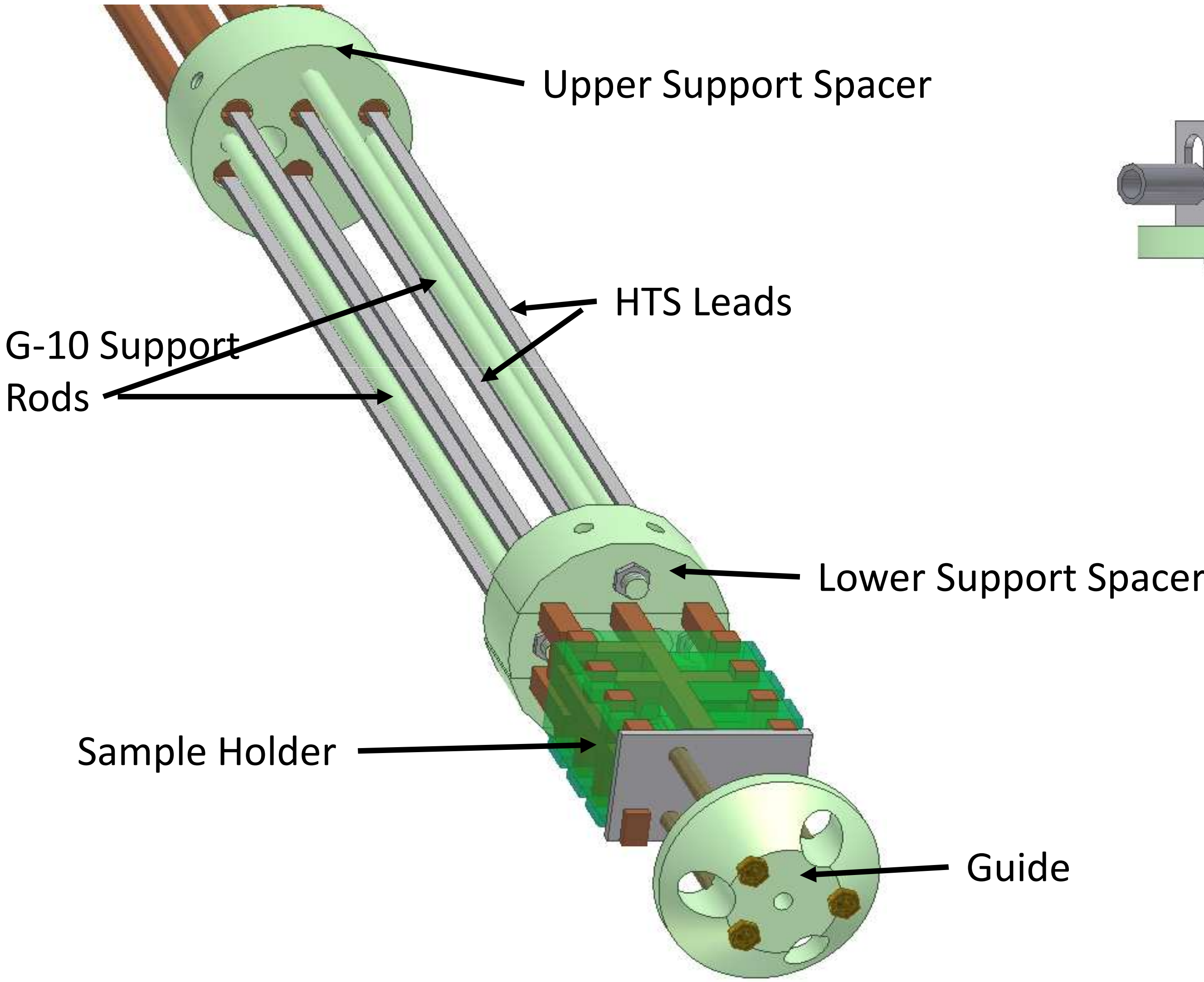


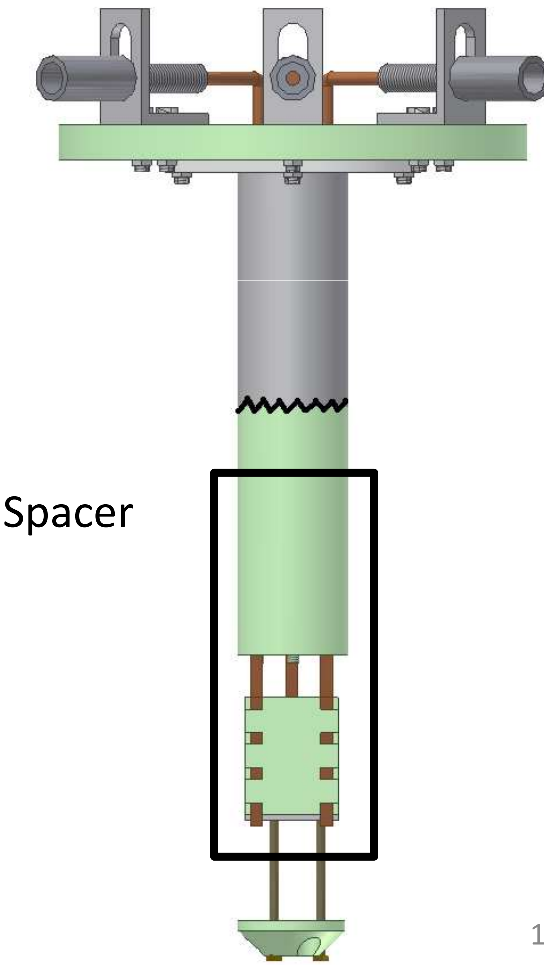
Final Design – Current Leads



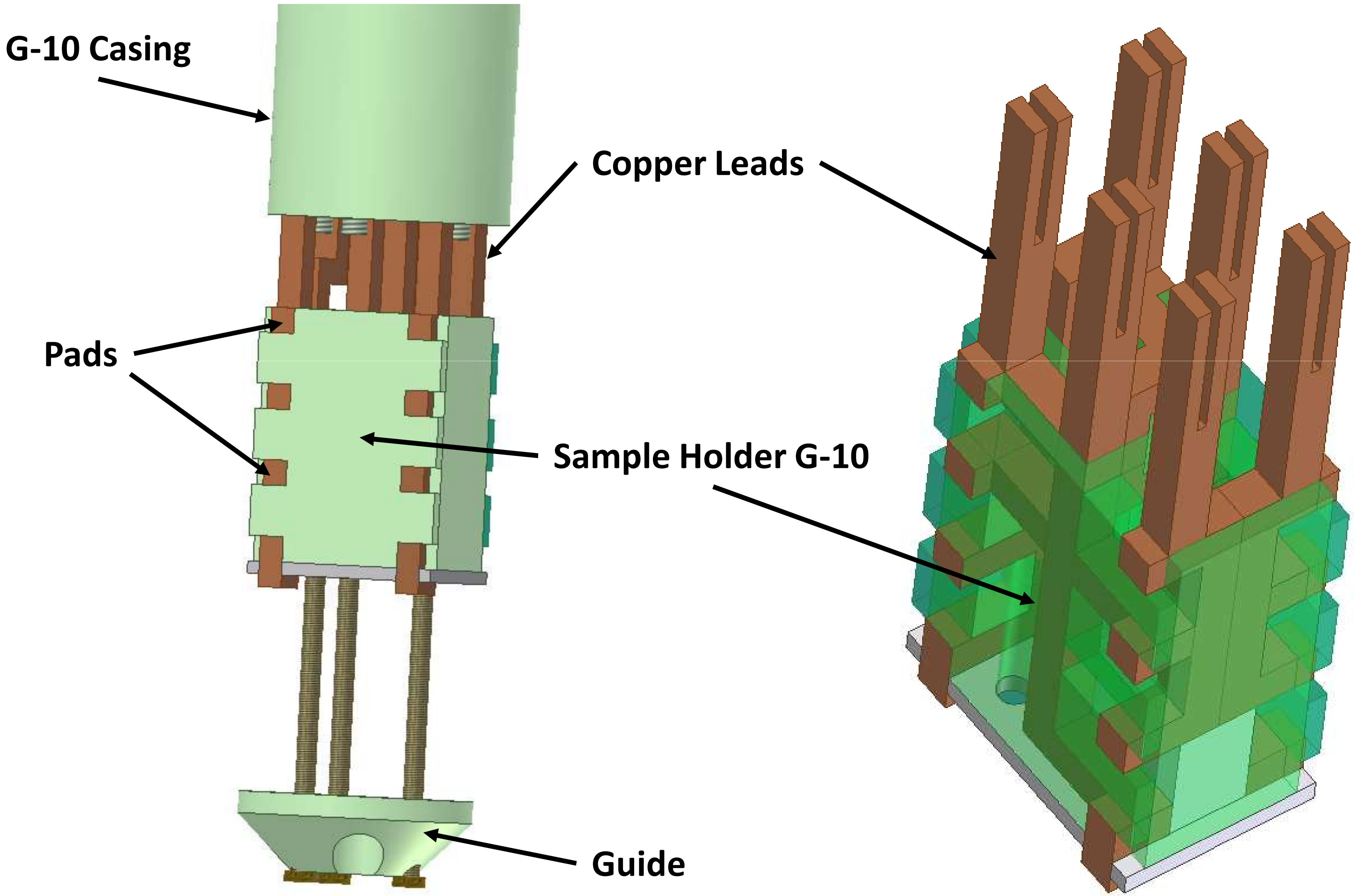


Final Design - HTS





Final Design - Sample Holder

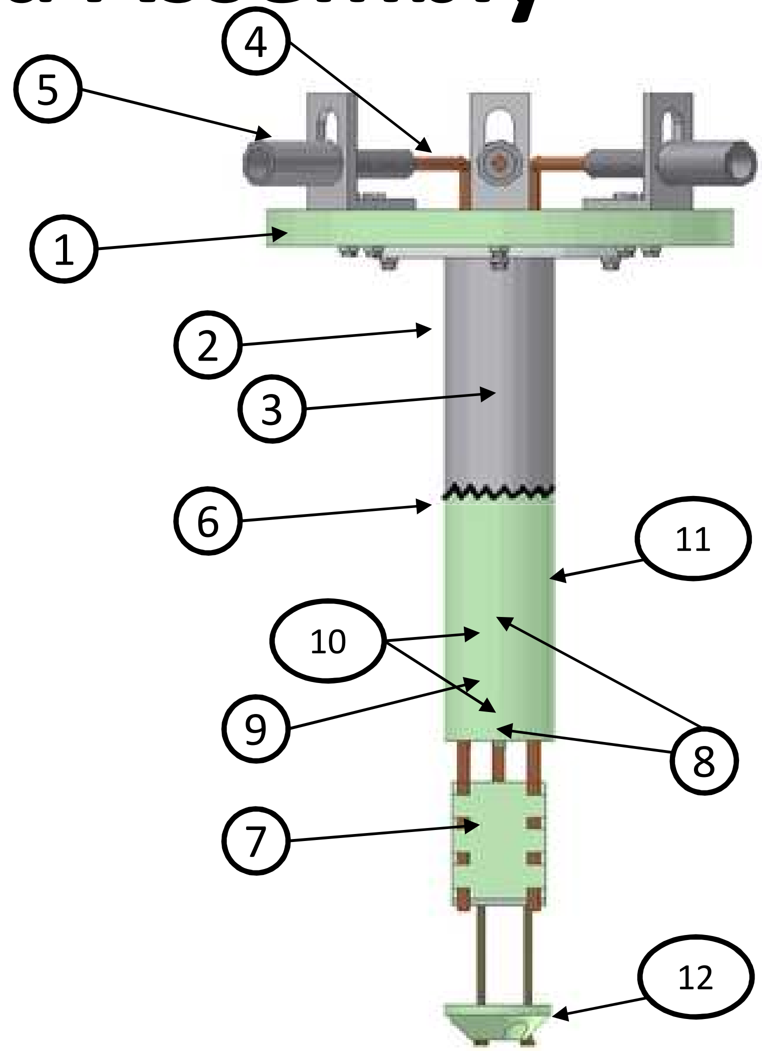


Final Design

Top Flange
Current Connects
Stainless Steel Jacket
Liquid Helium Dewar
G-10 Connector
G-10 Jacket
Nitrogen Dewar
(Preliminary Tests)
Sample Holder

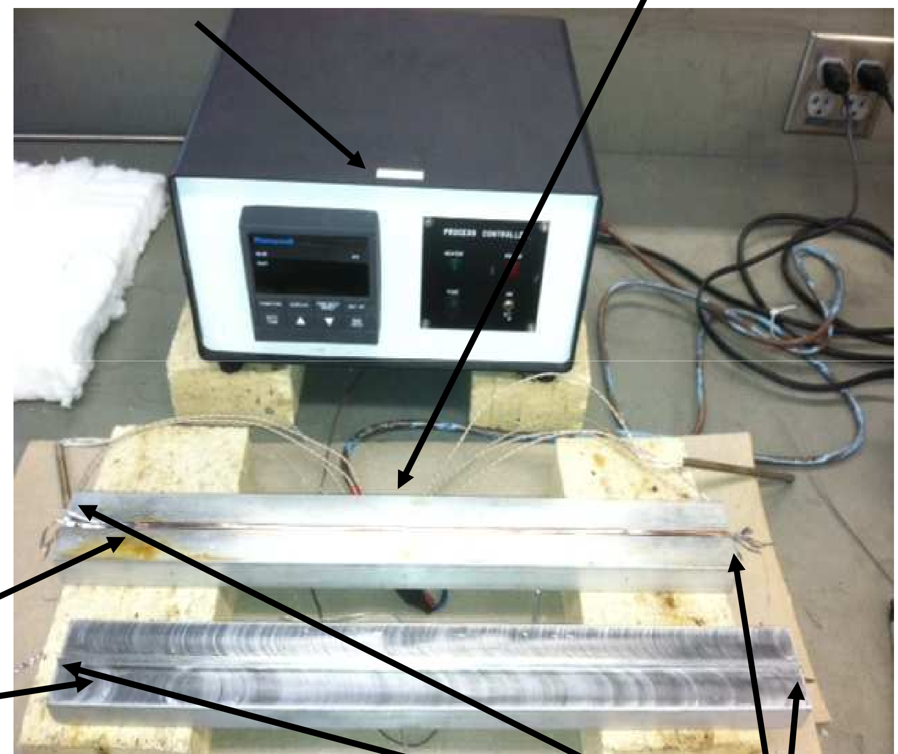
Manufacturing and Assembly

- **Assembly**
  1. **Top flange/Angle brackets**
  2. **Stainless steel jacket**
  3. **Spacer**
  4. **Copper leads**
  5. **Current connects**
  6. **G10 connector**
  7. **Sample holder**
  8. **Soldering of HTS leads**
  9. **HTS support system**
  10. **Voltage taps**
  11. **G-10 Jacket**
  12. **Guidance cap**



Soldering of HTS Leads

- **Special device was created to solder 8 HTS tapes together**
  - **Measure and control temperature precisely**
- **Soldering to copper leads using various heating methods**



Environmental/Safety Hazards

- G-10
- Flux
- Cutting Fluid
- Machining Hazards
- Heating Hazards
- Handling Liquid Helium
- Electric Current
- Weight
- All members went through
  Safety training - lab and shop

G-10

Flux

Economics

- **Budget of $4000**

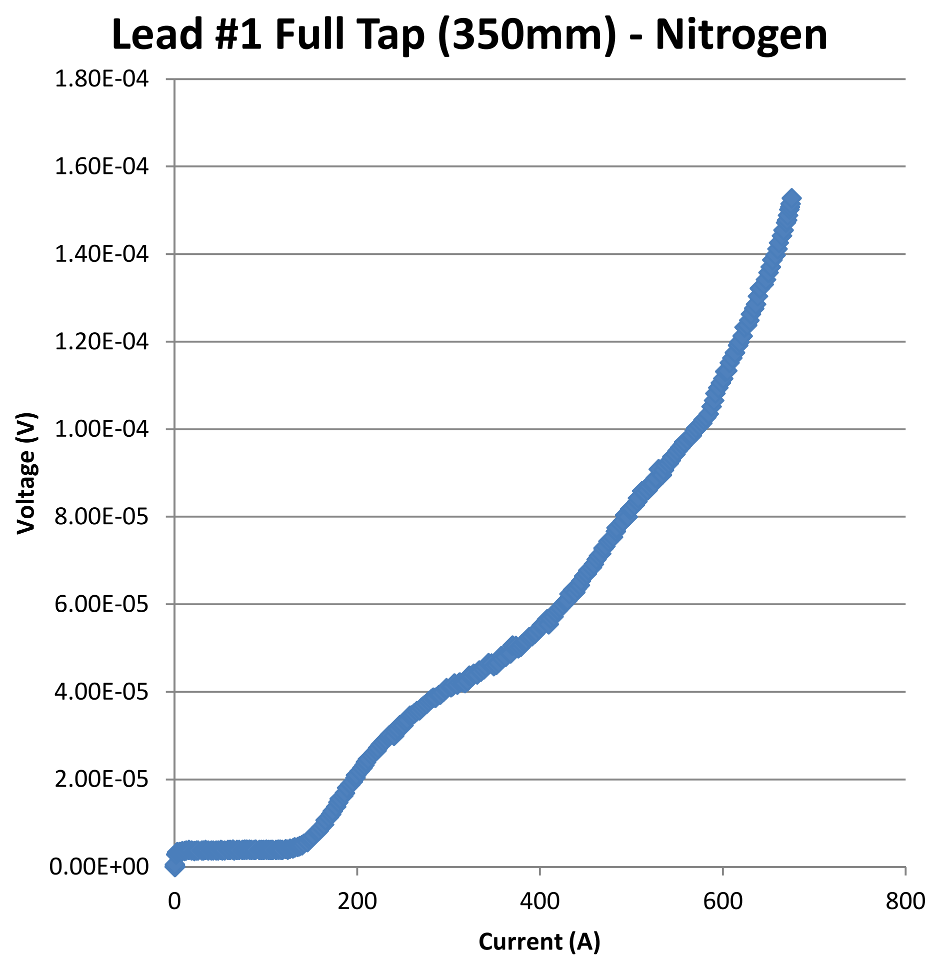
material	quantity	cost
110 Alloy Copper rods	6	$291.00
G-10	1	$952.63
Stainless steel plate	1	$81.49
90deg angles steel	1	$44.06
Sockets threaded, current connects	6	$180.00
copper	1	$126.47
aluminum bar	1	$49.34
cartridge heater	9	$287.76
wing nut	1	$11.21
compression springs	2	$26.72
Exotic Machining	1	$400.00
YBCO (19 meters)	1	$1,235.00
	Total	$3,682.68

Testing

- **Took place at the NHMFL**
- **Lifted by crane into cryogenic bath**
- **Preliminary testing**
  - **To make sure HTS Lead was superconducting**
  - **Liquid Nitrogen (77K)**
- **Final testing in liquid Helium to measure burn off (4.2K)**

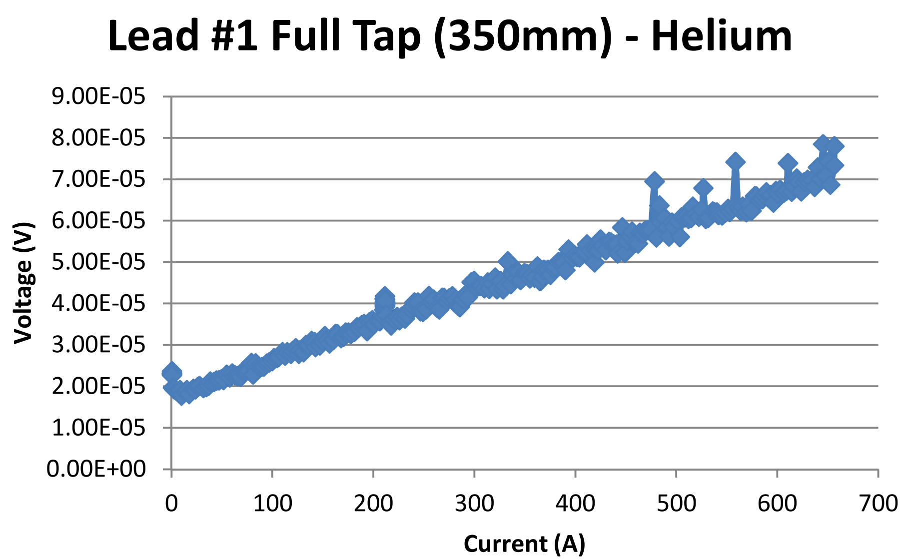
Liquid Nitrogen Test

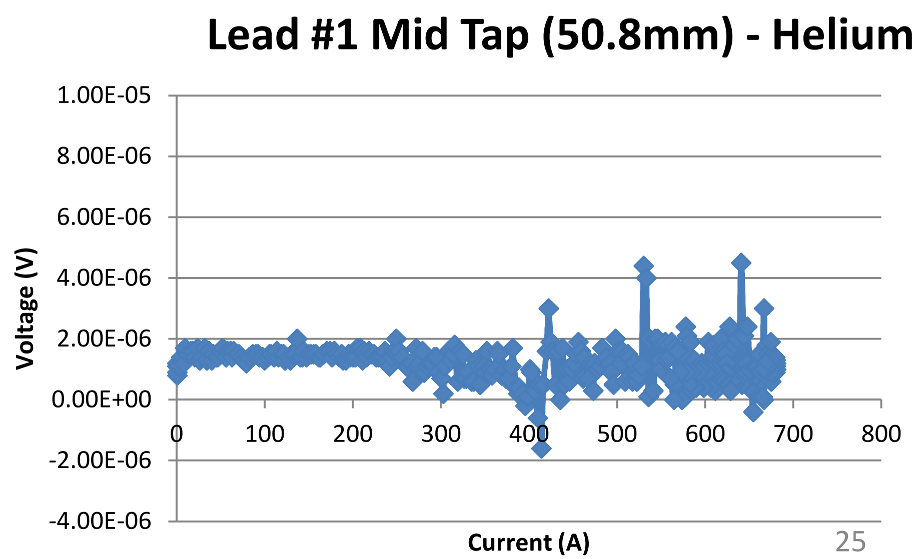
- **Preliminary test in liquid nitrogen (77K)**
  - Test if the leads were superconducting
  - Possible current sharing
  - Met the requirements to be used at 4.2 K



Liquid Helium Test

- Helium test in 4.2 K
  - Current sharing was confirmed
  - 0 or negligible heat is produced by HTS leads
  - Many tests confirm no degradation

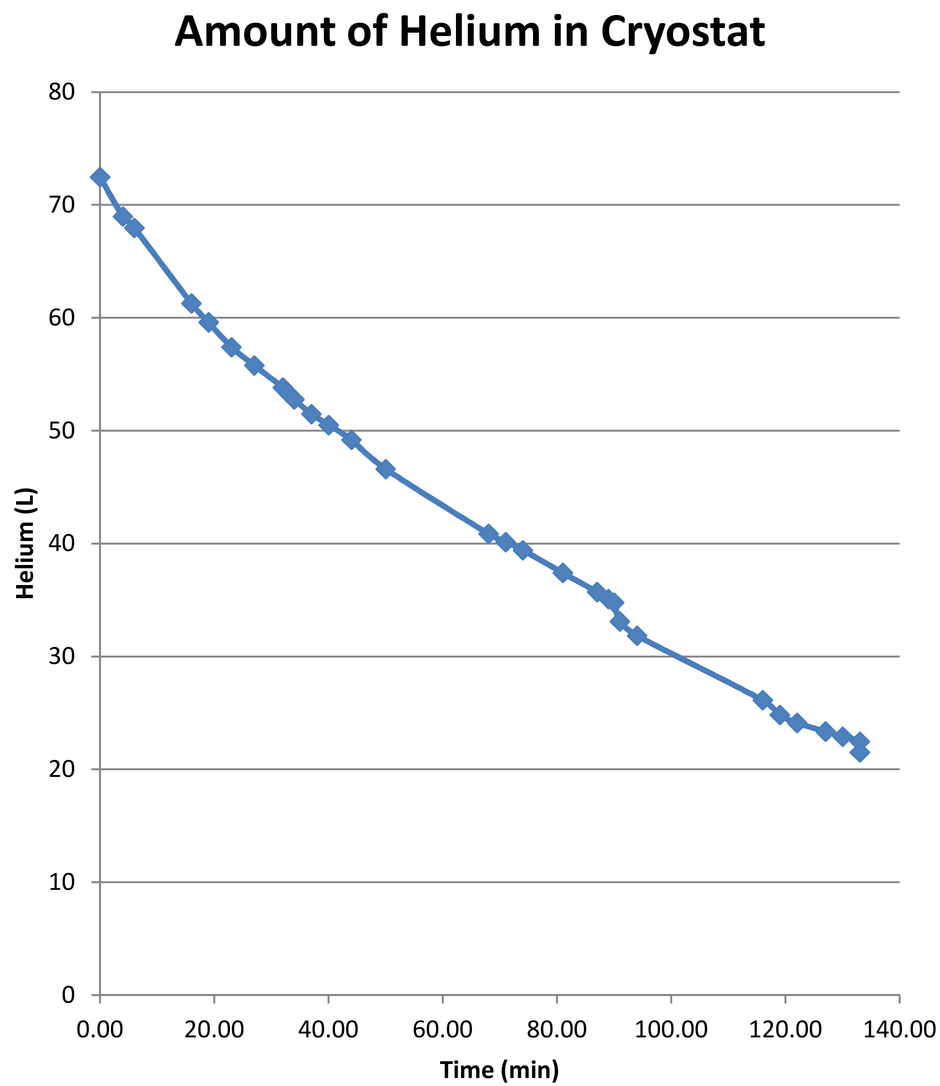




Helium Consumption

New Probe	Existing Probe
0.35 liters/min	0.83 liters/min
53 liters in 130 min segment of test	108.3 liters in 130 min segment of test
$265	$542

- **51% helium saved**
- **Savings of $277 per test**
- **$14,404 saved per year**



Conclusions

- **Probe reduces helium consumption compared to existing probe**
  - **Reduce thermal conduction**
- **New technology was developed to save helium**
  - **HTS leads**
- **Probe will be used on a weekly basis for an estimated 2-3 years**

Acknowledgments

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- Applied Superconductivity Center
- NHMFL
- Bill Sheppard, NHMFL Machine Shop
- Robert Stanton, NHMFL
- Bill Starch, ASC Machine Shop
- Dimitri Argonaut, ASC Machine shop

References

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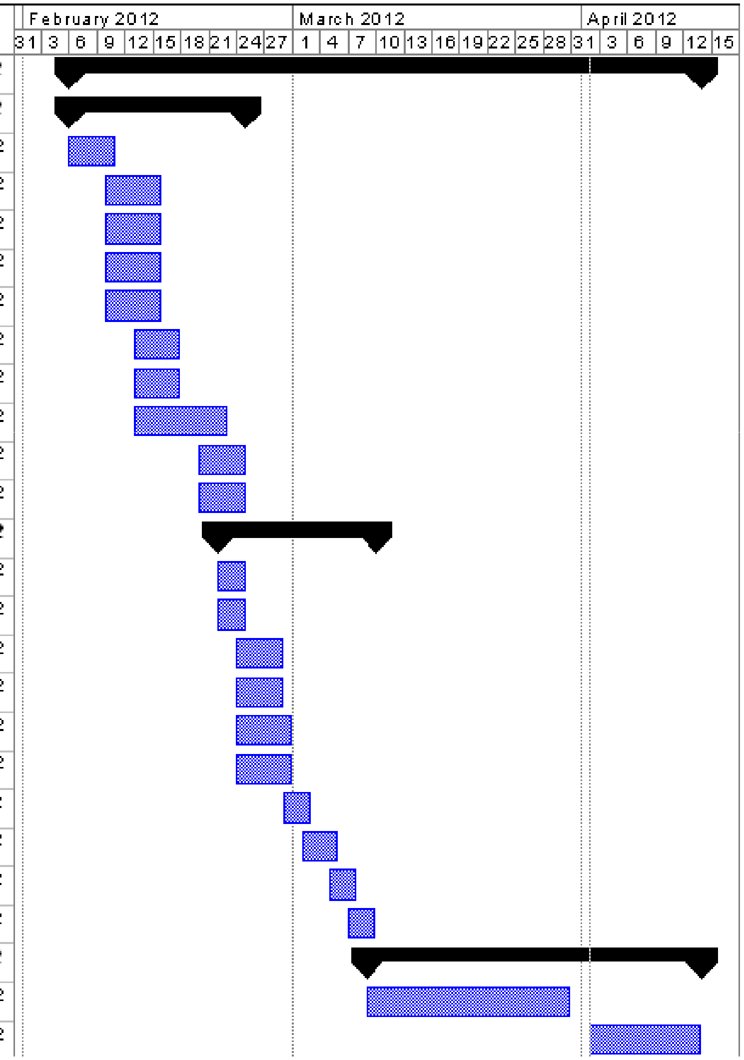
- Ekin, Jack W. . *Experimental Techniques for Low-temperature Measurements*. New York: Oxford UP, 2006. Print.
- Thomas, Lindon C. *Fundamentals of Heat Transfer*. Englewood Cliff, NJ: Prentice-Hall, 1980. Print.

Questions?

Project Plan

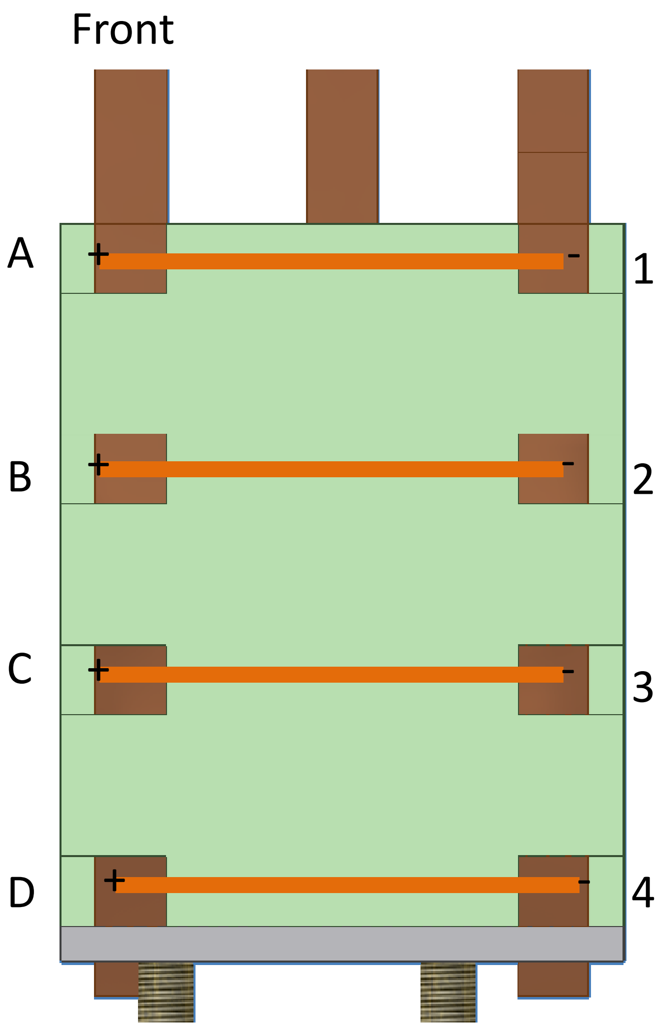
ID		Task Name	Duration	Start	Finish
1		**Construction**	**50 days?**	**Mon 2/6/12**	**Fri 4/13/12**
2		**Machining**	**15 days?**	**Mon 2/6/12**	**Fri 2/24/12**
3		S.S. top plate	5 days?	Mon 2/6/12	Fri 2/10/12
4		G-10 top flange	4 days?	Fri 2/10/12	Wed 2/15/12
5		Spacers	4 days?	Fri 2/10/12	Wed 2/15/12
6		Jacket Welding	4 days	Fri 2/10/12	Wed 2/15/12
7		Guide	4 days?	Fri 2/10/12	Wed 2/15/12
8		Sample Holder - G10	5 days?	Mon 2/13/12	Fri 2/17/12
9		Square spacer	5 days?	Mon 2/13/12	Fri 2/17/12
10		Copper Rods	8 days?	Mon 2/13/12	Wed 2/22/12
11		Sample Holder - Copper	5 days?	Mon 2/20/12	Fri 2/24/12
12		Current Connects	5 days?	Mon 2/20/12	Fri 2/24/12
13		**Assembly**	**13 days?**	**Wed 2/22/12**	**Fri 3/9/12**
14		G10 flange	3 days?	Wed 2/22/12	Fri 2/24/12
15		Top spacers	3 days?	Wed 2/22/12	Fri 2/24/12
16		Connecting spacer	3 days?	Fri 2/24/12	Tue 2/28/12
17		Stainless steel tube	3 days?	Fri 2/24/12	Tue 2/28/12
18		Sample Holder	4 days?	Fri 2/24/12	Wed 2/29/12
19		Square spacer	4 days?	Fri 2/24/12	Wed 2/29/12
20		Solder HTS Leads	3 days?	Wed 2/29/12	Fri 3/2/12
21		HTS Support system	2 days?	Fri 3/2/12	Mon 3/5/12
22		G10 Jacket	3 days?	Mon 3/5/12	Wed 3/7/12
23		Copper to Current connects	3 days?	Wed 3/7/12	Fri 3/9/12
24		**Testing**	**26 days?**	**Fri 3/9/12**	**Fri 4/13/12**
25		Dewar Testing	16 days?	Fri 3/9/12	Fri 3/30/12
26		Results	10 days?	Mon 4/2/12	Fri 4/13/12



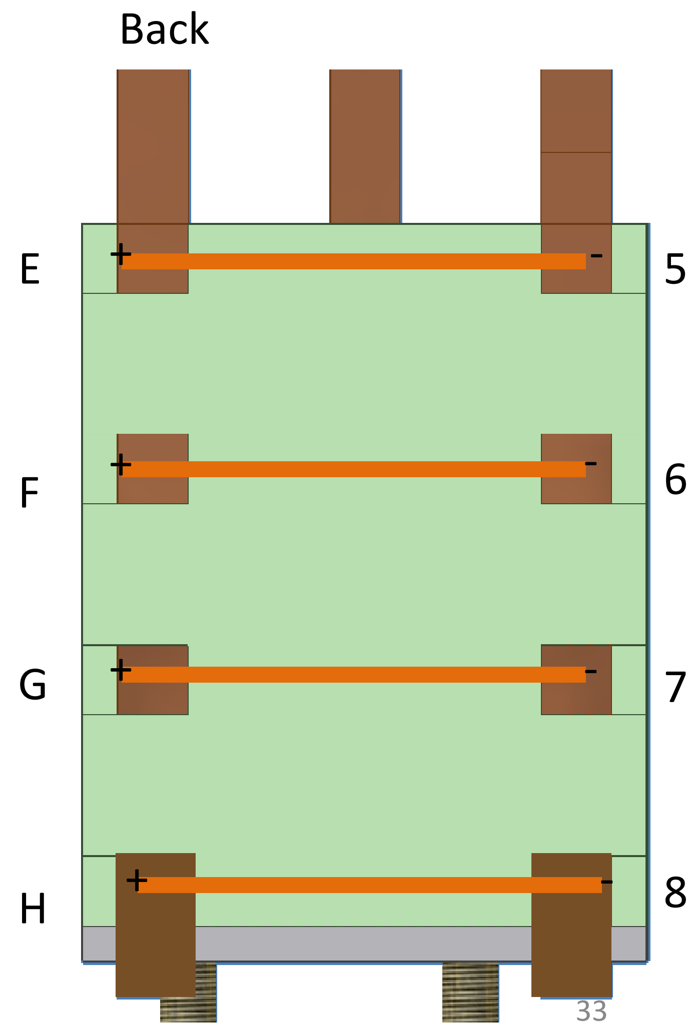
Manufacturing and Assembly

- Machining
  - ASC shop
  - NHMFL shop
  - Exotic Machining, Inc
- Assembly
  - Top flange
  - Stainless steel tube
  - Spacer
  - Copper leads
  - Current connects
  - G10 connector
  - Sample holder
  - Soldering of HTS leads
  - HTS support system
  - Voltage taps

Sample Holder



- **8+ pads**
  - **A ⟶ H**
- **8- pads**
  - **1 ⟶ 8**



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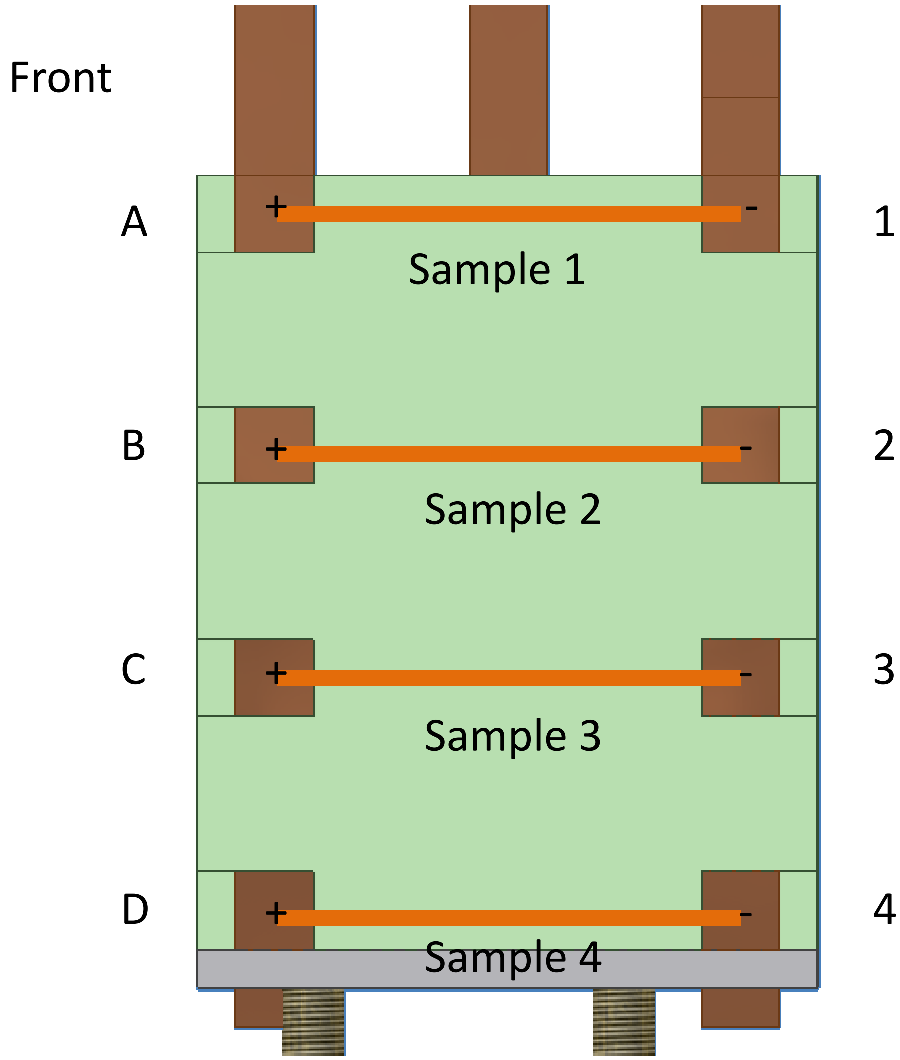
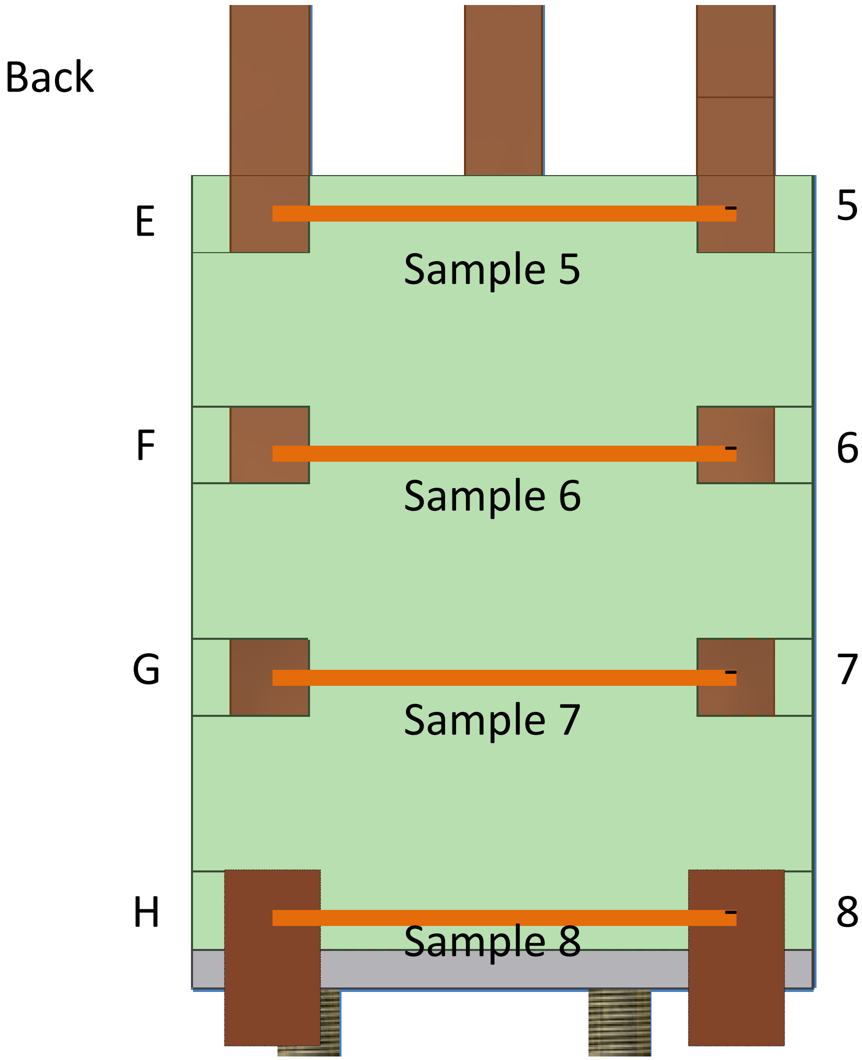


Sample #	Corresponding Label	Lead #s
1	A, 1	4, 3
2	B, 2	4, 2
3	C, 3	1, 3
4	D, 4	1, 2

Sample Design



Sample #	Corresponding Label	Lead #s
5	E, 5	4, 6
6	F, 6	4, 5
7	G, 7	1, 6
8	H, 8	1, 5

Critical Current

- **Critical current probes measure how much current a sample can take before it becomes non-superconducting**
  - **Temperature**
    - **4.2 Kelvin, 77 Kelvin**
  - **Magnetic Field**