High Field Solenoid Development for Axion Dark Matter Search at CAPP/IBS

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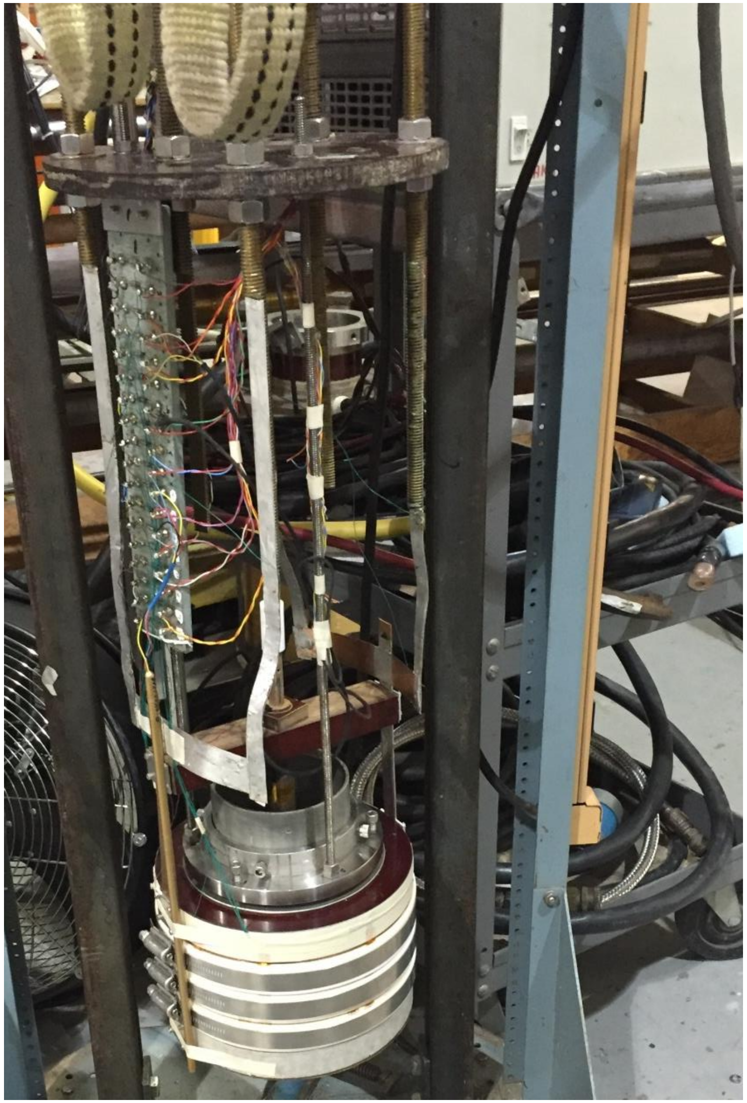
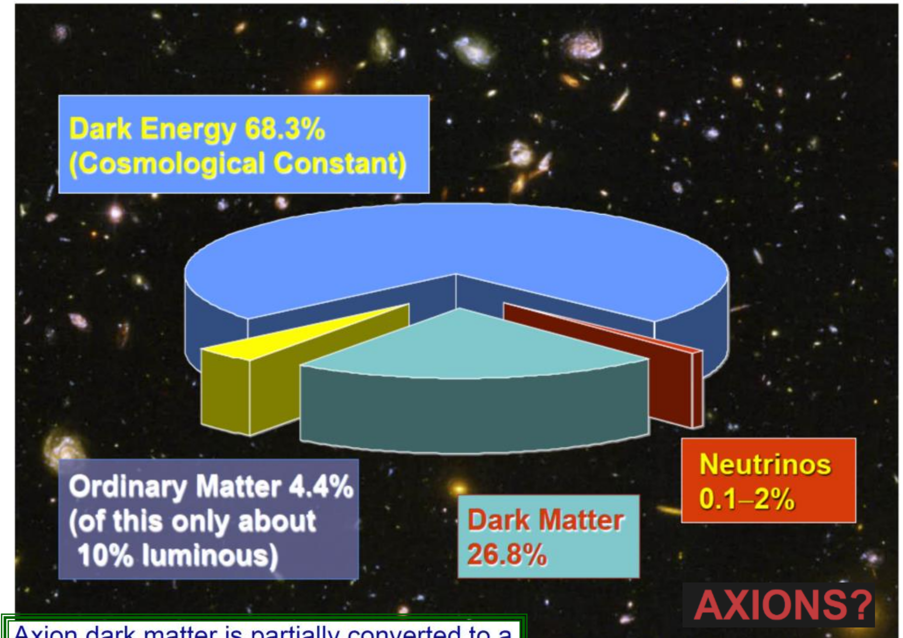
Overview

- Background
- Design Considerations
- Conductor
- Magnet Construction
- Test Results
- Summary



Background : Axion Dark Matter Search
(Courtesy : Yannis Semertzidis, CAPP/IBS)

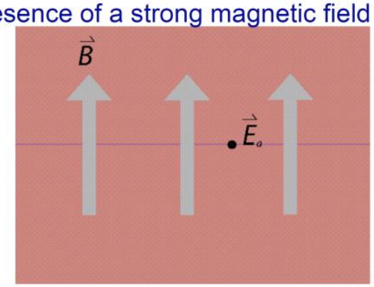
Cosmological inventory



Center for Axion and Precision Physics Research: CAPP/IBS at KAIST, Korea

- Four groups
- 15 research fellows, ~20 graduate students
- 10 junior/senior staff members, Visitors
- Engineers, Technicians
- Promised: New IBS building at KAIST

Axion dark matter is partially converted to a very weak flickering Electric (E) field in the presence of a strong magnetic field (B).



Animation by Kristian Themann

J. Hong, J.E. Kim, S. Nam, YkS
hep-ph: 1403.1576

$a \rightarrow \gamma$

The conversion power on resonance

$$P = \left(\frac{\alpha g_\gamma}{\pi f_a}\right)^2 V B_0^2 \rho_a C m_a^{-1} Q_L$$

$$= 2\cdot10^{-22}\ \text{Watt}\left(\frac{V}{500\ \text{liter}}\right)\left(\frac{B_0}{7\ \text{Tesla}}\right)^2\left(\frac{C}{0.4}\right)\left(\frac{g_\gamma}{0.36}\right)^2\left(\frac{\rho_a}{5\cdot10^{-25}\ \text{gr/cm}^3}\right)\left(\frac{m_a c^2}{h\ \text{GHz}}\right)\left(\frac{Q_L}{10^5}\right)$$

The axion to photon conversion power is very small, a great challenge to experimentalists.

What's there to improve over ADMX?

$$P = \left(\frac{\alpha g_\gamma}{\pi f_a}\right)^2 V B_0^2 \rho_a C m_a^{-1} Q_L$$

- B^2, energy density
- Q, resonator quality factor
- B-field/resonator volume V
- Ampl. noise/physical temperature, S/N

B-field possibilities

- Magnetic field B:
  - Develop 25T magnet.
  - 35T magnet based on high T_c.

Design Consideration

Large aperture, high field

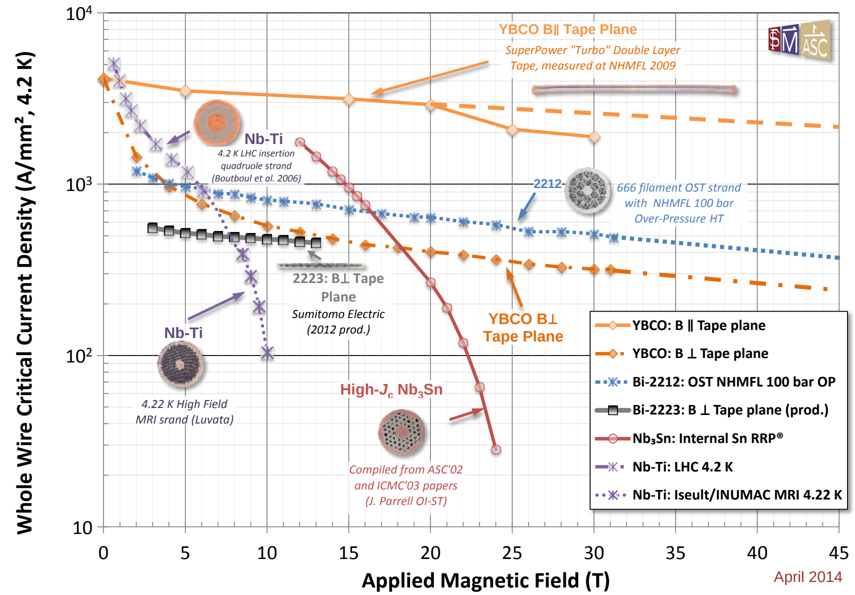
- ➢ 35 – 40 T , 100 mm

HTS must be used

- ➢ But HTS is expensive

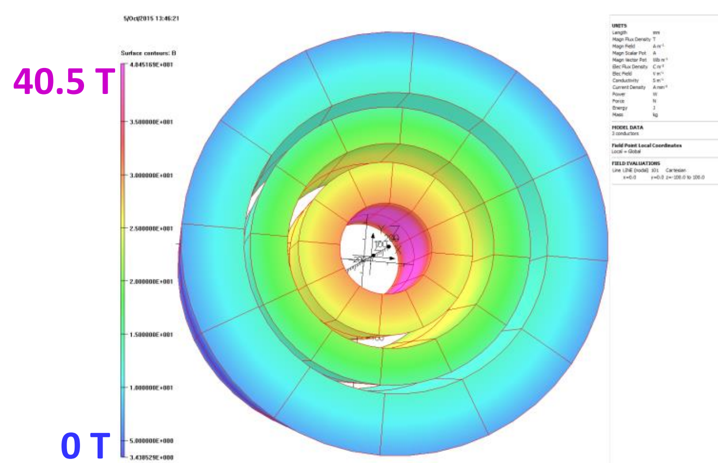
HTS/LTS hybrid design

- ➢ ~25 T HTS and 10-15 T LTS



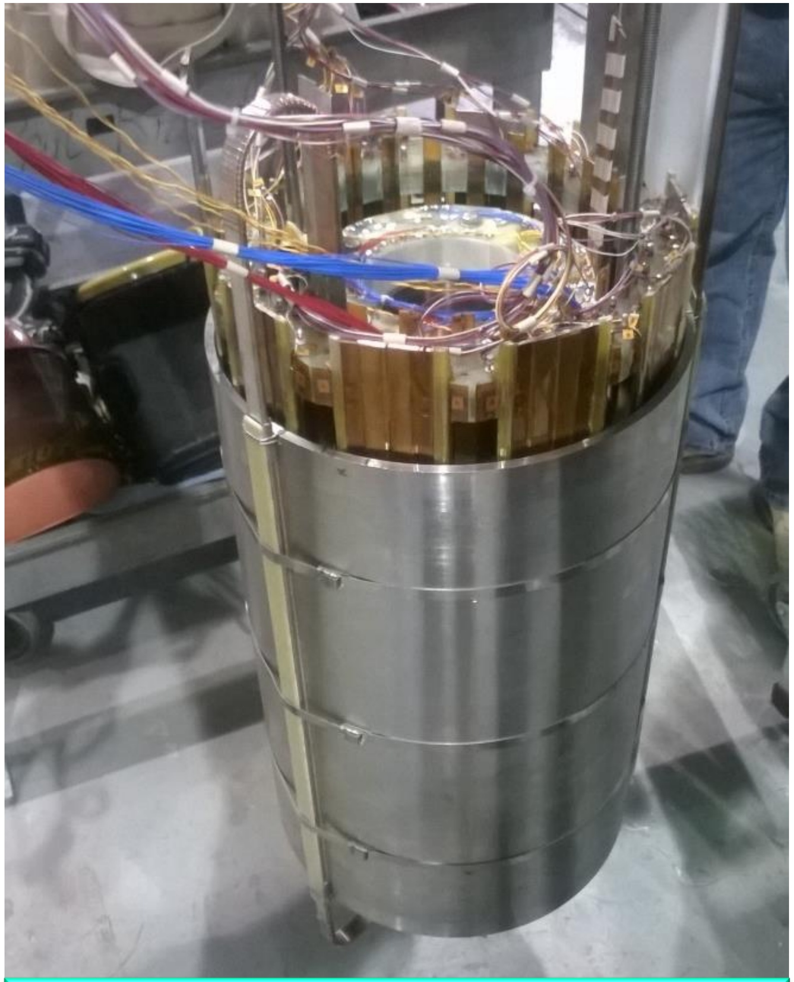
This magnet pose huge challenges

- ➢ Large stresses
- ➢ Quench protection
- ➢ New conductor



Previous experience with large aperture, high field solenoid?

HTS Solenoid for SMES



Just presented in another room

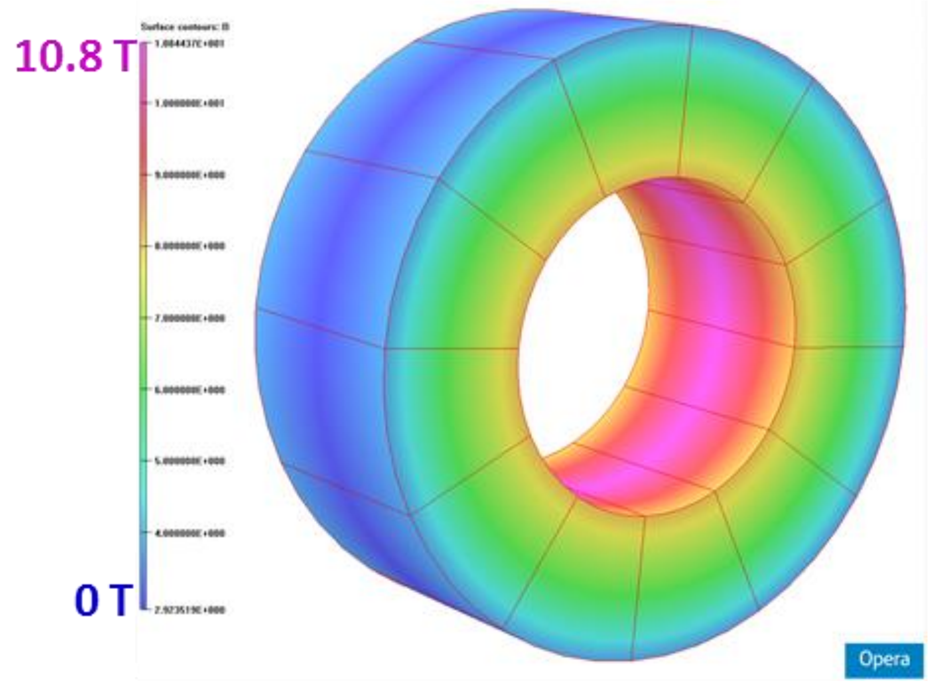
- **Field: 25 T@4 K**
- **Bore: 100 mm**
- **Stored Energy: 1.7 MJ**
- **Hoop Stresses: 400 MPa**
- **Conductor: HTS (2G)**

Amount of ReBCO HTS Used:

Over 6 km, 12 mm wide from SuperPower

- **Reached a critical field at 27 K 12.5 T (new record over >10 K in a magnet of this size)**
- **Test terminated due to the electrical issues**

CAPP/IBS Phase I HTS Solenoid



- **Peak Field : 10.8 T**
- **Aperture : 100 mm**
- **Stored Energy : 66 kJ**
- **Temperature : 4.2 K**
- **Number of Turns: 1881**
- **Number of Pancakes : 6**
- **Conductor: 12 mm wide ReBCO HTS Tape**
- **Insulation: Stainless Steel**

ReBCO HTS from SuNAM

Specifications:

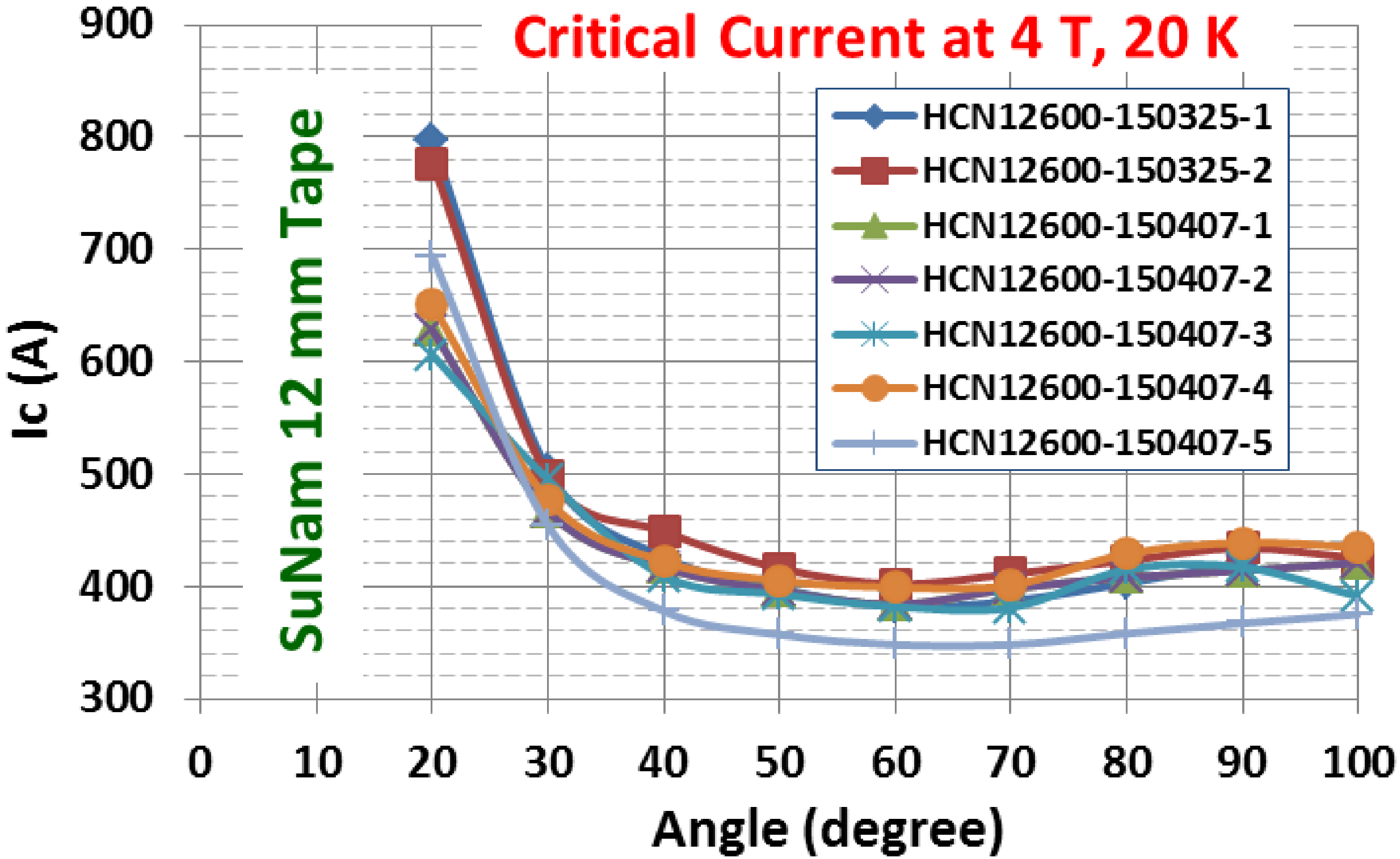
- I_c (77 K, self-field): > 600 A
- I_c (4K, 8T) : > 550 A (expected)
- Width: 12 mm
- Thickness : 100 micron
- Piece Length: 140 meter
- Internal splices: None
- Cu thickness: 40 micron

Observations about Tape:

- ❑ Uniform Properties
- ❑ Good Copper Plating

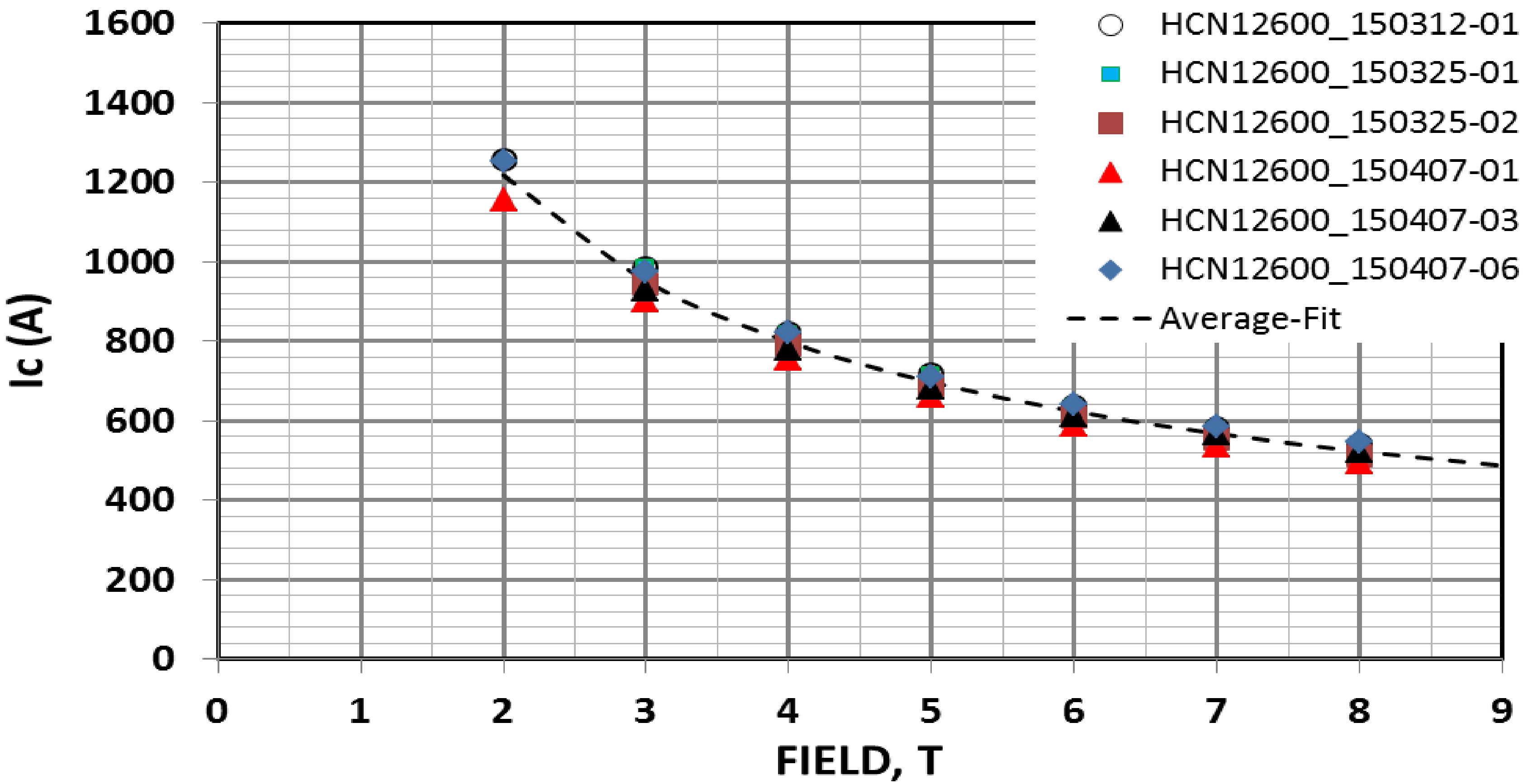
In field measurements: 20 K at SuNAM & 4 K at BNL

Measurements at SuNAM (@4T, 20 K - I_c Vs. θ)



Noticeably uniform performance

Measurements at BNL (@4K, $B_\perp$ - I_c Vs. Field)



Remarkably uniform performance

(specially for conductor delivered in 3 batches)

Summary of Conductor Measurements

CRITICAL CURRENT OF SHORT SAMPLES TAKEN AT BNL AND AT SuNAM

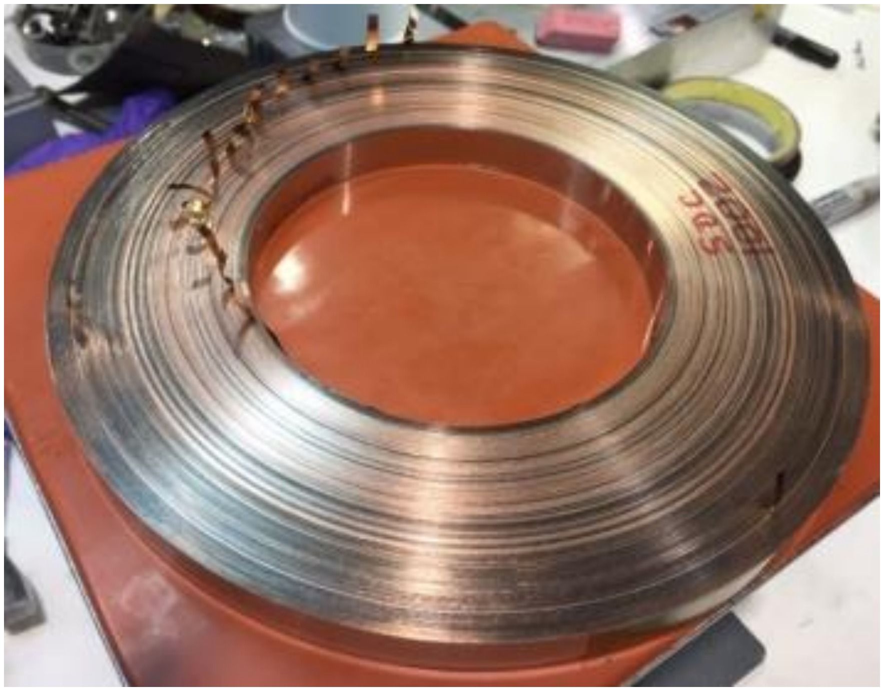
Lab	Temp.	Field	Average	σ	σ/Average
	[K]	[T]	[A]	[A]	
SuNAM	77	0	634	36	5.7%
SuNAM	20	4	423	28	6.7%
BNL	77	0	628	51	8.1%
BNL	4.2	4	793	28	3.5%
BNL	4.2	8	524	20	3.7%

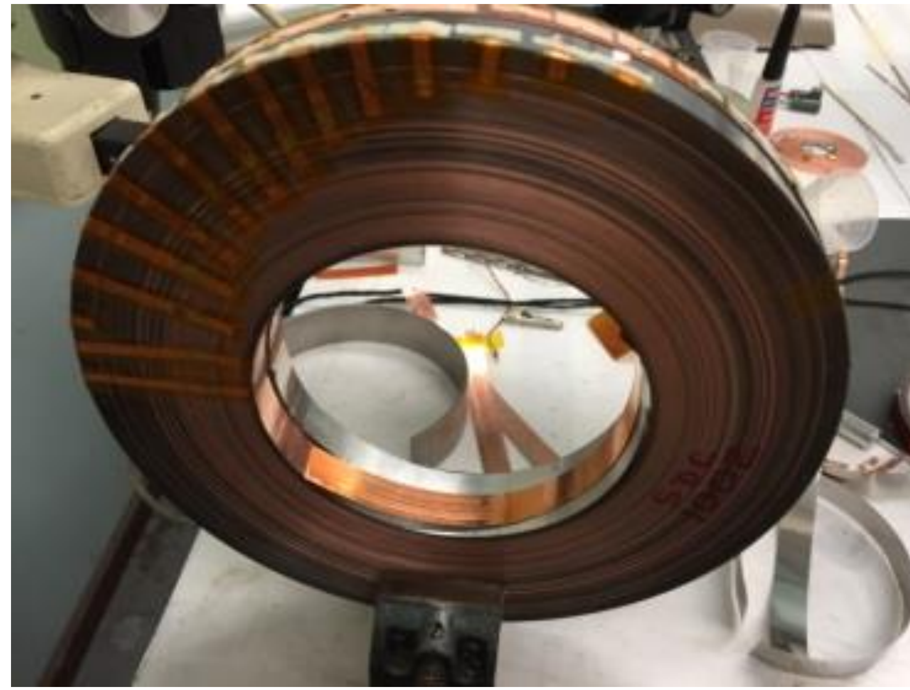
Pinning can improve the in-field performance at 4K

Construction

Coil Winding Machine

Pancake coils





V-taps for extensive QA

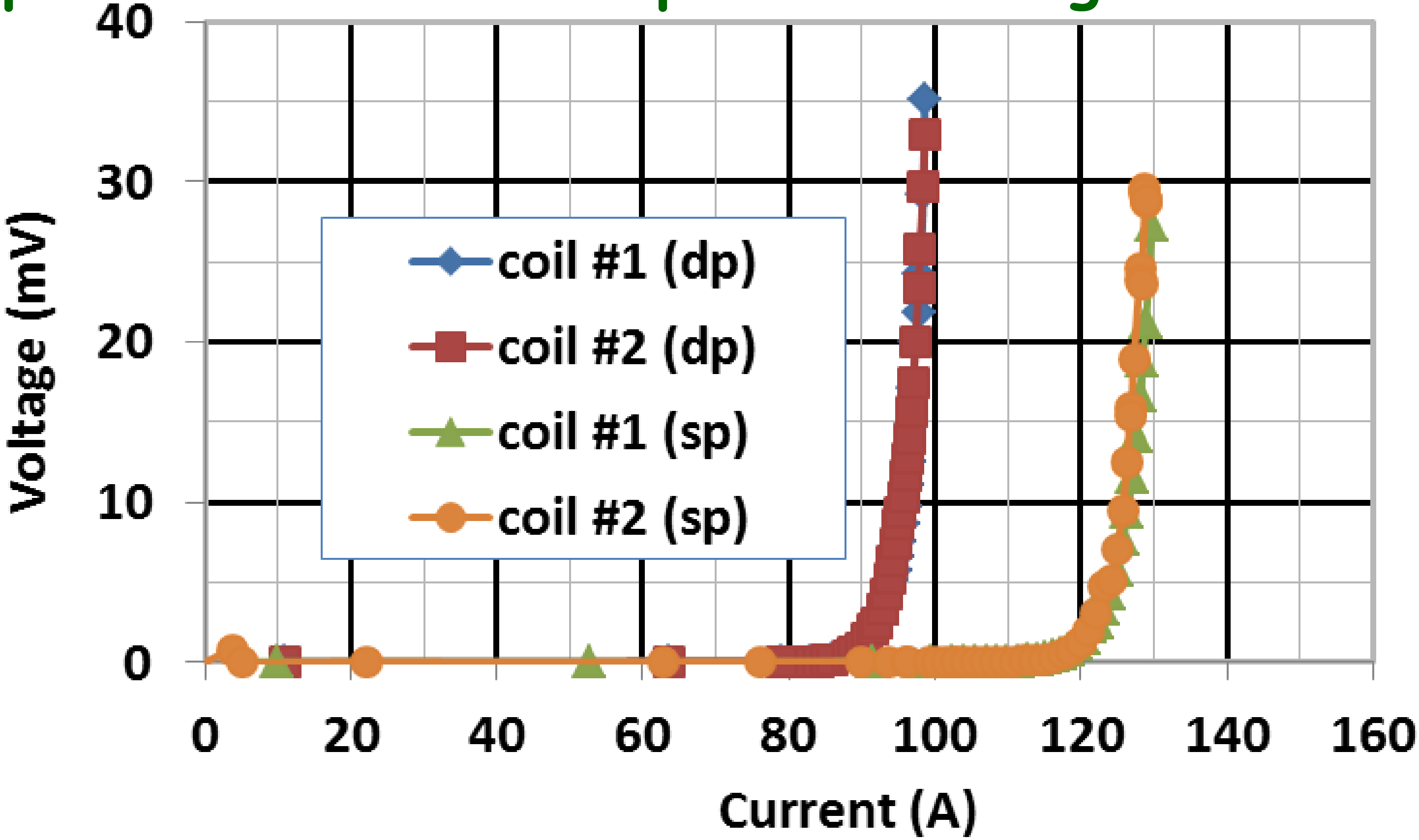
i.d.=101.6 mm, o.d.=192 mm

Spiral Splice for making Double Pancakes

(~300 meter, 12 mm tape)

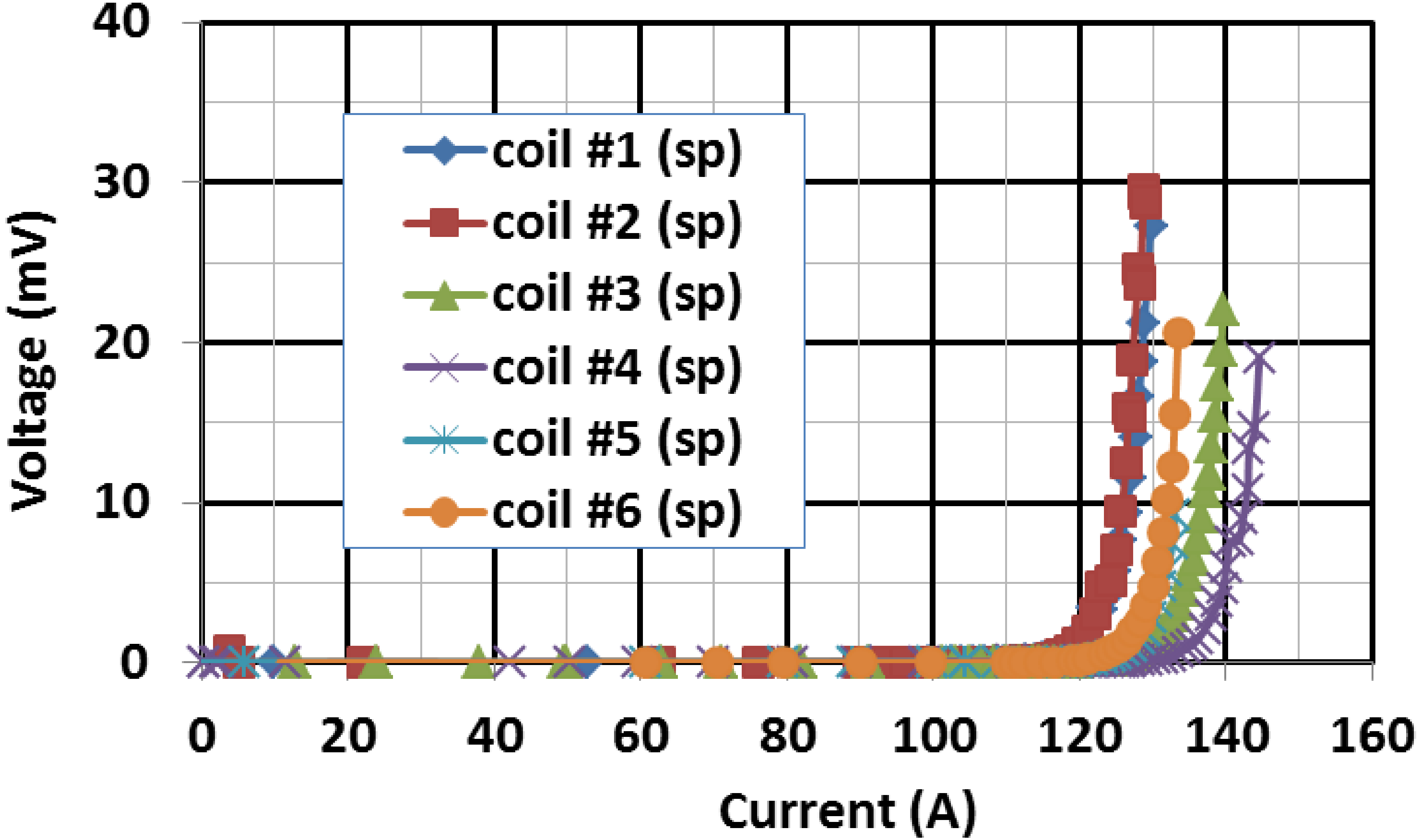
77 K QA Test of Double Pancakes

Three leads to power coils either in single pancake or in double pancake configurations

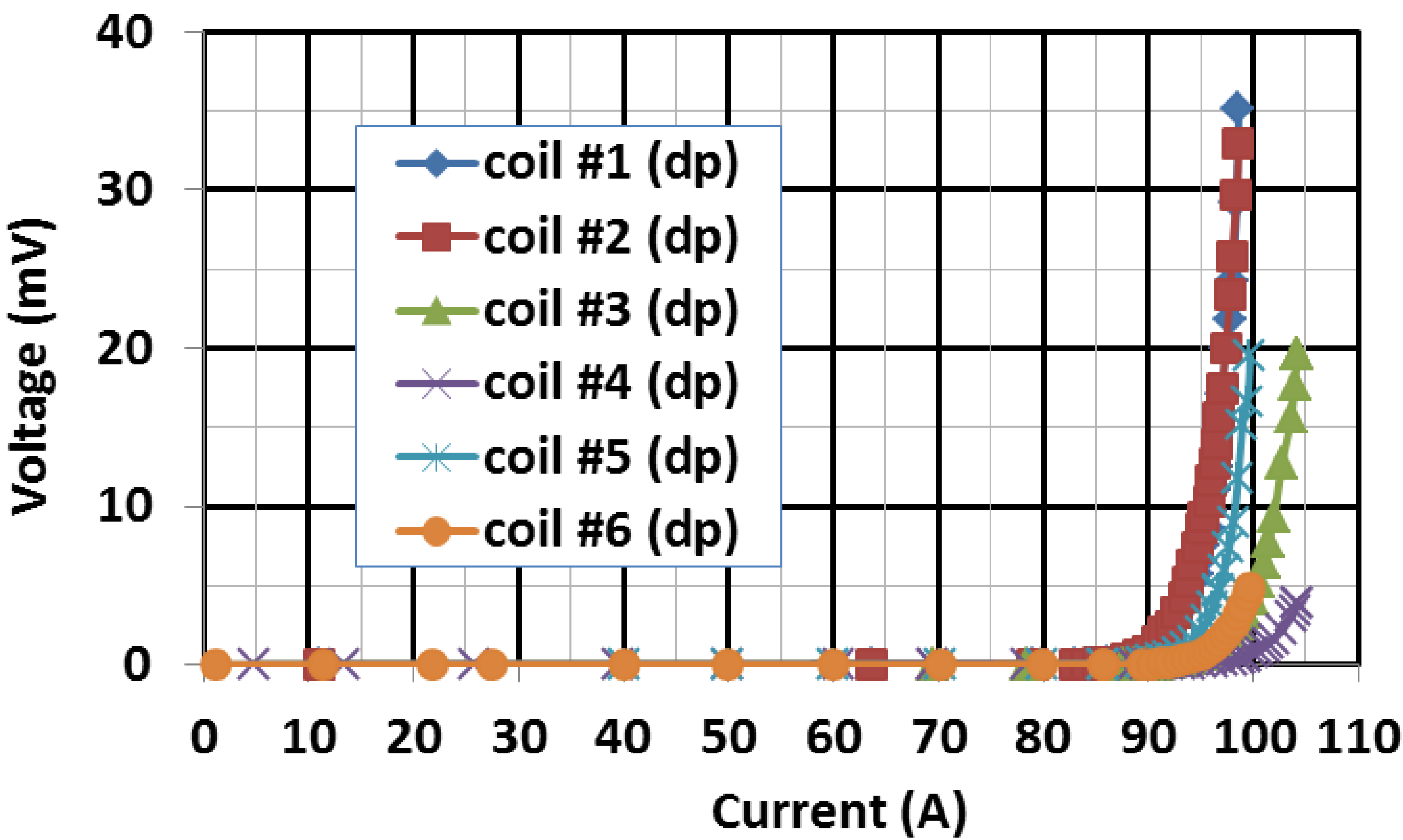


Higher field means lower current in a double pancake

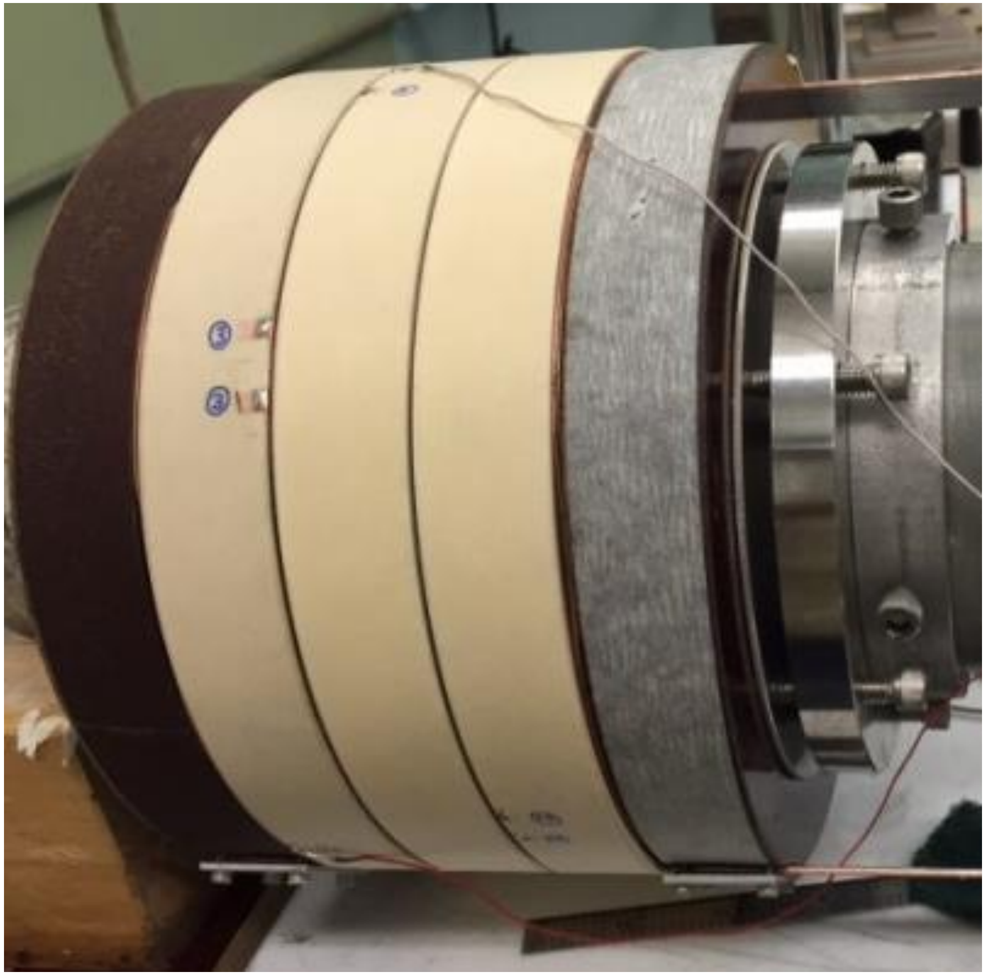
Performance of Six Coils
(Powered Individually as Single Pancakes)

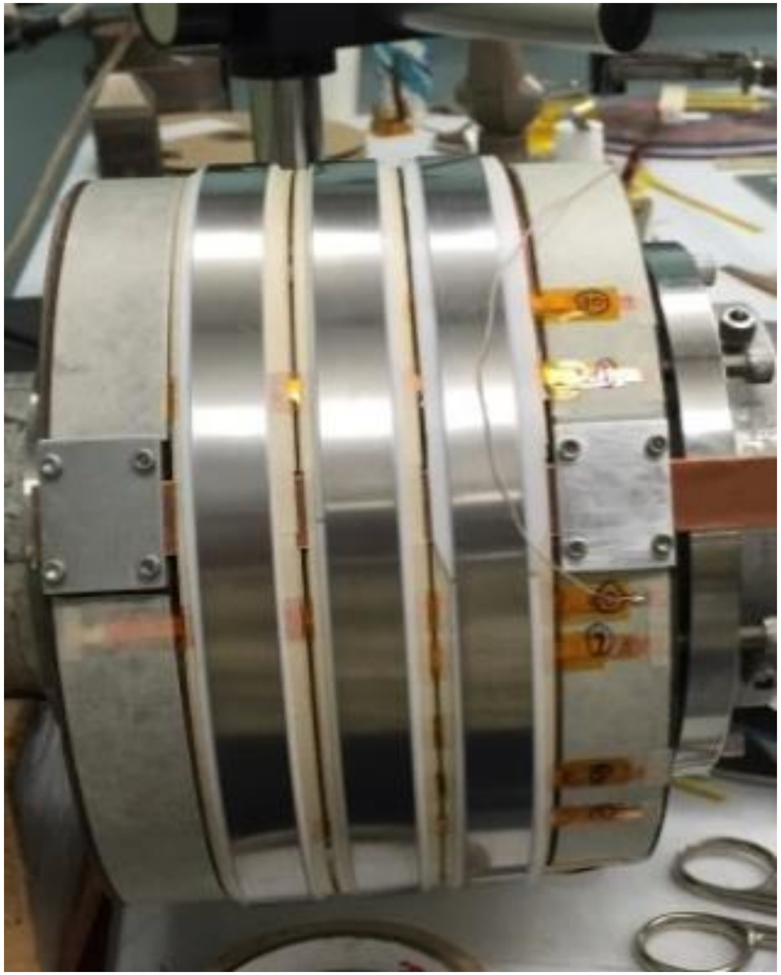


Performance of Six Coils
(Powered two together as Double Pancakes)

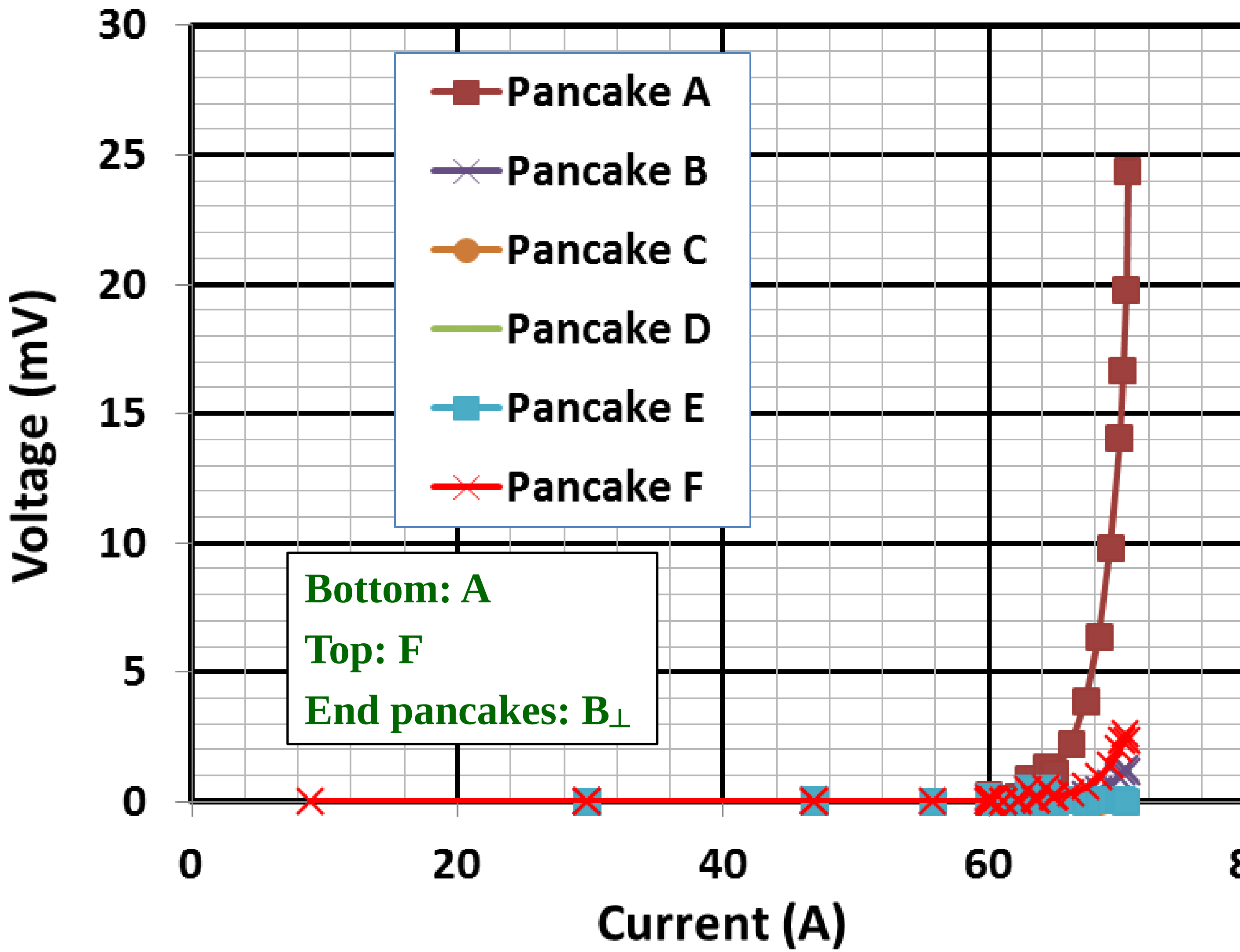


Final Solenoid Construction

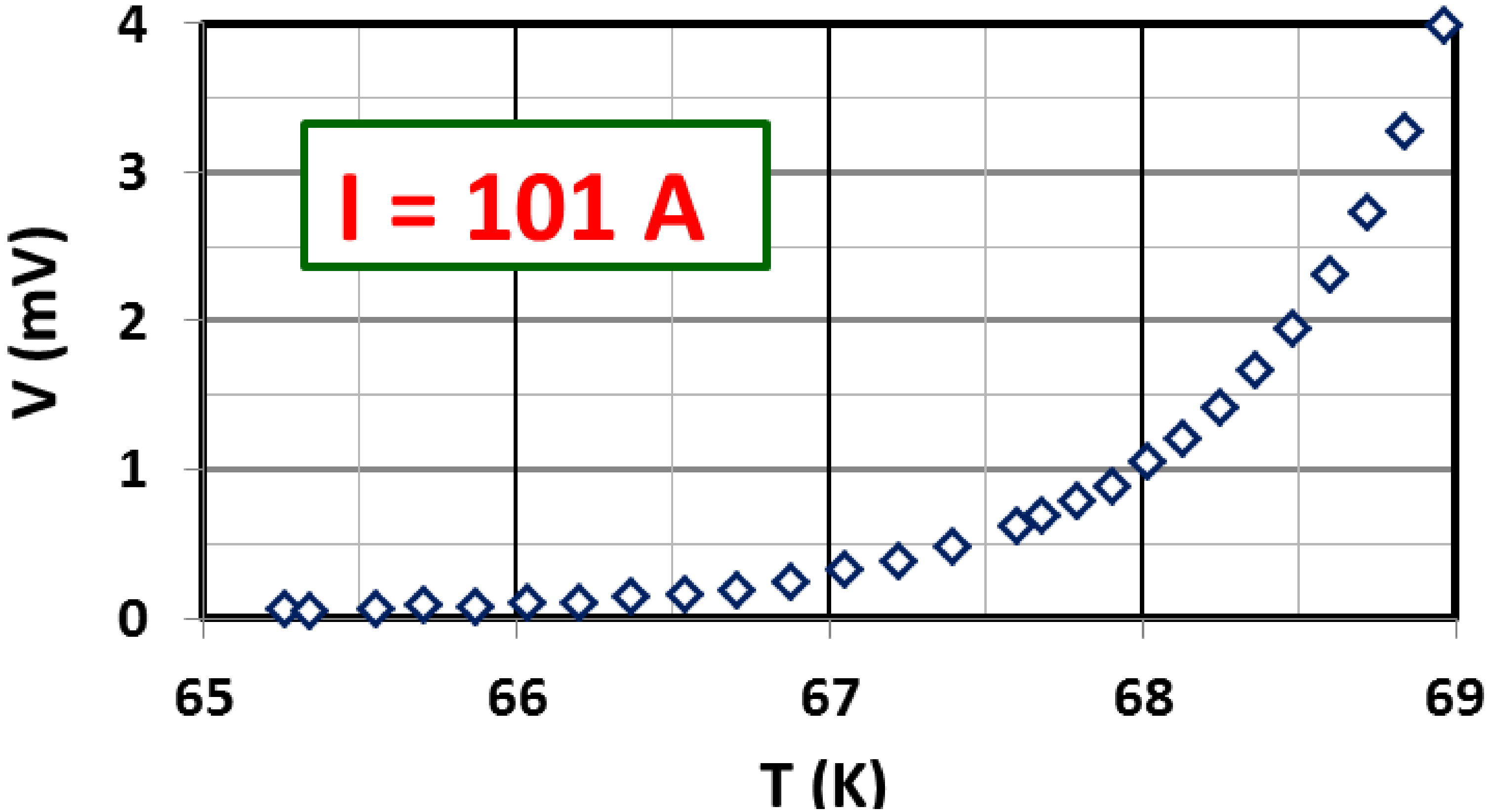




Six Pancake Solenoid @77 K
(V-I curve of each pancake, powered together)

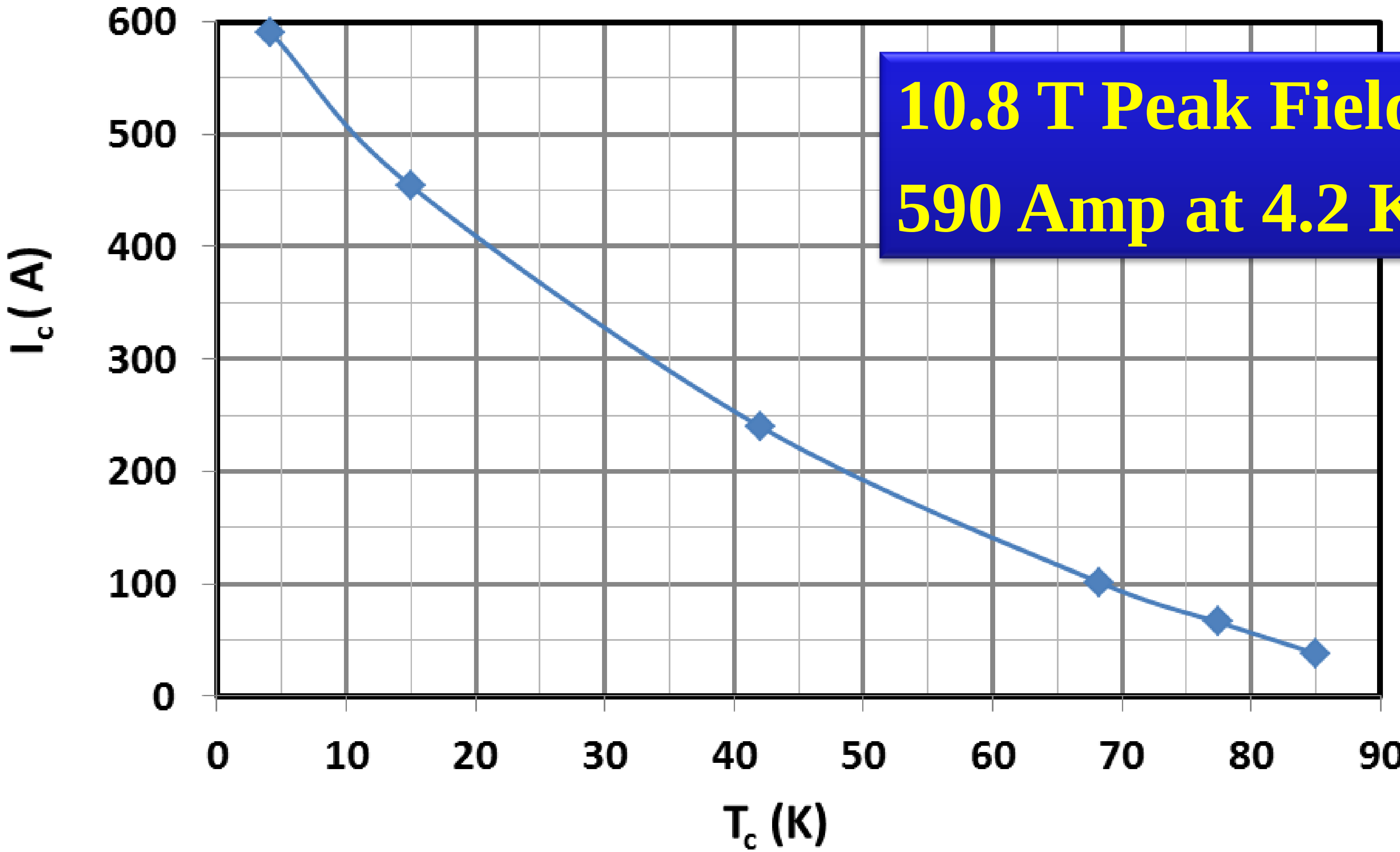


Critical Current Measurements



Least noise (least inductive voltage) when the current is held constant and temperature is allowed to rise slowly to hit the critical surface/temperature

Critical Current Vs. Temperature



10.8 T Peak Field
590 Amp at 4.2 K

SUMMARY

- HTS offers an opportunity to create very high fields.
- Major challenges due to large hoop stresses in a large in high field, large aperture solenoids. Other challenges: quench protection, new material, etc.
- Due to similar parameters, the design and technology developed for SMES at BNL is found to be directly applicable to CAPP/IBS.
- The performance of SuNAM HTS was uniform and copper plating strong. Nice performance at 77 K, pinning should improve 4 K.
- CAPP/IBS solenoid reached its Phase I goal of demonstrating over 10 T in a 10 cm solenoid with SuNAM HTS and SMES coil design.