Construction and test results of kapton insulated 2G HTS cosθ coil

L. S. Lakshmi*, E. Willen⋆, R. C. Gupta*

* Brookhaven National Laboratory, Upton, New York-11973
⋆ Particle Beam Lasers Inc., Northridge, California -91324

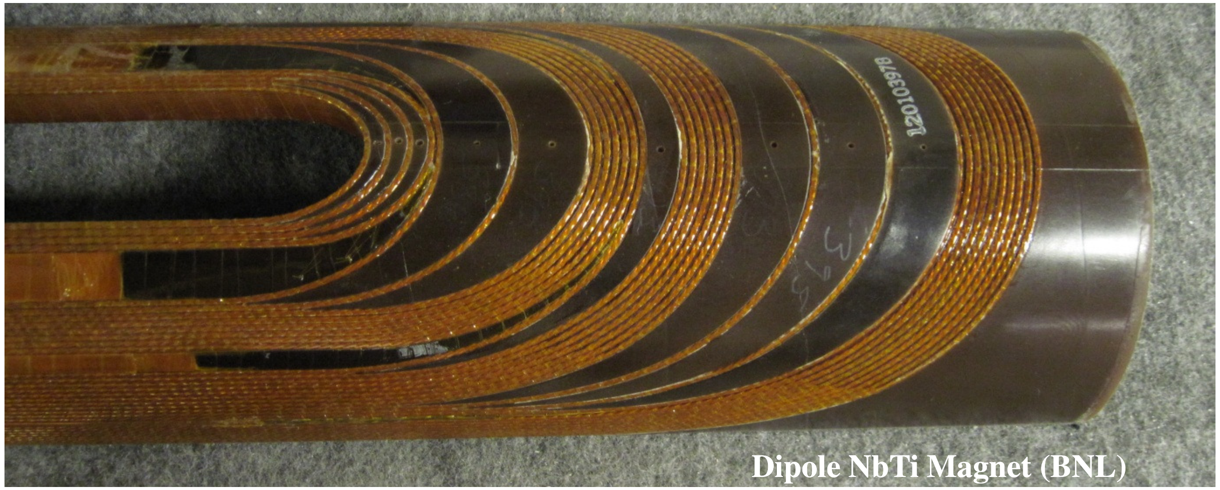
Presentation outline

- Technical Objective
- Conductor details
- Coil geometry, winding and testing
- Test results
- Summary and Future plan

This work is part of HTS Dipole STTR with Particle Beam Lasers Inc. (PI: Eric Willen)
Grant Award Number: DE-SC0007738

Technical context

- To demonstrate a high field (>20 T) cosine theta magnet technology for the particle accelerator program
- The proposed energy and luminosity upgrade of LHC at CERN will require high field dipole and quadrupole magnets



Dipole NbTi Magnet (BNL)

Quadrupole Nb_3Sn Magnet
(Courtesy: Bill Sampson, BNL)

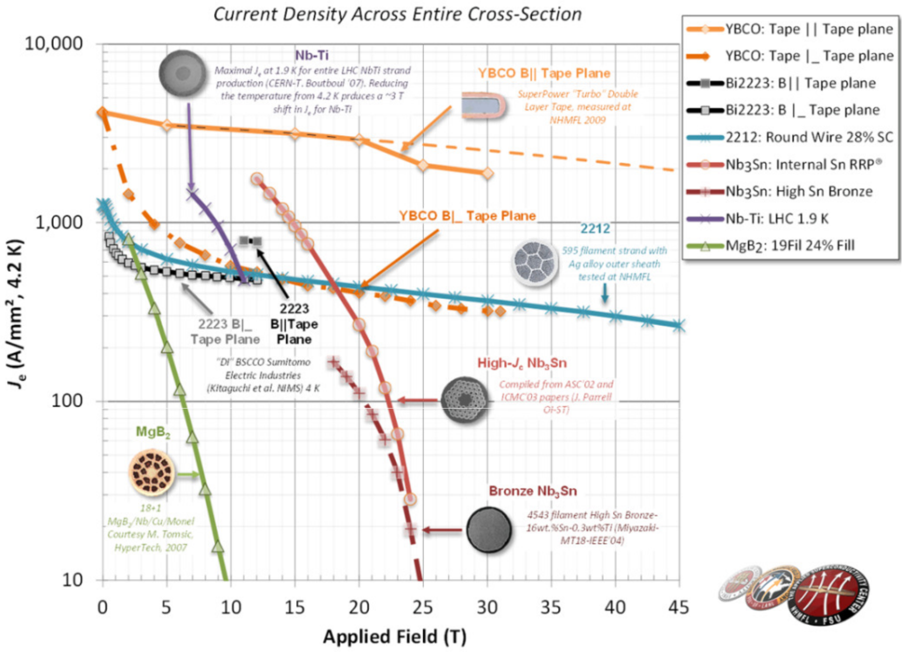
Cosine theta prototype magnets built in BNL using LTS materials

- There is a compelling need to look for a conductor technology beyond the conventional LTS materials.
- What are the alternate choices? How do we make them “fit for purpose” ?

BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

Alternate conductors: HTS



Reference: http://fs.magnet.fsu.edu/~lee/plot/plot.htm

Key features of 2G (REBCO) conductors

- **High current carrying capability at 4 K**
  It decreases slowly with field
- **Robust mechanical properties**
  Endures high mechanical stress (> 700 MPa) and high mechanical strain (>0.5%)
- **Withstands large heat loads**
- **Friendly for "react and wind" technology**

Note:

- *Anisotropic electrical and mechanical properties*
- *Critical bend radius is 6 mm*
- *Material cost is significant*
  complete replacement of conventional LTS might not be a cost-effective solution

☞ **High field magnets in a hybrid structure (LTS+HTS)**

a practically viable new generation magnet technology for the LHC upgrade

Objective

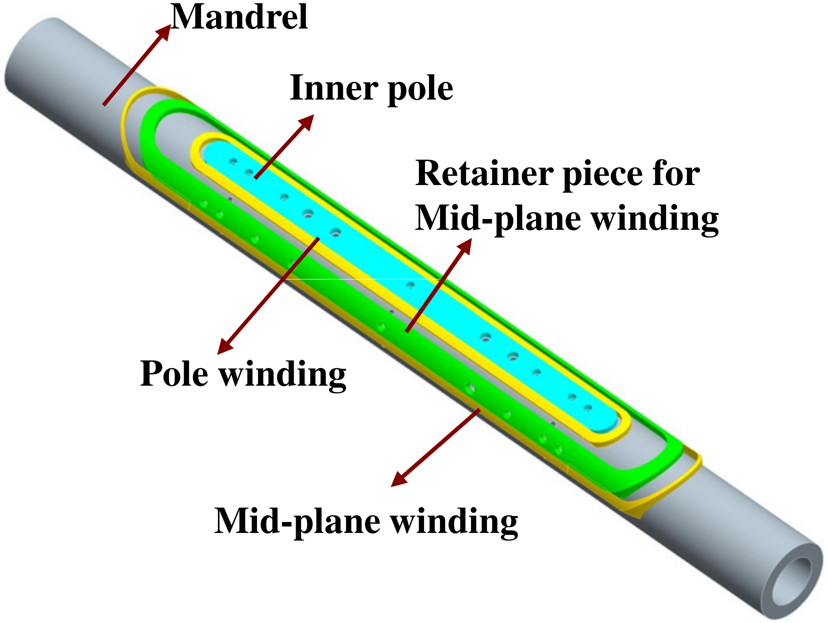
Feasibility study

➲Design and build prototype 2G HTS cos θ coils and a flat coil for a performance comparison

- Pole winding ($\theta = 70^0$) and mid-plane winding with complex end-geometry
- Optimize the winding parameters and tooling for the complete coil

➲Suitability of Kapton CI wrapping for turn-to-turn insulation and conductor protection- a unique and important design feature of this magnet.

➲ Electrical test at 77 K : to understand the conductor / coil performance in the complex end geometry of a cos θ magnet

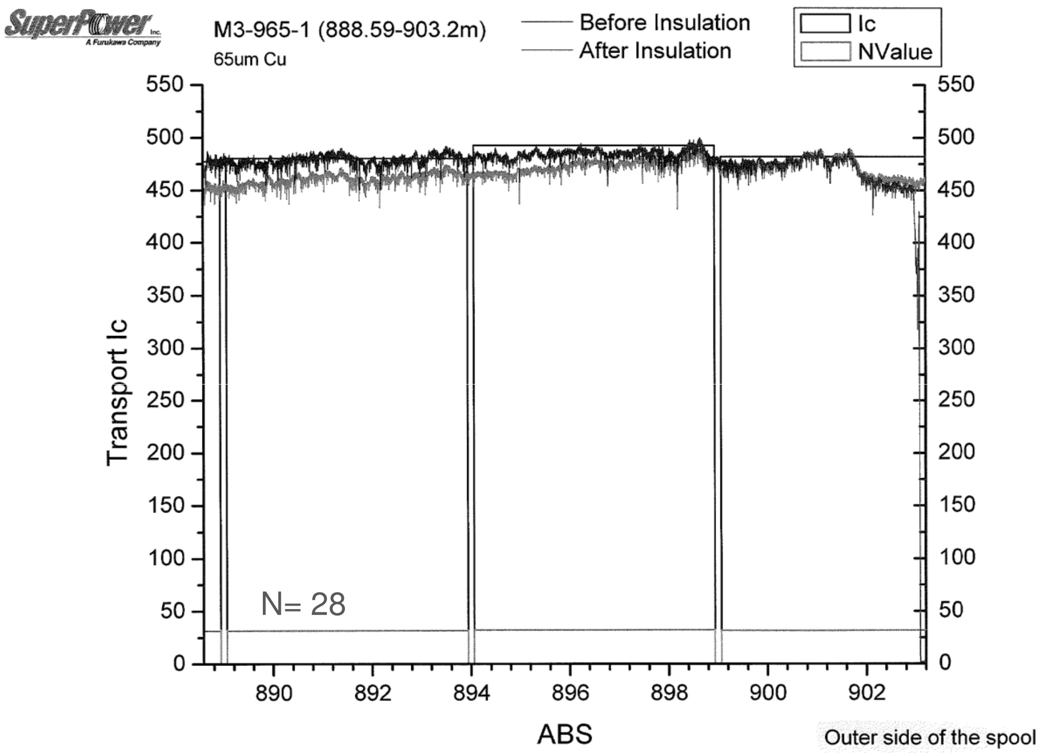


BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

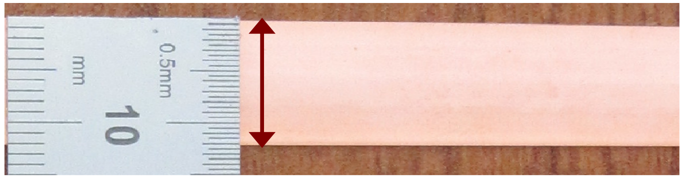
Conductor details

Kapton CI wrapped 2G conductor (supplied by SuperPower Inc.)



Note : Transport current was tested at every 5 m at 77K; Ic is defined under the voltage criterion of 1μV/cm

Bare conductor specification



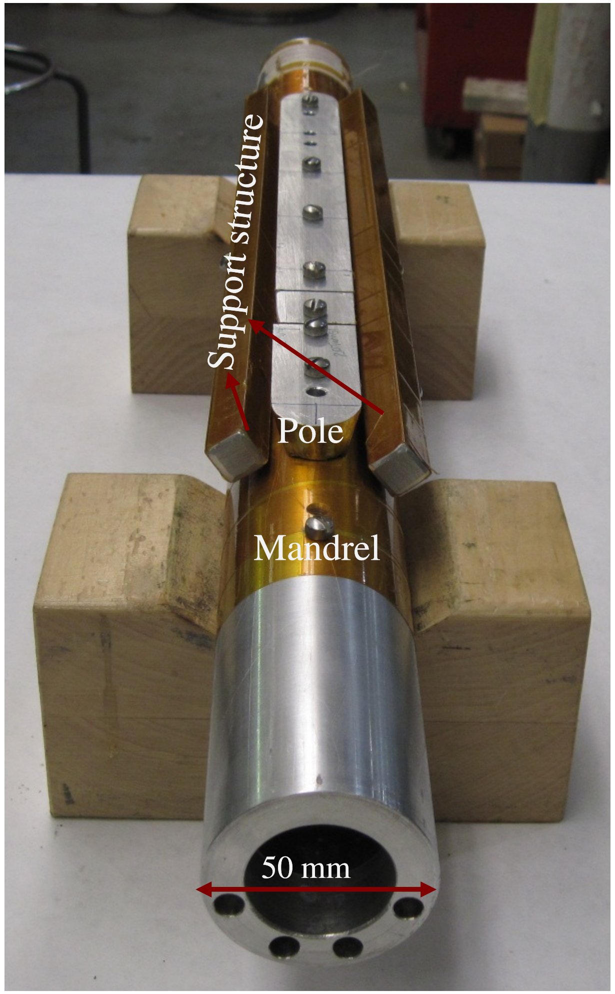
Width: 12.14 mm; Thickness: 0.12mm; Total length : 14 m
Thickness of
HTS layer: 1μm; Hastelloy : 50μm; Cu Stabilizer: 65μm
Transport properties at 77 K, self field
Average Ic : 483 A; Minimum Ic : 477 A

After kapton CI wrapping

Spirally wrapped with about 30% overlap between the adjacent Kapton layers
Thickness of the kapton CI tape : 25 μm
Thickness of the wrapped conductor: 0.177-0.240 mm

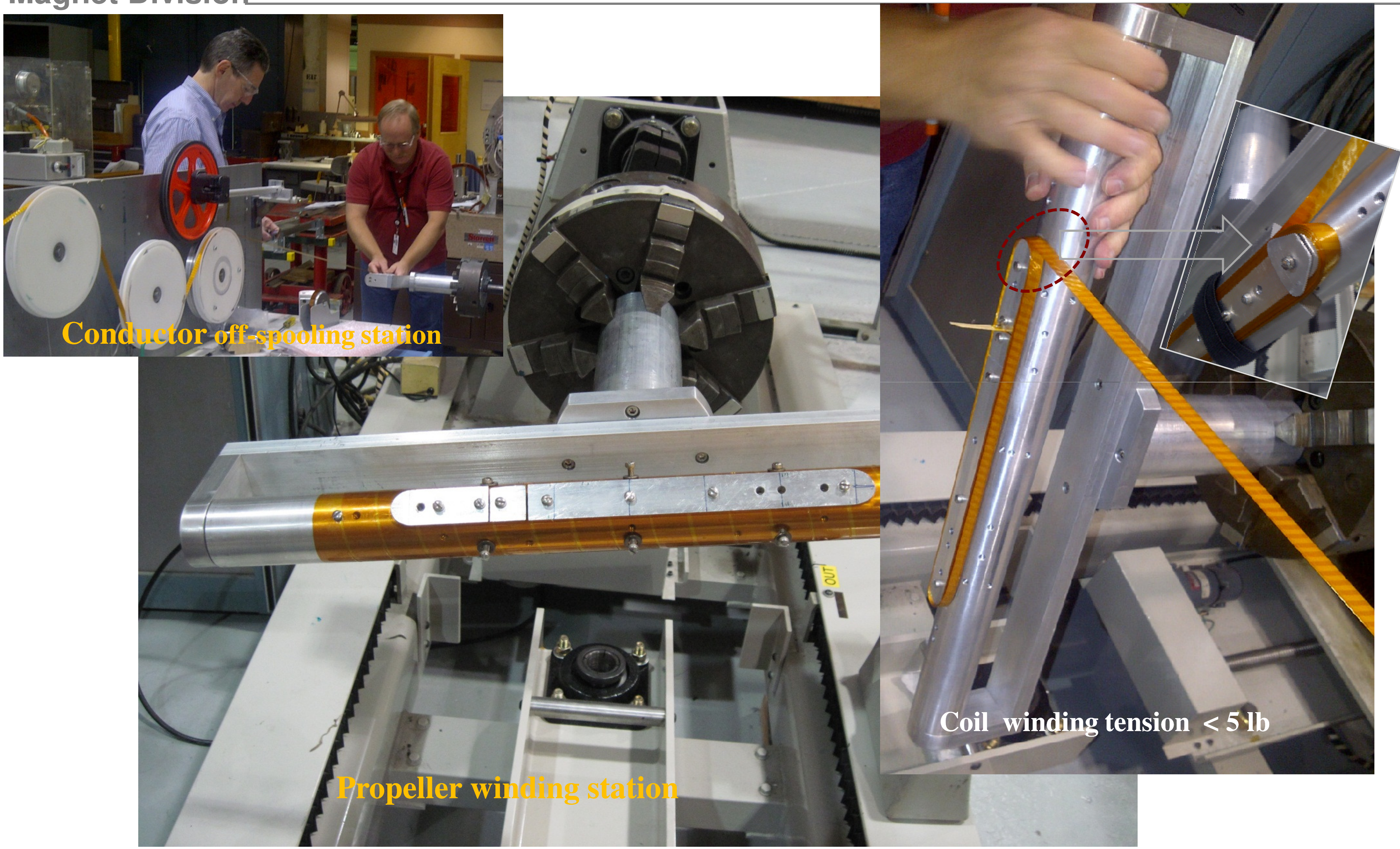
- ➲The conductor Ic is very uniform along the entire length.
- ➲Kapton wrapping process did not cause any Ic degradation

Pole winding: fixtures



Material: aluminium

Pole winding

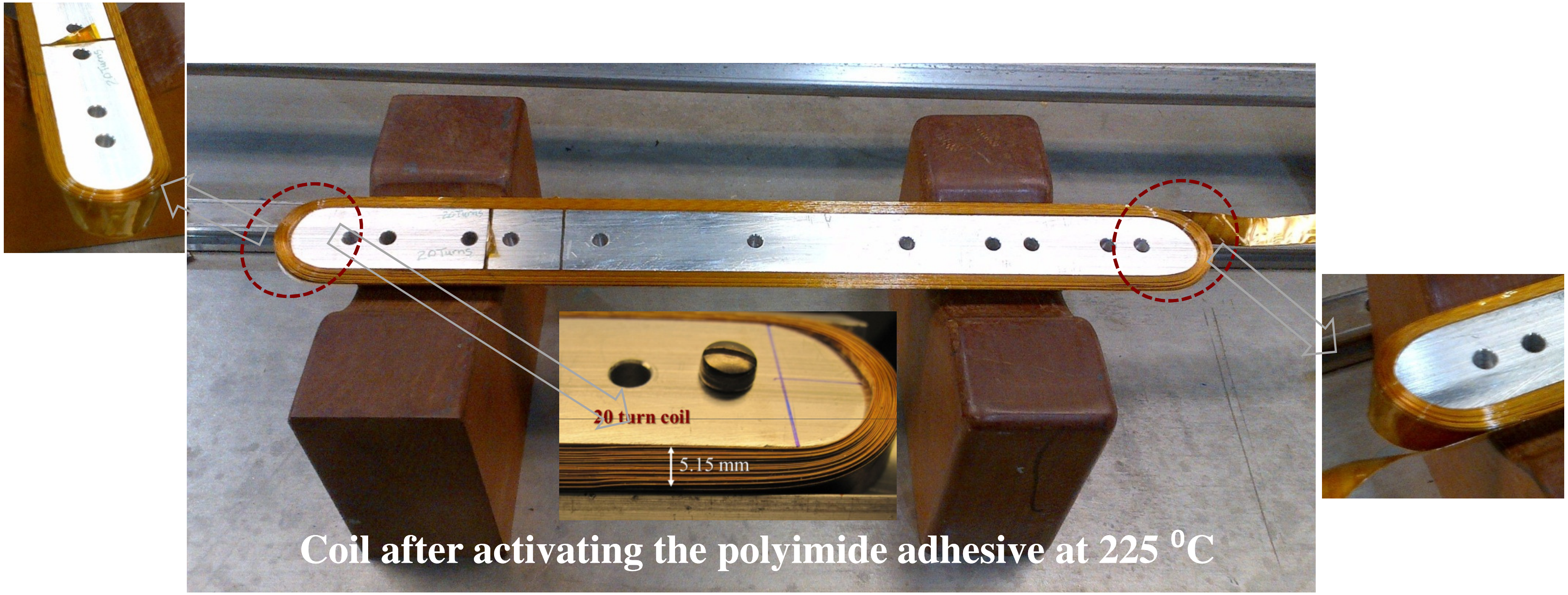


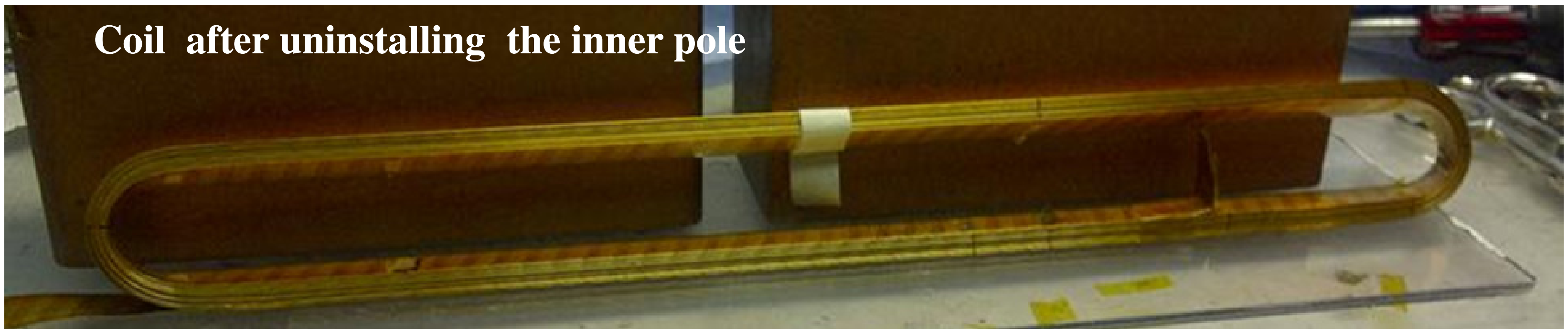
Conductor off-spooling station

Propeller winding station

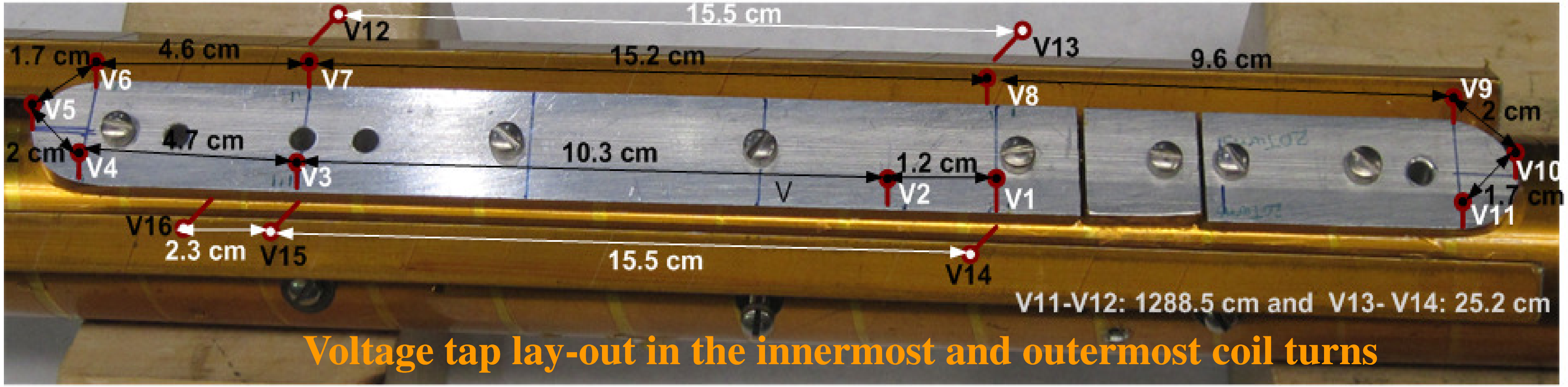
Coil winding tension < 5 lb

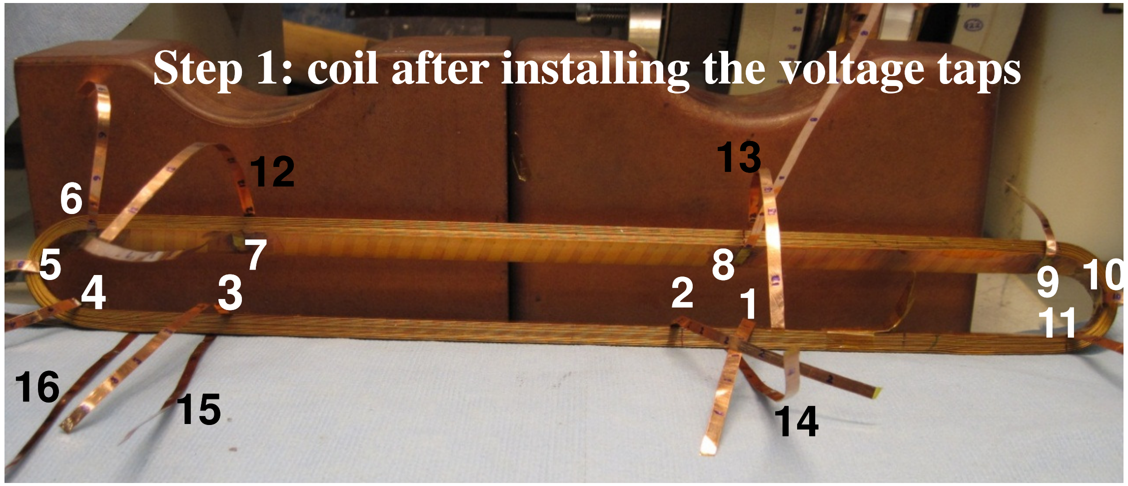
coil after the curing process





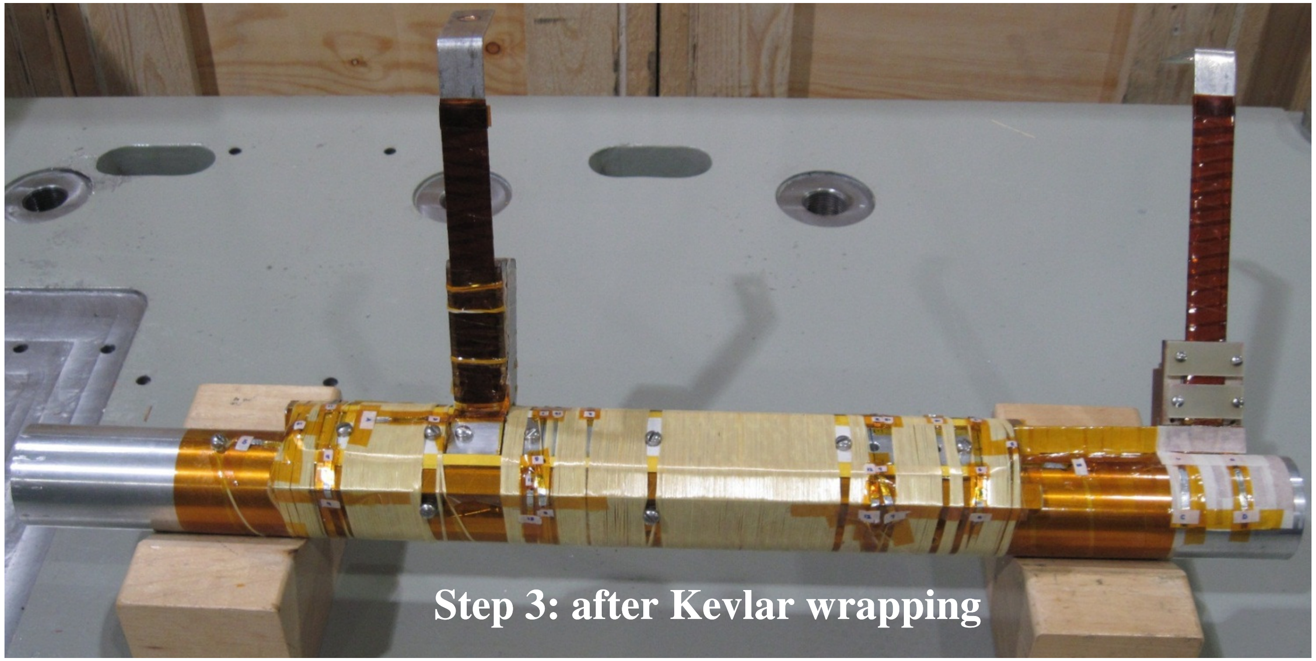
Voltage tap lay-out in the coil



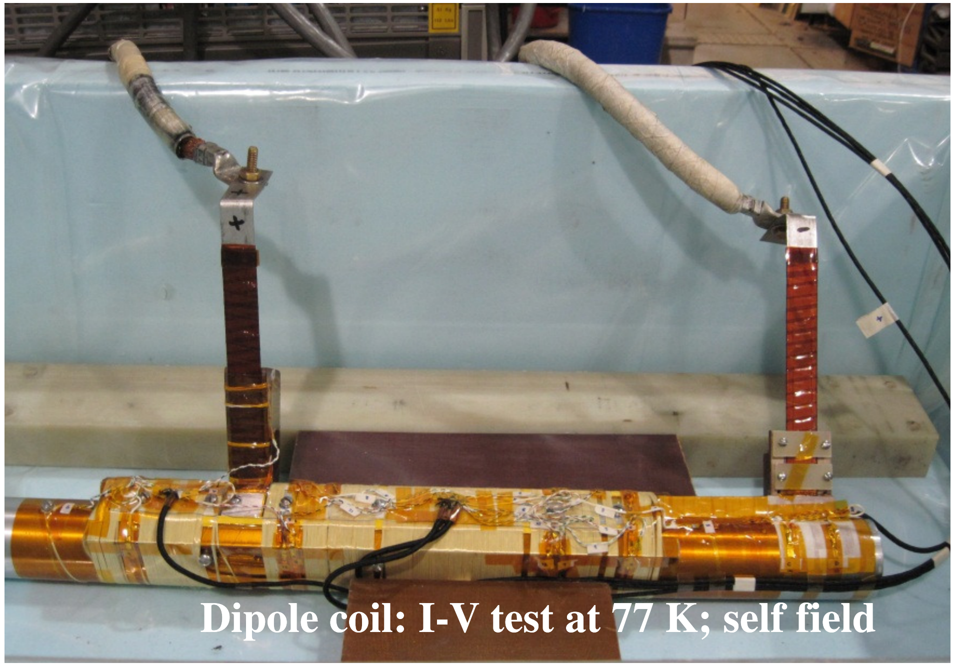


☞voltage taps are installed in the smaller straight and critical bend sections of the innermost coil turn

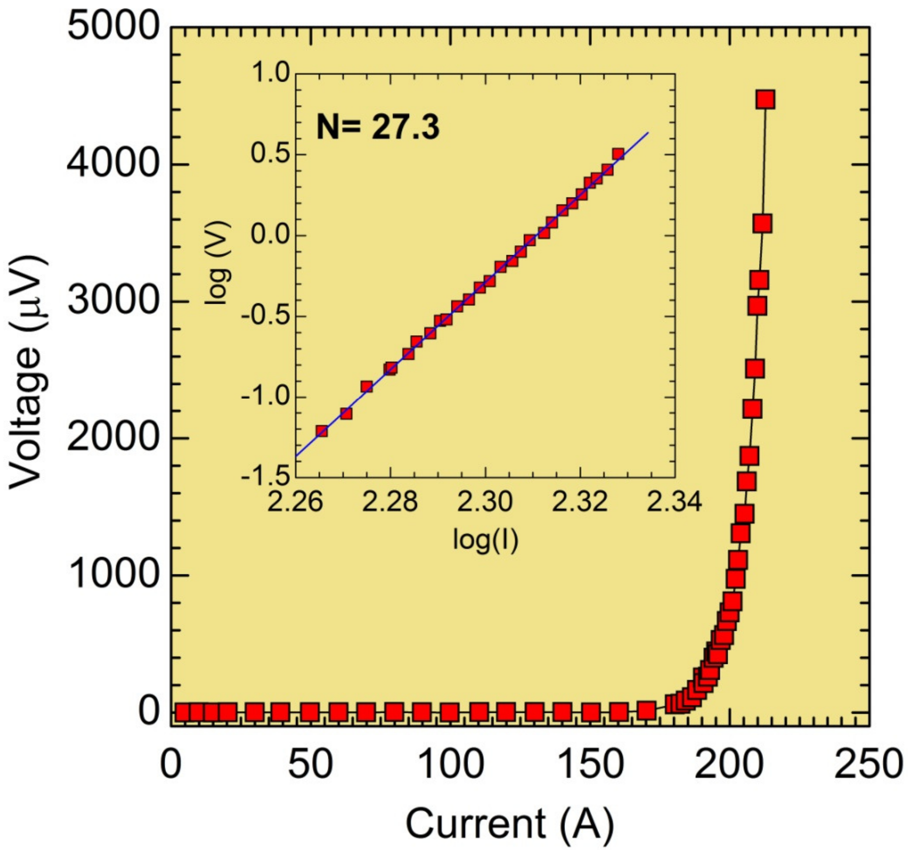
Electrical Test : Preparation



Test results



Y axis represents the end-to end voltage in the coil block (V1-V16)

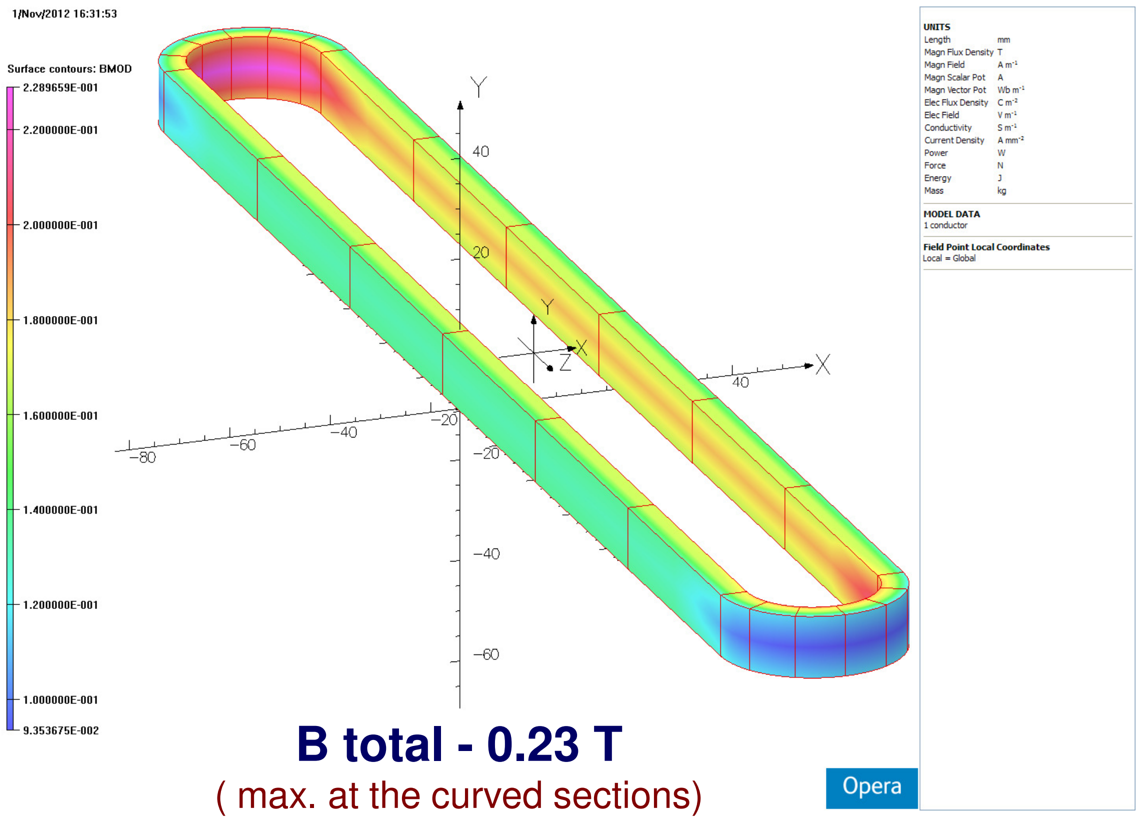


Based on

1μV/cm criterion: Ic= 204 A

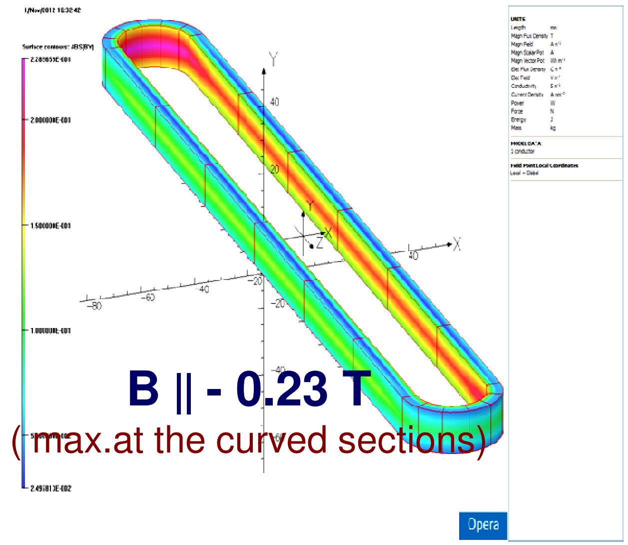
0.1μV/cm criterion: Ic= 187.8 A

Field components at 77 K; I = 200A



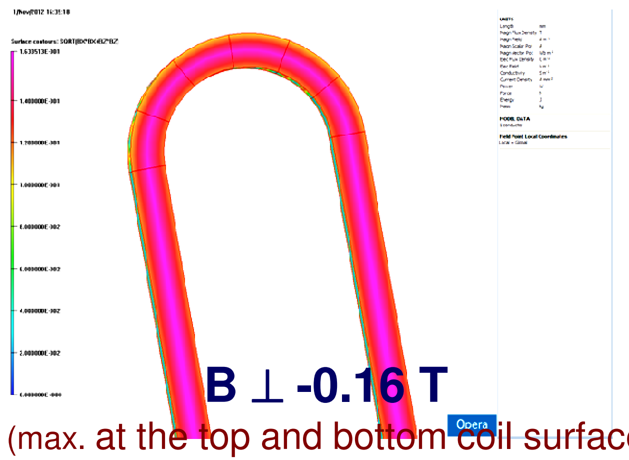
B total - 0.23 T

(max. at the curved sections)



B || - 0.23 T

(max.at the curved sections)



B ⊥ -0.16 T

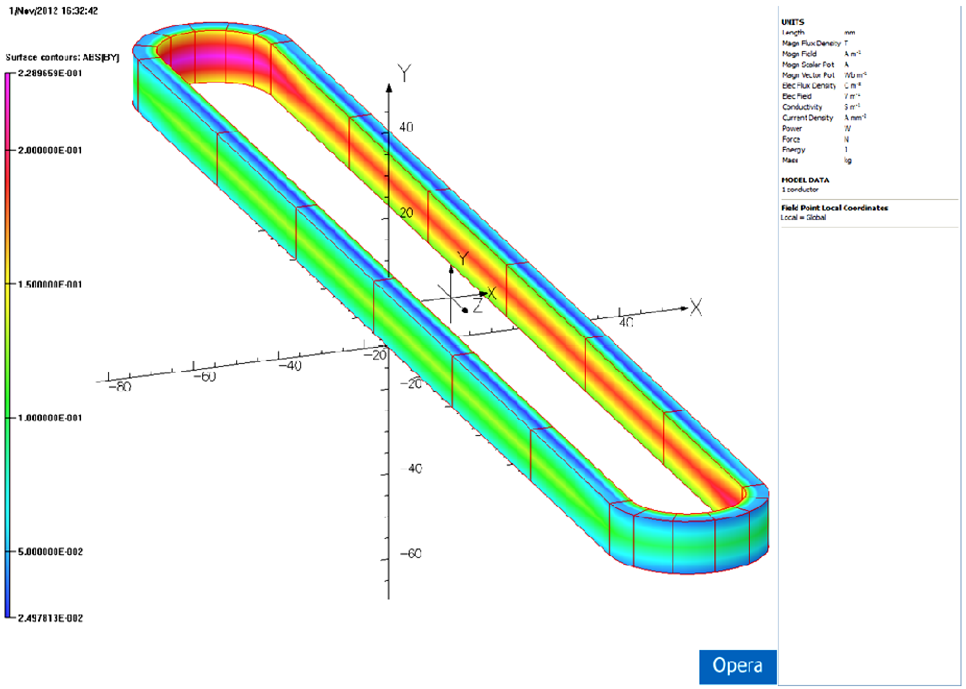
(max. at the top and bottom coil surface)

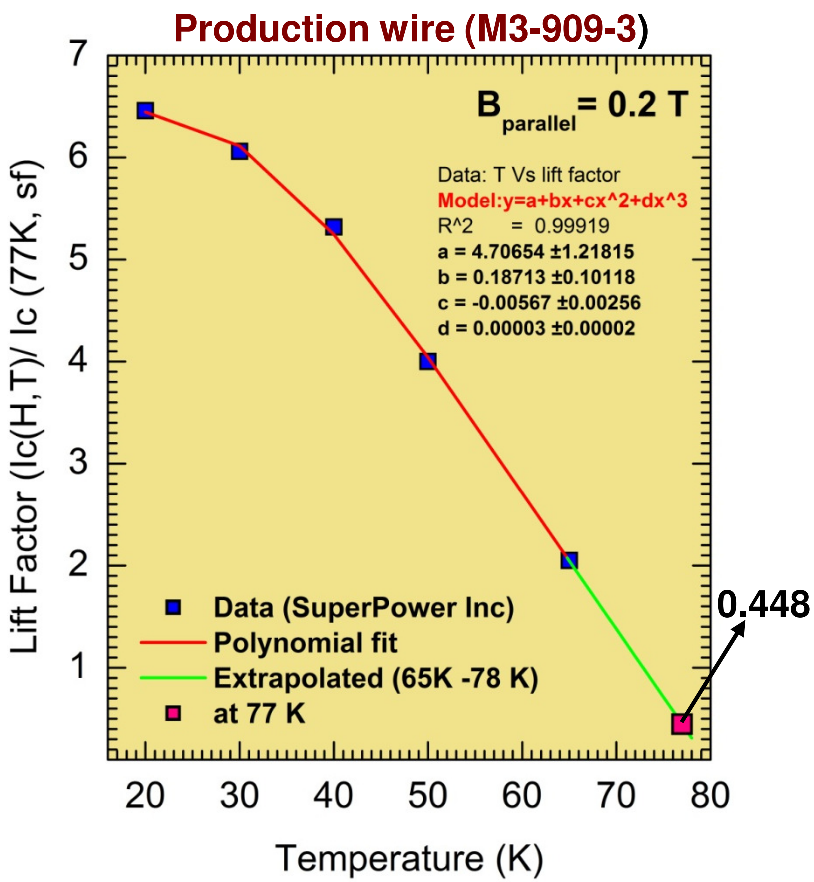
Courtesy : Ramesh Gupta

Ic (expected) :pole winding

B || - 0.23 T

(maximum at the curved sections)



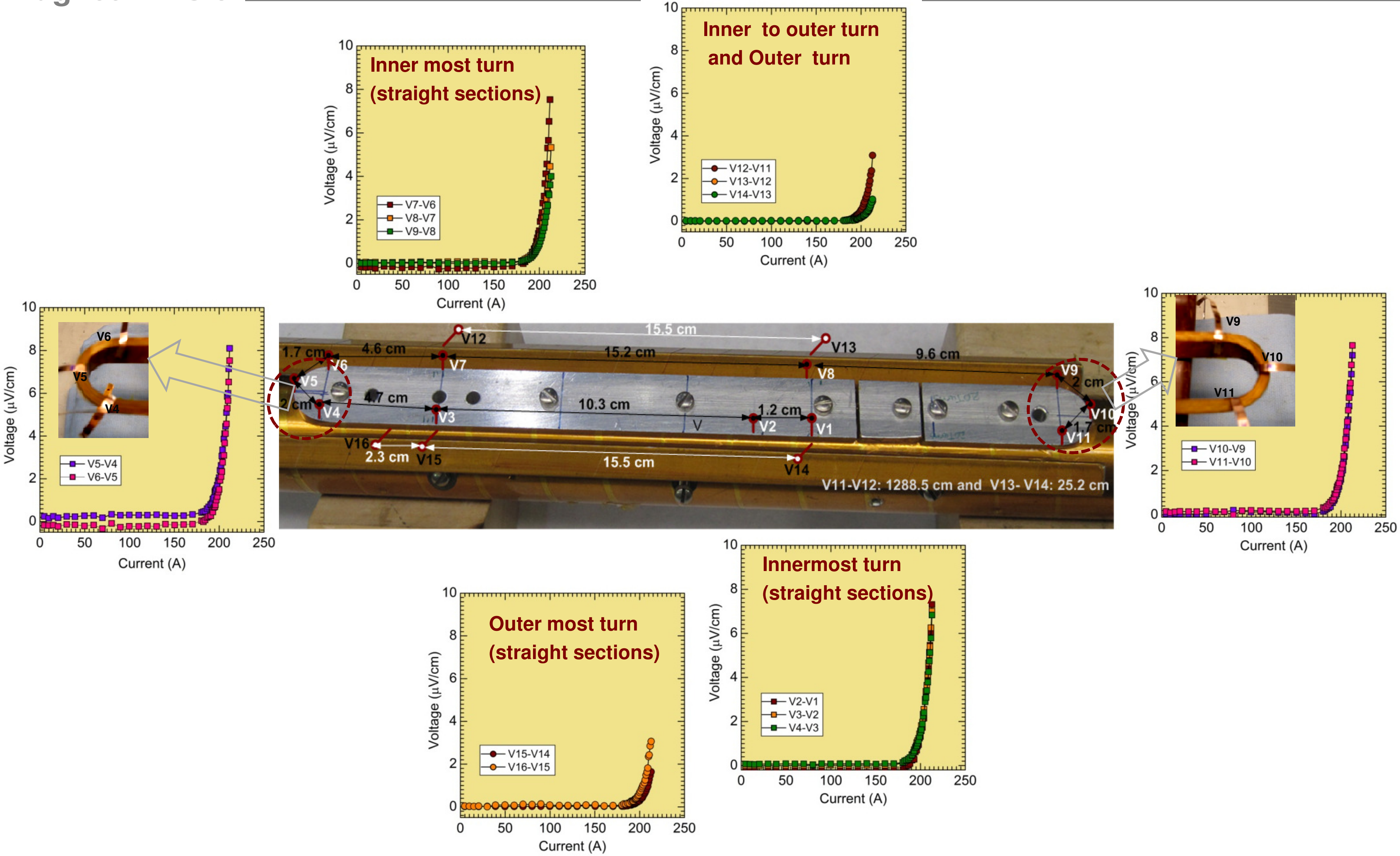


Ic (average)= 483 A (bare conductor)

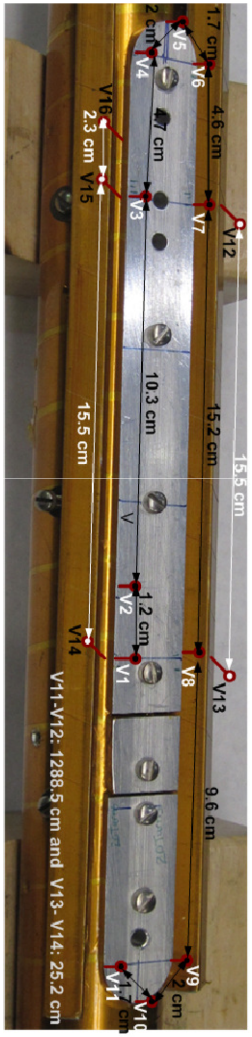
Ic (measured) = 204 A (pole winding, 77 K)

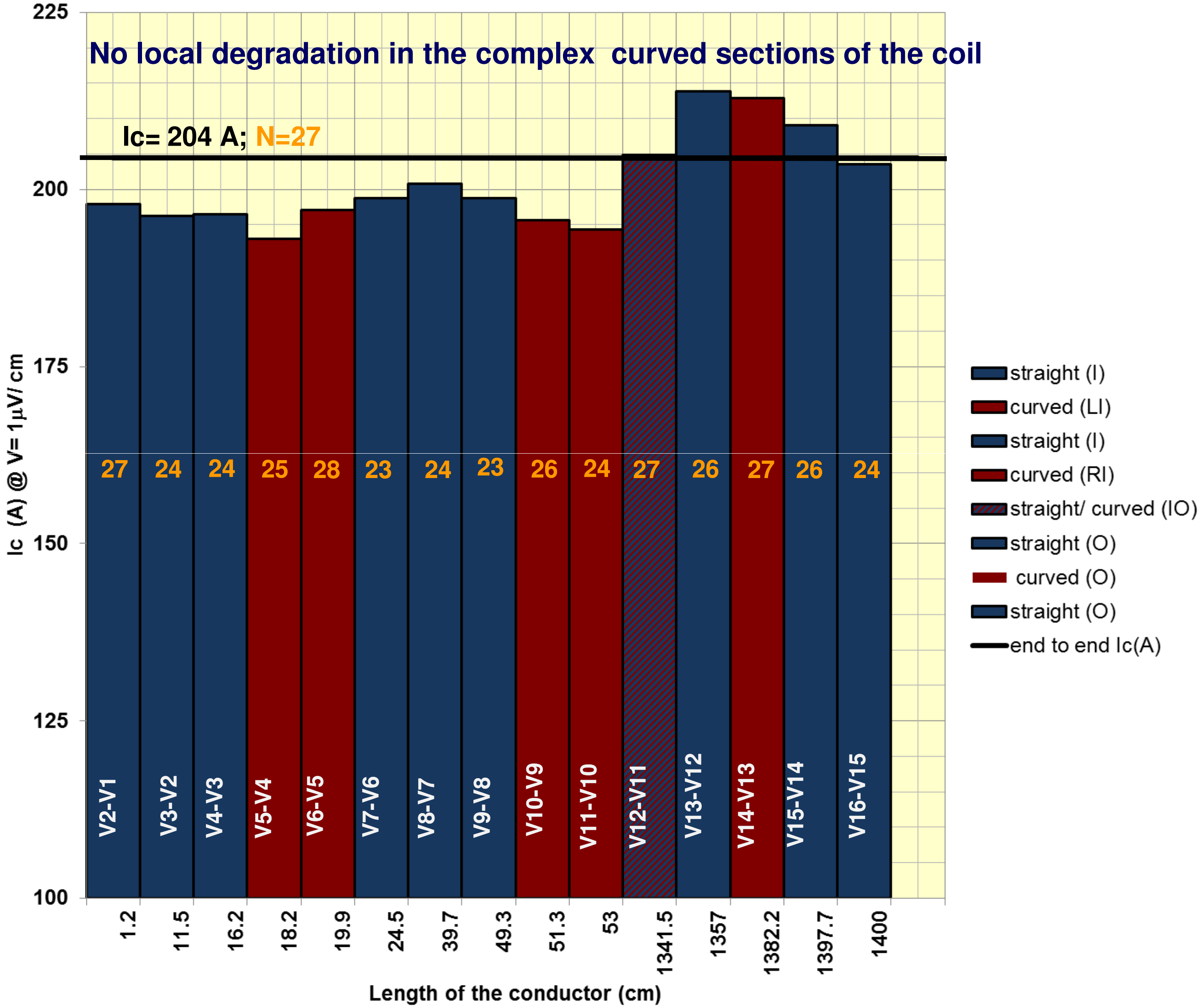
Ic (calculated) in the coil=217 A (Lift factor* Ic(average)of the bare conductor)

How do the small coil sections behave?



current distribution in the coil





Summary and future plans

- cos θ magnet using 2G HTS material is practically feasible.
- Kapton CI insulation provides good mechanical stability.
- The coil carries significant current 204 A at 77 K, self field condition (as expected)
- No significant current drop–out across the complex bend sections.
- High N value (>25) of the coil and the small critical bend sections confirms that the winding and curing process caused no electrical/ mechanical degradation.
- Mid-plane winding will be tested at 77 K.
- Next phase-design, build and test two-layer dipole coil. Measure the field harmonics. Test the coil in a hybrid coil set up in the future.

Acknowledgement

We acknowledge the contribution of our engineers and the technical staff members.