



US LHC Accelerator Research Program

bnl - fnal- lbnl - slac

**LARP Collaboration Meeting 11
October 27-28, 2008**

2.4 Materials – Conductor R&D and Procurement

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Outline

- Conductor Procurement and Inventory
- Cabling Activity
- Strand R&D
- Cable Test - Update



Conductor Procurement

- In FY08
- Took delivery of 180 kg of RRP 108/127 (increased spacing)
 - 37 kg at 0.7 mm
 - 30 kg at 0.8 mm
 - 114 kg at 1.07 mm
- 85 kg has been ordered in FY08
 - 54/61 at 0.8 – 1.0 mm
 - Delivery in Dec'08
- A second 75 kg order placed in Sep'08
 - Strand design 54/61
 - Delivery in July-Aug '08
- In FY09
 - Plan to order 100 kg of wire



Nb₃Sn Strand Specification

LARP-MAG-M-8002 Rev-B

| | |
|---|--------------------------------|
| Process | Ternary RRP Nb ₃ Sn |
| Strand Diameter, mm | 0.8 – 1.0 ± .003 |
| J _c (12 T) at 4.2 K, A/mm ² | ≥ 2650 |
| J _c (15 T) at 4.2 K, A/mm ² | >1400 |
| D _s , μm (subelement diameter) | < 100 |
| J _s , A/mm ² | >3000 |
| Cu-fraction, % | 53 ± 3 |
| RRR (after full reaction) | ≥ 60 |
| Twist Pitch, mm | 14 ± 2 |
| Twist Direction | right-hand screw |
| Minimum Piece length, m | 350 |
| High temperature HT duration, h | ≥ 48 |

s/d ratio increased from 0.09 to 0.13



LARP Procurements

| Order Date | Ship Date | Adjusted Ship Date | Quantity, kg | Actual Completed, kg | PO | Program | Billet No. | Cables |
|------------|-----------|--------------------|--------------|-------------------------------------|---------|---------|---|-------------|
| 11/7/05 | 7/2/06 | at LBNL | 30 | 13.6 | 6803608 | LARP | 8817 | |
| " | " | at LBNL | 30 | 38.2 | 6803608 | LARP | 8879 | 953R TQ+LQ |
| " | " | at LBNL | 30 | 38.4 | 6803608 | LARP | 8904 | 973R LQ |
| 1/20/06 | 9/6/06 | at LBNL | 30 | 10.2, 4.6, 15.8 | 6804489 | LARP | 9151 9318 9271 | Quarantined |
| " | " | at LBNL | 30 | 27.1, 3.0 | 6804489 | LARP | 9152 9385 | Quarantined |
| " | " | at LBNL | 30 | 7.5, 22.5 | 6804489 | LARP | 8817 9420 | 975R LQ |
| 2/23/06 | 10/25/06 | at LBNL | 30 | 16.1 | 6805346 | LARP | 9420 | |
| " | " | at LBNL | 30 | 37.7 | 6805346 | LARP | 9532 | 979R LQ |
| " | " | at LBNL | 30 | 36.4 | 6805346 | LARP | 9533 | 978R LQ |
| 5/23/06 | 1/15/07 | at LBNL | 30 | 2.4, 28.2 | 6807116 | LARP | 9533 9534 | 983R LQ |
| 11/1/06 | 5/30/07 | at LBNL | 50 | 10.6, 38.7 | 6813112 | LARP | 9534, 9560 | 984R LQ |
| | 9/30/06 | at LBNL | 150 | 13.1, 24.7, ,37.6, 38.9, 38.6 | " | LARP | 10045, 10046, 10067, 10068 | |
| 8/30/07 | 2/28/08 | at LBNL | 180 | 37.1, 30.2, 36.6, 38.9, 39.2 | 6826007 | LARP | 10400, 10425, 10428, 10429, 10433 | 982R TQ |
| 4/15/08 | 12/1/08 | | 85 | | 6846777 | LARP | | |
| 9/8/08 | 7/31/09 | | 75 | | 582020 | LARP | | |

840



Conductor Inventory Summary

- 26 kg required for UL of LQ
 - 6 UL's have been made
 - Present 54/61 strand inventory is 232 kg
 - Plans are to fabricate 6 more UL's in FY09
 - That will leave about 82 kg of wire for 3 UL's
- 60 kg of 54/61- 0.7 mm wire from five billets available for practice coils
- 180 kg of RRP 108/127 (increased spacing)
 - 30 kg at 0.8 mm
 - 114 kg at 1.07 mm



Strand Production

| | 54/61 kg | 108/127 kg | MAGNET | Strand Req. kg | Inventory of 54/61 kg | Inventory of 108/127 kg |
|--------|-------------|---------------|--------------|-------------------|--------------------------|----------------------------|
| Oct-07 | | | | | 386 | 0 |
| Nov-07 | | | LQ01-C03-PC | 28 | 359 | 0 |
| Dec-07 | | | | | 359 | 0 |
| Jan-08 | | | LQ01-C04 | 26 | 333 | 0 |
| Feb-08 | | 180 | LQ01-C06/C07 | 51 | 282 | 180 |
| Mar-08 | | | | | 282 | 180 |
| Apr-08 | | | | | 282 | 180 |
| May-08 | | | LQ01-C08/C09 | 51 | 231 | 180 |
| Jun-08 | | | TQS03 | 35 | 231 | 145 |
| Jul-08 | | | | | 231 | 145 |
| Aug-08 | | | | | 231 | 145 |
| Sep-08 | | | | | 231 | 145 |
| Oct-08 | | | LQ-C10/C11 | 51 | 180 | 145 |
| Nov-08 | | | LQ-C12/C13 | 51 | 129 | 145 |
| Dec-08 | 85 | | HQ-C01/C02 | 36 | 178 | 145 |
| Jan-09 | | | LQ-C14/C15 | 51 | 127 | 145 |
| Feb-09 | | | HQ-C03/C04 | 36 | 91 | 145 |
| Mar-09 | | | HQ-C05/C06 | 36 | 55 | 145 |
| Apr-09 | | | | | 55 | 145 |
| May-09 | | | | | 55 | 145 |
| Jun-09 | | | | | 55 | 145 |
| Jul-09 | 75 | | | | 130 | 145 |
| Aug-09 | | | | | 130 | 145 |
| Sep-09 | | | | | 130 | 145 |
| Oct-09 | | | | | 130 | 145 |



LARP Cable Plan FY-09

- 6 UL of LQ
 - 2 UL Oct. 2008
 - 2 UL Nov. 2008
 - 2UL Jan. 2009
- 6 UL of HQ
 - 2 UL Dec. 2008
 - 2 UL Feb. 2009
 - 2 UL Mar. 2009
- Time window for possible relocation of cabling facility
 - April-June 2009
- Ready to fabricate cable contingency
 - July or August 2009



HQ prototype Cable B0986R

HQ second prototype cable fabricated July-7, 2008

- Strand diameter: 0.80 mm
- No. strands: 35
- Thickness: 1.445 mm
- Width: 15.143 mm
- Keystone angle: 0.74 degrees

HT needs to be optimized for 15T, target 665C/72-96hrs.

Using 665C/60hrs gives a J_c of 3000A/mm^2 at 12T, RRR ~ 200

Extracted strands from this cable showed no J_c degradation with RRR ~ 155-190.

Stability Current Density is in the range of $3100 - 4100\text{ A/mm}^2$



Strand R&D

Self-Field Instability

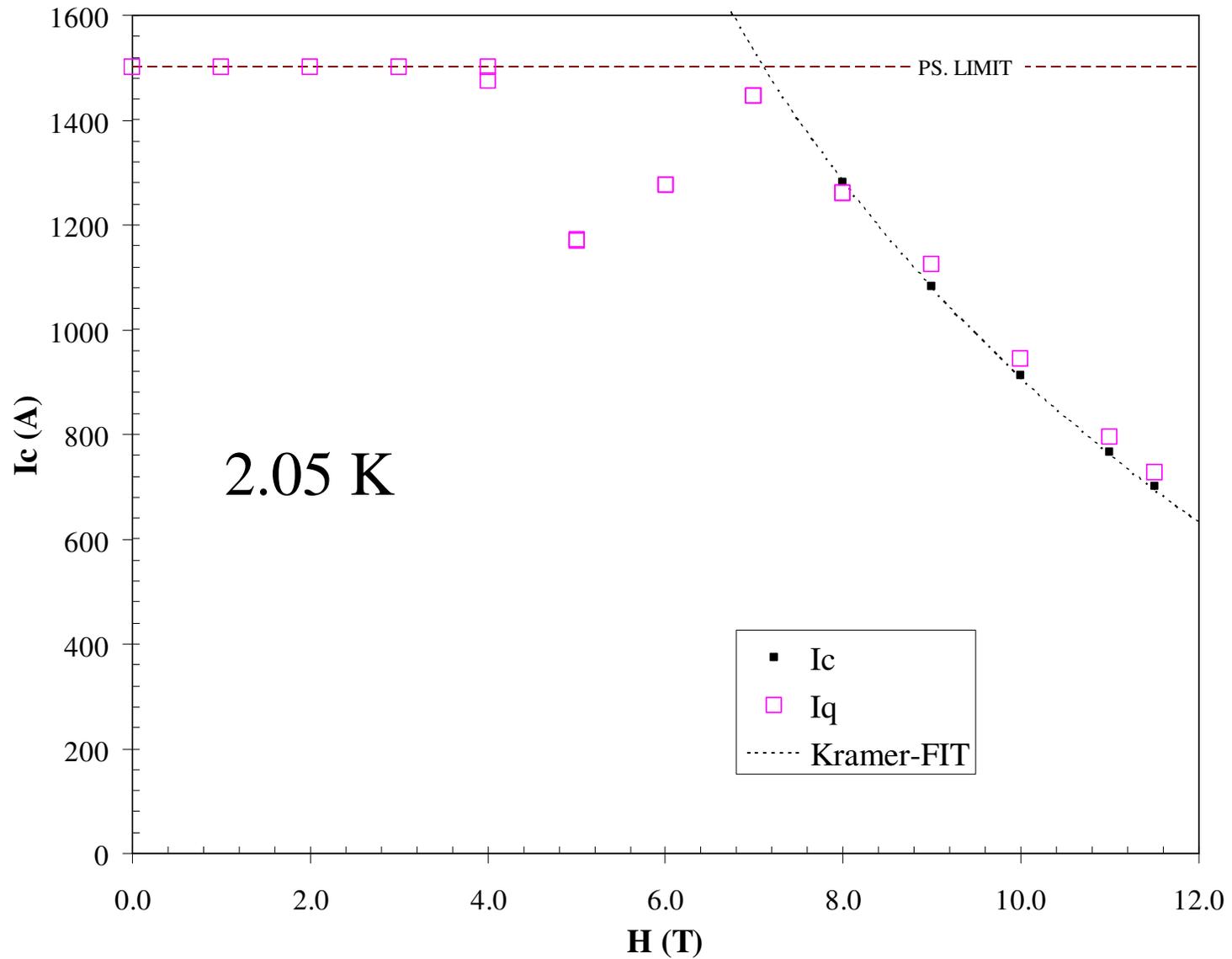
V-I Measurements

Instability more pronounced in superfluid helium at 2K than at 4.2K

Additional measurements on RRP 54/61 and 108/127 strand

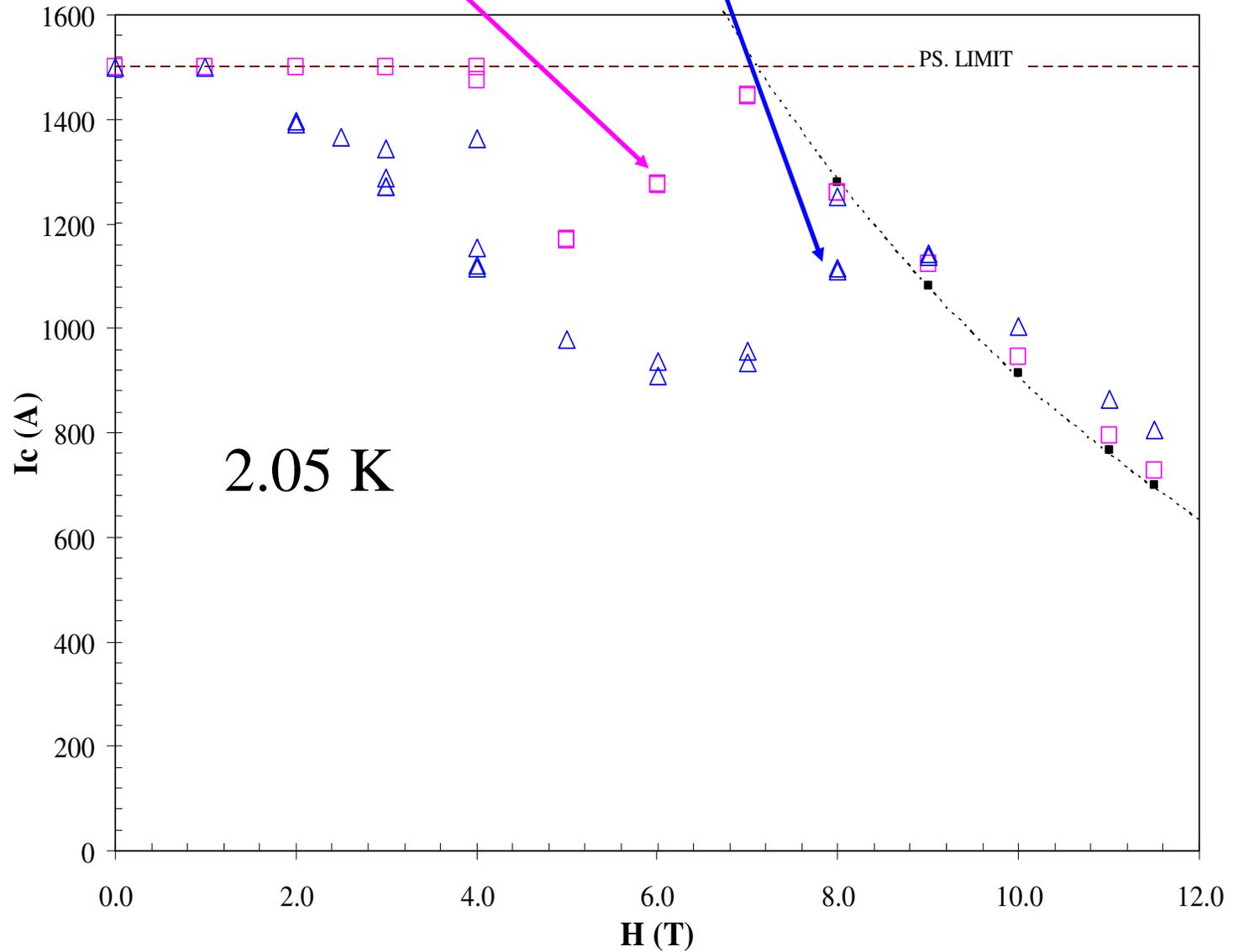


RRP 108/127 640C/48h RRR~ 310



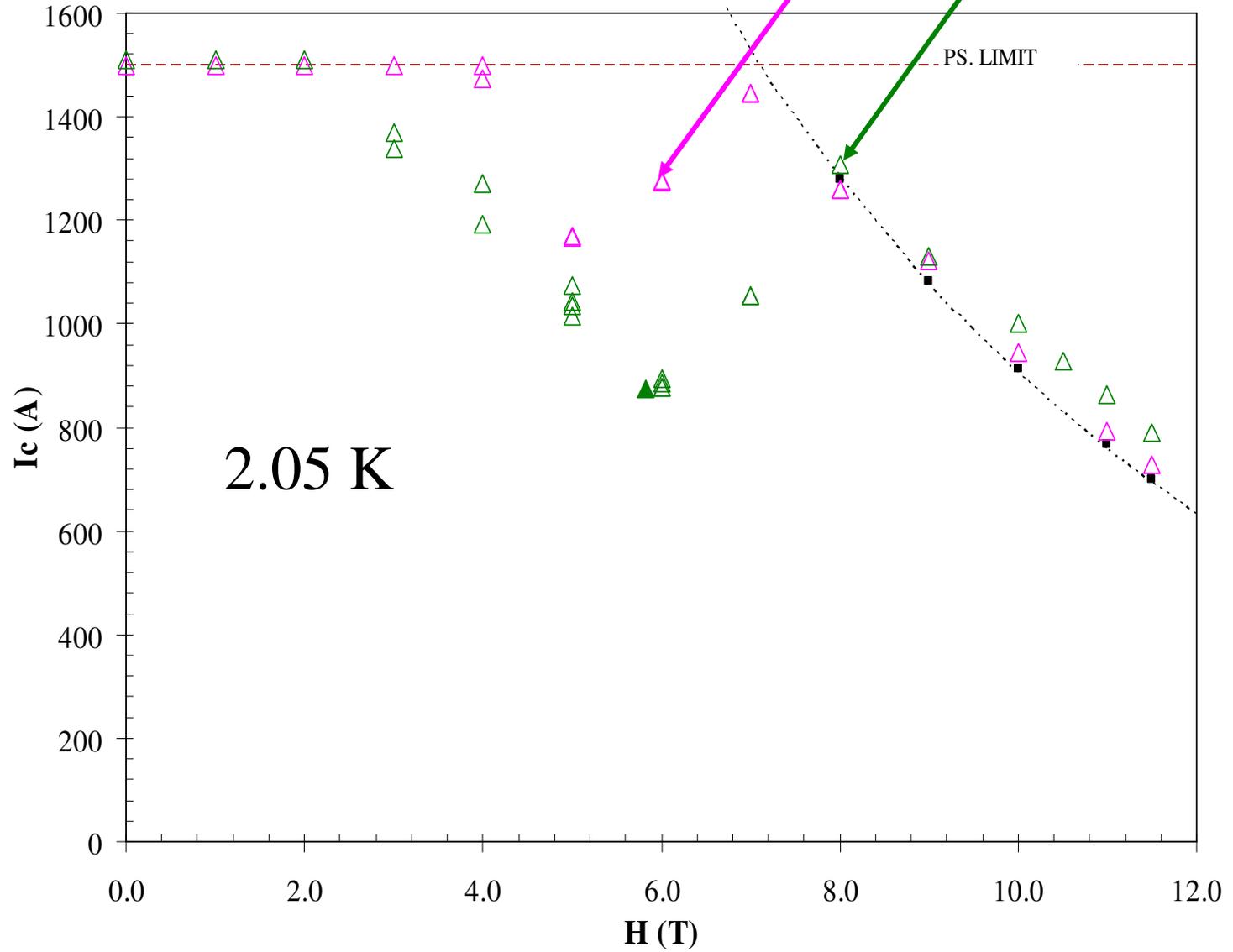


RRP 108/127 vs. 54/61 RRR~ 310



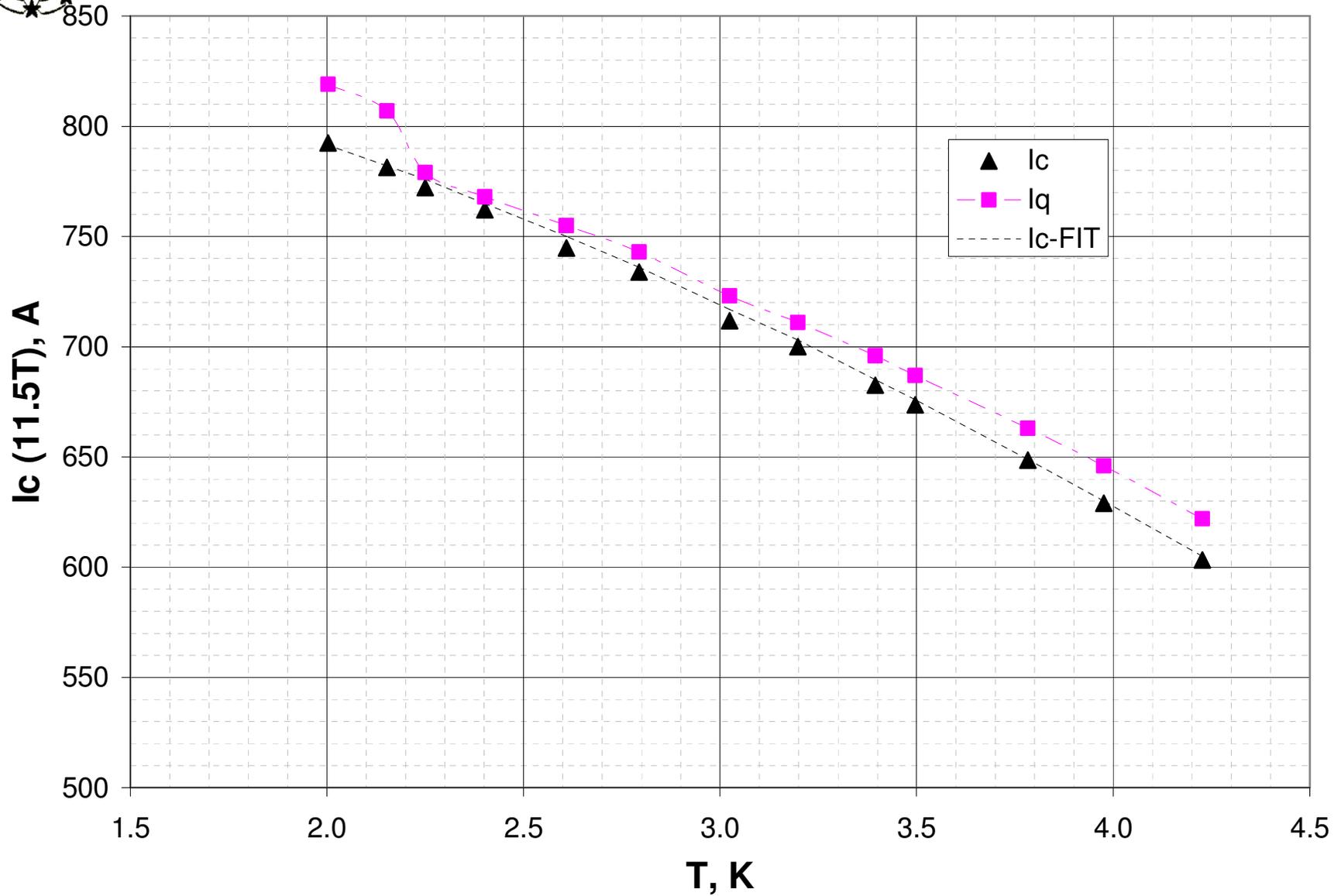


RRP 108/127, RRR of 310 vs. 80



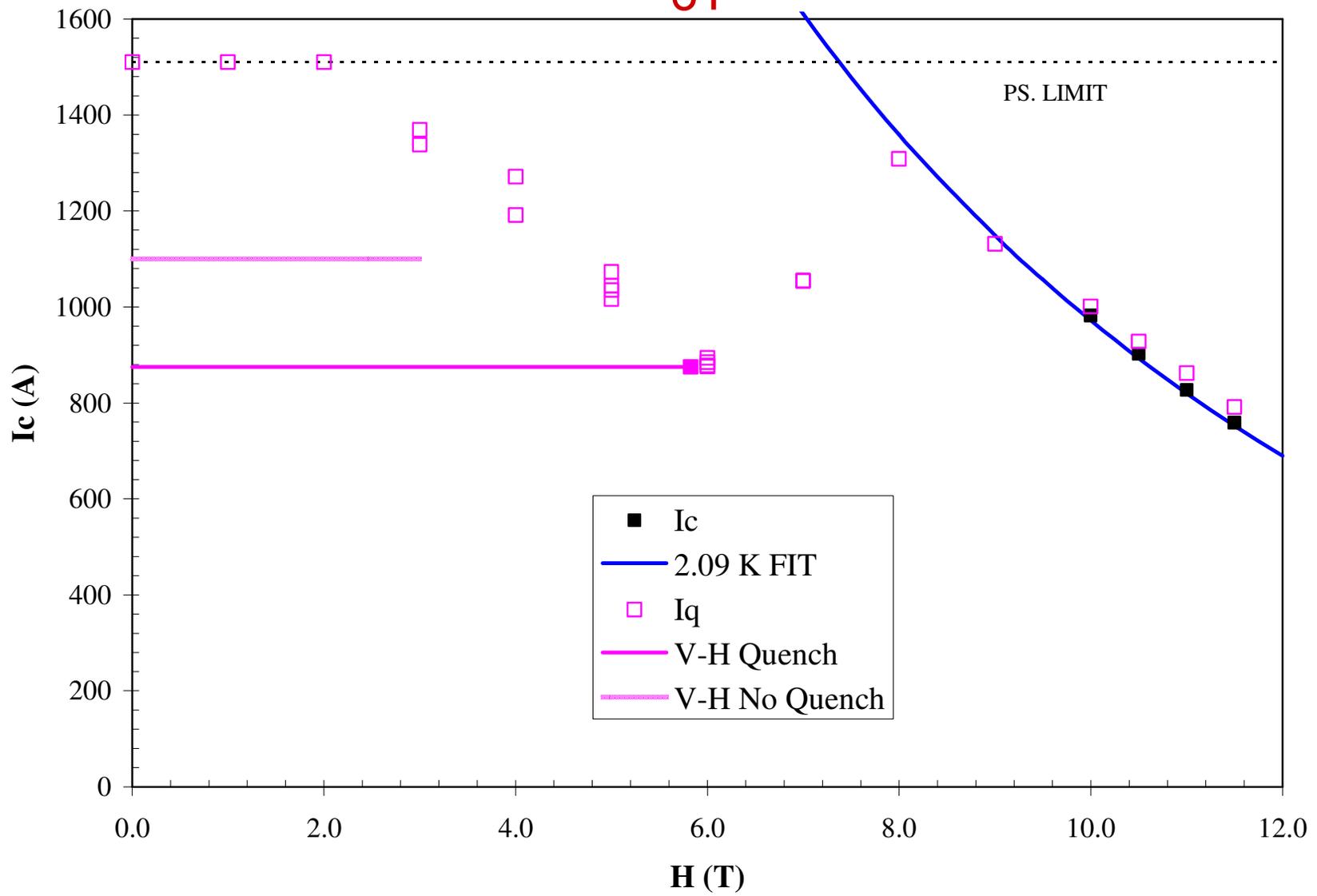


In high field strand follows predicted trend with T



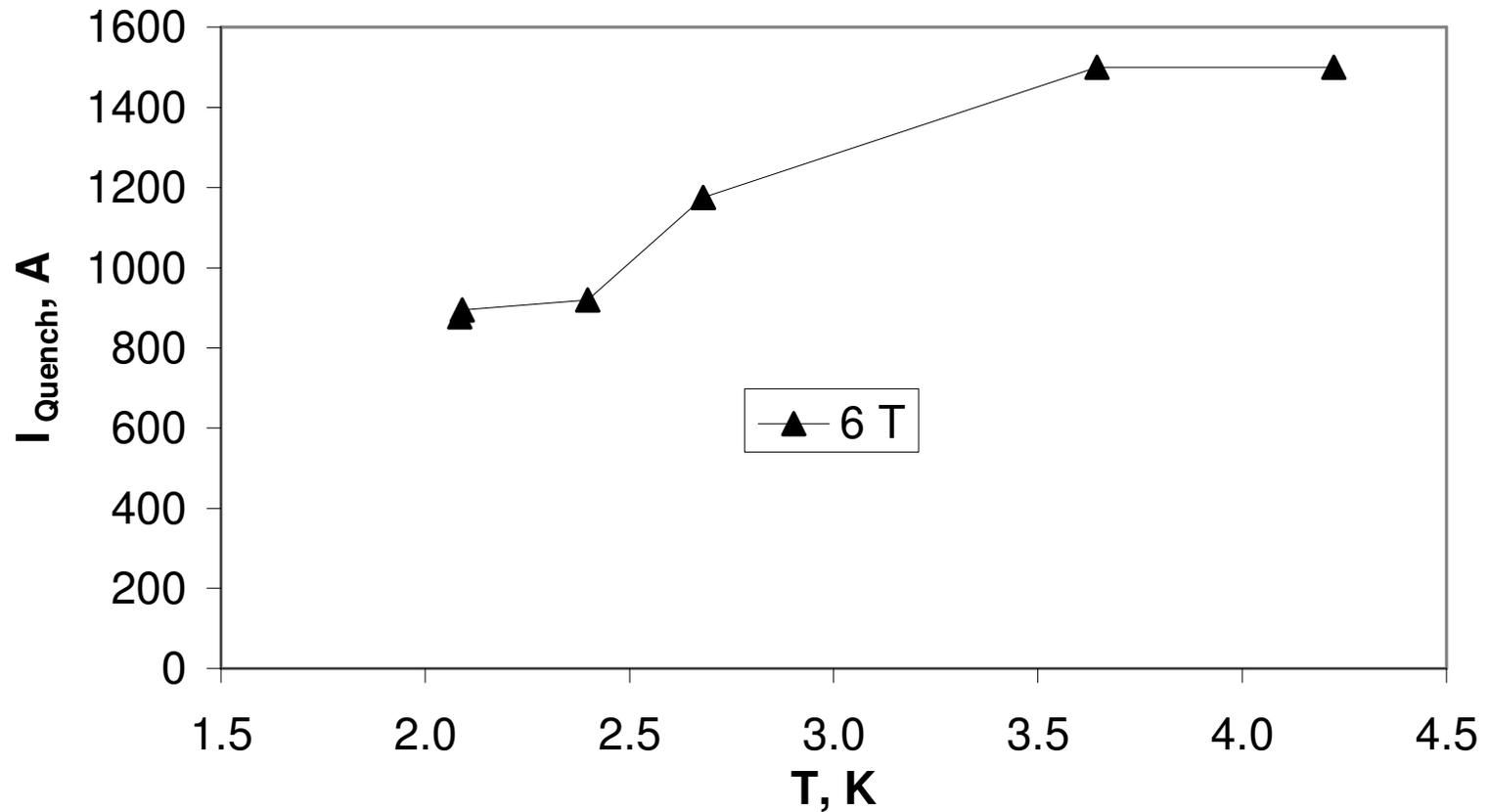


At low temperature strand instability in mid-field ~ 6T



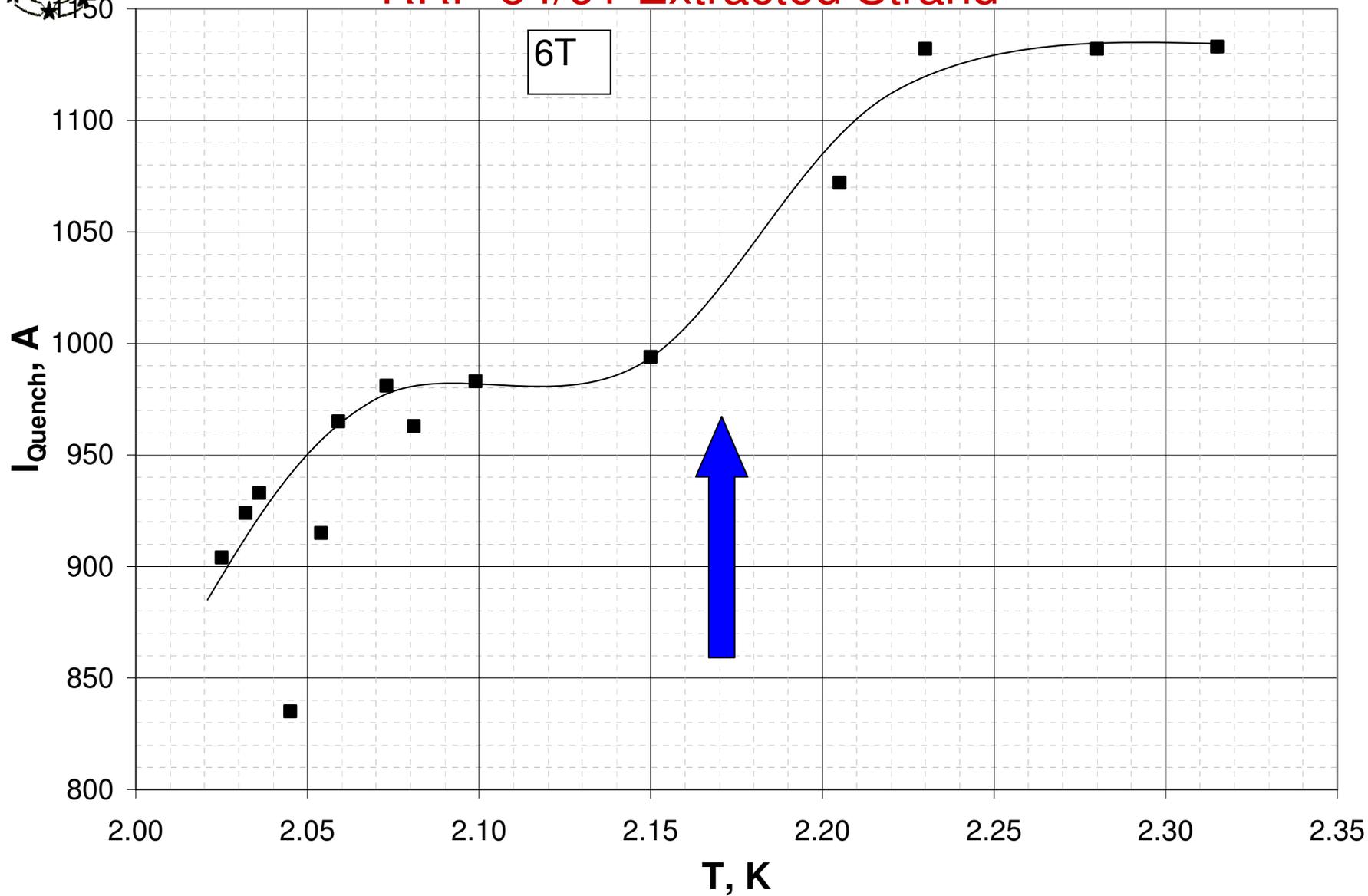


6T quench current on cool-down RRP 54/61





Warm-up at 6T from 2 K to 2.4K RRP-54/61 Extracted Strand





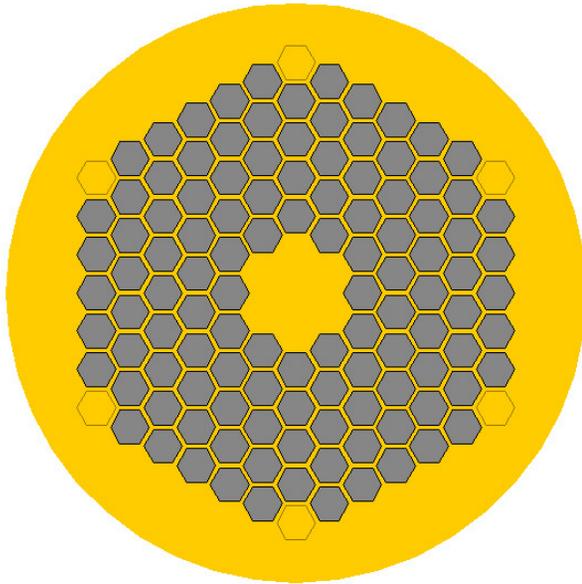
RRP 127 Strand Studies

E. Barzi



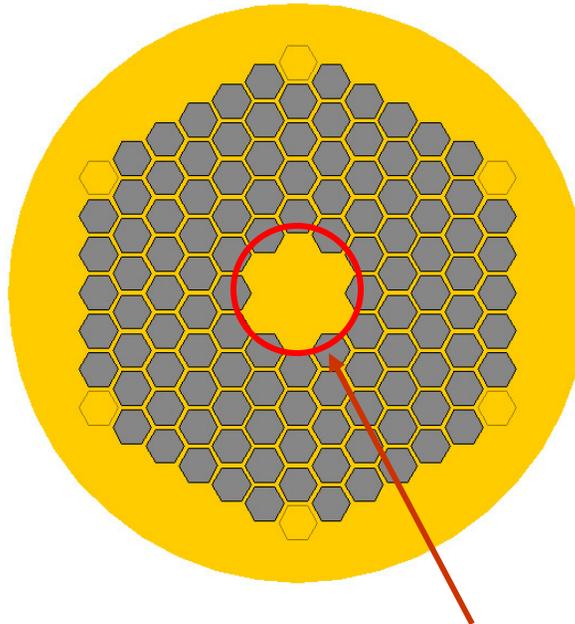
RRP 127 Restack Designs

114/127 restack with spaced SE's
 $J_{cmax} \sim 3000 \text{ A/mm}^2$



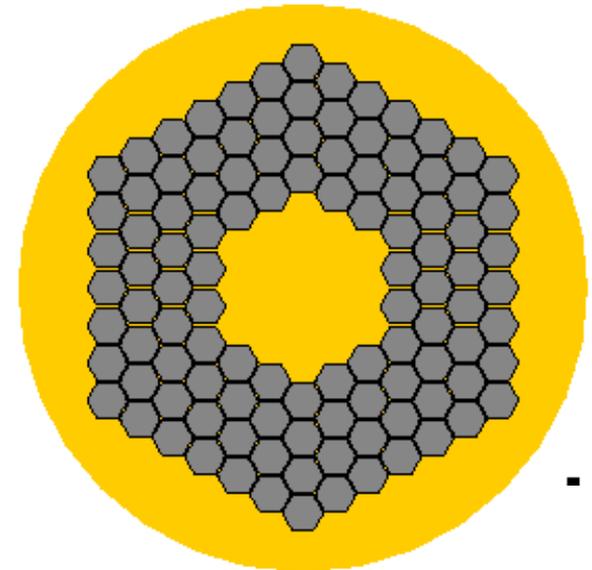
First R&D billet

102/127 restack with spaced SE's
 $J_{cmax} \sim 3000 \text{ A/mm}^2$



Remove inner row

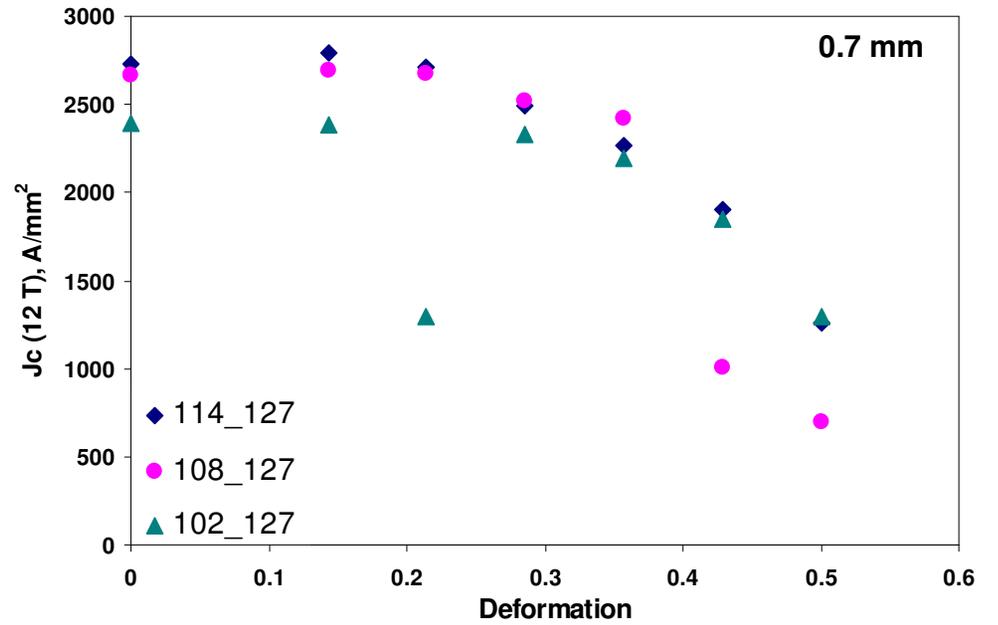
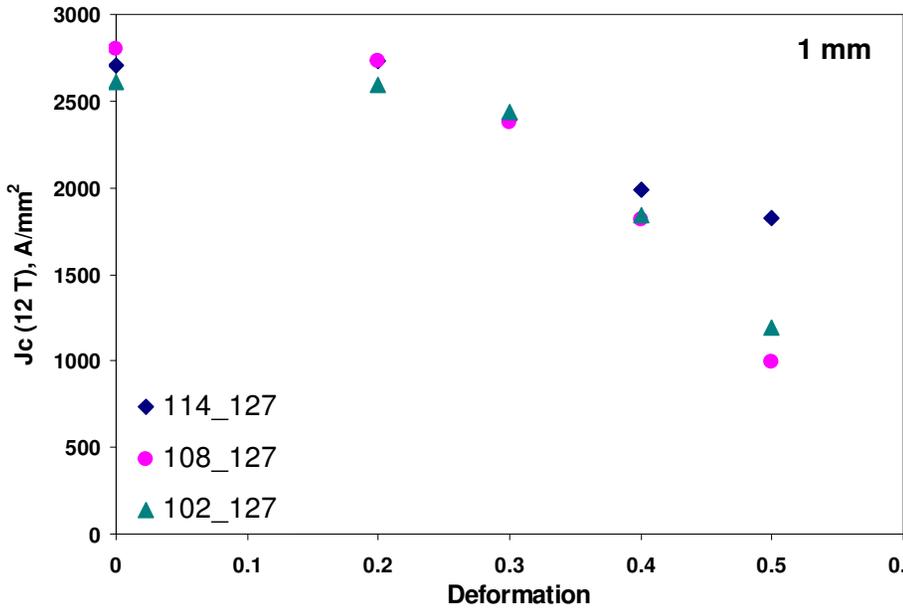
108/127 restack with spaced SE's
 $J_{cmax} \sim 3000 \text{ A/mm}^2$



Remove inner row and add back corners

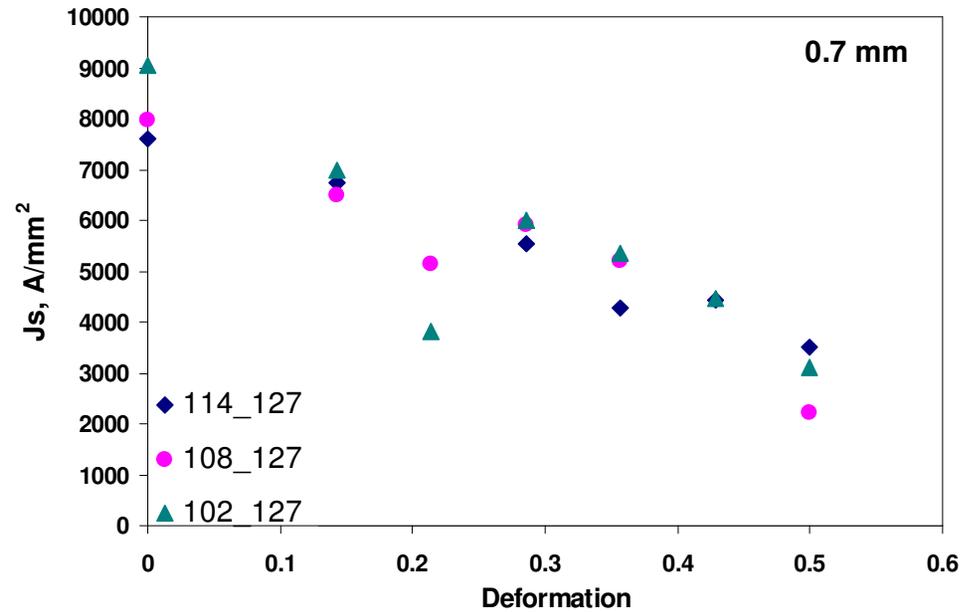
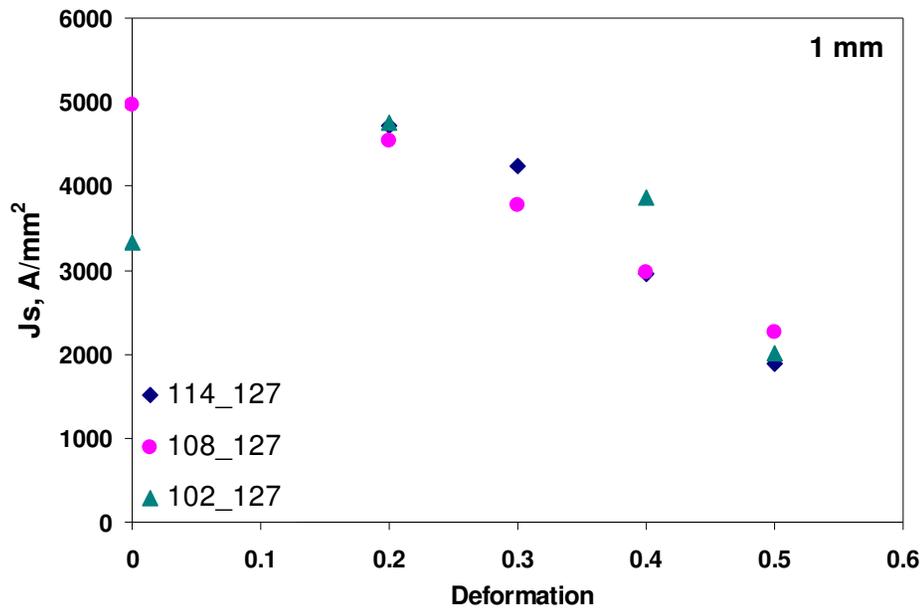


$J_c(12\text{ T})$ in the Deformation Study



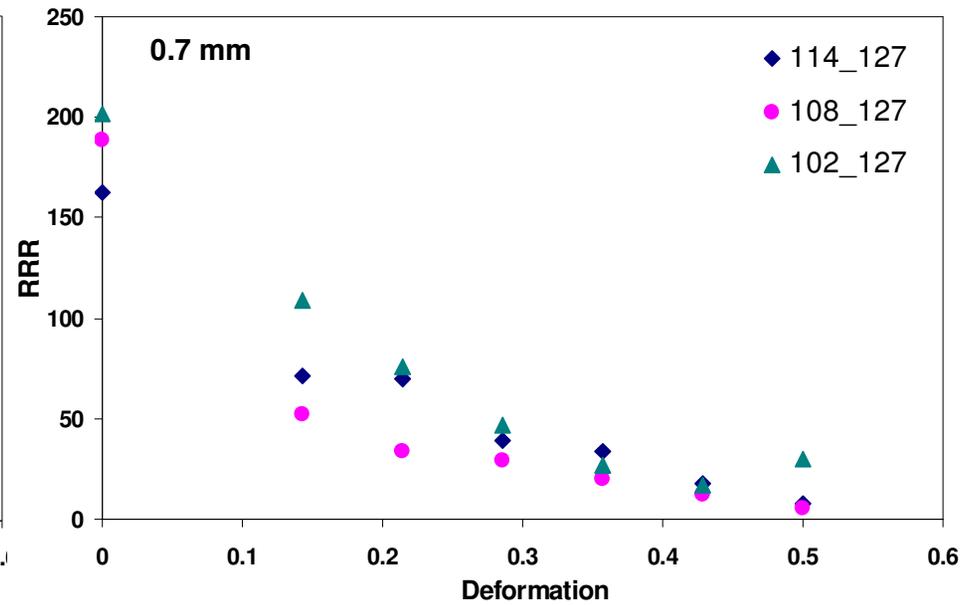
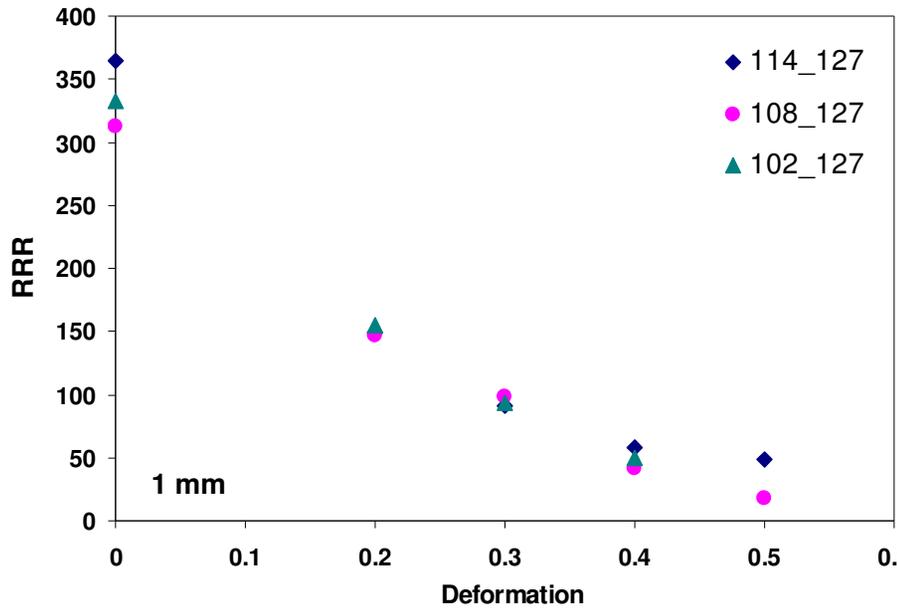


J_S in the Deformation Study





RRR in the Deformation Study





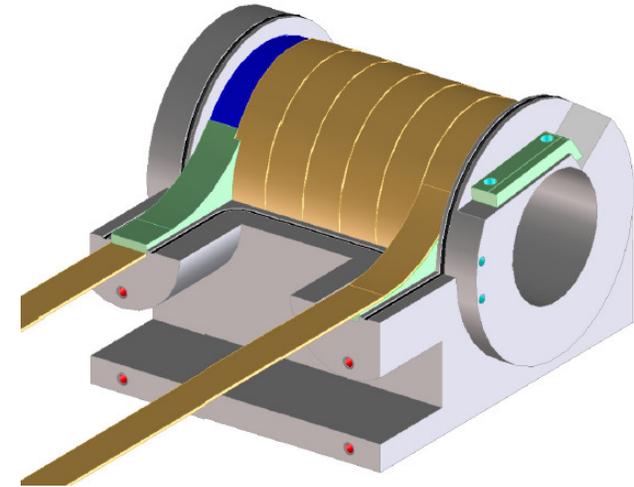
Cable Test

- Cable tests are essential in understanding the behaviour and limitations of the TQ magnets
 - Need to establish the compressive strain tolerance (NHMFL Tests)
 - Need to understand the instability at superfluid temperatures (CERN Tests)
- At FNAL, cable samples will be prepared in Dec'08 for test at CERN towards the end of second quarter of FY09
- At LBNL, samples have been reacted and present plans are to complete sample assembly in Nov'08. Testing is likely in Jan'09



LBNL Developments

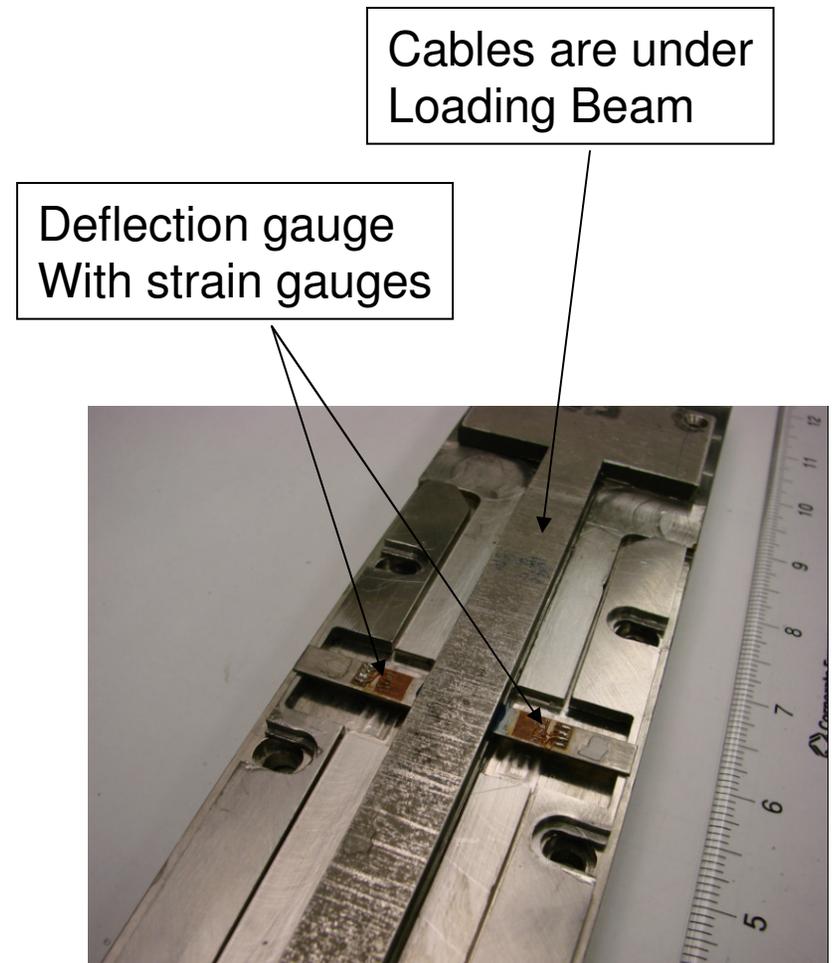
- LBNL is developing a 50,000 A transformer to power the cable samples
 - Reduced signal noise
 - Testing flexibility
 - Reduce LHe costs by ~\$20k
 - Would be useful for future LARP measurements
- Designing superconducting coils system to replace He gas bellows for loading the samples
 - Significantly improves system reliability





LARP Cable Preparations for NHMFL

- New cover plates and backing plates for testing 3 cables
 - Samples ready by Nov. 30
- Developing displacement gauge to measure strain on cable during transverse loading.
 - Gauges ready by Nov. 30
- Have requested testing time at NHMFL for Dec. or Jan.





Summary

- Present Procurement Plan
 - There is sufficient conductor for 9 additional UL's of LQ cable
 - For HQ magnets we have enough strand for 5UL's till the 75 kg order is delivered in July-Aug'09
 - There is 114 kg of 108/127 not assigned to any magnet
 - Additional 100 kg will be ordered when we have a better understanding of the program beyond FY09
- Cable R&D
 - 15 mm wide cable with 0.8 mm strand is nearly optimized
 - Cable B0987R, made recently is being checked for any cabling damage
 - Reaction parameter chosen so far is 665C/72h \Rightarrow 3000 A/mm² at 12T
 - This need to be optimized for high Jc at 14 -15T for the 0.8mm strand
- Strand Stability
 - At 4.2 K strand instability caused by magnetization flux-jumps at low fields < 3T
 - Mitigated by high RRR or going to smaller filament size RRP 108/127
 - At 1.9-2.1 K , instability is dominated by self-field instability at intermediate fields of 5T – 6T. Stability threshold is lower than at 4.2K
 - How do we mitigate this ?



End of Presentation



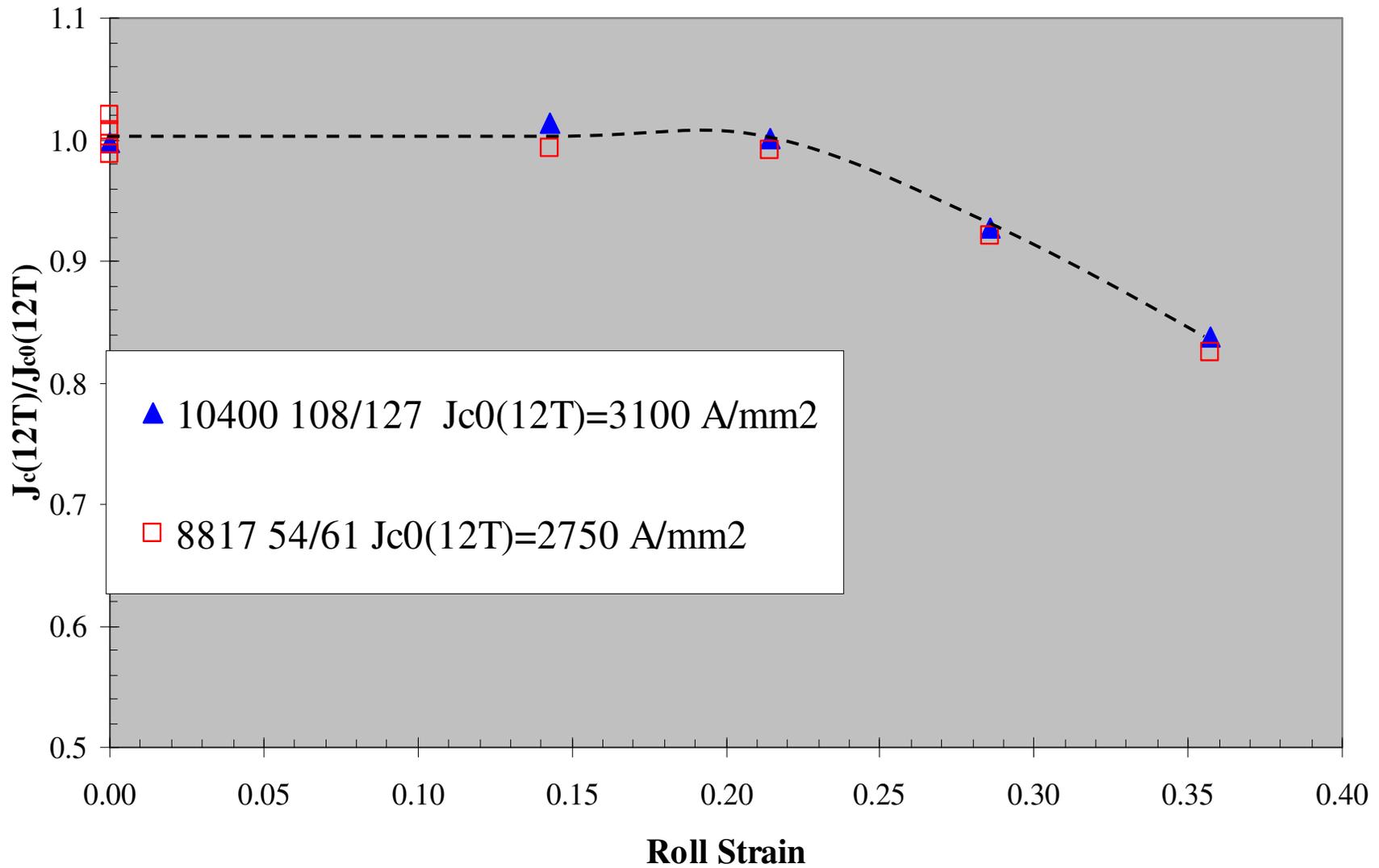
Roll Strand Expt.

- Strands of RRP 108/127 (Billet 10400 used for TQ03)
 - Rolled to 0.60, 0.55, 0.50, 0.45 mm
 - I_c , I_s and RRR measured
 - Comparison with RRP 54/61 billet 8857
 - J_c behaviour with roll-strain is very similar
 - J_s at low RRR is higher for 108/127 as compared to 54/61
 - At higher RRR J_s is comparable



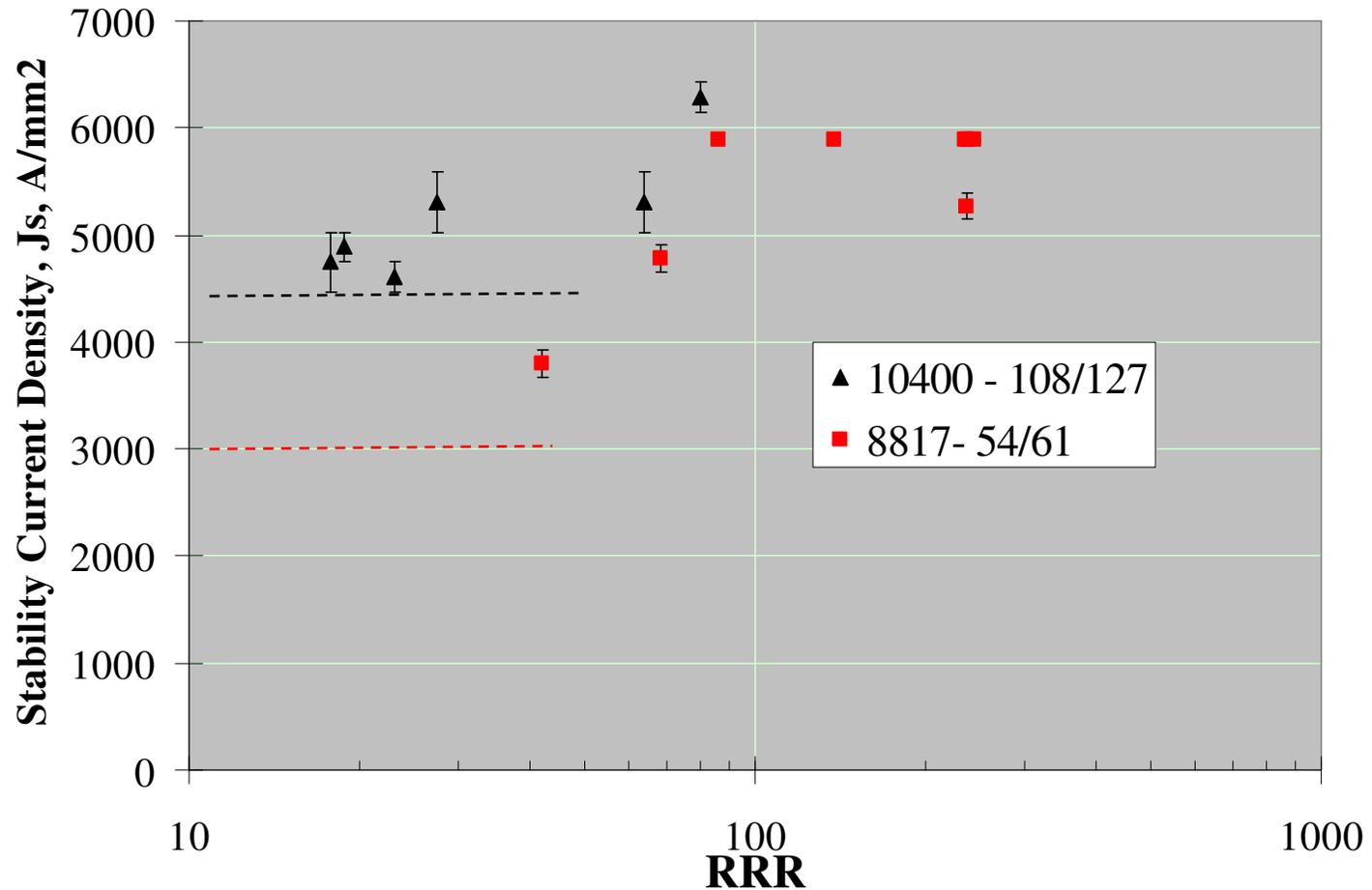
Jc trend with roll-strain

RRP 54/61 and 108/127 behave similarly





Stability Current Density vs. RRR



10440 samples reacted at 665C/72hrs hence starting RRR is low. However, at low RRR J_s for 108/127 is higher than for 54/61 because of smaller filament diameter



Ic-Strain Measurements at NIST

Najib Cheggour

