LARP

BNL -FNAL - LBNL - SLAC

LARP CM14
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FNAL

Nb_3Sn Conductor Status

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Outline

- Introduction
- OST 54/61 strand production
- Instability in superfluid helium
- RRP 108/127 strand
- Cable Production and R&D
- Electro-mechanical studies – NIST
- Production Plan for strand
- Summary

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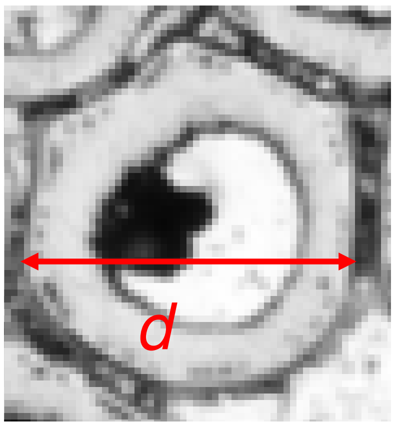
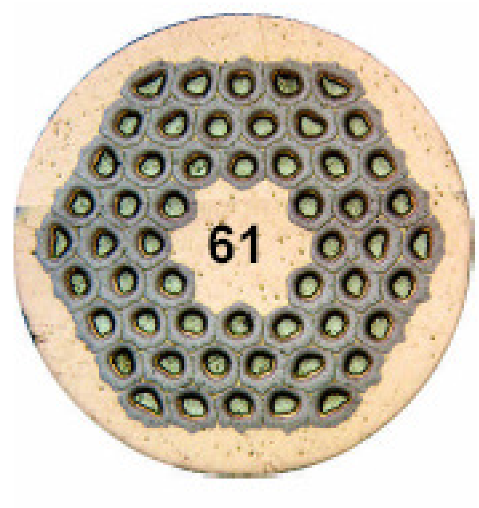
1. Introduction



- The first long quad-magnet LQS01 used RRP® - 0.7mm strand manufactured by Oxford Superconducting Technology -OST
  - ⇨27-strand cable with 1.0º keystone angle
  - Strand is the 54/61 design with d ~ 70 μm and Jc >2400 A/mm² at 12T



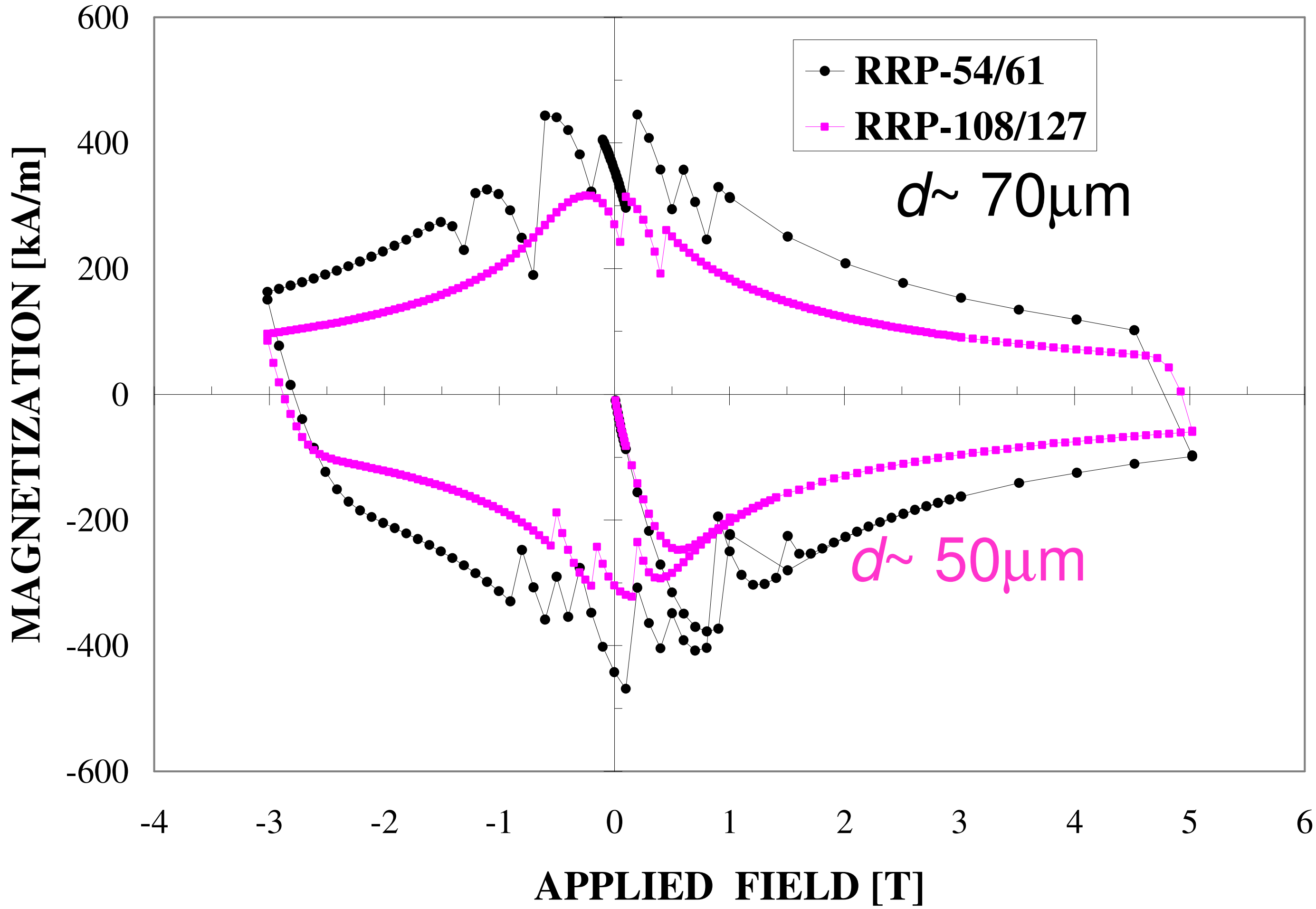
$$\beta = \frac{\mu_0 J_c^2 d^2}{4C(T_c - T_{bath})} < 3$$

Flux-jump instability at low field

Tc =Transition Temp.

T_{bath}= Bath Temp

Observed in Magnetization measurements ⇨ Persistent current collapses periodically at low fields



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Low-field instability

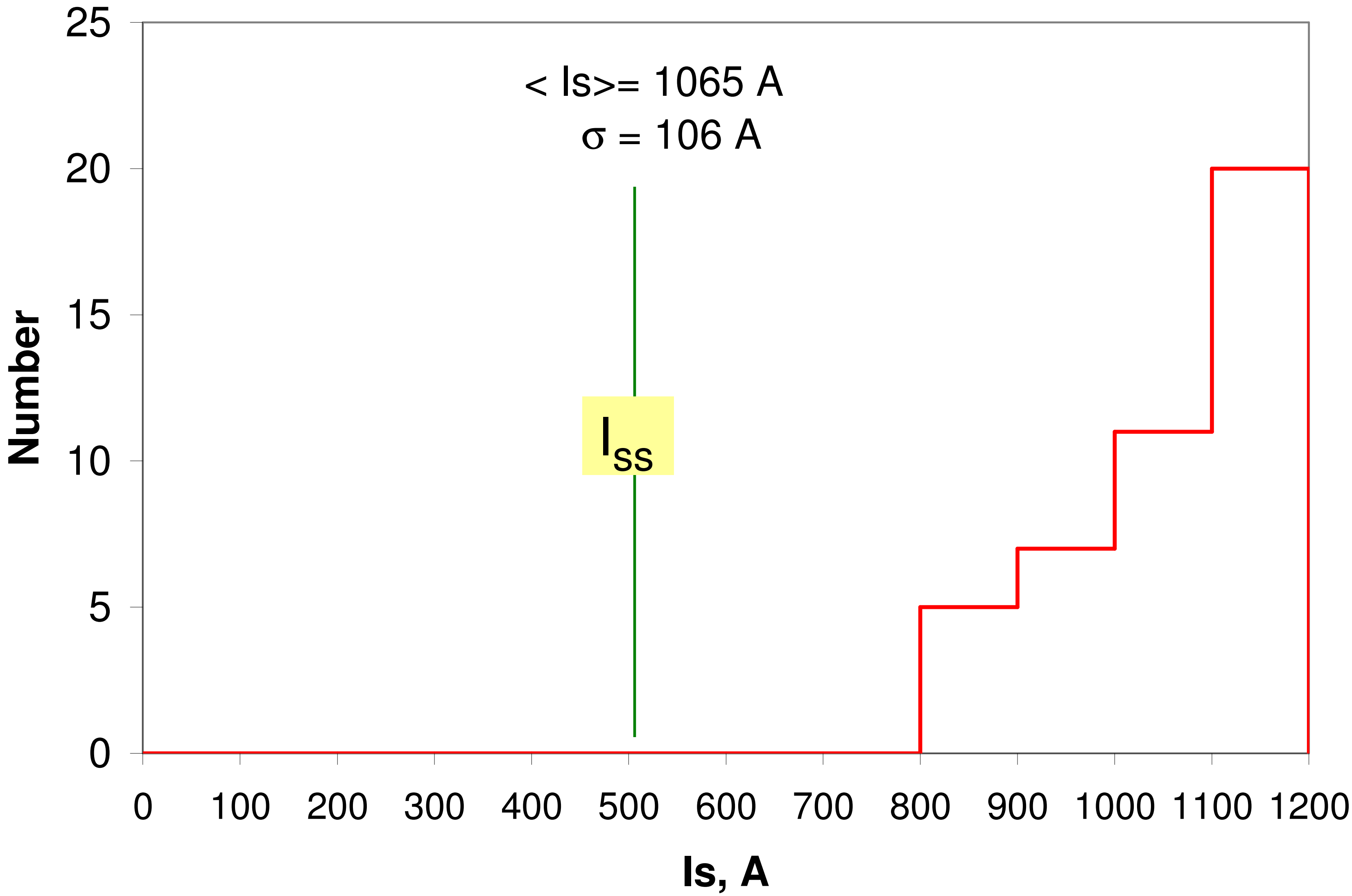
For high Jc RRP® 54/61 wires of 0.7 mm, flux-jumps are inevitable in low-field regions of magnets.

Instability is "managed" by ensuring that the copper stabilizer resistivity at low temperatures is low (high RRR) to provide sufficient "dynamic" stabilization so that the magnet can reach its operating current of 500 A/strand

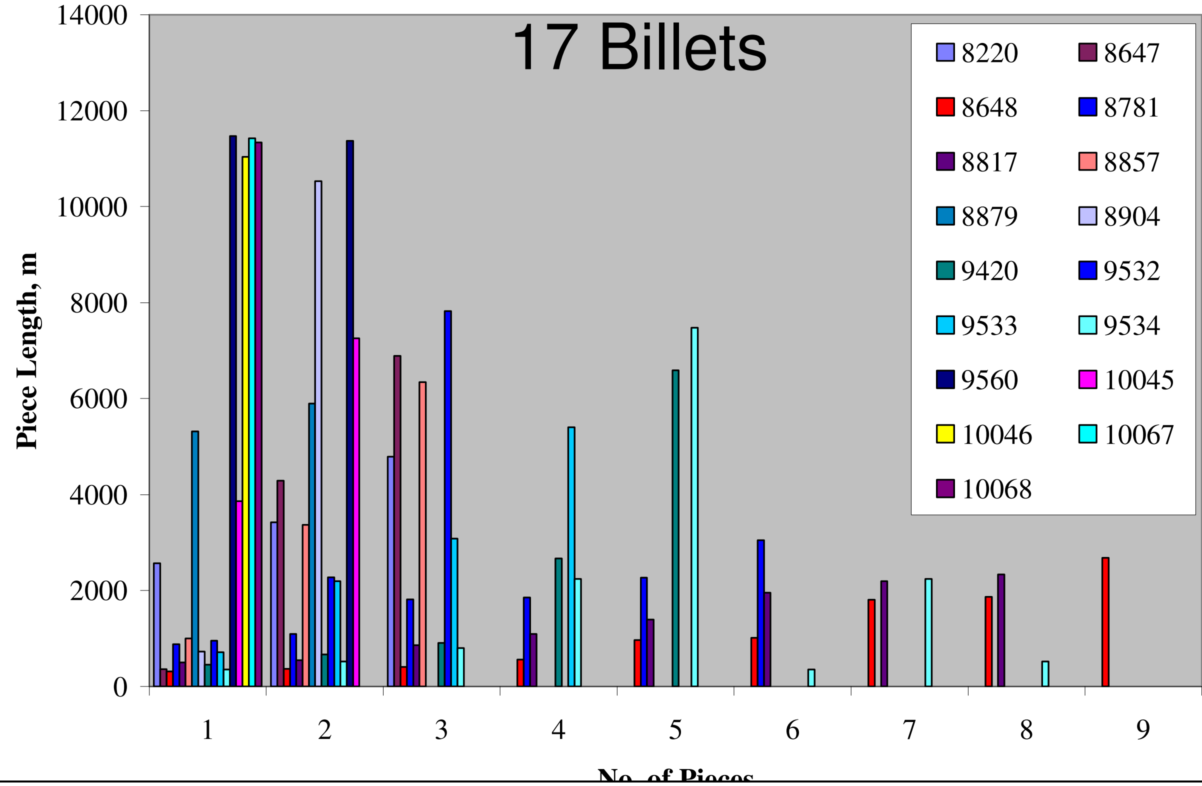
Using an "optimized" heat treatment
210C/72h + 400C/48h + 640C/48h

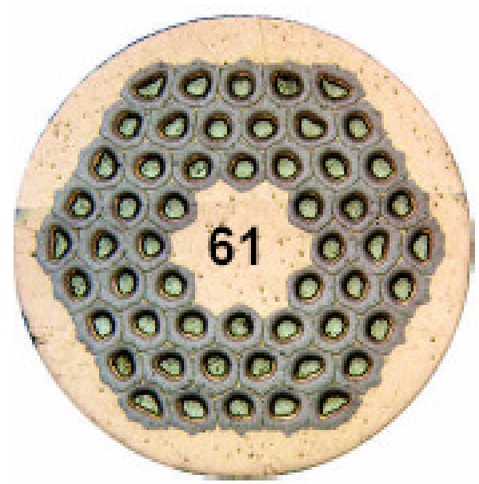
- Extracted strands from LQ cable have
  - ‣ Jc (12T,4.2K) is > 2400 A/mm^2 ,
  - **RRR >100**
  - stability current I_s >800A, well above magnet operating current I_{op}

Is of Strands Extracted from Cables



RRP 54/61 LARP Production at OST





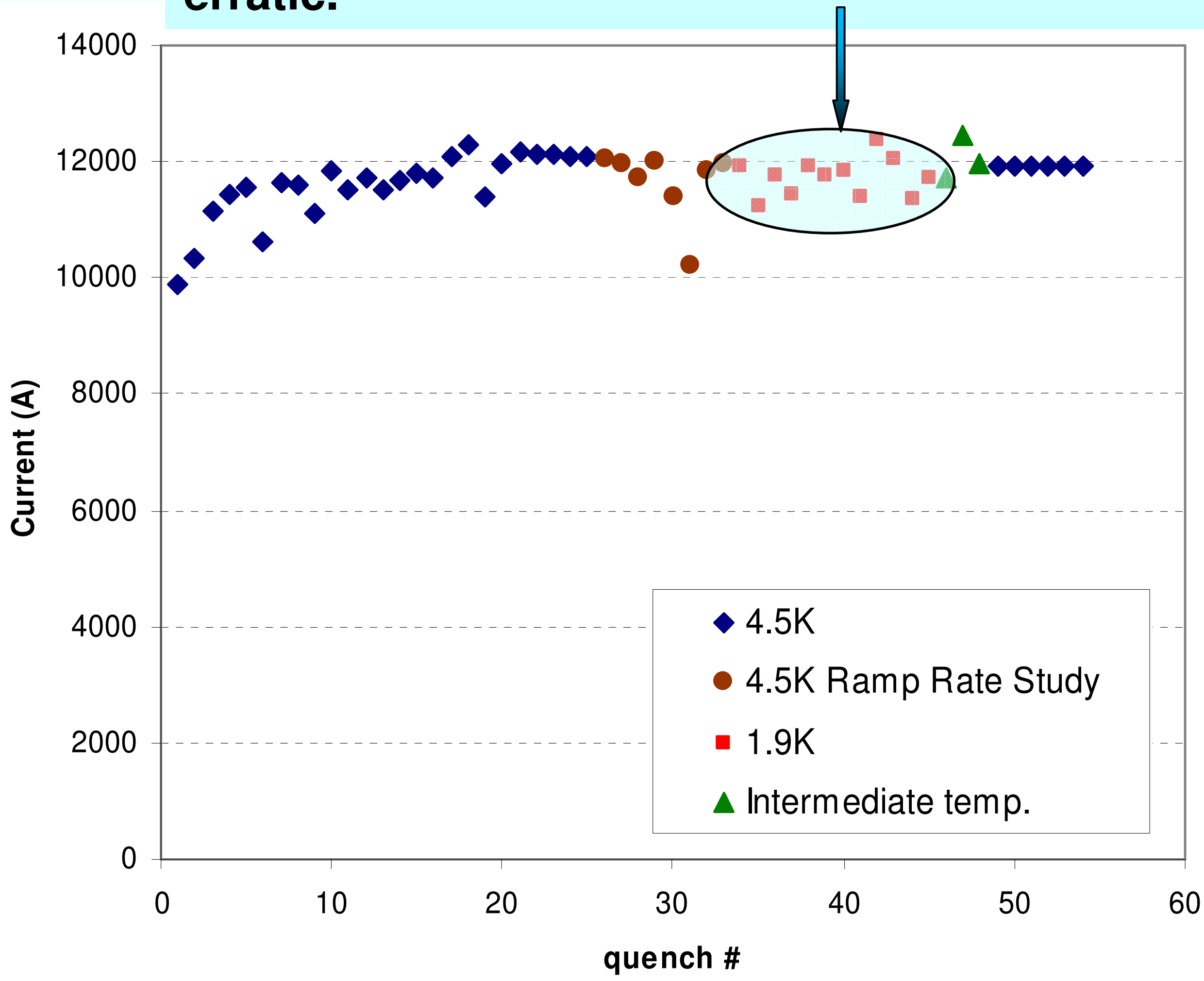
- 650 kg of wire delivered in FY07-FY09
- 93 % in lengths >1Km, 73% in lengths >3 km, **29% >10 km**

Long lengths ▸ sign of **Excellent** process control and stable production.

Instability in Superfluid Helium at 1.9 K

TQS02a Quench history

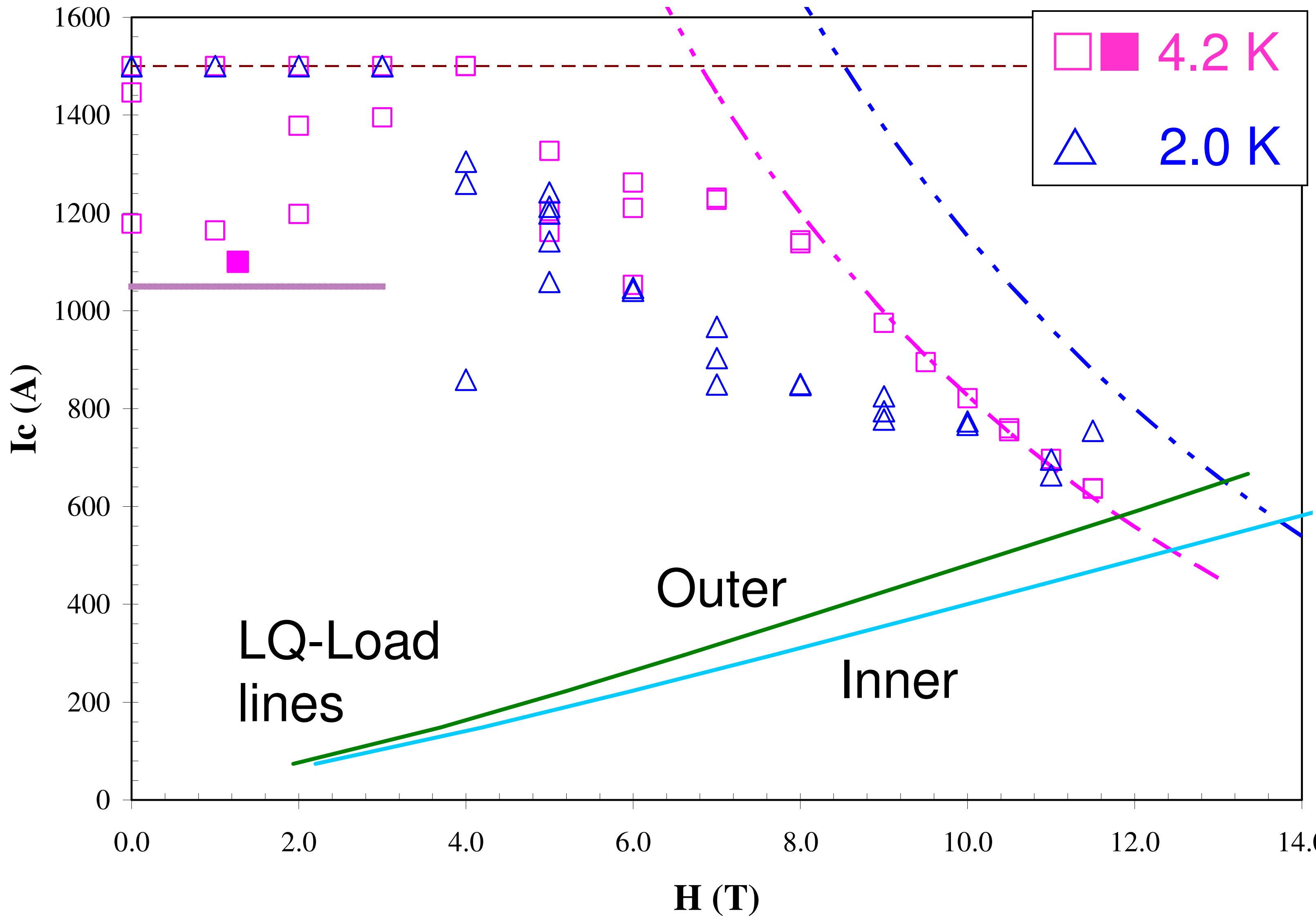
No Increase in quench current at 1.9 K. Quenching is erratic.



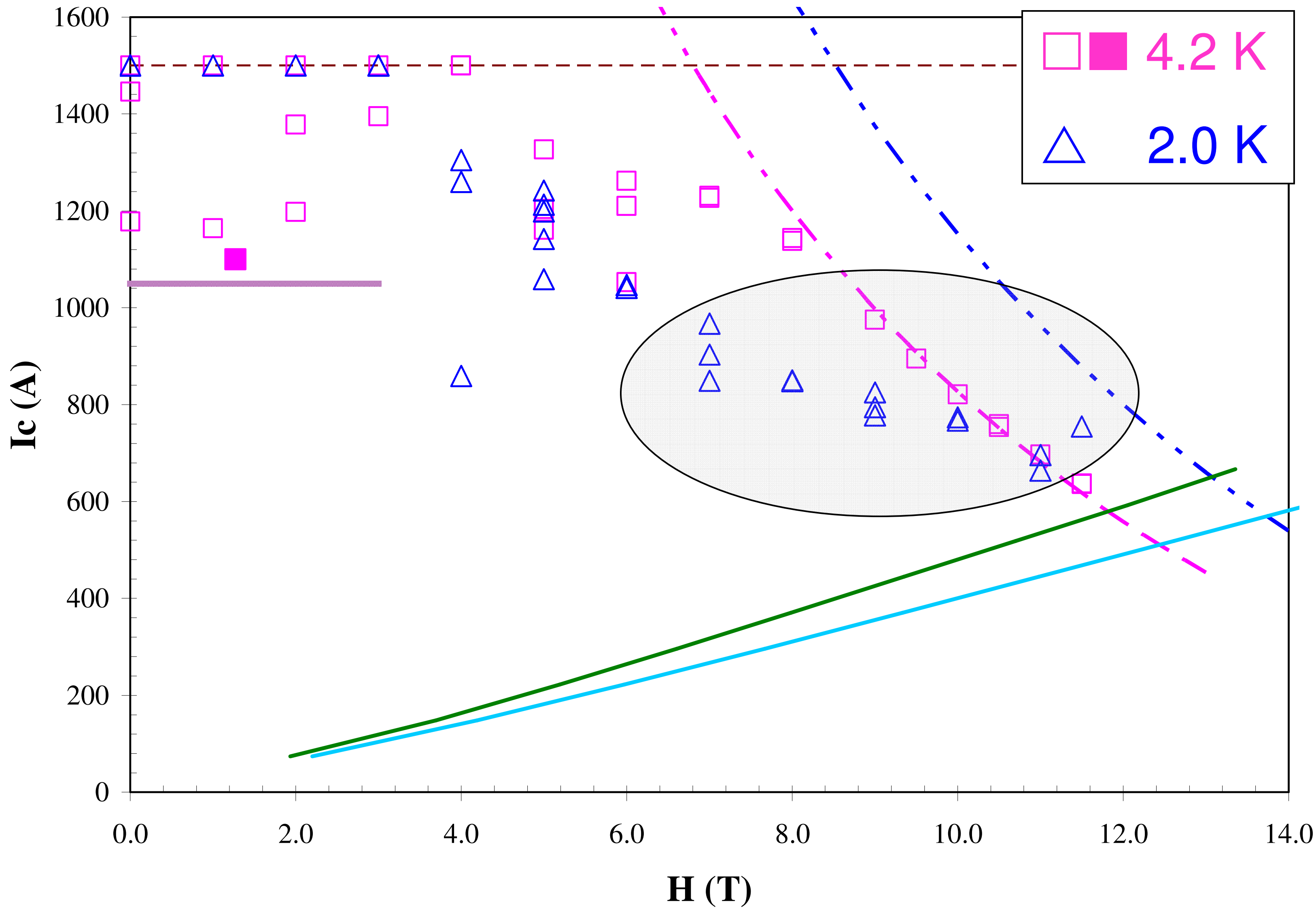
Strand Stability at 1.9 K

- Erratic quenching and no increase in quench current of TQ02 magnets in superfluid helium
  - Detailed measurements of the quench performance of LARP strands in superfluid helium.
    - Measurements on round and extracted RRP 54/61 and 108/127 strands in 4.2 K pool-boiling helium and in sub-pressure superfluid helium at 2K
  - Besides the "flux-jump" instability mediated by collapsing persistent currents at low fields,
  - Strands also exhibit "Self-Field" Instability due to transport current. This is usually gauged by measuring the quench current of strands in fixed external fields.

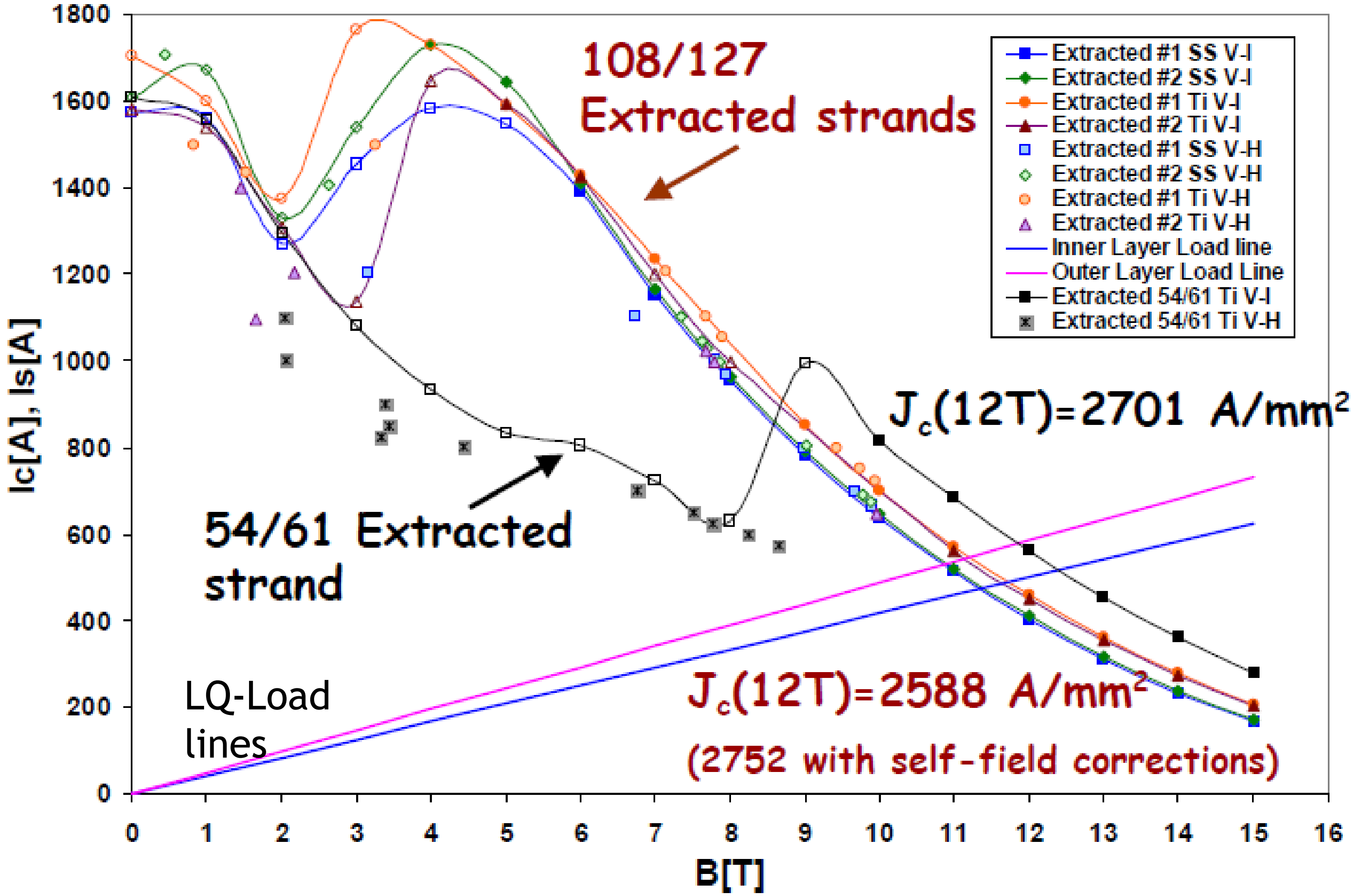
Quench Current of Extracted Strand from LQ Cable, RRP 54/61, (BNL data)



In superfluid, strand less stable than at 4.2 K



Comparison of 54/61 and 108/127 Extracted Strands at 4.2 K (FNAL Data)

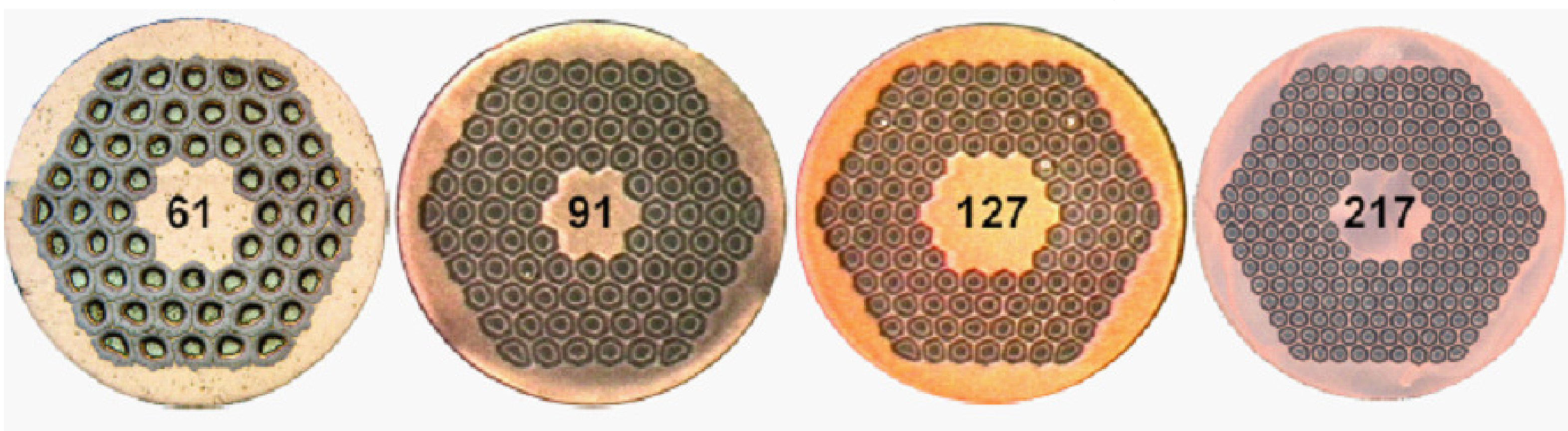


Stability increases by reducing filament diameter, *d*

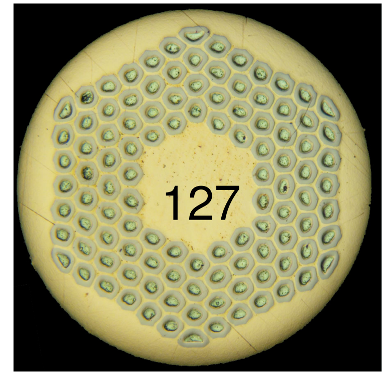
$$\beta = \frac{\mu_0 J_c^2 d^2}{4C\left(T_c - T_{bath}\right)} < 3$$

- Smaller sub-elements can minimize flux jumps and improve stability.
- Main driver has been DOE- HEP Conductor Development Program
- And FNAL R&D Program

70 μm → Smaller Filament Size → 35 μm



Qualification of 108/127-design strand

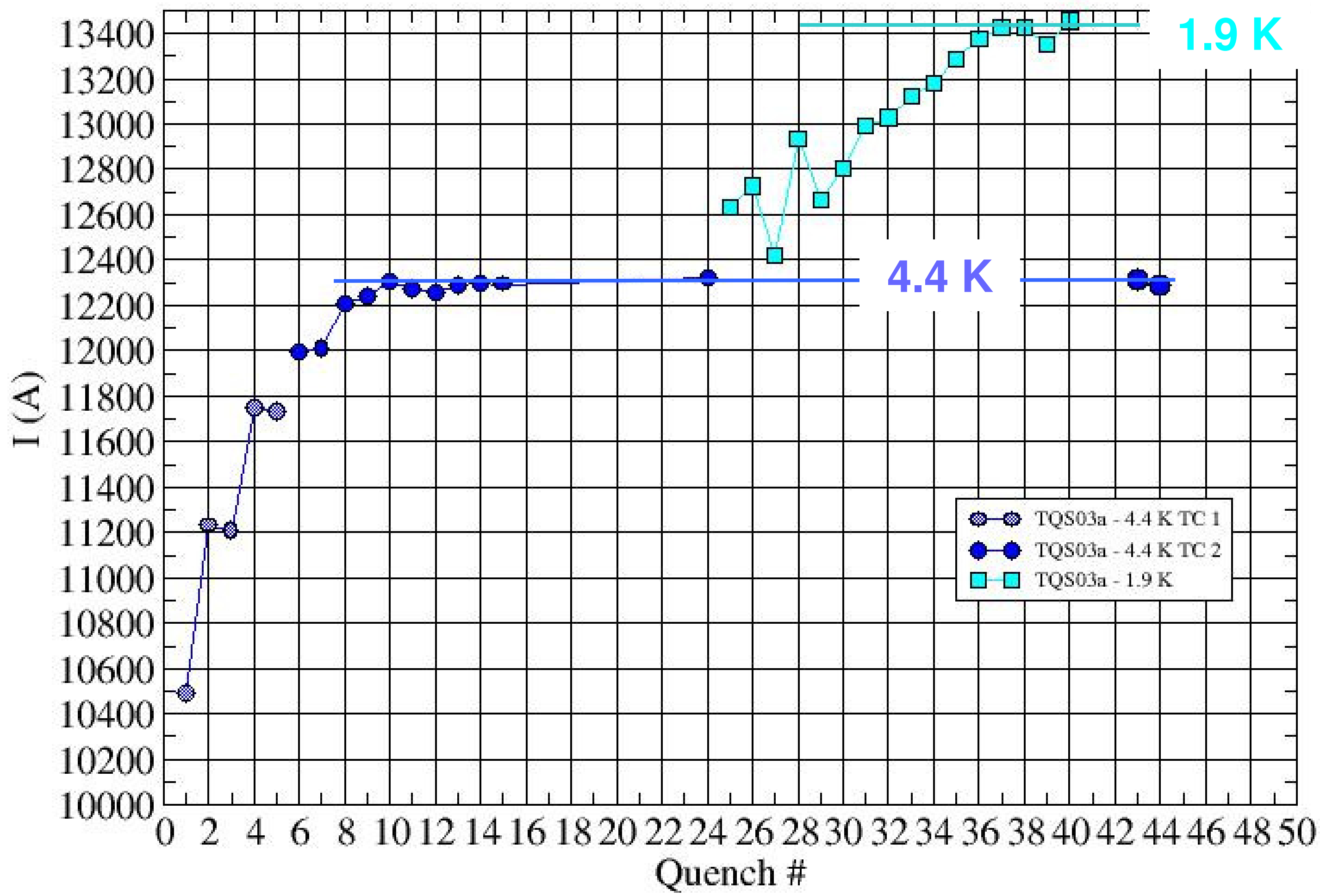


- In FY08 OST delivered 180 kg of high-Jc strand with the 127-stack design and larger spacing between sub-elements ⇨ *Cu fraction is 53% compared 47% in standard 54/61*
- Extracted strands from TQ cable (B0982R) made using 108/127 0.7 mm strand
  - Very low Ic degradation and Is > 1200 A
- Wind-react four TQ coils ⇨TQS03
- TQS03 magnet tested at CERN
  - Good performance at 4.2 K and at 1.9 K
- Extracted strands from HQ 15 mm wide cable with 0.75° keystone and using 0.8 mm strand
  - ➢ Low cabling degradation.

⇨ FNAL "core-program" : TQM03 mirror magnet test using 108/127 strand and cable fabricated at FNAL

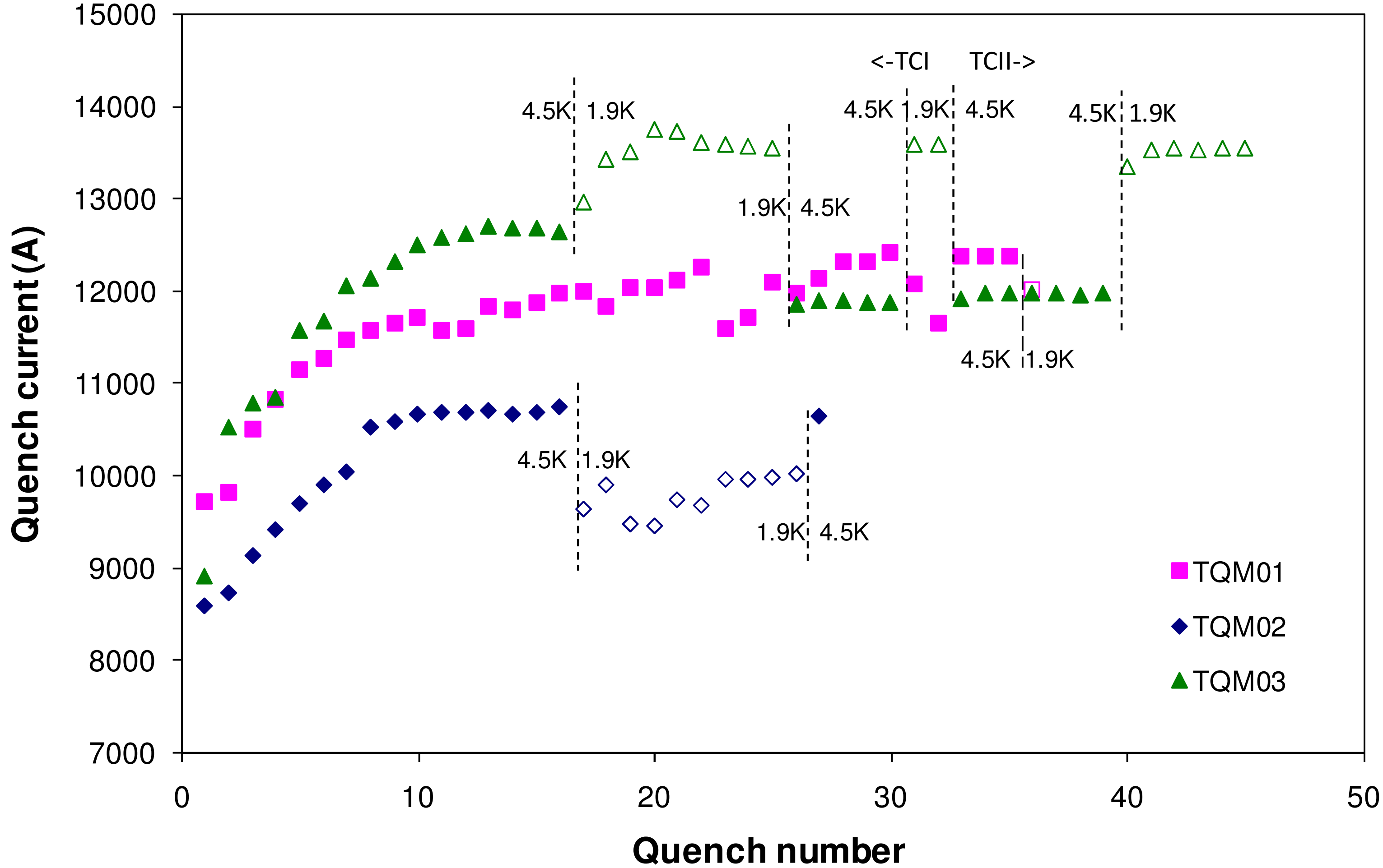
⇨ Good performance at 4.2 K and at 1.9 K

TQS03a Quench History

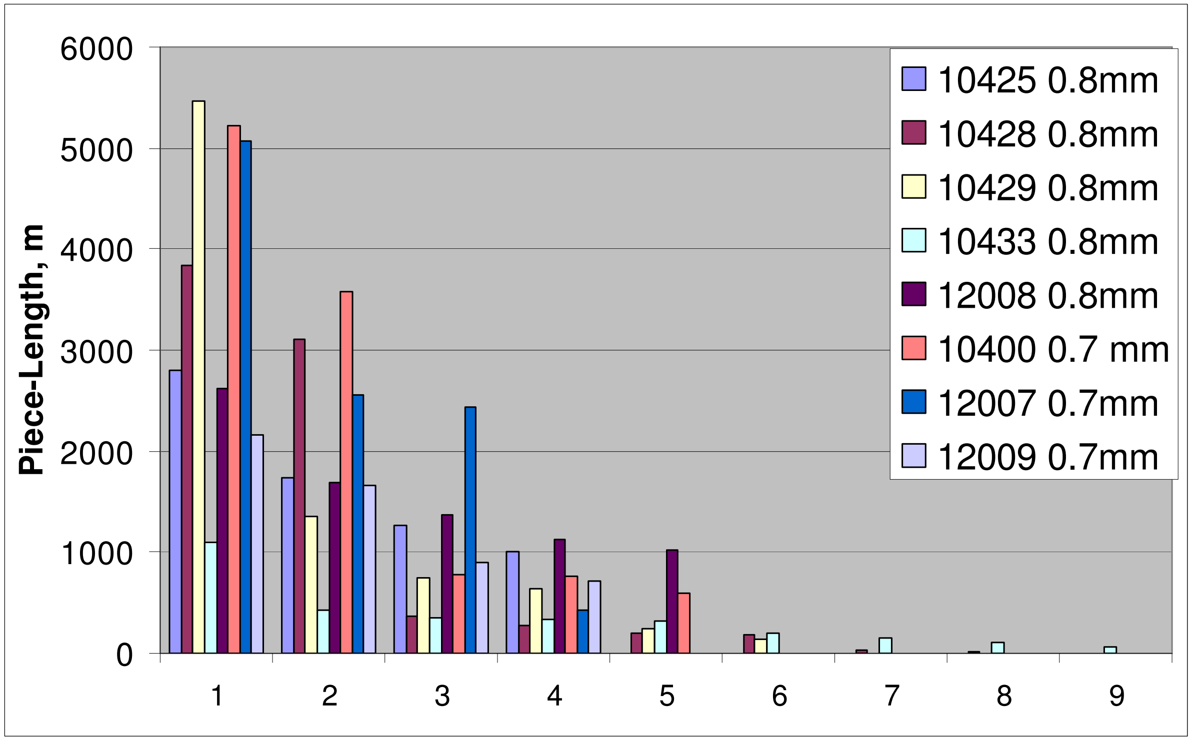


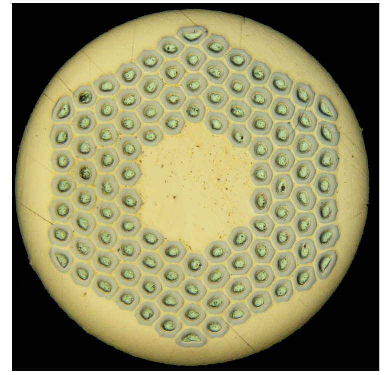
TQM03 Quench History

R. Bossert CM13



RRP 108/127 LARP Production at OST





- 245 kg of wire produced so far from 8 billets, single billet yield is ~ 35kg (~7.5 km)
- 85 % in lengths >1Km, 43% in lengths >3 km, **26% >5 km**

Cable Production and Development

LQ-Cable Production @ LBNL

LQ Specifications: Same as TQ Cable Specifications

Parameters	Units	TQ Final	Tolerance
Strands in cable	No.	27	NA
Strand diameter	mm	0.7	+/- 0.002
Width	mm	10.077 max.	+0.000, -0.100
Thickness	mm	1.26	+/- 0.010
Keystone angle	deg.	1.0	+/- 0.10

LQ- Cable unit length (UL) is 240 m

- 15 unit lengths of LQ cable made using 54/61
- 2 unit length of LQ using 108/127
- Jc-degradation due to cabling, typical is ~ 5%
- Cable production at LBNL is quite stable

HQ Cable Parameters

Strand Diameter	0.8mm
No. Strands	35
Thickness	1.44 mm
Width	15.15 mm
Keystone angle	0.75^o

- 5 unit lengths of HQ cable made from 54/61 strand
- 5 unit length made from 108/127 strand

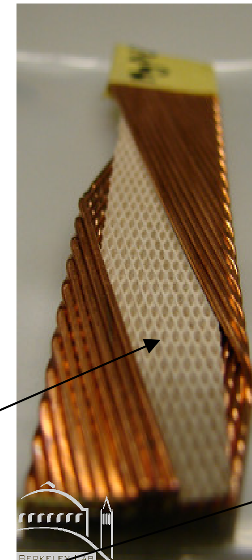
210C/72h + 400C/48h + 665C/72h

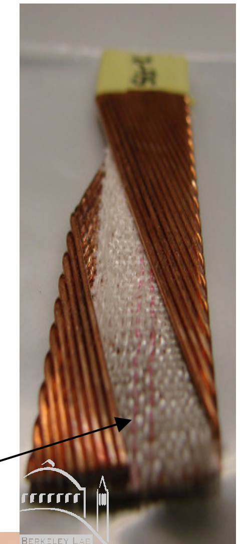
Jc(12T) > 2900 A/mm^2

RRR>100

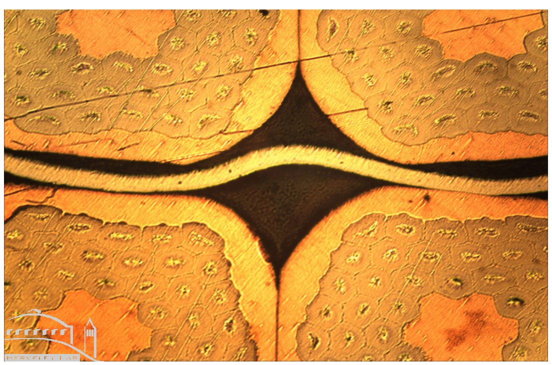
HQ-Cables with Cores- Development at LBNL

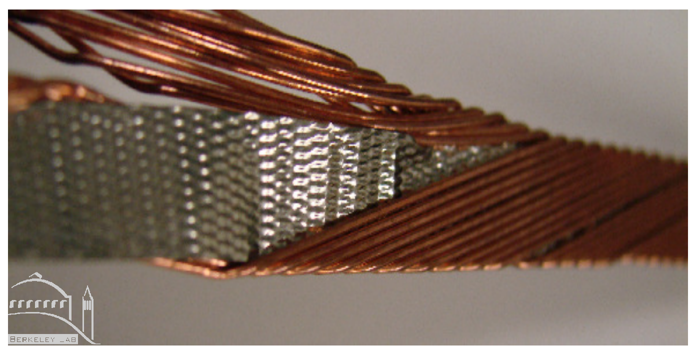
- Stainless Steel Core
  - Can not anneal and re-roll cable
  - Need to anneal strand
    - OST anneal prior to final draw and twist
  - Coil winding issues?
- Other Core Material experiments for annealed cables
  - MgO paper tape,
  - S-glass woven tape





Mandrel with slot





Cored-Cable development at FNAL

TQM04 features (coil #TQ35):

- New, unused coil with 108/127 strand.
- S-2 glass sleeve for cable insulation.
- Cable has 25 um thick stainless steel core.

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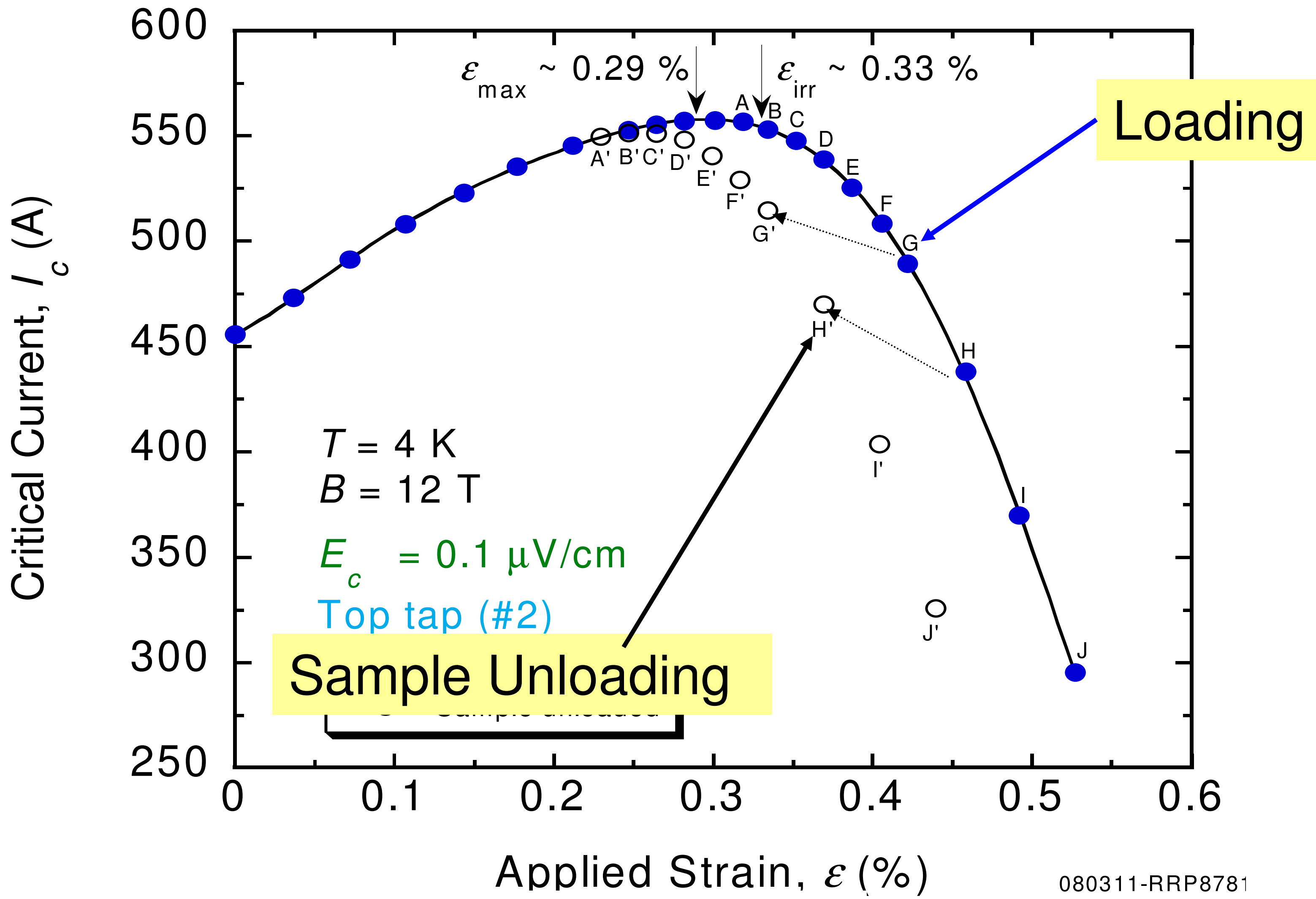
Electro-mechanical Measurements of
0.7 mm RRP strand
Collaboration with NIST

Najib Cheggour

NIST

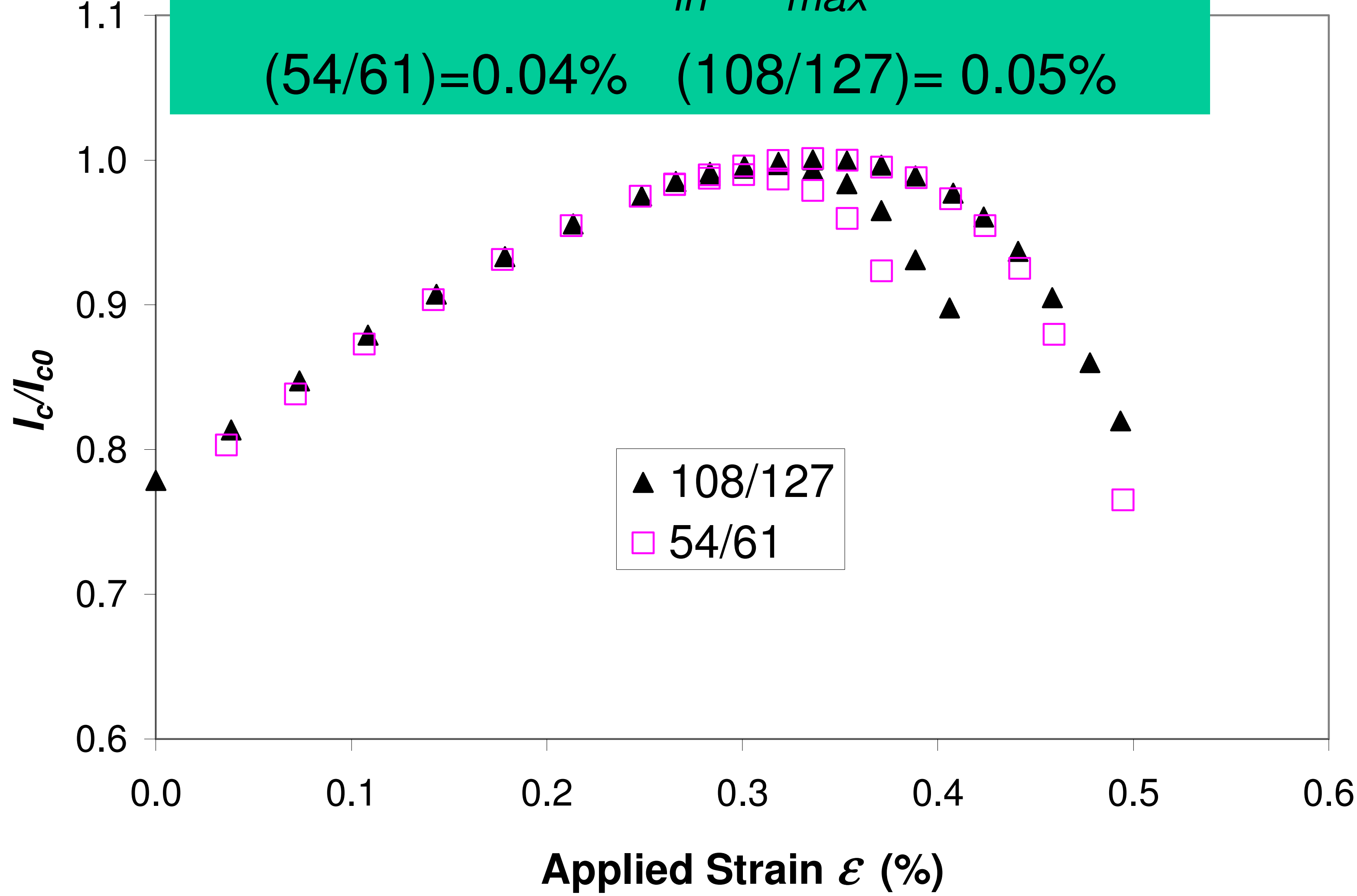
In tension, irreversible damage for 54/61 sets in at a strain just above $\varepsilon_{max.}$



In Tensile strain very little difference between 54/61 and 108/127

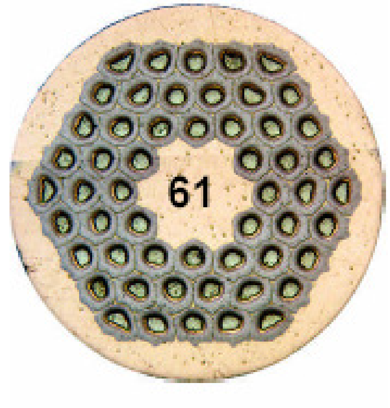
$\Delta\varepsilon = \varepsilon_{irr} - \varepsilon_{max}$

(54/61)=0.04%   (108/127)= 0.05%

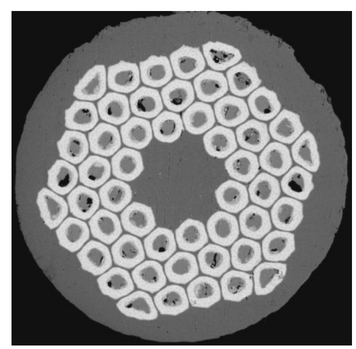


Ta- Ternary vs. Ti-Ternary

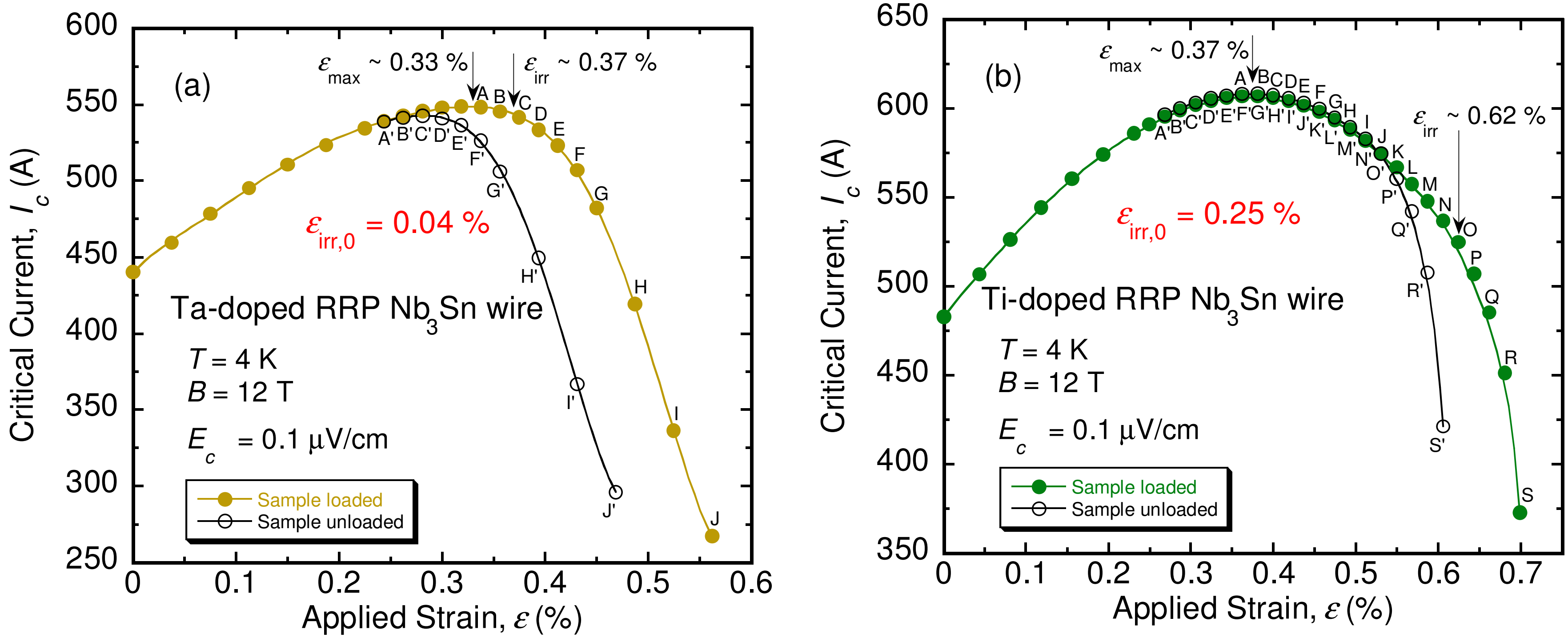
- **Ta-doped RRP-54/61** Nb-7.5wt%Ta-Sn
  - ➢ $(Nb\text{-}4.0a\%Ta)_3Sn$



- Compare with **Ti-doped RRP-54/61** **$(Nb\text{-}2.0a\%Ti)_3Sn$** (Ti introduced by distributed Nb-47Ti rods in the Nb-Cu matrix)



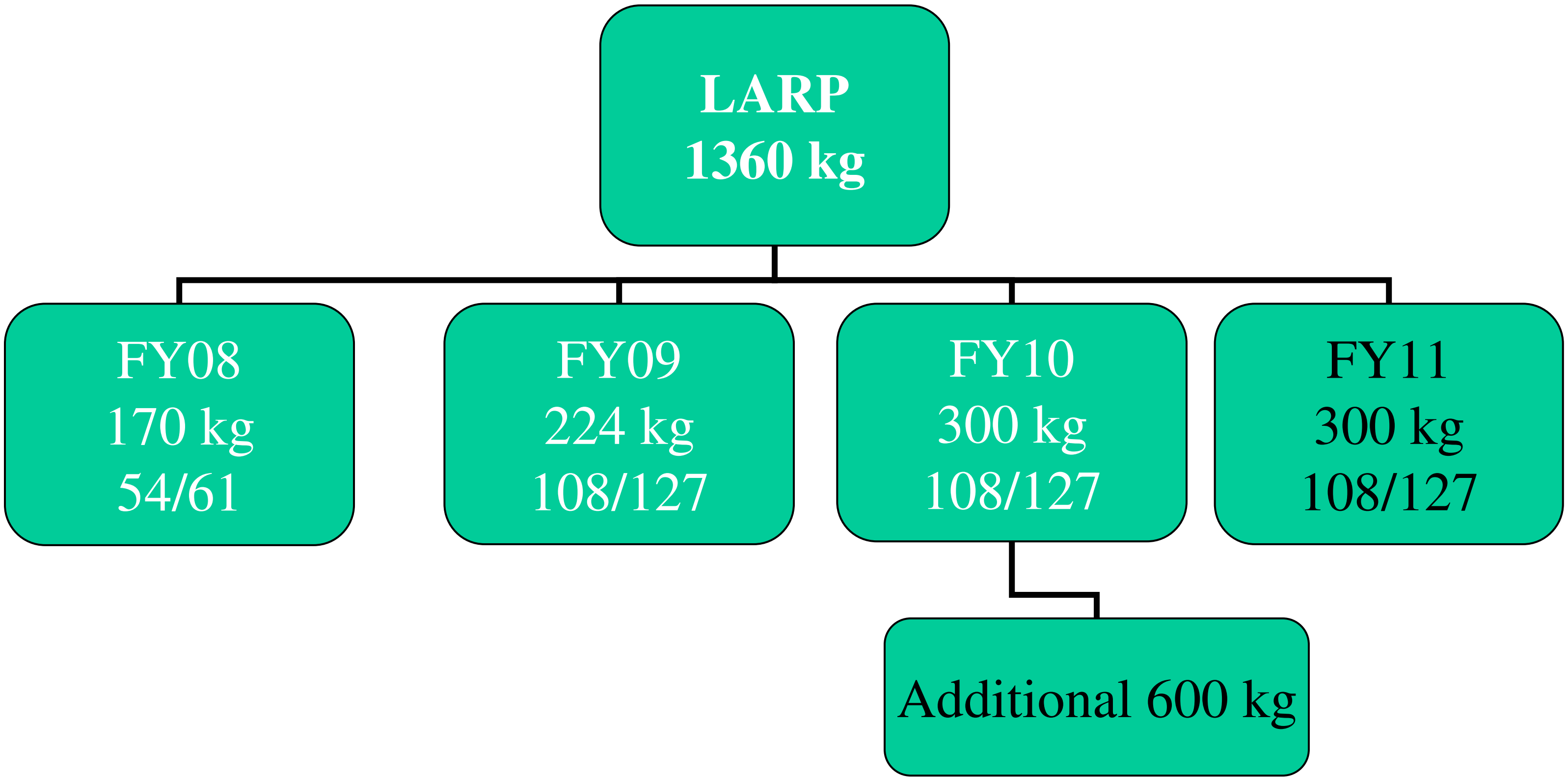
Ti-Ternary vs. Ta-Ternary



Ti-doped Nb_3Sn wire more strain tolerant than Ta-doped

Influence of Ta and Ti doping on the irreversible strain limit of ternary Nb3Sn superconducting wires made with restacked-rod process*
N. Cheggour, L. F. Goodrich, T. C. Stauffer , J. D. Splett , and X.F. Lu, A. K. Ghosh, G. Ambrosio
Supercond. Sci. and Tech., 20, (2010)

Procurement - Planning for Long HQ
Strand Lead time is 12 months



Conductor Inventory Status

In-stock

- 78 kg of 54/61 - 0.7 mm for LQ
- 54 kg of 108/127 – 0.8 mm for HQ

Future Delivery of RRP 108/127

- 68 kg in Aug'10
- 67 kg in Dec'10
- 180 kg in Feb'11
- 115 kg in Mar'11

430 kg

Planned Delivery

- 250 kg in June'11
- 400 kg in Aug'11
- 300 kg in Dec'11

950 kg

Summary

- LARP funded: Focused on strand procurement, cable production, strand and cable qualification, coil reaction schedules, strand and witness sample testing at 4.2 and 1.9 K
- CDP and core program funded: R&D towards developing the "next generation" conductor
  - Ti-Ternary 108/127
  - 217 stack design
- Conductor issues requiring more R&D is in
  - Transverse stress effects in cables
  - Instability in superfluid helium
  - Ti-Ternary versus Ta-Ternary
- The 108/127-stack design has matured significantly at OST so that it is considered a "production" wire
- Strand Inventory is being replenished for the longer HQ magnet program

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End of Presentation

Nomenclature

- RRP® Re-Stack Rod Process
- Ic Critical current usually quoted at 12 T, 4.2 K, A
- Jc Critical current density over the non-Cu area, A/mm^2
- Is, Js Low-field Stability current, current density, A, A/mm^2
- d filament diameter ~ sub-element diameter, µm
- RRR Residual Resistance Ratio of the Cu-matrix R(295K)/R(18K)
- Iq Quench current , can be > = or < than Ic, A
- C Volumetric Heat Capacity , J/m^3-K
- V-I Set field then ramp current till wire quenches
- V-H Set current at zero field then ramp field
- UL Length of cable required for a magnet coil
- ε_{max} applied strain for maximum Ic in Ic-strain measurements
- ε_{irr} applied strain when Ic degrades irreversibly