Nb_3Sn strand designs and heat treatments for high field magnet applications

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Outline

- Nb_3Sn is flexible in the marketplace
  - Accelerators
    - Key needs – high J_c & high RRR & low D_{eff}
  - High Field Solenoids
    - Key needs – highest J_e
  - Undulators
    - Key needs – low D_{eff} & high J_c
- Summary

Who is Bruker EST?

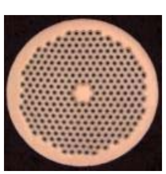
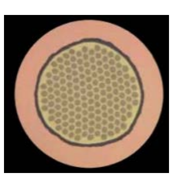
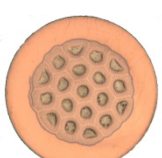
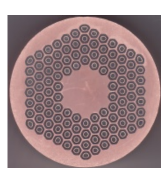
BEST is a US based company with operations in the US & EU

LTS

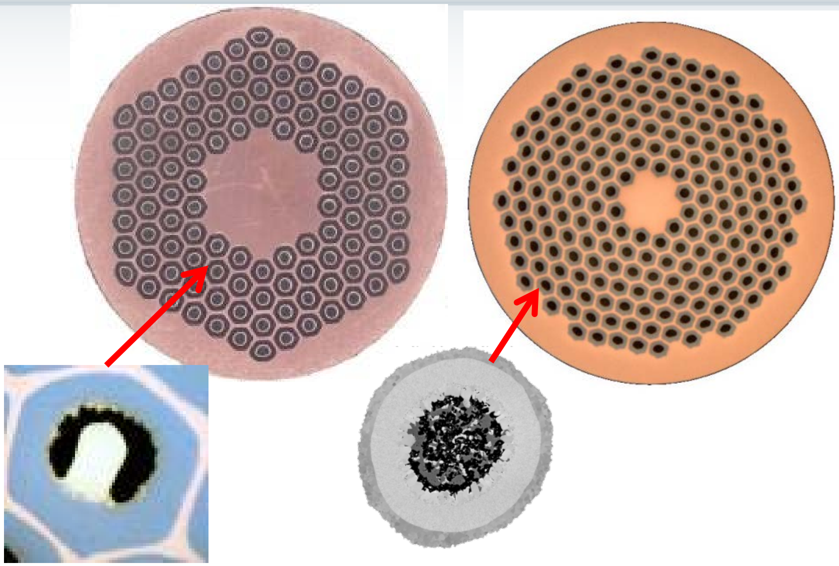
Bruker Corporation — Boston, MA

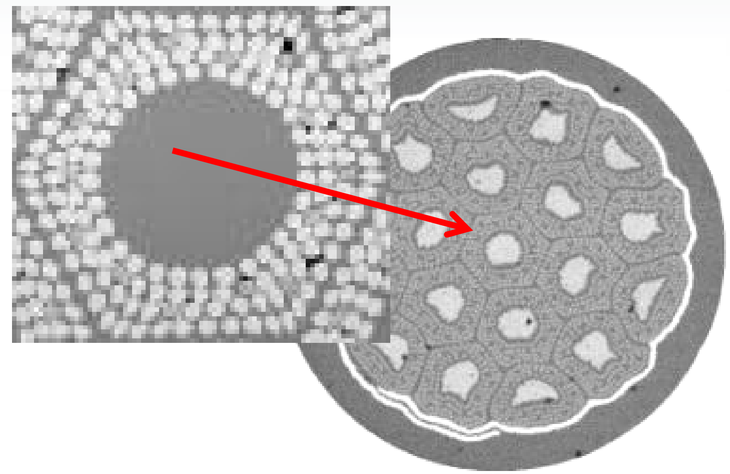
Bruker Energy & Supercon Technologies, Inc. — Boston, MA

- **Bruker EAS GmbH** — PIT, Bronze
- **Bruker OST LLC** — Single Barrier, RRP®
- **RI Research Instruments GmbH** — Accelerator & Beamline Technologies
- **HELi Ltd.** — Cuponal & Extrusion
- **Bruker HTS GmbH** — HTS

Nb_3Sn strand designs are flexible





Distributed Barrier: RRP® (B-OST) and PIT (B-EAS) – high Nb% and Sn% for highest J_c and J_e

Applications:
- High Field NMR
- Cyclotrons
- Accelerator grade high field magnets
- Hybrid magnet high field outserts
- Undulators

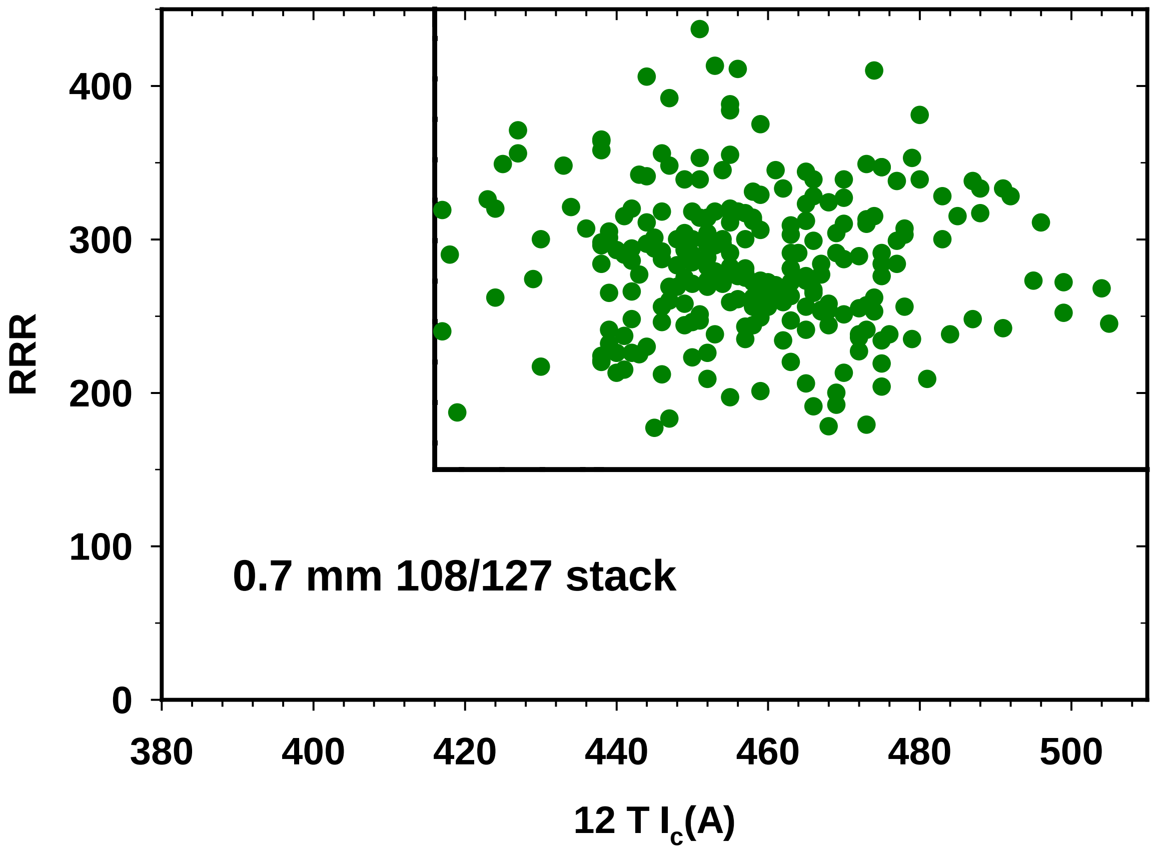
Single Barrier – Discrete filaments, lowest losses

Applications:
- ITER Coils
- low loss fast ramping magnets
- Cryogen free high field magnets

Conductor for Accelerators : 11 T dipole

0.7 mm 108/127 stack RRP® (D_s= 45 µm)

- 700 km manufactured to date

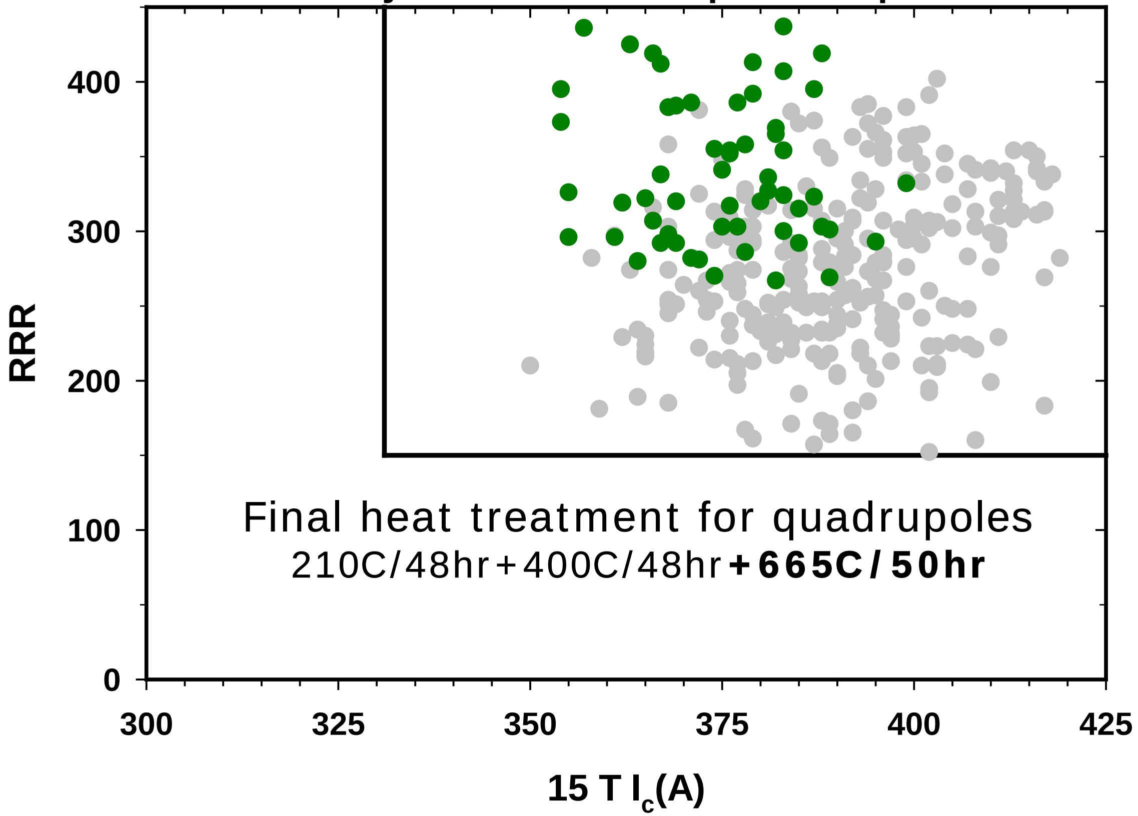


Margin sufficient to meet performance specs at industrial scale

Conductor for Accelerators : Quadrupoles

0.85 mm 108/127 stack RRP® (D_s= 55 µm)

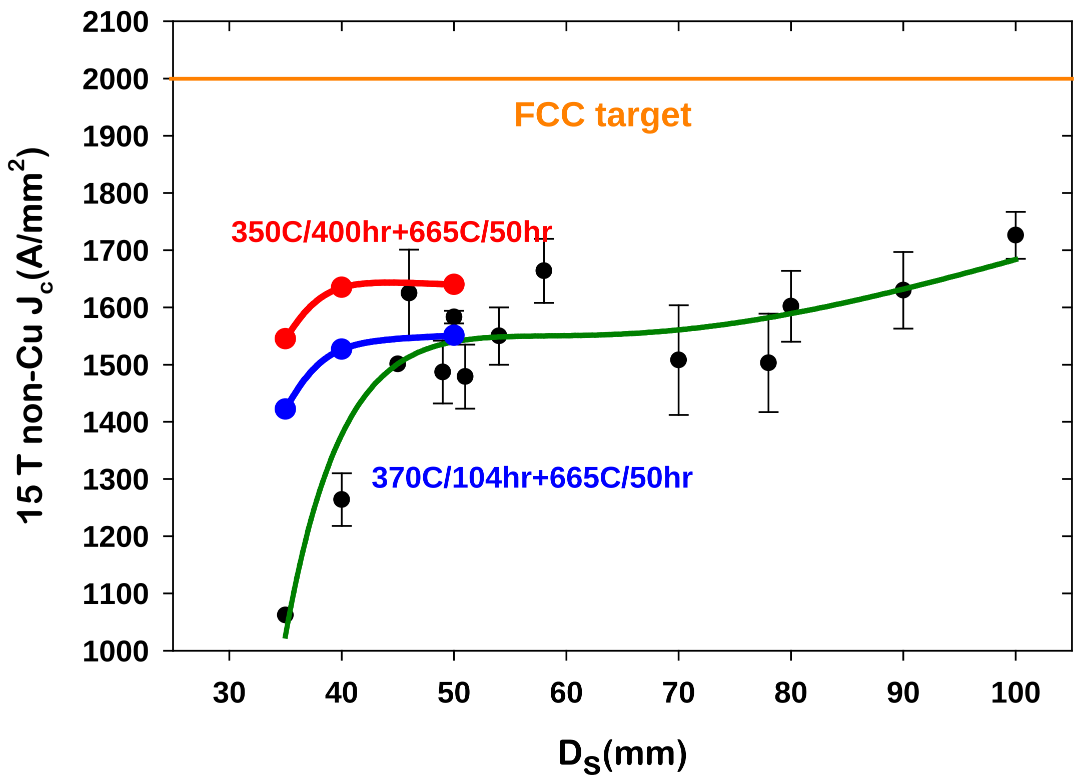
- 700 km manufactured to date
  - Heat treatment adjusted to improve performance margin



Future accelerators: room for RRP® gains

Reasons to be optimistic about the tug of war between J_c, D_{eff}, RRR:

- J_c data points are close to FCC needs
  - New understanding of what happens during heat treatments; i.e. minimizing Nausite formation to maximize fine grained Nb_3Sn (C. Sanabria, FSU-ASC Wed-Mo-Pl6)



Future accelerators: room for RRP® gains

- How do we get closer to J_c(15 T)= 2000 A/mm^2 ?
  - We need to understand and reduce variation
  - Renewed effort to modify strand for 16 T J_c (past emphasis on ~12 T and RRR)
    - now exploring changes to subelement to push up high field performance
      - Graded LAR
      - Quartenary – doping with Ti and Ta

- Extrinsic influences on RRR –can we use these for good, to boost RRR?
  - Influence on the reaction environment on the conductivity of the copper jacket

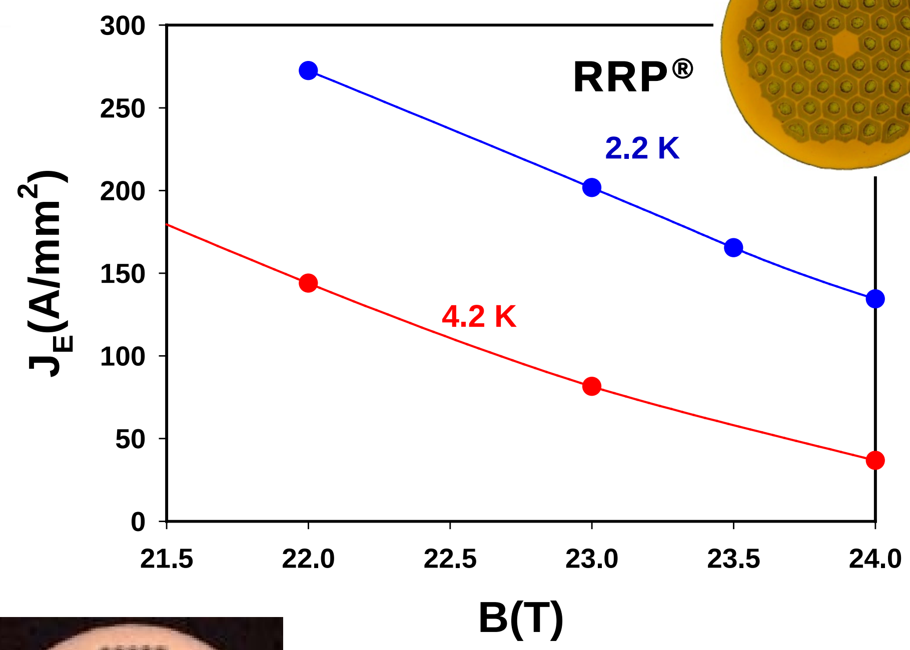
Conductor for Solenoids

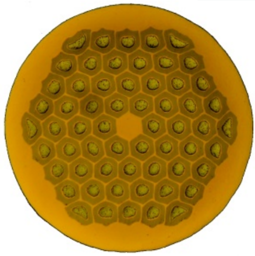
- Solenoids – lab magnets, NMR, cyclotrons – RRP® & PIT
  - Reliable persistent joints (Nb barrier, not Ta)
  - Homogenous filaments, high N values

- RRP® - Applications demand highest J_e, Cu:NC ~ 0.7

- PIT - 114…288 elements
  - D_s ~ 40 to 65 µm
  - Cu:NC ~ 1.20-1.35
  - J_c (non-Cu) > 2500 A/mm² @ 12 T, RRR > 100

Engineering Current Density for 1.2mm RRP®





PIT

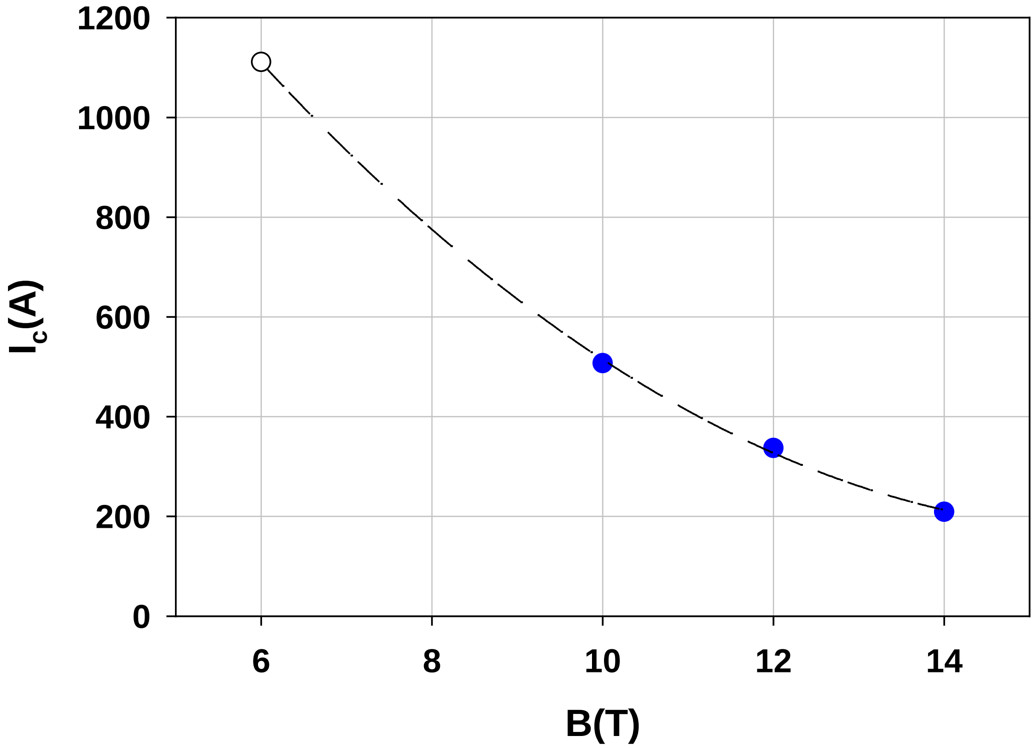
Conductor for Undulators

- Undulators - difficult to obtain both high J_c and high RRR when subelement size small (e.g. 35 µm)

Key adjustments to 169 stack 0.6mm (D_s= 35 µm) RRP® conductor design	J_c(4.2 K, 12 T)	RRR
Nb:Sn 3.4:1, standard barrier, 210C/48hr + 400C/48hr + 650C/50hr HT	2699 A/mm^2	11
Nb:Sn 3.6:1, 30% thicker barrier, 210C/48hr + 400C/48hr + 665C/100hr HT	1932 A/mm^2	124

Conductor for Undulators

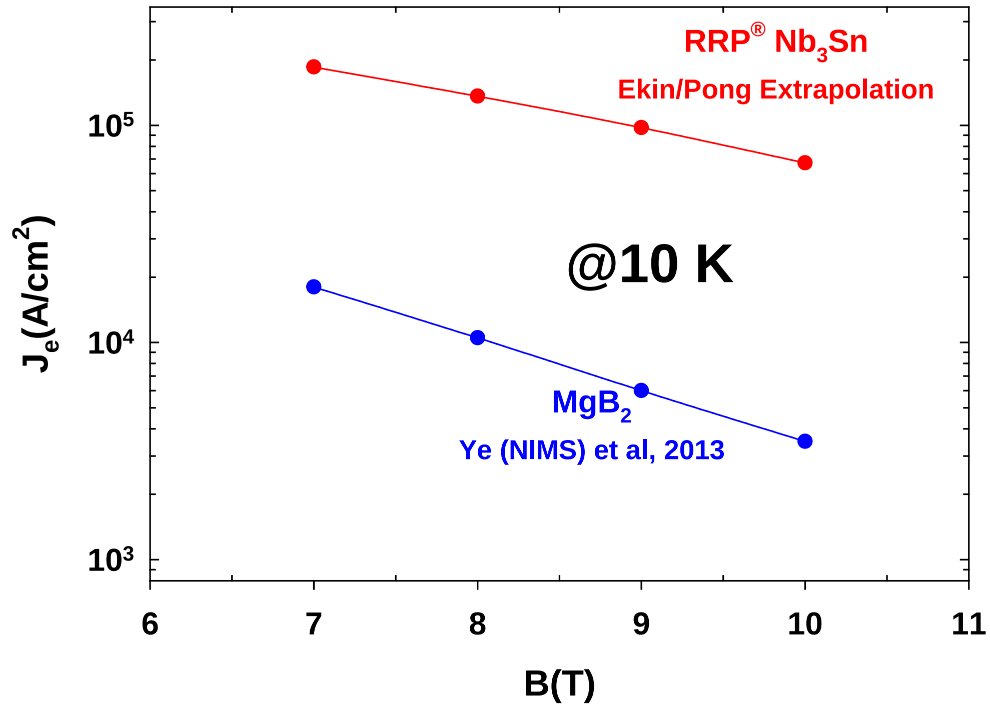
- Sanabria (FSU) developed a heat treatment approach to reduce Nausite layer allows for more useful currents at the small D_{eff} needed



1100 A @ 6 T
with RRR>150
dia. = 0.6 mm

Nb_3Sn at elevated temperatures

- T_c of ~18K coupled with high J_c means there is useful currents at elevated temperatures (cryogen free environments)



- Spreadsheet @ http://researchmeasurements.schralpit.com/ese-scaling-spreadsheet/
- Ekin et al., "Extrapolative Scaling Expression: A Fitting Equation for Extrapolating Full Ic(B,T,ε) Data Matrixes From Limited Data" IEEE Transactions on Applied Superconductivity, VOL. 27, NO. 4, June 2017

Summary

- Nb_3Sn RRP®, PIT, and single barrier conductors can be engineered to meet a wide range of performance needs
  - Accelerators : we are manufacturing large volumes, tweaked heat treatment to maximize performance margin
  - High Field Solenoids: both RRP® and PIT are suitable for high field persistent applications
  - Undulators: new improvements to heat treaments enable higher currents with good RRR at the D_{eff} needed
  - Cryogen free and elevated temperature applications are possible with Nb_3Sn