LARP

Nb3Sn Accelerator Magnet and Superconductor R&D at Fermilab

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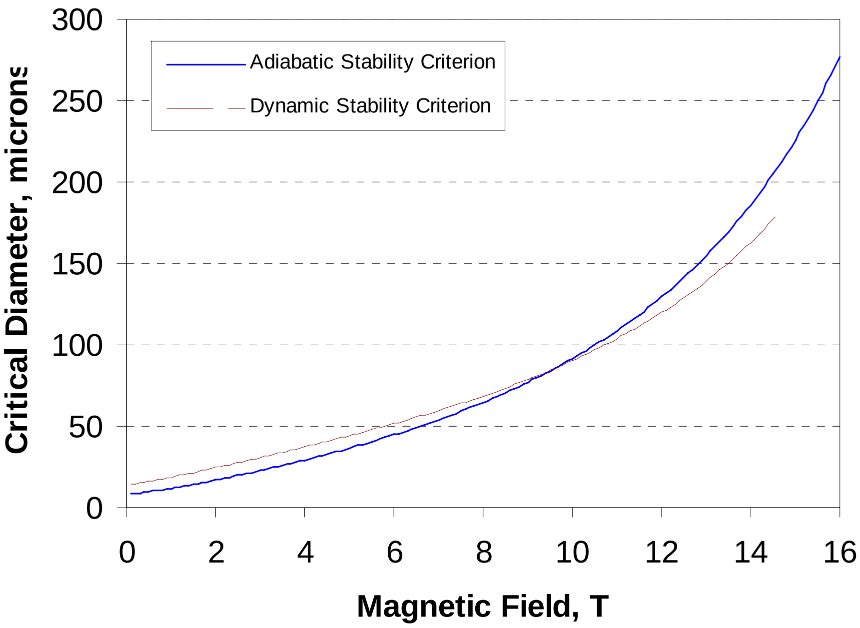
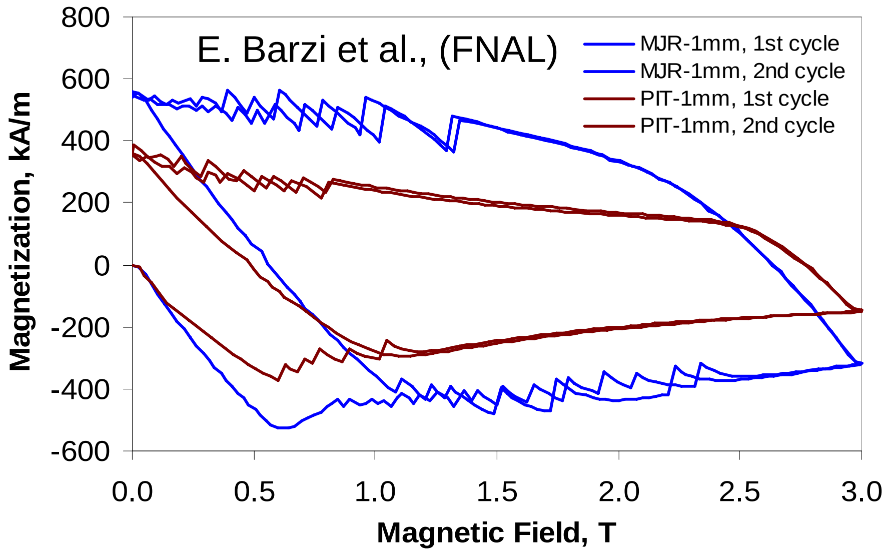
Introduction

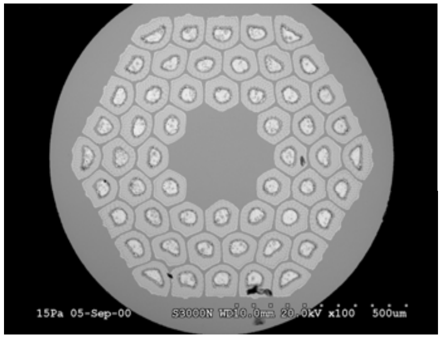
- Nb3Sn accelerator magnets at Fermilab since 1998.
- Strategic goal – technology for a new generation accelerator magnets with operation fields >10 T, large temperature margin and efficient coils for different applications.
- Short term goal - new IR quadrupoles for the planned LHC luminosity upgrades.
- Unique infrastructure for magnet and material R&D at Fermilab.
- Main R&D directions
  - Strands and cable
  - Coils
  - Mechanical structures
  - Performance and reproducibility demonstration
  - Technology scale up
  - Long-term performance and operation margins

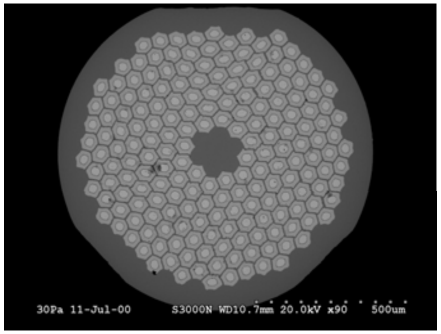
Nb3Sn Strands

LARP



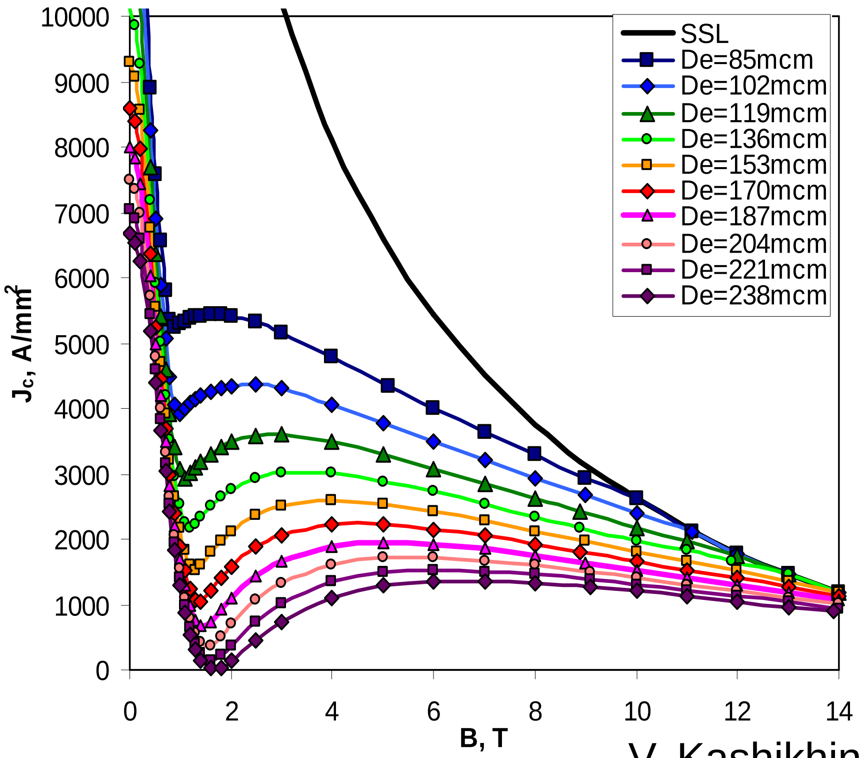




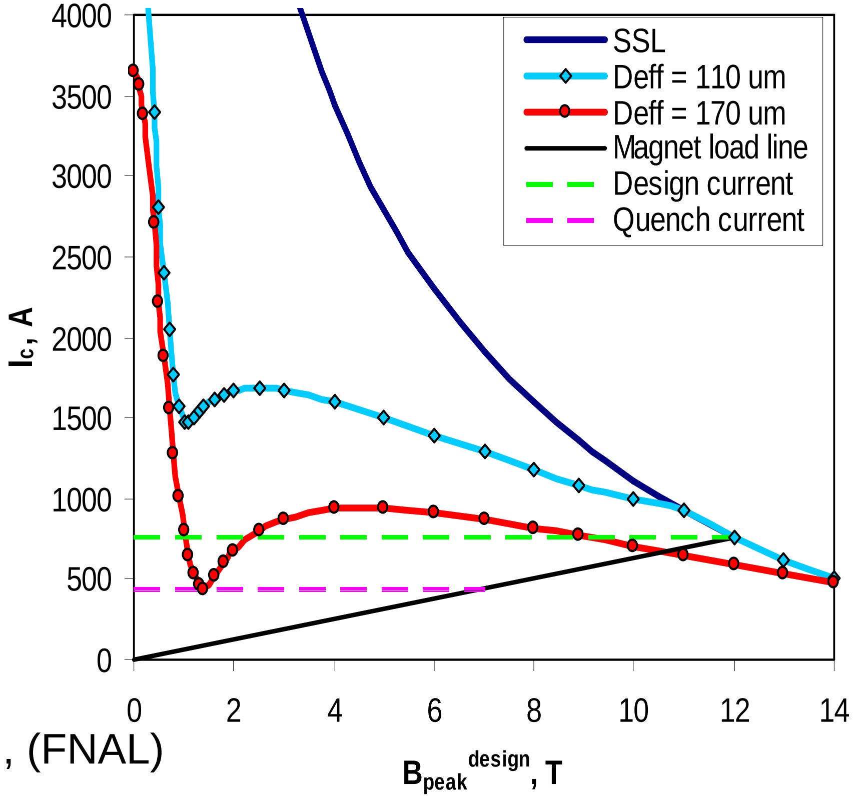


- **Two basic strands**
  - **IT – MJR, RRP (OST,US)**
  - **PIT – (ESC, EU)**
- **Strand properties**
  - **High Jc - > 2 kA/mm2**
  - **Relatively large Deff - >50 mcm**
- **Issues**
  - **Large magnetization**
  - **Flux jump instabilities**

Transport Current Limitations



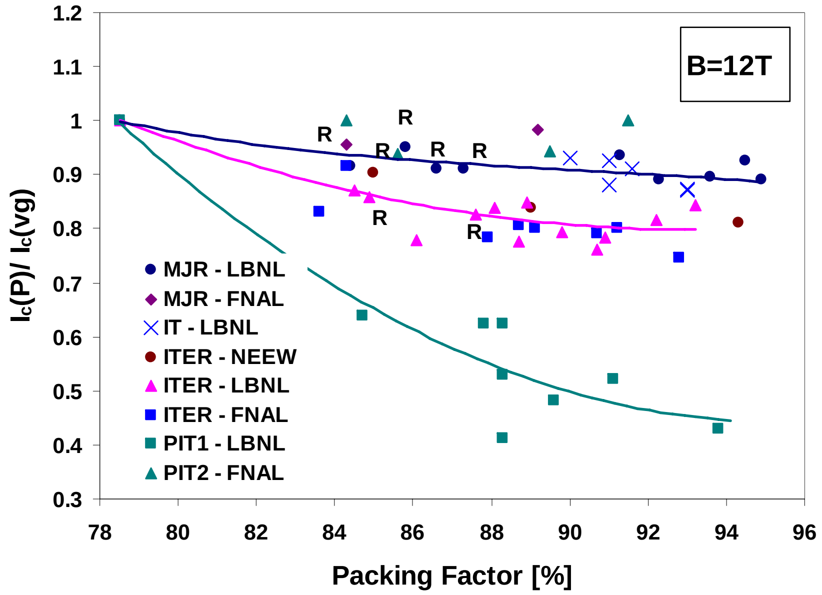
V. Kashikhin et al., (FNAL)

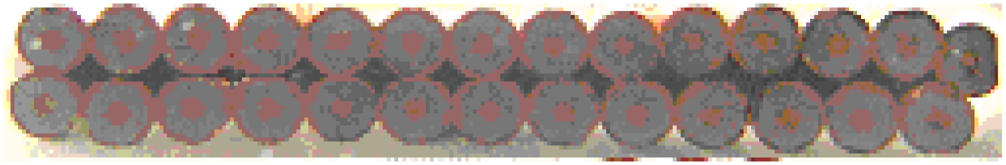


- **For strands with large Deff and high Jc (~Jc·Deff) the maximum transport current at low B can be smaller than at high B**
- **Effect on magnet performance => limit operation field range**

See also M. Sumption and B. Bordini (WAMSDO'2008).

Nb3Sn Rutherford Cable

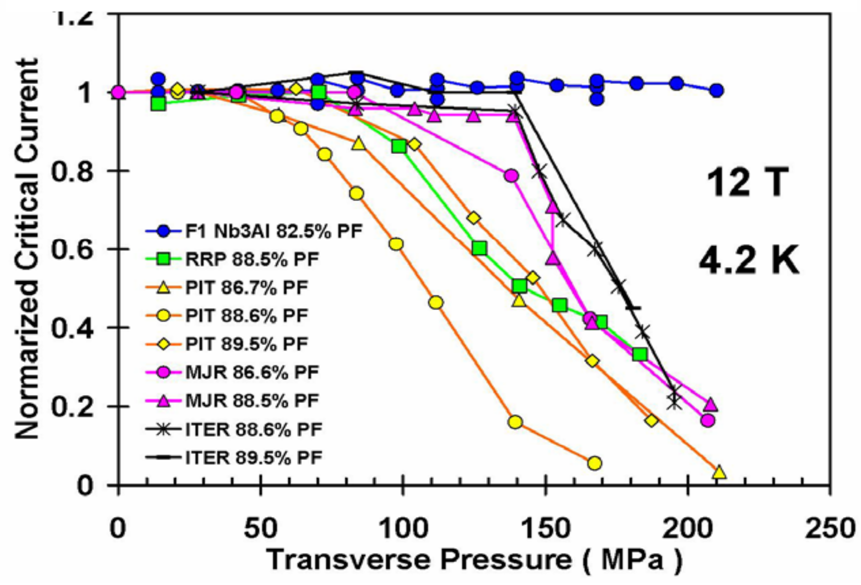




PIT, MJR and RRP cables were developed and studied

Issues:

- **Sub-element deformation, breakage and merging =>local increase of Deff, Ic and RRR degradation**
- **Strand sintering during reacting=>low non-uniform interstrand contact resistance**
- **High sensitivity to transverse**



See also A. Godeke et al. and T. Collings (WAMSDO'2008).

Nb3Sn Coil Technology

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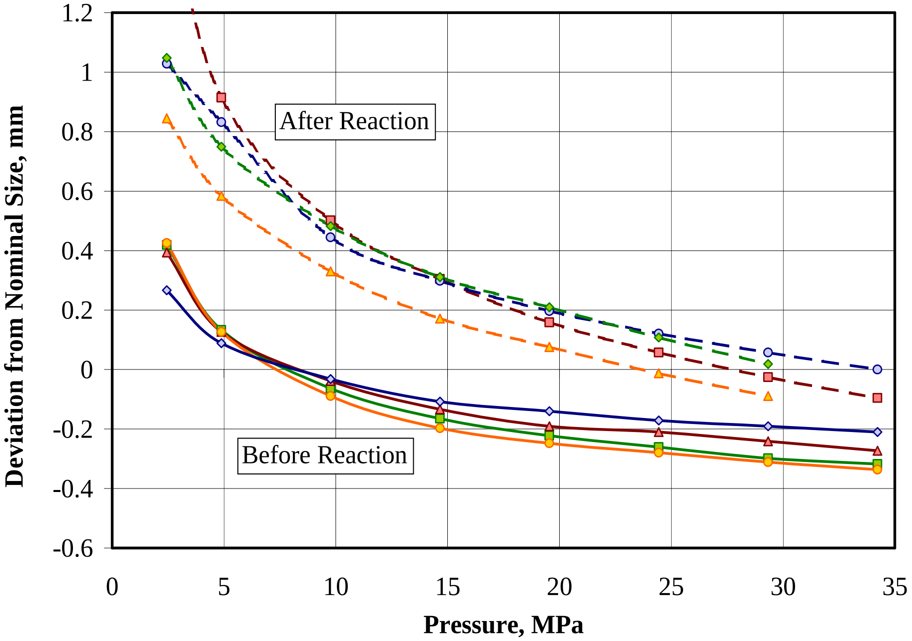
- Nb3Sn is brittle material
- Coil fabrication technology
    - W&R method
    - high-temperature insulations
    - metallic coil components
    - coil winding and curing with ceramic binder
    - horizontal coil vacuum impregnation with epoxy
- 1-m long coil production
    - 20 dipole coils (FNAL)
    - 29 quadrupole coils (LARP: FNAL+LBNL)
    - good size reproducibility
    - fabrication time comparable with NbTi technology
- Coil handling and transportation

Nb3Sn Coil Properties

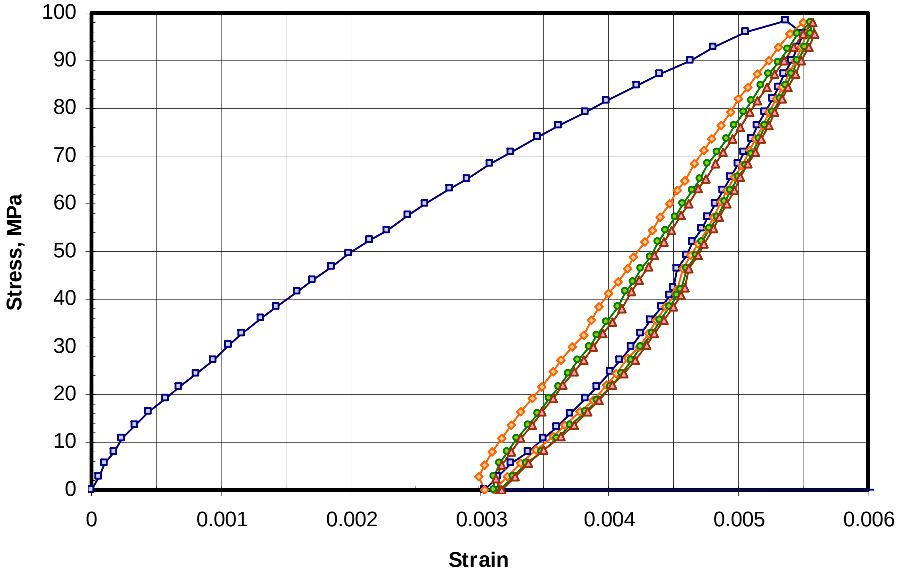


Conductor expansion during reaction

- ❖ **coil longitudinal extrusion**
- ❖ **controlled azimuthal gap to minimize elongation**

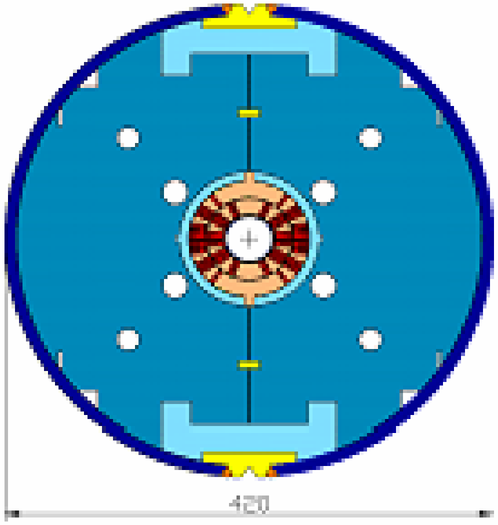
Coil plasticity

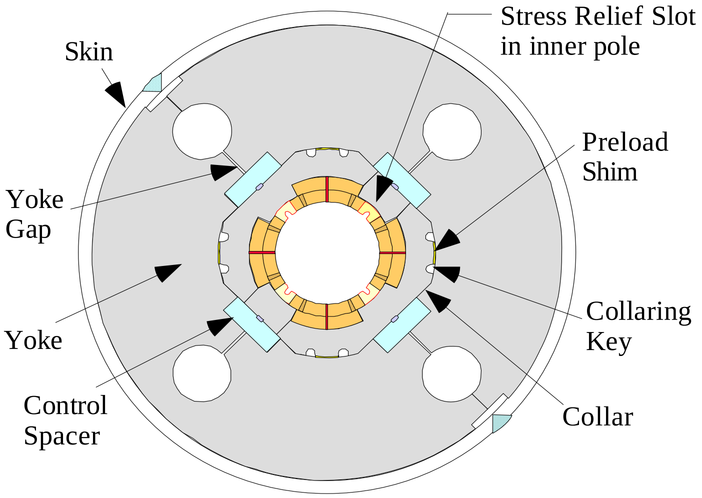
- ❖ **coil size measurement at low pressure**
- ❖ **new approach to coil pre-stress based on plastic model**



Mechanical Structures

- **Two structures**
  - **Spacer/yoke with Al clamps /12-mm SS shell structure - dipole**
  - **SS collar/yoke/12 mm SS shell structure - quadrupole**
- **Issues**
  - **safe coil pre-stress up to high stress (~150 MPa)**
  - **radial and axial coil support**
  - **precise geometry and alignment**
- **Specific issues**
  - **dipole structure - coil bending during horizontal preload**
  - **Quadrupole structure - partial coil compression during collaring, collar-yoke interference**





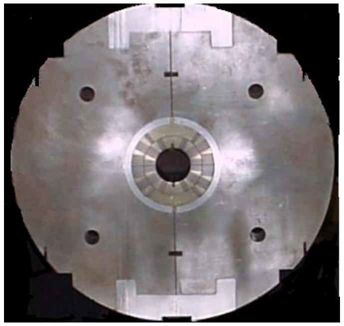
Short Model Parameters

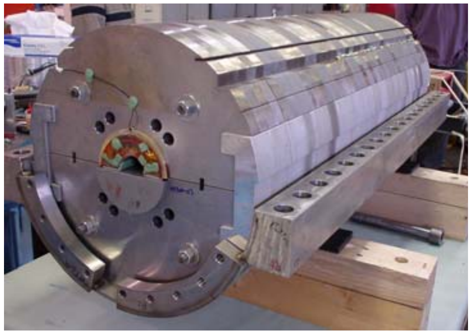
Nb_3Sn dipole models (HFDA):
- High-J_c 1-mm Nb_3Sn strand
- 27-28 strand cable
- 2-layer coil
- 43.5-mm diameter bore
- Maximum field ~11 T at 4.5 K

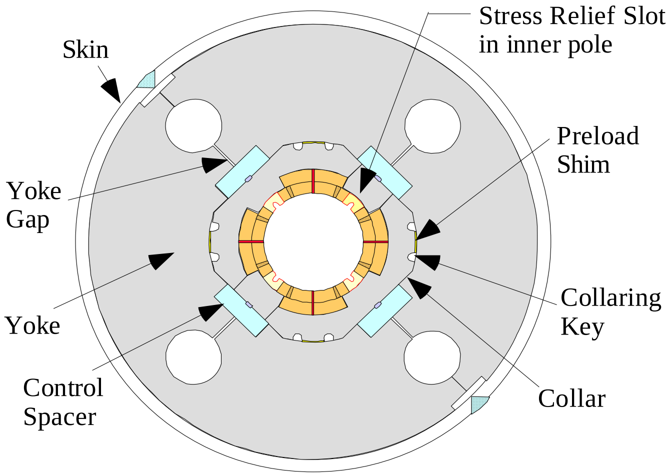
Magnetic mirror (HFDM):
- Same mechanical structure
- Advanced instrumentation
- Shorter turnaround time
- Lower cost

LARP Technology quadrupole (TQC):
- High-J_c 0.7-mm Nb_3Sn strand
- 27 strand cable
- 2-layer coil
- 90-mm diameter bore
- Gmax~230/250 T/m at 4.5/1.9 K
- Bmax~12-13 T

- **Structure comparison**
  - Similar forces and size



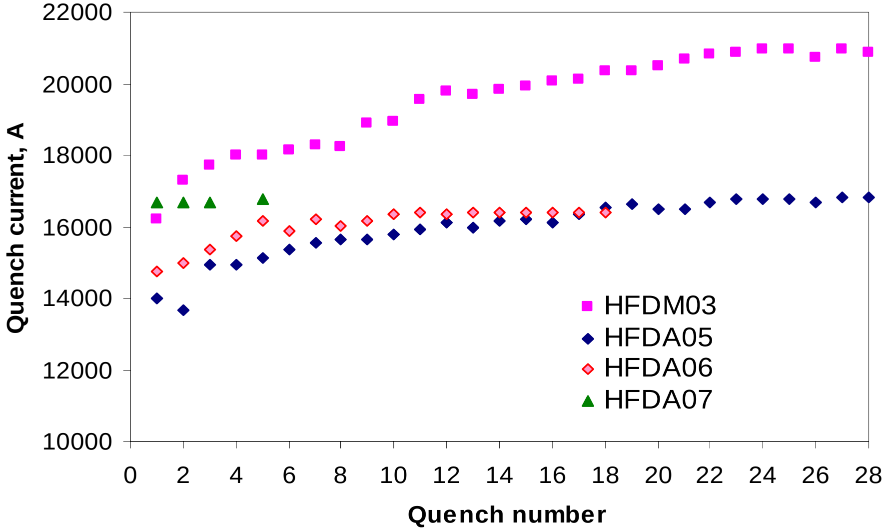


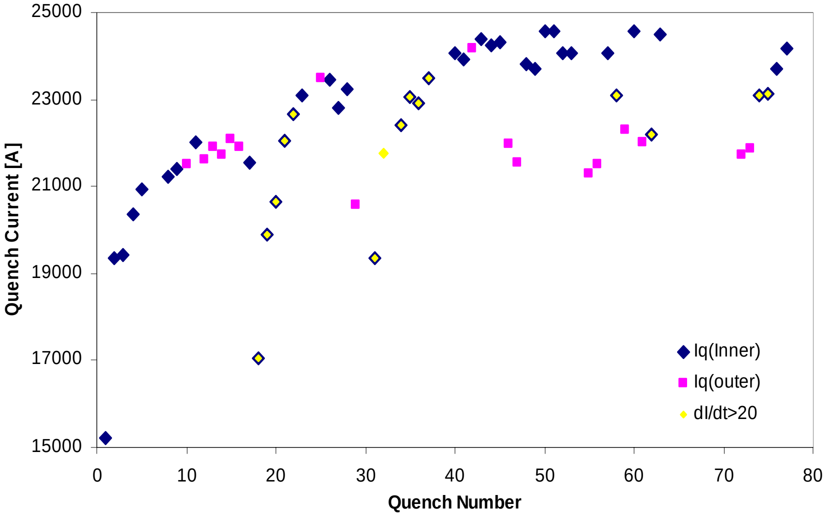


Dipole Model Quench Performance

6 1-m long dipole and 6 mirror models were fabricated and tested

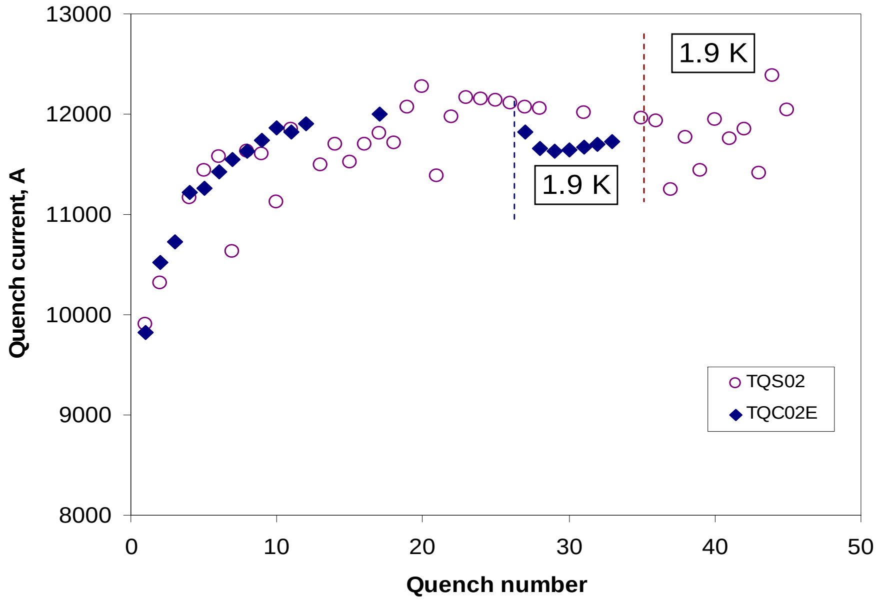
- **Models with 1-mm MJR-54/61 strand => flux jump limitations.**
- **Models with 1-mm PIT-196 strand reached 9.4 T @4.5K and ~10.2 T @2.2K (100% of PIT strand SSL with transverse pressure correction)**
  - **Coil re-assembly, training memory**
- **Dipole mirror model with 1-mm RRP 108/127 strand, reached ~11.4 T at 4.5 K (97% of SSL)**
  - **Some instabilities at ~21kA**
- **Robust mechanical structure**
- **General features**
  - **Training starts at ~80% of SSL**
  - **Quite long training**

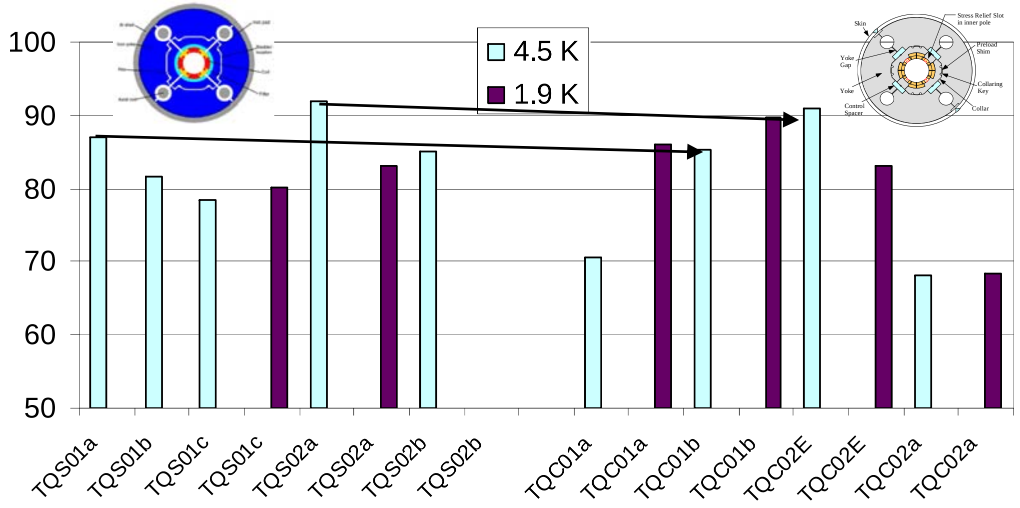




TQC Quench Performance

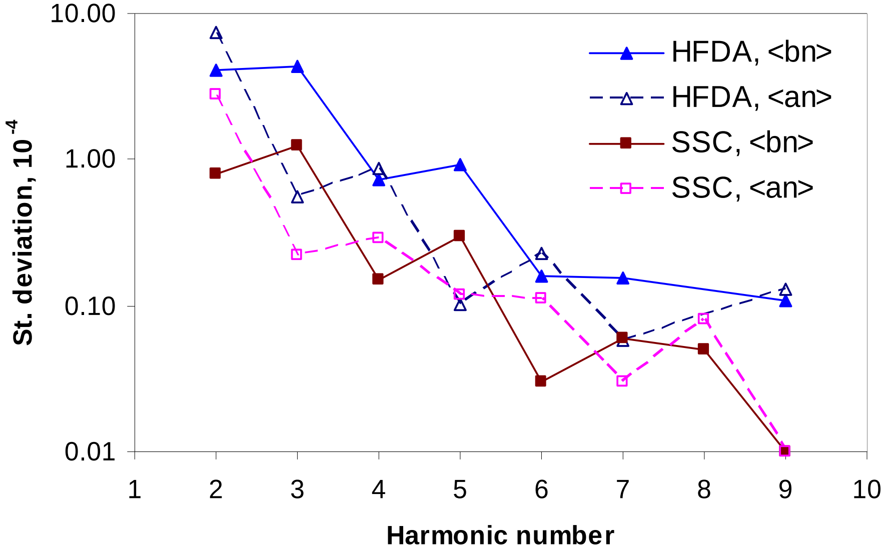
- **4 TQC models**
  - **MJR 54/61 - low Jc strand**
  - **RRP 54/61 - high-Jc strand**
- **Performance**
  - **Gmax~200 T/m**
    - MJR models at 1.9 K
    - RRP models at 4.5 K
- **Quite long training (similar to dipole models)**
- **TQC and TQS comparison:**
  - **~10% or higher degradation at 4.5K**
  - **flux jumps in models made of high-Jc RRP strands**
  - **Same fraction of SSL in case of coil exchange (!)**
- **Sound mechanical structure**
- **Possibility of Nb3Sn coil collaring was demonstrated**





Field Quality

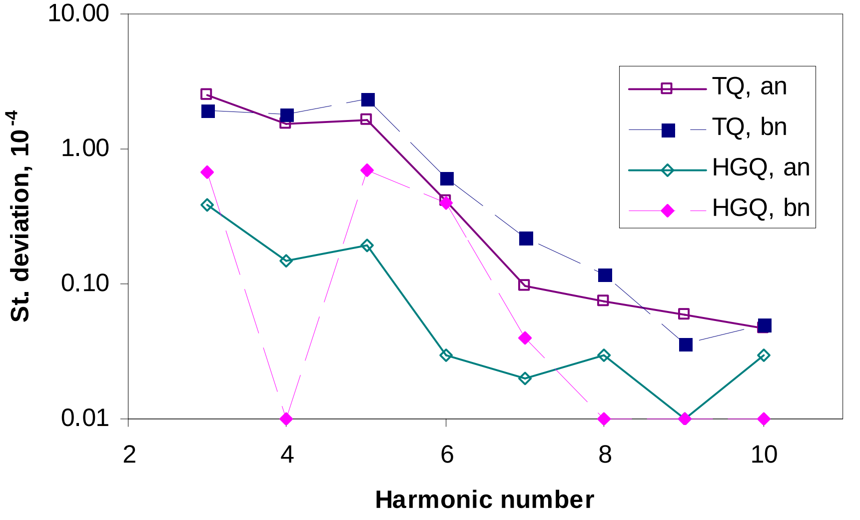
- **6 HFDA models vs. first 6 40-mm SSC dipole models**
- **4 Nb3Sn TQ (TQC and TQS) models vs. NbTi HGQ models.**



- **Geometrical harmonics are still larger in Nb3Sn models**

  <= new technology

- **The geometry and alignment of Nb3Sn magnets need to be improved**

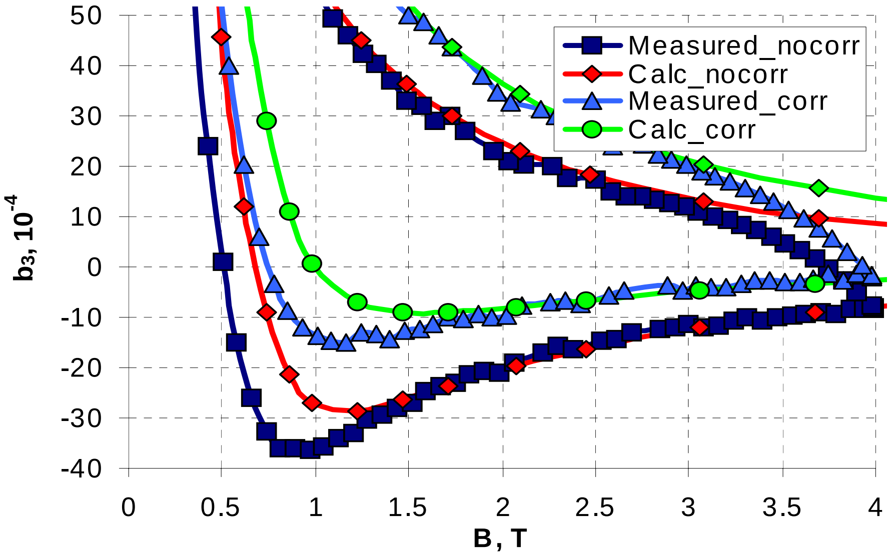


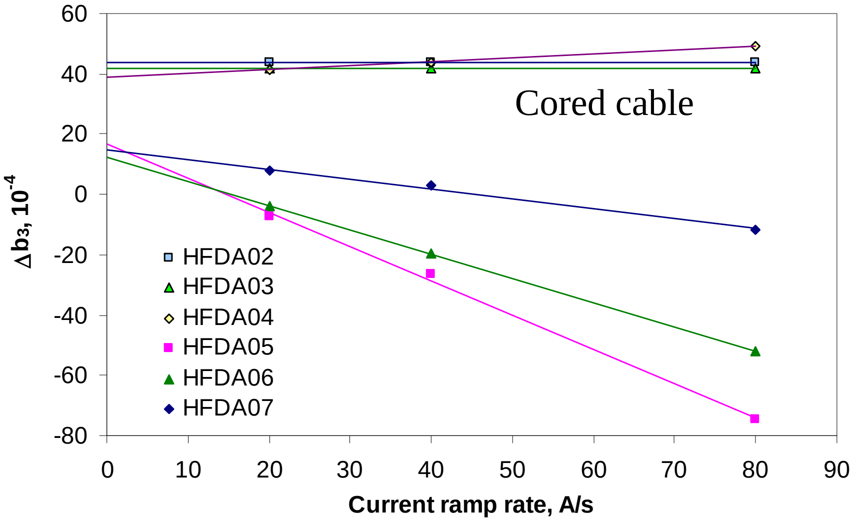
Coil Magnetization Effects

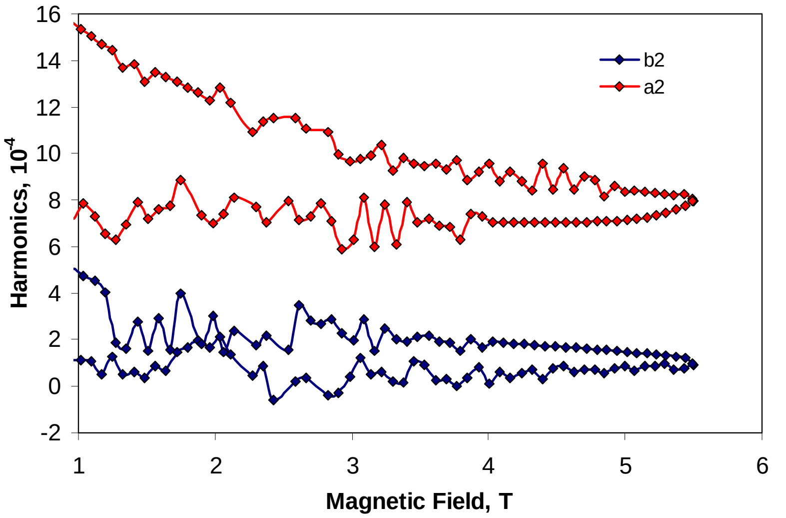
- **The persistent current effect is large but reproducible**
  - o **Smaller Deff and/or passive correction**
- **flux jumps in low order harmonics in dipole models**

  => smaller Deff
- **Large value and variations of the eddy current components**

  => Ra control with a SS core

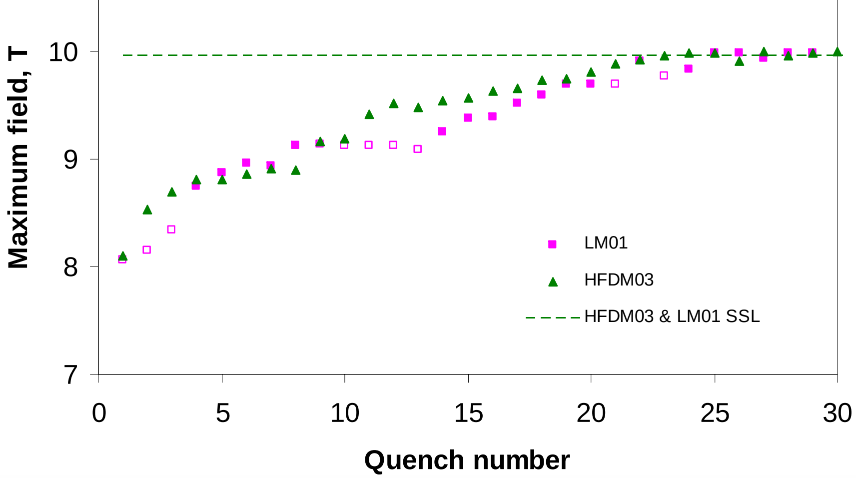


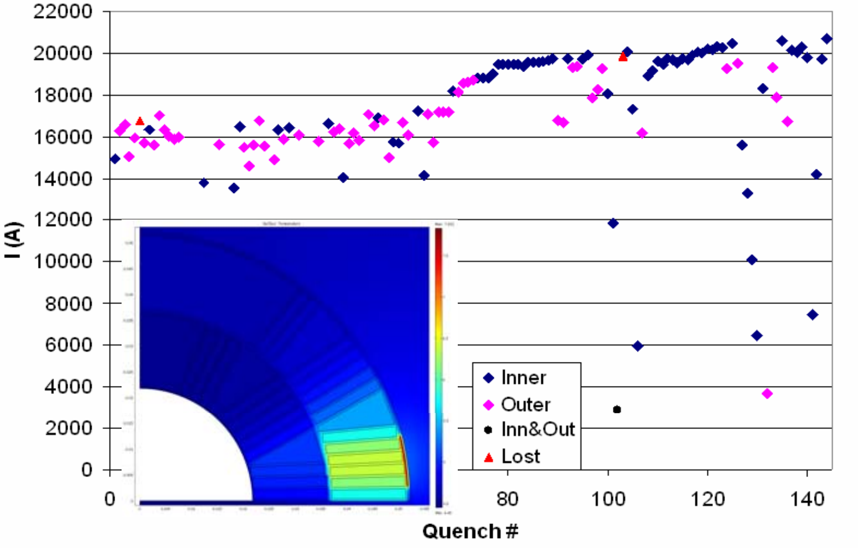




Nb3Sn Technology Scale Up

- **Goals:**
  - o **Long coil fabrication, handling, magnet assembly and testing**
  - o **Infrastructure for LARP and future LHC upgrade project**
- **2-m long PIT cos-theta coil (June 2007)**
  - o **1-m and 2-m long PIT mirror models reached their SSL**
- **4-m long RRP-108/127 cos-theta coil (December 2007-January 2008)**
  - o **Flux jumps at I~16kA in outer layer (suppressed with heater)**
  - o **training was not finished, Imax ~90% of SSL at 4.5 K**
- **Long coils**
  - o **survived the fabrication process**
  - o **expected quench performance**





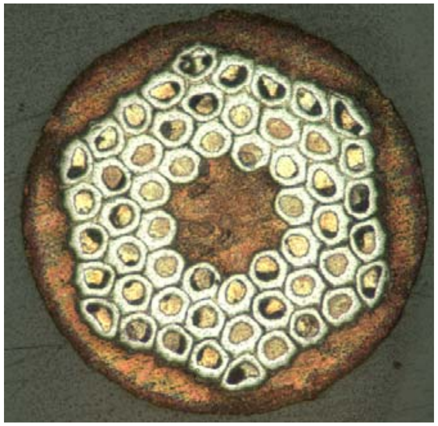
Nb3Sn Strand Improvement (OST)

Goal - more stable high-Jc Nb3Sn strand to improve magnet quench performance and field quality

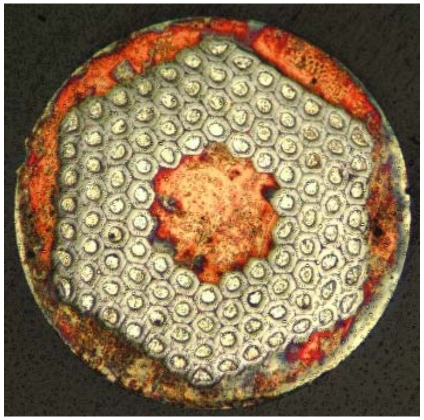
Directions:

- **Increase sub-element number without losing Jc, RRR**
  - **stability**
- **Sub-element number and layout optimization**
  - **reduce SE deformation and damage**
  - **increase Cu/nonCu ratio**

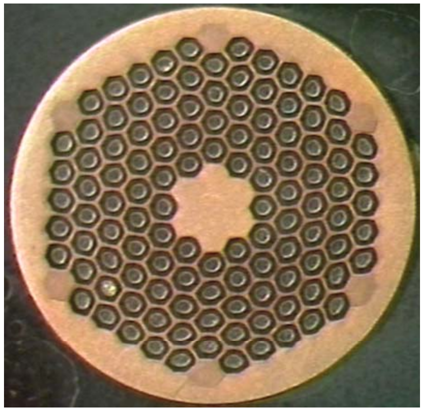
61 stack



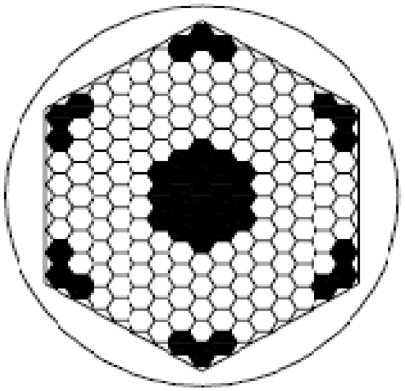
127 stack, 2005-2006



127 stack, spaced, 2007



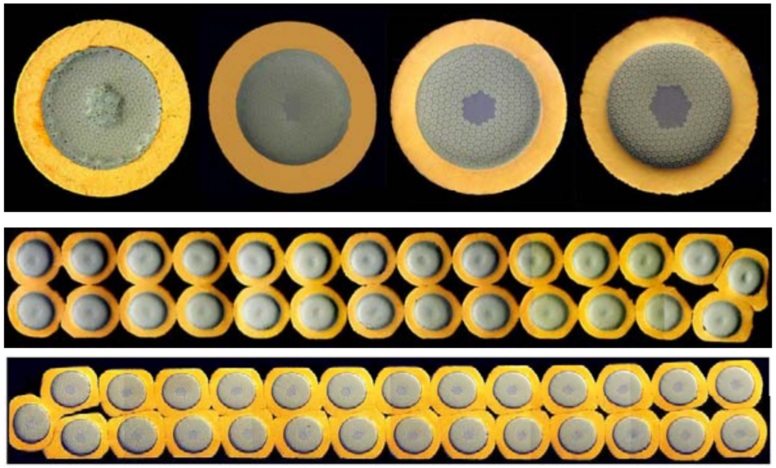
169 stack, spaced, 2008-2009



Nb3Al Strand and Cable (with NIMS)

- ❖ Conductor for high-field/high stress magnets
- ❖ Progress in Japan with Nb3Al strand technology (NIMS)
  - o **Four strand generations F1-F4**
  - o **Copper stabilizer electroplating**
- ❖ Cable development and test (FNAL)
  - o **Low and high compaction cables**
  - o **No Ic degradation up to 230 MPa**
- ❖ Racetrack coils
  - o **SR-04 (F1) - tested in 2006**
  - o **SR-05 (F3) – not tested**
  - o **SR-06 (F4) - test in June 2008**
- ❖ Next steps
  - o **Japan-US-CERN collaboration**

see K. Sasaki et al., (WAMSDO'2008)



Conclusions

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- **Good progress in Nb3Sn accelerator magnet R&D**
  - **robust coil W&R technology**
  - **robust mechanical structures**
- **The possibilities and present limitations of quench performance and accelerator field quality in Nb_3Sn dipoles and quadrupoles were demonstrated**
  - **performance improvement is possible**
  - **model magnet R&D need to continue**
- **The first results of Nb3Sn accelerator magnet technology scale up are quite encouraging**
  - **more work ahead**
- **The optimization and use of more stable high-Jc RRP strand is critical for magnet performance improvement**
- **Long-term performance and operation margins have yet to be demonstrated**