Nb3Sn Accelerator Magnet R&D at Fermilab

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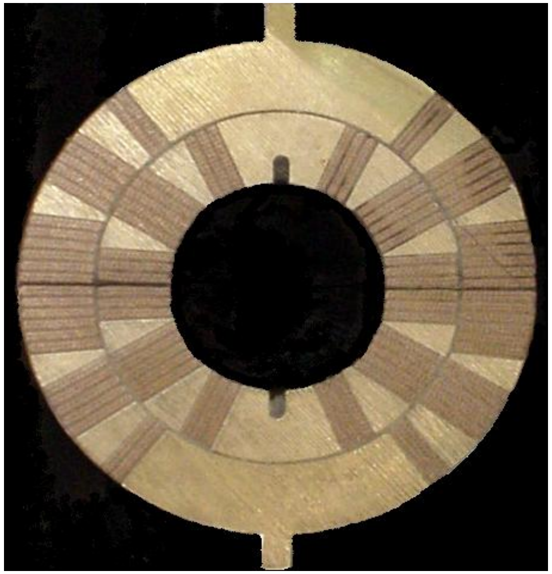
Introduction

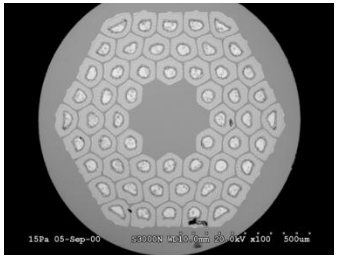
- During past decade the magnet R&D program has focused on the new generation accelerator magnets based on Nb3Sn superconductor
  – started in 1998 developing accelerator quality 10-12 T arc dipoles for a Very Large Hadron Collider (VLHC).
  – in 2003, the emphasis was shifted to the US-LARP work on Nb3Sn quadrupoles for a LHC IR upgrade.
- The most important breakthroughs in Nb3Sn accelerator magnet technology made at Fermilab
  – high-performance Nb3Sn strand and cables
  – reliable production-ready Nb3Sn coil technology
  – accelerator quality mechanical structures
  – coil pre-load techniques.

Nb3Sn Dipole (HFDA)

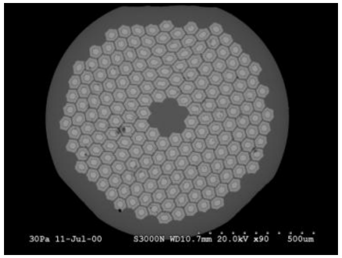
- Compact mechanical structure: collarless, Al clamps, yoke OD=400mm
- 2-layer 43.5-mm coil
- 1-mm Nb_3Sn strand
- 27 (28) strand cable
- Coil-yoke alignment
- Design B_{max}~12 T @4.5 K



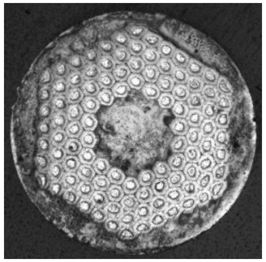
MJR-54/61

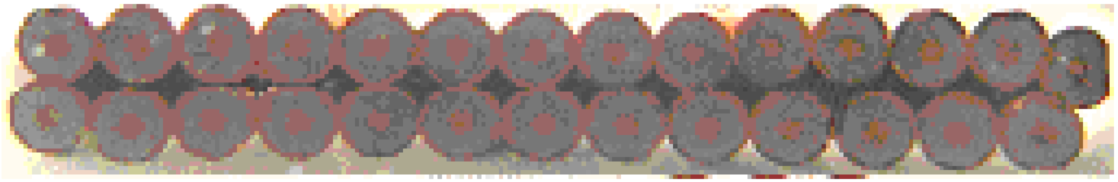


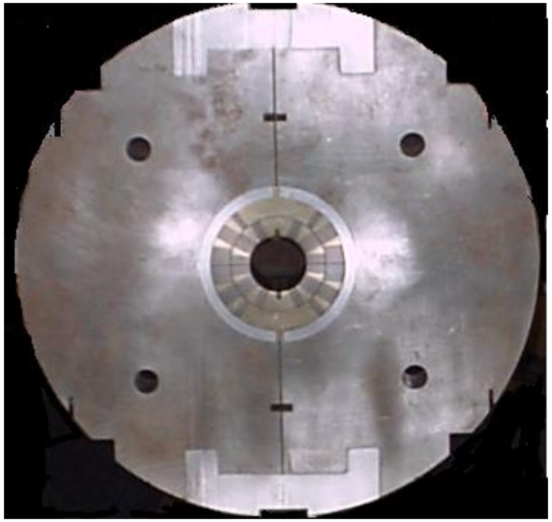
PIT-196



RRP-108/127

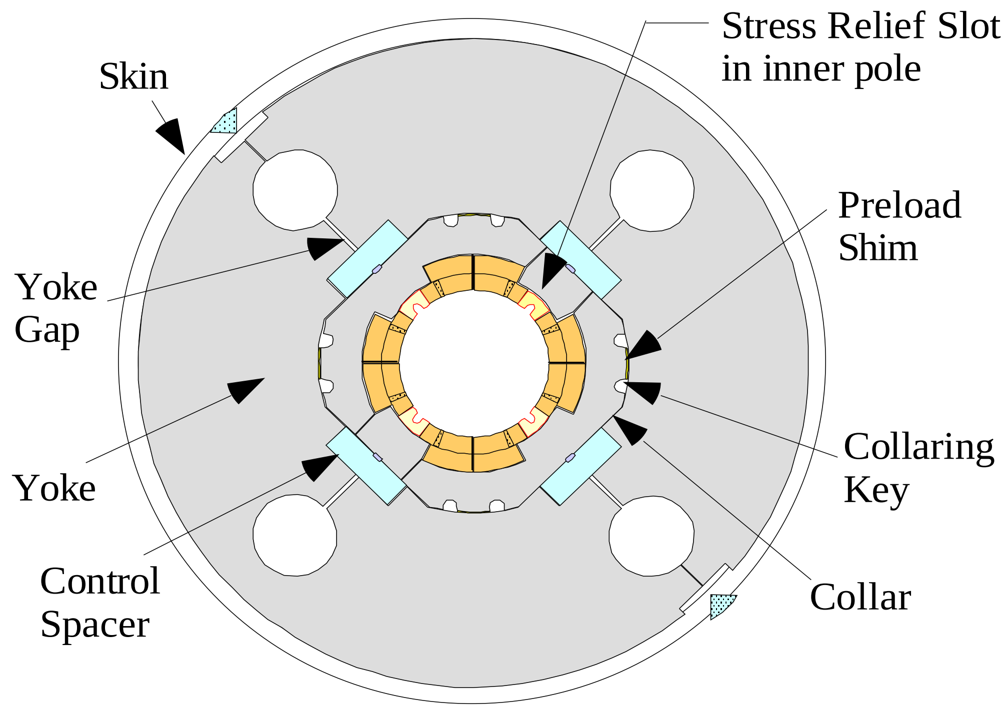




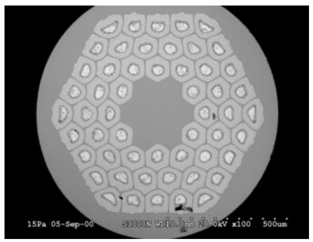


Nb3Sn Quadrupole (TQC)

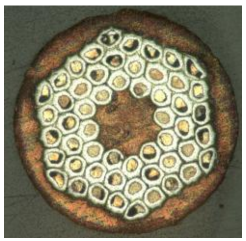
- Mechanical structure (MQXB): SS collar, yoke, skin
- 2-layer 90-mm coil
- 0.7-mm Nb_3Sn strand
- 27 strand cable
- Coil-yoke alignment
- Design G_{max}~230/250 T/m @4.5/1.9K (B_{max}~12-13 T)



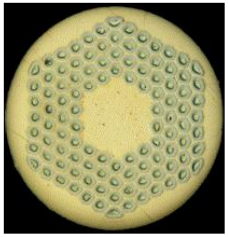
MJR-54/61

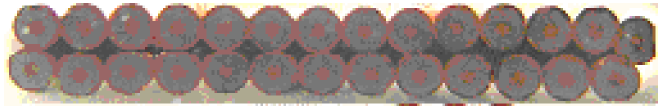


RRP-54/61



RRP-108/127

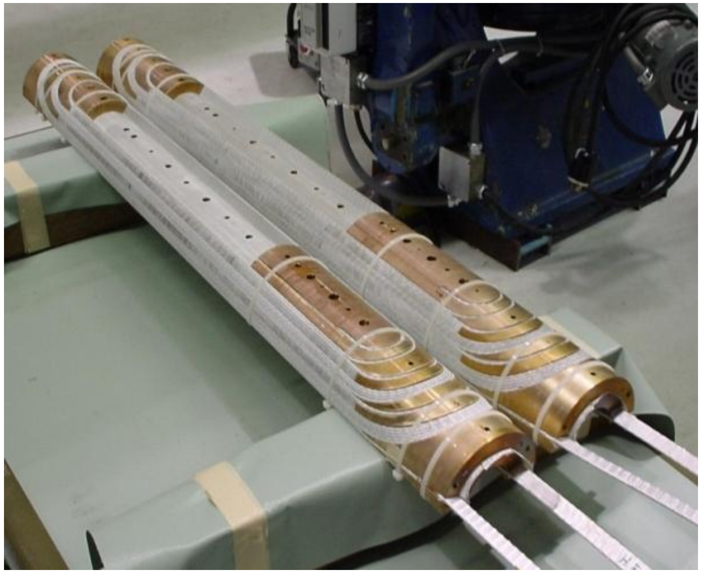


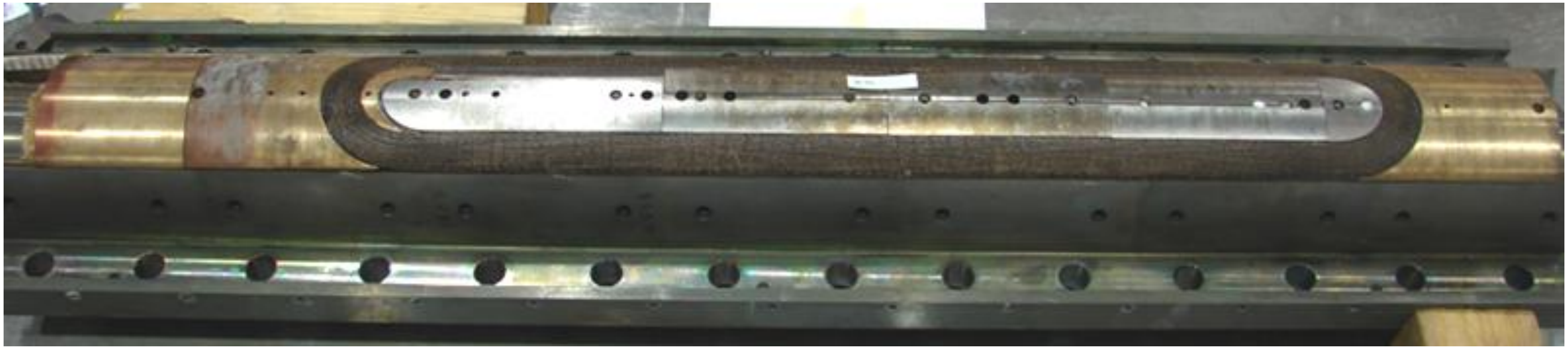


Nb3Sn Coil Technology

Coil fabrication technology:

- W&R method
- high-temperature insulation (ceramic, S2/E-glass)
- metallic components (bronze, Ti)
- *ceramic binder*
- coil vacuum impregnation (epoxy CTD101, liquid poliimid Matrimid)

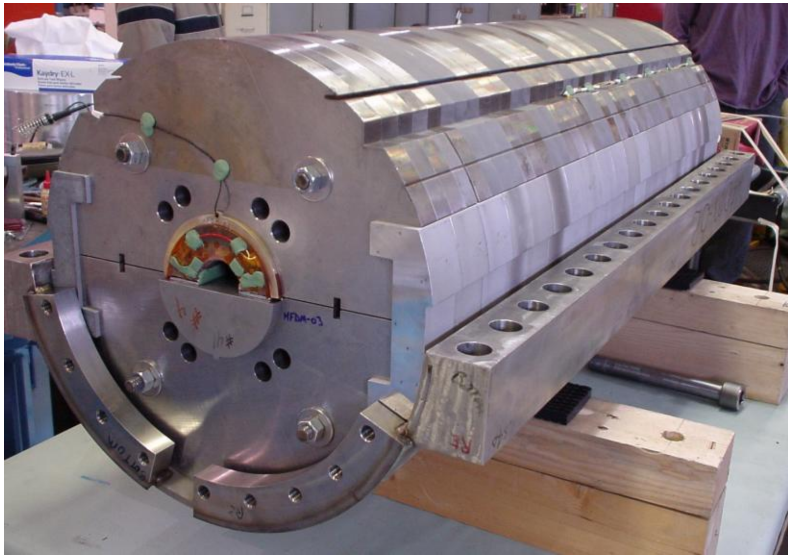


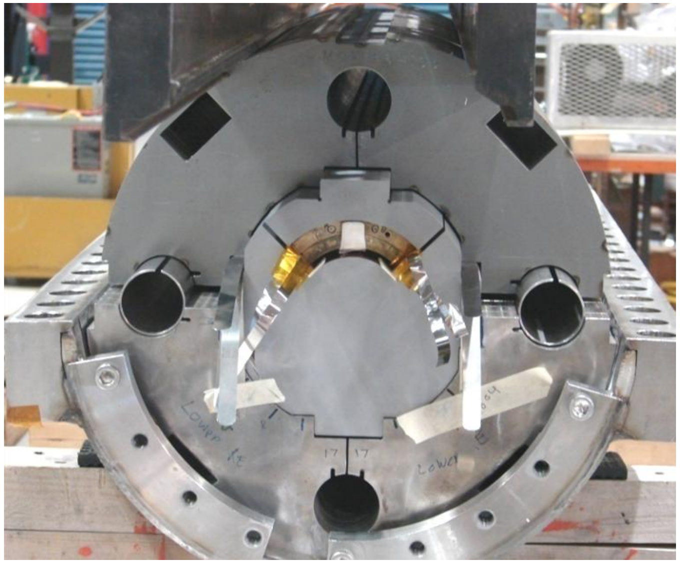


Coil Test Structures

Individual D and Q coils were tested and optimized using Coil Test Structures (CTS):

- similar level of magnetic field and its distribution
- comparable Lorentz forces
- same mechanical structure and assembly procedure
- advanced instrumentation
- shorter turnaround time
- lower cost

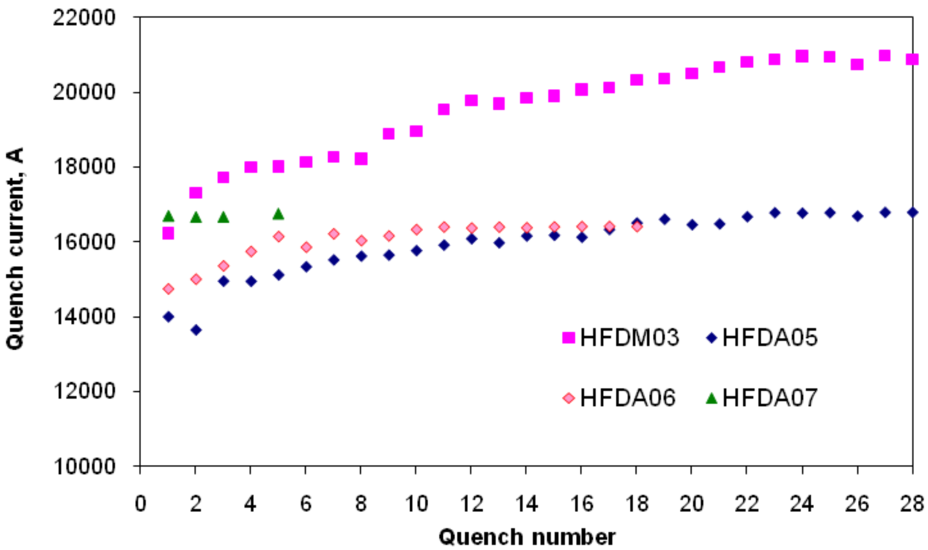


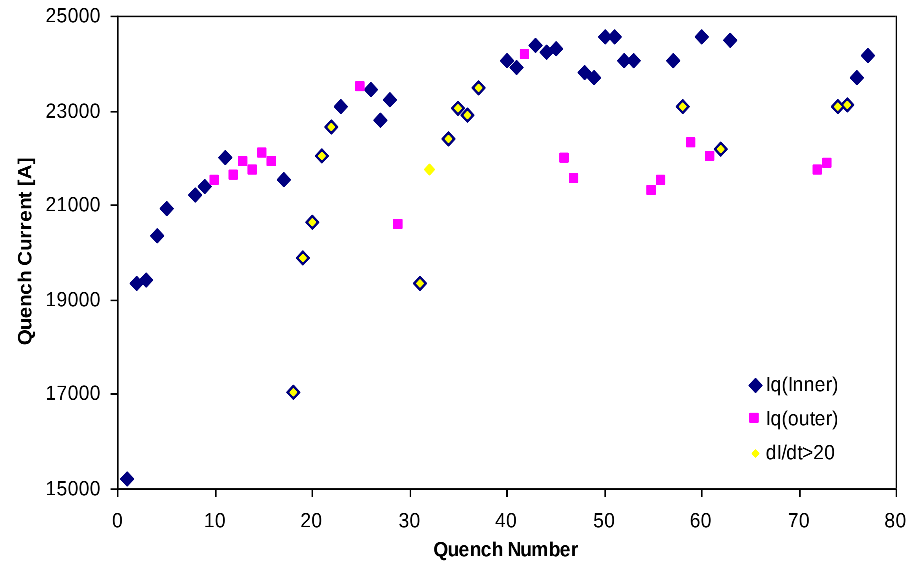


Dipole Quench Performance

6 short dipole and 6 CTS models were built and tested during 2002-2006:

- 2002-2003: first 3 D models with 1-mm MJR-54/61 strand suffered from flux jumps at B>6 T.
- 2004-2005: 3 D models with 1-mm PIT-196 strand reached B_{max}=9.4/10.2T @4.5/2.2K (100% of SSL).
- 2006: D CTS with 1-mm RRP-108/127 coil reached B_{max}= 11.4T @4.5 K (97% of SSL)



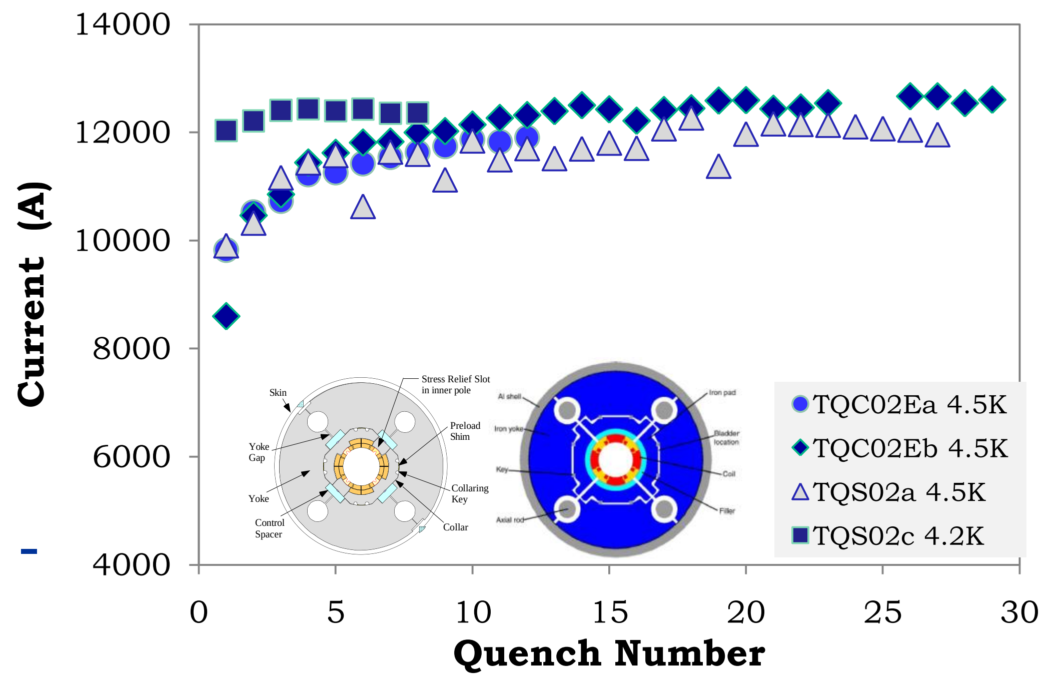


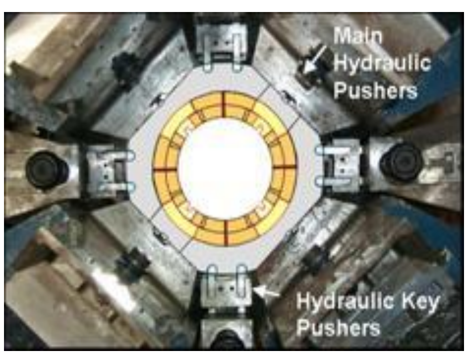
Quad Quench Performance

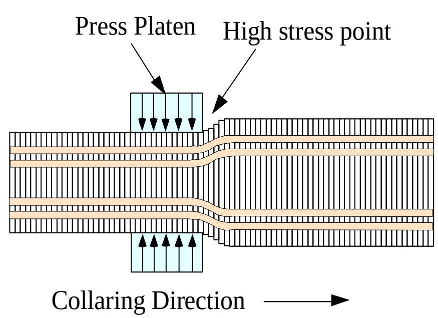
7 quadrupole models and

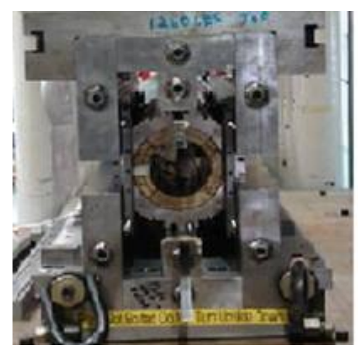
5 quadrupole CTS models during 2007-2010:

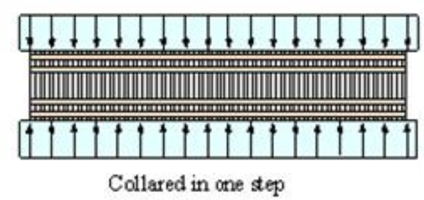
- 2 collaring techniques
- 2006: MJR Q models - G_{max}~200 T/m at 1.9 K
- 2007-2010: RRP models - G_{max}~211/217 T/m at 4.5/3 K (FJ at 1.9K)





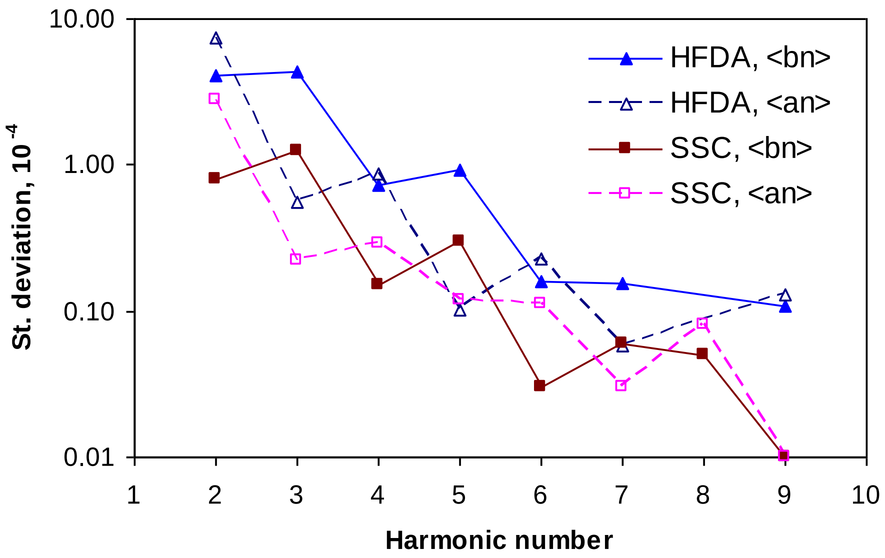


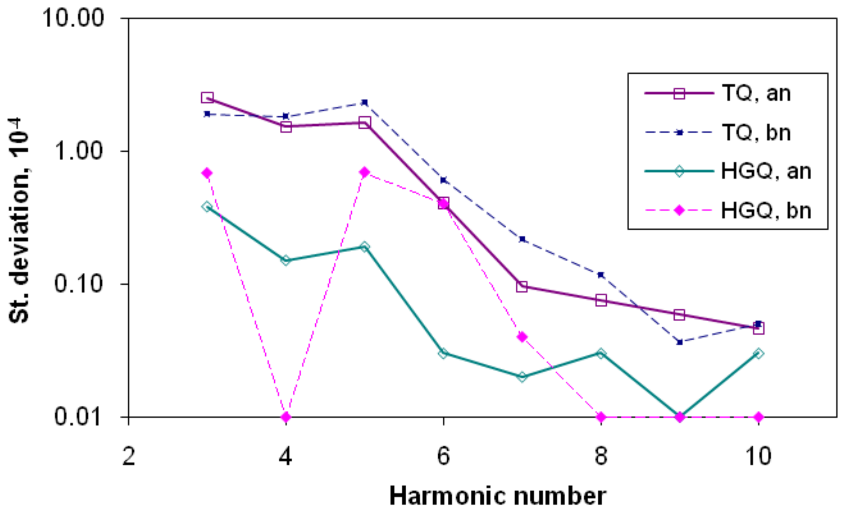




Nb3Sn D and Q Field Quality

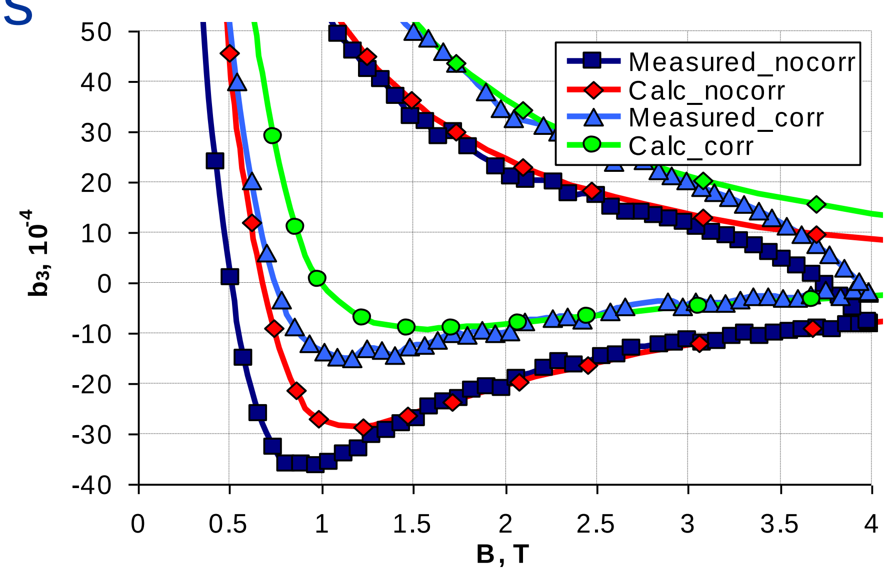
- 6 HFDA models vs. first 6 40-mm SSC dipole models
- 4 Nb3Sn TQ (TQC and TQS) models vs. NbTi HGQ models
- Field harmonics in Nb3Sn models are larger than NbTi models
  - new technology
- The geometry and alignment of Nb3Sn magnets need to (and can) be improved

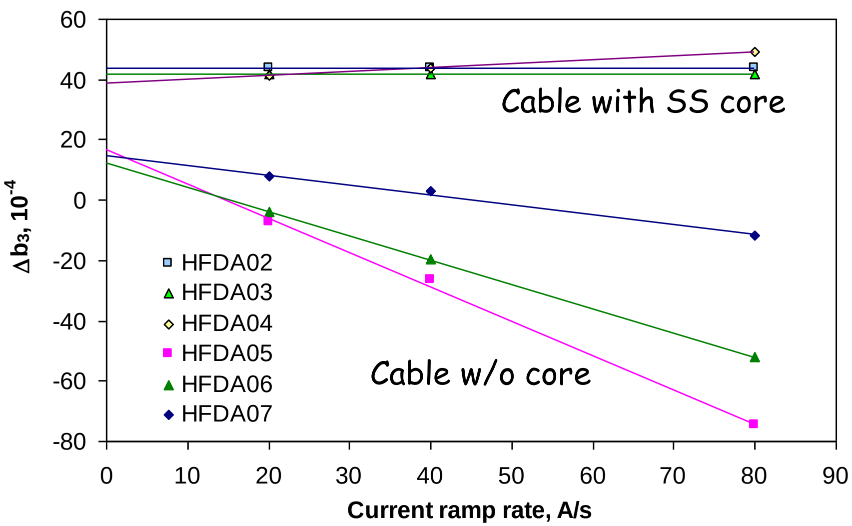


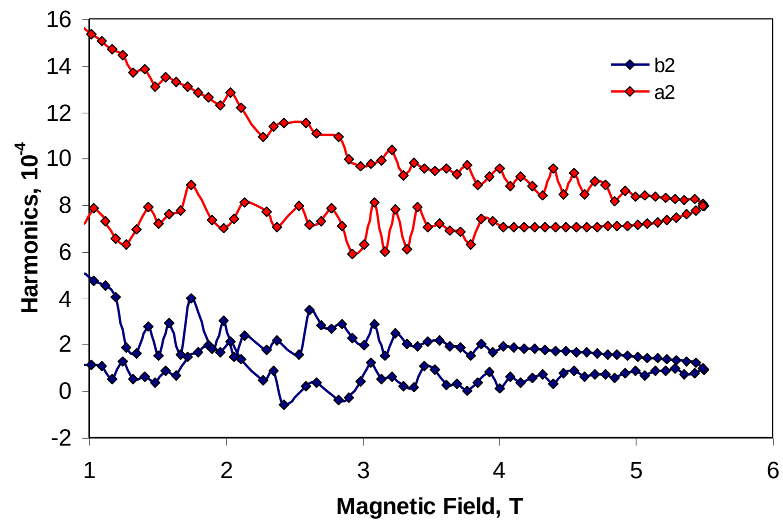


Coil Magnetization Effects

- The persistent current effect is large but reproducible => smaller D_{eff} and passive correction
- FJ in low order harmonics in dipole models => smaller D_{eff}
- Large eddy current components => SS core

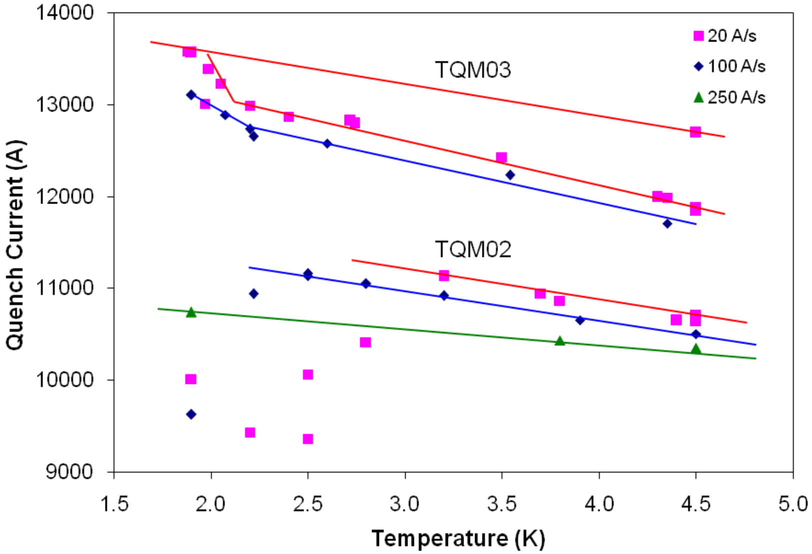


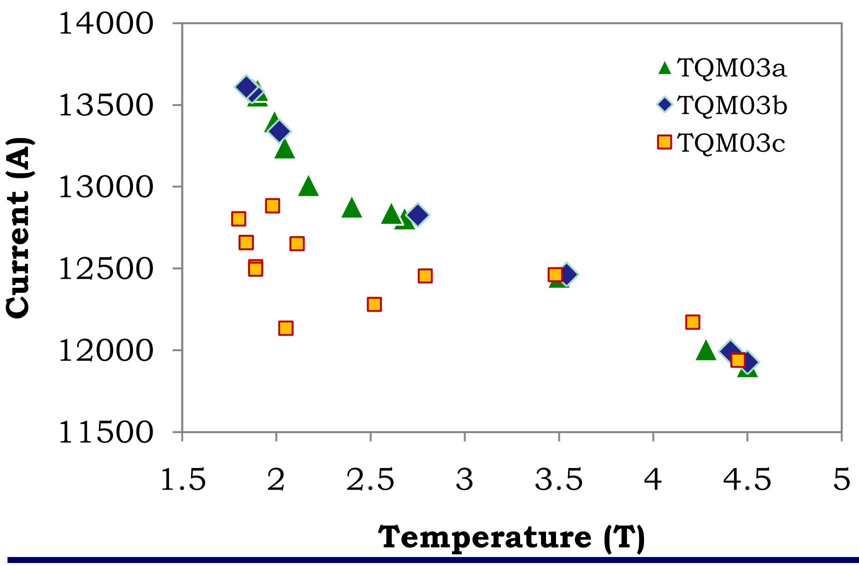


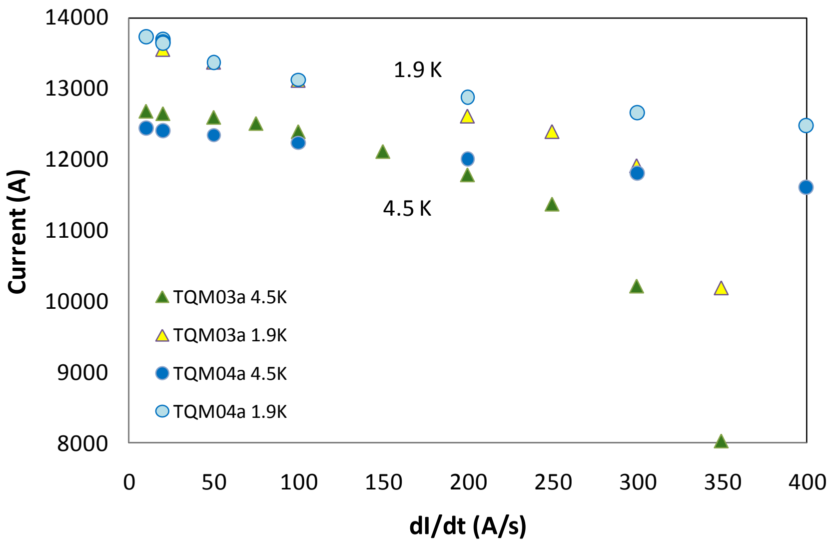


Nb3Sn Coil Studies

CTS	Coil #	Strand	Cable	Insulation	Pole material
TQM01	19	RRP-54/61	w/o core	S2-glass sleeve	Bronze
TQM02	17	RRP-54/61	-"-	S2-glass sleeve	Bronze
TQM03a,b,c	34	RRP-108/127	-"-	E-glass tape	Titanium
TQM04	35	RRP-108/127	25 µm SS core	S2-glass sleeve	Titanium

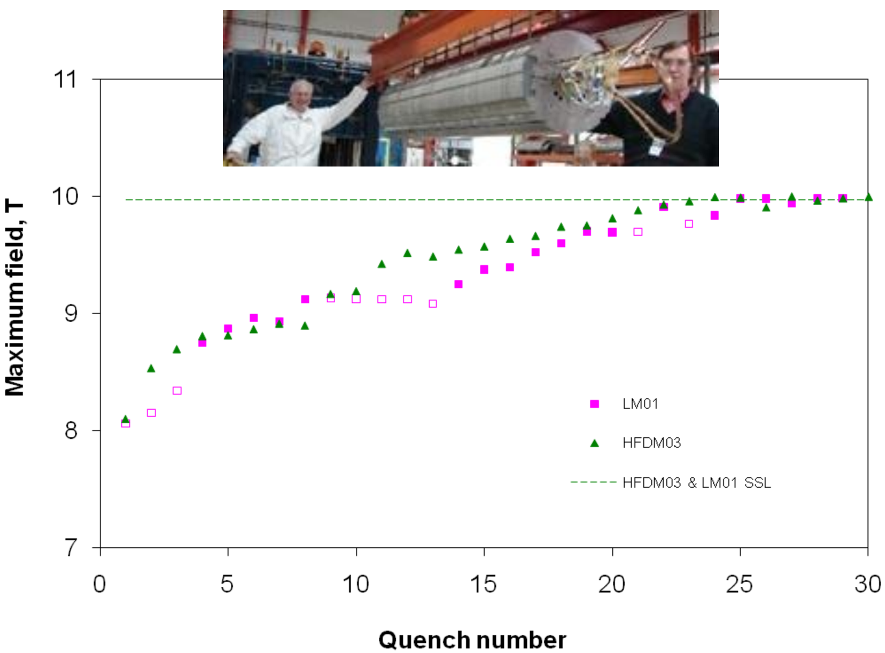


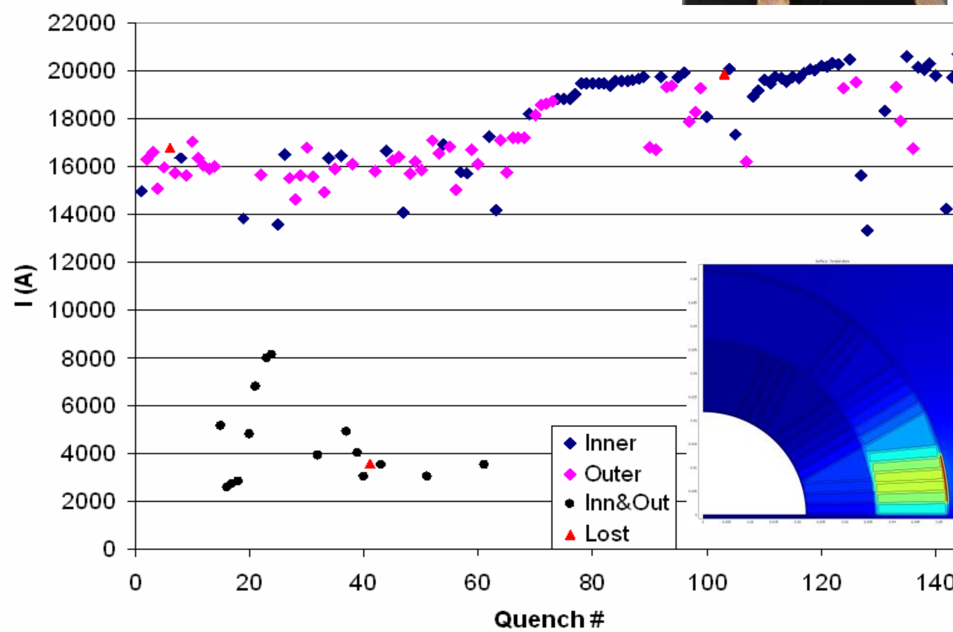




Nb3Sn Technology Scale-up

- 2007: 2-m long dipole coil, 1-mm PIT-196
  - 2-m PIT mirror model reached its SSL
- 2008: 4-m long dipole coil, RRP-108/127
  - 4-m RRP mirror Imax~90% of SSL at 4.5 K (with coil heating to suppress FJ)
- 2010: 4-m long quadrupole coil, 0.7 RRP-114/127



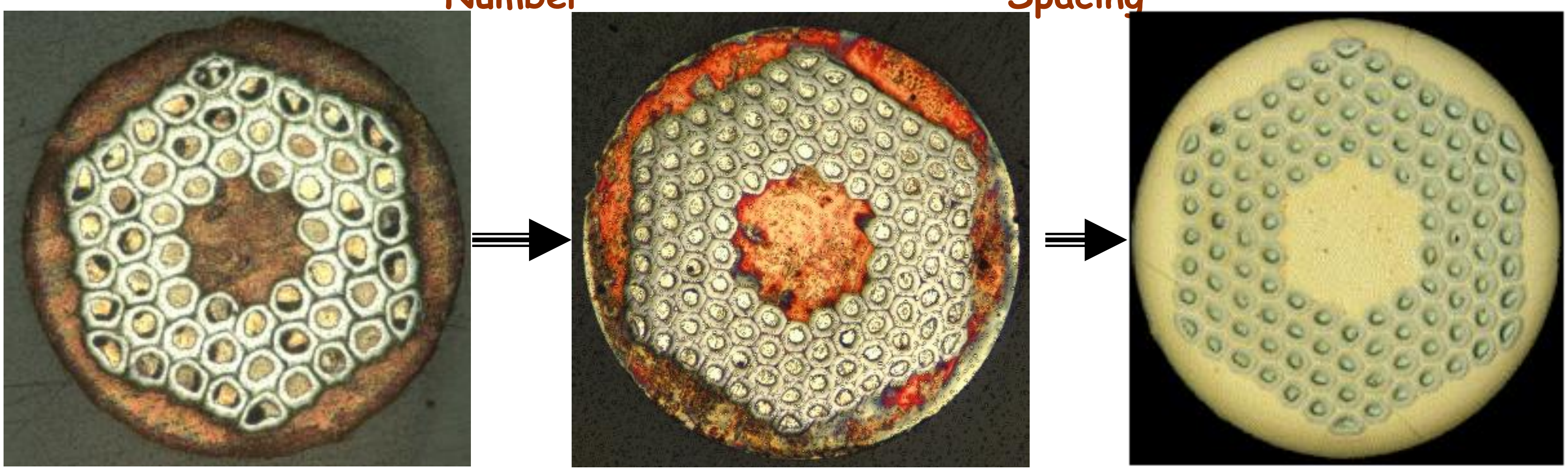


Nb3Sn Strand Improvement

Superconductor properties are critical for magnet quench performance, field quality, etc.

Collaborating with U.S. Industry on Nb3Sn strand optimization

- OST: RRP technology, 150/169 design
- HyperTech Research Inc.: TIT technology, 246+ SE
- Goal: to reduce the SE size without losing Jc, RRR



Nb3Sn Magnet R&D Summary

- Coil production experience:
  - 20 dipole and 35 quadrupole 1-m long coils
    - Good size reproducibility
    - Short fabrication time
  - 2 dipole and 14 quadrupole 4-m long coils
- SS shell-based and collar-based structures were tested
- Collaring of brittle Nb3Sn coils was demonstrated
- Multiple reassembly and test without degradation
- Coil and magnet handling and transportation across the country and Atlantic ocean
- Acceptable quench performance and field quality, room for improvement

The advances made in Nb3Sn accelerator magnet technology during the past decade make it possible for the first time to seriously consider such magnets with Bop<12 T (Bmax<15 T) in present and future accelerators.