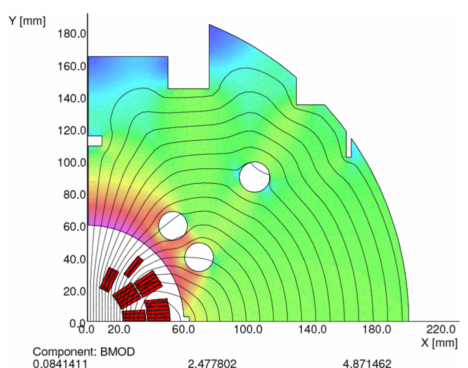
High Field Magnet at Fermilab

SC Magnets R&D

J. Alvarez, G. Ambrosio, N. Andreev, S. Austin, E. Barzi, B. Bordini, R. Bossert, S. Feher, S. Gould, V.S. Kashikhin, V.V. Kashikhin, M.J. Lamm, A. Levy, L. Litvinenko, L. Mokhov, F. Nobrega, I. Novitski, D. Nureczyk, D. Pasholk, E. Ruiz, A. Rusy, D. Turrioni, T. Van Raes, G. Velev, G. Whitson, R. Yamada, and A.V. Zlobin

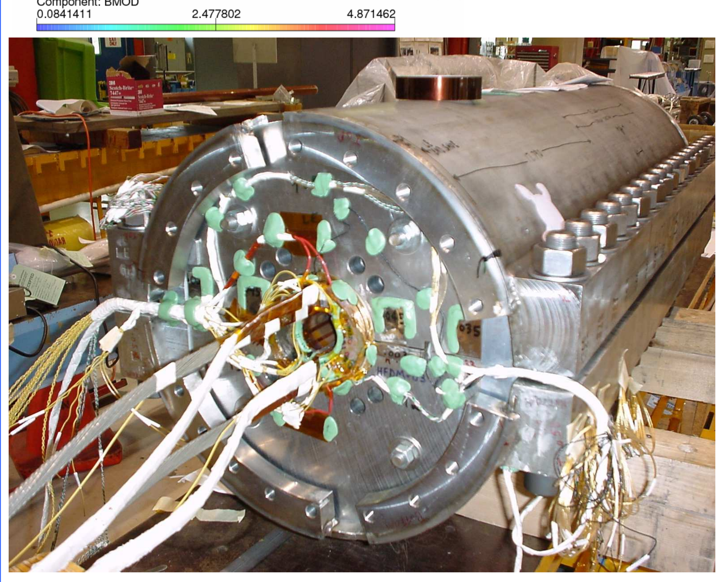
SC magnet R&D is an important part of Fermilab's mission. Present goals are the development of next generation SC *accelerator* magnets for HEP with high operating fields (>10 T at 4.5 K) and large operating margins.

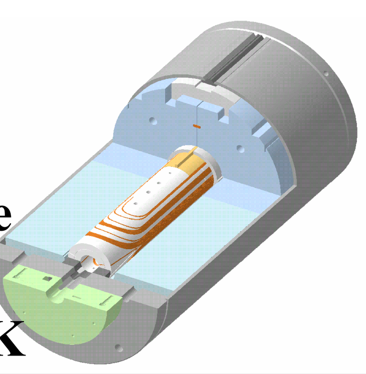
W&R Cos-Theta Dipole Models



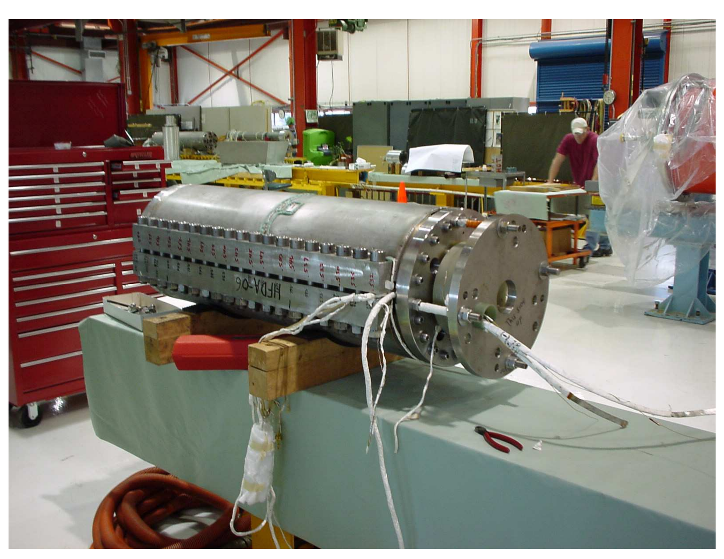
Main design features of our 1-m long cos-theta Nb_3Sn dipole models (HFDA):

- High-Jc 1-mm Nb_3Sn strand
- 28 strand cable
- 2-layer coil with cold iron yoke
- 43.5-mm diameter bore
- Maximum field of 12 T at 4.5 K

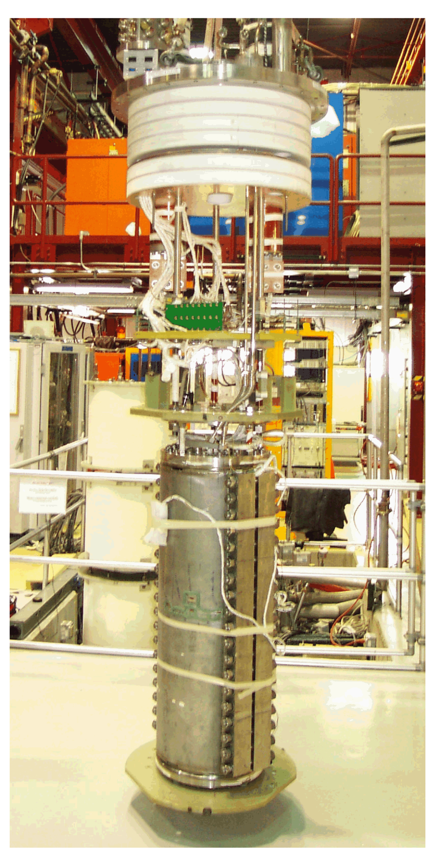




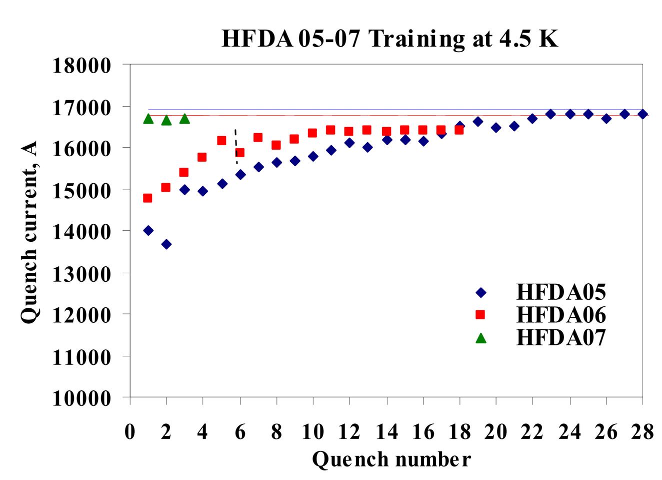
HFDA05 (lead end, before installation of end plate)



HFDA06 ready to be shipped at the test facility (VMTF)



Magnet connection with the top plate completed; ready to be inserted into the dewar and tested

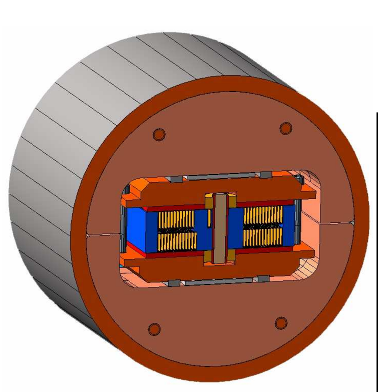


Three cos-theta magnets (HFDA 05, 06, 07) based on a stable Nb_3Sn strands (PIT) were successfully fabricated and tested.

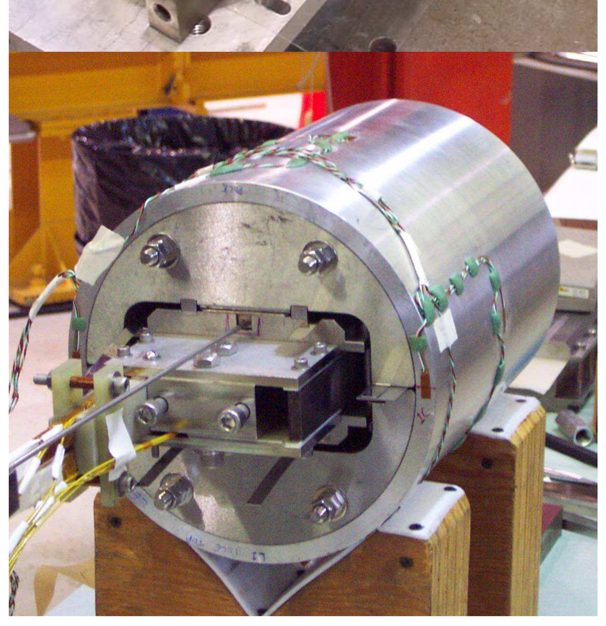
The magnetic field of 10 T has been reached in the Fermilab's dipole design.

The mechanical structure and technology developed for these magnets demonstrated reliable performance at fields up to 10 T.

Cable test with small racetrack



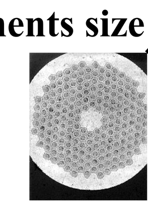
The small racetrack is a compact 2-layer coil (common coil configuration) for testing Nb_3Sn cables in real operation conditions; it implements the main features of Nb_3Sn W&R technology. The mechanical structure, developed at LBNL, is simple and reliable.



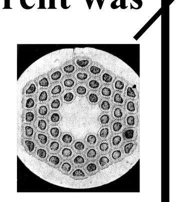
Fermilab small racetrack coil (up) assembled with LBNL-type mechanical structure.

Three cable type were tested in three small racetracks: SR 01, 02, 03.

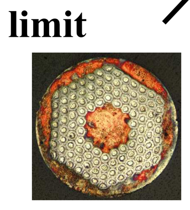
The 28-strand cables developed and fabricated at Fermilab were made of PIT, MJR, and RRP strands 1.0 mm in diameter. SR01, made of PIT strands, reached its the short sample limit at 4.5K. The PIT strand is a stable strand because the sub-elements size is relatively small (~50µm) and its copper stabilizer maintain a good RRR ~130 after cabling.

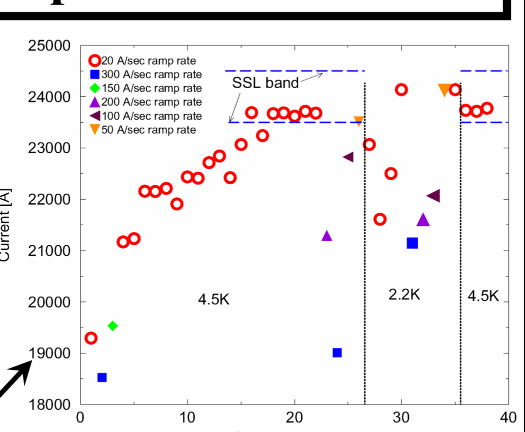


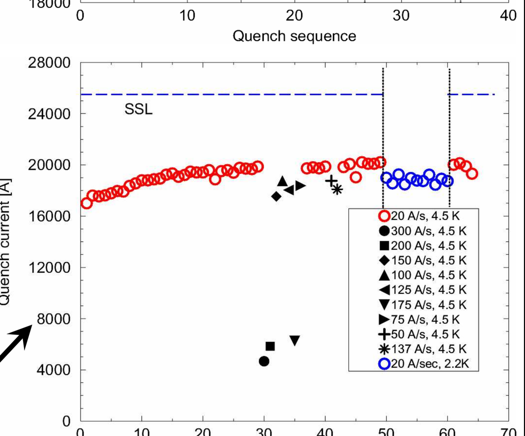
SR02, made of MJR strands, was limited by quenches in the low field region. The MJR strand has a bigger sub-elements (~110µm) than the PIT strand. The quench current was significantly increased with respect to the previous MJR cables (HFDA magnets) thanks to a much higher RRR ~125.

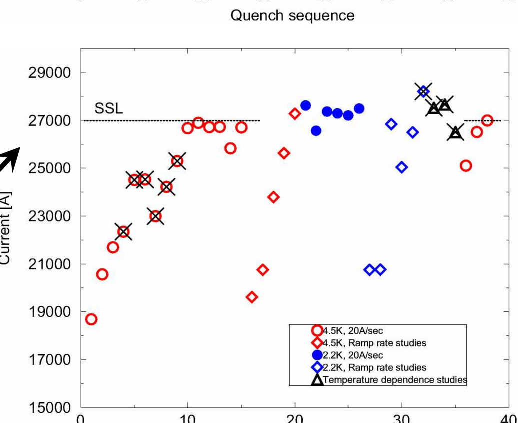


SR03, made of RRP strands with 108 sub-elements, reached its short sample limit at 4.5K. This strand has a sub-elements size of ~70 µm and the cable had a RRR ~140.





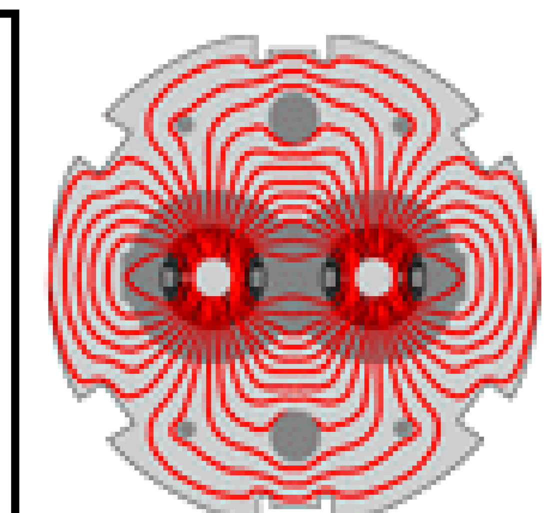




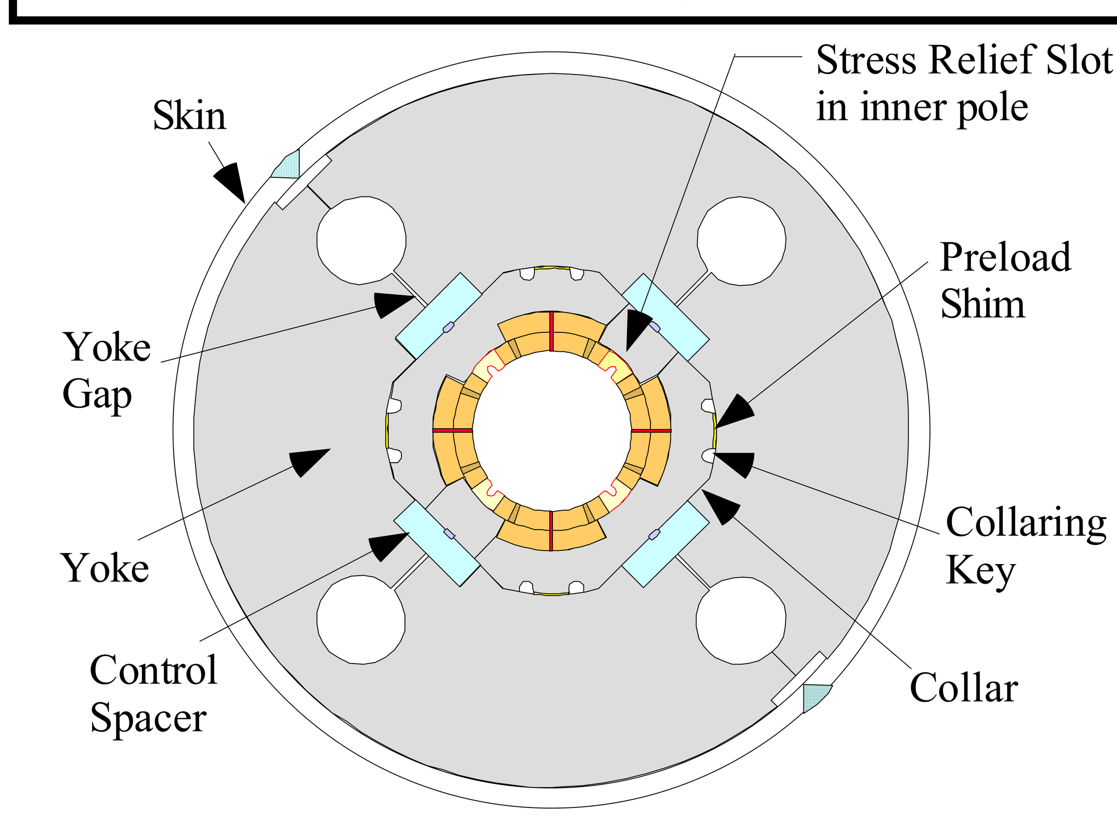
LARP Quadrupole Models

Overall goal of LARP magnet R&D:
To support the development of high performance quadrupole magnets, based on Nb_3Sn technologies, for a possible luminosity upgrade of the LHC.

- TQC magnets are technological quadrupole models based on the *collar-yoke-skin mechanical structure.*
- Design goals:
  - achieve G_{max}>200 T/m;
  - fabricate, test and evaluate 2-layer shell-type coil design without internal interlayer splices;
  - fabricate, test and evaluate mechanical structures based on collar-yoke-skin support;
  - develop and evaluate coil fabrication and magnet assembly technologies.
- Performance study:
  - magnet quench performance: training, re-training, SSL;
  - field quality: geometrical harmonics, coil magnetization, iron saturation, alignment, field quality correction;
  - quench protection: conductor parameters, quench heaters.

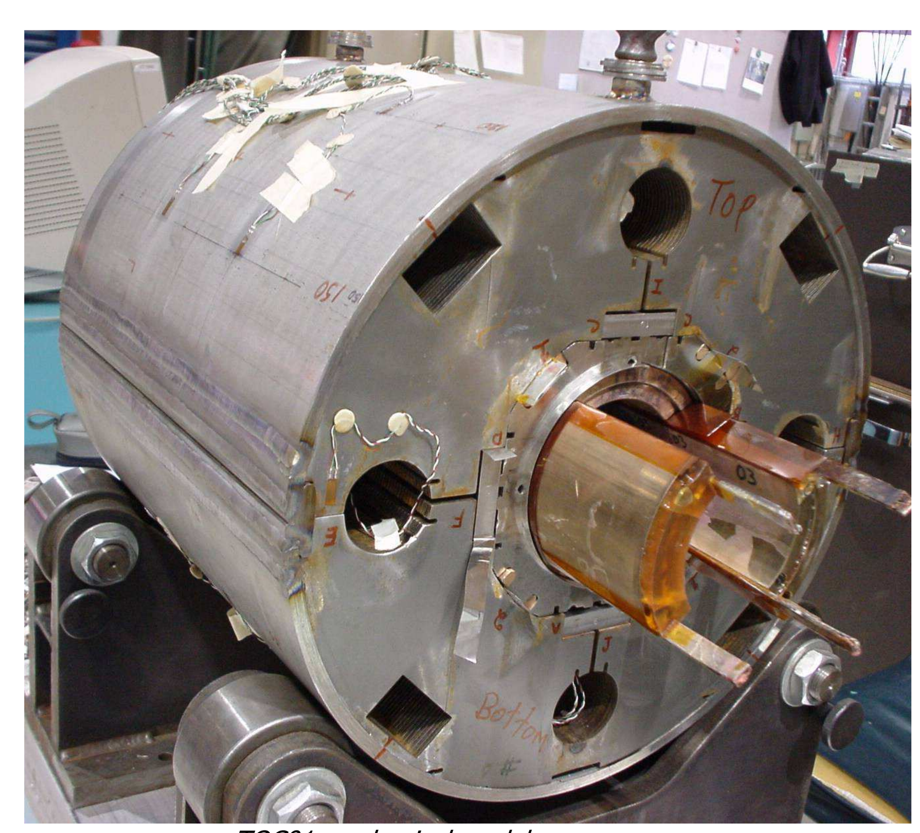


LARP

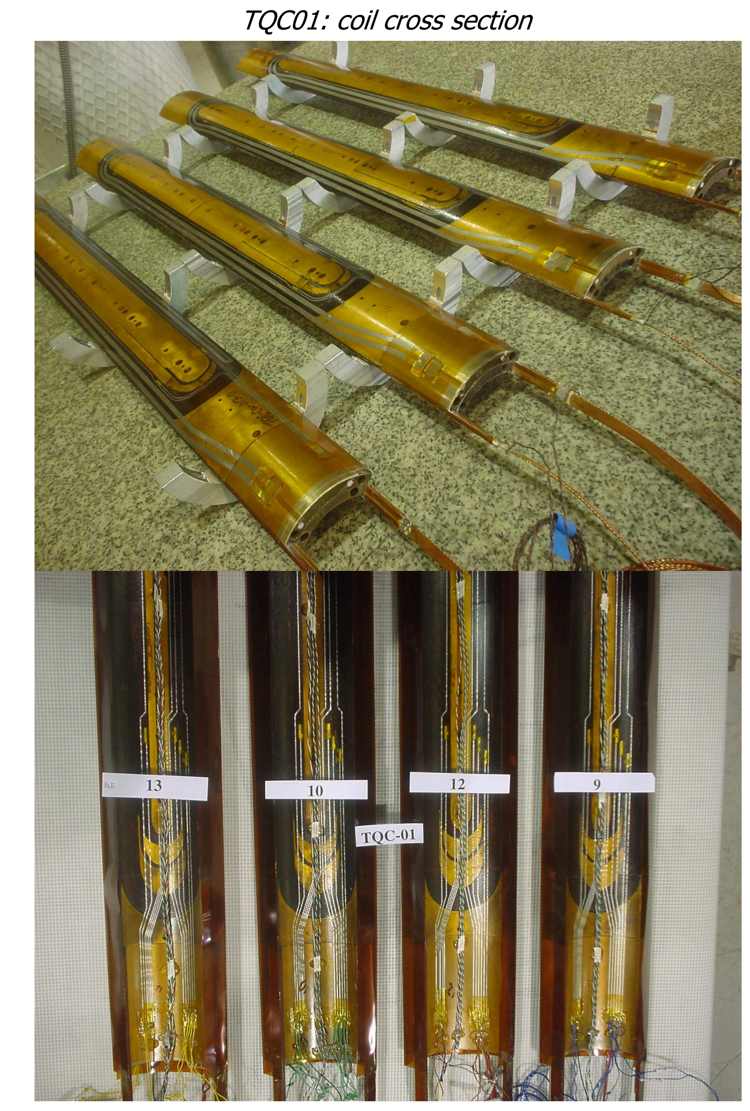


TQC01 cross section

TQC01: coil cross section



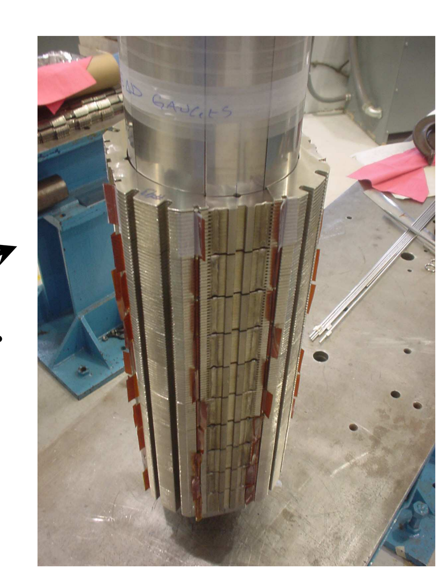
TQC01 mechanical model

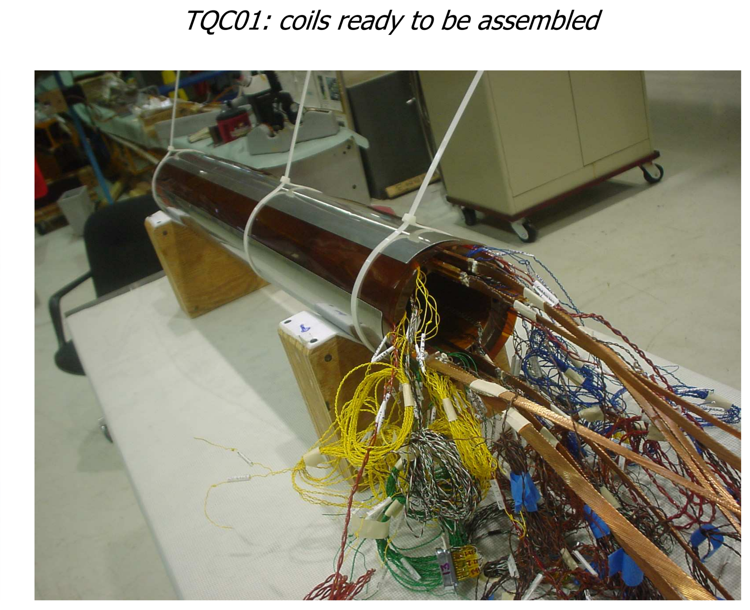


TQC01: coils ready to be assembled

Right now we are collaring the TQC01coils.

Following the success of the TQ short models, higher gradient and longer magnets will be needed.





TQC01: 4 coils assembled together

Fermilab

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SC Strand and Cable R&D

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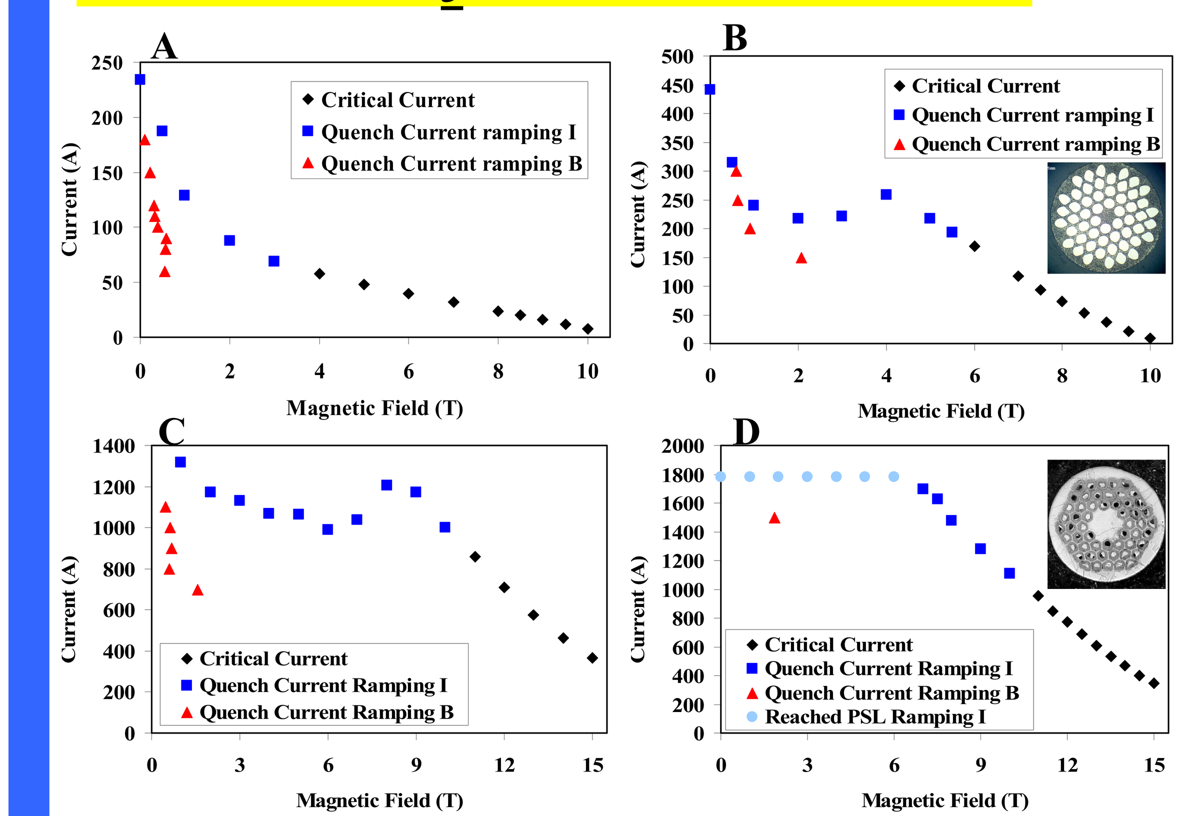
NbTi and Nb_3Sn instability studies

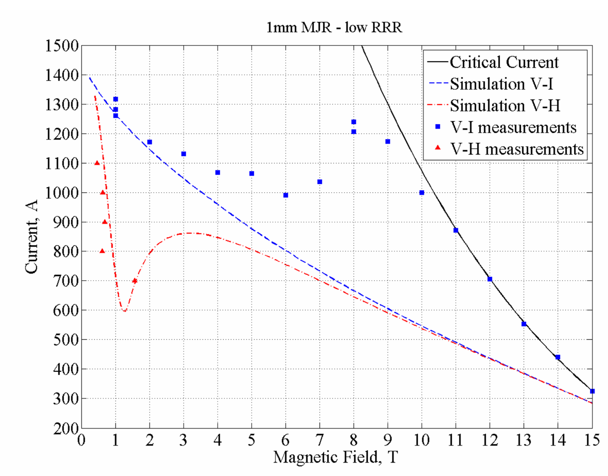
TESTED SAMPLES

	SC	Strand	Φ	Filaments	Matrix	Jc
A	NbTi	SUPERCON	0.3mm	1 (185μm)	Cu	1860A/mm² (5T)
B	NbTi	OST	0.5mm	54 (46μm)	CuNi	2600A/mm² (5T)
C	Nb_3Sn	OST-MJR	1mm	54 (110μm)	Cu (RRR 7)	1830A/mm² (12T)
D	Nb_3Sn	OST-MJR	1mm	54 (110μm)	Cu (RRR 130)	2000A/mm² (12T)

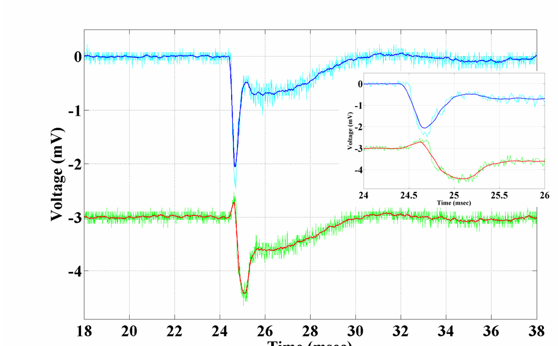


Quench current of samples: A,B,C,D

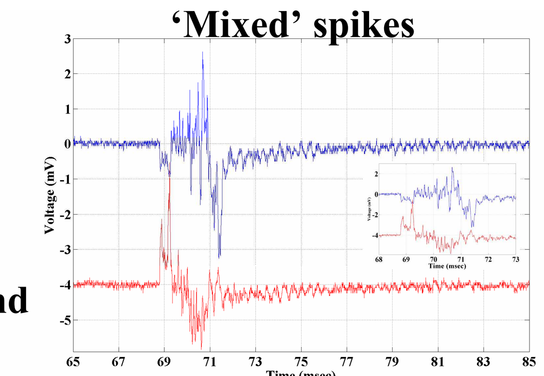
The sample A is self field stable and strongly affected by magnetization instability. The samples B and C are self field unstable and the magnetization energy further reduces the I_q. The sample D is more self field stable than sample C because of the better thermal and electrical conductivity of the Cu matrix.

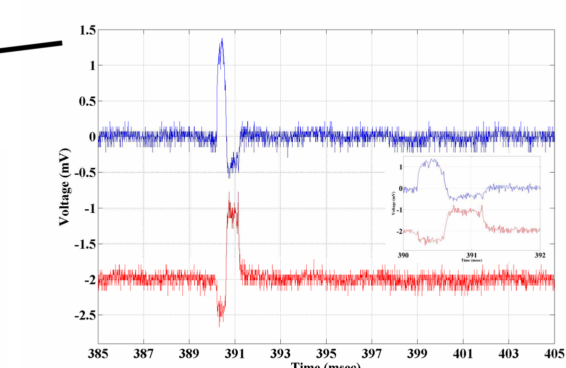


Two type of spikes, 'magnetization' and 'transport current' spikes, have been identified. Their origin is most likely related to the magnetization and self field instabilities respectively. Many of the signals observed are a combination of these two types of spikes and the combination of these two instability mechanisms is probably the cause of the minimum quench current. While ramping the magnetic field, quenches are always triggered by voltage spikes



'Magnetization' spikes are negative if the sample is negatively magnetized and positive if it is positively magnetized.

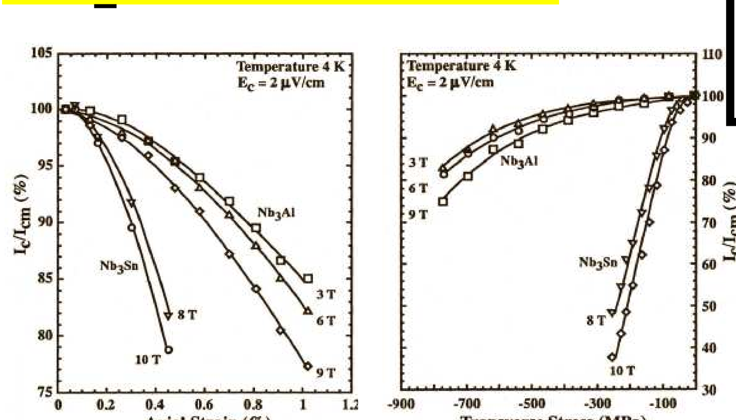


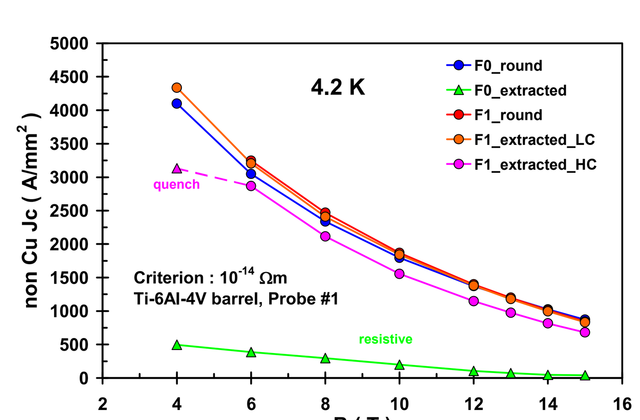


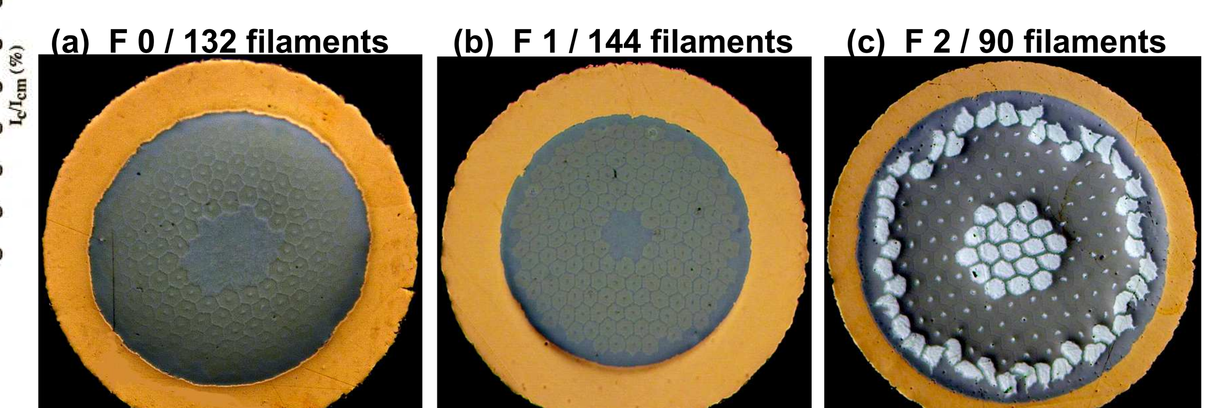
'Transport current' spikes are always positive.

Nb_3Al Development

Fermilab is collaborating with the NIMS (Japan) for the development of the Nb_3Al superconducting wires. This material has a better strain tolerance respect to Nb_3Sn and it is an interesting candidate for use in high field accelerator magnets



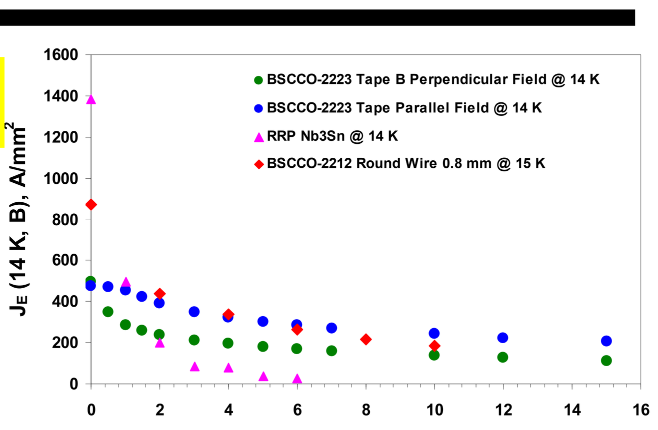


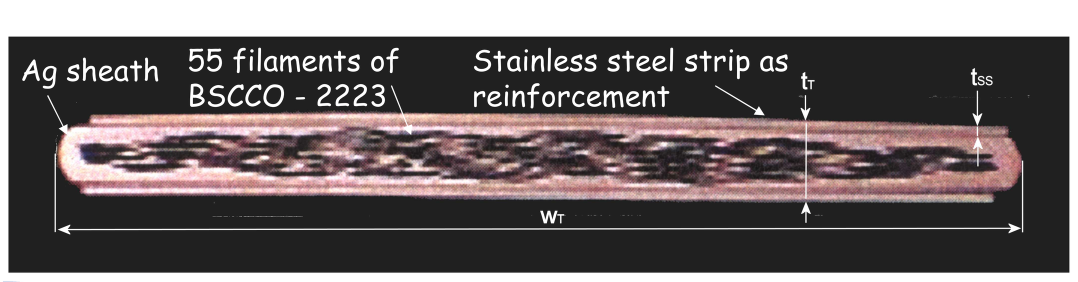


Strand ID	Area Reduction after RHQ, %	Surface Cleaning (anode oxidation process)	Ann. after Cu plating	Stabilization Type	Stabilizer Ratio, %	Strand Size, mm	Filament Number	Filament barrier	Filament Dia. μm	Total Strand Length, m	Arrival Date
F 0	73.1	NO	400 °C (air)	External Cu	50.0	1.03	132 / SC 19 / Nb dummy	Nb	50.0	240 (one peace)	11/14/05
F 1	70.8	YES	400 °C (air)	External Cu	50.0	1.03	144 / SC 7 / Nb dummy	Nb	50.0	1,250 (one peace)	02/18/06
F 2	58.2	YES	400 °C (N_2)	Internal Ag External Cu	26.3 / Ag 21.1 / Cu	1.00	90 / SC 61 / Ag stabilizer	Nb	56.0	600	04/13/06

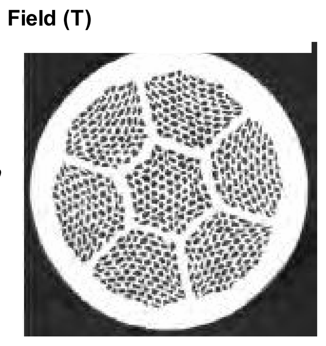
High Temperature Superconductors - BSSCO

Fermilab is collaborating with MUONS, inc for using HTS in high field superconducting magnets in order to realize a helical muon cooling channel.



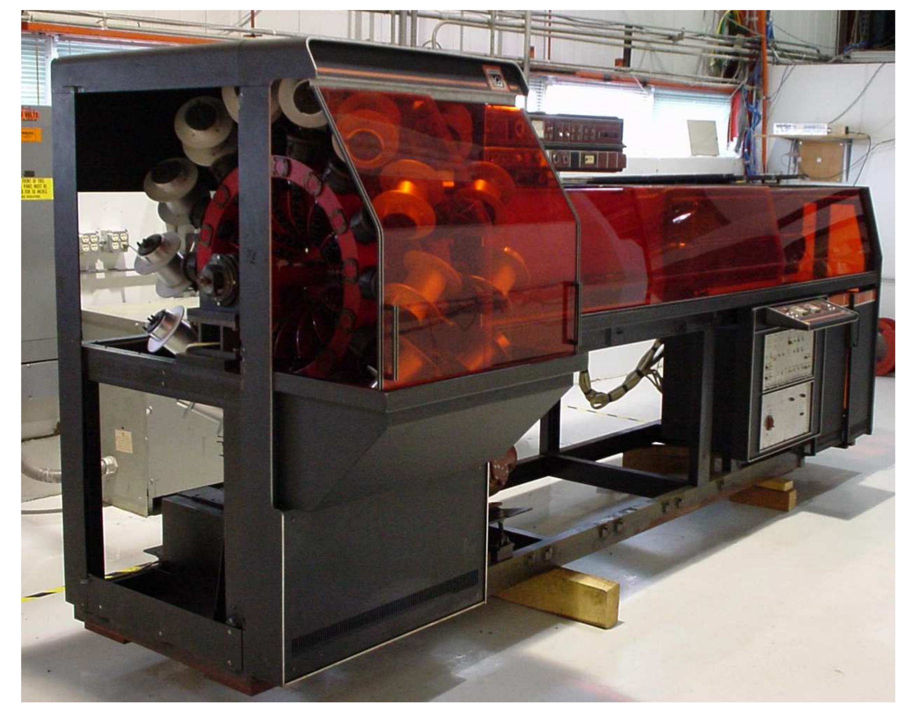


High strength BSCCO-2232 tape



BSCCO-2212 round wire

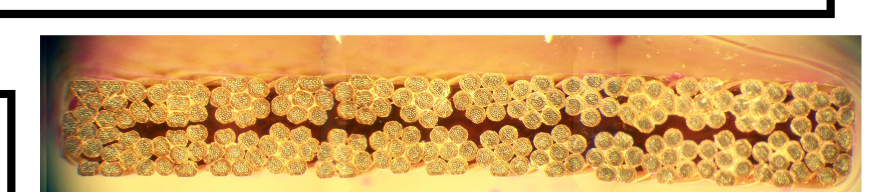
Cabling Machine and SC cables fabricated at Fermilab



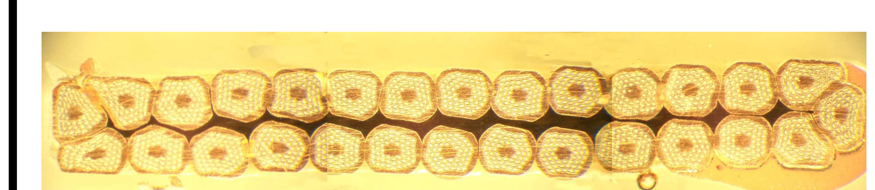
Last year the cabling machine was upgraded to fabricate cables with up to 42 strands. The strand diameters can be 0.3–1.5mm and the cable transposition angle 8–16 degree.

Cables made at Fermilab:

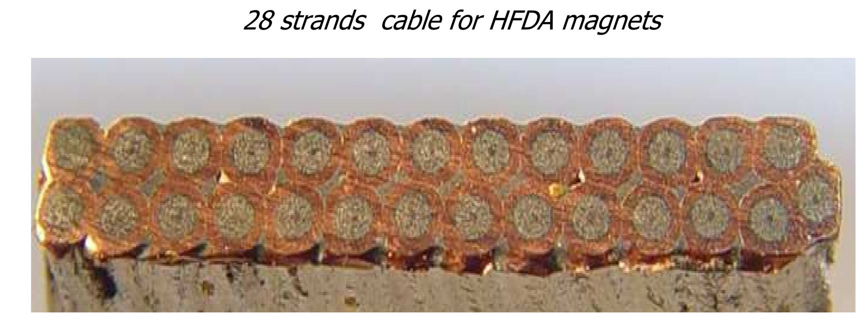
- **HFDA/M models & Small Racetrack cables:**
  - **number of strands 27-28**
  - **strand diameter: 1mm;**
  - **materials: PIT, MJR, RRP, NbTi.**
- **R&D cables:**
  - **number of strands 27-39, 28*7;**
  - **strand diameter: 0.7-1 mm;**
  - **materials: Cu, NbTi, Nb_3Sn, Nb_3Al.**



28*7 strands cable

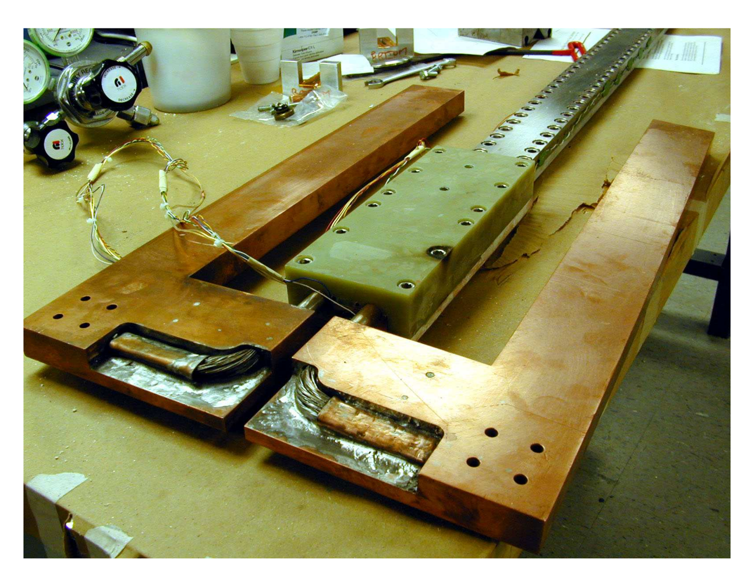


28 strands cable for HFDA magnets



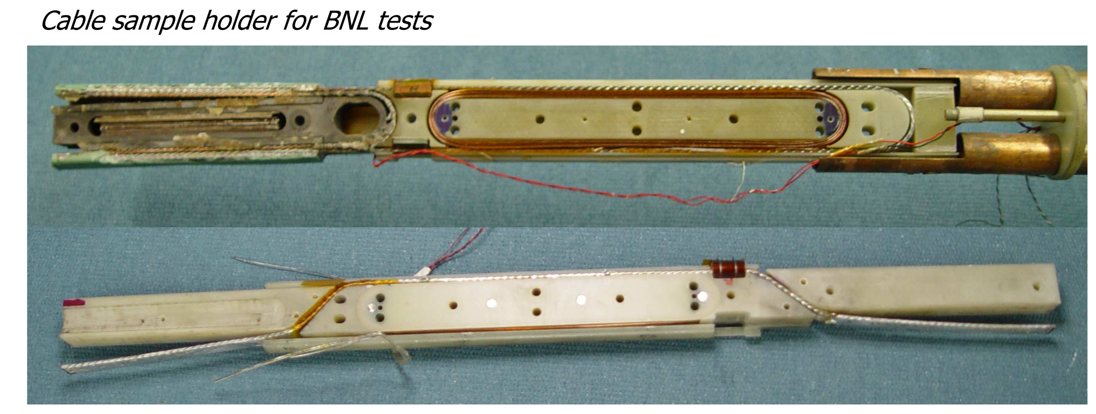
27 strands cable for first Nb_3Al small racetrack

Cable tests

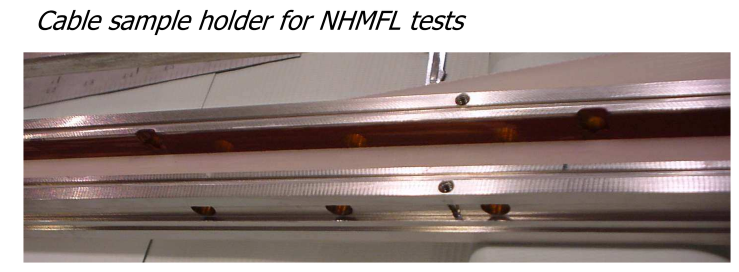


Cable sample holder for NHMFL tests

Cable sample holder for BNL tests

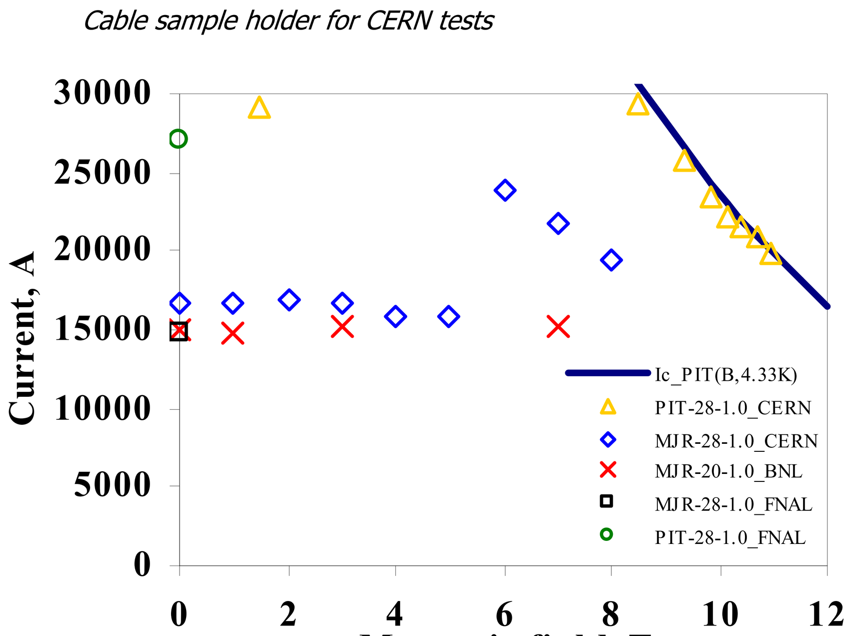


Superconducting transformer for cable test at Fermilab

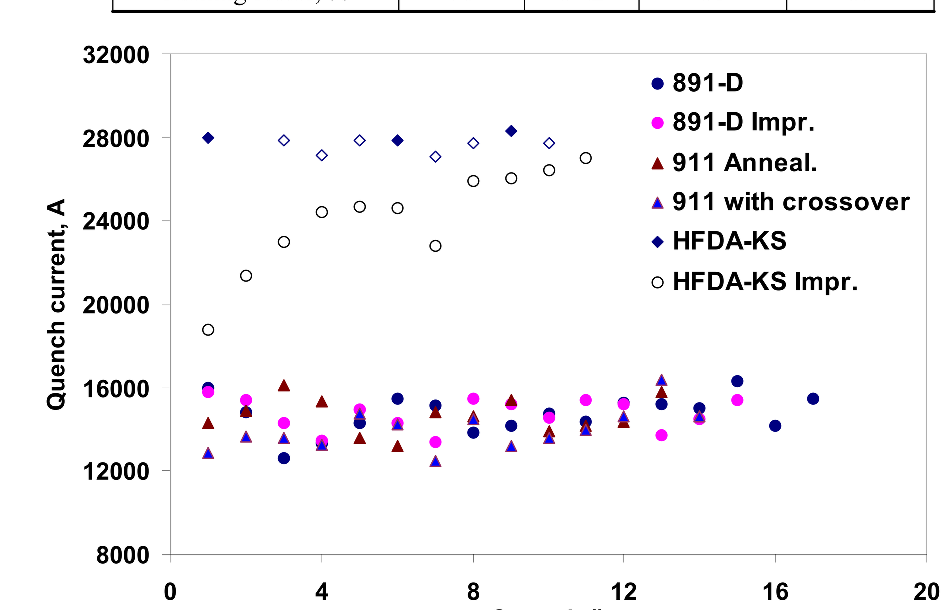


Cable sample holder for CERN tests

Cable ID	891-D	911	HFDA-RC	HFDA-KS
Billet ID	7054-60	7054-60	8197-97	8197-97
No. of strands	39	39	27	27
Strand diameter, mm	0.7	0.7	1.0	1.0
Cable cross-section	Keyst.	Keyst.	Rect.	Keyst.
Packing factor, %	90	87.2	81	86



Comparison of cables test results performed in different labs



Cables test results using the superconducting transformer

Fermilab