LARP

BNL -FNAL - LBNL - SLAC

U.S. LARP Magnet Programme

P. Wanderer

IR'07 - Frascati

7 November 2007

Progress: 2003 - 2007

Goal: Demonstrate "long strong" Nb_3Sn quad by the end of 2009
Focus: develop "building blocks" for Nb_3Sn magnets

- Materials: high current, stable Nb_3Sn conductor
- Model Magnets: 200 T/m, two support structure designs
- Supporting R&D: early development of long (3.6 m) Nb_3Sn coils with racetrack coils and one of the support structures; insulation, quench protection, cooling …
- IR Design Studies: magnet designs for possible IR optics (e.g., dipole first), magnet designs for larger aperture/ higher gradient quadrupoles

Plans: 2007 - 2009

Goal: Demonstrate "long strong" quad by the end of 2009

LQ (long quad): working to build, test 1-3 3.6 m, 90 mm quads by the end of 2009; support structure review at the end of November. Highest LARP magnet priority

Materials: increase Nb_3Sn strand diameter, improve understanding of strain sensitivity.

HQ (high gradient/aperture) : design, build 130 mm aperture quads $\Rightarrow$ use in Phase I (2012)??

JIRS (Joint IR Studies): joint magnet, accelerator studies, first priority: Phase I upgrade

LARP

This talk:

Materials

Model Magnets

Next talks:

HQ – G. Sabbi

LQ – G. Ambrosio

JIRS – A. Zlobin

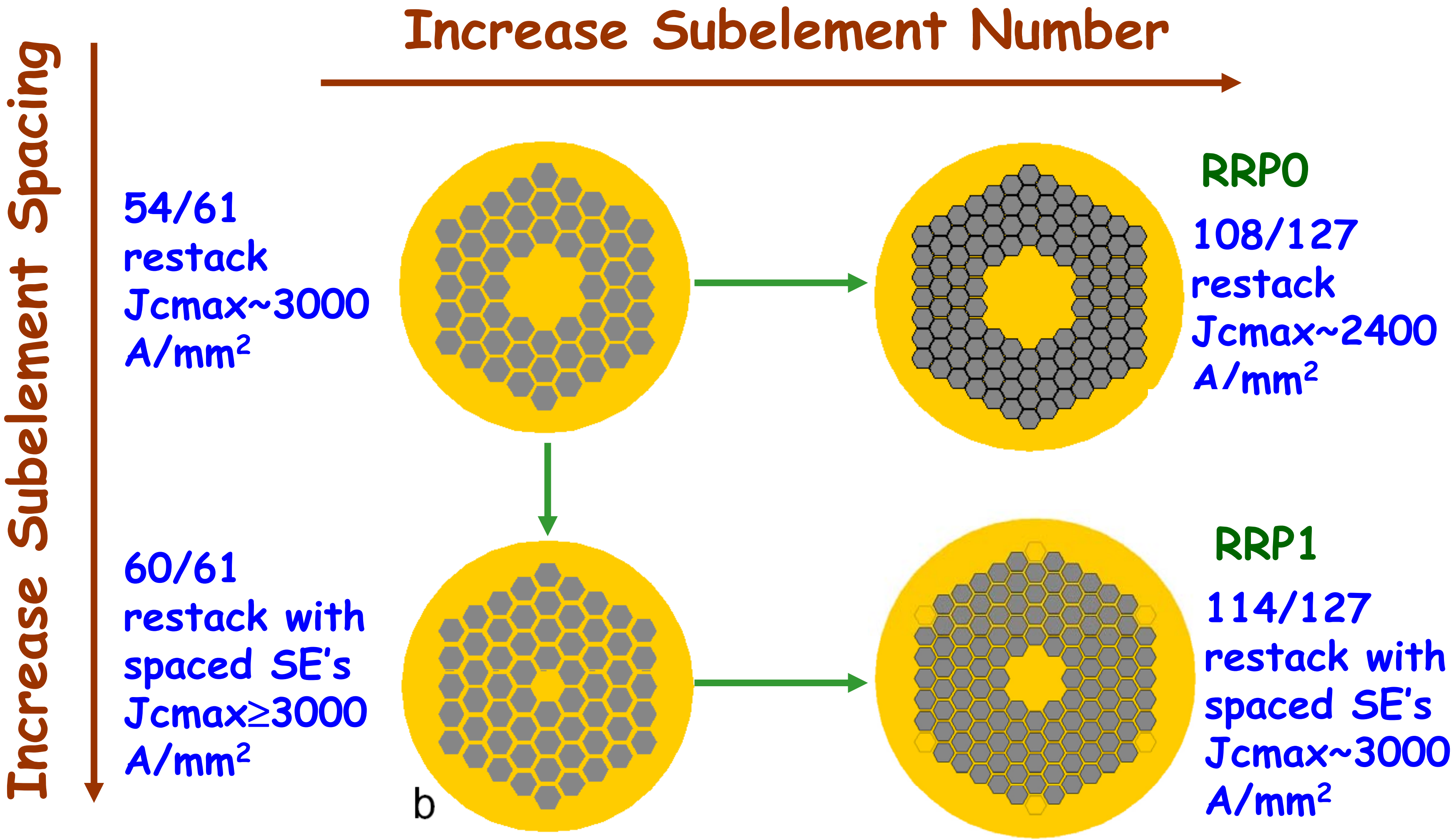
MATERIALS – STATUS AND PLANS

Nb_3Sn conductor developed to yield current-carrying capacity and magnet stability suitable for 200 T/m, 90 mm aperture quads. This material, called RRP, is now a "standard product." (US DOE Conductor Development Program, lab "base" programs helped.)

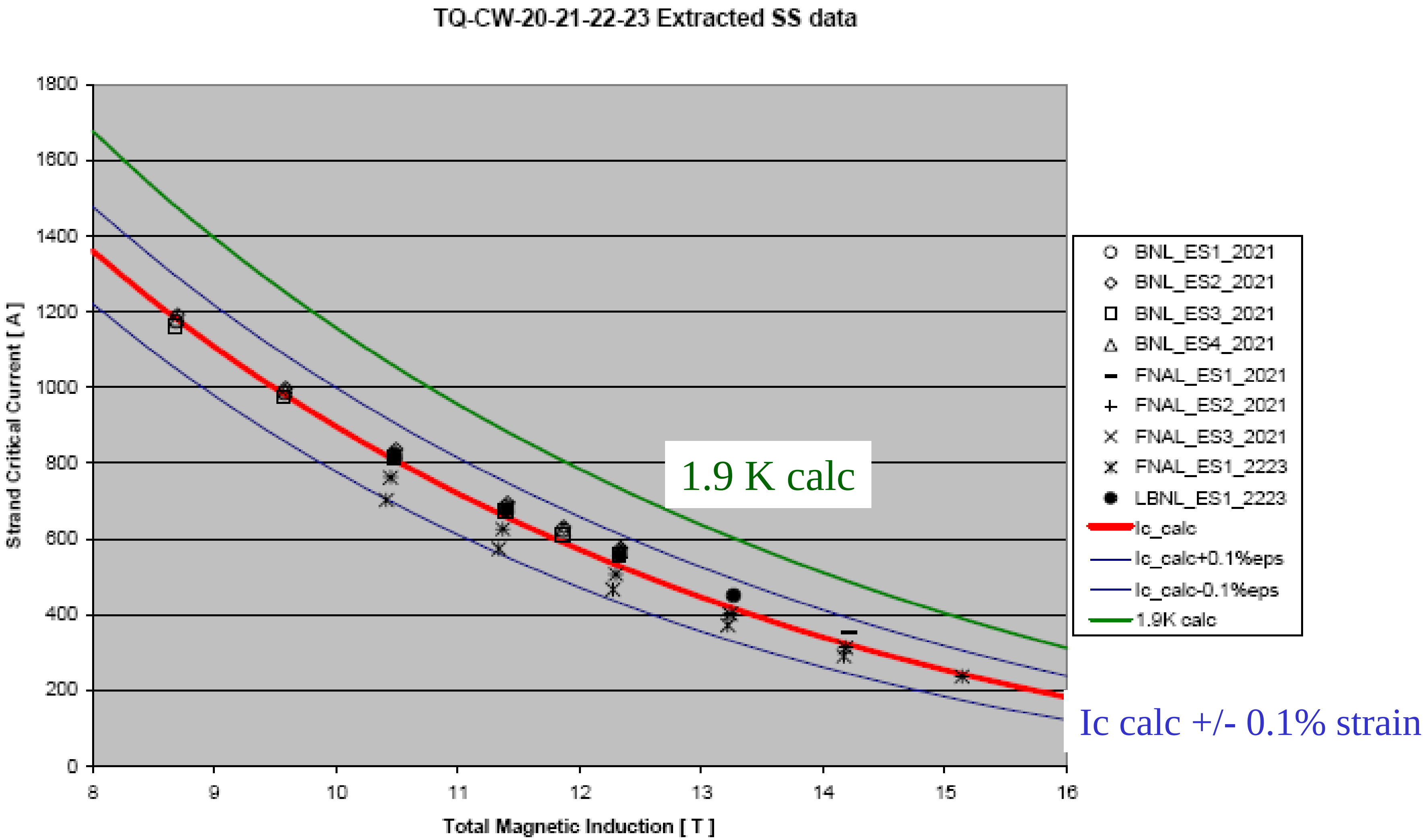
Next steps:

- Develop larger-diameter strand (needed for larger magnets)
  - this requires more, smaller filaments
- Test cables (as opposed to testing "extracted" strands)

RRP Strand Development with OST (Fermilab)



TQ Data: BNL-FNAL-LBNL



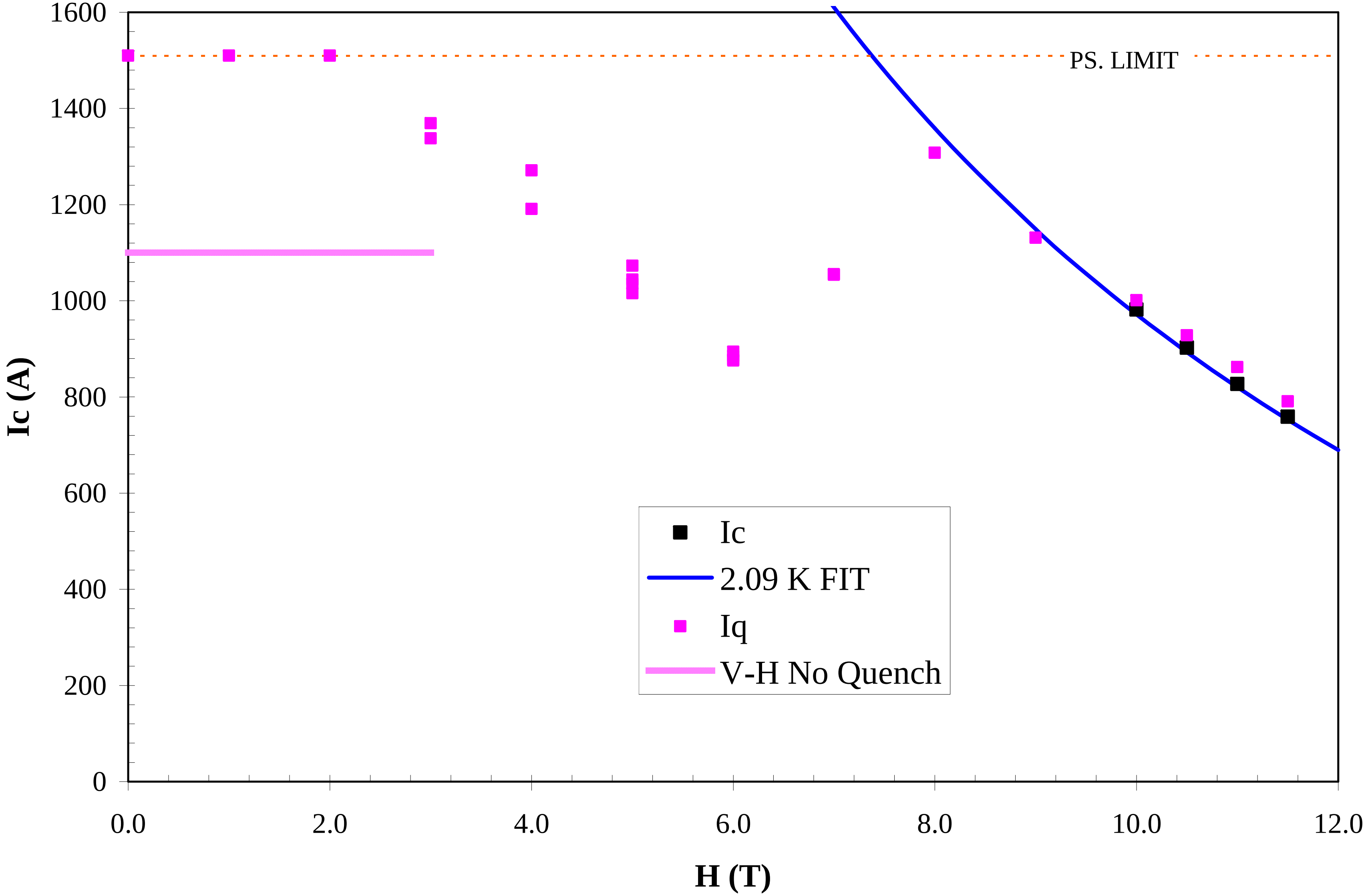
Strand Production

	54/61 kg	114/127 kg	MAGNET	Strand Req. kg	Inventory of 54/61 kg		54/61 kg	114/127 kg	MAGNET	Strand Req. kg	Inventory of 54/61 kg	Inventory of 114/127 kg
Oct-05	33		SR01	7	26	Oct-07					186	0
Nov-05	70				96	Nov-07					186	0
Dec-05					96	Dec-07		80			186	80
Jan-06					96	Jan-08					186	80
Feb-06					96	Feb-08		100	LQ02	165	186	15
Mar-06	90		TQC02	40	146	Mar-08					186	15
Apr-06			LRS01-C01	27	119	Apr-08					186	15
May-06	90		TQC02-R	35	174	May-08					186	15
Jun-06			TQS02	35	139	Jun-08		90			186	105
Jul-06					139	Jul-08					186	105
Aug-06					139	Aug-08		110	HQ01	165	186	50
Sep-06			LRS01-C02, SQ	36	103	Sep-08					186	50
Oct-06					103	Oct-08					186	50
Nov-06					103	Nov-08		200	FNAL	85	186	165
Dec-06	30		LQM01	37	96	Dec-08					186	165
Jan-07	90				186	Jan-09			CDP	180	6	165
Feb-07	30				216	Feb-09					6	165
Mar-07					216	Mar-09					6	165
Apr-07	50		LRS01-C03	30	236	Apr-09					6	165
May-07					236	May-09					6	165
Jun-07			SQ03		236	Jun-09					6	165
Jul-07					236	Jul-09					6	165
Aug-07			PCX01	0	236	Aug-09					6	165
Sep-07	150				386	Sep-09					6	165
Oct-07			LQ01, LQM02	200	186	Oct-09					6	165

60kg R&D Stock, only used for practice coils.

PC: Practice coil for LQ coil winding

RRP-8648, 0.7 mm RRR ~ 310 (2.09K)



LARP

Model Quadrupole Program

Technology Quadrupoles (TQ)

1 m long, 90 mm aperture

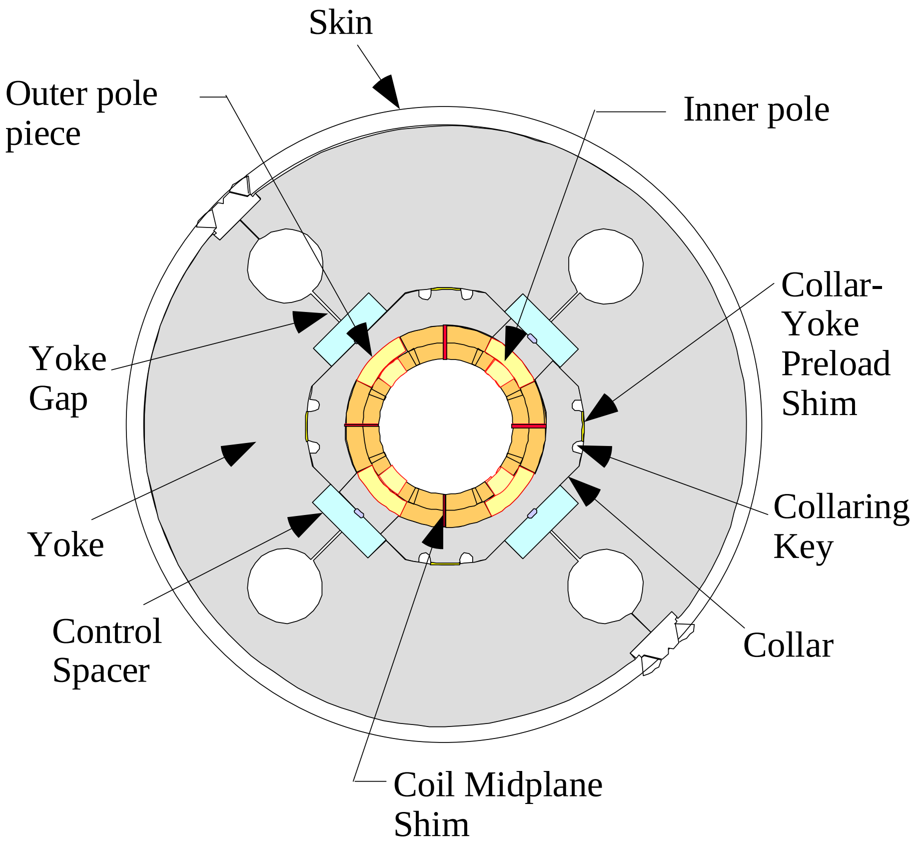
Coils made jointly by Fermilab and LBNL

Support structure options:

TQC: "collar" support

TQS: "shell" support

TQC Mechanical Structure



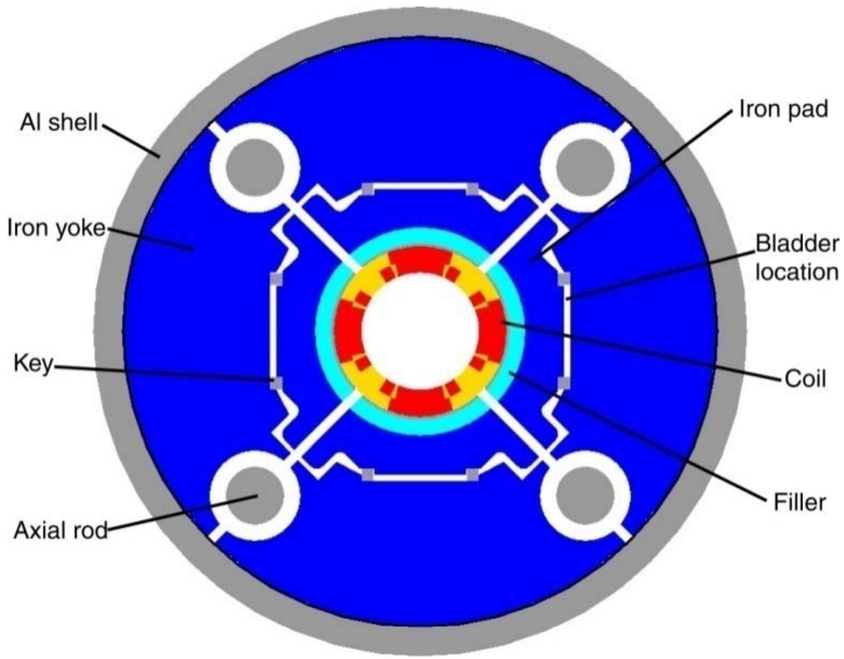
Azimuthal preload applied via collars and via shell.

Axial preload keeps coil ends in (light) contact with structure

TQS Mechanical Structure

Azimuthal preload applied via inflatable/removable bladders and keys.

Axial preload high (via rods)



Quench test: same coils in both structures:

Initial test: TQS02

Subsequent test: TQC02E (E = exchange)

note: RRP conductor

Results:

Both quads reached ~ 90% of the expected maximum performance of the conductor at 4.5 K (no correction for reduction in current-carrying capacity for strain)

Their gradients differ because the ratio G/I is not the same.

Neither magnet improved at 1.9 K. This is not yet understood.

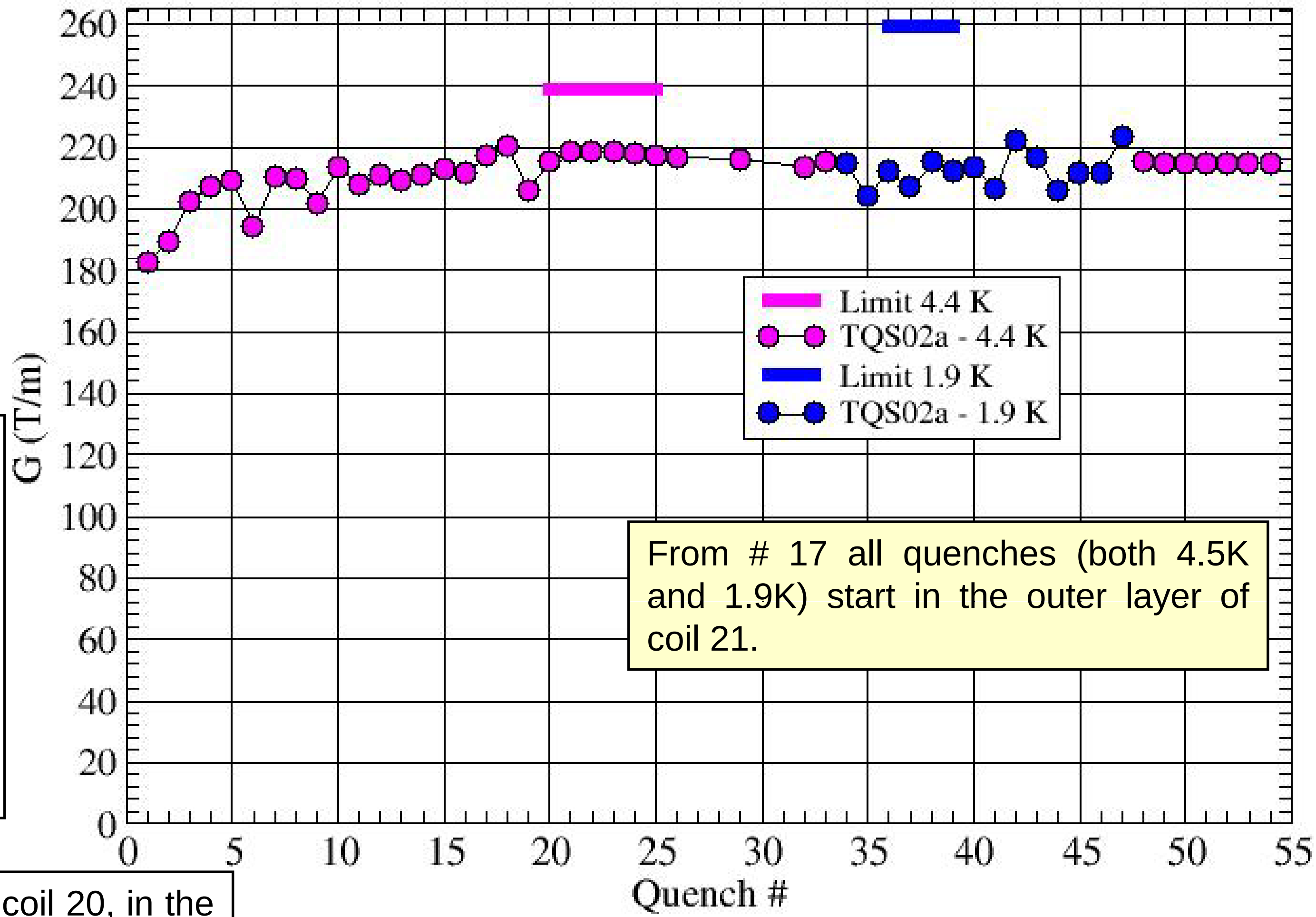
TQS02a Training

TQS02a

180 to 220 T/m, 20 quenches

Plateau coil 21 layer 2

No gain at 1.9 K

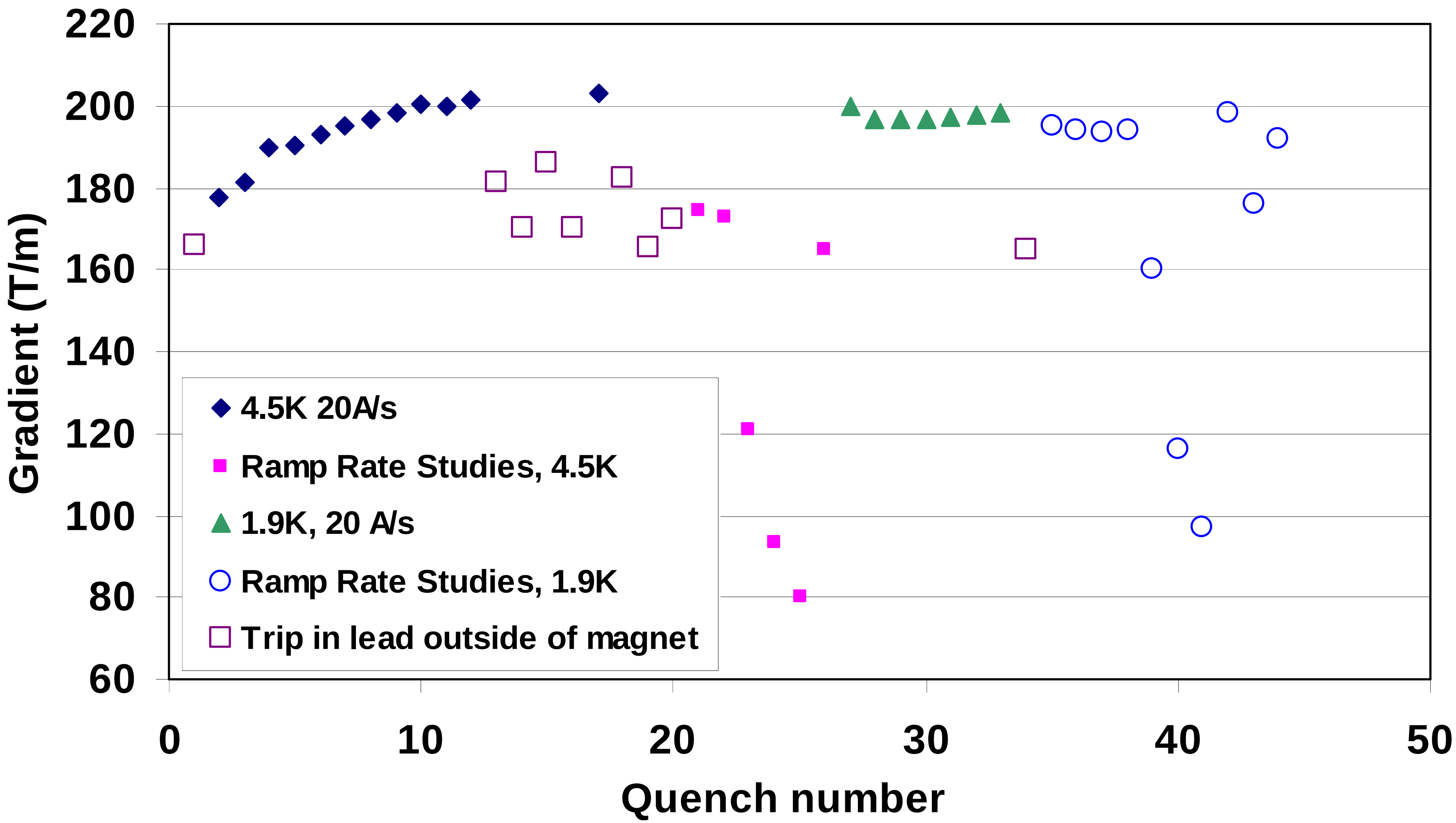


From # 17 all quenches (both 4.5K and 1.9K) start in the outer layer of coil 21.

Quench 1: inner layer pole turn, ramp and multi-turn
Quench 2-3: outer layer multi-turn followed by return end.
Quench 4: inner layer pole turn and multi-turn segment inside wedge.
Quench 5-6: outer layer multi-turn followed by pole turn.

Quench 8 to 16, inner layer of coil 20, in the turns inside the wedge.

TQC02E Quench Behavior



LARP

Quench data - two additional model quads (TQ)

TQS01a,b,c

- Three tests varying coils (i.e., replace the worst performing coil) and end preload. MJR ("old style" conductor)
- Result: reached ~ 90% of conductor limit at 4.5 K, did not advance much beyond this at 1.9 K.

TQC01a,b

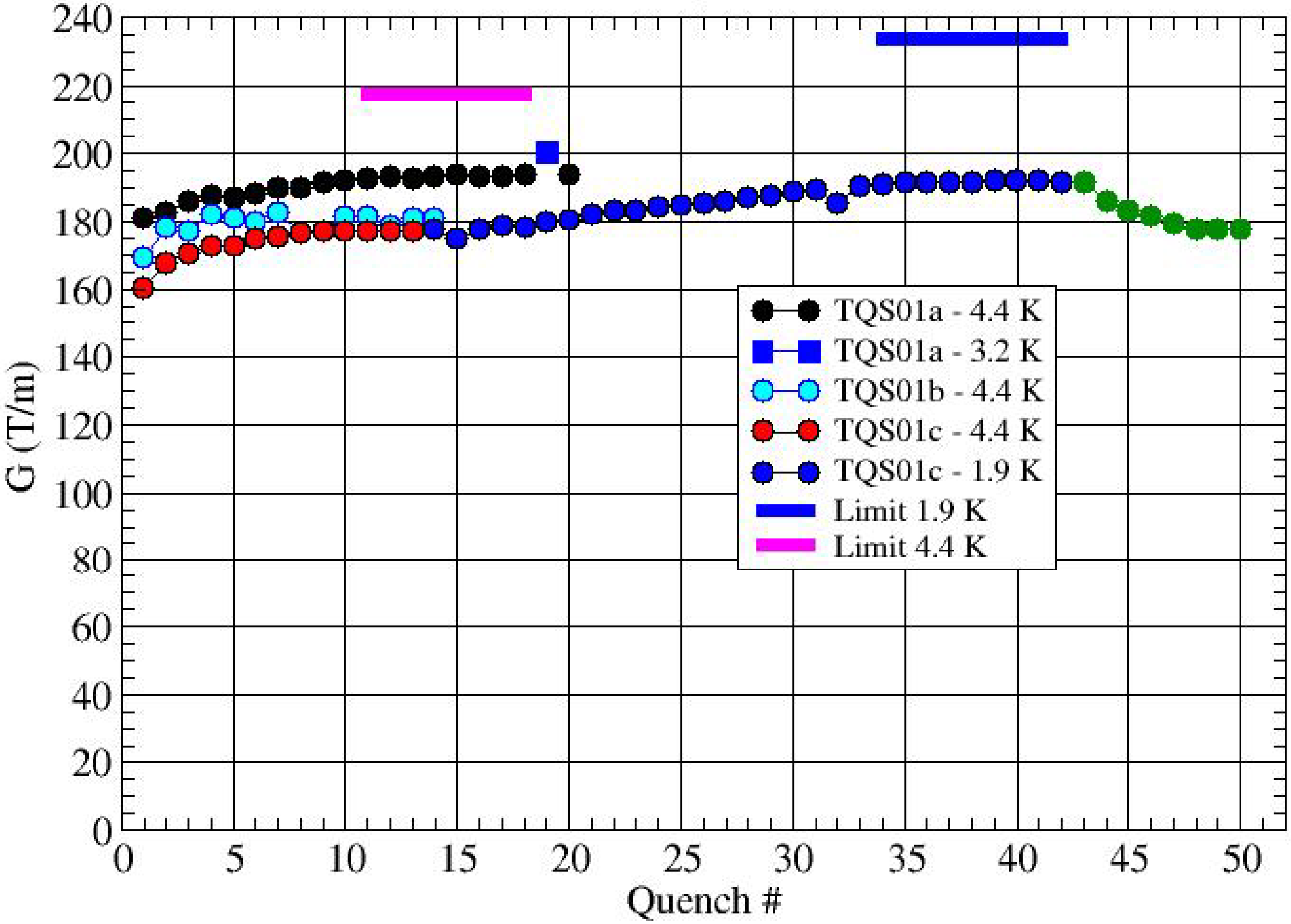
- Two tests varying coils (in second test 2 limiting coils were replaced with 2 TQS coils tested 3 times). MJR strand.
- Result: first test with very low pre-stress reached ~70% of conductor limit at 4.5K and ~86% at 1.9K, second test reached ~ 85% of conductor limit at 4.5 K and ~ 90 % at 1.9 K.

TQS01 Training

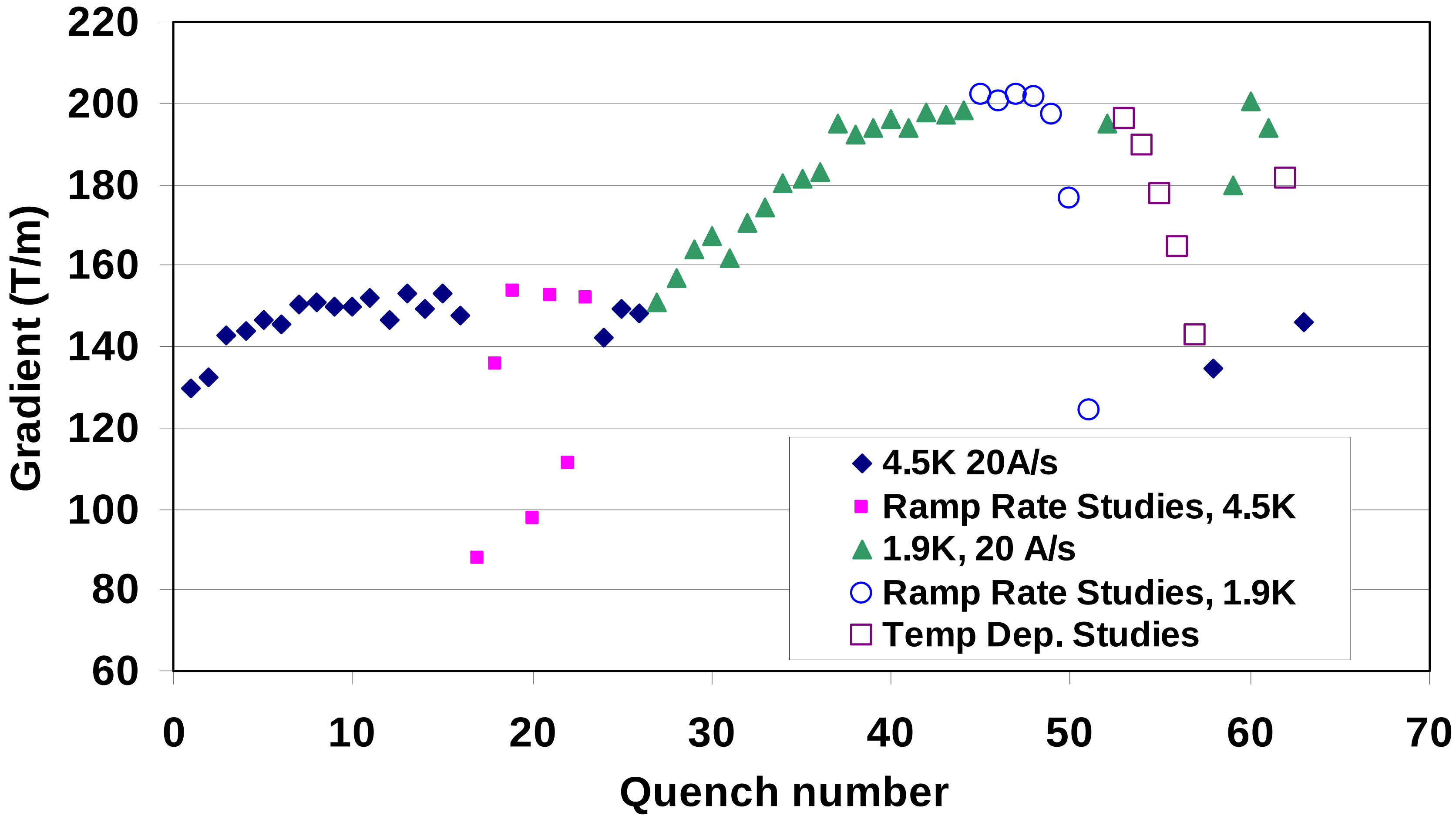
- •TQS01a
  - • 180 to 193 T/m 11 quenches
  - •Plateau coil 6
- •TQS02b
  - • 170 to 180 T/m 4 quenches
  - •Plateau coil 14
- •TQS01c
  - • 160 to 175 T/m 8 quenches (4.4 K)

(max at 182 T/m at high MIITS)

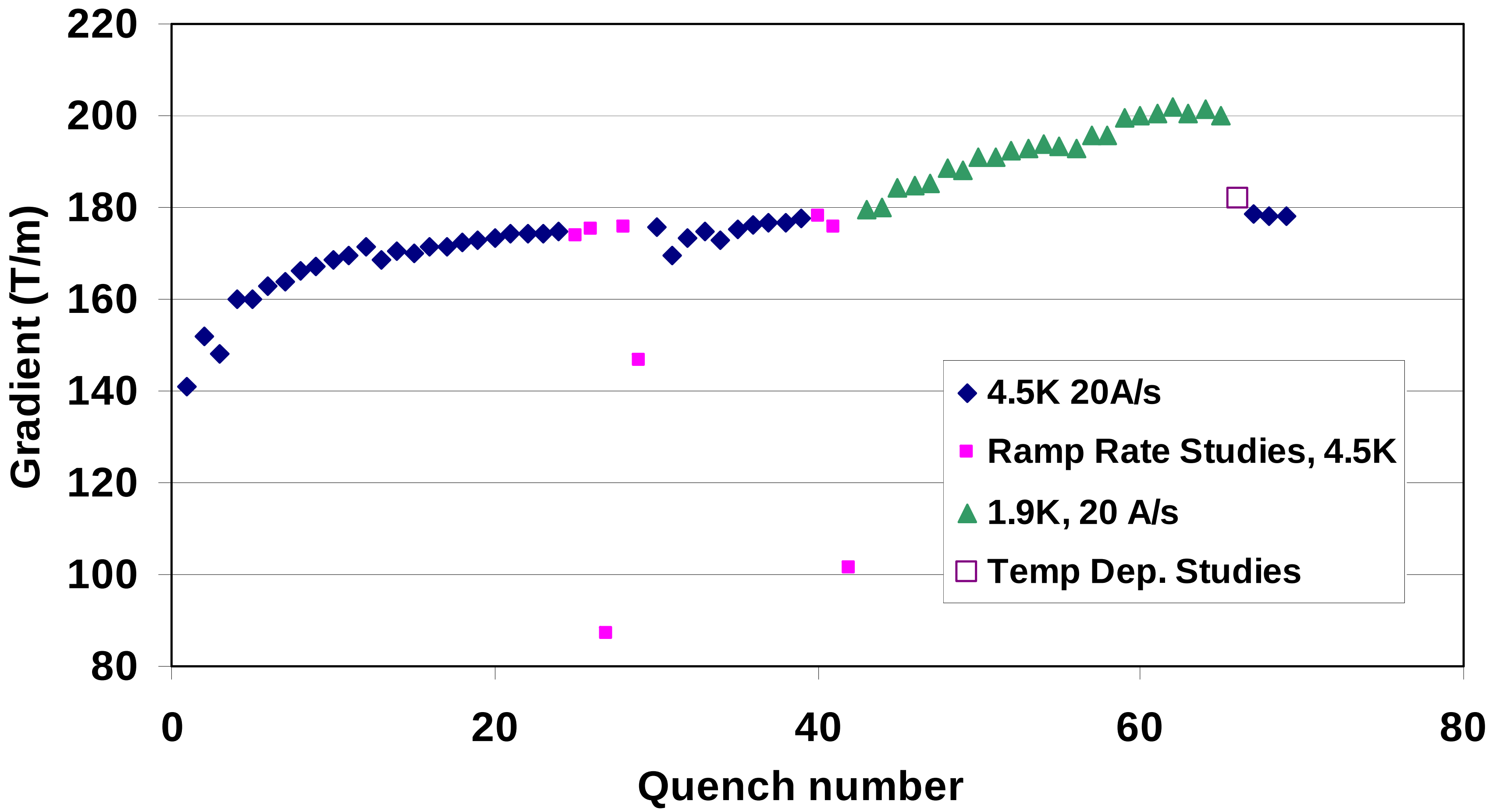
  - • 175 to 192 T/m 20 quenches (1.9 K)
  - •Plateau coil 15
- •All layer 1 pole quenches in the straight section



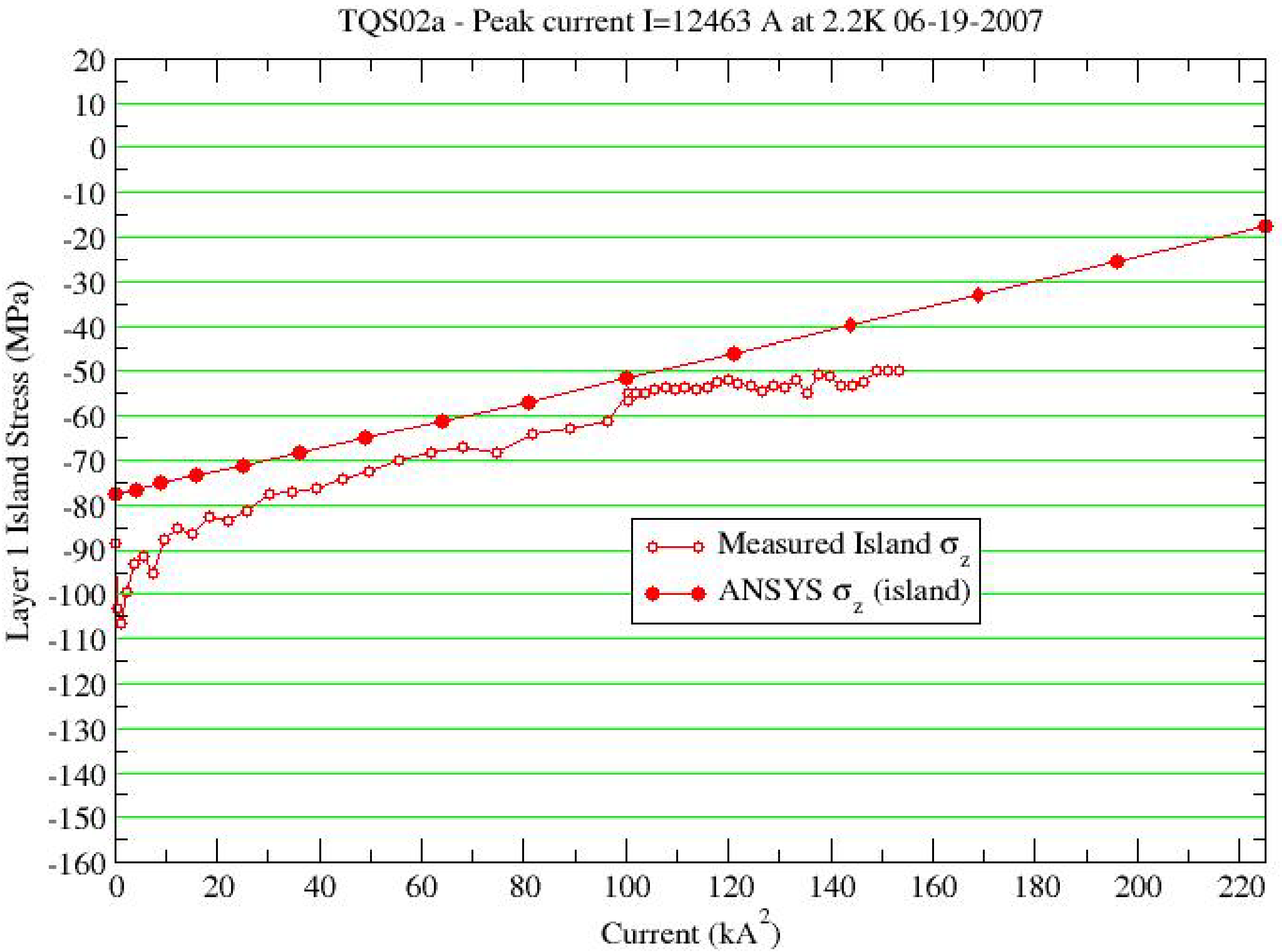
TQC01 Quench Behavior



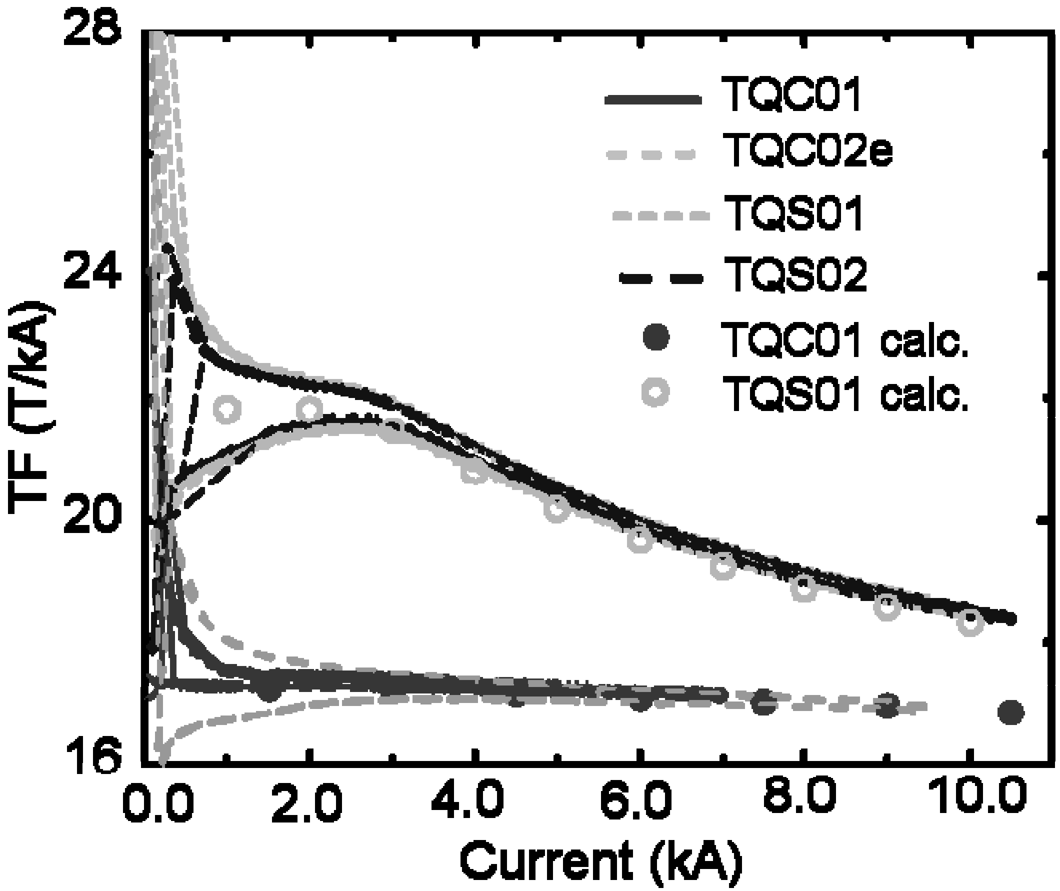
TQC01b Quench Behavior

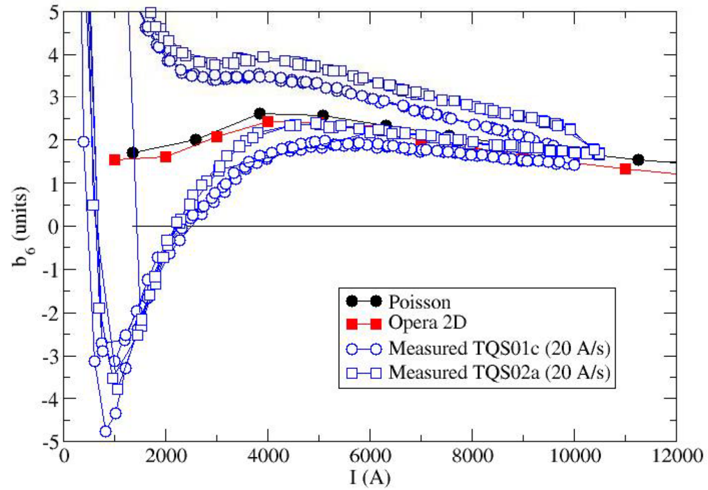


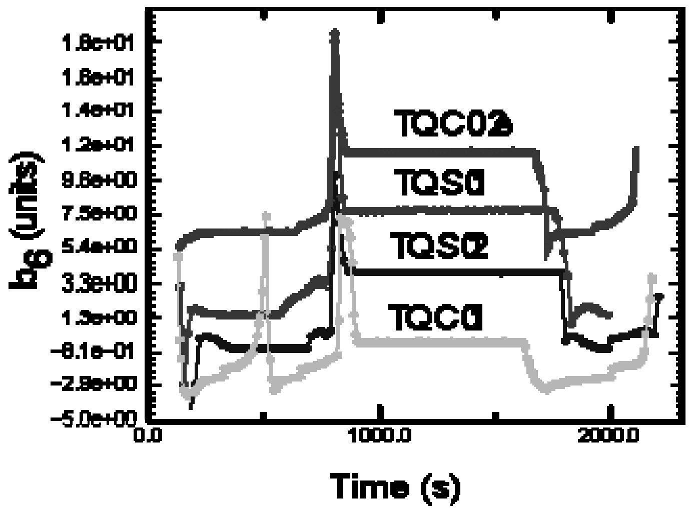
Stress, measured and calculated



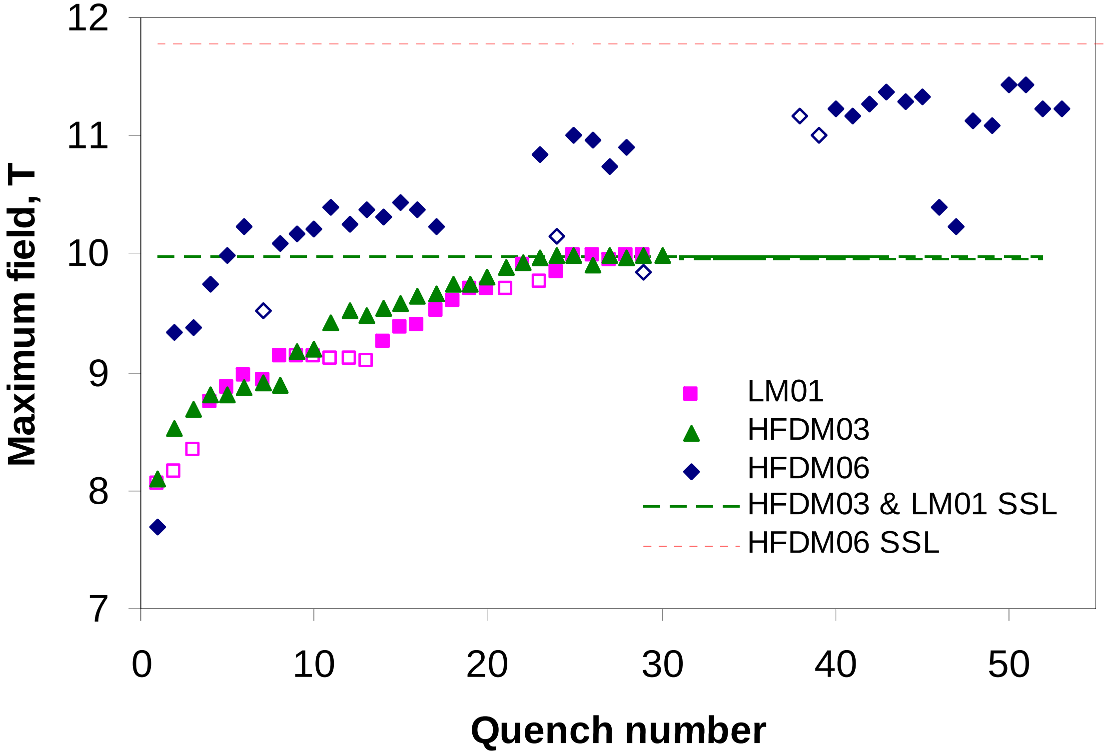
TQS and TQC – measured field







Nb_3Sn Mirror Dipole Quench Performance



Fermilab base program

1-m (HFDM03) and 2-m long (LM01) **PIT** mirror models reached SSL and Bmax ~10 T. Their quench performance is practically identical

1-m long mirror model (HFDM06) with **1-mm RRP-108/127** strand reached 97% of its SSL and Bmax>11 T.

This result has to be reproduced by the 4-m long RRP coil (LM02).

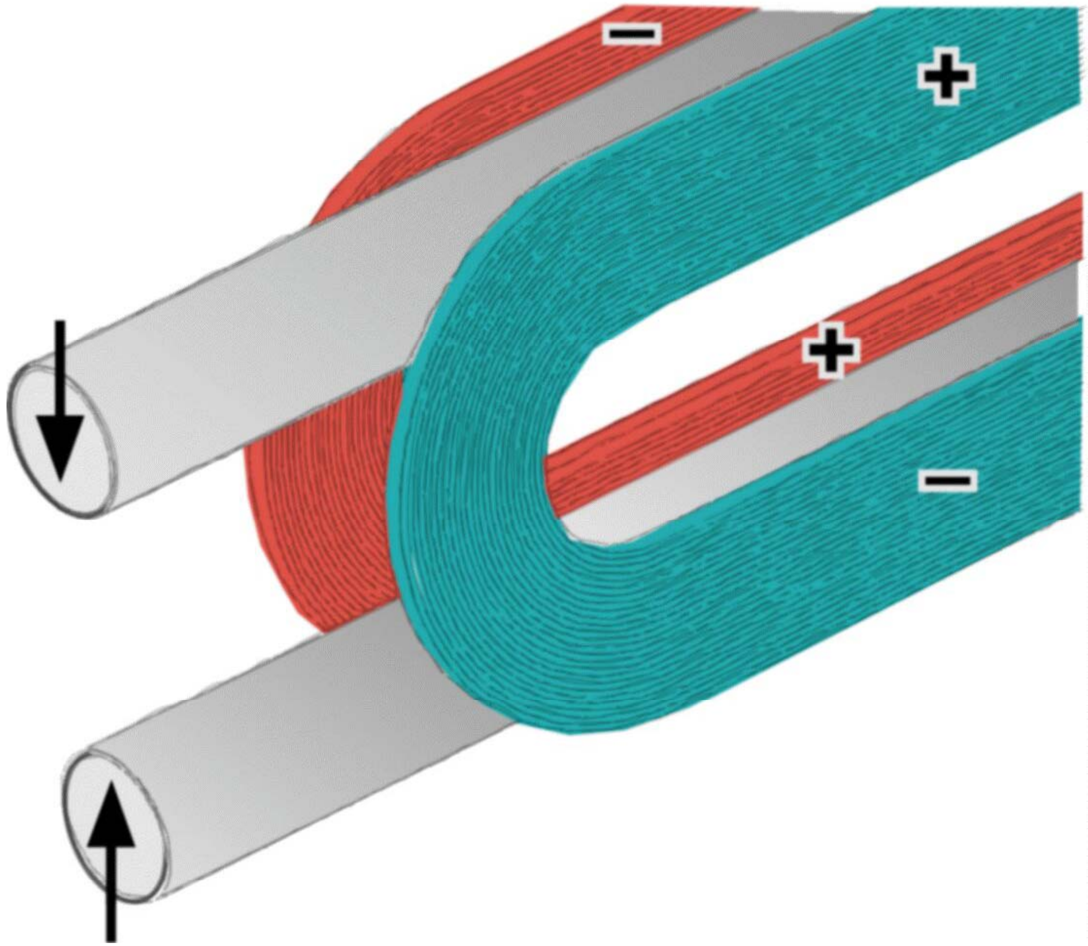
LARP

Conclusion: LARP has developed 1 m, 90 mm quads that reliably reach 200 T/m (90% I_{ss} at 4.2 K) . However, the factors affecting quench performance (e.g., at 1.9 K) are not yet fully understood.

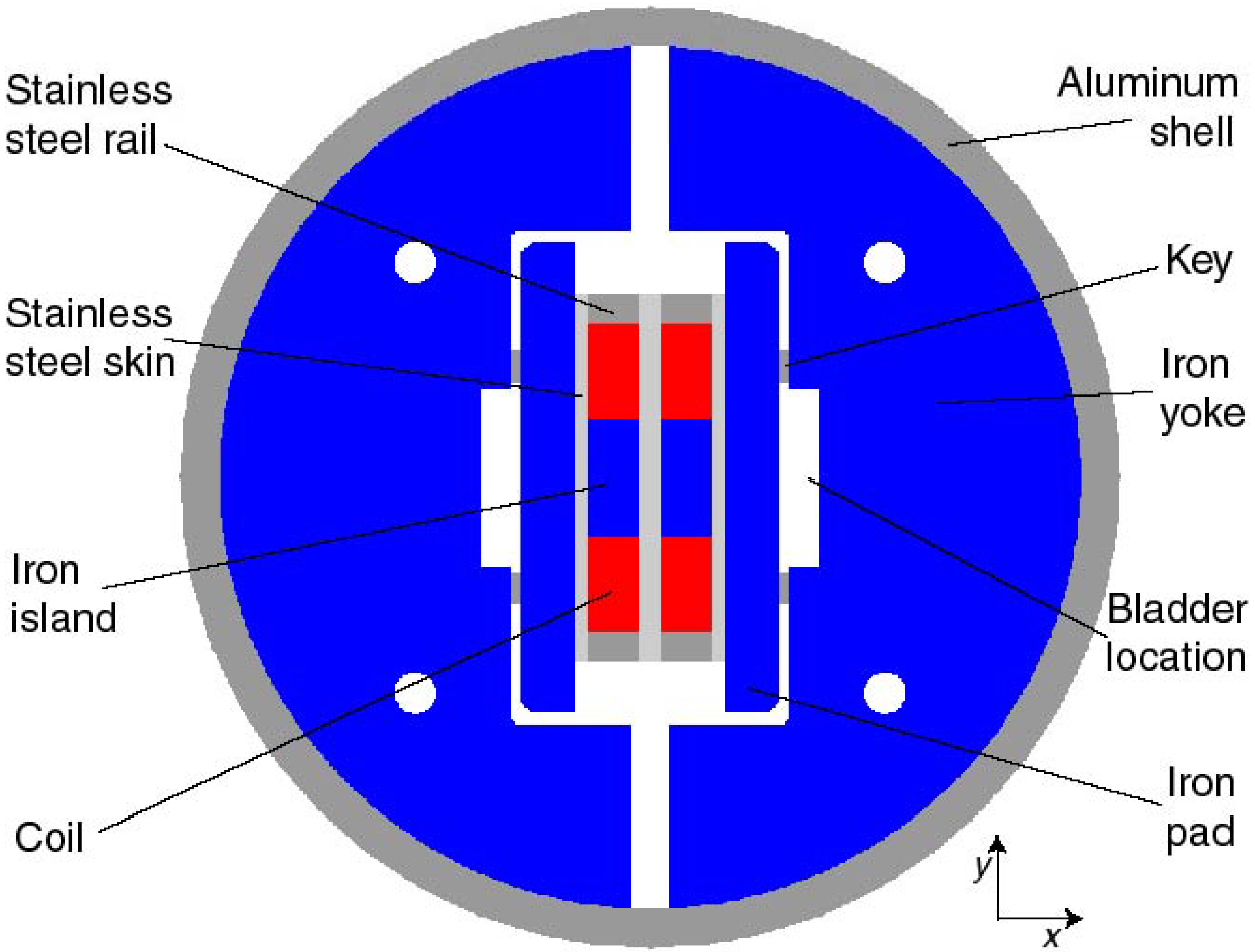
LR (long racetrack) 3.6 m, common coil

Relatively quick check for length effects in coil and shell support structure.

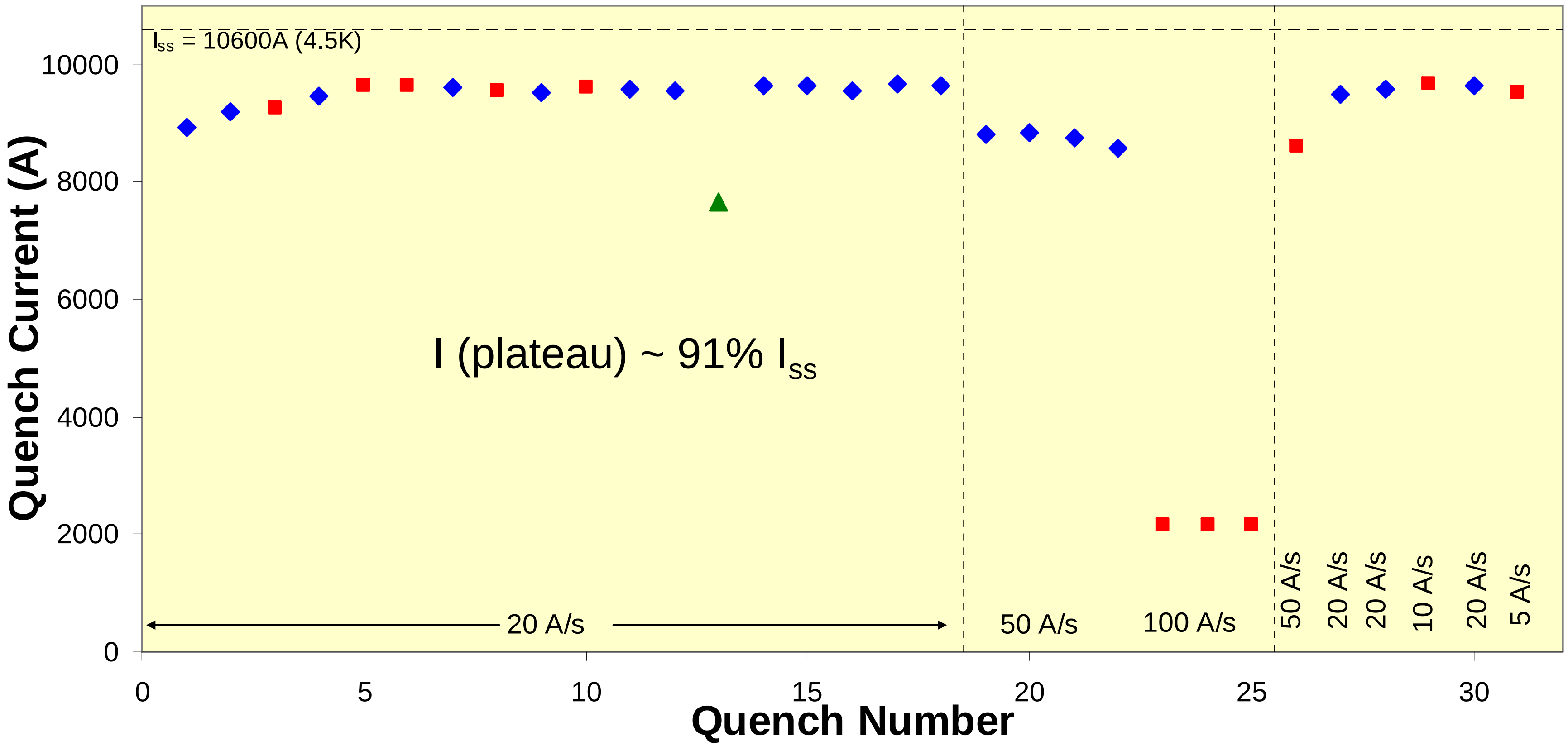
Coil from BNL, structure from LBNL.



LRS01 (long racetrack coils in shell support structure)



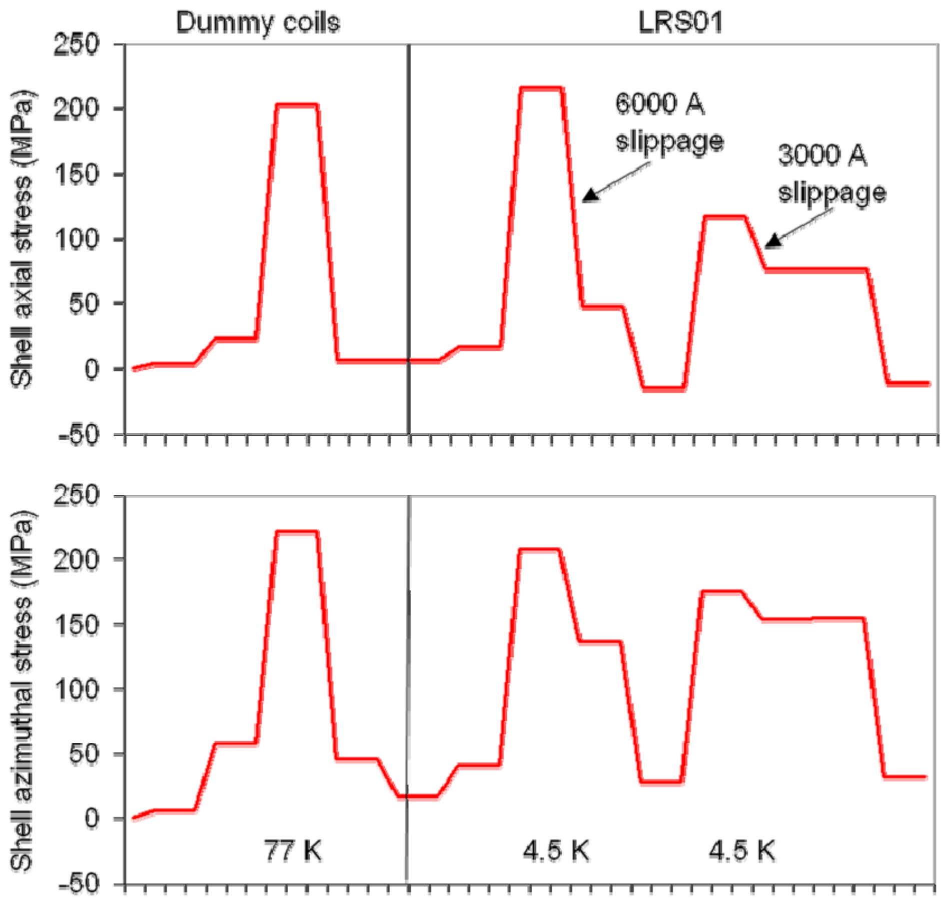
LRS01 - long racetrack, shell 3.6 m (4.5 K)
Peak field on the coil: 11T (no aperture)



LR Test Results

Strain gauge measurement and analysis - axial & azimuthal stress

- Average of the central gauge measurements
- 3 cool-downs in total
- During dummy coil test
  - At 77 K
    - Axial stress of 200 MPa
    - Azim. stress of 220 MPa



P. Ferracin

LARP

Conclusions for long coils and shell support structure:

Magnet quench performance (~ 90% of conductor limit) is nearly as good as that of a 0.3 m version of the same magnet ⇒ ok.

Shell support structure ok at 1 m, subject to stick-slip at 3.6 m ⇒ segment into 1 m lengths, join with pins. The "segmented" version of this magnet will be tested late this year.

LARP

Conclusion:

"Building blocks" – materials, model quadrupoles, 3.6 m racetrack coils and support – are in place. We are ready to move into longer length, larger aperture magnets.