"Limits of Nb_3Sn" Working Group

Topics for discussion & preliminary work plan

43rd INFN Eloisatron Workshop

Super Magnets for Supercolliders

Erice, October 26 – November 1, 2003

Magnet R&D objectives

1) Fundamental requirements:

- Achieve operating field
- Meet field quality specs
- Safely withstand quench
- Reasonable lifetime

2) Efficiency/cost issues:

- Operating point near short sample limit
- Minimum/no training
- Minimize conductor & structural materials
- Simple, reliable fabrication procedures

↔ ***Ultimate Goal:*** Accelerator Quality Magnets

Designing the most efficient path may require to separate these objectives

High Field Accelerators

9 10 11 12 13 14 15 16 T

VLHC (2-stage)

MUON COLLIDER

VLHC (HF)

LHC Upgrades

High field prototypes to date

9 10 11 12 13 14 15 16 T

LHC *(1988)*

MSUT *(1995)*

RD3c *(2002)*

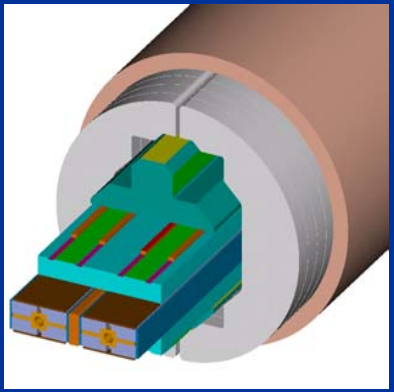
RT-1 *(1999)*

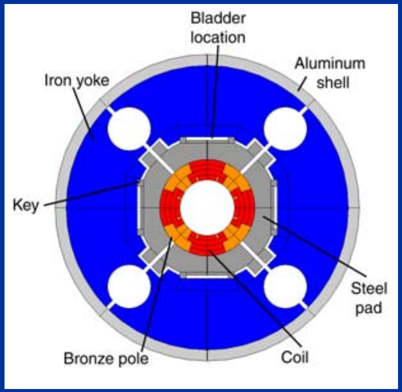
D-20 *(1996)* *1.9K*

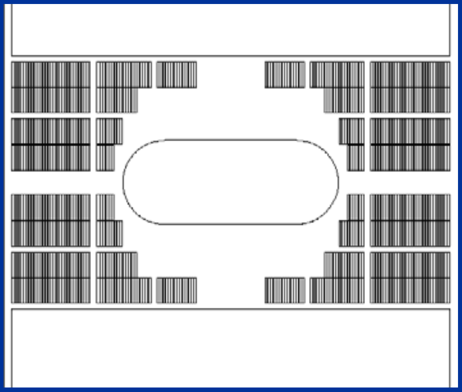
RD3b *(2001)*

HD-1a *(2003)*

Main components & specific issues







Arc Dipoles

- High field
- Injection FQ
- SR heat loads
- Magnet cost

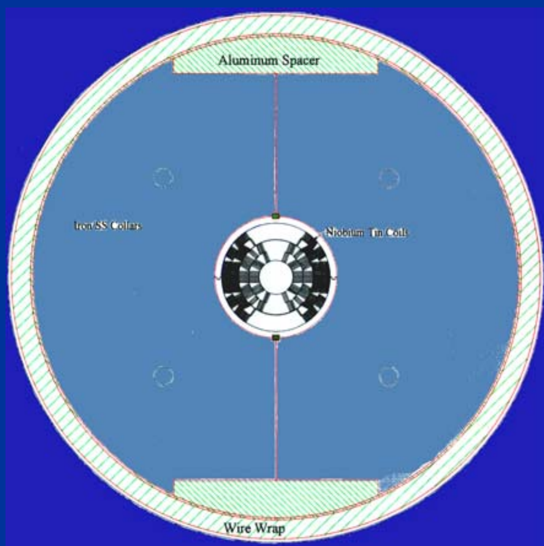
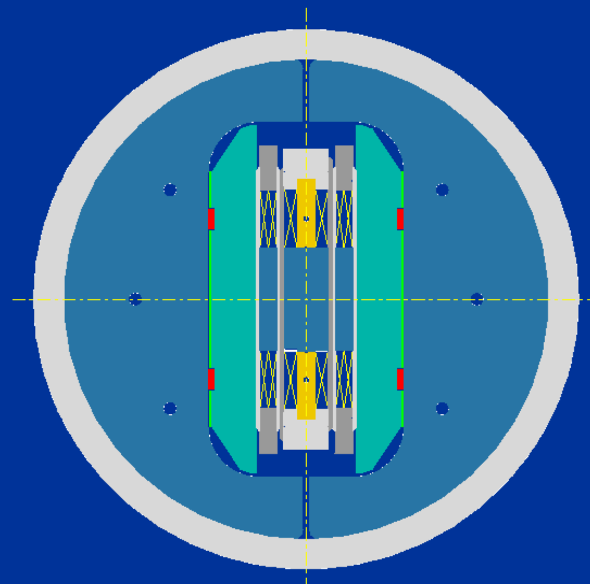
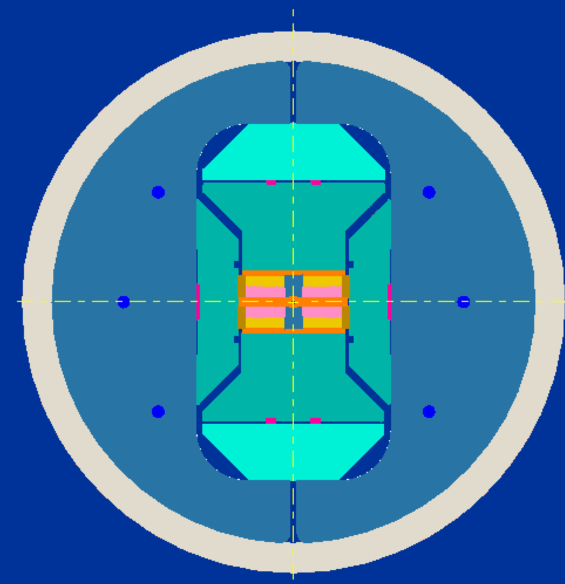
IR Quads

- Large aperture
- Collision FQ
- High gradient
- IR radiation

IR Dipoles

- IR radiation
- Coil stress
- Large aperture
- High field

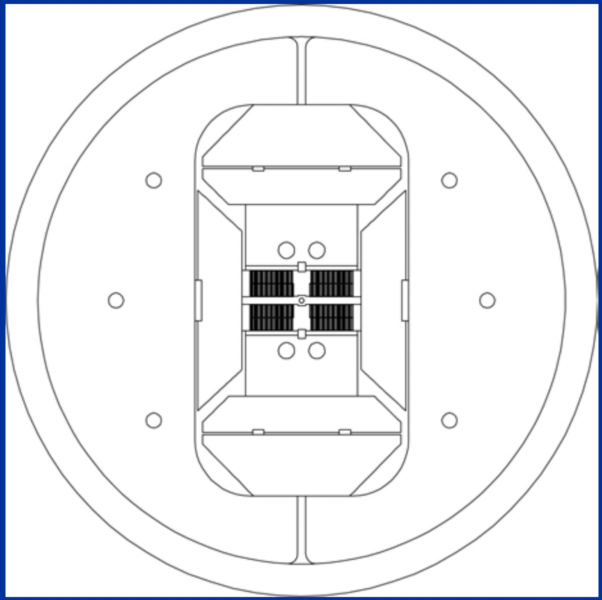
Coil Designs

Cos θ	Common Coil	Block
		
D20 (13.5 T)	RD3b (14.5 T)	HD-1 (16 T)

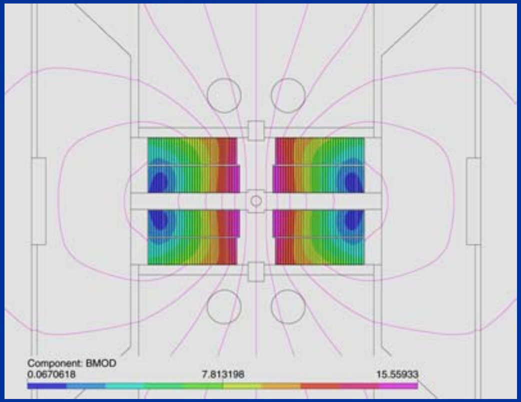
HD: testing field and stress limits

<u>Features:</u>

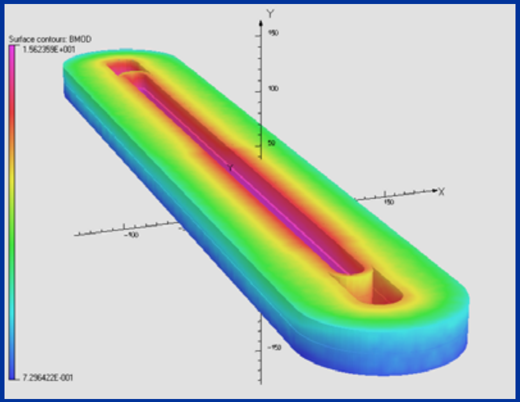
- Block-coil supported by yoke and shell
- Simple and cost-effective configuration
- Flat cables, double pancake coils
- Separation of high field/high stress points
- Bladder & key assembly



HD1 Magnet cross-section



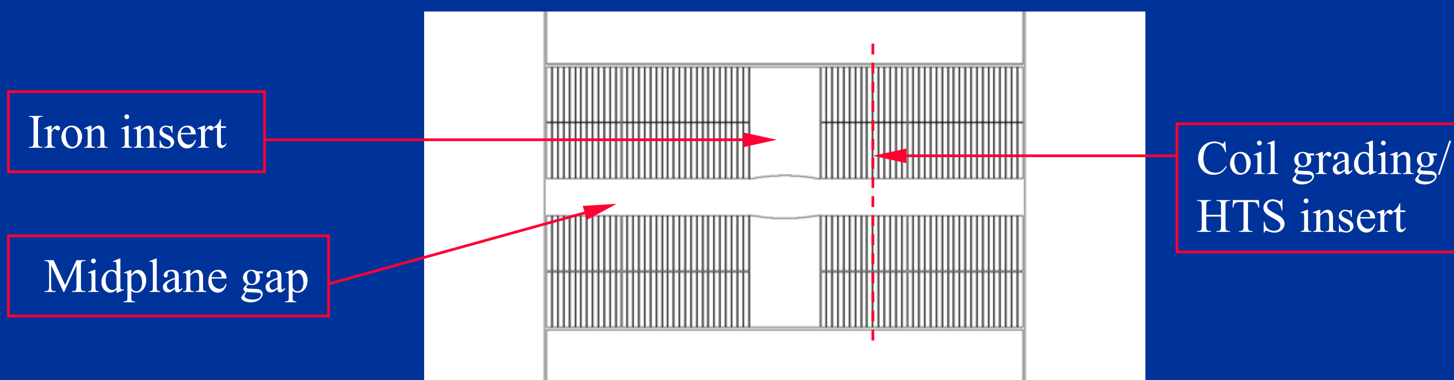
HD 1Coil cross-section



End field

High Field & Stress in HD

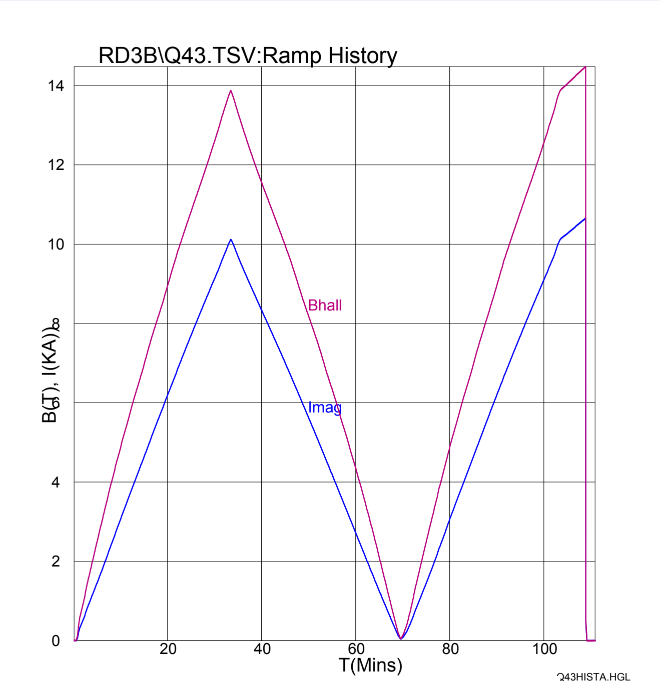
Design features	Dipole field (T)	Iss (kA)
HD1 reference (initial design)	16.2	10.5
RD3B conductor	15.3	10.0
Nb_3Sn graded coil 8 turns 1/2 dens	17.5	14.0
HTS insert 7 turns 0.8 mm 361 A @ 18 T	18.6	13.0



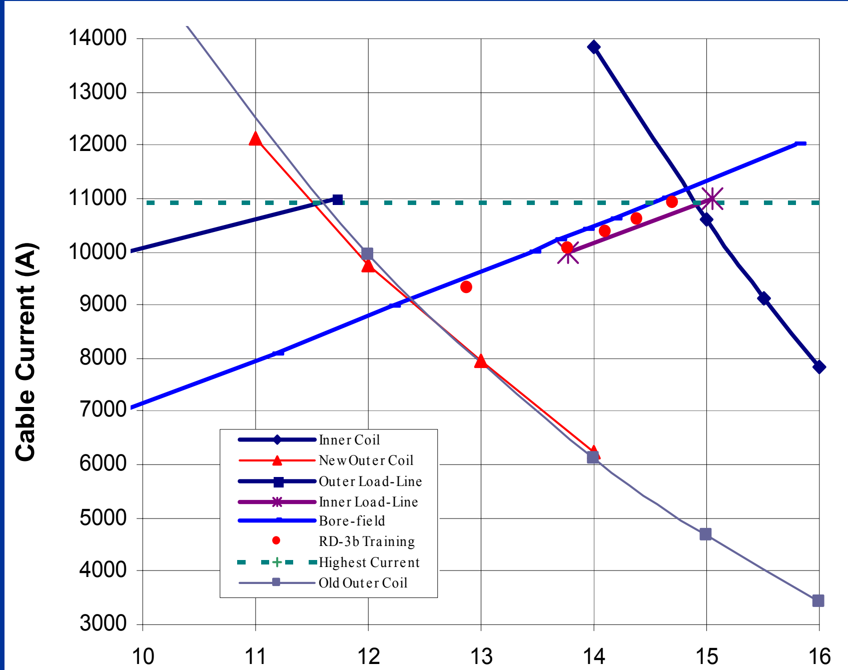
A test at 1.9 K is being considered

Stress analysis: 200 MPa @ 18 T

Stress limits - what we know today



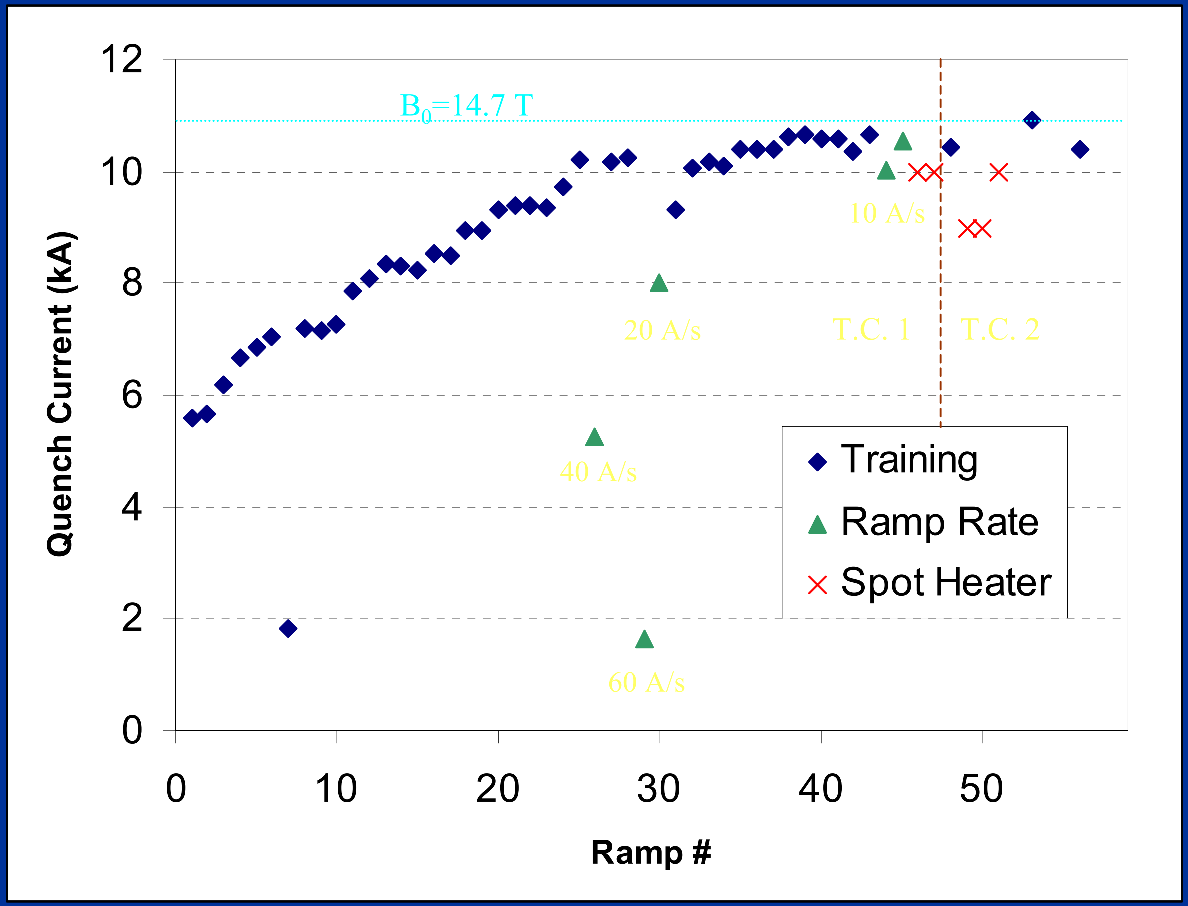
RD3B ramp cycle to quench (#43)



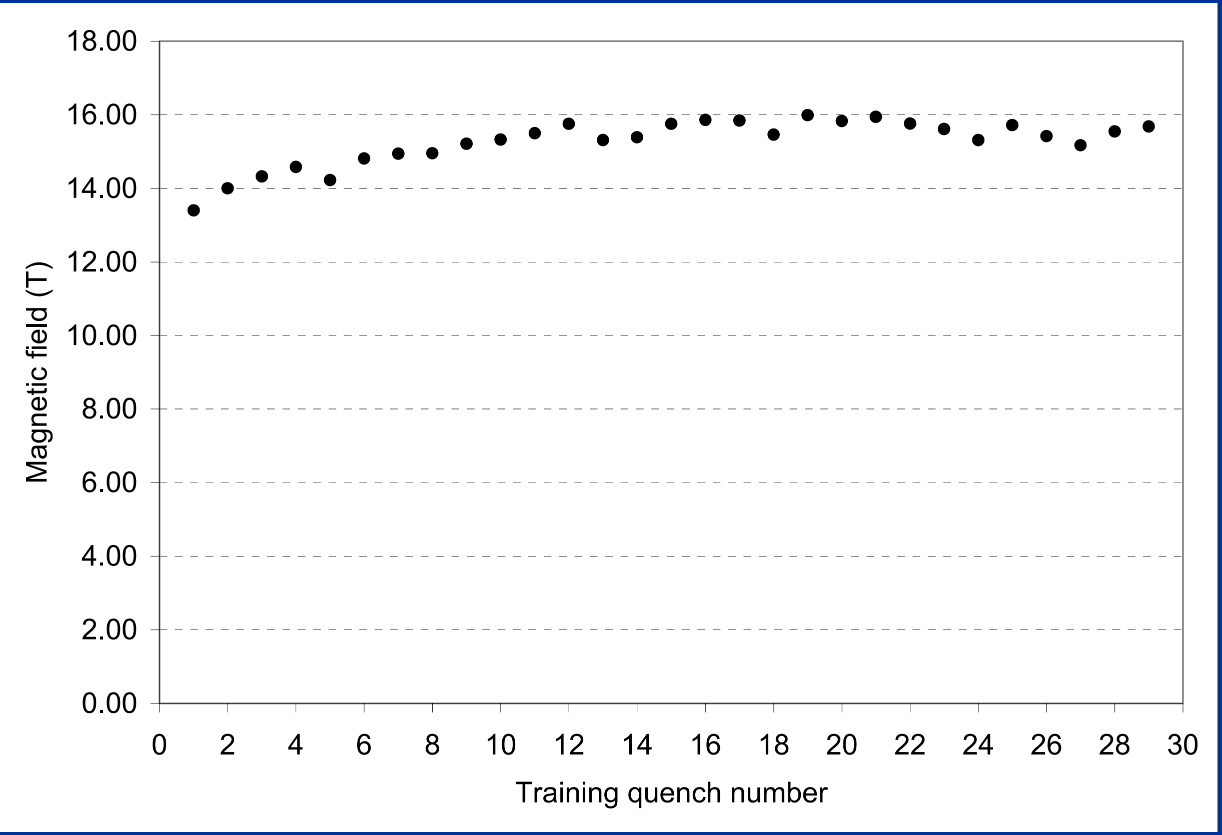
RD3B load lines and conductor limit **B [T]**

RT-1, RD3B – No performance degradation up to 14.7 T, 120 MPa
No definitive conclusions **yet** from HD-1 test at 150 MPa

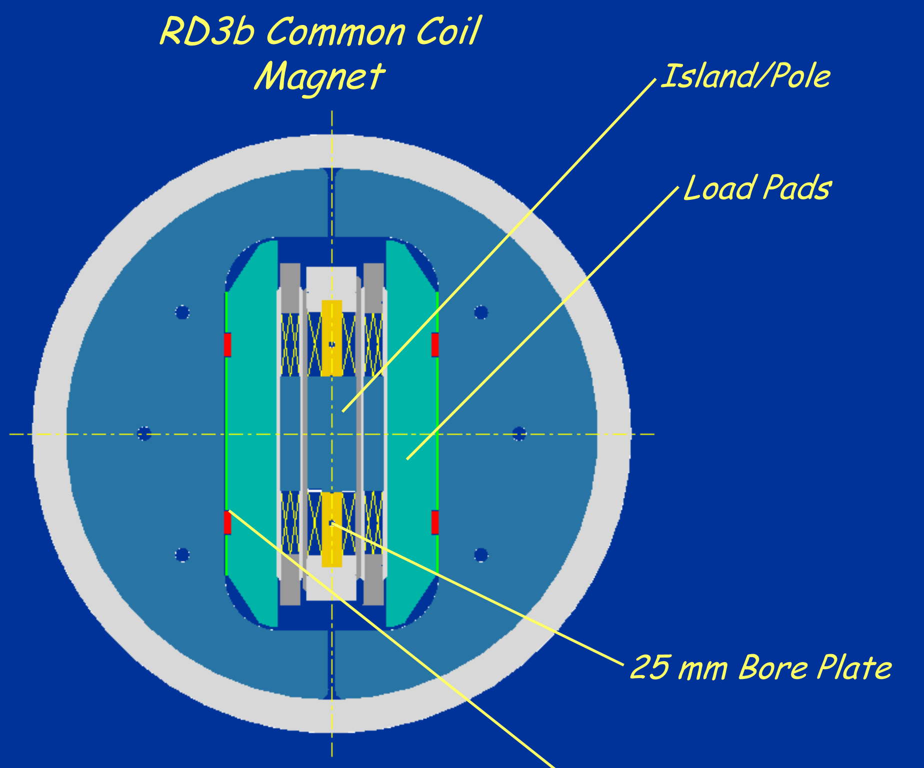
RD3b Training History



HD-1 Training History (1st cool down)

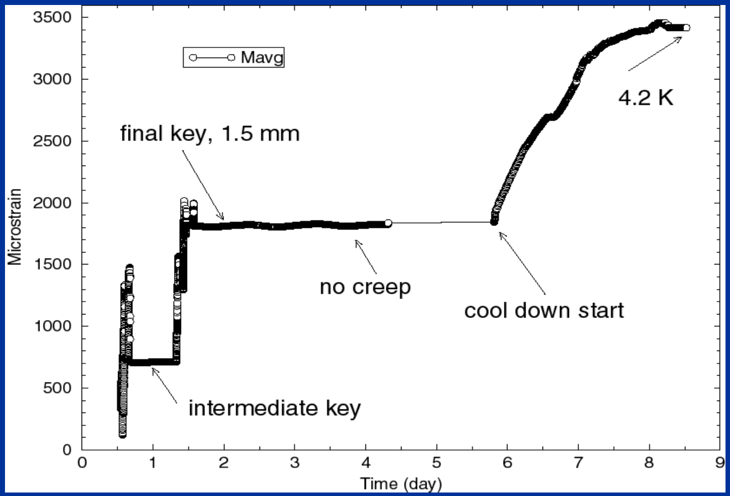


RD3b Support Structure



$F_x = 12$ MN/m @ 14.7 T

RD3b Magnet Assembly and Cooldown

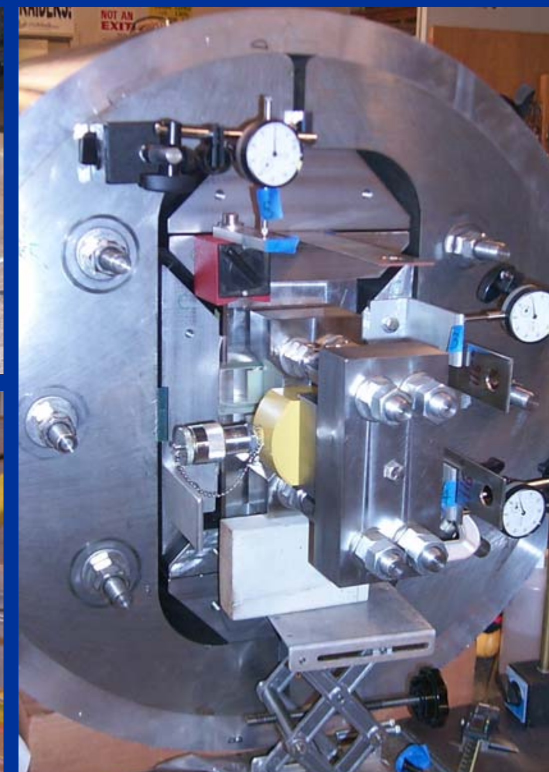


Pressurized Bladders

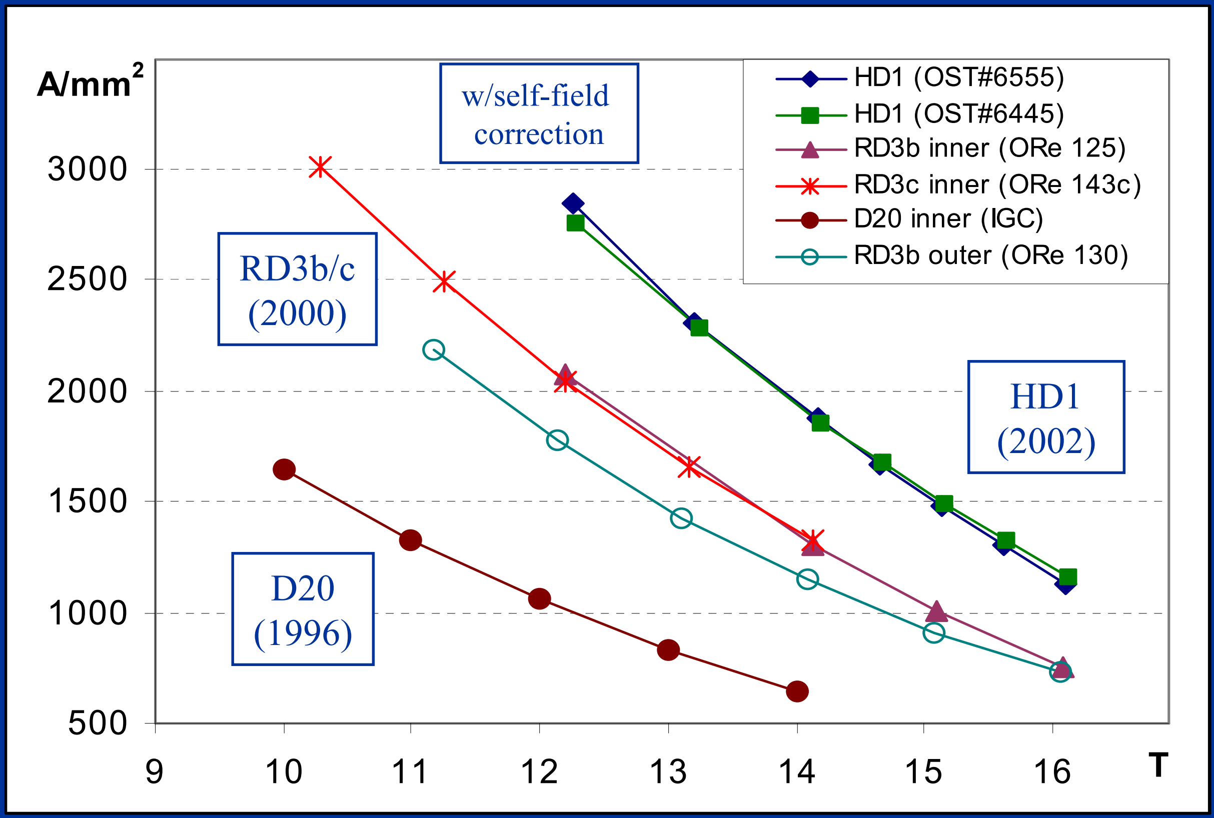
HD1 Support Structure

Design Features:

- RD3 shell & yoke
- Bladder & key assembly
- Horizontal+vertical bladders
- Four Al rods for axial support
- High load on broad cable face
- Non magnetic vertical pads in magnet ends (field reduction)



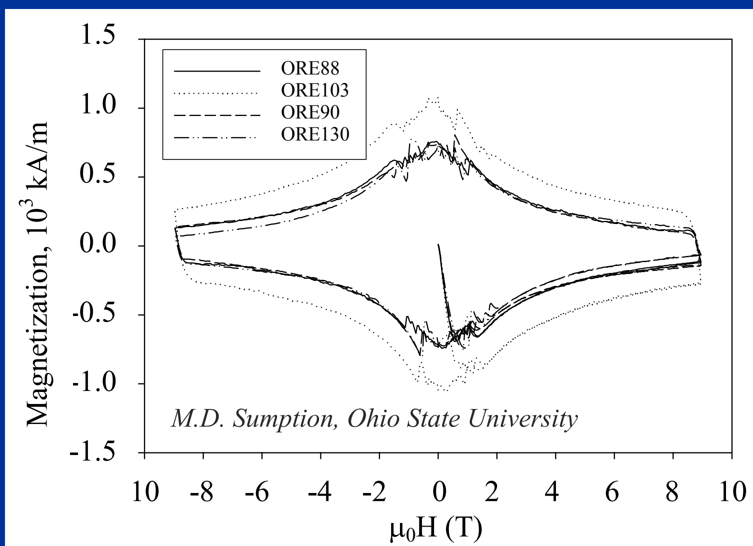
Conductor for High Field Prototypes



Can we go further?

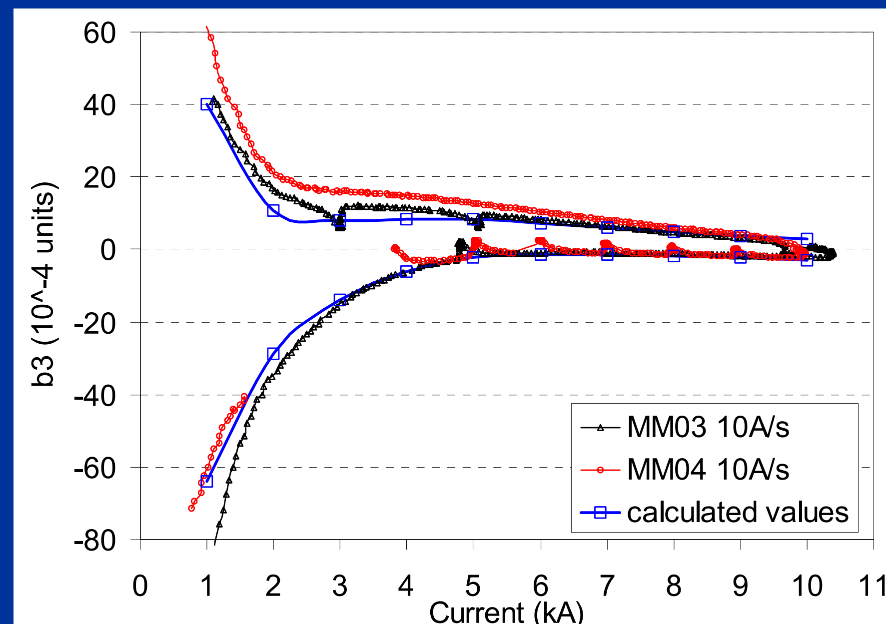
Persistent currents (RD3c)

Strand magnetization



J_c(12T,4.2K) = 2kA/mm^2 D_{eff} ~ **95 μm**

Normal sextupole hysterisis

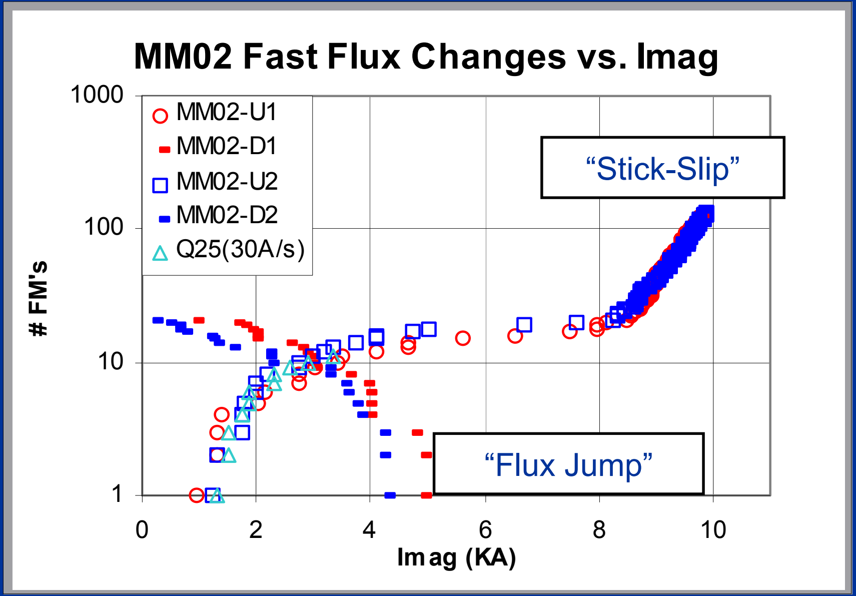


Flux Jumps at High J_c, D_{eff}

RD3C Fast Flux Changes

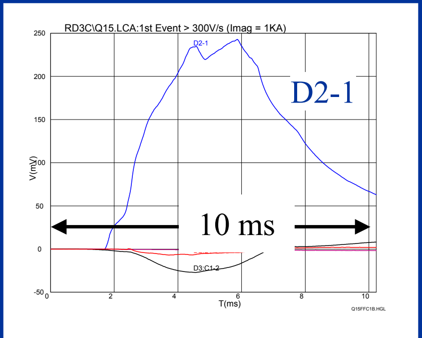
Flux Jump:
- "Slow" (10 ms)
- Low current
- No training
- Repeat at down ramp

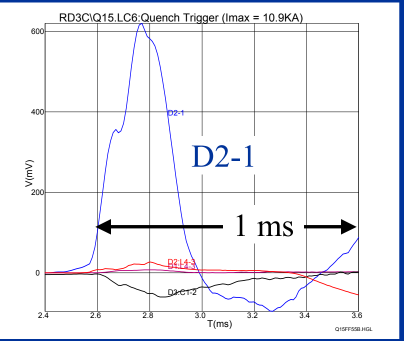
Stick-slip:
- "Fast" (0.1 ms)
- High current
- Trigger quenches
- Some training
- Not at down ramp



Flux jumps:

Can trigger quench detection system
Also observed in RT-1, RD3B





LARP R&D Phase 1 - Main issues

Magnet design:

- optimal bore size, coil geometry, support structure

Conductor R&D:

- conductor and cable optimization for different designs

Magnet performance:

- quench training, actual vs. expected gradient
- design margin required for production
- stress limits for different configurations
- fabrication tolerances and their impact on field quality
- strategies for operation under heavy radiation load

Nb_3Sn IR Quadrupoles

Assuming J_c(12T, 4.2K) = 3 kA/mm^2 T_{op}=1.9K

Maximum gradient

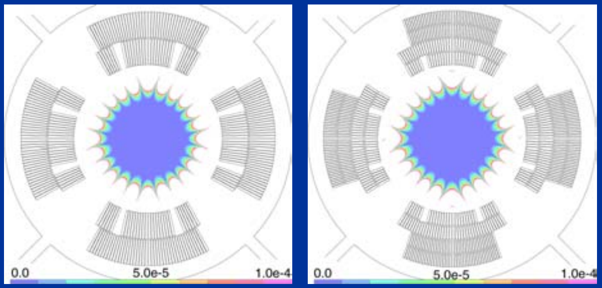
- 260 T/m (2-layer)
- 285 T/m (4 layer)

Conductor peak field

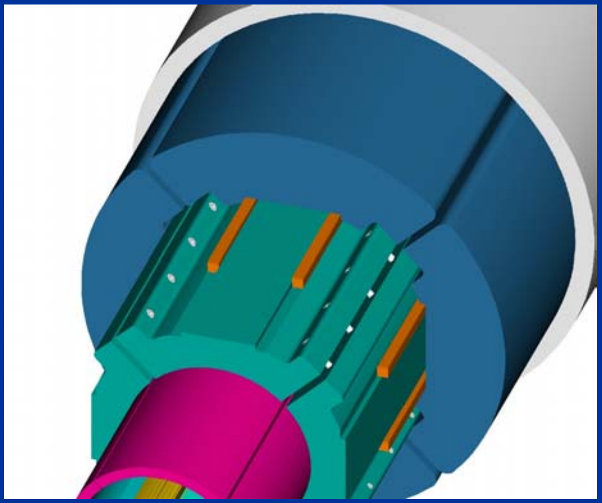
- 13.3 T (2-layer)
- 14.4 T (4 layer)

Stress analysis

	Inner (MPa)		Outer (MPa)	
	Midpl.	Pole	Midpl.	Pole
2-layer (270 T/m)	130	11	138	4
4-layer (300 T/m)	**162**	14	**170**	5



Two or four layer designs


Bladder and key assembly

Quench Protection Limits

Quench analysis for 2-layer and 4-layer designs (90 mm aperture):

- Heater: 26 μm thick stainless steel with distributed Cu plating
- Active sections are 100 mm long, 17% of total magnet length

PROTECTION SYSTEM PARAMETERS

Design	Voltage V	Capacitance mF	RC const. ms	G_{ss} T/m	T_{peak} K
Two-layer	440	13.2	26	245	200
Four-layer	750	6.2	23	266	300

ASC-02, Houston, August 2002

New analysis tools available - experiments are needed to verify results
Recent SM-05 test indicated good tolerance to high temperature/stress

"Dipole first" IR design

Potential advantages:

- reduced number of long-range beam-beam collisions
- beam on axis & local field error correction in the IR quads

D1 Dipole requirements:

- need to separate *and* accommodate both beams: 15 T, 120 mm bore
- need to withstand large power deposition from secondaries

Magnet R&D issues:

- Operating field, forces and stresses are "beyond the state of the art"
- Mitigation of the radiation load → split coils have been suggested

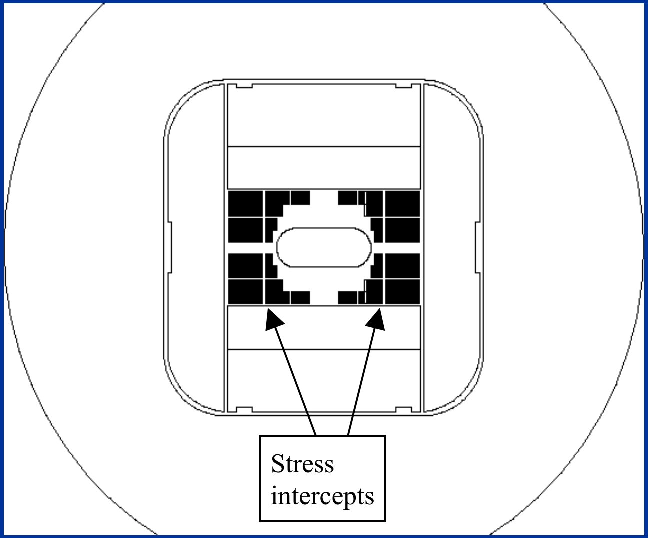
LARP block-coil cross-section

Added features:

- Intercepts to mitigate stress accumulation (Lorentz stress/block: < 150 MPa)
- Conductor grading for better efficiency (Dipole field: 15 T @ 9.5 kA)

Stored energy:	LARP: 3.9 MJ/m
	RD3: 1.2 MJ/m
	HD-1: 0.6 MJ/m
Inductance:	LARP: 90 mH/m
	RD3: 21 mH/m
	HD-1: 11 mH/m

(investigate wide cable/2 layers)



Field quality: need specs - optimize at beam radius along the horizontal axis?

Proposed work plan

- Concentrate on very high field magnets

  (LHC upgrade is the most likely application in the "near" term)

  Discussion Topics:

  - Coil Design
  - Mechanical support & assembly
  - conductor, operating temperature ⇔ conductor/materials w.g.
  - aperture, field quality, dyn. range ⇔ *accelerator physics w.g.*
  - stored energy, inductance ⇔ quench protection w.g.
  - radiation issues ⇔ ancillary systems w.g.
  - *magnet cost* ⇔ *all of the above*

- Establish R&D targets? (as for DOE conductor program)