PROSPECTS FOR NB_3SN MAGNET

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OUTLINE

- Status of LARP quadrupole magnets
- LBNL High Field base program
- Limits of Nb_3Sn dipoles

US LHC Accelerator Research Program
LARP
(Berkeley, Brookhaven, Fermilab)

Develop magnets for new higher luminosity IRs

Represents the first large-scale use of Nb_3Sn in an accelerator

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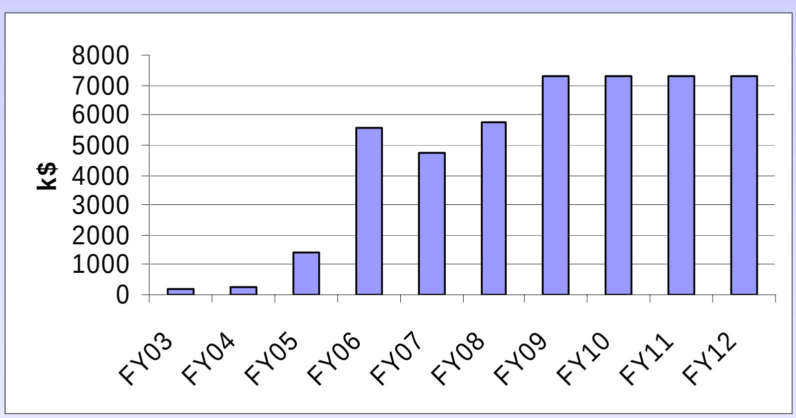
US LARP Magnet Funding



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Technology Quadrupole **<u>TQ</u>**

Two different structures and a simplified double layer coil - TQ1a, TQ2a .

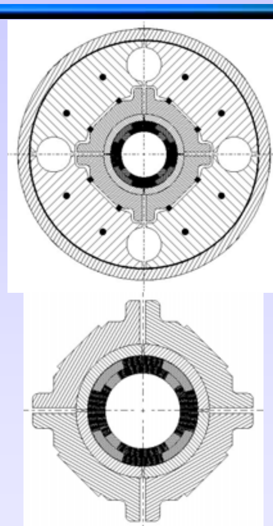
- **TQ1a** is based on a mechanical structure that uses **keys and bladders** (pads, yoke, aluminum shell, axial rods)
- **TQ2a** design is based on the **MQXB** mechanical structure (collar, yoke, skin, end plate).

Final coil

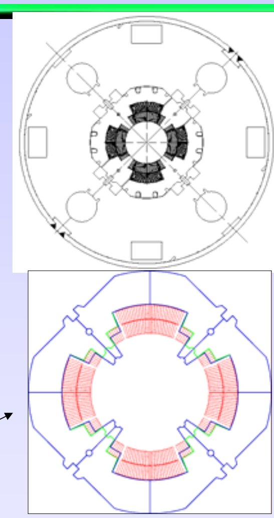
1. Two double layers
2. One triple layer

Similar coils in two different structures

TQ1a



TQ1b



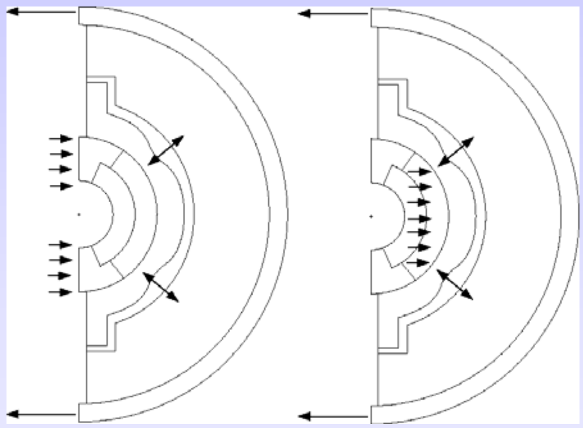
90mm aperture

Shell, Keys, and Bladders -Structural

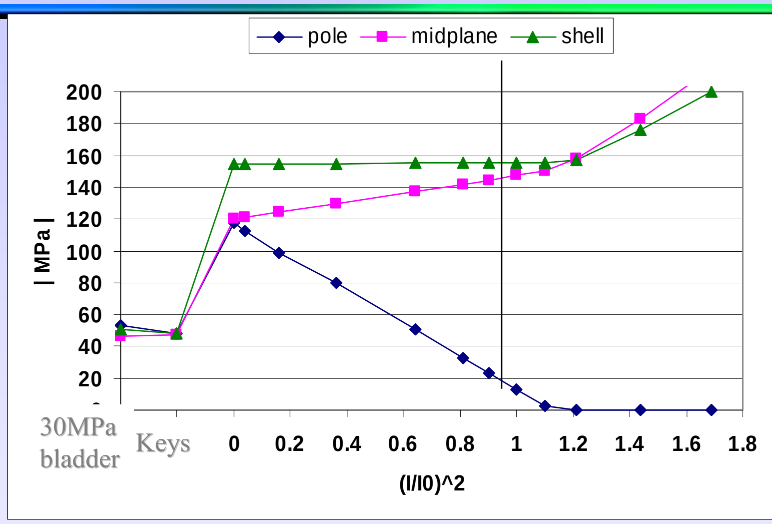
Shell –

Yoke and Key -

Coil -



Stress - Coil and Shell



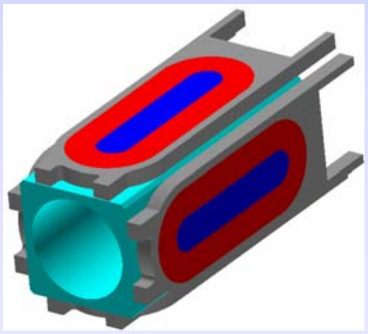
TQ1a – **Structure**

TQ1a -Work Plan and Schedule:

FY05		
Design of cable, coil, and tooling:	FNAL+LBNL	01/15/2005
Fabricate cable:	LBNL	02/15/2005
Insulate cable:	LBNL	03/01/2005
Procure coil fabrication tooling/parts:	FNAL	03/01/2005
Design and fabricate pad inserts	LBNL	03/31/2005
Design and fabricate axial rods + end plates	LBNL	03/31/2005
Fabricate practice coil:	FNAL+LBNL	04/15/2005
Wind/cure coils:	FNAL+LBNL	06/15/2005
React/impregnate coils:	LBNL	08/15/2005
FY06		
Assemble magnet:	LBNL	10/15/2005
Test magnet:	**BNL**	**12/15/2005**

Small Quad

- Coil aperture: 130 mm
- G_{ss} = 95 T/m



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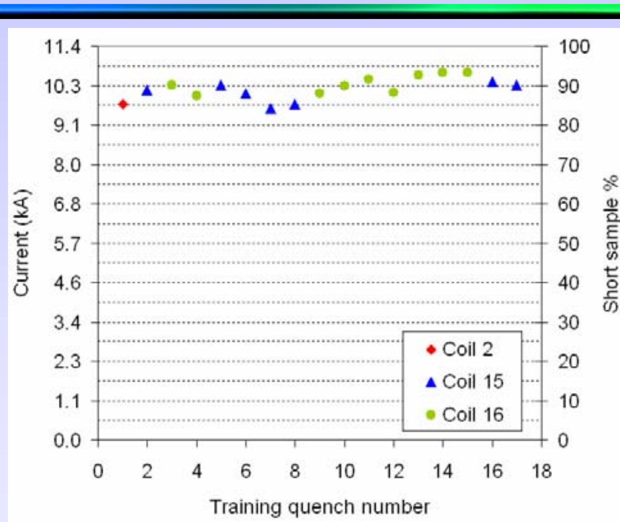
Quench performance



LBNL High Field Base Program

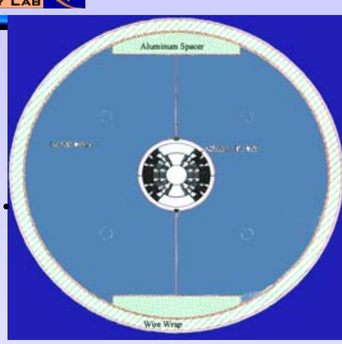
Mission - R&D on high field Nb_3Sn coils and structure.

Two sizes :

1. Full scale magnets – 750 mm dia., 1m long
2. 1/3 scale magnets

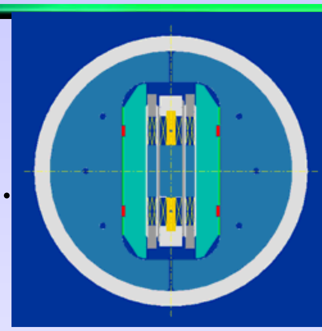
Large Scale in 3 Geometries

1 . .



D20 – Cosine-theta
50 mm bore
13.5 Tesla (1.9K)
12.8 Tesla (4.3K)

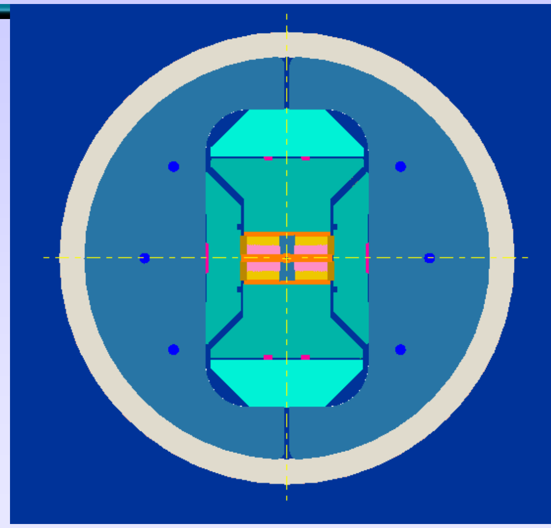
2 . .



RD-3b - Common-Coil
Dual-bore
14.5 Tesla (4.3K)

and 3 . . .

HD1 – Block coils
10 mm bore
16 Tesla (4.3K)
> 150 MPa

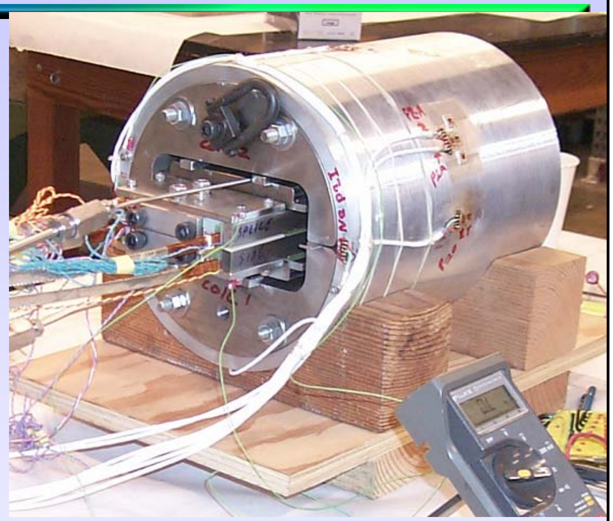


Summary

- Nb_3Sn coils perform successfully in different geometries
- Nb_3Sn coils can sustain stress of ~180 MPa
- Keys & bladders - high pre-stress delivery system
- Transverse pre-stress - outer aluminum ring
- Axial pre-stress - aluminum rods

1/3 Scale Structure (9-12 T)

Two-layer racetrack coils
In common coil configuration



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Small coils (5 kg of material per coil)

Traces:

•Voltage

•SG

•Heater

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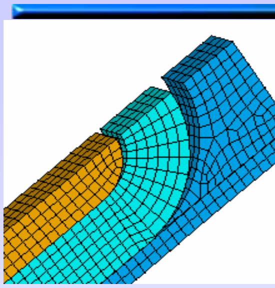
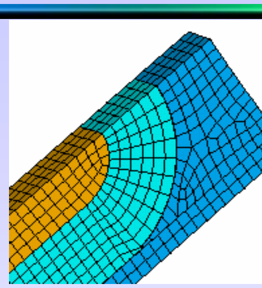
Full Scale Structure (12-16 T)

HD-1 - 16 Tesla

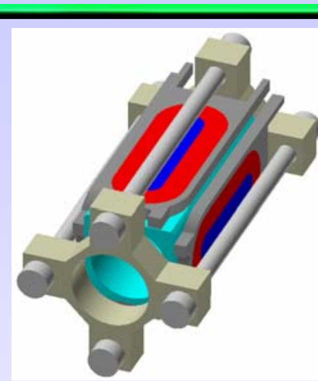
Axial support - Aluminum rods



Without axial support
Gap coil-island of 100 µm



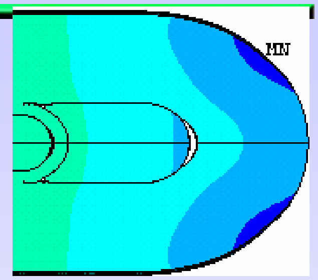
With axial support
No gap coil-island



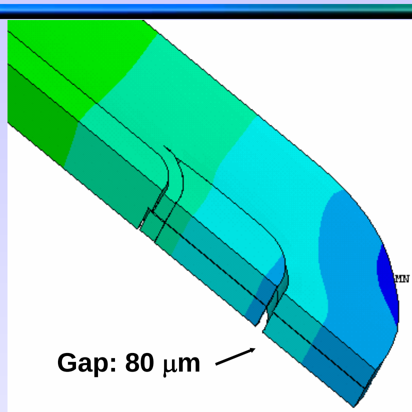
- Sub quad

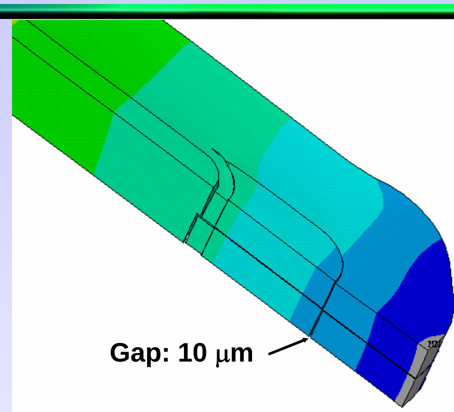
HD1: effect of Lorentz forces in the end regions

- 3D analysis
  - **Gap** of about 85 μm (peak field) between coil and end-spacer (**turn 6**)
- Most of training quenches occurred at gap location
- **Visual inspection** after disassembly
  - **Epoxy discoloration**



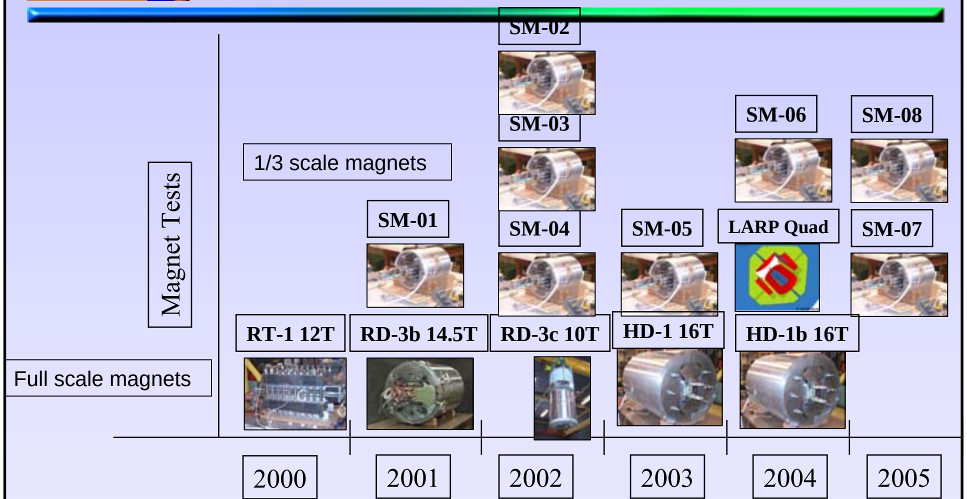
HD1 → HD1b





Old design: 80 μm gap **New design: 10 μm gap**

LBNL Nb_3Sn Magnet Tests



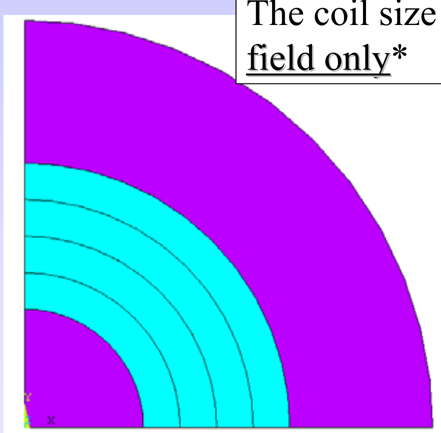
High Field Issues

- **Field and bore size**
- **Lorentz stress versus J_e**
- **Magnet size**
- **Field limits and high T_c - beyond Nb_3Sn**
- **Magnet workshop**

A simple Dipole model*

$$J = J_e \cdot \cos(\theta)$$

The coil size depends on the "short sample" field only*



δR

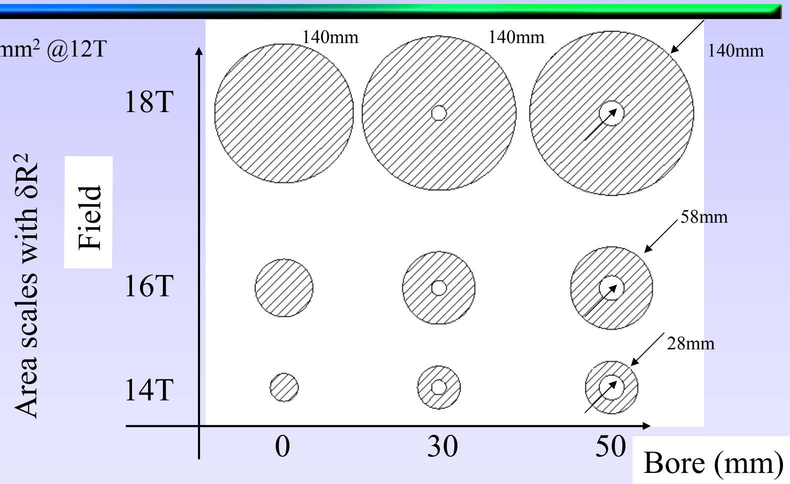
$$\delta R_{ss}(B_{ss}) = \frac{2B_{ss}}{\mu_0 \cdot J_e(B_{ss})}$$

* no iron

Field, Bore and Coil Size (no grading)

43.6% SC – the rest is copper, insulation and voids

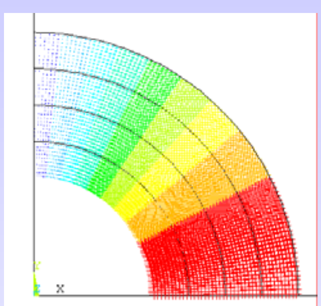
Nb3Sn 3000A/mm² @12T

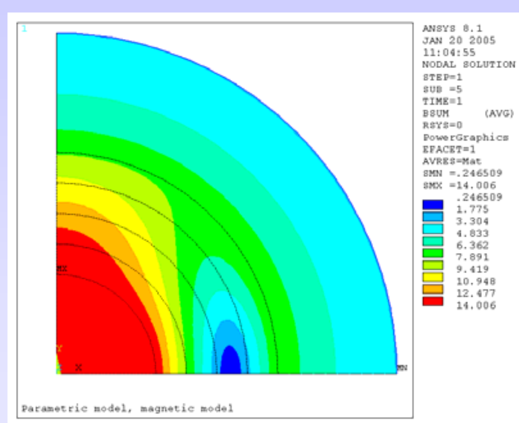


Drawing to scale

Area scaled with bore

$B_{center}=B_{conductor}$

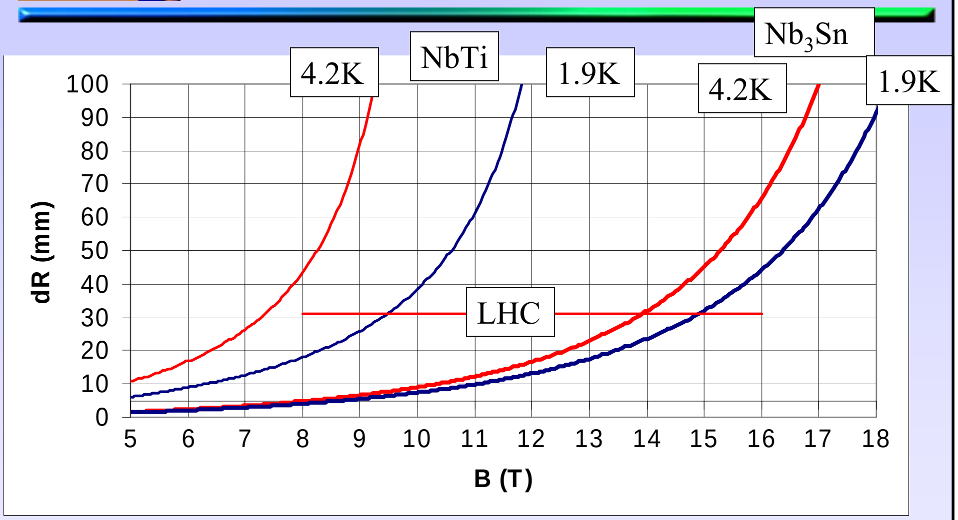




14T ANSYS example

Coil Thickness (not graded)

38.2% Superconductor



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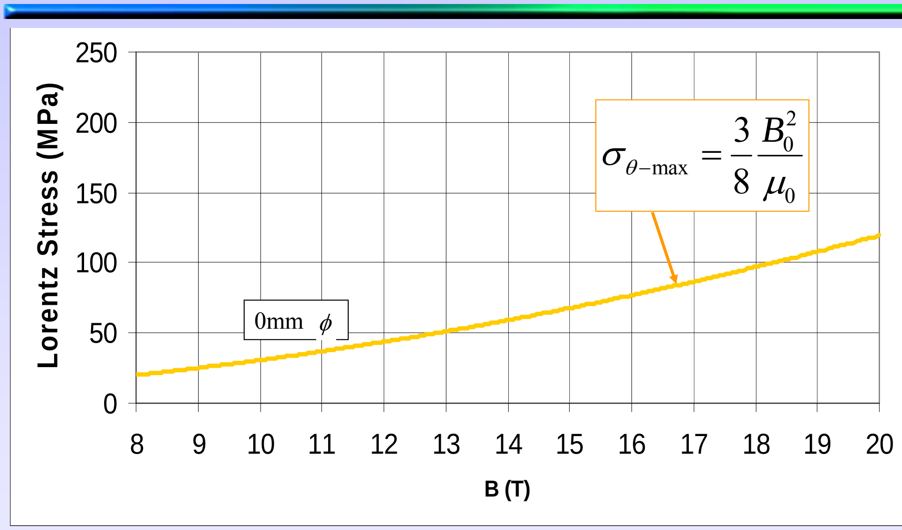
"Short Sample" Lorentz Stress (not graded)

A function of $\mathbf{B_0}$ only at **0 bore**



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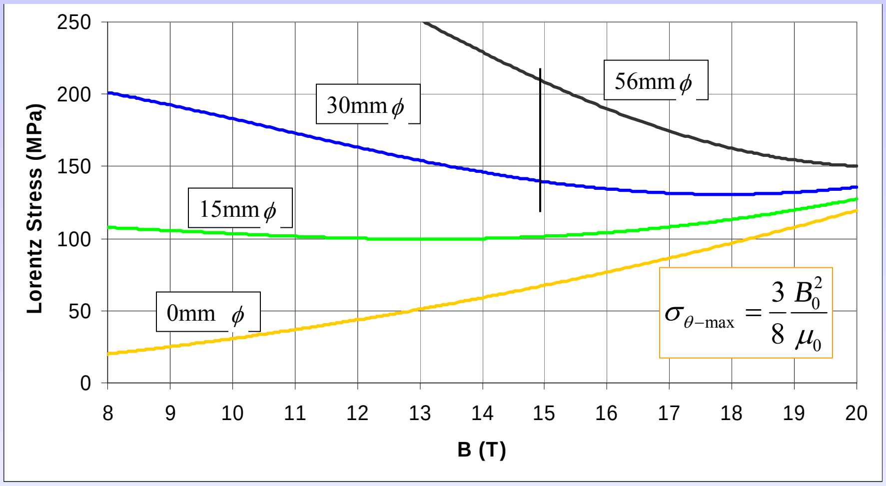
"Short Sample" Lorentz Stress (not graded)

Nb_3Sn 1.9K

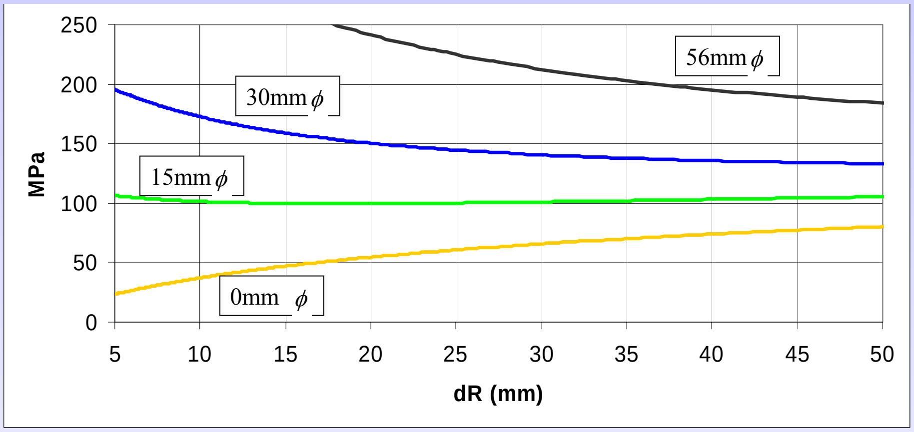


LHC – NbTi and Nb3Sn @ 1.9K
56mm bore

- A NbTi 31.25mm LHC coil (not graded) generates a 9.5T and 68 MPa Lorentz stress
- A Nb3Sn 31.25mm LHC coil (not graded) generates 14.9T and 210 MPa Lorentz stress
- Increasing the size to 2x31.25mm will raise the field to 17T and 175 MPa Lorentz stress

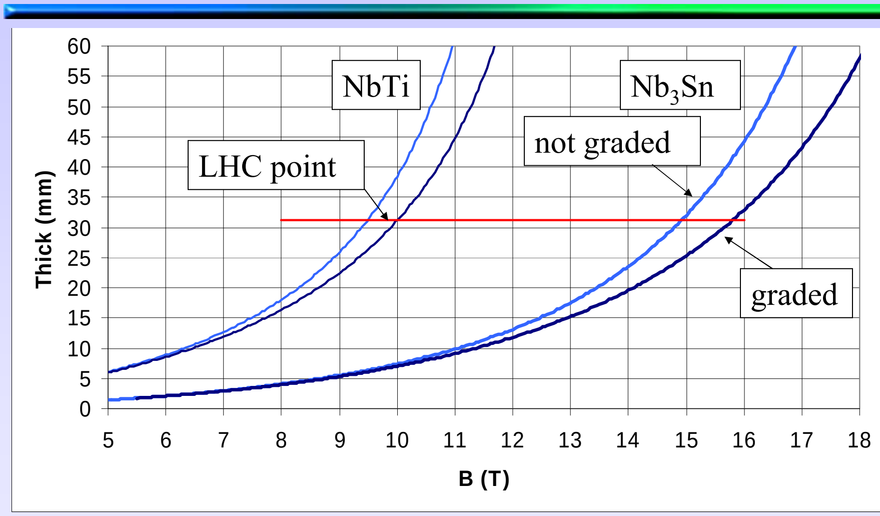
Lorentz Stress (not graded)

Nb_3Sn 1.9K



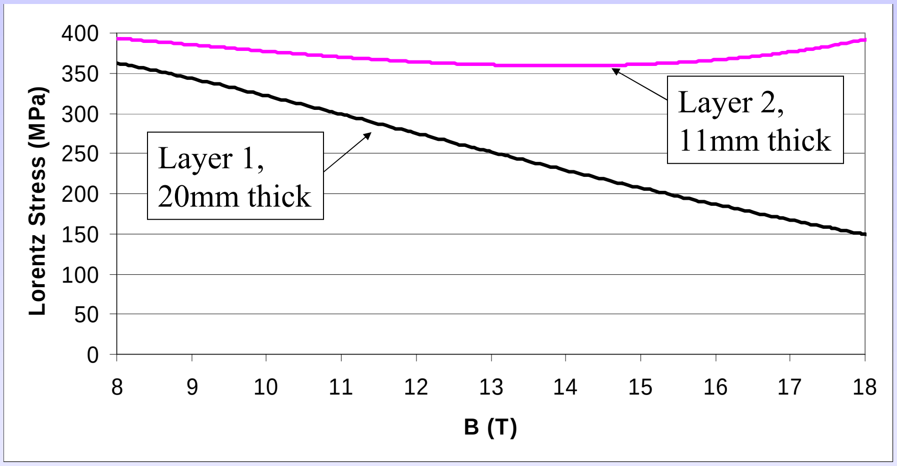
To grade or not to grade

56mm bore, NbTi and Nb_3Sn at 1.9K



Lorentz Stress – graded coil

56mm bore, Nb_3Sn at 1.9K

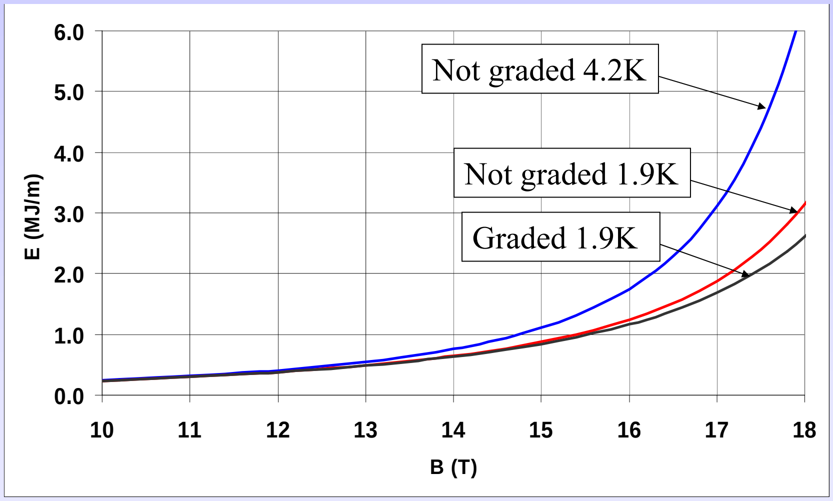


LHC – Nb_3Sn @ 1.9K
56mm bore

A Nb_3Sn 31.25mm LHC coil (**graded**) generates 15.8T and 190 MPa in layer 1 and 365 MPa in layer 2.

Stored Energy

56mm bore, Nb_3Sn



LHC – NbTi and Nb3Sn @ 1.9K
56mm bore

- The stored energy of 31.25mm LHC NbTi coil (not graded) is 384 (KJ/m)
- The stored energy of 31.25mm LHC Nb_3Sn coil (not graded) is 845 (KJ/m) (14.9T)

Conclusion

- Nb_3Sn coils can withstand compression of ~200MPa (HD1)
- We have a high pre-stress delivery system and structure.
- We can build one of a kind 20T dipoles today (expensive).
- Today's practical limit for an accelerator dipoles is around 16T.
- Grading will reduce coil size but increase the stress - R&D issue.
- Stress management reduces Je and field
- Accept high stress, and stress manage only where needed
- Higher stress is confined to the outer layer
- The increase in stored energy ($>B^3$) – R&D issue
- Beyond 16T-18T we should consider adding high T_c coils

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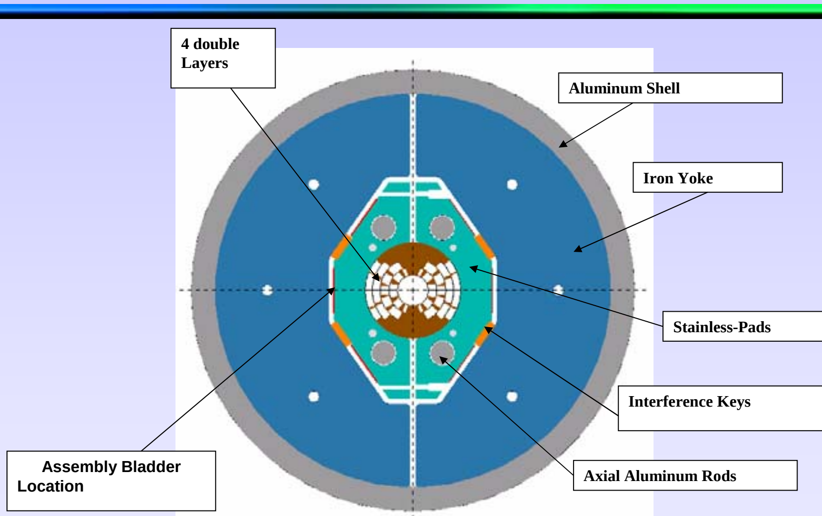
17T dipole 50mm bore



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