Towards Nb_3Sn accelerator magnets, challenges & solutions, history & forecast

Shlomo Caspi

Superconducting Magnet Group

Lawrence Berkeley National Laboratory

June 11, 2013

Nb_3Sn Accelerator magnets

- Programs and institutions
- What have we learned
- What is the forecast

Nb_3Sn Programs

- LARP (Hi-Lumi Quadrupoles) – BNL, FNAL, LBNL, CERN
- FRESCA-2 (Dipole) – CEA, CERN
- 11T (Hi-Lumi MBHSP Dipole) – FNAL,CERN

High Field Base Programs

- BNL/FNAL/LBNL/TAMU – HTS demonstration, Solenoids
  Nb_3Sn, Nb_3Al, Bi-2212 cables
  Nb_3Sn, Bi-2212 coils, 20T dipoles for Hi-Energy
- CERN/CEA – Nb_3Sn, HTS conductors, coils, magnet technology
- KEK – Nb_3Al racetracks

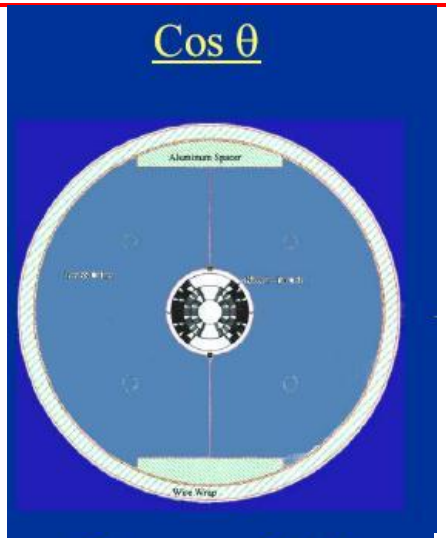
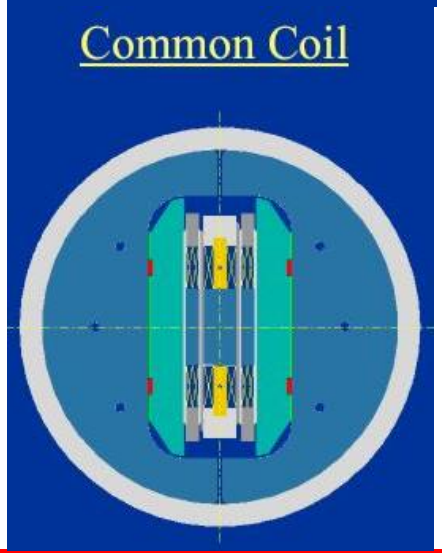
Accelerators, Superconductors, magnets

- Brittle coils
- Delicate assembly
- Bore size
- Coil stress
- Structure stress
- Protection

Superconducting Accelerator Magnets

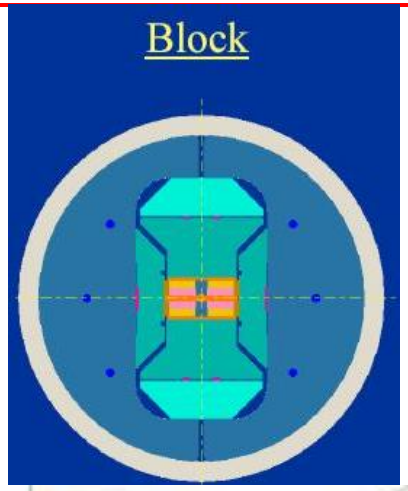
B (Tesla)	Accelerators	Superconductors	Magnets
20	Very high field e.g. Hi-Energy	Nb_3Sn + HTS+NbTi Nb_3Sn	Cosine-Theta Stress management Stress interception
15	High field e.g. Hi-Luminosity	Nb_3Sn	Cosine-Theta Common-Coil Block Block + stress management
10	SSC and LHC	NbTi	Cosine-Theta
5	Tevatron	NbTi	Cosine-Theta
0			

Nb3Sn High field magnets ….

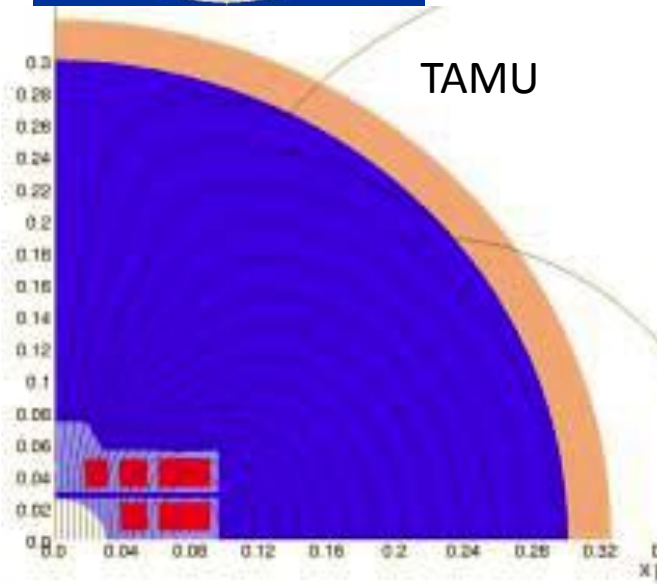
Magnet Type	Pros		
1. Cosine-theta	long history and experience **Cons** Coil accumulates stress		D20
2. Common-Coil	**Pros** simple race-track, double-bore **Cons** 2 bores in 1 structure, assembly		RD

Nb3Sn High field magnets ….

Magnet Type	Pros	
3. Block	simple cross-section	
	Cons	
	flared ends	
	Pros	
4. Block with stress management	lower stress	
	Cons	
	flared ends, pre-stress	



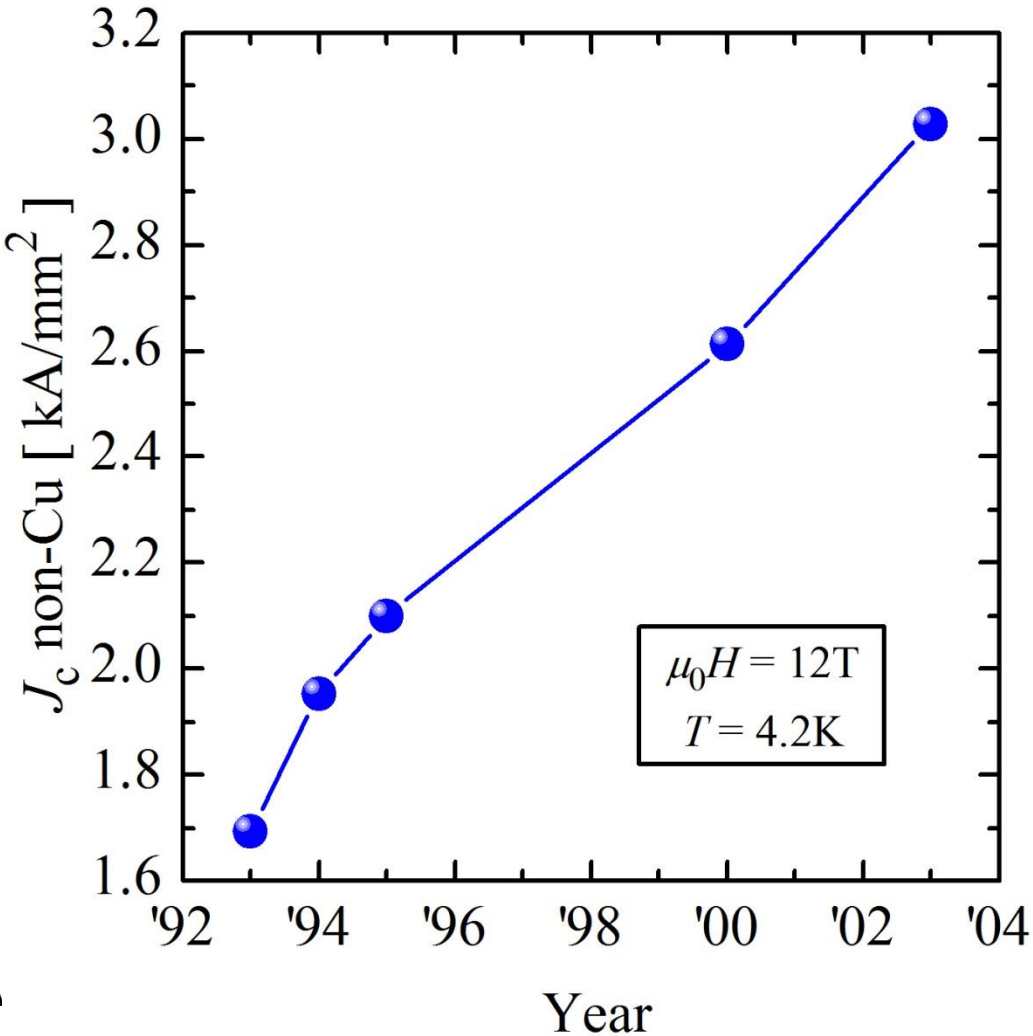
HD



TAMU

Progress in Nb_3Sn J_c

Nb_3Sn
3000 A/mm2 at 12T 4.2K
NbTi
3000 A/mm2 at 5T 4.2K

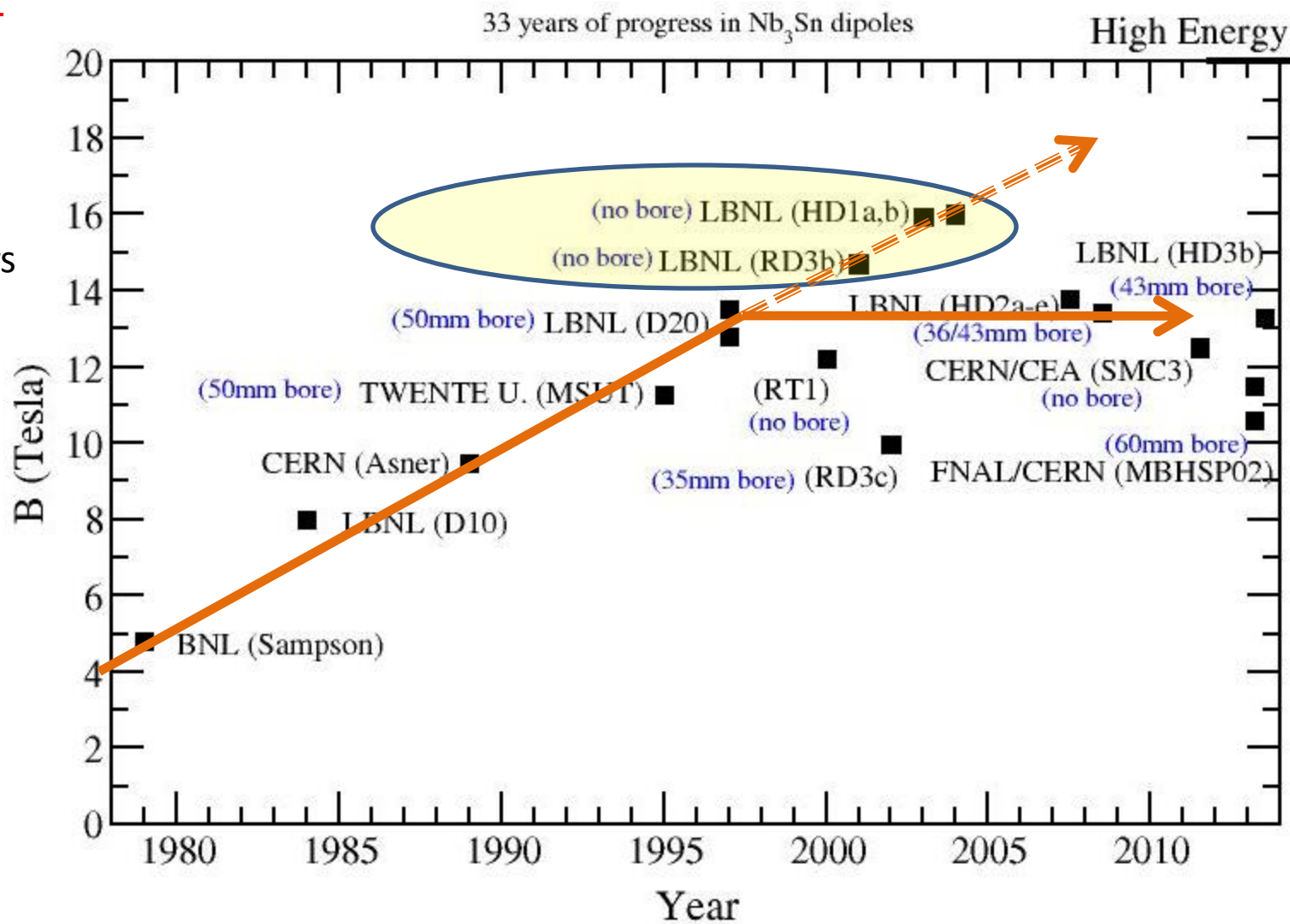


•Parrell, OST, A

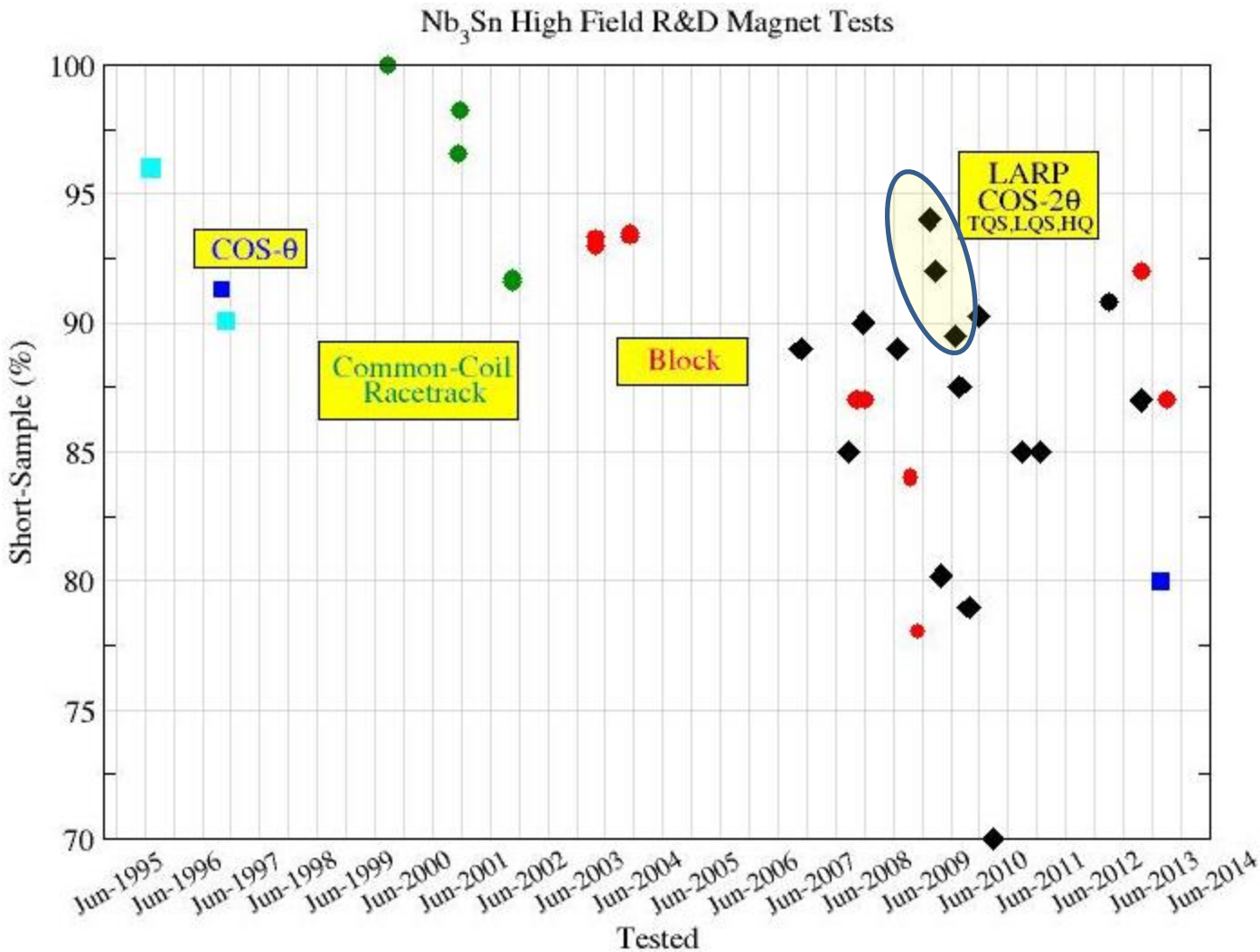
Nb3Sn Dipoles – **An historical perspective: 1979-2013**

- The first 16 years emphasized **conductor R&D**

- The second 16 years emphasized **magnet R&D**



Short-Sample



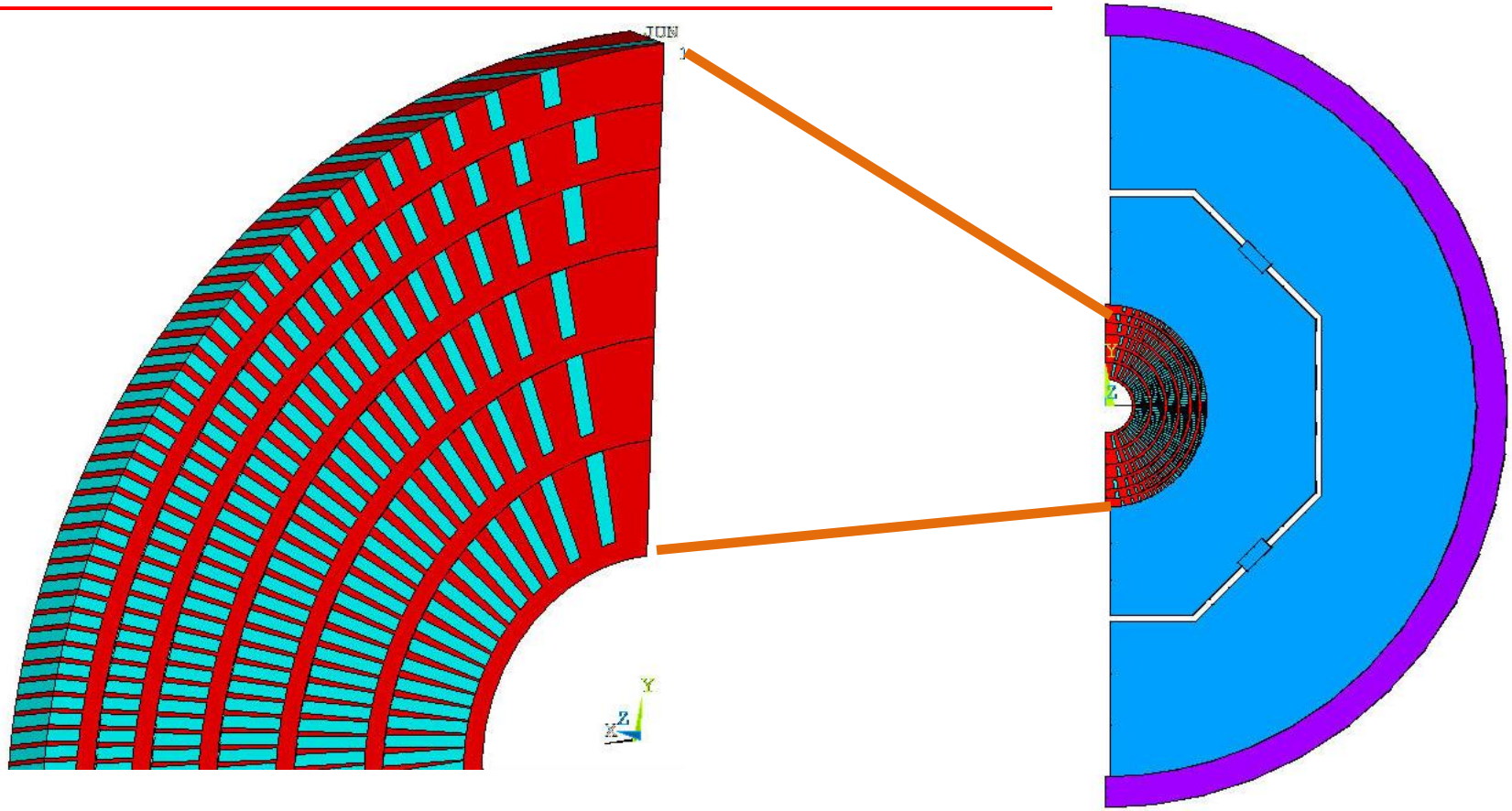
Nb_3Sn for High field magnets ….

- 15T accelerator magnets have reached a **stress limit** (150-200MPa)
- The result is an unpredictable **plateau** above 80% of short-sample
- Replacing individual coils can be used to raise the plateau (LARP)
- Key and bladder technology – delicate assembly, applied pre-stress
- The LHC High-Energy upgrade (20T) will require a “new” approach

Magnets beyond 15T

- The LHC High-Energy upgrade (20T) will need a “new” approach
- Consider an internal structure (in addition to an external one)
  - Include structural elements within the coil
- Intercept Lorentz forces of individual turns or small blocks
  - At 20T Lorentz stress in individual turns is 30/100MPa (tangential/radial)

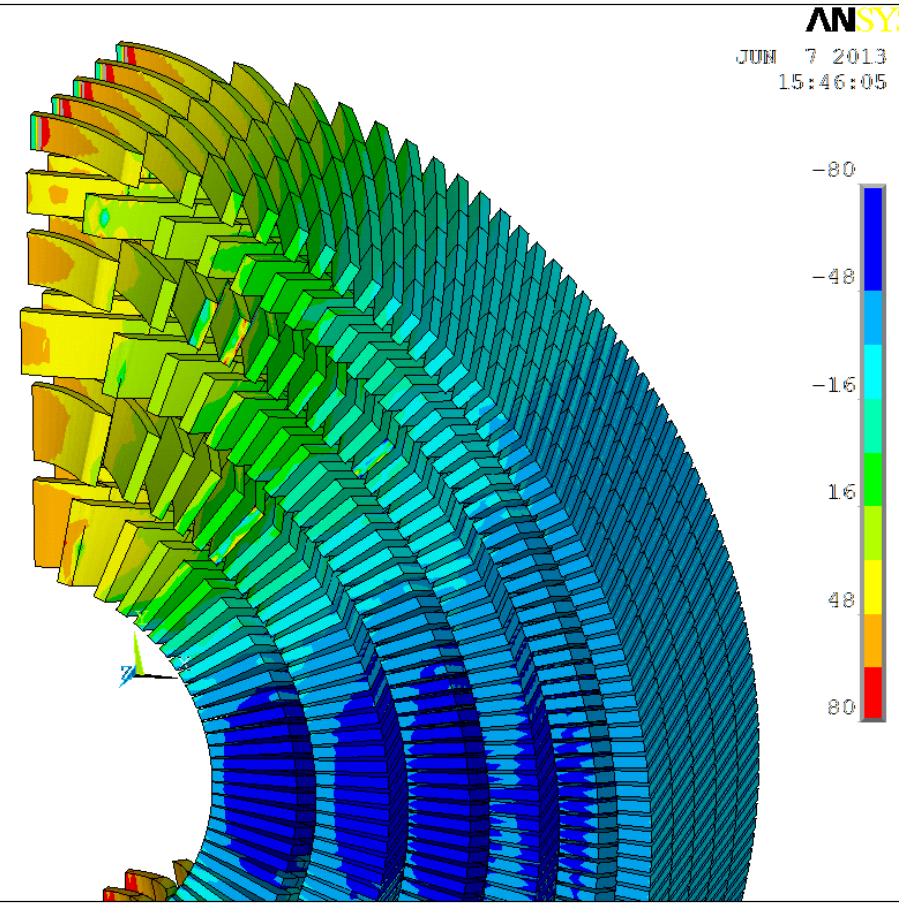
Example- **18T dipole with internal structure**

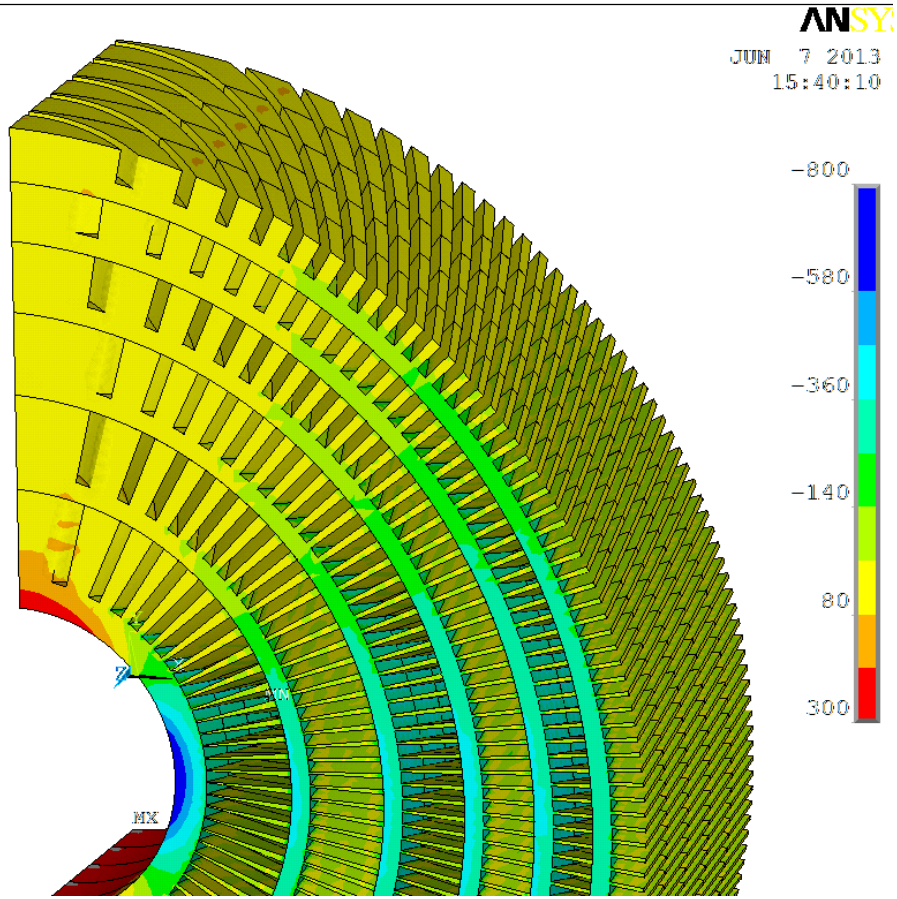


<u>With stress interception</u> **tangential stress is < 25MPa**

<u>Without stress interception</u> **mid-plane stress is 200-700MPa**

Azimuthal Stress in a 18T CCT configuration





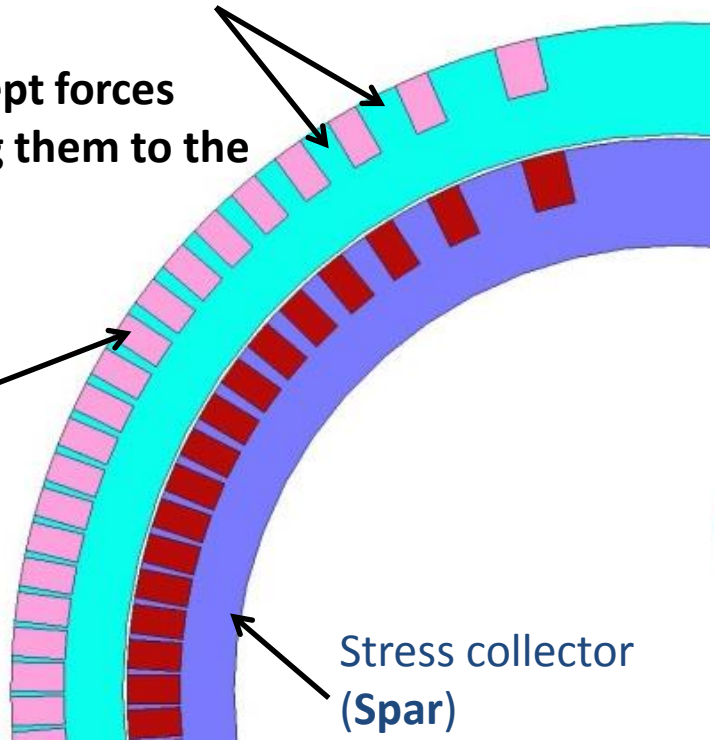
Conductor -80 to 80 MPa

internal structure -800 to 300 MPa

A Canted Cosine-Theta-Magnet* (CCT)

Individual turns are separated by **Ribs**

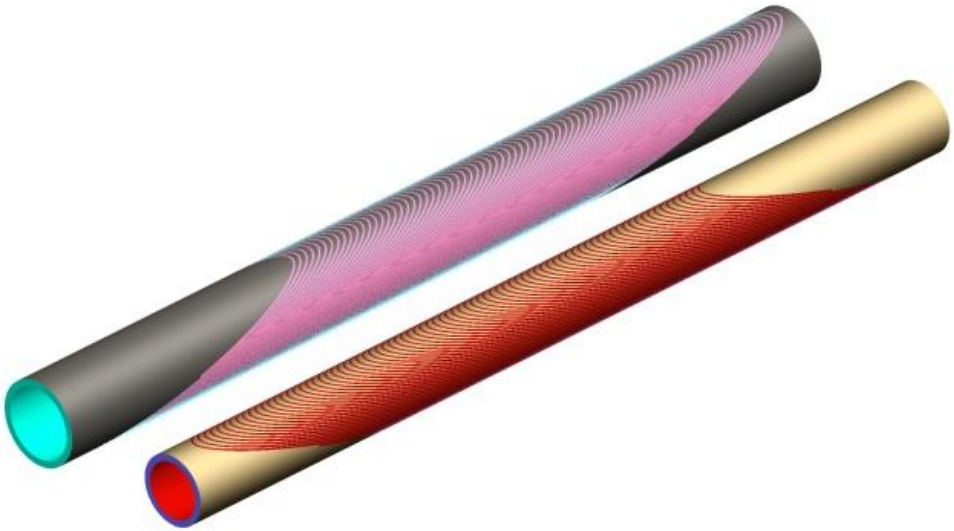
Ribs intercept forces transferring them to the spar



Individual turn

Stress collector (**Spar**)

Canted right:
Field - up dipole + right solenoid



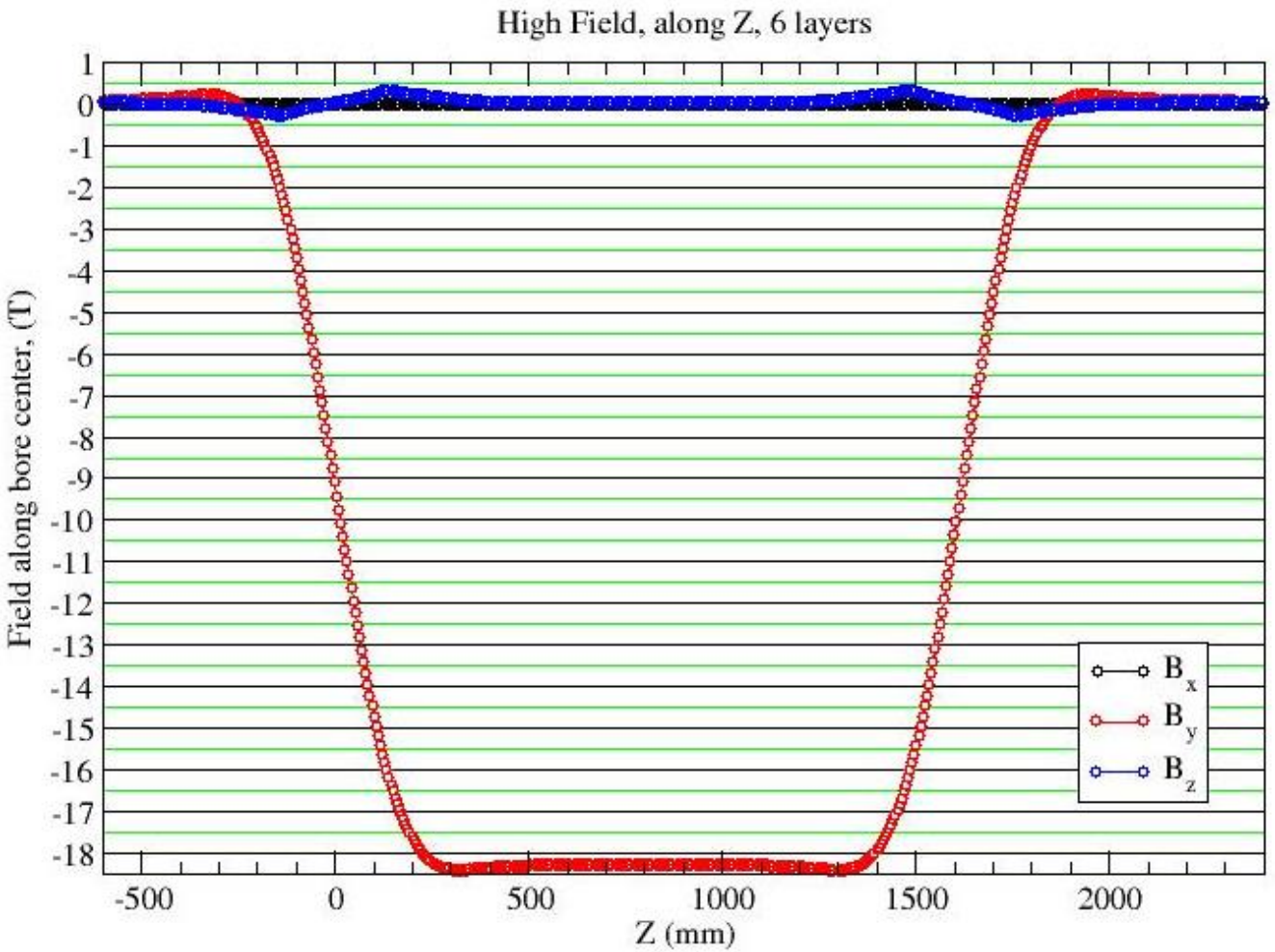
Canted left:
Field - up dipole + left solenoid

Unique turns distribution

$$J_z \sim \cos\vartheta$$

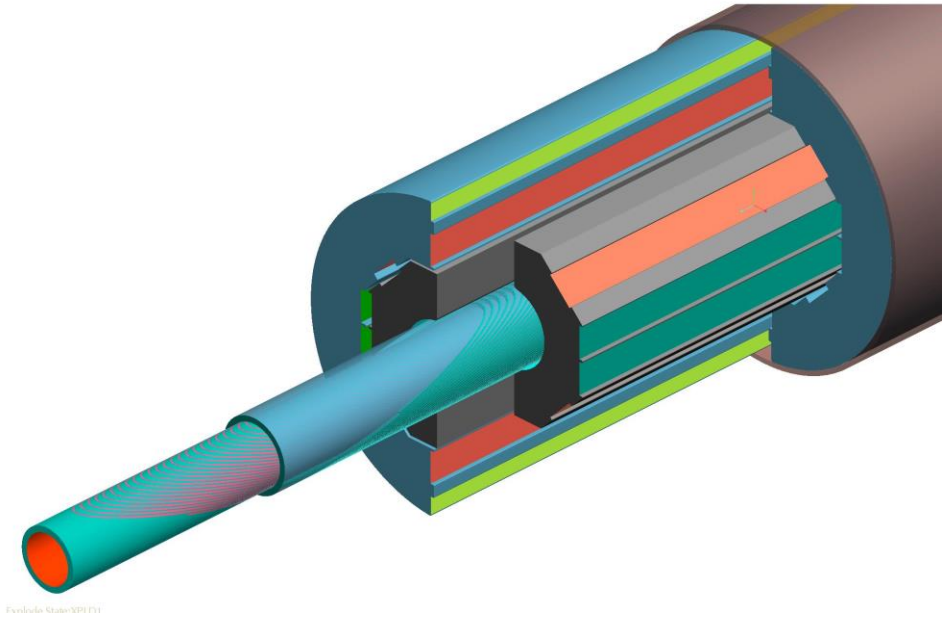
***D.I. Meyer and R. Flasck "A new configuration for a dipole magnet for use in high energy physics application", Nucl. Instr.and Methods 80, pp. 339-341, 1970.)**

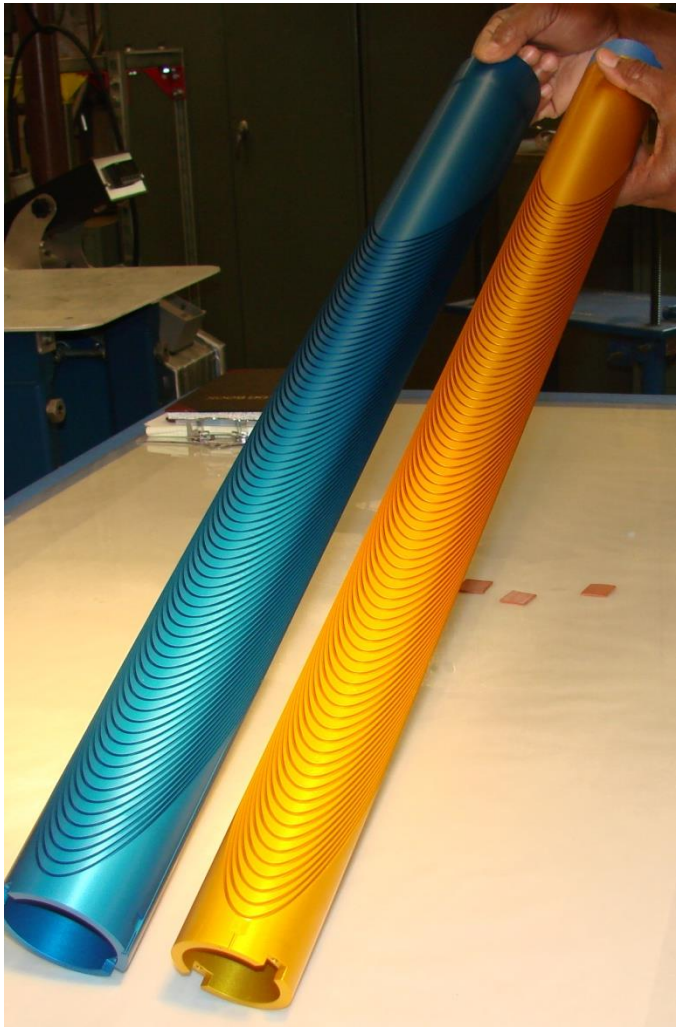
Example – 18T


High Field, along Z, 6 layers
Field along bore center, (T)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-500
0
500
1000
1500
2000
Z (mm)
B x
B y
B z

A NbTi model - CCT1

1. Test a 2 layer NbTi dipole – 50mm clear bore, 2.7T
   - Bladder technology
   - Aluminum spars and outer shell
   - **Evaluate manufacturing, test magnet performance**





2. HTS insert dipole

20T forecast

- Accelerator magnets above 15T will require a **new magnet type**

How do we get there:

- Intercepting **tangential Lorentz forces** using an **internal structure** –
  - minimize coil pre-stress
  - Pre-stress the structure not the coil
- Intercepting **radial Lorentz forces** using in addition an **external structure**
- Reducing stress will **reduce magnet training**
- Grading and large bore not a stress limit
- Technology compatible with HTS conductor