Common Coil Magnet R&D

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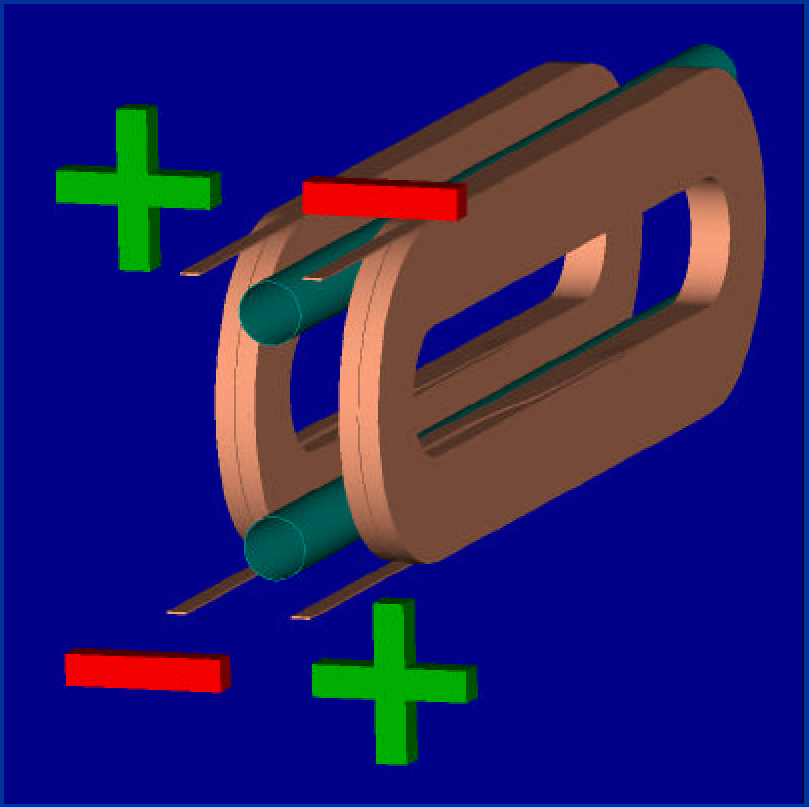
LBNL

Common Coil

- Features
  - It’s a different approach (potential for lower cost)
  - Large bend radii (R&W)
  - Intrinsic dual-bore geometry leads to simpler support structure



R&D Goals

- Common Goal for the Common Coil

- Develop a low cost ($\$ / \int B \cdot dl$) accelerator dipole with *acceptable* field quality and aperture

Best way . . .

- Approach from several directions

Program Profiles

React and Wind, HTS, rapid-turnaround design/technology studies

React and Wind, Nb_3Sn, 11 - 12 Tesla

Wind and React, Nb_3Sn, 12 - 15 Tesla

Exploring Parameter Space

Programs Address these issues

- Conductor utilization (Nb_3Sn/HTS)
- Coil Design
  - Field
  - Field Quality
  - Aperture
  - Simplicity
- Support Structures
- Fabrication/Infrastructure Development
  - Fabrication methods
  - Design tools/studies
  - Tooling/facilities

Conductor

- Advantages
  - High B_{c2}, T_c
    - Higher field magnets, thermal margin, stability, compact geometries
- Challenges
  - Strain Sensitivity and Cabling
    - A bigger challenge for HTS
    - More a fabrication issue for Nb_3Sn- not a problem up to 16 Tesla?
  - Magnetization
  - Cost

Conductor Expectations

What can we expect from conductor development program?

- Nb_3Sn
  - $J_c \leq 3{,}000$ A/mm^2
  - Filament Diameter ≥ 20 microns
  - Strain effects on J_c negligible up to 150 MPa (MJR)
- HTS
  - J_c cross-over with Nb_3Sn now at 14 Tesla
  - Keep working

Strain Sensitivity

- Degradation under Lorentz loads
  - Compressive stress
  - Bending stress
    - With adequate support not as big a deal as we thought for Nb_3Sn, but... Need more study on PIT and Internal Tin

e.g. at 10 T, 100 - 150 MPa, degradation of MJR material is about 10%

- Fabrication (Cabling, Bending)
  - R&W

React & Wind

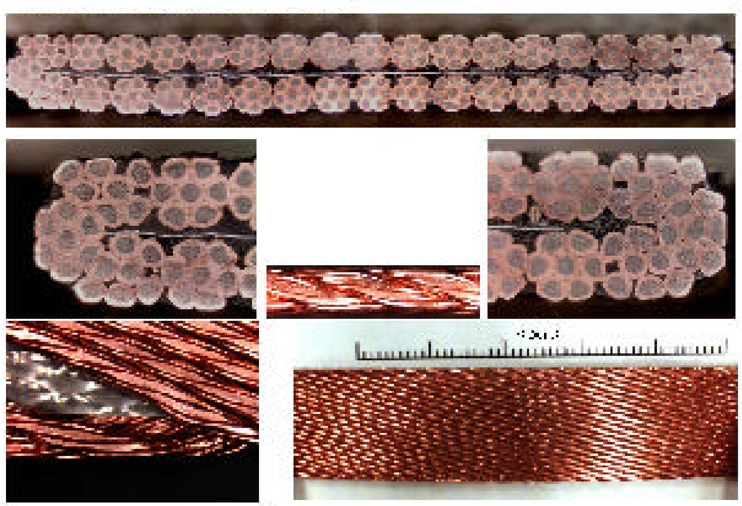
- Advantage
  - Eliminate reacting full size coils
- Challenges
  - Cabling Degradation (Fine strand conductor)
  - Bending Degradation

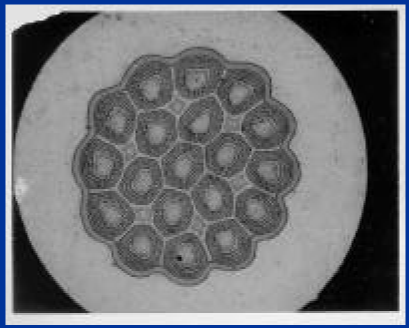
Coils with HTS/Nb_3Sn tapes, cables

Coils with Nb_3Sn cables

HTS/ Nb_3Sn cables

React and Wind Cable R&D

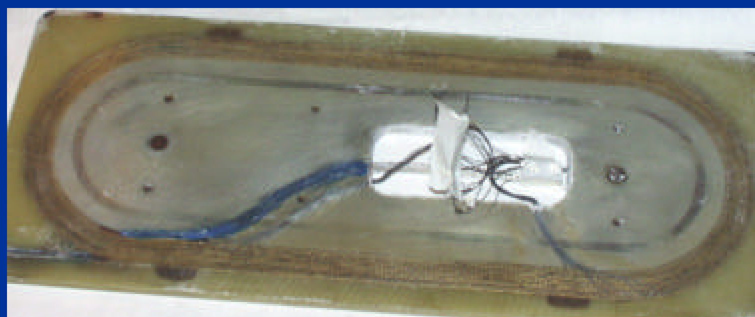


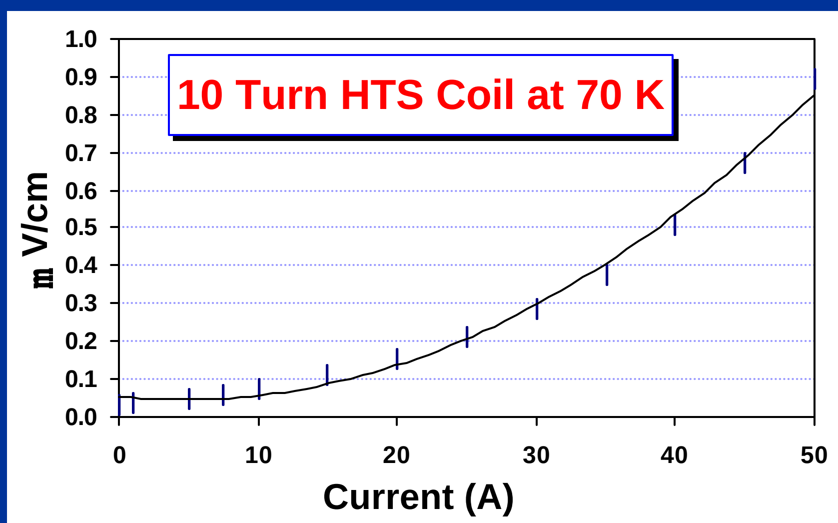


Using left-over ITER internal tin diffusion conductor made by IGC

Cable No.	Wire ∅	Str. No	Cable dimension	Core dimension	Min/max strain[1]
A1	0.7	41	15.04x1.22	none	0.170 / 0.365
A5	0.7	41	15.04x1.24	0.013x12.7	-||-
B1	0.5	57	15.01x0.86	none	0.122/0.260
B2	0.5	57	15.04x1.35	0.025x12.7	-||-
C1	0.3	7x36	15.05x1.53	0.013x12.7	0.196 / 0.421[2]
C2	0.3	7x36	15.05x1.51	none	-||-
D	0.7	60	21 wide	in progress	0.170 / 0.365

HTS Coils

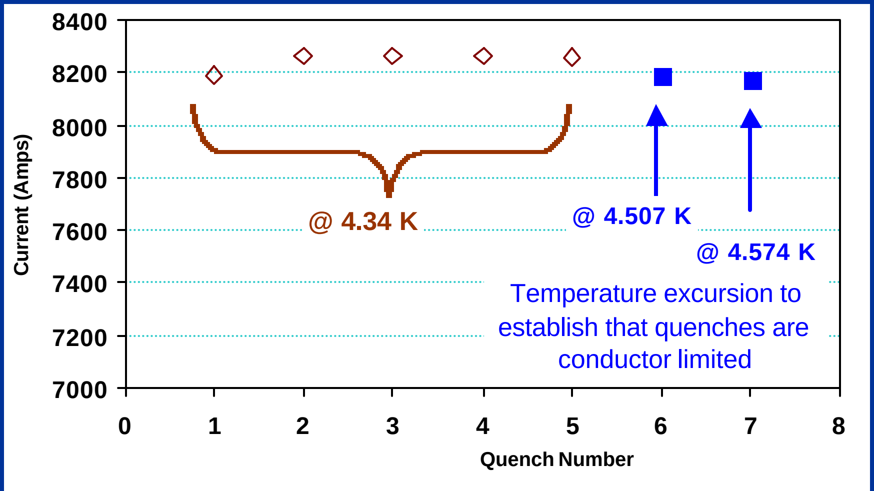


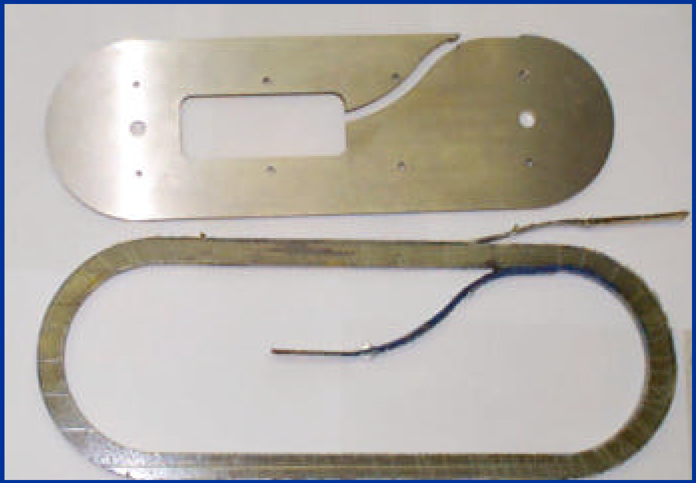


Bi-2212 Coils made with Rutherford cable (IGC/Showa/LBNL)

Early results show no degradation

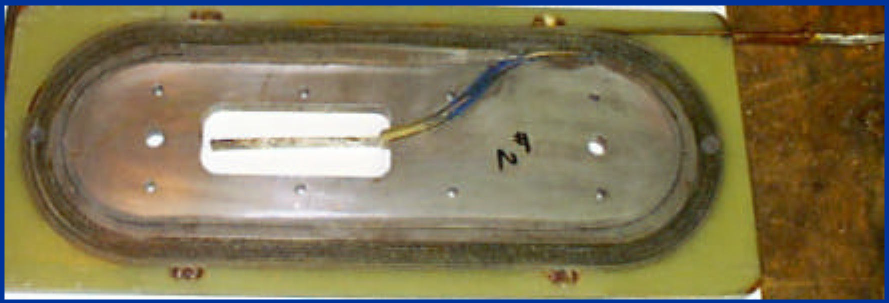
Nb_3Sn Coils



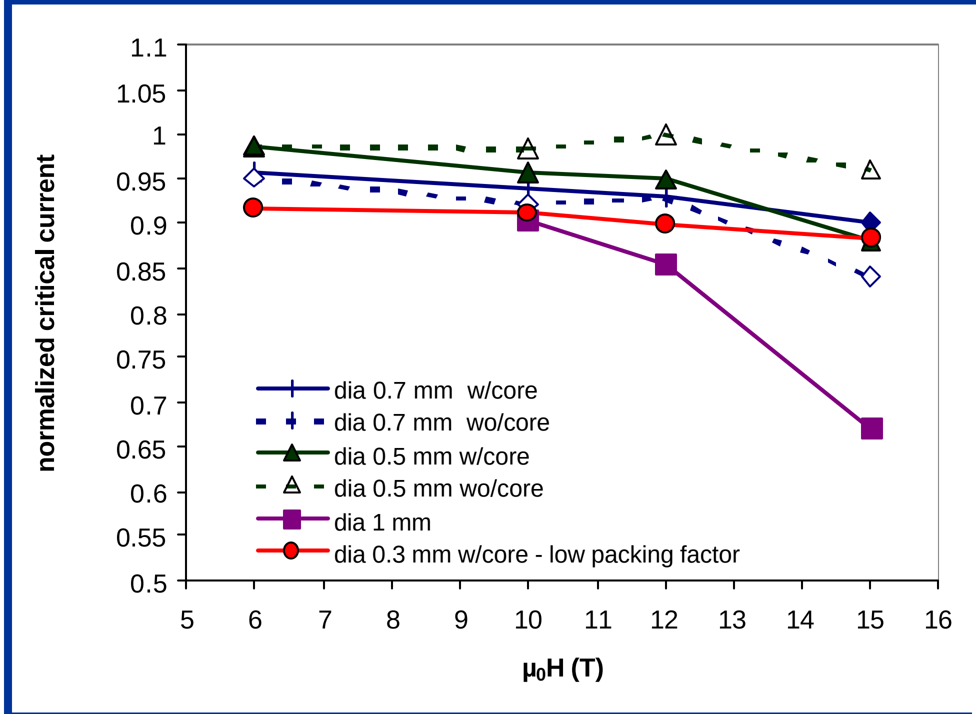


92% Short Sample

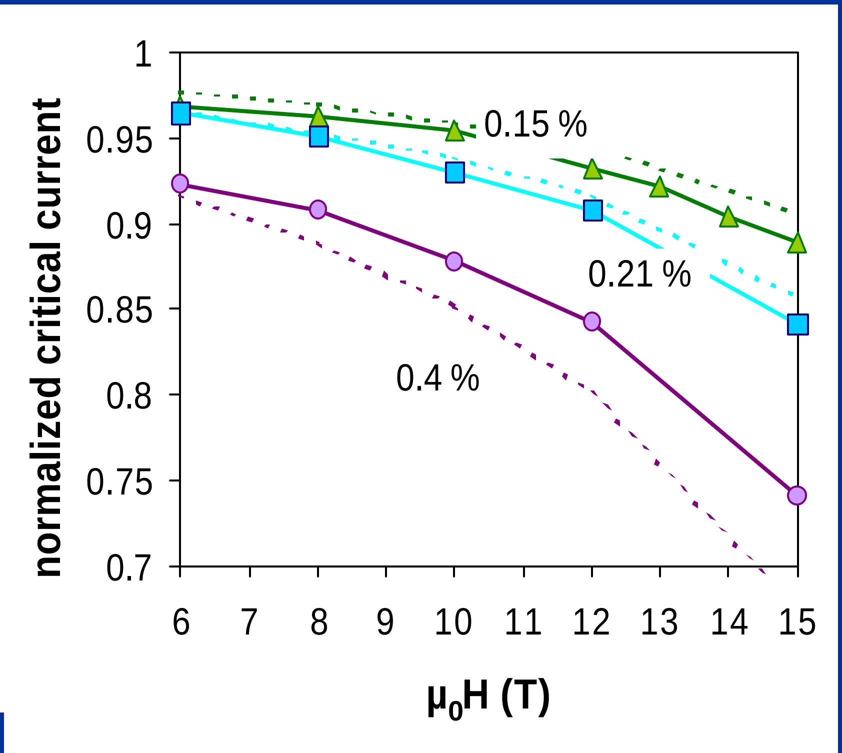
ITER Conductor



Nb_3Sn Degradation Studies



Cabling Degradation



Bending Degradation

React & Wind

Early results are promising …

but there is much more work to be done

- Cable degradation
- Design variations - cables and magnets
- Coil testing in magnet environment

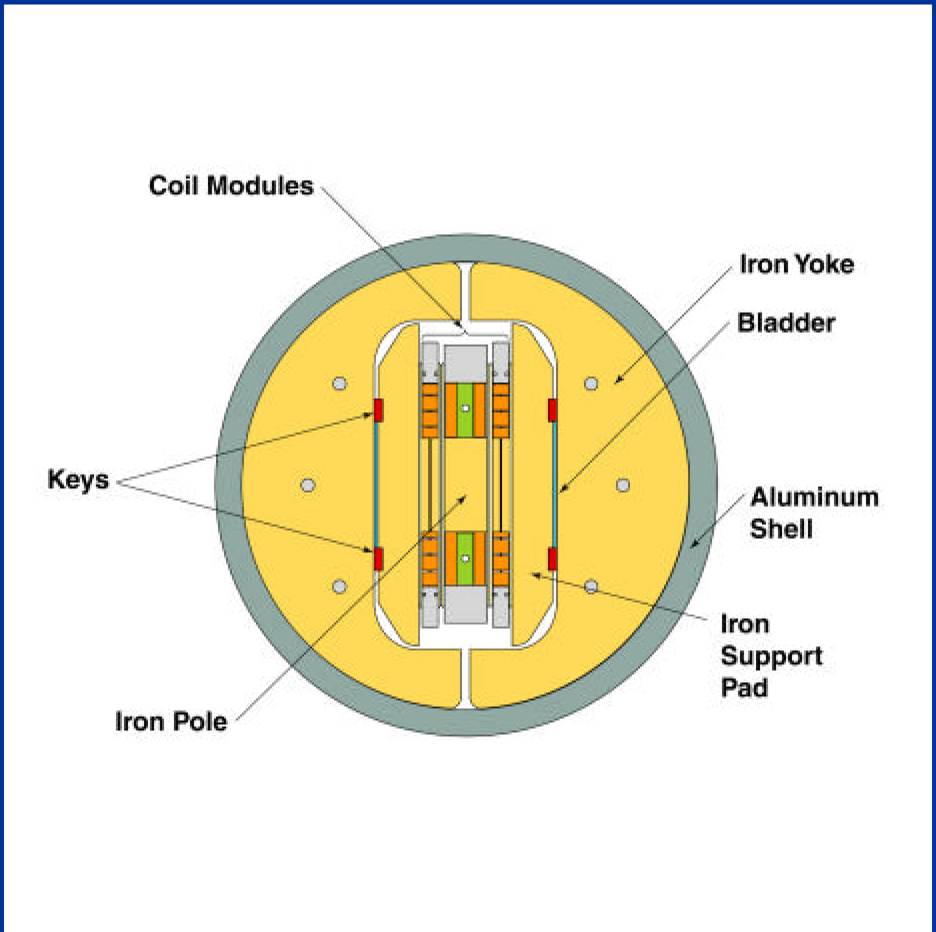
Coil Design

- Many, many options exist
  - Really depends on parameters one wants to optimize
- Some combination of these plus others
  - Field
  - Field Quality
  - Aperture

And . . . Simplicity - low cost

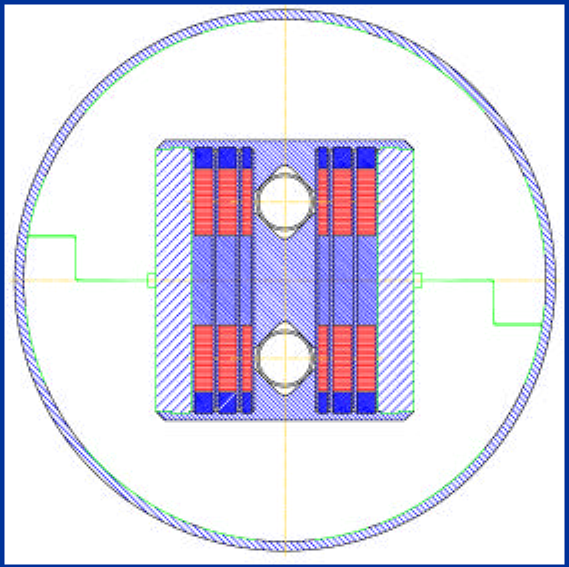
High Field

- RD-3
  - 14 Tesla
- High stress
- Support structure
- Fabrication methods



High Field

- 12.5 Tesla background field for insert tests
  - 2-Layer Nb_3Sn outer
  - Add inner HTS layer
  - Independently operate outer/inner



Field Quality

- Geometric
  - Many options exist
- Saturation
  - Same old problem, same solutions

BROOKHAVEN NATIONAL LABORATORY

BERKELEY LAB

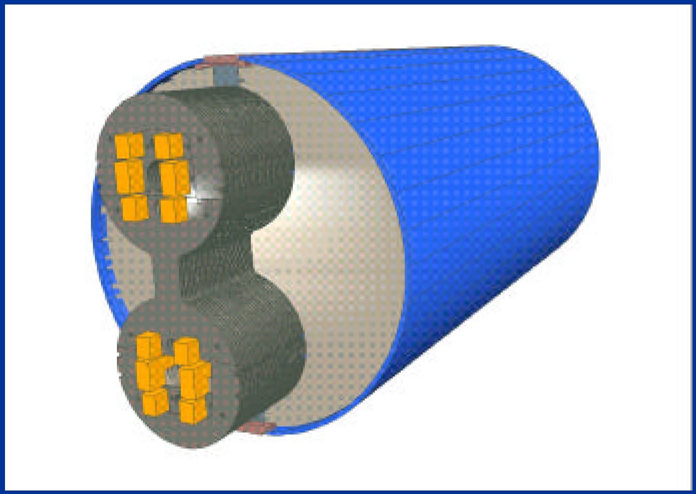
- Magnetization
  - Common problem for all high field magnets using Nb_3Sn/HTS
    - Large filament diameter and high J_c

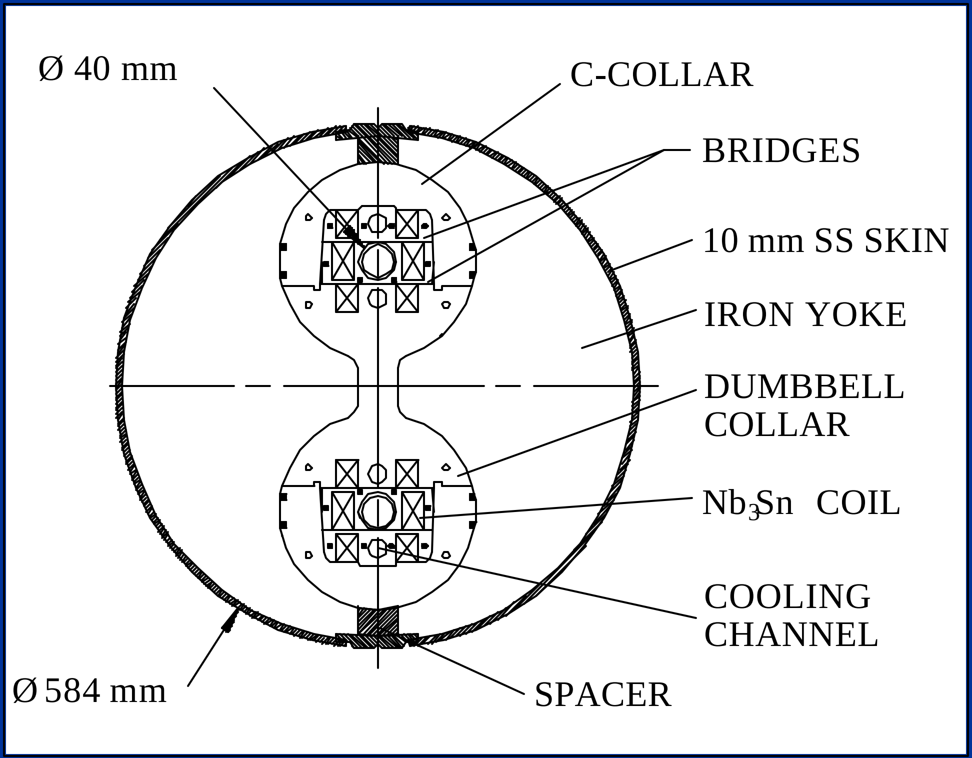
Several methods are being studied to mitigate the problem

  - Coil Geometry
    - Coil geometry can be optimized to alter or minimize the effect
  - Inserts
    - Several options for introducing iron into cross section

Still, AP must cope with it

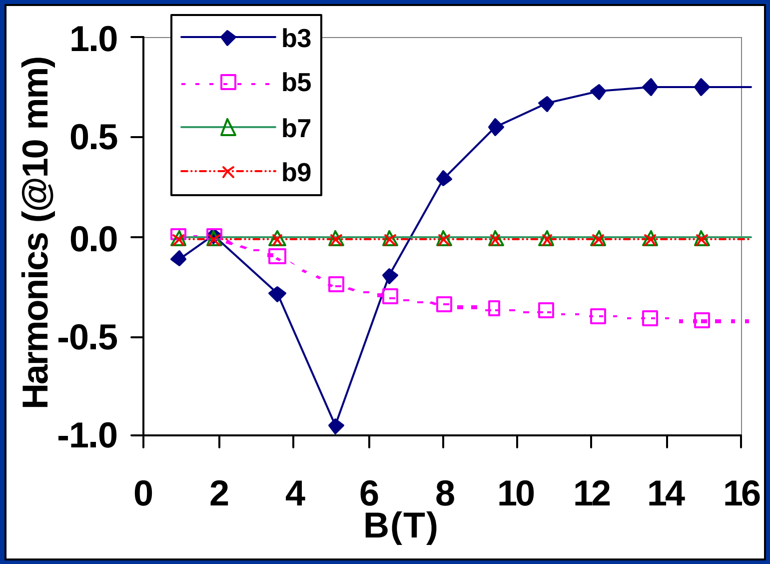
Field Quality

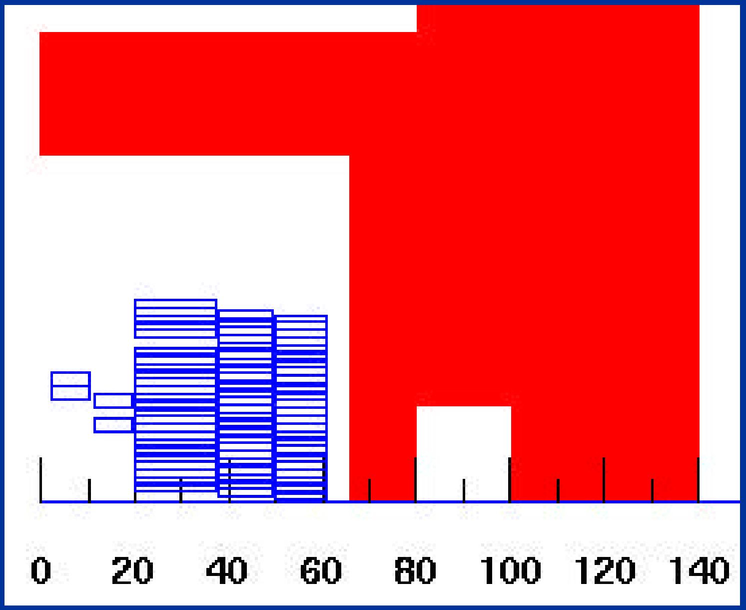




- 11 Tesla
- Single-layer Coils
- Intrinsically low magnetization

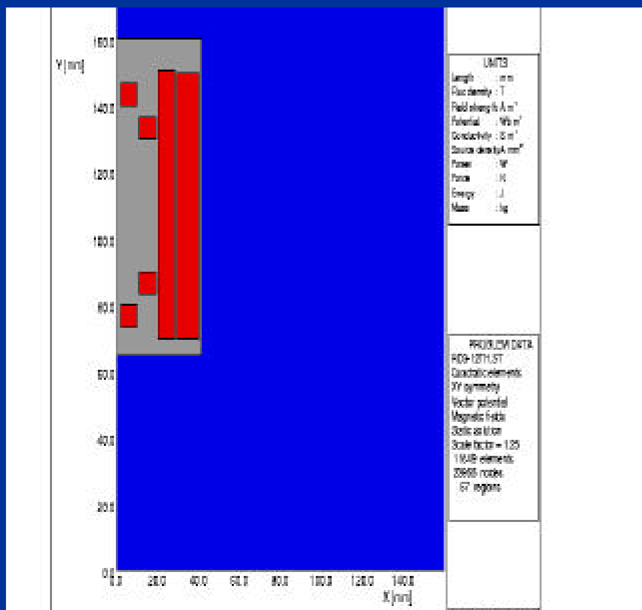
Field Quality

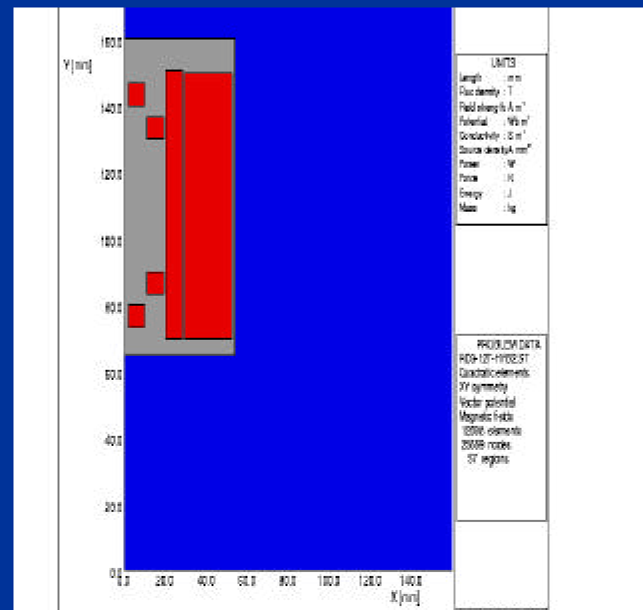




- Low saturation harmonics

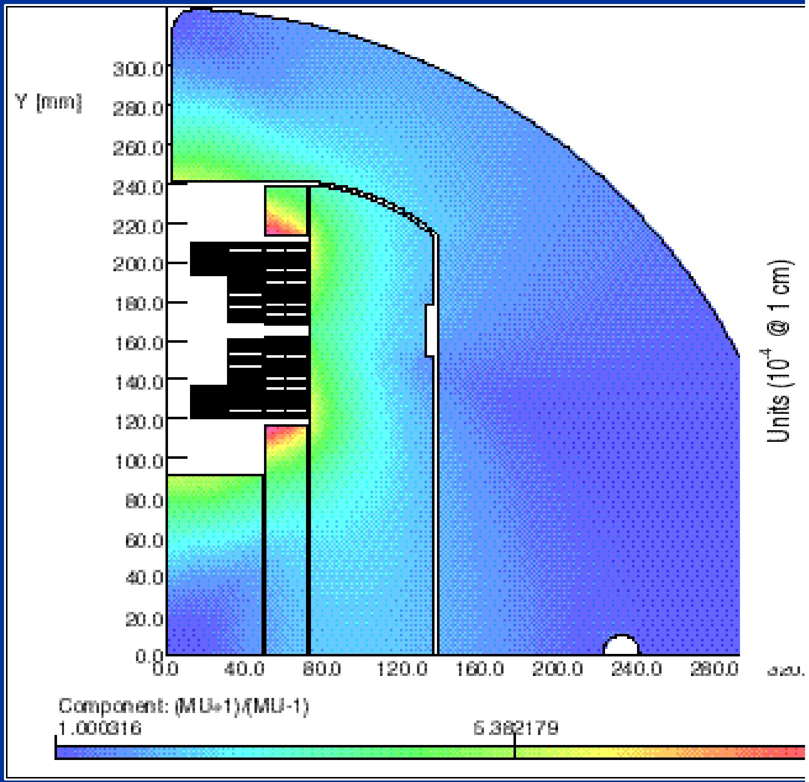
Field Quality





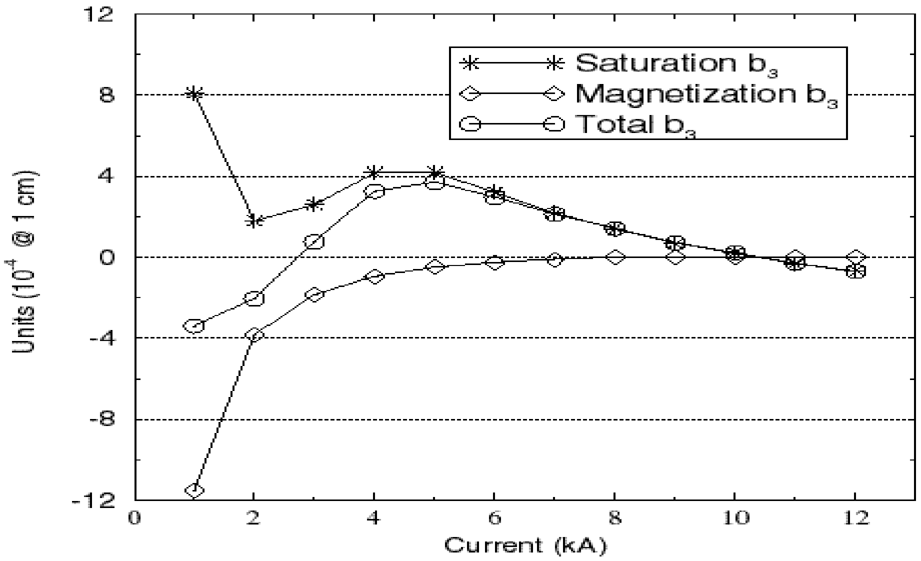
12.5 T Nb_3Sn and Nb_3Sn/NbTi hybrid

Field Quality



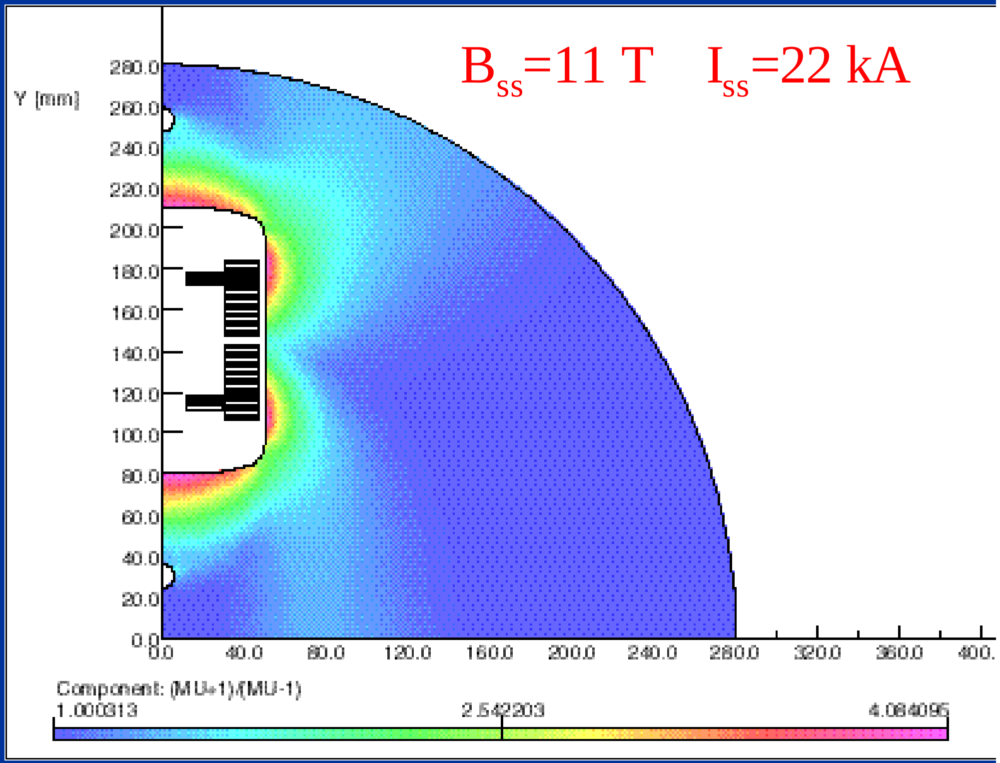
RD-5

B_{ss}=14 T I_{ss}=11.6 kA



Field Quality

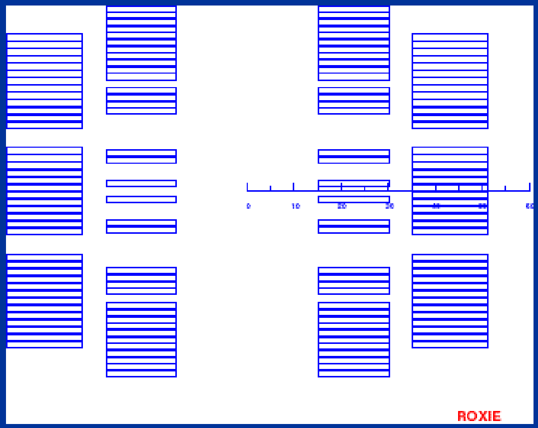
- VLHC Prototype
- Large Bore (> 35 mm)
- Based on < 2,000 A/mm^2

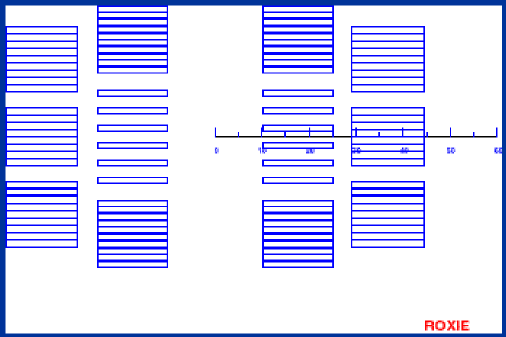


Small Aperture

Simple and efficient

- 30 mm
  - 11.5 Tesla
  - Flat coils
- 20 mm
  - 11.5 Tesla
  - Flat coils
  - One third less conductor





Support Structures

- Minimize conductor displacement under Lorentz loads
  - One of the more important aspects of high field magnet design
- Three issues
  - Compressive Stress
  - Bending strain
  - Field quality (conductor displacement)

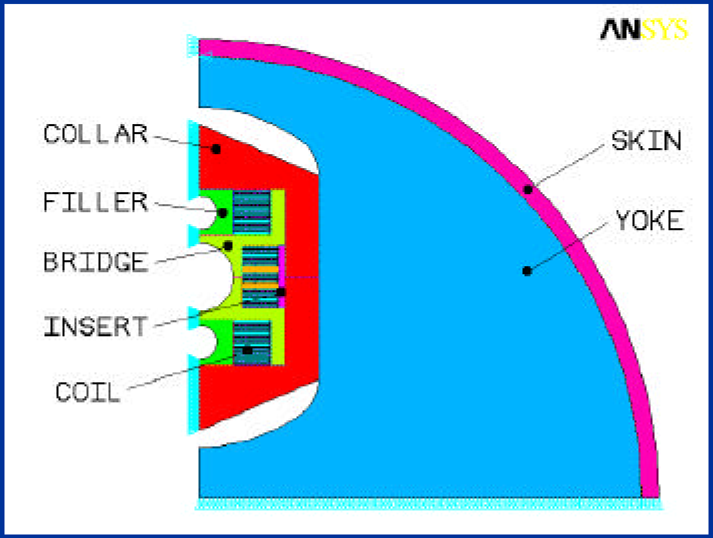
How conservative do we need to be?

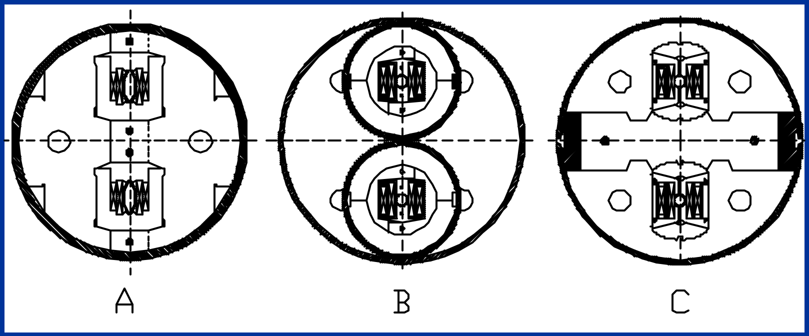
Support Structures

BNL Support Structure for
10-turn test coils

- Simple - fast turn-around

Support Structures





- Single-layer designs
- Al vs SS collars
- Fixed vs sliding coil/collar interface

- Two-layer designs
- Vertically split
- Horizontally split

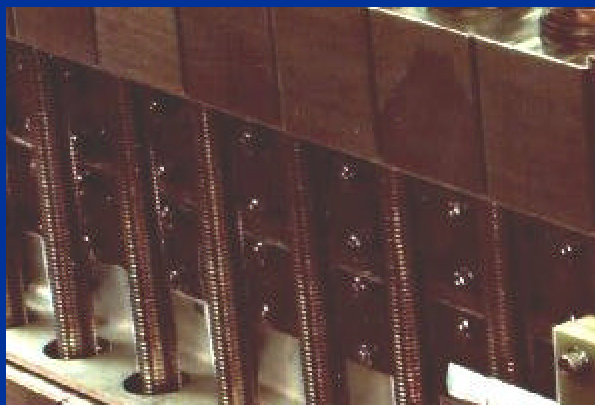
Support Structures

Pressurized Bladder System

(Internal press)

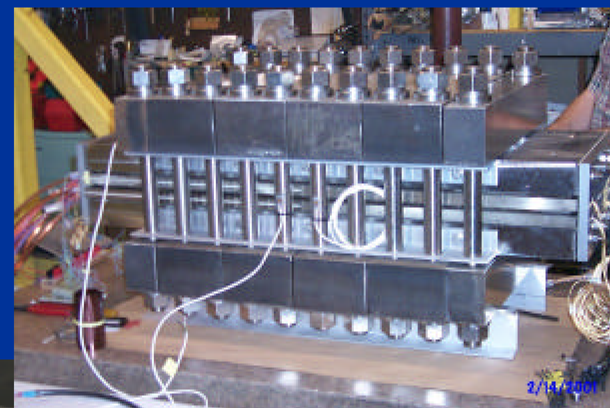
- Minimizes coil displacement
- Easily control distribution of prestress
- Low RT stress

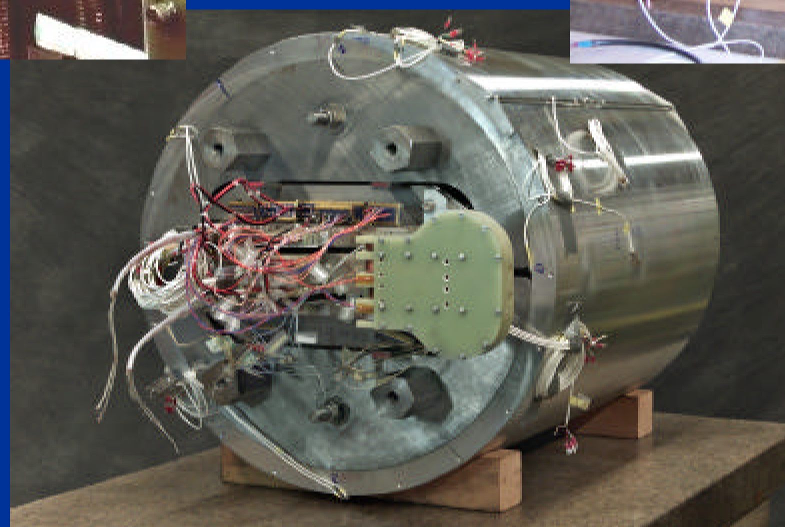
Support Structures



8 Tesla

12 Tesla





16 Tesla

Fabrication/Infrastructure

- Fabrication
  - Cost and Performance Related Issues
    - Insulation
    - R&W vs W&R
    - Basic fabrication methods
- Infrastructure
  - Existing infrastructure at BNL and LBNL for Nb_3Sn
  - FNAL has recently augmented their facilities

Fabrication/Infrastructure

- Progress will require upgrades
  - Power supplies > 25kA
  - Tooling and Facilities for long magnets

BNL Common Coil R&D

- Primary Goal
  - 12.5 Tesla Common Coil
  - React and Wind
  - HTS insert
- 10-Turn Coil R&D Program in progress
  - Nb_3Sn cable and tapes
  - HTS cable and tapes

FNAL Common Coil R&D

- 11 Tesla Accelerator Quality Common Coil Dipole
  - React and Wind
  - Single layer coils
  - Good field quality
  - Large bore
- Continued Studies
  - Design
  - React and wind cable issues
  - Fabrication methods

LBNL Common Coil R&D

- High Field Common Coil Dipoles
  - Fields greater than 14 Tesla (RD-3)
- Field Quality
  - 13+ Tesla (multi-layer) (RD-4)
  - 11 Tesla (single-layer)
- Continued Studies
  - Design
  - Fabrication methods
-

Common Coil R&D Status and Plans

- Common Coil R&D is well underway and making progress
  - Most, if not all the important issues for this stage are being worked on
  - The tools exist to form the basis of a development program
  - The programs are *very* complementary
    - That's good, because the parameter space is huge
- By this time next year, several magnets will have been tested

Common Coil R&D Addendum

- Considering that we are just beginning, we’re doing great
  - but projected progress is still way below the level of a true development program
- Looking at the long term, let’s put the situation in perspective by looking at the LHC dipole development program

LHC Dipole Development

20 years from start to turn-on

Began in 1987

- Phase I
  - Design trials
  - 5 years @ > 3 magnets/year

Total of over 80 short models

- Phase II
  - Second generation
  - 7 years @ 9 magnets/year

And it was all based on existing, well-developed technology