Magnet Design Approach and Strategy

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DOE Review of Superconducting Magnet Program

Overview of the Presentation

- **Common Coil Design Approach**

  The basic philosophy
  A brief description of the design and its advantages

- **Magnet Program**

  First Magnet ~ 7 T (under construction; almost completed)
  High Field Magnet ~ 14 T (under development; better J_c)

- **R&D Strategy**

  Experimental program for pre-stress and force containment

  High stress and high field (~16 T) configuration

Preface

- 10-15 years to VLHC; 5-10 years to do magnet research

- A rare opportunity to explore alternative approaches

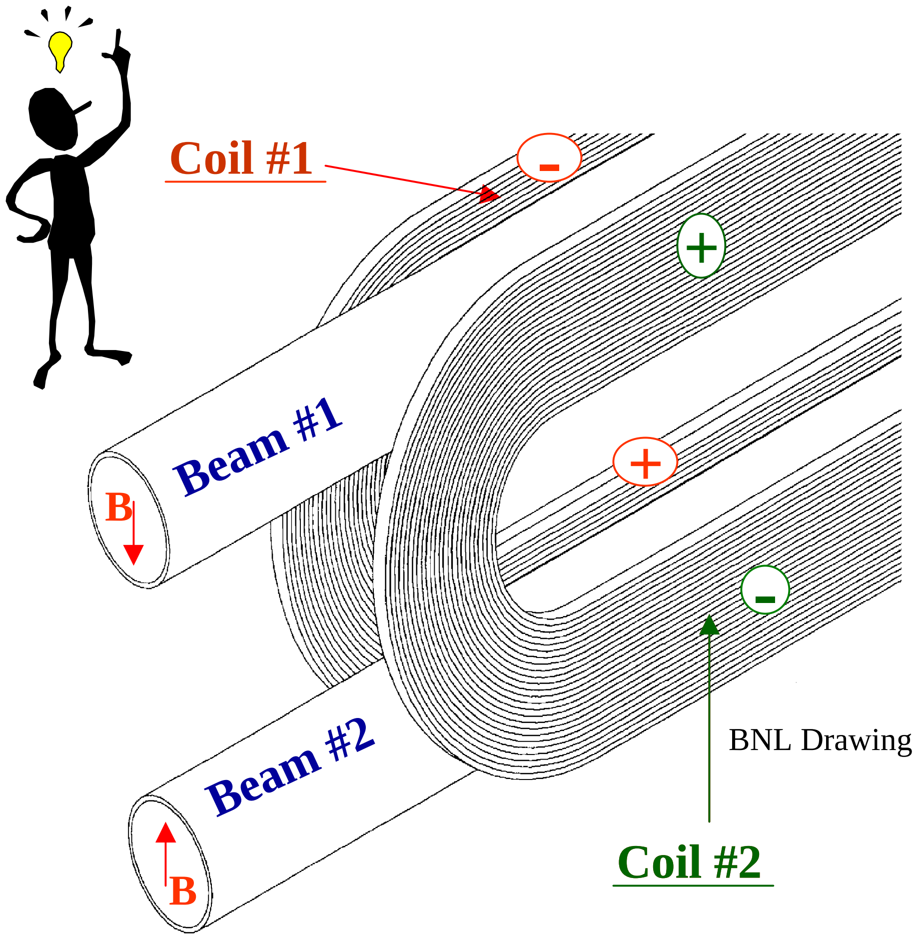
- Be innovative

  Alternate design concept

  "Magnet R&D Factory" for faster turn-around

  to explore/develop innovative magnet technology

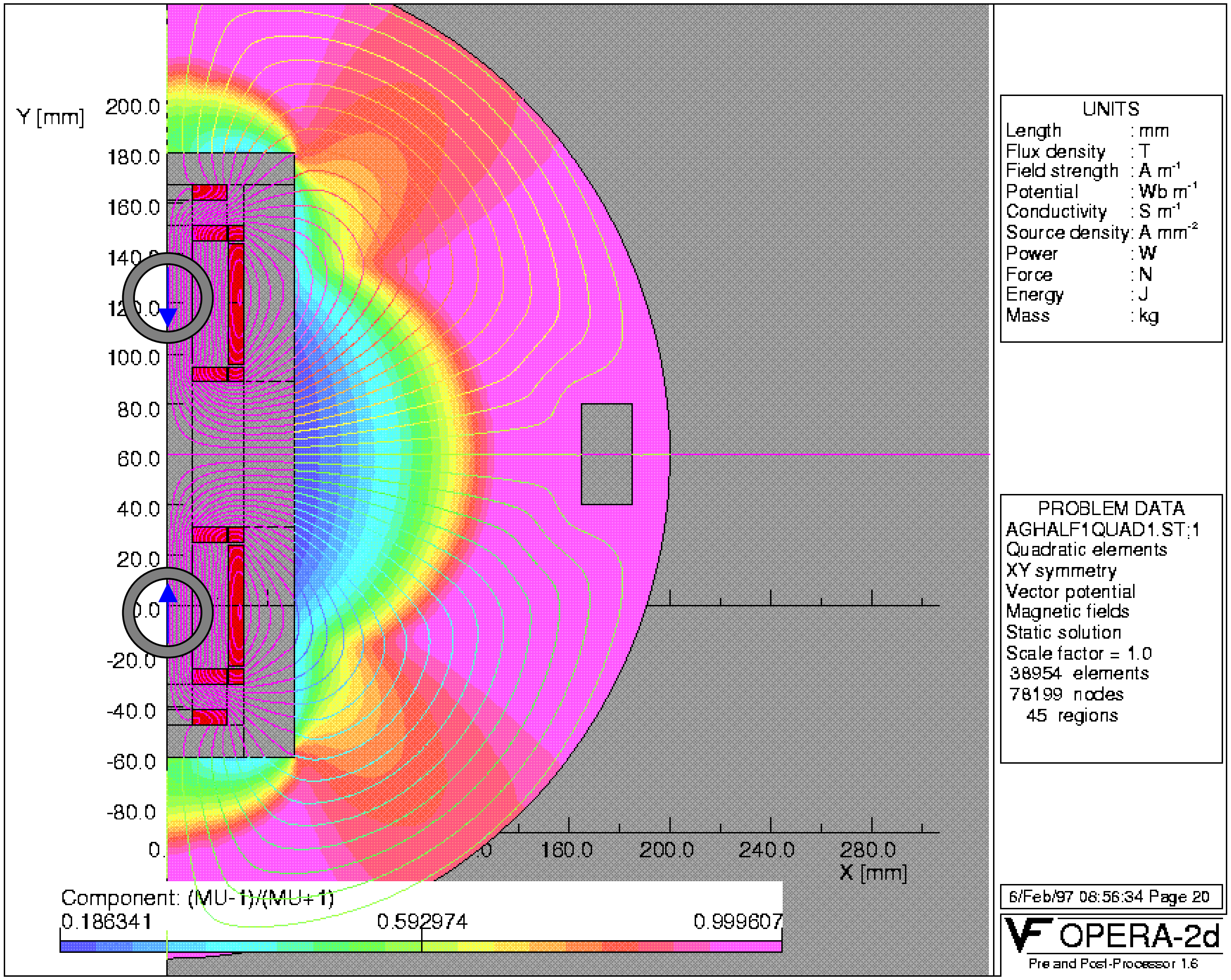
Common Coil Design Concept



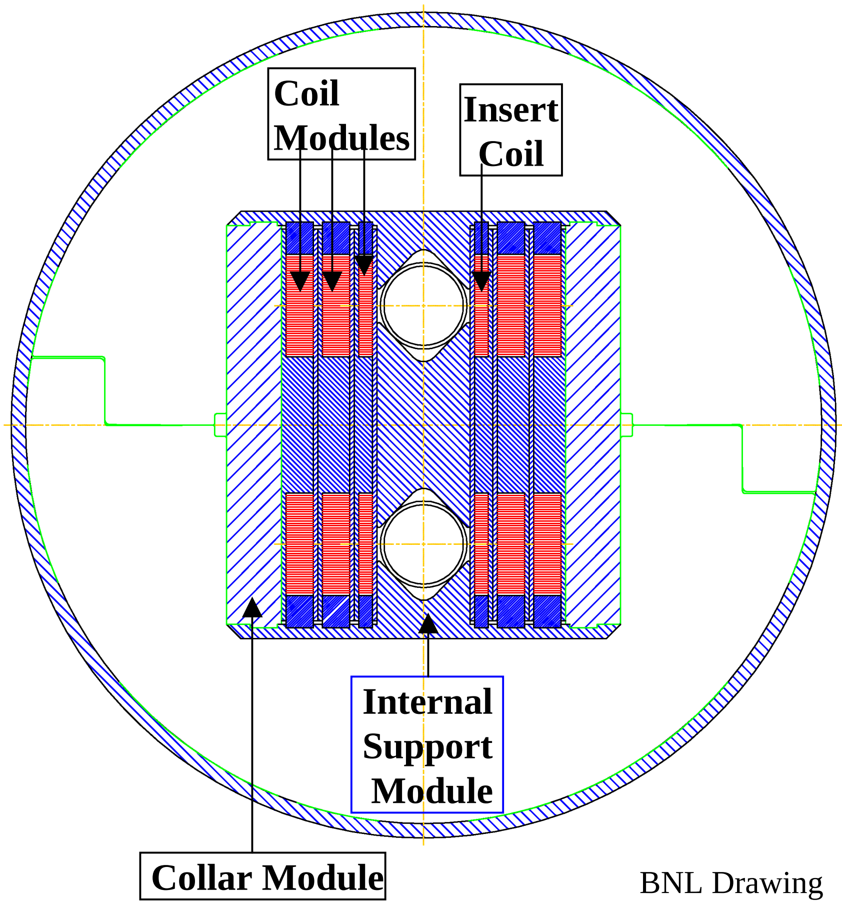
Main Coils of the *Common Coil Design*

- **Simple 2-d geometry with large bend radius (no complex 3-d ends)**
- **Conductor friendly (suitable for brittle materials - most are, including HTS tapes and cables)**
- **Compact (compared to D20, half the size for twice the apertures)**
- **Block design (for large Lorentz forces at high fields)**
- **Efficient and methodical R&D due to simple & modular design**
- **Minimum requirements on big expensive tooling and labor**
- **Lower cost magnets expected**

Field Lines at 15 T in a Common Coil Design Magnet



A Modular Design for a New R&D Approach



BNL Drawing

- Replaceable coil module
- Change cable width or type
- Combined function magnets
- Vary magnet aperture
- Study support structure

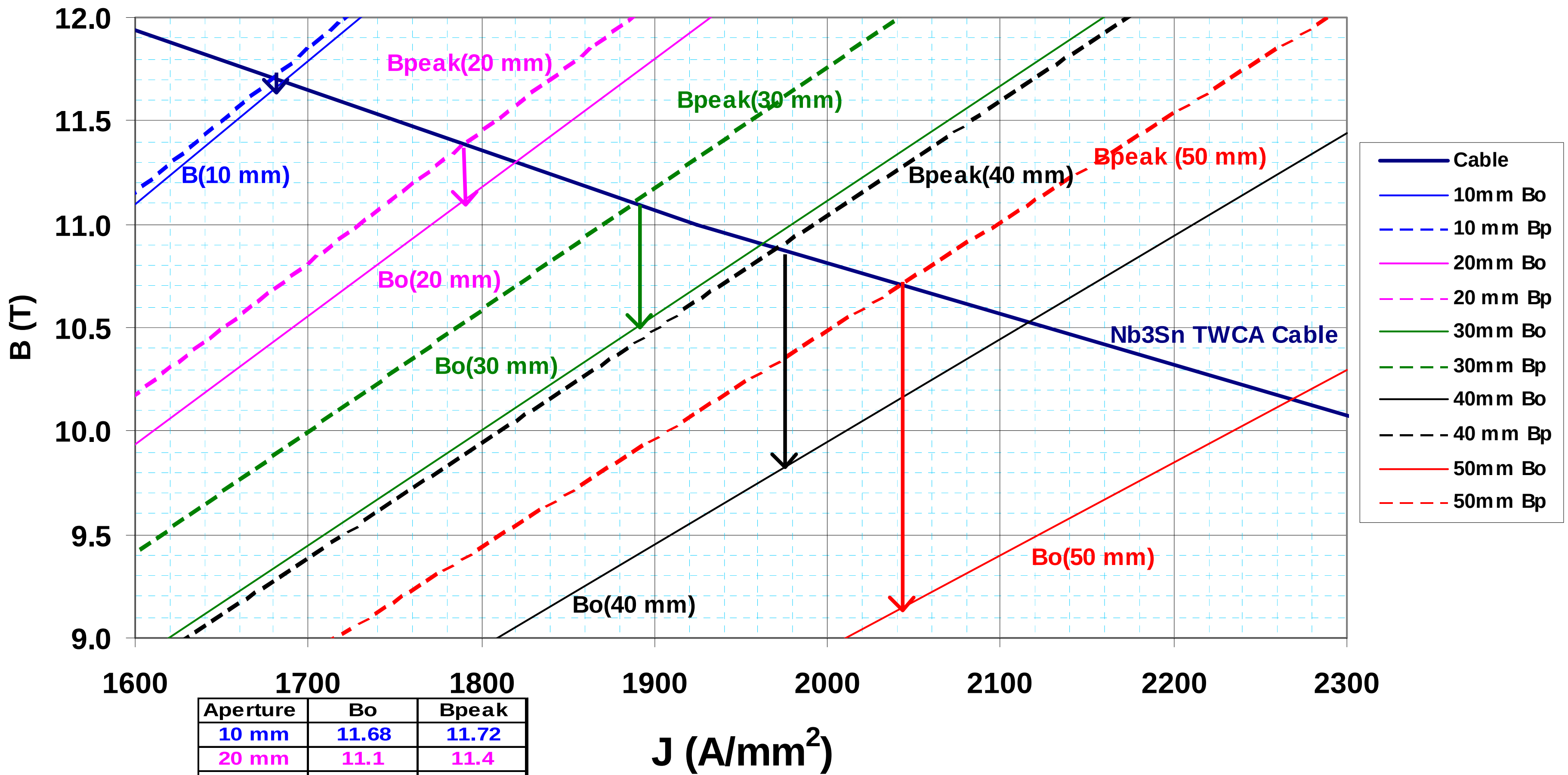
Traditionally such changes required building a new magnet

Also can test modules off-line

This is our Magnet R&D Factory

Change in Aperture for Various Field/Stress Configurations

Expected Performance of a Double Pancake Coil made with D20 Cable



Aperture	Bo	Bpeak
10 mm	11.68	11.72
20 mm	11.1	11.4
30 mm	10.5	11.1
40 mm	9.8	10.9
50 mm	9.1	10.7

I am not the only one to have suggested this type of crazy geometry

Danby, BNL (1983)

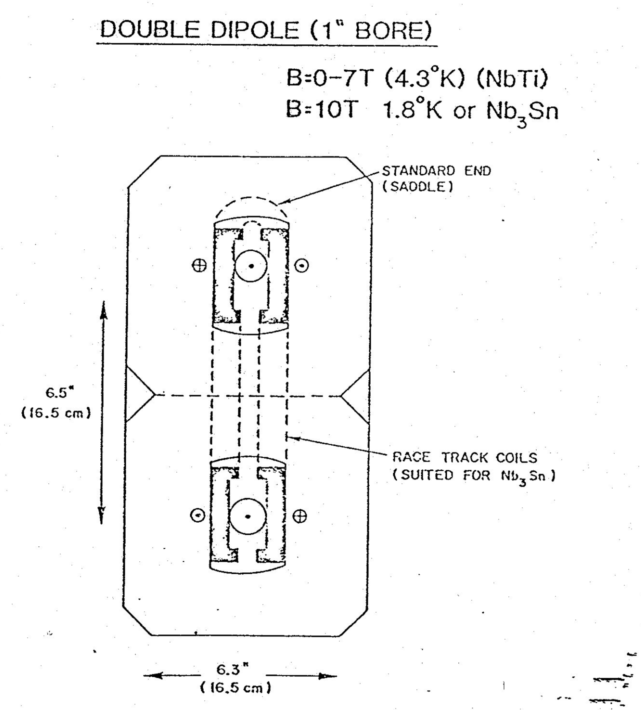


Fig. 3 High-field double dipole design with two coil return options.

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Had to come out of BNL to find what a very respected scientist thought there before I was born as a magnet person.

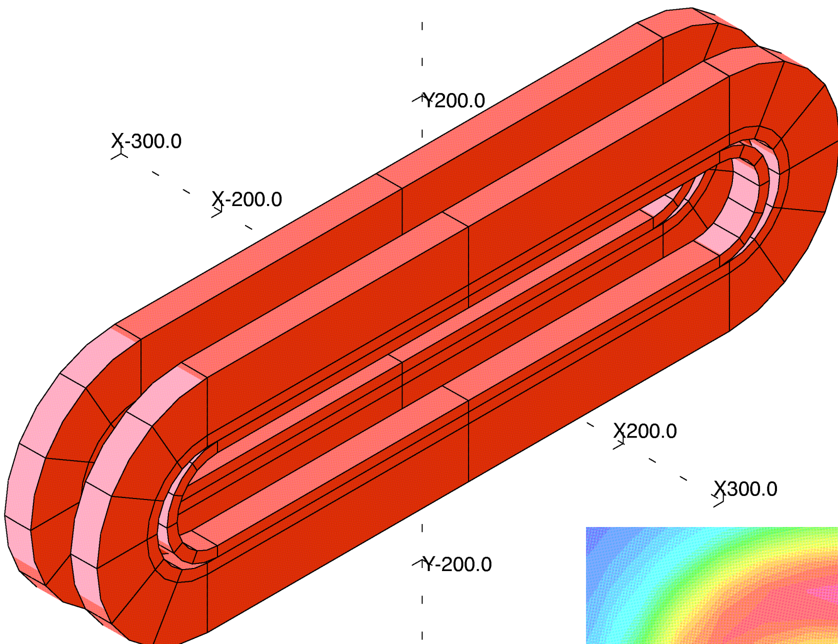
Similar, except that in Danby's design the pole coil must to be bent in a tight radius.

Common coil design has some more advantages in terms of compact, flexible and modular easy-to-fabricate structure, etc.

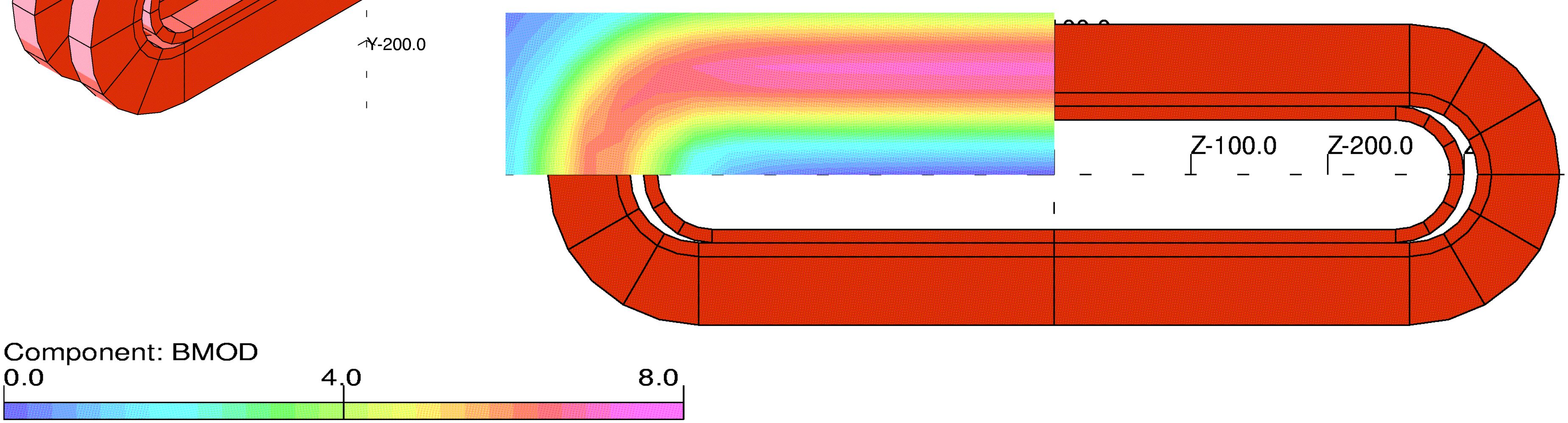
Design Parameters of the 1st Magnet

- **40 mm aperture 2-in-1 common coil design magnet**
  - **aperture and internal support structure can be changed**
- **Double pancake coils with one end-spacer to reduce peak field**
- **~13 mm wide cable made from existing Nb_3Sn ITER conductor**
  - **only 7-8 tesla field with this conductor**
  - **J_{sc}(12T,4.2K) ~675 A/mm^2, Cu/Sc Ratio = 1.5**
- **150 mm spacing between the two bores**
- **40 mm coil bend radius in the ends**
- **Straight section length 0.5 meter; overall length ~ 1 meter**
- **No iron yoke**
- **After initial testing, this magnet becomes a flexible R&D test facility to examine different concepts and insert coils**

TOSCA Analysis for Ends

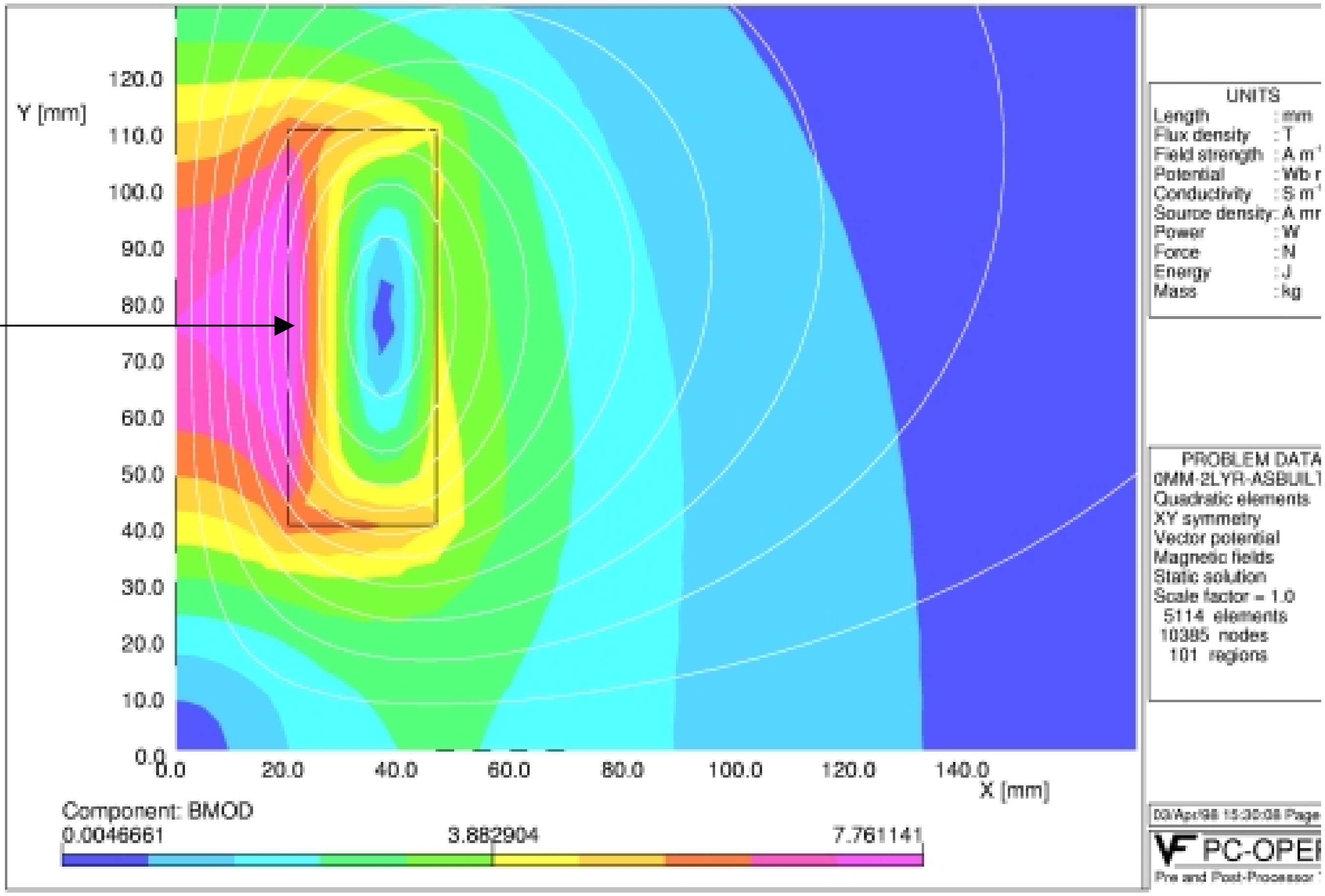


10 mm spacers (after 6 turns) to reduce peak field in the ends



Field Lines and Contour Plot at 7 T in the 1st Common Coil Design Magnet

Max. field point 7.7 T



High Field Magnet Design

- Use high performance, the best available, Nb_3Sn conductor
  - J_{sc}(12T, 4.2K) ~2000 A/mm^2, Cu/Sc Ratio = 0.7, 1.7
- 40 mm aperture (variable), 2-in-1 common coil design
- 50 mm bend radius (in ends), 170 mm bore spacing, iron yoke
- Three layers to generate ~14 T field with the specified cable
- Uses unconventional cable grading (more in 2nd talk)

  graded in width (NOT in thickness) for better efficiency and flexibility
- Field quality

  This is not a field quality magnet design yet

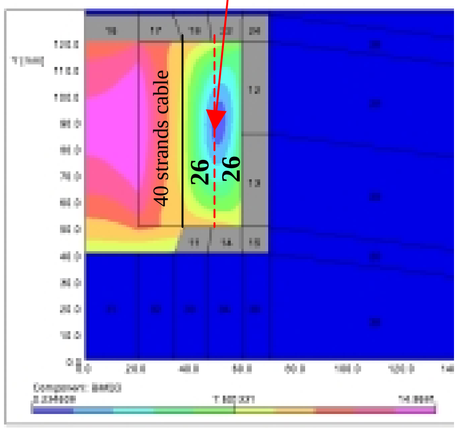
  Tools are being developed in collaboration with CERN

  Magnet assembly (with auxiliary coils) to be addressed later

Fields in High Field Magnet Design (40 mm aperture, 3 layers)

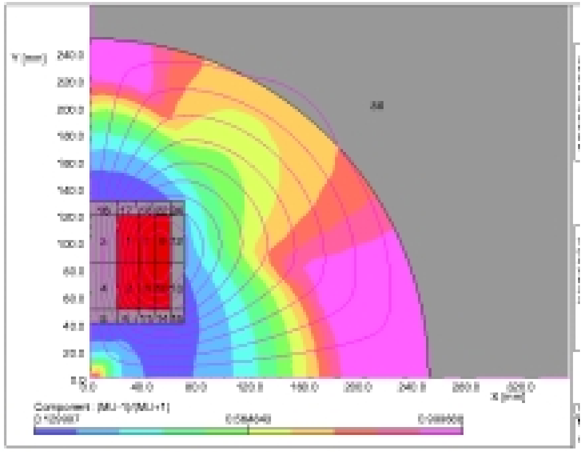
Max. accumulated stress region also has the maximum margin

In actual common coil design this block would return upward to clear the bore



Field in the coil and magnet aperture

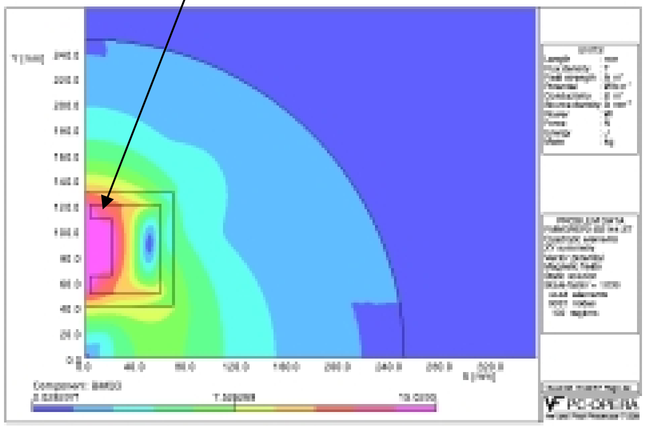
Inner layer cable: wider 40 strands
Outer 2 layers: narrower 26 strands.
B_{ss} ~ 13.8 (4.2K), ~14.5 (1.8 K)
[not including stress degradation].
B_{pk1} ~15 T (+8.5%), B_{pk2} ~10.5 T.



Field lines in a quarter of the magnet and iron saturation in the yoke

Max saturation between the two apertures.
Inter beam spacing increased by increasing coil bend radius from 40 mm to 50 mm.

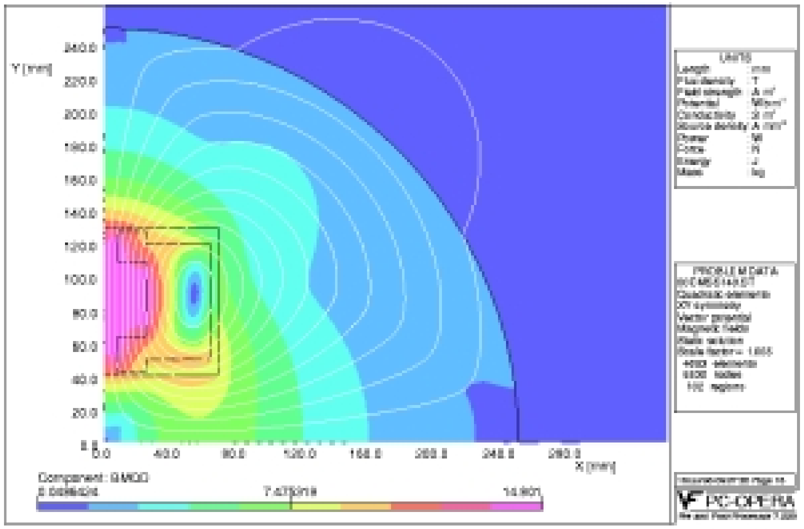
Note : Compact size (yoke o.d. = 50 cm)

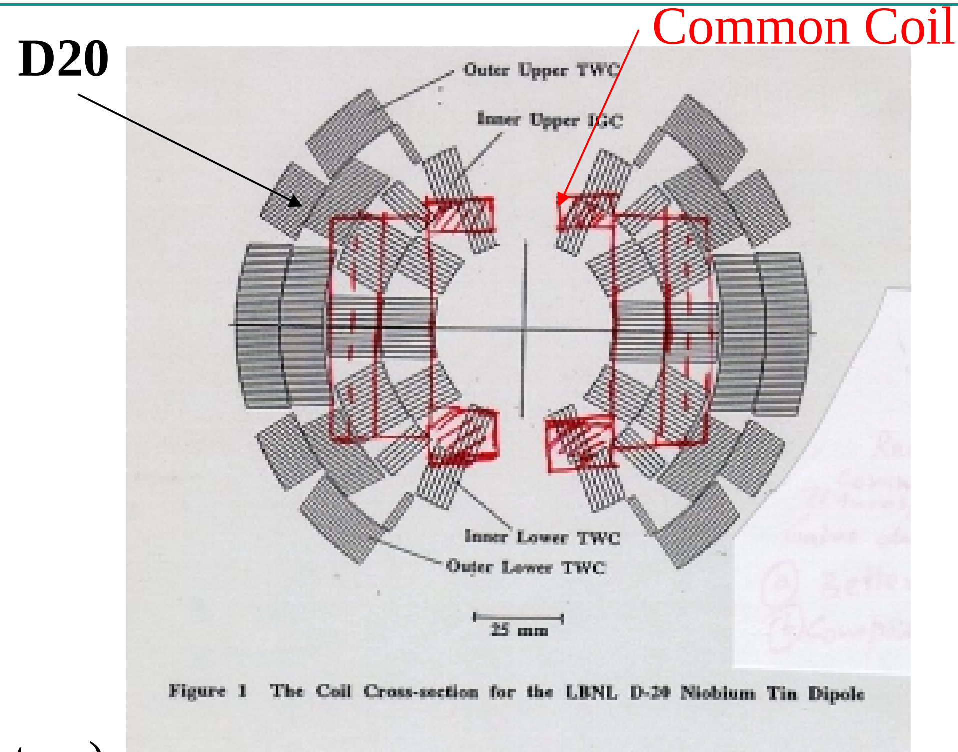


Field in a quarter of the magnet
Pole blocks included for some field uniformity (peak field reduced)

Inner 2 layers: wider cable 40 strands
Outer 2 layers: narrower 26 strands.
B_{ss} ~ 14.4 (4.2K), ~15 (1.8 K)
[not including stress degradation].
B_{pk1} ~15 T (+4%), B_{pk2} ~10.3 T.

50 mm Aperture Investigations (for comparison to D20)





Use 40 mm coil (not optimized for 50 mm aperture)

B_{ss} (at 4.3 K) 14.3 T, B_{pk} = 14.9 T

Compact design (Yoke cross-section half of D20)

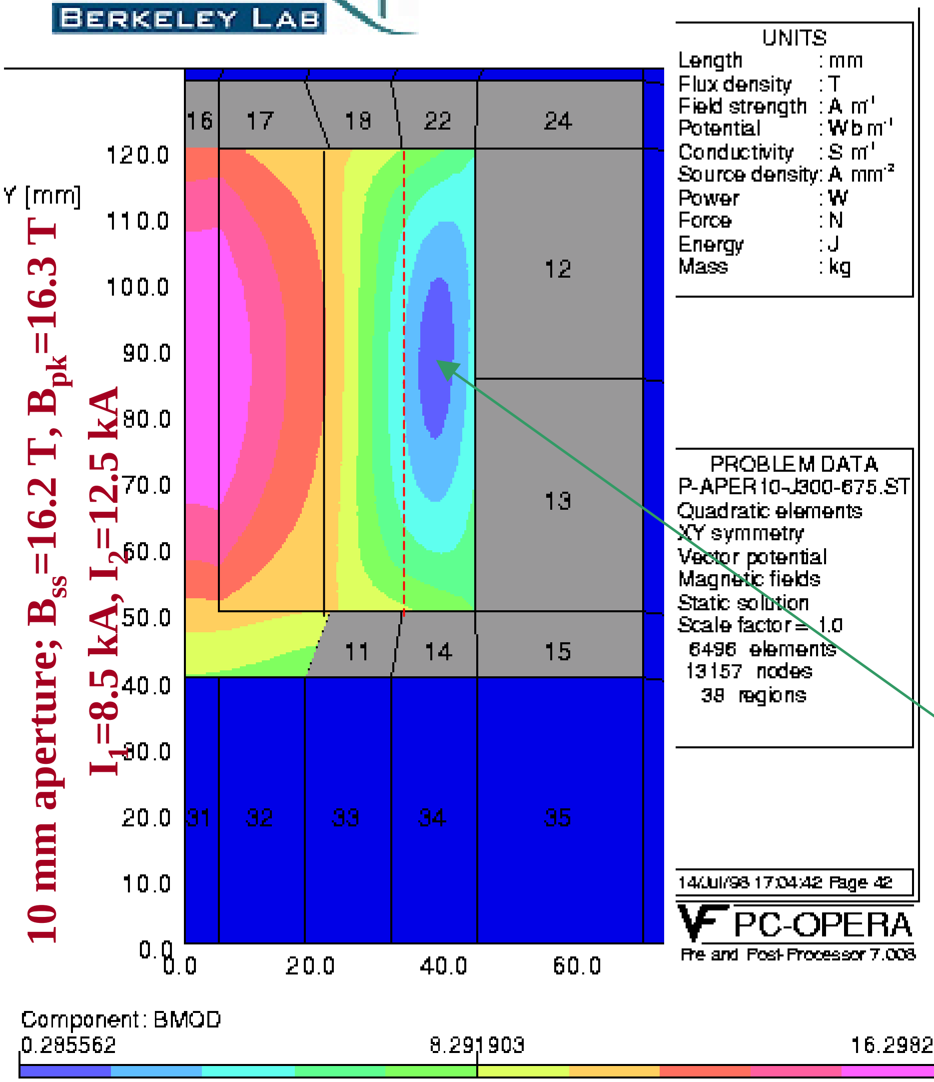
Number of turns per quadrant per aperture = 71

(D20 used 118 turns)

Uses much less conductor volume:

- No wedges for arc shape
- Pole turn in outer layers of D20
- Compact Design
- Better Conductor

Investigations for Very High Field (to probe the limit of technology)



Vary aperture after the coils are made

a unique feature of this design

Lower separation (aperture)

reduces peak field, increases T.F.

=> Higher B_{ss}

May not be practical for machine magnet

but an attractive way to address

technology questions

Determine stress degradation in an actual conductor/coil configuration

- Max. stress accumulation at high margin region

When do we really need a stress management scheme (cost and conductor efficiency questions), and how much is the penalty?

Simulate the future (better J_c) conductor

Pre-stress and Support Structure Studies/Experiments

Pre-stress

How much is needed? Past Experience?

Full/Intermediate/Low?

(conventional wisdom of full pre-stress puts a very high value which may be difficult, if not practical)

Vertical pre-stress: Try to determine experimentally. Experiments in first magnet?

Horizontal pre-stress: Not an option

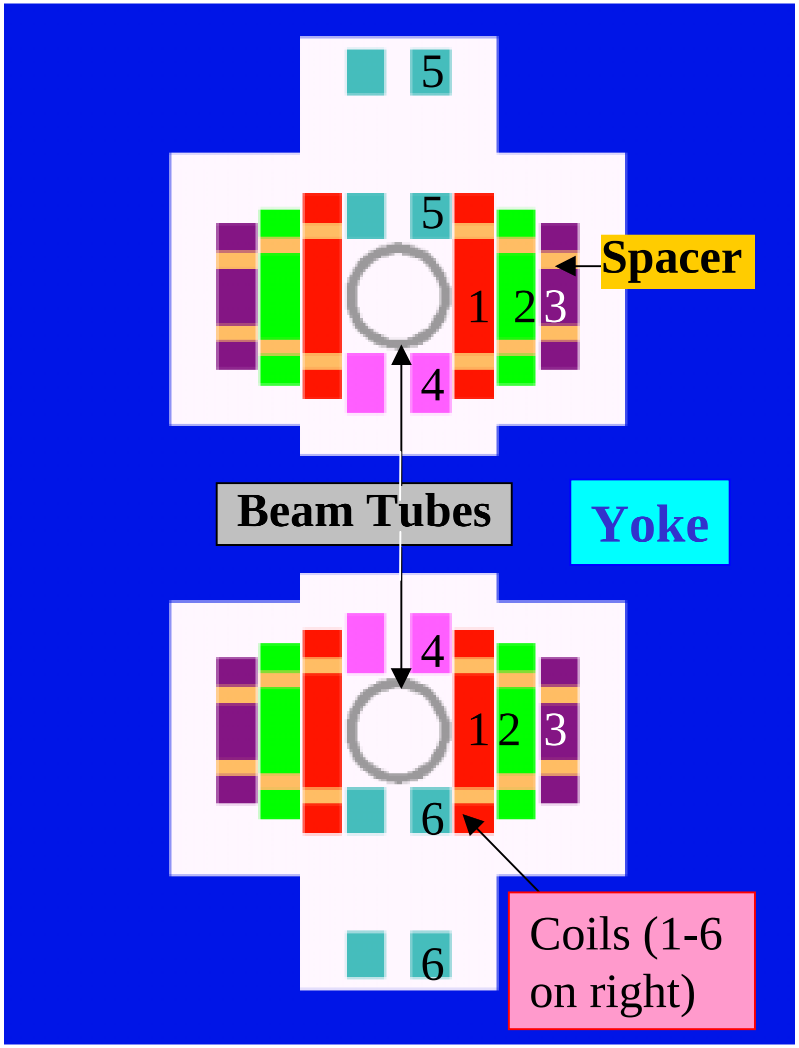
Conflict between beam aperture and internal support structure.

Strategy: Assure contact between coil and external support structure at low field

Outward Lorentz forces will help.

Test this approach in the first magnet.

Field Quality Design/Optimization (Conceptual)



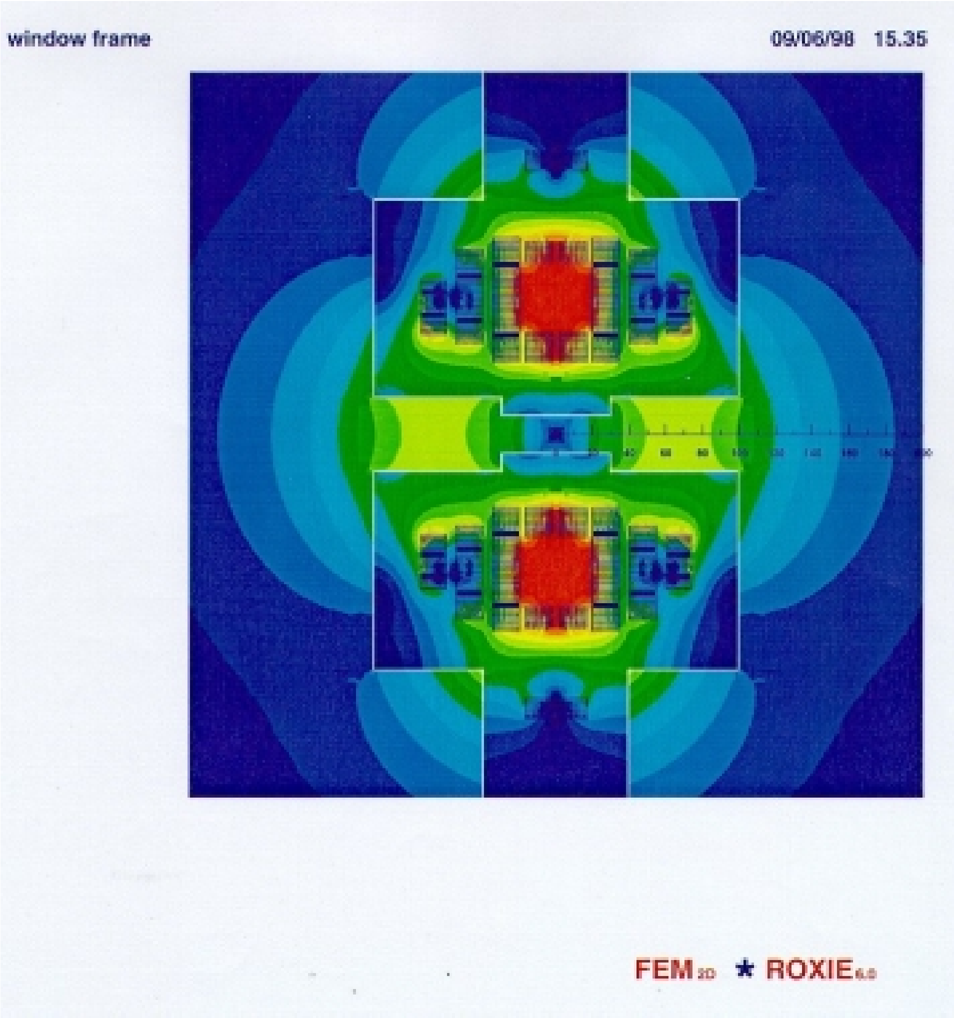
Parameters for optimizing

- **Each layer of coils (module) with different height**
- **Midplane and pole blocks**
- **Spacers (wedges)**
- **Iron between two apertures**
- **Top bottom asymmetry**

Lower random errors expected because of geometry

Systematic errors, including tools, will be optimized next year

Field Quality Design/Optimization (in collaboration with CERN)



ROXIE

by Stephan Russenschuck

- **Basic tools are in place to define the coil geometry and to do x-section and end optimization**
- **Refinement on how to better define geometry, do optimization and field calculations**
- **A fruitful collaboration**

Conclusions and Summary

- **A new flexible design to do modular, faster and innovative magnet R&D.**

  Geometry is suitable for high field magnets.

  It is also expected to produce lower cost magnets.

- **First magnet will have a modest field (7 T). It will test the basic concept and address basic design issues.**

- **The new conductor (with improved J_c) is expected to create ~14 T in a 3-layer coil design.**