A New Approach to Accelerator Magnet Design

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AFRD Review

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Overview of the Presentation

- **Common Coil design**

  The basic philosophy

  A brief design description

  It's capabilities

- **LBL Program**

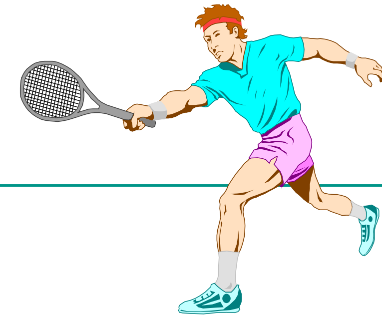
  Concept to reality

- **Longer term plan/possibilities**

  Our dreams - what we would like to do/deliver?

  (sky is the limit, or is it the funding?)

The Game Plan/Philosophy



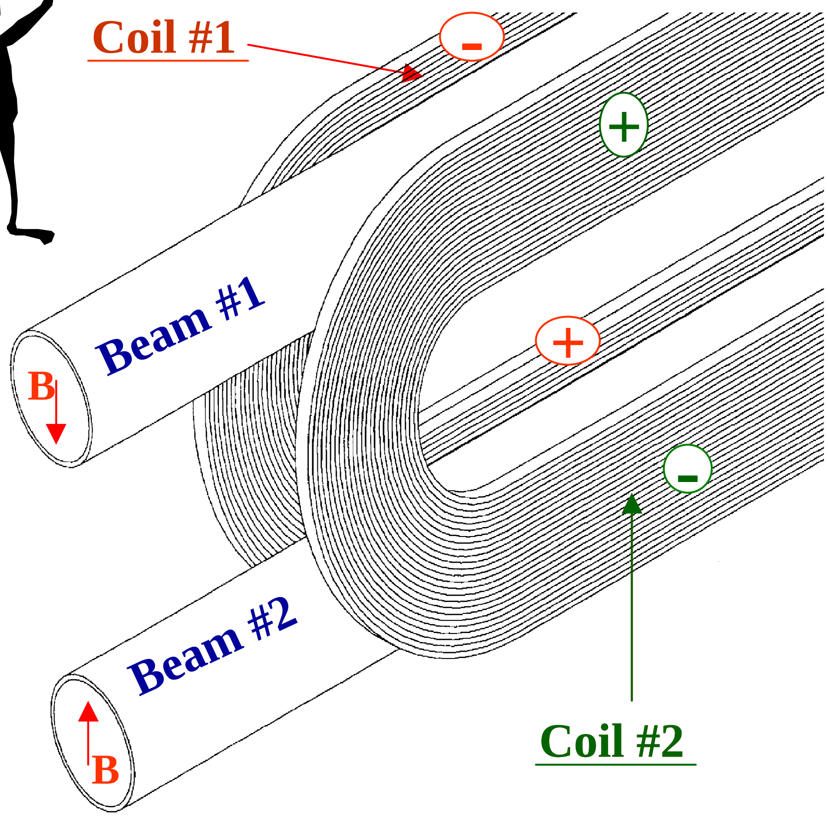
Where we are?

- **We are 10-15 years to the next machine**
- **We have 5-10 years to advance the supporting technologies to make a genuine impact on the cost or design of the future machine**
- **Magnets are the single most costly and critical technology component of the large hadron colliders**

What should we do? Our Response

- **Magnet design should have a longer term outlook (vision)**
- **This is the time to explore different approaches**
  - **Be innovative**
    - **Not only in the geometry, but the way we do magnet R&D**
  - **Develop an approach to give faster turn-around on R&D**
    - **Build "A Magnet R&D Factory"**
- **Don't just build magnets - develop technology and build magnets to demonstrate the technology. Build "The Technology Magnets"**
- **Think that how this R&D will lead to accelerator-quality magnets (and demonstrate parts of it, whenever possible)**
  - **Lower cost, long magnets and large volume production**

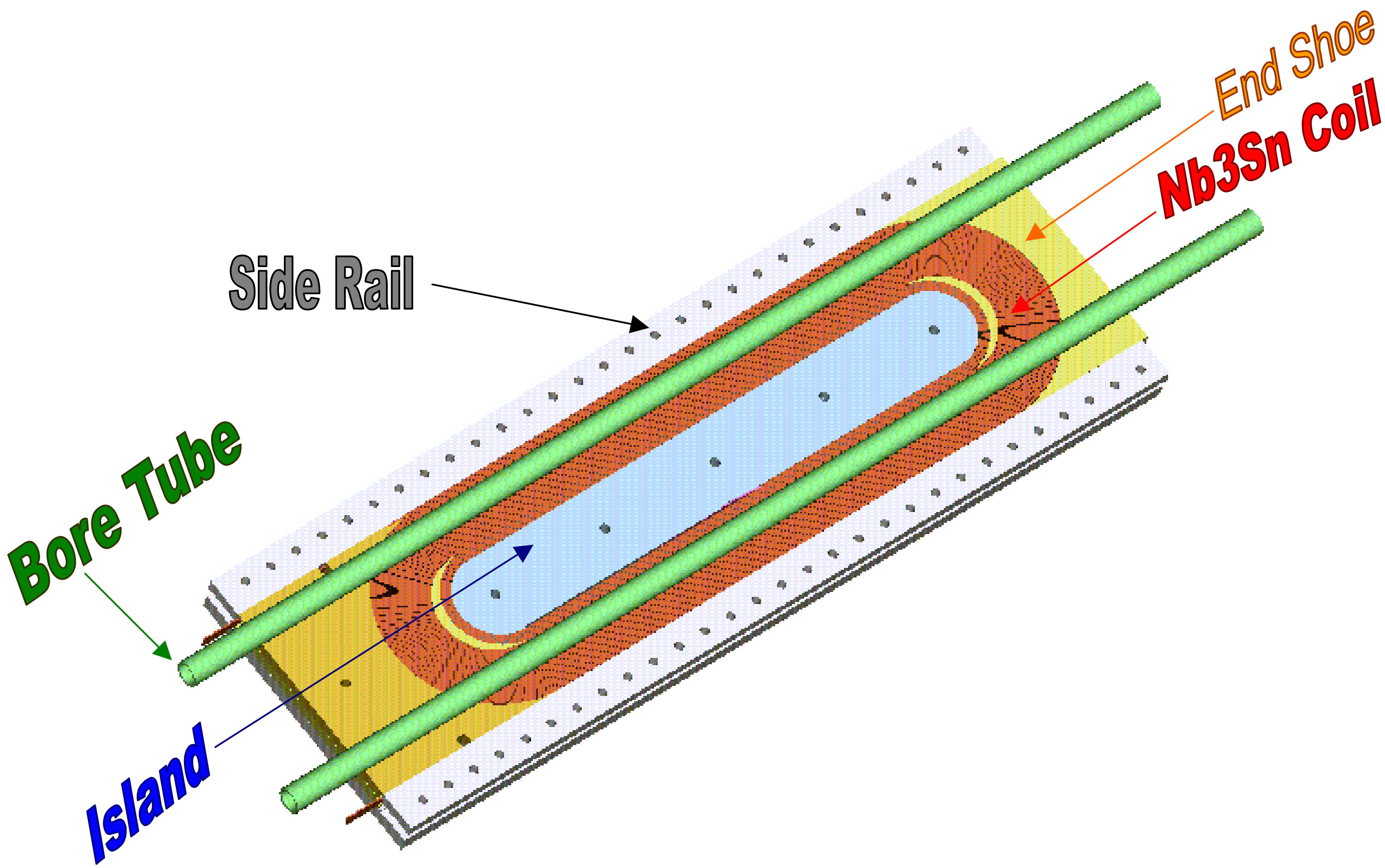
Common Coil Design Concept



BNL Drawing

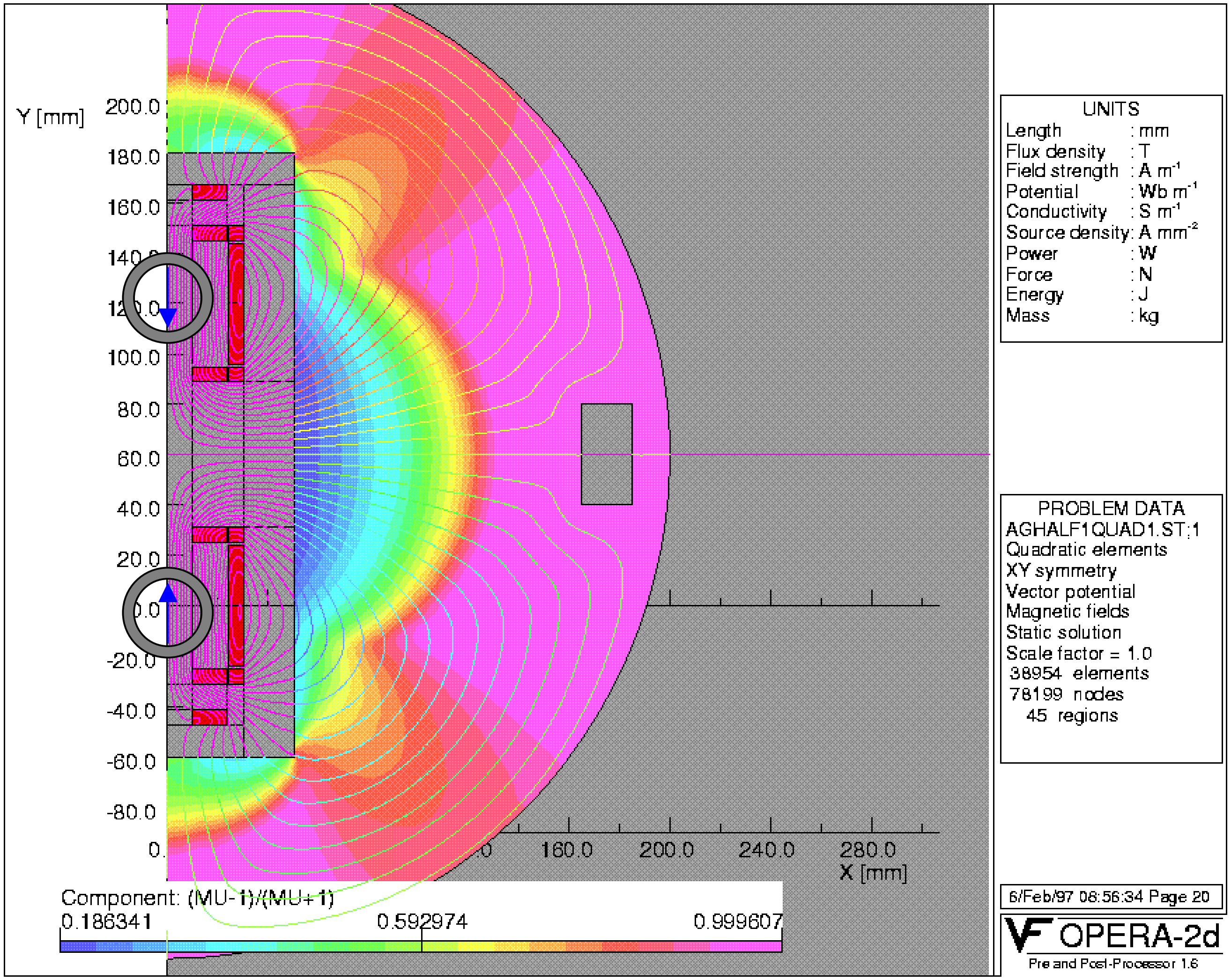
- **Simple 2-d geometry with large bend radius (no complex 3-d ends)**
- **Conductor friendly (suitable for brittle materials - most are, including HTS tapes and cables)**
- **Compact (5 cm, 2-in-1, 15 T magnet ~ 40 cm yoke o.d.)**
- **Block design (for large Lorentz forces at high fields)**
- **Efficient and methodical R&D due to simple & modular design**
- **Minimum requirements on big expensive tooling and labor**
- **Lower cost magnets expected**

Common Coil Design
A Basic Module with Bore Tubes

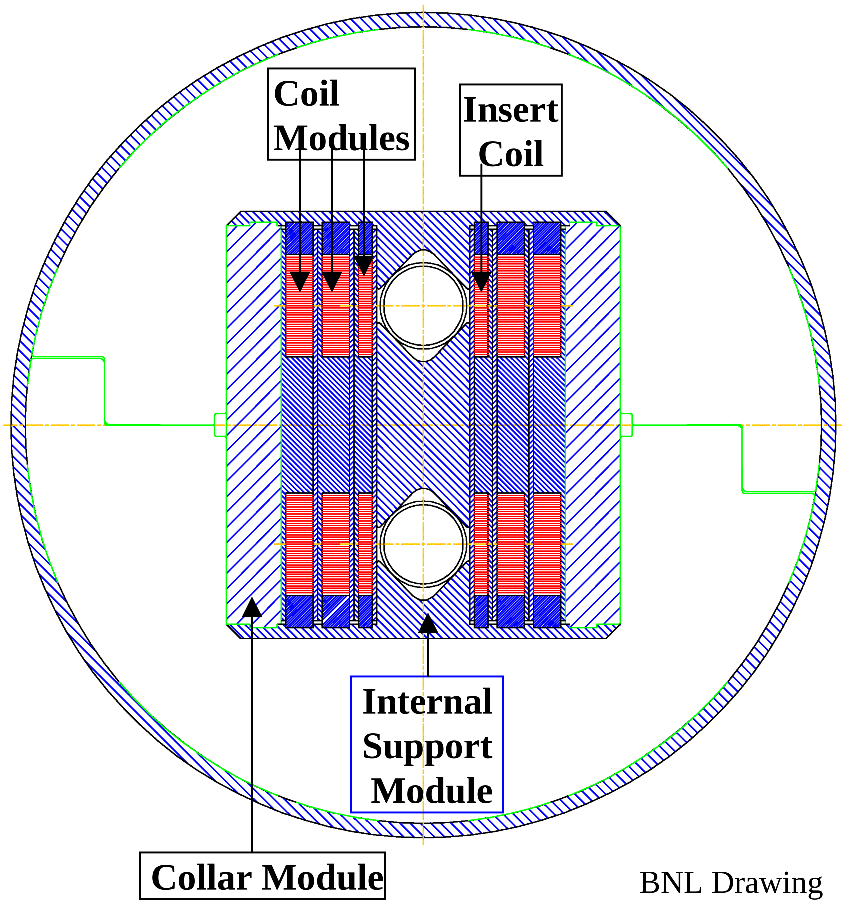


Ken Chow
Warren Harnden

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

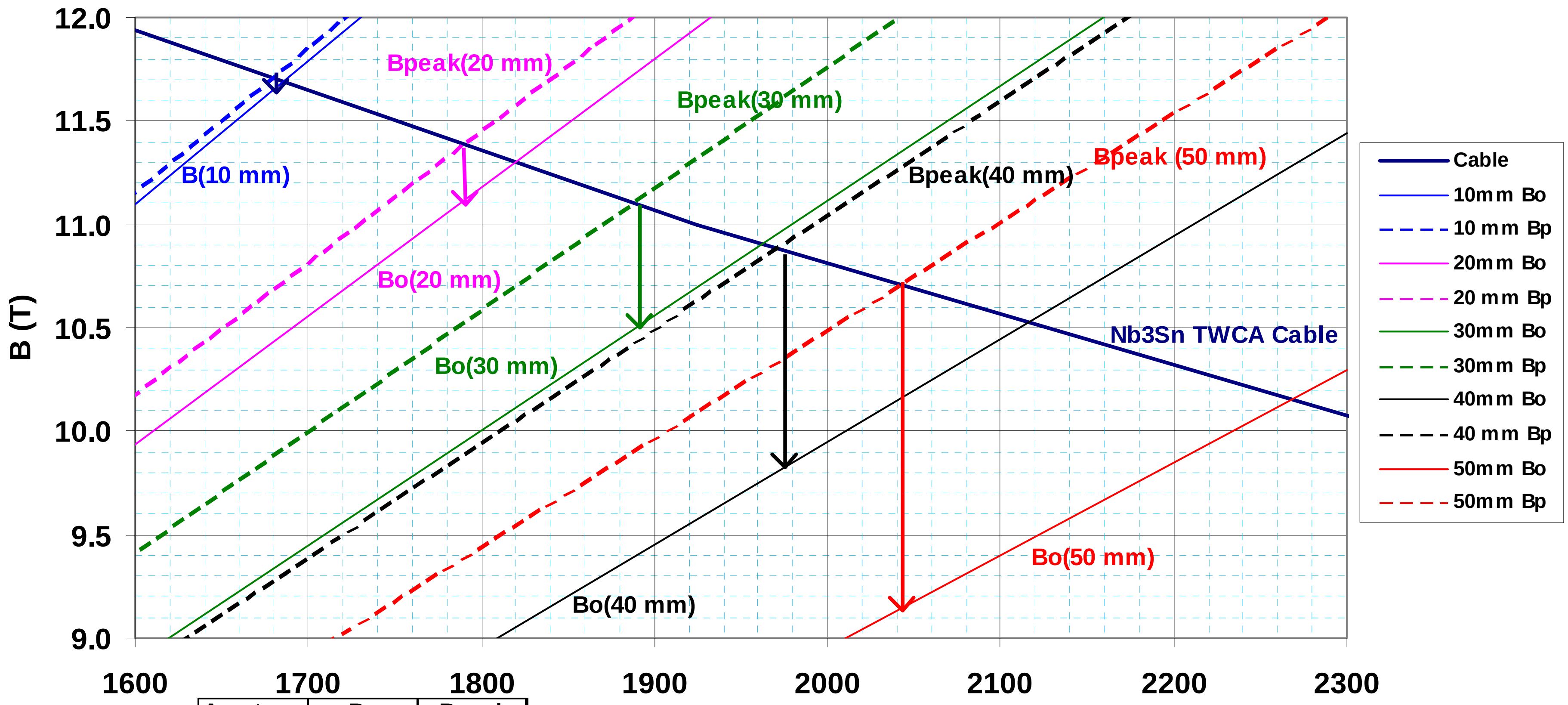
Traditionally such changes required building a new magnet

Also can test modules off-line

This is our Magnet R&D Factory

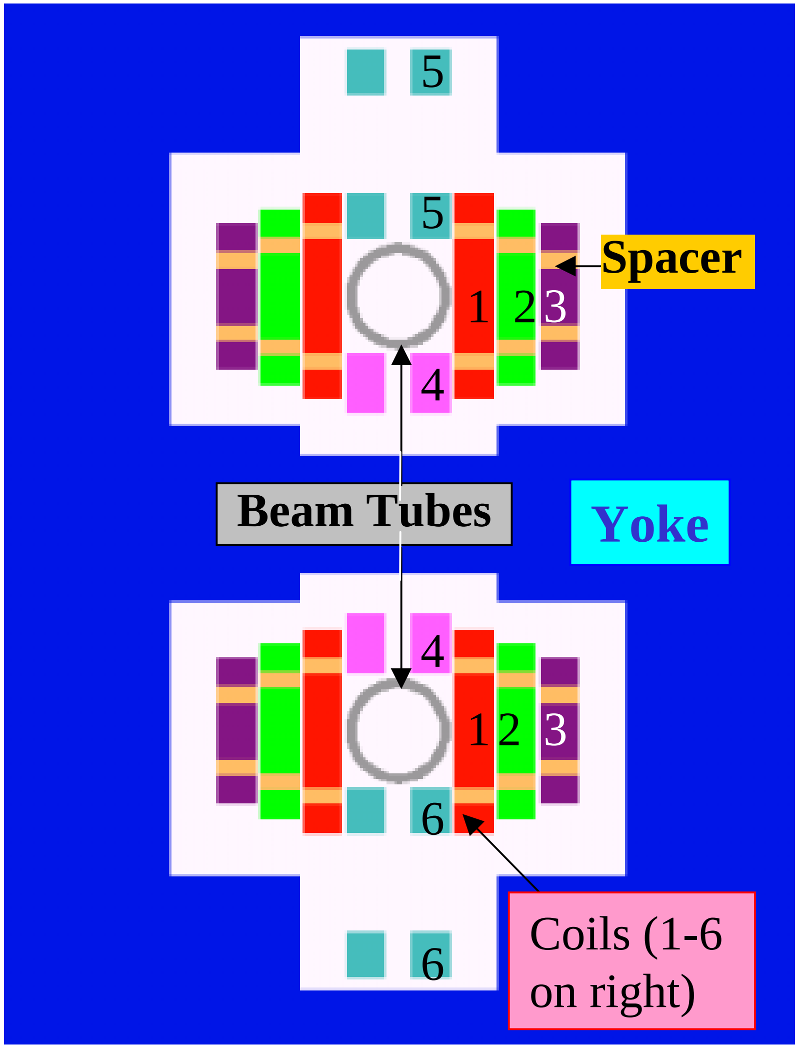
Change in Aperture for Various Field/Stress Configurations

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

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

The 1st Magnet Purpose and Goals

- **Go from concept to detailed engineering**
- **Test the basic design**
- **Use the conductor-type which can generate ~15 T today**

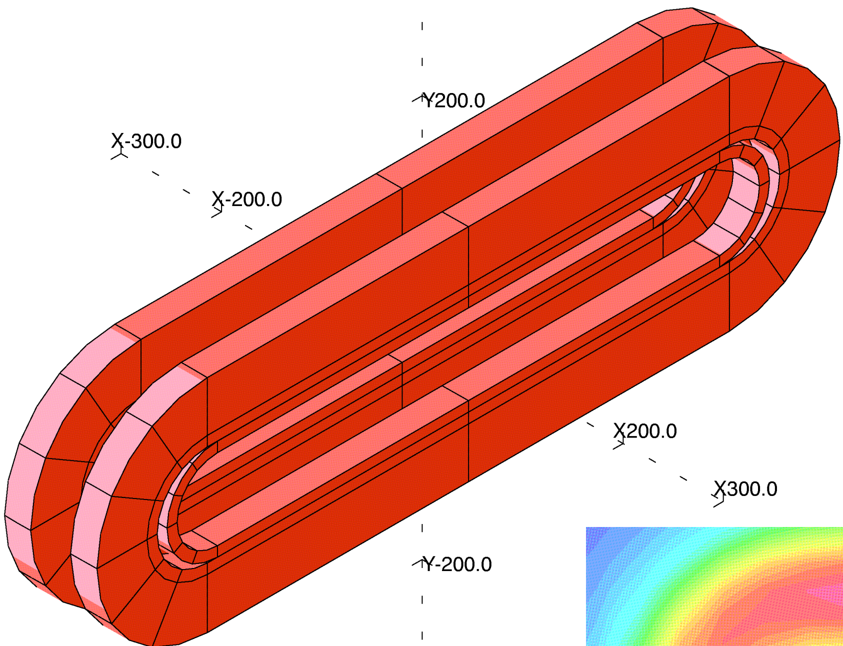
  the clear choice is Nb_3Sn
- **Use the conductor in stock (not the best possible)**

  start building the first R&D magnet ASAP
- **Do necessary R&D experiments in the first magnet to help develop a better design for the next high field magnet**
- **Later, turn the first magnet into a flexible R&D test facility where the insert coils of various materials can be examined in a background field**

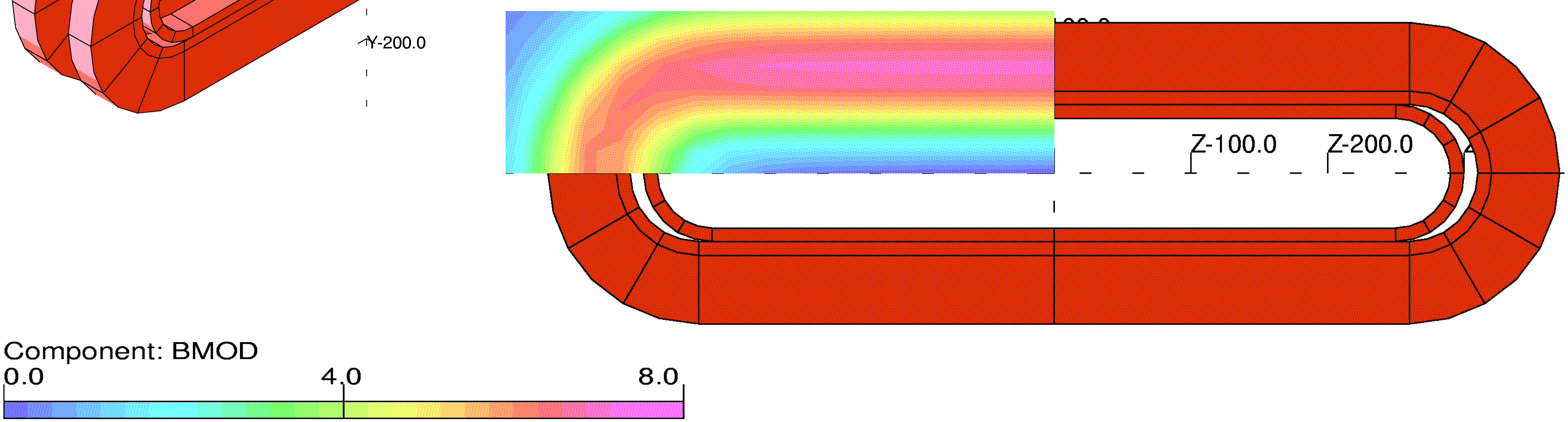
Design Parameters of the 1st Magnet

- Dual aperture 2-in-1 common coil design
- 40 mm aperture (can be changed)
- 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
- ~13 mm wide cable made with existing Nb_3Sn ITER conductor
- Only 7-8 tesla field with this conductor
- Two double pancake coils with one end-spacer

TOSCA Analysis for Ends

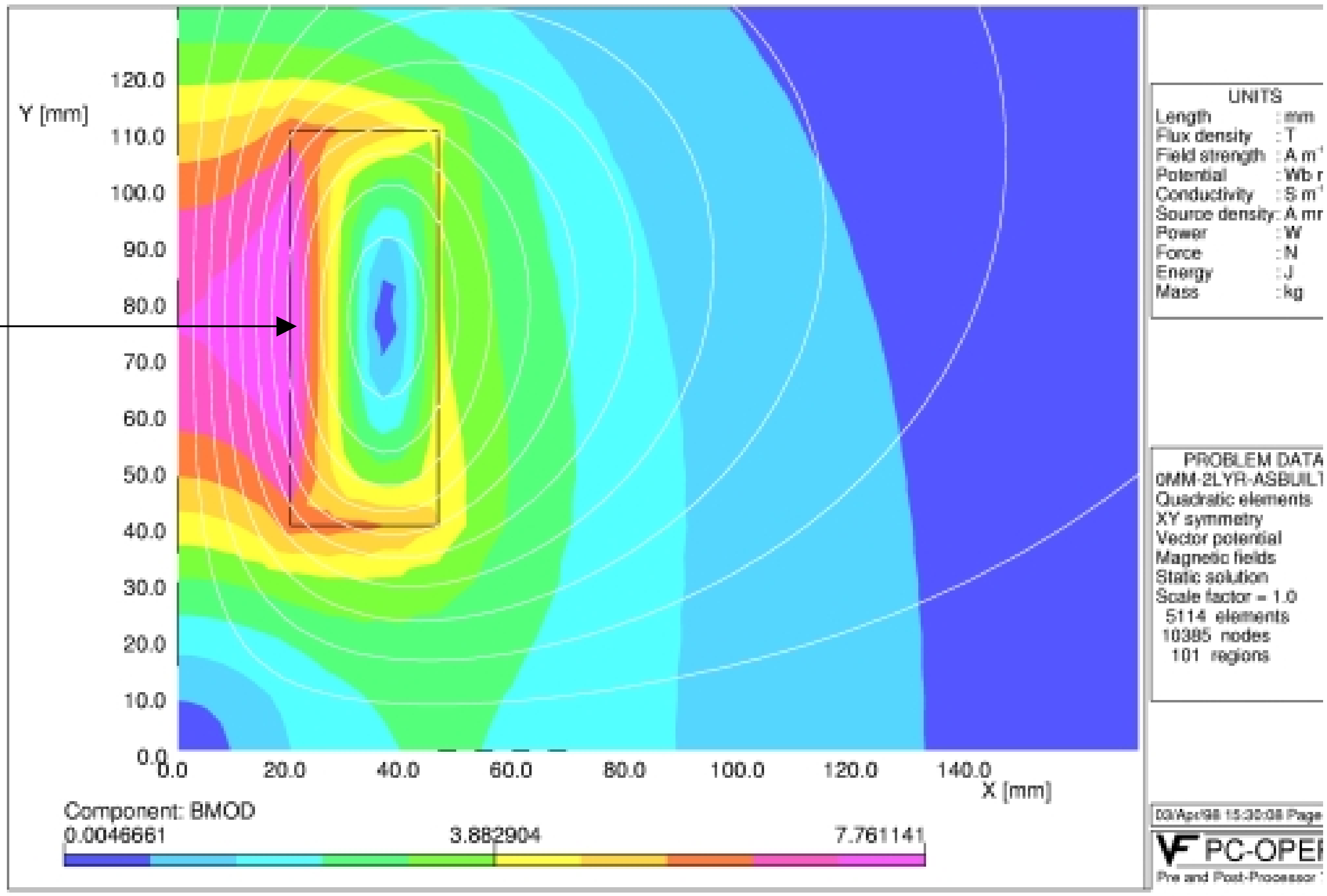


10 mm spacers (after 6 turns) to reduce peak field in the ends



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

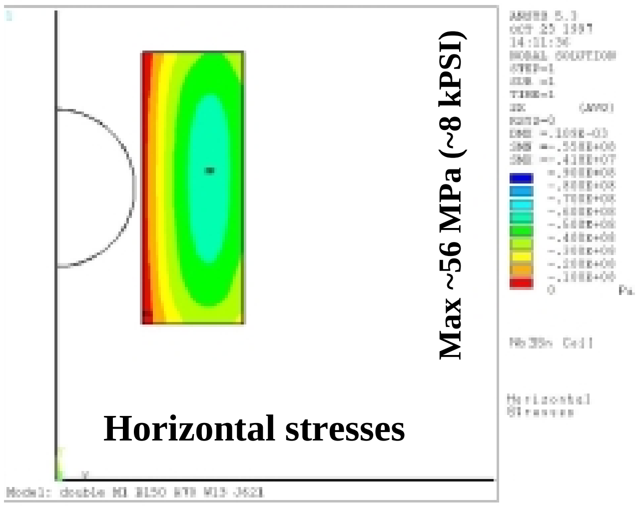
Max. field point 7.7 T



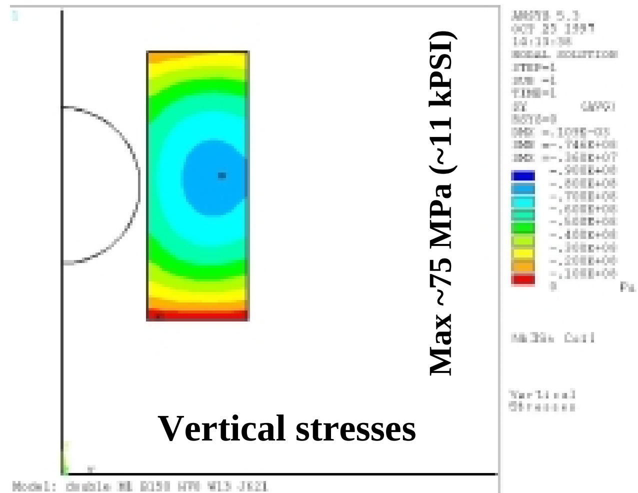
ANSYS Calculations

Computed at ~9.6 T (design field 7T)

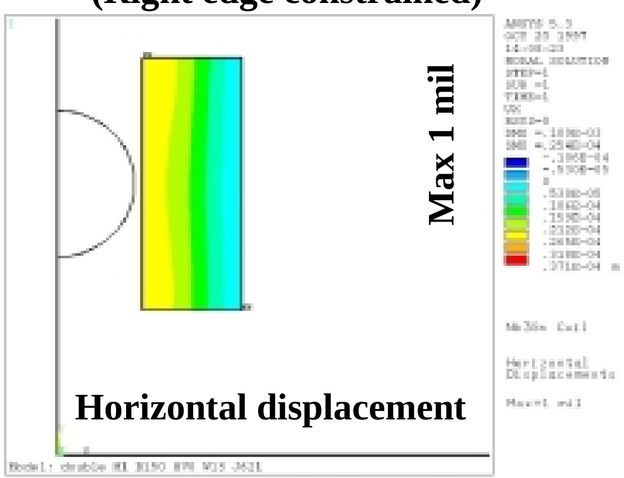
Ken Chow's Analysis

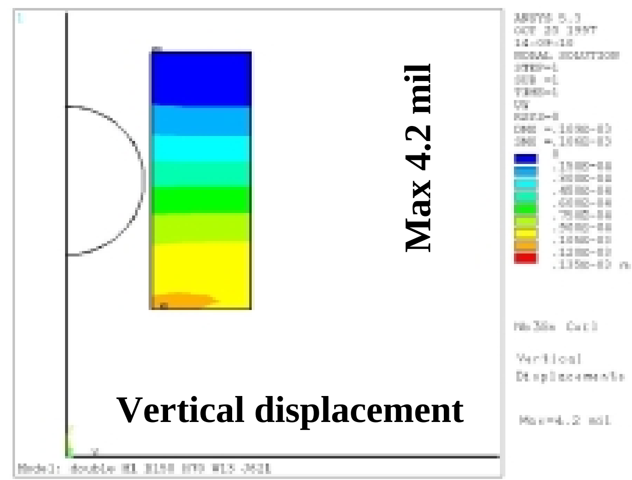


(Right edge constrained)



Upper edge constrained





Mechanical Design and Analysis (Work in Progress)

- **Structural components are chosen to better match the thermal contraction of coils**
- **Initial goal is a fully supported structure in both planes with a minimum strain on the Nb_3Sn conductor**
- **Estimated pre-stress (at the moment) :**

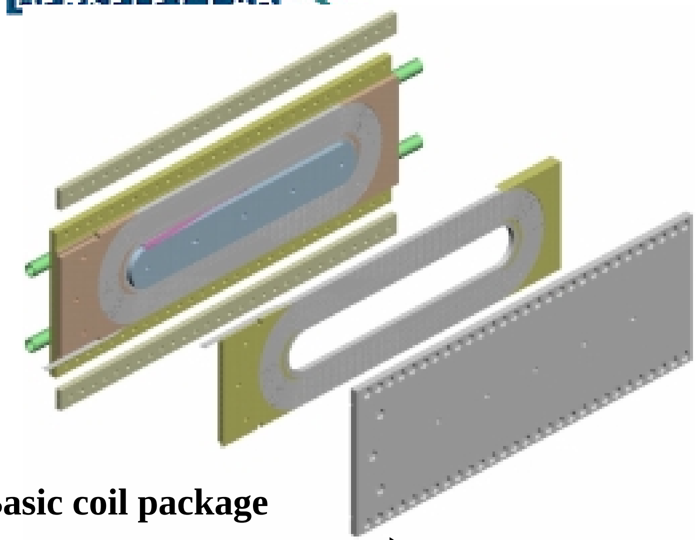
Room Temp. **Vertical ~50 Mpa (7 kpsi), Horizontal ~30 MPa (4 kpsi)**
4K energized **Vertical ~10 Mpa (2kpsi), Horizontal ~10 Mpa (2kpsi)**

Experimental studies for pre-stress later

- **Tests underway to obtain better value of coil modulus**

Note : Potting scheme to relax tolerances in parts

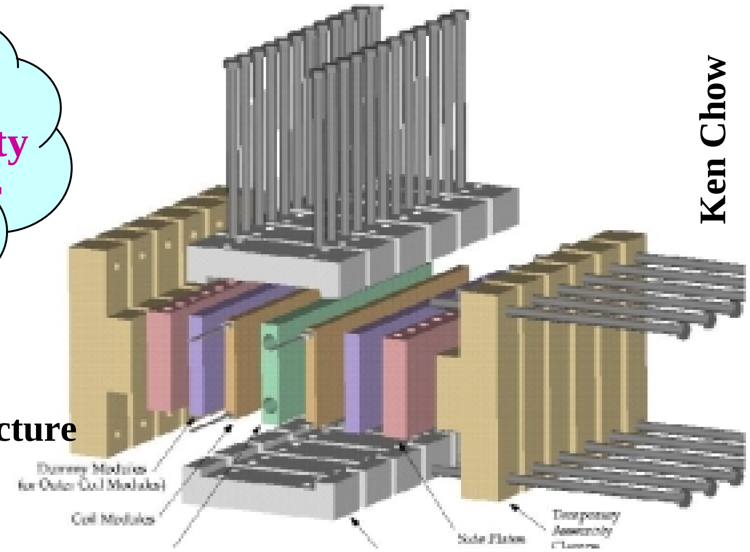
Magnet Components and Assembly
(An Earlier Concept, Work in Progress)



Basic coil package
(concept slightly modified)

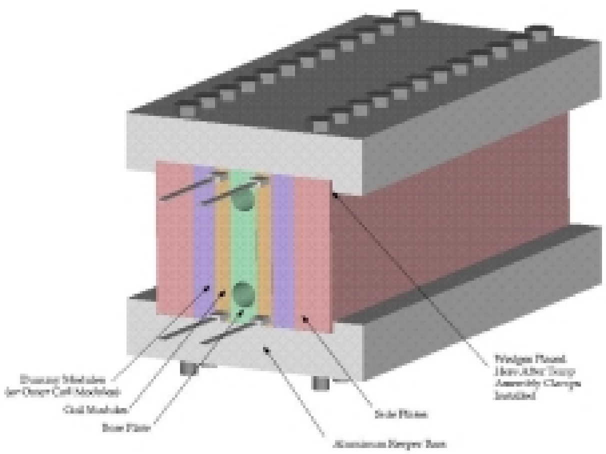
Never pass a chance to show pretty pictures from your colleagues

Coils in D10 support structure

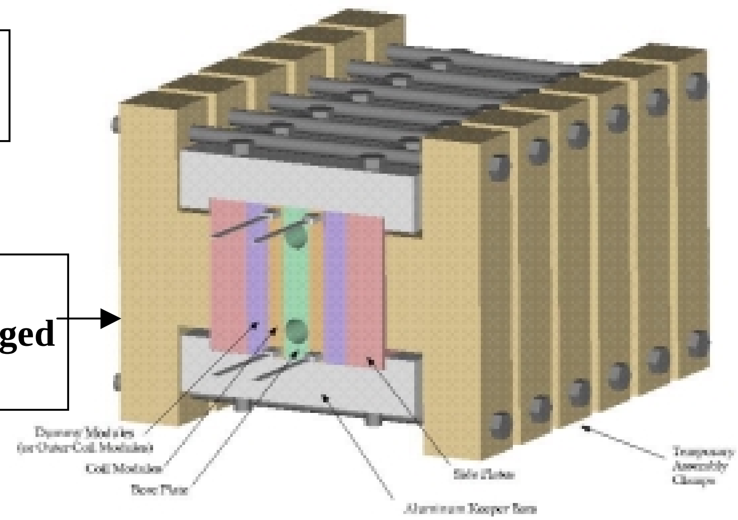


Ken Chow

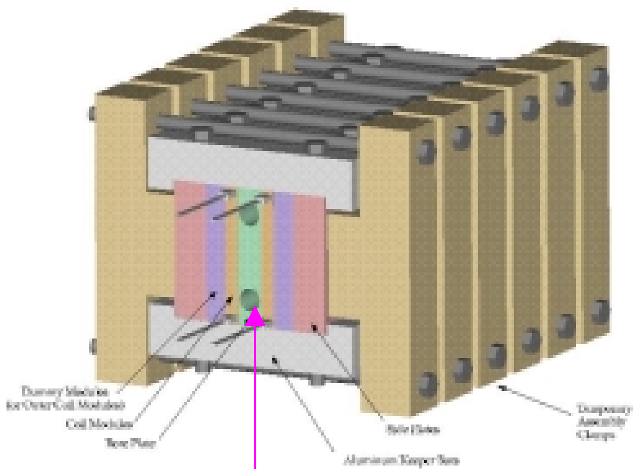
Vertical pre-stress in D10-type structure



Horizontal and vertical pre-stress could be changed with the bolts



Investigations with 1st Magnet



Internal support structure (occupying large space in the aperture of the 1st test magnet)

- **Remove/Reduce the internal support structure between two coils**
- **Vary pre-stress**

  Input to the next high field design.

  Minimize the expansive support structure.
- **Vary aperture (unique to this design)**

  Gives higher field

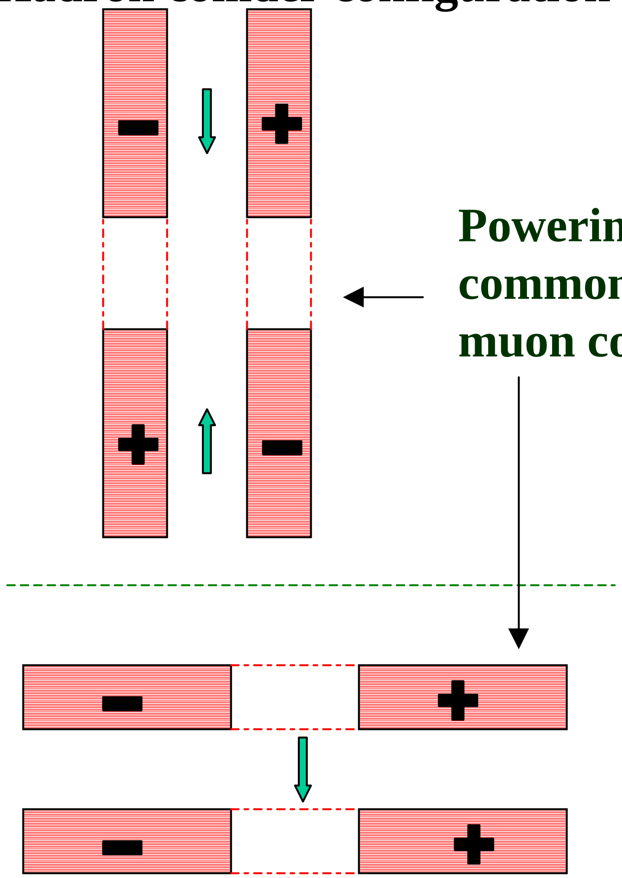
  Changes field/stress distribution
- **Insert coil test facility (productive use)**
- **Energize in single aperture mode**

  Study higher stress on Nb_3Sn

  Design study of muon collider dipole

Muon Collider Dipole Design and Configuration

Hadron collider configuration

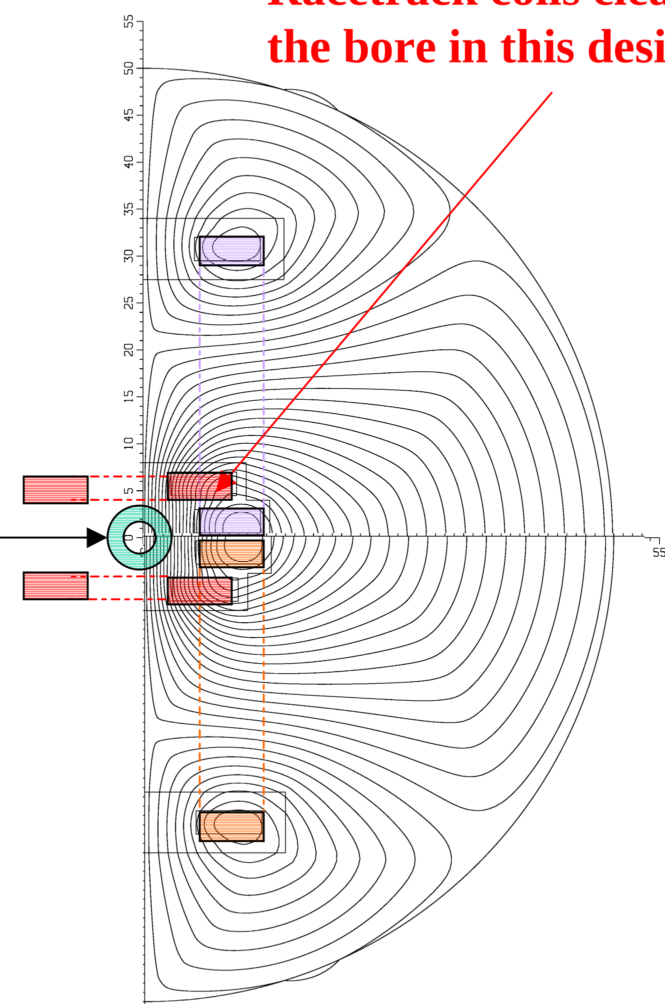


muon collider configuration

Powering differently changes common coil design test to muon collider design test

Note : A high stress test is created here

Racetrack coils clear the bore in this design



Tungsten & bore tube

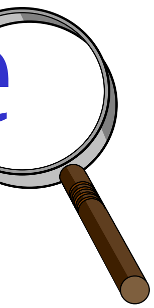
Basic Design of the 1st High Field Magnet

- Use high performance, the best available, Nb_3Sn conductor
- Three layers to generate 14-15 T magnet
- Conductor width 12-13 mm; graded for high field optimization
- 2-in-1 common coil design
- 40 mm aperture (variable)
- Support structure to be designed
- Field quality to be improved in the next magnet

Possible Long Term Magnet R&D

Remember VLHC (Jupiter) is 10+ years away

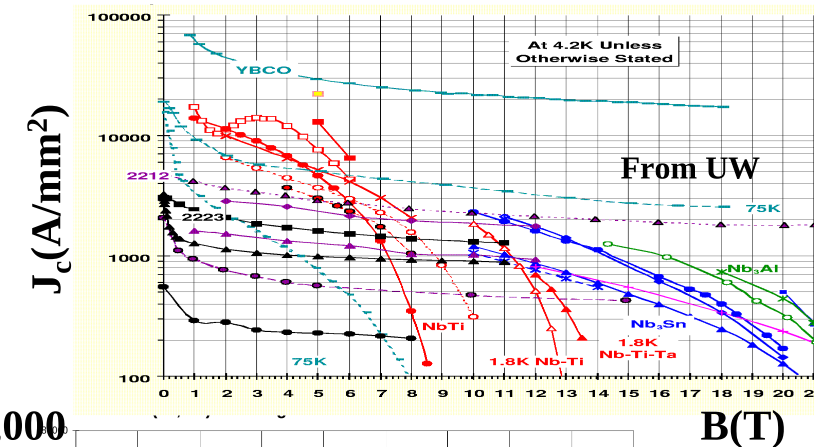
➡ **In addition to maintaining the base program, this is also a unique time to explore**

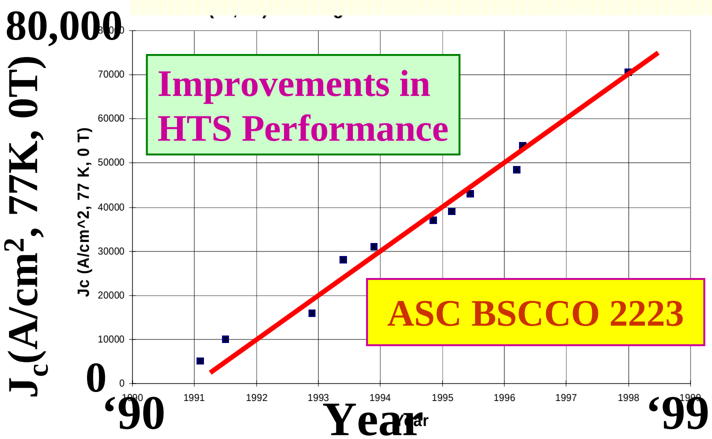


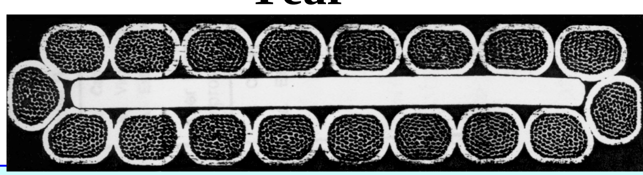
Explore the emerging technologies

Explore the innovative ways to reduce cost

Emerging Technologies : HTS







KAmp Rutherford cable : LBL-industry collaboration

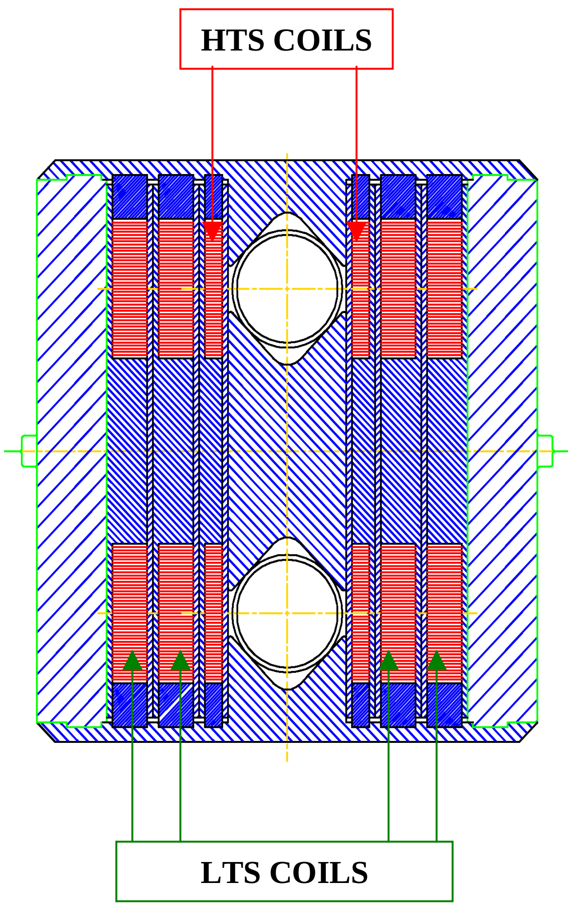
- HTS have made significant progress
- Not clear if they will be practical for large production (cost & technology)
- It takes long time to do magnet R&D (many technical questions remain)
- Start magnet R&D now, so that if the cost situation improves and if it can be made technologically feasible, we can use it in the next machine
- Examine other conductors and technologies also :

Newer Nb_3Sn, Nb_3Al

React & Wind magnet technologies

etc.

HTS in a Hybrid Magnet



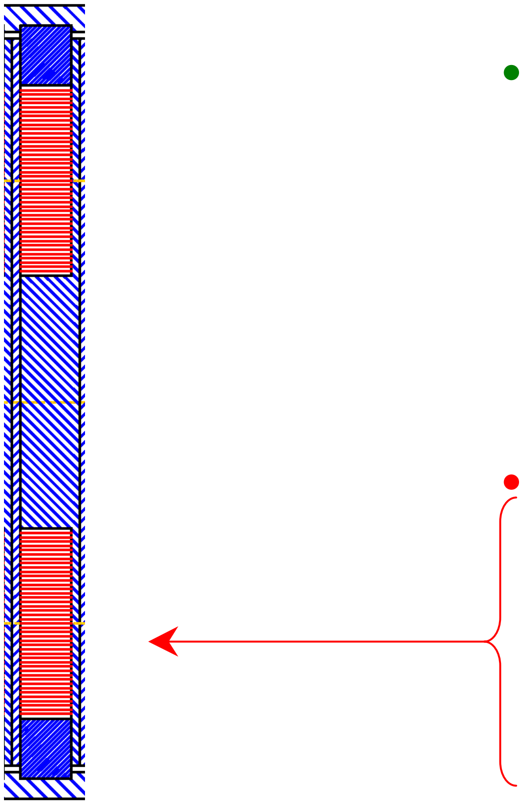
- **Perfect for R&D magnets now.**

  HTS is subjected to the similar forces that would be present in an all HTS magnet. Therefore, the most technical issues will be addressed.

- **Field in outer layers is 2/3 of that in the 1st layer. Use HTS in the 1st layer (high field region) and LTS in the other layers (low field regions).**

- **Good design for specialty magnets where the performance, not the cost is an issue.**

A Possible Low-cost Magnet Manufacturing Process



- **Reduce steps and bring more automation in magnet manufacturing**
- **Current procedure : make cable from Nb-Ti wires => insulate cable => wind coils from cable => cure coils => make collared coil assembly**
- **Possible procedure : Cabling to coil module, all in one automated step - insulate the cable as it comes out of cabling machine and wind it directly on to a bobbin (module)**

Conclusions and Summary

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

  Geometry is suitable for high field magnets.

- **A window of opportunity for exploring new magnet designs and conductor R&D to influence VLHC.**

- **An approach to produce lower cost magnets.**