

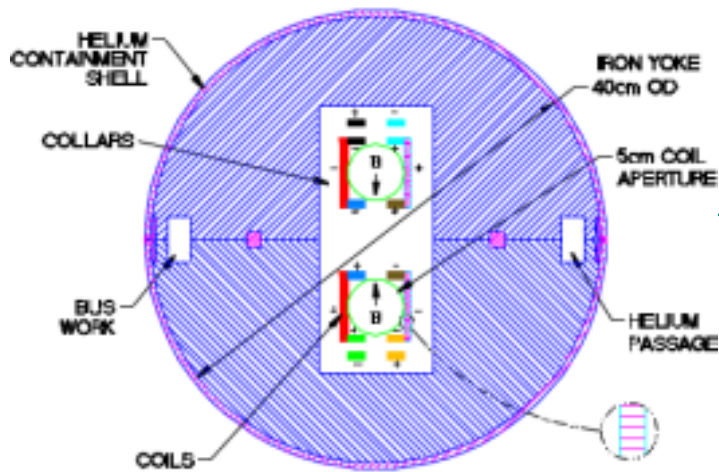


For earlier talks on Common Coil Magnets,  
please visit: <http://vlhc.org/>  
Workshops on Magnet Technologies  
and Accelerator Physics

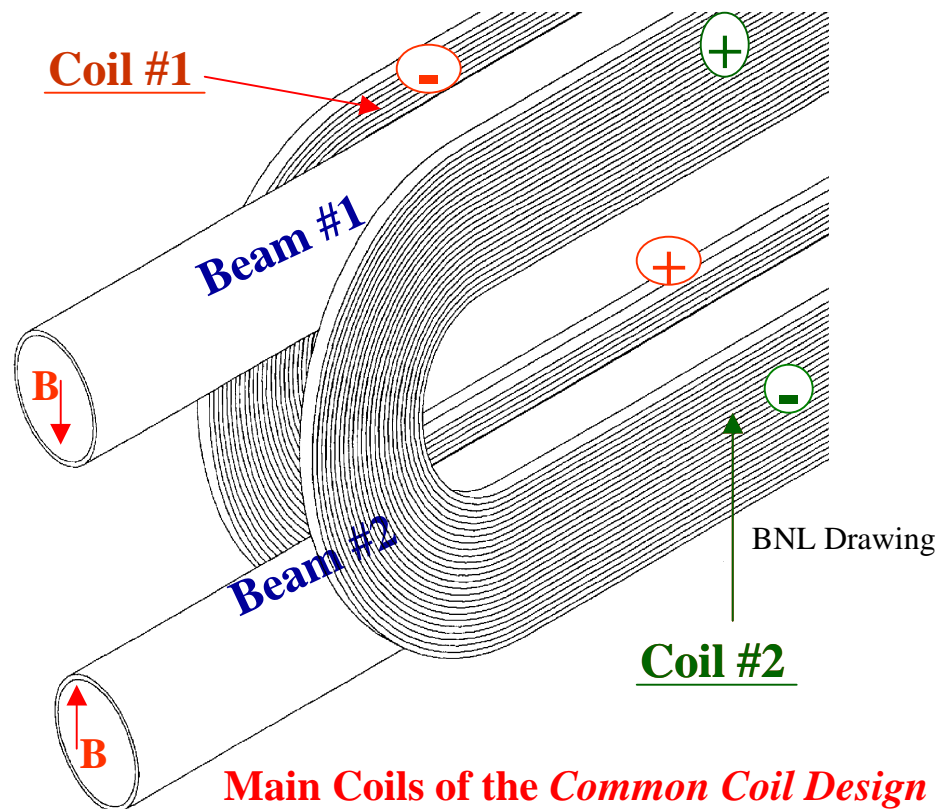
# Common Coil Magnets for Future Colliders

Ramesh Gupta, LBNL

New Superconductor Options for VLHC  
Lake Geneva, Wisconsin  
February 24-26, 1999



# Common Coil Design (The Original Concept)



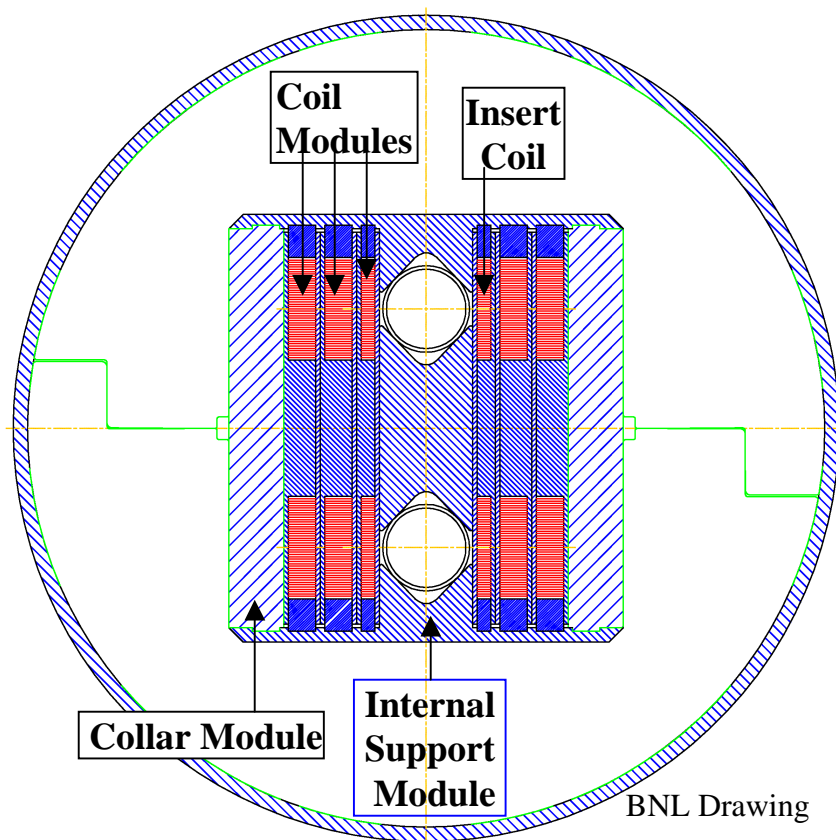
Main Coils of the *Common Coil Design*

- **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 single aperture D20 magnet, half the yoke size for two 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



# A Modular Design for a New and Low-cost Magnet R&D Approach

**\*This could be a Magnet R&D Factory\***



- Replaceable coil module.
  - Change cable width or type.
  - Combined function magnets.
  - Vary magnet aperture for higher fields.
  - Study support structure.
- # Traditionally such changes required building a new magnet.
- # One can also test modules off-line.

Not only that we must learn how to make magnets cheaper, we must also learn (due to limited funding), how to do magnet research cheaper which will lead to eventually making the magnets cheaper.

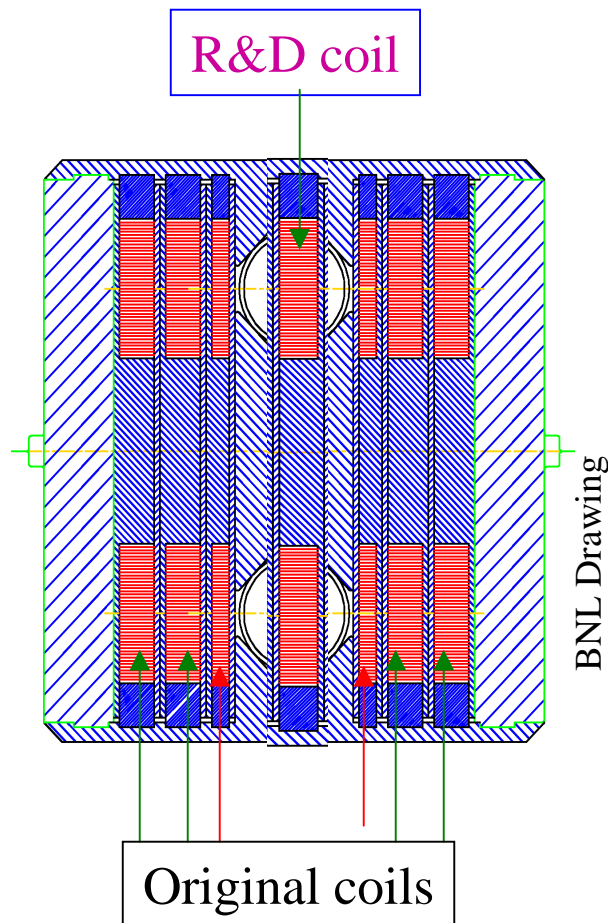
This is the time to explore and carry out an aggressive R&D program. Once the machine is funded, we are unlikely to take chances. The above facility allows that.

Ramesh Gupta

Common Coil Magnets for Future Colliders



## Possible use of R&D funding to small labs to support VLHC Magnet Research



- A Modular Design approach allows a dynamic R&D that was not possible before.
- An important part of this high field magnet research is the coil module -- be it conductor manufacturing, coil manufacturing, insulation, stress management, or whatever.
- The best is to test these concepts in a “real magnet” situation to avoid surprises.
- The critical module has a relatively moderate price tag. This allows different ideas, innovative R&D by small labs.
- Make this module anywhere and test it in the magnet. The forces, etc. on this module are similar to as if it was an integral part it.
- Use the successful results in the next magnet.



# What can one study with these modules

## Examples of systematic studies in a modular approach

- Different technologies
  - Wind & React Vs. React & Wind
- Different conductors
  - Nb<sub>3</sub>Al, HTS, etc.
- Different insulation
- Different geometry's
  - Tape, cable
- Stress Management/High Stress Configuration
- Coil Winding/Splice

**\* A Dynamic Program with fast turn-around time for exploring new frontiers/ideas \***



## Results from the first magnet based on the common coil design

- We have built and successfully tested the first magnet  $\text{Nb}_3\text{Sn}$  magnet based on the common coil design (moderate 6 T field, limited by the use of existing conductor).
- It proves the viability of the design.
- It also confirms the advantages that were initially identified:
  - A simple design that requires minimum tooling
  - A faster turn-around
- A magnet built at BNL also supports the above.

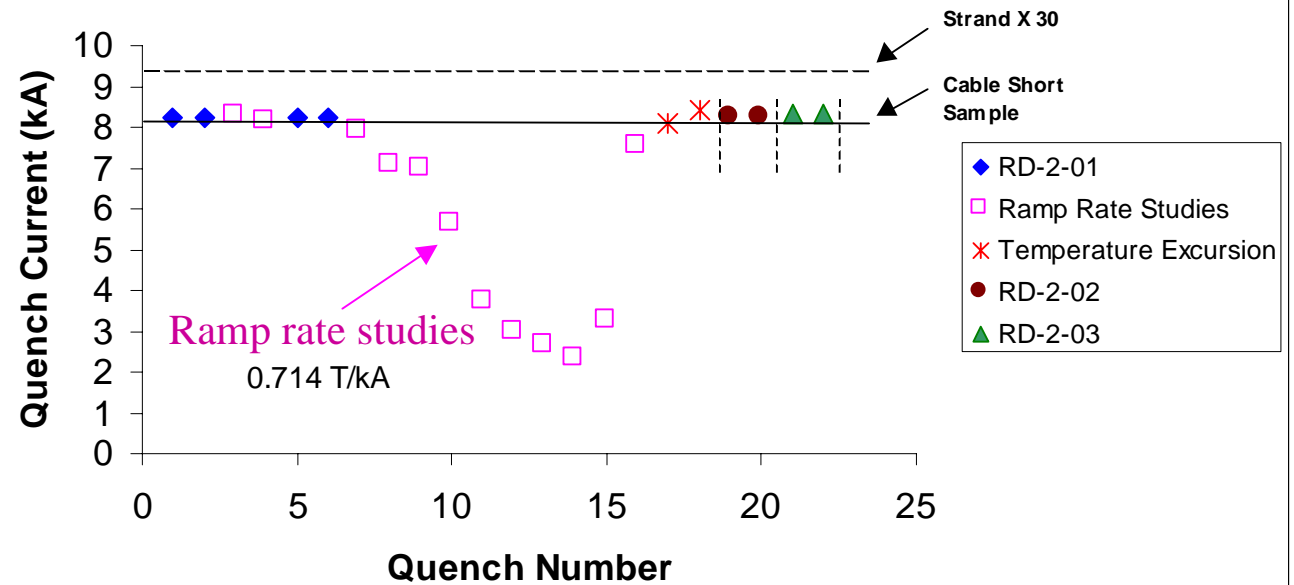




# Quench Performance of the First Common Coil Nb<sub>3</sub>Sn Magnet



**RD-2 Quench History (RD-2-01: High preload run)**  
 (RD-2-02 and RD-2-03 are low horizontal and low vertical preload runs)





# Persistent Current-induced Harmonics

(may be a problem in Nb<sub>3</sub>Sn magnets, if nothing is done)

Exploring the unusual options for the major cost savings while improving the performance. Magnet/machine designs to accommodate challenging superconductors.

Nb<sub>3</sub>Sn, with the technology under use now, is expected to generate persistent current-induced harmonics which are a factor of 10-100 worse than those measured in Nb-Ti magnets. In addition, a snap-back problem is observed when the acceleration starts after injection at steady state (constant field).

Garber, Ghosh and Sampson (BNL)

Persistent current induced magnetization :

Measured sextupole harmonic in Nb-Ti magnet

Measured sextupole harmonic in Nb<sub>3</sub>Sn magnet

Persistent current induced harmonic depends on the property of superconductor (They become small at high fields)

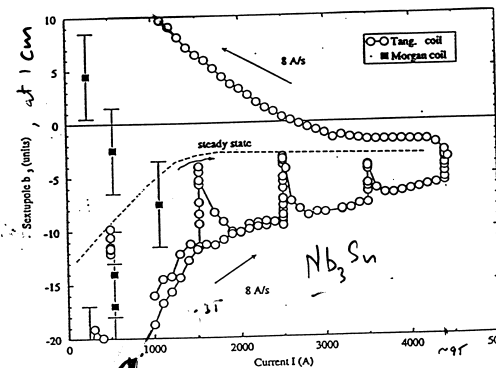
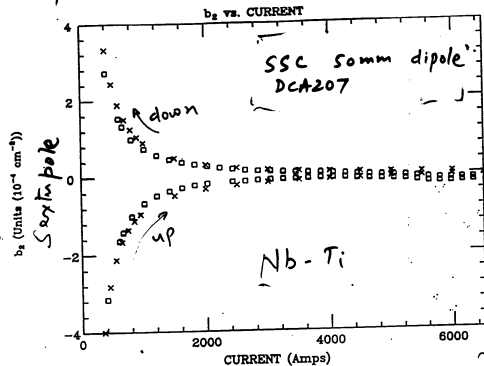


Fig. 6. Measured sextupole at low field (direction of arrow indicates up or down current).

LBL  
D20 50mm  
Dipole  
World Record  
holder: 13.5  
(e6709A)

$$2\mu_0 M = 2\mu_0 \frac{2}{3\pi} \nu J_c d \quad (1)$$

$J_c$ , CRITICAL CURRENT DENSITY  
 $d$ , FILAMENT DIAMETER  
 $\nu$ , VOL. FRACTION OF NbTi  
 $M_s = M/\nu \quad (2)$

Measured magnetization

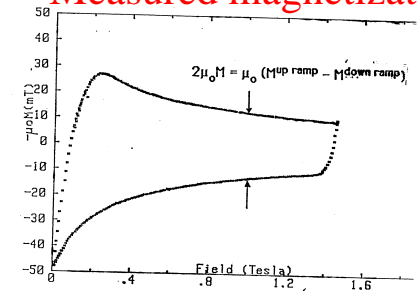


Fig. of a typical magnetization loop.

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Common Coil Magnets for Future Colliders

Superconducting Magnet Program







But we still care most about

$$J_{c'} \quad J_{c'} \quad J_C$$

## Next Transparency:

Continuing the design approach/philosophy for addressing conductor challenges in the unconventional magnet and machine designs.

“Dear Mr. Conductor Manufacturer”,

Please, keep your primary focus on conductor cost and, yes on,  $J_c$ ,  $J_{c'}$ ,  $J_C$ , and we will challenge us to be a better magnet/machine designer.

Idea: Persistent currents are not an issue in iron dominated magnets.

## Main Issue of VLHC: It's the Cost Stupid!



# A Common Coil Magnet System for VLHC

(Overcomes the persistent current problem in the magnet design)

A 4-in-1 magnet for a 2-in-1 ring

Transfer here at medium field and accelerate to high field

Iron dominated aperture Good at low field (0.1-1.5T)

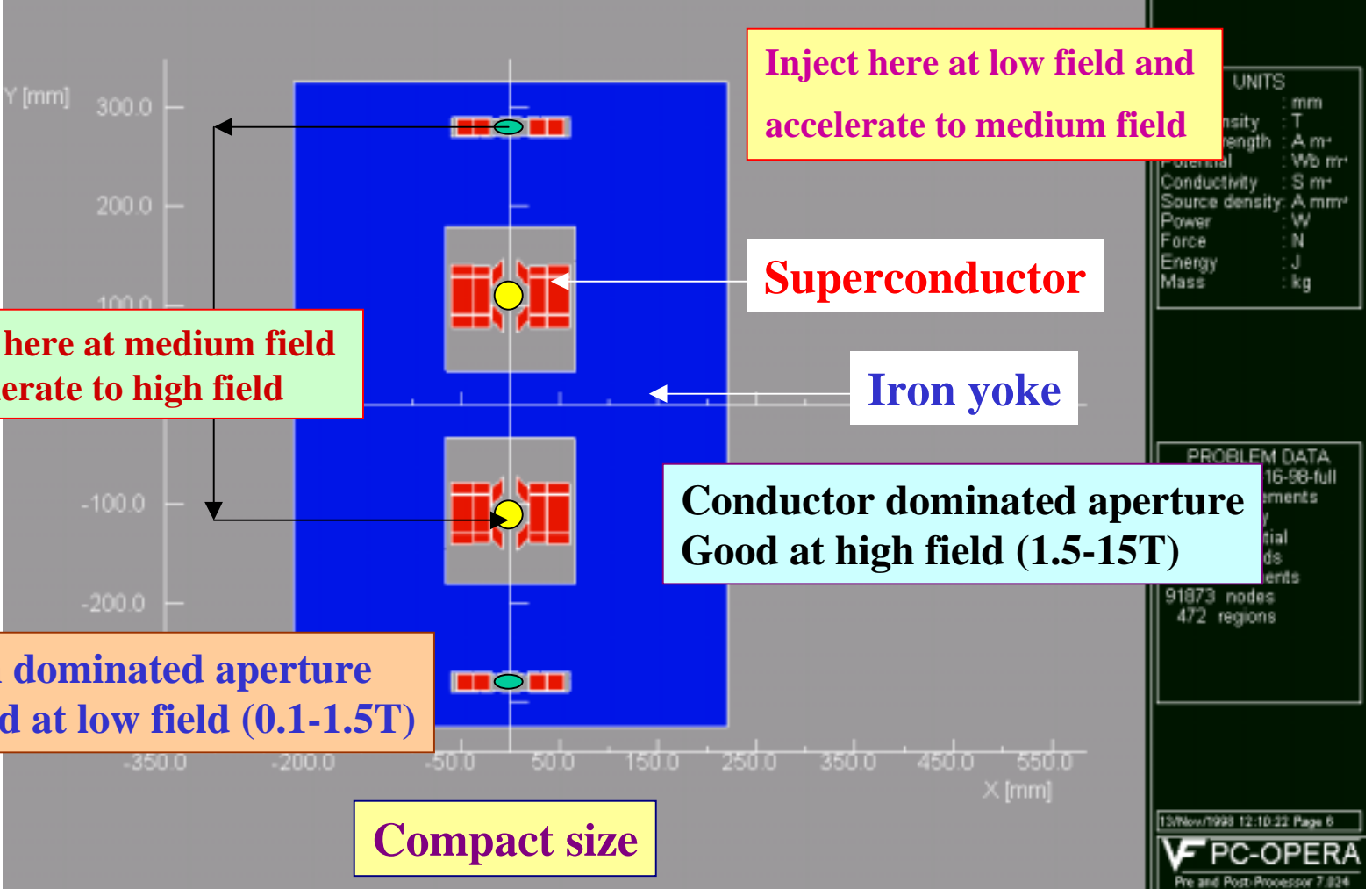
Inject here at low field and accelerate to medium field

Superconductor

Iron yoke

Conductor dominated aperture Good at high field (1.5-15T)

Compact size



UNITS	
Length	: mm
Density	: T
Length	: A m <sup>2</sup>
Potential	: Wb m <sup>2</sup>
Conductivity	: S m <sup>2</sup>
Source density	: A mm <sup>2</sup>
Power	: W
Force	: N
Energy	: J
Mass	: kg

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## Common Coil Magnet System with a Large Dynamic Range (Possible Advantages)

- **Large Dynamic Range**

~150 instead of usual 8-20.

*May eliminate the need of the second largest ring. Significant saving in the cost of VLHC accelerator complex.*

- **Good Field Quality  
(throughout)**

Low Field: Iron Dominated

High Field: Conductor Dominated.

*Good field quality from injection to highest field with a single power supply.*

- **Possible Reduction in High Field Aperture**

Beam is transferred, not injected  
- **no wait, no snap-back.**

Minimum field seen by high field aperture is ~1.5 T and not ~0.5 T.

The basic machine criteria are changed!  
Reduce high field aperture, say to 25 mm?

*Reduction in high field aperture =>  
reduction in conductor & magnet cost.*

- **Compact Magnet System**

*As compared to single aperture D20,  
4 apertures in ~70% of the yoke mass.*

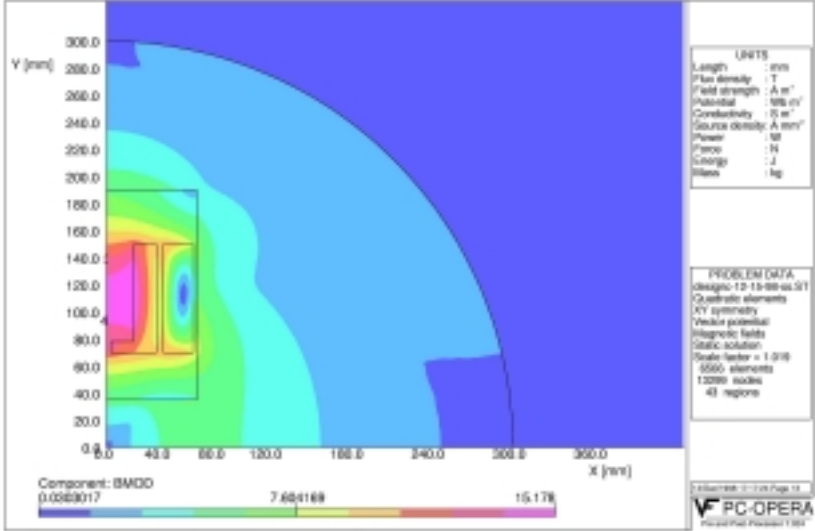
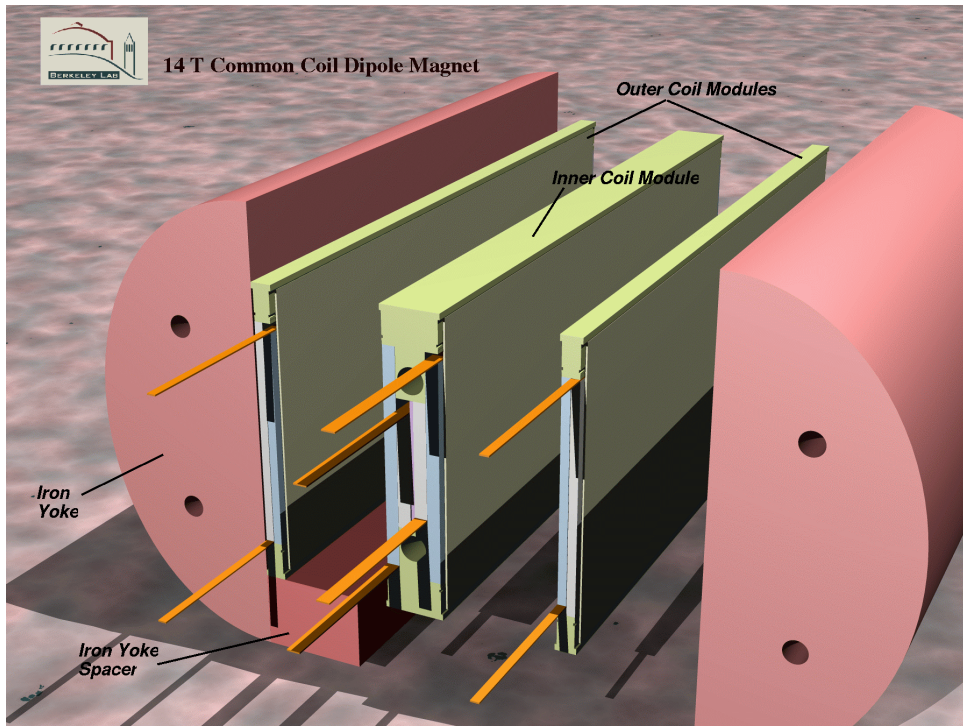


## 14 T Magnet Design Parameters (now under development)

- Uses the high performance, the best available, Nb<sub>3</sub>Sn conductor
  - $J_{sc}(12T, 4.2K) \sim 2000 \text{ A/mm}^2$ , Cu/Sc Ratio = 0.7, 1.7
- 40 mm aperture, 2-in-1 common coil magnet design
- 70 mm bend radius (in ends), 220 mm bore spacing
- Uses Iron yoke and iron insert
  - mechanically closer to an accelerator magnet
- Three layers to give a computed 14.3 T field
  - assumes no cable degradation and 4.2 k operation
- Uses unconventional cable grading
  - graded in width (NOT in thickness) for better efficiency and flexibility
- Field quality
  - not a field quality design yet, but the components of it may be used in a field quality design.



# Impressions of 14 T Common Coil Magnet (now under development at LBNL)



And a boring physicist (identity withheld)

An engineer turned into an artist (Ken Chow)



# Conclusions and Summary

## VLHC based on a common coil magnet system

- A new magnet and machine design for a possible lower cost VLHC.
- A conductor friendly approach for using “brittle” and “high magnetization” conductors. Hope it will allow using HTS and/or Nb<sub>3</sub>Sn in a competitive way.
- Major issues before a large scale production based on Nb<sub>3</sub>Sn become feasible:
  - Conductor cost. It must go down because
    - it is higher to begin with.
    - need to compensate for the complexities (cost) associated with the Nb<sub>3</sub>Sn magnets.
  - How to carry out a large scale industrial production
    - “Wind & React” Vs. “React & Wind”.
    - React and Wind is promising because of a large bend radius and 2-d structure.  
However, need to have more experience/demonstration before it can be accepted.