For earlier talks on
Field Quality and on
Common Coil Magnets,
please visit:
http://vlhc.org/mtworkshop.html

Common Coil Magnet System

(with a Large Dynamic Range)

Ramesh Gupta, LBNL

VLHC Workshop on Accelerator Physics

Lake Geneva, Wisconsin

Feb. 22-25, 1999

VLHC: It's the Cost Stupid!

A significant cost reduction is unlikely to come with the same way of doing things, i.e. by scaling up SSC or LHC technology.

We must look for alternatives and be open to those concepts which have not been tried before.

Another side benefit to a new promising idea:

It creates excitement, makes us more interested, more innovative.

At this stage, it will be easier to get more people work on VLHC with a challenging and novel ways rather than boring and old ways.

Face it: that's why we are in science - to look for innovative ways to have fun!

Now only if we can convince our funding agencies and managers that paying for this entertainment is a good investment for future, we will do just fine!

Recommendations from Gilman Panel and VLHC Steering Committee

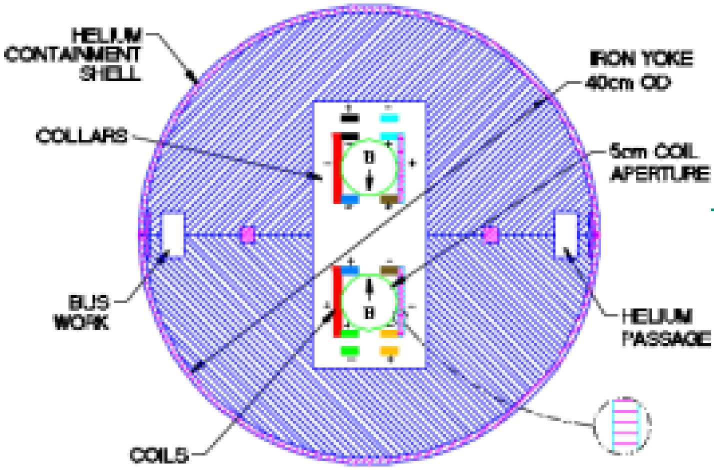
… The Gilman subpanel recommends an expanded program of *R&D on cost reduction strategies, enabling technologies*, and accelerator physics issues for a VLHC.

... identifying *design concepts for an economically and technically viable facility*.

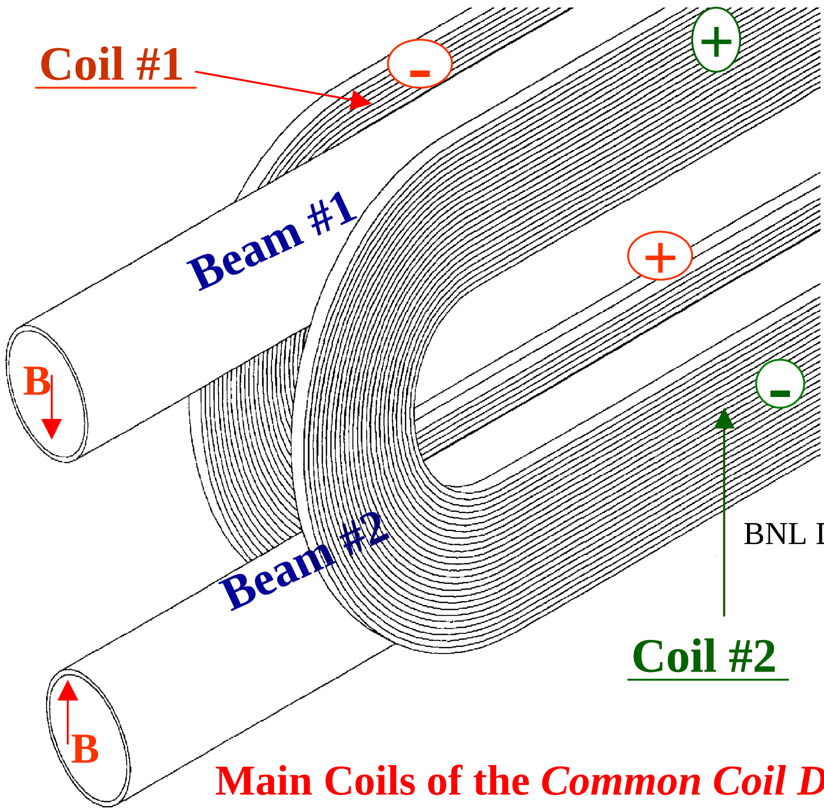
The charge from VLHC Steering Committee:

… explore and develop innovative concepts that will result in significant cost reductions.

- We have ~15 years to the next machine. That gives us a rare window of opportunity to work on a few alternate design concepts and demonstrate the feasibility (as much as possible) . Once the machine is funded, we are less likely to take risks.



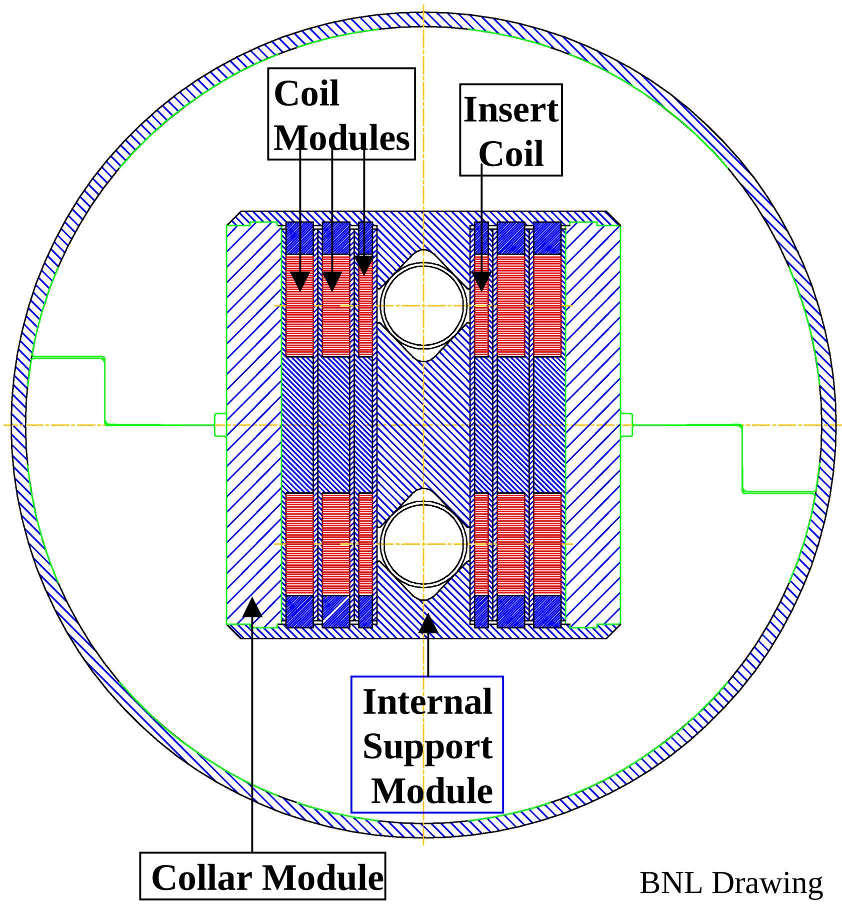
Common Coil Design
(The Original Concept)



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 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

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

BERKELEY LAB

Danby, BNL (1983)

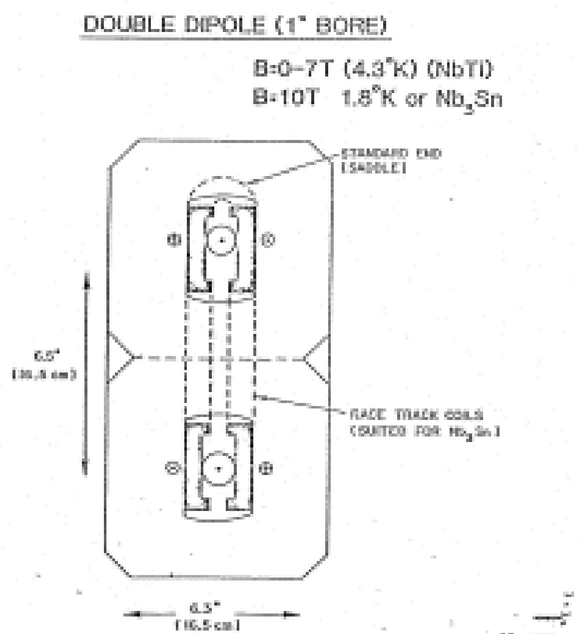


Fig. 3 High-field double dipole design with two coil return options.

-55-

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.

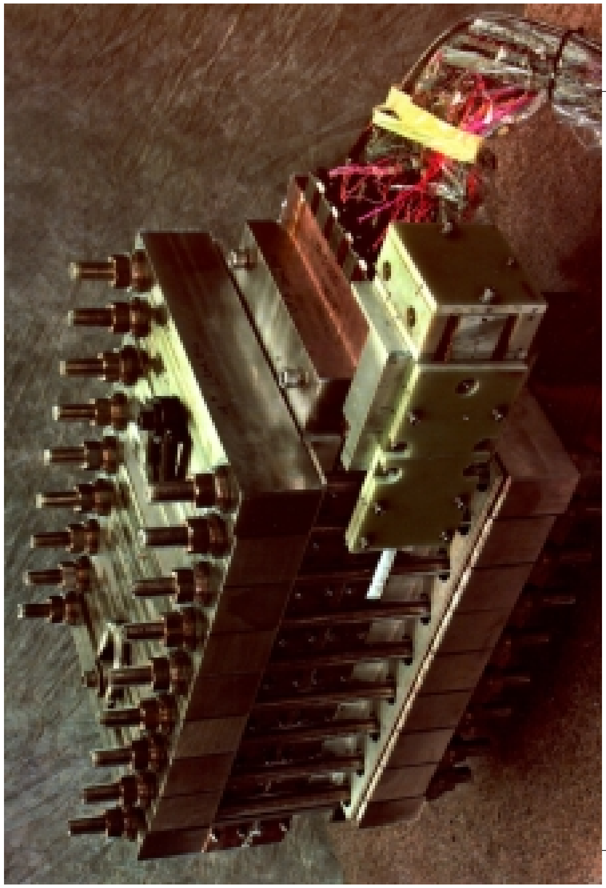
Common coil design has some more advantages in terms of compact, flexible and modular easy-to-fabricate structure, etc.

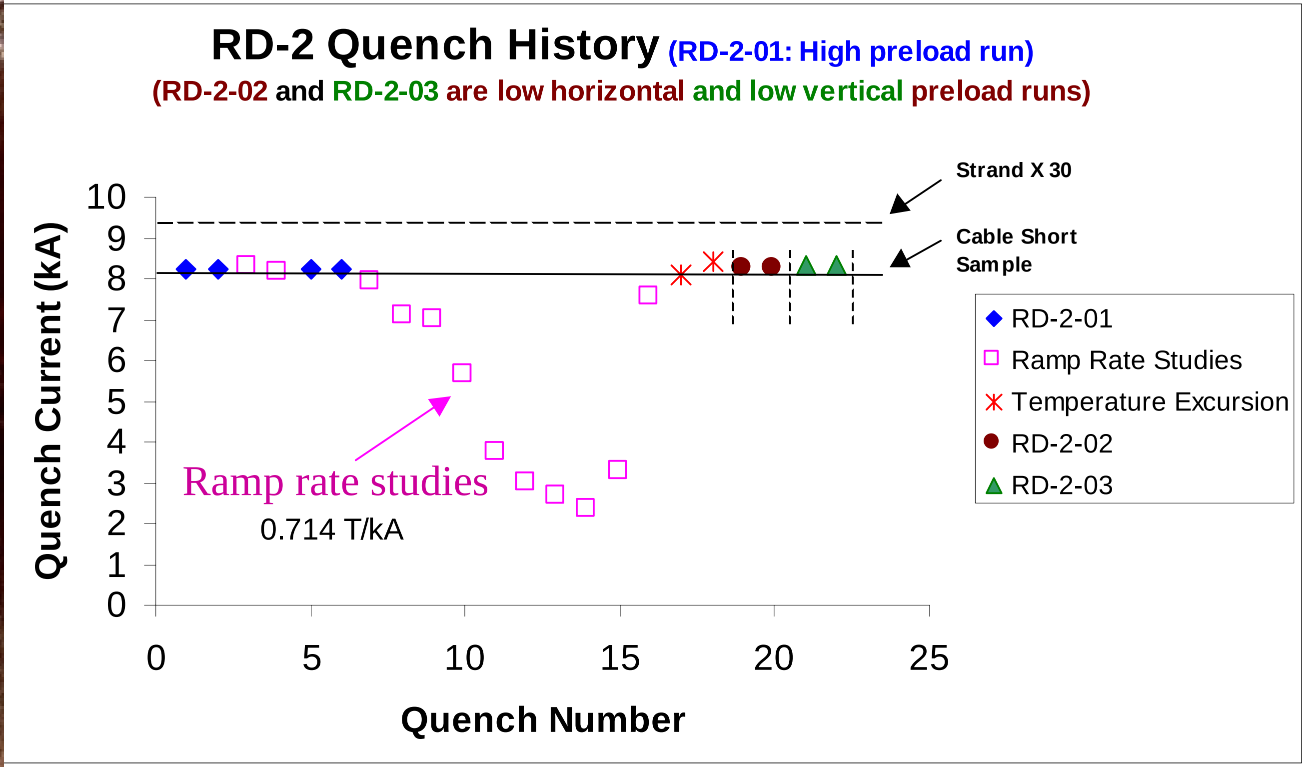
Results from the first magnet based on the common coil design

- We have built and successfully tested the first magnet Nb_3Sn 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_3Sn Magnet

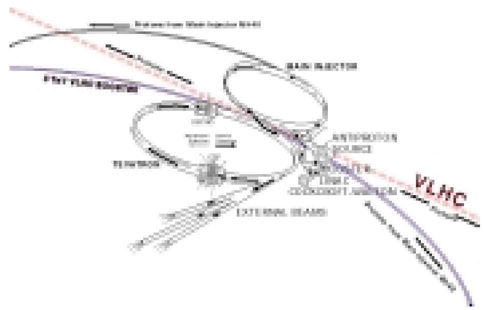




Extension of the Common Coil Design
- The Common Coil Magnet System

Looking for the major cost savings while improving the technical performance of the magnets and the machine …

- **Eliminate High Energy Booster**



- **Address superconductor issues in the magnet design**

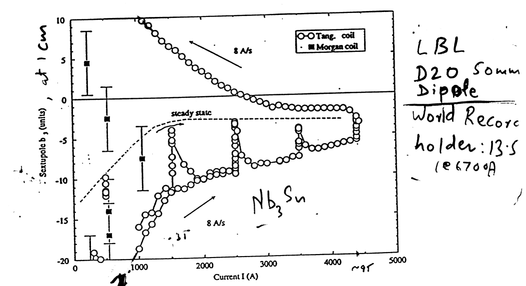


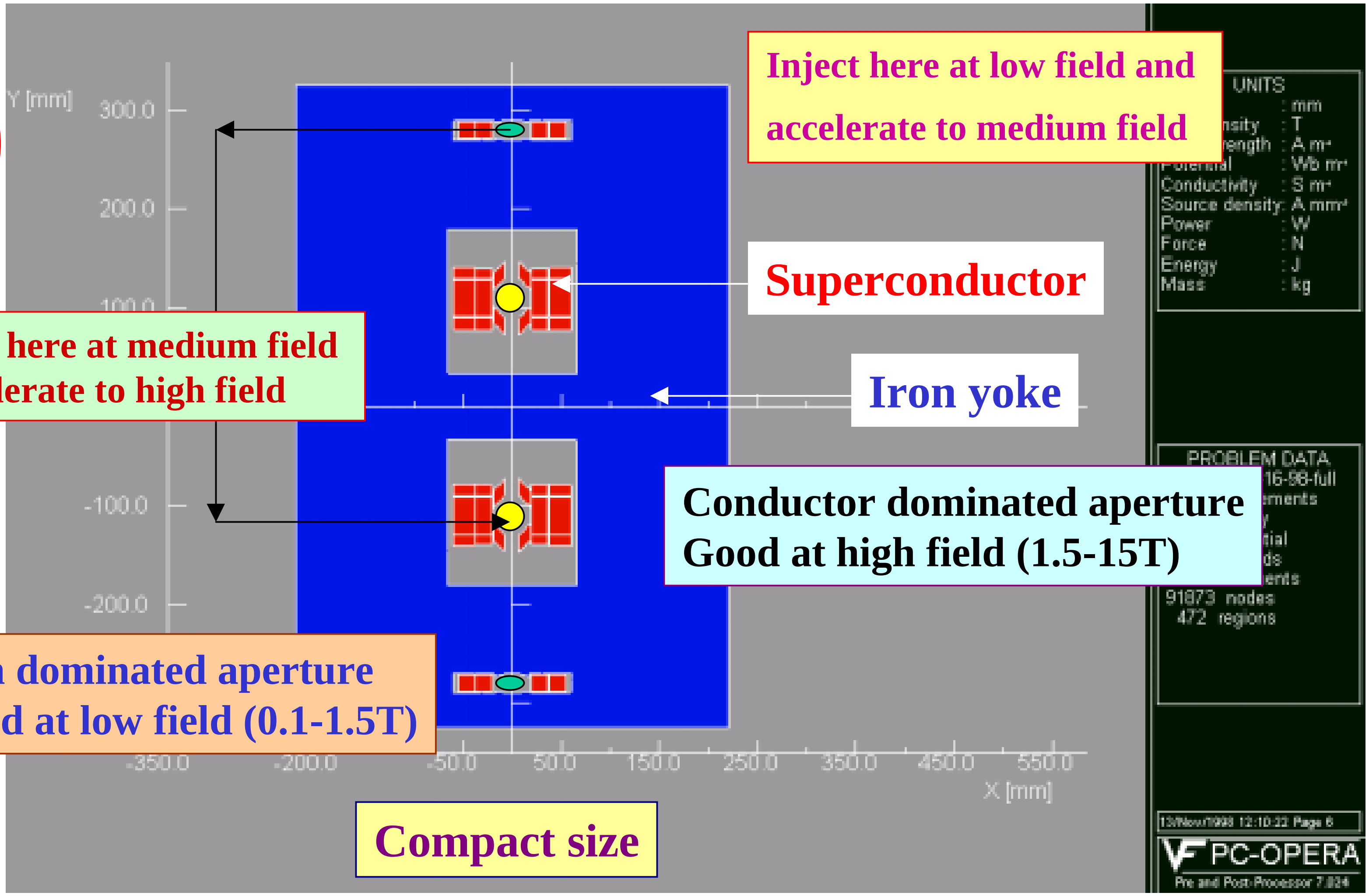
Fig. 6.. Measured sextupole at low field (direction of arrow indicates up or down current).

… and keep looking for the unusual solutions (large savings are unlikely to come from the old approaches).

A Common Coil Magnet System for VLHC

(May eliminate the need of a high energy booster)

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



Inject here at low field and accelerate to medium field

Superconductor

Iron yoke

Transfer here at medium field and accelerate to high field

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

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

Compact size

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.

Constraints Between 2 Rings for a VLHC Based on the Common Coil Magnet System

The two lattices may be different - only the machine layout must be the same.
The lattice quadrupoles may be between different number of "n" dipoles in the two rings.

For the low energy ring, a starting point for beam dynamics studies may be the low field VLHC option except that here the ring is about a factor of 8 smaller and that should help.

For example, one can consider combined function magnets (or a hybrid lattice for flexibility). If one has to, one can change the polarity of the focussing in the middle of the magnet.

In the region where the beam is transferred between the low energy ring and high energy ring, one can depart from the up-down machine configuration to side-by-side machine configuration to make situation easier (suggested by Gerry Dugan).

Abstract for PAC'99 Paper on

Field Quality in a Common Coil Design Magnet System

PAC99 Abstract #3338 revision of 04-NOV-98

Paper type: Poster . Sort code T10

MAG- 00120 Field Quality in a Common Coil Design Magnet System. *

R. GUPTA, LBNL;

This paper makes an initial estimate of the field quality in the accelerator magnets based on the "Common Coil Design" for a very large hadron collider (VLHC). In the common coil design, the main coils are shared between the two apertures in an over-and-under geometry. The auxiliary coils, used for field quality purpose, do not cross the bore tube either. Some of these auxiliary coils, like the main coils, are shared between the two apertures while some "other auxiliary coils" return away from the high field magnet apertures. It is proposed that within the same cryostat and coldmass these "other auxiliary coils" make two additional iron dominated magnet apertures where the field quality is good for beam injection for a field as low as 0.1 T. The beams are transferred from the low field apertures to the high field apertures at about 1.6-2.0 T. The estimated systematic errors in the field harmonics at 10 mm radius in a 40 mm high field (~15 tesla) aperture is expected to be a few parts in 10,000 with a single power supply. Past experience have shown that the random errors would be smaller than the systematic. The proposed "common coil design magnet system" is expected to significantly reduce the cost VLHC with the required field quality magnets having a dynamic range of 150. In the proposed system, the need of a separate outside ring for high energy booster is eliminated. Moreover, this may also help reduce the size of conductor dominated high field aperture as the beam is not injected in the conventional sense - it is transferred during an up-ramp.

*Work supported by the U.S. Department of Energy under Contract No. DE-A
D03-76SF00098.

Apertures used in the example

- **High field (conductor dominated) aperture**
  Nominal circular clearance: 40 mm

- **Low field (iron dominated) aperture:**
  Horizontal: 40 mm (same as in HF aperture)
  Vertical: 20 mm (same as in LF proposal)

These apertures are to be changed as per beam dynamics studies.

Reducing HF aperture would significantly save on the conductor volume.

Increasing LF aperture might require small amount of extra conductor and may be a separate power supply.

Flexibility in the Operations of Two Rings

Classical case: 2 apertures are coupled.

The field in the two is identical when the beam is transferred.

Flexible case: apertures de-coupled, with an extra power supply in low field aperture.

Cost of extra power supply will be recovered from the conductor cost.

Uses of Flexibility:

1. Lower energy ring can be filled while the experiments are being done in the high energy ring (increases the duty factor to experimentalists).

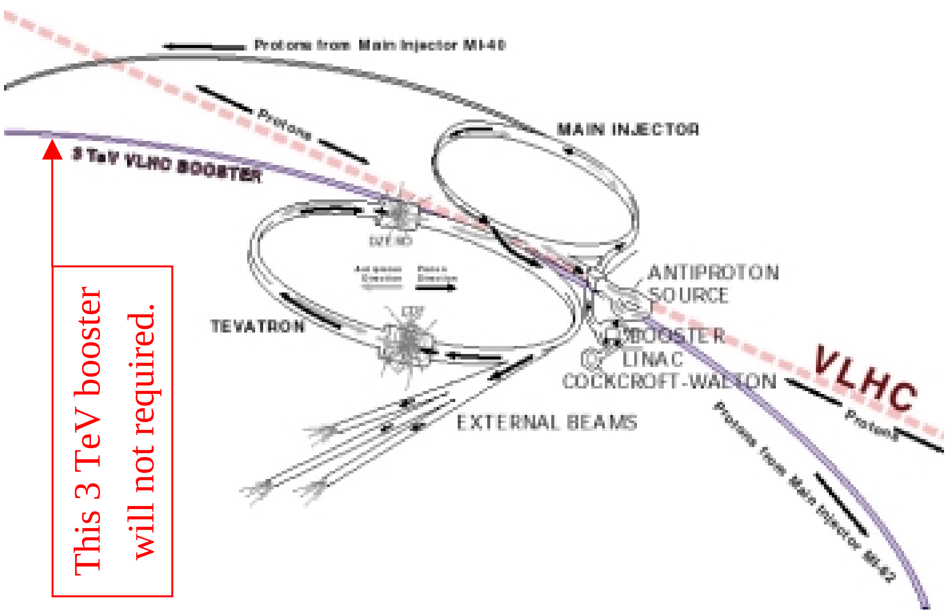
It also reduces the need to ramp the accelerator before (e.g. Tevatron) faster.

2. With two power supplies one can maintain the field quality in low field aperture to higher fields (2-3 T). It should help the beam dynamics in high field ring. Will it help reduce the aperture (saving in the cost and size of magnet system).

3. One can do collisions between the beams of different energies in two rings.

Case Studies for only one new tunnel for VLHC
(using the present Fermilab Infrastructure)

A schematic of the VLHC low field option using FNAL infrastructure (E. Malamud, W. Foster et al.).



The proposed common coil magnet system requires only one new complex for the center of mass energy up to 200 TeV (option 2 and 3).

Fermilab machine chain as VLHC injector:

Main Injector: 150 GeV (ejection energy)

Tevatron: 150-800 GeV (20% margin)

Option 1:

Low Field aperture: 0.8-5 TeV (0.24-1.5 T)

High Field aperture: 5-50 TeV (1.5-15 T)

Option 2:

Low Field aperture: 0.8-10 TeV (0.12-1.5 T)

High Field aperture: 10-***100 TeV*** (1.5-15 T)

Option 3:

Low Field aperture: 0.8-12 TeV (0.1-1.5 T)

High Field aperture: 12-***100 TeV*** (1.5-12.5 T)

Several other options are also possible.

Can raise the max. field in low field aperture, hence injection energy in high field aperture.

Injection Energies for 2 Rings (Range)

Low Energy Ring:

(a) Inject directly from Main Injector at 150 GeV : B_{inj} ~ 0.045 T

Dipoles show good field even at 0.04T

Beam instabilities issues?

(b) Inject from Tevatron at 850 GeV : B_{inj} ~ 0.25 T

How fast can one cycle tevatron (no time penalty if 2 rings are de-coupled)

Beam instabilities issues?

High Energy Ring:

(a) Inject at 5 TeV : B_{inj} ~ 1.5 T

Good field quality in low field aperture with single power supply

(a) Inject at 8.3 TeV (or even 10 TeV) : B_{inj} ~ 2.5 T (3 T)

Need 2 power supplies (no big deal, cost recovered from conductor cost)

Will it help reduce the high field aperture? Significant savings.

e-p and e^+e^- Collision Scenarios

Use Low Field Aperture for electrons

e-p, e^+-e^- collisions

(any one for e-e or p-p collisions with different energies?)

What is the largest practical/tolerable energy for the electron beam?

$$P = \frac{1}{6\pi\epsilon_0}\frac{e^4}{m^4c^2}B^2E^2$$

Consider LEP2 criterion: 26 km tunnel for 90 GeV per beam.

The 50 TeV VLHC tunnel (high field option) will be larger by about a factor of 4 (a factor of 8 for 100 TeV tunnel). For 200 GeV electrons, the power dissipated/length is about the same (the wall power goes up by a factor of 4).

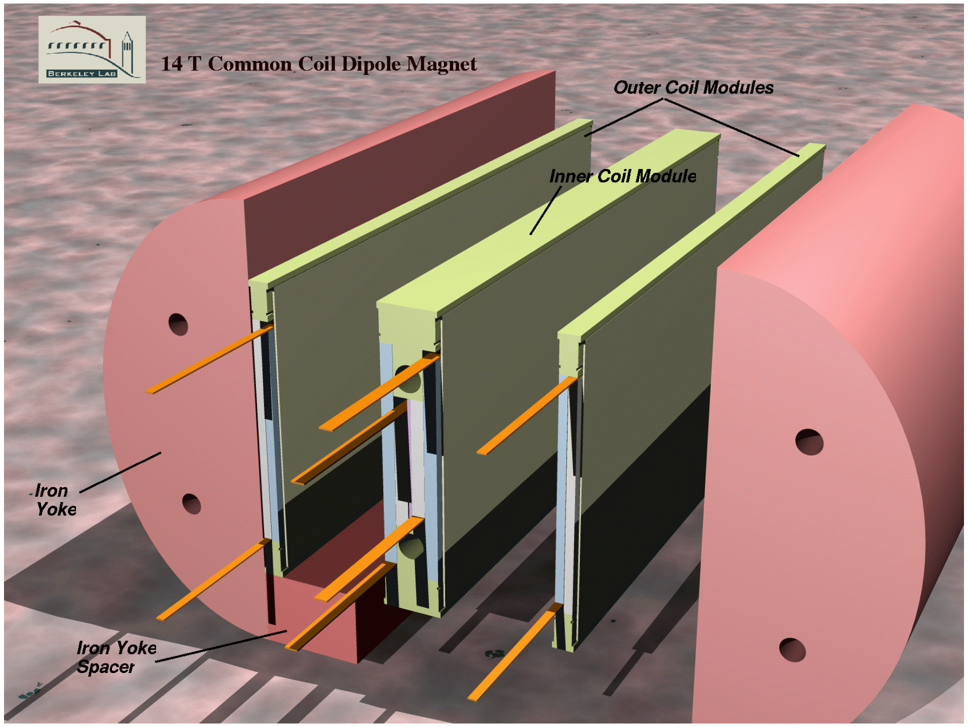
- **200 GeV electrons on 50 TeV protons**
- **400 GeV center of mass electron collider**

Are cold iron magnets ok for electrons? If not what can be done?

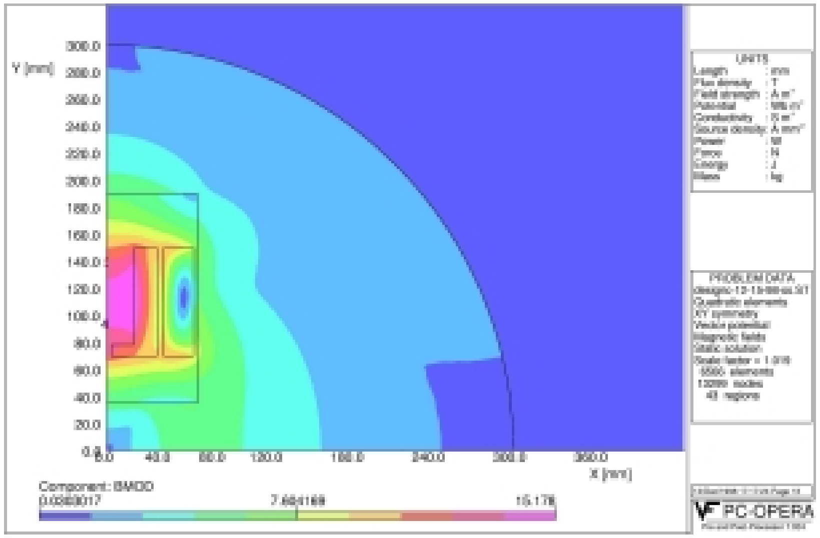
14 T Magnet Design Parameters (now under development)

- Uses the 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, 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)

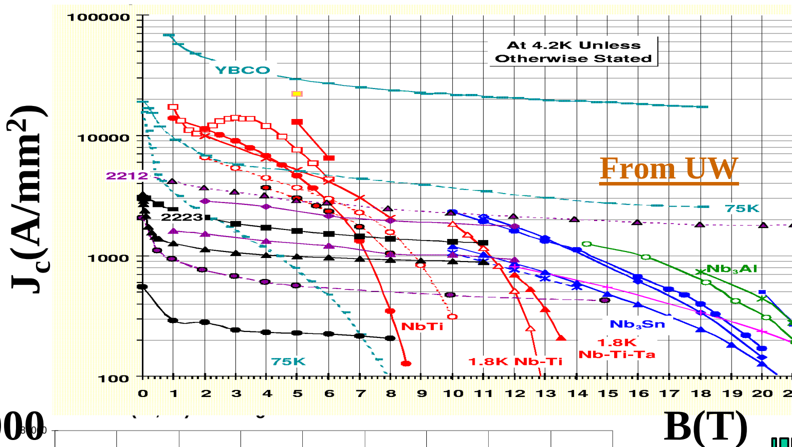


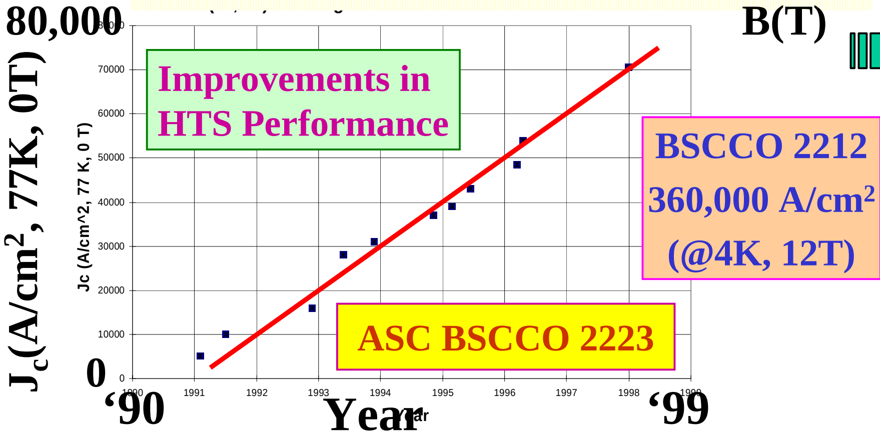
An engineer turned into an artist (Ken Chow)

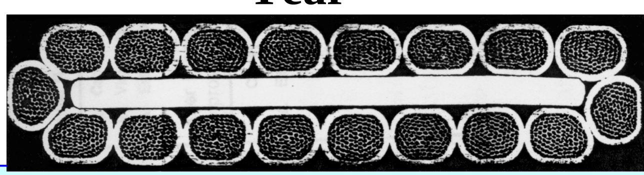


And a boring physicist (identity withheld)

Emerging Technologies : HTS







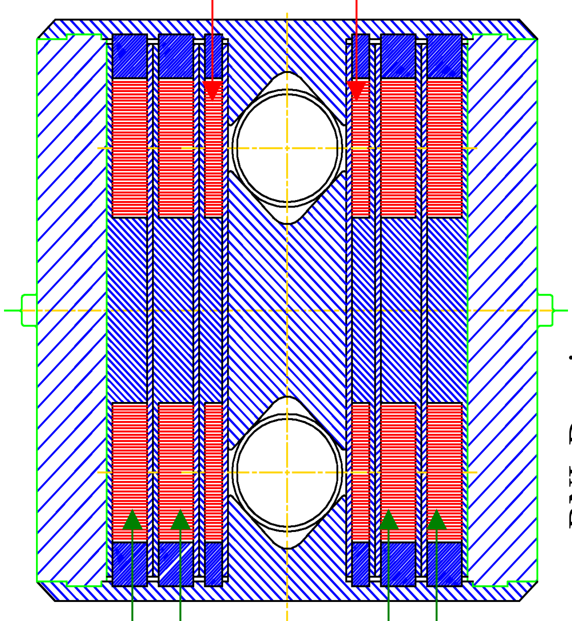
KAmp Rutherford cable : LBL-industry collaboration

- **HTS have made significant progress**
- **To be shown that it's 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 related technologies also :**

- ✧ **Newer Nb_3Sn, Nb_3Al**
- ✧ **React & Wind magnet technology**
- ✧ **etc.**

HTS in a Hybrid Magnet



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

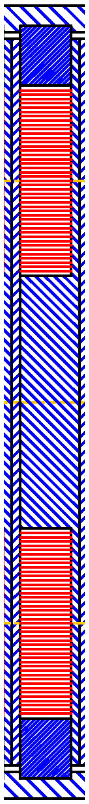
  HTS is subjected to the similar forces that would be present in an all HTS magnet. Therefore, the most technical issues will be addressed.

- **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. Also future possibilities for main dipoles.**

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

<u>**VLHC R&D based on a common coil magnet system**</u>

- **Explores new magnet designs and technologies.**
- **An approach to produce lower cost magnets and lower cost colliders.**
- **A proposal that eliminates the second largest ring (and associated complex) with several technical advantages.**