US LHC Accelerator Research Program
High-Field Magnet R&D

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Workshop on Accelerator Magnet Superconductors

Archamps, France - 22-24 March 2004

Outline

Overview of US LHC Accelerator Research Program (US LARP)

US LARP Magnet R&D Program Plans

US Base Program in High Field Accelerator Magnet R&D

What is the US LARP?

The US LHC Accelerator Research Program (US LARP) is a collaboration of four US National Laboratories, which in turn is working with CERN to advance performance of the LHC.

- Help commission the LHC:
  - Hardware systems that the US Labs are building now for LHC,
  - Beam commissioning of the entire complex.
- Develop beam instrumentation and 2^{nd} generation collimators to help commission LHC and bring it to design performance.
- Use the LHC as a vehicle for fundamental accelerator physics research.
- Perform accelerator physics studies and advanced magnet R&D directed towards timely LHC luminosity upgrade.

For more info, see http://www-td.fnal.gov/LHC/USLARP.html

Goals of the US LARP

Advance High Energy Physics

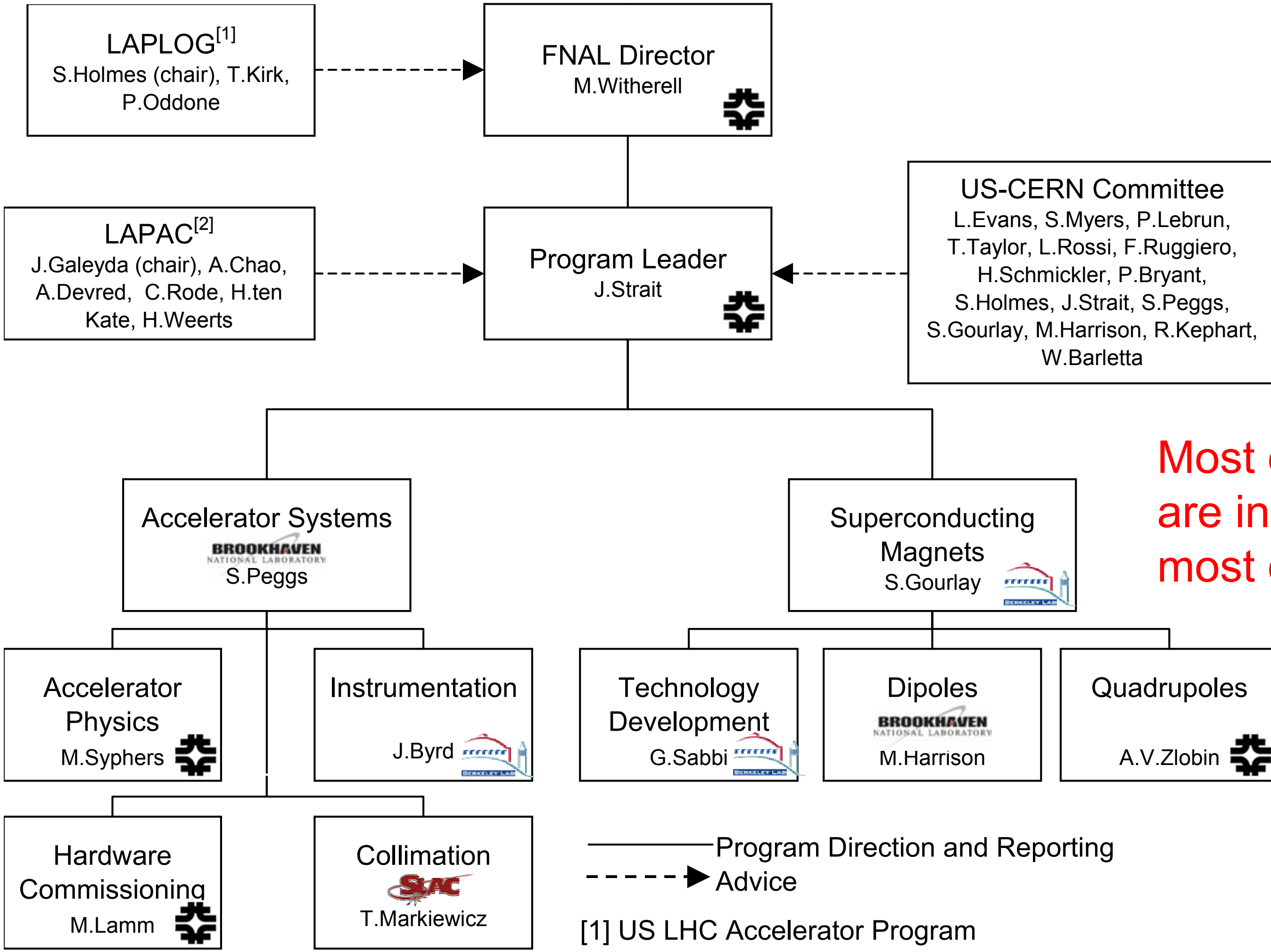
- Help bring the LHC on and up to design performance quickly.
- Improve LHC performance by advances in understanding and instrumentation.
- Use LHC as a tool to gain deeper knowledge of accelerator science and technology.
- Extend LHC as a frontier HEP instrument with a timely luminosity upgrade.

Advance U.S. Accelerator Science and Technology

- Keep skills sharp by helping commission the LHC.
- Conduct forefront AP research and development.
- Advance U.S. capabilities to improve the performance of our own machines.
- Prepare U.S. scientists to design the next generation hadron collider.
- Develop technologies necessary for the next generation of hadron colliders.

Advance International Cooperation in the High Energy Accelerators

Organization



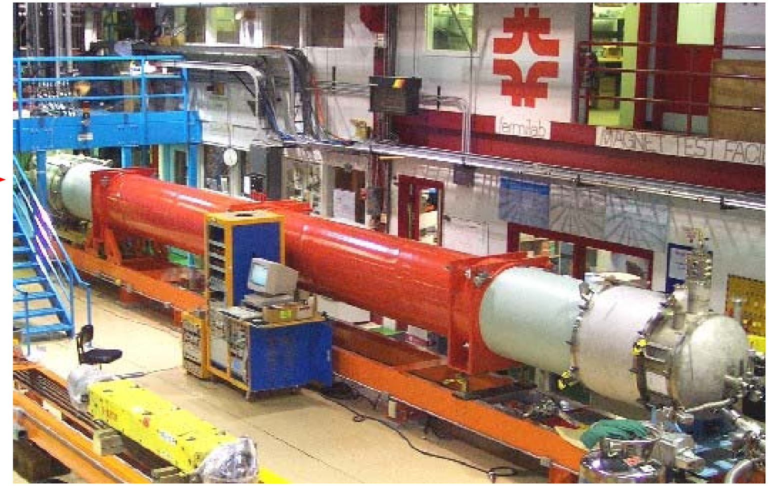
Most of the labs are involved in most of the tasks

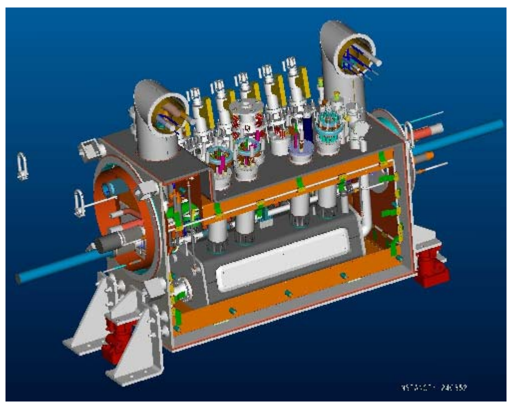
[1] US LHC Accelerator Program Laboratory Oversight Group
[2] US LHC Accelerator Program Advisory Committee

Commissioning the LHC

The US labs are making a major contribution to the construction of the IRs:

- **IR Quads (FNAL)**
- Beam Separation Dipoles (BNL)
- IR Feedboxes (LBNL+**FNAL**)
- IR absorbers (LBNL)





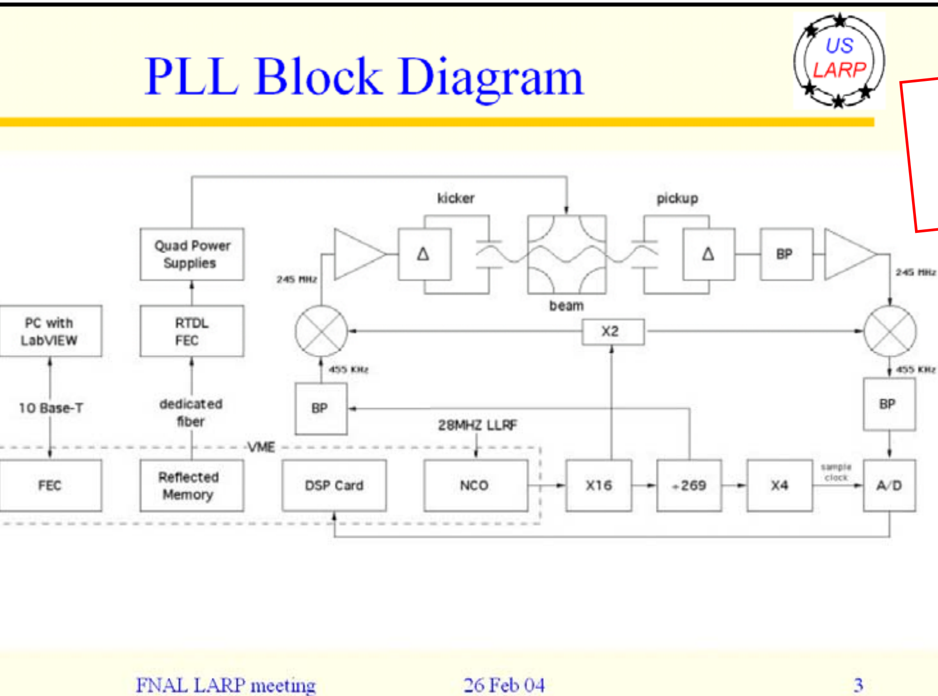
We will work with CERN to ensure that the US provided equipment is integrated and commissioned efficiently with the other systems.

Commissioning the LHC

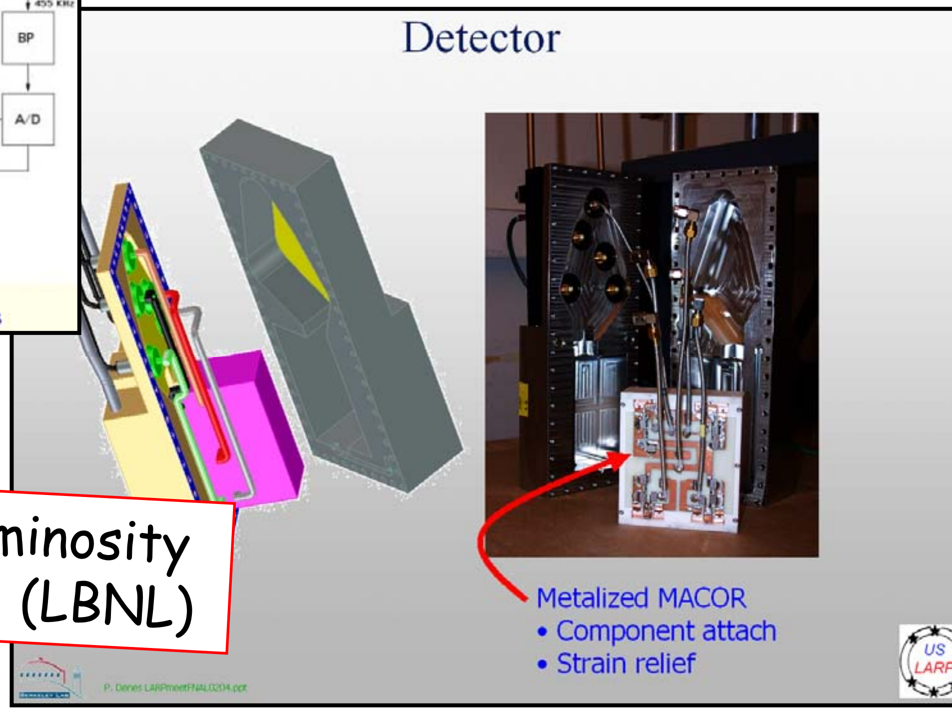
Beam Commissioning

- The participation of experienced US accelerator physicists – *one on each shift* – will help bring the LHC to design luminosity more quickly.
- Participation is also a direct benefit to the U.S. programs, since commissioning colliders is a once-in-a-decade opportunity:
  Maintaining a core of (young) experience is vital for the present and future capabilities of hadron colliders in the U.S.
- We are currently discussing with the CERN operations group how to integrate the US physicists into the overall LHC team.
- Injection tests provide early opportunities to start to work together:
  - SPS to LHC transfer line test in September/October 2004
  - Injection test into 1st LHC sector in 2006.

Beam Instrumentation



Tune Feedback (BNL+FNAL)



Fast Luminosity Monitor (LBNL)

Beam Instrumentation

Abort Gap Monitor

Goal: detect presence of
harge in gap for abort
icker rise time
LHC Spec

Possible solution: detect
ynch light with gated
MCP/PMT.

HAMAMATSU

GATEABLE MICROCH
PHOTOMULTIPLIER TU
R5916U-50 SE

Featuring Fast Gating Function with Improved Time Re
and Switching Ratio

FEATURES
- High Speed Gating by Low Supply Voltage (+10V)
  - Gate Rise Time : 1 ns
  - Gate Width : 5 ns
- Fast Rise Time : 180 ps
  - Narrow TTS : 90 ps
- High Switching Ratio : 10^8 at 500 nm
- Low Switching Noise
- Low Dark Noise
- Variety of Photocathode Available

APPLICATIONS
- Environmental monitoring
- Satellite laser ranging
- Fluorescence decay analysis

Similar approach used in light sources to measure parasite bunches.

Effort not funded by LARP in FY04. Increase to 140k$ in FY05.

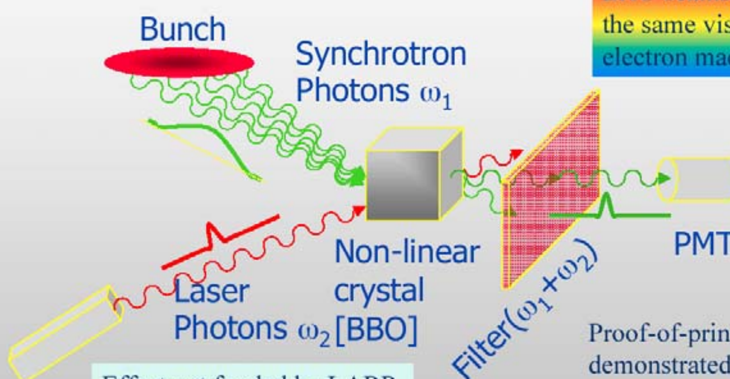
LARP Mtg, 26-27 Feb 2004 page 11 John Byrd

Abort Gap Monitor (LBNL)

Optical Sampling Technology

- Use mixing of synchrotron radiation with a short laser pulse to sample the longitudinal bunch profile

LHC beams (γ=7000) emit the same visible light as electron machines



Proof-of-principle demonstrated on the ALS. Developed in collaboration with femtoslicing program.

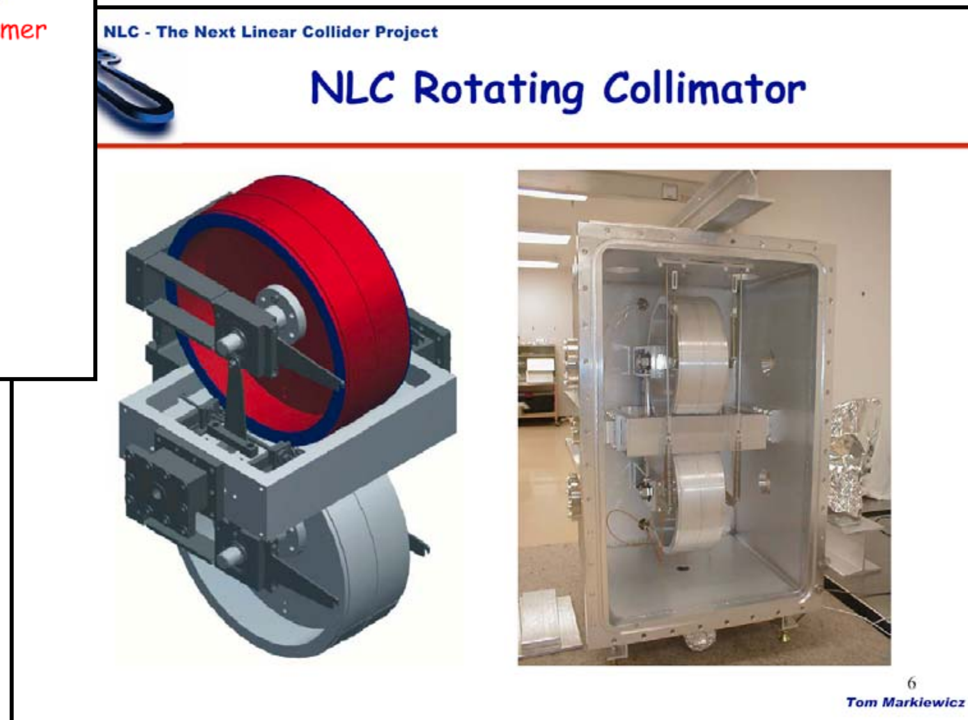
Effort not funded by LARP in FY04. Increase to 140k$ in FY05

LARP Mtg, 26-27 Feb 2004 page 10 John Byrd

Longitudinal Density Monitor (LBNL)

R&D for Phase II Collimation System

Baseline LHC collimation system (carbon primary absorbers) will limit bunch intensity to <30~40% of nominal
=> L < 10~15% of nominal.



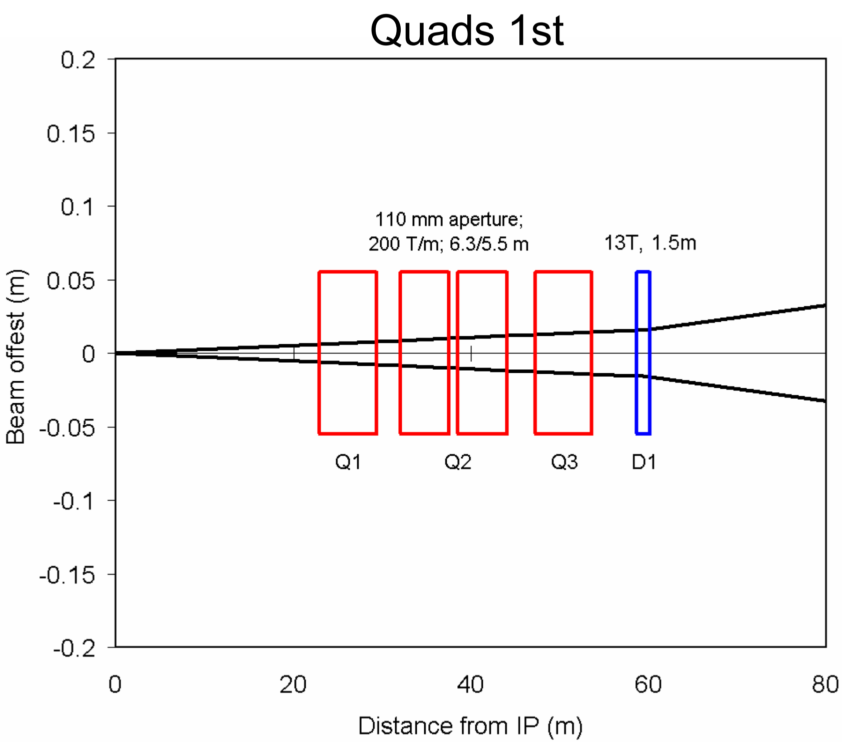
Propose to develop rotating metal collimators for a Phase II system to allow LHC to come to design luminosity.

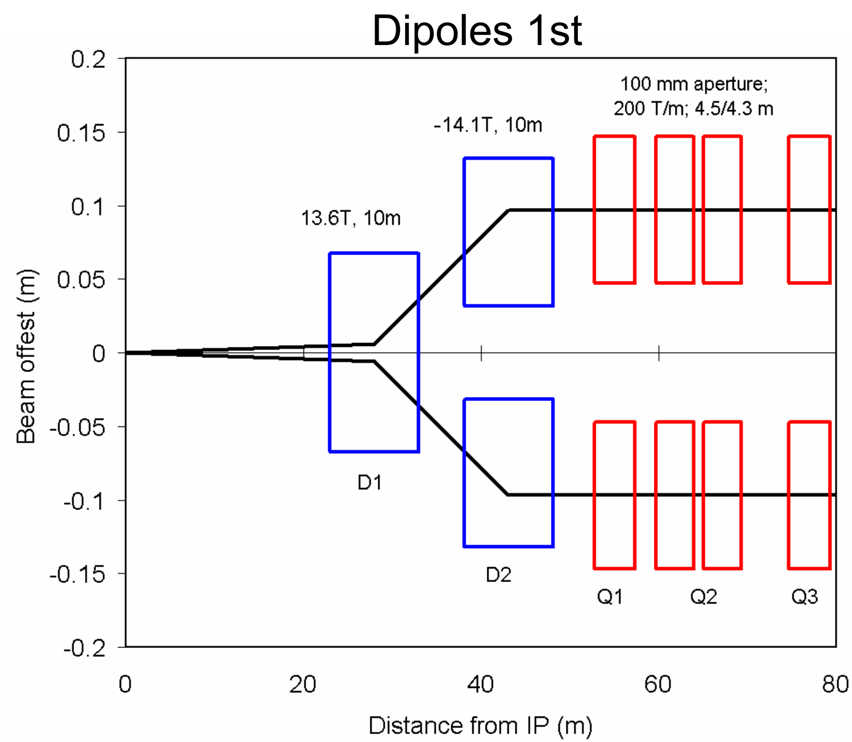
Accelerator Physics

The LHC will be *the* forefront hadron collider of the future, and US Accelerator Physicists are pursuing a number of areas of Accelerator Physics research related to it:

- Beam-Beam Interaction
  - RHIC and Tevatron to study issues of relevance to LHC.
- Electron cloud and other vacuum effects
  - RHIC & the Tevatron as cryogenic test beds. Synch light.
- LHC upgrade optics
  - synergy with magnet program.
- Interaction Region compensation
  - before & after upgrade.
- Energy deposition and beam loss scenarios
  - before & after upgrade
  - synergy with magnet and collimation programs.

New IRs for Luminosity Upgrades:
Accelerator Physics and Magnet R&D





J. Strait, et al., Towards a New LHC Interaction Region Design for a Luminosity Upgade, PAC 2003.

Magnet R&D for a Luminosity Upgrade

- We plan to pursue R&D on both quadrupoles and dipoles:
  - Quads with the largest possible aperture[1] with $G_{op} > 200$ T/m, required for any new IR.
  - Large-aperture dipoles for the extreme radiation environment[2] of a dipole-first IR.
  - Vigorous program to develop Nb_3Sn magnet technology is required.

- Deliverables will be successful R&D, leading to accelerator-ready magnet design(s), ready for production on the time scale required for for a luminosity upgrade.

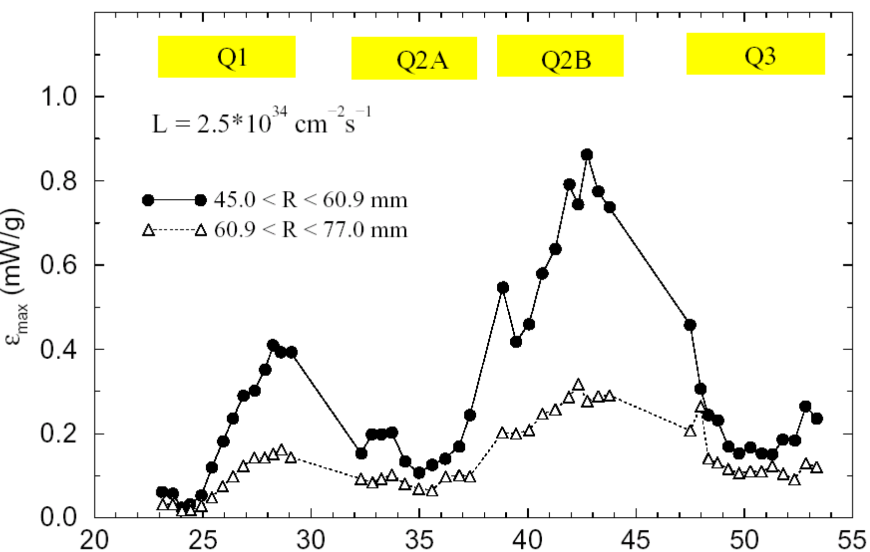
- This work is a stepping stone to the magnets required for the next, higher energy hadron collider.

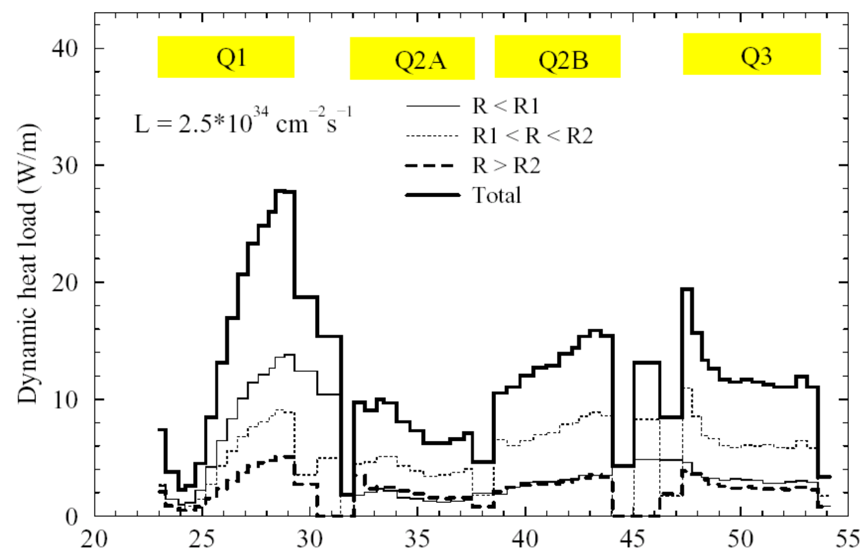
[1] A.V. Zlobin, et al., Aperture Limitations for 2nd Generation Nb_3Sn LHC IR Quadrupoles, PAC2003.
[2] N.V. Mokhov, et al., Energy Deposition Limits in a Nb_3Sn Separation Dipole in Front of the LHC High-Luminosity Inner Triplet, PAC2003.

Energy Deposition

Energy deposition and radiation are *major* issues for new IRs.

- In quad-first IR, E_{dep} increases both with L and with quad aperture.
  - ε_{max} > 4 mW/g, $(P/L)_{max}$ > 120 W/m, $P_{triplet}$ >1.6 kW for $\mathcal{L} = 10^{35}$ cm^{-2} s^{-1}.
  - Radiation lifetime for G11CR < 6 months at hottest spots.

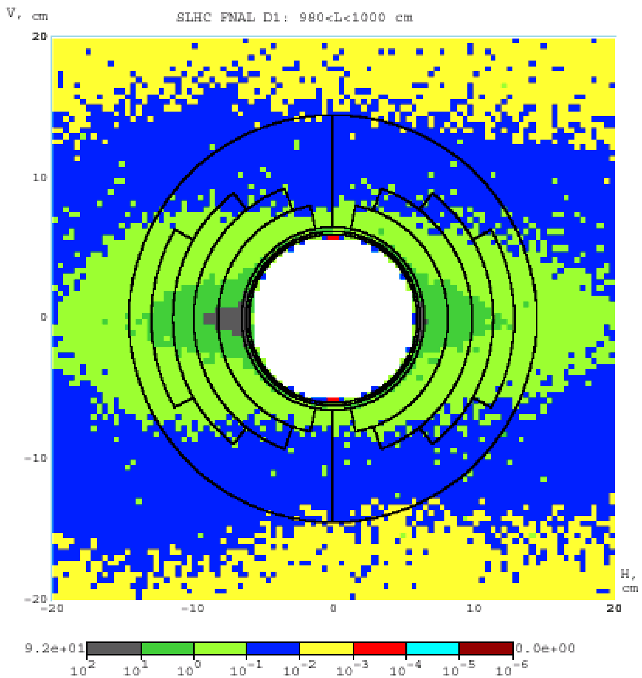


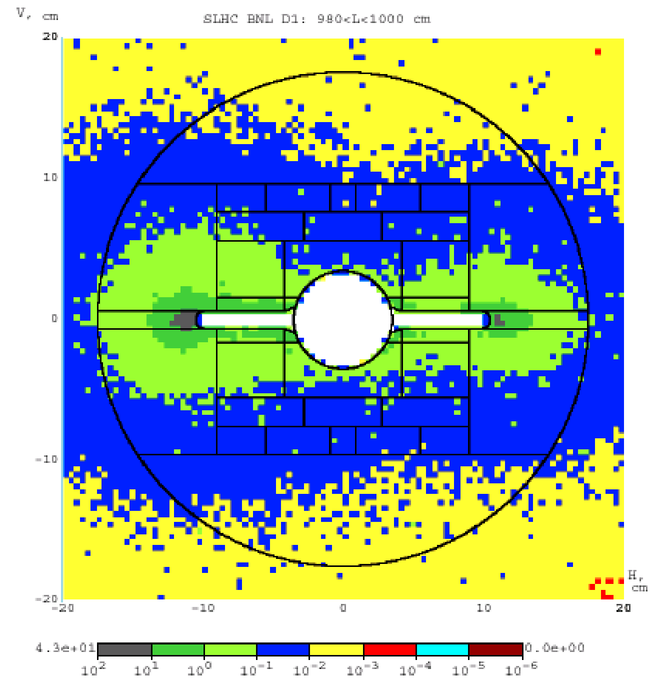


T. Sen, et al., Beam Physics Issues for a Possible 2nd Generation LHC IR, EPAC 2002.

Energy Deposition

- Problem is even more severe for dipole-first IR.
  - ε_{max} on mid-plane ~ 50 mW/g; P_{dipole} ~3.5 kW for $\mathcal{L} = 10^{35}$ cm^{-2} s^{-1}.
  - "Exotic" magnet designs may be required, whose feasibility is not known.





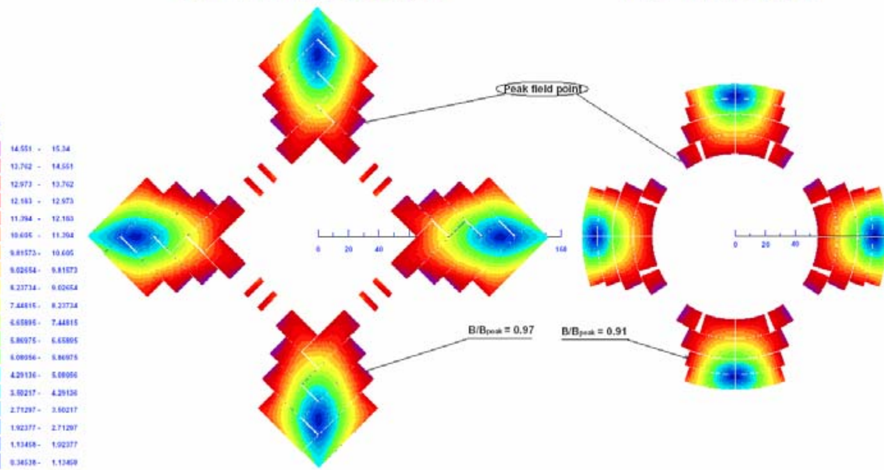
N.V. Mokhov, et al., Energy Dep.Limits in a Separation Dipole in Front of the LHC High-L Inner Triplet, PAC 2003.

IR Quadrupole Design Studies

Goal – largest possible aperture for $G_{operating}$ ~ 200 T/m

Fermilab **Peak field**

92-mm racetrack 110-mm shell



Cable grading in the racetrack magnet is ineffective.

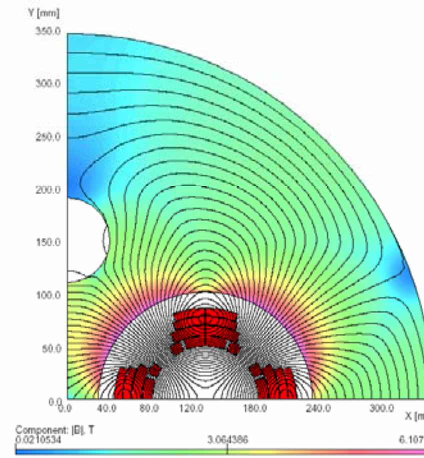
US LARP Collaboration Meeting
26-27 February 2004
Vadim Kashikhin

Fermilab **Next steps**

Analysis of 2-in-1 quadrupole magnet

Questions to address:

- aperture limit with LHC beam separation;
- field quality;
- “cold” vs. “warm” yoke design;
- symmetric vs. asymmetric coil.



US LARP Collaboration Meeting
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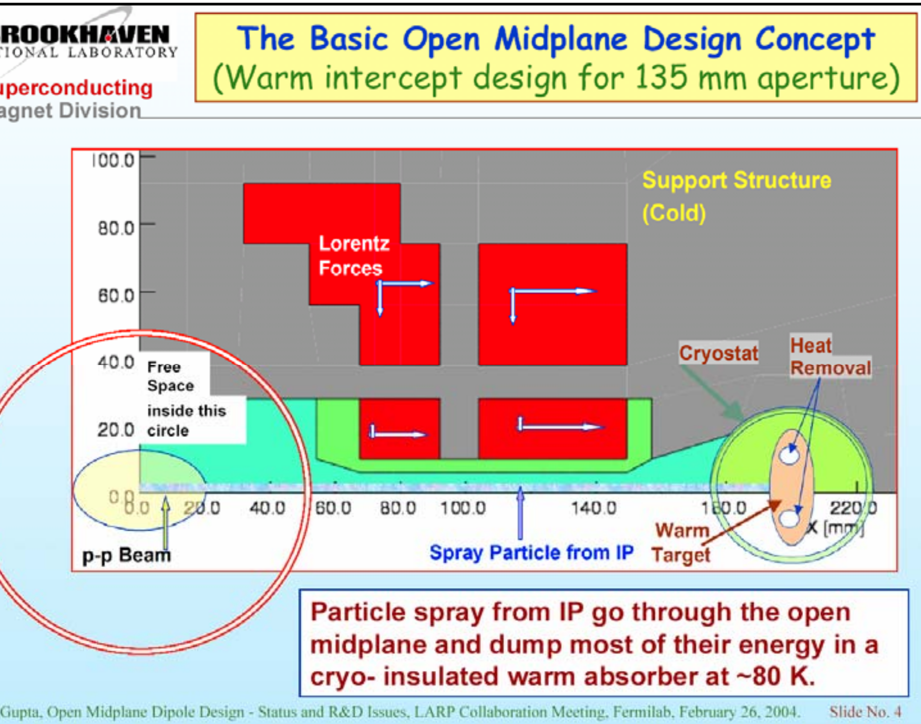
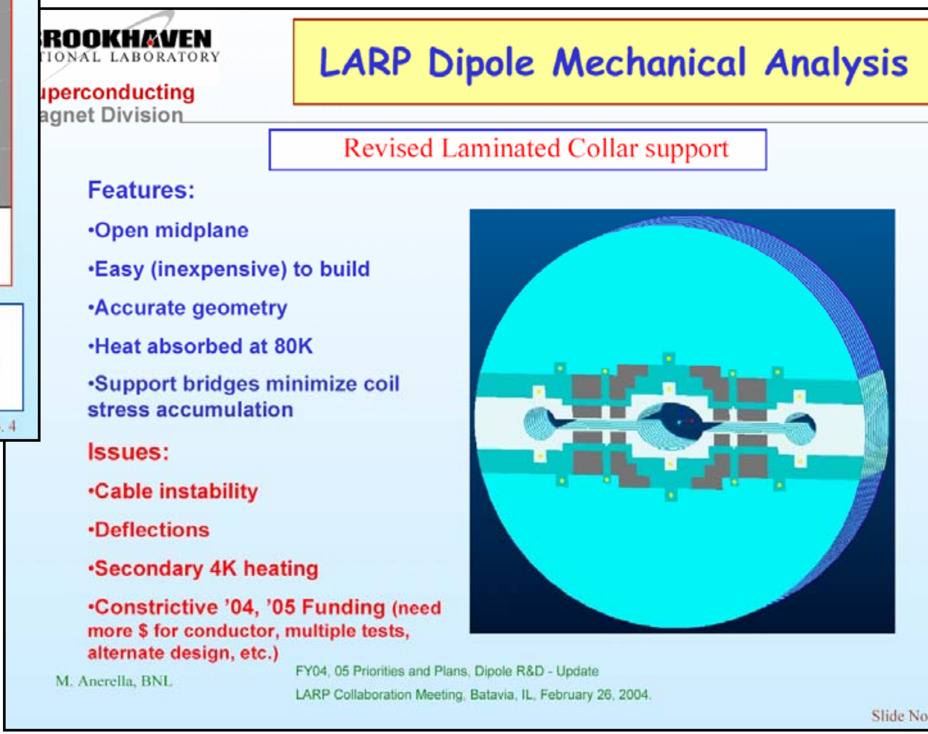
Vadim Kashikhin

IR Dipole Design Studies

Challenges: - Highest possible operating field.
- Extreme radiation heat load on mid-plane.

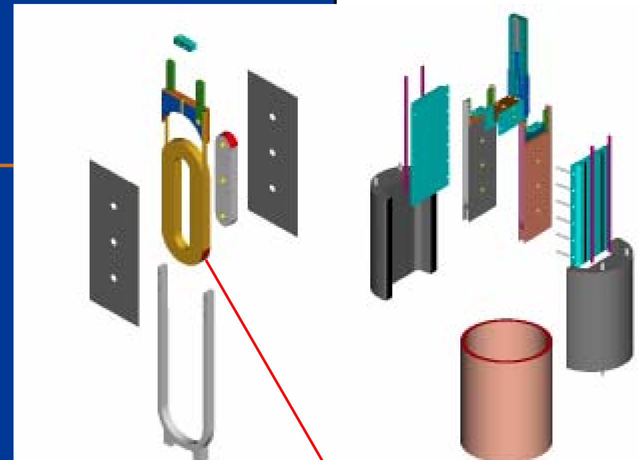


Open mid-plane design:
- Mechanics?
- Field quality?
- Field strength?



Technology Development

Subscale Models

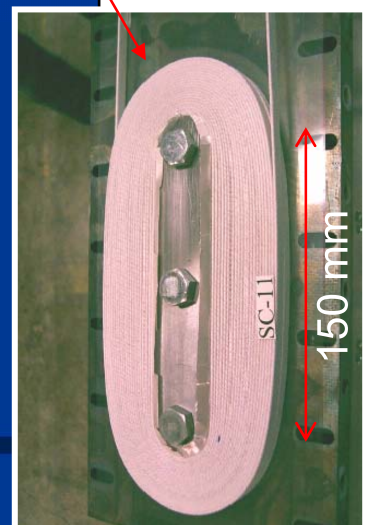


FY04:

- New instrumentation
- Coupled thermal/stress analysis during quench
- Conductor development with SM cable

FY05-FY06:

- Rad hard materials testing (insulation, epoxy)
- Test new cable designs
- …
- Start study of length scaling issues using a “long subscale”?



BERKELEY LAB

LARP Meeting 2/26-27, 2004 *Superconducting Magnet Program* Gian Luca Sabbi

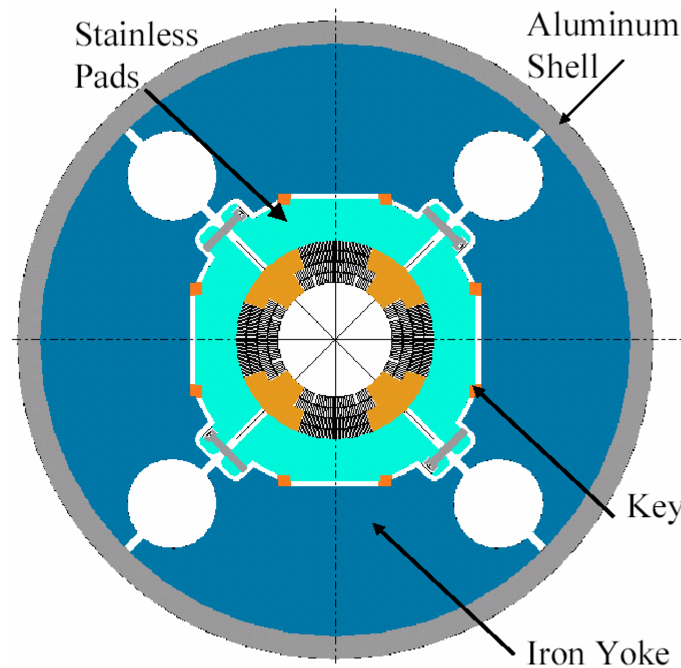
Strategy for Luminosity Upgrade R&D

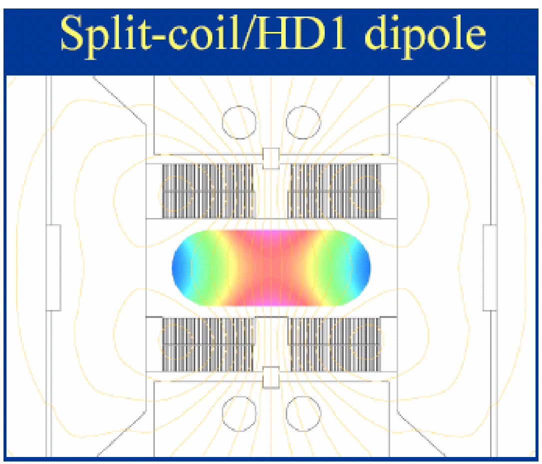
- 2004-05:
  - Accelerator physics studies of IR issues.
  - Magnet design studies, to identify feasible designs and critical R&D issues.
  - Start technology R&D focused on critical topics.
- 2006-09:
  - Model magnet R&D to develop quad and dipole technologies and learn what are feasible goals for IR upgrade designs.
  - Continue focused technology development.
  - Continue AP studies, including beam studies with LHC.
  - Choose IR design for upgrade by 2009~2010.
- 2010-12:
  - Develop final designs to production ready state.

All work to be done in close collaboration with CERN.

Near-Term Plans (1~2 years)

- Conceptual design studies, coordinated with accelerator physics studies.
- Conductor and technology development.
- (First) Construction and test of simplified quad model
  - 2 layers of eventual 4-layer quad using "bladder and key" assembly method.
- (Later) Construction and test of simplified open mid-plane dipole using LBL "HD-1" coils".





US Base Program in High Field Accelerator Magnet R&D

The US LARP magnet R&D program builds on a base program at the three US labs in the development of high-field accelerator magnets for use in future hadron colliders:

LBL Program Focus:

- Development of new technologies.
- Push for highest possible field (B_{max}>16 T).

FNAL Program Focus:

- Practical magnet designs for accelerator applications.
- Moderately high field ($B_{operating}$ = 10~12 T).

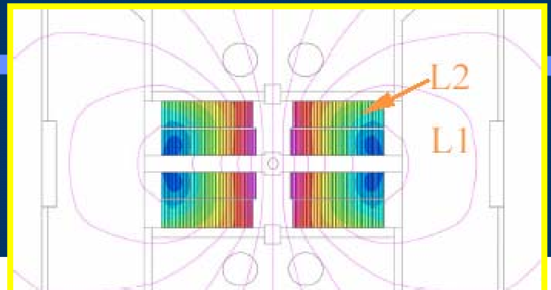
BNL Program Focus:

- React and Wind technology for Nb_3Sn and HTS.

LBNL

- Accelerator Magnet Program emphasizing development of new technology for HEP
  - Issue-driven accelerator magnet program
  - Explore parameter space and challenge existing limits
    - High fields/gradients
    - Accelerator quality
    - Training
    - Cost effective designs

- To Date:
  - Record dipole fields in 3 coil geometries
    - D20 - Cos-theta (13.5 T)
    - RD-3b - Common Coil (14.5 T)
    - HD-1 - Block (16 T)
  - Productive "sub-scale" magnet program
    - Targeted R&D



HEPAP 2/10/04

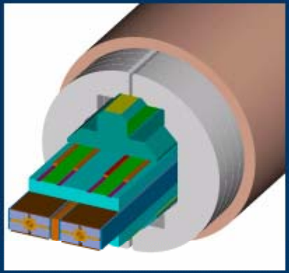
S. Gourlay, LBNL

LBNL Plans

Goal: demonstrate the feasibility of an LHC doubler

After HD-1

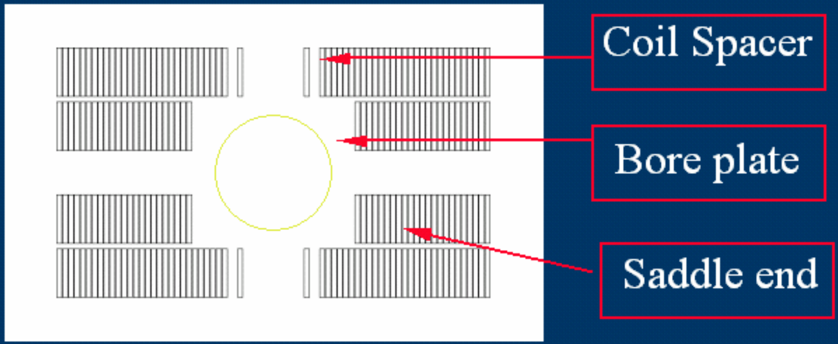
Reconfigure HD-1 for 1.8 K
Possibly 17 T? Maybe 18 T?



Accelerator quality issues:

1. Saddle ends for efficiency
2. Clear bore size and support
3. Spacers & field quality

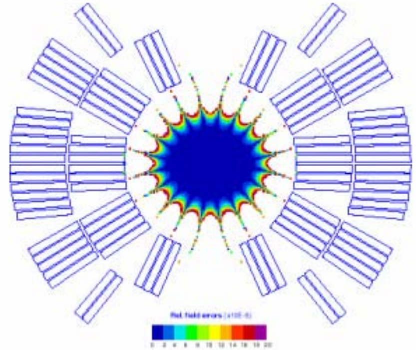
HD-2, 3. . .
Larger bore
Field quality
Dual-bore configuration



HEPAP 2/10/04

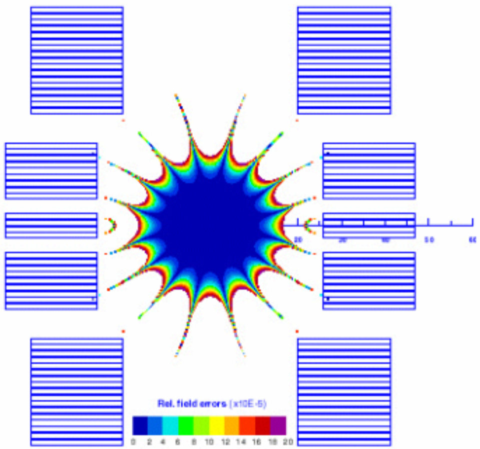
S. Gourlay, LBNL

Design Approaches



We are working with two basic dipole coil designs:

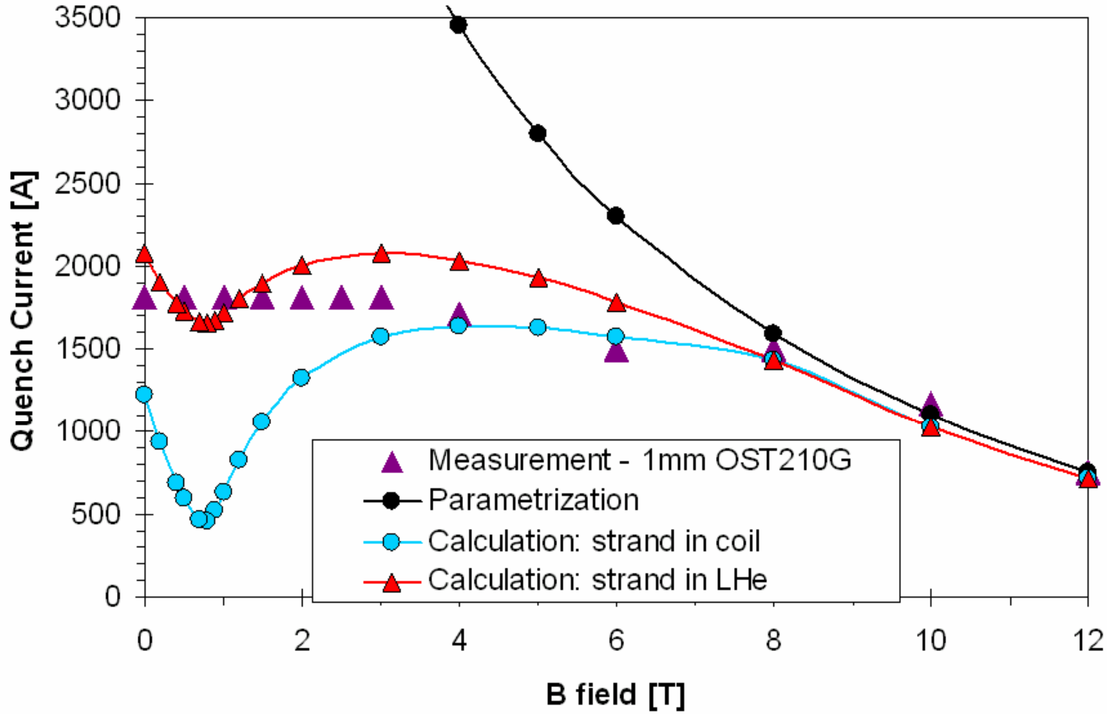
- shell-type coils with a cos-theta azimuthal current distribution
  - Traditional coil design for SC accelerator magnets, due to small bending radii requires W&R approach
- block-type coils arranged in the common coil configuration
  - Friendly to brittle conductors thanks to large bending radii, allows R&W approach



Both designs have advantages in different applications and both need to be studied and optimized.

Strand Instability Studies

SC Magnets
at Fermilab



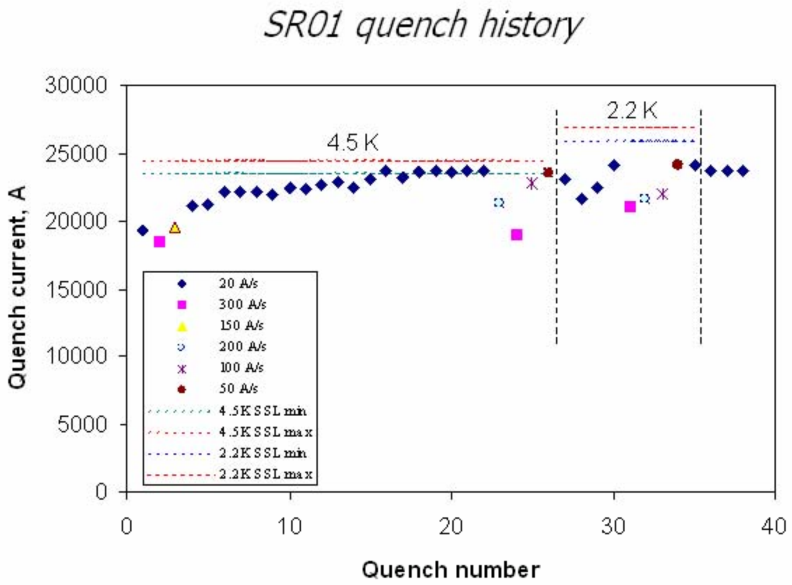
Strand stability calculations and measurements revealed serious instability problems for the 1 mm MJR Nb3Sn strand used in our cos-theta dipole models.

Annual DOE Program Review,
March 24, 2004

Instabilities Workshop
Fermilab 28-30 April 2004
http://tdserver1.fnal.gov/NB3SN/Workshop/index.html

Small Racetracks

SC Magnets at Fermilab



We testing cable using the technique developed at LBNL. The goals are:

- Test and optimize real full-size cables before using in magnets
- Use simple reliable mechanical structure to avoid test setup effects

❖ 2 LBNL-type racetracks have been fabricated, test TBD with LBNL.

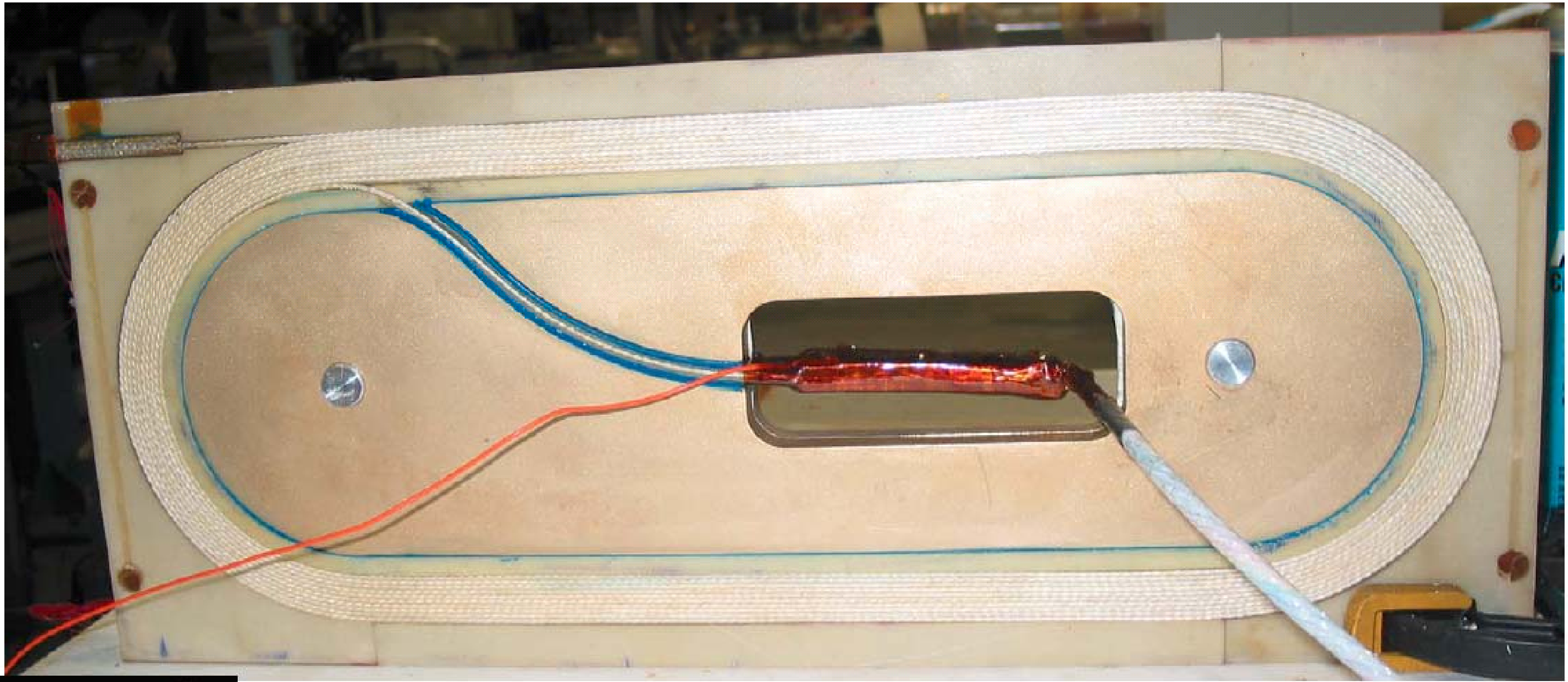
❖ 1st (PIT1.0) Fermilab racetrack: tested in January-March 2004
- Racetrack SR01 reached the short sample limit @4.5K (see quench history)

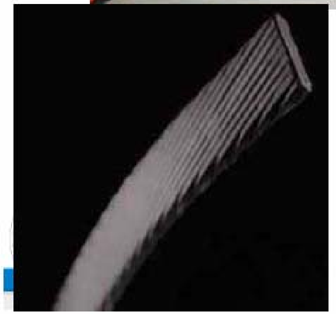
❖ 2nd (MJR1.0) Fermilab racetrack: tests in April-May 2004.

❖ 3rd (RRP0.7) and 4th (MJR0.7) coils - tests in July-August 2004.

HTS Coil for Accelerator Magnets

We use "Rutherford cables" in "conductor friendly" accelerator magnet designs using "racetrack coils" and "React & Wind technology".





A 10-turn racetrack R&D coil recently built and tested at BNL.

Minimum bend radius 70 mm; Cable thickness ~1.6 mm.

Bending strain 1.4% or 0.7% depending on whether the wires in the cable are sintered or not.

Ramesh Gupta, Status of High Temperature Superconductor R&D at BNL, MT-18, 10/21/03 Slide No. 6

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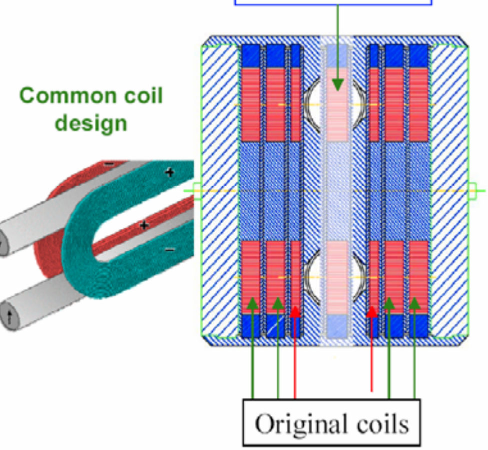
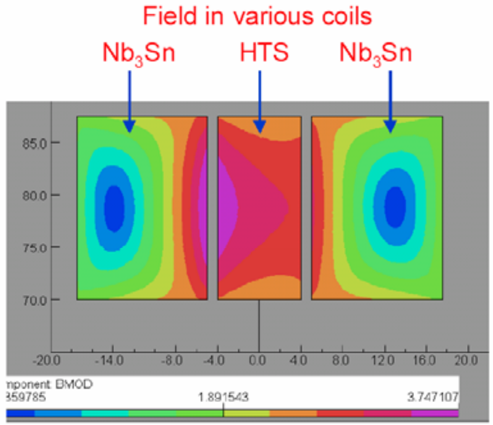
Superconducting Magnet Division

Test Results at Higher Fields Using the Common Coil Magnet as the Background Field Test Facility



Background field test configuration



Nb_3Sn coils provide a backg… HTS coil in a common coil …

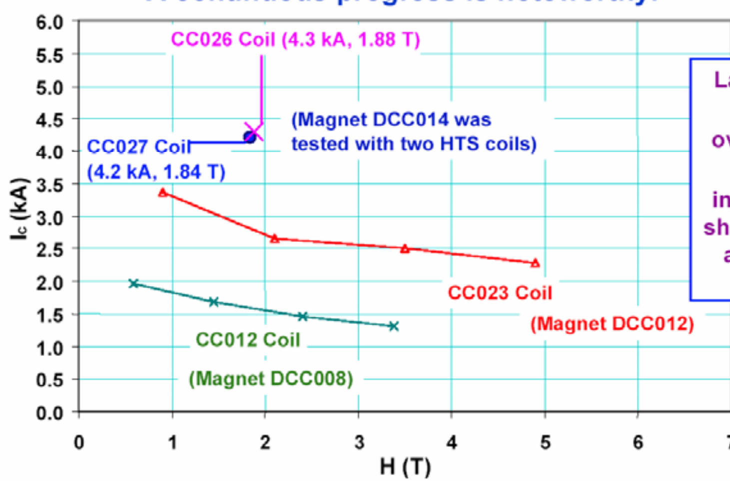
Ramesh Gupta, Status of High Temperature Superconductor R&D at BNL, MT-18

BROOKHAVEN NATIONAL LABORATORY
Superconducting Magnet Division

Progress in the Current Carrying Capacity of HTS Coils at Higher Fields

HTS coils can now be made with the cable carrying a respectable current at higher fields (Note that the current carrying capacity does not fall much beyond 5 T).

A continuous progress is noteworthy.



Latest coils were tested for over 4 kA at ~2 T. Extrapolations indicate that they should carry ~3 kA at any arbitrary high field.

Ramesh Gupta, Status of High Temperature Superconductor R&D at BNL, MT-18, 10/21/03 Slide No. 12

Summary

- The US LARP is starting to work with CERN to advance performance of the LHC.
- Magnet R&D aimed at a luminosity upgrade is a major part of the program:
  - Large aperture (~100 mm) quadrupoles with $G_{operating} \geq 200$ T/m.
  - Large bore (~130 mm) dipoles with $B_{operating} \sim 13\text{-}15$ T.
  - Significant technology development is required to meet these goals.
- The LARP Magnet R&D program builds on a vigorous base program developing high-field magnets for the next generation of accelerators:
  - $B_{max} = 16$ T achieved in small aperture coil at LBNL.
  - Fermilab program to develop practical designs is currently addressing conductor stability issues.
  - BNL program focusing on react and wind Nb_3Sn and HTS coils.