BNL Magnet Program for LHC Upgrade

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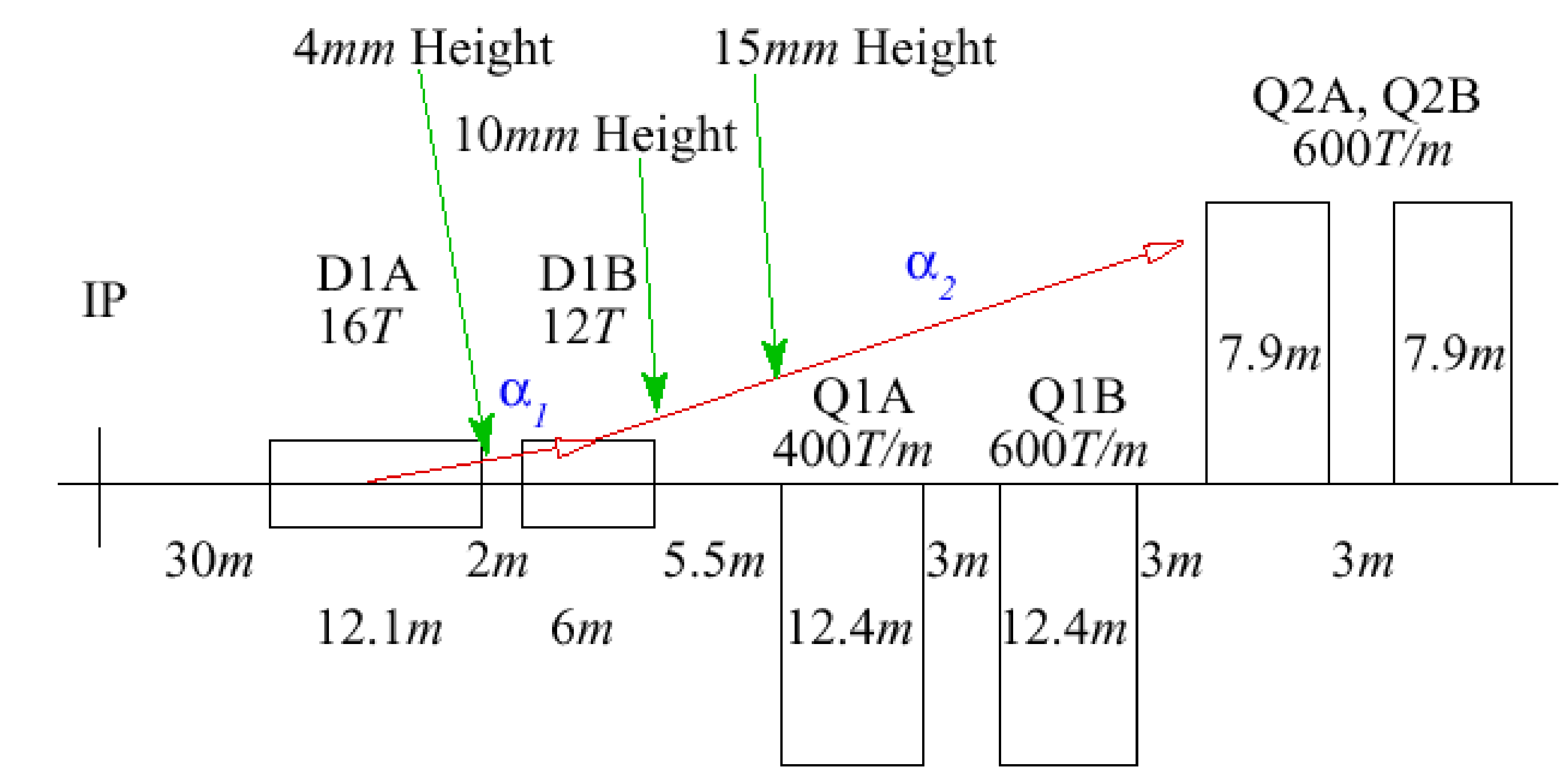
- Dipole First Design Concept for LHC IR Upgrade
- Nb_3Sn Magnet R&D at BNL
- Brief Status of HTS Work at BNL

BNL Position on LHC Upgrade Program

- BNL is examining the “dipole first” scenario for IR upgrade.
- In particular, we are looking in to various high field Nb_3Sn dipole designs that can reduce the energy deposition in coils --- an important issue for a large increase in luminosity.
- *We are developing “React & Wind” magnet technology that can be used in the above dipole*

  (successful development of these magnet designs and technology will, of course, be useful to any future program).

VLHC-2 IR Layout with Dipole First Beam Optics



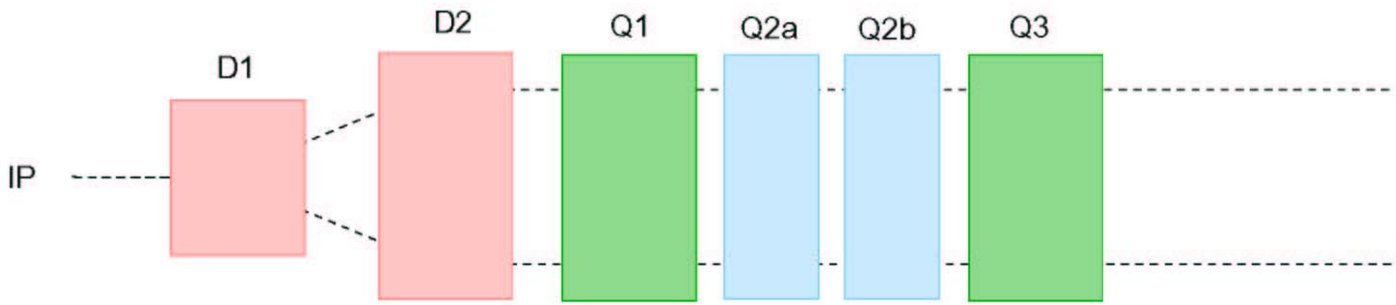
- Radiated beam power from IP in VLHC-2 : ~ 23KW

Note: RHIC uses "Dipole First" Optics for independent reasons

Dipole First Scenario for LHC Upgrade

Separate Triplet Magnets

- ***2-in-1 triplet magnets:***



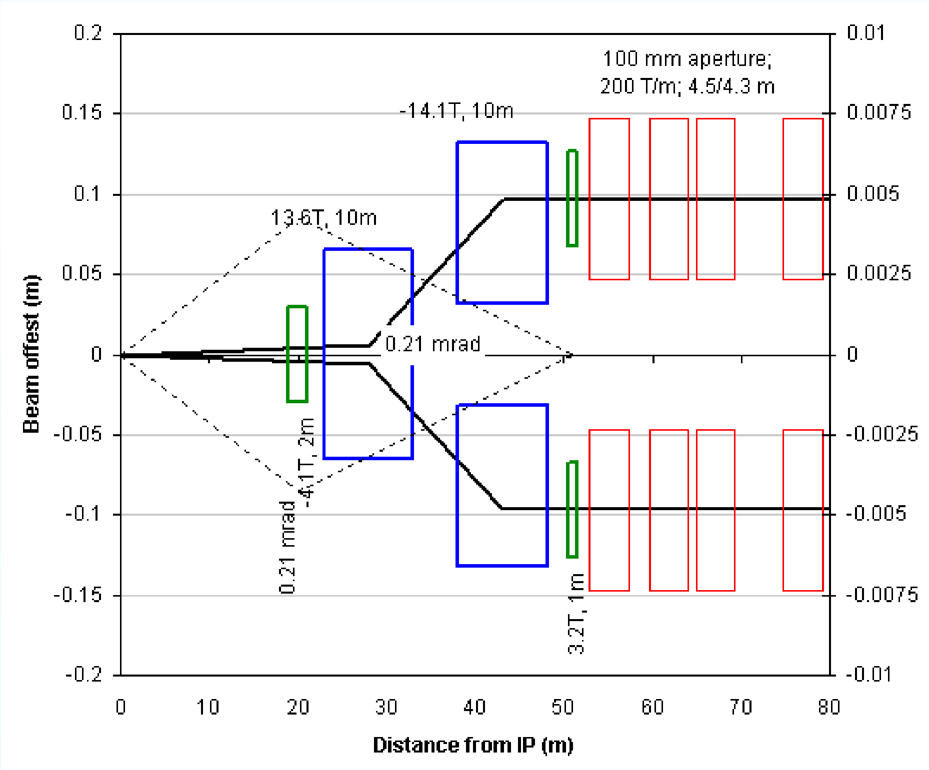
- increased L^*

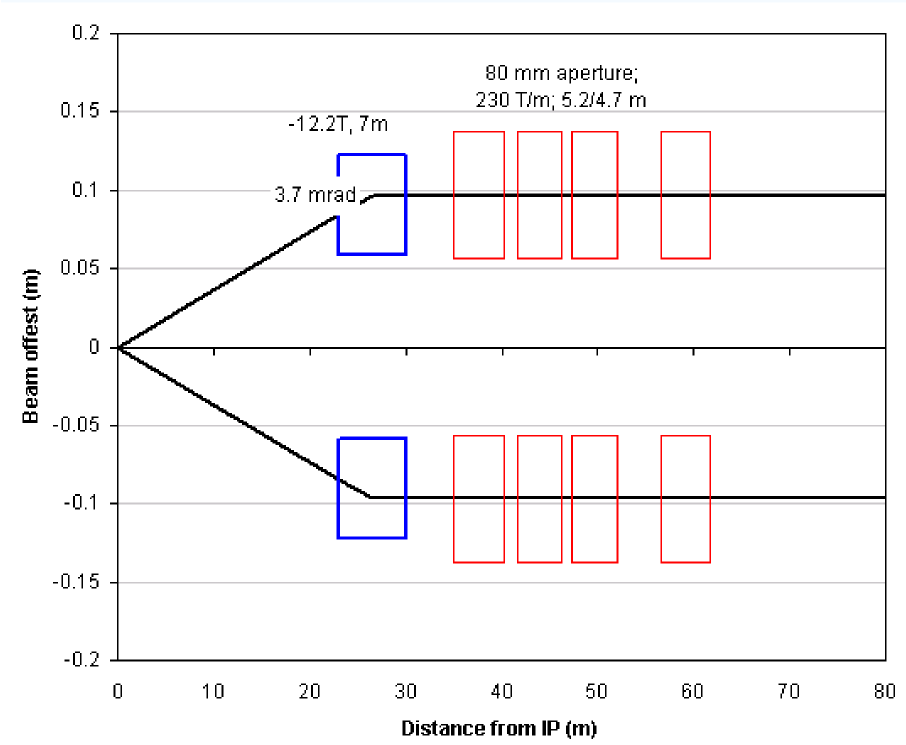
- $\beta(s) = \beta^* + \frac{(s - s_{IP})^2}{\beta^*}$

Courtesy:
Oliver Bruning, CERN
Last IR Workshop

11.3.2002; LHC Luminosity Upgrade — Oliver Bruning/CERN

Possible Layouts of LHC IR Upgrade Optics for "Dipole First" Option





Small crossing angle

Large crossing angle

Courtesy: Jim Strait

Some Special Considerations for LHC Upgrade Magnet Designs

- Need high field/gradient and/or large aperture magnets
  - Use superconductors that has not been used in accelerator magnets before: Nb_3Sn, Nb_3Al, HTS, etc.
- Hostile environment for superconducting magnets due to large amount of particle spray from Interaction Point (IP): ~9 kW of power from each beam for 10^{35} luminosity
  - Expected energy densities (several hundreds of W/m) in D1
  - Energy deposition is anisotropic, large peak at the midplane
  - Consider quench and radiation damage issues due to this large local energy deposition. Cryogenic and thermal performance of magnets may pose significant challenge
- BNL has been developing alternate magnet designs based on racetrack coils with open midplane to deal with such issues.

Magnet Design for ν Factory

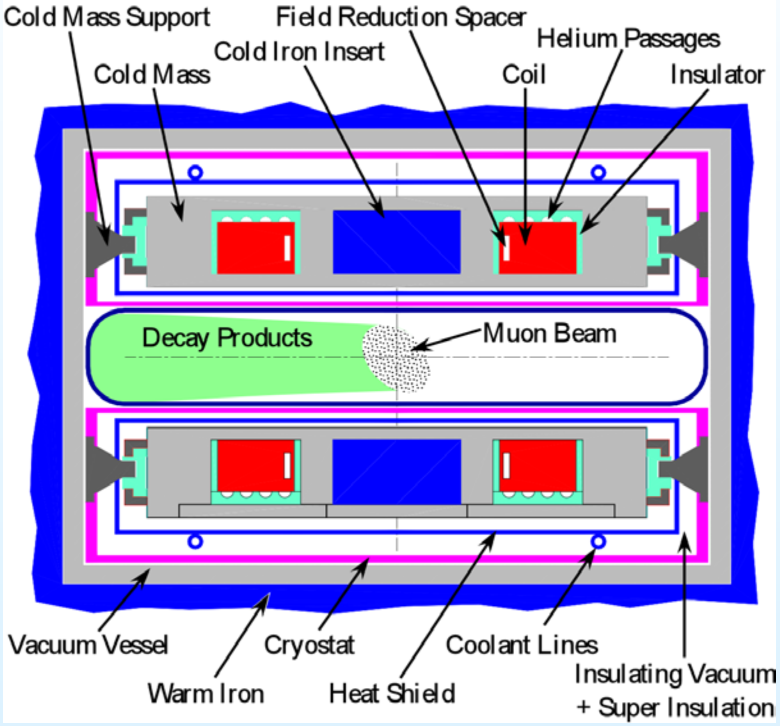
Decay products clear s.c. coils

- **Flat coils with open midplane gap**

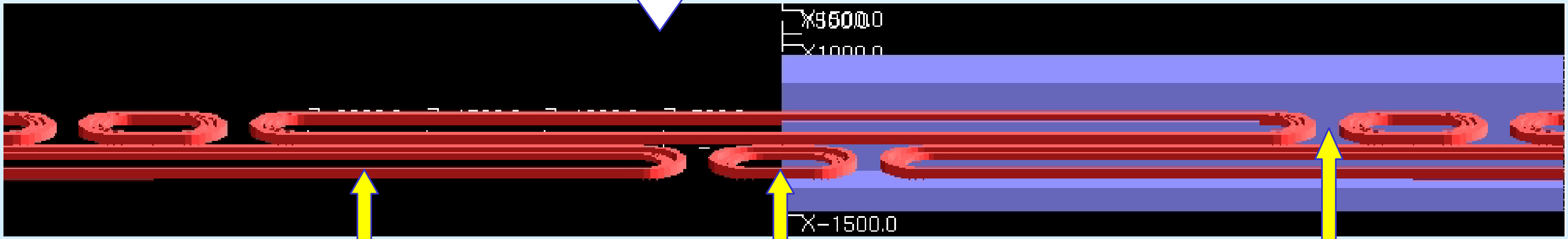
Minimize environmental impact

- High field magnets, efficient design

Simple racetrack coils with large bend radii



Bx, By errors in the ends get automatically cancelled



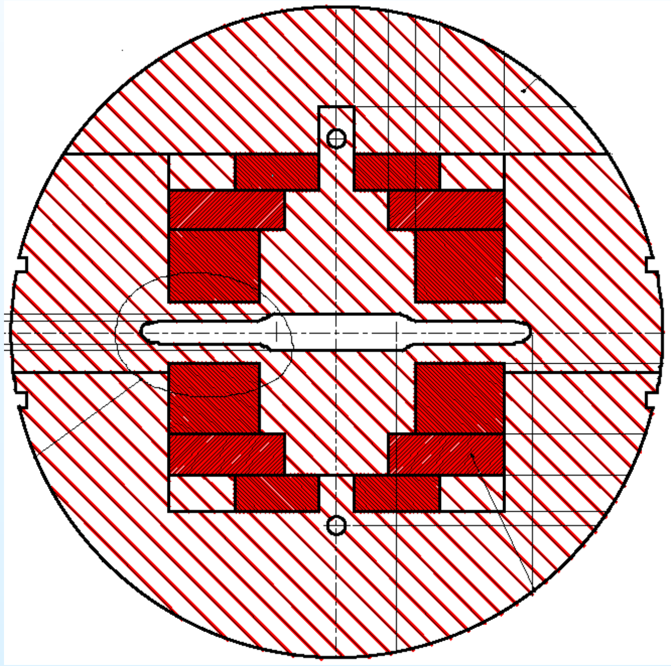
Normal Coils Dipole

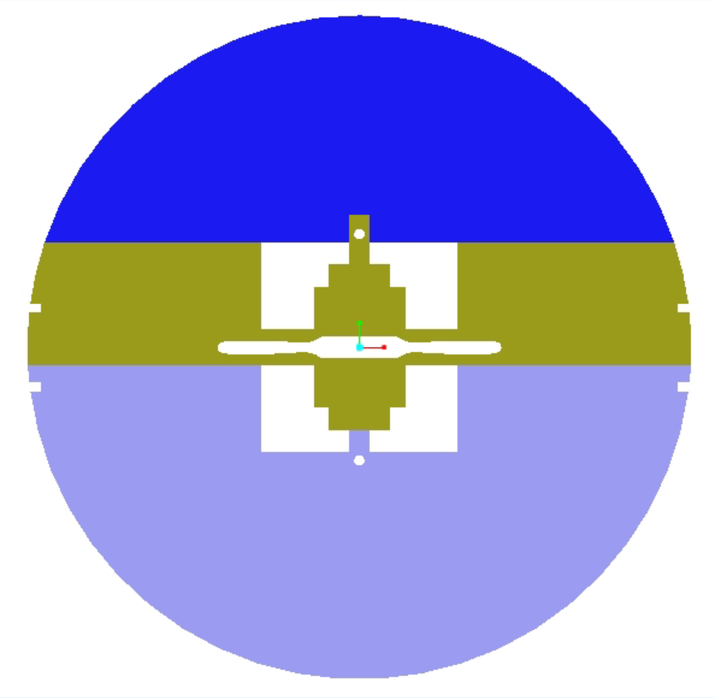
Reverse Coils Skew Quad

One Coil 1/2 & 1/2

LHC IR Dipole: Collared Coil Support Structure (Preliminary)

Open midplane for decay products to pass through without hitting the coils.





Open midplane means no coil or support structure; otherwise showers are created which hit the coil.

Bss: ~15T
Aperture:
H: ~90 mm
V: 20 mm

Decay products hit the external structure at 4K.

The magnetic and mechanical designs will be optimized more after the initial energy deposition calculations (NEWS FLASH: just completed).

Field quality is poor and the coils should be brought closer to midplane.

Mechanical Analysis:
Collar deflections at the design field

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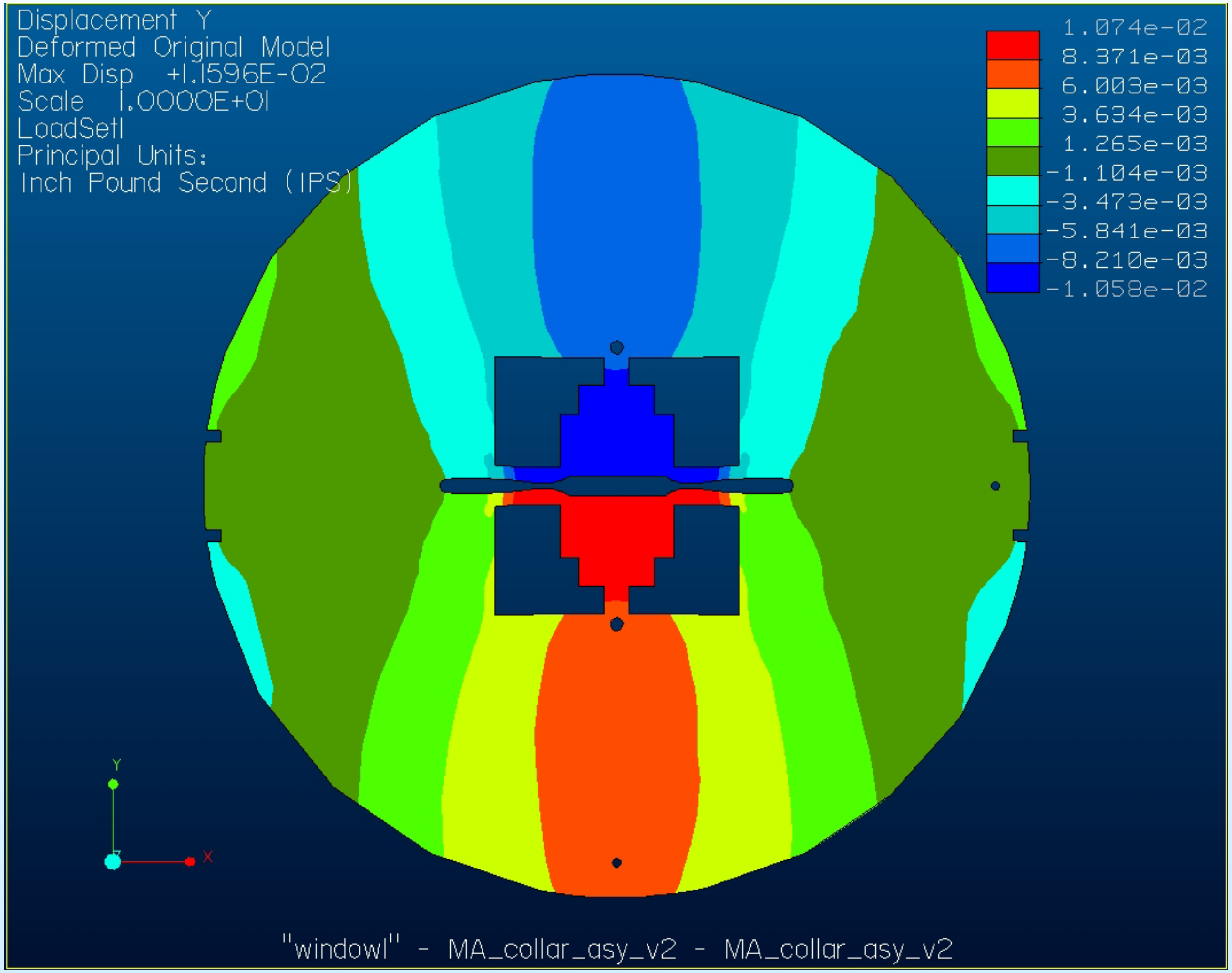
Preliminary design and analysis



See relative change in deflection at the bottom of support structure.

For quench performance, a variation in displacement may be more relevant than the absolute value.

Further reduction in deflections possible through distributed support tiers.

Maximum vertical deflection: ~ 11 mil (0.28 mm)

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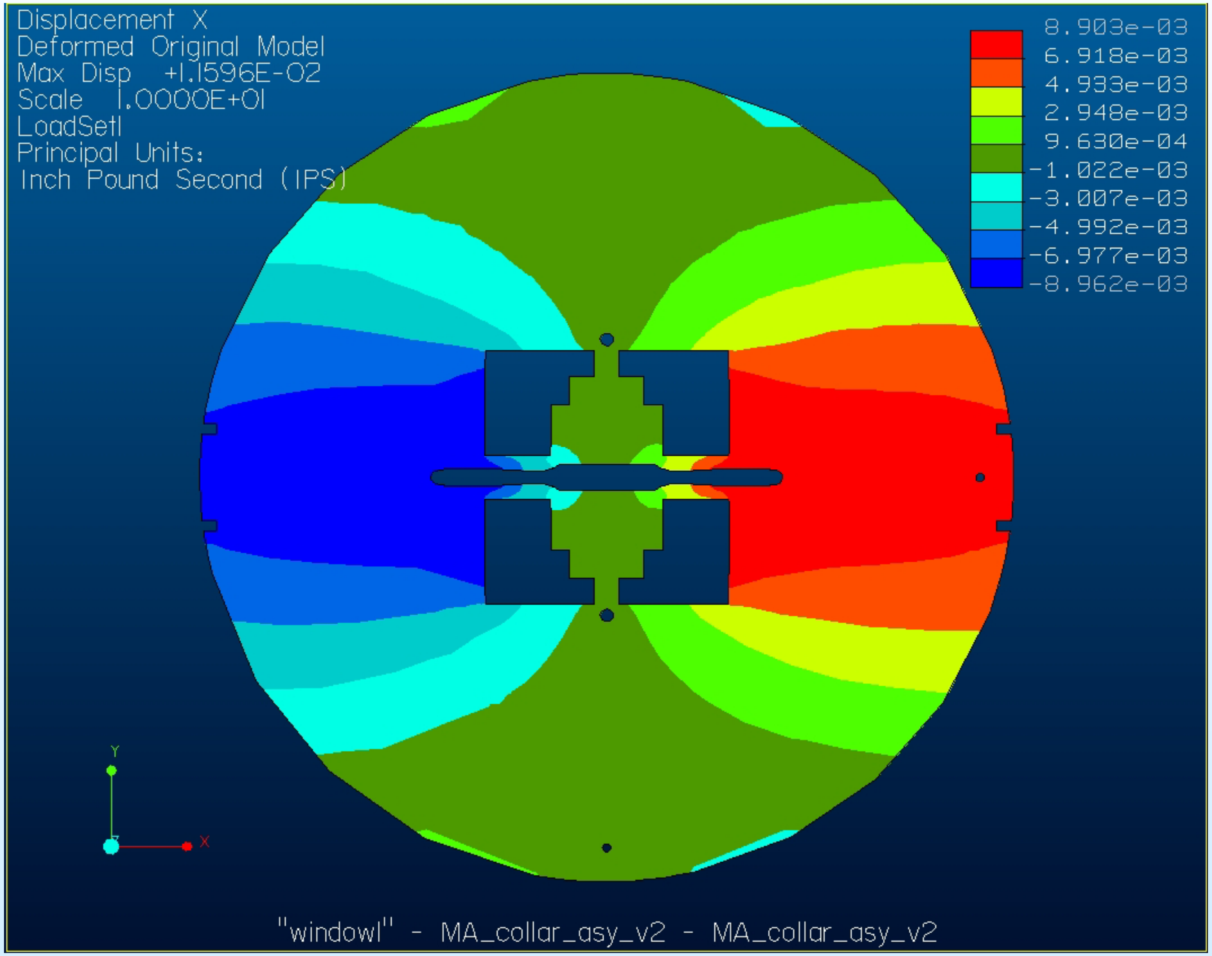
Mechanical Analysis: Collar deflections at the design field

Preliminary design and analysis

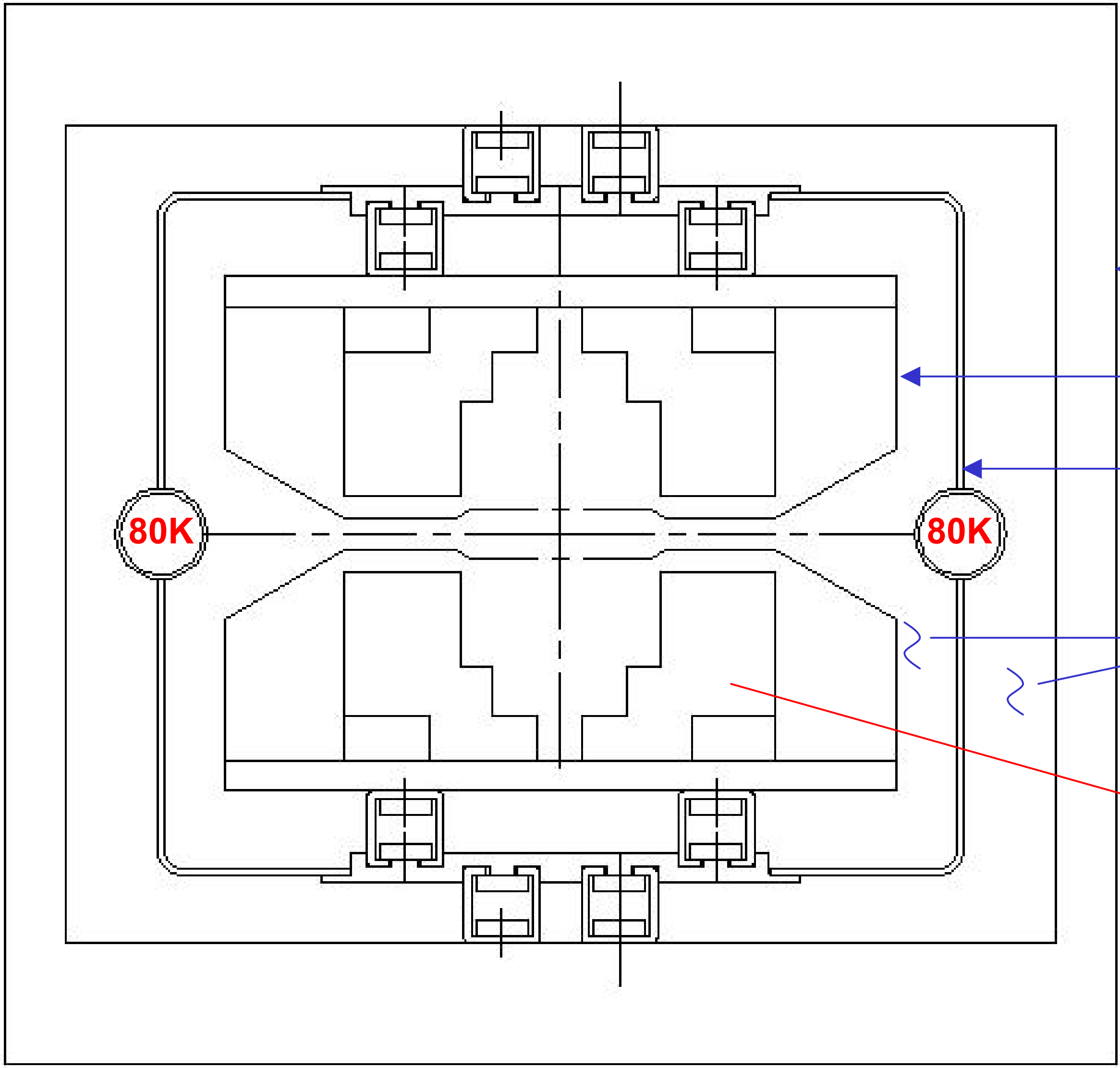


Collar thickness can be increased, as necessary, to reduce horizontal deflections.

Next: Examine the displacement within the coil structure.

Maximum horizontal deflection: ~ 9 mil (0.23 mm)

LHC IR Dipole: Another Concept for Support Structure



Dump IP shower in a relatively warmer structure
(more efficient heat removal)

Cryostat (300K)

Coldmass (4K)

Heat Shield (80K)

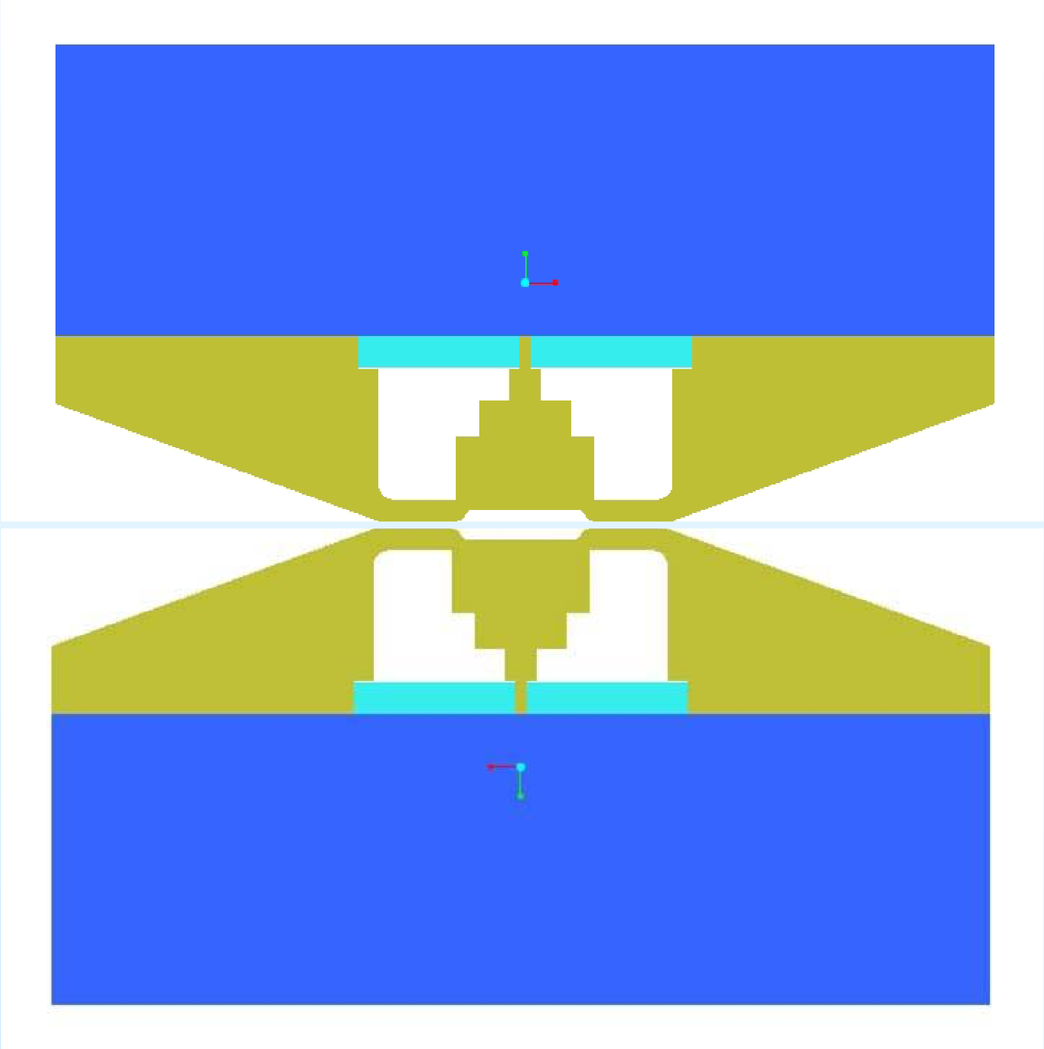
Vacuum Space

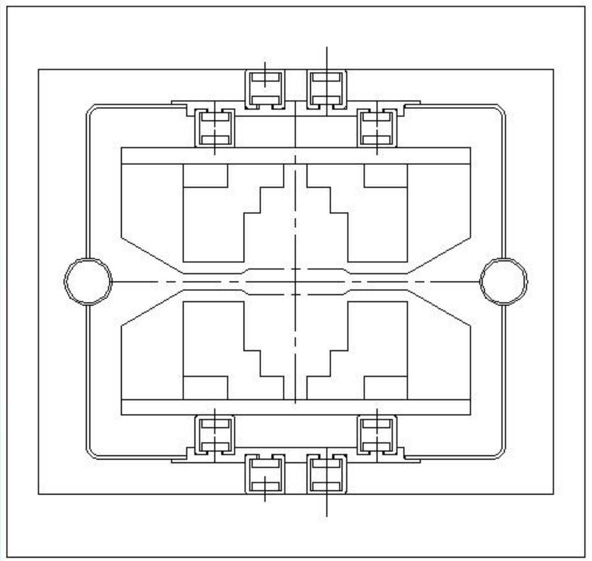
Superconducting coils

Warm Iron Design

LHC IR Dipole: Another Concept for Support Structure

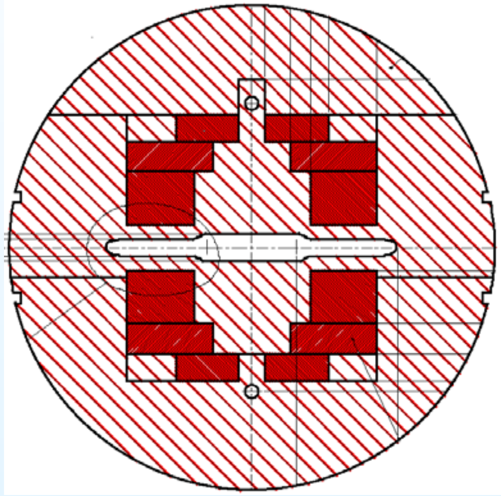
Mechanical design and analysis of the concept, where heat is deposited in a relatively warmer region, has just started.

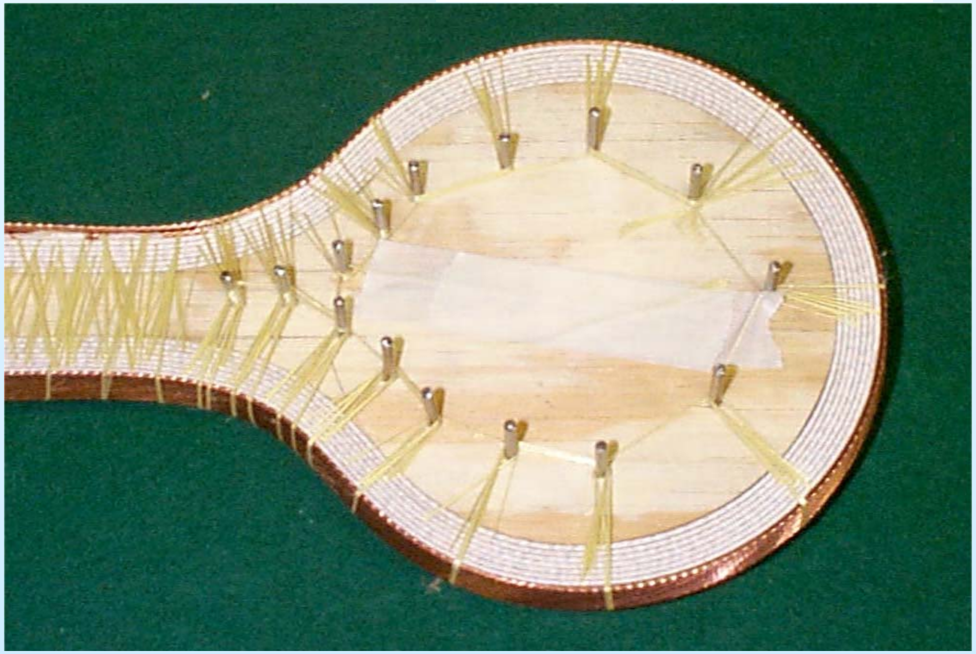




End Concept for "React & Wind" Dipole

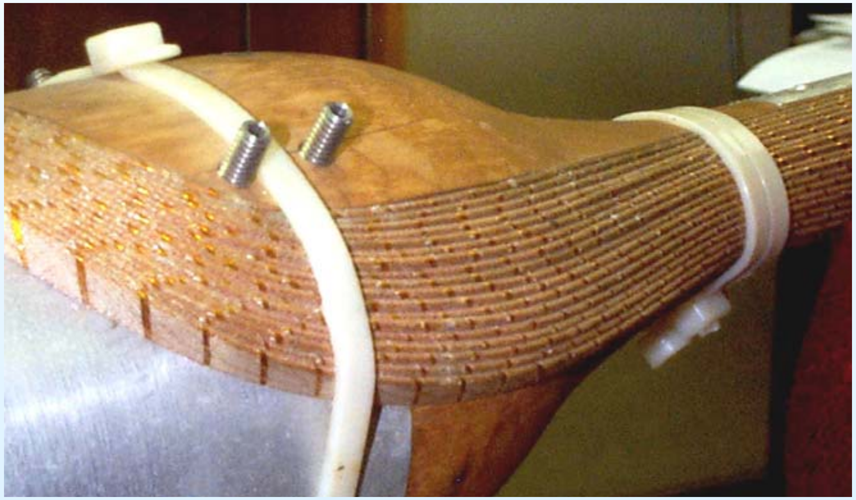
The following type of ends will retain a flat racetrack coil geometry





Earlier Design:

Dogbone Ends (~20 years ago)



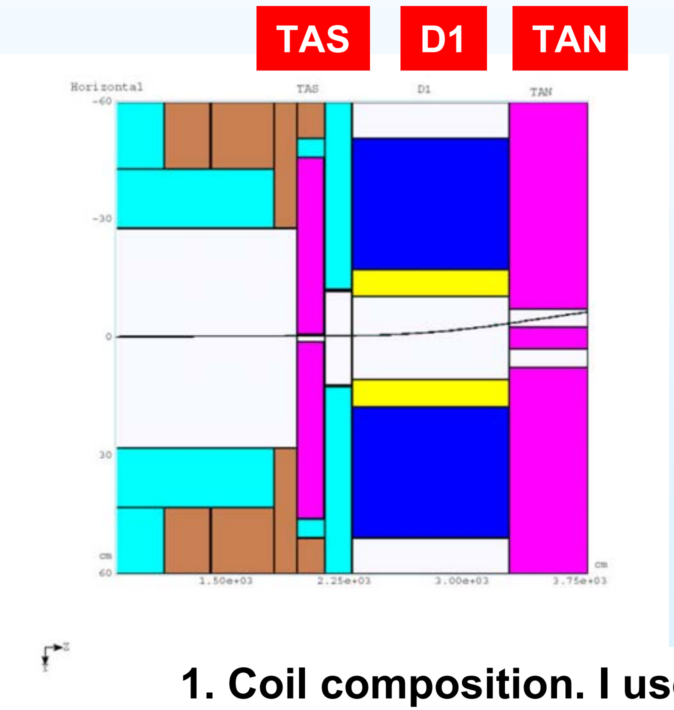
New Techniques:

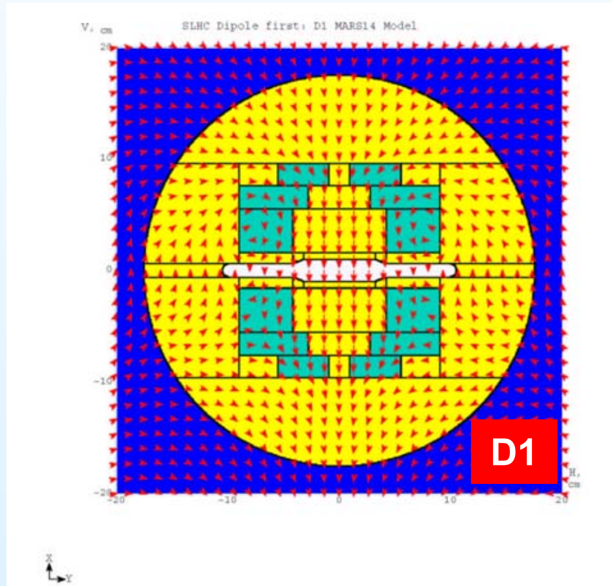
Kevlar Strings for Reverse Bend

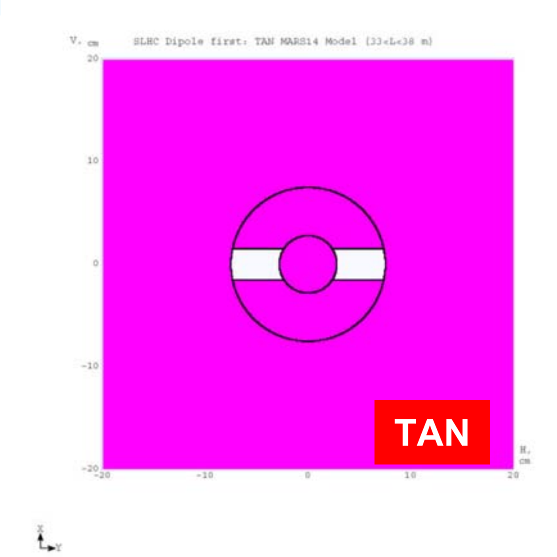
Energy Deposition Calculations

Basic Geometry

Calculations by Nikolai Mokhov, Fermilab





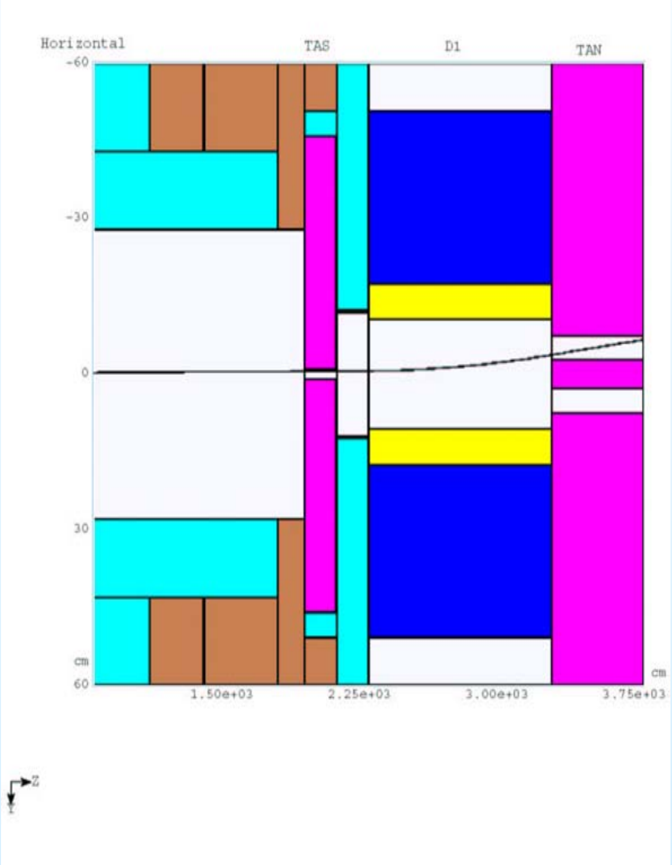


1. Coil composition. I use the first one out of two models I have:
   NbSn SC coil, 0.02 He + 0.38 Cu + 0.2 Al + 0.4 (Nb3Sn)
   0.24 Nb3Sn + 0.70 CuSn + 0.06 Ta
2. D1 is L=10 m, B=13.6 T, with 50.8-cm radius yoke, no cryostat yet,
   but I can add it if you give me its parameters.
3. Horizontal separation, horizontal crossing with a half-angle of 0.21 mrad,
   1.8-m long TAS in front of D1, no corrector, no field

More Details on Model

The current model with Ramesh's 13.6 T, 10-m long dipole, horizontal crossing, 10^35 luminosity, includes:

1. CMS detector with 4-T solenoidal field.
2. Copper TAS at 19.45 < z < 21.25 m with a 9-mm radius round aperture, 900-mm OD; note Ramesh's minimal half-aperture at the axis is 10 mm; it will be smaller if we include a beampipe in D1; we should always avoid a direct vision of the IP by D1 inner parts.
3. SS beam pipe at 21.25 < z < 23 m, 240-mm ID, 246-mm OD (no rather complicated warm-to-cold transition (between TAS and D1) with pumps, liners, instrumentation etc as we have in the baseline LHC model) -> please advise.
4. Detailed geometry, materials and magnetic field in D1 up to 508-mm radius, but currently there is no
   - end plates -> please advise;
   - cryostat and any yoke supports at r > 508 mm -> please advise;
   - beam pipe inside D1; based on preliminary tracking I am not sure about its parameters -> please advise and then we will converge taking into account 3-D energy deposition distributions of the no-pipe runs;
   - corrector or any other magnet combined with the TAS absorber.
5. A copper "TAN" at 33 < z < 38 m with two apertures I determined on the basis of beam tracking plus LHC standard margins.



Cheers,

Nikolai

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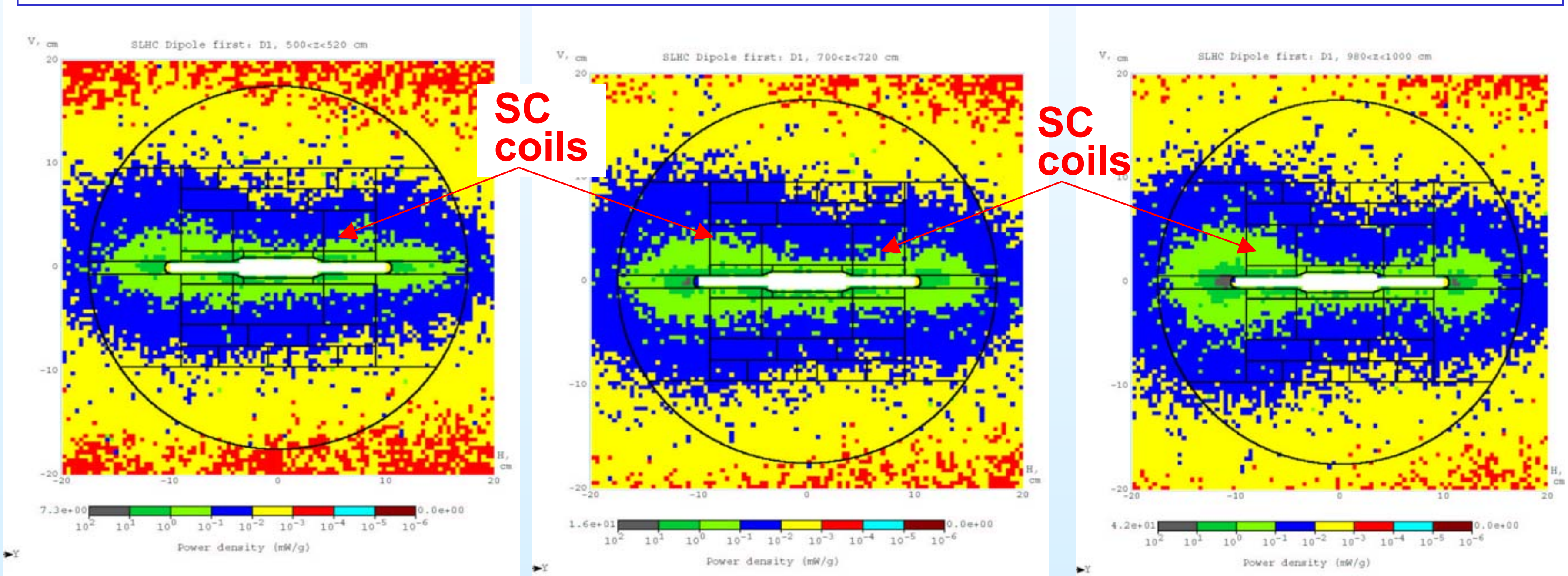
Energy Deposition Calculations

Energy deposition at various axial position along the axis

Computed by Nikolai for a Luminosity of 10^{35} (10X over present design)



@Middle (z=>5m-5.2m)   @70% (z=>7m-7.2m)   @End (z=>9.8m-10m)

Peak power density in the superconducting coils is only 1-1.3 mW/g, i.e., below our current quench limit of 1.6 mW/g even at 10^35 luminosity!!!

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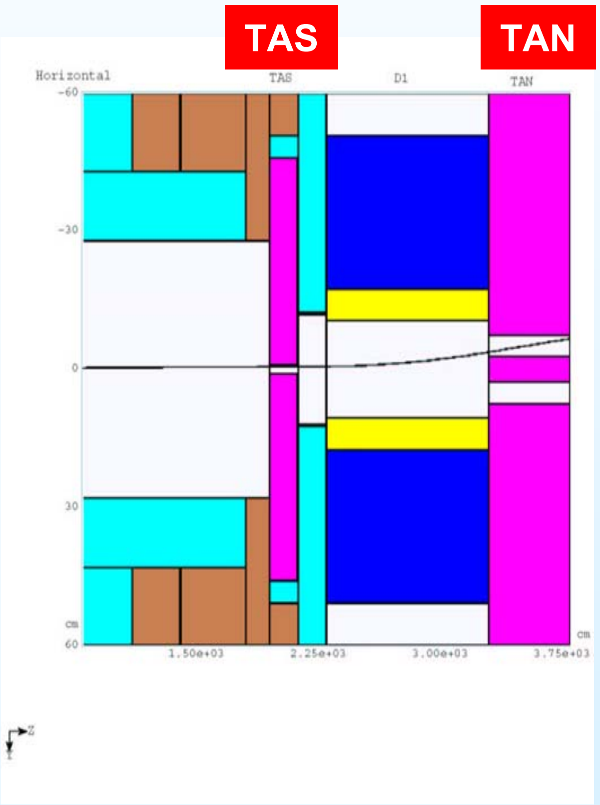
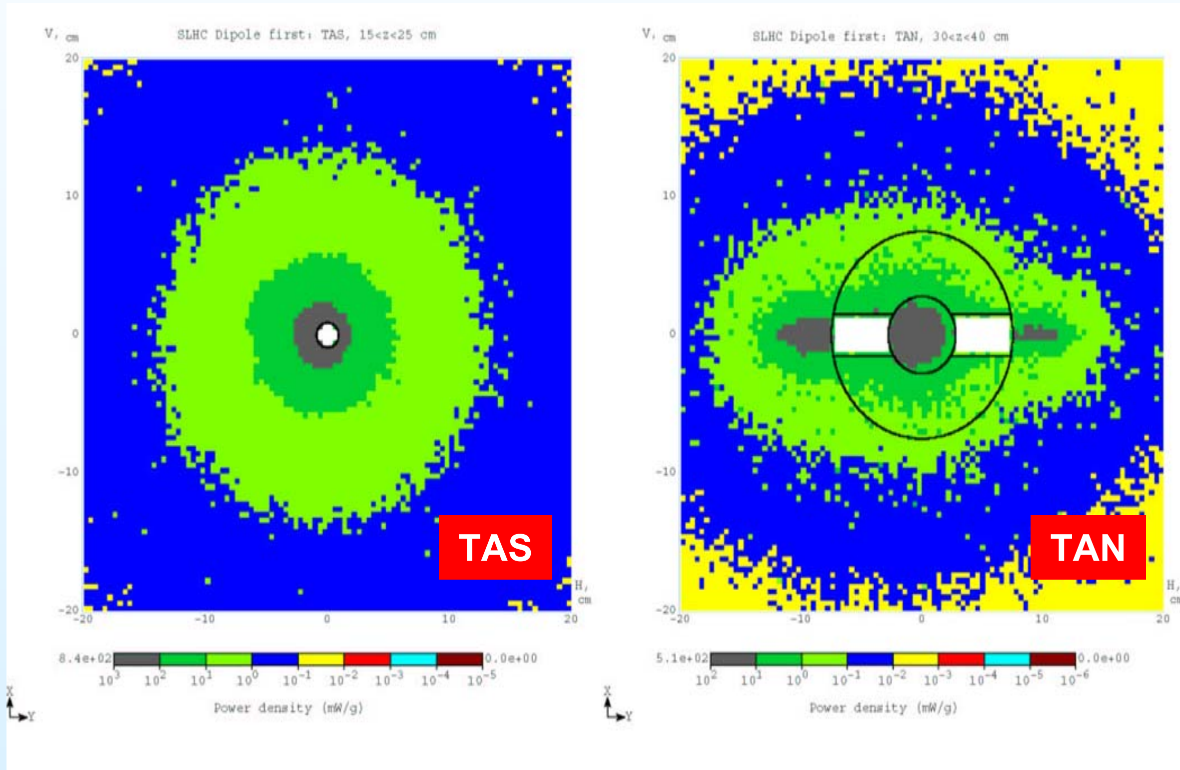
Energy Deposition in TAS & TAN





Total power dissipation:

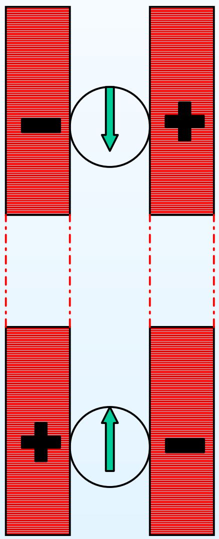
TAS: 3.17 kW, D1: 0.90 kW, TAN: 2.45 kW.

High Field Magnet Program at BNL

- React & Wind R&D with ITER Nb_3Sn cable
  - Good results from both cable short sample and magnet tests
  - Test magnets reach short sample without any quench
- React & Wind R&D with High Performance Nb_3Sn cable
  - Degraded performance observed in both cable and magnet tests
  - Program underway to find and eliminate the source(s) of degradation
- HTS Cable Magnet Program
  - BNL measurements of Showa cable continue to show an upward trend
  - No significant degradation observed between cable & coil performance
- Specific Magnet Projects
  - Common coil 12 T "React & Wind" dipole for cable and insert coil tests
  - Beginning of LHC IR upgrade magnet design program

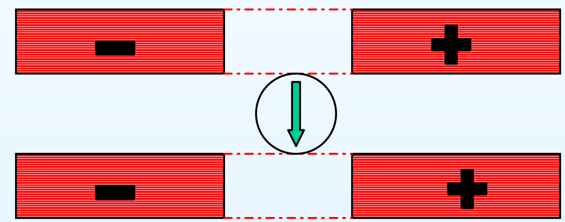
Common Technology Development between 2-in-1 Common Coil Dipole and Single Aperture Open Midplane Dipole

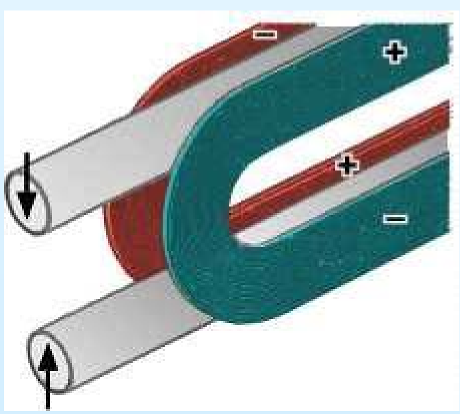
Common Coil Design

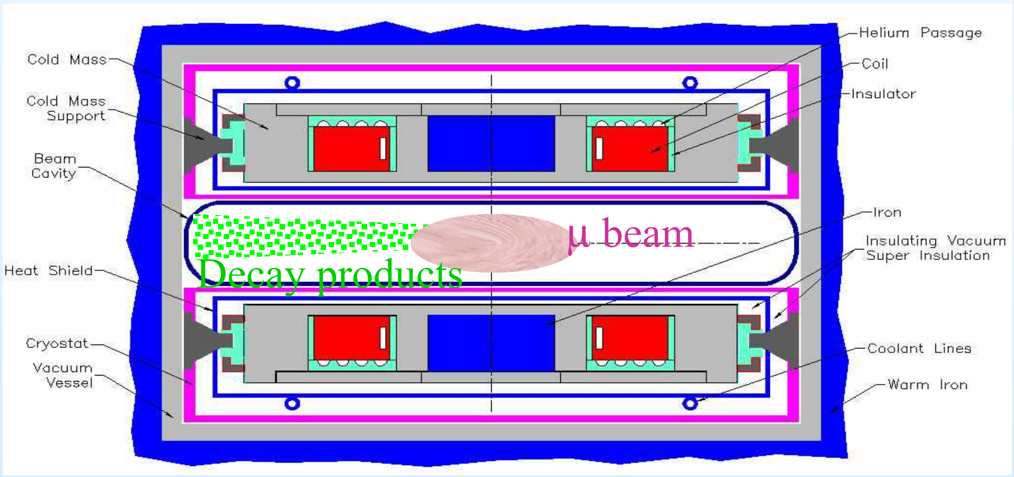


Powering differently changes a common coil design test to an open midplane dipole design test

Open Midplane Dipole configuration







Note: Both designs use simple racetrack coils. These two different types of dipoles may be constructed using the same racetrack coils.

BNL 12 T Nb_3Sn Common Coil Background Field Dipole

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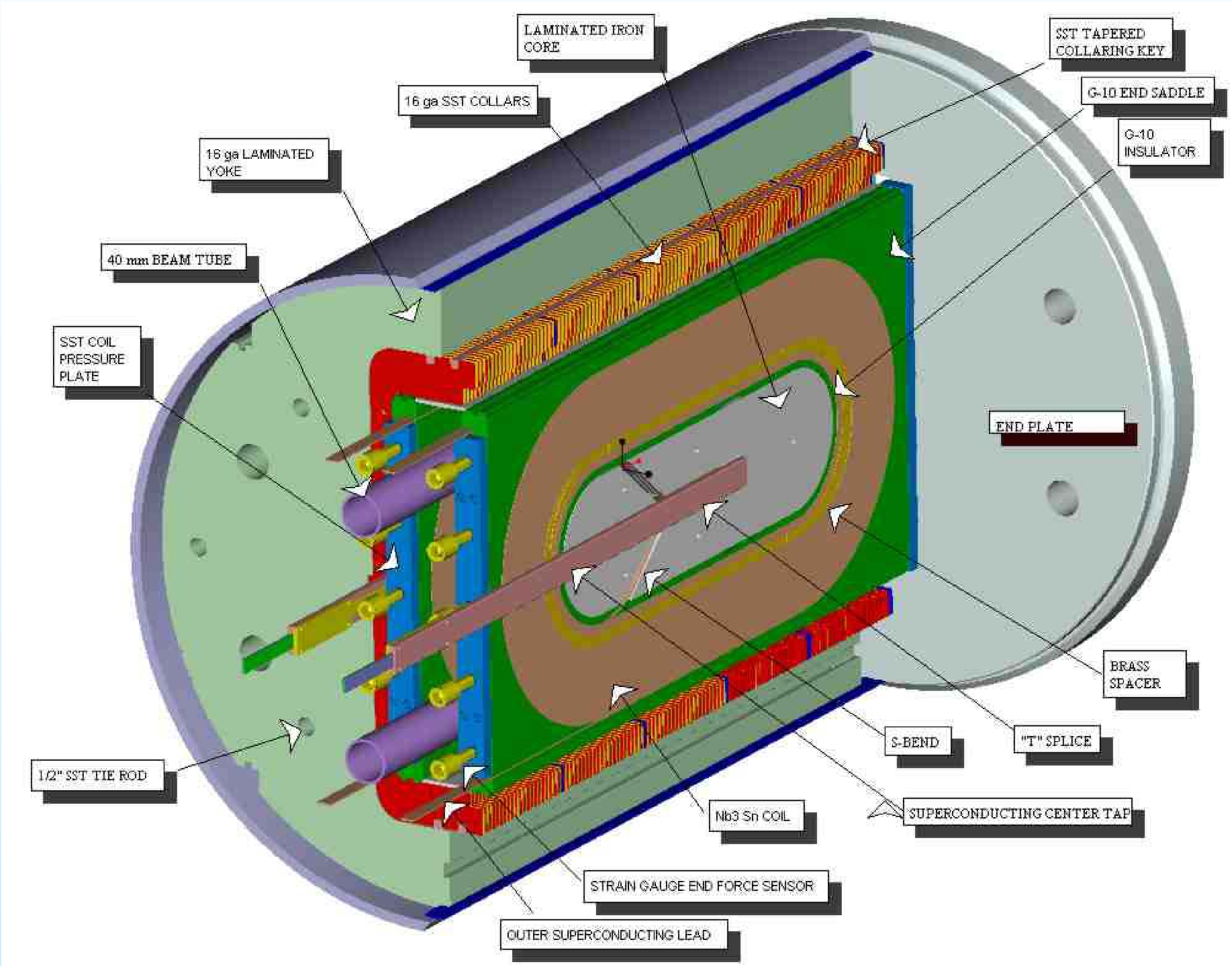

Nb_3Sn conductor for both inner and outer layers is provided by OST

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Nb_3Sn Reaction Process at BNL

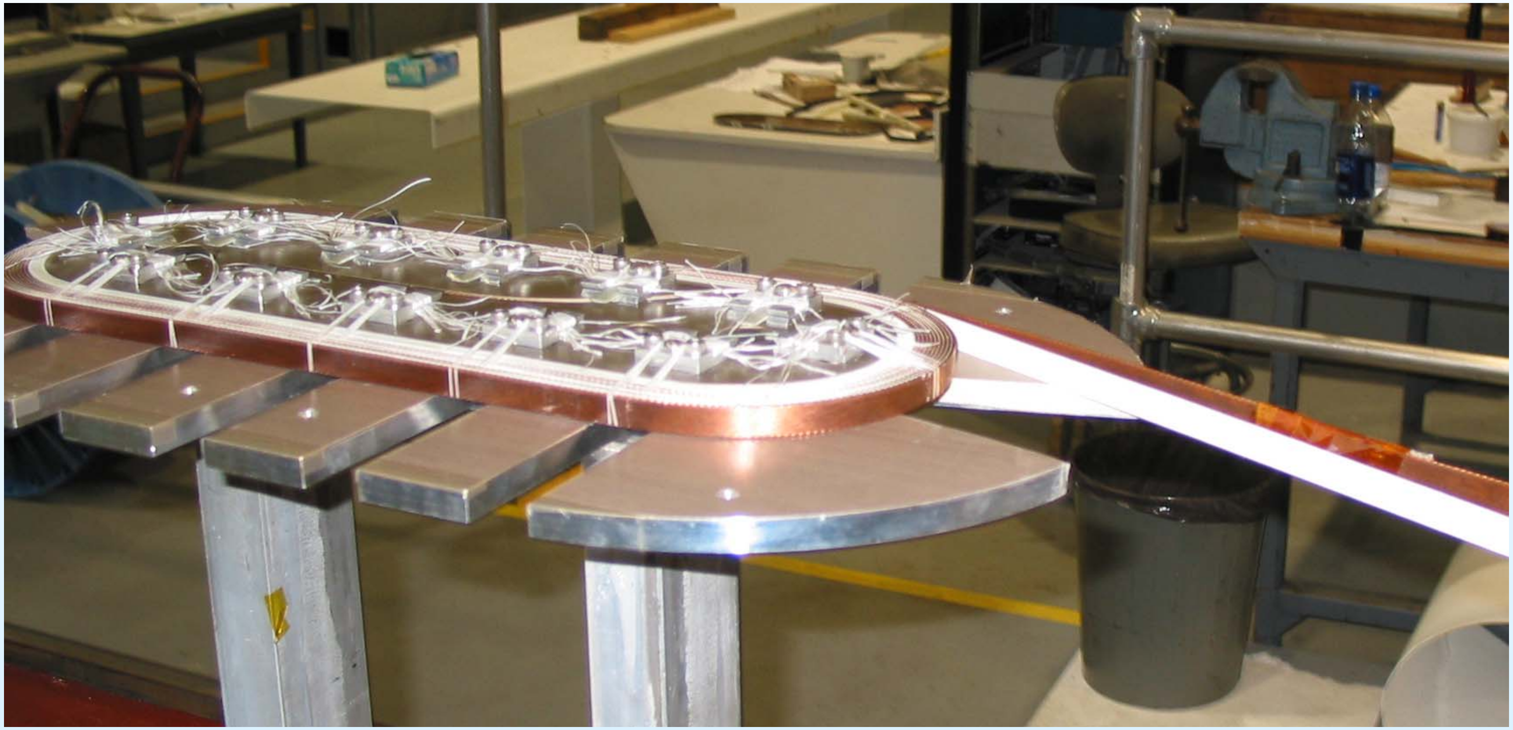
The bending radii of reaction spool is about twice the minimum bend radius of our common coil design. This splits bend strain between straight section and ends. Computed bend strain ~0.3% (considered acceptable) if the wires in cable are not sintered; strain becomes ~0.6% if the wires are sintered.

New oil impregnation fixture to vacuum impregnate the cable. Mobile-1 coating on the surface of wire inside the cable should eliminate sintering, if any, during reaction process.

In an attempt to push technology BNL program has been deliberately aggressive. BNL uses 0.8 mm wire and 70 mm bend radius as compared to Fermilab 0.7 mm wire 90 mm bend radius. The bending strain in BNL program is ~50% more.

2 transparancies, one will include the photo of reaction furnace and other l

Use of Nomex Tape Insulation



Nomex tape insulation, co-wound with cable. This is the first time Nomex insulation is being used in cable magnet – a robust insulation which also reduce turn-to-turn spacing (~4 mil, 0.1 mm, turn-to-turn).

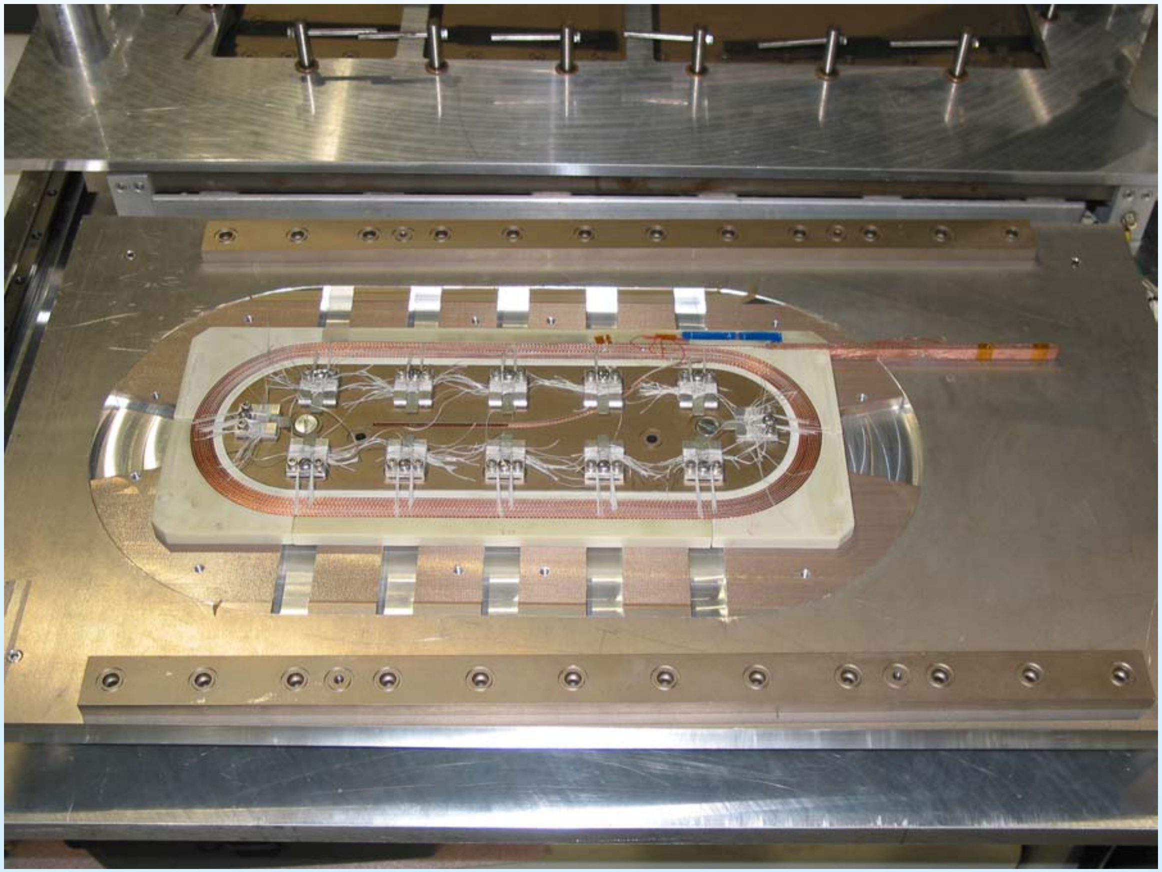
Earlier we used fiberglass, spiral-wrapped over reacted cable.

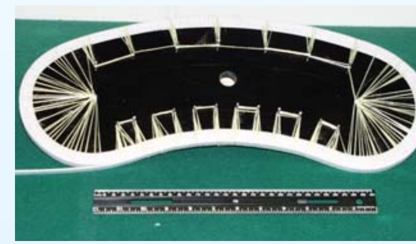
New Coil Winder for Brittle Materials

New multi purpose facility under construction for winding coils, etc. with brittle material

New Tooling and Techniques for Making Coils

Kevlar strings allow compact coils. The coils can be made in any shape.





These tooling and techniques are being developed for 12 T magnet and are being currently tested in 10-turn coil program.

New tooling for impregnation with vacuum bag to pot any shaped coil

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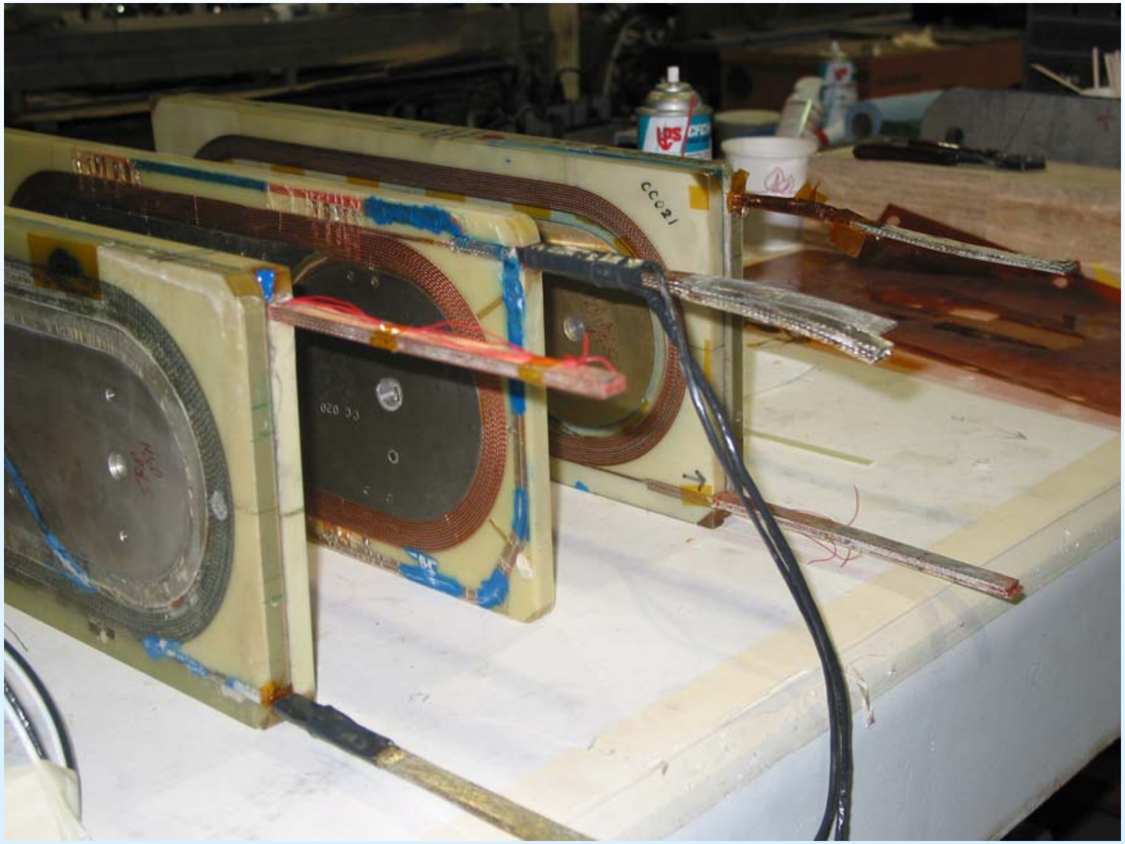
Racetrack Coil Cassettes for Rapid Turn Around Magnet R&D Facility



5 cassettes for a 2/3 layer magnet test

BNL makes racetrack coils in modular structure. These modules (cassettes) can be mixed and matched for a variety of experiments in a rapid turn around fashion.

For example, one can easily change aperture, number of layers, type of magnet, etc.

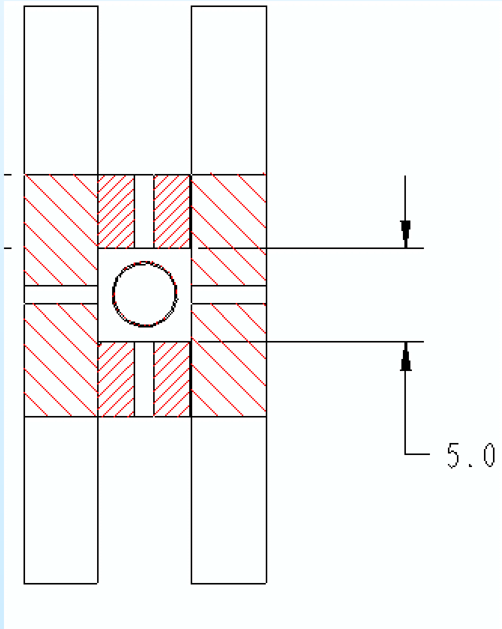
Try such things in a cosine theta magnet!!!

Magnet Scientists dream of systematic, cost–effective and rapid turn around magnet R&D. The way science used to be, I am told!

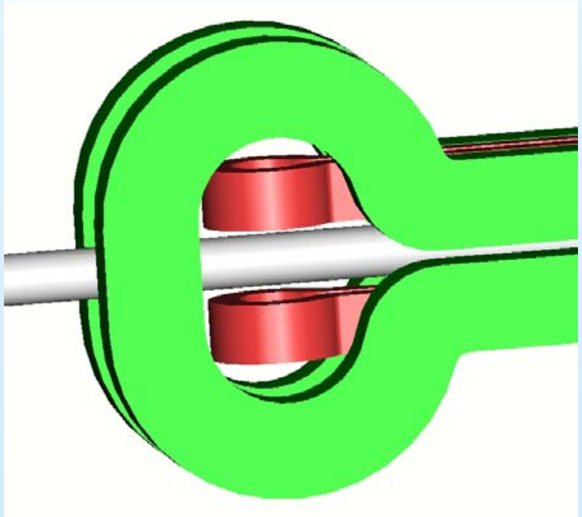
New End Design Concepts

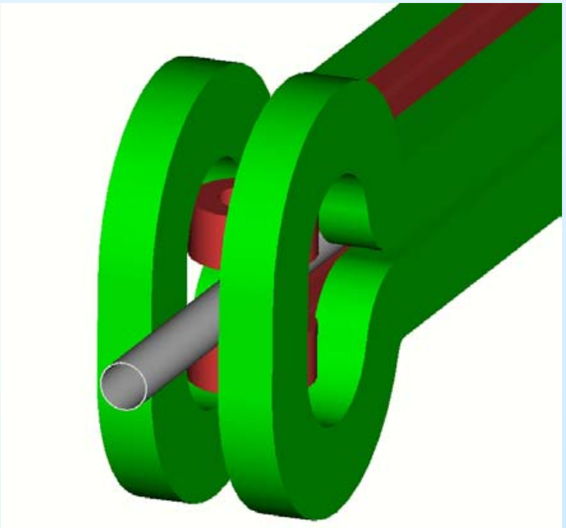
Following few slides will present a number of thought techniques for "React & Wind Ends". These conceptual geometries may be used in evolving some new end designs that have good mechanical and magnetic characteristics.

Main Goal: Large bend radius and properly supported cable through out the ends.



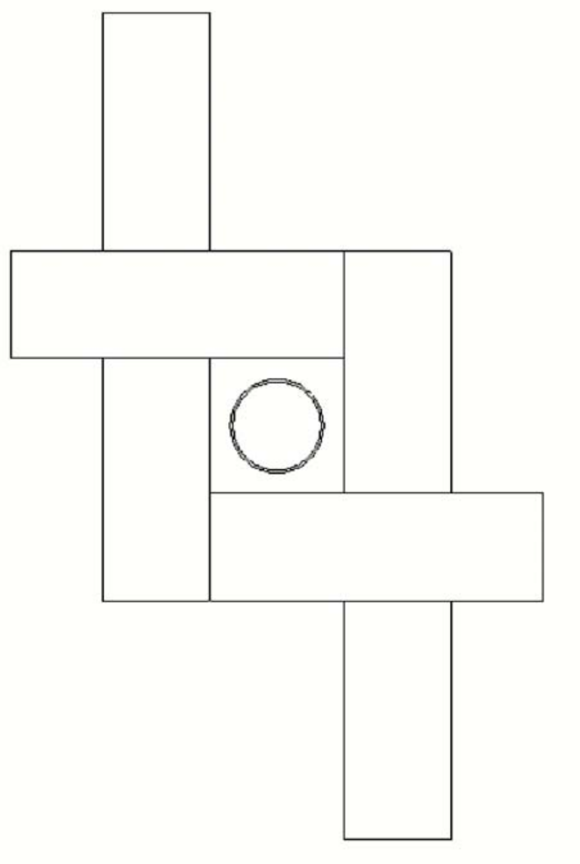
Flat Coil Ends: Nested Coils

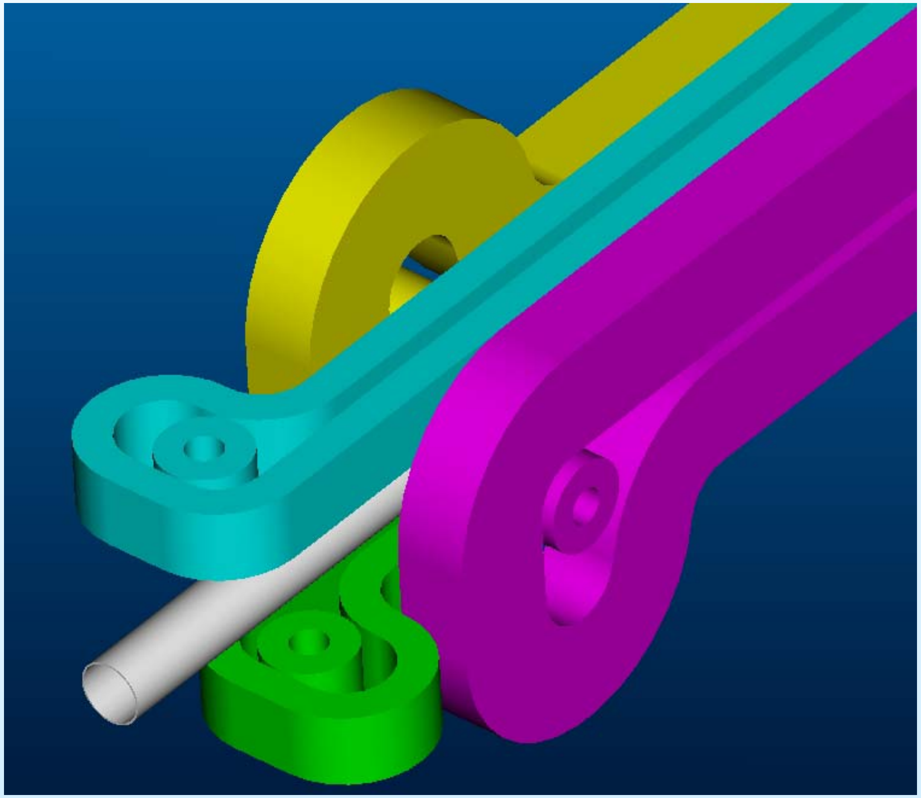




New End Design Concepts (contd.)

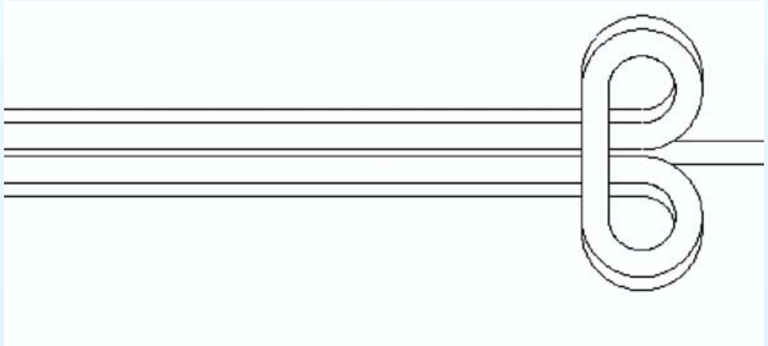
Flat Coil Ends: Sideway Overlap

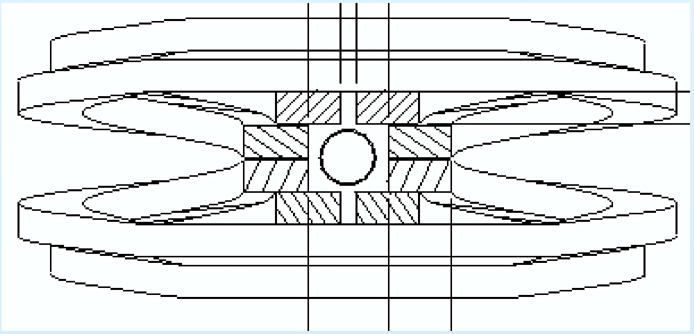


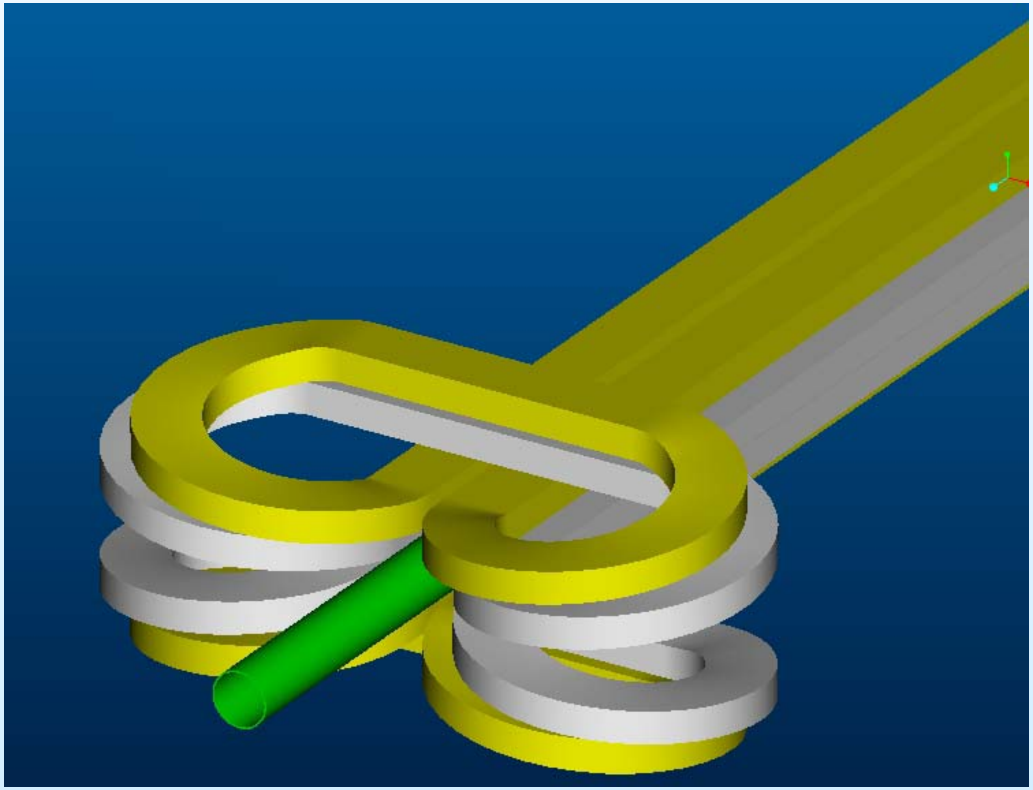


New End Design Concepts (contd.)

Overpass/Underpass (Clover Leaf) Ends: NO Reverse bend needed



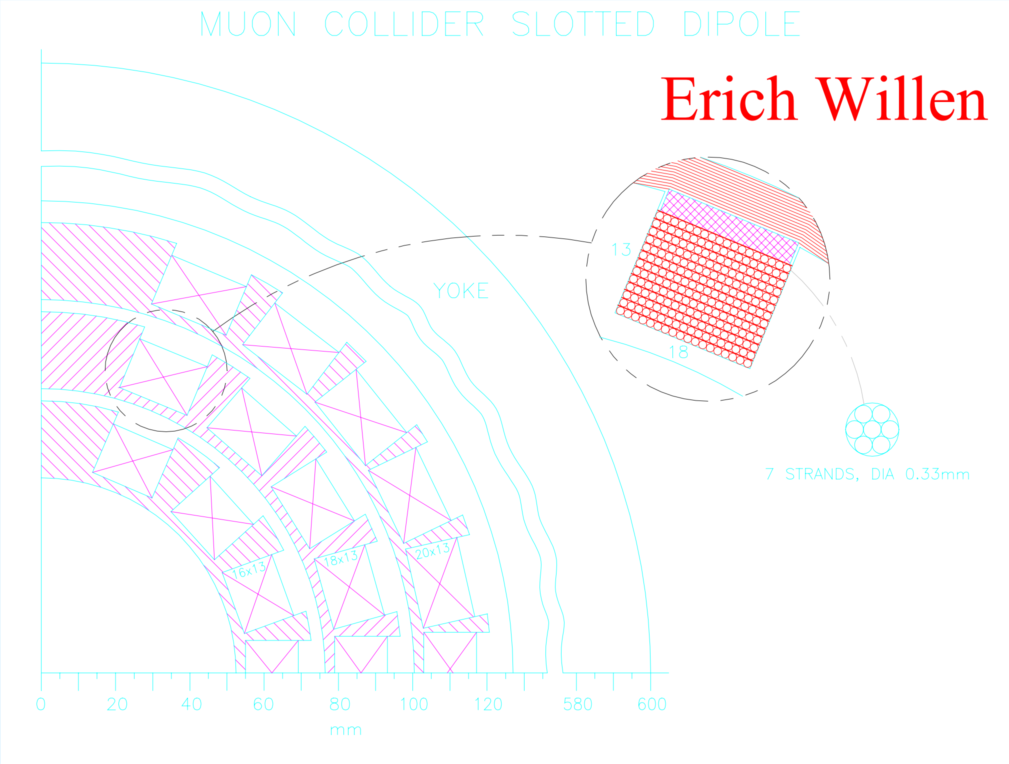




Magnets with Flexible Wire

Recently flexible pre-reacted Nb_3Sn wire has become available. BNL is trying to use that in magnets in magnets that require small bend radii in the ends (example LHC IR upgrade and muon collider)

- The Lorentz forces are contained in the individual blocks and do not pile up on the midplane as in conventional cos Θ magnets



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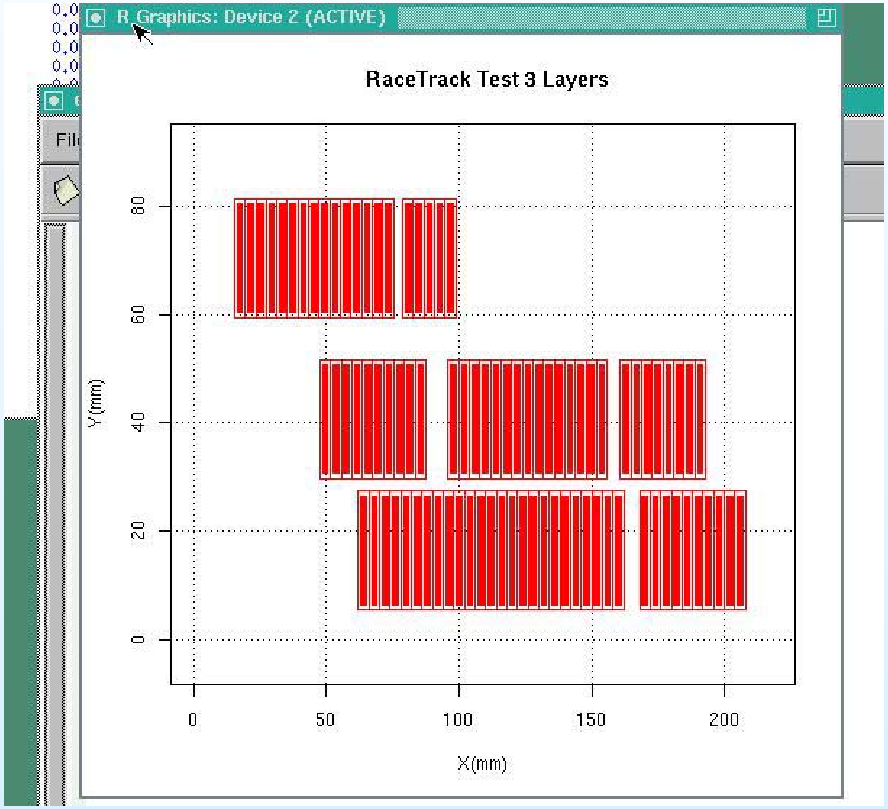
Software Development at BNL for Magnet Design



BNL has a long ongoing program in software development for magnet design and analysis.

RHIC uses a variety of magnets. Some require very high field quality and some are quiet novel in design. They require special software. All RHIC coils have been designed using local software.

We are fortunate to have Gerry Morgan and Pat Thompson come back from retirement and help us bring these software up-to-date and develop some new, as needed.

The above is an example of new program being developed by me and (mostly) Pat Thompson to optimize racetrack coil magnets. This uses CERN library. These programs, after sufficiently tested, will be available to scientific community as a part of collaboration.

Status and Possibilities of using HTS in LHC Upgrade

High Temperature Superconductors (HTS) have a way to go before they can be used in very high field accelerator magnets. The high field and high temperature properties of HTS are very promising.

However, as an end user, we continue to see progress in the material we receive for the manufacture. BSCCO wires in piece length of 0.5 km are now available.

BNL has made and tested cables and a variety of short coils/test magnets; the results so far have been encouraging (next few transparencies).

For LHC IR upgrade, an hybrid option (with Nb_3Sn and HTS) offers an interesting possibility.

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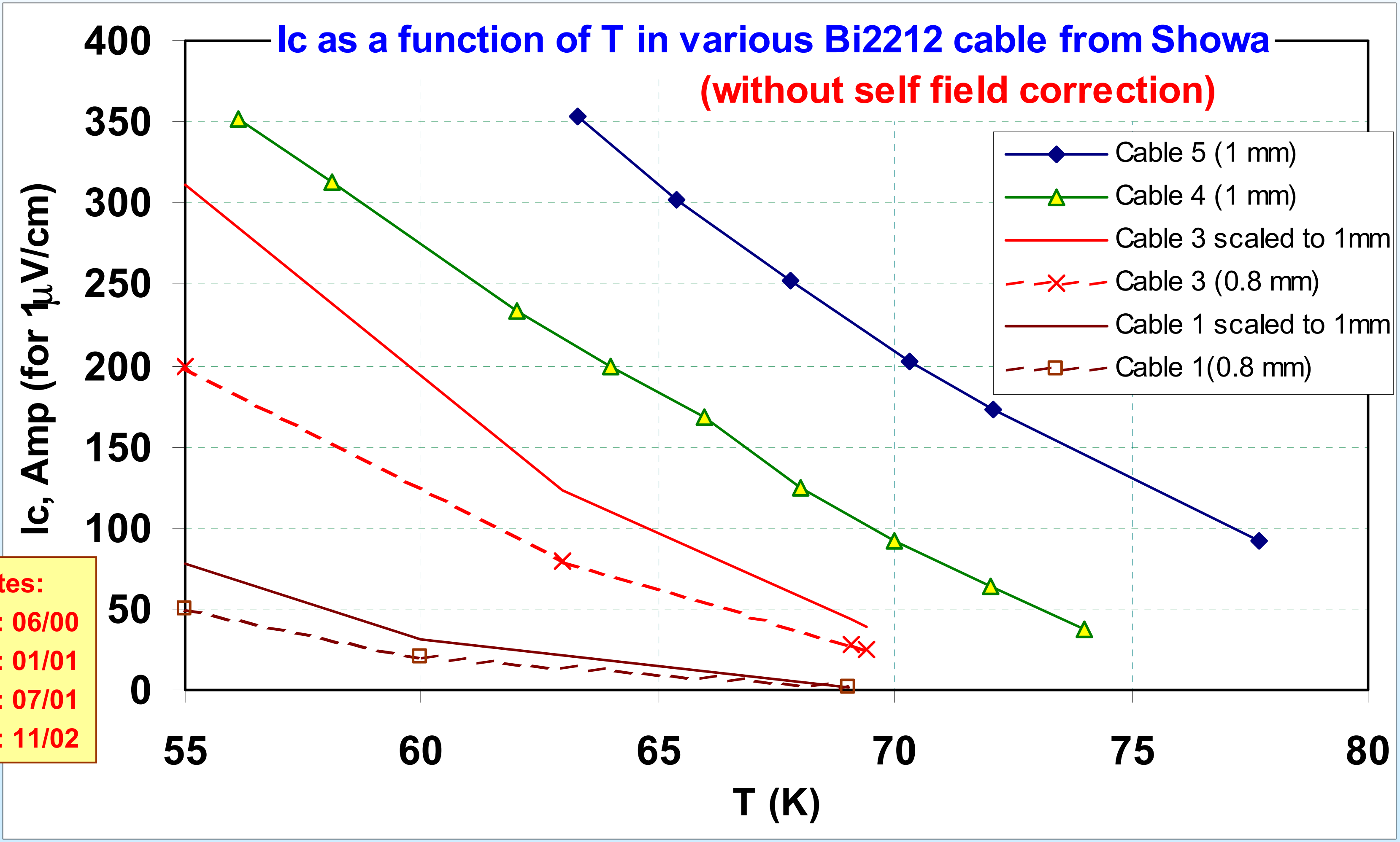
BNL Measurements of Various Cables from Showa (Note: Continuous progress in cable performance)

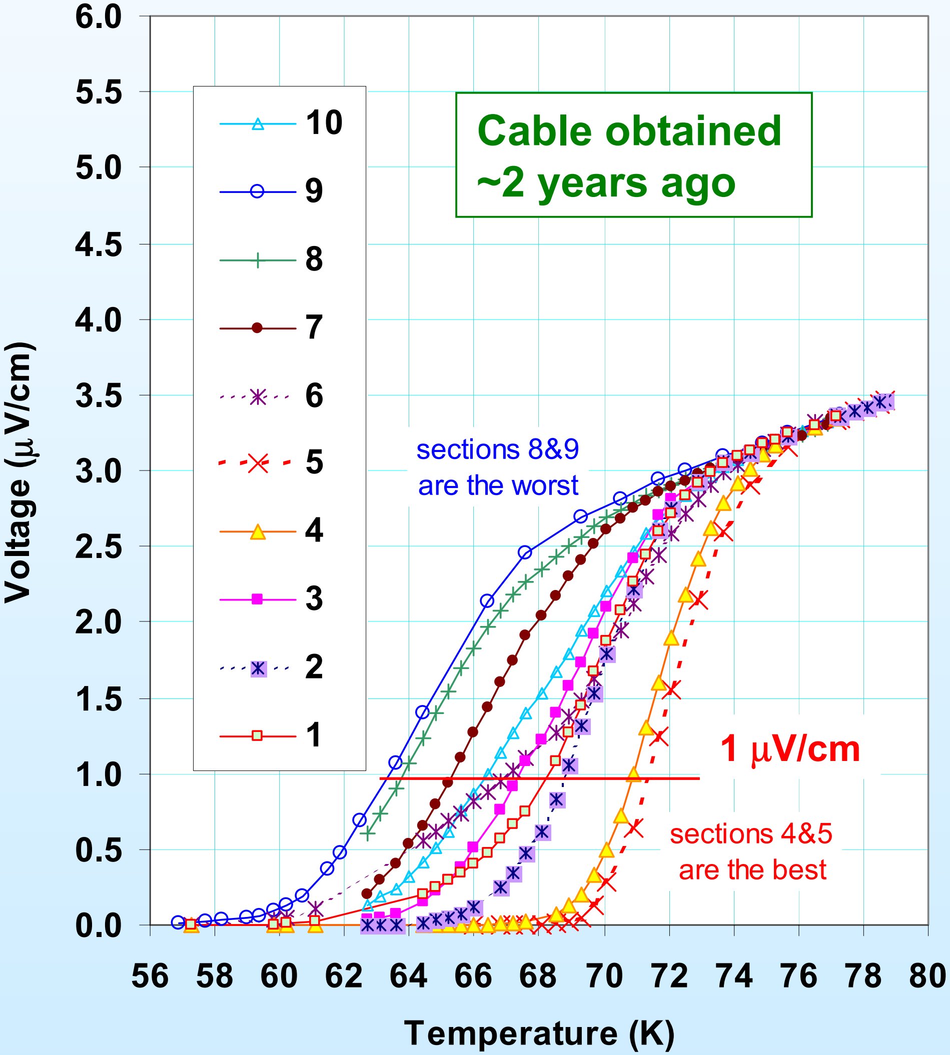
Extrapolated 4 K performance of 20 strand cable (#5) (wire dia = 1 mm) : ~5 kA at high fields and ~9 kA at zero field

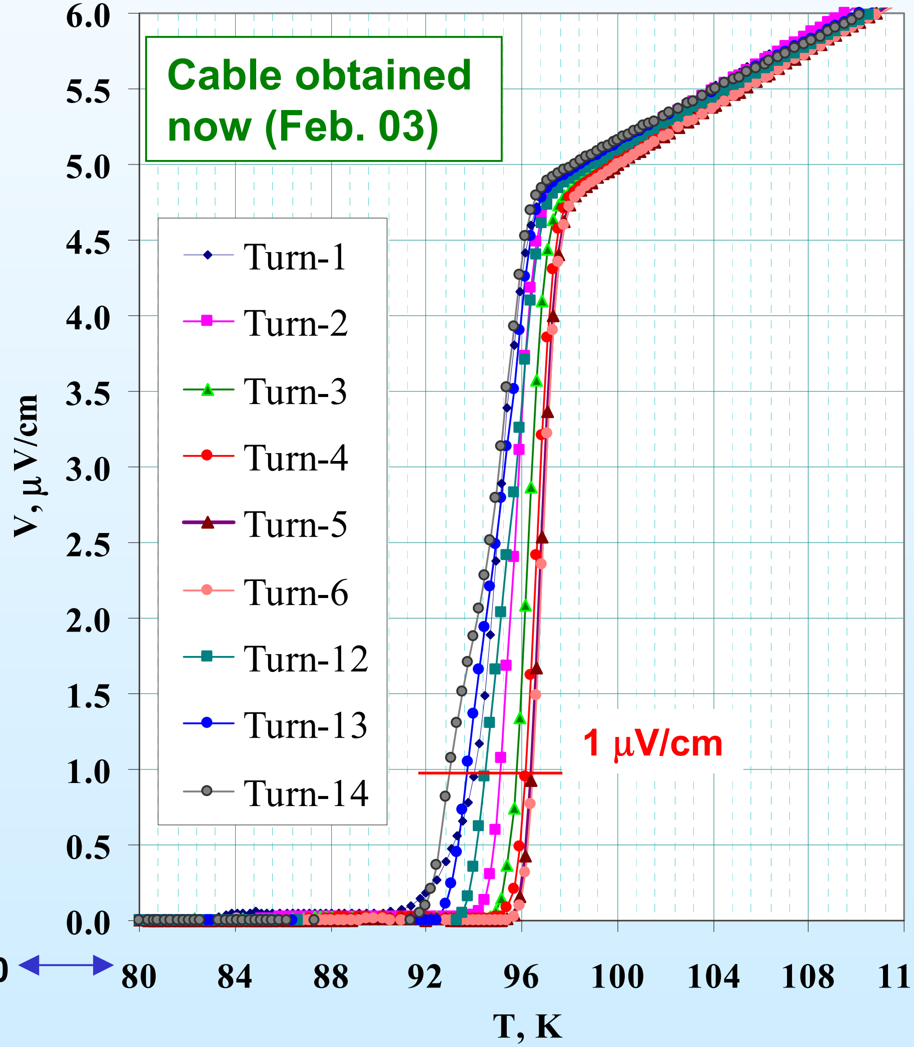


Test Dates:
Cable 1: 06/00
Cable 3: 01/01
Cable 4: 07/01
Cable 5: 11/02

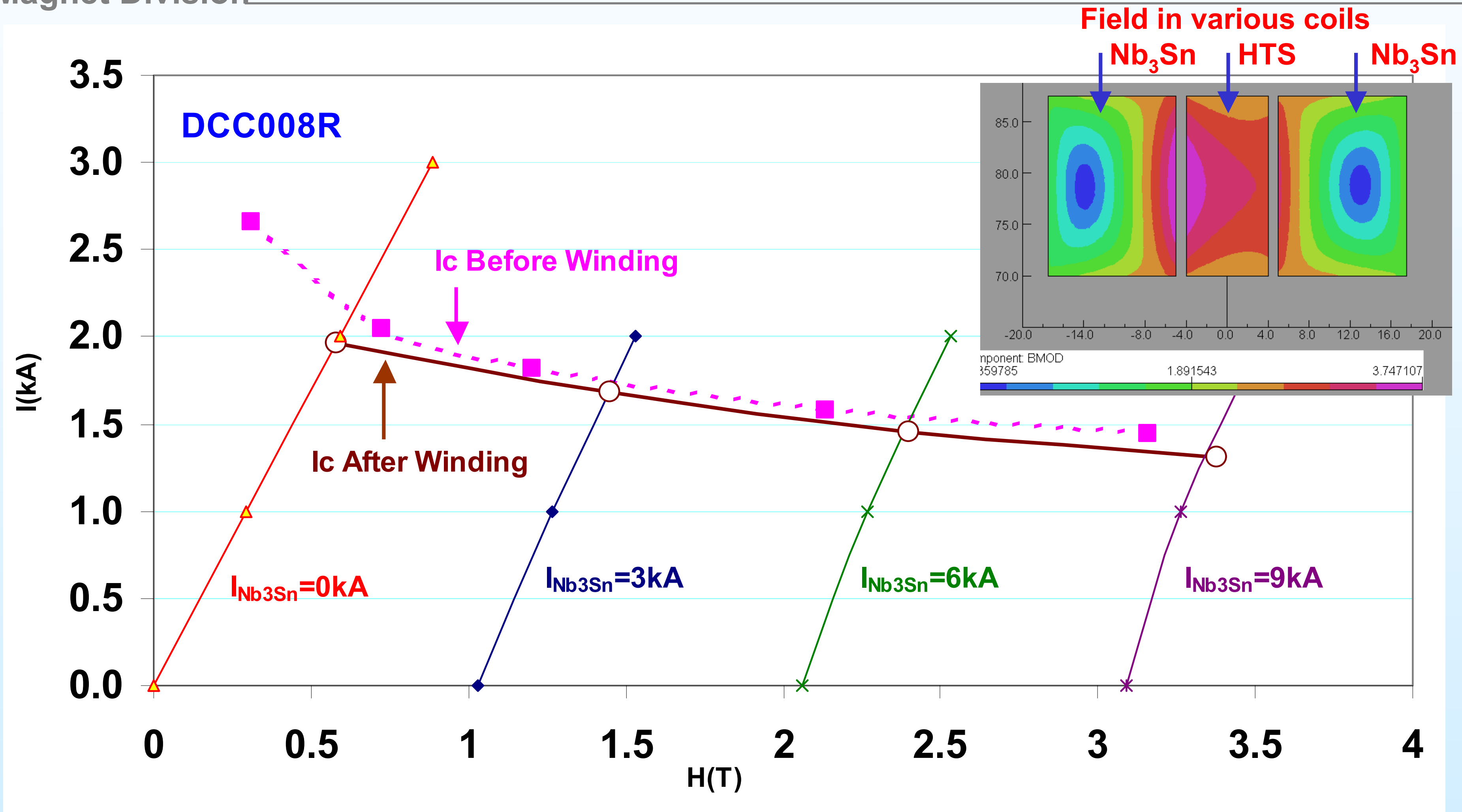
Improvement in Tc of BSCCO2212 Cable from Showa

Note the improvements both, in the absolute value and in the spread.





Performance of HTS Coil in the Background Field of Nb_3SN Coils



HTS coil was subjected to various background field by changing current in "React & Wind" Nb_3Sn coils (HTS coil in the middle and Nb_3Sn on either side)

Summary

- **"Dipole First" with "Open Midplane" offers an interesting alternative for Next Generation LHC IR in dealing with the challenges associated with a large increase in luminosity.**
- **The design work is very preliminary but the results of initial analysis (including Mokhov's analysis) are encouraging:**
  - The energy deposition in superconducting coils is quiet manageable (below quench limit).
  - It may be possible to remove heat at higher temperature and thus offering a significant savings.
  - The overall system design (including TAS & TAN) appears attractive.
- **Next Step: Carry out a more detailed optics, magnet and overall system design that fulfills all requirements.**
- **Do magnet R&D in parallel so that the base technology, not necessarily the exact design, is ready at the "decision time".**