U.S. MAGNET DEVELOPMENT PROGRAM

BNL Common Coils Experience

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4th Joint Common-Coils Meeting

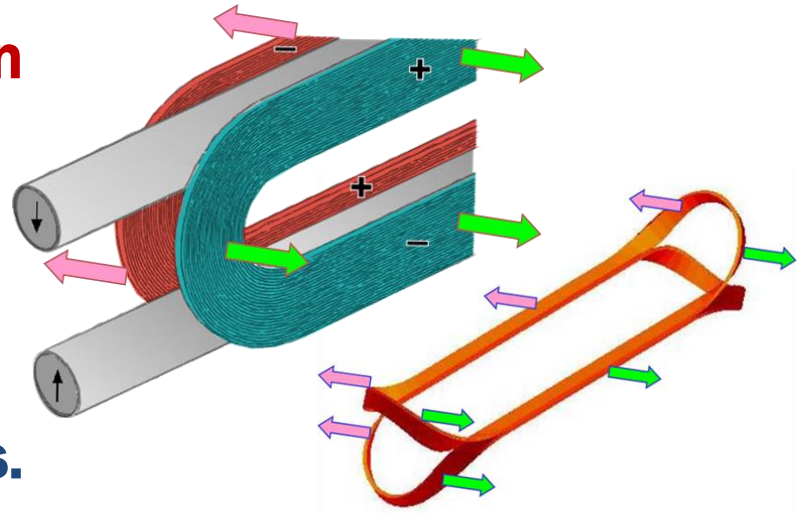
Common Coil Programs at BNL

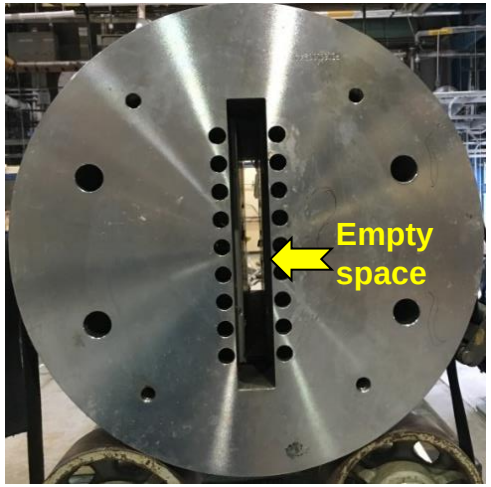
- Part I – Initial design development and proof-of-principle demonstration magnet(s), leading to DCC017 R&D dipole
- Part II – MDP work for designing an accelerator quality 20 T HTS/LTS hybrid dipole with 15% margin, which can eventually be built in industry

➢ Both designs try to take advantage of the unique common coil geometry

Part I: Primary Goals & Demonstration

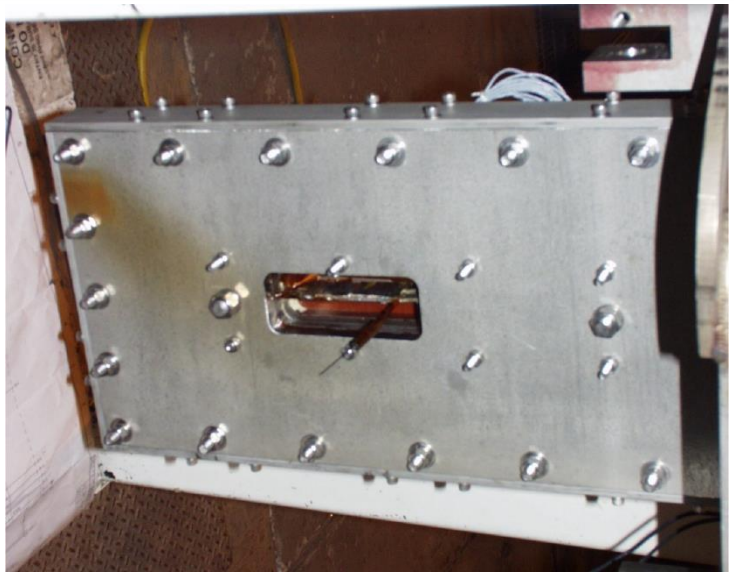
- **Demonstrate common coil design for a respectable field Nb_3Sn dipole (10 T at that time)**
- **Demonstration of "React & Wind" technology (BNL and community had failed in earlier attempts for React & Wind). The general thinking was that it's not a viable technology for accelerator magnets despite being attractive for many reasons.**
- **Mechanically handles the large Lorentz forces differently from cosine theta and block coil geometries (each coil layer moves as a block, allowing much larger deflections with minimum strain on conductor & requires much smaller support structure)**
- **Facilitate rapid-turn-around R&D program where a coil test becomes an initial magnet test at high fields (this should facilitate and encourage innovative and systematic studies)**



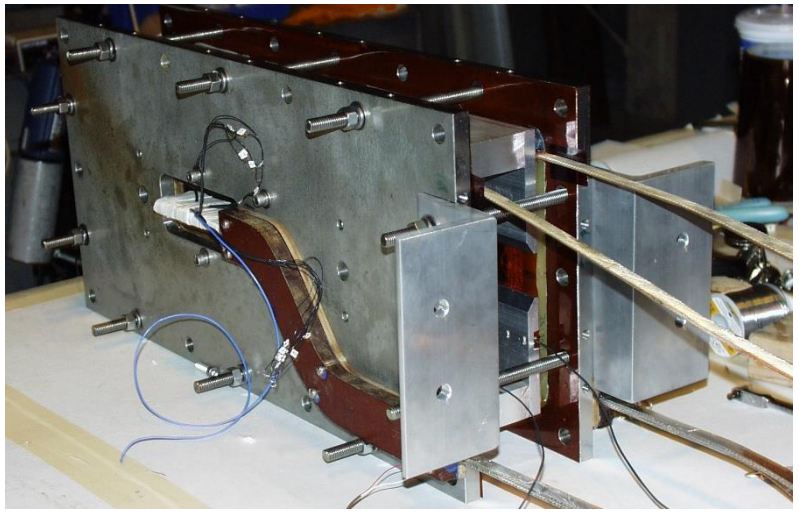


DCC017 met these goals - ambitious at that time

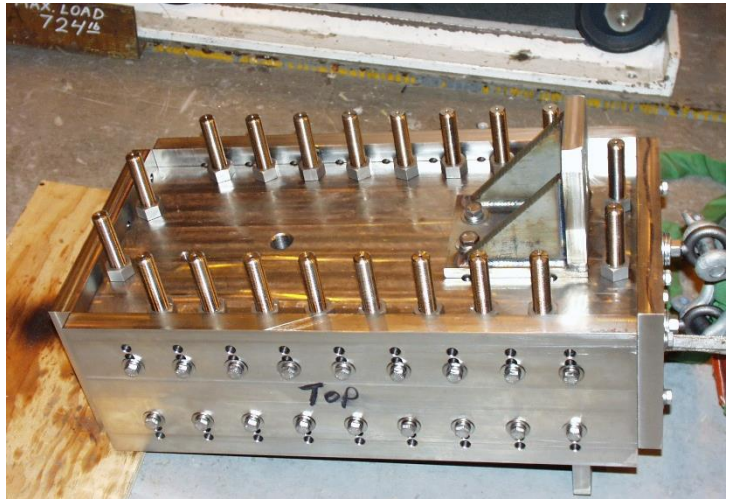
Types of Structure



Aperture increased



Flexible bolted structure for testing a different number of coils having different width and different spacing



DCC017

Part I: What we failed to plan & demonstrate

- **While we demonstrated several benefits of the common coil design (simple racetrack coils, in particular), demonstrating field quality was not an integral part of the initial R&D programs.**
- **Achieving good field quality was done via computer models that in most cases required coils which didn't have racetrack geometry. Moreover, many required a more complex internal structure.**
- **This created a negative narrative of the common coil which we need to overcome to make common coil design widely acceptable. Initial design must incorporate possible addition of coils which create good field quality, even if they are not part of the 1st test.**

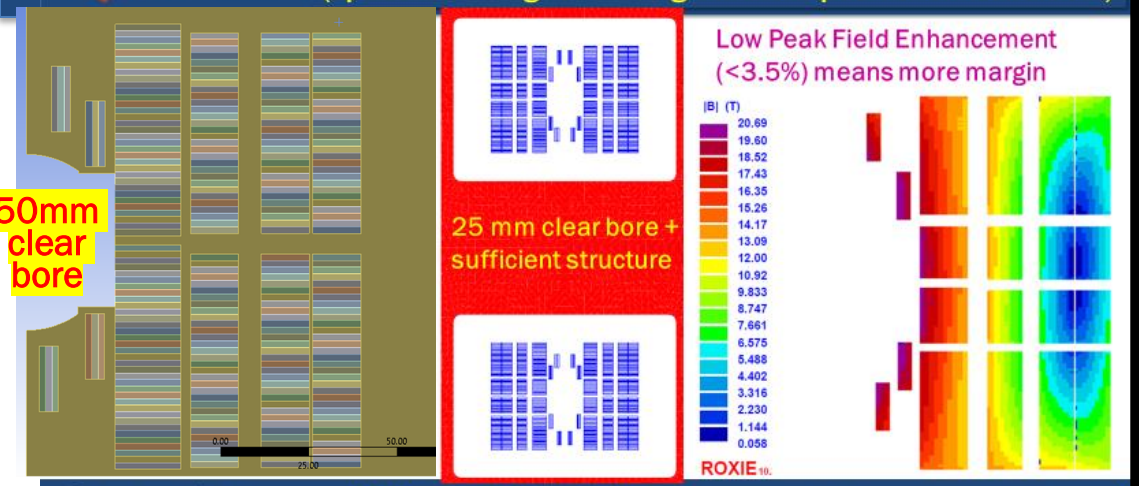
Part II – Guiding Principles

- In DCC017, we demonstrated that moving each coil layer as a block is ok if the relative deflections (which cause strain in the conductor) are small. This is a major benefit of the common coil geometry and must be taken advantage of.
- To qualify the common coil design for particle colliders, make field quality an integral part of the design. Demonstrate a good field quality magnet, even if not in the first test but make that an integral part of the program.
- Optimize the conductor amount (another perception against the common coil)
- Take advantage of the common coil geometry in easily segmenting coils/layers for hybrid dipole (HTS/LTS or Nb_3Sn/NbTi).
- We will be making a series of magnets (not just one). Take advantage of the modular nature of the common coil geometry to allow rapid R&D program and/or reusing the coils (one can't do that in cosine theta as the radii change).

20 T MDP Common Coil Design

New 20 T HTS/LTS Hybrid Design (May 2022)

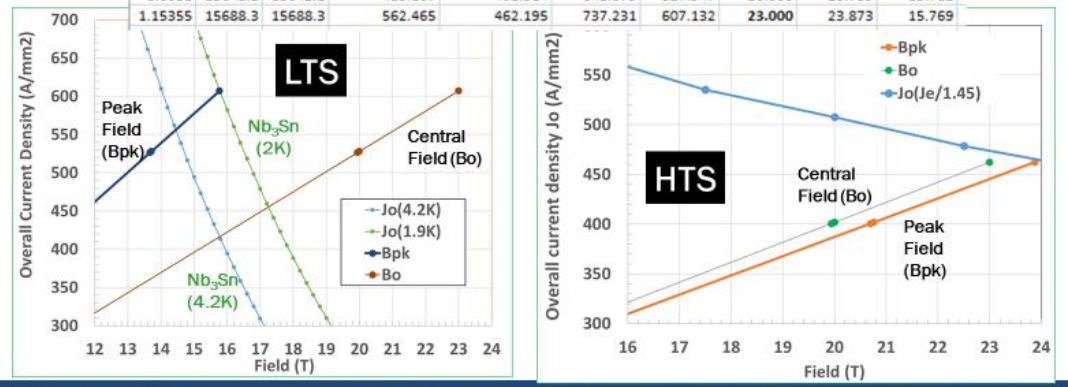
(spacers in magnetic design takes input from mechanical)



- All Nb_3Sn coils identical
- Well balanced margin between HTS & LTS coils
- Excellent field quality
- Simple stress-managed structure

Magnetic Design (May 2022) with 15% Margin

I(HTS), A	I(Nb3Sn)	Je(HTS), A/mm^2	Jo(HTS), A/mm^2	Je(Nb3Sn)	Jo(Nb3Sn)	Bo (T)	Bpk(HTS), T	Bpk(Nb3Sn)
0	0	0	0	0	0	0	0	0
13600	13600	487.60	400.672	639.10	526.316	**19.938**	20.695	13.670
13642.2	13642.2	489.107	401.914	641.079	527.947	20.000	20.759	13.712
15688.3	15688.3	562.465	462.195	737.231	607.132	**23.000**	23.873	15.769



Magnetic Design (May 2022) Good Field Quality

MODEL	mdp_may2022-v2
BI2212R	BI2212
Bare w	1.52
Bare h	18.35
Insulation	0.15
Ins w	1.82
Ins h	18.65
Ins Area	33.943
Current	13600
Je [A/mm^2]	487.60
Jo [A/mm^2]	400.67
Bpeak (T)	20.6951
MDPH2	Nb_3Sn
Bare w	1.6
Bare h	13.3
Insulation	0.15
Ins w	1.9
Ins h	13.6
Ins Area	25.840
Current	13600
Je [A/mm^2]	639.10
Jo [A/mm^2]	526.32
Bpeak (T)	13.6701
Bo	19.9382

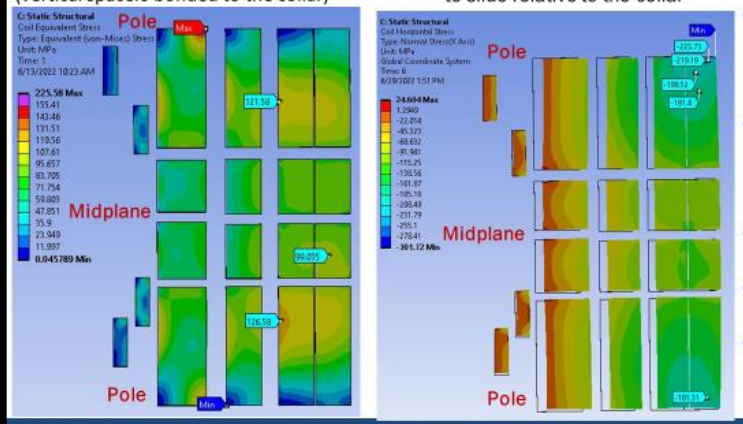
```
NORMAL RELATIVE MULTIPOLES (1.D-4):
b 1:  10000.00000  b 2:     -0.00000  b 3:      0.05059
b 4:     -0.00000  b 5:      0.09440  b 6:      0.00000
b 7:     -0.78244  b 8:      0.00000  b 9:     -0.92602
b10:      0.00000  b11:     -0.18313  b12:     -0.00000
b13:     -0.02800  b14:      0.00000  b15:     -0.01273
b16:      0.00000  b17:     -0.00410  b18:     -0.00000
b19:     -0.00094  b20:      0.00000

SKEW RELATIVE MULTIPOLES (1.D-4):
a 1:      0.00000  a 2:     -0.00405  a 3:      0.00000
a 4:     -0.02333  a 5:     -0.00000  a 6:     -0.15914
a 7:      0.00000  a 8:      0.20675  a 9:      0.00000
a10:      0.08678  a11:     -0.00000  a12:      0.00779
a13:      0.00000  a14:      0.00593  a15:     -0.00000
a16:      0.00258  a17:      0.00000  a18:      0.00056
a19:     -0.00000  a20:      0.00019  a
```

All harmonics <1 unit

Developing Mechanical Structure

Original Case (vertical spacers bonded to the collar)

SST vertical separators are allowed to slide relative to the collar



- Stresses and Strain are within acceptable limits at most places See John Cozzolino's presentation
- However, at pole the exceed the limit either in HTS or in LTS, depending on the contact (bonded or sliding)
- Attempt to make things better for decreasing the local peak
- Enhanced peaks are because of the bending of the coil layer.
- The two cases show that it can be balanced out

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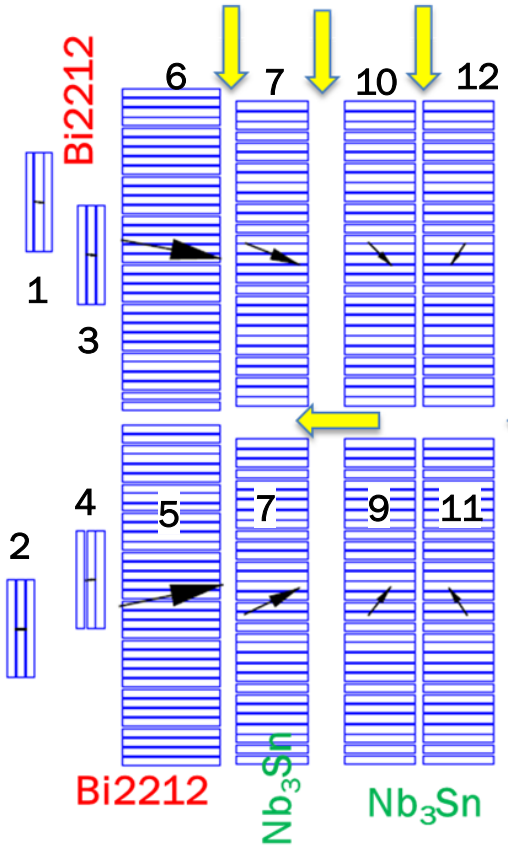
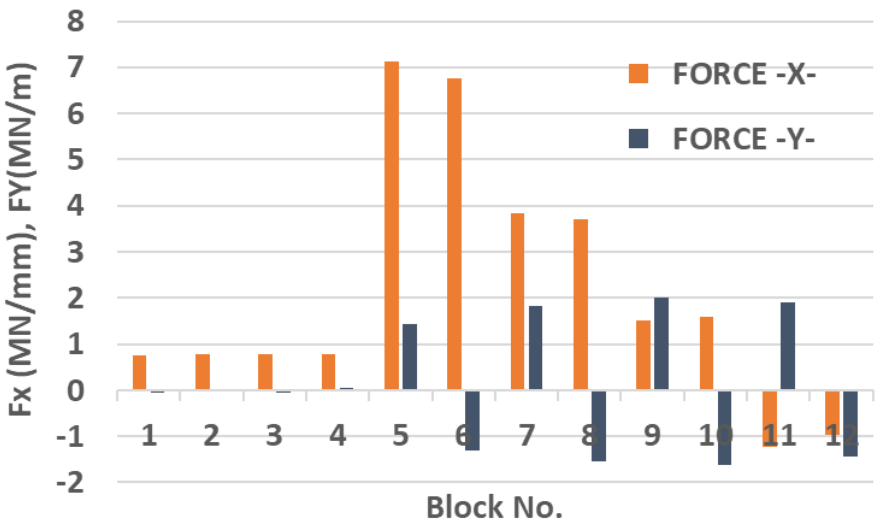
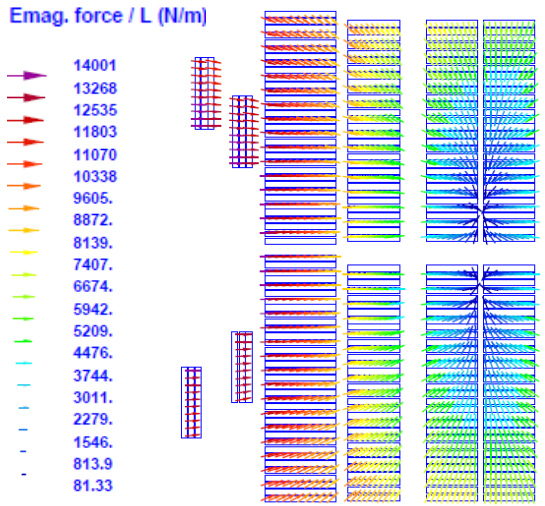
Lorentz Forces in the Common Coil

(design advantageous in dealing with large forces)

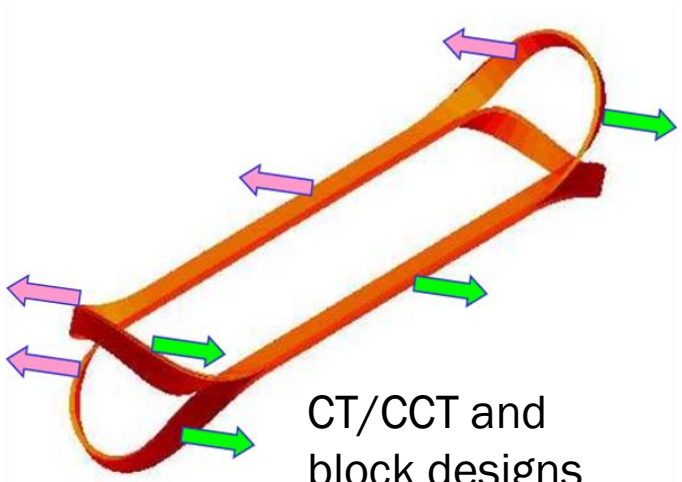
Concept of Stress-managed structure



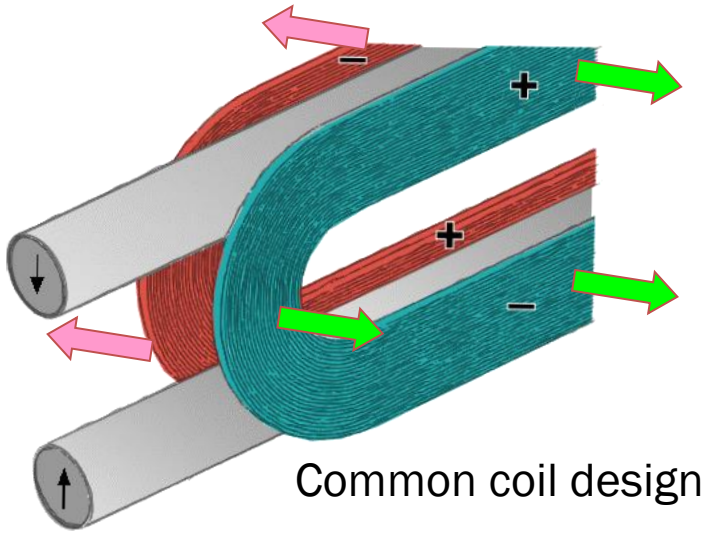




- Horizontal forces much larger than vertical (maximum vertical is 1/3 of horizontal)
- Large horizontal deflection can be tolerated since coils move as a unit - without causing much strain in the end or transition regions
- BNL common coil had 200 μm horizontal deflections and low vertical pre-stress
- Small forces on pole (mostly horizontal)

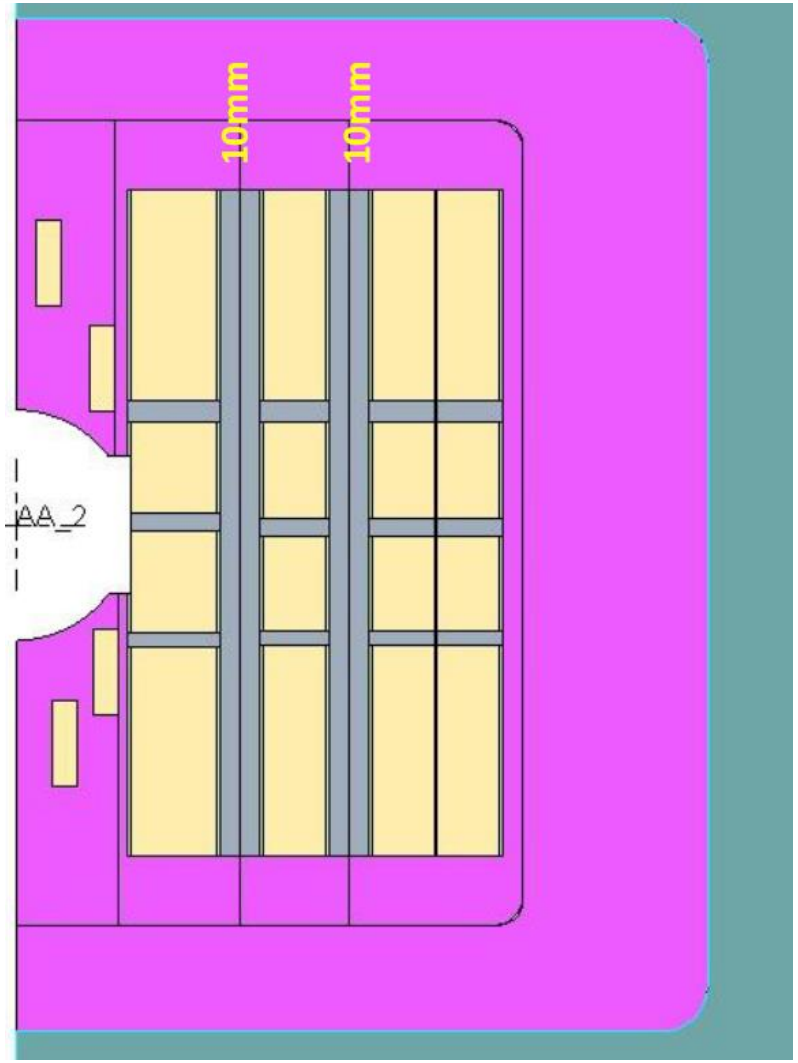


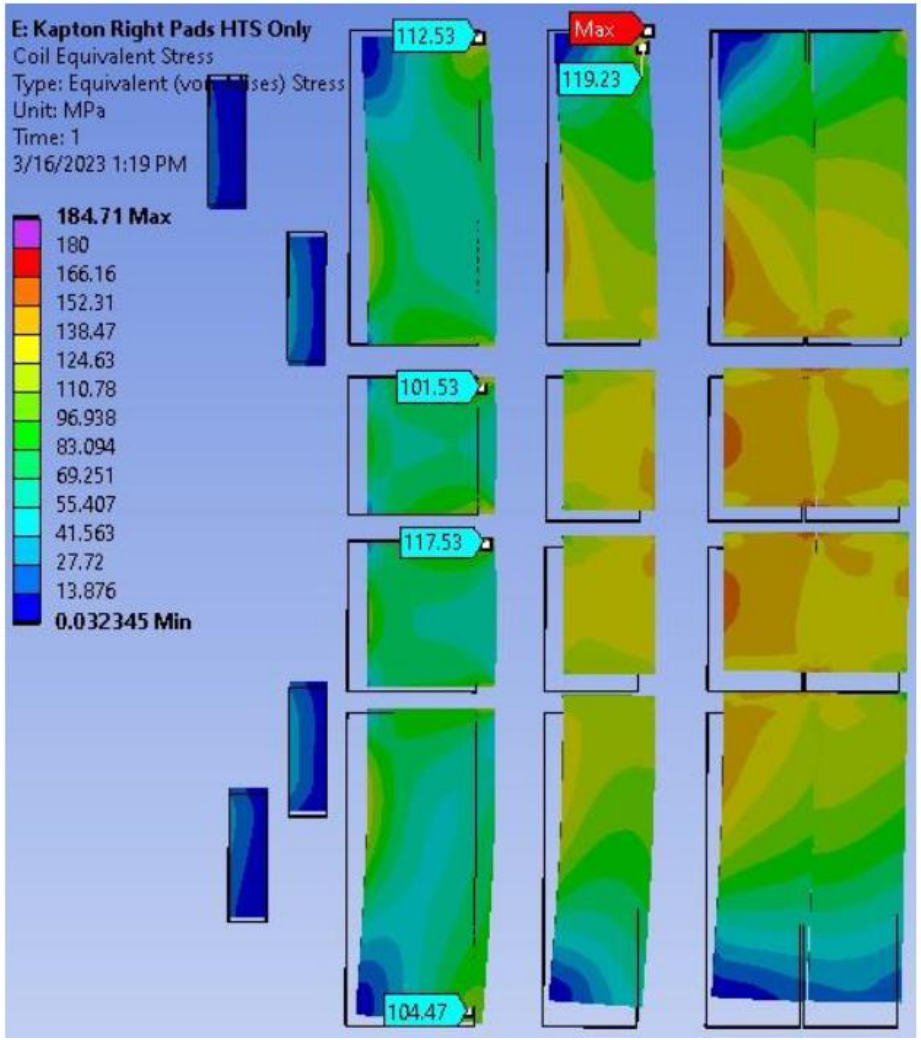
CT/CCT and block designs



Common coil design

Mechanical Analysis of 20 T CC Dipole (Anerella, Cozzolino, Runyan)





- Coil Equivalent Stress – Fixed Vertical Separators
- Stainless steel collars are fully bonded together.
- Right pads are Kapton on HTS only. All others are stainless steel
- Horizontal stress supports are stainless steel.

✓ 112MPa max in HTS
✓ ~180MPa max* in LTS

* 184MPa in corner, to be corrected via mesh refinement…

Extra Slides

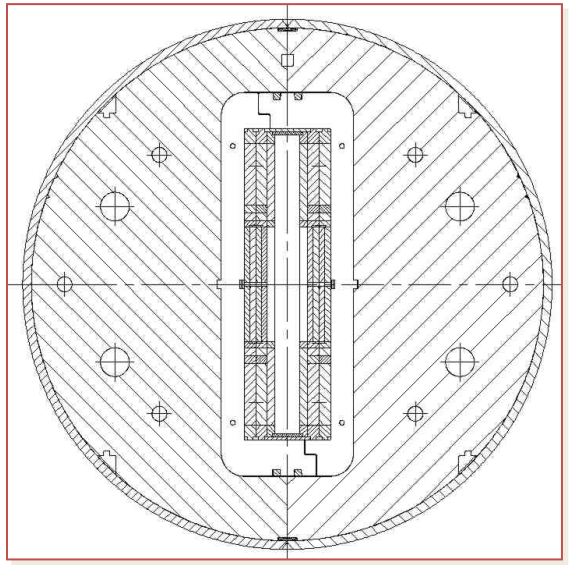
Overview & Summary

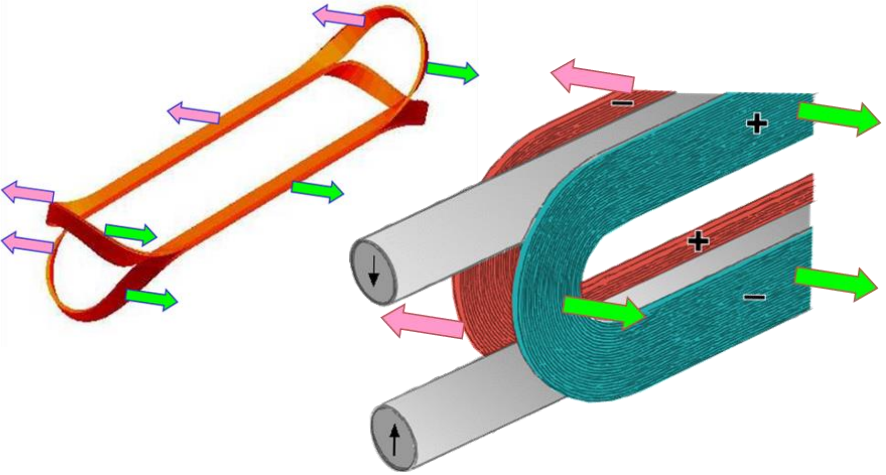
Note: This will not be a technical presentation/discussion (will do that in future)

- **The intended goal is to help devolve a general vision and specific plans**
  - **Opportunities: common coil design offers a few opportunities which are not possible with other designs (R&D programs, technologies, manufacturing)**
  - **Challenges: common coil design is still considered a new design with no field quality dipole built and tested (necessary to increase acceptability)**
- **Review past programs**
  - **What has worked (both in design and in experiments), and what was missed**
- **Suggested guidelines for building a plan**
  - **Demonstrate some thing in short term (simple design helps) and plan for a long-term program (keep final goal in mind). Both goals can be integrated.**

Take Advantage of Some Unique Features of the Common Coil Design

Modular design allows coils of different width, etc.





- **Identical design** can be used for many coils (splice in low field region)
- **Spacing (aperture)** can be changed for a higher field configuration
- **Conductor friendly design** with large bend radii allows both "**React & Wind**" and "**Wind & React**" technologies
- **Efficient segmentation** between HTS and LTS coils for 20 T dipole or possibly between Nb_3Sn and NbTi 14 T dipoles (to be examined)
- **Mechanically handles the large Lorentz forces well** with coil layers moving as a block (creating little internal strain on conductor despite large movement). Only need to minimize relative deflections not the total (very different from the cosine theta or block coil designs)
- **Stressed management with simple structure** as demonstrated recently in various designs and experimental programs
- **Simple magnet geometry** and **simple tooling** allows faster and lower costs for both for starting R&D and for large-scale manufacturing
- **Allows rapid-turn-around, lower-cost** program for systematic studies and high-risk, high-reward novel R&D (important at this stage)

A Unique Common Coil Design Dipole at BNL

(facilitates low-cost, rapid-turn-around variety of R&D)

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BNL common coil design experience has been very productive for low, cost rapid-turn around R&D for a variety of purpose.

Identical design may not work everywhere, but a similar approach may.

For example, fully open space may be replaced by removable insert for a field quality coils; or build a structure that can be disassembled easily.

Five steps for testing new design

1. Magnet (dipole) with a large open space
2. Coil for high field testing
3. Slide coil in the magnet
4. Coils become an integral part of the magnet
5. Magnet with new coil(s) ready for testing