Towards a 5 T Solenoid for SiD

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Fermilab

Solenoid & Steel of SiD

- What's Novel, Defined, Undefined
- HEP Solenoid Evolution
- Choosing an "Existence Proof"
- Extrapolationg CMS to SiD: Coil, Iron
- Winding Design
- Steel Yoke Concepts
- Coil Stress Analysis
- Cold Mass Support Ideas
- Towards a Conceptual Design

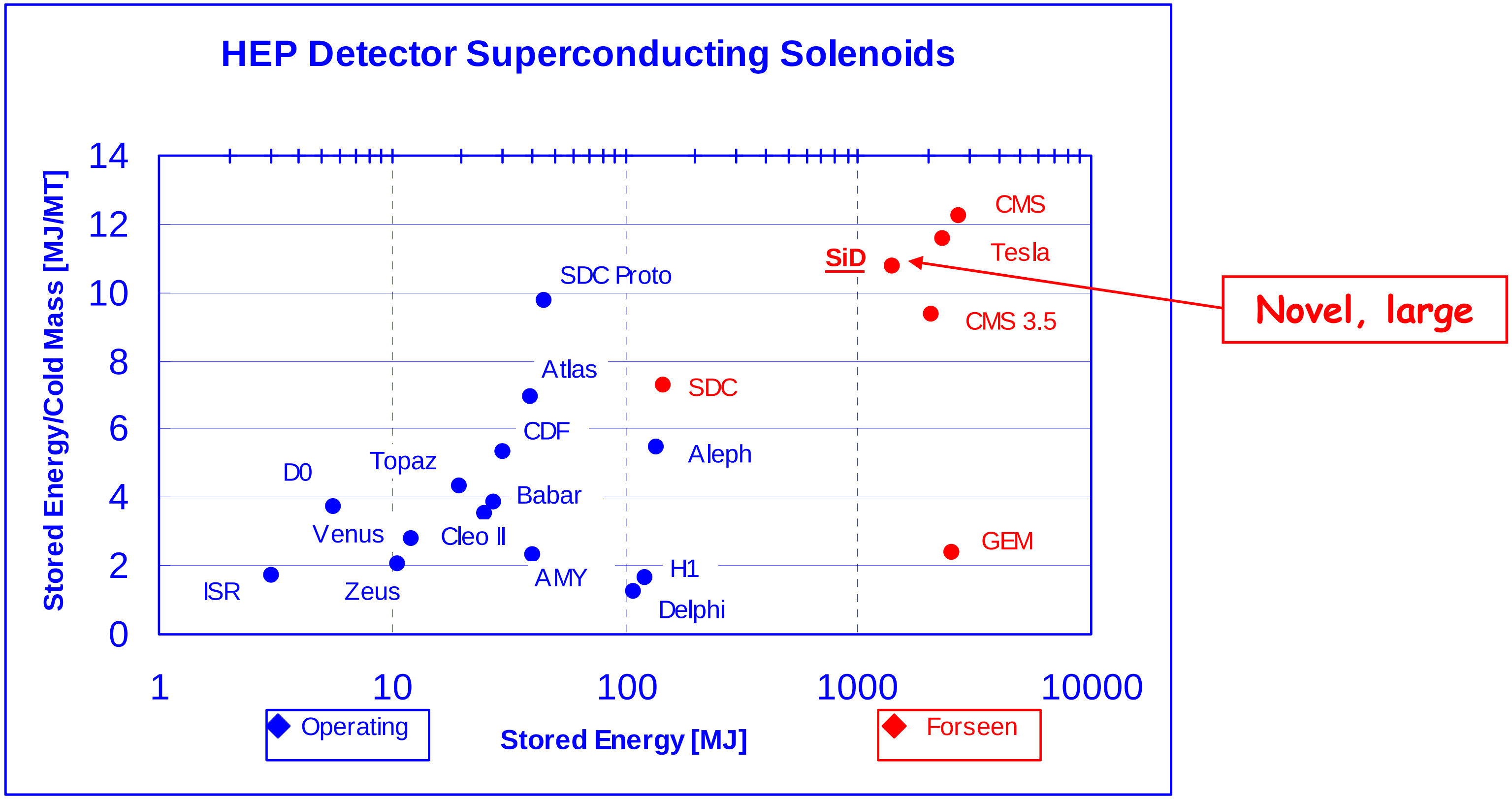
Getting Started…

- B(0,0) = 5T
- Clear Bore Ø~ 5m; L = 6 m
- ➔Stored Energy ~ 1.4 GJ
- Laminated Iron Yoke, End Laminations not re-entrant
- Field Homogeneity not specified
- Radiation Transparency not specified
- "Fallback" field (below which physics is compromised) not specified

Novel

Large

History of HEP Solenoids



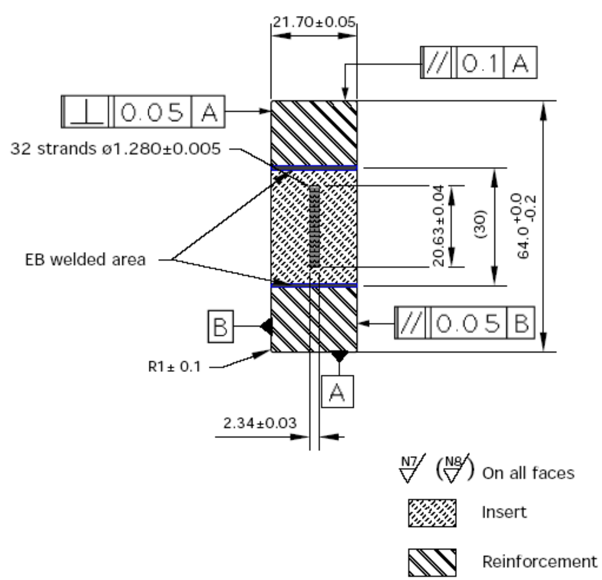
- Quench Safety…

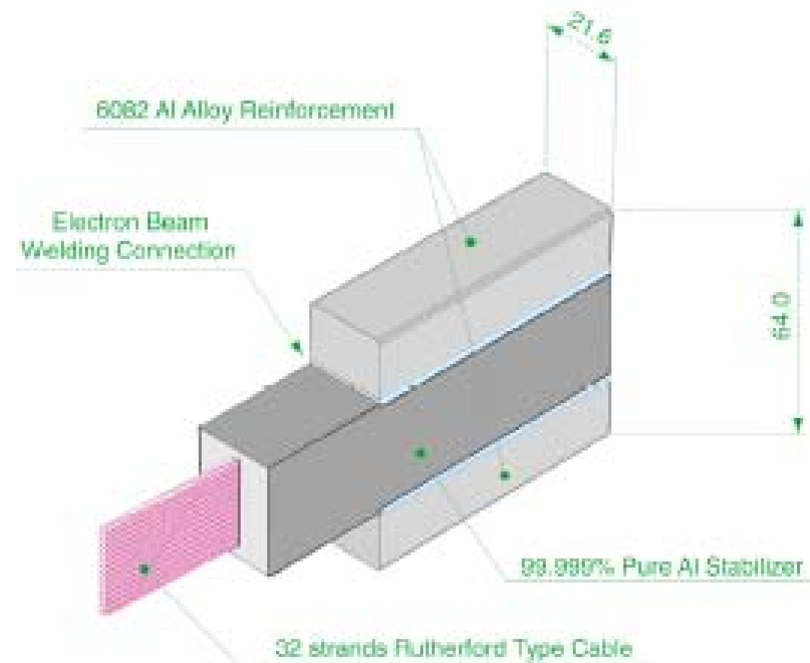
Recent High-Field HEP Solenoids

- High Field, Large Size create many challenges
  - Look for Proof of Principle!
    - Only "High Field" Operating Solenoids at 2T: DØ, Atlas; at 3T: AMY
  - Closest is (may be?) CMS: 4 T, 2.7 GJ, Ø = 6m, L = 13 m
- Develop Preconceptual Design "Along Lines of" CMS
  - Expedites Approach to Credible Conductor/Winding Designs
  - Credible Engineering Approach for Industrial Fabrication
  - Credible Cost Estimates
- Not Inappropriate to examine AMY approach (cryostable; mixed Al/CU conductor)

CMS Conductor Design

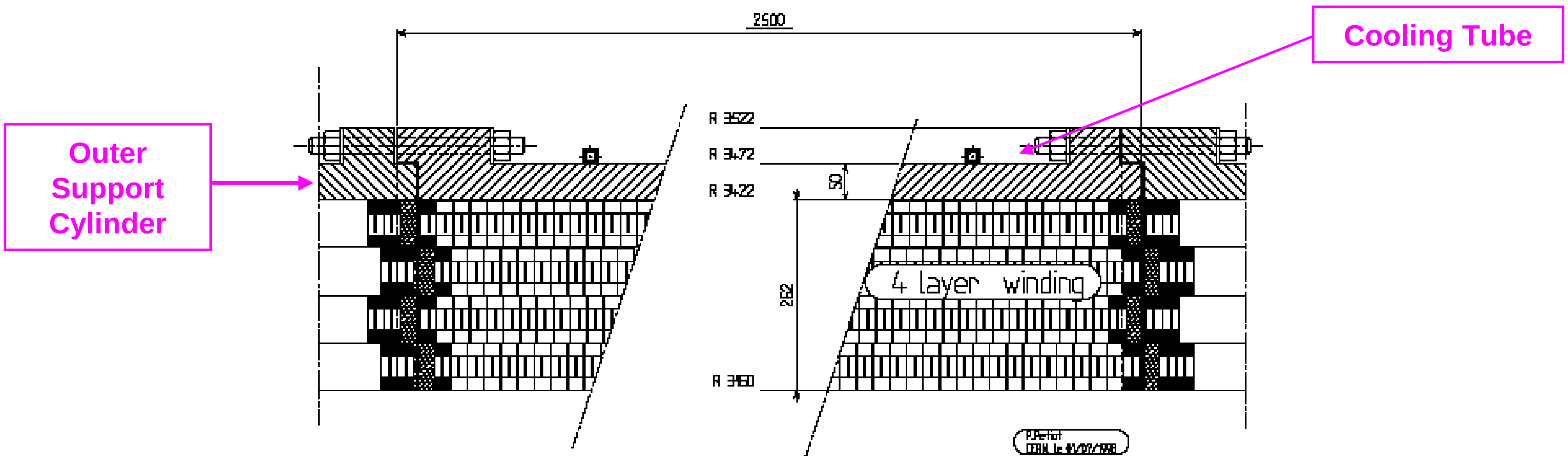
- *Aluminum Stablized (low magnetoresistivity)*
- *Aluminum Reinforced (high strength)*





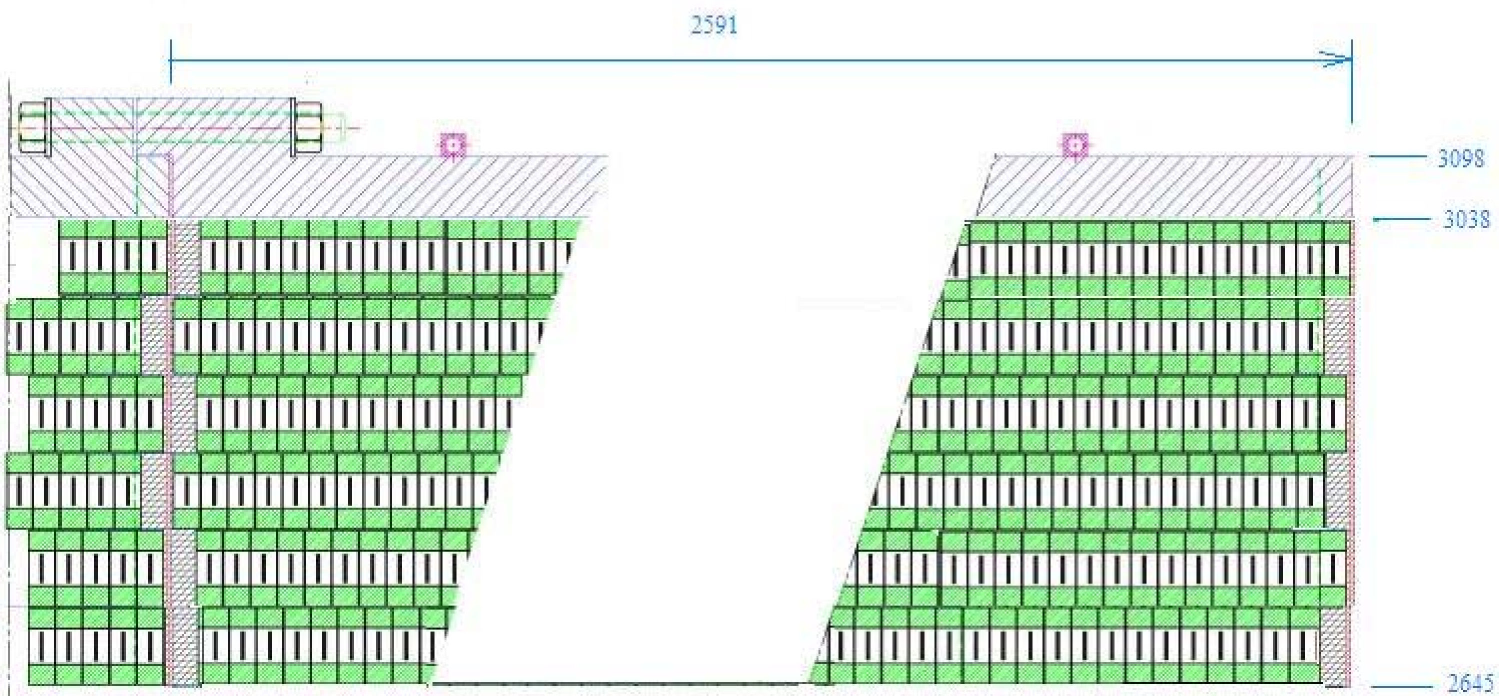
FNAL/ETHZ/Saclay/CERN/INFN

CMS Winding Design



- CMS Coil wound in 5 separate Modules, each 2.5 m long
- 4 Winding Layers (108 turns/layer)
  - 2.7 km long conductor length (one per layer) => no joints in layer; all on coil OD
  - Interturn insulation 0.64 mm, Interlayer 1.04 mm
- Outer "Support" Cylinder for "quenchback" quench safety, supports external forced-flow (two-phase) cooling via thermosiphon; provides anchor points for cold mass support links

SiD Winding Design

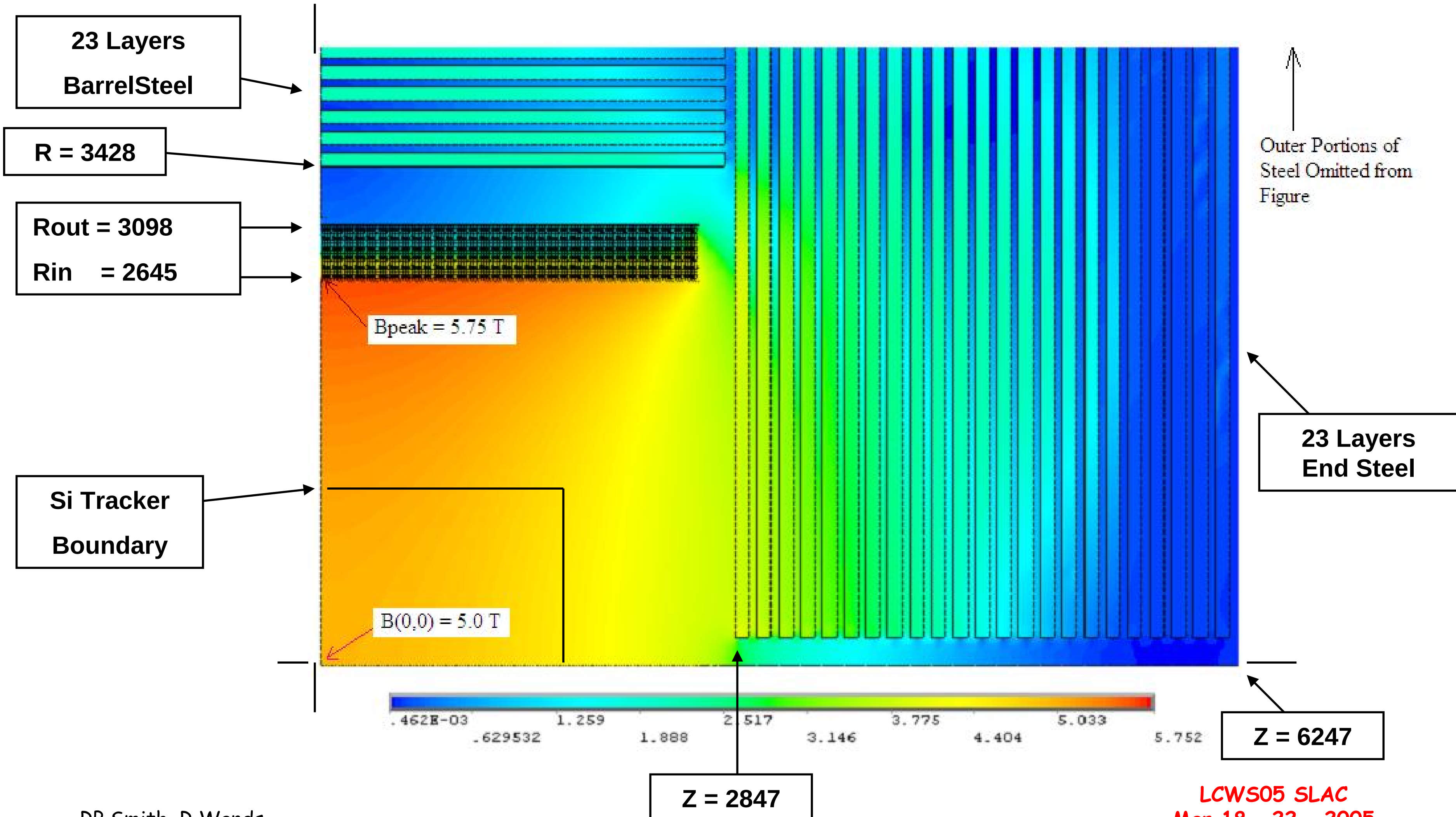


SiD Half-coil 6 layers x116 t/l

Specifics for SiD

- Choose 6 layers (tradeoffs), "derate" CMS conductor to 5.8 T peak field (vs. 4.6 for CMS). I (CMS) = 19500; I (SiD) = 18000.
  - Critical current Ic(4.2K,Bpeak) derates 46900/59000 ~ 0.79
  - Iop derates ~ 0.92
  - <u>Stability expectations require modeling; 32 CMS strands => 34 for SiD?</u>
- Have one module per coil half
  - Bolted joint at Z = 0 for easy assembly, transportablilty
  - Conductor length OK; Winding prestrain > CMS though
  - Winding, vacuum impregnation per CMS
- Outer support cylinder per CMS, except 60 mm thick
- FEA studies for Energization stress, conductor strain; Cooldown stresses
- Stored Energy per Kg cold mass (<CMS) → quench safety ~OK?
- Cooldown, Energization Stresses and Strains OK ?

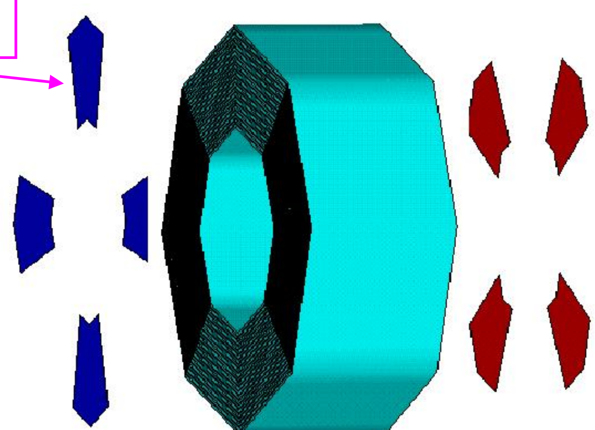
First ANSYS 2D, 3D Modeling



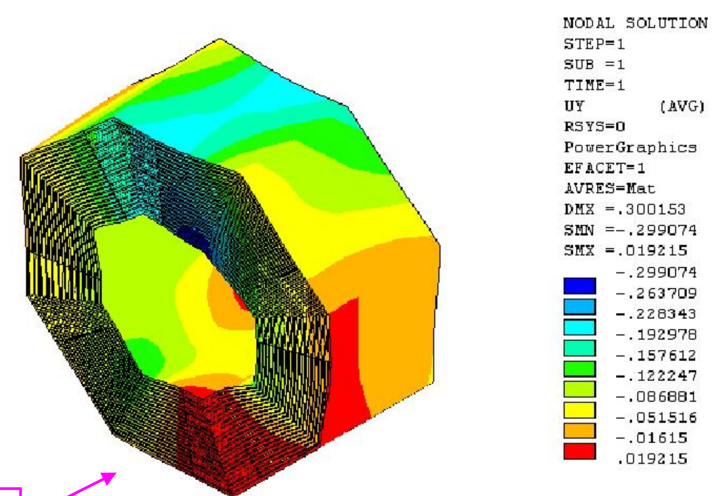
Supporting the Steel, Off Which Everything Hangs

- Muon system/Flux Return: 10 cm thick Iron, 5 cm chamber gaps
  - Overall Octagonal Shape of Barrel Yoke; can "tile" chambers at vertices for hermiticity
  - Barrel Octagon Layers Spaced/Supported by Staggered Corner Gussets
  - Allows Insertion of Muon Chambers from Alternate Ends, "tile" at centerline

Corner Plates tie barrel shells together

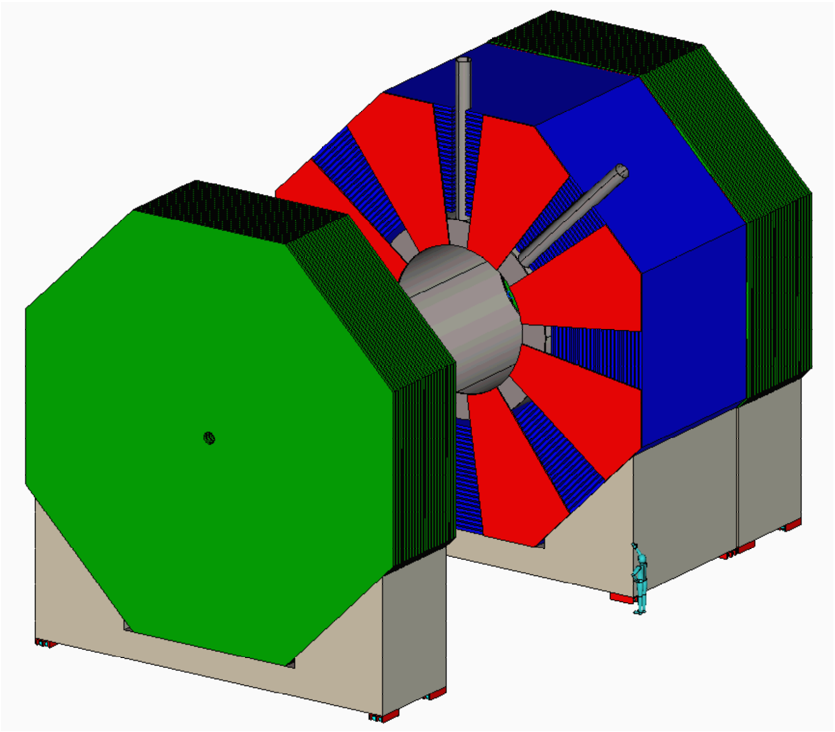


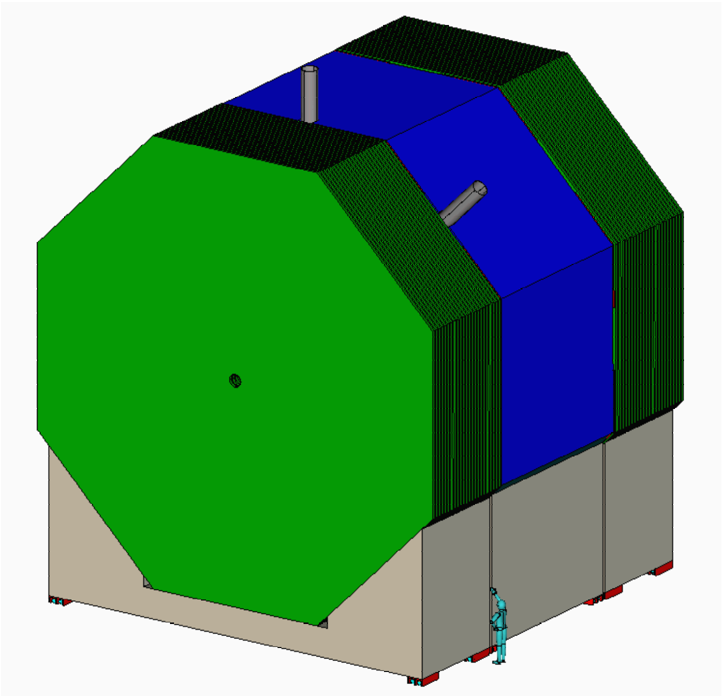
Resulting Structure shows acceptable deflections (~0.3 in)



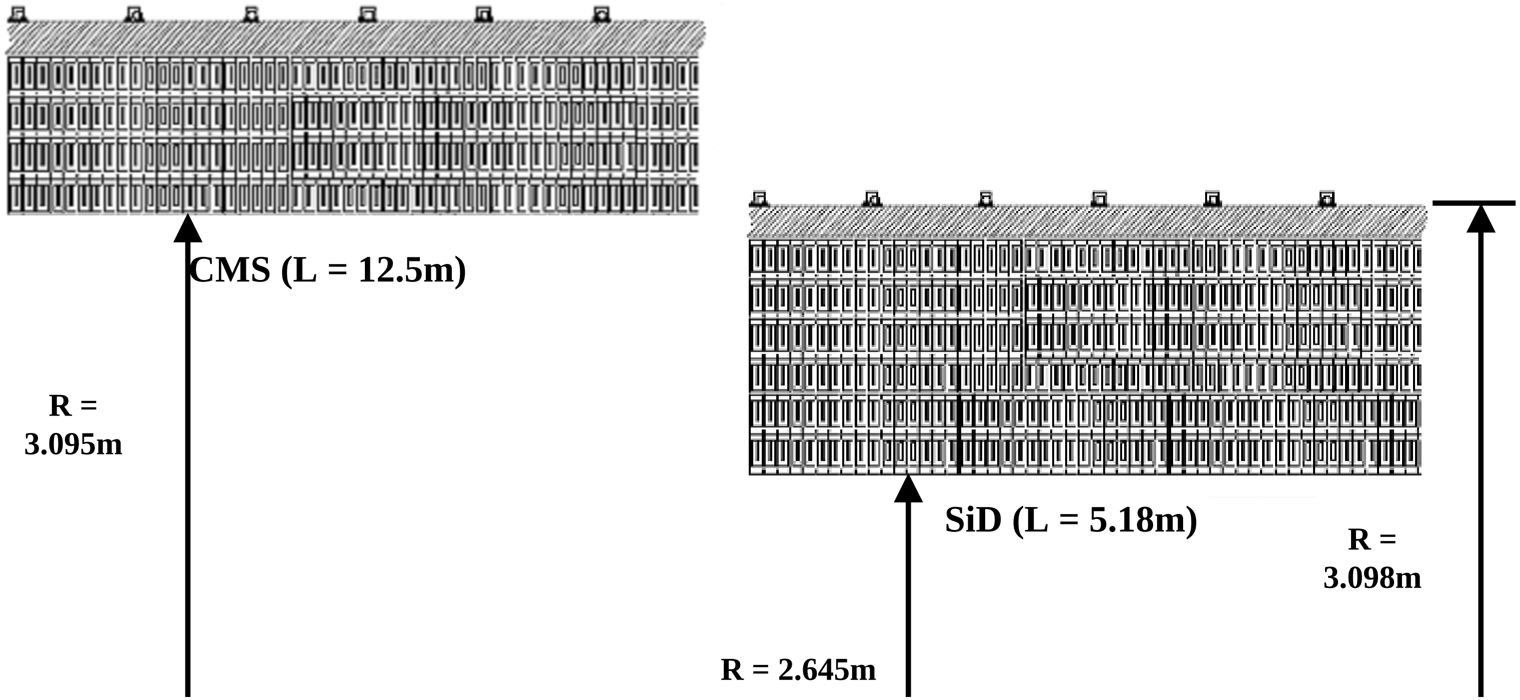
Vertical Deflections for Staggered Barrel Iron Connections
(units = inches)

Overall Detector





FEA: Stress, Strain



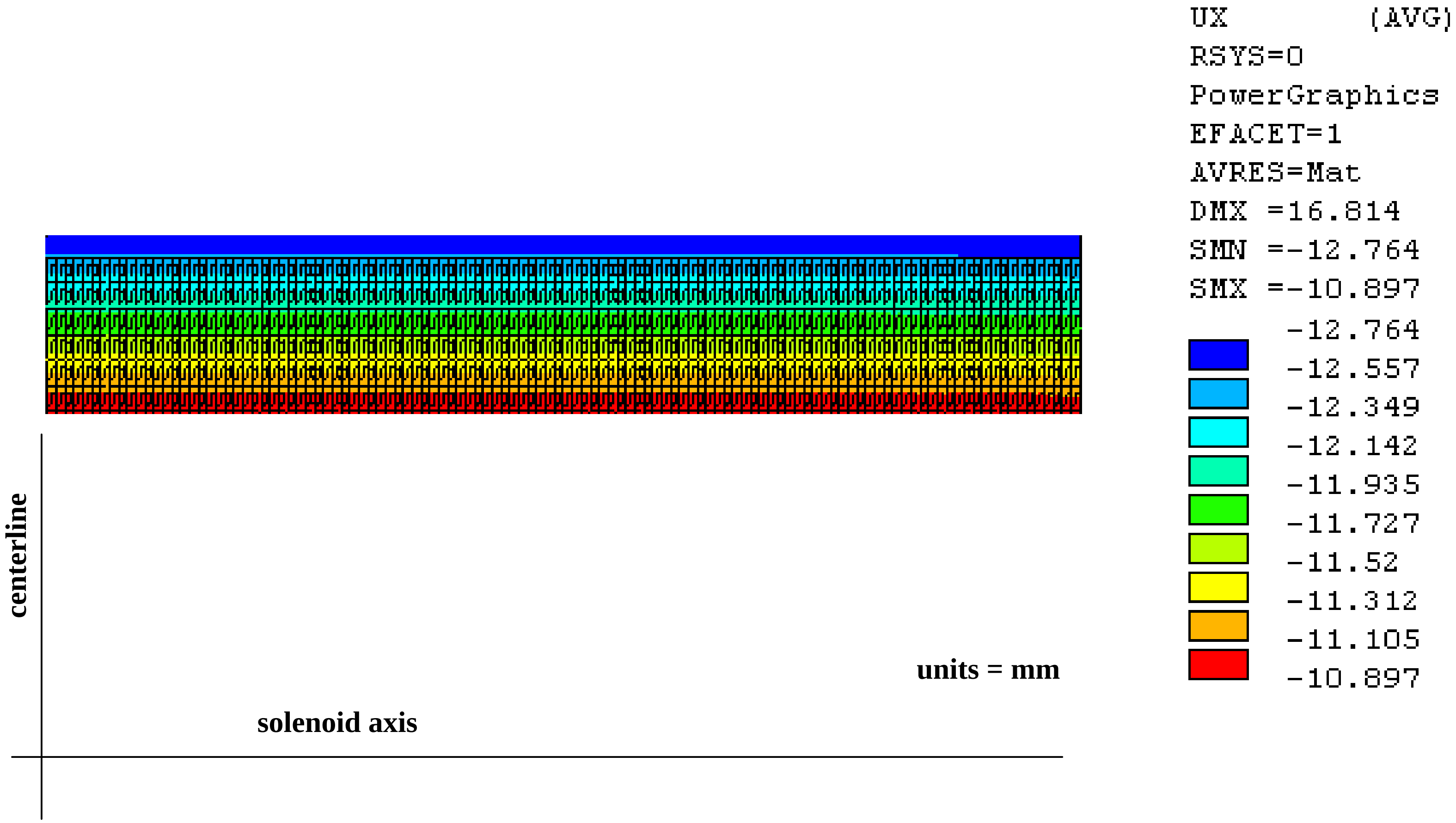
Comparison of Hoop Stress Behavior

- Assume solenoid behaves as thin-walled cylinder under internal pressure, with $P = B^2/2\mu_o$
- Define figure of merit as $B^2 r_m/t_{al}$, where B = central field, r_m = mean coil radius, and t_{al} = thickness of aluminum
- For CMS: B = 4T, r_m = 3.26m, t_{al} = 0.325m; FOM = 160
- For SiD: B = 5T, r_m = 2.87m, t_{al} = 0.453m; FOM = 158
- Hoop stresses should be very similar for both solenoids

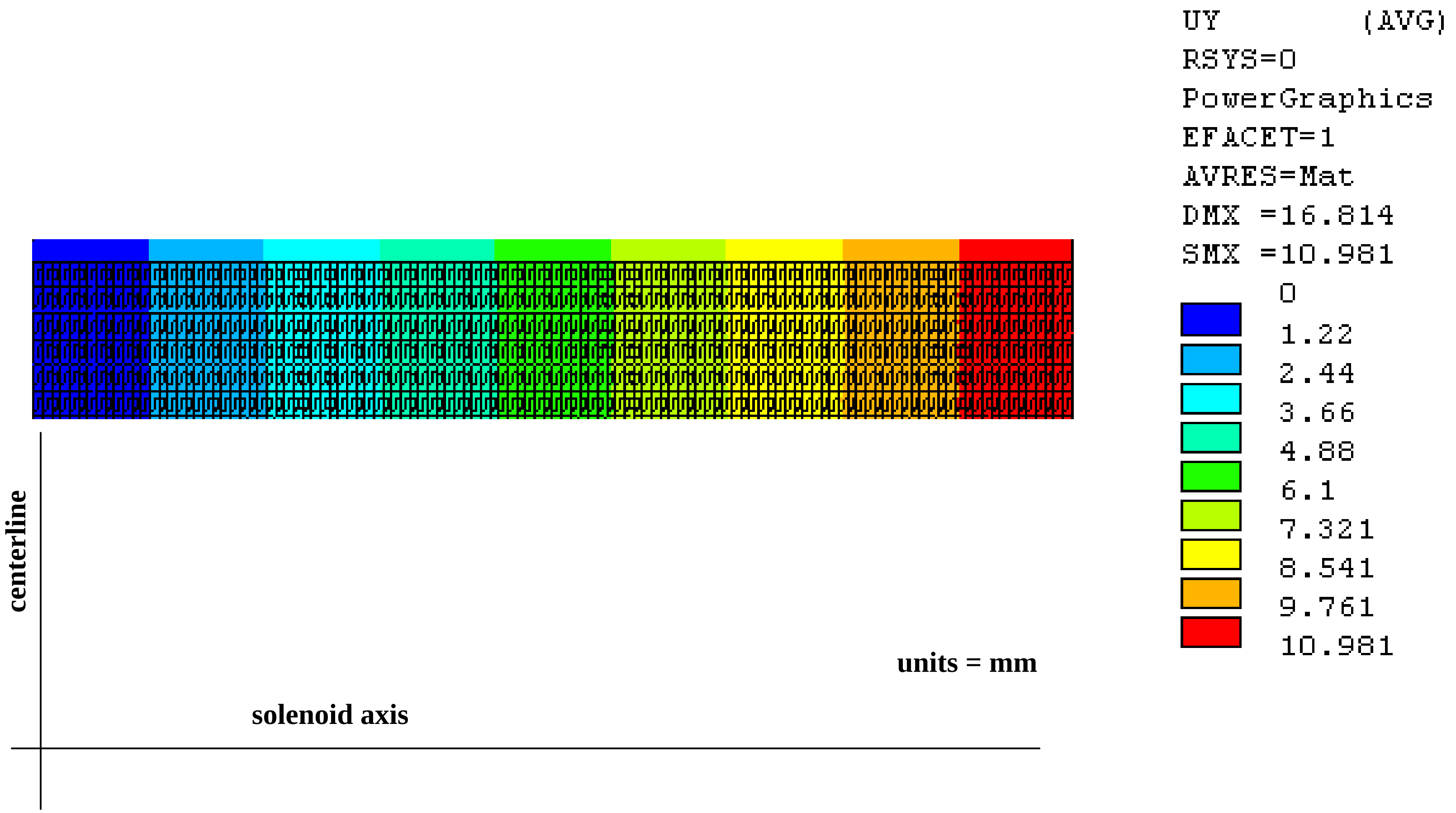
Comparison of Axial Stress Behavior

- The smaller aspect ratio of SiD (L/r_m= 1.8 for SiD, vs. 3.8 for CMS) makes it more likely to experience larger axial compressive forces due to field wrap-around at the ends
- As measure of axial stiffness, calculate $r_m t_{al}/L$
- SiD solenoid $r_m t_{al}/L$ = 0.25 ; CMS solenoid $r_m t_{al}/L$ = 0.085
- The SiD solenoid is about 3 times stiffer axially relative to magnetic forces applied at ends
- SiD is likely to experience higher axial forces, but lower axial displacements, compared to CMS

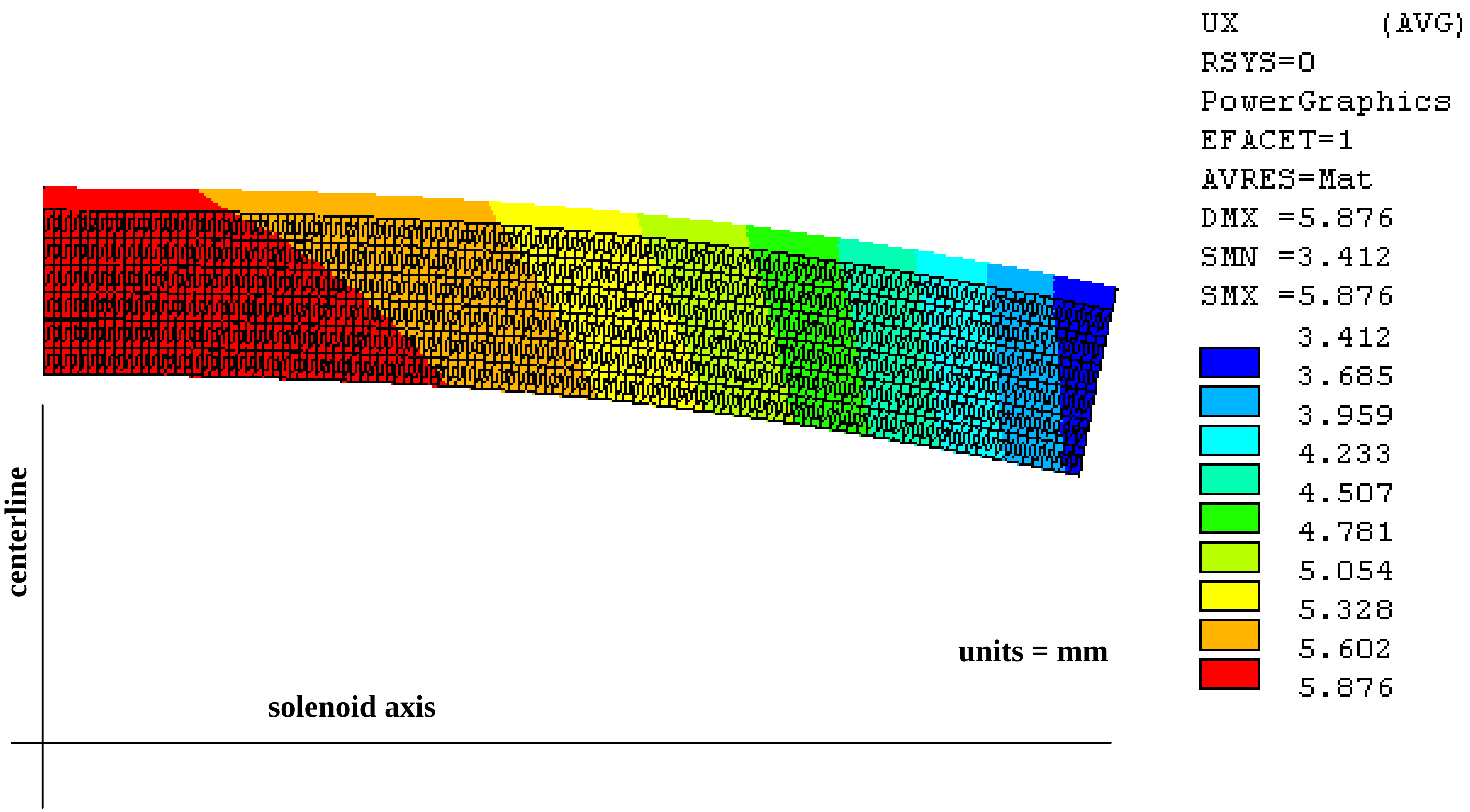
Cooldown Radial Displacements



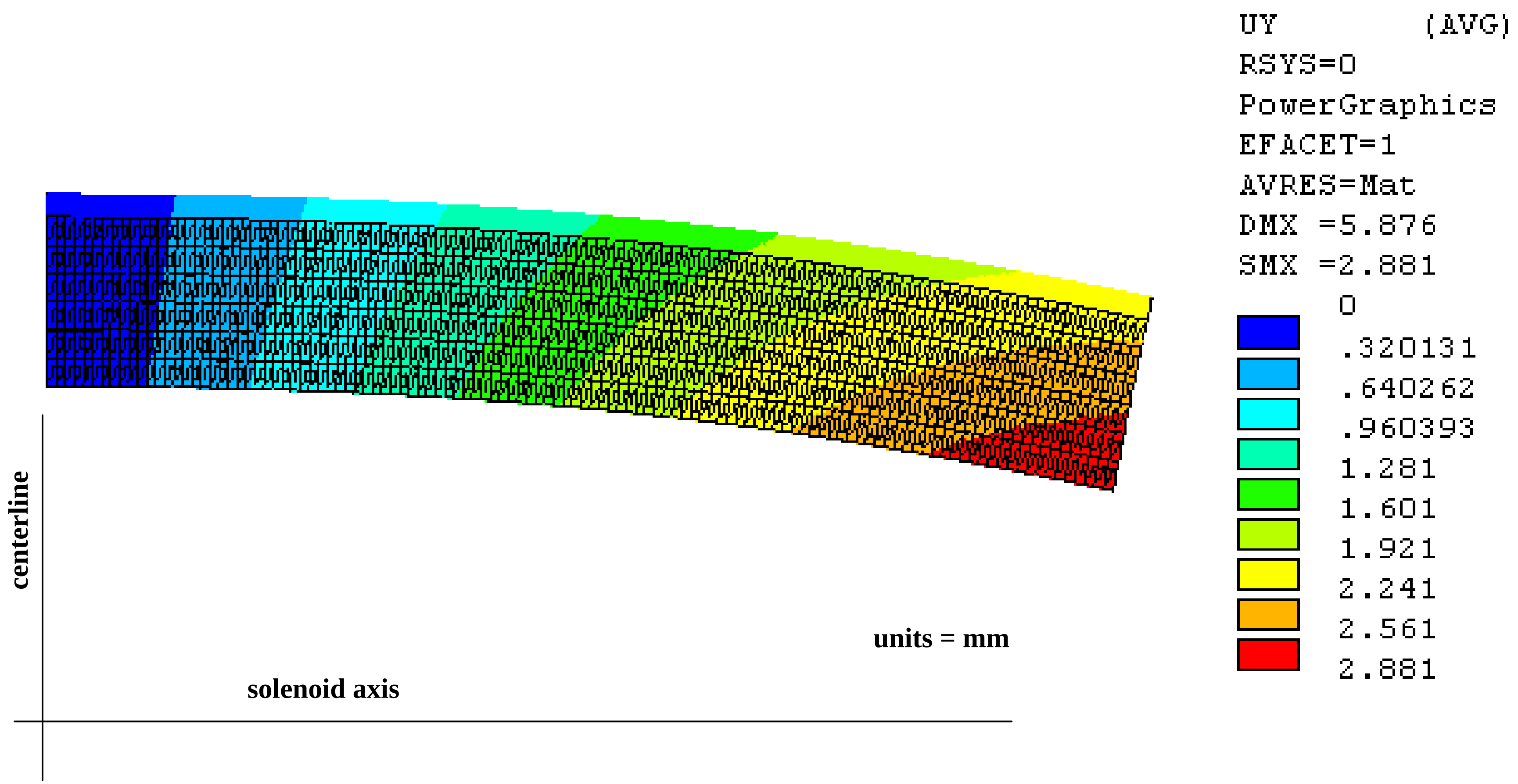
Cooldown Axial Displacements



Energization Radial Displacements



Energization Axial Displacements



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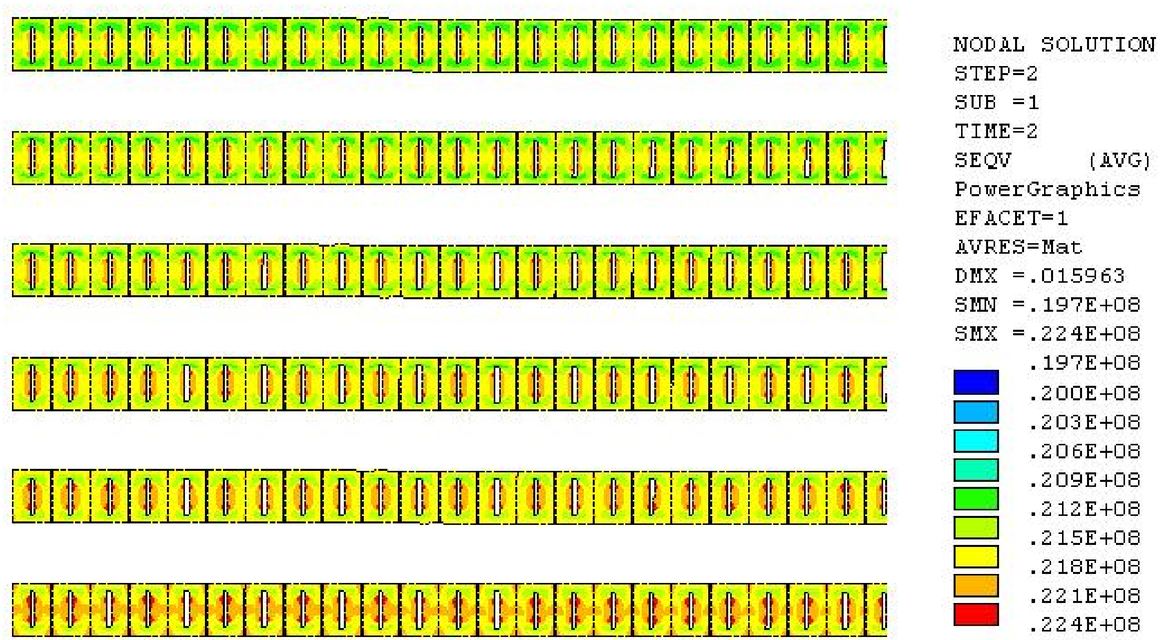
Von Mises Stress in HP Al, Cold & Energized



22 Mpa = 3190 psi

Compare CMS, SiD Cooldown+ Energization Stresses, Displacements

Quantity	SiD	CMS (from Desirelii CERN; Pes SACLAY)
Von Mises Stress in High-Purity Al	22.4 MPa	22 MPa
Von Mises Stress in Structural Al	165 Mpa	145 MPa
Von Mises Stress in Rutherford Cable	132 MPa	128 MPa
Maximum Radial Displacement	5.9mm	~5mm
Maximum Axial Displacement	2.9mm	~3.5mm
Maximum Shear Stress in Insulation	22.6 MPa	21 MPa

Compare CMS, SiD Decentering Forces, Stored Energy

Quantity	SiD	CMS
Radial Decentering	38 kN/mm	38 kN/mm
Axial Decentering	230 kN/mm	85 kN/mm
Stored Energy	1.4 GJ	2.8 GJ

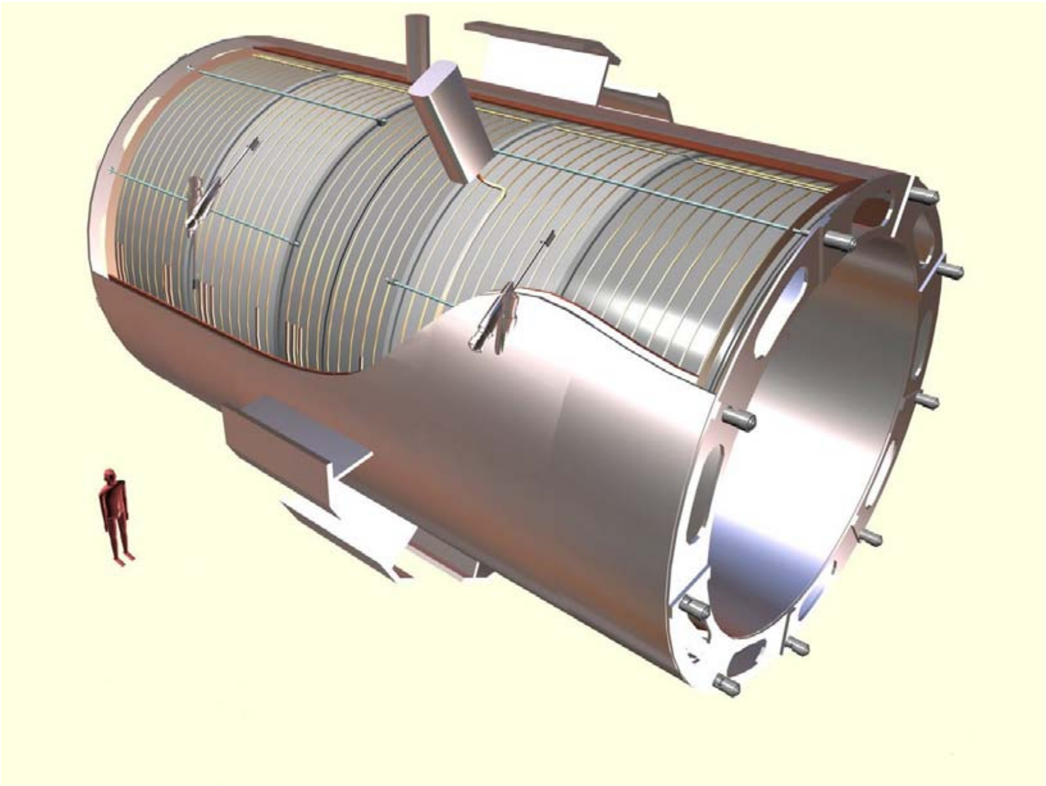
Cryostat, Cold Mass Support Design Concepts

Requirements

- Cold mass support – 130 Mt
- React decentering forces, seismic, cooldown, steady-state operation

CMS Concept

- Thin metallic rods preloaded in tension
- Axial rods for axial loads
- Vertical rods for dead weight
- Additional tangential rods (in preloaded pairs) for radial loads



Conclusions

- Need iterations with Detector/Physics Groups to select "most probable" performance parameters
  - How to "Open" detector ?
  - Must Detector Roll "off beamline" ?
  - Compensators (dipoles/solenoids) ?
  - Final Focus Quads?
  - EndCap Steel Details
- Need Overall Management Plan which leads to Preconceptual Design, Cost Estimate
- Continue to Look for "Show Stoppers", Cost Savings
- Collaborative Effort among Engineering Teams/Institutions/Physicists