Overview of ILD Magnet

E-JADE
Europe -Japan Accelerator
Development Exchange Programme

Toshiba Visit

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HELMHOLTZ
ASSOCIATION

DESY

Outline

- Overview ILD Detector
- Magnet Requirements
- Present design of coil and yoke
- Fabrication of coil
- B-field calculations
- Option: reducing size of detector
- Conclusions

References:

- Conceptual Design of the ILD Detector Magnet System, LC-DET-2012-081, F.Kircher et al.
- The International Linear Collider, Technical Design Report, Vol. 4: Detectors 2013

Magnet Requirements

Coil

- Solenoidal B-field: B = 3.5T nominal (4.0T max.) for precision tracking
- Modest field homogeneity, field measurements important
- Outside calorimeter
- Anti-DID (Detector Integrated Dipole)

Yoke

- Flux return
- Stray field (determines thickness and cost of yoke)
- Large magnetic forces
- Main mechanical structure of detector, supports coil
- Radiation shielding (should be self-shielding)

Challenges

- Cost
- Stray field
- Transportation issues in Japan

Magnet General Design

Coil (based on CMS experience)

F.Kircher, O.Delferrière, L.Scola, B.Curé, C.Berriaud

- Superconducting solenoid
- 3 modules, 4 layers nominal current ~20 kA
- Vacuum tank, modules supported by tie-rods
- Supports calorimeter and tracking detectors

Anti DID (Detector Integrated Dipole)

B.Parker

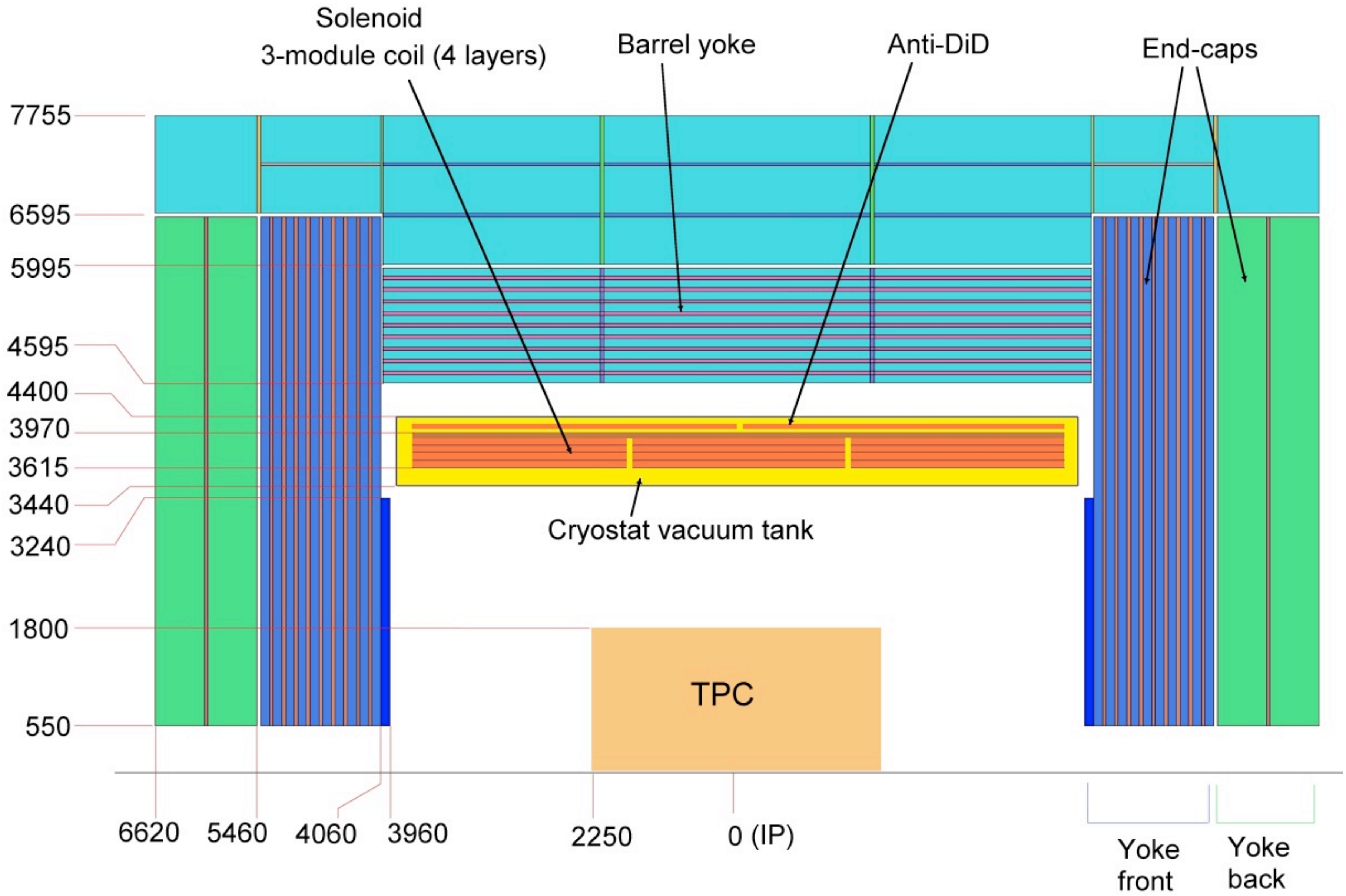
- Horizontal dipolar field max. 0.035T at z = 3m from IP
- Suppress beam background

Iron yoke

K.Büsser, M.Lemke, A.Petrov, K.Sinram, U.S., R.Stromhagen

- Barrel: 3 rings, central ring supporting vacuum tank with coil (calorimeter, tracking detectors,…)
- Endcap: 2 pieces
- Main mechanical detector structure

Coil and Yoke Cross-Section



Coil Design

Based on CMS design

Coil

- Inner winding technique with 50mm thick Al-alloy support cylinder
- External mandrel: support cylinder, path for indirect cooling and quench back tube
- Anti-DID and support ties-rods are attached to mandrel
- Electromagnetic forces contained by local reinforcement of conductor and external mandrel
    - Max. stress 145 MPa, hoop strain < 0.15%

Cryostat

- Stainless steel vacuum tank attached to yoke central ring
- Thermal shields covered with multilayer insulation
- Two axial cylinders with end plates

Coil cooling

- Indirectly cooled by saturated liquid He at 4.5K, thermo-syphon mode

Supports

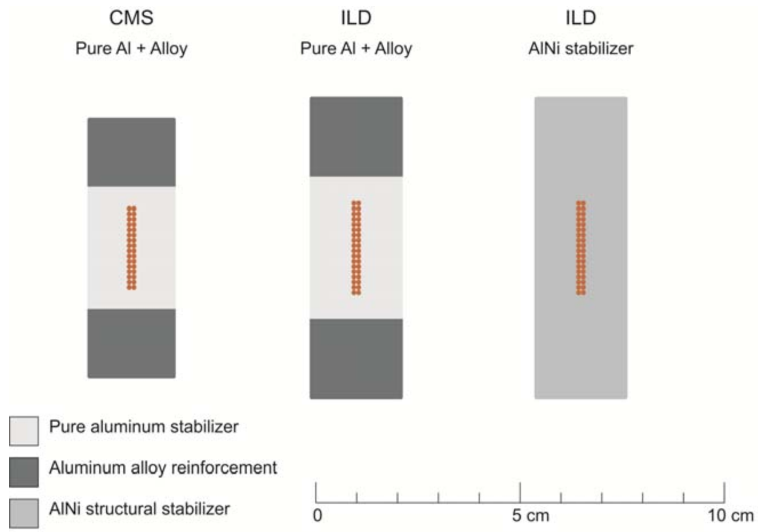
- 3 sets of ties-rods: vertical, radial and longitudinal

Coil Main Parameters

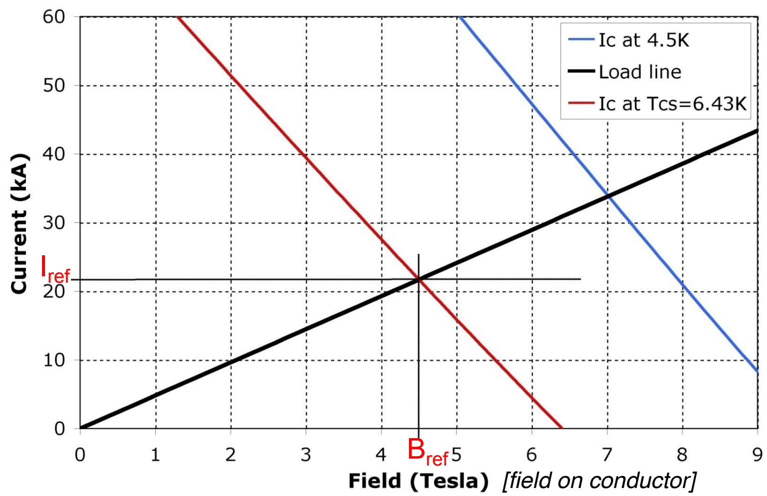
Max. central B-field (T)	4.0	Max. field on conductor (T)	4.6
Nominal current (kA)	22.4	Total ampere-turns (MA t)	27.65
Field integral (T m)	32.65	Inductance (H)	9.2
Stored energy (GJ)	2.3	Stored energy/cold mass (kJ/kg)	13
Coil inner radius (mm)	3615	Outer radius	3970
Cryostat inner radius (mm)	3440	Outer radius	4400
Coil length (mm)	7350	Cryostat length (mm)	7810
Cold mass weight (t)	170		

Superconducting Conductor

- Superconducting Rutherford cable enclosed inside stabilizer and mechanically enforced
  - Micro-alloyed material (ATLAS solenoid), R&D program at CERN studying Al Ni stabilizer (Ni 0.1%), largest cross section made so far 57mm x 12mm
  - Two Al alloy profiles electron beam welded to central high purity Al stabilizer (CMS cond.)
- NbTi superconducting strands (36, instead of 32)



Superconducting strand in virgin state	
Strand diameter	1.28 mm
(Cu+Barrier)/NbTi	1.1±0.1
SC strand critical current density	3300A/mm^2 at 4.2K, 5T
Rutherford cable	
Number of strand	36
Cable transposition pitch	185 mm
Final conductor	
Overall bare dimensions	74.3 * 22.8 mm^2
SC strand critical current density	≥ 3000A/mm^2 at 4.2K, 5T
Ic Degradation during manufacturing	≈ 7 %
Critical current	67500A at 4.2K, 5T

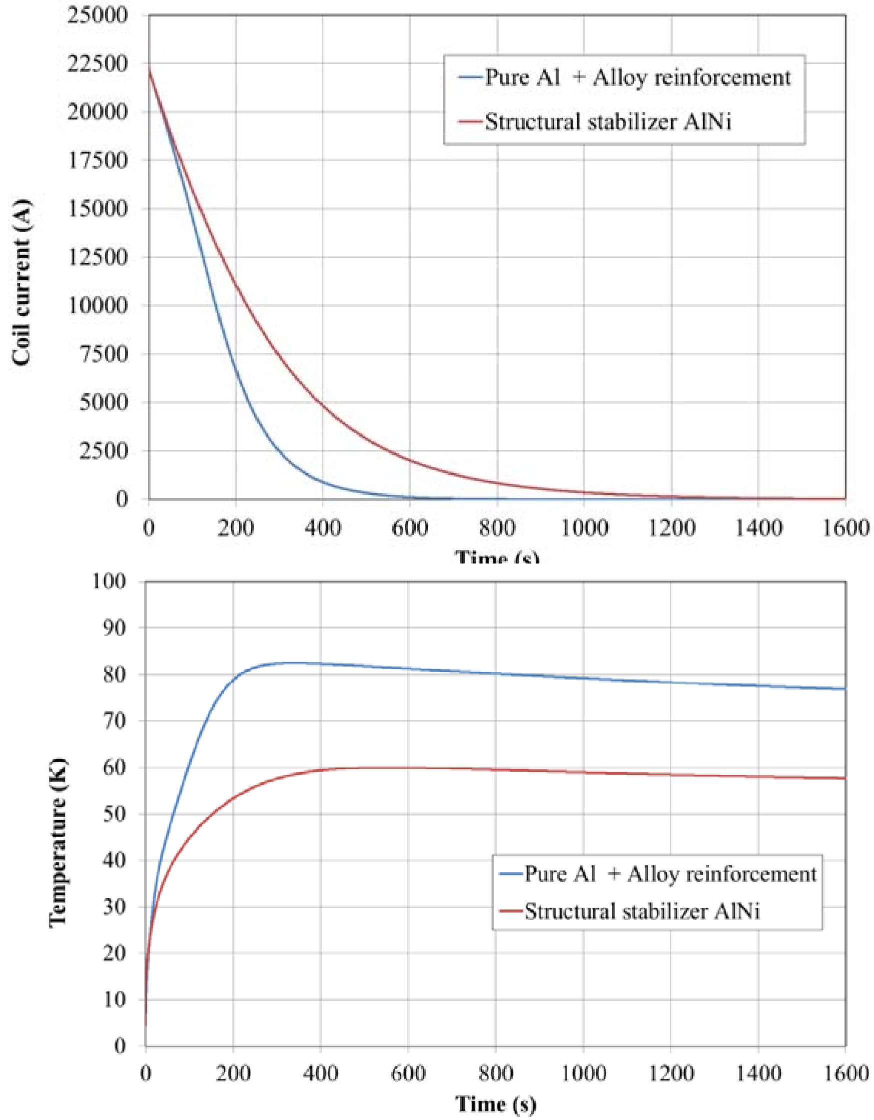


Temperature margin 1.85K for operating temperature of 4.5K

Coil Protection

- Coil protection in case of quench uses external dump circuit
- 56% of stored energy discharged in dump resistor with pure Al stabilizer (RRR = 2000) for 600V dump voltage, 80% with AlNi stabilizer (RRR = 590)
- Max. coil temperature 82K pure Al, 60K AlNi stabilizer
- AlNi stabilizer better results

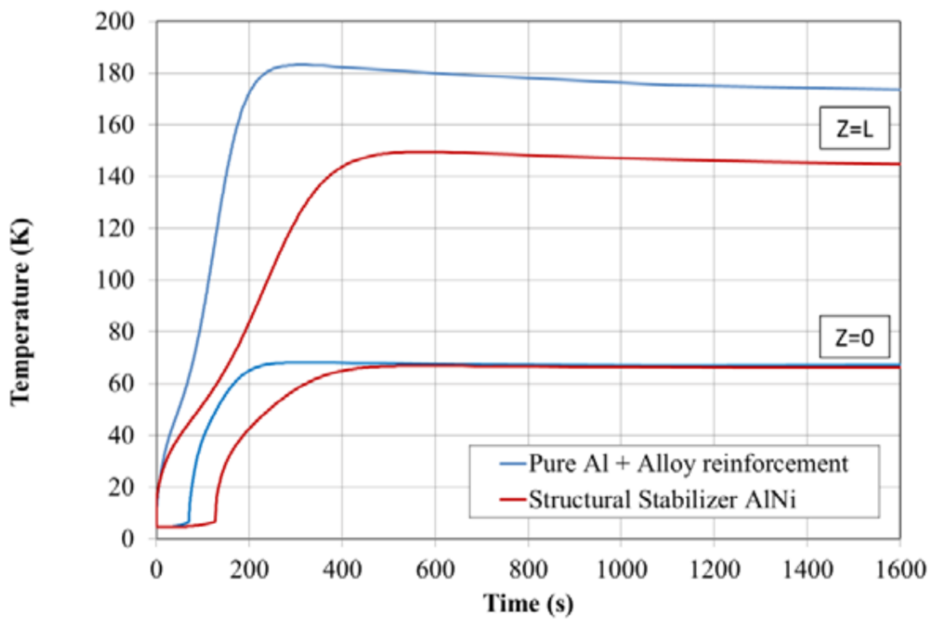
Fast dump on external resistor



Coil Protection

- Large redundancy will be used for quench detection and main switch breaker for fast dump of the magnet energy
- Studied temperature increase in case external dump process is accidentally not activated
- Assuming quench on one side of coil, propagating to opposite side
- Max. temperatures 185K for pure Al, 150K for AlNi stabilizer
- Temperature gradient over entire coil < 120K

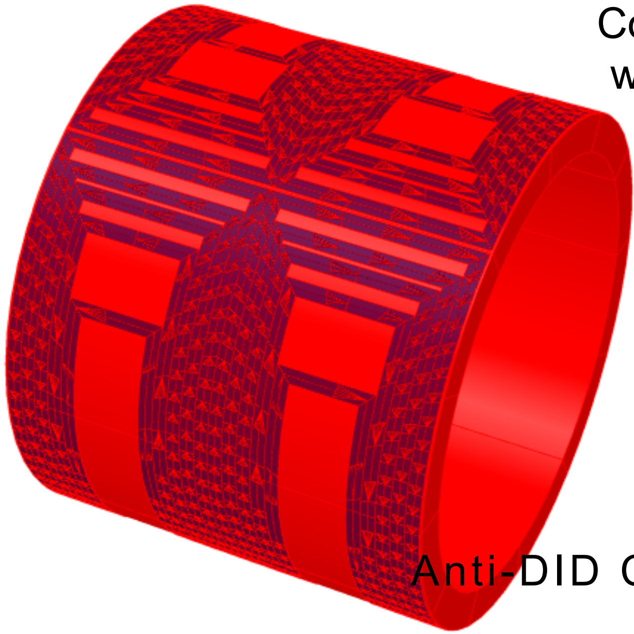
Coil temperature in case of quench



Short Anti-DID Design History Review

- Detector Integrated Dipole (DID) was first proposed by A. Seryi & B. Parker† to enable use of the large crossing angle needed for the ILC Gamma-Gamma IR scheme.
- With the present 14 mrad crossing angle, an opposite polarity DID (Anti-DID) can be used to help guide beamstrahlung produced pairs out of the detector to reduce the background.
- While incorporating the DID coils with the main detector solenoid avoids introducing material inside the detector acceptance (that would adversely impact physics), coming up with a practical scheme for implementing the anti-DID coils is by no means trivial!
- Directly winding a complex coil structure outside the detector solenoid is challenging (production infrastructure) and wrapping a flat wound anti-DID coil around the solenoid is not easy either (anti-DID conductor stress).

Slide B. Parker



Coils are directly wound on cylindrical surface

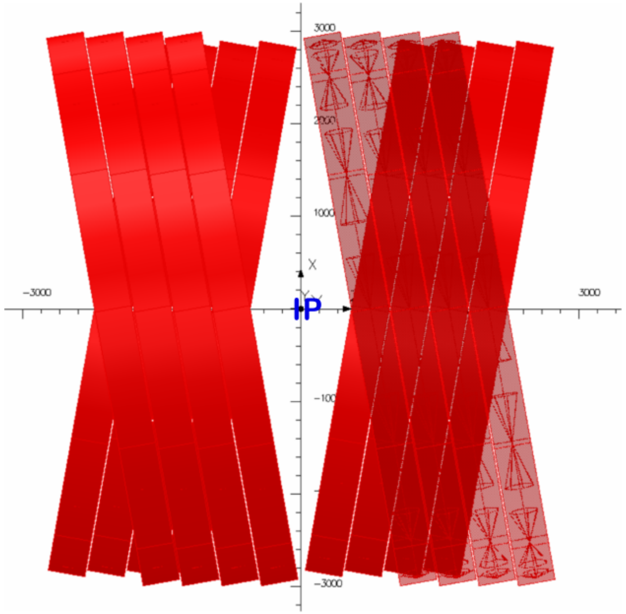
One Early Anti-DID Coil Concept

†B. Parker and A. Seryi, "Novel Method of Compensation of the Effects of Detector Solenoid on the Vertical Beam Orbit in a Linear Collider," Rev. Mod. Phys. 2727(84) , April 2005. DOI: 10.1103/PhysRevSTAB.8.041001

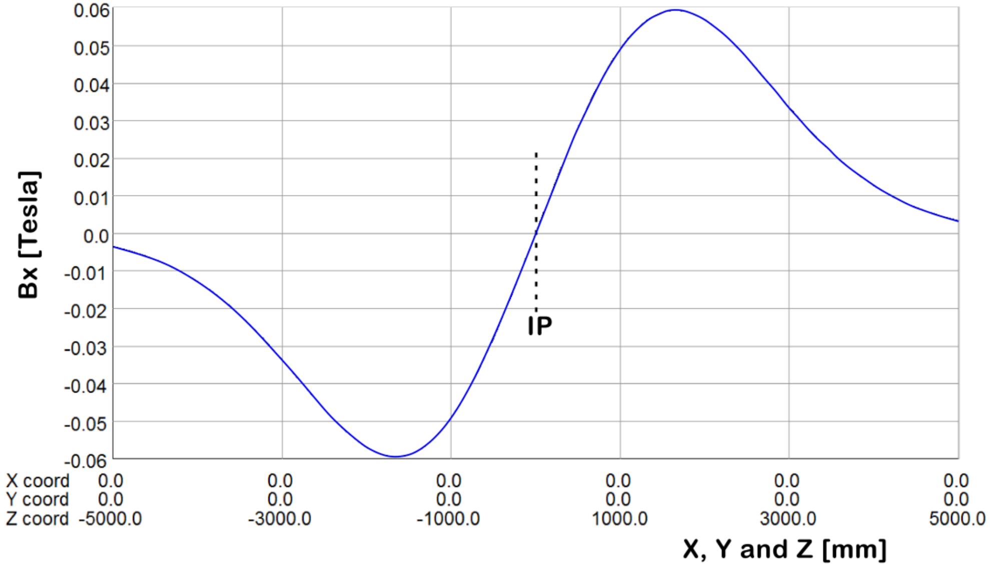
Different Anti-DID Production Geometry

Slide B. Parker

Simple Two Layer Anti-DID Coil, Top View



Plot of Horizontal Field, Bx, at the Detector Axis



- Consider using helical coil† (also know as canted coil) winding technique to produce anti-DID; this setup makes transverse field but does not couple to main solenoid.
- This scheme is schematically illustrated above where we have tilted the solenoidal turns in two different radial layers in opposite directions and given them opposite currents.
- The longitudinal field, B_z, from the two layers cancels but the transverse field component, B_x, adds constructively to give the field profile shown ("air coil" example).
- Should consider winding such "solenoid like" coils on separate structure. They could be integrated with the main solenoid cold mass and independently powered.

†H. Witte, et.al., "The Advantages and Challenges of Helical Coils for Small Accelerators—A Case Study," IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 22, NO. 2, APRIL 2012.

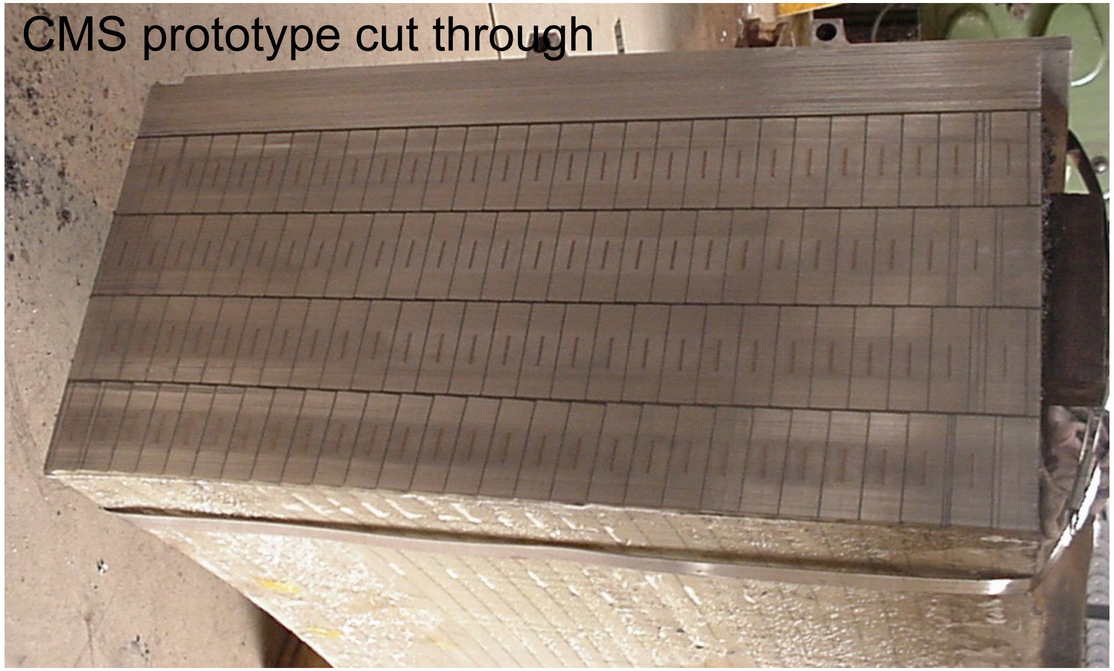
Anti DID - Remarks

- Main purpose of anti-DID reduction of beam induced background
- Difficult to produced required magnetic field distribution
- Fabrication of coil with anti-DID very challenging
- Further iterations of magnet design and physics/background simulations needed to conclude on technically feasible and background-wise acceptable anti-DID field shape
- Task force recently formed

Coil Manufacturing and Assembly

similar to CMS

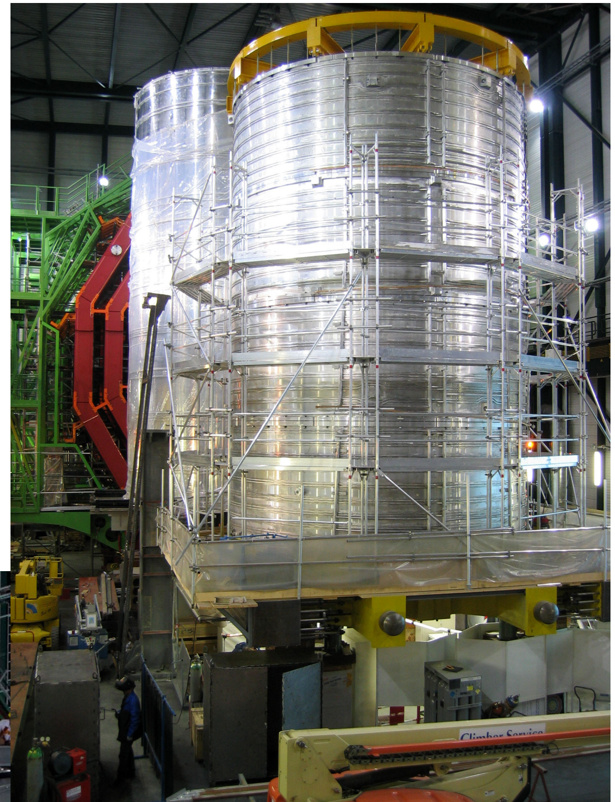
- Inner winding technique supporting external cylinders used as external mandrels
- Mandrels machined and welded outside of winding and assembly hall
- Material: aluminum alloy 5083, 50mm thick
- Several shoulders assembled on mandrels for tie-rods and anti DID supports
- Helium cooling circuit assembled on mandrel, designed to withstand deformation during cool-down and due to magnetic forces
- After all 4 layers are wound, each module vacuum-impregnated
- Electrical layer-to-layer joint made after impregnation
- Each module transferred to final magnet assembly location

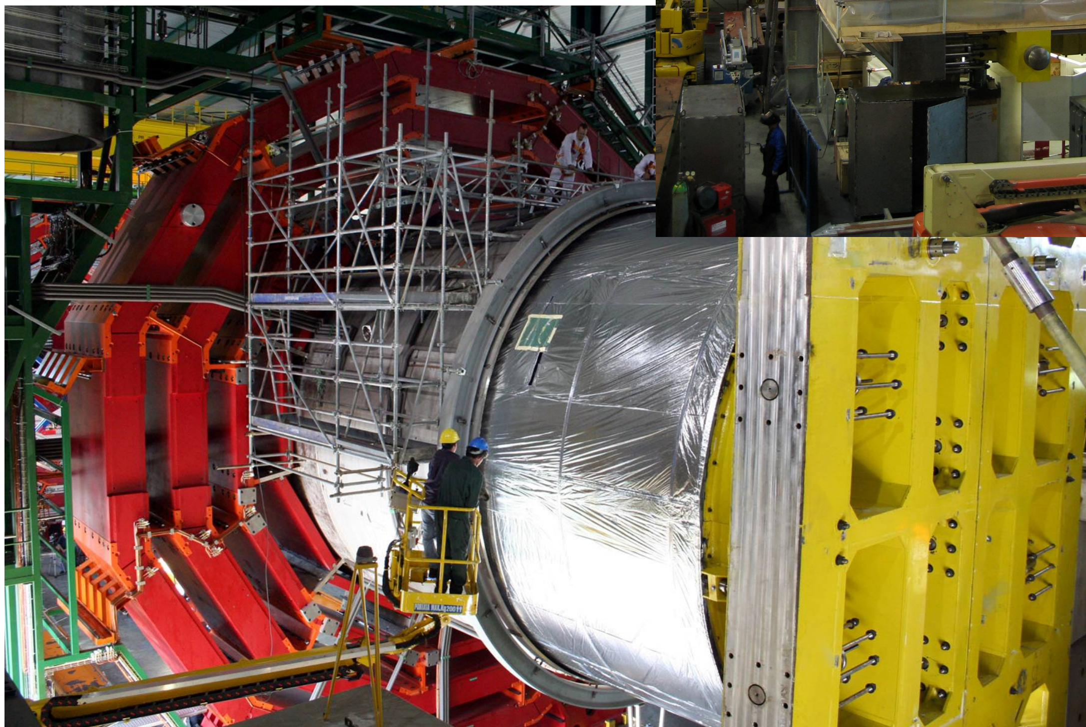

CMS prototype cut through

Coil Manufacturing and Assembly

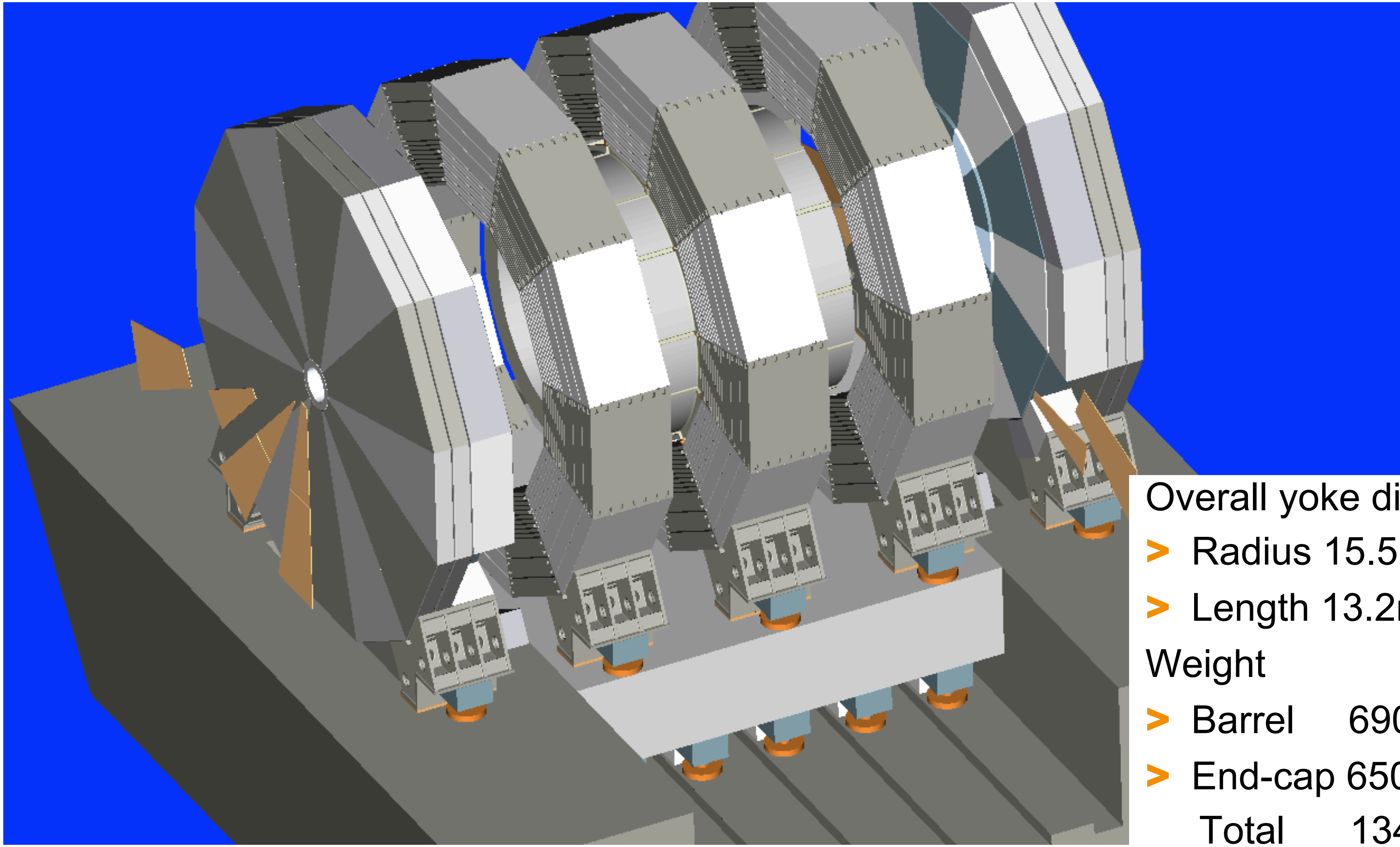
- Three modules stacked vertically for mechanical coupling
- Electrical joints and cooling pipes
- Assembly of anti-DID
- Installation of thermal screens and insulation
- Cold mass rotated to horizontal position
- Inserted into outer cylinder of vacuum tank
- Tie-rods connected
- Vacuum tank closed

CMS





Yoke Overview



Overall yoke dimensions

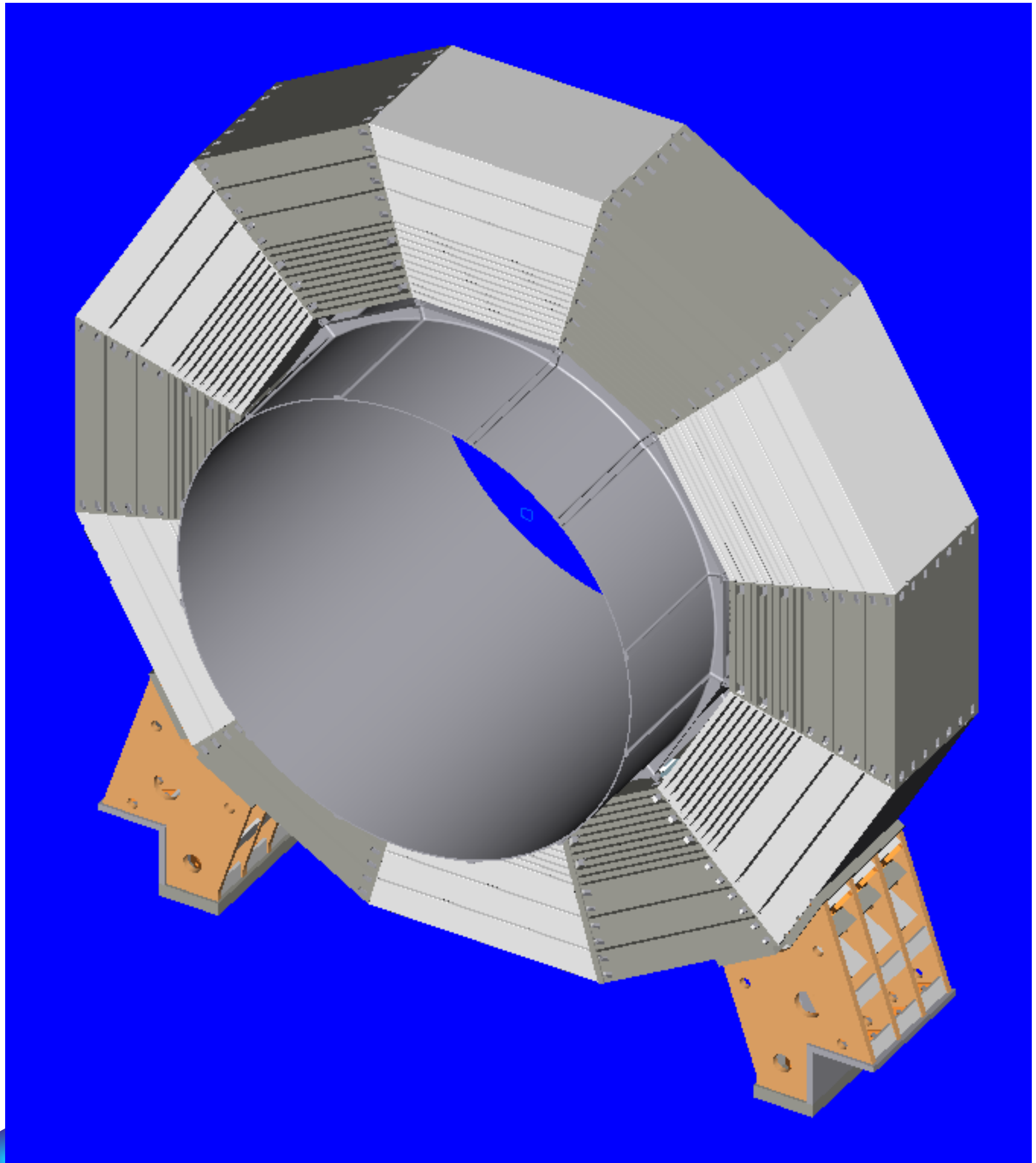
- Radius 15.5m
- Length 13.2m

Weight

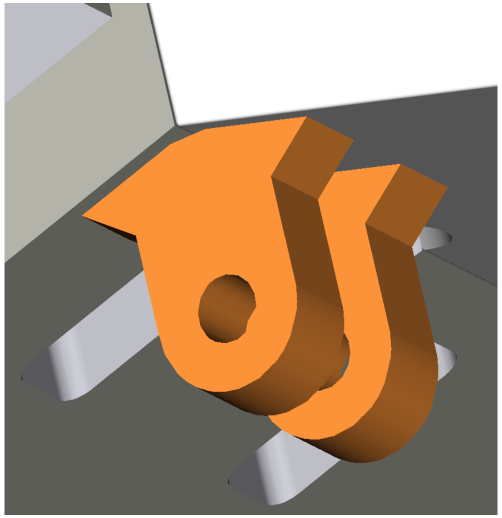
- Barrel 6900t
- End-cap 6500t

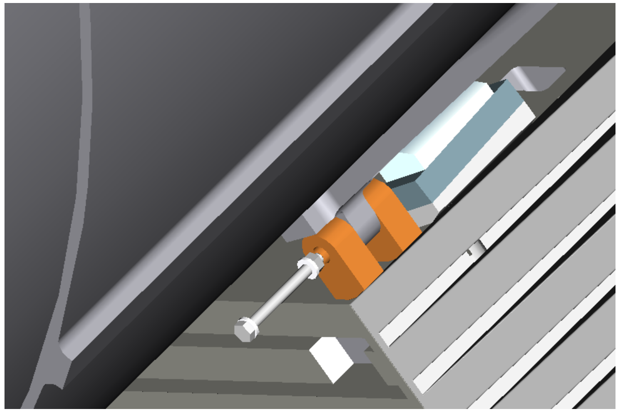
Total 13400t

Yoke Central Barrel Ring

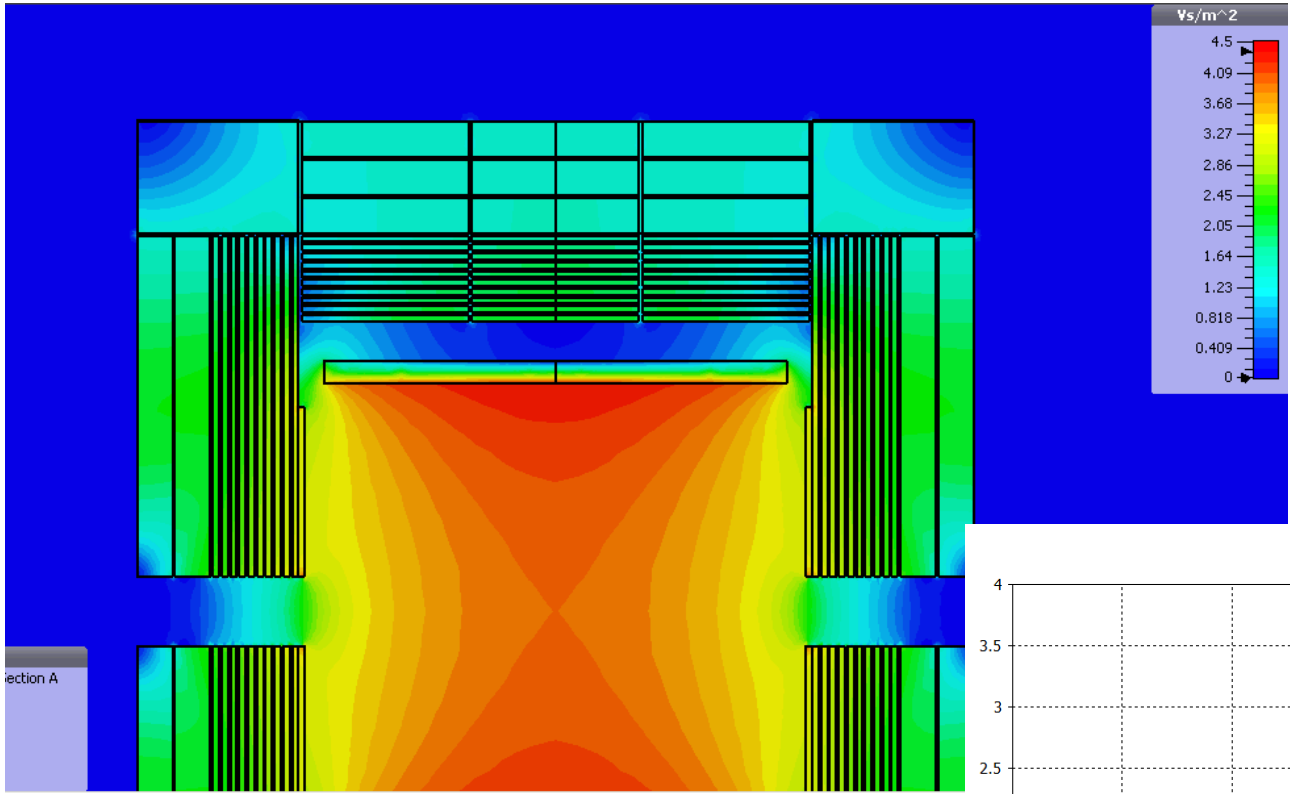


Support of cryostat, R.Stromhagen



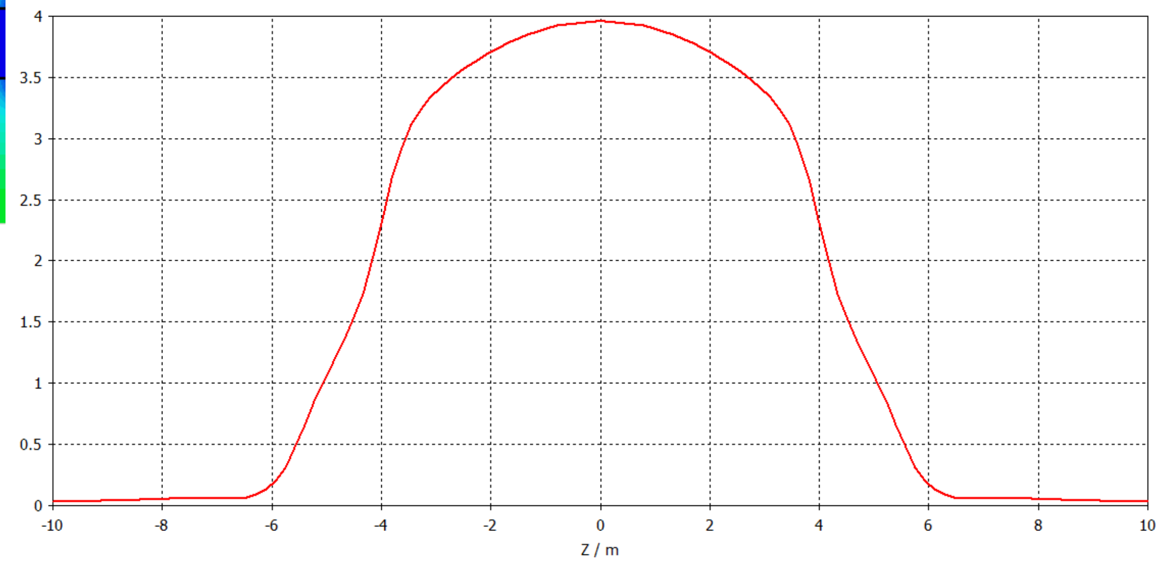


Field Calculations



Uniform current distribution

B along beam line



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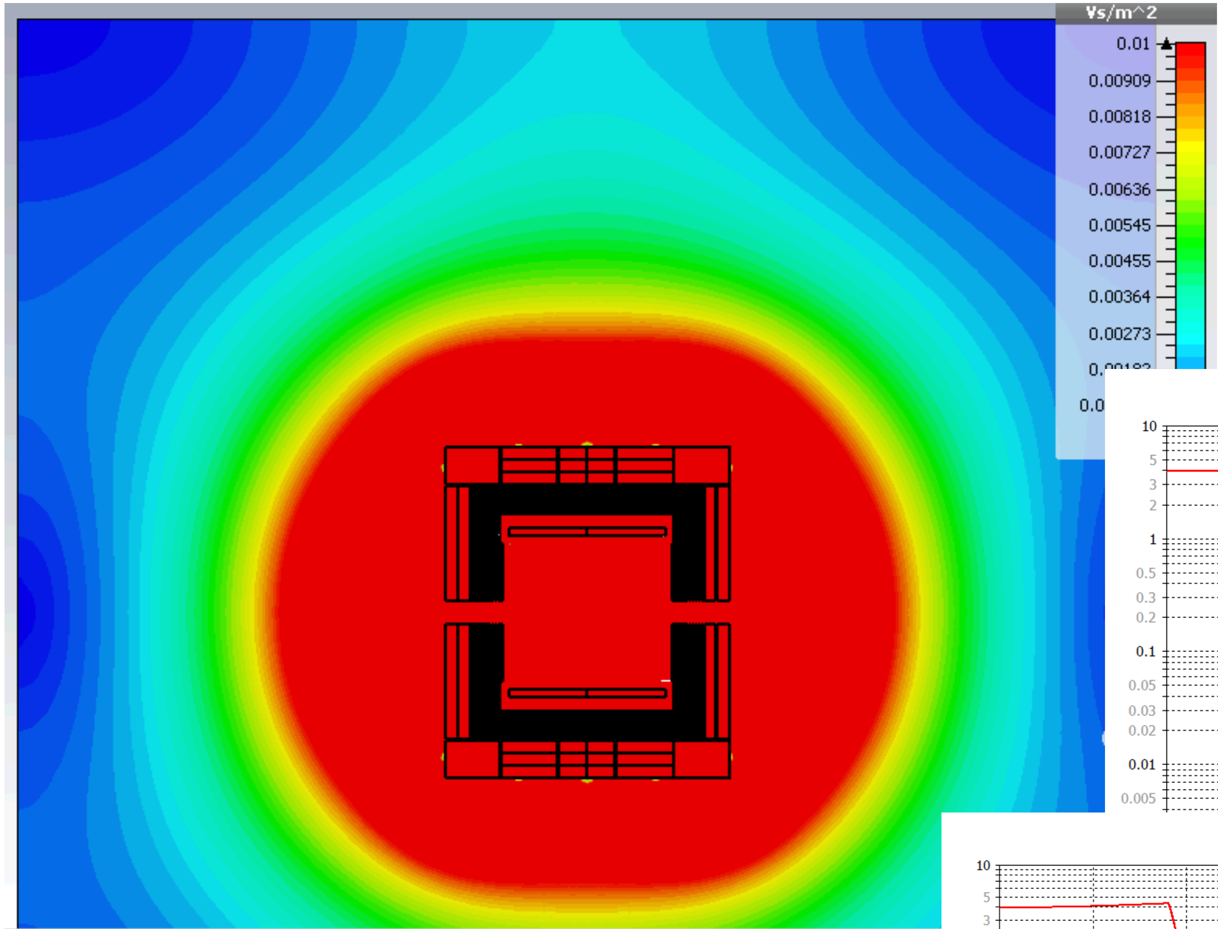
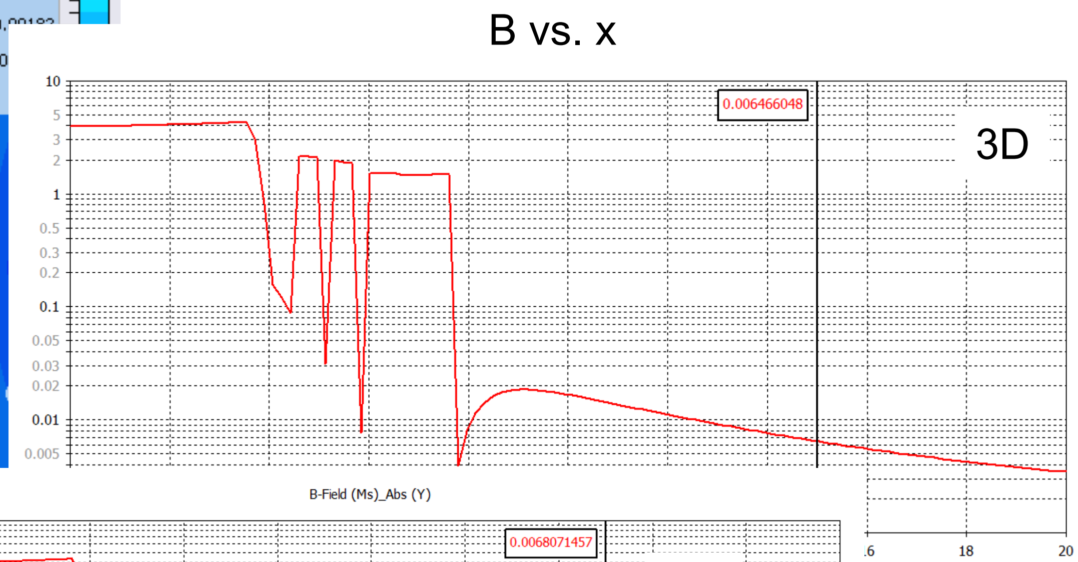
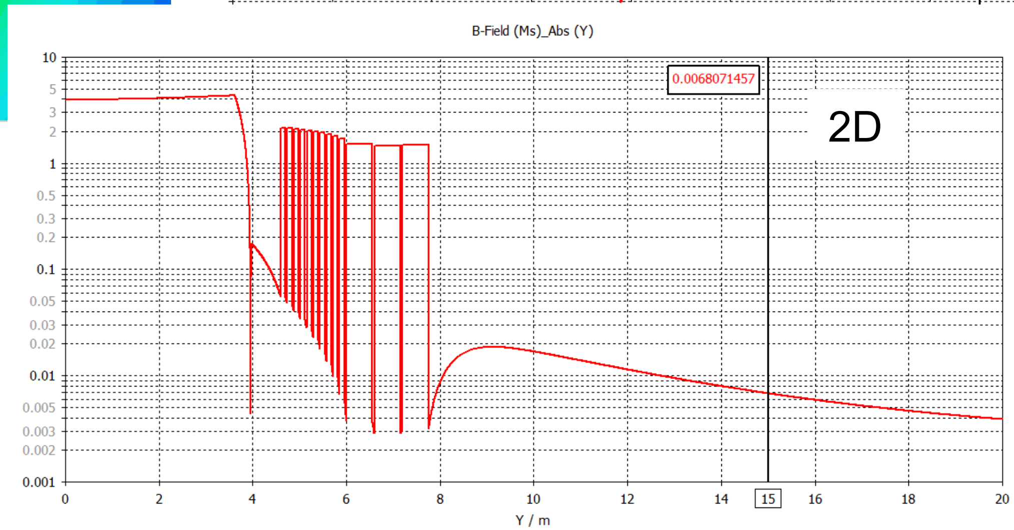




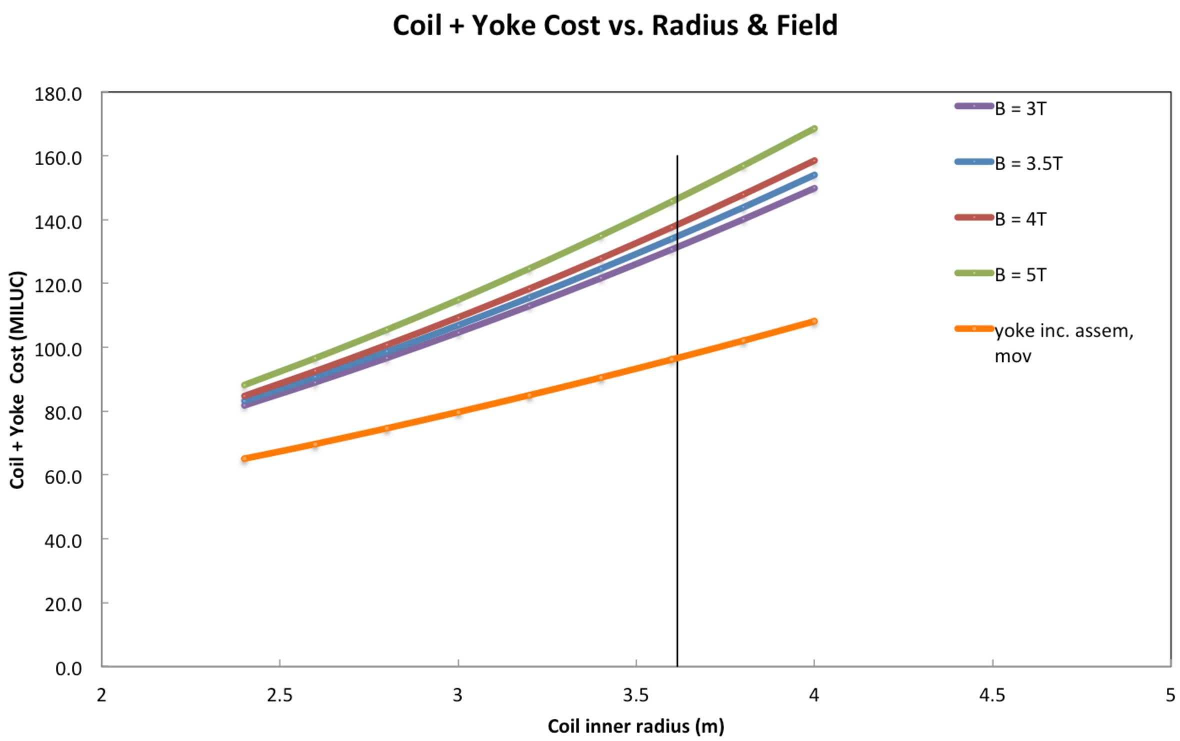


Stray field at 15m distance from beam line 6.5 mT

Goal 5.0mT

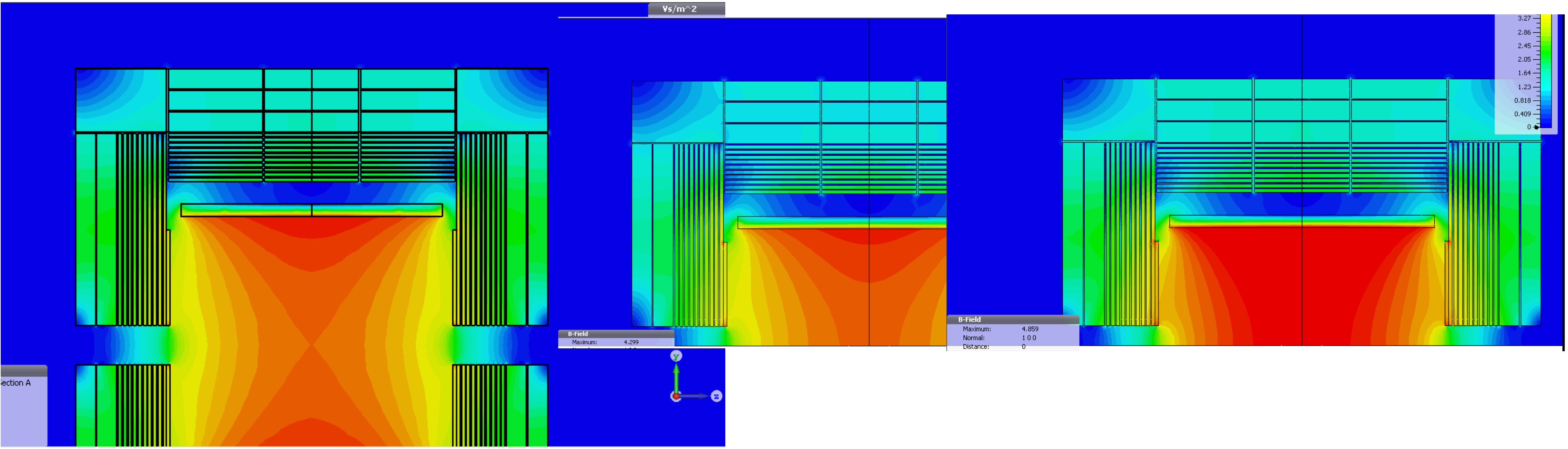
Detector Performance/Cost Optimization

- Detector cost dependents significantly on size and magnetic field
- Presently, studying performance with reduced size
  - Radius of tracking detector, solenoid and yoke reduced by 340mm (yoke 284mm ?)
  - Considering 4.5 instead of 4.0T

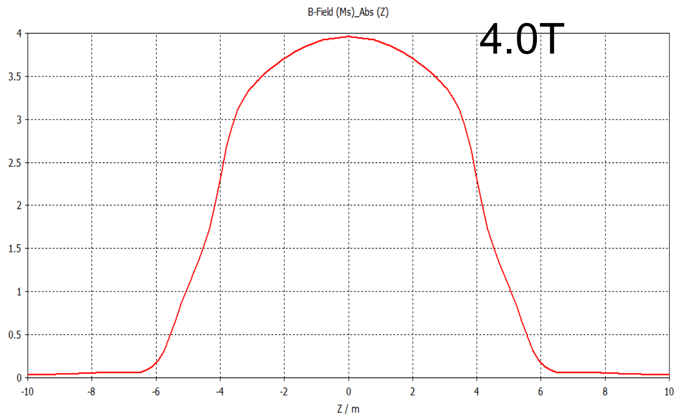


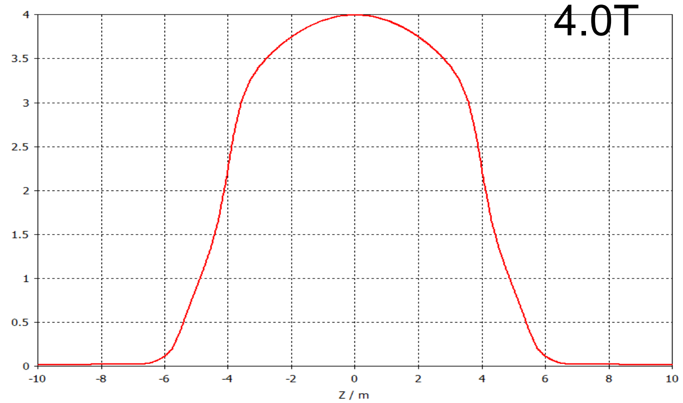
Field Calculations

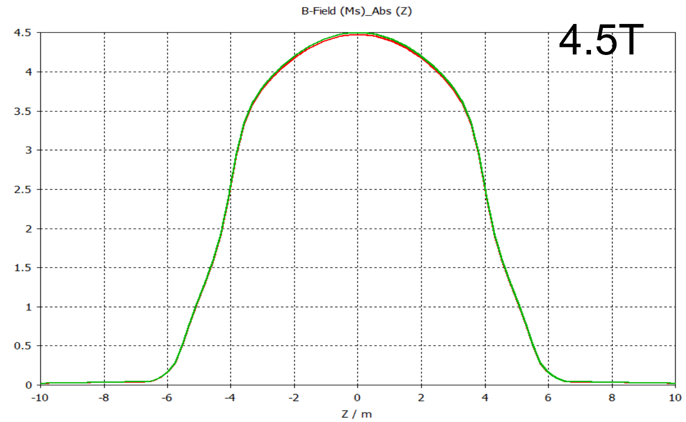
Nominal, 4.0T | Small 4.0T | Small 4.5T



B_z (T) along z axis

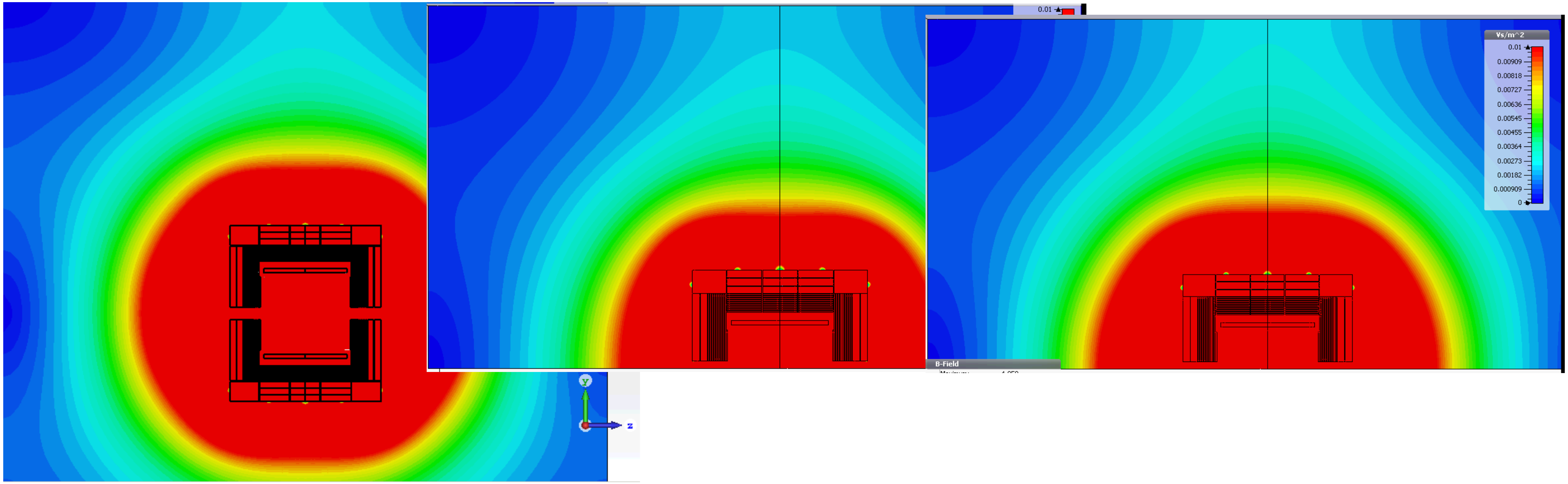






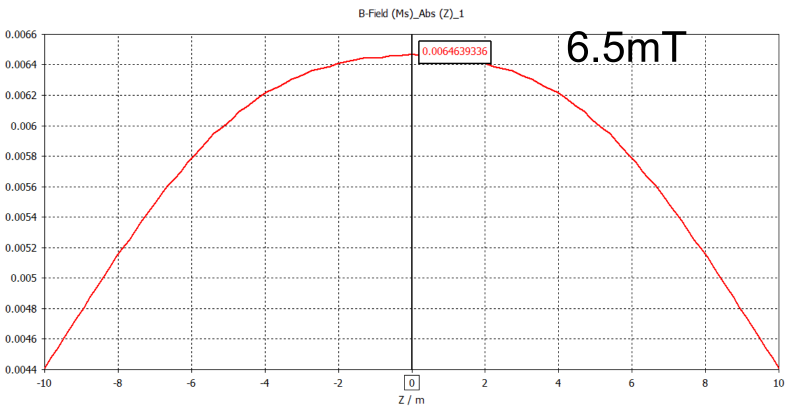
Field Calculations

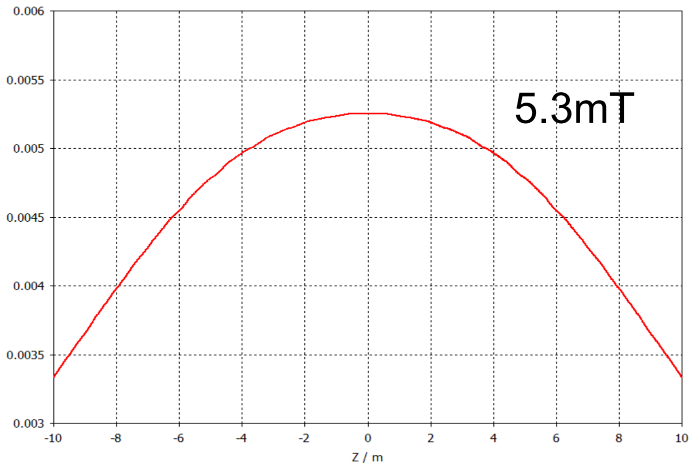
Nominal, 4.0T | Small 4.0T | Small 4.5T

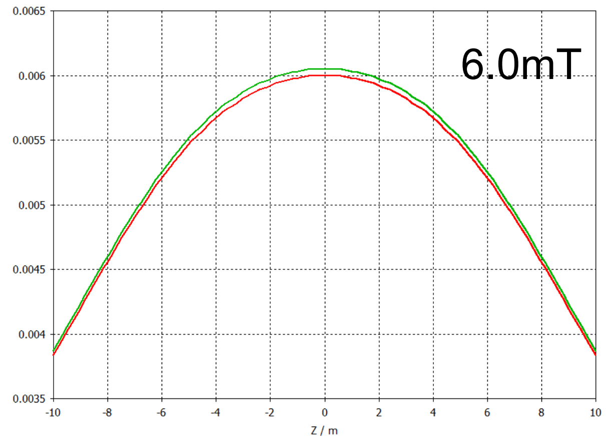


B_z (T) at x = 15m

Same coil thickness







Field Calculations – Coil Size

ILD	Nominal		small		
B (T)	3.5	4.0	4.0	4.5	4.5
$r_{coil,I}$ (mm)	3615	3615 →	3.275	3.275	3.275
d (mm)	355	355	355	355 →	411
I (kA)		21.7	21.3	24.2	24.2
J_{Al} (A/mm^2)		12.8	12.6	14.3	12.0
Numb strands		36	36	36 →	40
J_{SC} (A/mm^2)		468	460	521	469
E_S (GJ)		2.23	1.81	2.27	2.27
Cold mass (t)		170	155	155	180
E/m (kJ/kg)		13.1	11.7	14.6	12.7
B (x=15m) (mT)		6.8	5.3	6.1	6.1

Increased coil thickness
C. Berriaud

Estimate of ILD Magnet Cost

Cost estimate similar to DBD/TDR 2013

ILD	nominal	small	
B (T)	4.0	4.0	4.5
$r_{coil,i}$ (mm)	3615	3.275	3.275
d (mm)	355	355	411
m_{yoke} (t)	13400	12000	12200
Cost coil (MILCU)	42	38	41
Cost yoke (MILCU)	81	72	73
Cost magnet (MILCU)	123	110	114

Conclusions

- ILD magnet design quite advanced
- Coil design very similar to CMS
  - Two options for stabilizer
  - Still need R & D program on AlNi stabilizer
- Not much progress on manufacturing
- Anti-DID
  - Still two options
  - Presently considering whether anti-DID really needed
- Yoke: still some transportation issues/redesign of yoke modules
- Considering reducing radial size of outer detector components by 340mm