ILD Magnet Activities

LCTPC Coll. Mtg.

Nov. 2017

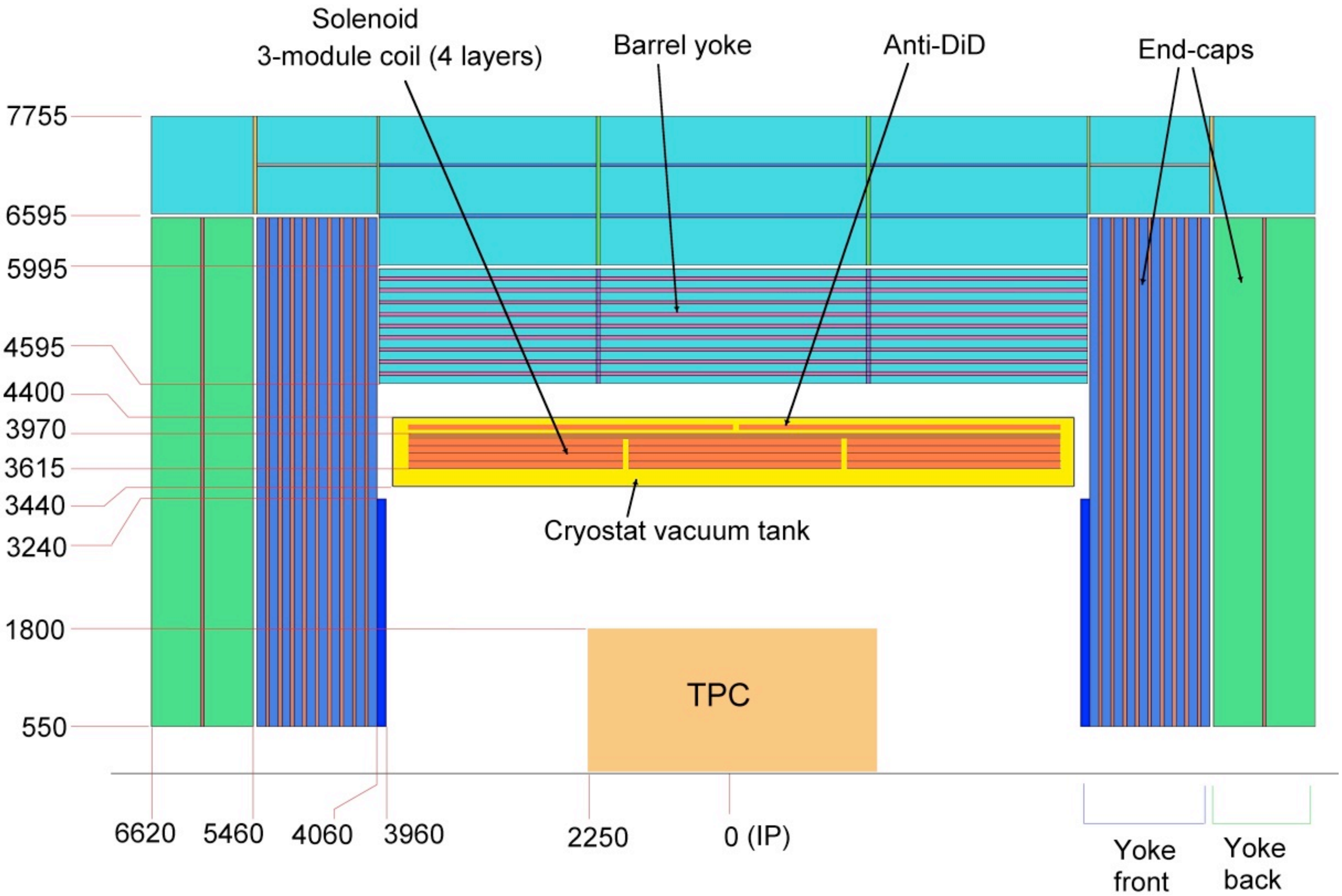
Uwe Schneekloth, DESY

Magnet Activities since ILC TDR/DBD

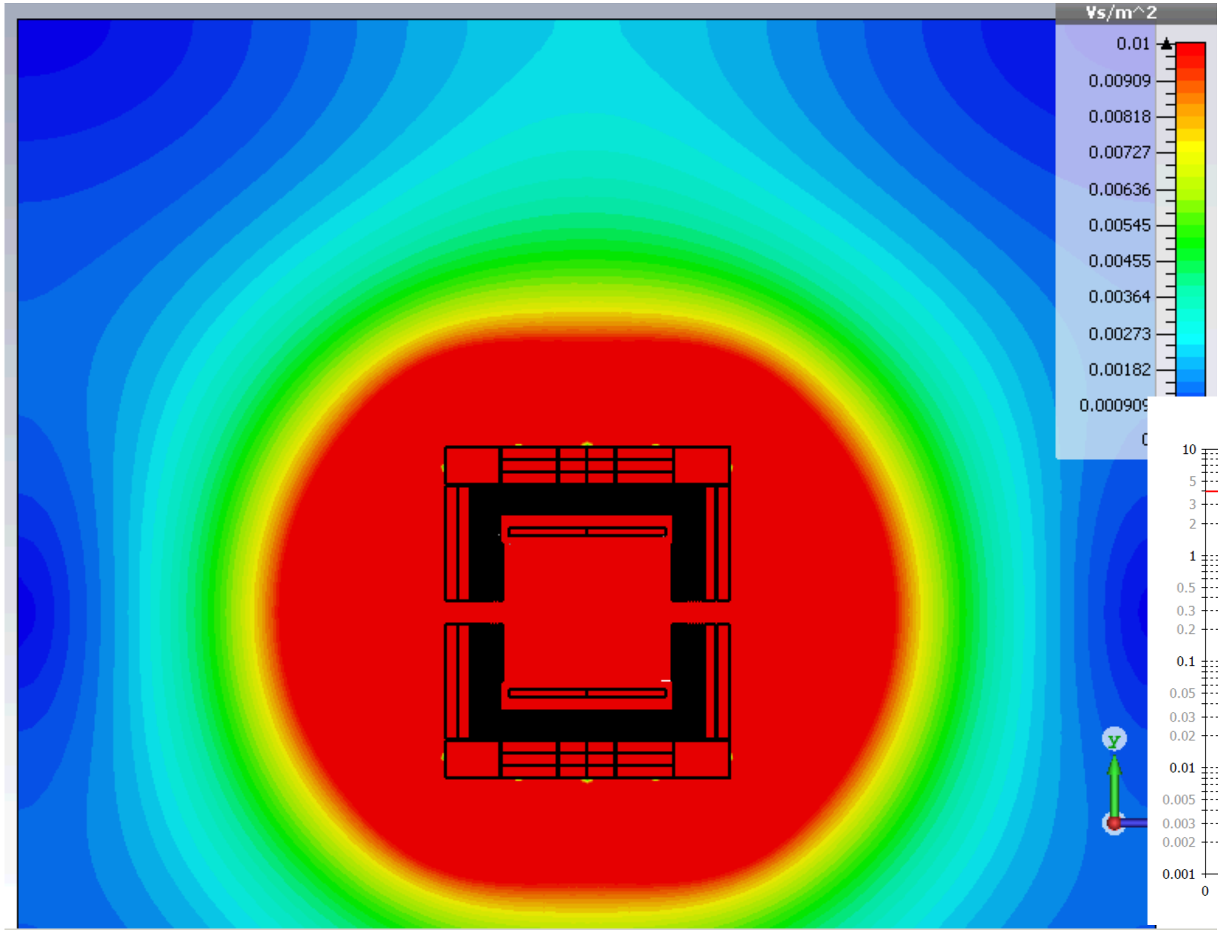
- Solenoid
  - No progress as far as I know, except
  - reduced size, increased field requires increase in thickness (50-60mm)
- Yoke
  - Systematic study of field calculations, differences now understood
  - Main concern stray field and cost
  - Tried to optimize geometry
  - Several yoke/coil options
- Anti-DID

  New options
  - Tilted coils, integrated into solenoid module, Brett Parker
  - New design, KEK, Hitachi, Toshiba

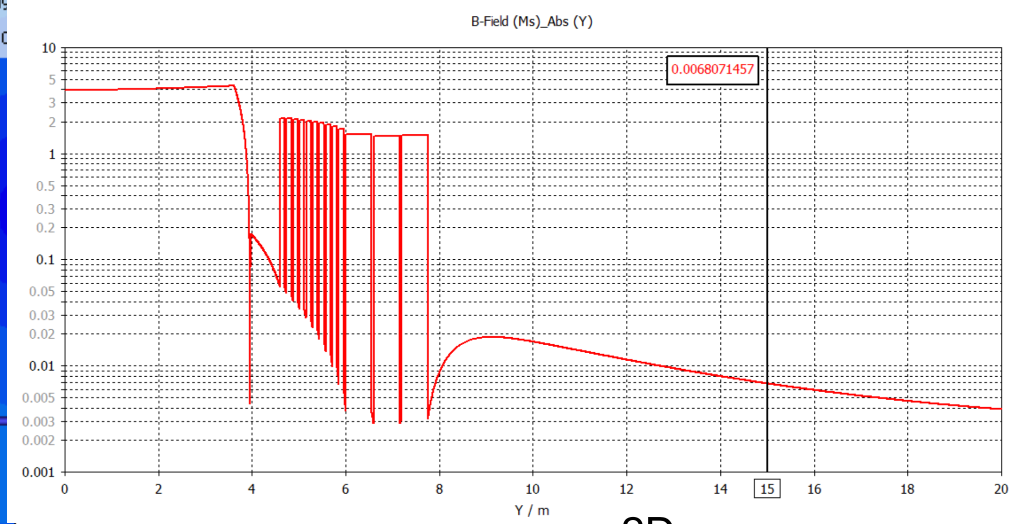
Coil and Yoke Cross-Section



Field Calculations – Yoke Thickness



B vs. x



2D

Thickness and cost of yoke determined by requirements on stray field

- 5.0mT (50 G) at 15m distance from beam
- Present stray field 5 – 6mT (previously 3 – 4 mT)

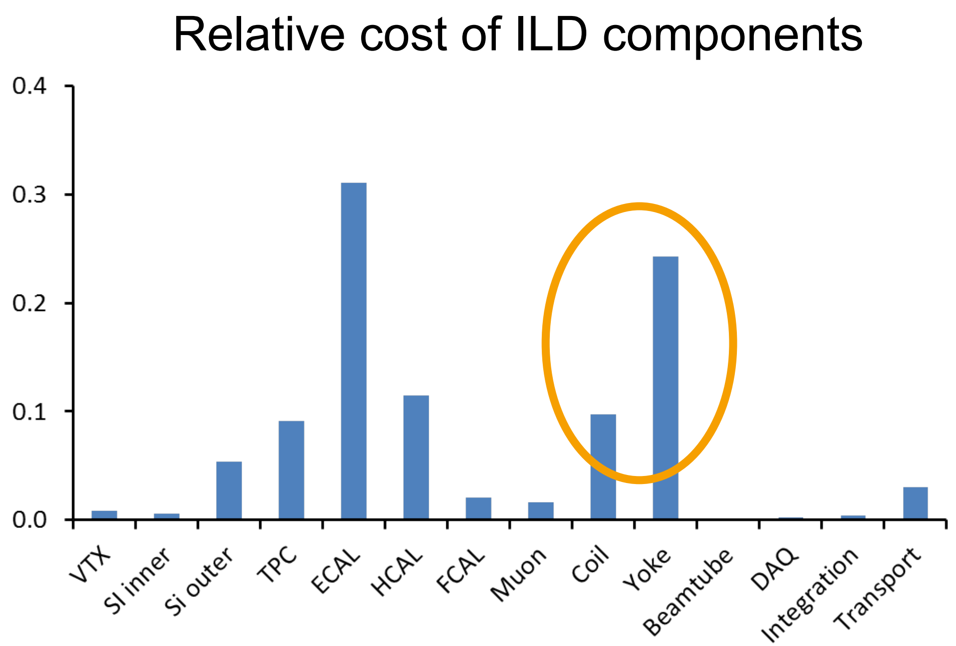
Yoke Issues and Cost

- Review of field calculations
  - Need good understanding

- Look at cost vs. size and field

- ILD presently studying reduced size detector
  - TPC outer radius reduced by 340mm
  - Max. B-field 4.0 → 4.5T

- Alternatives/Options
  - Modified segmentation/geometry?
  - Double solenoid???
  - Inner yoke with compensation coil ??
  - Reduced yoke with shielding wall?



Magnet expensive part of ILD

ILD Field Calculations since 2008

	B (mT) z=y=0, x = 15m
> O. Delferriere (CEA), OPERA 3D/TOSCA old model: coil design, stray field	5.5
> A. Petrov (DESY), 2008-11, CST Studio 3D, simple model and CAD model: stray field and forces	3 - 4
> B. Krause (DESY), 2008, OPERA 2D, simple model: stray field	
> Y. Sugimoto, Y. Yamaoka (KEK), 2008: mainly GLD	
> M. Lemke (DESY), 2012 ANSYS, CAD model: forces, stress and deformation	15
> B. Curé (CERN), 2012 ANSYS, simple model	5
> Efremov group, 2014, several codes, reduced yoke (600m less in radius): stray field	(10)
> K. Büsser (DESY), 2015 CST Studio 3D, CAD model: stray field	< 3
> Recently U.S., CST Studio 3D, simple model: systematic studies, stray field, forces, alternatives	initially 3 – 4, finally 6 – 7

So far have assumed stray field of ≤4 mT at 15m from beamline

No systematic review so far

ILD Field Calculations: Summary

		B (mT) z=y=0, x = 15m
> O. Delferriere, OPERA 3D/TOSCA old model: detailed mesh		(5.5)
> A. Petrov, 2008-11, CST Studio 3D:	mesh not sufficient	(3 – 4)
> M. Lemke (DESY), 2012 ANSYS:	limited surrounding background	(15)
repeated with sufficient background		5
> K. Büsser, 2015 CST Studio 3D:	mesh not sufficient	(< 3)
> B. Curé (CERN), 2012 ANSYS, simple model		5
> Recently U.S., CST Studio 3D	mesh not sufficient	(3 – 4)
	detailed mesh	6 - 7

Smaller yoke (600mm less in radius):

> Efremov group, 2014, several code	detailed mesh	9.7
> Recently U.S., CST Studio 3D	mesh not sufficient	(8.0)
	detailed mesh	9.5

Calculations now very consistent

- Stray field now 5 - 6mT, instead of 3 - 4mT
- Some fine tuning still possible

Magnetic Field in Central Region

> All recent calculations (≥ 2012) done with uniform current distribution in coil
  - No correction coils (not used anymore)
  - Usually no anti-DID

> Central field depends on yoke
  - In particular on end-caps, correct meshing of gaps
  - Poor mesh (EC gaps) changes central field as well
  - Make sure correct simulation is used for generating field map

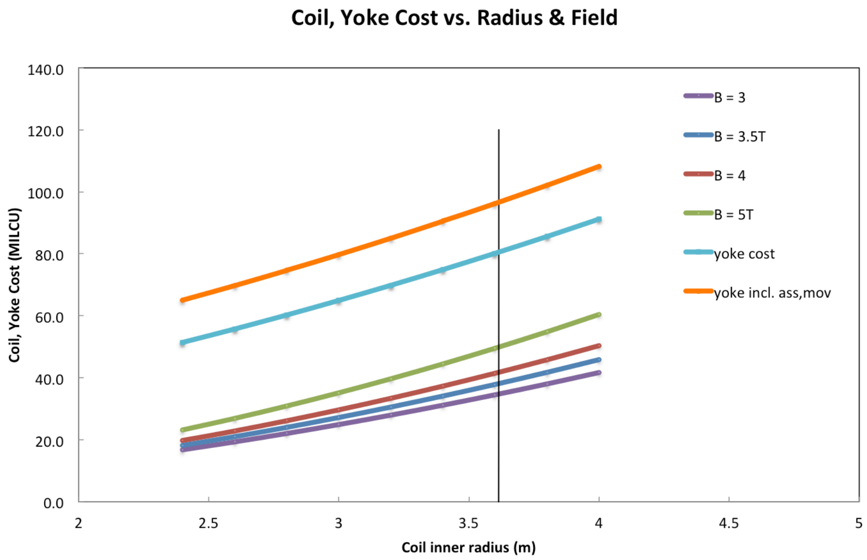
> How important is field uniformity in TPC volume?
  - Ron "Homogeneity not import, need precise measurement of field"

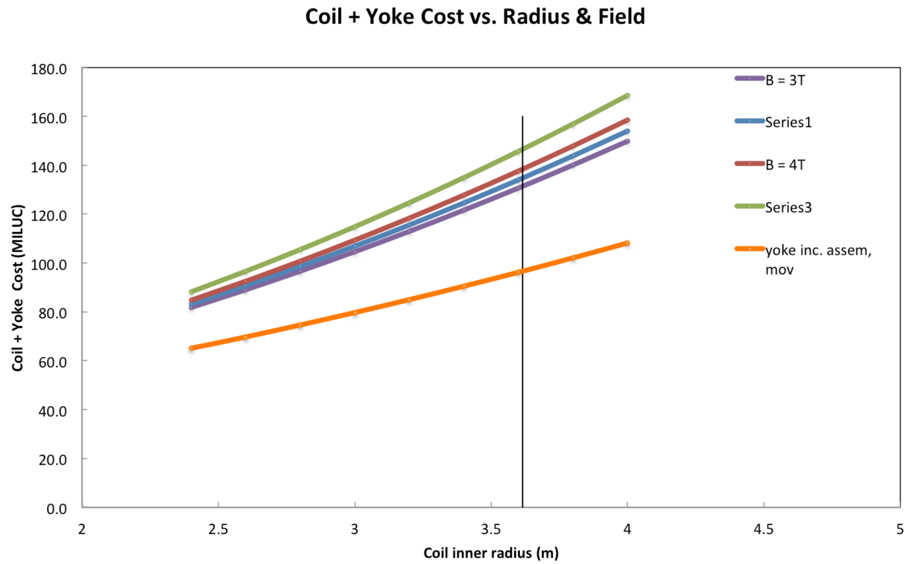
> Accidentally, reduced coil length from 7.35 to 6.135m (typo): (initial mesh)
  - Field along z less uniform: 3.5T at TPC end-plate, instead of 3.8T
  - Field integral should not be affected $\int_{l_{drift}} \frac{B_r}{B_z} dz$
  - End-cap forces reduced from 19 to 10ktons
  - Cost of coil reduced by 5 MILCU

Yoke Cost vs. Size and Field

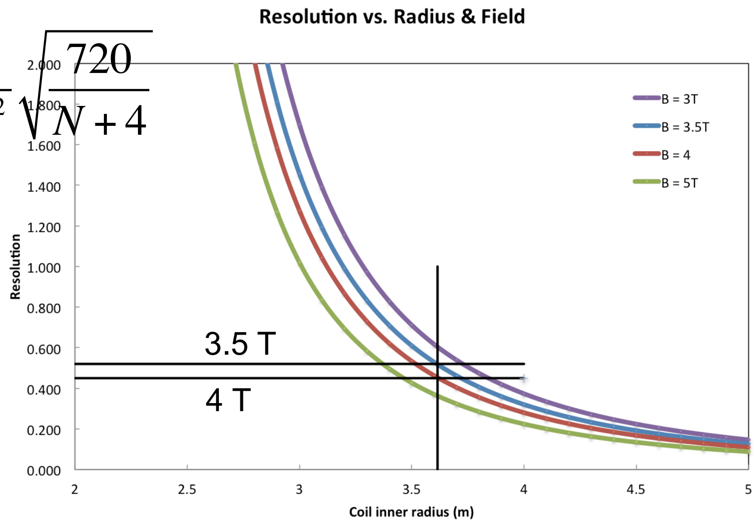
- Rough cost estimate similar to DBD (1 ILCU = 1$ = 0.97€ , 1 € = 1.5 CHF)
- Coil cost using parametrization of A.Herve

Cost of yoke for fixed iron thickness
(Thickness increases with B field)





$$\frac{\sigma(p_T)}{p_T^2\sigma_x} = \frac{1}{0.3BL^2}\sqrt{\frac{720}{N+4}}$$



	Cost of steel (MILCU)		Steel and Coil (MILCU)	
thick plates	ri 3.615	ri 3.165	ri 3.615	ri 3.165
B3	81	68	123	104
B2	66	55	108	91

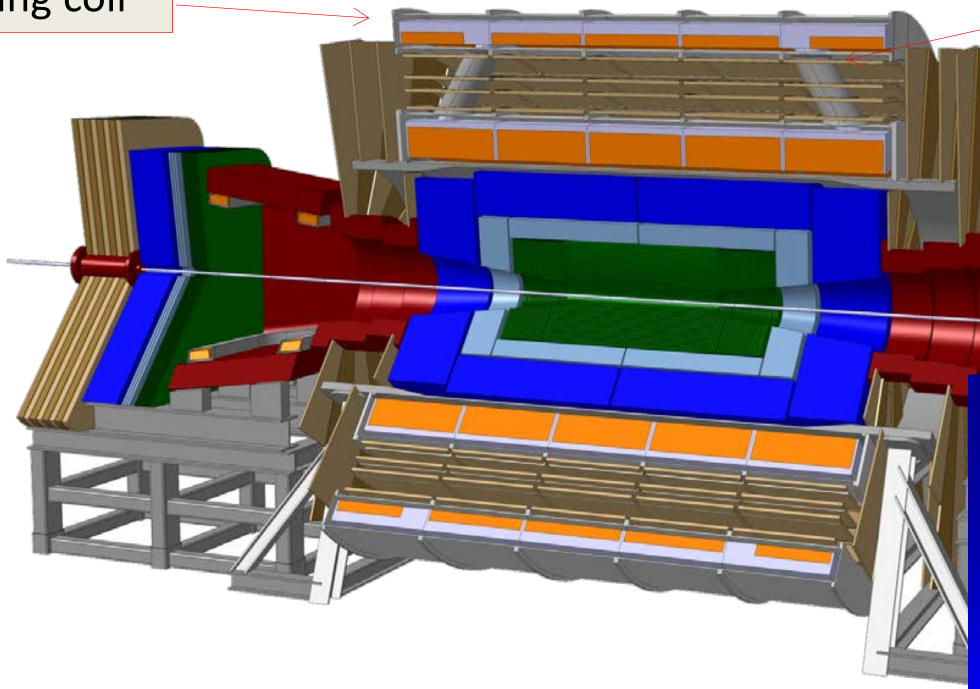
Double Solenoid Without Yoke

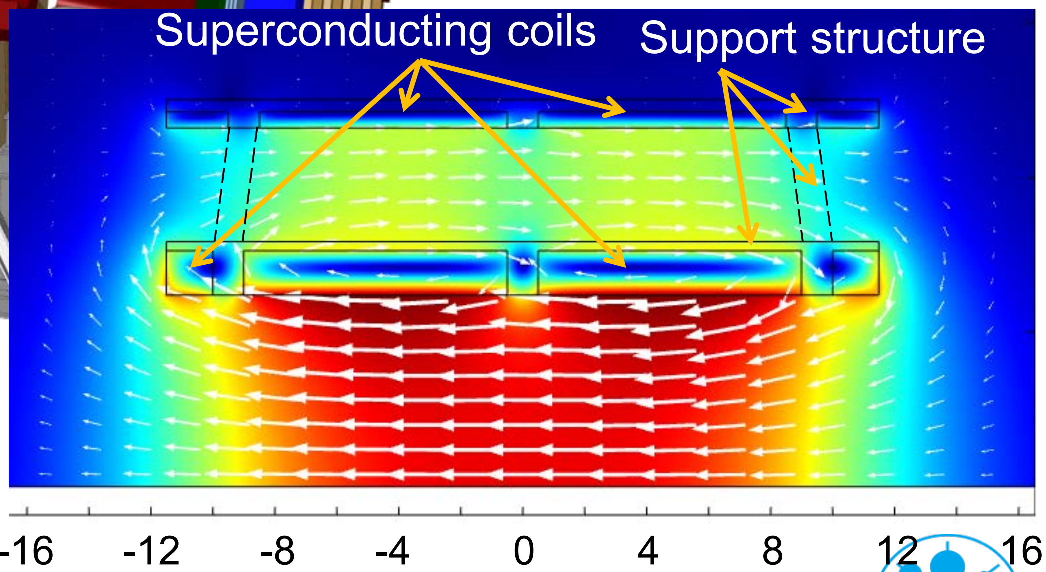
Flux return by outer solenoid: much lighter, muon tracking space, possibly cheaper

- 4th Concept
- Recently being studied by FCC Detector Working Group, H. ten Kate et al.

shielding coil

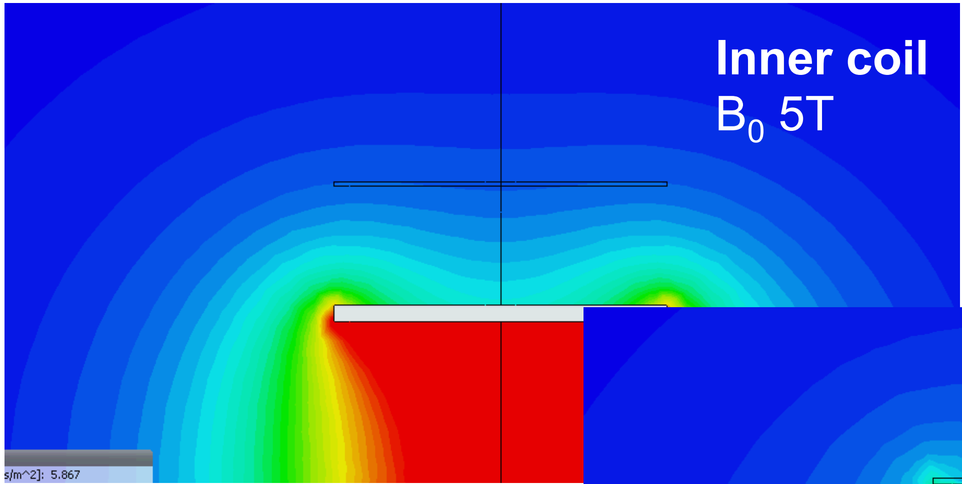
Gap filled with 3 T and muon chambers



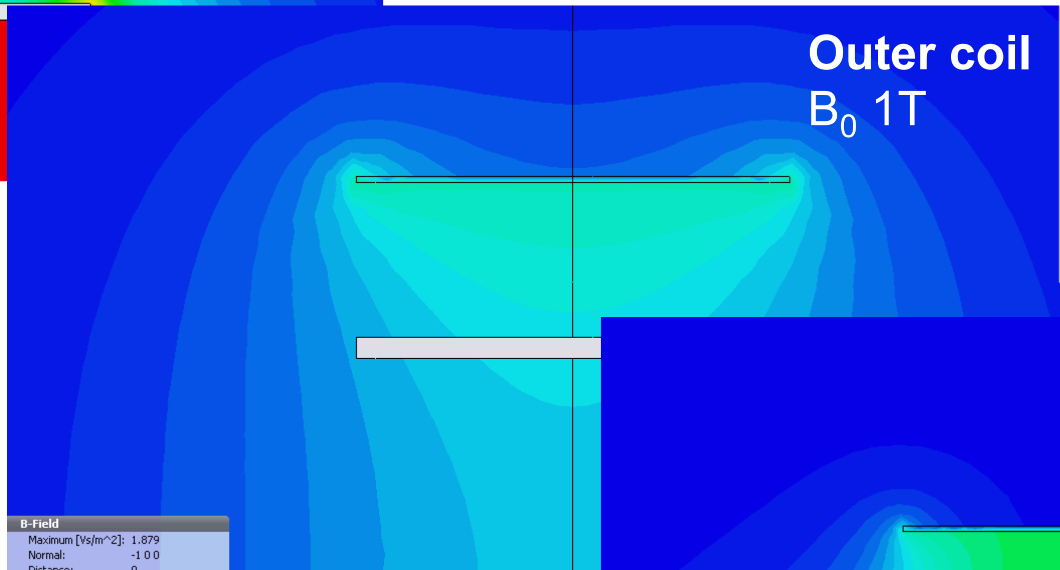


Several options being studied
Not cheap

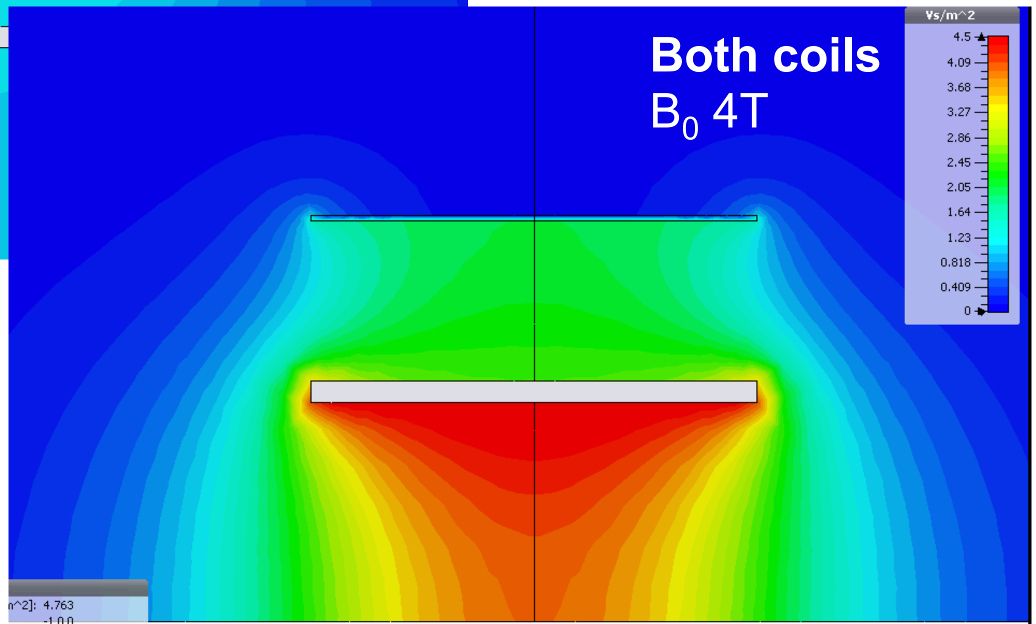
Double Solenoid Without Yoke



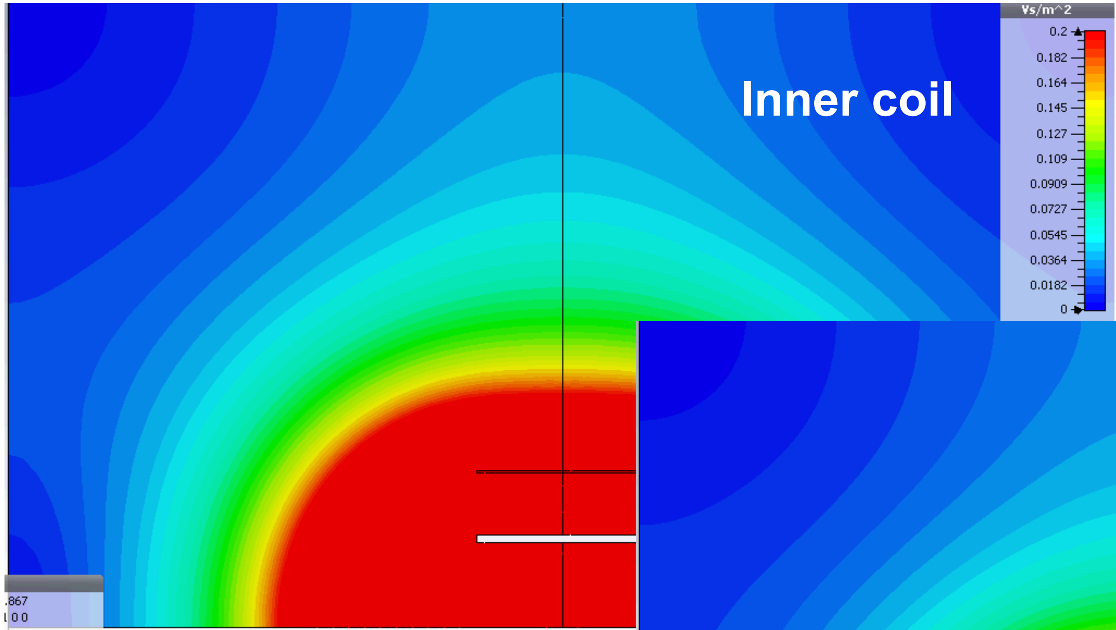
ILD coil with additional outer (superconducting) coil



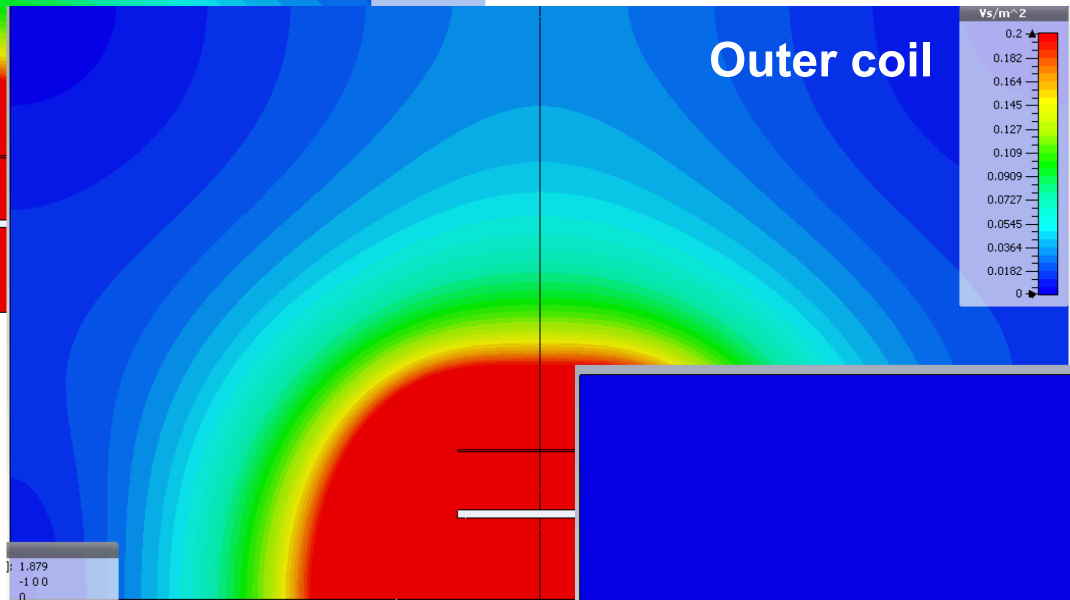
Scale 4.5T



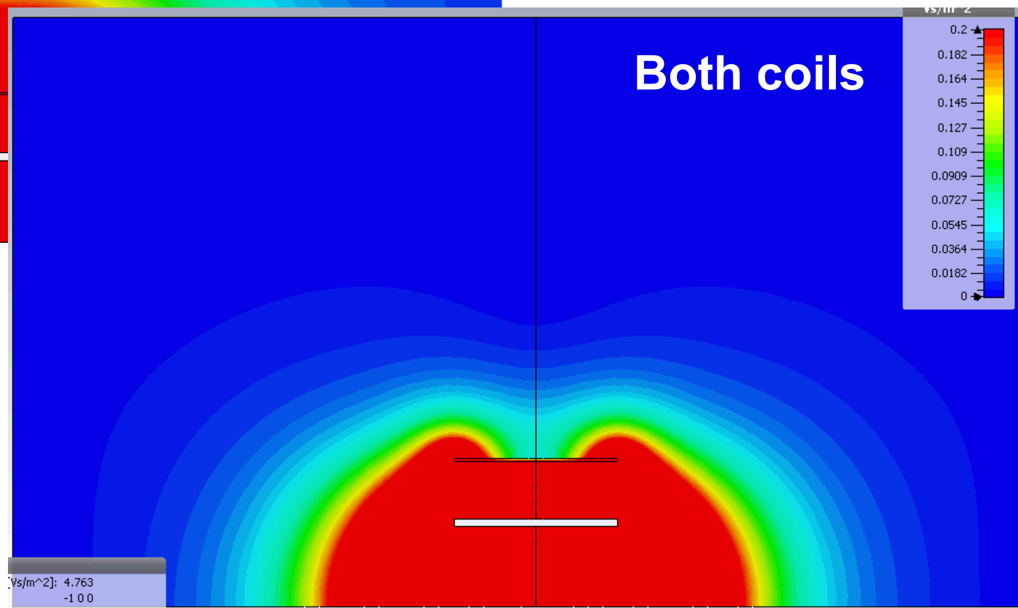
Double Solenoid Without Yoke



ILD coil with additional outer (superconducting) coil

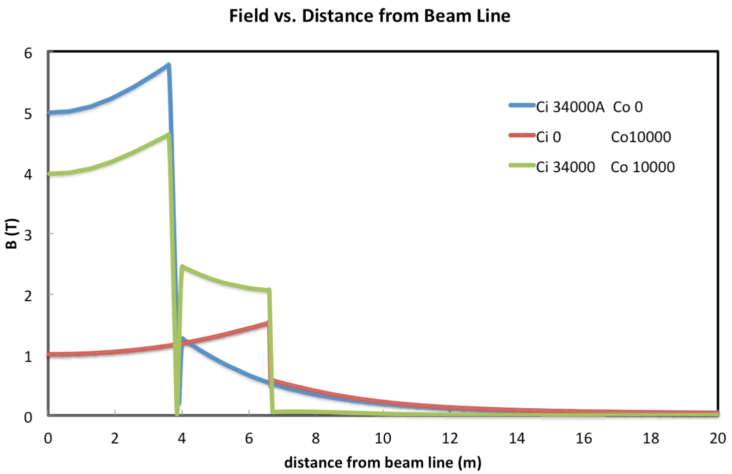


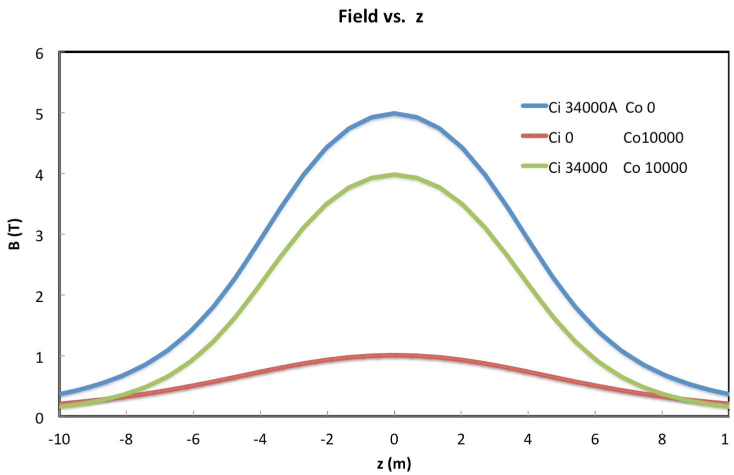
Scale 0.2T

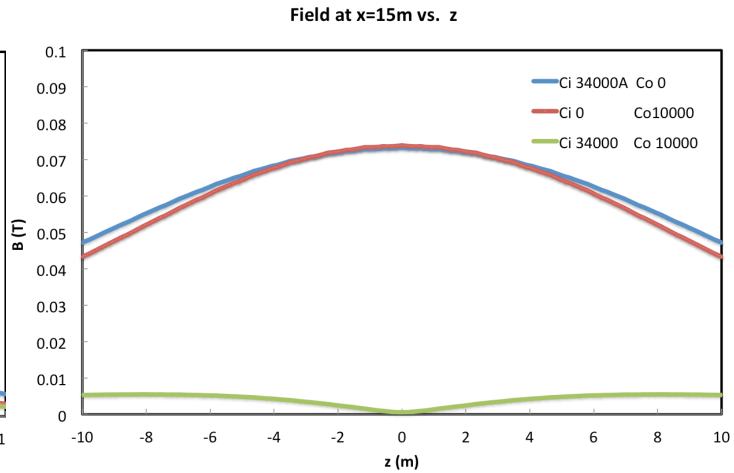


- Stray field reduced by compensating coil
- Could be tuned, less dependent on field calculations

Double Solenoid Without Yoke







field less homogeneous

Rough cost estimate (MILCU)

	Present design	Double solenoid
Inner coil	43	56
Outer coil	-	47
Yoke	81	-
Support	12	12
Sum	136	115*

*) in addition

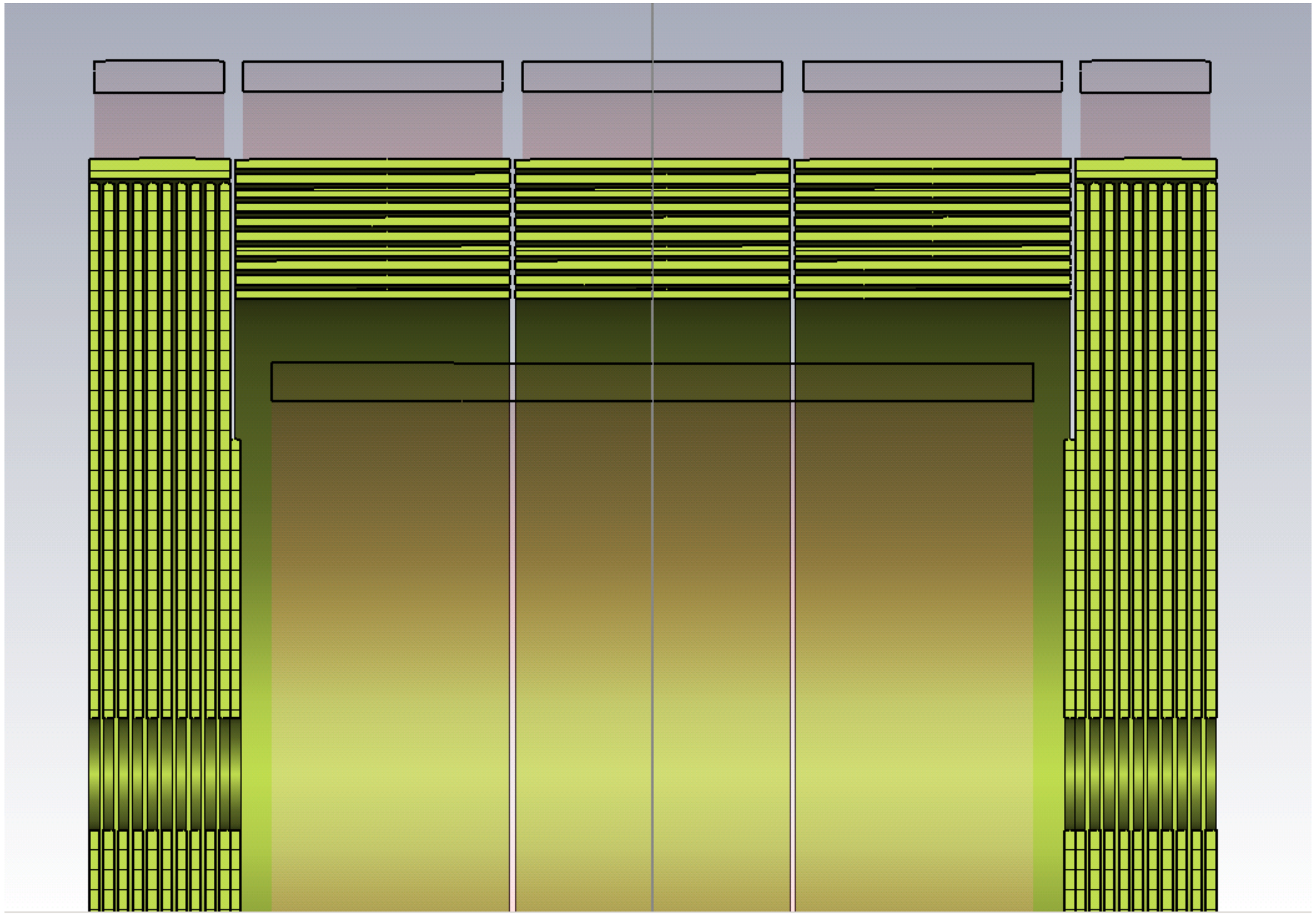
- Radiation shielding (concrete)
- Power supply for outer coil
- Infrastructure and larger cryo plant

Similar cost

Inner Yoke with Compensating Coil

Stray field reduced by compensating coils

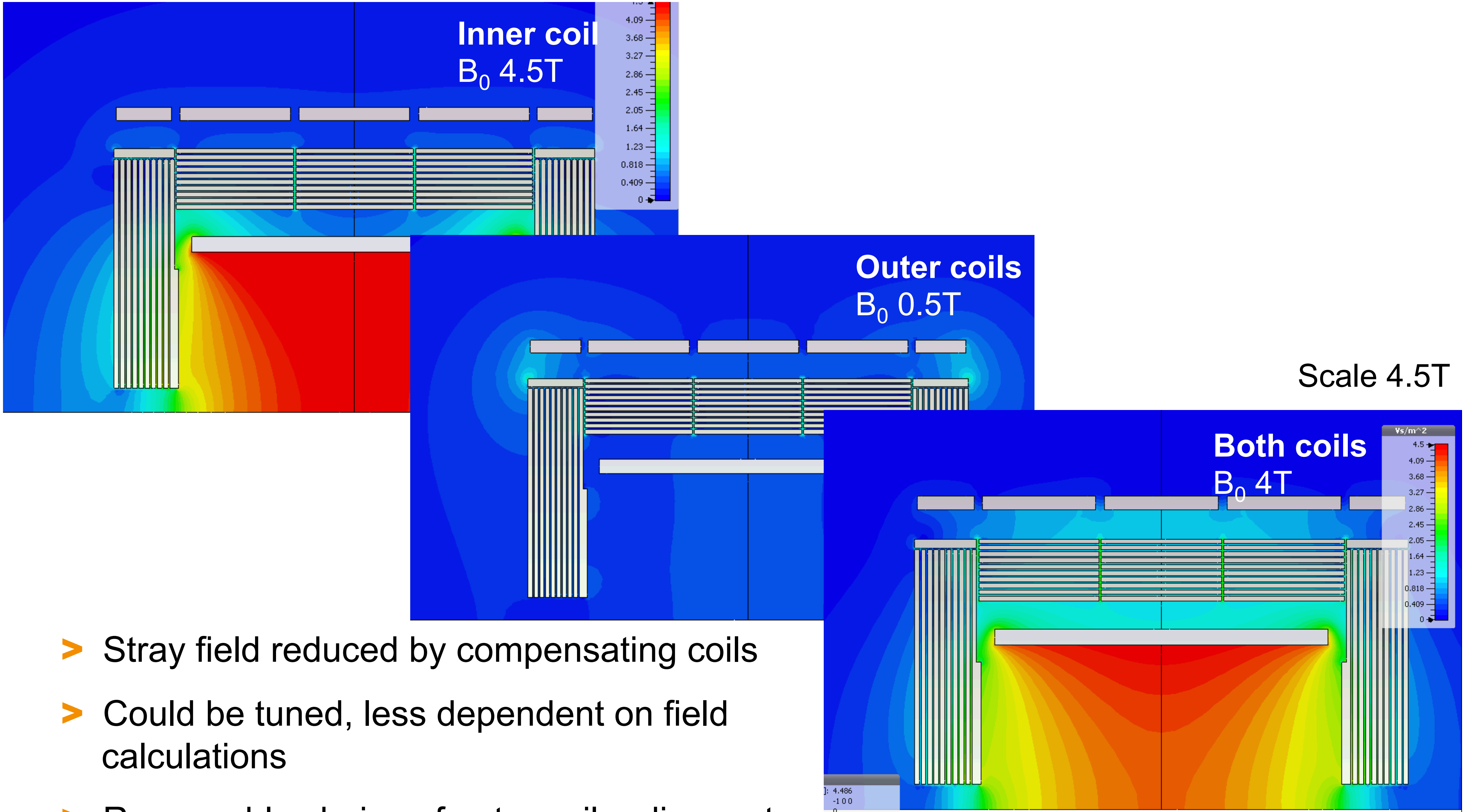
Radius reasonable choice, not optimized



Yoke

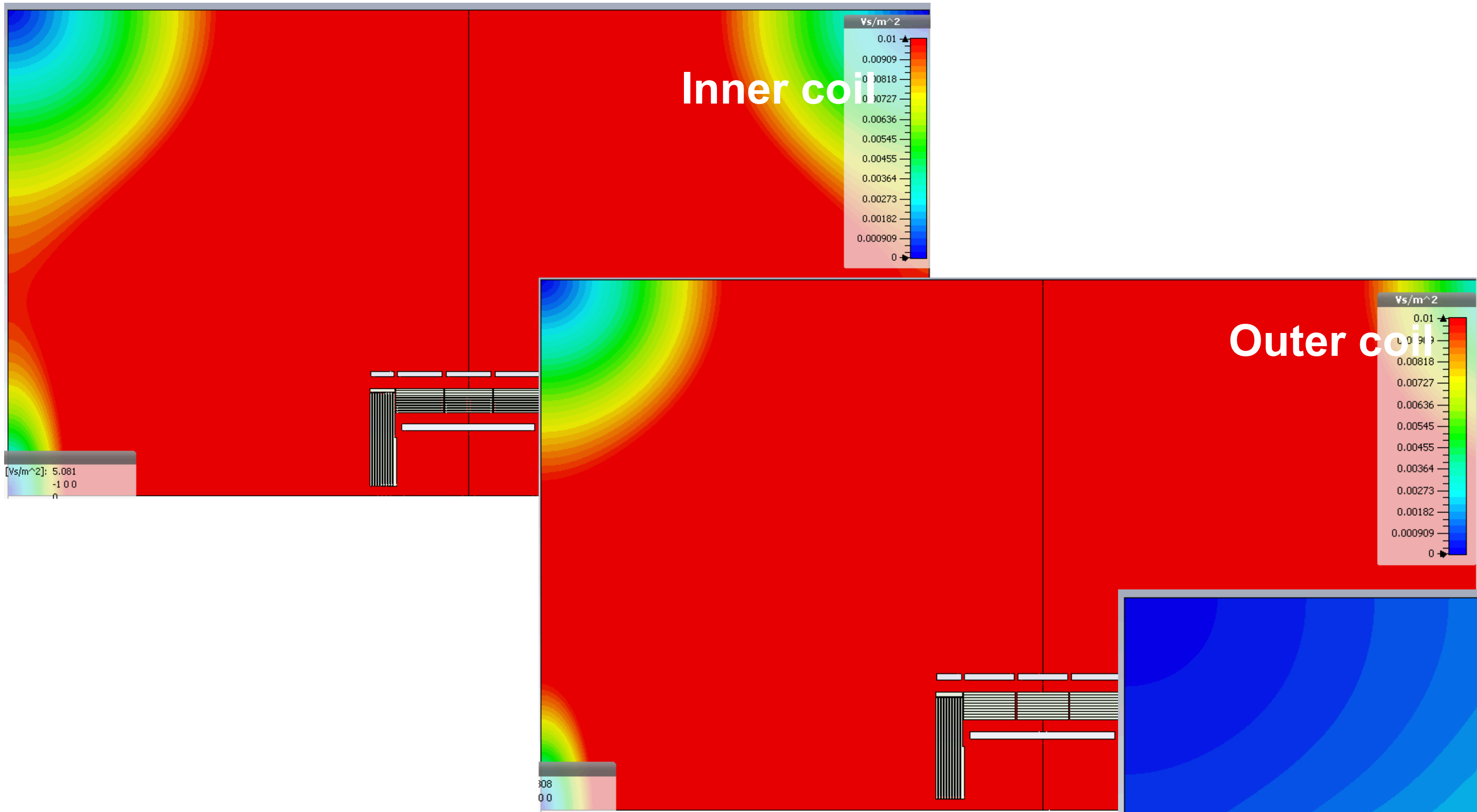
- weight 4000 instead of 13400t
- cost 24 instead of 81MILCU

Inner Yoke with Compensating Coil

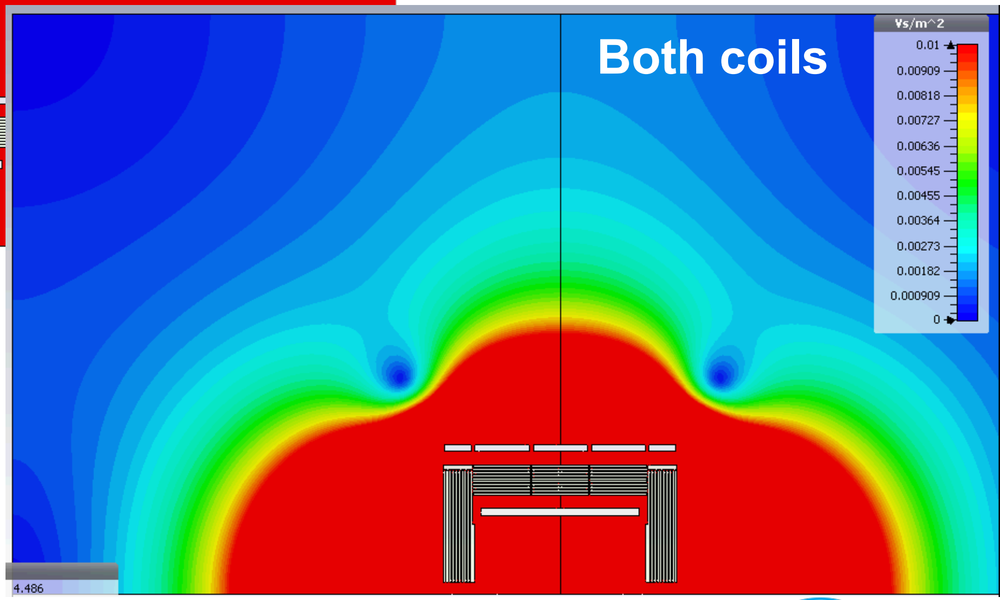


- Stray field reduced by compensating coils
- Could be tuned, less dependent on field calculations
- Reasonable choice of outer coil radius, not optimized

Inner Yoke with Compensating Coil



Scale 0.01T



- Stray field reduced by compensating coils
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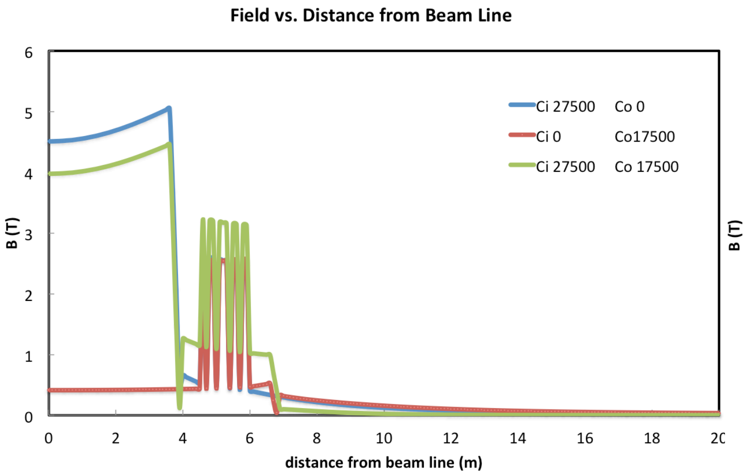
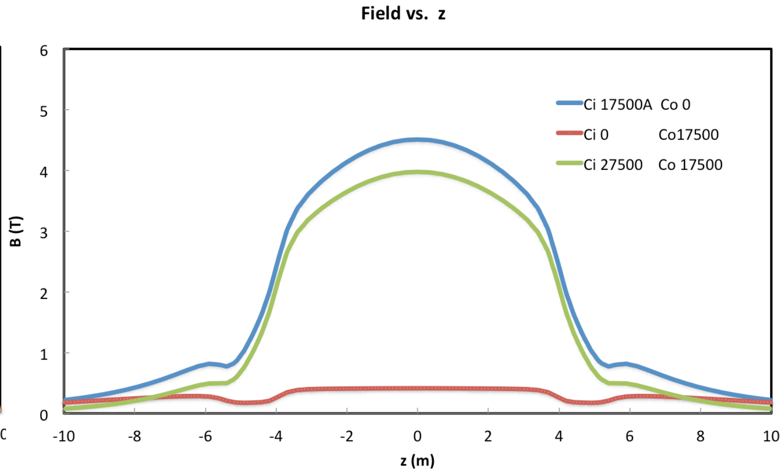
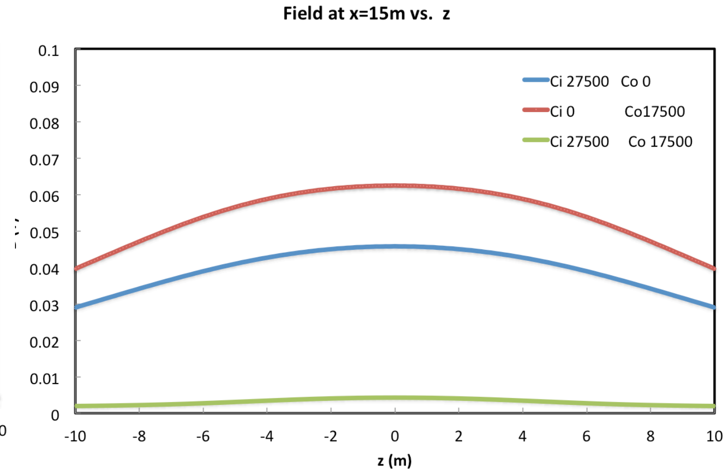
Inner Yoke with Compensating Coil







Rough cost estimate (MILCU)

	Present design	Inner yoke compensating coil	
		SC coil	NC coil (Cu)
Inner coil	43	46	46
Outer coils	-	51	18 (34) 17(8.7)MW, 9(4.5)MILCU/y
Yoke	81	24	24
Support	12	12	12
Sum	136	133*	100 (116)* power bill 90(45)MILCU 10y

* In addition

- Some radiation shielding (concrete)
- Infrastructure, larger cooling or cryo plant

Electricity cost assuming:
ILC 80%, push pull 50%, 15ct/kWh

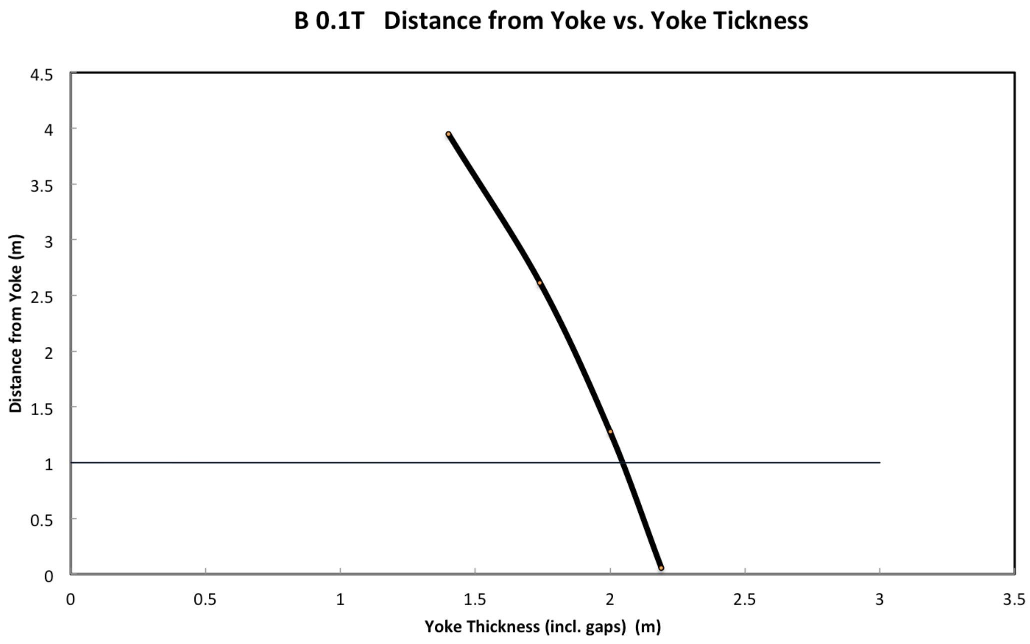
Reduced Yoke – Shielding Wall

Stray field considerations

- 5mT limit at 15m in order not to disturb SiD in park position
  - Access to detector for installation and maintenance
- ILD in beam position
  - Data taking
  - Hall should be accessible, no installation work, only non-magnetic tools
  - Acceptable B field

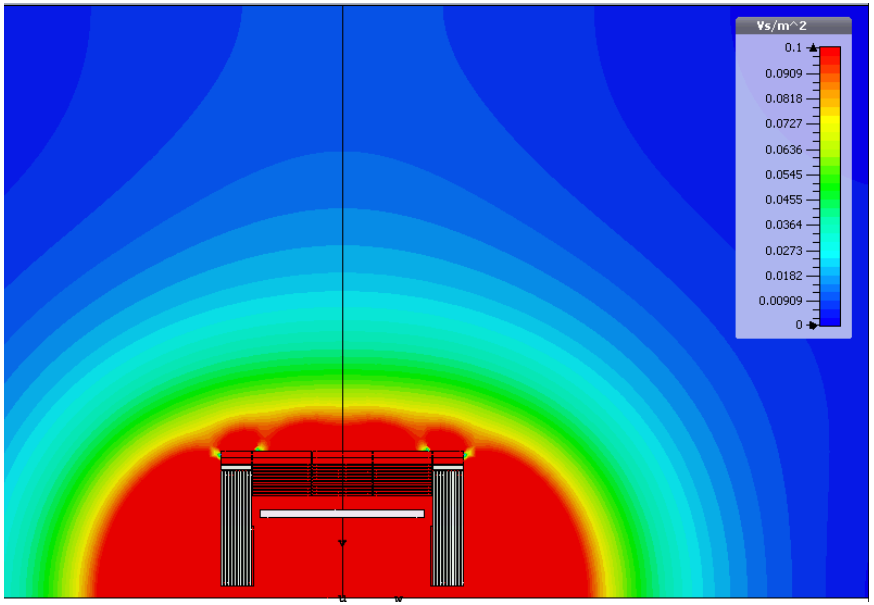
    < 200mT: human safety, CERN regulation for full working day (8h/d)
    < 100mT: operation of magnetically sensitive equipment
- Reduce size of yoke: 100mT at 1m distance from yoke
  - Have to check radiation shielding
  - May have to add concrete shielding, cheaper than iron
- Use shielding wall to reduce field at SiD
  - Could be part of radiation shielding during accelerator commissioning

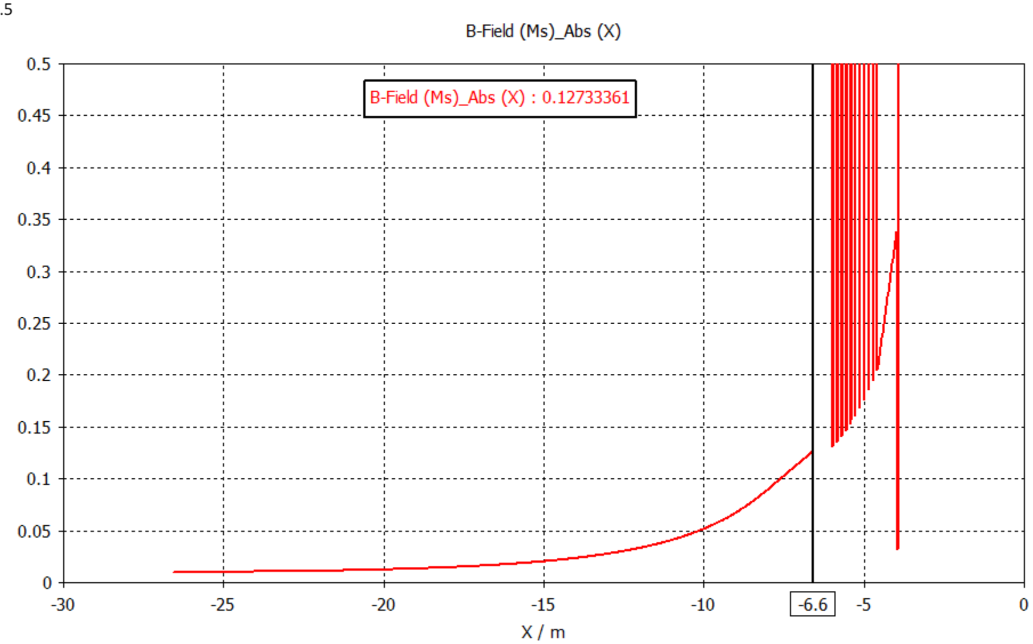
Reducing Yoke Thickness



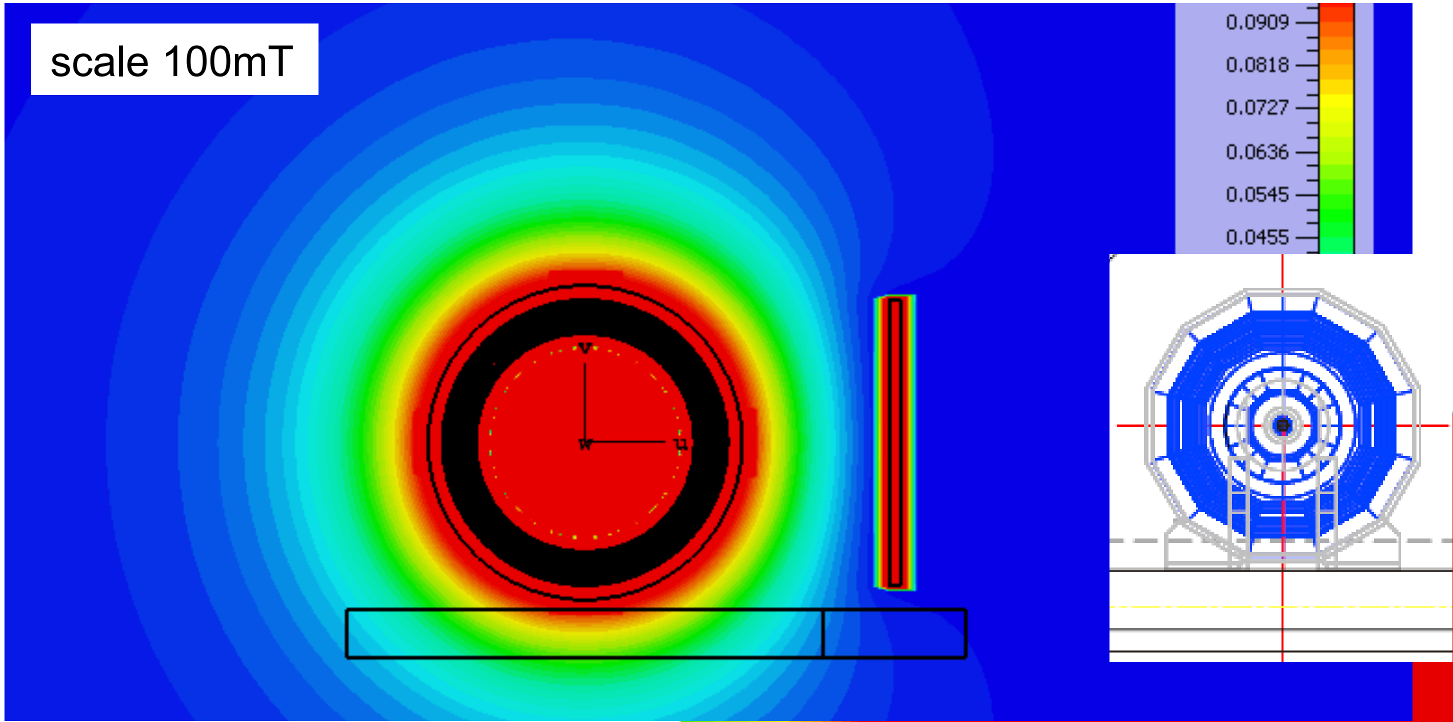
Yoke size and thickness reduced

- B 0.1mT at 1m from yoke for
  - R_{out} = 6.6m (instead of 7.76m)
  - iron thickness 2.04m including gaps





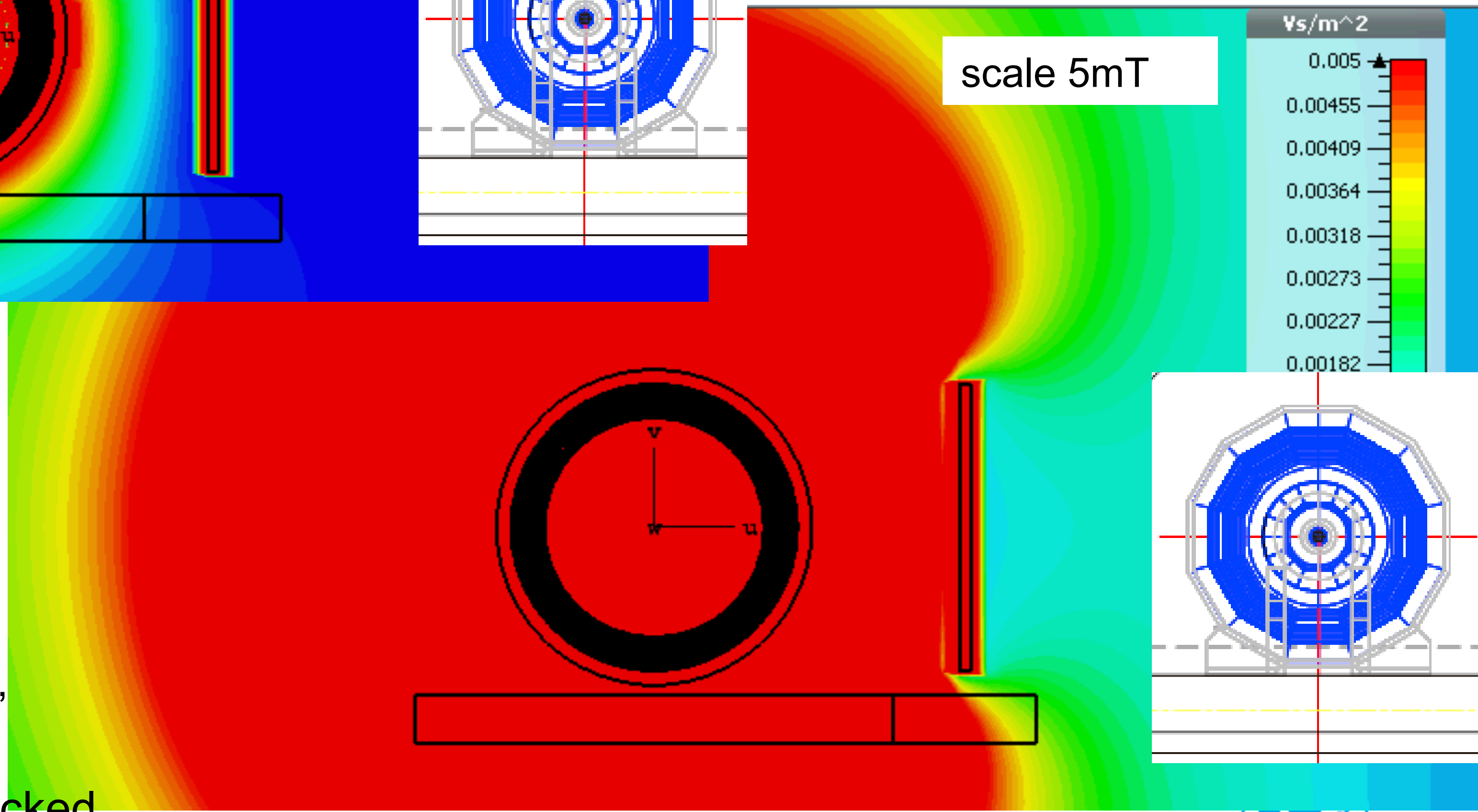
Reduced Yoke – Shielding Wall



Preliminary, hexahedral mesh

Movable iron shielding wall

- 13m from beam line
- 25m x 12m x 0.5m



ILD in beam position

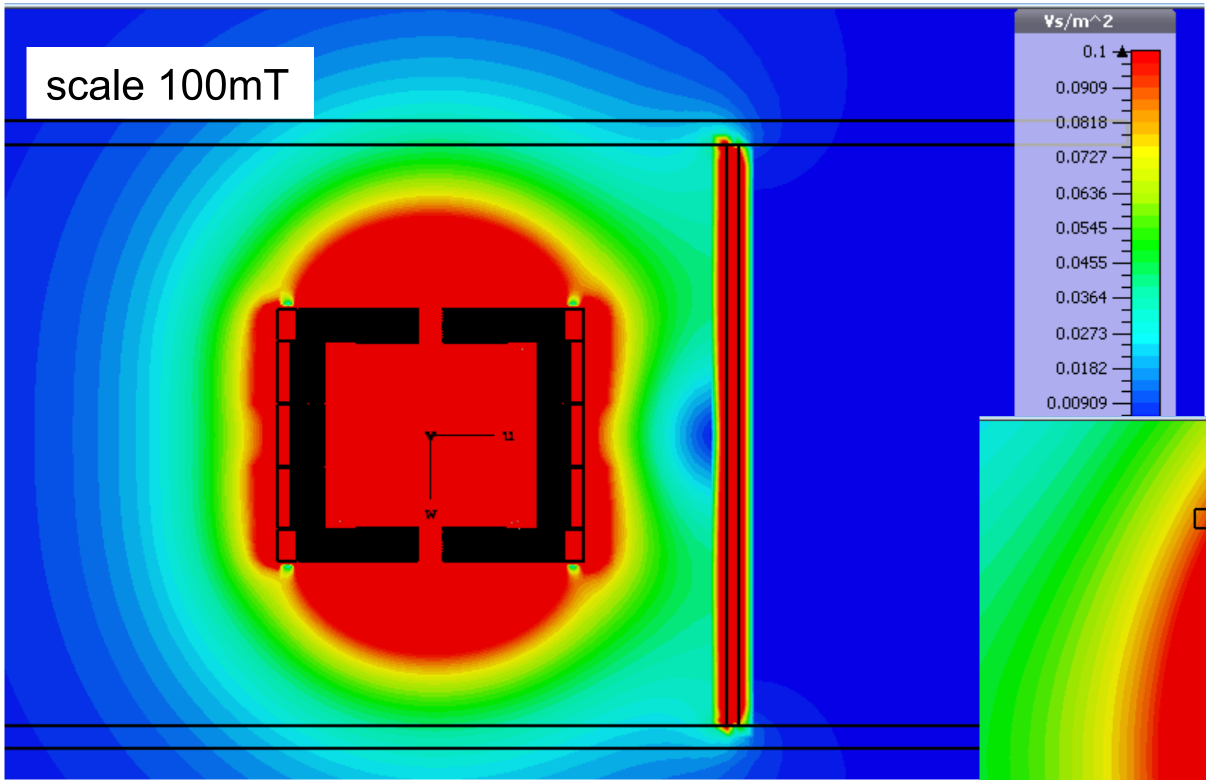
- Hall accessible with non magnetic tools

SiD in off beam position

- Unlimited access (installation, maintenance)

Radiation shielding to be checked

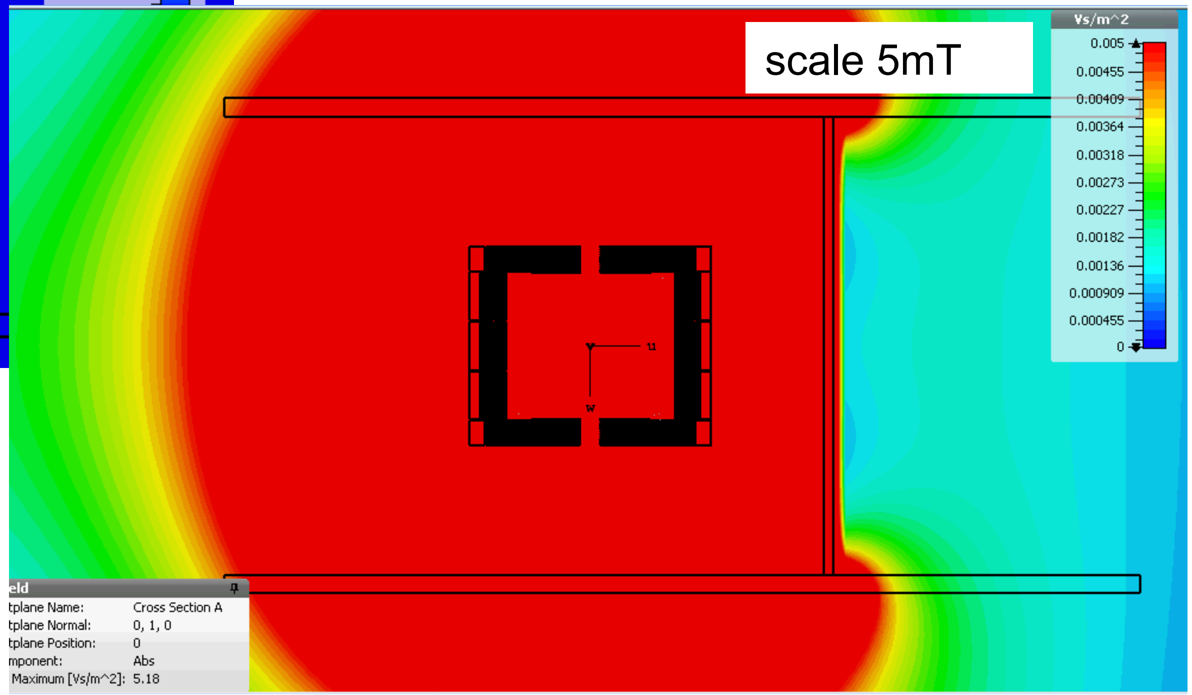
Reduced Yoke – Shielding Wall



Preliminary, hexahedral mesh (confirmed with tetrahedr. mesh)

Movable iron shielding wall

- 13m from beam line
- 25m x 12m x 0.5m



Rough cost estimate

- Yoke 37 instead of 81MILCU
- Shielding wall O(7MILUC), assuming same unit cost as for yoke (Should be cheaper, but need moving platform)
- Could reduce hall height by approx. 1m
- May need some concrete shielding

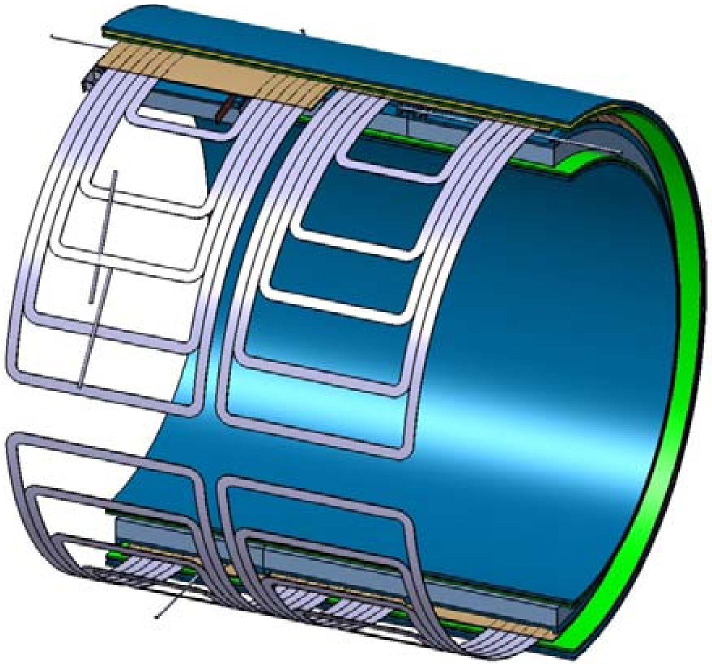
(Restared shielding simulations (Sanami)

Asymmetry in outer field
-> small asymmetry in central field

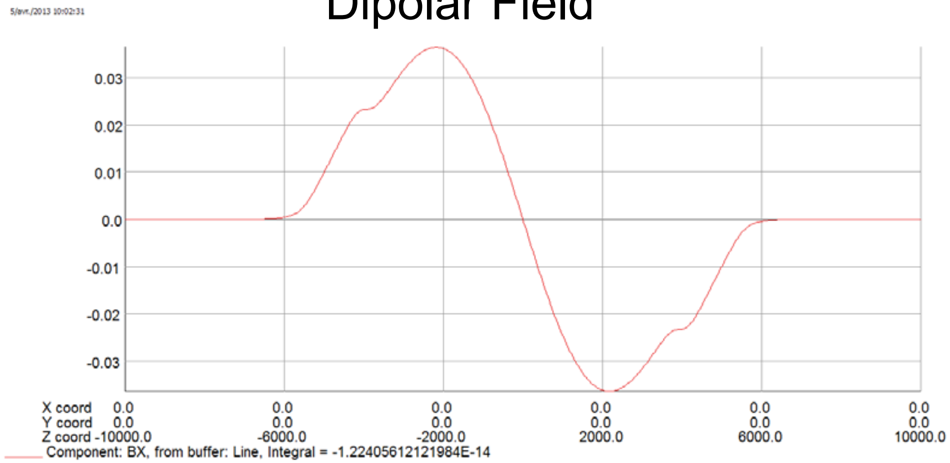
Anti DID: Conceptual Design – BDB v1

Requirement:

- Max field Bx 0.035 T at z = 3m

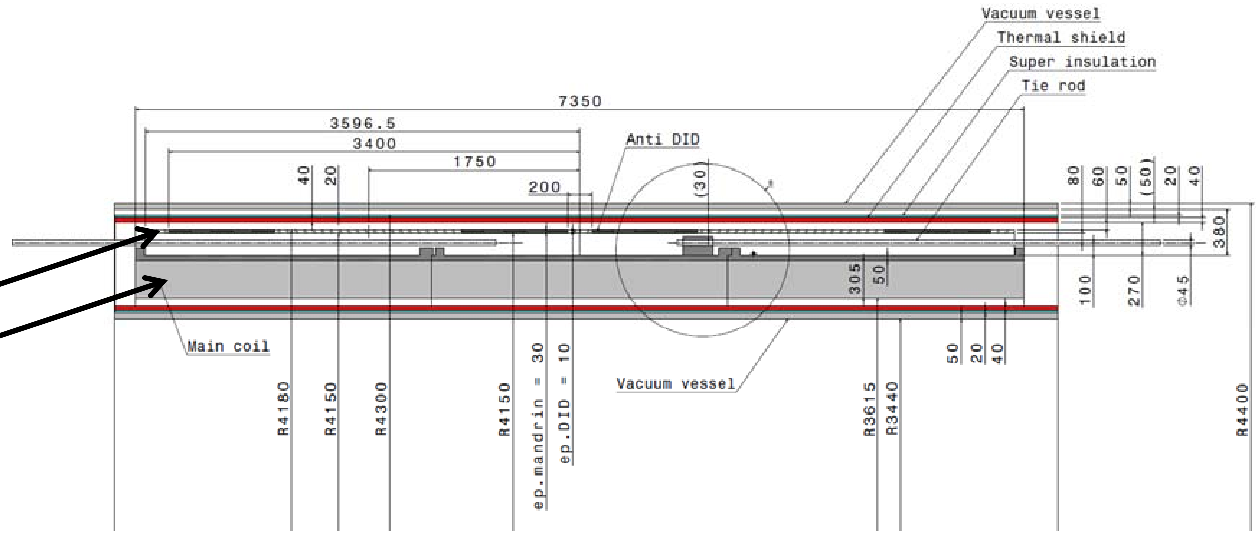


Dipolar Field



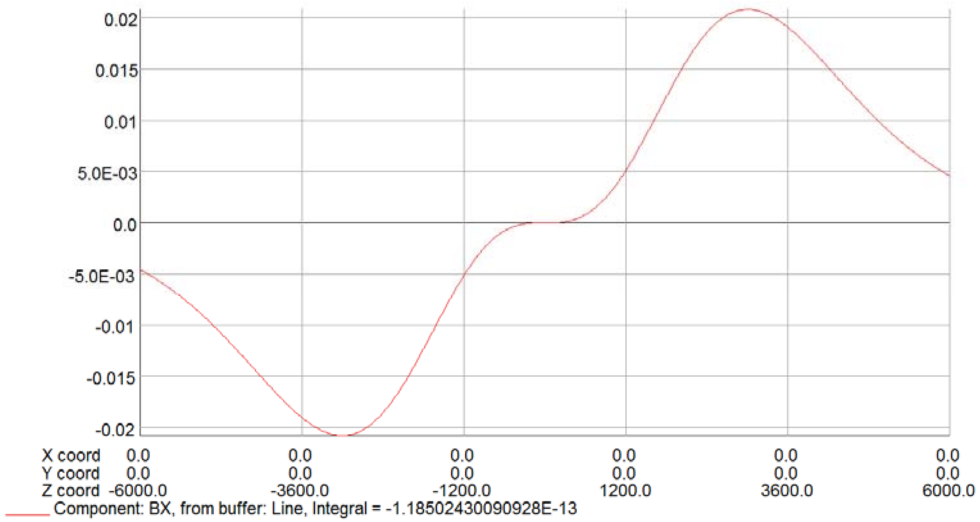
Saclay group
Magnet note
LC-DET-2012-081

Integration in Cold Mass

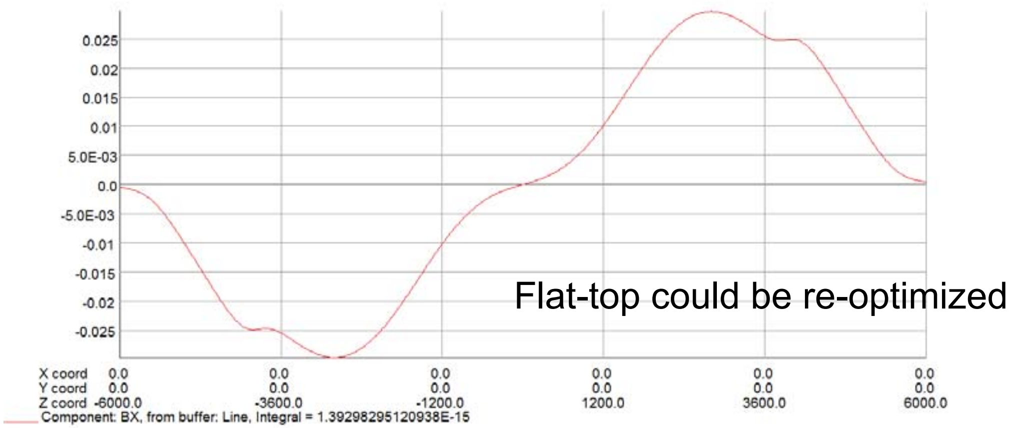


Conceptual Design - DBD Version 2

Dipole Field w/o Yoke



Dipole Field with Yoke



Saclay group
Magnet note
LC-DET-2012-081

Requirements:

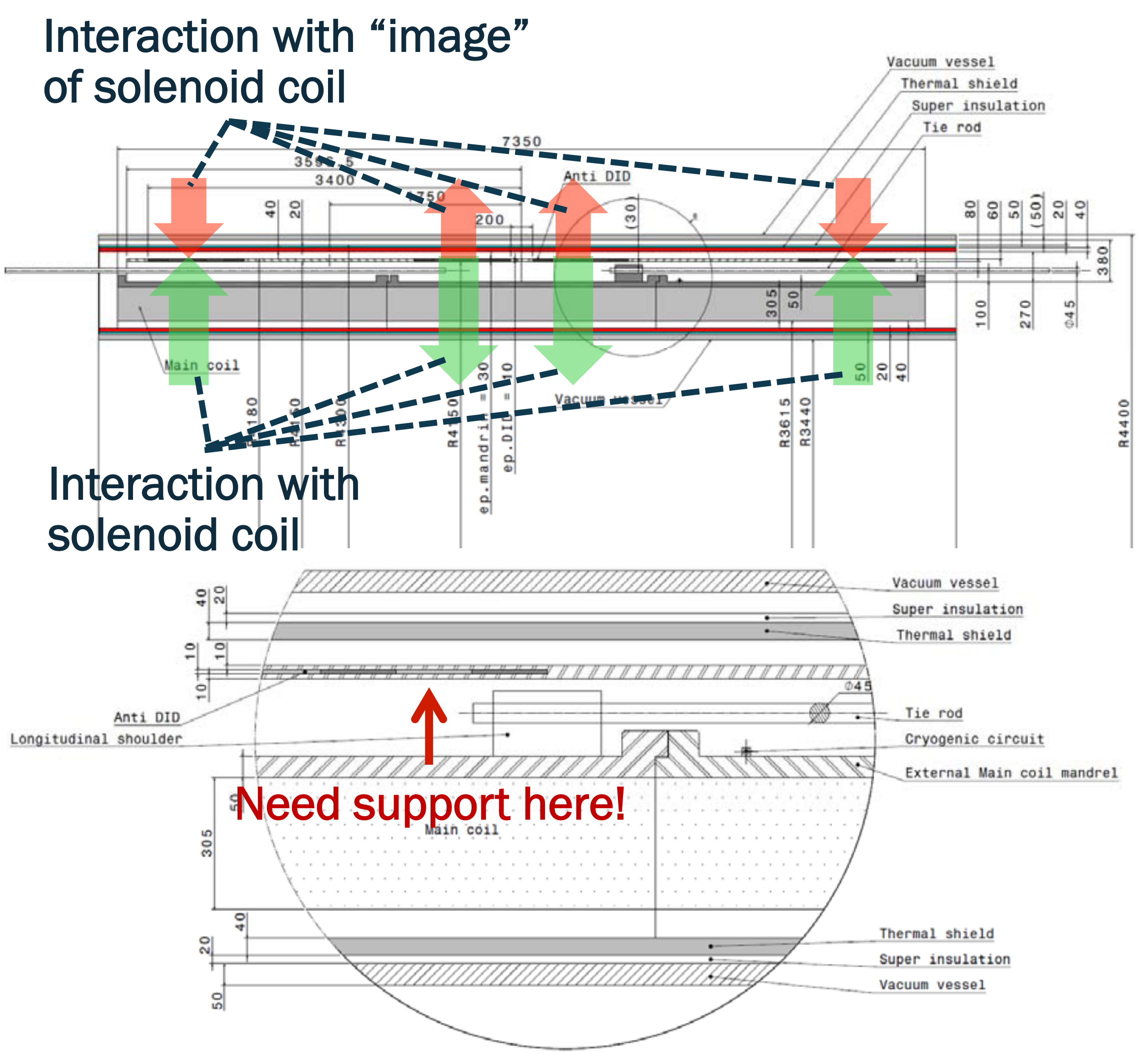
- Max field Bx 0.035 T at z = 3m
- Flat-top zero field ± 0.5m around IP

Coil Design

- Each dipole consists of 2 parts
  - Different, much higher currents
- Coils are complicated
- Should be avoided if not absolutely necessary (B.Parker)

Some AD Construction Considerations

Slide B. Parker



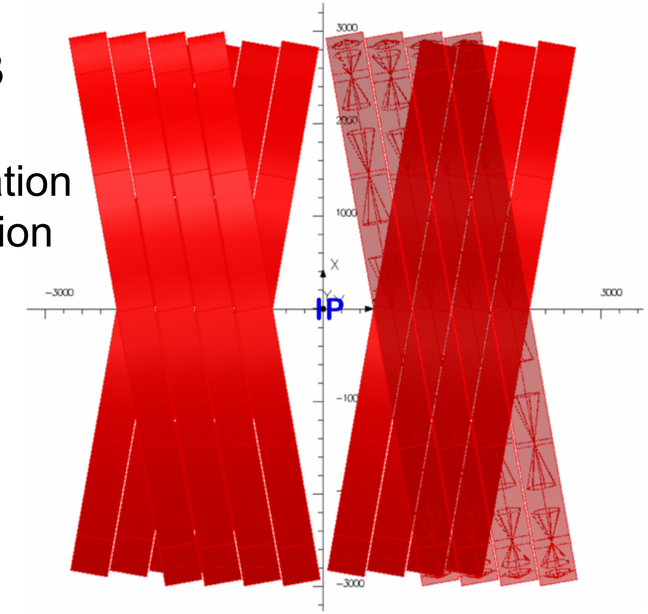
- AD should not experience any net force due to main solenoid but each AD half experiences net torque from forces at ends.
- Torque leads to a bending moment in horizontal plane.
- End turn forces are reduced a bit due to magnetic interaction with yoke (image of main solenoid in the highly saturated yoke).
- Bending forces should be calculated if AD structure is not supported at critical points (structure looks quite thin).
- Method A has pattern gaps to make radial connections to outer cryostat; the Method B coil covers most of the available surface.

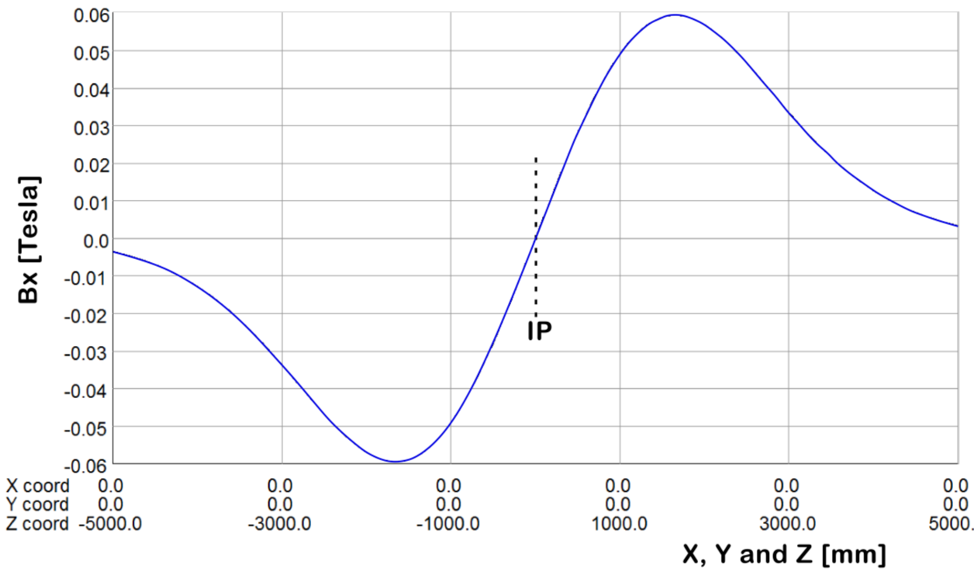
Different Anti-DID Production Geometry

Slide B. Parker

Method B

Approximation for simulation

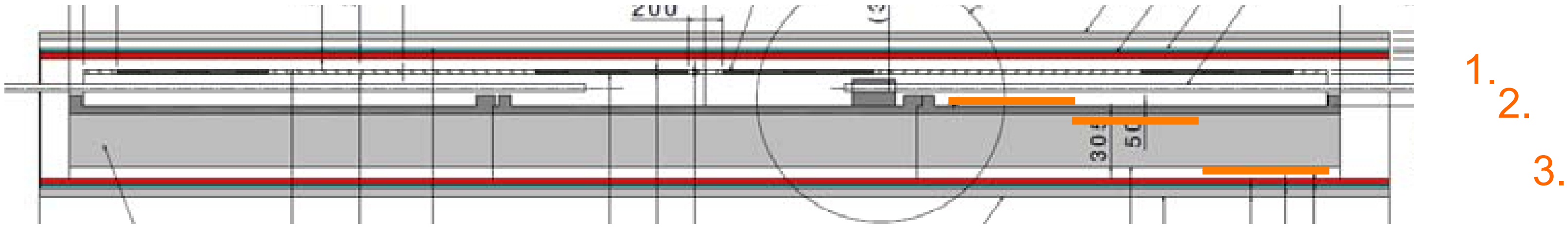




- Consider using helical coil† (also know as canted coil) winding technique to produce anti-DID; setup makes transverse field but does not couple to main solenoid.
- Scheme is schematically illustrated above where we have tilted the solenoidal turns in two different radial layers in opposite directions and given them opposite currents.
- The longitudinal field, B_z, from the two layers cancels 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. Could be integrated with main solenoid cold mass and independently powered.

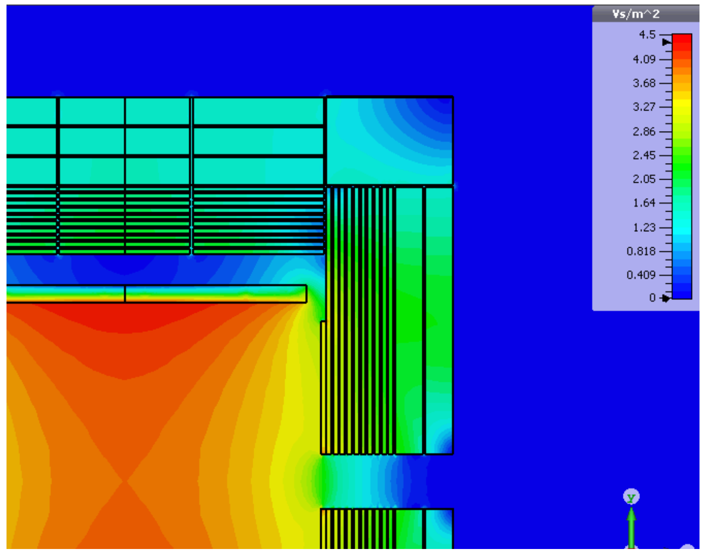
†H. Witte, et.al., "The Advantages and Challenges of Helical Coils for Small Accelerators—A Case Study," IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 22, NO. 2, APRIL 2012.

Different Anti-DID Production Geometry



Location of direct wind anti-DID conductor

1. Outside solenoid support cylinder
   - In conflict with cooling tubes, current leads and tie-rods
   - Low magnetic field, low forces
   - Would require new, additional winding machine
2. Between support cylinder and solenoid
   - Reduced cooling contact between solenoid conductor and support
   - Transfer of forces during quench
   - Still low magnetic field and forces
   - Could use modified main winding machine
3. Between support cylinder and solenoid
   - Still low magnetic field and forces
   - Could use modified main winding machine



Meeting at CERN with CMS magnet experts
(B.Parker. H.Gerwig, B.Cure   Dec. 2016)

Propose

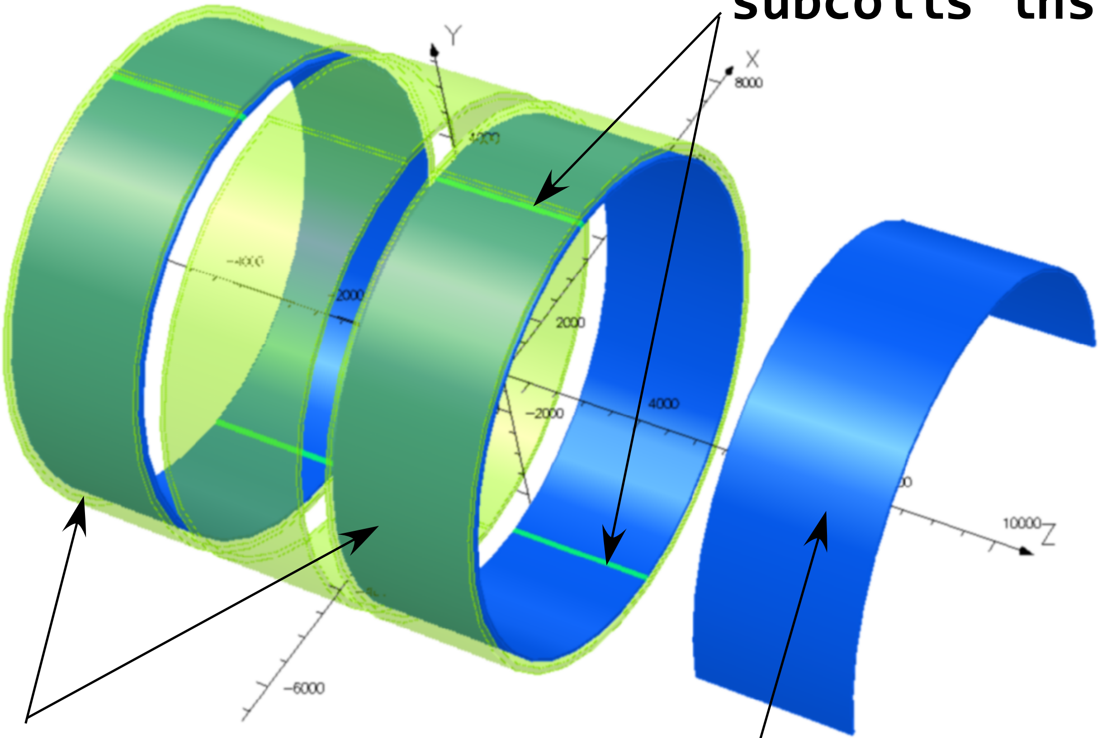
> Anti-DID between solenoid and support (2.)
> Conductor in grooves cut into support cylinder
> Use dipole winding

New Concept – B.Parker

Slide B. Parker

ILD split in three sections (the mandrel pieces are shown translucent)

Key spacers are used to fit and align the DID subcoils inside mandrel



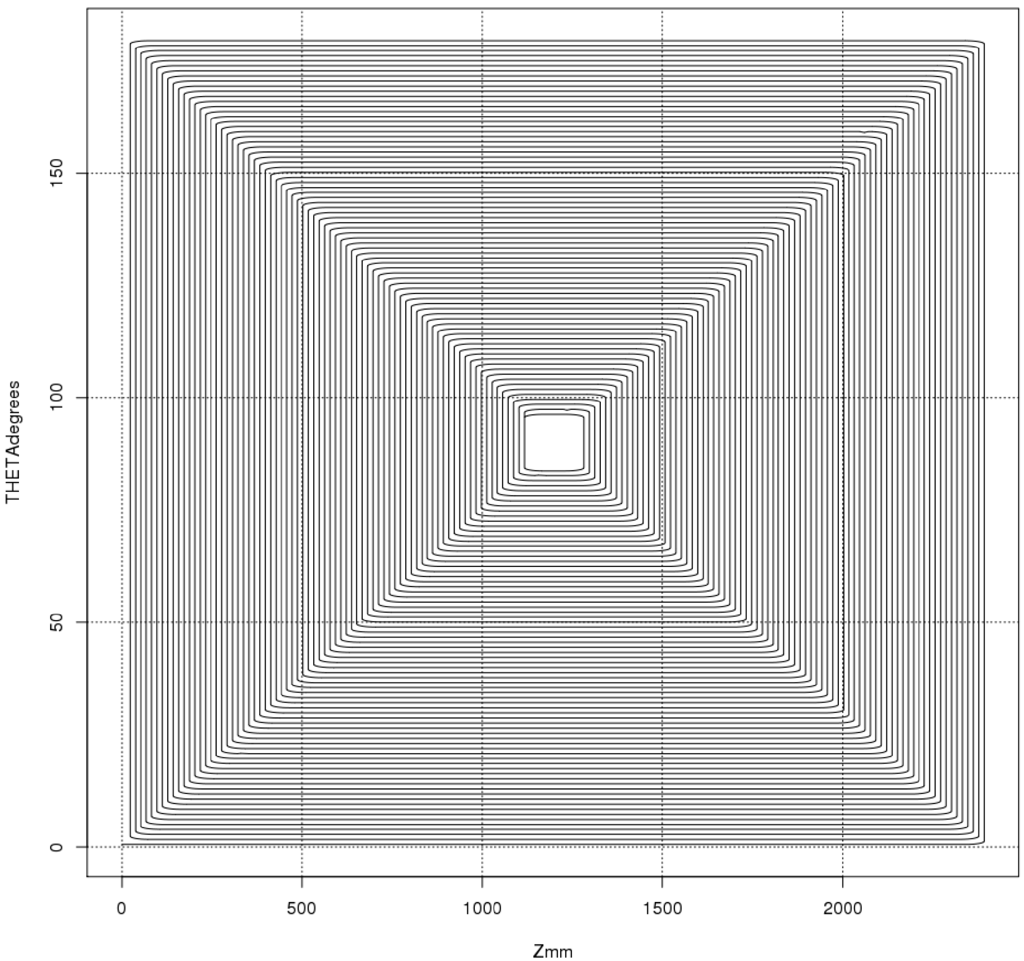
Two outer sections get two pairs of horizontal dipole half coils

DID subcoils are wound in to grooves cut into the half-cylinder support structures

New Concept – B.Parker

Slide B. Parker

Z-Theta Projected View of Subcoil Pattern



Note:

- Uniform z-spacing.
- Uniform angular spacing.
- Nearly uniform* bend radius at the corners for each turn.

*As shown on the next slide one set of the four corners must be different due to the need to connect turn N to turn N+1.

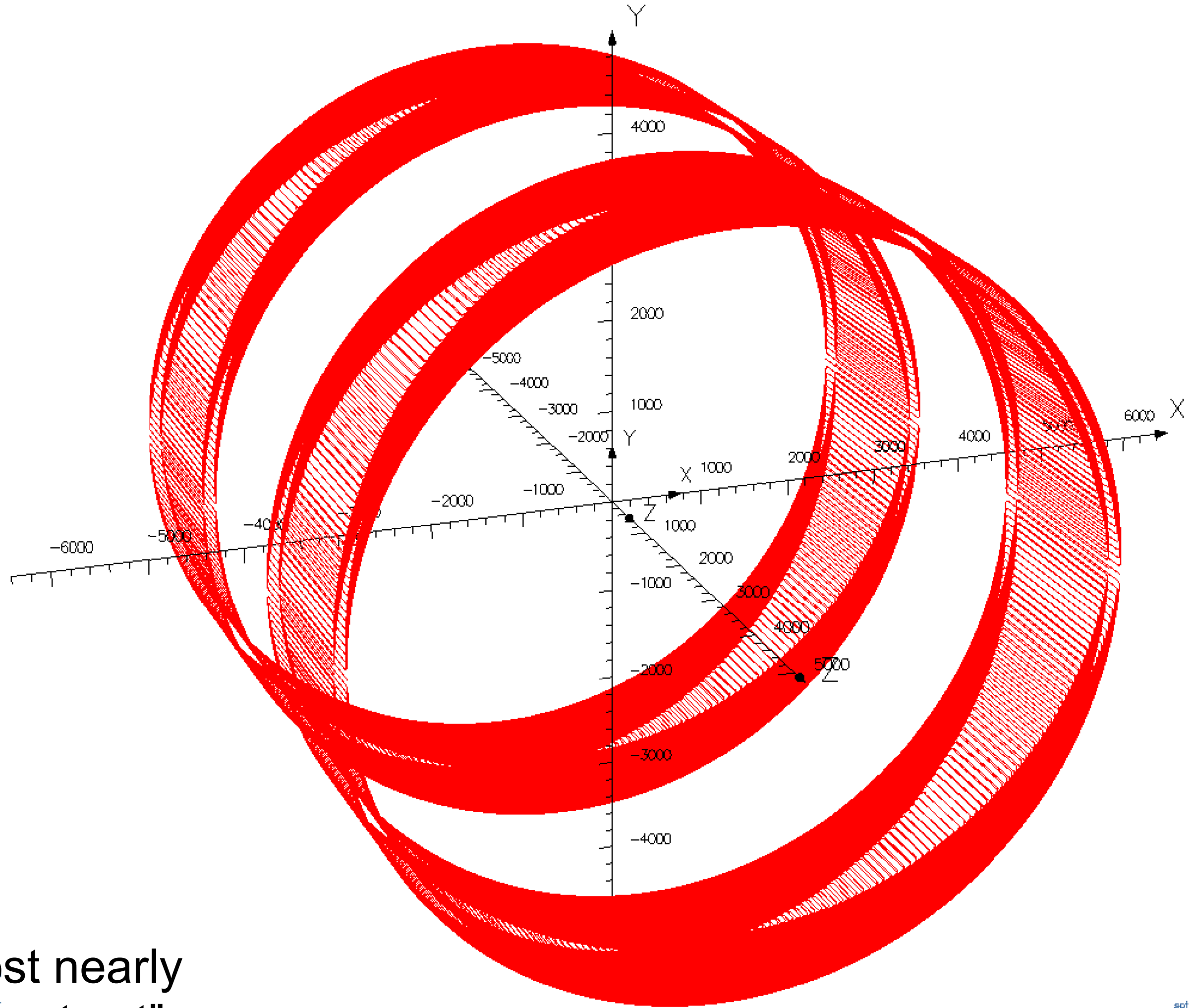
Comment on inner part of winding (U.S.):

- Not important for B-field
- Main reason transfer of forces and heat due to spacing to conductor

New Concept – B.Parker

Slide B. Parker

ILD anti-DID Coil Using the Two Outer Solenoid Sections

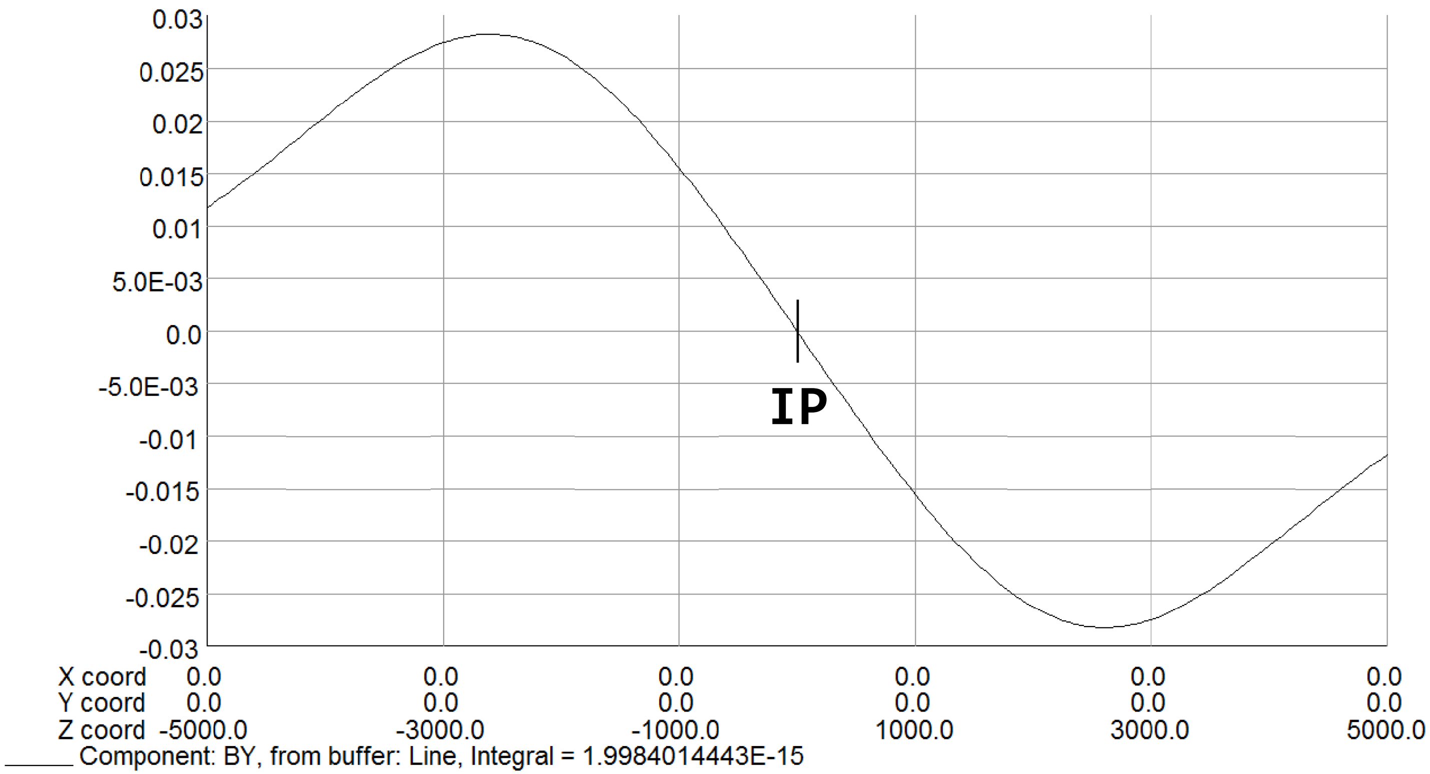


Brett: “ the most nearly buildable concept yet”

New Concept – B.Parker

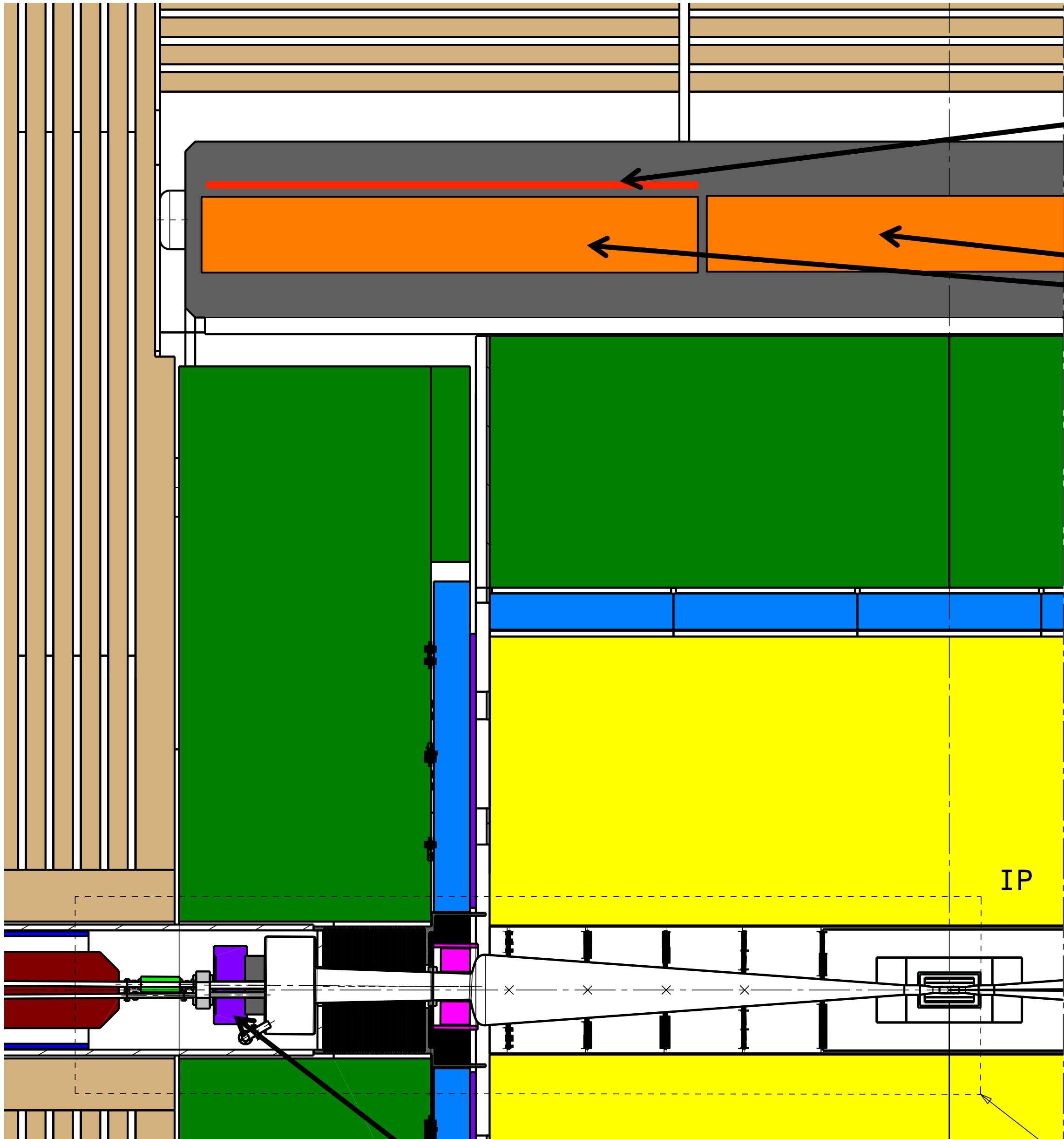
Slide B. Parker

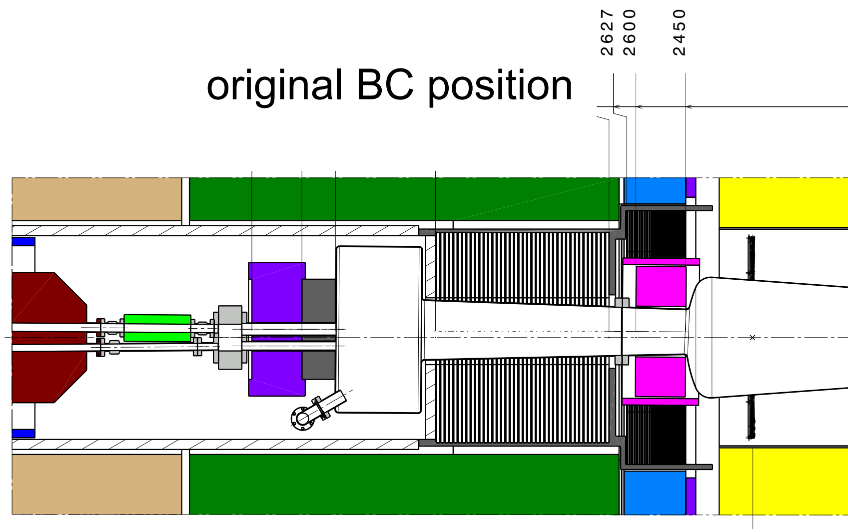
Field Profile From Simple Double Air Coil*



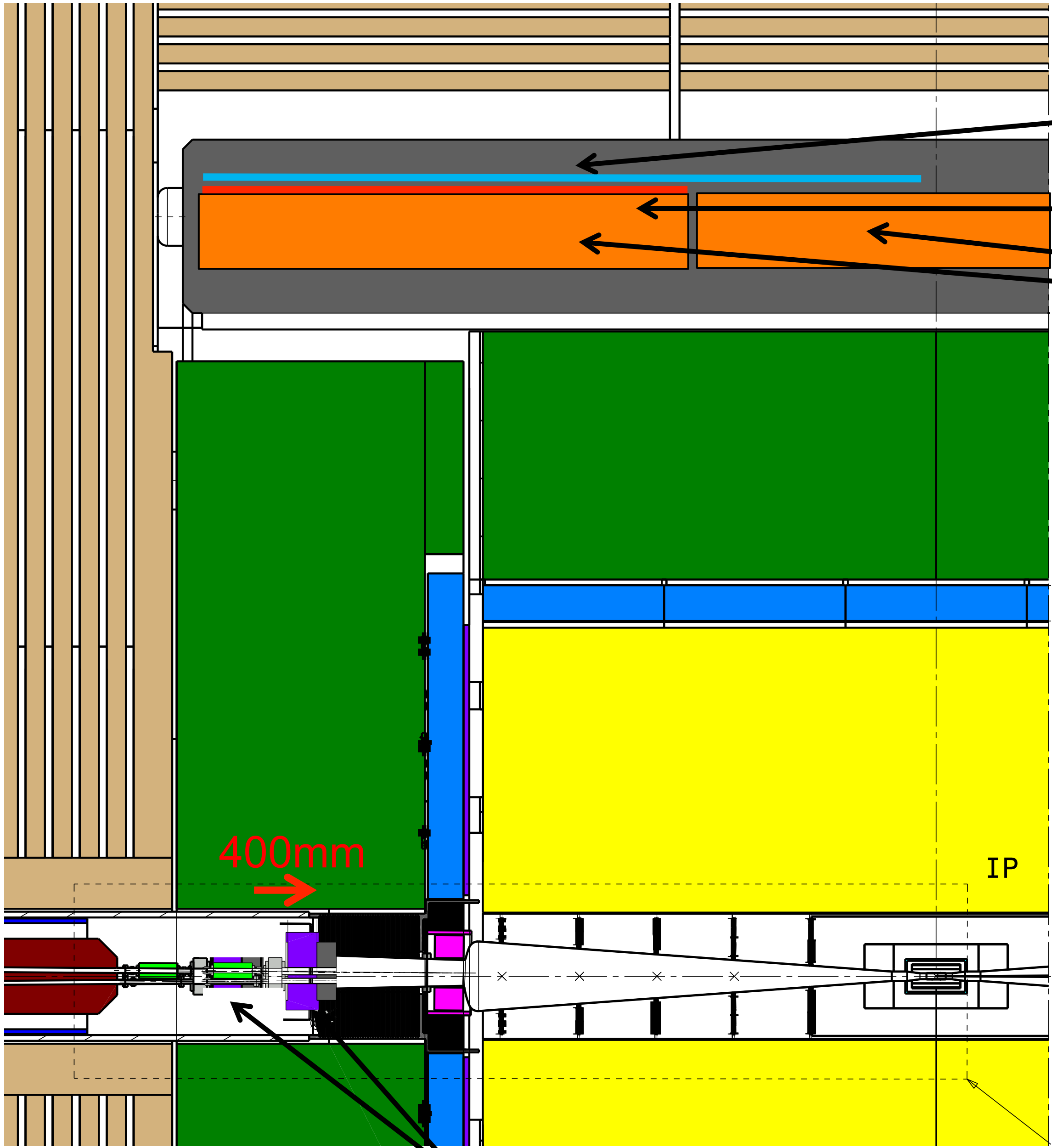
*For ILD this coil needs to be rotated 90 degrees to create horizontal field, Bx, instead of By shown. Also the ILD yoke with enhance the the peak fields shown while truncating the long-range field tails of this air coil at the yoke ends.

Solenoid – Beam Cal

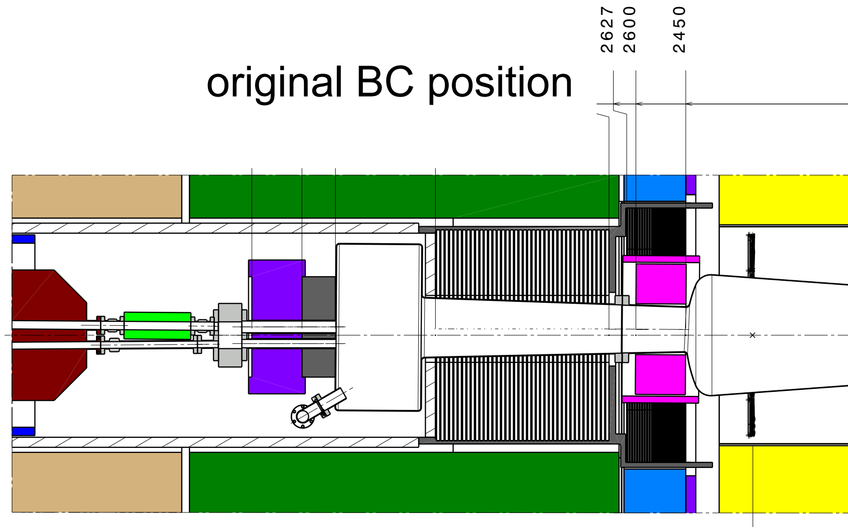




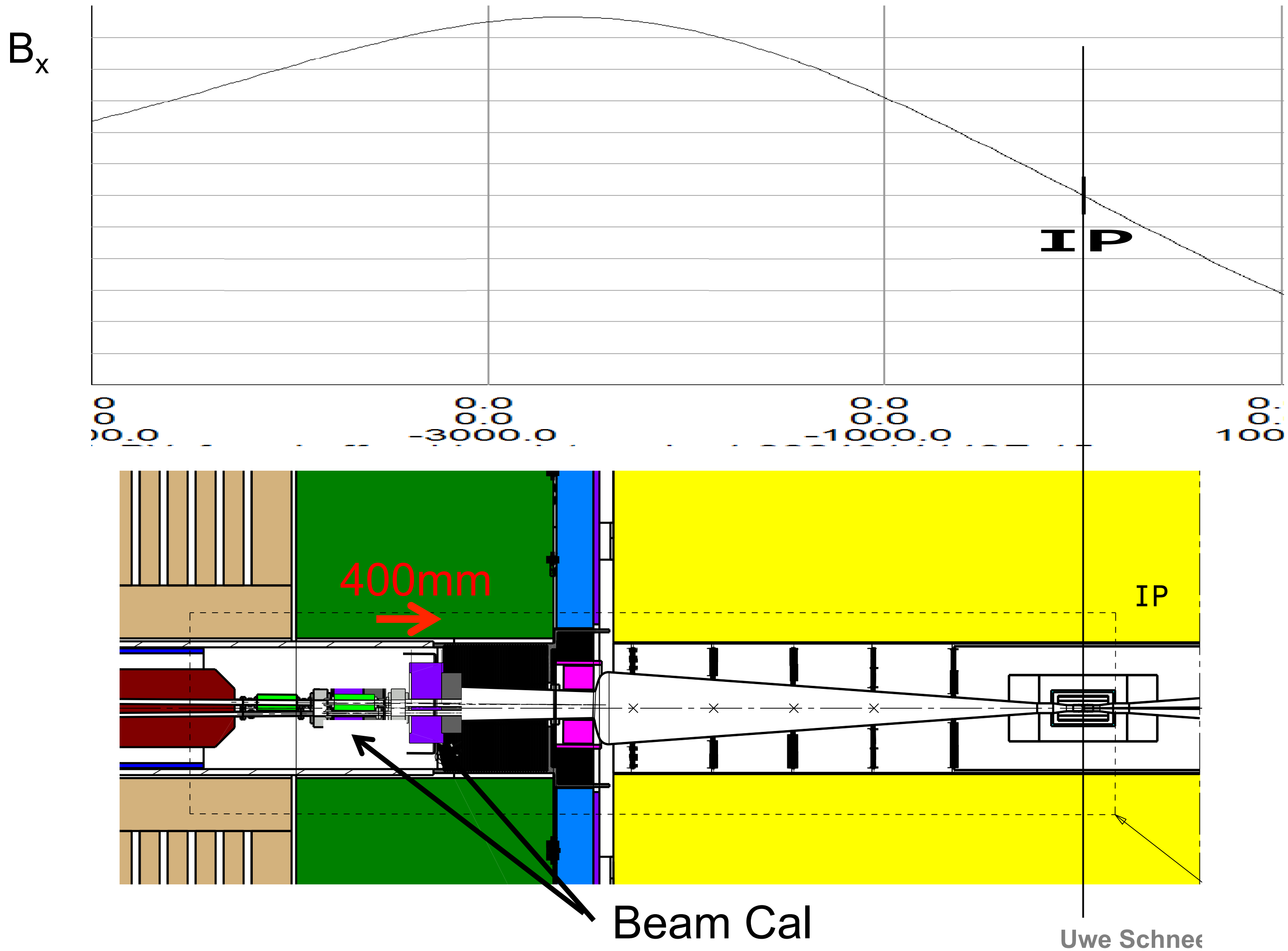
Solenoid – Shifted Beam Cal (l* 4m)



Background simulation should be performed with shifted BC



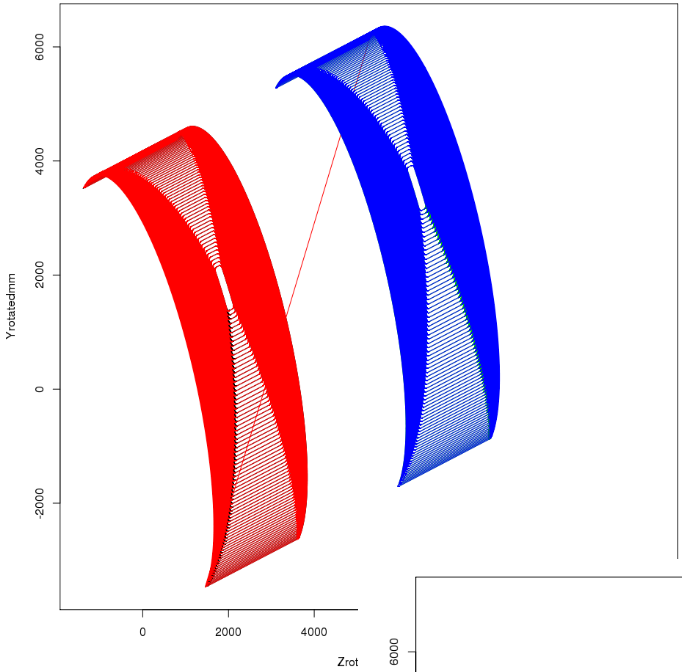
Solenoid – Shifted Beam Cal (I* 4m)

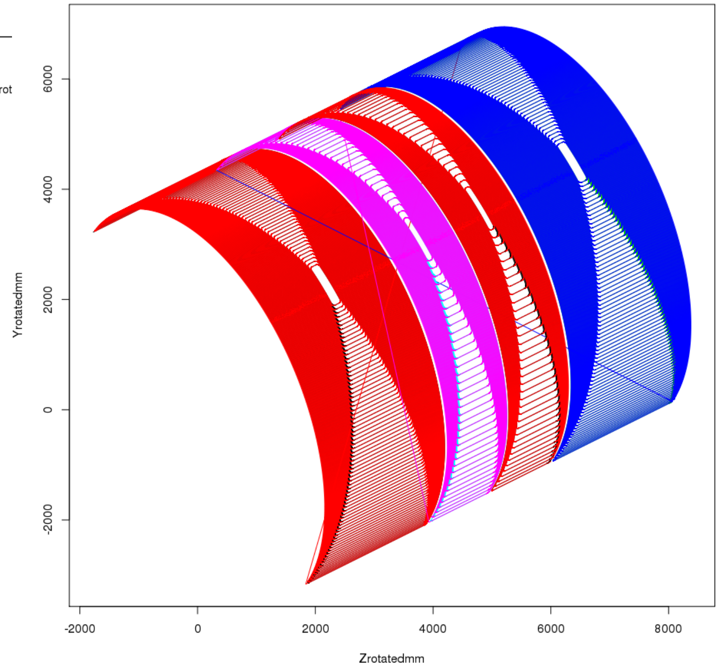


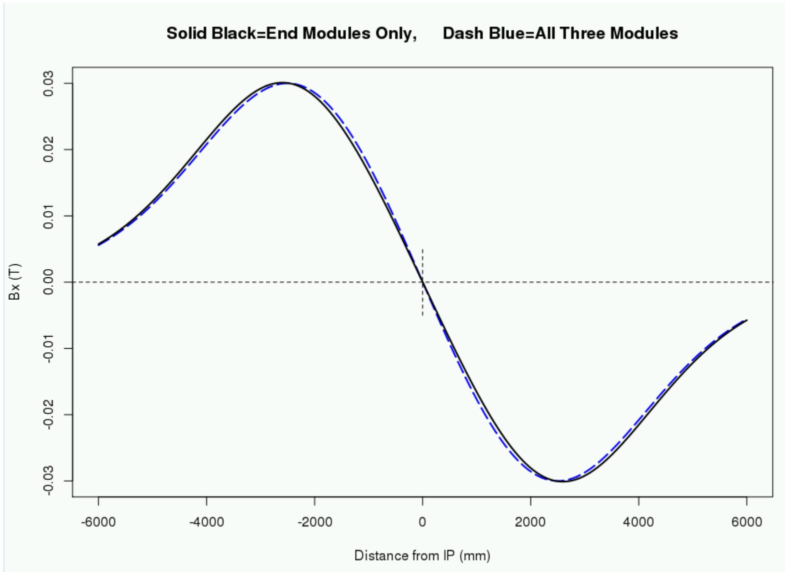
- Field for anti-DID in outer solenoid modules
- Max. field would be shifted towards IP if anti-DID over whole length of solenoid
- Field will be distorted by iron yoke

New Concept – Anti-DID in all Modules

B. Parker



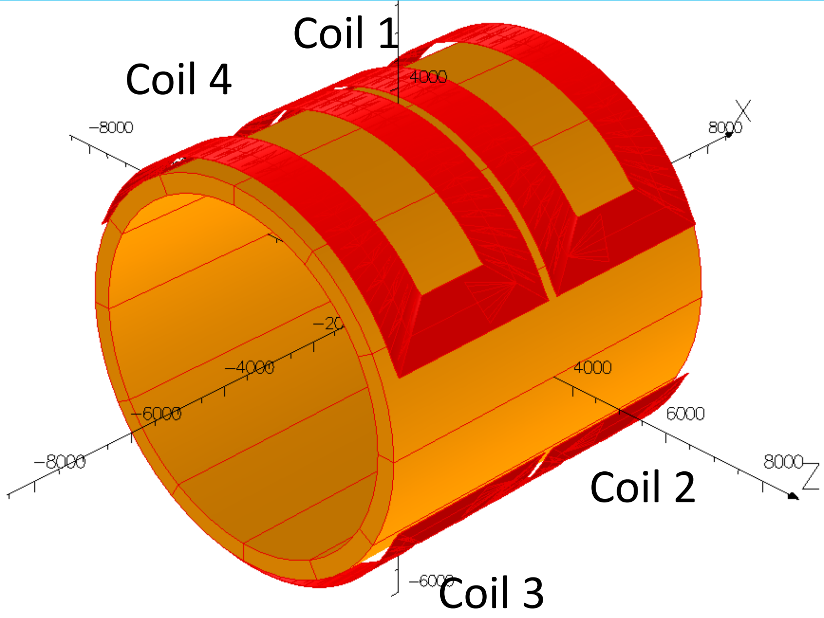


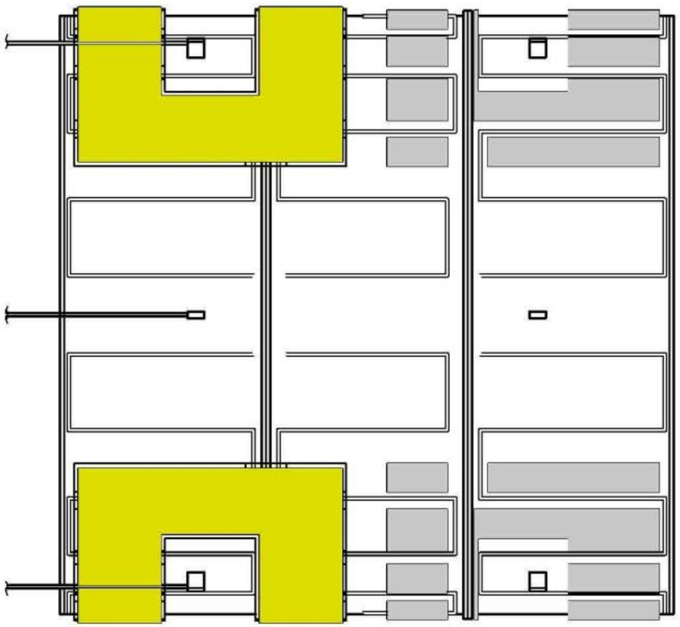


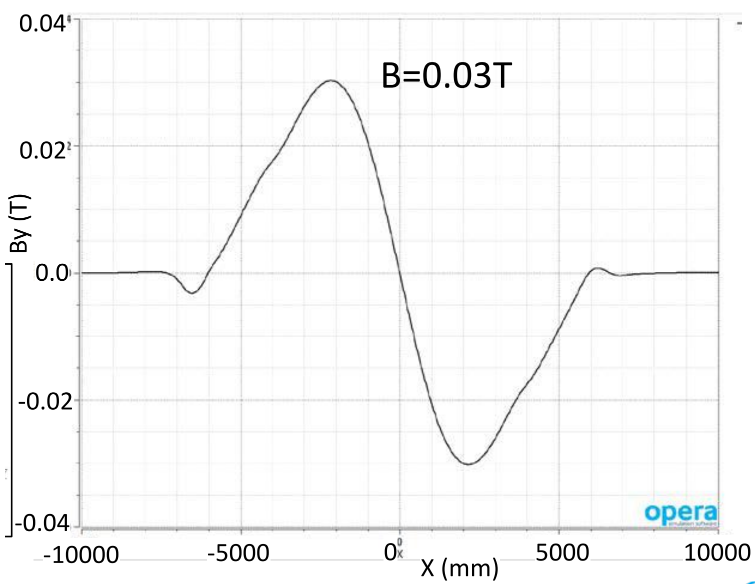
- No significant shift of peak field
  - Could increase current, but more complicated (peak current,…)
  - Not worth the effort
- Only option going back to independent anti-DID

Comments on Toshiba/Hitachi Design

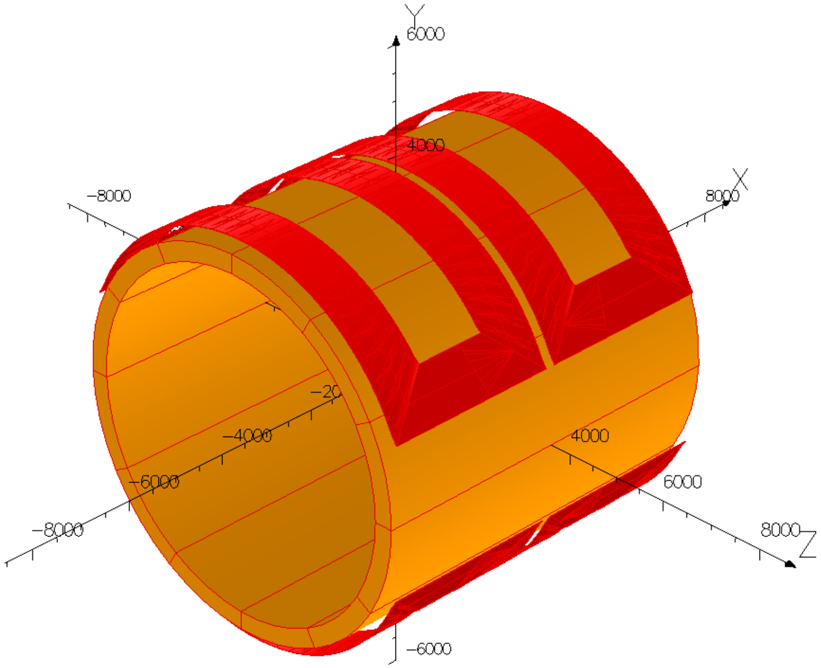
- Peak of B-field again shifted towards IP (+)
- Needs new, additional winding machine (-)
- Divided coil:
  - Field more inhomogeneous
  - Fabrication and transport easier.



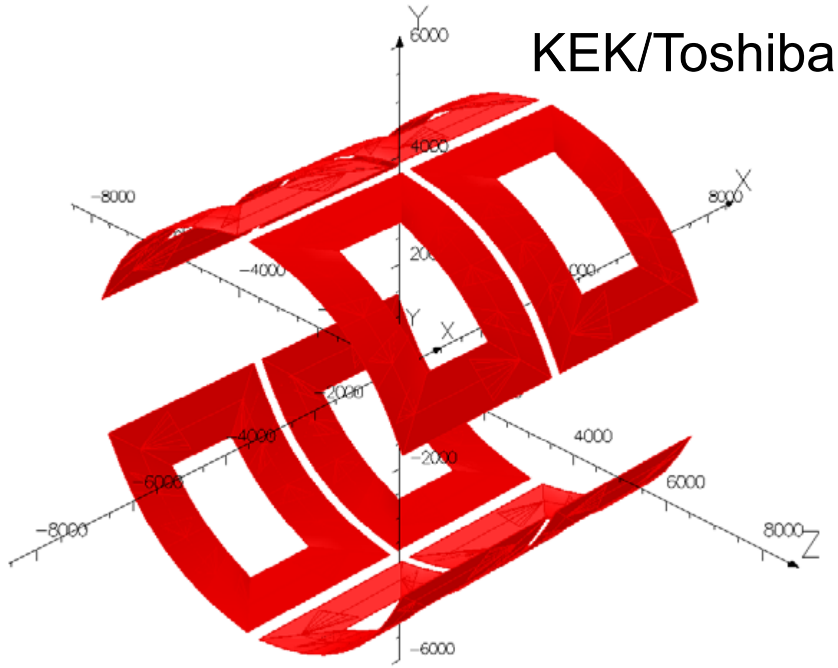


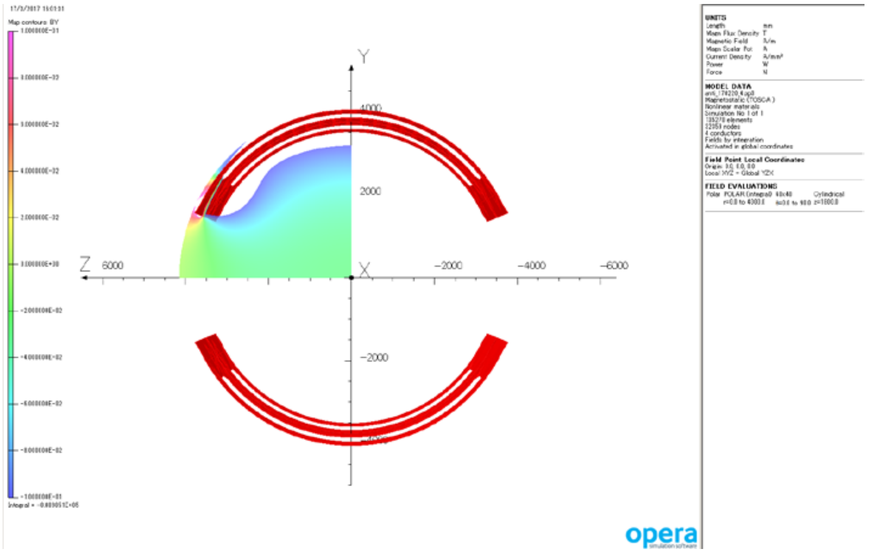


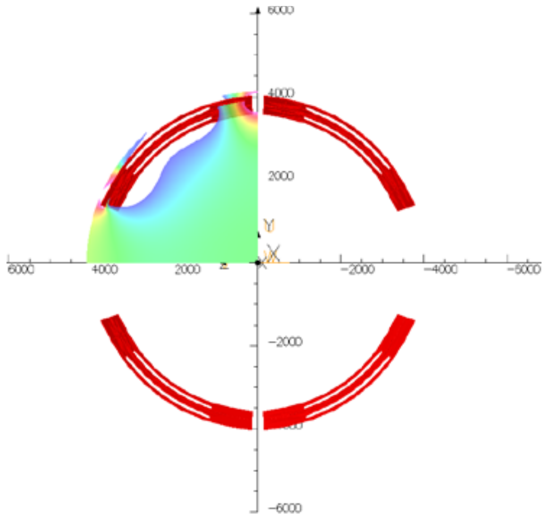
Two Options



KEK/Toshiba Design

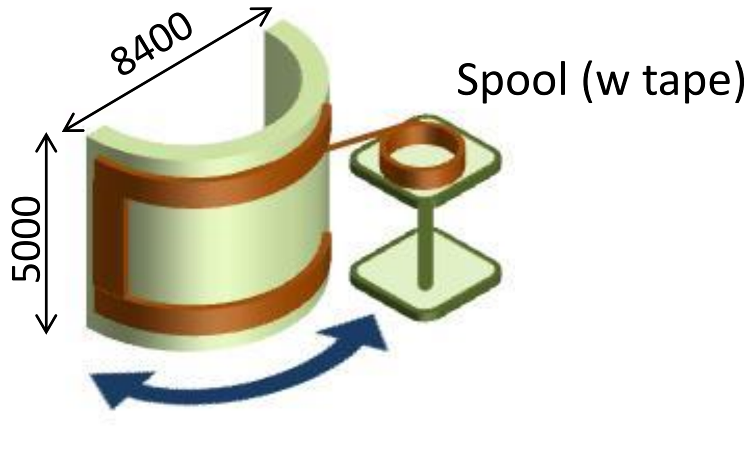




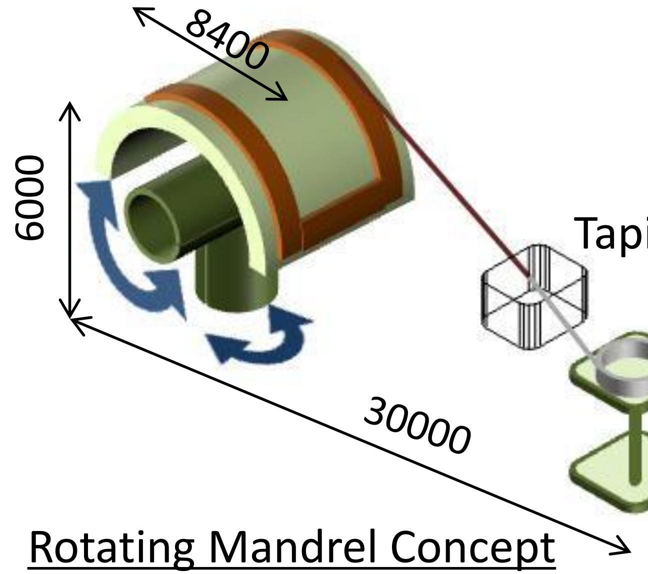


Fabrication Methods Hitachi

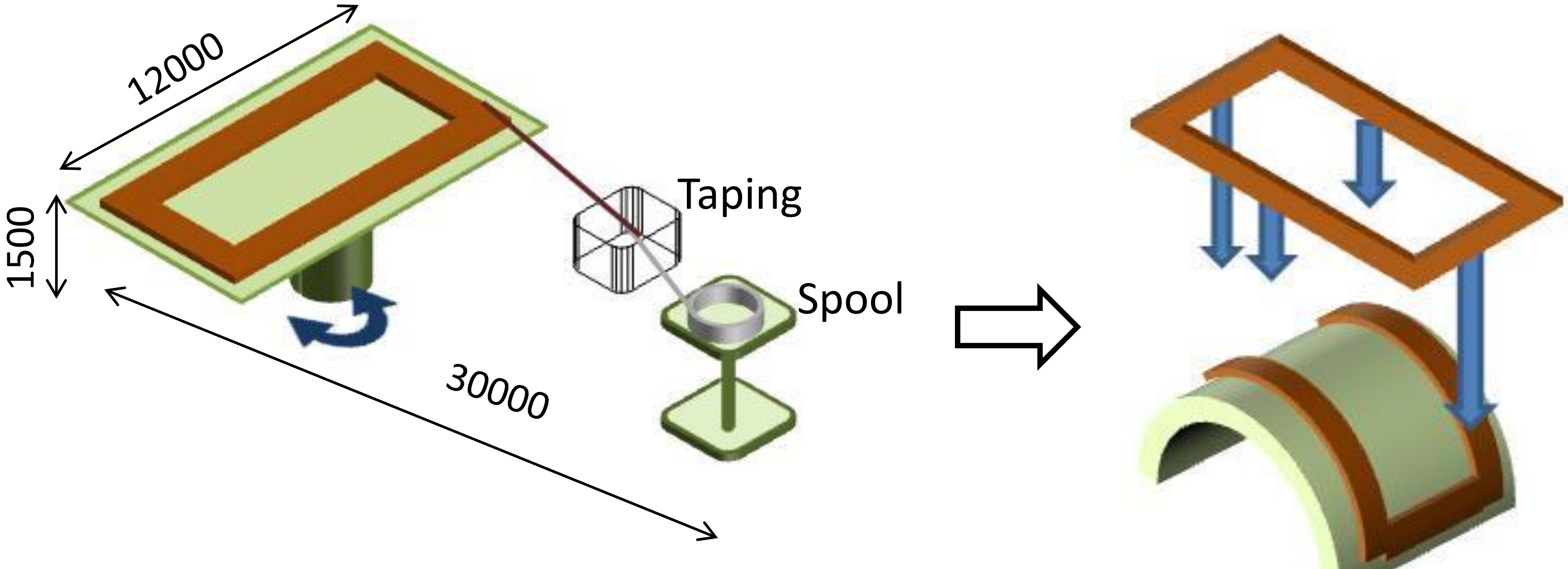
Slide Y.Makida



Moving Spool Concept



Rotating Mandrel Concept

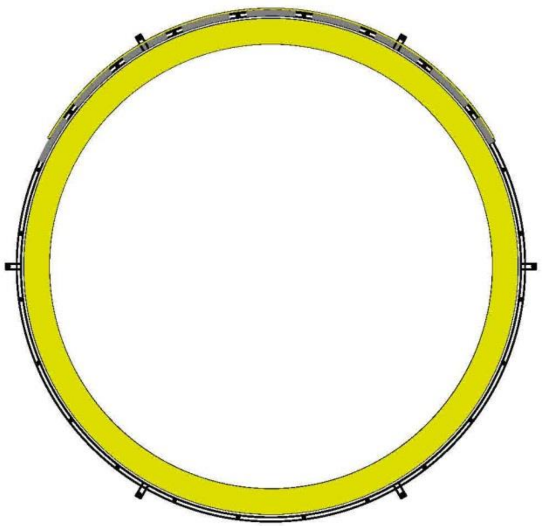


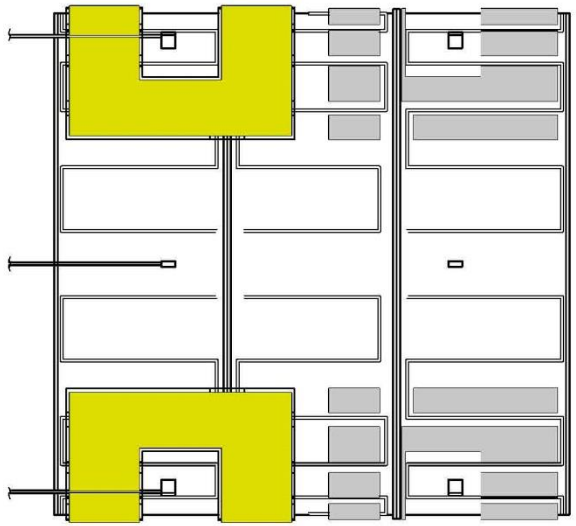
Racetrack winding and Coil Bending

Anti DID Support

Slide Y.Makida

Anti-DID Coils are Directly fastened on Solenoid Shell





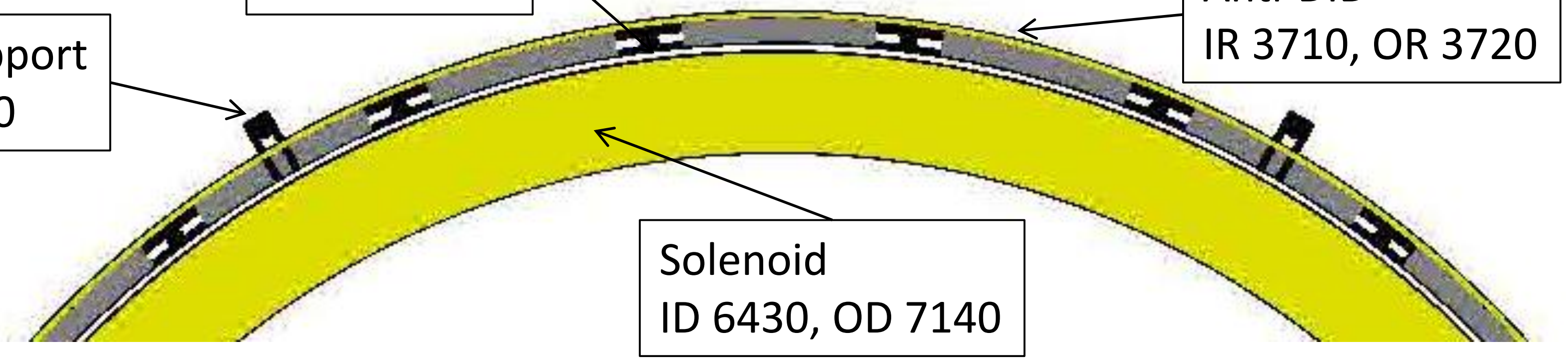
Cooling Pipe
Forced Flow Scheme
Thermo-siphon Flow
is also Possible

Both factories have a large turning stage where each support cylinder is set and end-mill machined.

Cooling Pipe
ID 30, OD 36

Anti-DID
IR 3710, OR 3720

Axial Support
PCD 7600



Solenoid
ID 6430, OD 7140

Conclusions

- Good understand of field calculations
- Studied alternative yoke and coil geometries
  - 30 or 45° barrel/end cap transitions slightly better, but more complicated and reduced access
- Field compensation using outer solenoid
  - Double solenoid w/o yoke no option
  - Inner yoke with compensation

    Not really. Large electrical power in case of normal conducting coils.
- Reduced yoke with shielding platform looks quite attractive
  - Significant cost saving
  - Have to check radiation shielding

    Recent progress (T. Sanami)

Conclusions

Recent progress

- Independent anti-DID versus integrated into solenoid modules

  Independent anti-DID

  - Issue with support and forces
  - Max. field close to IP

  Integrated into outer solenoid modules

  - Recently, good progress on conceptual design
  - Max. field closer to Beam Cal
  - (Integrating anti-DID into all three modules not worth the effort)
- Back to more traditional like dipole coils
  - Helical/tilted compensating solenoids more difficult to integrate into solenoid modules
- Good progress on Toshiba/Hitachi design
- Need background simulations (in progress)