ILD Yoke/Coil Alternatives

MDI Workshop, KEK

Sept 2017

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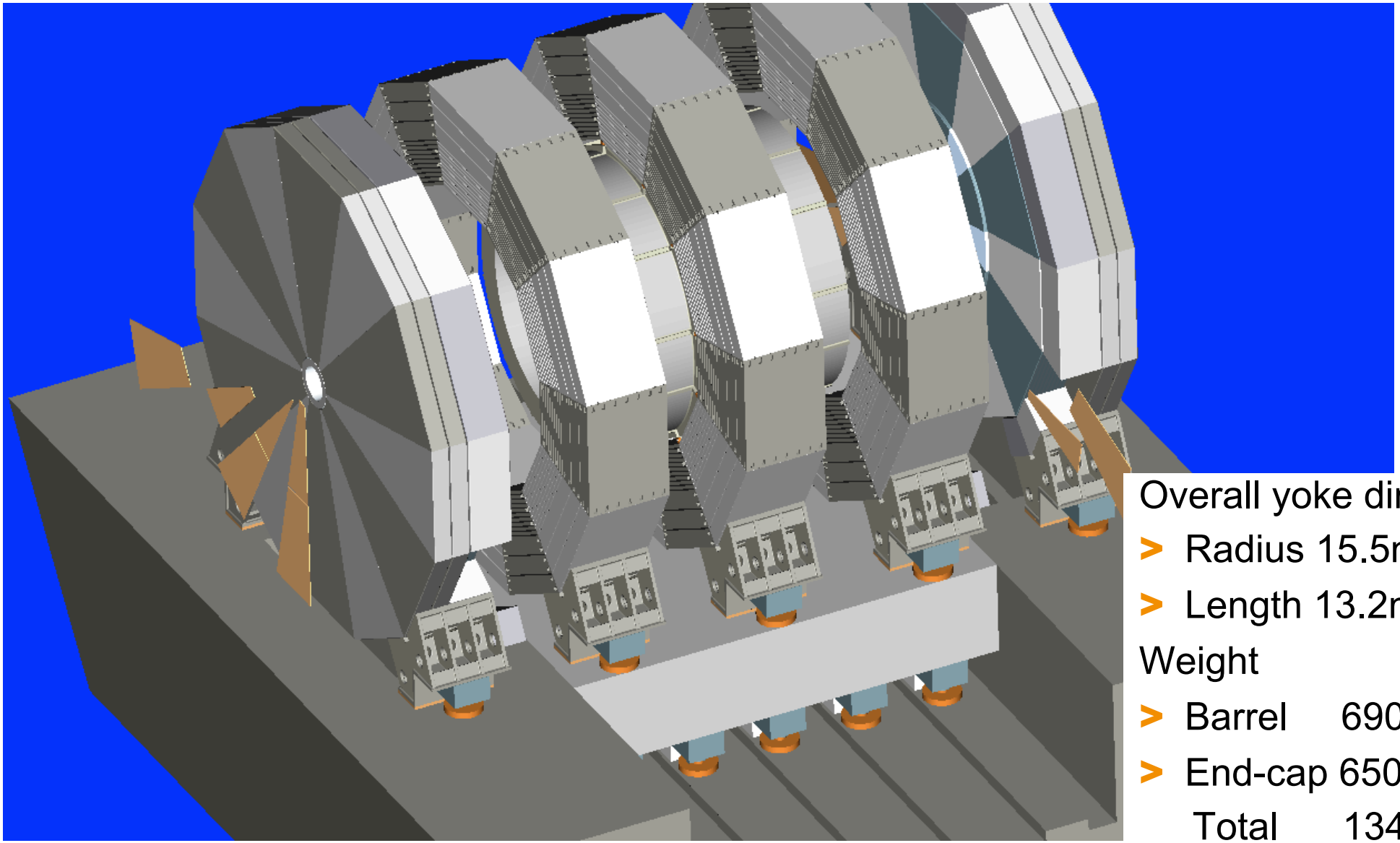
HELMHOLTZ ASSOCIATION

DESY

Outline

- Yoke overview and cost
- Yoke (and coil) options
- Shielding wall
- Conclusions

Present Design



Overall yoke dimensions

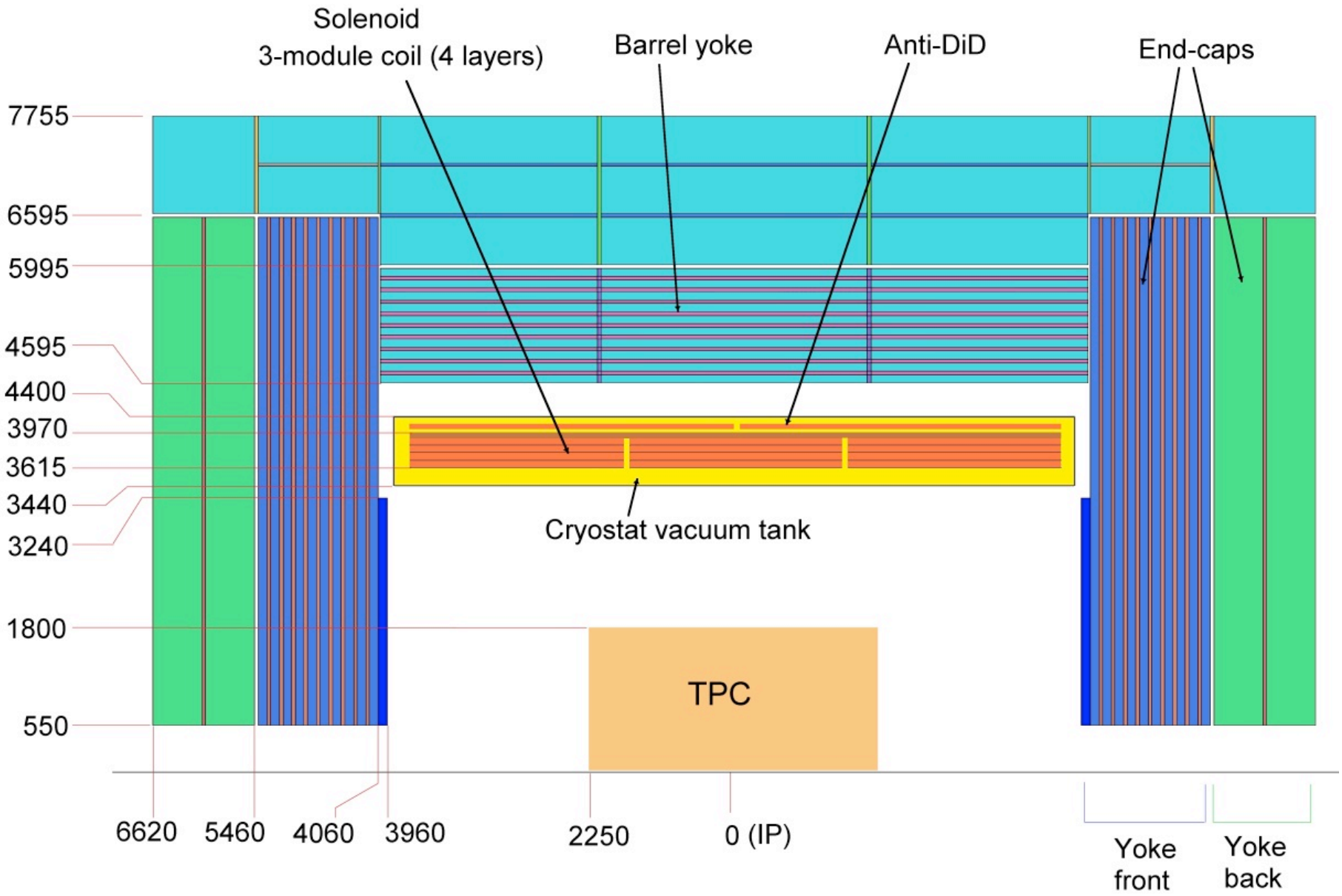
- Radius 15.5m
- Length 13.2m

Weight

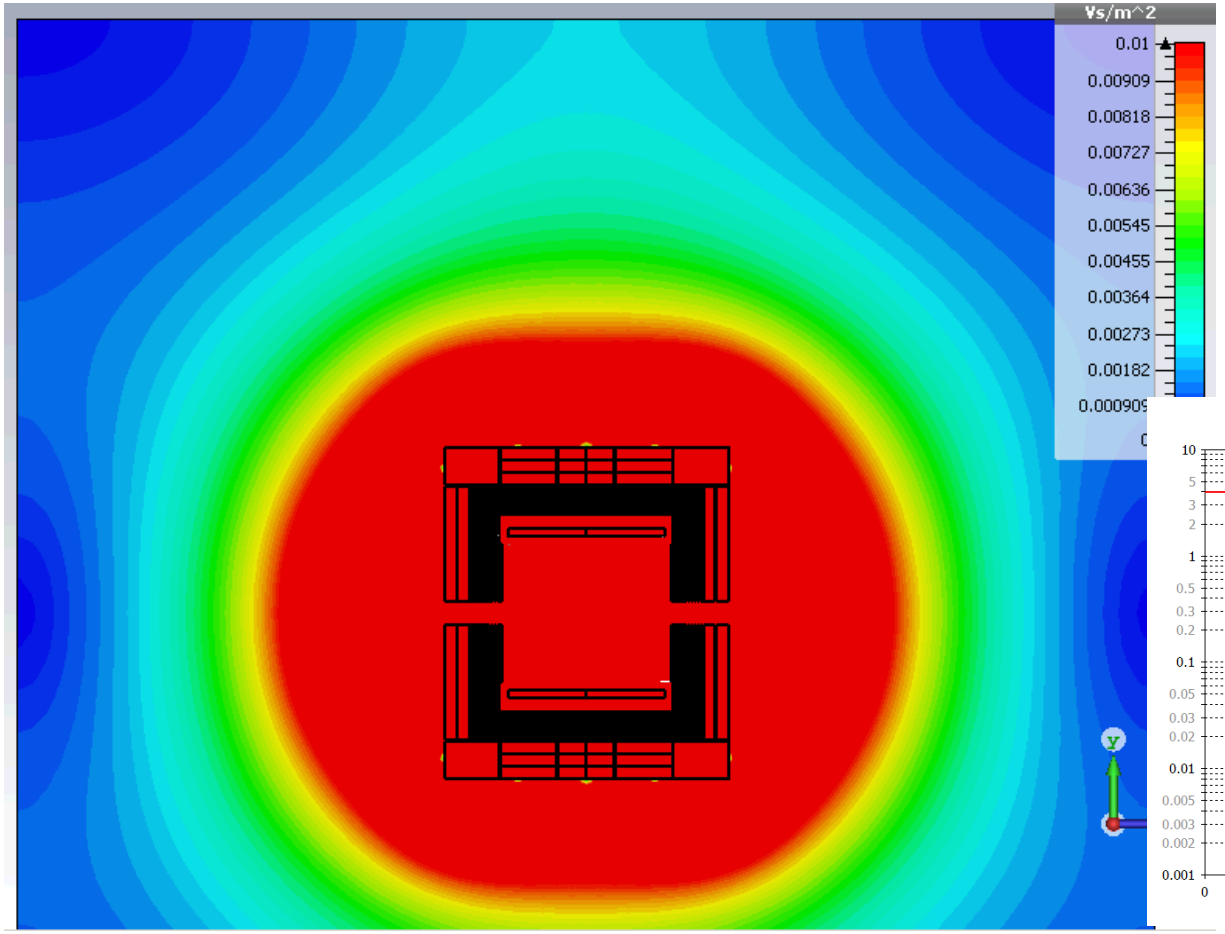
- Barrel 6900t
- End-cap 6500t

Total 13400t

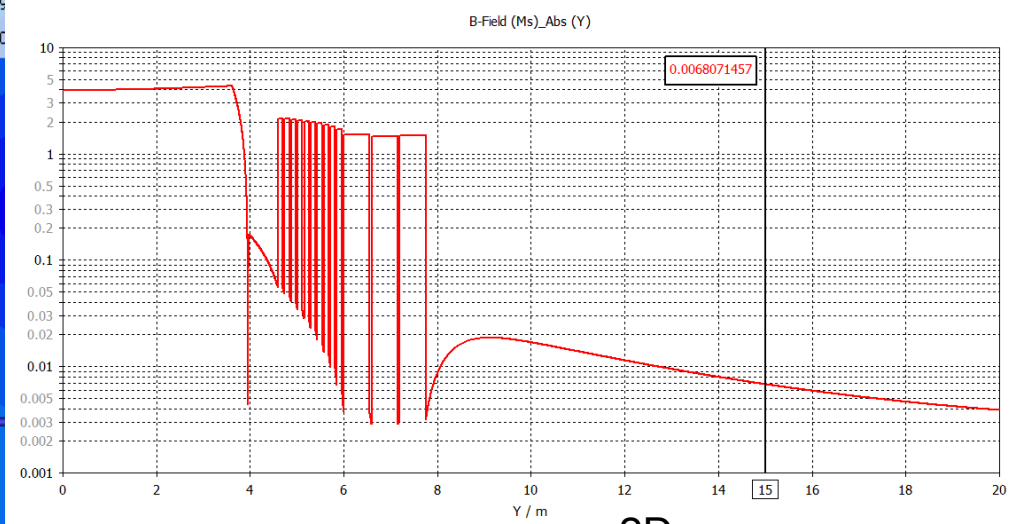
Coil and Yoke Cross-Section



Field Calculations – Yoke Thickness



B vs. x



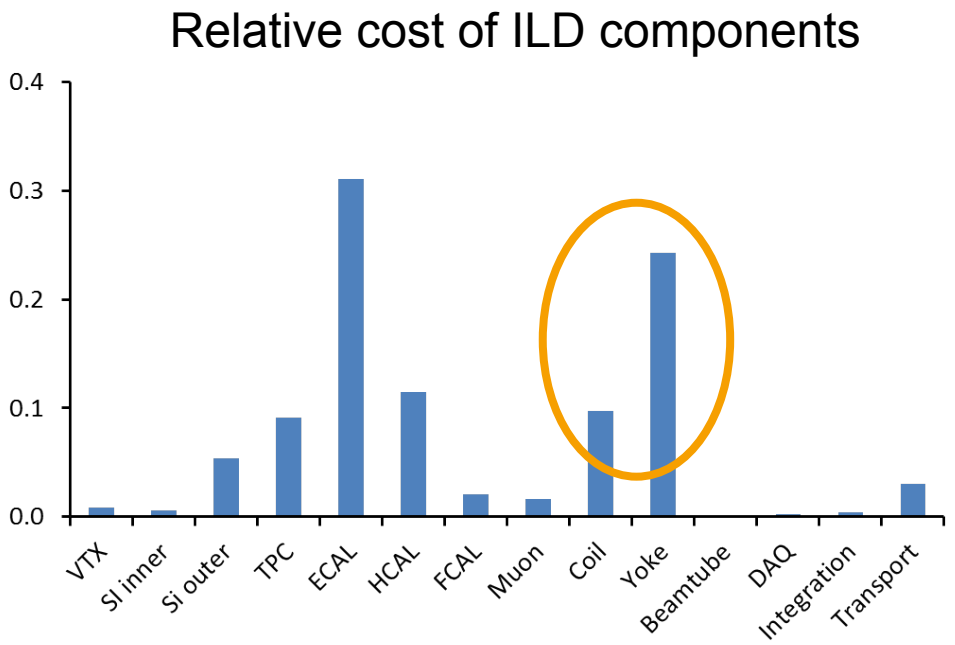
2D

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?

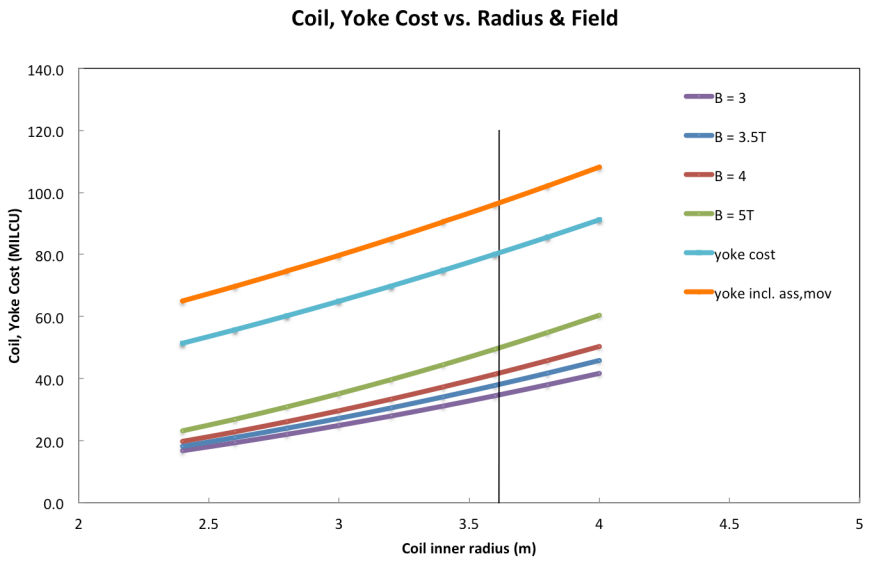


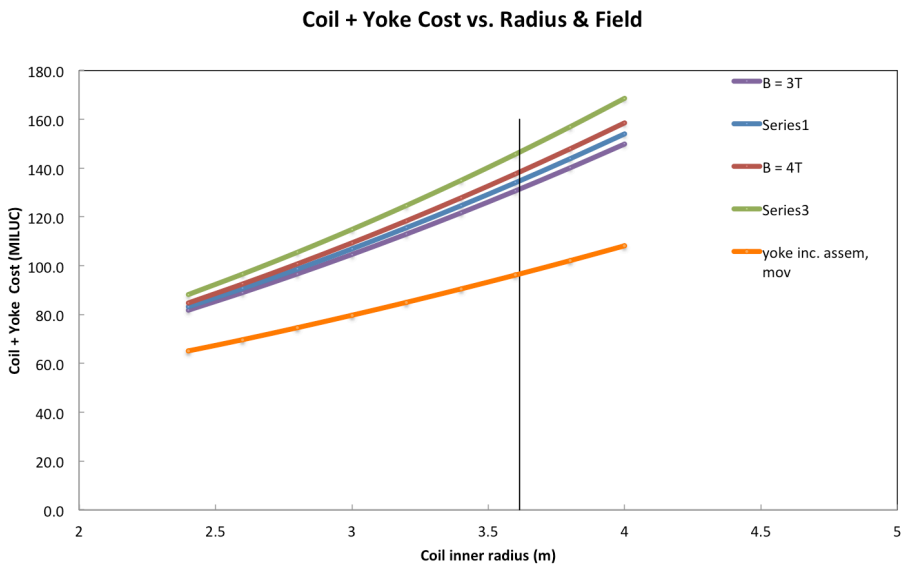
Magnet expensive part of ILD

Yoke Cost vs. Size and Field

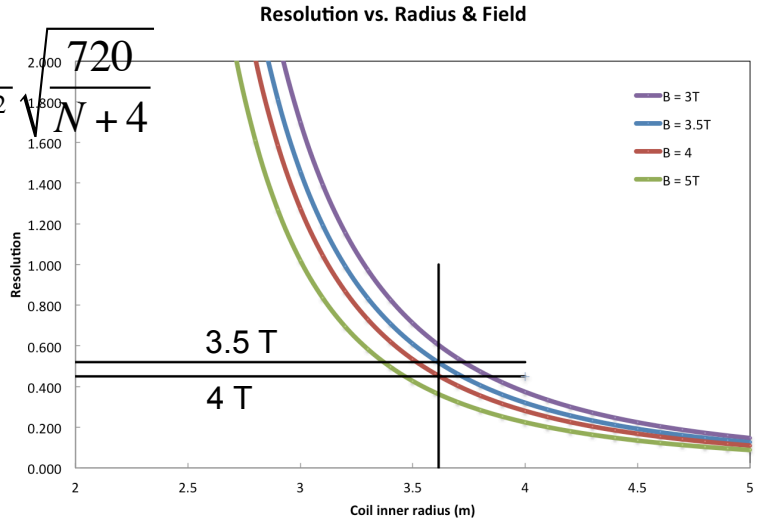
- Rough cost estimate similar to DBD (1 ILCU = 1$ = 0.97€ , 1 € = 1.5 CHF)
- Coil cost using parametrization of A.Herve

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





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

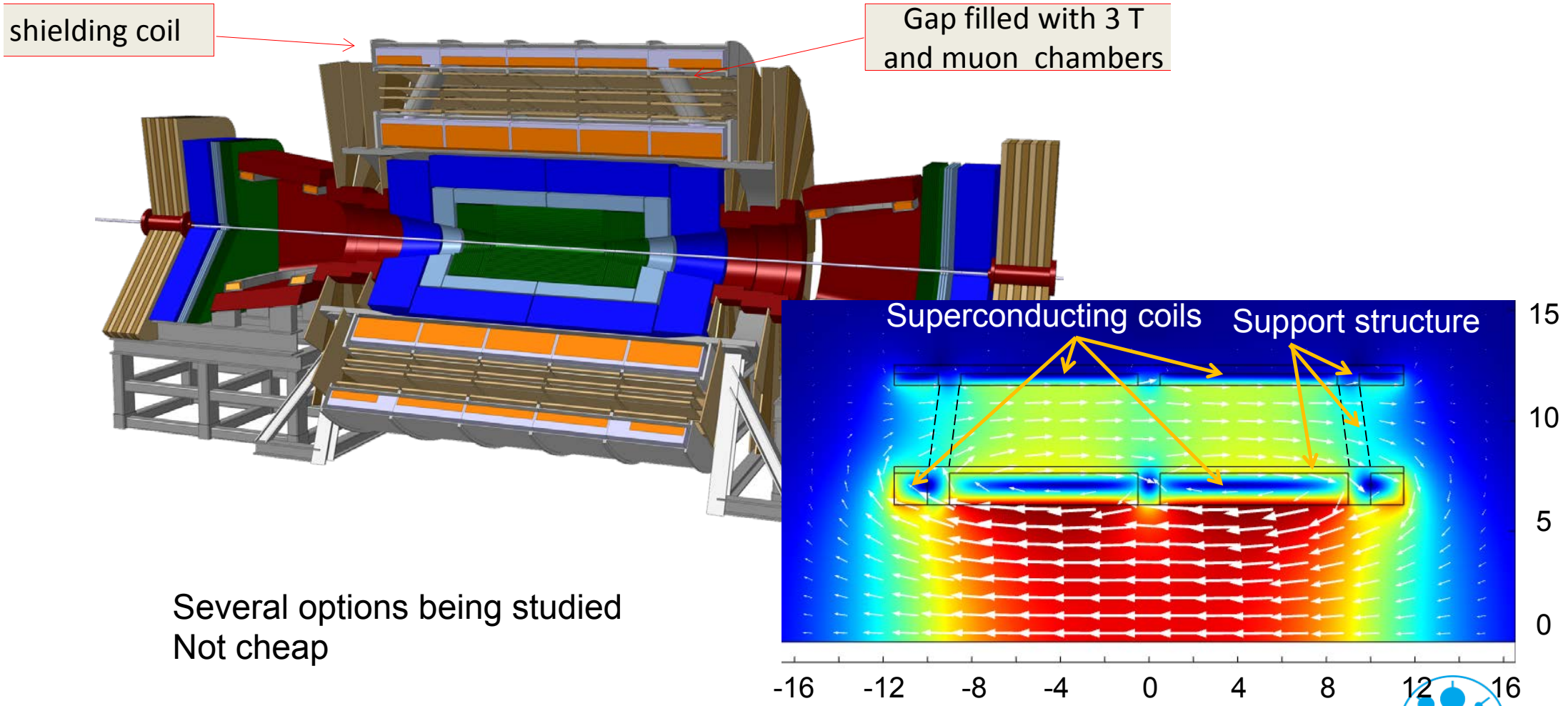


	Cost of steel (MILCU)		Steel and Coil (MILCU)	
thick plates	ri 3.615	ri 3.165	ri 3.615	ri 3.165
B3	81	68	123	104
B2	66	55	108	91

Double Solenoid Without Yoke

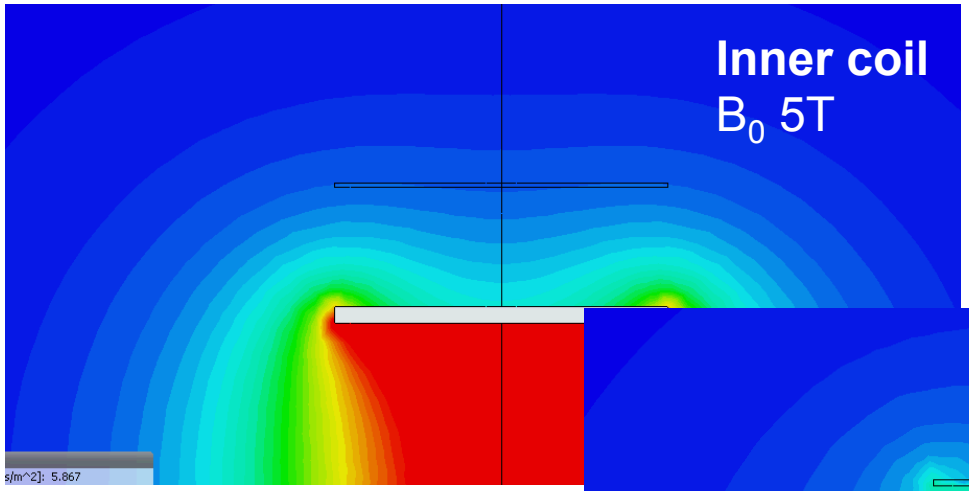
Flux return by outer solenoid: much lighter, muon tracking space, possibly cheaper

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

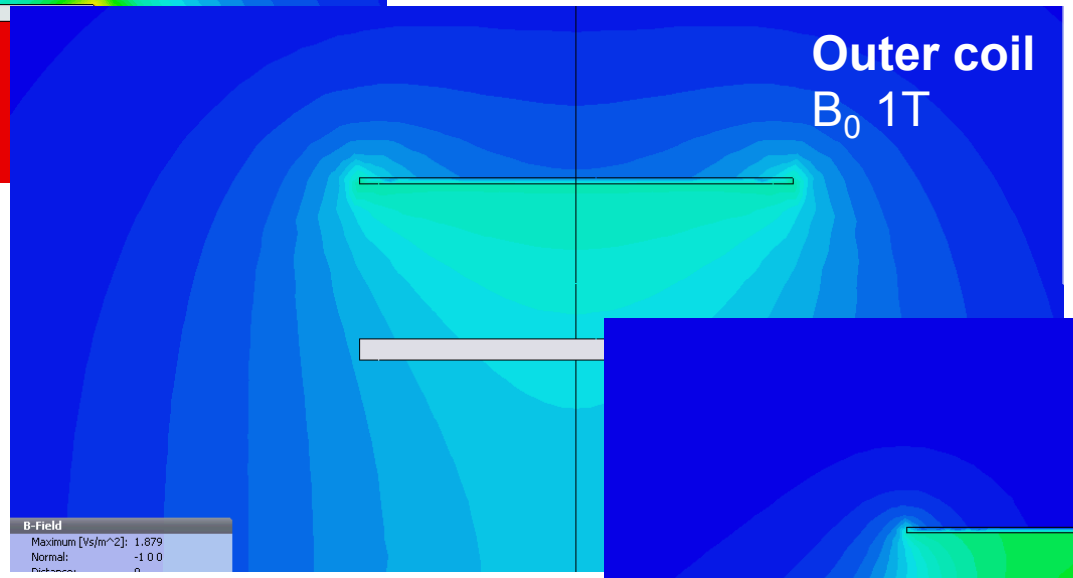


Several options being studied
Not cheap

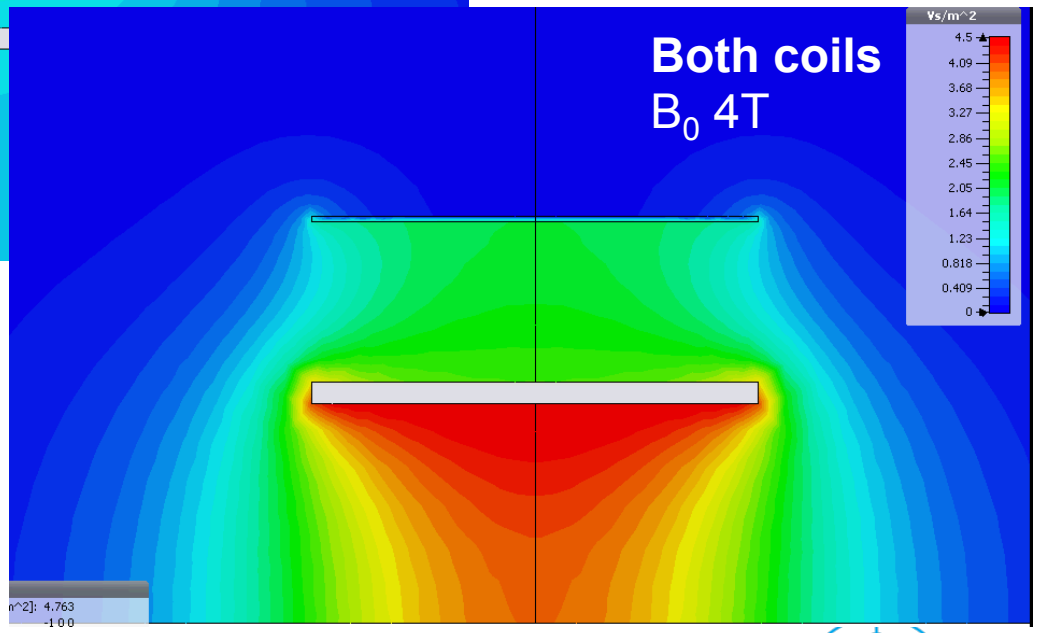
Double Solenoid Without Yoke



ILD coil with additional outer (superconducting) coil



Scale 4.5T



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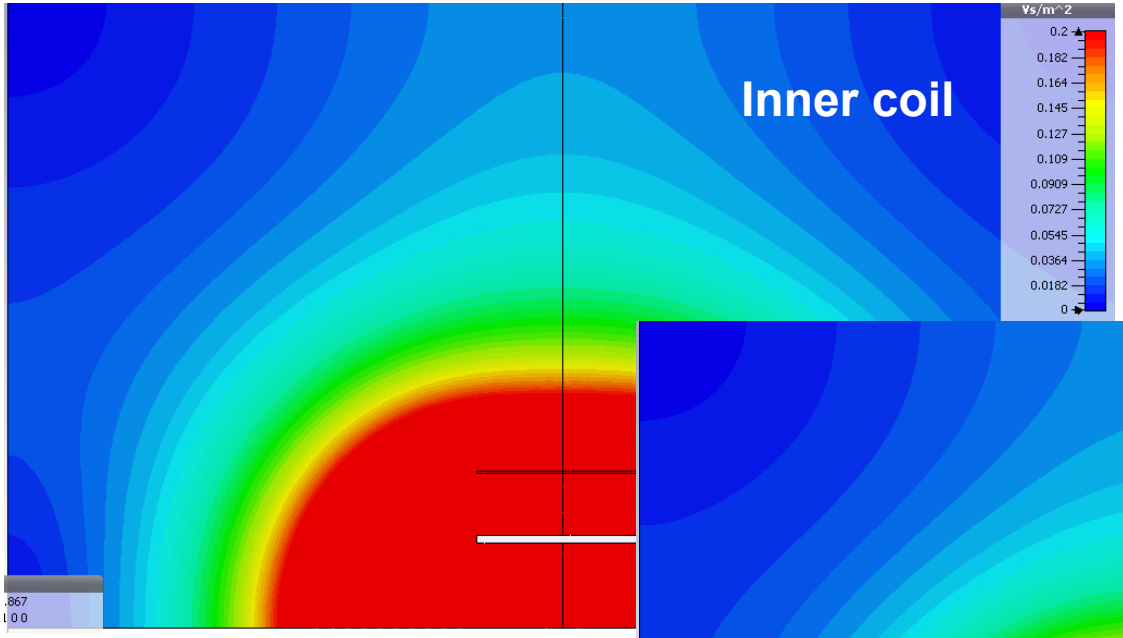

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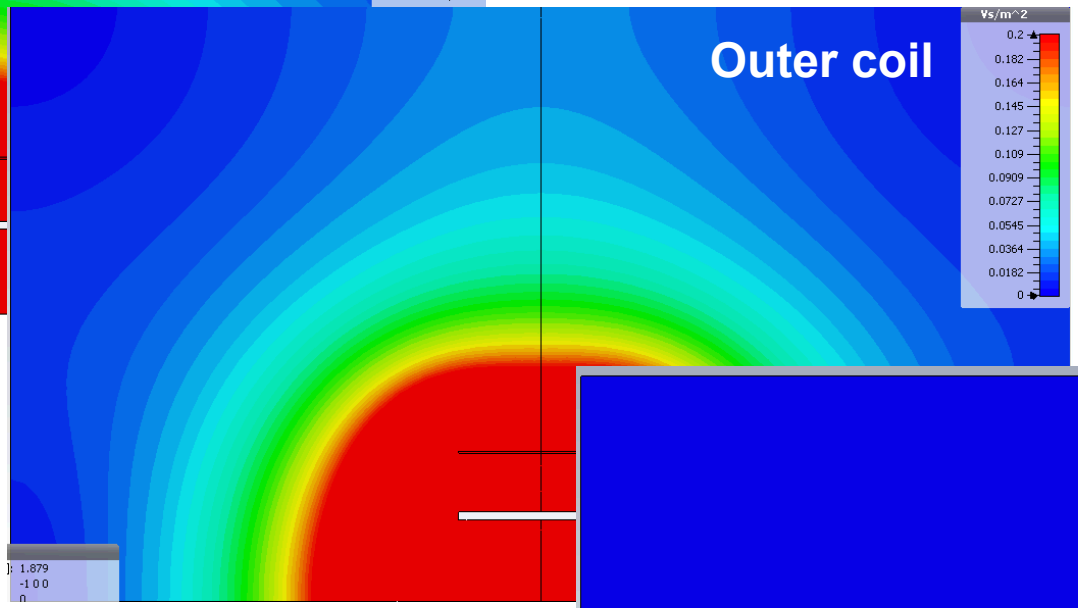
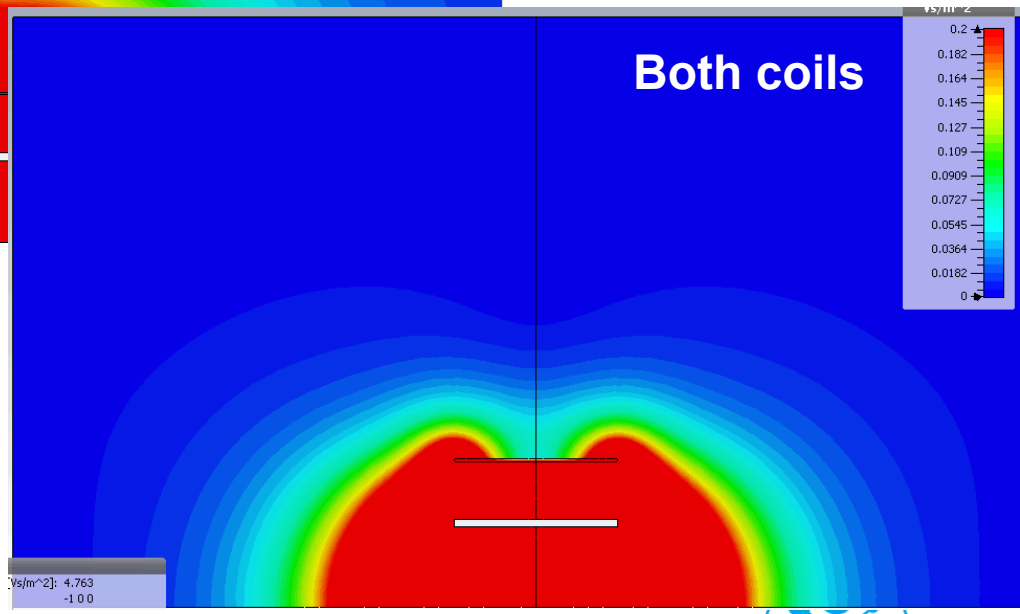
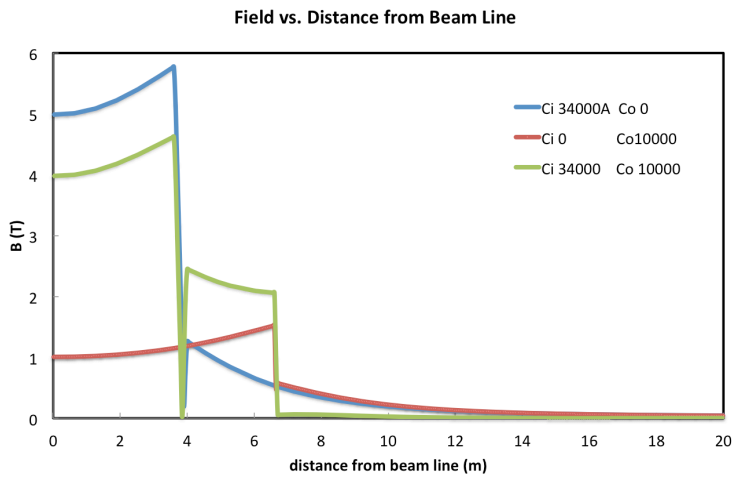


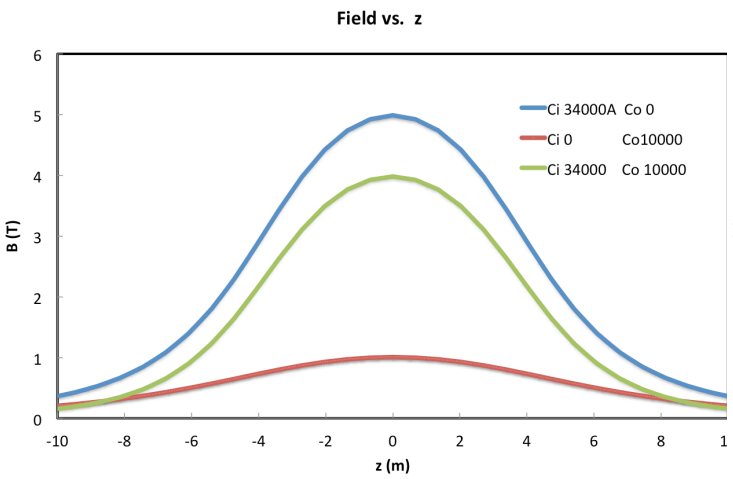
Scale 0.2T

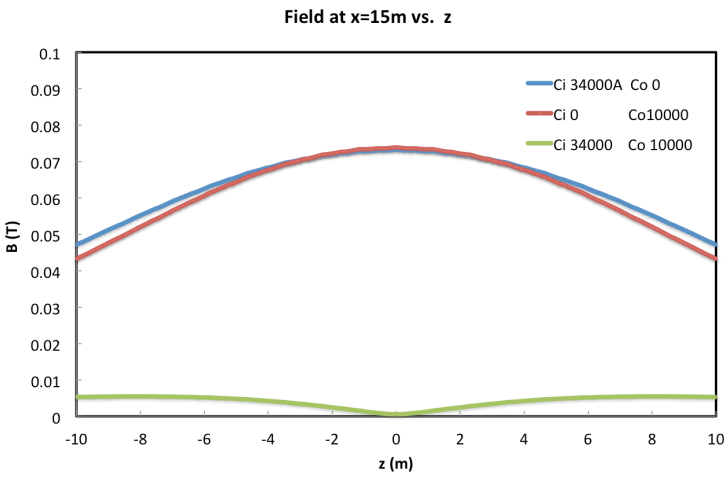


- Stray field reduced by compensating coil
- Could be tuned, less dependent on field calculations

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

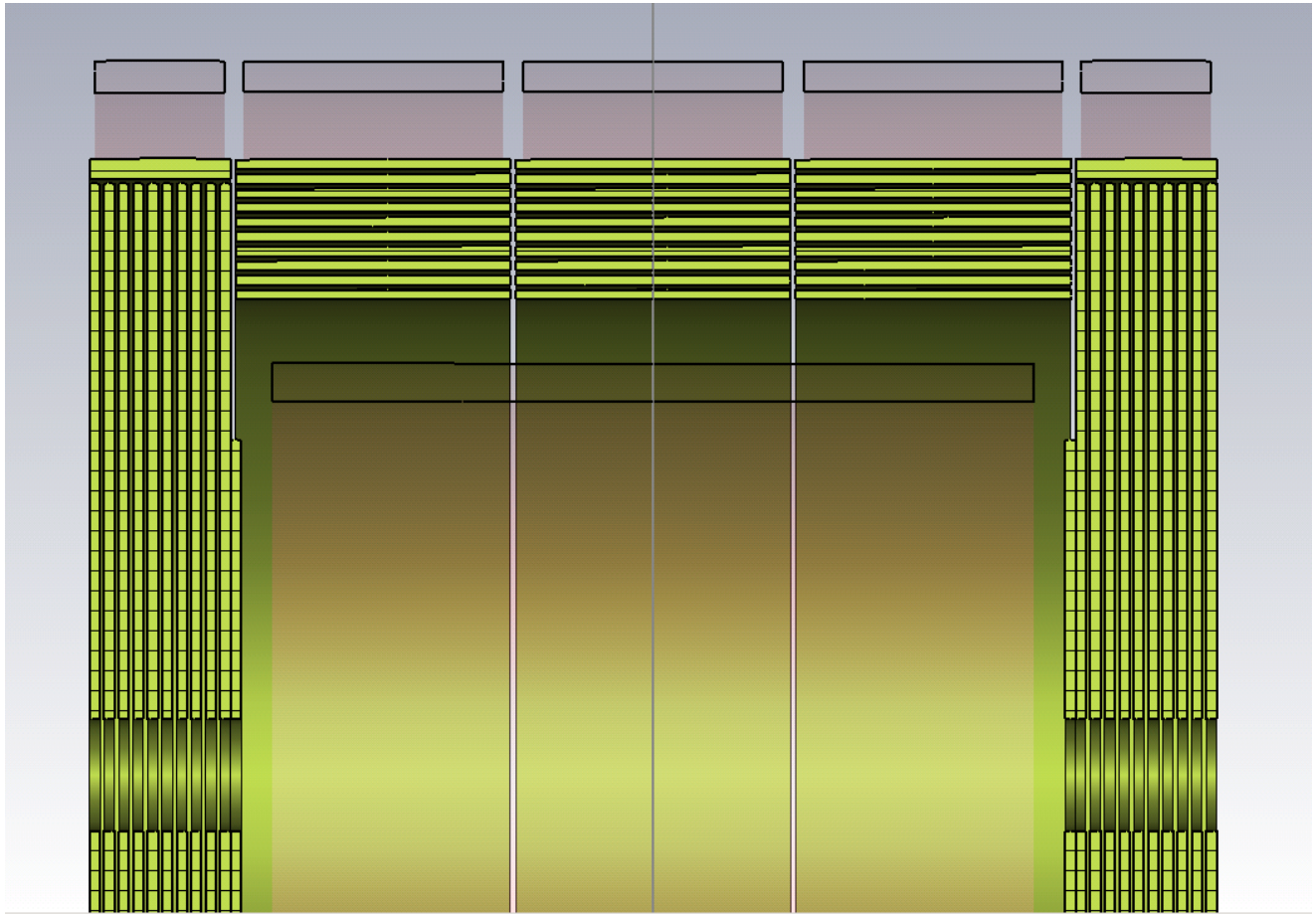
- Radiation shielding (concrete)
- Power supply for outer coil
- Infrastructure and larger cryo plant

Similar cost

Inner Yoke with Compensating Coil

Stray field reduced by compensating coils

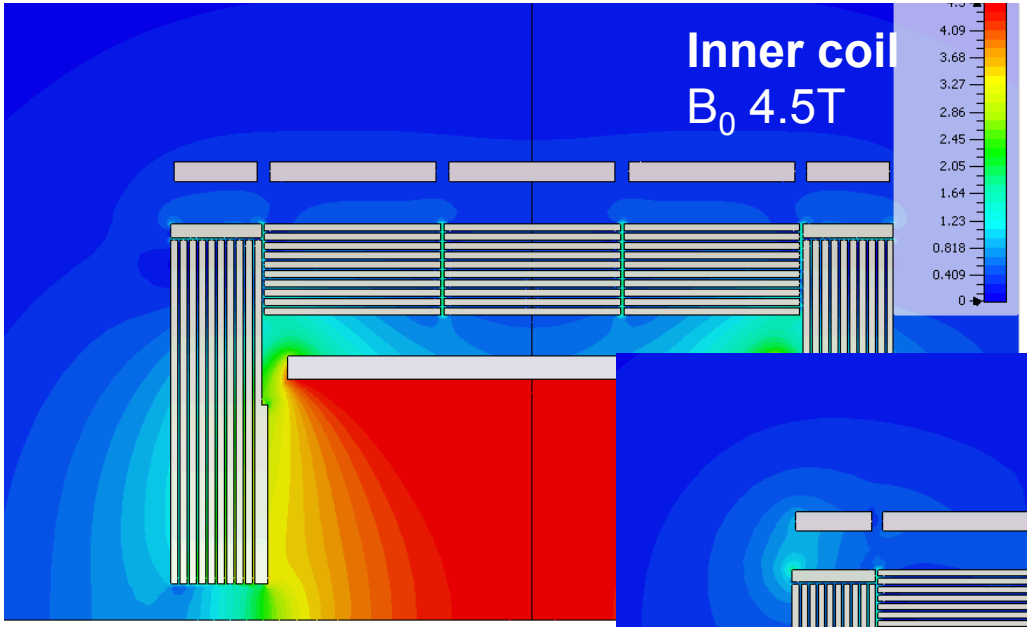
Radius reasonable choice, not optimized

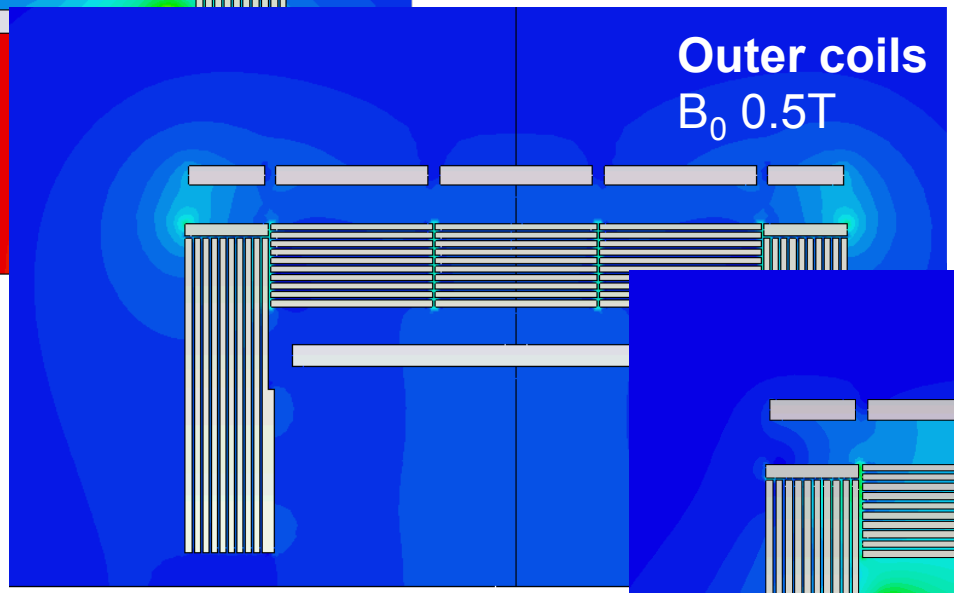


Yoke

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

Inner Yoke with Compensating Coil





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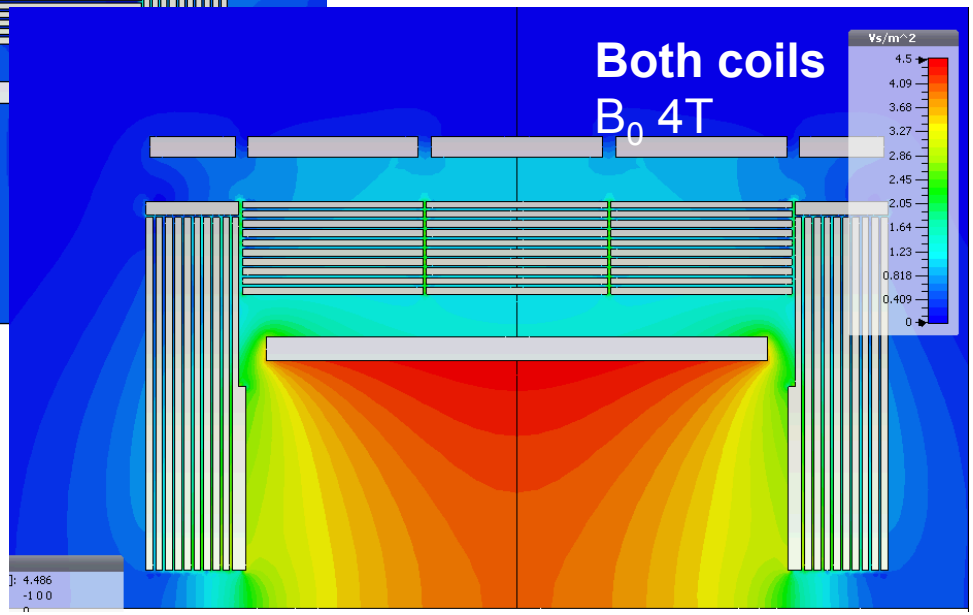
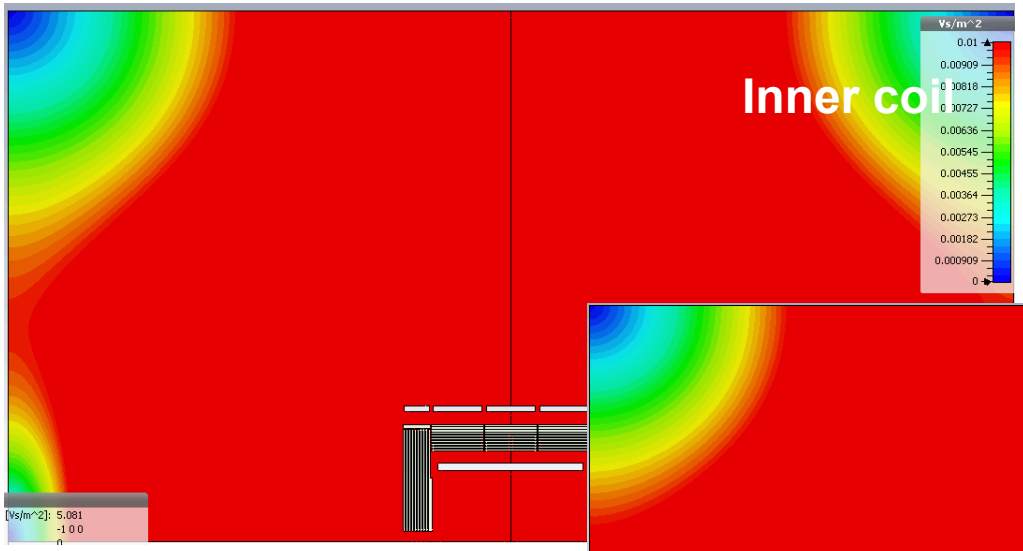
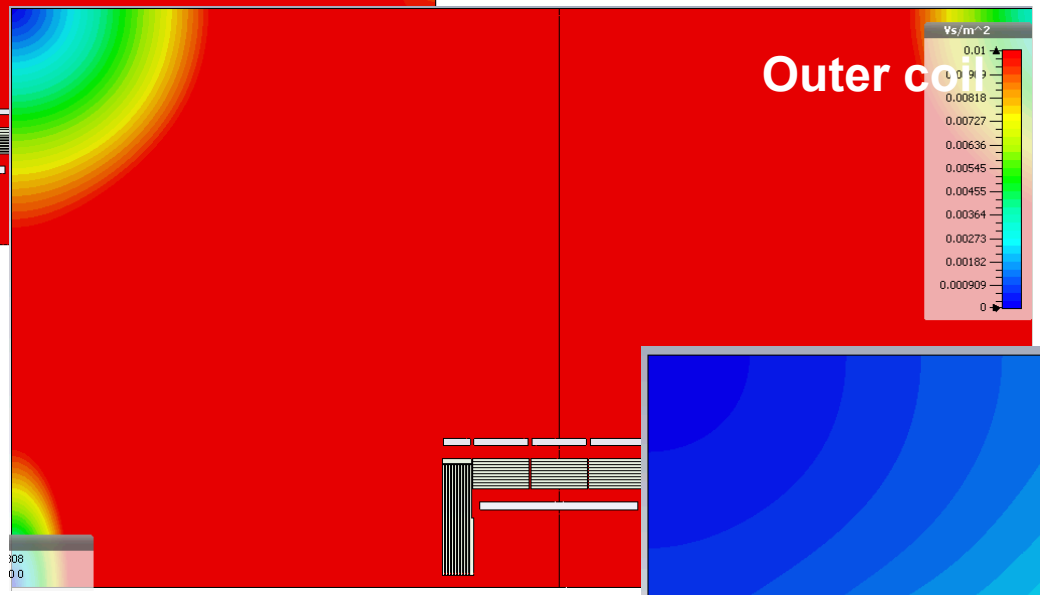


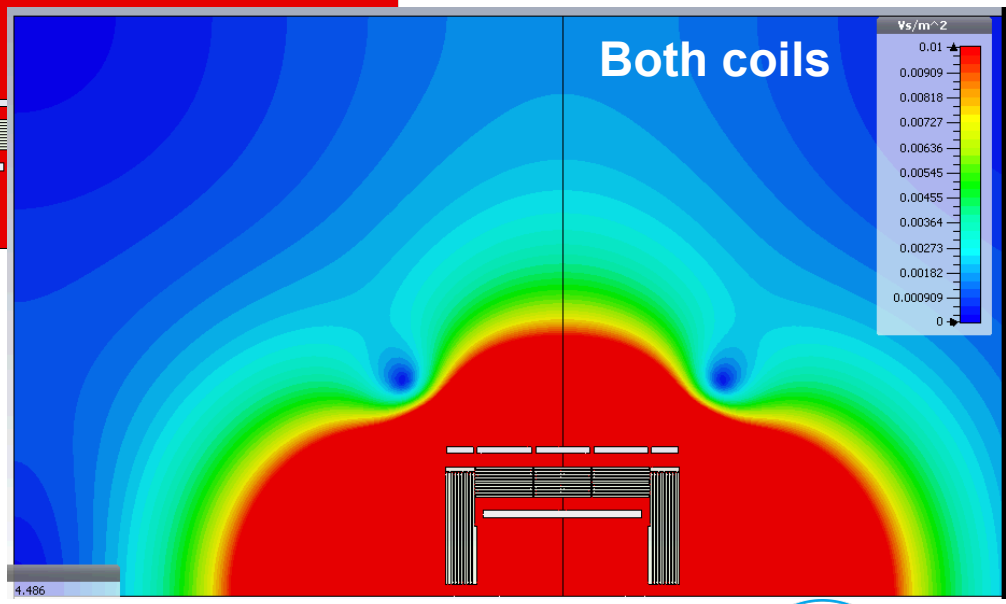
- Stray field reduced by compensating coils
- Could be tuned, less dependent on field calculations
- Reasonable choice of outer coil radius, not optimized

Inner Yoke with Compensating Coil





Scale 0.01T



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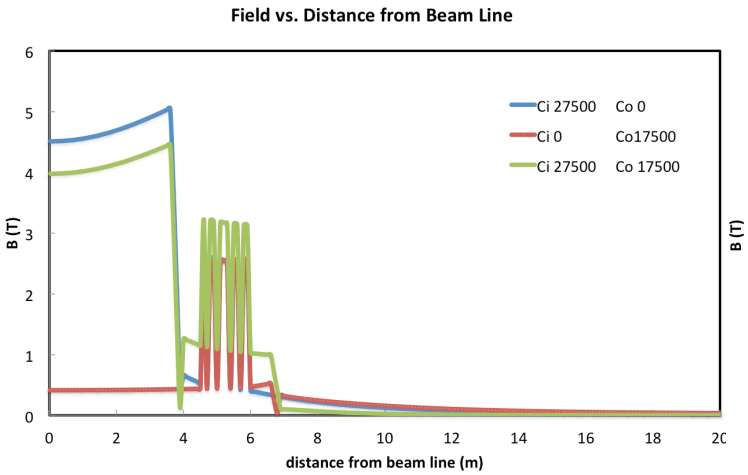
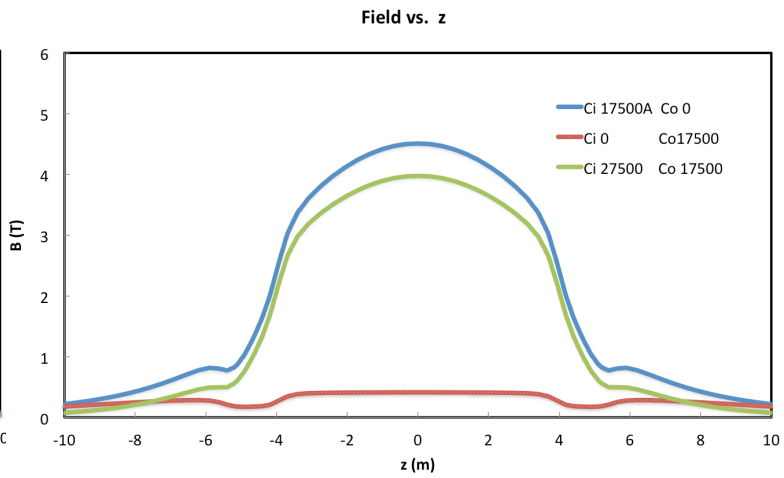
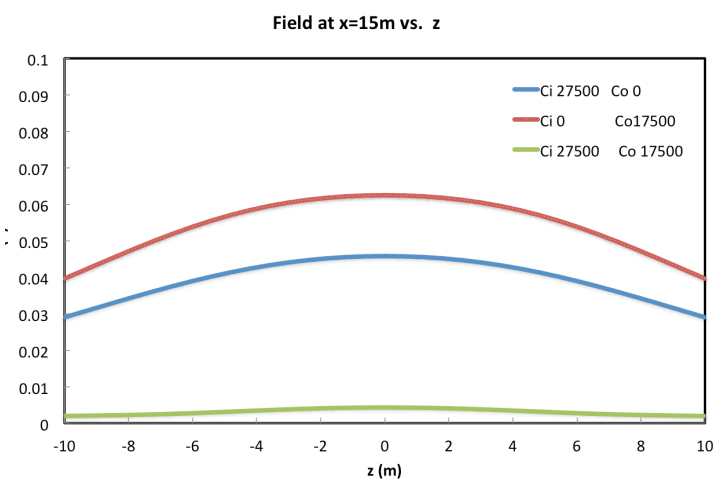






Rough cost estimate (MILCU)

	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

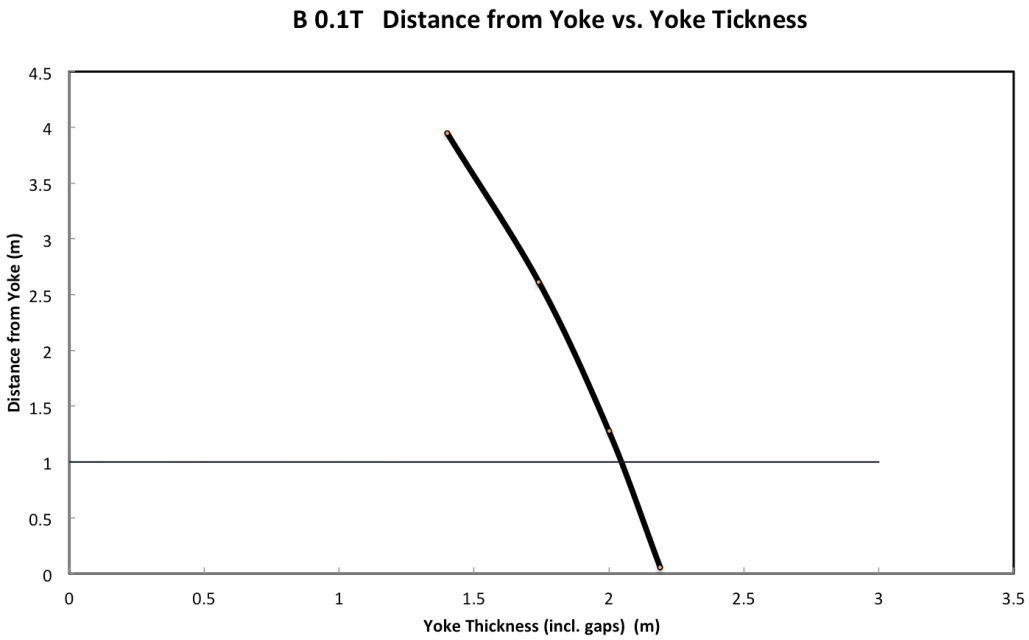
Stray field considerations

- 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

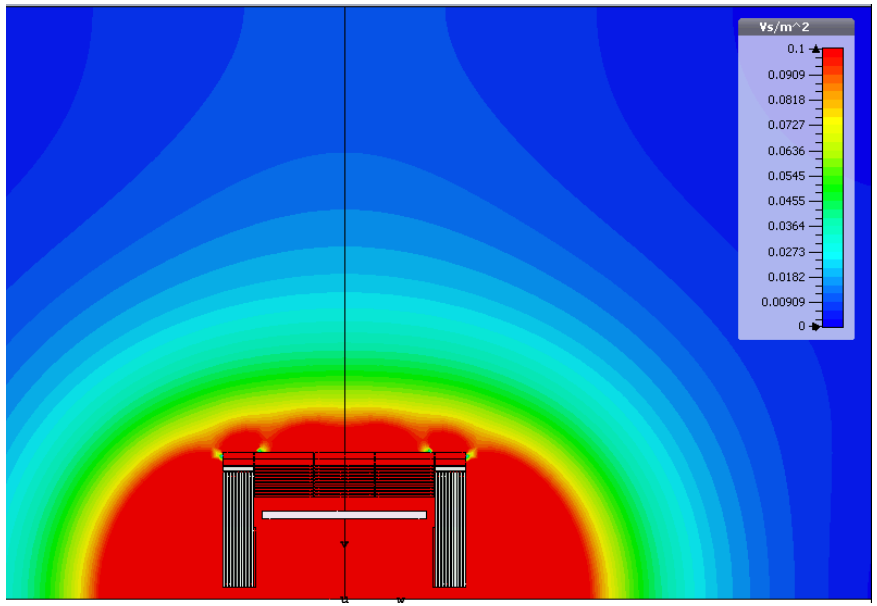
DESY

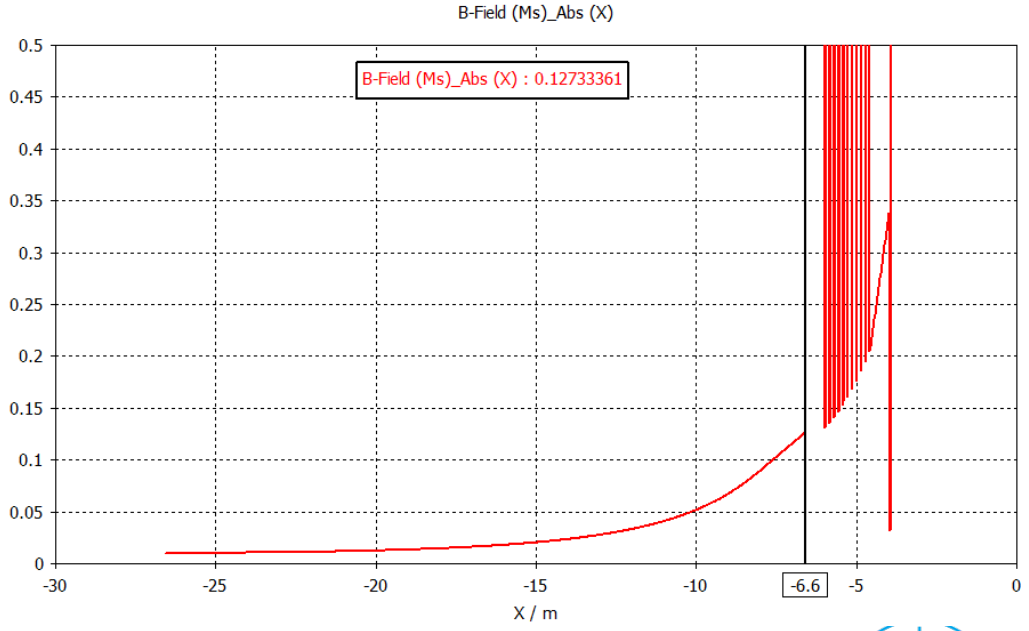
Reducing Yoke Thickness



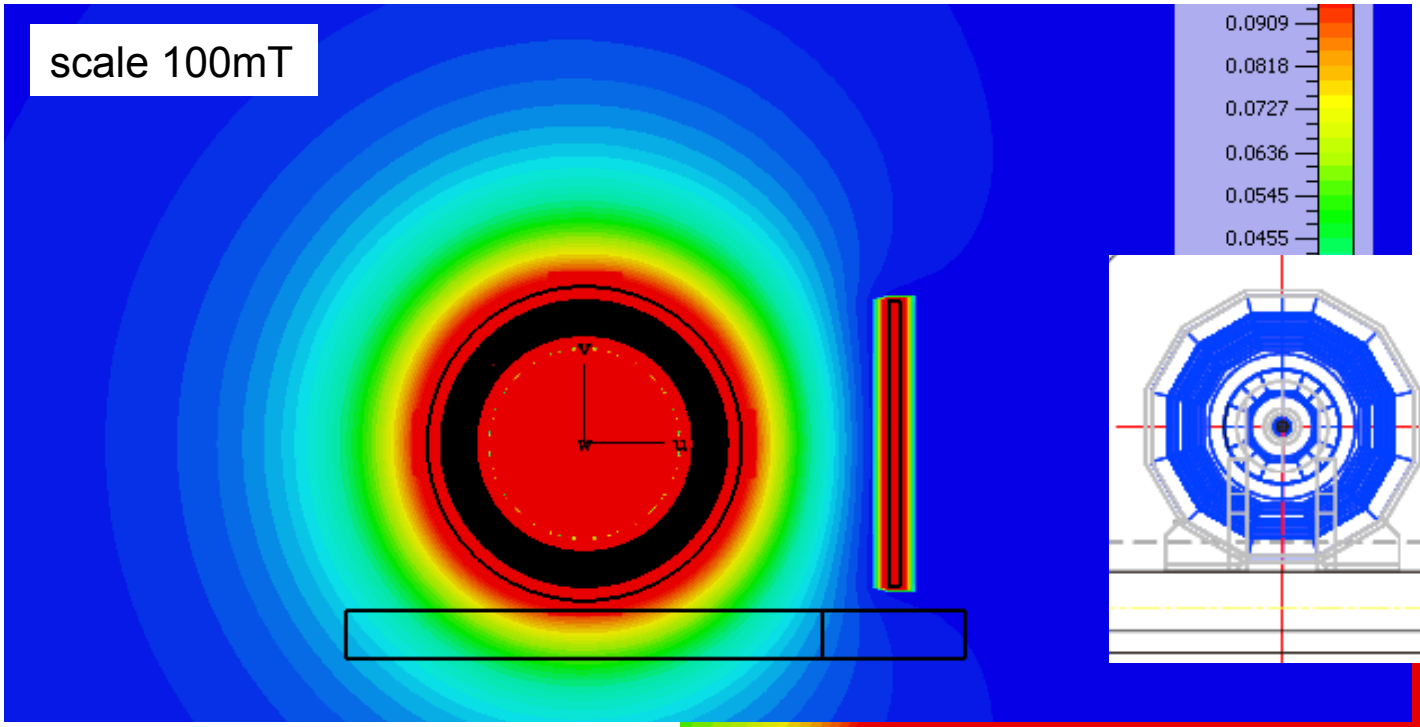
Yoke size and thickness reduced

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





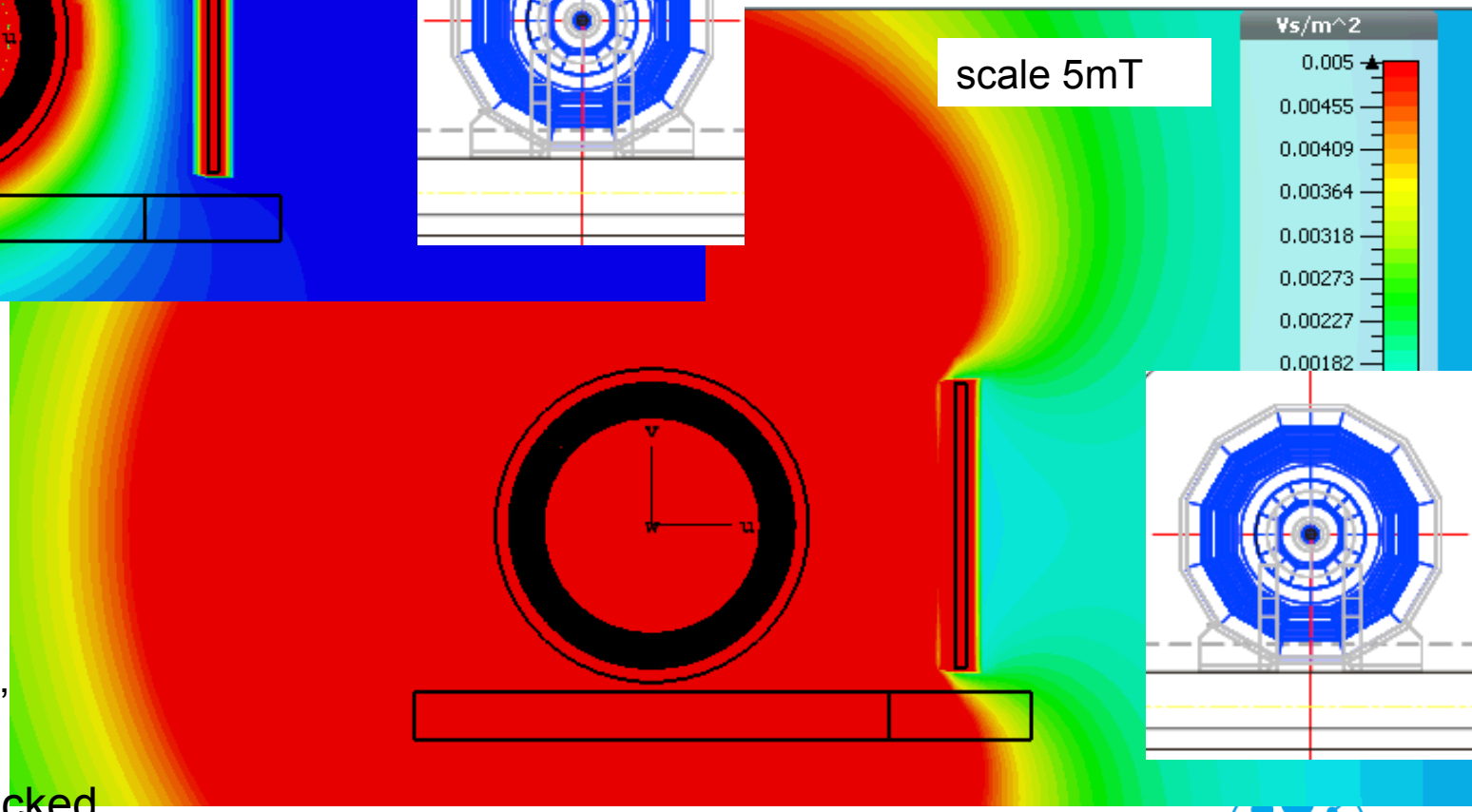
Reduced Yoke – Shielding Wall



Preliminary, hexahedral mesh

Movable iron shielding wall

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



ILD in beam position

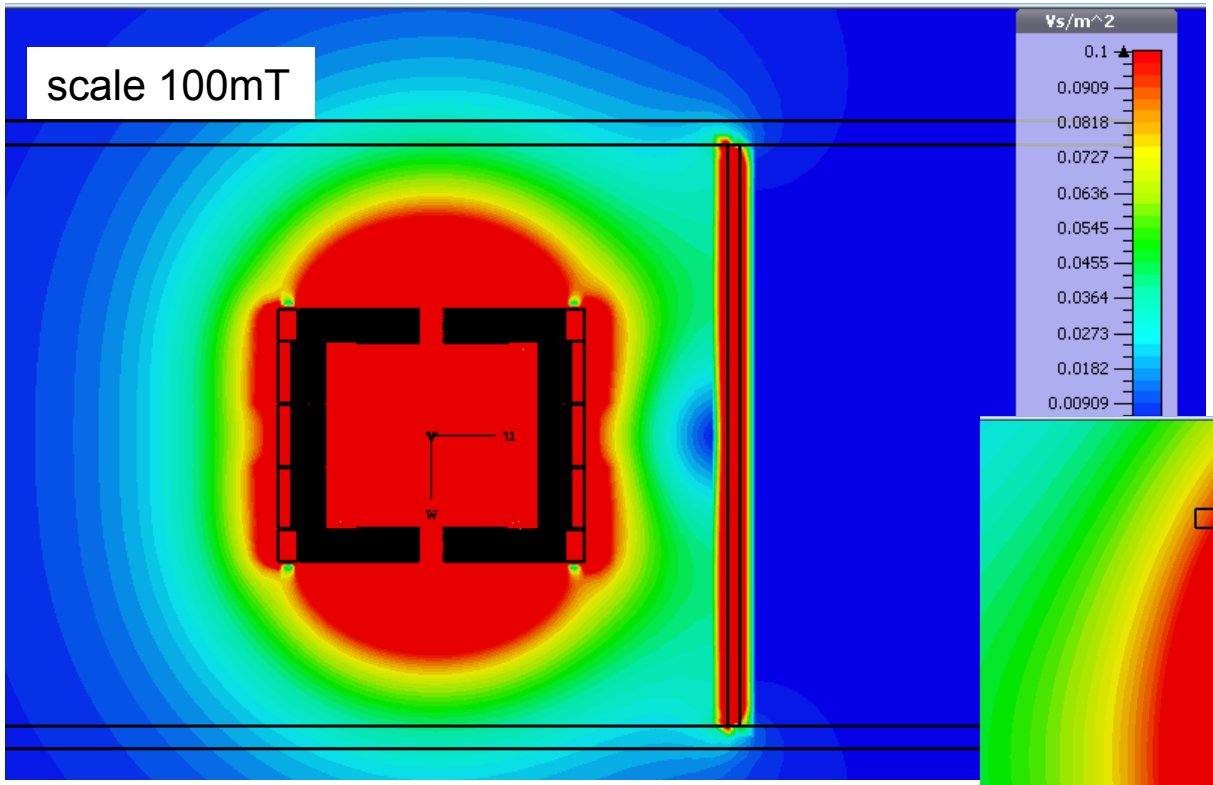
- Hall accessible with non magnetic tools

SiD in off beam position

- Unlimited access (installation, maintenance)

Radiation shielding to be checked

Reduced Yoke – Shielding Wall



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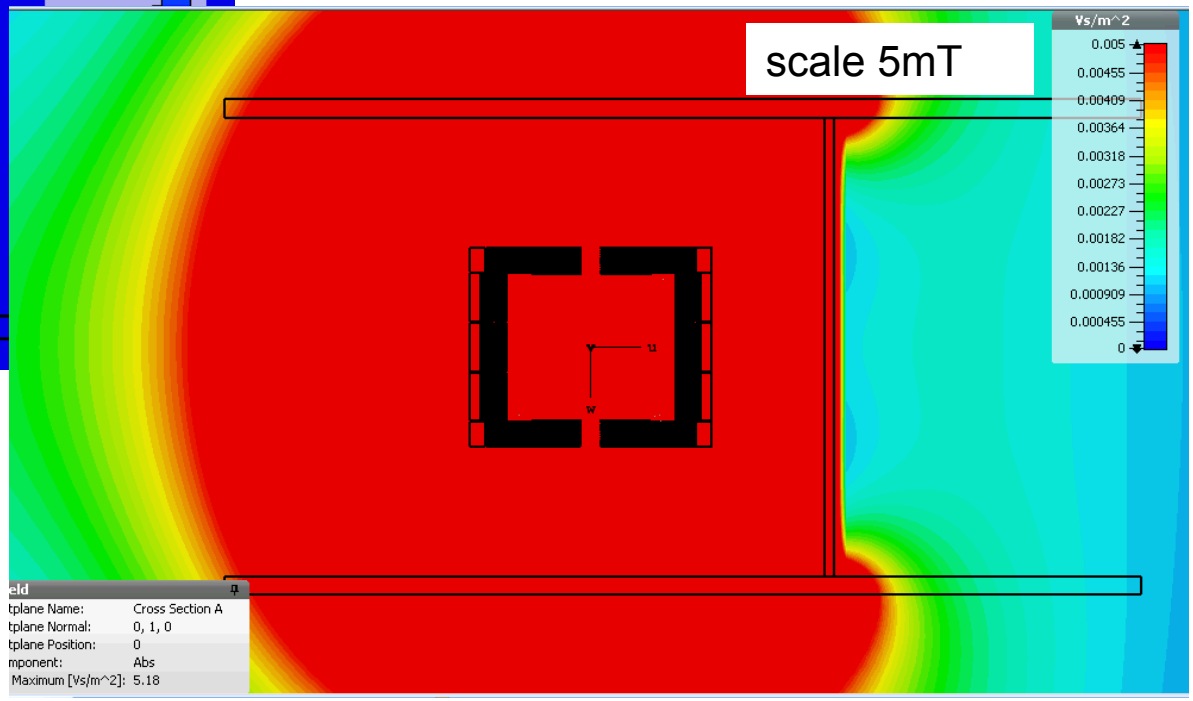


Rough cost estimate

- 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

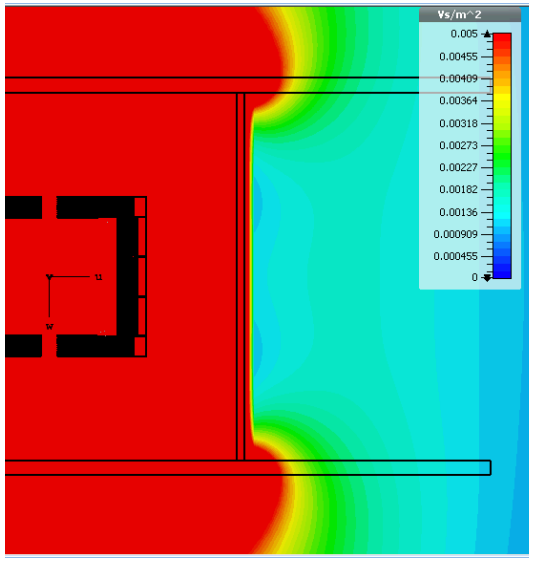
Reduced Yoke – Shielding Wall

Experience with CST Studio calculations

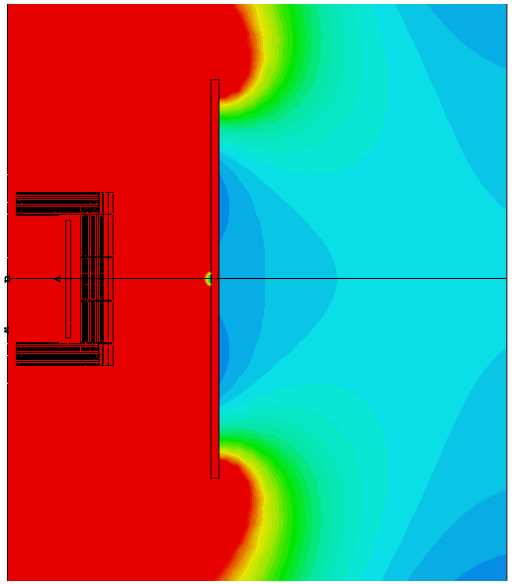
- Hexahedral mesh:
  - Yoke gaps not meshed properly, stray field usually too small
- Tetrahedral mesh
  - Good meshing, stray fields higher, in agreement with other codes
- Previous calculations
  - First, hexahedral mesh (faster)
  - Tetra mesh for final results
- Reduced yoke with shielding wall
  - Hex mesh results
  - Problems running 3D tetra mesh
  - Compare with 2D tetra mesh
  - Similar results

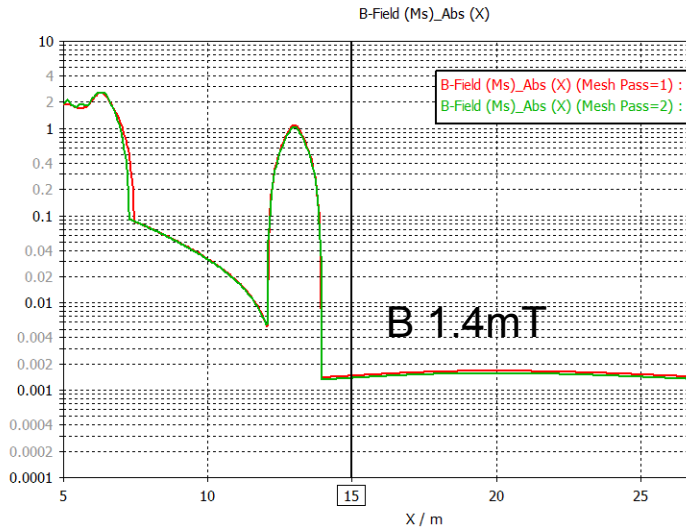
both 5mT scale

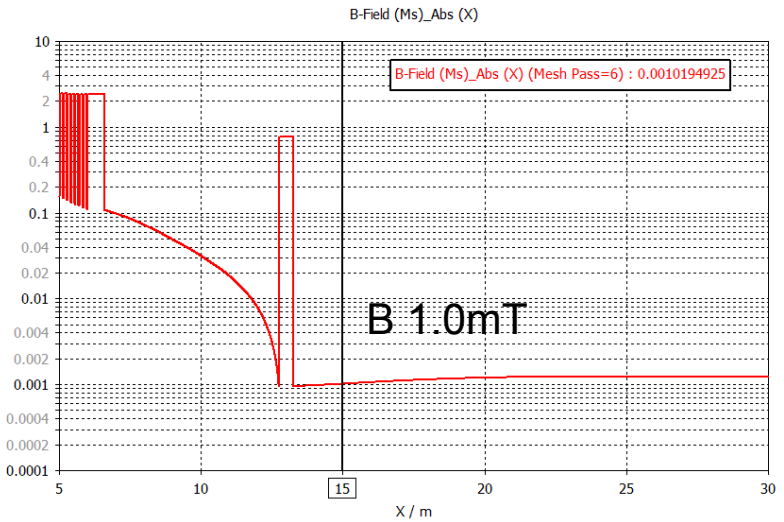
Hexahedral mesh



2D tetrahedral mesh





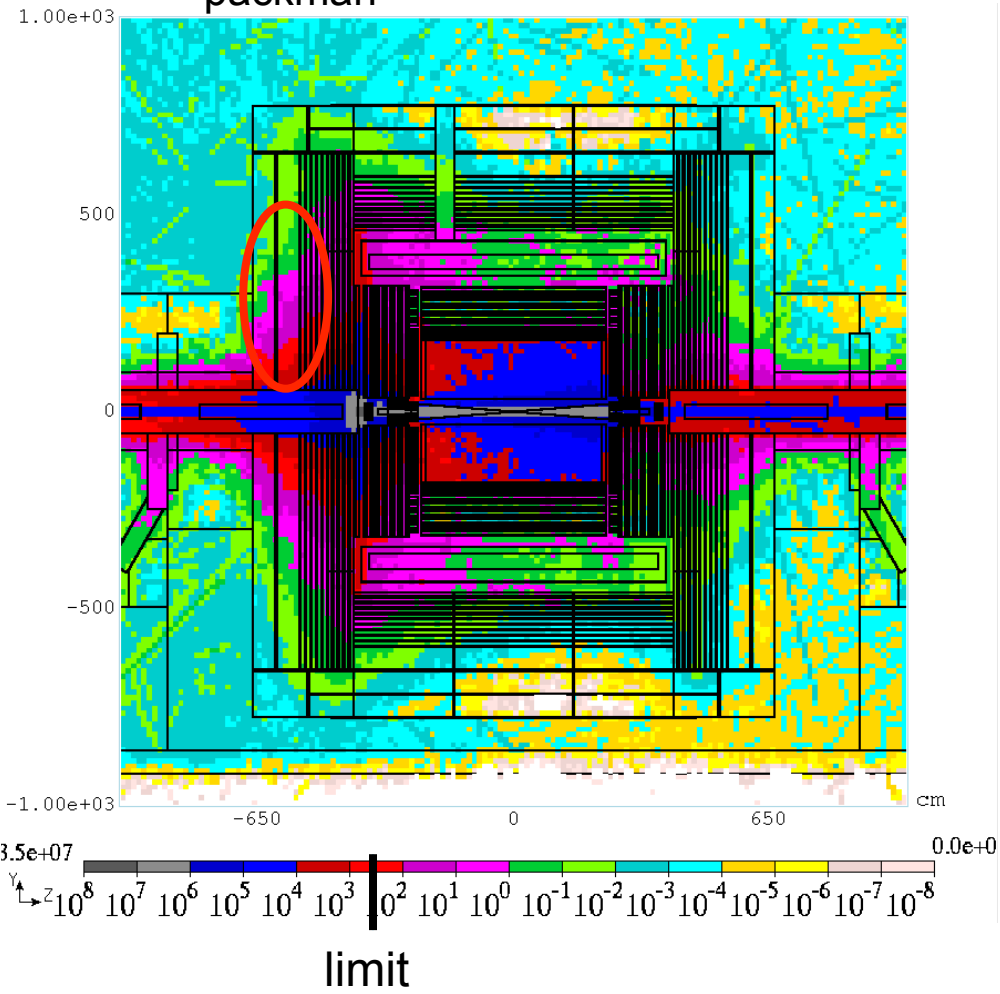


Reduced Yoke – Radiation Shielding

Radiation dose estimates, T. Sanami et al. 2009

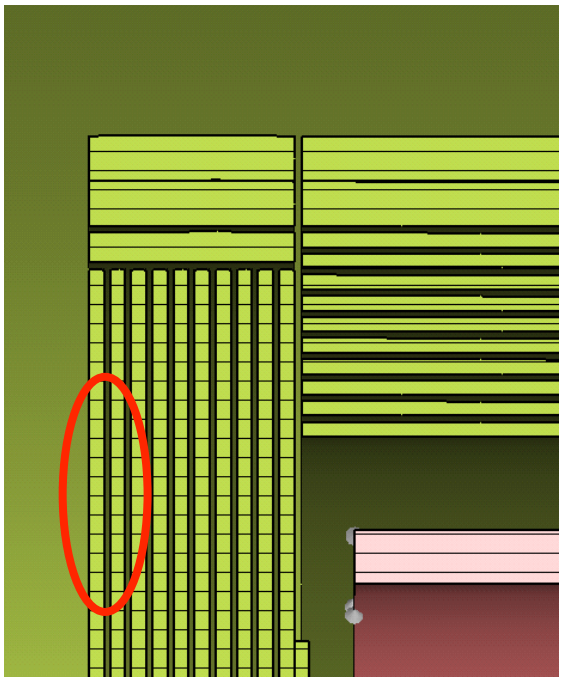
Old end-cap design

- Fulfills requirements
- weak spot: transition between EC and packman



Reduced yoke may need some modification

- thicker EC plates or additional shielding

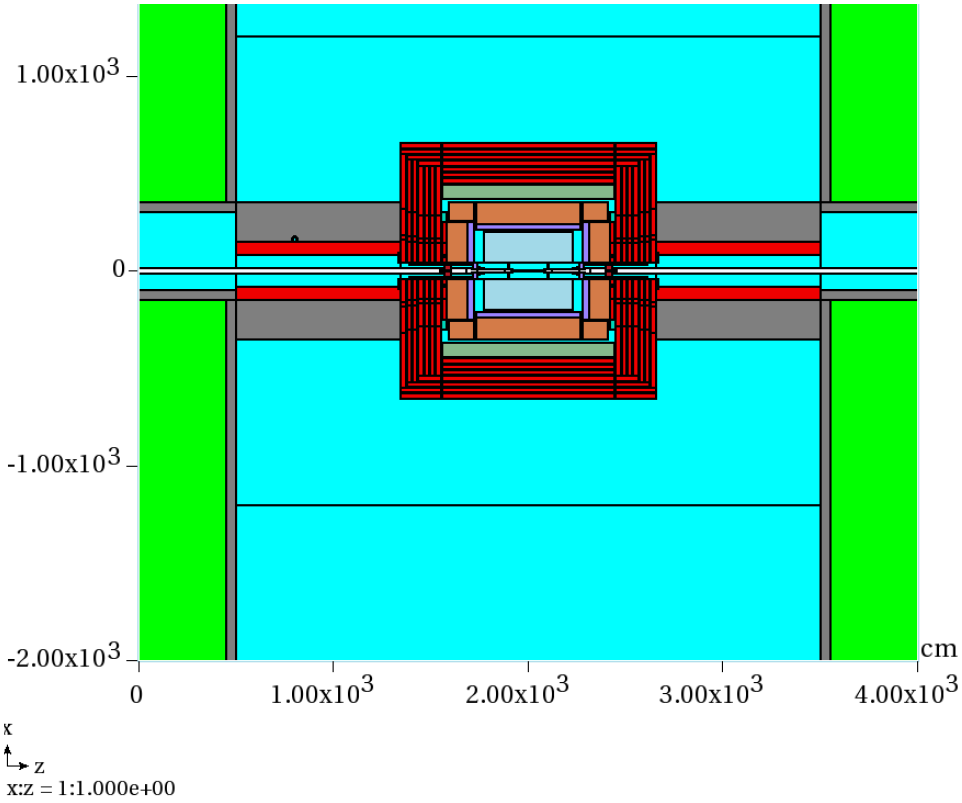


Radiation Shielding

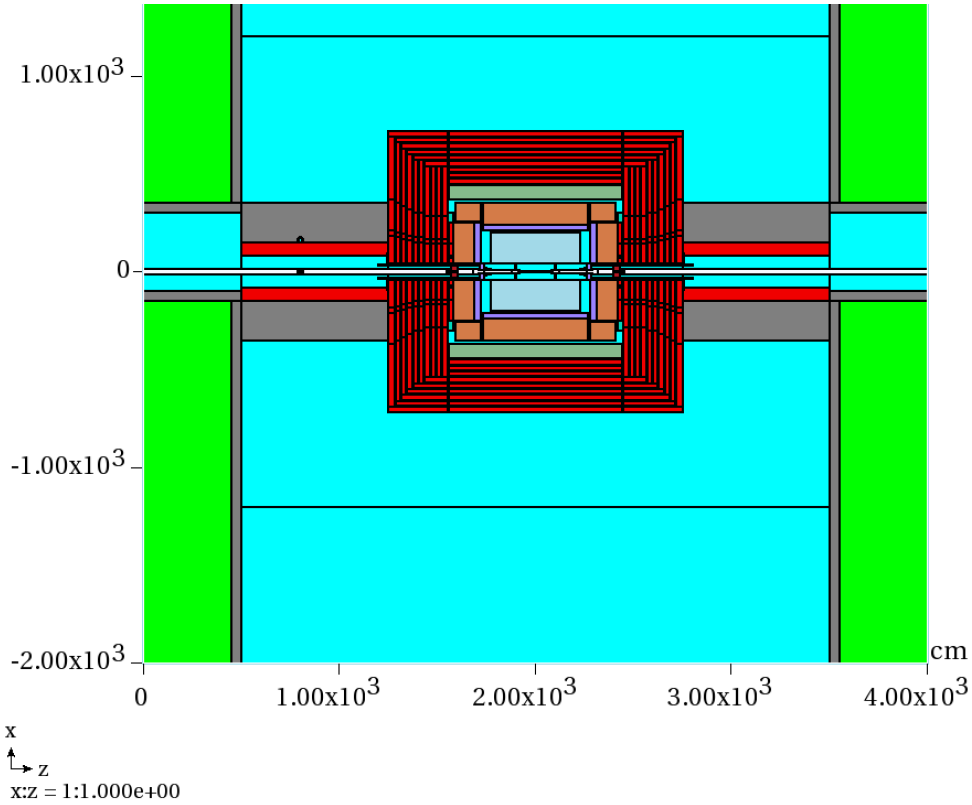
Recently, re-activated shielding calculations, T. Sanami

GLD detector

reduced size



full size



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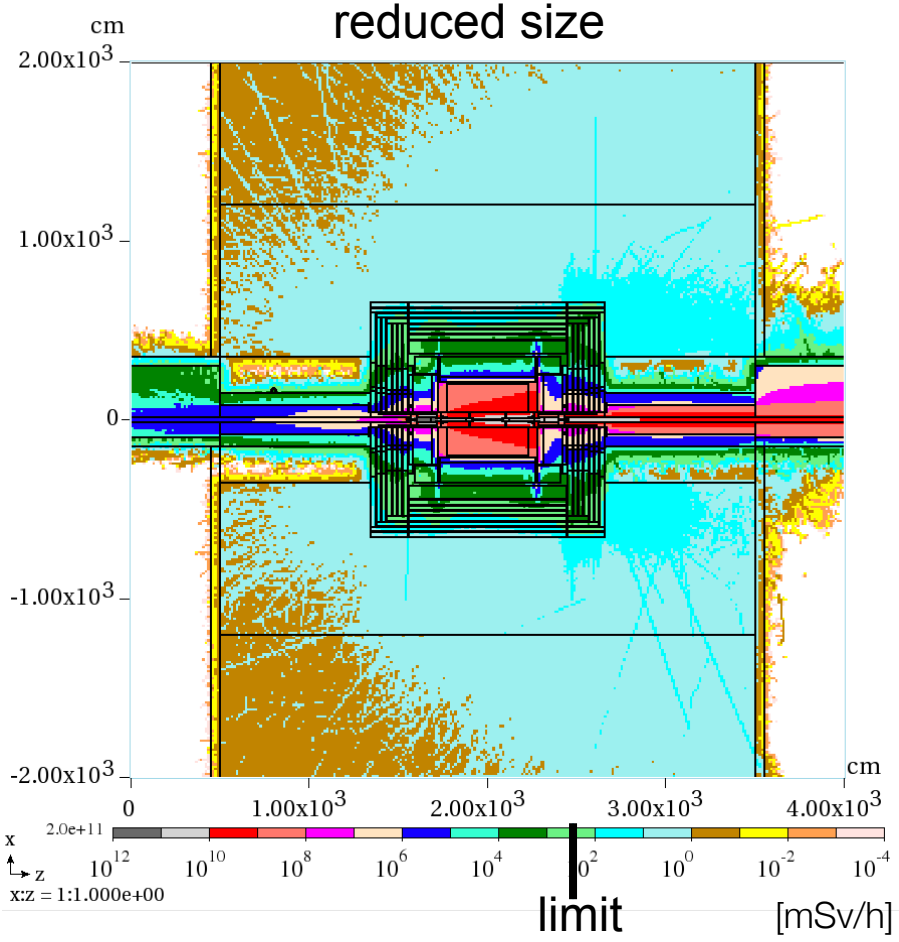

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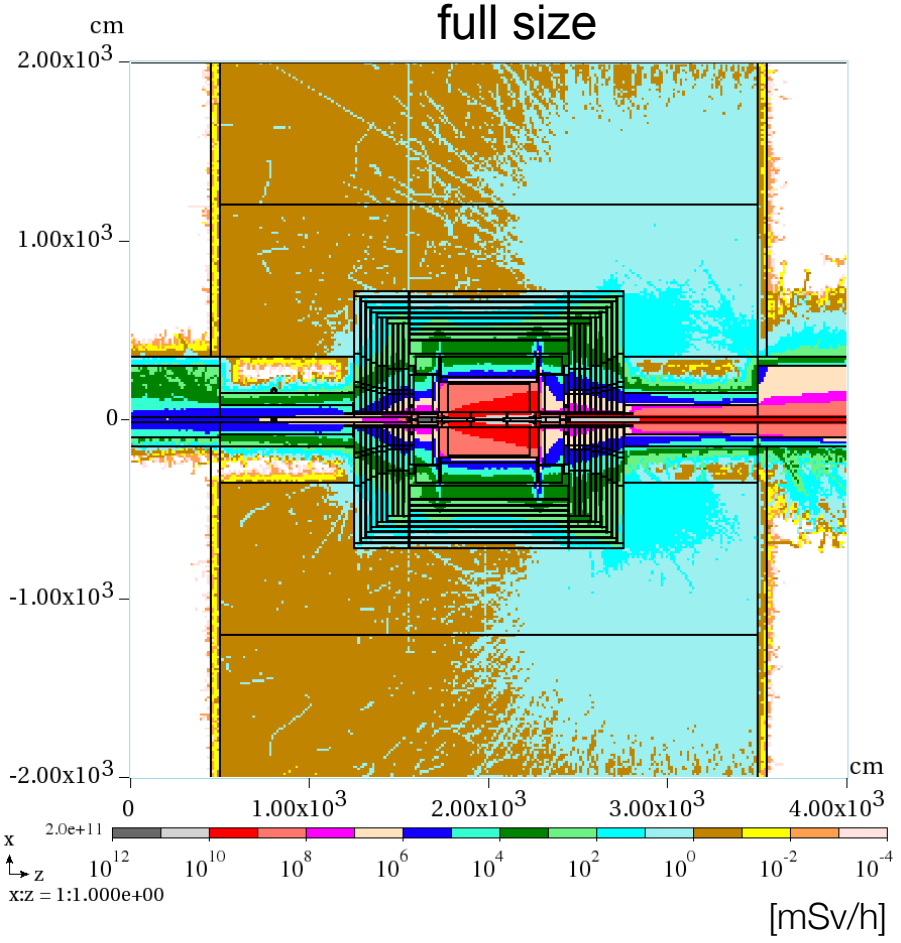

EC iron thickness in reduzed GLD still 2.0m, instead of 1.0m for reduced ILD

Conclusions

- Studied alternative yoke and coil geometries
- 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)
  - Any other issues?