International Workshop on Future Linear Colliders 2014

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CLIC detector B-field with reduced end-cap yoke

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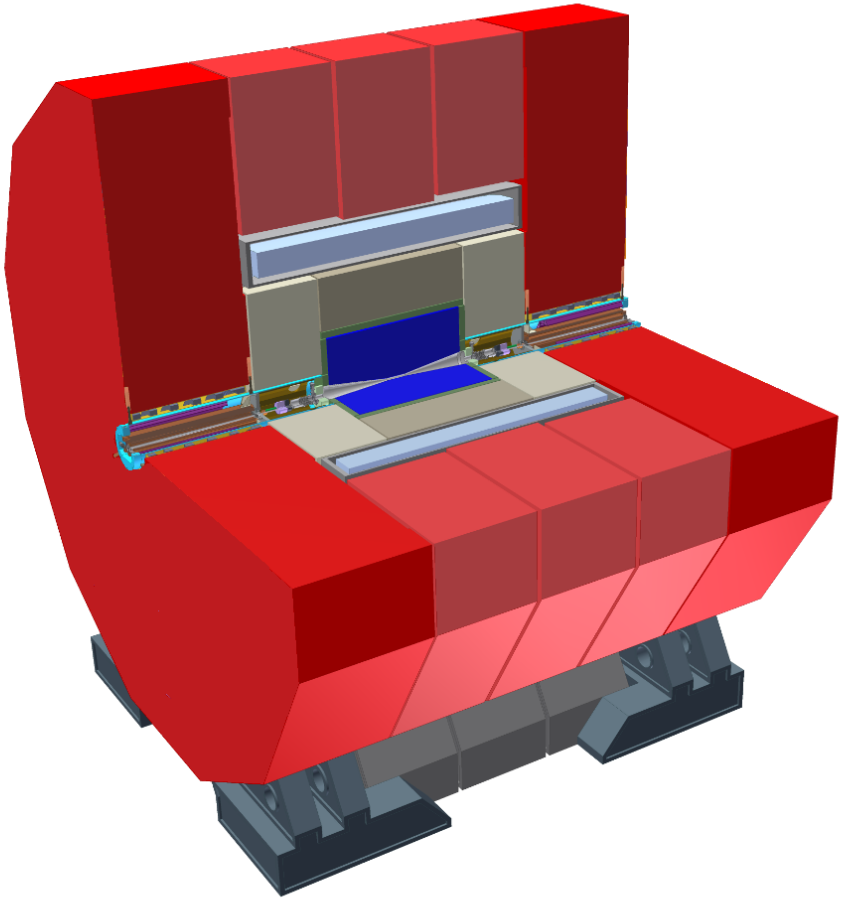
CERN
On behalf of the CLICdp Collaboration

Reference design, used for comparison:

initial CLIC_SiD layout (taken from CLIC Conceptual Design Report)



Massive iron return yoke: 10800 tons

2 end-caps (2900 tons each),

a barrel section split in 3 rings (5000 tons total).

Total yoke length **12.4 m.**

One **superconducting solenoid**, Lz=6.23m.

Aperture : **5.5 m**

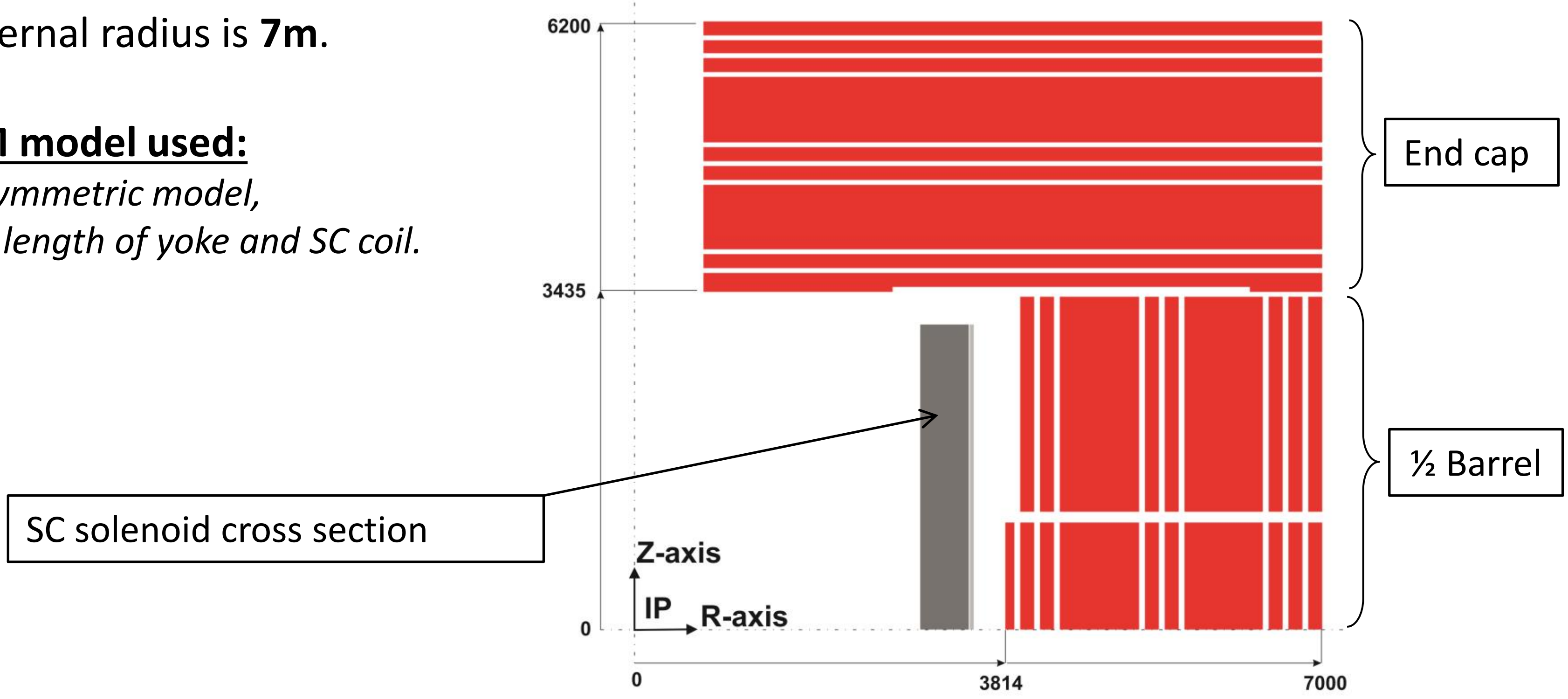
Central field at IP : **5 T**

Reference design, used for comparison:

- CLIC_SiD layout with detector **half length L=6.2m,**
- End cap iron thickness is **2445mm**,
- **8 muon chamber** stations inside the yoke end cap.
- External radius is **7m**.

Longitudinal section :
detector axis is VERTICAL.

FEM model used:
Axisymmetric model,
Half length of yoke and SC coil.

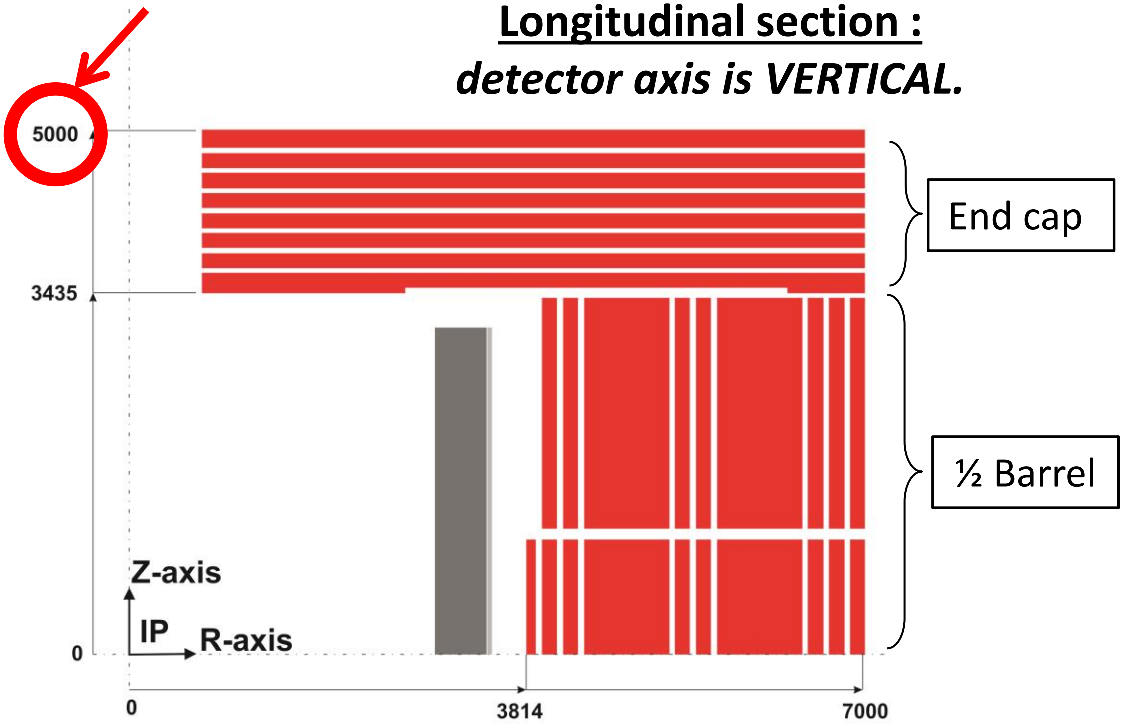


New design : shorter detector with QD0 out of the detector.

- detector **half-length reduced to L=5m**
- End cap iron thickness reduced to **1285mm** (reduction of **1160mm**).
- **7 muon chamber** stations inside the yoke end cap.
- Solenoid length kept at 6.23m,
- External radius identical (7m),
- **No modification of barrel yoke.**

<u>**Longitudinal section :**</u>

detector axis is VERTICAL.



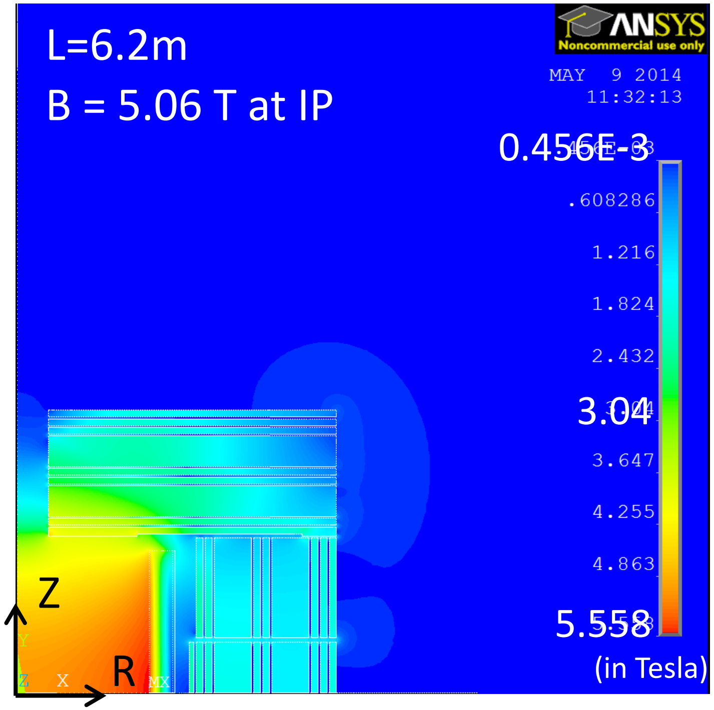
<u>**FEM model used:**</u>

Axisymmetric model,

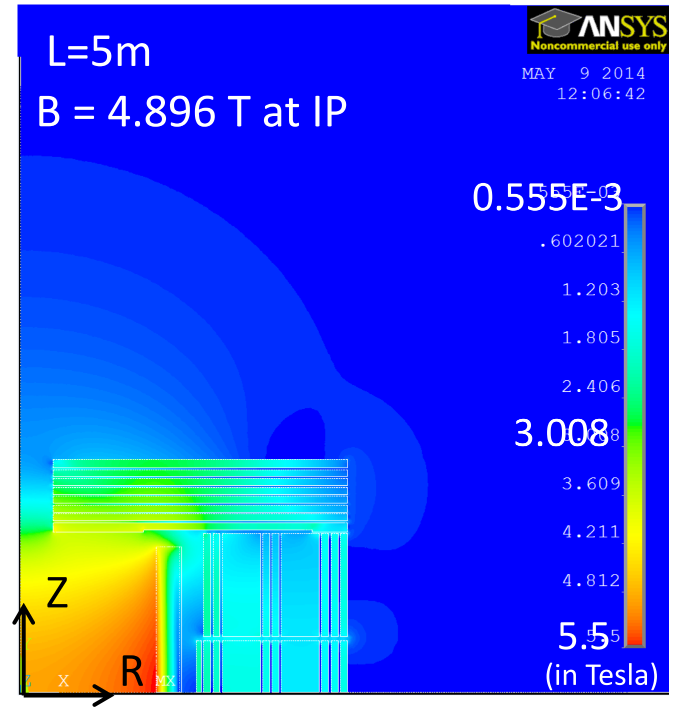
Half length of yoke and SC coil.

Qualitative comparison of the 2D B-field vector sum map:

(SC solenoid current identical in all models) **(Detector axis is vertical on the maps)**



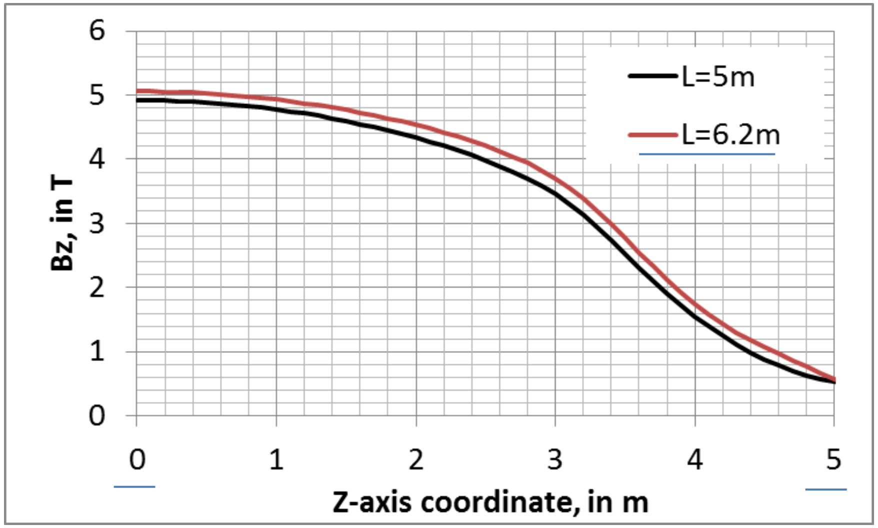
Axial force on coil: -164MN
Axial force on end cap: -170 MN

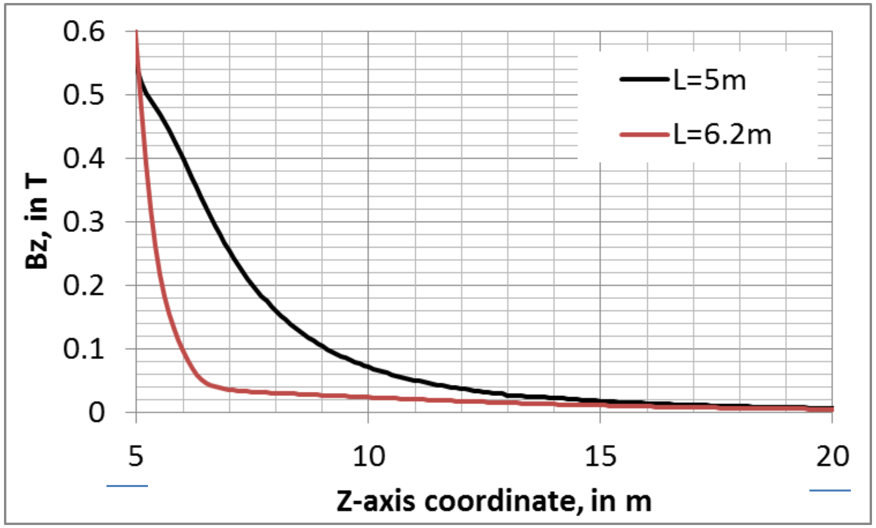


Axial force on coil: -194 MN ⟶ **acceptable**.
Axial force on end cap: -120 MN

⇒ **Area most affected is around the detector axis outside the EC yoke.**

Comparison of the B-field Bz(R=0) vs Z, on detector axis:





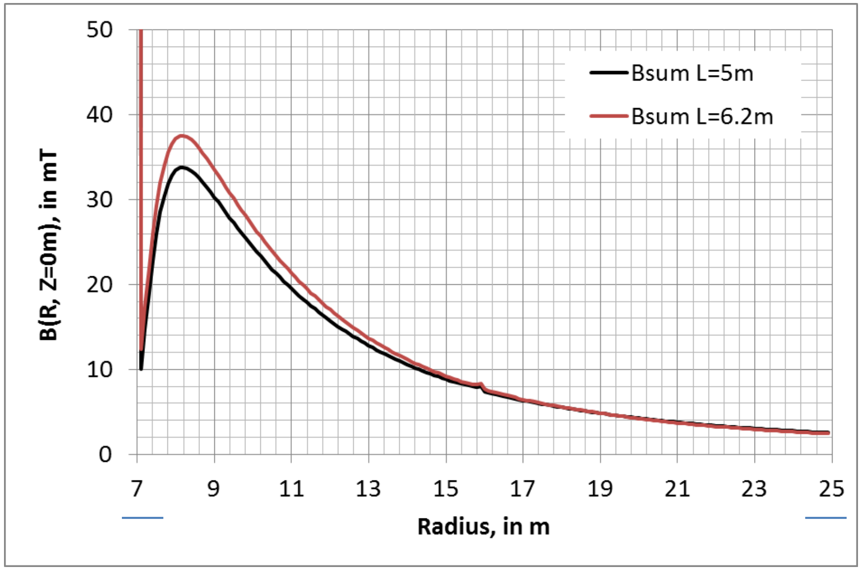
- Slight field reduction in the central volume of the detector (3.2% lower at IP),
- Larger stray field on the beam line outside the yoke end cap.

⇒ the design with reduced EC yoke length has to be improved to reduce the stray field in the QD0 region.

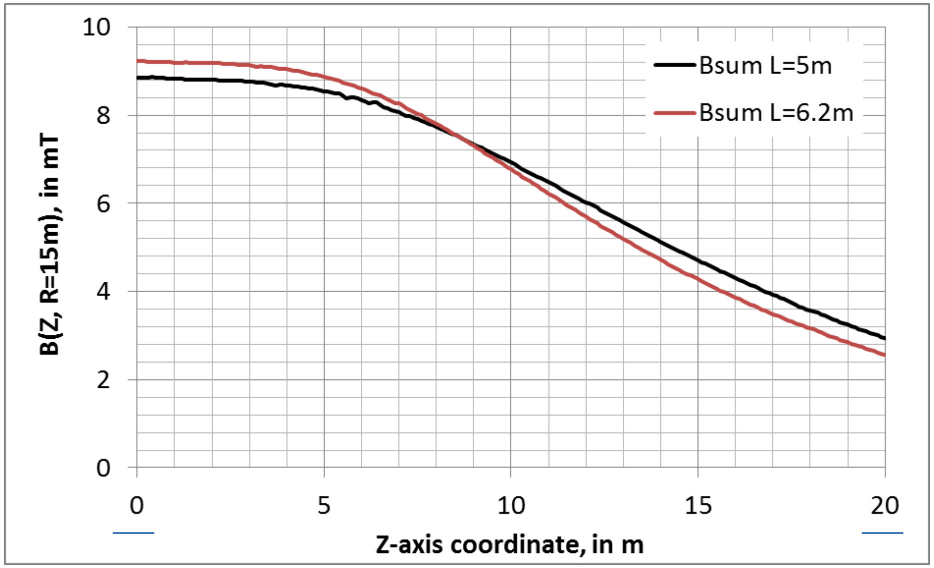
Comparison of the stray field around the yoke:

B-field vector sum :

Transverse plane Z=0m



At radius R=15m , parallel to Z-axis



Far region : Less significant effect of reduced length, **stray field lower than 9mT at R=15m.**

⇒ **Modification of design can help to reduce the stray field.**

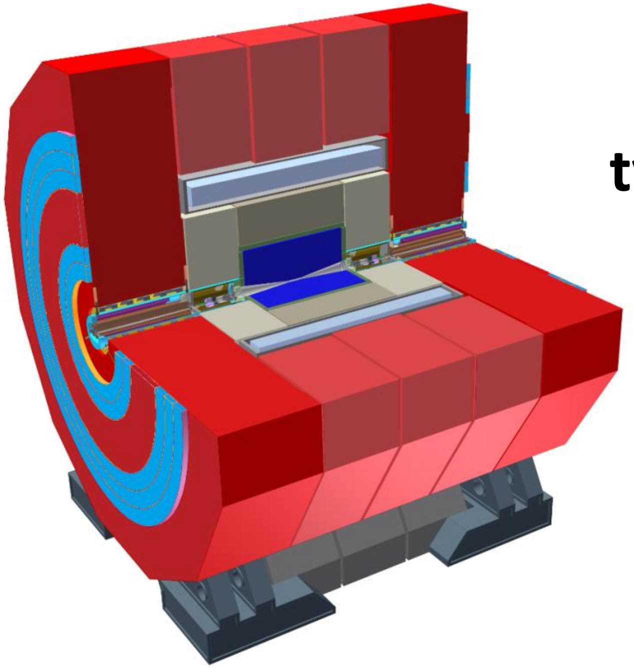
New design improvement with ring coils

Improvement of the new design :

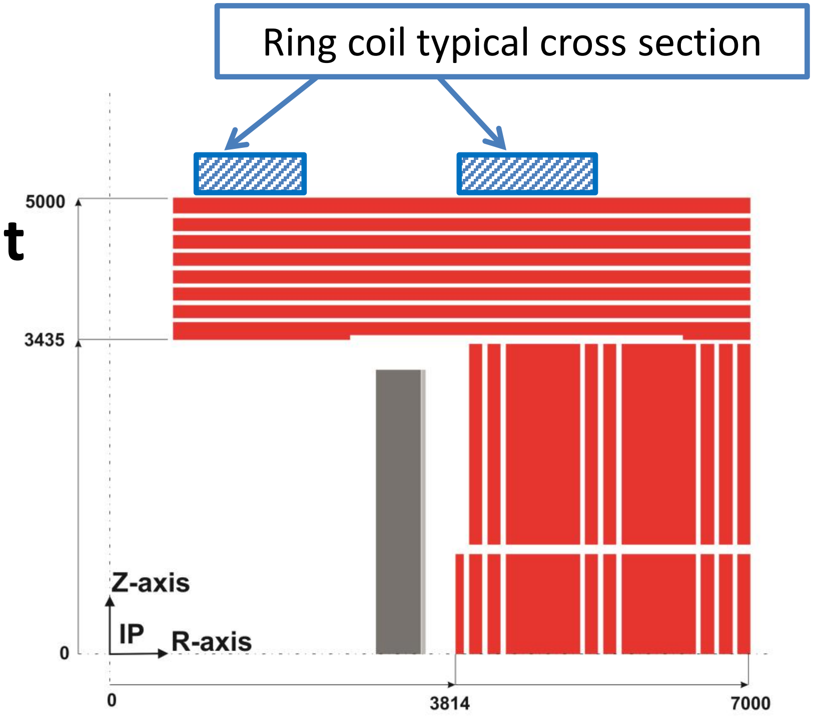
With ring coils located outside the End Caps. Ring coils and detector are coaxial.

RCs are used in order to lower the stray field :

- near the beam line, outside the yoke end cap,
- and more generally around the detector.



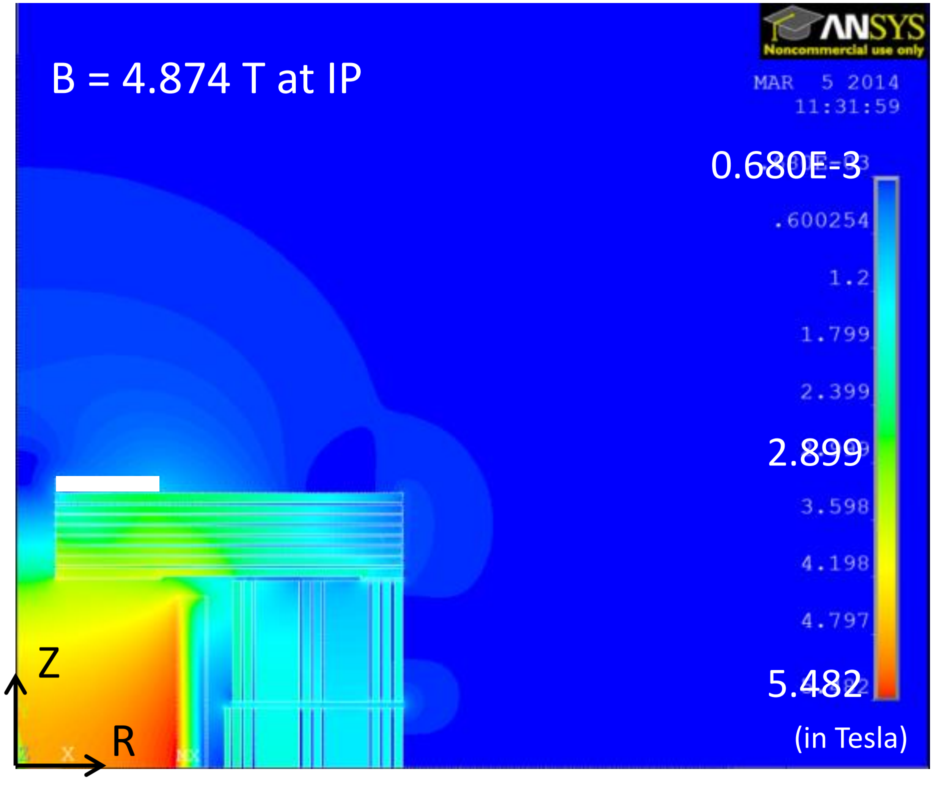
Ring coils typical layout



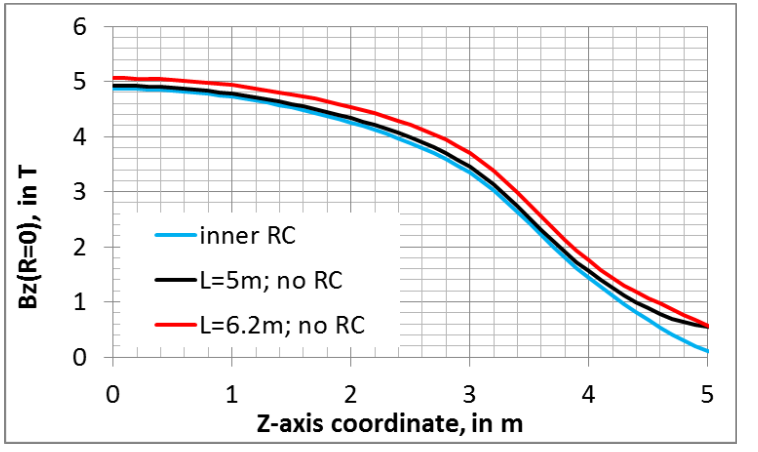
Effect of the ring coils on the B-field

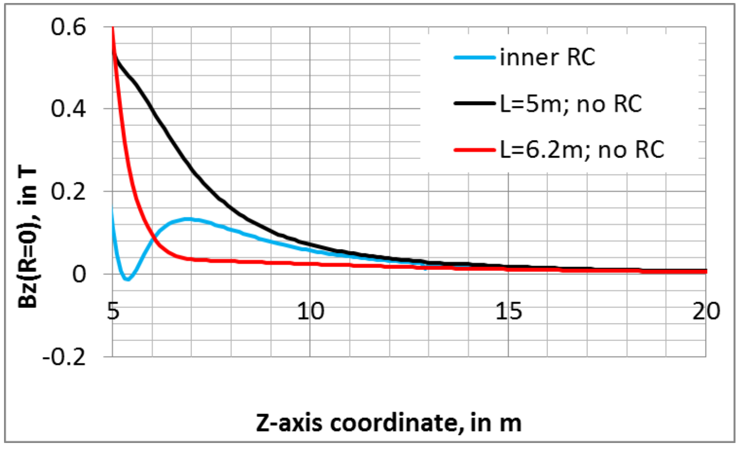
How the ring coils modify the B-field :

1 Ring Coil on INNER radius, J=3A/mm².



Axial B-field Bz(R=0) on detector axis:



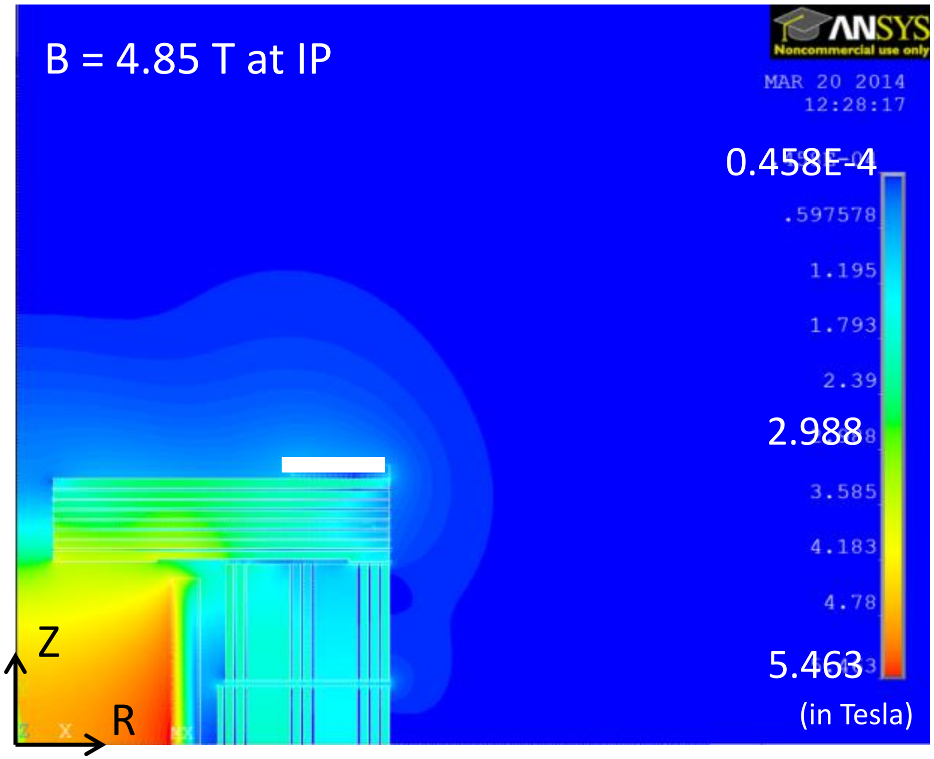


⇒ **Strong decrease of field around the detector axis near the EC yoke.**

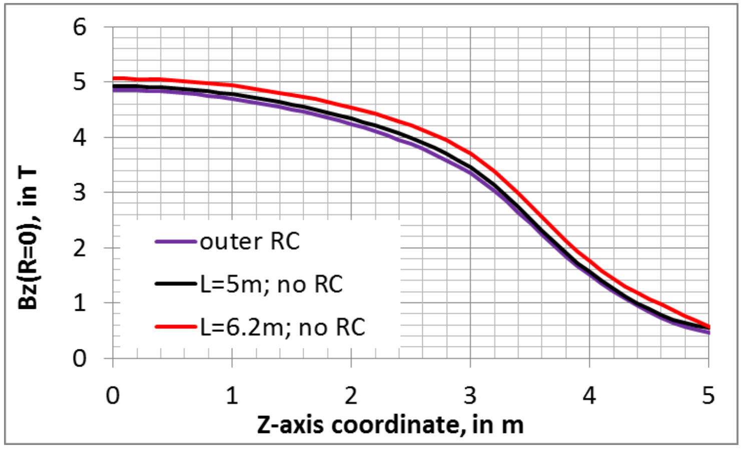
Effect of the ring coils on the B-field

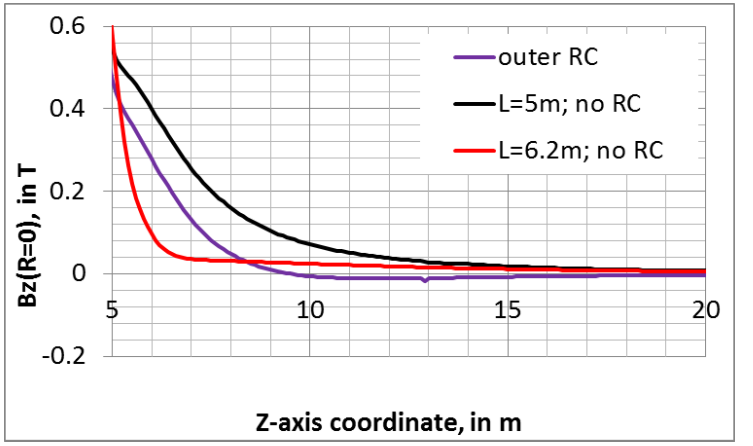
How the ring coils modify the B-field :

1 Ring Coil on OUTER radius, J=3A/mm².



Axial B-field Bz(R=0) on detector axis:



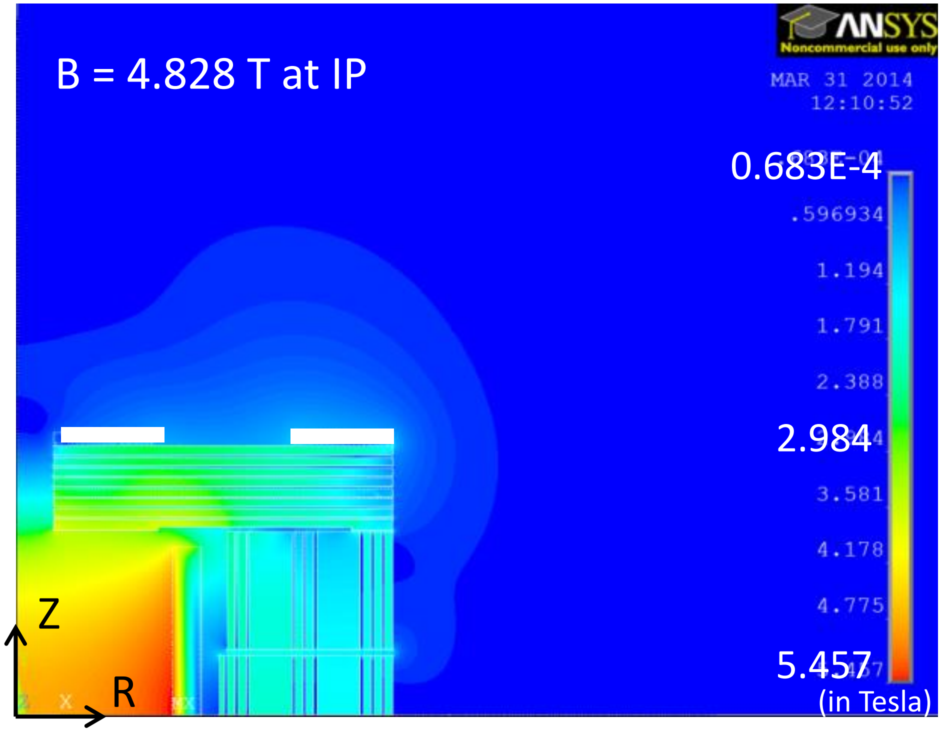


⇒ **Small decrease of the field everywhere.**

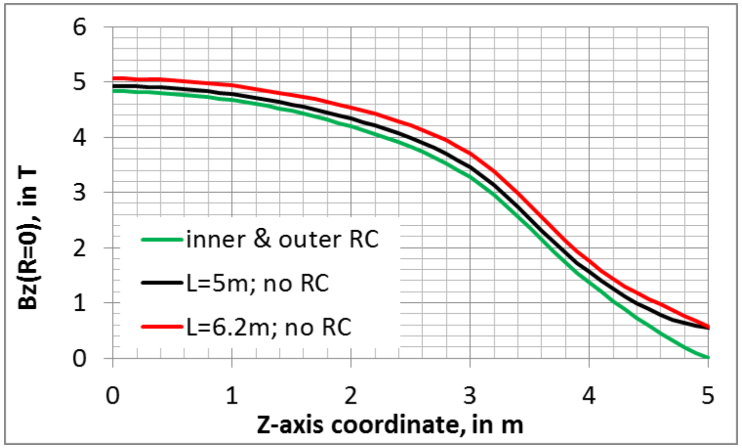
Effect of the ring coils on the B-field

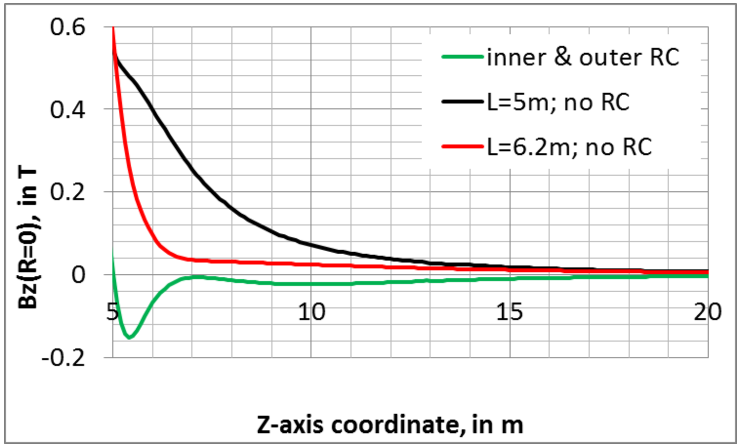
How the ring coils modify the B-field :

2 Ring Coils on INNER & OUTER radius, J=3A/mm^2.



Axial B-field Bz(R=0) on detector axis:

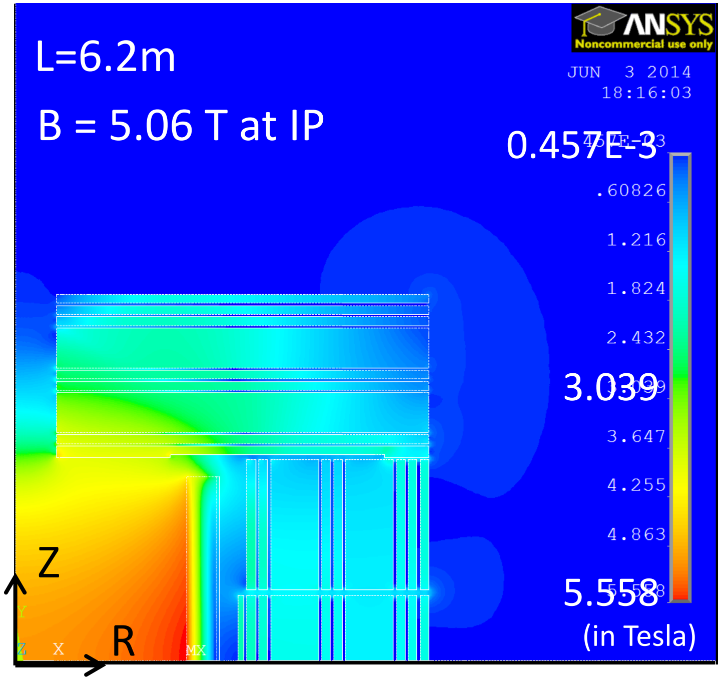




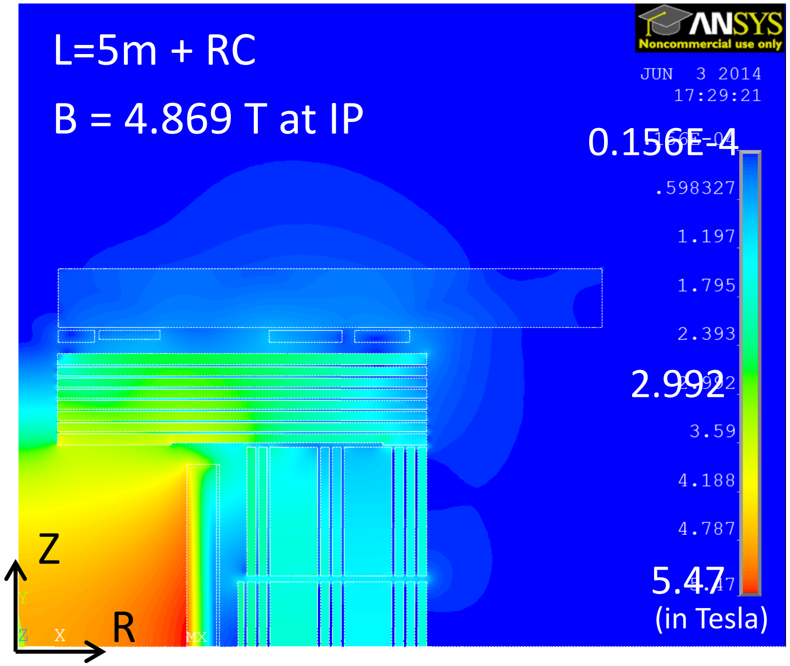
⇒ **Strong decrease of field close to the EC yoke and smaller elsewhere.**

Configuration giving a low field on Z-axis near the end cap with L=5m:

- 4 RCs with resistive copper conductor (water cooled , Jrc=3A/mm^2),
- Effect of iron in concrete cavern wall included in the FEM model (filling factor : 10% of iron),
- Assumption to have the ring coils attached to the cavern wall (less parasitic vibration to detector).

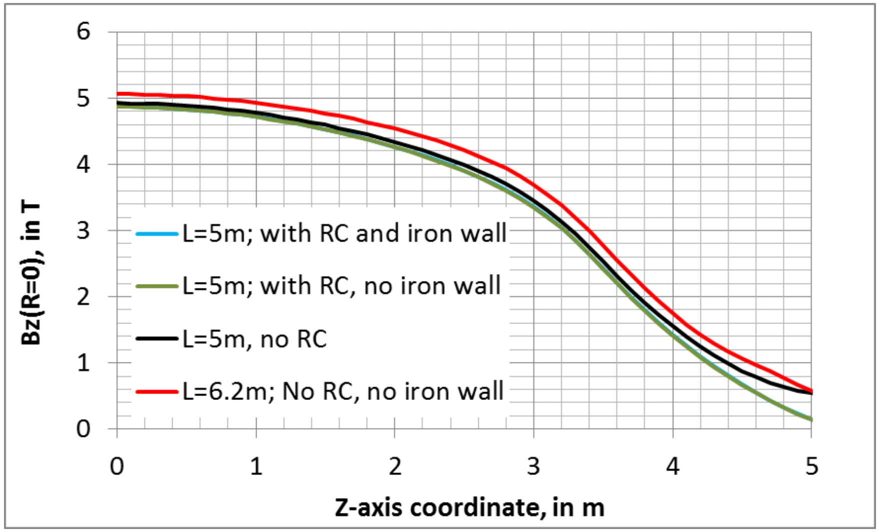


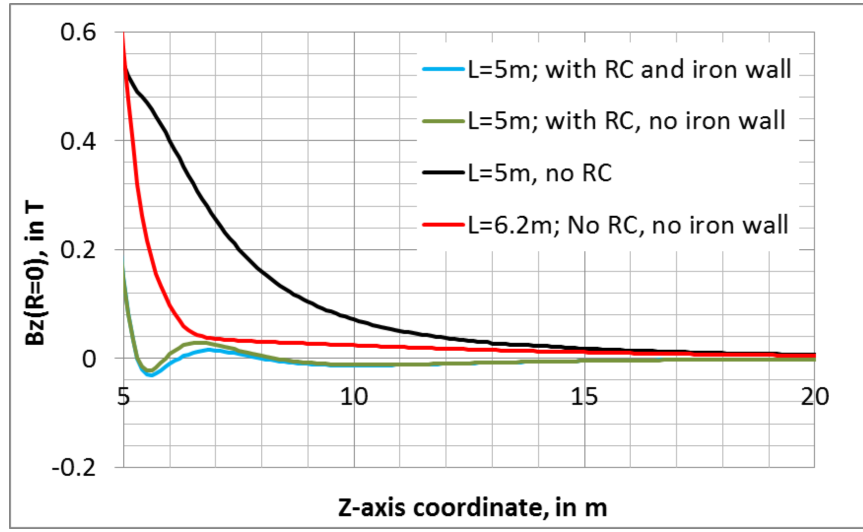
Axial force on coil: -164MN
Axial force on end cap: -170 MN



Axial force on coil: -207 MN ⟶ **Still acceptable.**
Axial force on end cap: -100 MN

Comparison of the B-field Bz(R=0) on detector axis vs Z:





With respect to the initial design (L=6.2m):

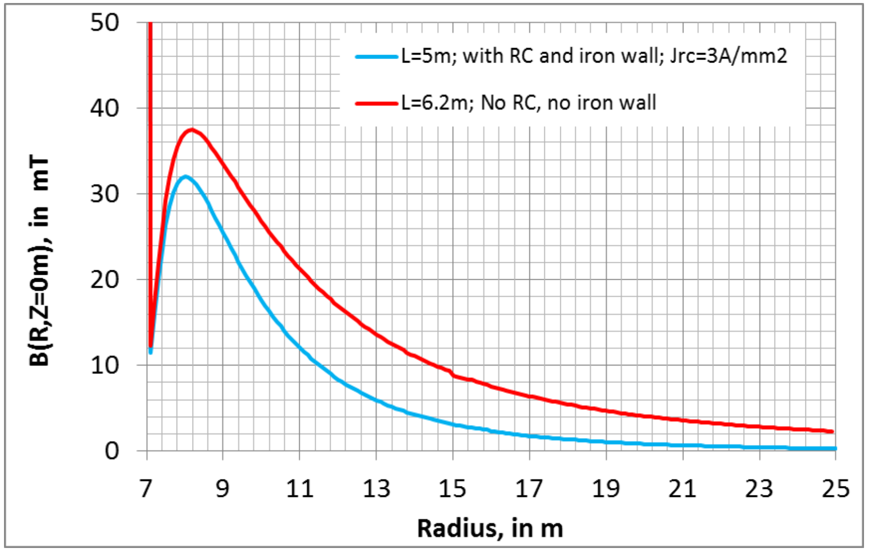
- quite uniform field reduction on the Z-axis in the detector, field at IP is 3.8% lower,
- The stray field in and outside the EC is much lower.

Improved layout (with L=5m + RCs) gives a field of **150 mT** on detector axis at Z=5m.

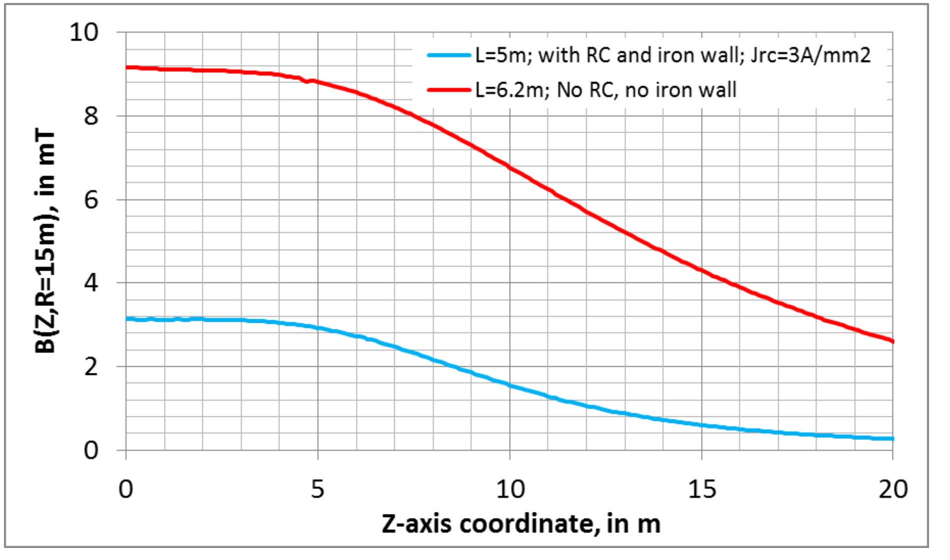
Comparison of the stray field around the yoke:

Lower wrt initial design L=6.2m.

Transverse plane Z=0m, outside the yoke



At radius R=15m , parallel to Z-axis

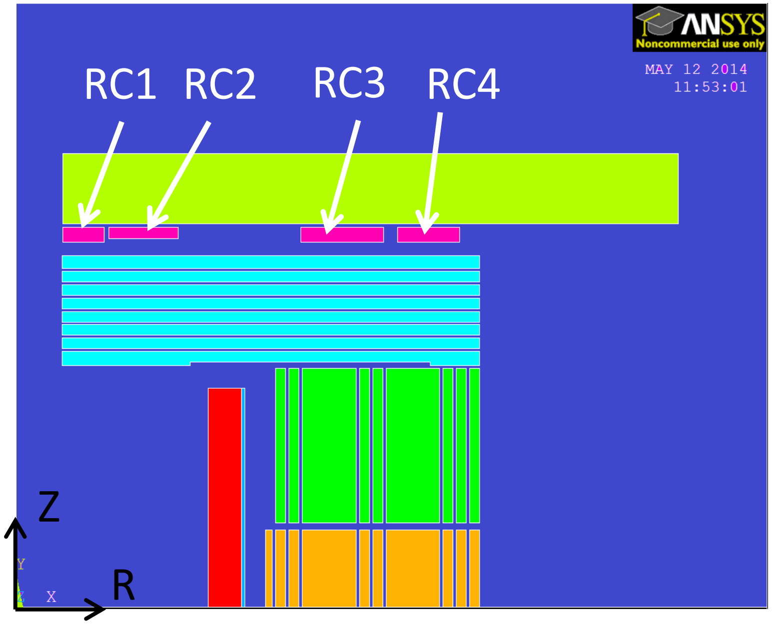


⇒ **Stray field lower than 3.2mT at R=15m (was max 9mT without RCs).**

Characteristics of ring coils

- Same copper conductor for all RCs,
- Total electrical power of RCs (2 end caps): **2 x 2.26 MW**,
- Total copper weight : **250 tons** (for 2 end caps),
- Suppressed steel mass wrt CLIC_SiD (L=6.2m) ≈ **2800 tons** for 2 end caps**,**
- Space available for radiation chicane on the end cap faces.

Coil	Nb. turns	Copper mass (ton)	Resistance (1e-3 ohm)	Voltage drop (V)	Power (kW)
RC1	4x12	5.6	2.7	16.5	101
RC2	3x20	13.3	6.4	39.1	240
RC3	4x24	54.4	26.2	**160.4**	**984**
RC4	4x18	51.7	24.8	**152.2**	**934**



Water cooling system characteristics:

- Total water flow (2 end caps): **2 x 57 m^3/hour**,
- Estimated temperature increase ≈ **45°C**.

Characteristics of ring coils

Parameters obtained are very similar to LHCb dipole ones (*) : realistic !

	LHCb dipole (*)	CLIC (L=5m + RC)
Conductor	50x50mm^2 aluminum 99.7, ∅24mm	50x50mm^2 copper, ∅24mm
Excitation	2 x 1.3 MA.turns	2 x 1.7 MA.turns
Total power	4.2 MW	4.5 MW
Stored energy	32 MJ	2 x 16.8 MJ
Inductance	2 H	2 x 0.9 H
Current density	2.9 A/mm^2	3 A/mm^2
Current in conductor	5.8 kA	6.1 kA
Total resistance	125 mΩ	2 x 60mΩ
Total water flow	125 m^3/hour	115 m^3/hour

(*) LHCb Magnet, TDR, CERN/LHCC/2000-007, 1999.

How the magnetic field is changed, pushing the limits, with:

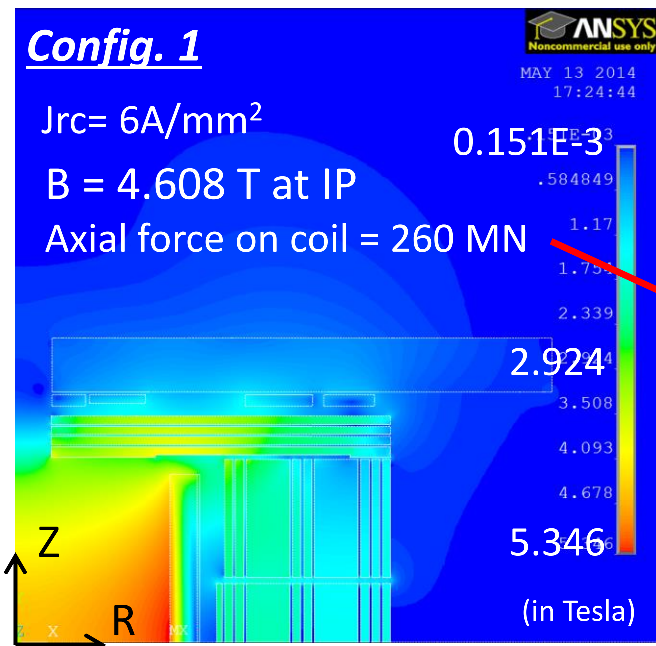
Configuration 1: Reduction of the end cap to 4 iron disks (half length reduced to L=4.205m),

Configuration 2: No end cap iron yoke.

The RCs are kept **identical** & in **same positions** in both models.

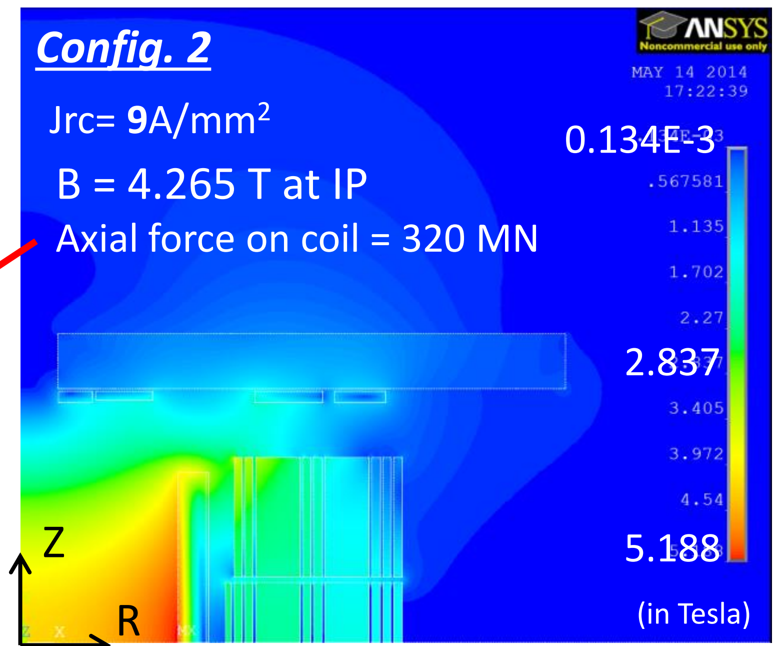
As a first approach, only the **current density** is increased in the model to lower the stray field in acceptable limits.

The resistive **ring coil size** would have to be increased to keep a realistic conductor and current density.

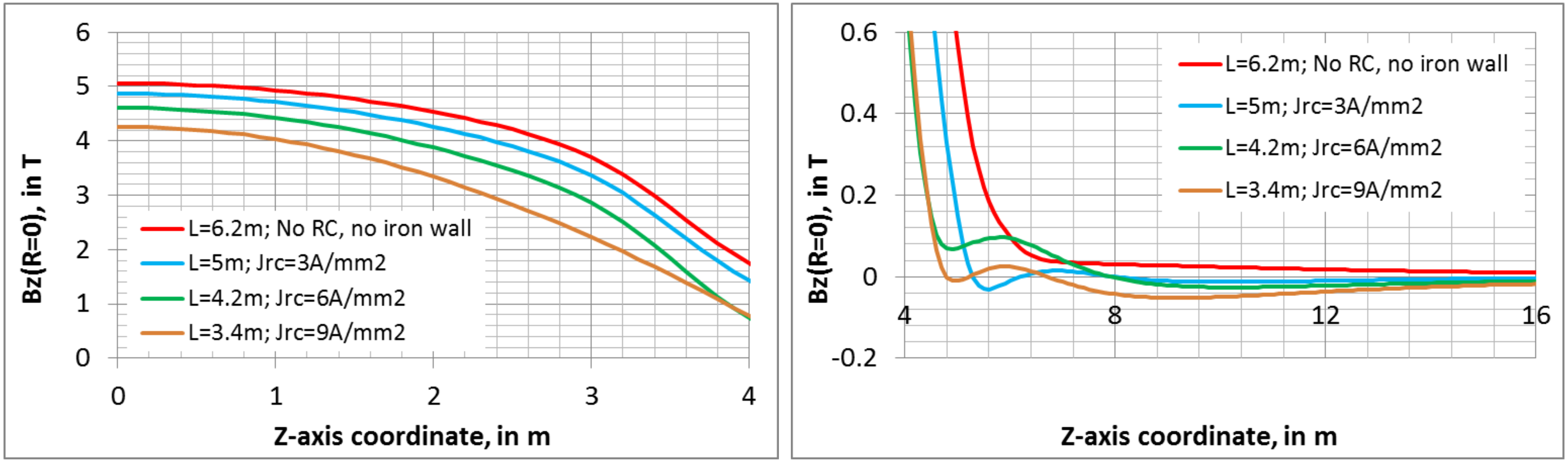


Larger field gradients

Little margin on mechanical properties of SC coil



B-field **on the detector axis**



- The **magnetic field at IP is reduced** for config. 1 and 2 (resp. **8.9%** and **15.7%** wrt L=6.2m) and **the field distortion** in the inner detector volume is increased.
- It is still possible to obtain a quite **good reduction** of the stray field outside the detector.
- **Higher axial forces** on the SC solenoid, at the limit of acceptable level.
- **Small space** available in front of the detector for either big resistive ring coils or SC ring coils in their cryostats.

$\Rightarrow$ **the proposed new design (L=5m + RC) is better than these 2 configurations.**

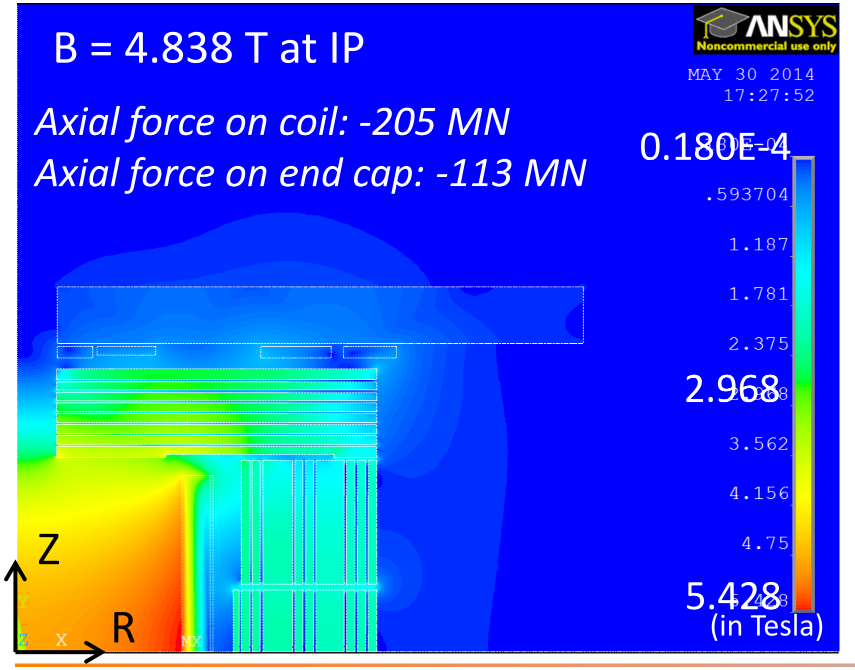
Next step: study the reduction of the external diameter of both end cap and barrel yoke:

External radius modified to **Rext = 6.35m**, applied to model with reduced length L=5m.

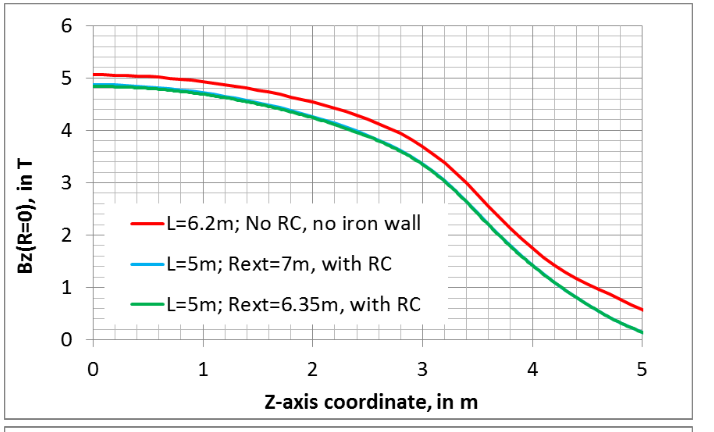
All other parameters unchanged :

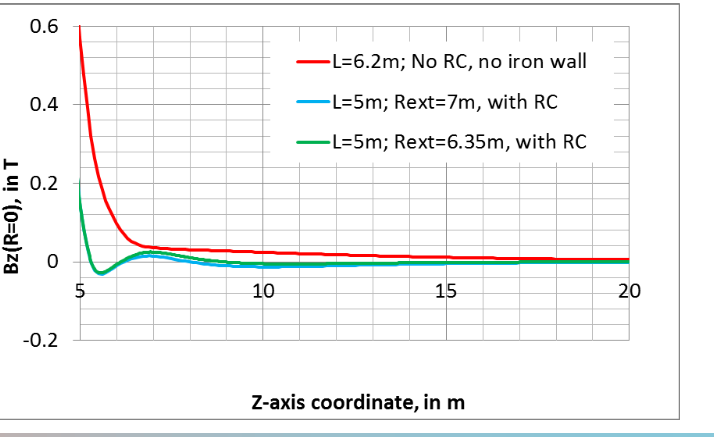
- RCs at same position, same current density,
- Detector half length L=5m.

Field at IP is 4.4% lower wrt {L=6.2m; Rext=7m}.



negligible change of B-field on the detector axis **with external radius reduction**



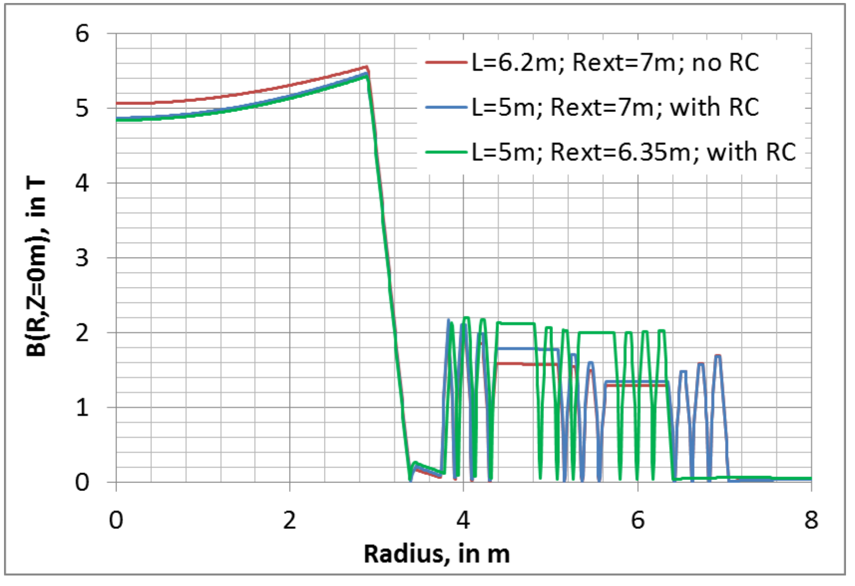


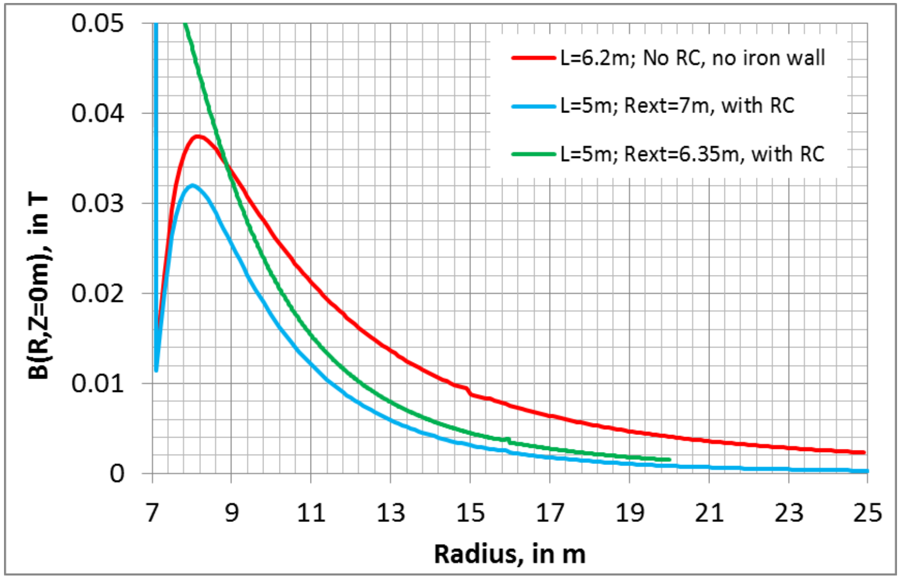
Reduction of the external radius

With external **radius** of **6.35m and L=5m with RCs**:
barrel yoke iron saturation is more uniform (around **2T**).

$$\int_{R_{int}}^{R_{ext}} B_z . dr = 4\ T.m$$

B-field vector sum in central transverse plane:





Stray field lower than **4.5mT at R=15m**.

Total reduction of iron mass (reduced length of end caps + reduced external radius of end cap and barrel yoke) ≈ **4700 tons** wrt CLIC_SiD L=6.2m (43.5% of initial design iron mass).

Conclusions

End cap with reduced length is possible with ring coils, provided the field homogeneity in the central volume is acceptable for physics.

The end cap yoke is still useful to provide support for muon stations, radiation shielding, and magnetic field shaping.

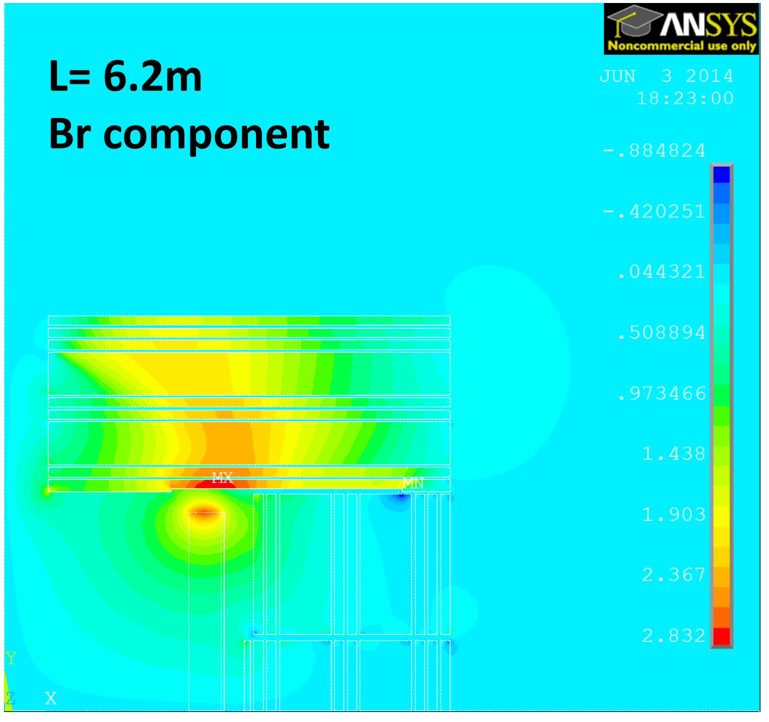
The **barrel yoke could also be reduced in diameter**: if there is only one detector in the experimental cavern (with no access to cavern during physics run), then it can be compatible with radiation level due to accidental beam loss.

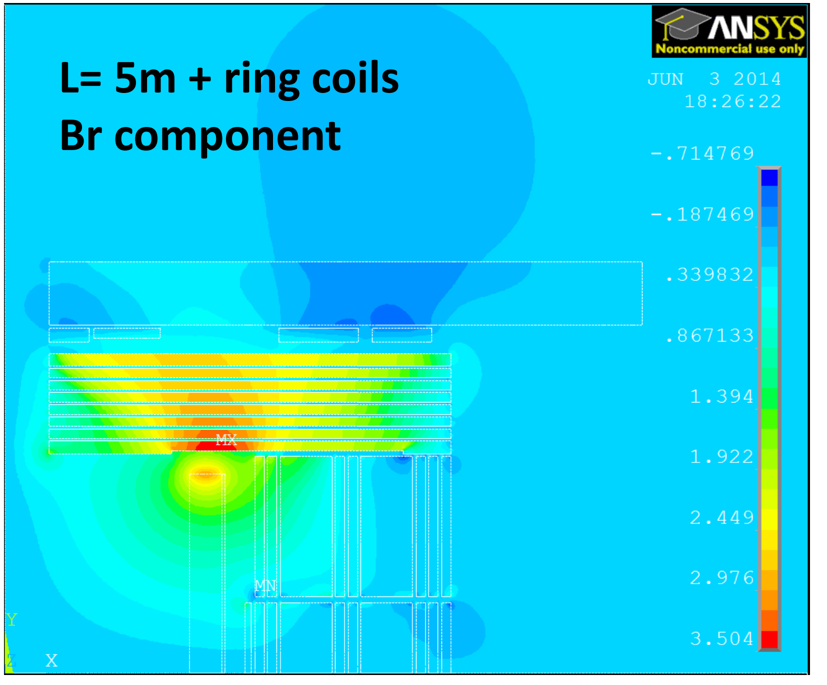
The **cost estimate** for manufacturing, infrastructure and operation of the ring coils **should be compared** to the saving on the yoke cost.

Back up slides

Comparison of radial B-field component

Comparison of new design (L=5m+RC) to initial on (CLIC CDR, L=6.2m)

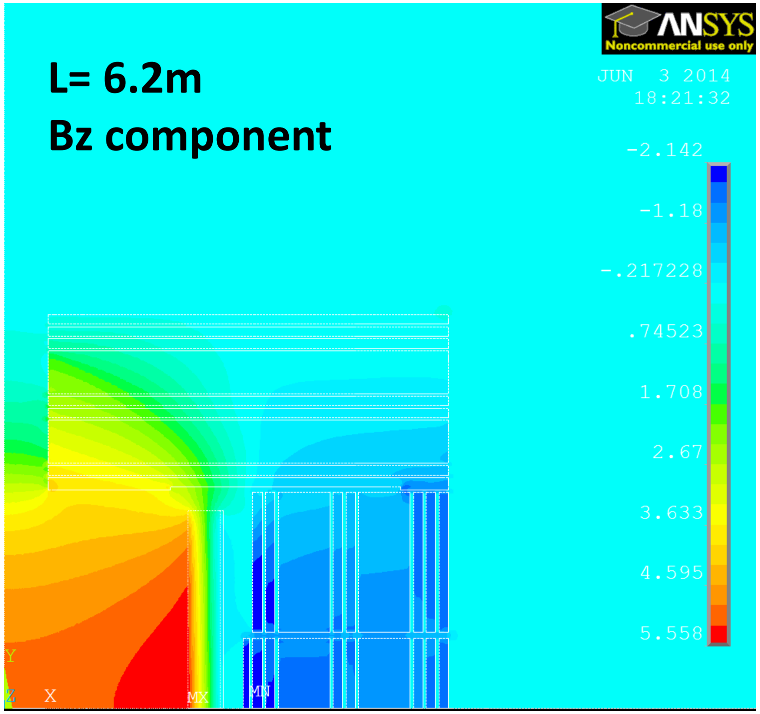




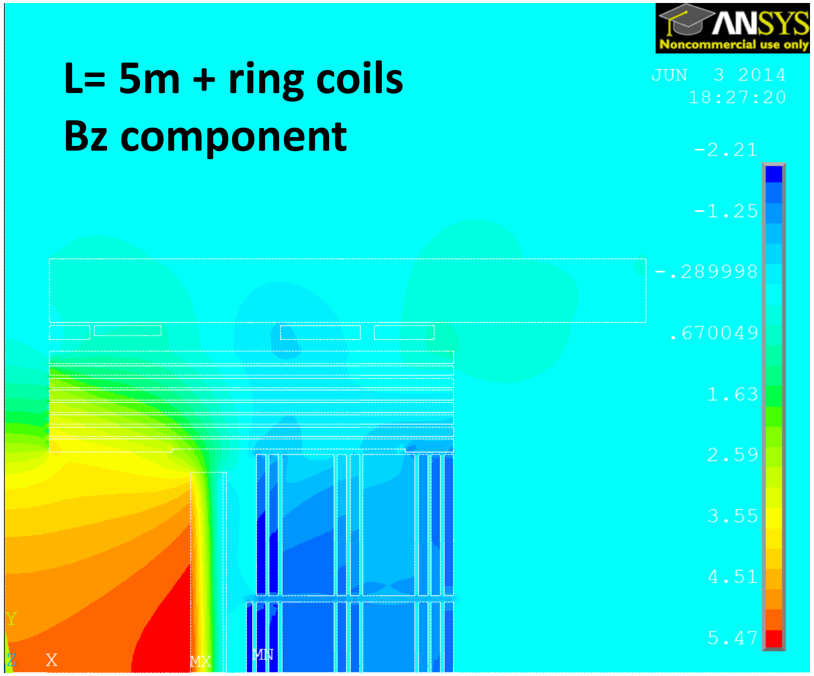
Comparison of axial B-field component

Comparison of new design (L=5m+RC) to initial on (CLIC CDR, L=6.2m)

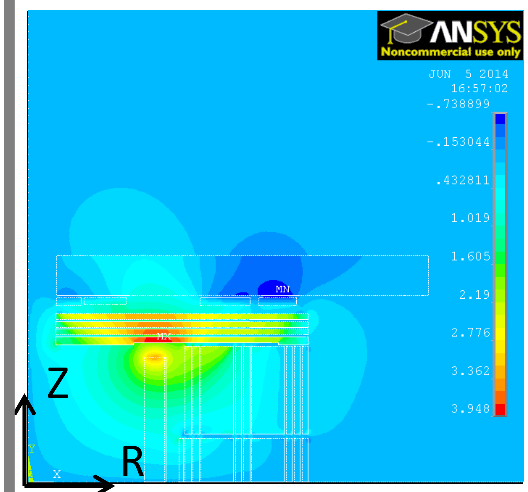
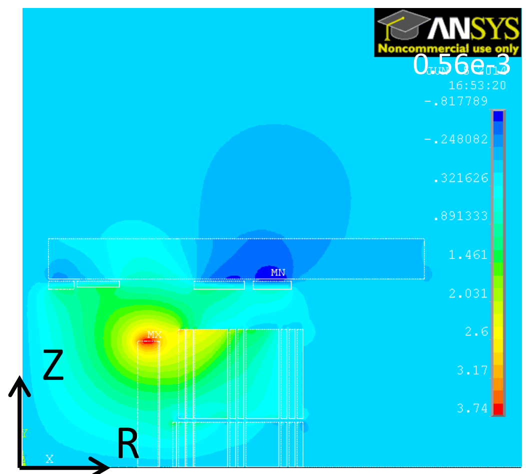
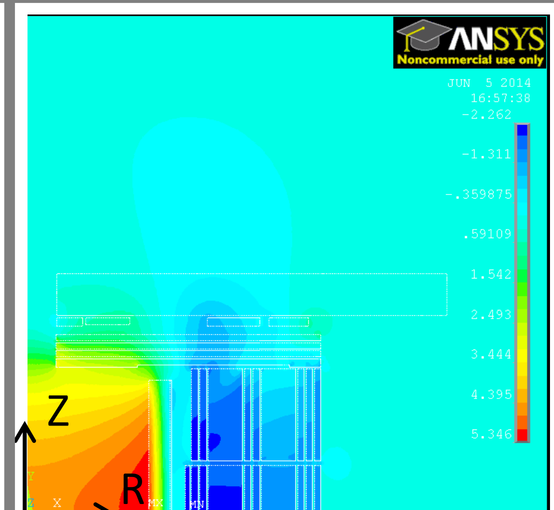
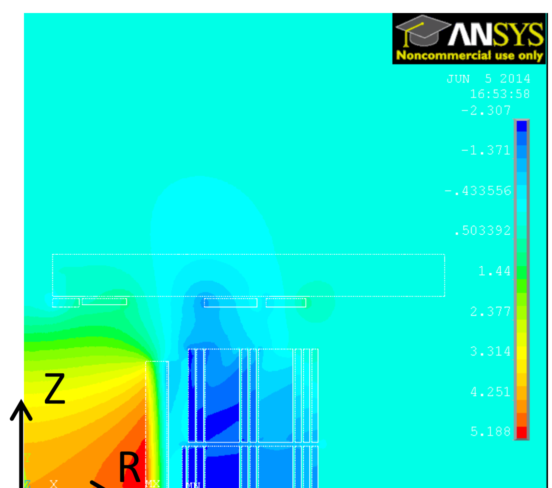
L= 6.2m



L= 5m + ring coils



Extreme layouts: configuration 1 and 2

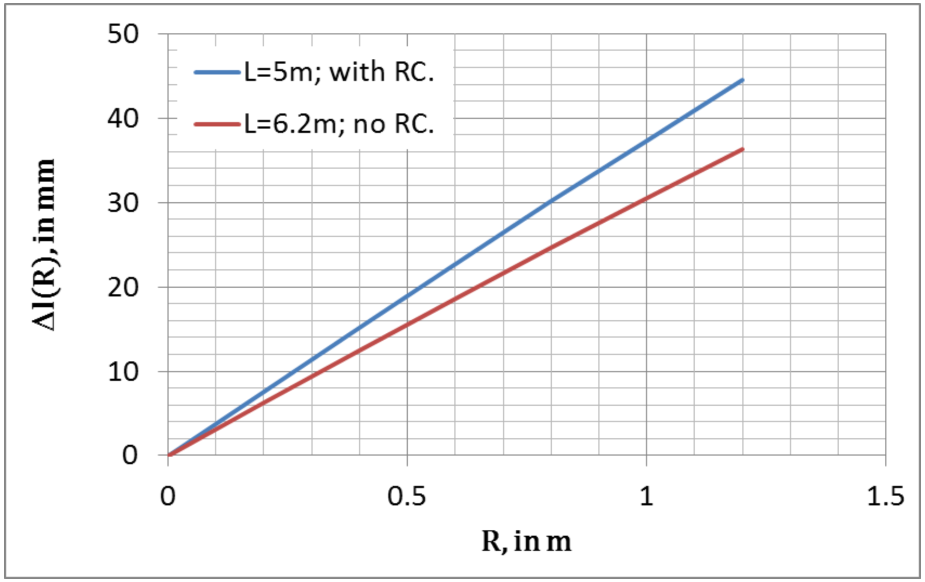
	Config. 1: L=4.205m	Config. 2: no end cap
Br component		
Bz component		

⇒ Stronger gradients

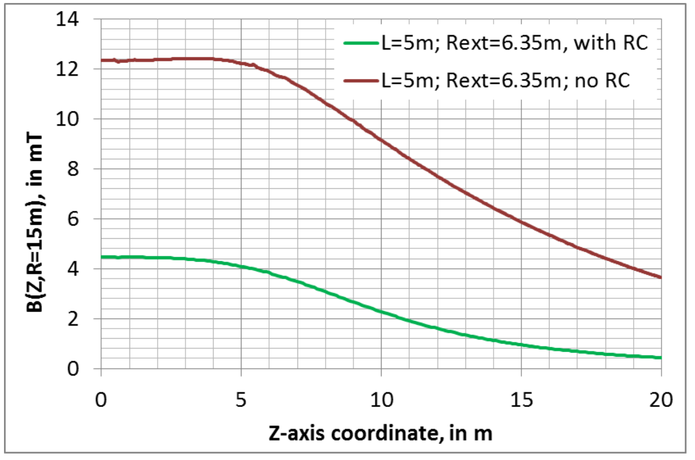
Influence of the reduced end cap length and ring coils on the magnetic field distortion for a detector with a TPC (external radius 7m):

Inside the barrel volume: $$\Delta l(r,z) = \int_0^z \frac{B_r(z)}{B_z(r)} dz \quad , \quad z \in [0\,,1.54]$$

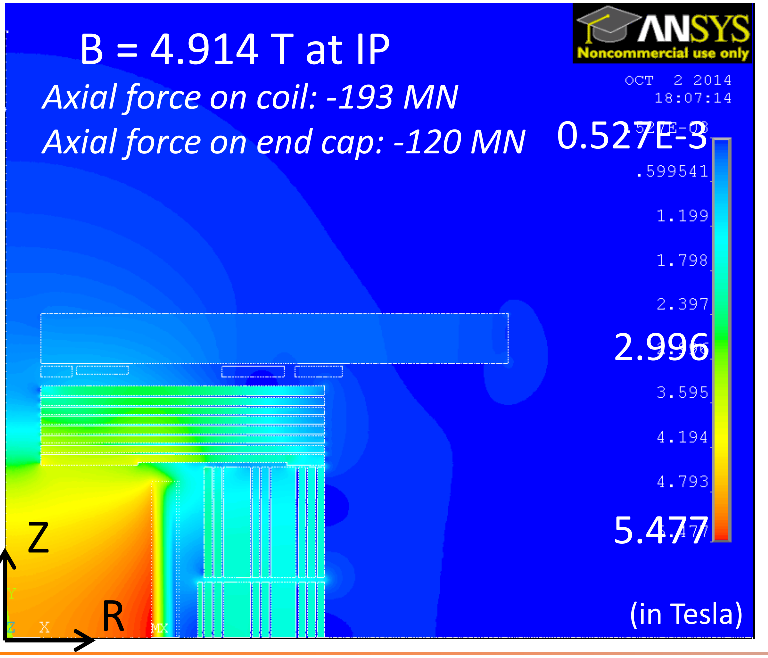
Increase of 23% wrt initial design (L=6.2m).



No RC with L=5m and R=6.35m



Max stray field at R=15m :12.3mT
(with Ring Coils energized: 4.5mT).



Axial B-field component **on the detector axis:**