Design of Solenoid Field

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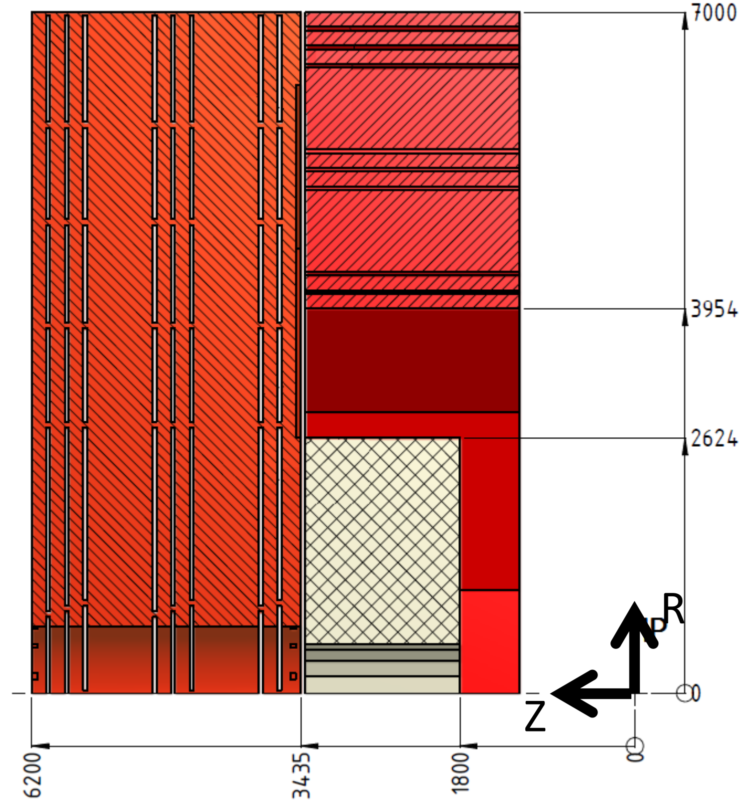
CLIC Detector optimisation – Design of solenoid field

Reference design layout : initial CLIC_SiD layout with detector **half length L=6.2m**
End cap iron thickness is **2445mm**.
8 muon chamber stations in the yoke end cap.

<u>**Longitudinal section :**</u>
quarter view,
detector axis horizontal,
only end cap and one barrel shown.

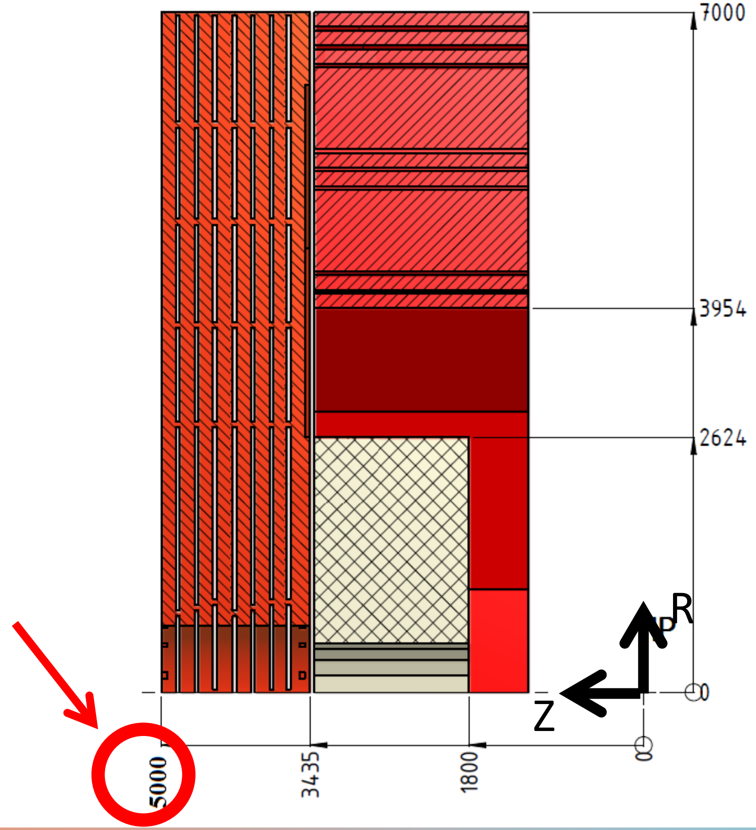


CLIC Detector optimisation – Design of solenoid field

New design layout : reduced detector **half-length to L=5m**
End cap iron thickness reduced by **1160mm** (**2445mm to 1285mm**).
7 muon chamber stations in the yoke end cap.

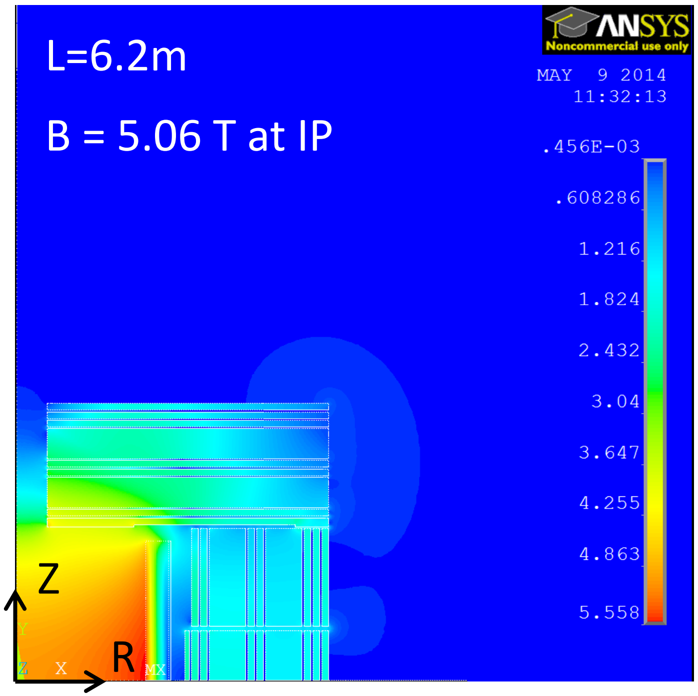
<u>**Longitudinal section :**</u>
quarter view,
detector axis horizontal,
only end cap and one barrel shown.

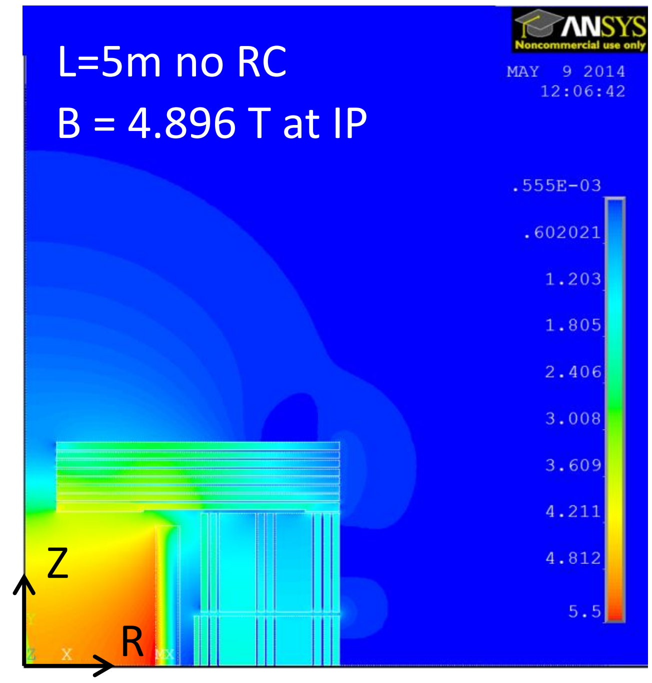
- Solenoid length kept at 6.23m,
- External radius identical,
- No modification of barrel yoke.



Comparison of the two layouts (no ring coils): B field vector sum map

(Detector axis is vertical on the maps !)



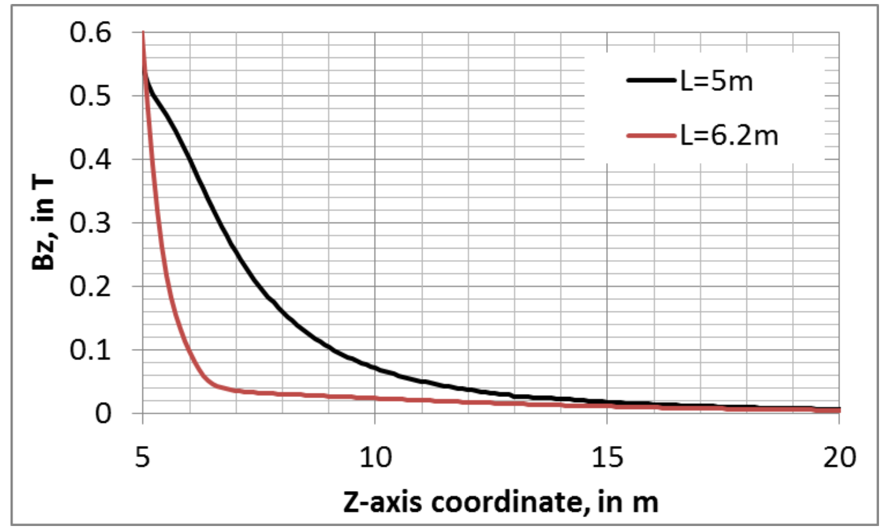


B-field 2D map : Area most affected is around the detector axis and outside the yoke.

Far region : Less significant effect, **Bmax=9mT at R=15m.**

Comparison of the two layouts (no ring coils):

Axial B-field component Bz(R=0) **on coil axis**:



$\Rightarrow$ Improve the design with reduced length by **implementing ring coils** to :

- lower the stray field,
- lower the field near the beam line outside the yoke end cap.

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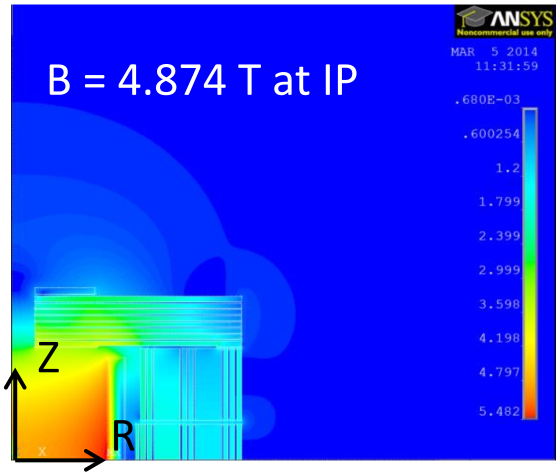
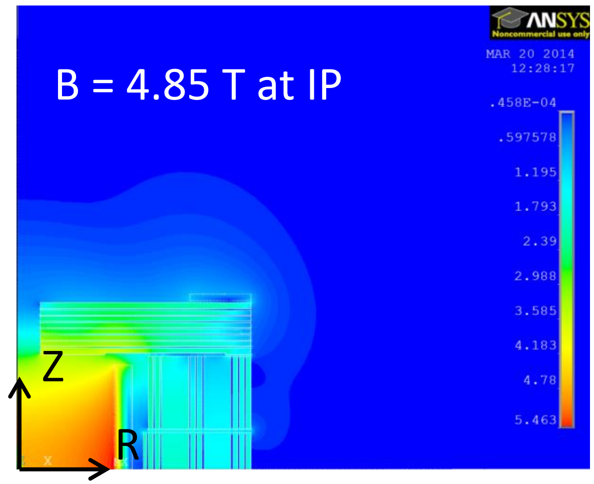
Effect of ring coils on B-field with L=5m: 3 configurations: J=3A/mm^2, same cross section.

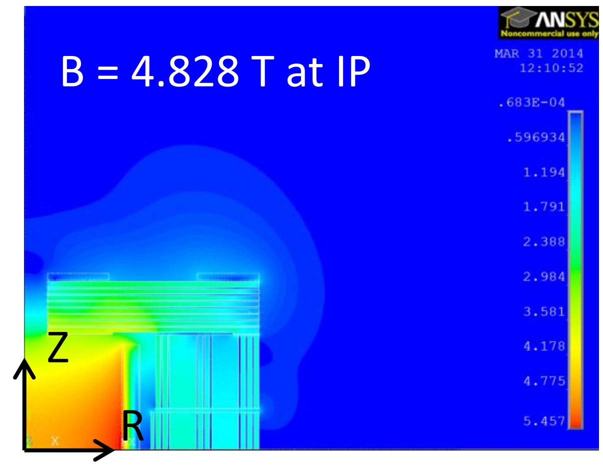
1 RC on inner radius



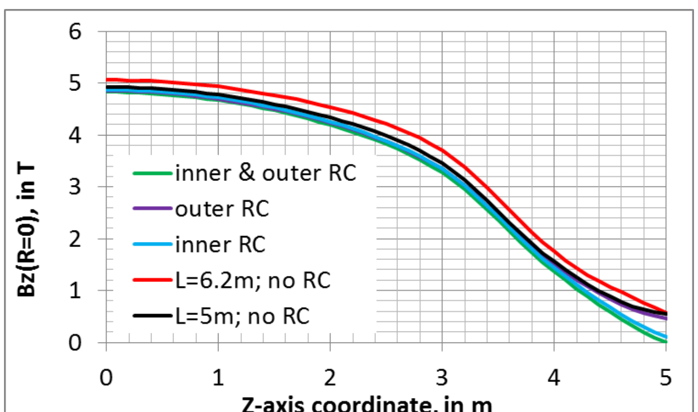
1 RC on outer radius

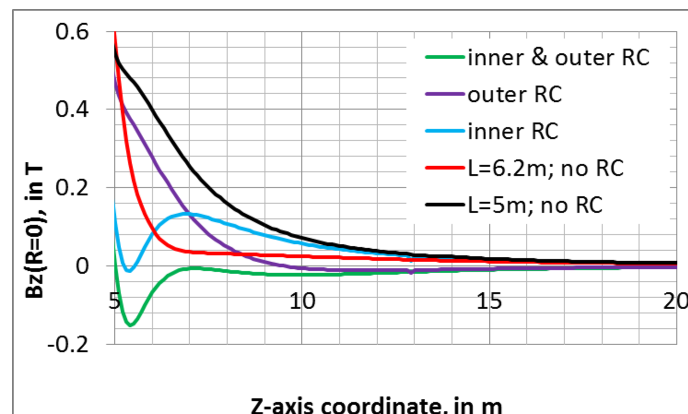


2 RC on inner and outer radius



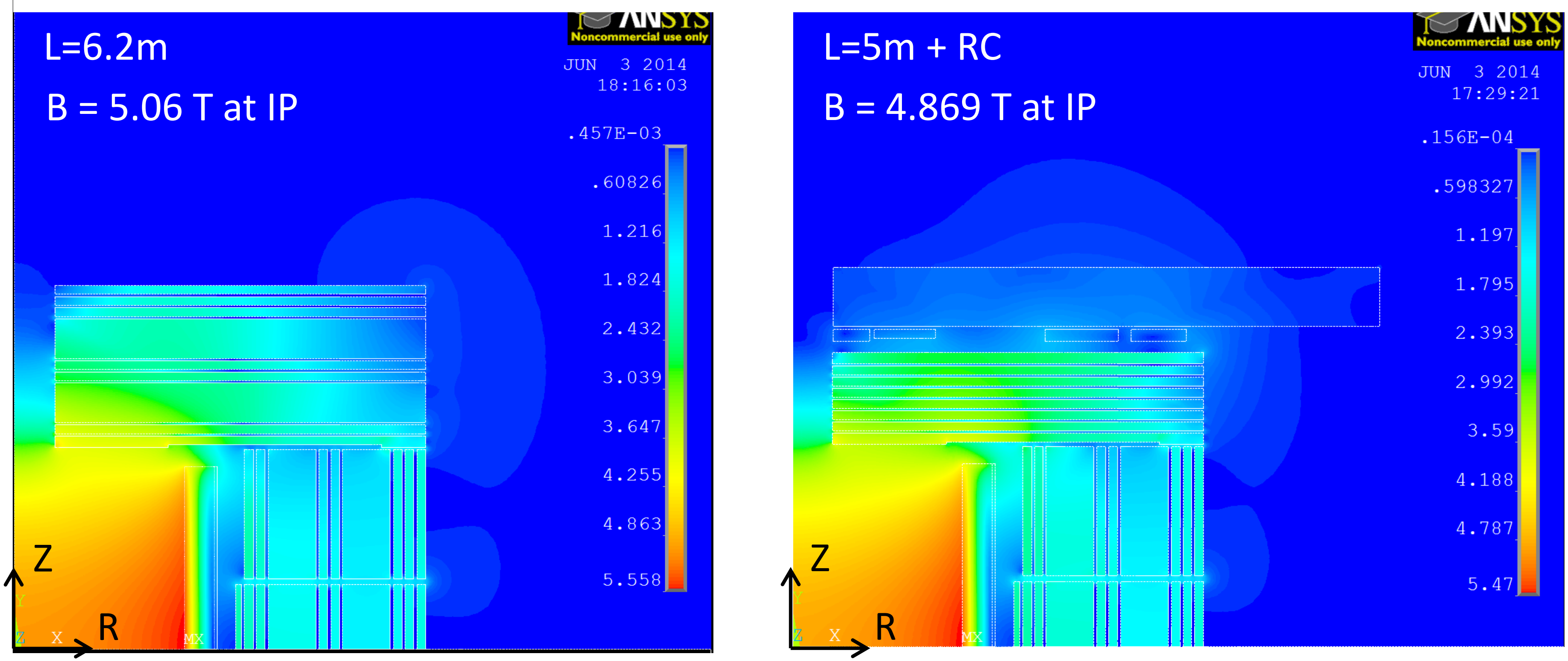
Axial B-field component Bz(R=0) on coil axis:





Ring coils with L=5m: Configuration giving a lower field on Z-axis.

- Effect of iron in concrete cavern wall (B-H curve = 10% of iron),
- 4 RCs with resistive conductor and Jrc=3A/mm^2,
- Assumption to have the ring coils attached to the cavern wall (increased gap).

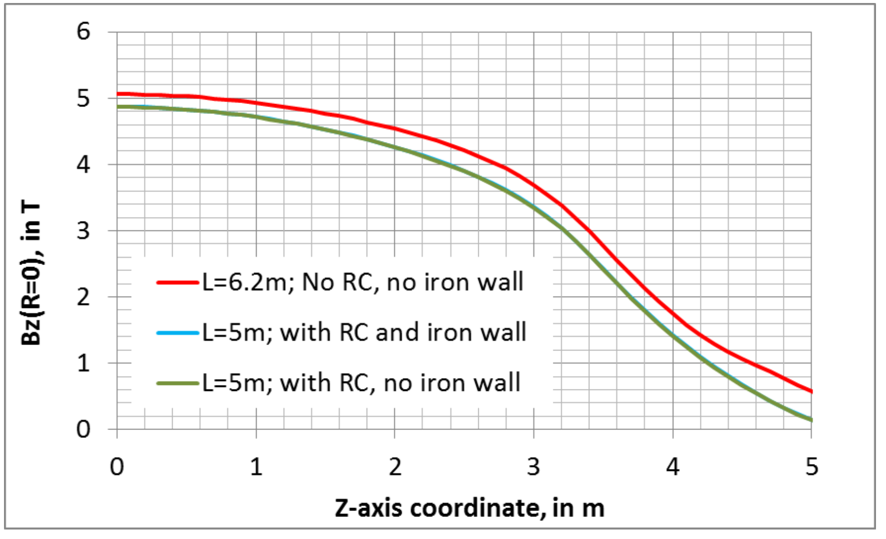


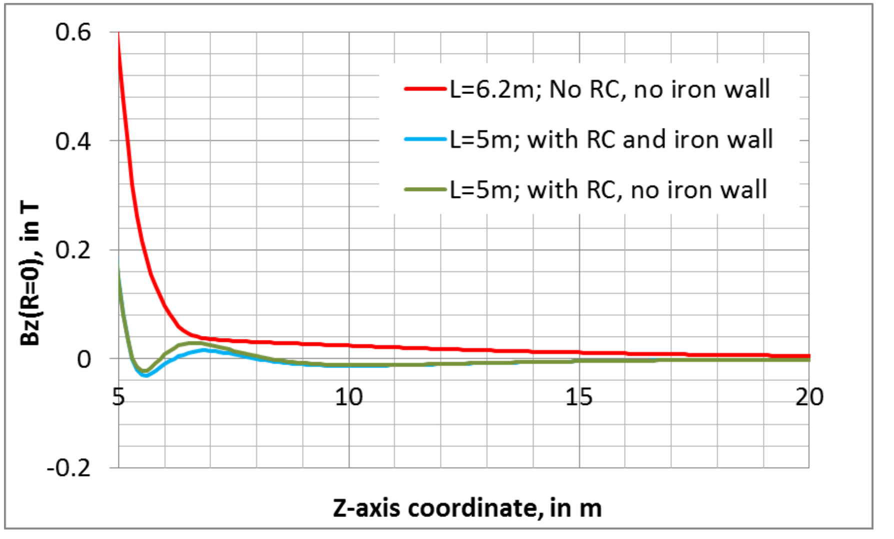
B-field magnetic flux density vector sum maps

Field at IP is **3.8% lower wrt L=6.2m.**

Ring coils with L=5m:

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





Bfield on detector axis at Z=5m: **150 mT**

<u>Forces on end cap and yoke:</u>

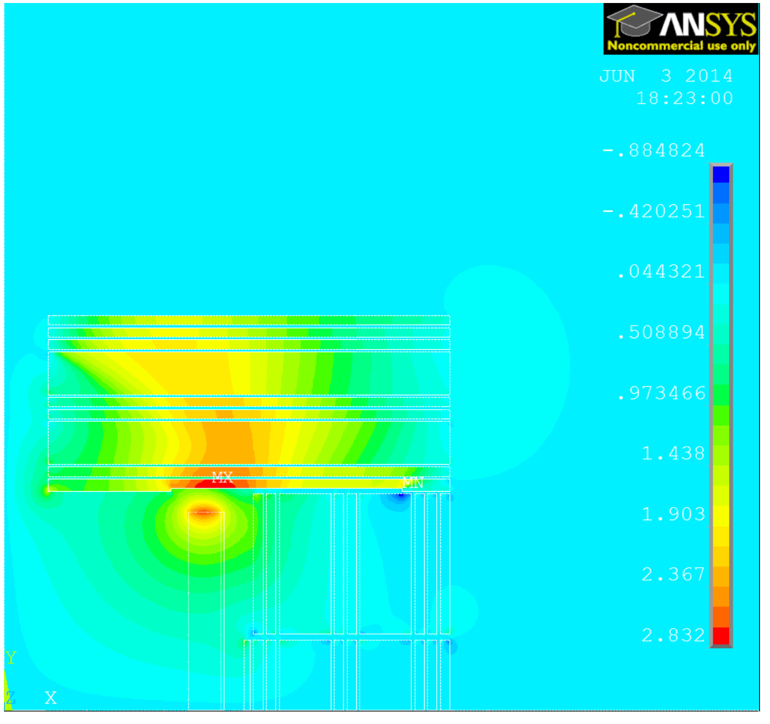
Attractive axial force on end cap : 100 MN (170 MN with L=6.2m),

Compressive axial force on main coil : 207 MN (164 MN with L=6.2m).

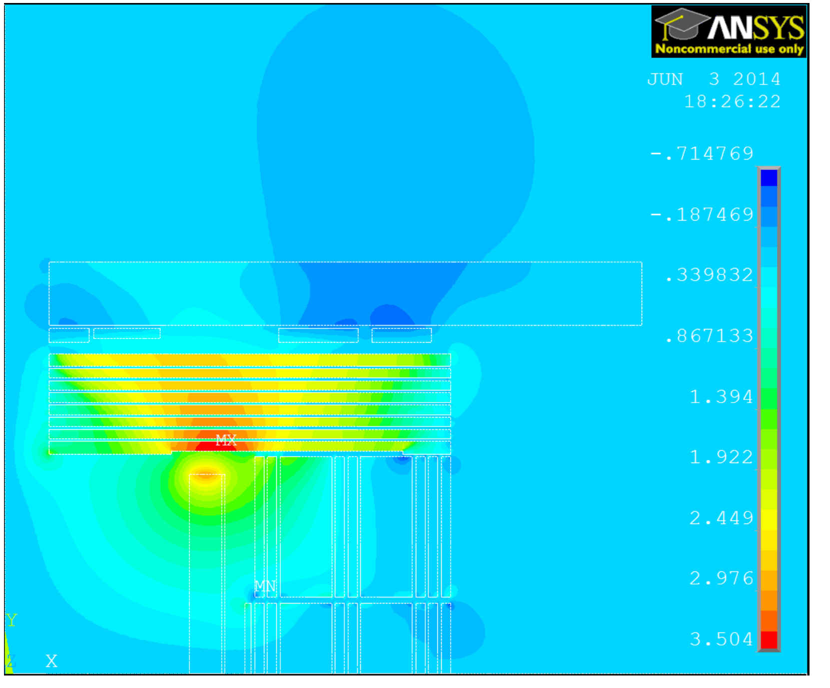
Ring coils with L=5m:

Radial B-field component

L= 6.2m



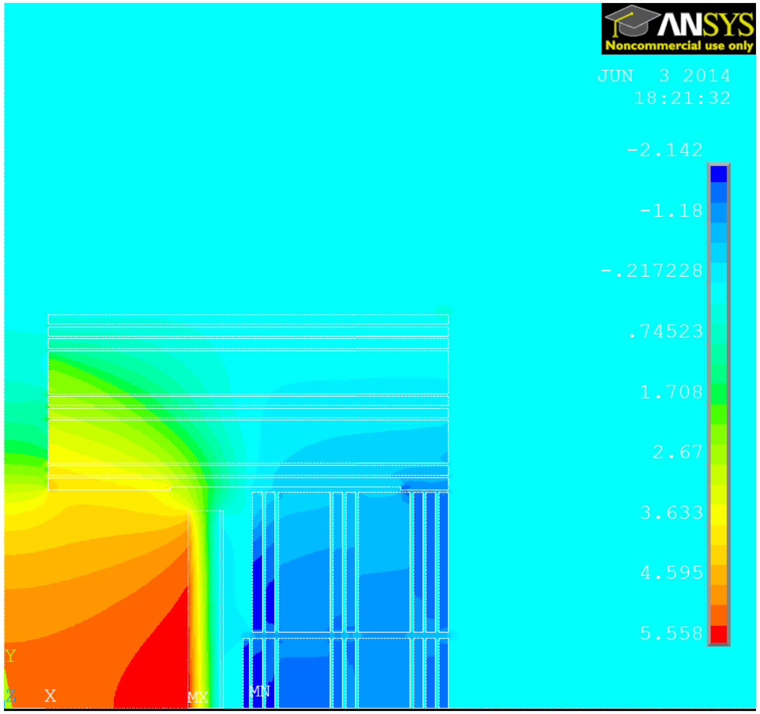
L= 5m + ring coils



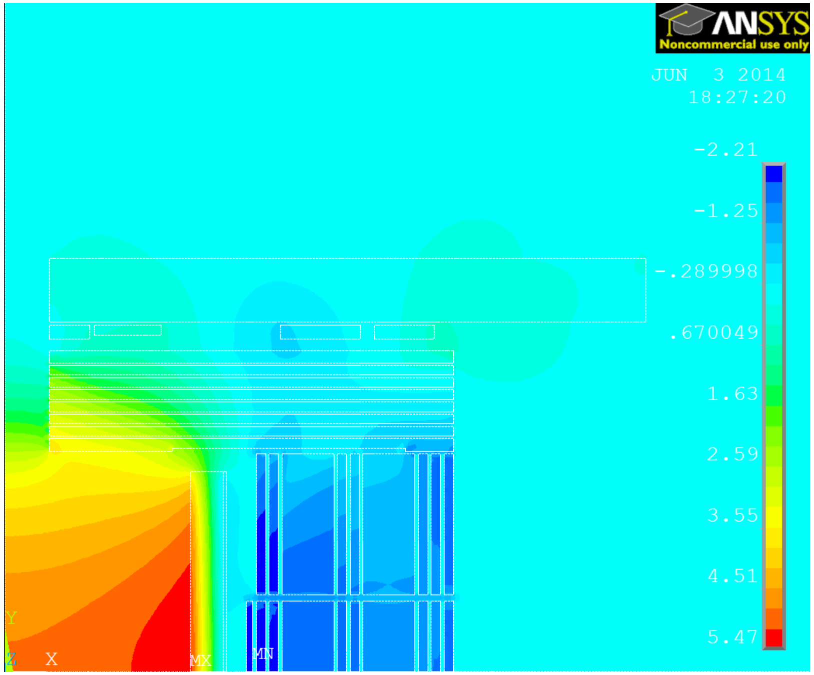
Ring coils with L=5m:

Axial B-field component

L= 6.2m



L= 5m + ring coils

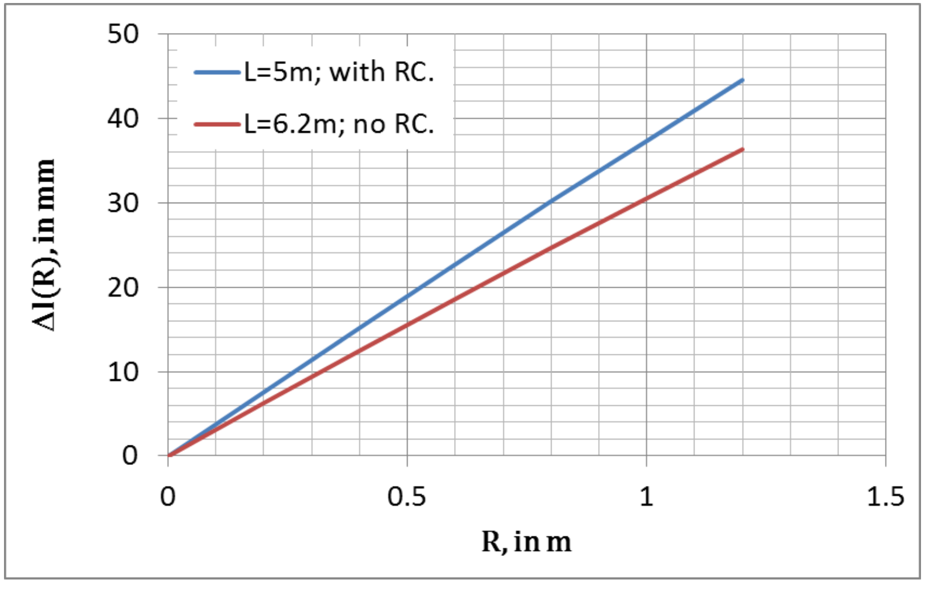


Ring coils with L=5m:

Magnetic field distortion in barrel tracker volume :

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

Increase 23% wrt L=6.2m.



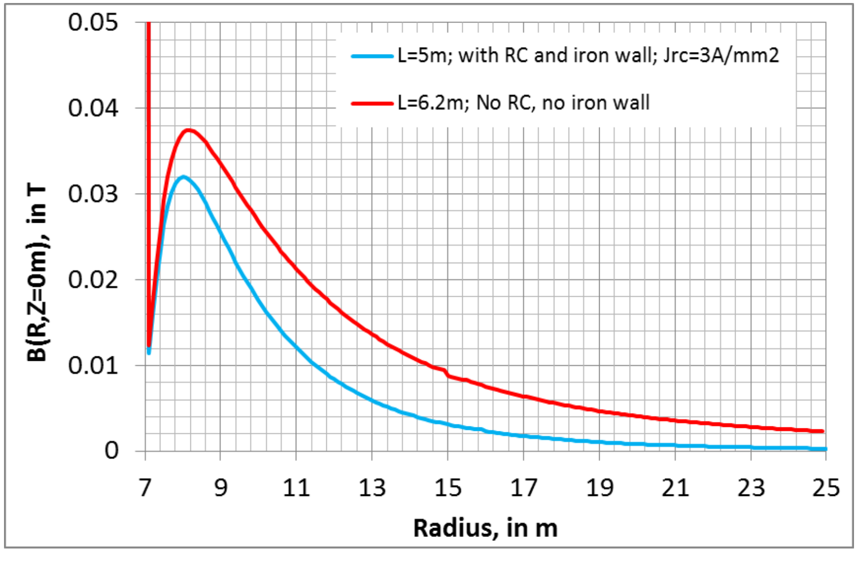
CLIC Detector optimisation – Design of solenoid field

Ring coils with L=5m:

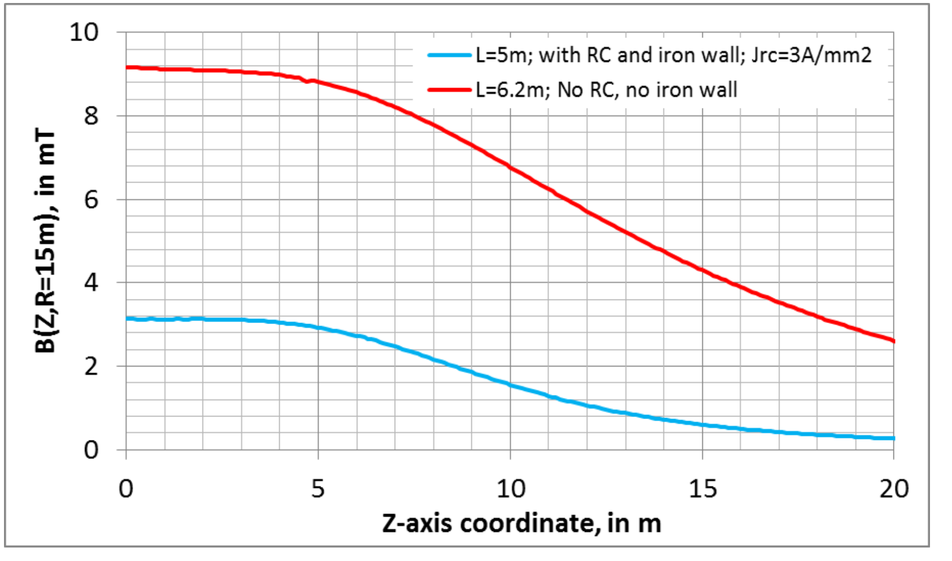
→ Stray field **lower than 3.2mT at R=15m**.

B-field vector sum :

Transverse plane Z=0m



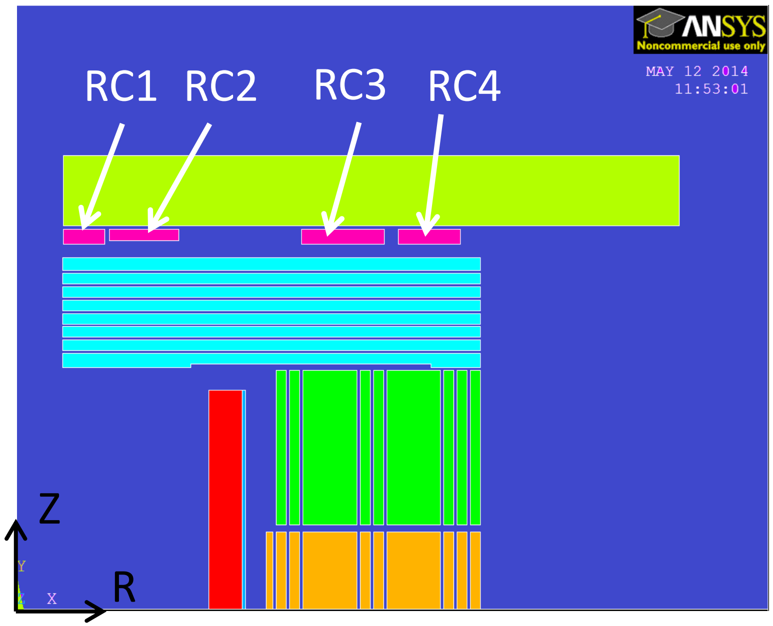
At radius R=15m , parallel to Z-axis



Characteristics of the ring coils on the cavern wall with L=5m :

- Arbitrary gap from RC to yoke end cap: **192mm** (RC1, RC3 & RC4) and **244mm** (RC2),
- Space available for radiation chicane,
- Same copper conductor for all RCs,
- Total copper weight : **250 tons** (for 2 end caps). Suppressed steel mass wrt. L=6.2m (2 end caps)≈ **2800 tons,**
- Total electrical power of RCs (2 end caps): **2 x 2260 kW**.

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:

- Estimated temperature increase ≈ **45°C**,
- Total water flow (2 end caps): **2 x 57 m³/hour**.

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Characteristics of the ring coils on the cavern wall with L=5m :

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

	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.

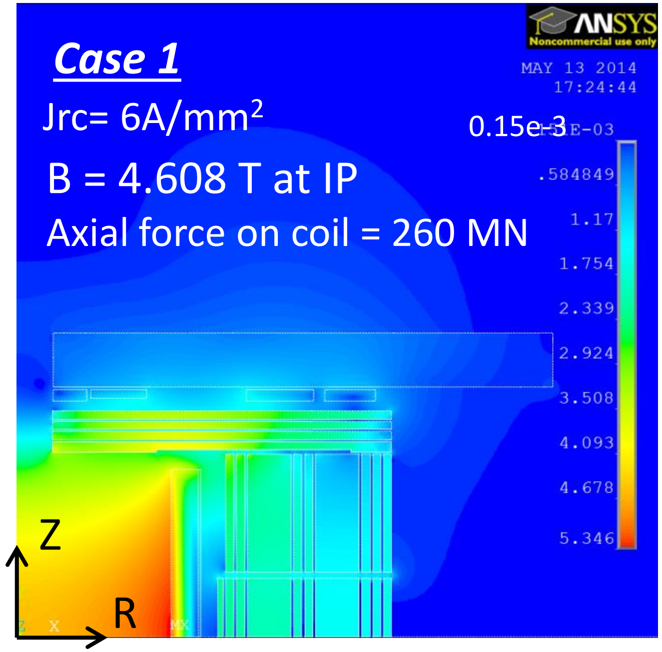
Other cases:

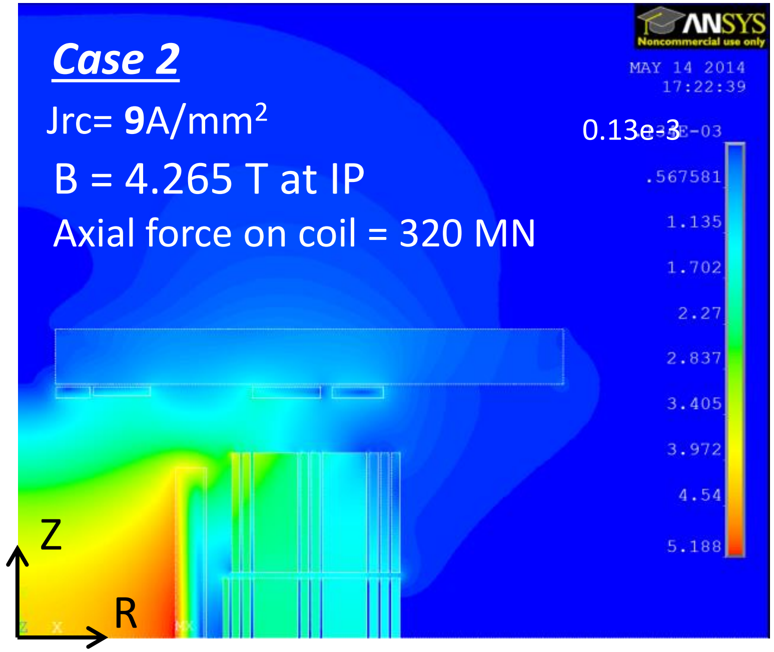
1- Reducing the iron thickness to 4 disks then L=5m to 4.205m,

2- No end cap iron yoke.

As a first approach, only the **current density** was increased. The RCs are **identical** and in **same positions** in both models.

With resistive ring coils, the ring coil sizes would have to be increased to keep a realistic conductor and current density. **SC coils would be more appropriate**.



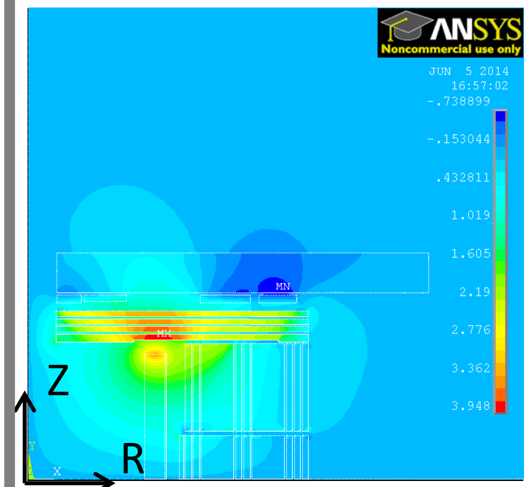


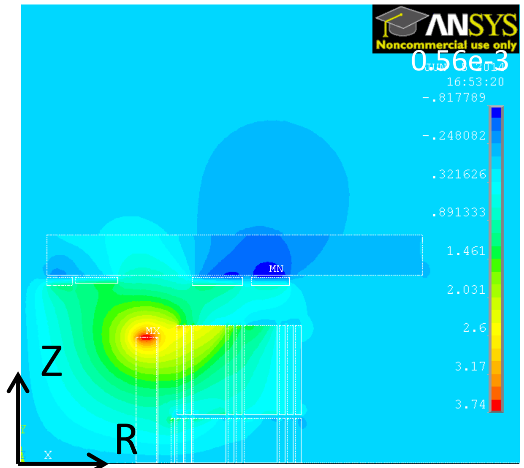
CLIC Detector optimisation – Design of solenoid field

Case 1: L=4.205m

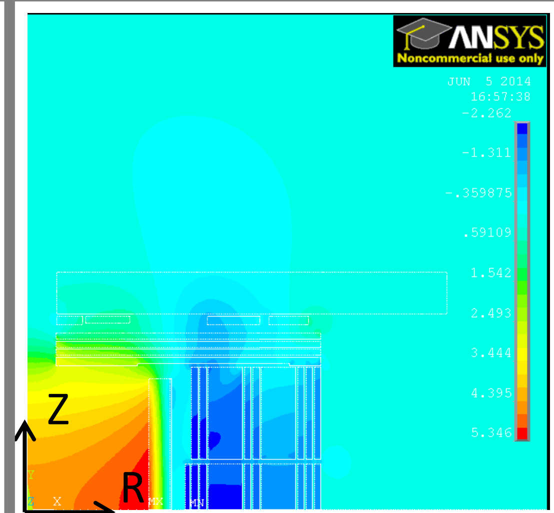
Case 2: no end cap

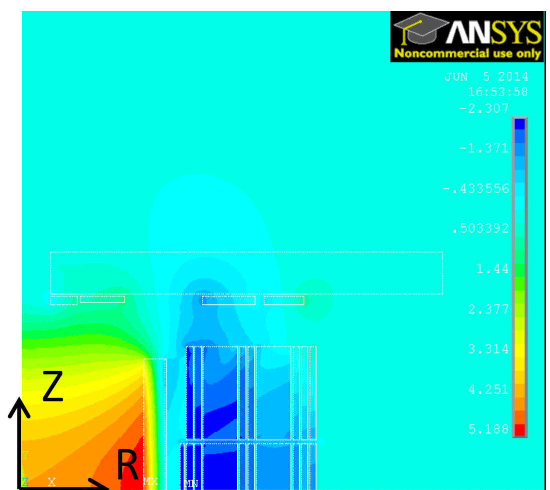
Br component





Bz component





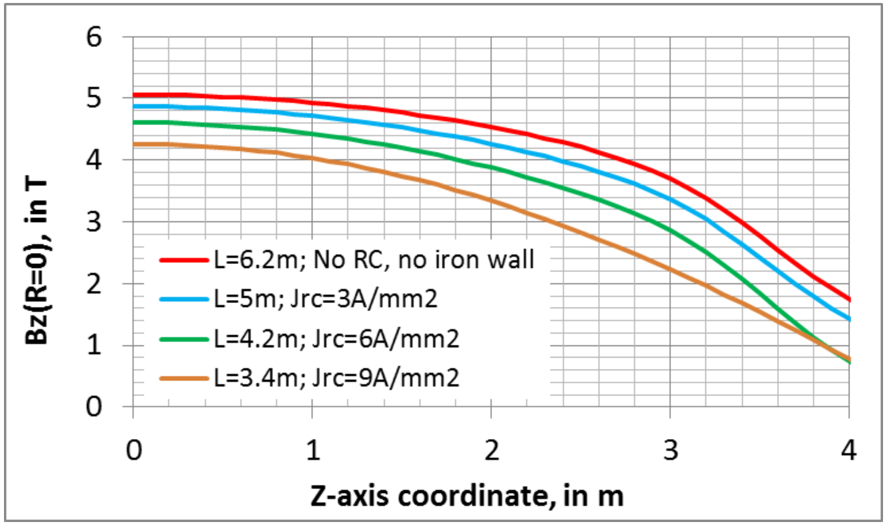
Wrt the ring coils defined for L=5m:

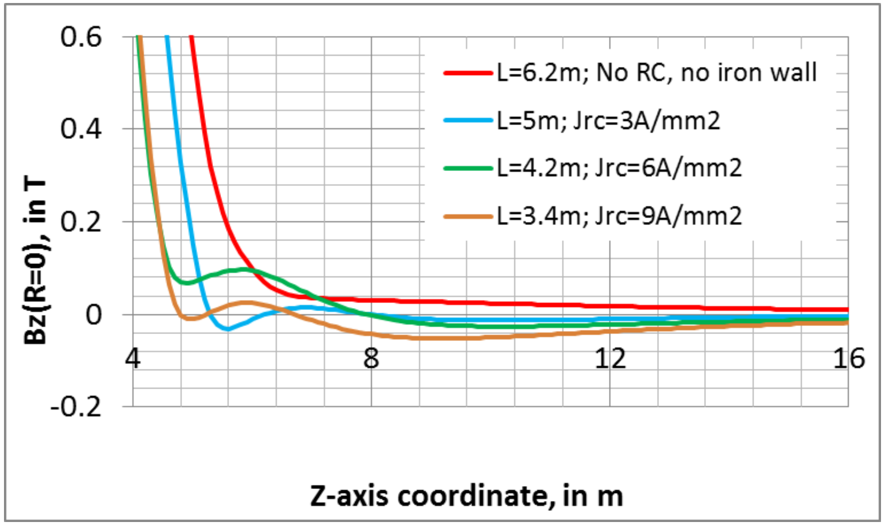
Case 1- Resistive ring coils x2 in size, total power x2.
Case 2- Resistive ring coils x3 in size, total power x3.

The magnetic field at IP is reduced (resp. **8.9%** and **15.7%** wrt L=6.2m) and the field distortion in the inner detector volume increases.

The EC iron yoke helps to shape the field.

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





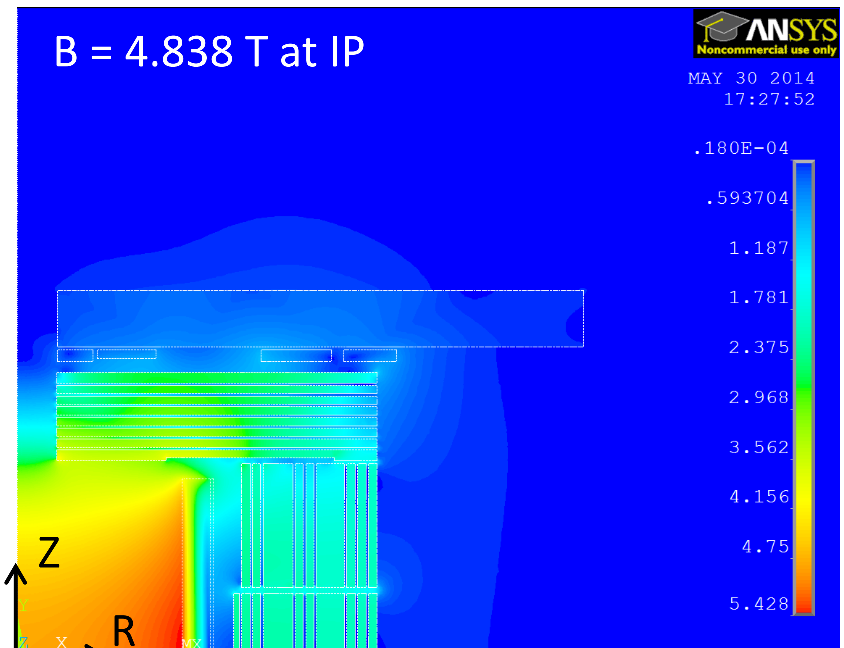
Reduction of external diameter of both end cap and barrel yoke:

Modified parameter: External radius Rext = 6.35m.

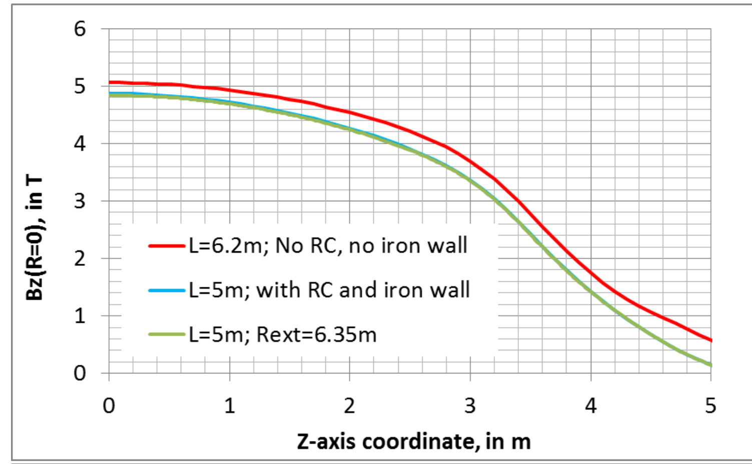
All other parameters unchanged :

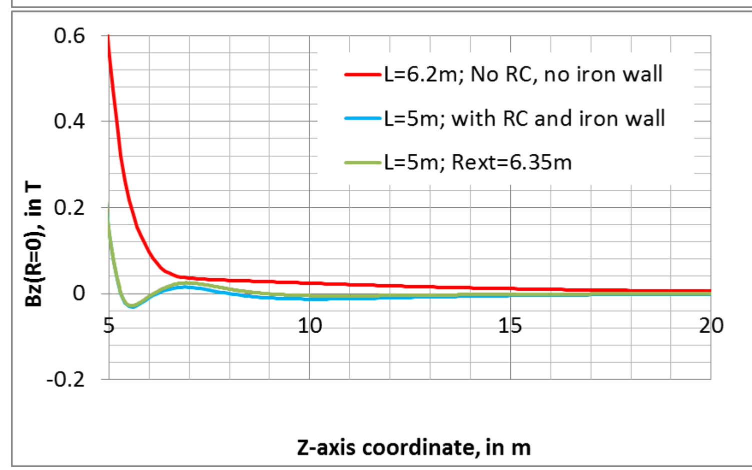
- RCs at same position, same current density,
- Detector half length L=5m.

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



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





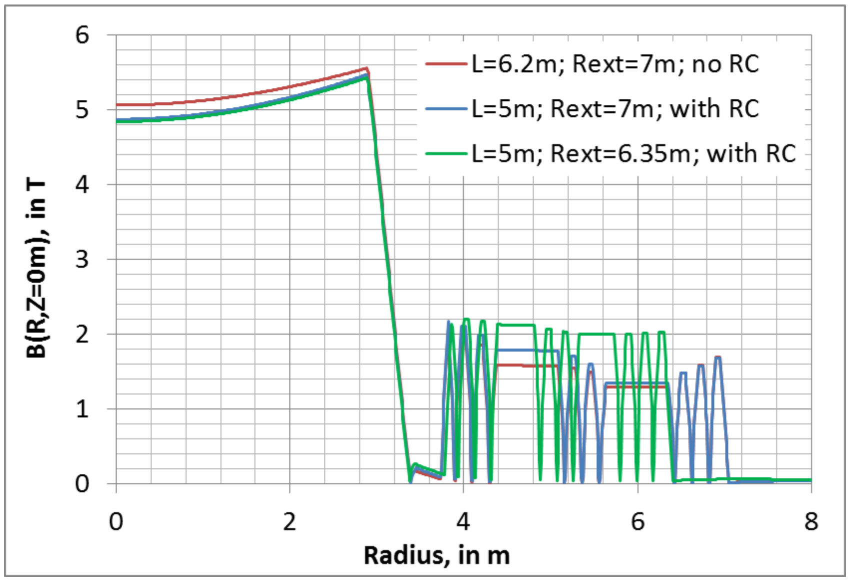
CLIC Detector optimisation – Design of solenoid field

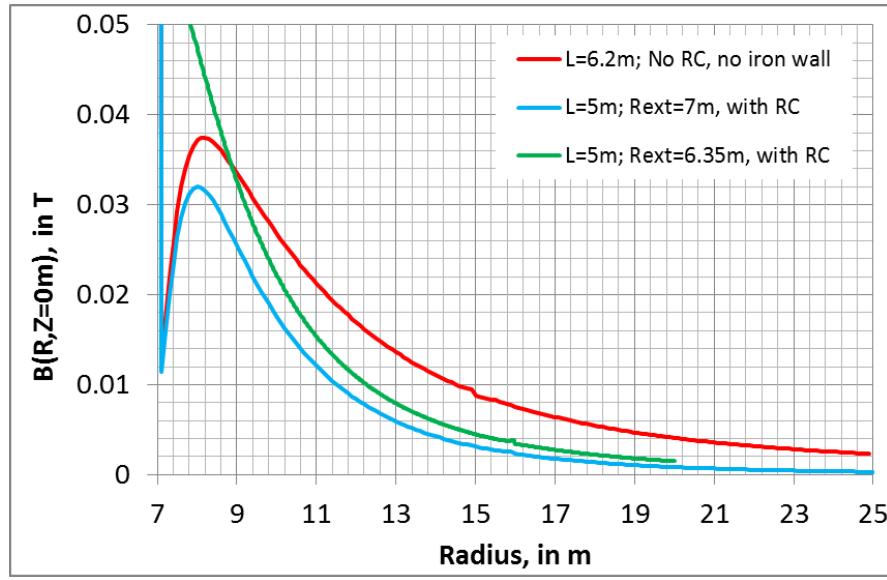
Reduction of external diameter of both end cap and barrel yoke:

With external **radius** of **6.35m and L=5m + RC**:
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 on iron mass (reduced length + radius)≈ **4700 tons** wrt CLIC_SiD L=6.2m.

Conclusions:

Reduced end cap in length is feasible with ring coils, provided the field homogeneity in the central volume is acceptable for physics.

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

The yoke material + manufacturing budget can be considerably reduced with ring coils.

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

The barrel yoke could also be reduced in diameter:

- the fringe field is reduced by the ring coils,
- If there is only one detector in the experimental cavern (no access to cavern during beam run), then it can be compatible with radiation due to accidental beam loss.