Reducing the Iron in the Endcap Yoke of CLIC_SiD

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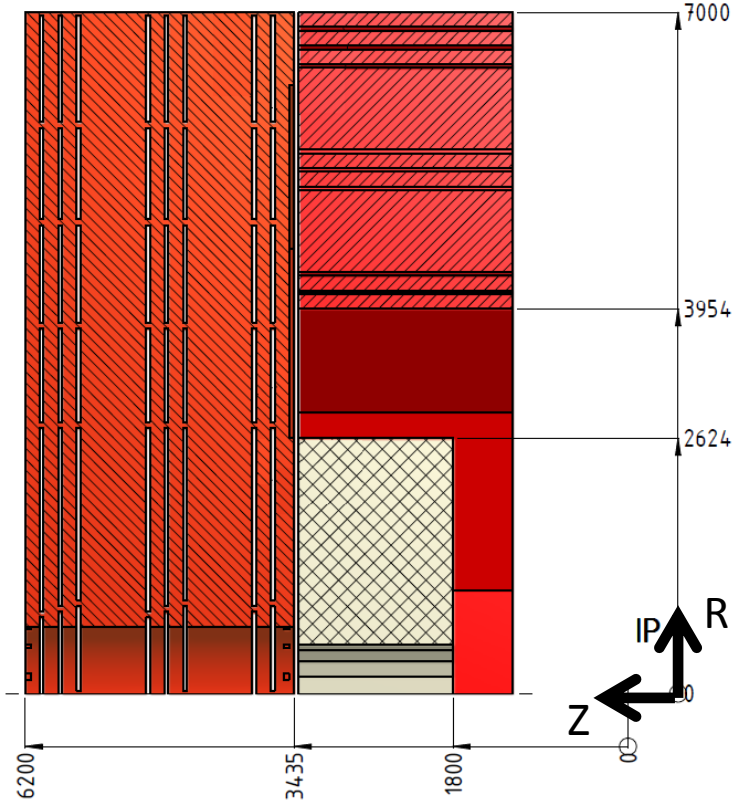
Layout : reduced detector half-length to L=5m (was L=6.2m)

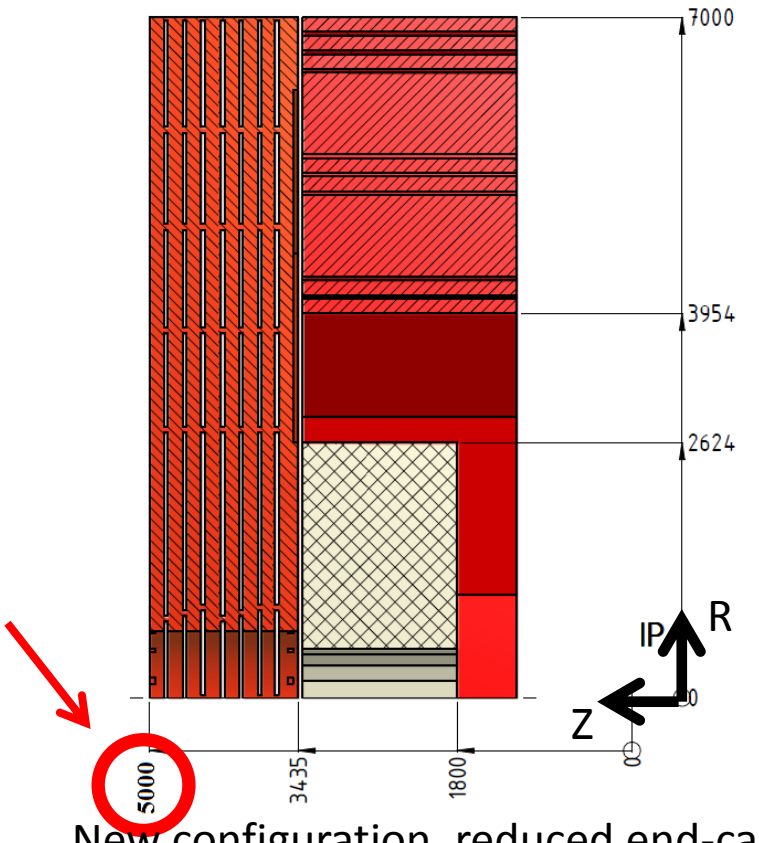
End cap iron thickness reduced by 1160mm (2445mm to 1285mm).

7 muon chamber stations in the yoke end cap (8 with L=6.2m).

Longitudinal sections : (solenoid length kept at 6.23m, no modification of barrel yoke).



Former configuration, wide end-cap



New configuration, reduced end-cap

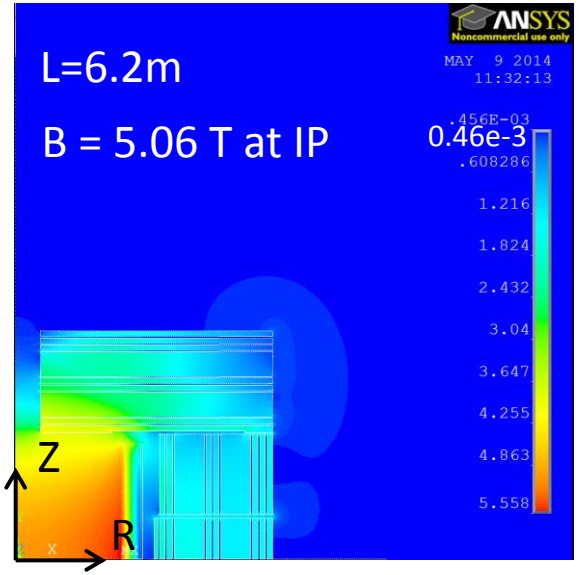
Comparison (no ring coils):

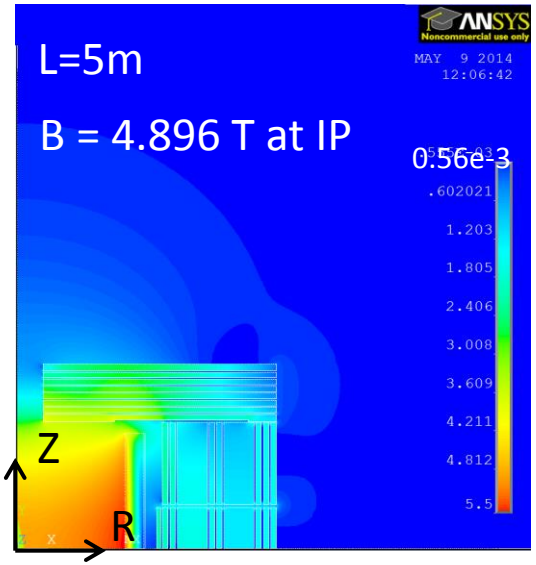
B-field 2D map :

Area most affected is around the detector axis outside the yoke.

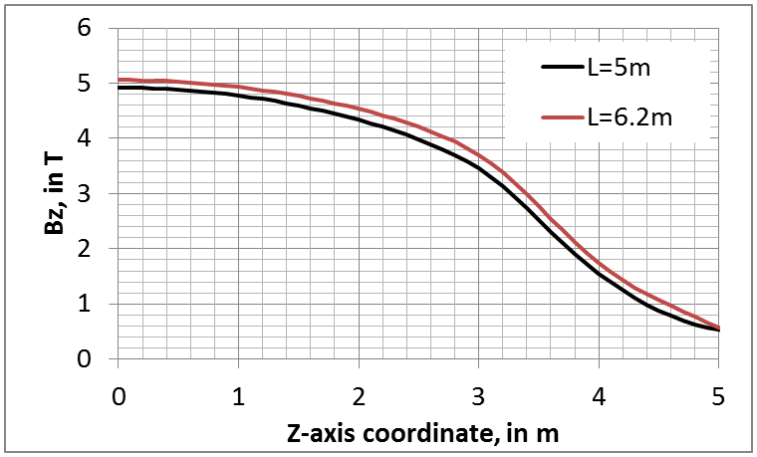
Far region :

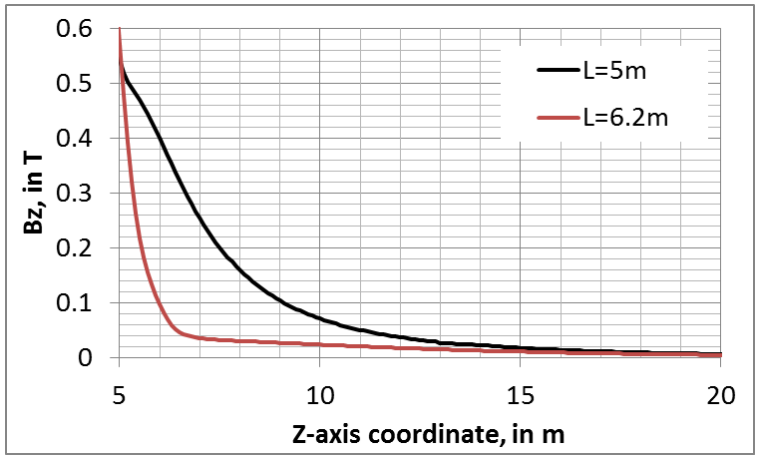
Less significant, Bmax=9mT at R=15m.





Bz(R=0) on coil axis:

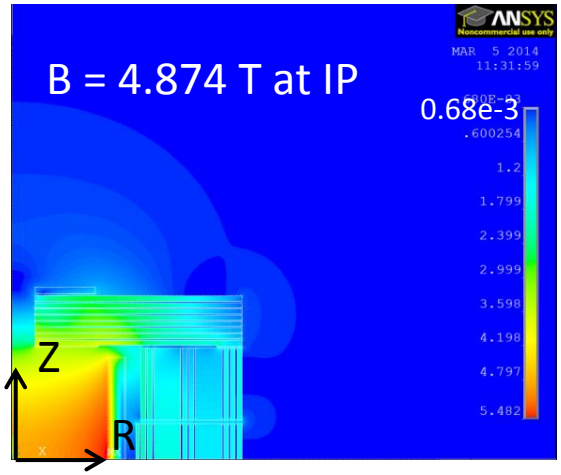




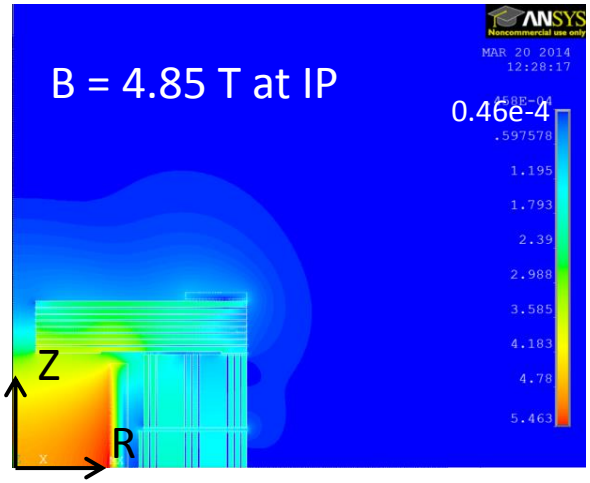
Ring coils on the end cap with L=5m:

J=3A/mm^2 on RC section, same cross section.

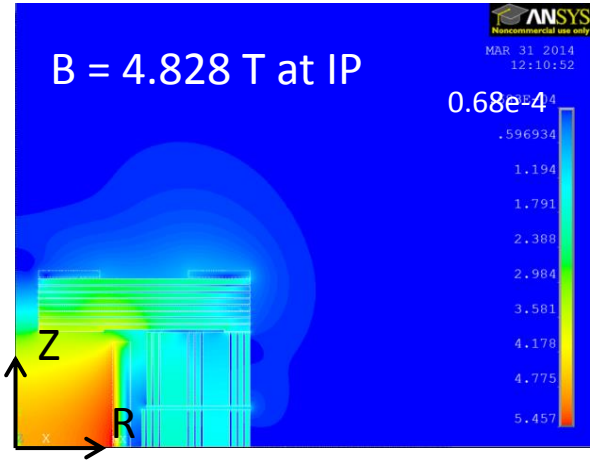
1 RC on inner radius

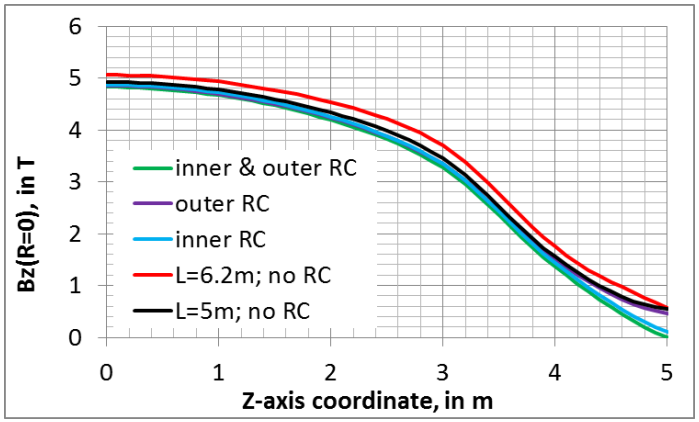


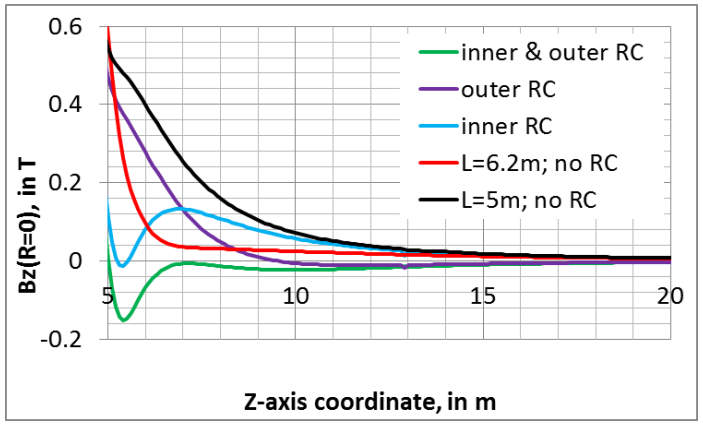
1 RC on outer radius



2 RC on inner and outer radius





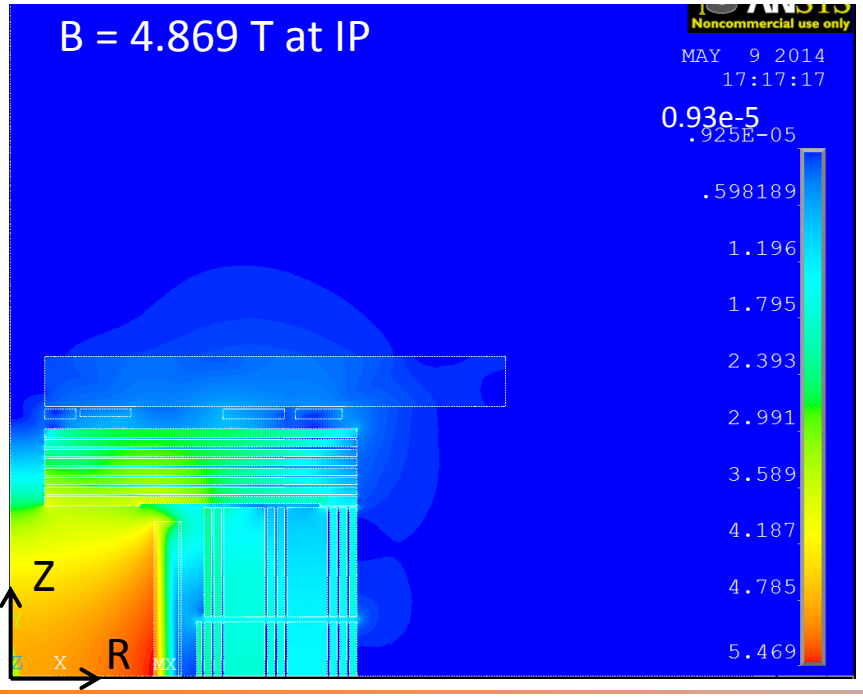


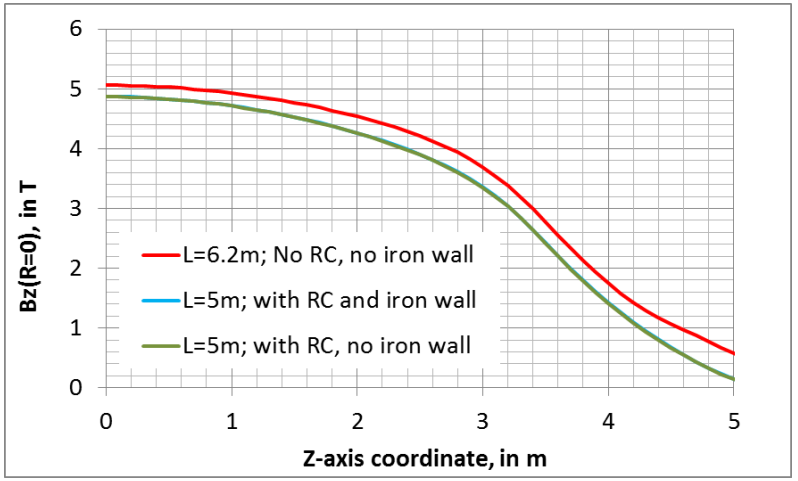
Ring coils on the cavern wall cap with L=5m: Configuration giving a lower field on Z-axis.

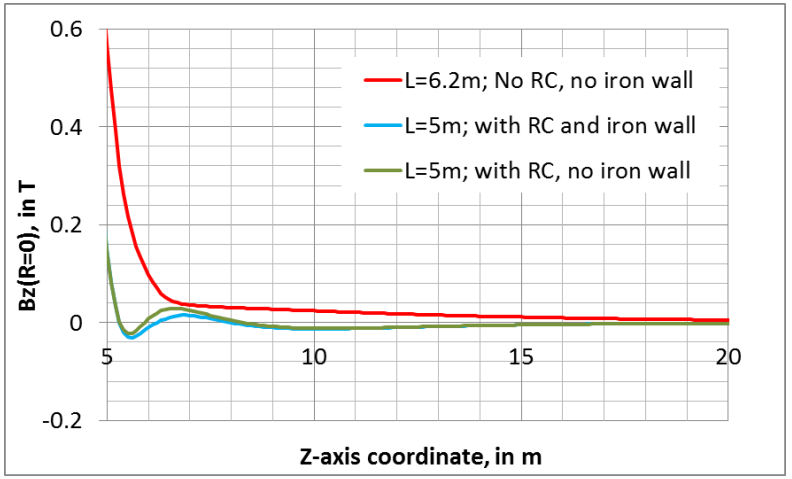
Effect of iron in concrete cavern wall (B-H curve = 10% of iron). 4 RCs with resistive conductor and Jrc=3A/mm^2.

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

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).





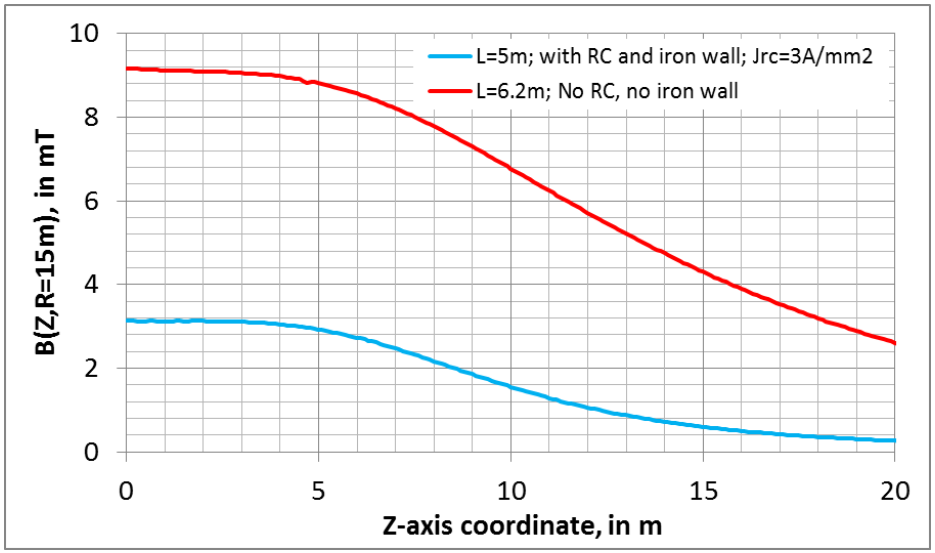


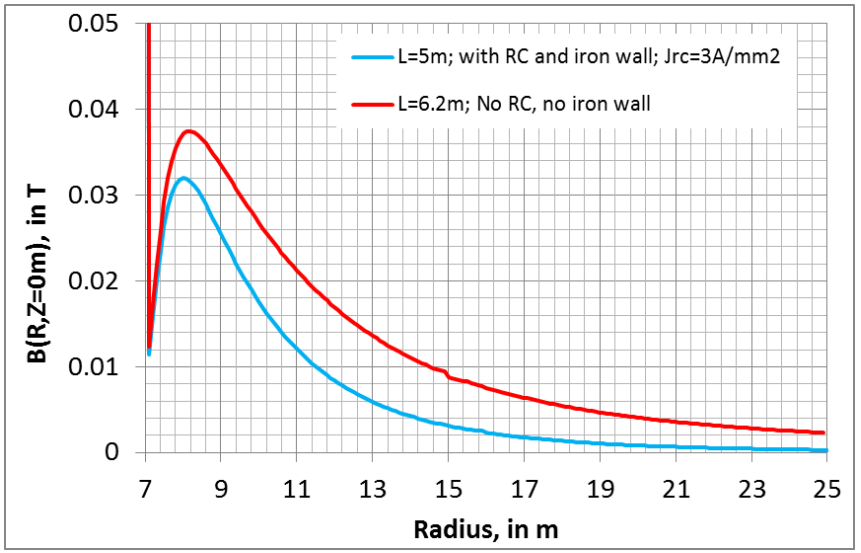
Ring coils on the cavern wall cap with L=5m:

Effect of iron in concrete cavern wall included (B-H curve = 10% of iron).

Current density Jrc=3A/mm^2 in all ring coils.

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



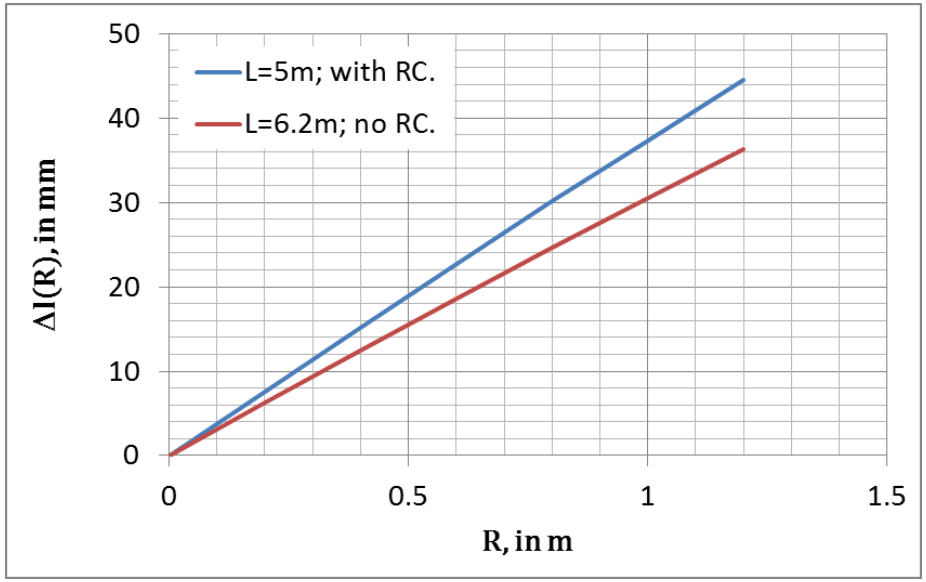


Ring coils on the cavern wall cap with L=5m:

Magnetic field distortion in barrel tracker volume :

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

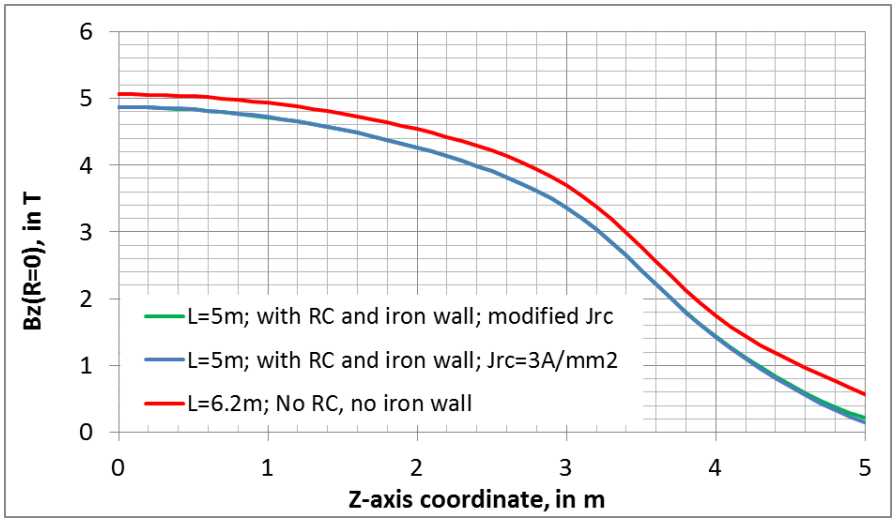
Increase 23% wrt L=6.2m.

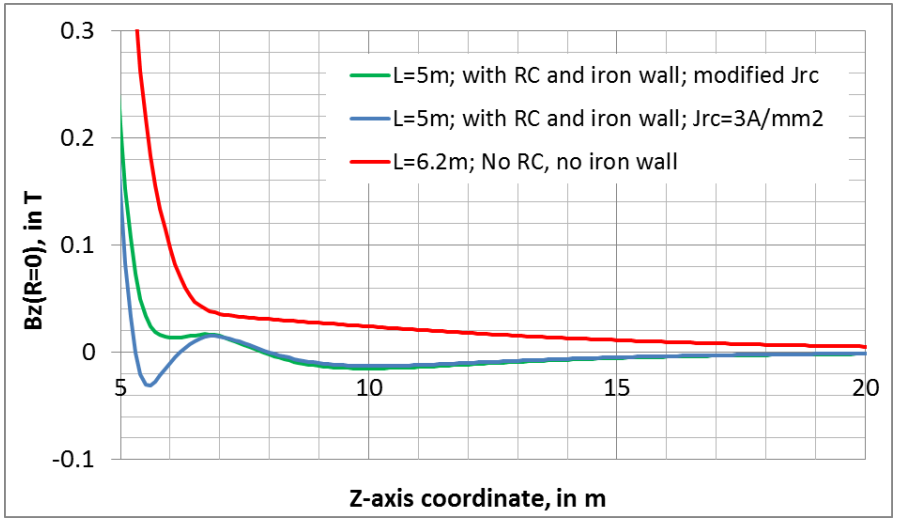


Ring coils on the cavern wall cap with L=5m:

- Another configuration with same geometry,
- Modified current densities (Jrc1=2A/mm^2, Jrc2=3A/mm^2, Jrc3=3.1A/mm^2, Jrc4=3.1A/mm^2).
- Effect of iron in concrete cavern wall included (B-H curve = 10% of iron).

→ Reduced variation on Z-axis, but slightly higher B-field at Z=5m (212mT against 150mT).





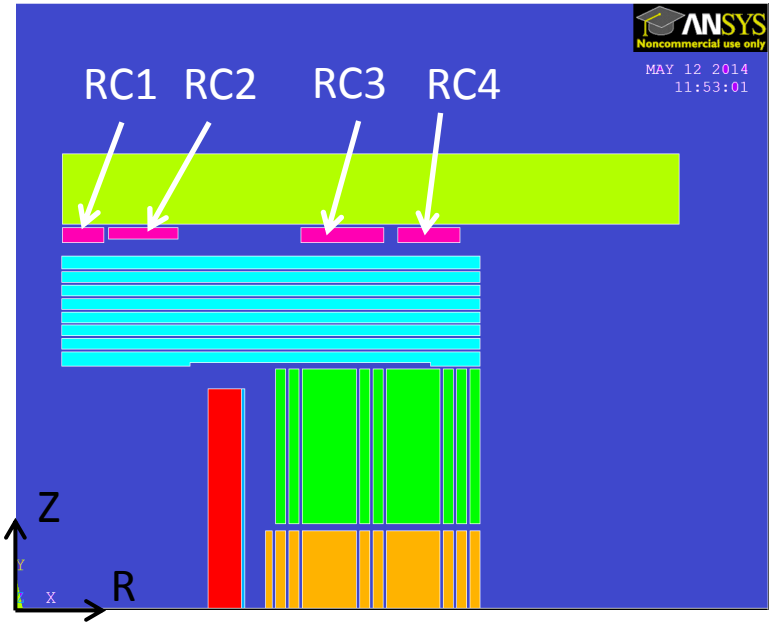
Characteristics of the ring coils on the cavern wall cap with L=5m :

- Arbitrary gap from RC to yoke end cap: **192mm** (RC1, RC3 & RC4) and **244mm** (RC2).
- Space available for radiation chicane.
- Same conductor for all RCs, insulation thickness 1mm.
- Total copper weight : **250 tons** (for 2 end caps). Suppressed steel mass wrt. L=6.2m (2 end caps): **2600 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 m^3/hour**.



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

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

	LHCb (*)	CLIC_SiD
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.

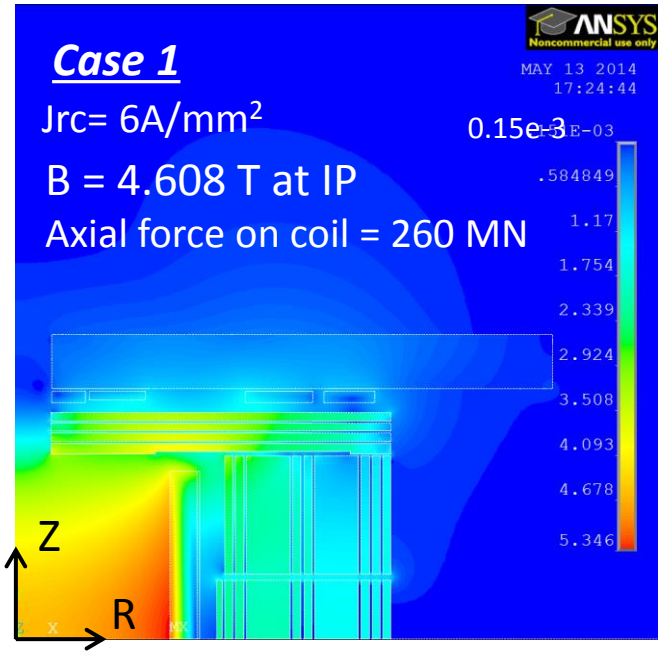
Other cases:

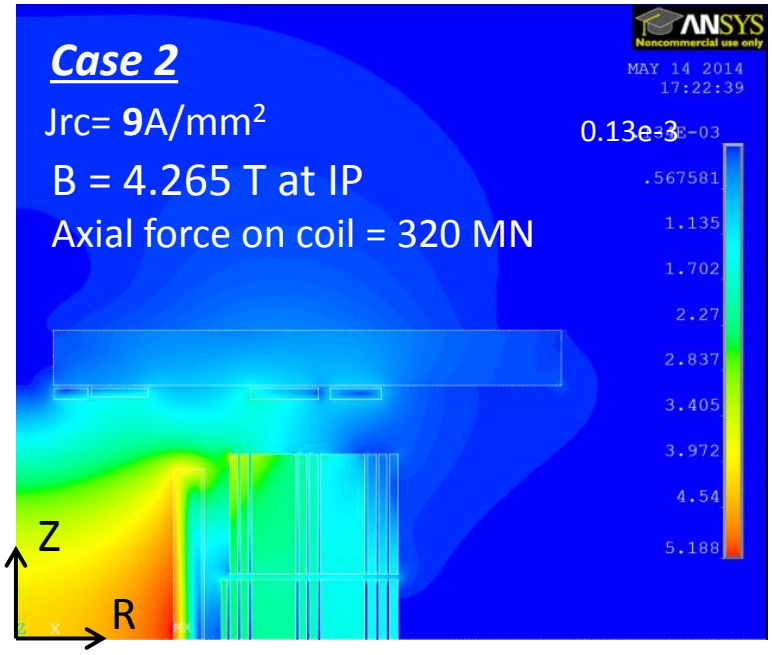
1- Reducing the iron thickness to 4 disks then L=5m to 4.205m,
2- No end cap iron yoke.

As a first approach, only the current density was increased (same RCs).

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

The RCs are in same positions in both models. SC coils would be more appropriate.





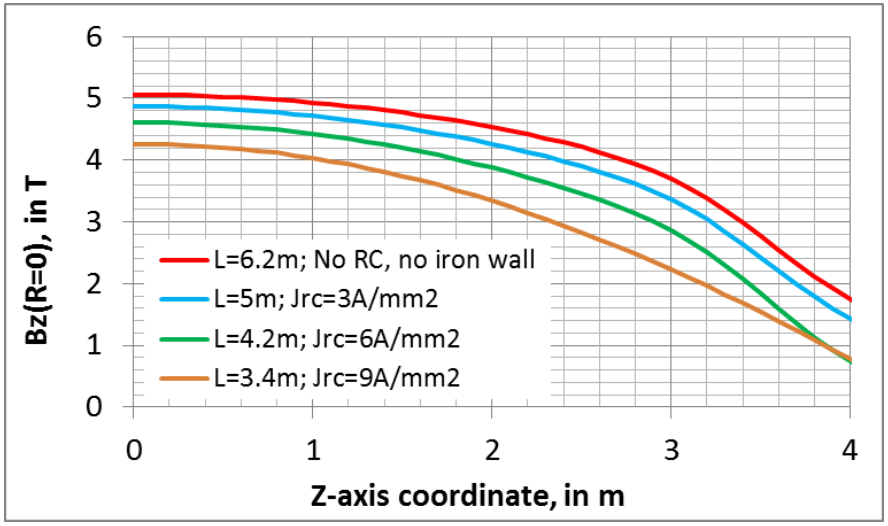
Other cases:

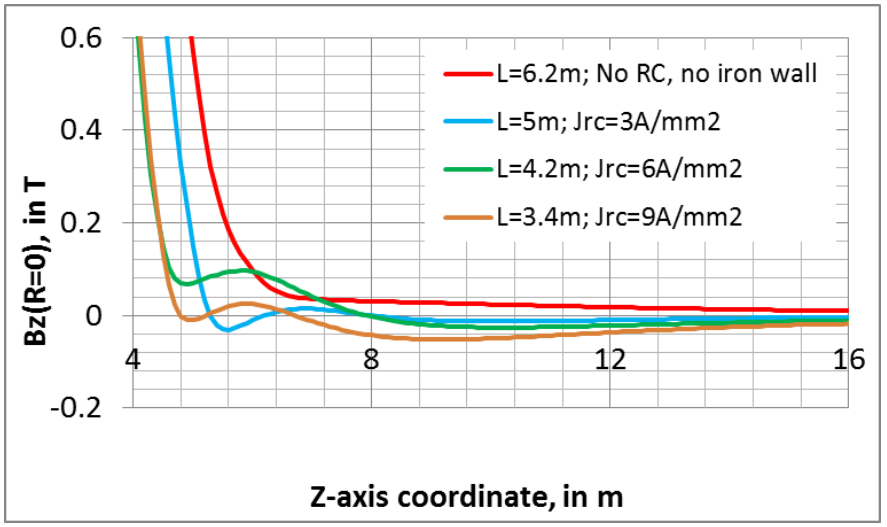
Wrt the ring coils defined for L=5m:

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.



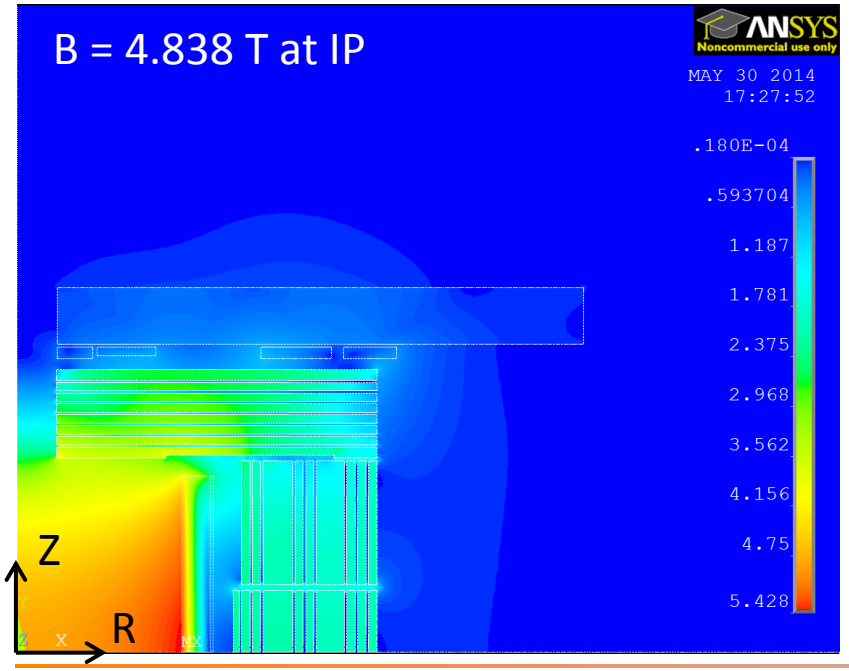


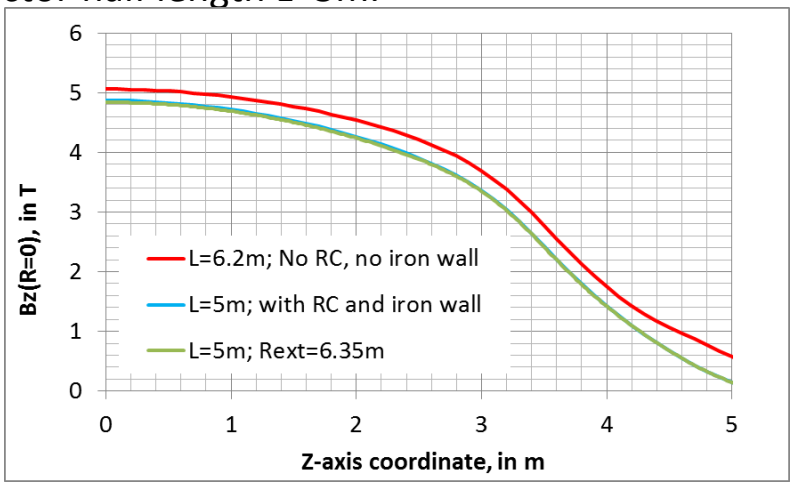
Reduction of external diameter of both end cap and barrel yoke:

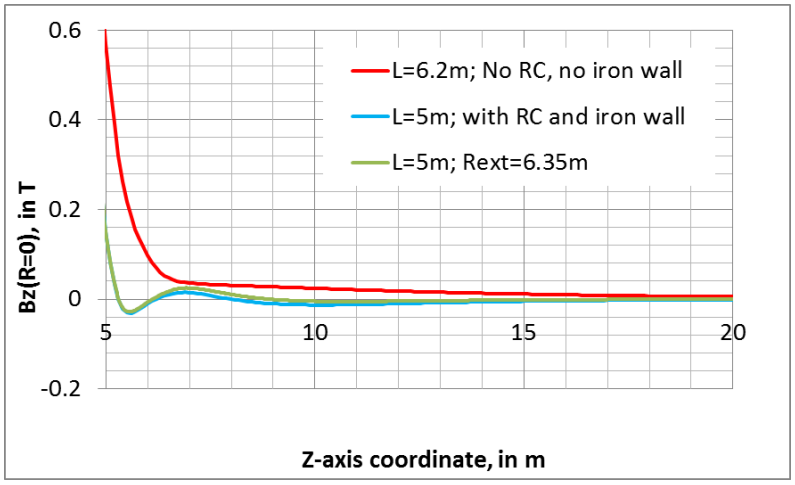
External radius **Rext = 6.35m**. RCs at same position. Detector half length L=5m.

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

Total reduction on iron mass: **3800 tons** wrt L=6.2m.





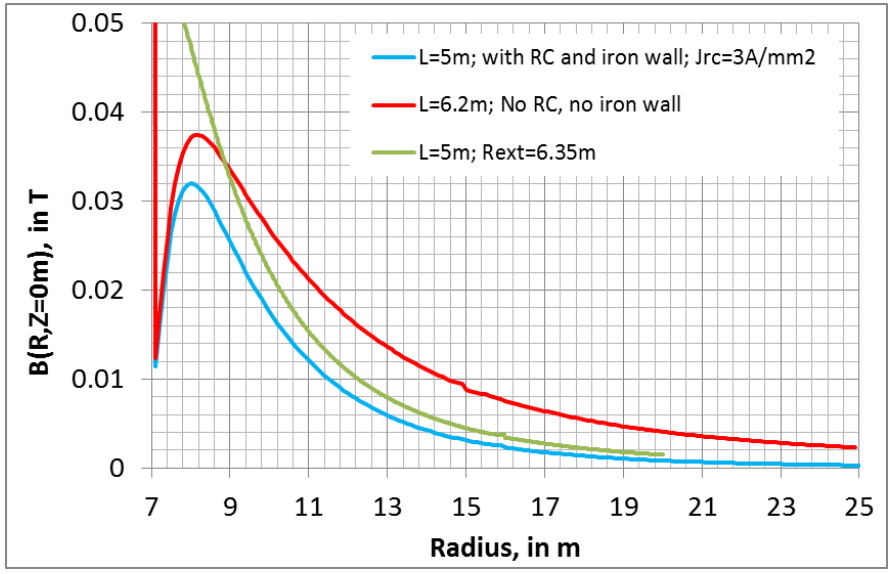


Reduction of external diameter of both end cap and barrel yoke:

Effect of iron in concrete cavern wall included (B-H curve = 10% of iron). Current density Jrc=3A/mm^2 in RC.

Comparison yoke barrel radius 7m and 6.35m

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



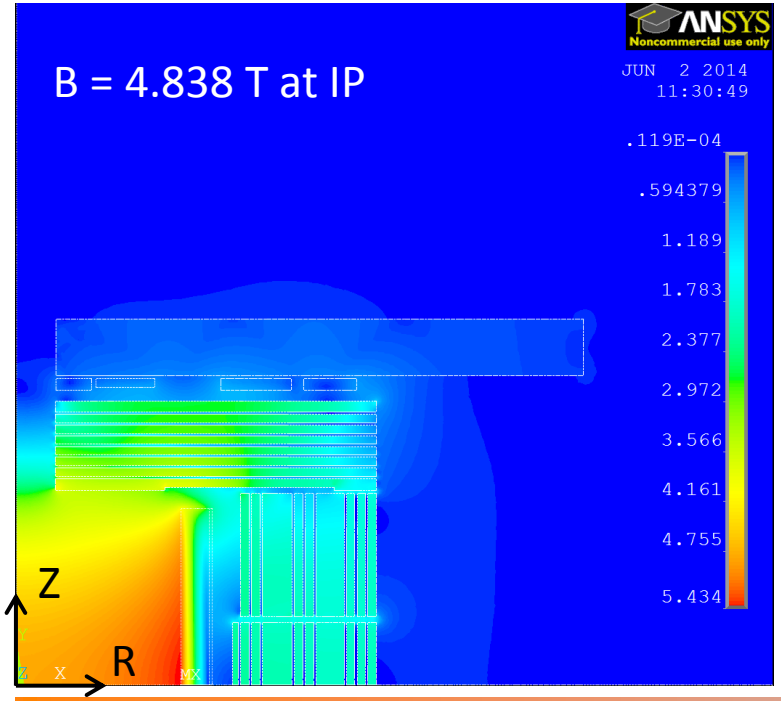
Reduction of external diameter of both end cap and barrel yoke:

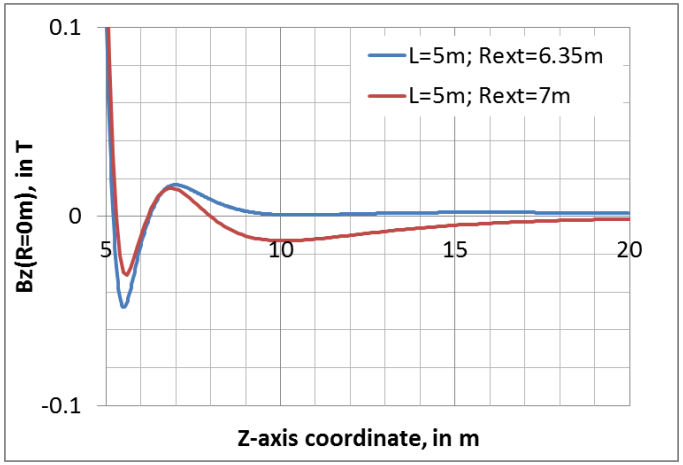
External radius **Rext = 6.35m**. **RC 3&4 with reduced diameter,** same amp.turns. L=5m.

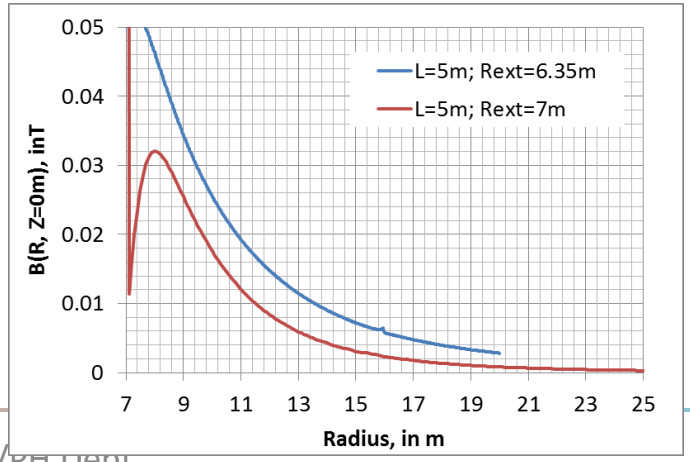
Field at IP is 4.4% lower wrt {L=6.2m; Rext=7m}. Stray field **lower than 7.2mT at R=15m**.

Total reduction on iron mass: **3800 tons** wrt L=6.2m.

Ring coils copper mass: 225 tons.







Conclusions:

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

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.