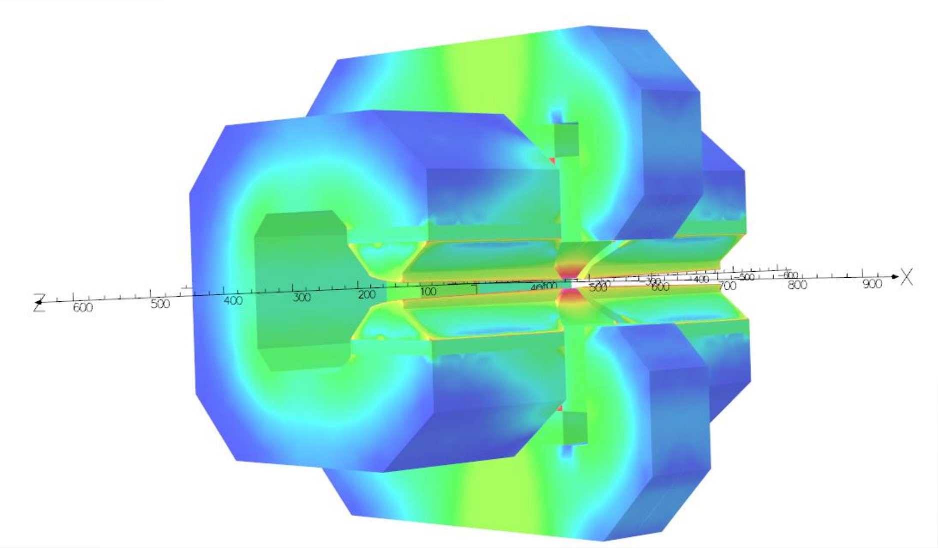
CLIC DR
Gradient Dipole



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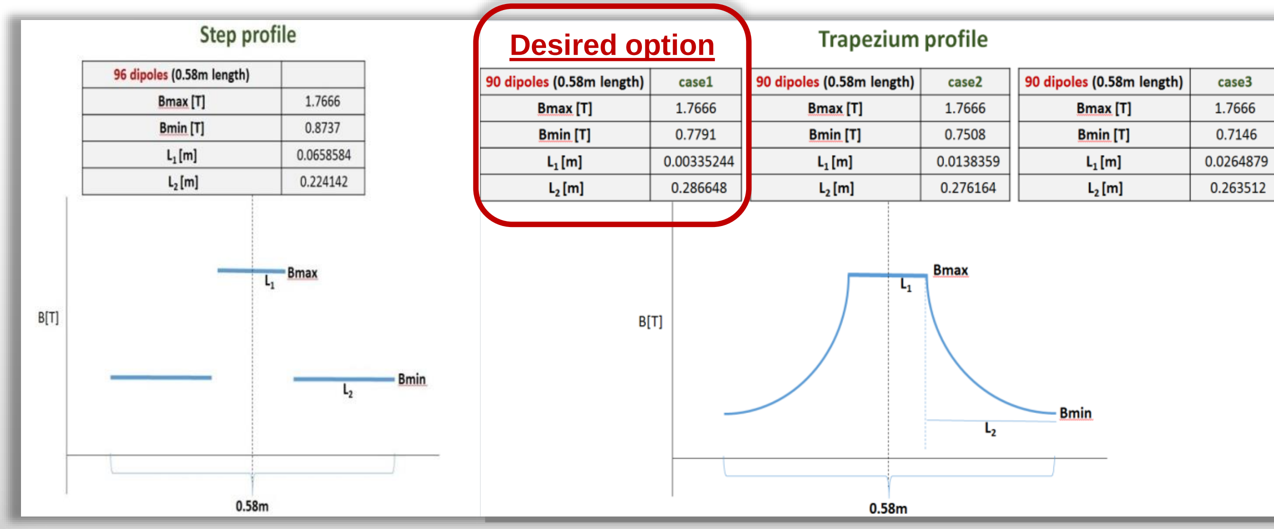
Index

1. Technical specifications
2. Magnetic design
3. From 1.77 T to 2.3 T
4. Results
5. Field trimming
6. Conclusions & next steps

Technical specifications

- 96 dipoles with fixed longitudinal and transverse gradient
- Possibility to include a small correction of the field amplitude (~5%)
- Good field region radius (rGFR): 5 mm
- Field quality ~ $1*10^{-4}$
- Transverse gradient: 11 T/m, vertical focusing
- Longitudinal gradient: two possibilities, step or trapezoidal.



Step profile

96 dipoles (0.58m length)	
Bmax [T]	1.7666
Bmin [T]	0.8737
L_1 [m]	0.0658584
L_2 [m]	0.224142

Trapezium profile

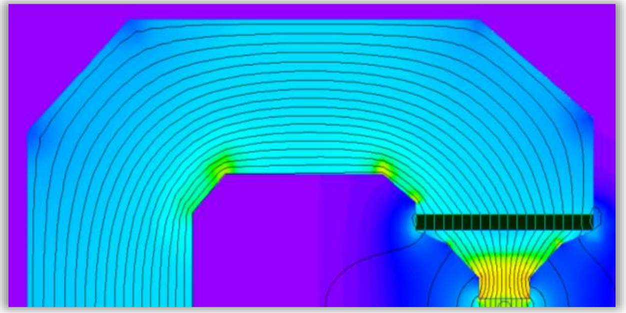
90 dipoles (0.58m length)	case1
Bmax [T]	1.7666
Bmin [T]	0.7791
L_1 [m]	0.00335244
L_2 [m]	0.286648

90 dipoles (0.58m length)	case2
Bmax [T]	1.7666
Bmin [T]	0.7508
L_1 [m]	0.0138359
L_2 [m]	0.276164

90 dipoles (0.58m length)	case3
Bmax [T]	1.7666
Bmin [T]	0.7146
L_1 [m]	0.0264879
L_2 [m]	0.263512

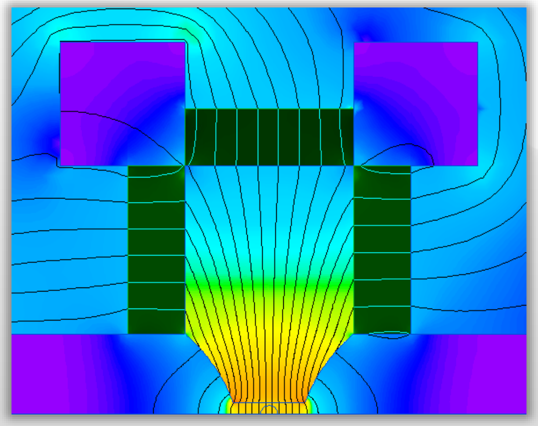
Magnetic design: 2D

- C-shaped magnets is the best layout for efficient use of space.
- Gap is pointing outwards to ease synchrotron radiation evacuation



- Low field region.
  Achieved ΔB/B = 1*10-4, rGFR = 5mm

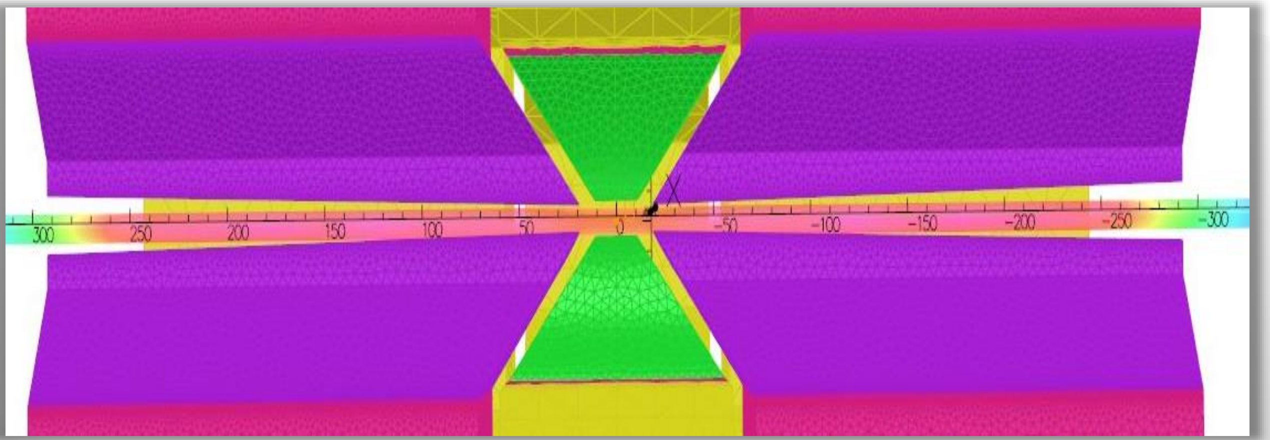
- High field region. Different configuration:
  - Three magnets working in parallel to preserve the pole dimensions within reasonable limits
  - Achieved ΔB/B = 1*10-4, rGFR = 5mm
  - The above conditions were much more difficult to reach as the pole tip iron is saturated.
    The field quality is more sensitive to any minor change in the dimensions.



Magnetic design: 3D

- Trapezium profile:
  - More effective to reduce beam emittance

- Different trials to achieve the desired trapezium profile:
  - 1st option: Trying to keep the gap constant along Z axis
    - Low field region with pole cuts. Each part with different PM grades
    - Variable pole width
    - Not feasible according to simulation results
  - 2nd Option: Variable gap along Z axis.

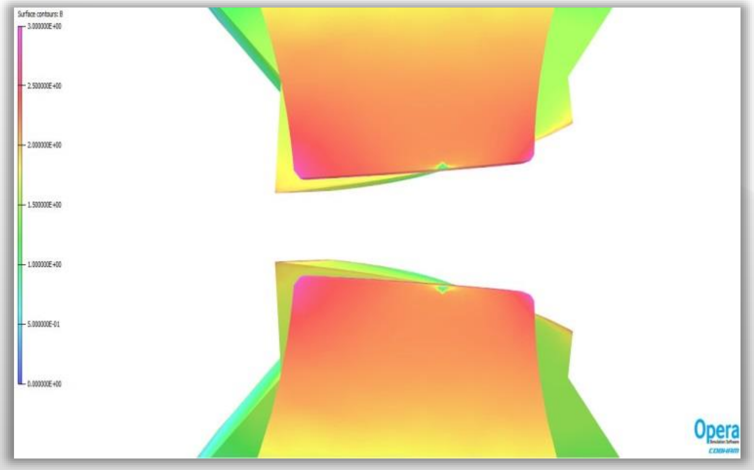


Magnetic design: 3D

- Short magnet length (0.58m) makes 2D simulations diverge from 3D, specially in the case of the high field section (pole tip $\approx$ 14mm!)

- High saturation in the high field region pole leads to undesired multipole values and higher flux leakage. These effects are reduced using Iron-Cobalt (Vacoflux) in the pole

- The saturation in this pole led as well to a different pole tip design. It does not match the theoretical calculations and had to be adjusted and optimised based on simulations



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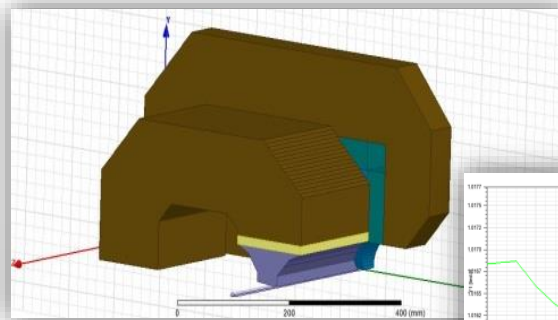
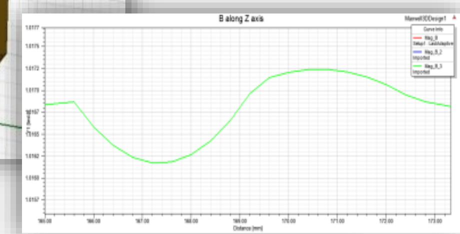
Magnetic design: FEM suites

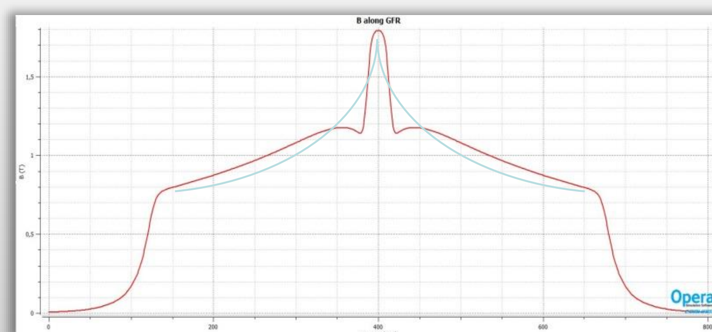
- Ansys Maxwell:
  - First simulations. Very difficult to achieve numerical accuracy to evaluate the field harmonics, even with dense meshes: good quality field region is very close to curved surface of pole.
  - Ruled out due to poor accuracy of field harmonics.





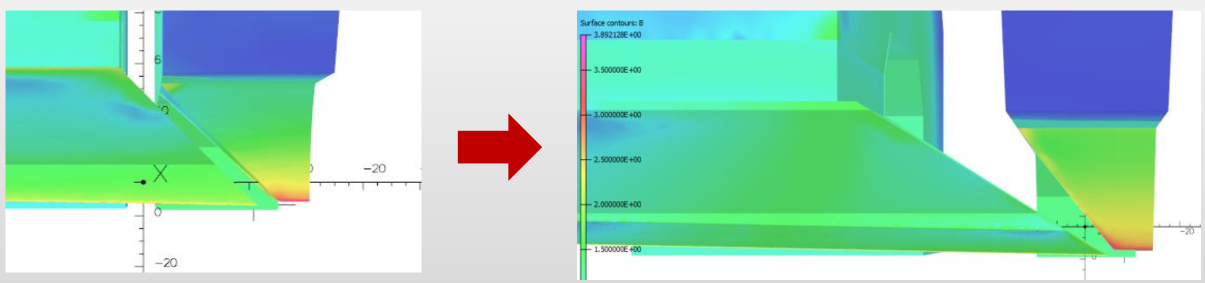
- ROXIE:
  - Reference for fields and multipoles
  - Impossible to extrude a variable gap (ruled out for trapezium profiles)

- Comsol and Opera:
  - Models already done and simulated
  - Results fully validated with Roxie



From 1.77 T to 2.3 T

- Once the objectives of the desired option technical specs (trapezium profile, case 1) were practically met, during one of our exchanges with CERN, a new possibility came into play: “it could be preferable to have a bigger bump in the center of the magnet while keeping the same integrated field… Is it possible?”
- 🤔 … Yes, why not? Let’s push it further!!!!
- A bigger separation between low and high field regions combined with a different extrusion of the low field region pole tip, shows less cross-talk and therefore allows a higher field peak.



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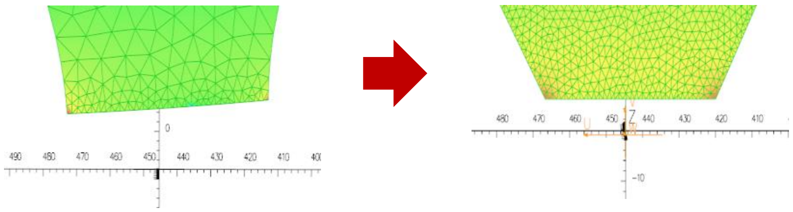
From 1.77 T to 2.3 T

- High field region:
    - No gradient (integrated gradient is reached anyway)
    - Straight sides instead of curved
    - Wider pole tip (30mm) to reduce saturation

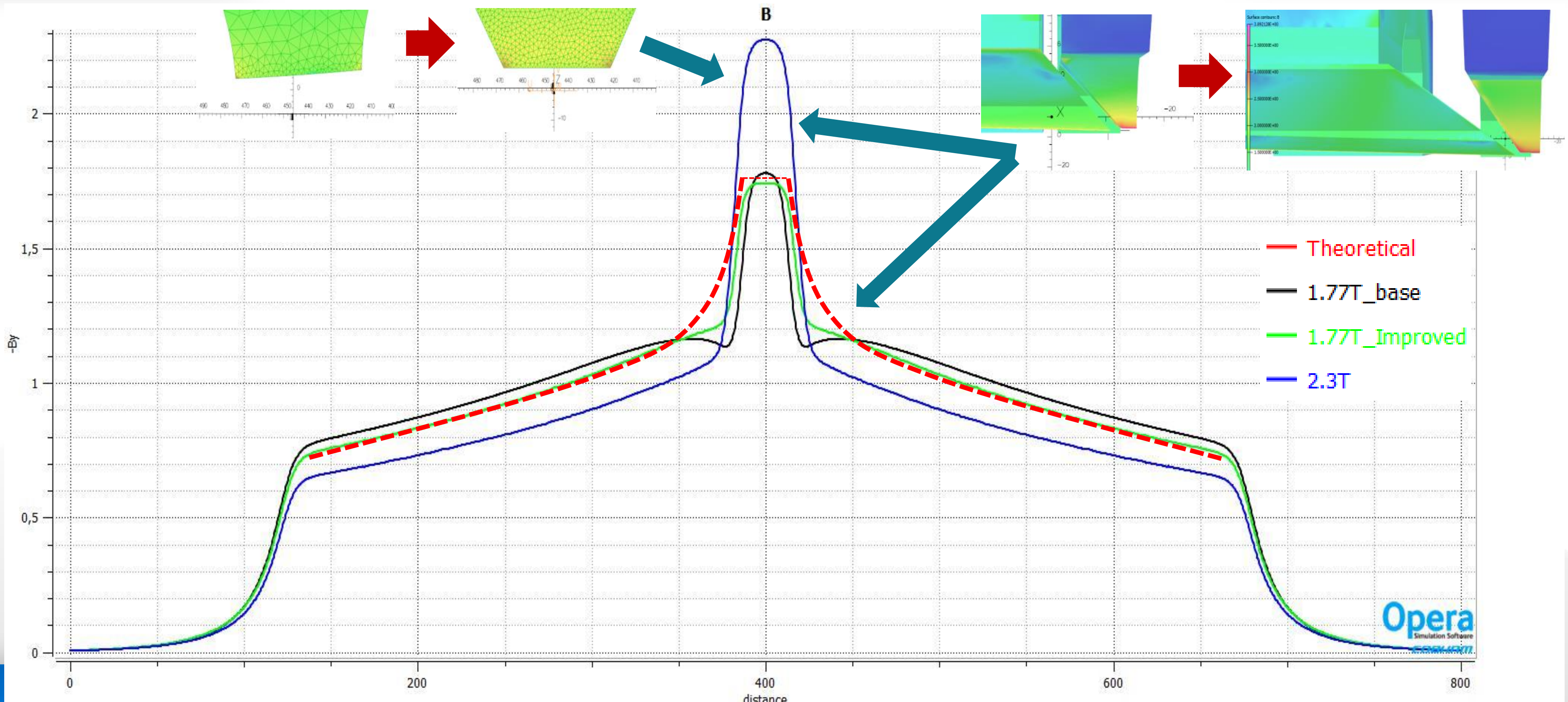


- Low field region:
    - Improved hyperbolic profile to compensate the HF region gradient loss
    - Wider profile to reduce multipoles

- As a result of these changes we came to the following results:

Normalized multipoles	
b1	10000.00
b2	-536.37
b3	-1.28
b4	3.11
b5	-0.54
b6	-0.29
b7	-0.16
b8	0.09
b9	-0.18
b10	0.13

Results



B
-By
distance
0
0,5
1
1,5
2
200
400
600
800
Theoretical
1.77T_base
1.77T_Improved
2.3T
Opera
Simulation Software

Field trimming

- Among the first discussions about the project there was the possibility of varying the magnetic field +-5%

- Two solutions:
  - Active: adding coils and its corresponding power supply
    - Pros:
      - Fast field trimming. Can be adjusted during operation
    - Cons:
      - More expensive
      - More complex design
  - Passive: with moving yoke parts that can adjust the flux
    - Pros:
      - Less expensive
      - Simple design
    - Cons:
      - In principle the field cannot be adjusted during operation. However, if needed, this could be solved adding remote actuators

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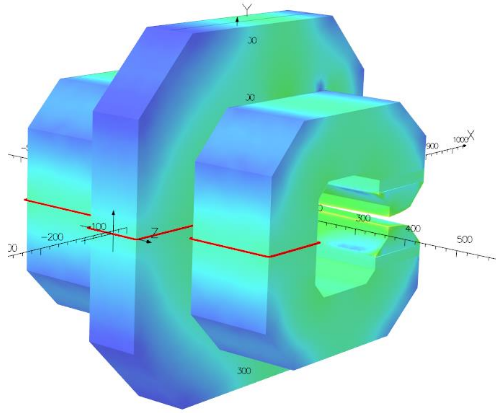
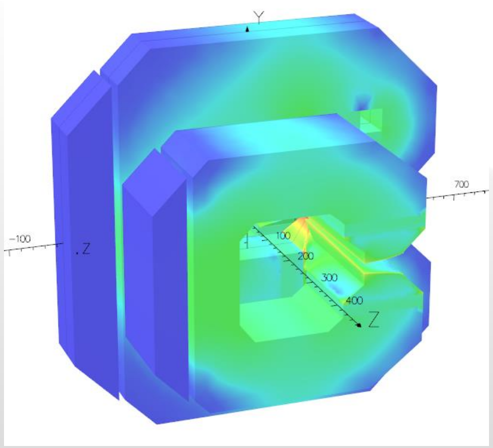
Field trimming

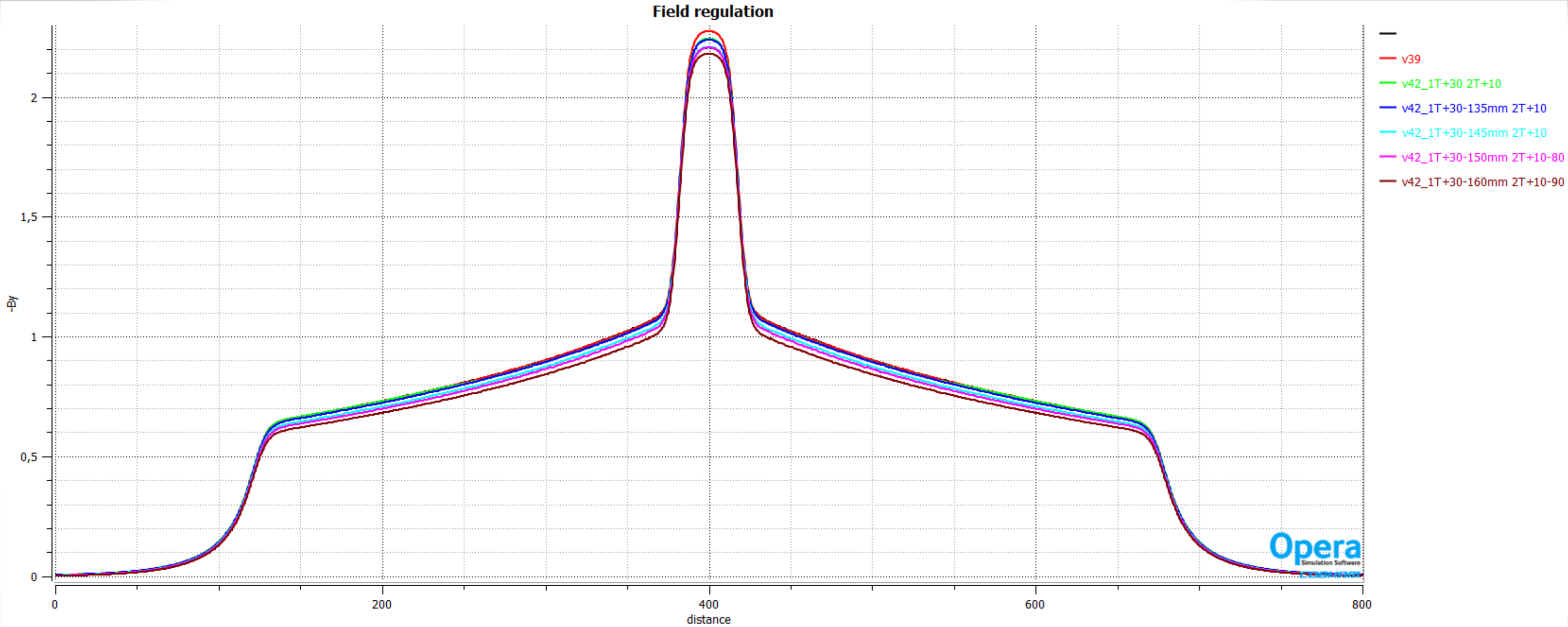
- We have explored further and simulated two solutions
  - Active: due to the high iron saturation, the coils should be too large, powerful and need water cooling.
    We understand that this gets away from the spirit of a permanent magnet dipole.
    From our point of view, this is already ruled out.



  - Passive: according to our preliminary simulations it should be feasible simply splitting the central part of the yoke in two parts and adjusting the gap between them.



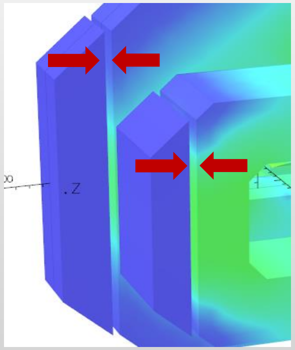
Field trimming



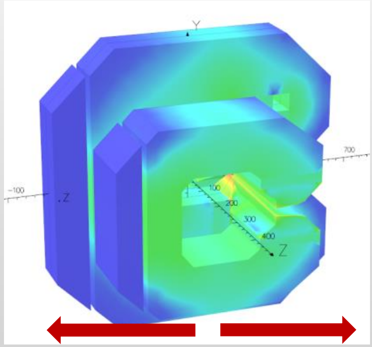
- Passive:
  - Achieved almost independent adjustment of +-5% in High and Low field region. There could be a minor influence in some cases as a result of the crosstalk between regions.
  - It doesn't affect the field quality

Field trimming

- With the presented solution we can adjust both fields, dipole and quadrupole at the same time, in the same magnitude, say +-5% for both (*). It is impossible in that way to separate the trimming for dipole and quad.
- Moving the whole magnet along x axis(**), it is possible to adjust only the dipole field while the quad field remains constant. This implies that combining both movements, we can adjust the quad to the desired value and then compensate the loss/gain in the dipole field simply moving the magnet horizontally.
- The direct drawback of this solution is that the multipoles will forcibly increase when moving the magnet horizontally. In our preliminary simulations, moving +-1mm means that b3 goes up to 8 and b4 up to 7, instead of 1.4 and 3 respectively, while the quad field remains constant and the dipole field varies by 4%



(*) Adjusting these gaps, both dipole and quad fields are fitted



(**) Moving the magnet horizontally, the dipole field is fitted while the quad remains constant

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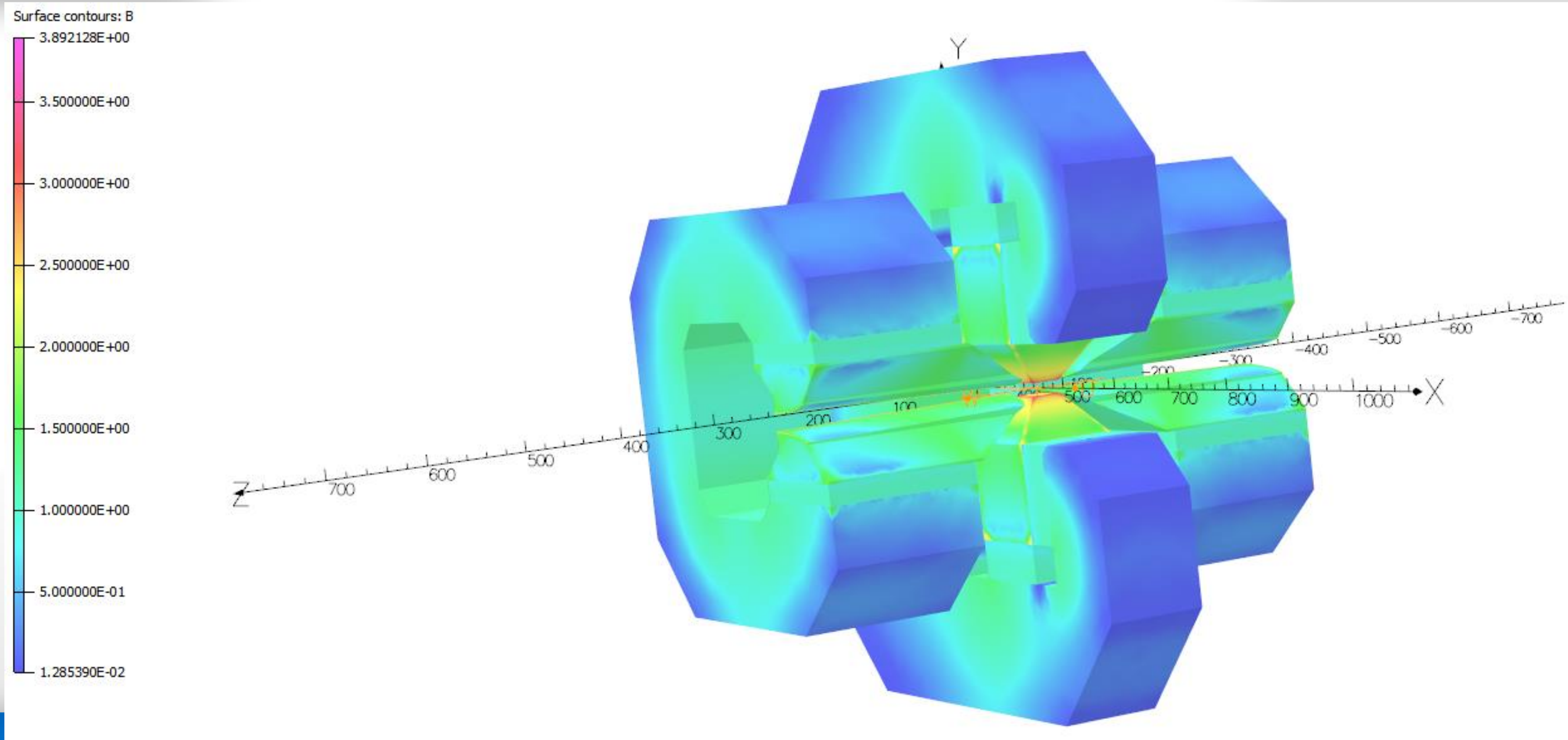
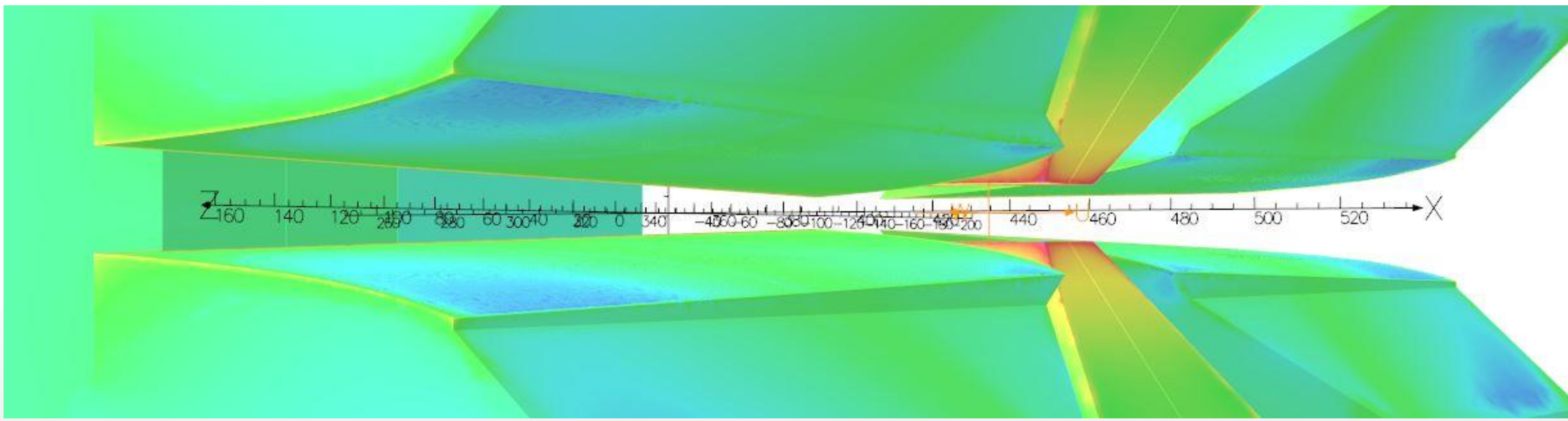
Conclusions & next steps

- A variable gap combined function magnet has been magnetically designed for the CLIC Damping Rings
- A comparative of FEM suites (Maxwell, Roxie, Comsol & Opera) has been carried out. Finally, Opera is the one which better fits to our needs.
- New solutions have been studied to increase the peak field from 1.77T to 2.3T.
- The possibility of a field trimming of +-5% has been simulated and proposed
- Next steps:
  - Field profile validation
  - Mechanical design
  - Fabrication drawings

Thank you for your attention!



Surface contours: B
3.892128E+00
3.500000E+00
3.000000E+00
2.500000E+00
2.000000E+00
1.500000E+00
1.000000E+00
5.000000E-01
1.285390E-02
Y
X
Z



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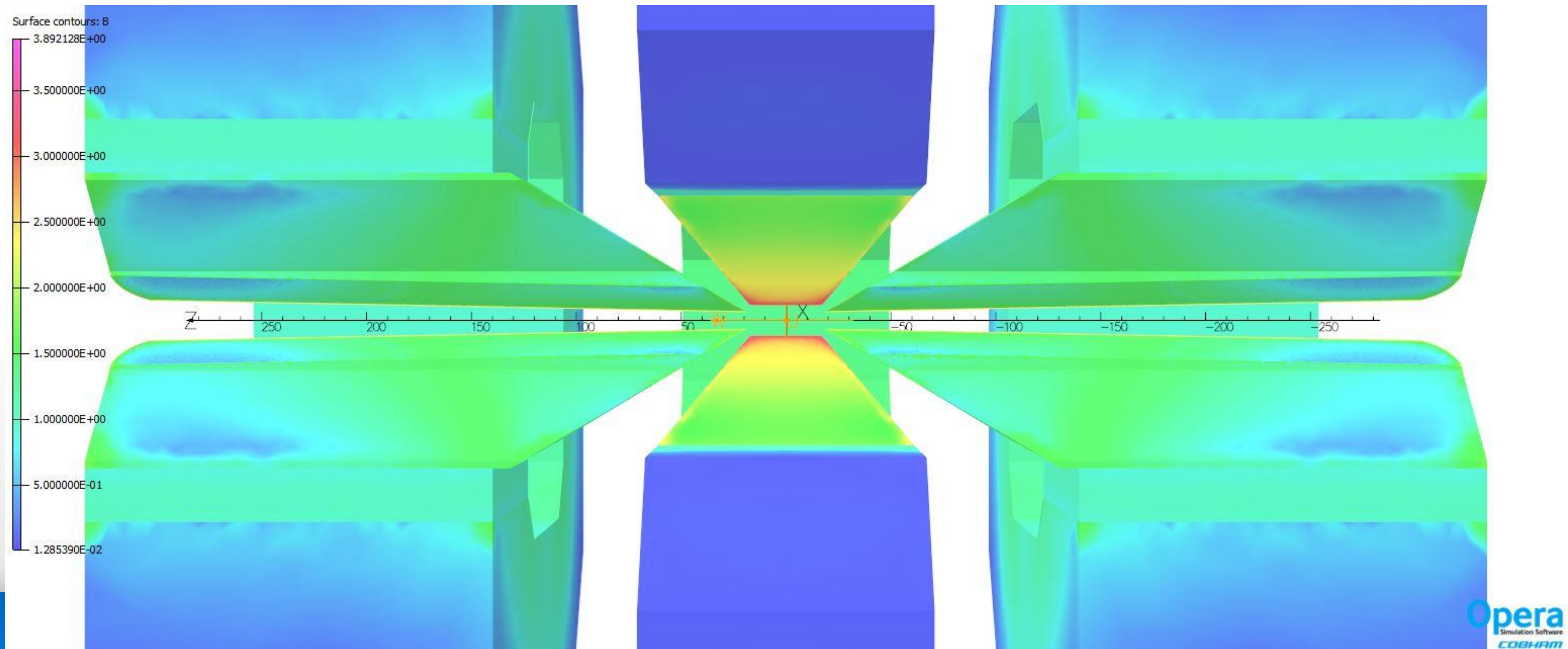
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5.000000E-01
1.285390E-02
Z
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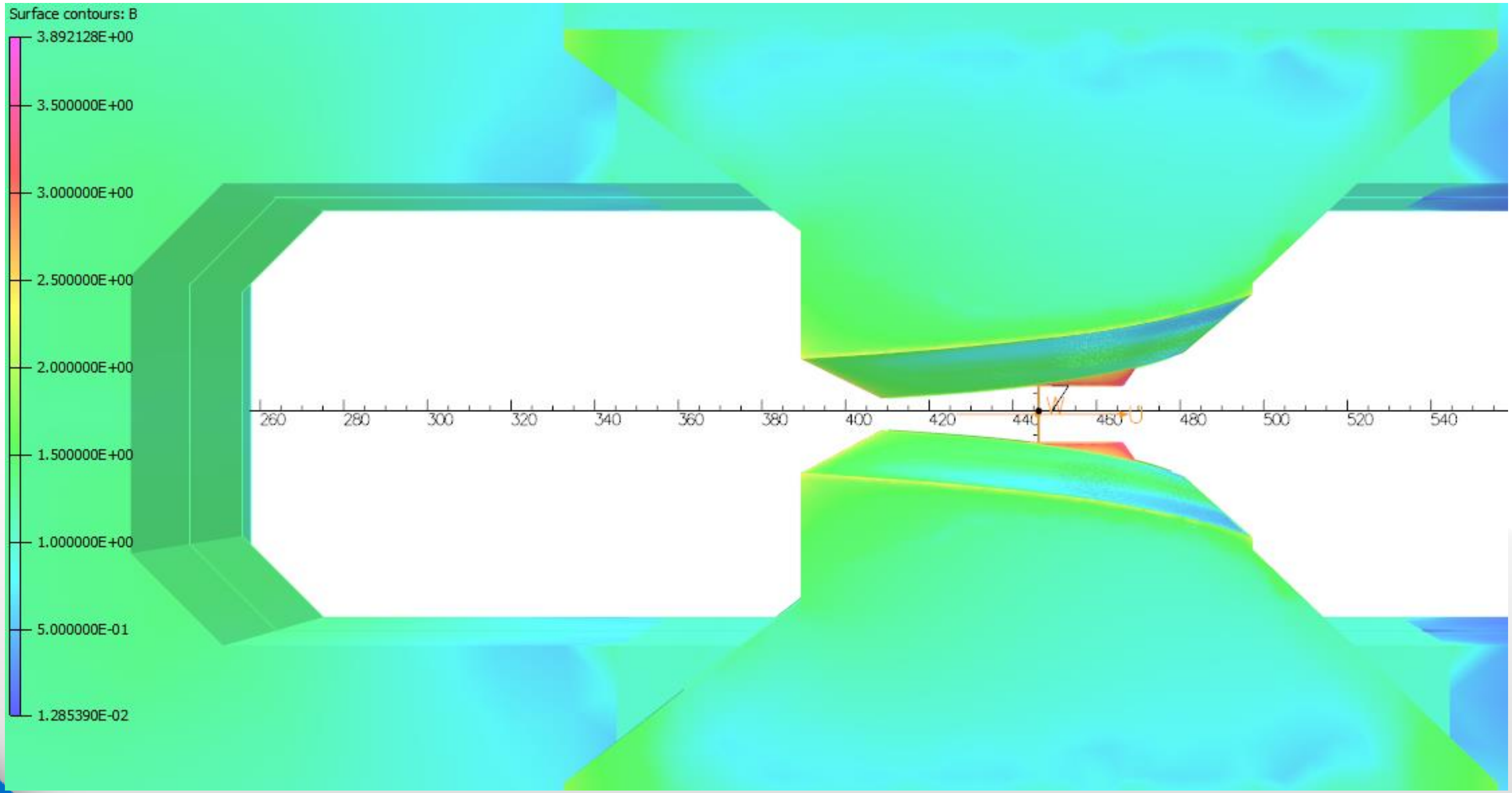
Opera
Simulation Software
COBHAM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5.000000E-01
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260
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