FETS-FFA magnet prototype

G. Aymar, S. Gallimore, K. Geiger, **J.-B. Lagrange**,
A. Letchford, S. Machida, I. Rodriguez, J. Speed,
ISIS, RAL, STFC
S. Brooks, BNL

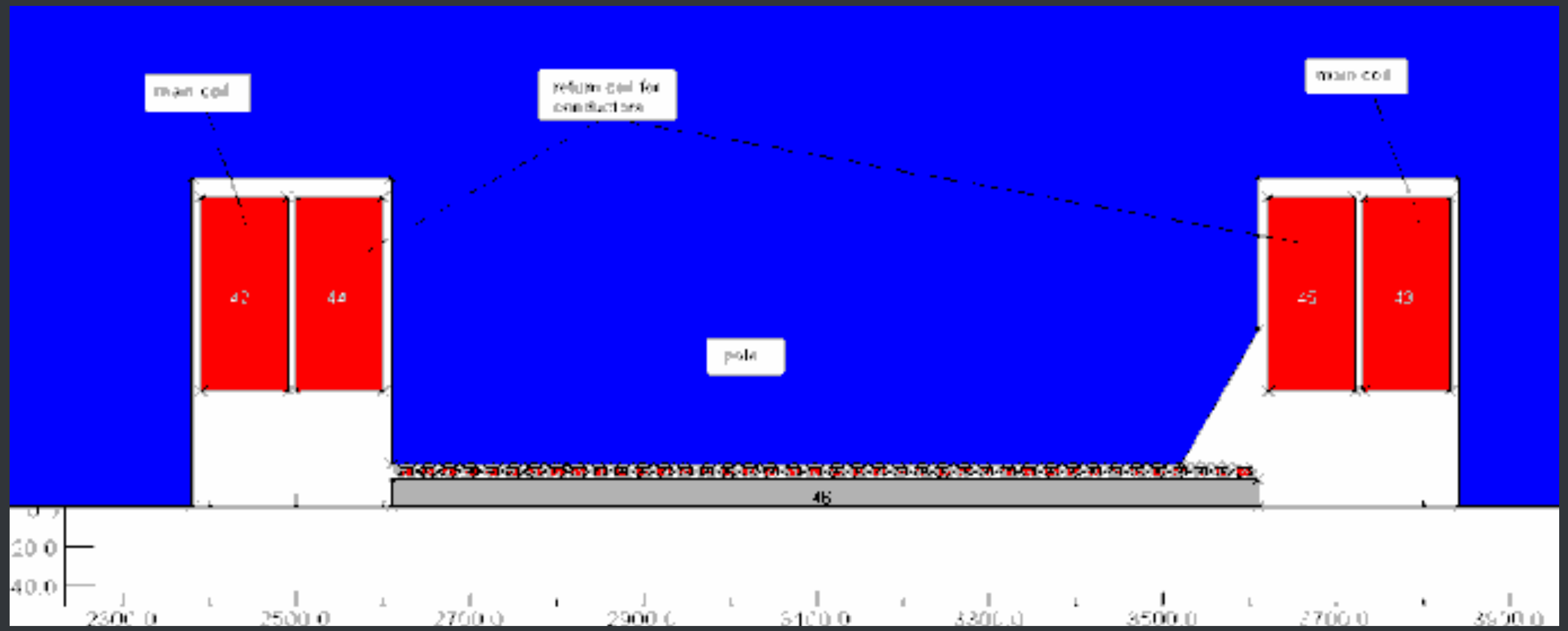
Magnet specifications

- Scaling spiral FD doublet magnet
- 3 - 12 MeV proton energy range
- Minimum full gap height: 80 mm
- k-value: 6 - 11 (Central scenario: k=8)
- Spiral angle: 45 deg
- Max magnetic field in the good field region ~0.8 T
- Magnet length at r=4 m: 31 cm (F), 15 cm (D), 15 cm between F and D

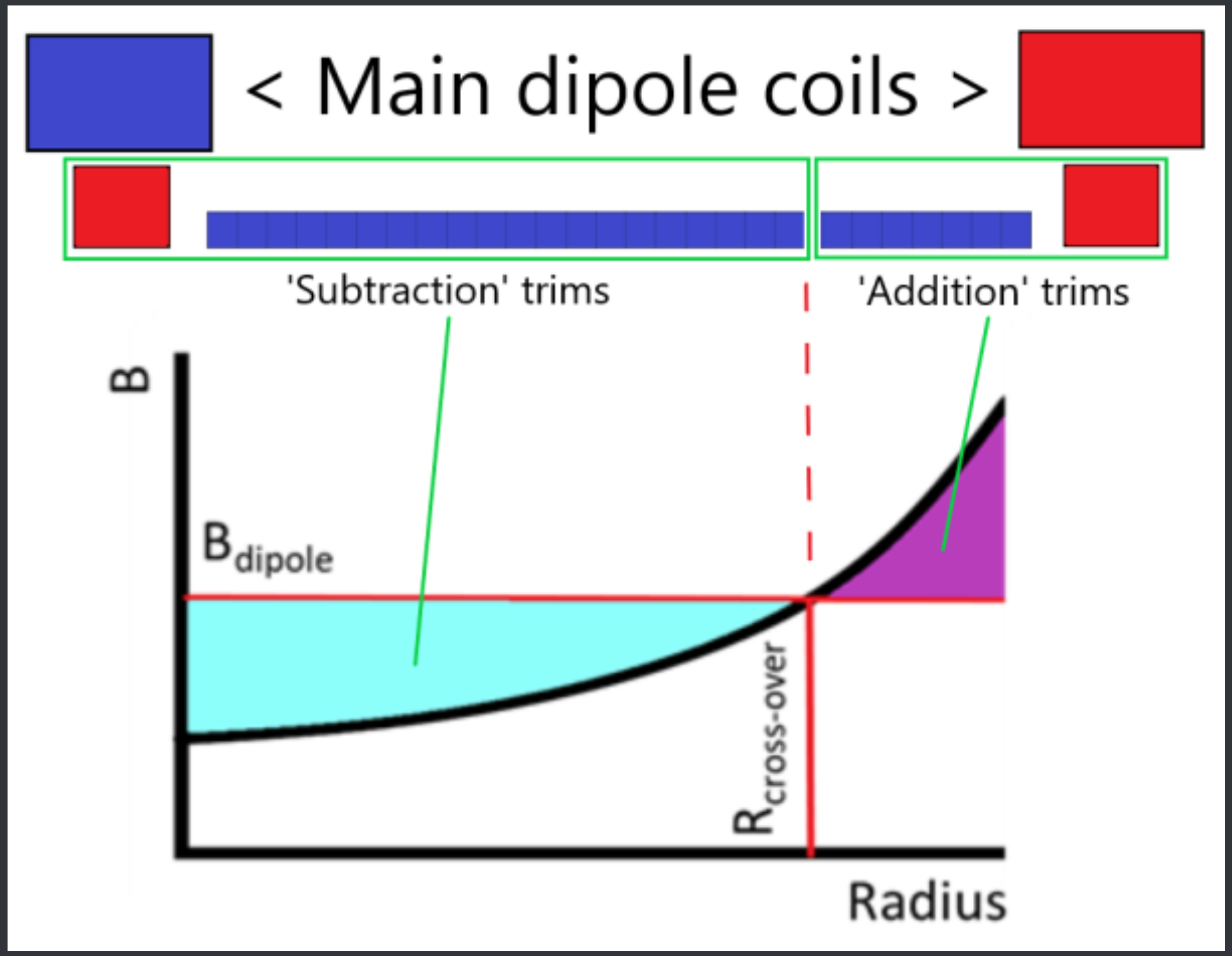
Beam excursion

- To accommodate 3 to 12 MeV protons, the excursion is going to vary for different k-values.
    - k=6: 45 cm excursion
    - k=8: 35 cm excursion
    - k=11: 27 cm excursion
- Need to fix a point (injection, extraction?)

Trim coils

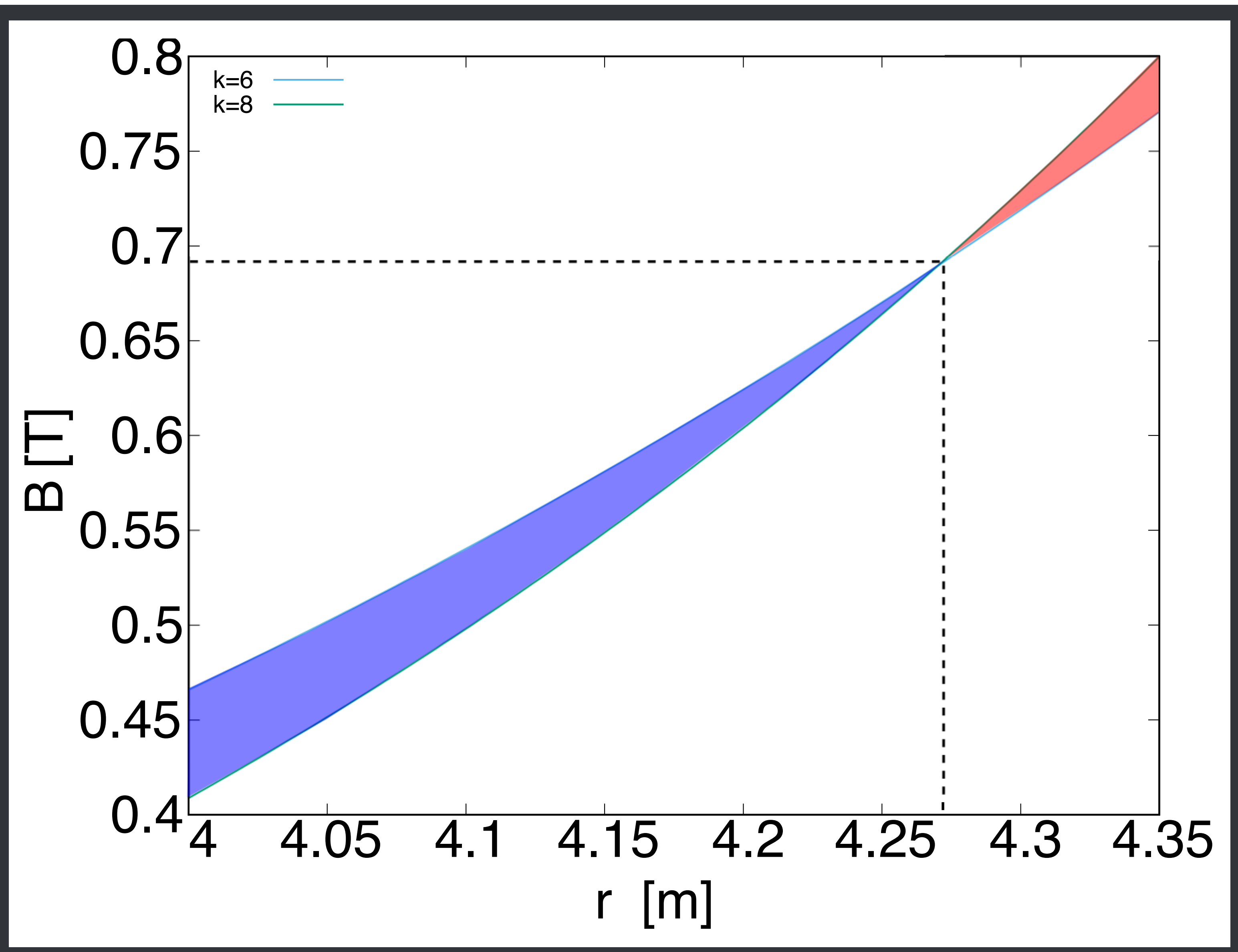


D. Neuvéglise, PAC09, FR5REP095



- Flat sheet of trim coils below the pole
- Necessary to tune the k-value

$$B_{\mathrm{trim}}(r) = B_0 \left[\left(\frac{r}{r_0} \right)^{k_2} - \left(\frac{r}{r_0} \right)^{k_1} \right]$$



Taylor series around r_0:

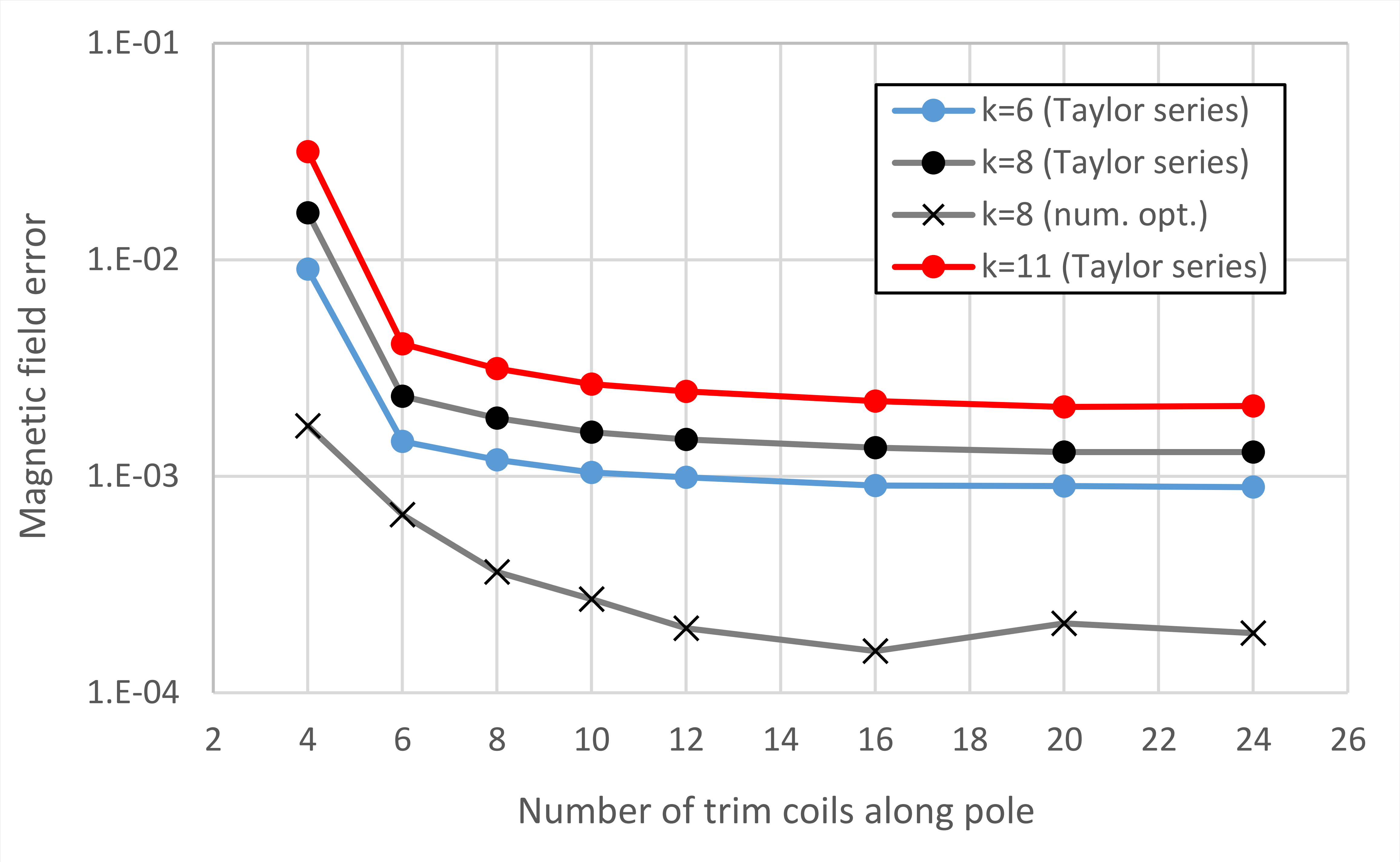
$$B_{\mathrm{trim}} = B_0 \sum_{m=1}^{\infty} \frac{\prod_{n=0}^{m-1} (k_2 - n) - \prod_{n=0}^{m-1} (k_1 - n)}{m!\ r_0^m} (r - r_0)^m$$

Science and Technology Facilities Council

Valid also for k_1=0 (flat pole)

Number of trim coils

- Flat sheet of trim coils across the pole.
- Reasonable minimum number of trim coils (>12) to achieve sufficient field quality after numerical optimisation.



Science and Technology Facilities Council

Manufacturing options

Flat pole

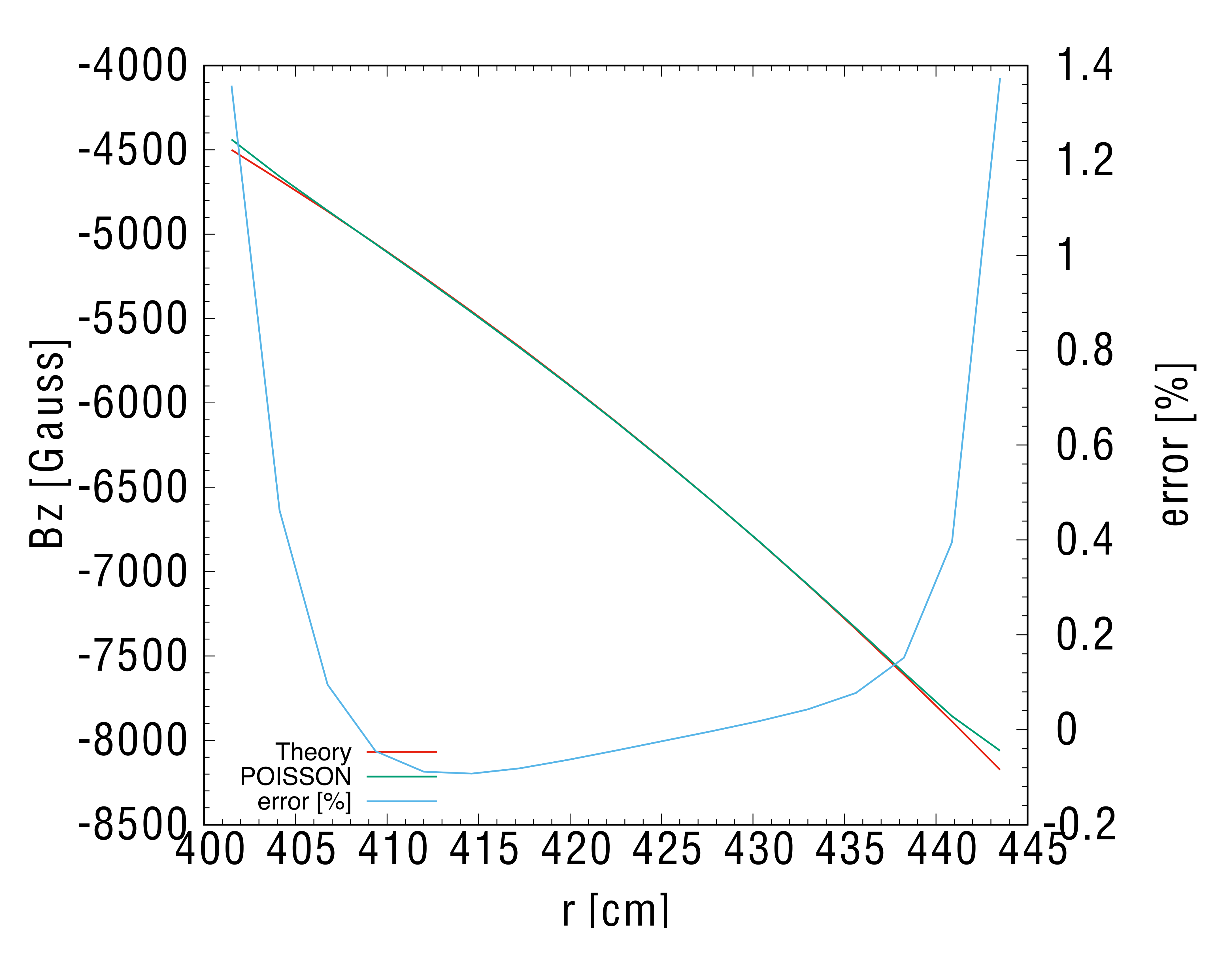
- Pros:
  - Easier (faster) to design
  - Better control of fringe field with radius
- Cons:
  - Less energy efficient
  - Stronger trim coils

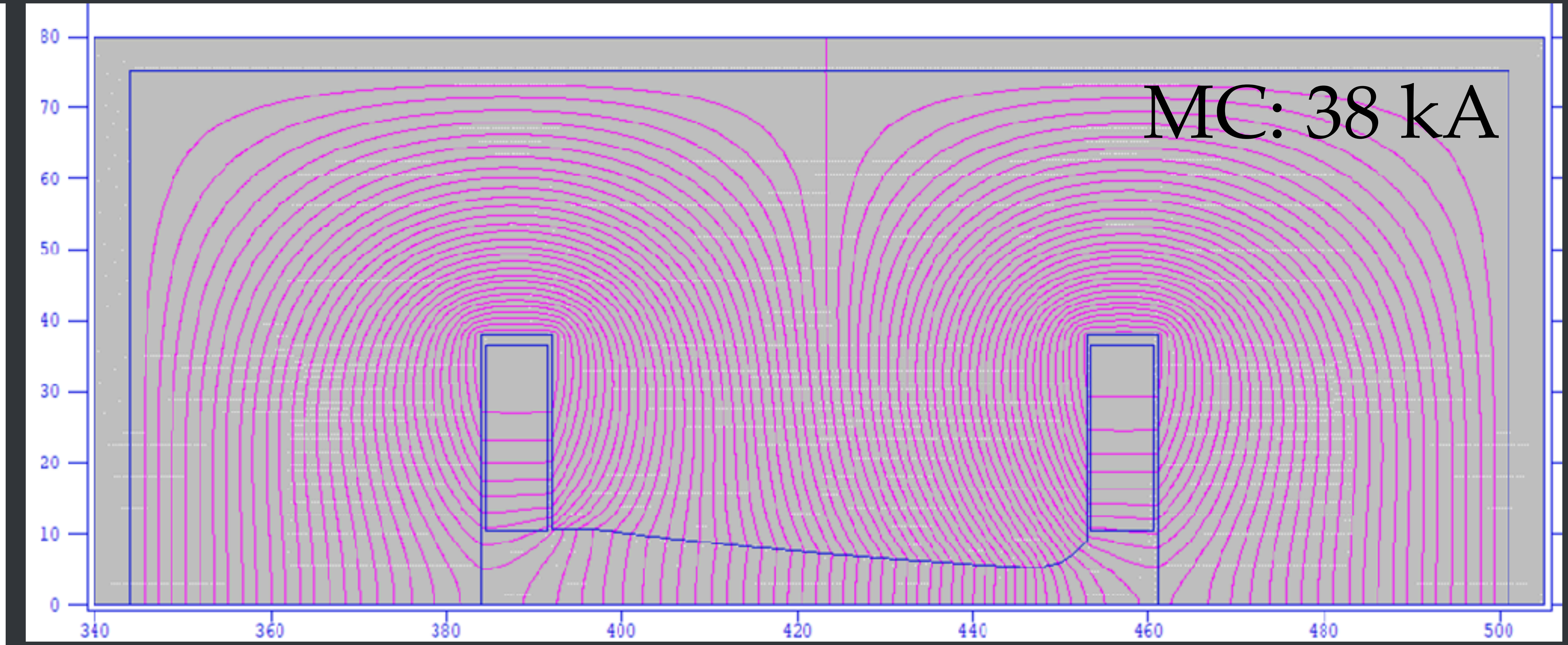
Shaped pole

- Pros:
  - Energy efficient
  - Small trim coils
- Cons:
  - Gap shape opposite of fringe field extent
  - Pole shape to optimise (longer design)

Pole shape solution k=6

Minimum half-gap: 53.5 mm

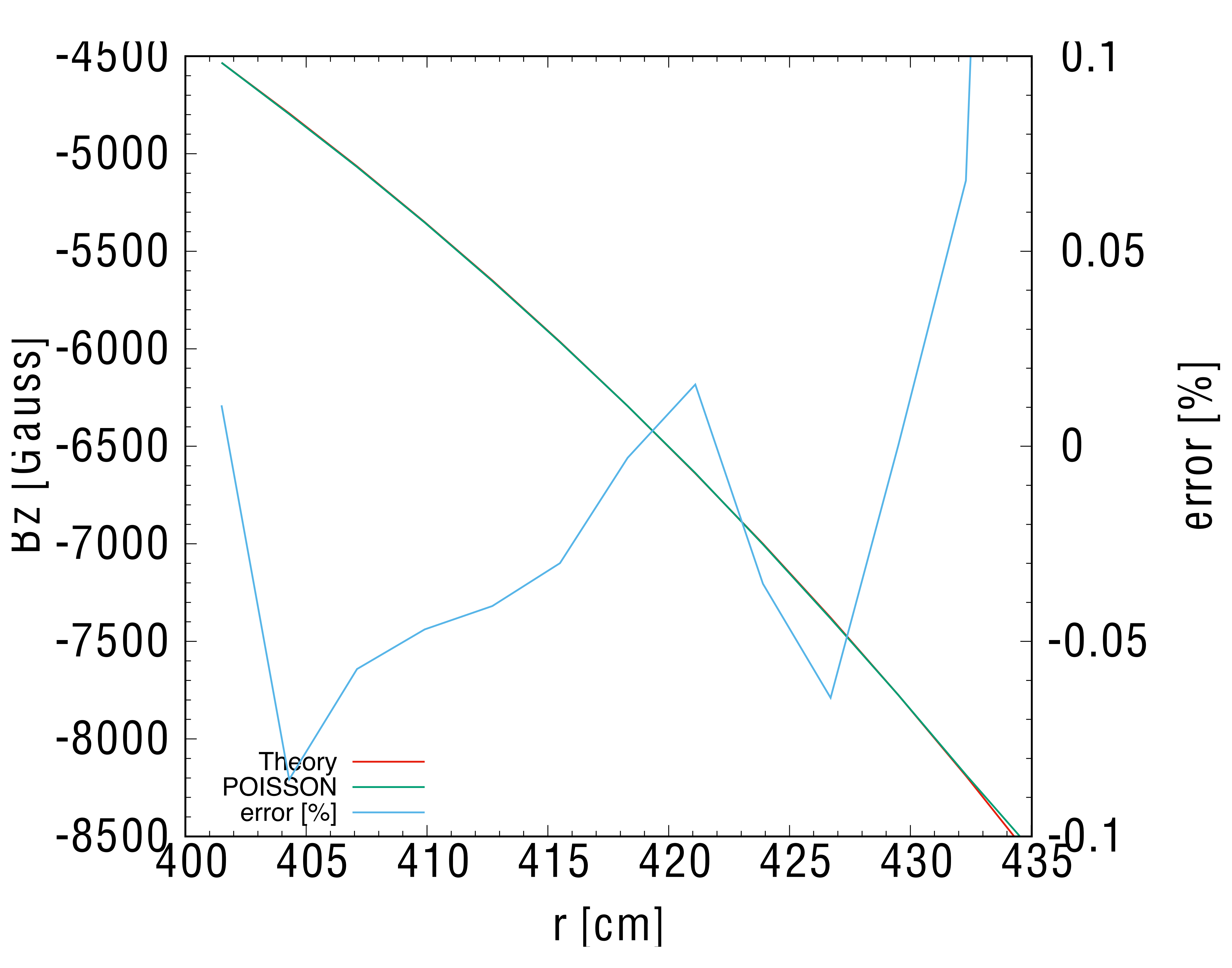


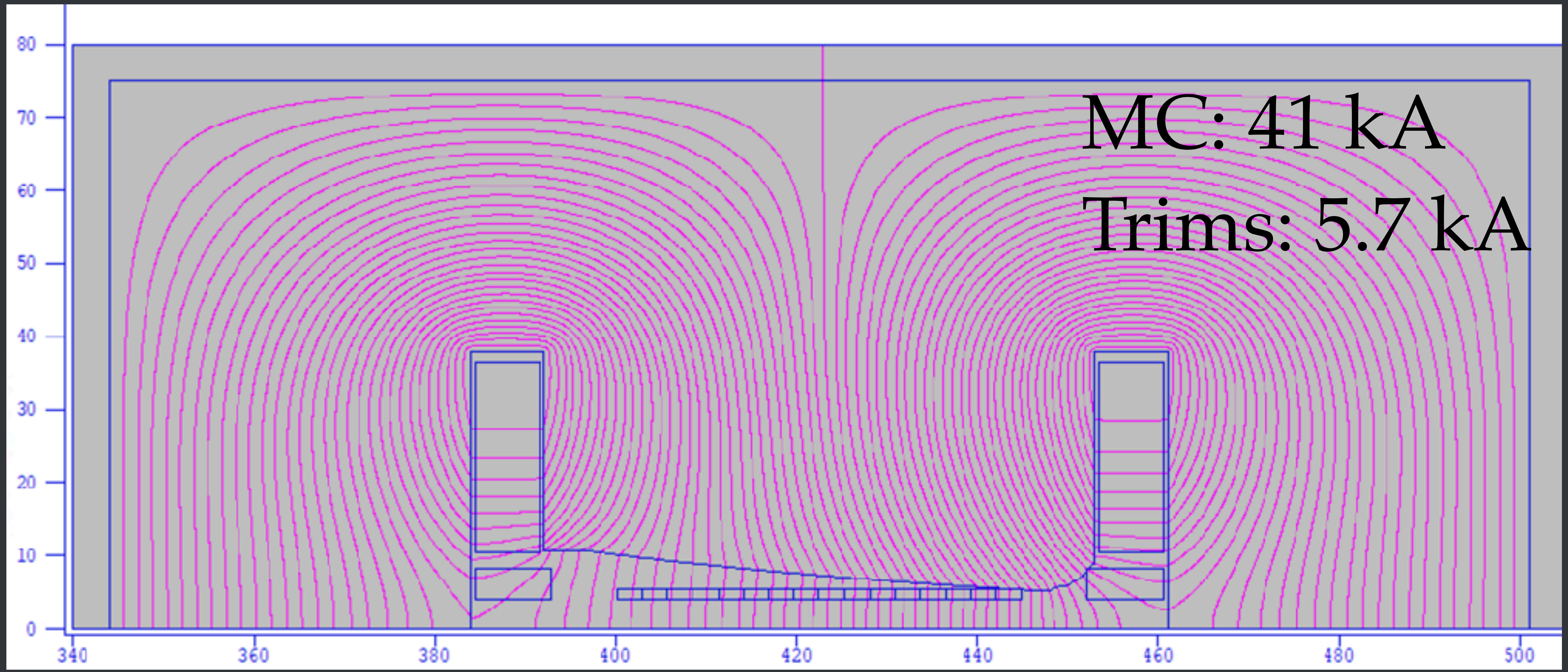


Coil current adjusted for B(r=428.1cm)=0.6612 T

Gap shape: $g(r) = g_0 \left(\frac{r_0}{r}\right)^k$

Pole shape solution k=8



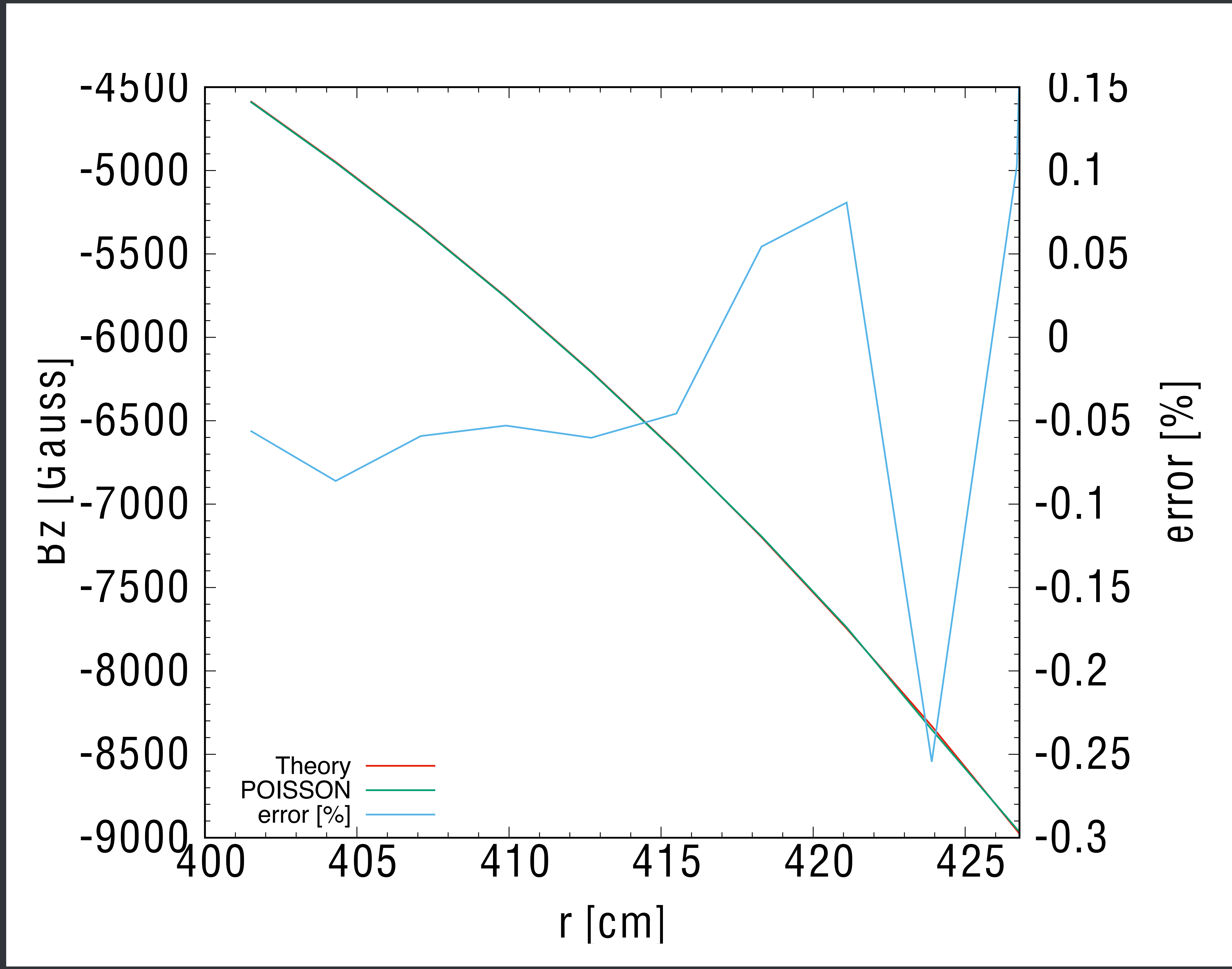


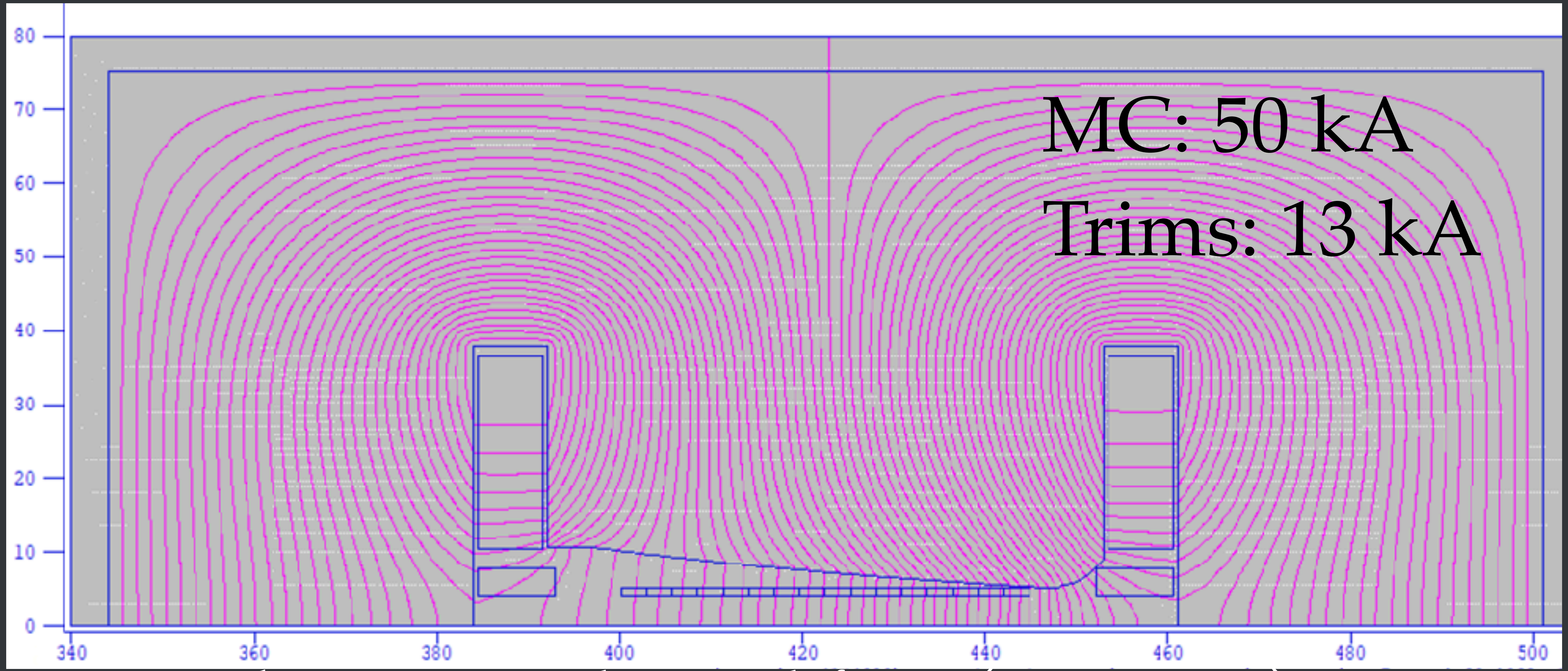
Main coil current adjusted for B(428.1 cm)=0.7574 T

12 trim coils used (max density 2.6 A/mm²)

Science and Technology Facilities Council

Pole shape solution k=11

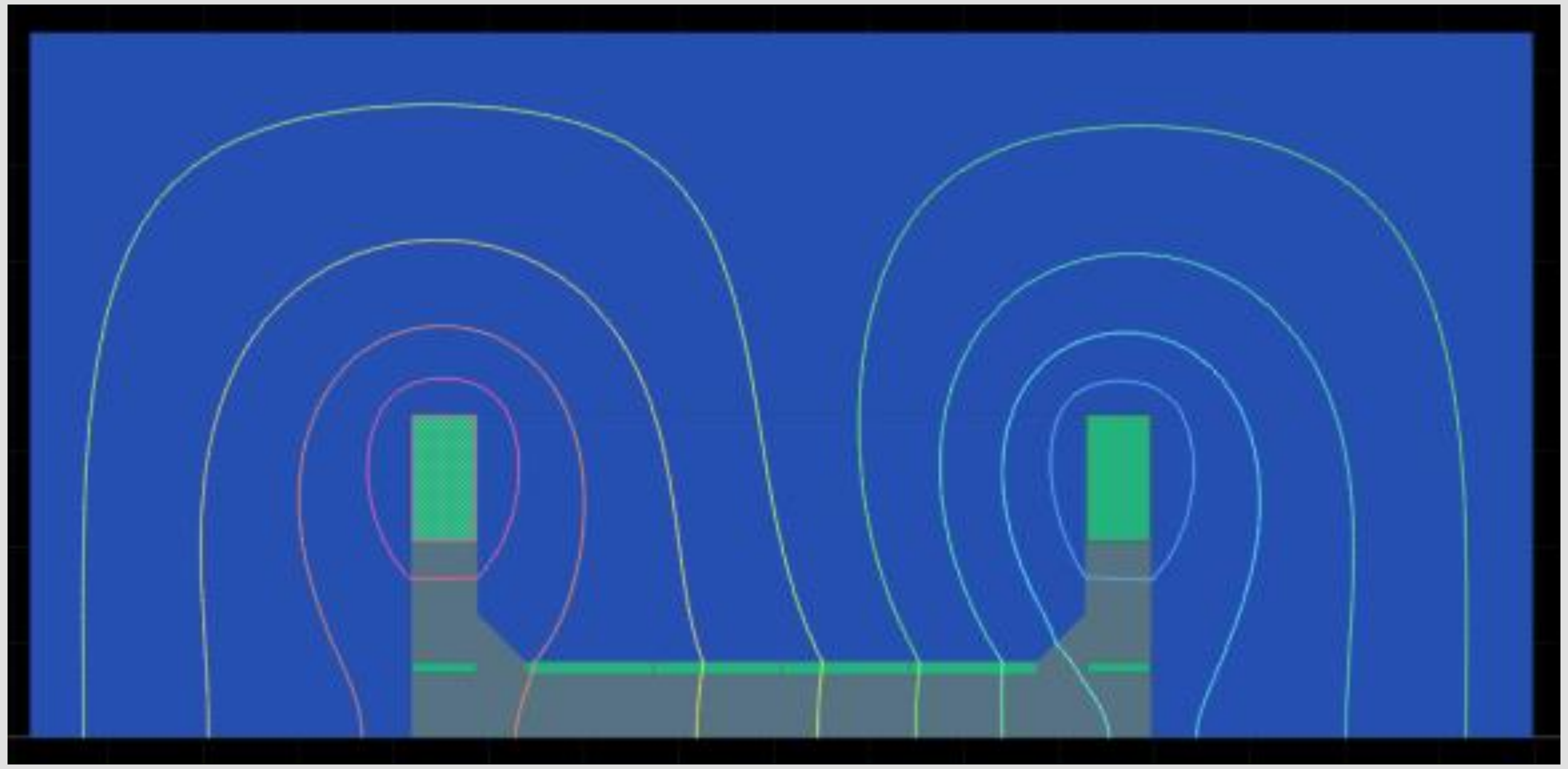


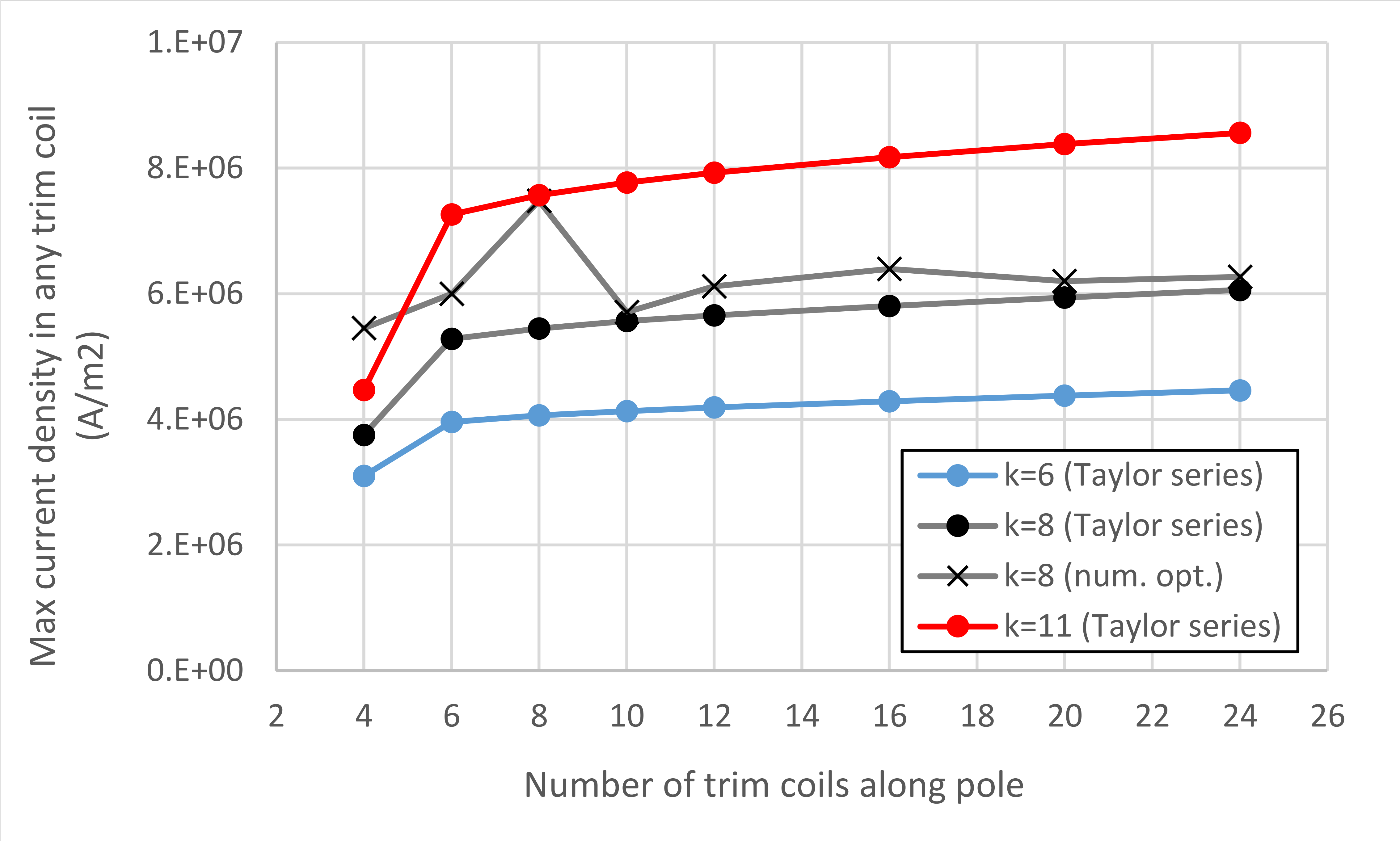


Main coil current adjusted for B(428.1 cm)=0.9285 T

10 trim coils used (max density 8 A/mm^2, bad optimisation?)

Flat pole solution

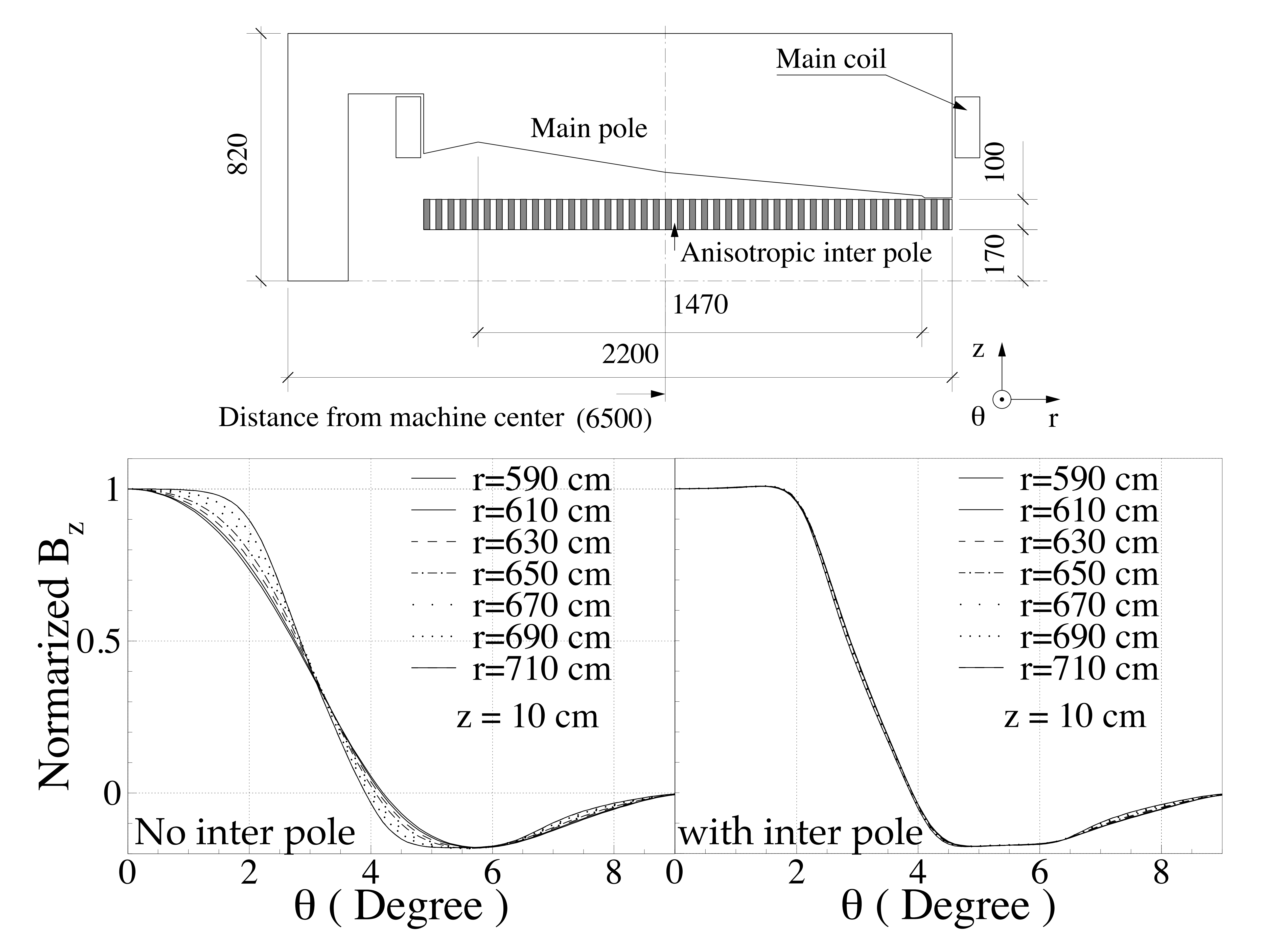




Larger current density than in pole shape solution (~x 2-3), but still feasible

Anisotropic iron

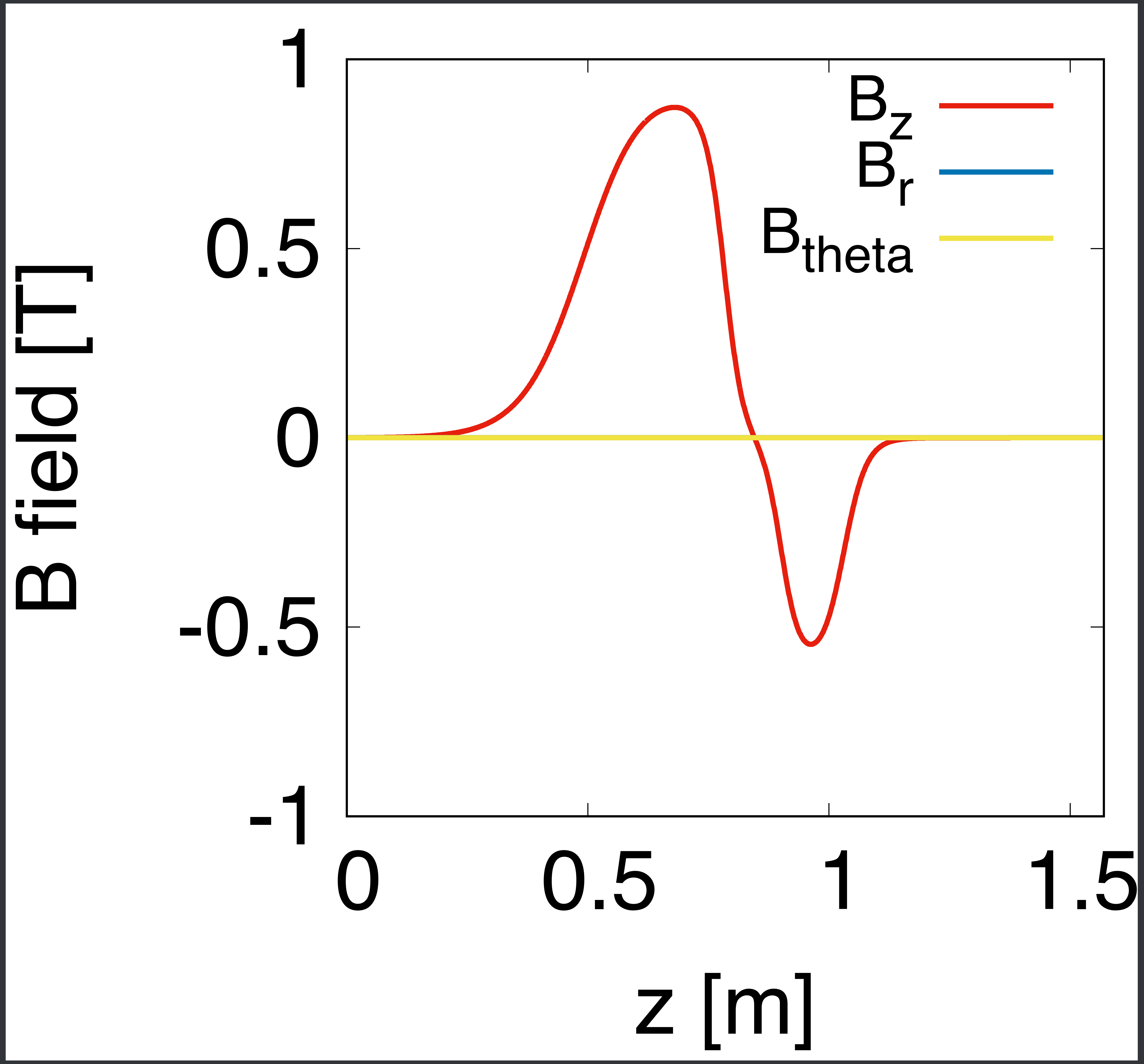
- Concept from Y. Iwashita (2004)
- 2 advantages:
  - Control the extent of fringe field (scaling law)
  - Low pass filter for discrete number of trim coils



Y. Arimoto, Nuclear Physics B, 149 (2005) 277–279

Fringe field fall-off

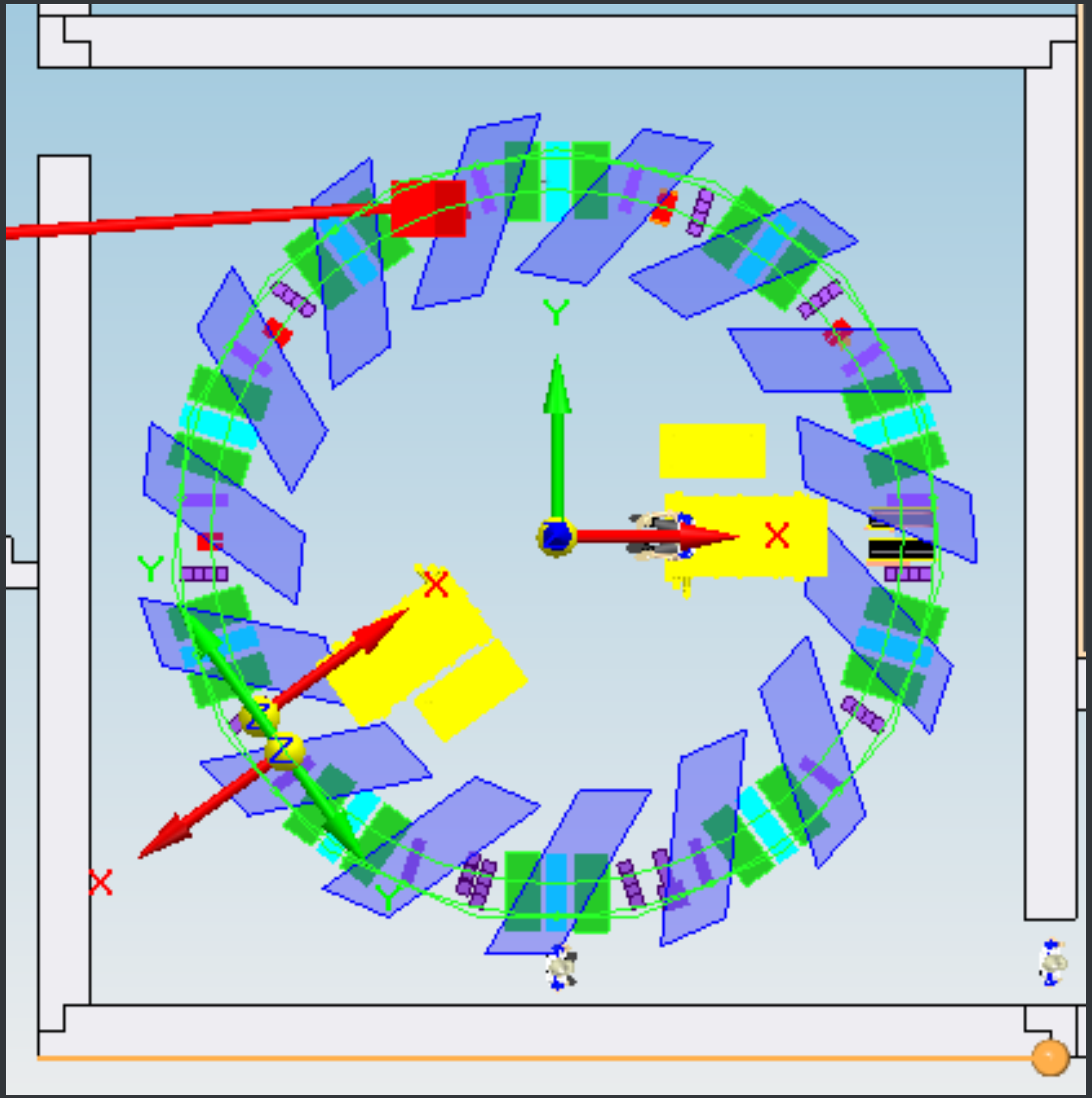
- Fringe field extent used in field model for lattice design to be confirmed in 3D magnet design
- Dynamic aperture limited by octopole component in fringe field
- Need to control fringe fields, not only from integral of the fields but also from harmonic analysis



Science and Technology Facilities Council

Ring size

- Reasonable outer radius of FETS-FFA would be 4.7 m to fit in building R9.
- At the moment with the H-type magnet, the outer radius is ~5 m.
- 2 solutions to overcome the issue:
  - C-type magnet (magnet design)
  - Reduce extraction radius (lattice design)



Summary

- Magnet prototype to be completed by 2025
- 2D study almost finished
- 3D model in OPERA-TOSCA to be started soon