Magnet system design for the new 18 GHz ECR ion source at GSI

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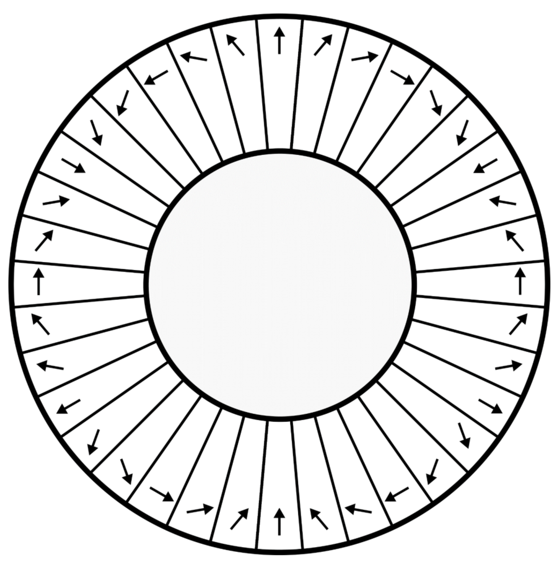
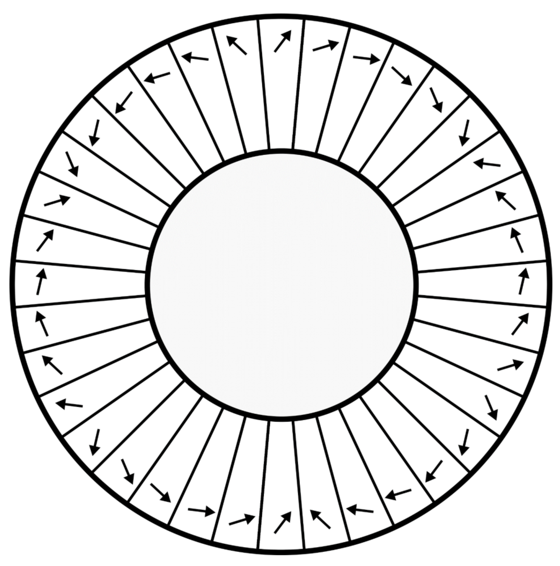
Abstract: In order to increase intensities and charge states of available ion species, a new room-temperature ECR Ion Source (ECRIS) operating at 18 GHz is currently under development at GSI. The new ECRIS is based on a Heavy Ion Ion Source Injector (HIISI), developed at the Department of Physics, University of Jyväskylä (JYFL), and features three normal conducting coils and a permanent magnet hexapole for plasma confinement. The latter has to be installed inside a refrigerated hexapole chamber, allowing to achieve the required radial confining field and avoiding demagnetization of permanent magnets. Computer simulations are carried out with Opera software package for two Halbach hexapole arrangements and the resulting three-dimensional magnetic fields are compared. The demagnetization of permanent magnets due to the superposition of fields generated by the coils and the hexapole is also simulated for both arrangements.

Magnet system design

- The new 18 GHz ECRIS is based on the design of HIISI with a **room-temperature** magnet system [1]
- **Axial confinement:** 3 normal conducting coils
- **Radial confinement:** 36 segments permanent magnet Halbach hexapole
- **Permanent magnets:** NdFeB permanent magnet grade N45SH with B_{rem}=1.35 T and H_{cJ}= 1592 kA/m

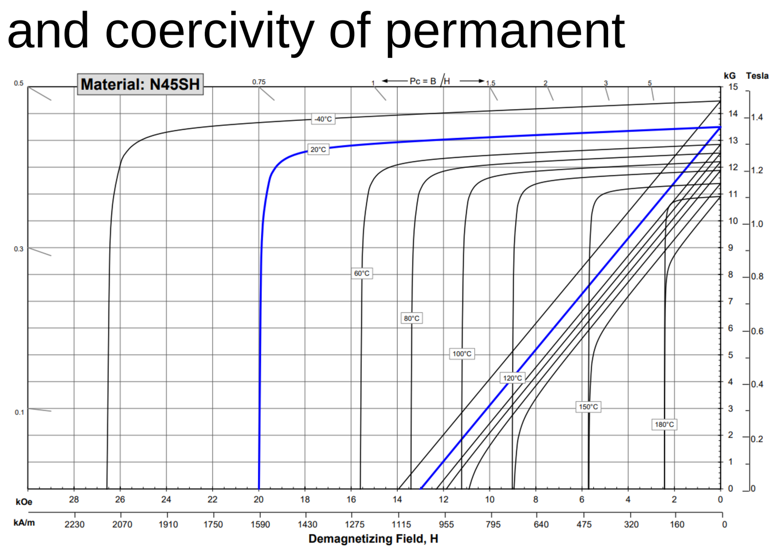


Typical Halbach arrangement



Offset-Halbach arrangement

- Offset-Halbach: magnetic poles are located between the magnet pieces [2]
- **Refrigerated hexapole chamber** to increase remanence and coercivity of permanent magnets



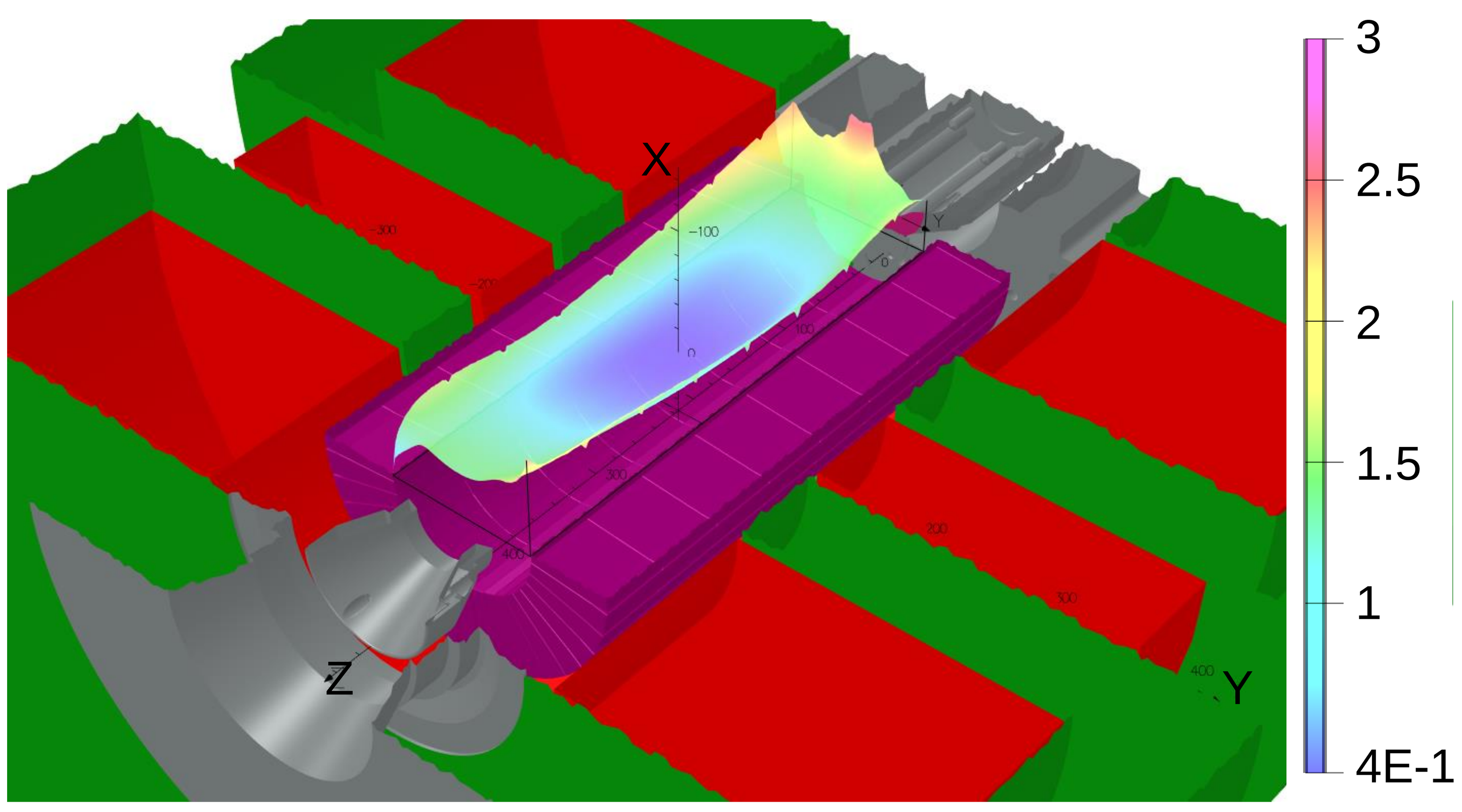
Demagnetization curves: courtesy of Arnold Magnetic Technologies

Magnet system design parameters

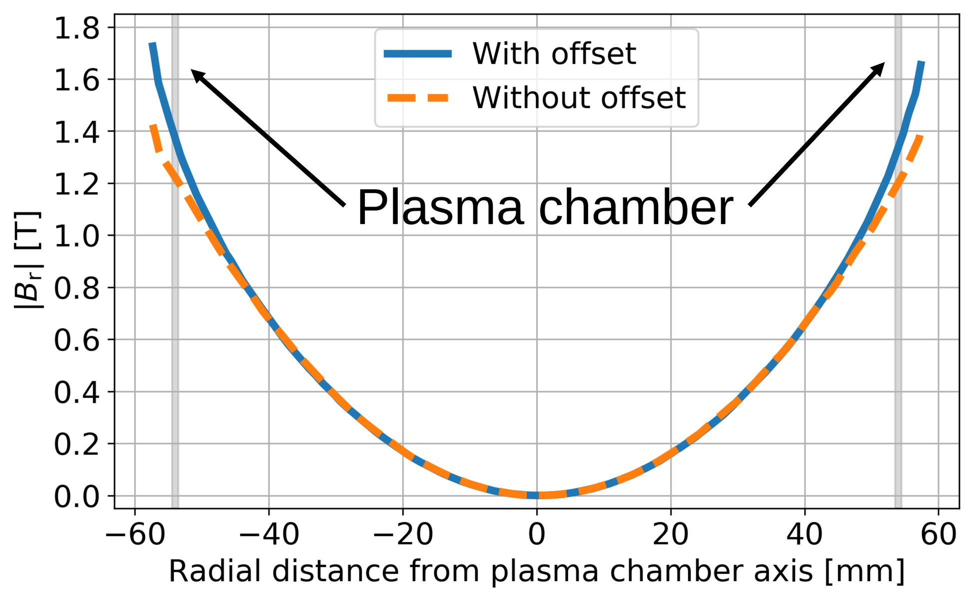
Magnetic field at injection	2.8 T
Magnetic field at center	0.45 T
Magnetic field at extraction	1.3 T
Nominal currents of coils (Inj. / Center / Ext.)	1000 / -300 / 820 A
Inner radius of the hexapole	58 mm
Outer radius of the hexapole	120 mm
Length of the hexapole	420 mm

Magnetic field structure

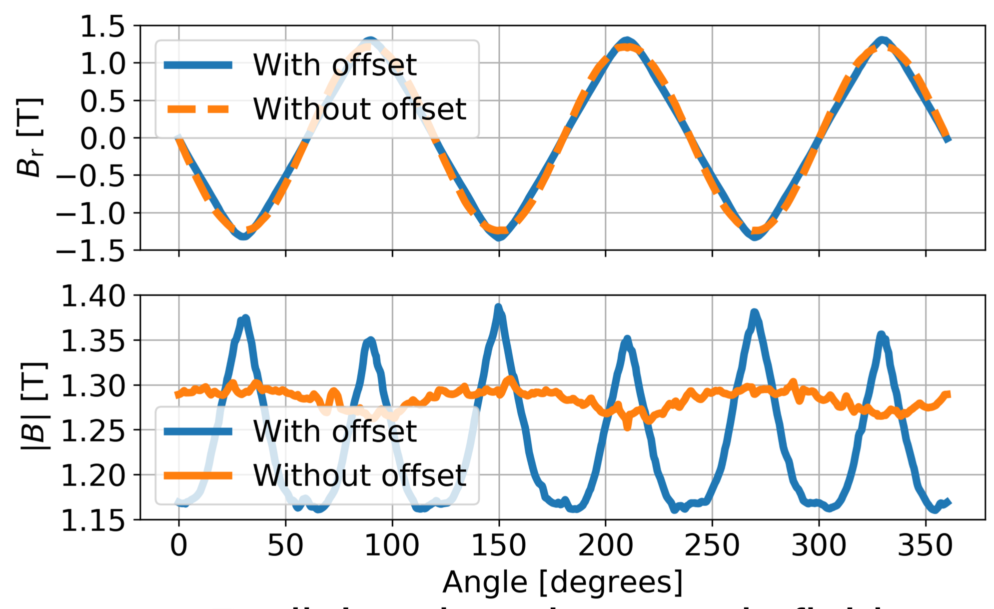
- Complete magnetic system is simulated with the Opera software package [3]
- Max. magnetic fields achieved with offset-Halbach: B_{r}=1.35 T and $|B|$=1.39 T at the inner surface of the plasma chamber
- Max. magnetic fields achieved with typical Halbach: B_{r}=1.21 T and $|B|$=1.31 T at the inner surface of the plasma chamber



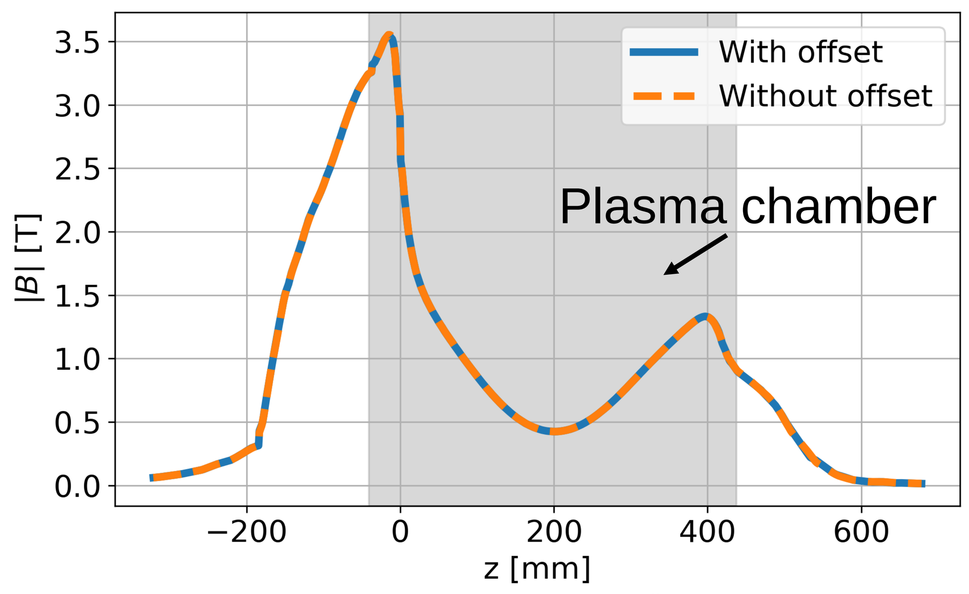
Magnetic field structure (Min-B), |B| [T]



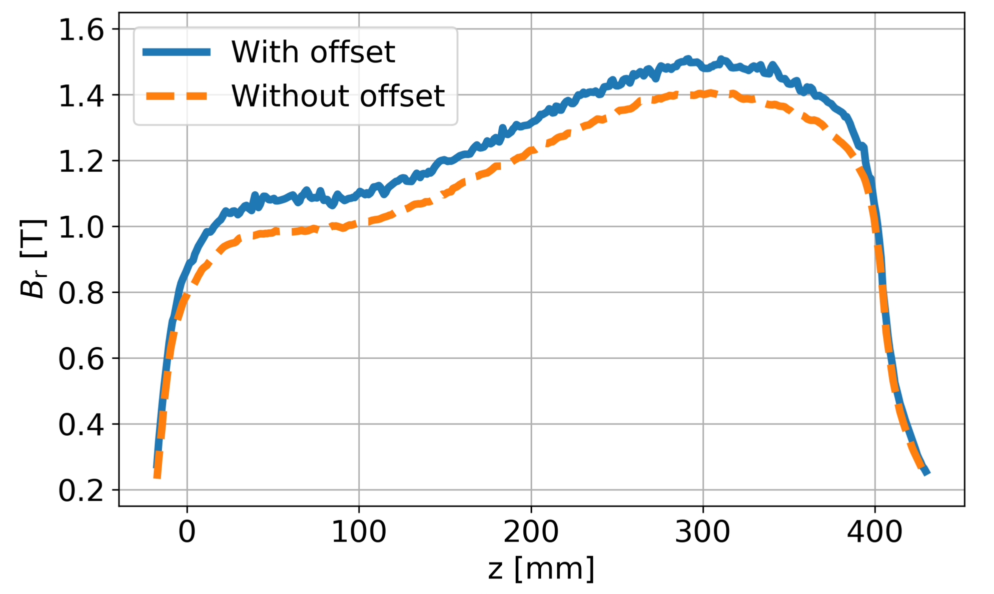
Radial magnetic field along radius



Radial and total magnetic field at plasma chamber



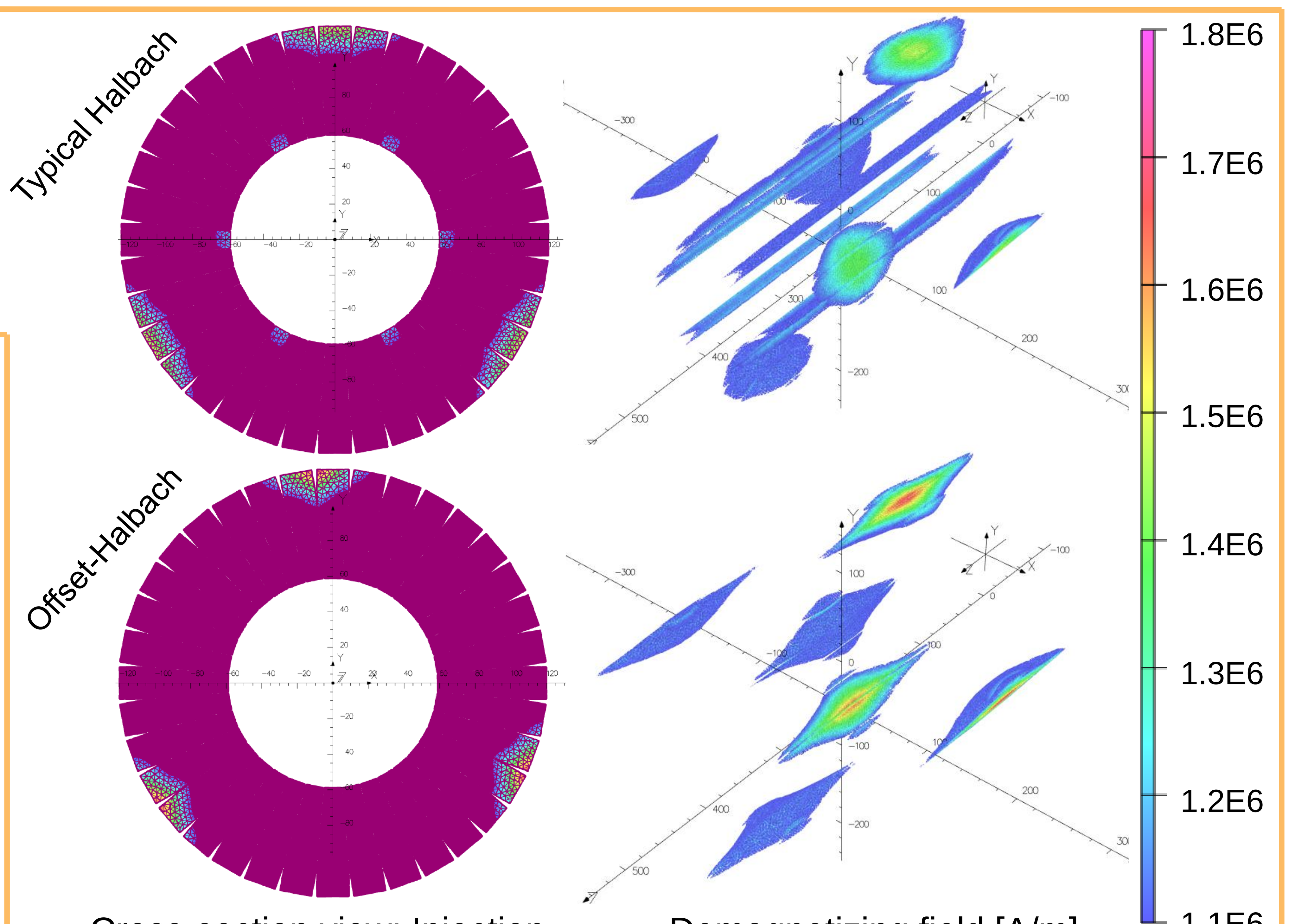
Axial magnetic field



Radial magnetic field at plasma chamber (axial direction)

Demagnetization analysis

- **Demagnetizing fields** up to 1.49 kA/m (typical) and 1.74 kA/m (offset-Halbach)
- Volume of permanent magnet material exposed to fields higher than 1.1 kA/m: 306 cm³ (offset-Halbach) and 428 cm³ (typical)
- Typical Halbach: partial demagnetization of permanent magnets occurs along the inner and outer radii of the hexapole assembly



Cross-section view: Injection   Demagnetizing field [A/m]

Conclusion

The offset-Halbach arrangement is a more attractive design for the permanent magnet system of the new ECRIS due to:
- **7 % increase** of the provided radial magnetic field
- **30 % reduction** of volume of the permanent magnet material subjected to the demagnetization

References

[1] H. Koivisto *et al.*, "HIISI, new 18 GHz ECRIS for the JYFL accelerator laboratory", in *Proc. ECRIS'14*, Nizhny Novgorod, Russia, Aug 2014, paper TUOMMH05, pp. 99–103
[2] P. Suominen *et al.*, "Optimization of the Halbach-type magnetic multipole for an electron cyclotron resonance ion source", *Rev. Sci. Instrum.*, vol. 75, no. 1, 2004
[3] Opera electromagnetic and electromechanical simulation software, URL: *https://www.3ds.com/products-services/simulia/products/opera*