Comparison among possible design solutions for the Stray Field Shielding System of the DTT Neutral Beam Injector

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Introduction

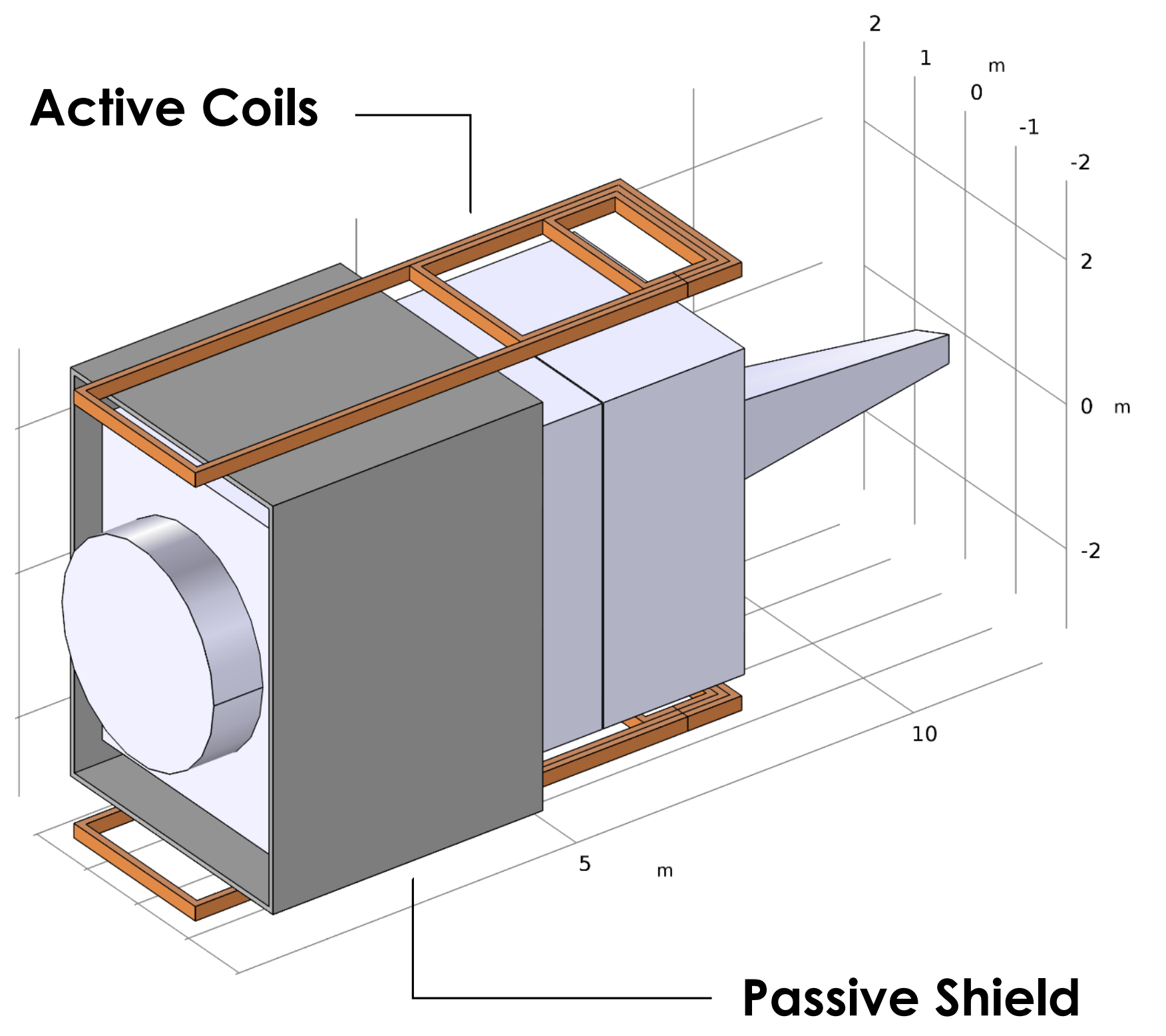
- The Divertor Test Tokamak Neutral Beam Injector (DTT NBI) will deliver part of the 45 MW of additional heating power needed for the tokamak to access DEMO – relevant scenarios.
- During operation however, while the toroidal field is contained, the poloidal field generated by the plasma current and the poloidal and central coil systems can extend and influence the operation of other devices up to a radius of over 20 m from the tokamak axis. This is called the poloidal stray field.
- The NBI is especially interested, since the charged particles of the extracted beam can be deflected on the walls by the stray field even before neutralization, making the entire system useless.
- A Stray Field Shielding System (SFSS) is needed, to reduce the field to acceptable levels.

Main design specifications

- Injected power: 10 MW
- Beam energy: 510 keV
- Accelerated current: 40 A of D⁻ (1360 apertures) subdivided in 4 vertical beam blades
- 5 grids, 1 extr. gap and 3 acc. gaps
- Vacuum system based on Non-evaporable Getter (NEG) pumps + turbo-molecular pumps

SFSS components and objectives

- A SFSS usually consists of a Passive Shield (PS), that reduces the field within its boundaries, and Active Coils (ACs) capable of guaranteeing the minimum field condition even when the scenario evolves.



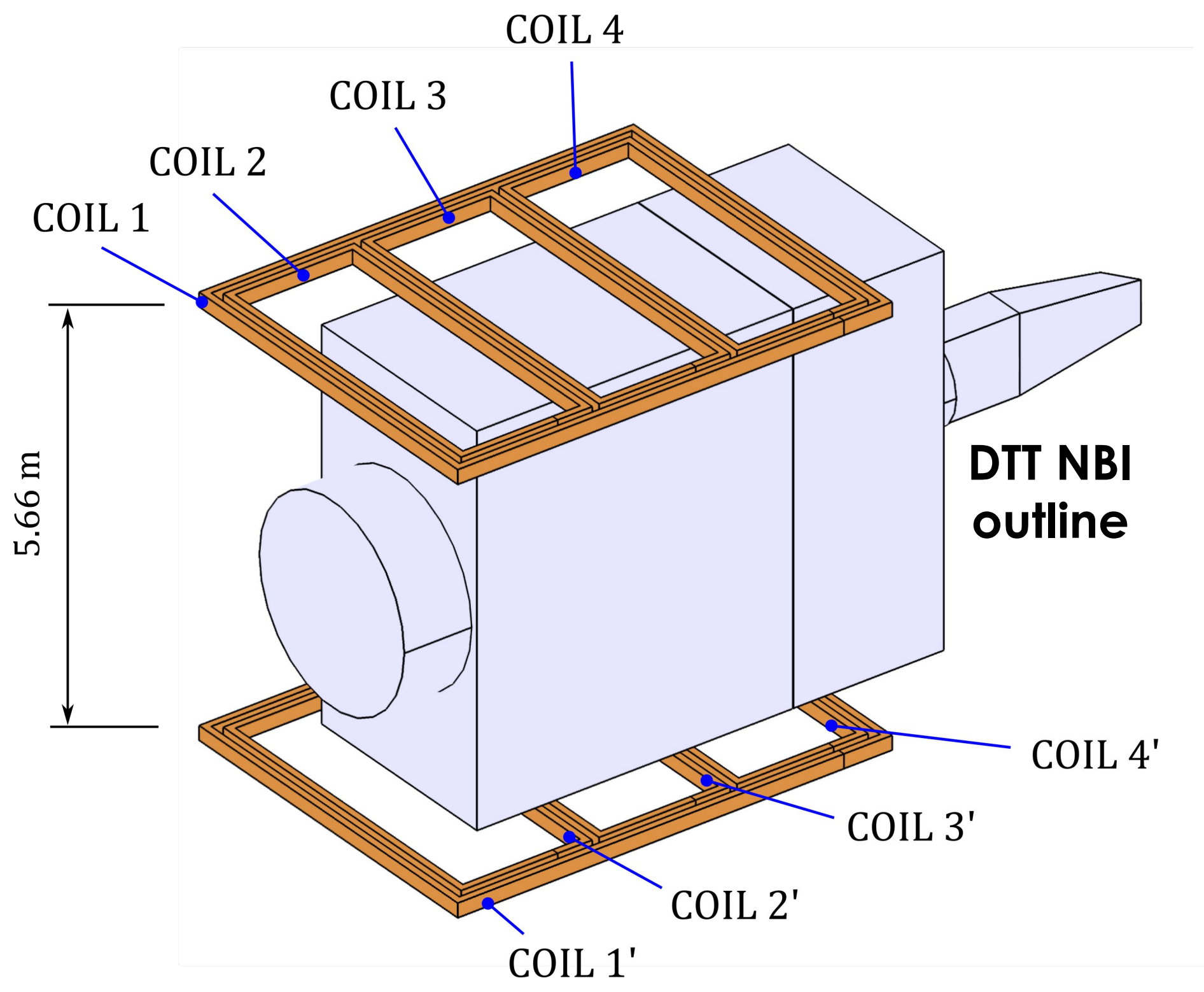
- ➢ Either can be inside or outside of the Vacuum Vessel.
- ➢ Their shape and position should not hinder other components (e.g., voltage holding, obstructing gas flow if inside, etc.).
- ➢ If active, the coil currents should be as low as possible to limit the needed power supplies.

In DTT NBI, where the high-voltage beam source is exposed to the air and the overall available space is limited, an **internal SFSS is preferable.**

Note: Without SFSS, the "compensation" efficiency is $\eta_{stray} \approx 1\,\%$

Three configurations were considered:

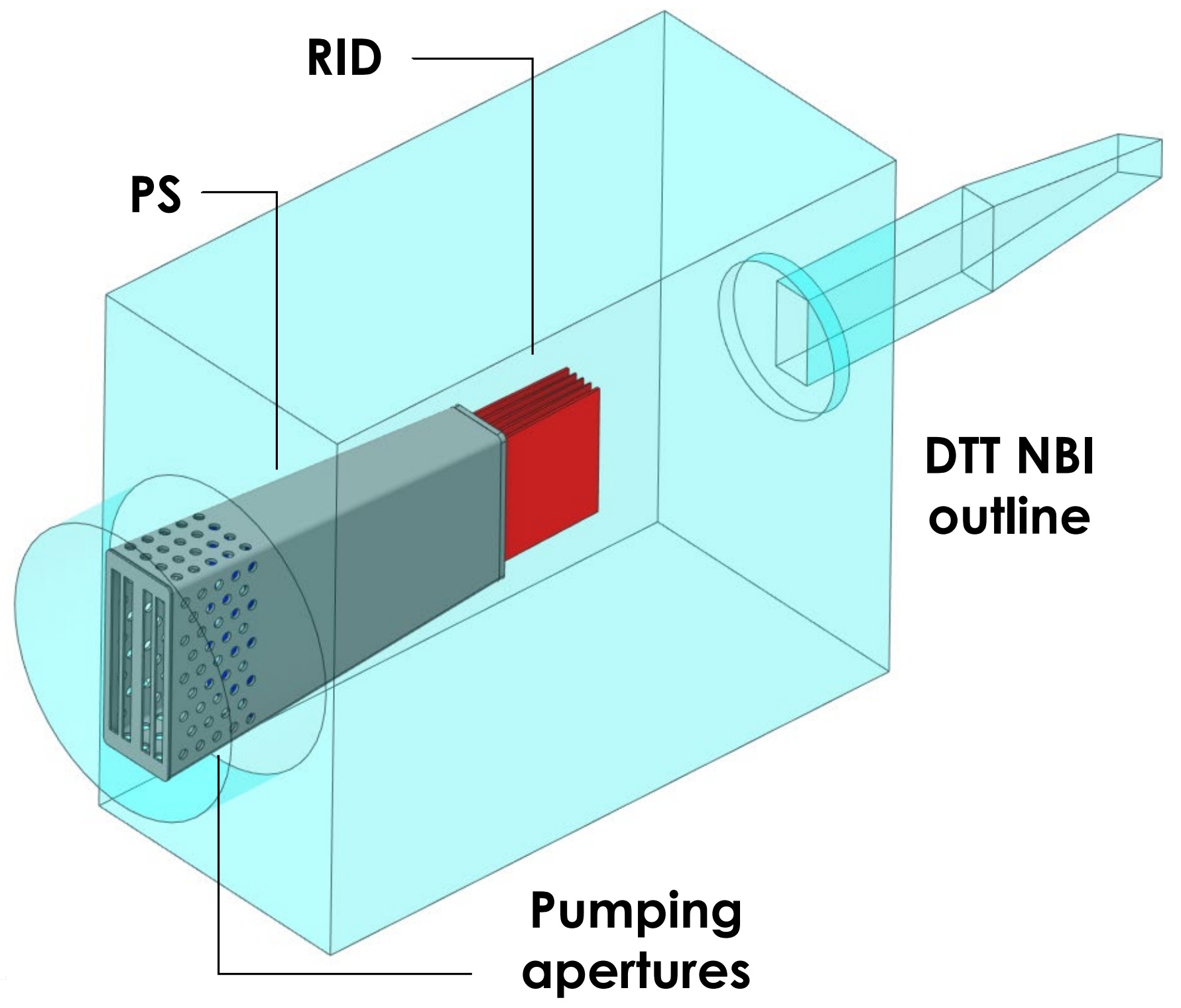
Coils only



- ➢ The "reference" case, the first to have been proposed and used to check the entity of the correction needed to operate the NBI.
- ➢ Uses 4 pairs of external nested coils, operated in Helmholtz configuration, with no shield. Their positioning can mimic the stray field distribution.
- ➢ The minimization procedure was able to find a solution able to suppress the effect of the stray field, but at the cost of extremely high coil currents.

$\eta_{stray} = 98.7\,\%$ $\quad I_c \approx 500\ \mathrm{kAt}$

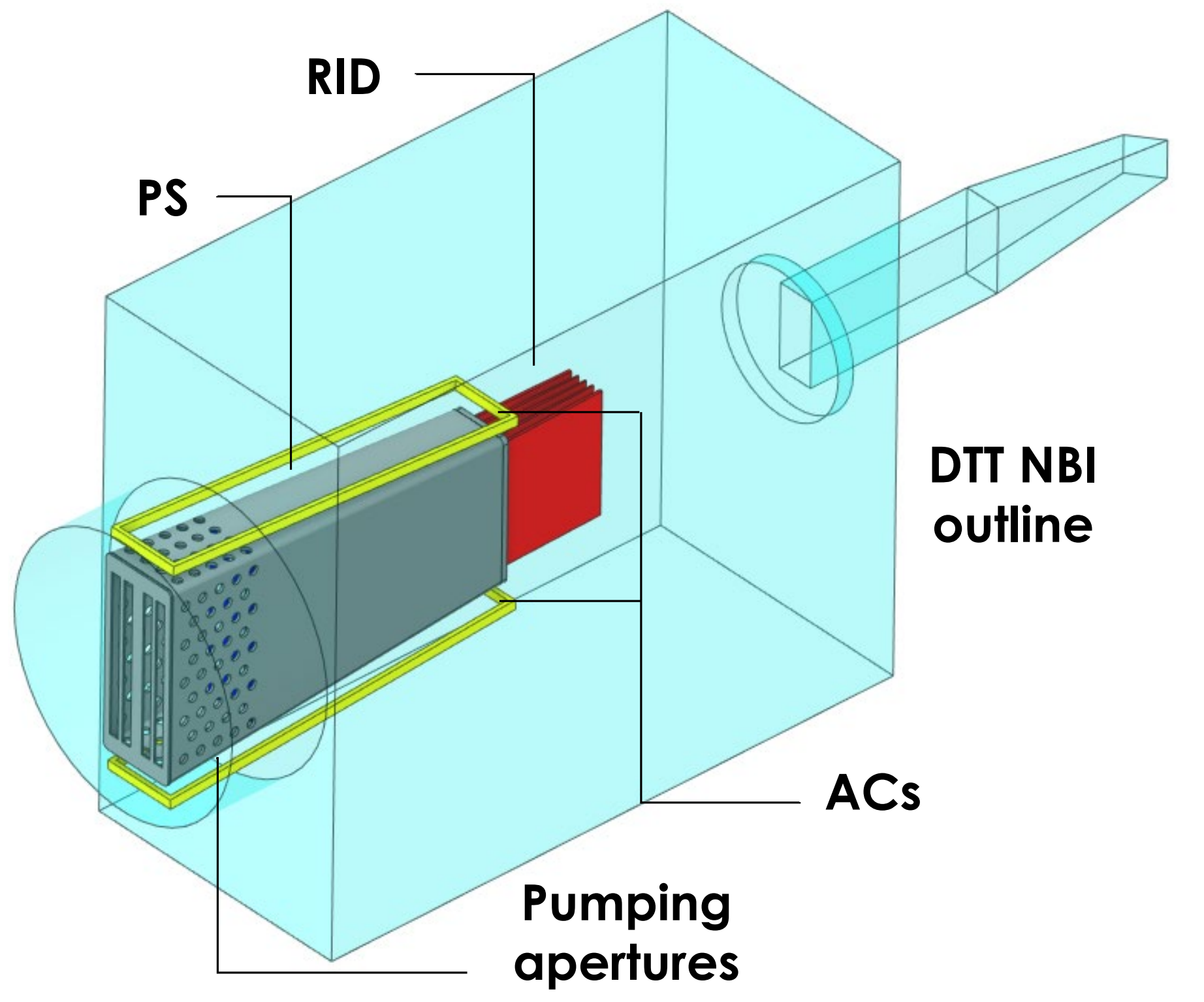
Shield only



- ➢ The diametrically opposite approach to the first case, applying a compact internal shield covering the region from the beam source exit to the Residual Ion Dump (RID).
- ➢ The design features a series of holes in the region between beam source and the neutralizer to allow pumping in that critical region.
- ➢ The clear advantage is the possibility of a fully passive SFSS, able to suppress the effect of the stray field without the need of additional power supplies.

$\eta_{stray} = 96.1\,\%$

Passive and active compensation

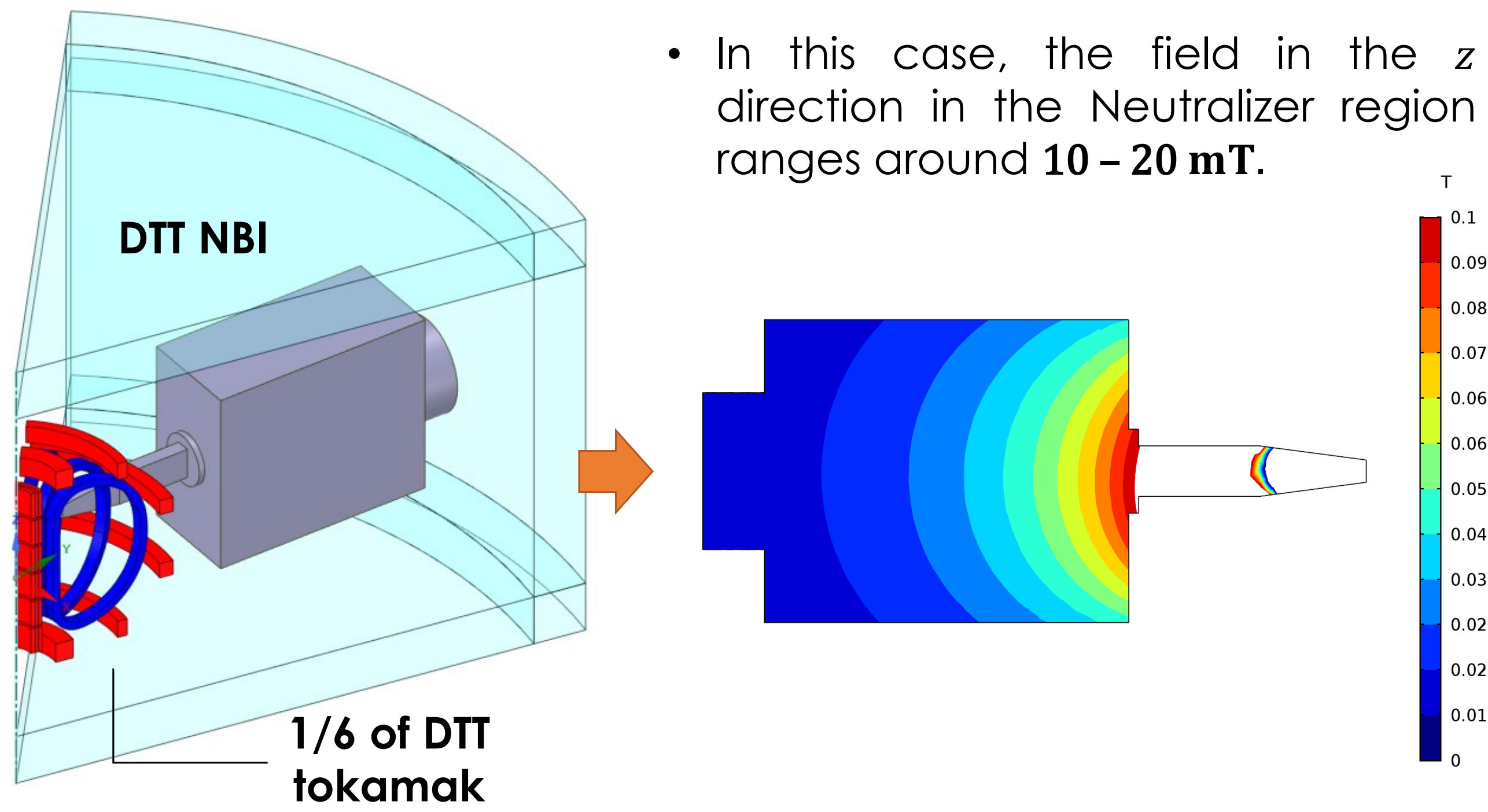


- ➢ This case takes the "shield only" case and pairs it with a single pair of internal Helmholtz coils to give it an additional capability of following the evolution of the field and the minimum condition.
- ➢ These coils rest upon the shield and fit through the beam source aperture with no issue.
- ➢ The increased complexity pays off with an increased compensation of the effect of the stray field, at a fraction of the coil currents needed in the reference case.

$\eta_{stray} = 98.1\,\%$ $\quad I_c \approx 30\ \mathrm{kAt}$

Simulation setup

- The geometry of DTT NBI, the chosen SFSS, and a sector of the DTT tokamak is modeled in a multi-physics Finite Element Method (FEM) COMSOL®, to obtain the field distribution using the currents for a typical Single Null scenario.
- **The analysis is then limited for the case with the highest field in the NBI.**



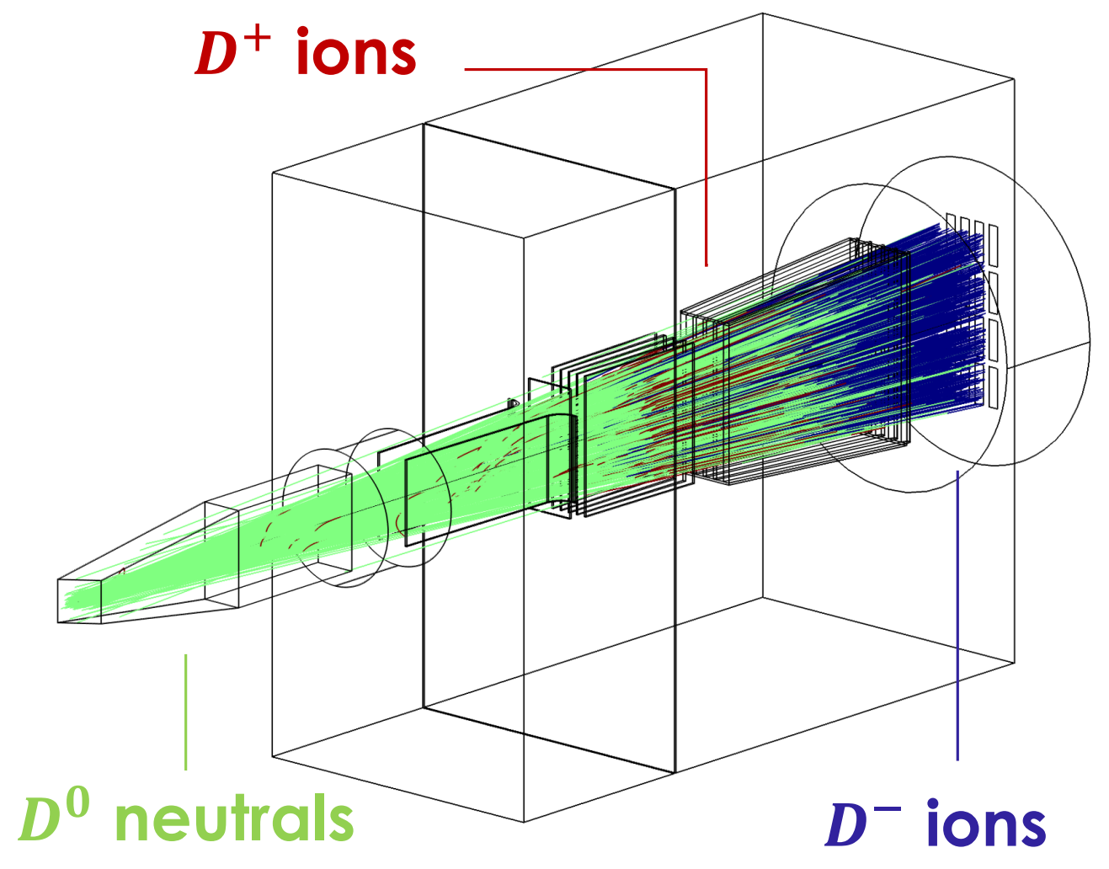
- In this case, the field in the z direction in the Neutralizer region ranges around $\mathbf{10-20\ mT}$.

Minimize

$$\sum_{i}^{N_{coil}} B(P)_{c,i_z} \cdot I_{c,i} + B(P)_{stray_z}$$

$$\forall\, point\ P \in V$$

- Under linear assumption, eventual compensation fields are scaled and summed to the stray field solving the **least squares problem** over a cloud of points of interest within the evaluation volume V.
- The compensated field is then used in a full-NBI particle tracing simulation to check on the efficacy of compensation and the overall NBI power balance.



- The figure of merit can be defined as:

$$\eta_{stray} = \frac{P_{plasma}}{P_{plasma,\,no-field}}$$

Conclusions

- A selection of conceptual designs of the SFSS for DTT NBI has been produced, estimating for each one their performance in suppressing the poloidal stray field.
- Each one has advantages and drawbacks, with room for improvement. Future improvements will need to consider the more advanced scenarios planned for DTT, as well as considering the time evolution of the fields.