ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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Scattering of mm-waves by turbulent structures in magnetically confined fusion plasmas

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SUMMARY

mm-waves in the electron cyclotron frequency (80-170GHz) are widely used in magnetically confined fusion devices to perform heating and current drive as as well as instability control. Along their propagation, they can be scattered by turbulent structures resulting in efficiency losses.

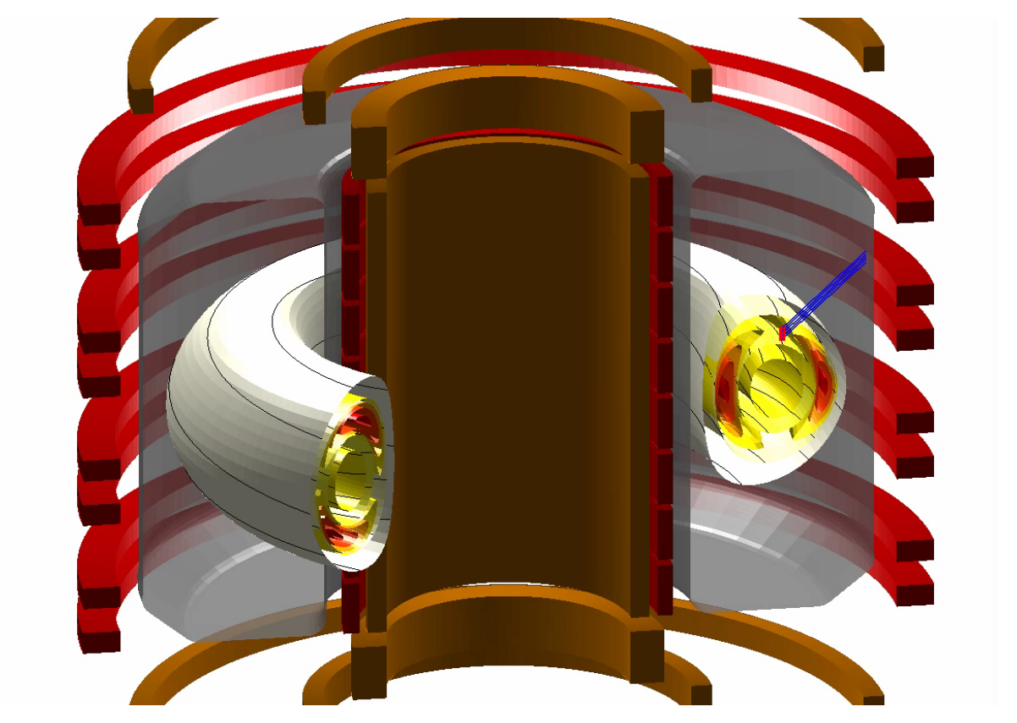
- Building a predictive tool for (i) simulating radio frequency wave scattering by turbulent structures at the edge and scrape-off layer of tokamaks; (ii) comparing simulation results with experimental data

- Simulations show how the propagation of a mm-beam is dependent upon the nature of the electron density perturbation through the dielectric permittivity

- Simulation results are compared with scattering experiments on TORPEX, a simple magnetized torus, and show promising predictive capabilities

1.MOTIVATIONS

- In magnetically confined fusion devices, radio frequency power deposition is of major importance for plasma heating, current drive and instability control [1]



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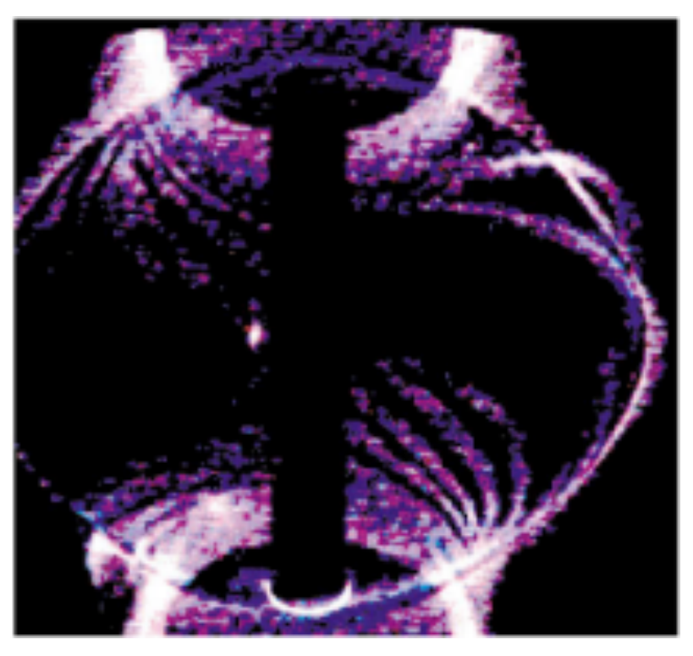

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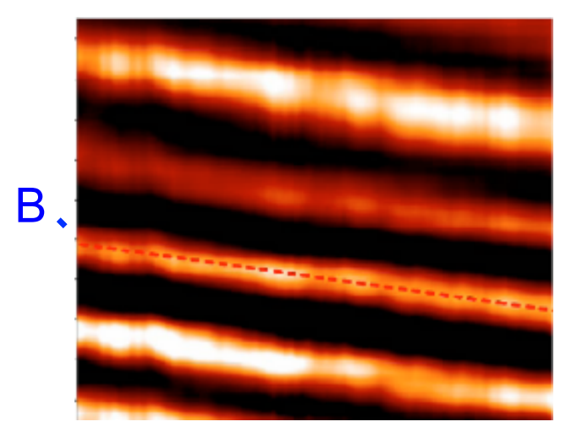

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•Turbulent structures such as blobs may scatter the mm- waves, resulting in less precise targeting or broadening of the absorption [2]

2.COMPUTATIONAL METHOD

- Full-wave simulations using the RF module in the frequency domain
- Solving the three components of the electric field in the wave equation
- 2D geometry

$$\nabla(\nabla.\tilde{E})-\nabla^2\tilde{E}=\frac{\omega^2}{c^2}\varepsilon_r(\omega,x)\tilde{E}+BC$$

3.A MODEL FOR THE PLASMA

- Hypotheses: cold, inhomogeneous. magnetized, unbounded plasma
- ε_r derived within the framework of the fluid model
- The electron density n_e and the magnetic field B_0 uniquely define ε_r and thus the plasma optical properties

$$\varepsilon_r(\omega,\vec{x})=\begin{pmatrix}\varepsilon_1(\omega,\vec{x}) & -i\varepsilon_2(\omega,\vec{x}) & 0\\ i\varepsilon_2(\omega,\vec{x}) & \varepsilon_1(\omega,\vec{x}) & 0\\ 0 & 0 & \varepsilon_3(\omega,\vec{x})\end{pmatrix}$$

where

$$\varepsilon_1(\omega,\vec{x})=1+\frac{\omega_{pe}^2(\vec{x})}{\Omega_e^2(\vec{x})-\omega^2}$$

$$\varepsilon_2(\omega,\vec{x})=-\frac{\Omega_e}{\omega}\frac{\omega_{pe}^2(\vec{x})}{\Omega_e^2(\vec{x})-\omega^2}$$

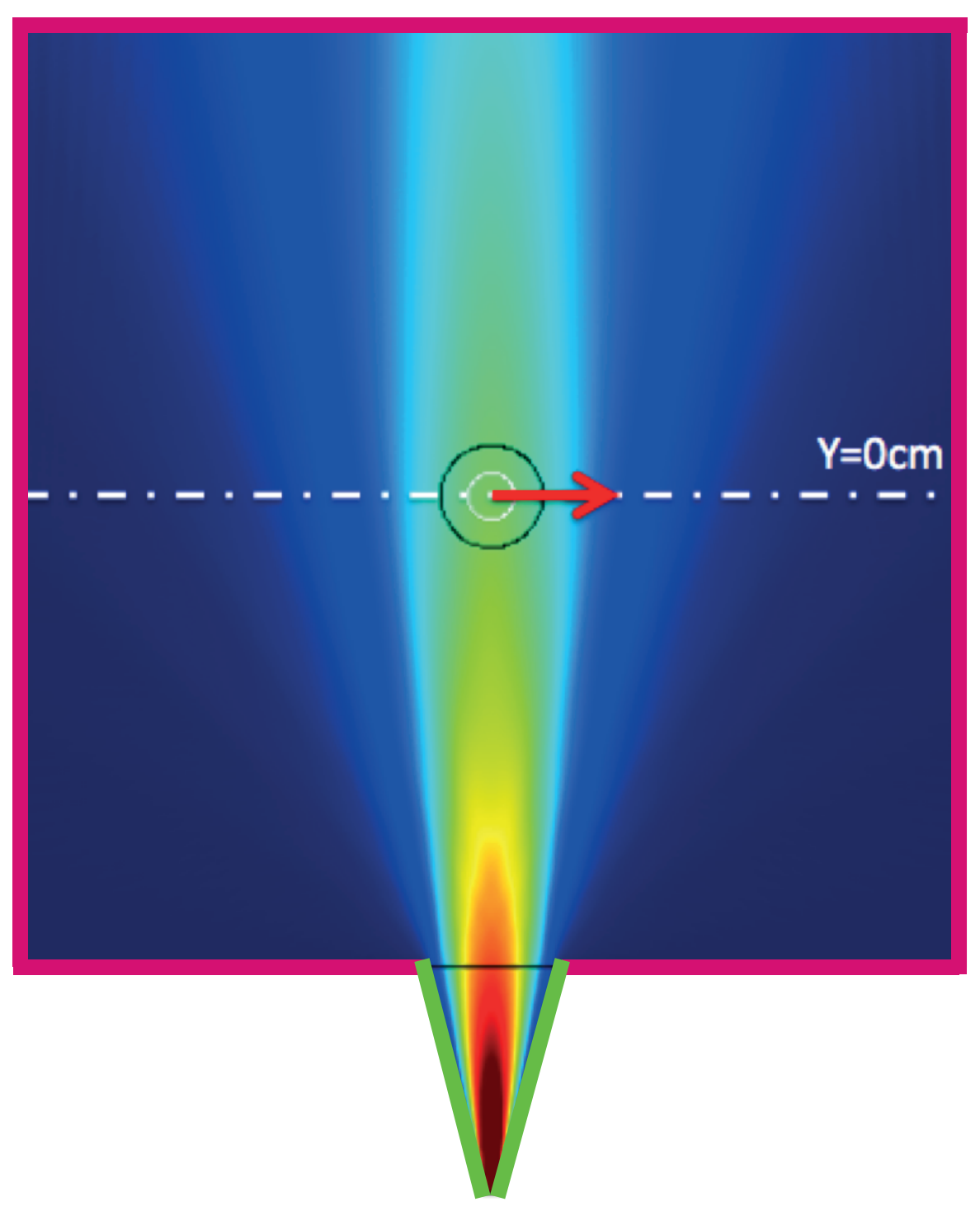
$$\varepsilon_3(\omega,\vec{x})=1-\frac{\omega_{pe}^2(\vec{x})}{\omega^2}$$

and

$$\omega_{pe}=\sqrt{\frac{e^2n_e(\vec{x})}{\varepsilon_0 m_e}}$$

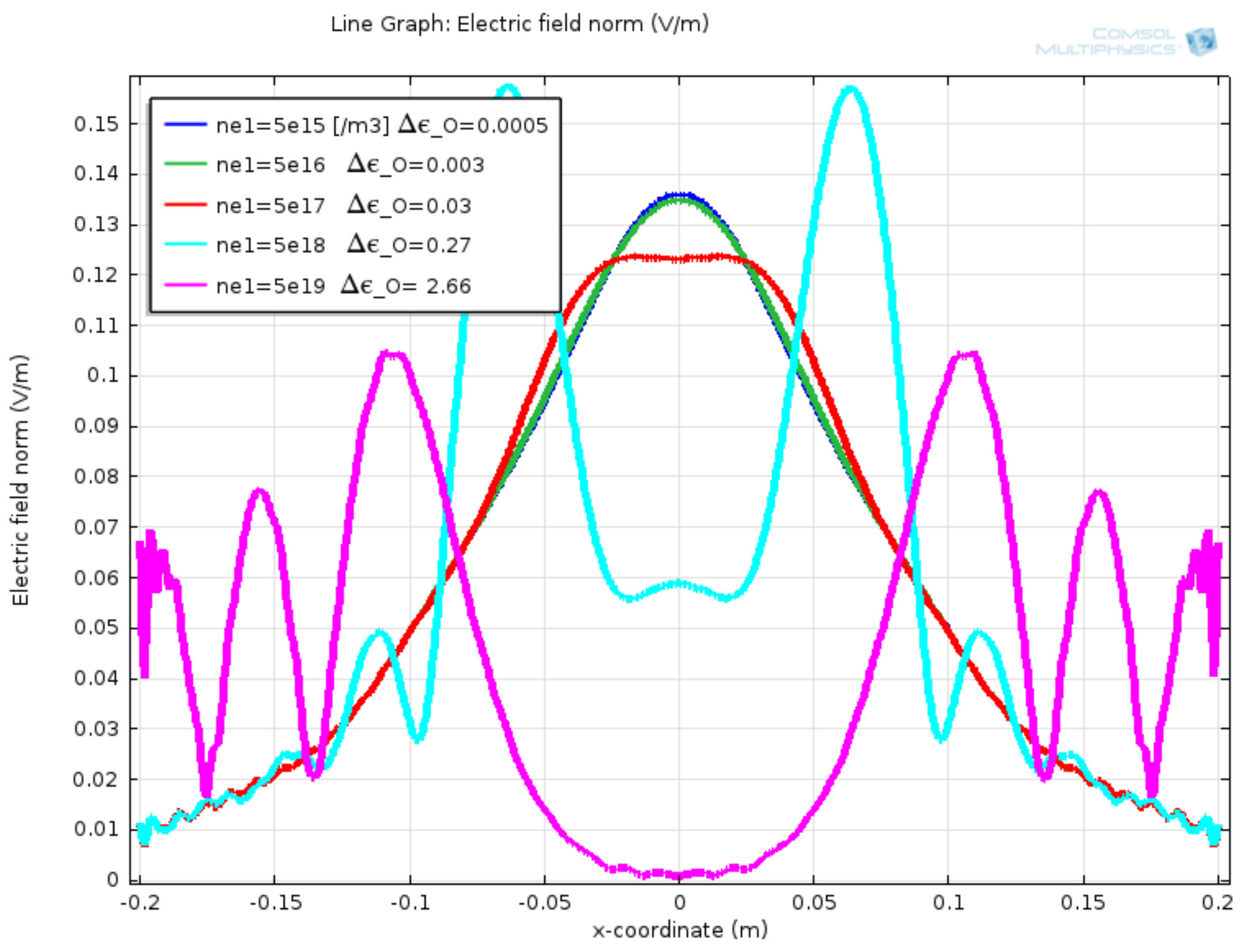
$$\Omega_e=\frac{eB_0(\vec{x})}{m_e}$$

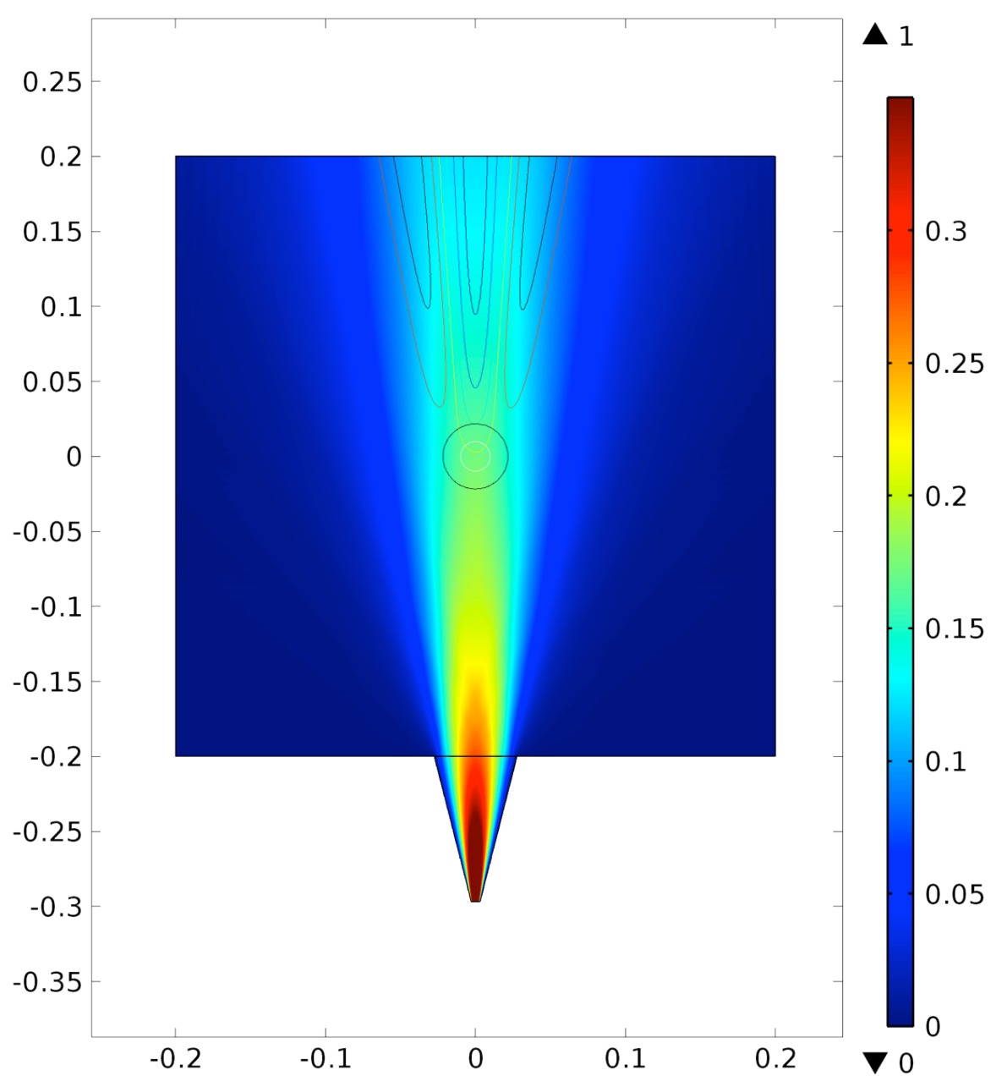
4.GEOMETRY



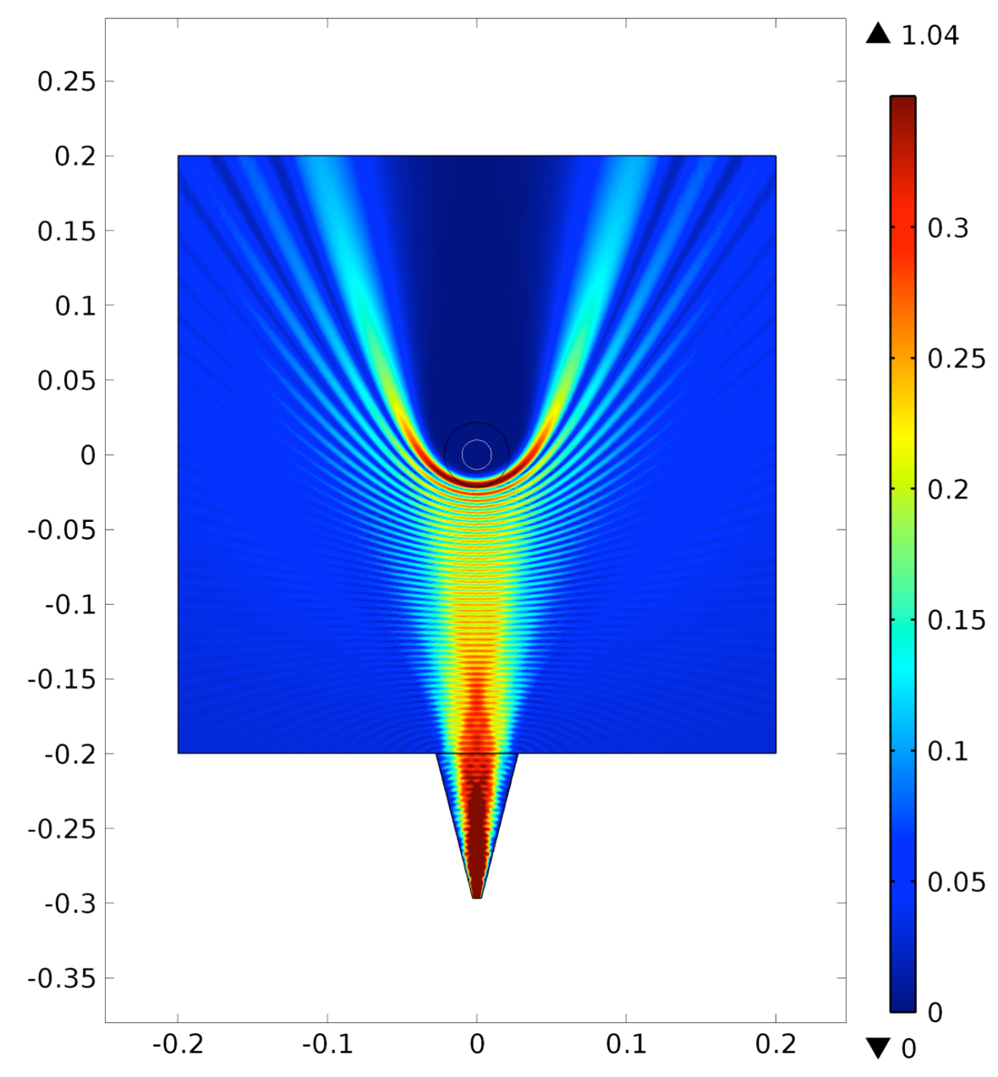
- Excitation in the O-mode at 39GHz
- Gaussian distribution of n_e
- Free-space propagation simulated using second order scattering boundary conditions
- Antenna simulated using copper impedance boundary conditions
- Computational area: 20x20cm
- Mesh: free triangular with $\frac{\lambda}{9}\leq size\leq\frac{\lambda}{5}$

5.THE EFFECT OF THE ELECTRON DENSITY





$n_e=10^{17}m^{-3}$



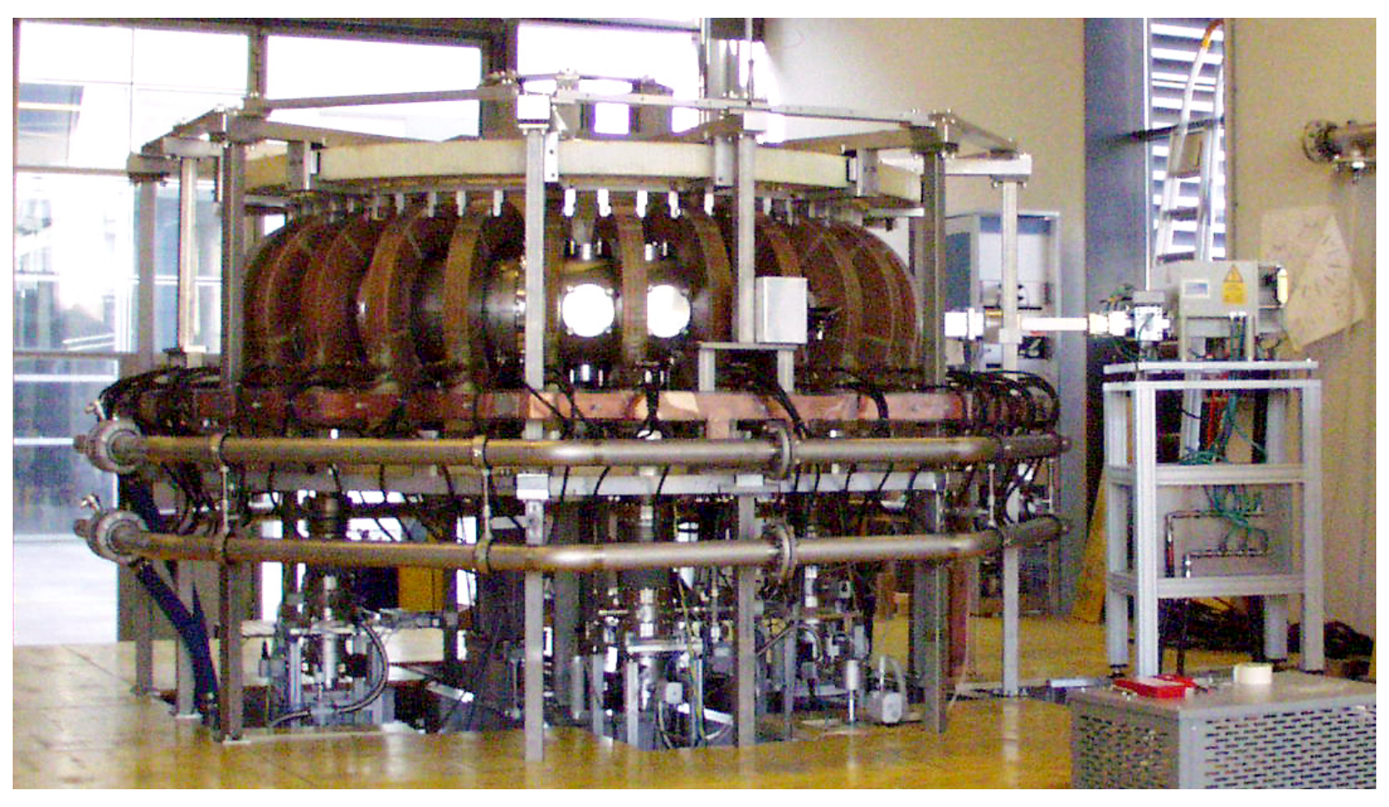
$n_e=10^{19}m^{-3}$

- For $\delta\varepsilon/\overline{\varepsilon_r}\leq 1\%\rightarrow$ no macroscopic effect on the beam propagation.

- For $\delta\varepsilon/\overline{\varepsilon_r}\geq 1\%\rightarrow$ broadening of the beam until the reach of a complete shadowing of the line of sight

- This first model enables a physical understanding of the scattering mechanism in a simple geometry

6.THE TORPEX EXPERIMENT

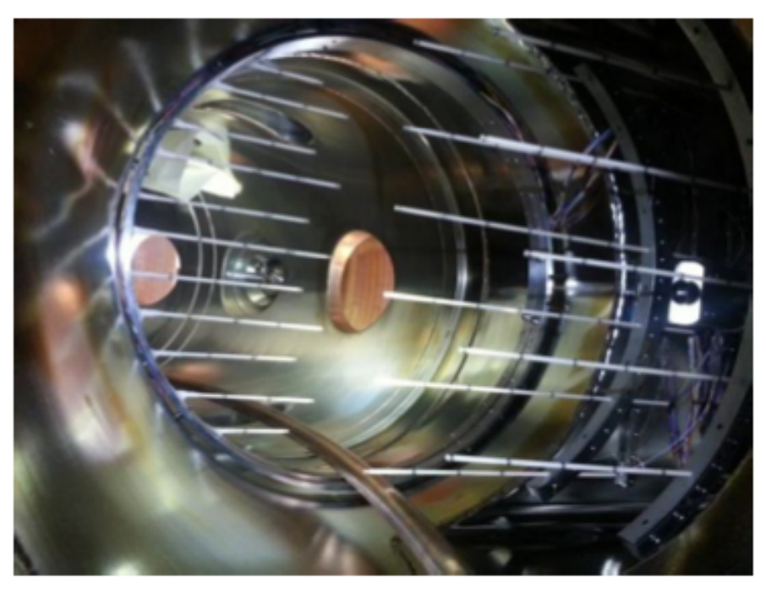


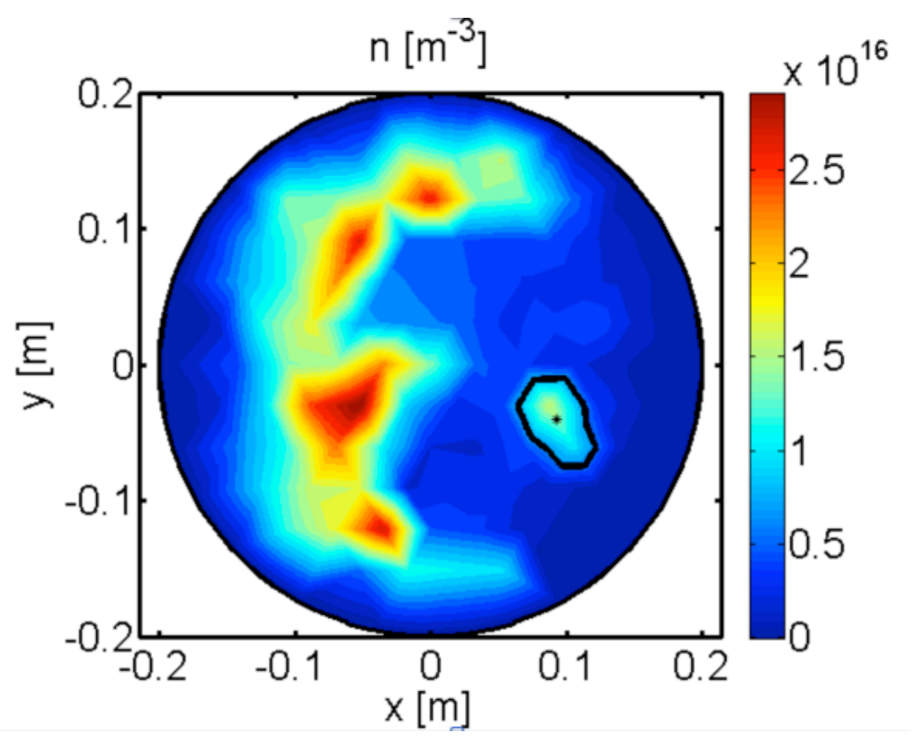
- Simple magnetized torus
- Open field lines configuration

- Extensive set of langmuir probes enabling a spatial resolution of ~3cm for the plasma density profile

- Main parameters:

  - B_v up to 5mT
  - B_T up to 0.1T
  - $n_e\approx10^{15}$-$10^{16}m^3$
  - $T_e\approx$5-10eV

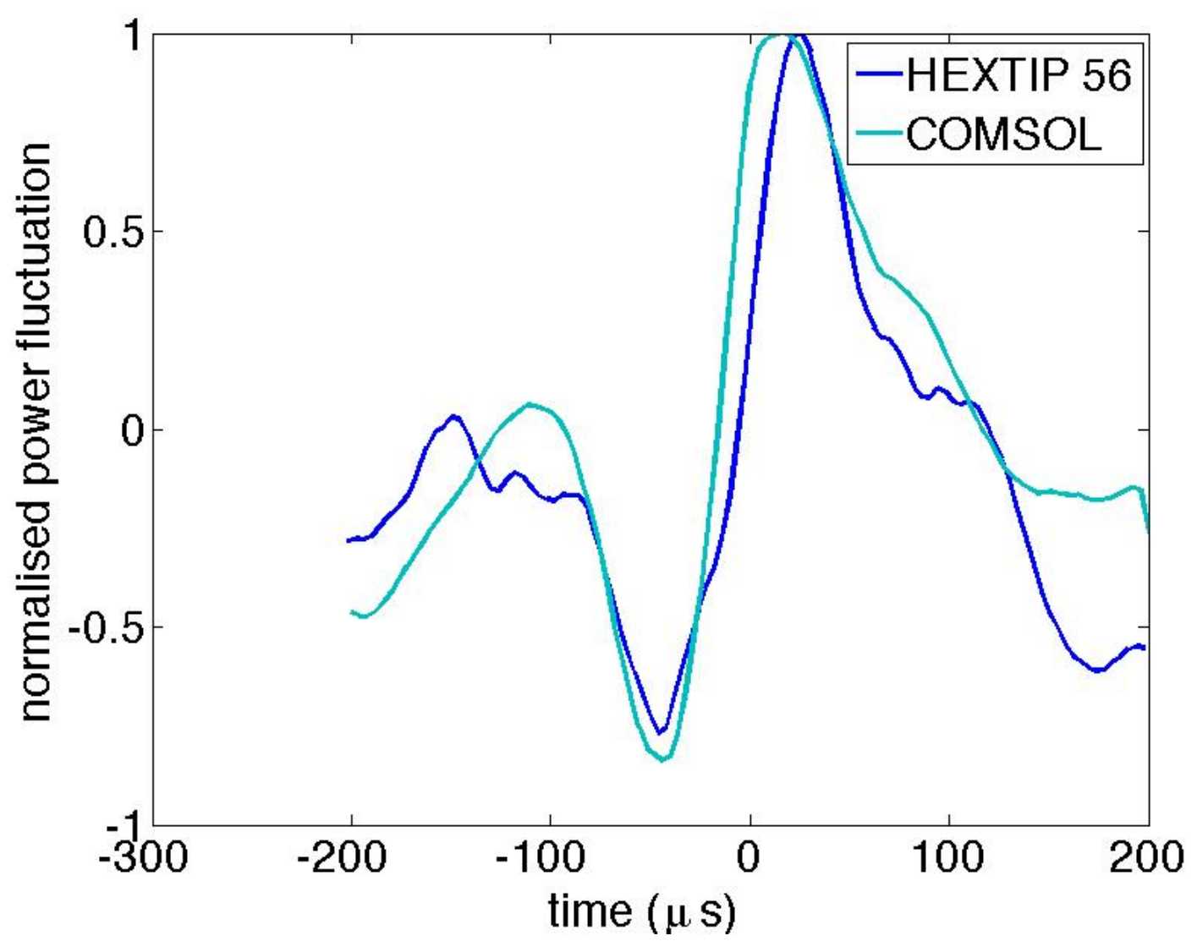


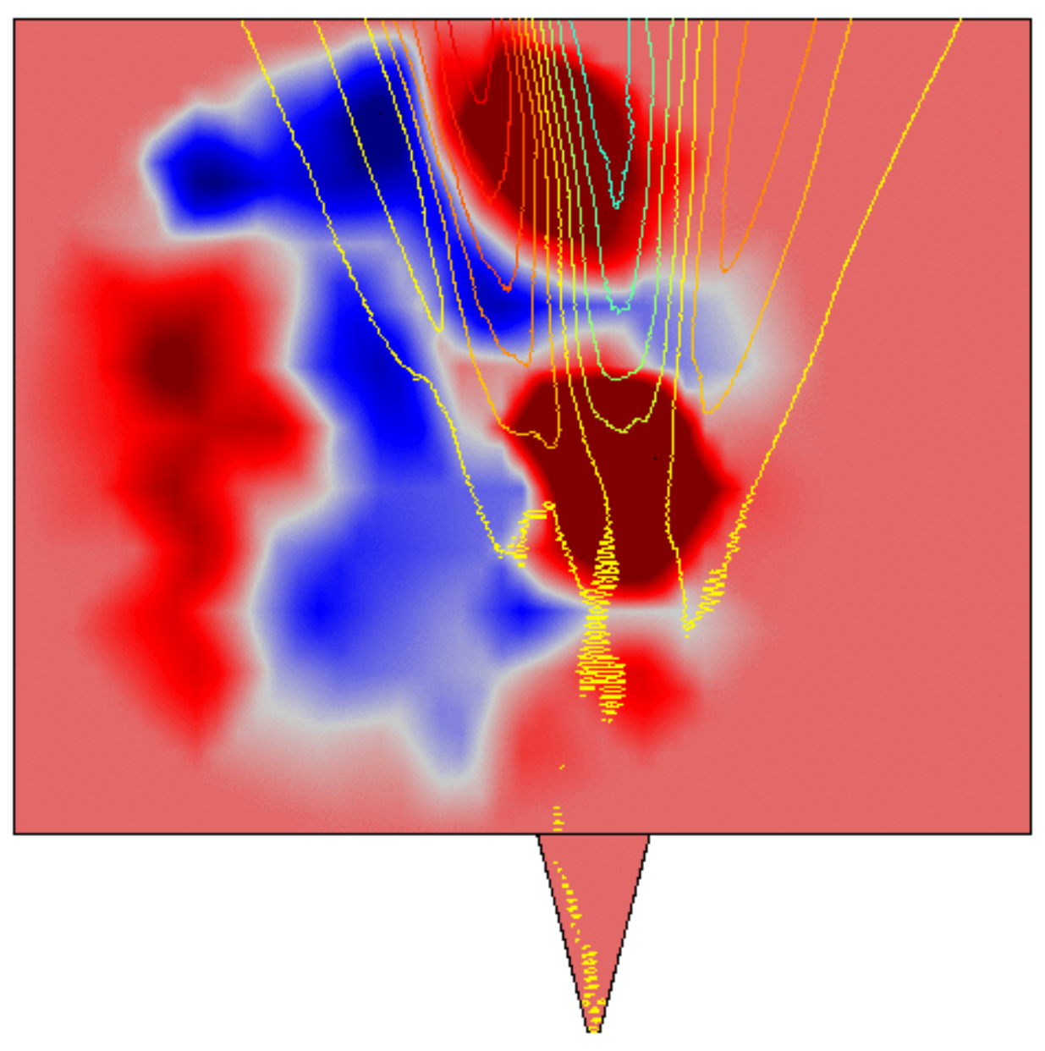


- The TORPEX open field line configuration features the presence of blobs similar to those observed in tokamaks [3].

- They are characterized by $\delta n/\overline{n}\sim100\%$, a size $a\sim$ 3-5 cm and a radial velocity $v\ \sim$ a few km/s

7.ON THE WAY TO BUILDING A PREDICTIVE TOOL





- Experimental electron density evolution is used to run simulations in COMSOL

- Promising results are obtained simulating free space propagation

8.OUTLOOK

- Implementing the TORPEX real 2D geometry and boundary conditions

- Simulating the propagation in the scrape-off layer using the electron density calculated by the GBS code to deduce the typical broadening of the mm-beam [4]
- Enlarging the calculation volume, and starting 3D simulations

- Using data and parameters from TCV (Tokamak à Configuration Variable) and comparing the simulations to those experimental results

REFERENCES

[1] A.Fasoli et al., *Nucl. Fusion* **55** (2015)
[2] T.R.N. Williams et al., *Plasma Phys. Controlled Fusion* **56** (2014)
[3] I. Furno et. al., *J. Plasma Physics* **81** (2015)
[4] P. Ricci et al., *Plasma Phys. Controlled Fusion* **54** (2012)
[5] C. Theiler et al., *Phys Plasmas* **15** (2008).
[6] A. K. Ram et al., *Phys. Plasmas.*, **20** (2013)

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