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Study of Very High-Order Volume Modes as Possible Alternatives to the TE34,19 Operating Mode of the KIT 2 MW 170 GHz Coaxial-Cavity Gyrotron

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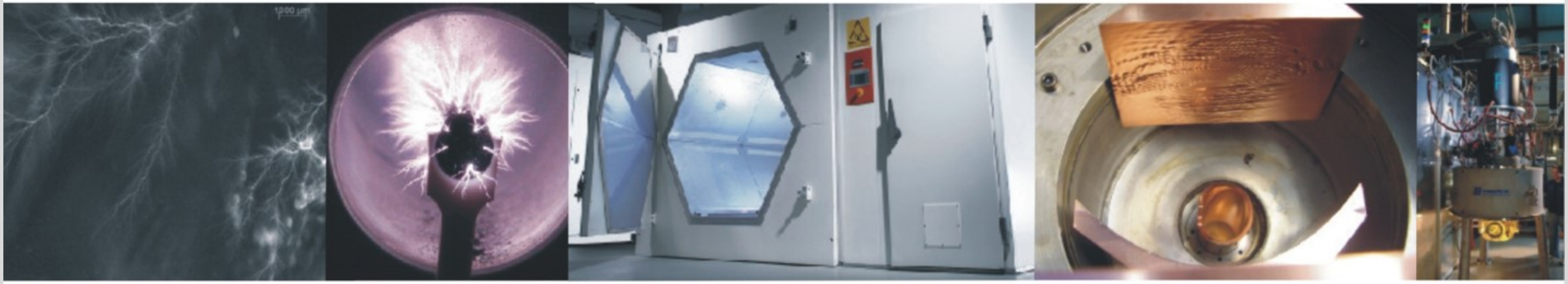


Outline

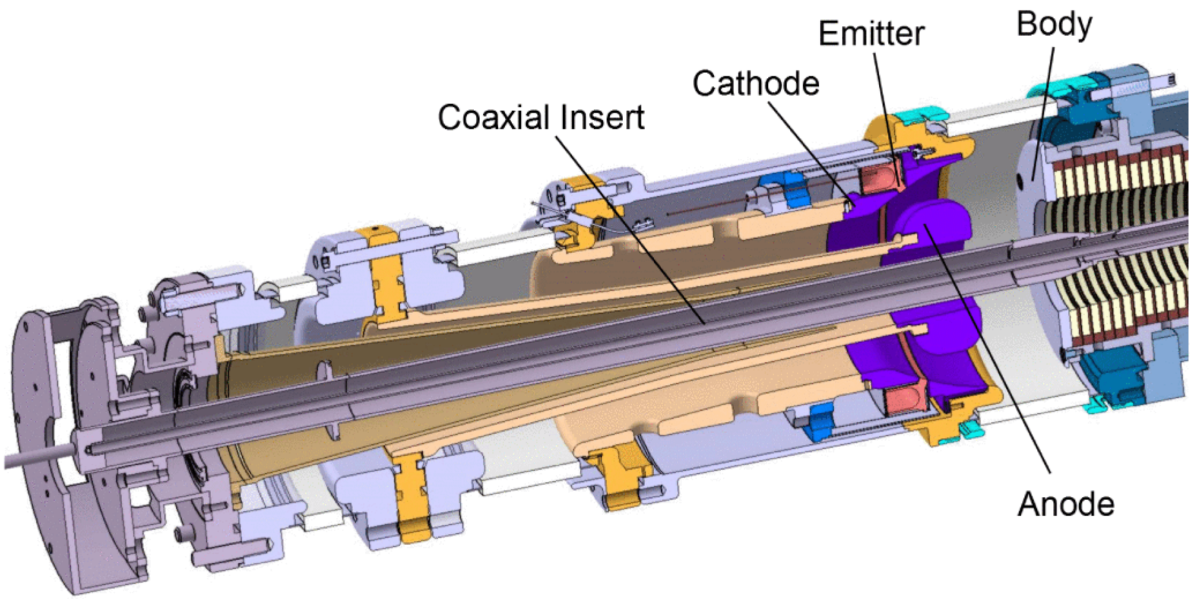
- Introduction
- State of the art: The $TE_{34,19}$ operating mode
  - Basic operational parameters
  - Startup simulation
- The $TE_{25,22}$ operating mode as possible alternative operating mode
  - Basic operational parameters
  - Startup simulation
  - Cavity geometry comparison
  - Thermal simulation of coaxial insert
  - $TE_{25,22}$ geometry at 204 GHz
- $TE_{25,22}$ mode: Conclusion

Motivation

The gyrotron design for the KIT 170 GHz 2 MW coaxial-cavity gyrotron, can be downsized by 25 %. Achieved by downsizing the IMIG.

→ **Decrease of warm bore of SC magnet and e-beam radius by 25 %**

→ **Significant decrease in overall gyrotron size and cost**



→ Find a high-order operating mode, which corresponds to this significantly smaller electron beam radius (R_{beam} = 7.4 mm)

Constraints in the Mode Selection

- Mode selection is directed by the two main constraints:

Thermal Constraints	Operational Constraints
- Coaxial insert (0.2 kW/cm^2) - Cavity walls (2.5 kW/cm^2)	- A mode with optimal **mode stability** and **efficiency** has to be selected. - Maximal beam current and acceleration voltage are determined by the limitations of the HV power supply

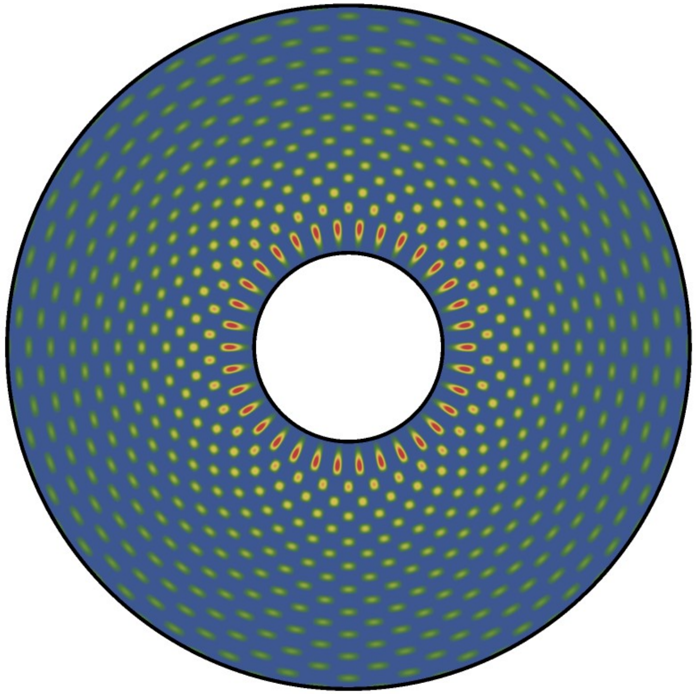
- The Eigenvalue (χ_c) of the selected mode should be close to the χ_c of the $TE_{34,19}$ operating mode, in order to achieve similar mode stability.
- The operating frequency is ≈ 170 GHz
- The coaxial cavity for this mode
  - has to be manufacturable, and
  - has to provide enough space for the cooling system.

→ $TE_{25,22}$ operating mode

TE$_{34,19}$ OPERATING MODE AS A REFERENCE OPERATING MODE

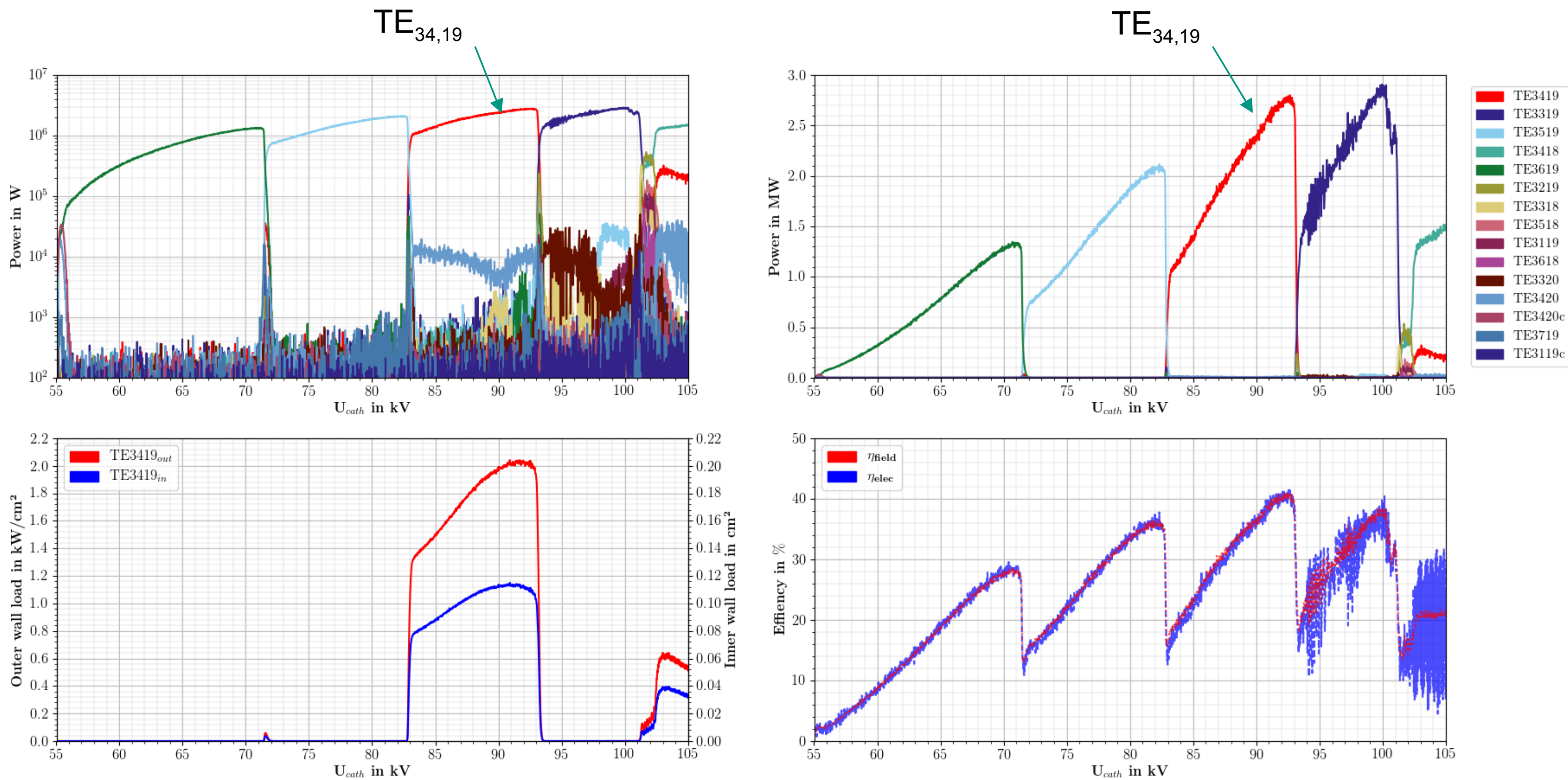
$TE_{34,19}$ Mode Overview

- **Input Parameters**
  - χ_c ≈ 105.19296
  - R_{beam} = 10 mm
  - R_{out} = 29.550 mm
  - R_{in} = 8.0 mm
  - U_{cath} = 90.0 kV
  - I_{beam} = 75 A
- **Simulation Results**
  - P_o = 2.5 MW
  - ρ_{out} = 2.0 kW/cm²
  - ρ_{in} = 0.12 kW/cm²
  - η_{elec} = 37 %



$\mathbf{H}_z$ of the $TE_{34,19}$ operating mode (non-rotating)

Reference Simulation ($TE_{34,19}$ Operating Mode)

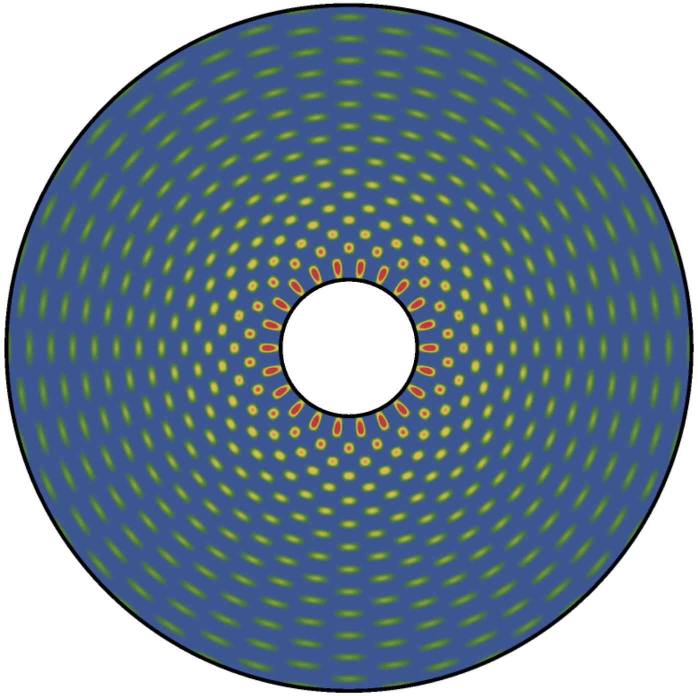


$TE_{34,19}$ has an output power of 2.5 MW at 90 kV. The mode is lost at 93 kV. Electron and field efficiency coincide. η_{elec} = 37 % at 90 kV. Field and electron efficiency coincide.

THE NEW $TE_{25,22}$ OPERATING MODE

$TE_{25,22}$ Mode Overview

- **New Input Parameters**
  - χ_c ≈ 102.44572
  - R_{beam} = **7.4** mm
  - R_{out} = 28.90 mm
  - R_{in} = 5.65 mm
  - U_{cath} = 90.0 kV
  - I_{beam} = 75 A

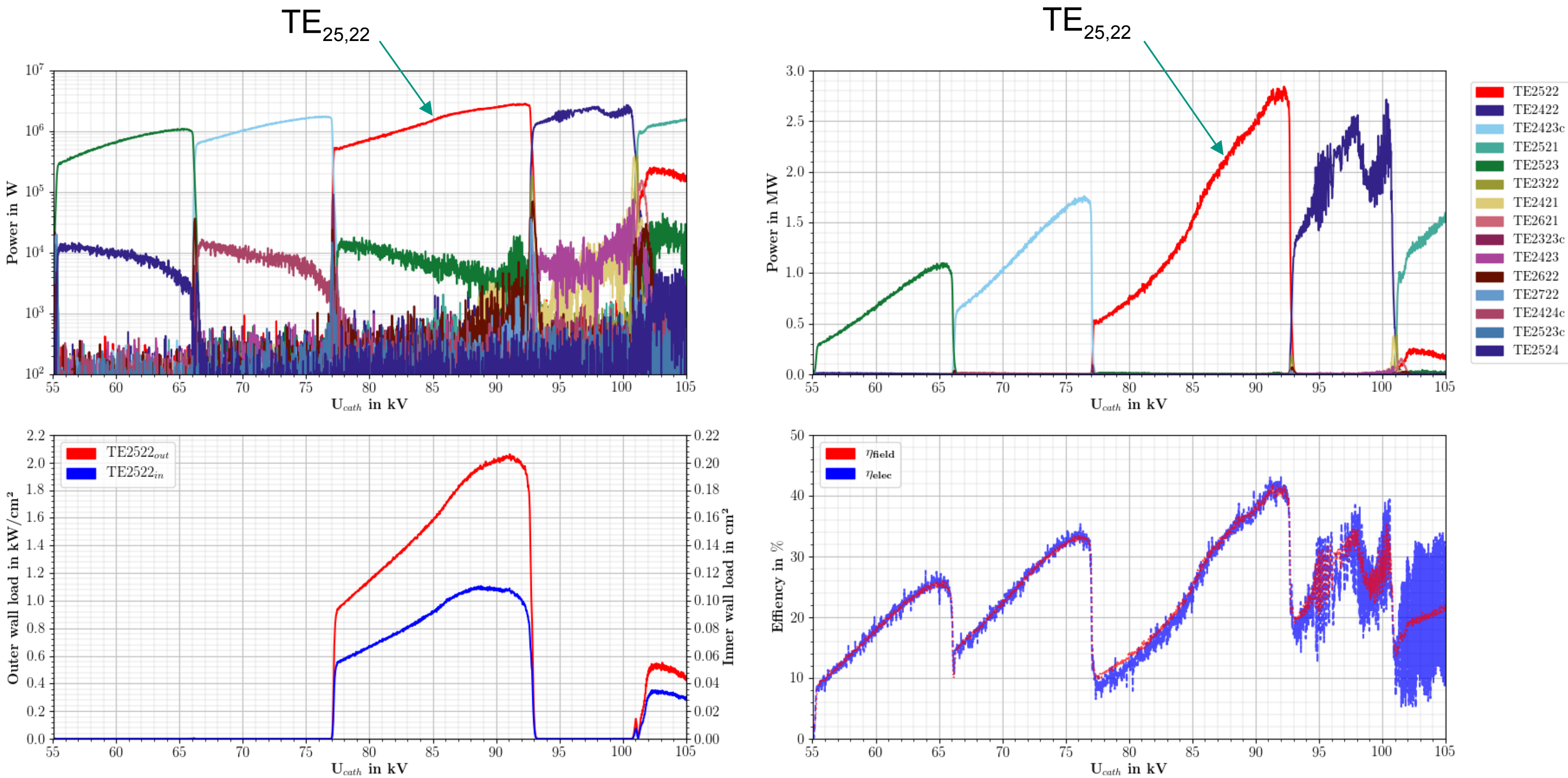


H_z of the $TE_{25,22}$ operating mode

- **Simulation Results**
  - P_o = 2.5 MW
  - ρ_{out} = 2.0 kW/cm^2
  - ρ_{in} = 0.11 kW/cm^2
  - η_{elec} = 37 %

The $TE_{25,22}$ mode can be operated with the reduced beam radius. Simulation shows outputs parameters close to the $TE_{34,19}$ mode

Simulation ($TE_{25,22}$ Operating Mode)

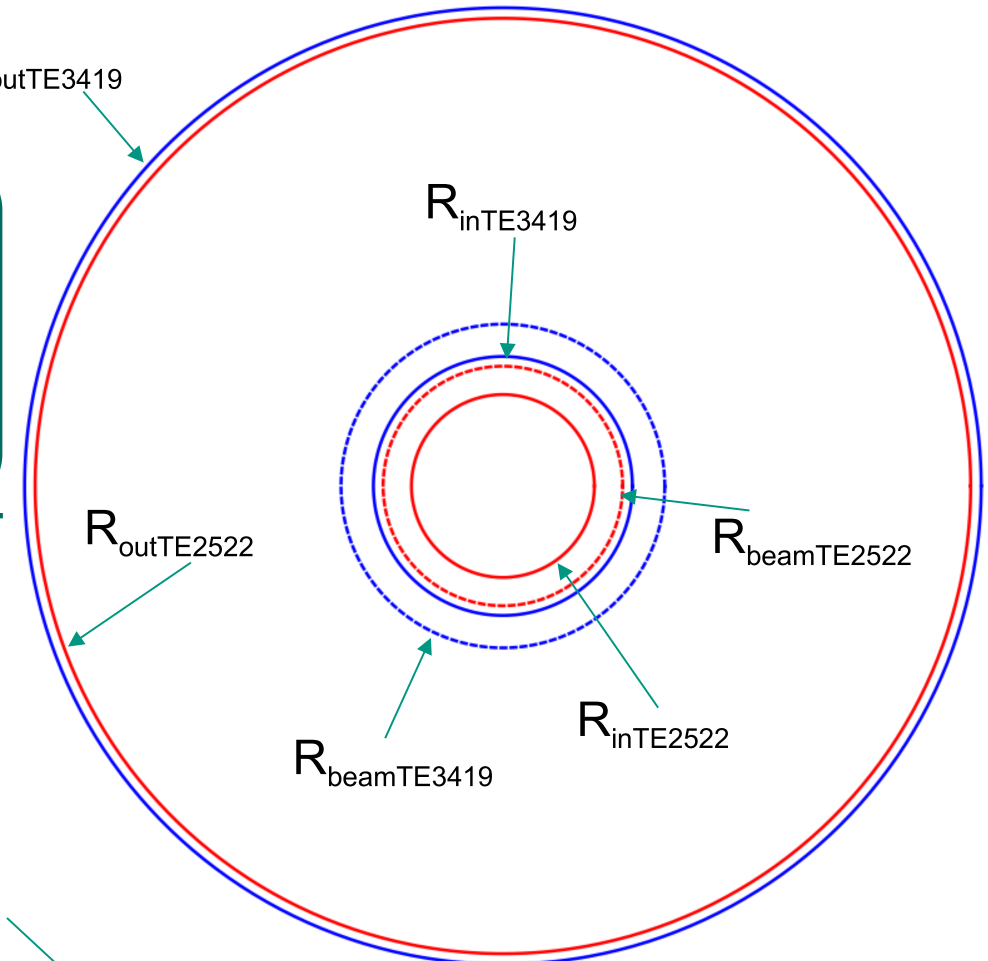


$TE_{25,22}$ shows a stable startup with an output power of 2.5 MW. Mode is lost at 93 kV. η_{elec} = 37 % at 90 kV. Field and electron efficiency coincide!

CAVITY GEOMETRIES OF THE MODES $TE_{34,19}$ AND $TE_{25,22}$

Comparison of the Cavity Cross Section for the Modes $TE_{34,19}$ and $TE_{25,22}$

$TE_{34,19}$ and $TE_{25,22}$ modes have similar outer cavity radii, but the insert radius of $TE_{25,22}$ is much smaller compared to that of $TE_{34,19}$.



[mm]	TE34,19	TE25,22
R_{out}	29.55	28.9
R_{in}	8.0	5.65
R_{beam}	10.0	7.4

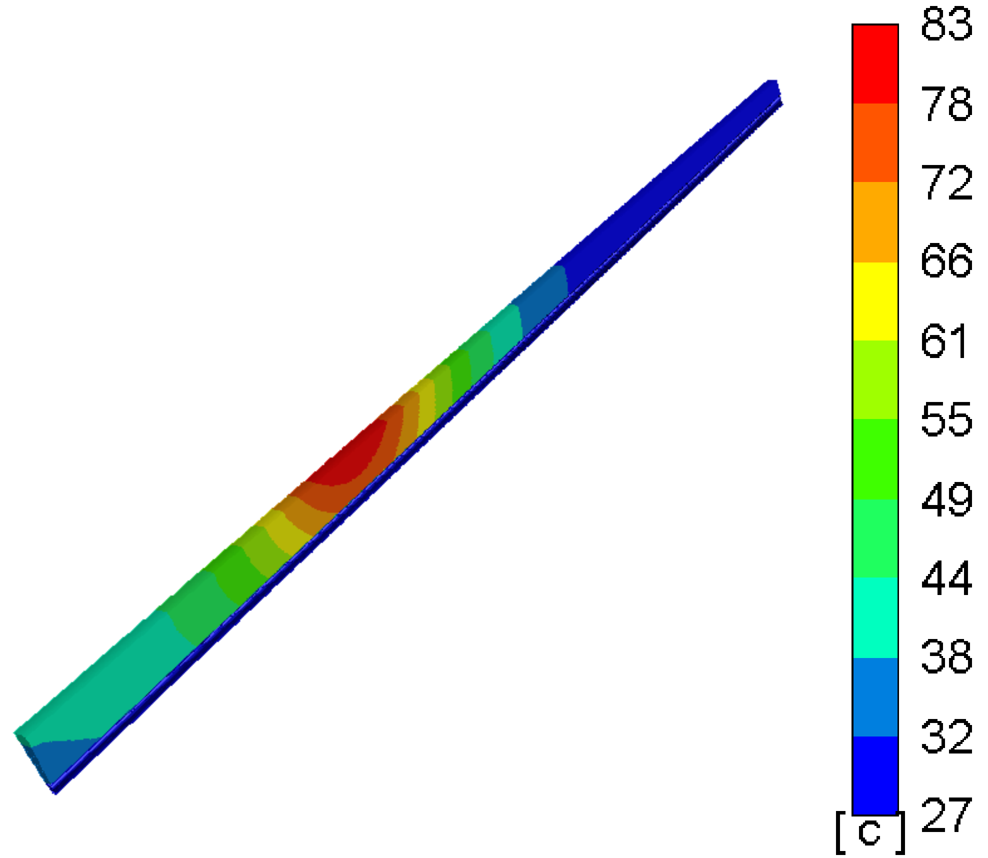
Is the insert cooling possible?

THERMAL SIMULATION OF THE INSERT FOR THE $TE_{25,22}$ OPERATING MODE

Thermal Load on the Coaxial Insert ($TE_{25,22}$)

Simulation of the coaxial insert using „*Ansys fluent V 18.1 – Thermal-Hydraulic simulation*" shows no critical temperature on the insert.

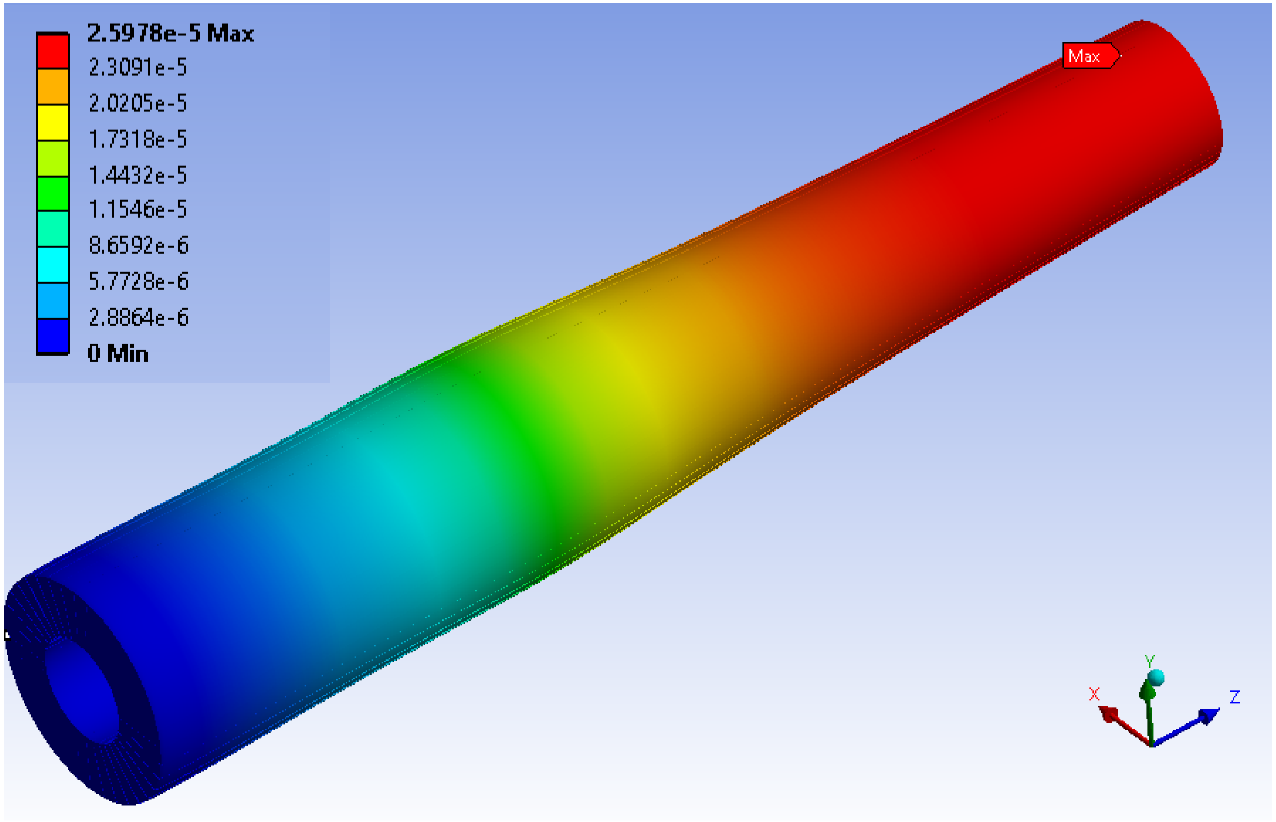
Simulation parameters	
Water velocity	5.89 m/s
Mass-flow rate	4.37 L/min



Temperatur profile along the coaxial insert

Thermal Deformation of the Coaxial Insert ($TE_{25,22}$)

Simulation of the coaxial insert using „Ansys mechanical - static-structural simulation" yields a maximum deformation of **2.6 µm**, which is negligible.



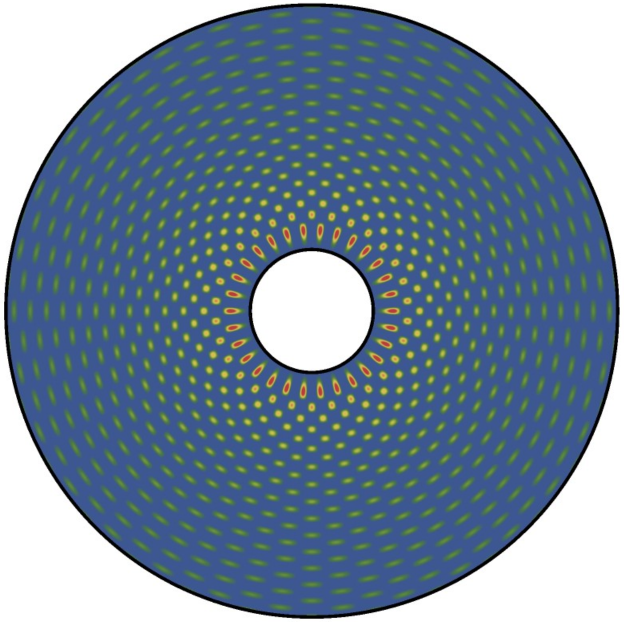
Deformation of the coaxial insert

OPERATION OF $TE_{25,22}$ MODE CAVITY (170 GHZ) AT 204 GHZ → $TE_{30,26}$ OPERATING MODE

$TE_{30,26}$ Mode Overview

- **Input Parameters**
  - χ_c ≈ 122.76158
  - R_{beam} = 7.42 mm
  - R_{out} = 28.90 mm
  - R_{in} = 5.65 mm
  - U_{cath} = 83.0 kV
  - I_{beam} = 70 A

- **Simulation Results**
  - P_o = 1.8 MW
  - ρ_{out} = 2.2 kW/cm^2
  - ρ_{in} = 0.02 kW/cm^2
  - η_{elec} = 36 %

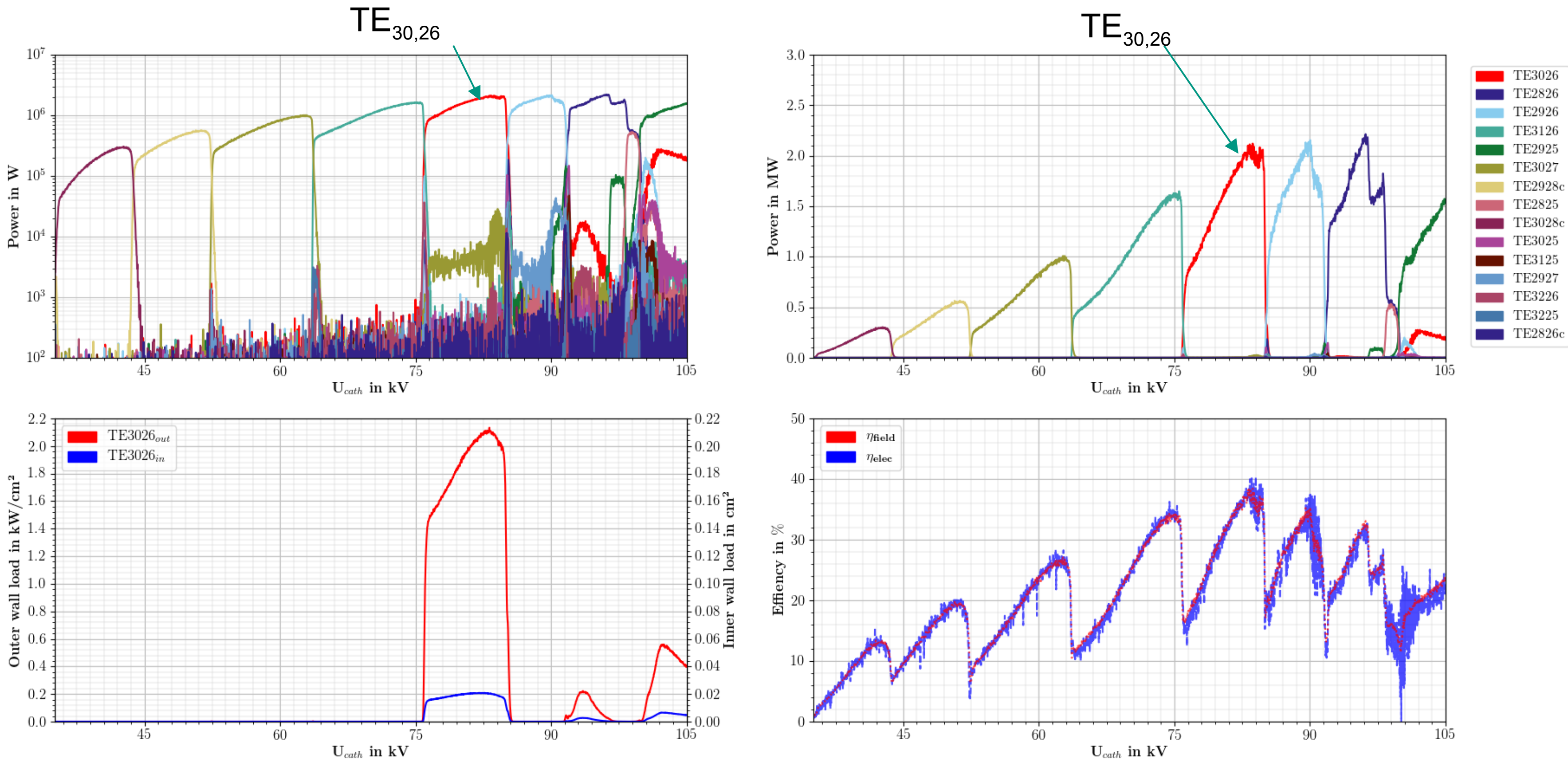


$\mathbf{H}_z$ of the $TE_{30,26}$ operating mode

$TE_{30,26}$ mode at 204 GHz corresponds to the $TE_{25,22}$ mode at 170 GHz.

Simulation ($TE_{30,26}$ Operating Mode)

Karlsruhe Institute of Technology



$TE_{30,26}$ mode shows good performance, but has stability problems due to mode competition with the mode $TE_{30,27}$. Mode is lost at 85 kV.

SUMMARY

Summary: $TE_{25,22}$ mode versus $TE_{34,19}$ mode

- **Advantages of the $TE_{25,22}$ Operating Mode**
  - Generates a high output power of **2.5 MW**

    ➔ even higher output powers are possible (2.8 MW)
  - Cooling of the the cavity is unproblematic
  - An operation of the cavity at 204 GHz is possible
  - Reduction of warm SC magnet bore hole by 25%
    ➔ **Significant cost reduction for the magnet (at least 25 %)**

- **Future Tasks**
  - Sensitivity of the coaxial insert to mechanical vibrations, caused by the cooling liquid has to be checked
  - Key components like uptaper and launcher have to be designed

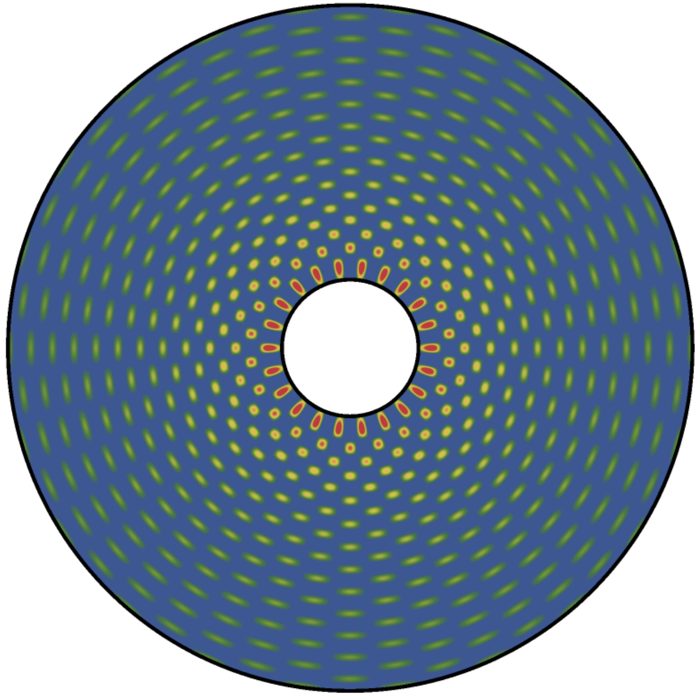
Thank you for your attention

Please ask questions!

$TE_{25,22}$ Overview

- **Input parameters**
  - χ_c ≈ 102.44572
  - R_{beam} = 7.4 mm
  - R_{out} = 28.90 mm
  - R_{in} = 5.65 mm
  - U_{cath} = 90.0 kV
  - I_{beam} = 85 A

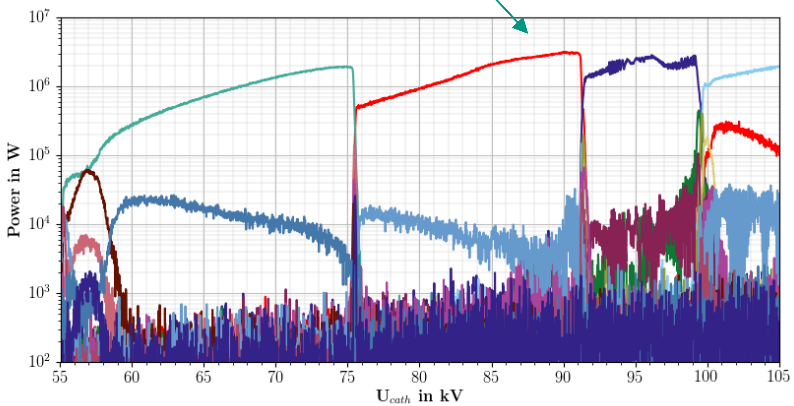
- **Results**
  - P_o = 2.8 MW (*2.5*)
  - ρ_{out} = 2.2 kW/cm² (*2.0*)
  - ρ_{in} = 1.4 kW/cm² (*0.12*)
  - η_{elec} = 38 % (*37*)



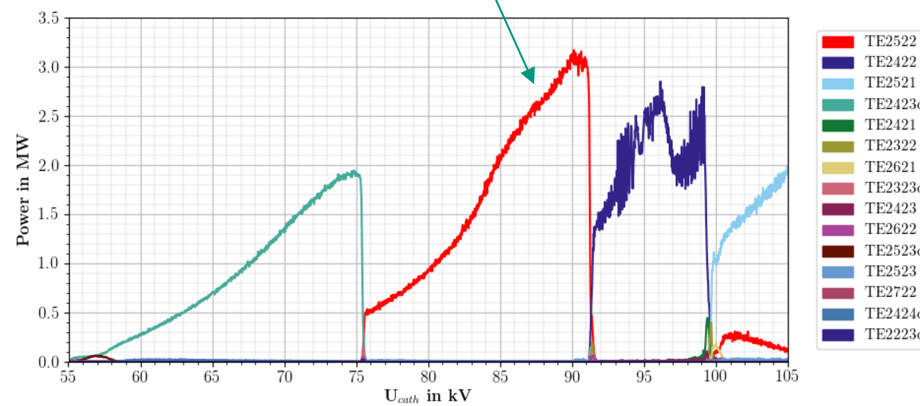
$\mathbf{H}_z$ of the $TE_{25,22}$ operating mode

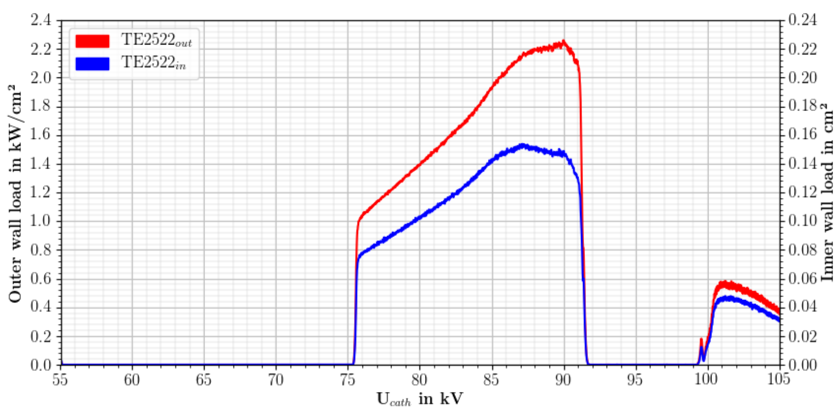
Simulation ($TE_{25,22}$ Operating Mode) I_{beam} = 85 A

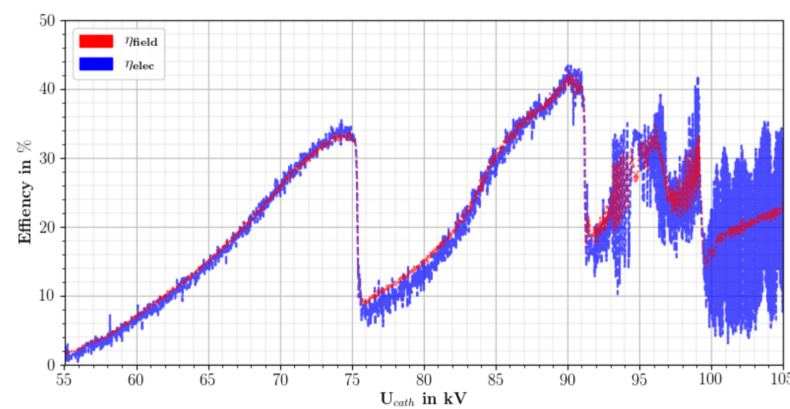
$TE_{25,22}$



$TE_{25,22}$







$TE_{25,22}$ is able to produce **2.8 MW** output power with a beam current of **85 A**. Mode stability is not affected and thermal loads are well bellow the limits and can be cooled.