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An Advanced Highly Automated Test System for the Verification of Quasi-Optical Gyrotron Components

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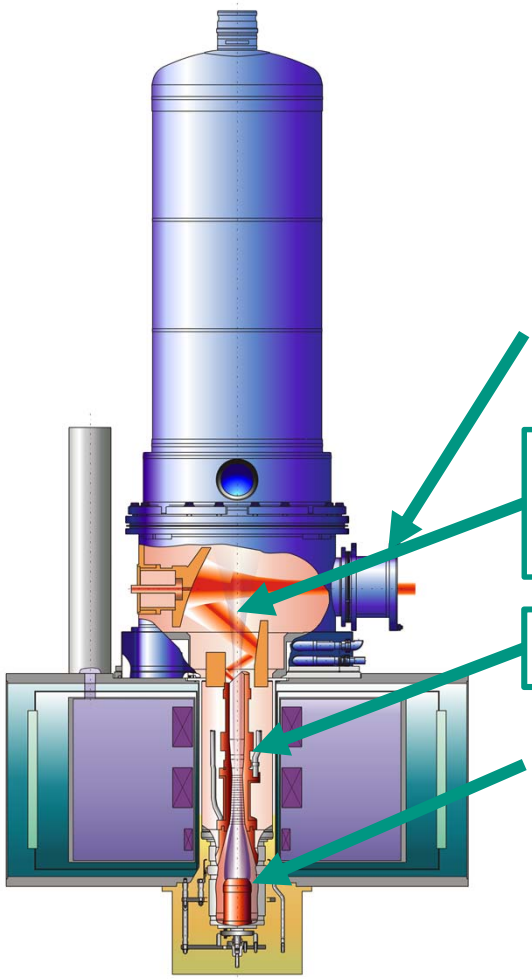
Gyrotron Components

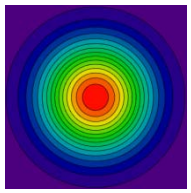


Output window

Quasi-optical mode converter

Cavity

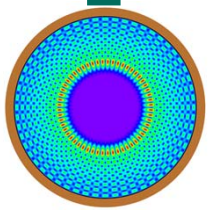
Electron gun



Gaussian mode

Mirror system

Launcher



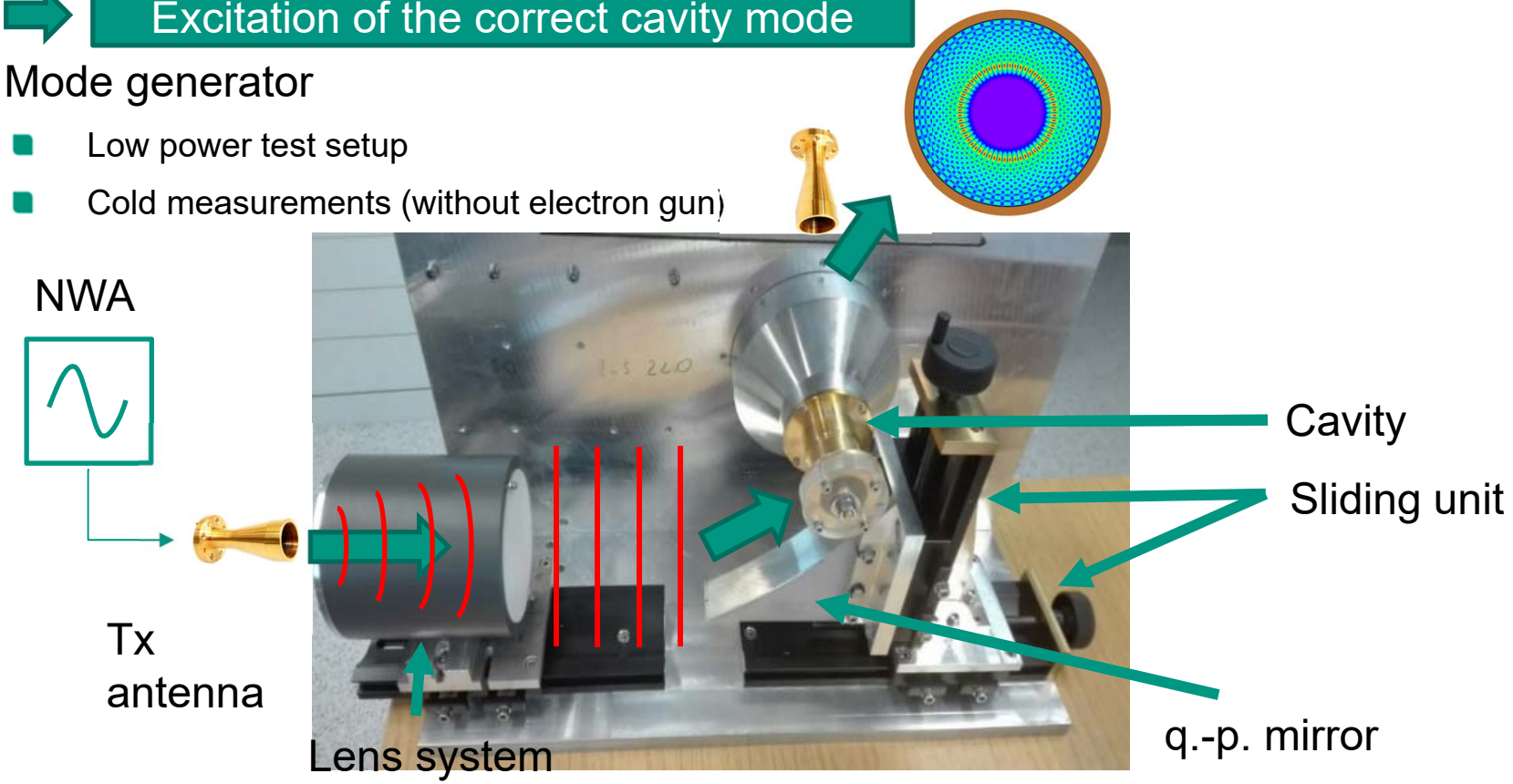
Cavity mode $TE_{28,8}$

Verification of Quasi-Optical Components

- Launcher and mirror system has to be tested
  - Check fabrication tolerances (launcher & mirror system)
  - Check the alignment of the Gaussian beam at the window plane

➡ Excitation of the correct cavity mode

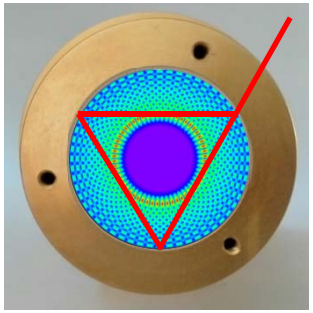
- Mode generator
  - Low power test setup
  - Cold measurements (without electron gun)

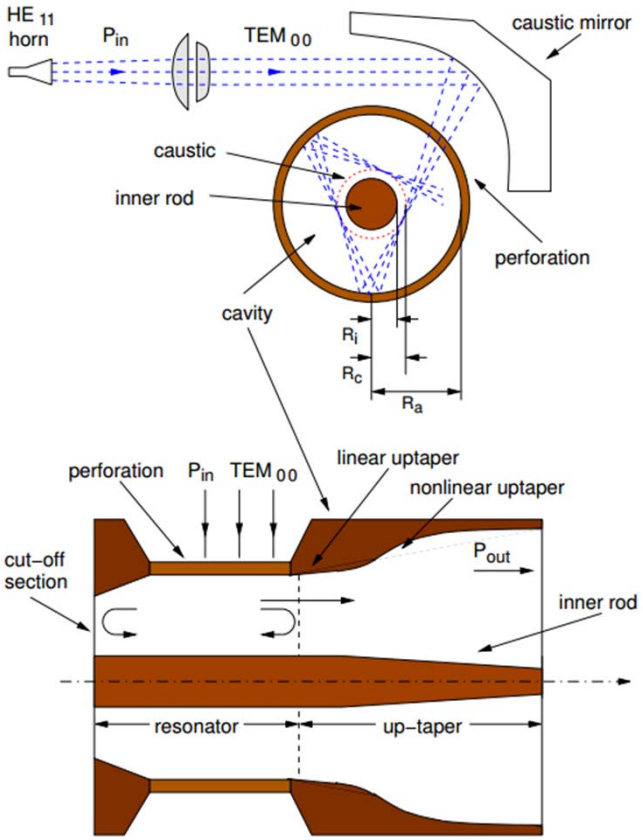


Mode Generator - Cavity

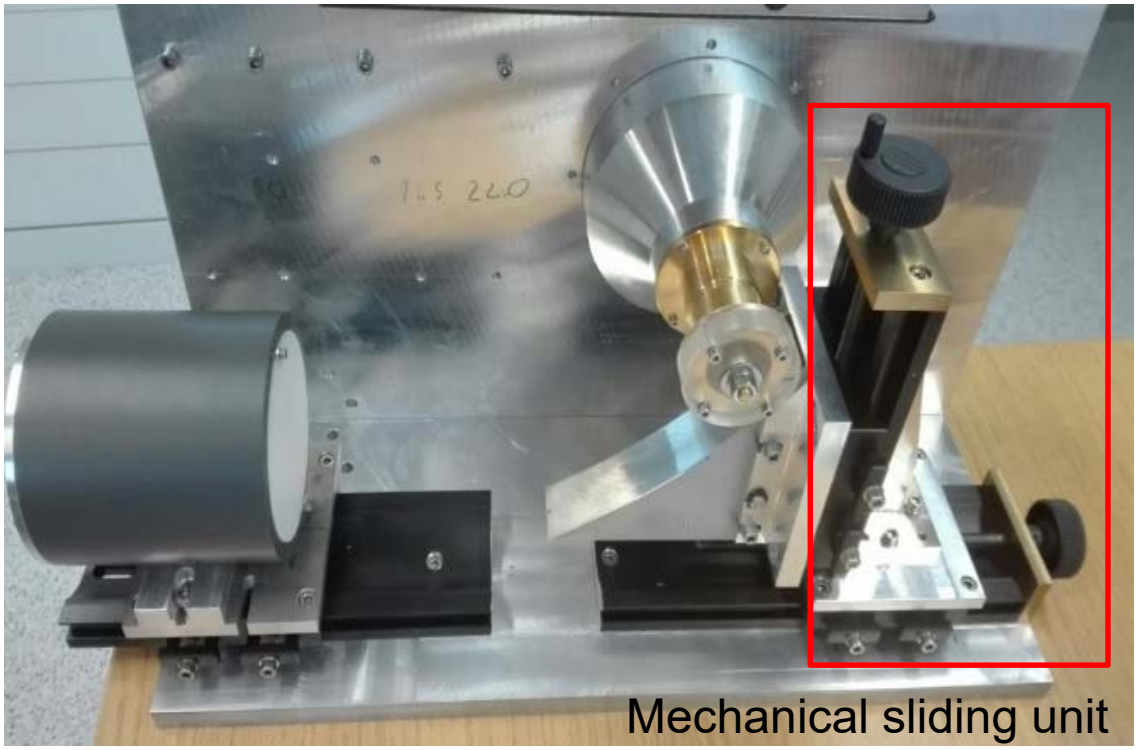
- Insert improves mode selection
- Perforated wall → leads to increase of the effective cavity radius
- Q.-p. mirror focus the rays on caustic of the mode

Excitation of the rotating mode





Aim of the Work


Mechanical sliding unit

Issues:

- Several degrees of freedom → hard to handle
- Hysteresis → not repeatable
- Human attendance

Conclusion

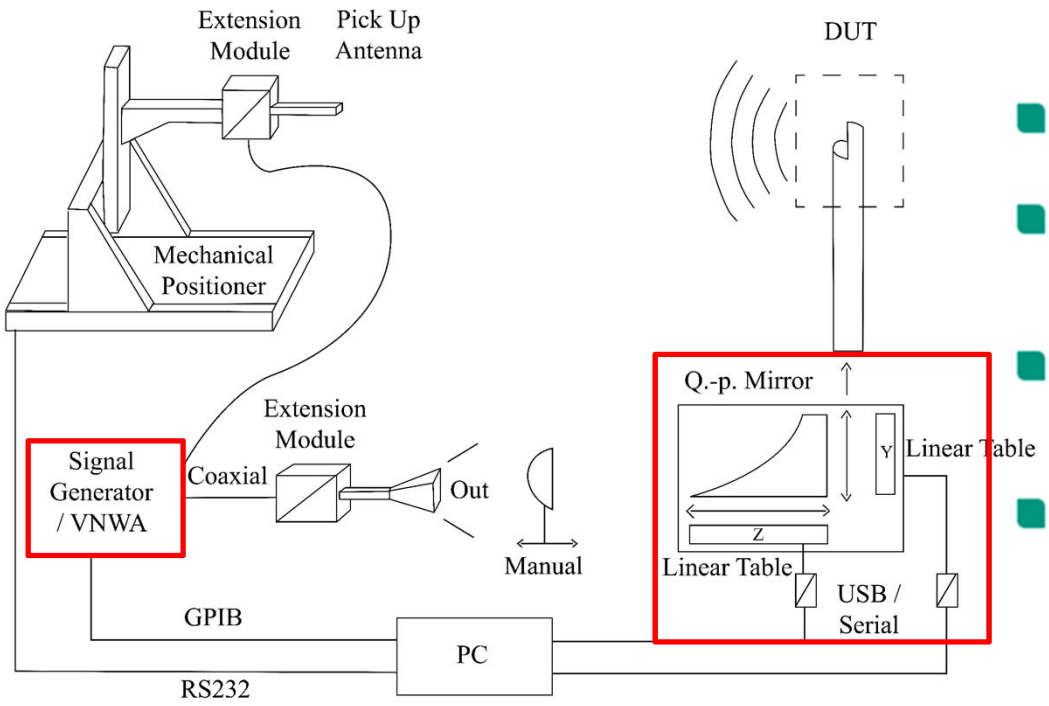
Long machine set-up time

Problematic for frequencies above 200 GHz

Goals

- Simulation tool for starting point
- Improve tolerance critical components (test setup)
- New advanced and time saving test sequence (automation)

New Automatic Measurement Setup



- New NWA for higher accuracies
- Frequency range from 140 – 330 GHz
- Stepper motors for precise adjustment and control via PC
- Computer-based evaluation of the measurement data (intelligence)

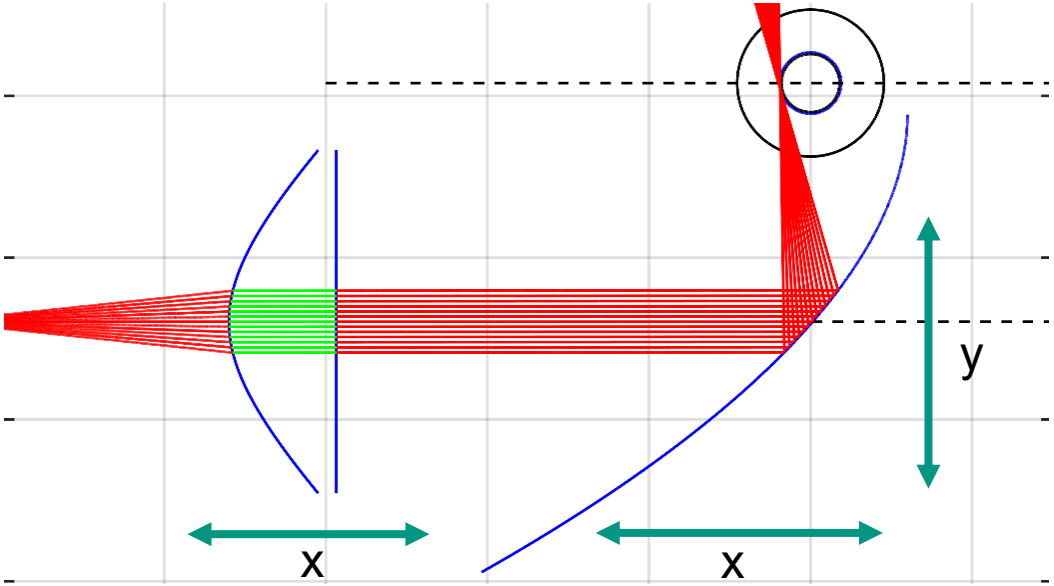
Procedure to find the correct Mode

Simulation Tool

Goal → Determination of the starting point

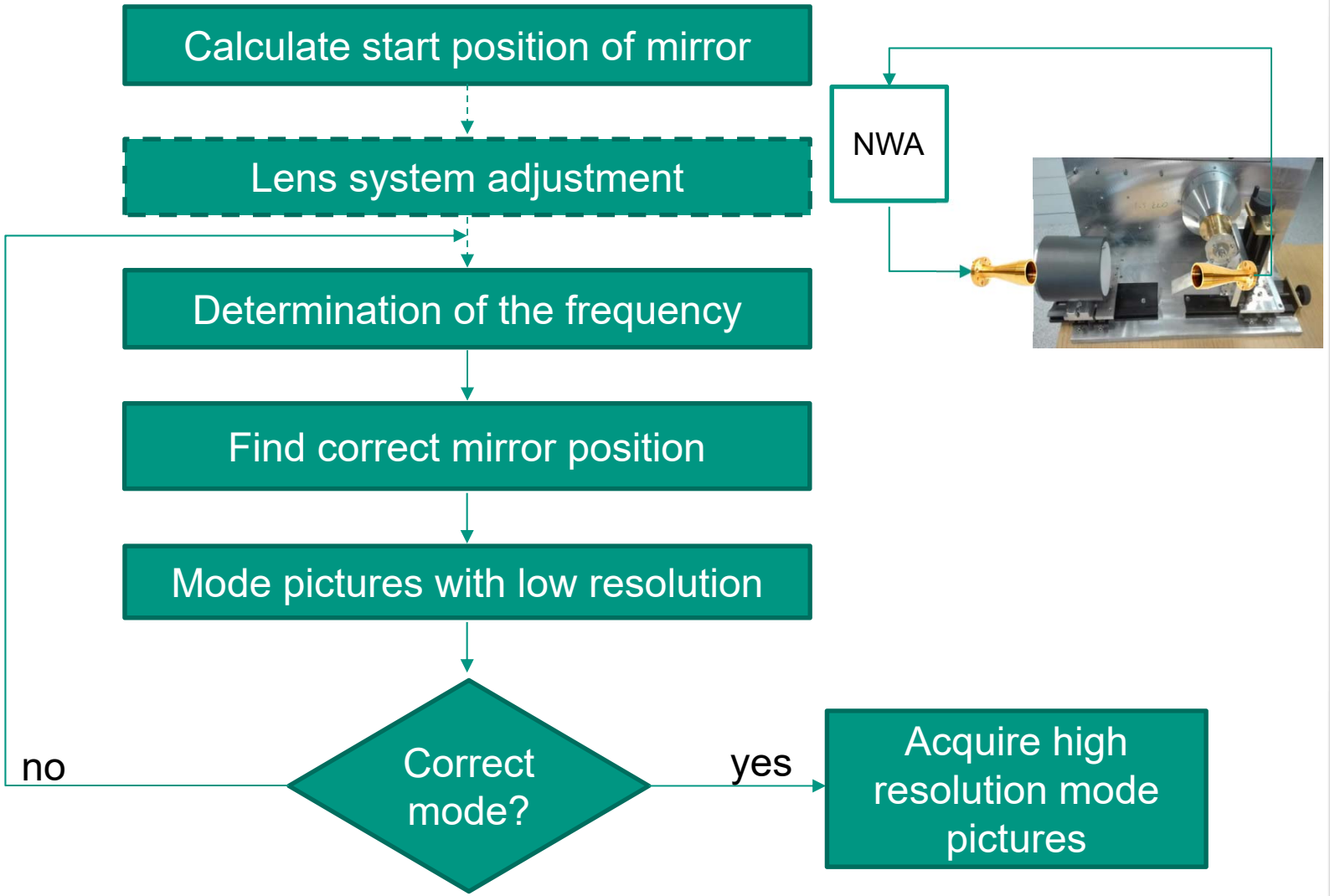
Implementation

- First step assumption: geometrical optics
- Snell‘s law
- 2-D implementation in MATLAB
- Components can be moved and rotated



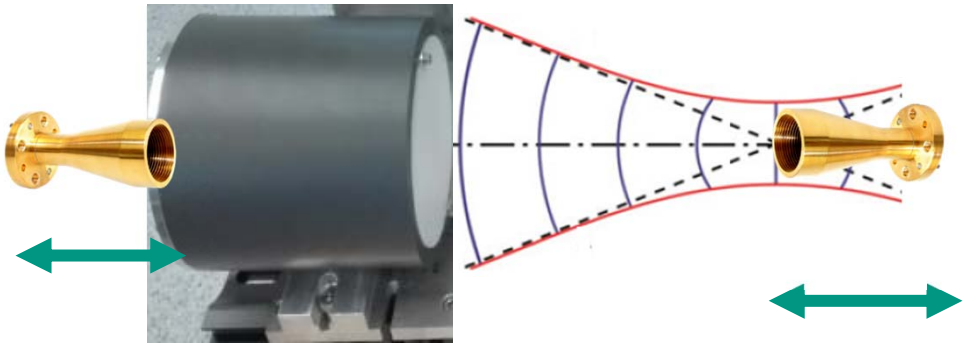
→ In progress: Gaussian optics

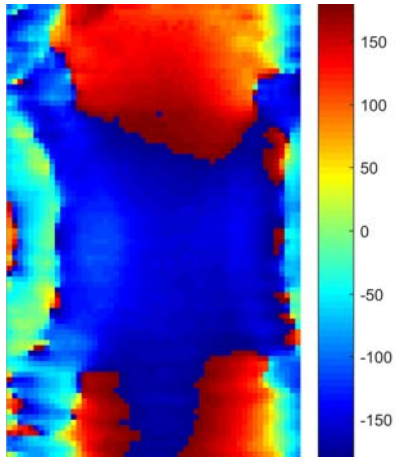
Procedure to find the correct Mode



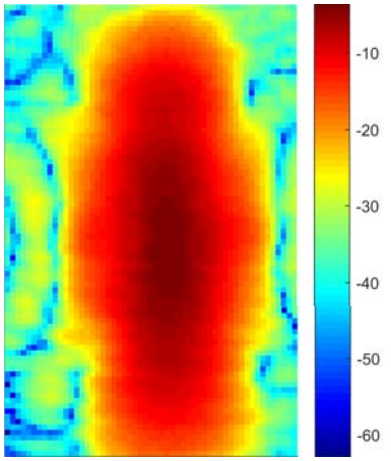
Adjustment of the Lens System

- Find correct distance between
  - Antenna and lens system
  - Lens system and mirror





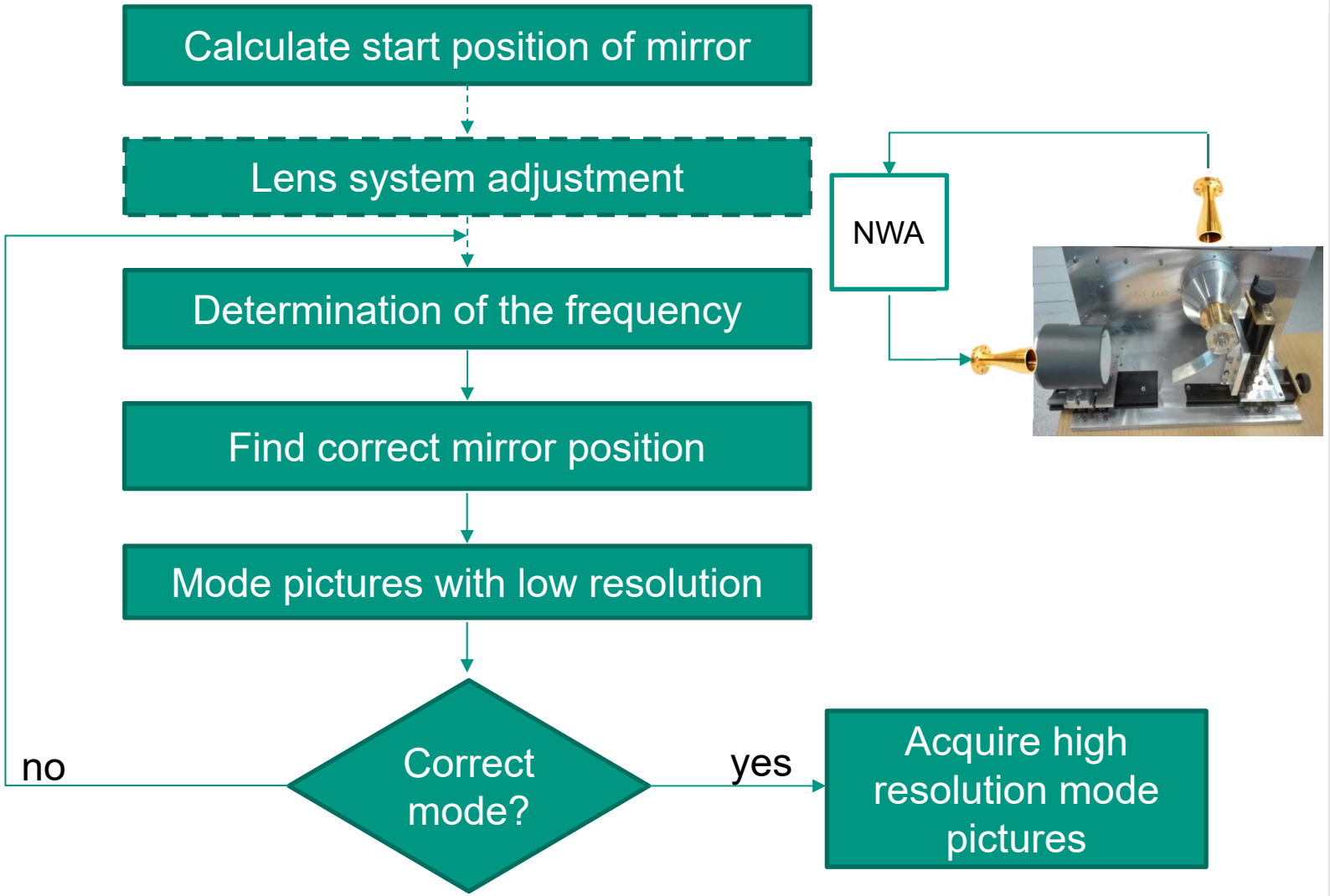
Phase / deg.



Amplitude / dB

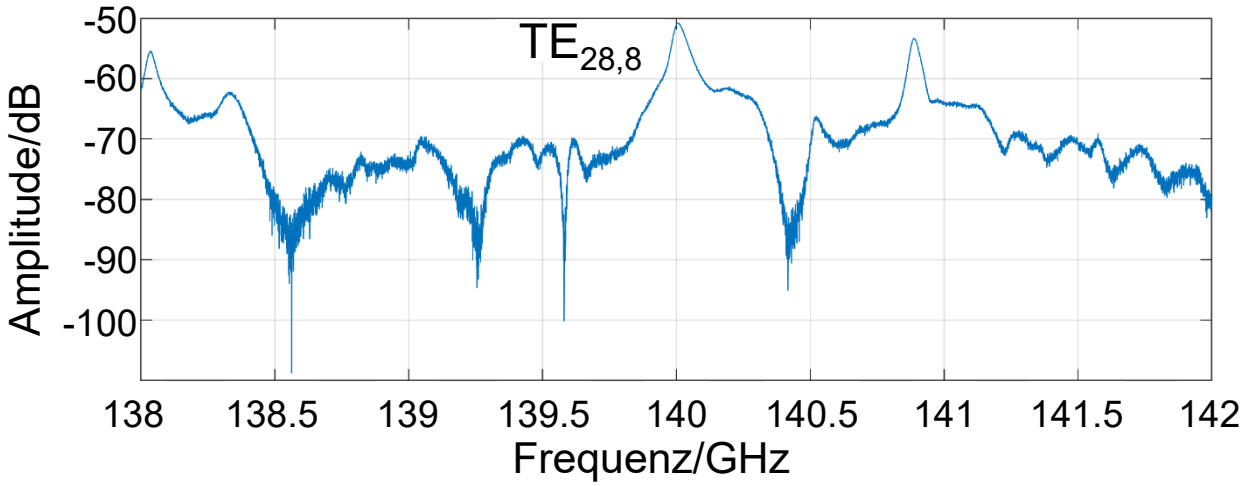
Procedure → Variation of the distance between lens and Rx antenna → Perfect distance: plane wave in the center

Procedure to find the correct Mode



Frequency Spectrum

Mode generator

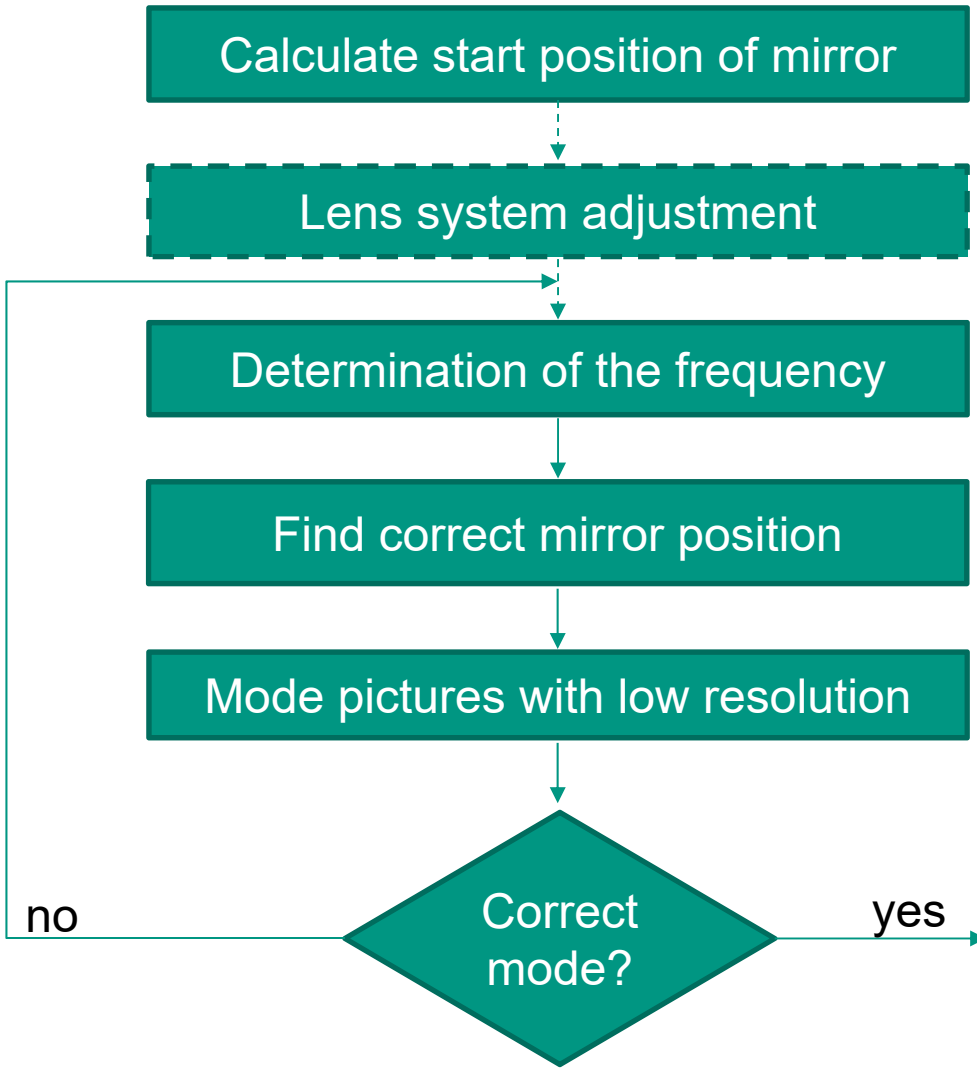


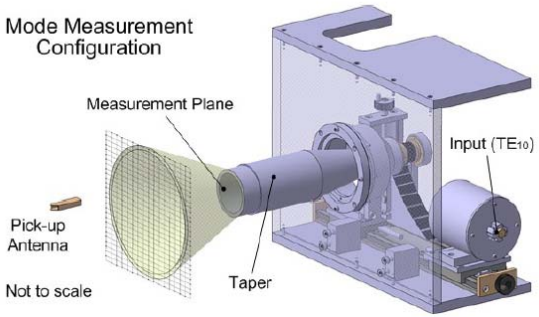
- Rx-Antenna is positioned on caustic radius
- Measured frequency band from 138 GHz to 142 GHz

- Measured frequency 140.006 GHz
- Determined quality factor Q = 2548 (Design 2533)

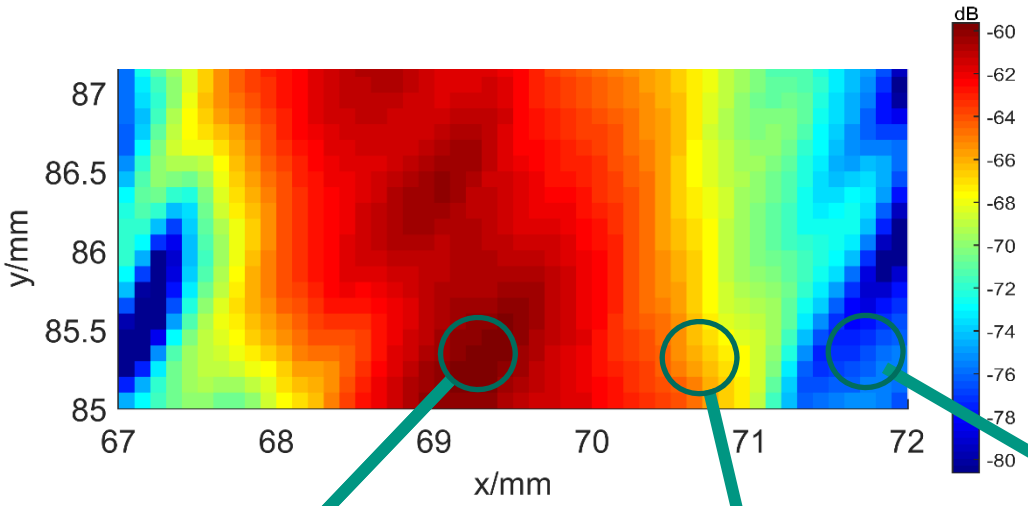
$$Q = \frac{f_{res}}{B_{3dB}}$$

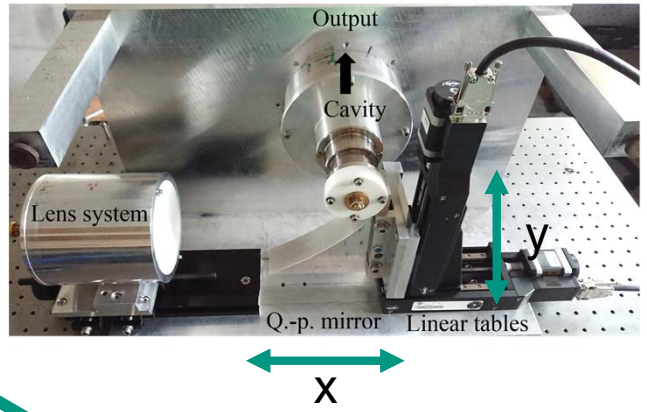
Procedure to find the correct Mode

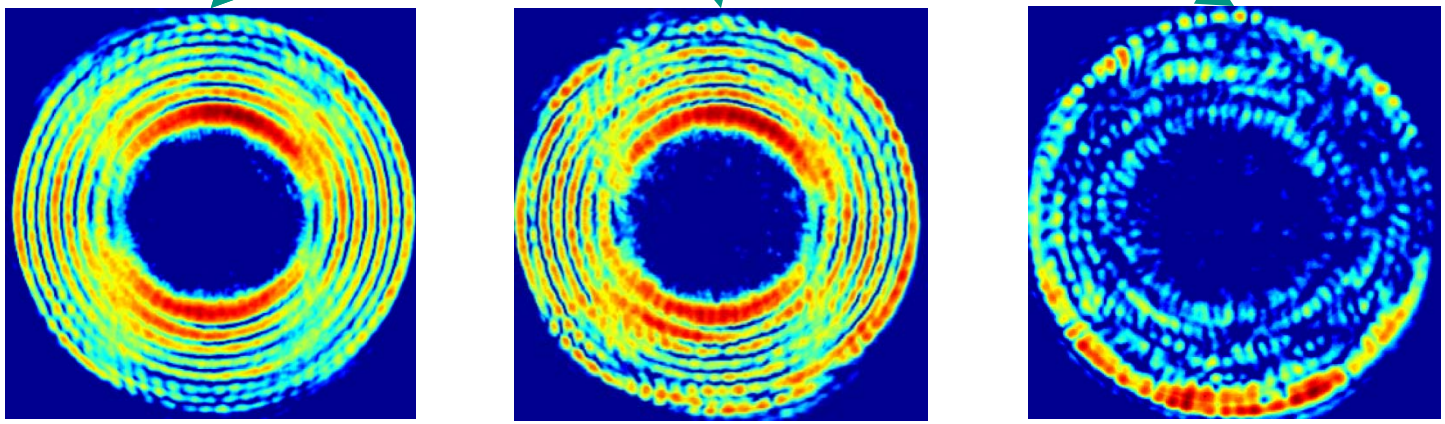




Field Measurements for different Mirror Positions

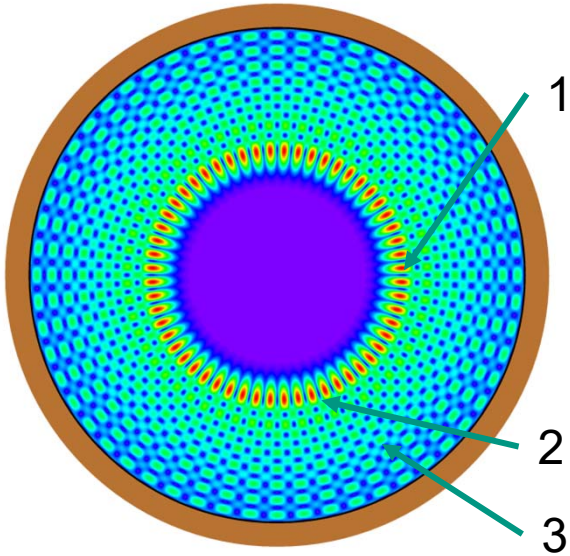




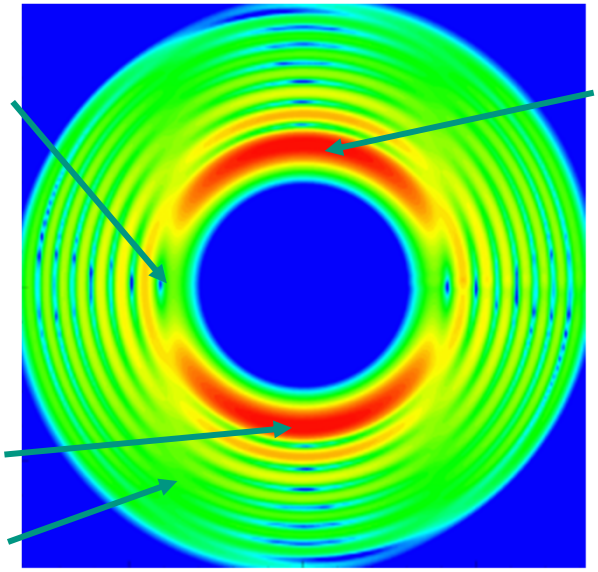


Comparison of Measurement and Simulation

Simulated $TE_{28,8}$-mode



Simulation and measurement of the $TE_{28,8}$-mode concerning the measurement setup



1: measurement is limited to one polarization

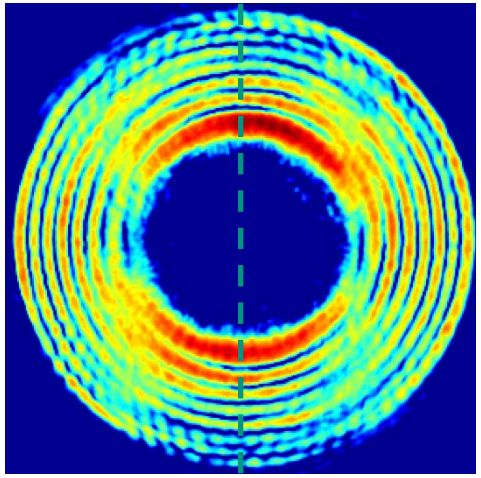
$$E_y = E_r \cdot \sin\varphi + E_\varphi \cdot \cos\varphi$$

2: excitation of a rotating mode

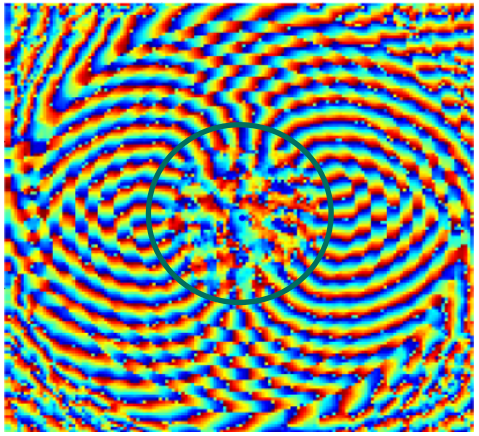
3: blurred area (both components are measured)

4: nodes → not symmetric excitation of the mode

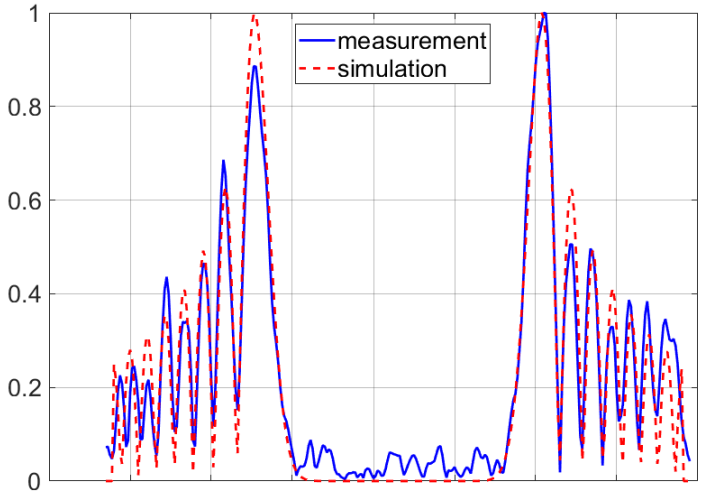
Evaluation Techniques I ($TE_{28,8}$ mode)

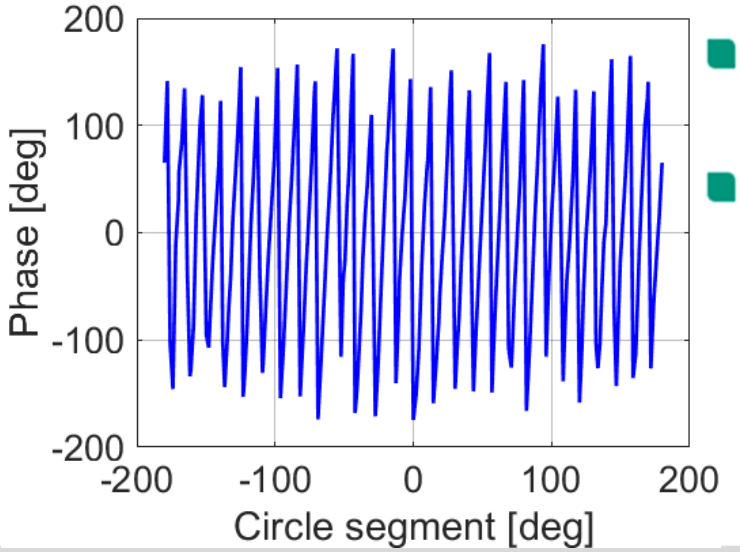


Amplitude



Phase



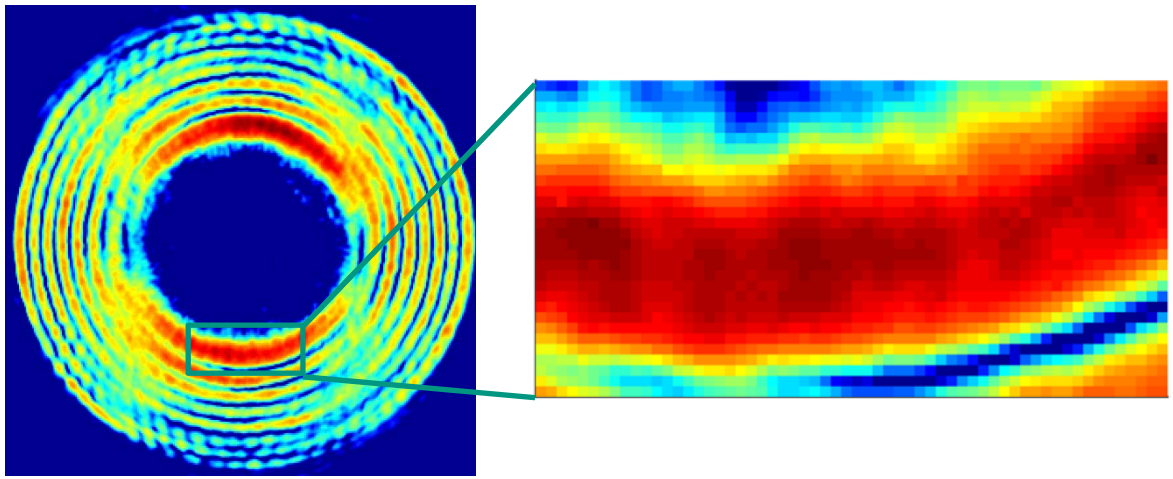


- Determine radial index
- Scalar mode content: 94.5 %
- Very good agreement

- Determine azimuthal index
- m-1 peaks can be counted

Evaluation Techniques II ($TE_{28,8}$ mode)

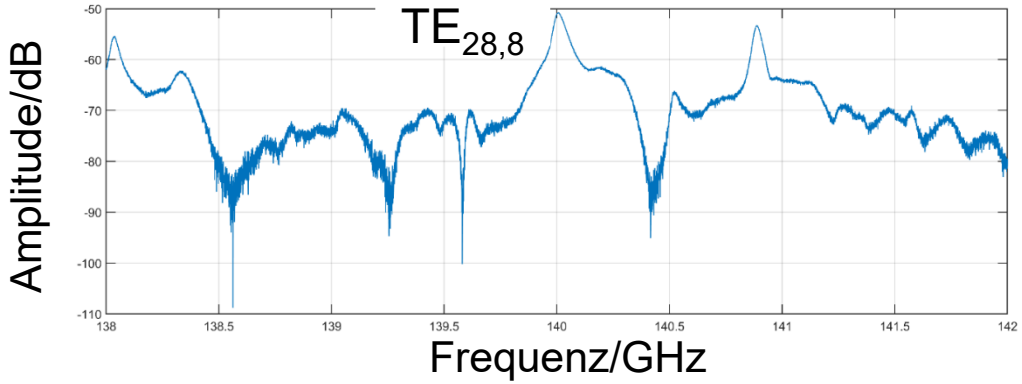
- Counter-rotating amount



$$\frac{P_-}{P_+} = \left(\frac{1 - \sqrt{\frac{P_{\min}}{P_{\max}}}}{1 + \sqrt{\frac{P_{\min}}{P_{\max}}}} \right)^2$$

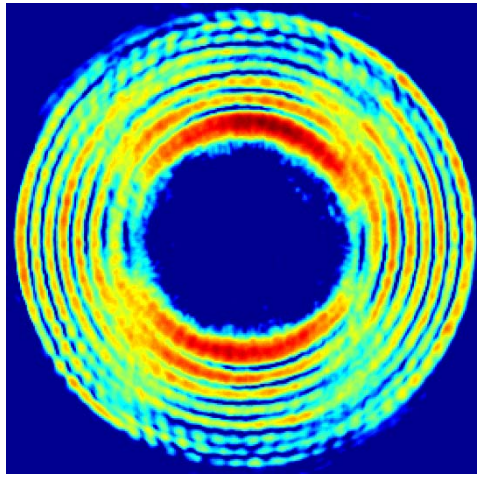
$$\frac{P_-}{P_+} = 0.33\ \%$$

- Quality factor

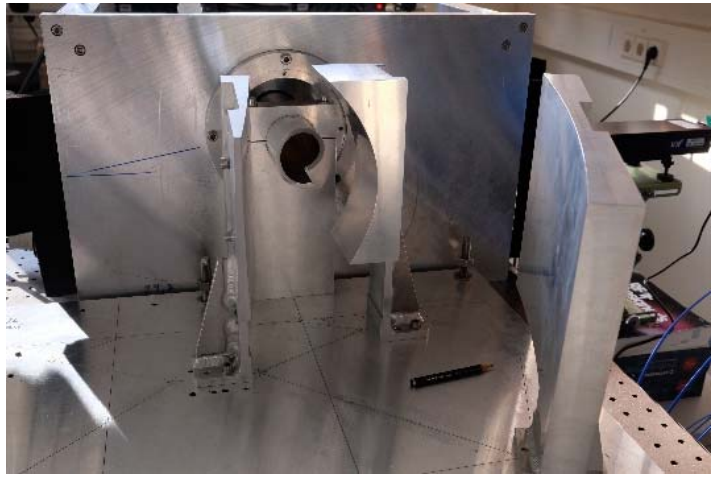


- $Q = \frac{f_{res}}{B_{3dB}}$
- Determined quality factor
  $Q = 2548$ (Design 2533)

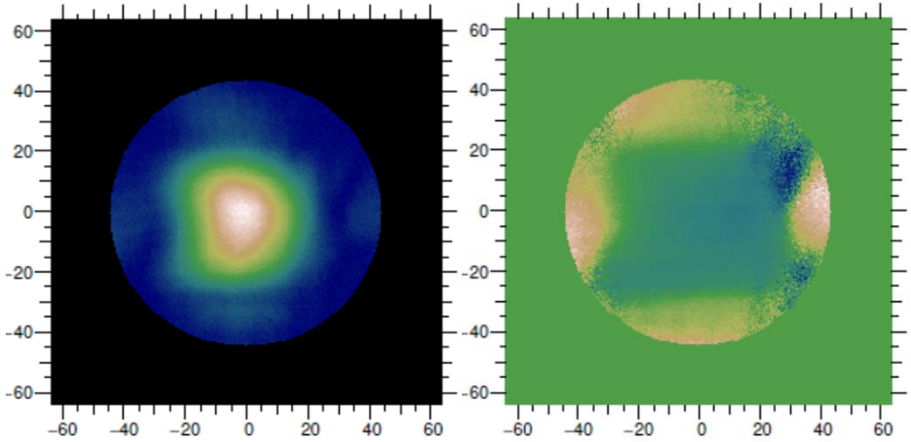
Measurement with Mode Converter System



$TE_{28,8}$-Mode



Output window



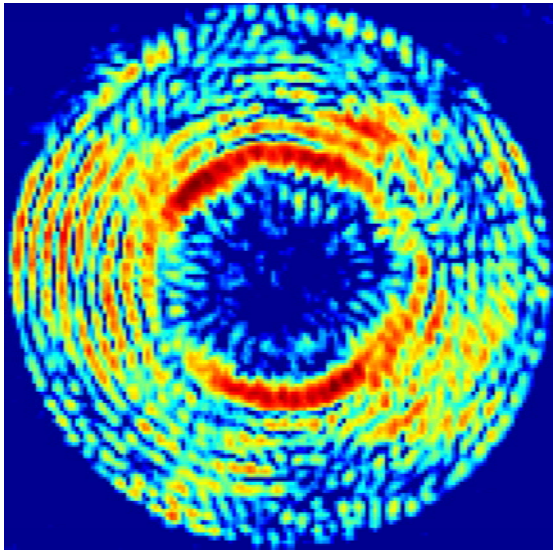
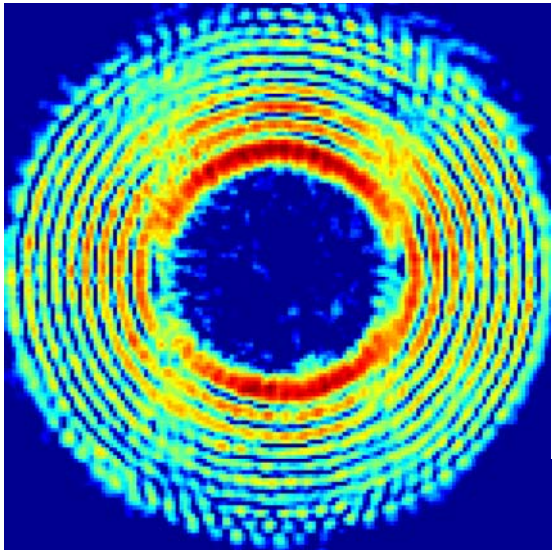
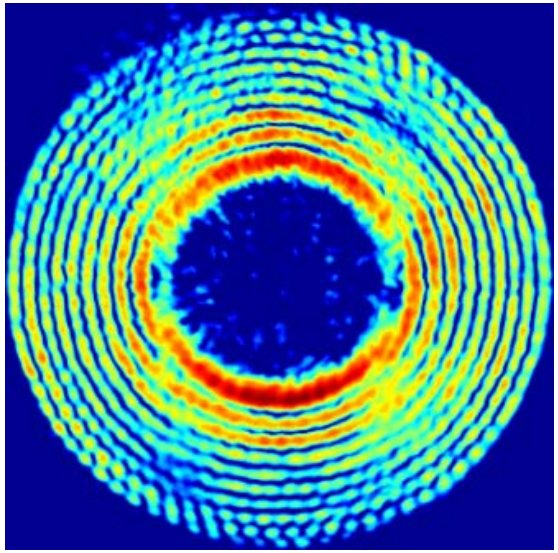
Amplitude

Phase

Vectorial Gaussian mode content of ~97%

Repeatability of the Procedure for an other Cavity Mode

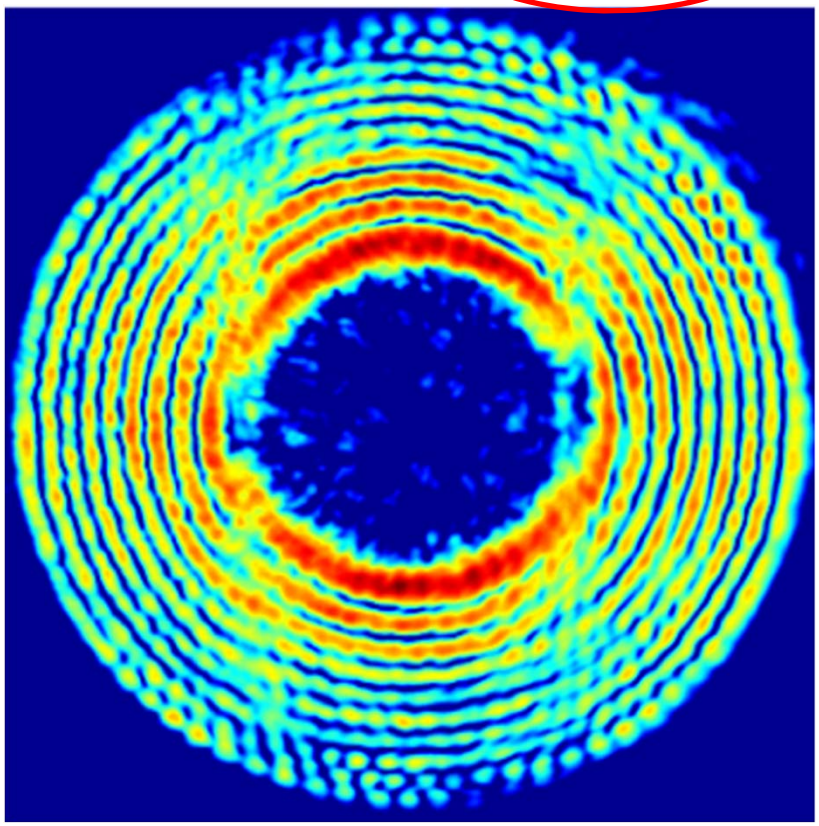
Goal New 1.5 MW Gyrotrons for Wendelstein 7-X Upgrade ($TE_{28,10}$)

Original test setup	New test setup with new measurement procedure	
		
Result after one month	5 h (bad resolution)	2 days (high resolution)

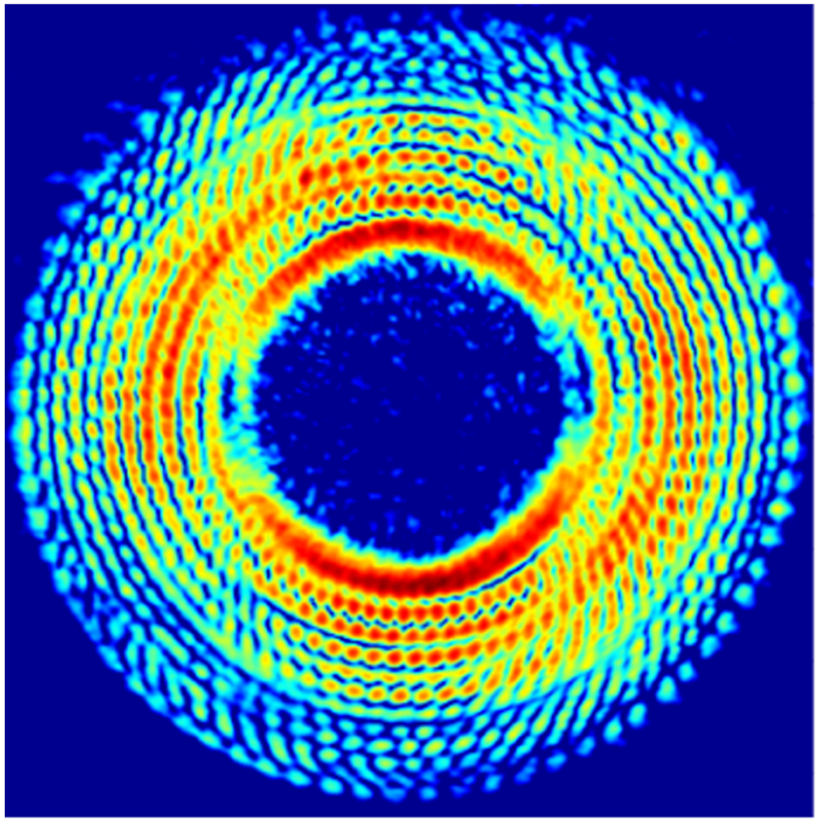
Dual-Frequency Operation of W7-X Upgrade Gyrotrons

$$f_{op} \sim \chi_{m,n} \sim \frac{R_{\text{cavity}}}{R_{\text{insert}}}$$

$TE_{28,10}$-mode at 140.155 GHz

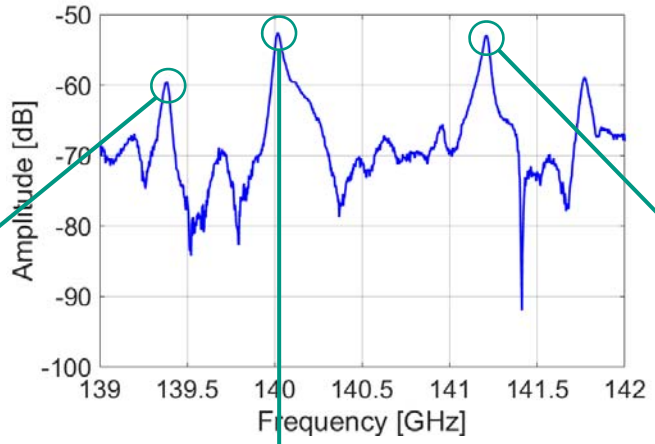


$TE_{36,12}$-mode at 175.995 GHz

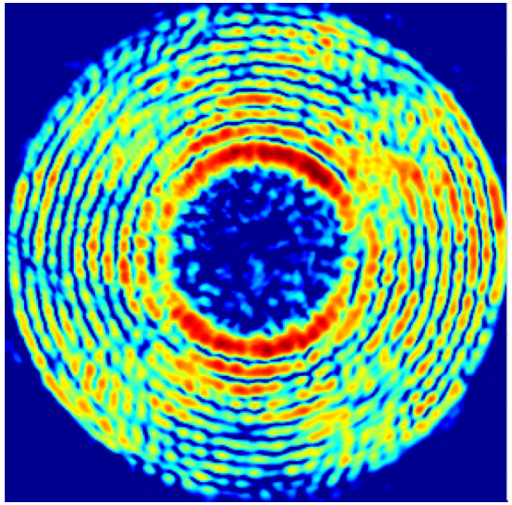


K. A. Avramides, *et al.*, 20th Joint Workshop on Electron Cyclotron Emission (ECE) and Electron Cyclotron Resonance Heating (ECRH), May 2018, Greifswald, Germany

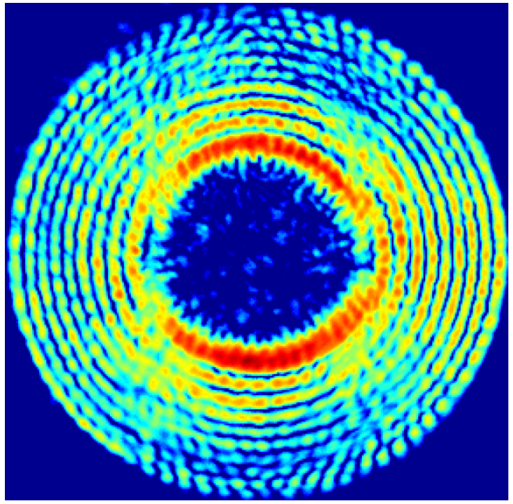
Frequency Spectrum



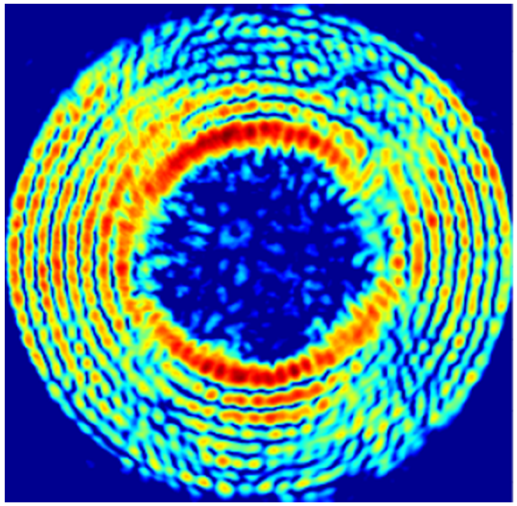
$TE_{25,11}$ @ 139.4 GHz



$TE_{28,10}$ @ 140.01 GHz



$TE_{31,9}$ @ 141.25 GHz

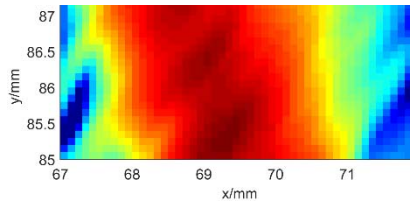


Measurement Results of $TE_{28,10}$-Mode at 140.01 GHz

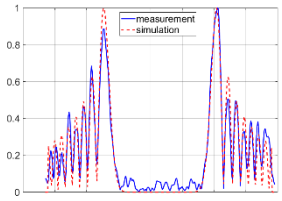
Parameter	Results
Frequency [GHz]	140.01
Scalar mode purity [%]	92.2
Amount of counter-rotating mode [%]	0.57
Quality factor	2522 (design: 2506)
Time saving to the old measurement system	> 94 %

Conclusion

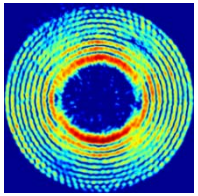
New measurement procedure has been developed having a high time saving of 94 % and even more



Five different mode evaluation techniques has been implemented



New measurement procedure is repeatable for any kind of cavities (e.g. $TE_{28,10}$)



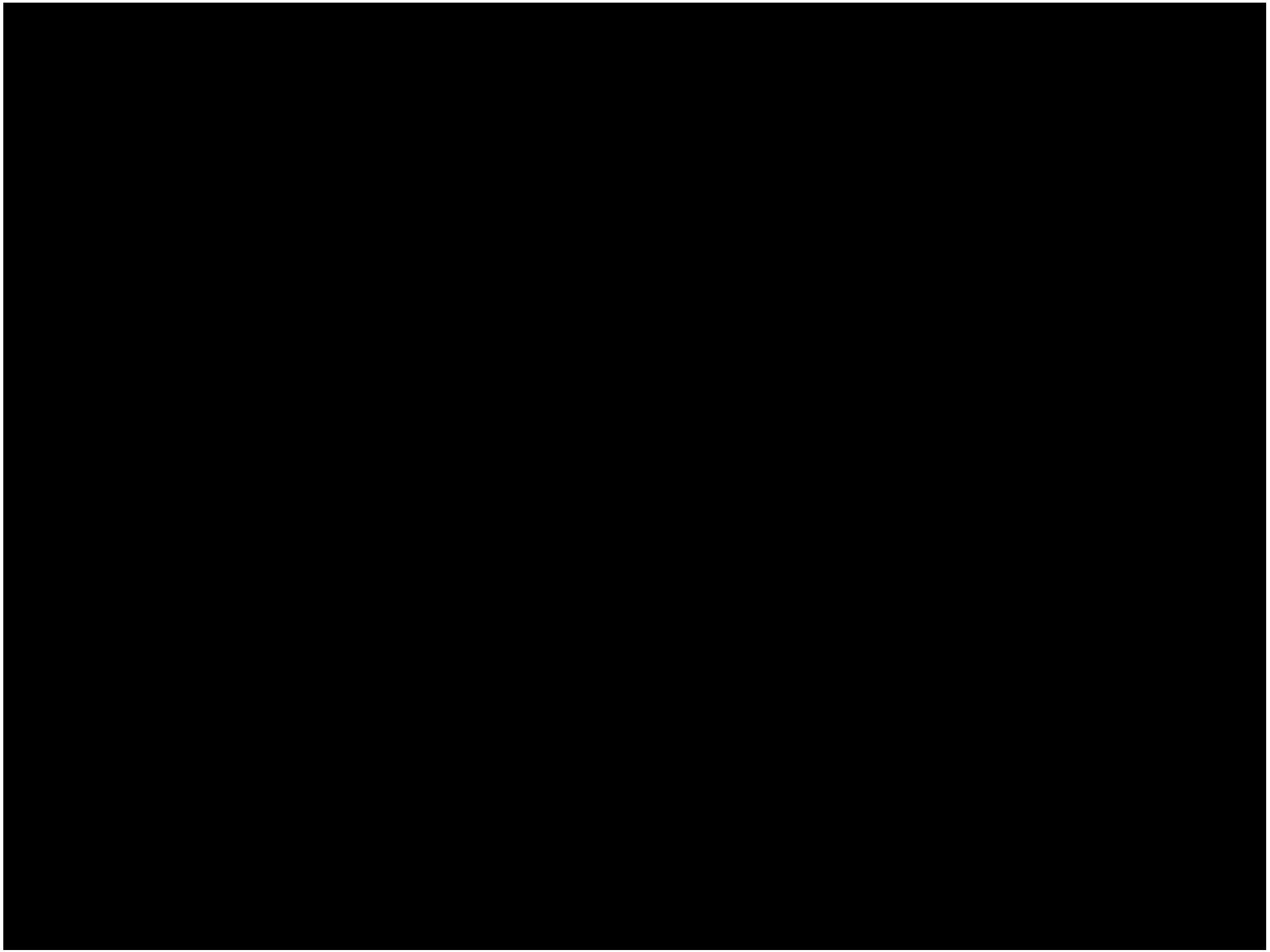
Outlook

Further automation steps:

- Rotating mirror
- Combine programs (just before ending)

Future projects:

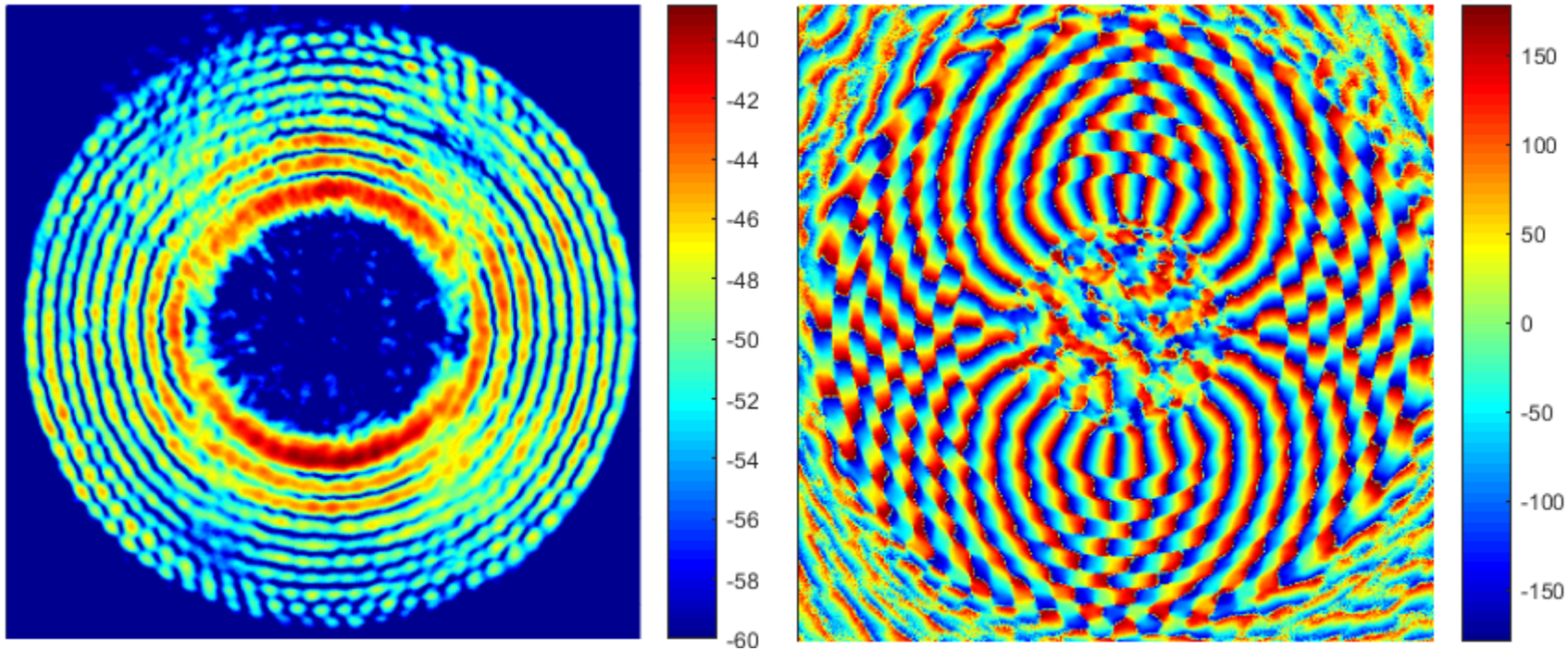
- $TE_{28,10}$-mode launcher + mirror system
- Design and test DEMO relevant components (above 200 GHz)



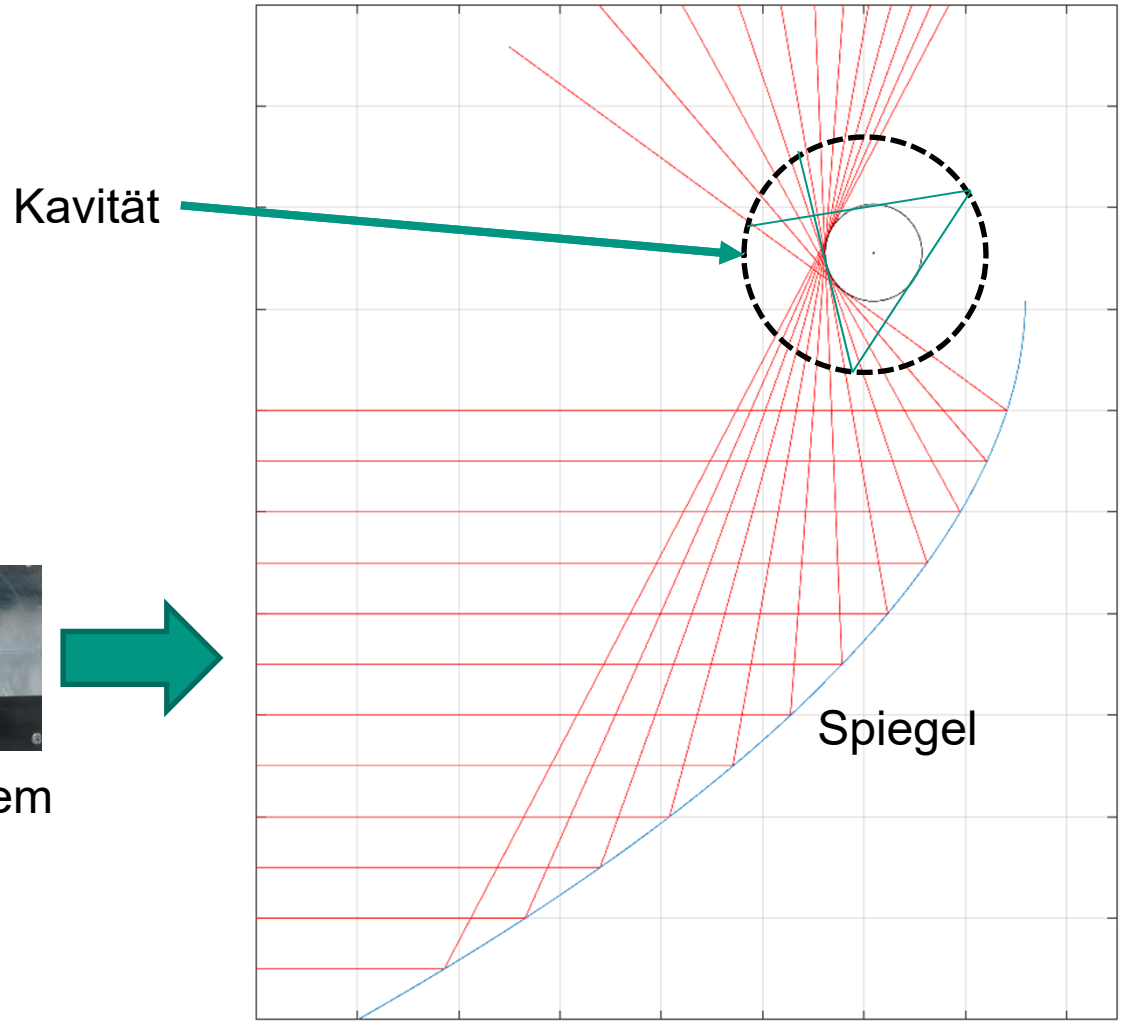
References

- [1] Ruess, Tobias – Internes Schreiben 04.2018
- [2] https://www.iter.org/sci/whatisfusion
- [3] Jin, Jianbo – Internes Schreiben 04.2018
- [4] Wagner, Dietmar – Internes Schreiben 04.2018
- [5] High-Order Modes used in High-Power Microwave Applications –Gärtner, Manuel

Measurement Results for $TE_{28,10}$ Mode



Quasi-parabolischer Spiegel



Linsensystem