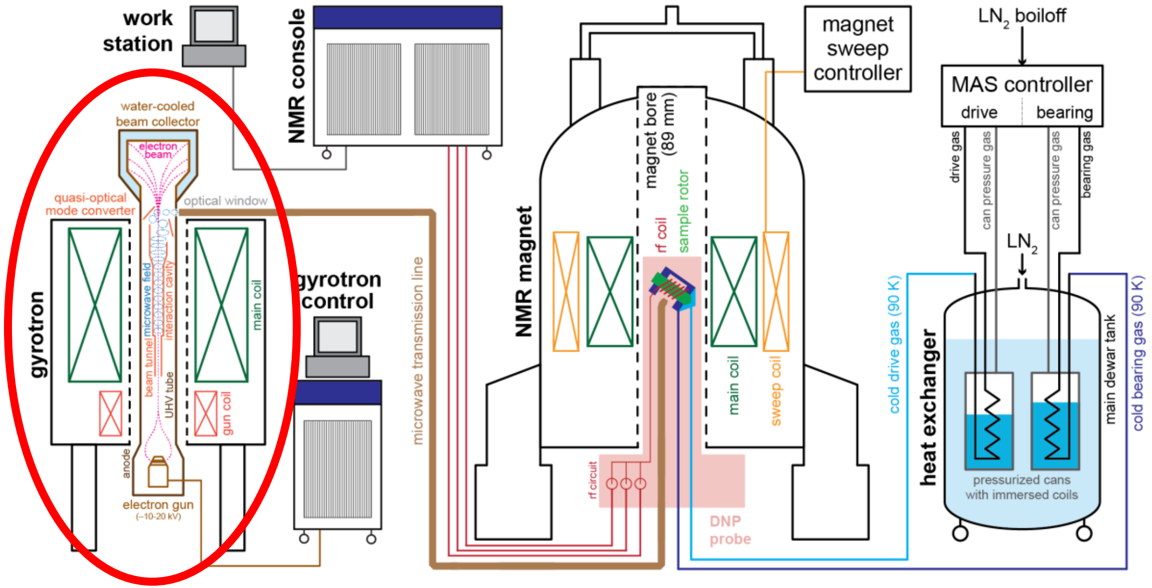
Ongoing Development of a Helical-Type Gyro-TWT for 263 GHz DNP-NMR at IHM

Max Vöhringer

Motivation



Gyrotron can only produce CW power

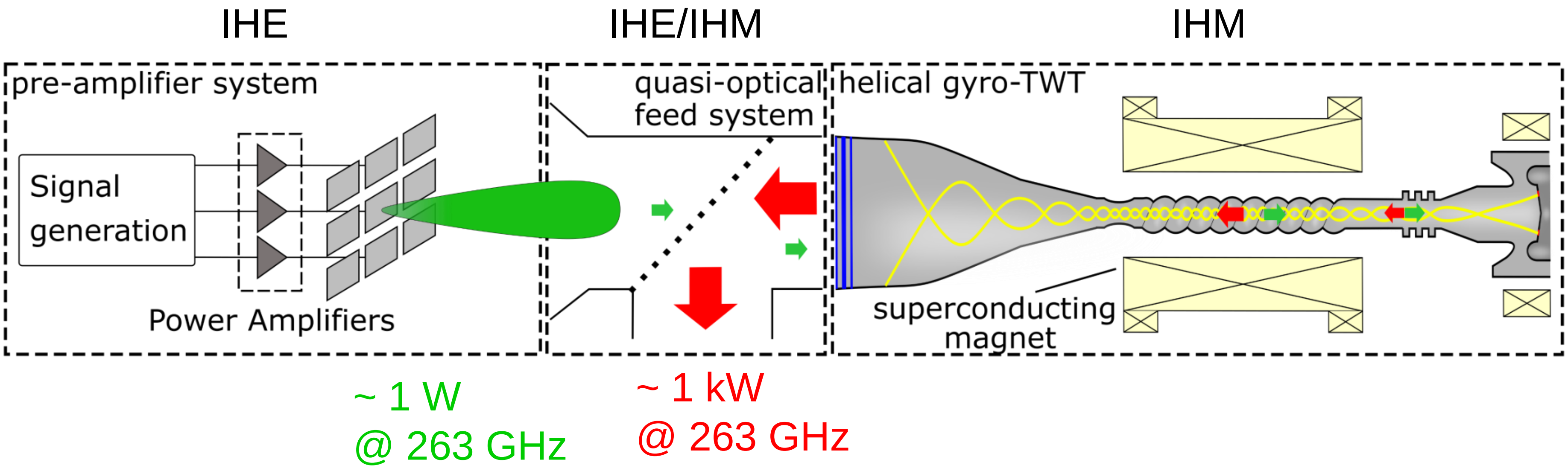
Coherent pulse sequences are desired

Microwave amplifier

https://www.corzilius.chemie.uni-rostock.de/en/hauptmenue/research/methods/dynamic-nuclear-polarization-dnp/

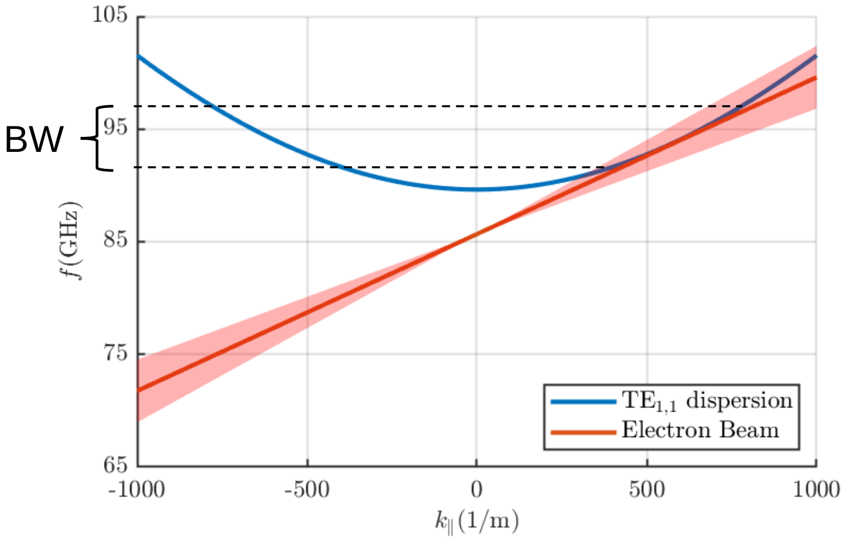
Project B01

- Broadband sub-THz high-power amplifier system for high-field pulsed DNP



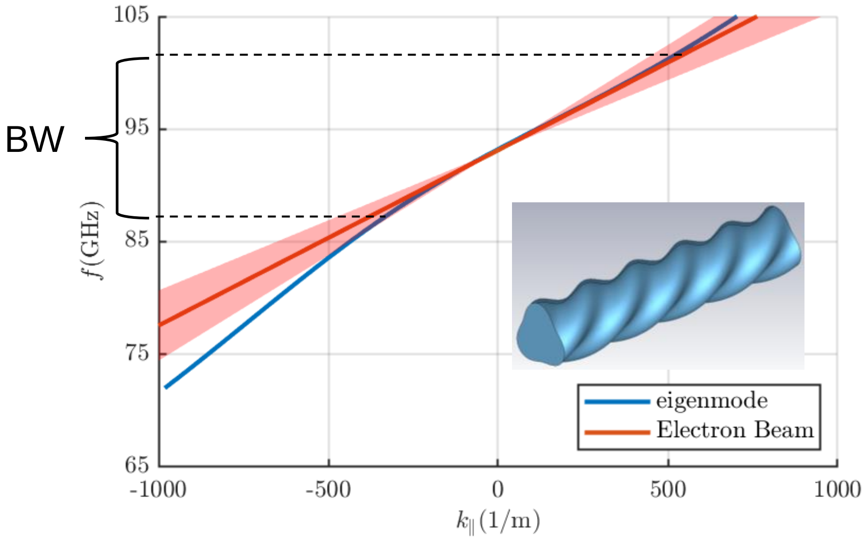
Interaction Region

Circular Interaction Region



$$\omega \approx s\omega_c + k_\parallel v_\parallel$$

Helically Corrugated Interaction Region (HCIR)



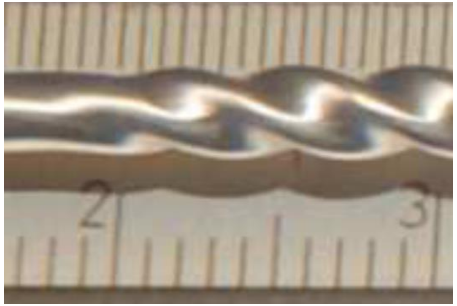
→ higher bandwidth

→ better resilience against velocity spreads

Helically corrugated interaction region (HCIR)

$$r(\theta, z) = r_0 + r_1 \cos\left(m_B\theta + \frac{2\pi z}{d}\right)$$

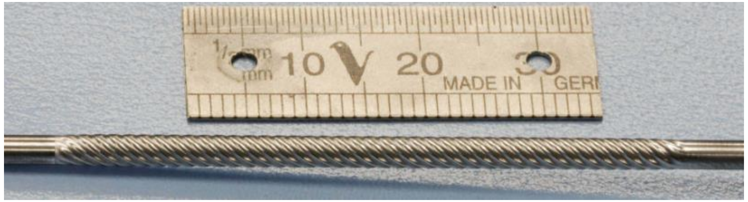
$m_B = 3$



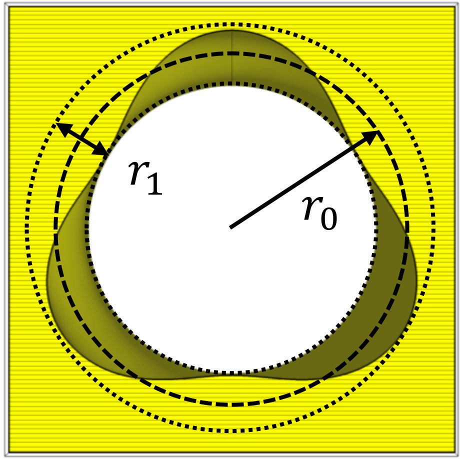
[1]

[1]

$m_B = 8$



[2]



[1] C. R. Donaldson, L. Zhang, C. W. Robertson, P. MacInnes, and C. G. Whyte, "Helically corrugated interaction regions for W-band gyrotron-Traveling Wave Amplifiers," doi: 10.23919/EuMC58039.2023.10290435.
[2] C. R. Donaldson et al., "8-Fold Helically Corrugated Interaction Region for High Power Gyroresonant THz Sources," doi: 10.1109/LED.2021.3105435.

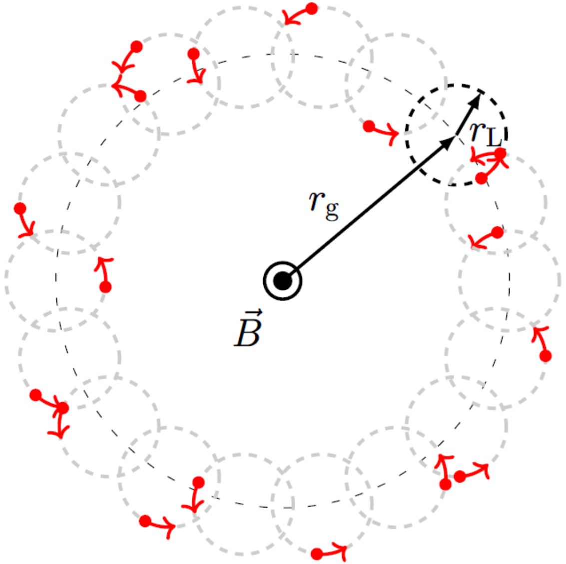
Helically corrugated interaction region (HCIR)

First trials milling a mandril at 94 GHz

Mandril for the first electroplating trials at 94 GHz

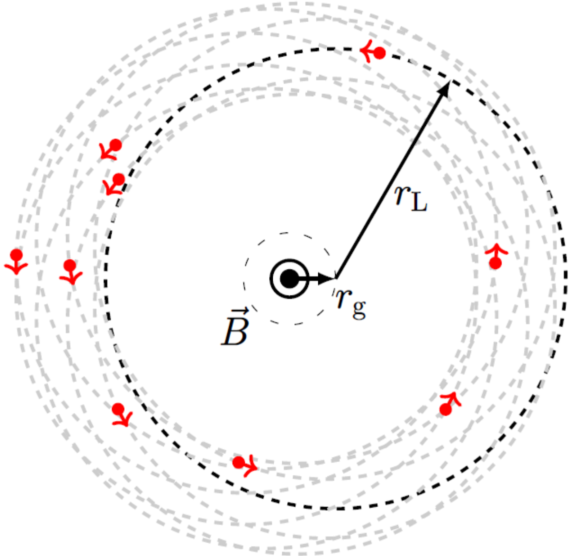
Electron Beams at the Interaction Region

Small Orbit Beam



- Usually used in high power gyrotrons
- Interacts with higher order modes

Large Orbit Beam

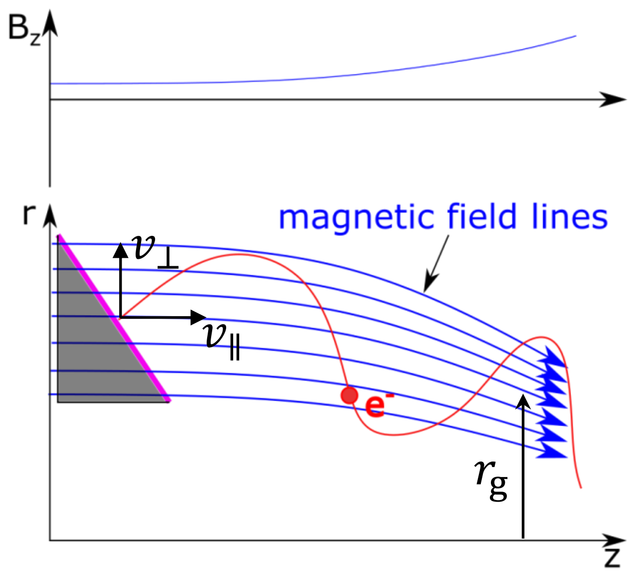


- Only interact with $TE_{s,1}$-modes
- Remember: Eigenmode of HCIR similar to $TE_{2,1}$
  $\rightarrow s = 2$: 2nd – harmonic operation

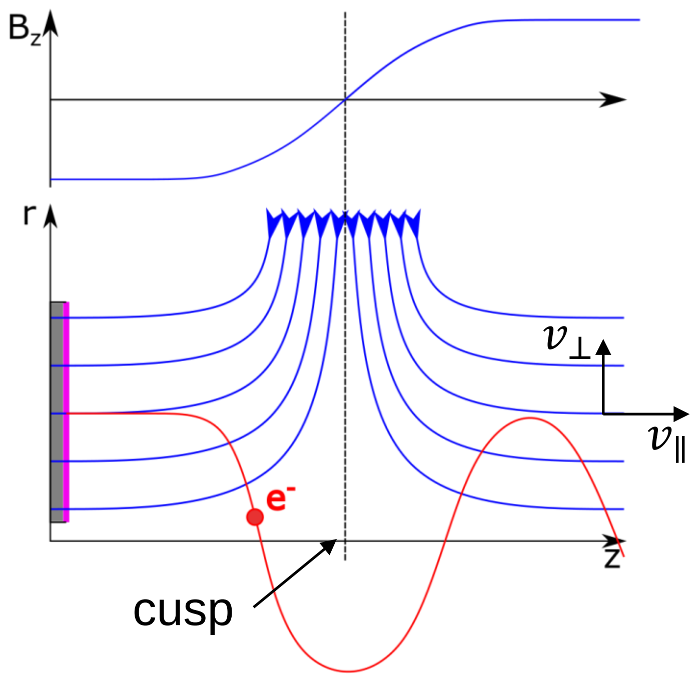
Generation of Electron Beams

Karlsruhe Institute of Technology

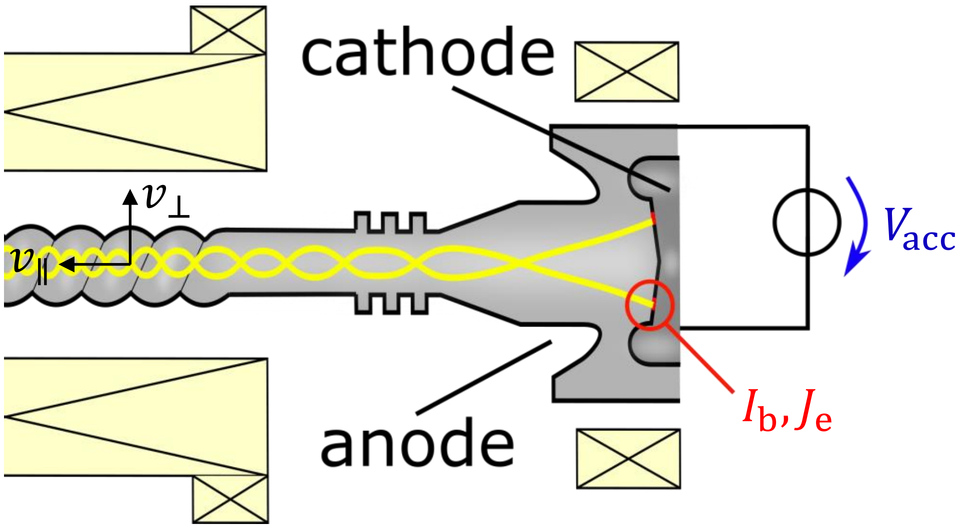
Small Orbit Beam



Large Orbit Beam



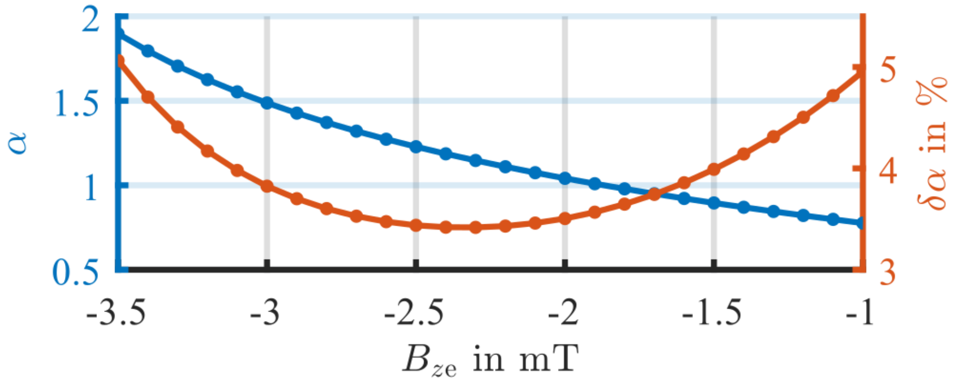
Generation of Electron Beams



- Pitch factor $\alpha = \frac{v_\perp}{v_\parallel} = 1.0$
- Acceleration voltage $V_{acc} = 50\ \mathrm{kV}$
- Electron beam current $I_b = 0.25\ \dots 0.6\ \mathrm{A}$
- Emitter current density $J_e < 4\ \frac{\mathrm{A}}{\mathrm{cm}^2}$
- Magnetic flux density at the interaction region $B_{zi} = 5.1\ \mathrm{T}\ \widehat{=}\ 263\ \mathrm{GHz}$

Change of operation frequency

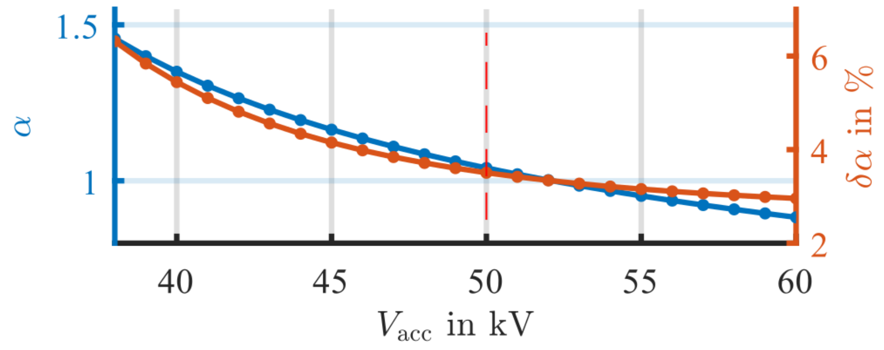
Change of Pitch Factor α

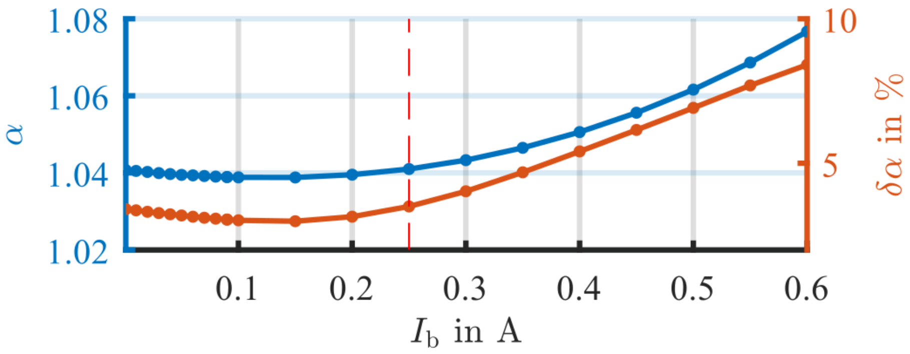


- Pitch factor α can easily altered by a slight change of the magnetic flux density
- Only slight change of $\delta\alpha$ operation from $\alpha = 0.8$ … 1.9 is possible.

- The Pitch Factor $\alpha = \frac{v_\perp}{v_\parallel}$, which indicates the energy content in transversal dimension, can be adjusted

Change in beam power





- Voltage change causes large change in α
- $\delta\alpha$ increases only for lower voltages

Can be compensated by adjusting B_{ze}

- Current change causes small change in α
- $\delta\alpha$ increases for higher currents

Increase of power via I_b is limited by $\delta\alpha$

Operation at 94 and 140 GHz

Operation at 94 GHz

- $B_{\mathrm{zi}} = 1.82\ \mathrm{T}$
- $\delta\alpha = 3.3\ \%\ (\mathrm{RMS})$, for $\alpha = 1.0$

To keep the pitch factor α constant, the magnetic flux density must be changed to $B_{\mathrm{ze}} = -6.0\ \mathrm{mT}$

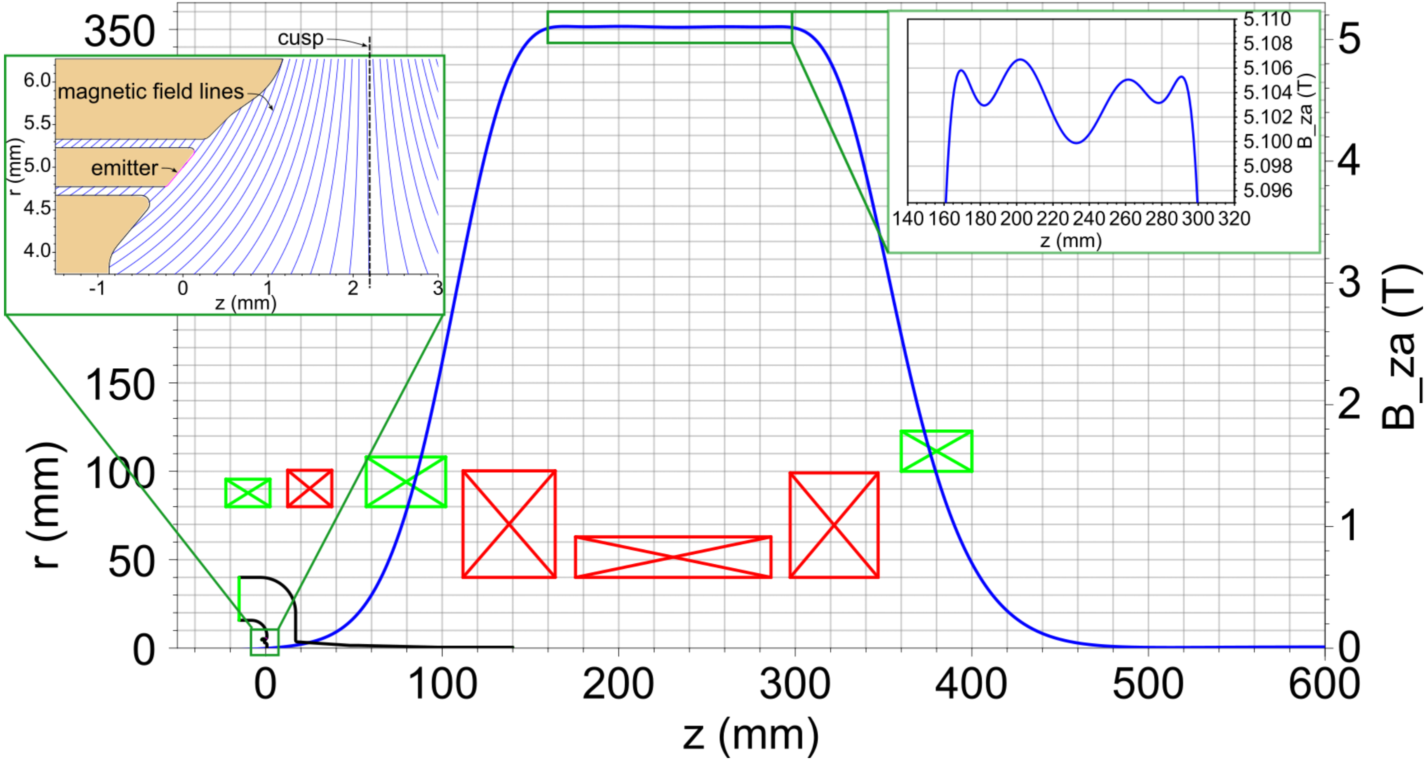
Operation at 140 GHz

- $B_{\mathrm{zi}} = 2.71\ \mathrm{T}$
- $\delta\alpha = 2.5\ \%\ (\mathrm{RMS})$, for $\alpha = 1.0$

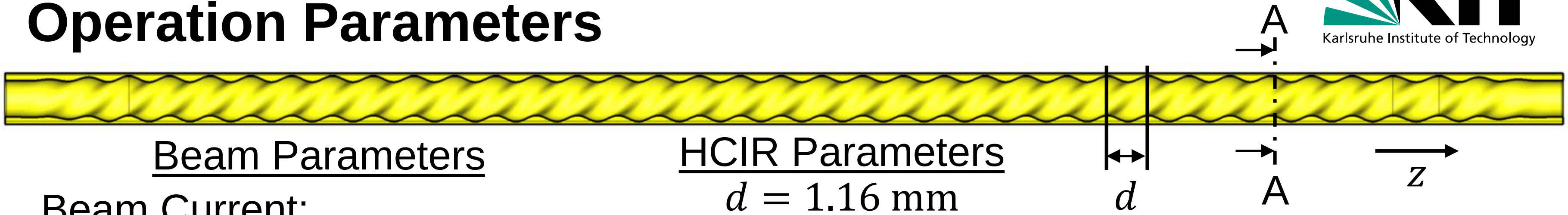
To keep the pitch factor α constant, the magnetic flux density must be changed to $B_{\mathrm{ze}} = -4.5\ \mathrm{mT}$

Magnetic flux density at the interaction region, as well as at the emitter must be adjustable

Superconducting Magnet



Operation Parameters



Beam Parameters

Beam Current:

$$I_b = 0.6\ \text{A}$$

Acceleration Voltage:

$$V_{acc} = 50\ \text{kV}$$

Pitch Factor:

$$\alpha = \frac{v_t}{v_z} = 1.0$$

Input Signal

Input power:

$$P_{in} = 1\ \text{W}$$

HCIR Parameters

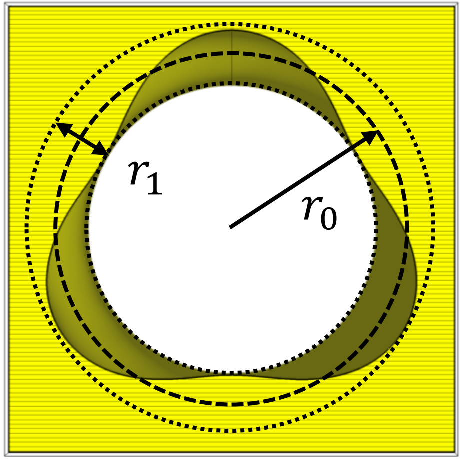
$$d = 1.16\ \text{mm}$$
$$r_0 = 0.544\ \text{mm}$$
$$r_1 = 0.08\ \text{mm}$$
$$\text{Length} = 32 \cdot d$$

Output Power:

$$P_{out} = 1\ \text{kW}$$

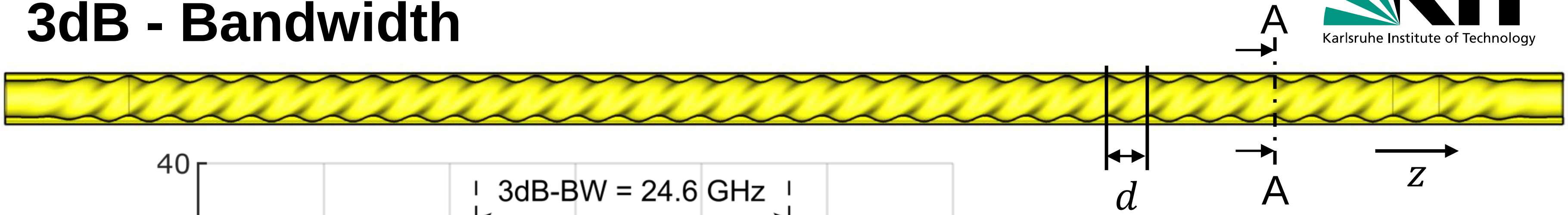
Gain:

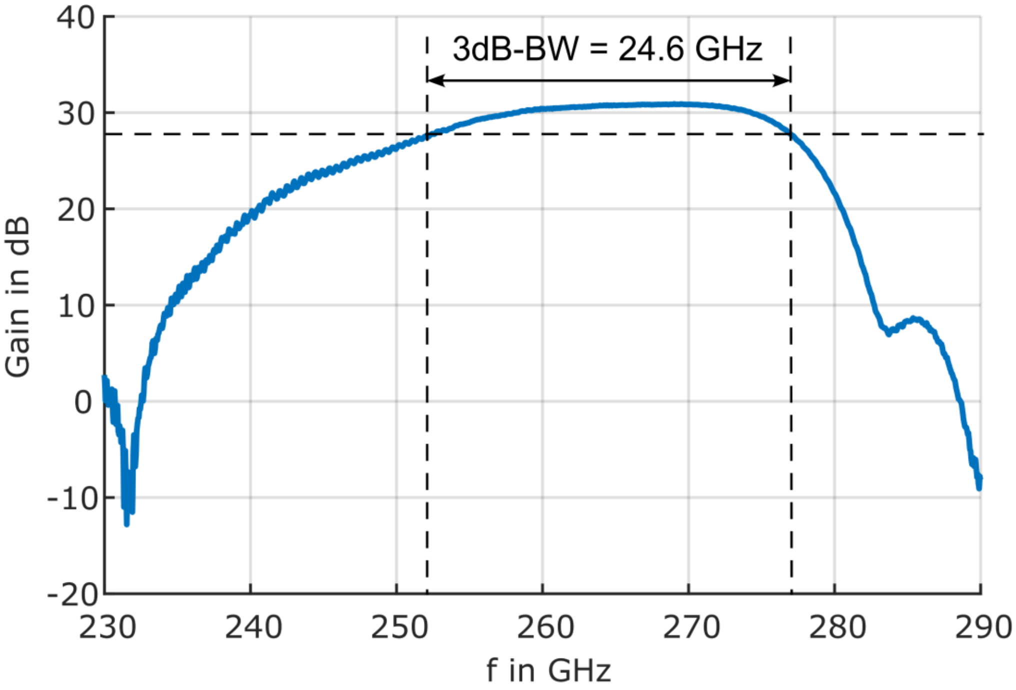
$$G = 30\ \text{dB}$$

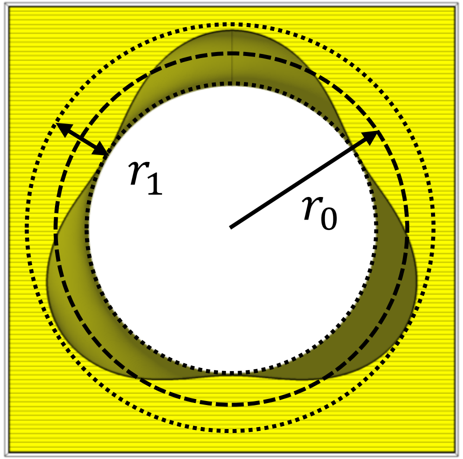


A - A

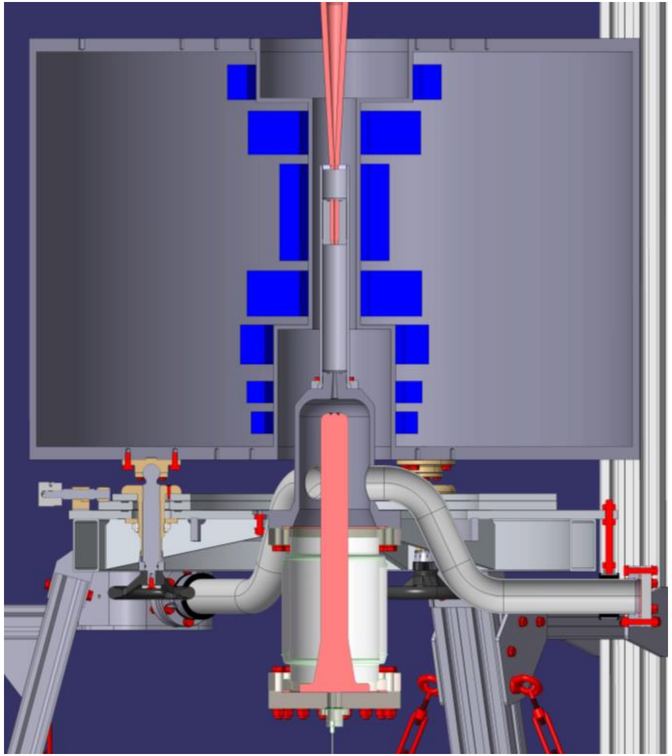
3dB - Bandwidth

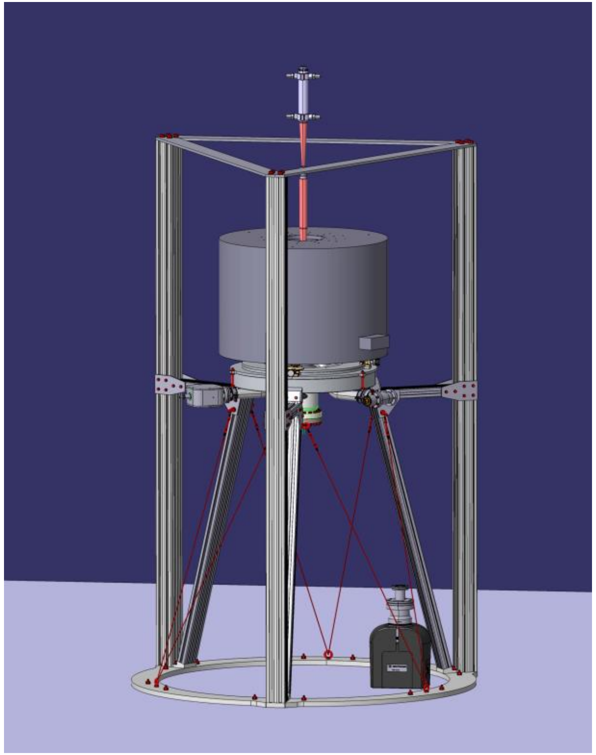






Mechanical Design and Teststand





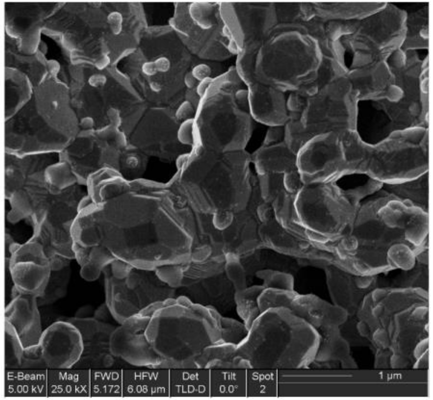
Conclusion and Outlook

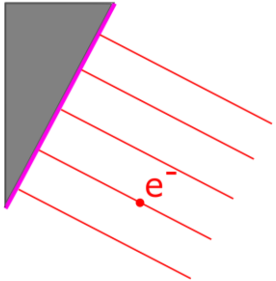
- Manufacturing of 94 GHz HCIR started
- Electron gun for multiple operation points and frequencies is designed
- Superconducting magnet is ordered

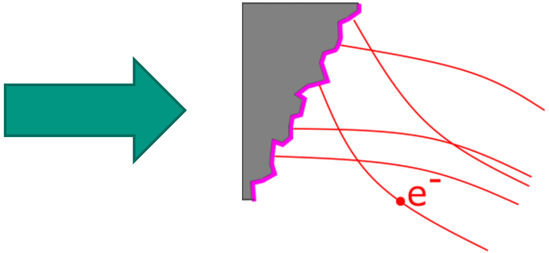
- Manufacturing of 263 GHz mandril
- Manufacturing of teststand
- Ordering of the electron emitter and manufacturing electron gun

Backup Slides

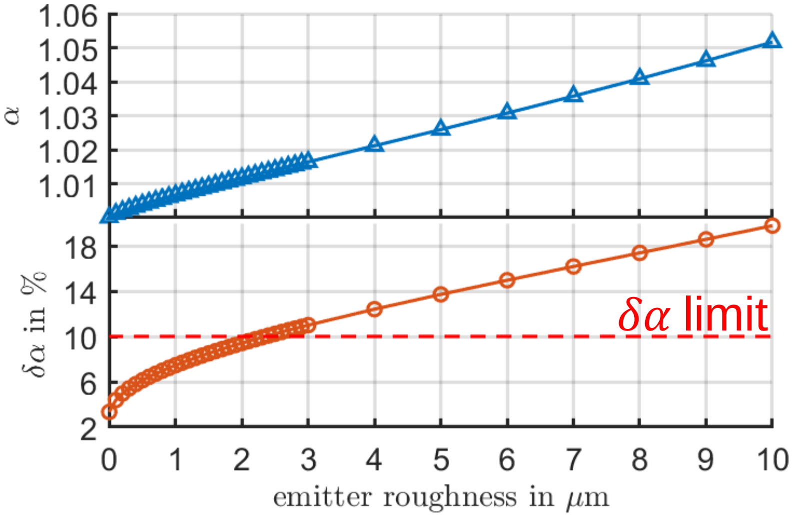
Emitter Roughness







$\delta\alpha = 3.45\ \%$



- With increasing surface roughness the pitch factor spread increases rapidly

→ A $\delta\alpha \leq 10.0\ \%$ can be reached up to a surface roughness of $2.3\ \mu\mathrm{m}$.

D. M. Kirkwood et al., "Frontiers in Thermionic Cathode Research," *IEEE Transactions on Electron Devices*