# Influence of Parasitic Backward Waves on Gyrotron Operation

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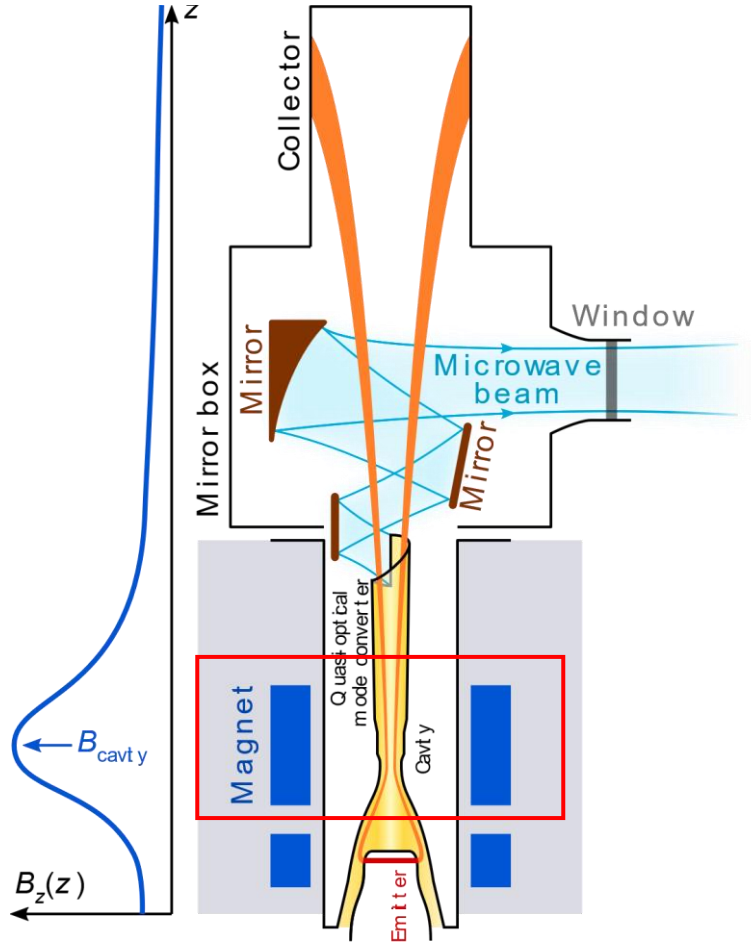
# Gyrotron

- Overmoded cavities possible

→High output power

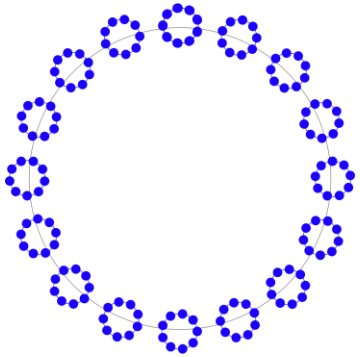
- No structures in size of the wavelength
  - Cyclotron frequency $\Omega_c = \frac{e}{m_e \gamma} B$
  - RF-Frequency $\omega \approx s\,\Omega_c$

→High frequencies

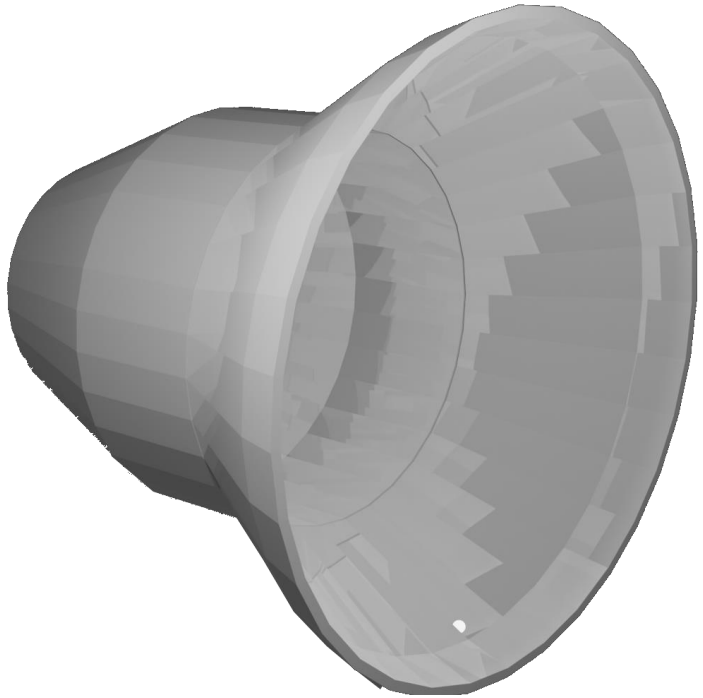


# Second Harmonic Interaction

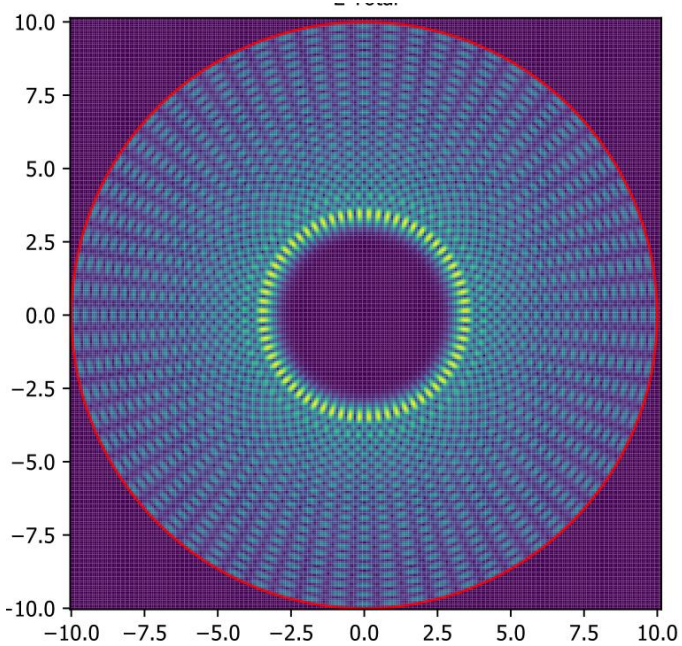
Electron Beam



Cavity



RF Field




$$\Omega_c = \frac{e}{m_e \gamma} B$$

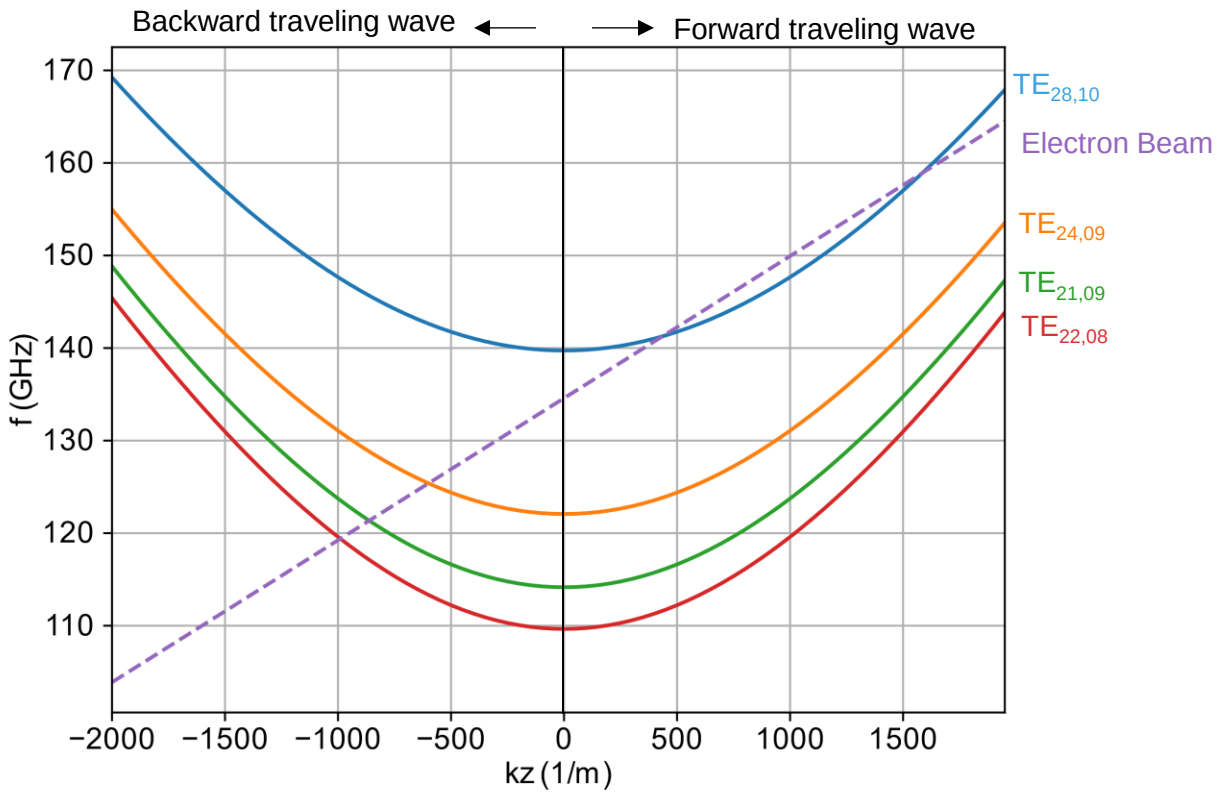
$$\omega \approx s\,\Omega_c - k_z v_z$$

# Dispersion Diagramm

- Cyclotron resonance condition

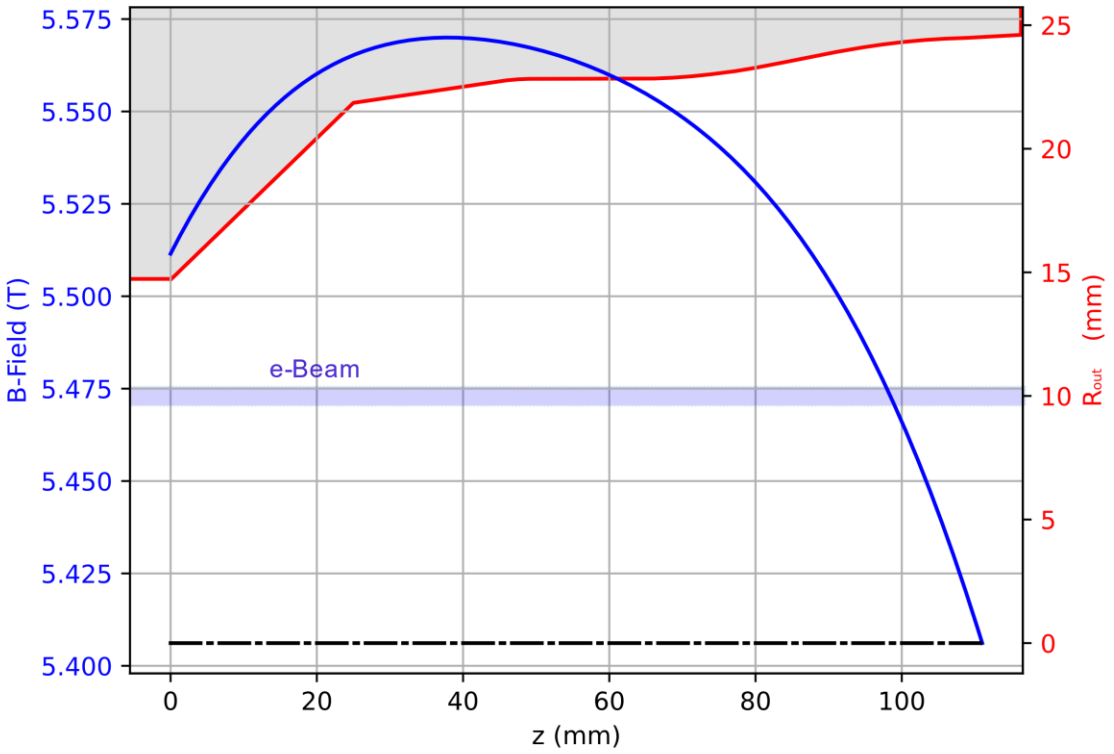
$$\omega \approx s\,\Omega_c - k_z v_z$$

- Properties of the backward waves in gyrotrons:
  - Propagation in negative $z$ direction
  - Interaction at lower frequencies than the operating mode
  - Much lower $Q$-Factors than the operating mode

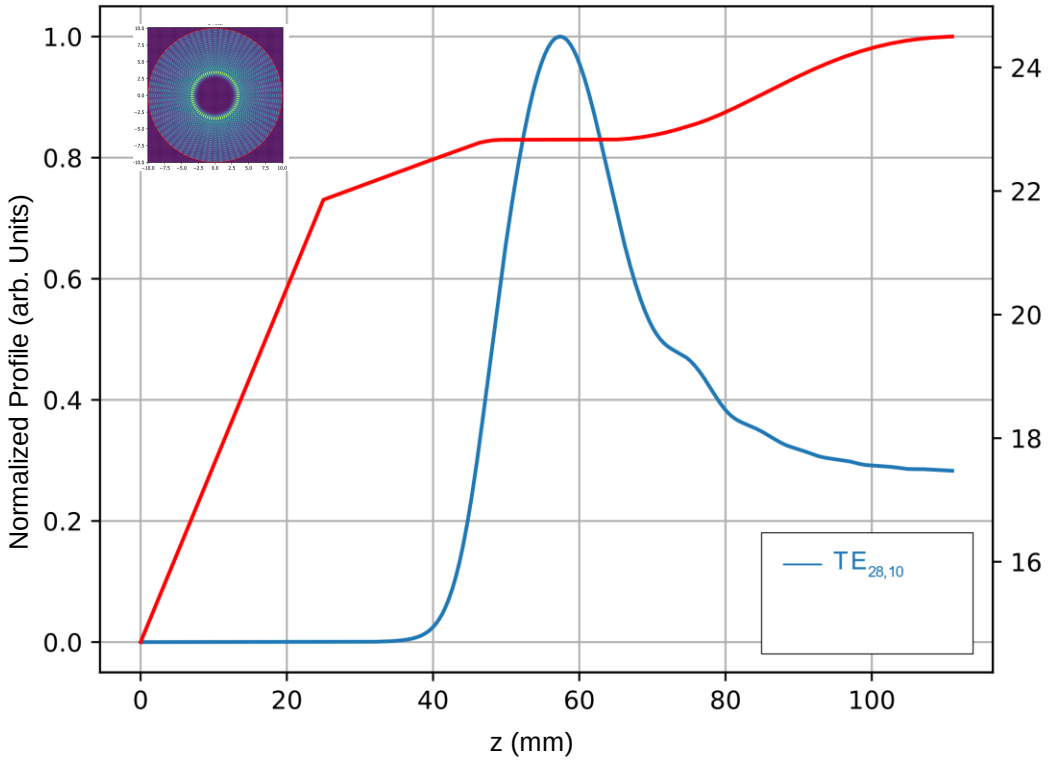


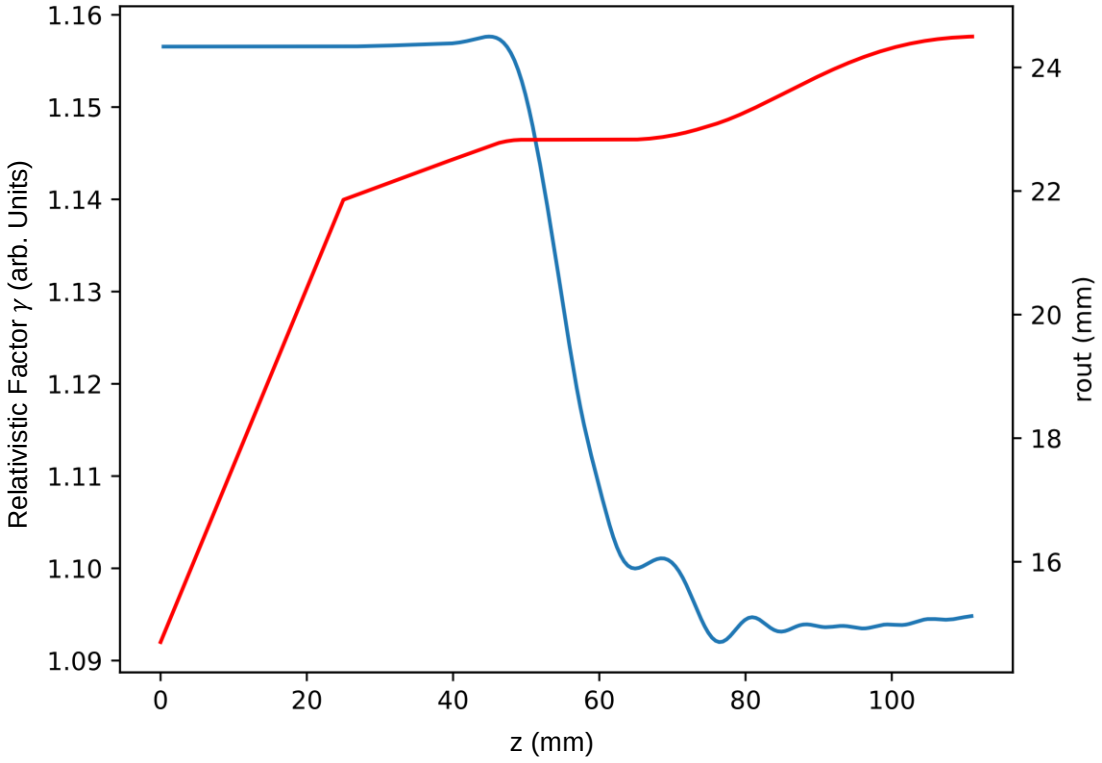
# Operating Conditions

- 140 GHz gyrotron
- $TE_{28,10}$ operating mode
- Special operating point
  - $E_{\mathrm{kin}} = 80\ \mathrm{keV}$
  - $I_b = 55\ \mathrm{A}$
  - $\alpha = \frac{v_\perp}{v_z} = 1.4$
- Spreads assumed:
  - $\Delta\gamma = 0.02\ \%$
  - $\Delta\alpha = 5.0\ \%$
  - $\Delta r_{\mathrm{gc}} = 1.8\ \%$



# Effect of Backward Wave



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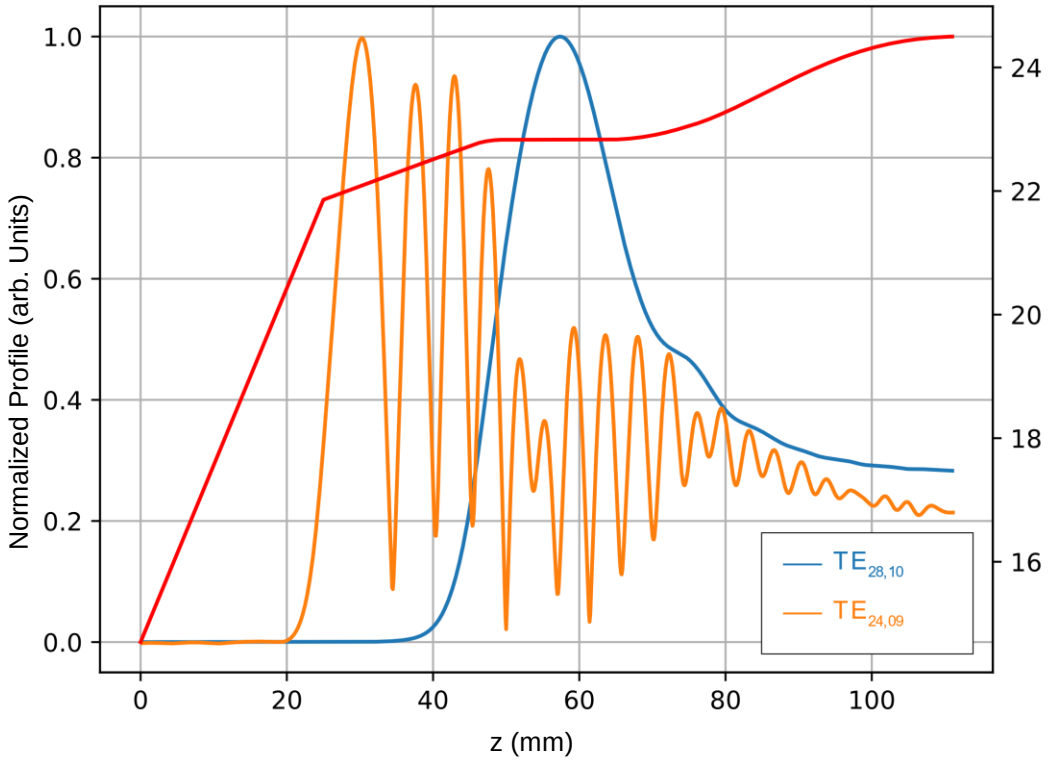
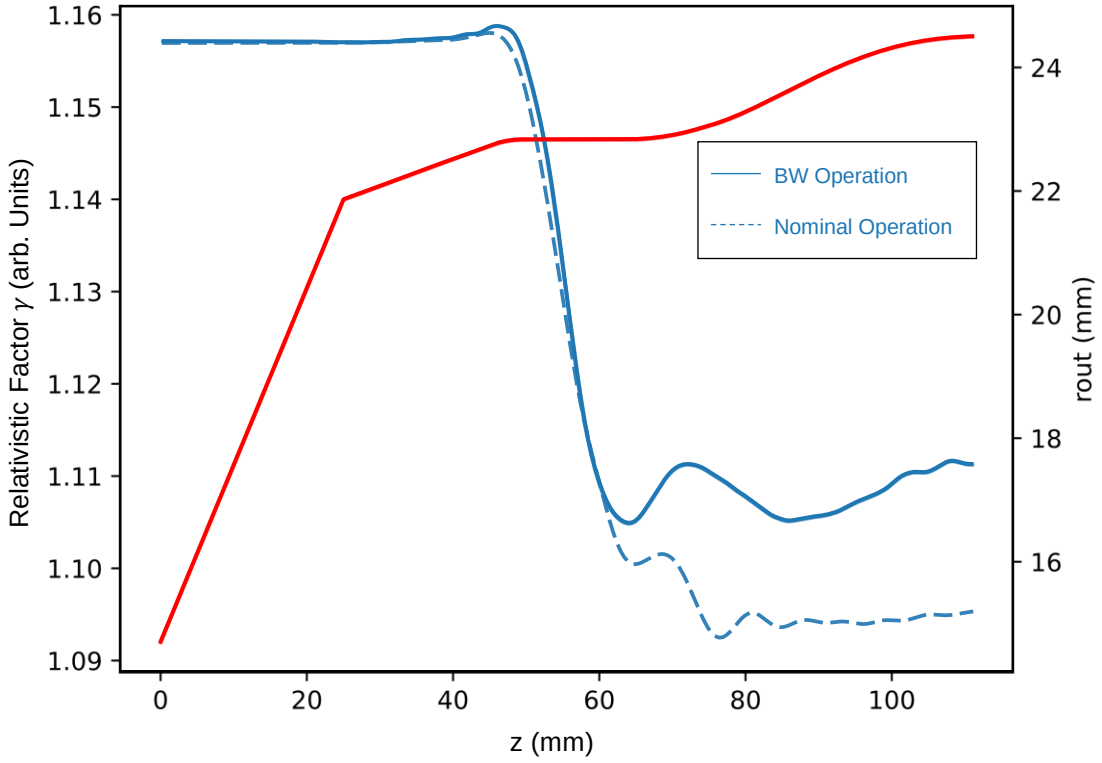
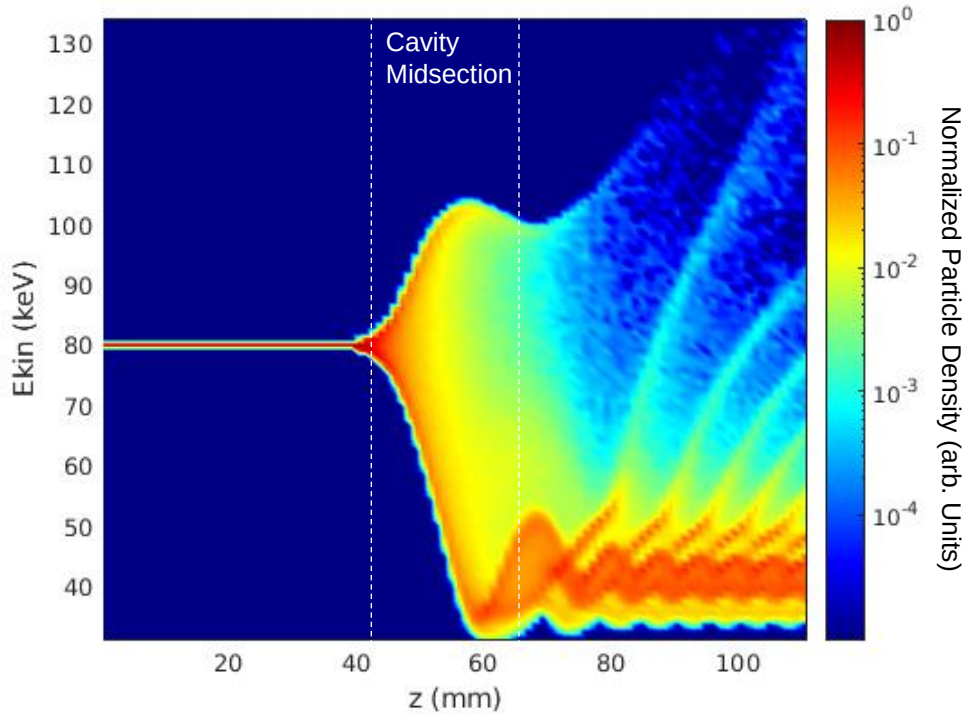


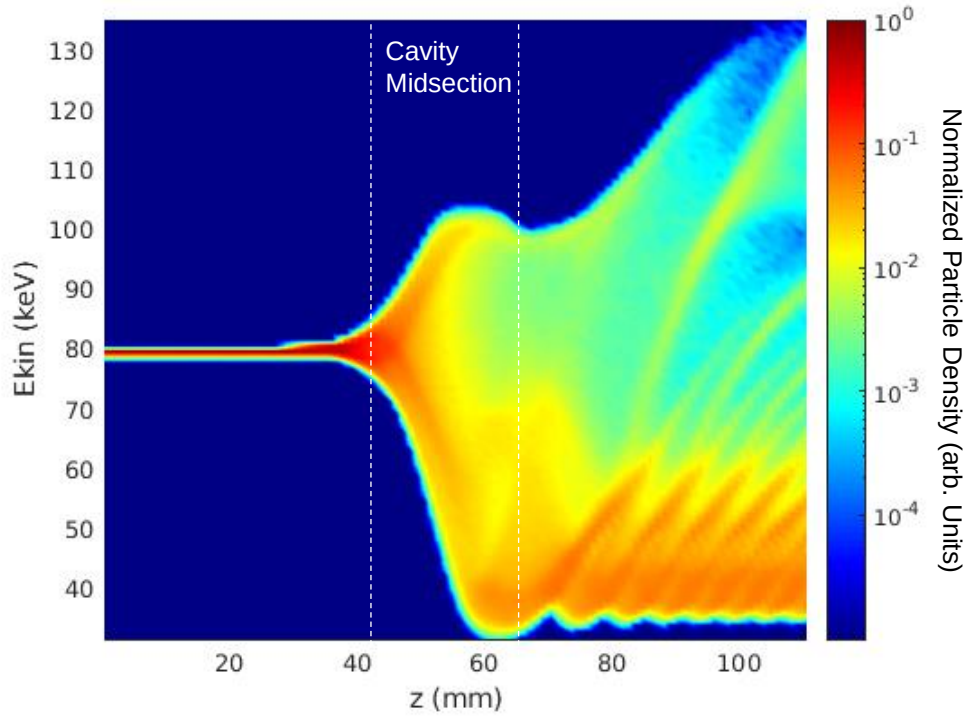



# Backward Wave Influence on Particles

## Without Backward Waves

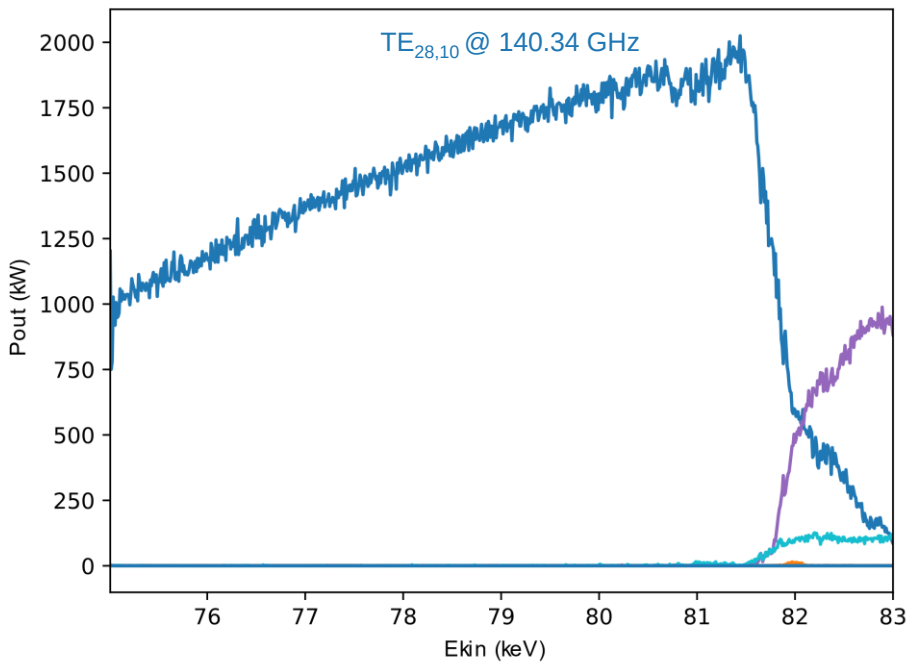



## With Backward Waves

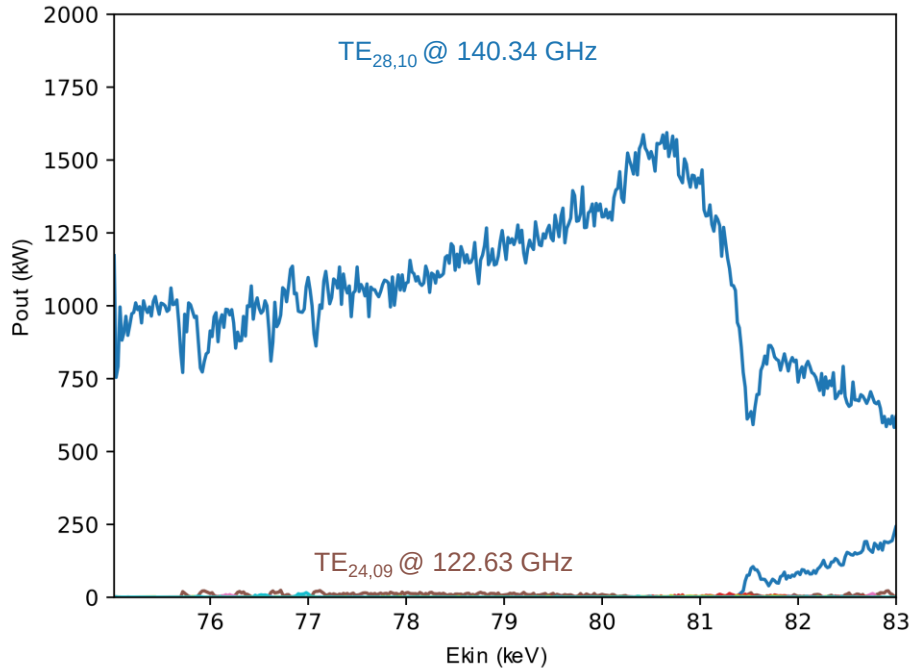


# Effect on Output Power

## Without Backward Waves




## With Backward Waves

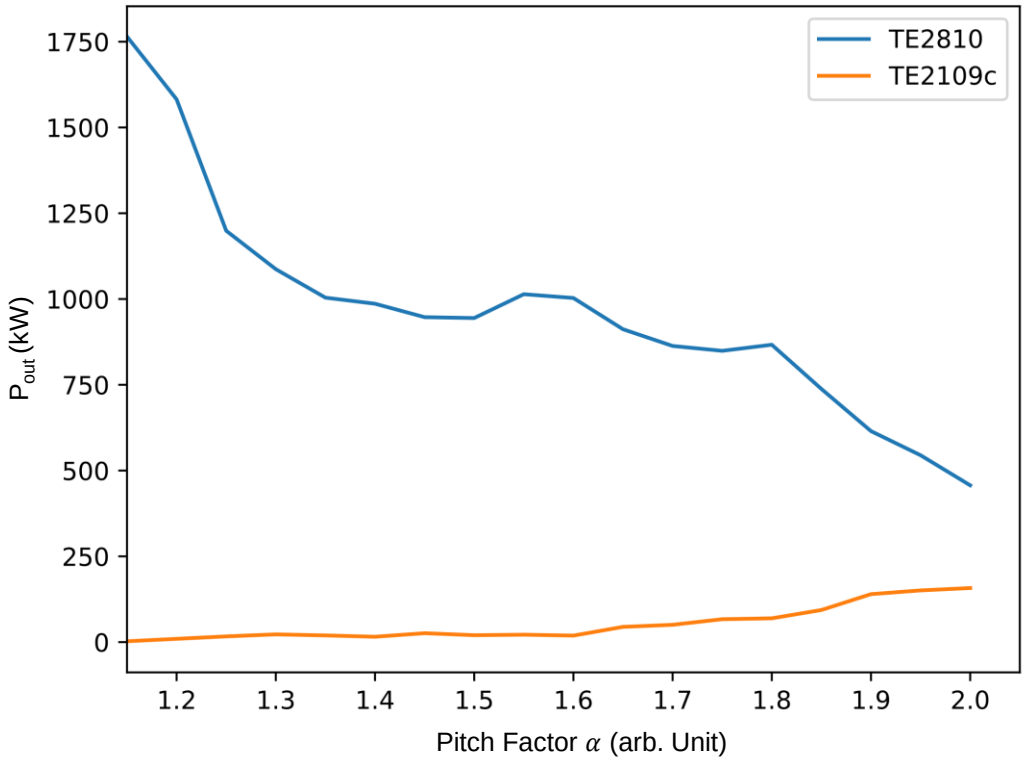


# When do Backward Waves Occur?

- Highly depended on electron beam parameters
- Most influence of pitch factor $\alpha = \frac{v_\perp}{v_z}$
- Highly depended on magnetic field after the cavity

# Dependence on Pitch Factor

- High pitch factor $\alpha$ leads to high backward wave excitation
- Disturbances caused by the parasitic counteract the actually higher output power of the operating mode
- Significantly lower power in the operating mode





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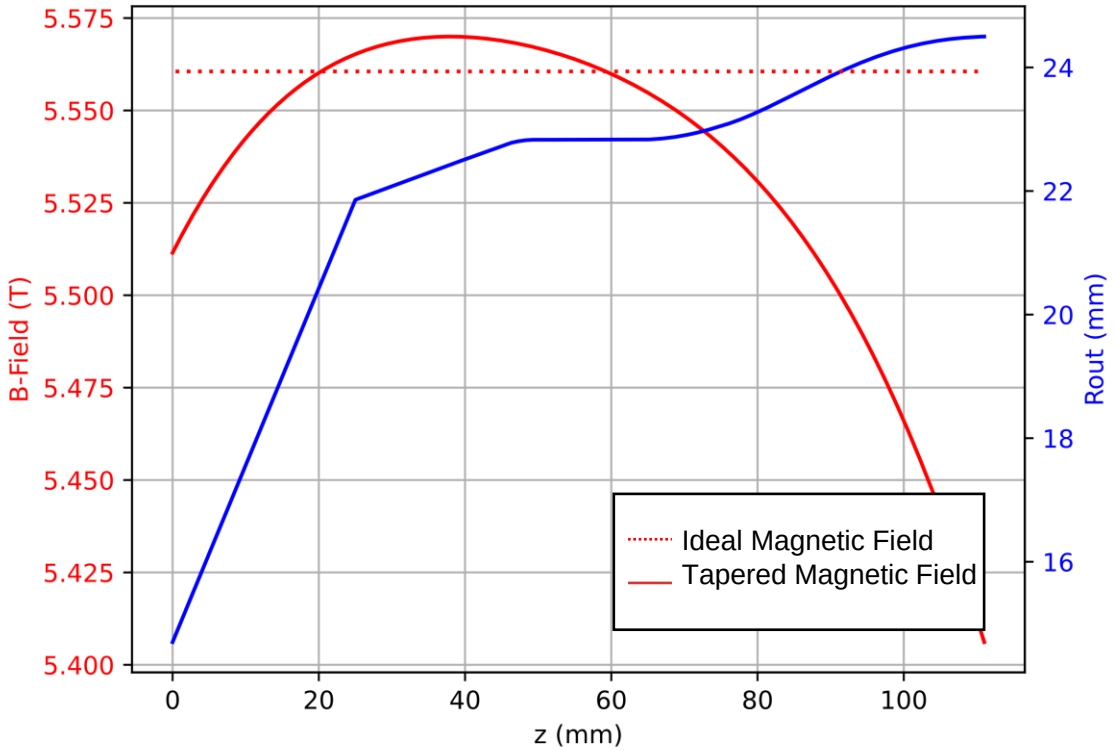
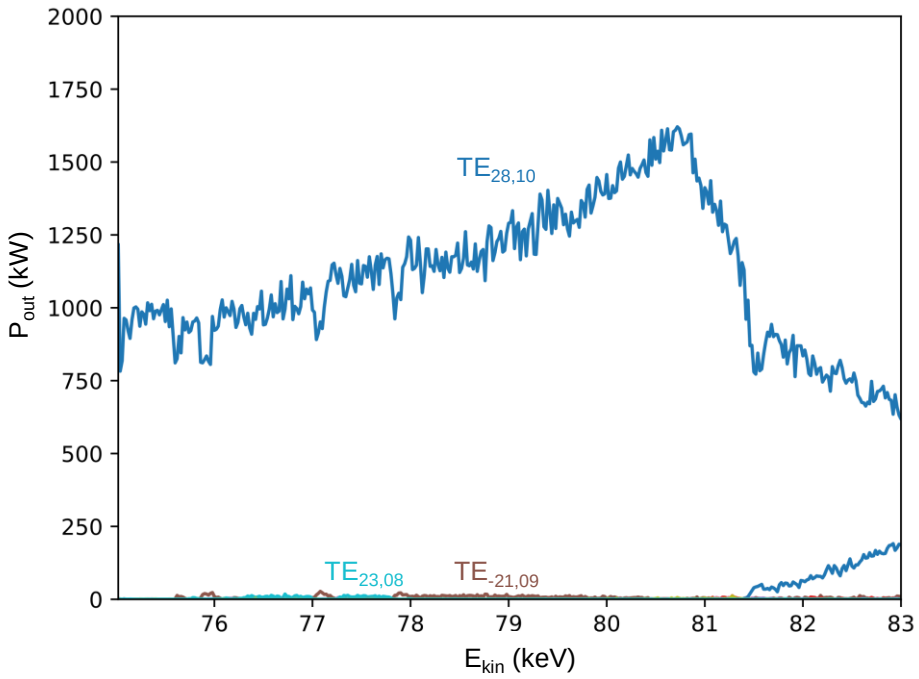
# Dependence on Magnetic Field Taper

- Excitation of the parasitic happens after the middle section
- Faster decrease of the $B$-fields backward waves
- Almost no influence on the operating mode

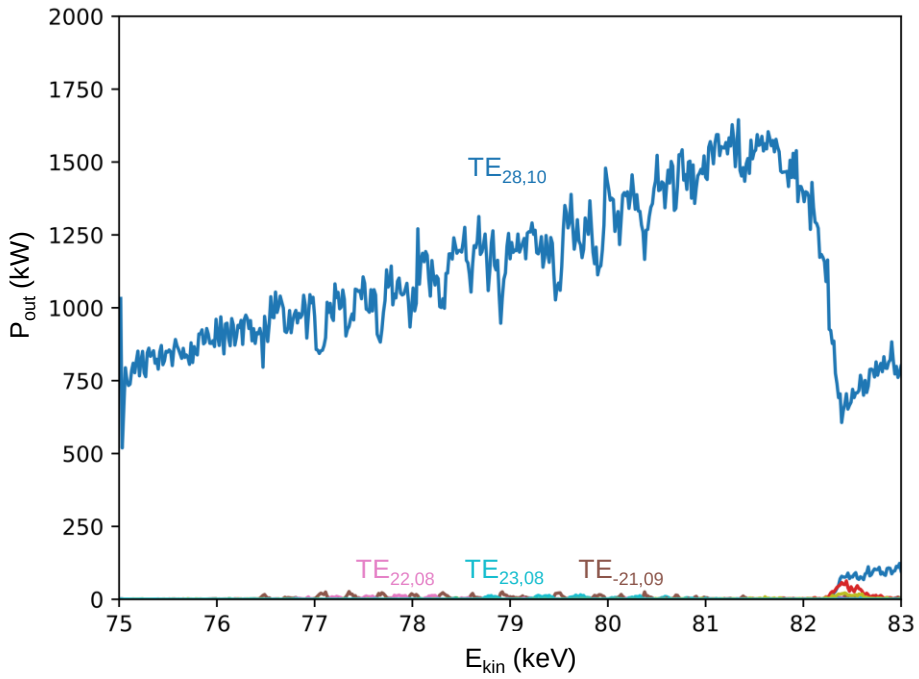


# Dependence on Magnetic Field Taper

## No $B$-field taper

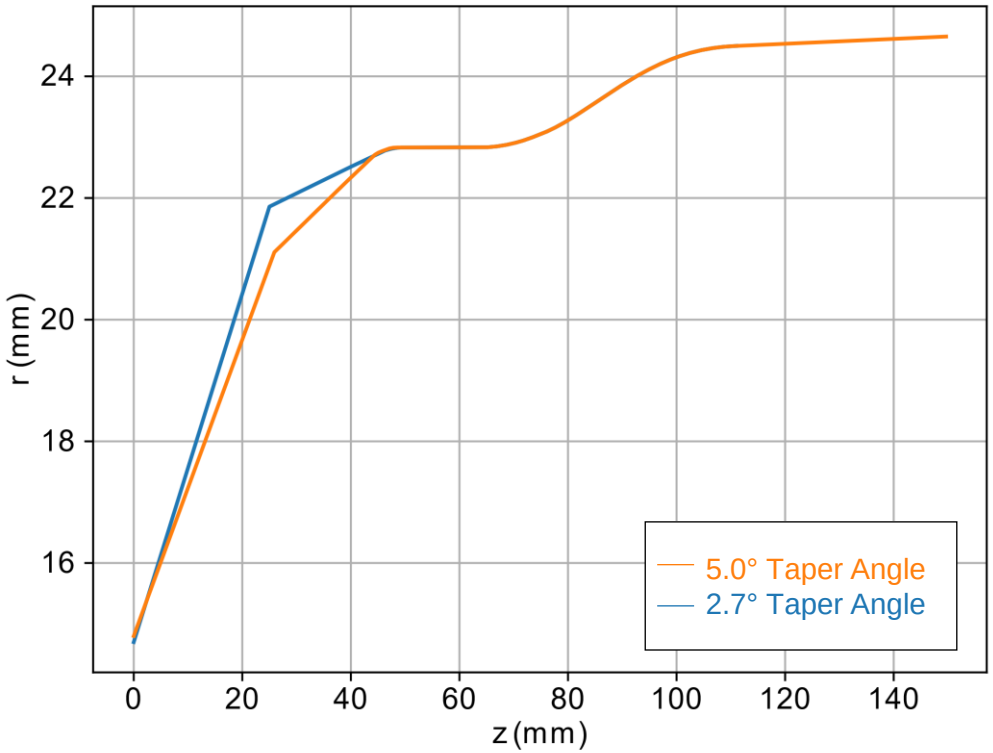



## Tapered $B$-field



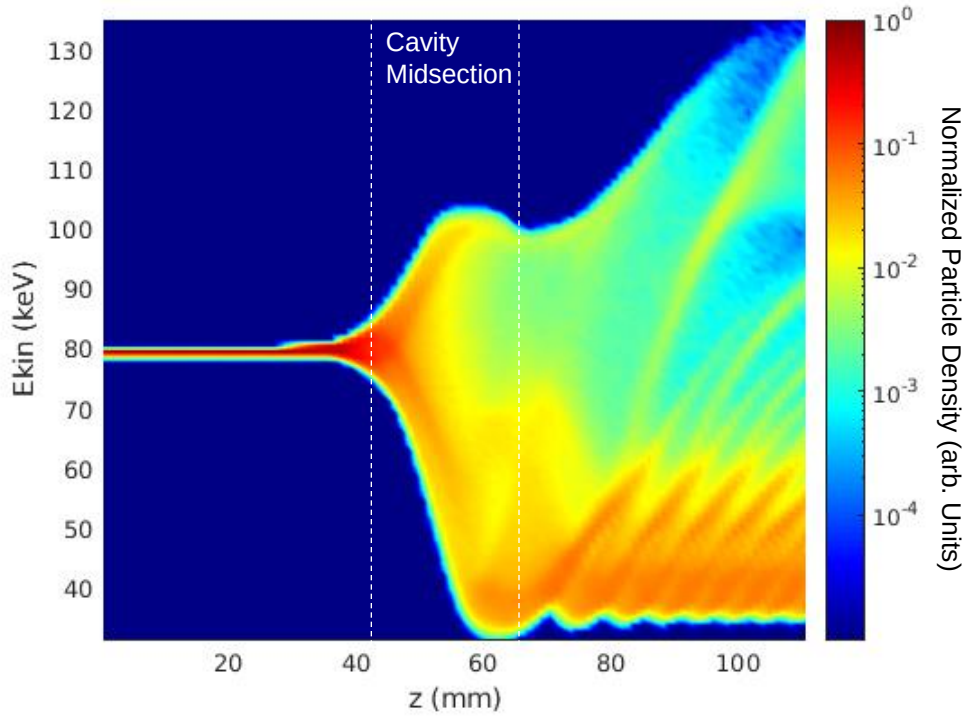
# New Down Taper and Spacer

- BW have lower cutoff frequency than operating mode
- BW penetrate “deeper” into the down taper/ spacer region
- Steeper down taper reduces distance between the cutoff radius of the BW and the operating mode

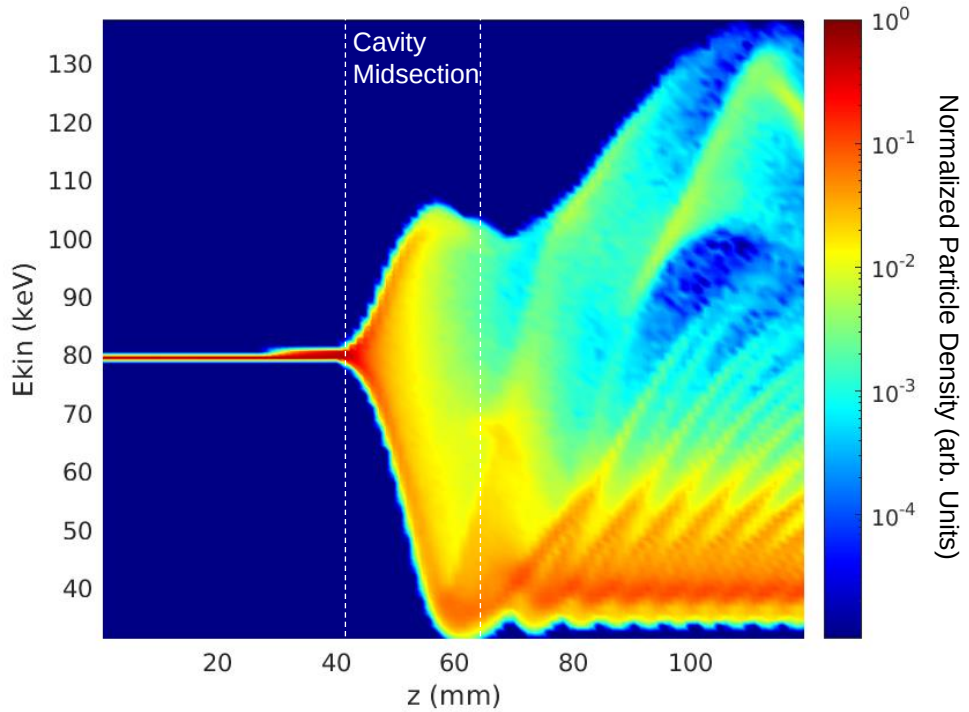


# New Down Taper and Spacer

## Original Geometry

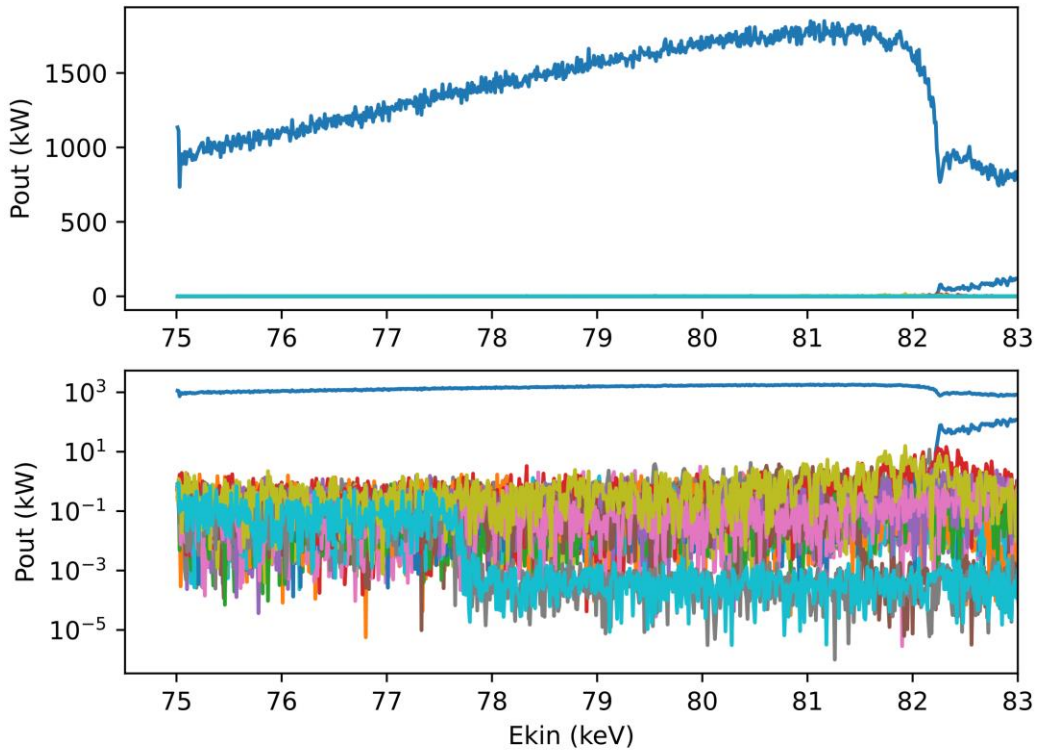



## Improved Down Taper



# New Down Taper and Spacer

- Influence of backward wave reduced significantly
- No BW excitation for $\alpha = 1.4$
- Even at $\alpha = 1.8$ only minor influence on the operating mode



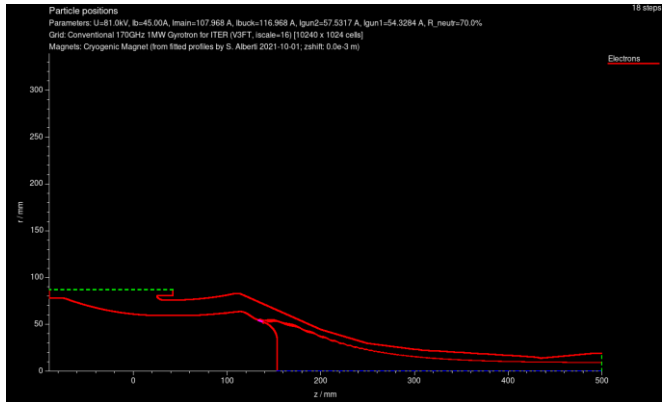
# Conclusion

- Parasitic backward waves can significantly degrade the beam quality before interaction with the operating mode
- The influence of the backward waves leads to reduced output power
- Three main strategies to prevent BW or mitigate their influence
  - Choose a low $\alpha$ operating point
  - A rapid decrease of the magnetic field leads to reduced BW excitation
  - Steeper design of the down taper region

# Thank You!

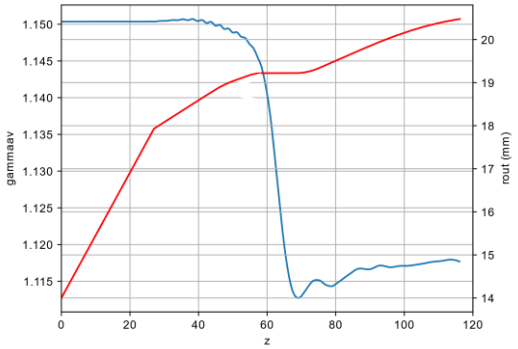
# Methods

Long Pulse – Gun Simulation for Beam Parameters

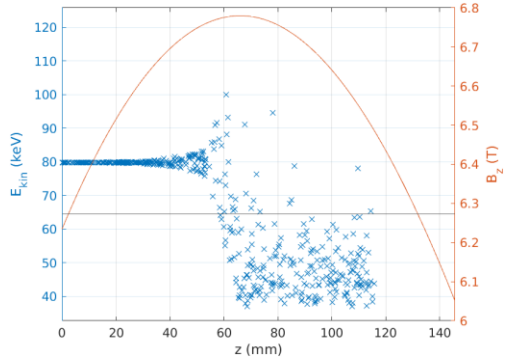



Short Pulse – Beam Parameters by Approximated Schottky Emission

Interaction Simulation and Optimization with simplified Model

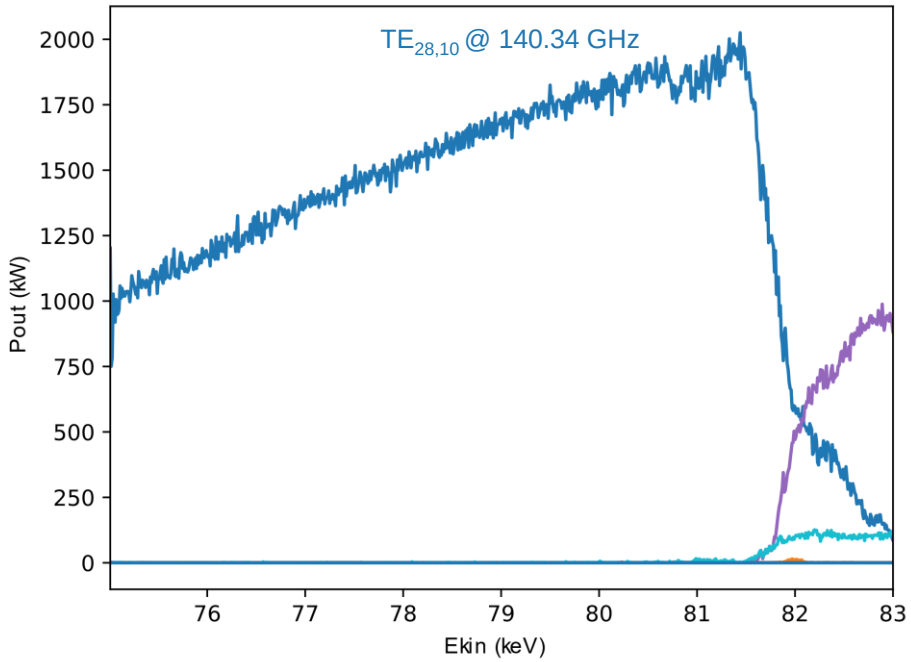



Verification with Particle-in-Cell simulation tool

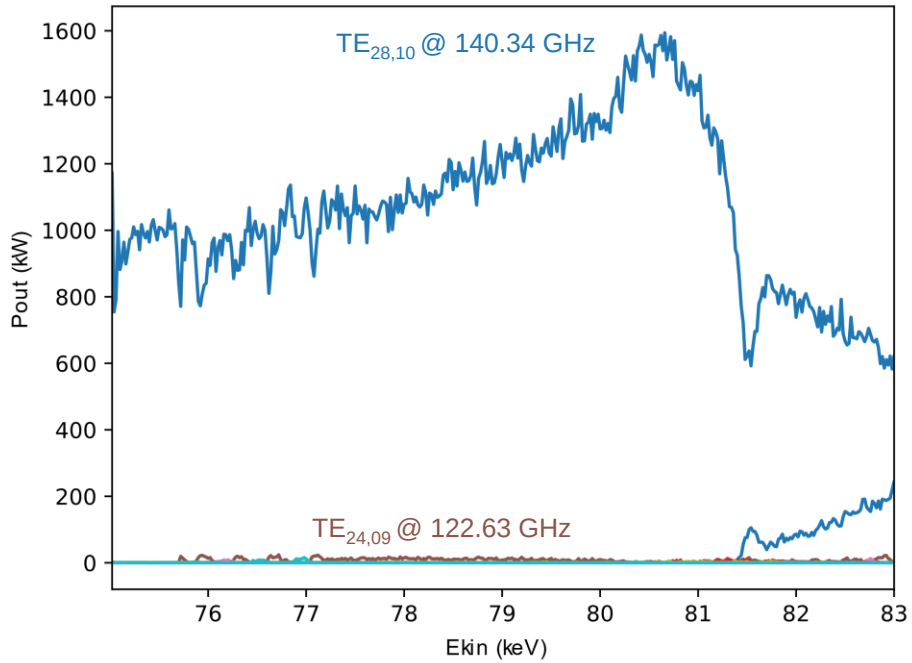


# Effect on Output Power

## Without Backward Waves




## With Backward Waves



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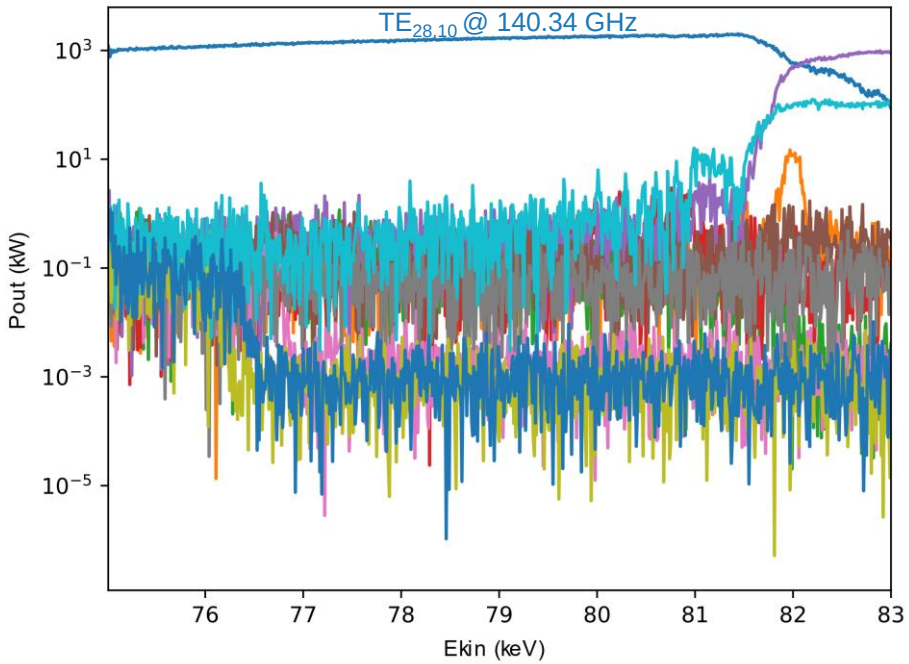
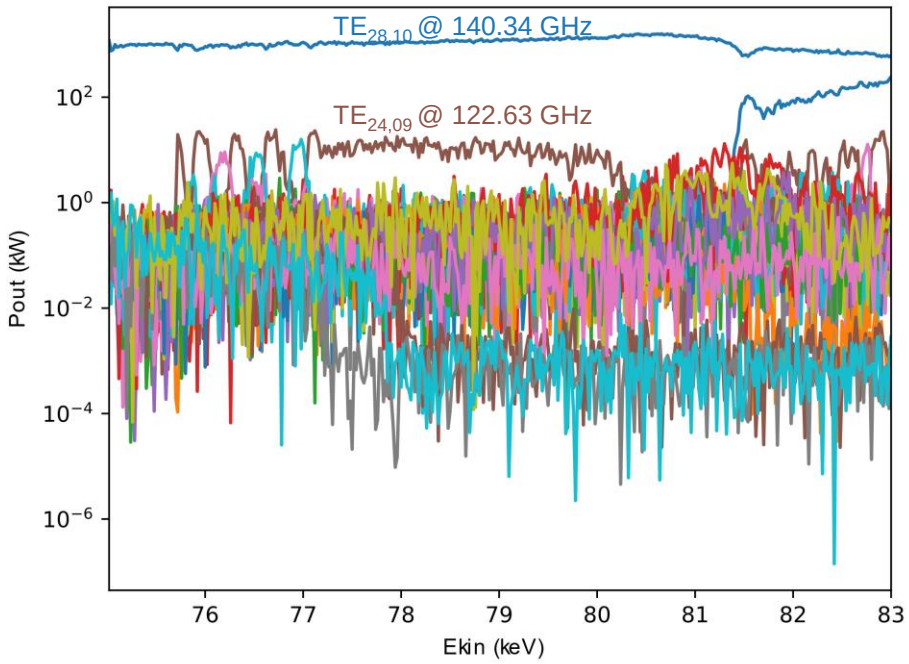
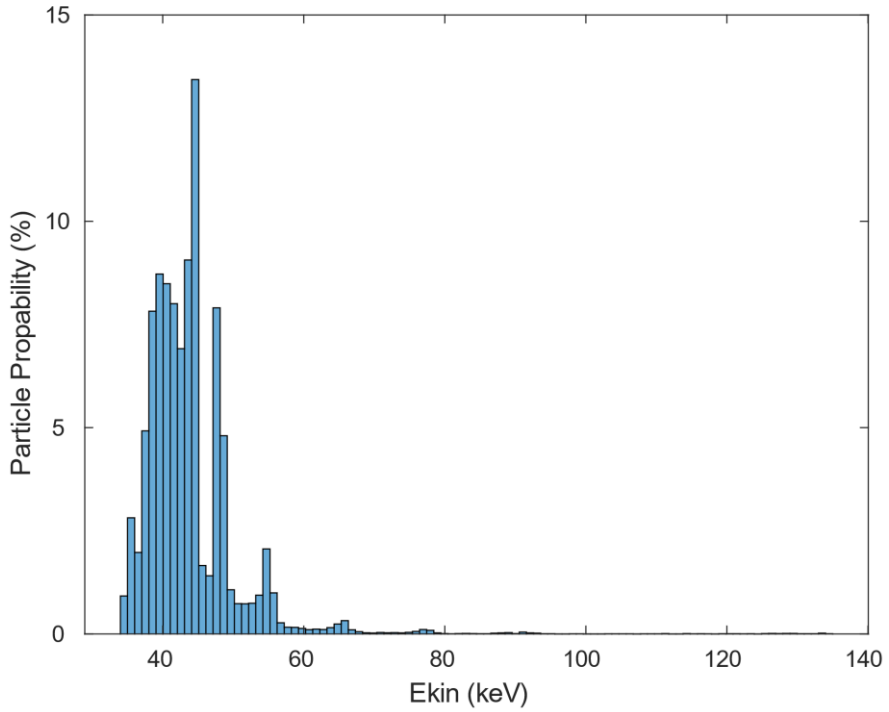



## With Backward Waves



# Particle Disribution

## Without Backward Waves

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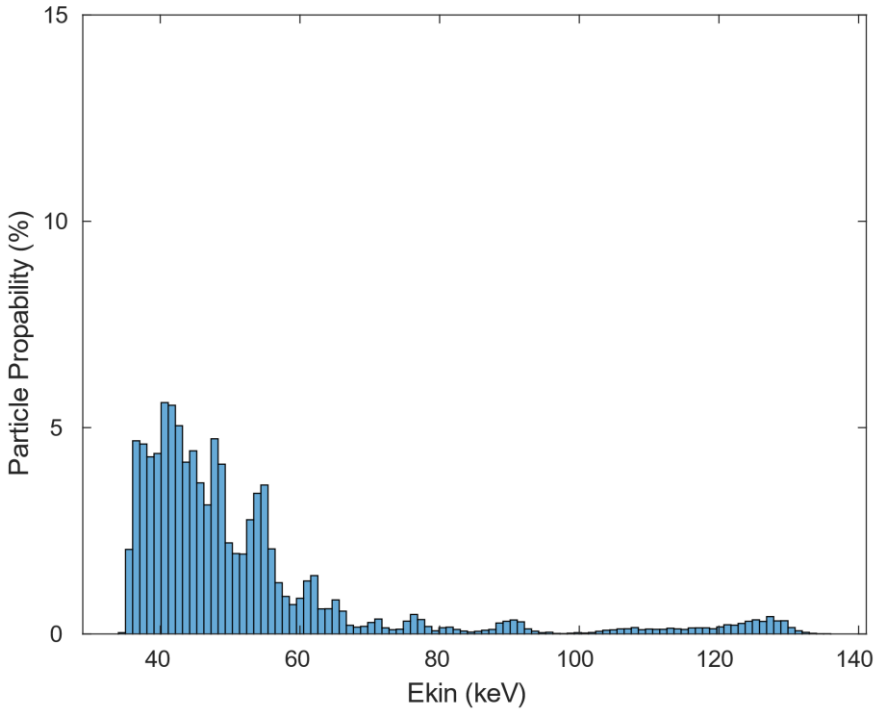
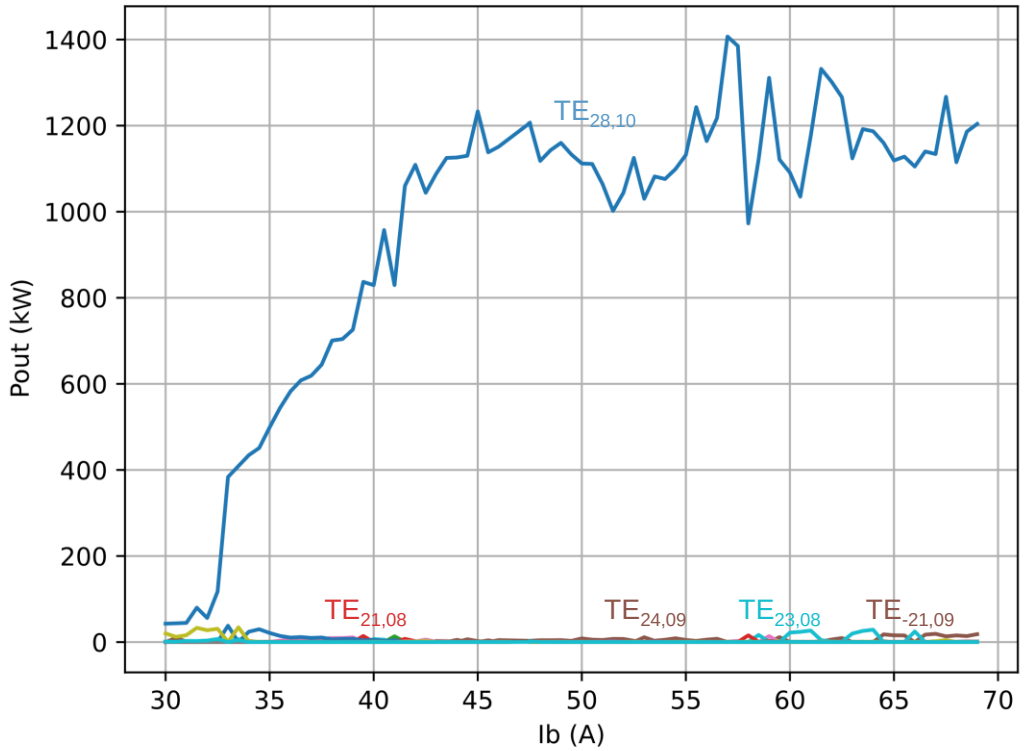


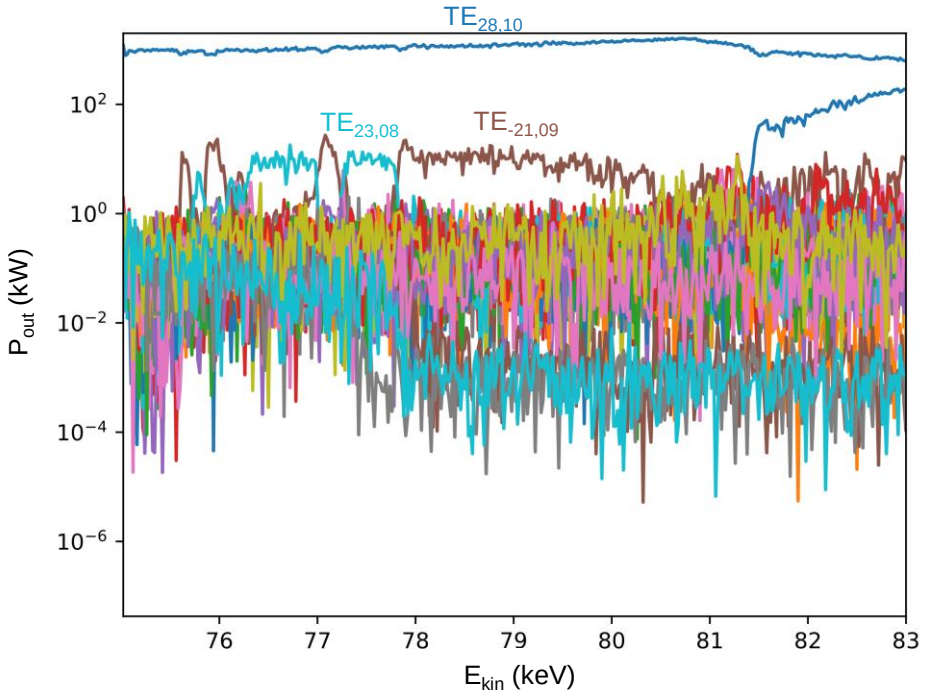
# Dependence on Beam Current

- Backward wave almost independent on beam current
- Output power of operating mode varies with BW power



# Dependence on Magnetic Field Taper

## No $B$-field taper

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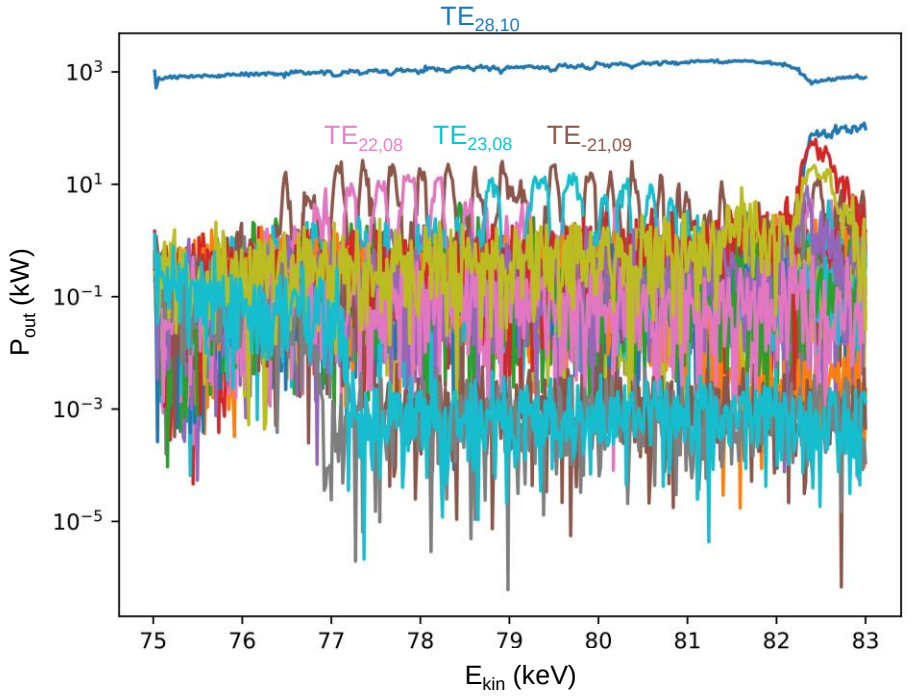
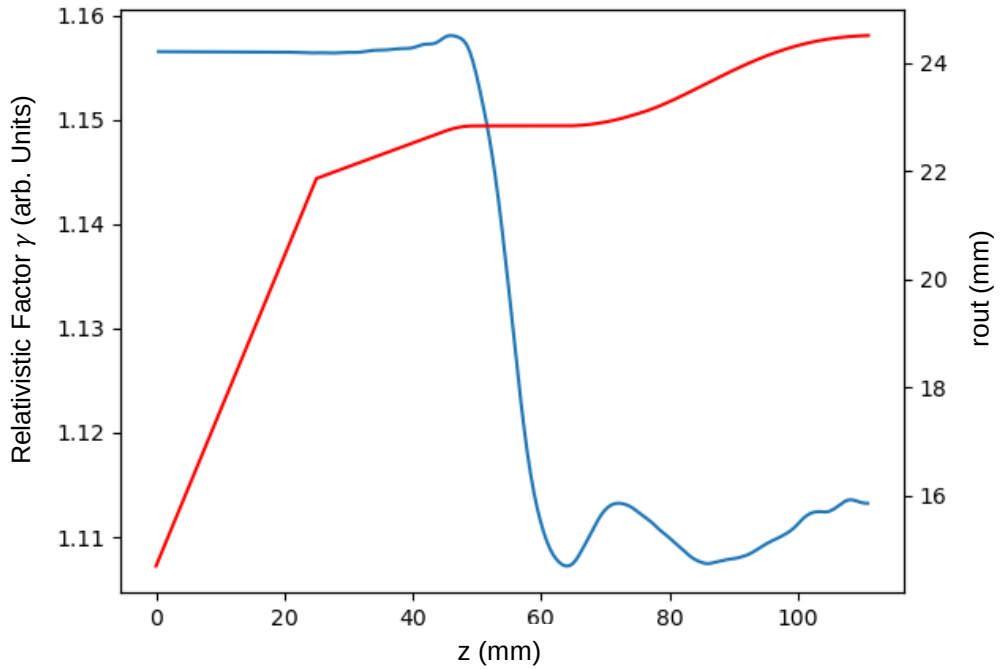
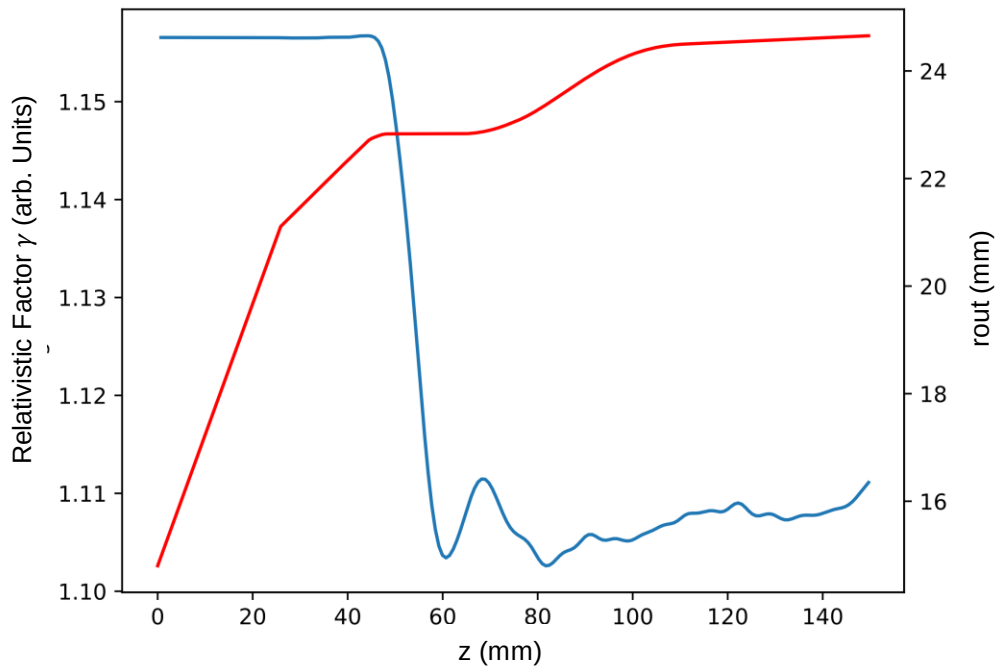


# Solution: New Down Taper and Spacer

## Original Geometry




## Improved Down Taper



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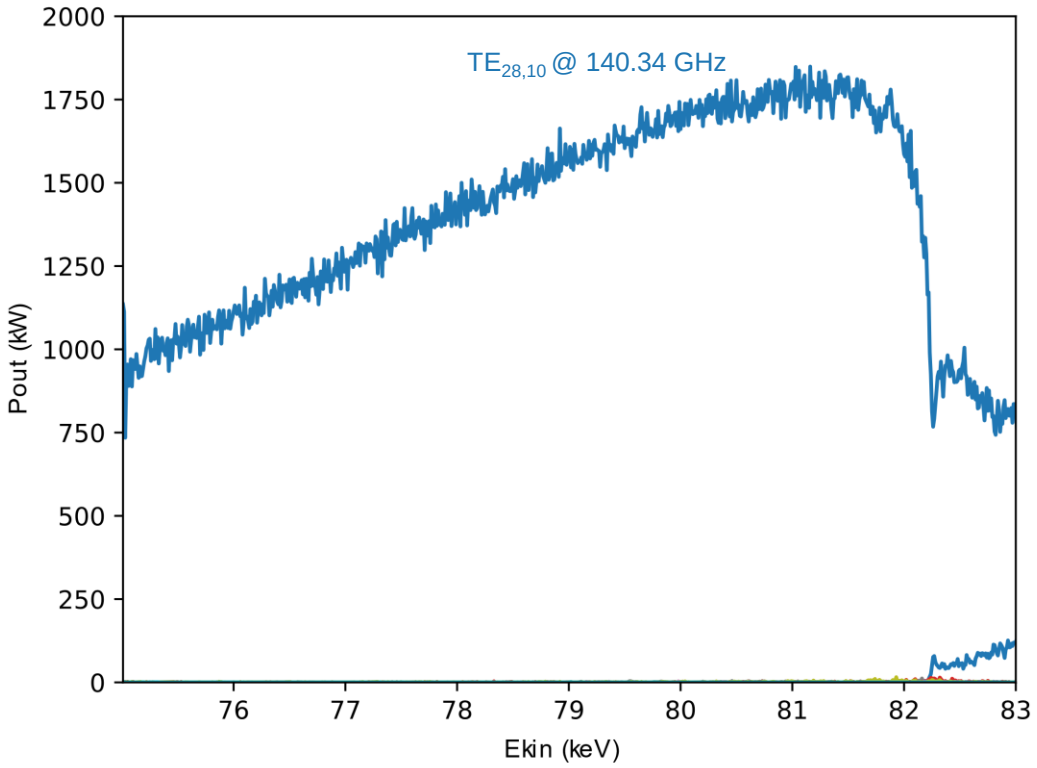


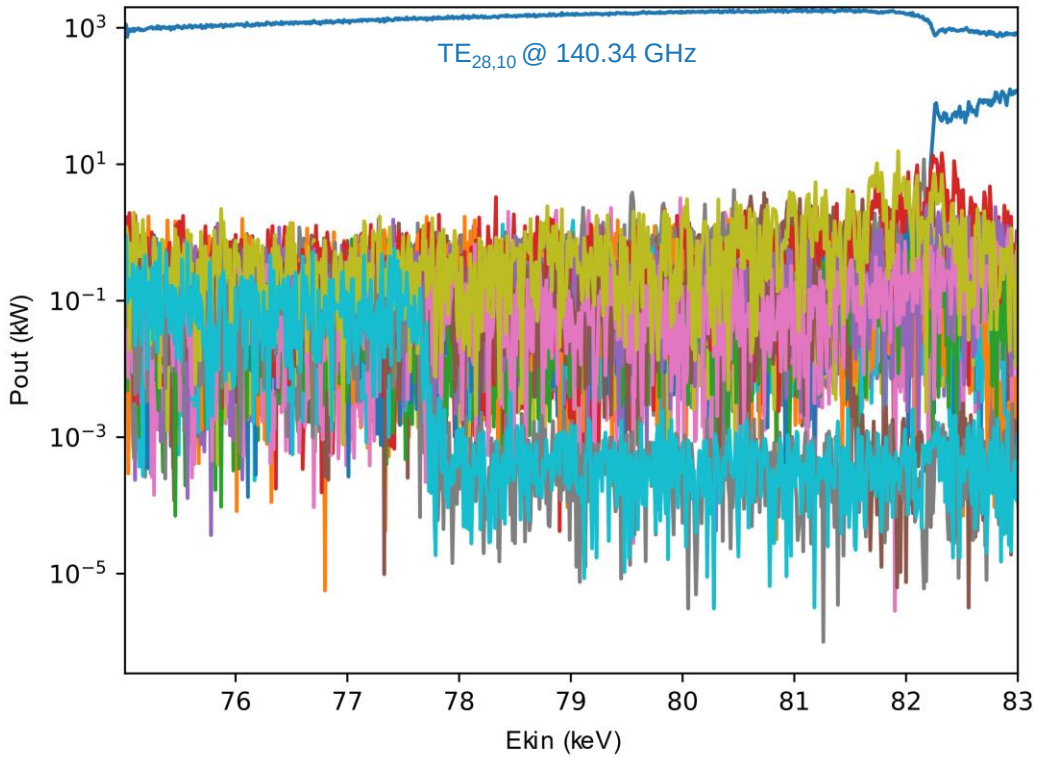

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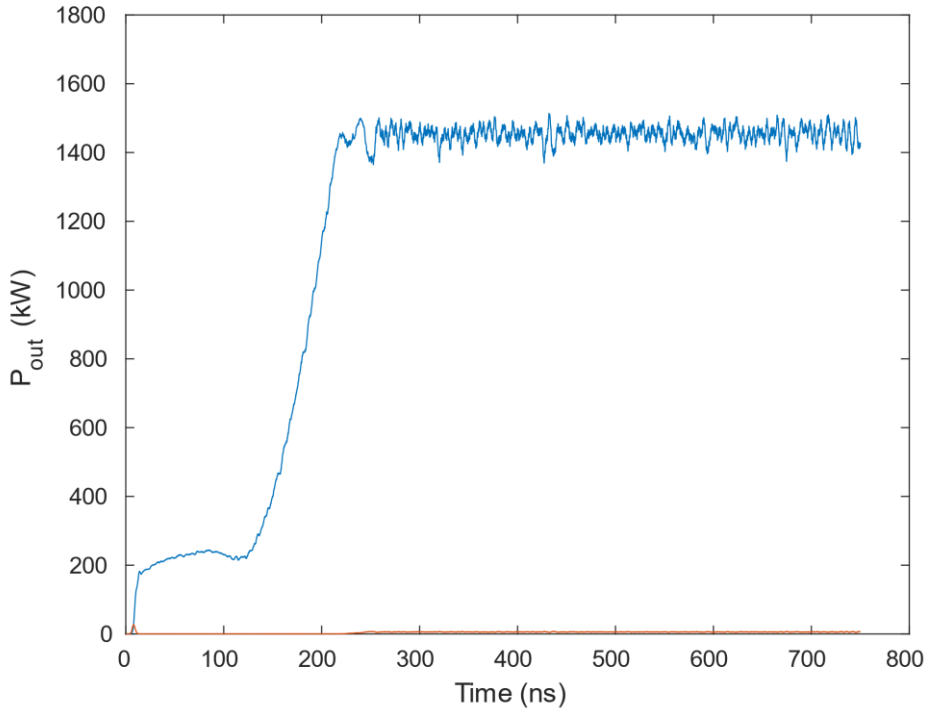


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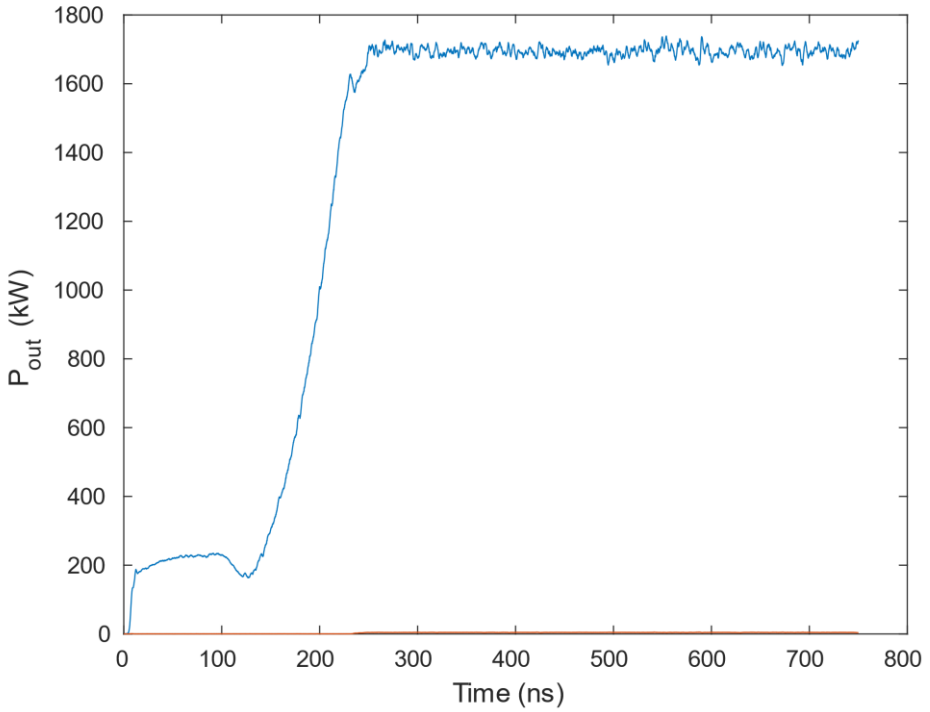

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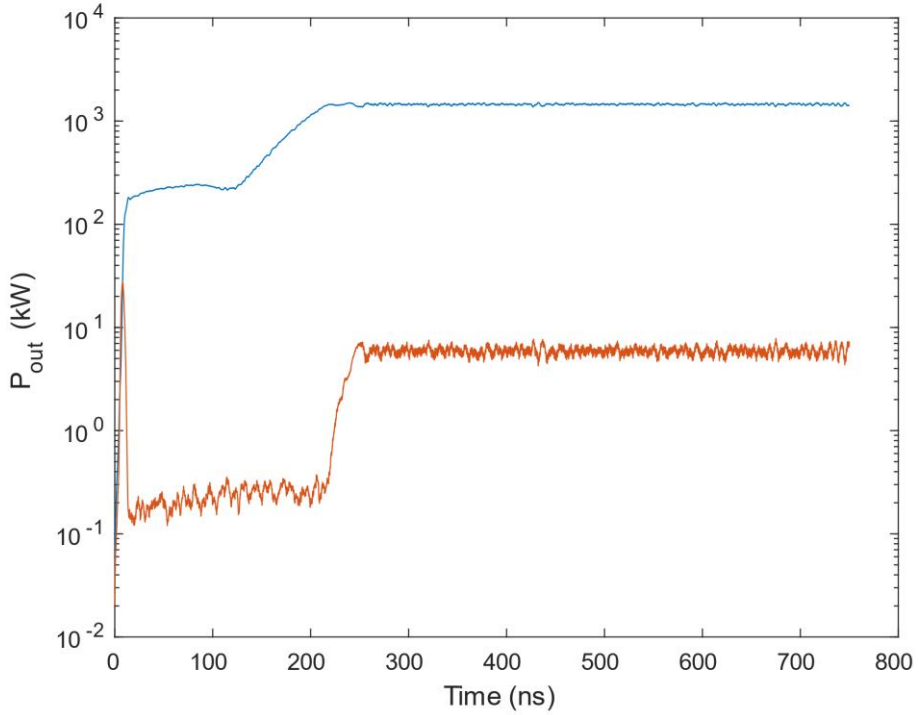


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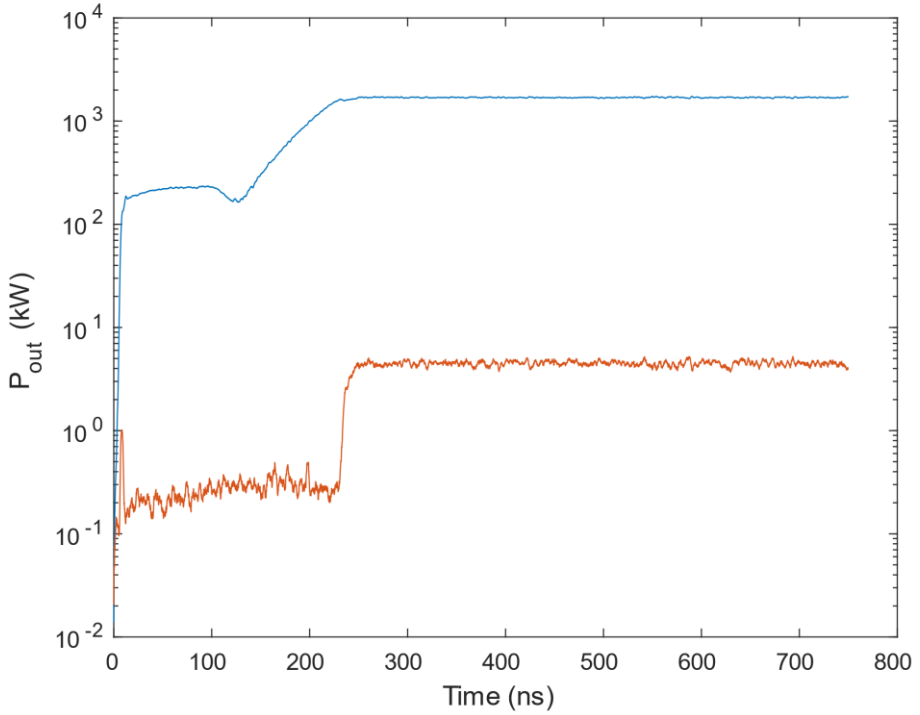

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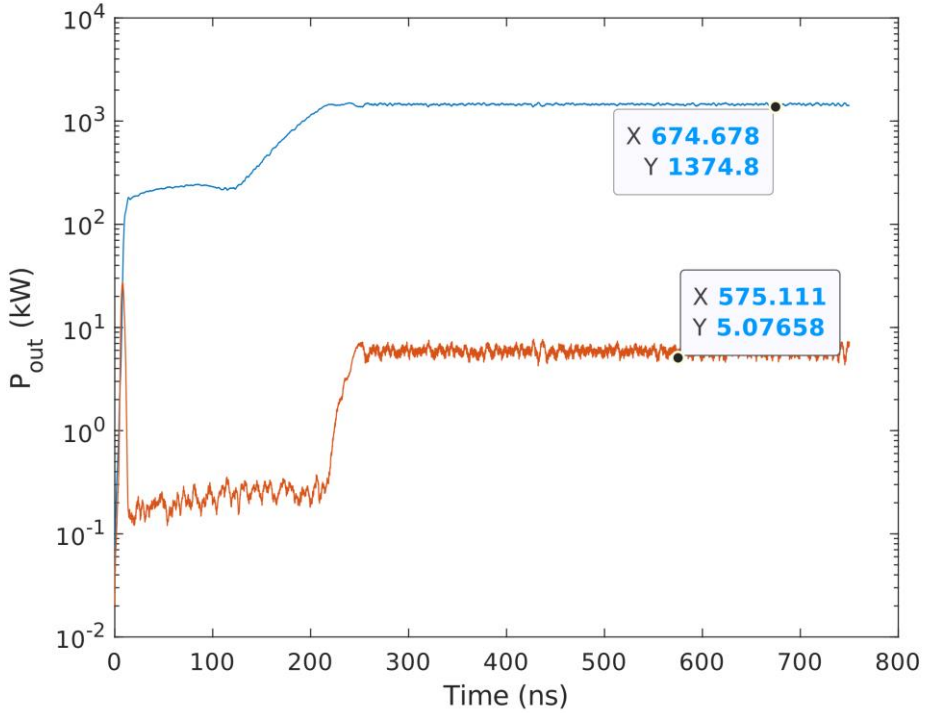


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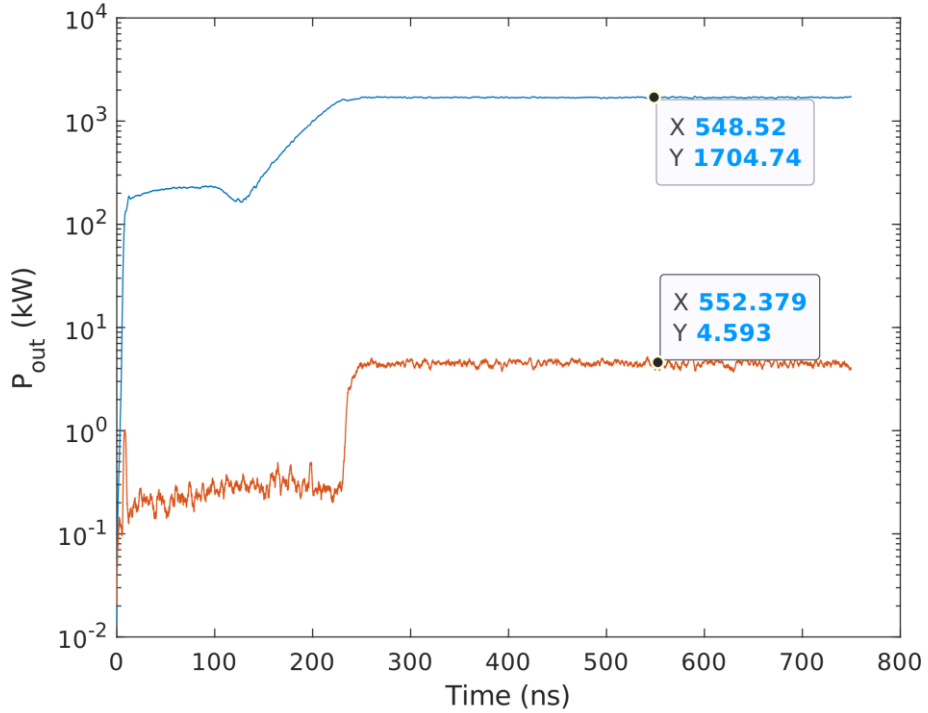

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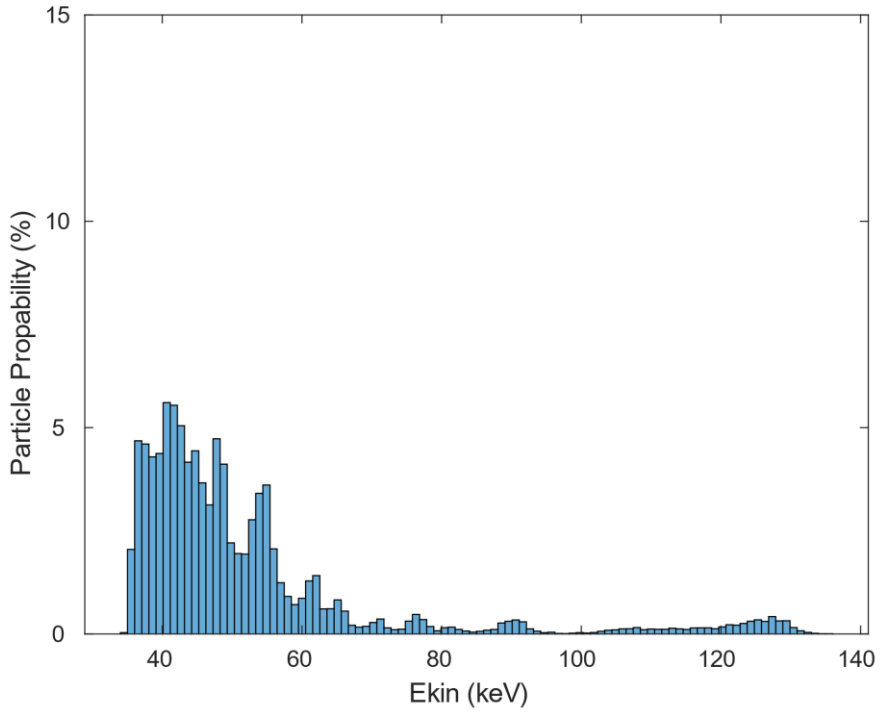


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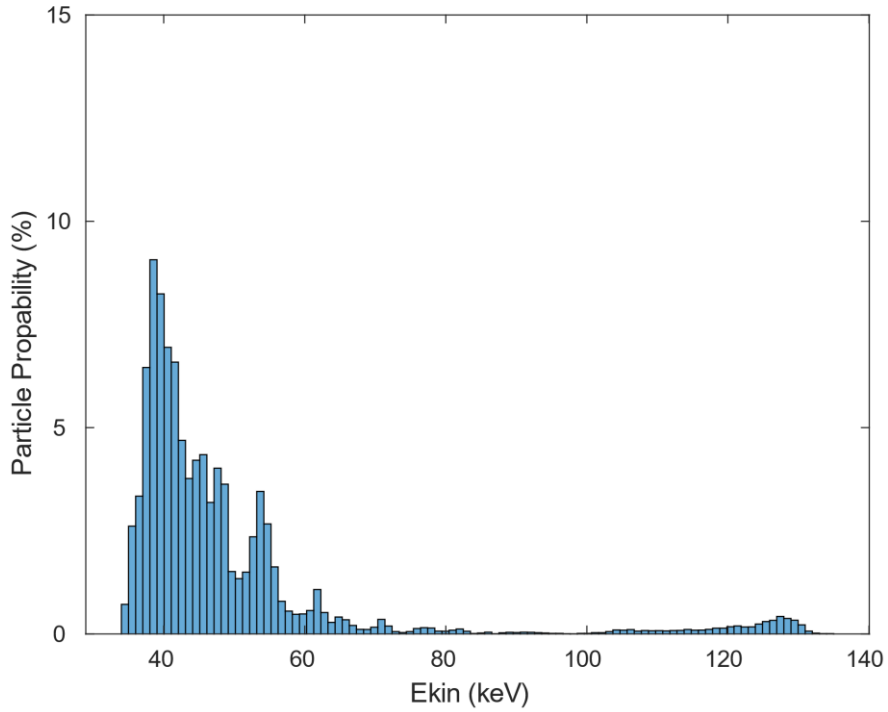

# Strategies to Suppress Backward Waves

- Lower risk of excitation
  - Choose low $\alpha$ operating point
  - Taper magnetic field after the cavity
- Mitigate the parasitic influence
  - Design cavities with a steeper down taper