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Ongoing developments for the KIT 2-MW 170-GHz Coaxial Cavity Gyrotron Prototype

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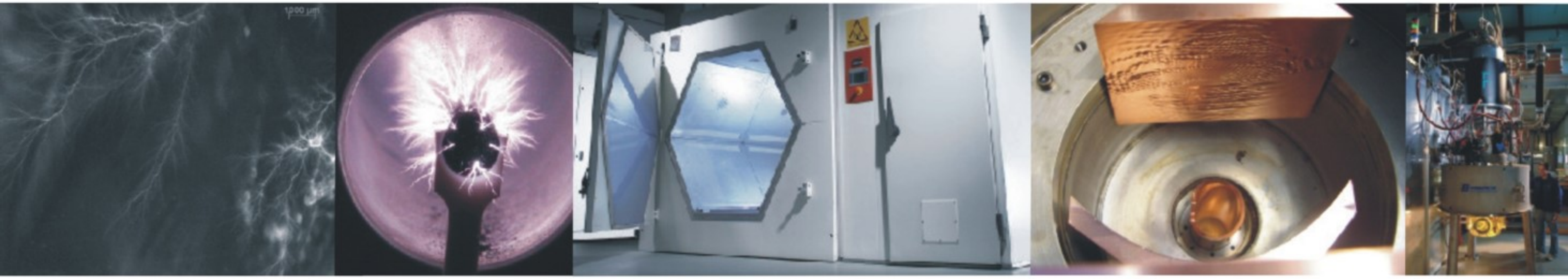


Outline

Part 1

- Motivation and Today's Constraints of Electron Guns
- Final Gun Design
- Tolerance Studies and Solutions

Part 2

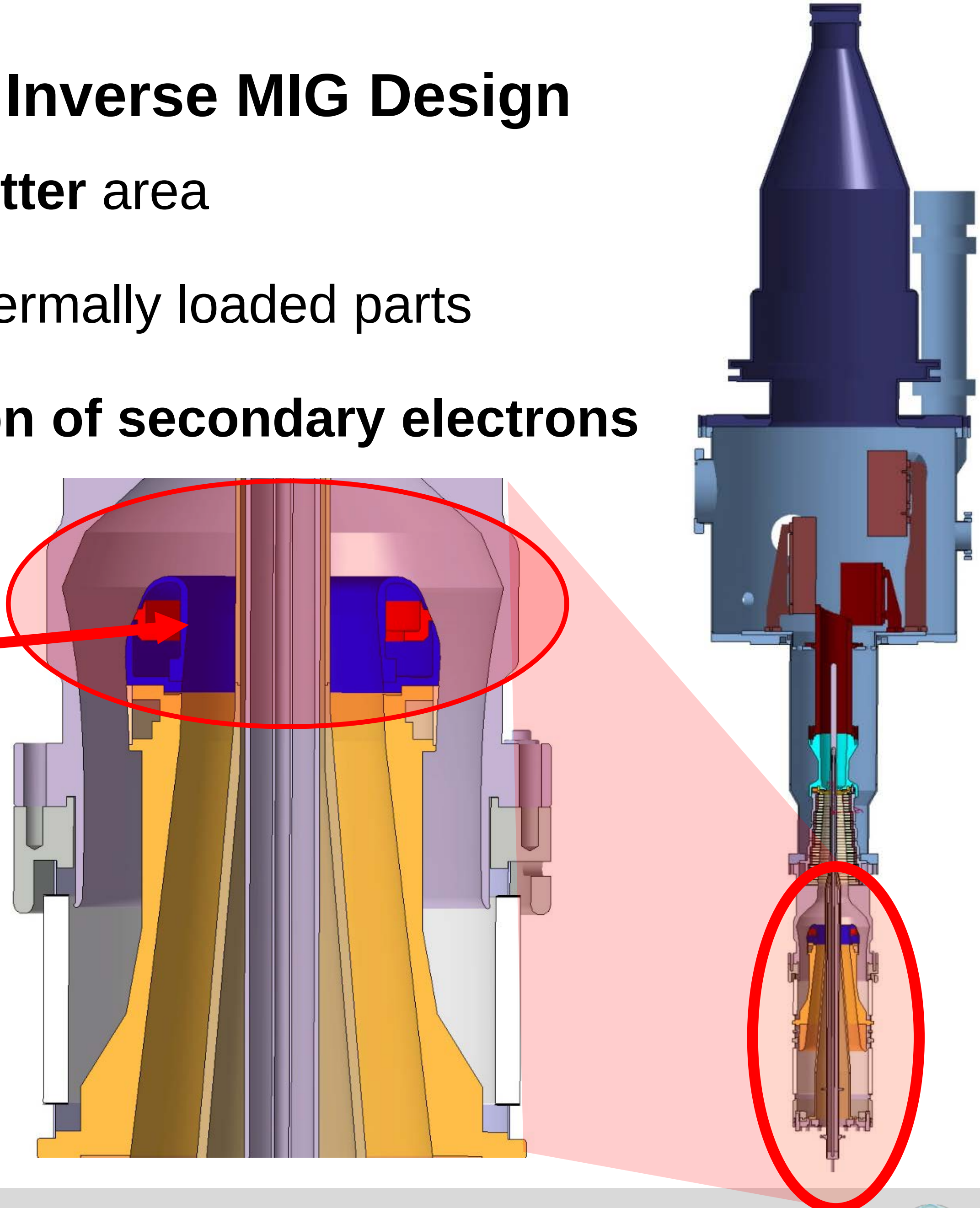
- KIT 2 MW Long Pulse Design
- Conclusion

Motivation for New Inverse MIG Design

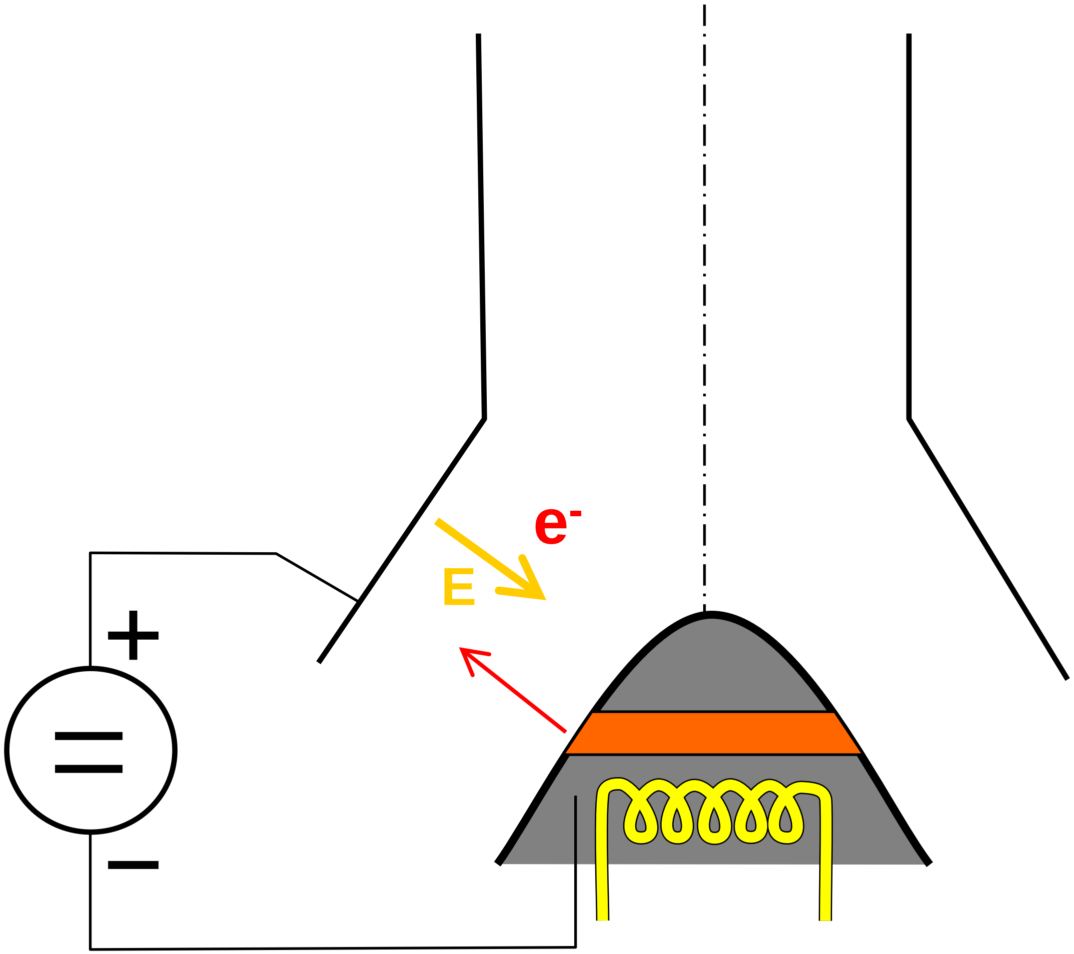
- **Larger** effective **emitter** area
- **Direct cooling** of thermally loaded parts
- Efficient **suppression of secondary electrons**

Area of concern:

Spatial arrangement of emitter ring, anode and related cooling concept



Introduction: Generation of Annular, Helical Electron Beam



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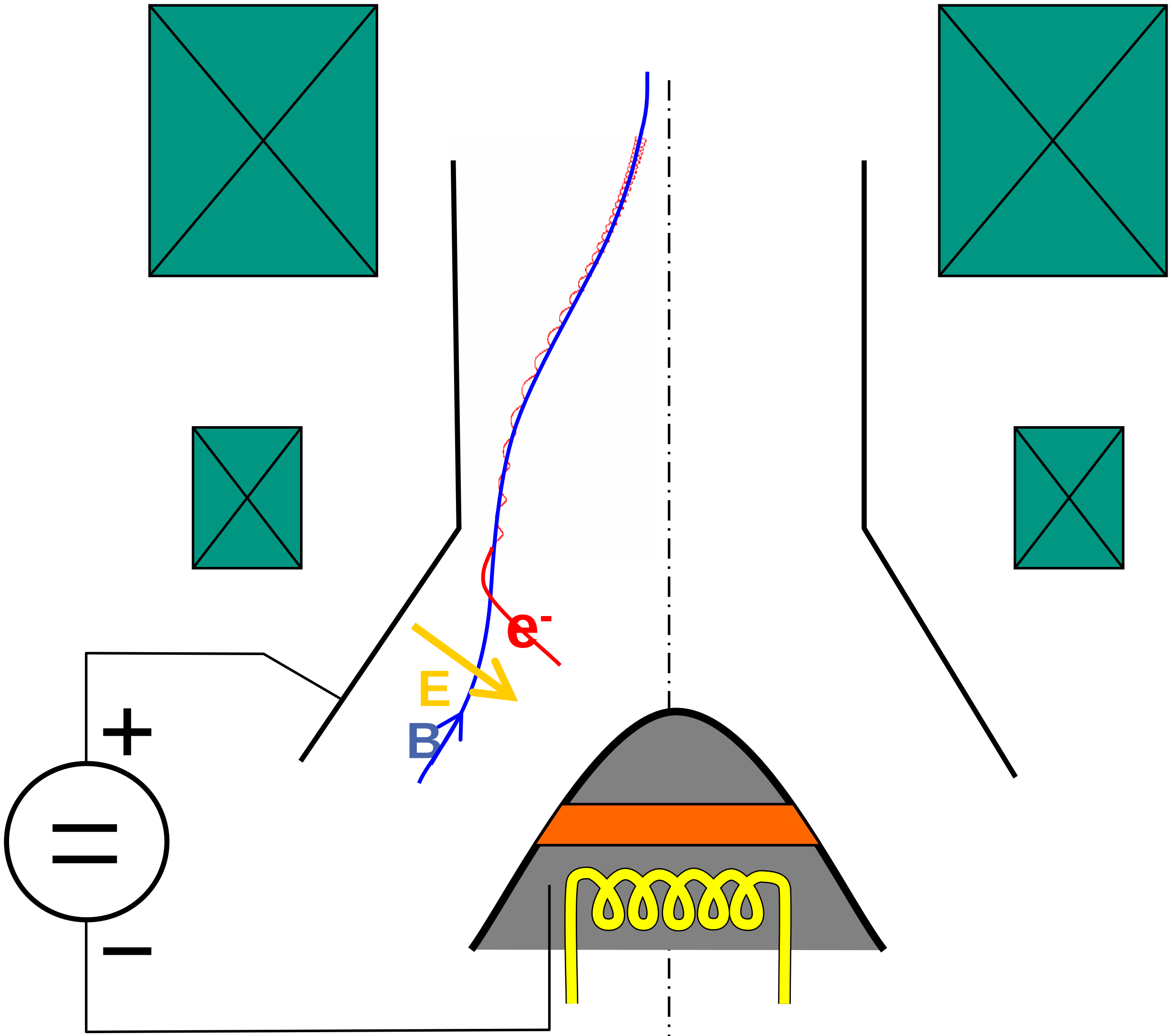

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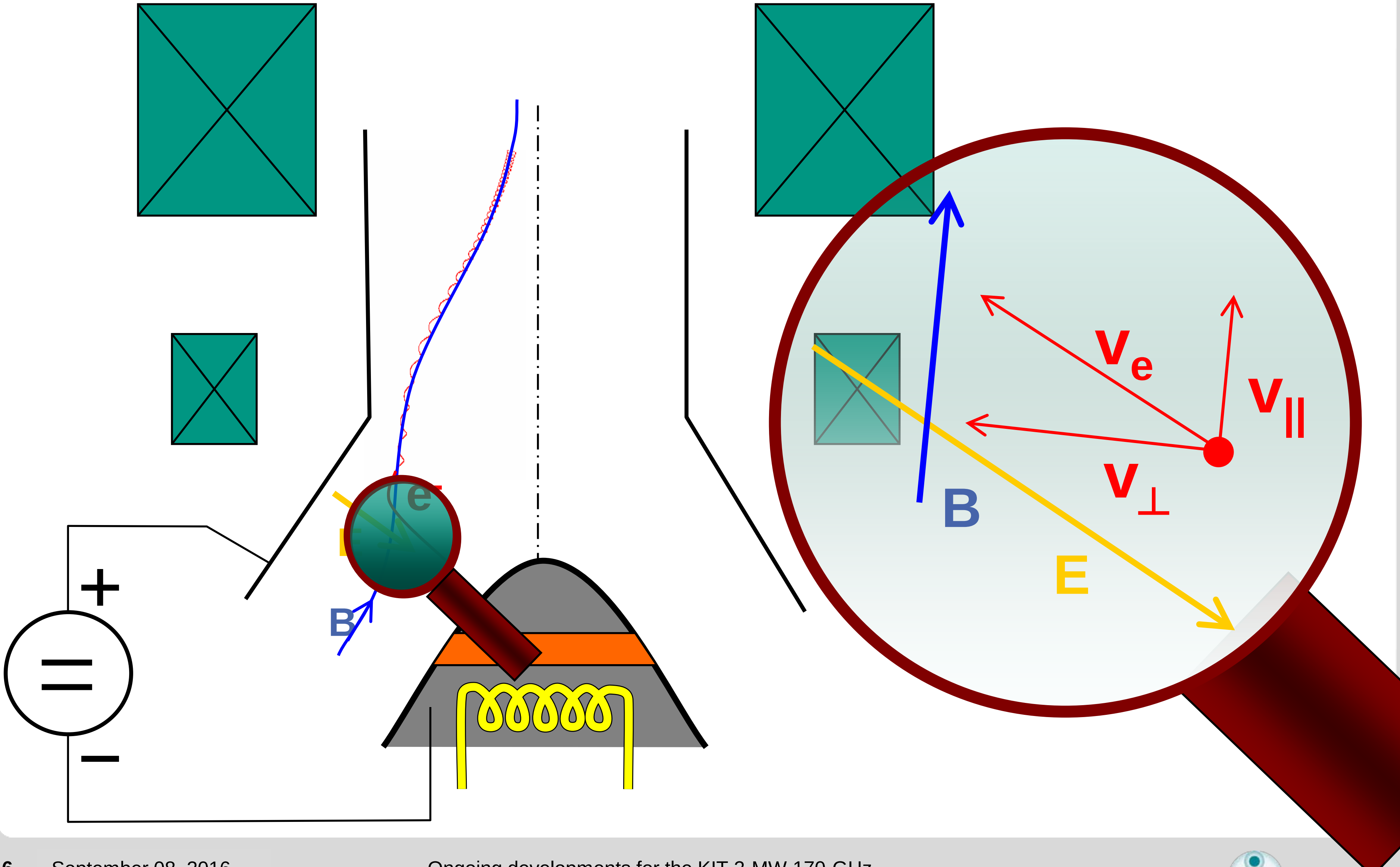

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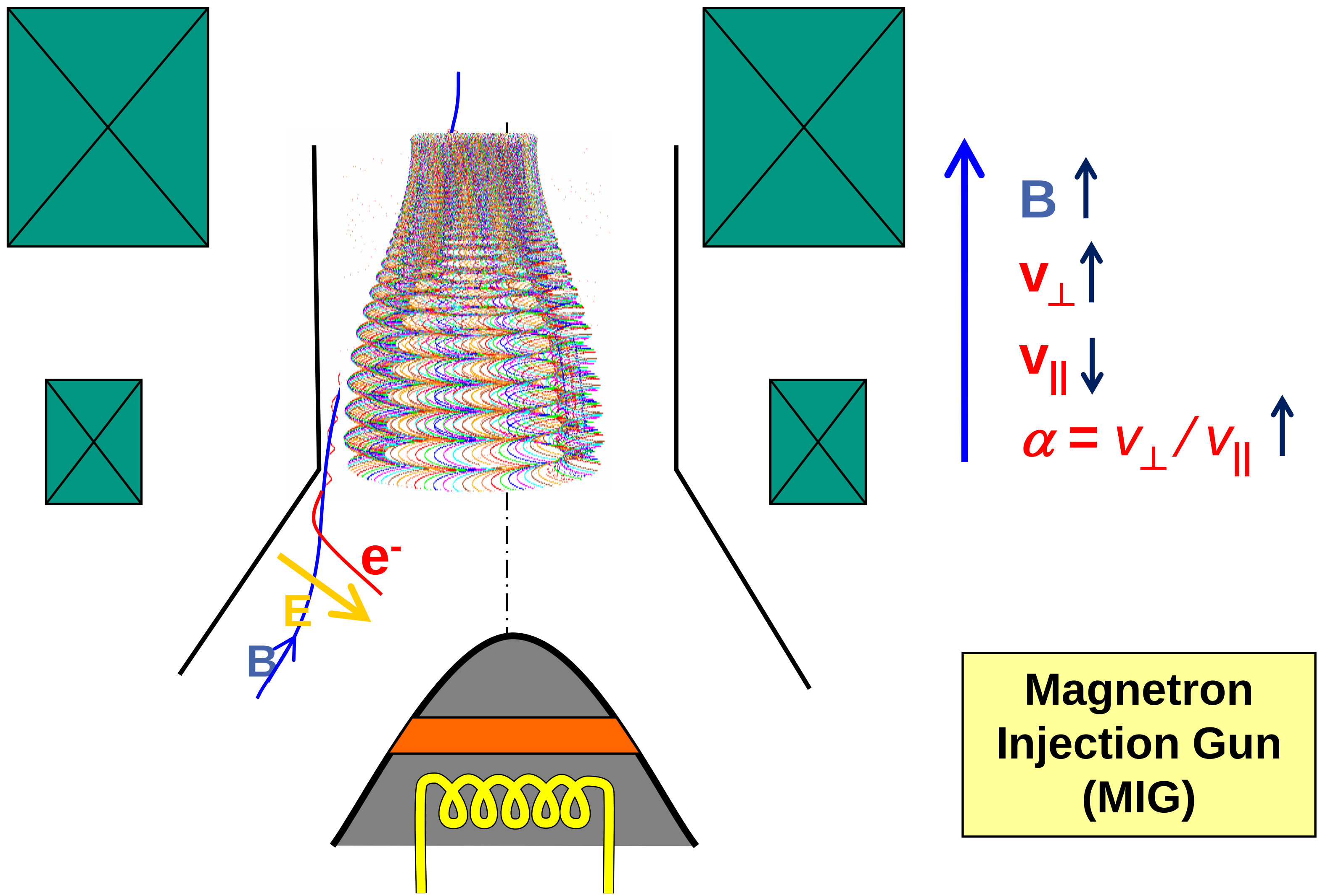


Magnetron Injection Gun (MIG)

Today's Constraints for Gyrotron Emitters

Emitter current of a gyrotron is defined as:

$$I_b = 2\pi \cdot \sqrt{b} r_b \cdot \Delta l_e \cdot J_e$$

- **Emitter current density is limited by technology**

  → for reasonable life time $J_e < 4$ A/cm²

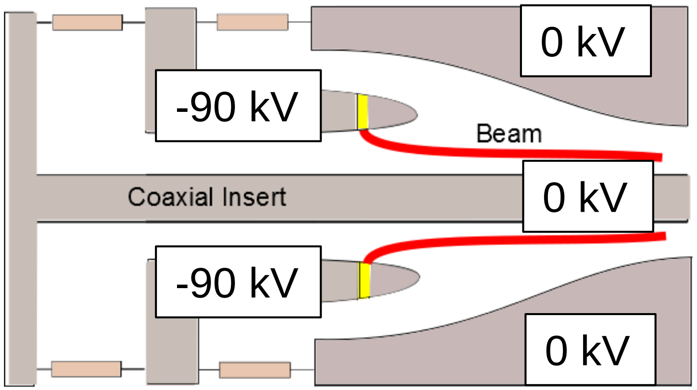
- **MIG diameter is limited by size of magnet bore hole**

  → limited emitter radius $r_e = \sqrt{b}\, r_b$ dependent on the magnet

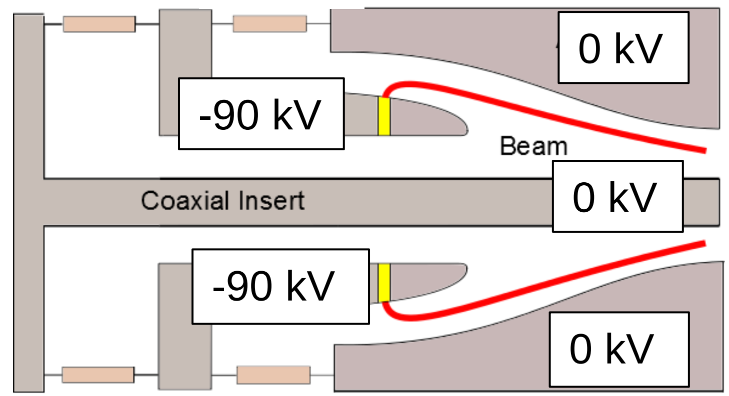
- **Beam thickness is limited by RF-beam interaction**

  → $\Delta r_b < \lambda/5$ at the cavity center, with $\Delta r_e = \sqrt{b}\, \Delta r_b$

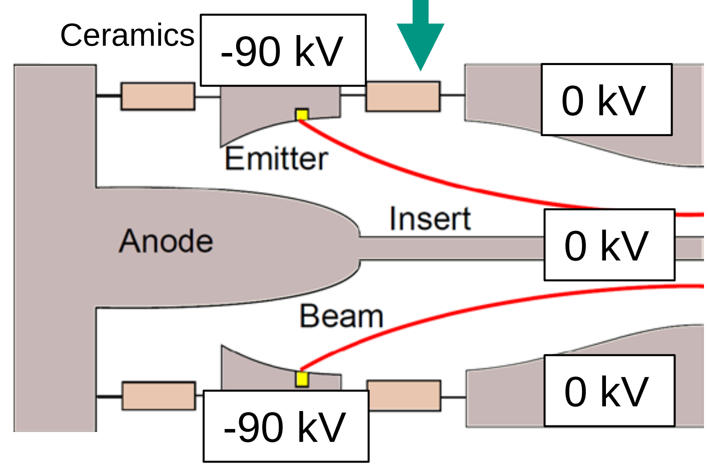
Conclusion: Alternative MIG Concept



V.K. Lygin, et al., “Inverse magnetron injection gun for a coaxial 1.5 MW, 140 GHz gyrotron” Int. J. Electronics, (79), pp. 227-235, 1995.



B. Piosczyk, "A novel 4.5 MW electron gun for a coaxial gyrotron" IEEE Trans. Electron Devices, vol. 48, 2001, 2938-2944



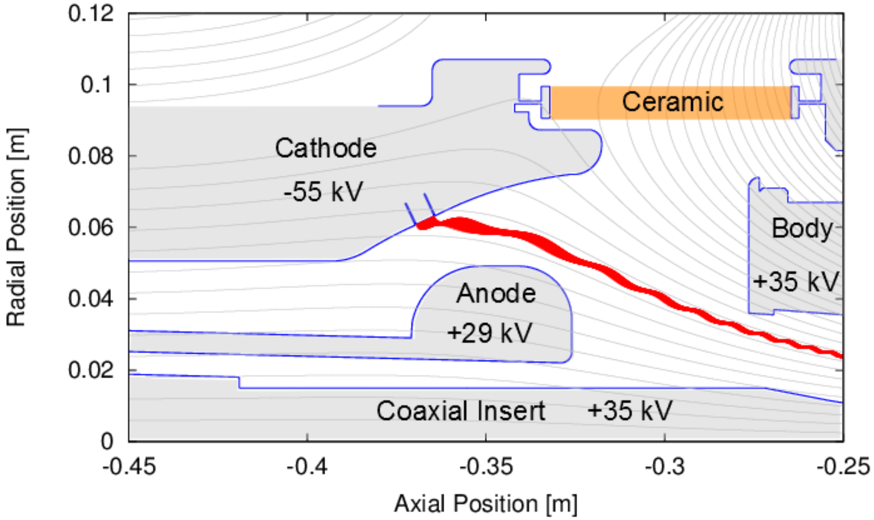
R. Advani, et al., Experimental Investigation of a 140-GHz Coaxial Gyrotron Oscillator, IEEE Transactions on Plasma Science, Vol. 29, No. 6, December 2001

Result:

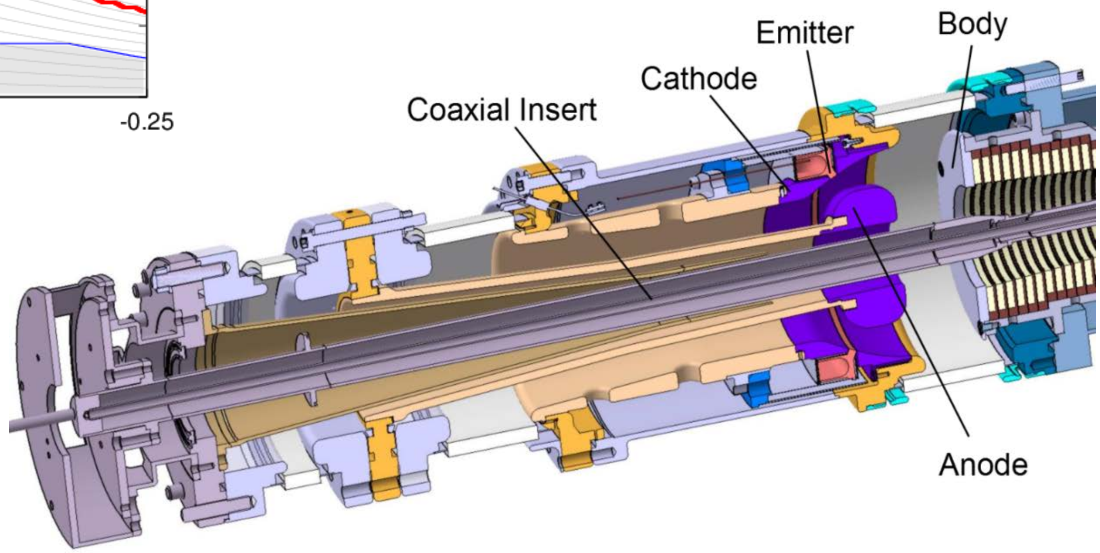
- **Sandwich construction** related to electric potential **removed**!
- **Direct cooling of cathode parts** next to emitter ring achieved!

Final IMIG Concept

Triode configuration including efficient suppression of trapped electrons

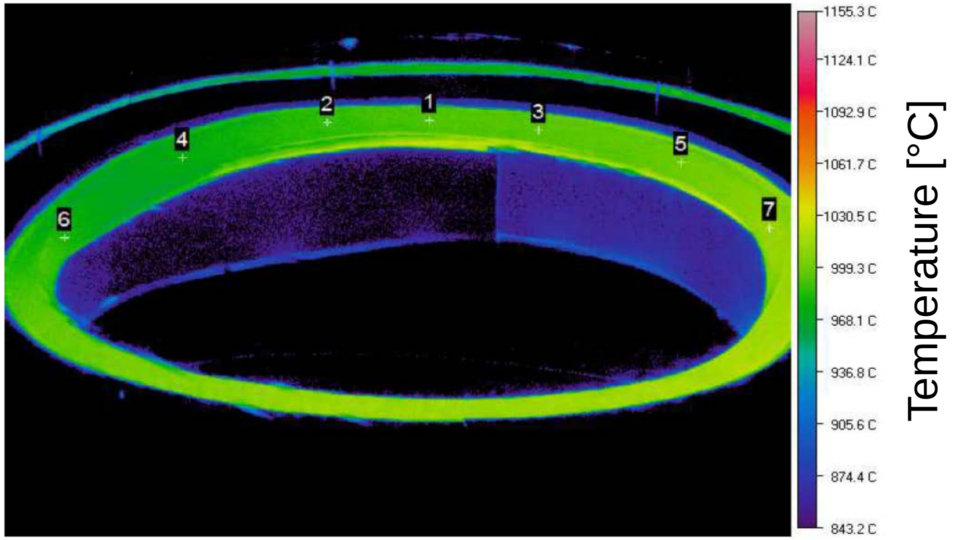


S. Ruess, I. Gr. Pagonakis, „An Inverse Magnetron Injection Gun for the KIT 2-MW Coaxial-Cavity Gyrotron", IEEE Transactions on Electron Devices, **63**, 2104-2109, 2016, DOI:10.1109/TED.2016.2540298



- **Beam Parameters:**
  - Beam radius r_b= 10 mm
  - Pitch factor $\alpha = {}^{v_\perp}/_{v_{||}} \sim 1.3$
  - Velocity spread $\delta\beta_t$ = 2.2 %

First Results of the IMIG Emitter



- Emitter Parameters:
  - Diameter d_{emt} = 124 mm
  - Angle φ_{emt} = 25°
  - Thickness Δl_e = 5 mm
- Measured temperature deviation of ±7°C.

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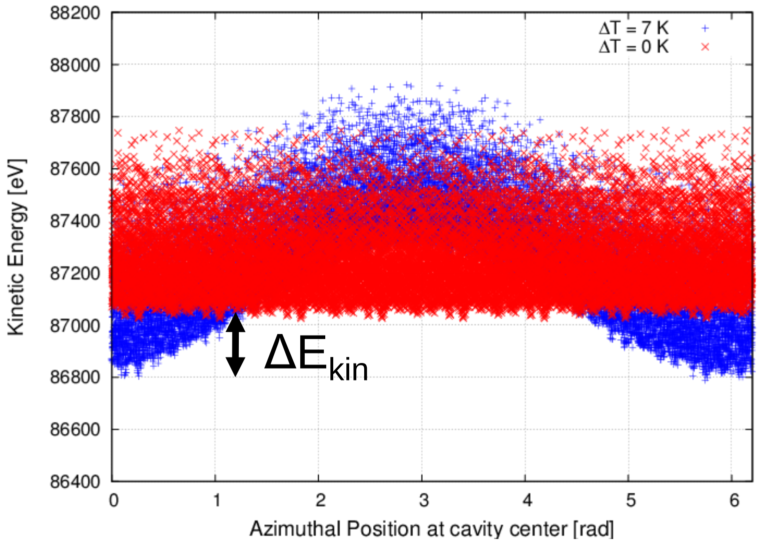
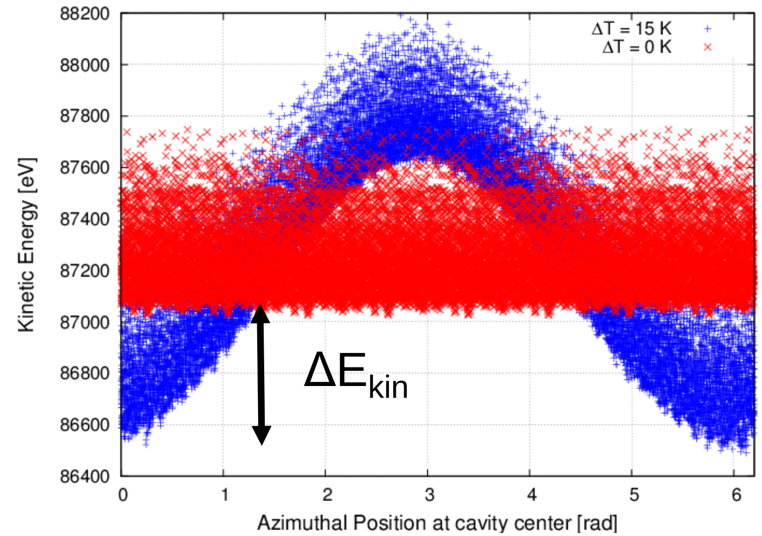
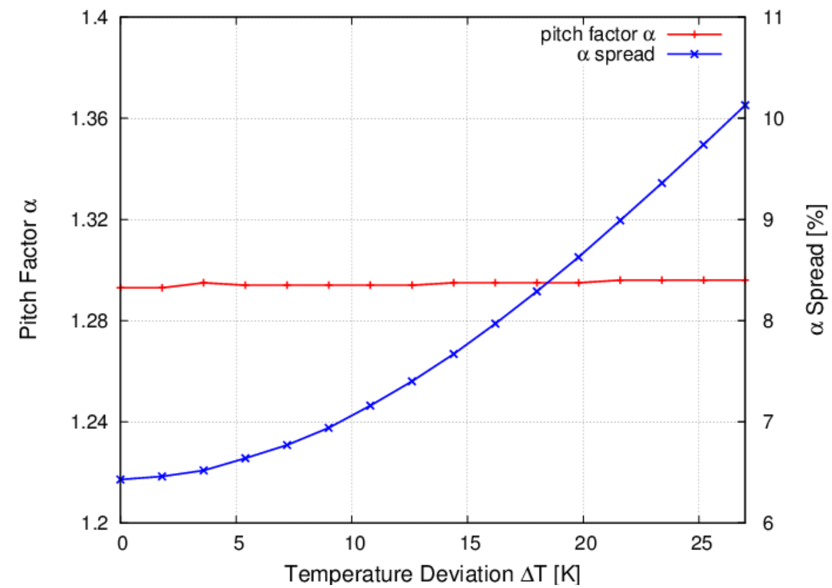
Emitter manufactured by Ceradyne Inc., D. Busbaher

Influence of the Emitter Temperature Inhomogeneity

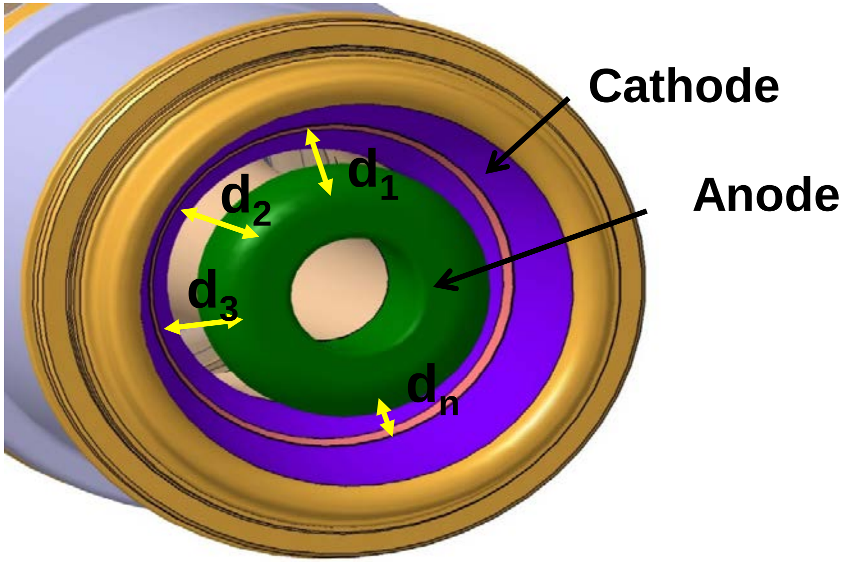




- Beam parameters depends strongly on the temperature distribution
- Inverse emitter shows excellent temperature distribution of ± 7°K (current emitter ±15 K)



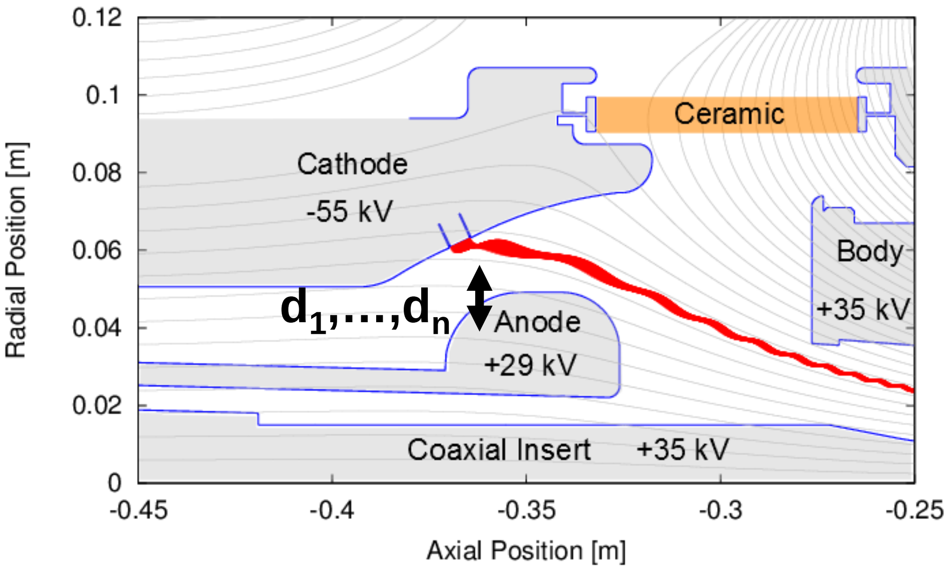
Most Critical Element in the Selection of the Material Composition



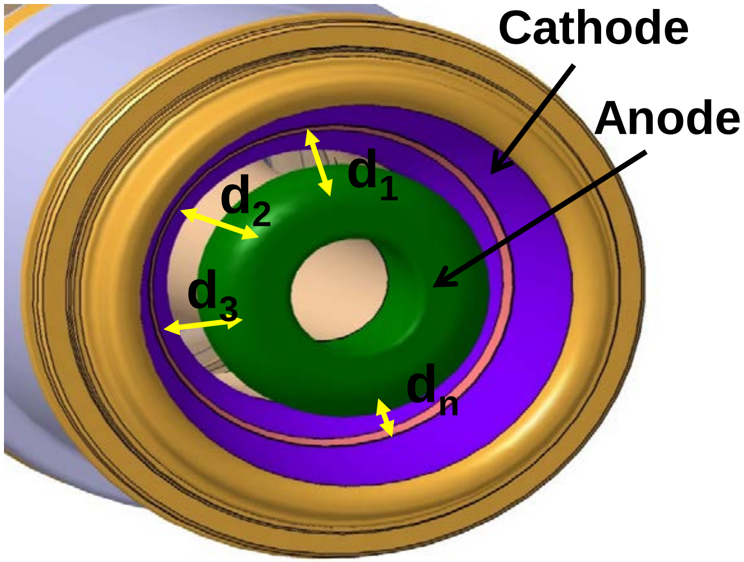
- Requirements
  - Small anode misalignment
  - Low temperature of the neighboring emitter regions
- Requirements for MIG materials
  - High stability
  - Very low thermal expansion
  - High thermal conductivity
  - Weldable

Transformation of 2D into 3D Model

Process:



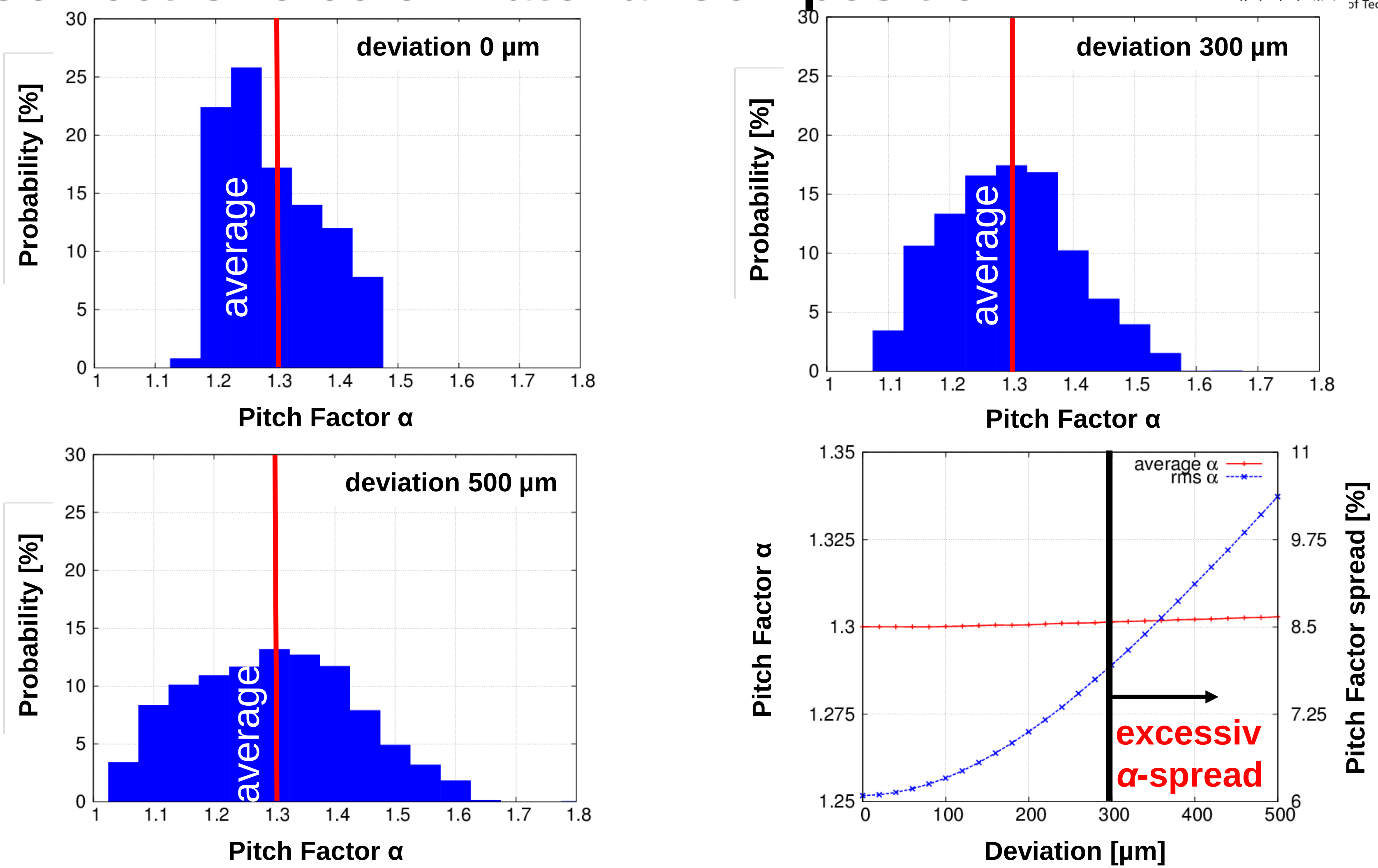
2D Model



3D Model

Objective:
Calculation of the maximum allowable anode misalignment

Simulation of the Anode Misalignment for the Correct Choice of Material Composition



→ **Maximum allowable radial anode misalignment of 300 µm**

Solution for Reduction of Anode Misalignment

- Reasons for anode misalignment
  - Manufacturing tolerances
  - Tolerances in the braze point at the ceramics
  - Thermal expansion

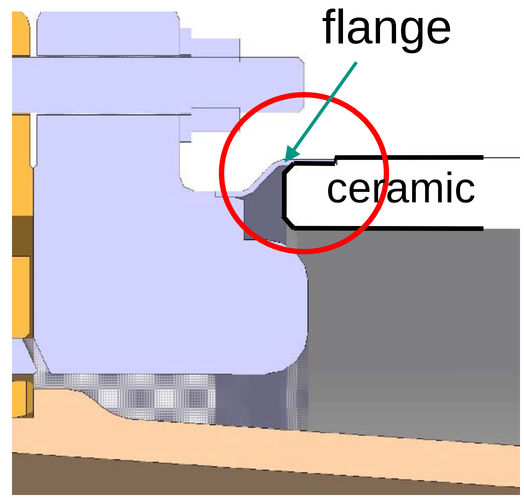
On the face side brazing

Advantages:
- **Simpler alignment** of the flange
- **Better absorption of torsion forces**

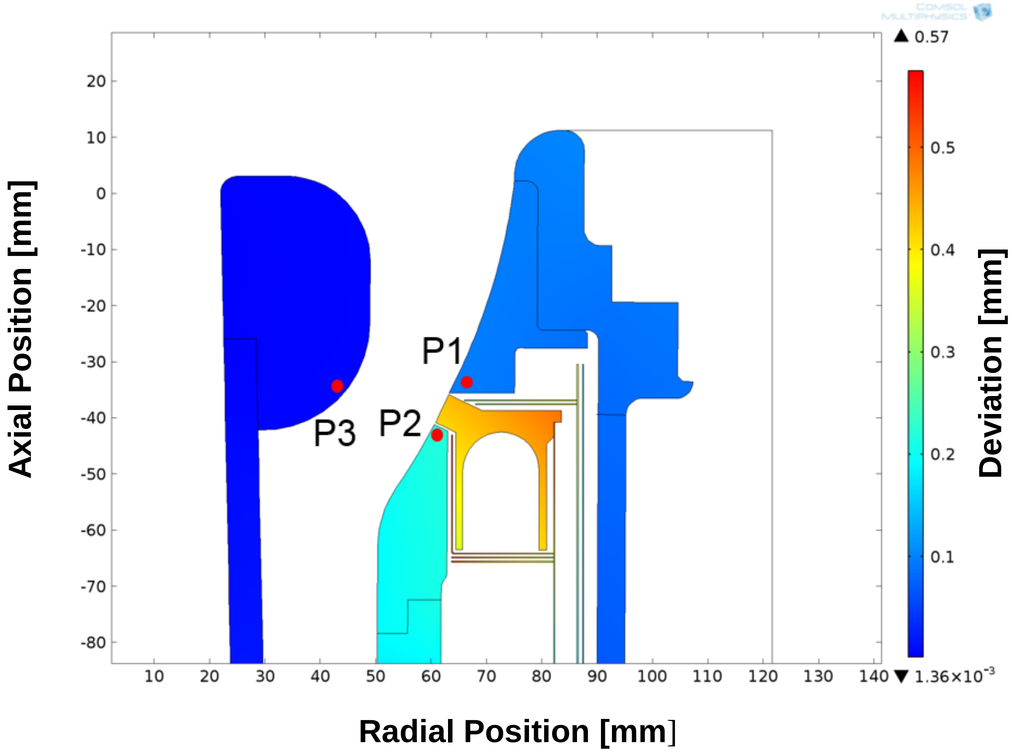
→ **Post processing** after welding of main components

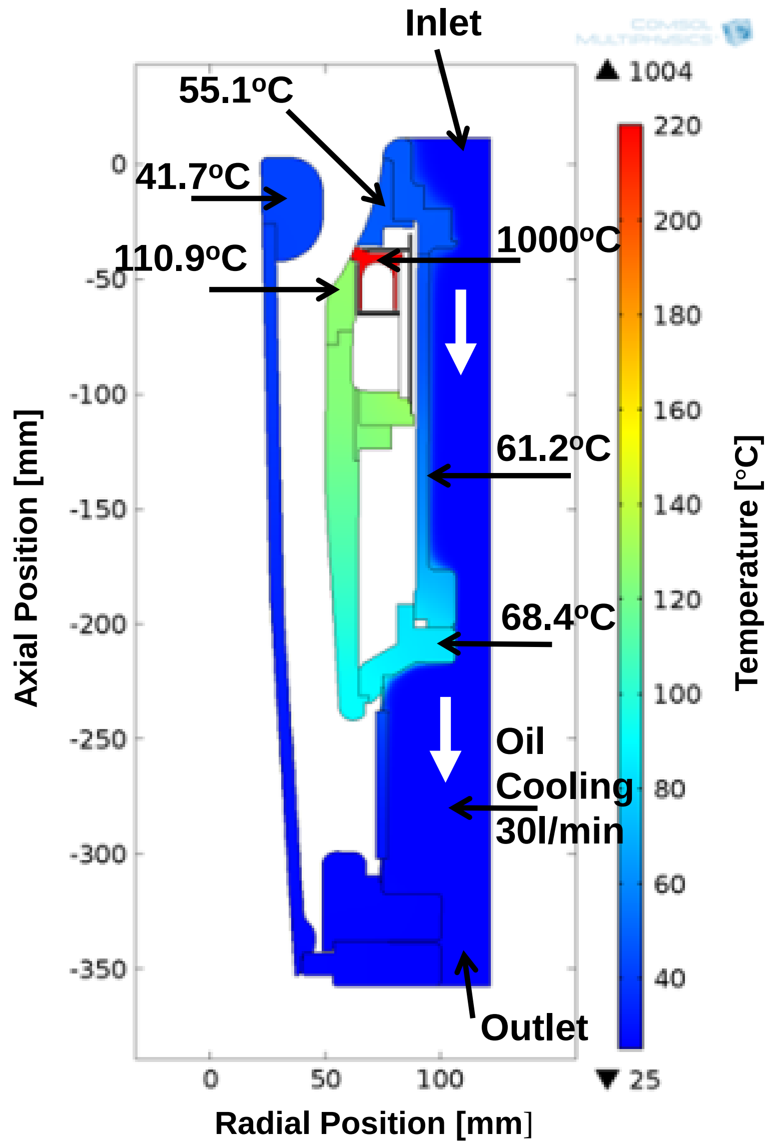
→ Further **reduction of misalignment**

Peripheral brazing



Reduction of Misalignment



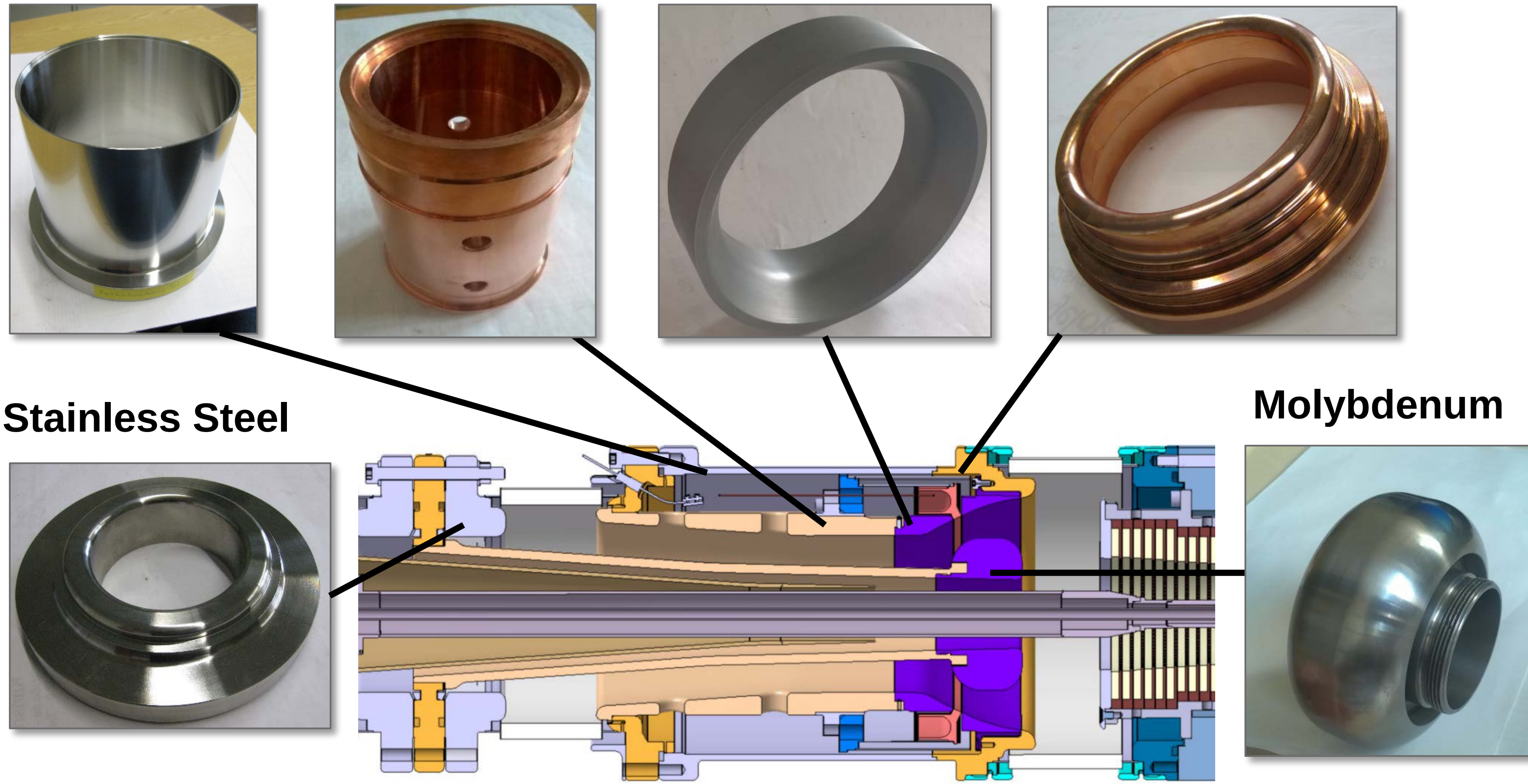


Component	Expansion Δ*r* [µm]	Expansion Δ*z* [µm]
Cathode Nose (P1)	17	-5
Cath. Prolongator (P2)	14	126
Anode (P3)	3	0.6

Conclusion for Material Composition

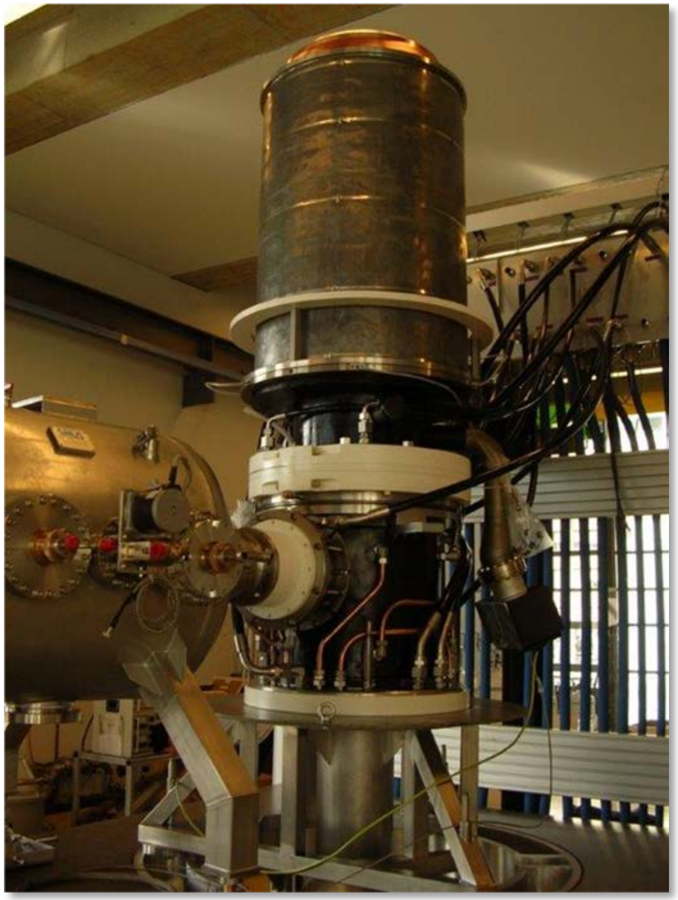
Stainless Steel | CuCrZr | Molybdenum | CuCrZr

Stainless Steel | Molybdenum



Excellent material composition for lowest expansion and misalignment

Outline



- Motivation and Today's Constraints
- Final Gun Design
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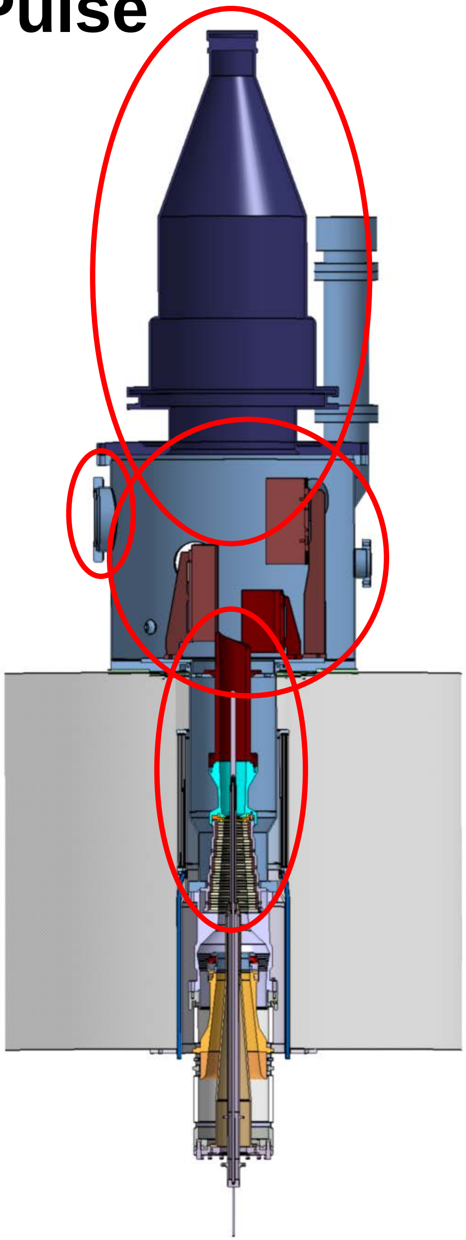
Limits & Modifications for Long Pulse Operation

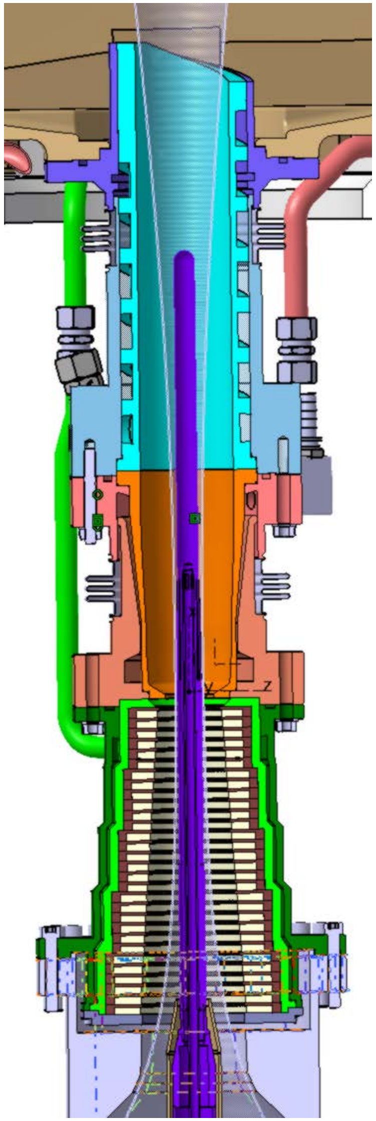
Beam Voltage V_{beam}	90 kV
Beam Current I_b	75 A
Cavity Magnetic Field B_{cav}	6.86 T

- Pulse length up to 100 ms
  - Modular water cooling system for beam tunnel, cavity and launcher.
- Pulse length > 100 ms
  - CW collector
  - Water cooled diamond output window
  - Water cooled mirrors

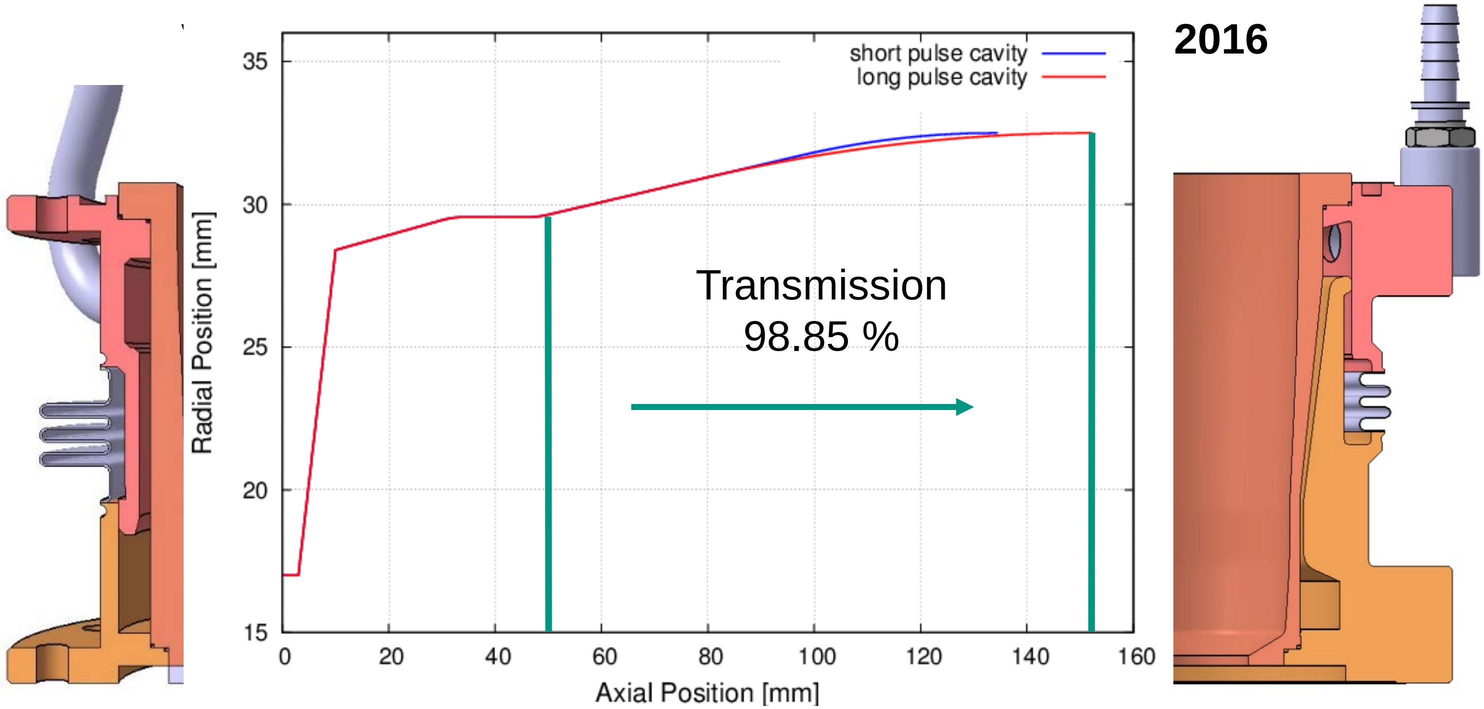


Requirements & Assumptions

- Requirements:
  - Conservation of **modularity**
  - **Reduction** of **radial dimensions**
- Assumptions
  - Water flow of 8.14 m/s (inlet)
- Overall absorbed power at:
  - Beam Tunnel: 25 kW
  - Launcher: 35 kW
  - Cavity: 50 kW



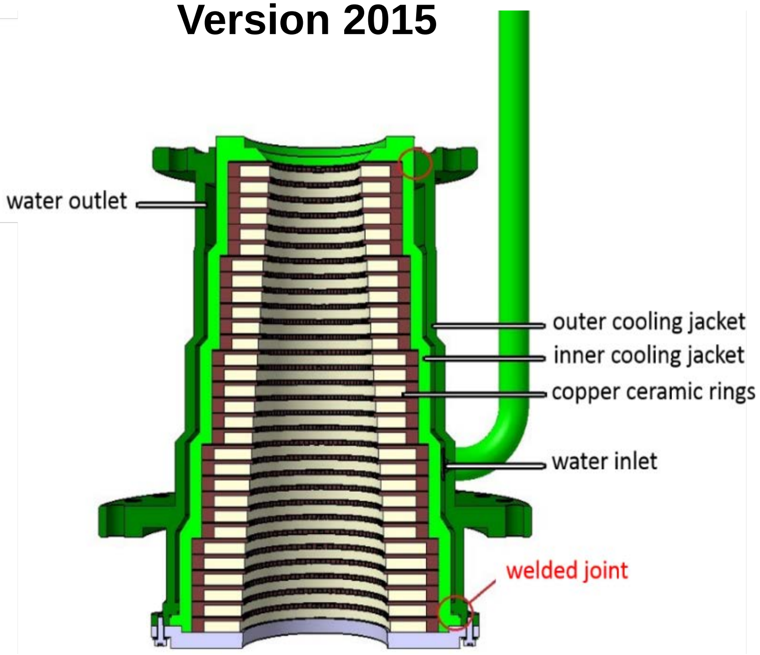
Long Pulse Cavity Design



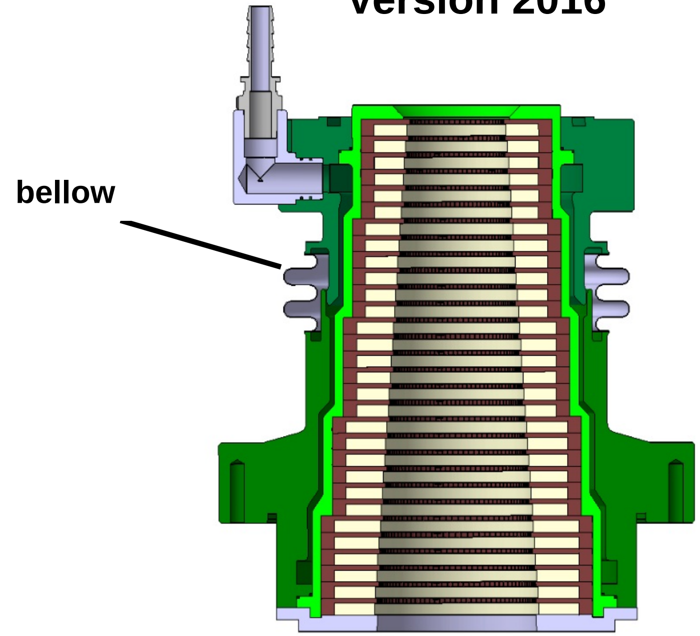
- Inner **contour similar** to the **coaxial short pulse design**.
- Simulated temperature at the **cavity is 323°C @ 1s pulse length** (Version 2015)
- **Longer uptaper** due to the use of the industrial mirror box.
  - Transmission: 98.85 % smoothing → cavity outlet
  - Mode-conversion to TE $_{34,18}$ of 0.85%

Long Pulse Beam Tunnel Design

Version 2015



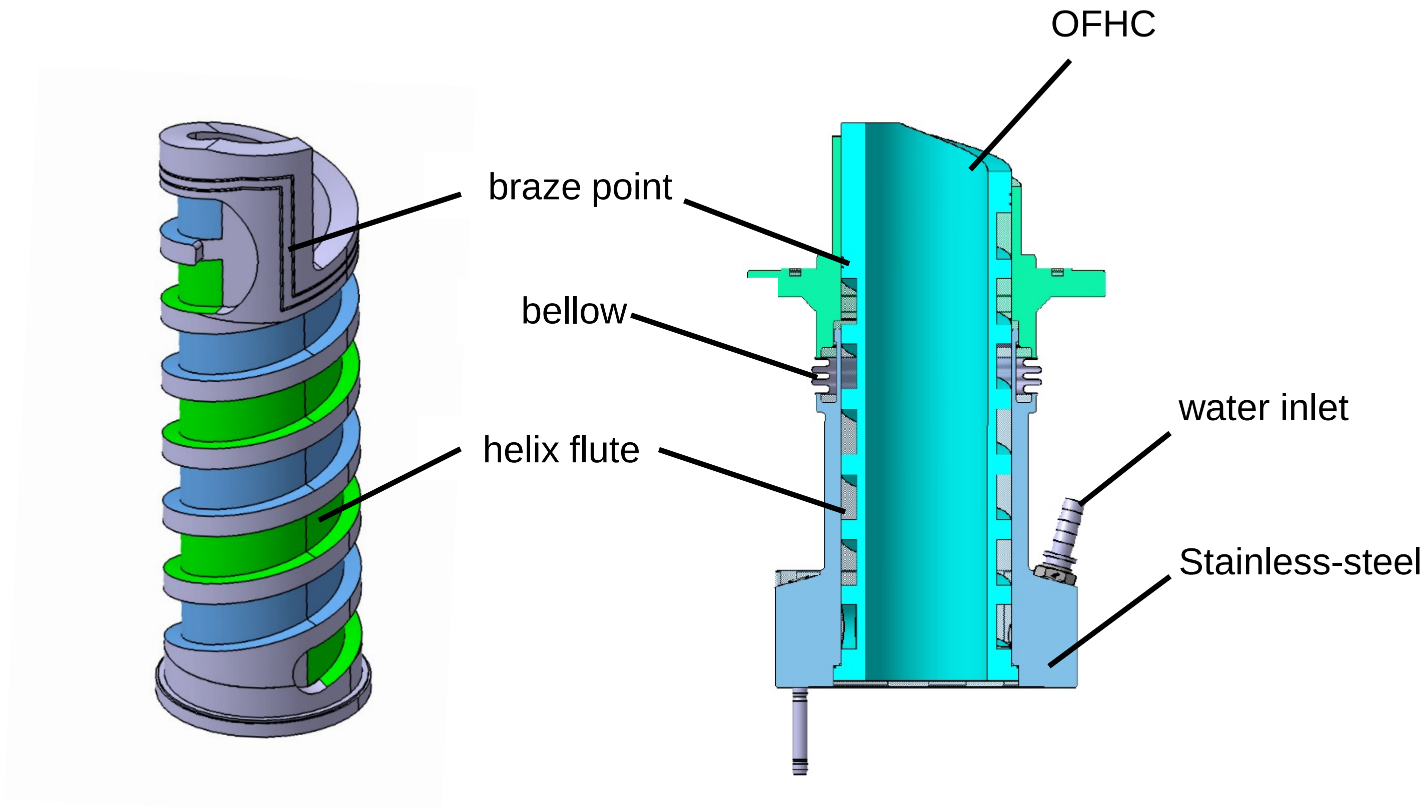
Version 2016



- **Contour similar** to the **coaxial short pulse beam tunnel**
- Beam tunnel with ceramics (*Robax*)
- Full metallic beam tunnels are under development

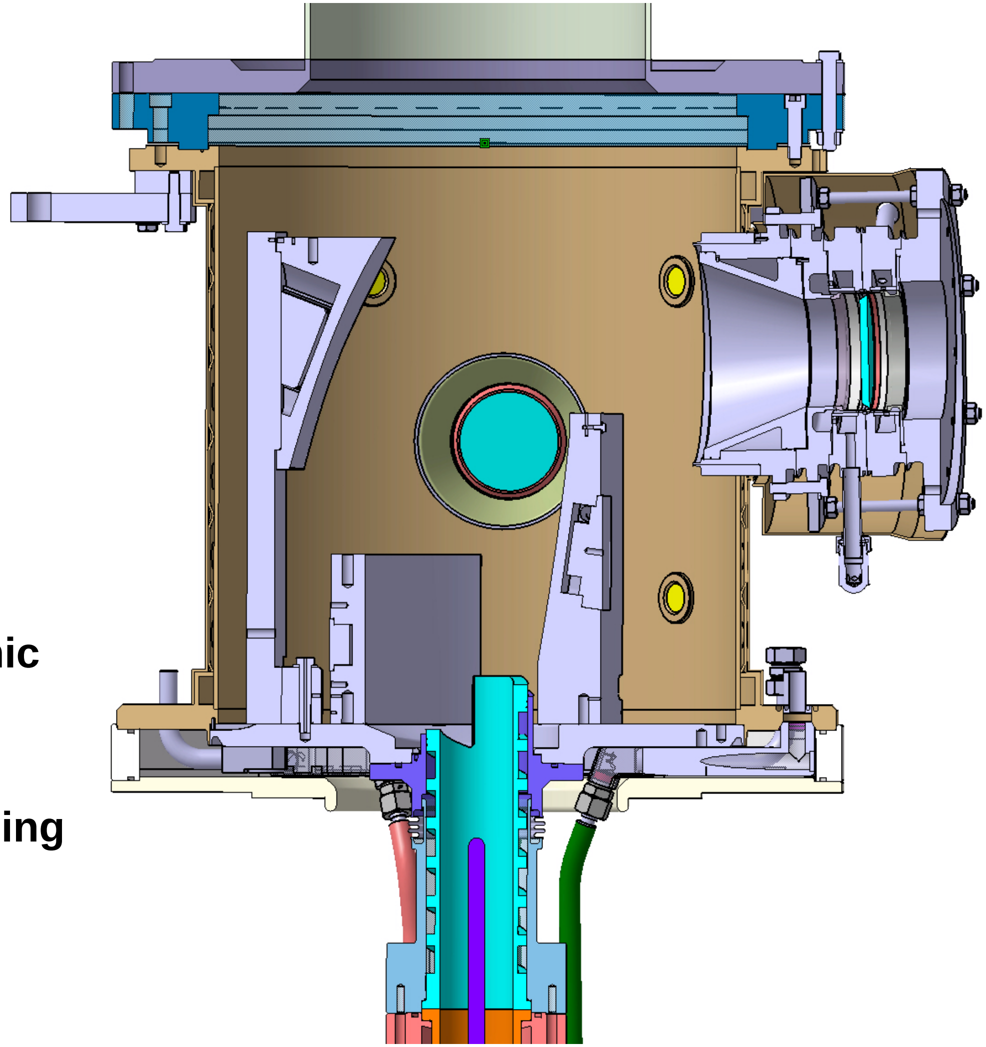
Long Pulse Launcher Design

- **Use of an optimized launcher** compared to the industrial 2 MW coaxial gyrotron
- **Helix** shaped **water channels**
- Launcher made of oxygen-free cooper (OFHC)



Mirror Box Design

- Use of the **mirror box** from the **industrial coaxial tube**
- **New launcher** is **compatible** to the **industrial mirror system**
- Necessary modifications:
  - Adapter for the collector
  - **Removing** of the **absorber ceramic**
  - Adding of **two relief windows**
  - **Modification** of the **window housing**



Conclusion

- Optimized IMIG **convenient for higher power and higher frequency** gyrotrons, including
  - Satisfaction of the ***required beam parameters***
- ***Small misalignment*** and ***thermal expansion*** of the components, due to
  - Materials with high ***thermal conductivity*** and ***stability***
  - ***Better cooling conditions***
- **Modular CW components** are under **development and manufacturing**.

Outlook

- ***Operation*** of the IMIG ***at > 2.0 MW*** and ***170 GHz***
- Operation ***without coaxial insert***
- Sequentially extending for **longer pulse lengths** (~100ms)
  - Replace **remaining short pulse components** (cavity, beam tunnel, launcher) by **cooled CW parts**
- Development of a ***full metallic beam-tunnel***