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# TH2167HE KLYSTRON FOR LHC

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**Workshop on efficient RF sources,**
***Toledo, Spain*, 23-25 September 2024**



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# Outline

- TH2167 upgrade objectives
- Simulation results
- Mechanical design & manufacturing
- Measurement results
- Conclusion

# TH2167 upgrade objectives

- 30 TH2167 klystrons delivered to CERN (400 MHz, 300 kW CW at 58 kV, 8.4 A, ~60-62% efficiency)
- Developed in 2002, with 16 units commissioned in 2008
- High Luminosity LHC upgrade requires more RF power
- Target: at least 350 kW per klystron at ~58 kV, 9 A
- Efficiency needs to increase to a minimum of 67%.
- This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730






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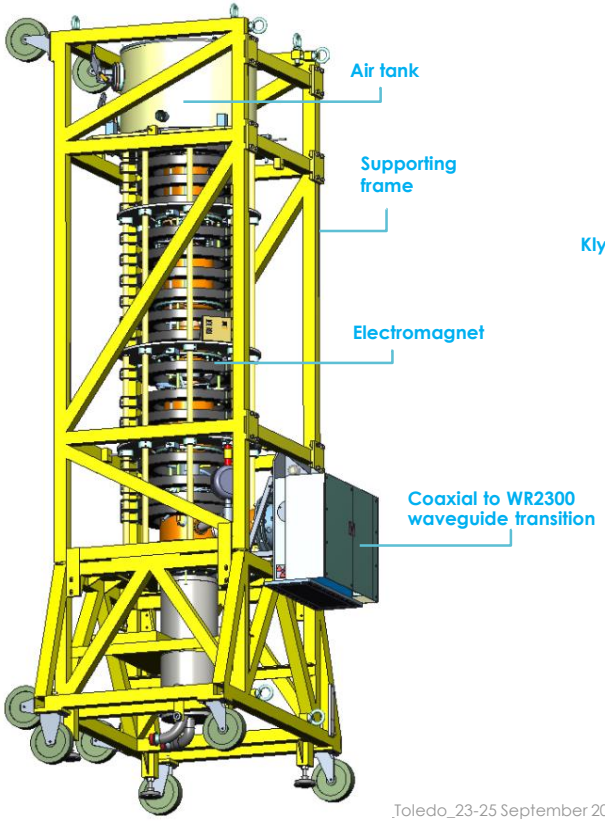
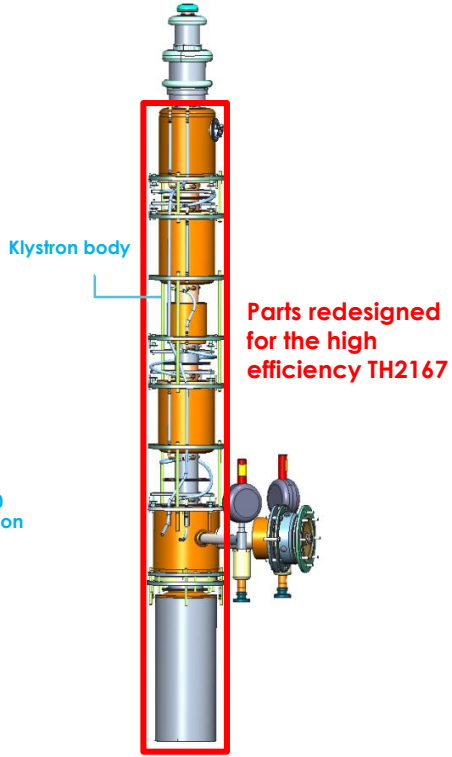
# TH2167 upgrade objectives




## Main requirements

| Parameters | Unit | TH2167 | TH2167HE |
|---|---|---|---|
| Frequency | MHz | 400.8 | |
| Power | kW | 300 | **350** |
| Efficiency | % | 60-62 | **> 67** |
| Gain | dB | 37 | 36 |
| Bandwidth | MHz | +/- 1 | +/- 0,7 |





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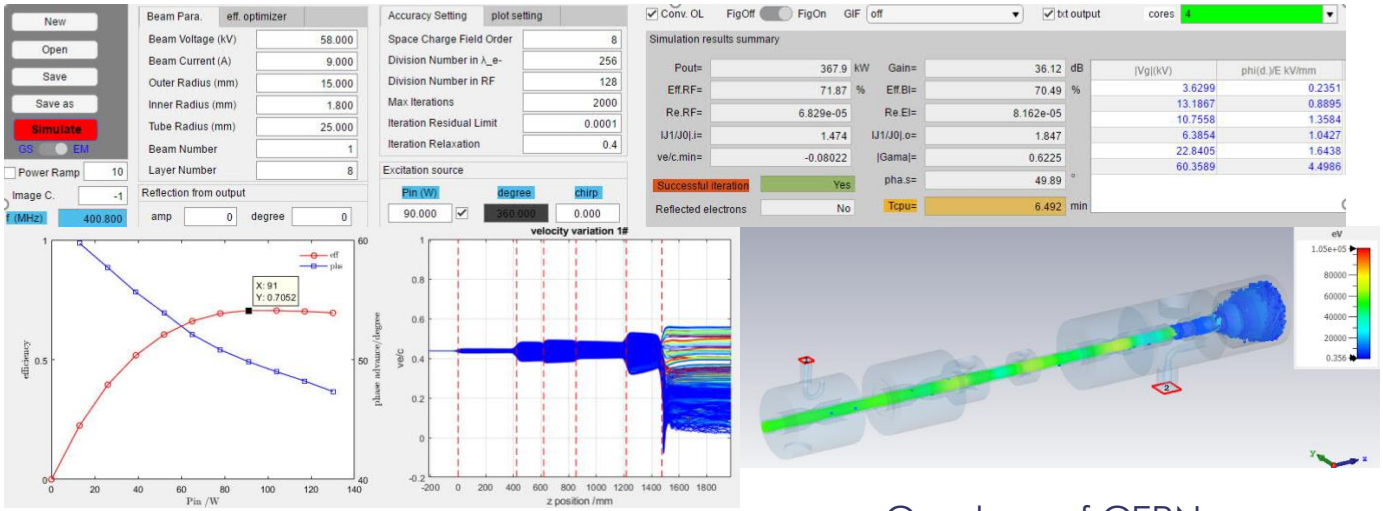
# Simulation results

## CERN DESIGN (by I. Syratchev & J. Cai)

- New interaction structure design with harmonic 3 cavity
- Baseline structure from KLYC and CST 3D simulations
- Predicted power is 368 kW at 58kV 9A with 70,5% efficiency and 36,5dB gain (at saturation)
- 173 mm shorter  than the initial structure

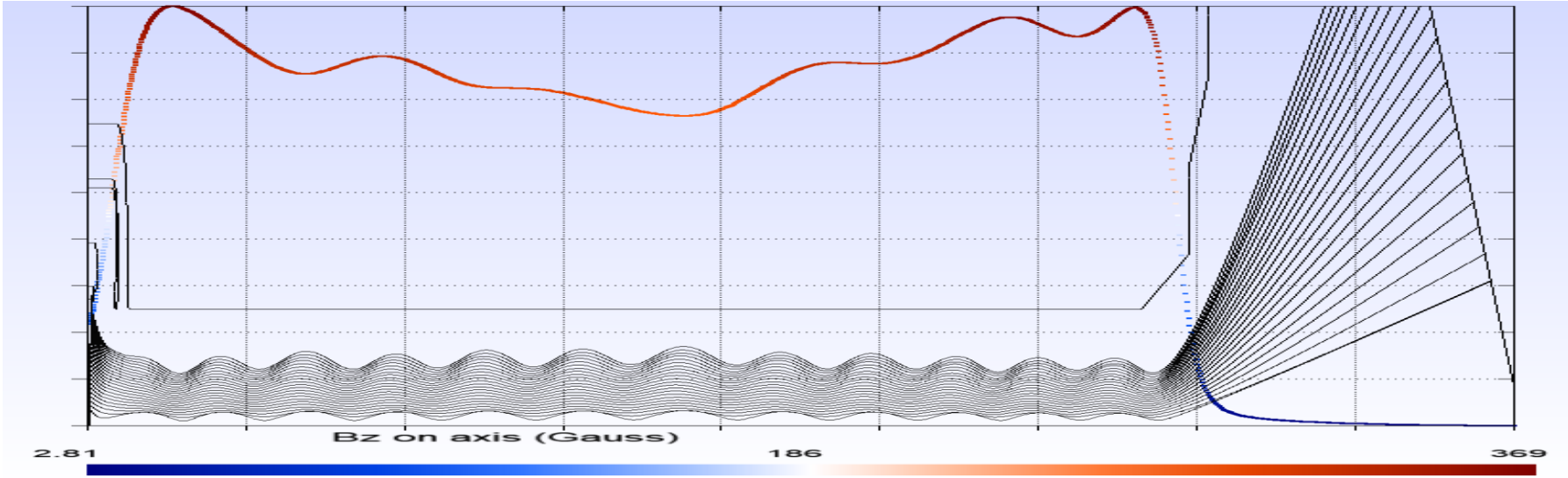



Courtesy of CERN

# Simulation results

## Electron beam

- Same beam as TH2167 generated from a  triode gun; low convergence beam with 14,2 mm radius; ripple is about 14% (= (rmax-rmin) /  (rmax+rmin)),
- Drift tube radius 25 mm
- Operating point at 57.7 kV x 9 A with a mod anode voltage of 31.2 kV; beam perveance is 0,65 µperv





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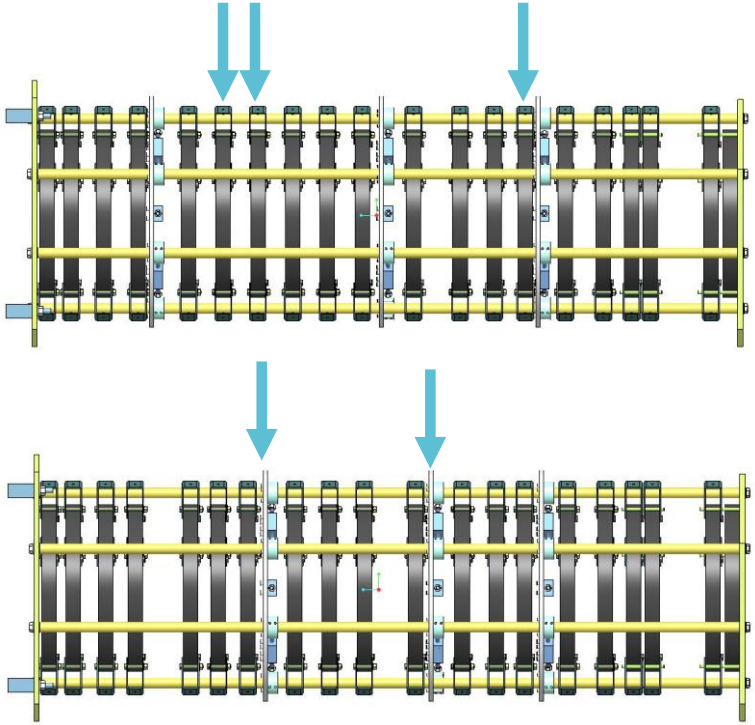
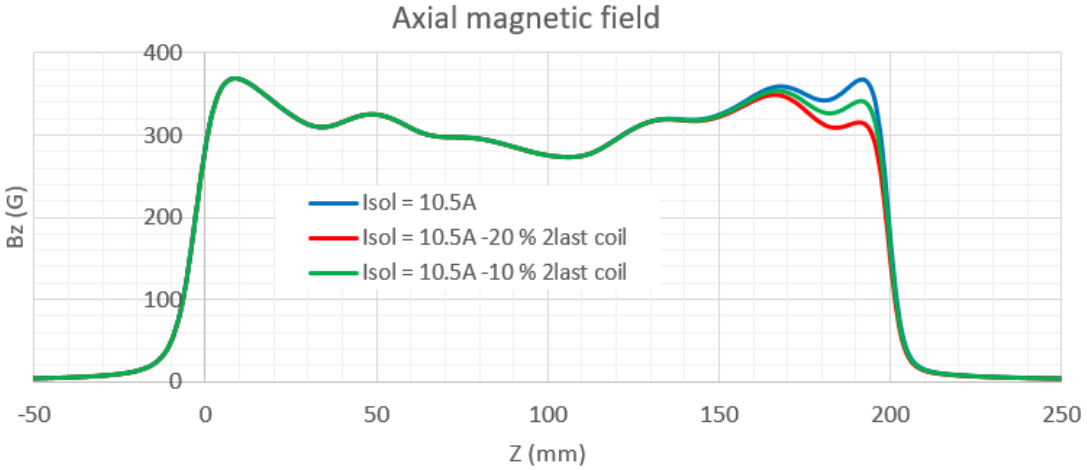
# Simulation results

## Electromagnet modifications

- Re-adjusted the position of some coils and supporting plates to allow the access to cavities tuners.
- increase coil current from 9,4 A to 10,5A
- second power supply added for the last two coils to optimize magnetic field profile close to the OP cavity,

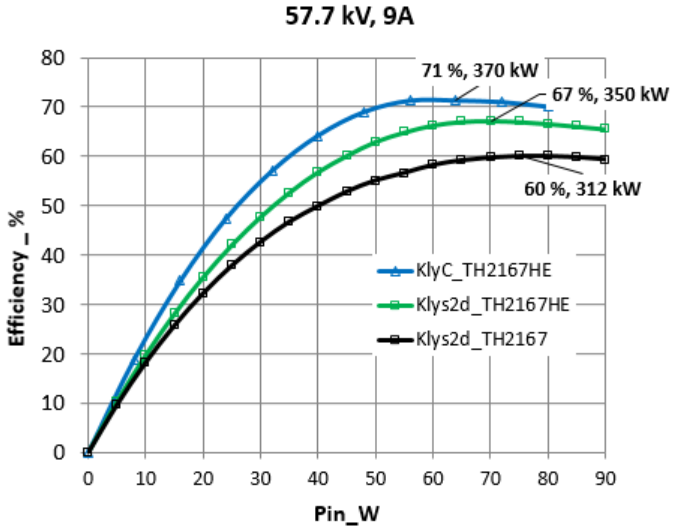


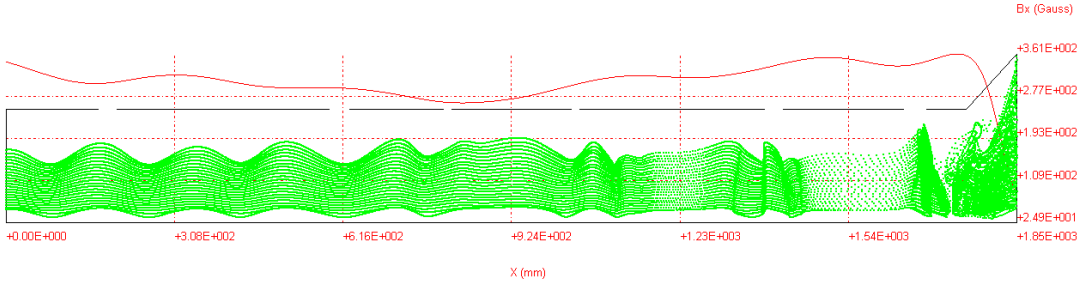


# Simulation results

## TH2167 Vs TH2167HE

- Beam wave simulation with KlyC & internal PIC code Klys2D
- TH2167_ Bz@Icoil=9.4 A, TH2167HE_ Bz@Icoil=10.5A
- Klys2d input data aligned with KlyC, coupling factor from HFSS simulation of cavities
- Predicted efficiency with Klys2d 67.3% (350kW saturated), 3 pts less than KlyC;





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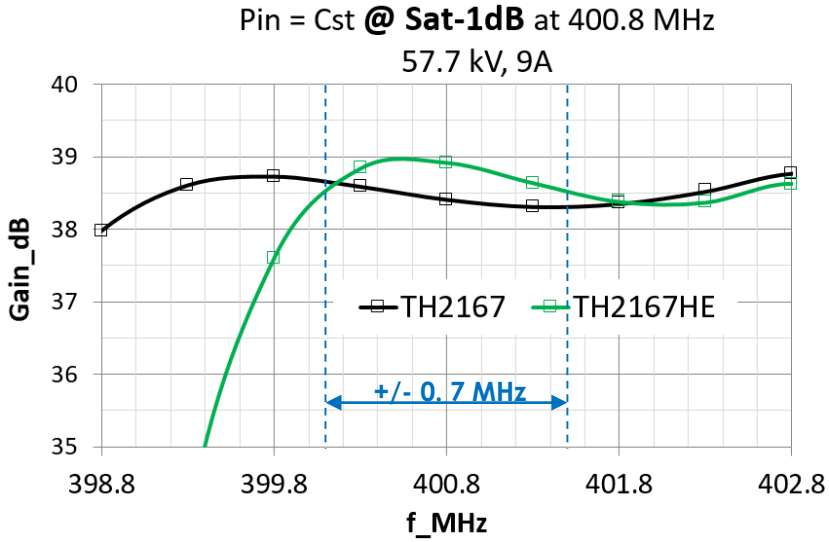
# Simulation results

## TH2167 Vs TH2167HE (Klys2d)

- Bandwidth is shorten at lower edge due to Harmonic 3 cavity
- The gain variation within +/- 0.7 MHz of the center frequency is less than 1 dB at Sat-1dB.





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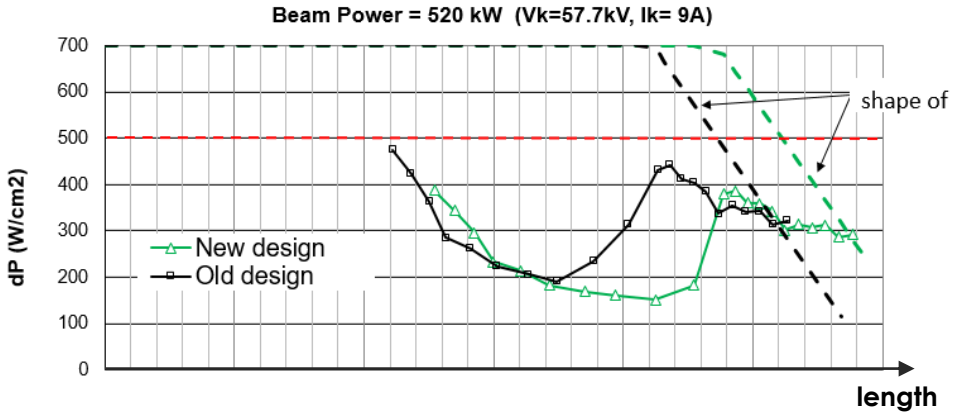
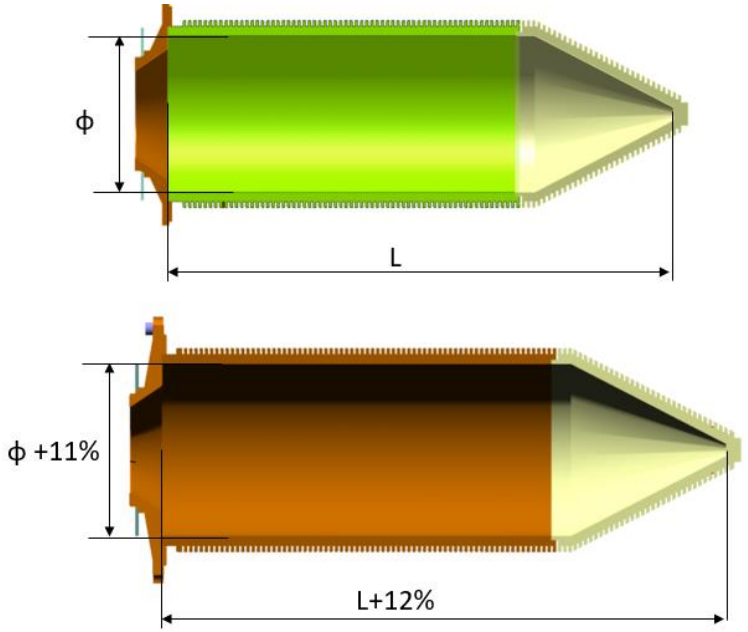
# Simulation results

## Collector resizing

- Increase inner diameter and length of the collector
- To have more margin in case we need to increase the beam power





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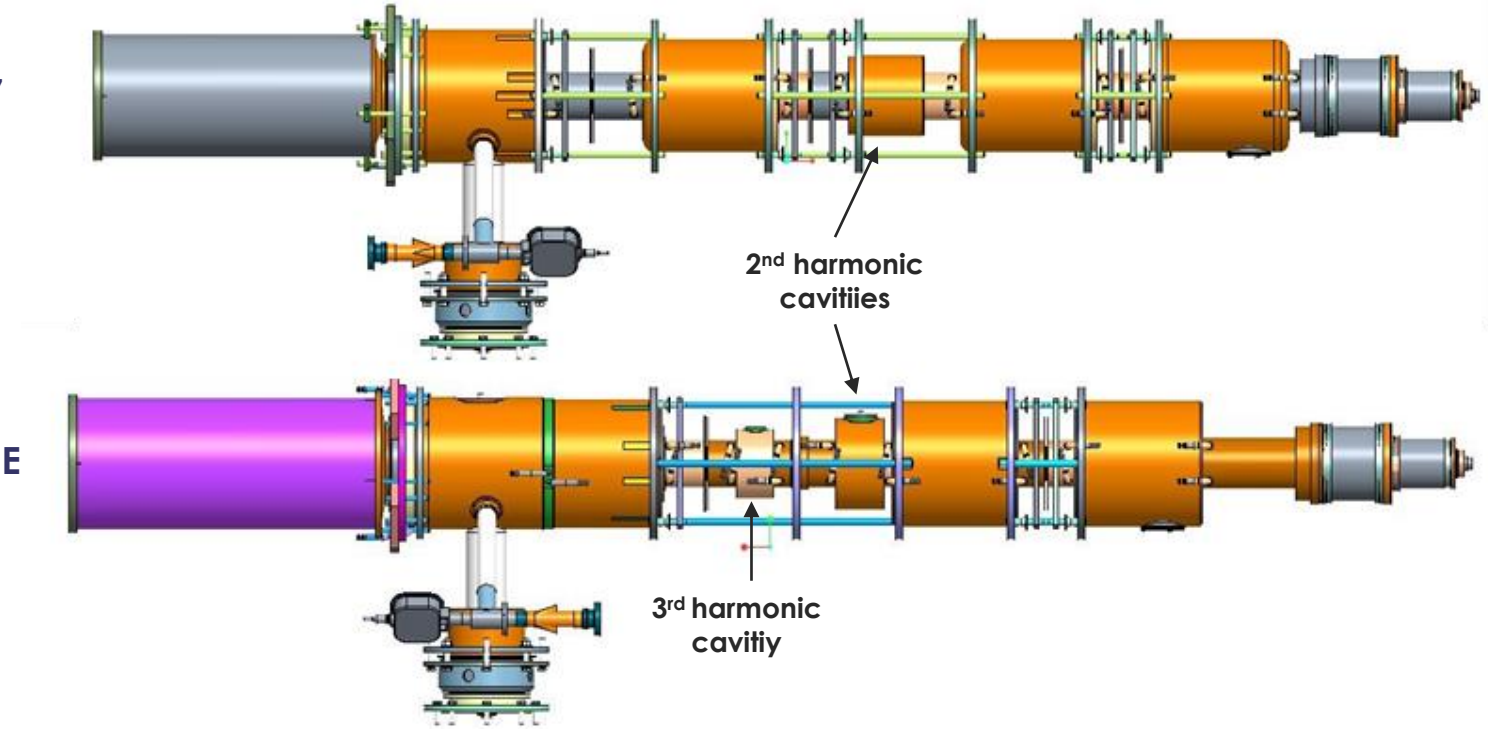
# Mechanical design & manufacturing

## Design changes (pumped tube)

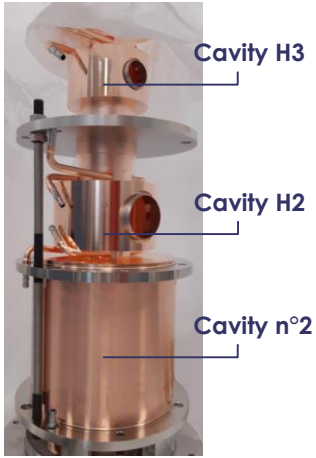


# Mechanical design & manufacturing

## Parts assemblies

gun

Input cavity




Intermediate cavities

penultimate and last cavities + window

collector

# Mechanical design & manufacturing

Inside the baking & exhaust station





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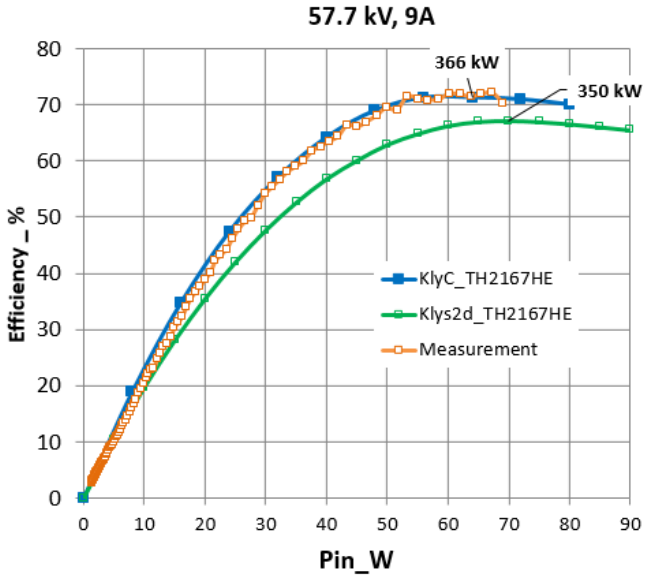
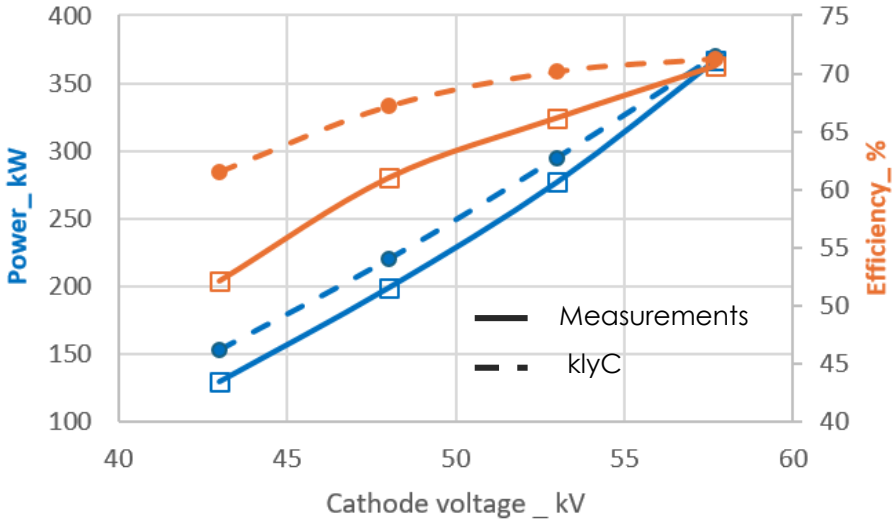
# Measurement results

## Measurement Vs simulations




- 70 % efficiency measured @ 57.7 kV
- Good agreement between Measurement and KlyC calculations @ nominal voltage
- High efficiency (61%) maintained at 200 kW (mode I), 6 points higher than the TH2167
- Discrepancies are mainly due to tube adjustments, not fully evaluated for retro-simulation yet.





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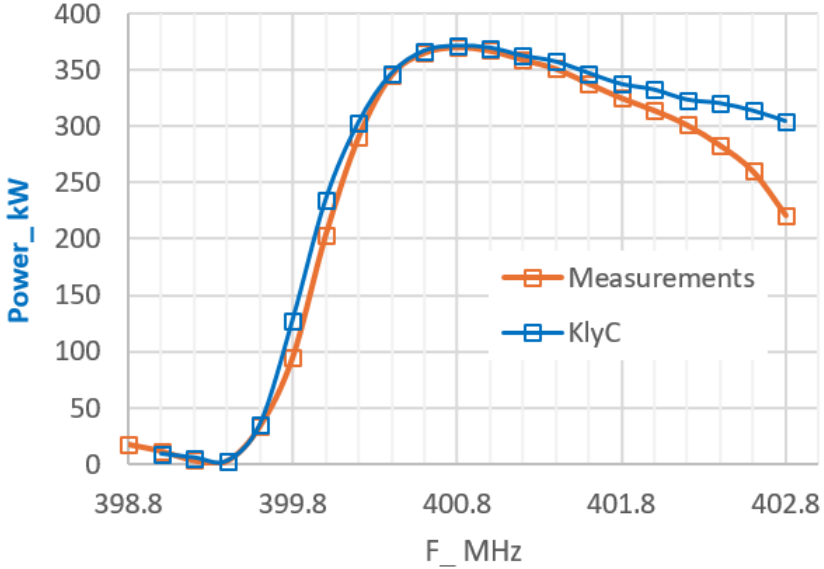
# Measurement results

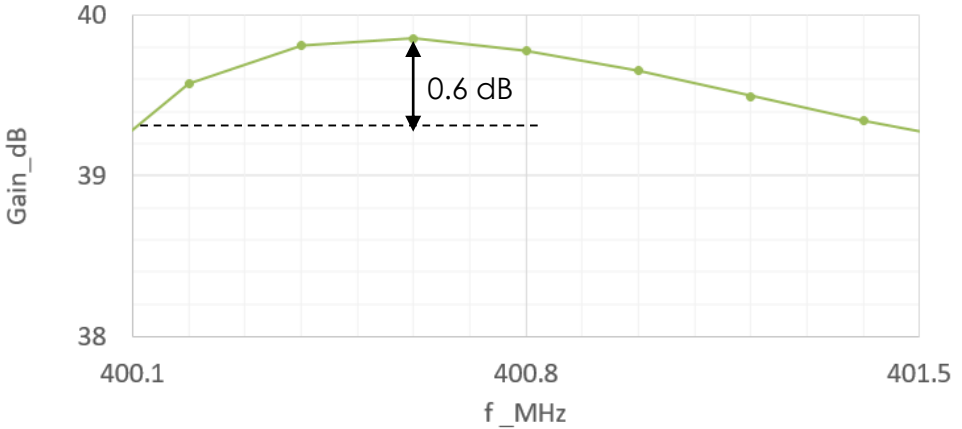
## Measurement Vs Simulations (KlyC)

**@ Pin=60W_57.7 kV, 9A**




**@ Psat-1dB_57.7 kV, 9A**

**The measured bandwidth zoom @ +/- 0.7 MHz**




- Good agreement between measurement and KlyC calculations
- The bandwidth is compliant





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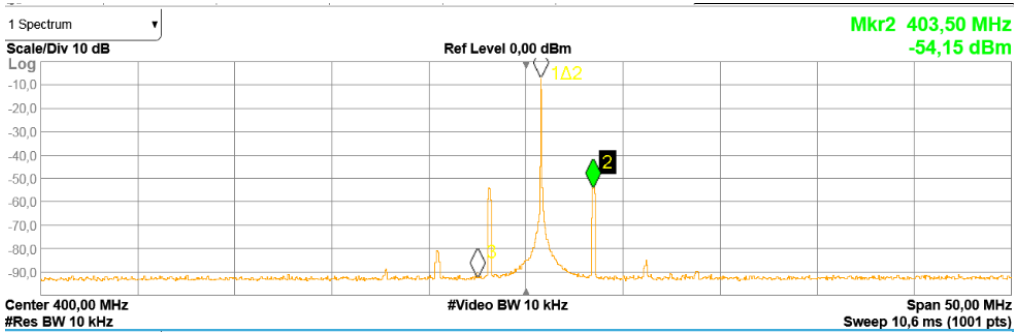
# Measurement results

## Side bands

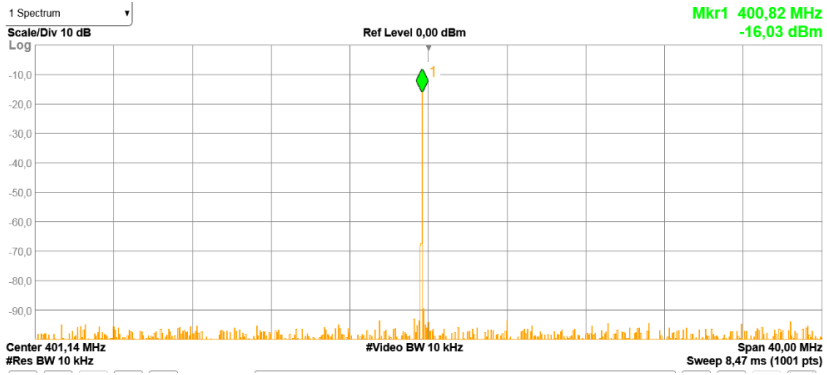
- Sidebands appeared at 403.5 MHz before saturation.
- Attenuated and pushed after saturation by adjusting cavity 5
- Eliminated by adjusting the current of the main coils.

### Before settings




| | MODE | TRC | SCL | | X | Y | F |
|---|---|---|---|---|---|---|---|
| 1 | Δ2 | 1 | f | (Δ) | -2,70 MHz (Δ) | 47,31 dB | |
| 2 | N | 1 | f | | 403,50 MHz | -54,15 dBm | |

### After settings





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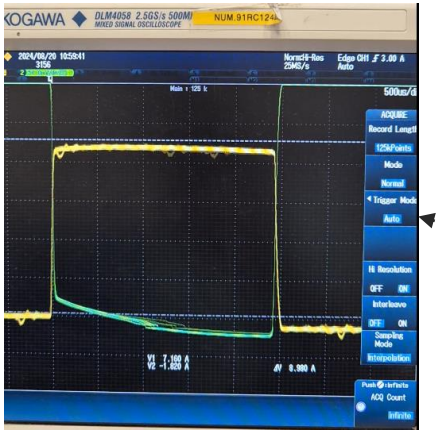
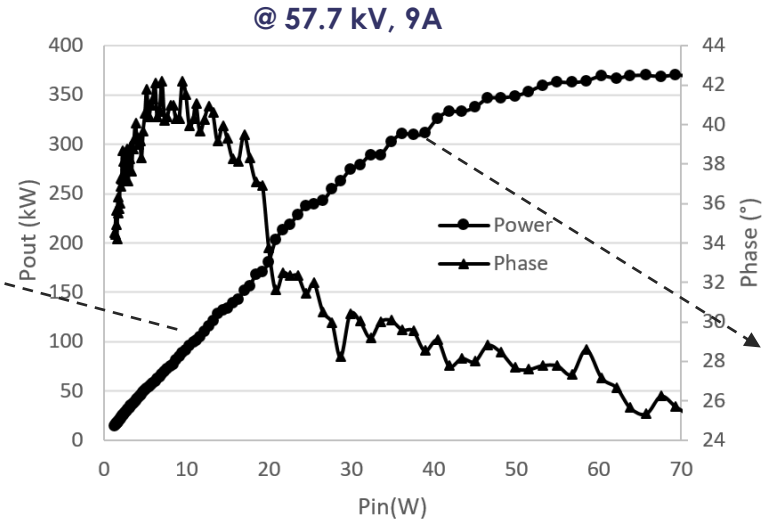
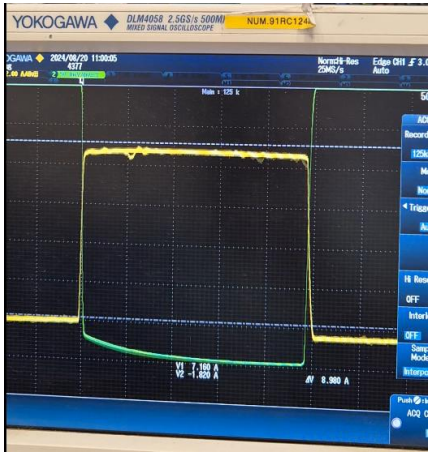
# Measurement results

## Multipactor: Disturbance of the transfer curve and the pulse signal.

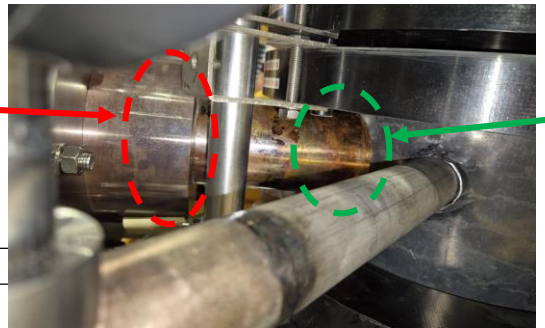




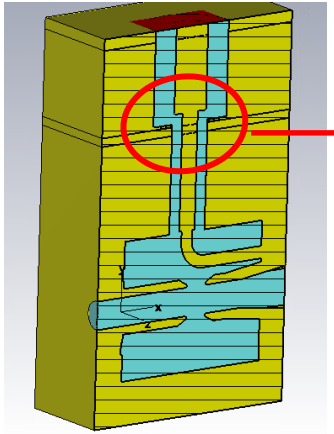
Green: The output signal pulse
Yellow : cathode current pulse

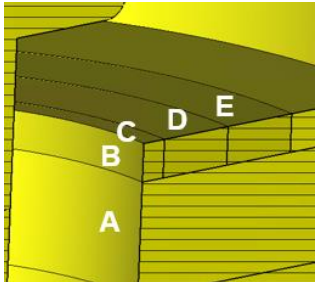
Blue color
→ sign of overheating

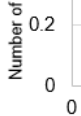


Copper color →no overheating

# Multipactor: CERN simulation (F. Peauger)



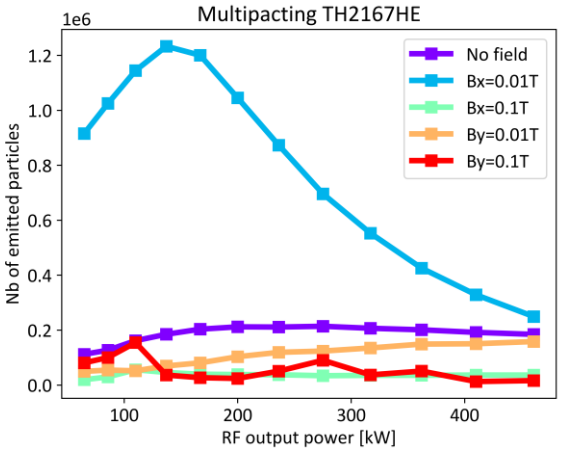






**With static magnetic field**




- The Multipactor phenomenon was demonstrated through simulation
- Emissions would occur at surfaces A, B, and C
- It can be eliminated by applying a static magnetic field along the coaxial axis





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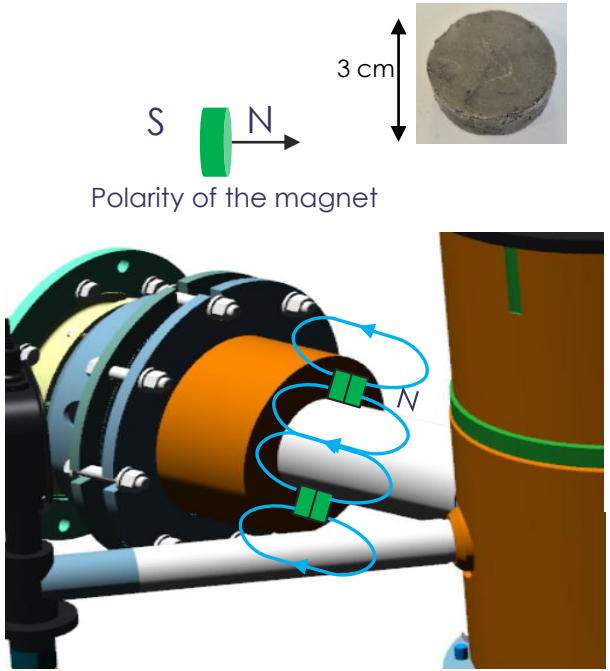
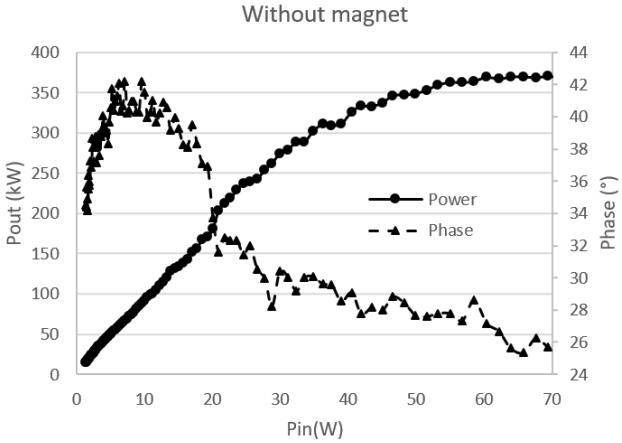
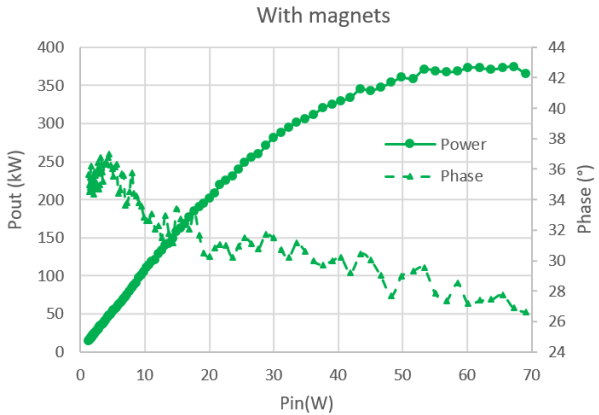
# Measurement results

## Multipactor: elimination of disturbances with a static magnetic field.




✓ **Monotonous transfer curve**

✓ **No more coax overheating**





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# Conclusion

- New klystron with 3rd Harmonic cavity designed by CERN and manufactured by Thales
- The prototype achieves an efficiency of 70%, as calculated by the KLYC and CST codes.
- The klystron will be delivered and tested at CERN to confirm the factory performances
- Collaboration with CERN has been highly successful and very close, from design to testing
- Significant advances in simulation, usable as a "digital tuning."

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