FROM RESEARCH TO INDUSTRY

KLADISTRON – THE KLYSTRON WITH ADIABATIC BUNCHING

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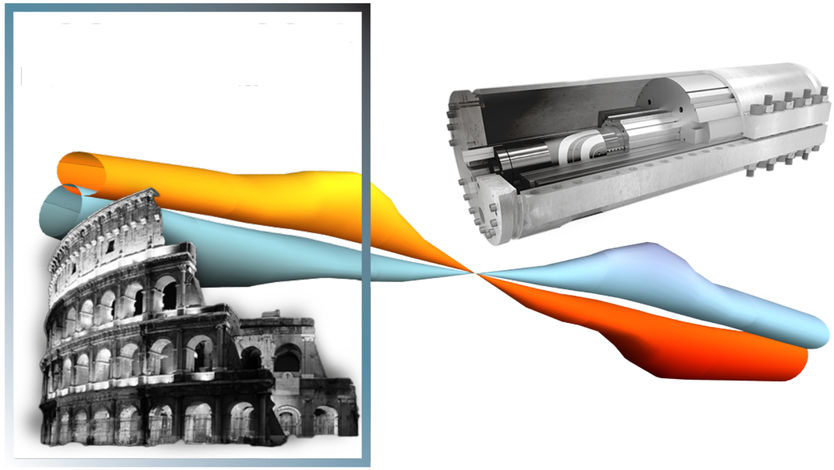

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1. Klystron characteristics
2. High-power RF source design
3. Kladistron (high-efficiency klystron) principle
4. Kladistron prototype design based on 5 GHz TH2166
5. 5 GHz kladistron cavities fabrication

1. KLYSTRON CHARACTERISTICS

REMINDER: WHAT IS A KLYSTRON?

It is a vacuum microwave electron tube amplifier where:

- The input cavity prebunch slightly a DC beam provided by an electron gun
- The intermediate cavities develop an RF voltage induced by the beam loading (image charges). These induced voltage intensify the bunching process.
- The beam is strongly decelerated in the output cavity and a high RF power is created
- The decelerated beam is collected in a collector
- The beam is focused by an axial magnetic field (solenoid)
- Klystron efficiency is the ratio of the output power to the electron gun supply power: $\eta = P_{out}/V_k/I_b$ (perveance: $\mu P = I_b * 10^6 / V_k^{3/2}$)

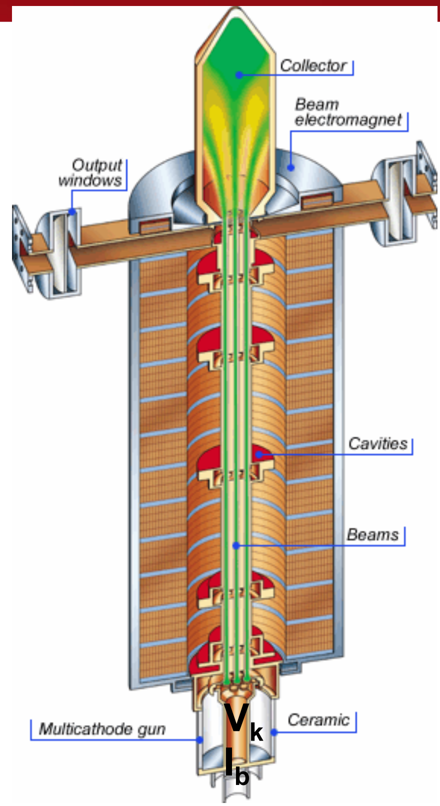
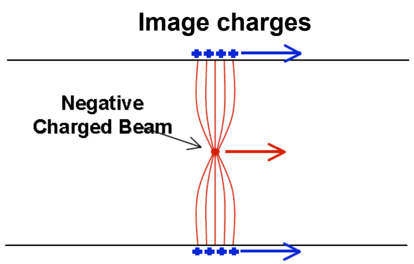
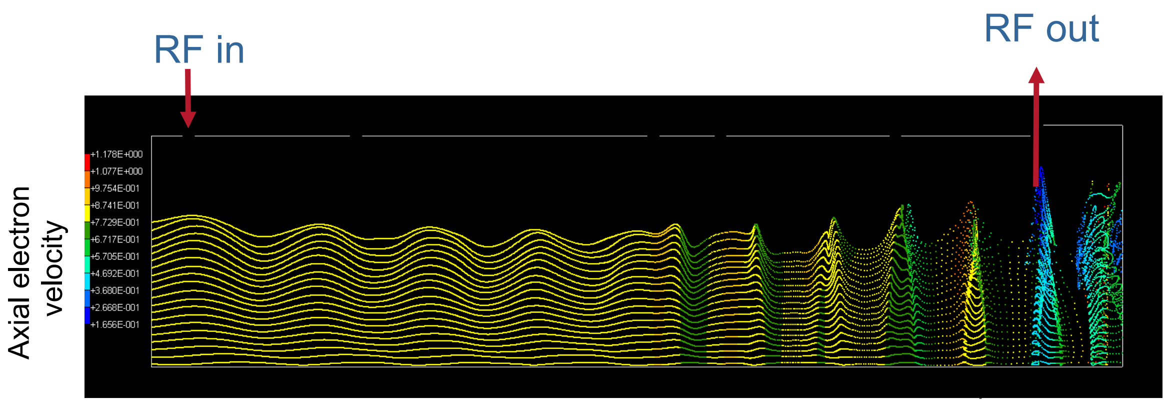


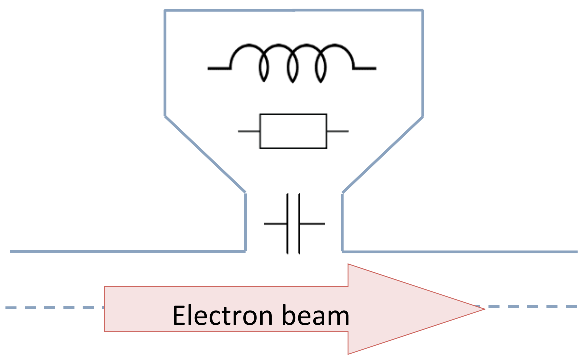
Image: courtesy of Thales Electron Devices





BEAM/CAVITY INTERACTION MODEL

- One can characterize beam/cavity interaction by a **lumped circuit**.
- **Circuit's parameters** are linked to the electromagnetic field and thus cavity's **dimensions and materials properties**.
- AJDisk and Klys2D are **lumped circuits-based codes**.



$$Q_0 = \frac{R}{\omega_0 L} = \frac{\omega_0 \mu_0 \iiint |B|^2 \, dV}{\iint R_S |B|^2 \, dS}$$

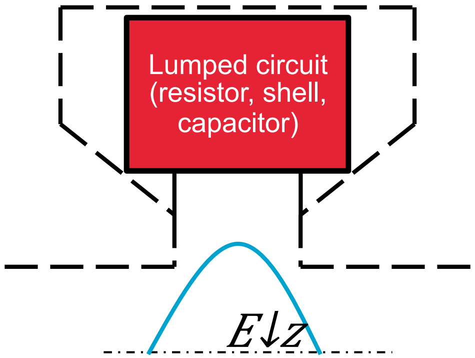
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$\frac{R}{Q} = \sqrt{\frac{L}{C}} = \frac{\left| \int \vec{E} dz \right|^2}{\omega_0 \varepsilon_0 \iiint |\vec{E}|^2 \, dV}$$

KLYSTRON SIMULATION CODES USED IN THIS PROJECT

- *AJDisk*

- *SLAC 1D-code*
- *No magnetic field needed*
- *Klystron cavities characterized partly by lumped circuits (f, R/Q, Q0, Qext)*

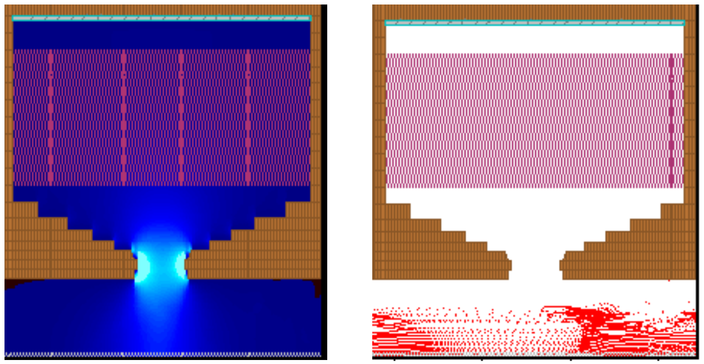


- KLYS2D

- Thales Electron Devices (TED) 2D-code
- Magnetic field needed
- Klystron cavities characterized by lumped circuits (f, R/Q, Q0, Qext)

- Magic2D

- ATK 2D-code
- Finite differential code
- Magnetic field needed
- Klystron cavities dimensions needed



2. HIGH-EFFICIENCY RF SOURCE DEVELOPMENT

THE HIGH-EFFICIENCY KLYSTRON PROJECT

WP12 : Innovative RF Technologies
2013 - 2017

*« In this sub-task, CEA will develop and search for innovative concepts of X band RF power sources and components. The objective is to propose **affordable and reliable** solutions for future testing capabilities for the CLIC accelerating structures. The task includes the design and the fabrication of prototype RF devices to demonstrate the feasibility of the new concepts proposed. »*
Budget available to build a (small) part of the RF power source or component

Collaboration with THALES ELECTRON DEVICES :
PhD work of **Antoine Mollard** funded 50% CEA/50% Thales (Contrat de Thèse CEA Industrie)
Supervised by :
Juliette Plouin/Franck Peauger/Claude Marchand @ CEA
Armel Beunas/Rodolphe Marchesin @ Thales

Collaboration with CERN in the scope of HEIKA : Igor Syratchev, Walter Wuensch…
PIC code (MAGIC) paid on CERN funds (CEX).

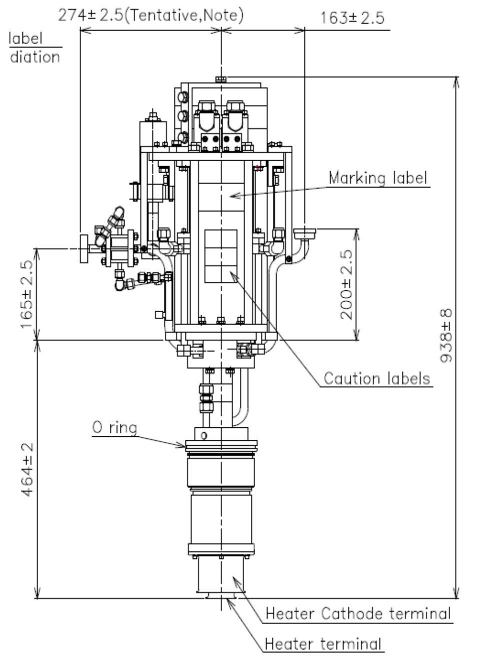
☞ **Activity fully oriented towards R&D**

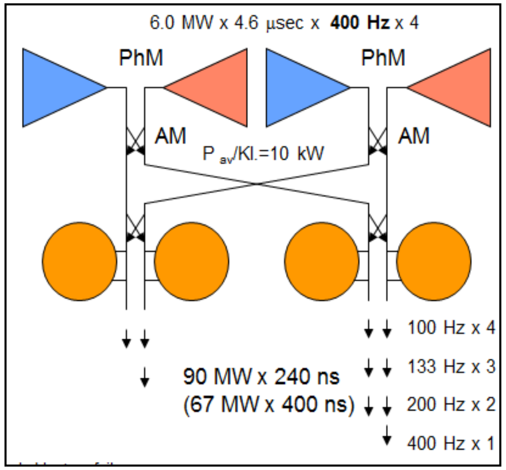
MASSIVE CONDITIONNING AND TESTING CAPABILITIES OF 12 GHZ ACCELERATING STRUCTURES

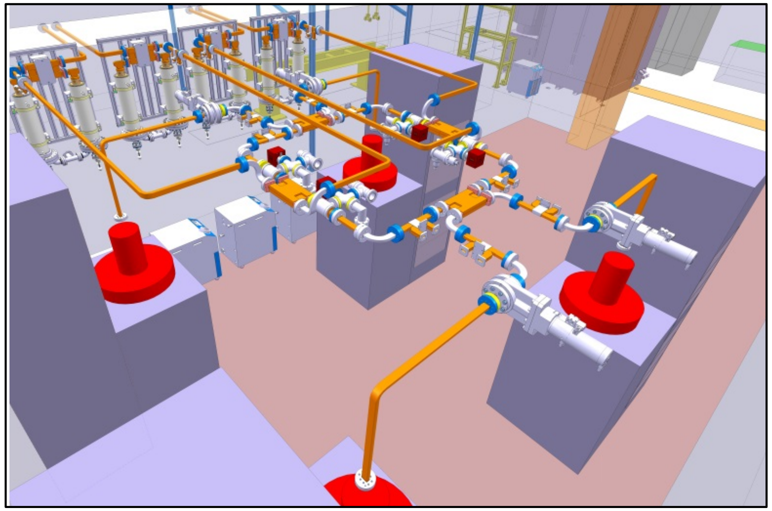
- The XBOX3 test stand at CERN will use four Medium Power X-band klystrons recombined and compressed to produce a 50 MW power level

TOSHIBA klystrons parameters

Frequency: 12 GHz
Peak power: 6 MW
Beam Voltage: 150 kV
Beam current: 90 A
Average power: 12.4 kW
Efficiency: 47.5%







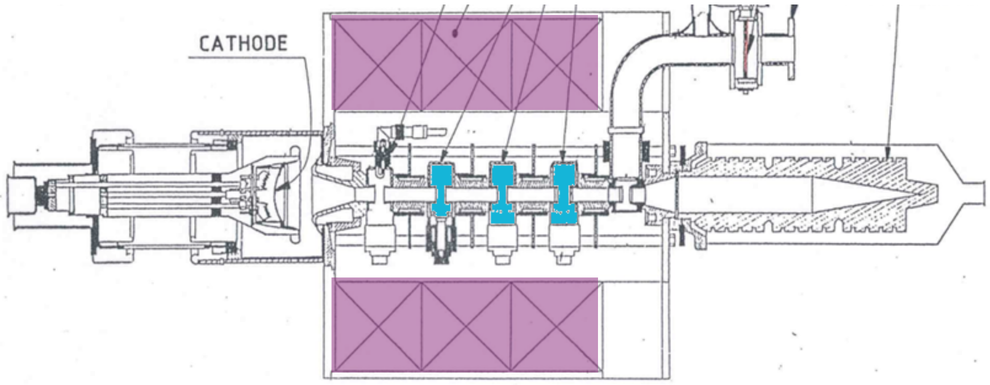
I. Syratchev, G. McMonagle, N. Catalan Lasheras

We propose to design a new 12 GHz klystron with very high efficiency:
→ 70% for 12 MW output power

It will <u>double</u> the testing capability of an XBOX3 type test stand

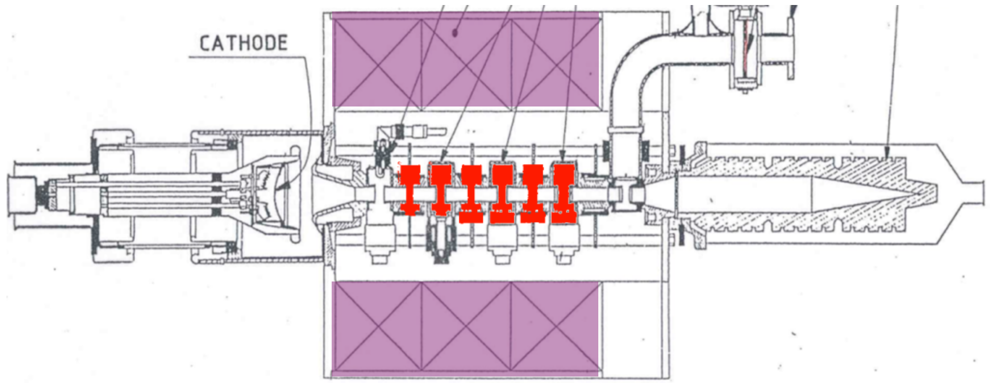
3. KLADISTRON (HIGH-EFFICIENCY KLYSTRON) PRINCIPLE

KLADISTRON



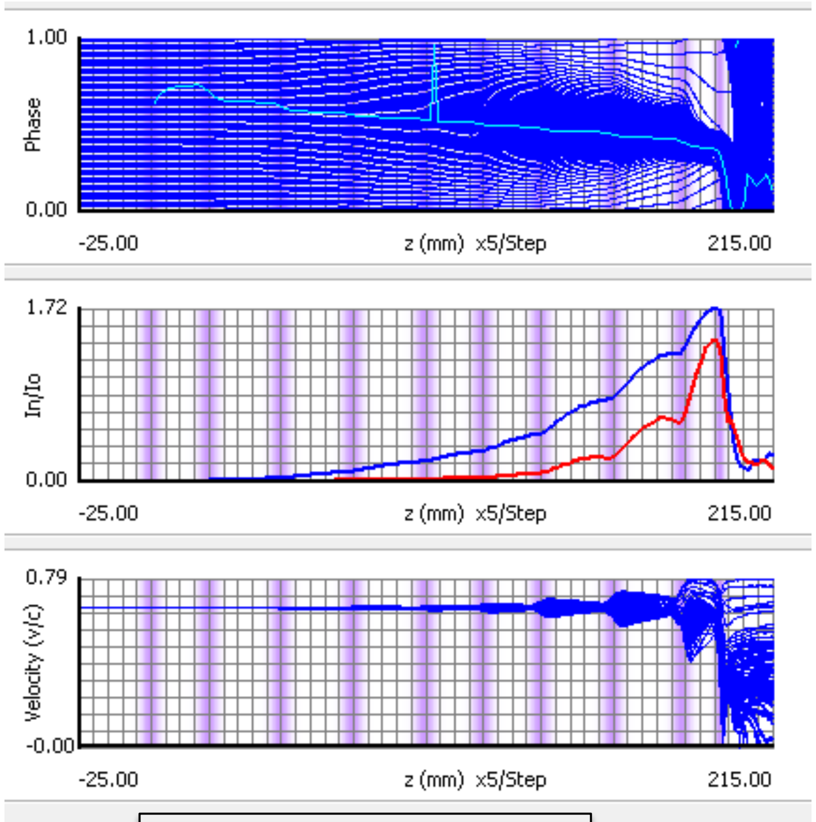
A Kladistron (Kl-adi(adiabatic)-stron) is a high-efficiency klystron with a large number of cavities (at least twice as many as in a classical klystron).

$N_{cavities}$ ↗ => Efficiency (η) ↗

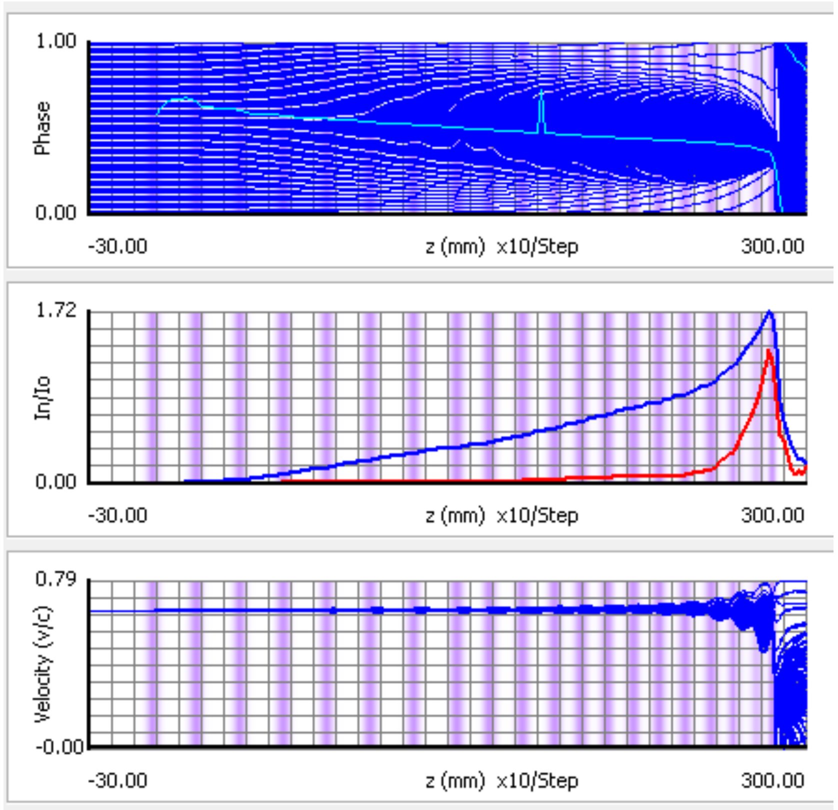


Inspired by RFQ, this architecture leads to a smoother bunching and thus to a higher efficiency due to better collection in decelerating cavity.

AJDISK 1D-SIMULATIONS OF A 12GHZ-KLADISTRON



10 cavities
Efficiency 67.2 %
Length 197 mm



20 cavities
Efficiency 78 %
Length 285 mm

In the proposed design, the cavities are weakly coupled to the beam (low R/Q) and largely detuned to avoid strong bunching.

KLADISTRON AND CLASSICAL KLYSTRONS

Klystron Efficiency vs. Perveance

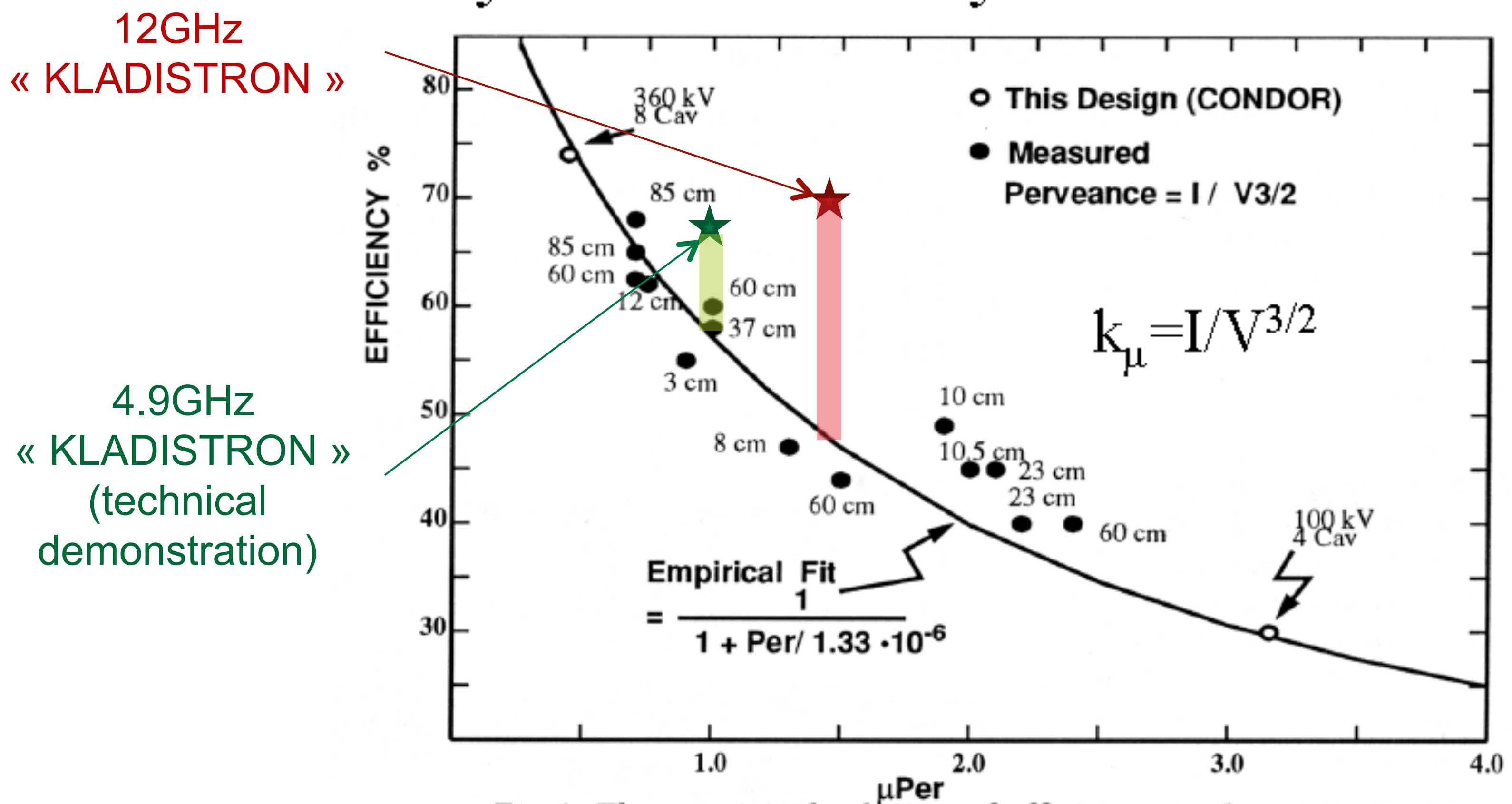


Fig. 1 The empirical relation of efficiency to the perveance.

Taken from R. Palmer, *et al*, "Status of the BNL-MIT-SLAC Cluster Klystron Project", AIP Conf. Proc. 337, p. 94ff, (1994).

4. TH2166 KLYSTRON AND THE KLADISTRON PROTOTYPE DESIGN

TH2166 KLYSTRON

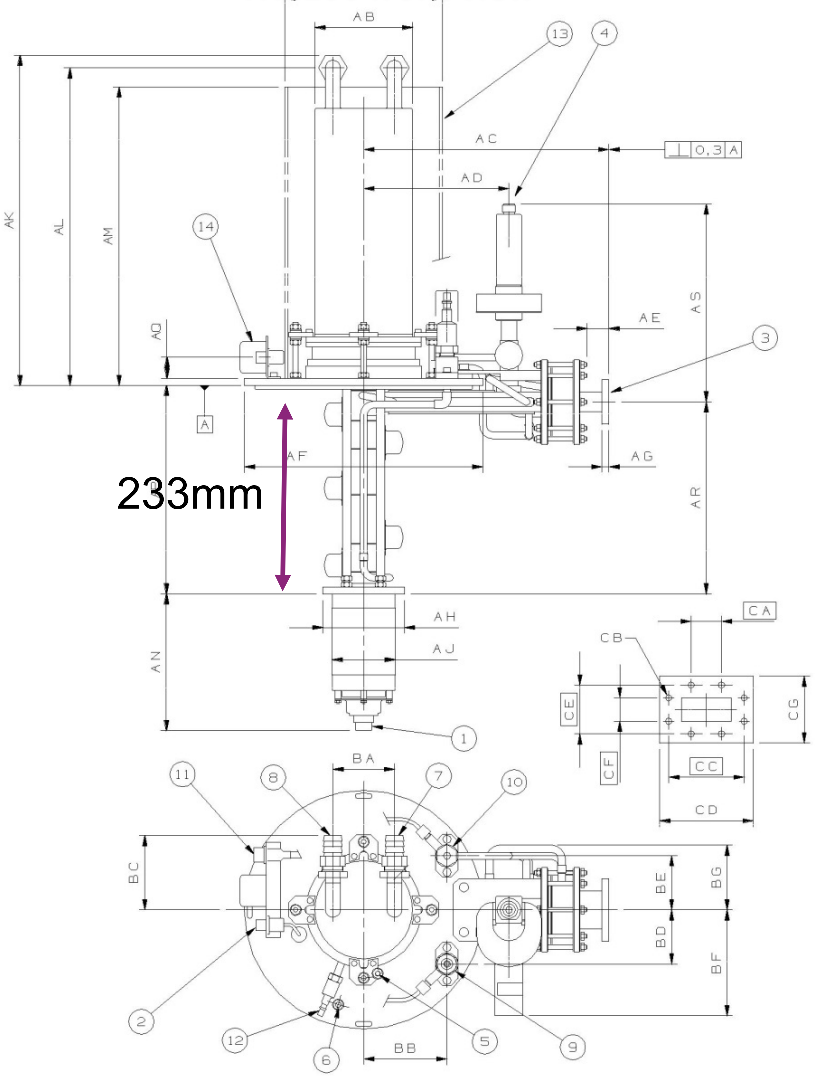
THALES

MAINZER MIKROTRON

TH2166 klystron was designed by Thales electron devices (TED) for Mainz Microtron.

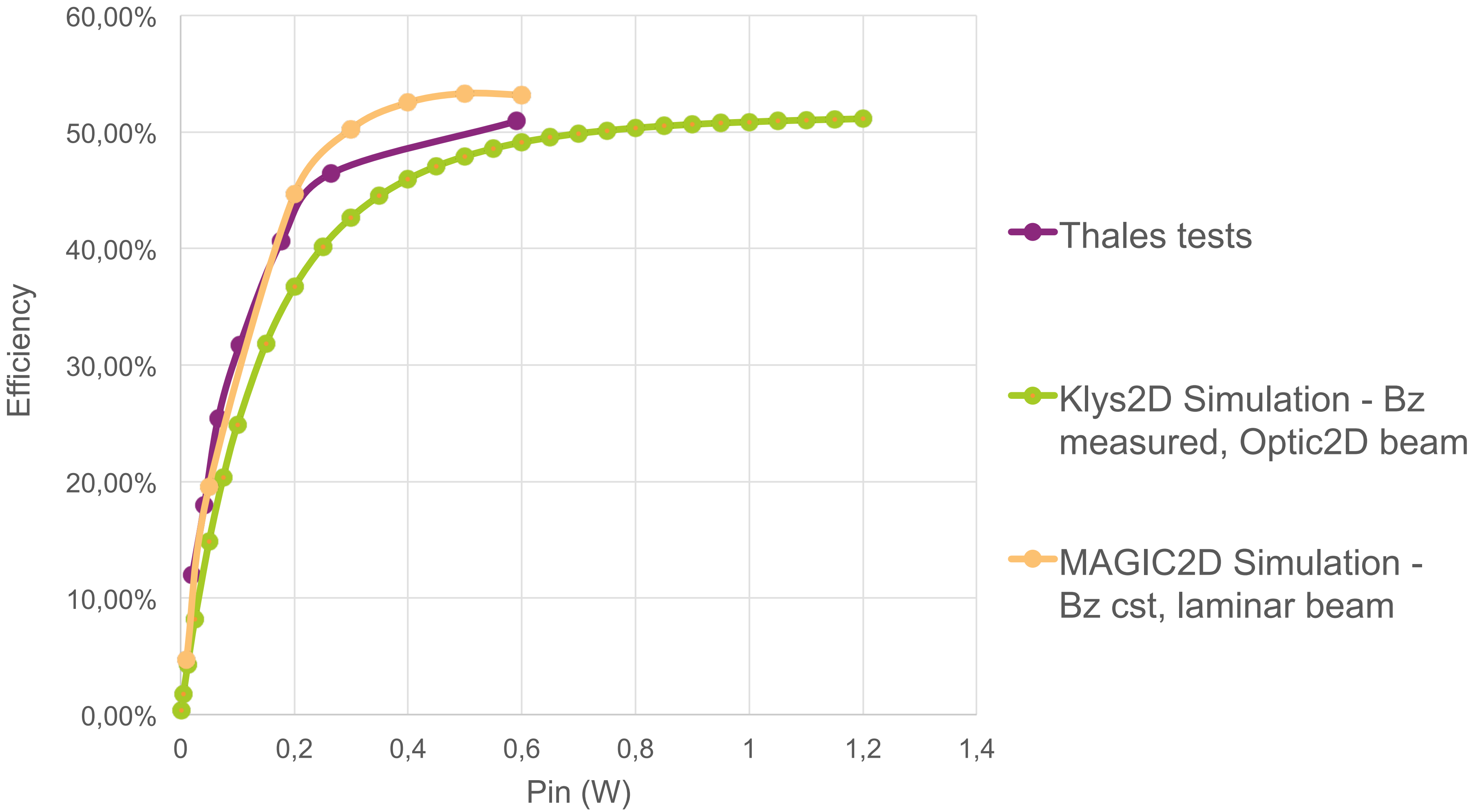
Features	
Frequency	4.9 GHz
Output power	**56 kW**
Efficiency	**50%**
Vk	26 kV
µP	1.066
Bmax	0.27 T
Gain	>40 dB
Number of cavities	**6**
Interaction line length	**233mm**

TH2166 front view



This klystron will be modified to verify the kladistron principle.

TH2166 EFFICIENCY AS A FUNCTION OF THE INPUT RF POWER: CODES VALIDATION

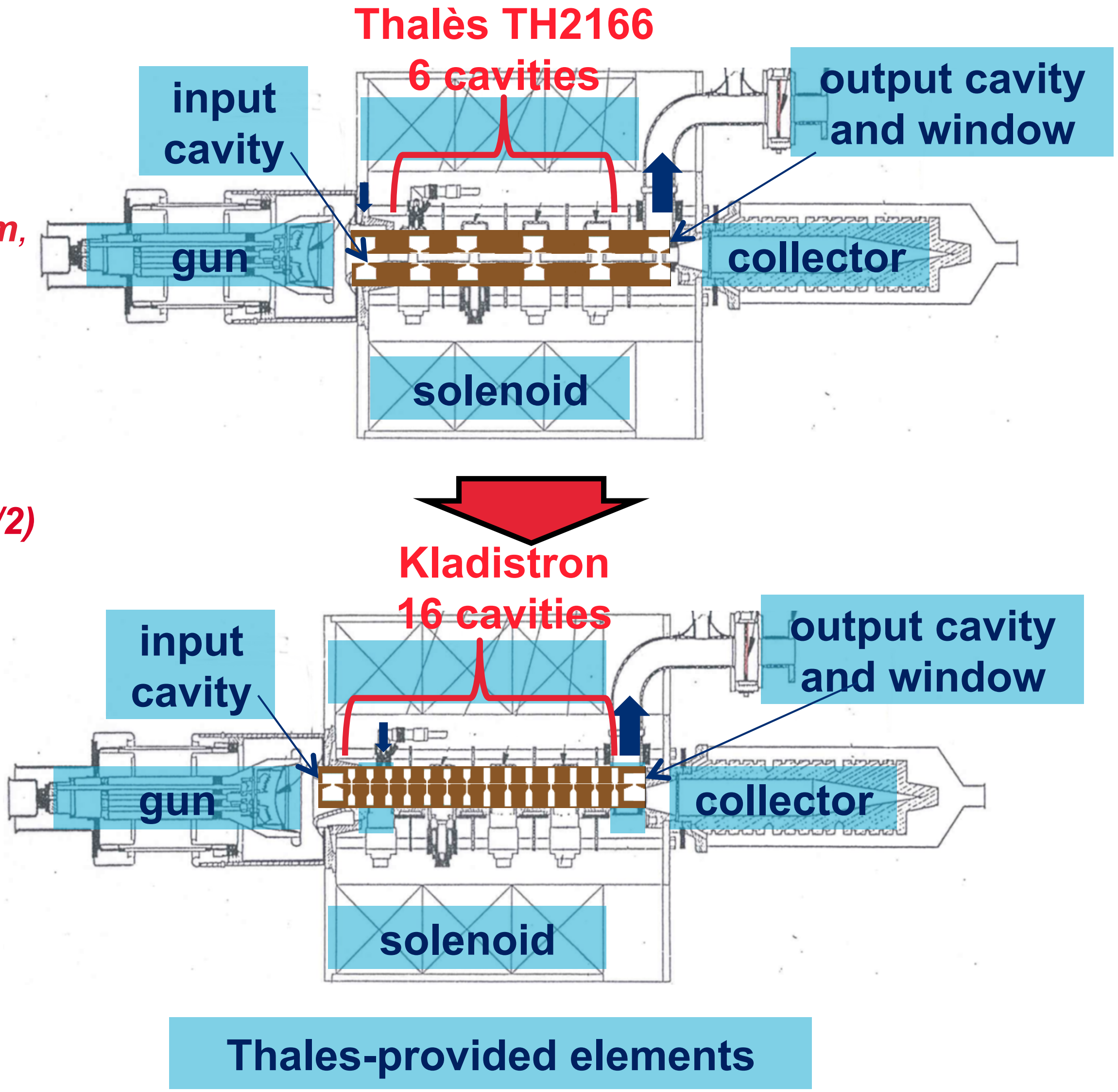


Our simulation results are close to tests results.

TH2166 “KLADISTRON” LAYOUT

The design constrains are the following :

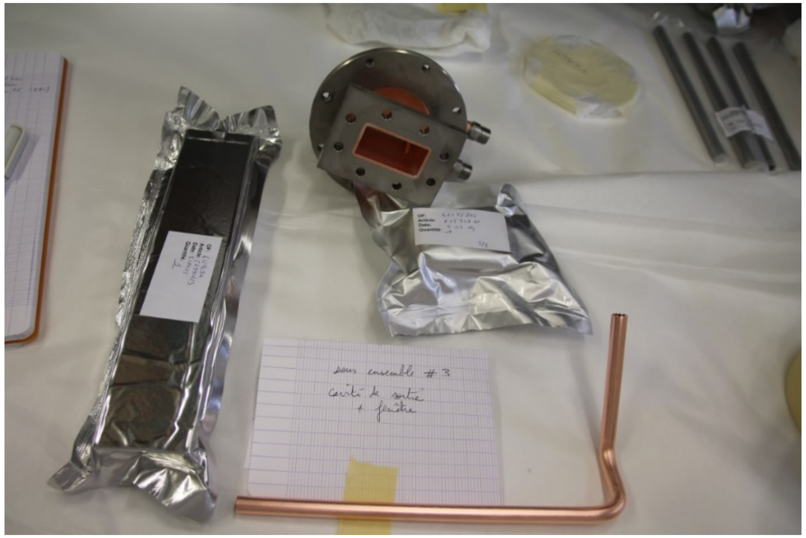
- Use the TH2166 klystron test and conditioning bench
  ➔ *Total interaction line length of **233mm**, same **input and output cavities**, same **solenoid***
- Use the TH2166 klystron electron gun and collector
  ➔ *Same microperveance of **1µA.V^(-3/2)***
- Check the kladistron principle
  ➔ *More than **6 cavities***
- Avoid cavities coupling
  ➔ *Drift space between cavities larger than **9mm***
- Avoid gain peaks
  ➔ ***Low** R/Q and Q0 values*



THALES-PROVIDED ELEMENTS

Collector

Steel rods and
Ionic pump

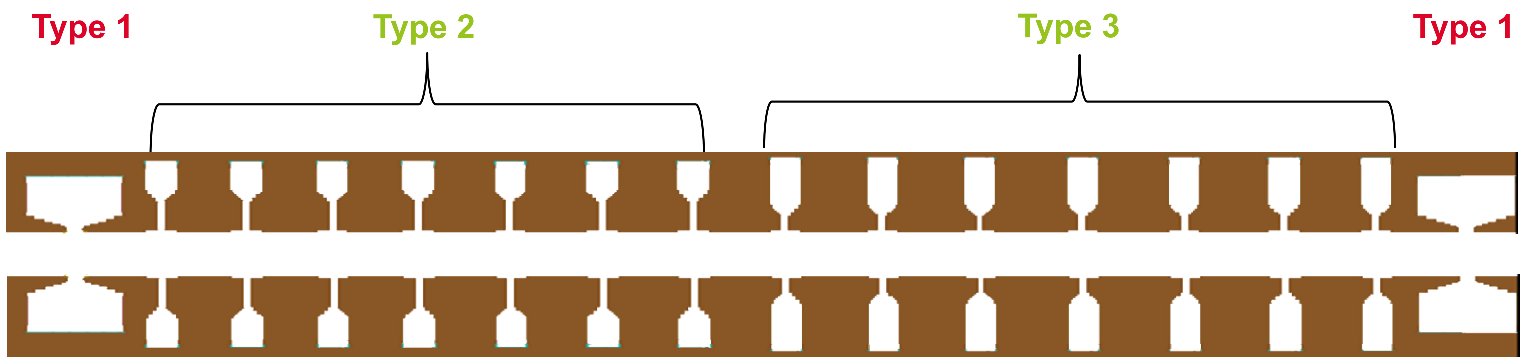


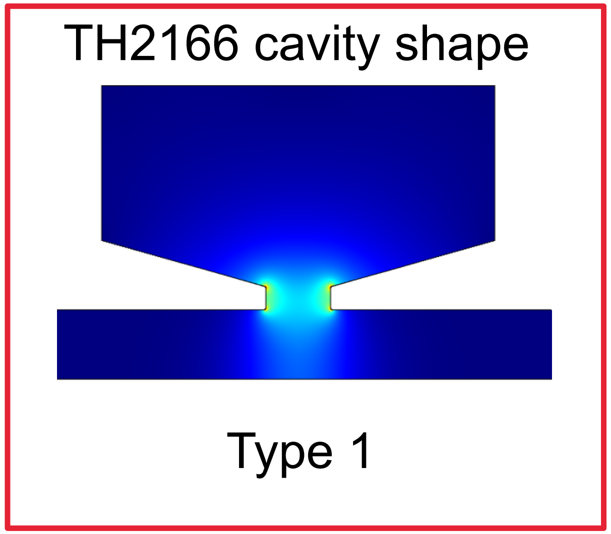
Wave guide,
Output cavity and
Output antenna

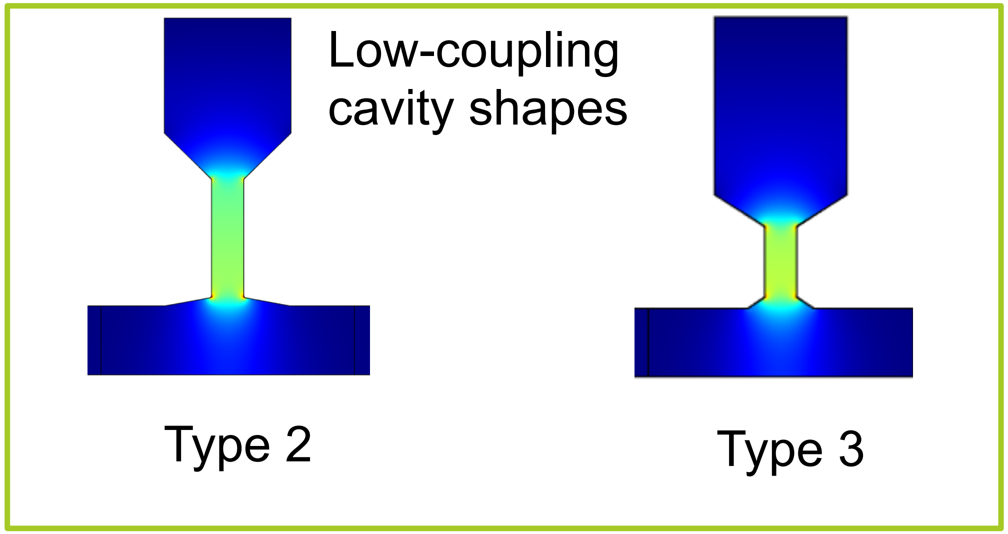
These elements have already been delivered.

TH2166 KLYSTRON ENHANCEMENT CAVITIES PRELIMINARY DESIGN

WORK IN PROGRESS



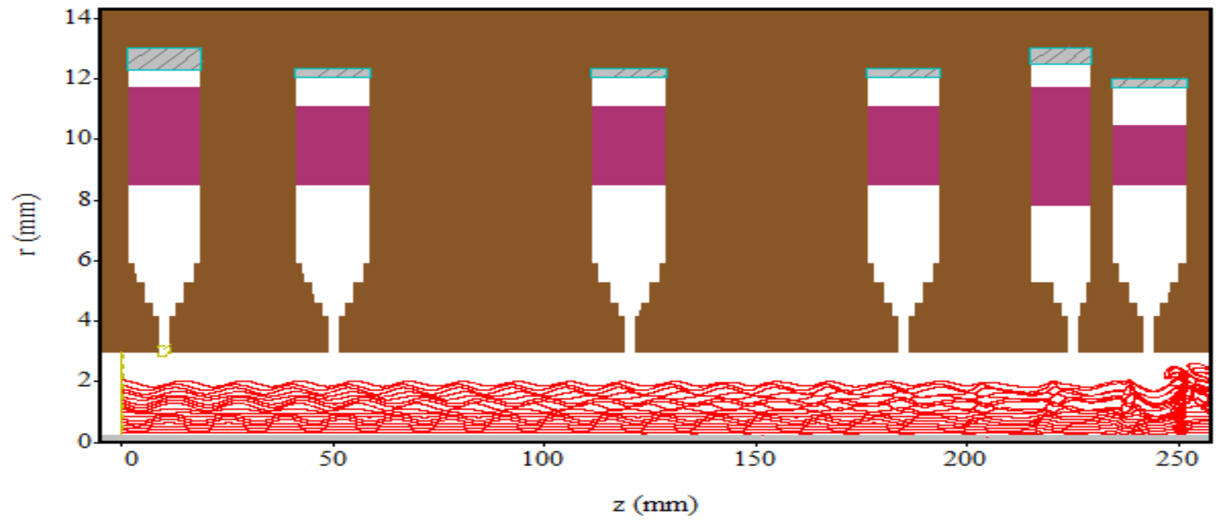


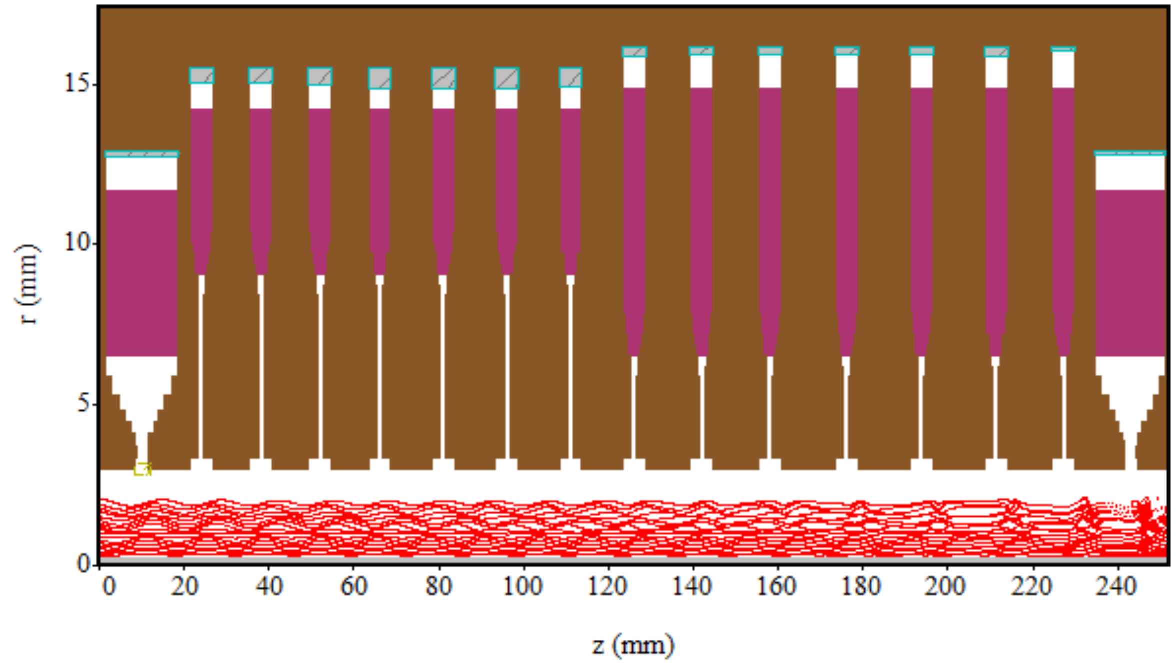


According to our COMSOL simulations, these low-coupling cavities are fit for smooth electron bunching. On the other hand, the strong electric fields and narrow cavities gap may generate multipacting.

TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

WORK IN PROGRESS

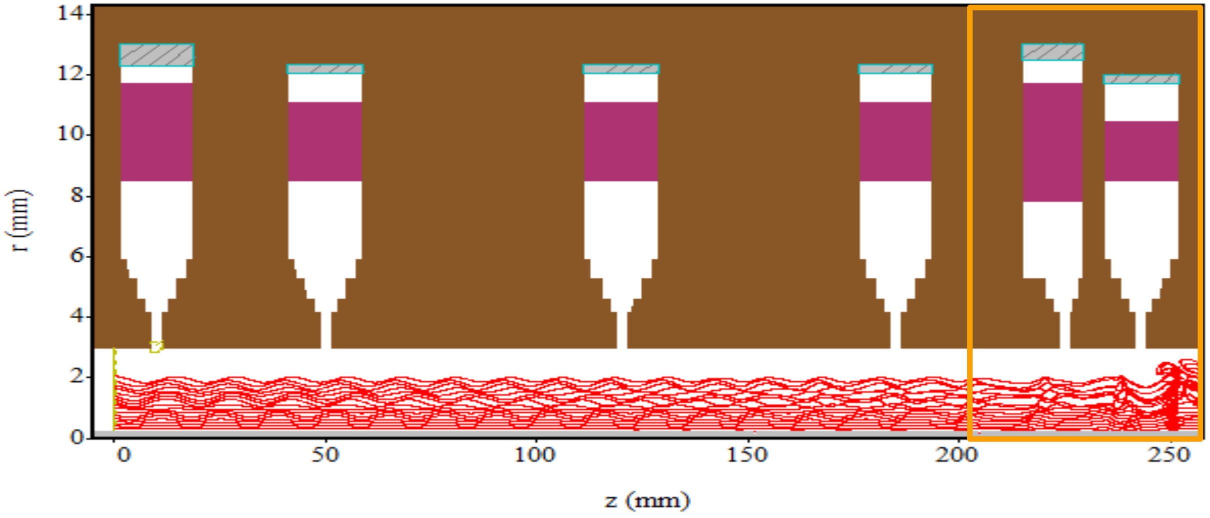




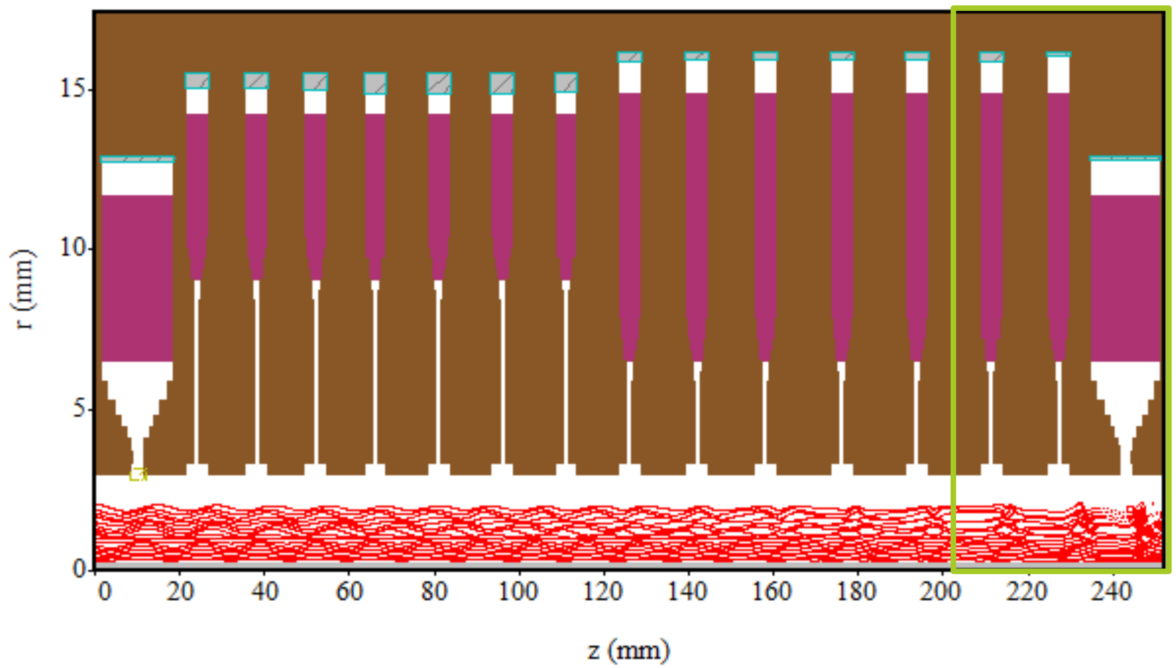
Electron bunching improvement.

TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

WORK IN PROGRESS

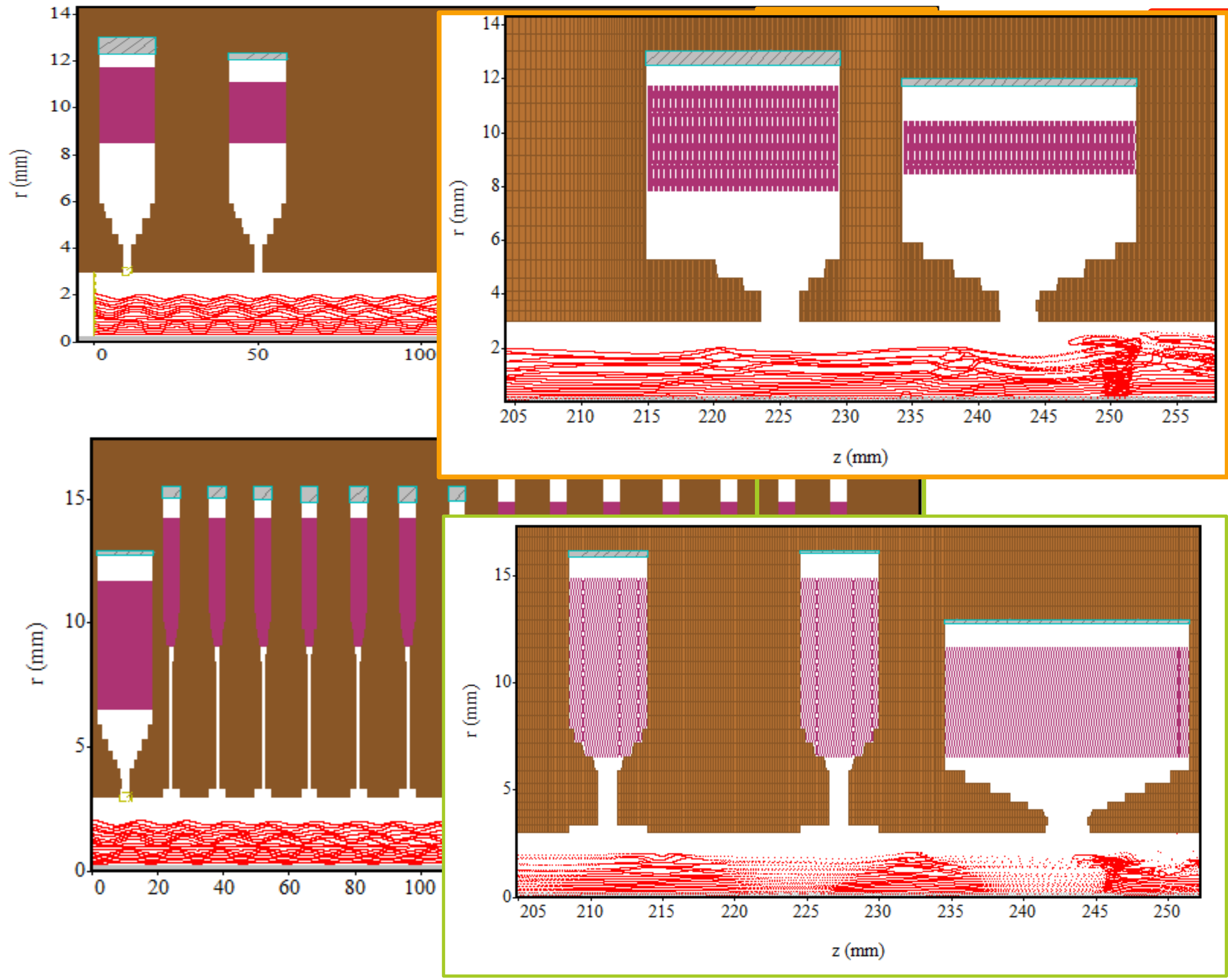


Electron bunching improvement.



TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

WORK IN
ROGRESS



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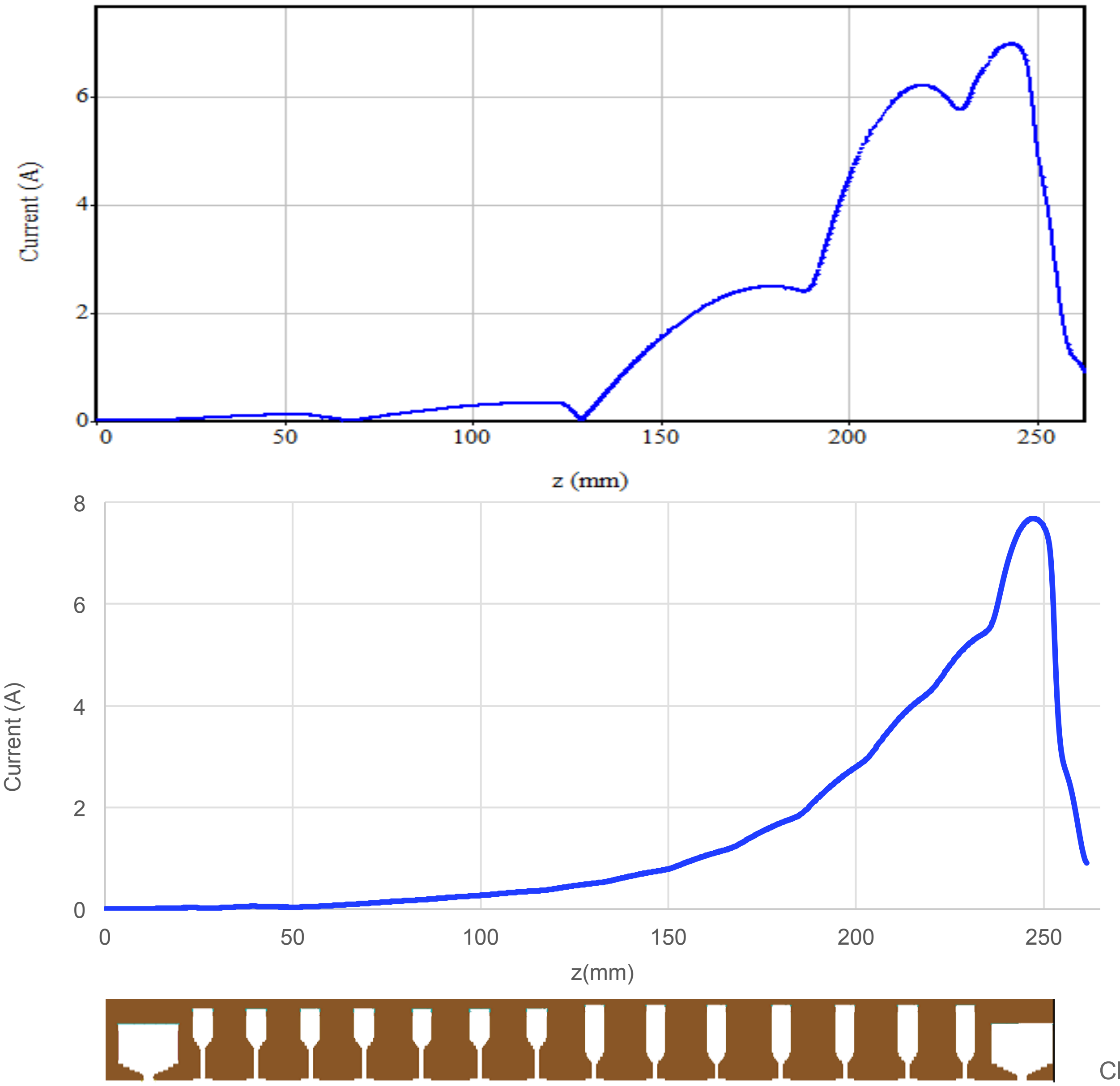
TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

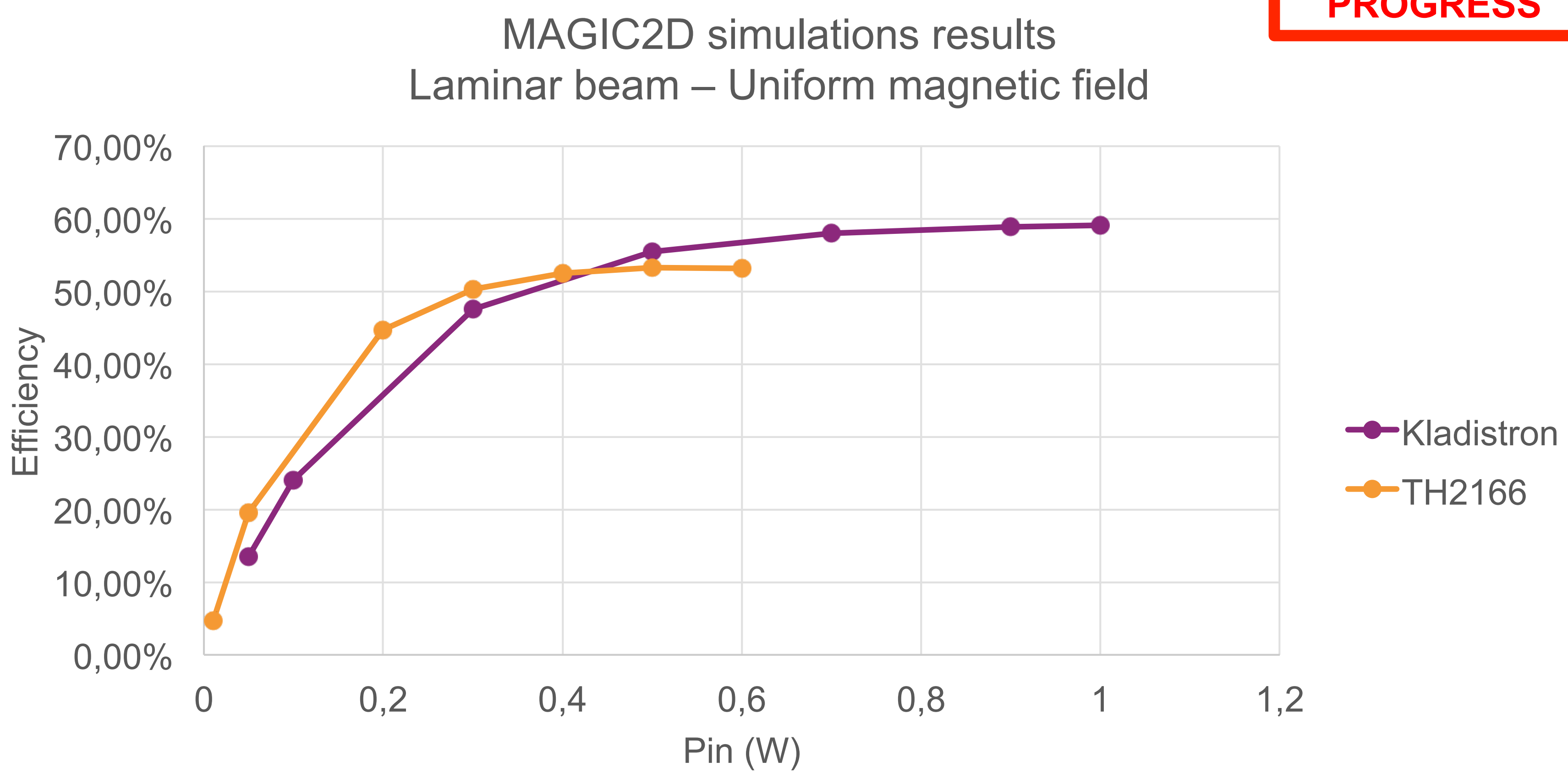
WORK IN PROGRESS



Beam current improvement.

TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

WORK IN PROGRESS

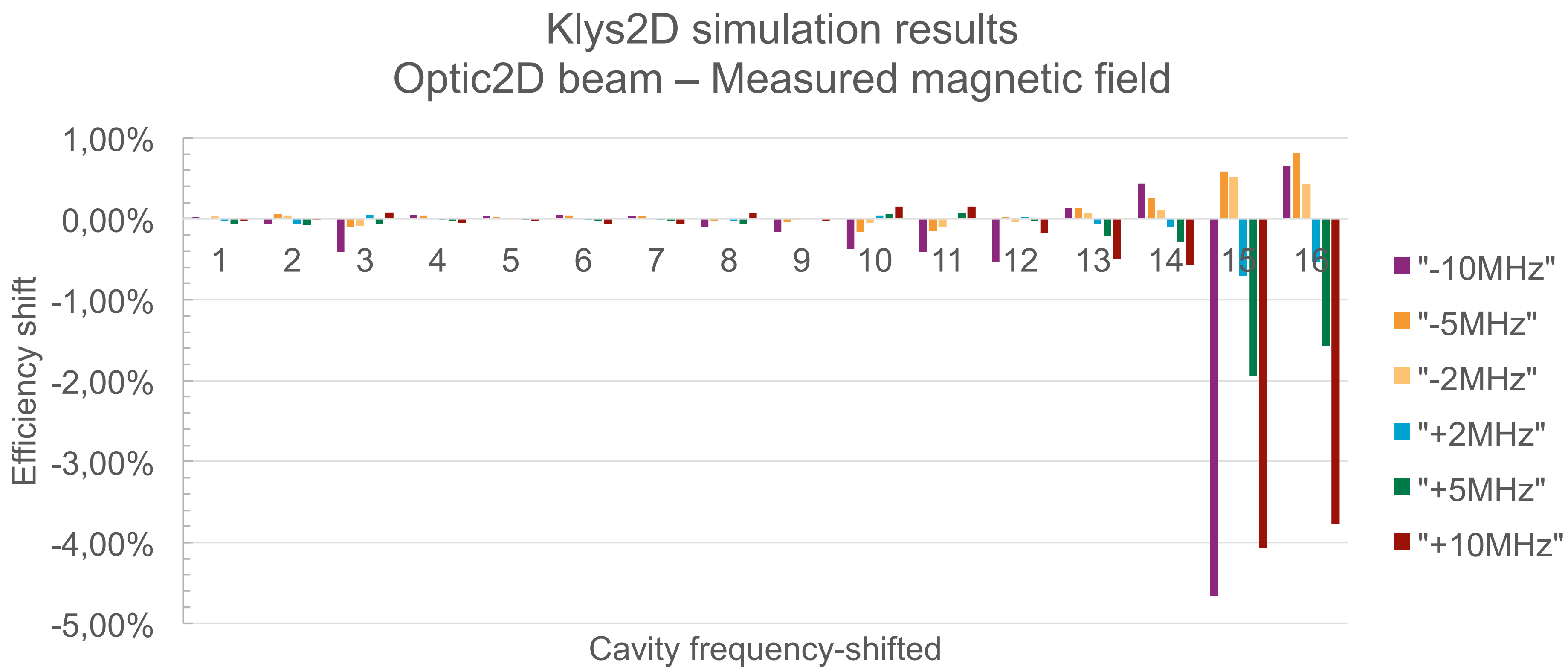


For the moment, our kladistron simulation results reach an efficiency of six points above TH2166 simulation results.

5. CAVITIES FABRICATION

FREQUENCY SHIFT : A RELIABLE TUNING SYSTEM IS REQUIRED

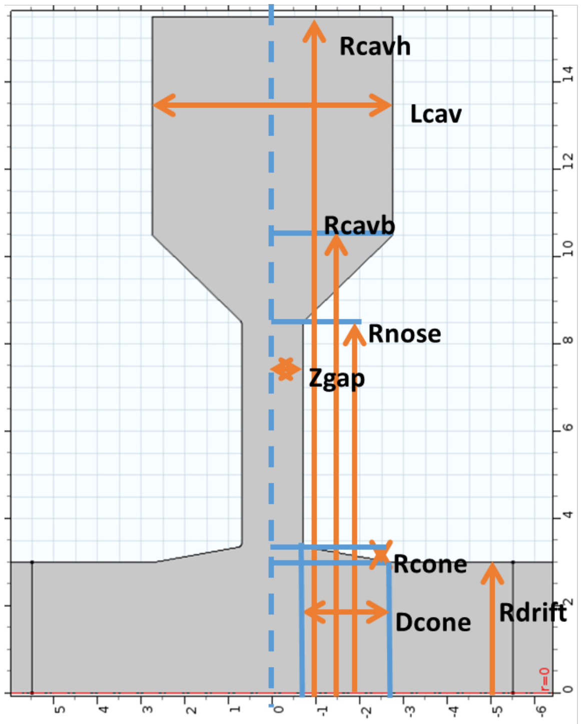
WORK IN PROGRESS



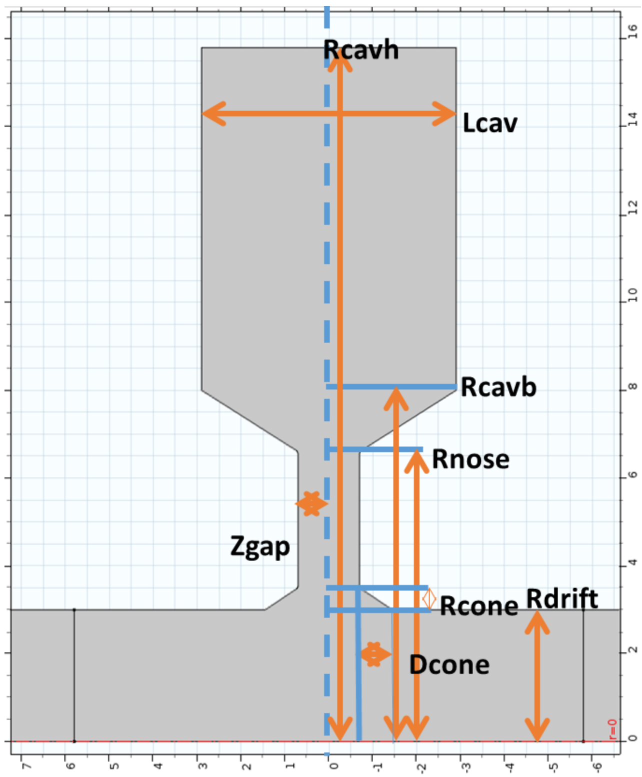
Kladistron efficiency is sensitive to its cavities frequency shifts, especially at the end of the interaction line.

FREQUENCY SHIFT : A RELIABLE TUNING SYSTEM IS REQUIRED

WORK IN PROGRESS



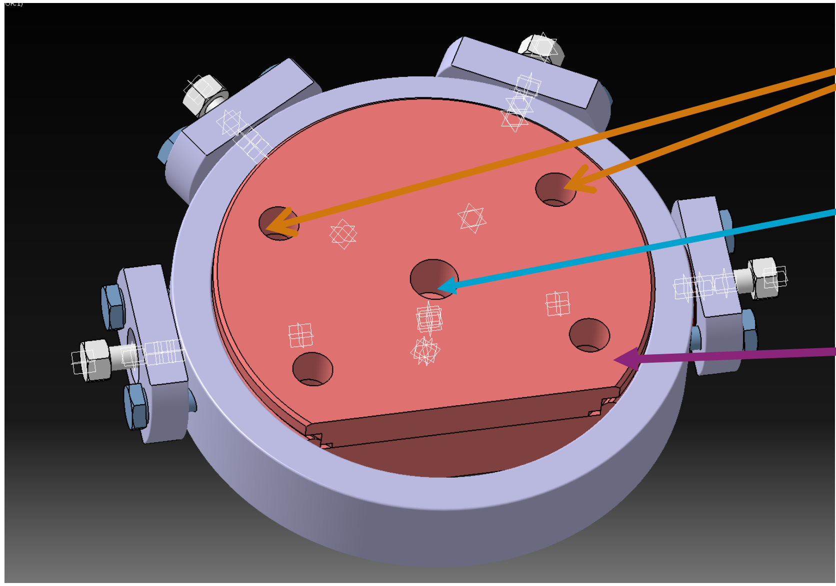
Type 2

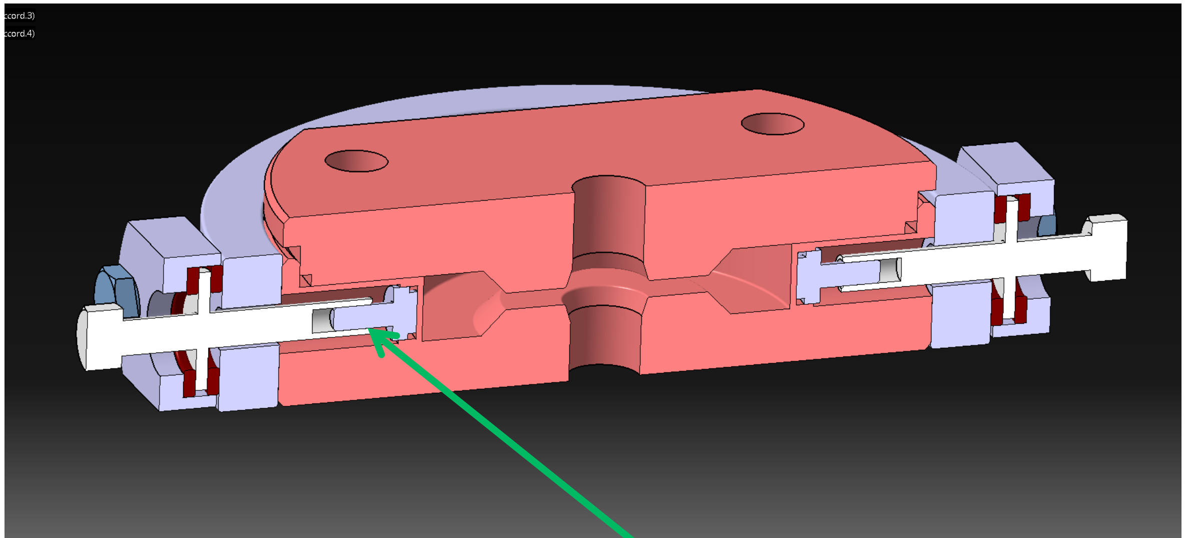


Type 3

Type	Rnose (MHz/µm)	Rcavb (MHz/µm)	Dcone (MHz/µm)	Rcone (MHz/µm)	Lcav (MHz/µm)	Rdrift (MHz/µm)	Zgap (MHz/µm)	Rcavh (MHz/µm)
2	-0.106	0.09	0.003	0.116	-0.362	0.132	**2.5**	-0.34
3	-0.2454	0.0433	0.0309	0.1251	-0.3439	0.1901	**2.3**	-0.25

CAVITIES AND TUNING SYSTEM PRELIMINARY DESIGN

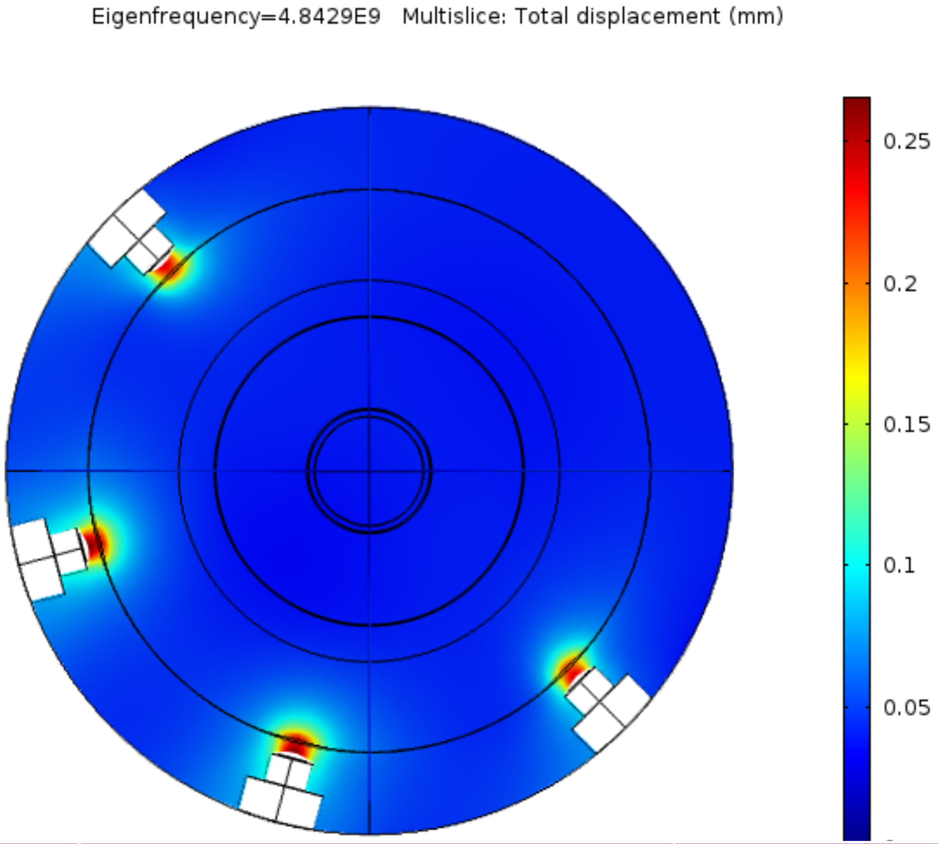




This preliminary design is under study and it takes into account the surrounding of the cavities (cooling system, solenoid,…).

The tuning system is inspired by CLIC accelerating cavities design ; a thight copper membrane is used to adjust cavities frequencies. The strain is controlled by an accurate screw thread.

TUNING SYSTEM PRELIMINARY DESIGN
COMSOL SIMULATIONS



Displacement (mm)	Δf (for each tuning system) (MHz)	Δf (for 4 tuning systems) (MHz)
0.26	4.02	16.03

Type 2 and type 3 prototype cavities under construction
to validate tuning system and brazing process.

CONCLUSION AND OUTLOOK

- ✓ *PIC codes validated for 4.9 GHz TH2166 klystron*

- ✓ *Preliminary design of 4.9 GHz kladistron done*

- ➢ **Starting construction phase of "improved" TH2166:**
  - Copper purchased
  - Most of TH2166 elements (except cavities) fabricated
  - Prototype cavities for tuning and brazing checks

- ❑ TH2166 Kladistron assembly and testing by end of year

- ❑ Multipactor study

Thank you for your attention

KLADISTRON « STABILITY »