FROM RESEARCH TO INDUSTRY

cea

PROGRESS IN HIGH EFFICIENCY KLYSTRON DESIGN

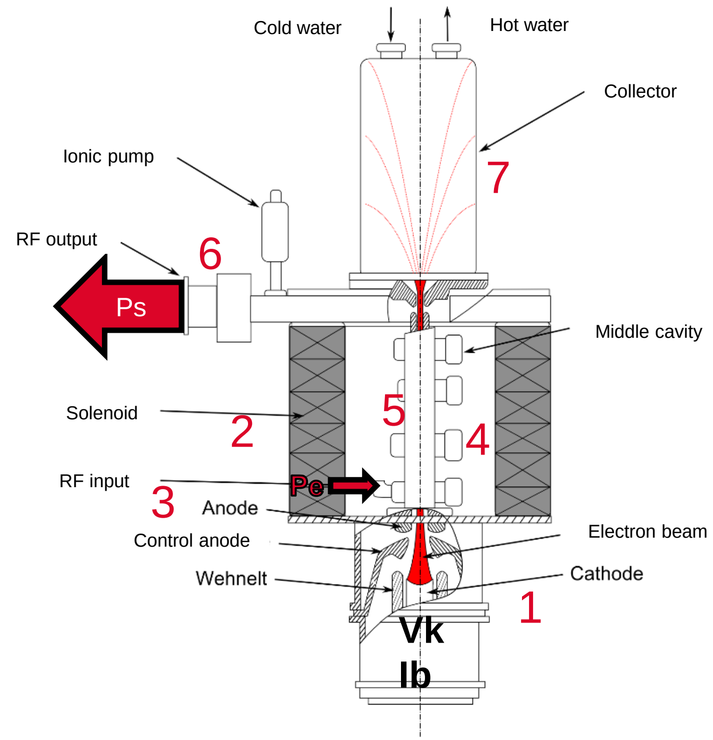
3rd Annual Meeting of the EuCARD-2 WP12 | *Mollard Antoine* antoine.mollard@cea.fr

1. KLYSTRON PRINCIPLE

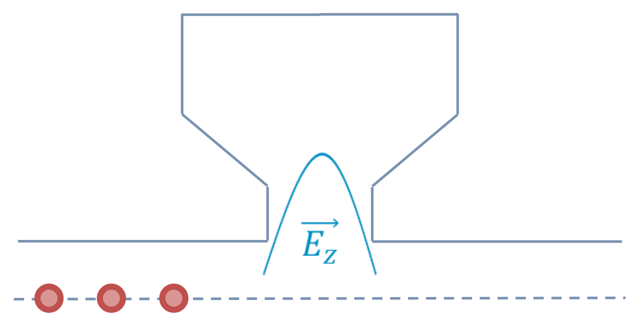
KLYSTRON PRINCIPLE

Linear-beam vacuum device which is used as a narrow bandwidth amplifier for high radio frequencies (100 MHz-100GHz)

1. Creation of a stream of electrons by the electron gun (thermionic emission)
2. Confinement by an external magnetic field
3. Triggering of the beam modulation by the wave in the input cavity
4. Modulation of the beam into a set of electron bunches in the gain cavity/ies
5. Drifting of the electron bunches
6. Energy transfer between the bunches and the output antenna
7. Absorption of the lower energy electron beam by the collector



Klystron efficiency is the ratio of the output power to the electron gun supply power.



$$\eta = \frac{P_{out}}{V_k * I_b}$$

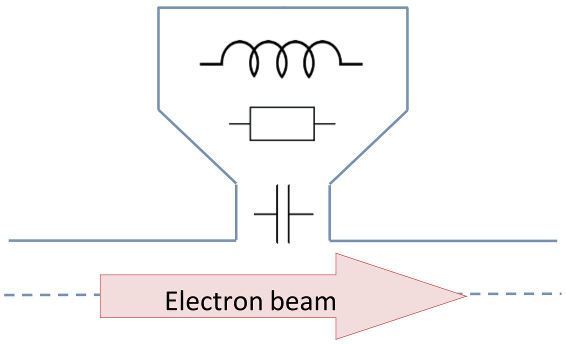
$$\mu P = \frac{I_b * 10^6}{V_k^{3/2}}$$

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**.



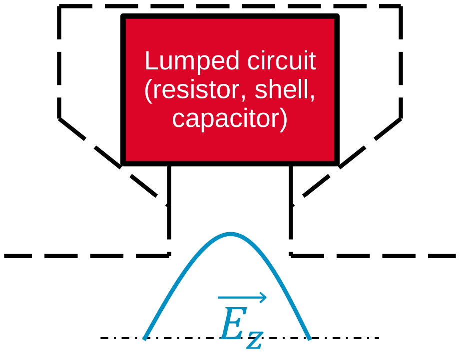
$$Q_0 = \frac{R}{\omega_0 L} = \frac{\omega_0 \mu_0 \iiint |B|^2 dV}{\iint R_S |B|^2 dS}$$

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

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

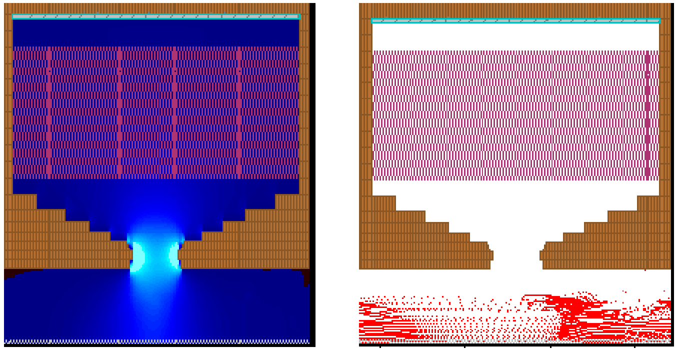
KLYSTRON SIMULATION CODES USED IN THIS PROJECT

- ***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

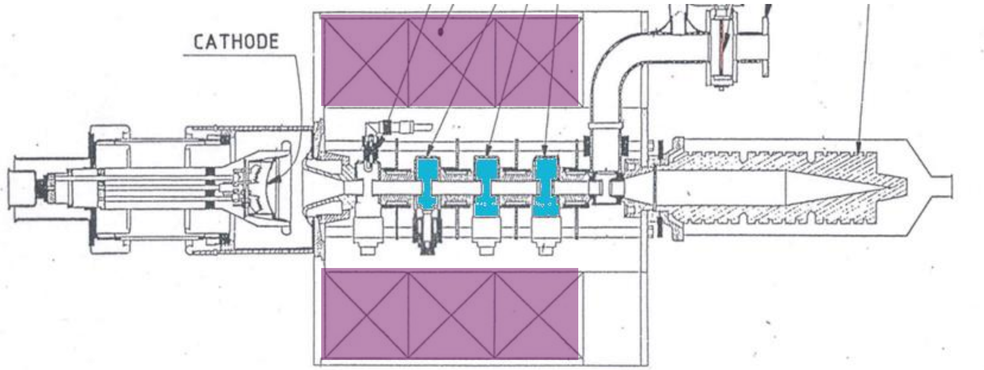
Collaboration with THALES ELECTRON DEVICES :
PhD funding : 50% CEA/50% Thales (Contrat de Thèse CEA Industrie)
Co-supervisation :
Juliette Plouin/Franck Peauger/Claude Marchand @ CEA
Armel Beunas/Rodolphe Marchesin @ Thales

Collaboration with CERN : Igor Syratchev, Walter Wuensch…
MAGIC bought by CEA with *“contribution exceptionnelle de la France au CERN”*

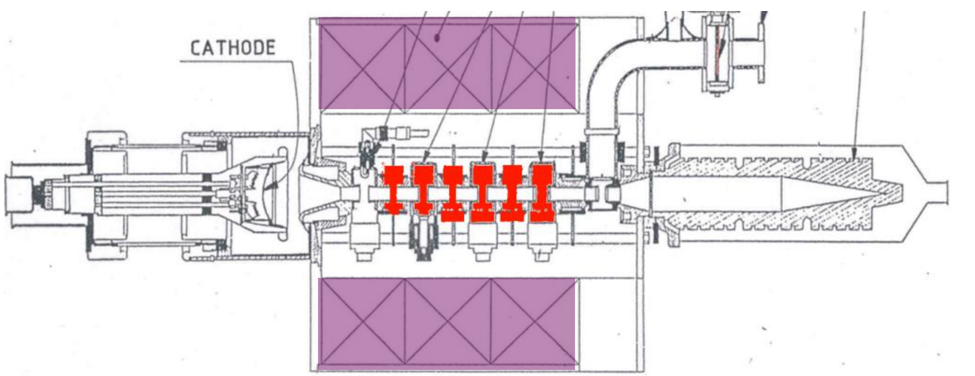
☞ **Activity fully oriented towards R&D**

3. KLADISTRON (HIGH-EFFICIENCY KLYSTRON) PRINCIPLE

KLADISTRON



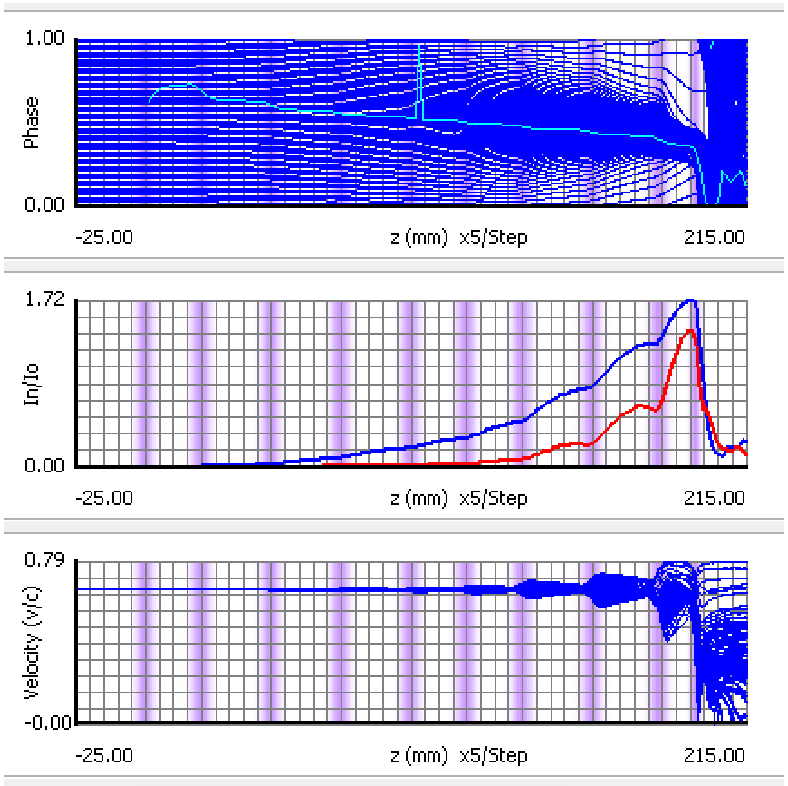
$$\begin{cases} N_{cavities} \nearrow \\ \frac{R}{Q} \searrow \end{cases} \Rightarrow \textbf{Efficiency } (\eta) \nearrow$$

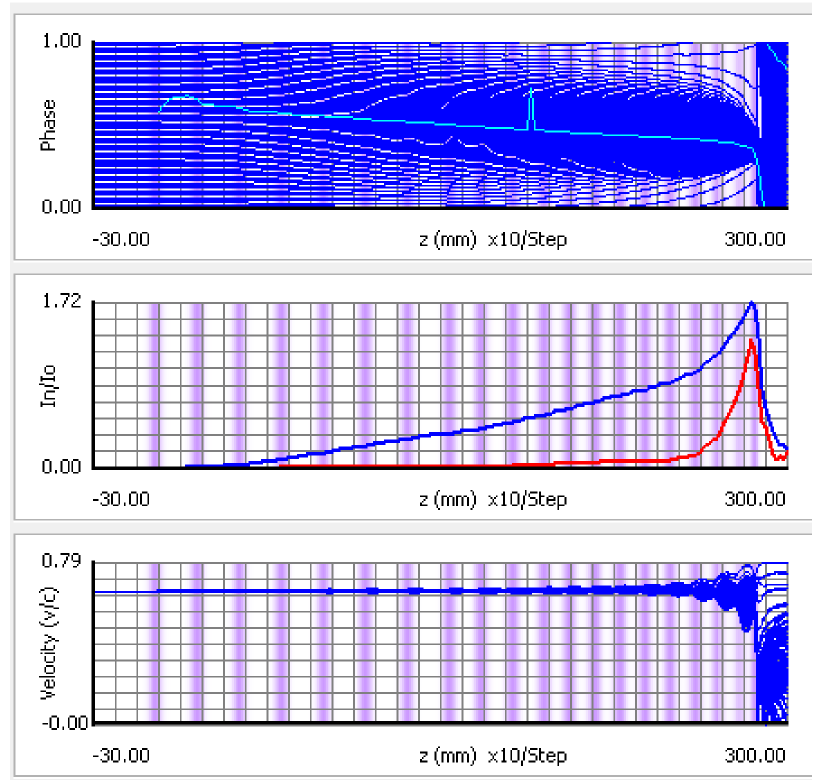


A Kladistron (Kl-adi(adiabatic)-stron) is a high-efficiency klystron with a large number of cavities (at least twice as many as in a classical klystron).

Inspired by RFQ, this architecture leads us to a smoother bunching and also a higher efficiency.

AJDISK 1D-SIMULATIONS OF A 12GHZ-KLADISTRON





10 cavities
Efficiency 67.2 %
Length 197 mm

20 cavities
Efficiency 78 %
Length 285 mm

In the design proposed, 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

12GHz
« KLADISTRON »

4.9GHz
« KLADISTRON »
(technical
demonstration)

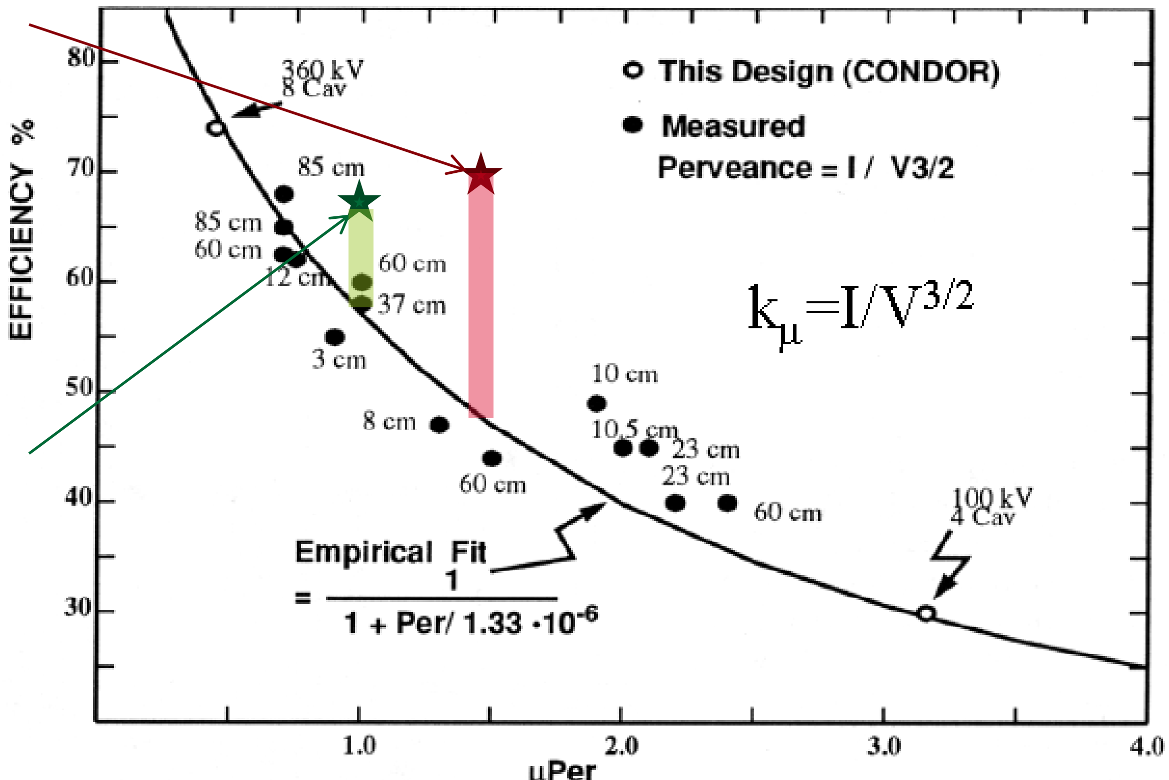


Fig. 1 The empirical relation of efficiency to the perveance.

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

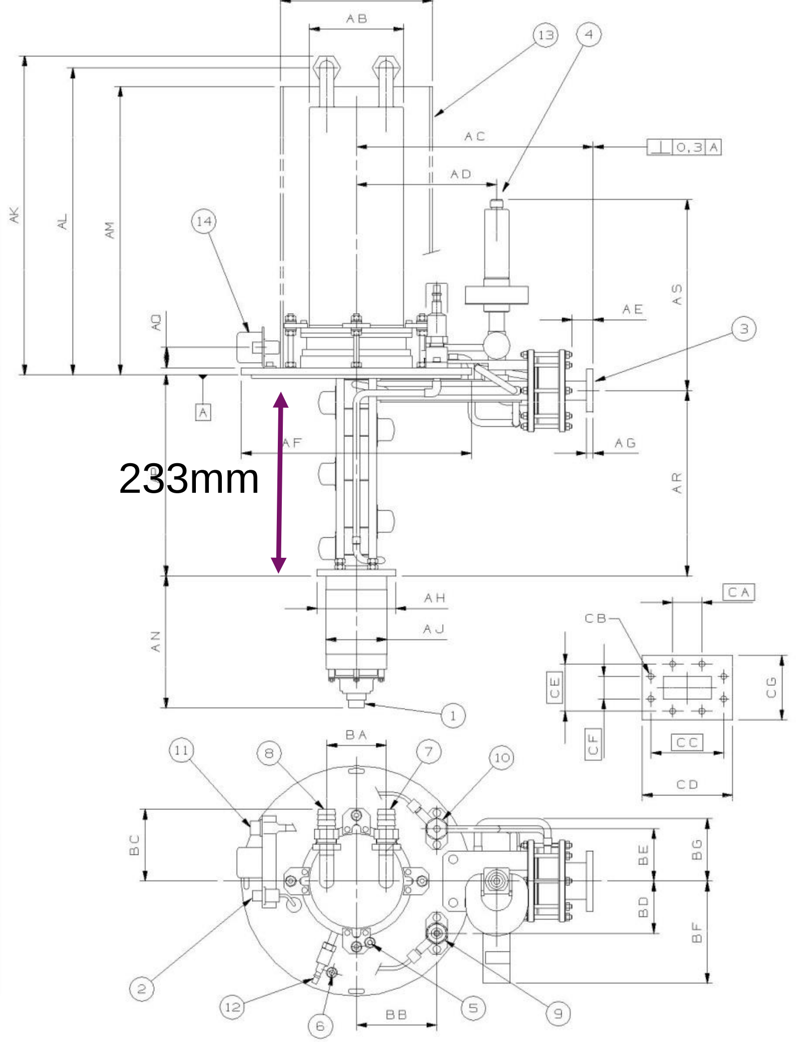
TH2166 KLYSTRON

THALES

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

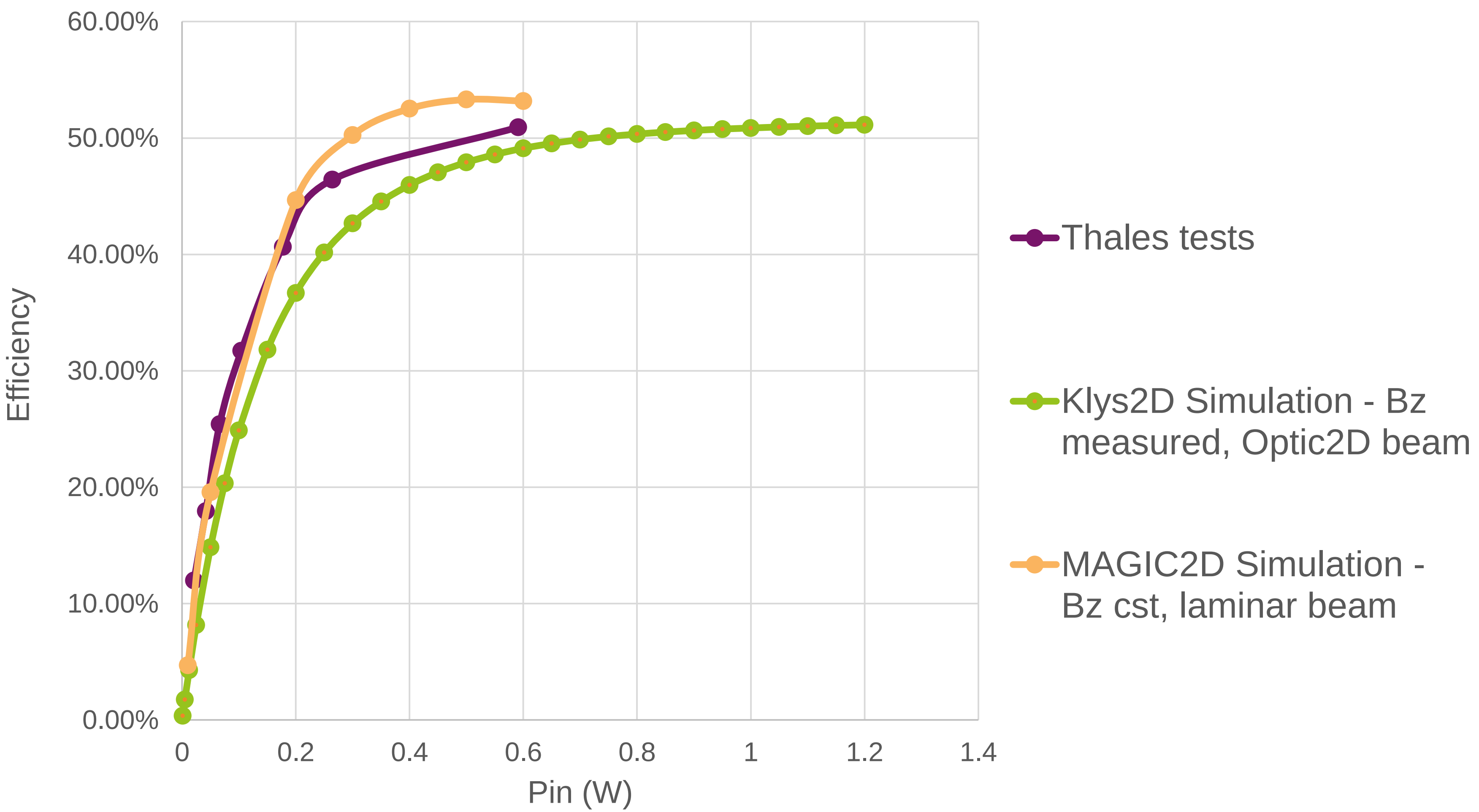
Features	
Frequency	4.9 GHz
Output power	**56 kW**
Efficiency	**50%**
Vk	26 kV
µP	1.066
Bmax	0.27 T
Gain	>40 dB
Number of cavities	**6**
Interaction line length	**233mm**

TH2166 front view



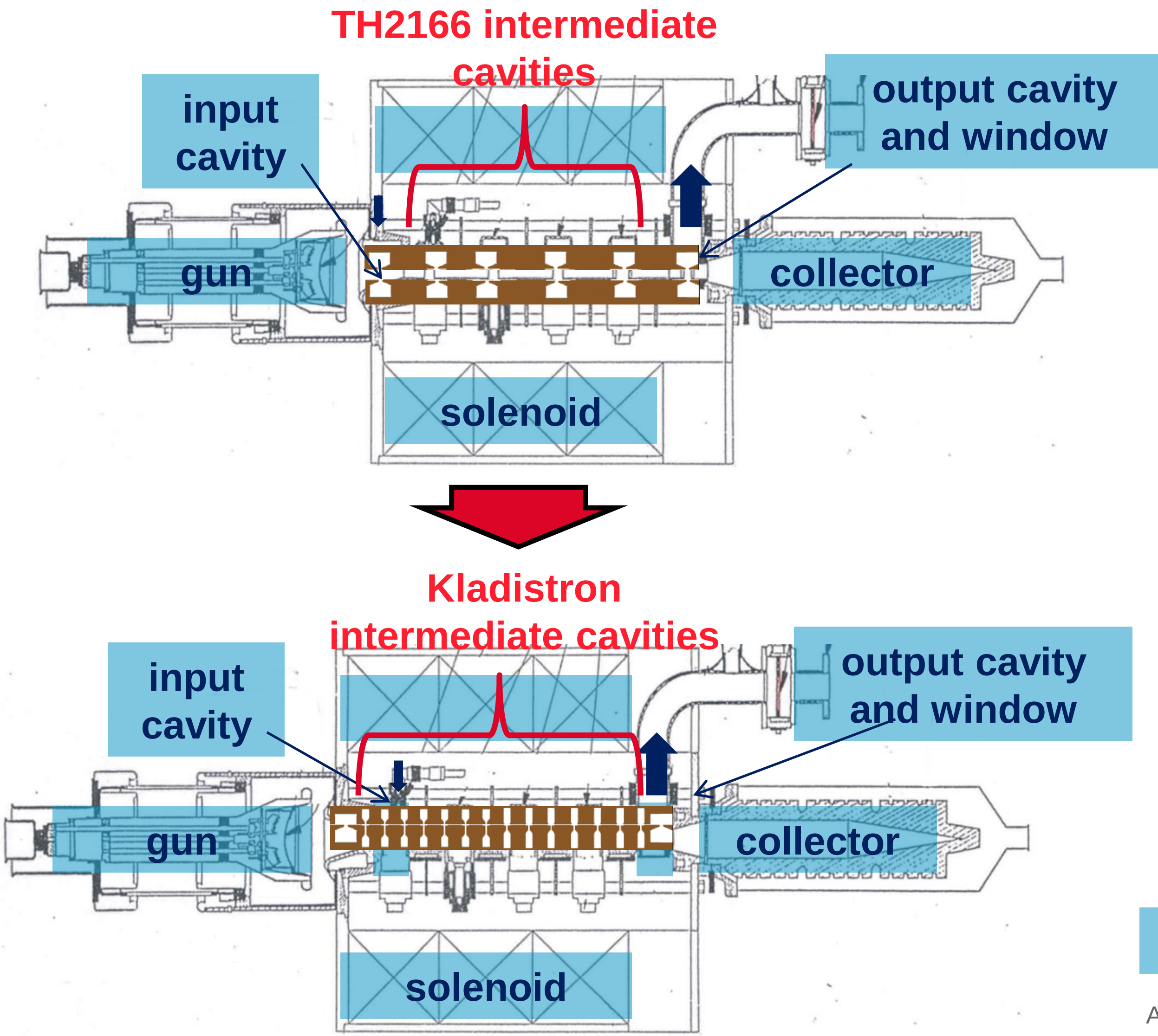
This klystron will be modified to verify the kladistron principle.

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



Our simulation results are close to tests results.

KLYSTRON TH2166 ENHANCEMENT
MODIFICATION OF THE INTERACTION LINE



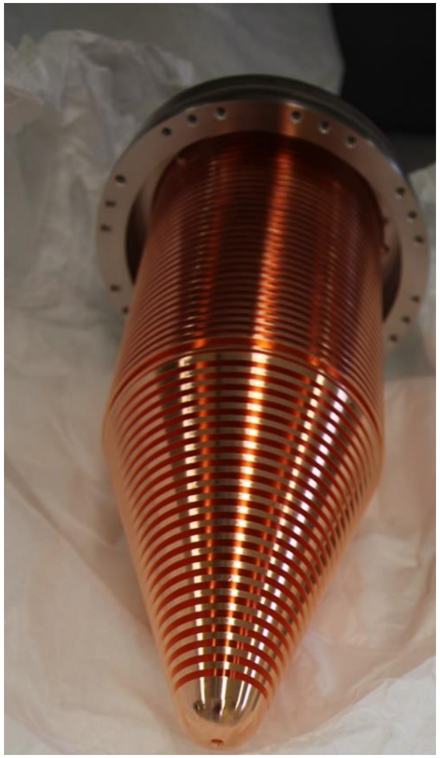
Thales TH2166 klystron 6 cavities

CEA TH2166 kladistron 16 cavities

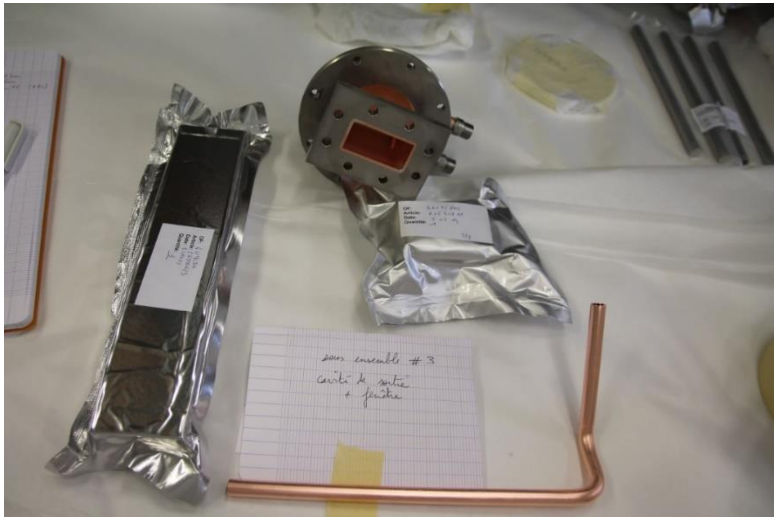
Thales-provided elements

THALES-PROVIDED ELEMENTS

Steel rods and Ionic pump



Collector



Wave guide, Output cavity and Output antenna

These elements have already been delivered.

KLYSTRON TH2166 ENHANCEMENT CAVITIES PRELIMINARY DESIGN

The design we are looking for would let us :

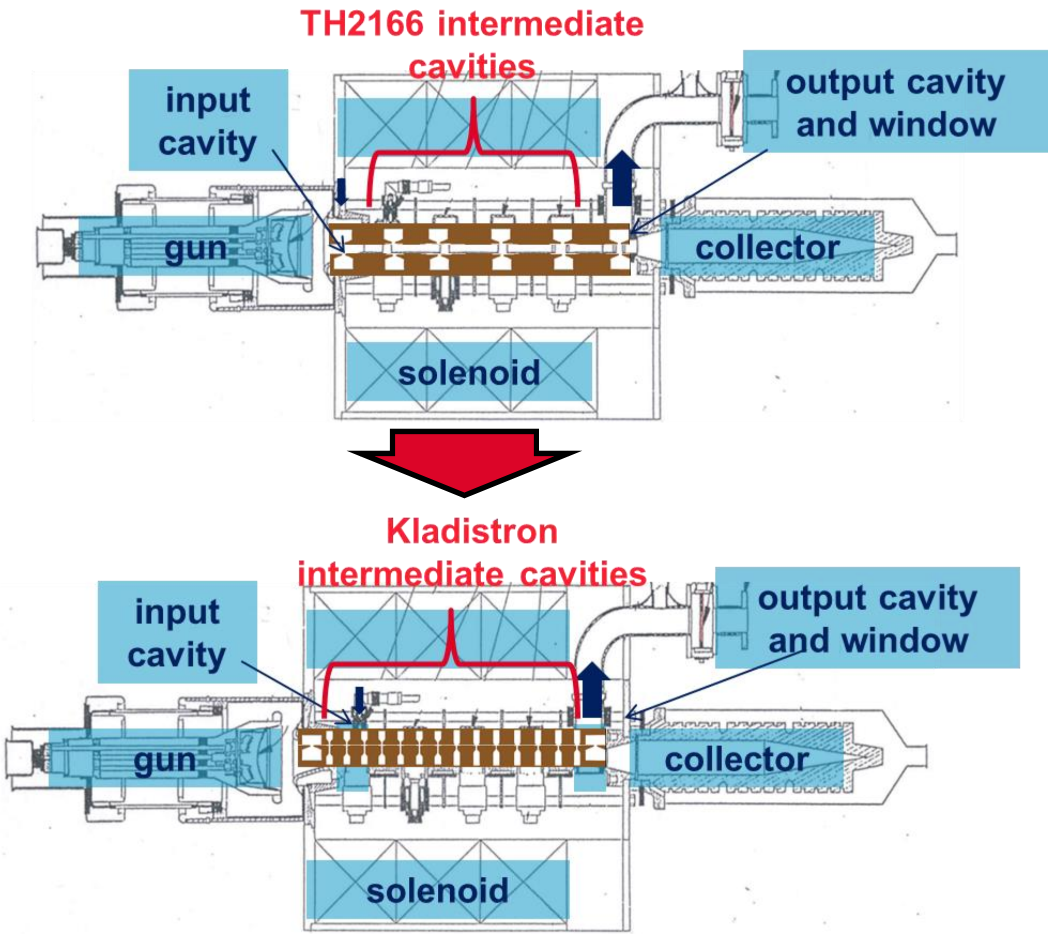
- Use the TH2166 klystron test and conditioning bench
  ➔ *Total interaction line length of **233mm**, same **input and output cavities**, same **solenoid***

- Use the TH2166 klystron electron gun and collector
  ➔ *Same microperveance of **1µA.V^(-3/2)***

- Check the kladistron principle
  ➔ *More than **6 cavities***

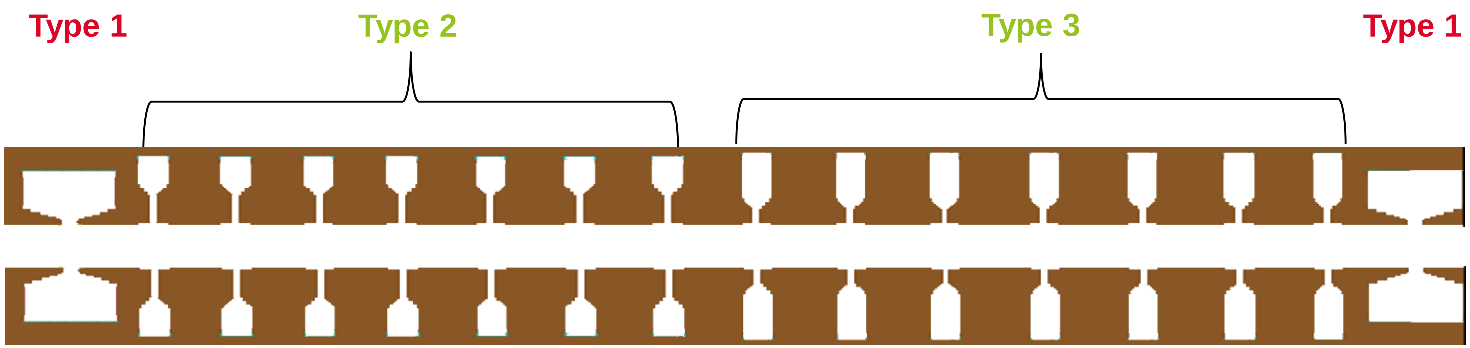
- Avoid cavities coupling
  ➔ *Drift space between cavities larger than **9mm***

- Avoid gain peaks
  ➔ ***Low** R/Q and Q0 values*

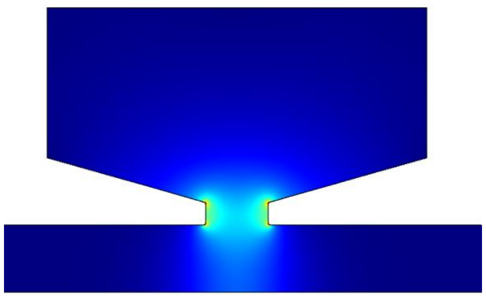


KLYSTRON TH2166 ENHANCEMENT CAVITIES PRELIMINARY DESIGN

WORK IN PROGRESS

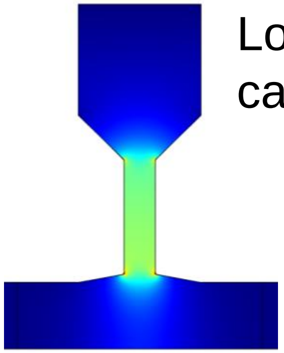


TH2166 cavity shape

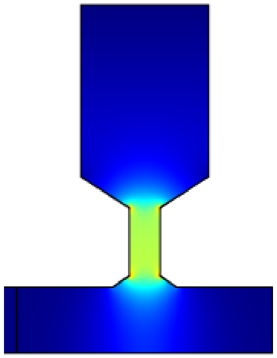


Type 1

Low-coupling cavity shapes



Type 2

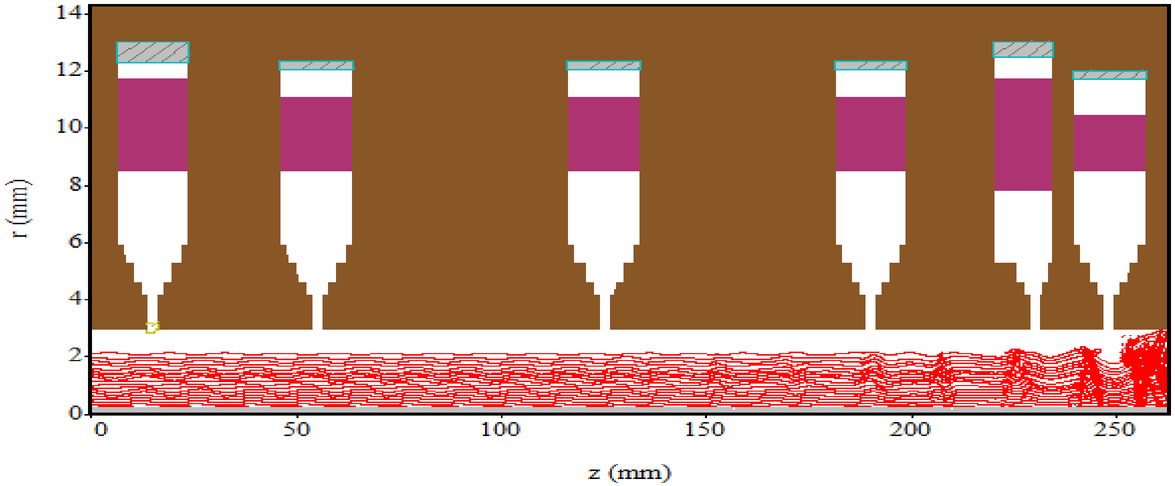


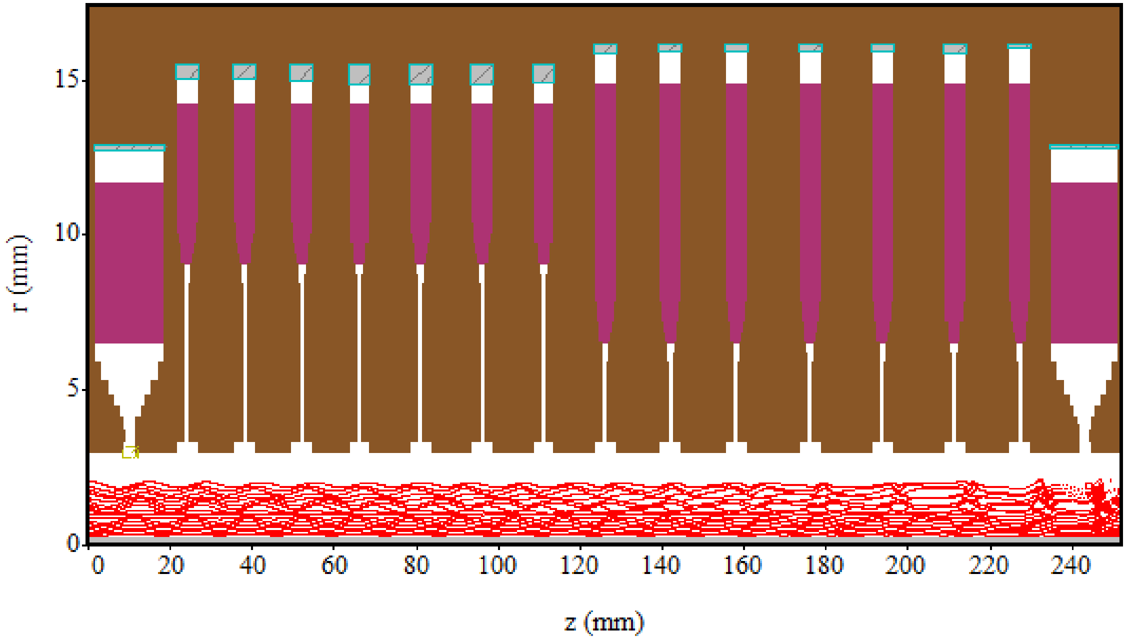
Type 3

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 are responsible for multipactor phenomenon.

TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

WORK IN PROGRESS





Electron bunching improvement.

TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

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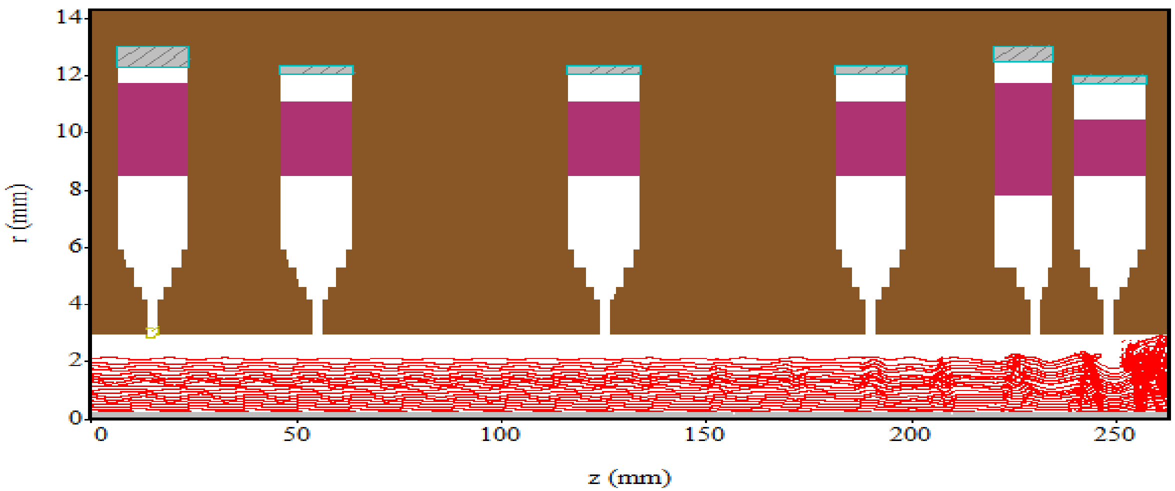

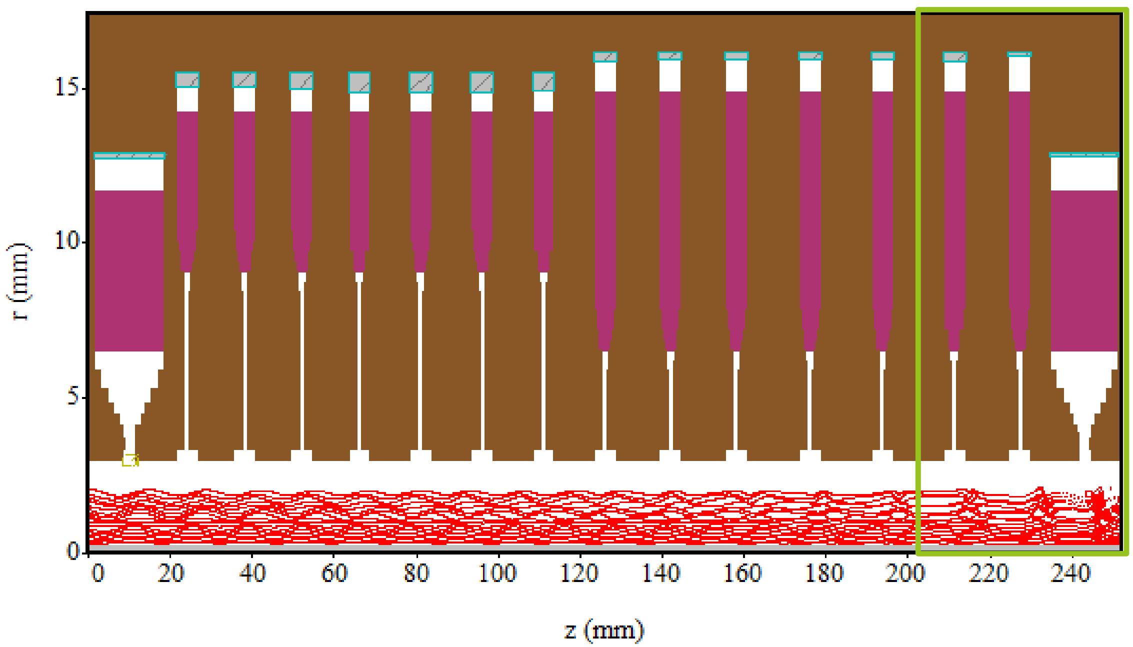

Electron bunching improvement.

TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

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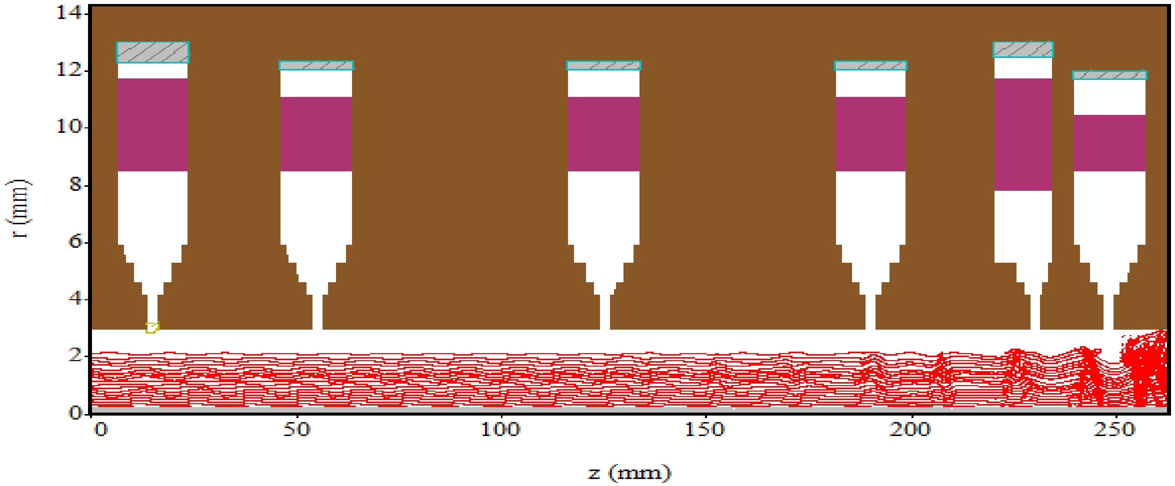
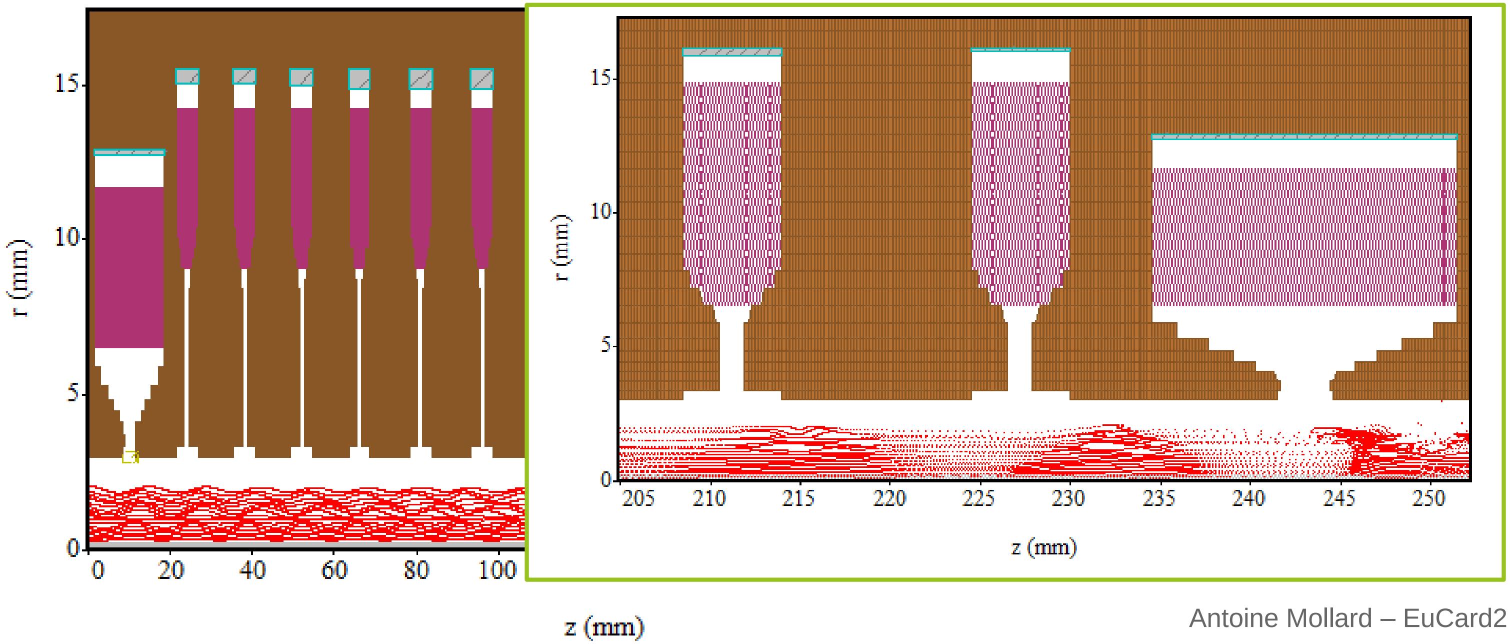


Electron bunching improvement.



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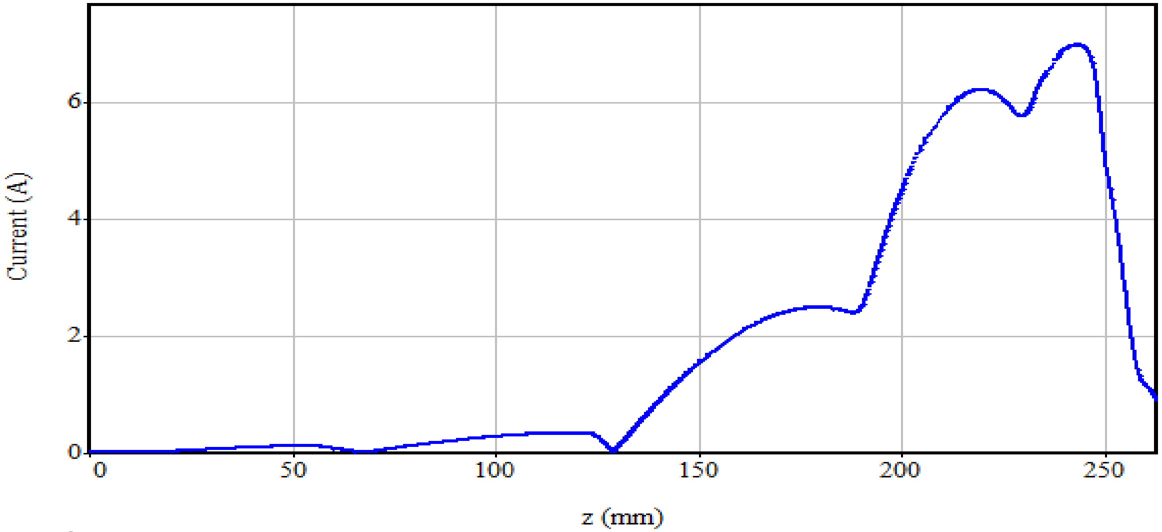
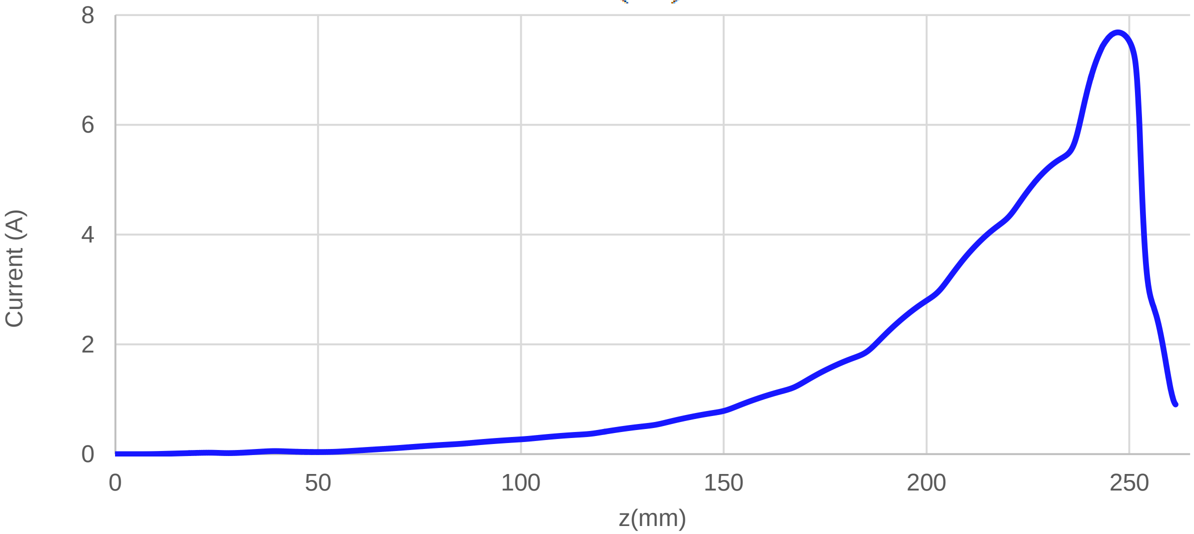
WORK IN PROGRESS

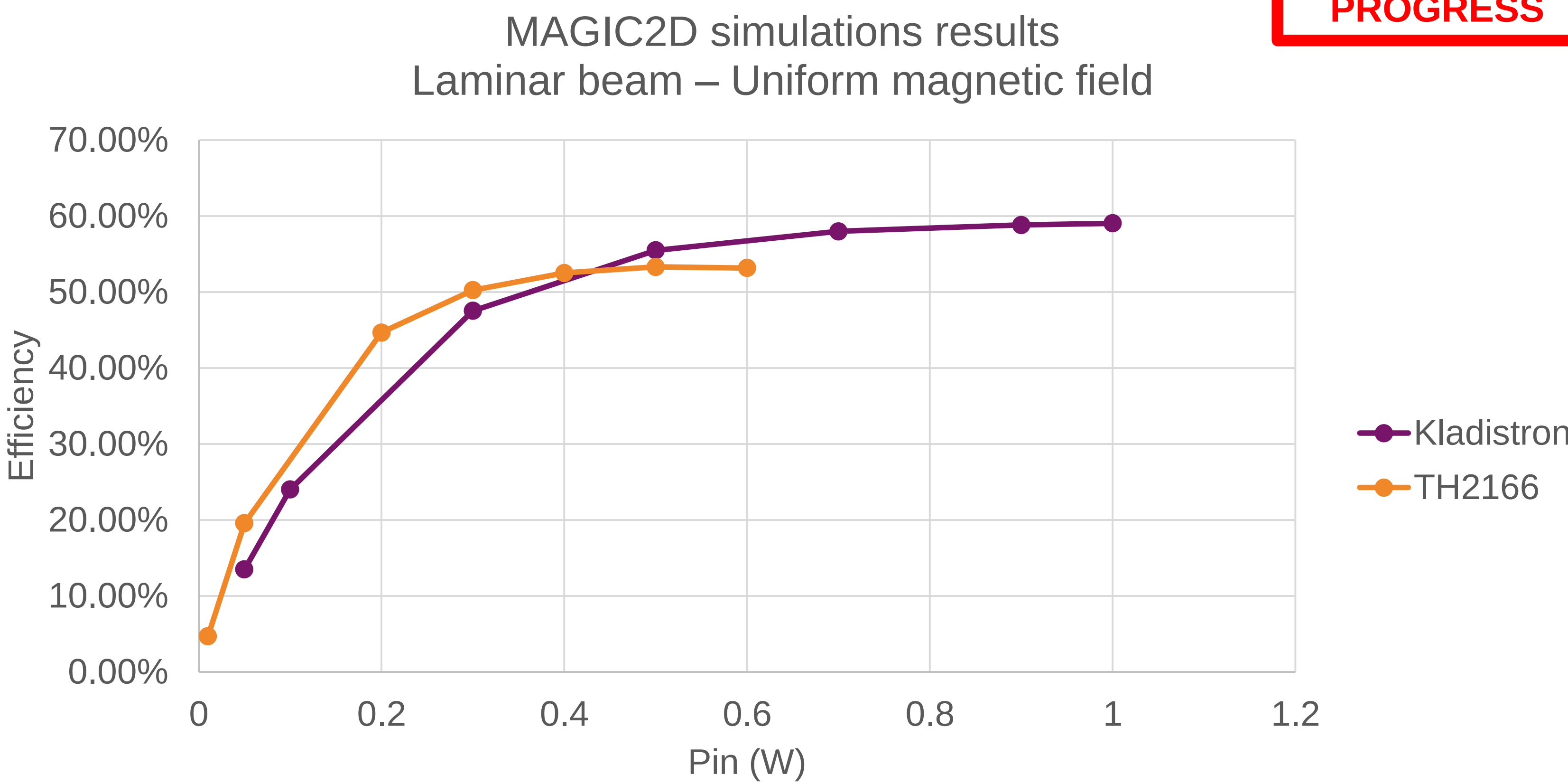




Beam current improvement.

TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

WORK IN PROGRESS

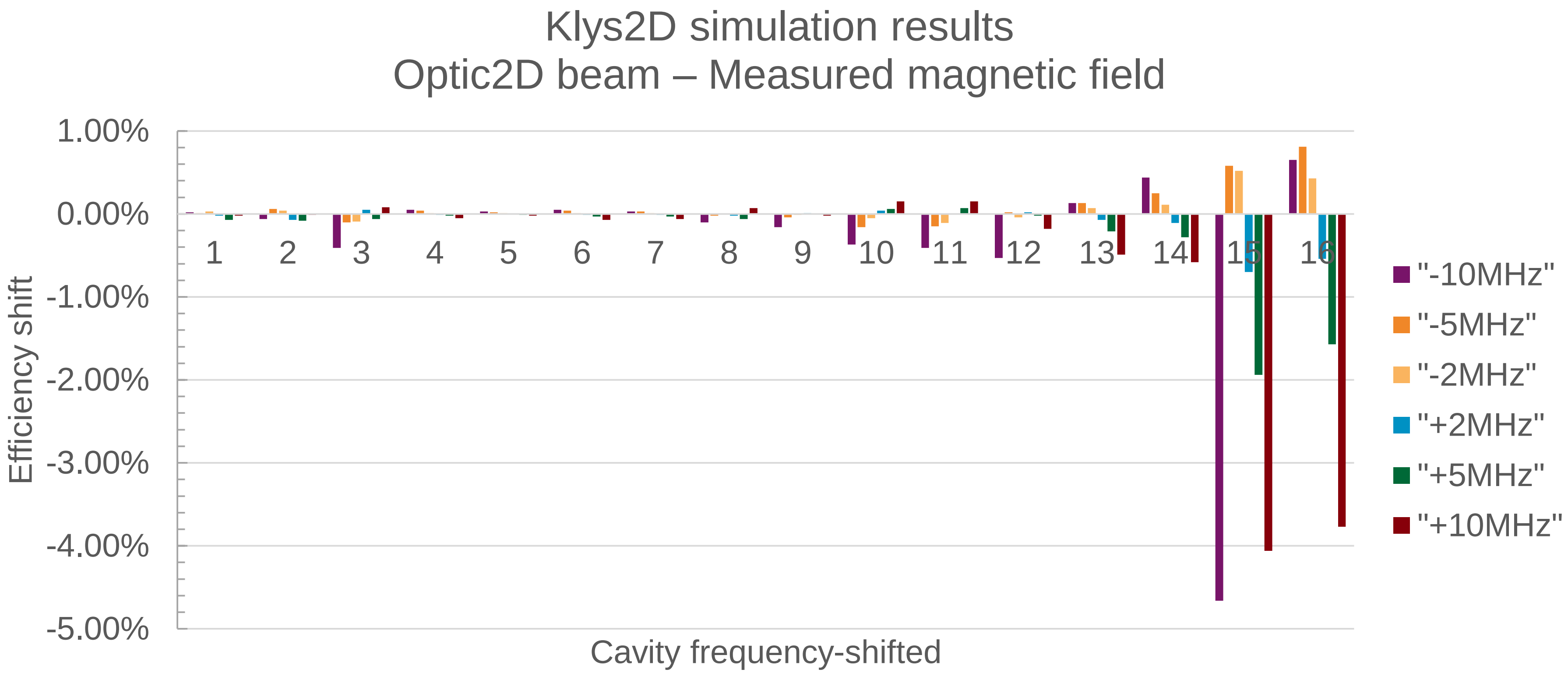


For the moment, our kladistron simulation results reach an efficiency of six points above TH2166 simulation results.

5. CAVITIES FABRICATION

FREQUENCY SHIFT : A RELIABLE TUNING SYSTEM IS REQUIRED

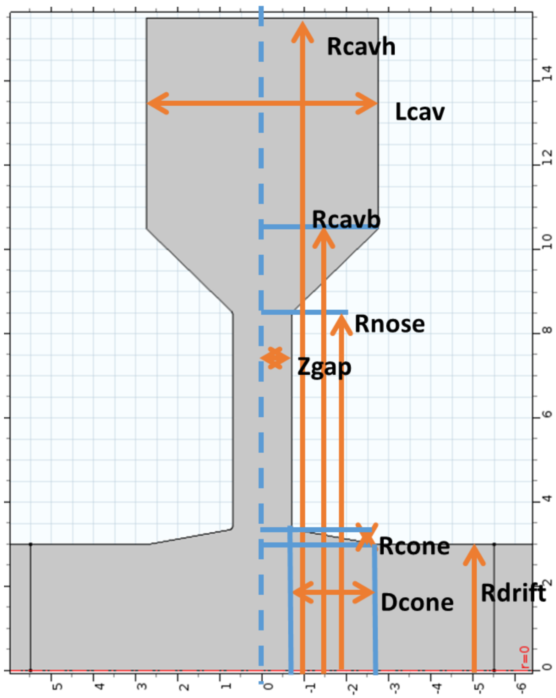
WORK IN PROGRESS



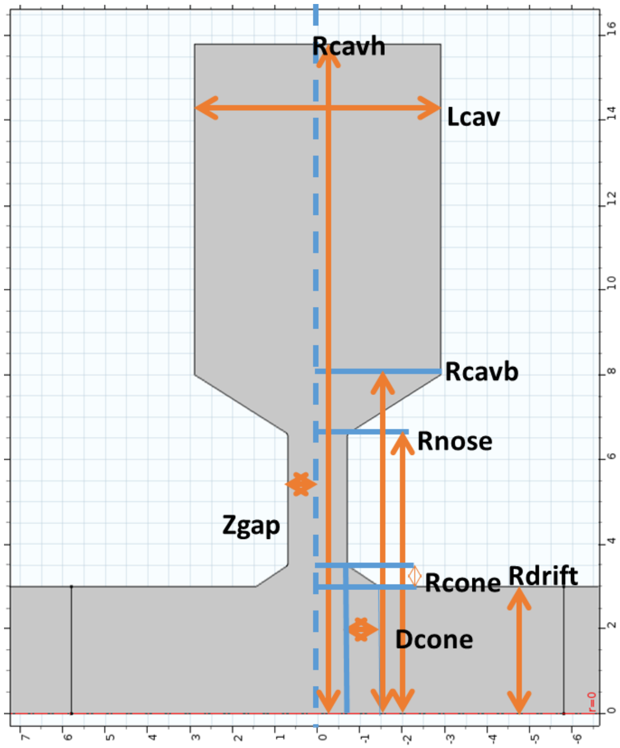
Kladistron efficiency is sensitive to its cavities frequency shifts, especially at the end of the interaction line.

FREQUENCY SHIFT : A RELIABLE TUNING SYSTEM IS REQUIRED

WORK IN PROGRESS



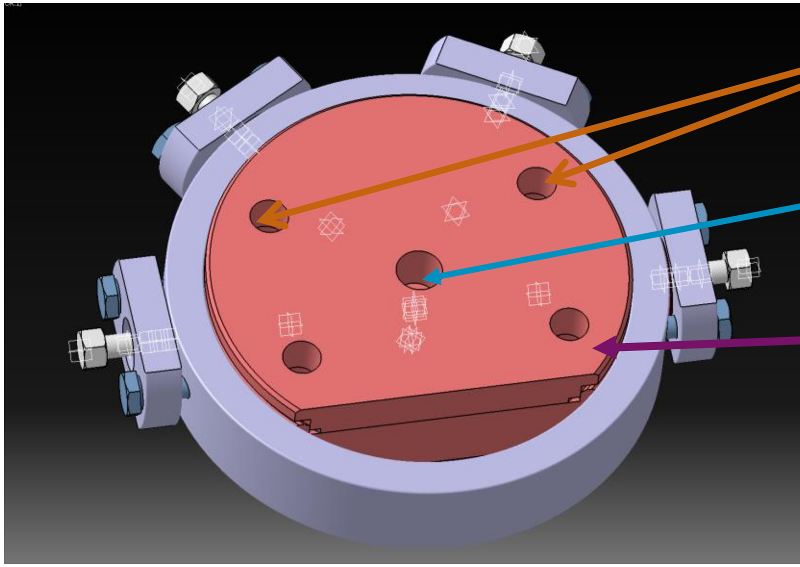
Type 2

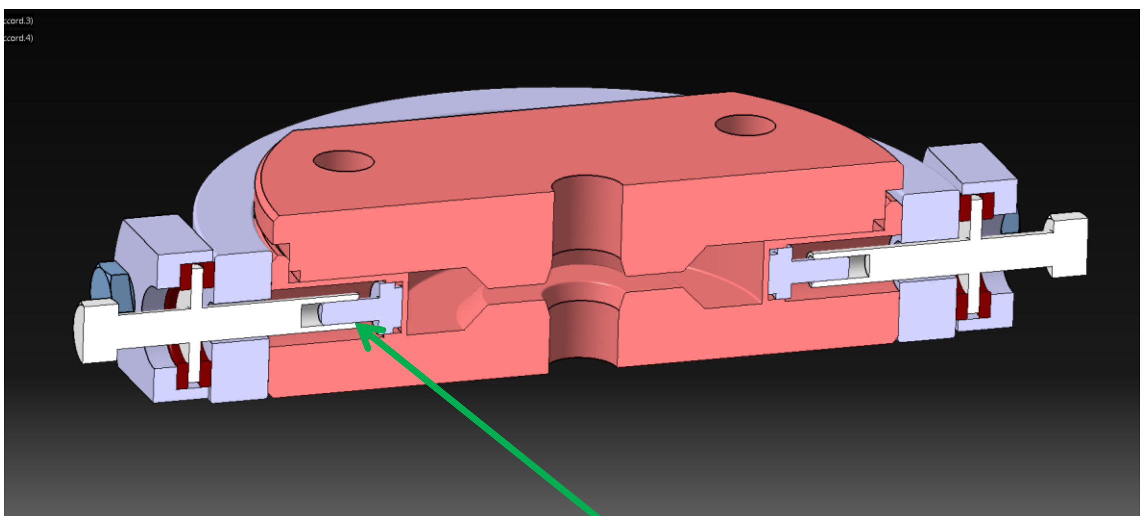


Type 3

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

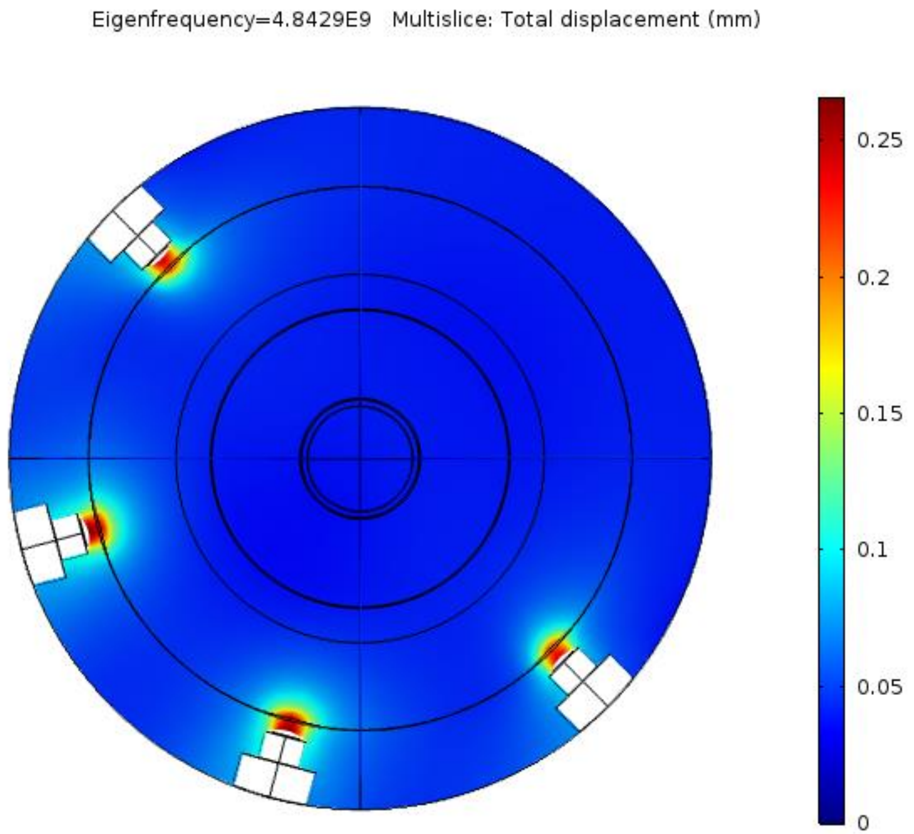




This preliminary design is under study and it is considering the surrounding of the cavities (cooling system, solenoid,…).

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

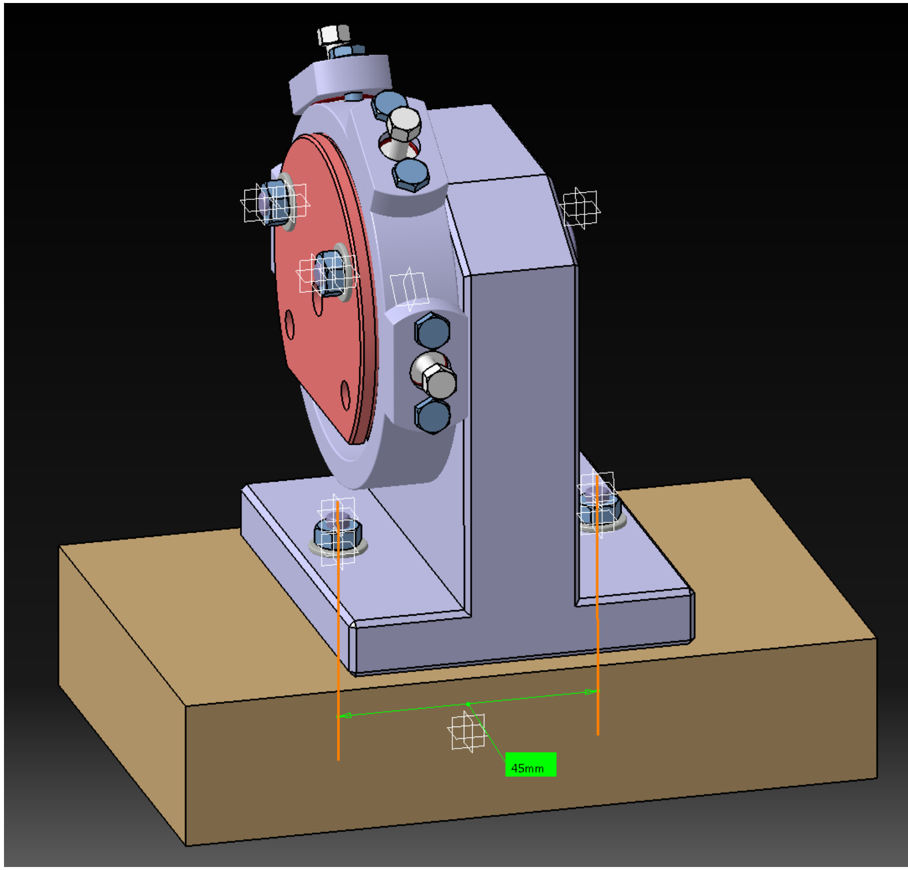
TUNING SYSTEM PRELIMINARY DESIGN
COMSOL SIMULATIONS



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

NEXT STEP : PROTOTYPE CAVITIES TO TEST

RF antenna



Pivoting arm

Prototype test bench

Type 2 and type 3 prototype cavities to be tested to validate tuning system and brazing process.

CONCLUSION AND OUTLOOK

- ✓ *TH2166 klystron study*
- ✓ *Codes validation*
- ✓ *TH2166 kladistron preliminary design*
- ➢ **Kladistron's cavities design started**
  Copper purchased
  TH2166 elements fabricated
  We will soon test two first prototype cavities.
  IVEC presentation
- ❑ TH2166 Kladistron assembled and tested by the end of the year.
- ❑ Multipactor study

Thank you for your attention