FROM RESEARCH TO INDUSTRY

DEVELOPMENT OF A HIGH-EFFICIENCY KLYSTRON BASED ON THE KLADISTRON PRINCIPLE

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1. CLIC and the Kladistron project
2. TH2166 klystron and the kladistron prototype design
3. TH2166 kladistron cavities development
4. TH2166 kladistron fabrication and testing

1. CLIC AND THE KLADISTRON PROJECT

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

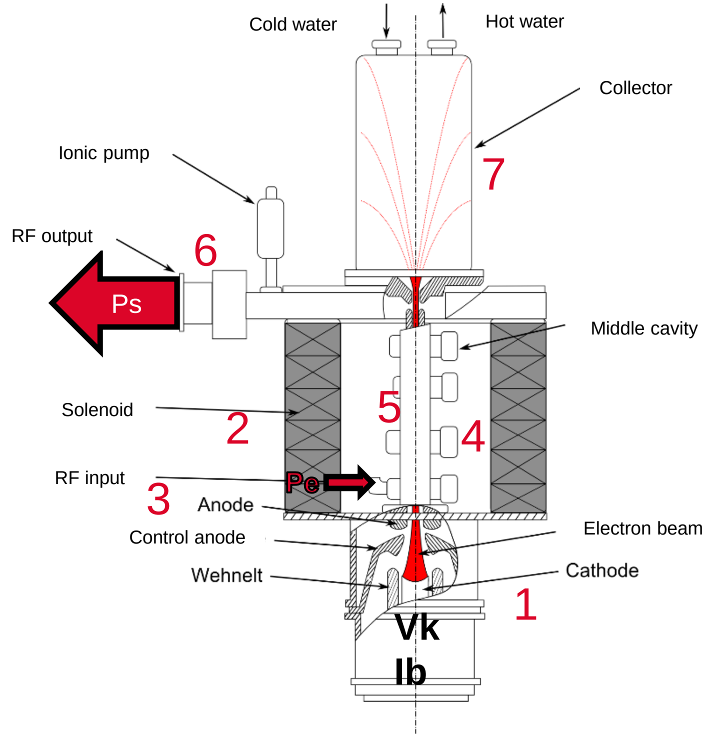
Collaboration with CERN : Igor Syratchev, Walter Wuensch…
MAGIC bought by CEA with *“contribution exceptionnelle de la France au CERN”*

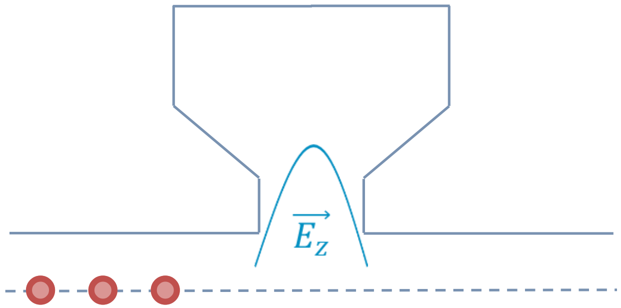
☞ **Activity fully oriented towards R&D**

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





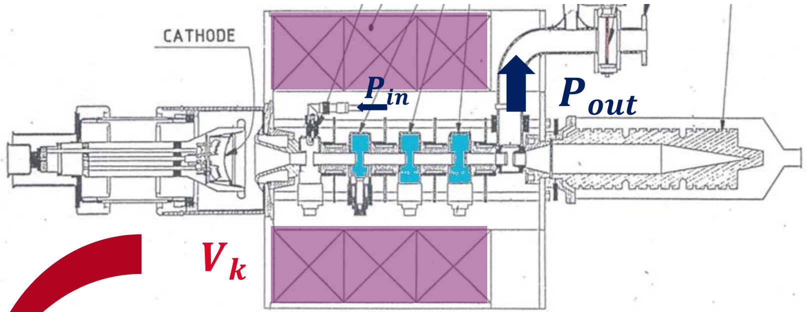
Klystron efficiency is the ratio of the output power to the electron gun supply power.

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

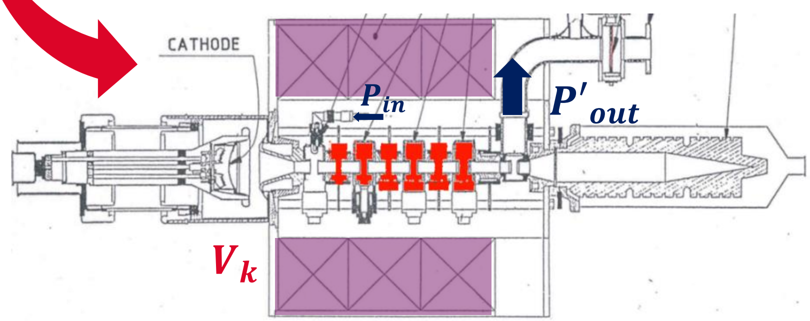
$$\mu P = \frac{I_b * 10^6}{V_k^{3/2}}$$

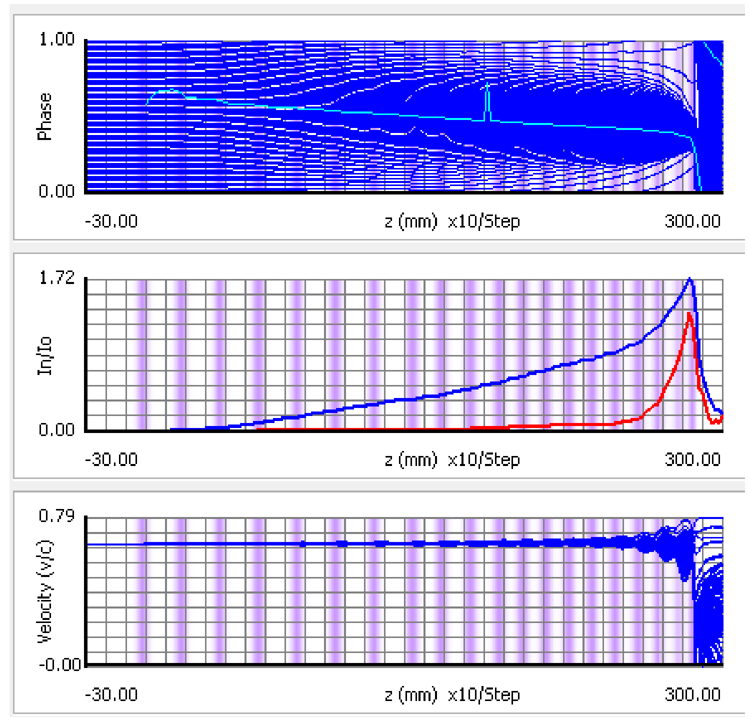
KLADISTRON PRINCIPLE

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).



$$\left\{ \begin{array}{l} N_{cavities} \nearrow \\ \frac{R}{Q} \searrow \end{array} \right. \Rightarrow \text{Efficiency } \left(\eta = \frac{P_{out}}{V_k * I_{beam}}\right) \nearrow$$





20 cavities – 12GHz
μP = 1.5 A.V^-3/2
Efficiency 78 % (AJDisk simulation)
Length 285 mm

CLIC Project needs a 12GHz-high-efficiency klystron, with a microperveance of 1.5 A.V^-3/2. Our preliminary AJDisk results show a higher efficiency than what we can expect from a klystron with such a high microperveance.

KLADISTRON AND CLASSICAL KLYSTRONS

Klystron Efficiency vs. Perveance

12GHz
« KLADISTRON »

4.9GHz
« KLADISTRON »
(technical demonstration)

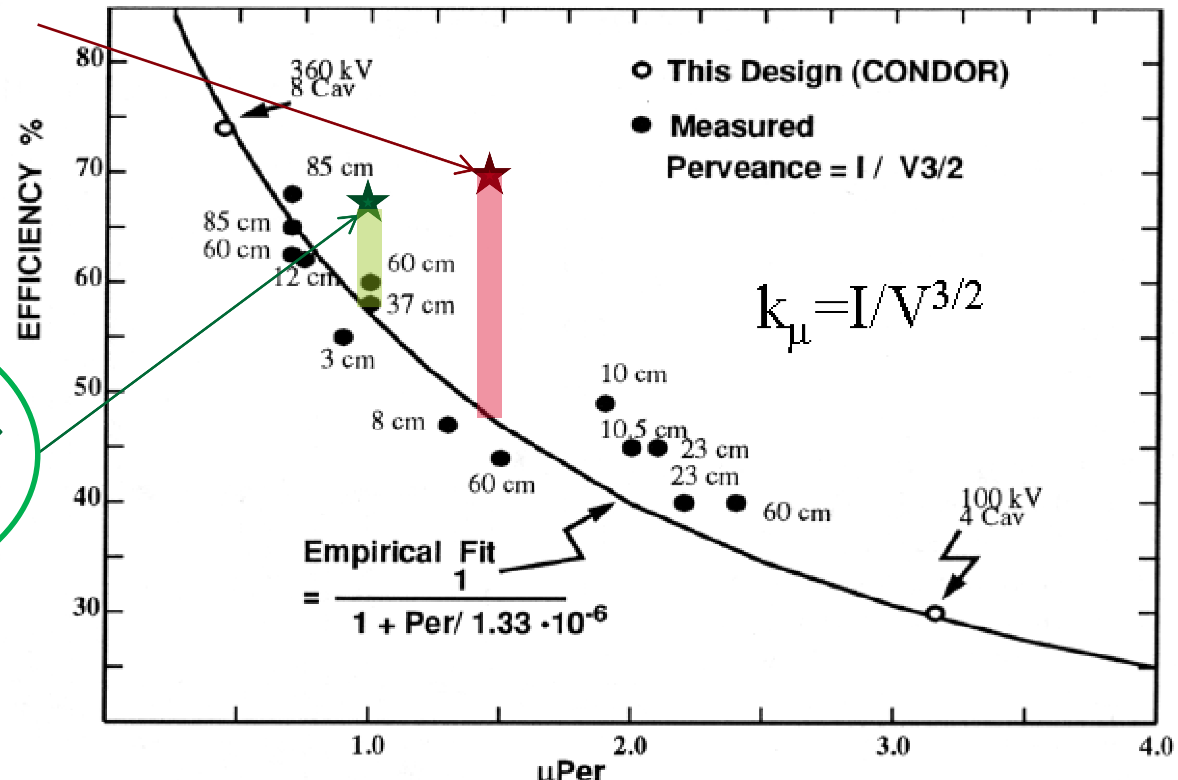


Fig.1 The empirical relation of efficiency to the perveance.

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

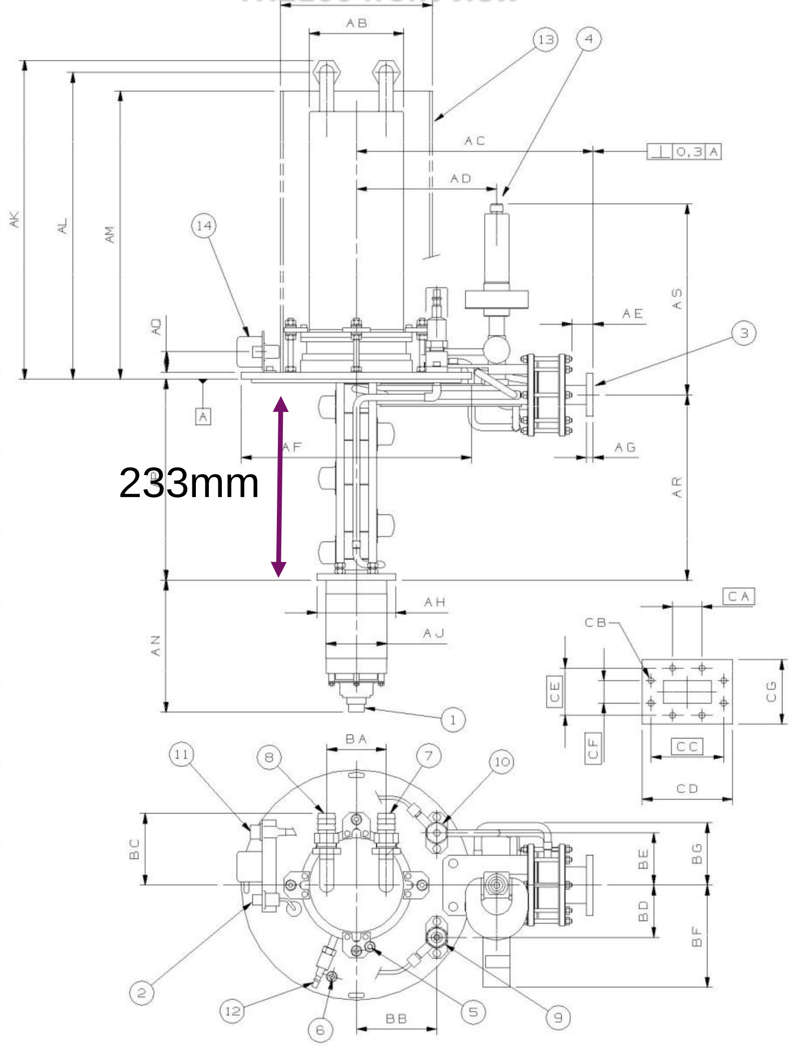
2. TH2166 KLYSTRON AND THE KLADISTRON PROTOTYPE

TH2166 KLYSTRON

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

Features	
Frequency	4.9 GHz
Output power	**56 kW**
Efficiency	**50%**
Ibeam	4.3 A
Vk	26 kV
µP	1.066
Number of cavities	**6**
Interaction line length	**233mm**

TH2166 front view



This klystron will be modified to verify the kladistron principle.

KLYSTRON TH2166 ENHANCEMENT CAVITIES PRELIMINARY DESIGN

The design we are looking for would let us :

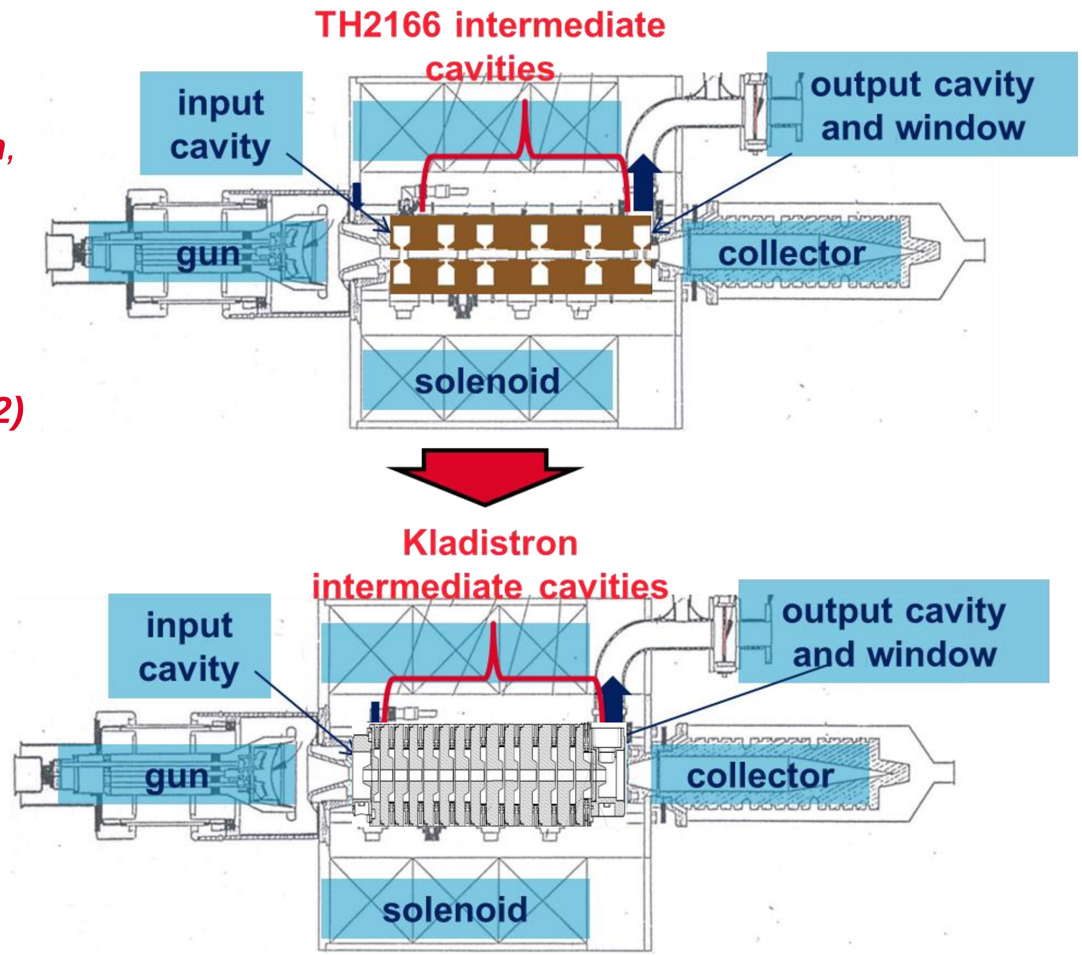
- Use the TH2166 klystron test and conditioning bench
  ➔ *Total interaction line length of* ***233mm****, same* ***input and output cavities****, same* ***solenoid***

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

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

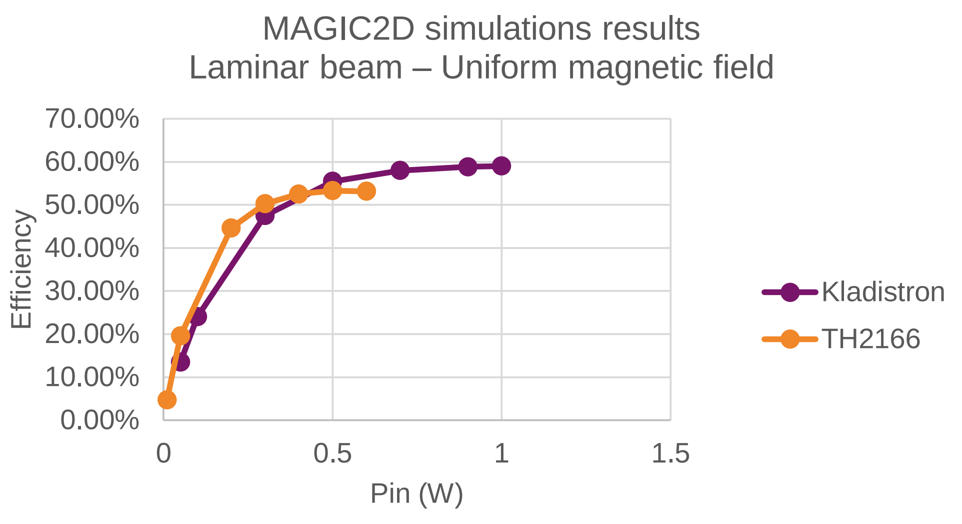
- Avoid cavities coupling
  ➔ *Drift space between cavities larger than* ***9mm***

- Avoid gain peaks
  ➔ ***Low coupling cavities***
  *(****low*** *R/Q and Q0 values)*



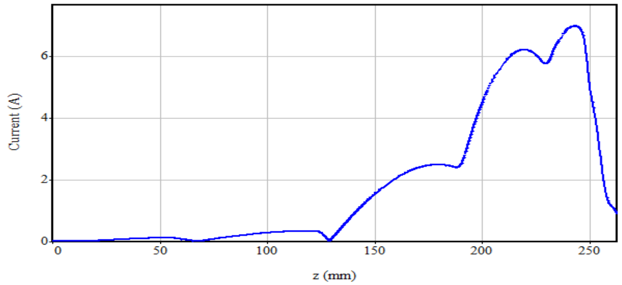
Thales-provided elements

TH2166 KLYSTRON AND KLADISTRON COMPARISON MAGIC2D SIMULATIONS

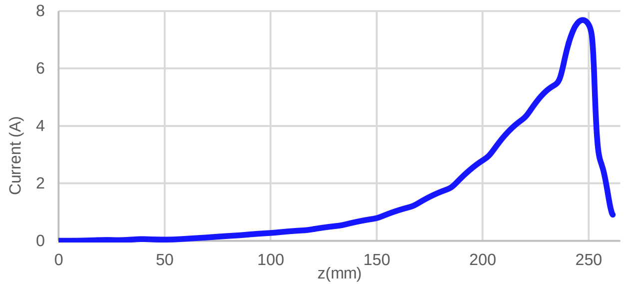


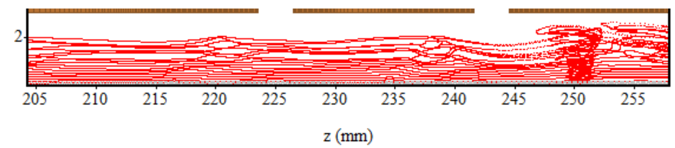
Our kladistron simulation results reach an efficiency of six points above TH2166 simulation results. The electron bunching and the beam current growth are also smoother.

TH2166 beam current along the interaction line

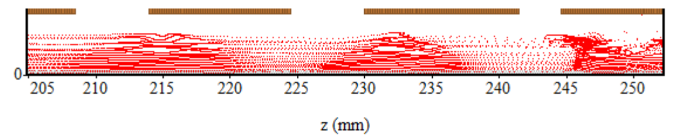


Kladistron beam current along the interaction line





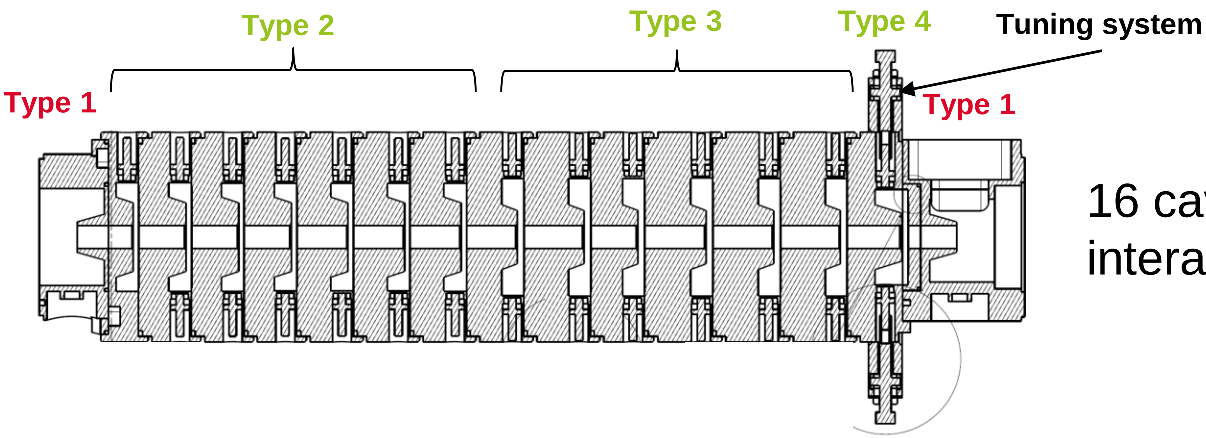
TH2166 electron beam



Kladistron electron beam

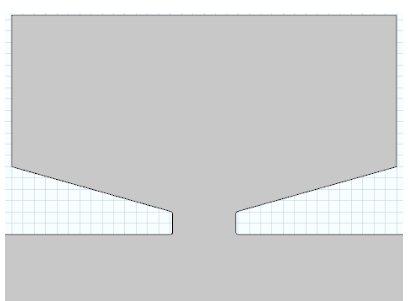
3. TH2166 KLADISTRON CAVITIES DEVELOPMENT

KLYSTRON TH2166 ENHANCEMENT CAVITIES PRELIMINARY DESIGN



16 cavities interaction line

TH2166 cavity shape



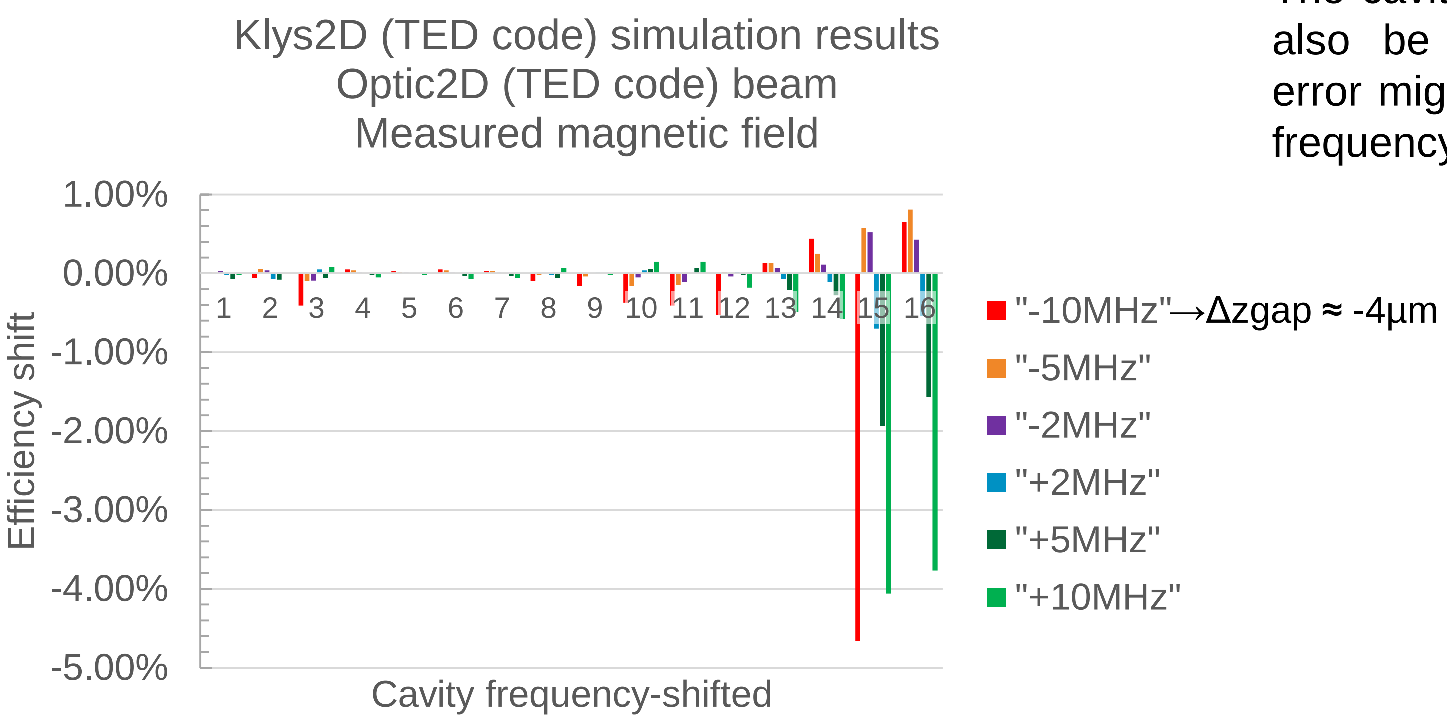
Type 1

Low-coupling cavity shapes

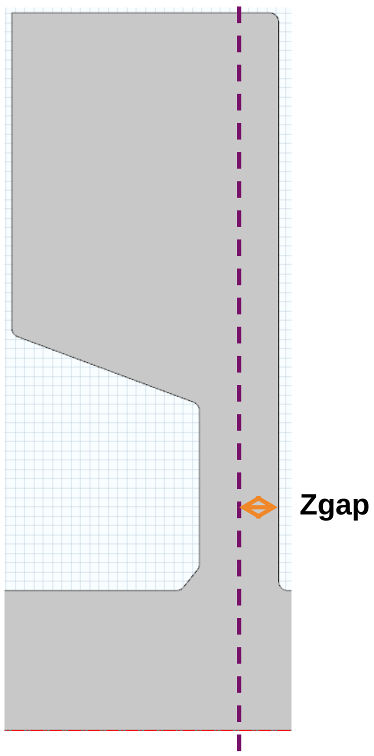
Type 2 | Type 3 | Type 4

According to our COMSOL simulations, these low-coupling cavities are fit for smooth electron bunching.

FREQUENCY SHIFT : A RELIABLE TUNING SYSTEM IS REQUIRED



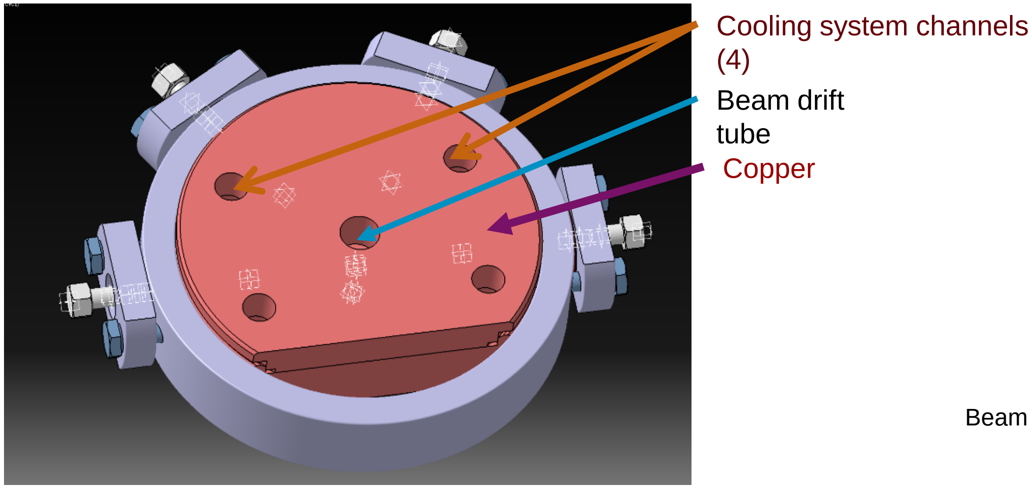
The cavities fabrication must also be accurate: a 1-µm error might induce a 2,5MHz frequency-shift (COMSOL).

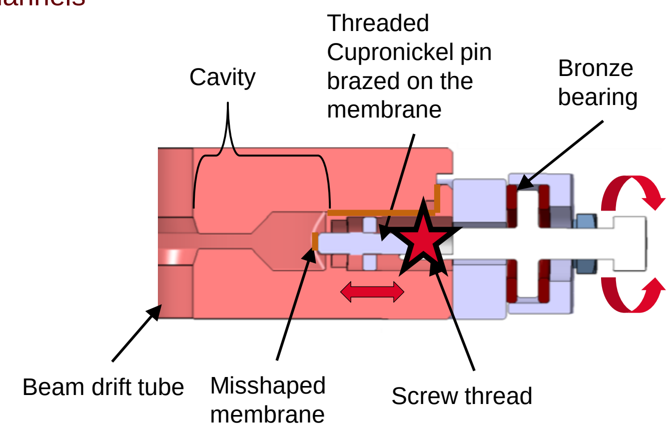


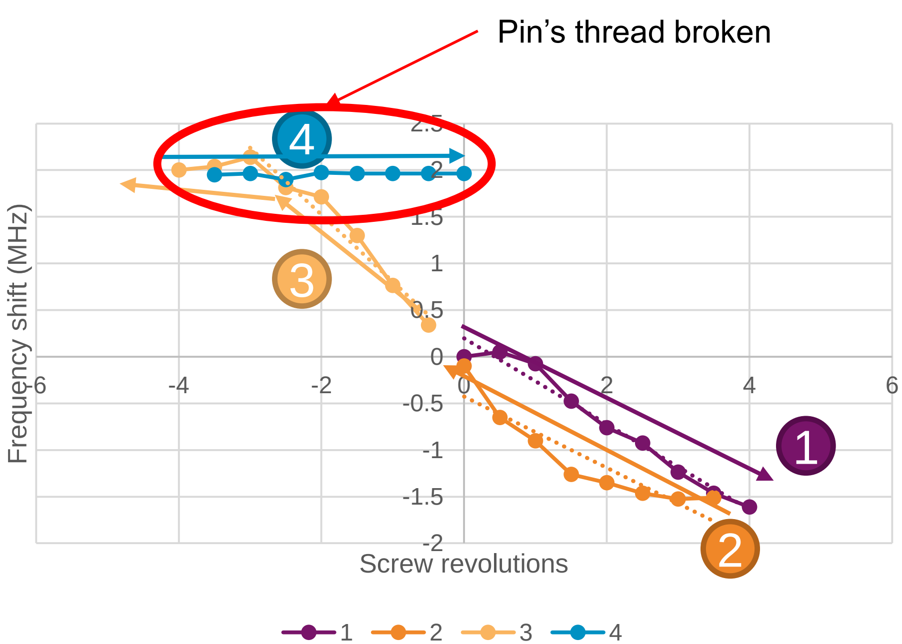
For each computation we shift the frequency of one of the cavities.
Kladistron efficiency is sensitive to its cavities frequency shifts, especially at the end of the interaction line.

$\Delta f/\Delta zgap \approx 2.5 MHz/\mu m$

TUNING SYSTEM DESIGN AND TEST



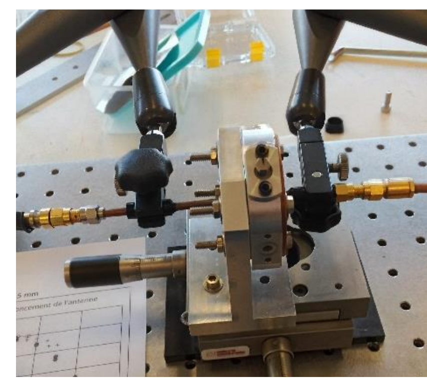




Tuning system (x4 at 60°)

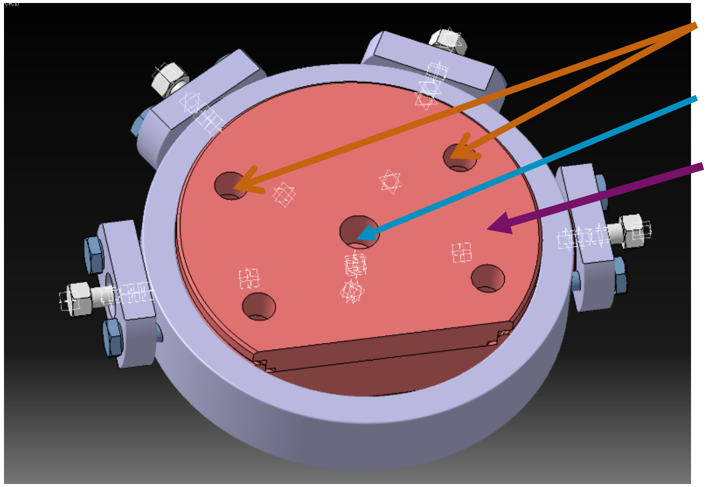
The tuning system we designed is inspired by CLIC accelerating cavities design; a thigh copper membrane is misshaped to adjust cavities frequencies. This strain is controlled by an accurate screw thread.

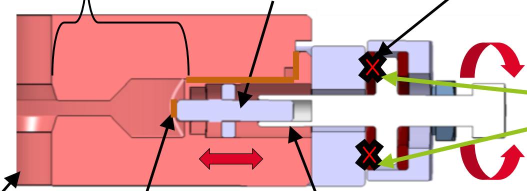
Although the airtightness had been preserved during our tests, the pin's thread had been broken. The tuning system assembling is too rigid and the extra mechanical stress is reported on the screw thread.



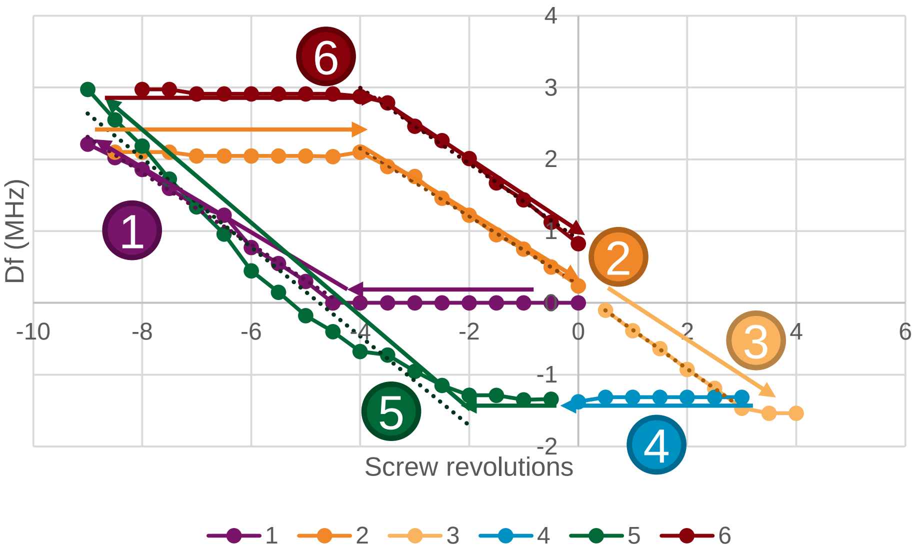
Prototype test bench

TUNING SYSTEM DESIGN AND TEST



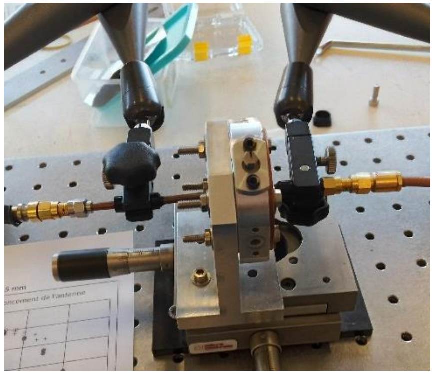


Tuning system (x4 at 60°)



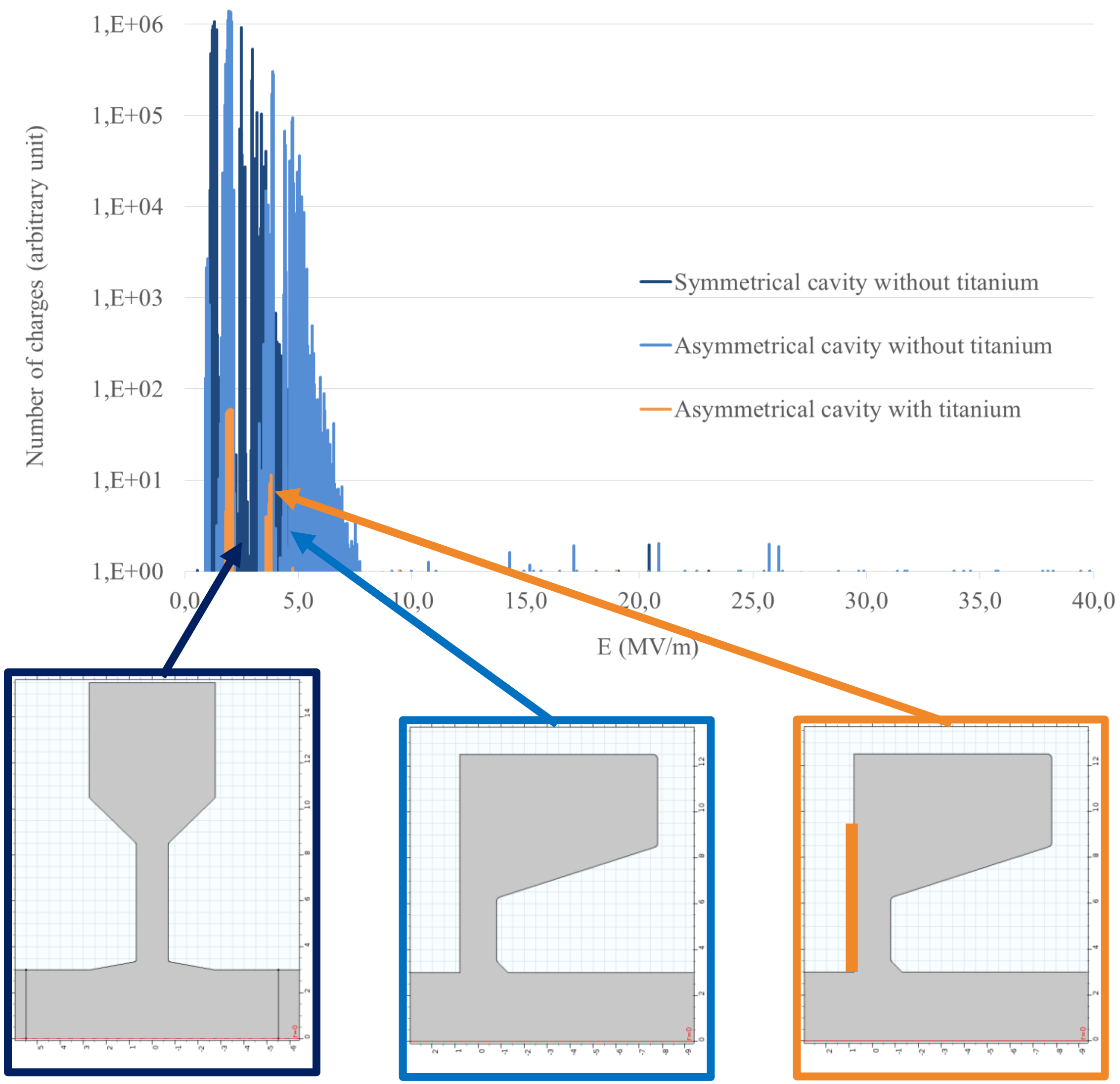
We then removed one of the bronze bearing to make the assembling more flexible. We tested our tuning system on two complete cycles (+4/-8 screw revolutions). The overall frequency shift is +3MHz/-1,5MHZ.

Despite the hysteresis induced by the assembling modification, the overall frequency shift after two complete cycles is negligible. **We validate our tuning system design.**



Prototype test bench

MULTIPACTOR AND TITANIUM DEPOSITION MUSICC3D SIMULATIONS

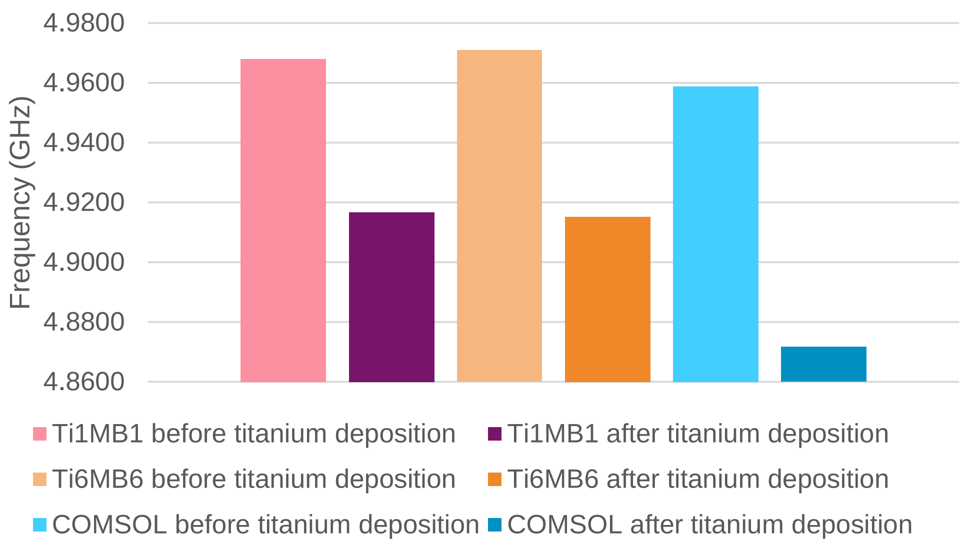


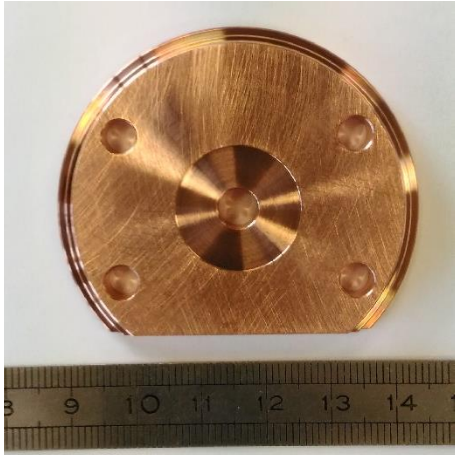
- Our preliminary Musicc3D (CNRS code) simulations demonstrated that we would face multipactor phenomenon in our cavities' gaps. We then designed new asymmetrical cavities to apply a titanium layer.

- The graph on the left is the number of charges generated in the cavity's gap, in a Musicc3D simulation: an electron is sent from a chosen area; an electric field with a given phase and amplitude is applied on the charge. The simulation stops after the 20th electron impact, if it has not been absorbed by the material.

- Without titanium, a single electron in an electric field of 2MV/m can extract up to **10^6** charges in the cavity's gap. With a titanium layer, the maximum number of charges extracted drops to **60**.

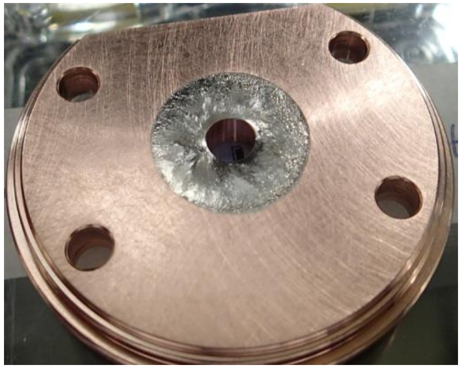
MULTIPACTOR AND TITANIUM DEPOSITION PROTOTYPE TESTS





Flat part without titanium

Concave part



Flat part with a titanium sheet brazed

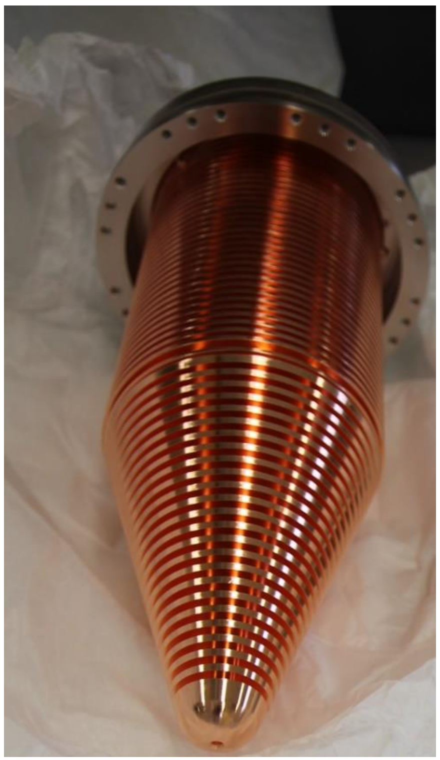
We designed and ordered 6 prototype cavities to test our titanium deposition method. The "flat" parts (Ti1 to Ti6) have a 0,1mm deflection for the titanium deposition. We cut and brazed titanium discs on these parts. The "flat" and the "concave" parts were assembled to form a cavity to test.

The titanium sheet was misshaped during the brazing process therefore the frequency shift is below our expectations. Although these pieces are being machined to fit the drawings dimensions, **we are also working on the improvement of this brazing process to guarantee the adequate cavity geometry.**

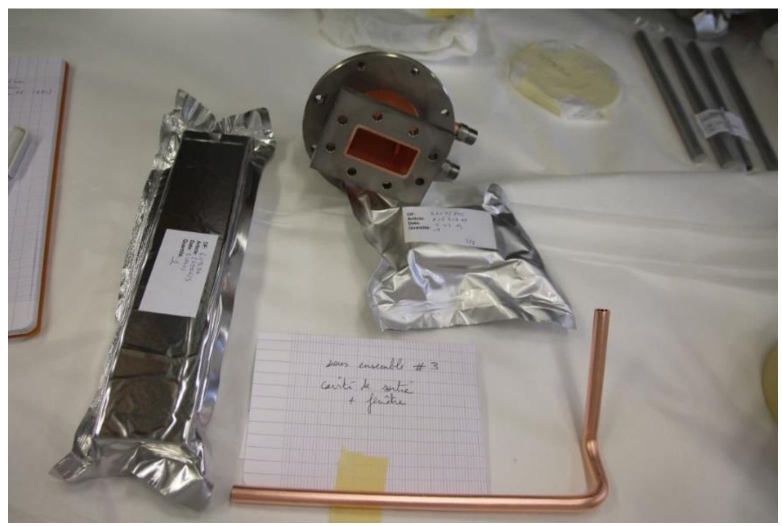
4. TH2166 KLADISTRON FABRICATION AND TESTING

THALES-PROVIDED ELEMENTS

Steel rods and
Ionic pump



Collector

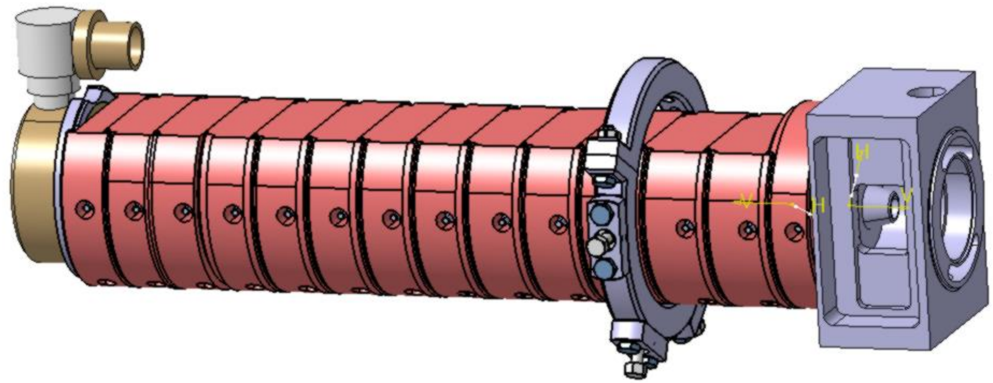


Wave guide,
Output cavity and
Output antenna

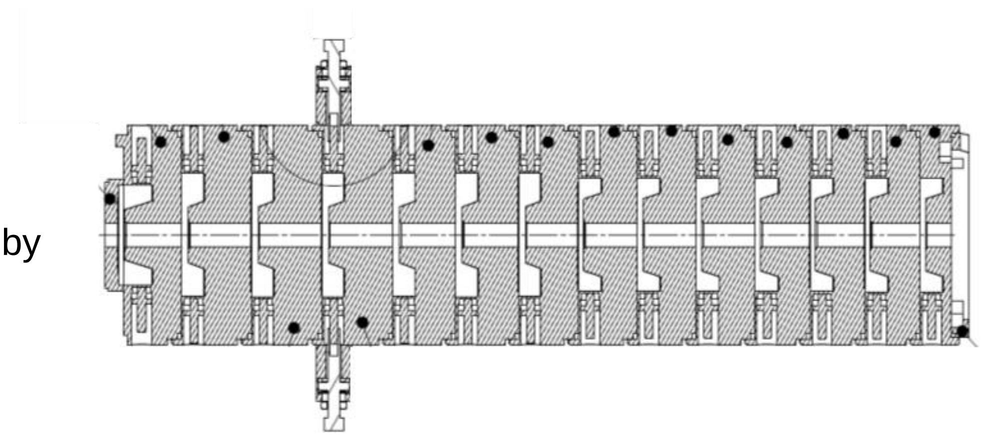
These elements have already been delivered.

CAVITIES AND TUNING SYSTEM FABRICATION AND ASSEMBLING

TH2166 kladistron interaction line and tuning system



Pieces provided by VDL



The company VDL (Netherland) won the call for tenders and will machine the pieces of the interaction line and the tuning system. We expect the pieces to be delivered by the end of the month.

Assembling and brazing operations and the kladistron tests will stand at Thales Electron Devices Vélizy.
We are working on the assembling, brazing and test procedure.

CONCLUSION AND OUTLOOK

- ✓ *Tuning systems and titanium deposition method tested*
- ✓ *TH2166 kladistron's cavities fabrication almost finished*
- ➢ **Assembling, tuning and test procedure validation**
- ❑ TH2166 Kladistron to be assembled and tested in April, May and June.

Thank you for your attention