FROM RESEARCH TO INDUSTRY

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THE KLADISTRON: A NEW HIGH EFFICIENCY KLYSTRON DESIGN

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UNIVERSITY OF MALTA
L-Università ta' Malta

CERN

EuCARD²

SEVENTH FRAMEWORK PROGRAMME

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3rd EuCARD-2 Annual Meeting
26-28 avril 2016
University of Malta

PROJECT ARTICULATION

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

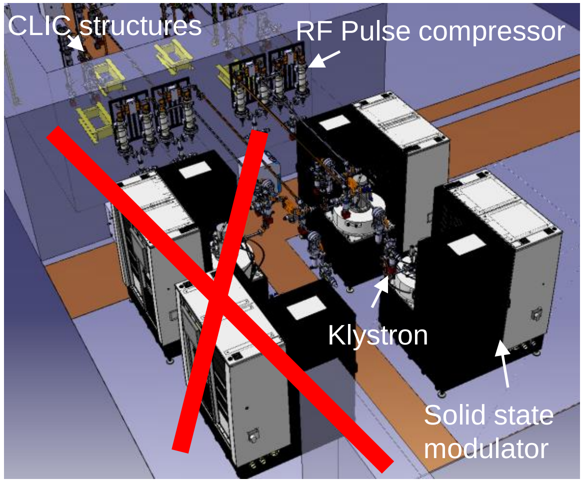
- CLIC RF team (Walter Wuensch): PIC code (MAGIC) and some hardware paid on CERN funds (“Contribution Exceptionnelle de la France au CERN” – 2008-2012)
- HEIKA collaboration (Igor Syratchev)

MASSIVE CONDITIONNING CAPABILITIES OF 12GHZ CLIC ACCELERATING STRUCTURES

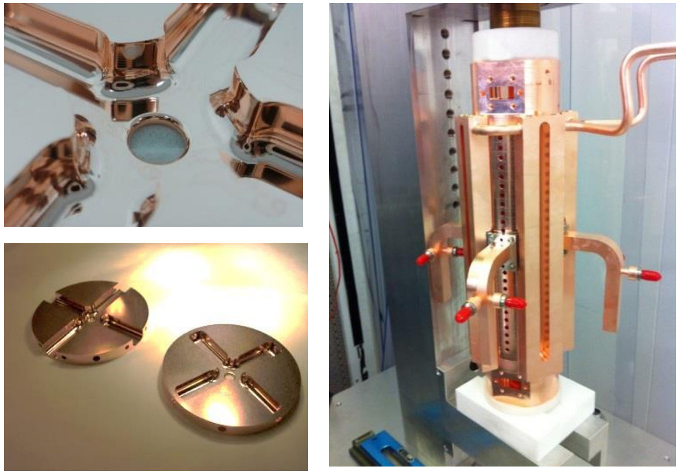
- The XBOX3 test stand at CERN will use four Medium Power X-band klystrons recombined and RF compressed to produce 50 MW peak power and 100 MV/m accelerating gradient

TOSHIBA E37113 klystron

Frequency: 12 GHz
Beam Voltage: 150 kV
Beam current: 90 A
Peak power: 6 MW
Average power: 12.4 kW
Efficiency: 45%



XBOX3 layout (I. Syratchev, G. McMonagle, N. Catalan Lasheras, B. Woolley)



Example of a 12 GHz 100 MV/m CLIC accelerating structure built by CEA Saclay (2012)

We propose to design a new 12 GHz klystron with very high efficiency:

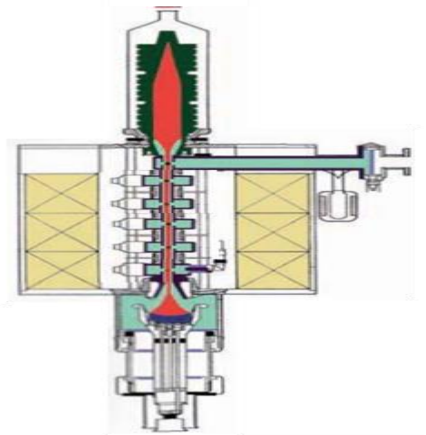
→ η = 70% , output power = 12 MW

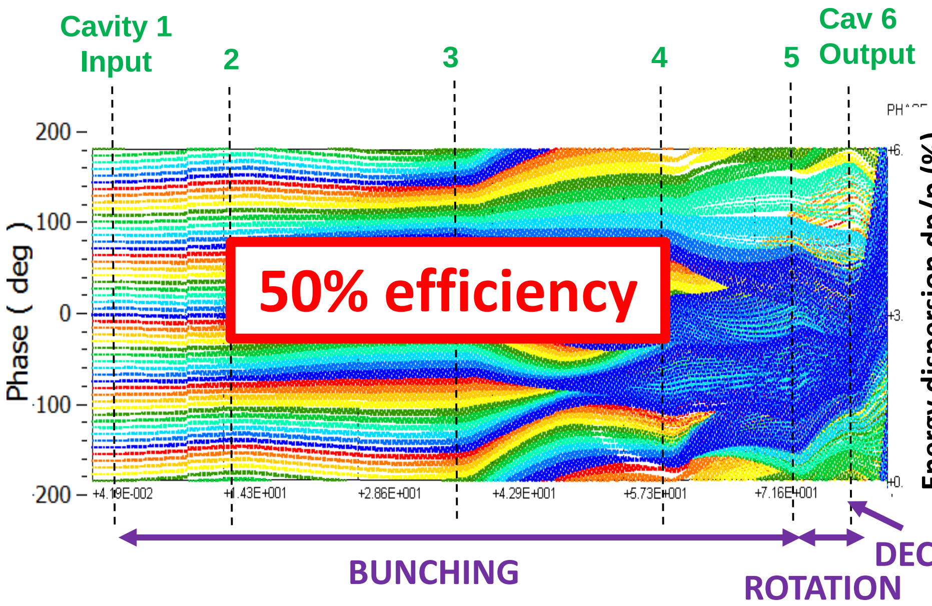
It would double the testing capabilities of an XBOX3 type test stand

KLYSTRON

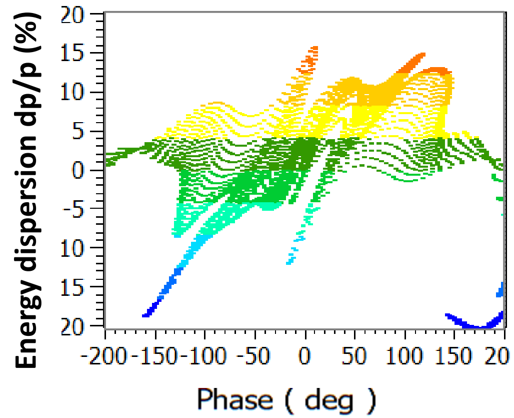
RFQ

Conventional klystron with 6 cavities:

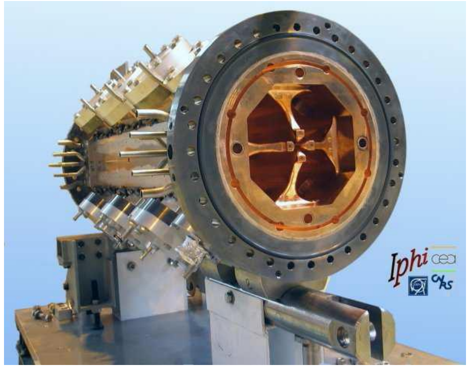




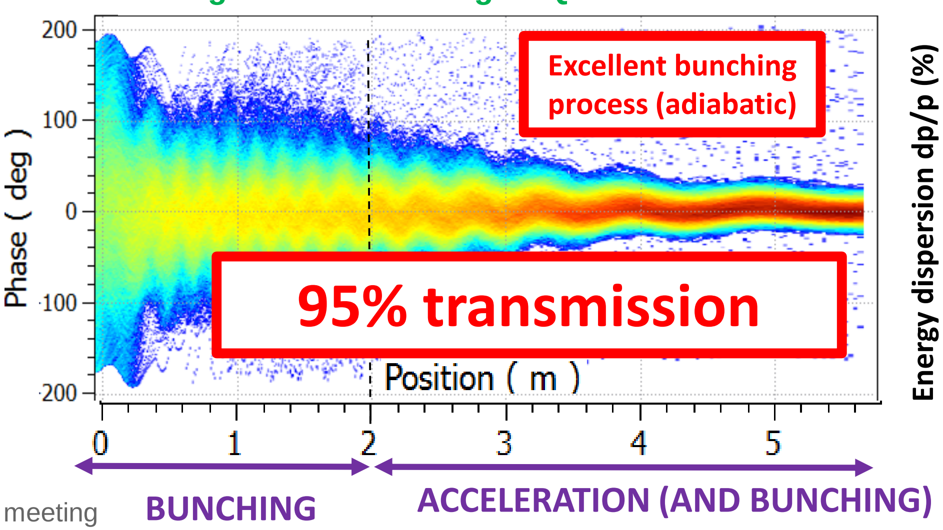
At the cavity 5 entrance:



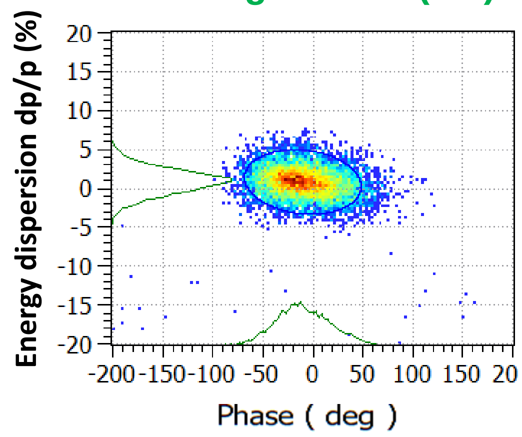
IPHI RFQ (3 MeV, protons):



Along the 6 meter long RFQ:

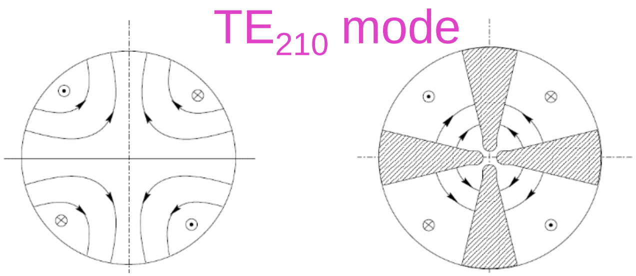


At the end of the bunching section (2m):

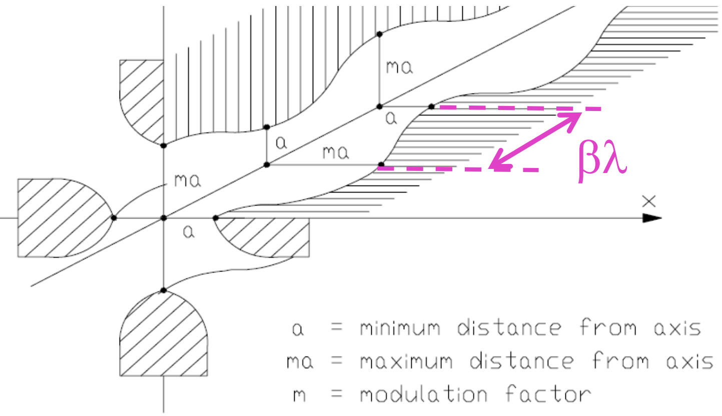


KLADISTRON: THE KLYSTRON WITH ADIABATIC BUNCHING

How does a RFQ works ?



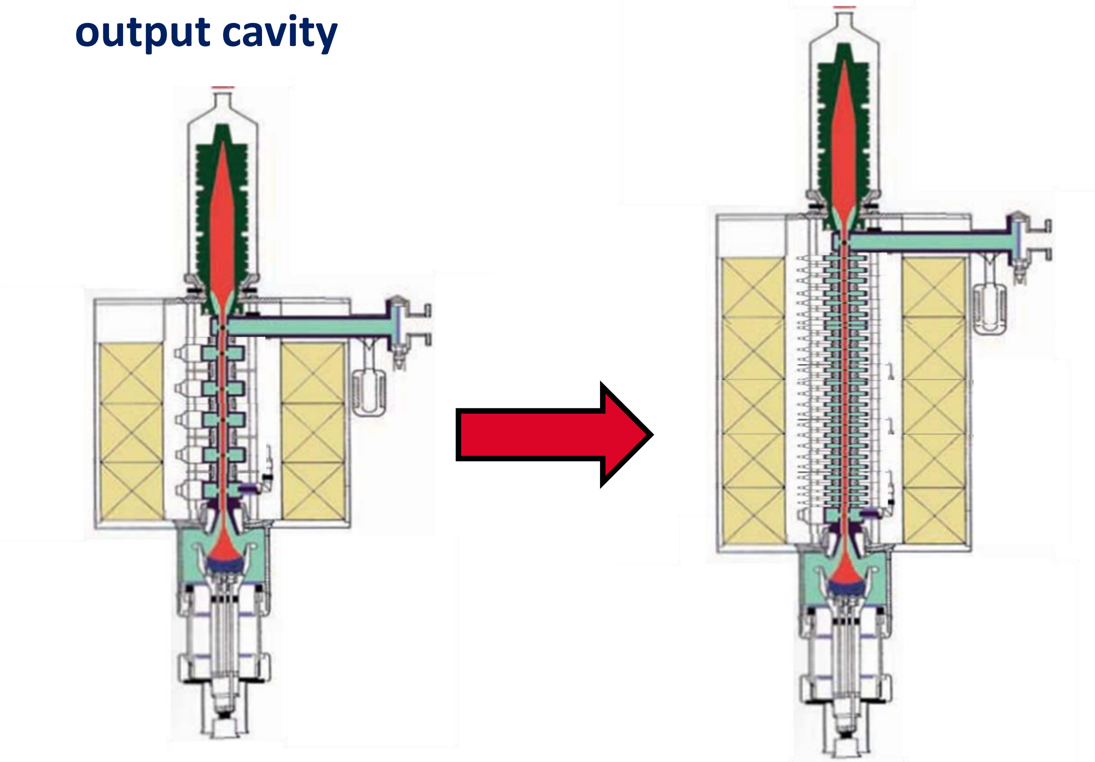
- longitudinal modulation on the electrodes creates a longitudinal component in the TE mode that bunch and accelerate the beam



- In the IPHI RFQ (3 MeV, 6m, 352 MHz), around 350 cells are used to bunch the beam

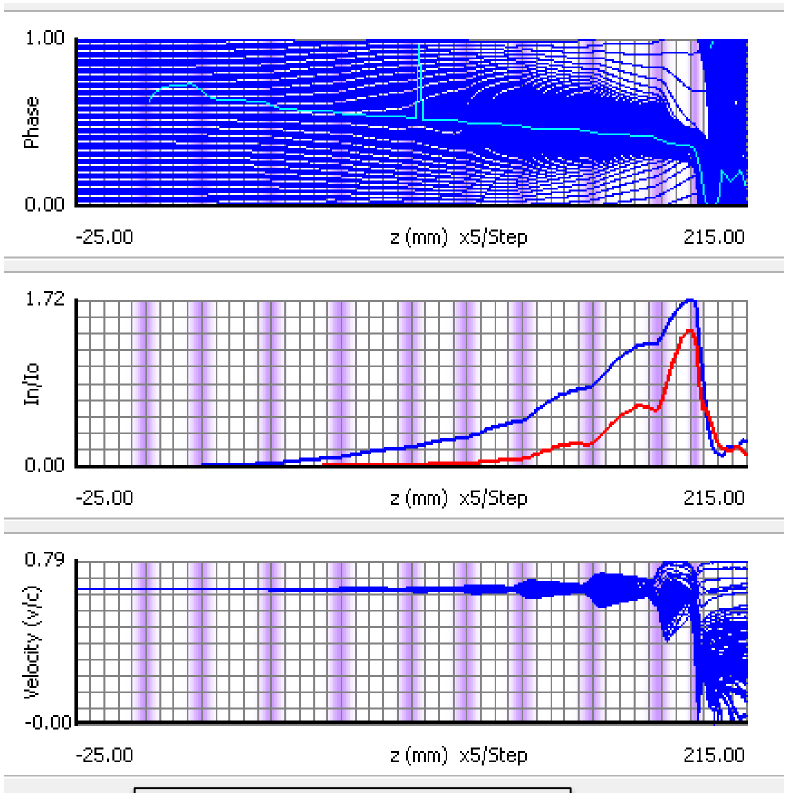
- A Kladistron (Kl-adi(adiabatic)-stron) is a high-efficiency klystron with a large number of cavities working on the usual TM_{010} mode

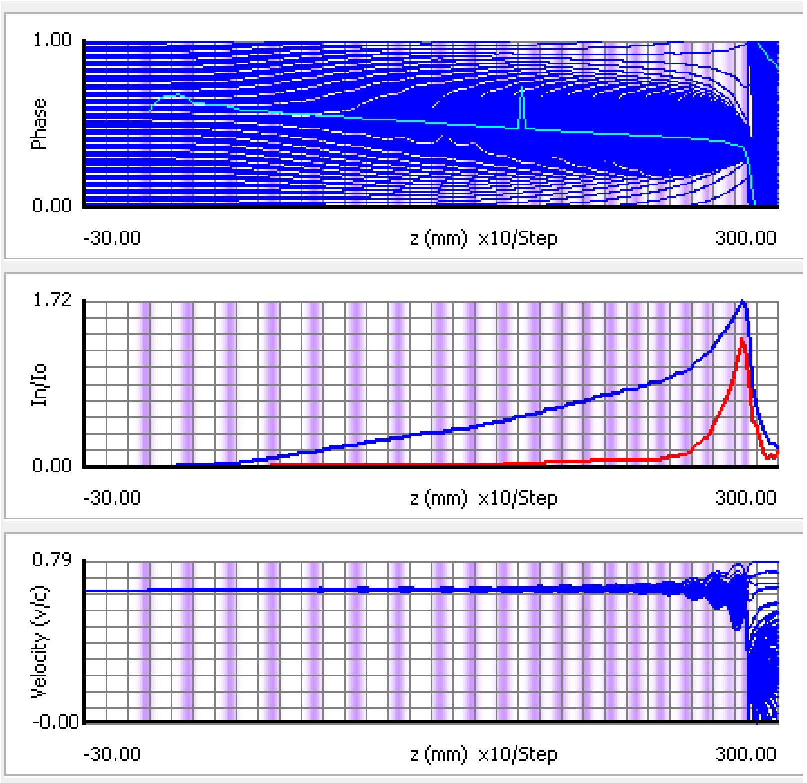
- Inspired by RFQ, this architecture leads to a smoother bunching and thus to a higher efficiency due to better electron capture in the output cavity



$N_{cavities}$ and length ↗ => Efficiency (η) ↗

AJDISK 1D-SIMULATIONS OF A 12GHZ-KLADISTRON





10 cavities
Efficiency 67.2 %
Length 197 mm

20 cavities
Efficiency 78 %
Length 285 mm

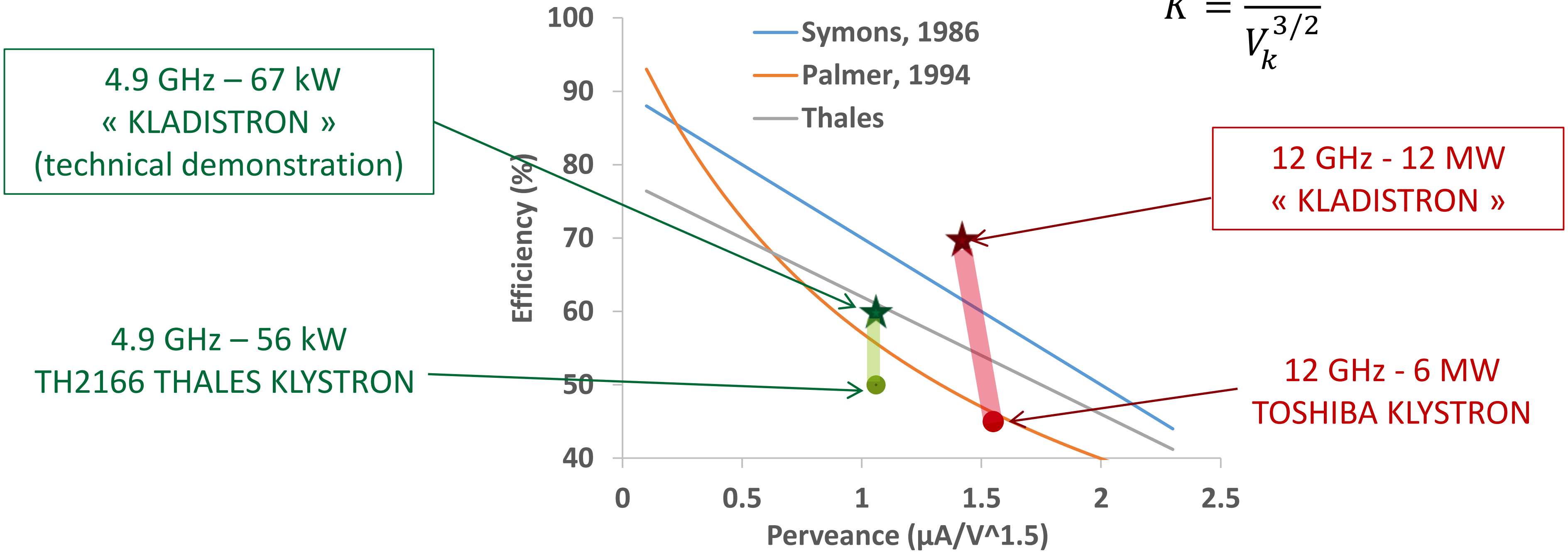
- In the proposed design, the cavities are weakly coupled to the beam (low R/Q) and largely detuned to avoid strong bunching

AN INTERMEDIATE STATE TO DEMONSTRATE THE KLADISTRON FEASIBILITY

- Low single beam perveance means low space charge forces and enables strong beam bunching and consequently high efficiency
- Several empirical relations describe this tendency

Perveance:

$$K = \frac{I_k}{V_k^{3/2}}$$

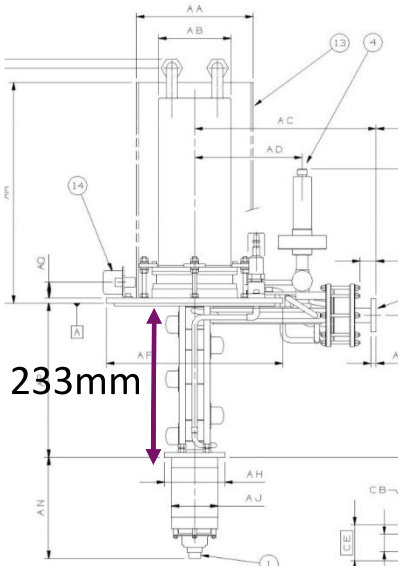


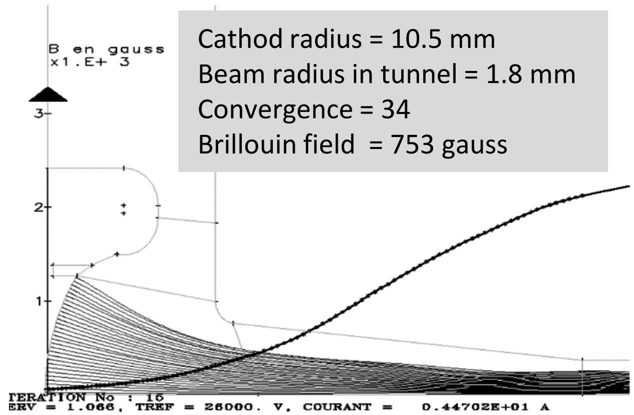
- The TH 2166 4.9 GHz klystron from THALES will be modified into a 4.9 GHz kladistron to give a proof of principle with the objective to achieve an efficiency of 60 % minimum

MORE DETAILS ON THE 4.9 GHZ TH2166 KLYSTRON

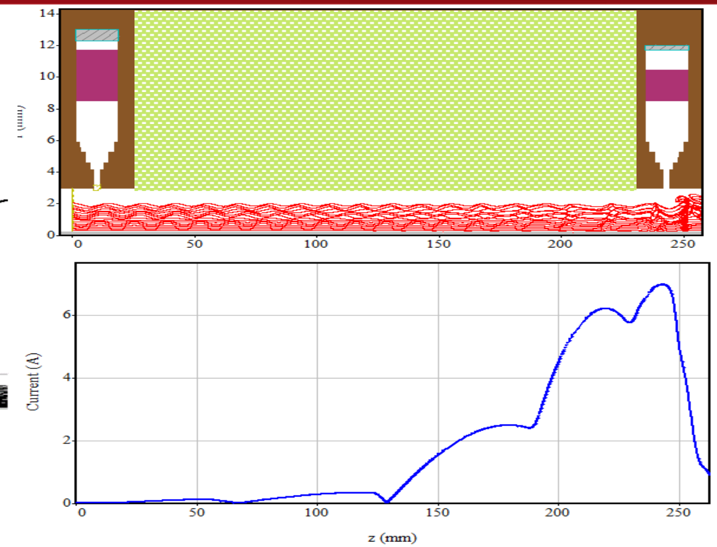
THALES TH2166 klystron

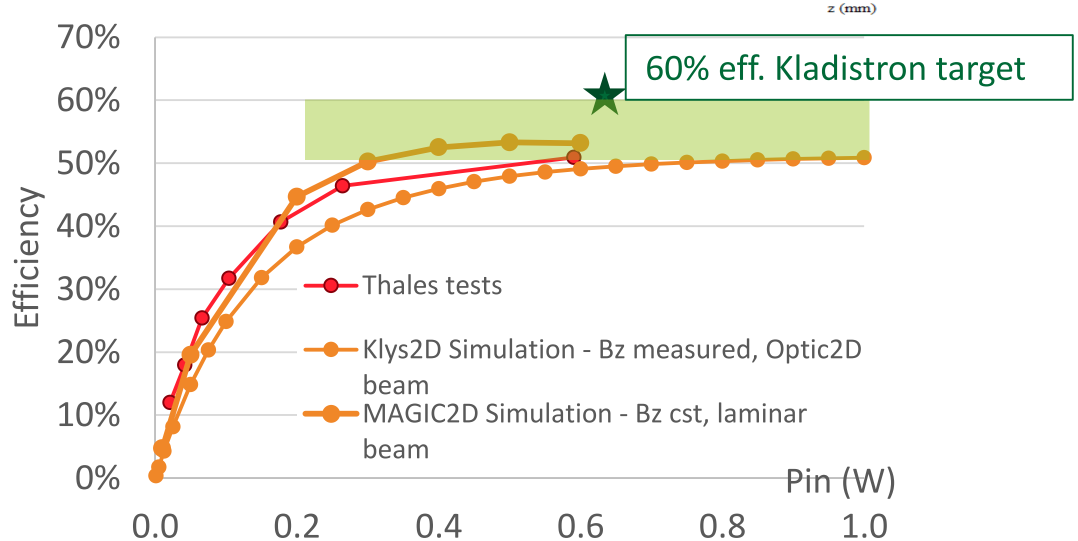
Frequency: 4.9 GHz
Output power: 56 kW
Operation mode: CW
Gain: 40 dB
Beam Voltage: 26 kV
Beam current: 4.3 A
Microperveance: 1.06 $\mu A/V^{1.5}$
Efficiency: 50%
Number of cavities: 6





Cathod radius = 10.5 mm
Beam radius in tunnel = 1.8 mm
Convergence = 34
Brillouin field = 753 gauss

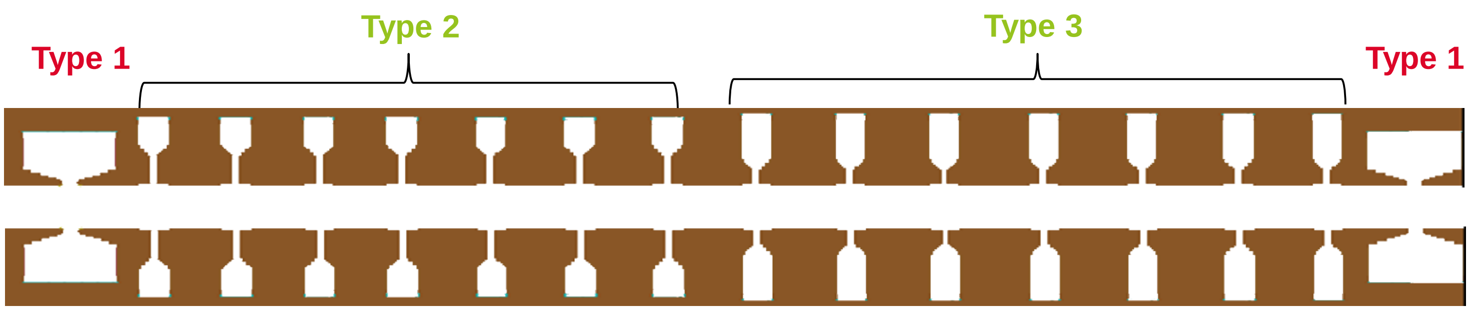


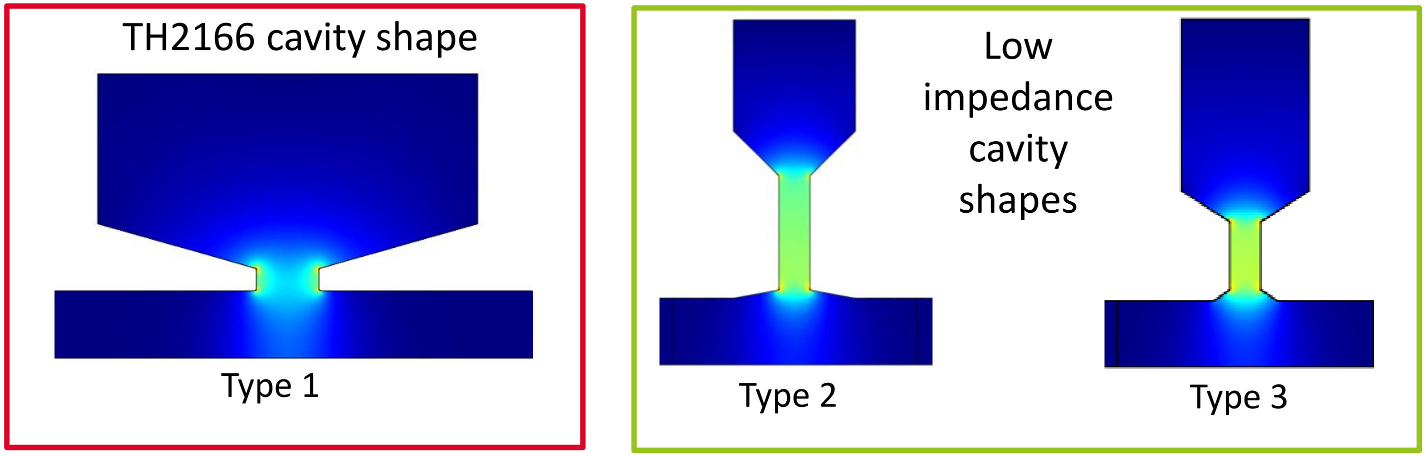


- The modification will consist in changing the intermediate bunching cavities while keeping the input and output cavities and the same interaction length (to keep to same solenoid)

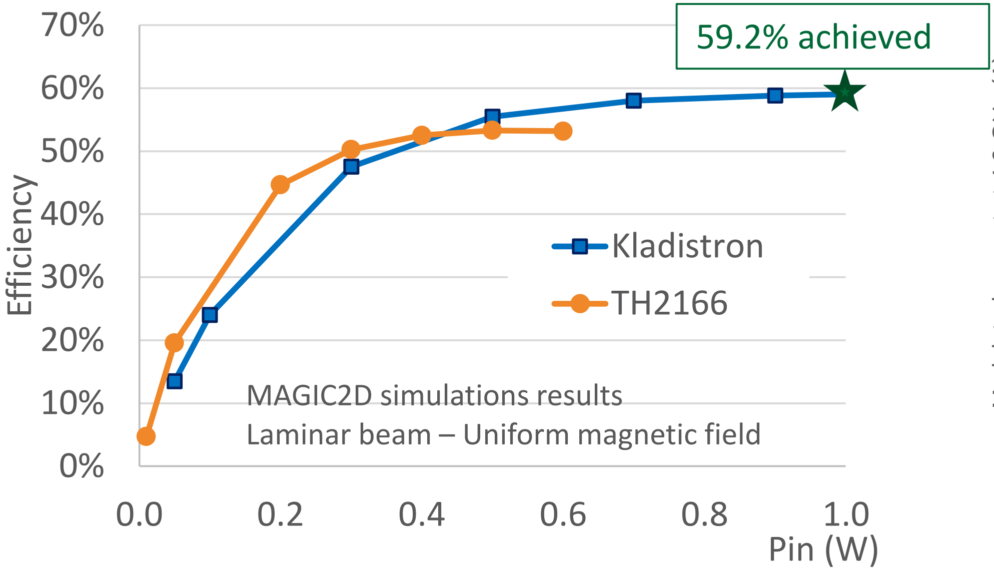
4.9 GHZ KLADISTRON PRELIMINARY DESIGN

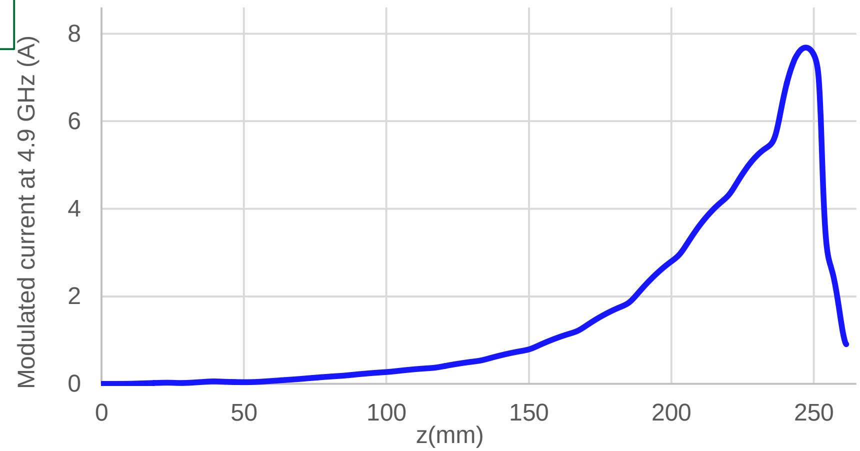
- The 4.9 GHz kladistron will contain a total of 16 cavities with two new cavity types which resonate around 4.9 GHz and has low impedance (low R/Q and Q0)
- This low impedance particularity is mandatory in a kladistron to allow soft longitudinal kicks and smooth bunching

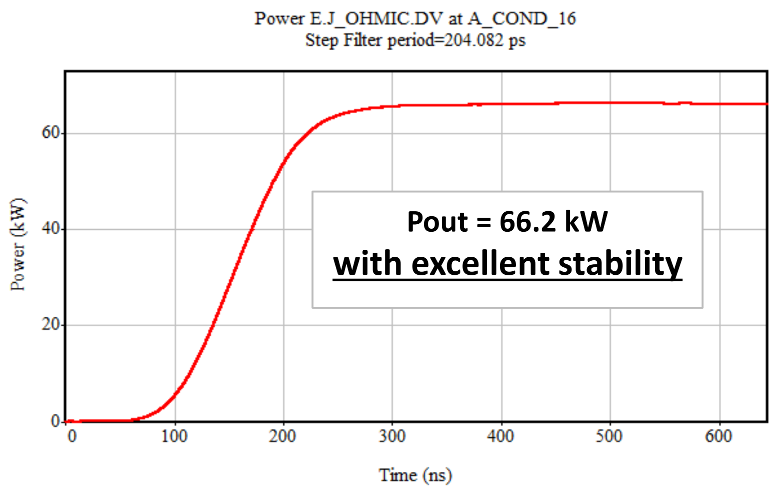


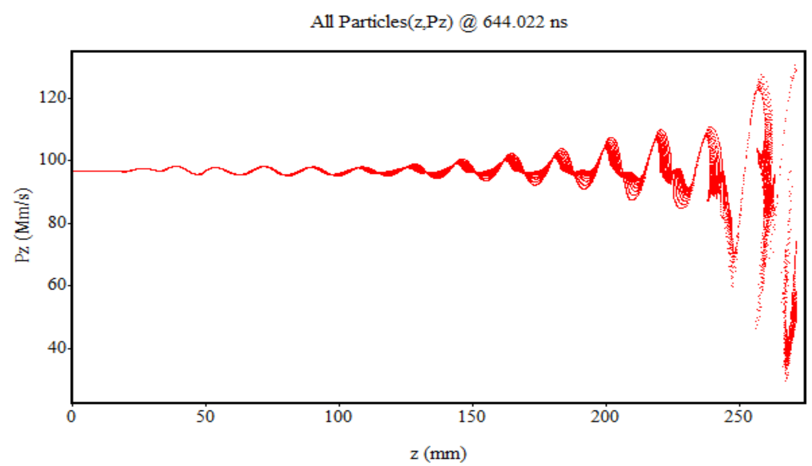


4.9 GHZ KLADISTRON FIRST SIMULATION RESULTS (WITH MAGIC2D)





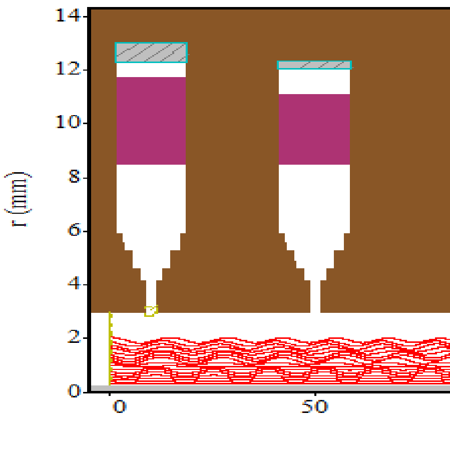


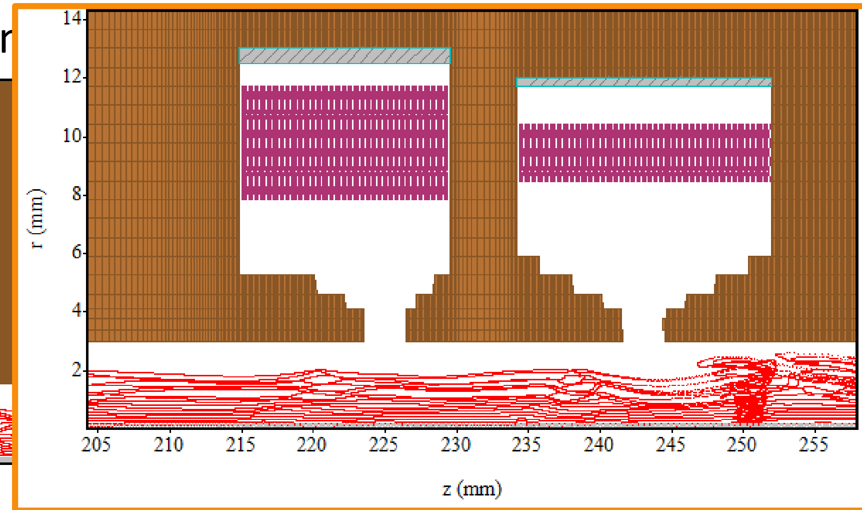


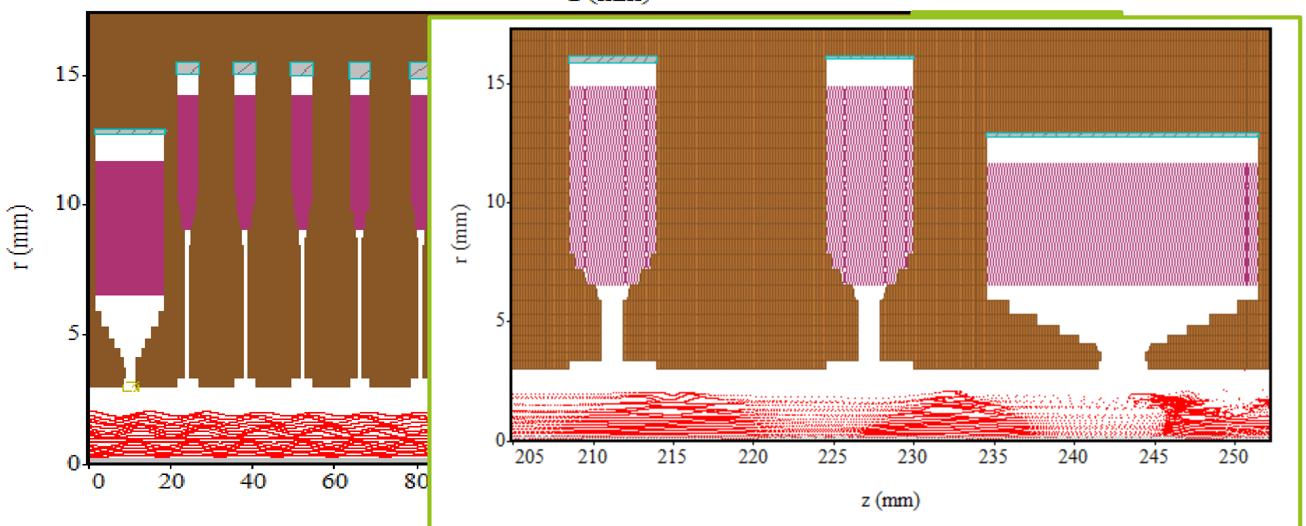
- For the moment, our kladistron simulation results reach an efficiency of six points above TH2166 simulation results

ELECTRON BUNCHING IMPROVEMENT

- Comparison between the TH2166 ar …) code



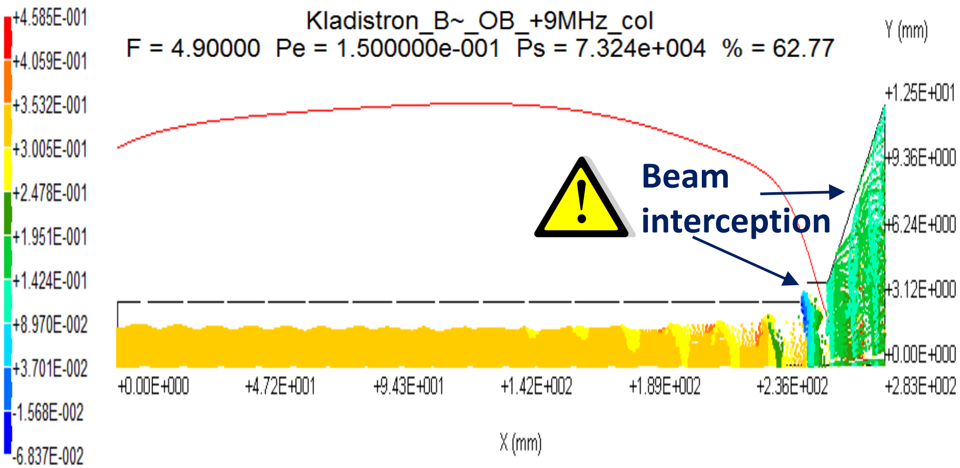


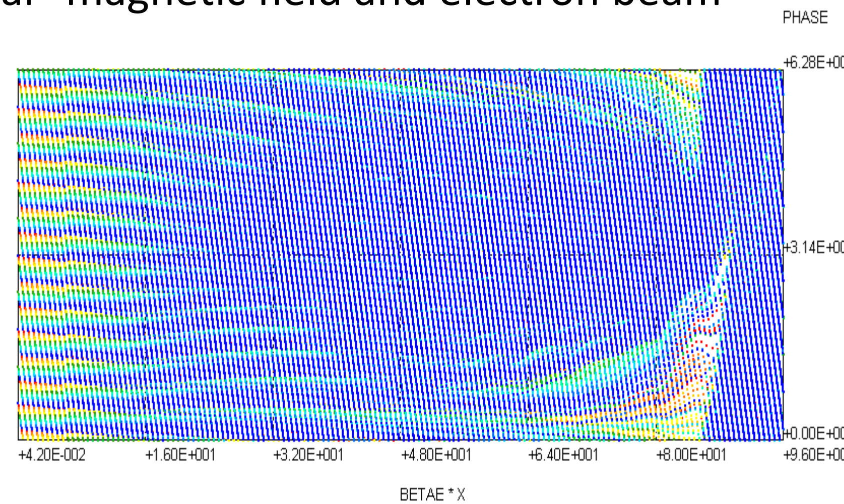


- The bunch formation is clearly improved with the kladistron, with very few particles between 2 adjacent bunches

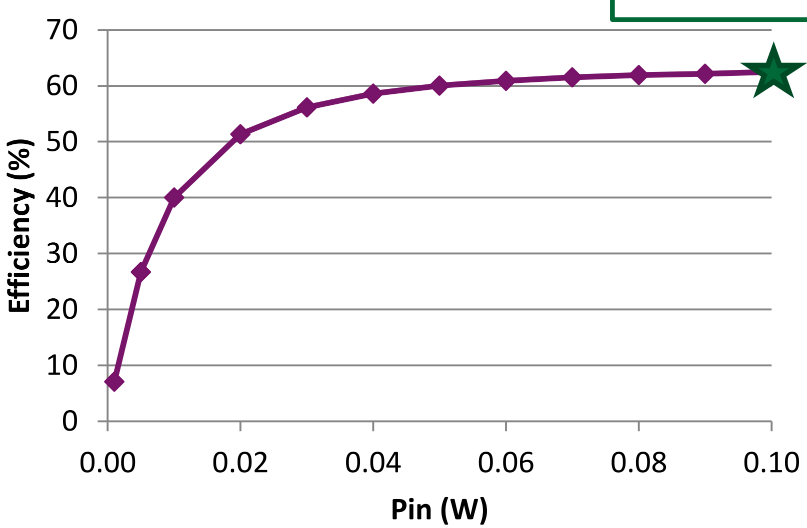
KLADISTRON SIMULATION RESULTS AFTER OPTIMIZATION

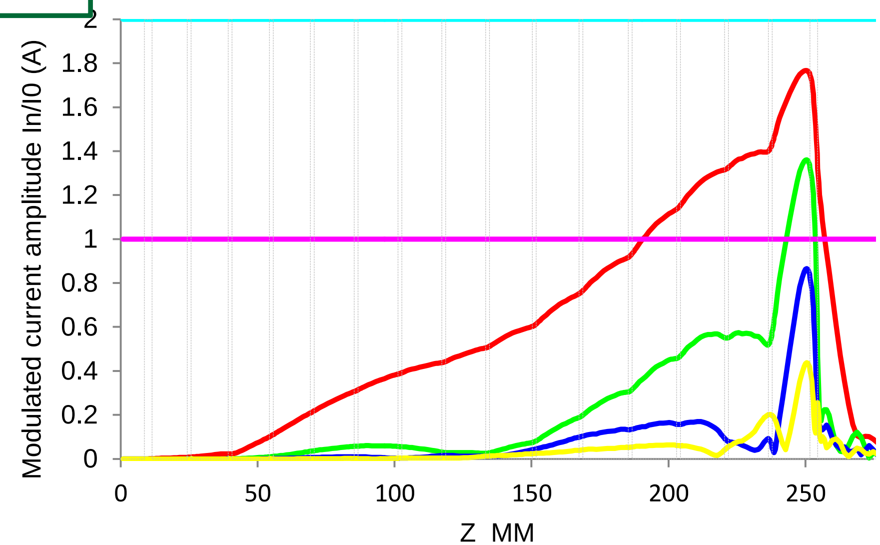
- Optimization using KLYS2D Thales code with “real” magnetic field and electron beam



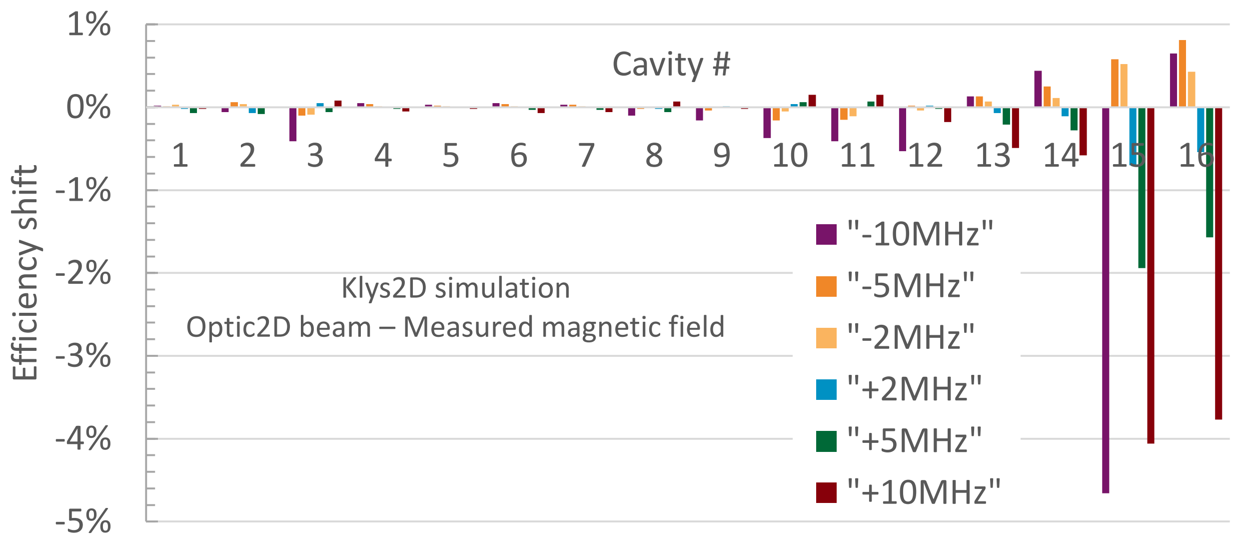


62.8% achieved





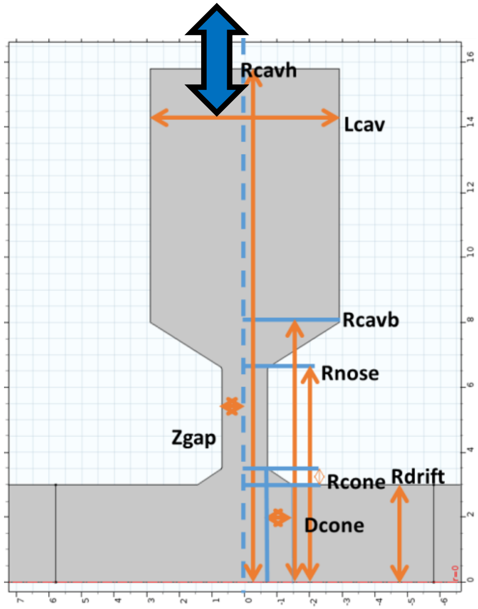
- Kladistron interaction efficiency is sensitive to its cavities frequency shifts, especially at the end of the interaction line



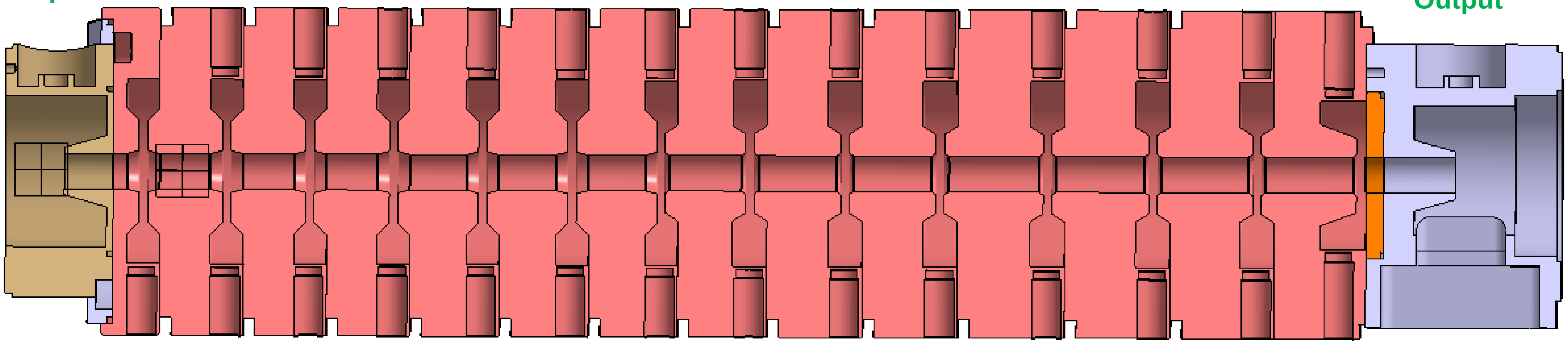
- The low impedance cavities geometry leads to the following frequency sensitivity (in MHz/µm)

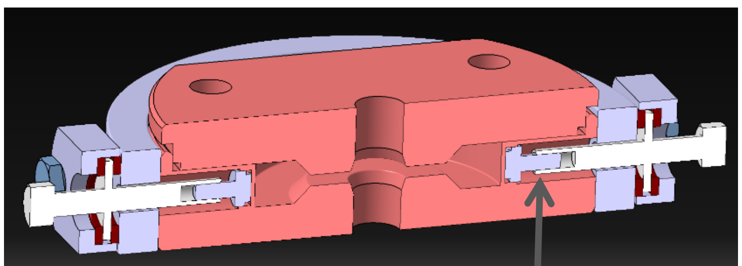
Type	Rnose	Rcavb	Dcone	Rcone	Lcav	Rdrift	Zgap	Rcavh
2	-0.106	0.09	0.003	0.116	-0.362	0.132	2.5	-0.34
3	-0.2454	0.0433	0.0309	0.1251	-0.3439	0.1901	2.3	-0.25

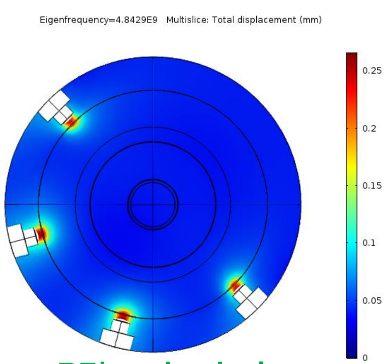
Tuner



ENGINEERING DESIGN







RF/mechanical simulation (COMSOL)

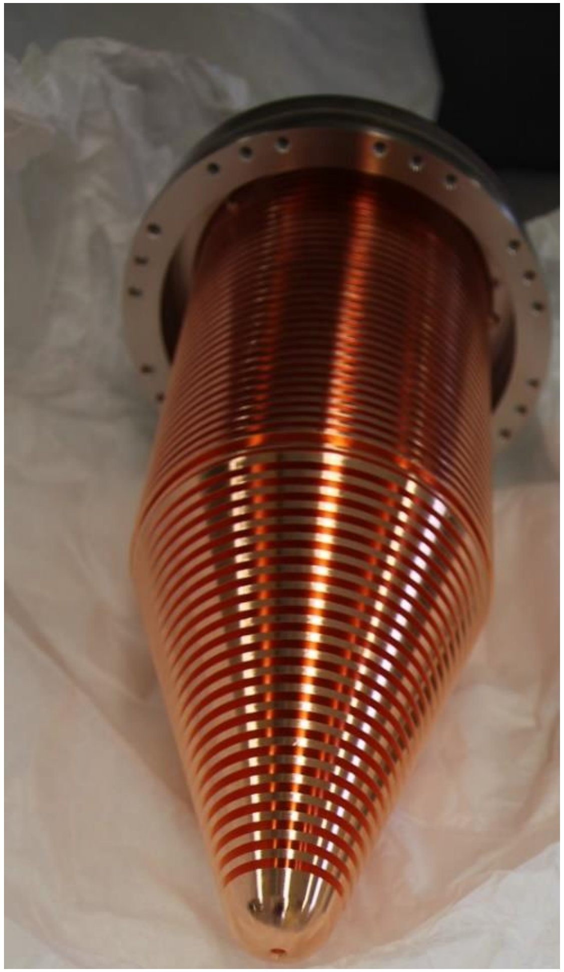
<u>TUNERS</u>
Mode: push-pull
Displacement : 0.26 mm
Freq. shift with 1 tuner: 4.02 MHz
Freq. shift with 4 tuners: 16.03 MHz

- This preliminary mechanical design is plug compatible with the existing input and output cavities and take into account the surrounding of the cavities (cooling system, solenoid,…)

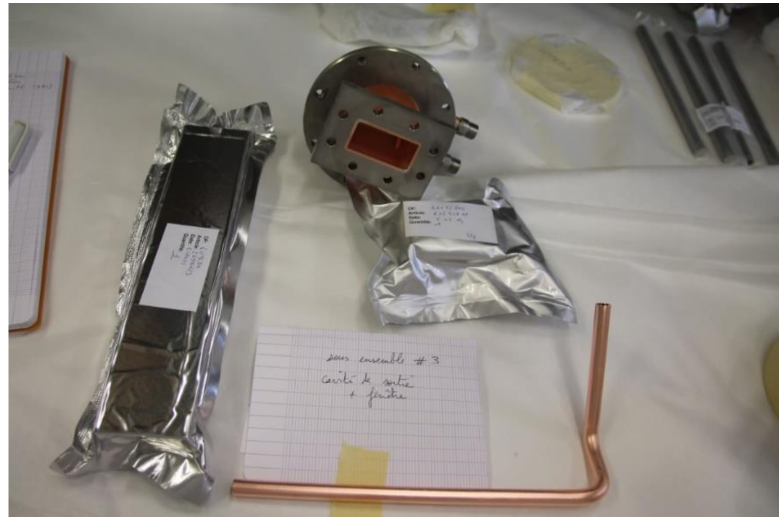
- The tuning system is inspired by CLIC accelerating cavities design ; a thin copper membrane is used to adjust cavity frequencies. The strain is controlled by an accurate screw thread

- 2 prototype cavities will be built to check the tuning accuray and range and to validate the brazing technology

DELIVERED ELEMENTS



Collector



Wave guide, output cavity, RF window

Steel rods and ion pump

- These elements have already been delivered and are properly stored in THALES

CONCLUSION AND OUTLOOK

- ✓ *New concept of high efficiency klystron proposed with adiabatic bunching (kladistron)*

- ✓ *Preliminary design of "proof of principle prototype" 4.9 GHz kladistron done*

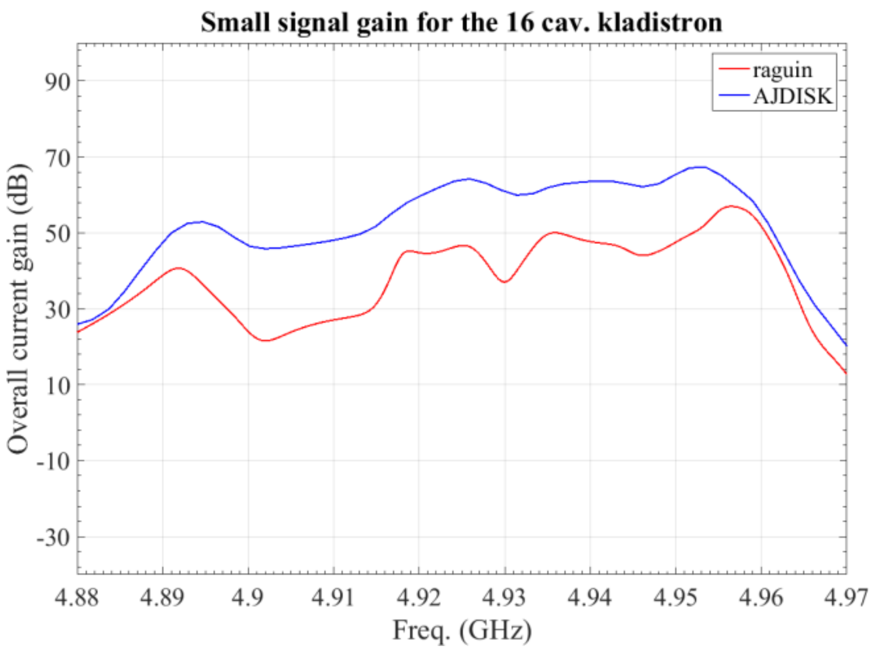
- ➢ **Starting construction phase of 4.9 GHz kladistron:**
  - Copper purchased and prototype cavities lunched
  - Final assembly and testing expected by end of 2016

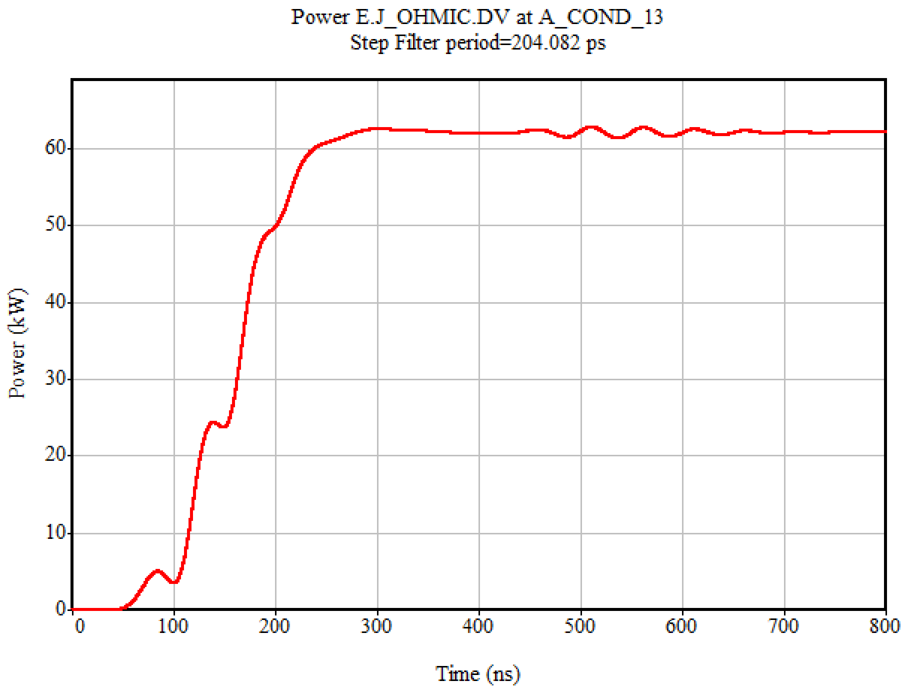
- ➢ **Detailed design of the 12 GHz kladistron foreseen in beginning of 2017**

Thank you for your attention

KLADISTRON « STABILITY »

- Small signals peak gains shall not exceed 65 to 70 dB on the full bandwidth
- This is to avoid self oscillation (starting from the noise) and time domain instabilities

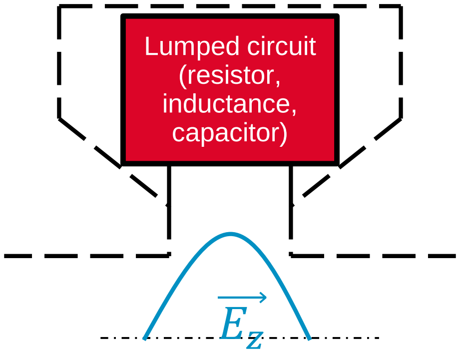




KLYSTRON SIMULATION CODES USED IN THIS PROJECT

- *AJDisk*

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



- KLYS2D

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

- Magic2D

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