New dual frequency RF system for Cyclone 30XP

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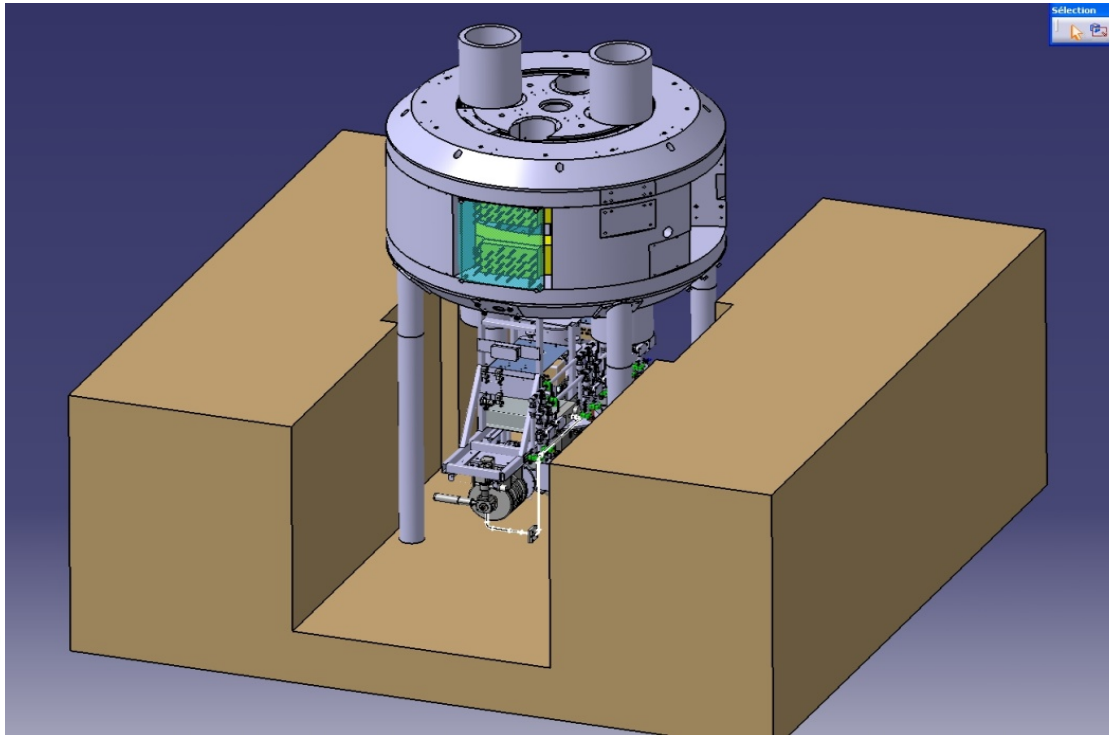
Introduction

- Cyclone® 30XP is a new multi-particle accelerator able to accelerate Protons, Deuterons and Alpha largely based on the Cyclone® 30
- This completely redesigned machine has been sold to the German Jülich Research center close to the Belgian border with a relatively short delivery time.
- In the past IBA realized such a machine but without alpha's. It was equipped with RF cavities containing RF "switches" in order to short circuit a part a the Dee stem for the highest frequency
- This solution created serious issues in terms of reliability and multipactoring (that we never really understood...)
- In order to maximize energy gain per turn and to simplify the central region we decided to keep the same principle, i.e. all the particles would be accelerated on the same harmonic mode (H4)
- A new principle has been used to avoid sliding contacts

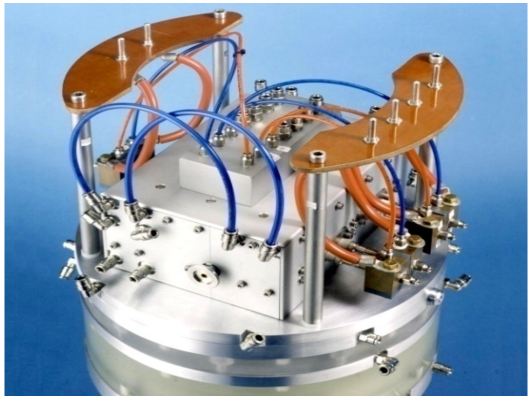
Introduction

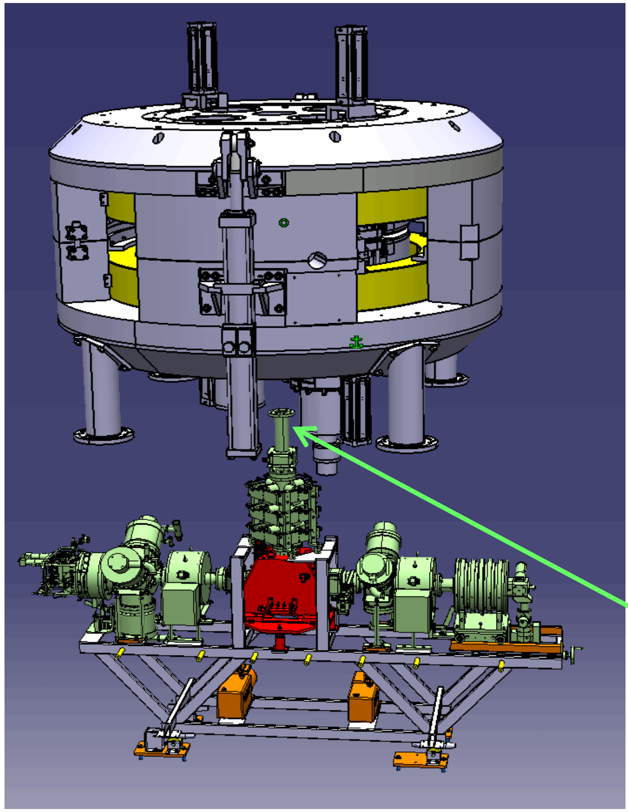


- The new machine is equipped with an axial injection system and a source bench located underneath the machine.
- One multicusp ion source delivers H- and D-.
- An ECR source is dedicated to the alpha's generation.

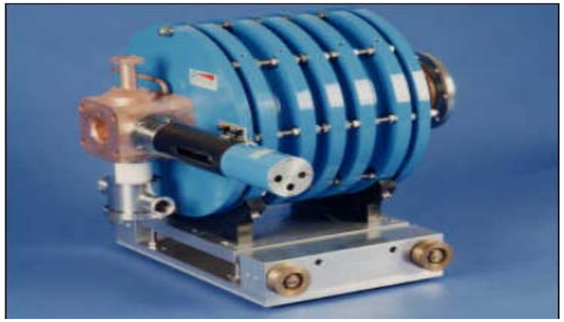
Injection: Based on the C70 design

- Source MULTICUSP 7 mA H-



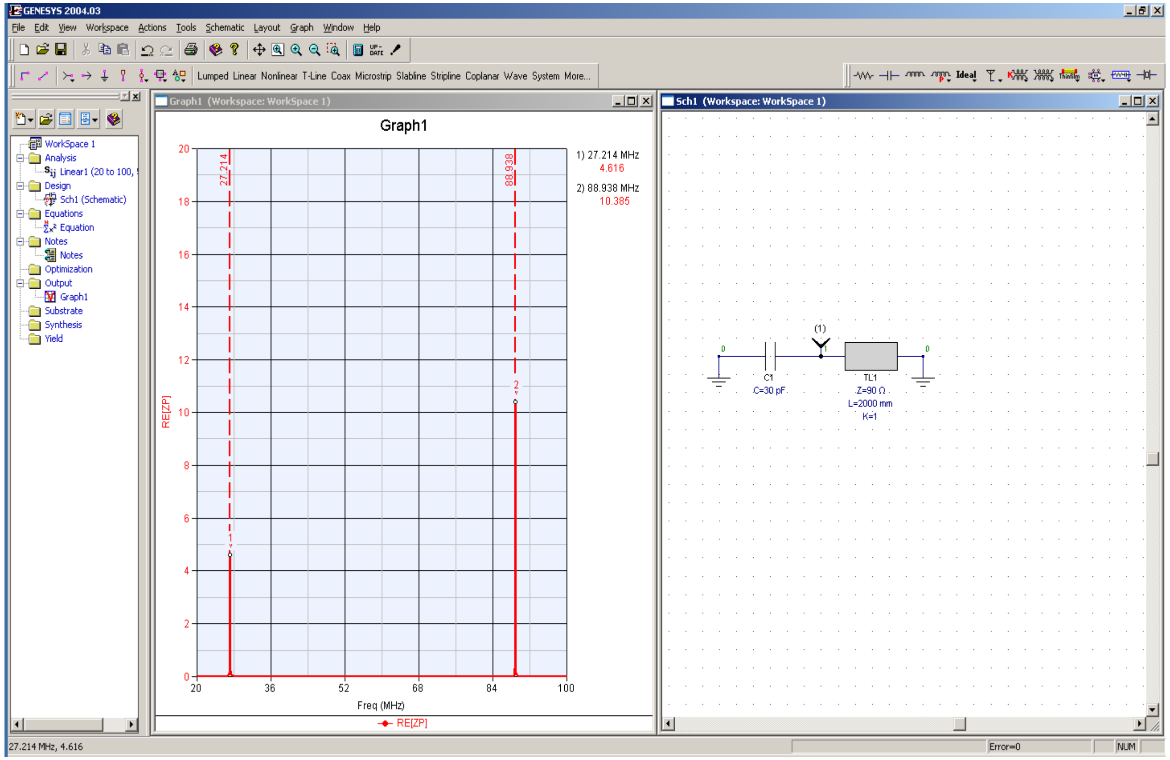


Source ECR Pantechnik 1mA He++



- One injection solenoid replaced by ES lens due to lack of space (RF resonators).

A bit of theory…

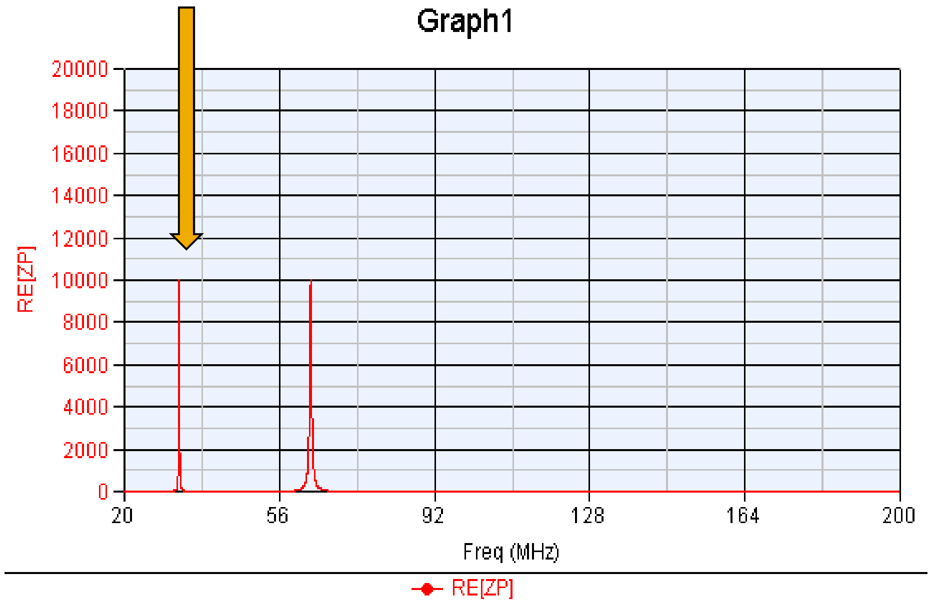


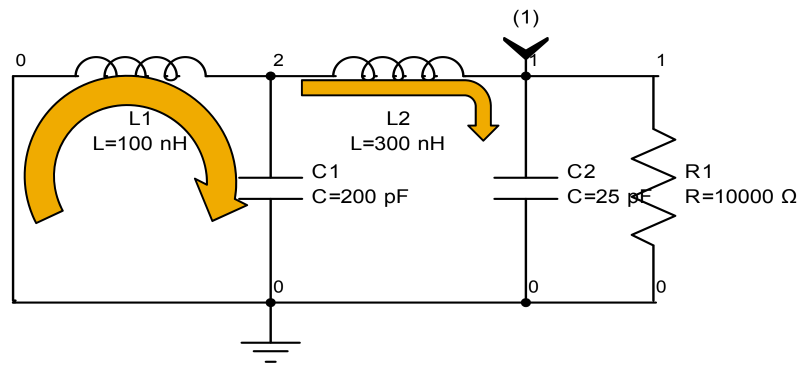
First mode: 27MHz

Second mode:90MHz

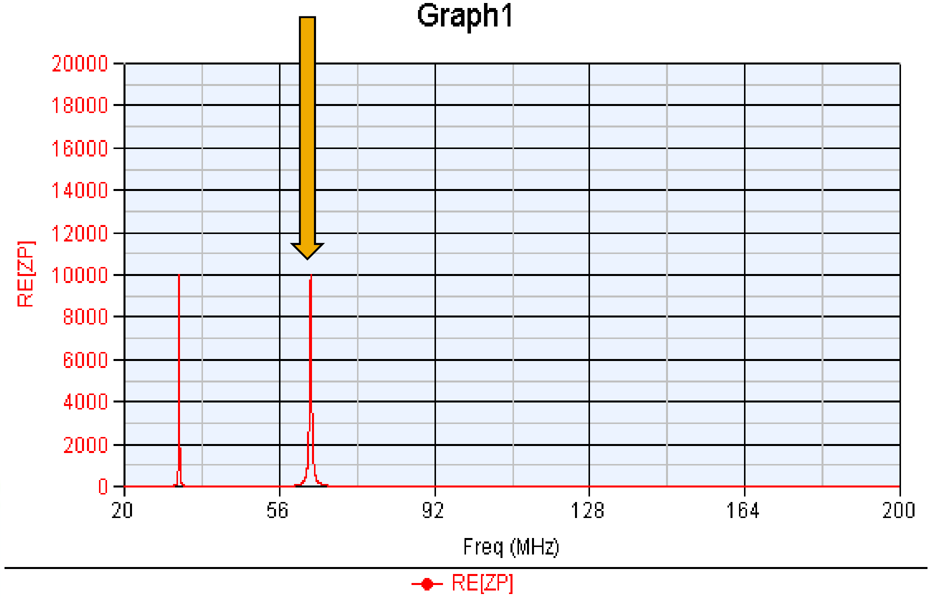
Dual mode-low frequency

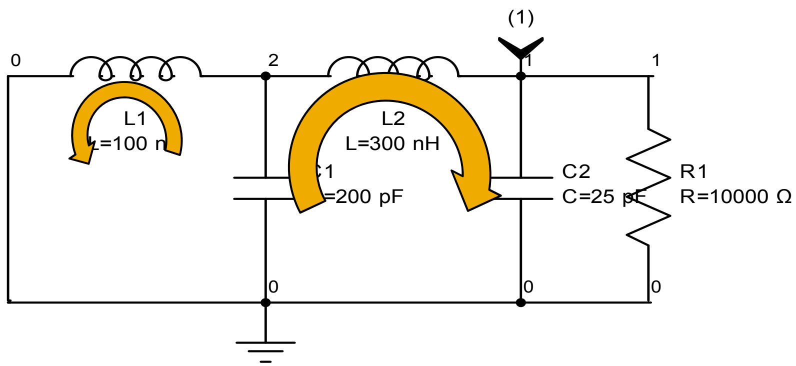
In order to get the ratio of 2 between the two modes, we can place a capacitor in the middle of the transmission line (stem)





Dual mode-high frequency





Patented idea

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 2 410 823 A1**

(12) **DEMANDE DE BREVET EUROPEEN**

(43) Date de publication:
25.01.2012 Bulletin 2012/04

(51) Int Cl.:
H05H 7/02 (2006.01) ***H05H 7/18*** (2006.01)
H05H 13/00 (2006.01)

(21) Numéro de dépôt: **10170531.7**

(22) Date de dépôt: **22.07.2010**

(84) Etats contractants désignés:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK SM TR
Etats d'extension désignés:
BA ME RS

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Remarques:
Revendications modifiées conformément à la règle 137(2) CBE.

(54) **Cyclotron apte à accélérer au moins deux types de particules**

(57) La présente invention concerne une cavité résonante (6) bi-fréquence pour cyclotron qui comprend un dé (10), un pilier (20) et une enceinte conductrice (40) englobant ledit pilier et ledit dé, une extrémité du pilier étant solidaire de la base de l'enceinte conductrice et une extrémité opposée dudit pilier (20) supportant le dé (10). L'enceinte conductrice et le pilier forment une ligne de transmission comportant au moins trois portions (20a, 20b, 20c) ayant chacune une impédance caractéristique (Z_{c1}, Z_{c2}, Z_{c3}). L'impédance caractéristique Z_{c2} de la portion intermédiaire (20b) est substantiellement inférieure aux impédances caractéristiques Z_{c1} et Z_{c3} des deux autres portions (20a, 20b), ce qui permet de faire résonner la cavité selon deux modes afin de produire deux fréquences distinctes sans devoir faire usage d'éléments mobiles tels que par exemple des courts-circuits glissants ou des plaques mobiles.

La présente invention concerne également une méthode de conception d'une telle cavité résonante, basée sur l'utilisation d'outils de simulation électromagnétique et radiofréquence.

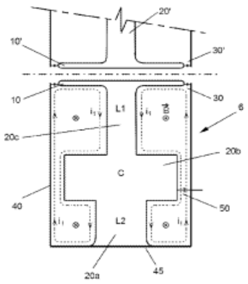
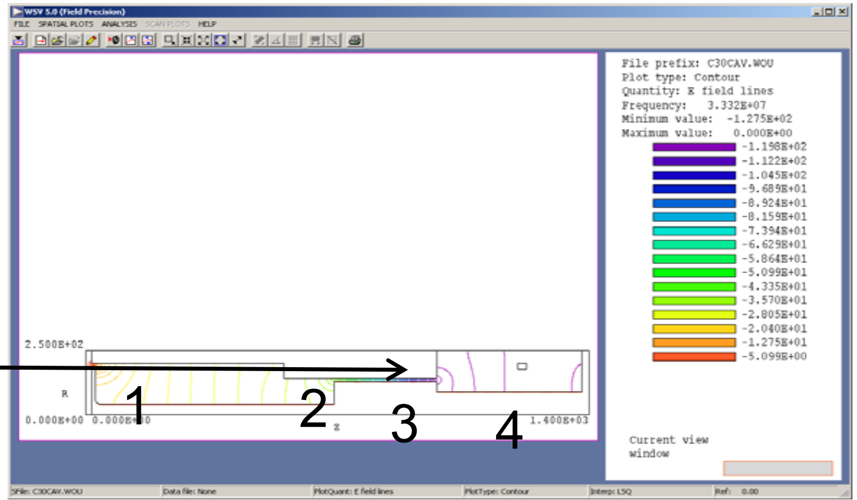


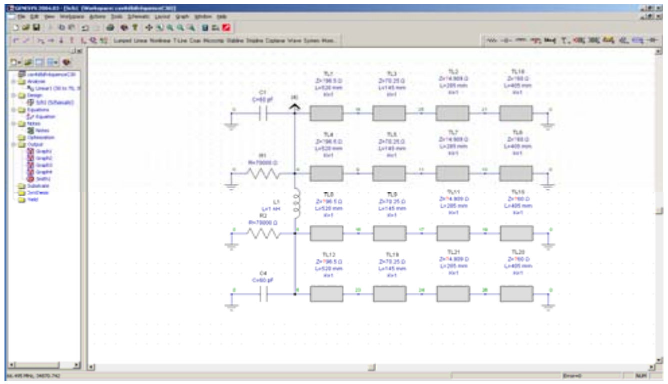
Fig. 2a

iba

Practicle realization

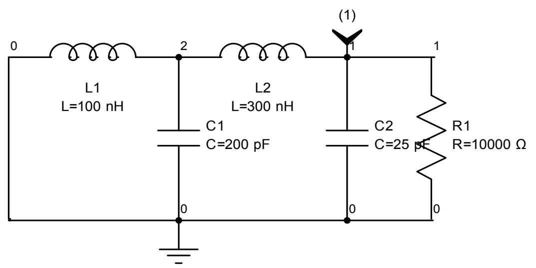
- In reality after optimization it looks like in this figure. We have basically four transmission lines in series with a low impedance line in the middle.





Calculated value of Q and dissipation

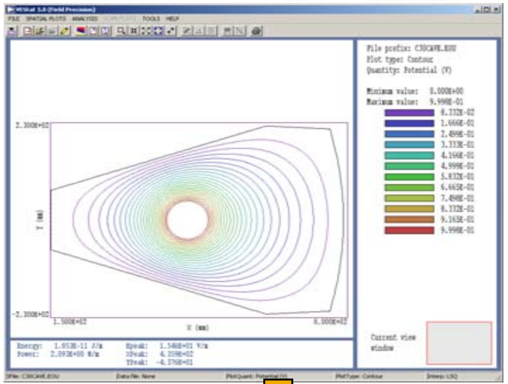
	33MHz-25kV	66MHz-50kV
Region 1(W)	20	128
Region 2(W)	280	1705
Region 3(W)	1437	320
Region 4(W)	1002	250
Region 5(W)	29	296
Q factor	6700	10000
Total(W)	2768	2699
Voltage low Z	16kV	10kV



If your look at the simplified equivalent circuit you see that you have 3 degrees of freedom.

We need at least two to define the right frequencies. I used the last one to reach the same cavity dissipation at 34 and 68 MHz (taking into account size constraints)

Calculation method

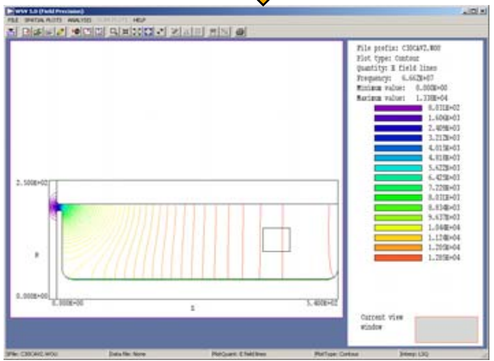


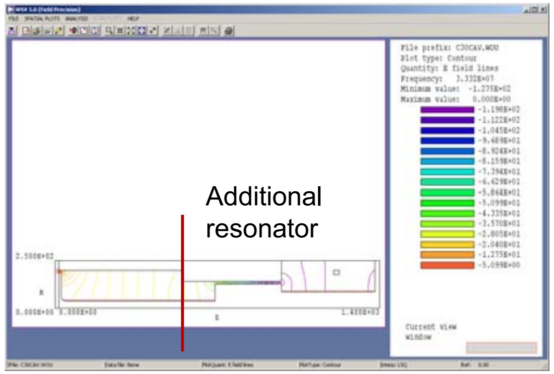
$$Z0 = \frac{1}{C/_{m} \times v}$$

$$Z0 = 60 \times \ln\left(D/_{d}\right)$$

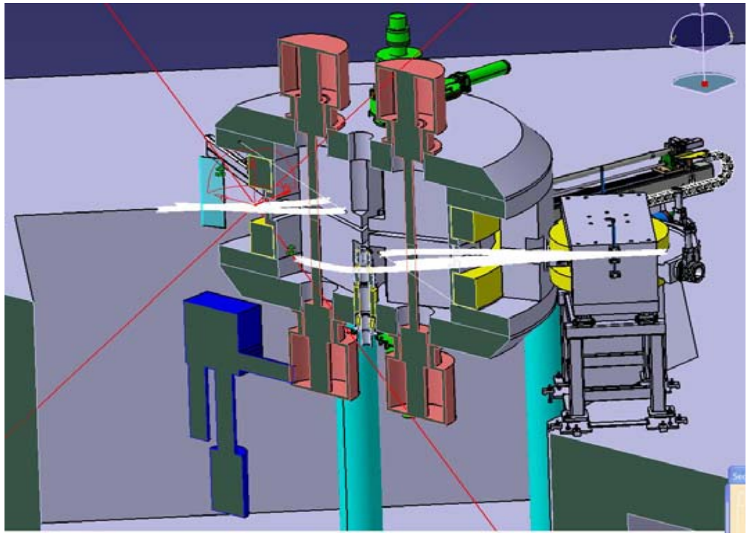
$$D = d \times e^{\left(\frac{Z0}{60}\right)}$$

- Calculation of the characteristic impedance of the Dee stem by a 2D electrostatic simulation.
- Make a 2D EM model (rotational symmetry) of cavity, loaded by a fake circular Dee, that have the same height and the same resonating frequency as the physical cavity.
- Use this model and merge to it the low frequency part, which is rotational symmetry in practice.



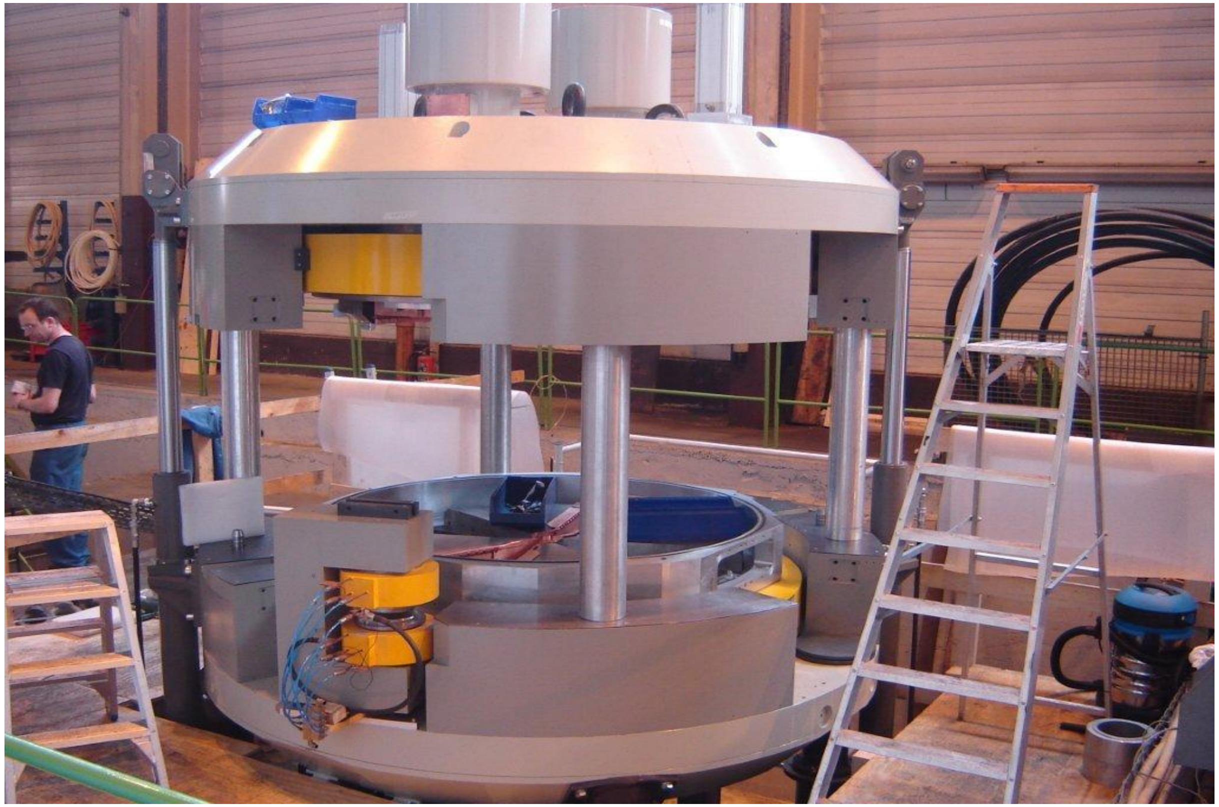


Practical realization

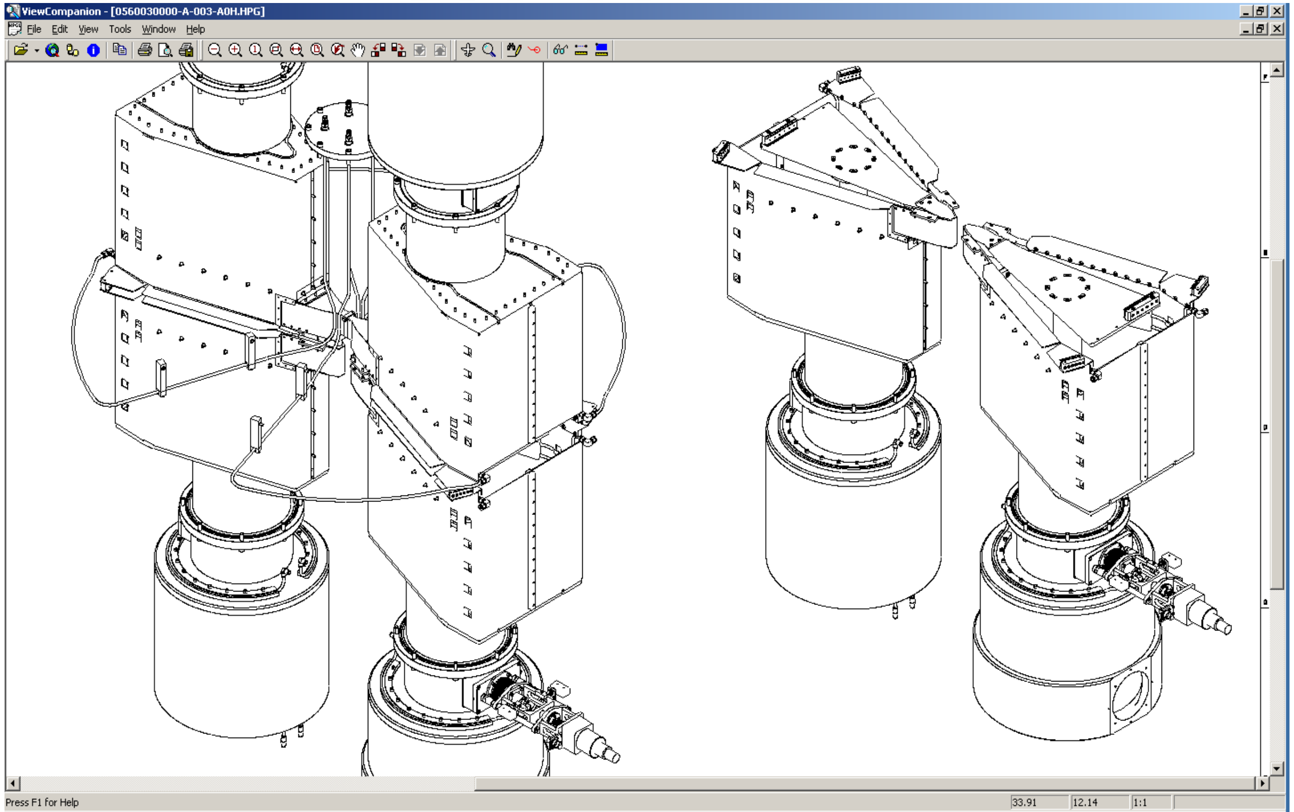


- The cavity has been realized in OFHC copper and electron beam welded to reduce the machining time and the quantity of raw material
- Two clear advantages of the solution:
  - Very robust pillars
  - Quite short of for a 34MHz resonator

Practical realization (other views)



Practical realization (other views)

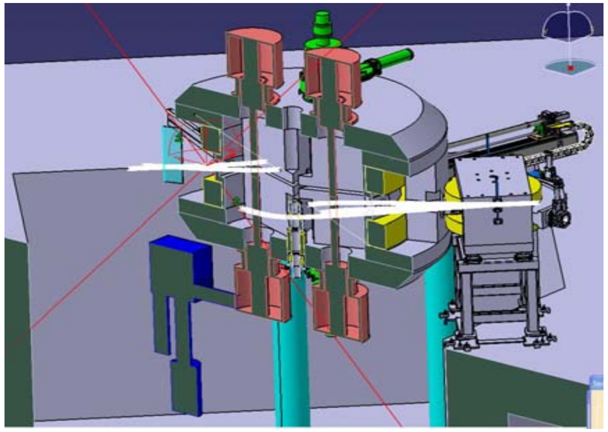


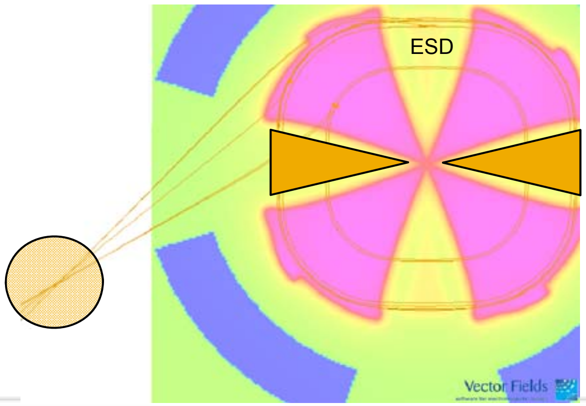
Tuning the final cavity dimensions

- Thanks to the sensitivity analysis made before, the final dimensions of the Dee pillars have been found very quickly. Only two iterations were needed to reach the final goal.
- The final dimensions of the various diameters were at +/- 1mm from the calculated ones, which validates the calculation method
- The measured Q at 68MHz was 80% of the calculated one
- The measured Q at 34MHz was 95% of the calculated one

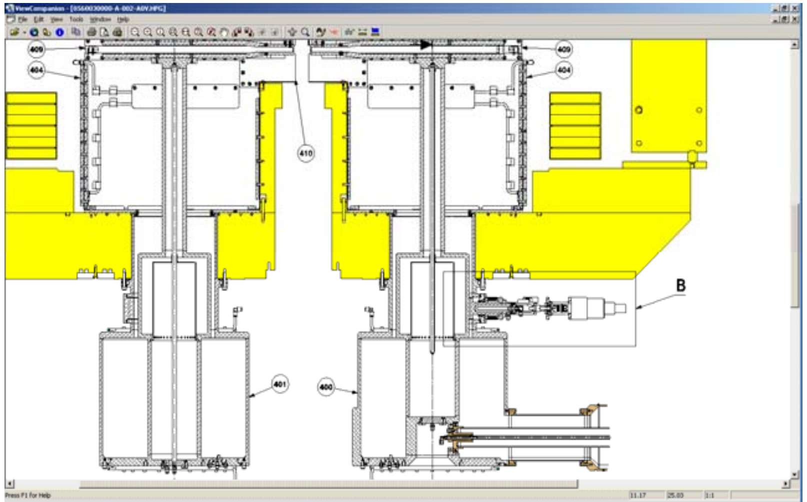
	Ø int (mm)	f1(MHz)	f2(MHz)		df1/dØ (kHz/mm)	df2/dØ (kHz/mm)
Z1	71.86	33.114	65.203		-2.5	157.6
Z1	80	33.094	66.486		-4.5	149.3
Z1	89.25	33.052	67.867			
Z2	169	31.982	66.255		74.1	15.4
Z2	184	33.094	66.486		76.9	19.4
Z2	200	34.324	66.796			
Z3	256.12	33.909	67.352		-433.5	-460.6
Z3	258	33.094	66.486		-499.4	-454.5
Z3	259.76	32.215	65.686			

Tuners and amplifier positioning

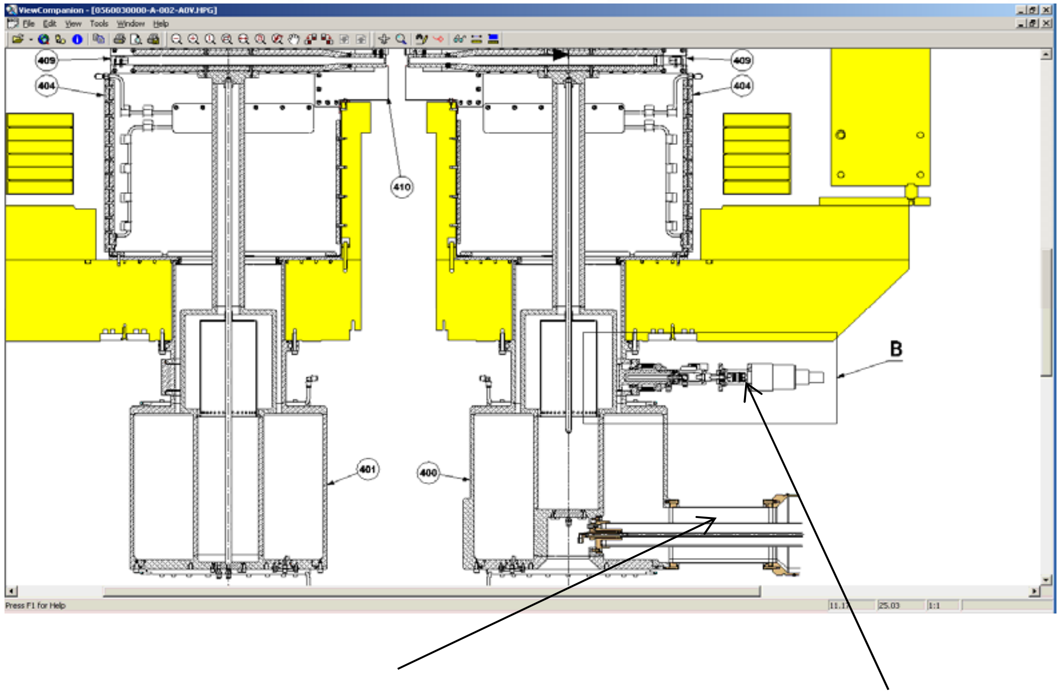




- H- and D- exit the magnet inside a valley already occupied by the Dee's.
- The tuners and the amplifier cannot be positionned in the median plane.



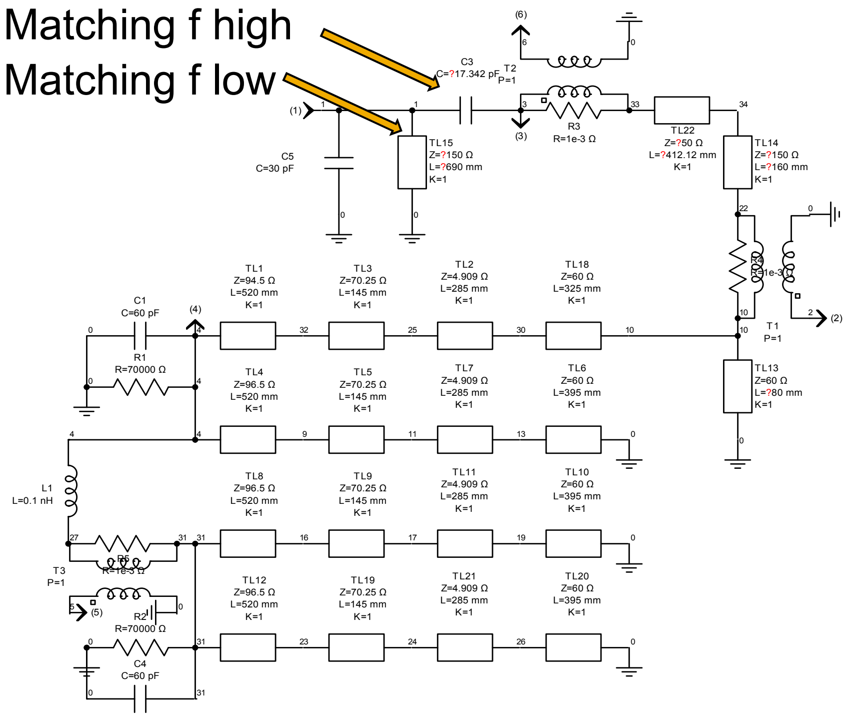
Tuners and amplifier positioning



Amplifier **Tuner**

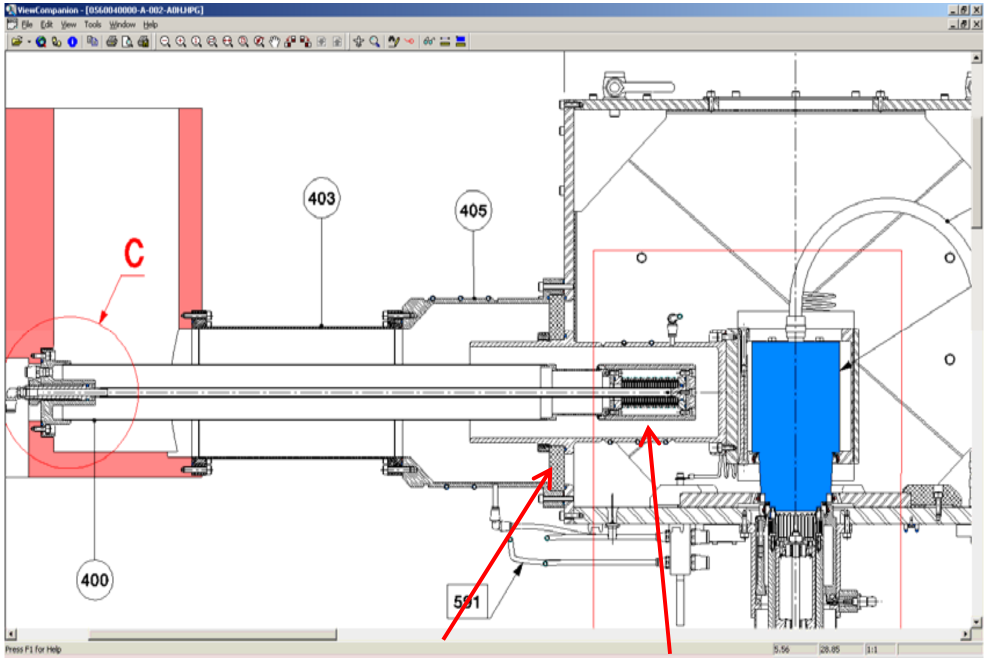
- The tuning mechanism found a nice location close to the magnet yoke.
- The amplifier is directly coupled in the bottom of the cavity.

Amplifier design



- Solution of Solid-state amplifier rejected for FPA:
  - Impossible to pay off the NREC costs (not available off-the-shelf)
  - Demonstrated only in a few labs
  - Development time…
- Based on a tetrode.
- Matching « knobs »for the two frequencies are quasi independant.
- There is no tuning needed (reactive power exchange with the cavity)

Amplifier design- Output circuit

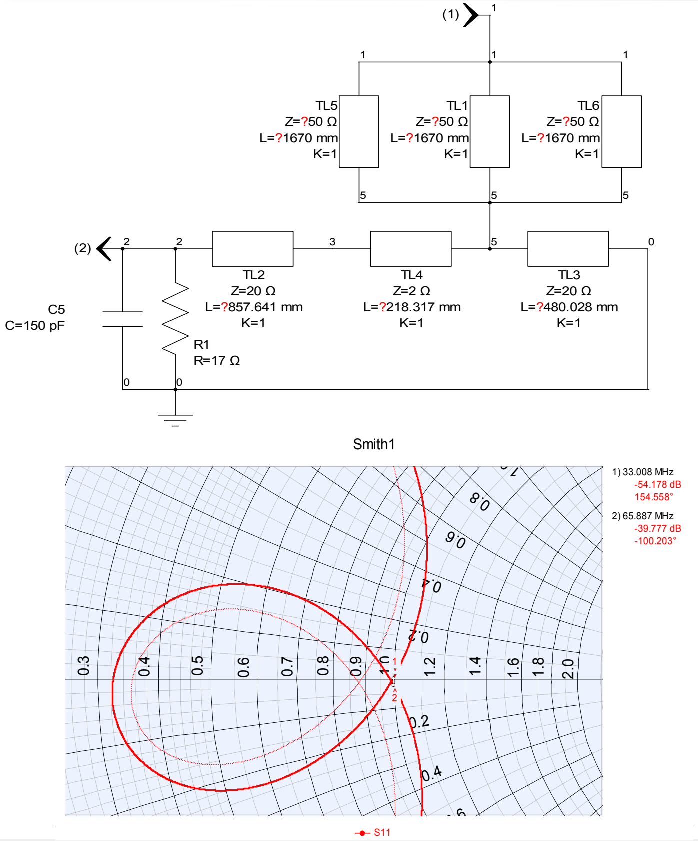


Vacuum feed-through

Coupling capacitor

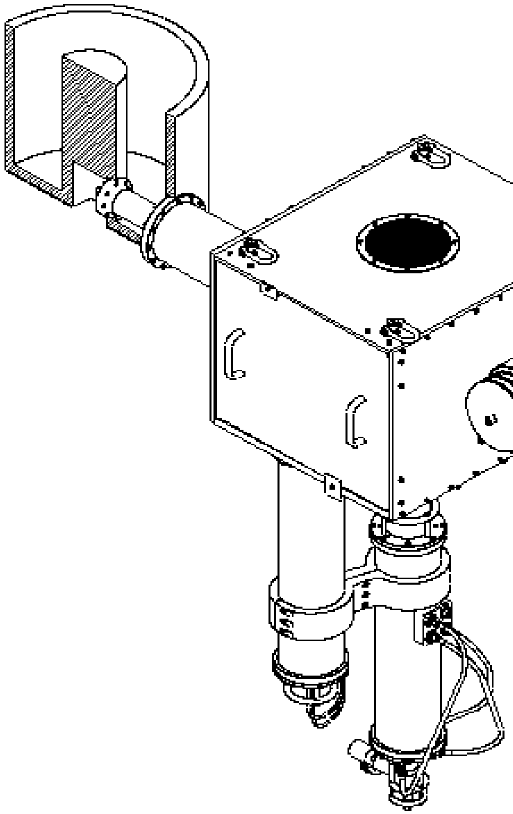
- The amplifier has been designed around a tetrode from Thalès able to deliver 60kW CW.
- The tube is cathode driven.The high gain (16dB) allows the use of a small 1kW broadband solid-state driver

Amplifier design- Input circuit



- The input circuit has no switching device.
- The cathode resonator work in ¼ wave and ¾ wave.
- The final matching is done by a 16 ohms line (three 50 ohms cables in //).

Amplifier design



- Amplifier is easily removable (sliding on rails) for servicing.
- Manufacturing and assembly fully outsourced

Amplifier cold tuning

Input circuit:

- Tuning made with a Network Analyser.
- Cathode loading impedance simulated with a 17ohms resistor.
- Good matching found easily for the 2 different frequencies.
- No need of mechanical changes.

Output circuit:

- A bit more complex…
- Need to change the length of the coupling line by 5 cm to find the good matching.
- Measurement was done with two different Network Analysers to improve the accuracy
- The impedance to be measured where high (2kOhms).
- The impedance were calculated based on the measured « Q » value and impedance shunt.

Starting-up of the amplifier chain

- Since the amplifier doesn't have a 50Ohms output, no test on dummy load could be done. The amplifier was then directly started on the cavity.
- No special issues have been faced and it took only 2 days to have the system working on the two frequencies.
- FPA Input matching was excellent and no retuning was needed.
- Output matching was good too but could be improved a bit at 68MHz by playing on the coupling capacitor. The tube RF voltage was 70% from saturation for nominal Dee voltage. It was 90% for f low.
- Dee voltage calibration was done by measurement of the X-ray spectrum emitted by the cavity. Done through a thin Plexiglas window.

Summary of RF paramters

Parameter	F low (25kV)	F high
Measured "Q"	6500	8000
Z shunt (kΩ)	31	104
I tube (A) I tube max. (A)	1.5 6	2.1 6
V tube(V)	10.0	10.0
P driver (W) P driver max (W)	250 1300	380 1300

Conclusions

- The New C30XP was born with a new and innovative RF system that makes the machine easy to operate and maintain due to the simplicity of the concept. This system has been designed with the help of modern computer codes that gave very accurate predictions. The development costs have been quite low for such an “a priori” complex RF system due to the very short tuning-up period.

Thanks to all my IBA colleagues who help in achieving this result!

Thank you