FCC Week 2016
ROME 11-15 April

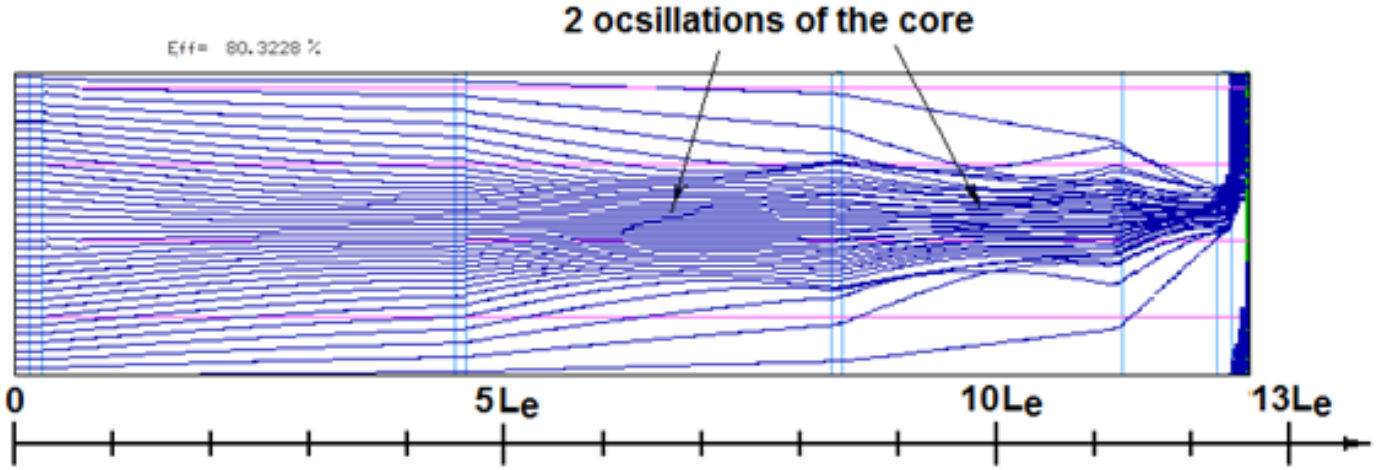
Recent developments and perspectives

Bunching, Alignment and Collecting (BAC) method for the high efficiency klystrons.

A. Guzilov (VDBT), I. Syratchev (CERN)

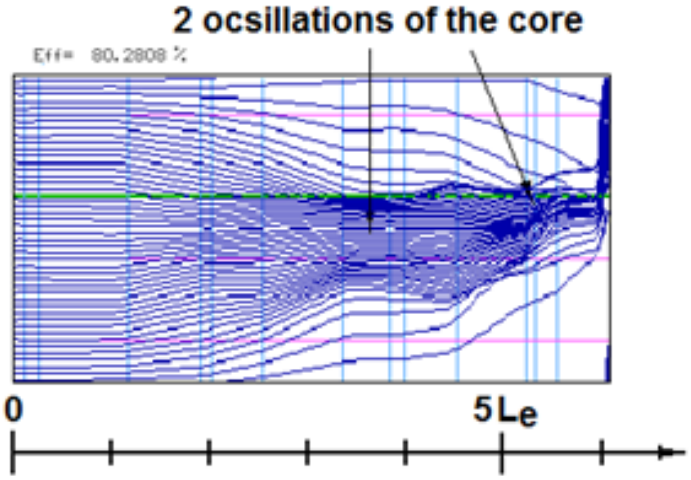
Bunching-Alignment-Collecting (BAC) technology

BAC is technical extension of COM, where the impedances of the cavities triplet allows to reduces dramatically the spatial wavelength of the core oscillations, thus for the same efficiency the tube length can be dramatically reduced.



U=180 kV

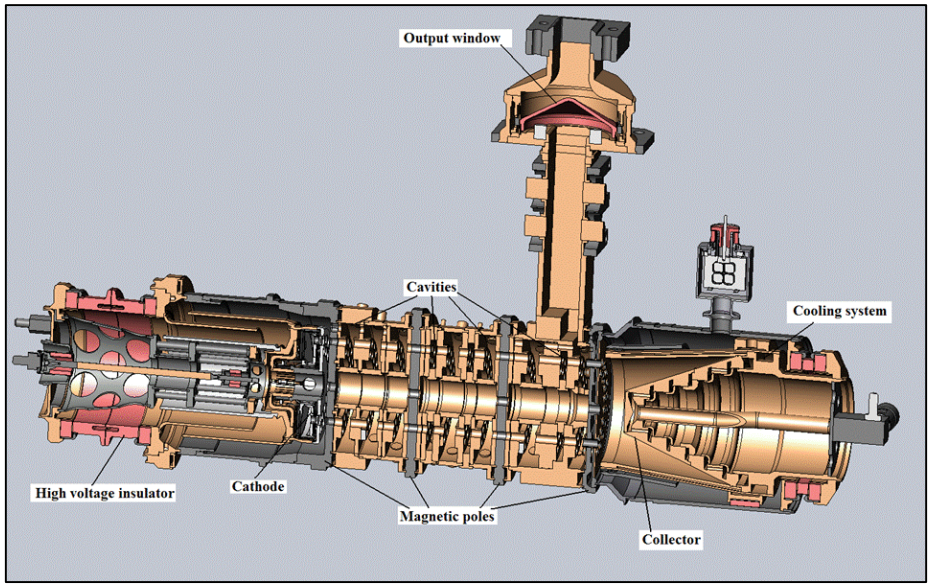
L = 3.0 m



CLIC 20 MW L-band MBK example

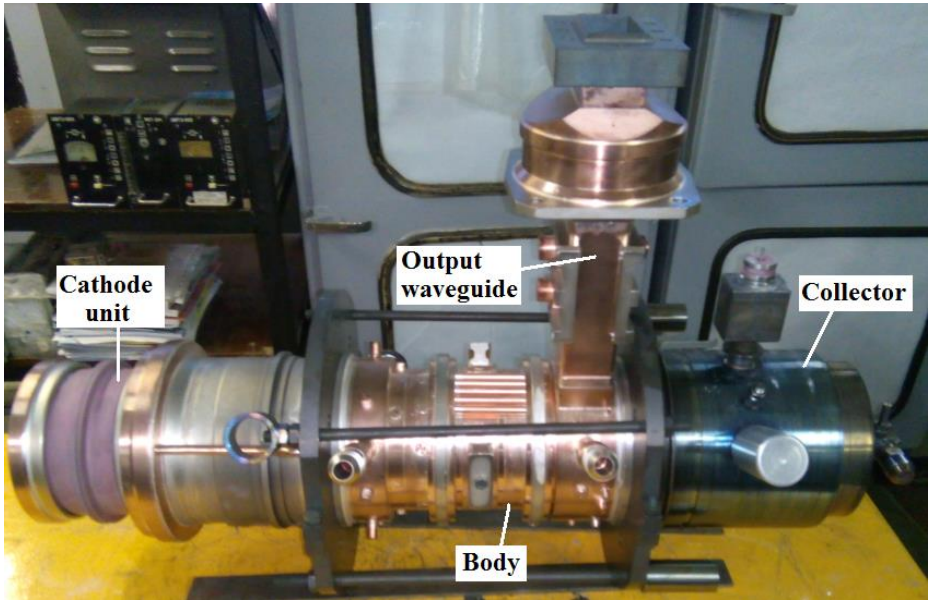
U=116 kV

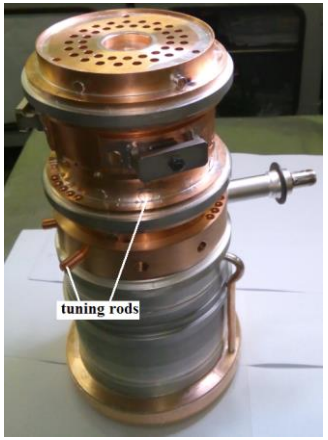
L = 1.2 m

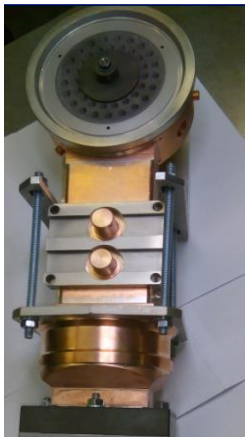


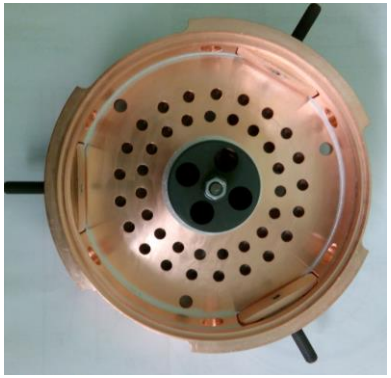
The first commercial (VDBT, Moscow) S-band MB tube which employs the new bunching technology (BAC):

- 40 beams
- Permanent Magnets focusing system
- Low voltage: 52 kV
- Peak power: 7.5 MW
- Pulse length: 5 microsecond
- Repetition rate: 300 Hz
- Average power: 30 kW









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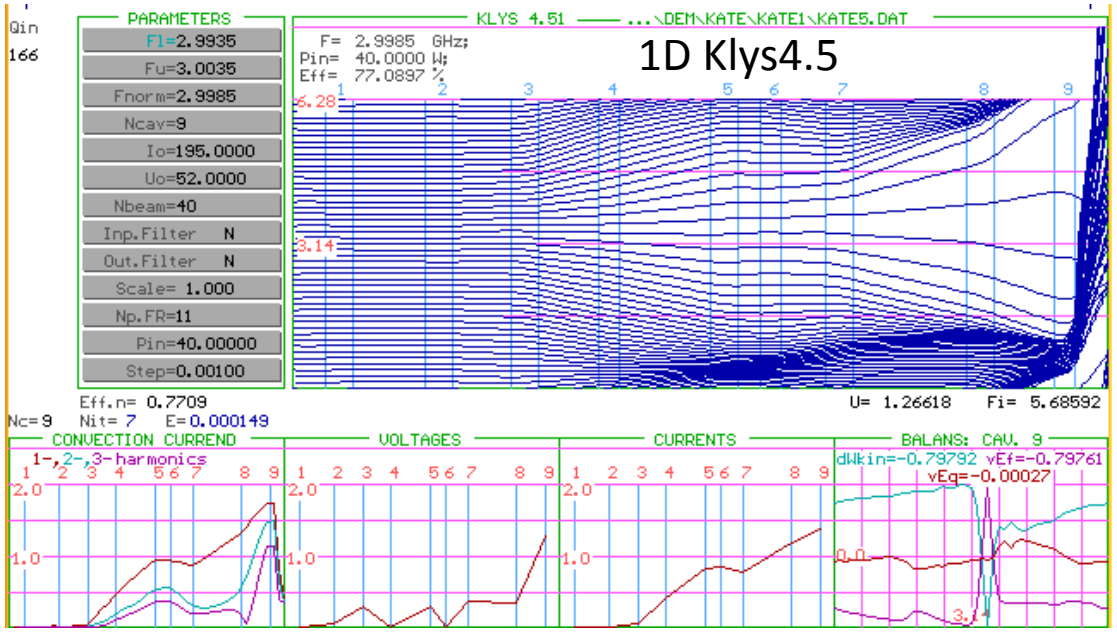
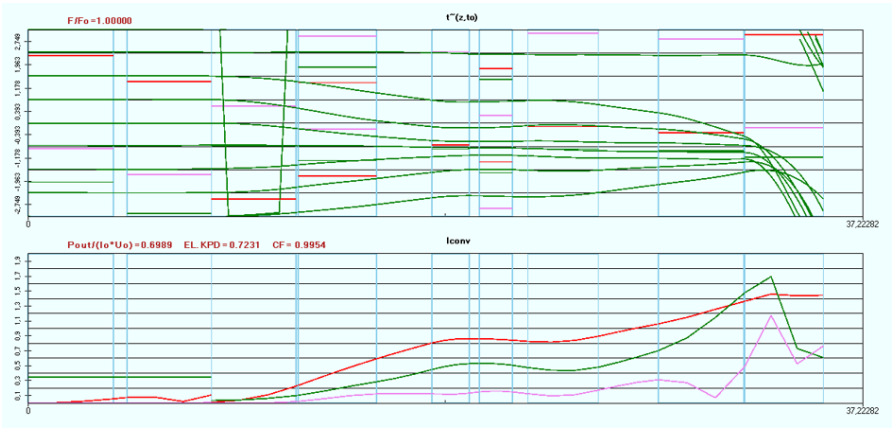
Expected efficiency (in simulations)

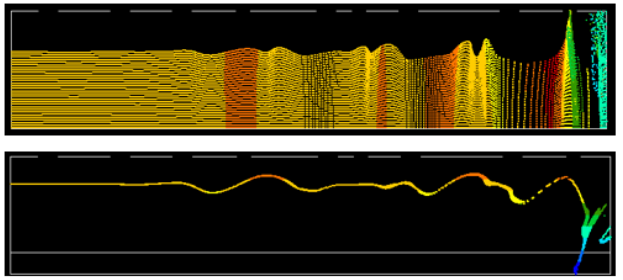
1D Klys4.5

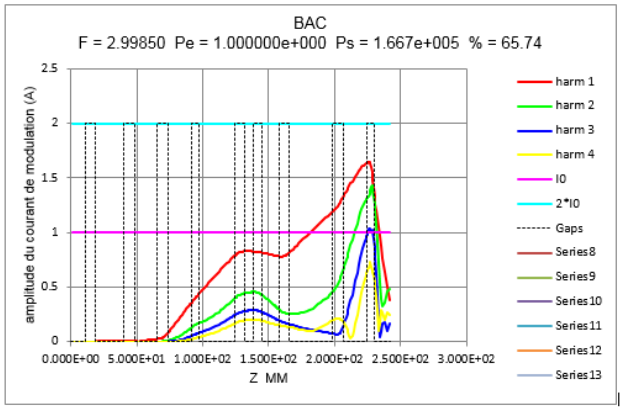


1D KlypWin



2D KLYS2D





1. Efficiency **77%**. (1D) Klys4.5, Original company code used to optimise the tube.
2. Efficiency **69.9%**. (1D) KlypWin (A. Baikov). The code used by HEIKA study for the basic design and optimisation of high efficiency klystrons.
3. Efficiency **65.74%**. (2D) KLYS2D is the code used at Thales.

All codes predicted the high efficiency of the device (cf. **42%** of original KIU-147 tube).

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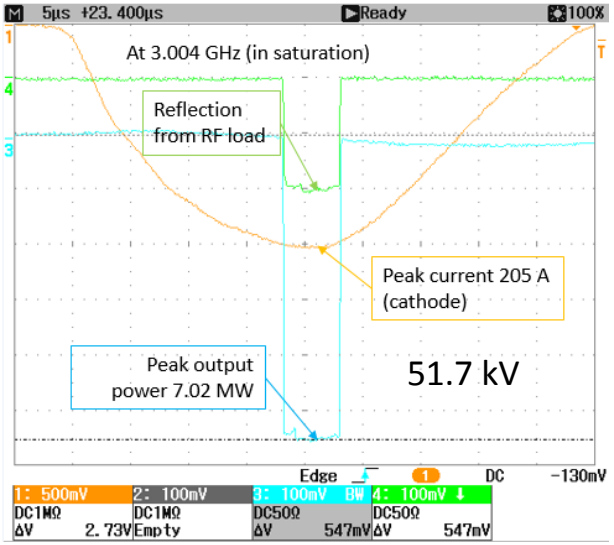
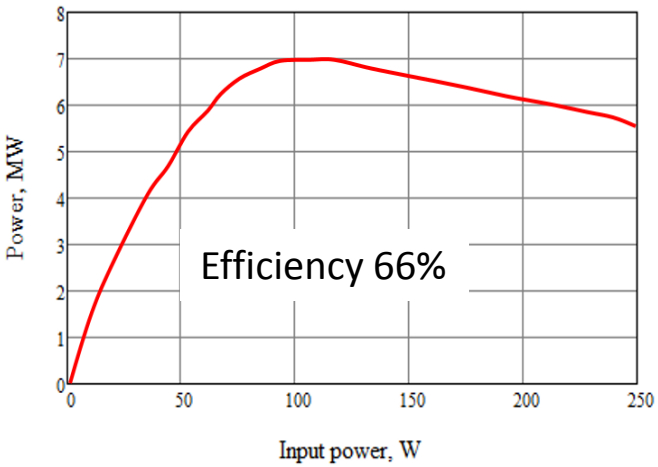
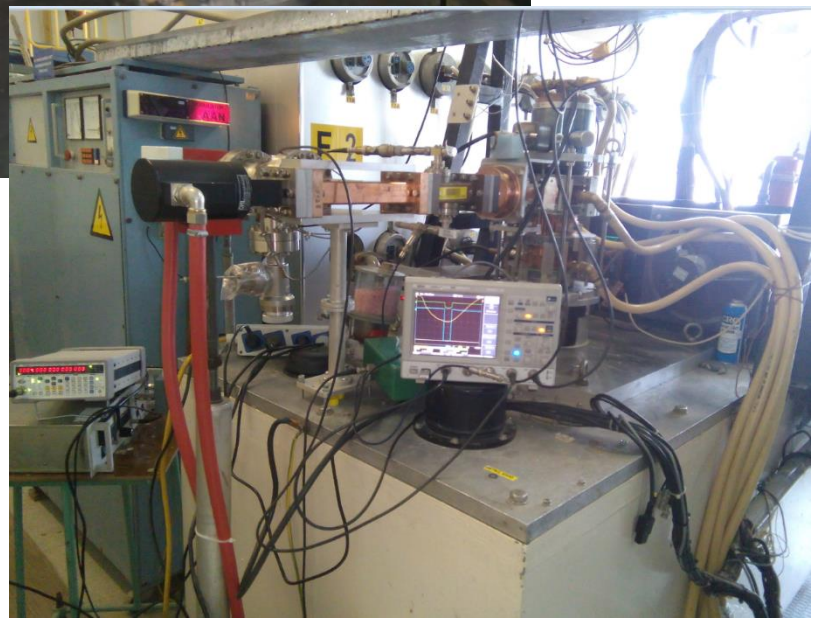
BAC MBK factory test results







The achieved S-band BAC MBK klystron performance confirmed the excellent potential of the new bunching technology. In this case by ‘simply’ replacing the klystron RF circuit (retrofit), the peak output RF power was boosted by almost 50%!

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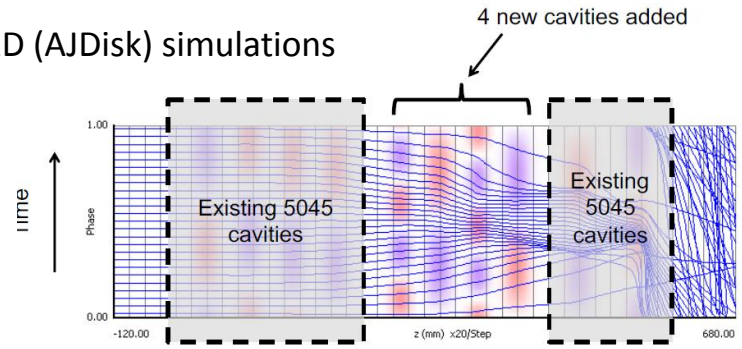
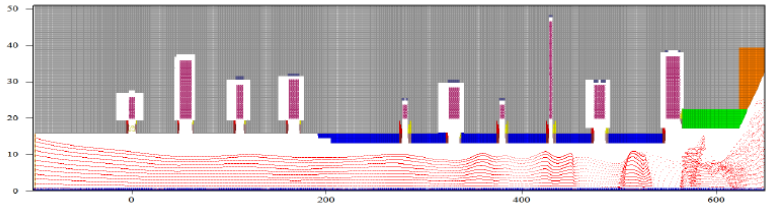
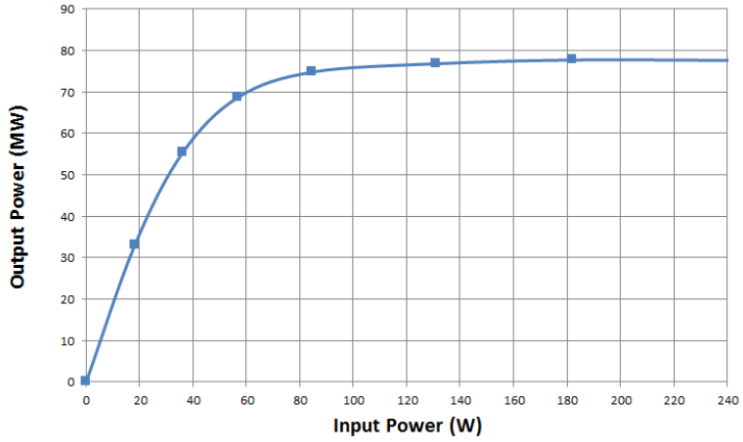
Status of the SLAC S-band klystron retrofit activity.

1D (AJDisk) simulations



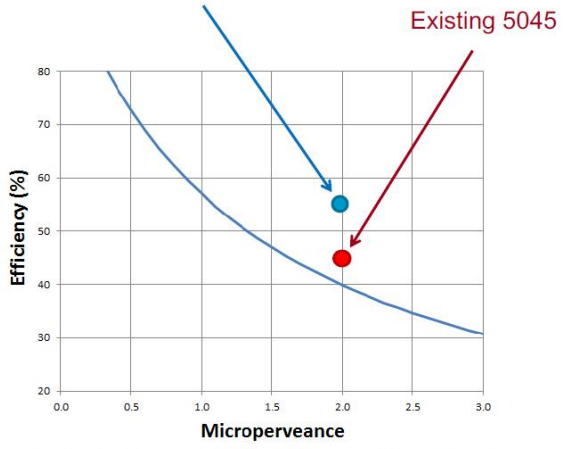
PIC (MAGIC) simulations





Conventional 5045 klystron

BAC retrofitted 5045*
**Efficiency limited by plug compatibility constraint and drift diameter*



Empirical relation between efficiency and perveance

- SLAC is developing a BAC inspired retrofit of the 5045 linac klystron.
- Simulations predict the new design will achieve ~80MW a big improvement over the existing design and state of the art (~60MW).
- Mechanical design, drafting, and machining are presently underway.
- A new solenoid is being rewound by Stangenes.
- Results will be reported at IVEC in April, 2016

Aaron Jensen, Andy Haase, Erik Jongewaard, Mark Kemp and Jeff Neilson

I. Syratchev

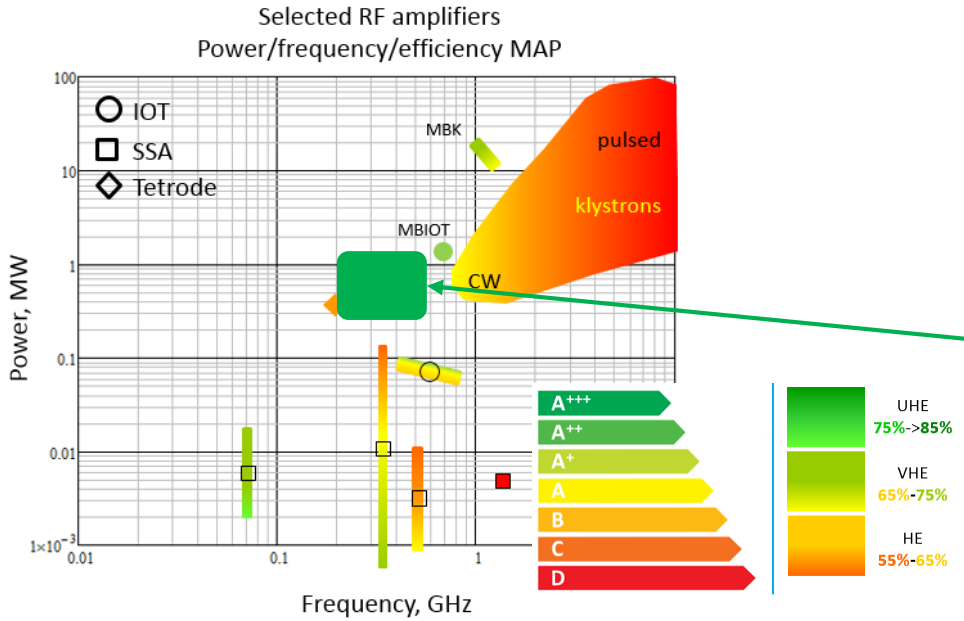
Recent developments and perspectives

Resotrode – RF amplifier with regeneration. Concept.

A. Yu. Baikov (MUFA), I. Syratchev (CERN)

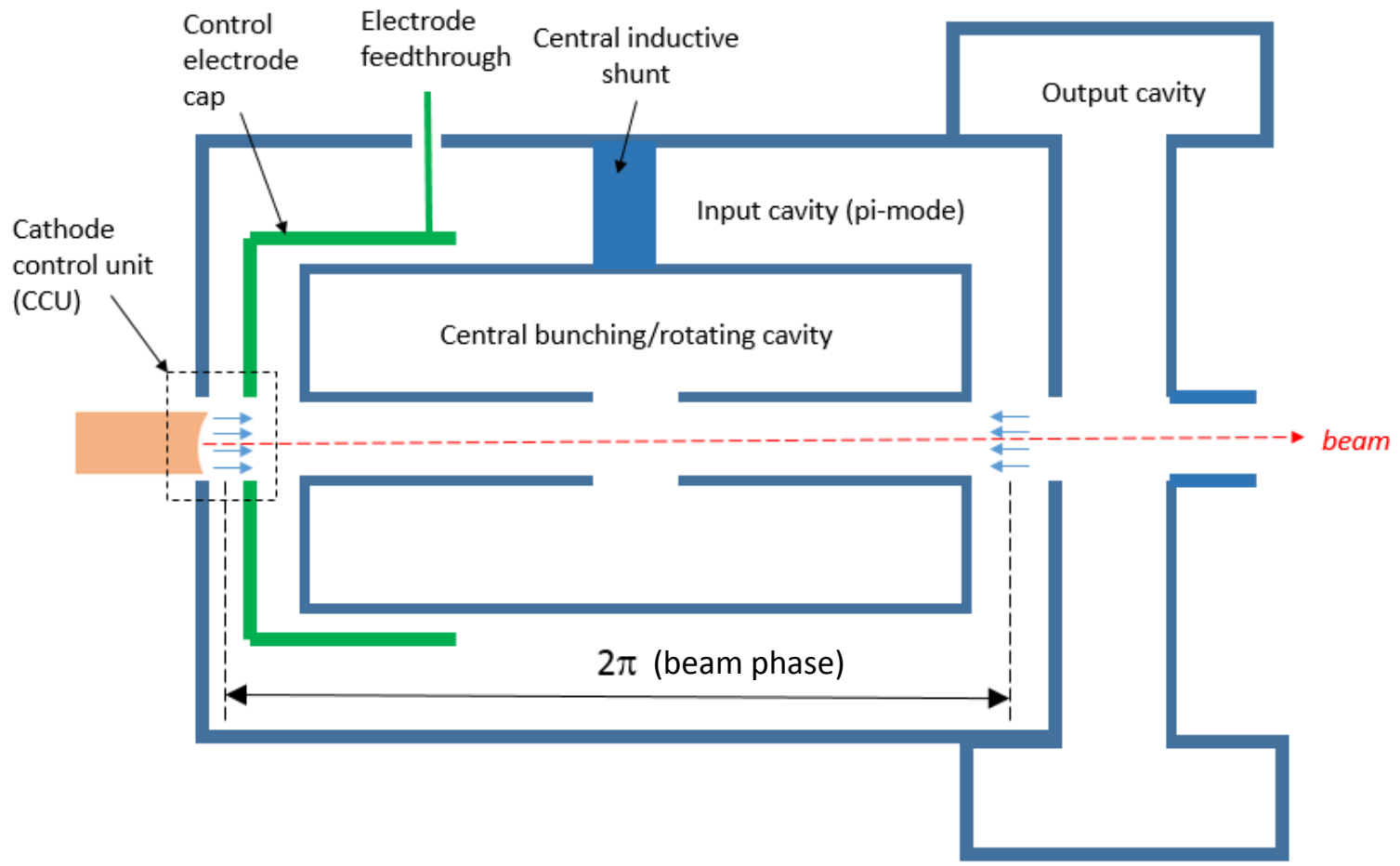
Motivations

- The LHC and FCC baseline frequency is 0.4 GHz. The electron synchrotrons like 0.5 GHz. Proton drivers require RF power sources ranging from 0.2GHz to 0.7 GHz (ESS). In terms of RF power, the RF plant should provide between few MW and few tens MW in continuous wave operation.
- In this frequency range one can chose from the wide list of possible candidates: tetrodes, SSPA, IOT and klystron (?phase locked magnetrons?). Anyone of them has particular advantages, but none can provide simultaneously the high efficiency, high peak power, high power gain, compact size (low cost) and long (>100 000 hours) life time.



Resotrode is a MW class device, which employs beneficial features of the different approaches and the new ideas. It has a potential to obtain in one device all the parameters at a 'high' level. It operates at low voltage (<50 kV) and is very compact. It is best fitted into the frequency range between 0.2 GHz and 0.5 GHz (higher frequencies on demand).

Resotrode concept



- Following the input cavity specific, the beam loading in the first gap can be fully compensated by RF power production in the second gap (power regeneration regime).
- At any moment of time, voltage in the 1st gap is negative and there is no current flow in the control electrode circuit.
- Multi-beam arrangement is a natural choice which allows to reduce high voltage and biased(RF) voltage.
- The central cavity should provide additional bunching and necessary bunch velocity congregation to assure the very high efficiency.

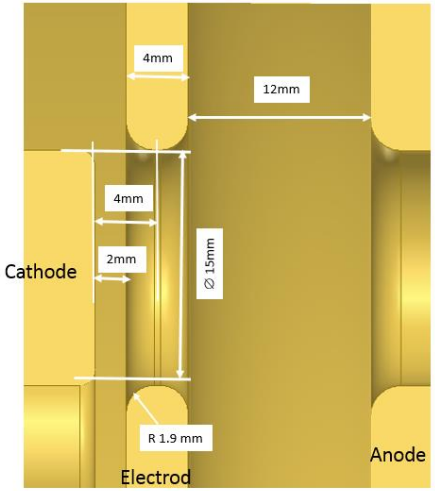
Device under study

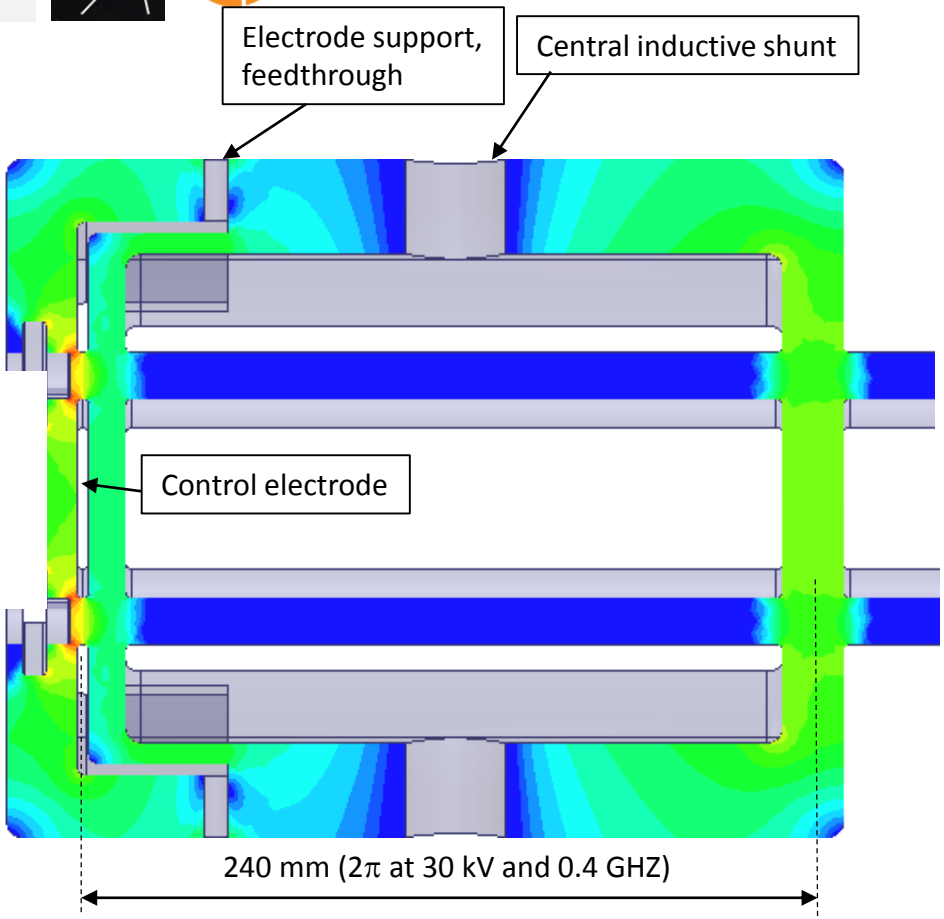
At few hundred MHz, MB Resotrode technology can be used to generate RF power at a multi-megawatt level. As the study case, the device peak RF power was chosen to be compatible with existing LHC klystron: 0.3MW.

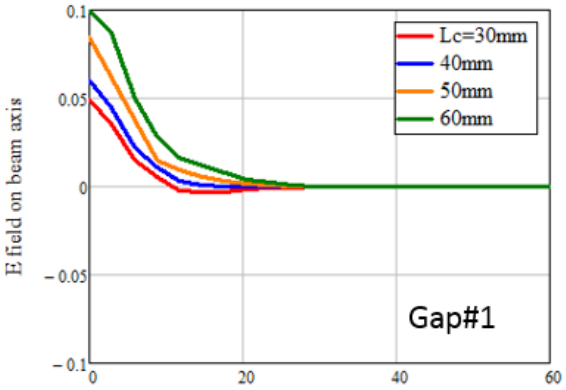
	LHC TH 2167 Klystron	Resotrode
Frequency, GHz	0.4	0.4
RF power (CW), MW	0.3	0.3*
Voltage. kV	54	**30**
Current (total), A	9	11.1
N beams	1	8
Efficiency, %	62	**90**
Power gain, dB	38	>30
Length, m	3.0	<0.5

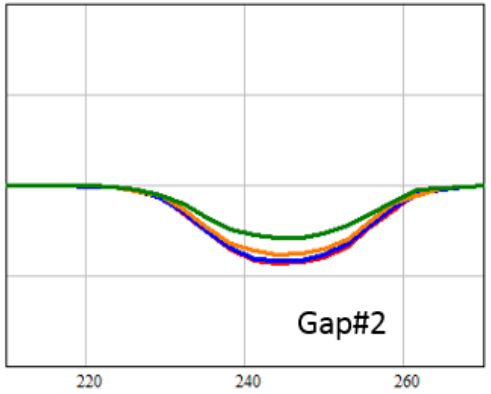
Input MB cavity RF design

'generic' CCU





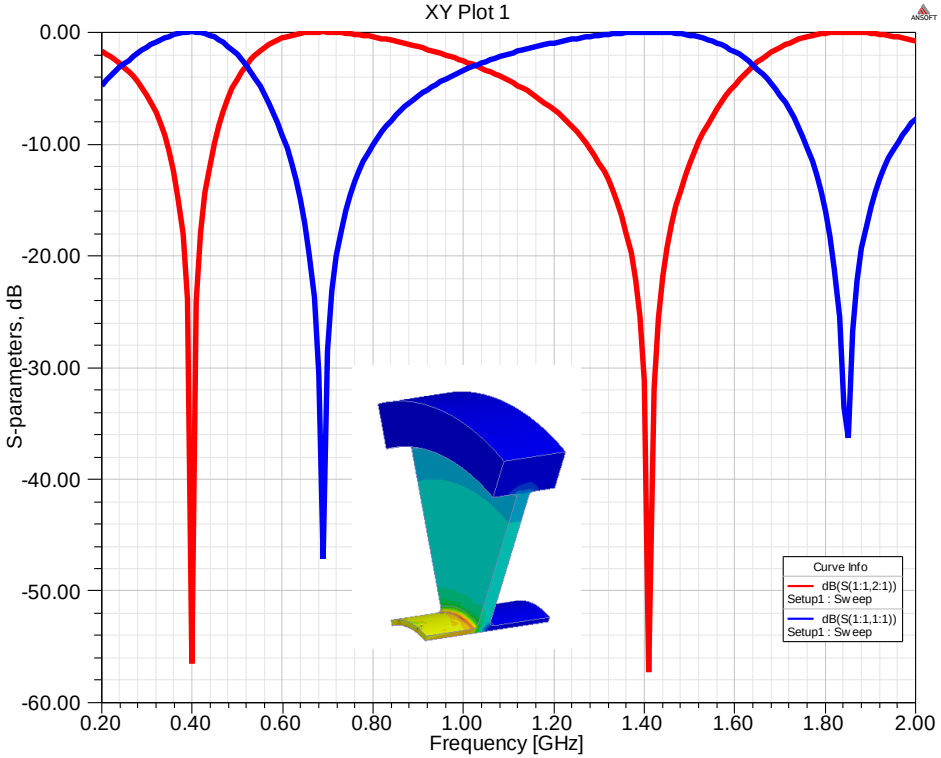




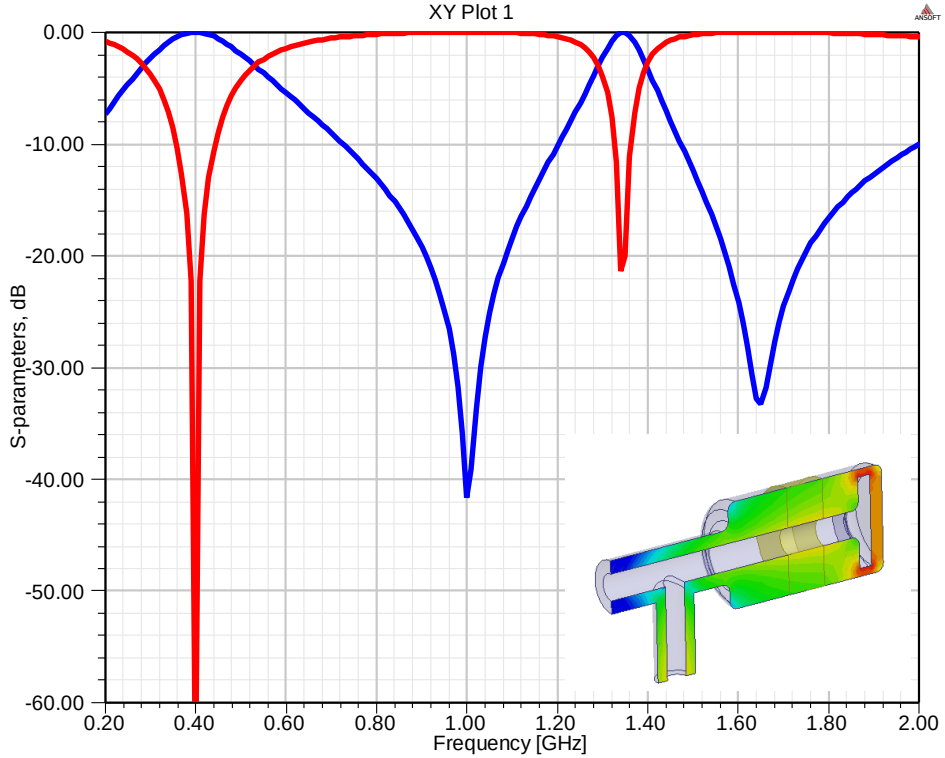
- By adjusting the electrode cap length, the two gaps impedances can be balanced in ether way.
- The cavity frequency is tuned then by changing the central shunts diameter.

Designs of RF filters

Cathode filter (radial choke cavity)



Electrode feedthrough filter (coaxial T-junction)

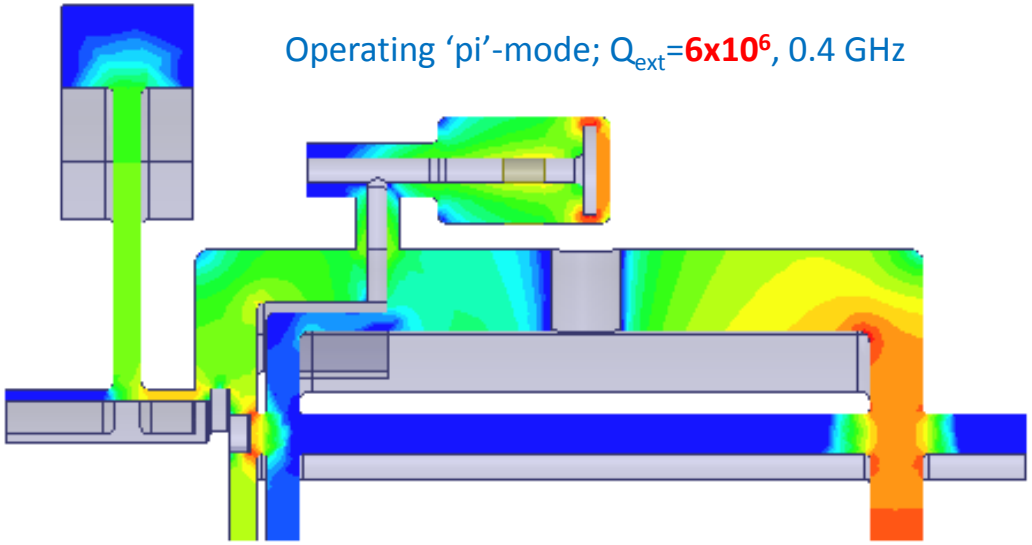


Both designs were optimised to avoid trapping at the harmonics of 0.4 GHz.

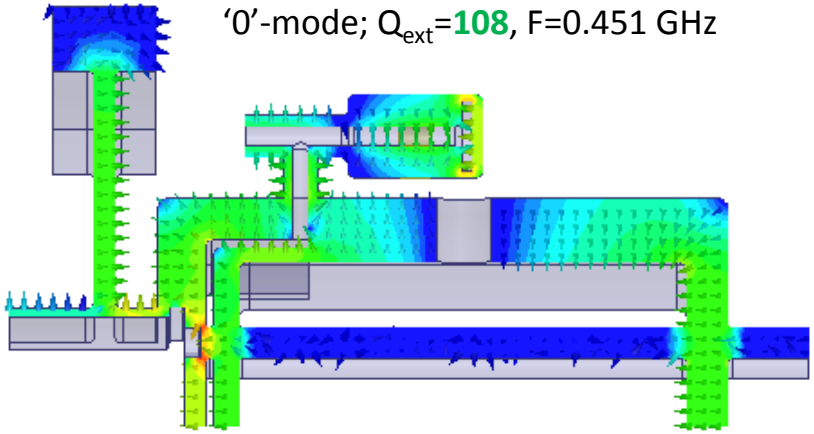
HOM suppression

E-field plots (log scale)

Operating ‘pi’-mode; Q_{ext}=**6x10^6**, 0.4 GHz

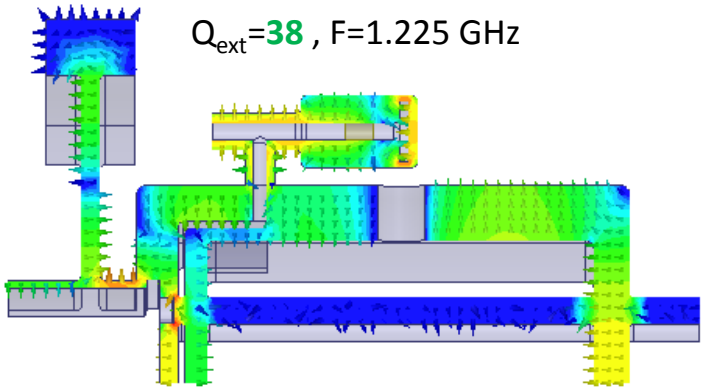


‘0’-mode; Q_{ext}=**108**, F=0.451 GHz

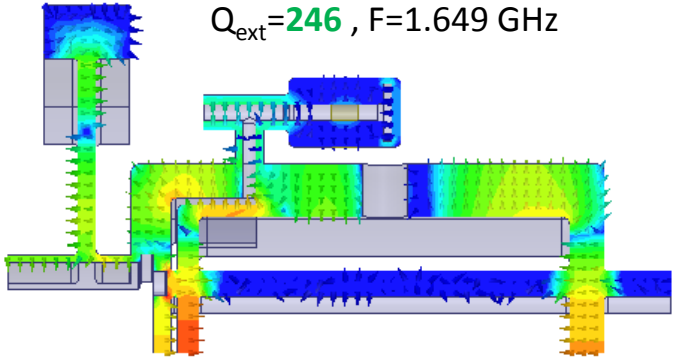


All the “dangerous” HOM are heavily damped.

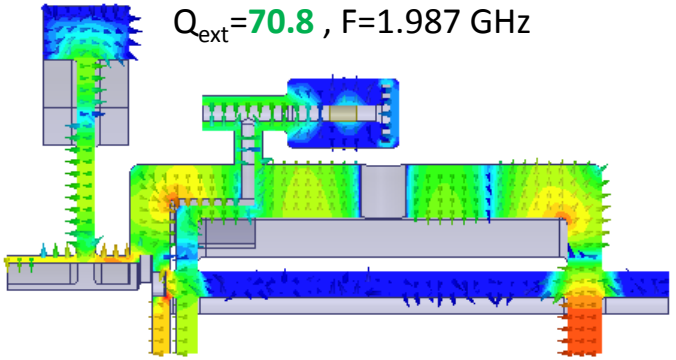
Q_{ext}=**38** , F=1.225 GHz



Q_{ext}=**246** , F=1.649 GHz

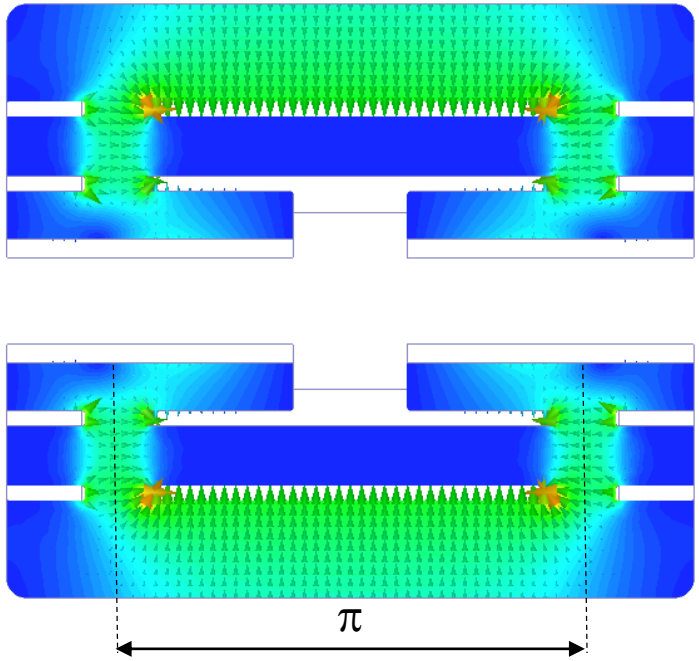


Q_{ext}=**70.8** , F=1.987 GHz

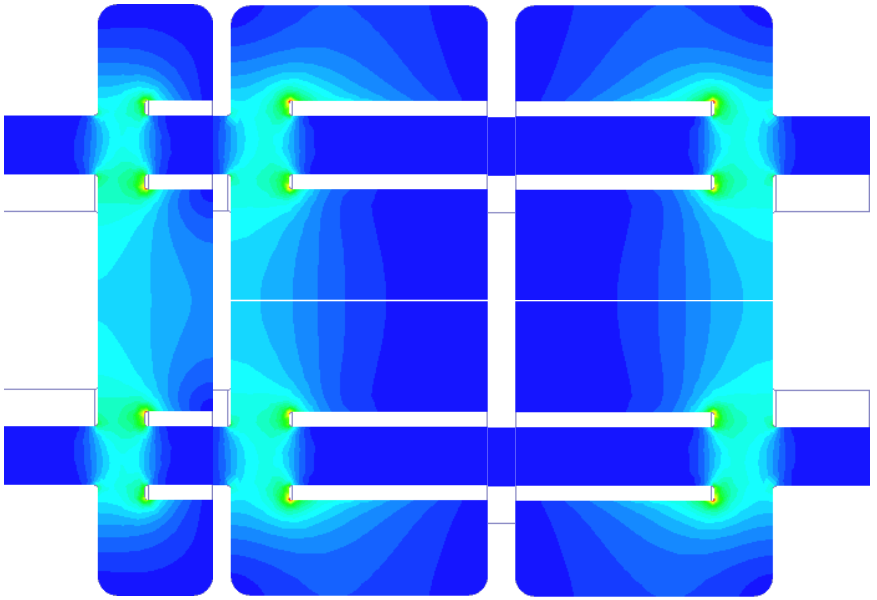


Central (BR) cavity options

1st harmonic doubled gap coaxial cavity

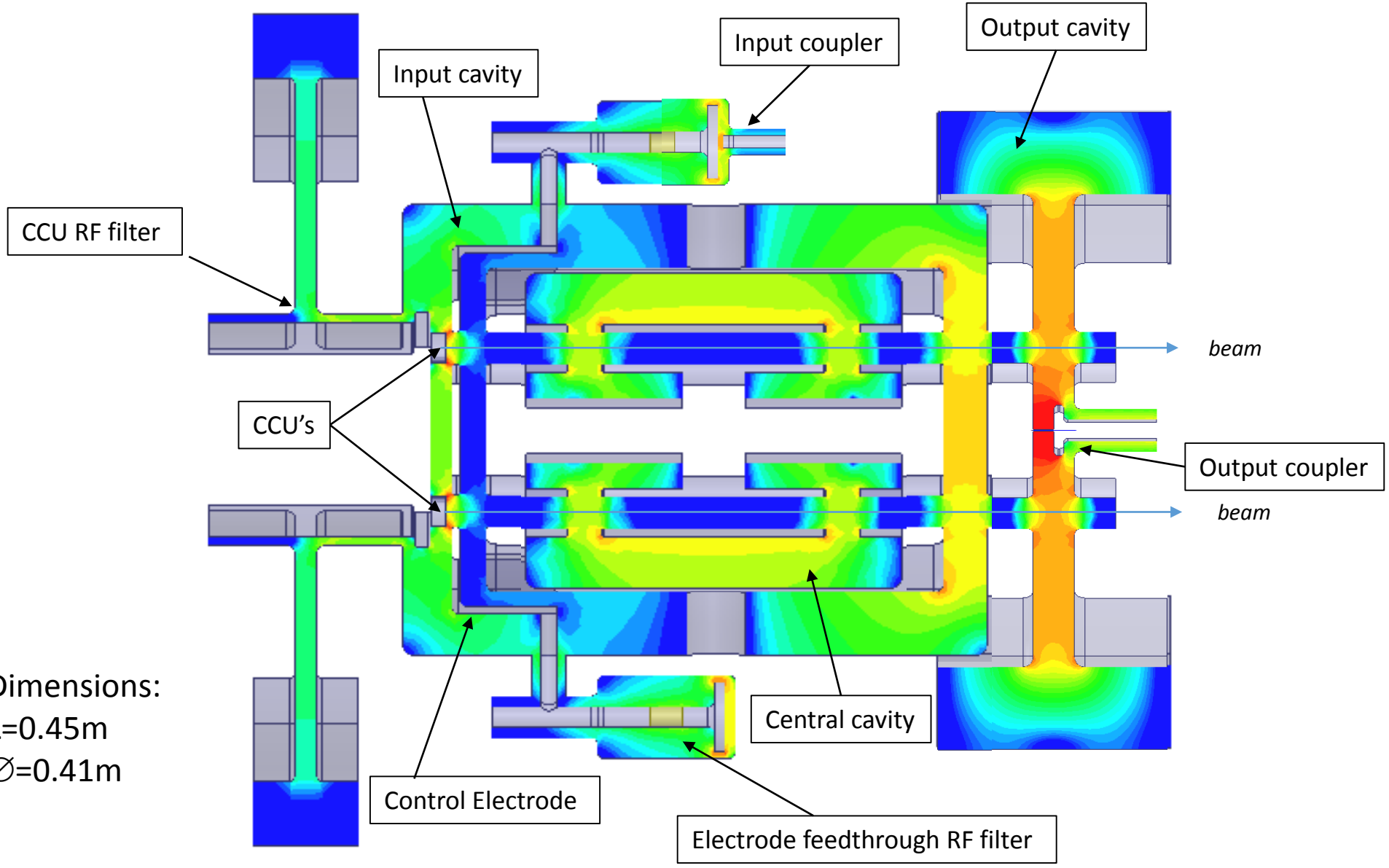


Higher harmonics cavities unit



In general the central cavity should provide additional bunching and necessary bunch velocity congregation to assure the high efficiency.

Modes E-field pattern in the complete Resotrode assembly.



Dimensions:
L=0.45m
∅=0.41m

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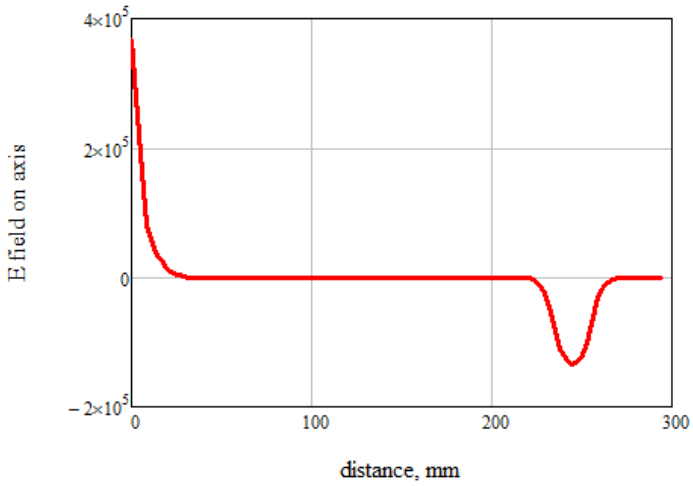
Power gain estimates

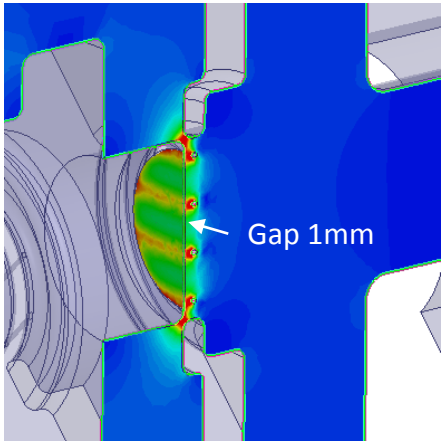


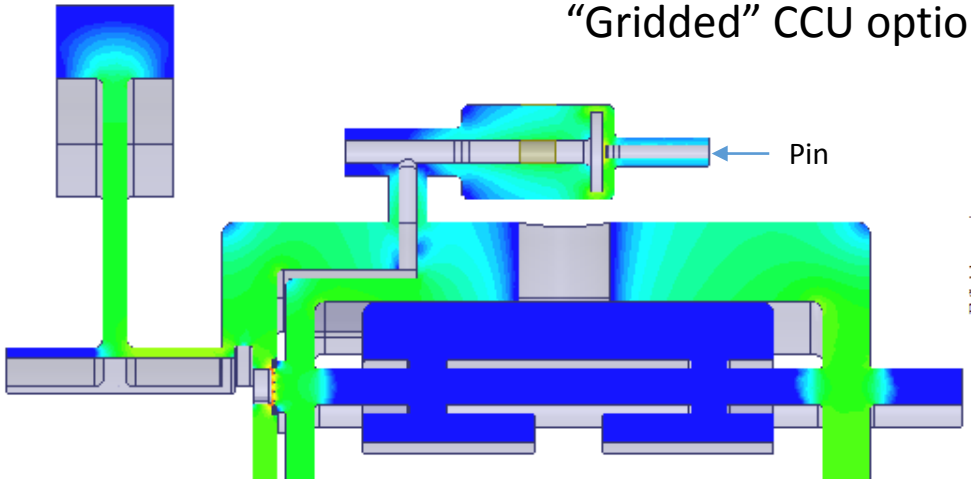
Assumptions:

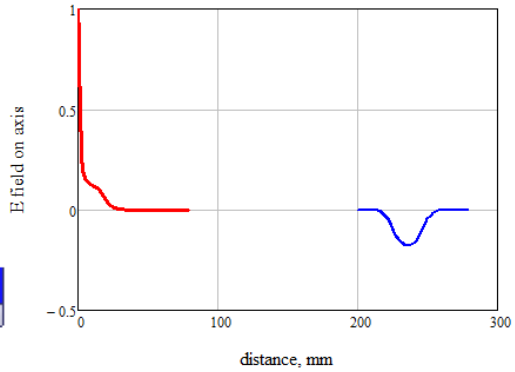
- The two gaps are balanced: the field integral along the beam trajectory is zero. As the first approximation, we may consider, that the net beam loading is zero as well.
- The input cavity is critically coupled: $Q_{ext}=Q_0$.
- The RF field integral along 1st gap is 3 kV - 10% of the cathode voltage.

Under these conditions, the input RF power is 170 W. For the output power of 300 kW, this corresponds to **32.4 dB** RF power gain

"Gridded" CCU option:







Integrated RF voltage across the #1 gap is 750 V (2.5% of the cathode voltage).
The power gain is **51 dB**

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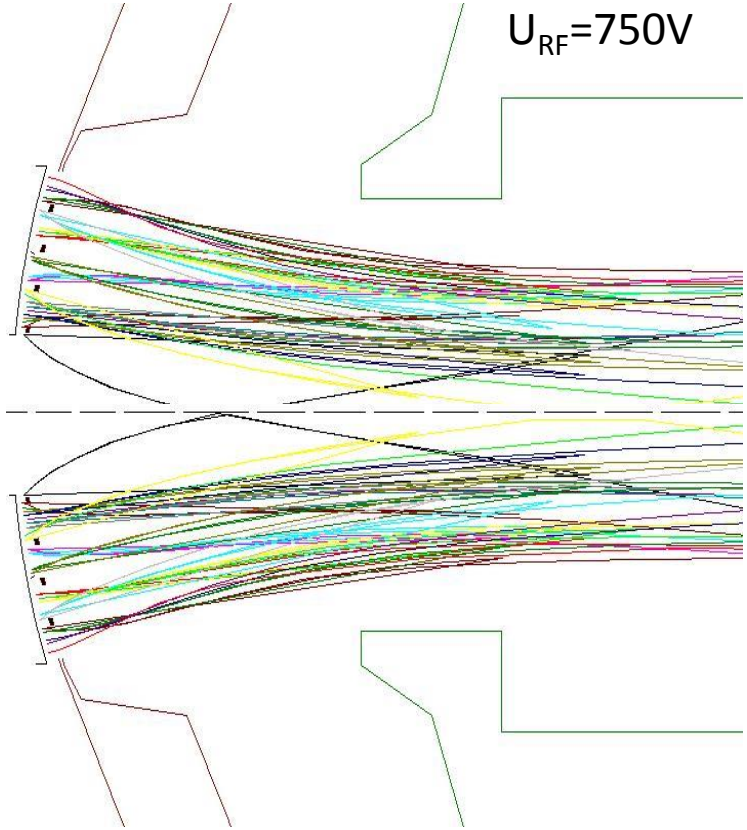
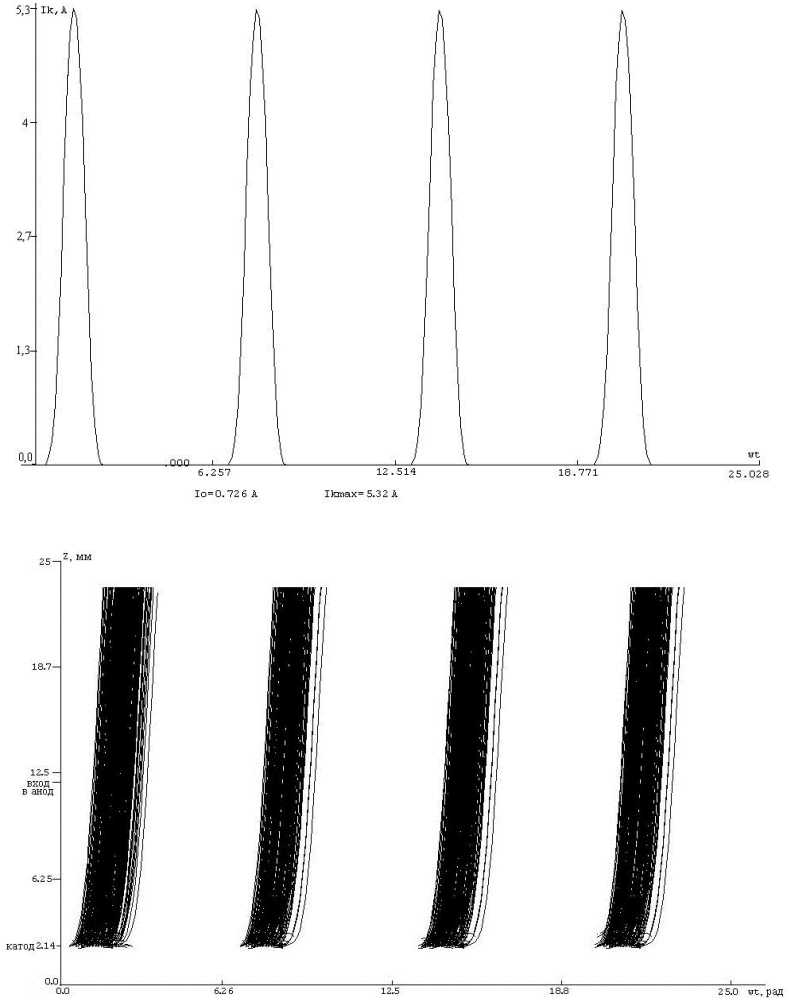
CCU issues.

Simulations by V. Kozlov, Ryazan State Radio Engineering University, Russia

Gridded CCU (gap 0.5 mm)



Bunched beam profile



I. Syratchev

Summary

- The new resonant RF power amplifier with regeneration (Resotrode) has been proposed and evaluated.
- Resotrode is a MW class device, with very high efficiency (~90%) and high RF power gain (30-50 dB). It is best optimised to operate at the frequencies transition region between UHF and L-band.
- Resotrode is compact (about 0.5 m long) device and its length practically does not depend on the operating frequency in the range between 0.2 GHz and 0.4 GHz.
- Resotrode can be considered as an excellent candidate to be used in RF power plants of LHC, FCC, electron synchrotrons, proton linear accelerators and cyclotrons.