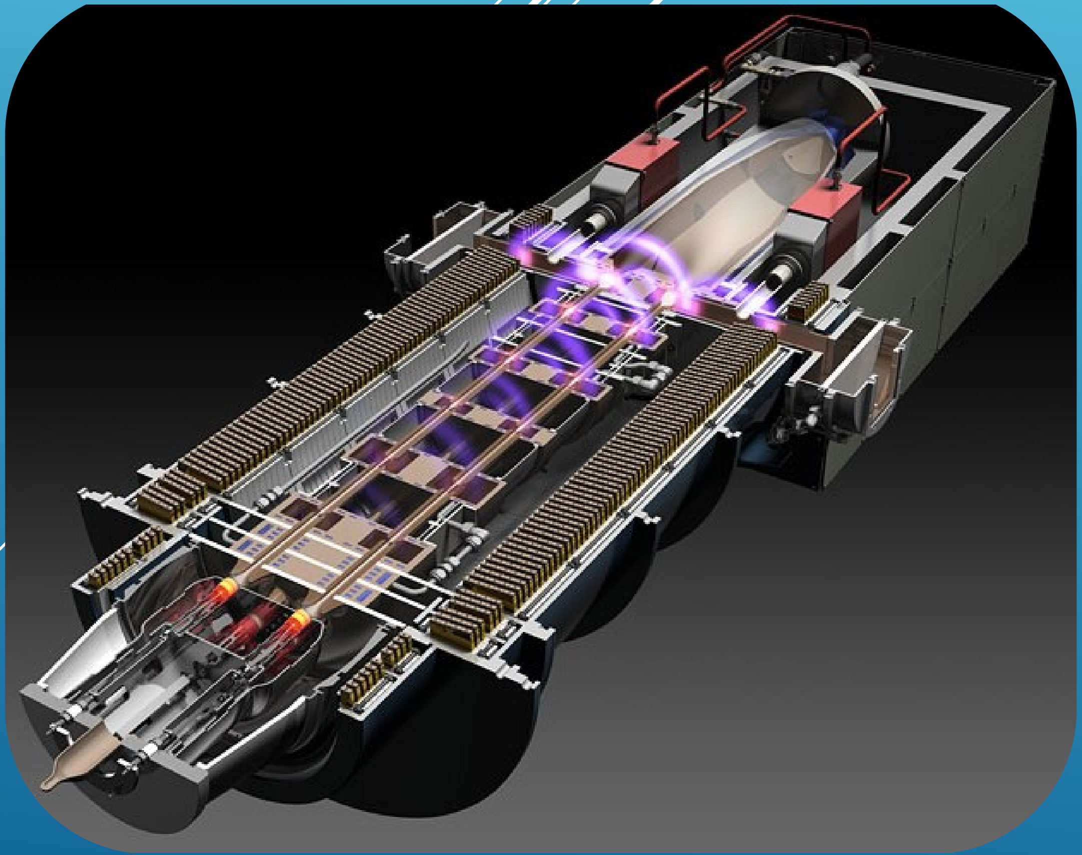
به نام خدا

MULTI-BEAM KLYSTRON

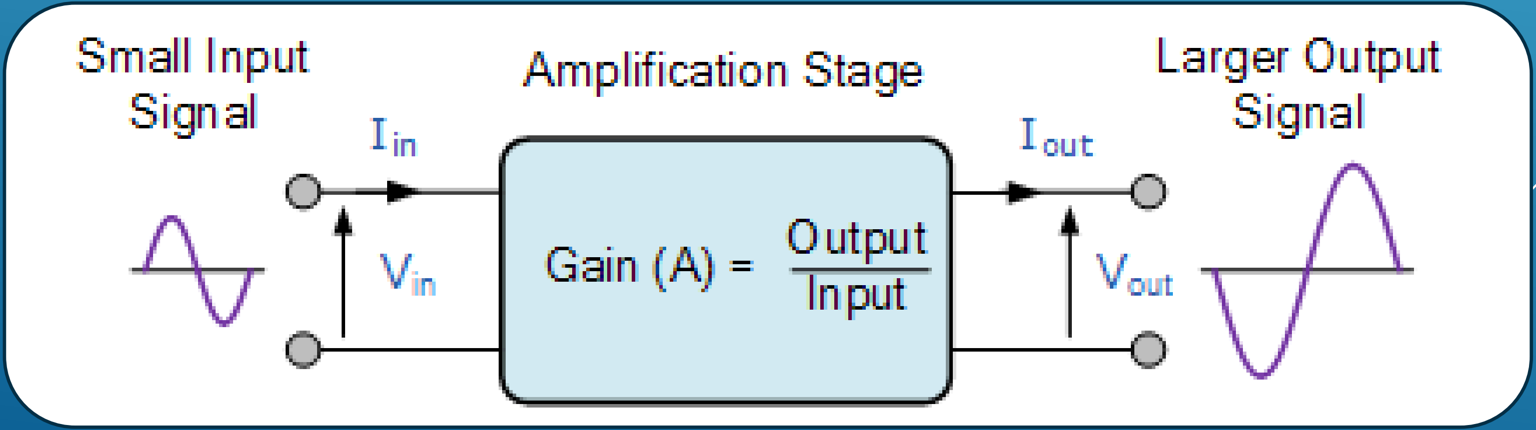


Mohammad Ostovar

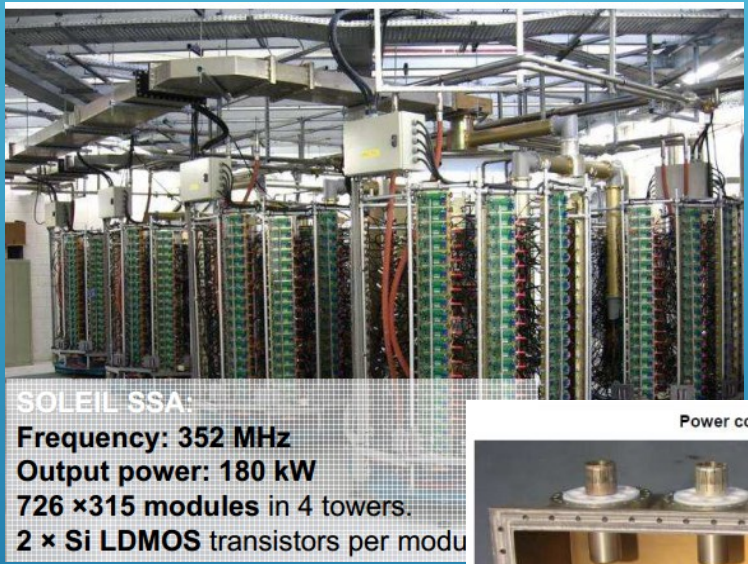
RF group, Iranian Light Source Facility (ILSF)

September 2021

INTRODUCTION (WHAT IS AMPLIFIER?)

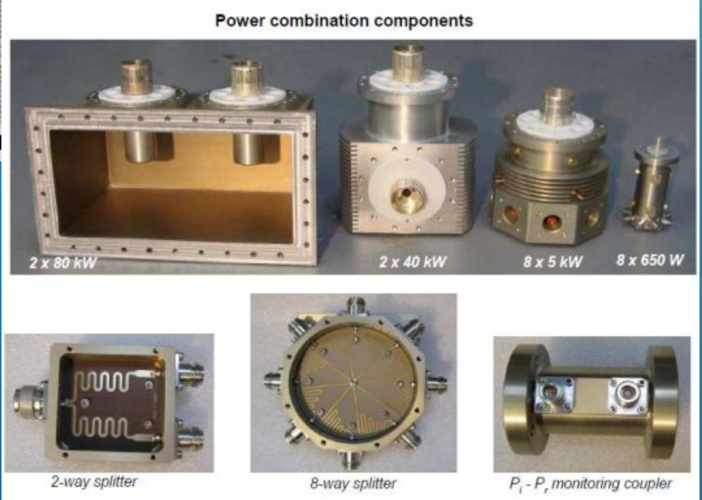


INTRODUCTION (CLASSIFICATION OF AMPLIFIERS)



Solid-state amplifier

Vacuum tube



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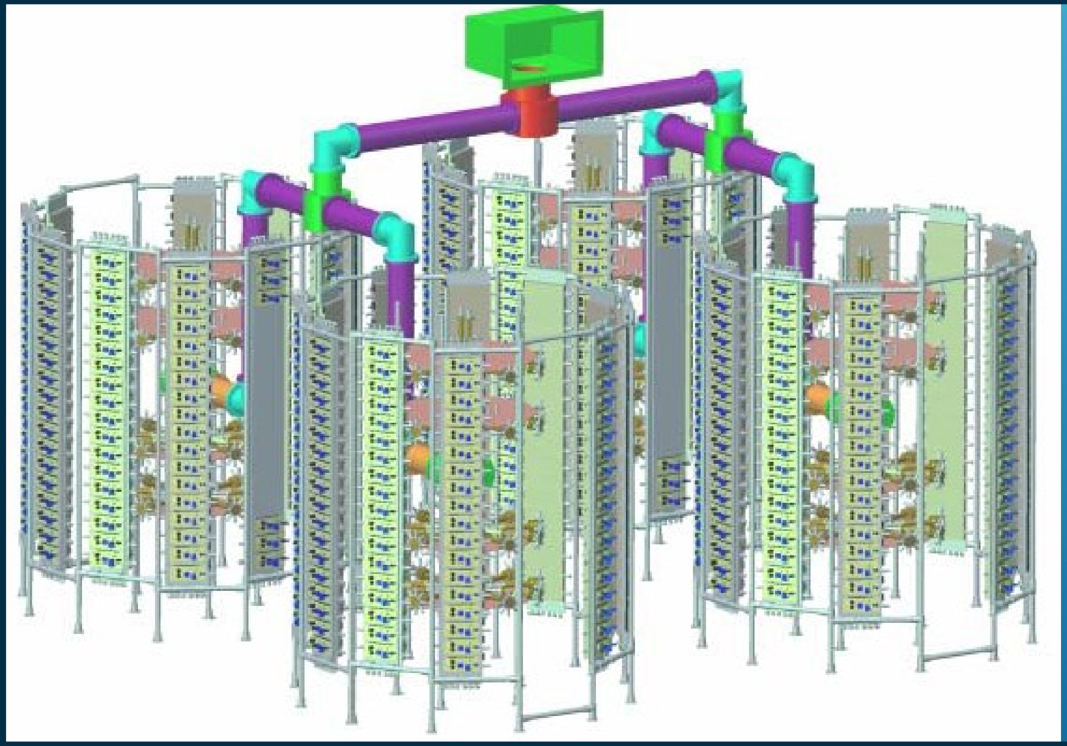
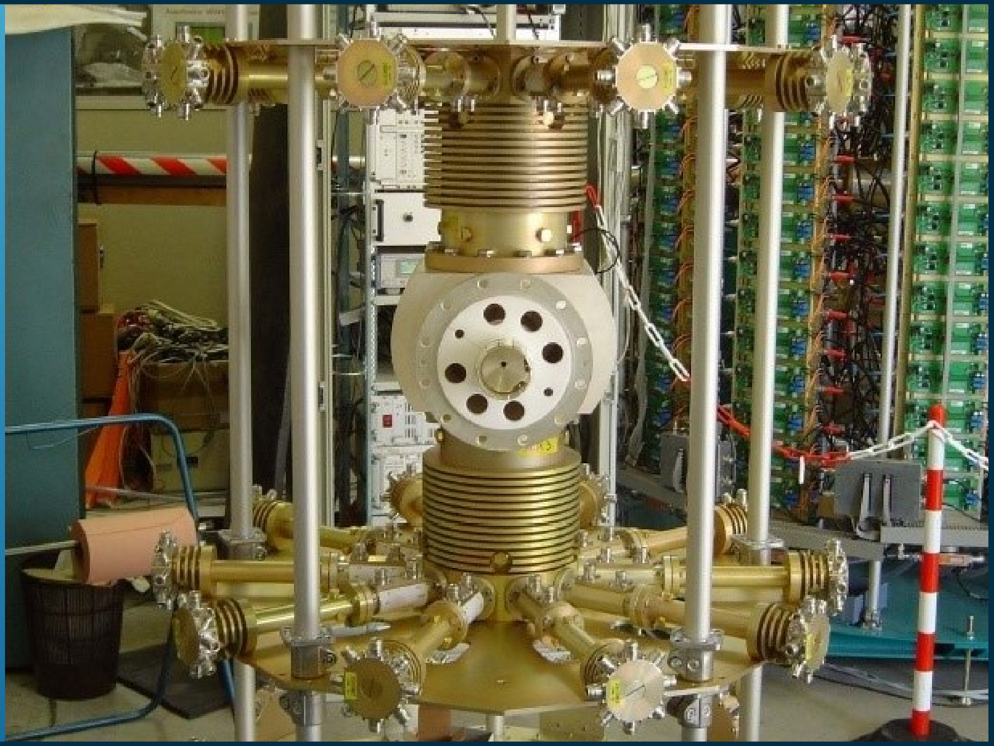
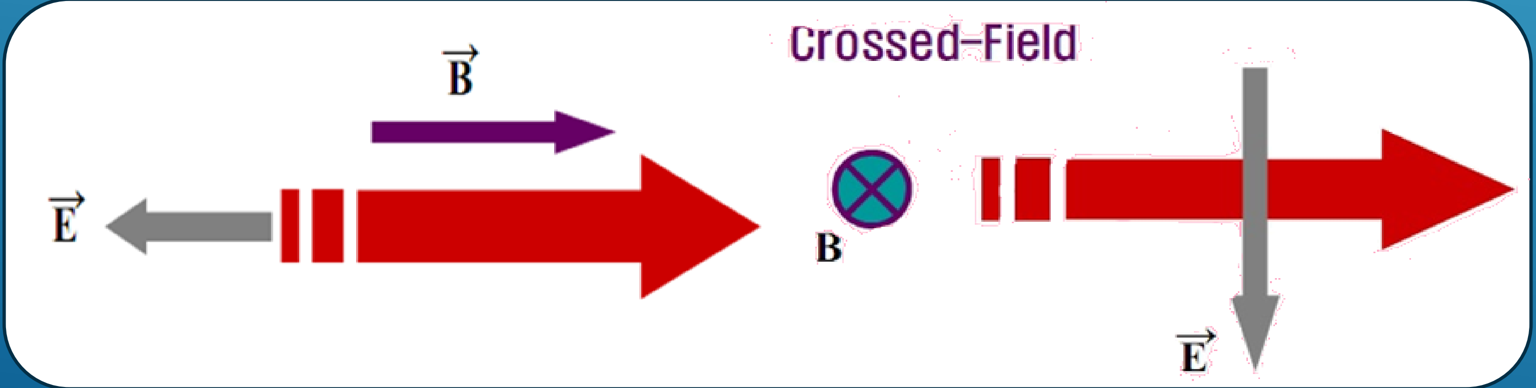




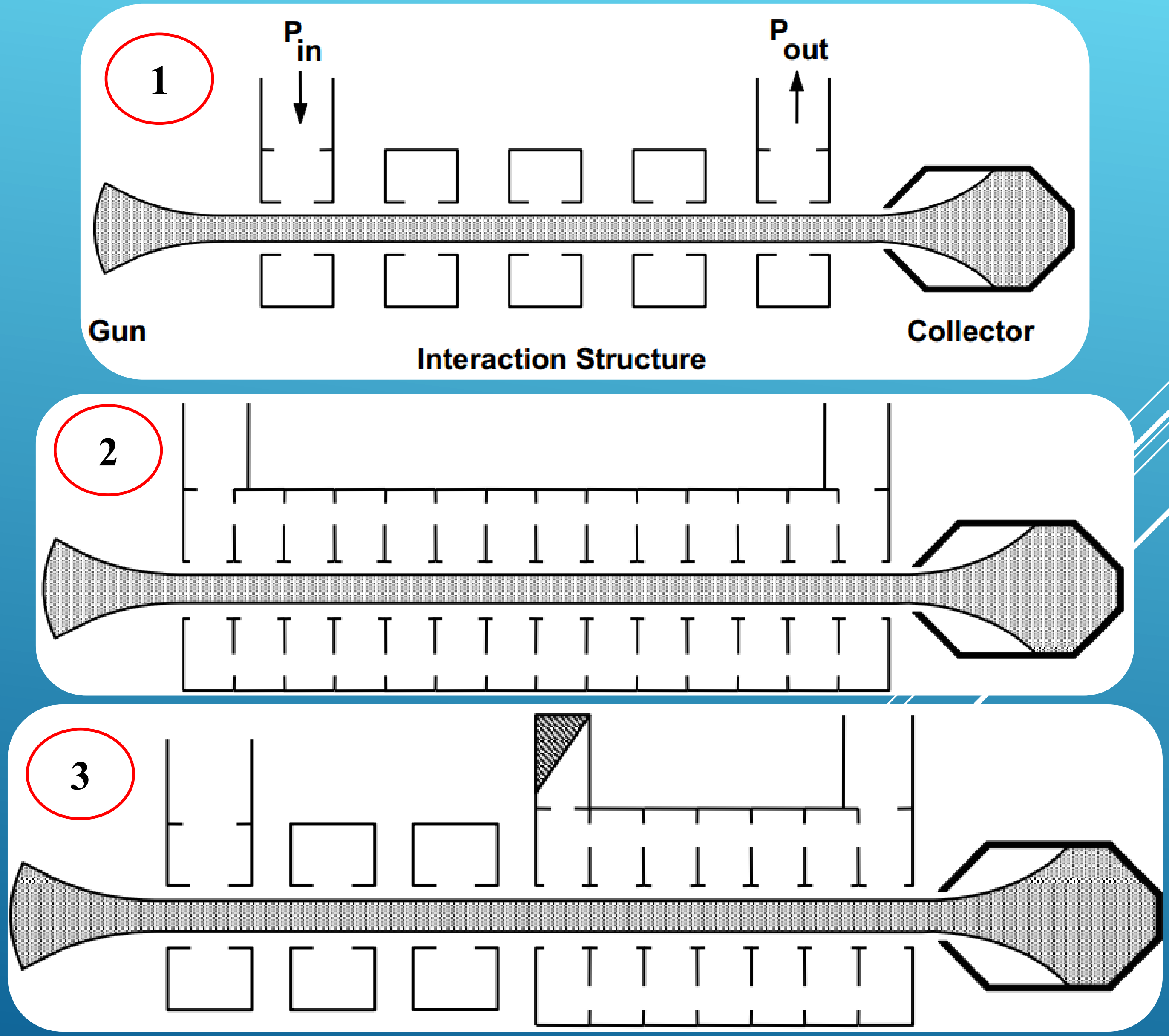
INTRODUCTION (MICROWAVE VACUUM TUBE)

	O-type (ordinary type) device	M-type (magnetic type) devices	Gyrotrons
Travelling wave devices	TWT (Travelling wave tubes)	TWT-M (Travelling wave tubes - magnetic), Amplitrons	Gyro-TWT
Resonant devices	Klystrons, IOT (Inductive output tubes)	Magnetrons	Gyroklystrons



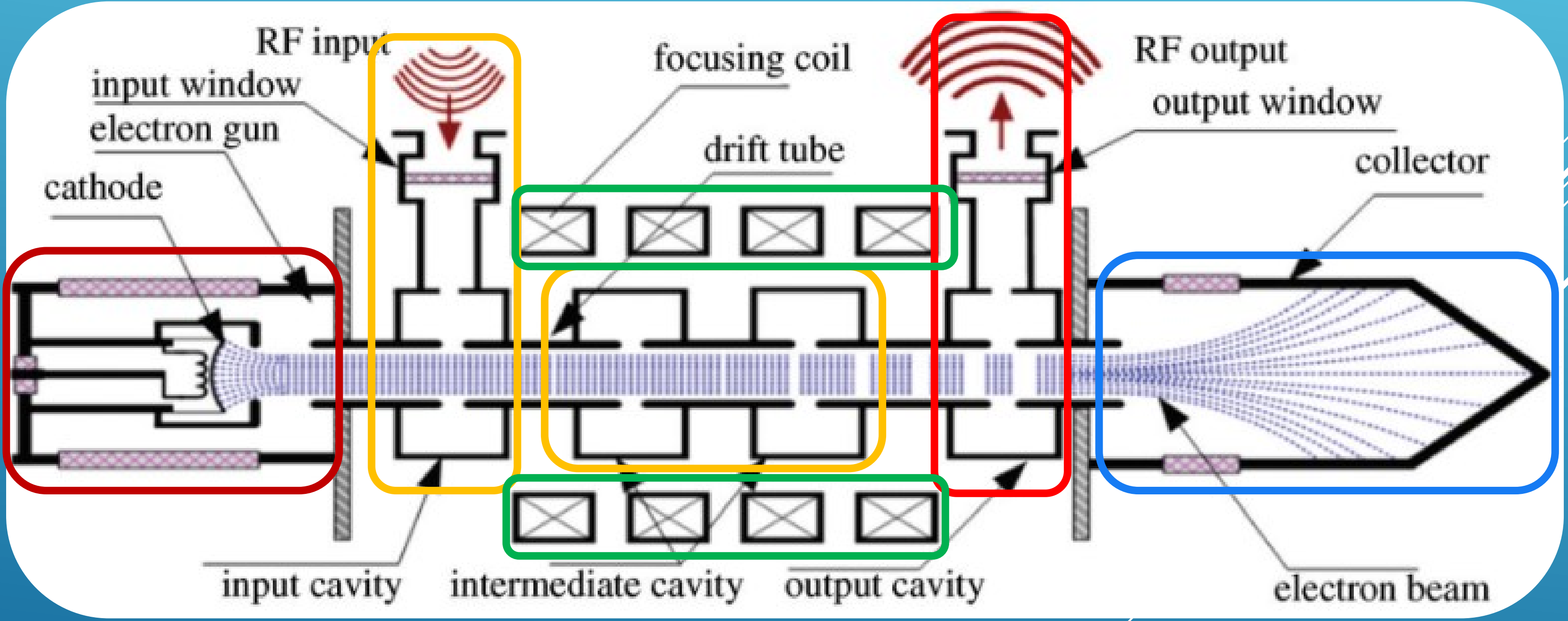
INTRODUCTION (MICROWAVE VACUUM TUBE)

- **<u>Linear beam tubes:</u>**
  1) Klystrons
     1) High power
     2) Narrow band
  2) TWTs
     1) Low and medium power
     2) Wide band
  3) Hybrid tubes (Twystrons)



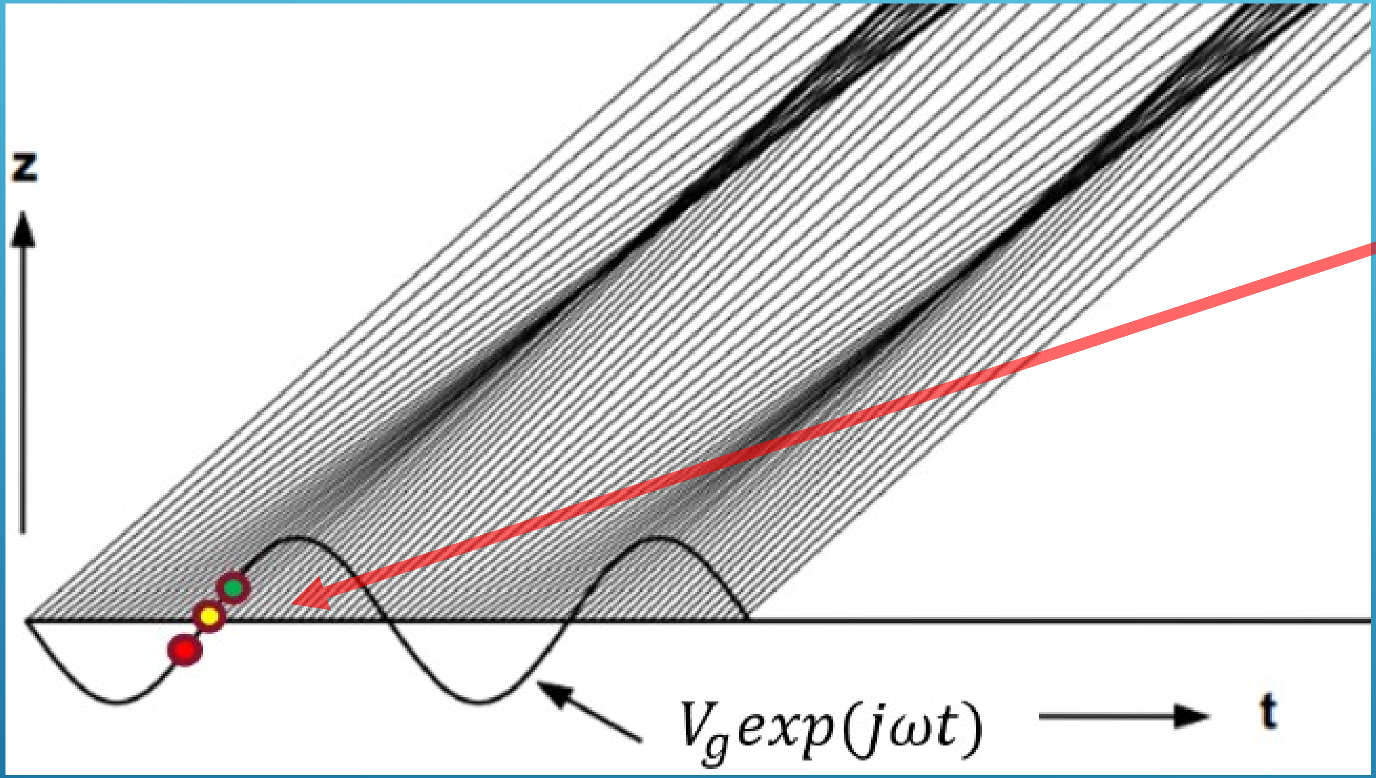
INTRODUCTION (KLYSTRON)

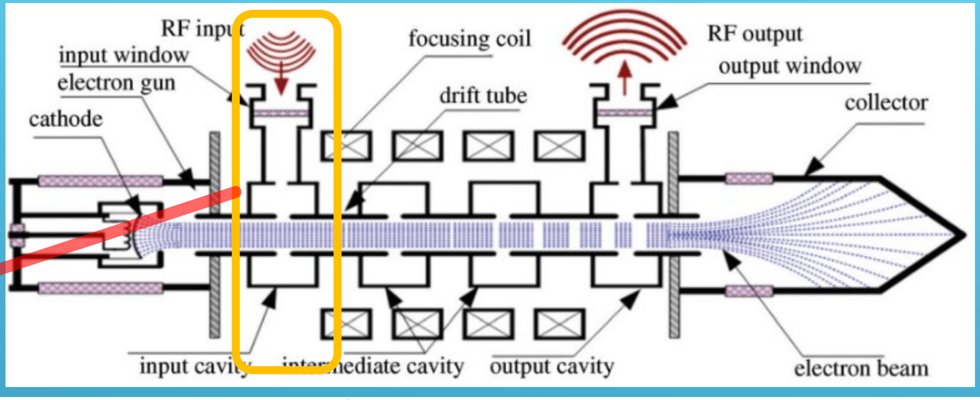
- **Components of Klystron:**
  1) Electron gun
  2) Input cavity
  3) Intermediate cavities
  4) Focusing magnets
  5) Output cavity
  6) Collector
  7) Windows

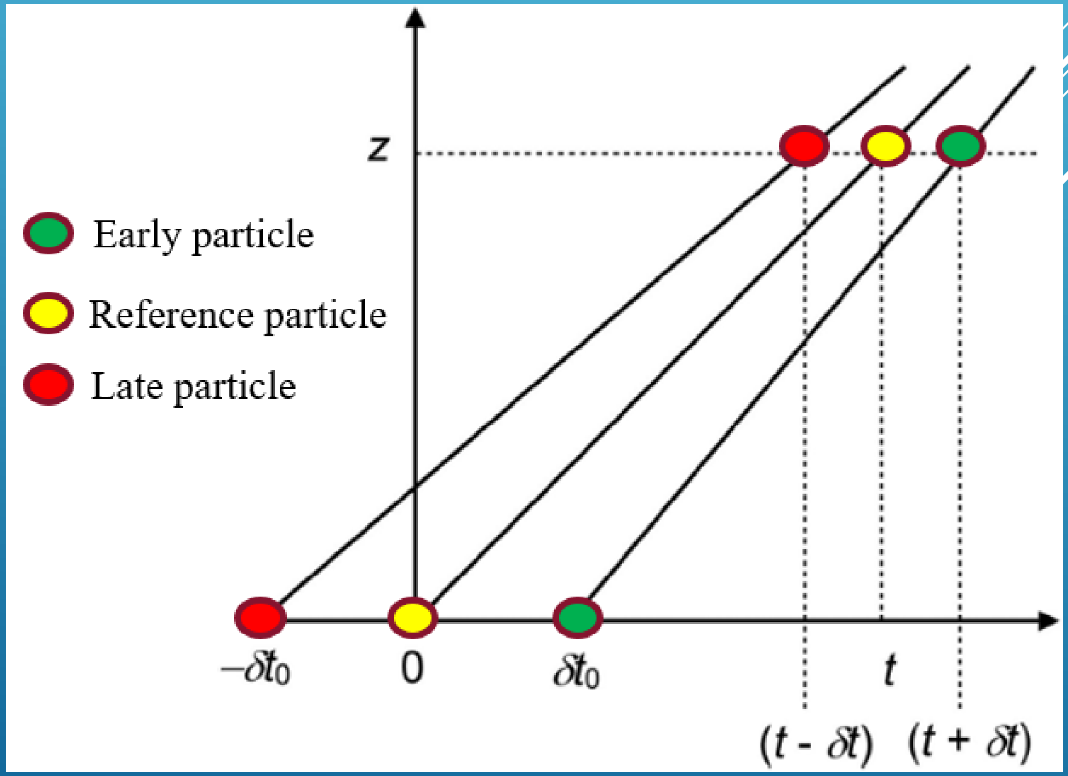


KLYSTRON

- **<u>How dose klystron work?</u>**







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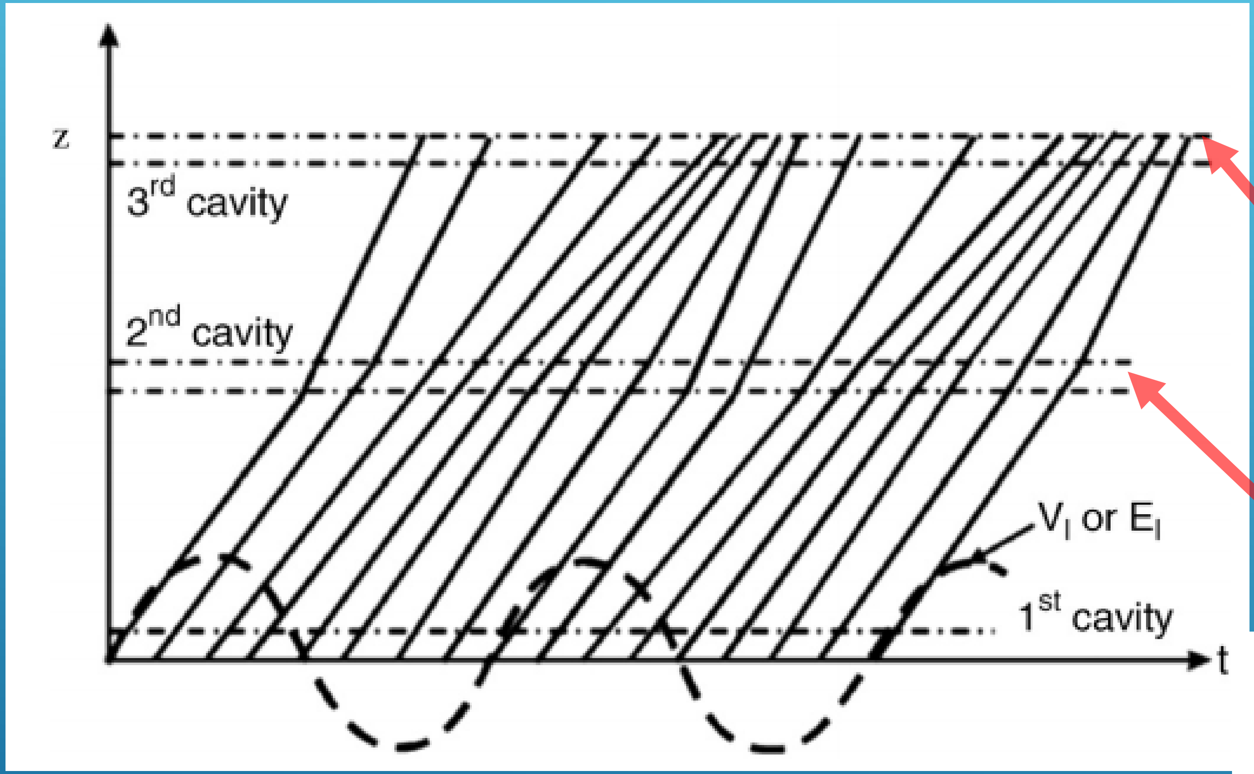

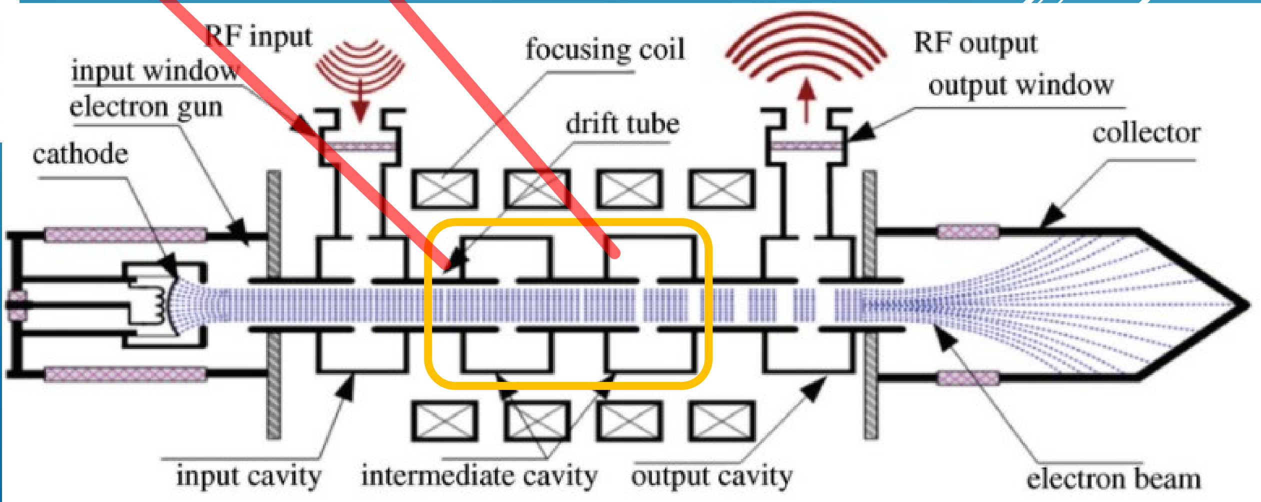

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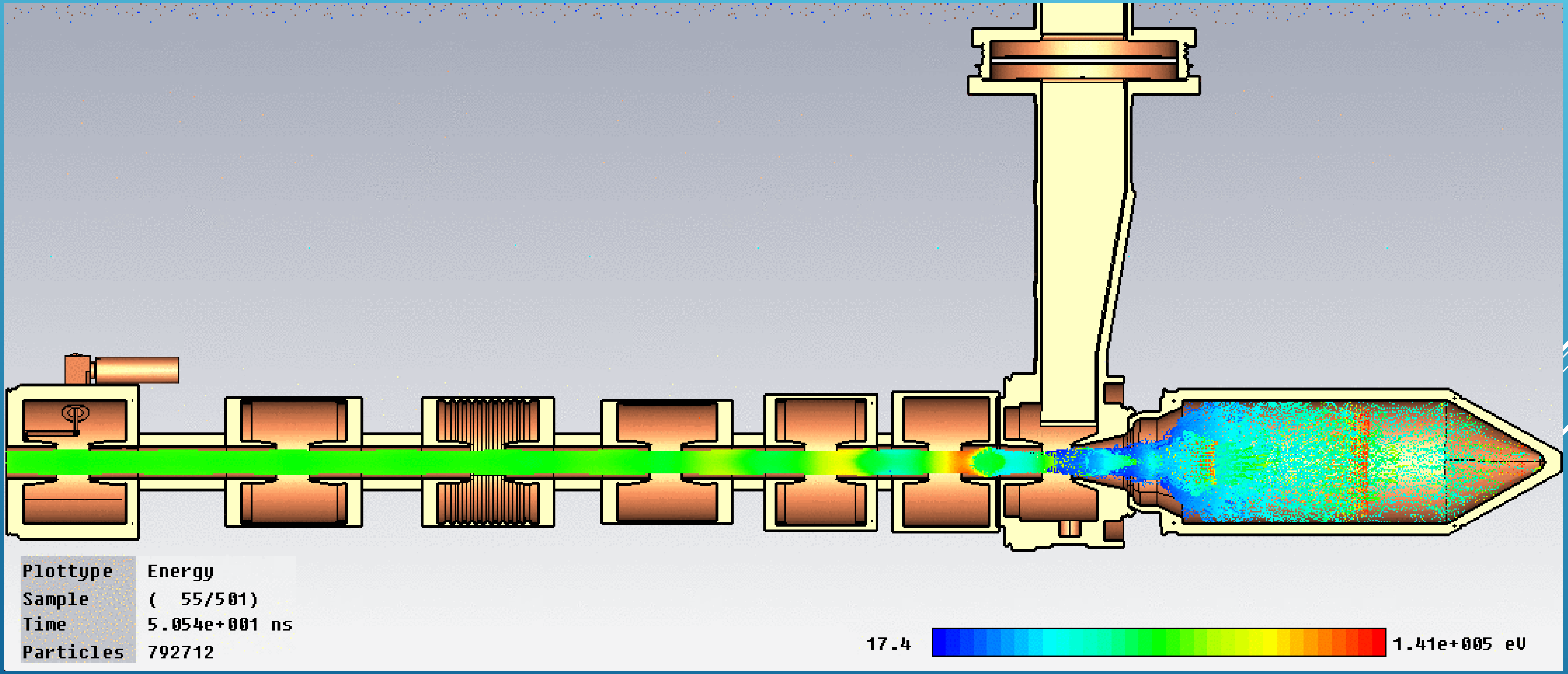

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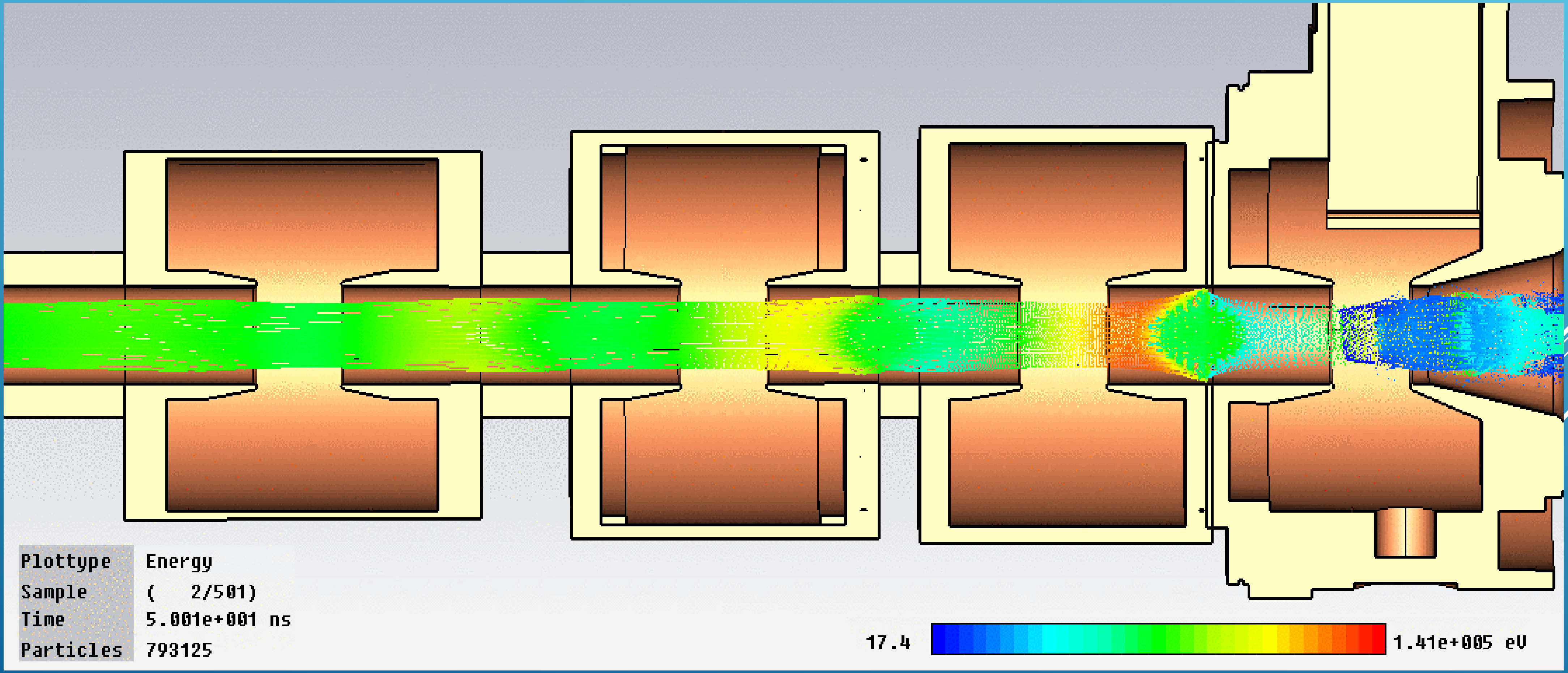

KLYSTRON

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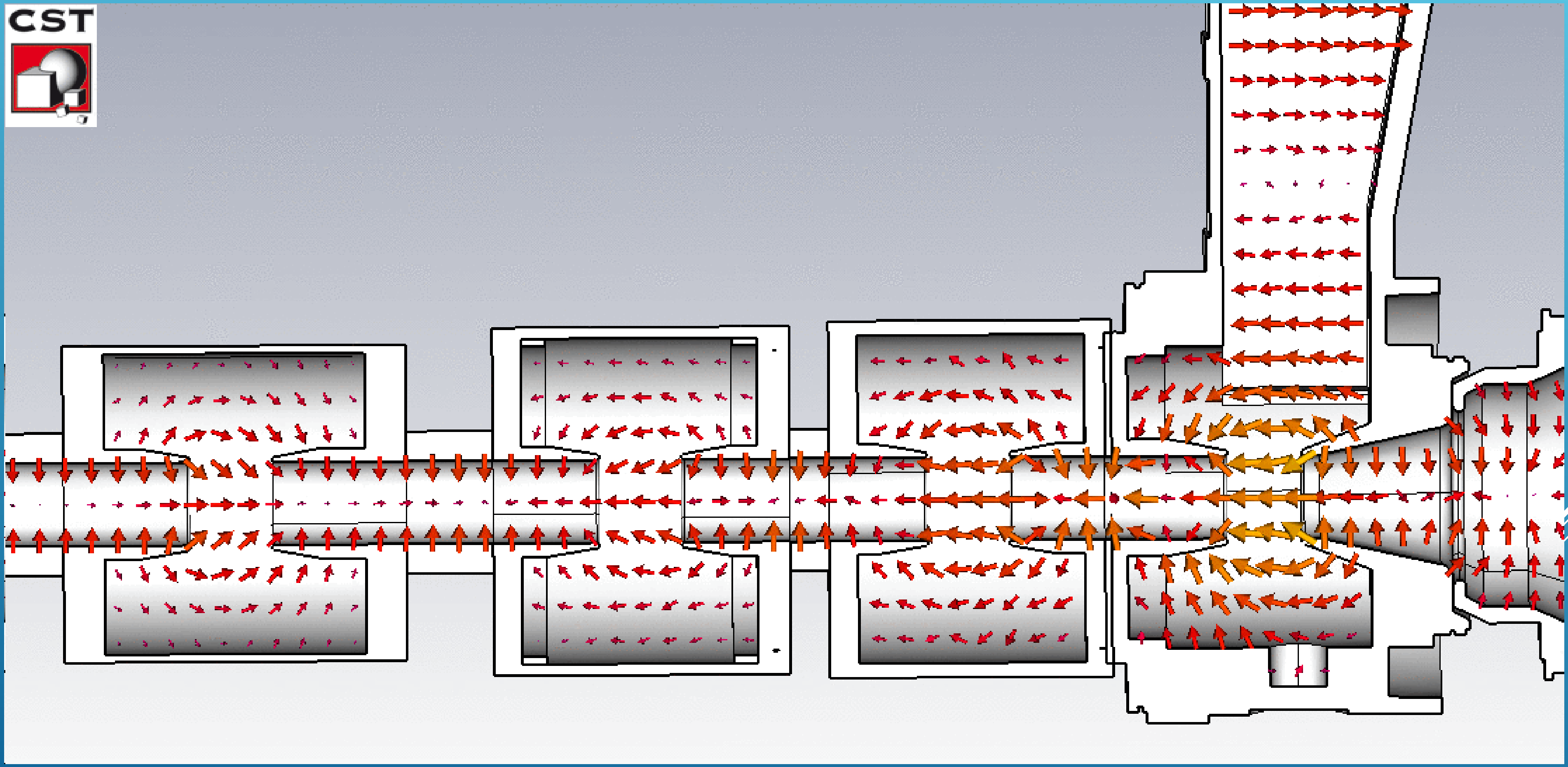
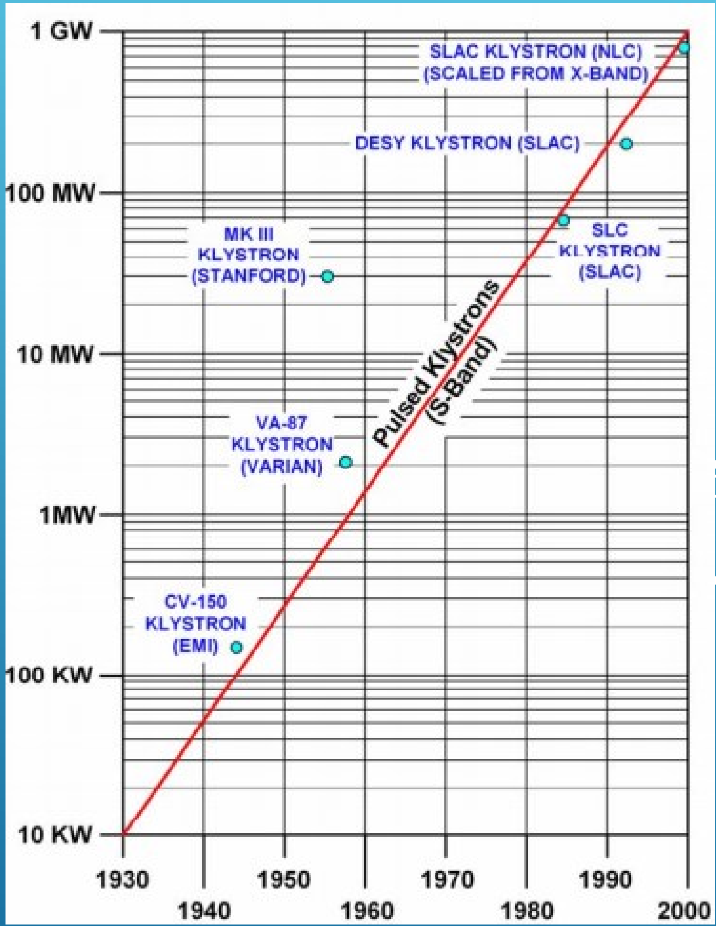
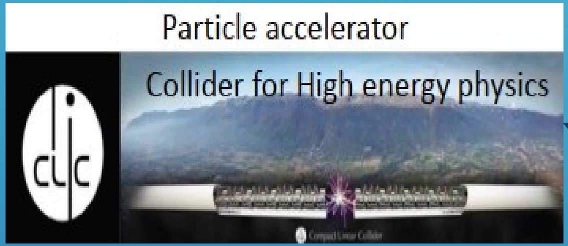


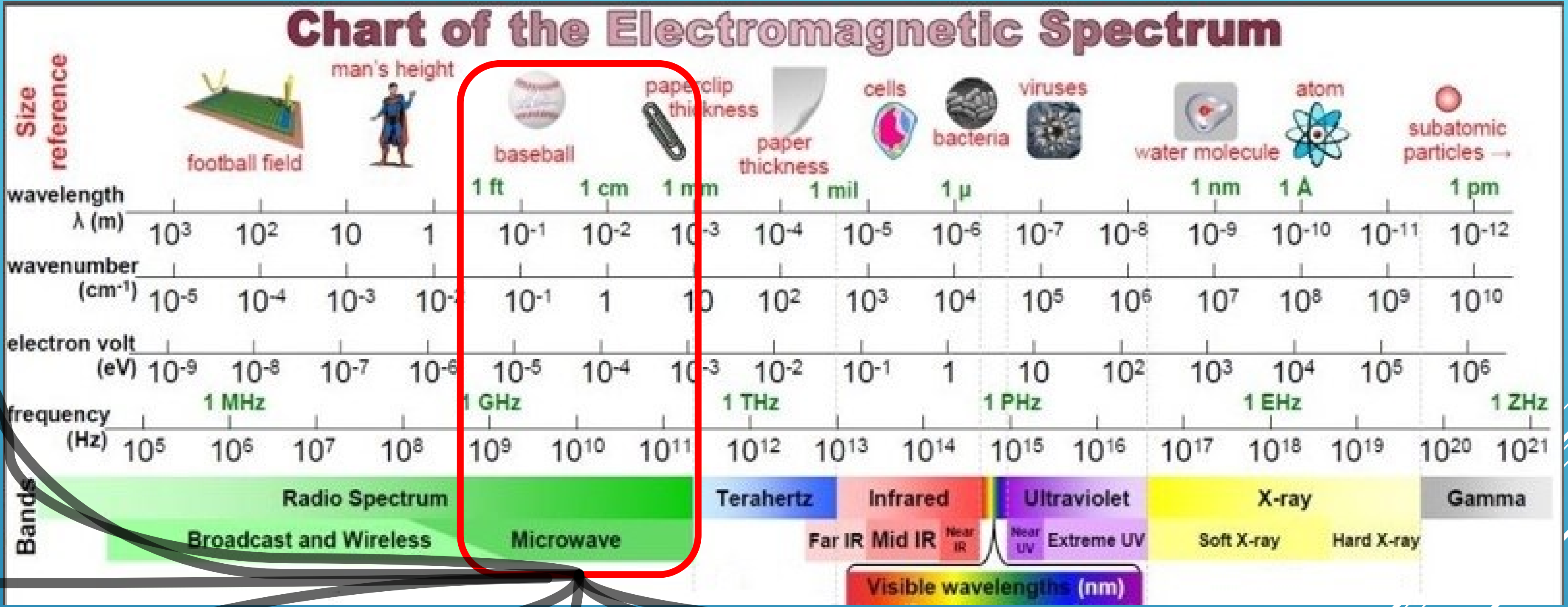
KLYSTRON

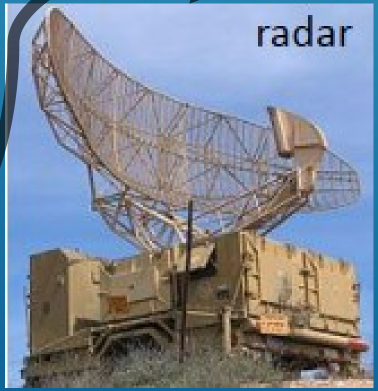
- **History of Klystron:**

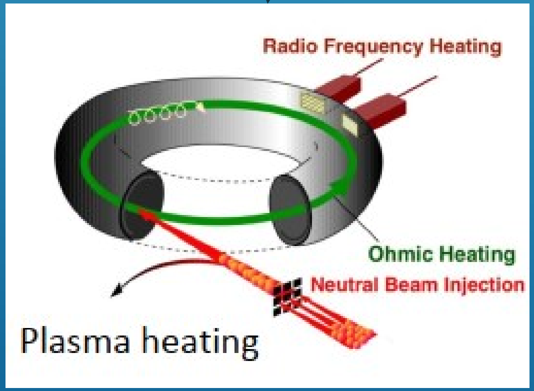


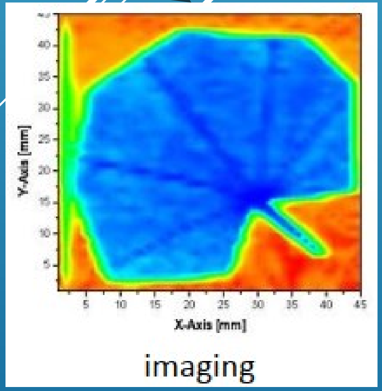
KLYSTRON (AREAS OF KLYSTRON’S APPLICATION)





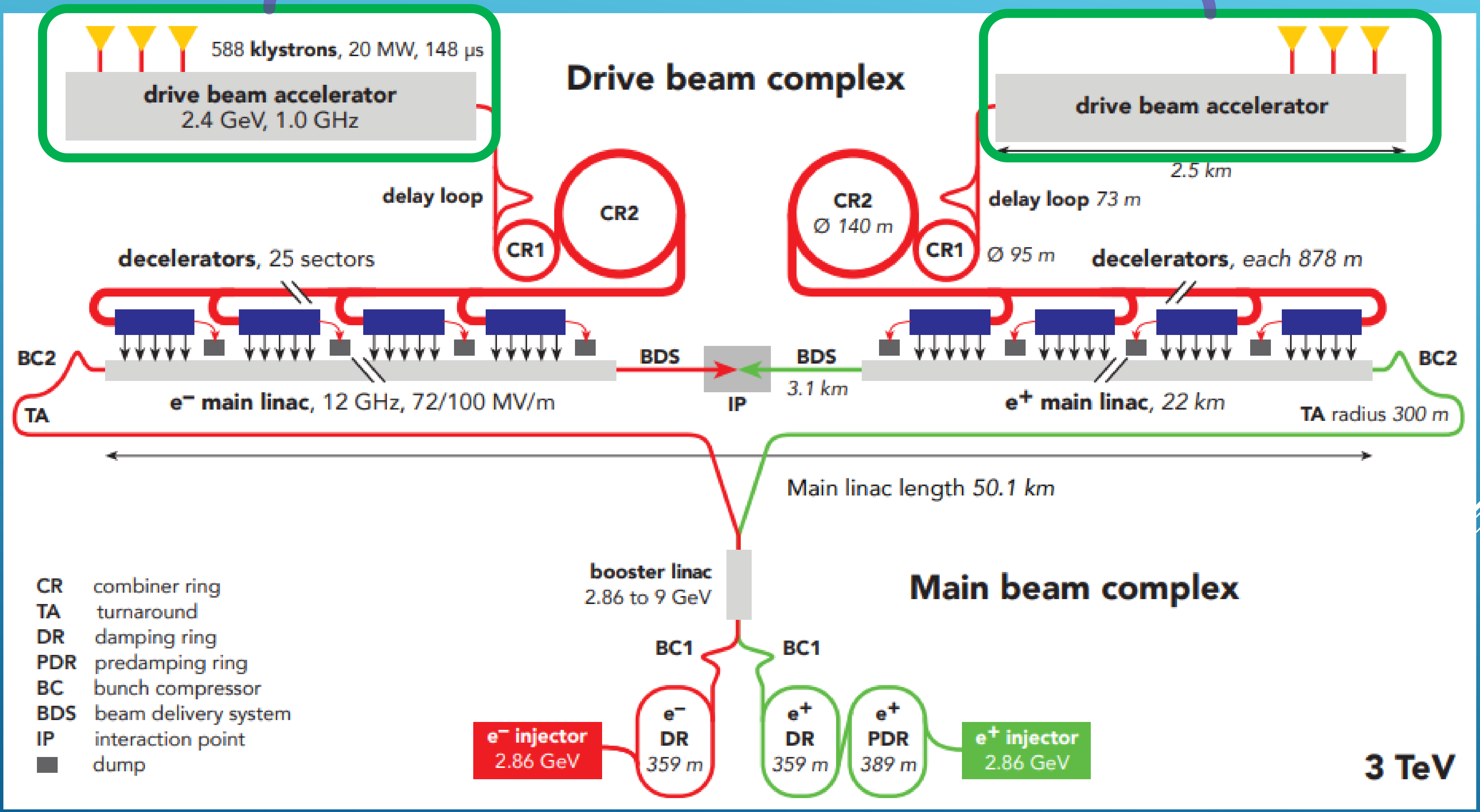






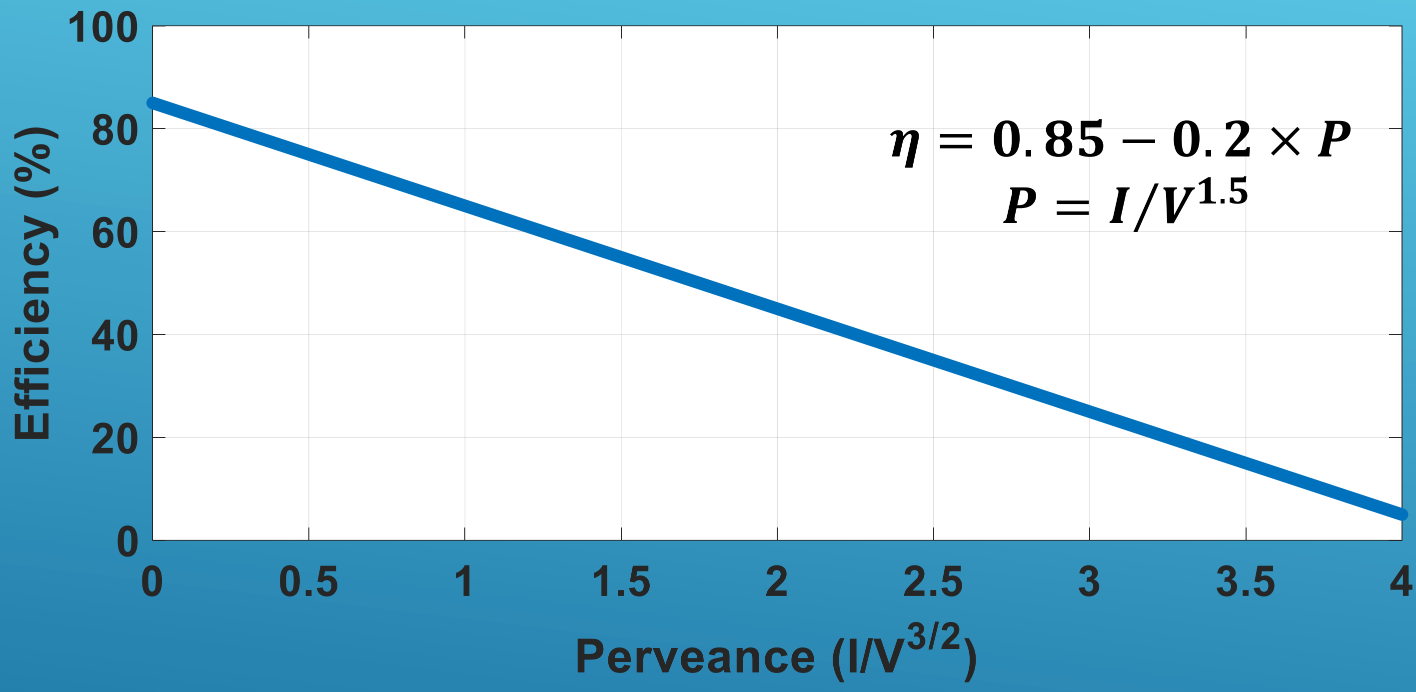
KLYSTRON (AREAS OF KLYSTRON'S APPLICATION)

Klystrons required: 1176



MULTI-BEAM KLYSTRON

- **High power and efficiency Klystron:**

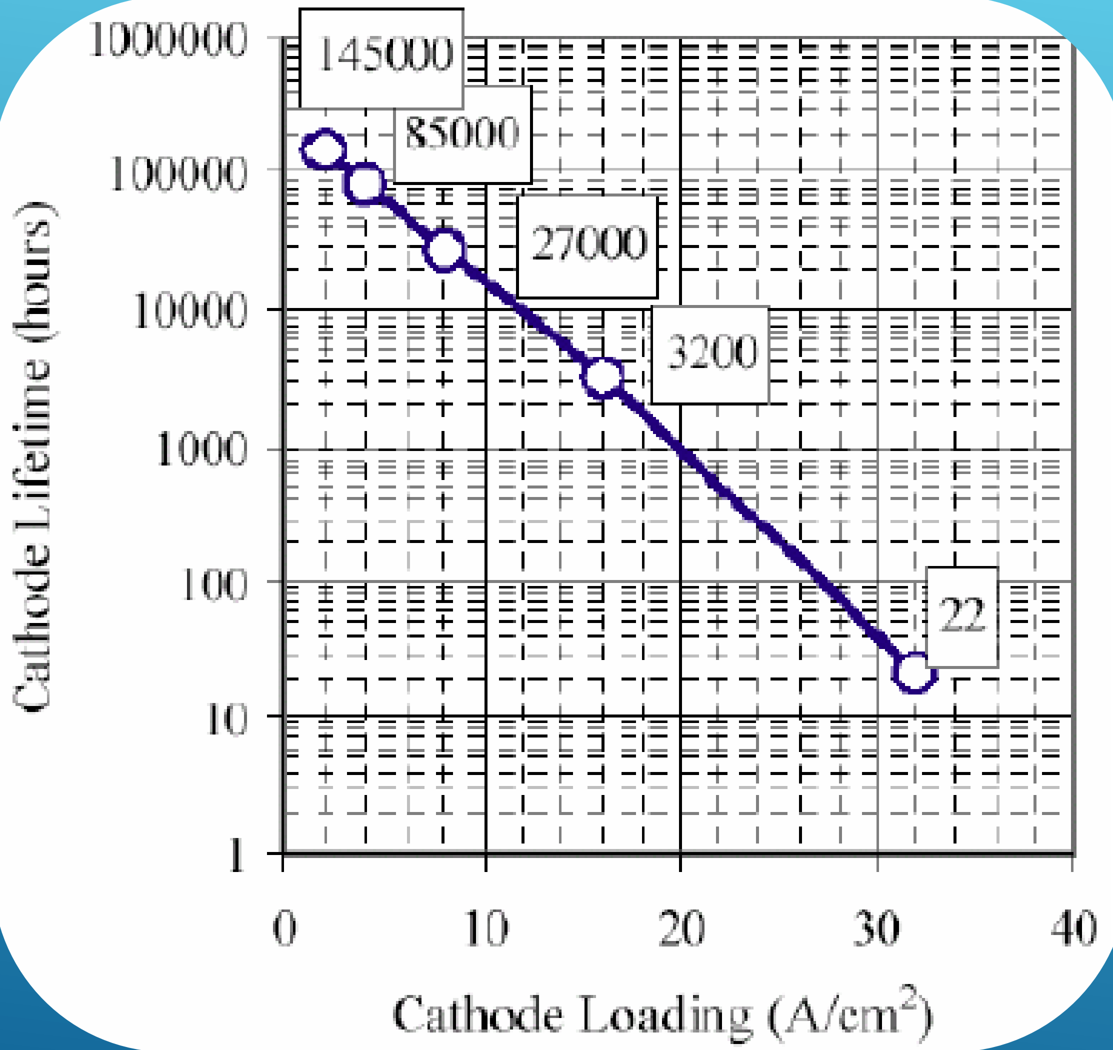


High power and efficiency → Low perveance → Low Current or/and High voltage → Multi-beam klystron

MULTI-BEAM KLYSTRON

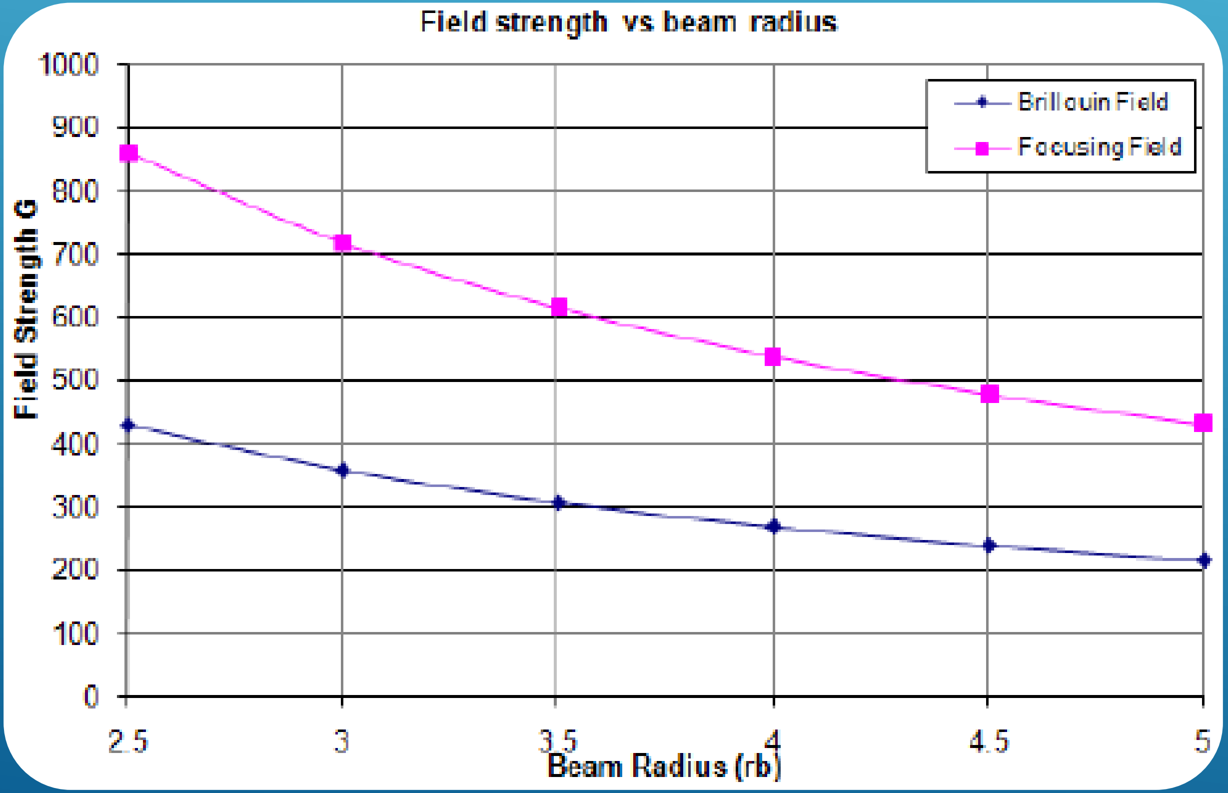
- **<u>Features of Multi-Beam Klystrons (MBKs)</u>**

1) Higher power and efficiency
2) Life time increasing



MULTI-BEAM KLYSTRON

- **Features of Multi-Beam Klystrons (MBKs)**
  1) Higher power and efficiency
  2) Life time increasing
  3) Reduction of focusing magnet's volume and weight



MULTI-BEAM KLYSTRON

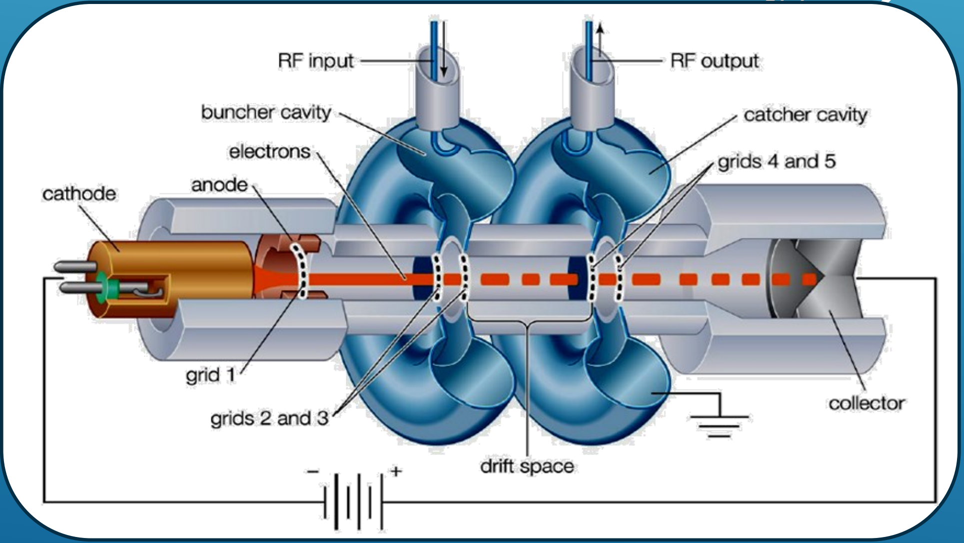
- **Features of Multi-Beam Klystrons (MBKs)**

1) Higher power and efficiency
2) Life time increasing
3) Reduction of focusing magnet's volume and weight
4) Higher stability

$$P = \mathrm{VI} = V^{2.5}\frac{I}{V^{1.5}} = V^{2.5}K \rightarrow \Delta P = 2.5\mathrm{K}V^{1.5}\Delta V \rightarrow \frac{\Delta P}{P} = 2.5\frac{\Delta V}{V}$$

$$\varphi = \omega t + \varphi_0 = \frac{\omega L}{v} + \varphi_0 \rightarrow$$

$$\Delta\,\varphi = \frac{-\omega L}{c}\,\frac{1}{(\gamma_R + 1)(\gamma_R{}^2 - 1)^{1/2}}\,\frac{\Delta V}{V} \rightarrow \Delta\varphi \propto \frac{\Delta V}{V} = \frac{\Delta E}{E}$$



MULTI-BEAM KLYSTRON

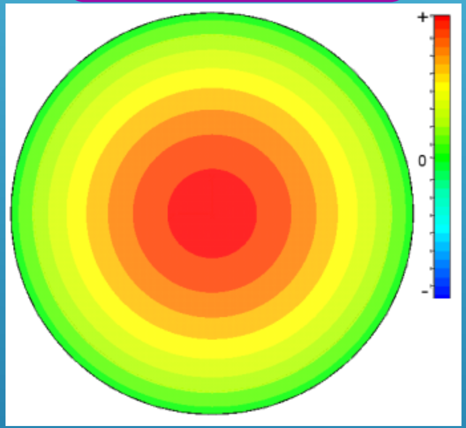
- **<u>Comparison between single and multiple beam Klystron:</u>**

Parameters	Single beam klystron	Multi-beam klystron
Efficiency	Lower	Higher
Peak power	Lower	Higher
Stability	Lower	Higher
Bandwidth	Lower	Higher
Lifetime	Lower	Higher
Size	Bigger	Smaller
Cooling	Higher	Lower
Structure complex	Lower	Higher
High voltage	Higher	Lower

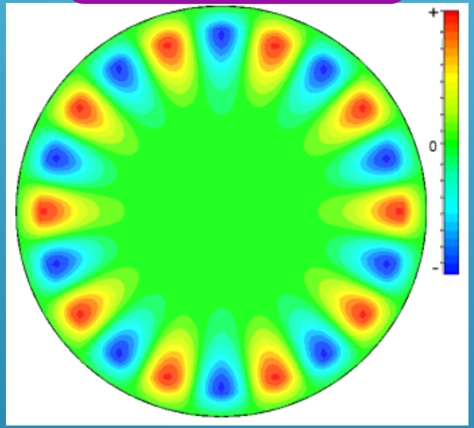
MULTI-BEAM KLYSTRON (CAVITY)

- One of the main difference between single and multiple klystron is cavities:

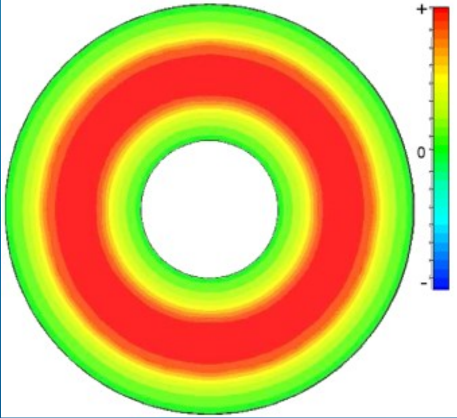
TM_{010} *cavity*



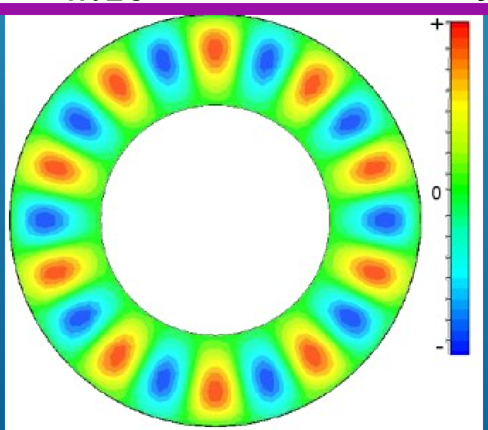
TM_{m10} *cavity*



TM_{010} *Coaxial cavity*



TM_{m10} *Coaxial cavity*

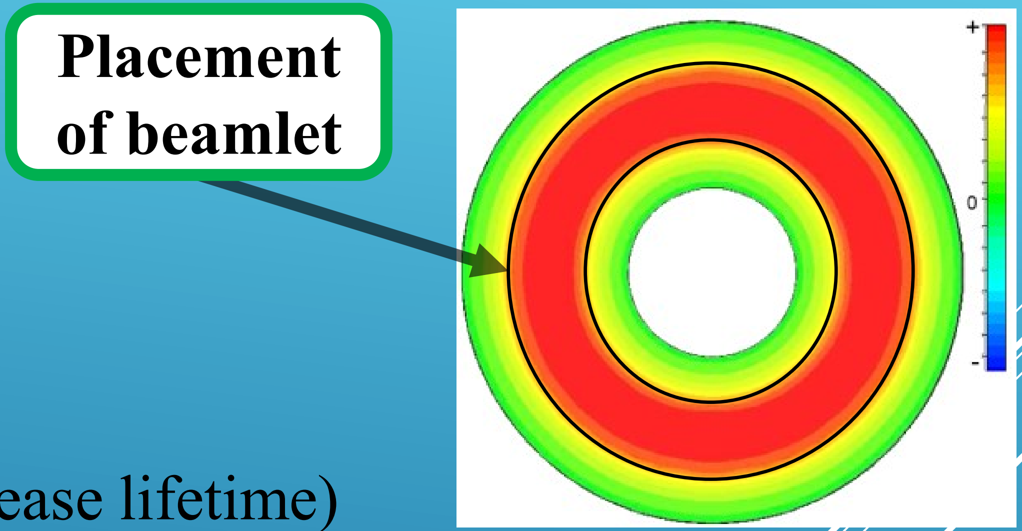


Dominant Mode
↓
Higher R/Q
↓
Shorter length of circuit
Higher induced voltage
↓
Smaller structure
Higher power

HOMs Modes
↓
Lower R/Q
↓
Longer length of circuit
Lower induced voltage
↓
Bigger structure
Lower power

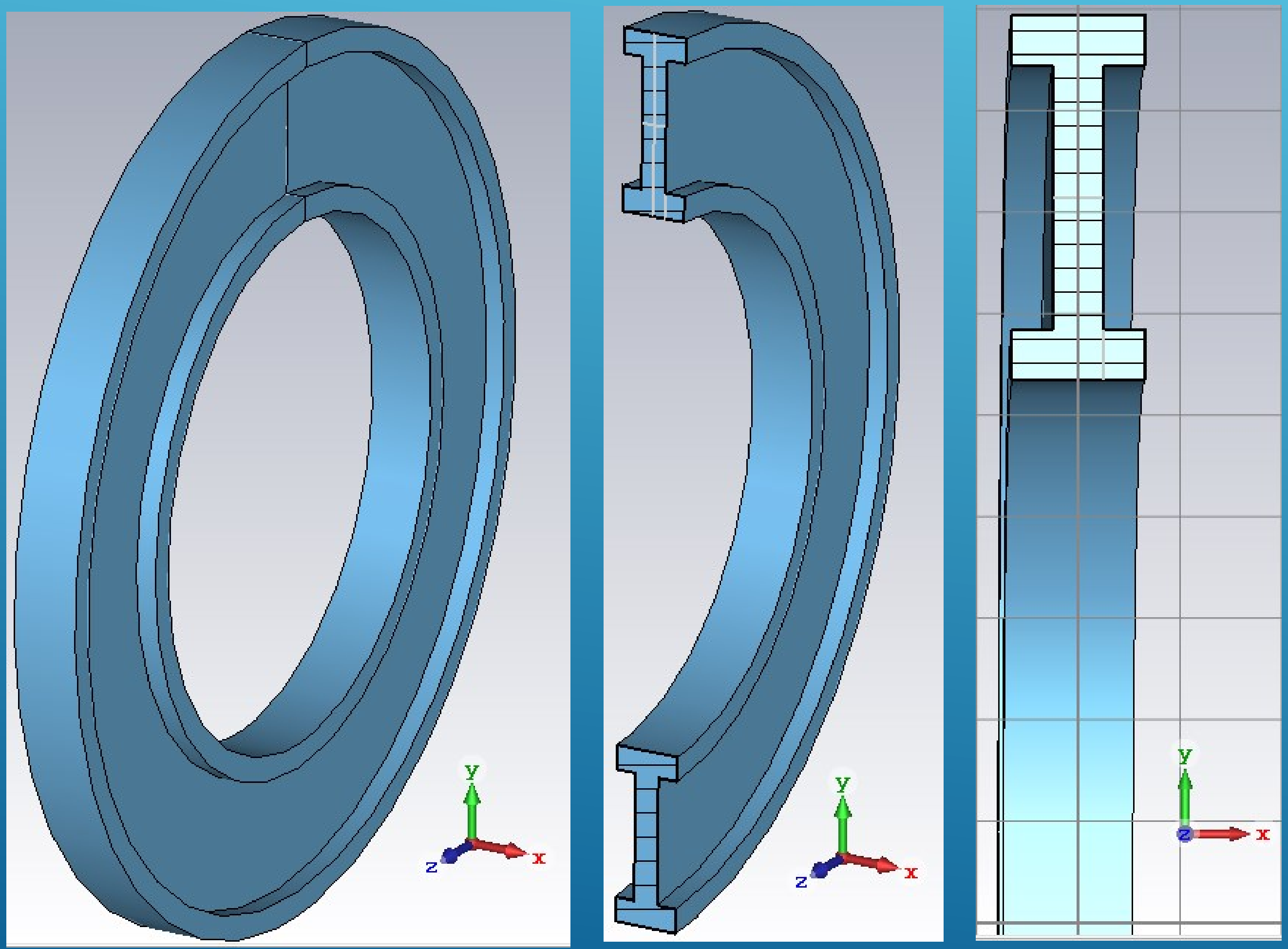
MULTI-BEAM KLYSTRON (SELECTION OF CAVITY)

- Dominant mode of coaxial cavity selected for the following reasons :
  1) Higher R/Q
  2) Higher bandwidth
  3) Flexible in design:
     1) Easier cooling
     2) Ability to increase cathode radius (increase lifetime)
     3) Ability to increase beamlet (increase power and efficiency)
     4) Ability to extract power from the inner wall of cavity (maintaining of field symmetry)



MULTI-BEAM KLYSTRON (CAVITY DESIGN)

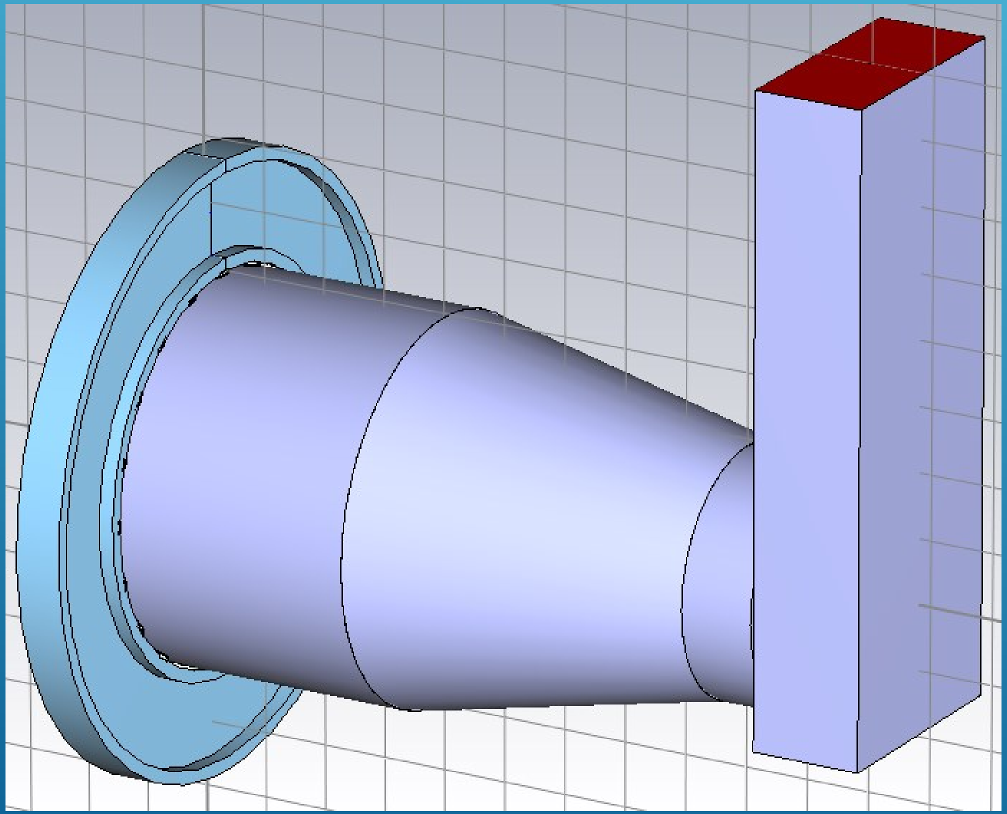
- **Cavity design:**

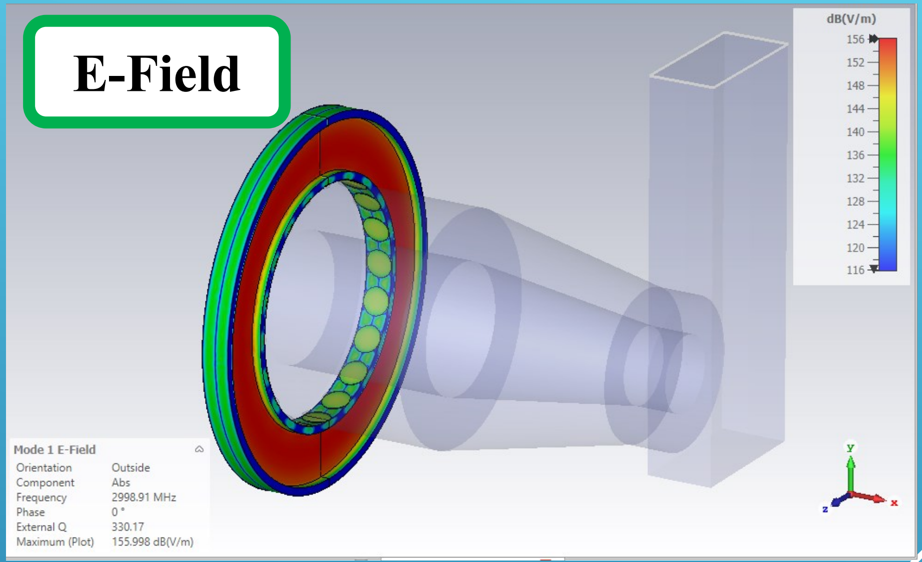


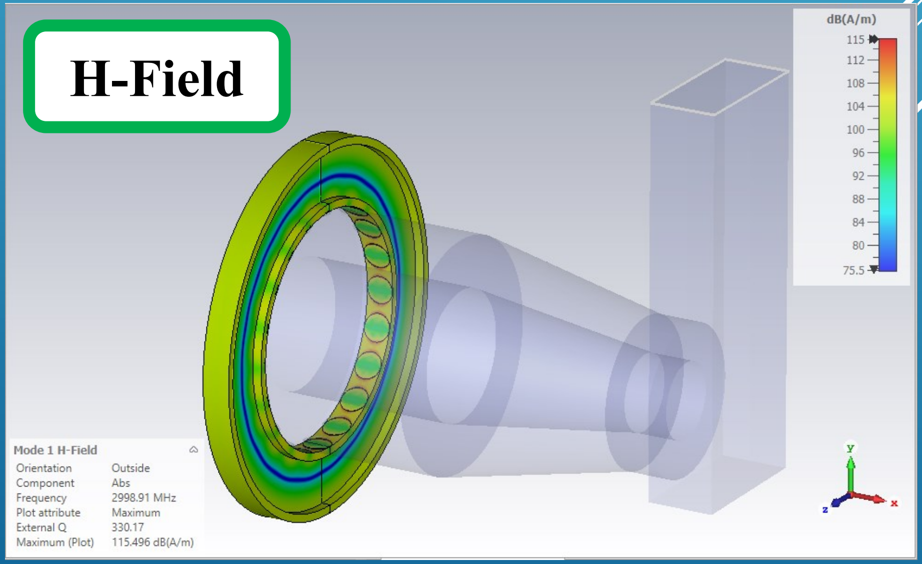
Spec of multi-beam klystron	Value
Frequency	2998.55 MHz
Peak power	7.5 MW
High voltage	55 kV
Number of beam	40
Pulse width	5 μs
Repetition rate	300 Hz

MULTI-BEAM KLYSTRON (POWER EXTRACTION)

- Placement of power extraction slot in the inner wall of the cavity to maintain field symmetry

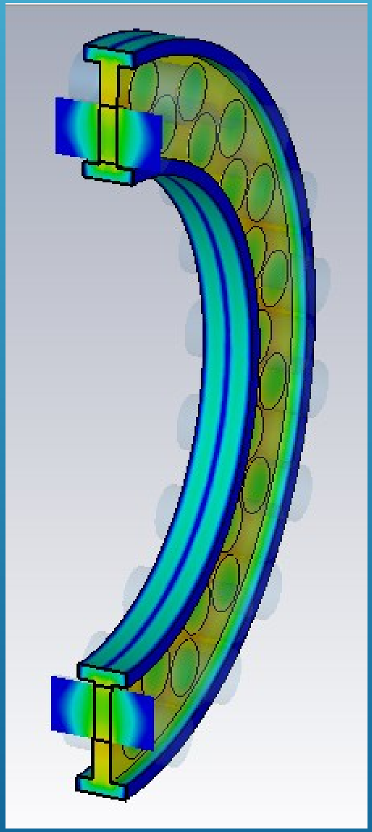
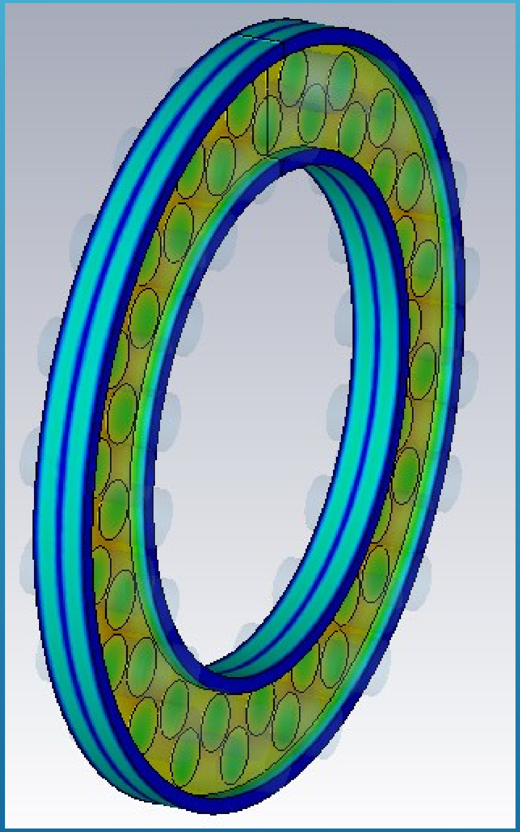
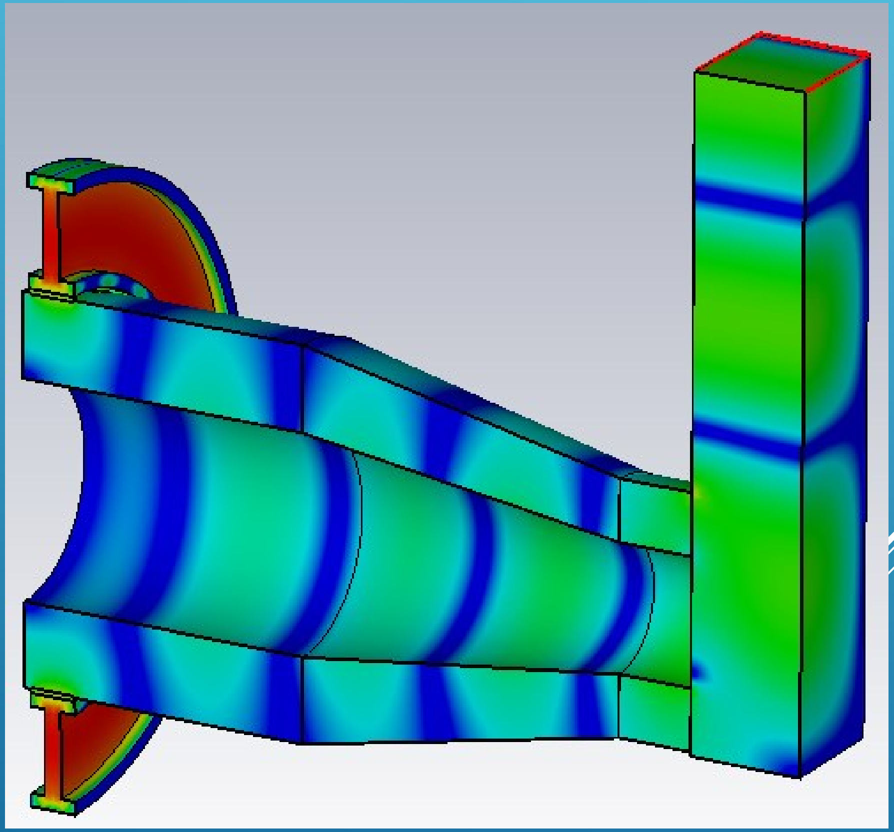






MULTI-BEAM KLYSTRON (POWER EXTRACTION)

- **Results (Cavity and coupler design with bandwidth 10 MHz):**

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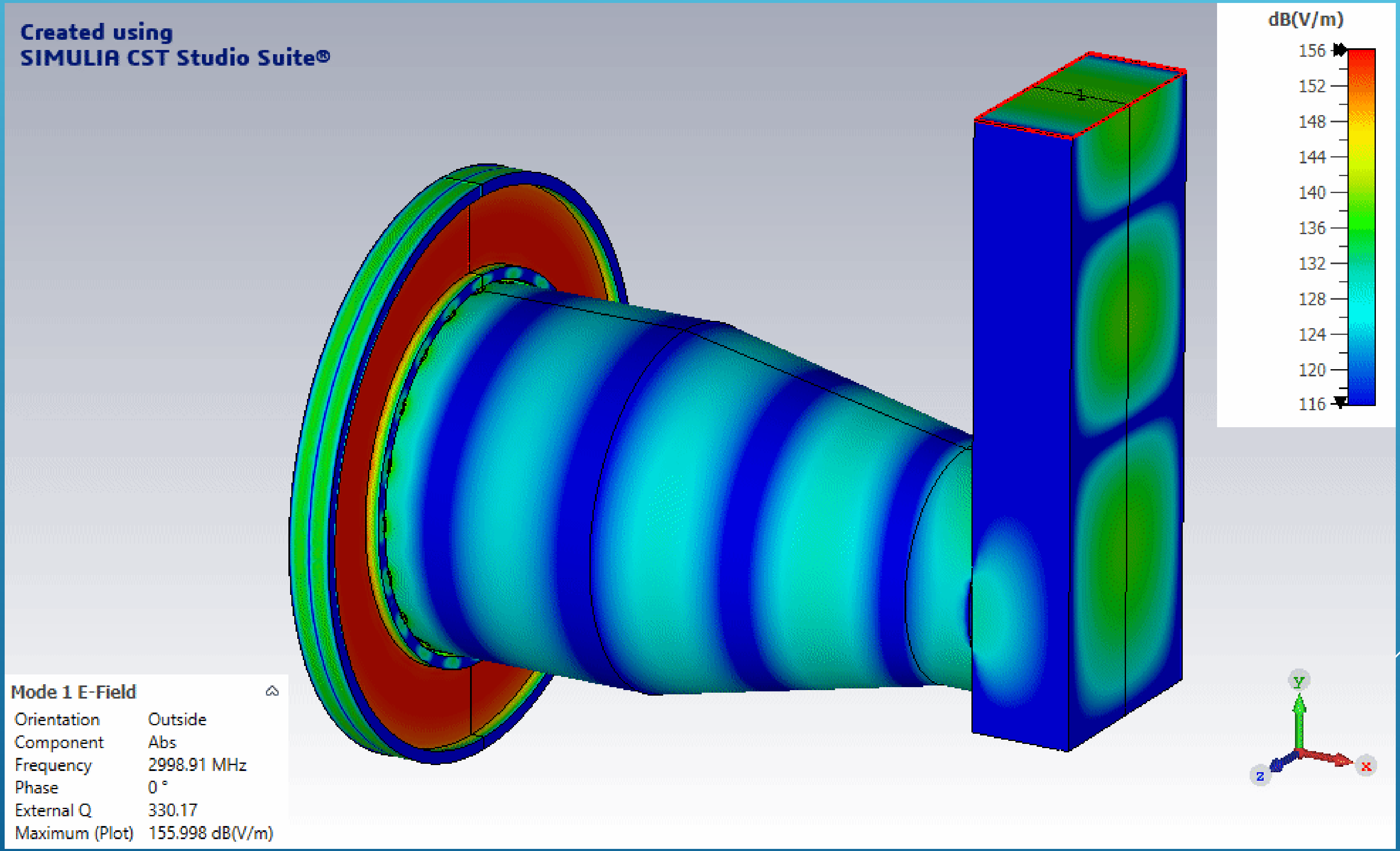

REFERENCE

1) Andrei Baikov and Olga Baikova, “New High-Efficiency Resonant O-Type Devices as the Promising Sources of Microwave Power”, Energies, 13, 2514, 2020. doi:10.3390/en13102514.

2) “High Power Microwave Technology and Effects”, A University of Maryland Short Course Presented to MSIC, Redstone Arsenal, Alabama, August 8-12, 2005.

3) David M Pozar, “Microwave engineering”, Book, 4th edition, 2012.

4) A. S. Gilmour, “Klystrons, Traveling Wave Tubes, Magnetrons, Crossed-Field Amplifiers, and Gyrotrons”, Book, 2011.

5) J. Webster, “Wiley Encyclopedia of Electrical and Electronics Engineering”, John Wiley & Sons, Inc, 2014.

6) “The Compact Linear Collider (CLIC)”, Summary report, CERN-2018-005-M.

7) Emmanuel, Tsesmelis, “Applications of Accelerators”, Graduate Accelerator Physics Course, John Adams Institute for Accelerator Science, CERN & University of Oxford, 11 October 2017.

8) George Caryotakis, High Power Klystrons: Theory and Practice at the Stanford Linear Accelerator Center, Stanford Linear Accelerator Center, January, 2005.

REFERENCE

9) https://www.cpii.com/product.cfm/1/20/107.
10) S. Choroba, “10 MW MBK Status”.
11) E. Jensen, P. Pearce, and I. Syratchev, “A novel idea for a CLIC 937 MHz 50MW multibeam klystron”, February, 2004.
12) E. Wright, et all, “Development of a 10-MW, L-band, multi-beam klystron for TESLA”, Proceedings of the Particle Accelerator Conference, 2003.
13) Richard G. Carter, “Microwave and RF Vacuum Electronic Power Sources,” The Cambridge RF and Microwave engineering series, 2018.
14) Vladimir E. Teryaev, Sergey V. Shchelkunov, Yong Jiang, and Jay L. Hirshfield, “100 kW CW Highly-Efficient Multi-Beam Klystron for a Future Electron-Ion Collider”, AIP Conference Proceedings, 2017.
15) Deepender Kant, Ayan Kumar Bandyopadhyay, Lalit Mohan Joshi, MV Kartikeyan, Vijay Janyani, “Design Studies for a 2 kW (CW) Power L/S Band Multi Beam Klystron”, IEEE International Vacuum Electronics Conference (IVEC), 24-26 April 2018.

Thanks for your attention