Latest progress of Klystron activities in UESTC

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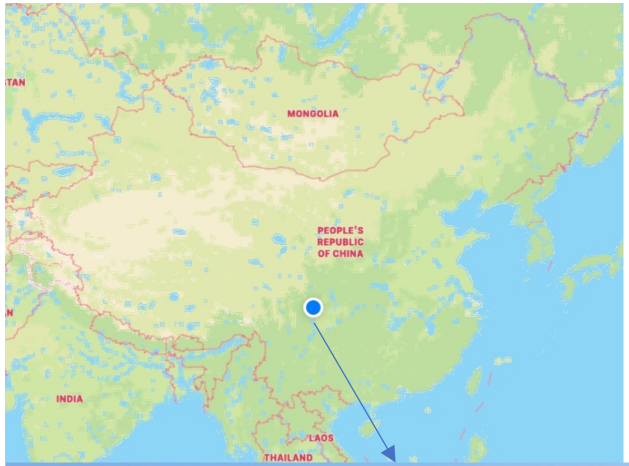
Outline

- Problems to be solved
- Broaden the bandwidth of Klystrons
- Make high efficiency Klystron more compact
- Instabilities in High-gain Klystrons
- Fast design methodology of MBK optics
- Make terahertz Klystron more efficiency
- Novel hybrid TWT/Klystron devices
- Summary and outlook

Introduction of UESTC

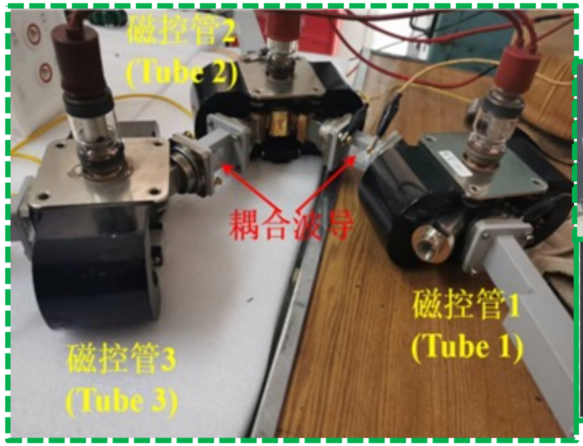


University Ranking

Sichuan 1#
China 20-30#
World 300-400#
E & E A+

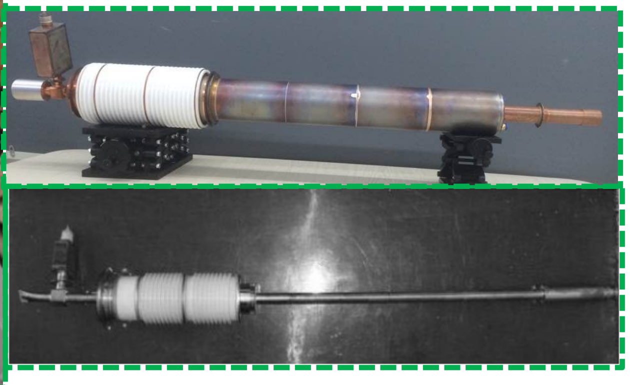
University of **E**lectronic **S**cience and **T**echnology of **C**hina (UESTC)

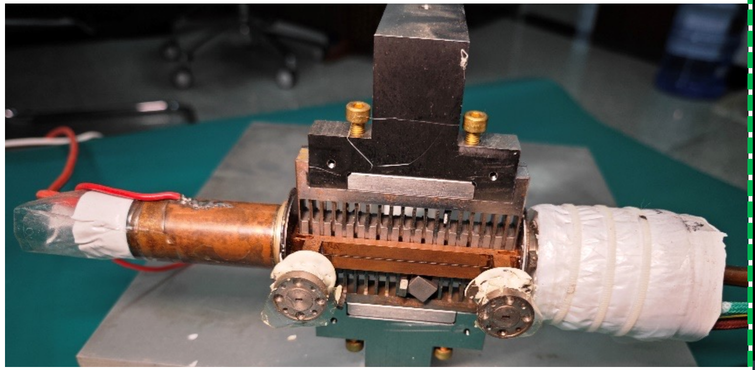
Featured Expertised Acadmics:
Vacuum Electronics



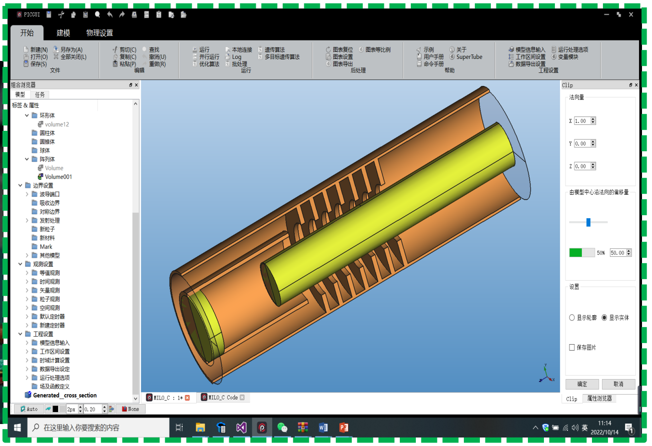
Magnetron

Gyrotron



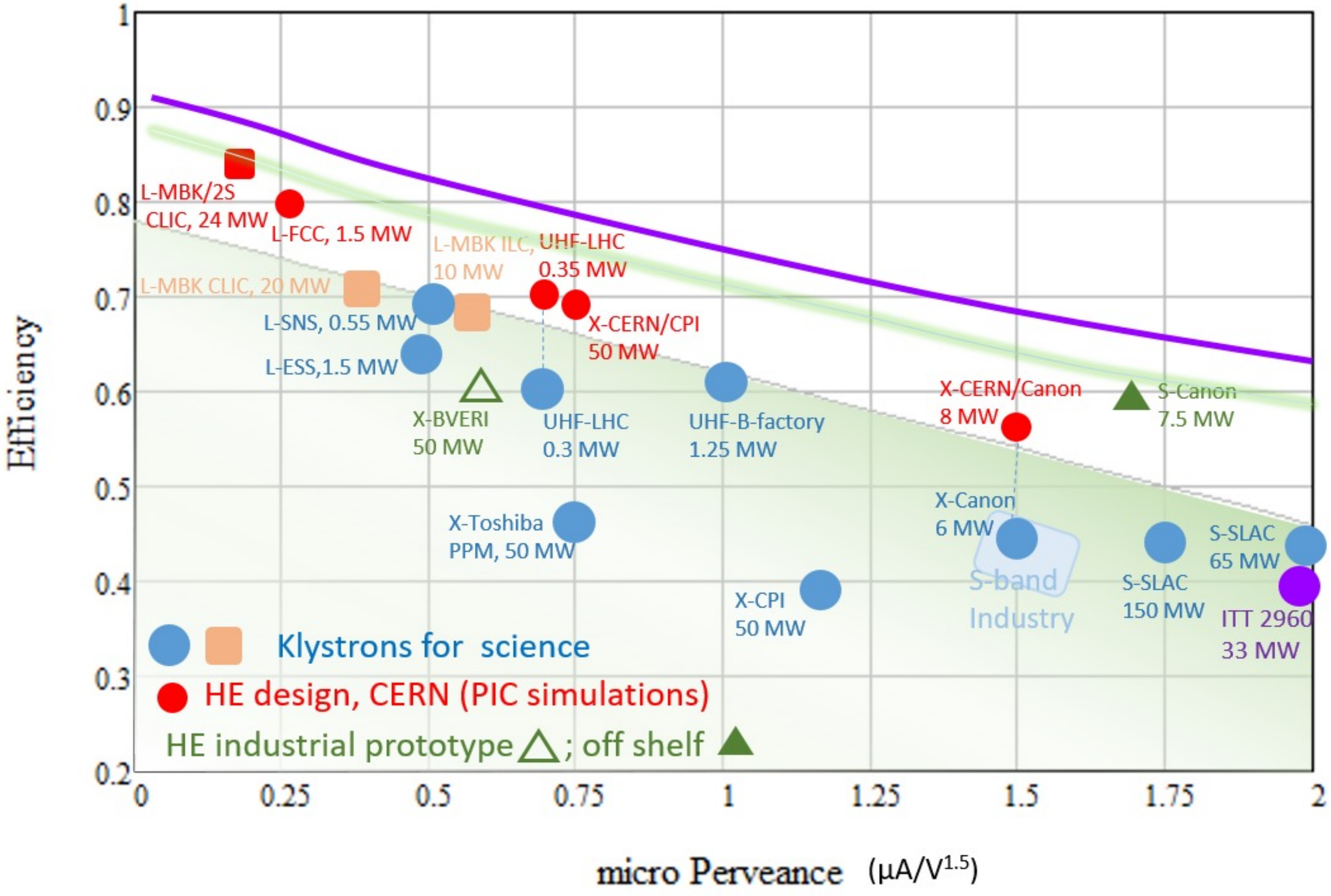


TWT



PIC software

High efficiency klystron development chart



- In recent years, varies types of HE Klystron technology has been proposed to boost Klystron efficiency by 10—30%.
- Apart from enhancing the efficiency performance of Klystron, there are some other critical issues to be addressed.
  - Bandwidth performance of Klystron
  - Compactness of Klystrons
  - Instabilities in Klystrons
  - MBK optics design still takes quite a long time
  - Terahertz/MMW Klystron operates at rather low efficiency
  - Novel Klystron-like devices to be explored

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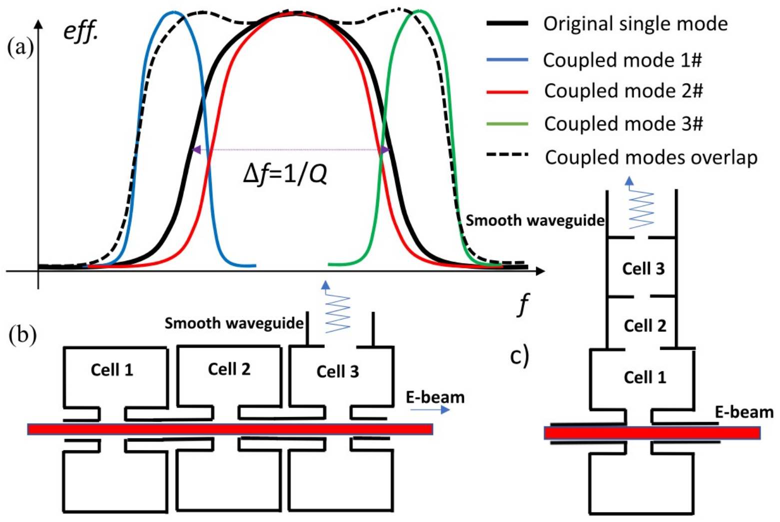
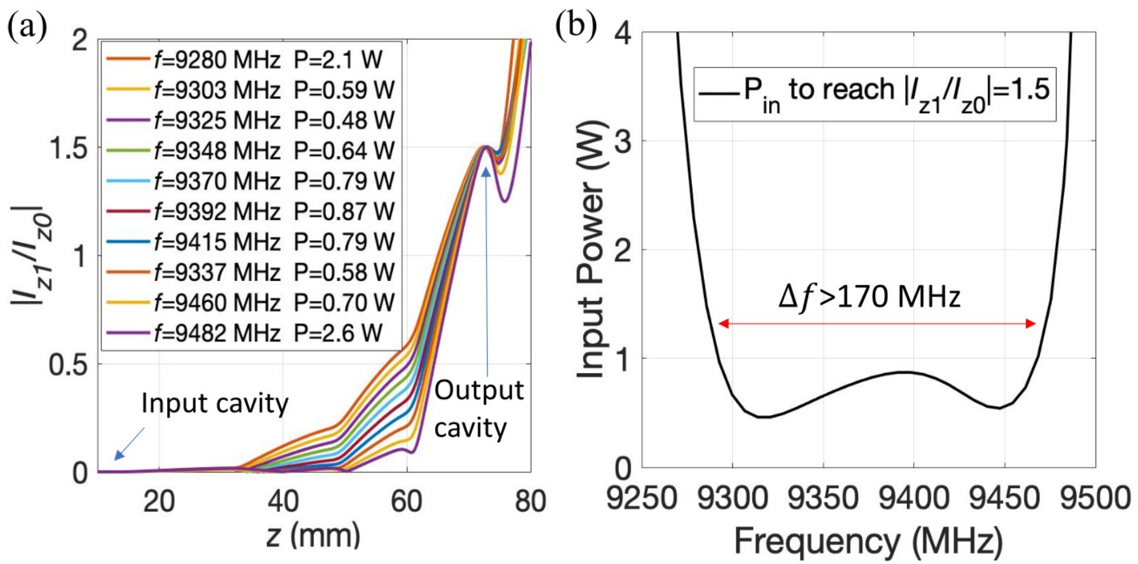
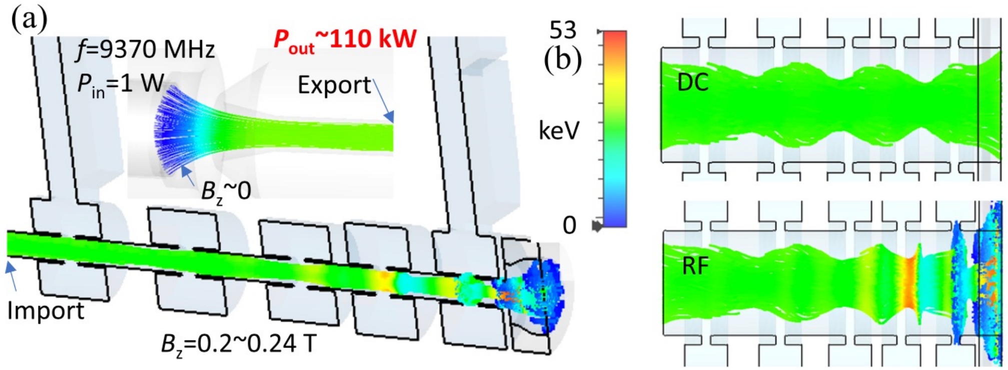
Broadband Klystron development

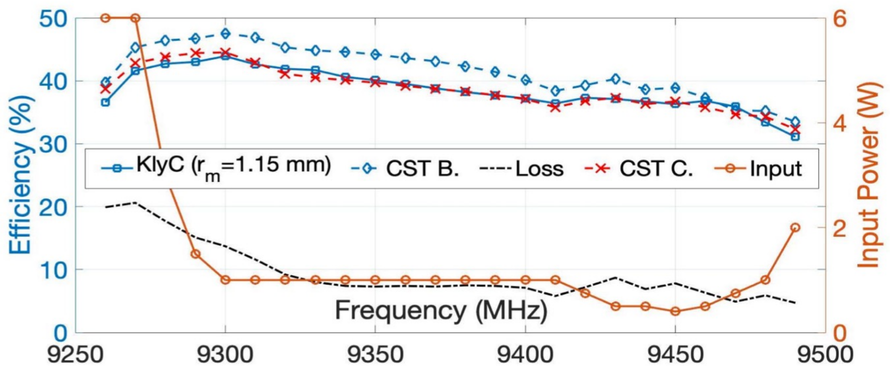


Use coupled mode theory to tackle the filter-loaded output cavity



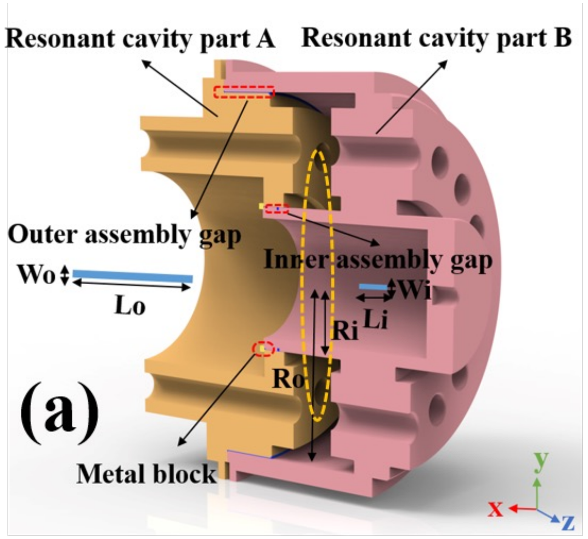
Use Small signal theory to handle staggered tuned bunching circuit

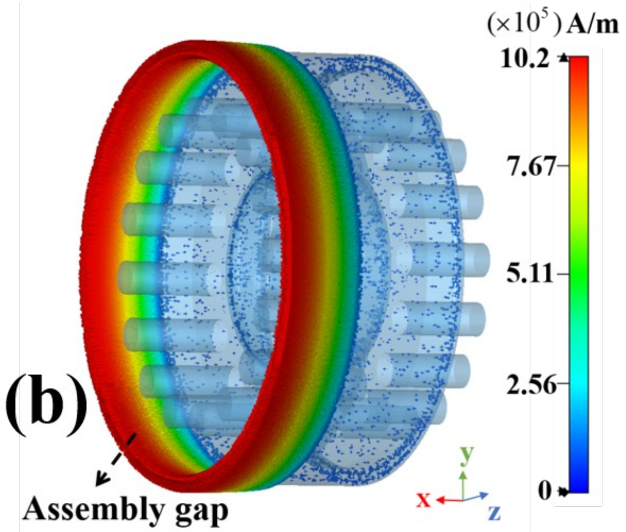


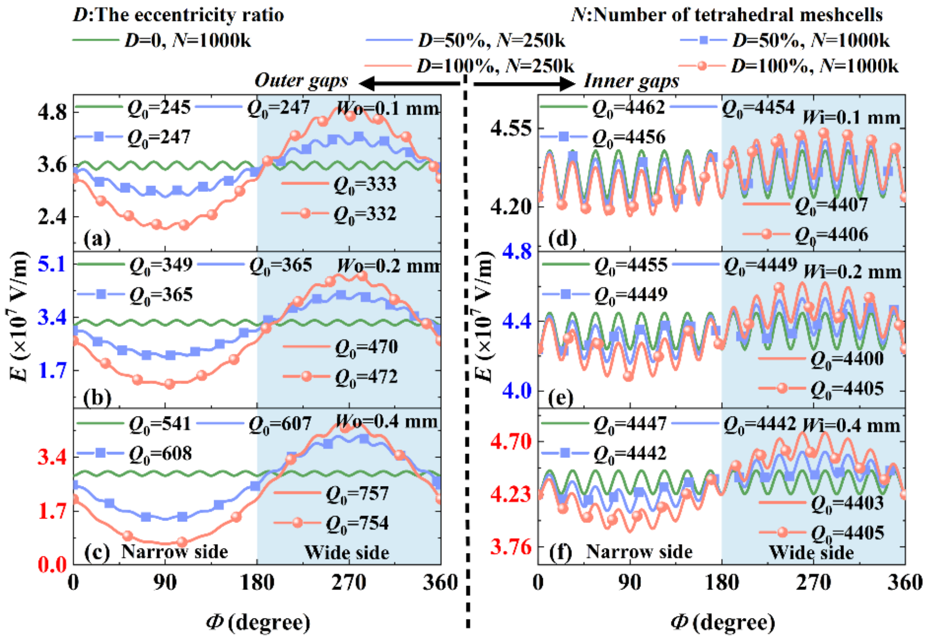


CST PIC benchmarking

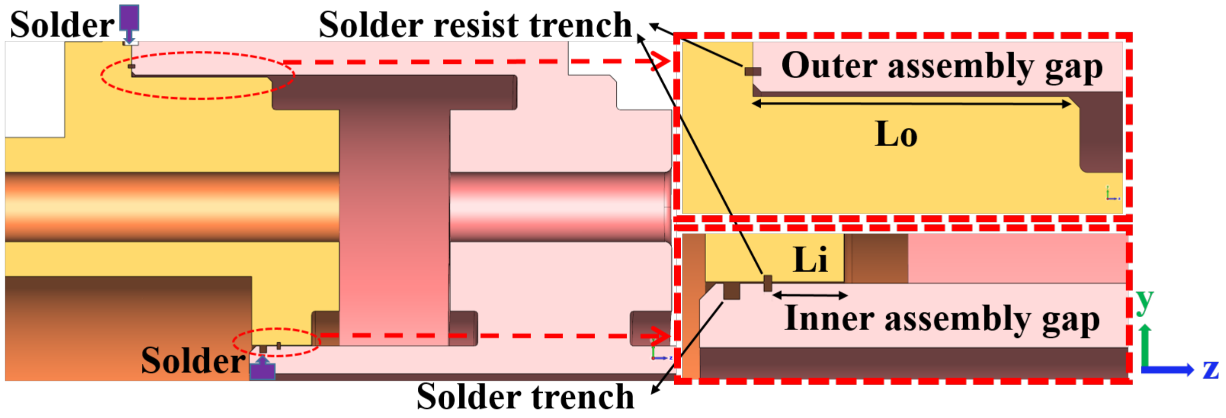
Investigation on the Effects of Assembly Gaps







Problems detected: Assmebly gap cause low Q



How to use it

Based on the findings, a new approach was proposed to conveniently reduce the Q0 of the resonant cavity via employing an appropriately long, relatively narrow gap (1/1000 of its radii, to ensure concentricity even in the worst scenario), thereby facilitating the development of broadband klystrons.

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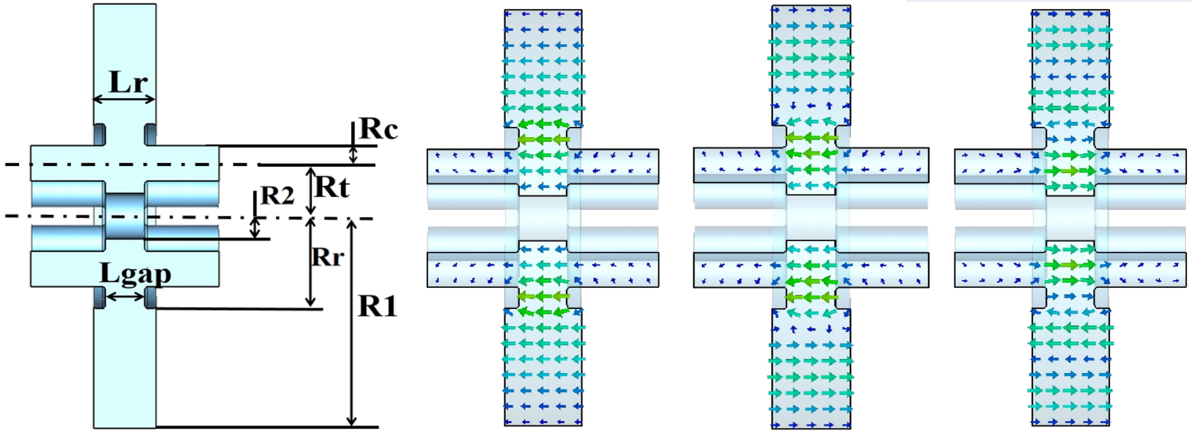
Ultra-compact HE CSM MBK Using Hybrid-modes Resonant Cavities

Parameter	Value
Operation Frequency (GHz)	1.3
Beam Voltage (KV)	110
Beamlet Current (A)	28
Number of Beams	6
Beam Tube Radius (mm)	10
Beam Radius (mm)	6.5
Cathode current emission density	≤8A/cm^2
Output Power (MW)	>10
Efficiency (%)	>50
Gain (dB)	>40

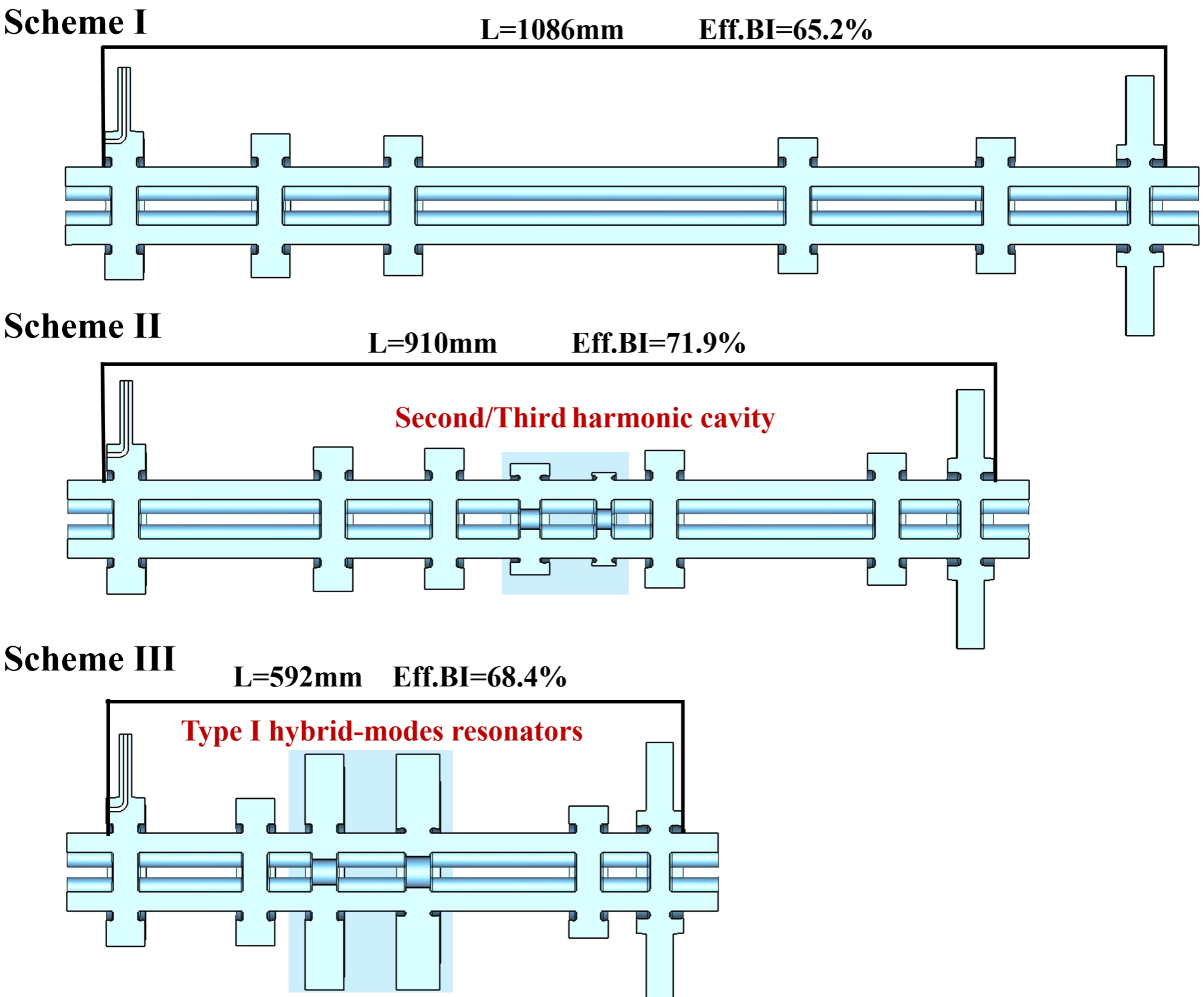
Cavity		Lgap(mm)	f(MHz)	R/Q (Ω)	M	R/Q*M²(Ω)
Fundamental mode cavity		25	1300	43.5	0.89	34.4
Second harmonic cavity		20	2600	24.5	0.69	11.6
Third harmonic cavity		15	3900	19.8	0.52	5.3
hybrid-modes resonant cavity	Type I (f-2f)	25	1300	11.3	0.89	8.9
			2600	9.4	0.62	3.6
	Type II (f-3f)	20	1300	8.1	0.91	6.7
			3900	3.4	0.43	0.6
	Type IIII (2f-3f)	30	2600	11.9	0.53	3.3
			3900	7.5	0.19	0.3



$$\frac{f_{TM_{020}}}{f_{TM_{010}}} \approx 2 \qquad \frac{f_{TM_{030}}}{f_{TM_{010}}} \approx 3 \qquad \frac{f_{TM_{030}}}{f_{TM_{020}}} \approx 1.5$$

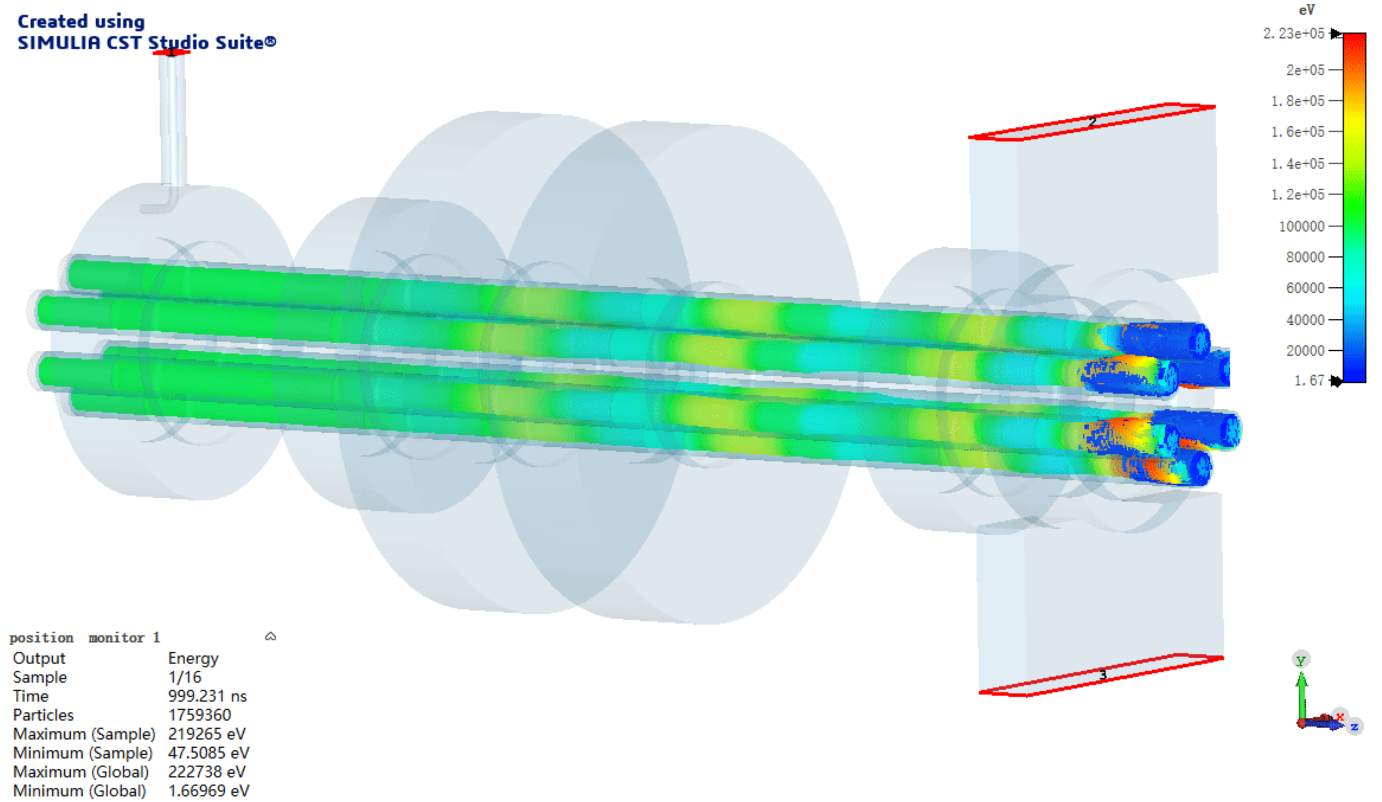
Ultra-compact HE CSM MBK Using Hybrid-modes Resonant Cavities

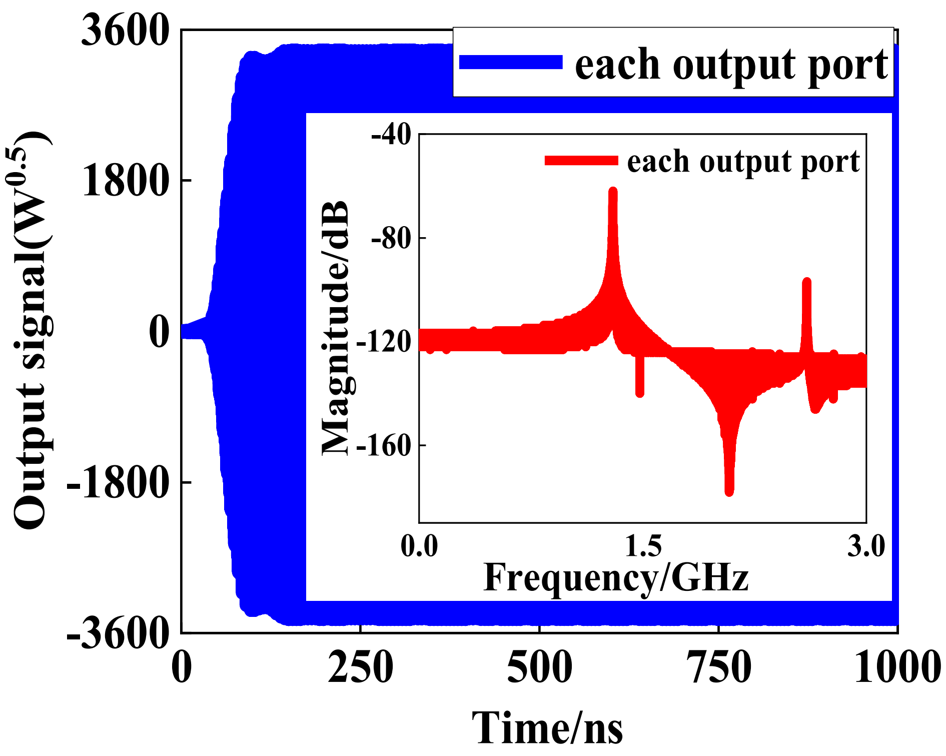
Scheme	Harmonic cavity	RF interaction circuit (mm)	Eff.BI (%)	Gain (dB)
I	f f f f f f	1086	65.2	47.8
II	f f f 2f 3f f f f	910	71.9	48.2
III	f f f-2f f-2f f f	592	68.4	48



Ultra-compact HE CSM MBK Using Hybrid-modes Resonant Cavities

Scheme	Harmonic cavity	Pin(W)	Eff.BI (%)	Pout (MW)
KlyC	f f f-2f f-2f f f	200	68.4	48
CST		220	65.9	47





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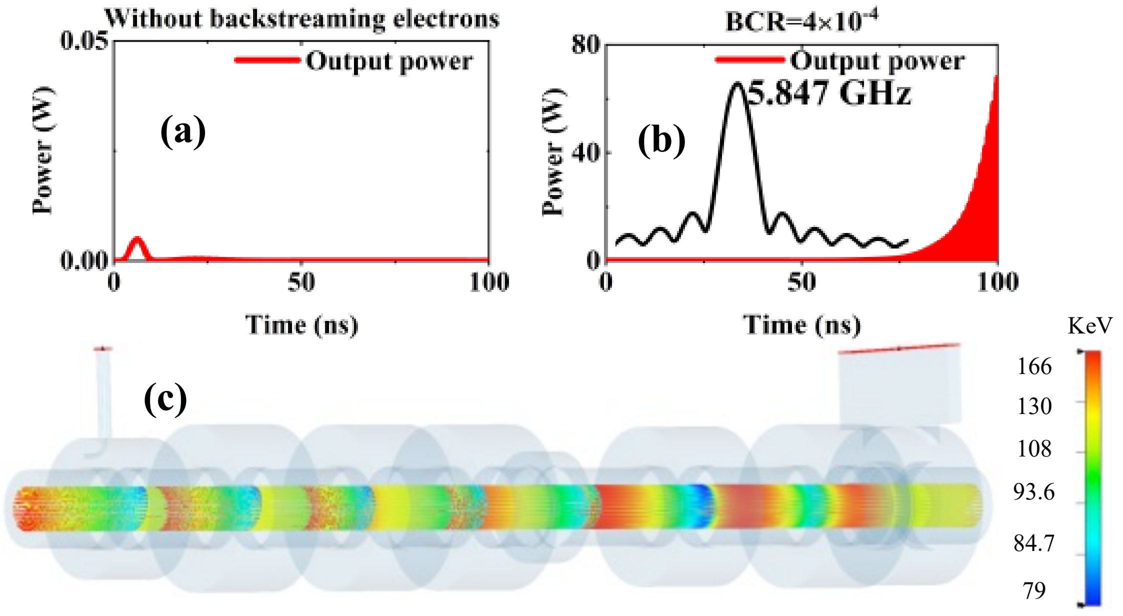
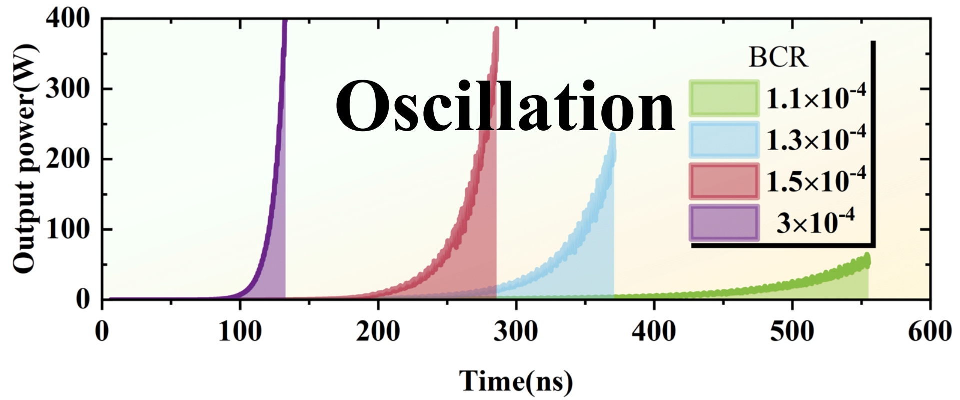
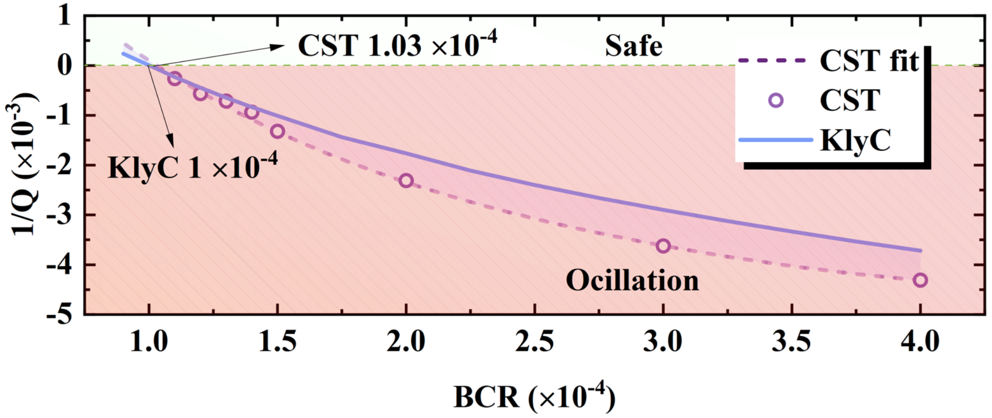
Threshold Prediction of Spurious Oscillation

Small signal model is improved to inlcude the effects of backstreaming electrons



C band klystron example

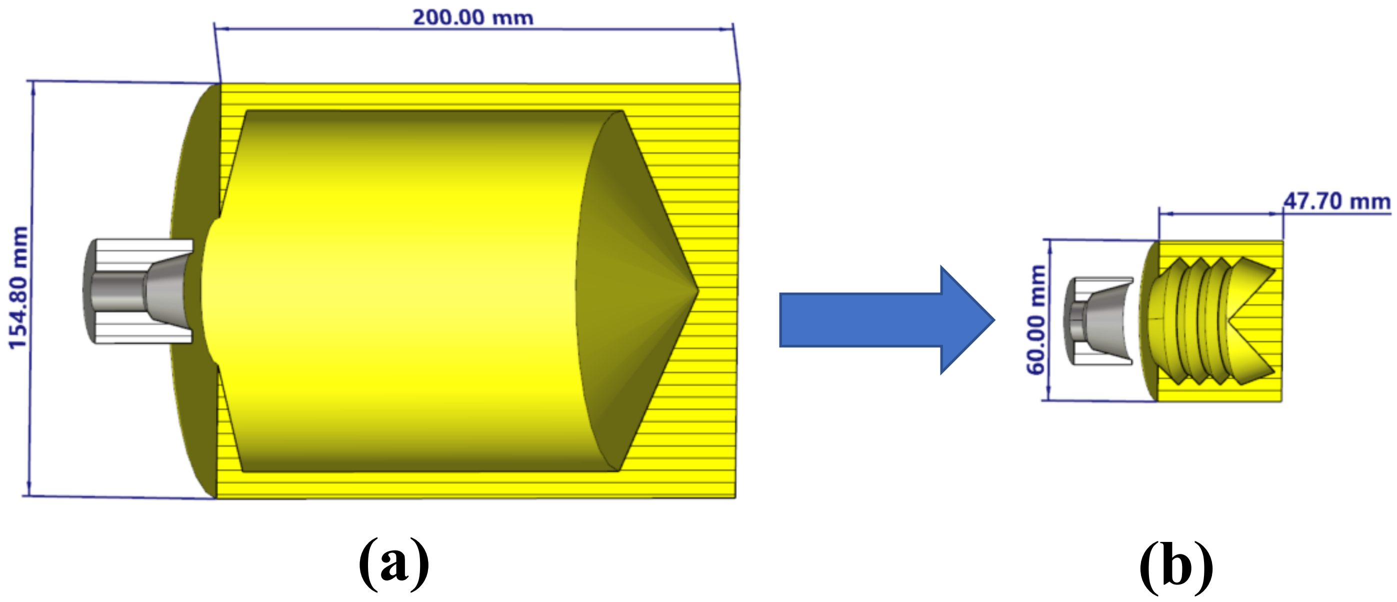


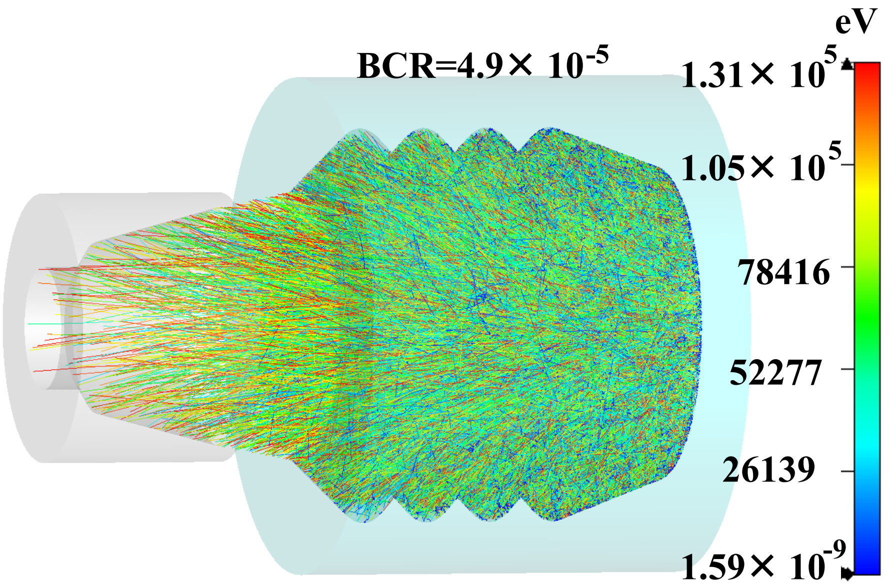


Kladistron might not be a good idea in this regards

Collector design acknowleding BCR threshold

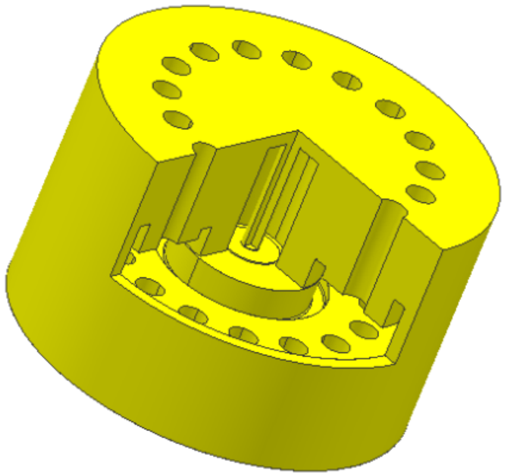
With the knowledge of BCR threshold, it is possible to rationally validate and then design the collector without the need for excessively large sizes.

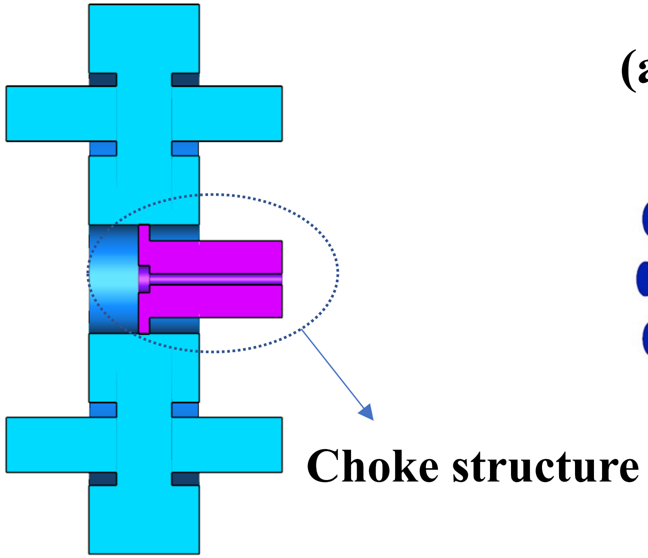


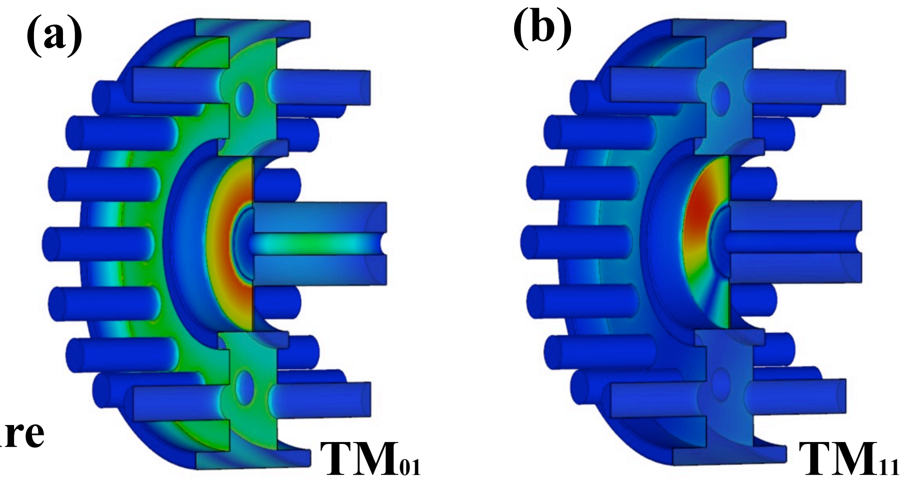


Collector of C band klystron

Suppress HOM Oscillations







A Choke structure to suppress high-order-modes (HOM) oscillations in MBK.

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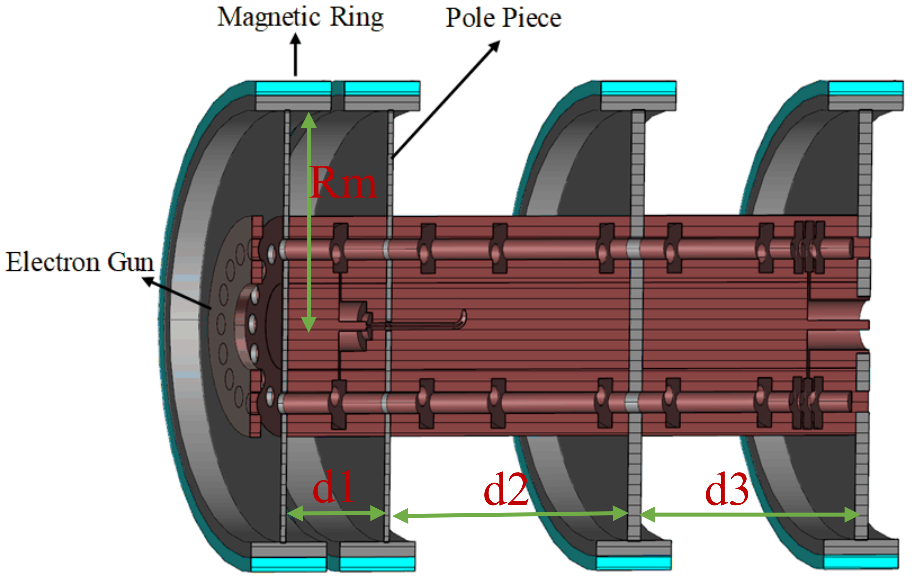
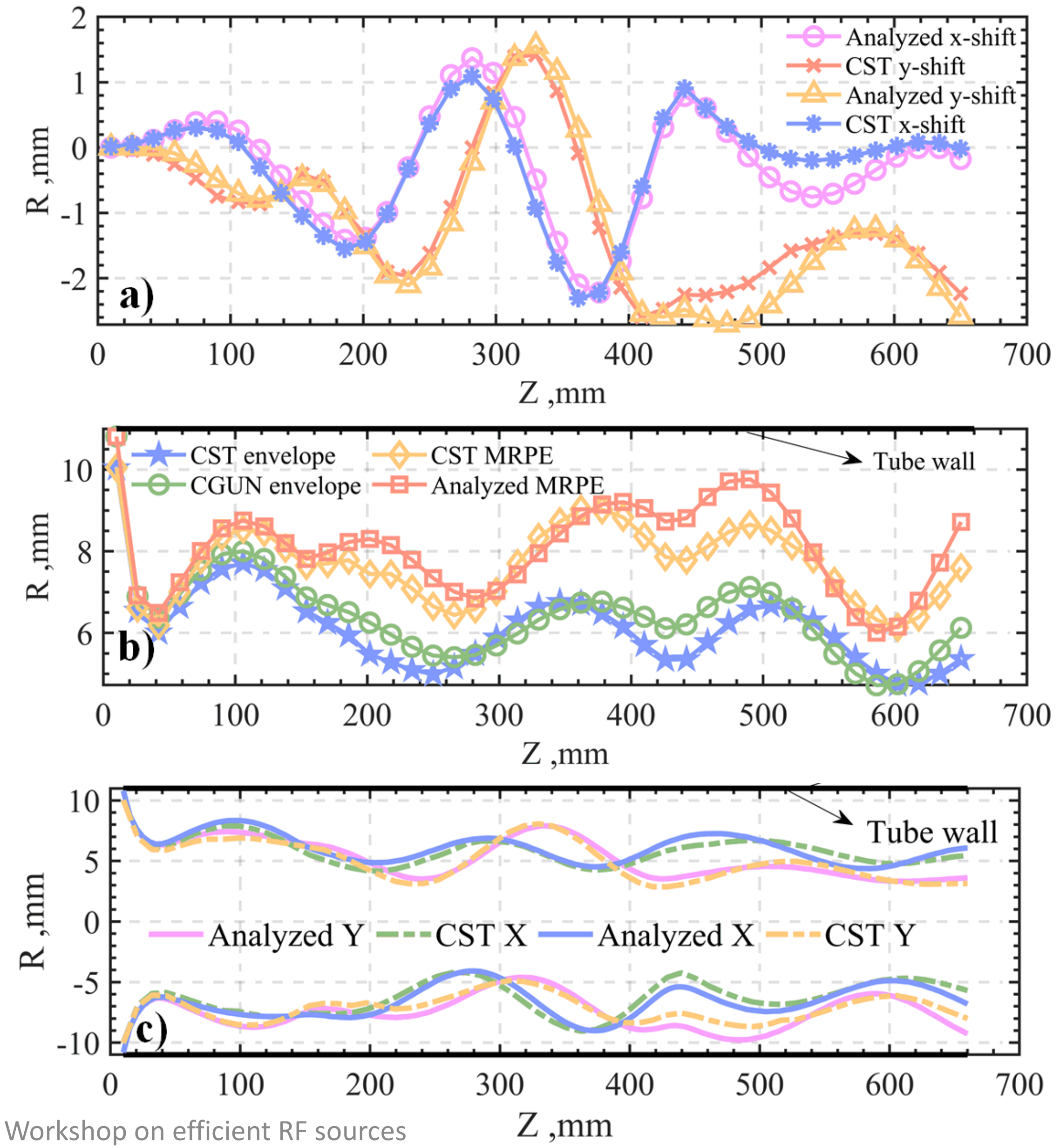
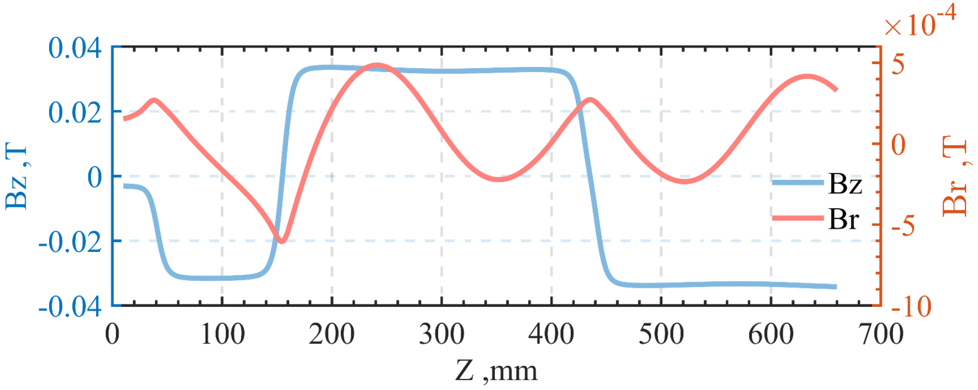
Fast model for MBK optics optimization



16-beam S-band HP HE MBK EOS





Design Methodology of Adjustable Magnetic System for Klystron

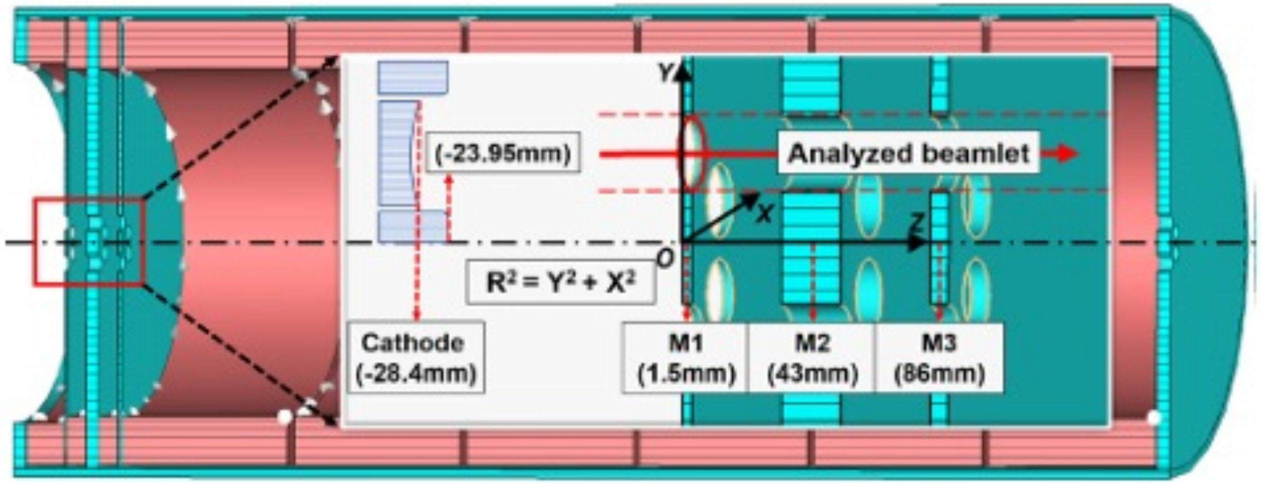


FIG. 11. 3D structure of the magnetic system modeled in CST, and the X-O-Y plane is located at the anode plane.

FIG. 12. (a) Topology of the six-beam gun. (b) 3D electron trajectories of the multi-beam gun in immersive flow strategy.

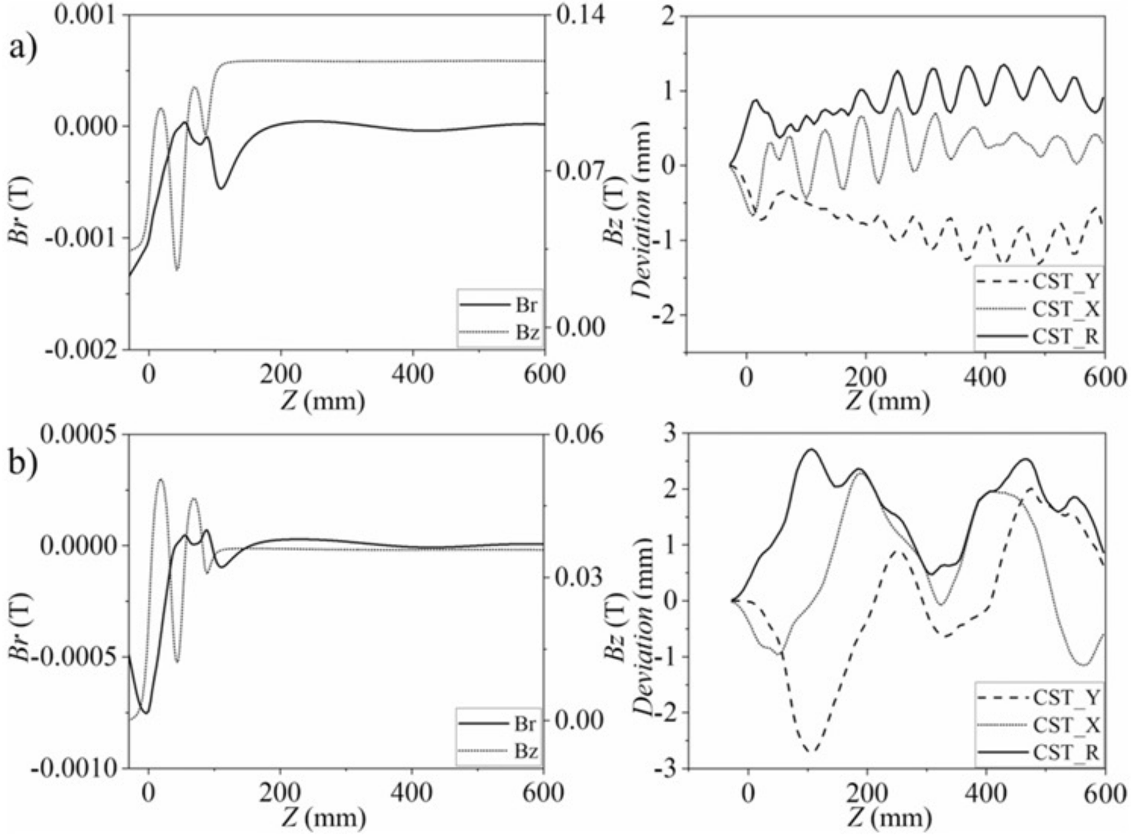


FIG. 13. (a) Beam axis offset in immersive flow mode in CST. (b) Beam axis offset in the Brillouin flow mode in CST.

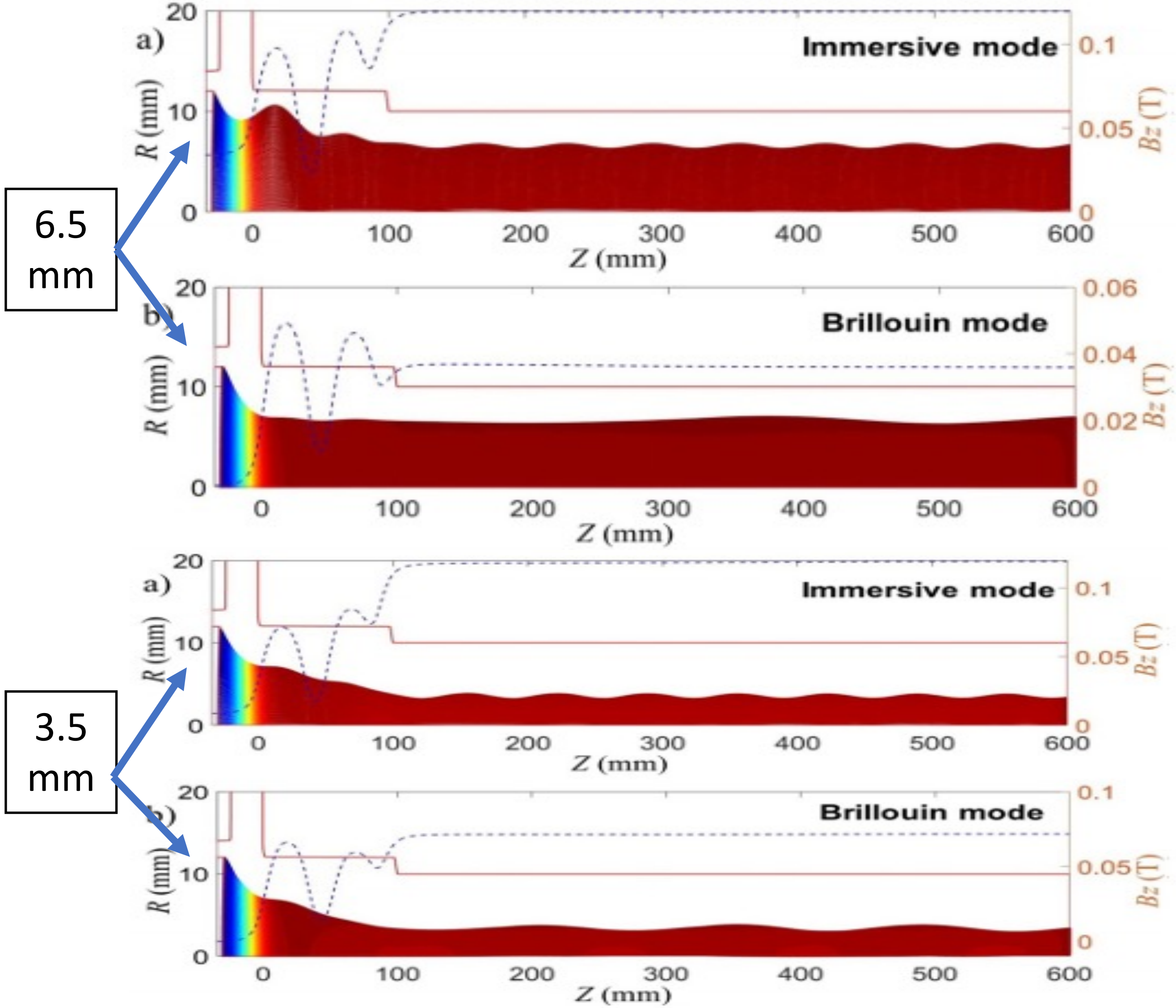
Design Methodology of Adjustable Magnetic System for Klystron

TABLE III. The gun of the L-band MBK design by the CGUN code.

Parameter	Value
Cathode radius	12 mm
Beam perveance	0.77 μP
Cathode–anode interval	28.4 mm
Voltage	110 kV
Current	28 A
Beam waist radius	6.5 mm
Maximum cathode loading	6.2 A/cm^2

TABLE IV. The magnetic system configuration for the L-band MBK. Current density data in the immersive mode are underlined, while that in the Brillouin mode is not.

Component	Thickness/current density (6.5 mm)	Thickness/current density (3.5 mm)
M1	3 mm	...
M2	20 mm	...
M3	6 mm	...
C0	1.386/−0.317 A/mm^2	1.346/−0.475 A/mm^2
C1	1.518/1.03 A/mm^2	0.924/1.4 A/mm^2
C2	1.32/0.634 A/mm^2	1.333/0.688 A/mm^2
C3	≈1.35/≈0.41 A/mm^2	≈1.37/≈0.82 A/mm^2



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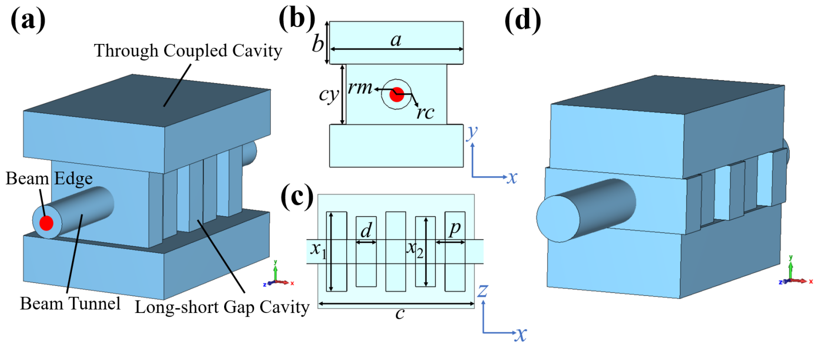
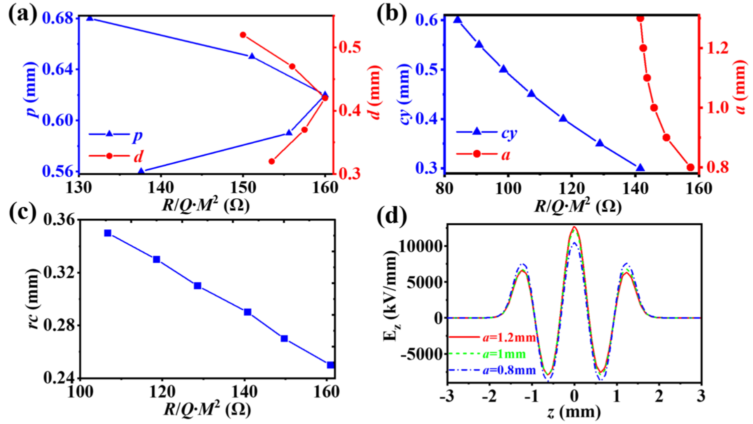
- **100GHz EIK cavity**



- **Sensitivity analysis of $R/Q{\cdot}M^2$**



- **Selection of operating voltage and current**

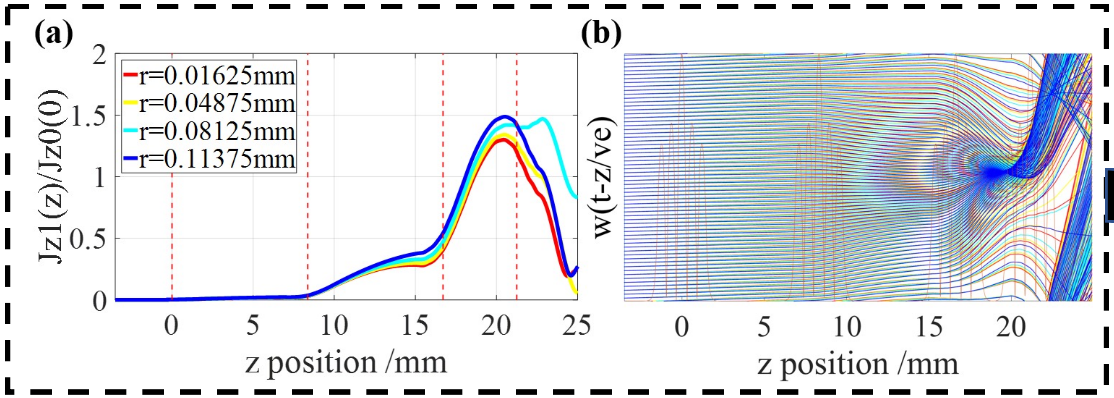
TABLE I

OPTIMAL OUTPUT AFTER OPTIMIZATION FOR DIFFERENT OPERATING VOLTAGES

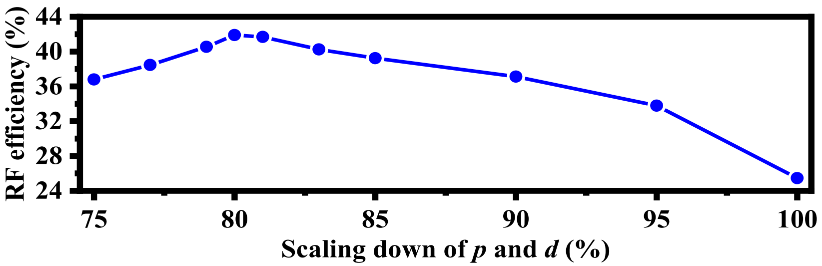
U (kV)	I (A)	P (μP)	R/Q (Ω)	M	Maximum electric field (kV/mm)	Ohmic loss	RF Efficiency
40	2.5	0.31	254	0.723	50.5	1.7%	16.9%
50	2	0.18	297	0.732	62.8	3.1%	25.5%
60	1.66	0.11	331	0.737	66.1	3.5%	28.5%
70	1.42	0.08	361	0.741	72.8	4.4%	29.7%
80	1.25	0.06	384	0.745	81.9	5.3%	30.6%

- **Initial circuit current modulation process(50kV,2A)**

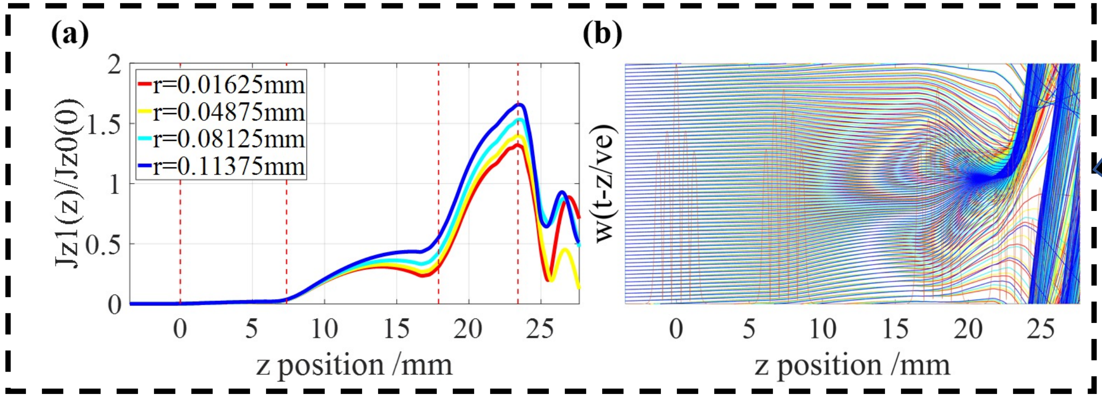
RF efficiency~25.5%, CMD~1.5



- **Resynchronization technology**



RF efficiency~42.5%, CMD~1.66



- **EIK circuit simulation model**

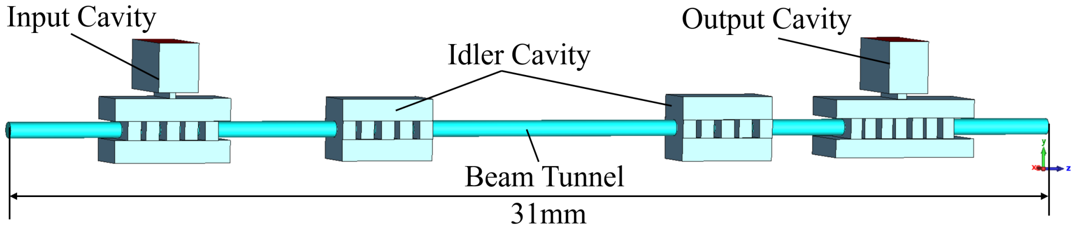
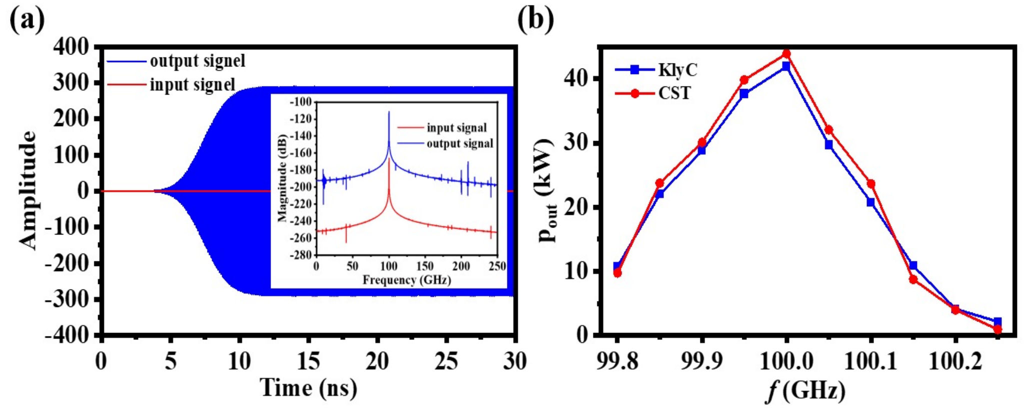


TABLE II

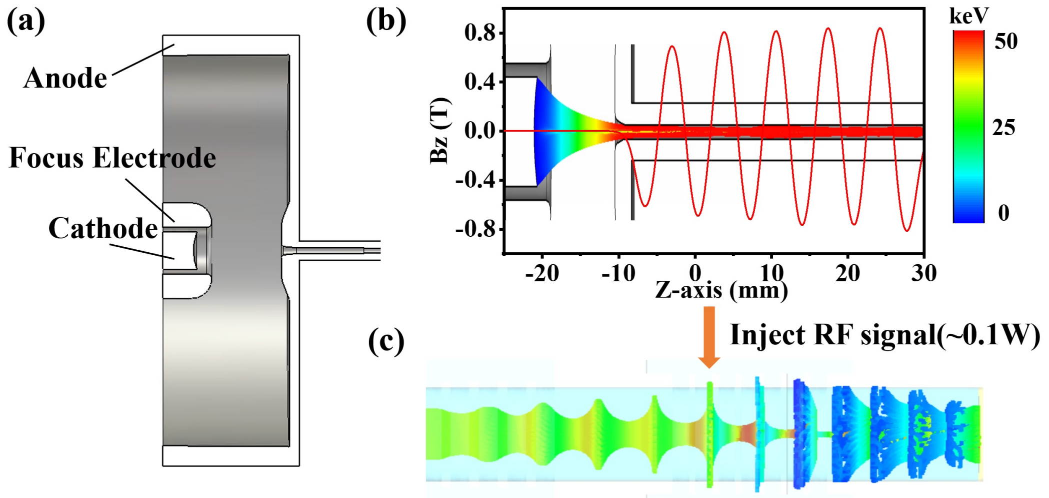
PARAMETERS OF EACH CAVITY

Cavity	*f*(GHz)	*R*/*Q*(Ω)	*M*	Q_e	Q_0	*z*(mm)	*L*(mm)
Input	100.3	297	0.7322	258	1117	0	3.7
Idler 1	100.38	305	0.7345	∞	1185	7.36	2.9
Idler 2	100.73	306	0.7297	∞	1194	17.9	2.9
Output	100.14	233	0.4645	155	1117	23.4	4.5

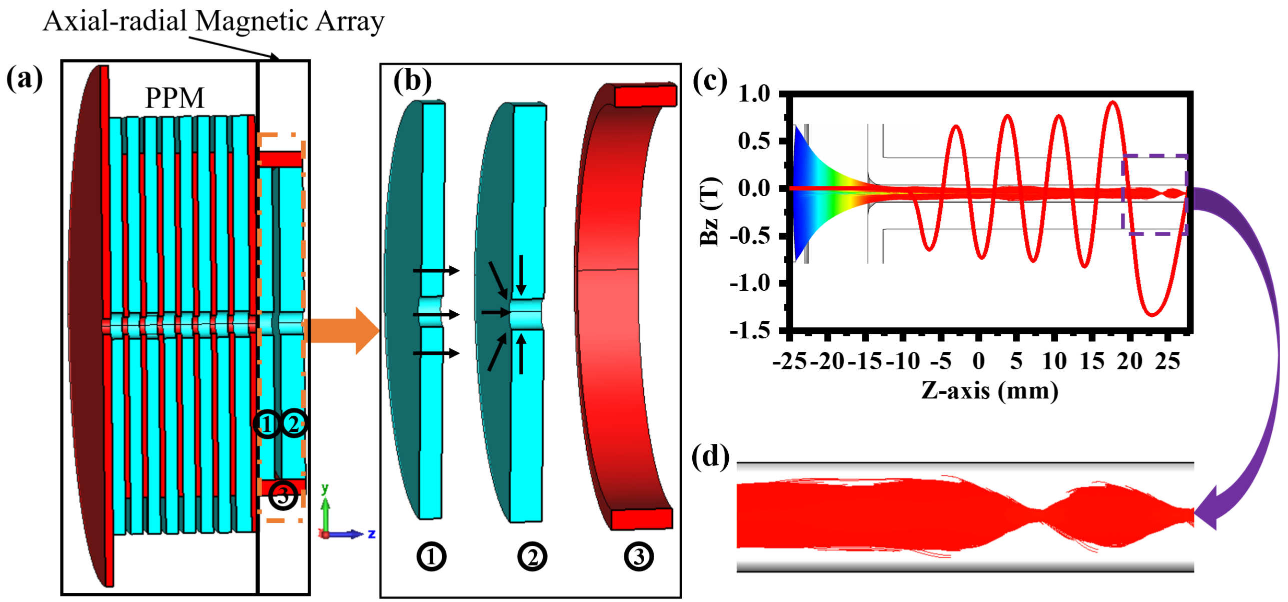
- **(a) Output and input signals**
- **(b) The bandwidth of KlyC and CST**



- **Electron gun and PPM bunching**



- **The 3D model of novel BOS**



- **3D PIC simulation of W-band EIK, conversion efficiency is close to 40%**

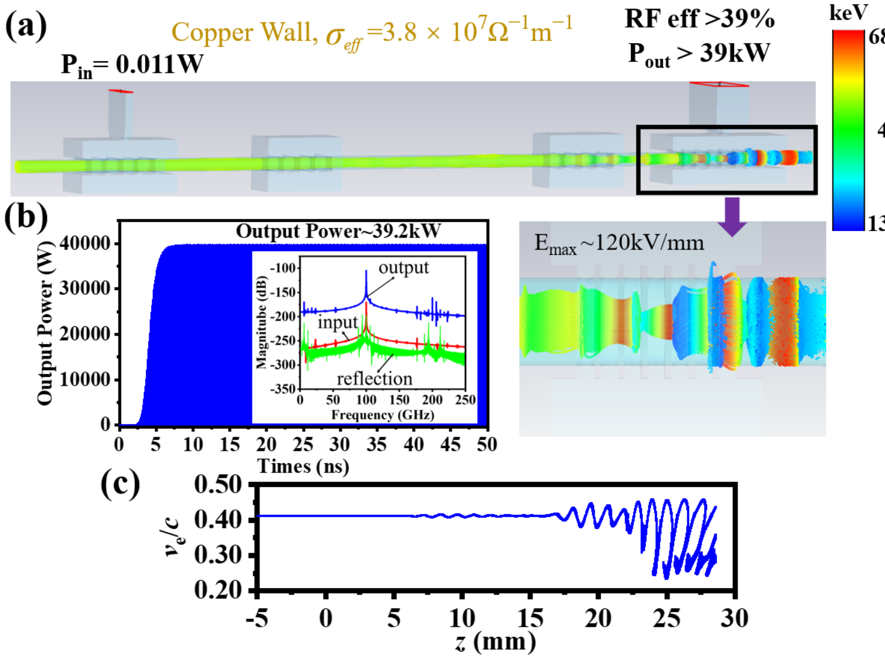
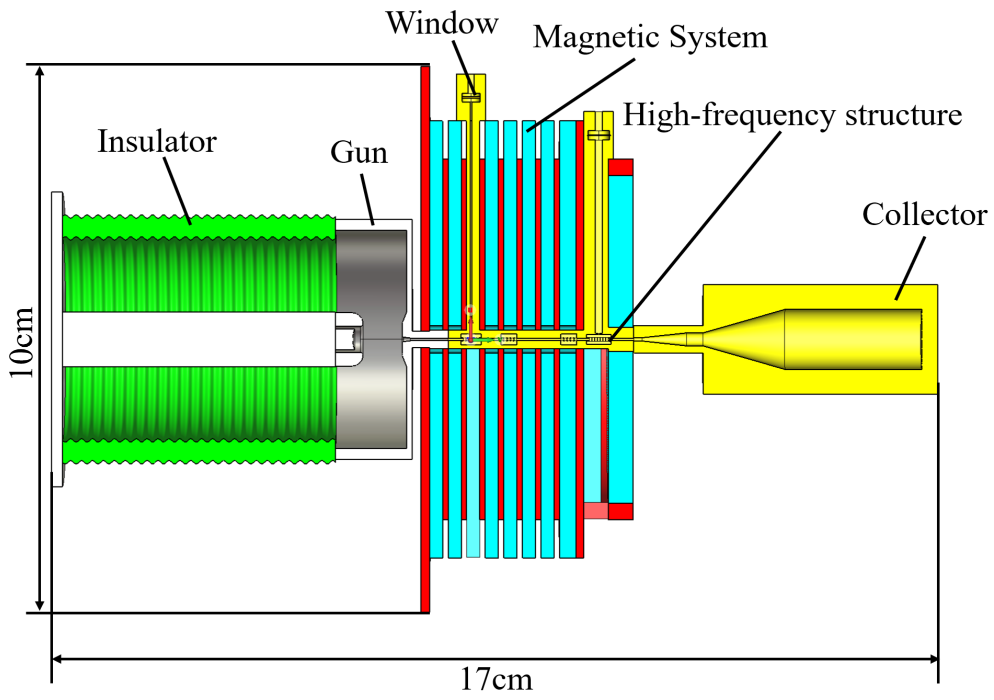


TABLE IV

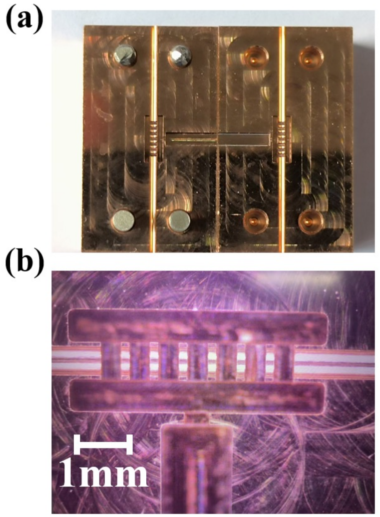
THE DESIGN PARAMETERS OF THE WHOLE EIK

Voltage (kV)	Current (A)	Maximum electronic efficiency	Maximum RF efficiency
50	2	44.5%	39.2%
Maximum RF power(kW)	Maximum electric field(kV/mm)	Gain (dB)	Bandwidth (MHz)
39.2	120	65.5	250
Beam transmission	Cathode current density(A/cm^2)	Length(cm)	Diameter (cm)
94.5%	17	17	10

- **Overall technical layout of 40kW W-band EIK**



- **Output cavity processing and cold test results**



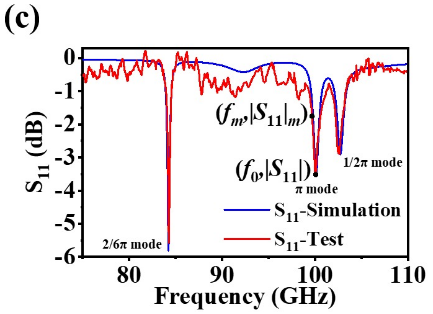


TABLE III

PARAMETER COMPARISON

		Numerical model	Measurement
	σ_{eff} ($\Omega^{-1}m^{-1}$)	3.8×10^7	3.8×10^7
Simulated eigenmode properties	f_0 (GHz)	100.13	100.07
	Q_e	140	140
	Q_0	920	911
properties calculated by $\lvert S_{11}\rvert$	f_0 (GHz)	100.16	100.07
	Q_e	139	140
	Q_0	732	725

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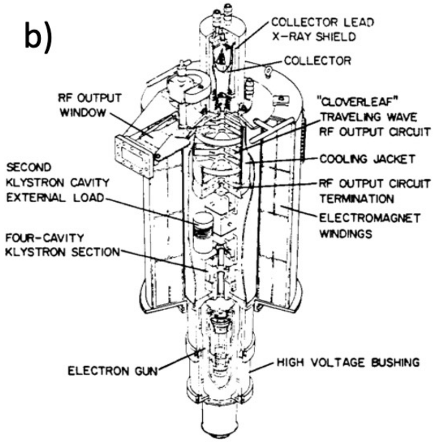
SW-TW hybrid device

a)

TYPICAL TWYSTRON AMPLIFIER CHARACTERISTICS

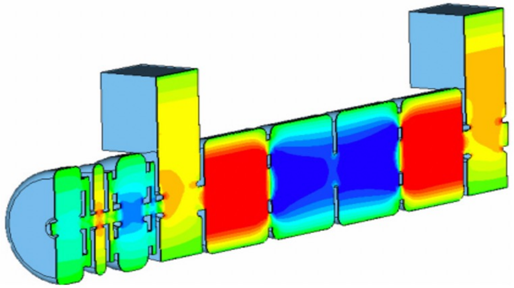
TUBE TYPE	VA-145	VA-915*	VA-146	VA-145LV
Frequency Bandwidth, GHz	2.7-2.9 2.9-3.1 3.0-3.2	3.1-3.6	5.4-5.9	3.1-3.5
Peak Power Output, MW	3.5	7.0	4.0	1.0
Average Power Output, kW	7.0	28.0	10.0	1.0
Pulse Width, μsec	10.0	40.0	20.0	50.0
Efficiency, %	35.0	30.0	30.0	30.0
Beam Voltage, kV	117.0	180.0	140.0	80.0
Beam Current, A	80.0	150.0	95.0	45.0
Drive Power, kW	0.3	3.0	2.0	1.0

b)

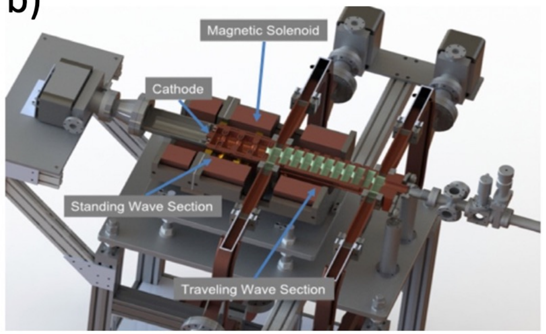


Twsytron, Varian Coporation, US, 1970

a)

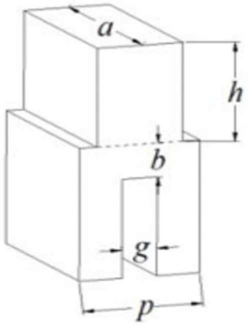


b)

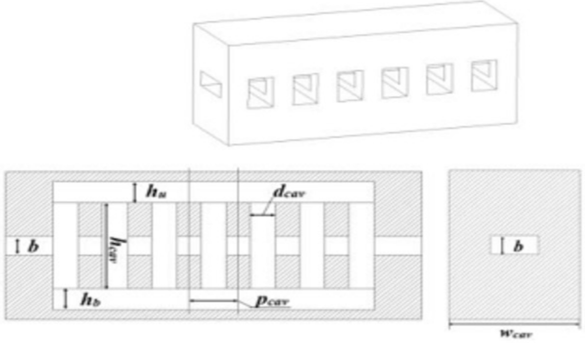


SW+TW RF GUN, UCLA&Roma Unv., 2011

a)

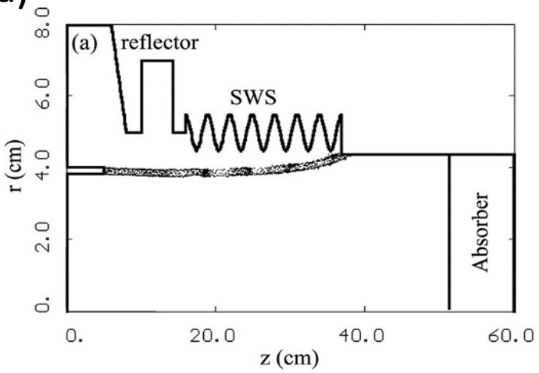


b)

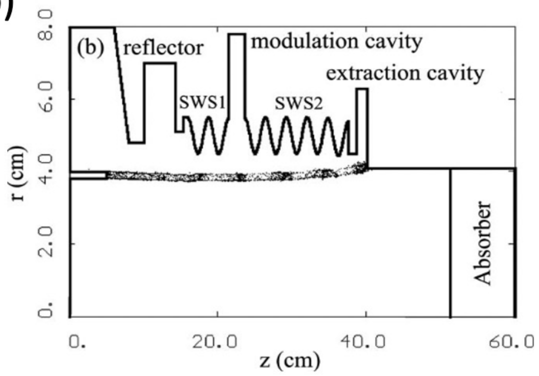


THz TWT, UESTC, China, 2020

a)



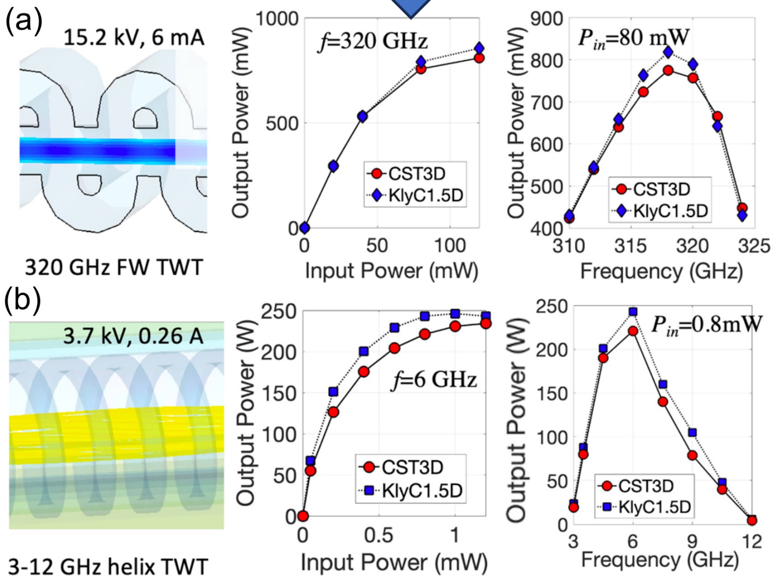
b)

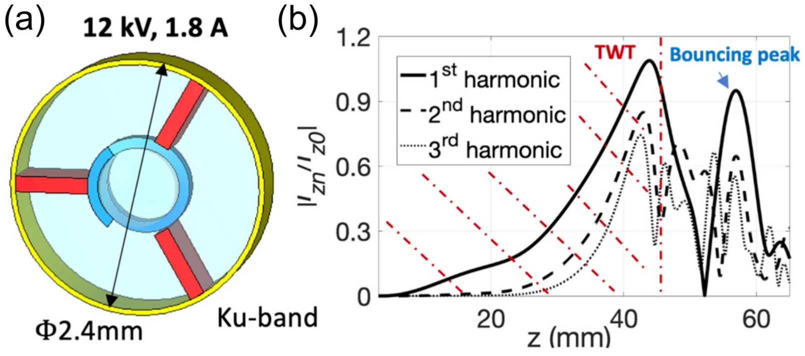


Klystron-like R-BWO, Northwest N.T, ., 2010

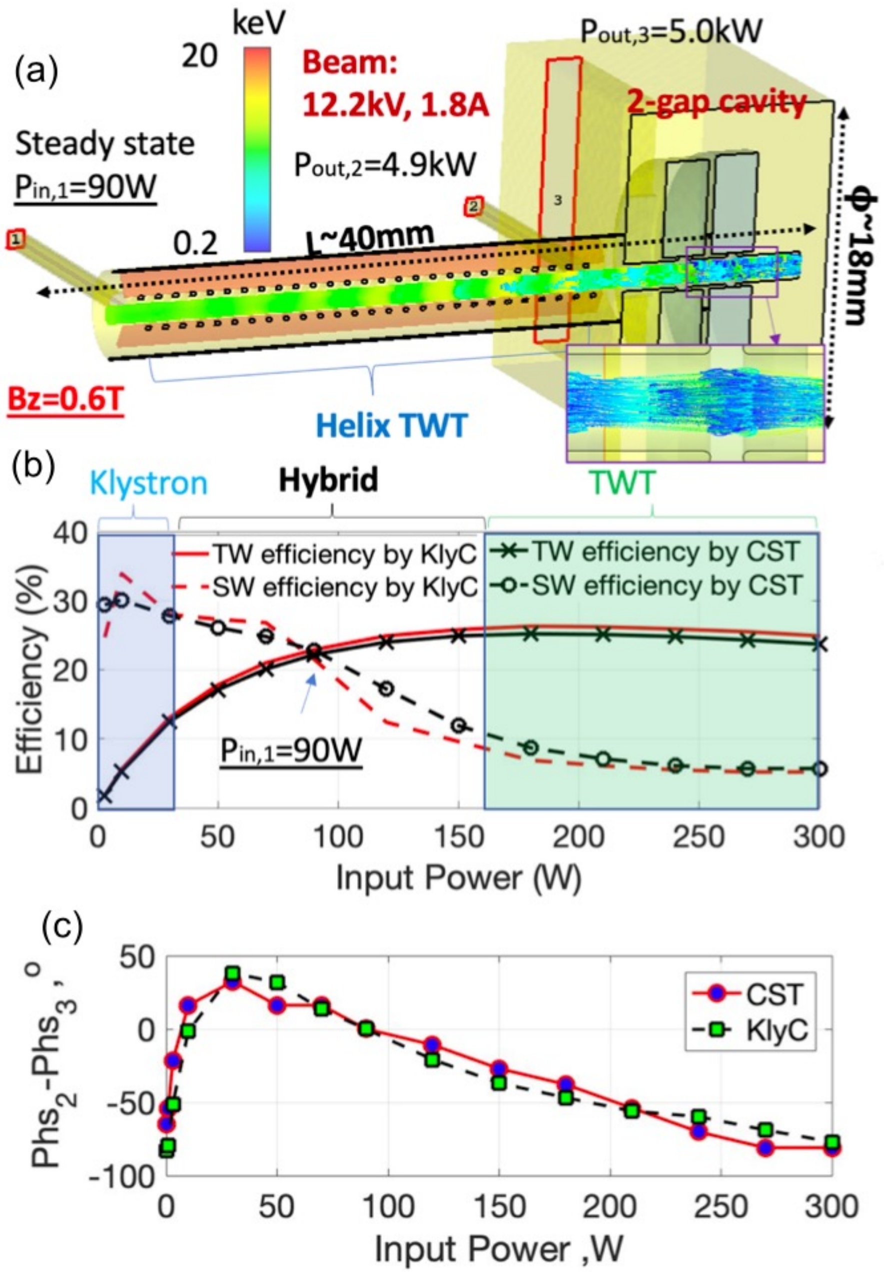
Novel hybrid device

Benchmark on TW module

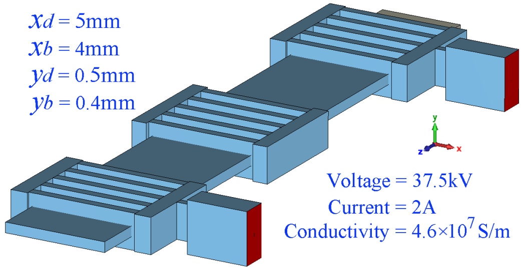




Secondary bunching process



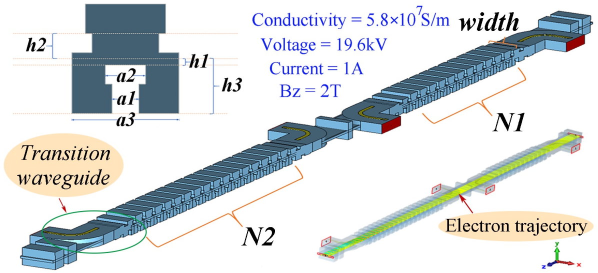
Accurate Space Charge Modeling for 1-D Large Signal Simulation of Sheet Beam TWTs

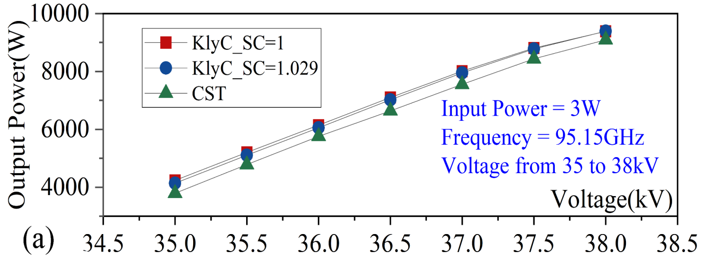


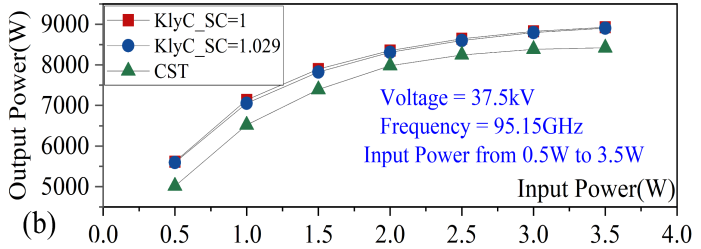
Benchmarking with CST-PIC

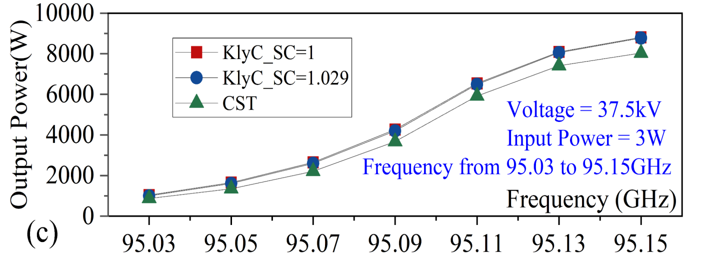
Extended interaction klystron

Traveling wave tube









Sc is very close to 1

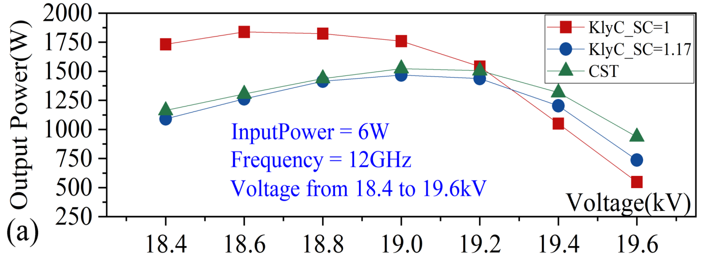
The output power curves of KlyC simulation code with and without modification are similar

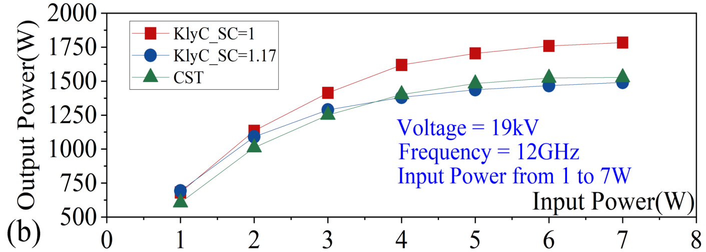
Acceptable to skip the proposed modification steps

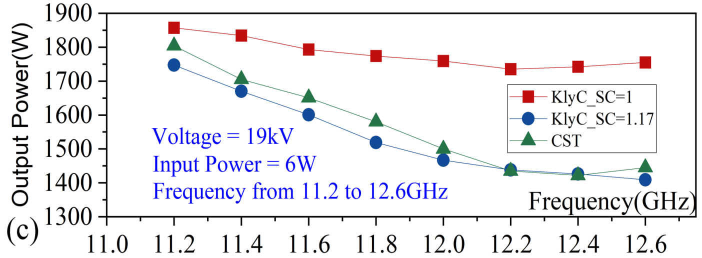
Sc is obviously greater than 1

The output curves of KlyC simulation code with modification are more consistent with that of CST

The accuracy of the large signal simulation is greatly improved by upgrading the space charge modeling.







Outline

- Problems to be solved
- Broaden the bandwidth of Klystrons
- Make high efficiency Klystron more compact
- Instabilities in High-gain Klystrons
- Fast design methodology of MBK optics
- Make terahertz Klystron more efficiency
- Novel hybrid TWT/Klystron devices
- Summary and outlook

Summary and outlook

- Lots of Work has been done in UESTC to address some critical issues in the development of Klystrons.
- KlyC has been updated to version 8 include more features (Small signal model, TWT module, Sheet beam module, etc) for more general purpose.
- Prototype of high efficiency S-band 5MW MBK is being developed at home, which will be reported in the next few month.

Thanks for your attention!

CGUN

Version 8