中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

CEPC 650MHz High-Efficiency Klystrons and MBKs

Zhou Zusheng

zhouzs@ihep.ac.cn

On behalf of CEPC RF power source team

Nov. 9, 2021

Outline

◆**Design consideration**

◆**R&D Status**

① High efficiency klystron fabrication

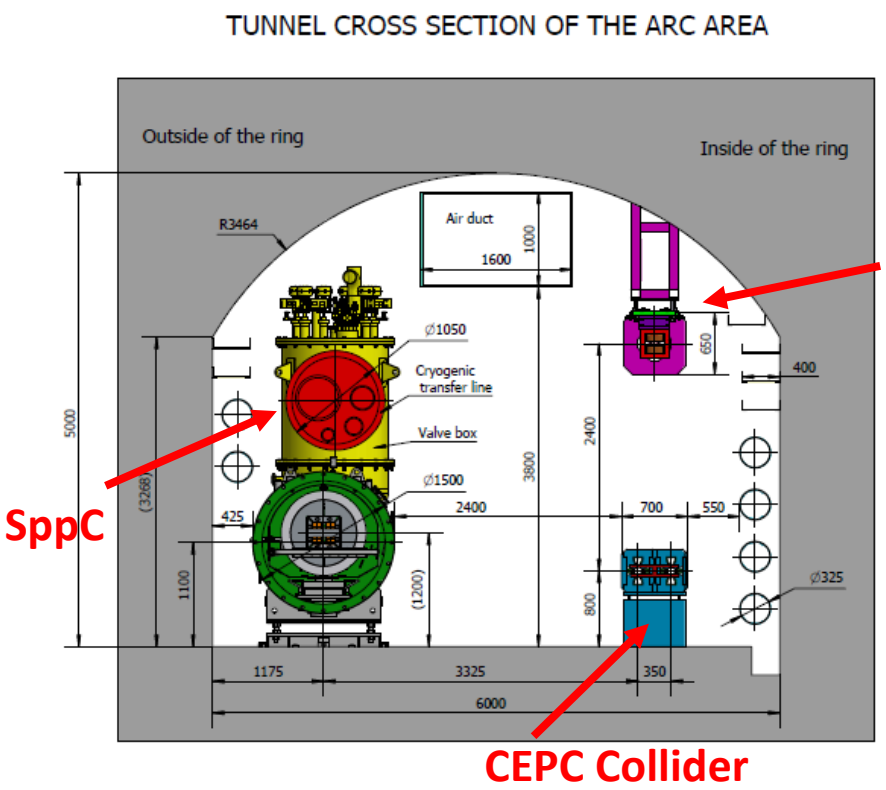
② MBK design

③ High power test stand preparation

◆**Summary**

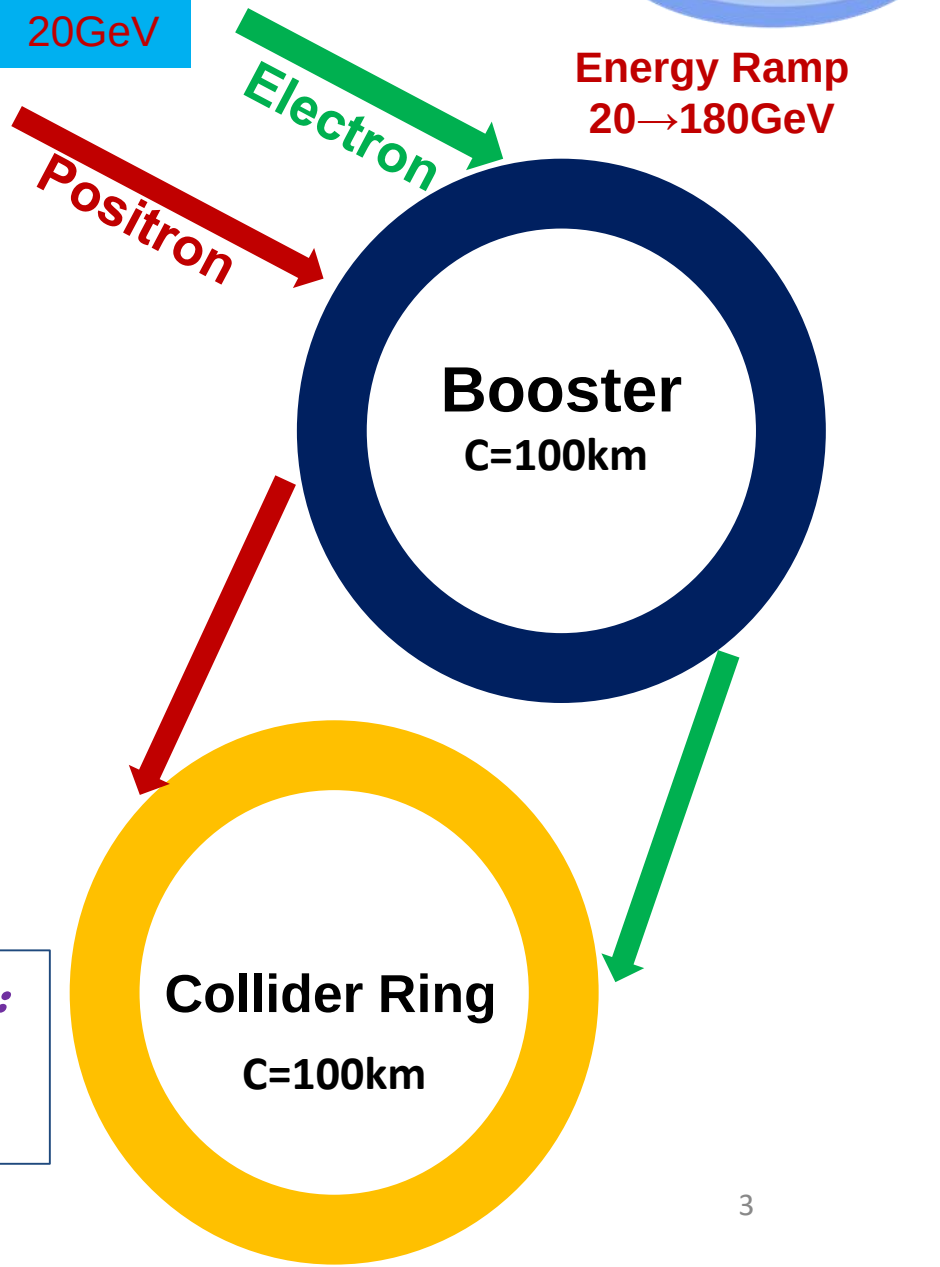
Design consideration

High power RF sources are required to provide the energy needed to accelerate particles or keep particles energy stable.



Three rings in the same tunnel：

- *CEPC Collider & Booster*
- *SppC*



中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

CEPC

The Collider beam power is more than 60 MW. The increase in efficiency of RF power sources is considered a high priority issue.

RF power sources - efficiencies

	Tetrodes	IOTs	Klystrons	SSA	Magnetrons
f range:	DC–400MHz	(200–1500)MHz	300 MHz – 1 GHz	DC – 20 GHz	GHz range
P class (CW):	1 MW	1.2 MW	1.5 MW	1 kW @ low f	< 1MW
typical η:	85% - 90% (class C)	70%	65%	60%	90%
Remark	Broadcast technology, widely discontinued			Requires P combination of thousands!	Oscillator, not amplifier!

High power klystrons are the more attractive choice because of their high efficiency, low cost and more stable than IOT and SSA for CEPC collider.

System overall efficiency

CEPC Collider SRF Wall Plug Efficiency

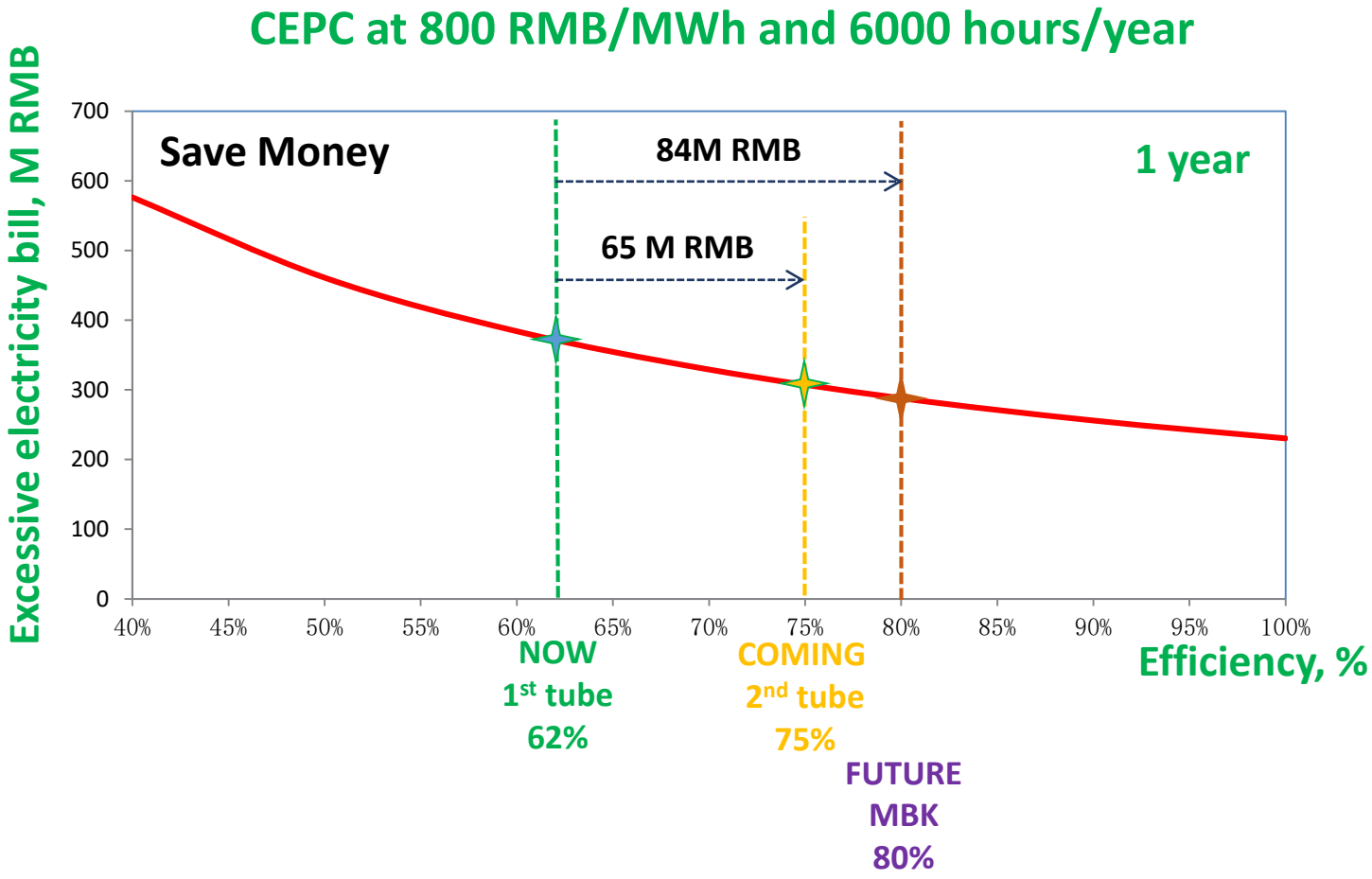
Wall to PSM power supply/modulator	95%
Modulator to klystron	96%
Klystron to waveguide	70%
Waveguide to coupler	95%
Coupler to cavity	~100%
Cavity to beam	~100%
Overall efficiency	**~60.6%**

Saturation: 80%
Linear region: 70%

The critical factor is klystron efficiency

Much higher efficiency, less energy consumption.

Efficiency impact on operation cost (Only considering operation efficiency of klystrons)



中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

CEPC

R&D Status

Design goal

- *The vast majority of the existing commercial klystrons in the electronic efficiency range between **40%** and **55%**. Only a few klystron available on the market are capable of operating with about **65%** efficiency or above.*
- *In a recent **theoretical calculation**， more than **80%** RF power conversion efficiency is achieved in CW klystron. **Considering this recent high efficiency approach, our design goal is to achieve around 80% on saturation point**.*

CEPC Klystron Key Design Parameters

Parameters	Units	Values
Centre frequency	MHz	650±0.5
Output power	kW	800
Efficiency(Goal)	%	80(70 linear)

① High efficiency klystron

a) *The high efficiency klystron prototype is being fabricated in Chinese company.*

b) *The klystron prototype has been completely manufactured and being baking out in the baking furnace. It will be delivered to PAPS site for high power conditioning and test next month.*

① High efficiency klystron

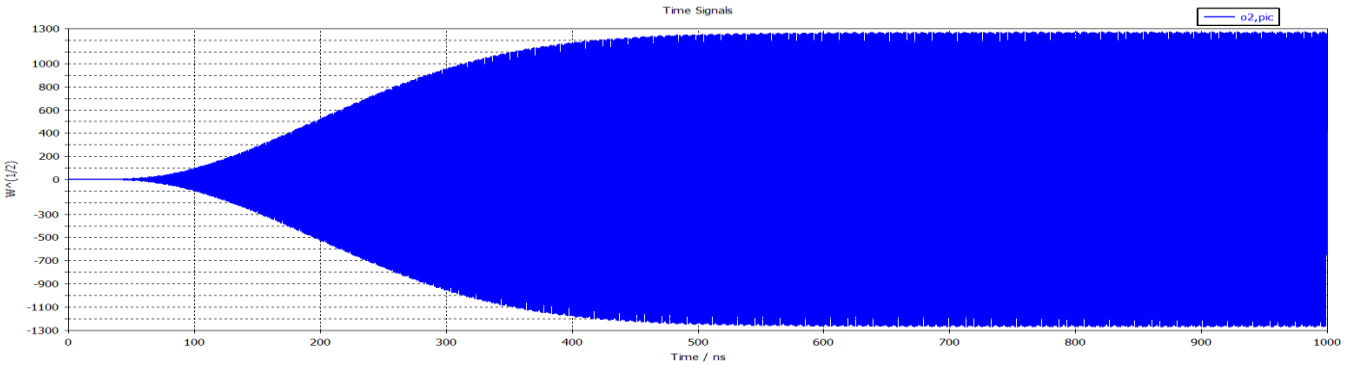
Design parameters

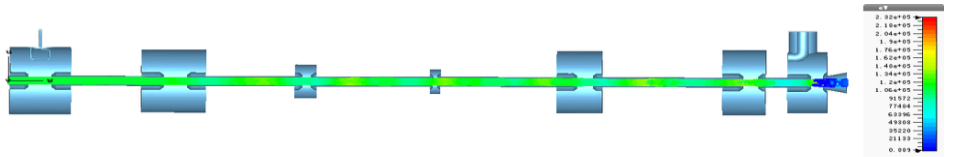
① *CST 3D efficiency: 77%*

② *Output power: 808.3kW(Beam power 1.05MW)*

③ *Gain(3D): 48.3dB*

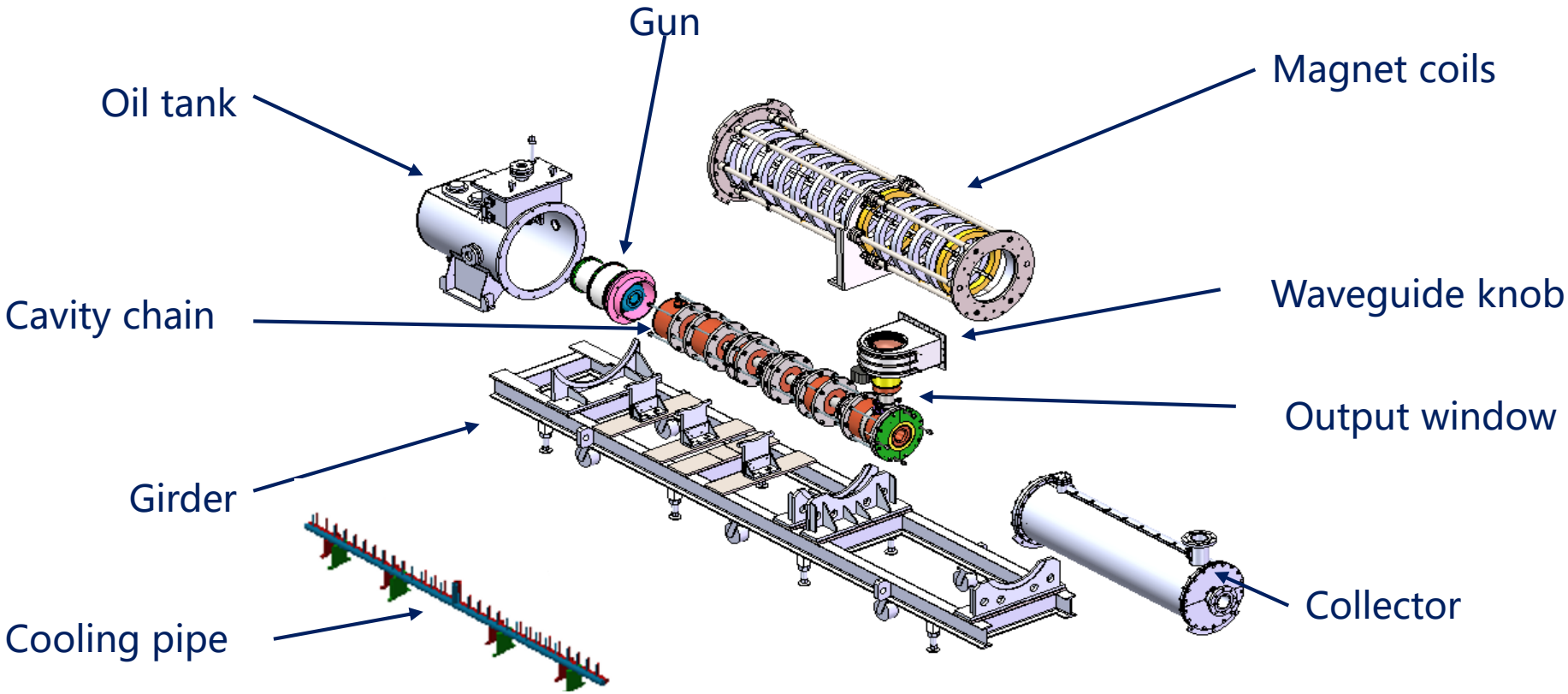
④ *Bandwidth(2.5D): ≥0.8MHZ*





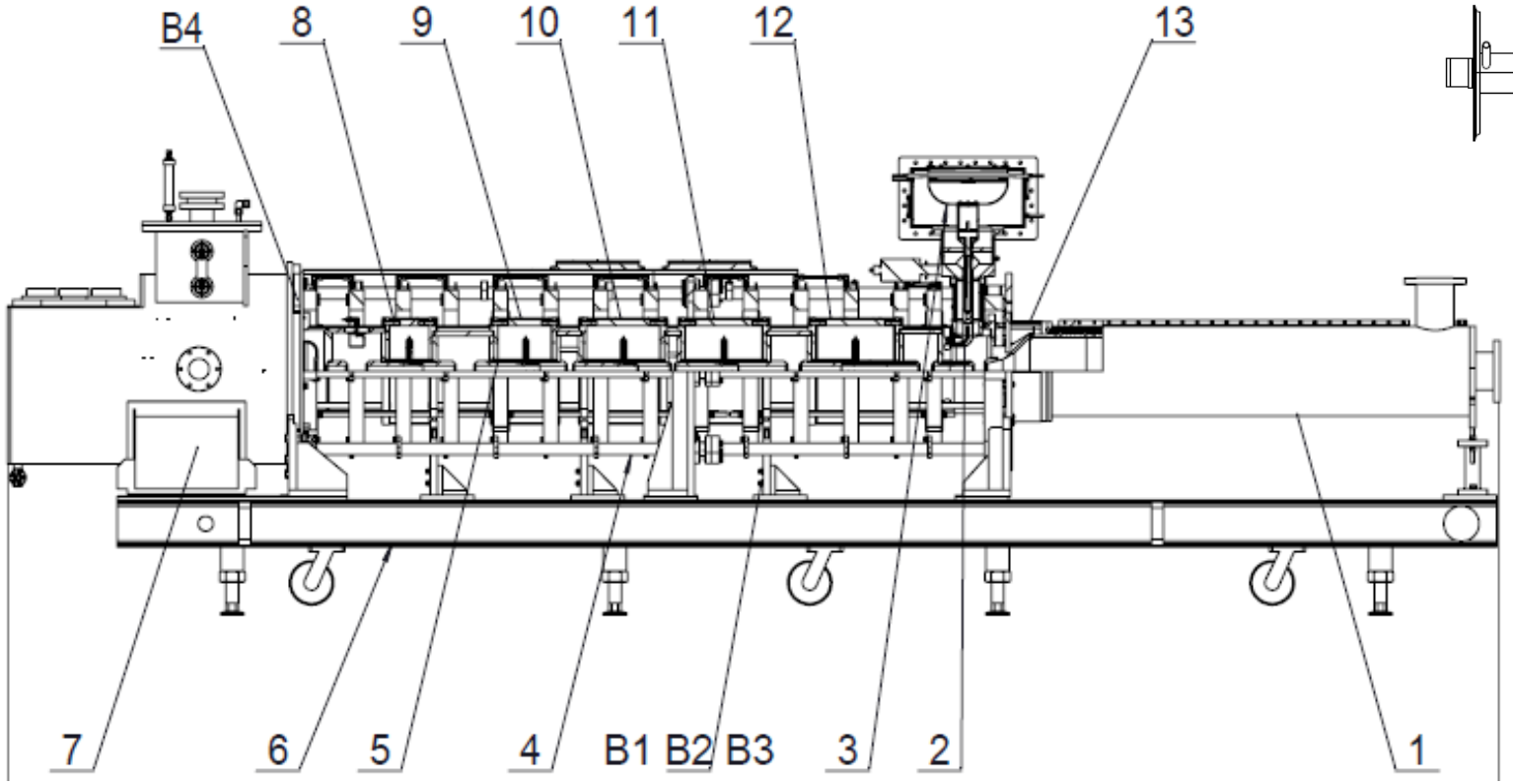
Mechanical design

After completing mechanical design at the end of 2020, klystron prototype manufacture is collectively started.

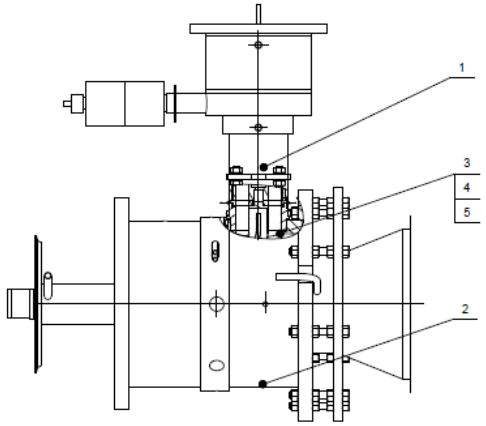


Klystron parts

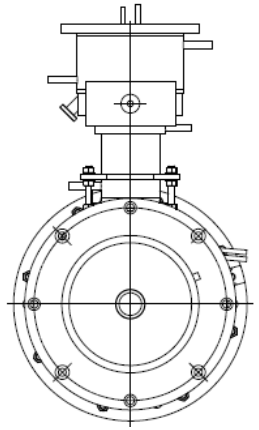
Mechanical drawing

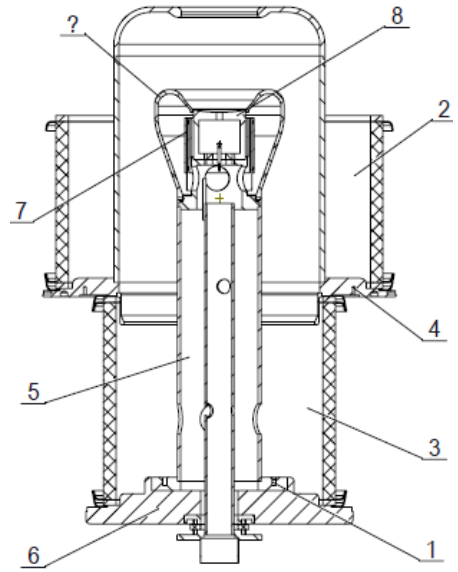


Klystron layout



Cavity





Gun

Fabrication status

Electron gun

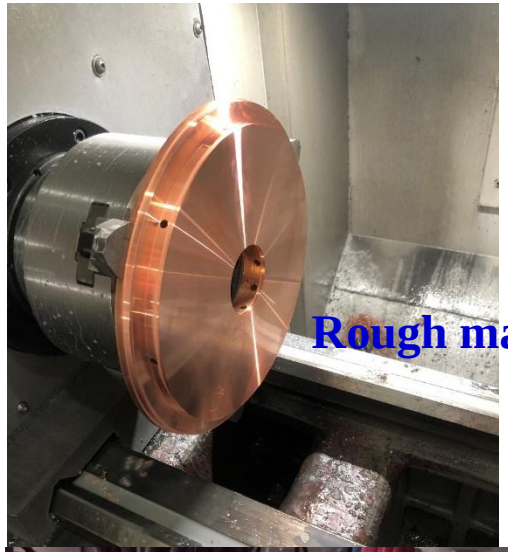
Ceramic insulator

Focusing electrode

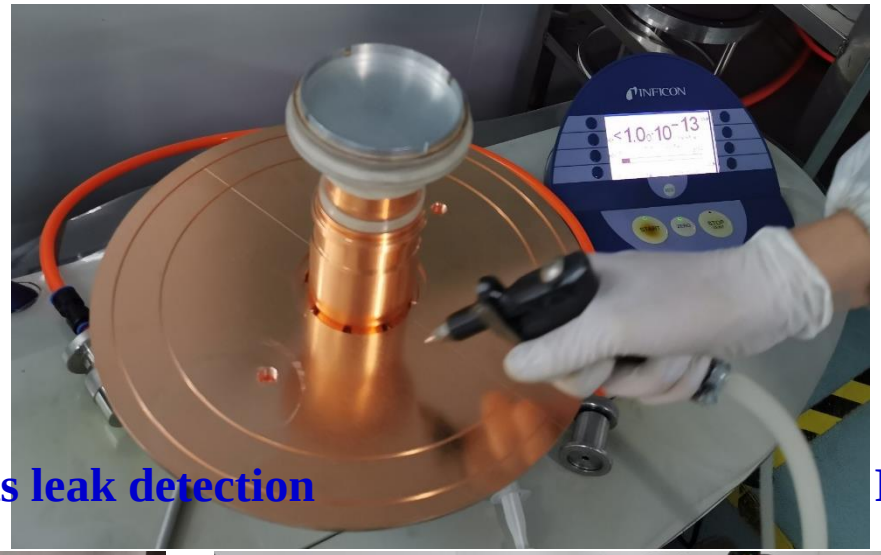
Modulator anode

Cathode Assy.

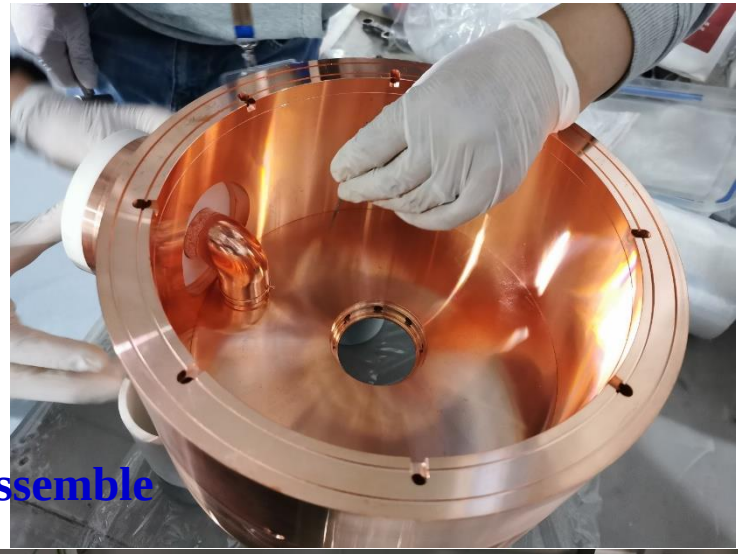
Fabrication status



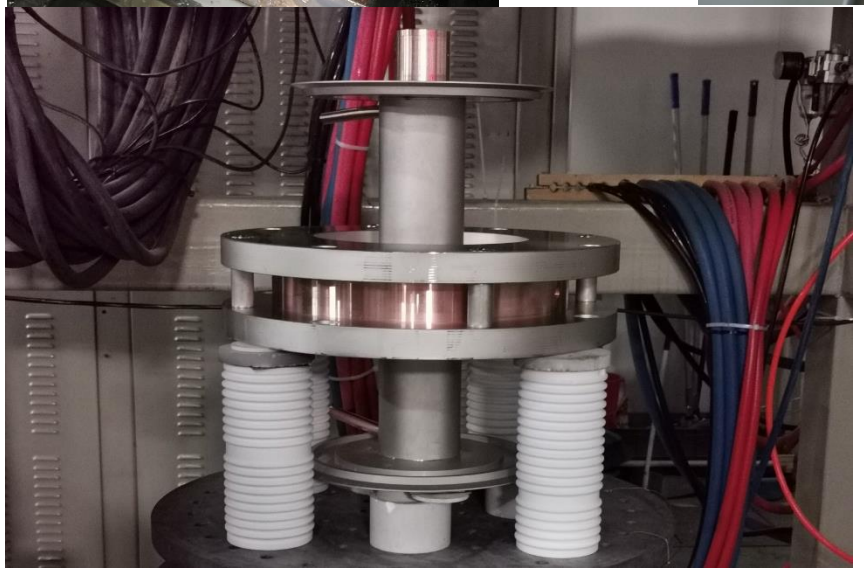
Rough machining



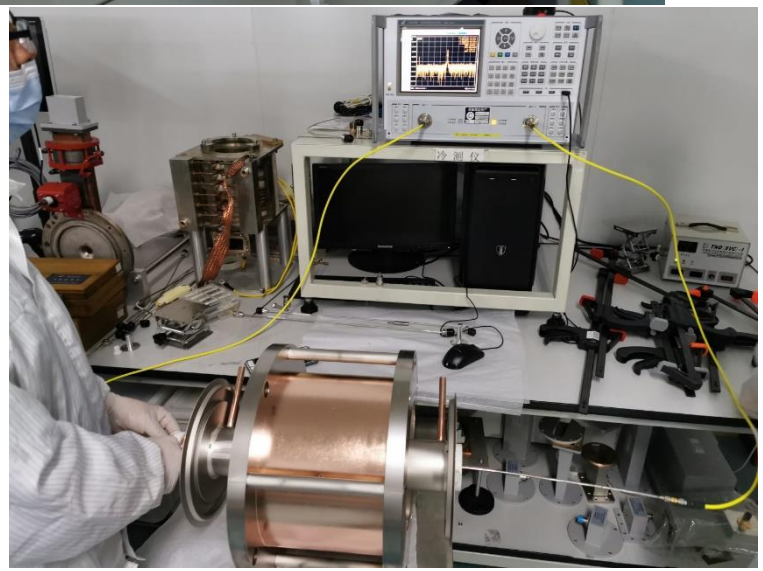
Parts leak detection



Parts assemble



Cavity brazing



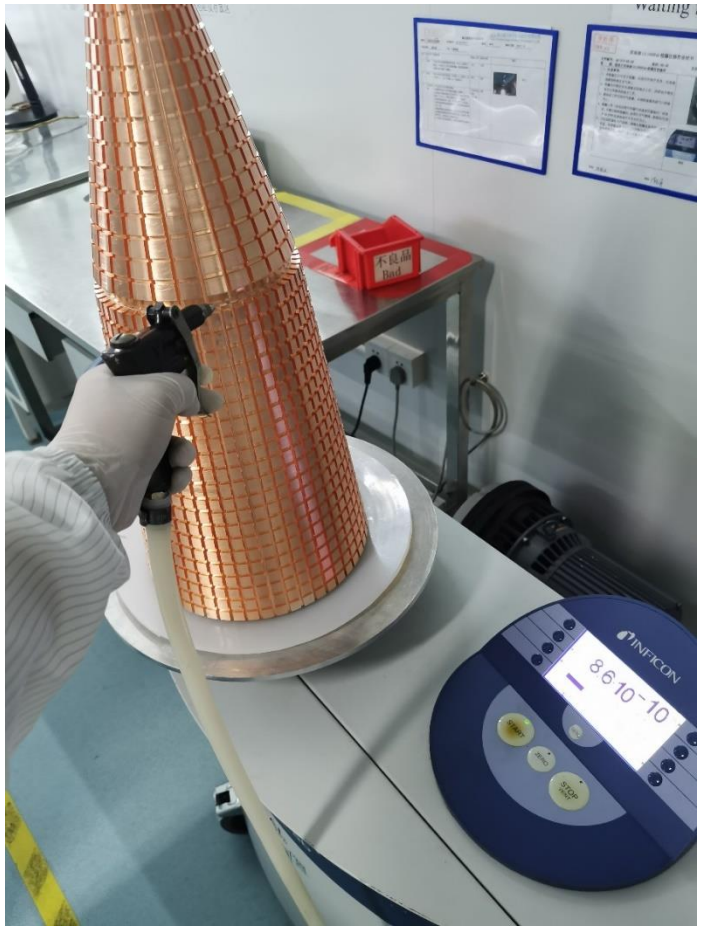
Cold test

Storage with nitrogen

Fabrication status

Collector

Collector body



Water jacket

Fabrication status

Focusing magnet

Fabrication status

Klystron girder and oil tank

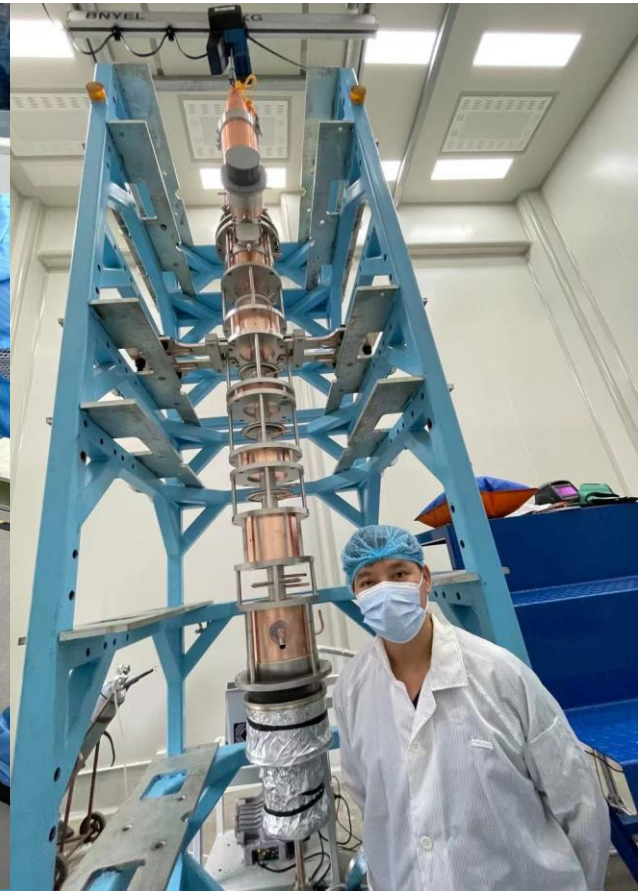
Electron gun processing

Cathode Temp. 975 degree C @Fil. 27V/6A

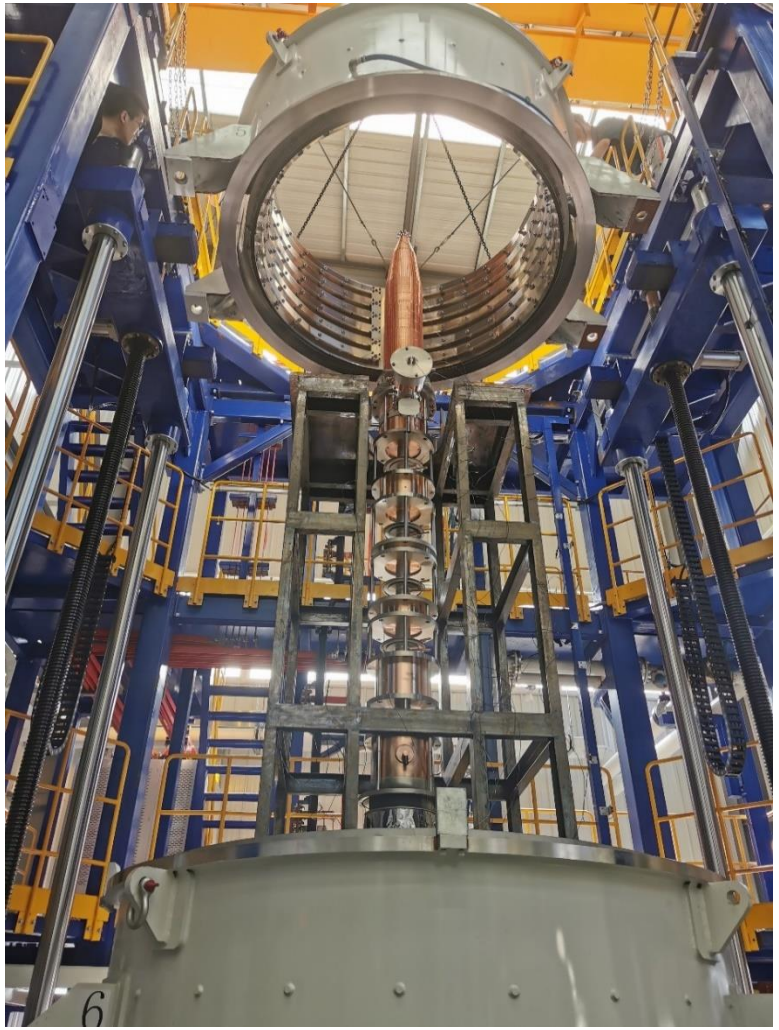
Klystron final assembly

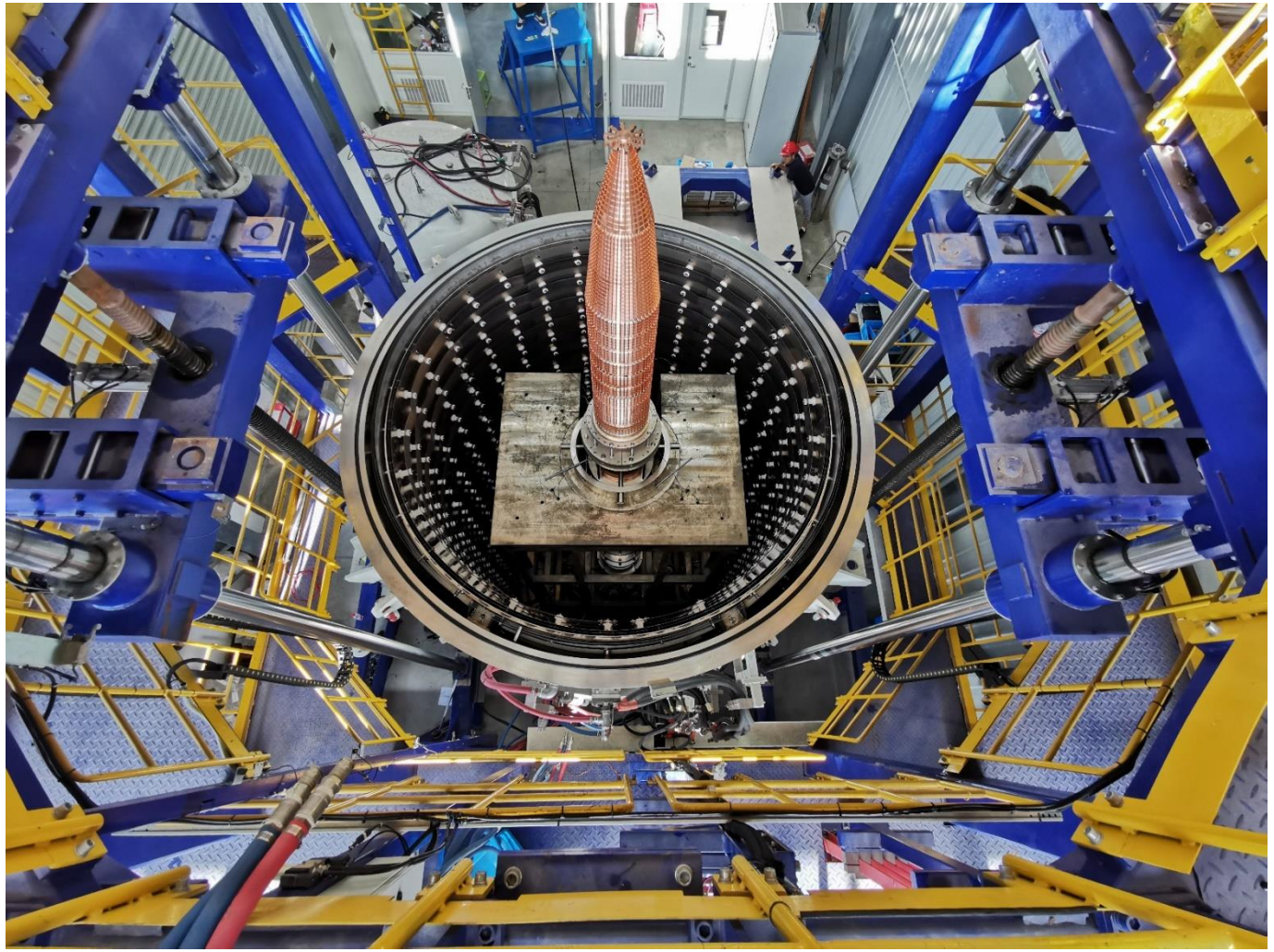
Klystron final assembly



Klystron baking out





② Multi-beam klystron

1) Design Parameters

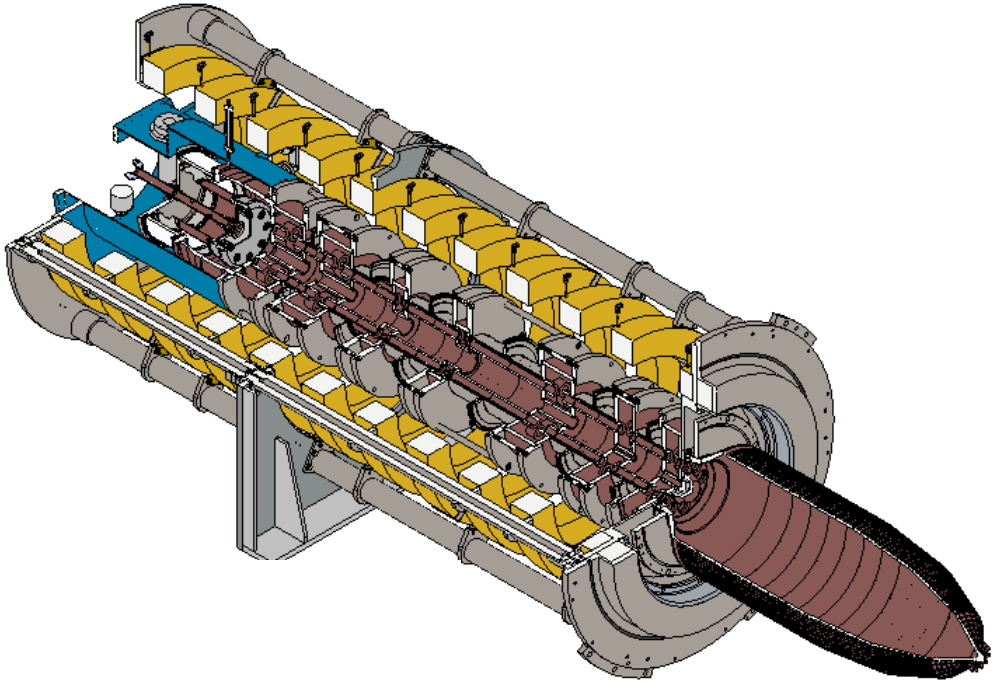
Parameters	Unit	Value
Gun Voltage	kV	54
Beam number		8
Beam perveance	μP	0.2
Output power	kW	800
1dB bandwidth (3-D simulation)	MHz	±0.75
Efficiency(3-D simulation)	%	80.5

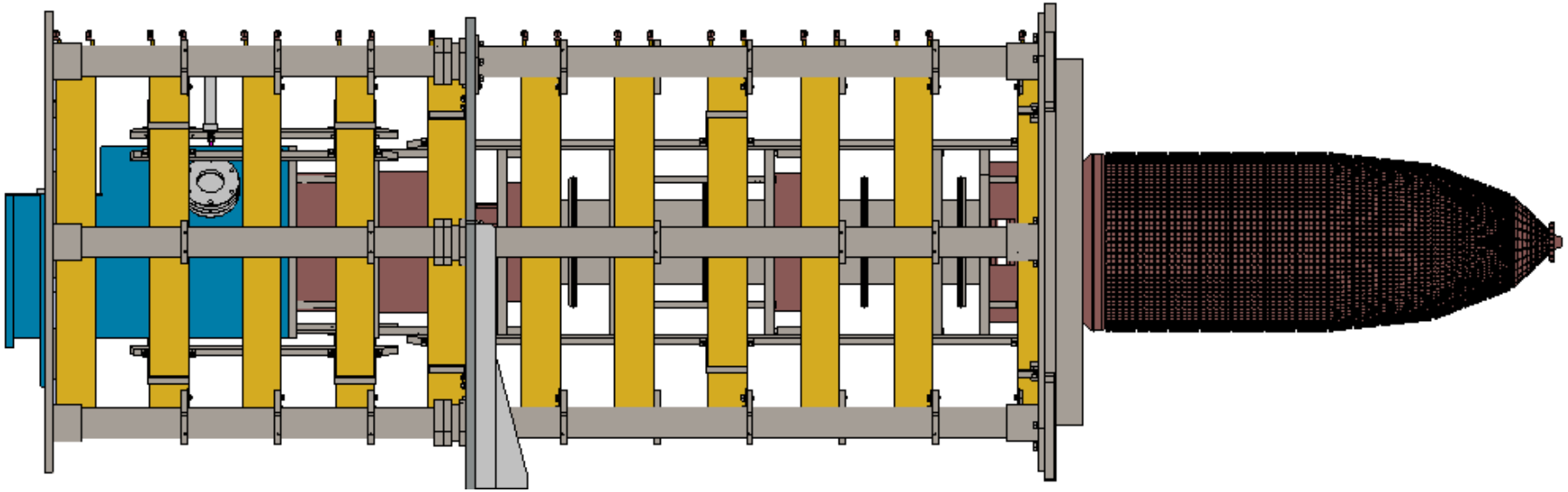
The MBK physical design is finished, including the interactive cavity, electron gun, focusing solenoid, window and collector. The final efficiency is about 80.5% with 3d simulation code.

② Multi-beam klystron

2) 3d mechanical drawing

- The preliminary 3d mechanical drawing is finished.





② Multi-beam klystron

3) Design review meeting

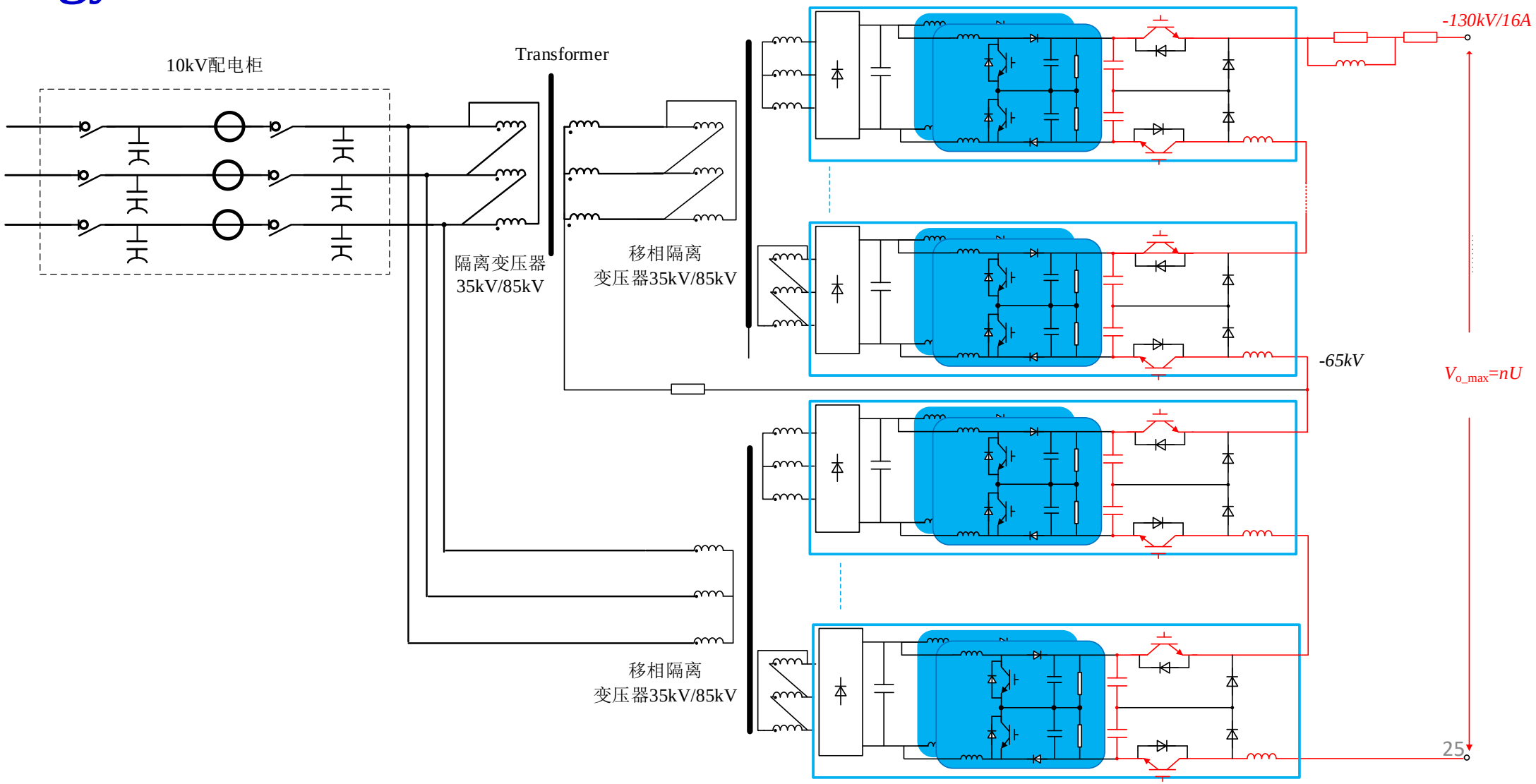
③ High power test stand

Design parameters

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Cathode Voltage (kV)	54	100	110	120	130
Beam current (A)	20	10.6	9.3	8.3	7.6
Operation Mode	Pulsed & DC				
Pulsed Width	500μs~DC				
Repetition Rate	0.1～100Hz				
Duty Factor	0～100%				
Power Supply Efficiency	≥97%				

③ High power test stand

Topology scheme



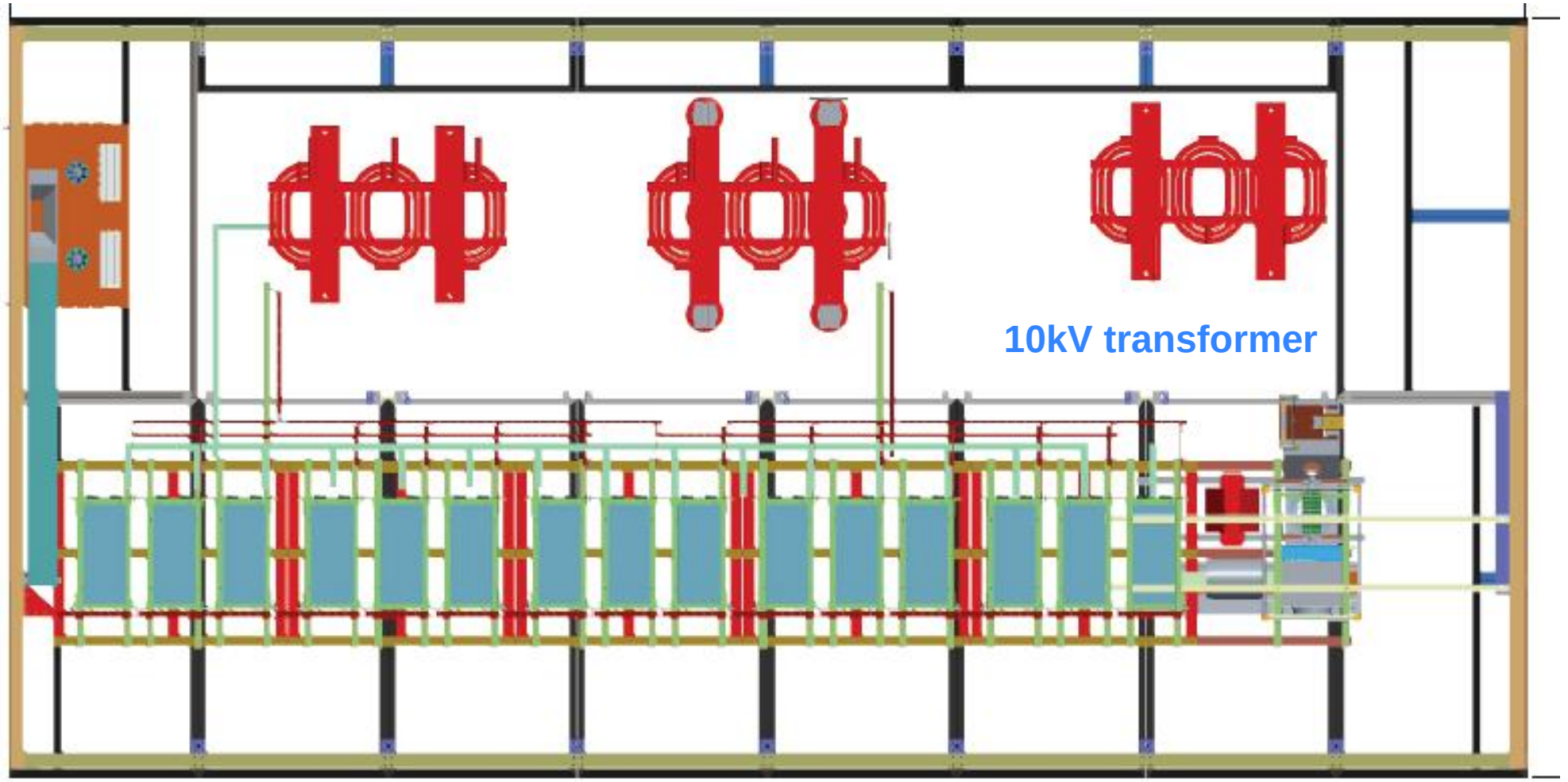
③ High power test stand

Design effect picture

③ High power test stand

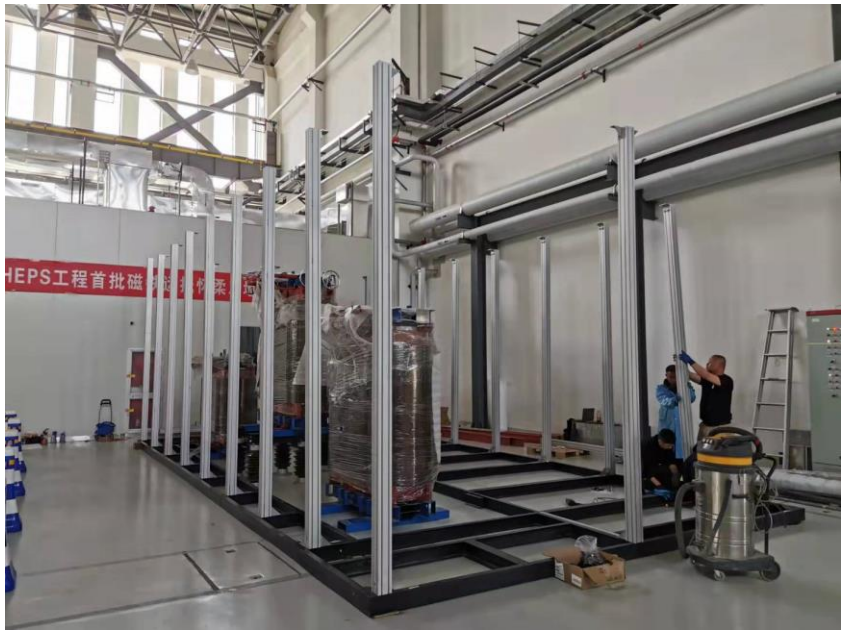
Top view

Control cabinet



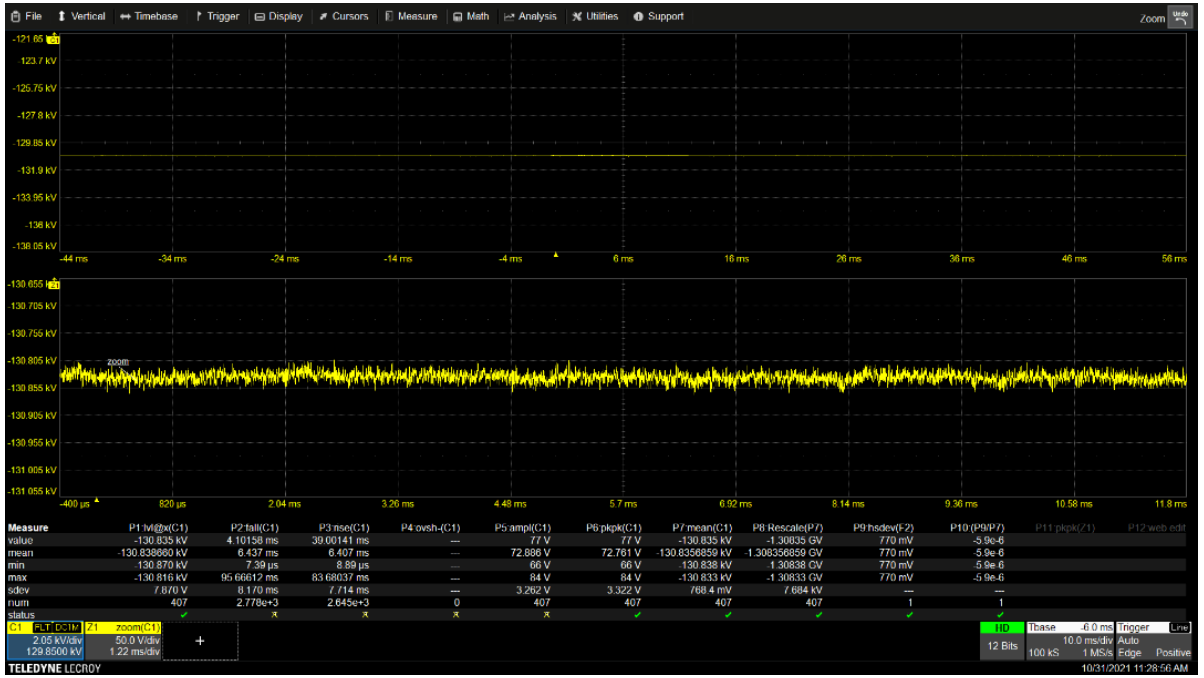
③ High power test stand

Site installation and test

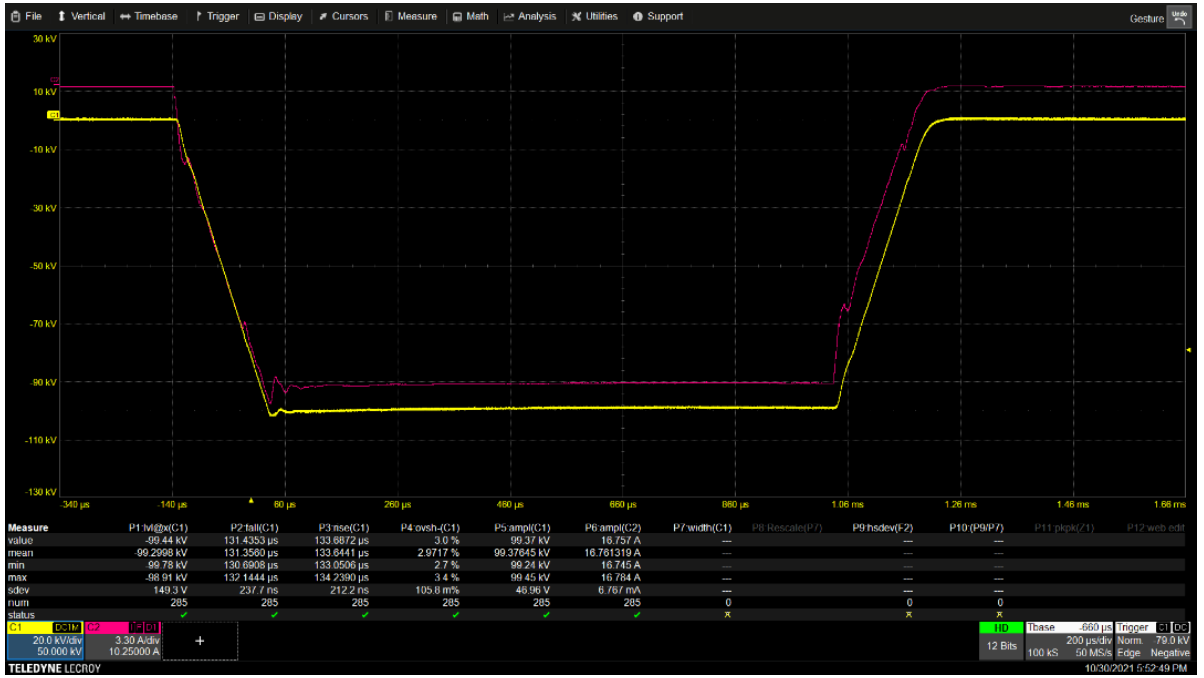


③ High power test stand

Test results



DC operation mode



Pulsed operation mode

③ High power test stand

130kV/16A PSM power supply is located in PAPS site and ready for klystron high voltage conditioning and test in the near future.

PSM Power Supply @PAPS site

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Summary

- *The increase in efficiency of RF power sources is considered a high priority issue.*
- *The manufacture of high efficiency klystron prototype will be completed at the end of next month.*
- *MBK will be immediately manufactured after design refine.*
- *The high voltage power supply is ready for test stand.*

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

CEPC

Thanks for your attention!