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

Progress on CEPC RF power source system

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On behalf of CEPC RF power source team

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Outline

◆**Design consideration**

- Collider
- Booster
- Linac injector

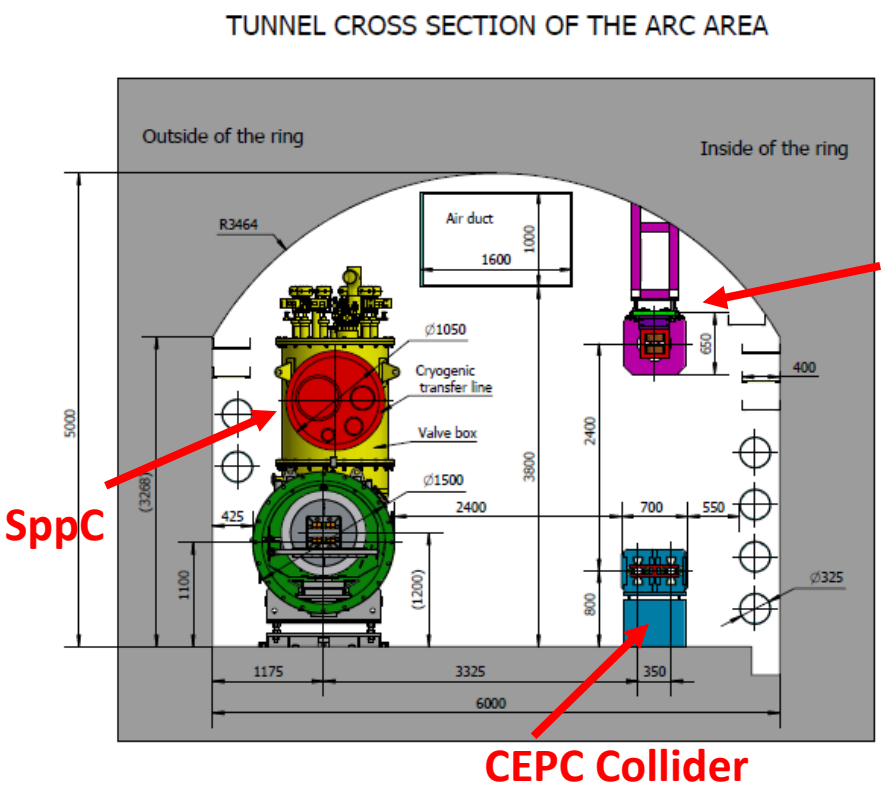
◆ **R&D Progress**

- High efficiency klystron fabrication
- MBK design

◆**Summary**

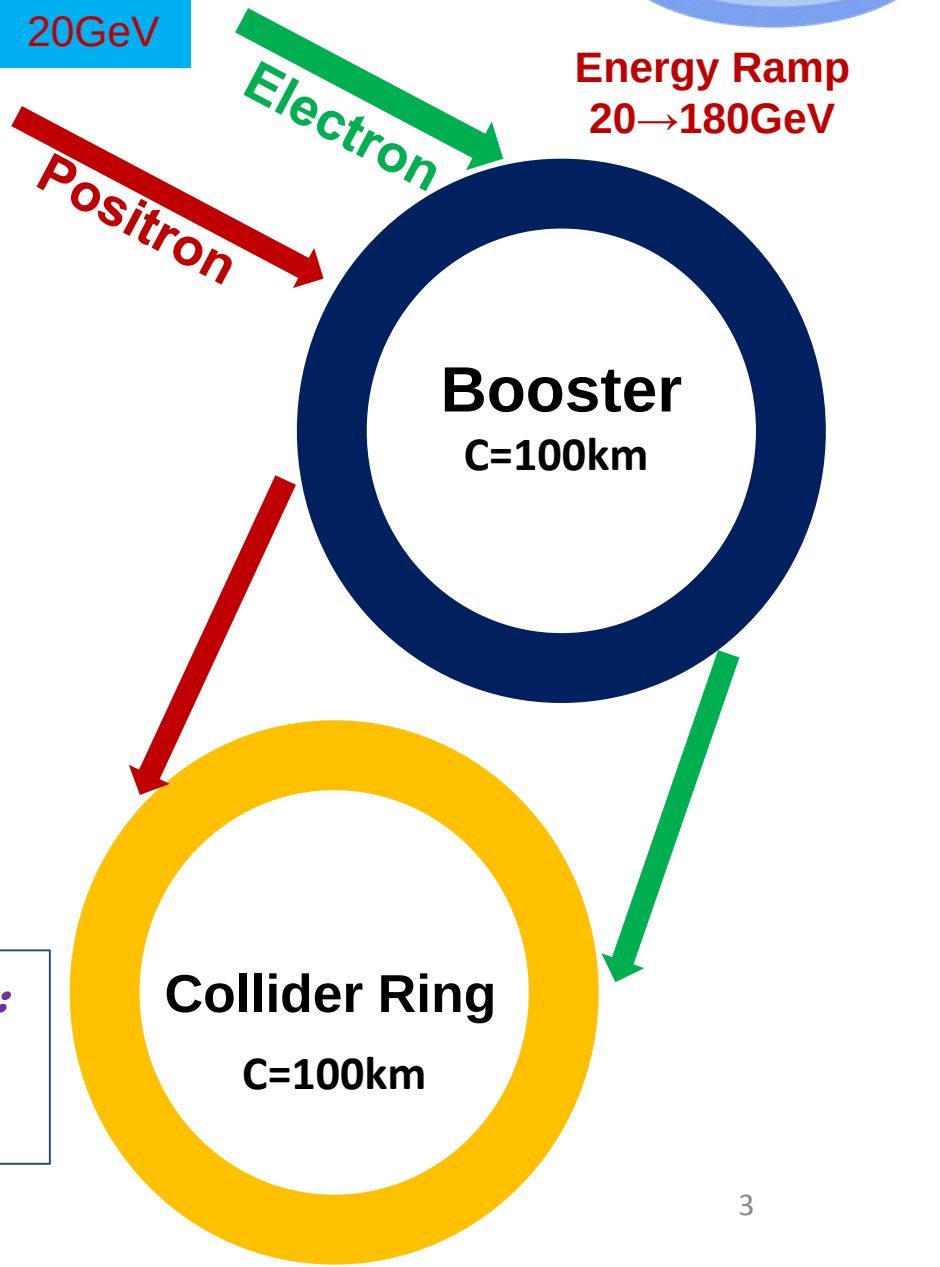
Design consideration

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*



Collider

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.

Collider

System overall efficiency

CEPC Collider SRF Wall Plug Efficiency

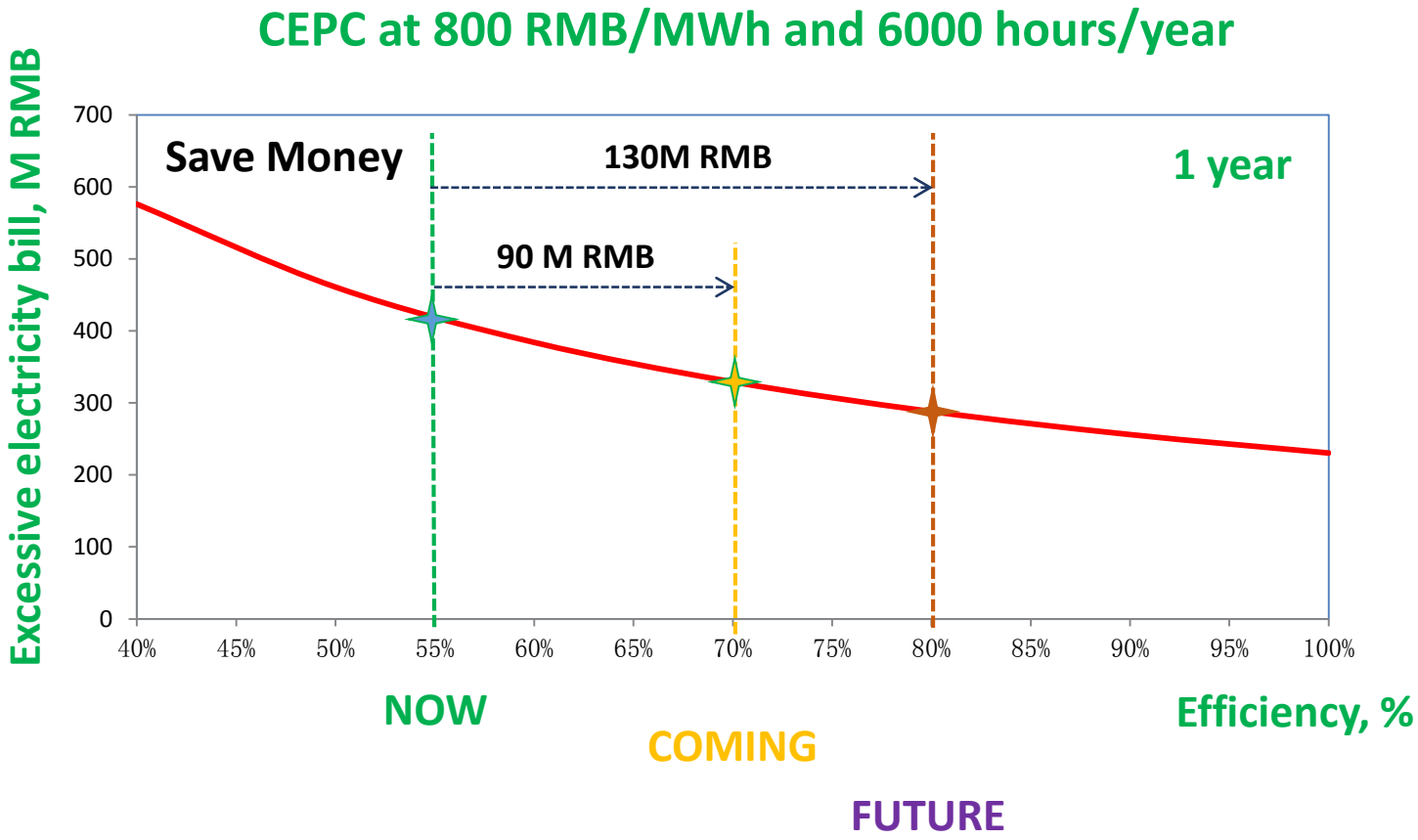
Wall to PSM power supply/modulator	95%
Modulator to klystron	96%
Klystron to waveguide	70%
Waveguide to coupler	95%
Coupler to cavity	~100%
Cavity to beam	~100%
Overall efficiency	**~60.6%**

The critical factor is klystron efficiency

Much higher efficiency, less energy consumption.

Collider

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



Transmission system

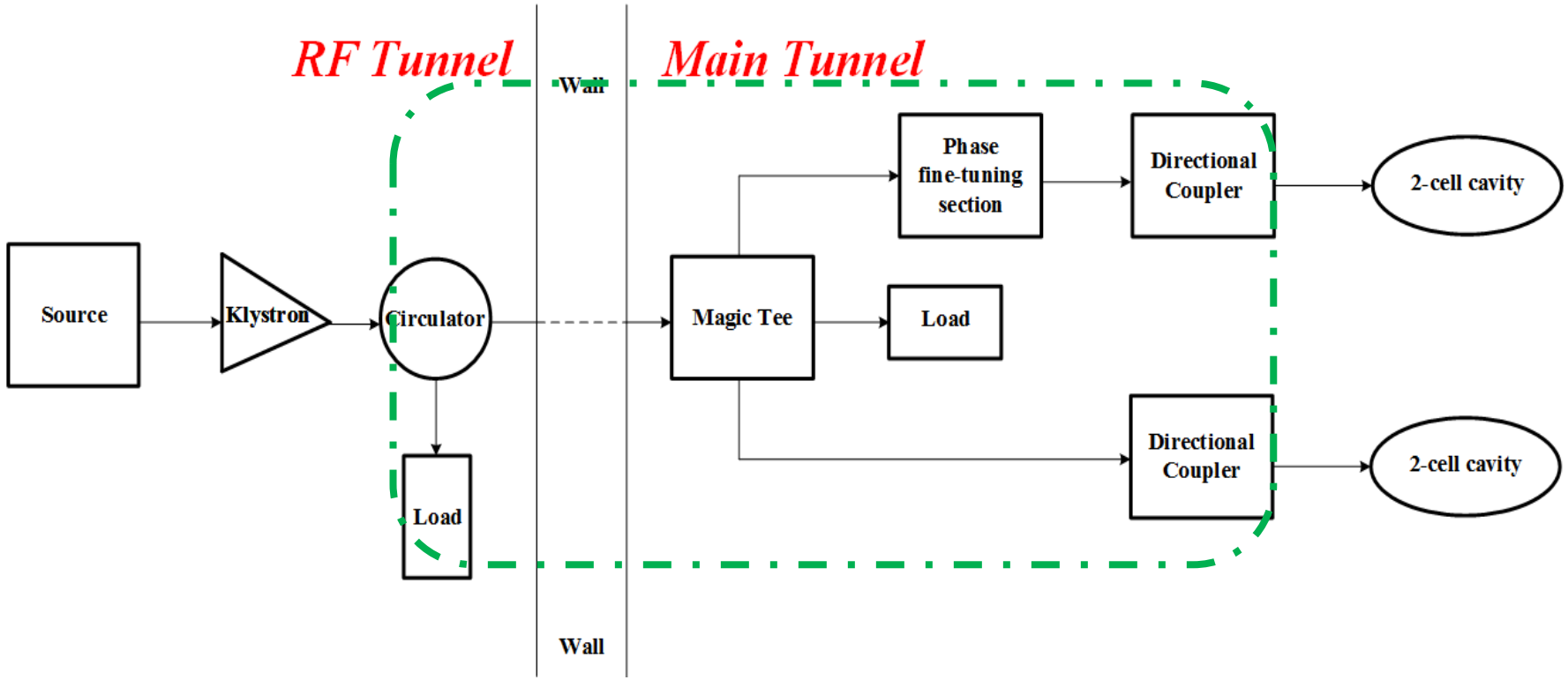
Superconducting Cavity power demands

Parameters	Value
Freq.(MHz)	650+/-0.5
Cavity No.	240
Coupler input power(kW)	300

- *Considering klystron lifetime, power redundancy and cost, the **2 cavities will be powered with one CW klystron** capable to deliver more than 800 kW.*
- *Distribution of RF power (800kW) to the cavities (300kW), including **waveguide, power divider, phase shifter, circulator and load**.*
- *Other Auxiliary PS, Interlock and Controls, LLRF, Pre-amplifier.*

Transmission system

Schematic of the RF Transmission System (RFTS)



PSM Power supply

PSM Design Parameters

Parameters	Units	Values
High voltage	kV	**130**
Current	A	**16**
Module quantity		168
Module voltage	V	800
Module switch frequency	Hz	1k
Module number of redundancy		9
Voltage stability	%	< 0.2
Efficiency	%	>95
Turn-off time	us	<5
Stored energy	J	<20

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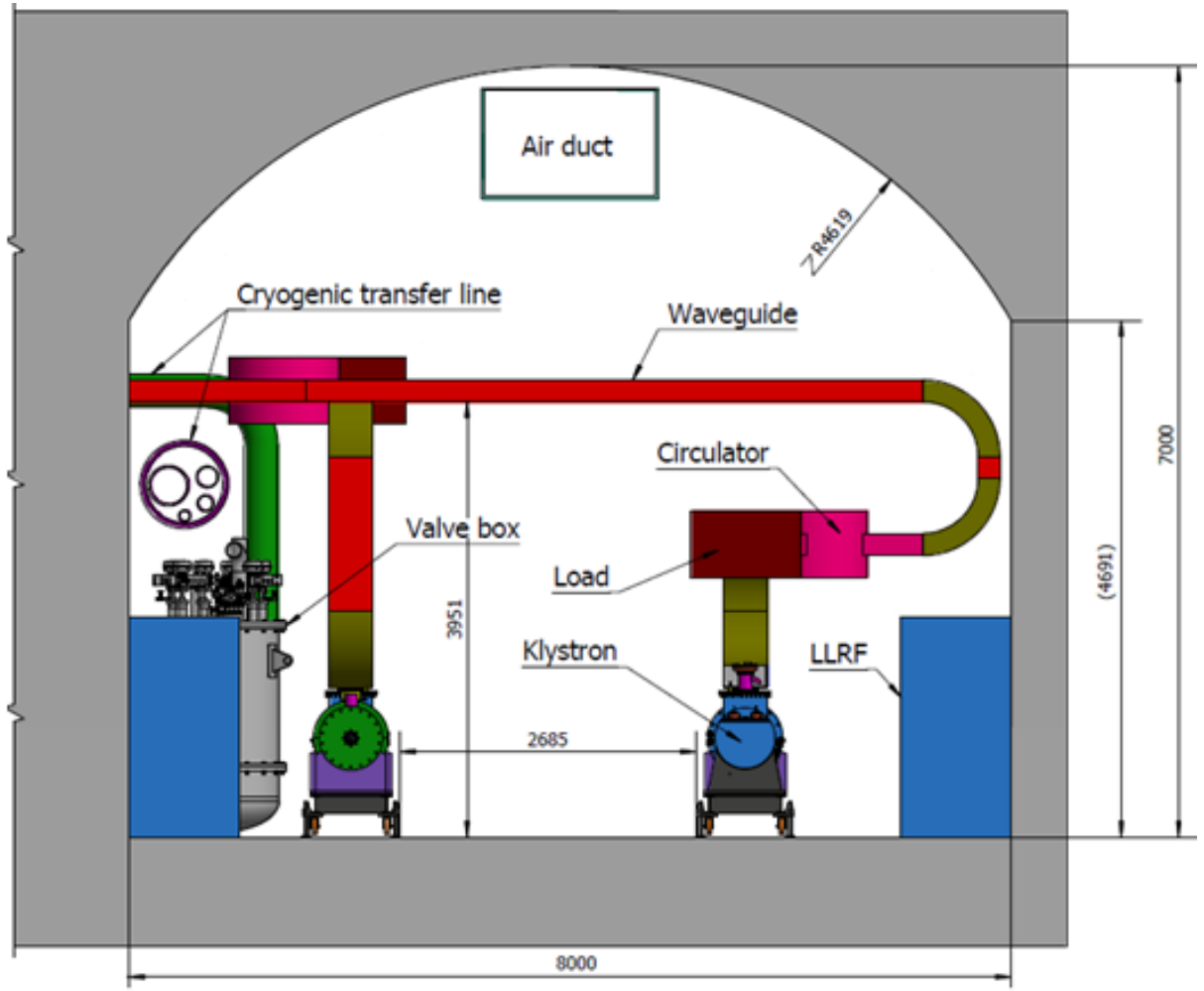
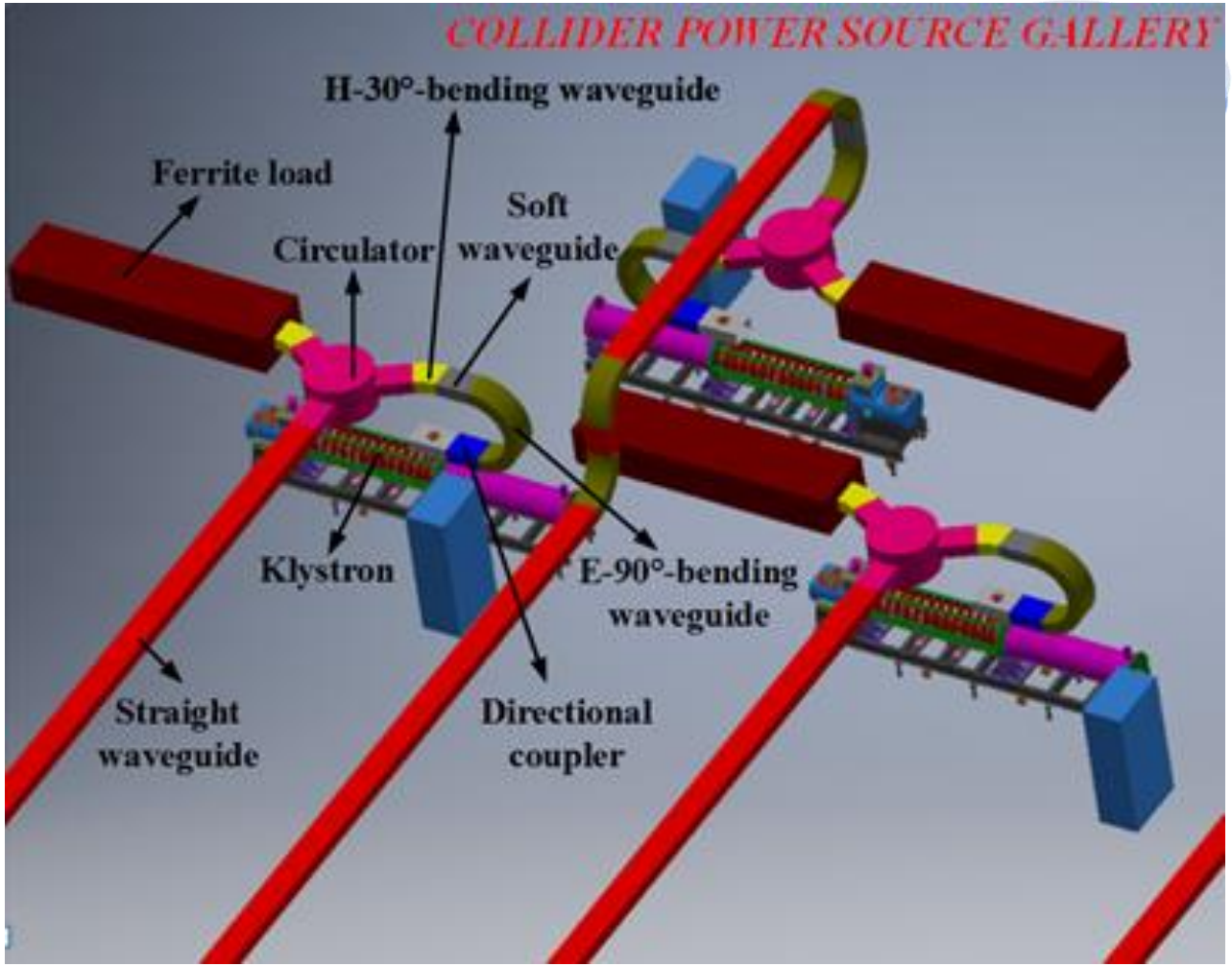
Collider Infrastructure

Collider Power Source Gallery





Klystron and transmission system are placed underground. ***PSM high voltage power supply*** *and related auxiliary power supply are* ***on the ground****.*

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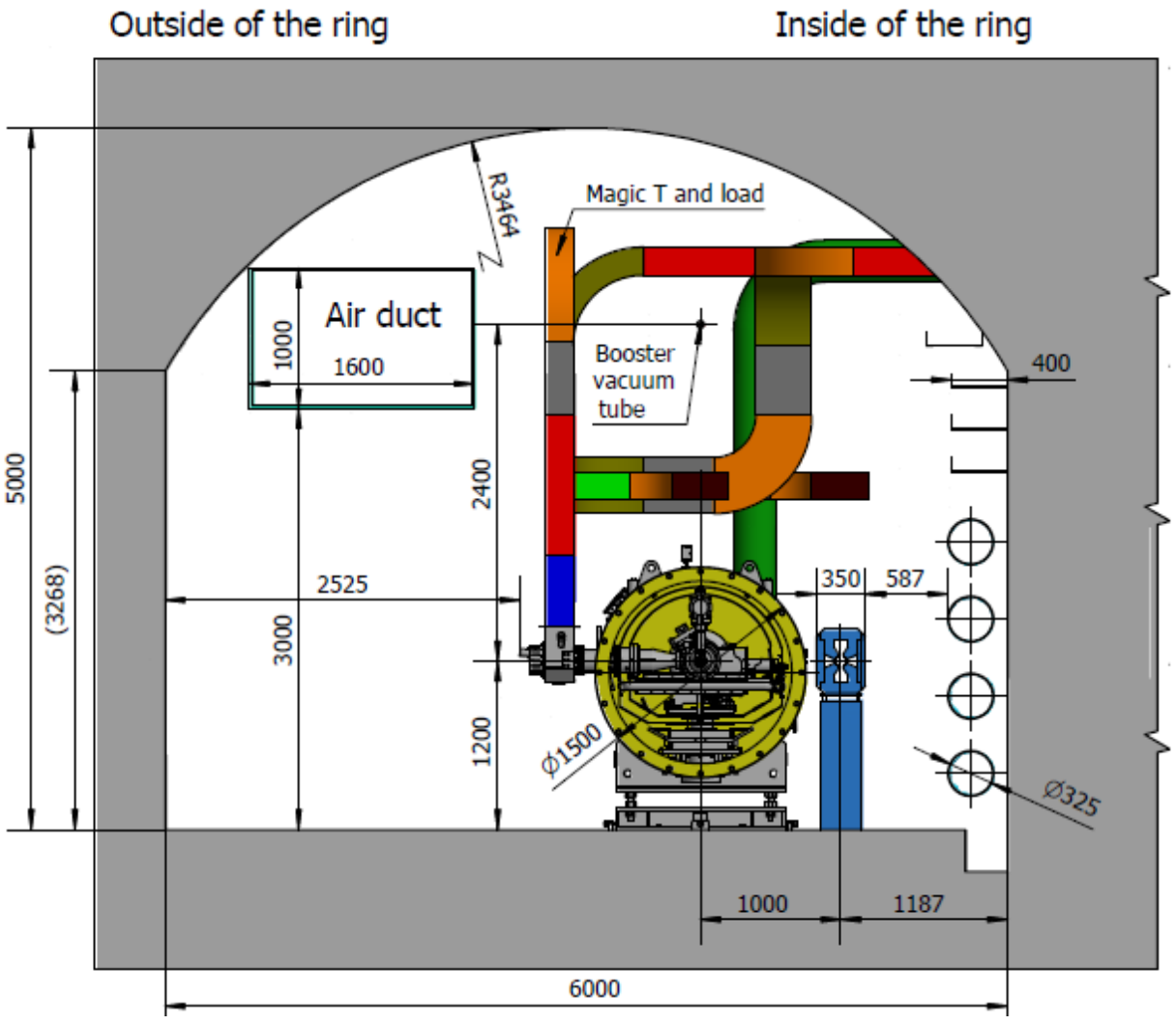
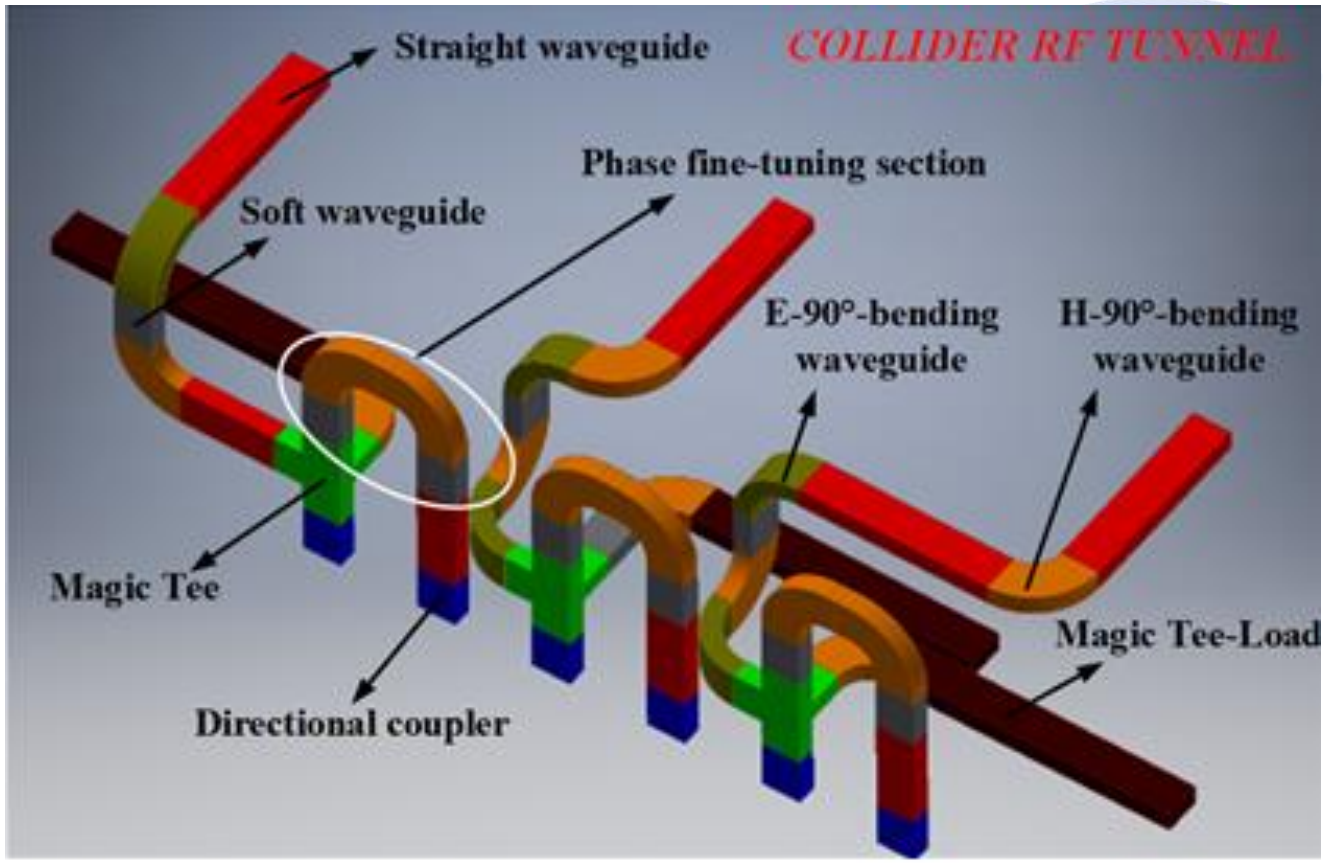
Collider

Infrastructure





*For space savings, **transmission system** in part are placed in **RF tunnel**.*

Booster

Introduction

- *The Booster RF system consists of 1.3 GHz superconducting RF cavities. There are 12 cryo-modules for Higgs operation, each containing eight 9-cell superconducting cavities.*
- *These cavities need **96** set **1300 MHz** power sources.*

Booster

Power source choice-SSA

- *Their capabilities extend from **a few kW to several hundred kW**, and from less than 100 MHz to above 1 GHz. Reasonable efficiency (~50%), high gain, and modular design provide high reliability.*
- *High **reliability** for redundancy design, high **flexibility** for module design, high **stability**, low maintenance requirements, absence of warm-up time and low voltage operation and reasonable efficiency.*
- *So the SSA has been chosen for the Booster RF power source system.*

Booster

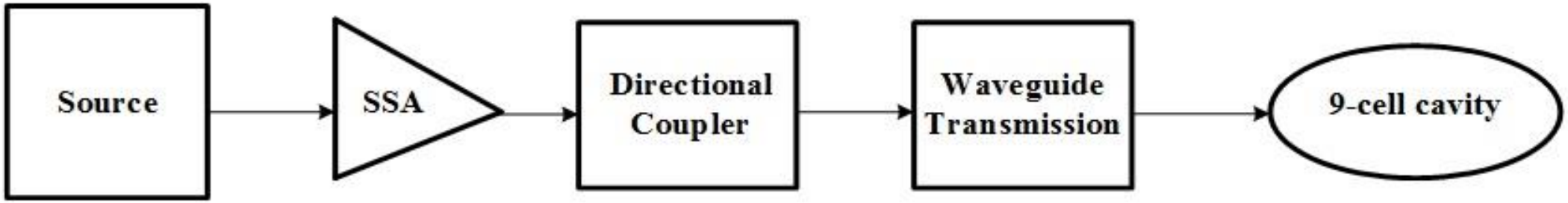
Solid state amplifier

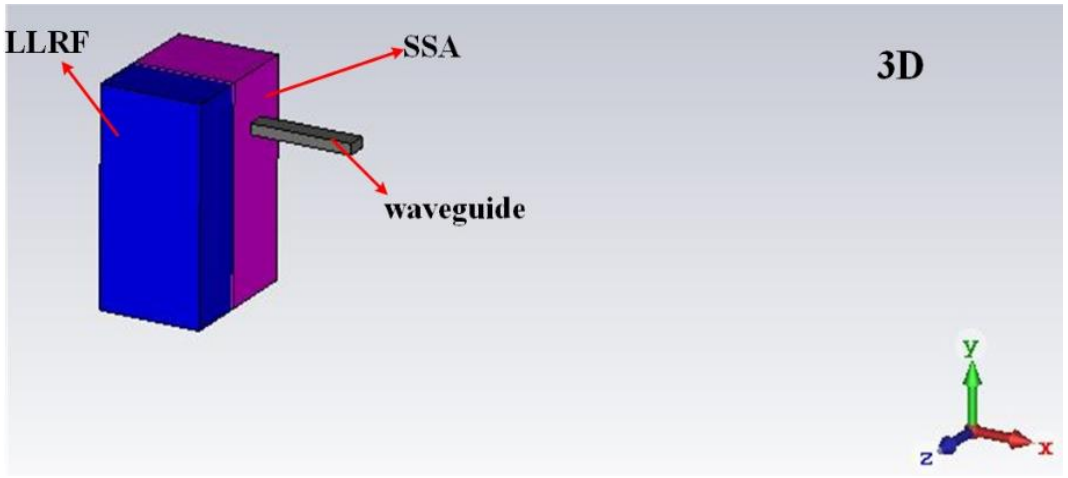
1.3 GHz/25kW SSA Specifications

Parameters	**Values**
Frequency	1.3 GHz
Power	25 kW
Gain	≥65 dB
Bandwidth (1dB)	≥ 1 MHz
Amplitude stability	≤0.1% RMS
Phase stability	≤0.1° RMS
Phase Variation	≤10°
Harmonic	< -30 dBc
Spurious	< -60 dBc
Efficiency at 25kW	≥45%
MTBF	≥30000 h
Redundancy	1 power module failure

Booster

RF Transmission system

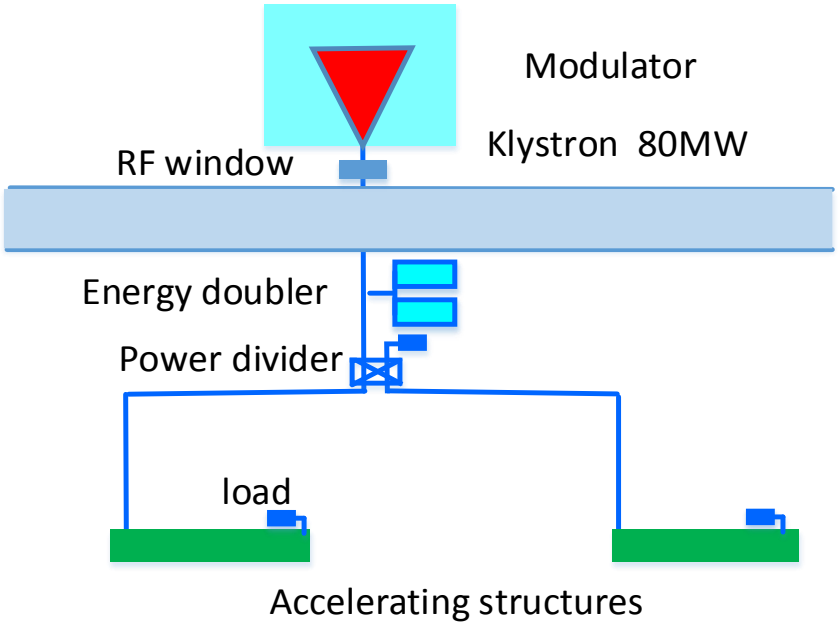


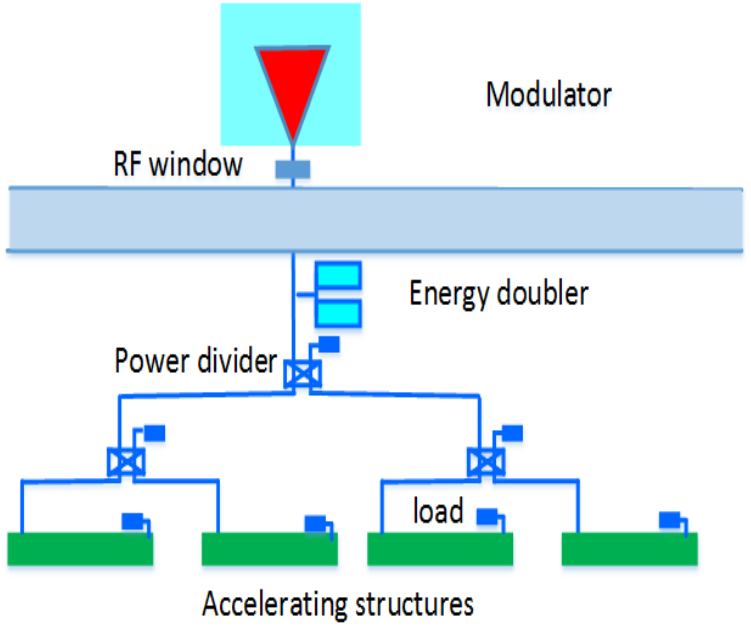


Linac injector

Introduction

- *The main high power RF components are 75 units of **80 MW S-band klystrons** and conventional solid state modulators.*
- *A waveguide system is used for power transmission from the klystrons to the accelerating structures, **75 klystrons** are used to provide power for **288 accelerating structures**.*





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R&D Status

High efficiency klystron

- *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)

High efficiency klystron

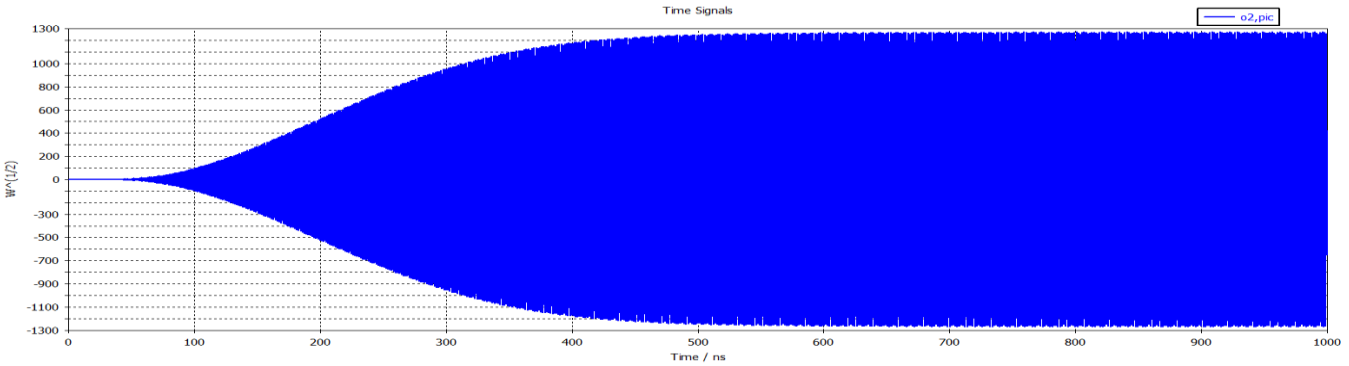
Design parameters

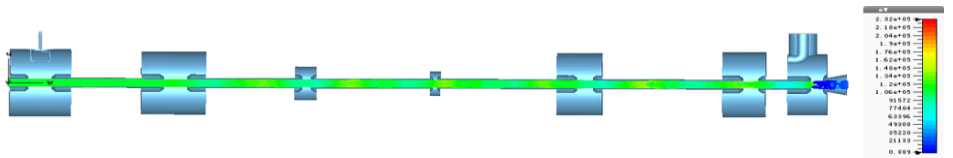
① *CST 3D efficiency: 77%*

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

③ *Gain(3D): 48.3dB*

④ *Bandwidth(2.5D): ≥0.8MHZ*





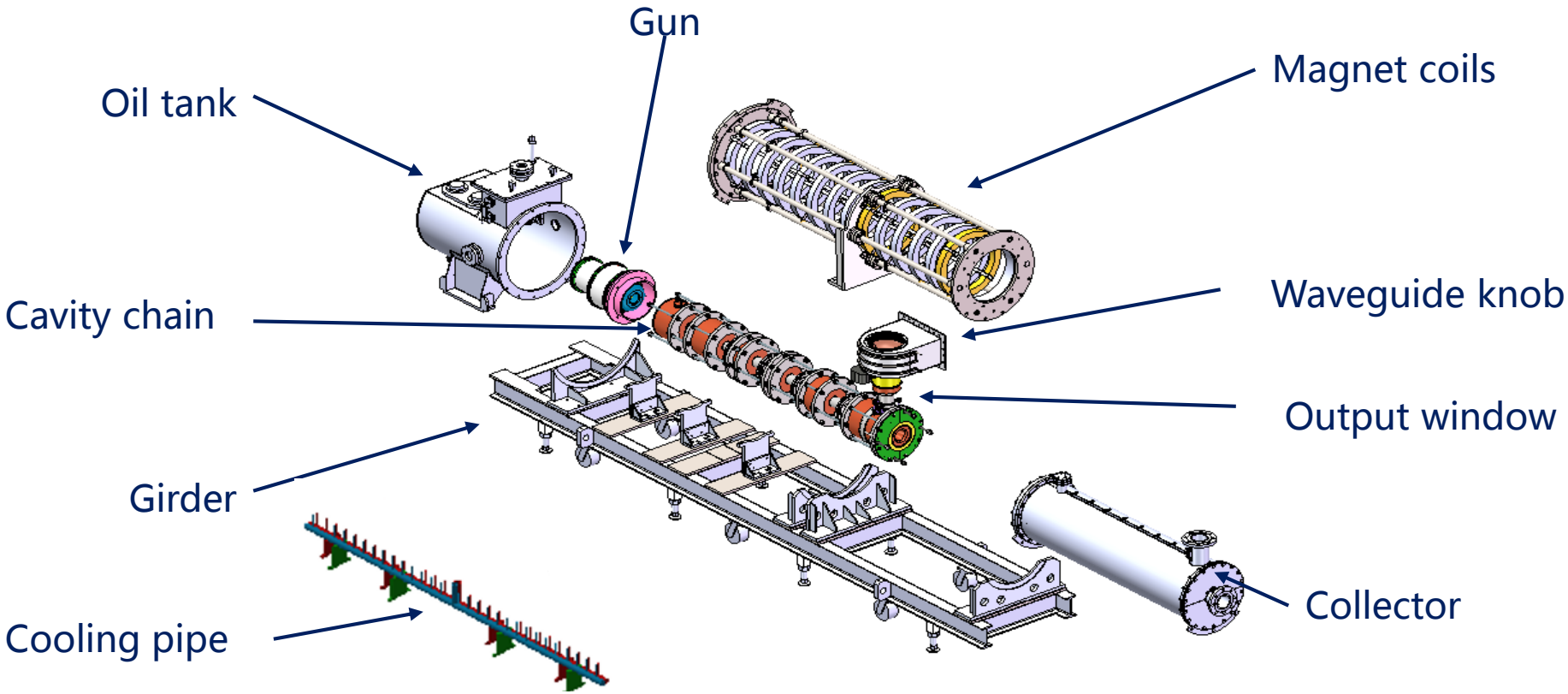
Manufacture status

① *The high efficiency klystron prototype is being fabricated in Chinese company.*

② *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.*

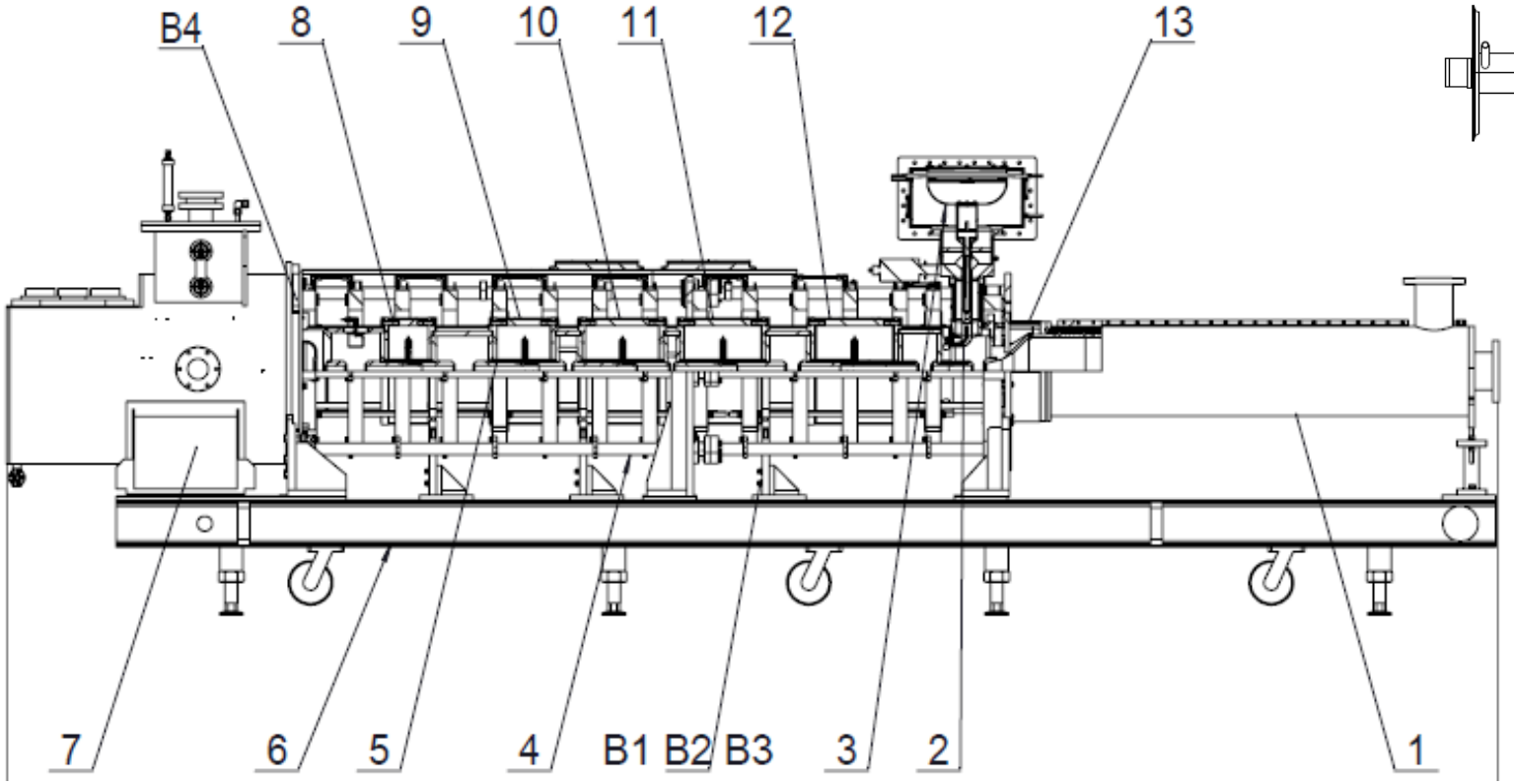
Mechanical design

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

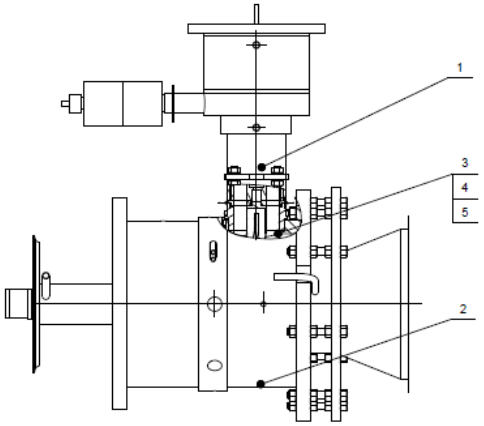


Klystron parts

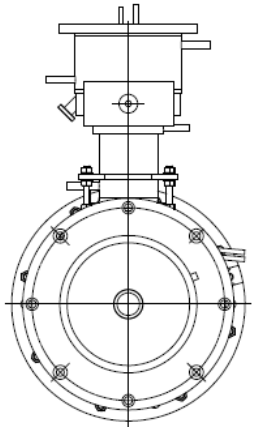
Mechanical drawing

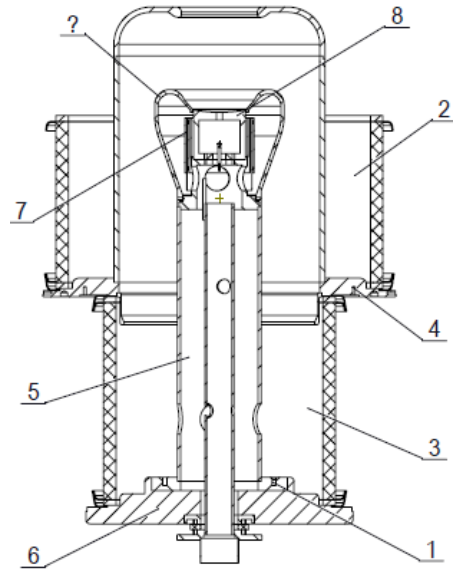


Klystron layout



Cavity





Gun

Fabrication status

Electron gun

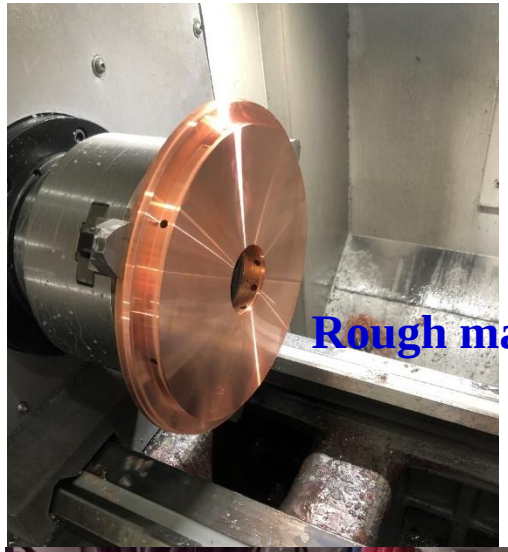
Ceramic insulator

Focusing electrode

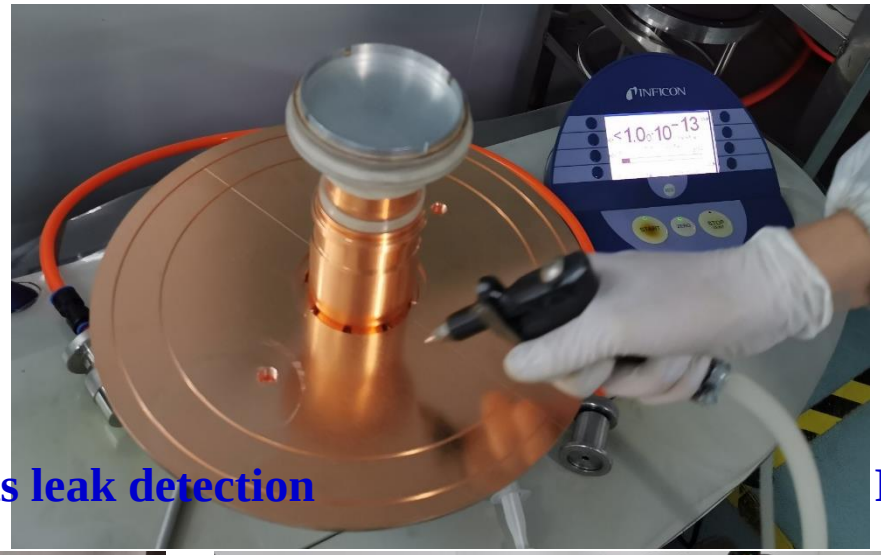
Modulator anode

Cathode Assy.

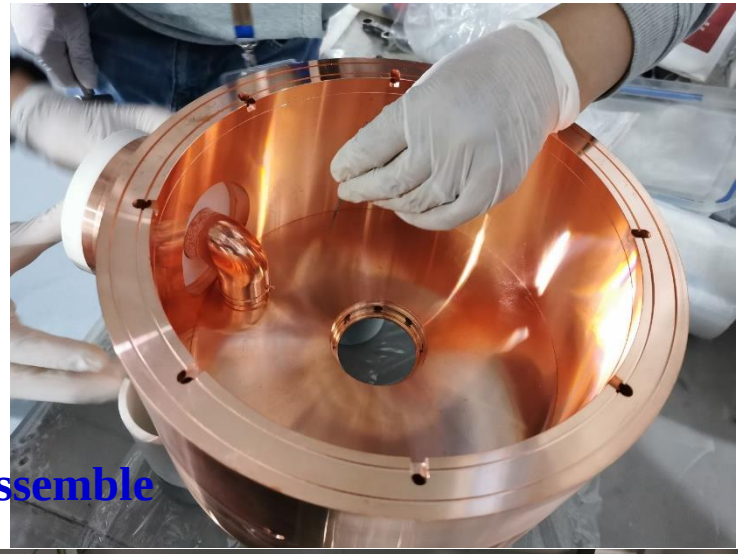
Fabrication status



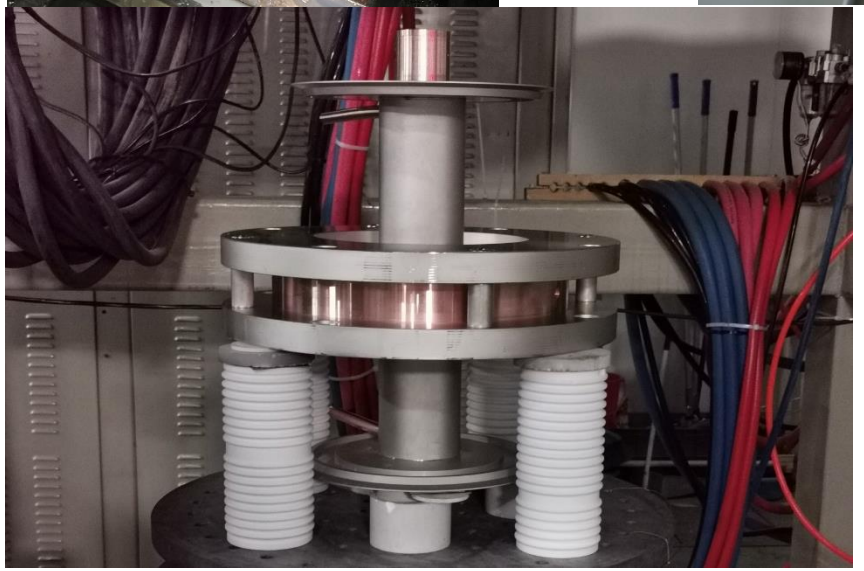
Rough machining



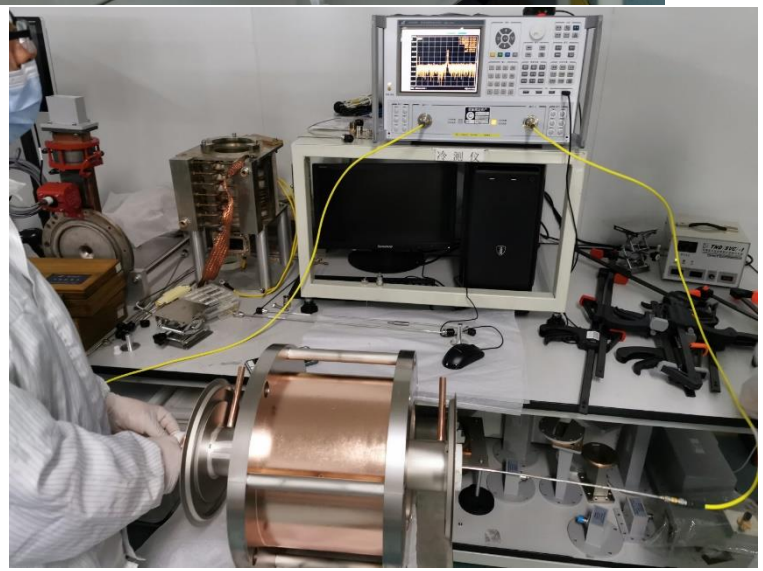
Parts leak detection



Parts assemble



Cavity brazing



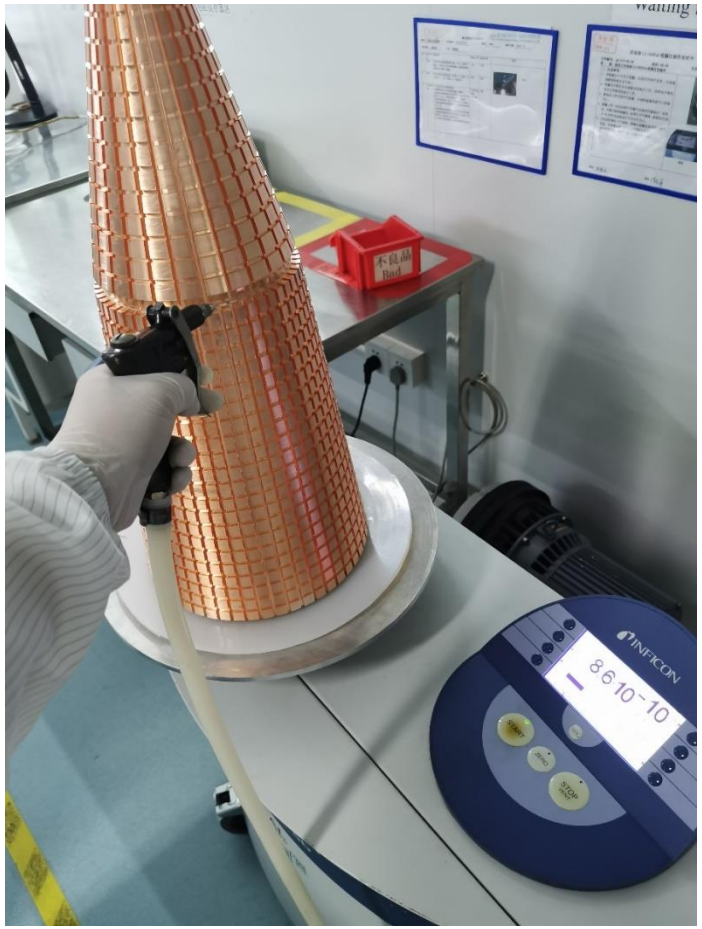
Cold test

Storage with nitrogen

Fabrication status

Collector

Collector body



Water jacket

Fabrication status

Focusing magnet

Fabrication status

Klystron girder and oil tank

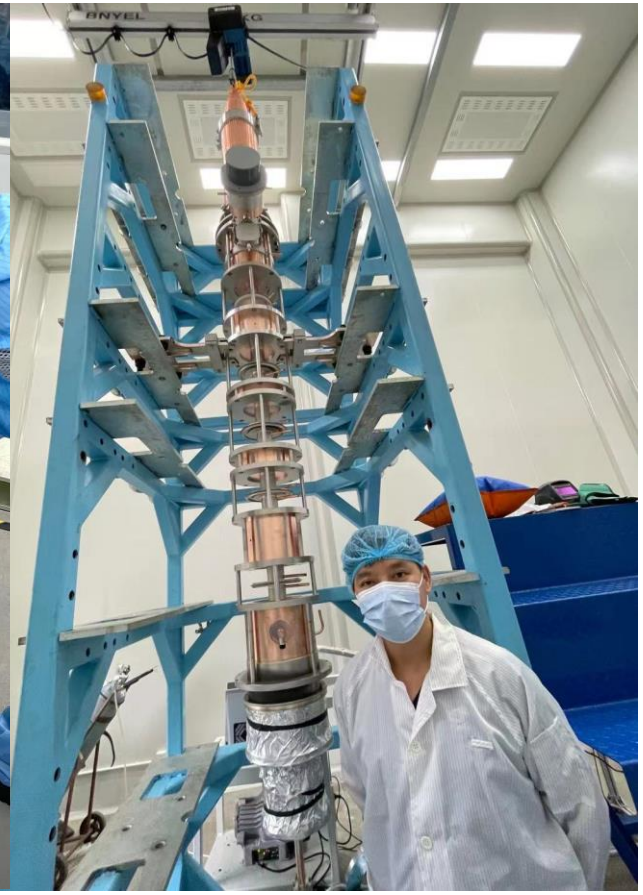
Electron gun processing

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

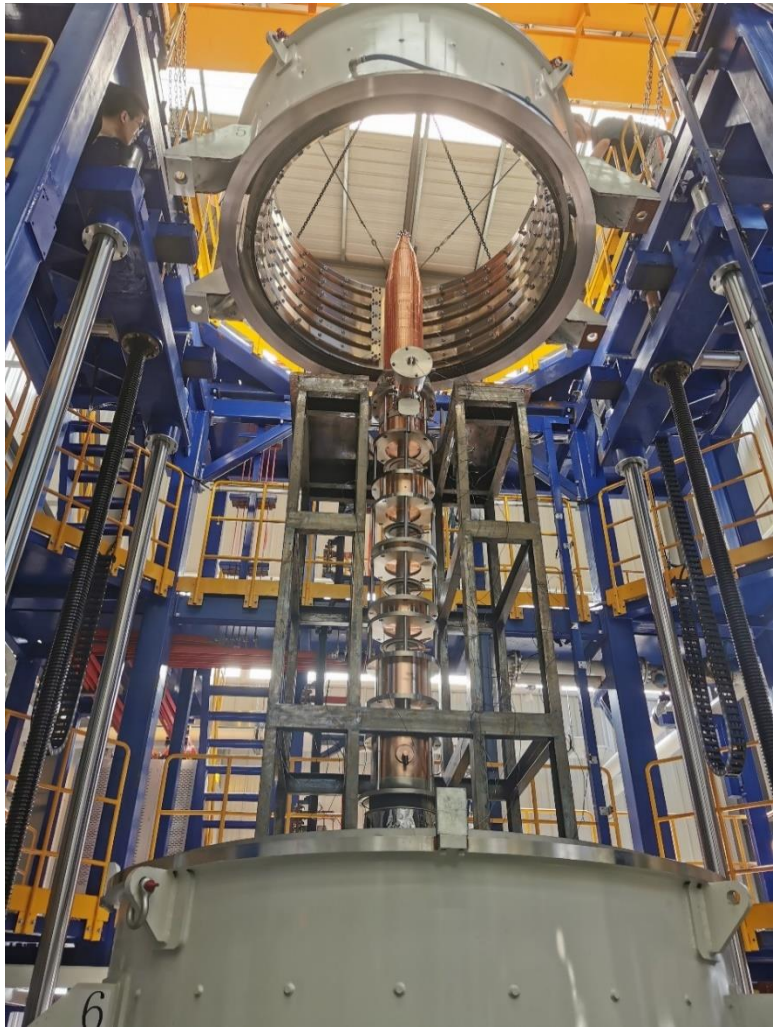
Klystron final assembly

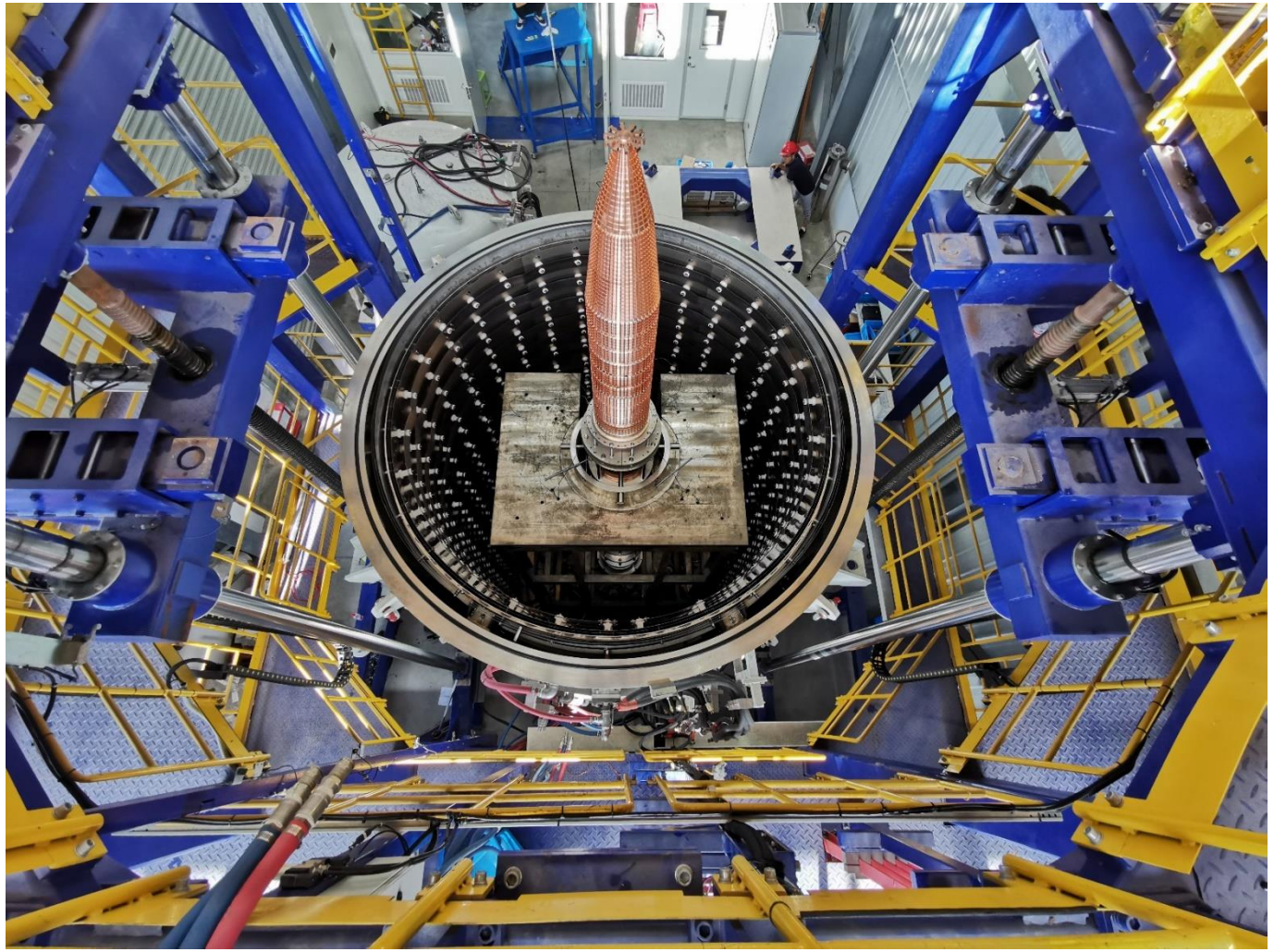
Klystron final assembly



Klystron baking out





High power test stand

130kV/16A PSM power supply is under adjusting and testing in PAPS site.

PSM Power Supply @PAPS site

Multi-beam klystron

1) Design Parameters

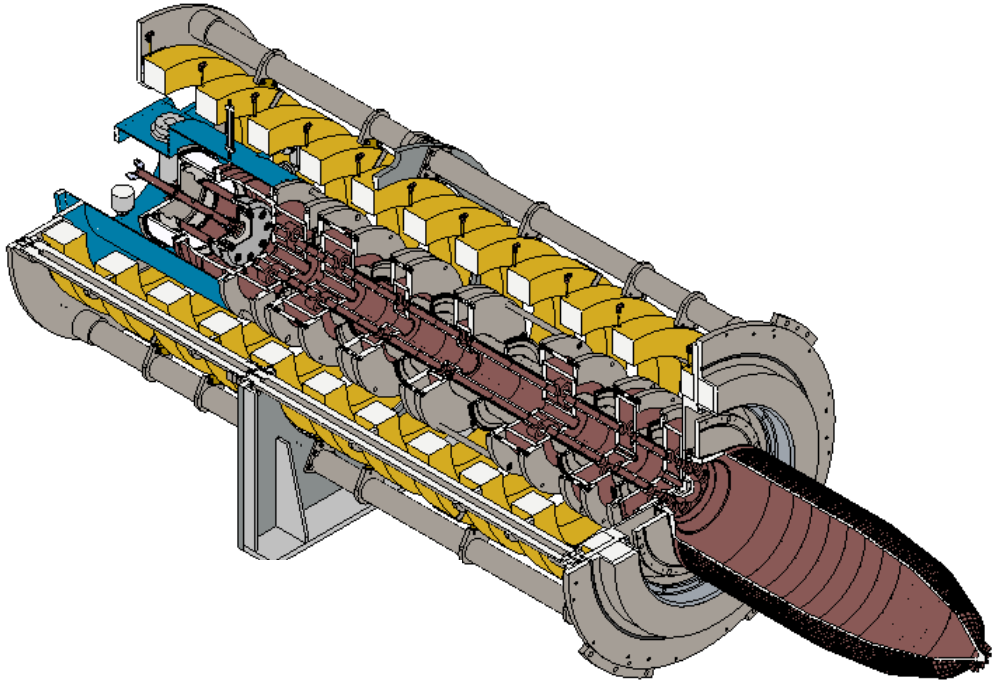
Parameters	Unit	Value
Gun Voltage	kV	54
Beam number		8
Beam perveance	μP	0.2
Output power	kW	800
1dB bandwidth (3-D simulation)	MHz	±0.75
Efficiency(3-D simulation)	%	80.5

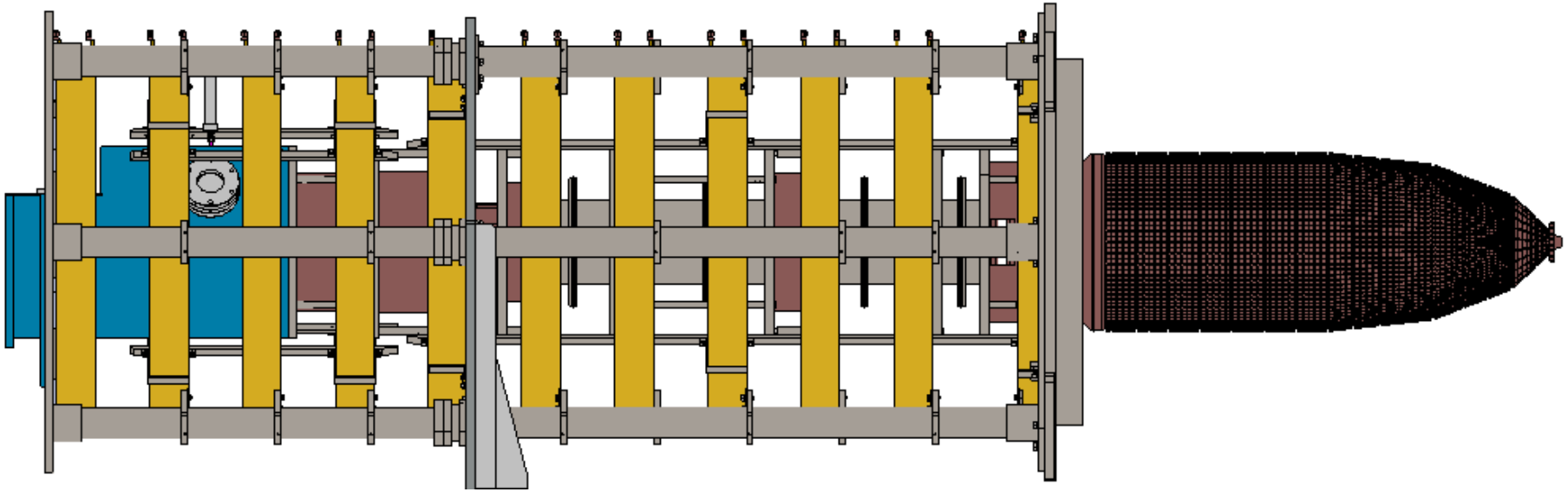
The MBK physical design is finished, including the interactive cavity, electron gun, focusing solenoid, window and collector. The final efficiency is about 80.5% with 3d simulation code.

Multi-beam klystron

2) 3d mechanical drawing

- The preliminary 3d mechanical drawing is finished.





Multi-beam klystron

3) Physical design review meeting and mechanical design review meeting were held not long ago.

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Summary

- *Design of RF power sources system for collider, booster and linac injector is showed.*
- *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.*

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Thanks for your attention!