Progress on CEPC High Efficiency Klystron

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On behalf of klystron development team
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Outline

- **Strategy and plan**
  - ✓ Goal：650MHz/800kW meets CEPC project demands;
  - ✓ Much higher efficiency, less energy consumption;
  - ✓ Evaluation target: >80% efficiency;
- **1st prototype development progress**
  - ✓ Beam dynamic, beam optic and cooling system;
  - ✓ Mechanical design, infrastructure preparation;
- **High efficiency consideration(2nd&3rd)**
  - ✓ Different method comparation;
  - ✓ 3 kind of gun schemes;
  - ✓ MBK

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Strategy and plan from 2016 to 2018

- 3 klystron prototypes in 6 FYs
- FY 2016: done
  - Finalize the gun and the collector design of the 1st conventional klystron prototype
  - Initialize the dynamics design
- FY 2017: done
  - Finalize the cavity chain design of 1st tube
  - Preliminary mechanical design
- FY 2018: being carried out
  - Finalize the mechanical design and fabrication
  - Infrastructure construction
  - Design studies on the 2nd and 3rd high efficiency klystron

Strategy and plan from 2019 to 2021

- FY 2019
  - 1st tube high power test
  - 2nd tube fabrication
  - Finalize design of the 3rd high efficiency klystron
- FY 2020
  - 2nd tube high power test(>70% expected efficiency)
  - Finalize the mechanical design of 3rd tube and start to fabrication
- FY 2021
  - 3rd tube high power test(>80% expected efficiency)
  - More klystron prototypes or klystron industrialization

Parameters for 1st tube

Conventional method based on 2nd harmonic cavity to investigate the design and manufacture technologies for high power CW klystron

Main parameters	Goal
Frequency (MHz)	650
Vk (kV)	81.5
Ik (A)	15.1
Perveance (μPerv)	0.65
Efficiency (%)	>60
Saturated gain (dB)	>45
Output power (kW)	800
1dB bandwidth (MHz)	±0.5
Brillouin magnetic field (Gs)	106.7
Reduced plasma wavelength(m)	3.47
N cavities	6
Normalized drift tube radius	0.63
Normalized beam radius	0.41
Filling factor	0.65

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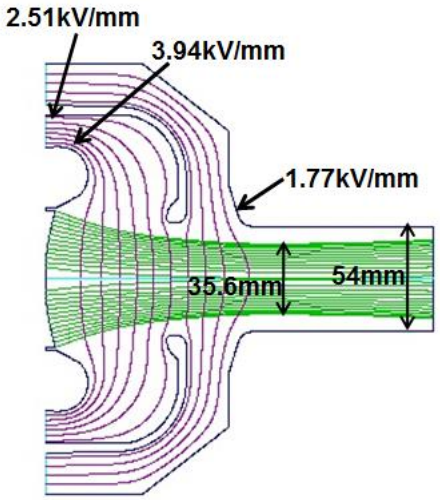
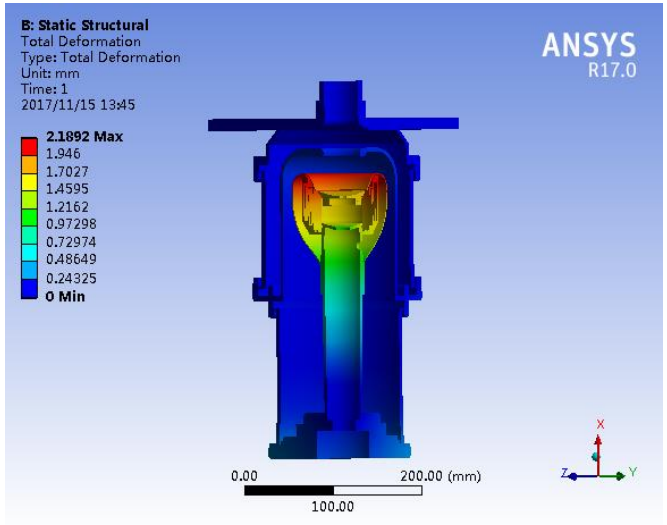
Electron gun for 1st tube

Different codes results for beam optics and thermal structure analysis

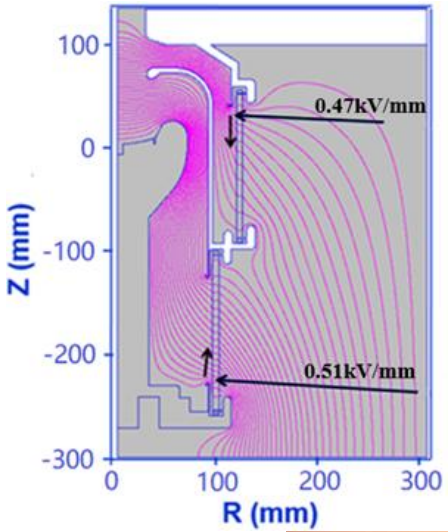
Main parameters	DGUN	EGUN	MAGIC2D	CST	Design goal
Beam waist radius (mm)	17.8	17.48	17.48	17.64	17.5
Perveance (μPerv)	0.64	0.64	0.65	0.64	0.65
Current density	<0.45	0.39~0.43			<0.5
Current uniformity		9.8%			<10%



Beam optics



Thermal deformation



Electric field distribution

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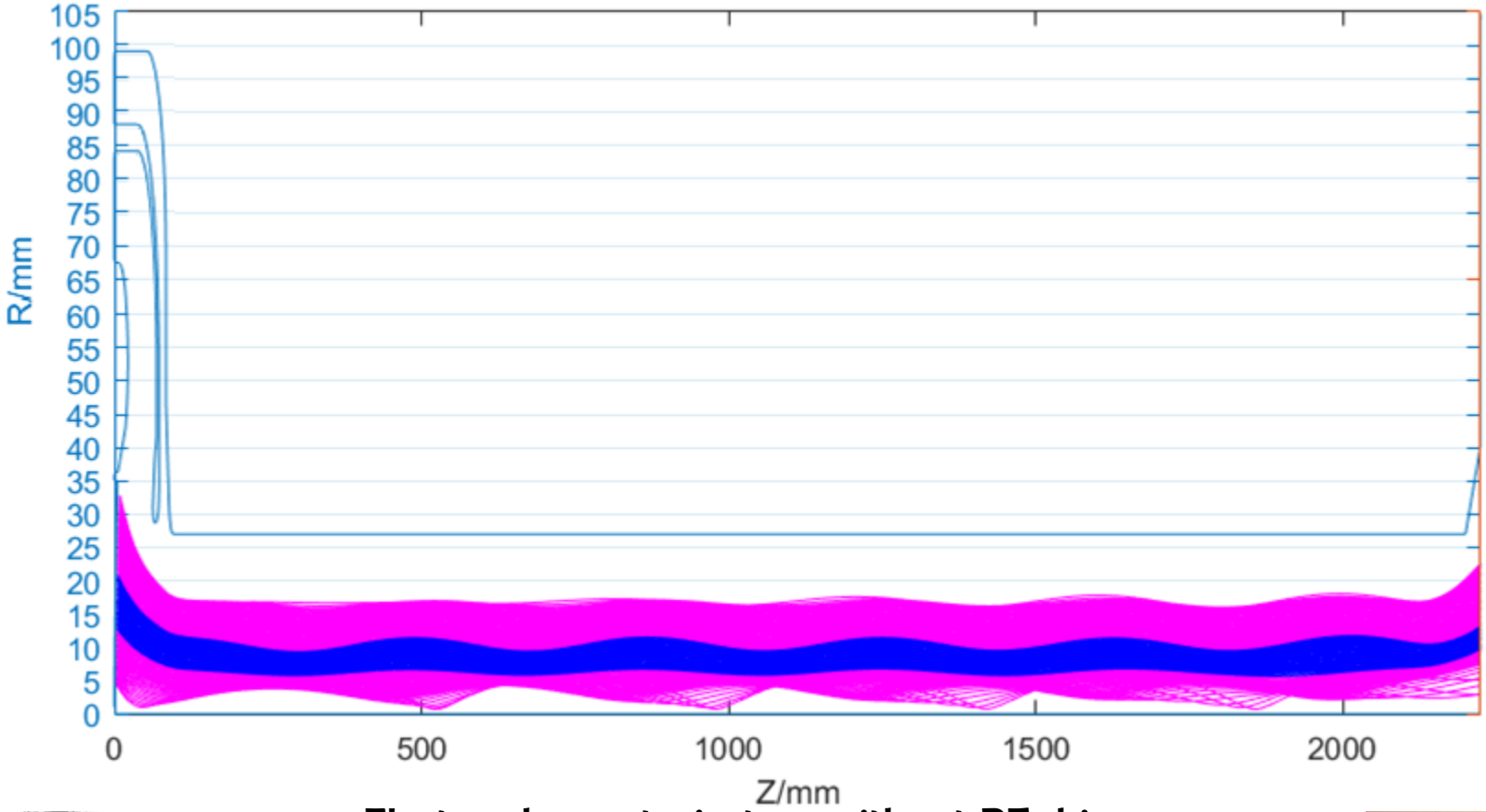
Dynamics for 1st tube

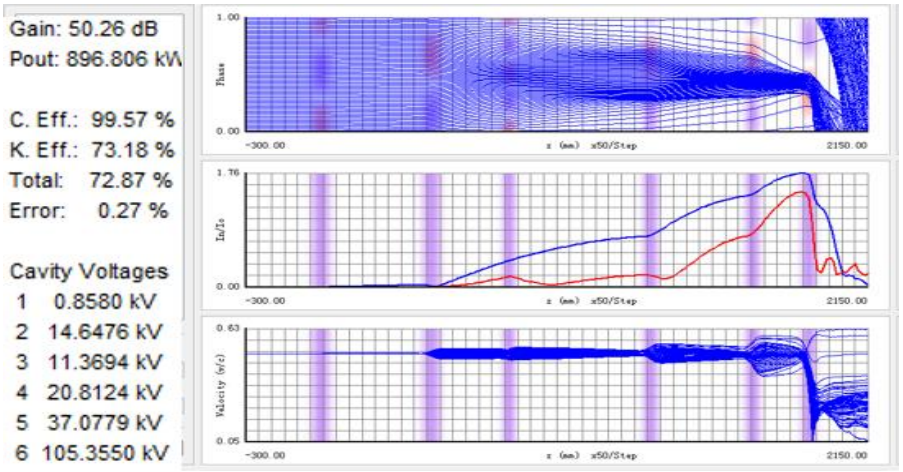
- Good trajectory laminarity from the gun to the collector
- Ripple rate less than 5%



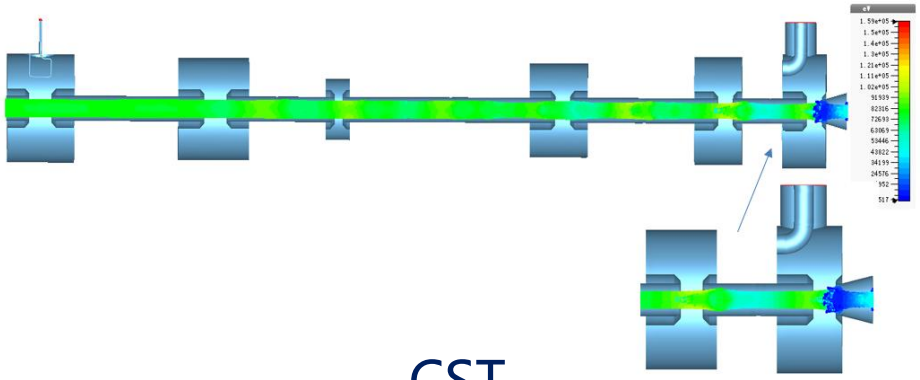
Electron beam trajectory without RF drive

Dynamics for 1st tube

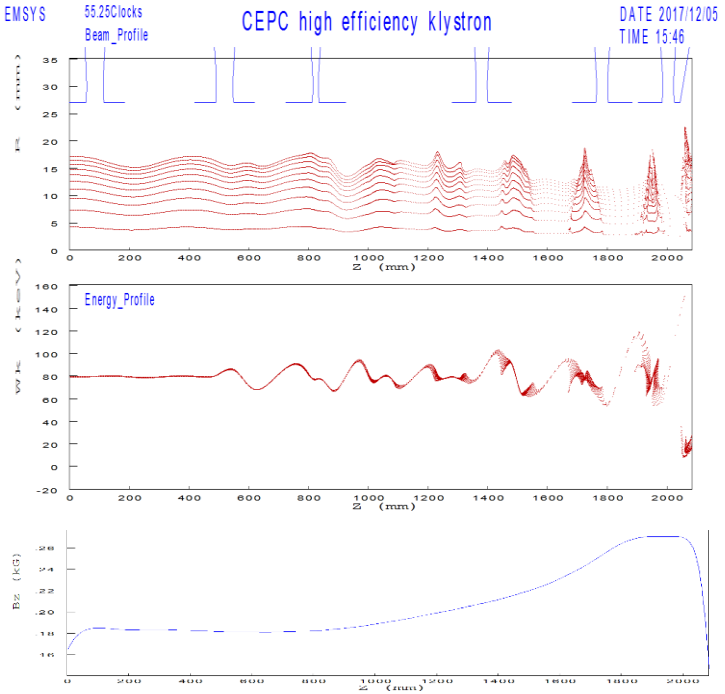
- 1D optimization on the dynamics and cross checked by 2D&3D
- 73%/68%/65% efficiencies for 1D/2D/3D



AJDISK



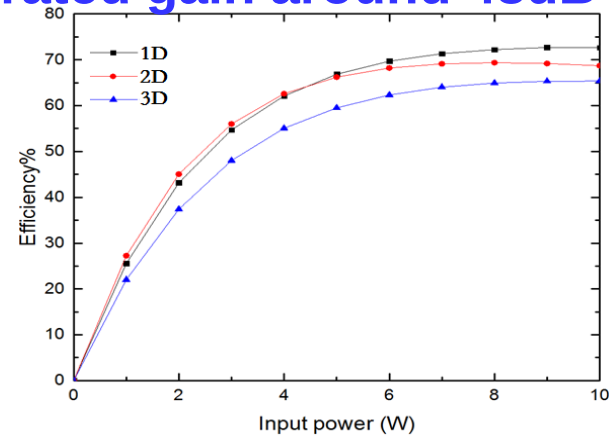
CST



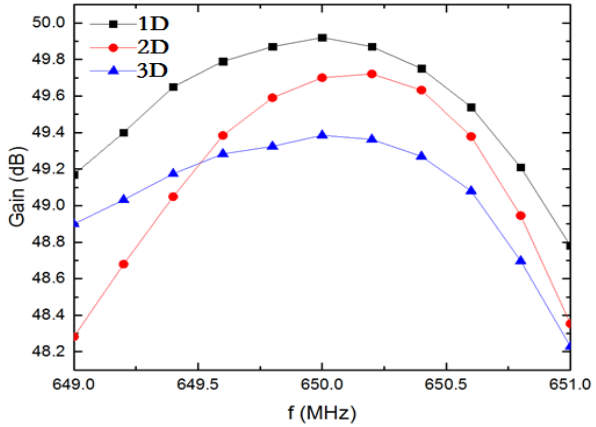
EMSYS

Dynamics for 1st tube

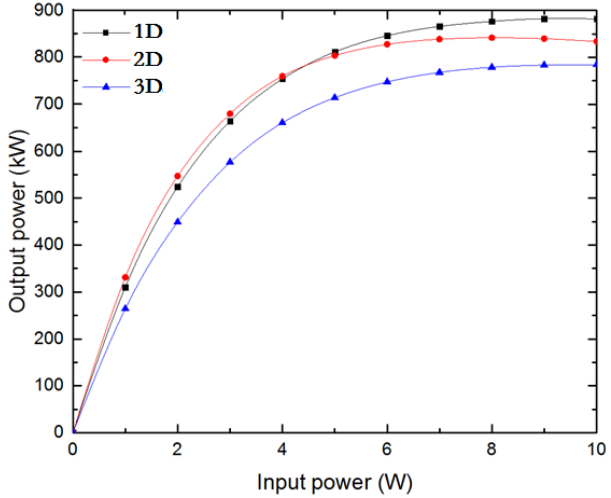
- 1dB bandwidth larger than ±1MHz
- Saturated gain around 48dB



Klystron efficiency curve



Klystron gain curve



Klystron transfer curve

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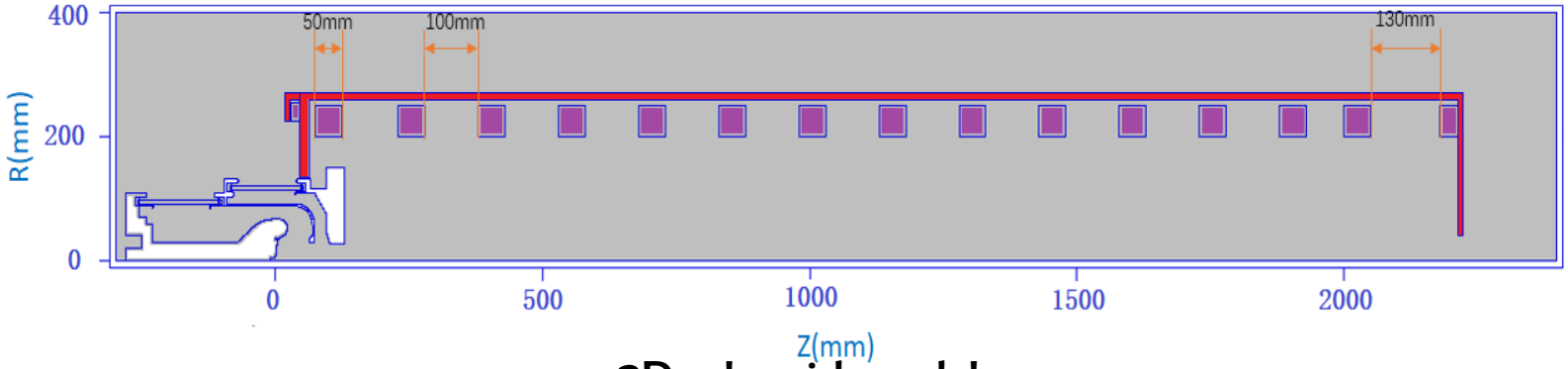
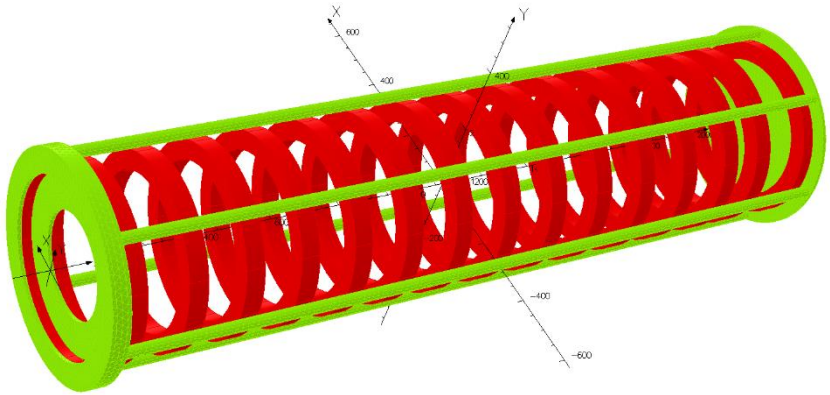
Coils for 1st tube

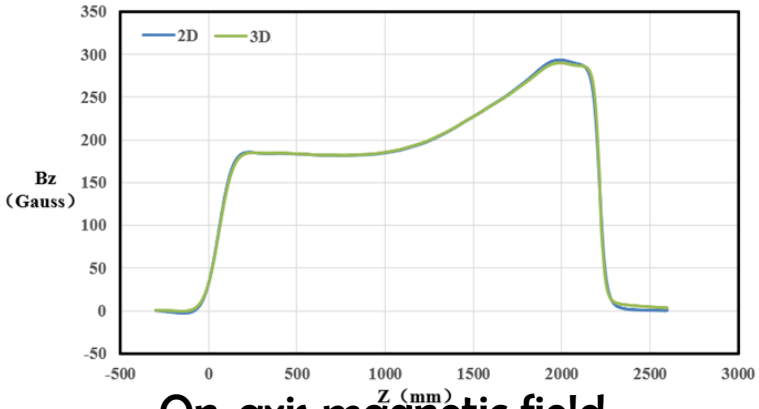
- Designed by 2D and cross checked by 3D, very good consistency
- 15 regular coils with 1 bucking coil near the gun
- Cathode: 32 Gauss, Gain cavity: 180 Gauss, Output cavity: 280 Gauss



2D solenoid model



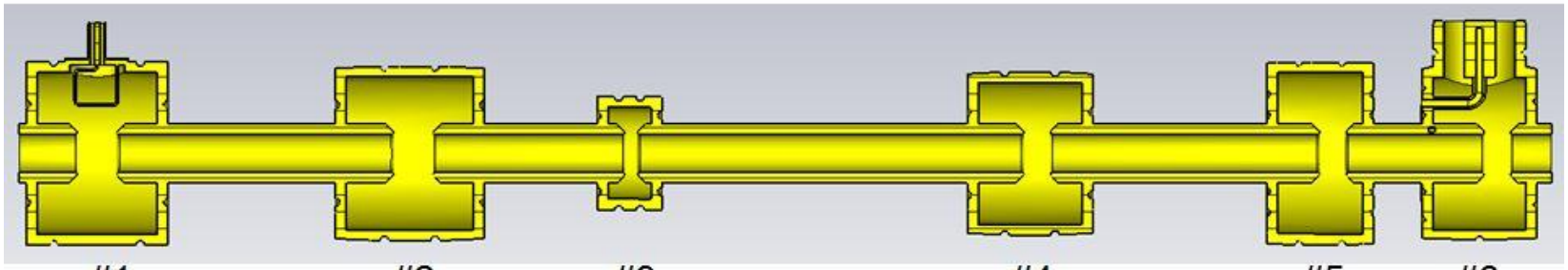
3D solenoid model



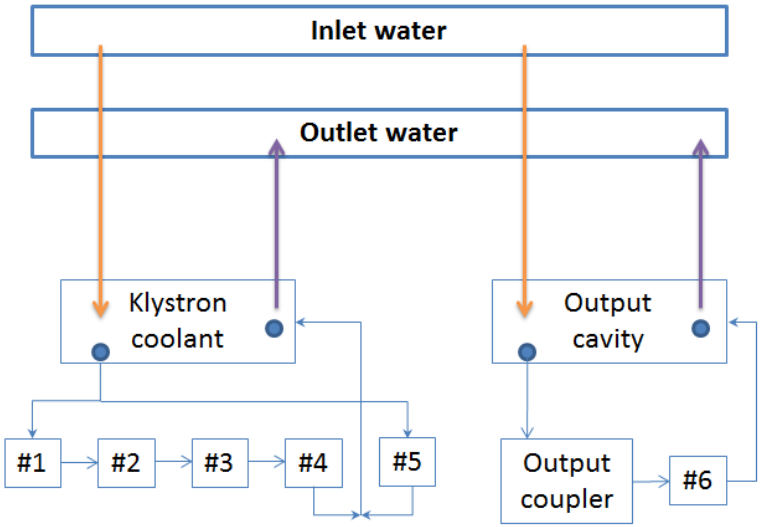
On-axis magnetic field

Cavity chain for 1st tube

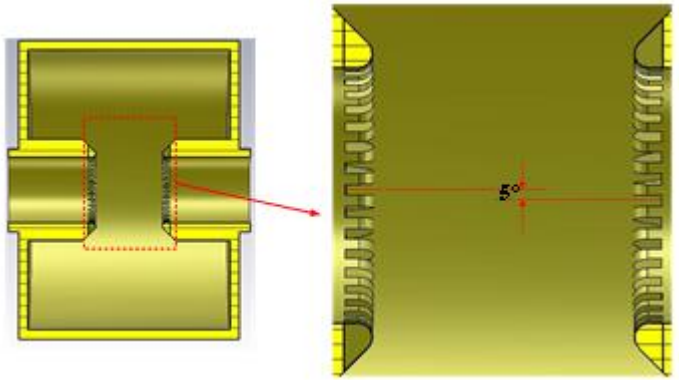
- RF design and cooling analysis conducted;
- Grooved nose cone for each cavity to suppress the multi-pacting effect



Cavity chain



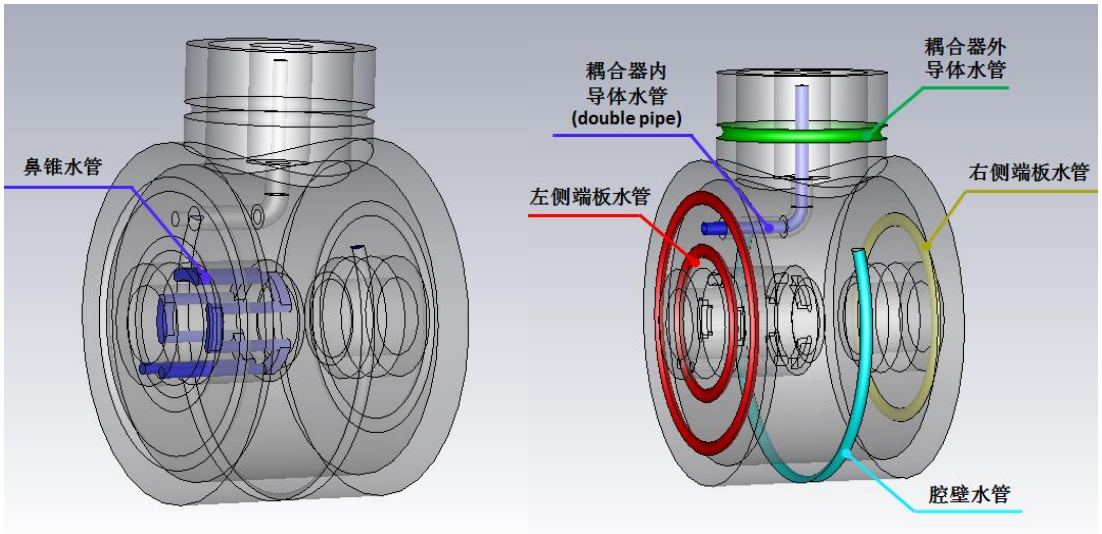
Klystron cavity chain cooling scheme



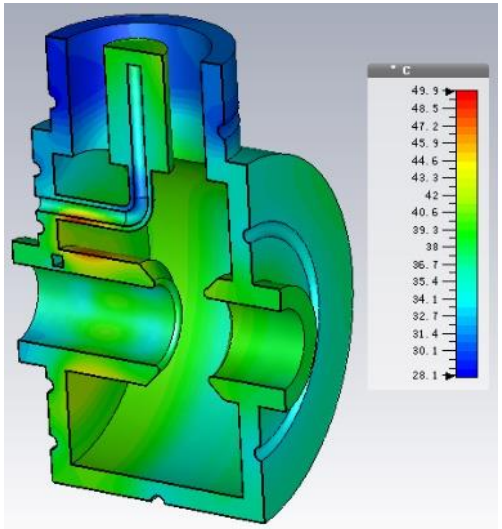
Grooved nose cone for each cavity

Output cavity cooling

- 87% of the total power loss for the cavity chain located at the output cavity
- Theoretical power loss around 3.9kW, cooling capability designed to be 8kW



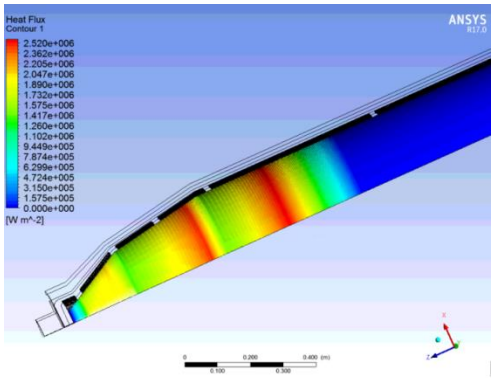
Cooling pipes distribution



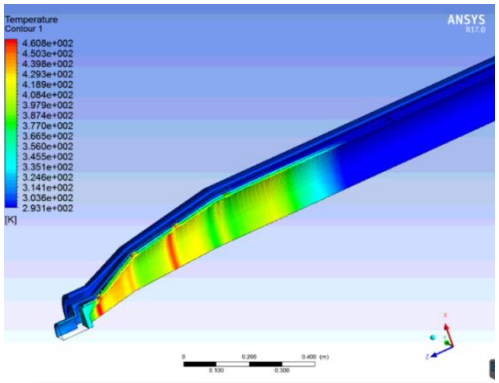
Temperature distribution

Collector for 1st tube

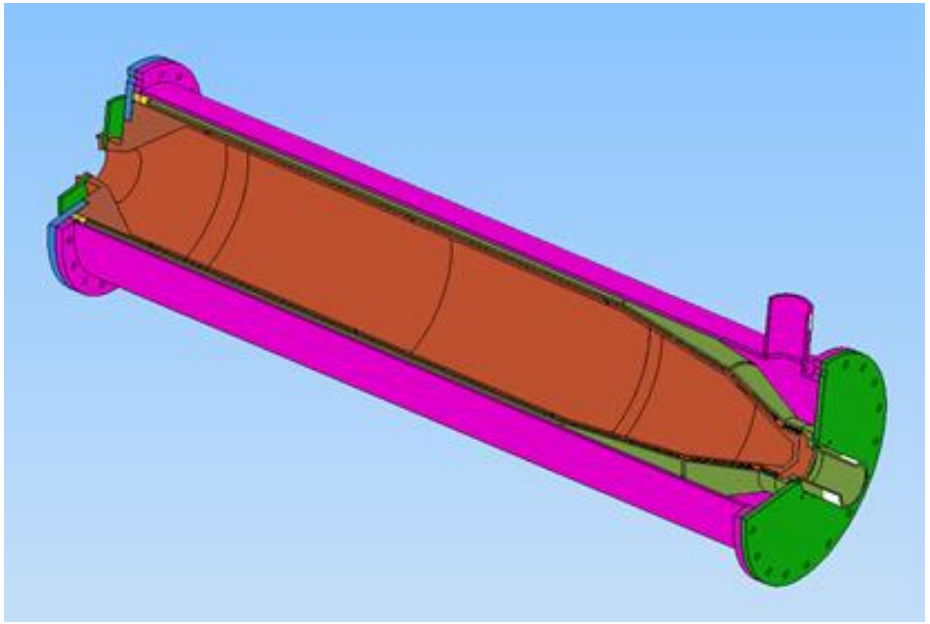
- ~2m long collector to sustain 1.23MW full beam power



Thermal load distribution



Temperature distribution

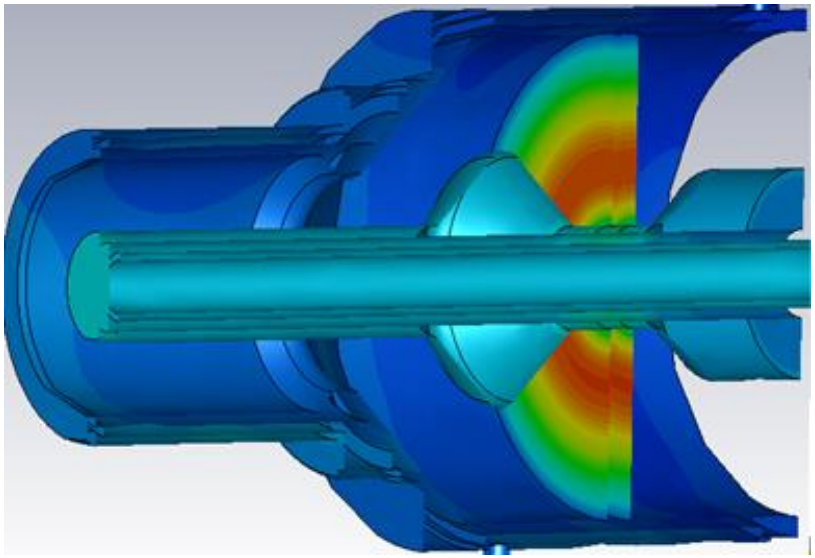


Mechanical design

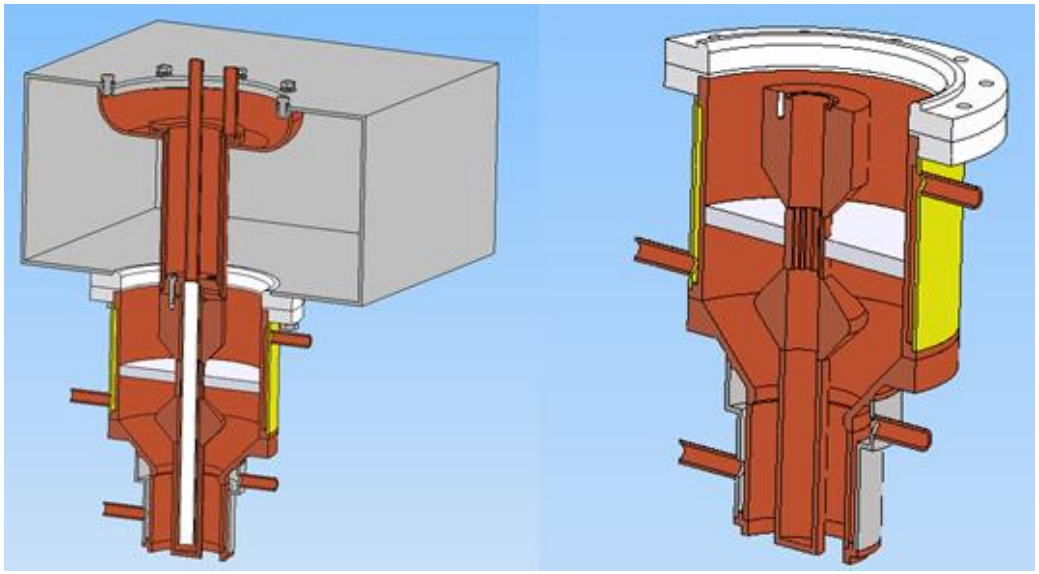
Duty factor (%)	Max. heat flux (W/cm^2)	Max. stress (Mpa)	Max. temperature (°C)
100	210	158	187

Output window for 1st tube

- Relatively simple design with door knob to facilitate the fabrication
- >800kW sustainable CW RF power @ 650MHz
- <1.05 VSWR @ 650±0.5MHz



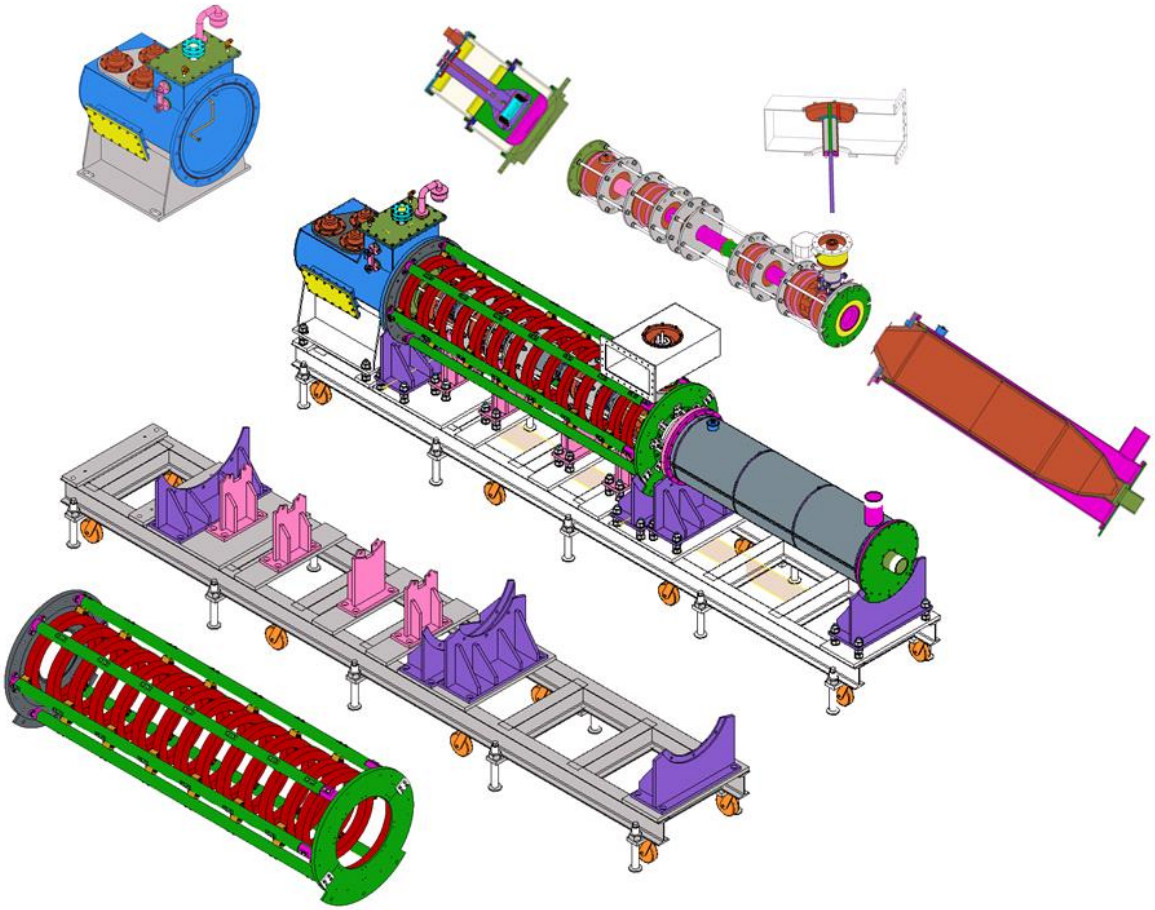
Temperature distribution



Mechanical design

Mechanical design for 1st tube

- Mechanical design achieved (L×W×H: 5.12m×0.87m×1.56m)
- Discussion on the manufacturing details being conducted



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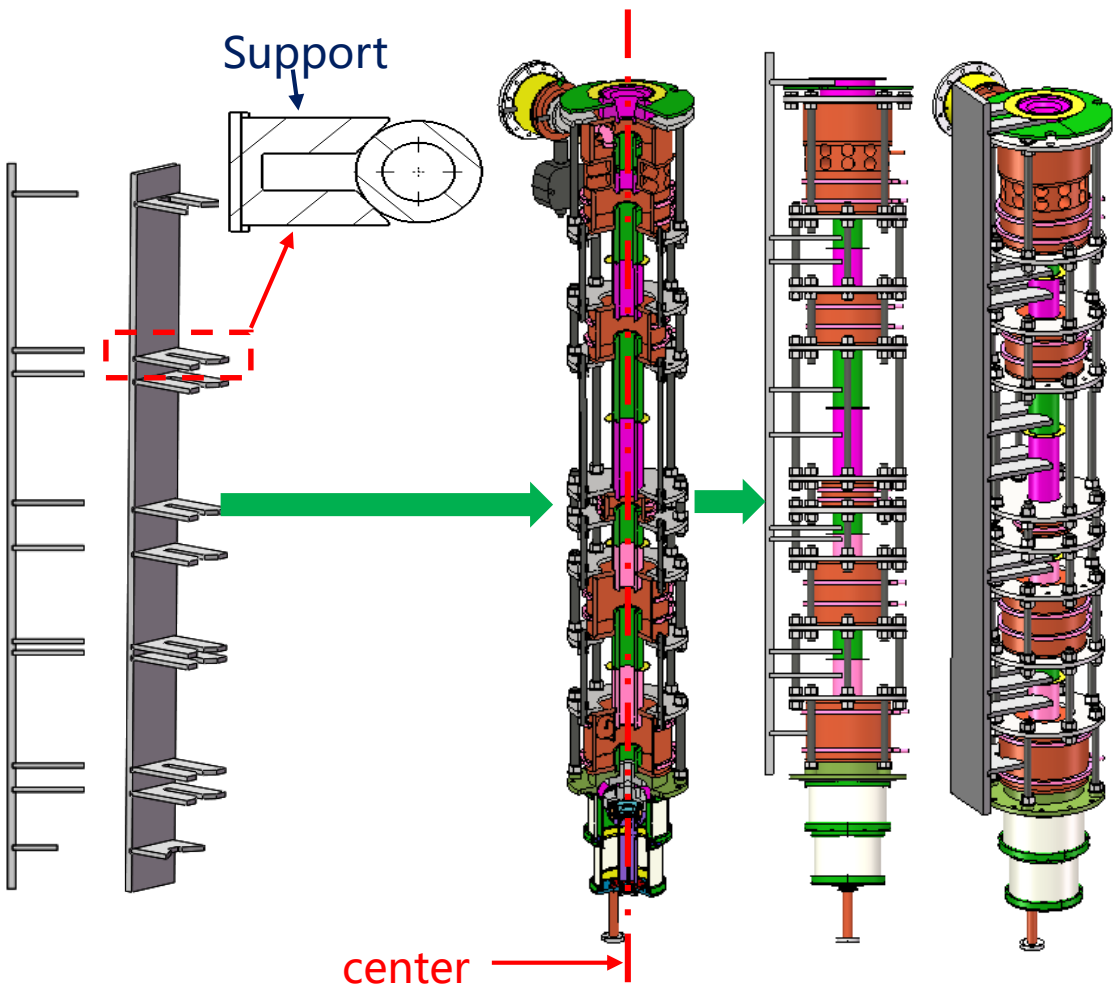
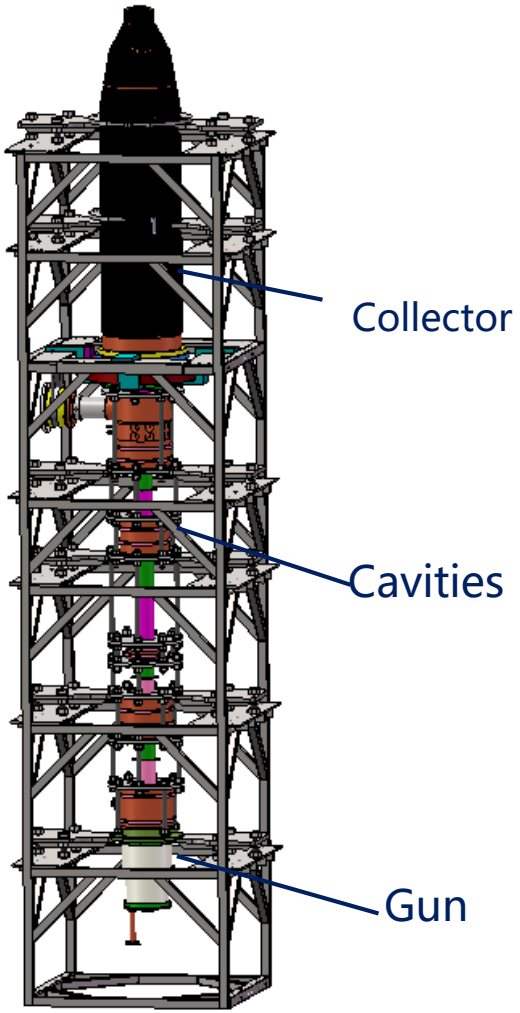
Assembly sequence

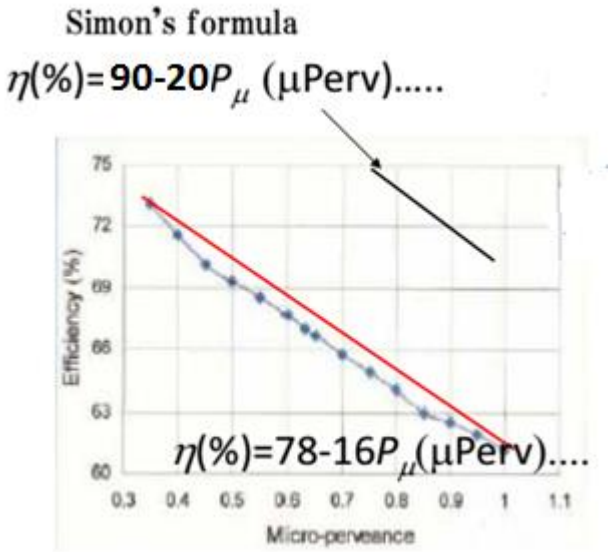




High Efficiency Consideration

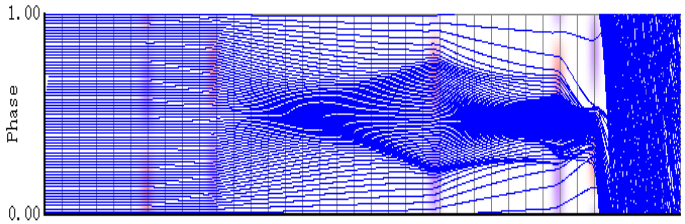
- **3 design schemes**
- **Scheme 1：optimize cavity chain by using the same gun as 1st tube**
- **Scheme 2 ： with high voltage gun (110kV/9.1A), low perveance**
- **Scheme 3：MBK, 54kV/20A electron gun**

Parameter	Scheme1	Scheme2	Scheme3
Freq (MHz)	650	650	650
Voltage (kV)	81.5	110	54
Current (A)	15.1	9.1	20(2.5×8)
Beam No.	1	1	8
Perveance (μP)	0.65	0.25	1.6(0.2×8)
Efficency (%)	>70	>80	>80
Power(kW)	800	800	800(100×8)

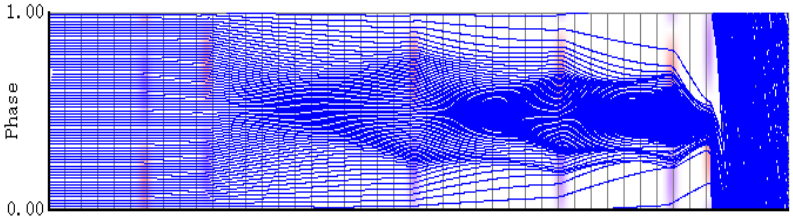


Progress on scheme 1

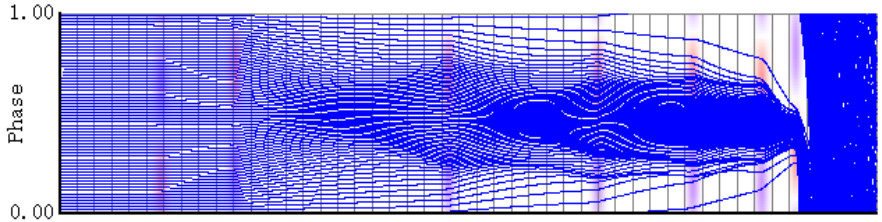
- Same gun with the 1st tube
- COM, more cavities



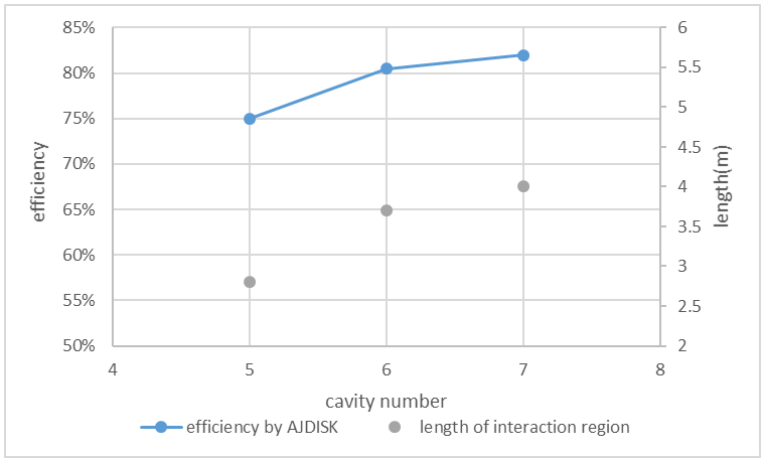
5 CAV/75%/2.8m

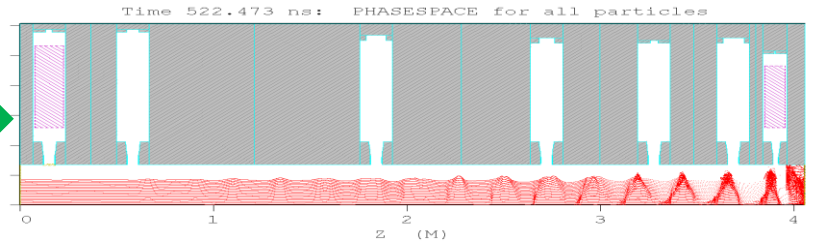


6 CAV/81%/3.7m



7 CAV/82%/4.0m





MAGIC_2D 74%

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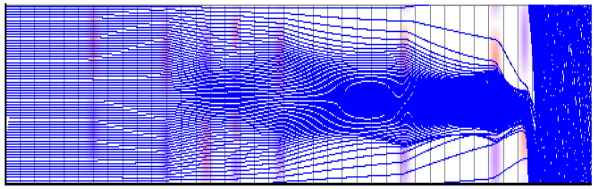
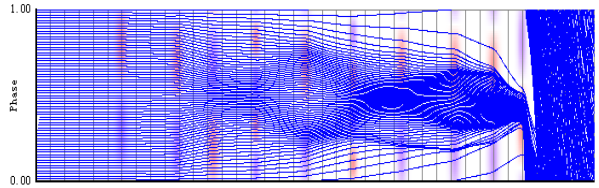
Progress on scheme 1

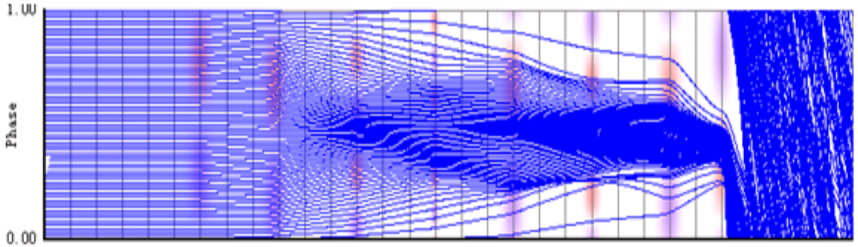
- **Based on 7 CAV**
- **Add 2nd and 3rd harmonic cavities to reduce tube length**



8 CAV/1 2nd harmonic CAV/80%/3.1m



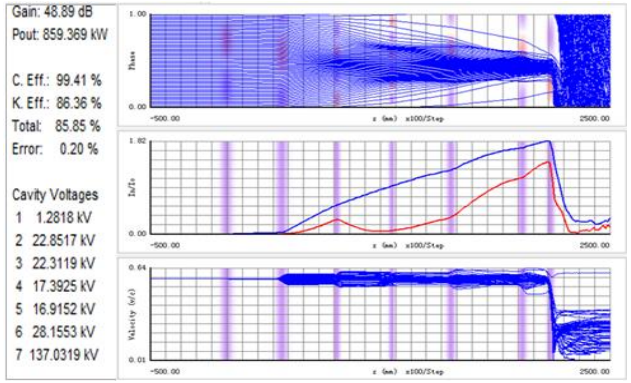
10 CAV/2 2nd harmonic CAV80%/2.9m



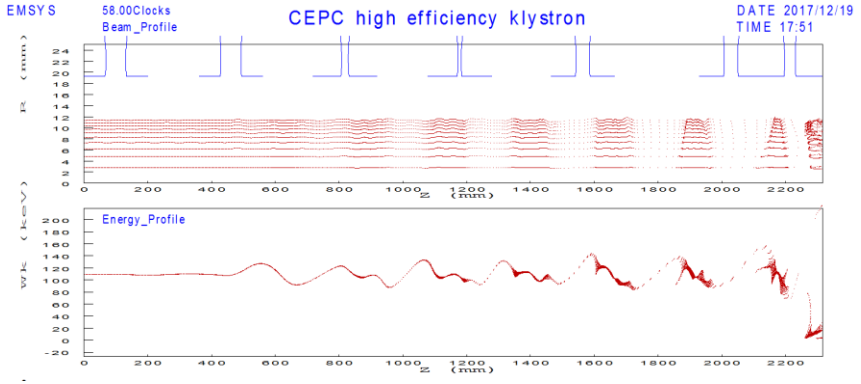
8 CAV/2 2nd harmonic cavities /1 3rd harmonic cavity /80%/2.2m

Progress on scheme 2

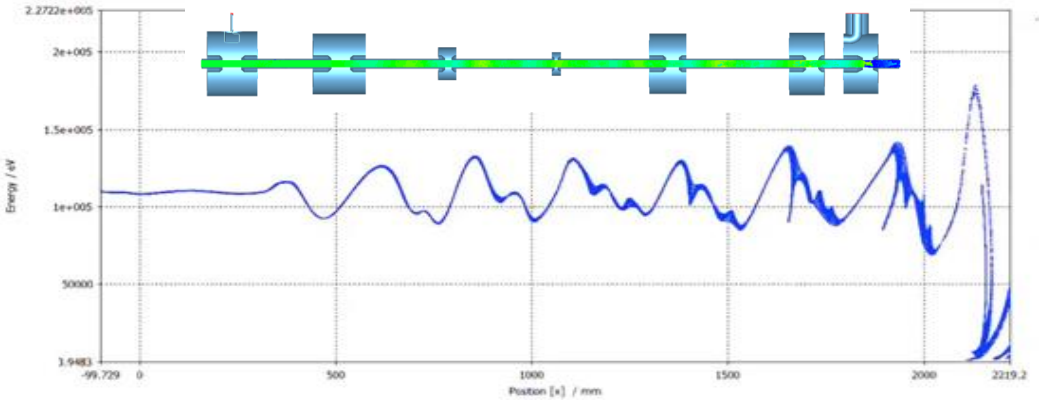
- Based on CSM，with 2nd and 3rd harmonic cavities
- Better bunching with shorter length
- AJDISK/EMSYS/CST 86%/81%/77%



AJDISK



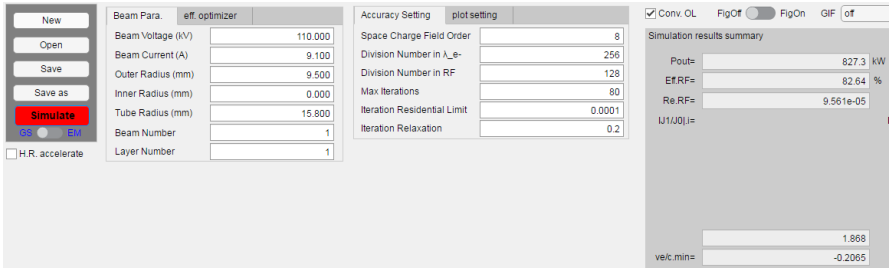
EMSYS



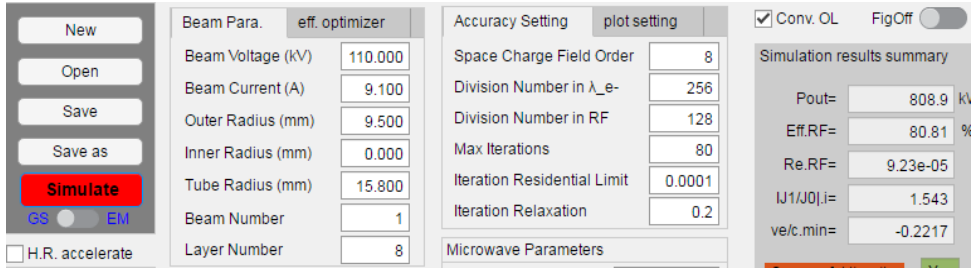
CST

Progress on scheme 2

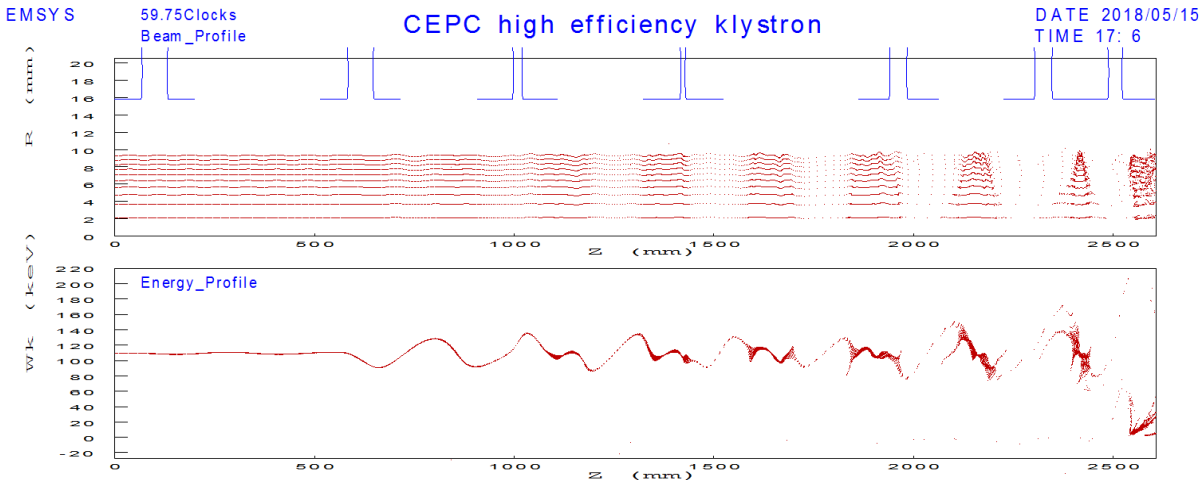
- Based on CSM，reduce the beam aperture and beam size(from 19.3mm/11.6mm to 15.8mm/9.5mm)
- KLYC 1D/ KLYC 2D/ EMSYS 82.6%/80.8%/81%



KLYC 1D



KLYC 2D



EMSYS

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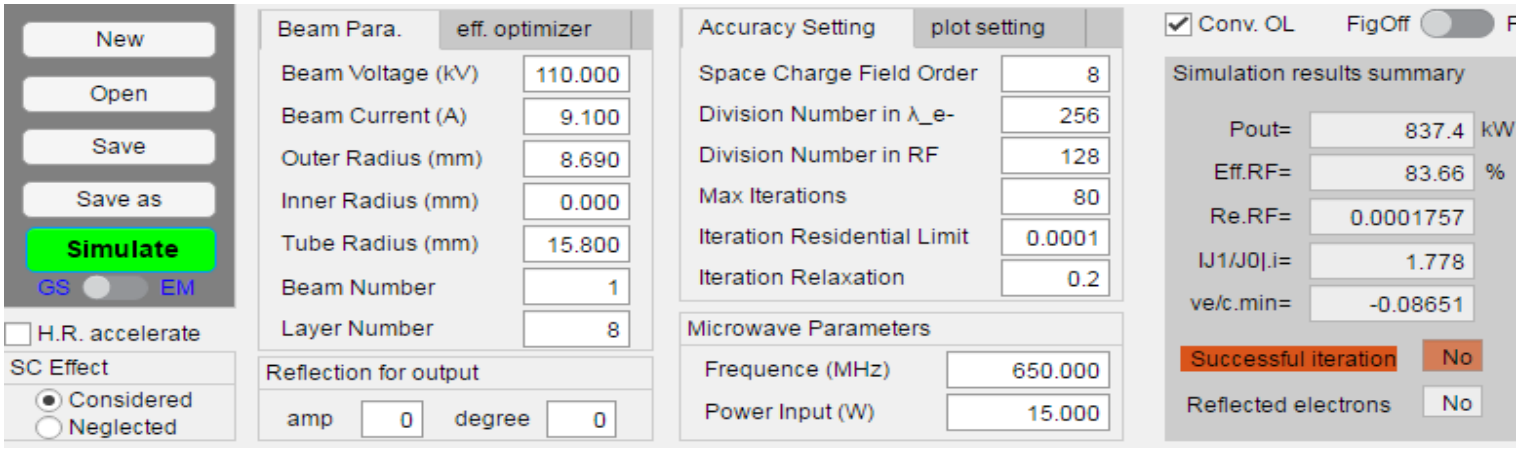
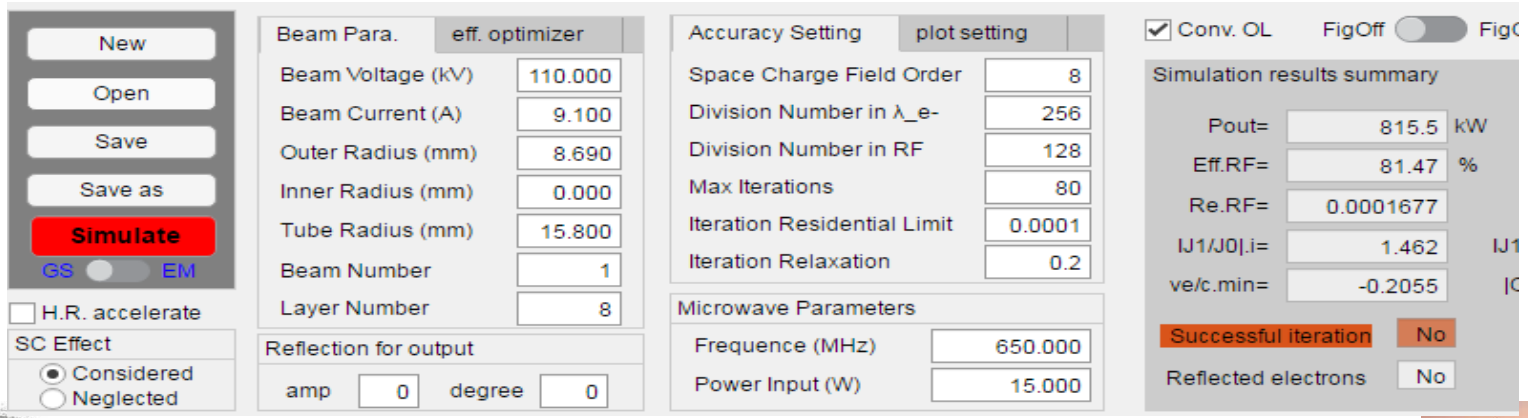
Progress on scheme 2

- **Based on CSM，reduce the beam size again (from 9.5mm to 8.69mm), KLYC 1D/ KLYC 2D 83.6%/81.5%**



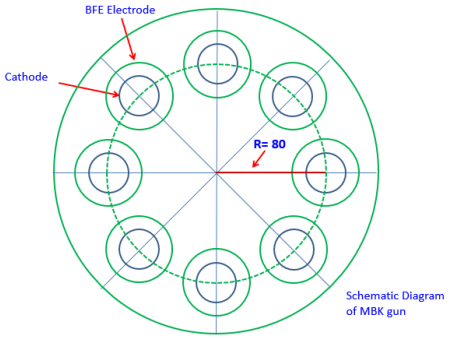
KLYC 1D

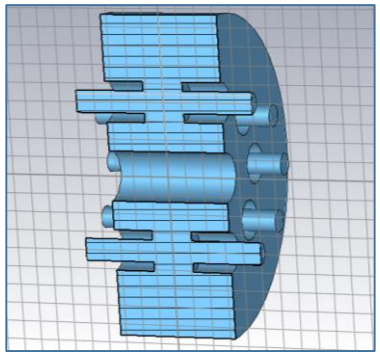


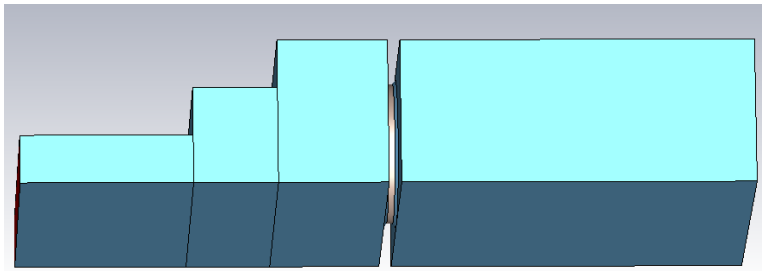
KLYC 2D

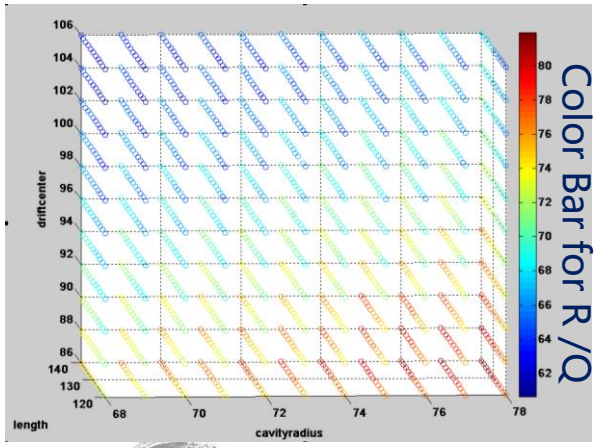
Progress on scheme 3

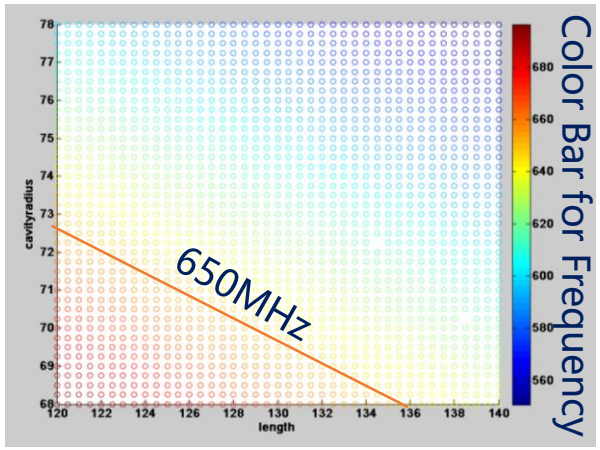
Parameter	Value
Freq. (MHz)	650
Voltage (kV)	54
Current(A)	20(2.5×8)
Beam No.	8
Pervence (μP)	1.6(0.2×8)
Beam size(mm)	7.5
Drift tube (mm)	12
Power(kW)	800(100×8)

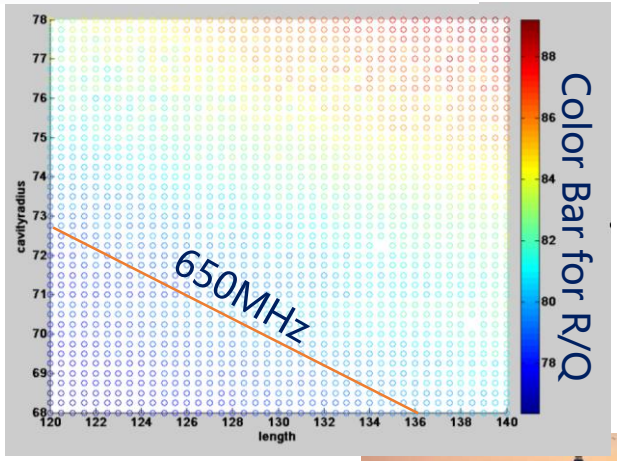












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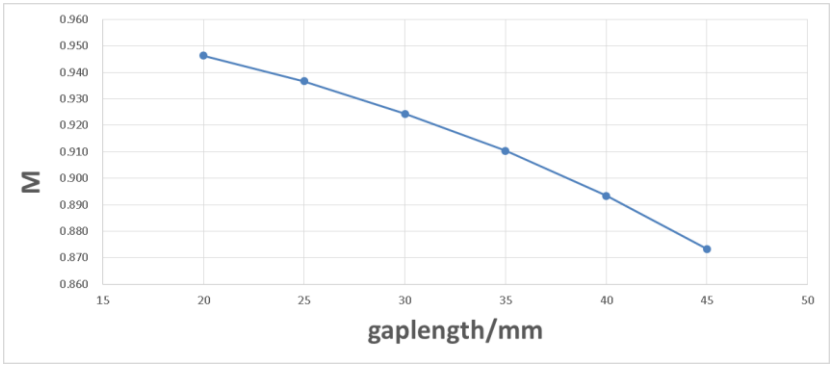
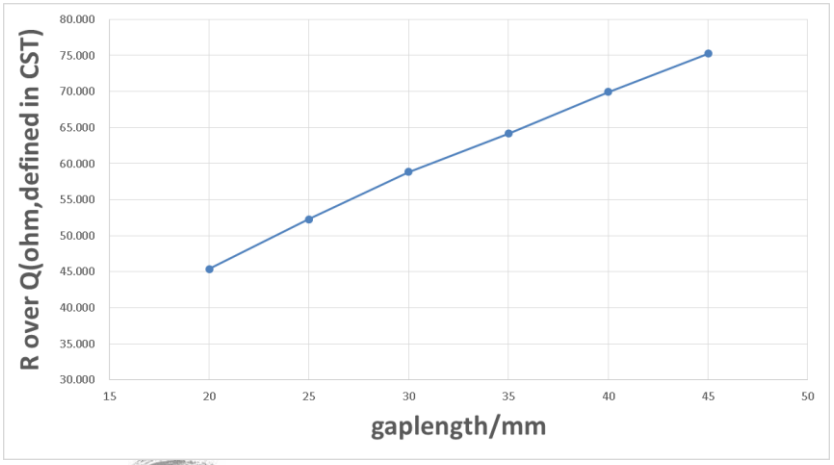
Progress on scheme 3

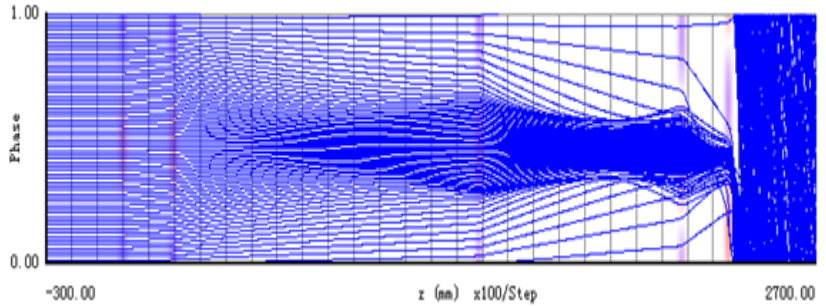
- **Based on COM，Dynamics on 54kV/2.5A**



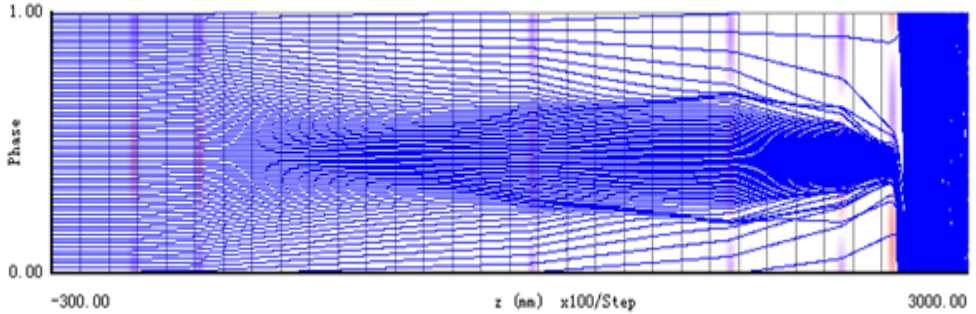
M vs. cavity gap



M vs. R/Q



5 CAV/2.5m/80%



6 CAV/2.9m/84.8%

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Summary

- Mechanic design on 1st prototype tube will be finished at the end of this month.
- The manufacture of the 1st tube will be completed this year and high power test will be started at the beginning of next year.
- The 3 schemes for the high efficiency design are ongoing based on 3 different gun design.
- The manufacture of the 2nd prototype will be started based on the successful high power test of the 1st prototype.
- MBK design will be gradually stepped up in the near future.

Thanks for your attention!

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