CEPC RF Sources System

Zusheng ZHOU(周祖圣)

Institute of High Energy Physics

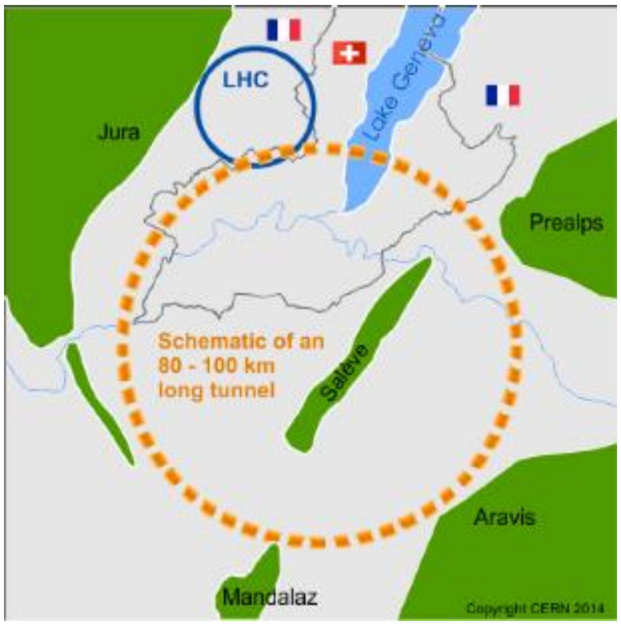
Jan. 25, 2017

Contents

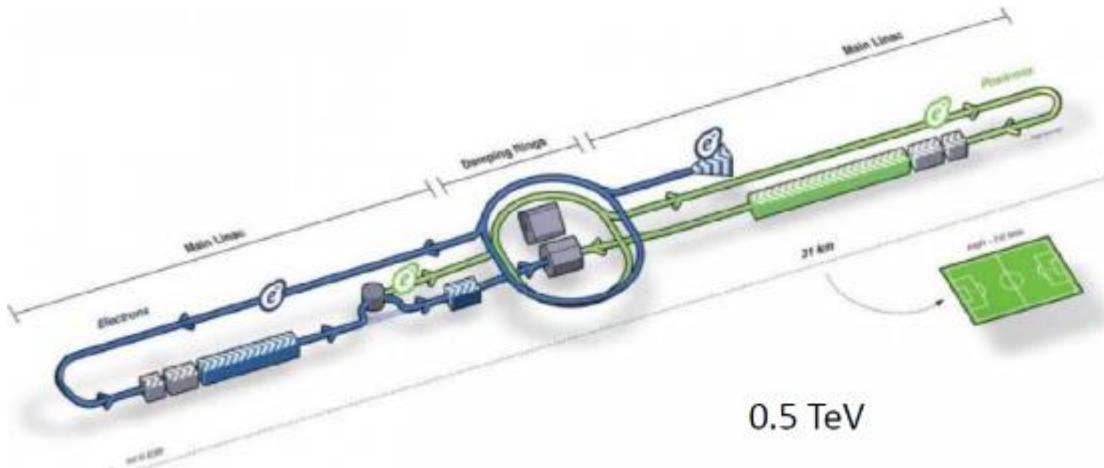
- *Design proposal*
- *R&D Progress*
- *Summary*

Design proposal

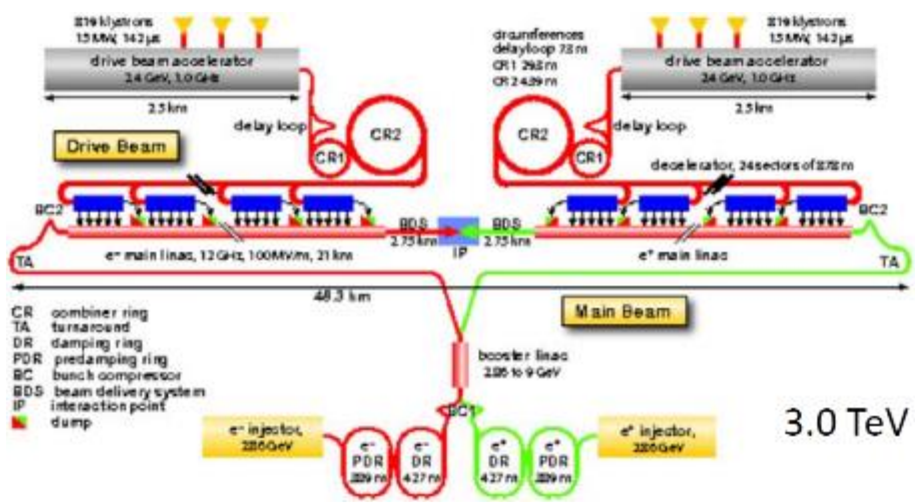
Future large accelerators



FCCee, CW, 800MHz, Prf=110MW

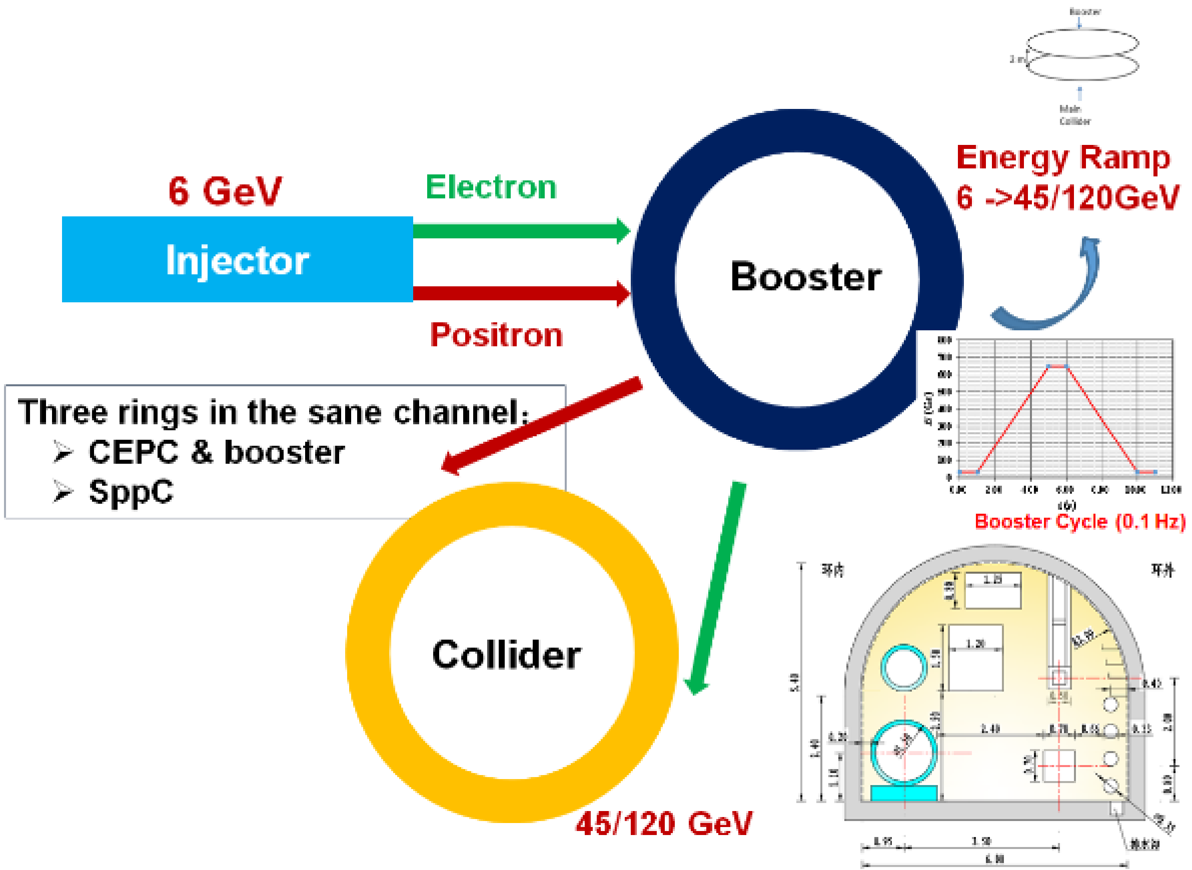


ILC, Pulse, 1.3GHz, Prf=88MW



CLIC, Pulse, 1.0GHz, Prf=180MW

Future large accelerators



CEPC-SppC,
CW,
650MHz,
Prf=100MW

Current situation

For future large accelerators, just like ILC, FCC and CEPC. It's beam power is very high, so high efficiency RF source is much more important.

	Tetrodes	IOTs	Conventional klystrons	Solid State PA	Magnetrons
f range:	DC – 400 MHz	(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%	50%	60%	90%
Remark				Requires P combination of thousands!	Oscillator, not amplifier!

Current situation

For future large accelerators, just like ILC, FCC and CEPC. It's beam power is very high, so high efficiency RF source is much more important.

	Tetrodes	IOTs	Conventional klystrons	Solid State PA	Magnetrons
f range:	DC – 400 MHz	(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%	50%	60%	90%
Remark				Requires P combination of thousands!	Oscillator, not amplifier!

RF sources for accelerator are IOT, klystron and solid state amplifier. From cost, frequency limitation and power level, klystron is still the first choice.

Current situation

- 2014 saw a breakthrough in klystron theory:
  - 1981, "**congregated bunch**" was re-introduced [V.A. Kochetova, 1981]

    (later electrons faster when entering the output cavity).
  - 2014, "**bunch core oscillations**" was introduced [A. Yu. Baikov, et al.: "Simulation of conditions for the maximal efficiency of decimeter-wave klystrons", Technical Physics, 2014]

    (controlled periodic velocity modulation)
  - 2013, BAC method was invented[I.A. Guzilov, O.Yu. Maslennikov, A.V. Konnov, "*A way to increase the efficiency of klystrons*", IVEC 2013]

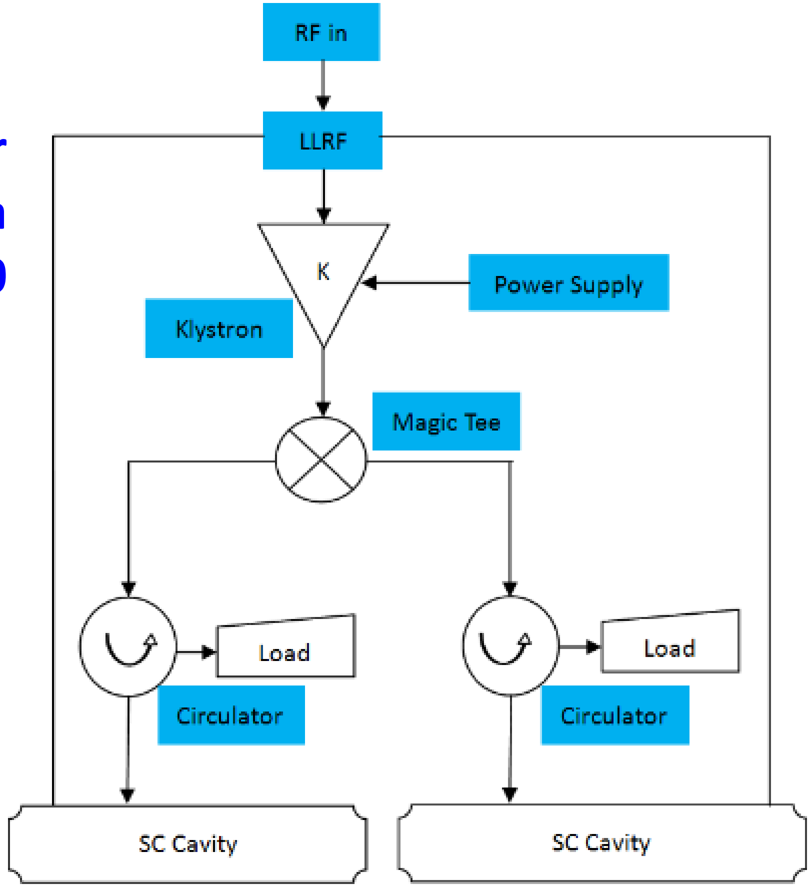
    (Bunch, Align velocities, Collect outsiders)
- These method together promise a significant increase in klystron efficiency(approaching 90%)
- A international collaboration has started. HEIKA – "High Efficiency International Klystron Activity" is evaluating and implementing this "breakthrough".

CEPC Collider RF sources

Baseline

Considering klystron lifetime and power redundancy, 2 cavities will be powered with a CW klystron capable to deliver more than 800 kW.

Parameters	Value
Operation frequency	650MHz+/-0.5MHz
RF input power (kW)	280 CW（250）
RF source number	160
Klystron output power (kW)	800 CW



1 klystron power 2 cavities

CEPC Collider RF sources

Klystron key design parameters

Parameters	Now	Future
Centre frequency (MHz)	650+/-0.5	650+/-0.5
Output power (kW)	**800**	**800**
Beam voltage (kV)	80	70
Beam current (A)	16	15
Efficiency (%)	**65** →	**80**

CEPC Collider RF sources

Klystron key design parameters

Parameters	Now	Future
Centre frequency (MHz)	650+/-0.5	650+/-0.5
Output power (kW)	**800**	**800**
Beam voltage (kV)	80	70
Beam current (A)	16	15
Efficiency (%)	**65** →	**80**

How to do?

CEPC Collider RF sources

Klystron key design parameters

Parameters	Now	Future
Centre frequency (MHz)	650+/-0.5	650+/-0.5
Output power (kW)	**800**	**800**
Beam voltage (kV)	80	70
Beam current (A)	16	15
Efficiency (%)	**65** →	**80**

How to do?

There are some R&D work supported by IHEP innovation funds.

R&D Progress

Klystron Schedule and strategy

Because of klystron efficiency is more than 80%, in order to fulfill this program, there may have following problems:

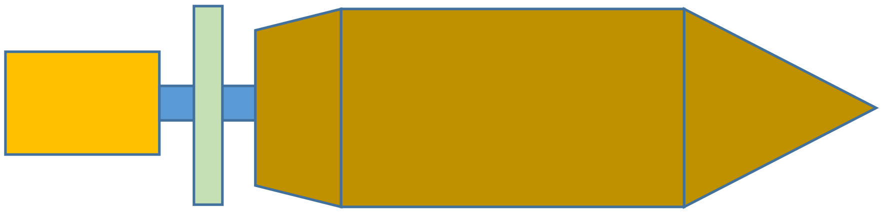
1) No experience and no related infrastructure on this kind of klystron;

2) Design and simulation are not enough and matured;

3) Let's start from beam tester, classical design and currently progressed design(higher efficiency design).

Klystron Schedule and strategy(2)

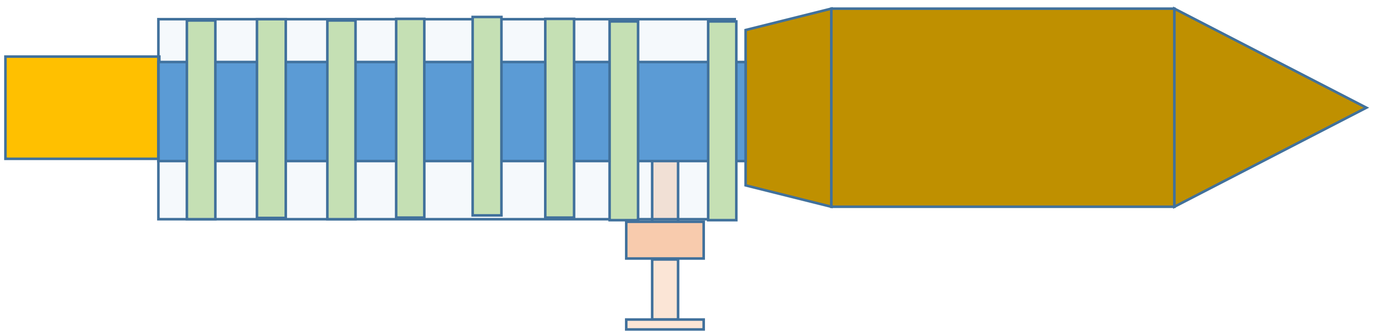
(1) Beam tester



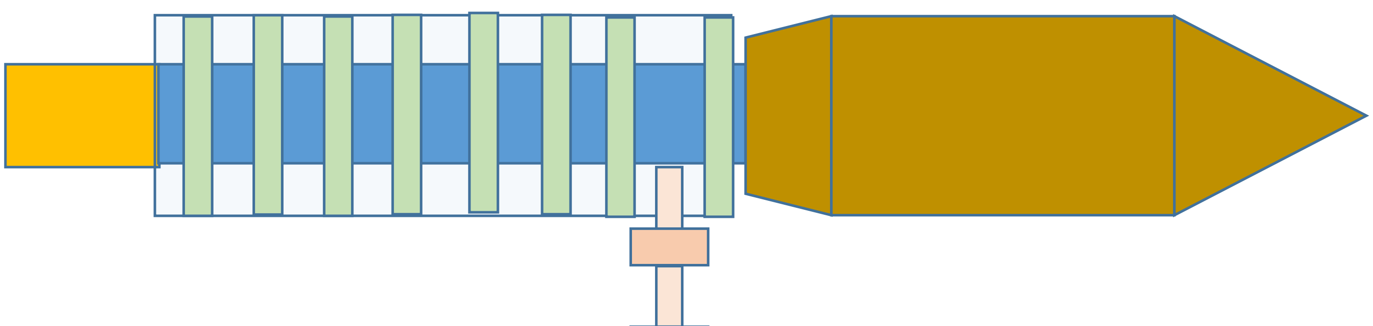
Merits

- Saving the money
- Saving the time
- Possible to try 2 or 3 designs

(2) #1 prototype



(3) #2 prototype



R&D-Electron gun

EGUN simulation result:

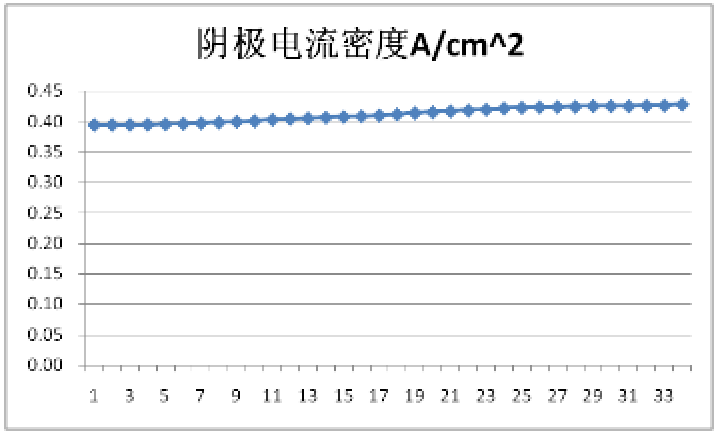
Area compression ratio : 4.4

Perveance: 0.647μP

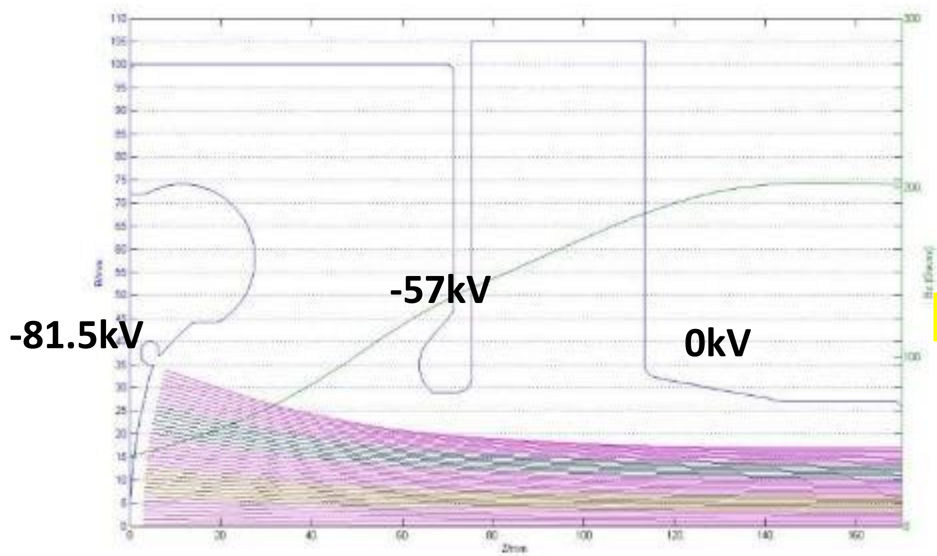
Cathode current density：

0.39A/cm2~0.43A/cm2

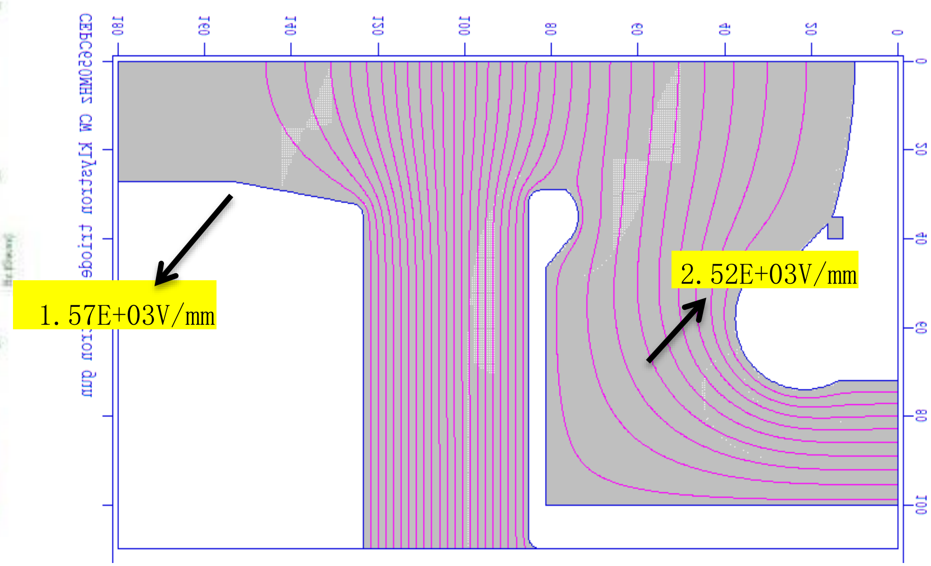
Max. electric field : 2.520kV/mm



Cathode current density



Gun region beam trajectory simulation with Egun



Electrode E fied density optimization with Possion

R&D-Electron gun

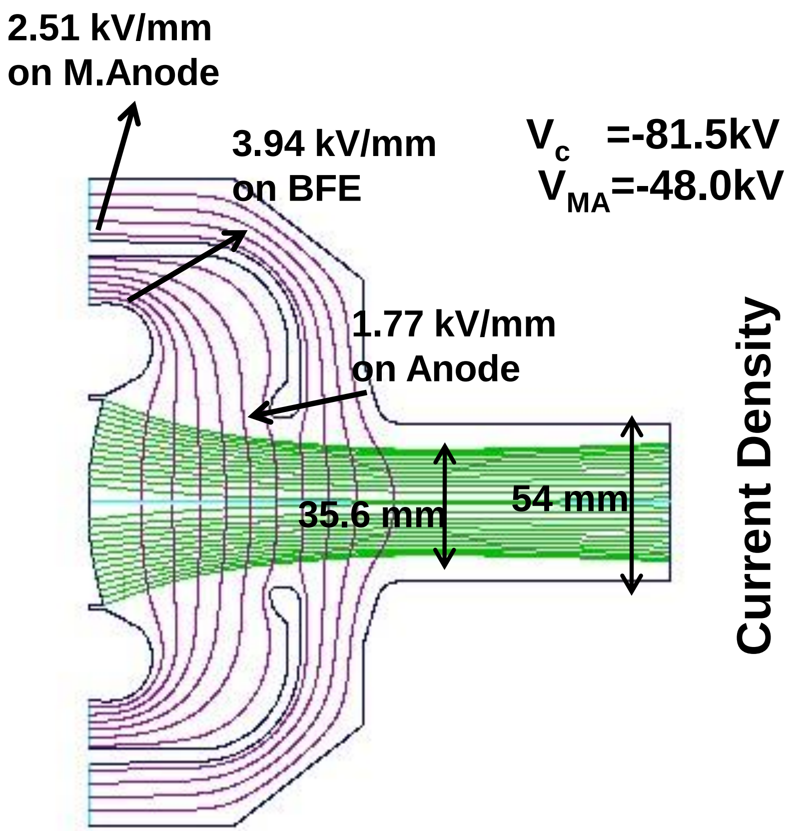
DGUN simulation results

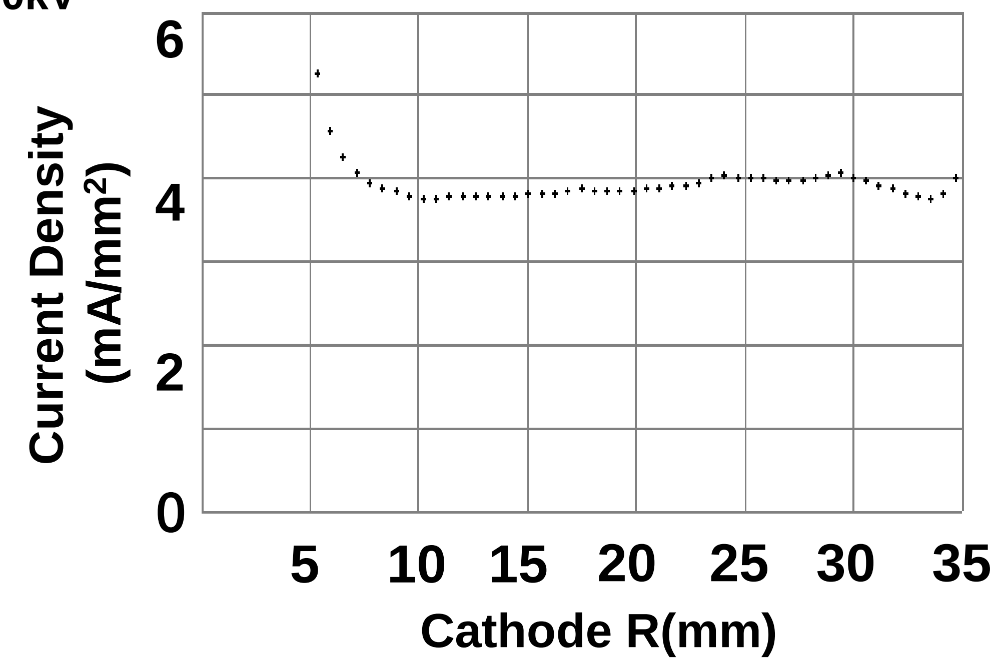
DGUN simulation result :

Beam Diameter=17.8mm

Current=15.12 A

Perveance= 1.43 $\mu A/V^{3/2}$

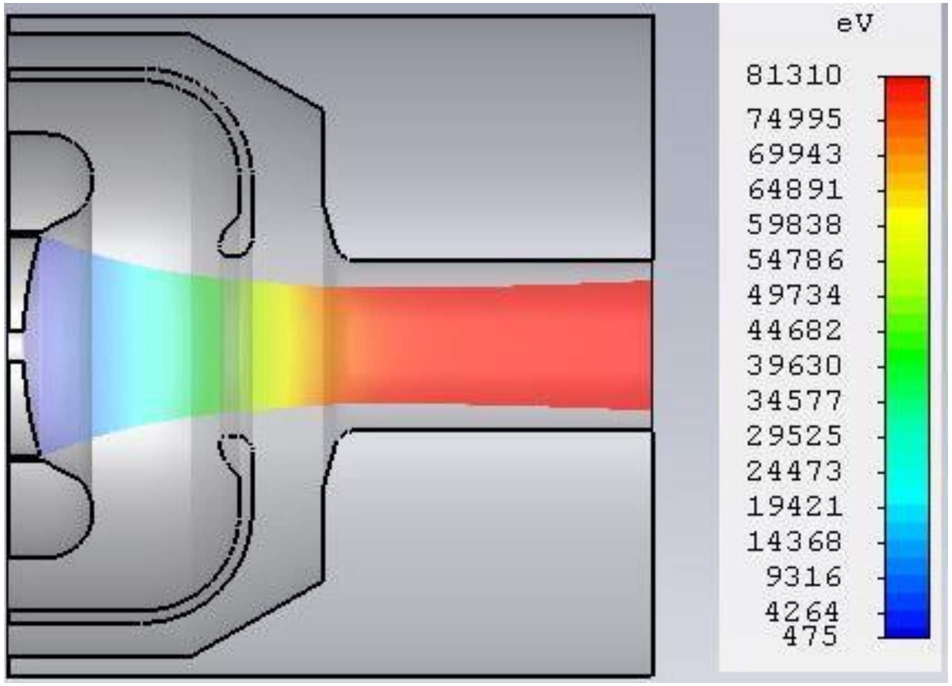




R&D-Electron gun

CST simulation results

Beam Diameter=17.7mm
Current=14.88 A
Perveance= 1.41 $\mu A/V^{3/2}$



R&D-Electron gun

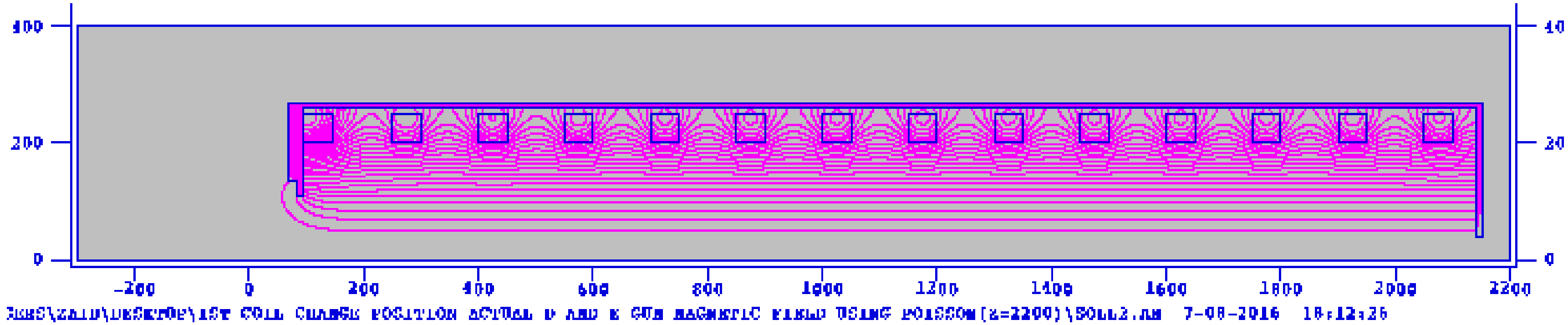
Simulation results comparison

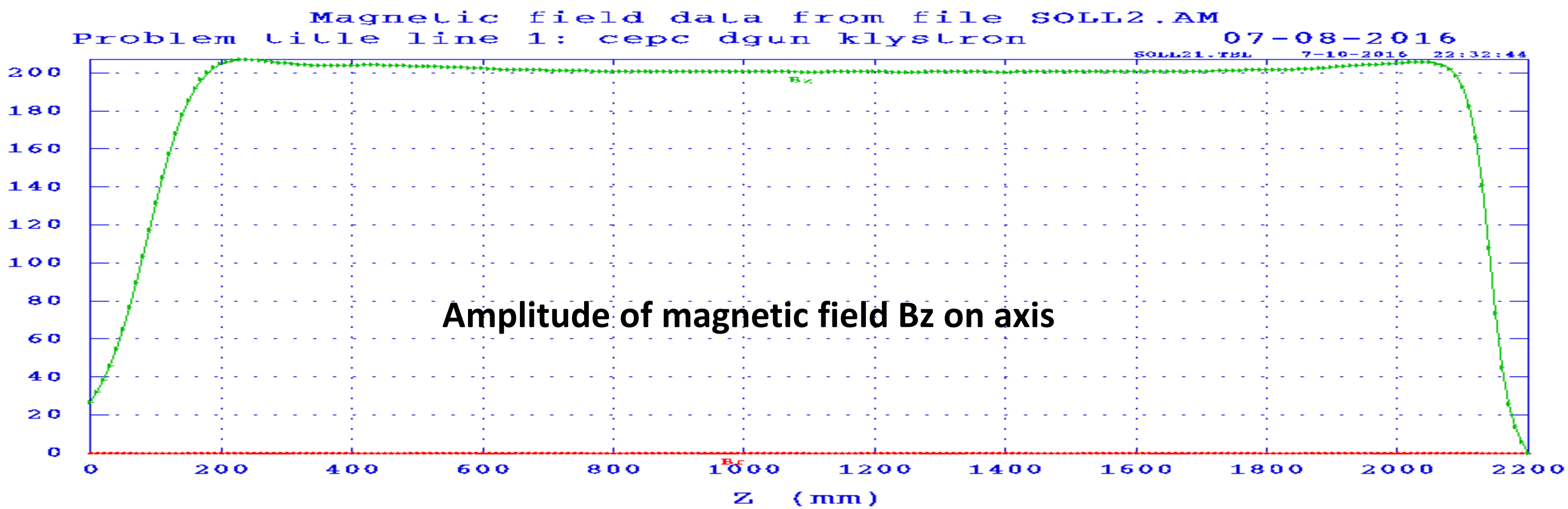
V_c =-81.5kV, V_{MA}=-48.0kV

Type	DGUN	EGUN	CST
Current(A)	15.12	14.88	14.88
Beam DIA(mm)	17.8	17.7	17.7
Perveance($\mu A/V^{3/2}$)	1.43	1.41	1.41

R&D-Electron gun

Simulation results comparison

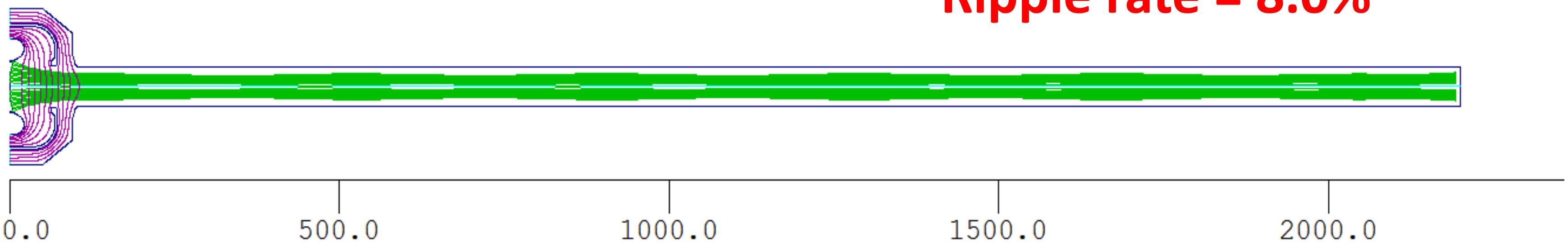


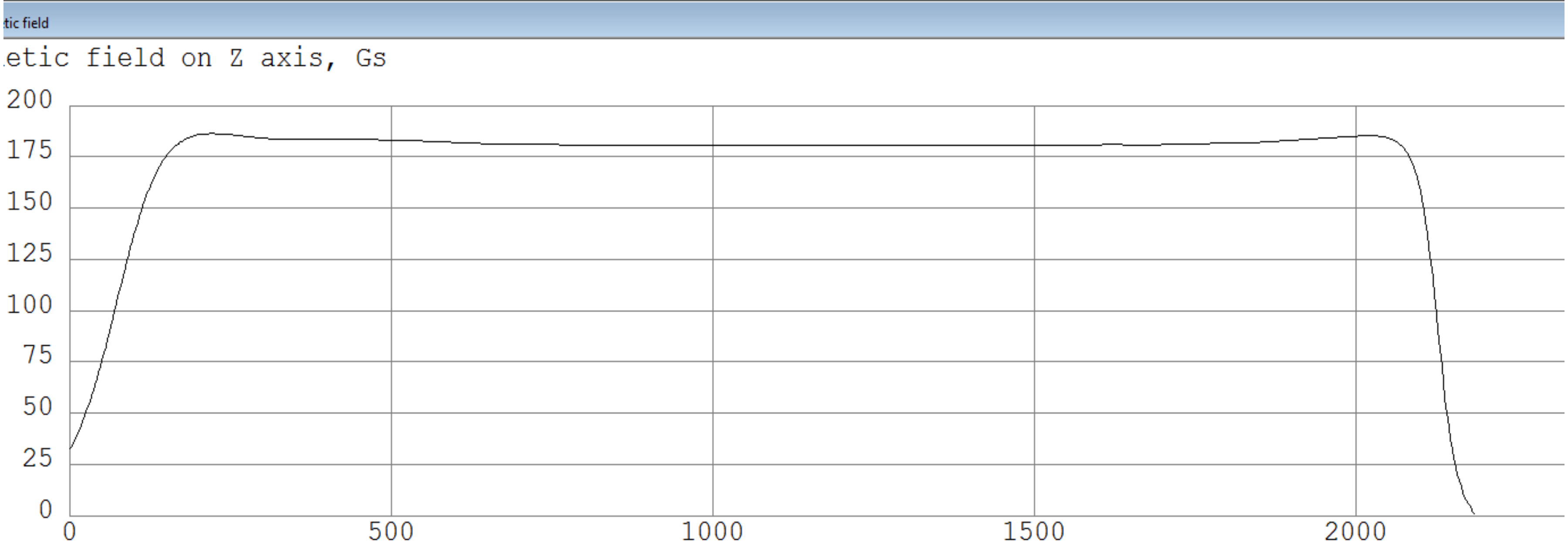


Amplitude of magnetic field Bz on axis

R&D-Beam trajectory

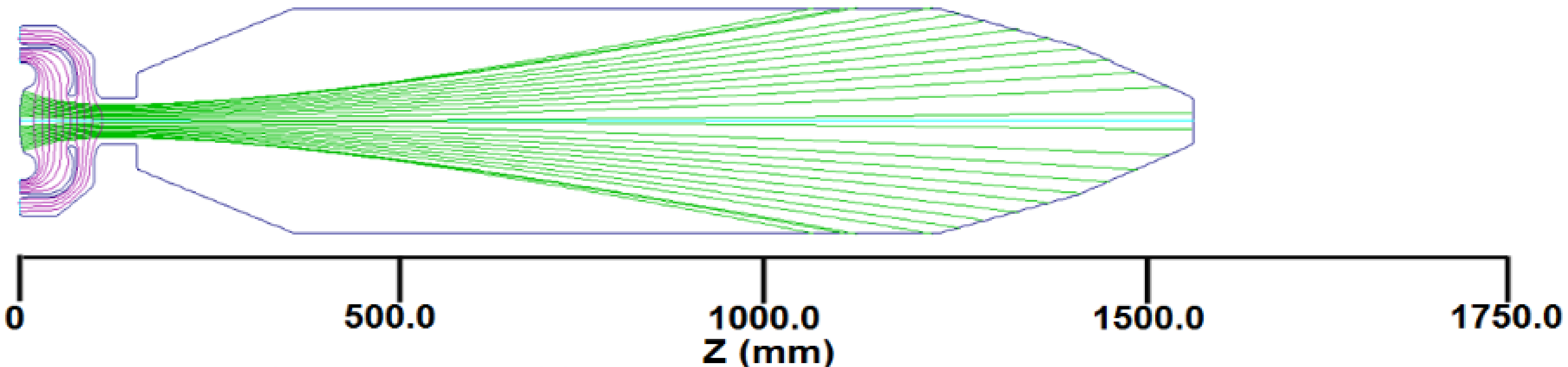
Ripple rate = 8.0%



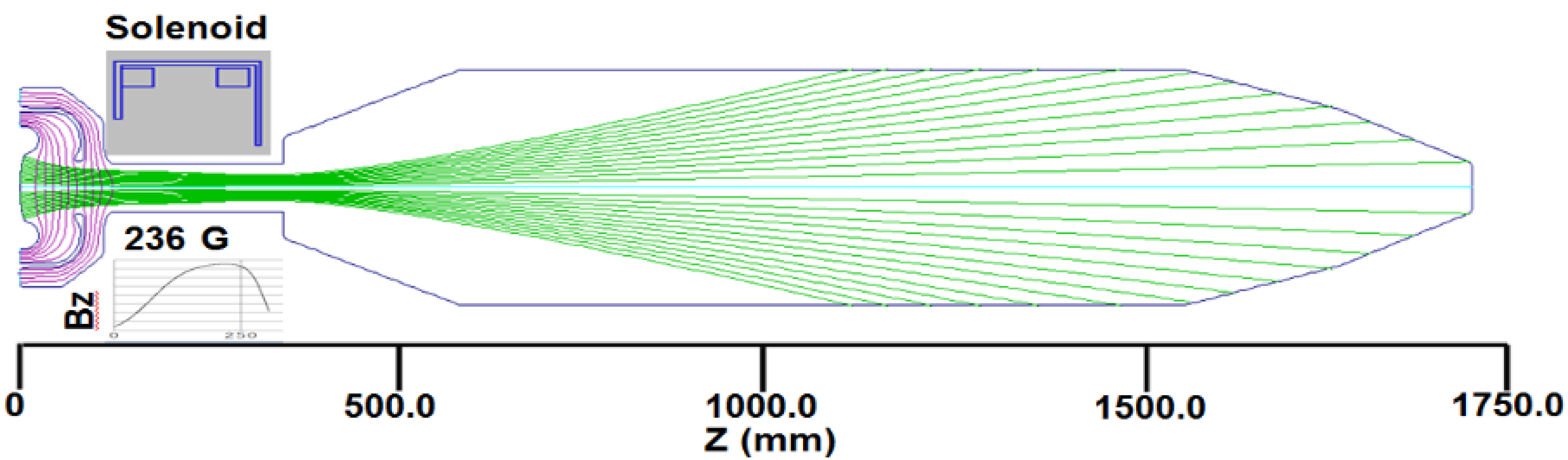


R&D-Beam trajectory

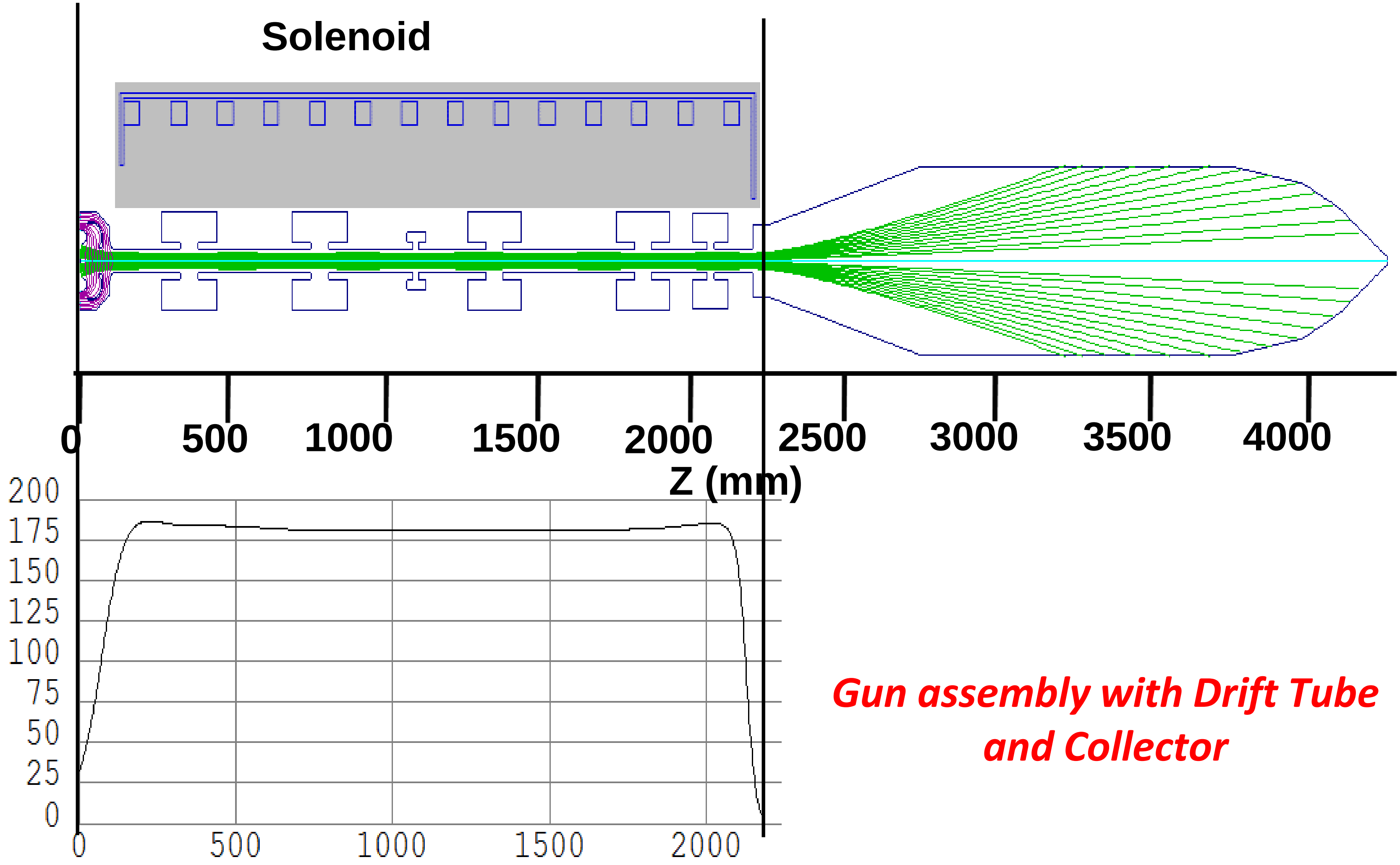
Beam Tester without Magnetic Field



Beam Tester with Magnetic Field



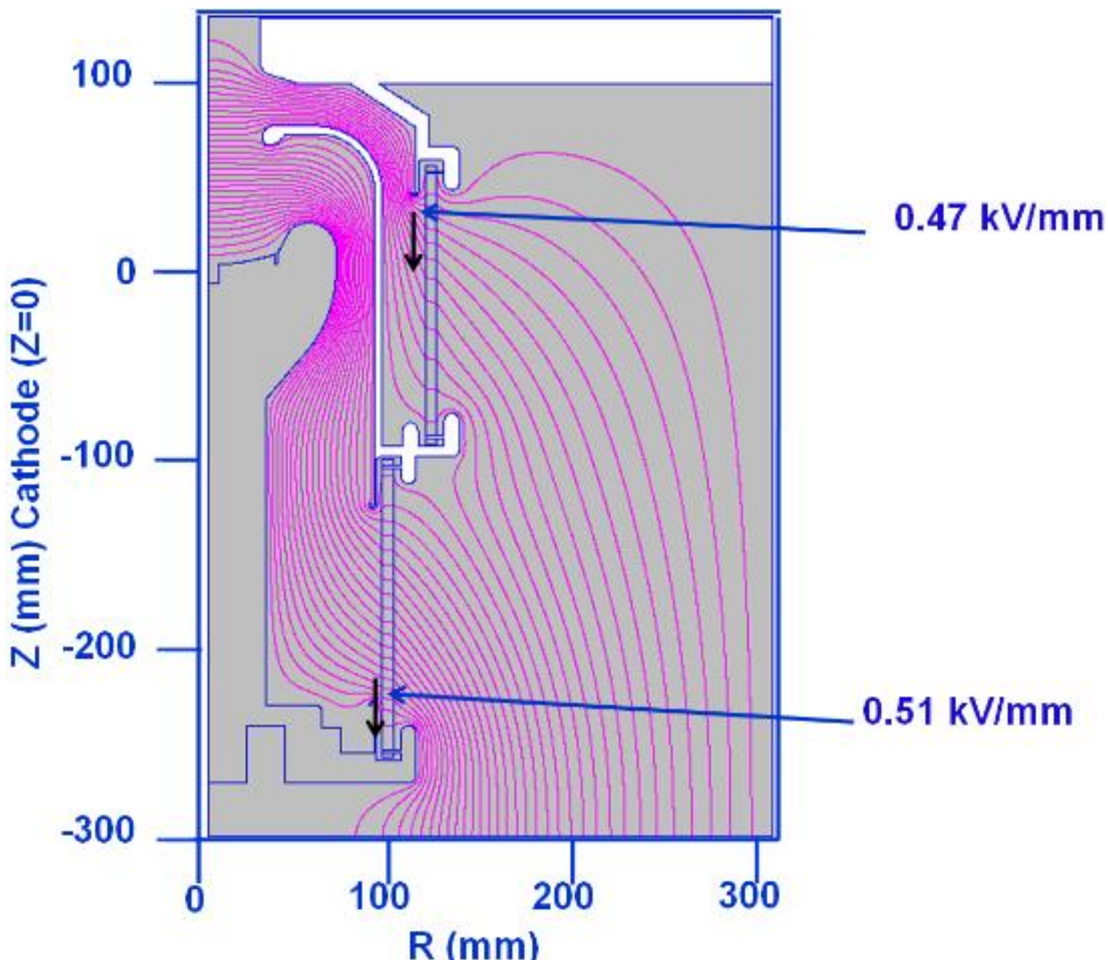
R&D-Beam trajectory



Gun assembly with Drift Tube and Collector

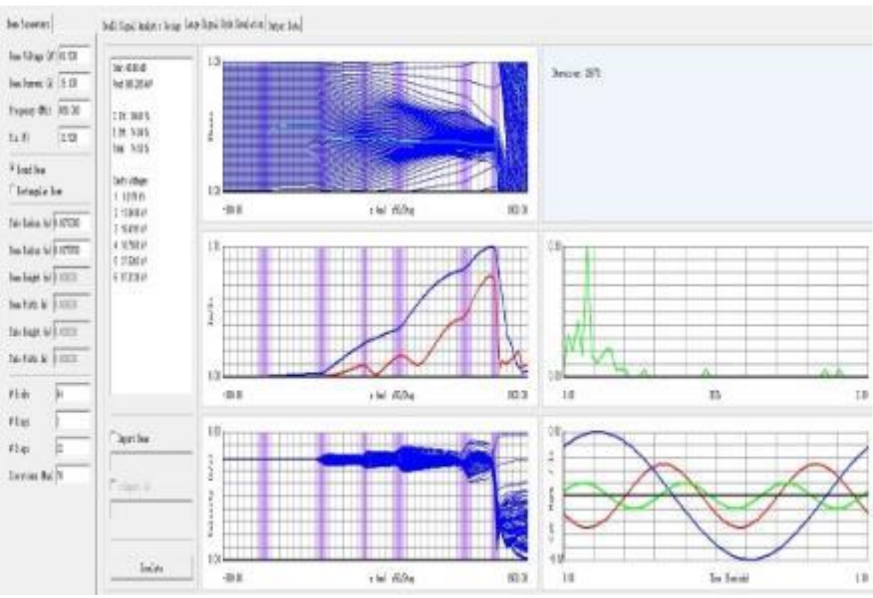
R&D-Electron gun

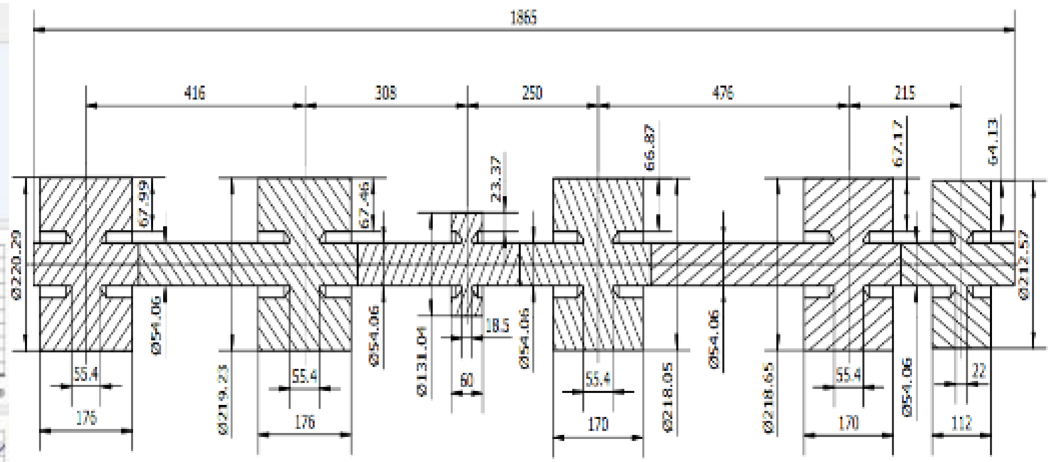
HV Gun Envelop for Electron Gun



R&D-RF interaction

5 fundamental cavities and 1 2nd harmonic cavity, 1 d simulation result shows 74.55% efficiency.



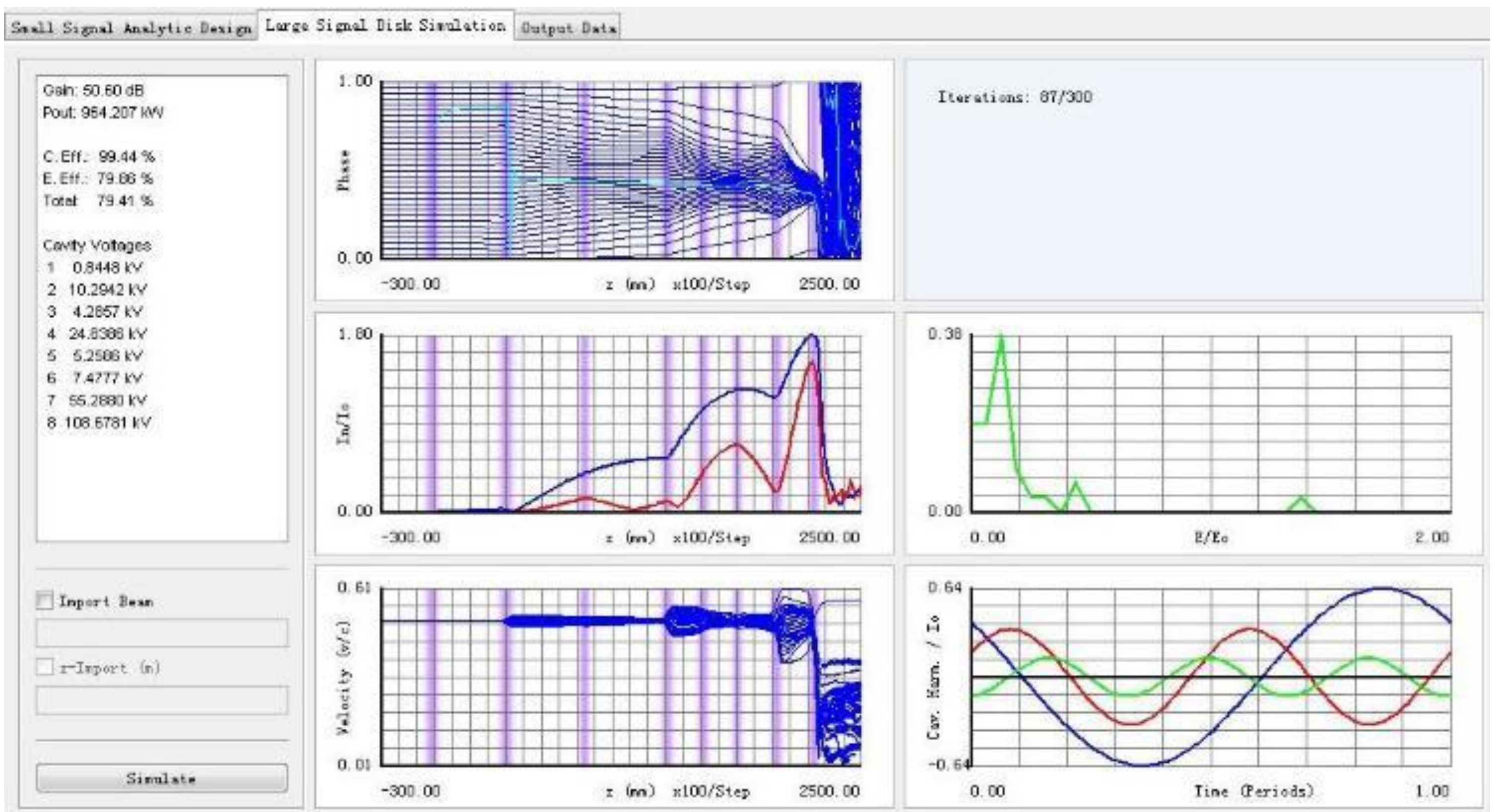


AJ disk design

Mechanical design

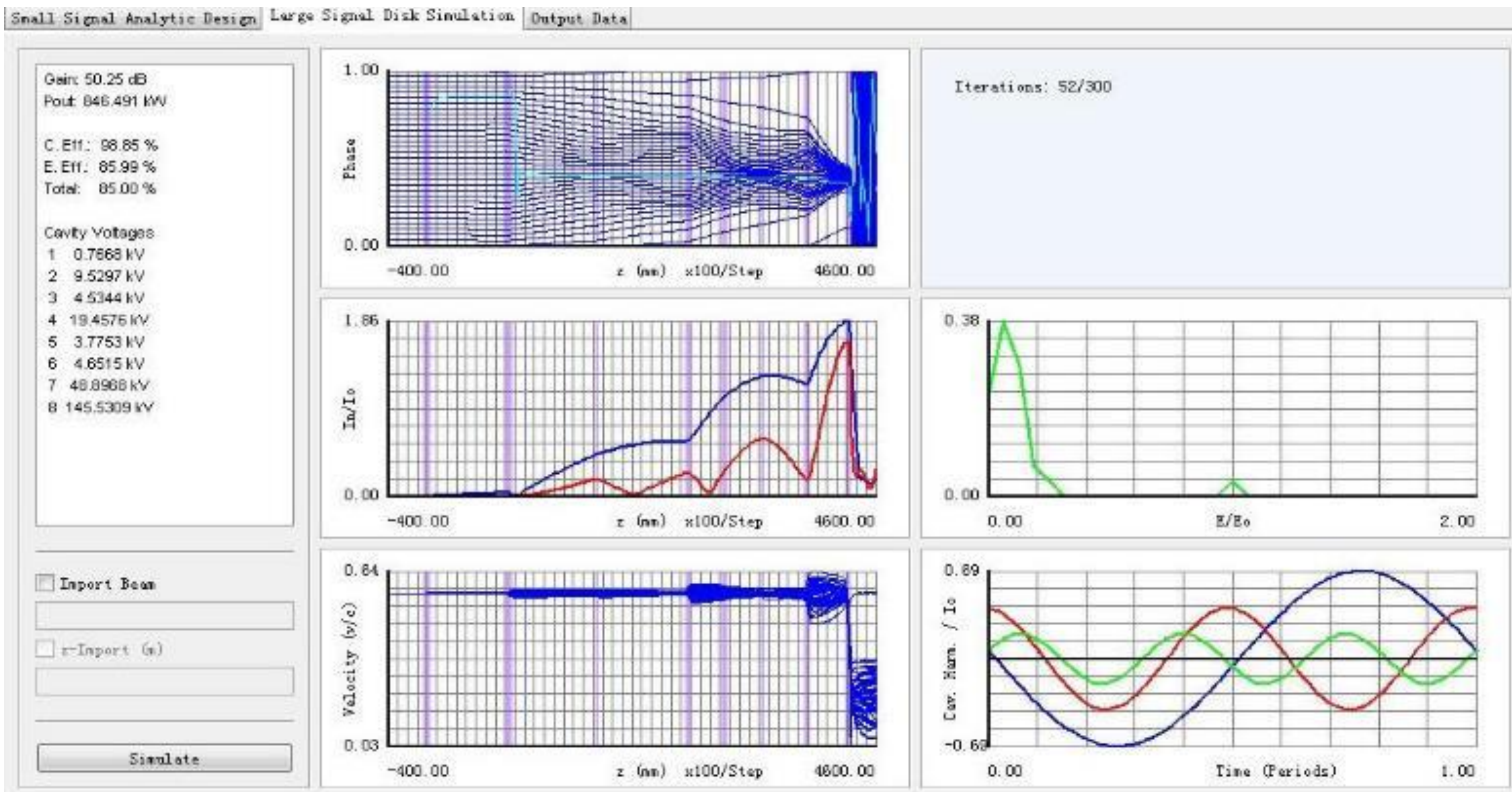
R&D-RF interaction

8 cavities and BAC method, 1 d simulation result shows 79.41% efficiency.



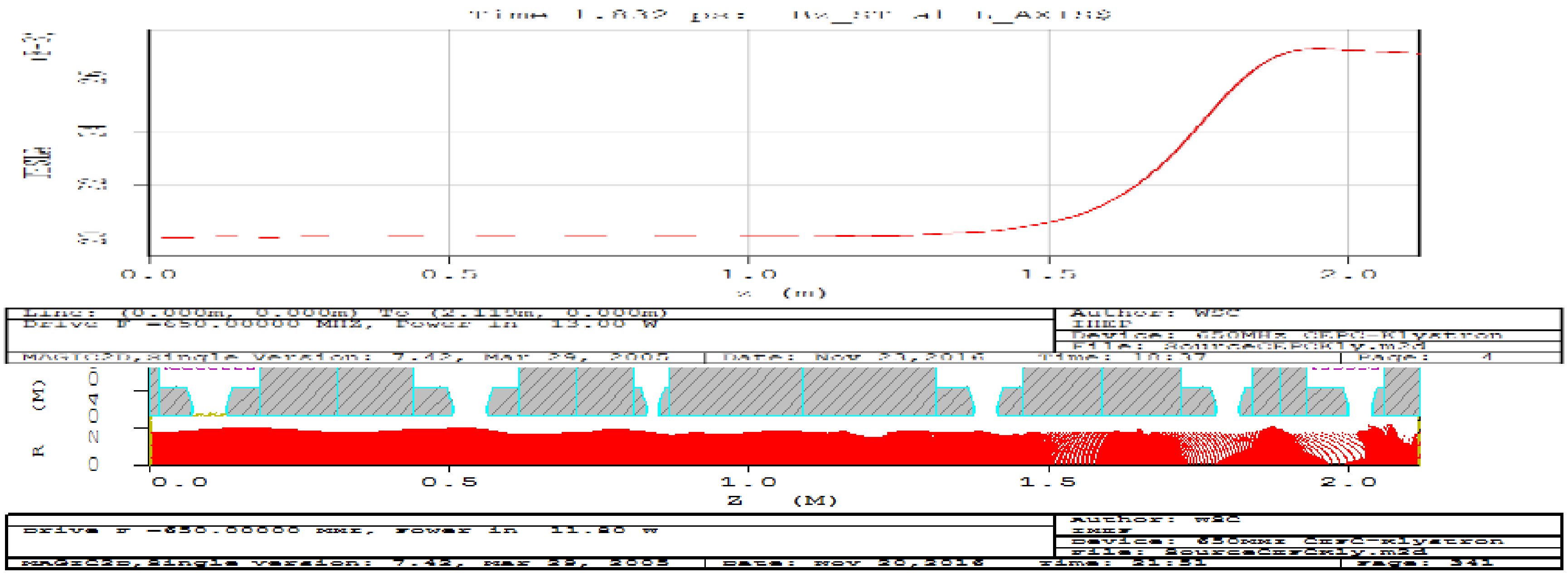
R&D-RF interaction

8 cavities, BAC method and low pervence gun, 1 d simulation result shows 85% efficiency.



R&D-RF interaction

We are doing more simulations in detail using other 2d and 3d codes. The final parameters of cavities will be given and then start to mechanical design with company engineers.

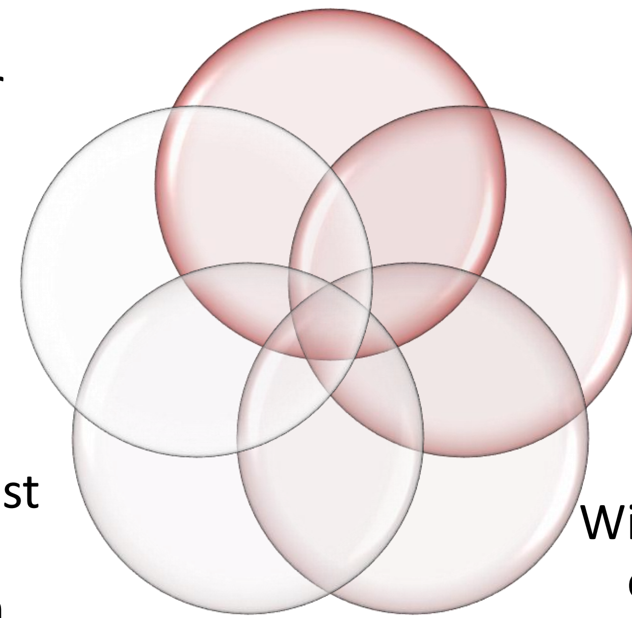


R&D-Output window

Simulation and optimization

Window coupler simulation and mechanical design

Window and coupler cooling system design

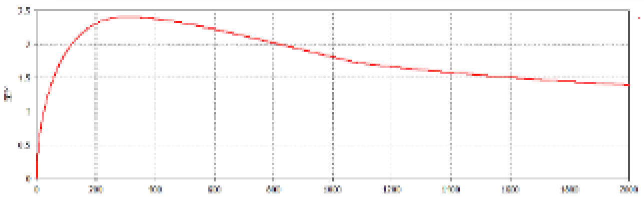


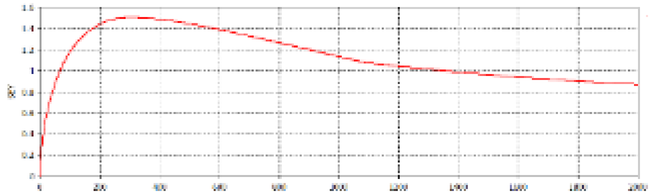
High power test stand construction

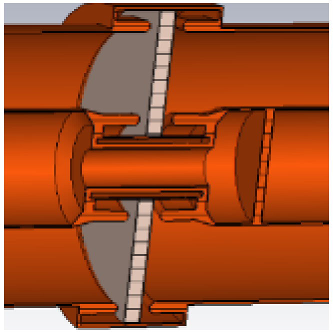
Window multipactor effector analysis

R&D-Output window

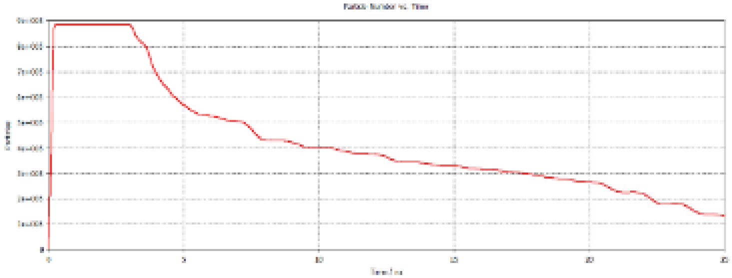
multipactor effector simulation

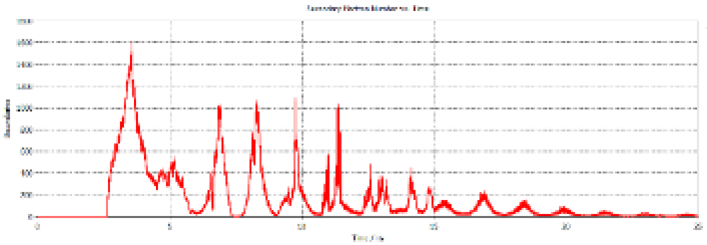


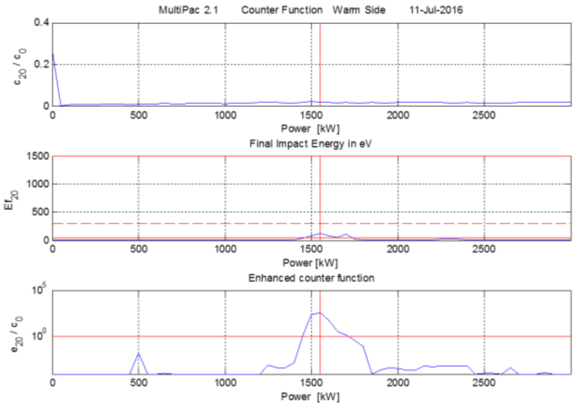


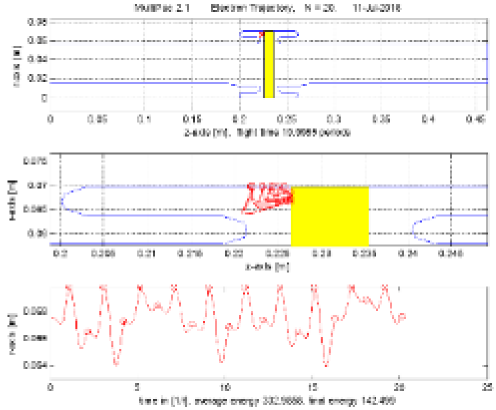


99.5% Al2O3 and OFC multipactor effector







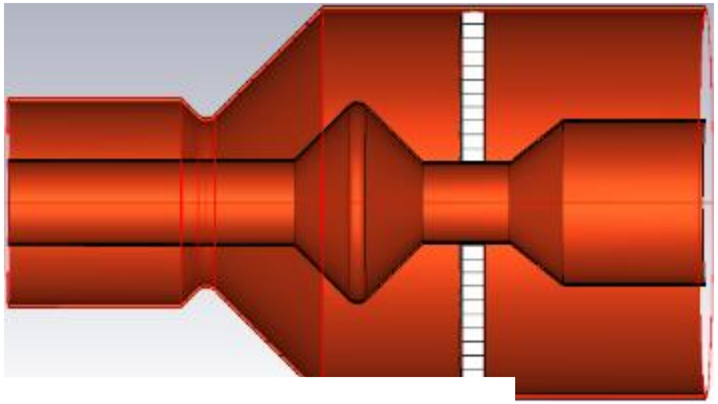


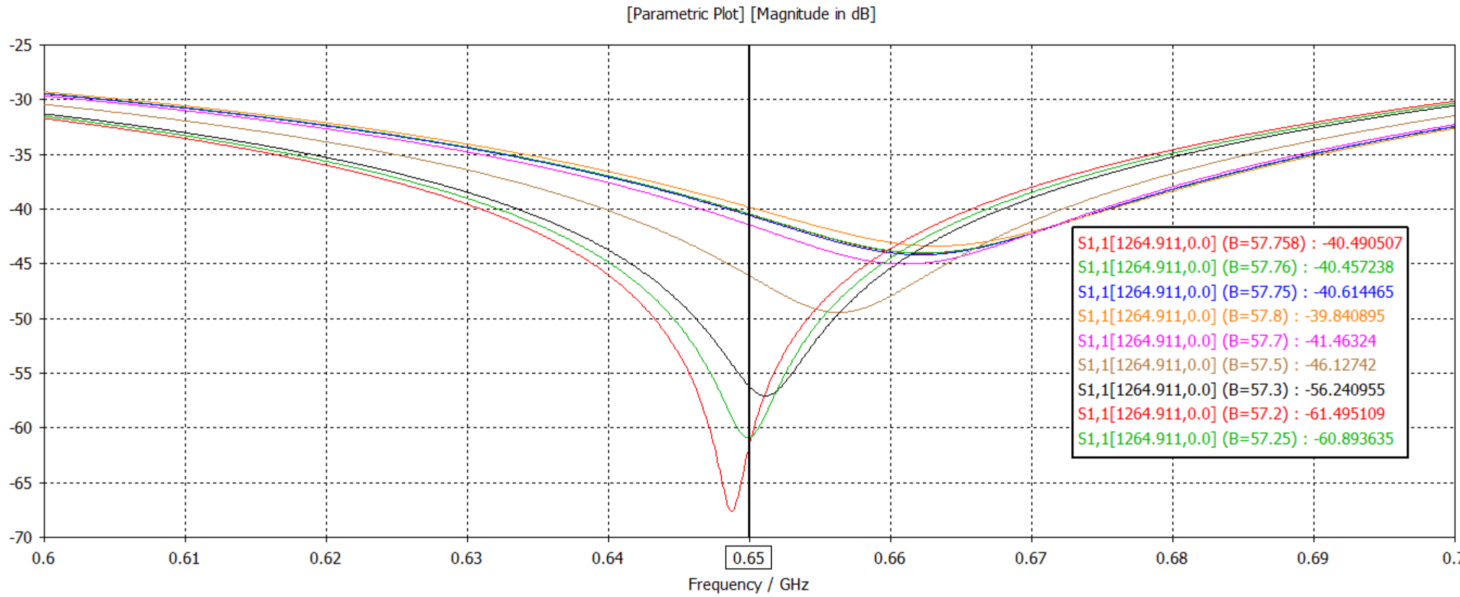
CST and MULTIPACT code simulation results

R&D-Output window

Structure optimization

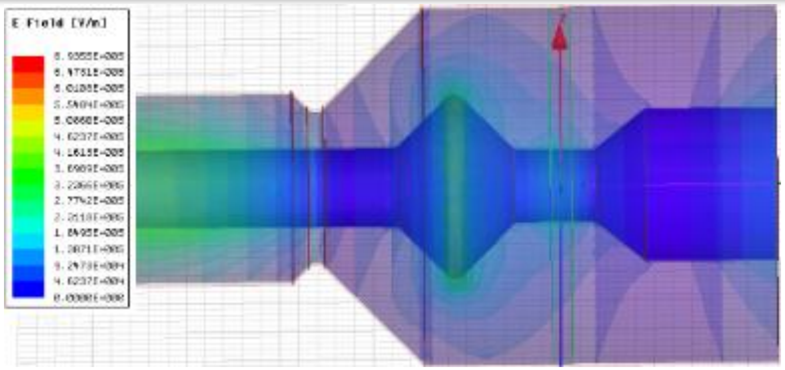
With 800kW power and 650MHz frequency, S parameters and VSWR meet demands.

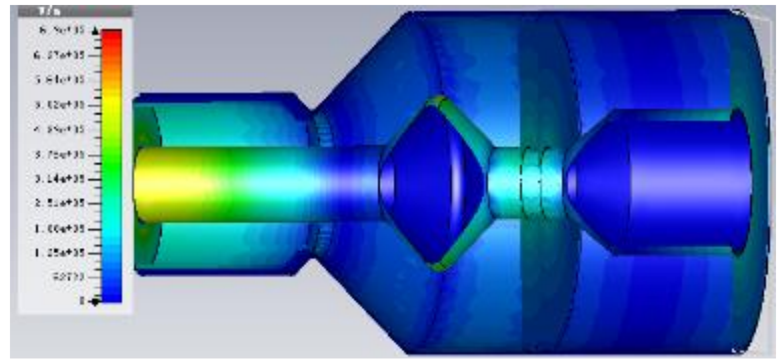




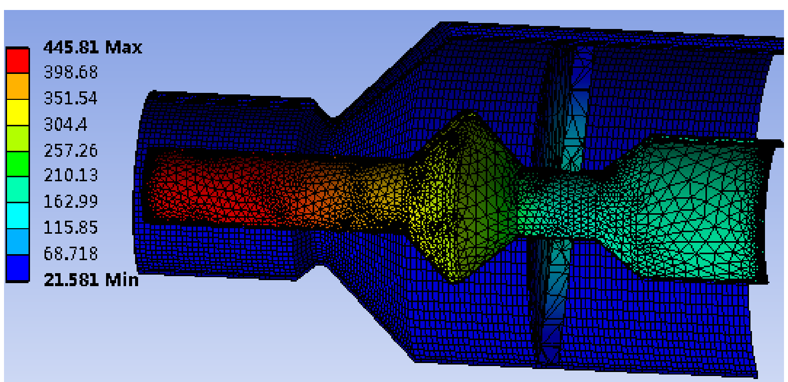
R&D-Output window

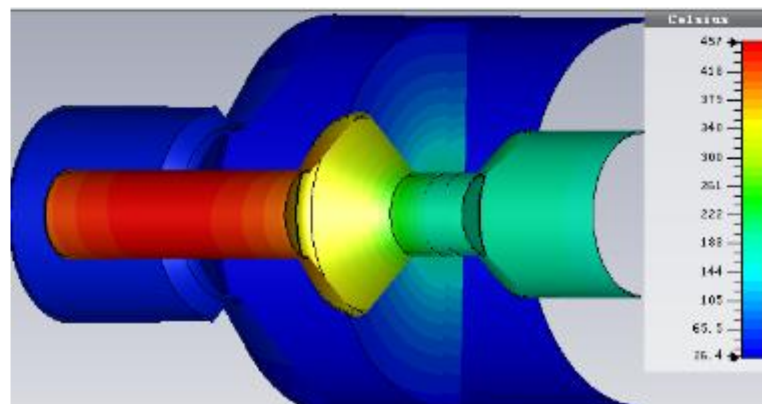
HFSS and CST electromagnet filed and thermal simulations





Electromagnet filed simulation



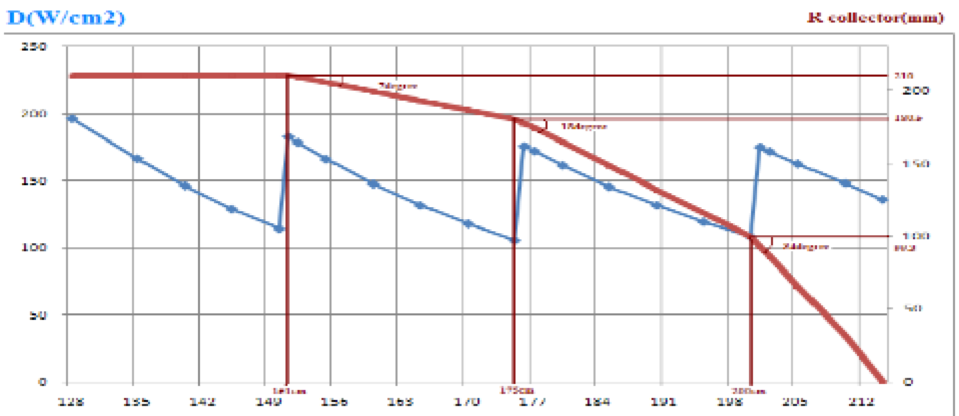


Thermal analysis simulation

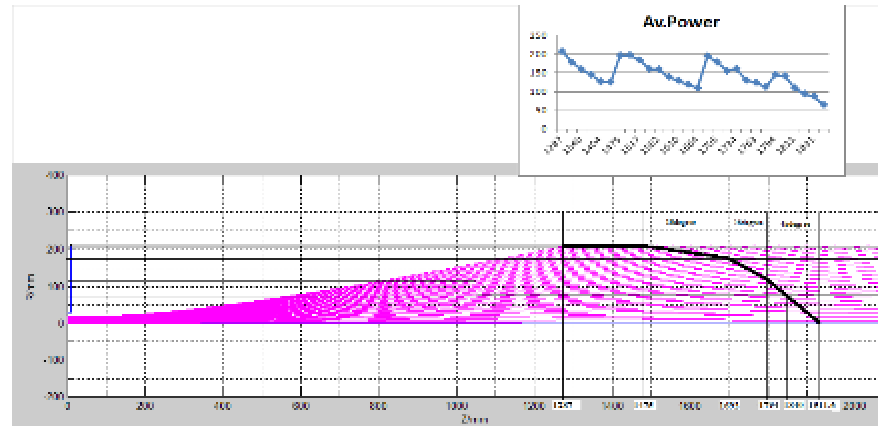
HFSS and CST simulations are in complete agreement

R&D-Collector

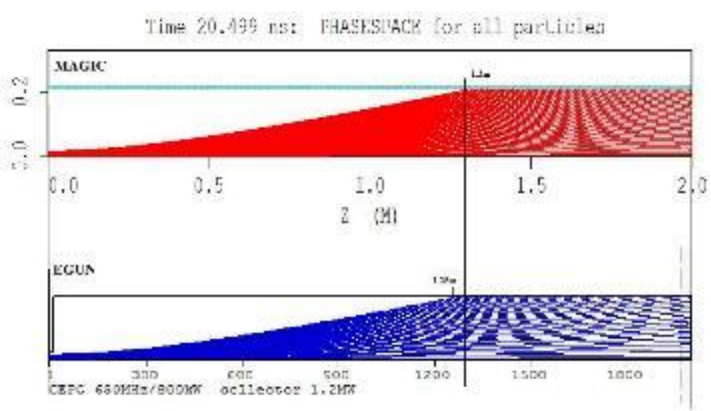
Collector shape and beam dissipation optimization



collector optimization using universal beam spread curve



collector optimization using EGUN code



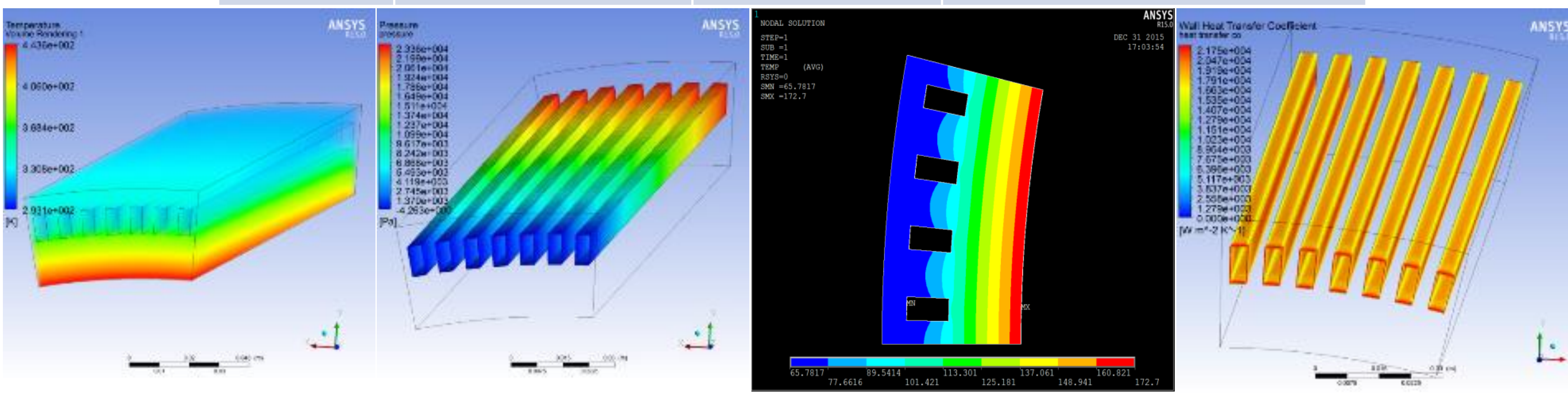
Crosscheck of beam trajectory with EGUN and MAGIC

	Analytic design	Numerical design
Collector Length	2147mm	1912mm
Collector radius	210mm	210mm
Total Beam power	1231kW	1230kW
Capability of power density in collector	150W/cm2	150W/cm2
Max power density in collector	197W/cm2	207W/cm2

R&D-Collector

Groove dimensions optimization

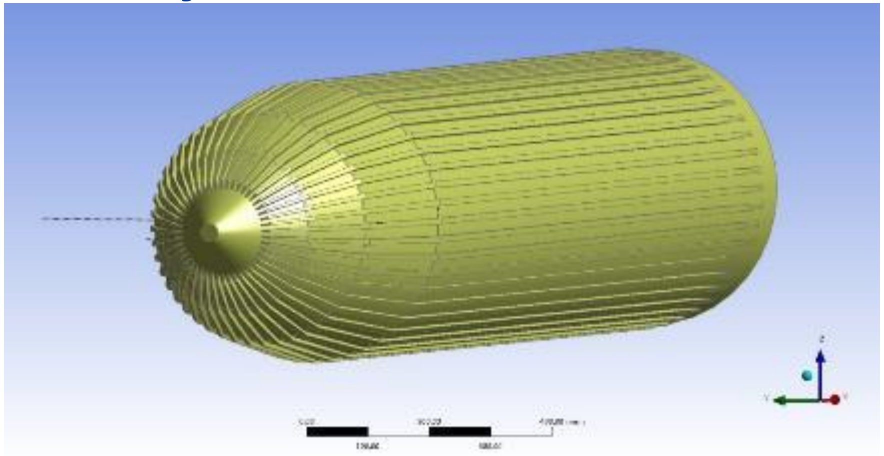
Groove number	Groove dimensions(a: b)	Total water flow rate	Water pressure loss for ideal smooth surface
180	1:2	1400kg/min	2.34E+4 Pa



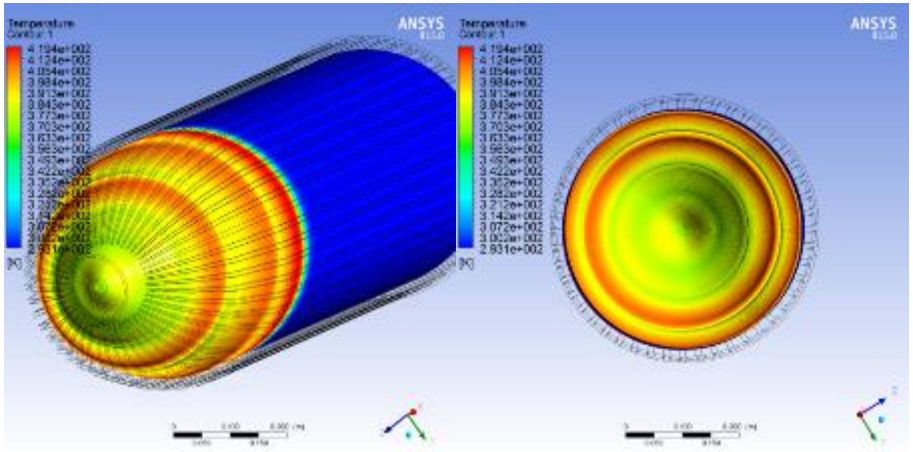
Contour of temperature and water pressure loss

R&D-Collector

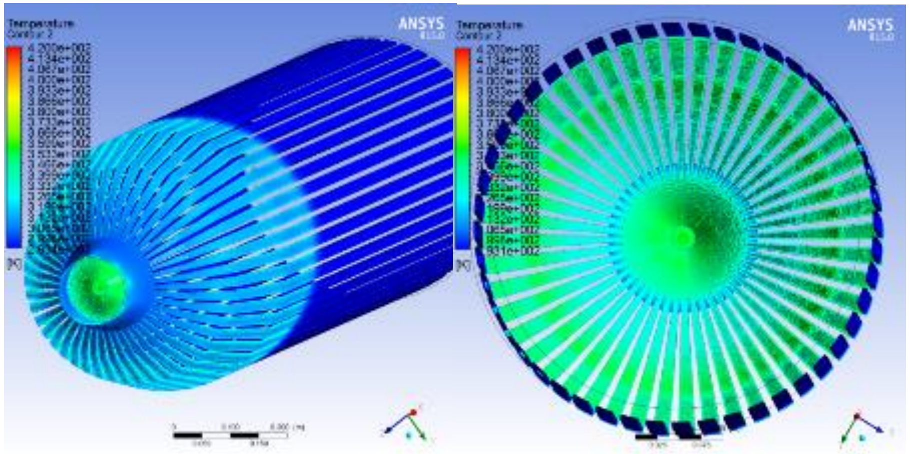
Collector Thermal analysis



Groove structure for 2 meter tapered collector in Ansys-CFX



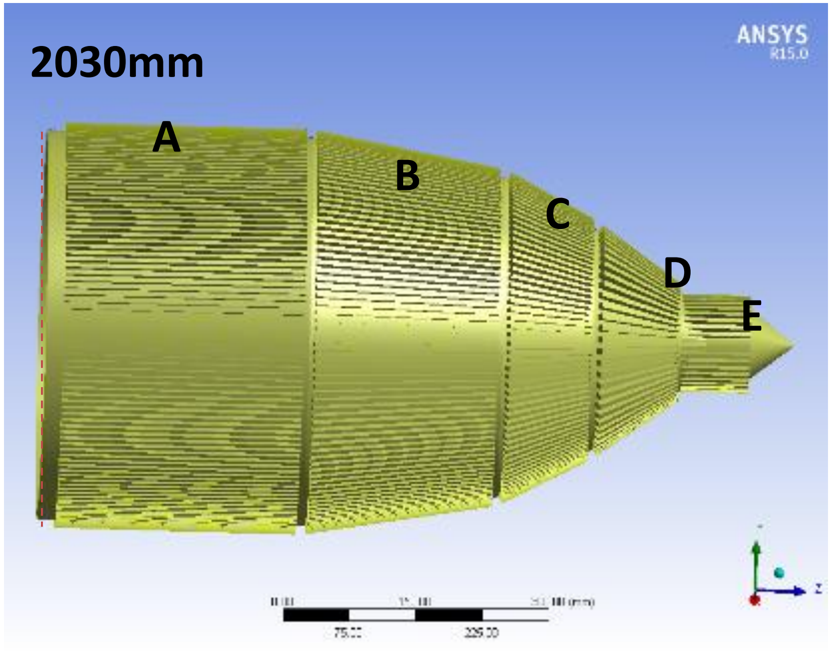
contour of temperature on inner surface of copper domain



contour of temperature of water domain

R&D-Collector

Collector geometry of tapered part

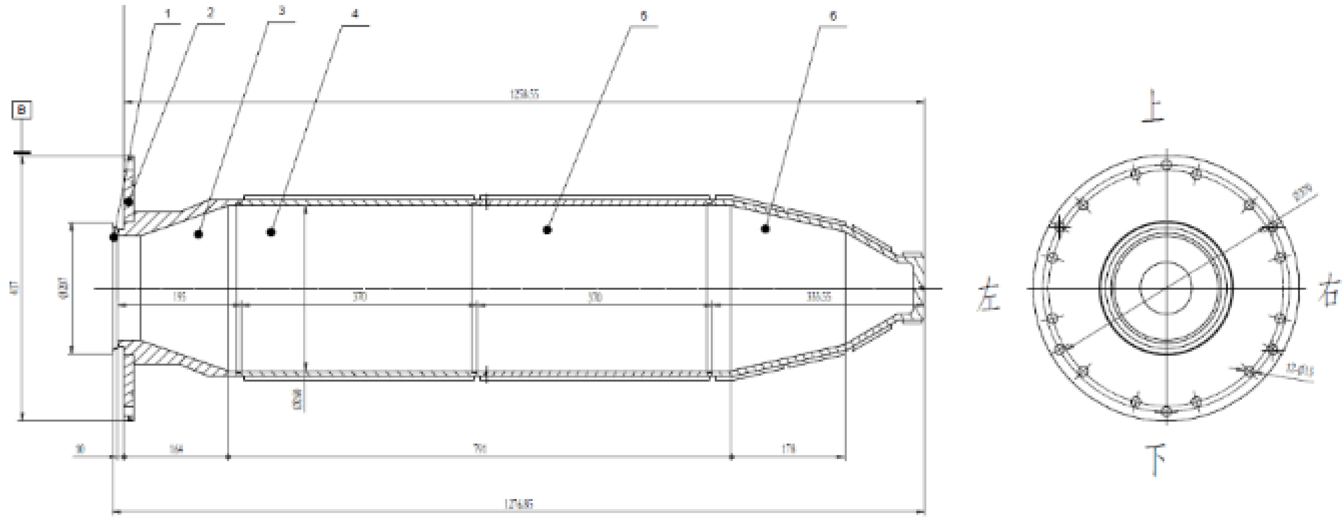


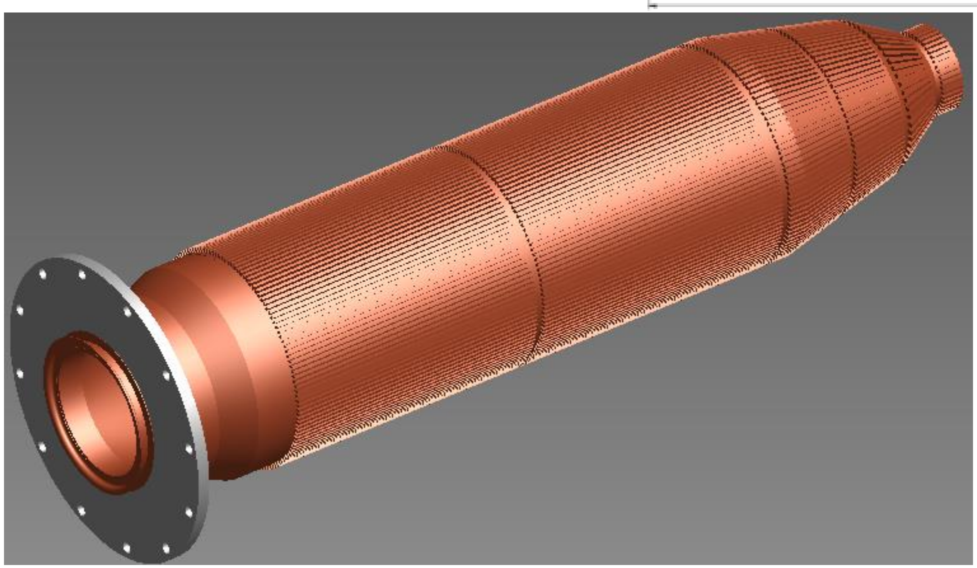
Geometry of collector tapered part

Section	A	B	C	D	E
groove number	180	150	120	60	40

R&D-Collector

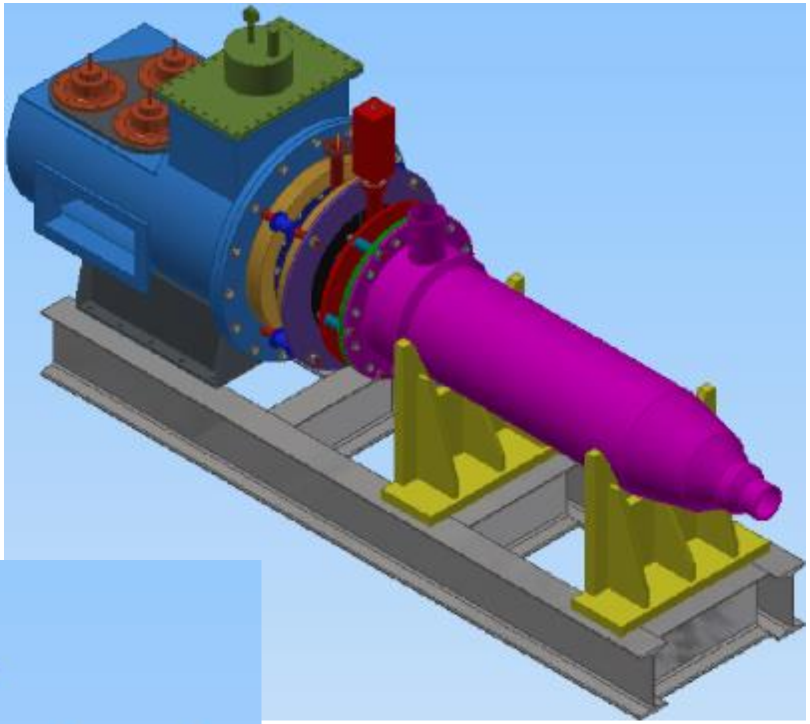
Final design

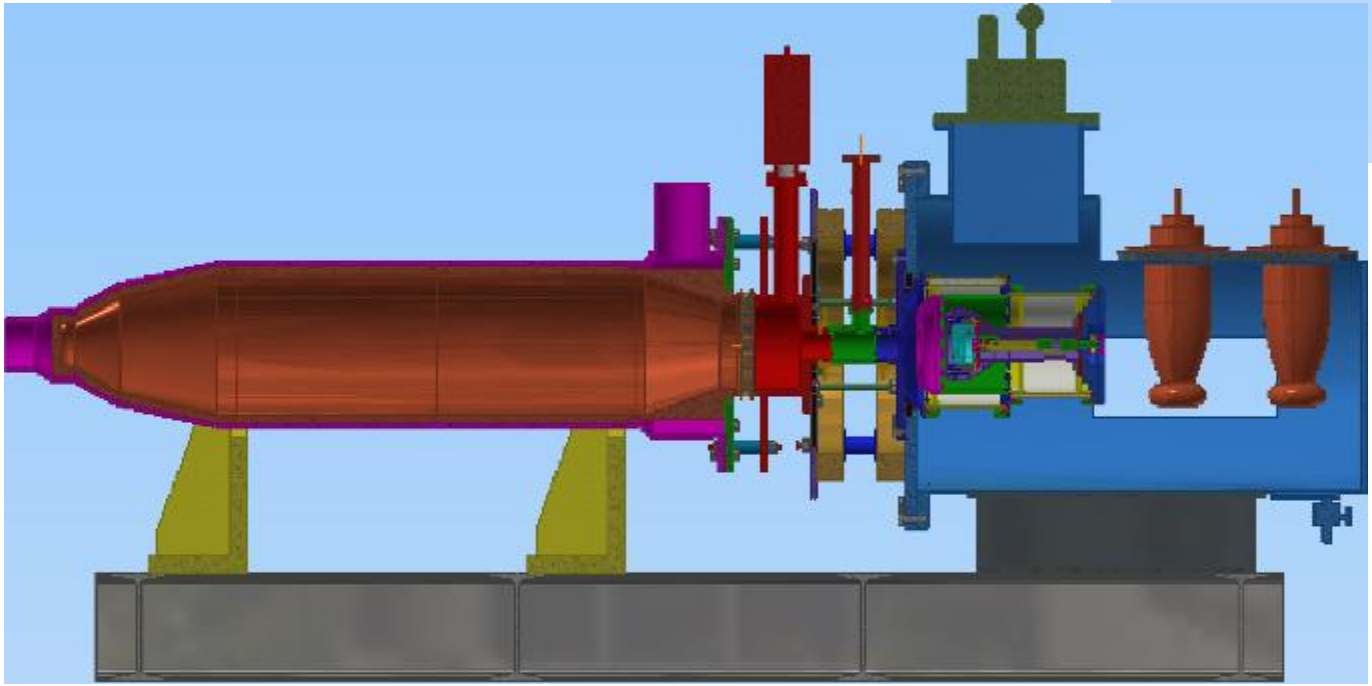




R&D-Beam tester

IHEP is taking bids now.





R&D-Current status

We form a joint institute with local government and Company: GLVAC Industrial Technology Research Institute of High Power Devices.

Summary

- ***The design of the electron gun and collector has been completed;***
- ***RF Section for classical design klystron is completed;***
- ***Mechanical design for beam tester is also completed;***
- ***IHEP is taking bids for fabrication of beam tester；***
- ***Mechanical design for classical design klystron is about to begin.***
- ***RF Section for high efficiency design klystron is almost completed.***
- ***Fabrication for high efficiency klystron will be discussed.***

Thanks for your attention!