# CEPC 650MHz High Efficiency Klystron R&D

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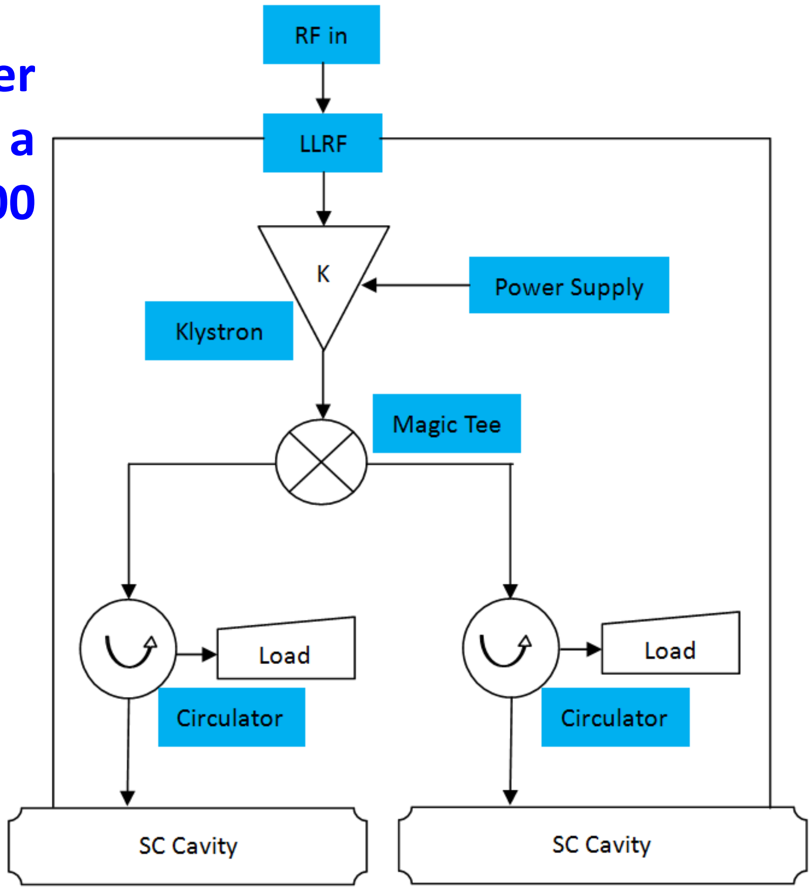
- Design proposal
- R&D Progress
- Summary

# Collider RF power source

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

| Parameters mode | Value |
|---|---|
| Operation frequency | 650MHz+/-0.5MHz |
| Cavity Type | 650MHz 5-cell |
| Cavity number | 384 |
| RF input power (kW) | 280 CW（250） |
| RF source number | 192 |
| Klystron output power (kW) | 800 CW |




**RF sources number: 192**

**1 klystron power 2 cavities**

# Collider RF power source

## Klystron key design parameters

| Parameters mode | 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** |

# Short term Schedule

| Year | 2015 | | | 2016 | | | | | | | | | | | 2017 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 |
| Cathode | | | Cathode Order | | | | | | | | | | | | | | |
| Ceramic | | | | Ceramic Order | | | | | | | | | | | | | |
| | | | Gun Design | | | Copper Block | | | | | | | | | | | |
| | | | Coil/Socket | | | | | | | | | | | | | | |
| | | | | | Collector Design | | | | | | | | | | | | |
| Total Design | | | | | | | | | | | | | | | | | |
| Drawing | | | Auto Inventor | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Start Manufacturing | | | | | | | manufacturing | | | | Baking | | | | | | |
| Test | | | | | | | | | | Gun test | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| Klystron Design | Classical Design | | | | | | | | | Comparison | | | | | | | |
| | | | 2nd similation /Output cavity | | | | | | | | | | | | | | |
| | | | | | | | | | | High Efficiency Design | | | | | | | |
| Window Design | | | | | Window design/Drawing | | | | | | | | | | | | |
| | | | | | | | manufacturing | | Testing | | | | | | | | |

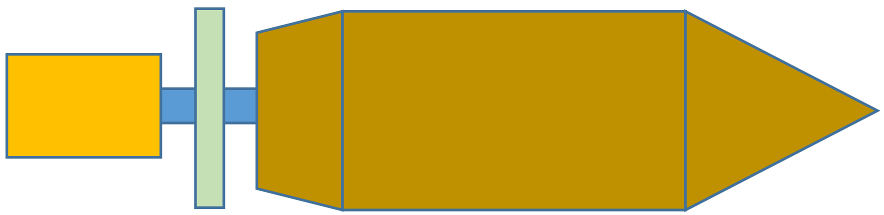
# Klystron Schedule and strategy

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

1) we (China) have not an experienced to manufacture the high power, UHF klystrons. There is not the big furnace infrastructure in China also.
2) Design and simulation are not enough and matured, therefore we need to step up one by one.
3) Let's start from beam tester, classical design and currently progressed design such as HEIKA.
4) In order to save the money and time, demountable structure is another way.

# Klystron Schedule and strategy(2)

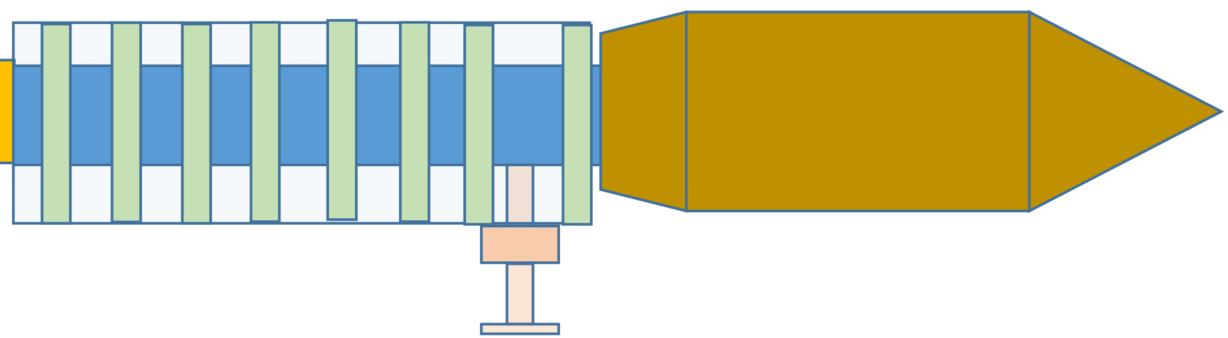
(1) Beam tester



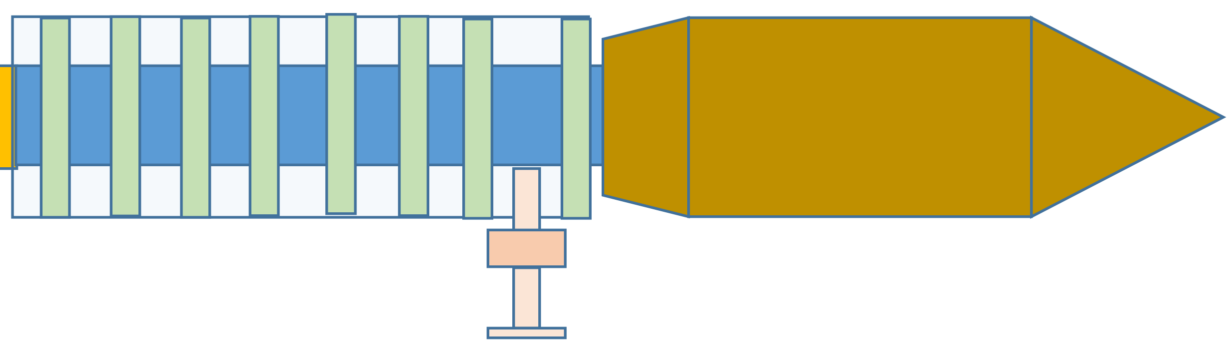
**Merits**

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

(2) #1 prototype



(3) #2 prototype



# Klystron Concept Design

## Rough Parameters

| Power | perveance | efficiency | Cathode current density | frequency |
|---|---|---|---|---|
| 800kW | 0.68μP | 65% | 0.5A/cm^2 | 650000000Hz |

## Parameters for Electron optics

| Voltage | Current | Depressed Beam Potential | Cathode radius | Beam Radius | Tunnel Radius | b /a | 阴极面积 | 电子枪面压缩比 | Beam Current Density |
|---|---|---|---|---|---|---|---|---|---|
| 80kV | 15.385A | 78.844kV | 34mm | 16mm | 25mm | 0.64 | 3674cm^2 | 4.57 | 1.91A/cm2 |

## Parameters for interaction region calculation

| Relativistic Mass Factor σ | v/c | βe | γ | γb | γa | cut-off freq of tube | | Brillouin Flux (Gauss) |
|---|---|---|---|---|---|---|---|---|
| 1.154 | 0.499 | 27.275 | 23.629 | 0.378 | 0.591 | 5.4 | 7.07 | 119.251 |
| | | | | | | 3.52E+09 | 4.60E+09 | |
| | | | | | | | | |
| Plasma Frequency | plasma propagation constant | plasma wavelength | Plasma Frequency Reduction Factor | Mbar | √Mbar | Reduced Plasma Frequency | Reduced Plasma propagation constant βq | reduced plasma wavelength |
| 1.29E+09 | 8.58 | 0.732 | 0.222 | 0.874 | 0.935 | 2.85E+08 | 1.905 | 3.298 |

# Electron Gun Design and Simulation

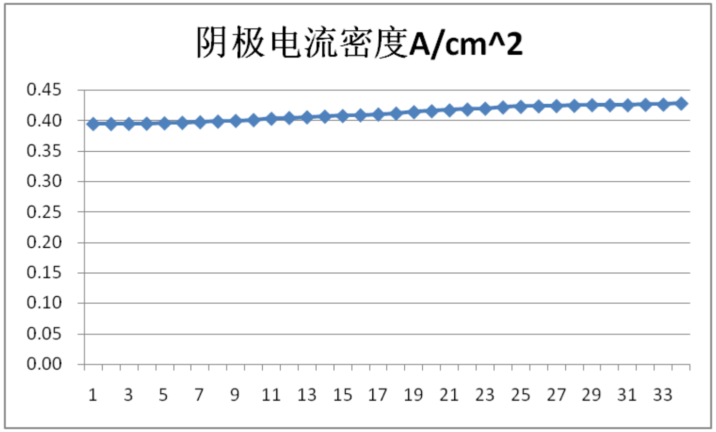
**Egun simulation result**:

**Area compression ratio** : 4.4

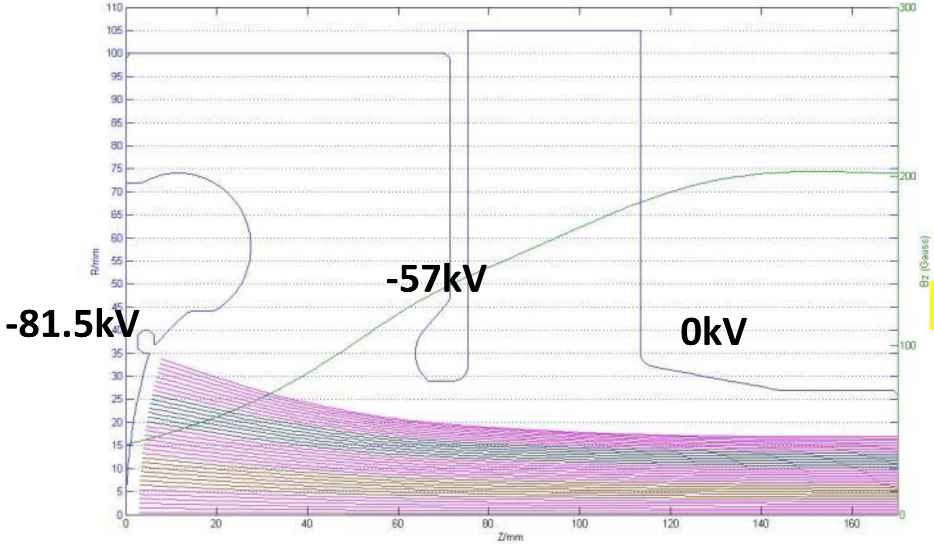
**Perveance**: 0.647μP

**Cathode current density**: 0.39A/cm2~0.43A/cm2

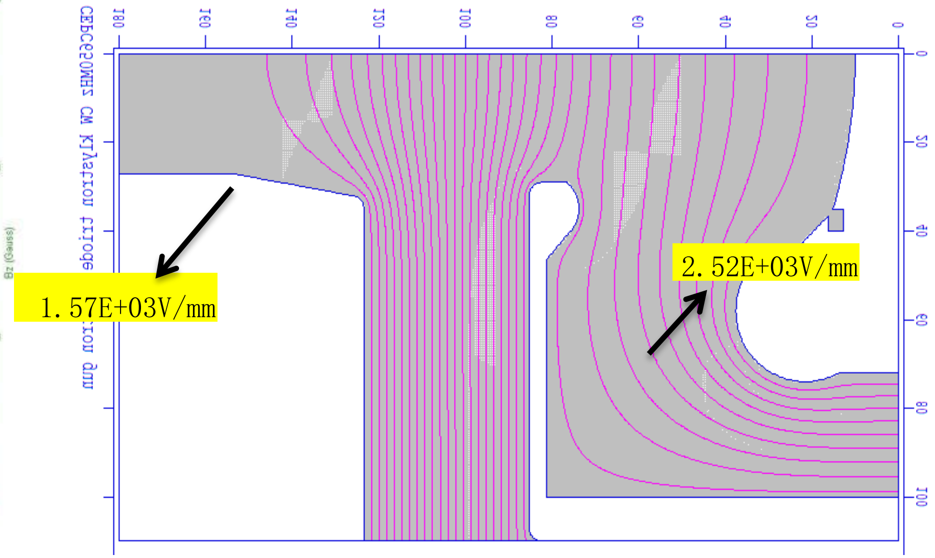
**Max. electric field :** 2.520kV/mm




**Cathode current density**

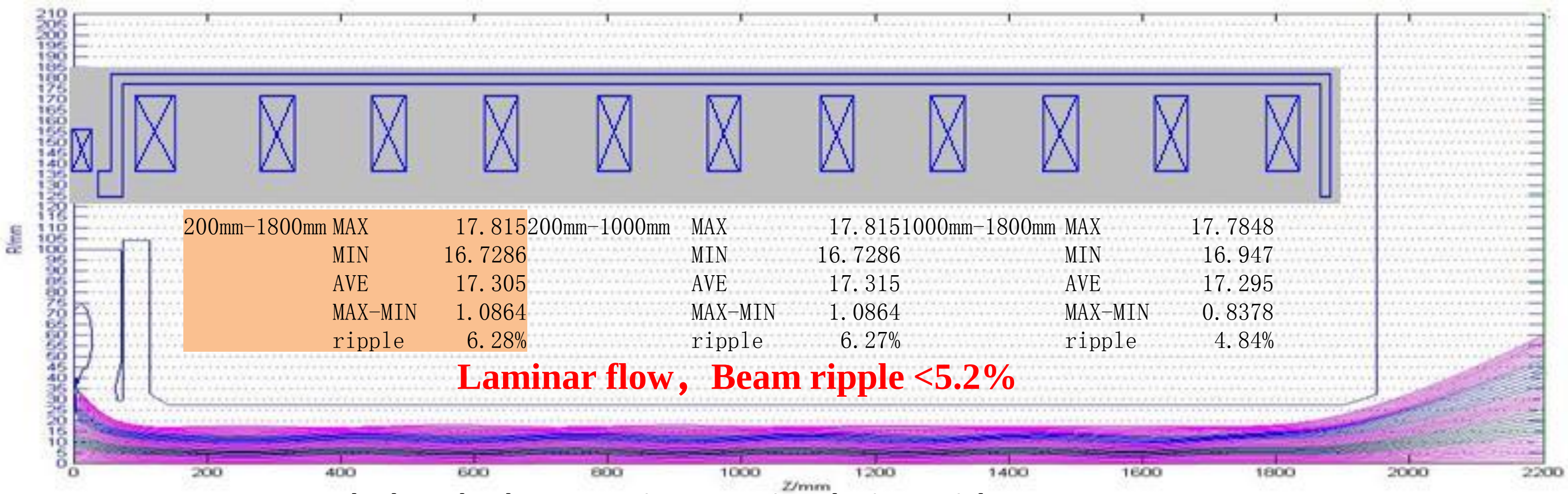



**Gun region beam trajectory simulation with Egun**




**Electrode E fied density optimization with Possion**

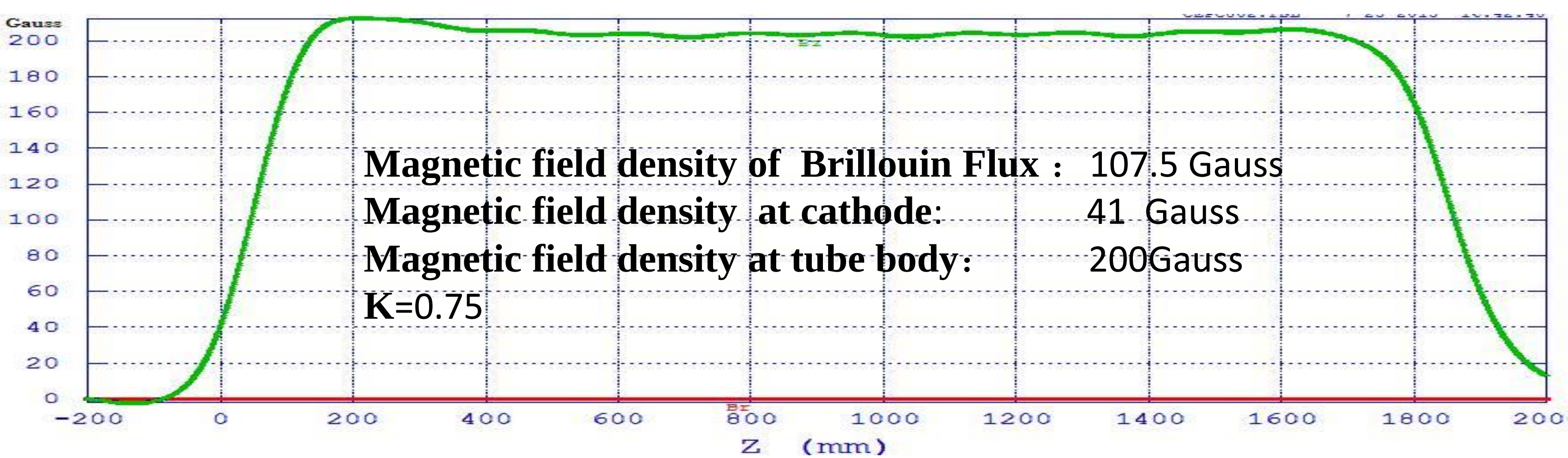
# Electron Optics Design and Simulation




| 200mm-1800mm | | 200mm-1000mm | | 1000mm-1800mm | |
|---|---|---|---|---|---|
| MAX | 17.815 | MAX | 17.815 | MAX | 17.7848 |
| MIN | 16.7286 | MIN | 16.7286 | MIN | 16.947 |
| AVE | 17.305 | AVE | 17.315 | AVE | 17.295 |
| MAX-MIN | 1.0864 | MAX-MIN | 1.0864 | MAX-MIN | 0.8378 |
| ripple | 6.28% | ripple | 6.27% | ripple | 4.84% |

**Laminar flow，Beam ripple <5.2%**

**whole tube beam trajectory simulation with EGUN**



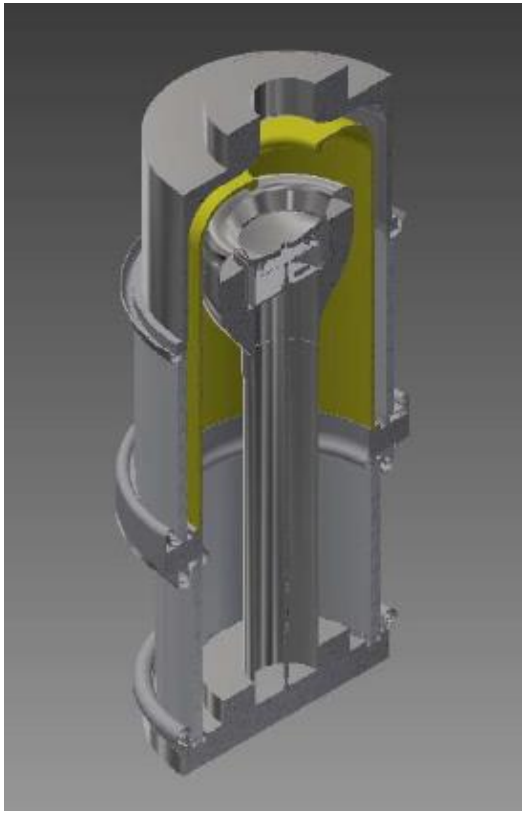

**Magnetic field density of Brillouin Flux：** 107.5 Gauss
**Magnetic field density at cathode:** 41 Gauss
**Magnetic field density at tube body：** 200Gauss
**K**=0.75

# Gun Assembly Design

**Basic drawing of gun assembly using Auto Inventor. Geometry is come from the POISSON calculation.**

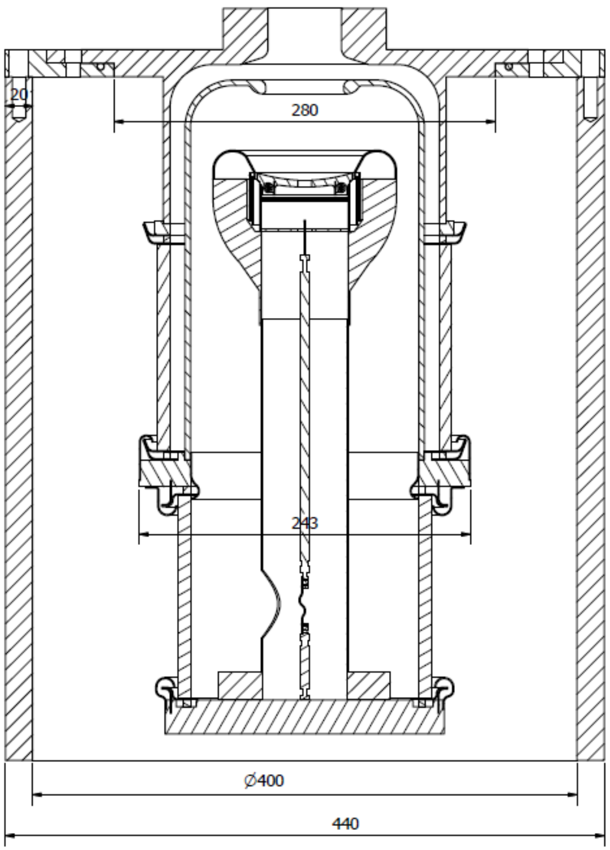
**Purpose is determine the ceramic sealing structure. And size to order to the company.**

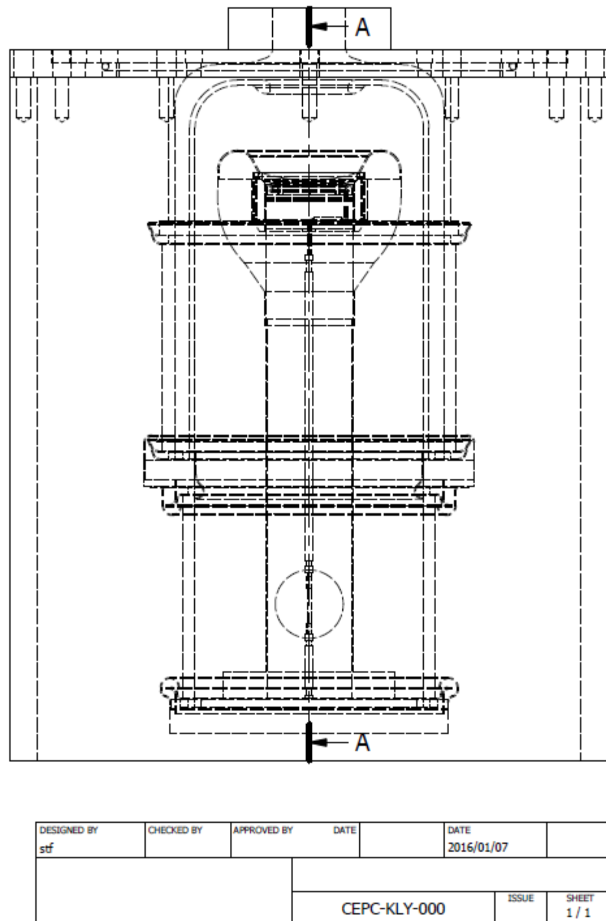
**Based on this first drawing, this will be revised by IHEP Mechanical Group to more complete drawing**

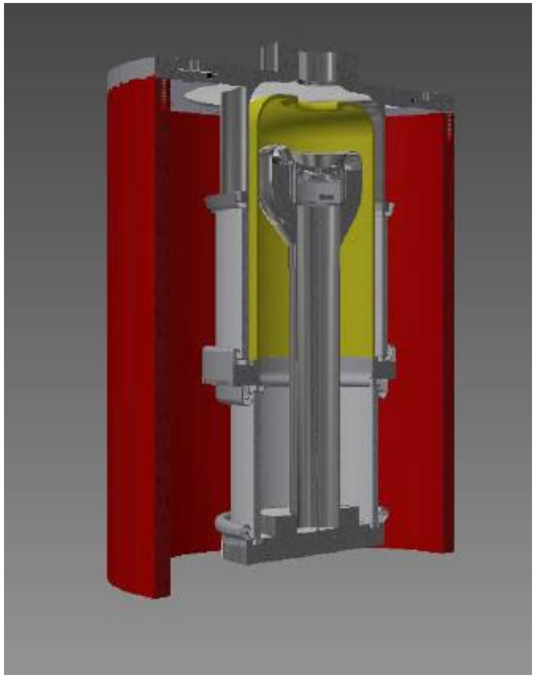


**Current stage of drawing**

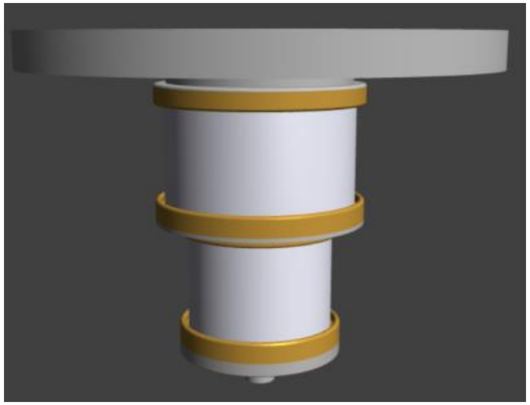
# Gun Assembly Design(2)



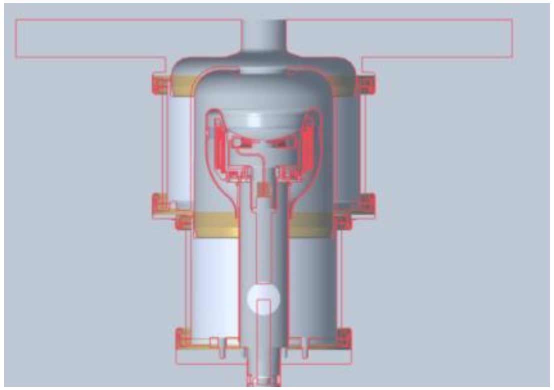



# Gun Assembly Design(3)



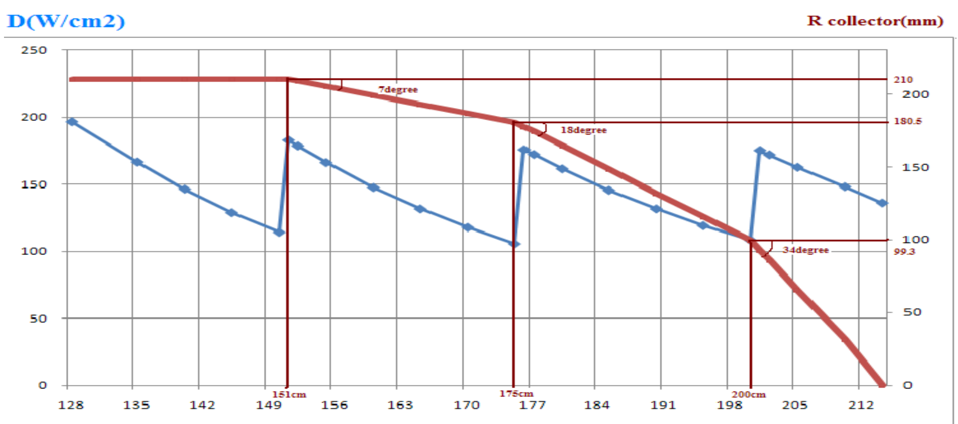
In order to study gun assembly problems, several problems occurred at the HV ceramic due to the multipactor are planed to be analyzed.

Those are simulated by POISSON and CST, and in order to make clear the geometry, basic drawings.

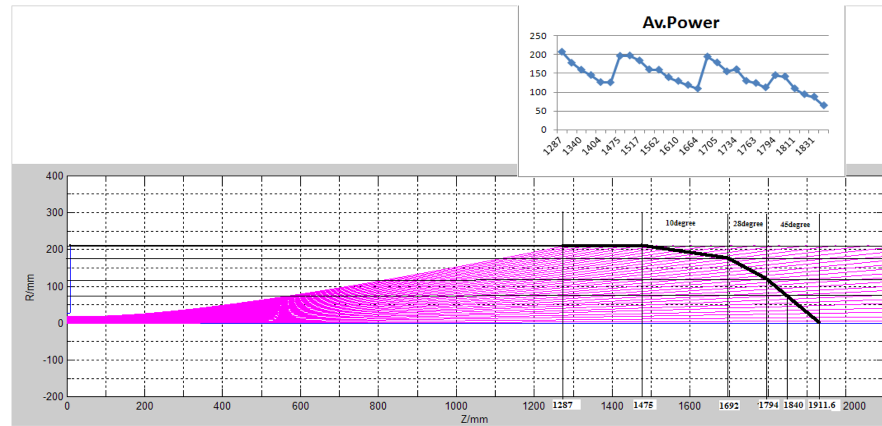


# Collector Design and Simulation

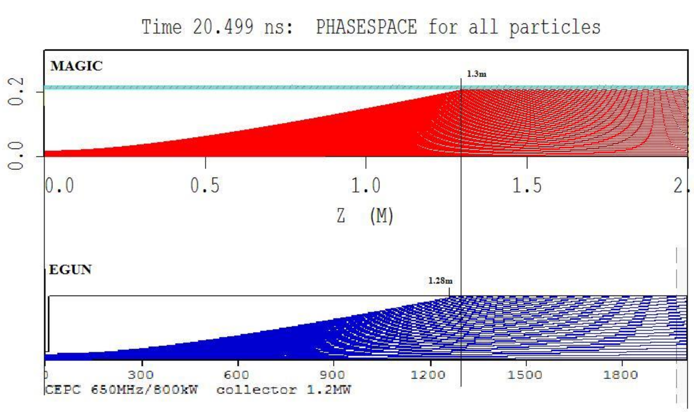
- Collector shape and beam dissipation optimization




collector optimization using universal beam spread curve




collector optimization using EGUN code



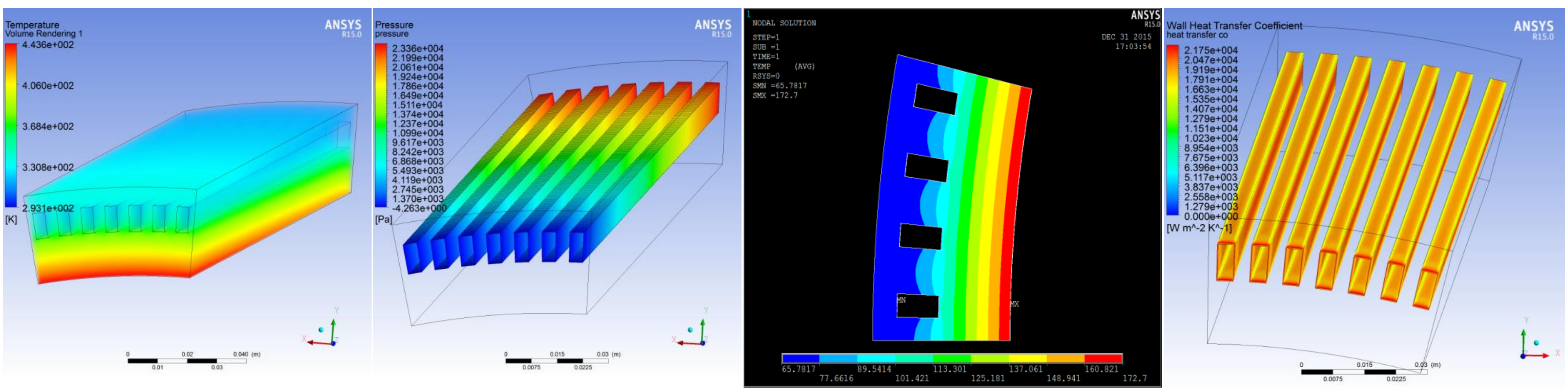

Crosscheck of beam trajectory with EGUN and MAGIC

| | 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 |

# Collector Design and Simulation(2)

## Groove dimensions optimization

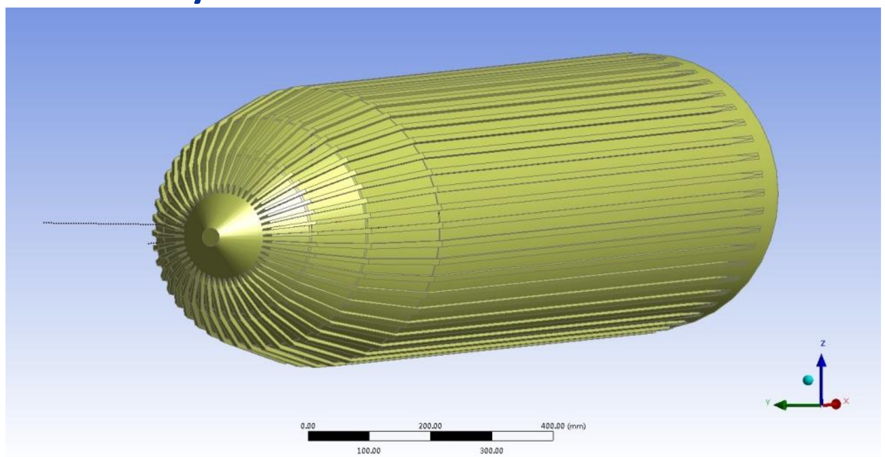
| Groove number | Groove dimensions(a:b) | Total water flow rate | Water pressure loss for ideal smooth surface |
|---|---|---|---|
| 180 | 1:2 | 1400kg/min | 2.34E+4 Pa |



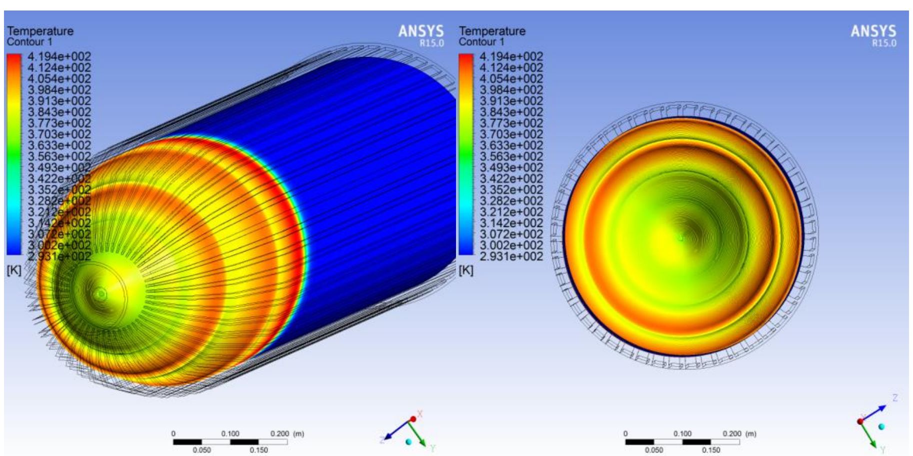

**Contour of temperature and water pressure loss**

# Collector Design and Simulation(3)

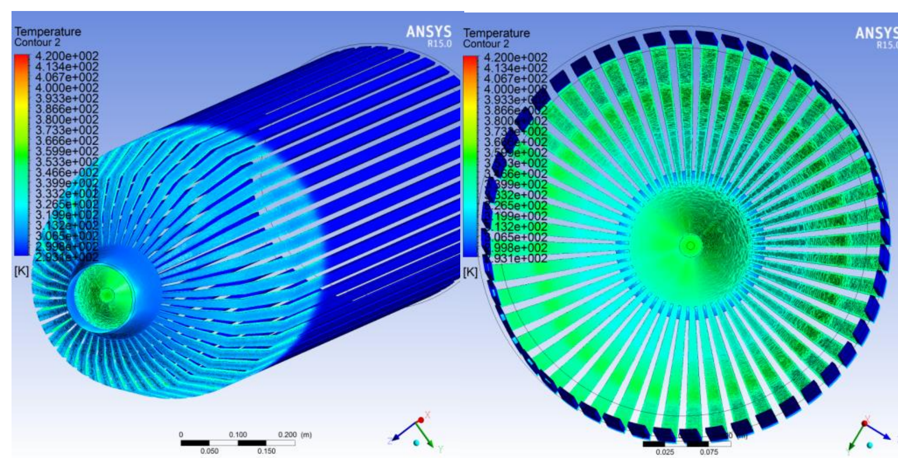
## Collector Thermal analysis




Groove structure for 2 meter tapered collector in Ansys-CFX



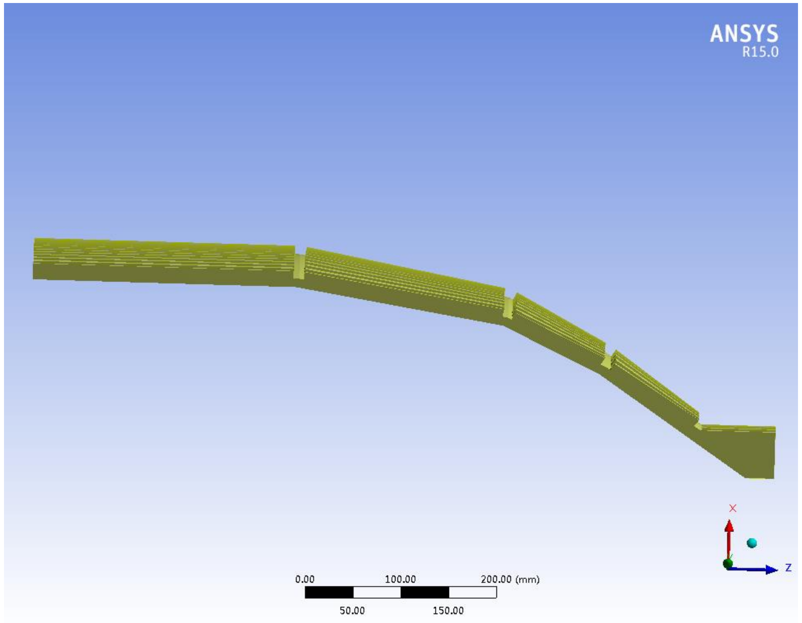

contour of temperature on inner surface of copper domain

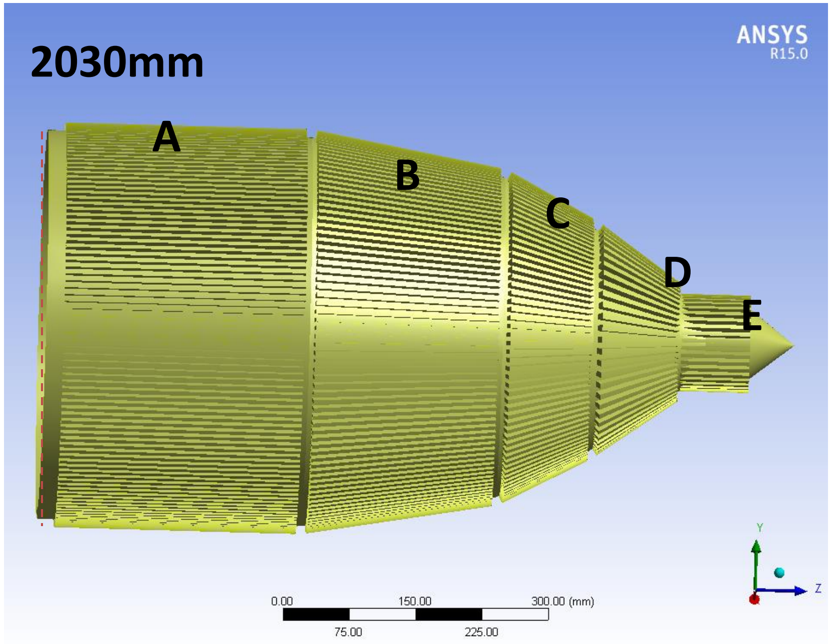



contour of temperature of water domain

# Collector Design and Simulation(4)

## Collector geometry of tapered part



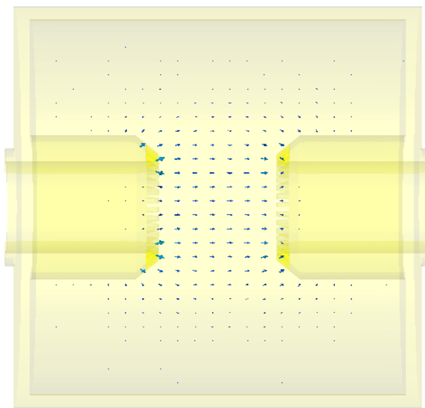



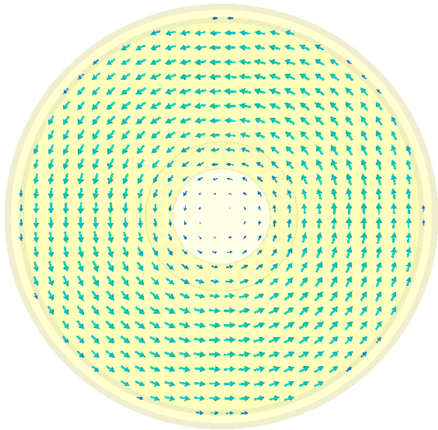

**Geometry of collector tapered part**

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

# Cavities design and optimization

Optimize cavity geometry to get the desired characteristic parameters and high R/Q.





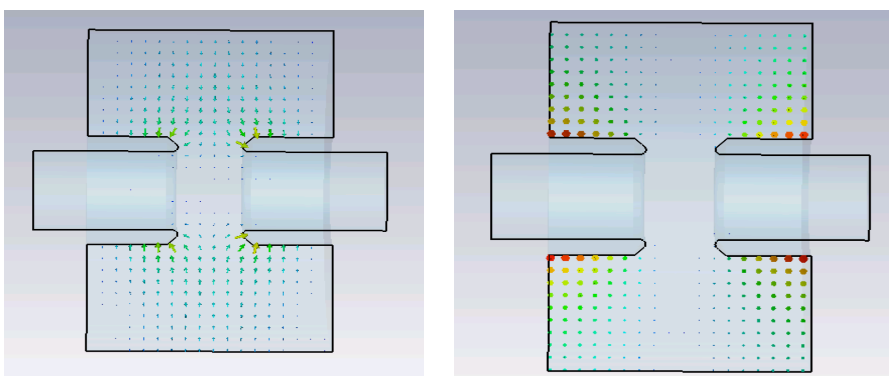
**$TM_{010}$ electromagnetic field pattern**

**Table 1 Cavity geometry and characteristic parameters**

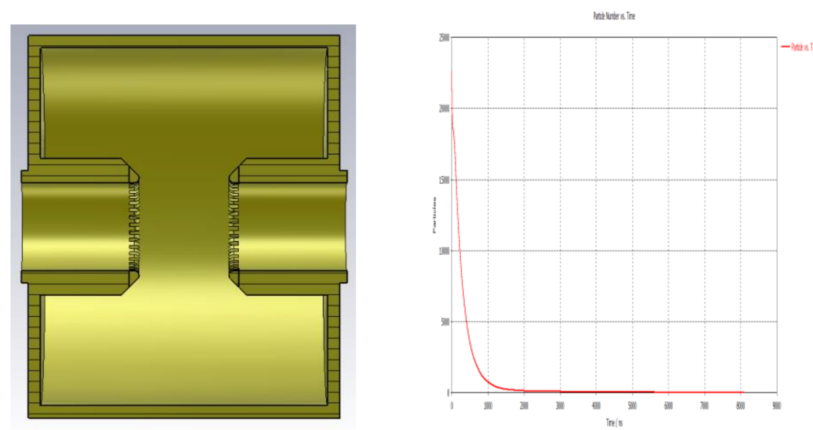
| Parameters | r_tube | L_right_cavity | r_nose | h_nose | Angle_nose | r_cavity | L_right_gap | f MHz | R/Q | Q | M |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Knife edge Output cavity | 27.03 | 70.71 | 3 | 10 | 45deg | 110 | 18.475 | 650 | 125 | 16984 | 0.8452 |
| Knife edge input cavity | 27.03 | 88.08 | 3 | 10 | 45deg | 110 | 27.7 | 650 | 153.5 | 17399 | 0.7932 |
| Knife edge 2nd harmonic cavity | 27.03 | 36.463 | 3 | 10 | 45deg | 60 | 9.25 | 1300 | 74 | 9146 | 0.616 |

# Cavities design and optimization(2)

1) Cavity high order mode suppression especially TM0nm within 4 times fundamental frequency range.
2) Cavity Multipacting suppression using TiN coat or groove
3) All cavities design will be finished 2 month later



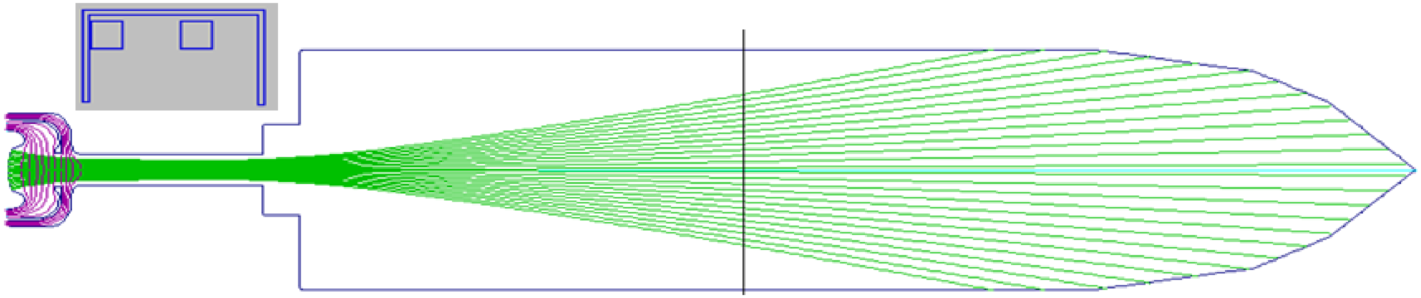
$TM_{010}$ electromagnetic field pattern



Multipacting simulation with groove

# Current Status -Beam tester

Concept



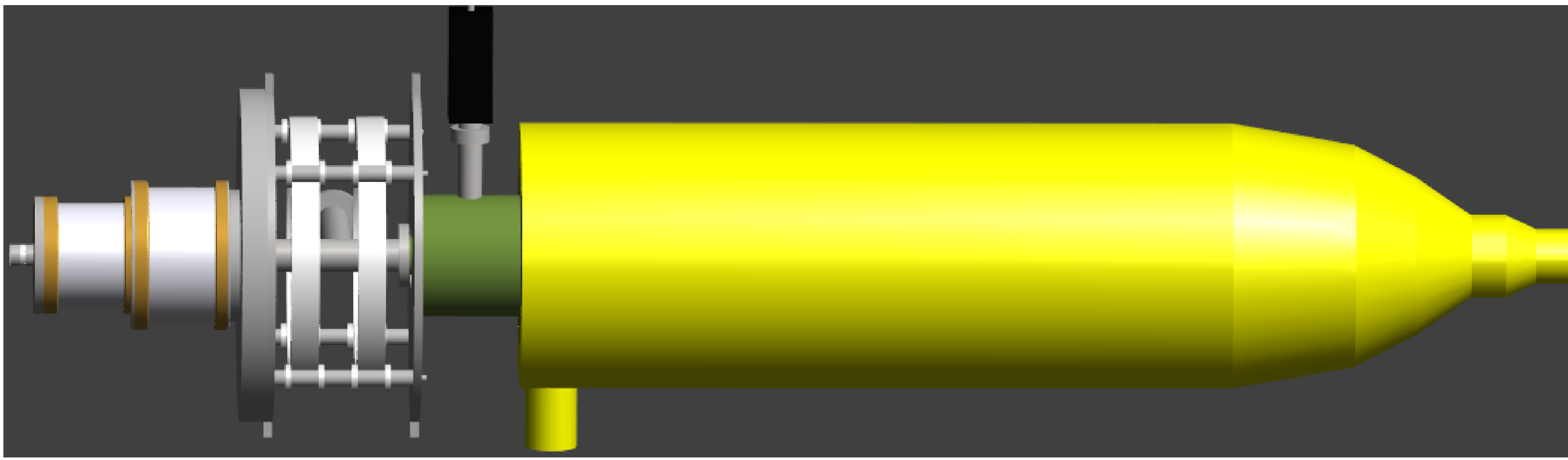
Simulation
- Gun
- HV Seal
- Collector

- Drawing

Gun HV Seal Drawing

Collector drawing will be proceeded

# Current Status -Beam tester



Latest drawing of Beam test stand

# Summary

- Complete gun design
- Order the cathode and ceramic
- Complete the collector design
- Complete the designing / drawing and start manufacturing
- In order to do the quick manufacturing, parallel schedule for manufacturing and cathode manufacturing and processing
- Furnace problem

There is no big furnace in China, we are looking for appropriate company to build it.

How long? We don’t know.

# Thanks for your attention!