近代物理研究所
Institute of Modern Physics

中国科学院
CHINESE ACADEMY OF SCIENCES

SC Cavity Development at IMP

Linac Group
Institute of Modern Physics, CAS
2011-09-19
IHEP, Beijing,CHINA

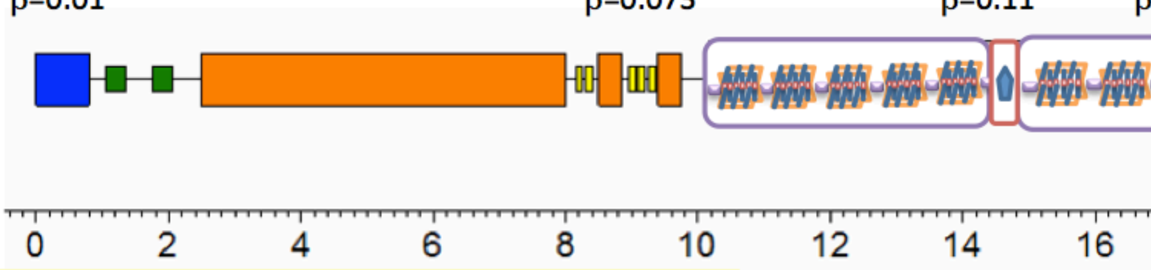
Outline

- Superconducting Cavity Choice
- HWR Cavity Design
  - EM Design & optimization
  - Mechanical design & analysis
  - Tuner & Coupler
  - Fabrication
- CH Cavity Design
  - EM Design & optimization
  - Mechanical & Fabrication

Superconducting Cavity Choice

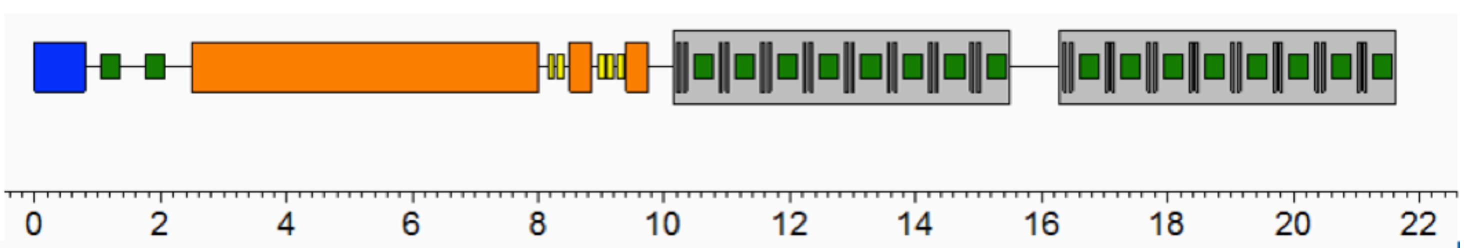
Scheme 1: RFQ + CH

ECR | LEBT 2*Sole. 50keV β=0.01 | RFQ 325MHz 2part./sect.*3sect. | MEBT FD-B-FDF-B 3MeV β=0.073 | CH C.M. 4.5m 5*CH+6*Sole. 5MeV β=0.11 | CH C.M. 3.5m 3*CH+4*Sole. 10MeV β=0.145

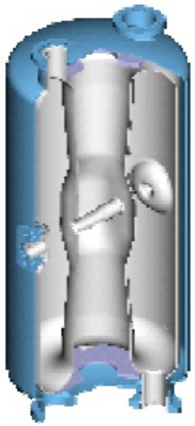


Scheme 2 (Backup): RFQ + HWR009

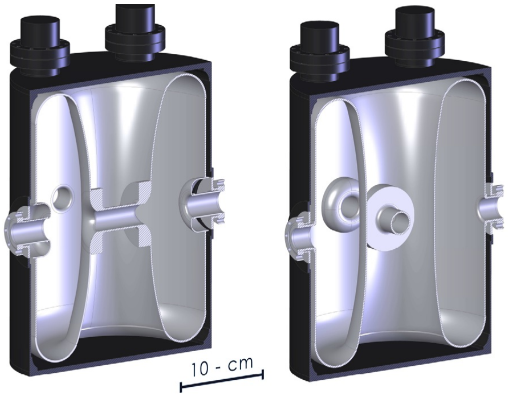
ECR | LEBT 2*Sole. 35keV β=0.009 | RFQ 5.5m 2part./sect.*3sect. | MEBT FD-B-FDF-B 2.1MeV β=0.067 | HWR C.M. 5.5m 8*(HWR+Sole.) 5.0MeV β=0.103 | HWR C.M. 5.5m 8*(HWR+Sole). 9.34MeV β=0.14



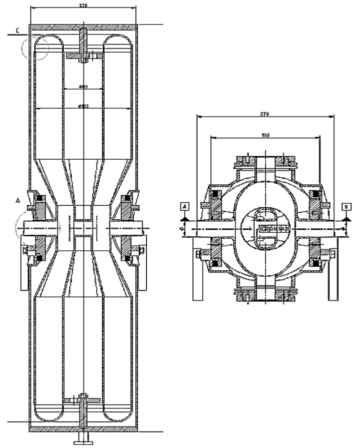
HWR of other Labs



ANL for RIA
(170MHz β =0.26)

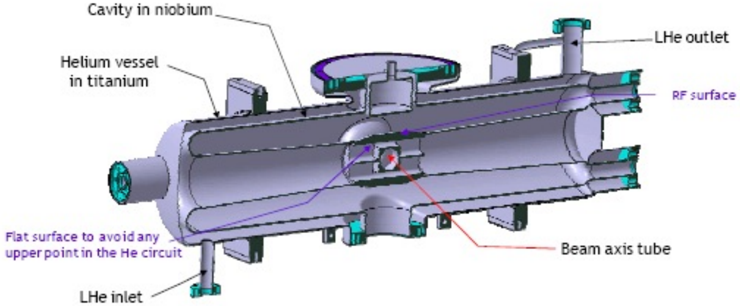


MSU for FRIB
(322MHz β =0.56)



ACCEL HWR
(176MHz β= 0.09)

INFN for SPES
(352MHz β= 0.17,0.31)



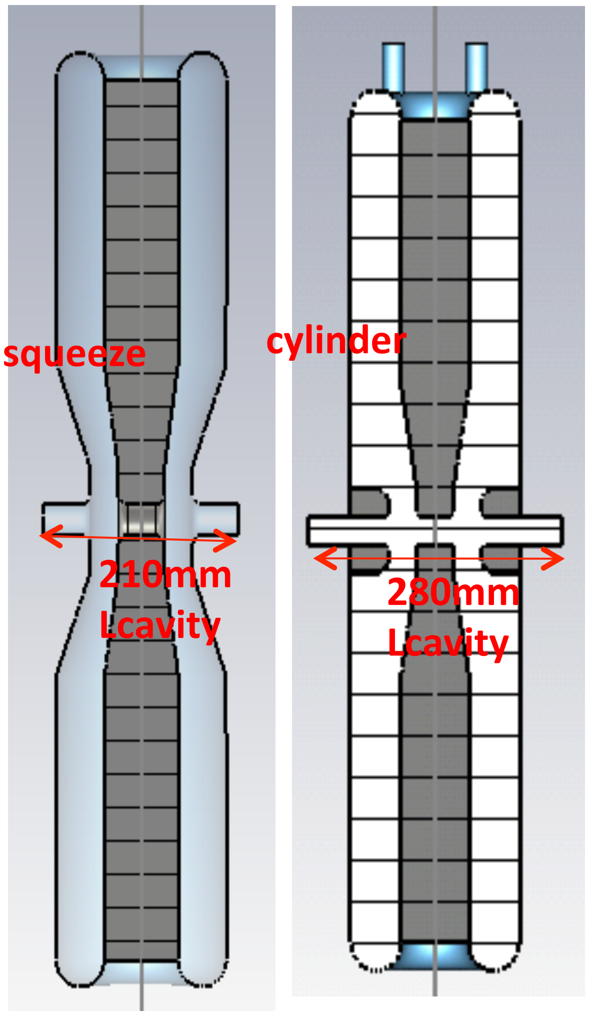
CEA-Saclay for IFMIF
(175MHz β =0.944)

FZJ for COSY-SCL
(160MHz β =0.11)

RF Design

Choice of the HWR structure

Two HWR structures



in the right table:

CST MWS simulation results considering:

Max Epeak ⩽25MV/m

Max Bpeak⩽ 50MV/m

Eacc(MV/m)(1) is defined by Uacc over βλ

Eacc(MV/m)(2) is defined by Uacc over Lcavity

The right type cavity can reach higher accelerate voltage
But the left type cavity have higher gradient when the accelerate gradient defined by Uacc over the cavity real length.

RF parameter	Left fig	Right fig
Frequency (MHz)	162.0	162.3
βG	0.09	0.09
Aperture diameter (mm)	**30**	**30**
Epeak (MV/m)	25	25
Bpeak (mT)	49.6	49.5
Uacc (MV)	**0.81**	**0.91**
Eacc(MV/m)(1)	4.94	5.5
Epeak/Eacc(1)	5.06	4.5
Bpeak/Eacc(1)	10.05	9
Eacc(MV/m)(2)	**3.86**	**3.25**
Epeak/Eacc(2)	6.47	7.69
Bpeak/Eacc(2)	12.84	15.23
R/Q0	174	204
Loss (W)	2.6	2.5
Energy (Joule)	3.8	4.1

RF Design

Setting in the CST MWS

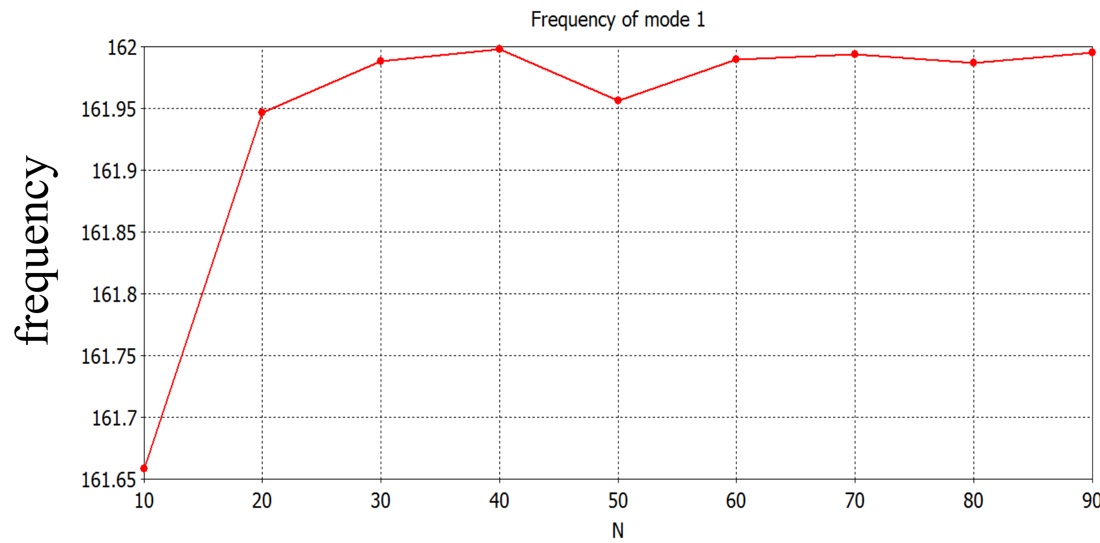
1.Mesh setting:

When N≥60, the frequency simulation results change a little. N is the lower mesh limit

Choose N=70(the overall HWR cavity mesh number is 9 million)

2.Symmetry planes setting:

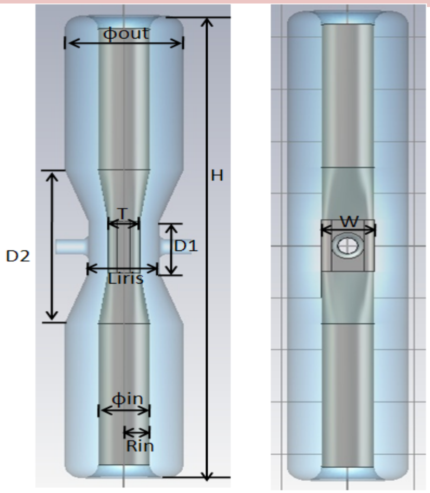
In order to save simulation time setting three symmetry planes: YZ plane, XZ plane and XY plane



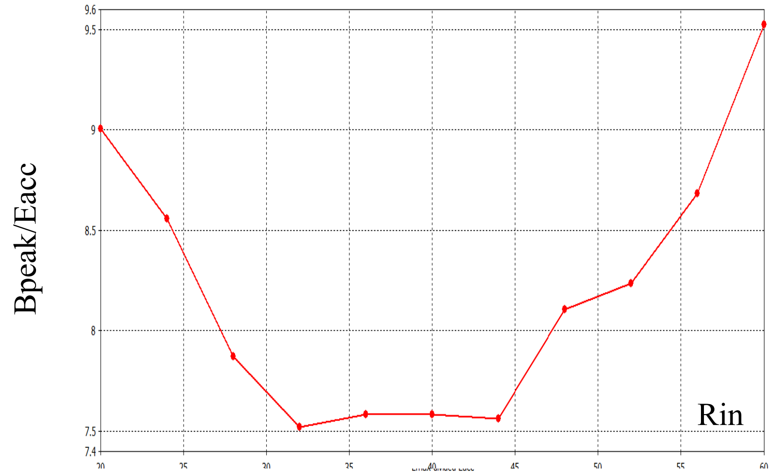
Lower mesh limit

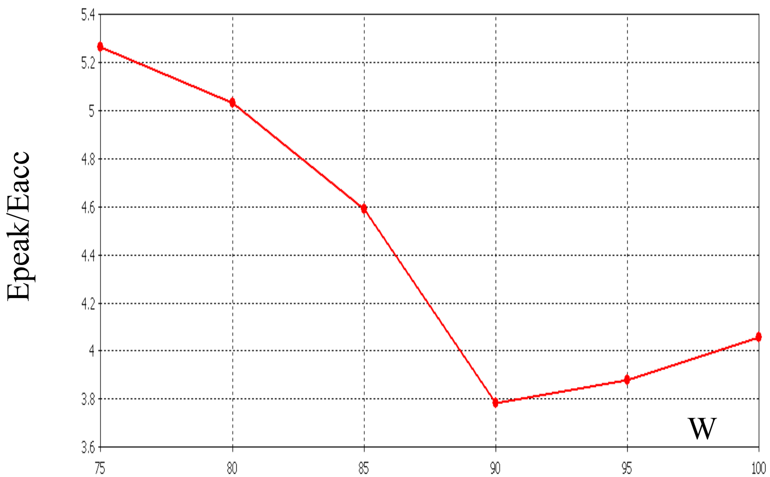
RF optimization

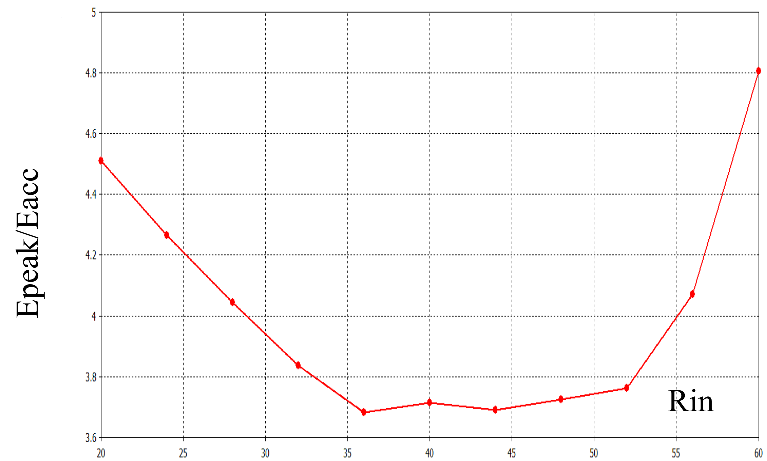
In order to :Lower Epeak/Eacc and Bpeak/Eacc,Using CST MWS to optimize geometry



Gβ	0.09
H(mm)	897
φin(mm)	80
φout(mm)	184
Liris(mm)	110
Lcavity(mm)	210
T(mm)	45
W(mm)	90





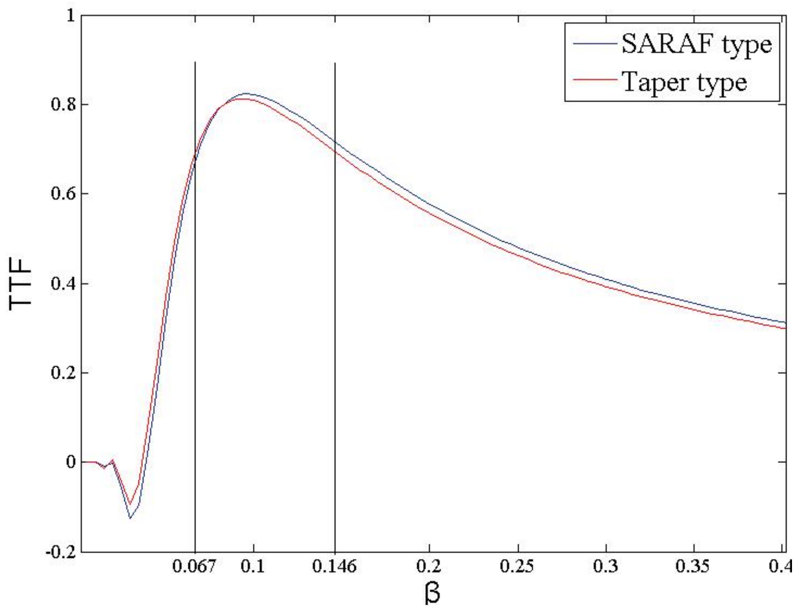


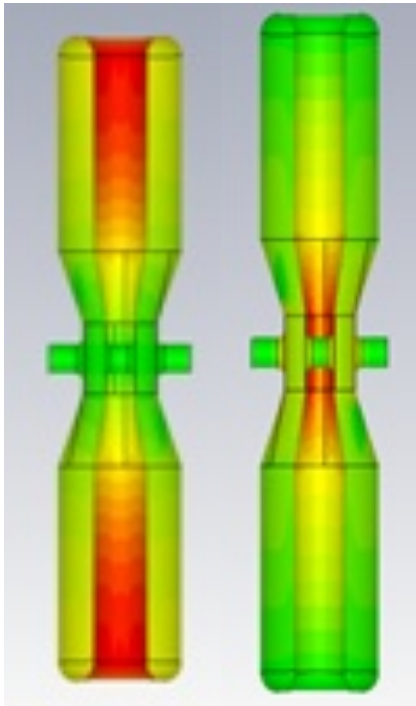
Optimize other geometry parameters (H, T, φin, D1, D2) by the same way

RF Parameters

- RF simulation settings:90 million mesh cells.
- $R/Q0=V^2acc/\omega U$.

Lab	ACCEL	IMP Cavity1	IMP Cavity2
f(MHz)	176	162.0	162.0
Gβ	0.09	0.09	0.09
Aperture diameter(mm)	**30**	**30**	**40**
Uacc(MV)	**0.845**	**0.81**	**0.78**
Epeak(MV/m)	25	25	25
Bpeak(mT)	80	50	50
G=Rs*Q0(Ω)	24.5	28.1	28.5
Q0(4.4K)	1.10E9	1.38E9	1.40E9





IMP Cavity1 is similar to ACCEL

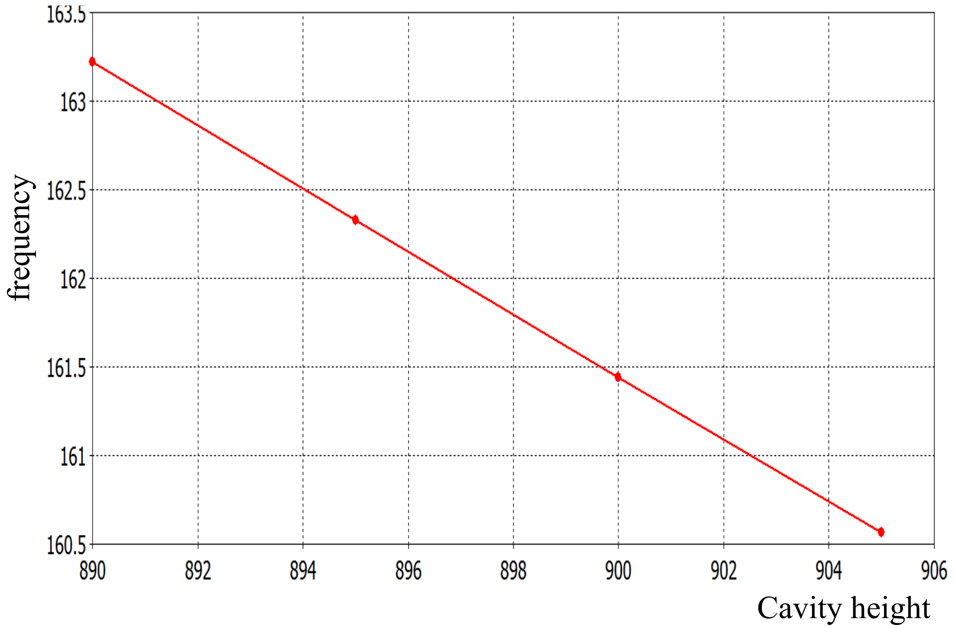
IMP Cavity2 is chosen

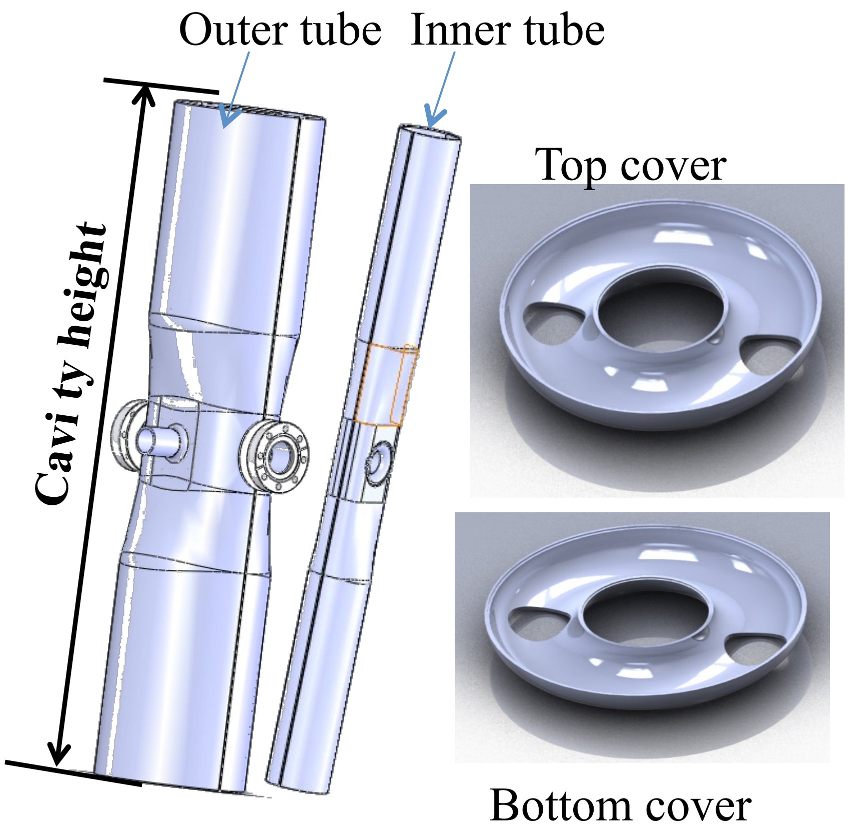
Accelerate proton : 2.1MeV ~10MeV

Beta =0.067-0.146

RF Parameters

Frequency changing due to the cavity height, with a sensitivity of 0.18MHz/mm



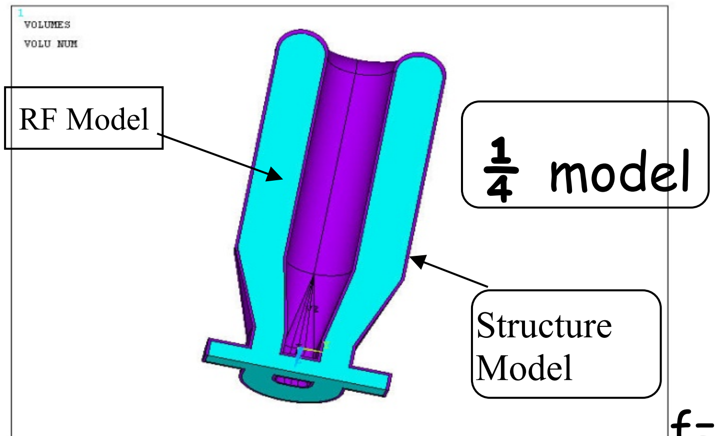


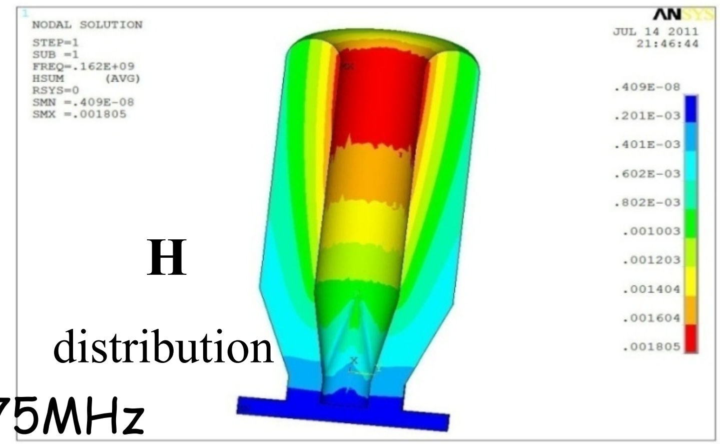
- ➢setting the margin 5mm on both sides of inner and outer tube.
- ➢During HWR fabrication, measure frequency before EBW .
- ➢ Then cut off margin of the inner and outer tube.

Mechanical analysis

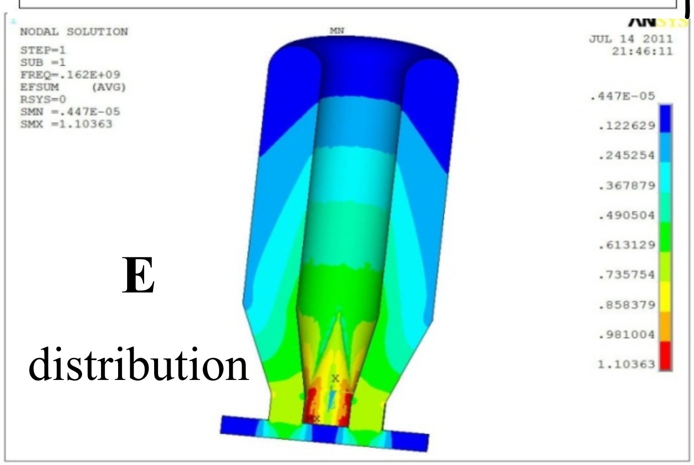
deformed

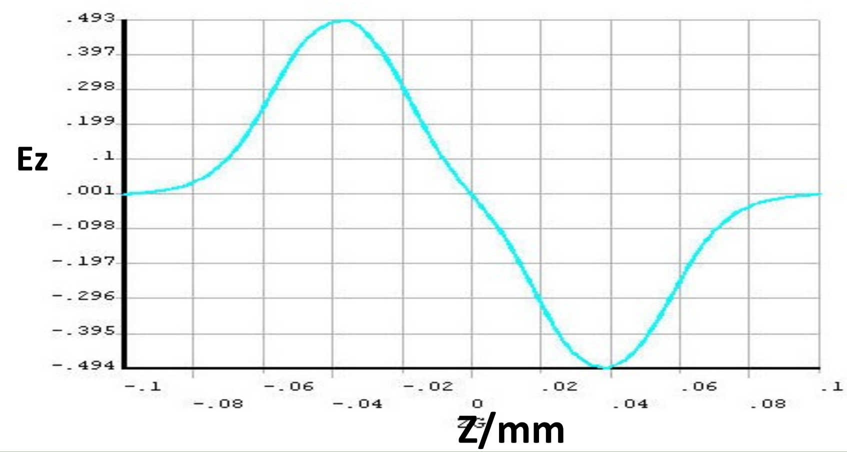
Procedure Simulation： RF Analysis—Structure Analysis—RF Analysis





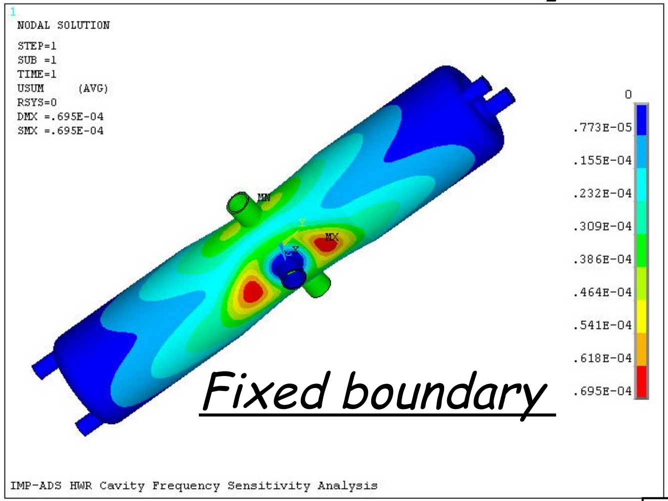
f=162.075MHz

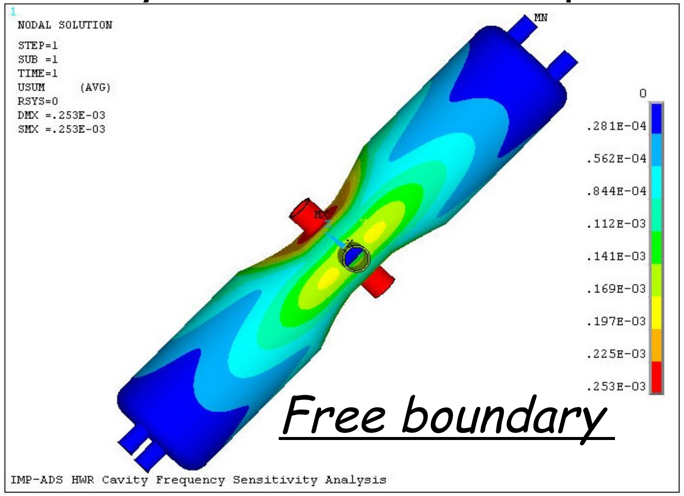




Mechanical analysis

Pressure Sensitivity--Deformed by Vacuum or Helium pressure





1 atm= 760 torr

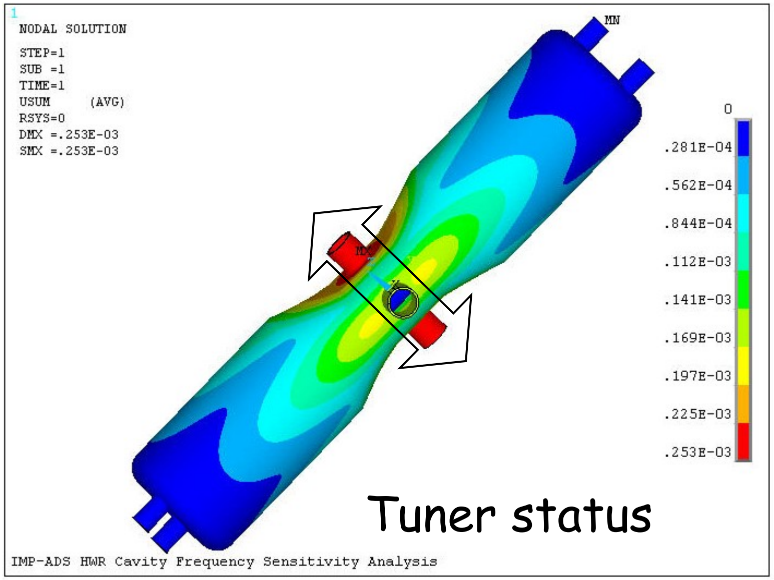
Yield Strength ≥500MPi=72Ksi

HWR cavity model-pressure sensitivity	1 atm pressure			df/ dp (Hz/ torr)
	Dis_{max} (mm)	$Stress_{max}$ (ksi)	Δf(KHz)	
Fixed boundary	0.0695	5.786	17.892	23.54
Free boundary	0.252	19.066	110.773	145.6

Mechanical analysis

Tuning Sensitivity

A.Slow below tuner: acts to reach the final operation frequency
B.Fast below tuner: acts against fast effect. For example:
(micphonics, Lorentz Force detuning, fast pressure variation during operation)



ΔF/ Δl = 2.178 KN/mm
Δf/ Δl = 359.89 KHz/mm

In the graphic,
when the displacement equals 0.5mm,
Peak stress= 74.67MPa=10.83 Ksi.

Yield Strength ≥500MPi=72Ksi

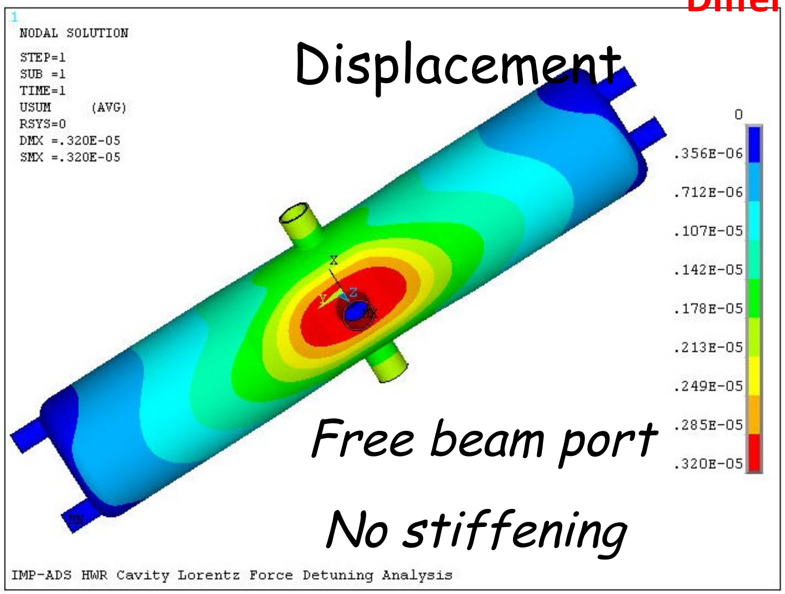
If the displacement equals 2mm, the peak stress may reach 43.32ksi. It is exactly safe, as the Yield strengths(4K) is more than 70ksi. And then the tuner range may reach more than +/- 720KHz.

Mechanical analysis

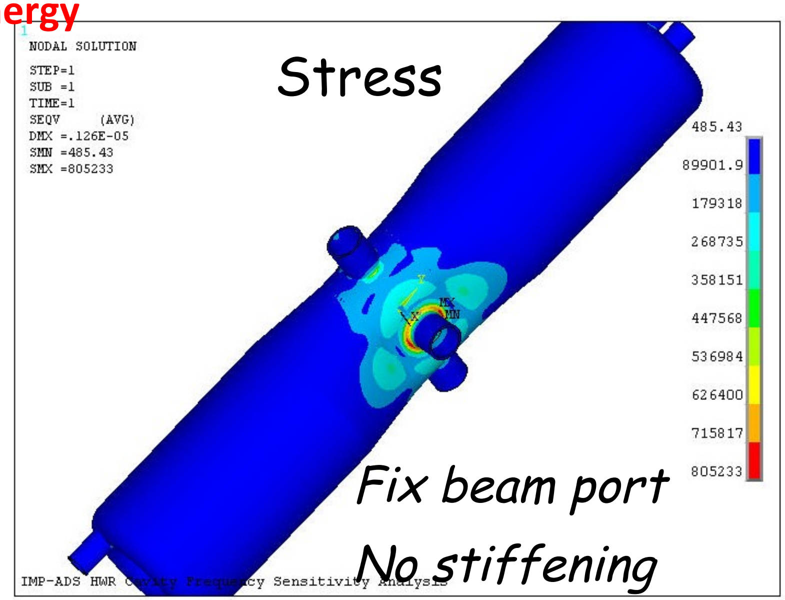
Lorentz Force Detuning Analysis

$$P = \frac{1}{4}\left(\mu_0 H^2 - \varepsilon_0 E^2\right) \qquad \Delta f = K_L E_{acc}^2$$

Different Energy



VS



Dis_{max}=3.2micron ； $Stress_{max}$=130.82Psi

Dis_{max}=1.26micron ； $Stress_{max}$=116.789Psi

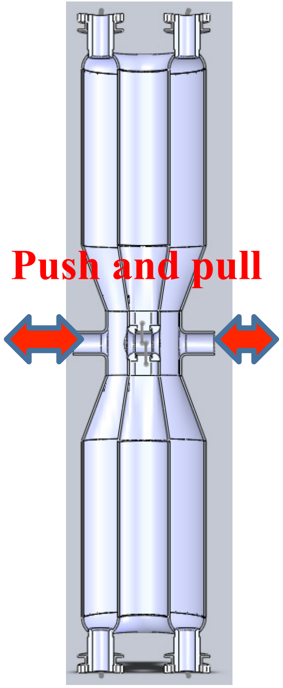
K_L= -16.903 Hz/(MV/M) ^{2}

Bandwidth：
$2f_{1/2}$=235.5Hz

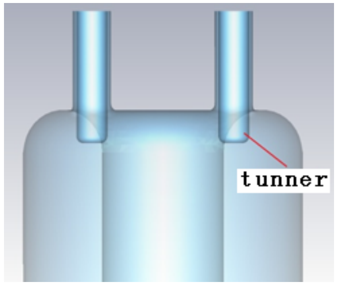
K_L= - 2.772 Hz/(MV/M) ^{2}

The boundary conditions are strongly influencing in the value for the Lorentz coefficient.

Tuner & Coupler

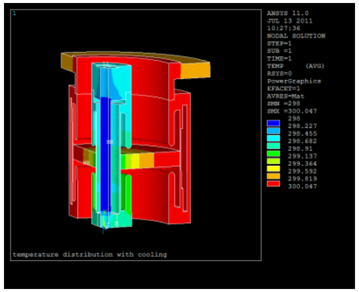


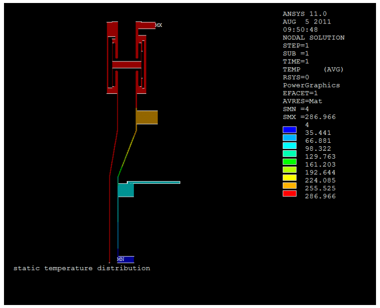
Dynamic tuner include Slow tuner and fast tuner:
Slow tuner Compensate for Cool-down and pump frequency shift;
Fast tunner Compensate for Microphonics;
Tuning sensitivity:283kHz/mm



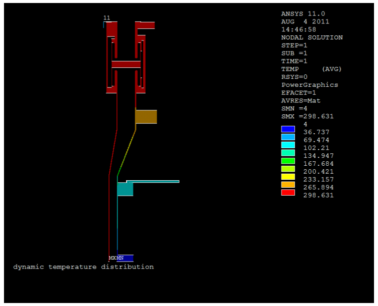
Static tuner:
Compensate for frequency variation due to process
Tuning sensitivity:16kHz/mm

Qe= 6.88E5
Antenna coupler
a 50-ohm coaxial structure
Single ceramic window
Power 15kW

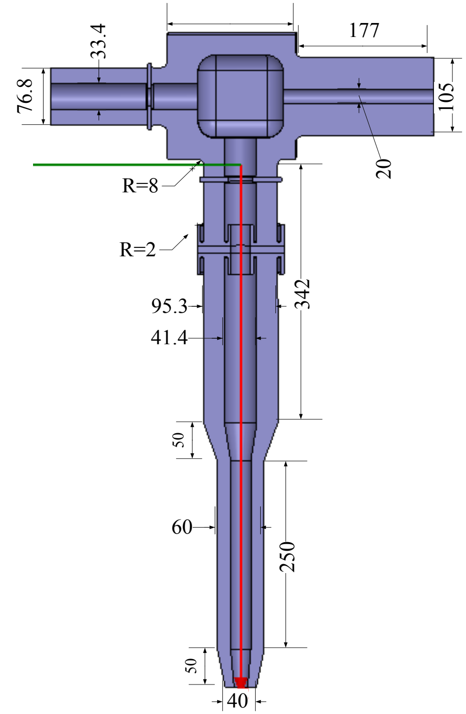




Ploss=1.014W



Ploss=3.888W

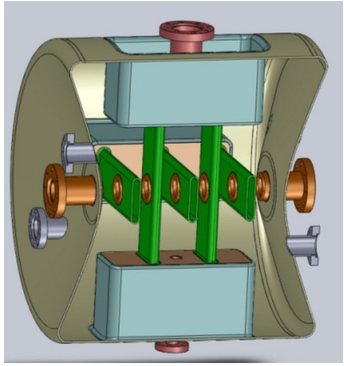


Copper Cavity Fabrication

CH cavity EM Design

	IAP	IMP(1)	IMP(2)
Frequency(MHz)	325.22	162.5	162.5
beta	0.1545	0.073	0.065
Accelerating cells	7	6	6
Length(mm)	505	636	560
Diameter(mm)	352.6	640	636
G(Ω)	64	52	47
Ra/Q0(Ω)	1248	1448	670
Ra/Q0 per cell (Ω)		241.3	111.6
RaRs(Ω^2)	80000	75296	31490
Ea βλ-definition(MV/m)	5	3.66	4.25
U(MV)		1.6	1.6
Ep/Ea	5.1	7.13	5.3(22.5)
Bp/Ea(mT /MV/m)	13	7.12	6.37(27)
W(J)		1.16	2.01
P(Rs=150nΩ)(W)		5.23	12.1
Pbeam(KW)		16	16
I (mA) CW		10	10
Qe		1.11*10^5	2.42*10^5

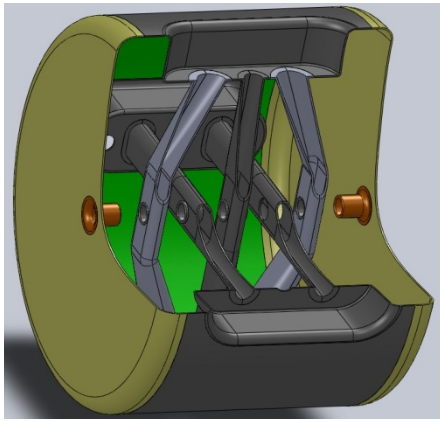
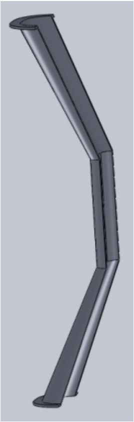
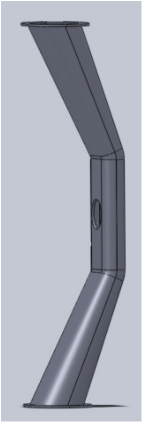
IMP1



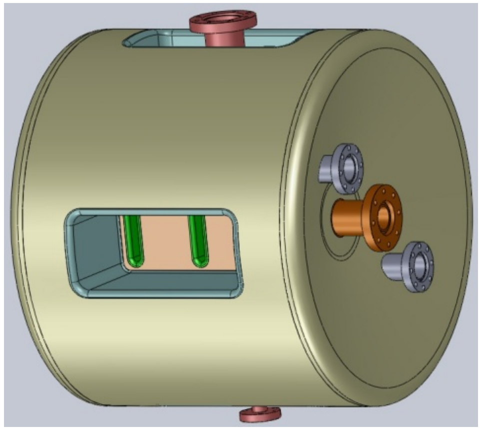
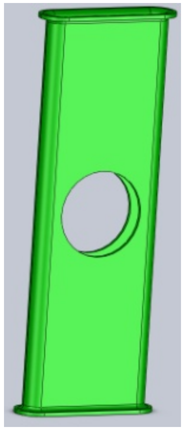
IMP2

easy to fabrication ;
enough coupling power

Structure Select

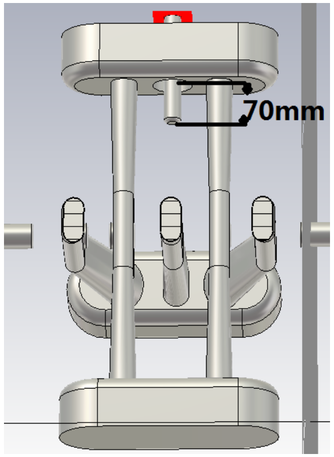




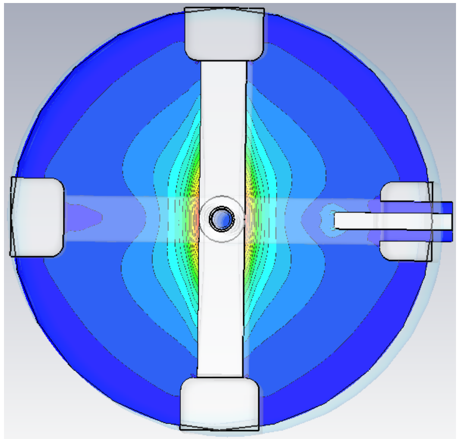
1 the IMP(1) CH cavity ,
bend stem,
Advantage:
helpful for the distribution of field ,
Disadvantage:
hard to fabrication
No

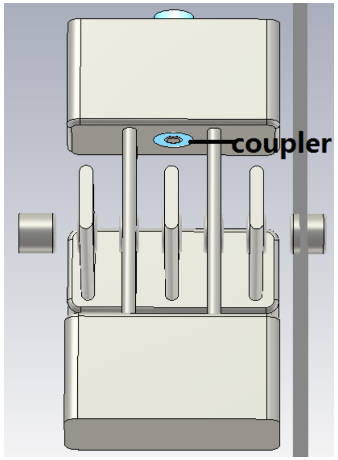
2 the IMP(2)CH cavity ,
stem ,
Advantage:
easy to fabrication
Disadvantage:
bad for the distribution of field
yes

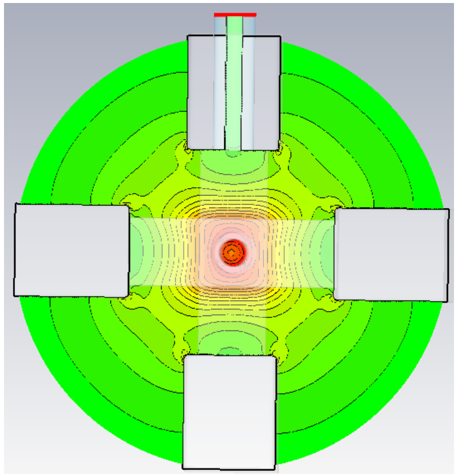
Structure Select





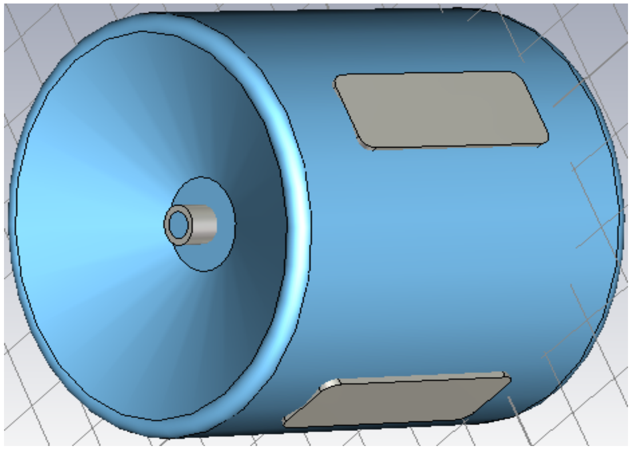
1 the IMP(1) CH cavity
for enough coupling ,the antenna must be 70 mm out of girder
Disadvantage:
the antenna make field not symmetry
No

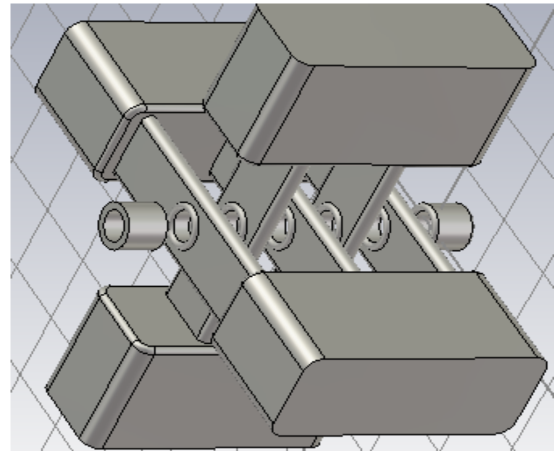


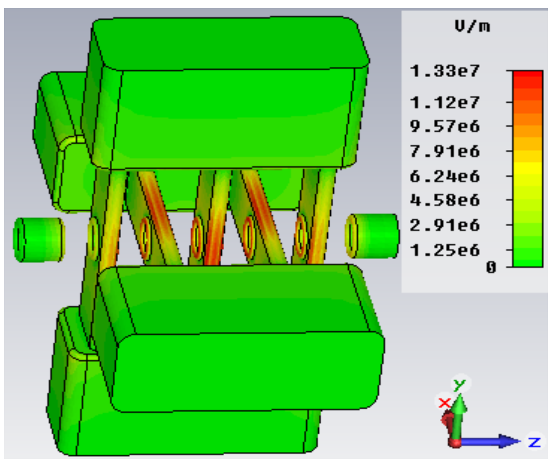


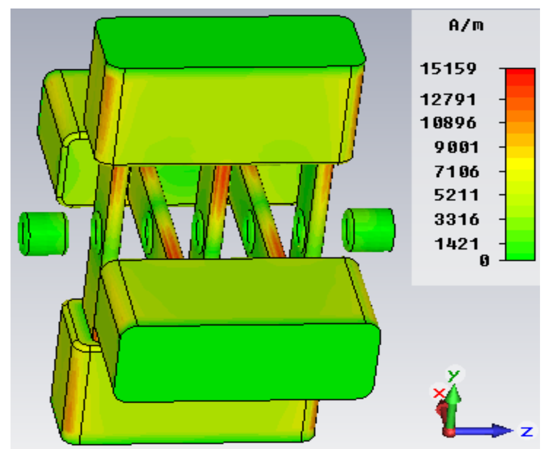
2 the IMP(2) CH cavity
for enough coupling ,the antenna didn’t need out of girder
advantage:
the antenna didn’t damage the field symmetry
yes

CH cavity EM optimization





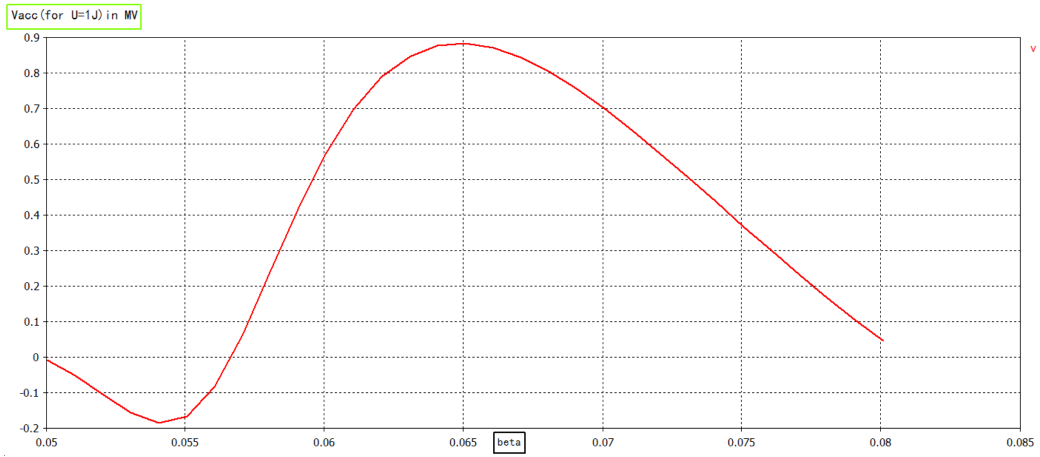




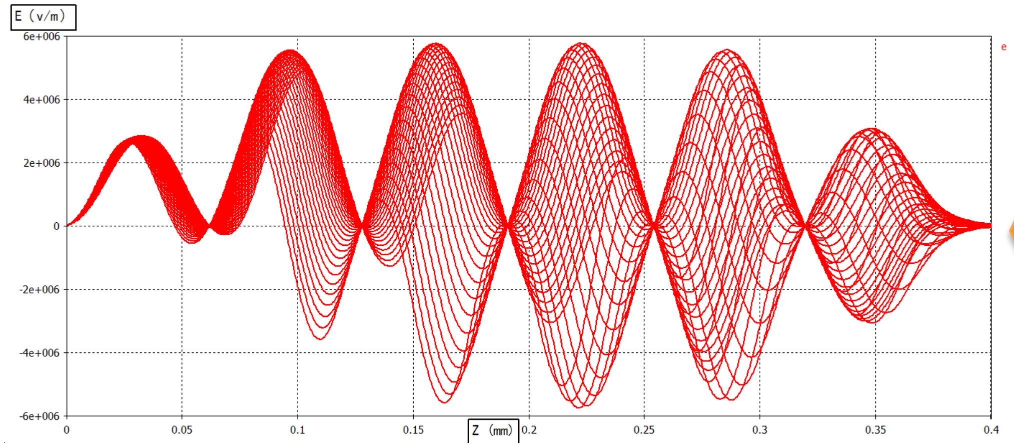
Optimization Epeak and Bpeak ;
Increase the power coupling;
Decrease power loss

CH cavity EM optimization

Uacc VS beta

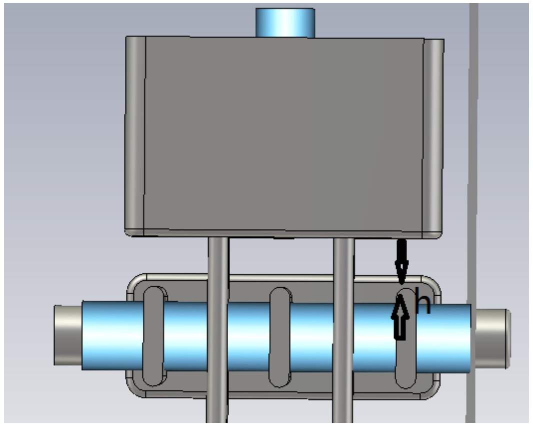


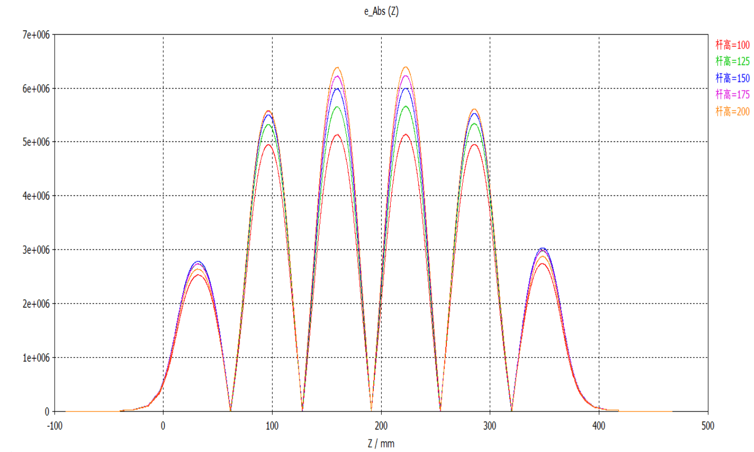
- The length of all cells are 63 mm
- Equal length is helpful for the distribution of E –field
- Equal distribution of E –field decrease the E peak



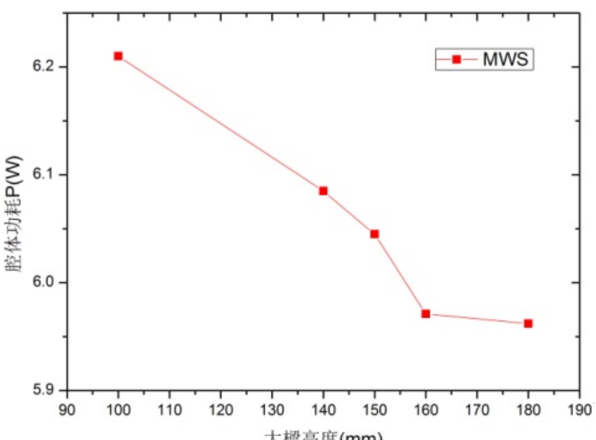
The real E –field for different beta

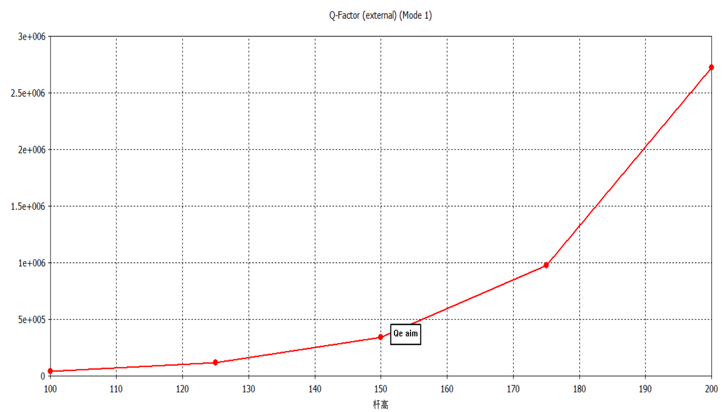
CH cavity EM optimization





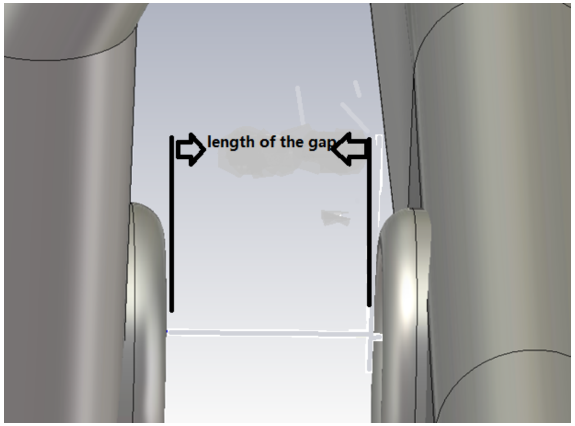
The height of girder can affect the E-field distribution, when the girder close to the tube ,the distribution will be better

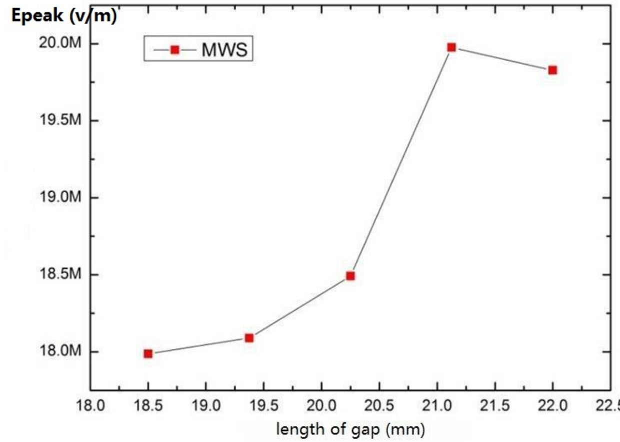




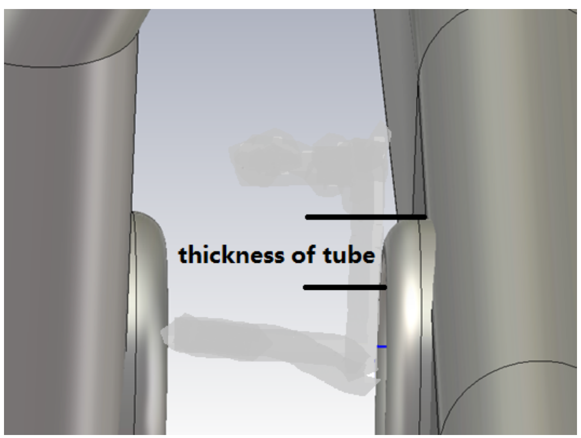
Choose the height of girder will focus on coupling , when the height of girder is 150mm ,can get the coupling we need ,at this height the dissipation is acceptable too

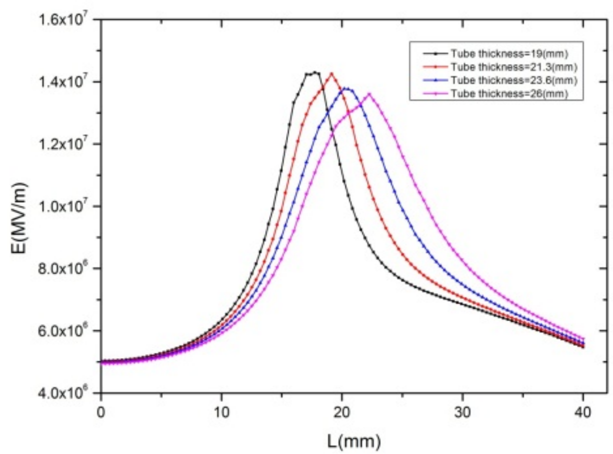
CH cavity EM optimization

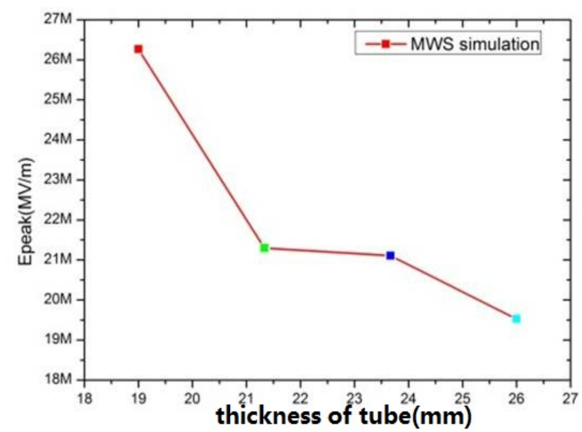




Tuning the length of gap can optimization Epeak ,use the longer gap can decrease the Epeak

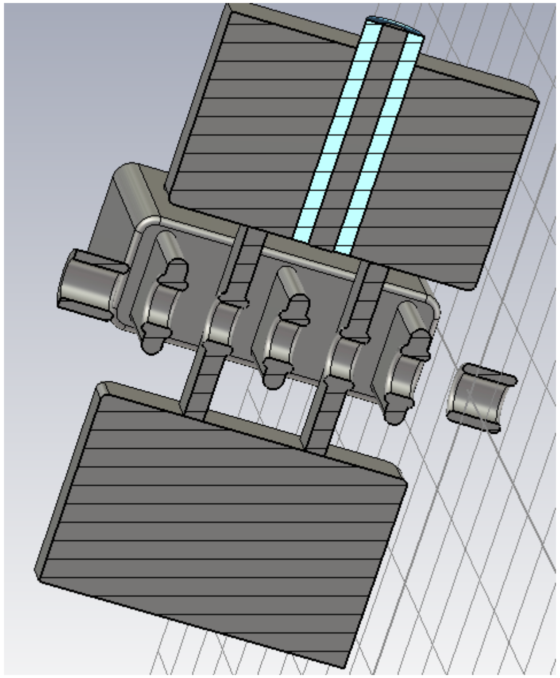






Large thickness of tube will decrease the Epeak –field

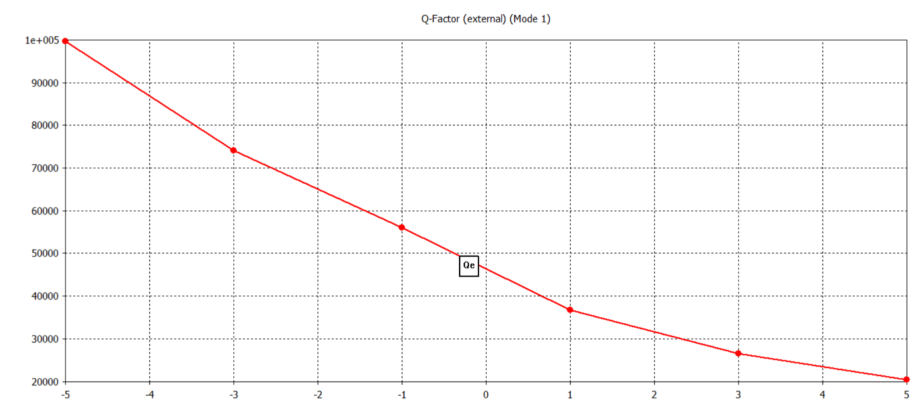
Coupler Design



Type of coupling	Capacitive power coupler
Diameter of coupler port(mm)	60
Diameter of coupler antenna(mm)	26
Length of coupler antenna(mm)	185
End sharp of coupler antenna	Cylinder
P(kw)	30
Qe	2.12*10^5
Heat to cavity (w)	1

1 satisfaction the require of beam power;
2 less affect on the E-field along the Axis;
3 easy to fabrication

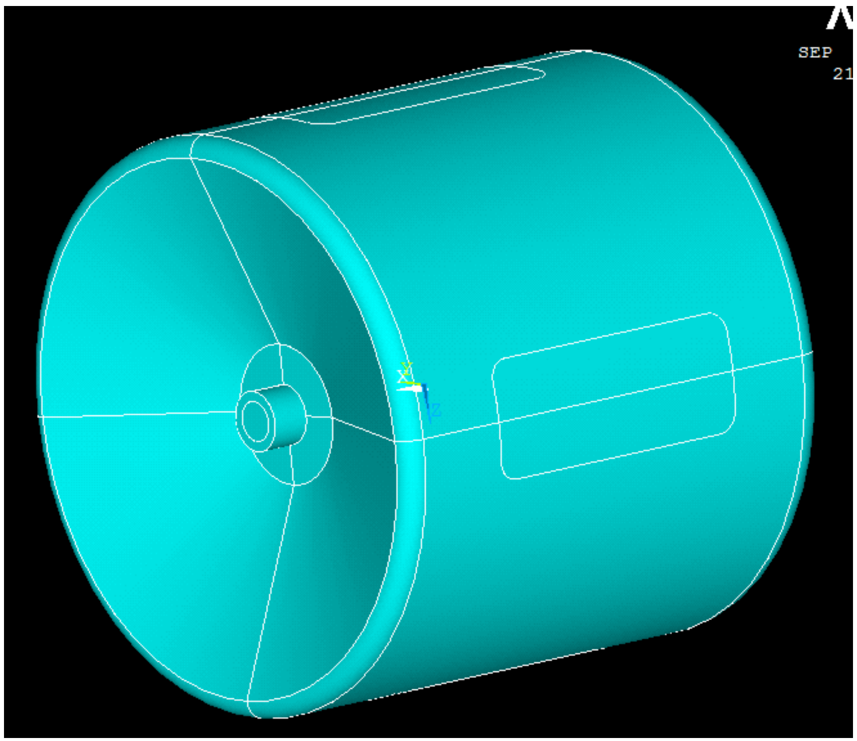
Short antenna can reach the power coupling



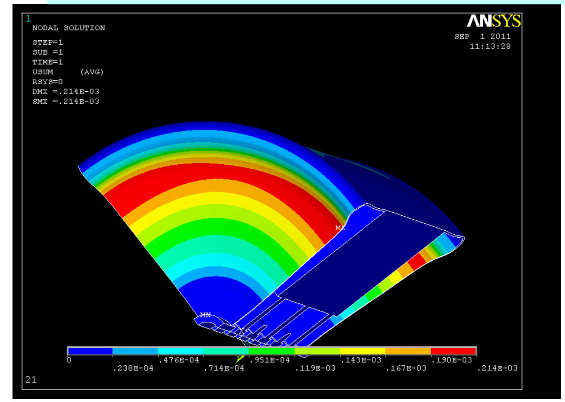
Mechanical performance analysis

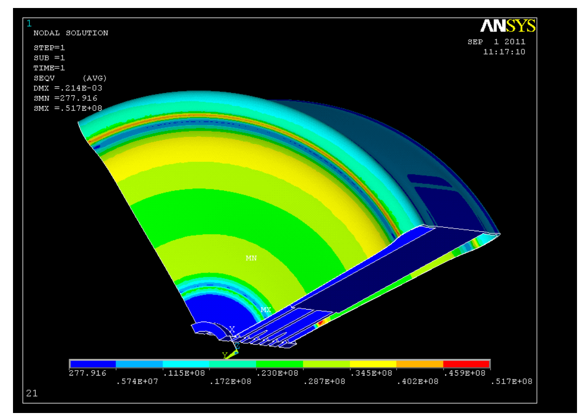
（an atmospheric pressure）

△f=33.5KHZ



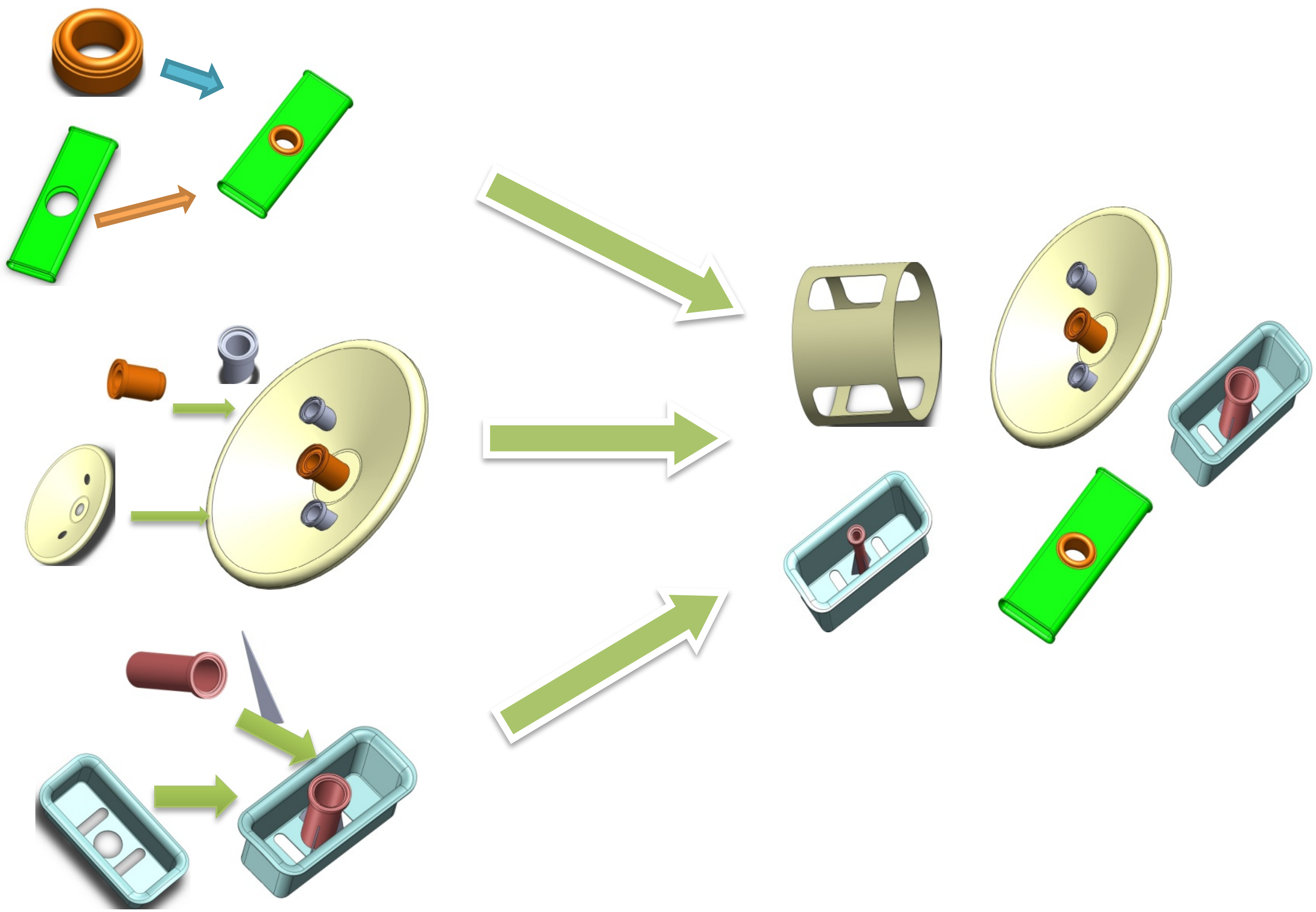
Max.displacement:0.214mm



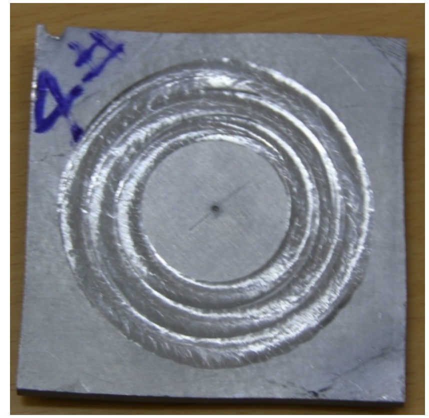


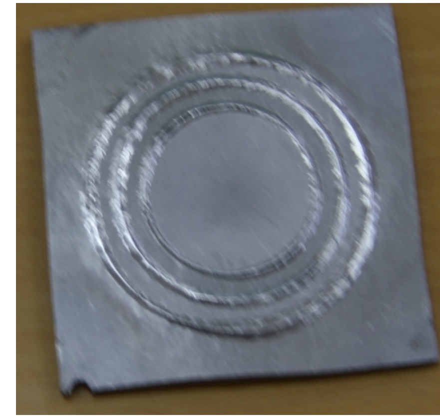
Max.von-stress:51.7Mpa

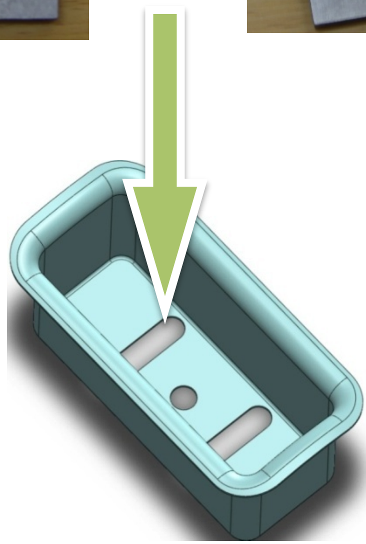
CH cavity Fabrication Procedure



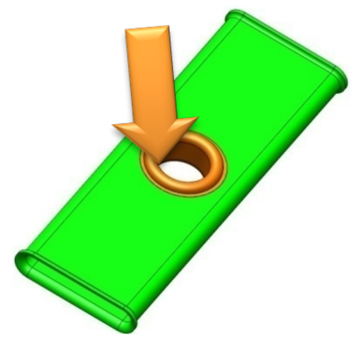
EBW experiment





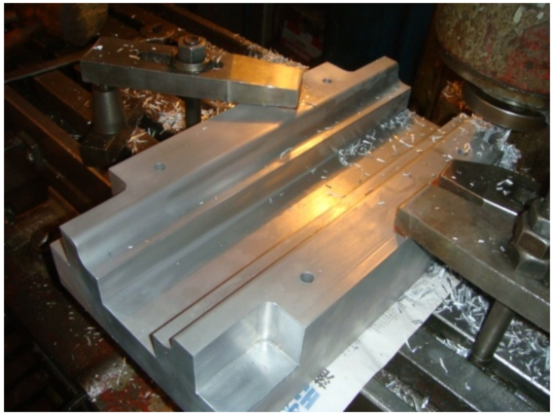


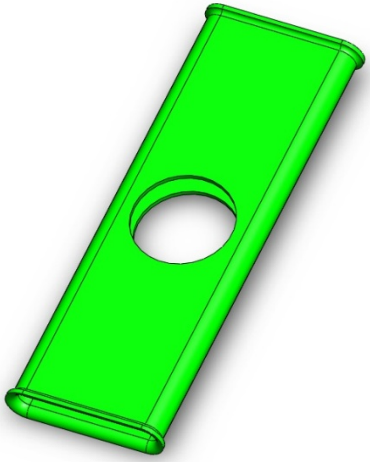
EBW between girder and stem

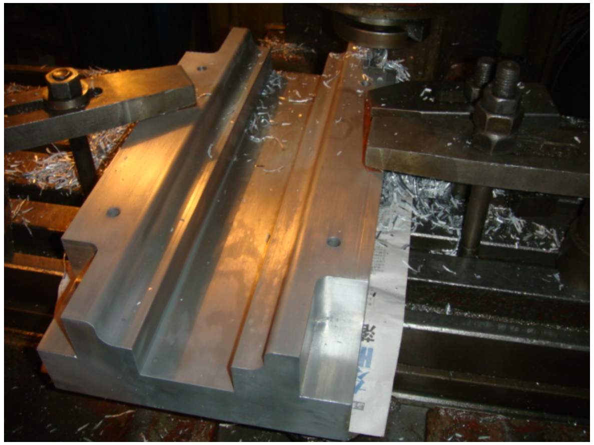


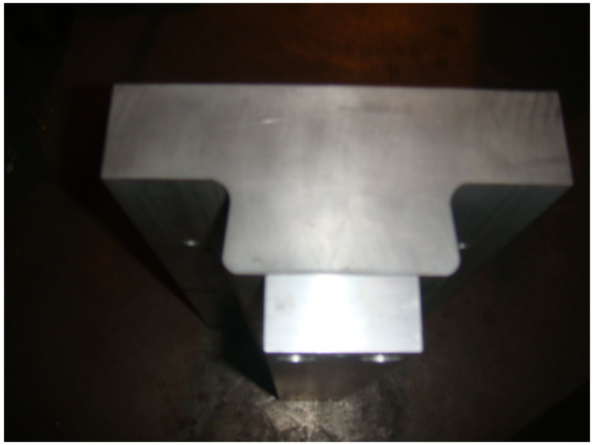
EBW between stem and tube

Die Process for Stem









Summary

- EM design of the two types of cavities has been done; the thermal analysis has been going on.
- The initial RF design of β=0.09 HWR cavity has been finished, and more optimization is going on now .
- The copper cavity of the HWR cavity is in process.
- Research of other components of the cavity, such as the tuner, the coupler, helium vessel, etc, is the main work in the future.
- The cavity fabrication is at the very beginning, more work need to be done in the future.
- EBW experiment is doing now.

Questions

- Is the input coupler diameter of 40mm too small for the transmission power of 15kW?
- Is the single ceramic window OK?
- Dose the HWR need stiff rid?
- Which type of the HWR tuner should be chosen?
- Does the CH cavity need a HOM coupler?
- What problems should be considered when designing the liquid helium vessel for CH cavity?

Thanks for your attention!