CSNS Linac

CSNS
CHINESE ACADEMY OF SCIENCES

Contents

1.Major Design Considerations

1, Major Design Considerations

- CSNS demands to accelerator:

  100kW, 25 Hz, 1.6GeV in phase 1

  upgradeable to 500kW

- Accelerator complex:

  81MeV H- Linac + 1.6 GeV RCS

  with a reserved space for linac energy increase for phase 2

- Major concerns:

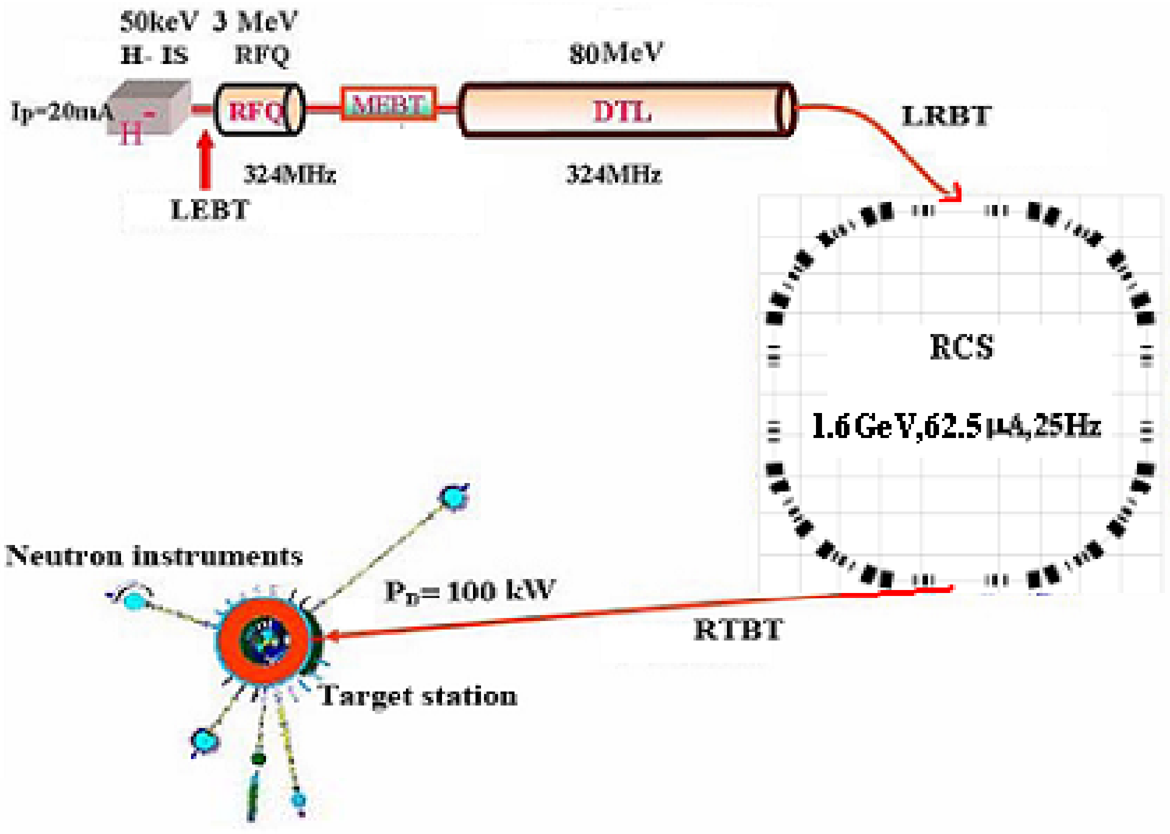
  beam loss control, rapid cycling related issues, low cost and high reliability.

- Major design reference:

  starting from Austron, then to J-PARC

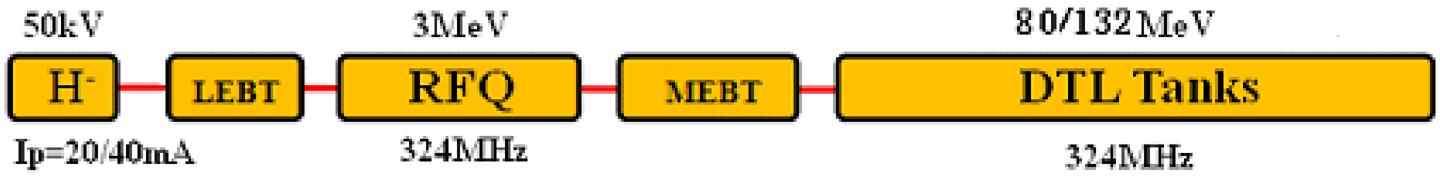
- Conservative design and mature technology

•CSNS Design



	CSNS-I	CSNS-II
Beam power (kW)	100	200/500
Repetition rate (Hz)	25	25
Target number	1	1
Average current (μA)	62.5	125/250
Proton energy (GeV)	1.6	1.6
Linac energy (MeV)	80	132/250

- **Linac design sketch**



	Ion Source	RFQ	DTL
Input Energy（MeV)		0.05	3.0
Output Energy(MeV)	0.05	3.0	80/132
Pulse Current (mA)	20/40	20/40	15/30
RF frequency (MHz)		324	324
Chop rate (%)		50	50
Duty factor (%)	1.3	1.05	1.05
Repetition rate (Hz)	25	25	25

•Major design parameters

1, RF frequency choice

- Existing RF power source (cheap, reliability, long-term supply).
- High frequency for high shunt impedance and low structure cost.
- Low frequency for EM quadrupole in Drift Tube with a large space;
- Frequency jump for high energy section.
- Availability of RF power source.

201MHz 324MHz 352MHz 402MHz

Major design parameters

2, Beam energy

Defined by the space charge tune spread of the injected beam in the ring.

higher beam energy, lower space charge effect.

Higher current requires higher beam energy.

I(uA)	62.5	125	250
E(MeV)	80	132	250

3, Beam current

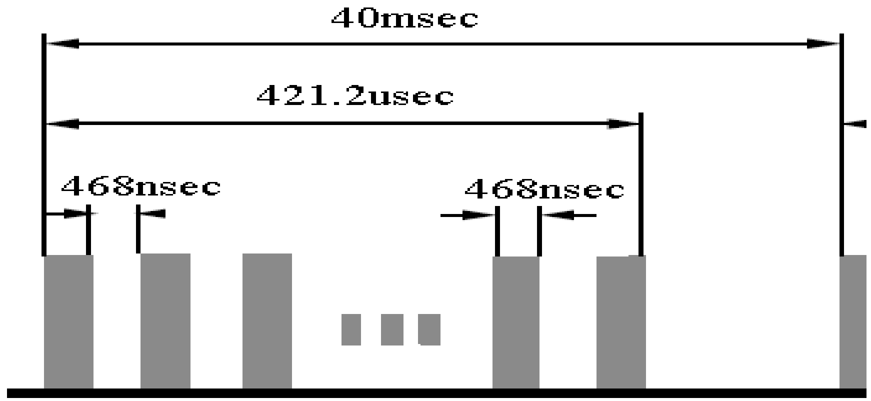
Ring current demand for power upgrade in future.

4, Pulse repetition rate

25Hz for neutron TOF measurement.

5, Pulse structure

Chopped for loss control at injection



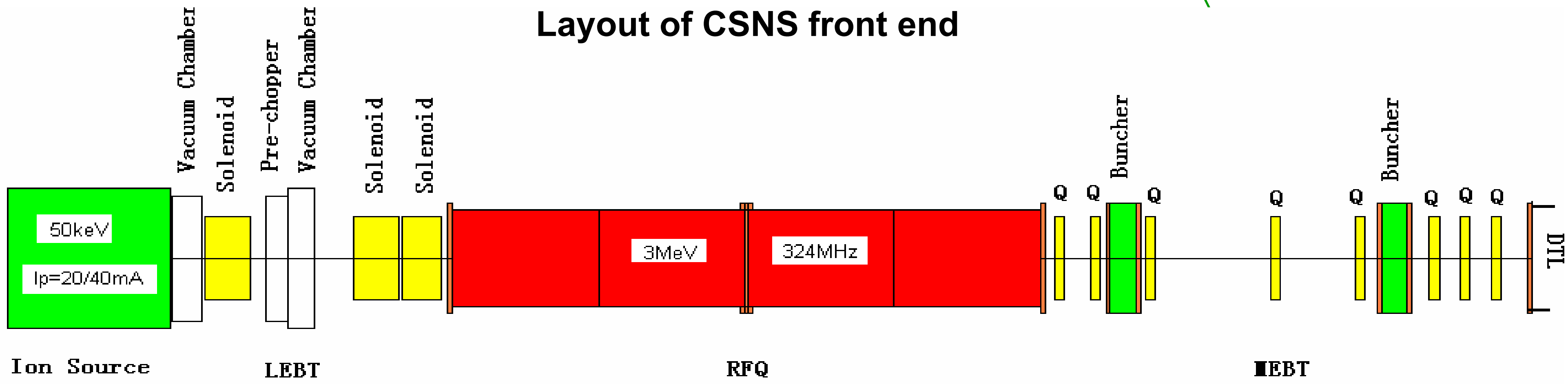
2, Physics design

2. Physics Design---Front end

Front End : **Ion source+LEBT+RFQ +MEBT**

Goal: **Stable operation with the required beam quality**

Layout of CSNS front end



2. Physics Design---Front end

Ion source

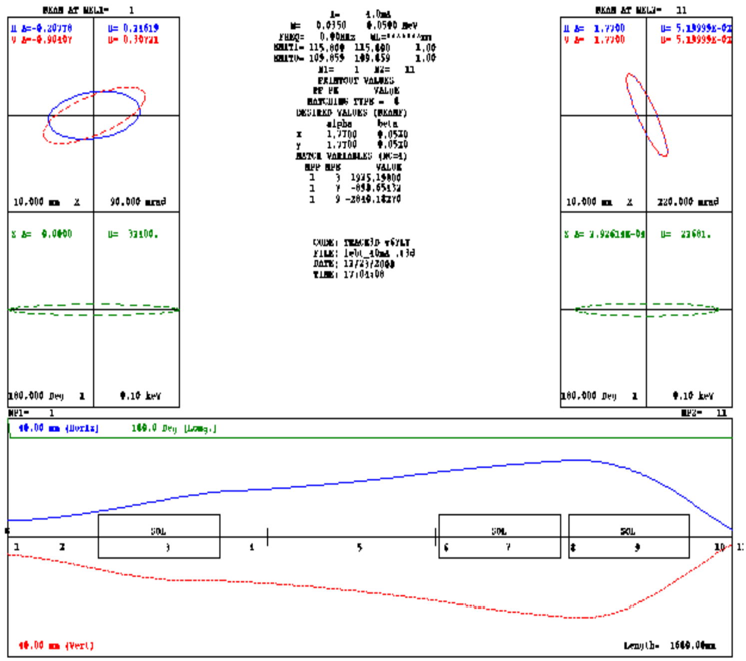
Main parameters of CSNS ion source

Ion	H^-
Energy (keV)	50
Current (mA)	20
Norm. RMS Emittance (π mm-mrad,)	<0.20
Repetition Rate (Hz)	25
Beam Width (μs)	~500
Lifetime (month)	~1

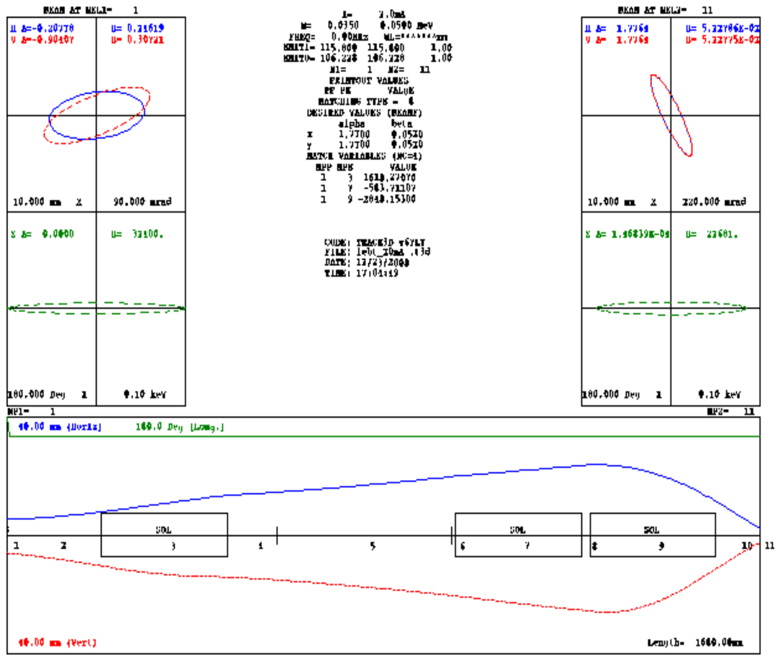
2. Physics Design---Front end

LEBT

Design for I=40mA



Design for I=20mA

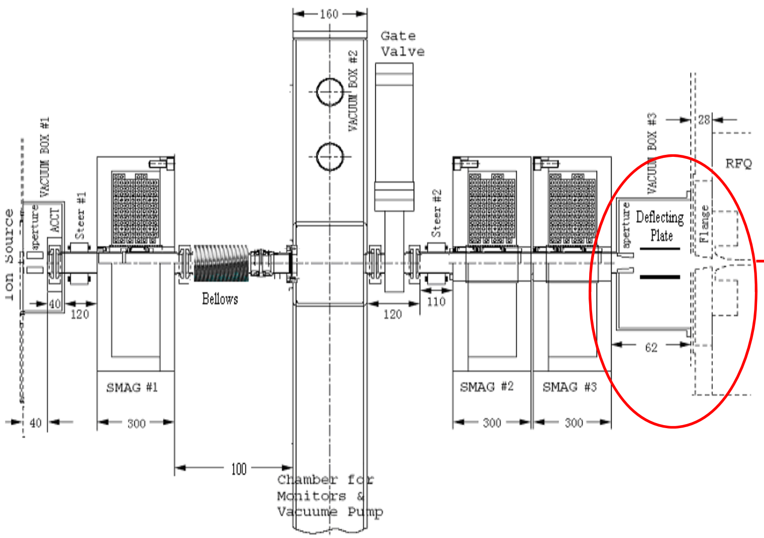


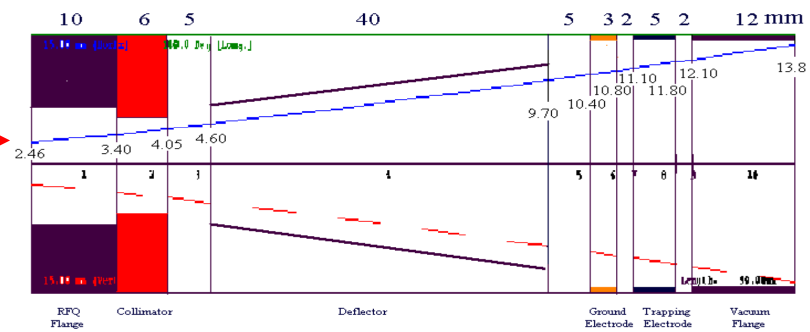
- **The length is shorten to 1680**
- **The maximum envelope is about 31mm at I=40mA.**
- **No waist**

2. Physics Design---Front end

LEBT (electrostatic pre-chopper)

- The sloping deflecting plates with varied width (as the envelope)
- Length: 40mm
- Ground electrode and electron trapper before the deflecting plate
- Beam collimator on the RFQ flange

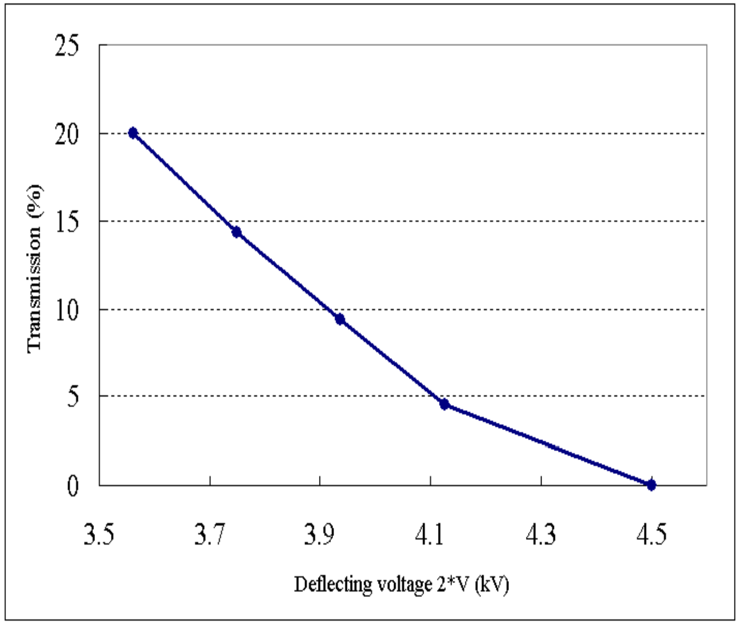




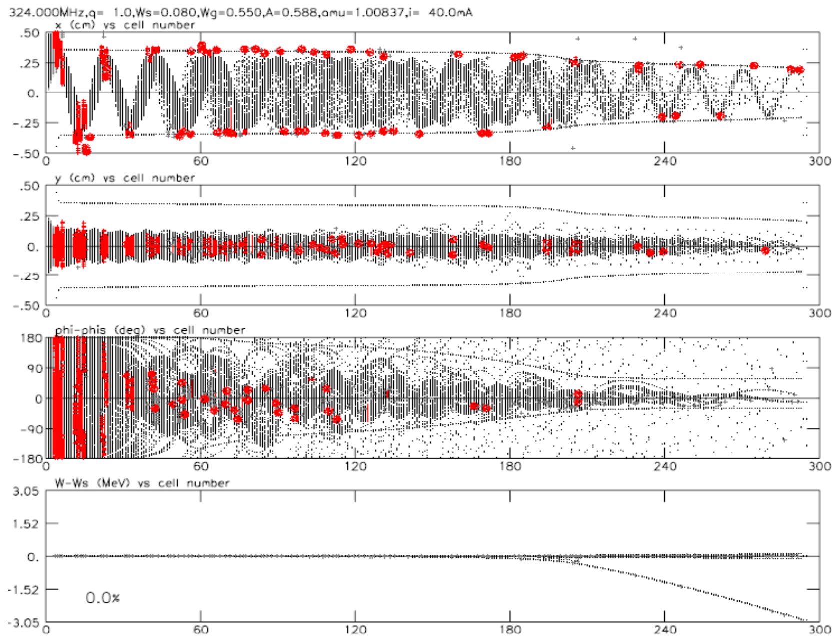
2. Physics Design---Front end

LEBT (electrostatic pre-chopper)

- The chopped beam is designed to lose in RFQ cavity
- The deflecting voltage V < 4.5kV



The chopped beam transmission in RFQ versus the deflecting voltage



The beam transmission is 0 at V = 4.5kV

2. Physics Design---Front end

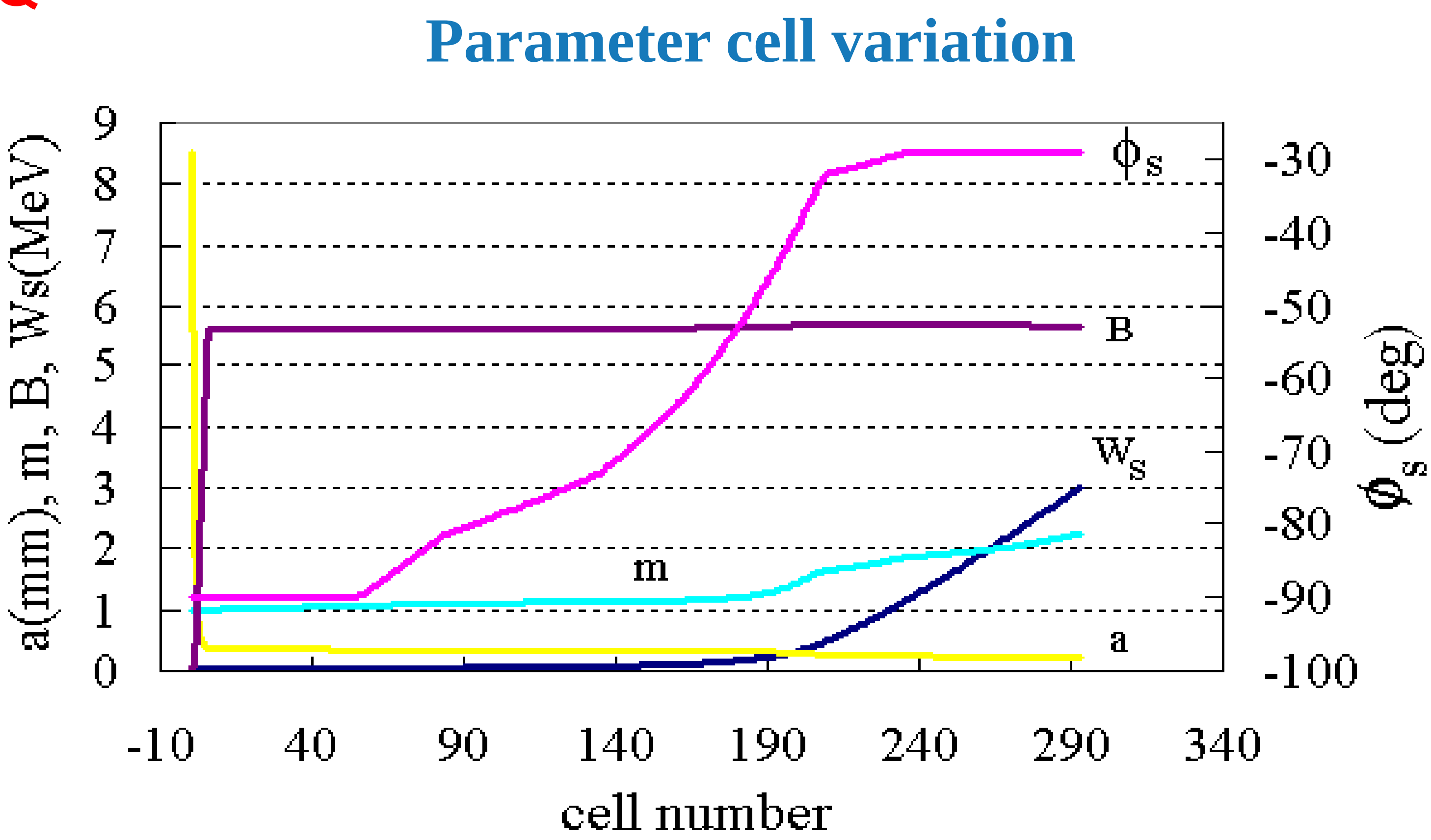
RFQ

Main parameters of CSNS RFQ

Parameters	CSNS	ADS
Frequency(MHz)	324	352.2
Injection Energy (keV)	50	75
Output Energy (MeV)	3.0	3.5
Pulsed beam current (mA)	40	50
Beam duty factor	1.05%	6%
Vane length (m)	3.603	4.731
Norm. rms input emittance (πmm.mrad)	0.2	0.2
Inter-vane voltage V (kV)	80	66.5
Maximum surface field (MV/m)	31.68(1.78Kilp)	33(1.8Kilp)
Average bore radius: r0 (mm)	3.565	2.93
Vane-tip curvature: ρt(mm)	3.173	2.93
Pulsed RF Power (kW)	510	630

2. Physics Design---Front end

RFQ



a: **minimum bore radius,** ***m***: **modulation factor,** ***B***: **focusing strength,**

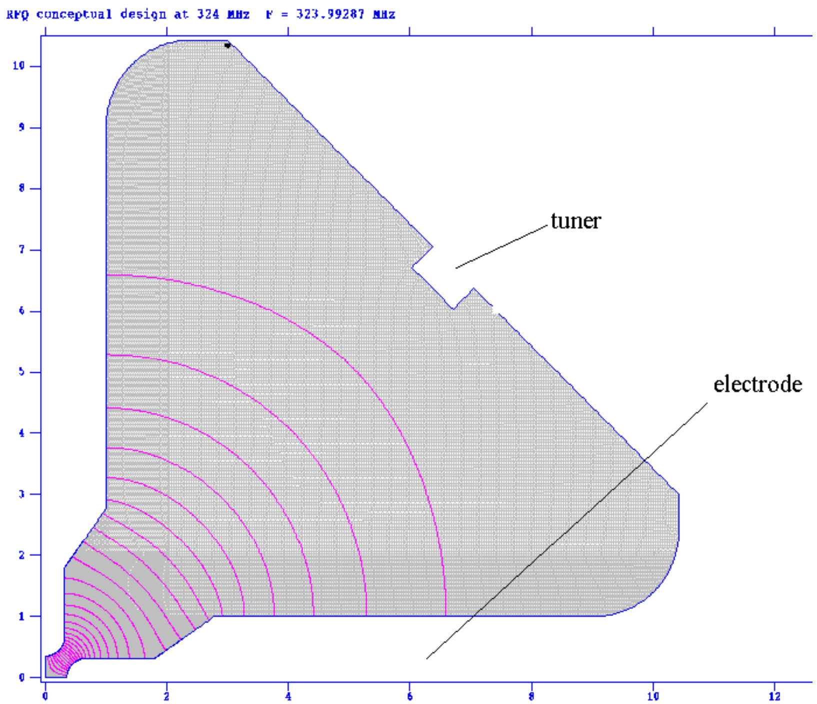
Ws: **synchronous energy,** **ϕ** ***s***: **synchronous phase.**

2. Physics Design---Front end

RFQ

The cross section of CSNS

➢ **Almost same cross section as ADS RFQ. The width Wb of electrode increases from 18mm to 20 mm to facilitate the water cooling channel drilling.**

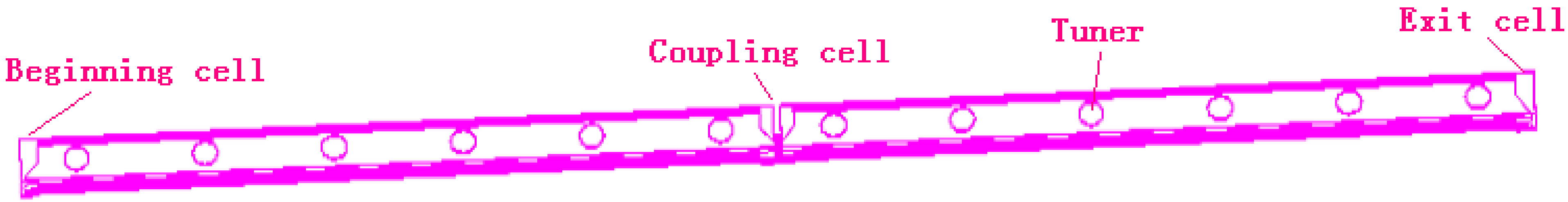


2. Physics Design---Front end

RFQ

Some structural characters for CSNS RFQ

- The total length 3.62m
- 2 segments with the coupling cell in the middle, each segment technically consists of 2 modules
- No dipole stabilized rod needed again
- 48 slug tuners
- 16 water cooling channels on the cross section



A quarter of CSNS RFQ

2. Physics Design---Front end

RFQ

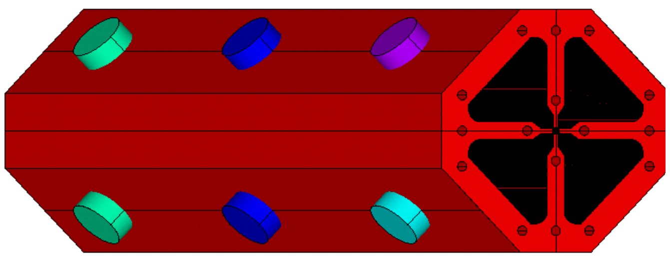
Thermal analysis

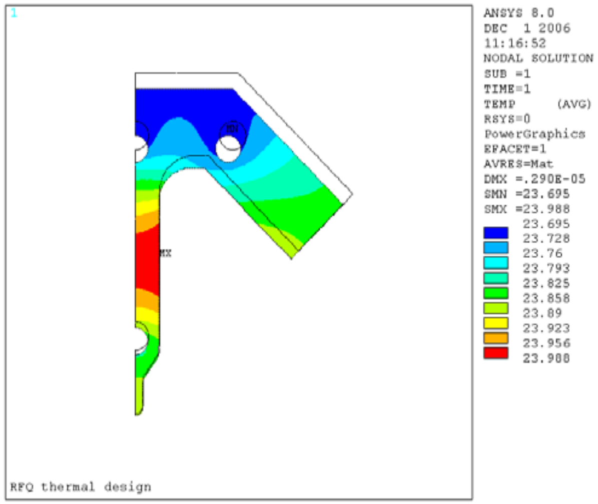
- **Water-cooling serves two functions in an RFQ**

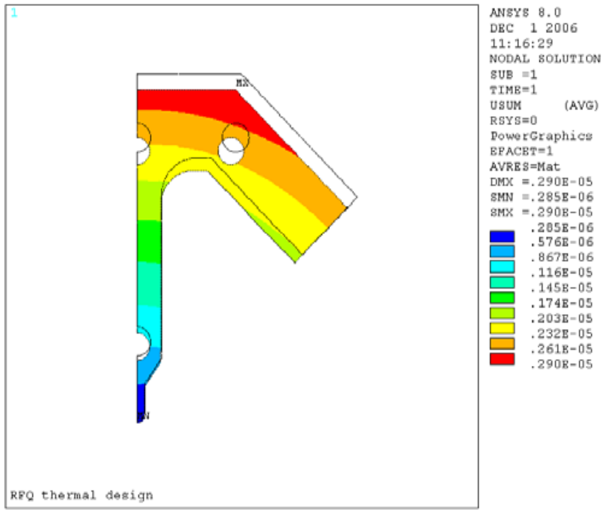
  To take away the power dissipation

  To tune the RFQ basically without effecting the field distribution

- **16 water-cooling channels on the cross section**







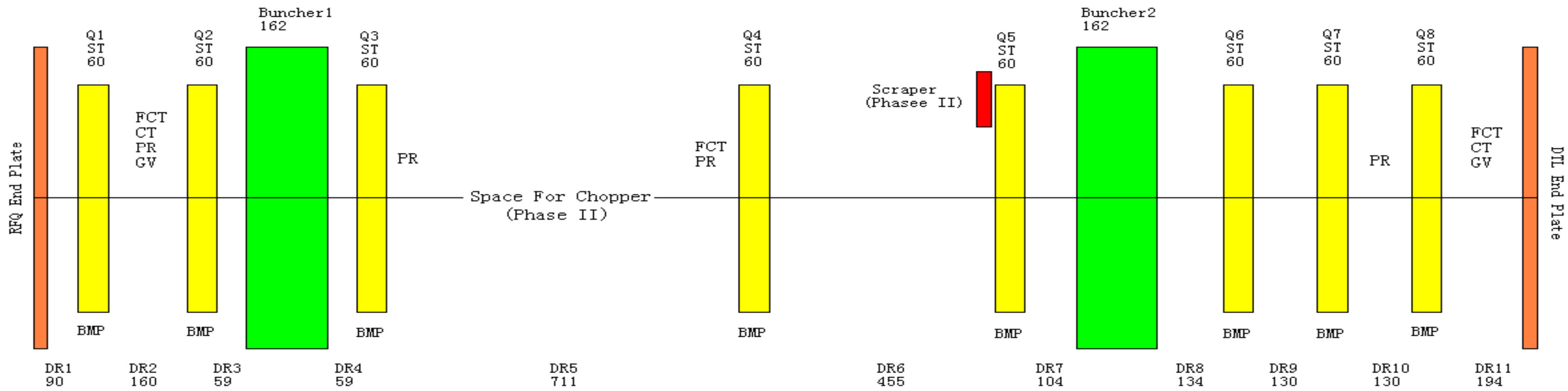
2. Physics Design---Front end

MEBT

- Total length =3030 mm
- 8 Q magnets in three bore groups

  (the first four Q's serve for beam chopping, the last 4 Q's for transverse beam match)
- 8 Steering magnets

  (incorporated into quadrupole magnets through wiring on the quadrupole magnet yokes)
- 2 bunchers for longitudinal beam match
- Beam diagnostic components: 8 BPM,4PR,3FCT,2CT
- Vacuum components: 2GV, 2 set pump systems



BPM=beam position monitor
PR=profile monitor

FCT=fast current monitor
CT=current monitor

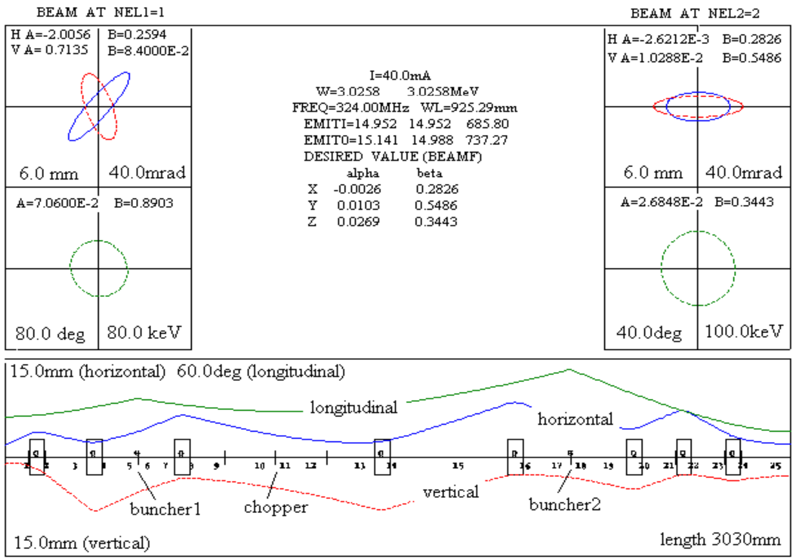
Q=quadrupole magnet
ST=steering magnet

GV=gate vale

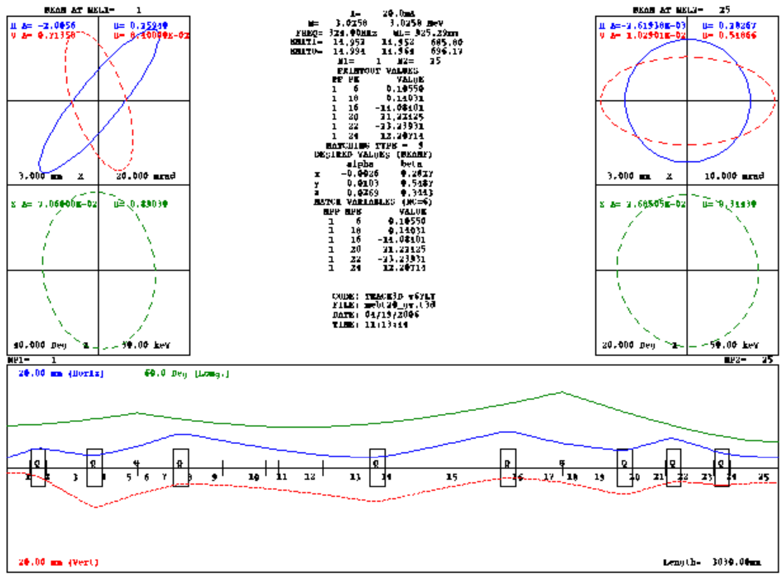
2. Physics Design---Front end

MEBT

- **The maximum envelopes (8.5mm) in x ,y at the centers of the fifth and the second quadrupoles, respectively.**
- **The maximum envelope (54°) in z at the center of the second buncher.**
- **The small envelope difference between 40mA and 20mA**



I=40mA



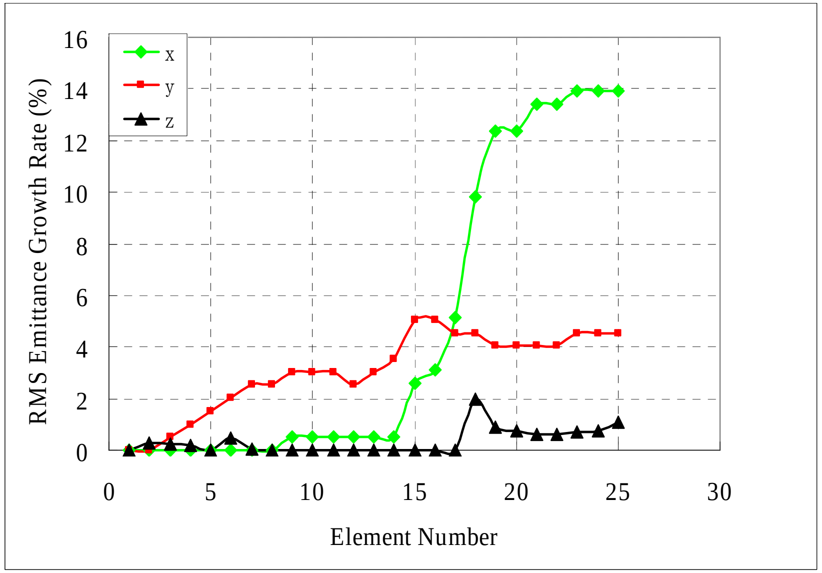
I=20mA

2. Physics Design---Front end

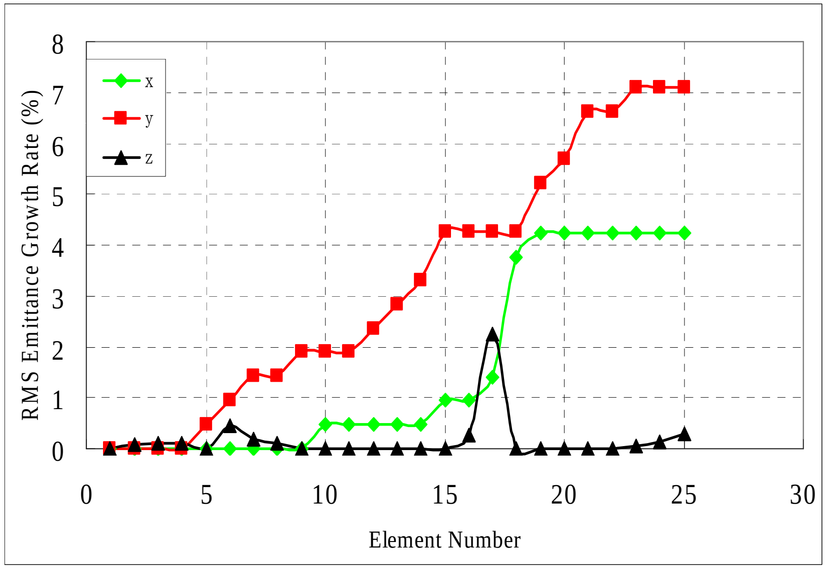
MEBT

- The RMS emittance growths in the x, y, z directions are respectively about 14%, 4. 5% and 1.1% for I=40mA

- The RMS emittance growths in the x, y, z directions are respectively about 7.1%, 4.25% and 0.3% for I=20mA



I=40mA



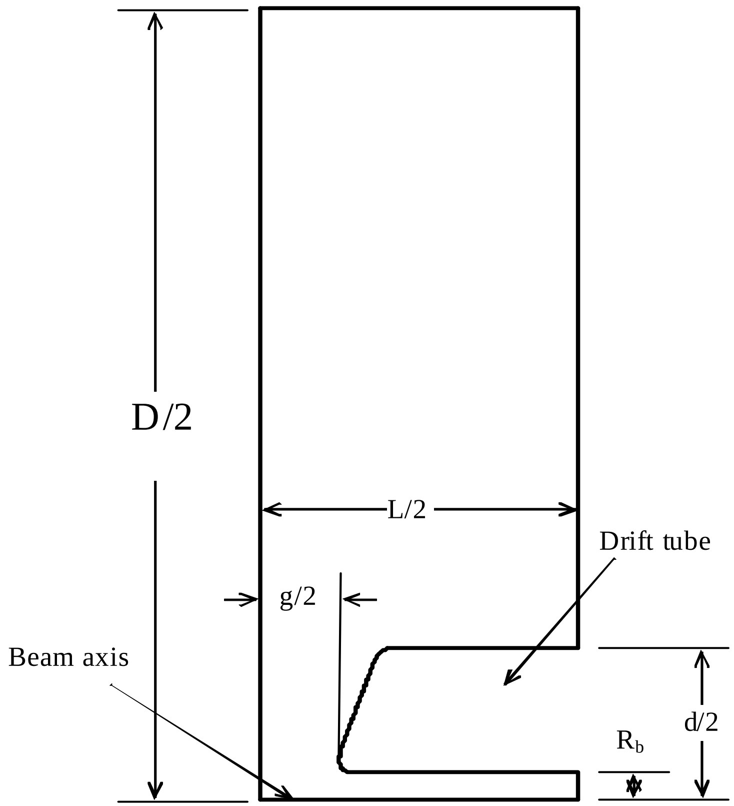
I=20mA

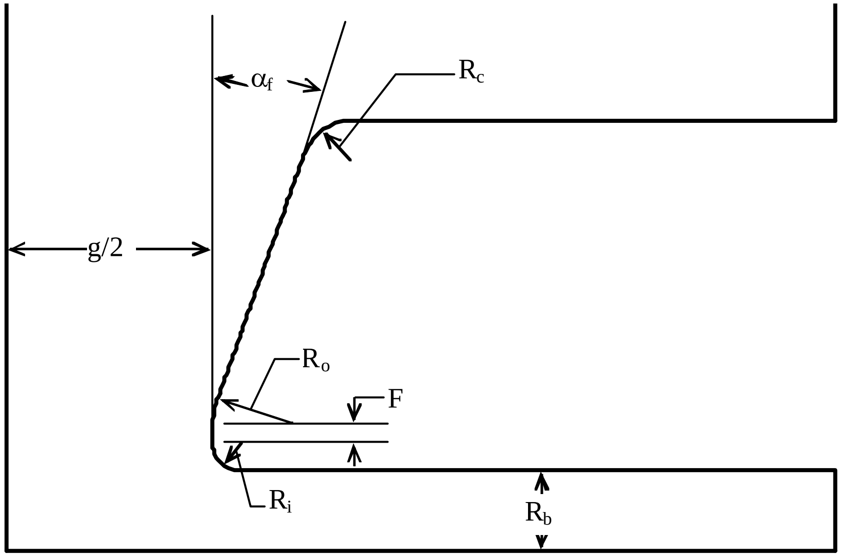
2. Physics Design---DTL

Cell geometry

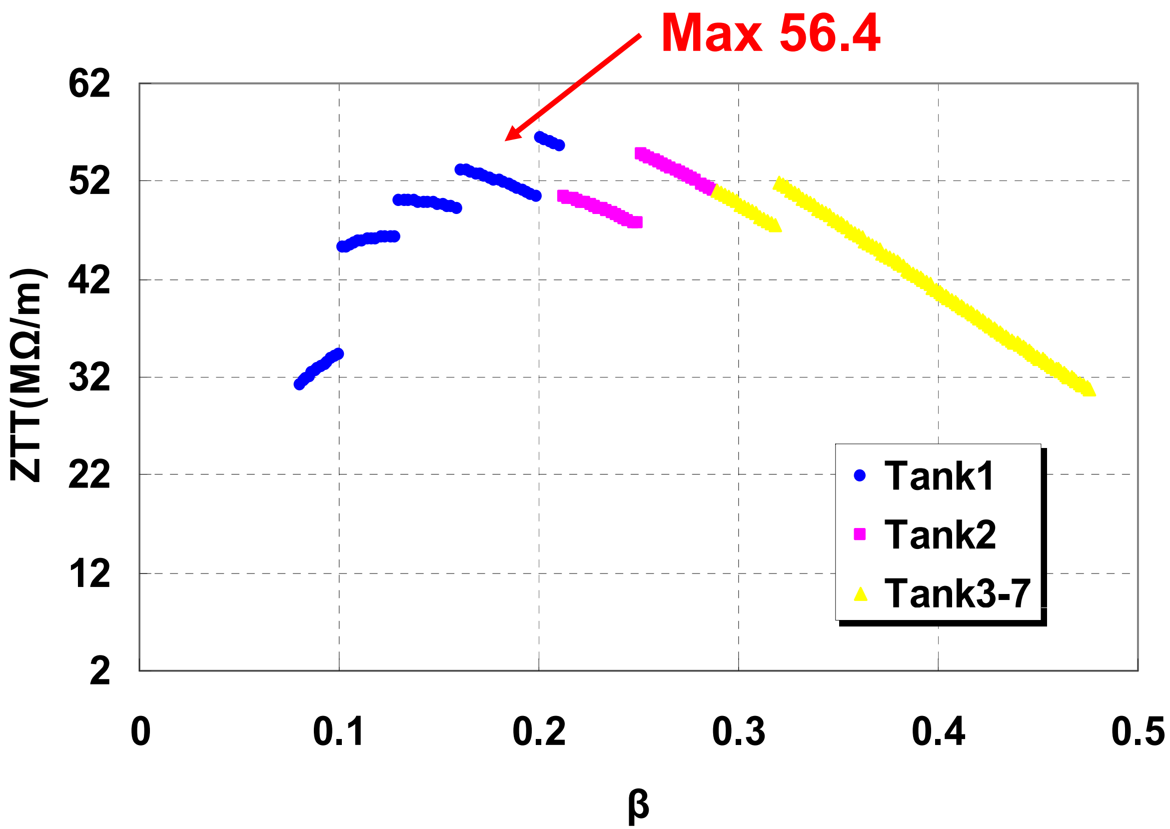
For optimization

- High ZT^2
- Kilpatrick <1.3
- Enough space for EMQ (electromagnetic quadrupole magnet)





2. Physics Design---DTL



The effective shunt impedance as a function of β
(no reduction in Z)

2. Physics Design---DTL

Tank parameters of CSNS DTL

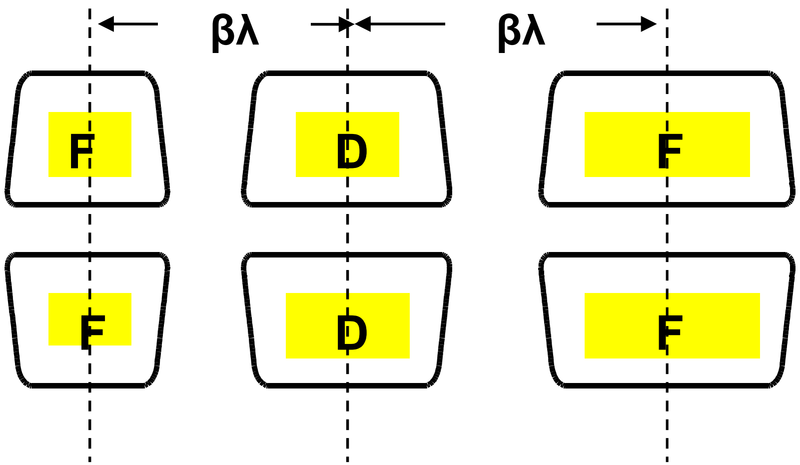
Tank number	1	2	3	4	5	6	7	total
Output energy (MeV)	21.76	41.65	61.28	80.77	98.86	115.8	132.2	132.2
Length (m)	7.99	8.34	8.5	8.85	8.69	8.57	8.67	59.6
space between tanks(m)	0.2	0.27	0.32	0.36	0.39	0.42		1.96
Number of cell	61	36	29	26	23	21	20	216
RF driving power (MW)	1.41	1.41	1.39	1.45	1.45	1.45	1.49	10.05
Total RF power (MW)	1.97	2.01	1.98	2.03	1.99	1.96	1.98	13.92
Accelerating field (MV/m)	2.2 to 3.1	3.1	3.1	3.1	3.1	3.1	3.1	
Synchronous phase (degree)	-30 to -25	-25	-25	-25	-25	-25	-25	

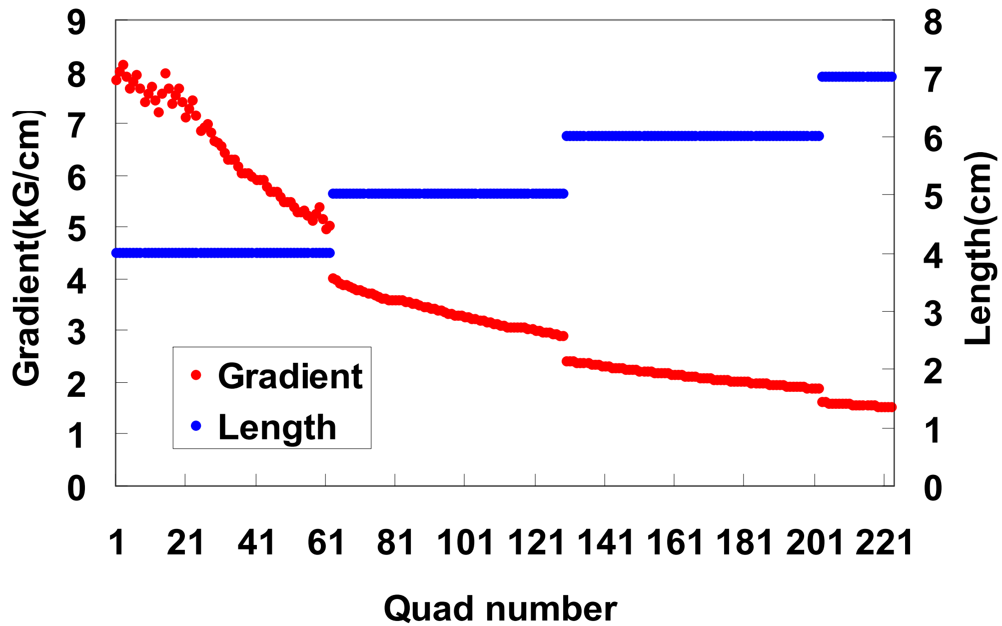
- The total RF power with a 30mA beam in a tank is about 2MW. Each tank is fed by a 2.5MW klystron.
- The length of the tank should be less than 9m.

2. Physics Design---DTL

Focusing design

FD (2βλ) is chosen for transverse focusing





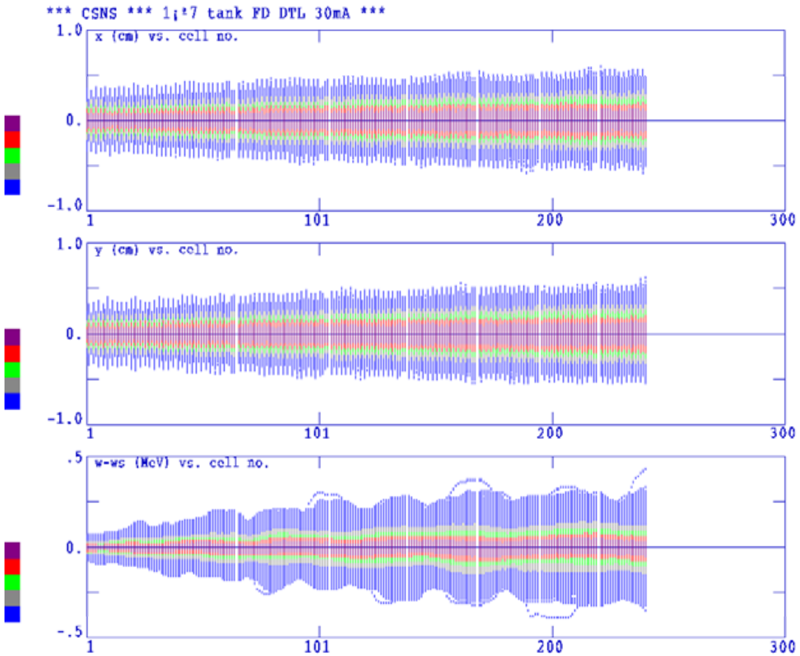
Magnet gradient and length

- **Strong focusing strength, small beam radius**
- **High tuning ability**

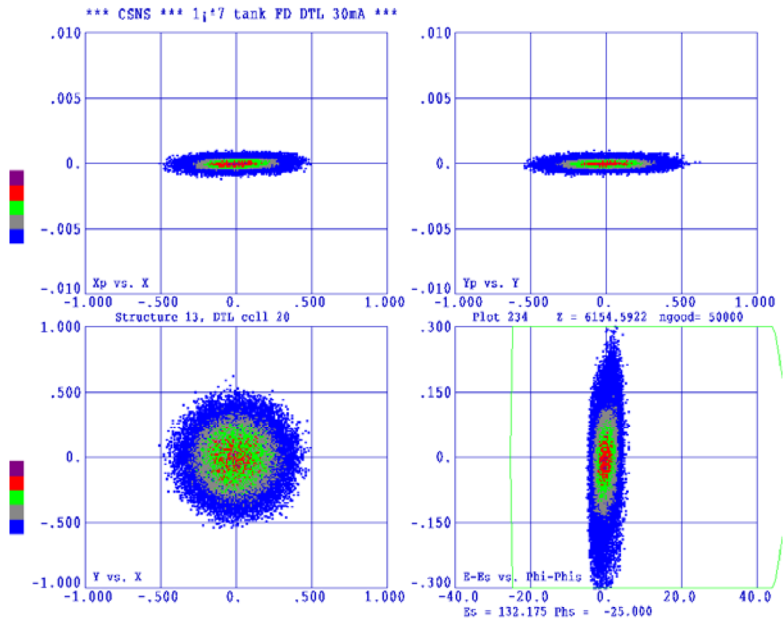
2. Physics Design---DTL

Beam simulation

- PARMILA, 50000, Gaussian distribution ,30mA
- 3D PICNIC, 15×15 meshes, mesh size 0.2cm
- $\varepsilon_x = \varepsilon_y = 0.26\,\mathrm{mm\,mrad(norm,RMS)} \qquad \varepsilon_z = 0.148\,\mathrm{MeV\,deg(RMS)}$

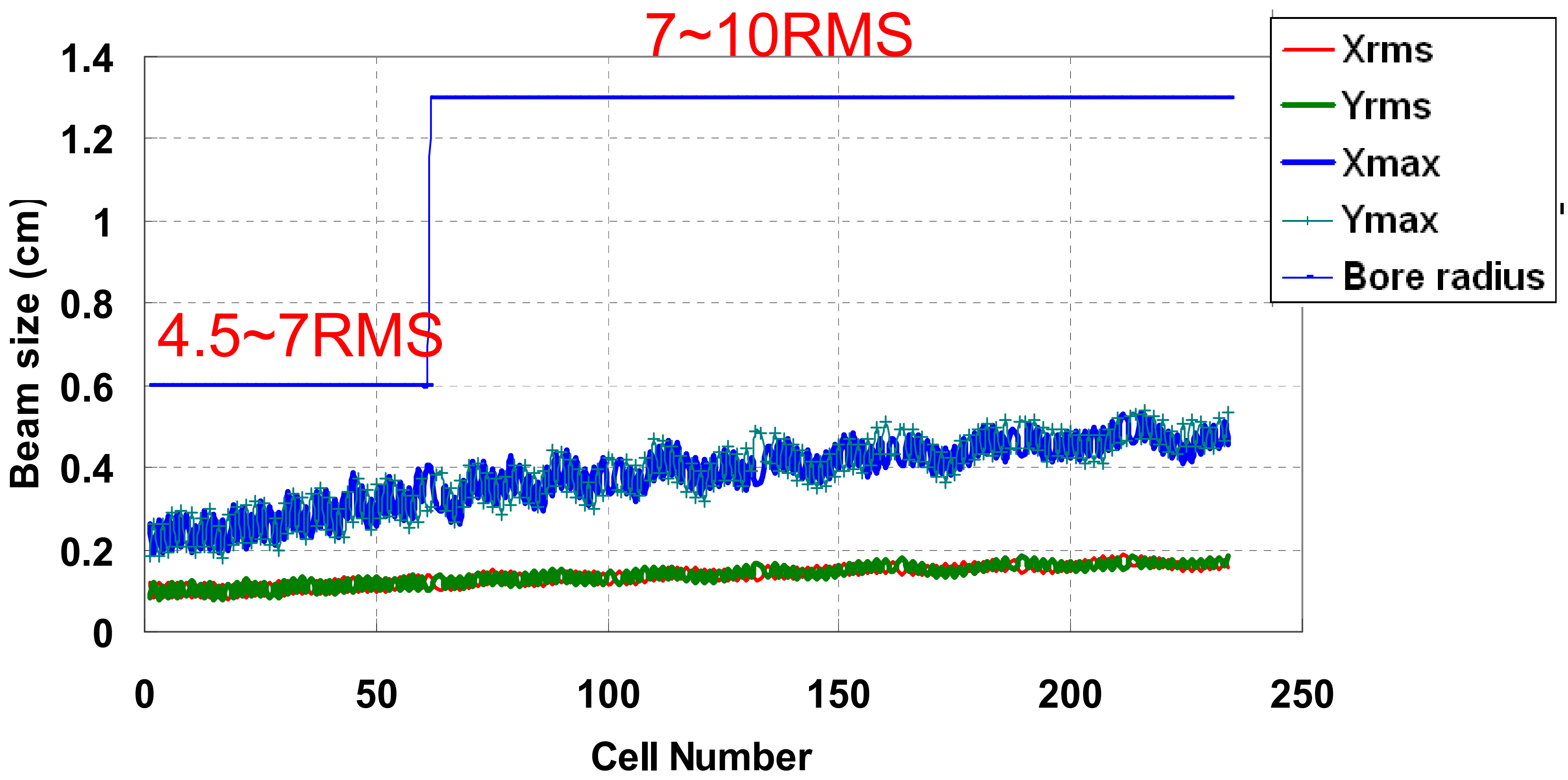


Envelope



Phase-space distribution at the exit of the DTL

2. Physics Design---DTL



RMS and total beam size

2. Physics Design---DTL

Error Simulation

- For the magnets:

  Transverse displacements: $\delta x,y=\pm 0.05$mm

  Rotations : $\varphi x,y,z=\pm 3$mrad

  Field : $\Delta G/G=\pm 1\%$

- For the accelerating field:

  Klystron field: ΔEklys/ Eklys=$\pm 1\%$

  Klystron phase:φklys=± 1deg

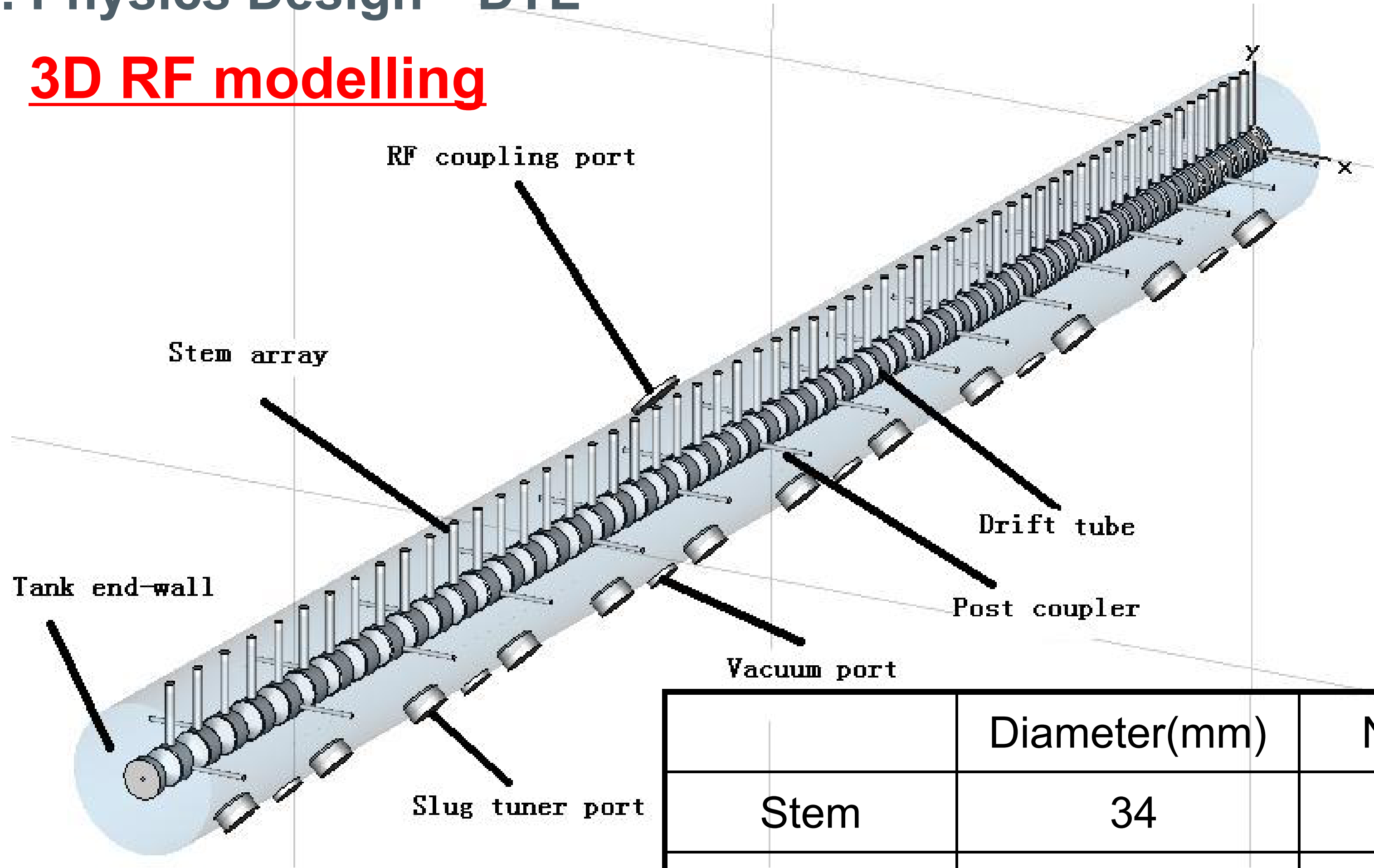
- For the DTL tank:

  Transverse displacements: $\delta x,y=\pm 0.1$mm (contain magnet error)

  Longitudinal displacements: $\delta z=\pm 0.1$mm

2. Physics Design---DTL

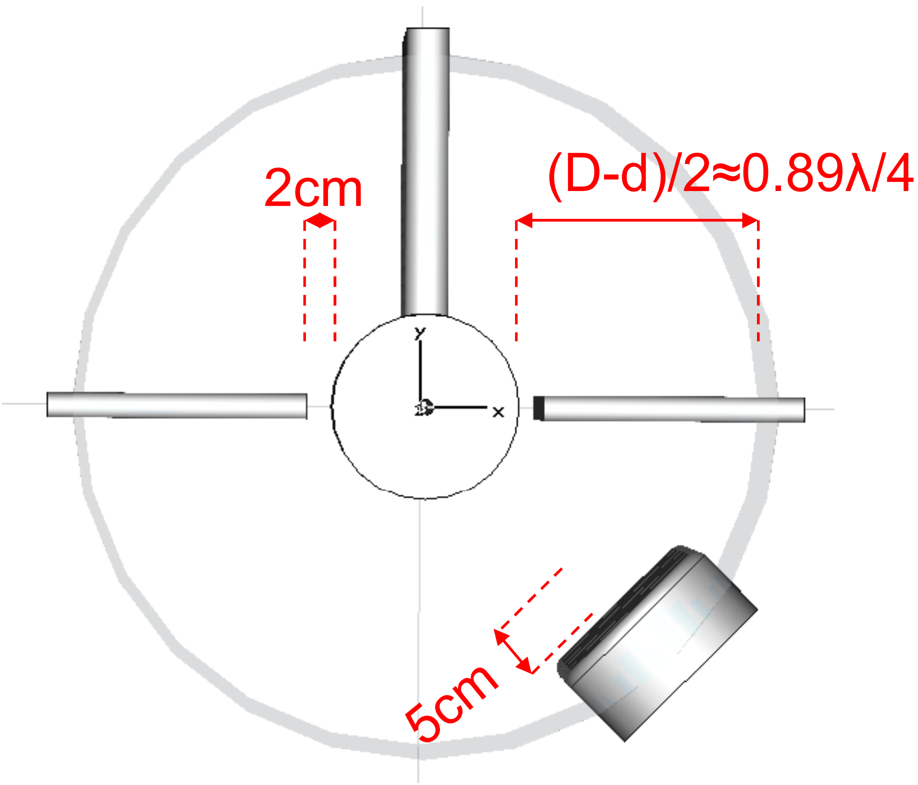
3D RF modelling



	Diameter(mm)	Number
Stem	34	60
Post coupler	20	30
Slug tuner	150	12
Vacuum port	120	

2. Physics Design---DTL

3D RF modelling



Post coupler, stem and slug tuner

- Frequency shifts include:

  stem and post couplers +1.5MHz

  half of tuner range +1MHz

- Adjusted the tank diameter

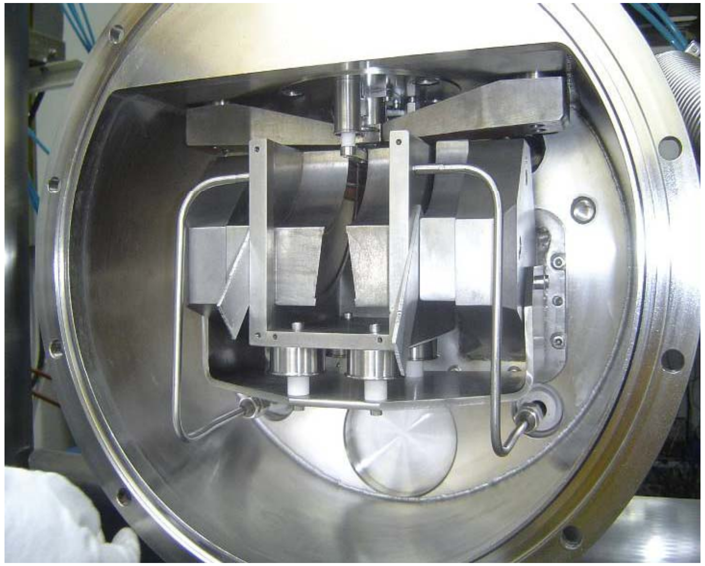
  D=56cm to D=56.627cm

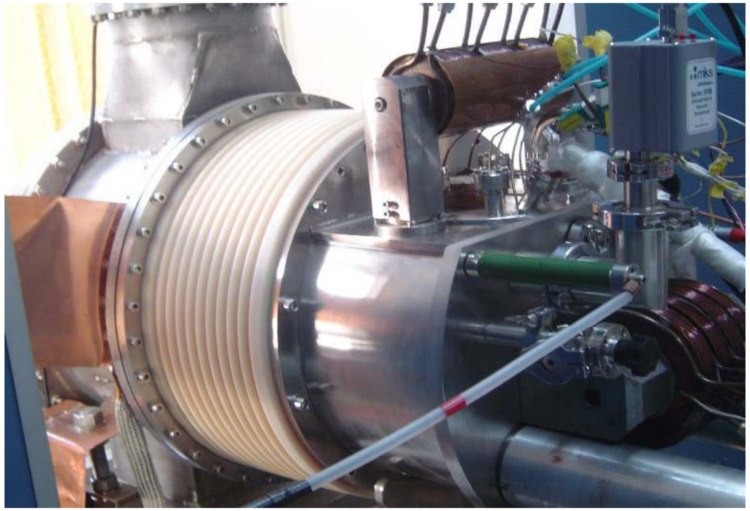
3, Technique Design

3, Technique Design--- Front End

Ion source

- Main body of ion source
  - Discharging chamber
  - Extractor
  - Flange for discharge chamber
  - Chamber for source body
  - Cold box and its support
  - Sector and Penning magnet
  - Accelerating insulation ring
  - Beam diagnostic chamber
  - Accelerating electrode
  - Protecting electrode

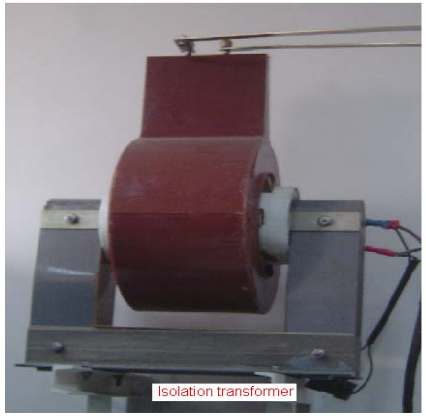




3, Technique Design--- Front End

Ion source

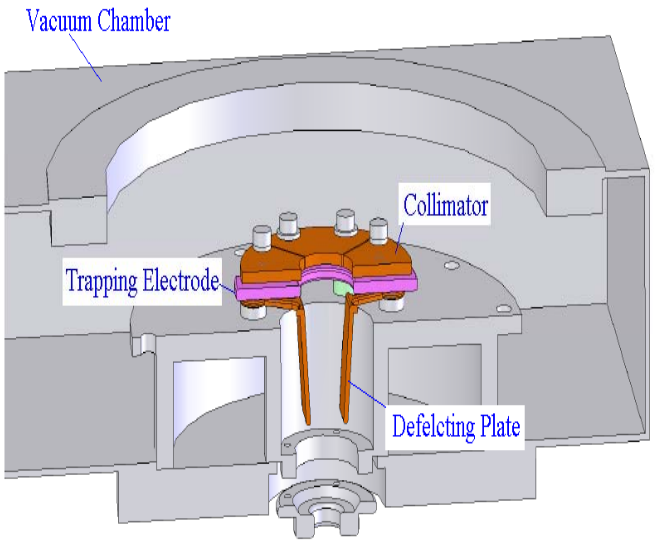
- **Power supply system**
  - **ARC power**
  - **Extracting power**
  - **Accelerating power**
  - **Gas valve power**
  - **Sector magnet power**
  - **Penning magnet power**
  - **Cs boiler power**
  - **Cs transport power**
  - **Isolating transformer**

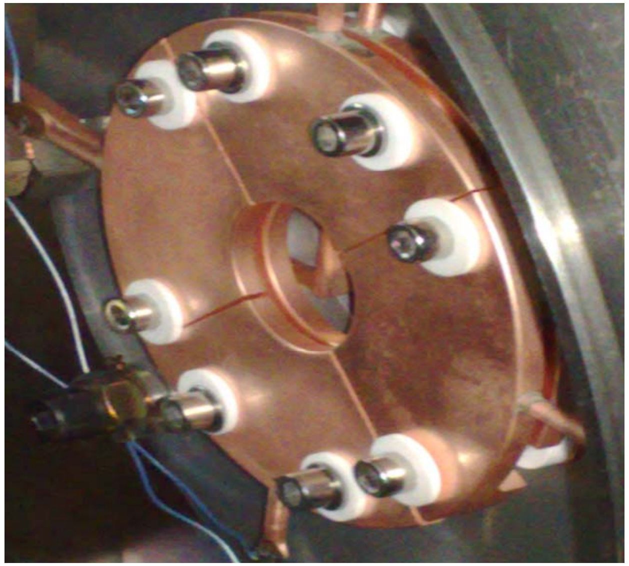


3, Technique Design--- Front End

LEBT

- **The plate length: 50mm**
- **The gap between plates: 20.16 ~33.84 mm (1.2*beam envelope)**
- **The width:25.2-42.3mm (1.5*beam envelope)**



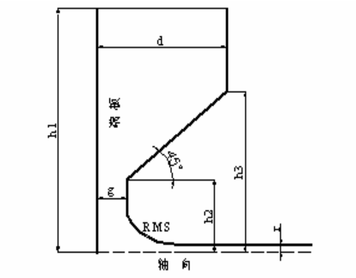


The deflector, the collimator and the electron-trapping electrode installed in the third chamber

3, Technique Design--- Front End

RFQ

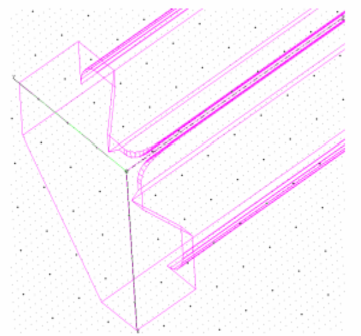
Shape and size of the beginning cell and the exit cell



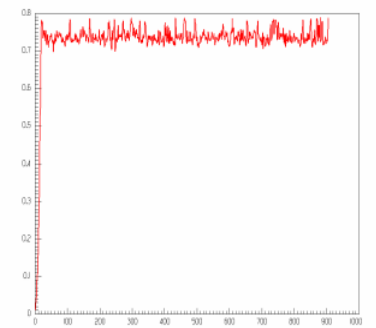
The two-dimensional schematic of the beginning cell

The geometric parameter value of the beginning cell

Parameters	Value
h1	104.238 mm
h2	27.500 mm
h3	59.745 mm
d	41.900 mm
r	3.173 mm
g	8.005 mm

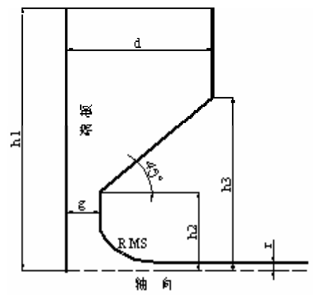


The 3-dimensional figure of the beginning cell from HFSS



The distribution of the amplitude of E along the longitudinal directionc

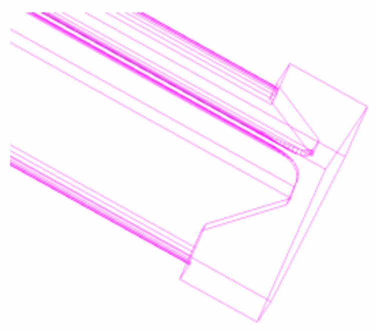
The beginning cell



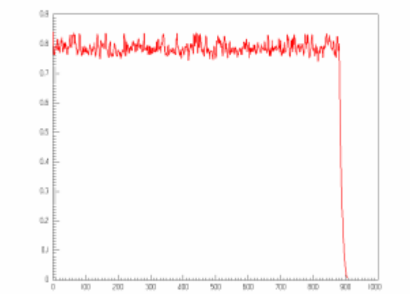
The two-dimensional schematic of the exit cell

The geometric parameter value of the exit cell

Parameters	Value
h1	104.238 mm
h2	27.500 mm
h3	63.730 mm
d	45.500 mm
r	3.173 mm
g	8.970 mm



The 3-dimensional figure of the exit cell from HFSS

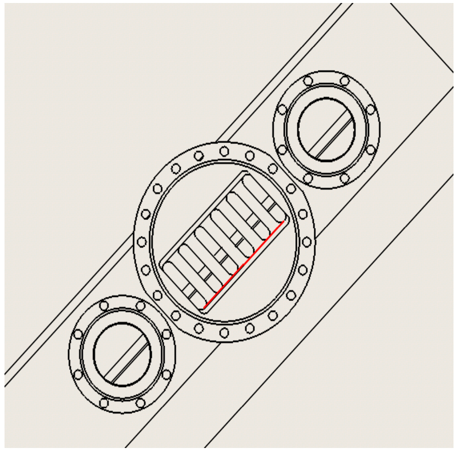


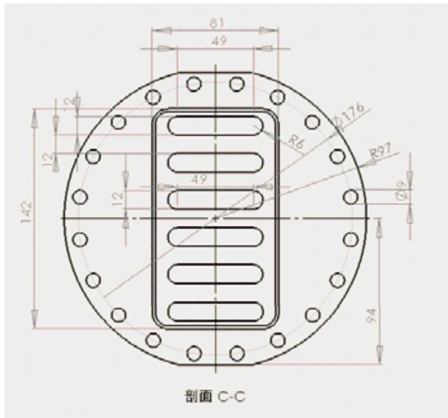
The distribution of the amplitude of E along the longitudinal direction at x,y=3.565 mm

The exit cell

3, Technique Design--- Front End

RFQ



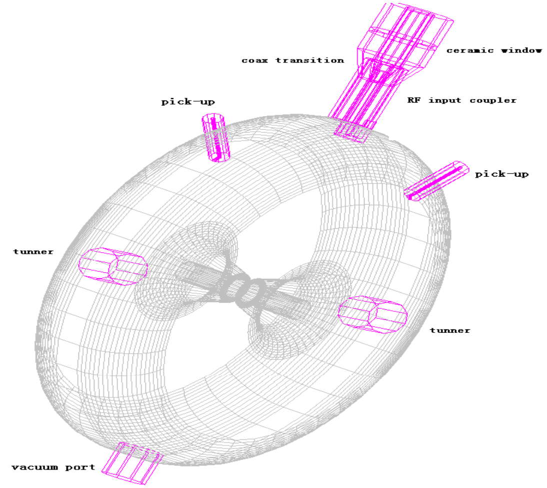


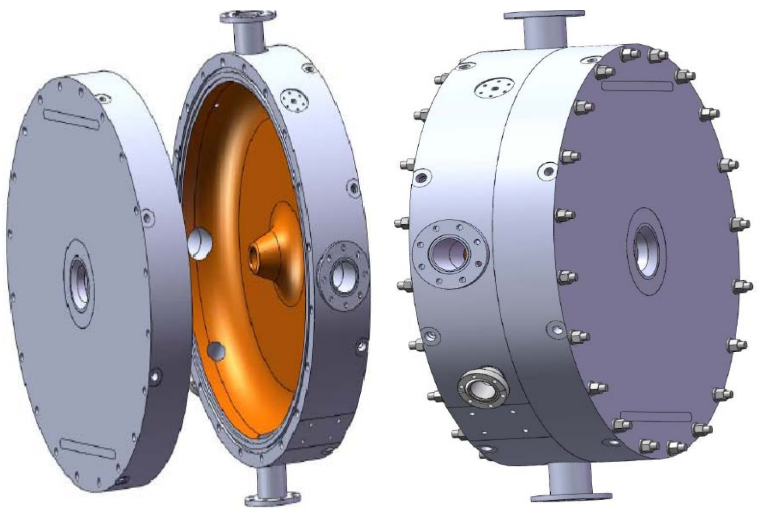
3, Technique Design--- Front End

MEBT

- The buncher is a copper-plated stainless cavity and the structure of two bunchers is completely same.

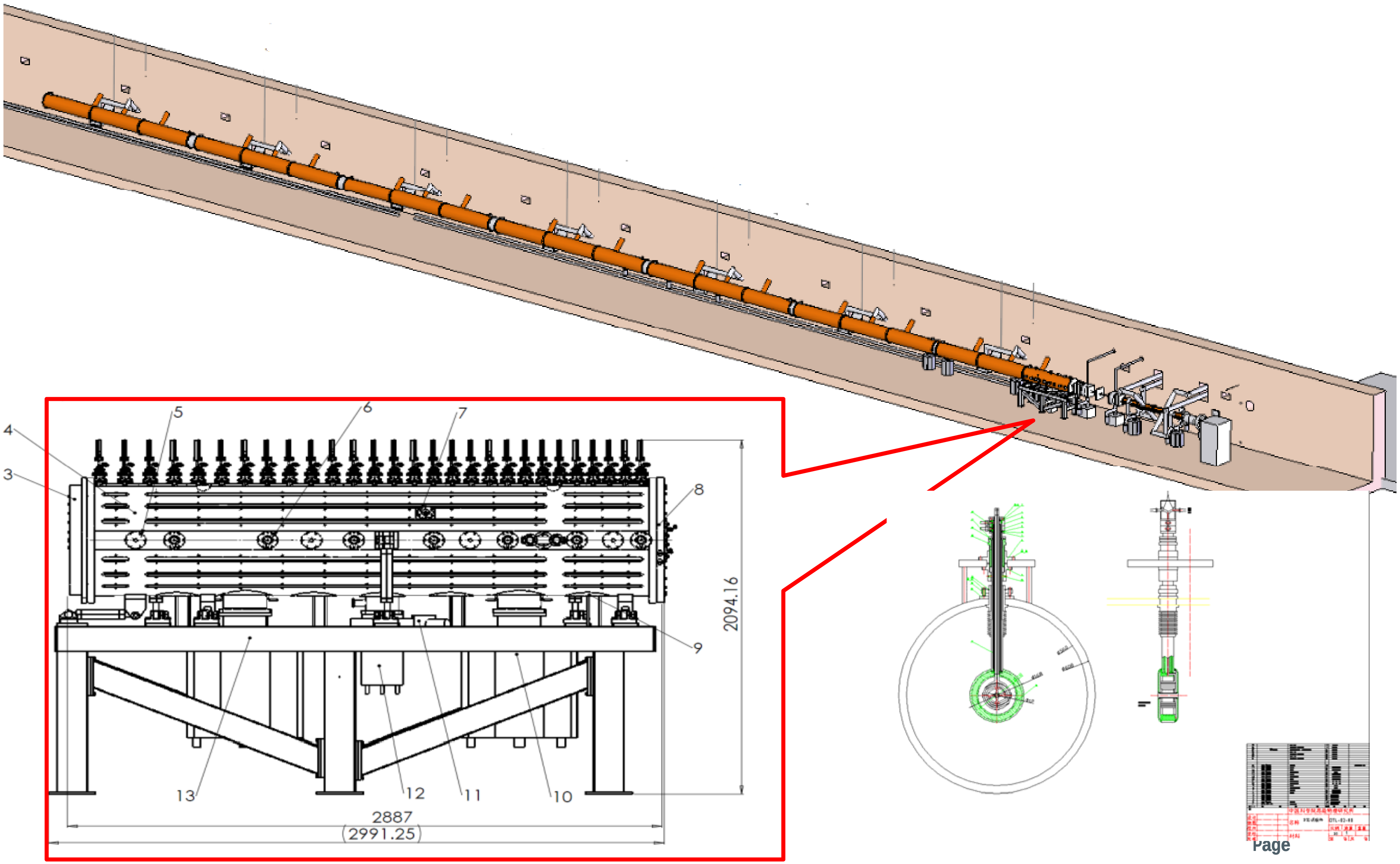
- There needs for both bunchers :
  - Two water-cooled tuners
  - One power coupler
  - Two phase pick-ups.
  - A vacuum port
  - Water cooling channels





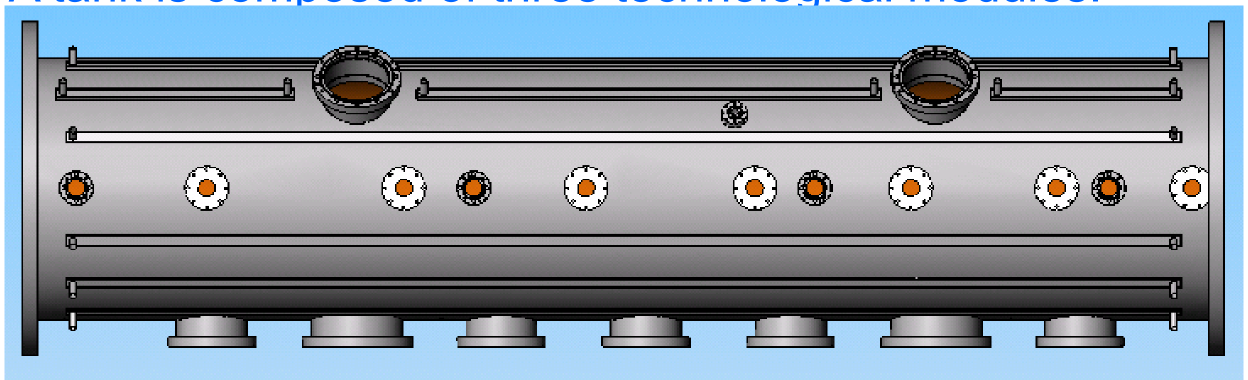
The mechanic drawing of the buncher

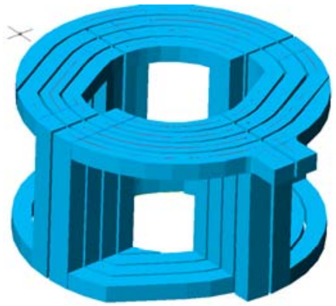
3, Technique Design--- DTL

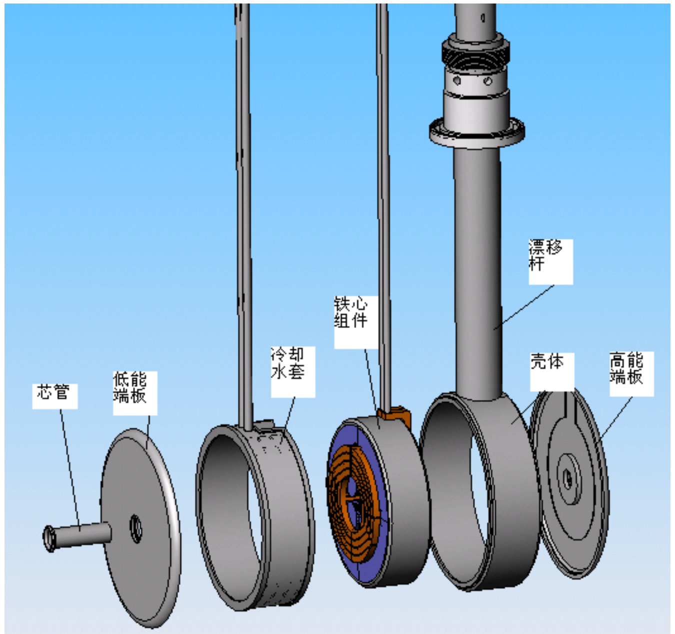


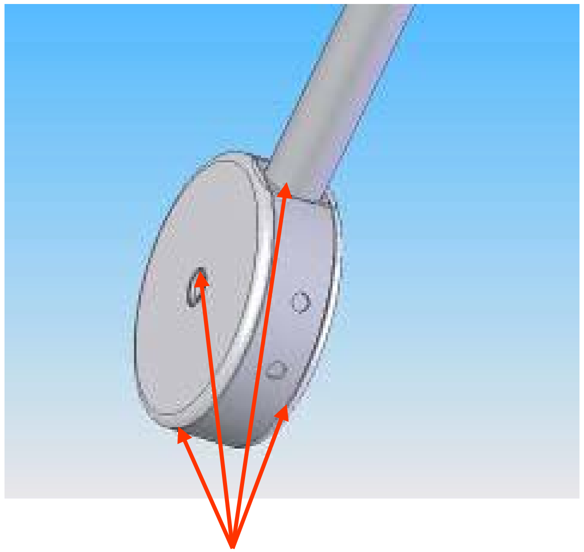
Design

A tank is composed of three technological modules.

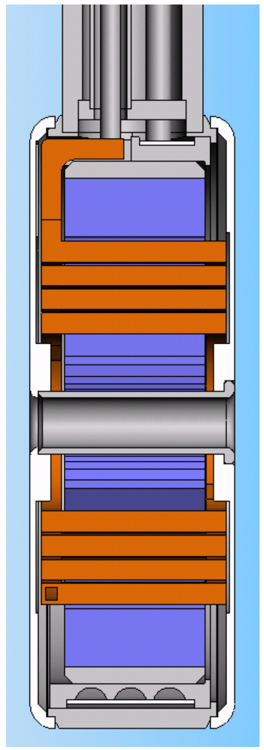








EBW



3, Technique Design--- DTL

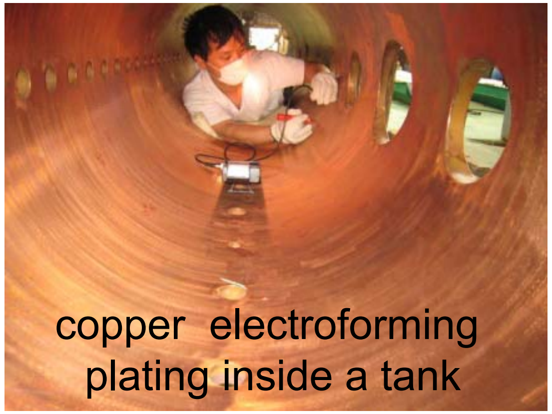
DTL tank

The tank body was made of carbon steel with a copper inner surface using the Periodic Reverse (PR) electroforming technology.

2007.6

2007.12

2008.4



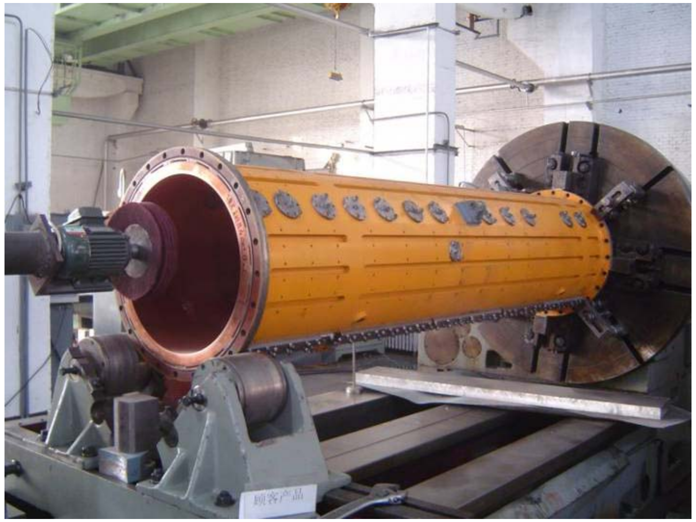
2008.6

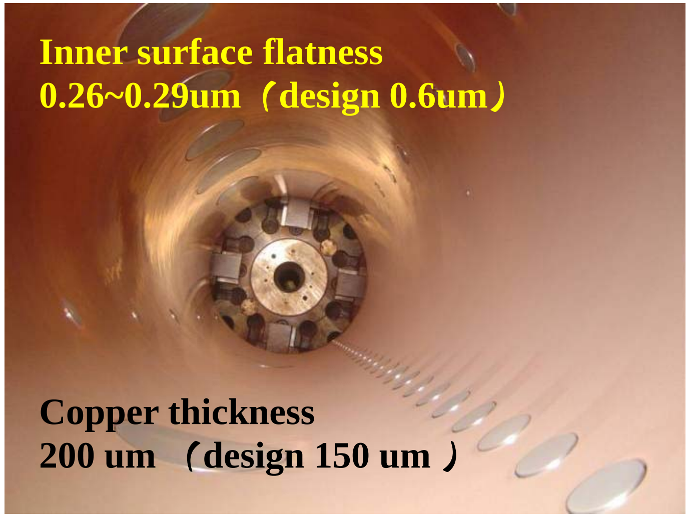
2008.9

2009.5

3, Technique Design--- DTL

DTL inner surface polish





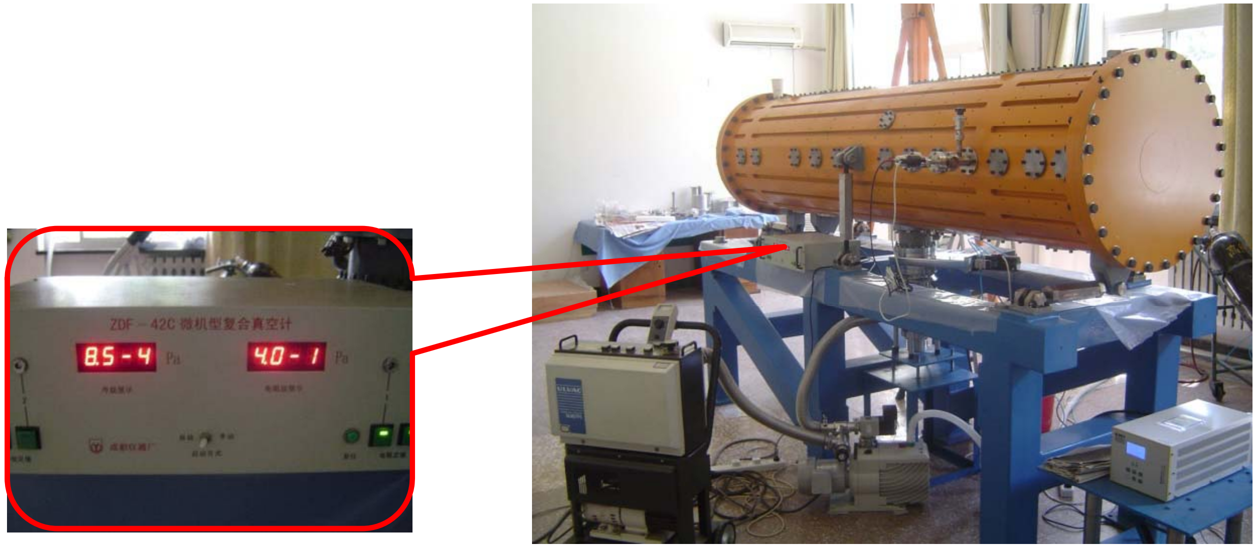
The copper-coated thickness of the inner surface of the tank body is 150 um.

3, Technique Design--- DTL

DTL Tank vacuum test

A pumping system for a test tank comprises two ion pumps (1.5 m^3 /s^{-1} for each) and a turbo molecular pump(0.6 m^3 /s^{-1}).

The vacuum test of the first unit tank was carried out in last May. The vacuum reached 8.5 $\times 10^{-4}$Pa only using a turbo molecular pump(0.6 m^3 /s^{-1}).

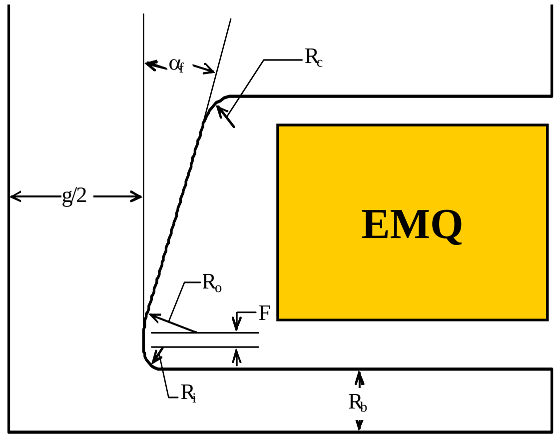


3, Technique Design--- DTL

Drift tubes with EMQ

In CSNS DTL,

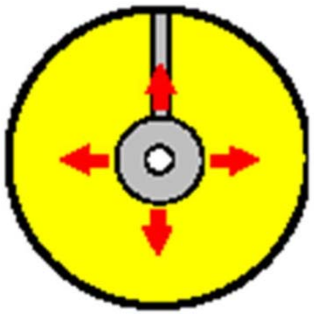
-The drift tube is made of Oxygen Free Copper (OFC) ;
-Magnet gradient = 75 T/m ;
- Electron Beam Welding ;
-The EMQ work in DC mode.



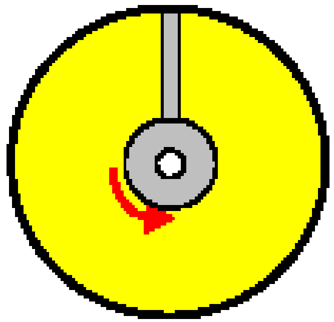
Tank number	1	2	3	4
Face angle (degree)	0-30	35-50	50-60	60
Inner radius (cm)	0.2-0.3	0.3	0.3	0.3
Outer radius Ro (cm)	0.2-1	1	1	1
Corner radius Rc (cm)	0.6	0.6	0.6	0.6
Diameter of drift tube (cm)	14.8	14.8	14	14
Flat length (cm)	0-0.5	0.5	0.5	0.5

3, Technique Design--- DTL

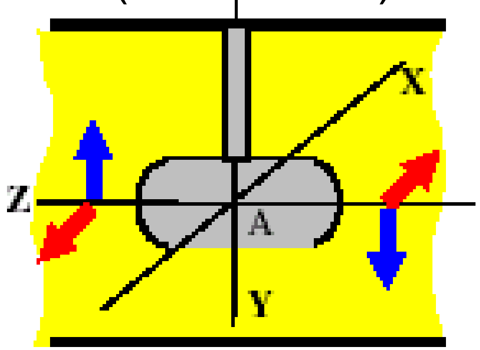
DTL alignment accuracy



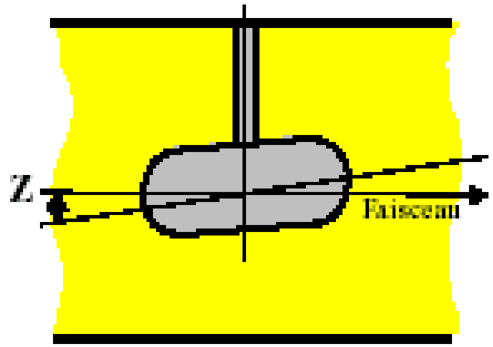
(± 0.05mm)



(3mrad)



(3mrad)



(3mrad)

DTL tanks:

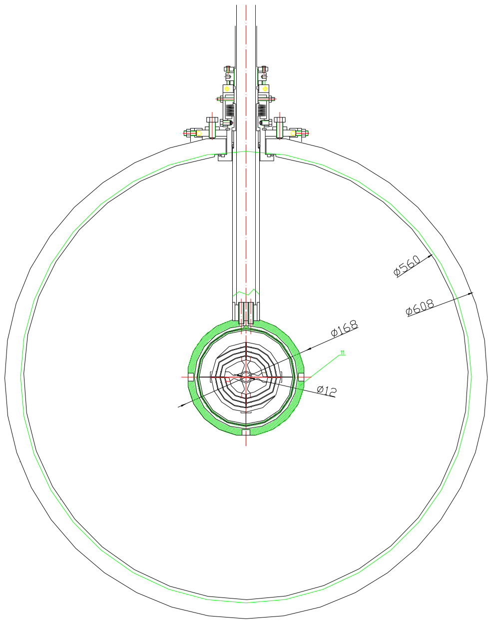
x (Horizontal), y (Vertical): < 0.1 mm (include DT error)

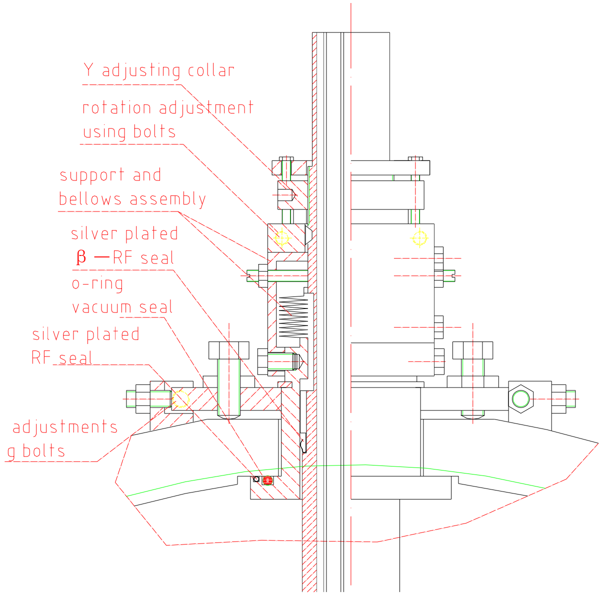
z (Longitudinal): < 0.1 mm

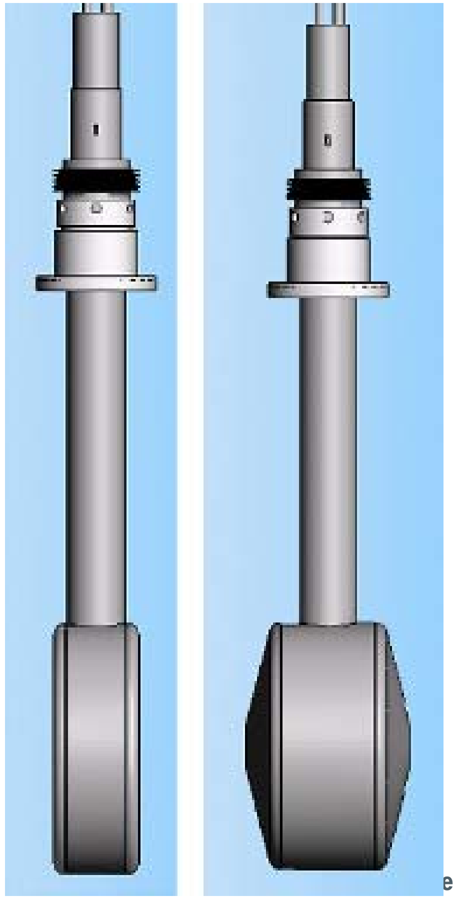
3, Technique Design--- DTL

Mechanical Design

DTL tank and drift tube adjustment design



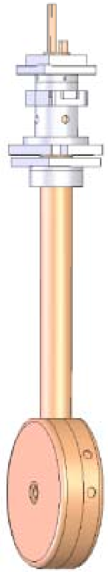


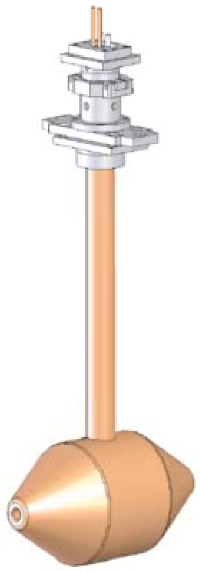


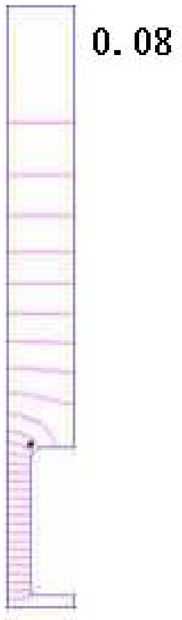
Drift tube assembly alignment and adjustment have been designed..

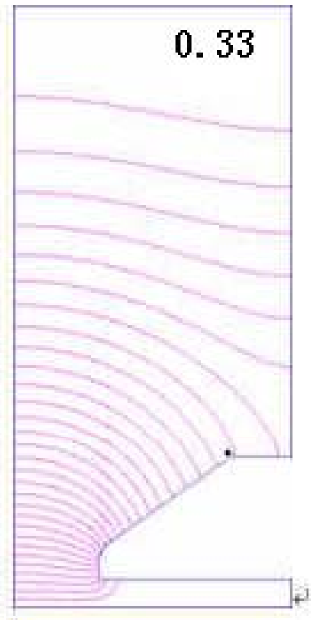
3, Technique Design--- DTL

Drift tubes



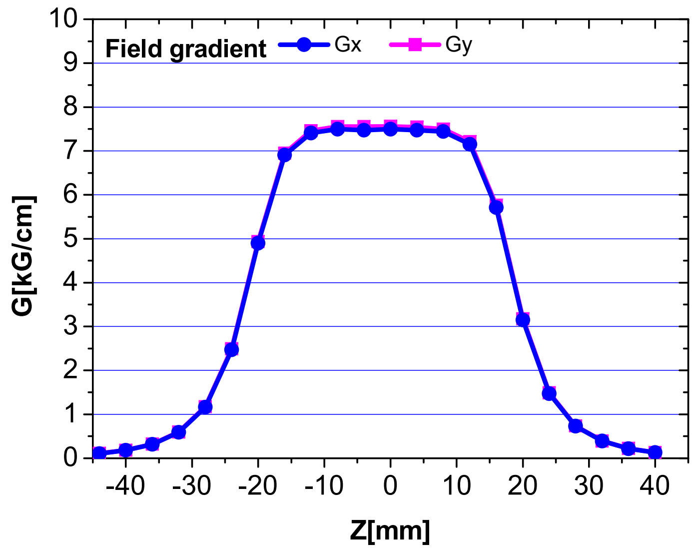


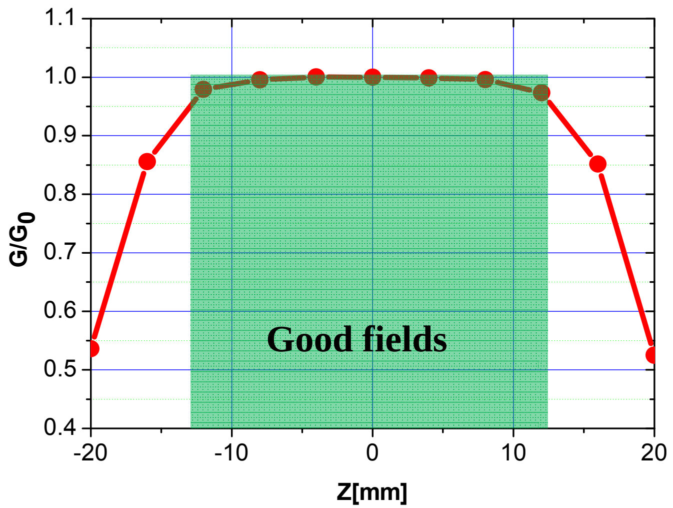




3, Technique Design--- DTL

Hall probe measurement





The measured effective field length：

x = 42.85[mm], y = 42.83 [mm].

L = (y + x)/2 = 42.84[mm](design 41.3)

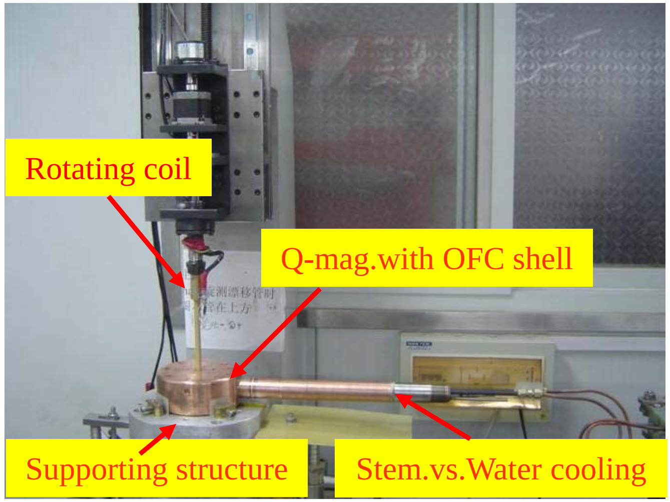
The good fields length(decrease 5%)：

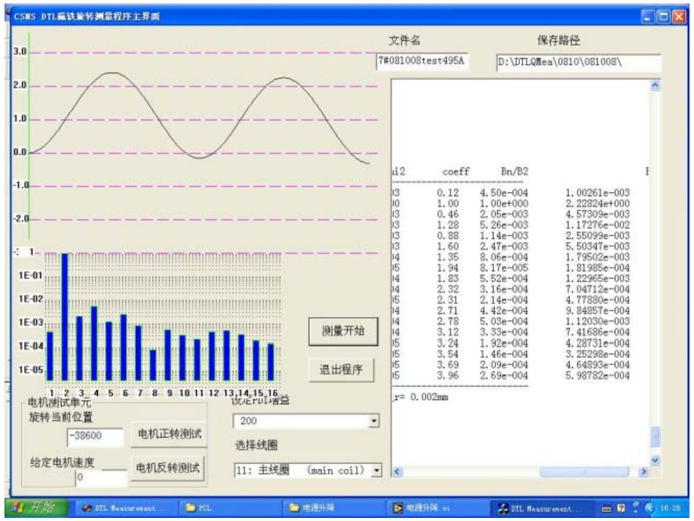
x = 28.52[mm], y = 29.39[mm] .

D = 28.96[mm]

3, Technique Design--- DTL

Rotating coil measurement





The magnetic field of the Q-magnet has been measured by a rotating coil.

Table 5: The measured higher-order components of EMQ

Harmonics. No.	Bn.L	Bn/B2
1	4.22587e-003	1.24e-003
2	3.41761e+000	1.00e+000
3	1.05112e-003	3.08e-004
4	1.36139e-002	3.98e-003
5	3.70343e-003	1.08e-003
6	3.79230e-003	1.11e-004
7	1.89259e-003	5.54e-004
8	1.16850e-003	3.42e-004
9	6.89847e-004	2.02e-004
10	5.73321e-004	1.68e-004
11	8.51207e-004	2.49e-004

3, Technique Design--- DTL

Rotating coil measurement

The higher order multipole components in the magnetic field center measured also by the rotating coil were sufficiently small, being less than 0.3% in comparison with the quadrupole component.

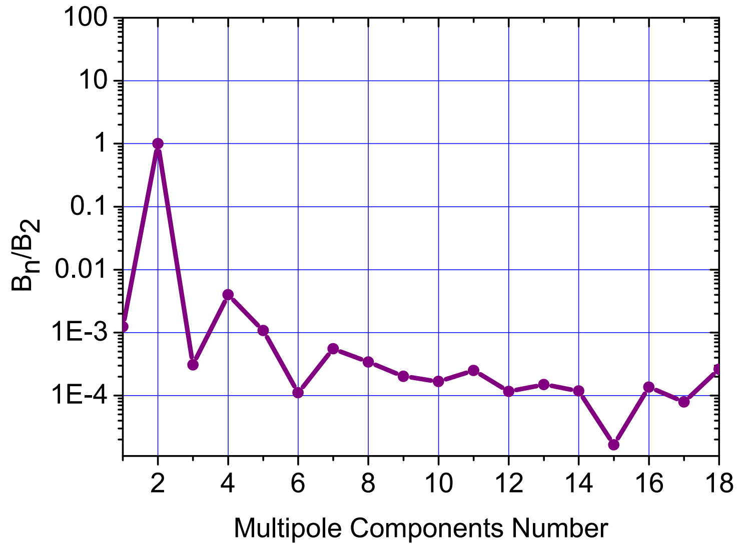


Figure 7: The multipole components in the center of the magnetic field and the prototype of drift tube

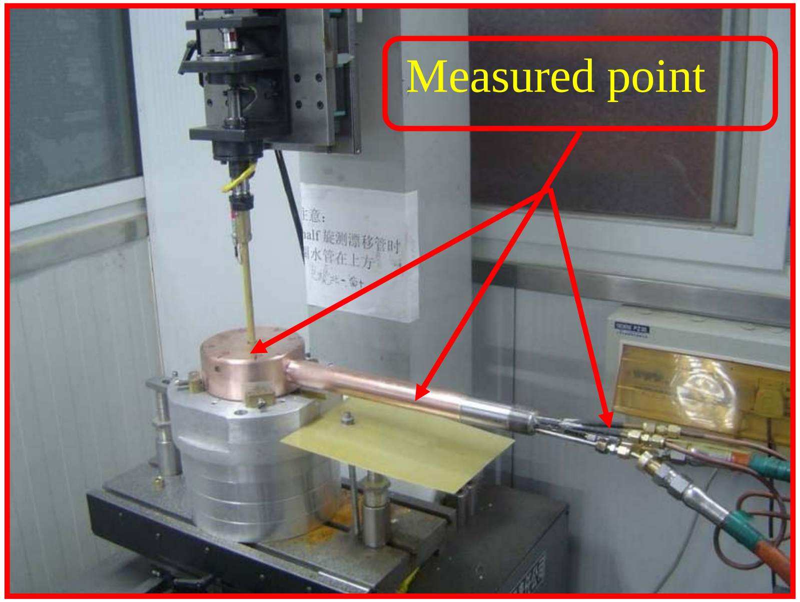
3, Technique Design--- DTL

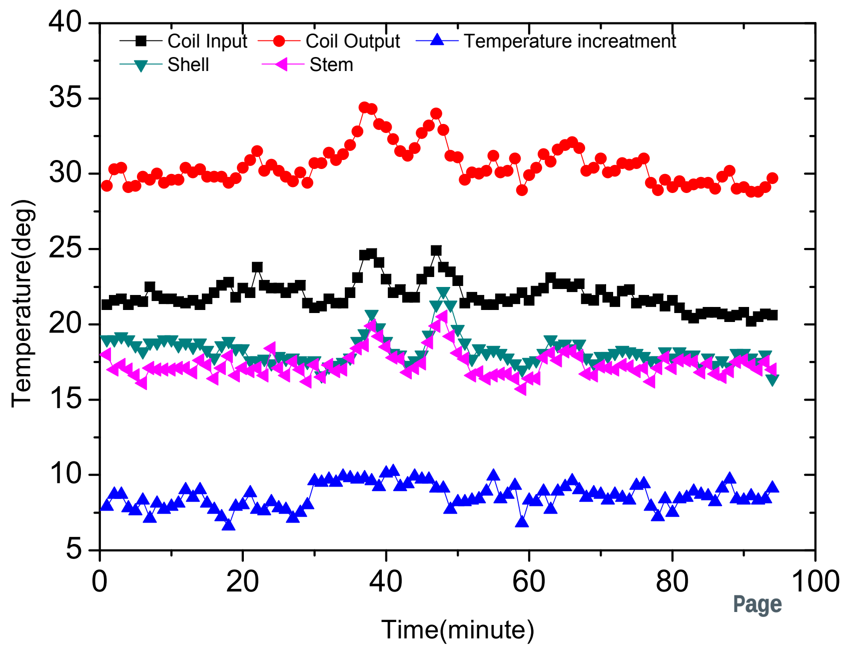
Cooling water experiment

-Environment temperature 21℃.
-Experiment duration48h.
-Working current DC495A.

Table 7: The temperature rise

	Temperature(℃)
Cooling water	16.2
Coil	24.8
Tube shell	22.2
Stem	20.5





3, Technique Design--- DTL

RF Coupler

Table10:Coupler Performance Requirements

Frequency	324 MHz
Peak Power	2.0 MW
Pulse Width	0.6 ms
Repetition Rate	25 Hz
Max. duty factor	1.5%
Average power transmitted	30kW

Two types of couplers:

a、coaxial type **b、waveguide type**

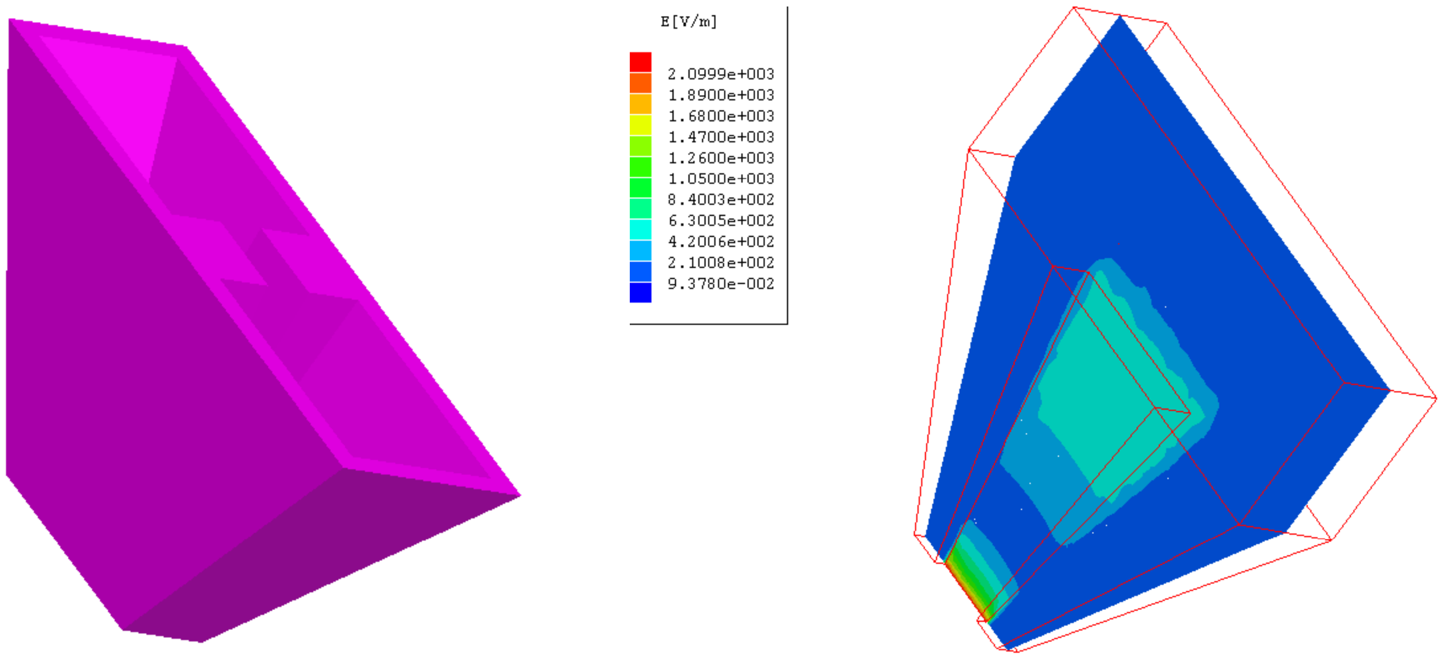
3, Technique Design--- DTL

Waveguide type(SNS,CSNS)

- **Only one coupler for each tank.**
- **Ridged-loaded tapered waveguides**

The design of RLWG is based on experience from the LEDA RFQ and SNS power couplers .

- **Successful application in LEDA,SNS, etc.**
- **Difficult to tune coupling factor in operation.**



Ridge loaded Iris waveguide provides RF power coupling.

3, Technique Design--- DTL

DTL vacuum system

The vacuum requirements:

-The static vacuum is 1×10^{-6}Pa

-The dynamic vacuum is 1×10^{-5}Pa

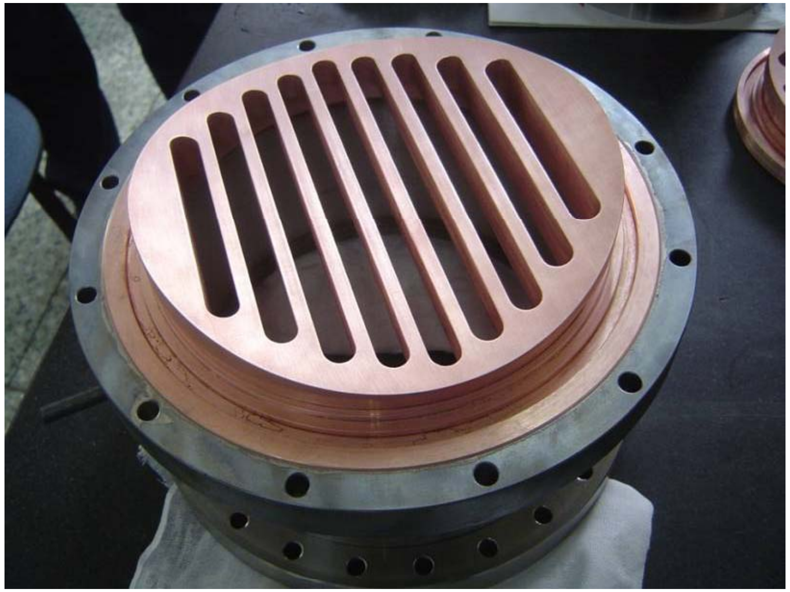
-24 ion pumps (1.5 m^3/s^{-1} for each) and 12 turbo molecular pump(0.6 m^3/s^{-1}).

-The outgassing characteristic of the electroformed lining was measured for the samples at room temperature. The conductance modulation method was applied. The measured outgassing rate was about 4.03×10^{-7} Pa·m³/s·m² for 100 hours pumping.

-For a test tank (process chamber), the total outgassing is 2.227×10^{-6}Pa•m³/s.

-All vacuum pumps will be attached to the bottom of the DTL tanks through ports provided with RF shields. The pressure of the system is estimated as 1×10^{-6}Pa.

Vacuum grill



4， Summary

- CSNS linac consists of an H- ion source, LEBT, 3MeV RFQ, MEBT and 80MeV DTL. It will upgraded up to 250MeV for 500kW CSNS.
- RF frequency is 324MHz.
- RFQ is four-vane type which requires a low dipole field and a flat quadrupole field pattern.
- DTL is designed with ramped field and synchronous phase.

Thank you very much
for your attention