Design and Construction Progress of a 7 MeV/u Cyclotron

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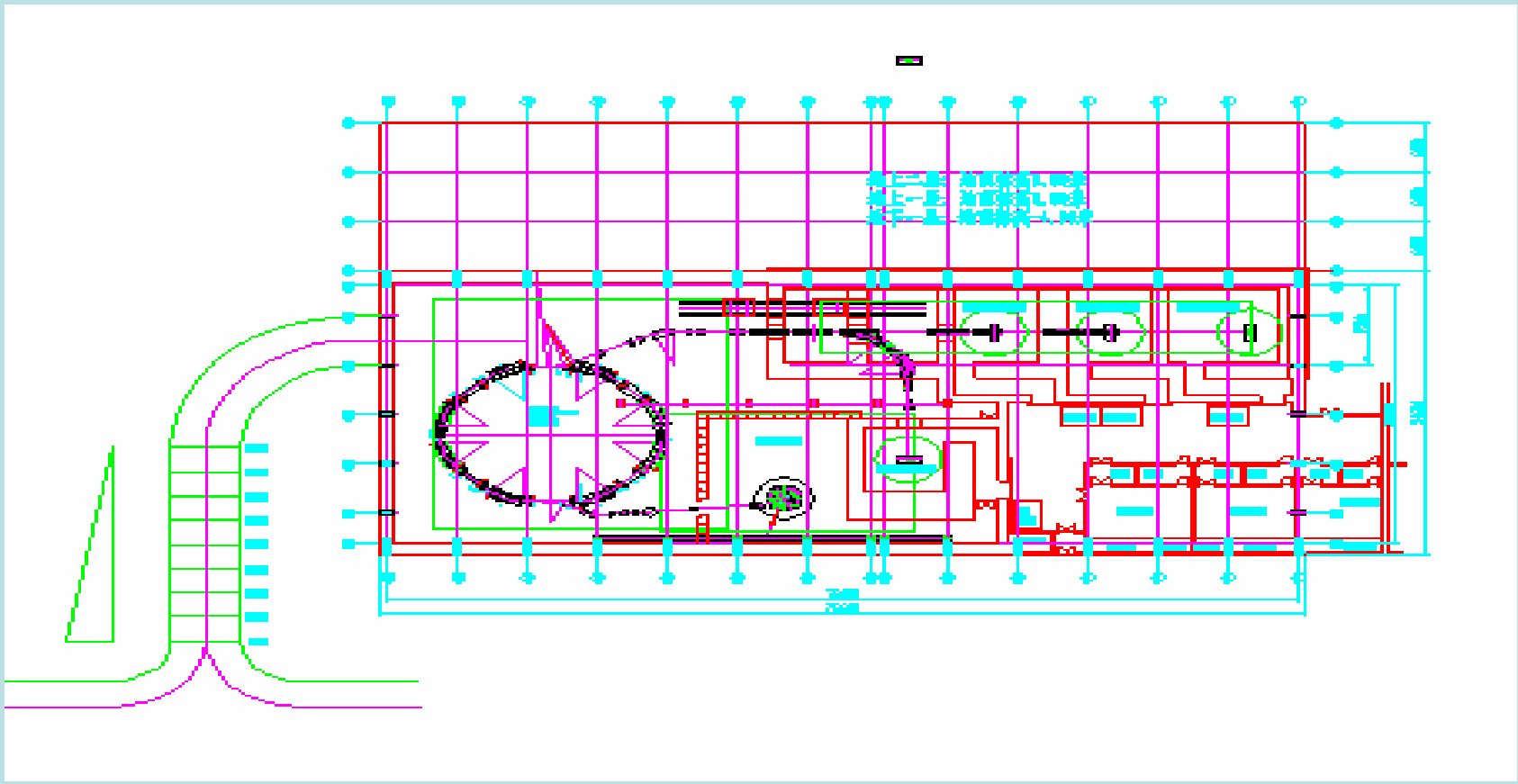
Outline

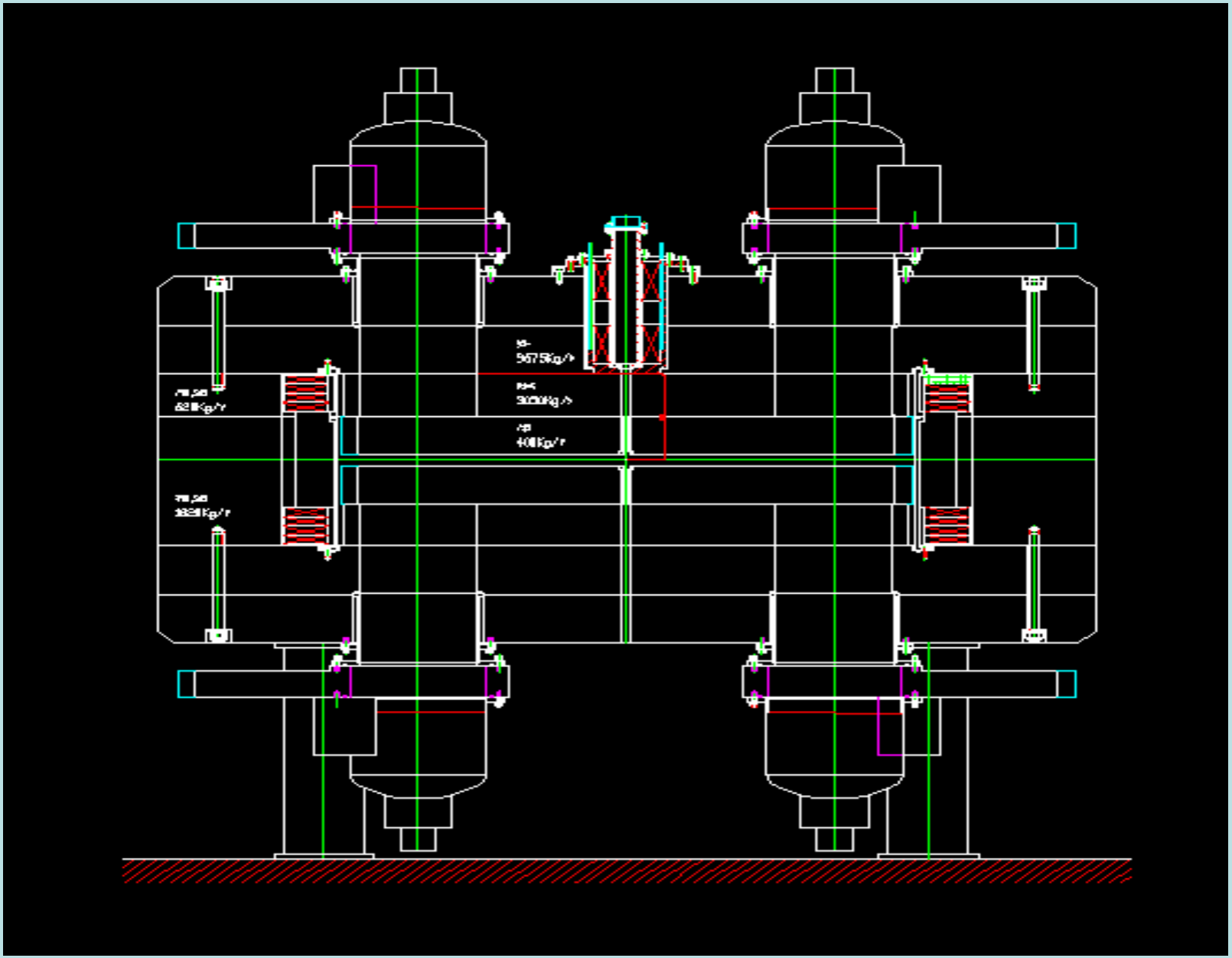
- Introduction
- Concept design
  - Magnet
  - rf system
  - ECR ion source and axial injection line
  - The central region
  - The extraction system
  - Transmission efficiency
  - Vaccum system
- Construction Progress
- Summary

Introduction

- Injector for the HITFiL(Heavy Ions Therapy Facility in LanZhou) synchrotron
- Compact Commercial Cyclotron
- $^{12}C^{5+}$ W_{ex}=7 MeV/u, I_{ex}=10 eμA, ε =20 π mm.mrad, $\Delta W/W \leqslant \pm 1\%$

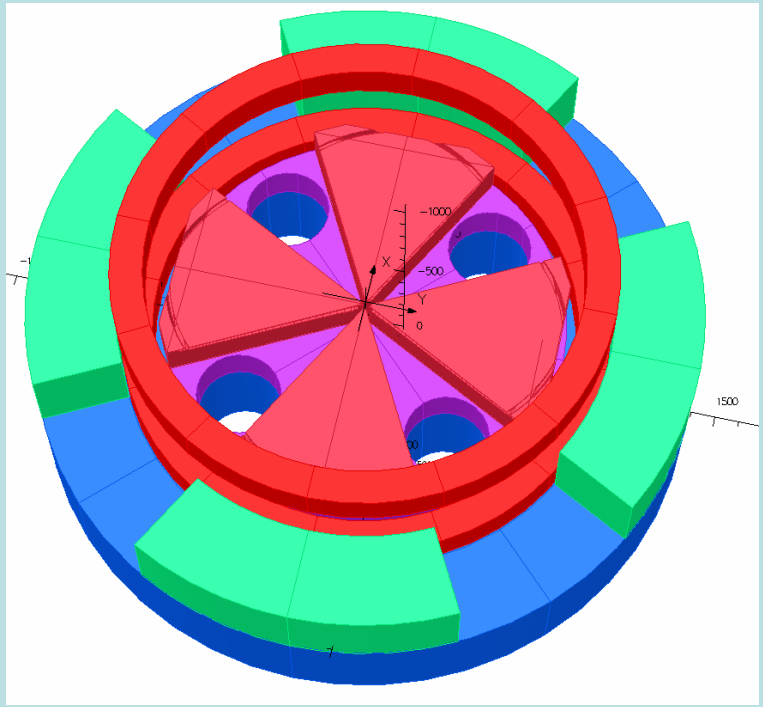


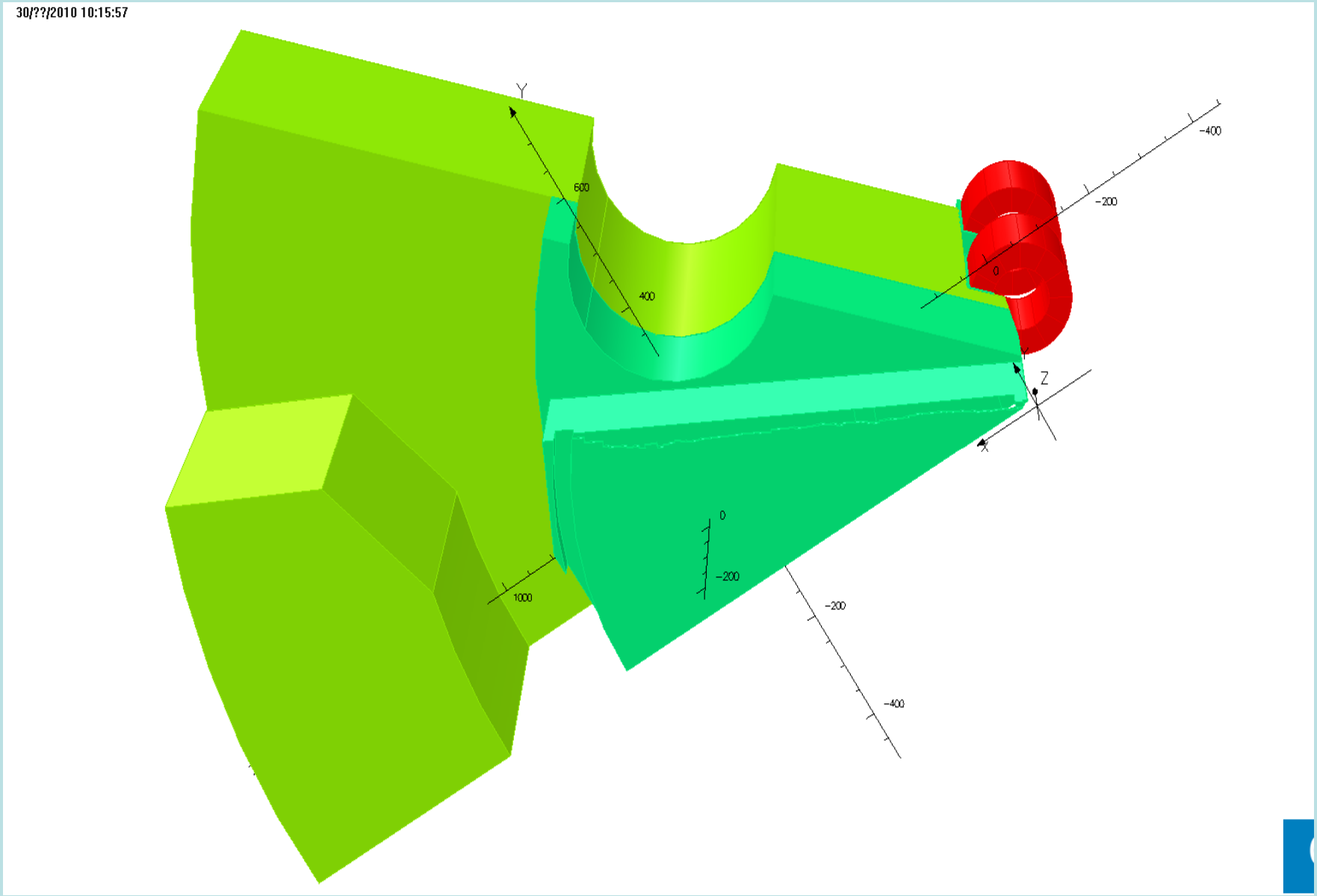
Configuration of the cyclotron

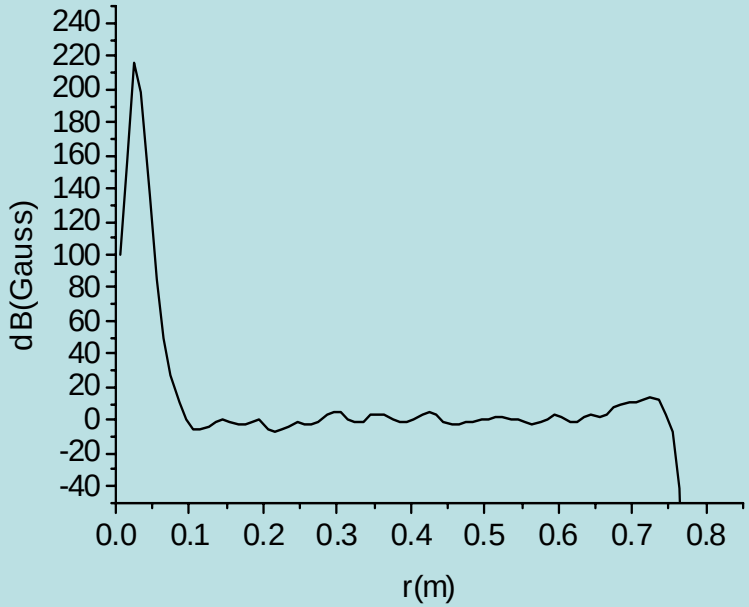


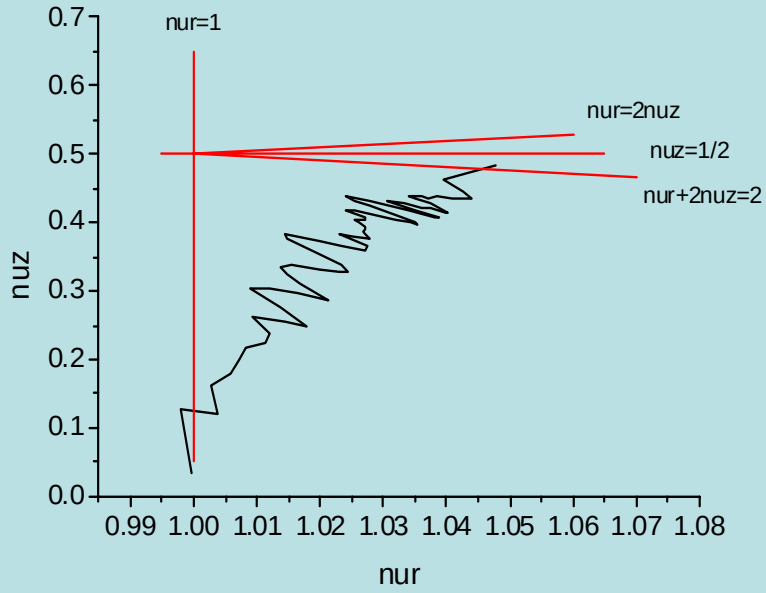
Magnet

Outer Radius of the Magnet	1440mm
Height of the Magnet	1600mm
Radius of the Pole	840mm
Mumber of Sectors	4
Sector Angle	56º
Gap between the Hills	50mm
Gap between the Valleys	360mm
Field in Hills	1.87T
Total Weight of Iron	70 t
Ampere-Turn Number of the Main coils	70 kAT



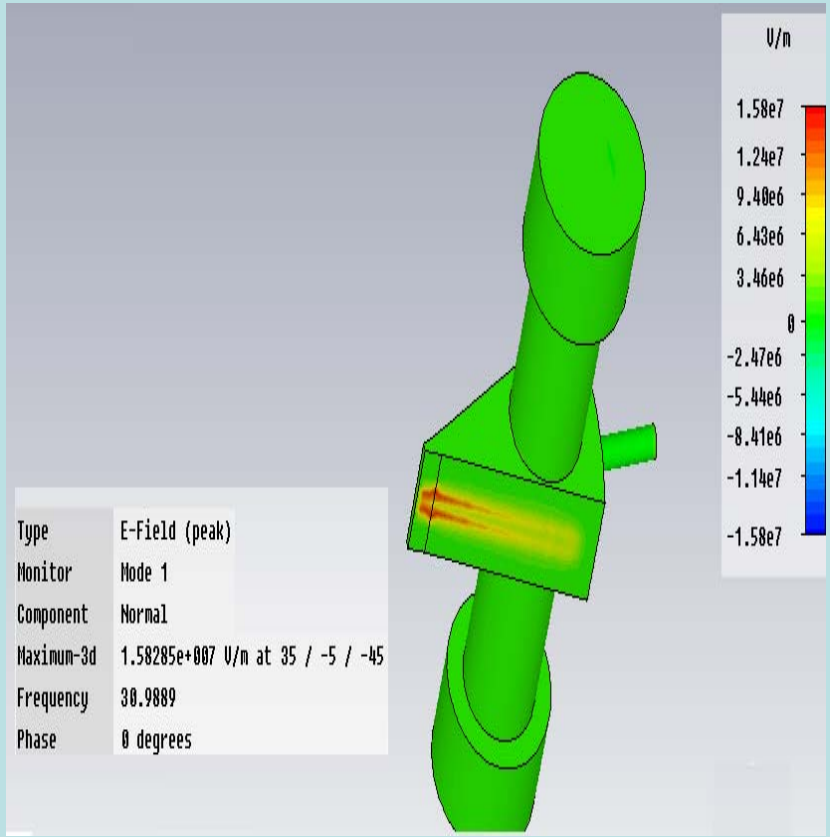

30/??/2010 10:15:57
Y
600
400
-400
-200
0
Z
X
0
-200
1000
-200
-400


dB(Gauss)
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
r(m)


nuz
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.99
1.00
1.01
1.02
1.03
1.04
1.05
1.06
1.07
1.08
nur
nur=1
nur=2nuz
nuz=1/2
nur+2nuz=2

rf system

rf Frequency	31.02MHz
rf Voltage	70 kV
Harmonic Number	4
Number of Dee	2
Angle of Dee	30º
Outer Radius of Dee	770 mm
Number of Cavity	2
Q Value	7800
Dissipated Power per Cavity	18 kW

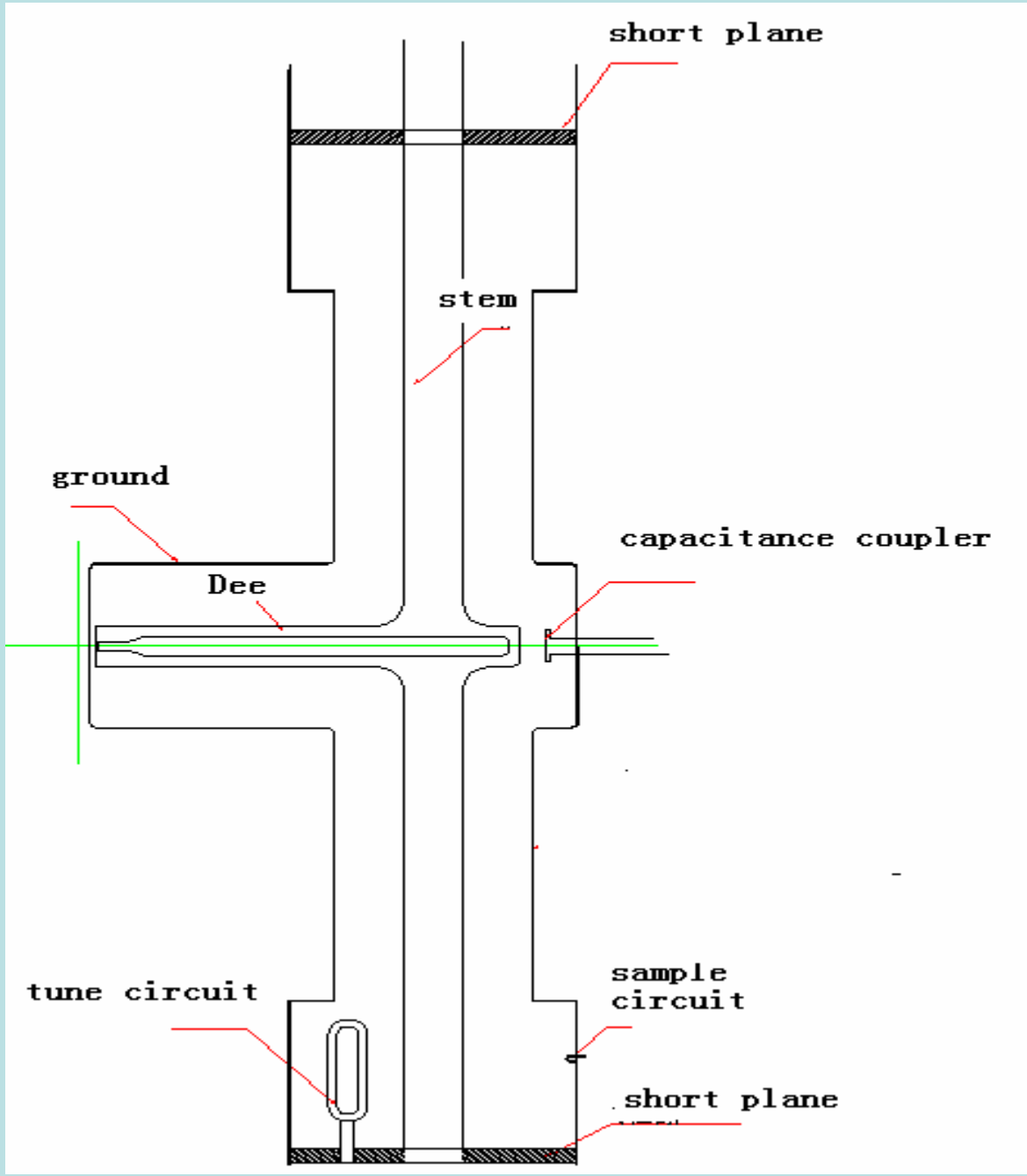


$\Delta V/V \leqslant \pm 5 \times 10^{-4}/24h$,

$\Delta f/f \leqslant \pm 1 \times 10^{-6}/24h$,

$\Delta \quad \phi \leqslant \pm 1^{\circ}$

Tow 50 kW rf amplifers



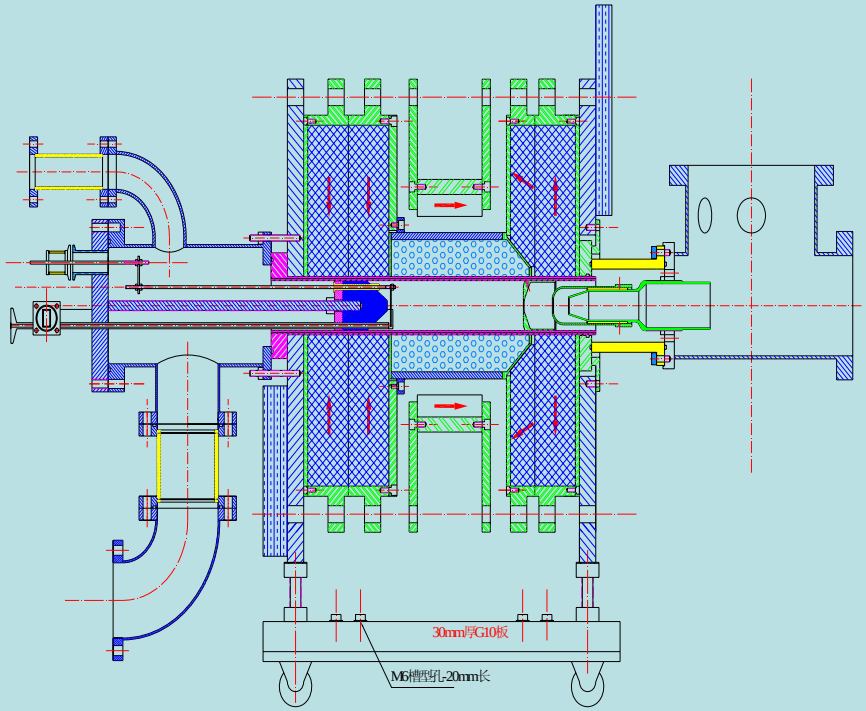
ECR ion source (LAPECR3)

Beam current 200euA

Extraction voltage 22.3 kV

Beam emmitance 120 pi mm mrad

Mw frequency 13.75-14.5 GHz



Main parameters of ECR ion source

	LAPECR3
Axial megnet（T）	2.0-0.40(~0.43)-0.94(~0.91)
Radial magnet B_w（T）	1.14
Width of magnet mirror（mm）	170
Mw frequency（GHz）	13.75-14.5
Plasma charmer diameter(mm)	50-51
Effective charmer（L）	0.33
Rf feed mode	WR62 rectangle wave guide
Charmer cooling	Water cooling
Max. extraction voltage（kV）	25-30
Max. mw power（kW）	0.75
dimension（mm）	Ø450×380
NdFeB weight（kg）	157
Main material	N50M & N42SH

Axial injection line

L=3.446 m,

4 solenoids

1 quadrupole

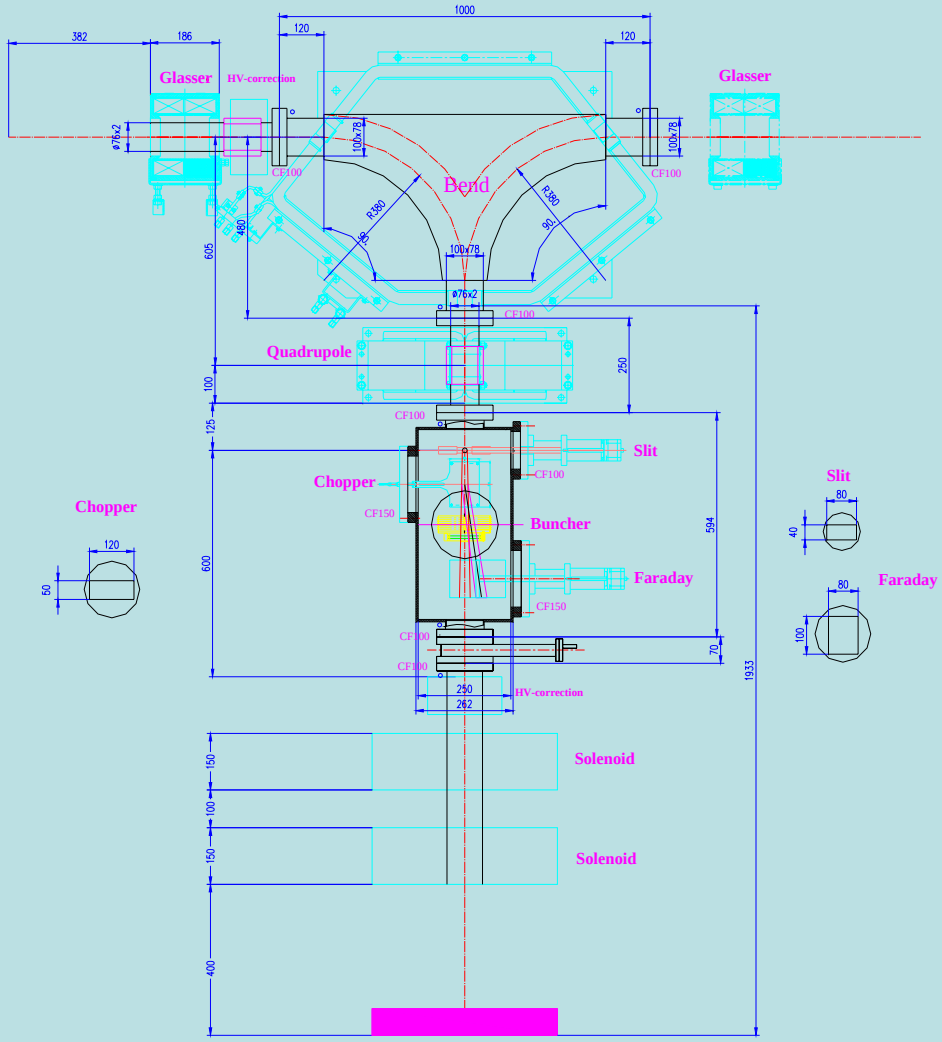
1 double 90ºmagnetic dipole

1 buncher

1 chopper

1 slit

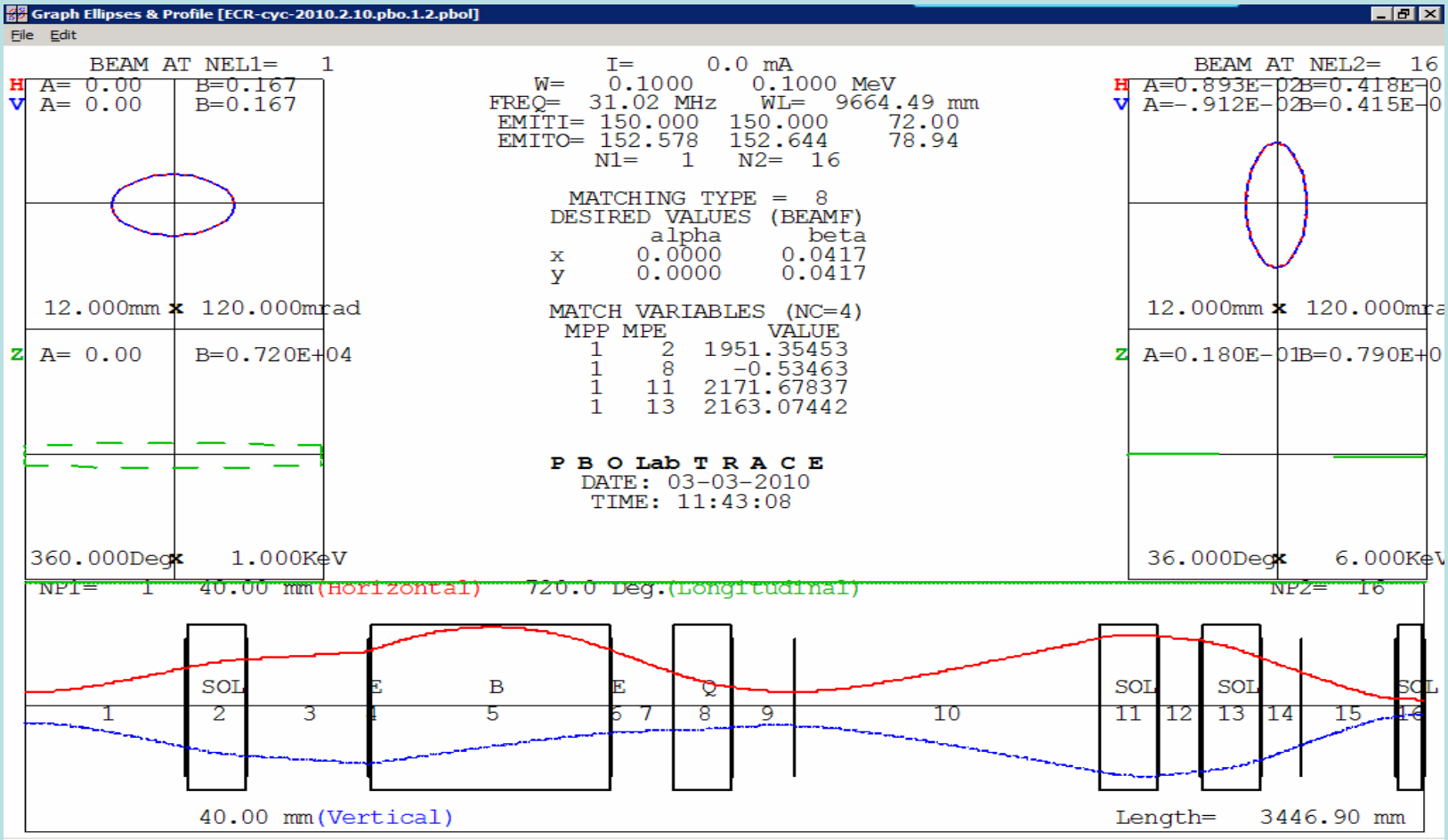
1 Farady Cup

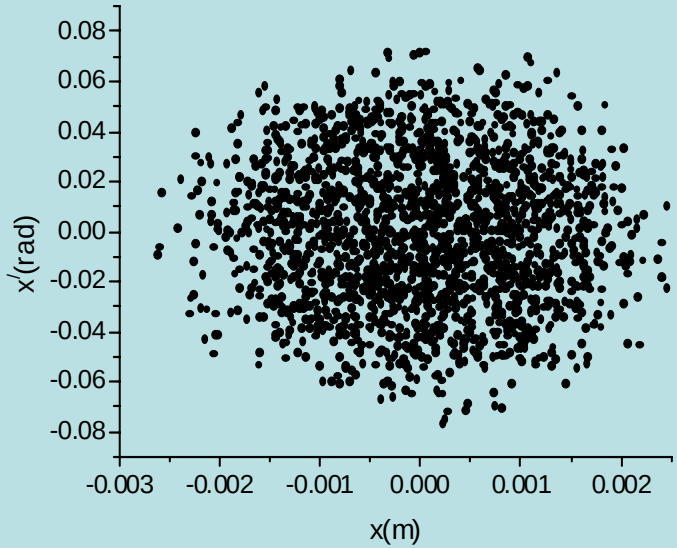


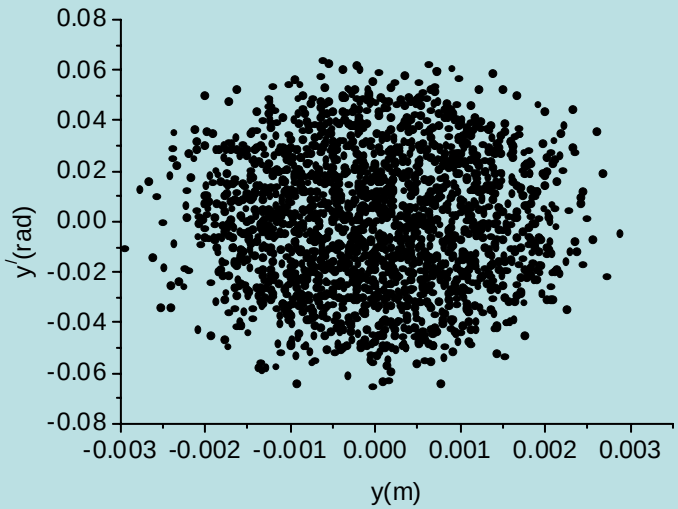
Elements parameters

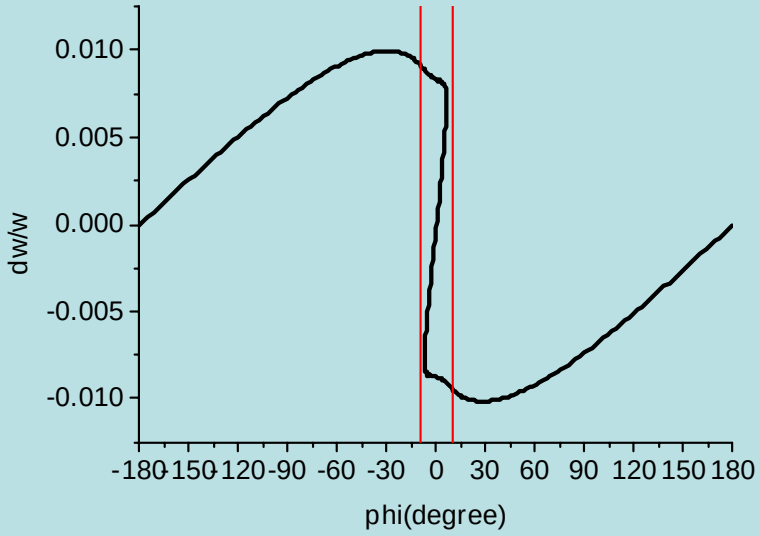
	Number	Effective length（m）			aperture（cm）		Field strength（kG，kV）
solenoid	4	0.15			10		3.5
quadrupole	1	0.15					0.1(kG/cm)
magnetic dipole (double 90 °)	1	radius	0.38		Pole gap	8	1.0
		Def. angle	90°				
		Edge angle	in	39 °			
			out	0°			
Chopper	1	0.12			Wid.	8	2.8
					Gap	4	
Buncher Sinoid 31.02MHz	1	—			8		1.5
Correction magnet	2	0.1			10		0.12

Envelope of the beam line







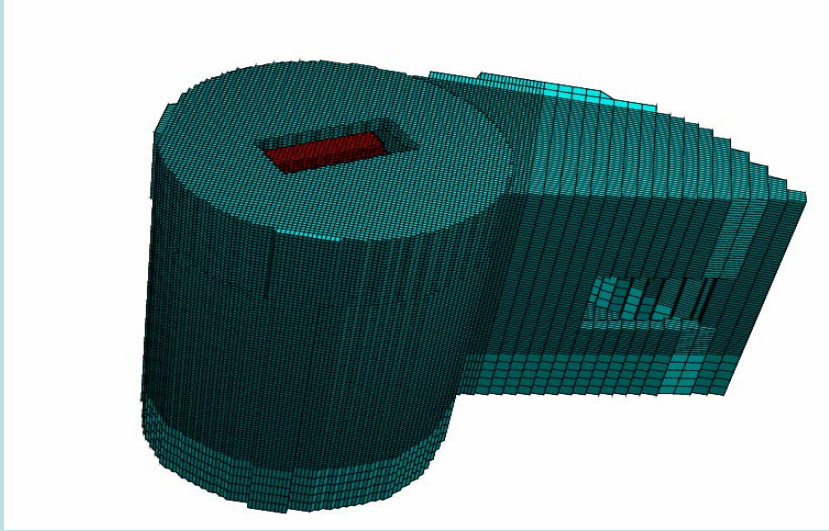


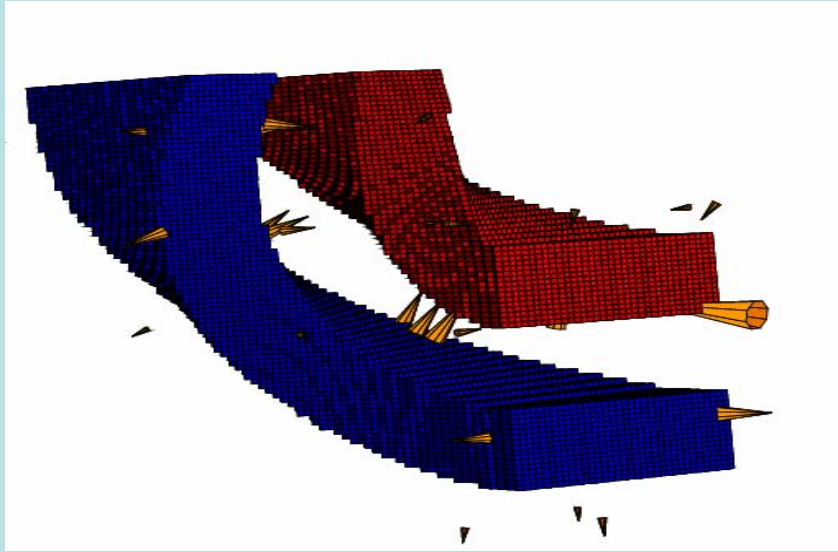
Buncher efficiency 45%

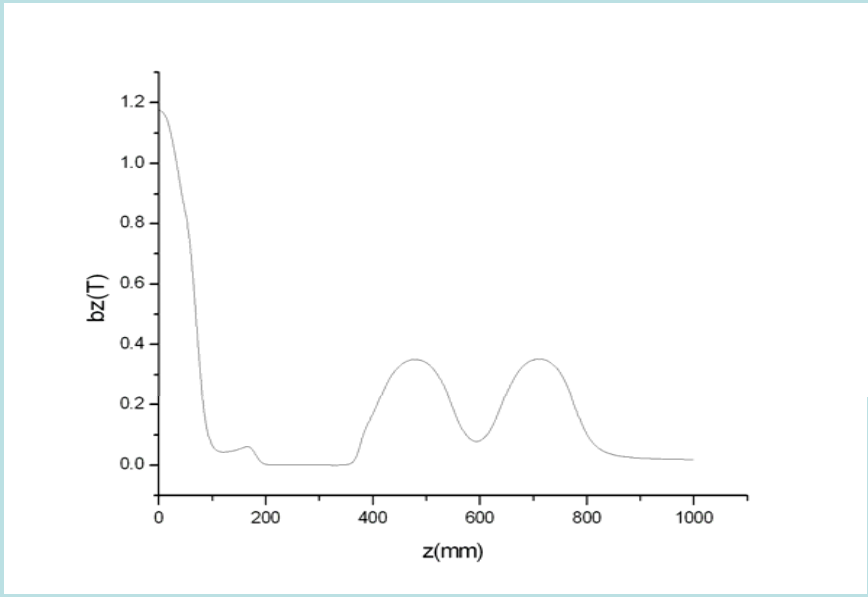
Phase width ±10º

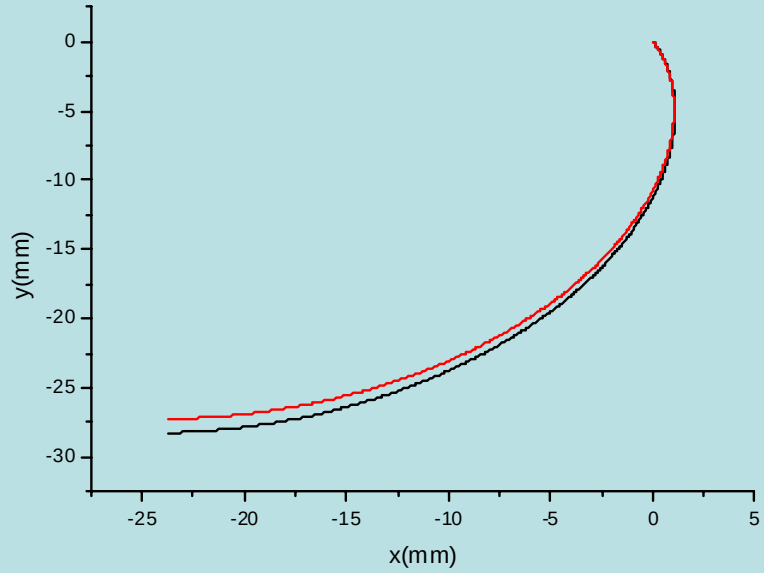
The central region

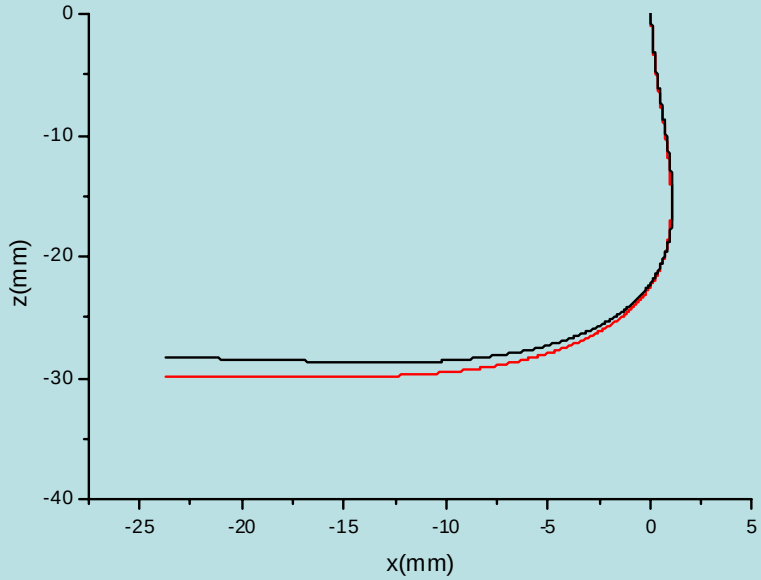
Electric bend radius	30 mm
Magnetic bend radius	27 mm
Electrod spacing	8 mm
Electrod width	16 mm
Orientation angle	-54º
Voltage of electrods	±5.5 kV

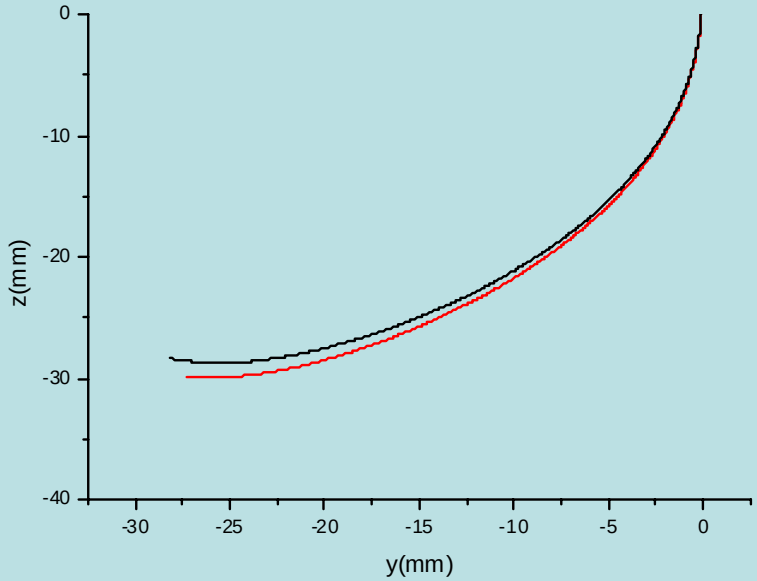


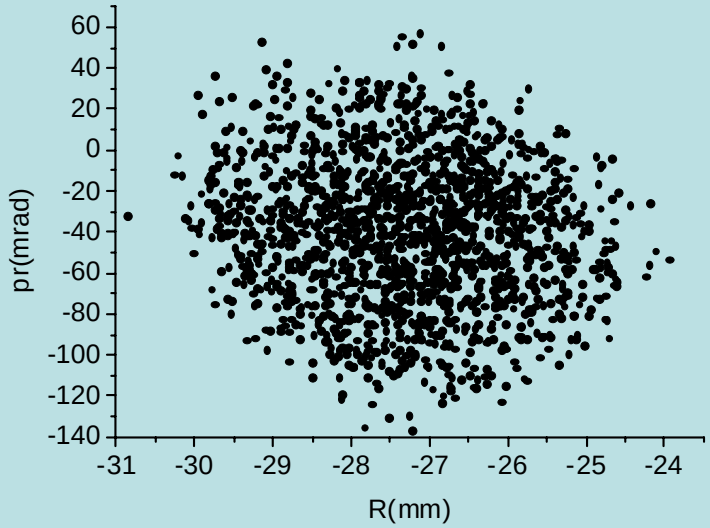


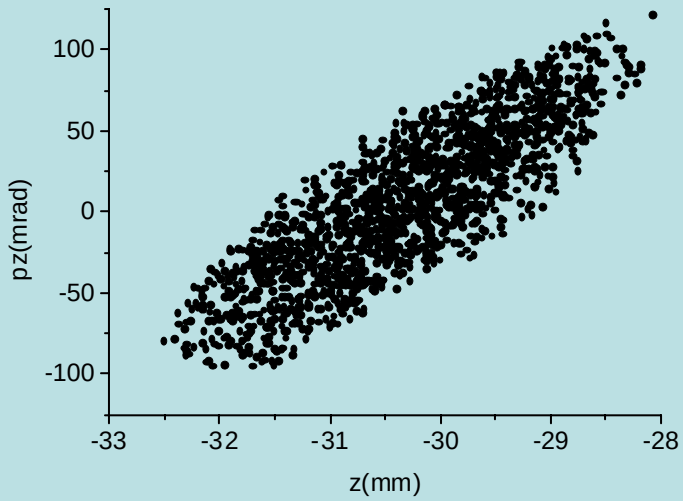

bz(T)
z(mm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000

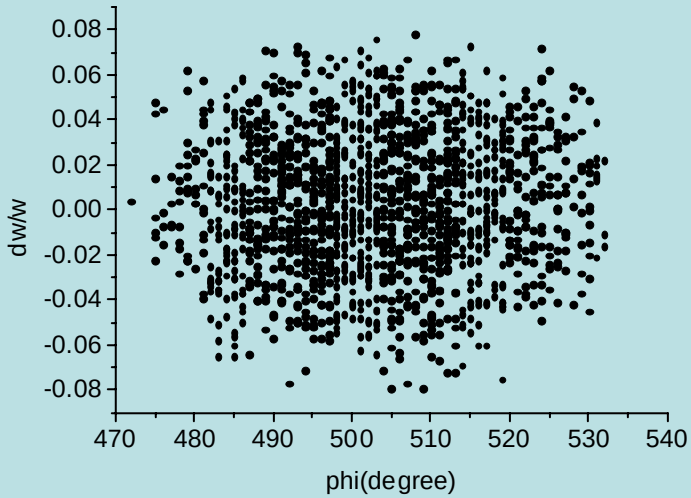

y(mm)
x(mm)
0
-5
-10
-15
-20
-25
-30
-25
-20
-15
-10
-5
0
5


z(mm)
x(mm)
0
-10
-20
-30
-40
-25
-20
-15
-10
-5
0
5

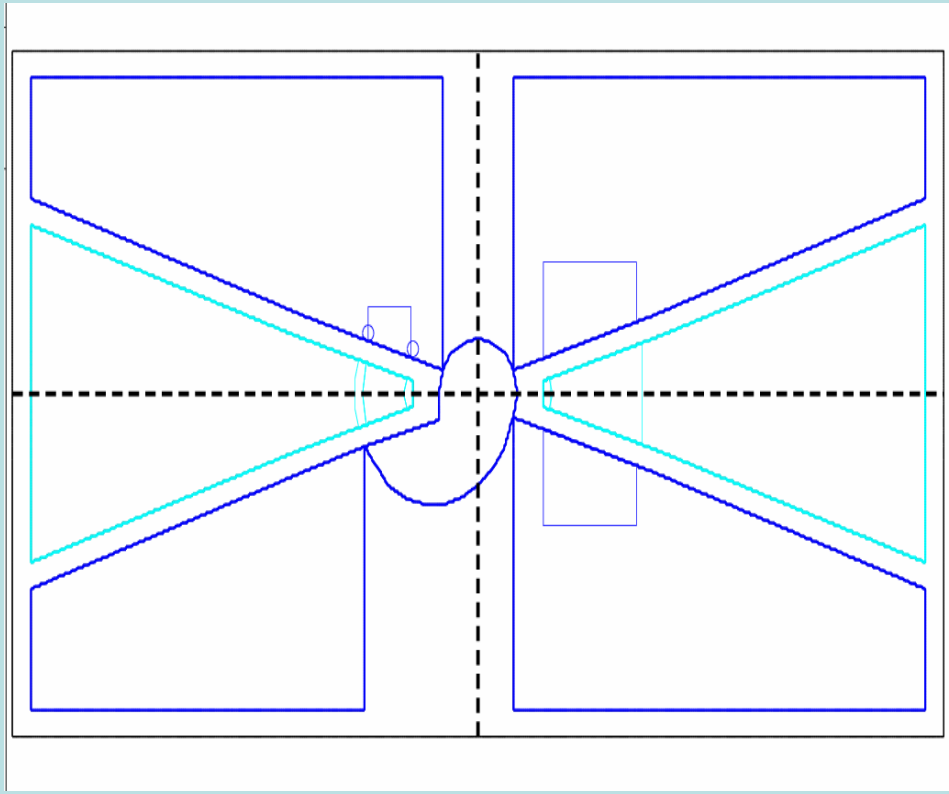

z(mm)
y(mm)
0
-10
-20
-30
-40
-30
-25
-20
-15
-10
-5
0


pr(mrad)
R(mm)
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-31
-30
-29
-28
-27
-26
-25
-24

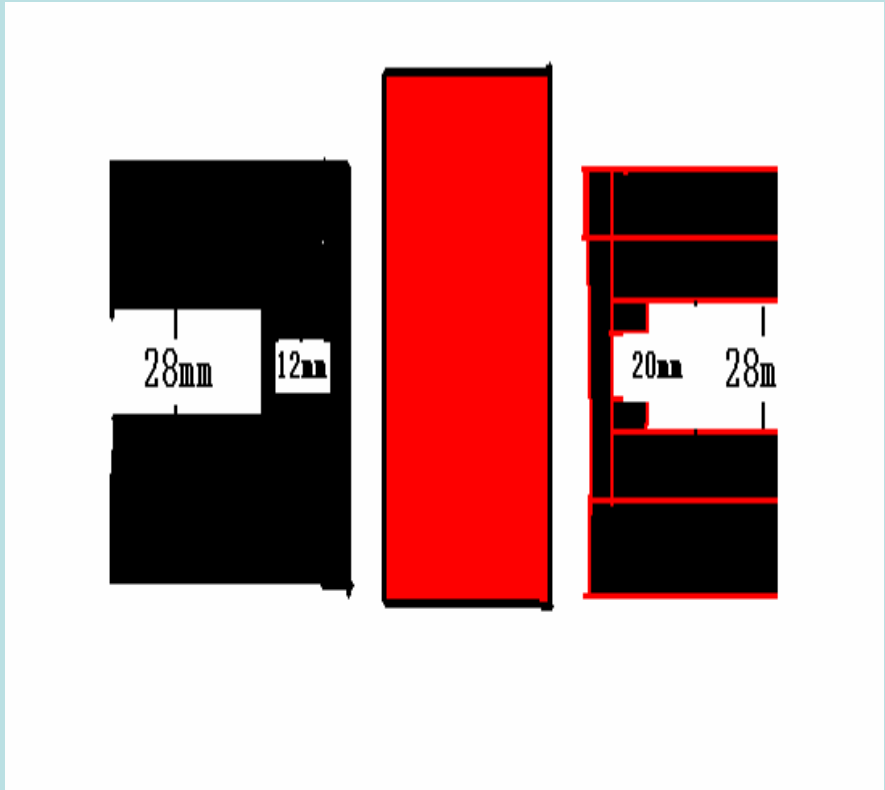

pz(mrad)
z(mm)
100
50
0
-50
-100
-33
-32
-31
-30
-29
-28


dw/w
phi(degree)
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
470
480
490
500
510
520
530
540

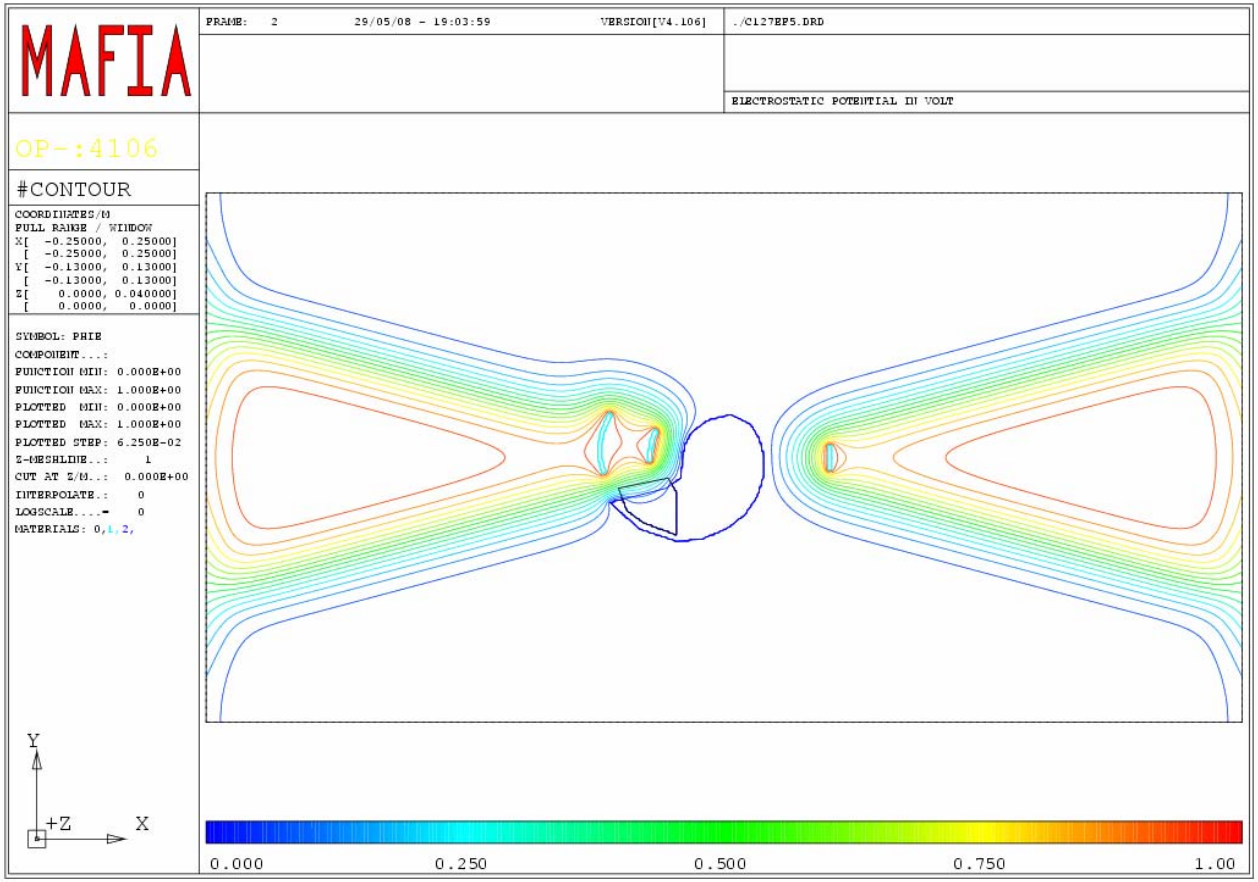
Configuration of central region



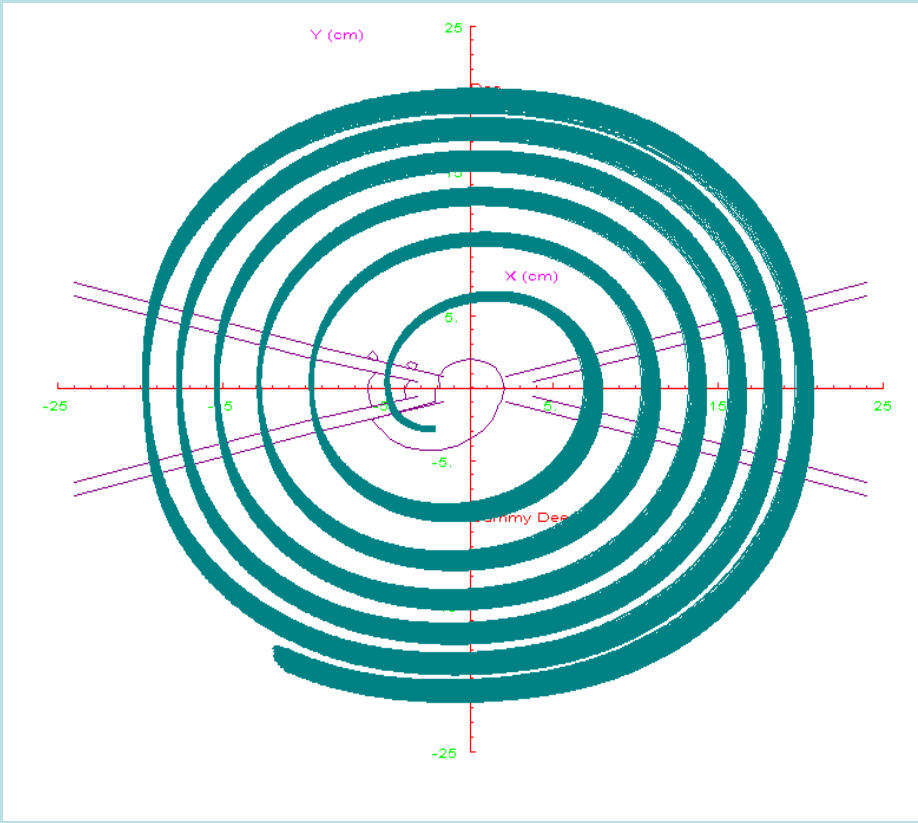
Overlook of the central region

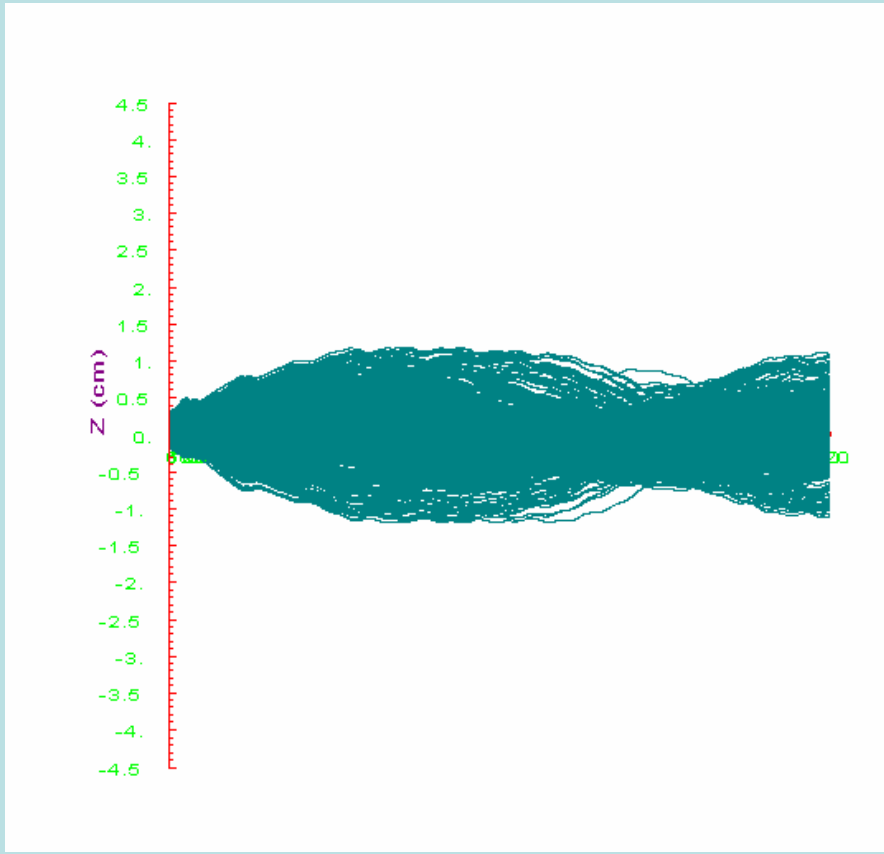


Lateral view of the central region



Median plane electric field map





Accelerating trajectories

Vertical motion

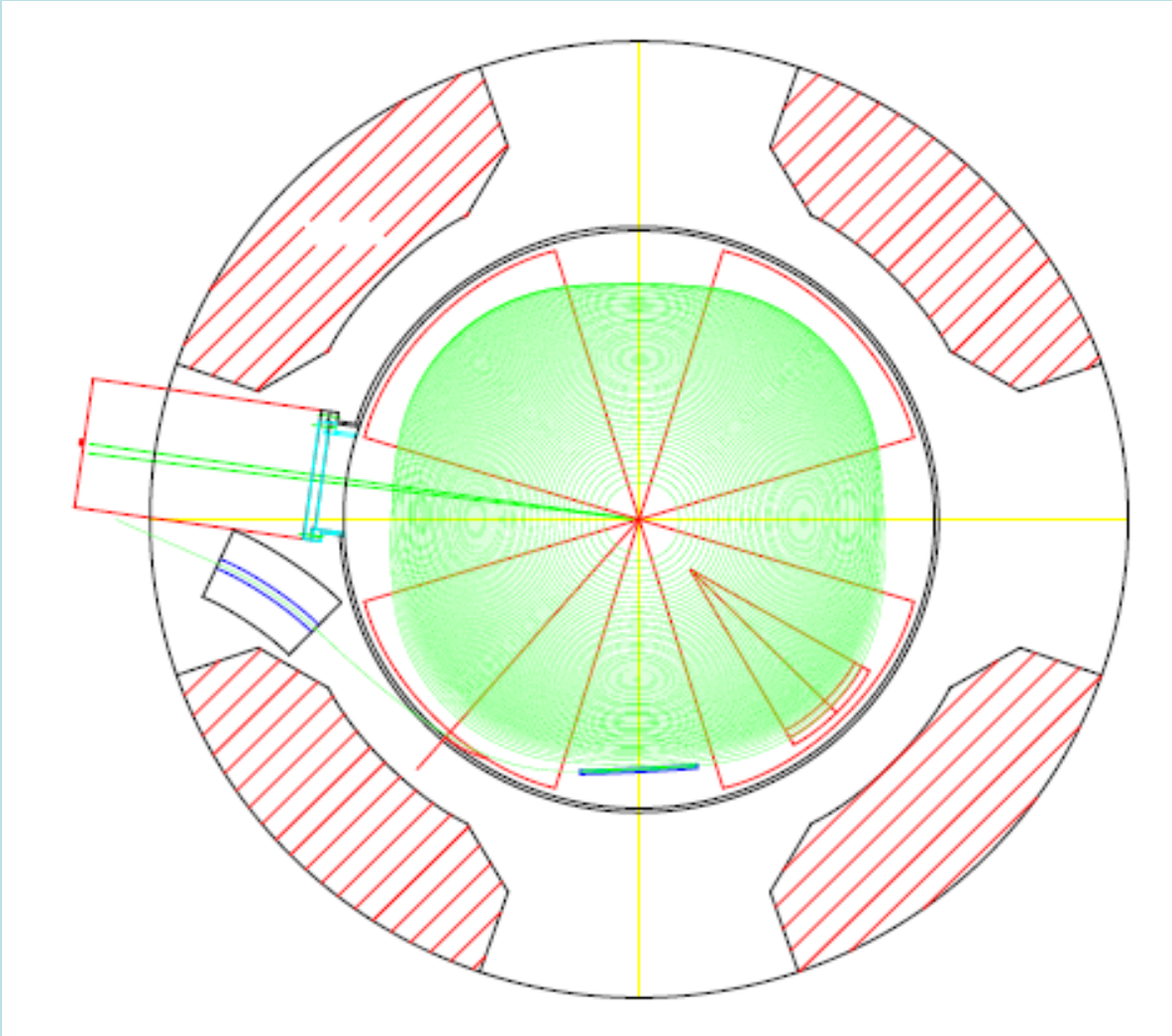
Extraction system

Extraction system

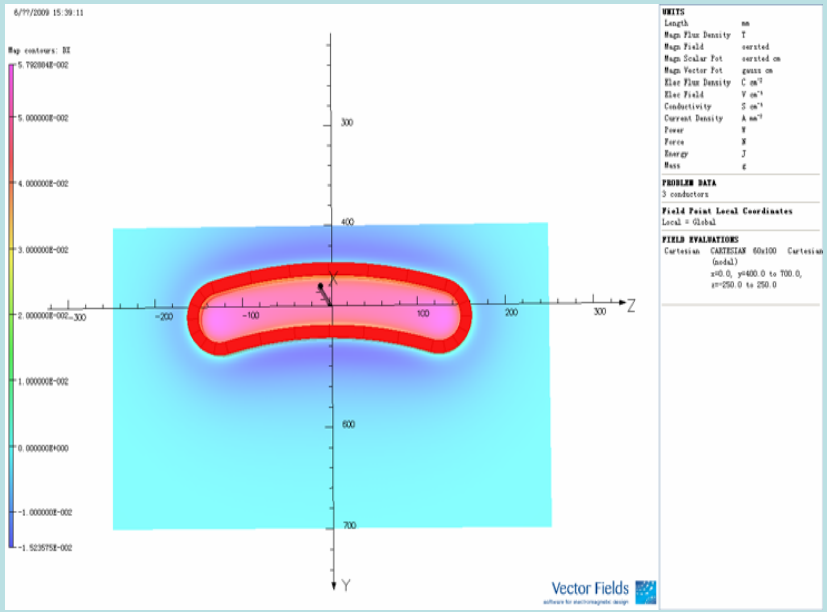
1 bump coil

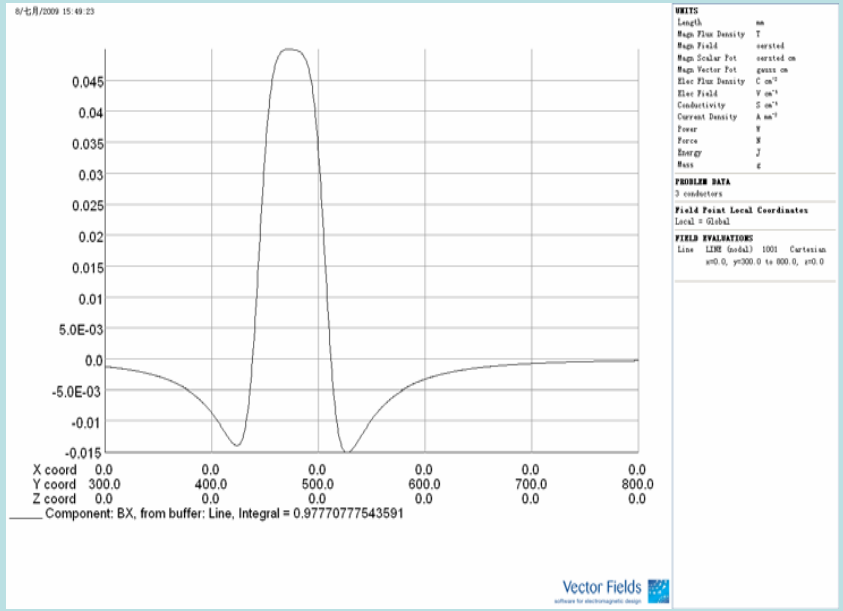
1 electrostatic deflector

1 deflect magnet



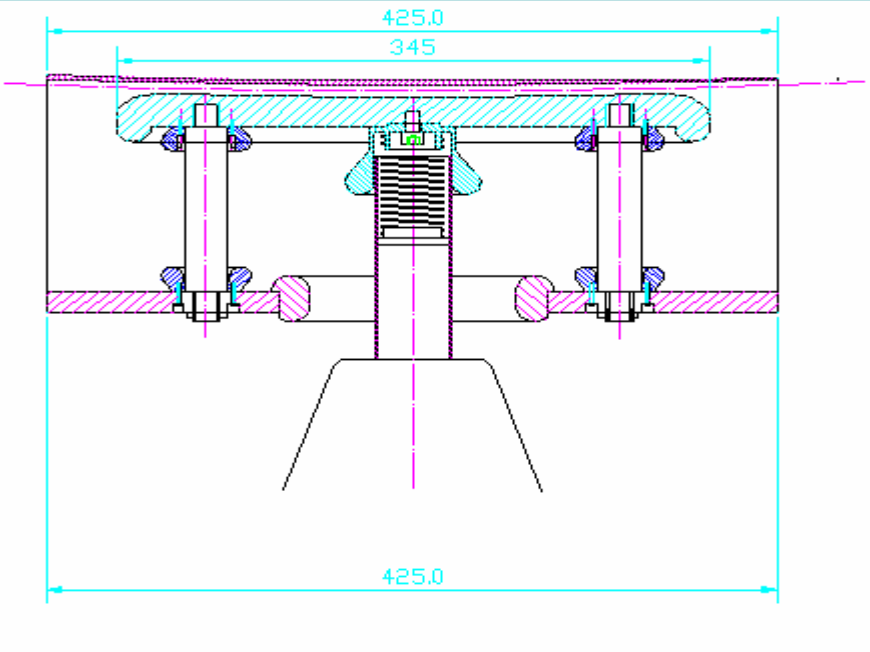
bump





maximum magnetic field 400 Gauss

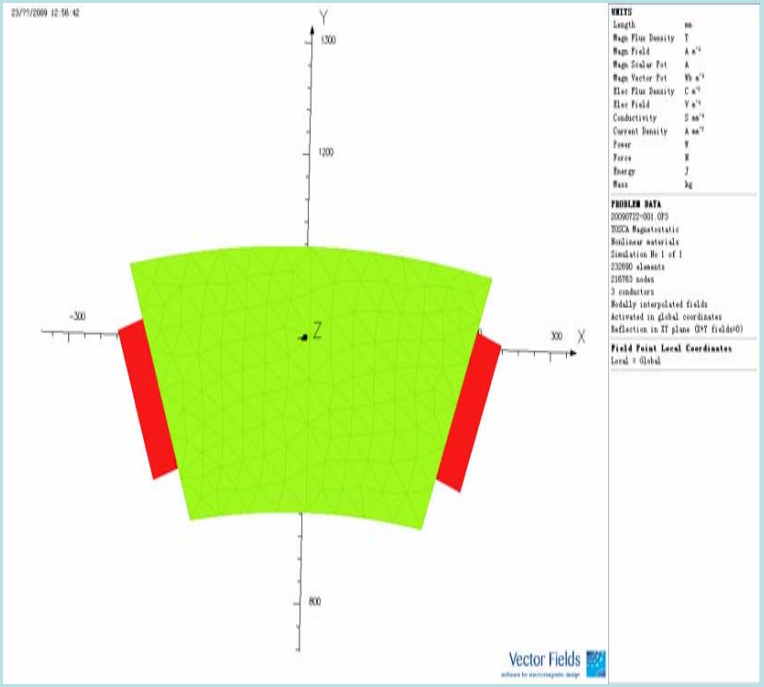
E1



Electric field 85 kV/cm

Gap 10 mm

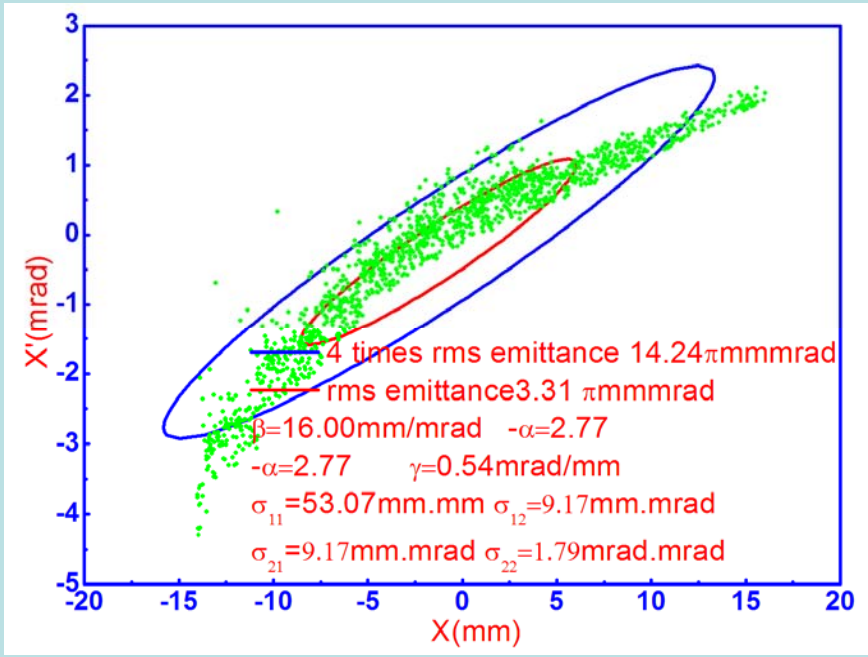
M2

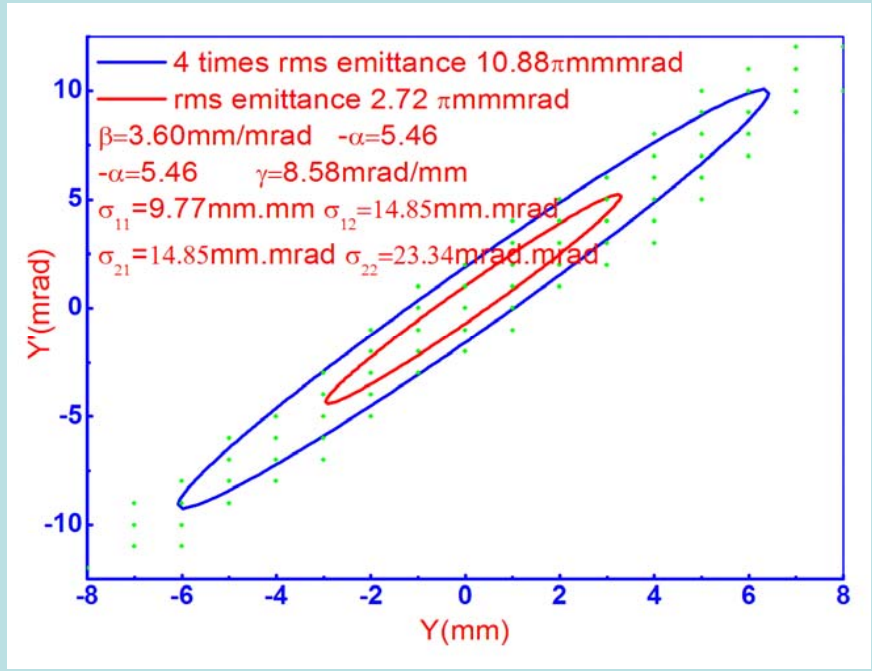


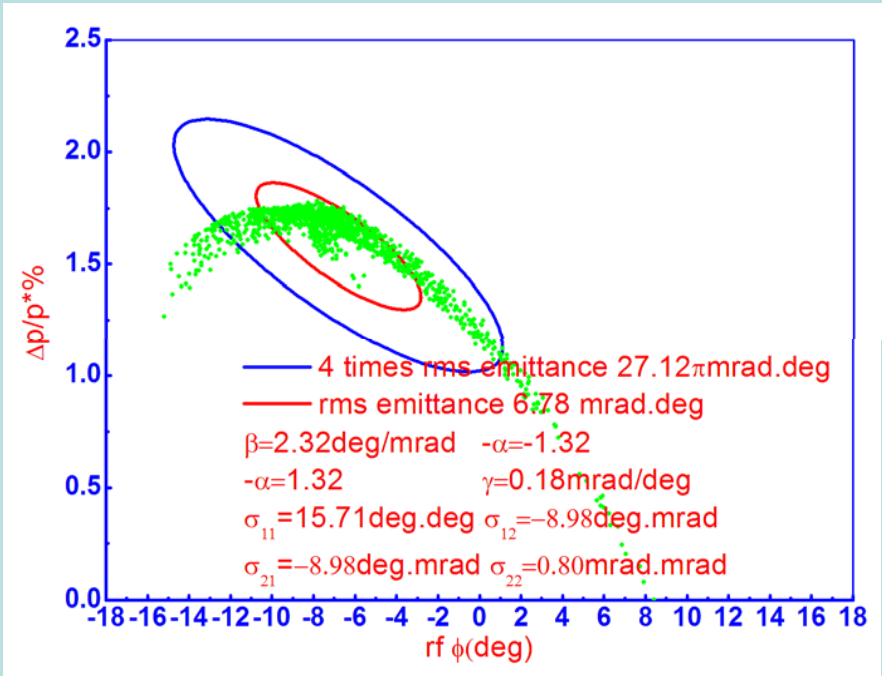
Magnetic field 1.1 T

Gap 30 mm

Width 30mm


4 times rms emittance 14.24πmmmrad
rms emittance3.31 πmmmrad
β=16.00mm/mrad -α=2.77
-α=2.77 γ=0.54mrad/mm
σ11=53.07mm.mm σ12=9.17mm.mrad
σ21=9.17mm.mrad σ22=1.79mrad.mrad
X'(mrad)
X(mm)


4 times rms emittance 10.88πmmmrad
rms emittance 2.72 πmmmrad
β=3.60mm/mrad -α=5.46
-α=5.46 γ=8.58mrad/mm
σ11=9.77mm.mm σ12=14.85mm.mrad
σ21=14.85mm.mrad σ22=23.34mrad.mrad
Y'(mrad)
Y(mm)


4 times rms emittance 27.12πmrad.deg
rms emittance 6.78 mrad.deg
β=2.32deg/mrad -α=-1.32
-α=1.32 γ=0.18mrad/deg
σ11=15.71deg.deg σ12=−8.98deg.mrad
σ21=−8.98deg.mrad σ22=0.80mrad.mrad
Δp/p*%
rf ϕ(deg)

Transmission efficiency

transmission efficiency=number of particles unlost/number of total particles

- Inflector entrance

  a buncher

  emmitance 120 π mm mrad ,

  $\Delta\ \phi = \pm 10^{\circ}$, Δ W/W=$\pm$1%, Buncher efficency 45%

  10,000 particles

- Central region (5 turns) 7997 particles
- Injection efficiency 35%
- Acelerated to 7 MeV/u and extracted at the end of M2
  extraction efficiency 20%

Total transmission efficiency 7%
Extracted beam current 14 e μ A

Vacuum system

- 4 cryogenic pumps of 5000l/s.
- vacuum of priciple chamber was 5×10-7 mbar
- vacuum of injection line was 1×10-7mbar.

Construction Progress

- *ECR Ion Source*
  The engineering design had been completed.
  Integrate the permanet magnetism material in IMP,CAS

- *RF System*
  The construction design of tow 50 kW rf amplifers had been finished.
  End of Construction: December 2010
  The cavity's engineering design is conducted.

- *Axial Injection Line*
  The engineering design had been finished.

- The power supplies for the magnet coil, injection and ectraction equipments had been contracted.

- The construction of other items, e.g. the magnet, the vaccum chamber, the spiral inflector, the electrostatic deflector is conducted.

Summary

- The beam dynamic study of the 7 MeV/u cyclotron had been completed.
- The concept design meet the requirment from synchrotron
- Engineering design of the cyclotron is conducted ,except ECR ion source ,rf amplifers, and injection line.

Thanks