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Status Report on the Cyclotron Injector for HIMM

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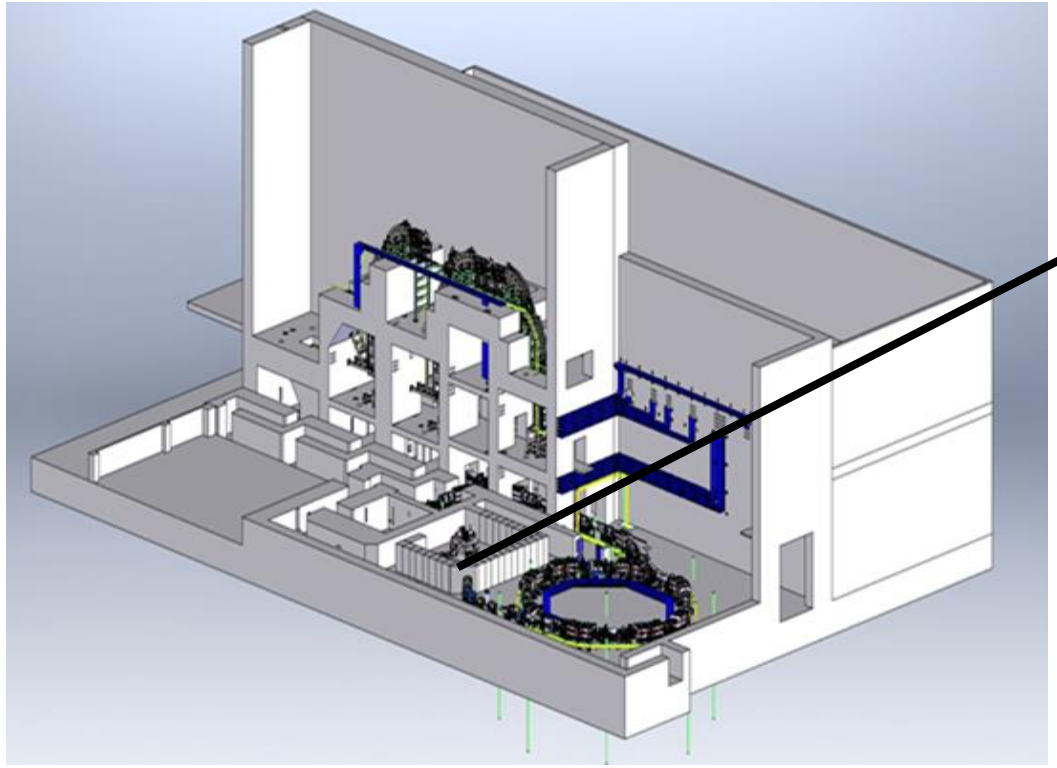
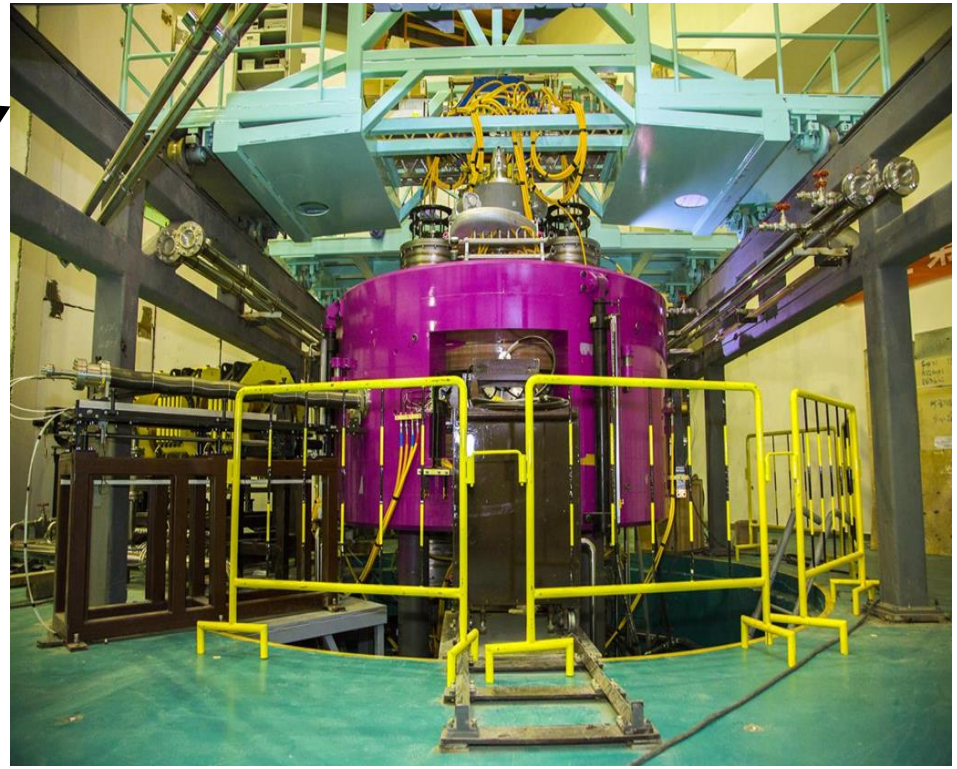
1. Introduction

HIMM (Heavy Ion Medical Machine) is an accelerator complex designed by Institute of Modern Physics, CAS. HIMM accelerates carbon ions to the energy 400 MeV/A for tumor therapy.



Layout of HIMM



Cyclotron Injector

1. Introduction

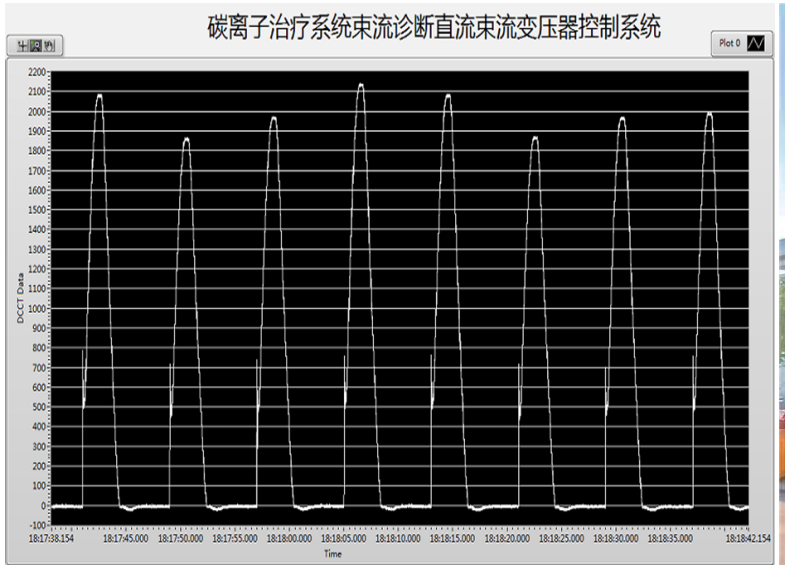
Cyclotron is used as the injector of the main accelerator (synchrontron), the unique design in the worldwide heavy ion therapy facilities.

Machine	Country	Ion	Energy（MeV/U）,main accelerator	Injector
Med-AUSTRON	Austria	Carbon	400, Synchrontron	Linac
CNAO	Italy	Carbon	400, Synchrontron	Linac
HIT	Germany	Carbon	430, Synchrontron	Linac
PTC	Germany	Carbon	430, Synchrontron	Linac
NRoCK	Germany	Carbon	430, Synchrontron	Linac
GUNMA	Japan	Carbon	400, Synchrontron	Linac
HIMAC	Japan	Silicon	800, Synchrontron	Linac
HIBMC	Japan	Carbon	320, Synchrontron	Linac
SAGA-HIMAT	Japan	Carbon	400, Synchrontron	Linac
HIMM	China	Carbon	400, Synchrontron	Cyclotron
Fudan University	China	Carbon	430, Synchrontron	Linac

1. Introduction

Three HIMMs have been constructed in China. The HIMM in Gansu Wuwei Tumor Hospital has treated more than six hundred cancer patients in the last two and a half years.

- ✓ Cyclotron extracted beam intensity: 5.5μA(CW)
- ✓ Beam intensity in sychrontron: 2000μA(pulsed)
- ✓ Beam Intensity on treatment terminals: $4*10^8$ ppp



Beam intensity in sychrontron

Gansu Wuwei Tumor Hospital

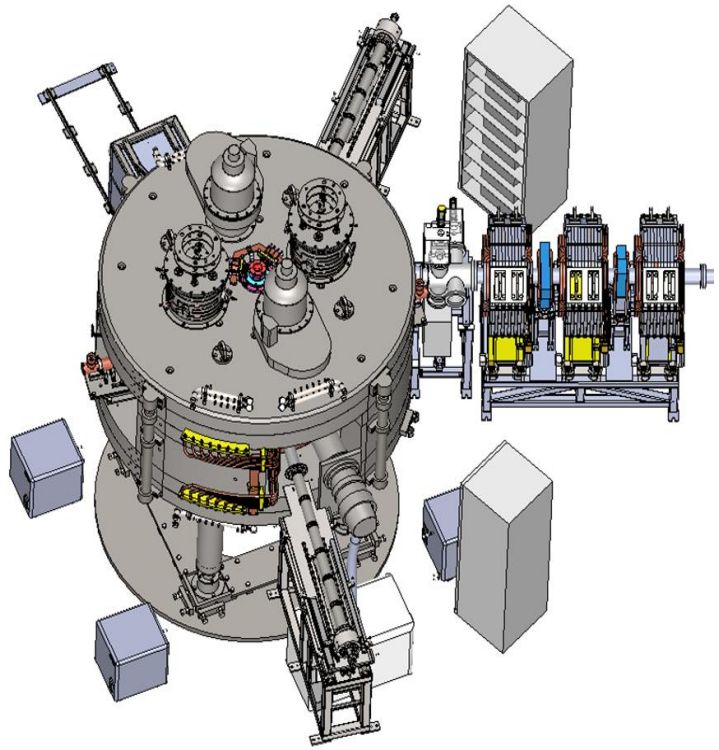
Lanzhou Heavy Ion Hospital

2. Characteristics of the Cyclotron

The cyclotron injector is a compact cyclotron. It is used for medical treatment. We focused on the stability and simplicity of the cyclotron in design and manufacture phase.

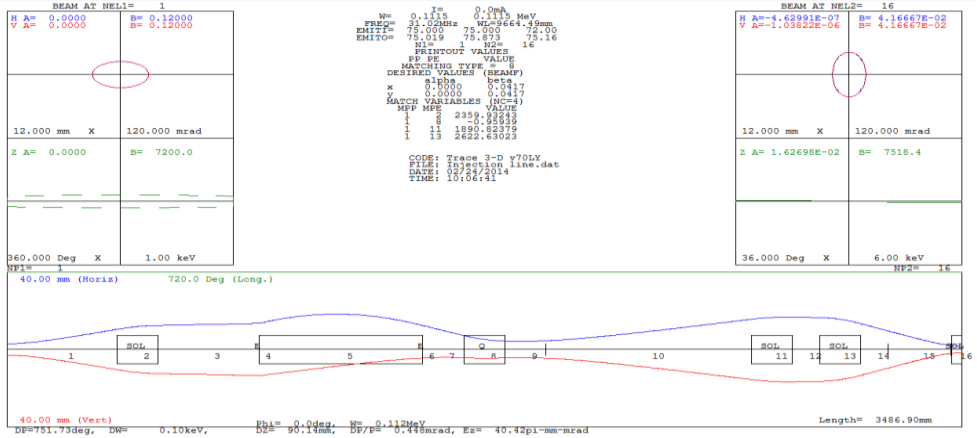
The Main Parameters of Cyclotron

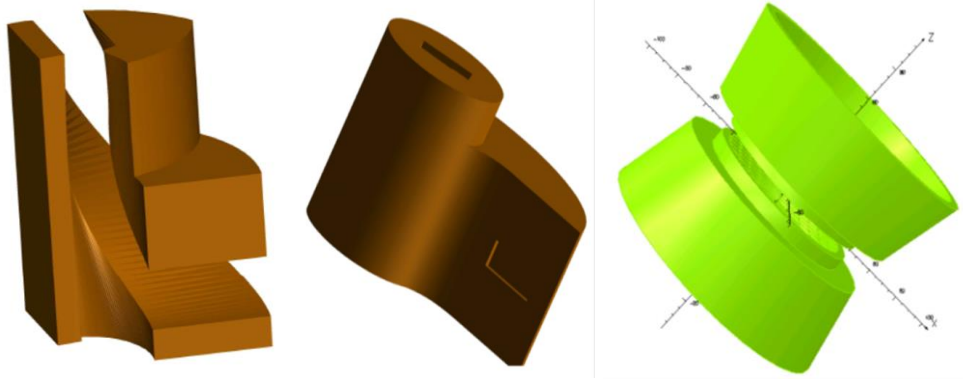
Ion	C_{12}^{5+}	rf frequency	31.02MHz
Energy	6.8 MeV/A	Harmonic	4
Beam intensity	10 eμA	rf cavities	2
Beam Emittance	20-25πmm.mrad	Ion source	2 ECR+axial injection line
Energy divergence	±1%	Extraction	1 ESD+1 BUMP+1 GCC+1MC
Central magnet field	1.212 T	Magnet Size	Φ2920mm*1520mm
Magnet sectors	4		
Sector angle	56º		
Pole radius	84cm		
Extraction radius	75cm		

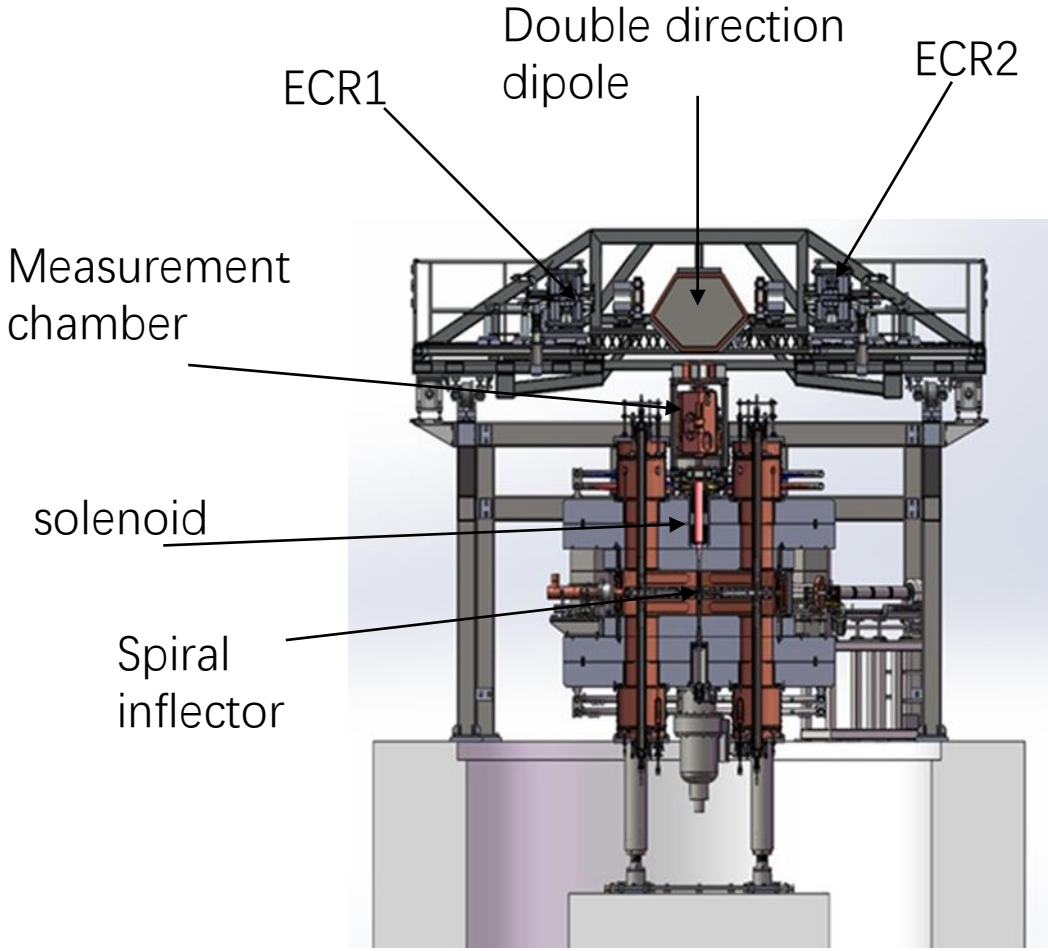


2. Characteristics of the Cyclotron (ion source, axial injection line)

- ✓Two permanent magnet ECR ion sources
- ✓Short beam line, 3.5m long
- ✓Mult-harmonic Bucher



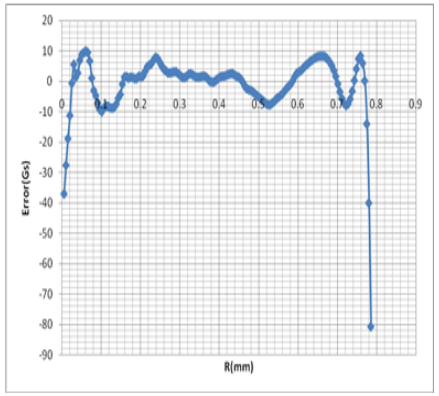




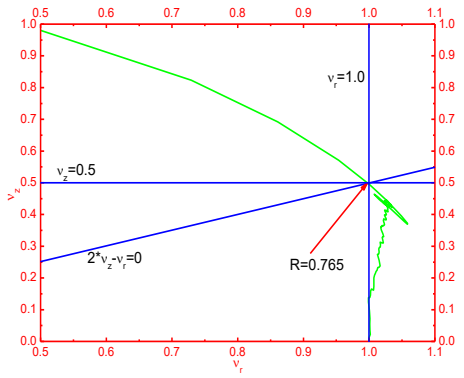
2. Characteristics of the Cyclotron (magnet)

- ✓None isochronous trim coils in the cyclotron
- ✓Trim the magnet sector's edge, optimum the sector's gap

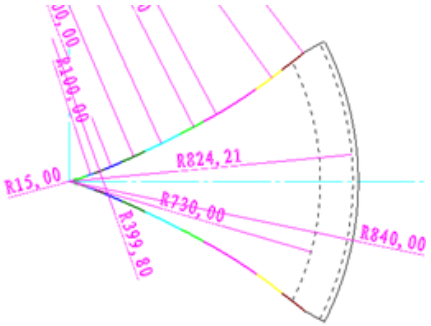
Central magnet field	1.212 T
Magnet sectors	4
Sector angle	56º
Pole radius	84cm
Hill gap	70-80mm
Valley gap	360mm



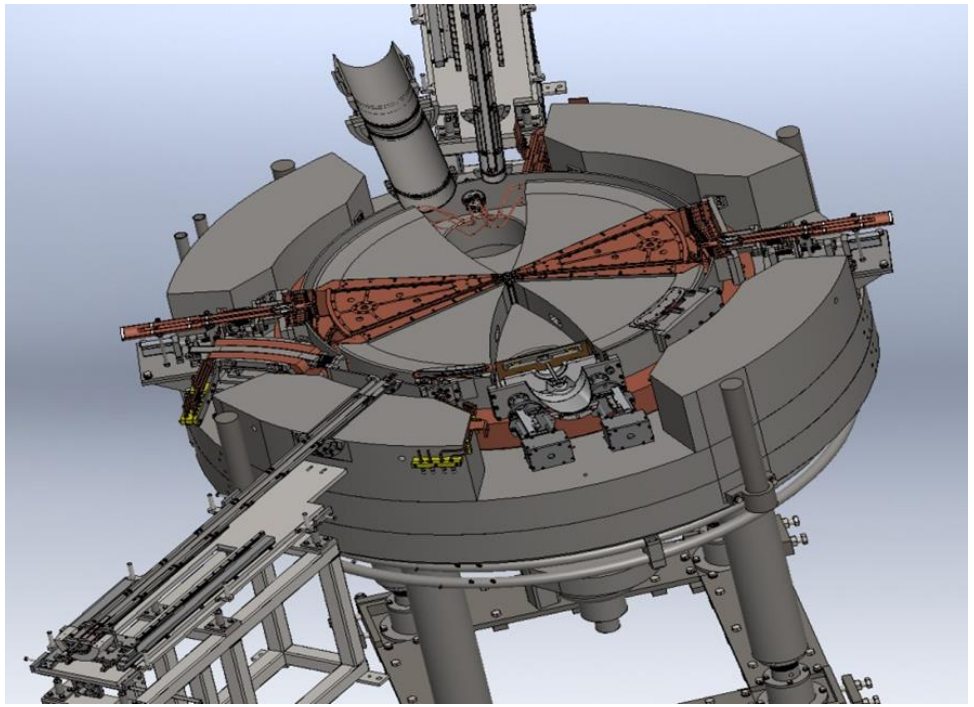
Magnet field error



work diagram



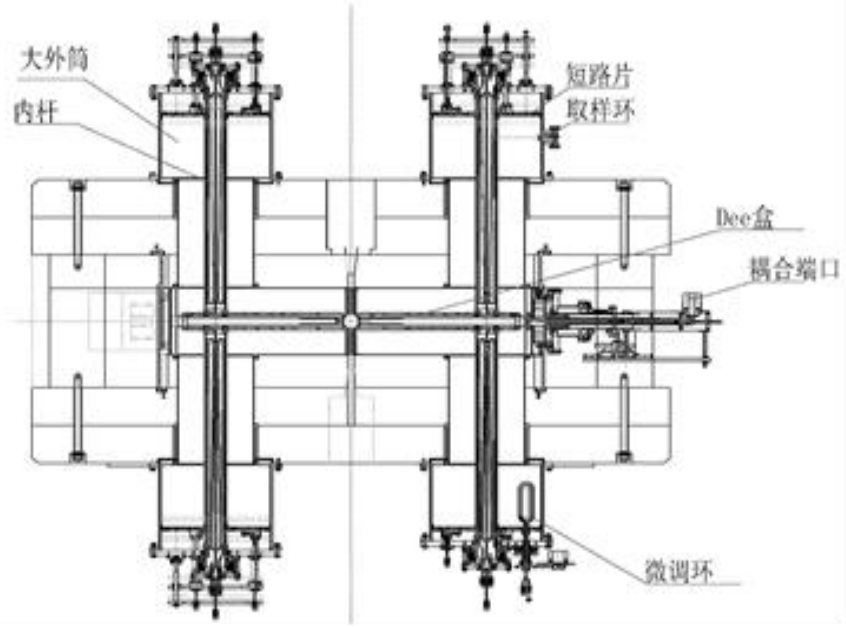
Magnet sector

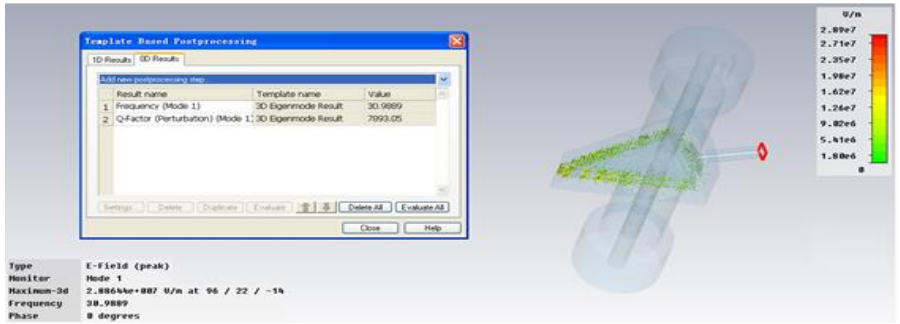


2. Characteristics of the Cyclotron (rf system)

✓High stability of the cavity amplitude, phase, frequency

rf frequency	31.02MHz
Dee voltage	70KV
Dee angle	30°
Cavity number	2
Outer radius	750mm
Inner radius	35mm
Phase stability	±1°
Amplitude stability	$\pm 5\times10^{-4}$/24hour
Frequency stability	$\pm 1\times10^{-6}$/24hour
Q value	7800
Amplifier number	2
Amplifier power	50kw

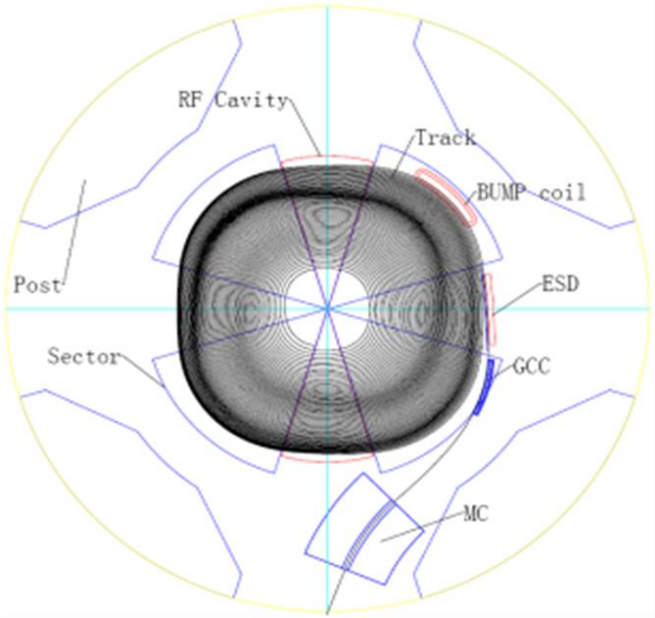


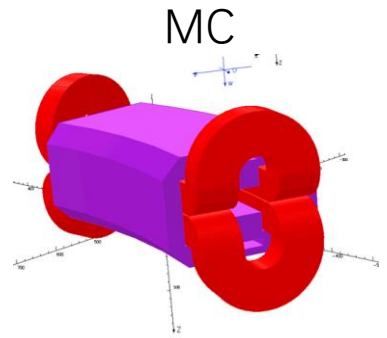


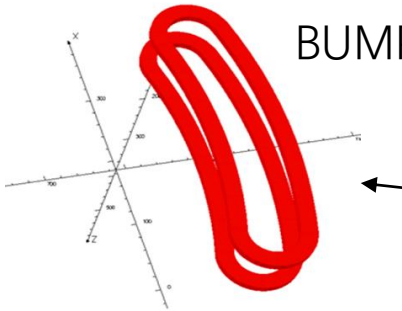
2. Characteristics of the Cyclotron (extraction)

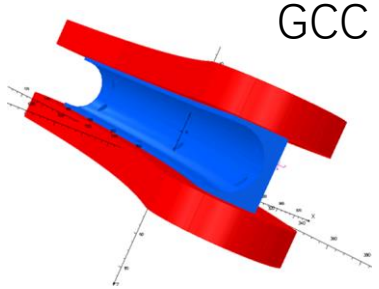
✓The elements of extraction system as less as possible.

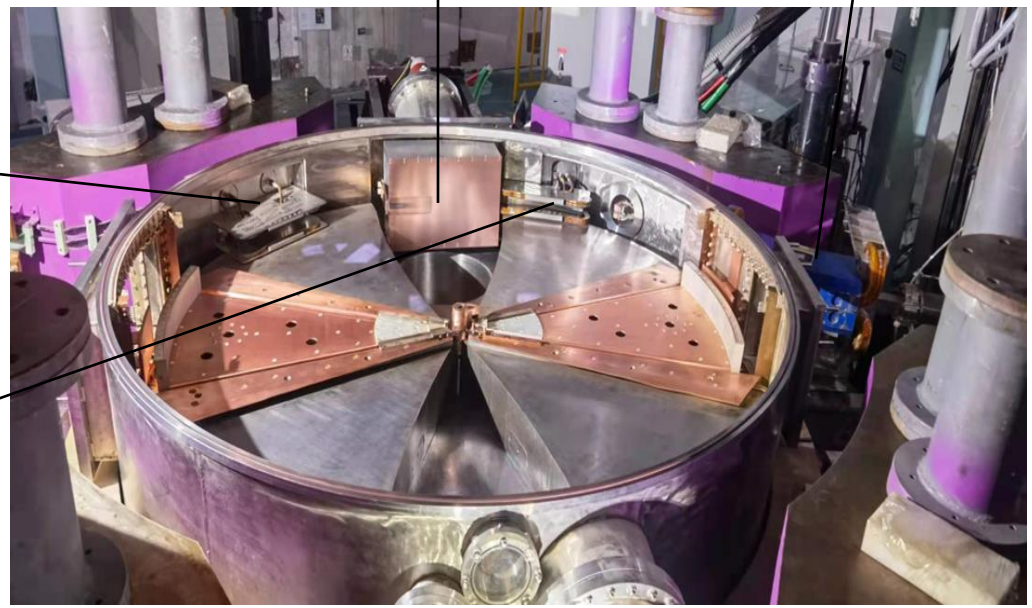
ESD E field	80-85 kv/cm
ESD Gap	10 mm
Bump B field	300 Gauss
GCC G field	**10 T/m**
MC B field	1.1 T
Turn separation	**10 mm**





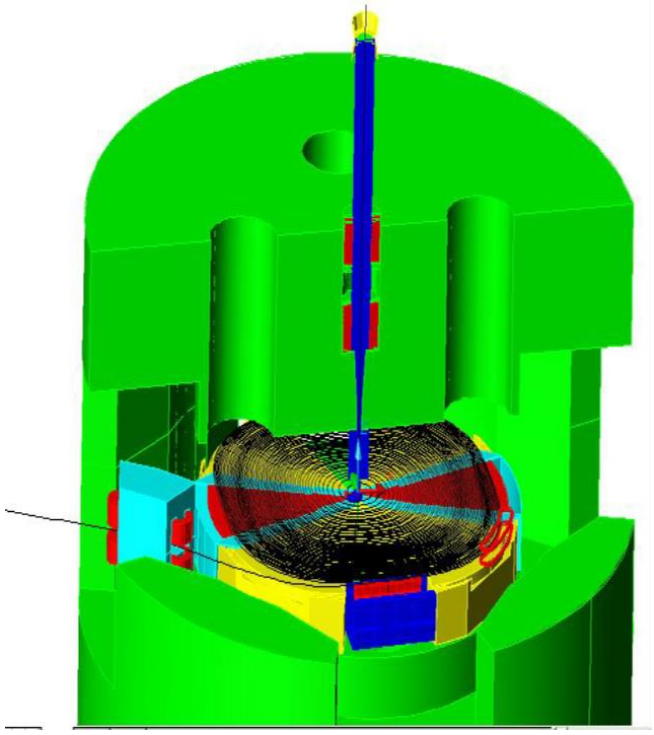






2. Characteristics of the Cyclotron (beam simulation)

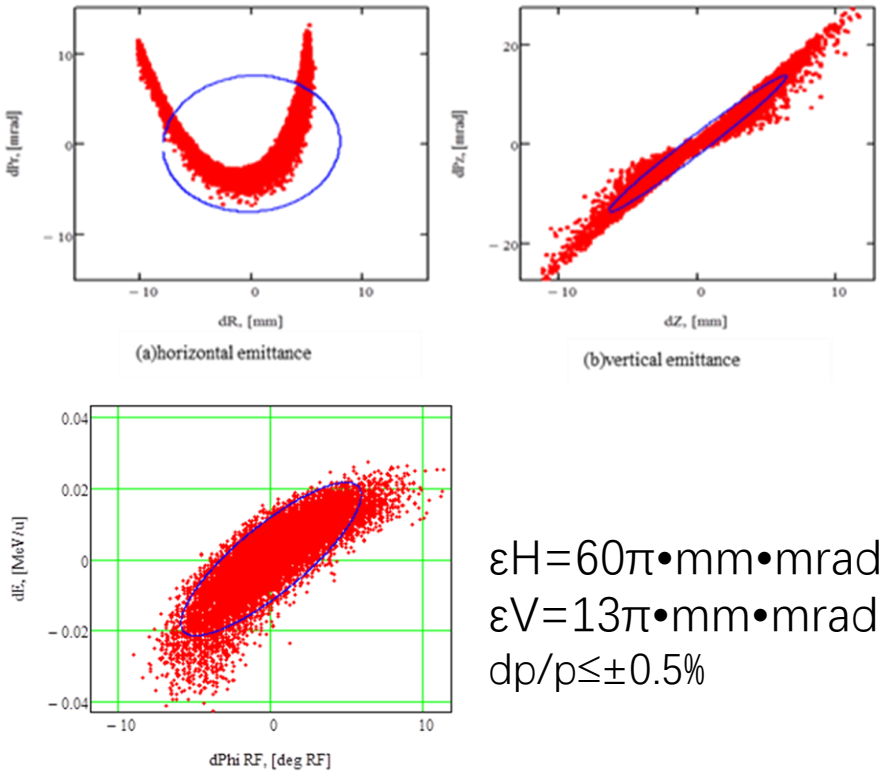
✓Simulate beam transport from ion source to match point to the middle energy beam line.



Transmission efficiency

Emittance of ECR	75 πmm.mrad
ECR beam intensity	100 eμA
Efficiency of beam line	90%
Efficiency of injection	**43%**
Efficiency of extraction	47%
Total transmission efficiency	**18%**

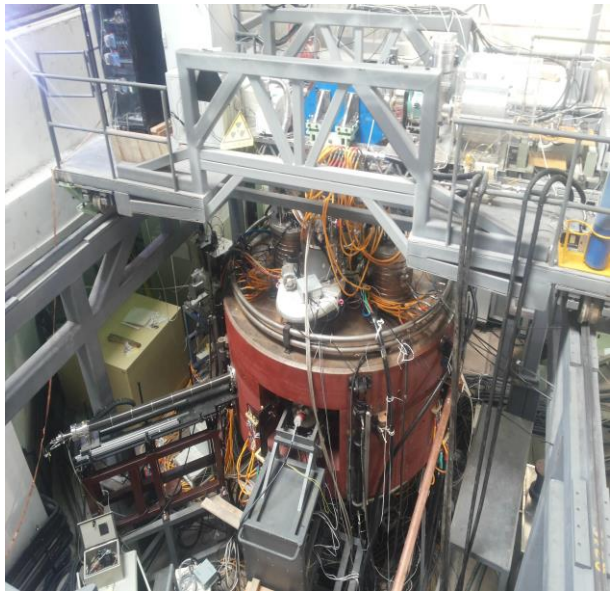
Extracted beam emittance on the match point

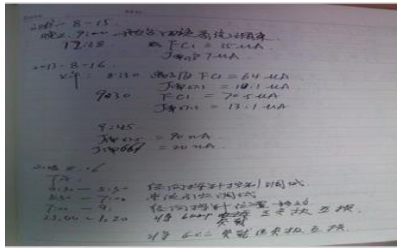


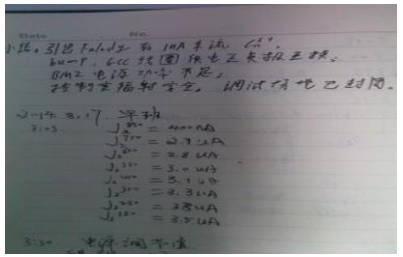
εH=60π•mm•mrad
εV=13π•mm•mrad
dp/p≤±0.5%

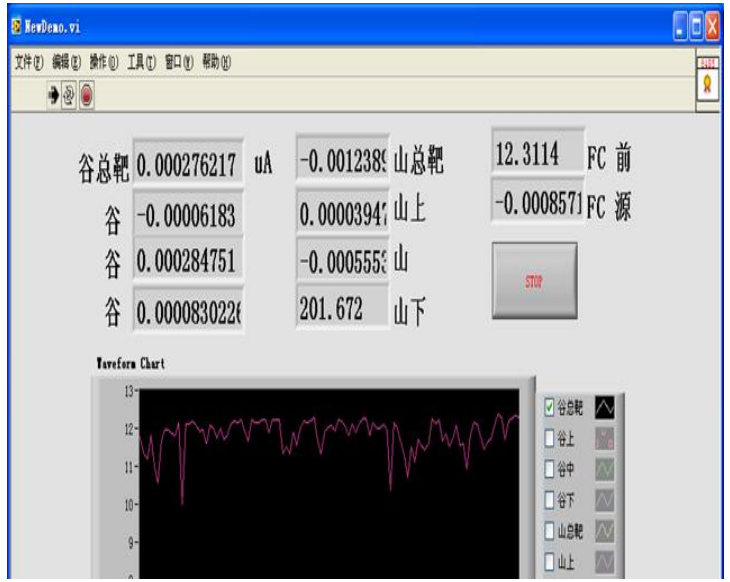
3. Manufactures and Operations

- ✓The design phase: 2006-2011
- ✓The first cyclotron installed in IMP: 2014.8
- ✓The first trimming cyclotron: 2014.8.15
- ✓The first extracted beam: 2014.8.16, 1nA beam extracted
- ✓The extracted beam intensity to be 12 μA: 2014.9.26







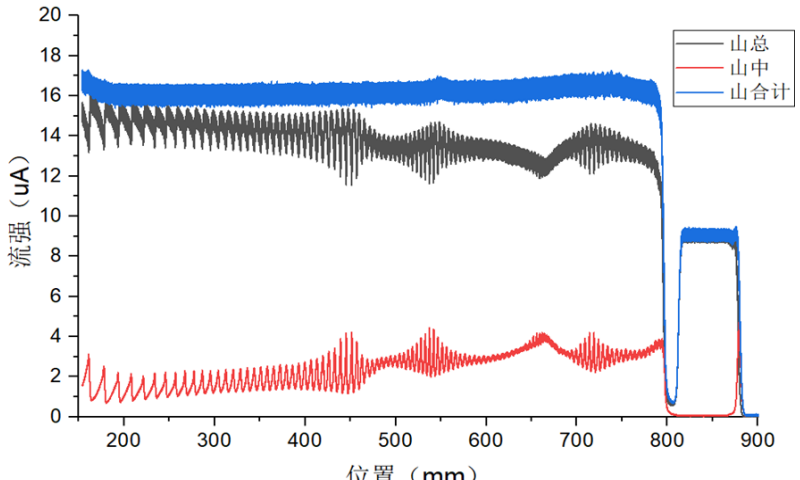


3. Manufactures and Operations

✓The first cyclotron installed in Gansu Wuwei Tumor Hospital in 2015
✓On April 1, 2020, they began to treat patients
✓More than 600 patients have been treated in the hospital

Scheme	Operation time(h)	Failure time(h)	Operating rate
March 26, 2020 - January 23, 2021	7296	31.62	99.57%
March 22, 2021- January 29, 2022	7536	66.05	99.12%
February 16, 2022- August 22, 2022	6936	54.15	99.22%

10FC01	50 eμA
Central region	19.2 eμA
Extraction region	18.94 eμA
30FC01	5.5 eμA
Efficiency of injection	38.4%
Efficiency of extraction	29%
Total transmission efficiency	11%



3. Manufactures and Operations

- ✓The second cyclotron has been completely installed in Lanzhou Heavy Ion Hospital, Lanzhou city, Gansu province, China, in 2017
- ✓The third cyclotron has been completely installed in Mazu Heavy Ion Hospital, Putian City, Fujian province, China, in 2020
- ✓These two cyclotrons have not been used for treatment

4. Summary

- ✓The cyclotron can be stably and reliably used as injector of sychrontron for heavy ion therapy
- ✓The design of the cyclotron injector for HIMM is feasible
- ✓The total transmission efficiency of the cyclotron injector and the extracted beam quality should be improved to better match the sychrontron.

Members

Cyclotron

Liangting. Sun, Qinggao. Yao, Xianwu. Wang, Jinquan. Zhang, Mingtao. Song, Hongwei. Zhao (Institute of Modern Physics, CAS)

Jian. Si, Lirong. Zhou (Lanzhou Ion Therapy Co., Ltd.)

Thanks you for your attentions!