Simulation and analysis of HIMM-IC beam dynamics with OPAL

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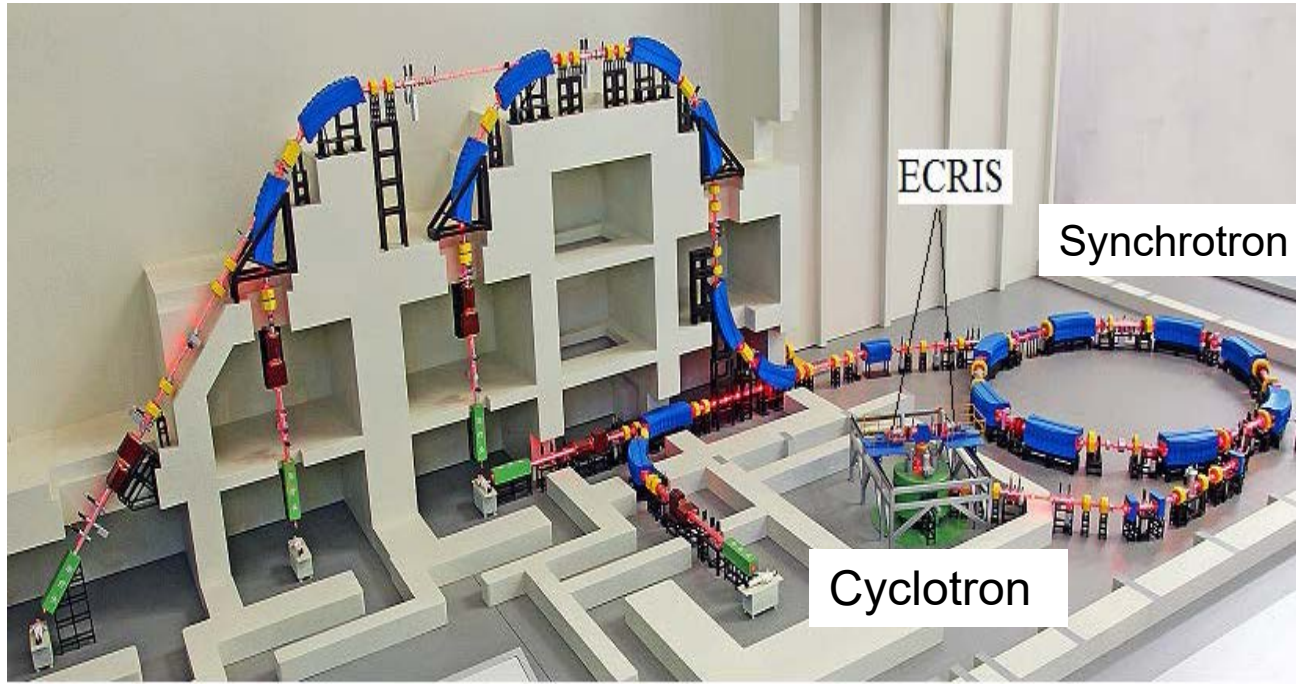
- Background
- Operation status and problems
- Simulation of Beam dynamics in OPAL
- Summary and Outlook

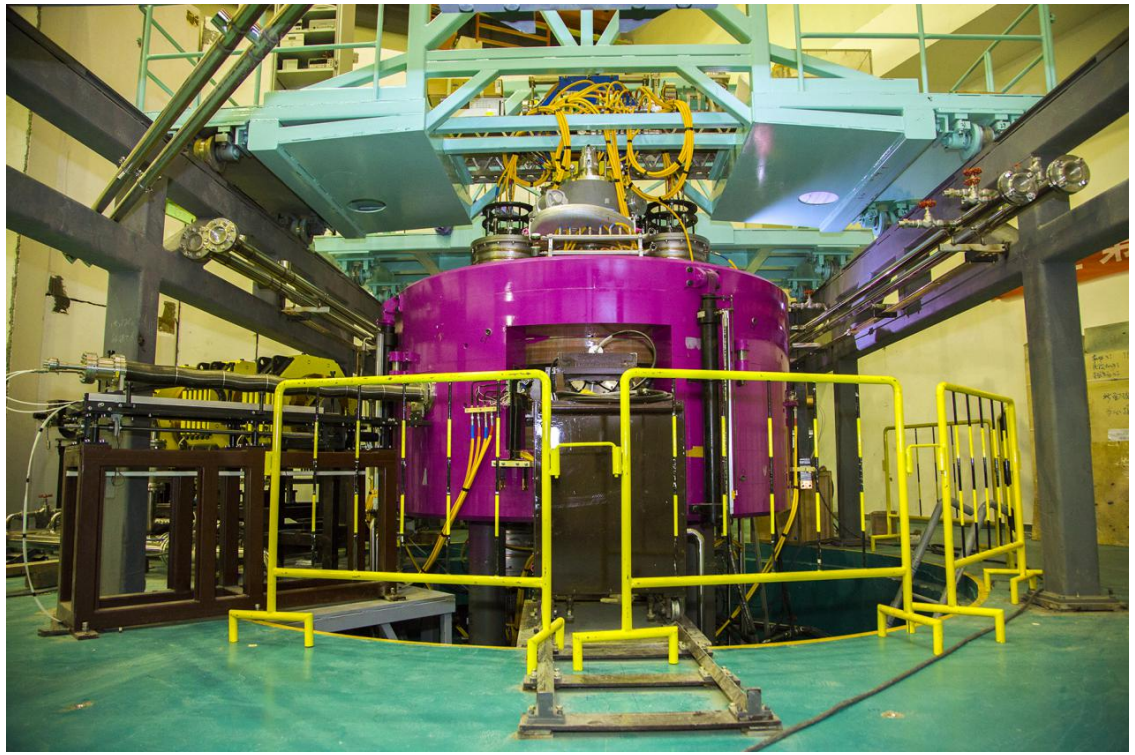
Background



Schematic view of HIMM

- 2 ECR ion sources
- ~7MeV/u Cyclotron
- 120-400 MeV/u Synchrotron
- 4 Treatment terminals
- 5 fixed irradiation ports
- Maximum particle number in the terminal (ppp) : 1.2E9

Background



HIMM-IC

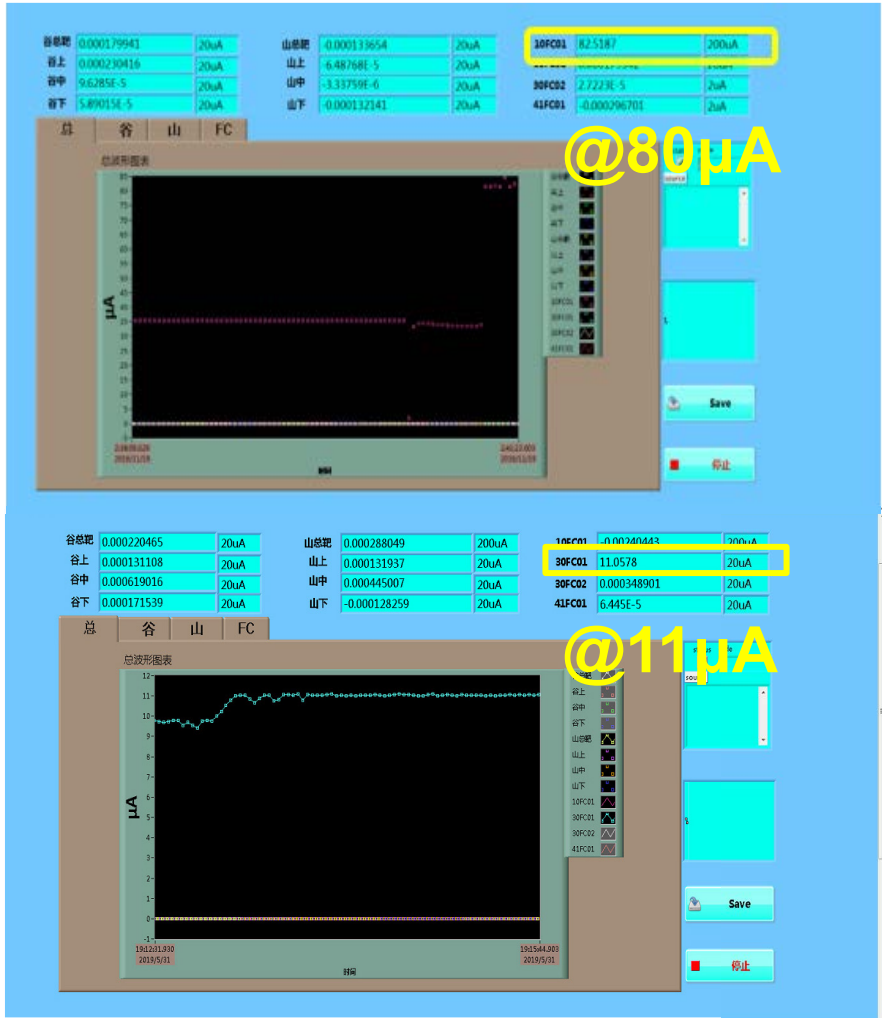
- Compact Cyclotron
- No Trimming coils
- 2.92m Diameter
- ~7 MeV/u 10 μA $^{12}C^{5+}$
- 4 straight edge Sectors
- Bc@1.212T Bmax@1.732T
- 2 RF resonators@31.02MHz
- Emax@70kV

Operation status and problems

■Operation status*,1

Year	Operation Time(h)	Breakdown Time(h)	Operation efficiency
2022	7296	31.62	99.57%
2021	7536	66.05	99.12%
2022	6936	54.15	99.22%

HIMM-IC Operation status



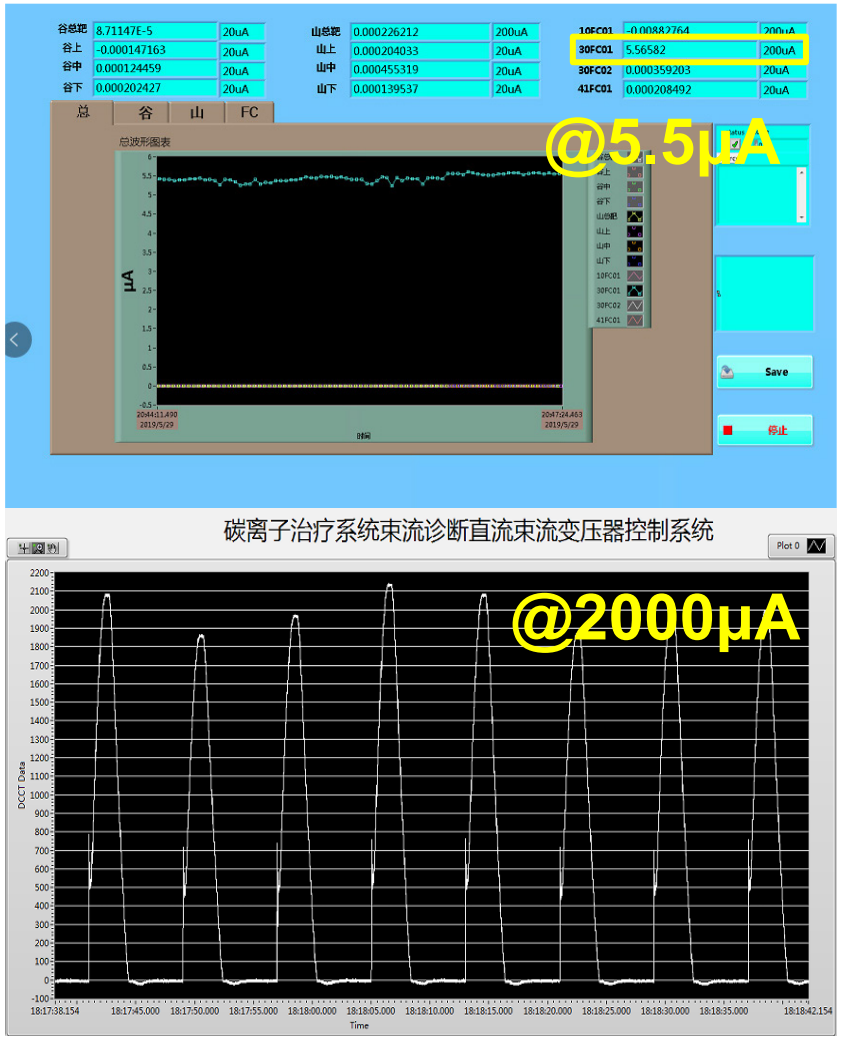
Maximum Beam Current(CW)

*THBI2 Status Report on the Cyclotron Injector for HIMM@Bing Wang(IMP, CAS)
[1]Operation of HIMM-IC in Wuwei@LANZHOU ION THERAPY CO. ,LTD

Operation status

Parameter	Value
Energy	~7MeV/u
Beam Current	≥10μA ($^{12}C^{5+}$)
Dispersion of momentum (δP/P)	≤0.5%
Emittance	≤25 π•mm•mrad(5σ)

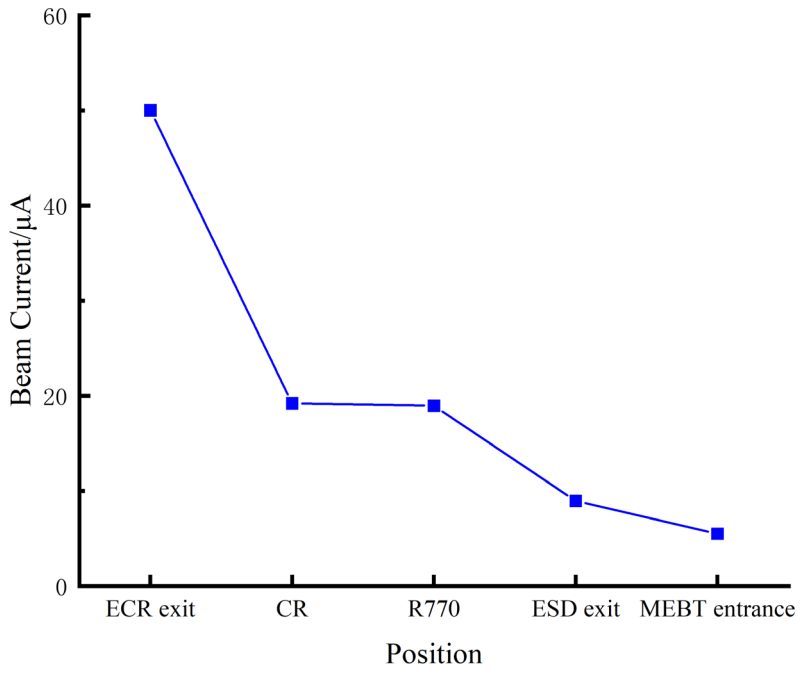
HIMM-SYN
Injection beam quality requirements[2]

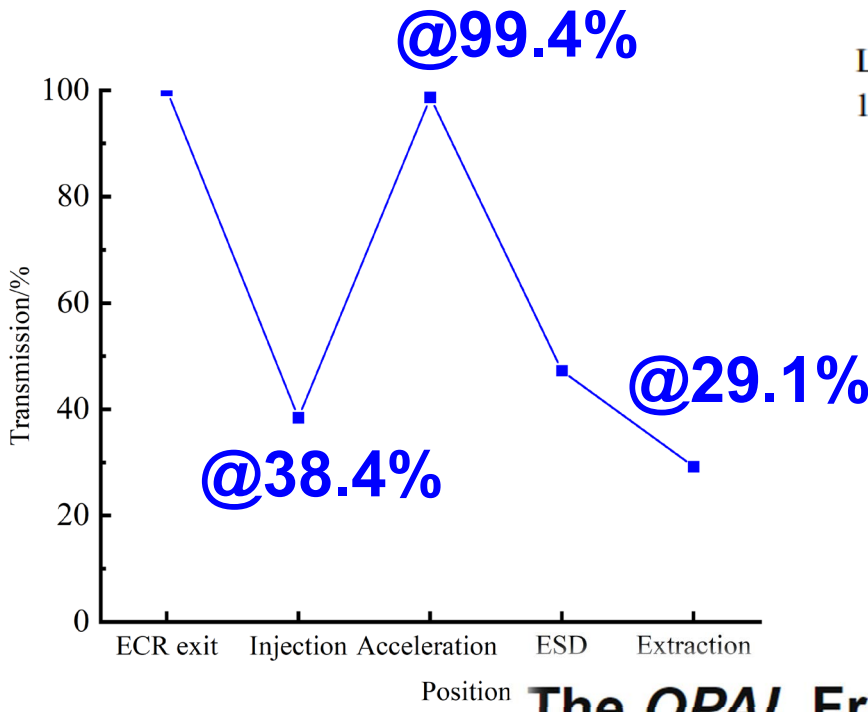


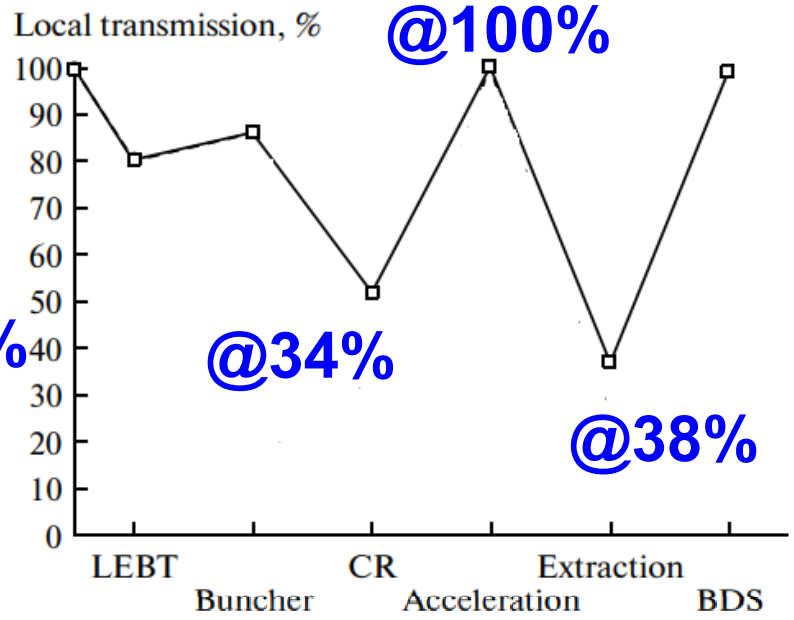
HIMM Steady Operation Beam Current[1]

[1]*Operation of HIMM-IC in Wuwei*@LANZHOU ION THERAPY CO. ,LTD
[2]*Design and Development of a 7MeV/u heavy Ion Cyclotron*@Huanfeng Hao(CIRP)

Transmission







Measurement Intensity and transmission

The *OPAL* Framework: Version 2.4

Andreas Adelmann (PSI) · Pedro Calvo (CIEMAT) · Matthias Frey (PSI) · Achim Gsell (PSI) · Uldis Locans (PSI) · Christof Metzger-Kraus · Nicole Neveu (SLAC) · Chris Rogers (RAL) · Steve Russell (LANL) · Suzanne Sheehy (Oxford) · Jochem Snuverink (PSI) · Daniel Winklehner (MIT) – 2021-10-21

[1] ***Operation of HIMM-IC in Wuwei*@LANZHOU ION THERAPY CO. ,LTD**

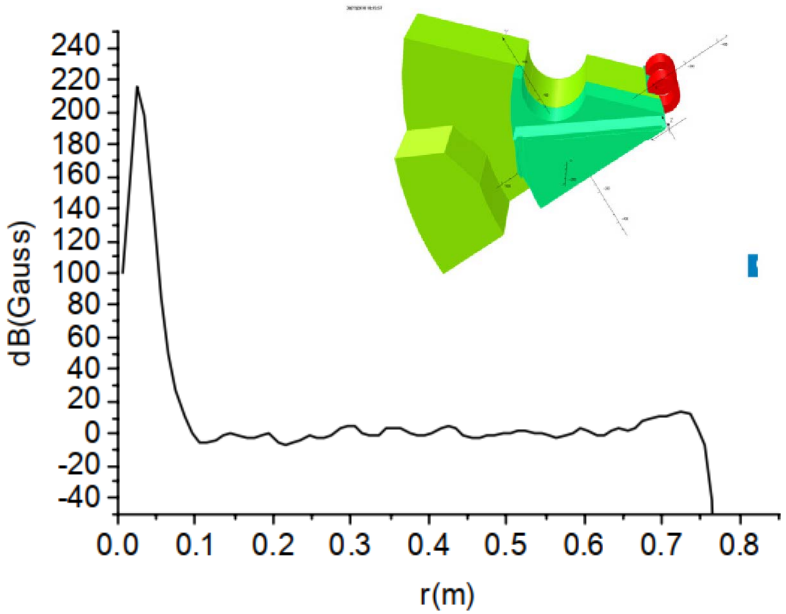
[3] ***Computer Design of a Compact Cyclotron(2012,PPNL)*@Bing Wang(IMP,CAS)et.al**

Simulations of beam dynamics

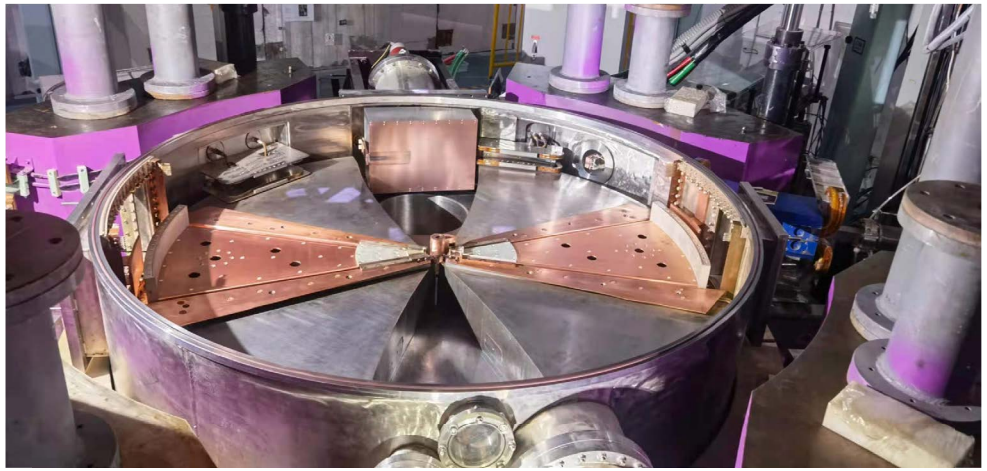
- Analysis of Isochronous magnetic field
  - Static Equilibrium Orbit
  - Tune Calculation
- Simulation of Acceleration(central region + accelerate region)
  - Single Particle
  - Multi-particles
- Simulation of Extraction System(still modeling)

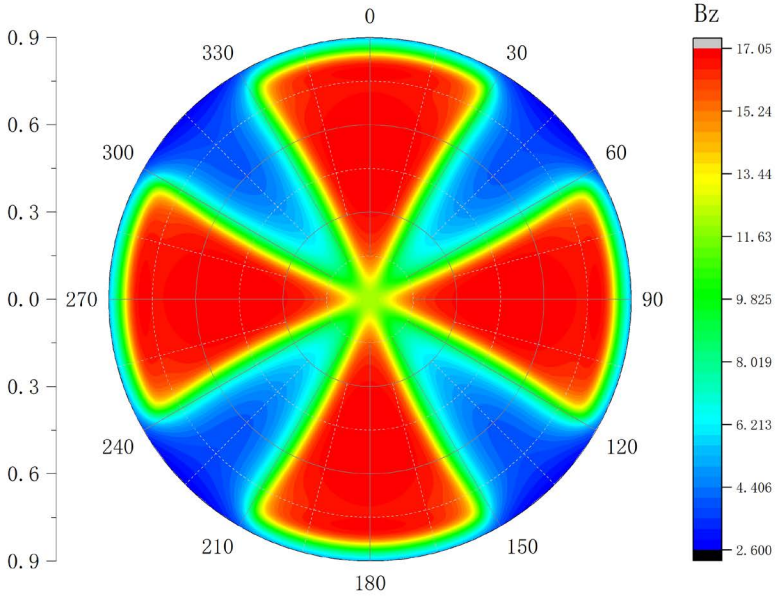
Simulations of beam dynamics

Analysis of Isochronous magnetic field



Design model errors with theoretical field[4]



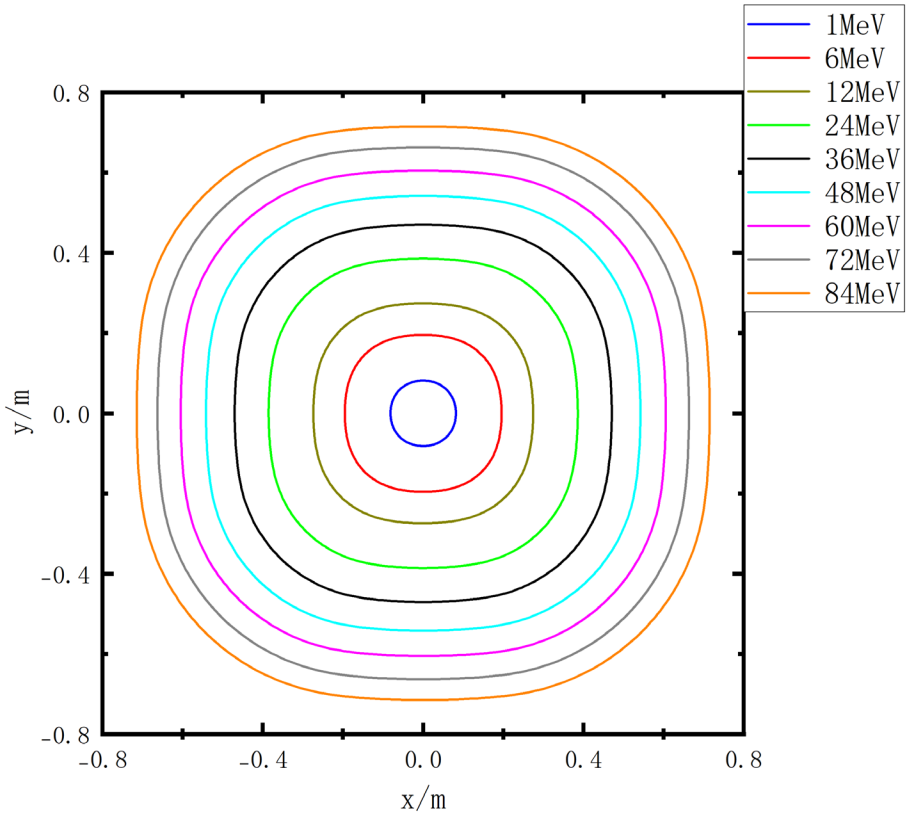


Measurement Bz Map

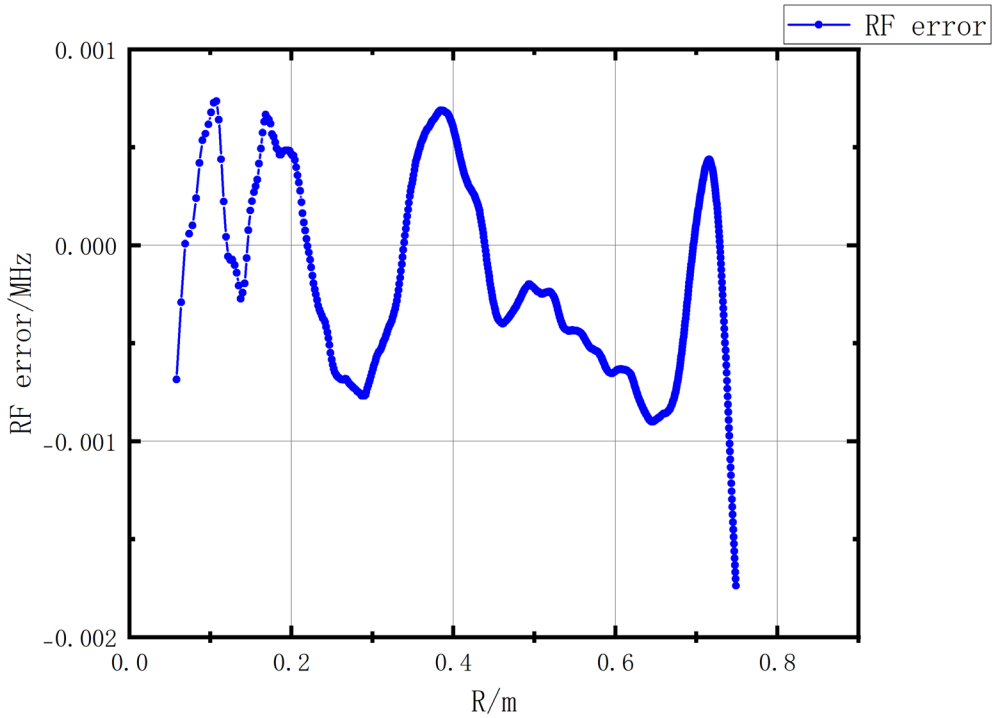
[4]*DESIGN AND CONSTRUCTION PROGRESS OF A 7MEV/U CYCLOTRON(2010, CYC2010)*@Bing Wang et.al

Analysis of Isochronous magnetic field

Static Equilibrium Orbit



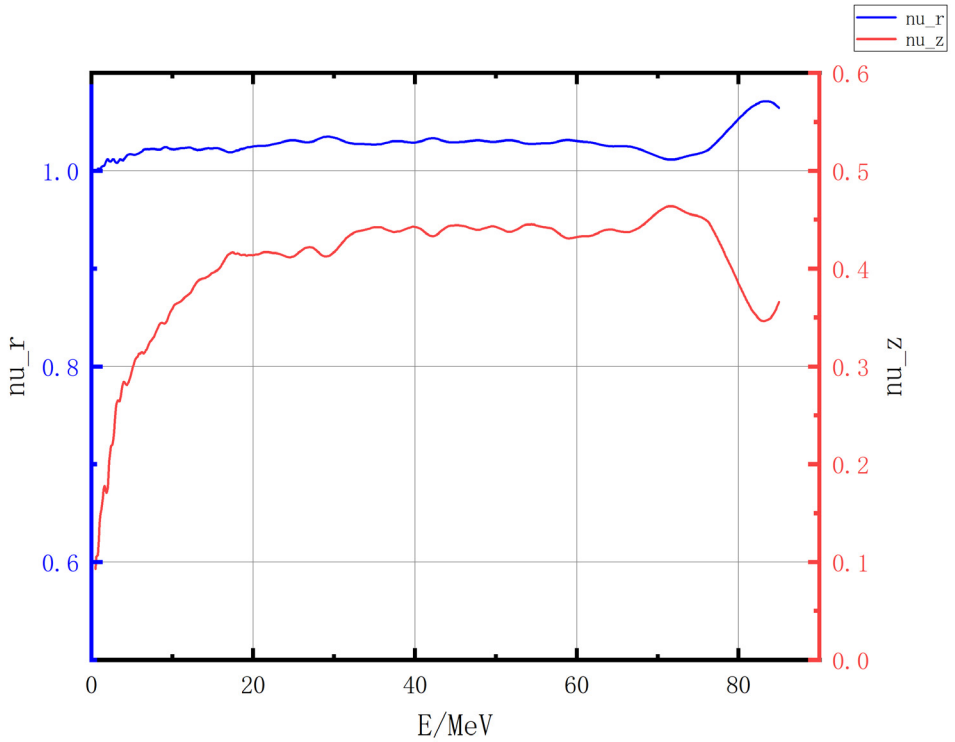
Static Equilibrium Orbit



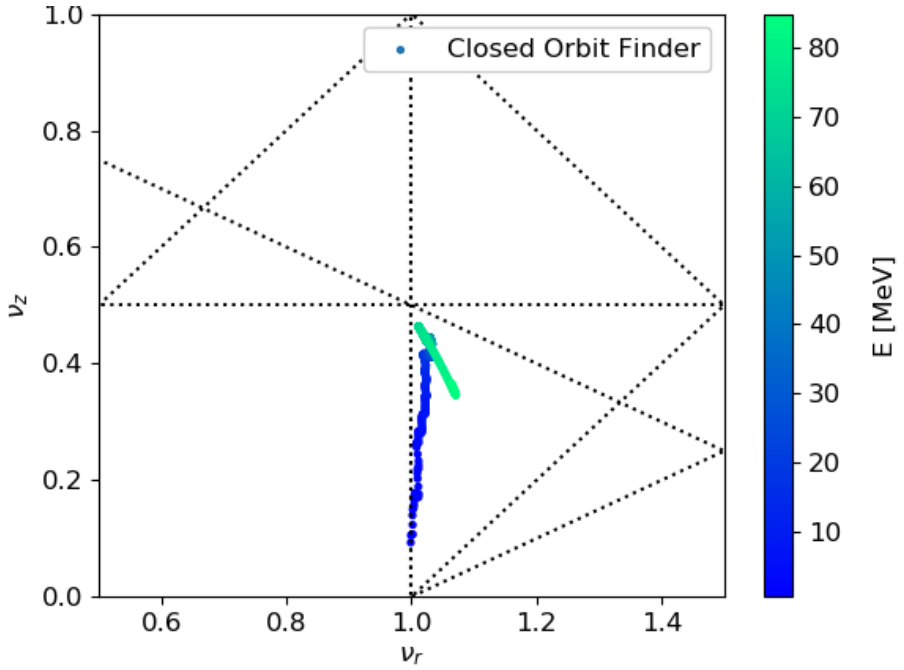
RF Error

Analysis of Isochronous magnetic field

Tune Calculation



Tune Calculation of Nu_z and Nu_r



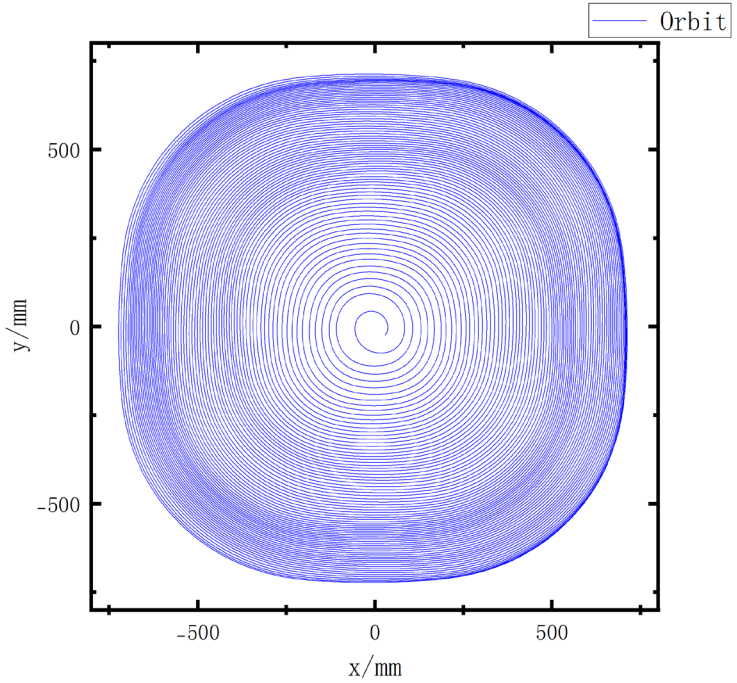
Tune Diagram

Simulations of beam dynamics

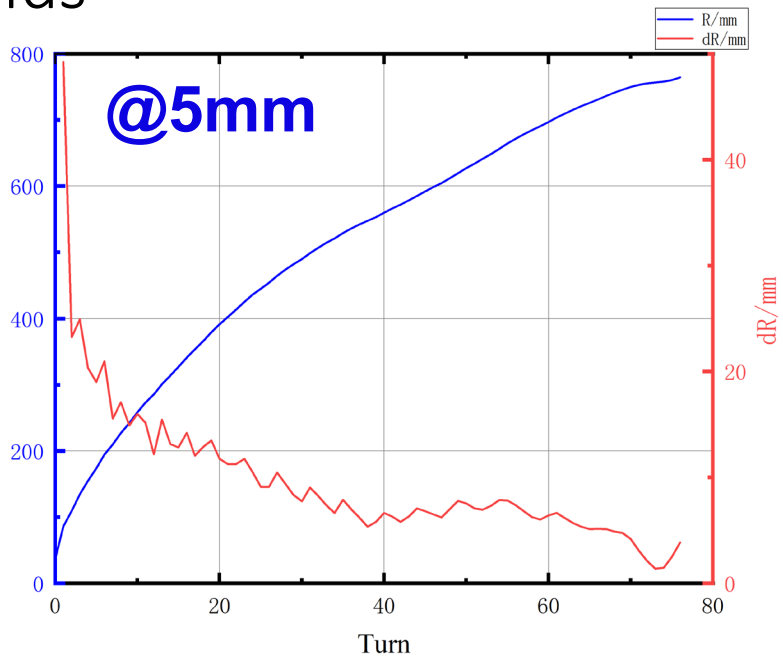
■Acceleration Orbit(Single Particle)

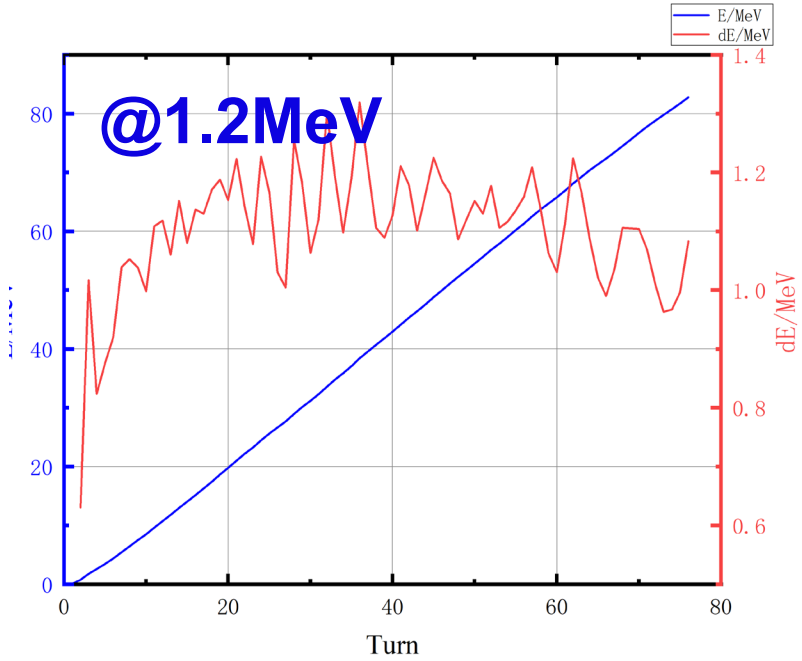
- ●3D RF E-fields
- ●2D Measurement B-fields

- 77 turn@0.1122-84.971MeV
- dR(77)~5mm
- dE(average)~1.2MeV



Acceleration Orbit



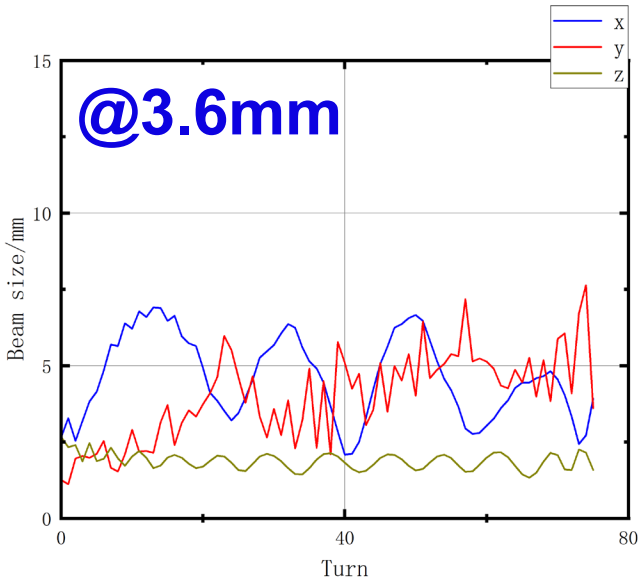


R-dR & E-dE

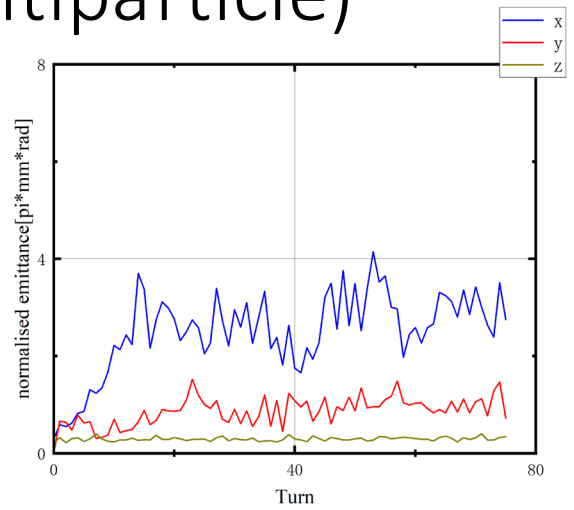
Simulations of beam dynamics

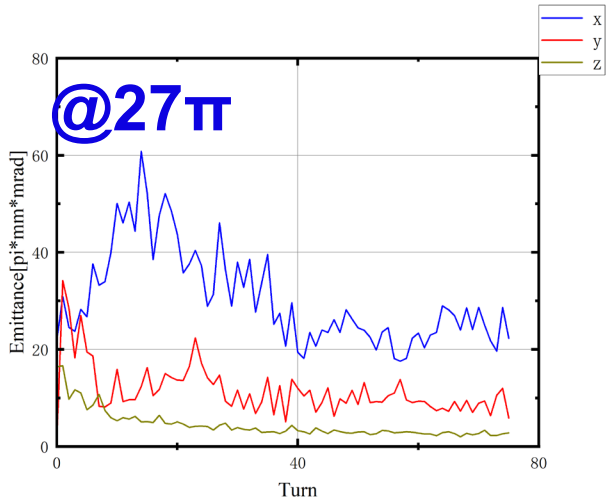
■Acceleration Orbit(Multiparticle)

●1e5 particle@20μA

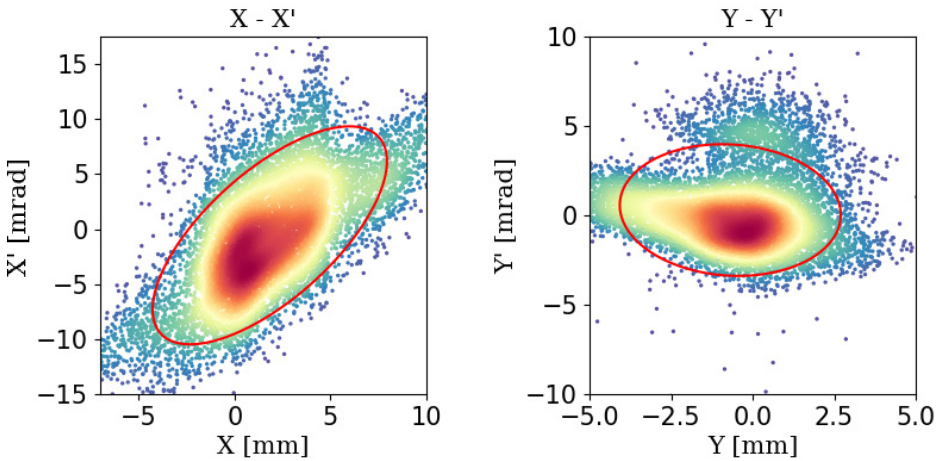


RMS Beam size

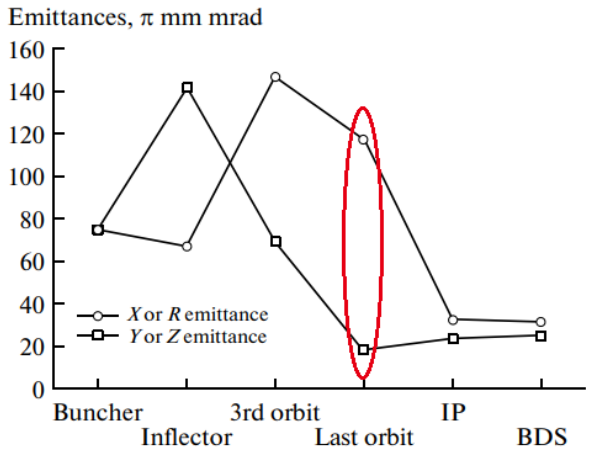




RMS Emittance

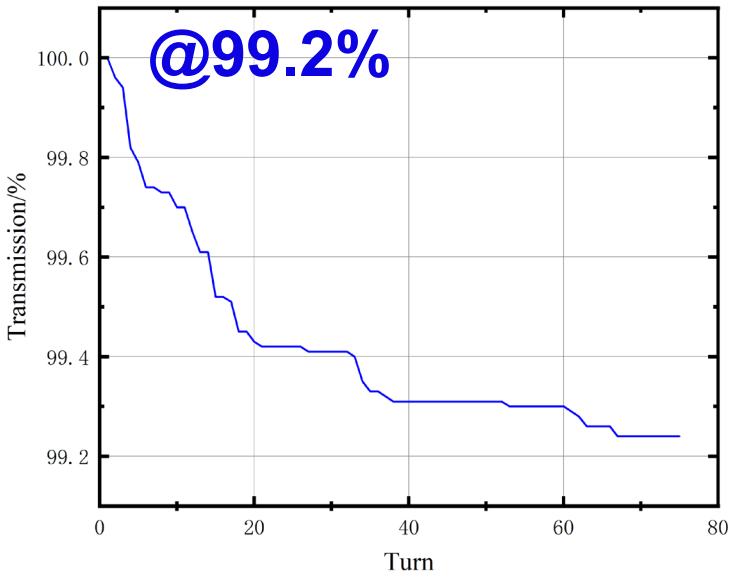


Transverse Phase space

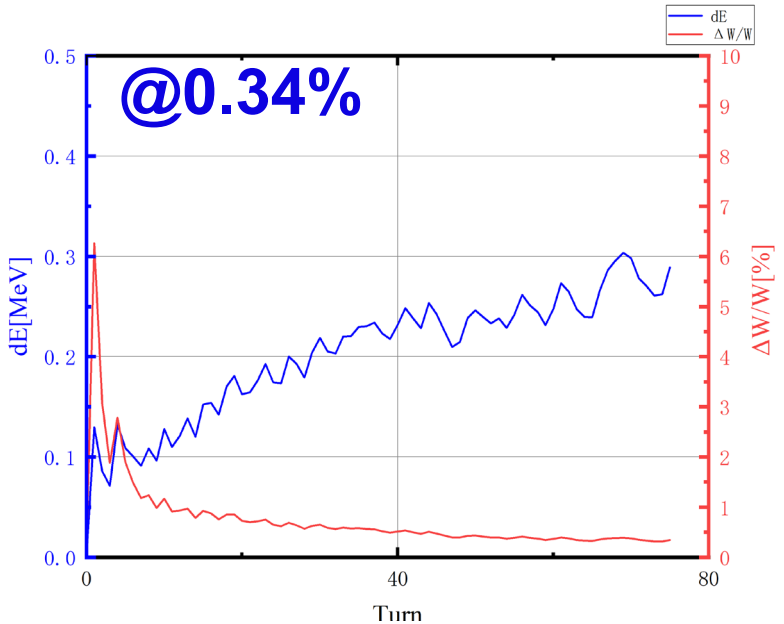


Emittance from SNOP

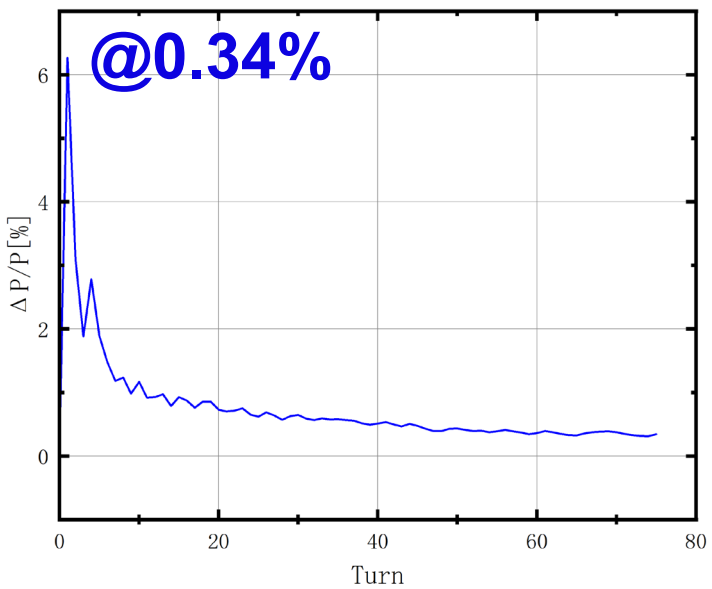
Acceleration Orbit(Multiparticle)



Acceleration Transmission

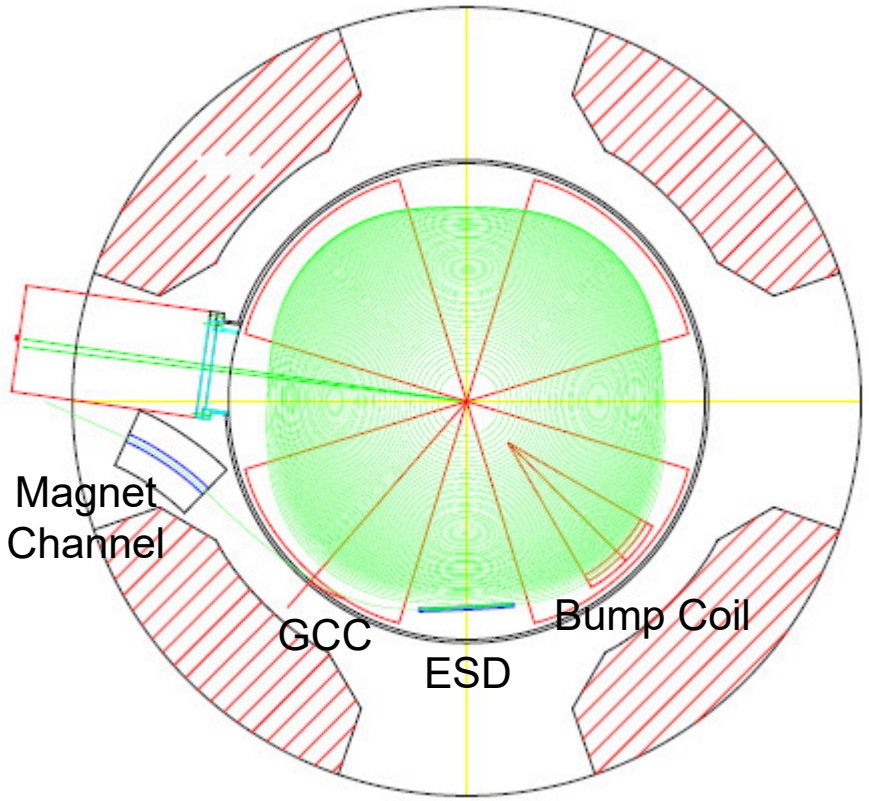


Energy Spread



Dispersion of momentum

Extraction System(still modeling)



Sechamtic of HIMM-IC

Some tips:

- OPAL-cycl
- Element: Collimator or Septum
- Polyline construction
- 3D E-fields and 2D B-fields

Summary and Outlook

Summary

- Isochronous and focusing of B-field is good;
- Transverse emittance in good agreement with SNOP;
- Acceleration transmission in good agreement with experimental data;
- Problems: big radial emittance and small turn separation.

Outlook

- Modeling of extraction system;
- End to end simulation.

Thanks for your attention!

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