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Design Considerations of Gantry Beamline for HUST Proton Therapy Facility

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Abstract

A proton therapy facility with two 360 degrees gantry treatment rooms and one fixed beamline is under development in HUST (Huazhong University of Science and Technology), which is based on isochronous superconducting cyclotron scheme. This paper presented the beam optics and main magnetic elements including dipoles, quadrupoles and fast scanning magnets of the gantry beamline. As well as the Energy Selection System (ESS) will be introduced which enable fast energy modulation of proton beam between 70 MeV to 240 MeV.

Image optics design for the gantry beamline

Compared to upstream scanning scheme, **downstream scanning** was chosen, with considerations:

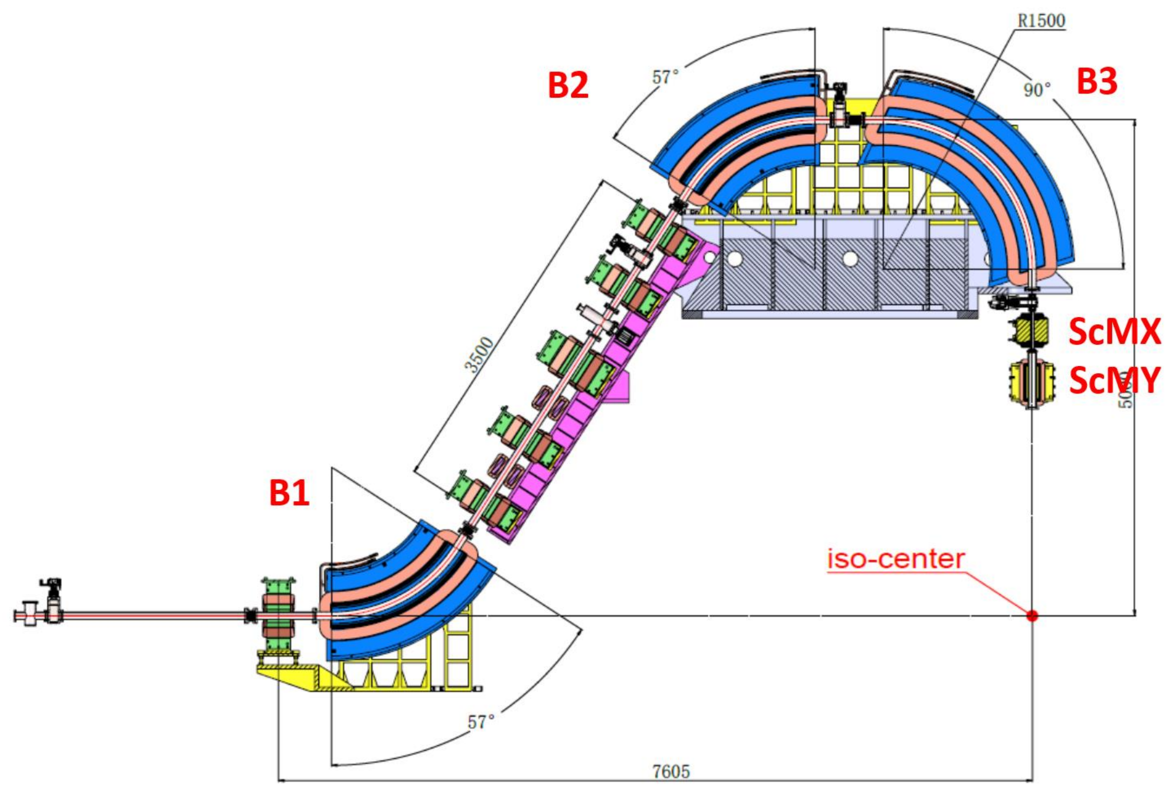
- ✓ to achieve a larger field size at the iso-center: 30cm × 30cm.
- ✓ the dependency between the excitation current and the beam position is linear, which relieve the PBS system design.
- ✓ to avoid the use of large aperture last 90 deg. dipole.

The point-to-point image optics is applied for fitting, by matching the first order transfer matrix ***R*** with $r_{11}≈r_{22}≈r_{33}≈r_{44}≈\pm1$, and $r_{12}≈r_{34}≈0$.

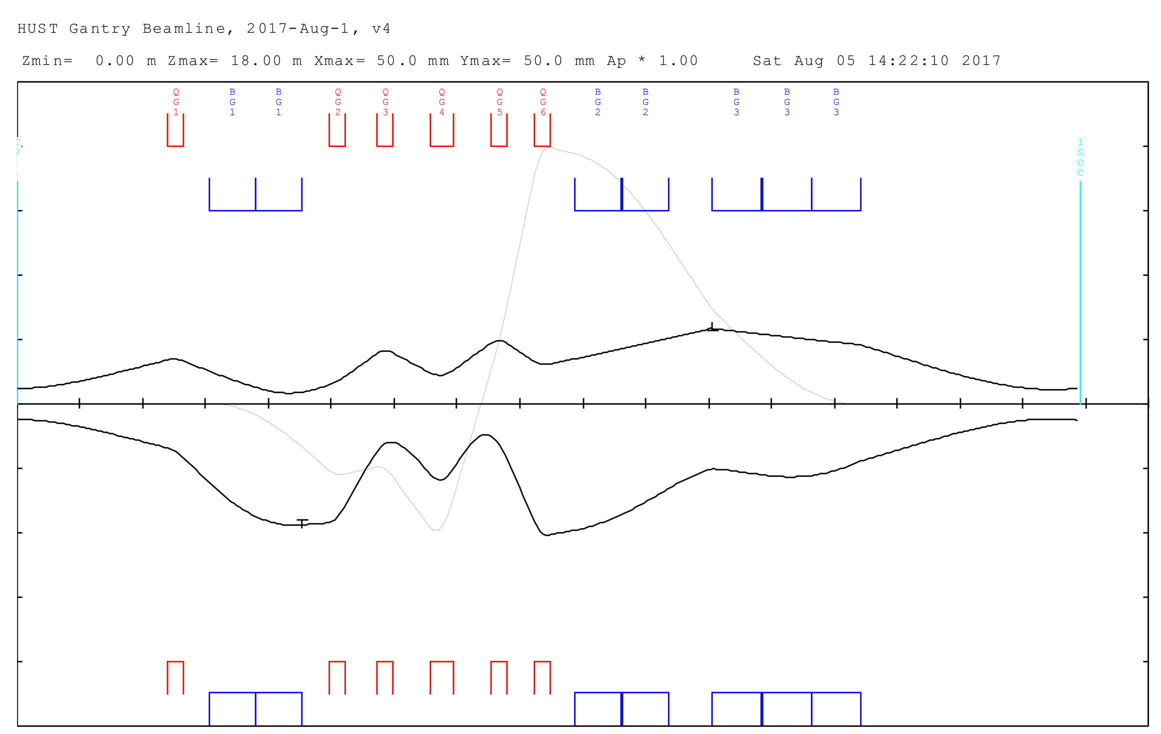
By using this image optics, the final beam size at the iso-center is highly dependent on the entrance beam size. Combined with the collimation at CP, the beam for treatment will be quite stable. To be noted, the tuning of the beam size can be done without changing the beamline optics.

TABLE II
1ST ORDER TRANSFER MATRIX ***R***
(FROM THE COUPLING POINT TO THE ISO-CENTER)

R	1(x)	2(x')	3(y)	4(y')	5	6(dp/p)
1	-1.057	0.011	0	0	0	-0.002
2	-0.445	-0.942	0	0	0	0
3	0	0	1.029	-0.014	0	0
4	0	0	0.478	0.965	0	0



Layout of the gantry beamline with downstream scanning scheme.



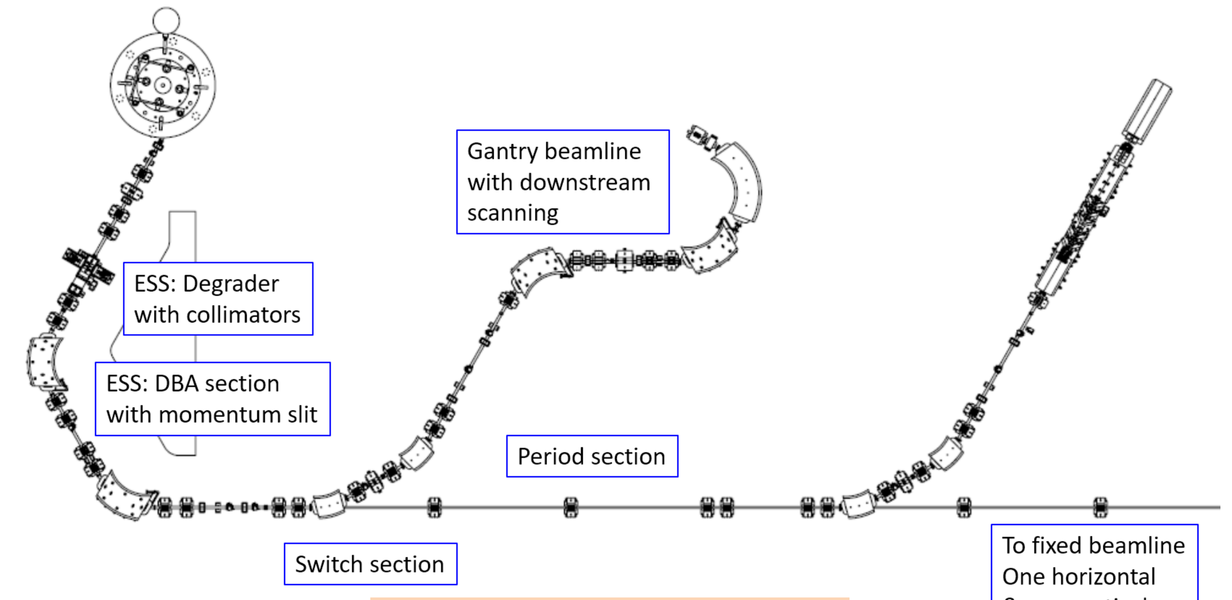
Beam envelopes (solid lines, upper is the vertical beam envelope and lower is the horizontal one) in the gantry beamline calculated by Transport code. The dash line is the dispersion function with unit mm/%. Initial beam condition at CP: x=y=2.5mm, x'=y'=2.8mrad, dp/p=±0.5%

Introduction and Background

HUST proton therapy (PT) facility is a 5 years National Key Research and Development Program of China. This facility is based on an isochronous superconducting cyclotron, two 360 degree rotation gantry treatment-rooms and one fixed beamline treatment station will be constructed at the first stage. Main specifications are listed in Table.1

TABLE I
MAIN SPECIFICATIONS OF HUST PT FACILITY

Parameter	Specification
Accelerator type	Isochronous superconducting cyclotron
Beam energy	250 MeV
Energy range from ESS	70-240 MeV
Energy modulation time	150ms per step
Gantry type	360 degree, normal conducting
Treatment scheme	Pencil beam scanning (PBS)
Max. dose rate	3Gy/L/min
Field size	300mm×300mm
References	8



Layout of the beamline

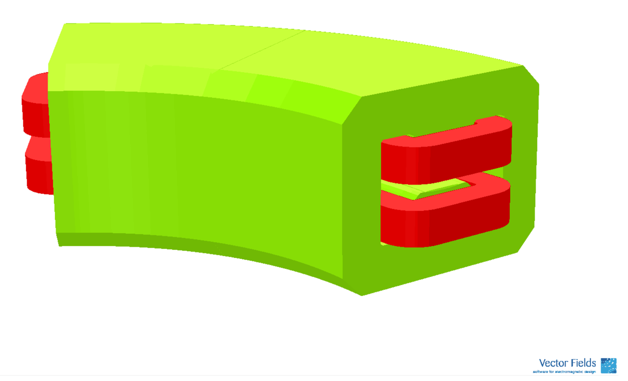
Magnets, beam diagnostics and other elements

Detailed magnet specifications of the gantry beamline are listed in table 3. Main requirements:

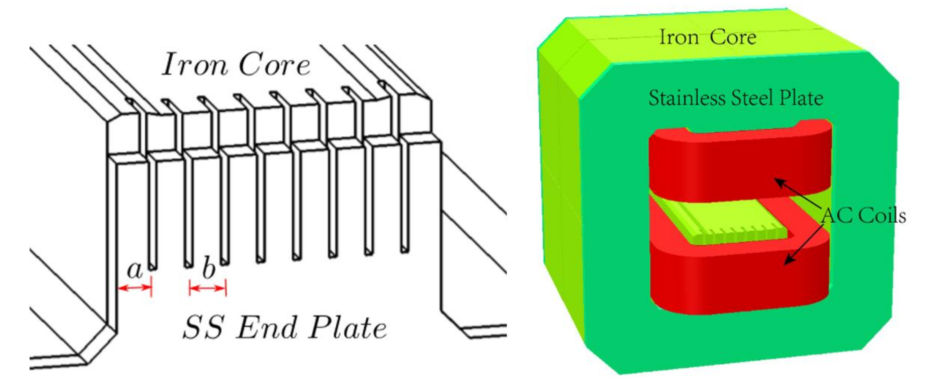
- ✓ Consistent magnetic field quality for high field and low field, which covers magnetic rigidity for 70 MeV to 240 MeV proton beam;
- ✓ Conservation of field linearity, which is important for dynamic feature of magnets during fast energy switch for treatment;
- ✓ Compact design for magnet structure.

TABLE III
MAGNET ELEMENTS AND MAIN SPECIFICATIONS OF THE GANTRY BEAMLINE

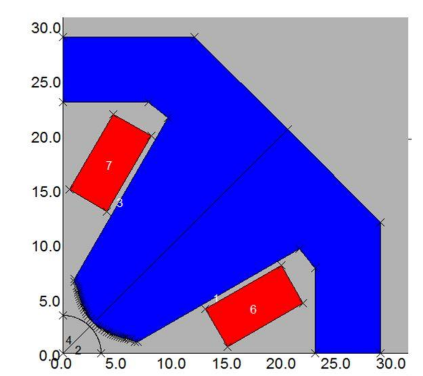
Type	Parameter	Value
57 degree dipole	Bending radius	1500 mm
	Maximum field	1.58 T
	Quantity	2
	Tilt angle	0 degree at entrance and exit
90 degree dipole	Bending radius	1500 mm
	Maximum field	1.58 T
	Quantity	1
	Tilt angle	25 degree at entrance and 17.5 degree at exit
Regular quadrupole	Effective length	270 mm
	Maximum gradient	17.5 T/m
	Quantity	5
Long quadrupole	Effective length	380 mm
	Maximum gradient	17.5 T/m
	Quantity	1
Steering magnet	Effective length	220 mm
	Maximum field	0.055T
	Quantity	2 set
Scanning magnet	Maximum deflection angle	55 mrad for ScMX (horizontal) ; 65mrad for ScMY (vertical)
	Maximum field	0.52 T for ScMX (horizontal) ; 0.39 T for ScMY (vertical)
	Maximum repetition rate	100 Hz for ScMX (horizontal)



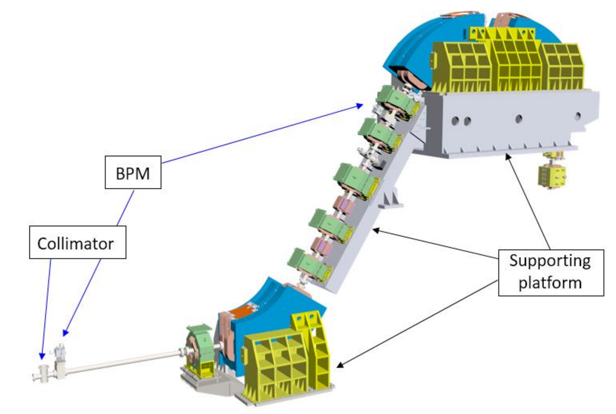
A 57 degree dipole model



(Left) Configuration of end slits in fast scanning magnet (ScMX); (Right) OPERA-3D/ELEKTRA model.



A 270mm length regular quadrupole model.

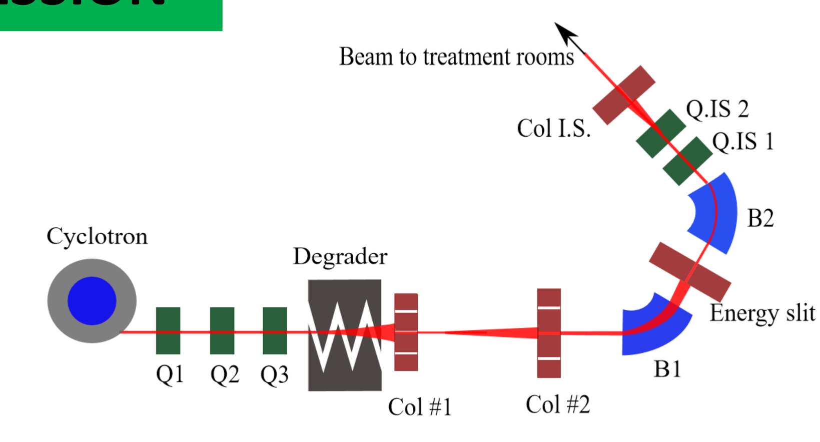


Beam diagnostic components and supporting platform for beamline magnets

Energy selection system with intensity suppression

The ESS is composed of a degrader, a DBA section with an energy slit, and a beam intensity suppression section after the DBA. A multi-wedge type degrader was chosen, due to its compactness and capability of continuous energy modulation.

For beam modulation range 70-240 MeV, the transmission varies significantly, leading to a dynamic intensity ratio about 200. To suppress this ratio to be less than 10, a primary method is to defocus the beam at difference energy spots by using two quadrupoles (Q.IS 1 and Q.IS 2) and then cut the beam with a downstream collimator (Col I.S.). The cyclotron will provide a beam current modulation interface (e.g. modulation of the deflector in central region) as an affiliated method for intensity suppression.



Layout of the energy selection system