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BEAM DYNAMICS SIMULATION OF THE EXTRACTION FOR A SUPERCONDUCTING CYCLOTRON SC240

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Abstract

In order to diversify the company's cyclotron, a design study has been carried out on a 240 MeV superconducting cyclotron SC240 for proton therapy, which is based on our experience in design of SC200. In order to increase turn separation and extraction efficiency, resonant precessional extraction method is employed in the extraction system. A first harmonic field consistent with the Gaussian distribution is added to introduce beam precessional motion. Its effects on phase space evolution and turn separation increase is studied by a high efficiency beam dynamics simulation code. According to the study, its amplitude and phase have been optimized to meet the requirements of extraction beam dynamics. Based on beam dynamics simulation, the parameters of extraction system elements (two electrostatic deflectors and six magnetic channels) are chosen. Besides, the effects of sectors spiral direction on beam extraction are studied. Extraction efficiencies and beam parameters have been calculated.

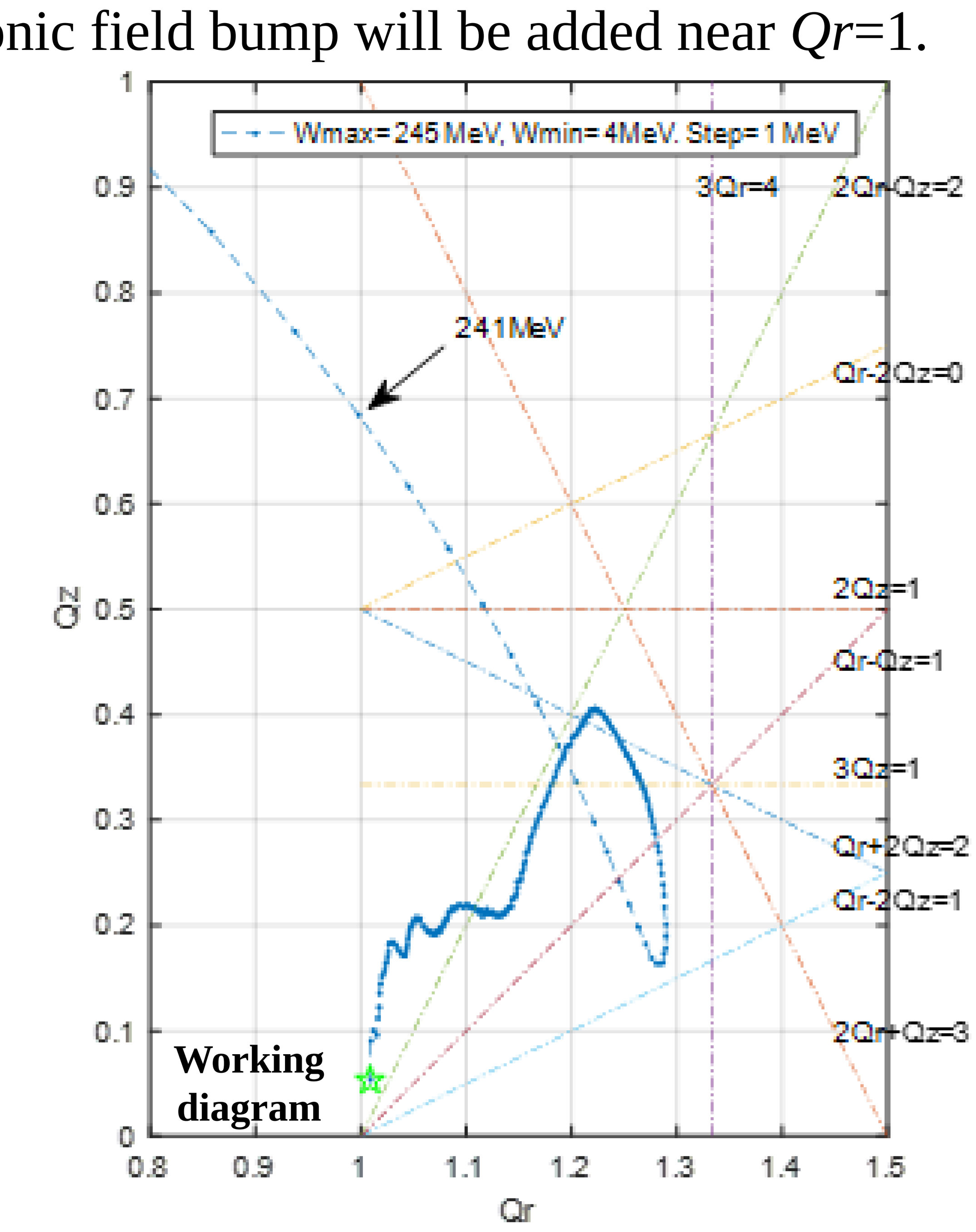
Generally Description

In order to increase extraction efficiency and decrease the voltage of deflectors as much as possible, the proposed extraction method is resonance extraction.

Parameters	Values
Extracted beam energy	244 MeV
Extraction radius	80.88 cm
Extraction mechanism	Resonance crossing and precessional motion
Spiral angle (maximum)	71°
Pole radius	84 cm
Outer radius of yoke	160 cm
Hill gap/Valley gap	5 cm/60 cm
Central field/Extraction field	2.39 T/3.01 T
Coil cross section	$dx82\times dy115$ mm^2
Current density	62.56 A/mm^2
Number of cavity	4
RF frequency	72.79 MHz
Harmonic mode	2
Cavity voltage	~100 kV

Beam Precession Design

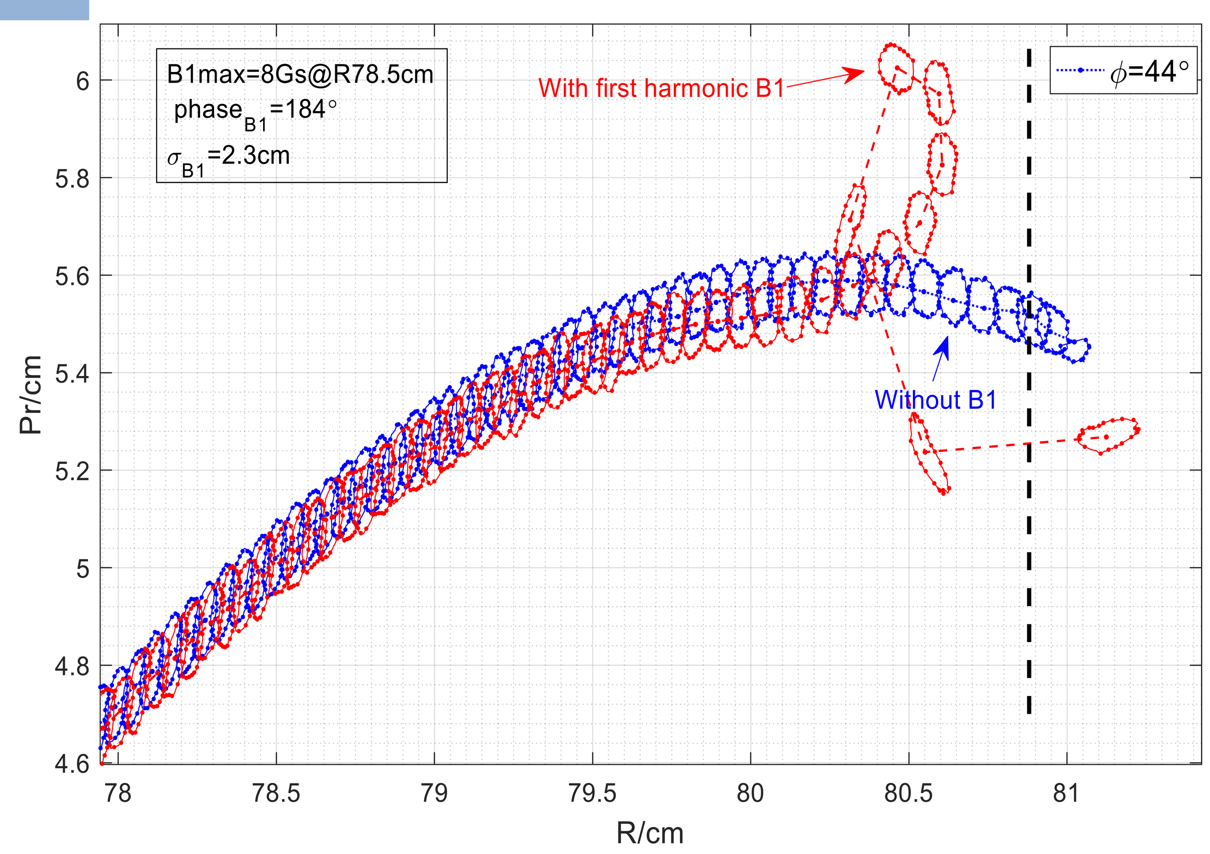
The working diagram of SC240 shows that *Qr* drops quickly in extraction region. The beam will cross *Qr*=1 resonance line when energy reaches 241 MeV. A first harmonic field bump will be added near *Qr*=1.



Working diagram

Beam Precession Design

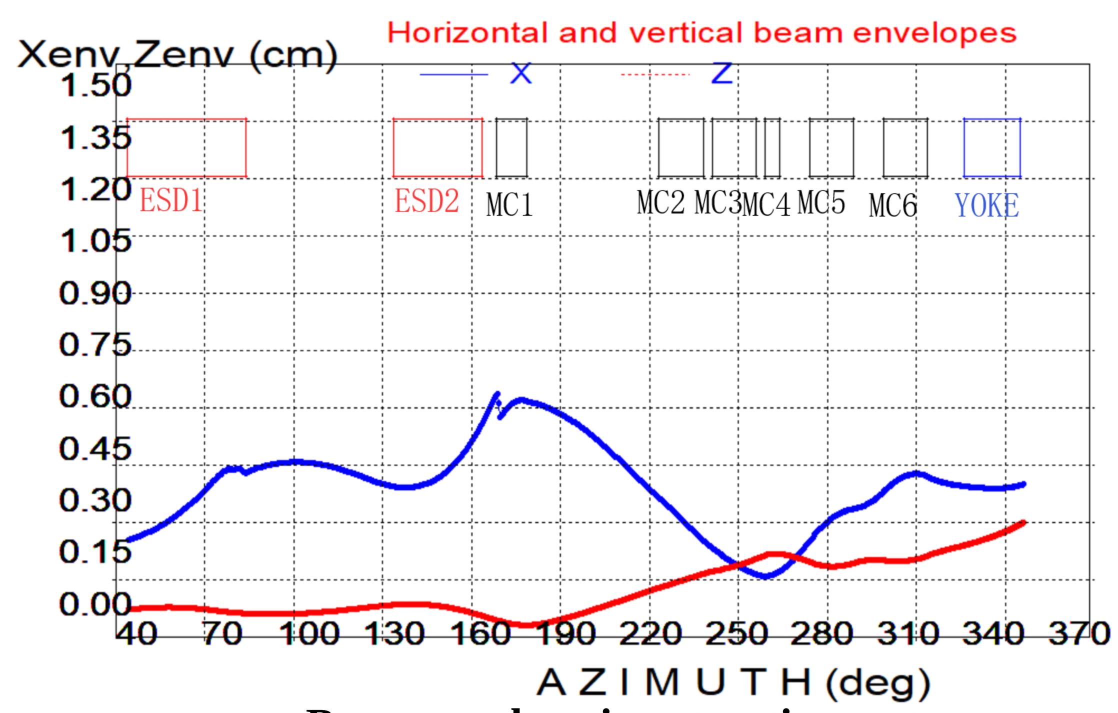
The radial distribution of 1st harmonic amplitude is consistent with the Gaussian distribution with a maximum amplitude equal to 8 Gs at centre position *R*c=78.5 cm, and a width σ=2.3 cm. The optimal phase of first harmonic is φ184° when the entrance of first deflector is at φ44° .



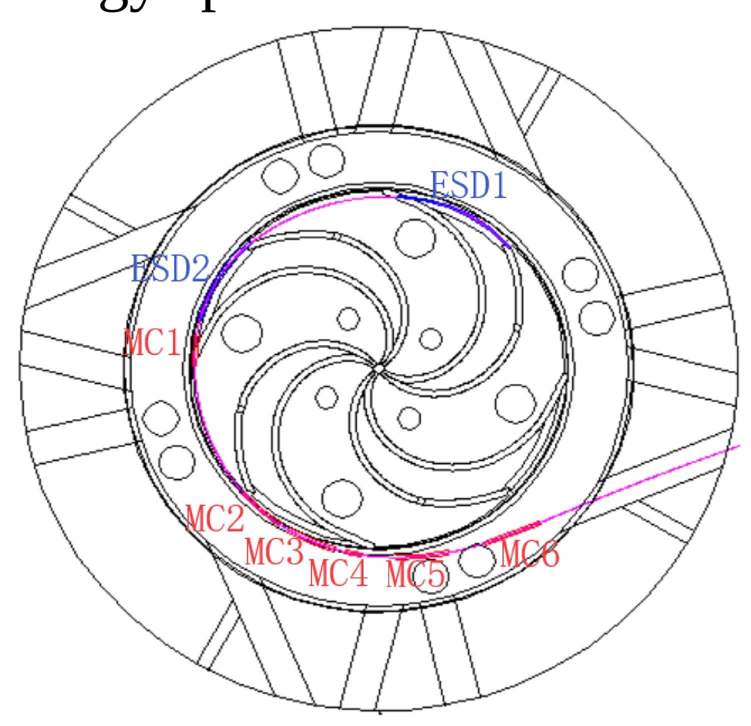
Radial phase space at extraction region

Extraction System Design

There are 2 deflectors placed at the adjacent hills and 6 passive magnetic channels. The output beam has emittance ε_x=7.81 π·mm mrad, ε_z=1.01 π·mm mrad, average energy=244 MeV and energy spread=±0.25%.



Beam envelope in extraction system



Central extraction trajectory

Elements	ϕ_1 (°)	ϕ_2 (°)	*Xc* (cm)	*Yc* (cm)	*Rc* (cm)	Δ*B* (kGs)	d*B*/dx (kGs/cm)
MC1	169	179	-3.181	3.568	78.935	-0.5	2.5
MC2	224	239	-0.384	-8.181	77.974	-0.2	2.5
MC3	242	257	4.734	-0.471	87.261	-0.2	2.5
MC4	260	265	7.134	7.258	95.376	-0.2	-2.0
MC5	275	290	8.194	25.809	114.012	-0.2	3.2
MC6	300	315	-41.92	181.892	278.180	-0.2	3.2
ESD1	44	84	6.103	12.092	68.479	*Er*=110 kV/cm	
ESD2	134	164	-11.26	4.209	71.000	*Er*=100 kV/cm	

Conclusions

It's easier to deflect beam in a resonance extraction system when the sector's spiral is in the same direction as the particle motion. We have generated a 5 mm turn separation by adding an 8 Gs 1st harmonic bump near *Qr*=1. In addition to 2 electrostatic deflectors, the proposed extraction system contains 6 sets of passive magnetic channels. The extracted beam envelop is less than 5 mm and extraction efficiency is about 76.4%.