OPTIMIZATION OF LOW-ENERGY SLOW EXTRACTION EFFICIENCY OF XiPAF

Z. J. Wang[1, 2], H. J. Yao[1, 2], X. Y. Liu[1, 2], Y. Li[1, 2], Y. Xiong[1, 2], S. X. Zheng[1,2 †], X. W. Wang[1, 2],
Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education, Beijing, China
Y. Yang, State Key Laboratory of Intense Pulsed Radiation Simulation and Effect(Northwest Institute of Nuclear Technology), Xi'an, China
[1] also at Laboratory for Advanced Radiation Sources and Application, Tsinghua University, Beijing, China
[2] also at Department of Engineering Physics, Tsinghua University, Beijing, China
†zhengsx@tsinghua.edu.cn

Background

- Xi'an Proton 200 MeV Application Facility (XiPAF) synchrotron is a **10**-200 MeV proton ring of 30.9 m circumference.
- In the low-energy slow extraction, the **space charge effect** is not negligible. The maximum incoherent tune shift for 9×10^{10} 10 MeV protons is about **-0.06**.
- In a past 10 MeV proton beam extraction experiment, the total **extraction efficiency** was over **65%** with $\mathbf{4.5\times10^{10} \sim 6.5\times10^{10}}$. But when the number of particles stored before extraction was increased to $\mathbf{9\times10^{10}}$, the total extraction efficiency was reduced to about **52%**.
- Due to the **lack of beam loss detectors**, the reduced extraction efficiency caused by the space charge effect is studied by **simulations** providing an optimal direction for the next beam commissioning to achieve high extraction efficiency.

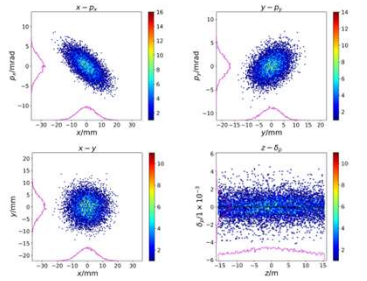

Figure 1: Initial 10 MeV beam distribution for simulation. Horizontal rms emittance is 10 π mm·mrad and rms momentum spread is 1 ‰. The simulated actual particle number is 1×10^{11}.

Table 1: Simulation parameters similar to the experimental condition

	Value		Value
Q_x	1.6627	Q_y	1.6305
Q'_x	-2.31	Q'_y	-1.43
$SR1$	14 m^{-3}	$SR2$	-36 m^{-3}
$SC1$	-12.5 m^{-3}	$SC2$	12.5 m^{-3}
A_{tri}	5.9 π mm·mrad	θ	2.9°
θ_{ES}	0 mrad	Δx	4 mm

The sextupoles' strengths rise to the design value during the first 5000 turns. RFKO is turned on from the 5001st until the 35000th turn.

Table 2: Simulated results with parameters similar to the experimental condition

	Value/ %		Value/ %
L_{bf}	20	L_{ms}	13
L_{ec}	20	L_{sb}	1
L_{ESc}	0		
E_{RFKO}	66	E_{to}	53

- L_{bf} : Loss fraction before turning on the RFKO
- L_{ms} : Loss fraction at MS of the circulating beam during RFKO extraction process
- L_{ec} : Loss fraction in the extraction channel during RFKO extraction process
- L_{sb} : Loss fraction at the bending magnets of the circulating beam during RFKO extraction process
- L_{ESc}: Loss fraction at ES of the circulating beam during the RFKO extraction process
- E_{RFKO}: Extraction efficiency during RFKO extraction process
- E_{to}: Total extraction efficiency

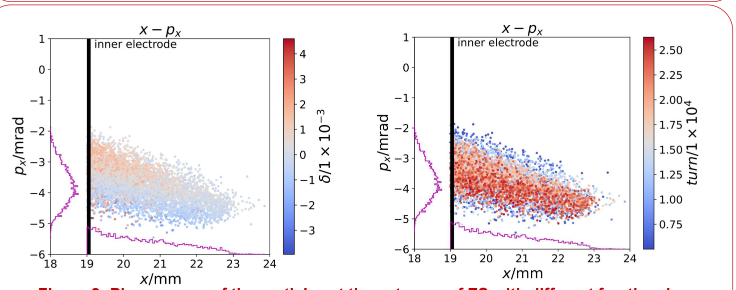

Figure 2: Phase space of the particles at the entrance of ES with different fractional momentum offset δ (left) and extracted turns (right).

Loss Analysis 1

- Due to the time varying incoherent shift and spread during extraction, the optimal Q_x and four sextupoles' normalised strengths can only be found by simulation to reduce L_{bf} and L_{ms}.
- At this point, the theory can roughly provide the direction for parameter optimization: increasing A_{tri} and reducing Δx. θ would be best limited between 0° and 30°.
- The 0.1 mm thick inner electrode which is shown in Fig.2 contributes to about 4% loss fraction in L_{ec}. The 4% loss fraction will increase when reducing Δx, as mentioned above.
- The θ_{ES} does not match the beam inclination angle at the ES inner electrode and this contributes to about 16% loss fraction in L_{ec}.
- (L_{ec}+L_{ESc}) won't be fully minimized since θ_{ES} is constant during extraction and the Hardt Condition lapses.

Table 3: Optimized simulation parameters

	Value		Value
Q_x	1.6633	Q_y	1.6316
Q'_x	-0.169	Q'_y	-2.56
$SR1$	6.7 m^{-3}	$SR2$	-5.7 m^{-3}
$SC1$	-12.5 m^{-3}	$SC2$	12.5 m^{-3}
A_{tri}	11.27 π mm·mrad	θ	14.5°
θ_{ES}	-1.25 mrad	Δx	2.5 mm

Table 4: Optimized simulation results

	Value/ %		Value/ %
L_{bf}	8	L_{ms}	3
L_{ec}	9	L_{sb}	1
L_{ESc}	5		
E_{RFKO}	82	E_{to}	75

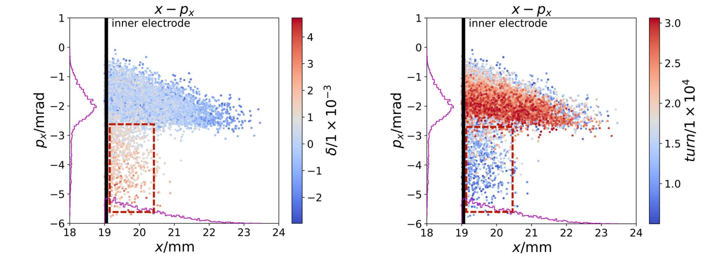

Figure 3: Phase space of the particles at the entrance of ES with different fractional momentum offset δ (left) and extracted turns (right). Particles with larger inclination angles are circled as a rough indication.

Loss Analysis 2

- Due to the horizontal chromaticity and dispersion, particles with positive momentum spread have bigger A_{tri} and may even exceed the allowed maximum stable region area at ES.
- Almost all the particles with positive momentum spread will be lost at the ES.
- It is natural to think to reduce the proportion of particles with positive fractional momentum offset to reduce L_{ec}.
- A possible way is to increase all magnets' strengths with the same ratio before turning on RFKO which is like the Constant Optics Slow Extraction (COSE) .

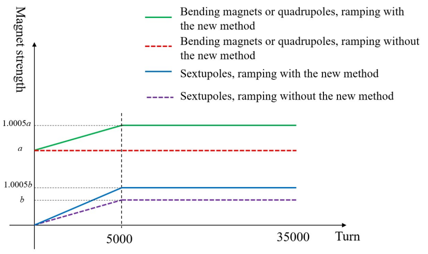

Figure 4: Schematic diagram of the ramping curves of th bending magnets, quadrupoles and sextupoles the during the extraction process.

Table 4:Simulation results with the new method

	Value/ %		Value/ %
L_{bf}	9	L_{ms}	3
L_{ec}	6	L_{sb}	1
L_{ESc}	1		
E_{RFKO}	89	E_{to}	81

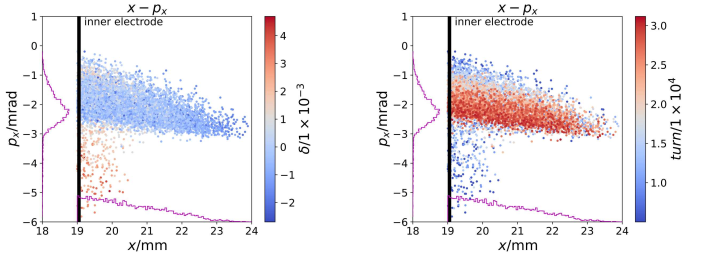

Figure 5: Phase space of the particles at the entrance of ES with different fractional momentum offset δ (left) and extracted turns (right) with the new method.

Conclusions

- Through 10 MeV proton beam extraction simulation and optimization, the total extraction efficiency and the extraction efficiency during RFKO process are improved to 81% and 89% with 1×10^{11} particles stored before ex-traction.
- The optimized parameters and the new COSE-like method will provide a reference for subsequent experiments.