



Design of a compact ring for Tsinghua advanced proton source

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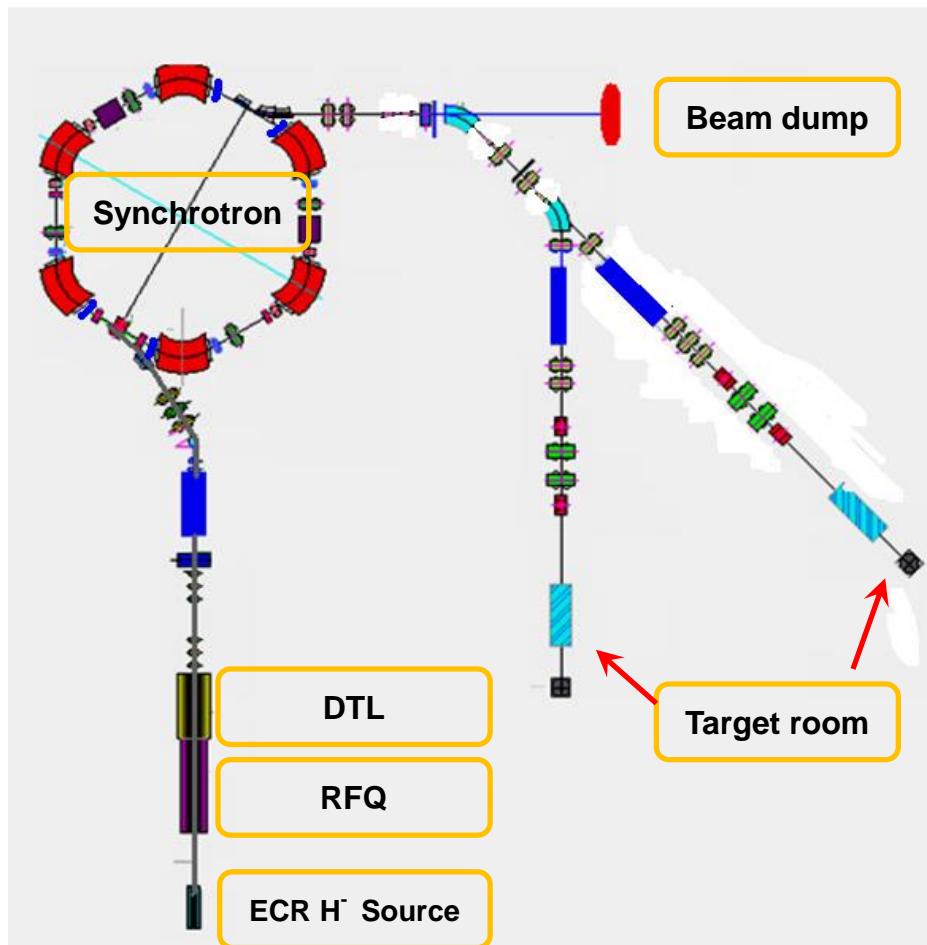
Outline

- Introduction
- Synchrotron design
 - *Lattice design*
 - *Injection*
 - *Capture and ramping*
 - *Slow extraction*
- Summary



Introduction

Layout of Tsinghua advanced proton source



□ Purpose

Space radiation effects, medical application...

□ Main parameter

Energy range: 60~230 MeV

Intensity: 2×10^{11} ppp

Pulse length: 1~10 s

Rep. rate: <0.5 Hz

□ Subsystem parameter

H^- Source : 50 keV, 10 mA

RFQ: 3 MeV

DTL: 7 MeV

Synchrotron: 60~230 MeV



Design concept of proton ring

□ Purpose

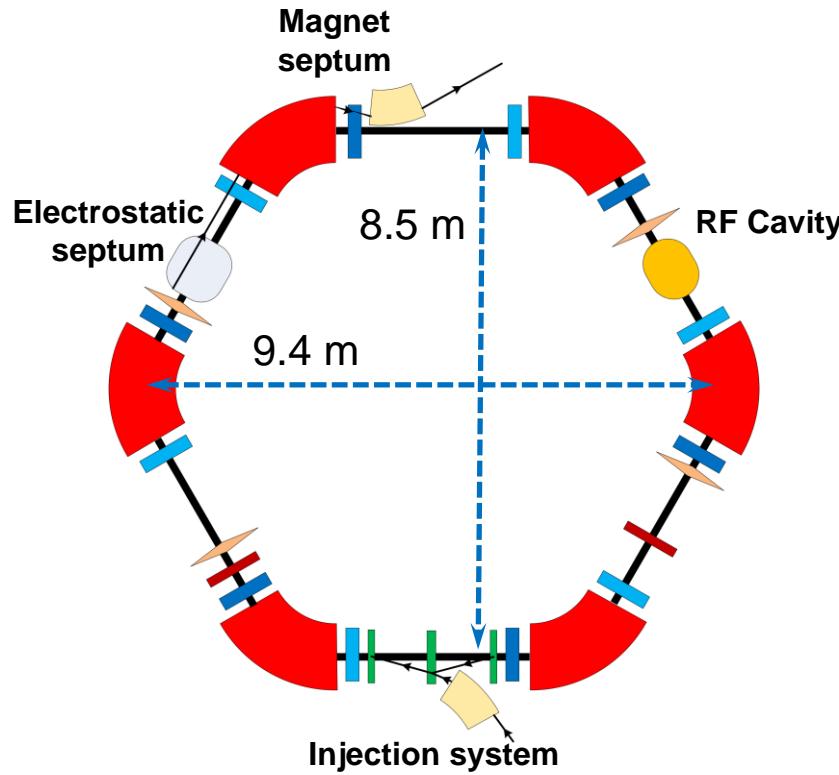
- Up to 230 MeV in less than 0.5 s
- Store 2×10^{11} protons
- Slow extraction
- Simple, reliability, free space...

□ Technology roadmap

- Injection: strip injection with painting
- Capture: adiabatic capture
- Extraction: 3rd order resonance extraction

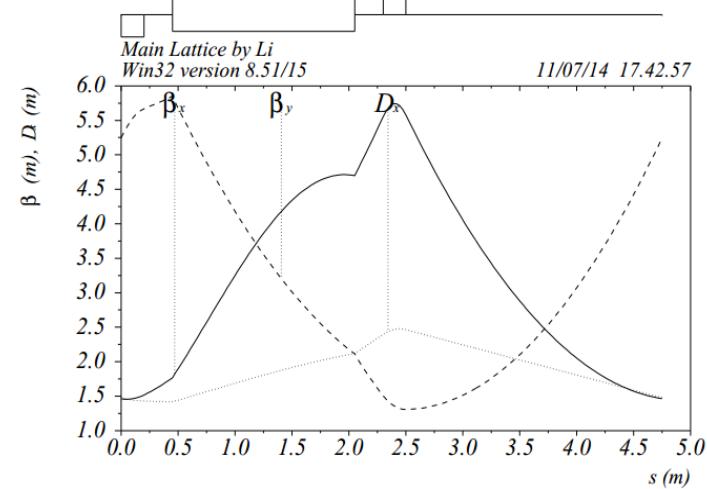


Lattice design



- Missing dipole cell
- Injection system based on chicane and bumper
- Two family sextupole for slow extraction

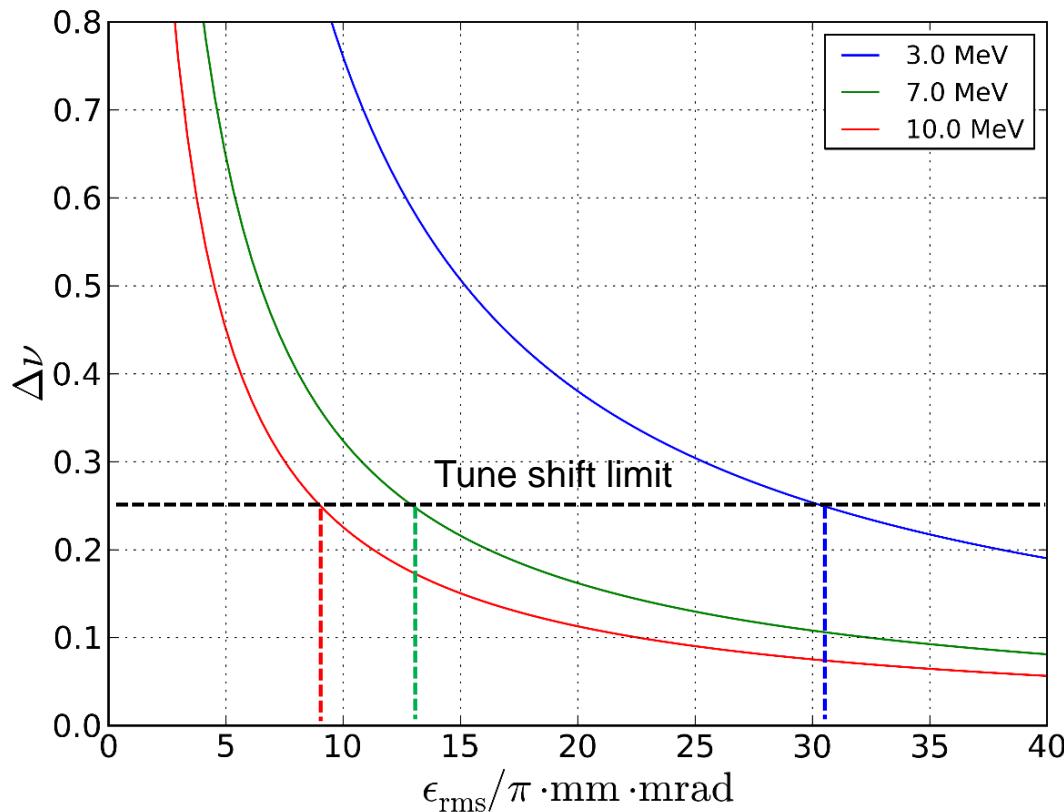
Optics of one missing dipole cell



Parameter	Value	Unit
Circumference	28.5	m
Dipole length	1.6	m
magnetic strength(max)	1.52	T
$\hat{\beta}_x/\hat{\beta}_y/\hat{D}$	5.6/5.8/2.5	m
v_x/v_y	1.68/1.79	
C_x/C_y	0.4/-1.9	
γ_T	1.59	



Injection consideration



@ $F_B=2$, $N_B=2 \times 10^{11}$

□ Incoherent tune shift

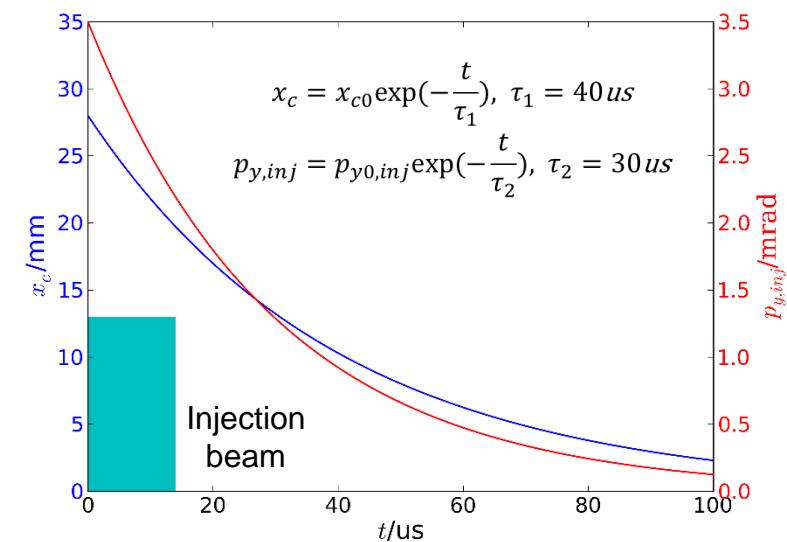
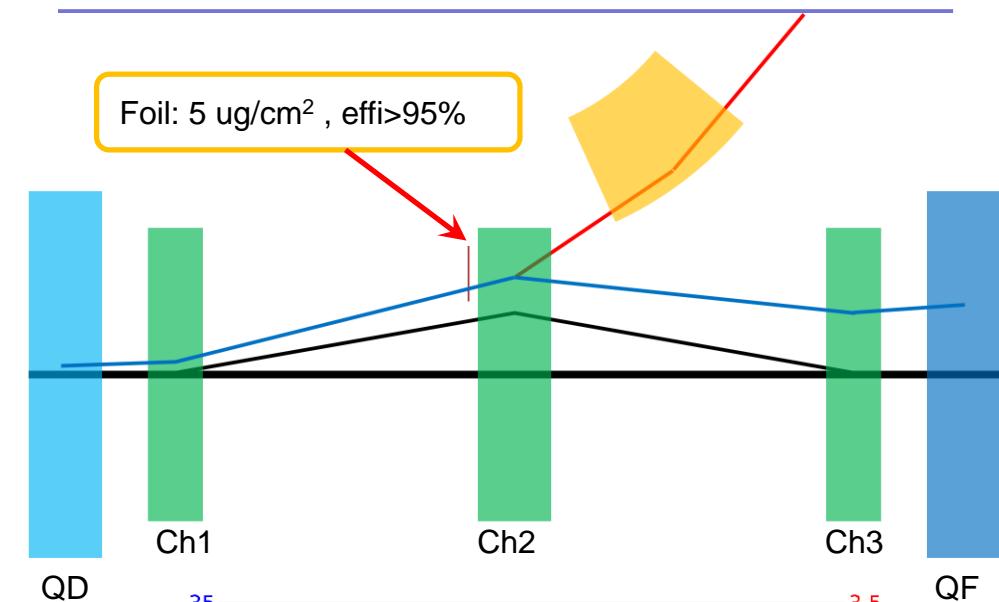
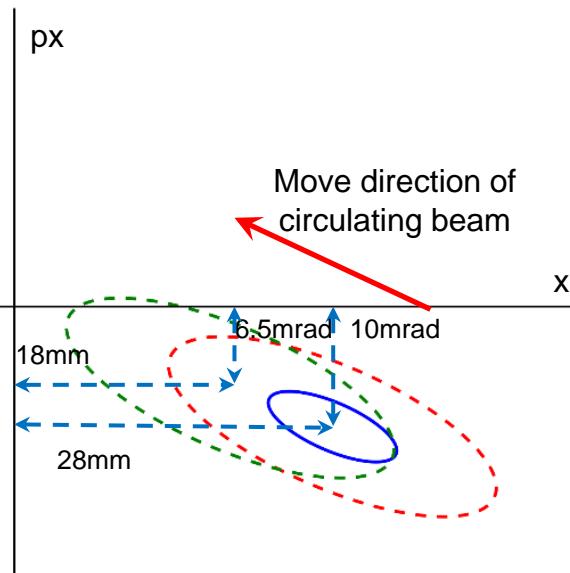
$$\Delta\nu = \frac{F_B N_B r_0}{4\pi\beta^2\gamma^3 \epsilon_{rms}}$$

□ Methods to improve intensity

- Improve injection energy
- Improve emittance
- Reduce bunching factor



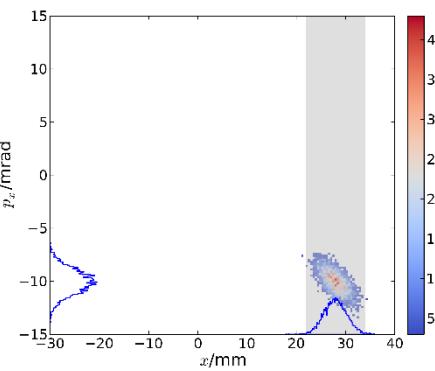
Injection system and painting scheme



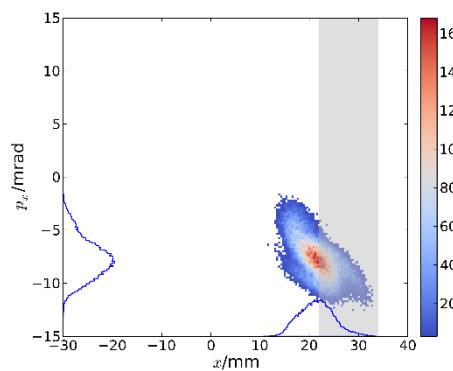


Injection simulation

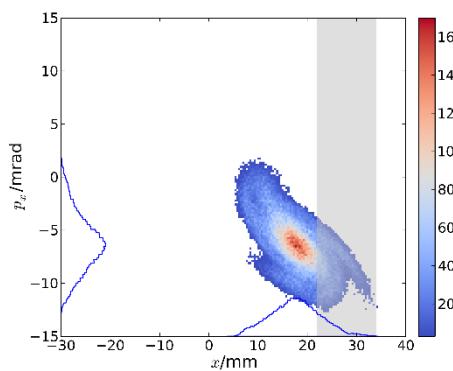
Turn 1



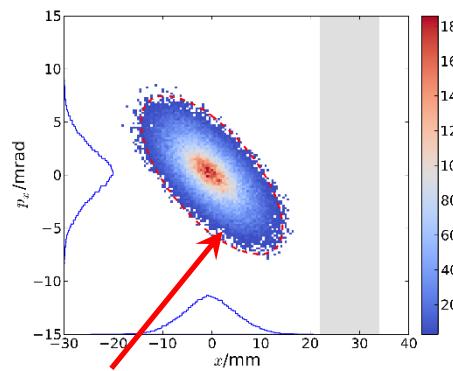
Turn 10



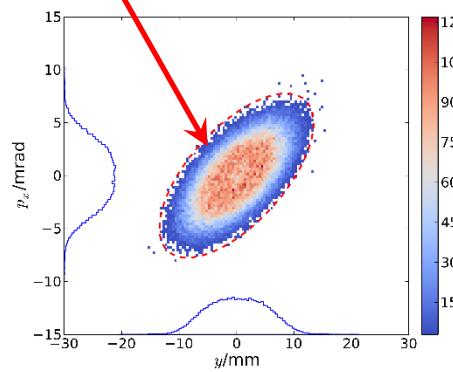
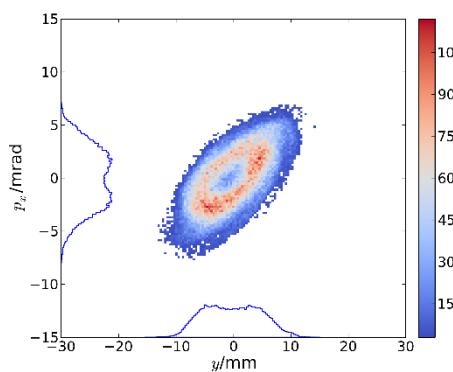
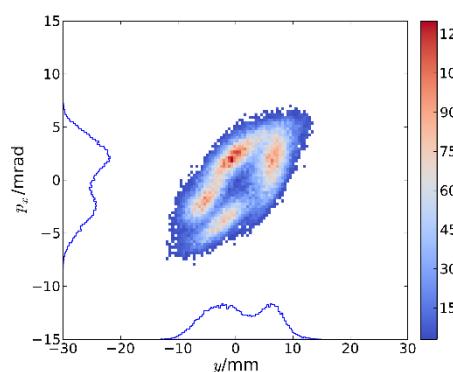
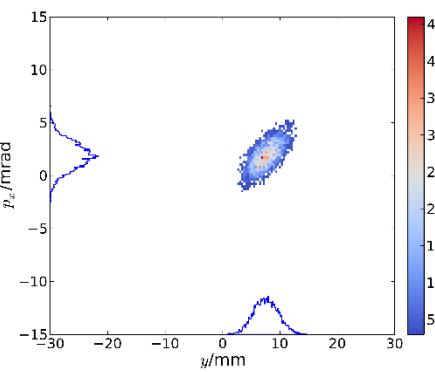
Turn 18



Turn 500



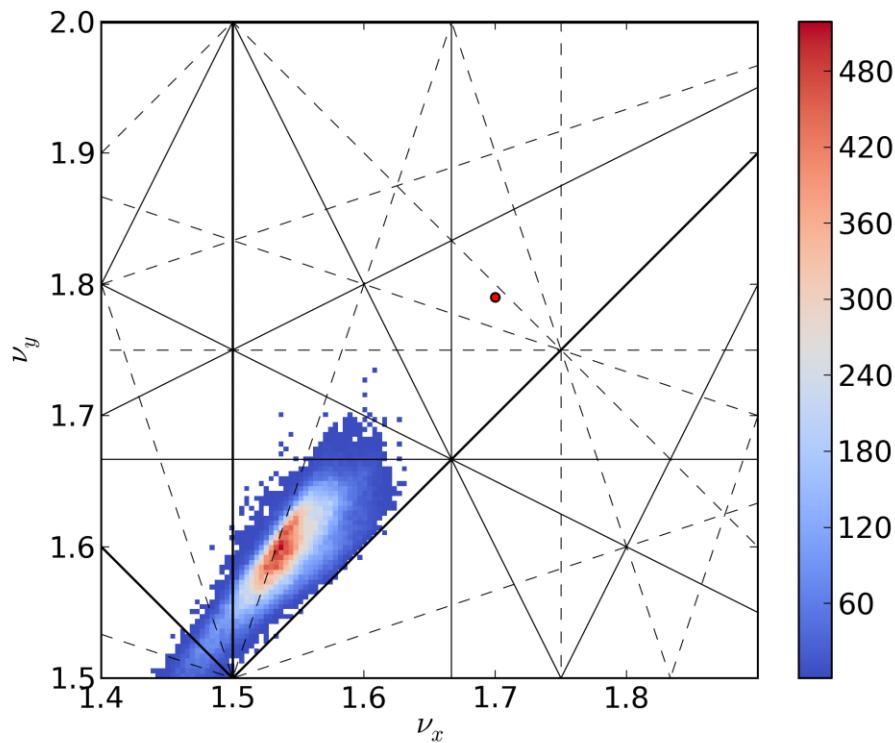
$80 \pi \cdot \text{mm} \cdot \text{mrad}$



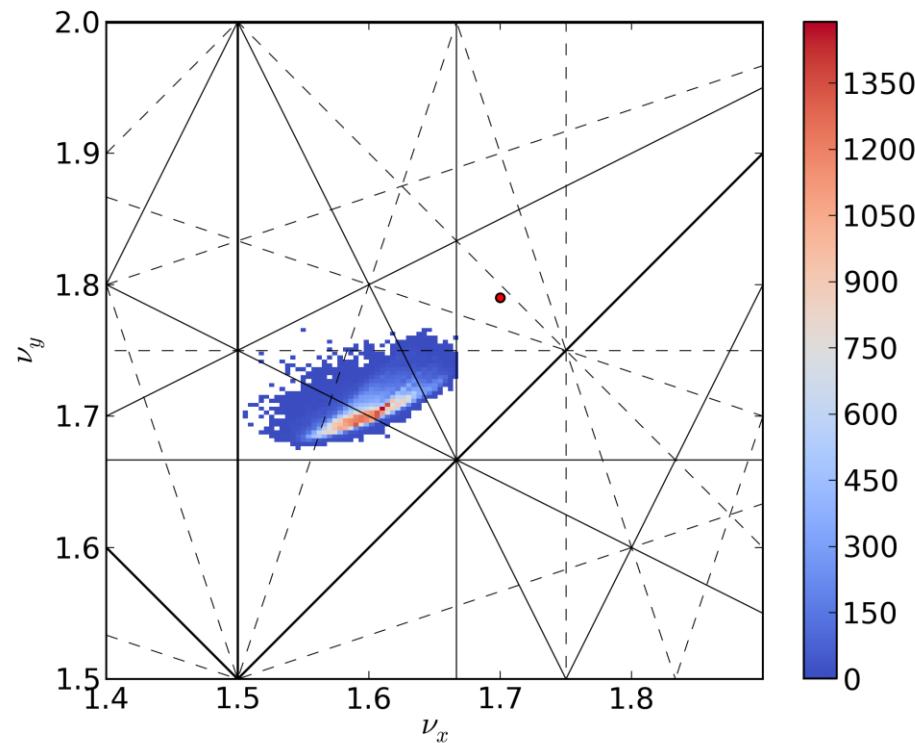
- No RF, No energy deviation, with space charge



Injection simulation



Without painting



With painting



Acceleration

□ Two stages

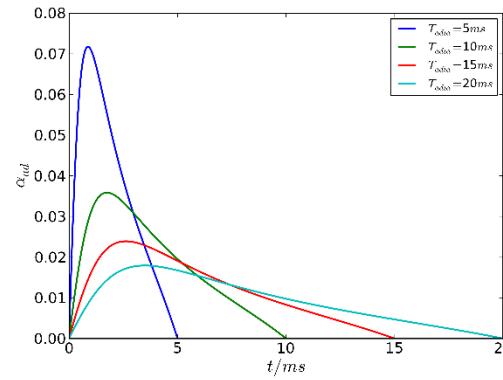
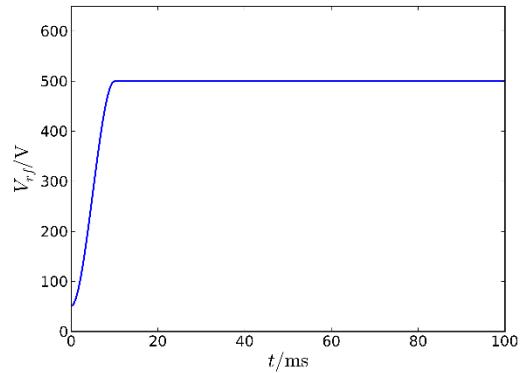
- Adiabatic capture
- Ramping

□ Main parameter

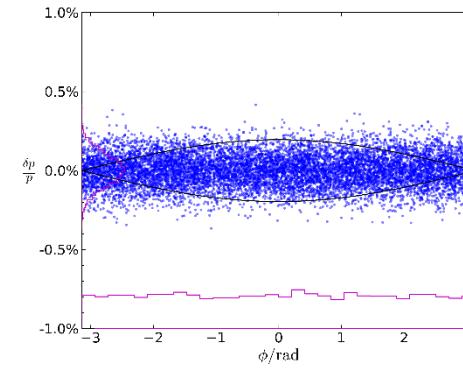
- Harmonic number: 1
- Frequency range: 1.28~6.27 MHz
- Maximum voltage: 500V
- Capture time: 10 ms
- Acceleration time: < 490 ms
- Maximum sync. phase: < 30°



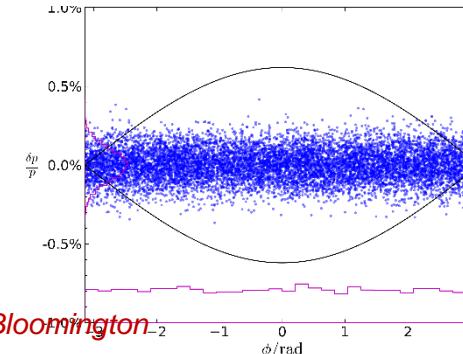
Adiabatic capture



Adiabatic



Non-adiabatic

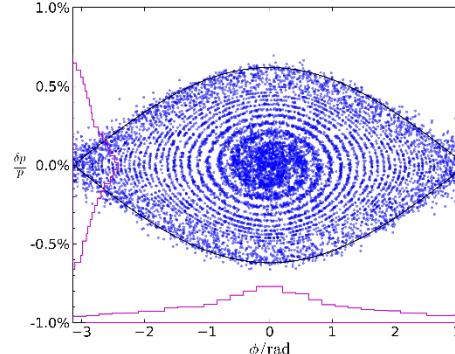
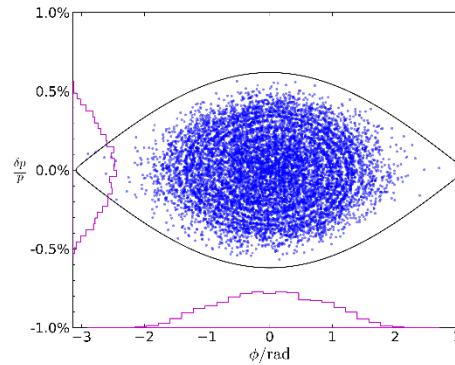


□ Voltage form

$$V_{RF}(t) = V_i + (V_f - V_i) \left[3 \frac{t^2}{T_1^2} - 2 \frac{t^3}{T_1^3} \right]$$

□ Adiabatic coefficient

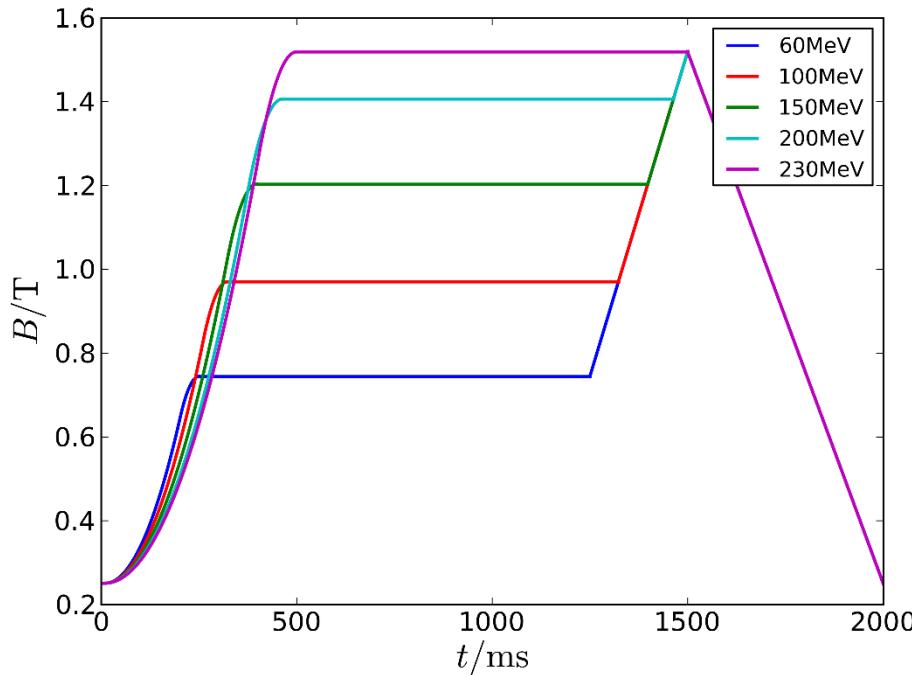
$$\alpha_{ad} = \frac{T_s}{4\pi V_{RF}} \frac{dV_{RF}}{dt}$$





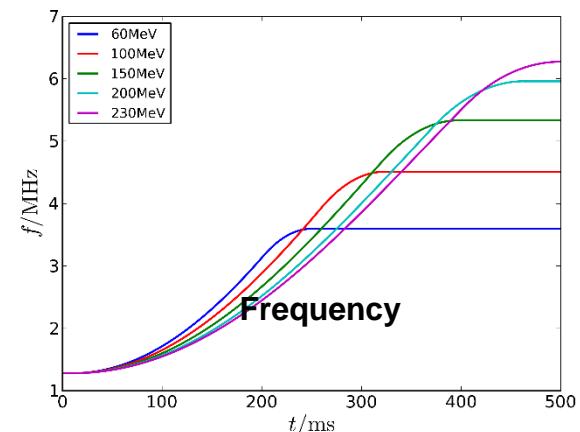
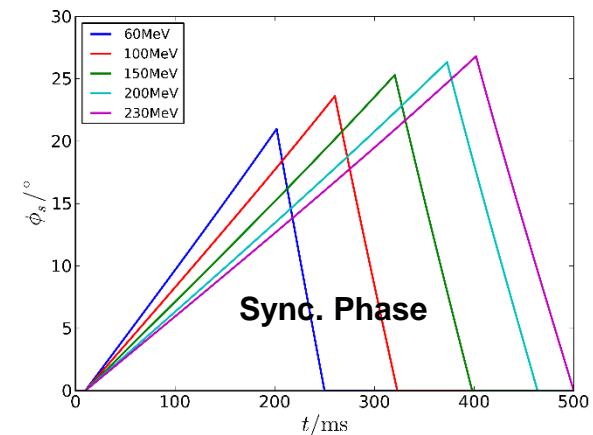
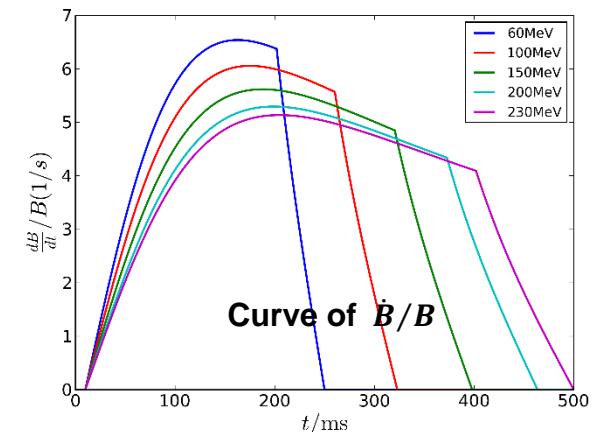
Ramping

One cycle of the dipole magnet field



❑ Ramping from

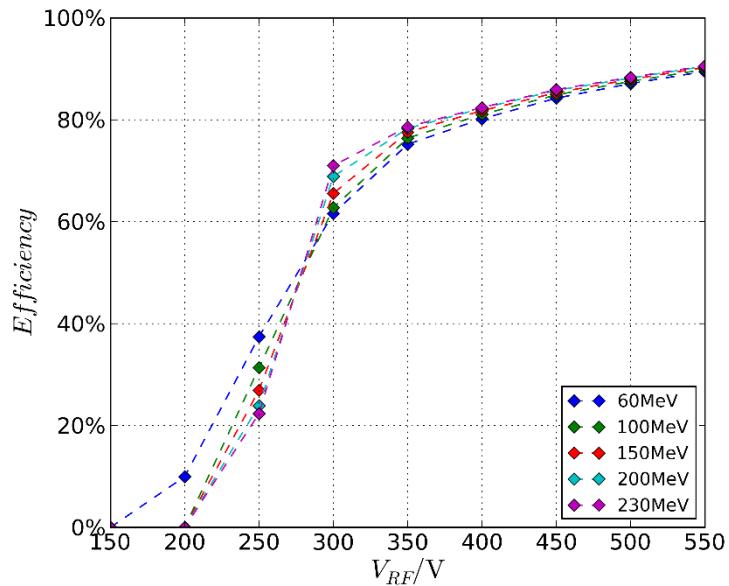
$$B(t)\rho = \begin{cases} B\rho_i + k_1(t/T_r)^2 & t < T_1 \\ B\rho_i + k_1(T_1/T_r) - k_2(1-t/T_r)^2 & T_1 \leq t \leq T_r \end{cases}$$



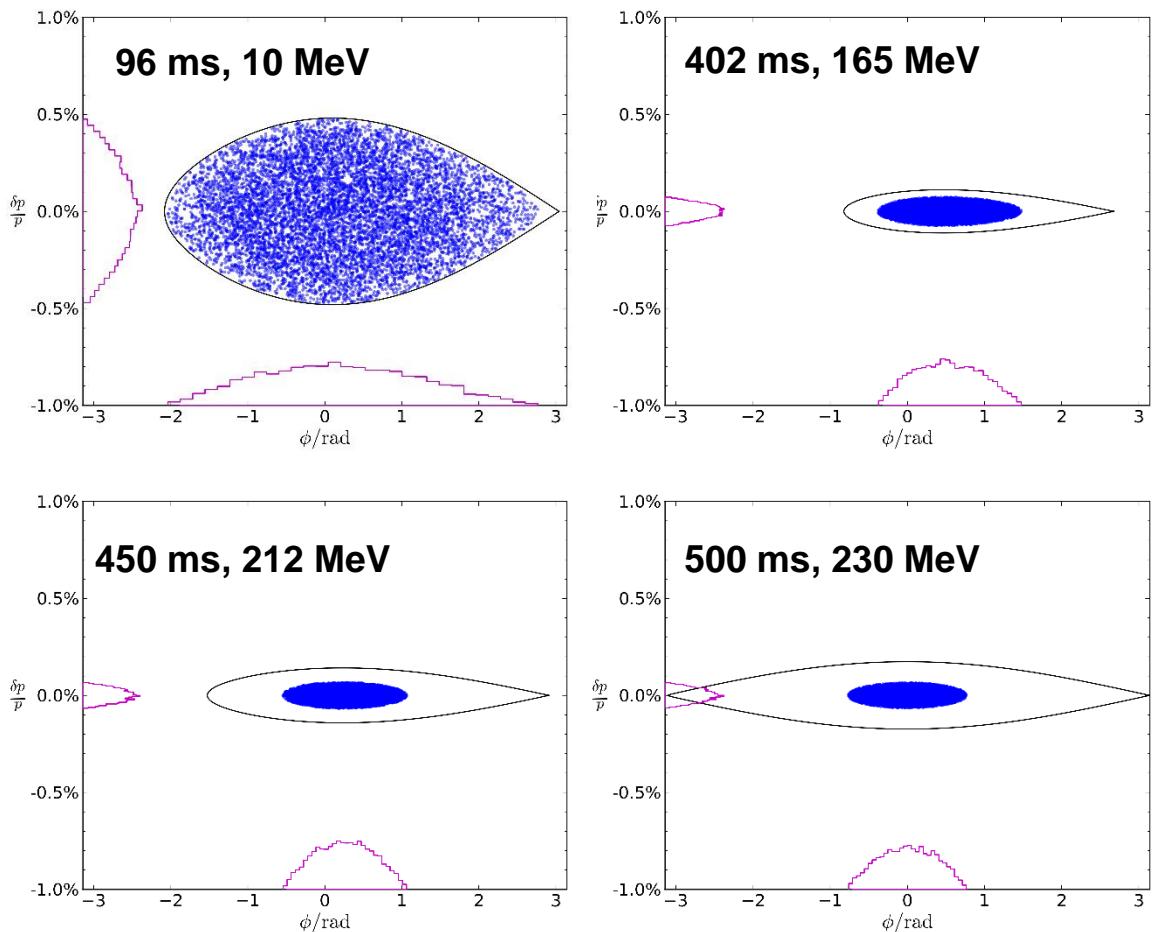


Ramping

Capture efficiency vs Voltage

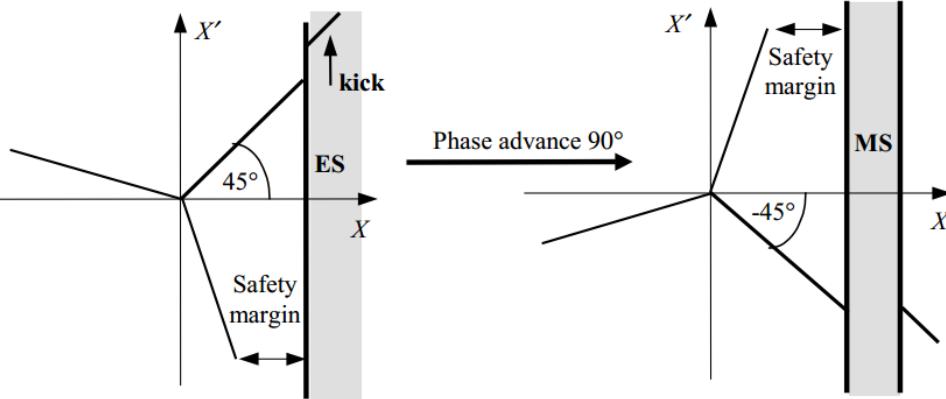


@ $\delta_{rms} = 0.23\%$

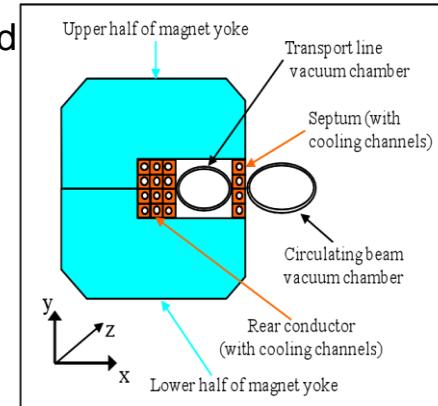




Extraction system

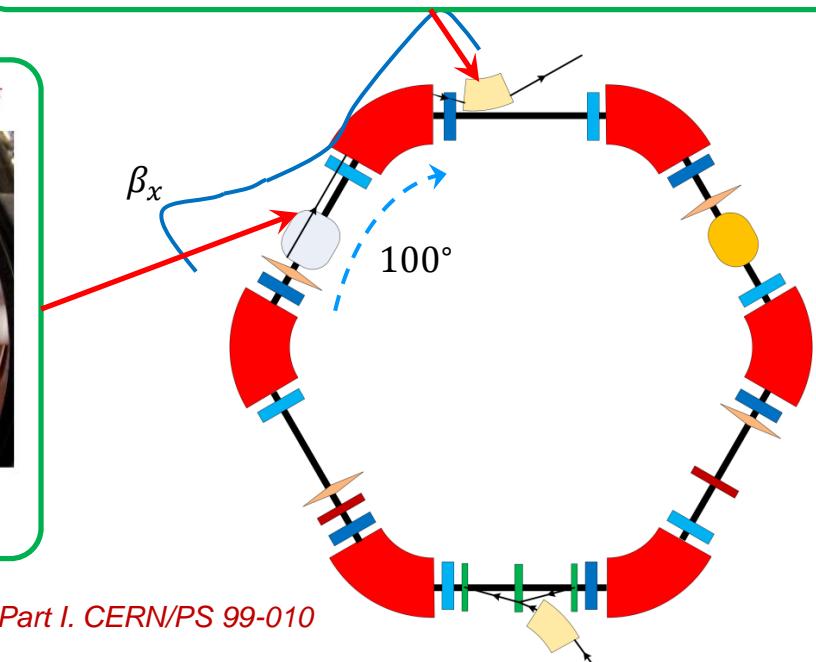
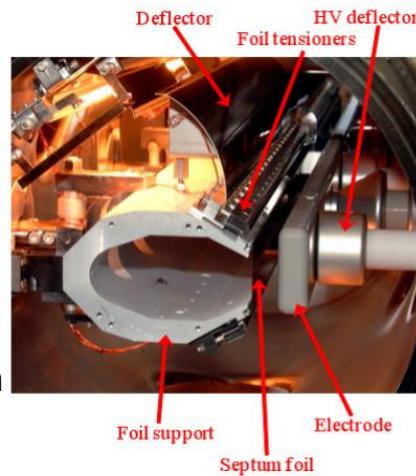


- Deflection: 69.8 mrad angle
- Length: 0.6 m
- Septum: 15 mm thickness
- Magnet field: 0.27 T



$$\Delta x = \theta \sqrt{\beta_{ES} \beta_{MS}} \sin \mu$$

- Kick angle: 9 mrad
- Length: 0.8 m
- Gap width: 15 mm
- Septum : 0.1 mm thickness
- E-field(Max): 4.7 MV/m
- Voltage: 70.5 kV

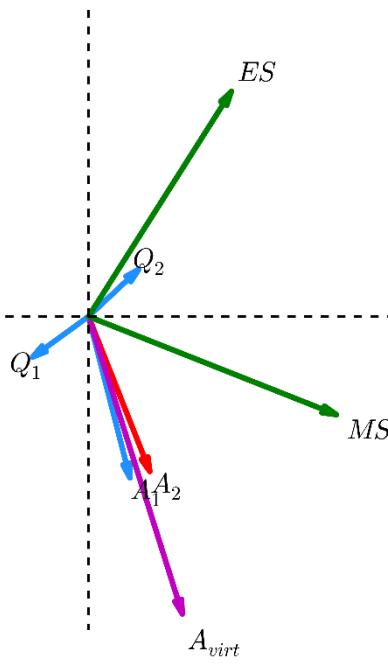


1) L. Badano, M. Benedikt, et al. Proton-ion medical machine study(PIMMS), Part I. CERN/PS 99-010

2) M. J. Barnes, J. Borburgh, et al. Injection and extraction magnets: septa.

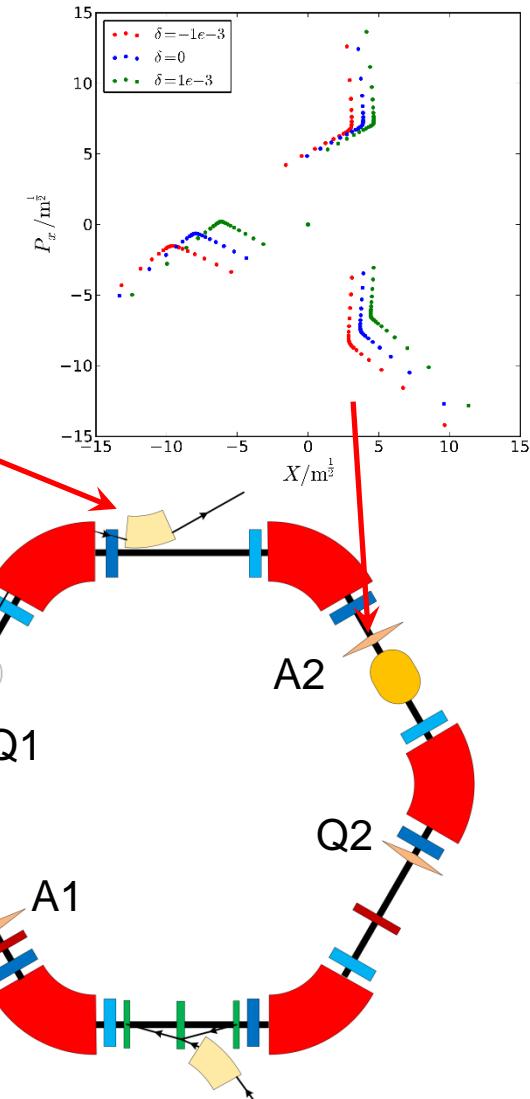
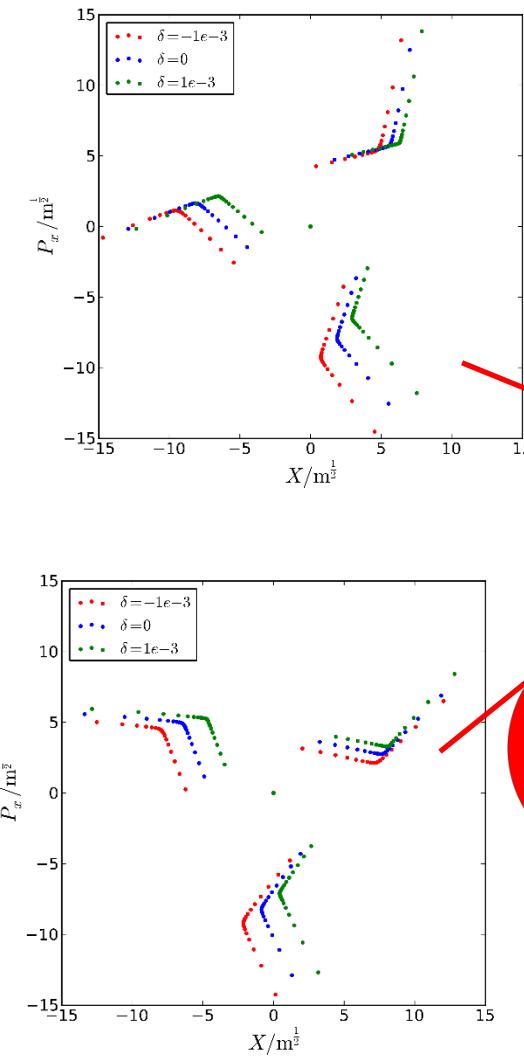


Extraction system



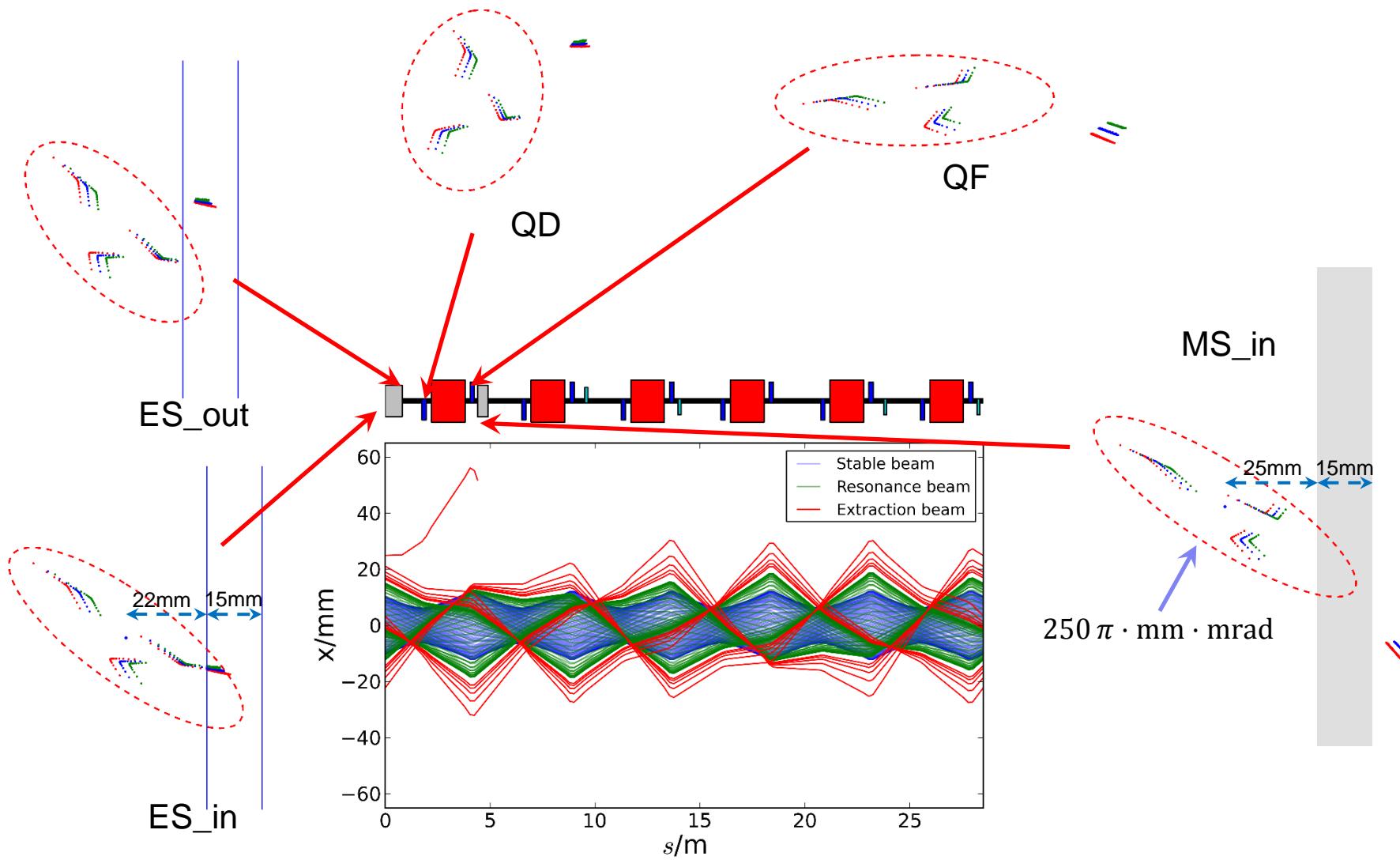
□ Virtual sextupole

$$S_{virt} \exp(i 3u_{x,virt}) = \sum_n S_n \exp(i 3u_{x,n})$$





Extraction process





Summary

□ Mission completion

- ✓ Up to 230 MeV in less than 0.5 s
- ✓ Store 2×10^{11} protons
- ✓ Slow extraction
- ✓ Lattice based on “Missing dipole” cell shows great simplicity and reliability, while providing much free space and good kick arm

□ Future work

- Optimized painting scheme
- Dual harmonic RF acceleration
- Fast extraction
- RF-Knockout



清华大学
Tsinghua University

Thanks