High-Intensity Heavy Ion Accelerator Facility
Institute of Modern Physics, Chinese Academy of Sciences

Beam dynamics study of the heavy ion bunch rotation with space charge effect in BRing at HIAF

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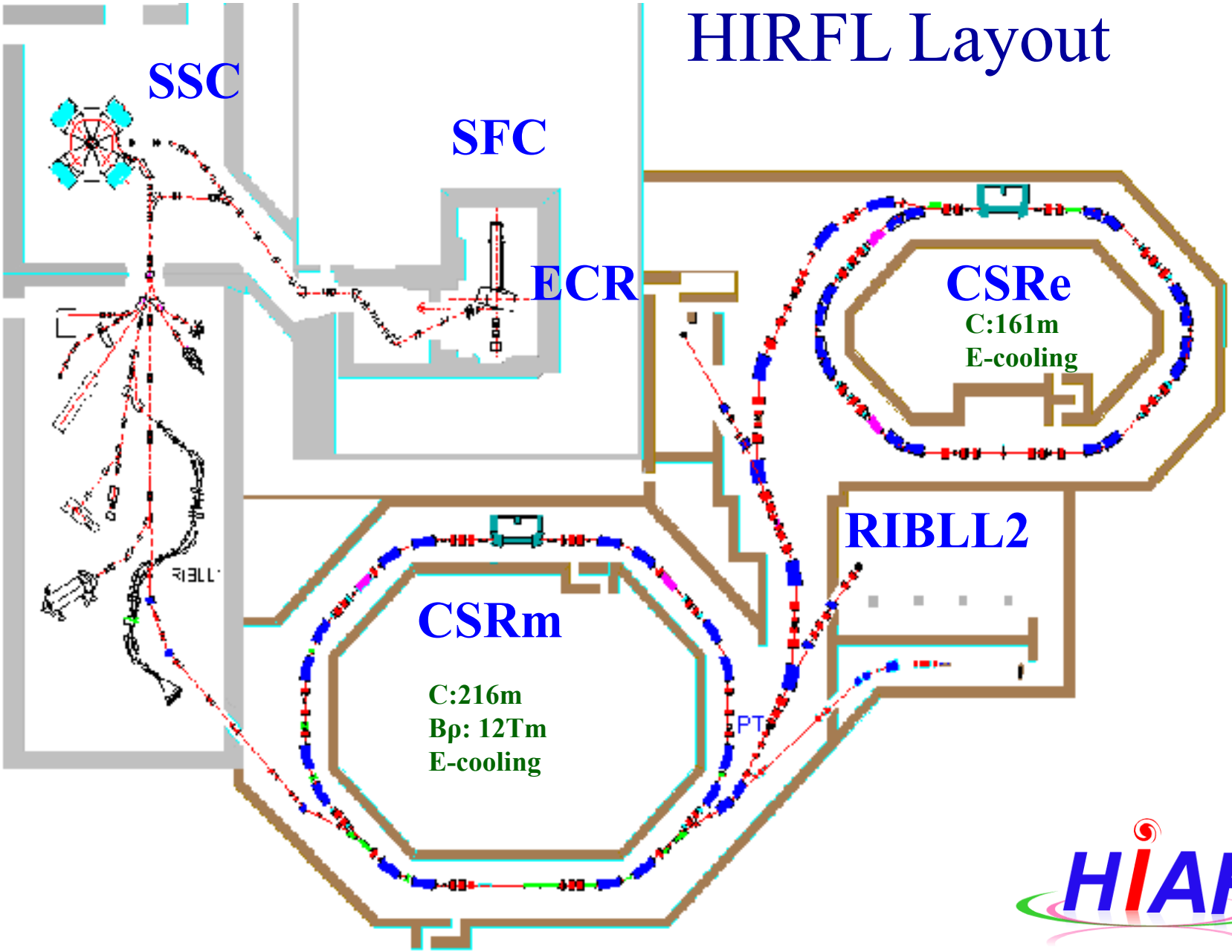
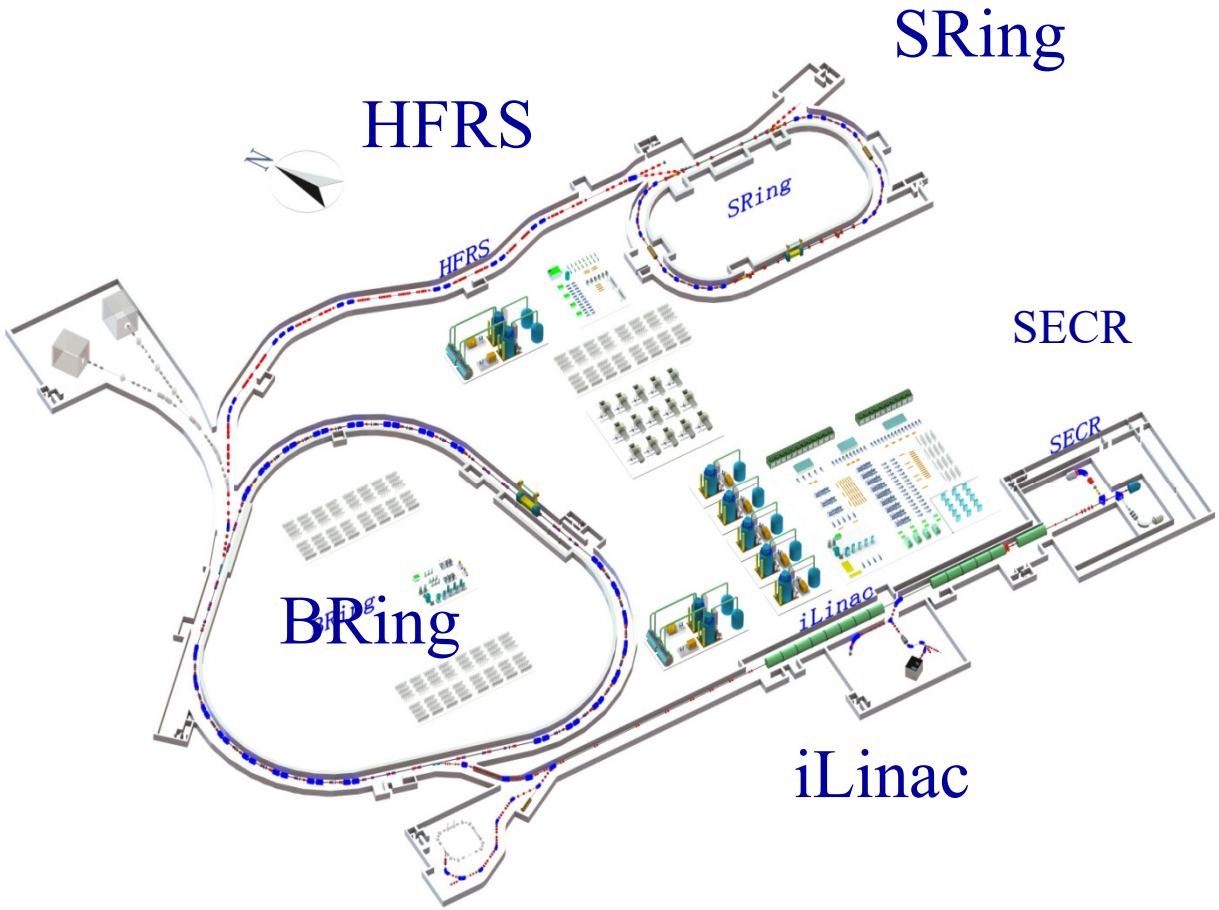
Outline

- **Introduction**
  - HIRFL HIAF & BRing
  - Content and motivation
- **Calculation and simulation of longitudinal beam dynamics**
  - Beam capture, acceleration &debunch
  - Fast bunch rotation
- **Conclusion and future plan**

Brief introduction to HIRFL



General description of HIAF



HFRS:
The radioactive ion beam line of HIAF

SRing: Spectrometer ring
Circumference:290m
Rigidity: 13Tm
Electron/Stochastic cooling
Two TOF detectors
Four operation modes

SECR :
Superconducting Electron-Cyclotron-Resonance ion source

BRing: Booster ring
Circumference: 569 m
Rigidity: 34 Tm
Beam accumulation
Beam acceleration
Beam rotation

iLinac: Superconducting linac
Length:100 m
Energy: 17MeV/u(U^{35+})

Comparison of HIAF and HIRFL

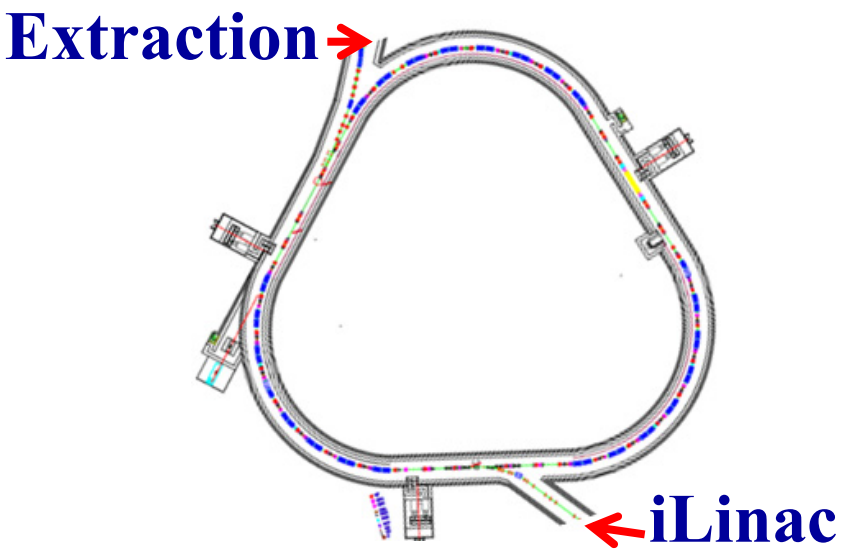
- **Primary beam intensity increases by × 1000 - × 10000(BRing)**
- **secondary beam intensity increases by up to × 10000**
- **Wide beam Energy: heavy-ion energy : × 10 - × 15(BRing)**
- **beam cooling (Electron, Stochastic, laser; high quality, very small spot) (BRing)**
- **Beam compression (Ultra-short bunch length: 50-150ns) (BRing)**

- Super long period slow extraction
(Super long, high energy, quasi-continuous beam)

Versatile operation modes:

- parallel operation, beam splitting
(increase of target time, high integrated luminosity)

Layout and Design parameters of BRing



Parameters	Value
Circumference/m	**569**
Beam Rigidity/Tm	**34**
Momentum acceptance	**±0.005**

Main parameters	
Injection beam parameters	
Ion species	Proton to Uranium
Injection energy (MeV/u)	**17** （$^{238}U^{35+}$）， **48**（**p**）
Beam current (pmA)	**0.028** （$^{238}U^{35+}$）， **1.0**（**p**）
Extraction beam parameters	
Energy(GeV/u)	**0.83** （$^{238}U^{35+}$） **9.3**（**p**）

HIAF

Two stages acceleration(U35+)

	Stage 1	Stage2
Beam parameters		
Energy/MeV/u	17-200	200-830
Revolution frequency/MHz	0.10-0.30	0.30-0.45
RF parameters		
h	3	1
frequency/MHz	0.30-0.90	0.30-0.45
Dipole magnetic rarameter		
Bdot(T/s)	12(fast)	1(normal)

- **accelerated as soon as possible-serious space charge effects at low energy**
- **minimization of ionization beam loss**
- **stabilisation of the dynamic residual gas pressure**

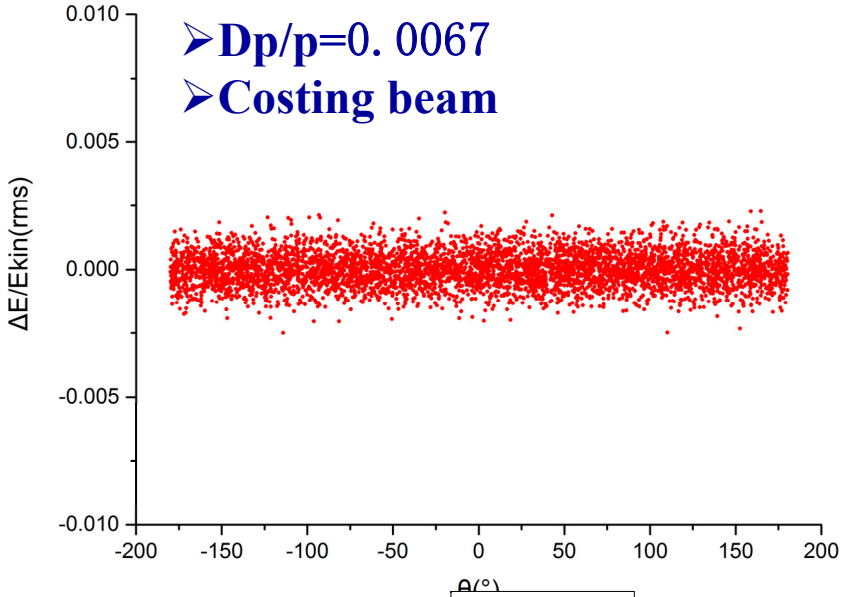
Content

	Stage 1	Stage2
Contents	capture	
	acceleration	
	Generation of single bunch	No
Method	theoretical calculation	
	Tracking simulation	
High beam power with short bunch duration!		

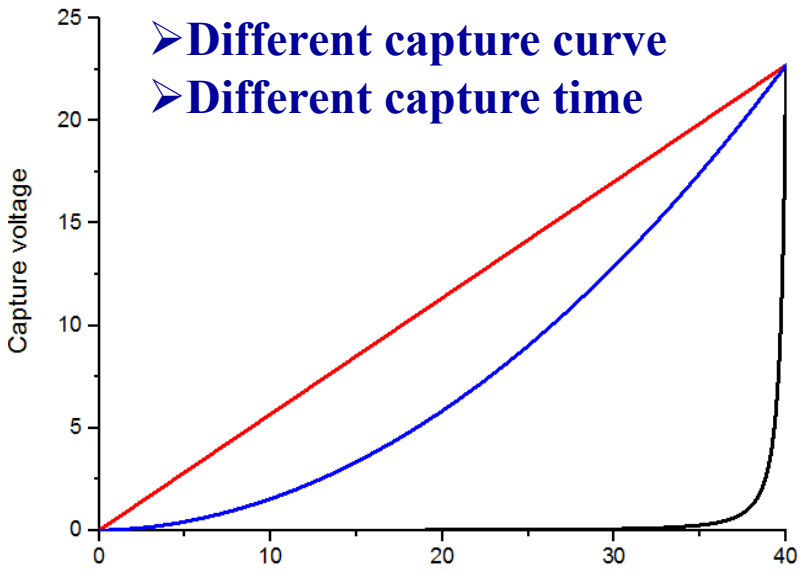
Purpose

- **minimize beam loss during the whole process**
- **Get high power beam with short bunch duration**

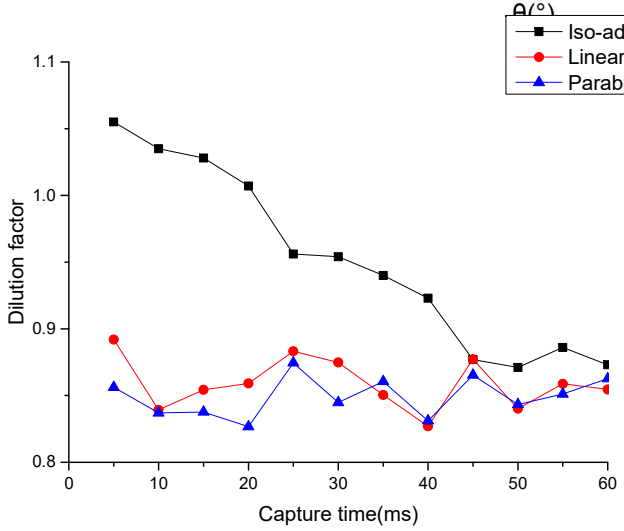
Stage 1_Capture(17MeV/u)

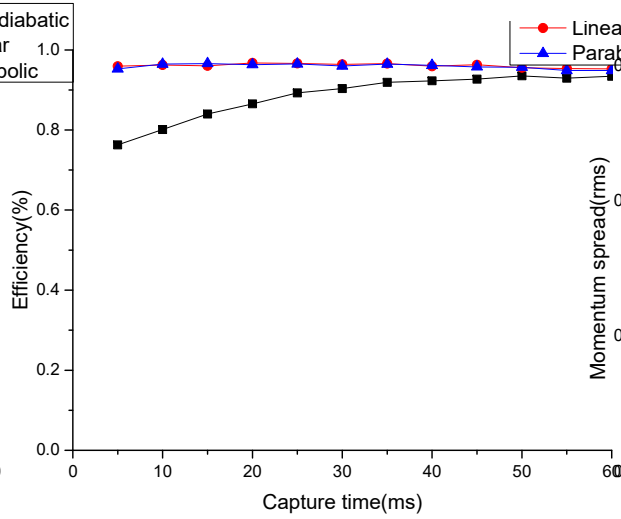


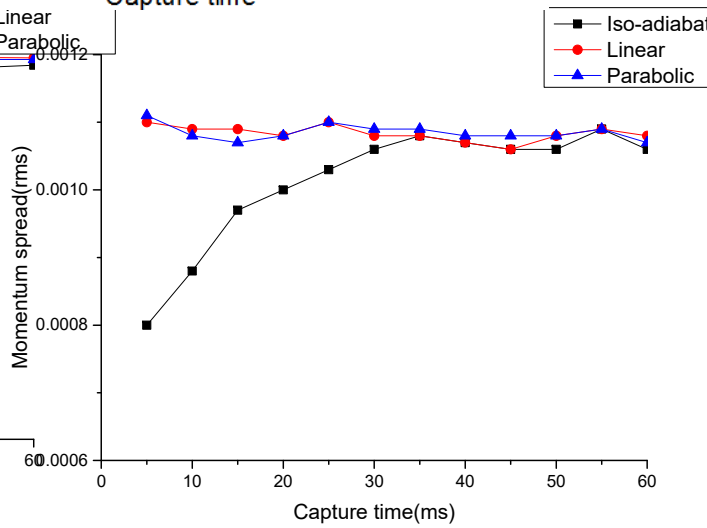
- Dp/p=0. 0067
- Costing beam



- Different capture curve
- Different capture time





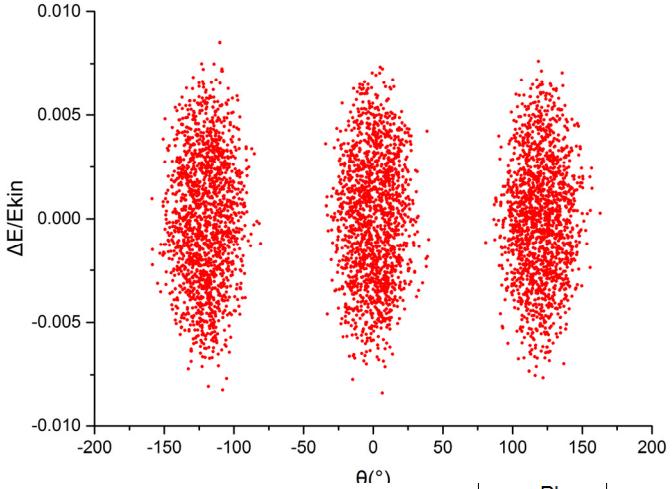


Capture:40ms+linear

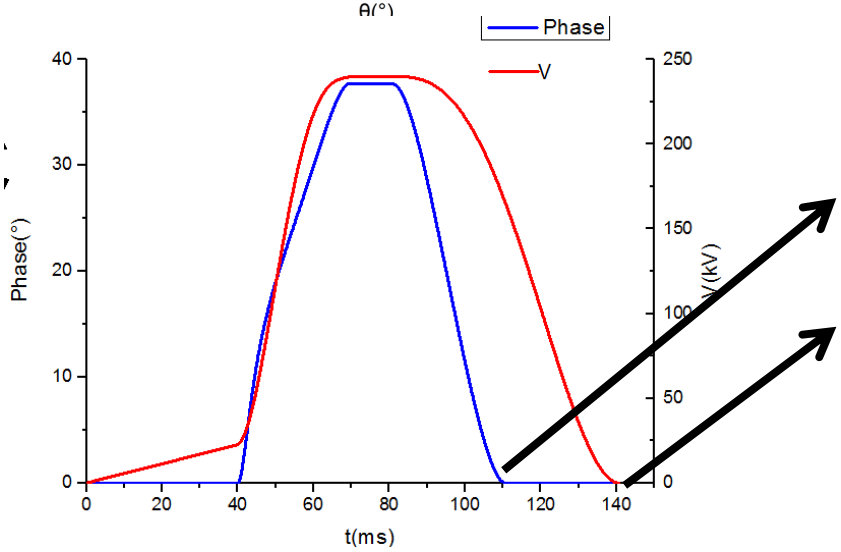
- **Dp/p=0. 0067 −0. 00107**
- **Effciency:96%**

Stage 1 (17-200MeV/u-12T/s)

The bunch distribution after the 1st capture and acceleration:



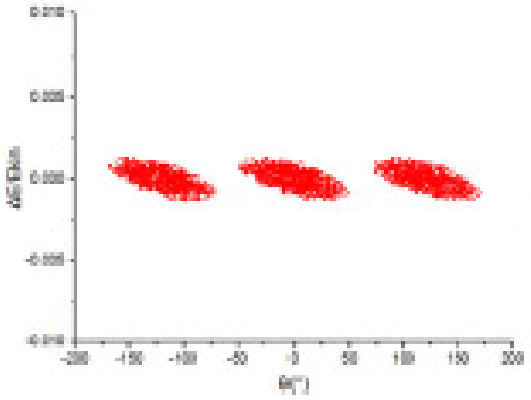
- 3 bunches
- Large momentum spread



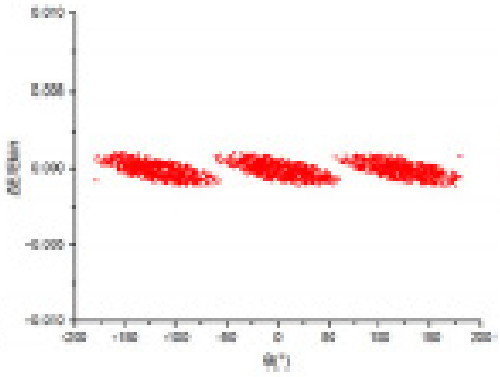
- acceleration end
- Debunch is processing
- Voltage is zero
- Debunch end

Stage 1 (17-200MeV/u-12T/s)

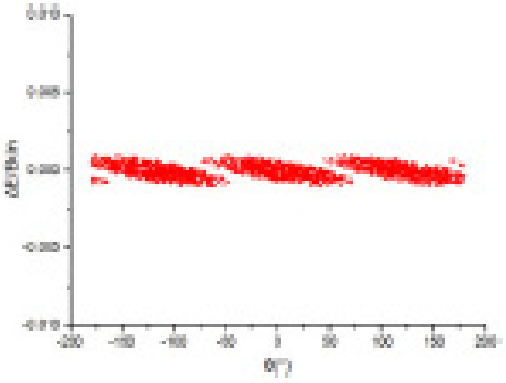
Different debunching time:



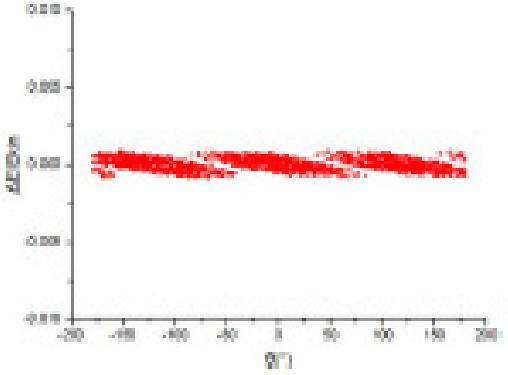
10ms.



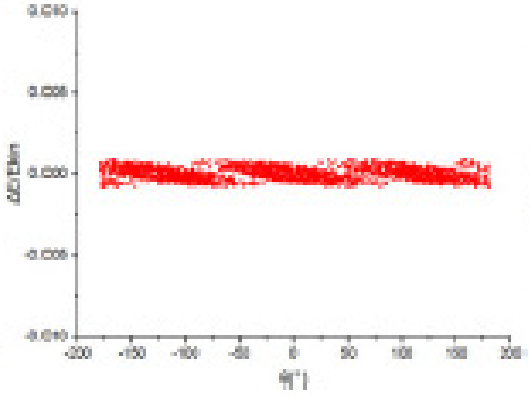
20ms.



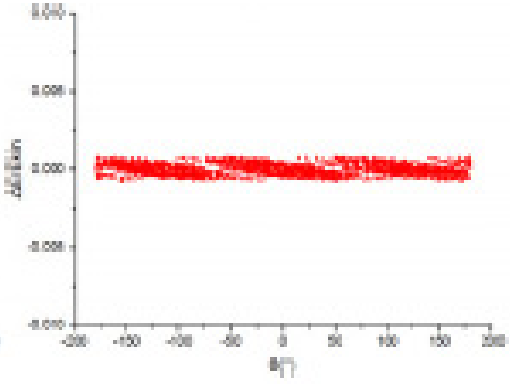
30ms.



40ms.



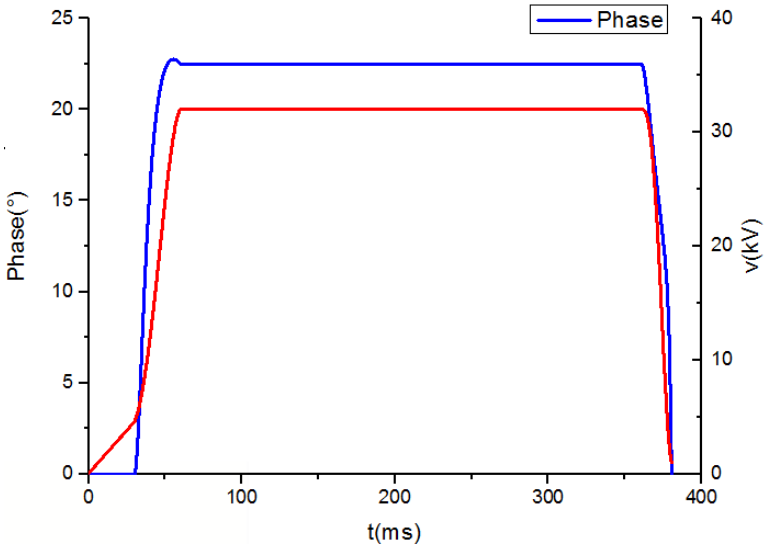
50ms.



60ms.

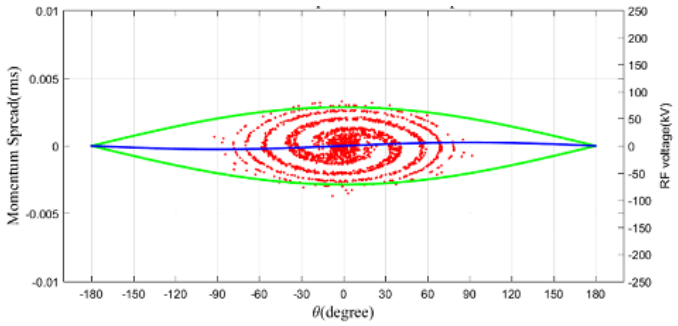
Stage 2 (200-required energy)

Acceleration curve:

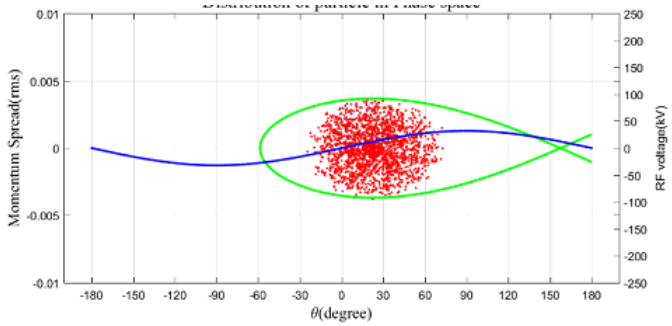


- Very small acceleration voltage (32kV-240kV(1st stage))
- Provide conditions for bunch rotation (voltage increase from 32kV-240kV)

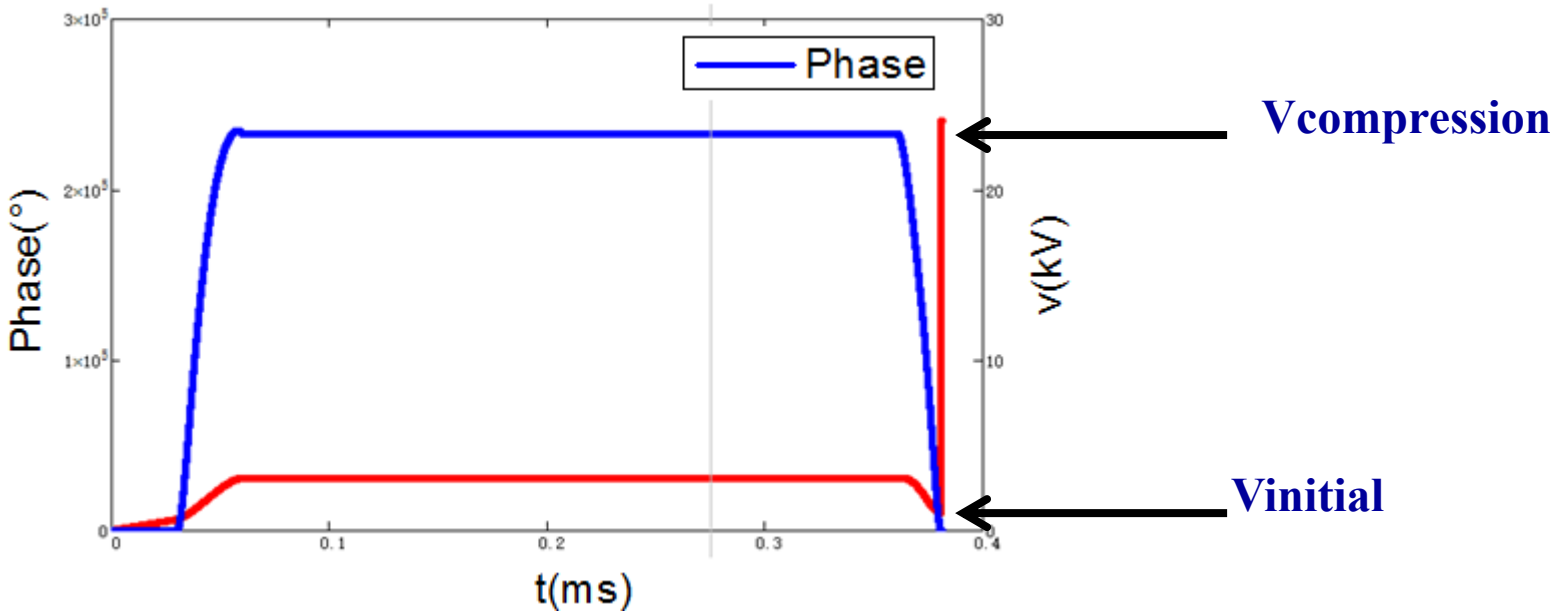
2nd stage capture end



2nd acceleration



Stage 2 (bunch rotation)



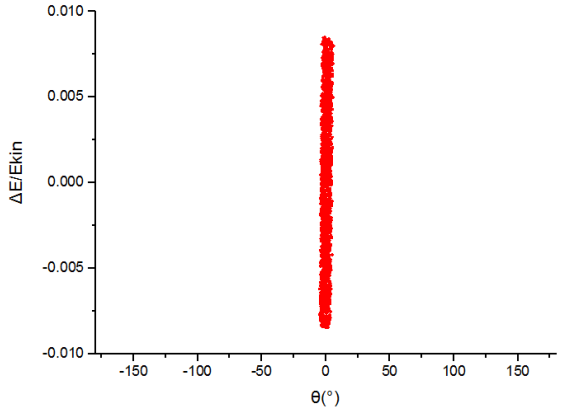
- Increasing Vinitial to Vcompression very fast
- the bunch distribution after bunch rotation depend on the the amplitude of Vinitial largely
- Beam acceleration and bunch rotation are performed with the same RF system, so the choice of Vinitial is important

Stage 2 (bunch rotation)

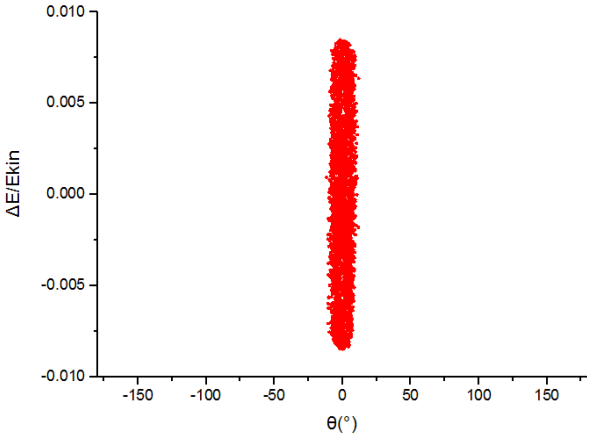
The bunch distribution dependence of Vinitial:

t(ms)

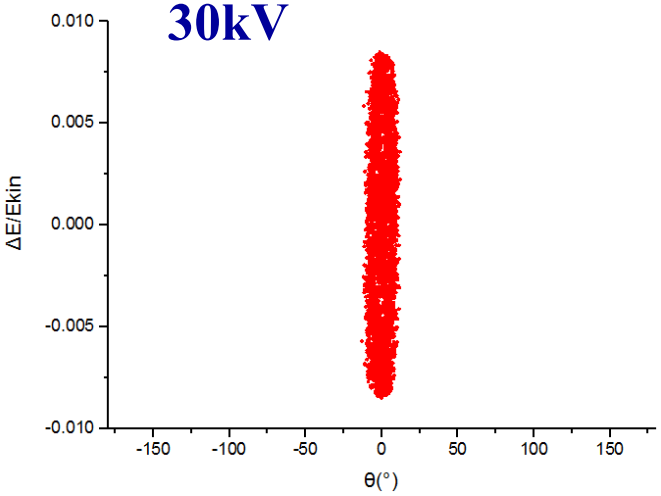
10kV

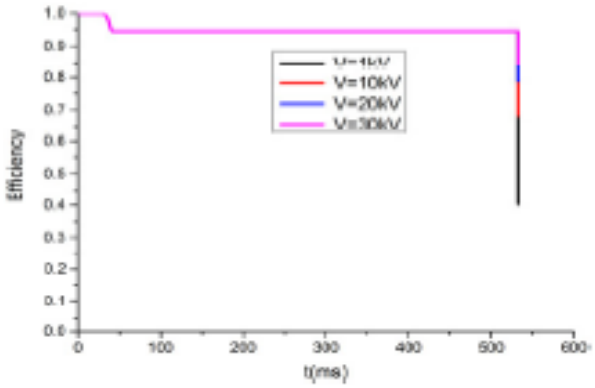


20kV

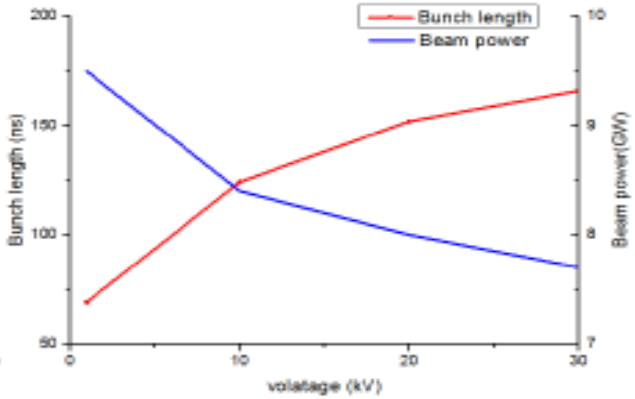


30kV





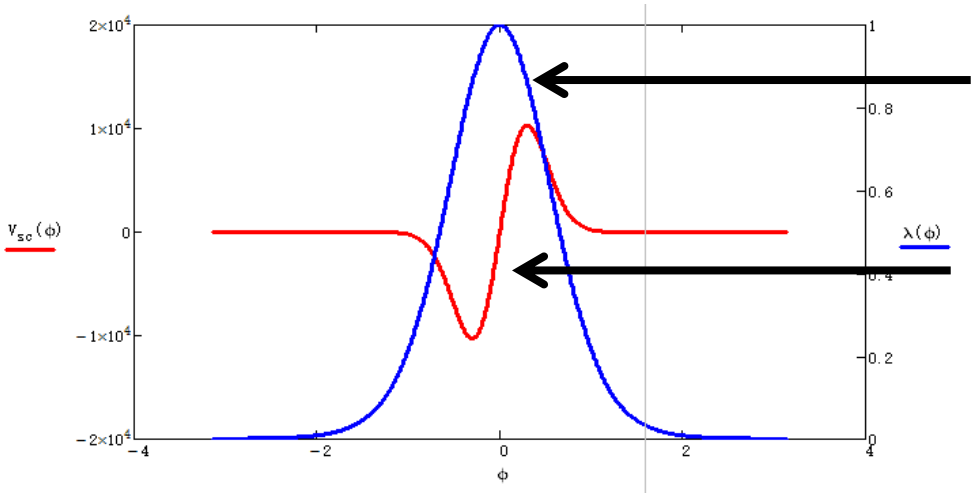
Beam loss.



Bunch length
beam power.

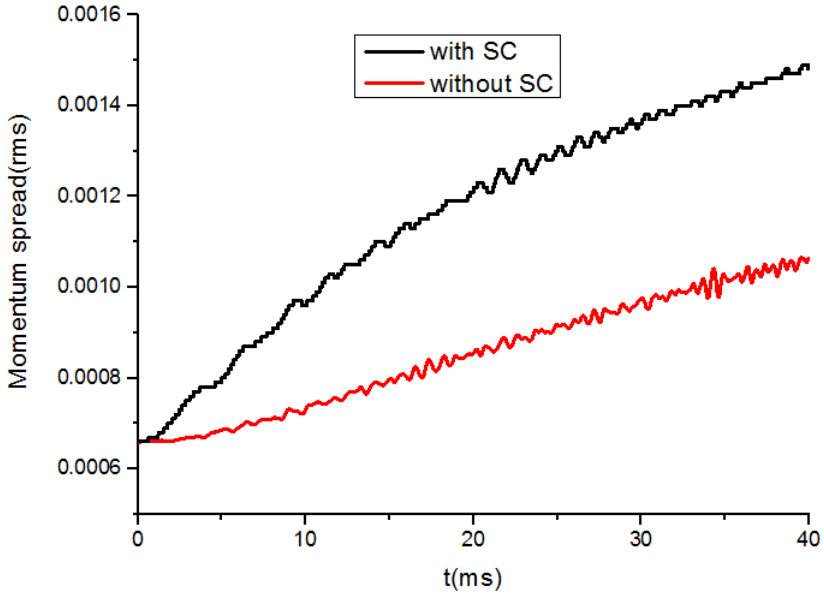
with the initial voltage increase, the beam loss is decreased, but the bunch length is increased, and the beam power is decreased

SC at injection of 17MeV/u



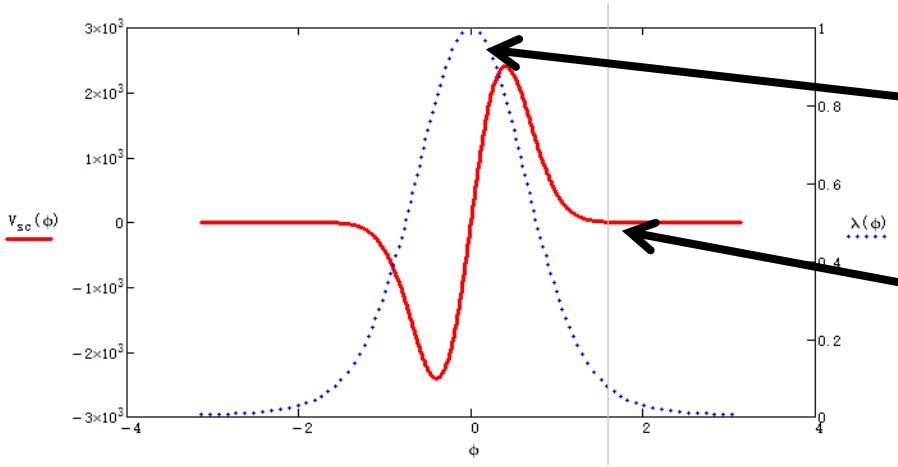
Bunch distribution

SC voltage



Momentum spread will increase 50% comprared thatwithout SC

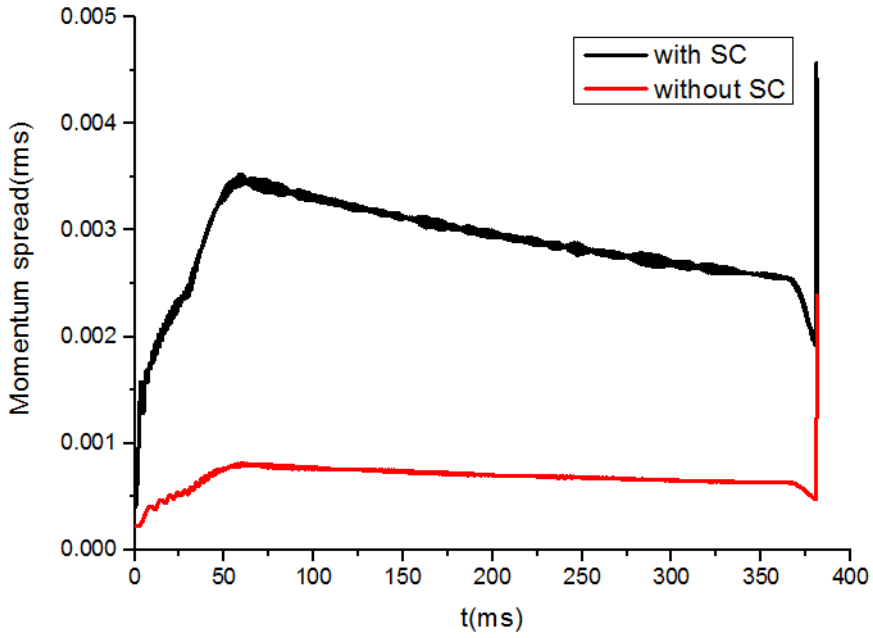
SC at injection of 17MeV/u



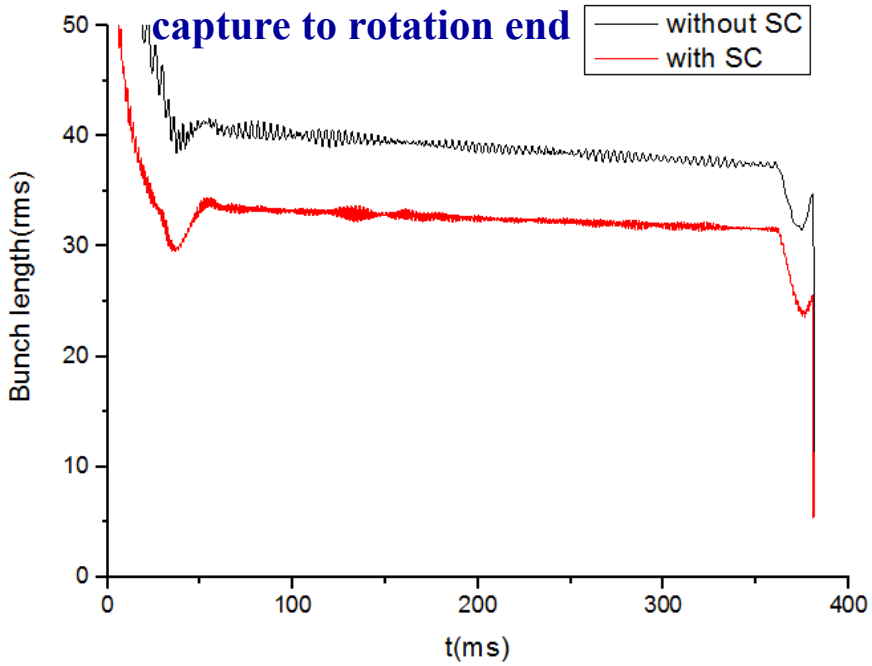
Bunch distribution

SC voltage

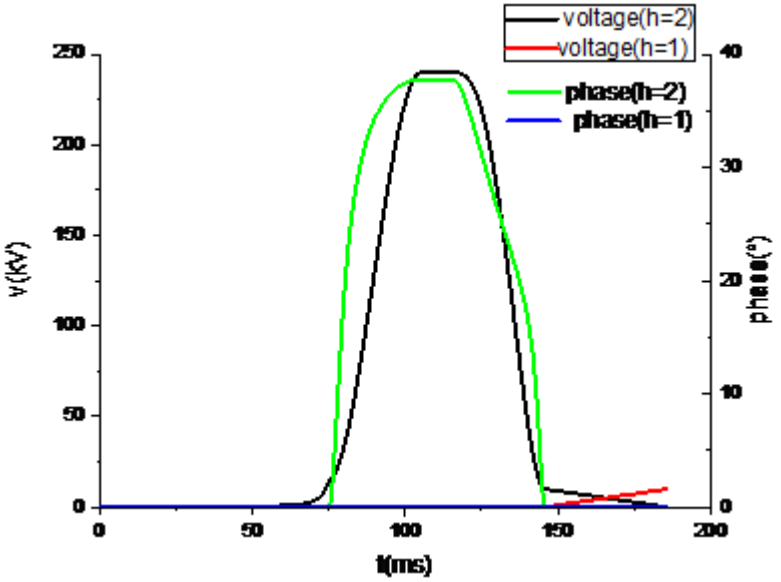
Momentum spread evolution



Bunch length evolution from capture to rotation end

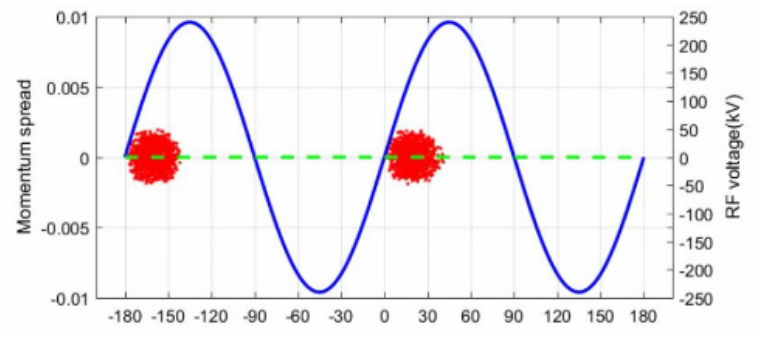


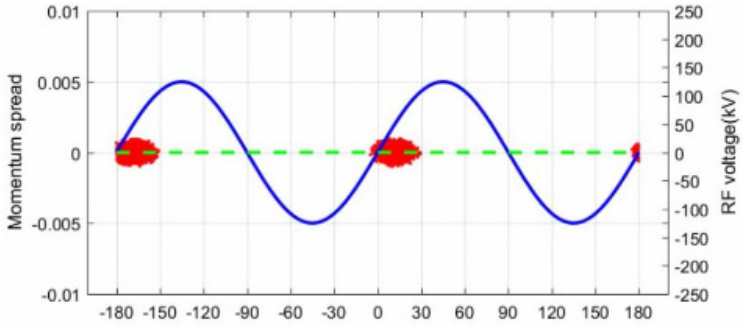
Bunch merging(h=2)

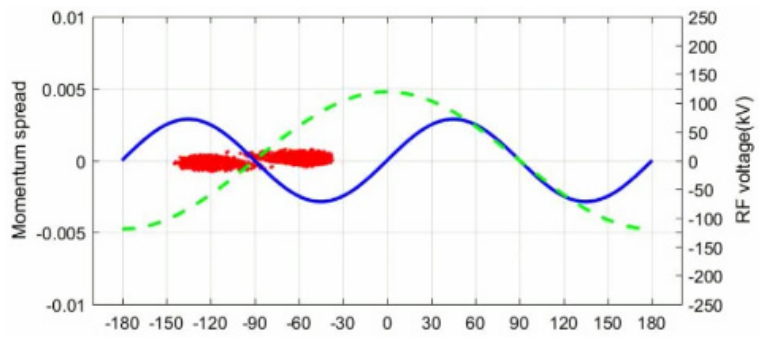


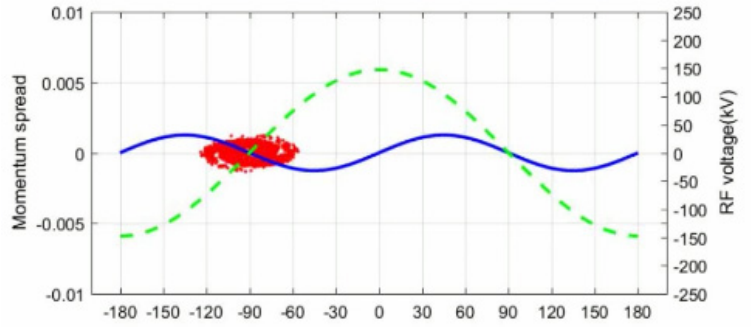
Bunch number:2-1

Voltage of RF cavity(h=2, black) Decrease, at the same time the voltage of RF cavity(h=1, red) increase

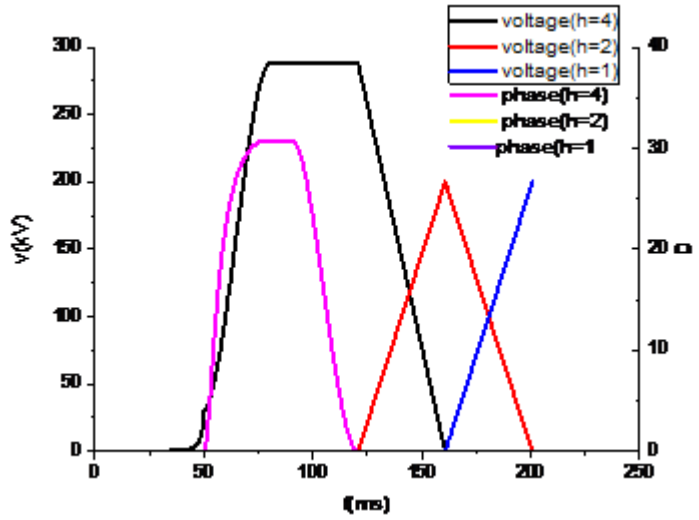








Bunch merging(h=4)

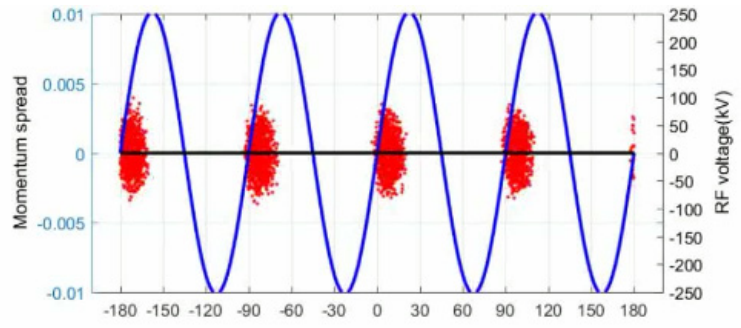


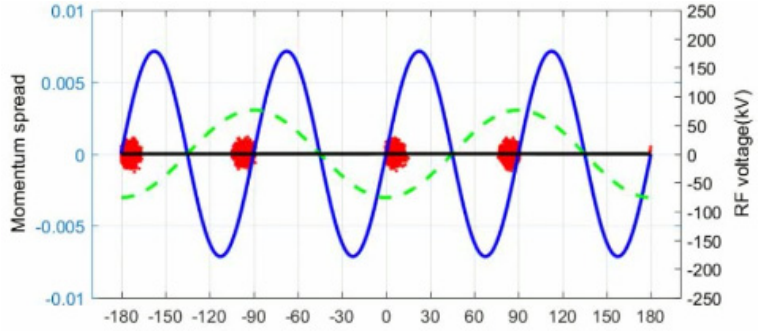
Bunch number:4-2

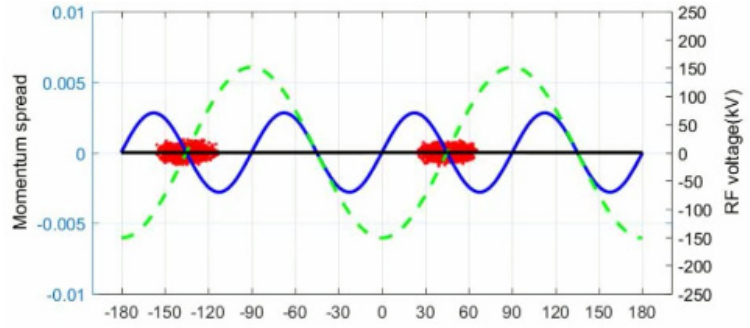
Voltage of RF cavity(h=24 black) decrease, at the same time the voltage of RF cavity(h=2, red) increase

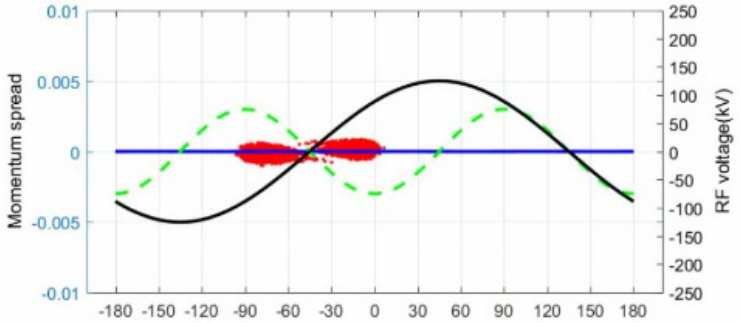
Bunch number:2-1

Red decrease, at the same time bule increase

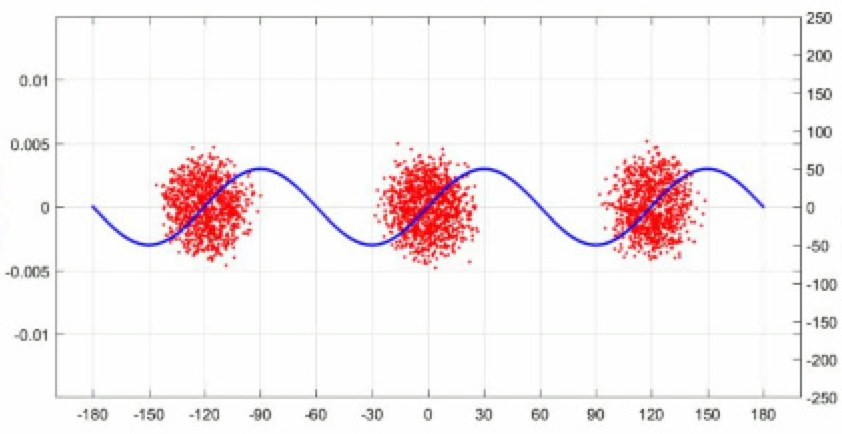


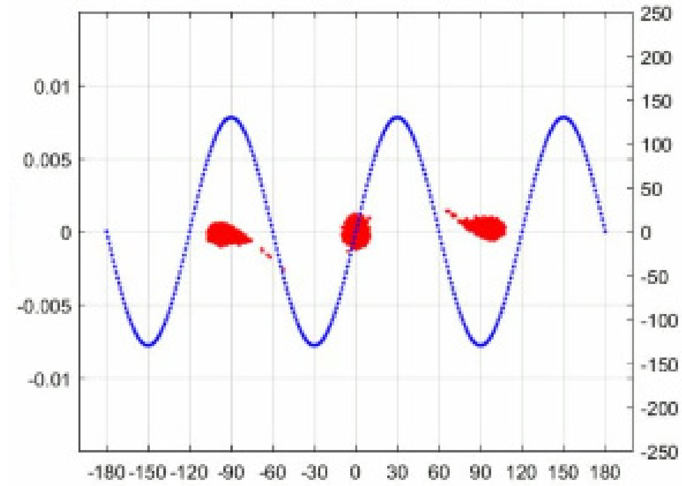


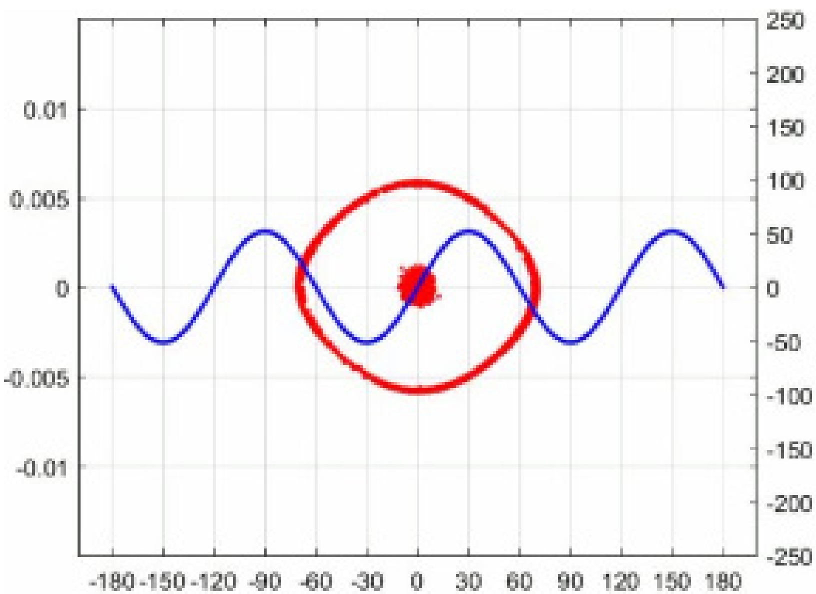




Bunch merging(h=3)

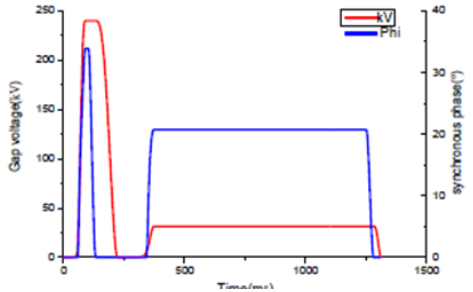




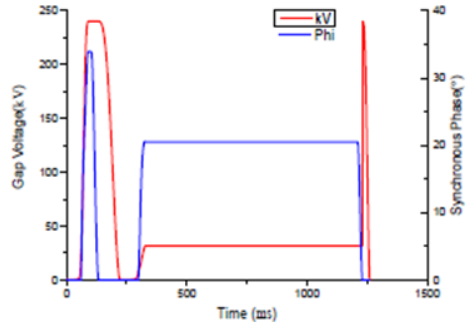


Bunch number:2-1
Voltage of RF cavity(h=3) iecrease, at the same time the voltage of RF cavity(h=1) increase
Debunch is the only way !

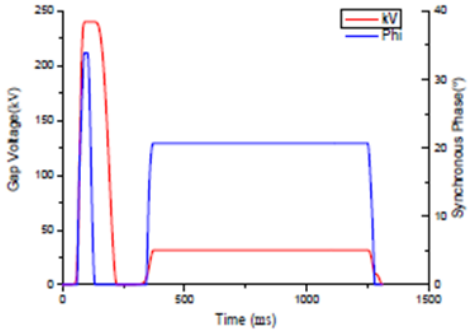
Operation mode



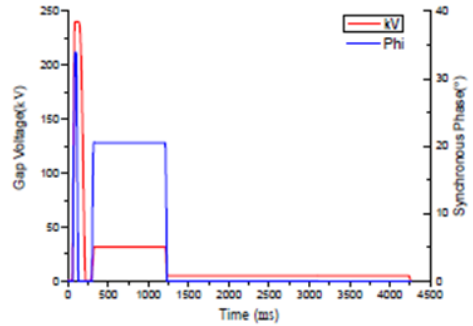
Normal：
When synchronous phase is zero, the RF voltage start to decline



Compression：
When the energy arrive the required value, the RF voltage increase rapidly to available value(240kV)



Bunch length and momentum spread manipulation：
During the late of beam acceleration, the RF voltage decrease in a certain way



Slow extraction：
In the time of extraction period, keep the RF cavity open, and the bunch length and momentum spread are subjected to amplitude of voltage

Conclusion:

Conclusion:

- **Through calculation and simulation, the low beam loss of less than 5% can be controlled in the whole process**
- **Beam parameters such as momentum spread and bunch length at extraction energy are obtained**
- **Get the optimized RF voltage and synchronous phase for RF system**
- **Use the same RF system perform acceleration, debunch and bunch compression**

Outlook:

- **Space charge effect has just started, and needs further understanding and research**
- **Interaction of high beam intensity and cavity will lead to beam loading which will be a critical issue to be studied.**

Thanks for you attention!