The Study of Space Charge Effects for RCS/CSNS

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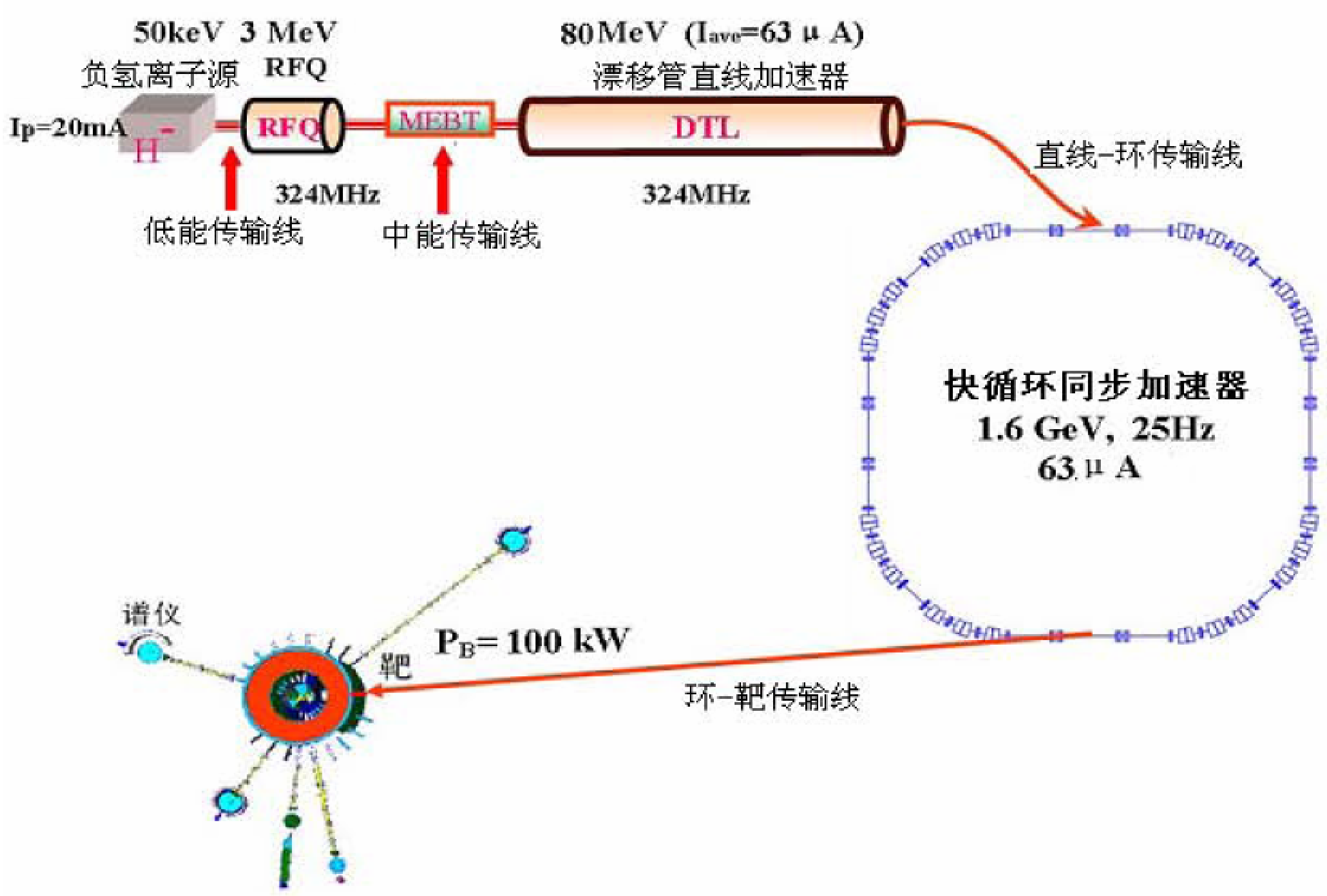
CSNS
CHINESE ACADEMY OF SCIENCES

Outline

- A brief introduction to CSNS
- Space charge effects in painting
- Space charge effects in ramping
- Operational tune
- Lattice type
- Summary

CSNS Layout


50keV 3 MeV
80MeV (I_ave=63 μ A)
负氢离子源 RFQ
漂移管直线加速器
Ip=20mA
H-
RFQ
MEBT
DTL
直线-环传输线
324MHz
324MHz
低能传输线
中能传输线
快循环同步加速器
1.6 GeV, 25Hz
63 μ A
谱仪
靶
PB= 100 kW
环-靶传输线

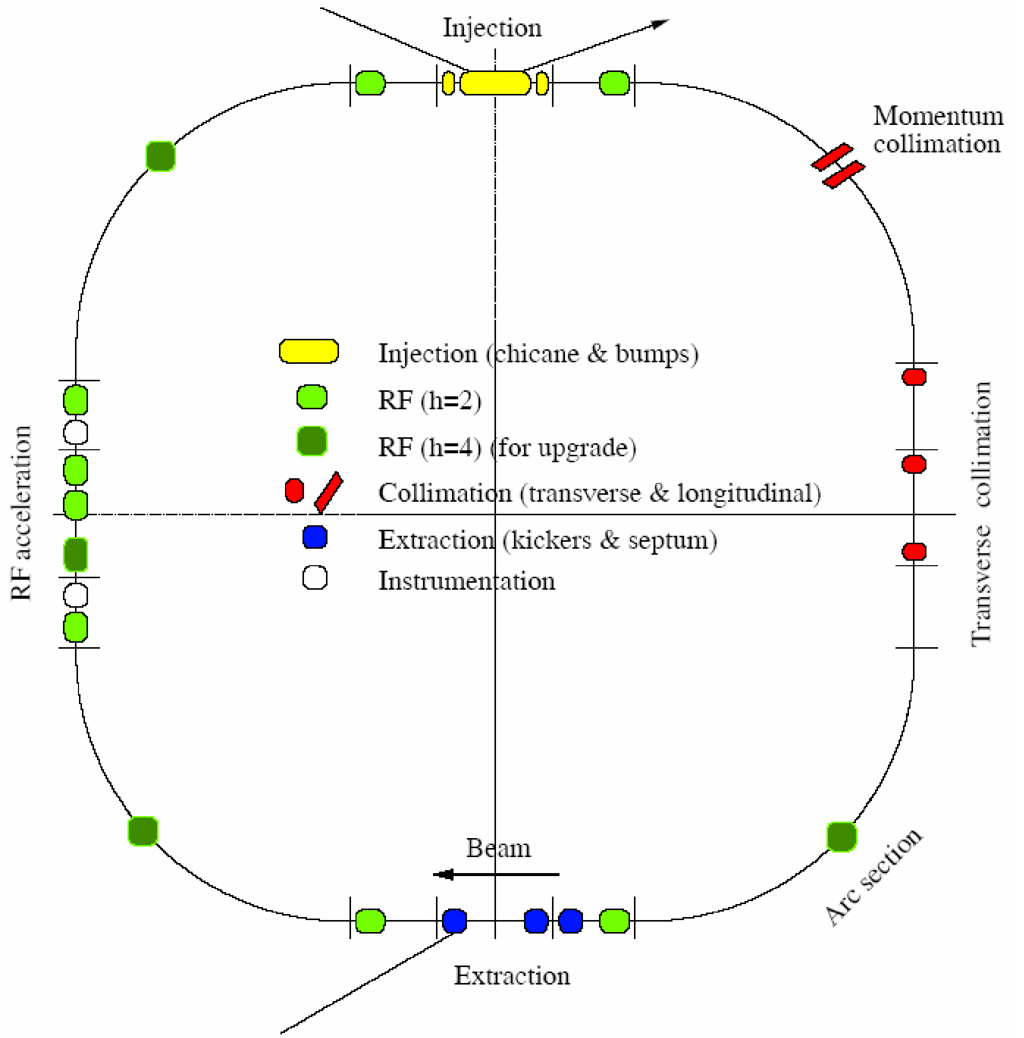
CSNS Parameters

Beam power on target [kW]	100
Beam energy on target [GeV]	1.6
Ave. beam current [μA]	63
Pulse repetition rate [Hz]	25
Protons per pulse [10^{13}]	1.88
Linac energy [MeV]	80
Linac type	DTL
Target number	1
Target material	Tungsten
Number of spectrometers	3(18)
Beam power upgrade capability (kW)	500

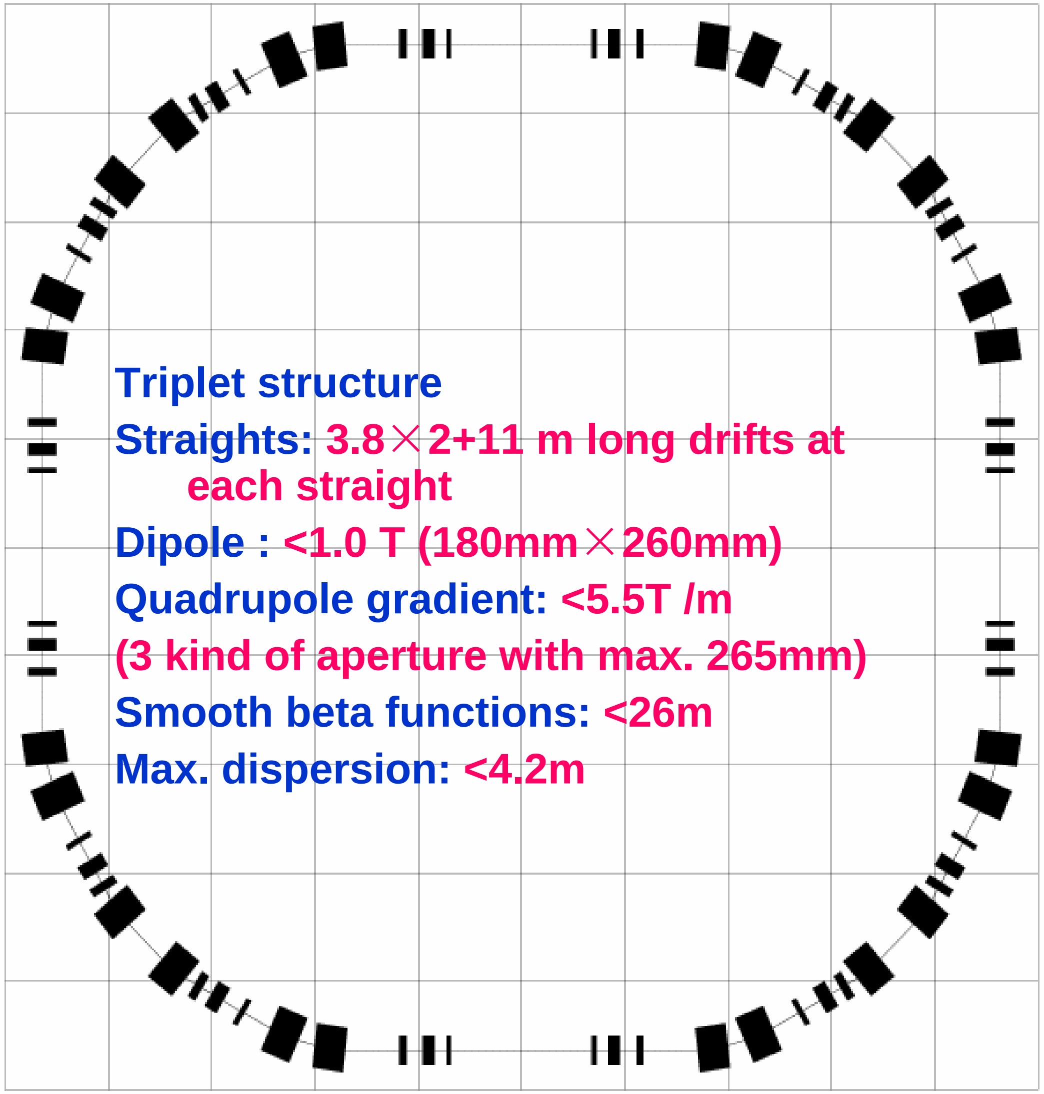
RCS Design

- To achieve hands-on maintenance: ~ uncontrolled beam loss below 1 W / m (Large acceptance and beam collimation)
- 4-fold symmetry: injection, extraction, collimation occupy a long straight section respectively
- One-turn extraction
- Increase the injection energy from 80MeV to 130MeV in the second stage, and the pulse repetition rate will be increased to 50Hz

Rapid Cycling Synchrotron Layout



RCS parameters



Triplet structure

Straights: 3.8×2+11 m long drifts at each straight

Dipole : <1.0 T (180mm×260mm)

Quadrupole gradient: <5.5T /m

(3 kind of aperture with max. 265mm)

Smooth beta functions: <26m

Max. dispersion: <4.2m

Circumference (m)	228
Superperiod	4
Number of dipoles	24
Number of long drift	12
Total Length of long drift (m)	75
Betatron tunes (h/v)	4.86/4.78
Chromaticity (h/v)	-4.3/-8.2
Momentum compaction	0.041
RF harmonics	2
RF Freq. (MHz)	1.0241~2.3723
RF Voltage (kV)	165
Trans. acceptance (πμm.rad)	540

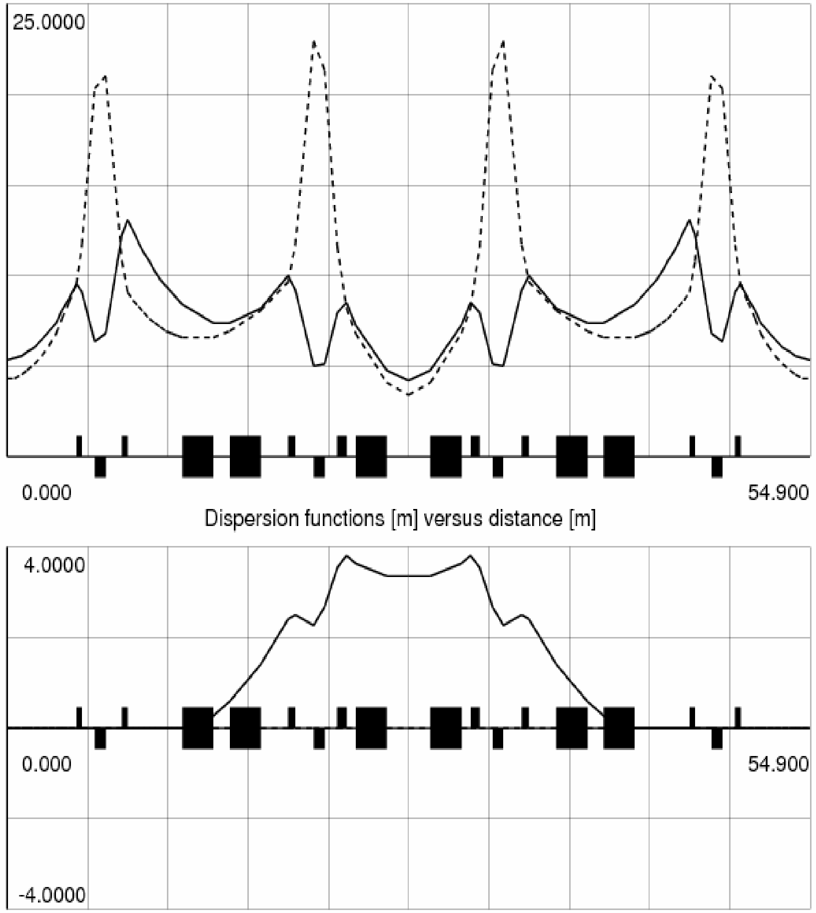
RCS-Lattice

- **Dispersion-free long uninterrupted straight**

  For collimation & injection/extraction

- **Straight at arc with large dispersion**

  High efficiency momentum collimation



Tune Diagram for 4-fold Structure

red:
1st order structure resonance

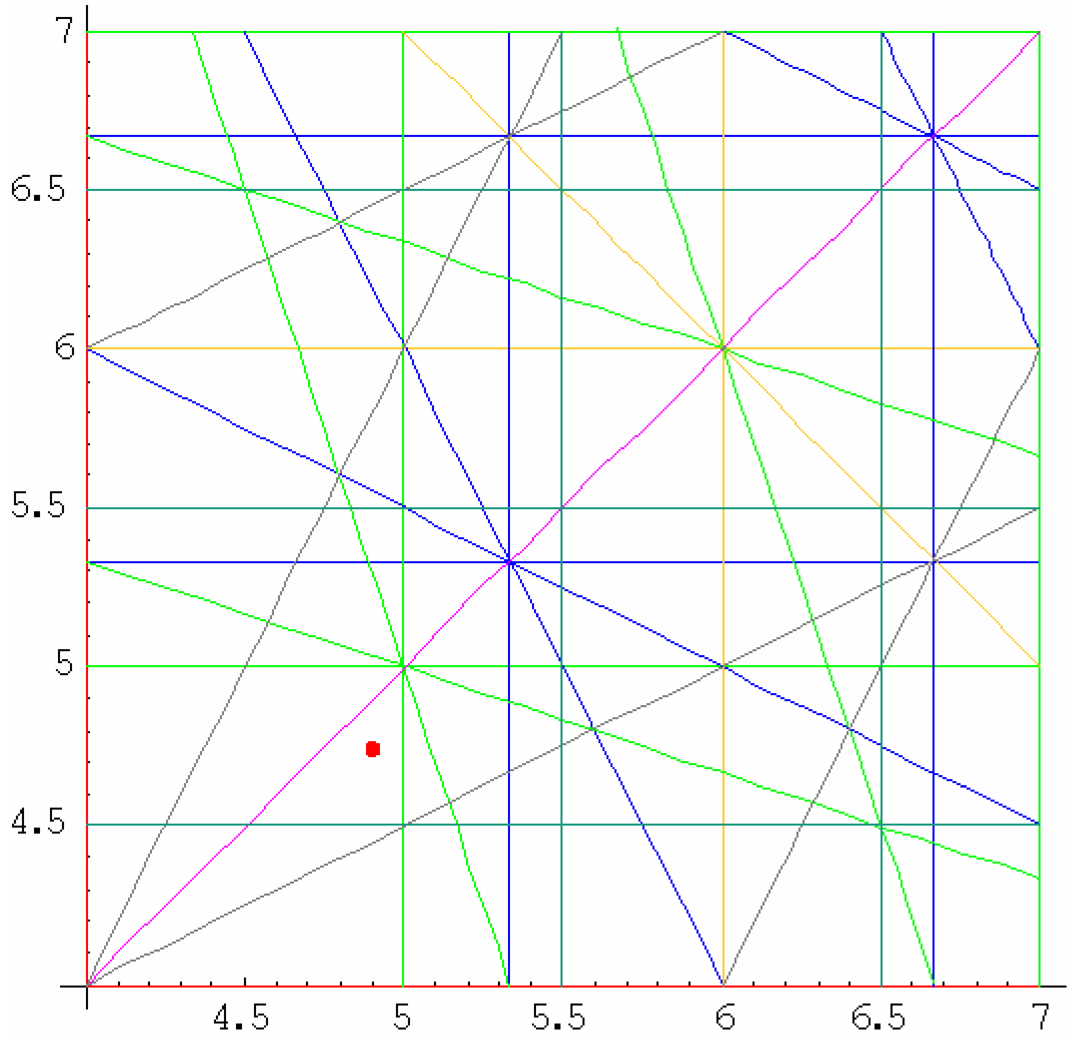
golden:
2nd order structure resonance

blue:
3rd order structure resonance

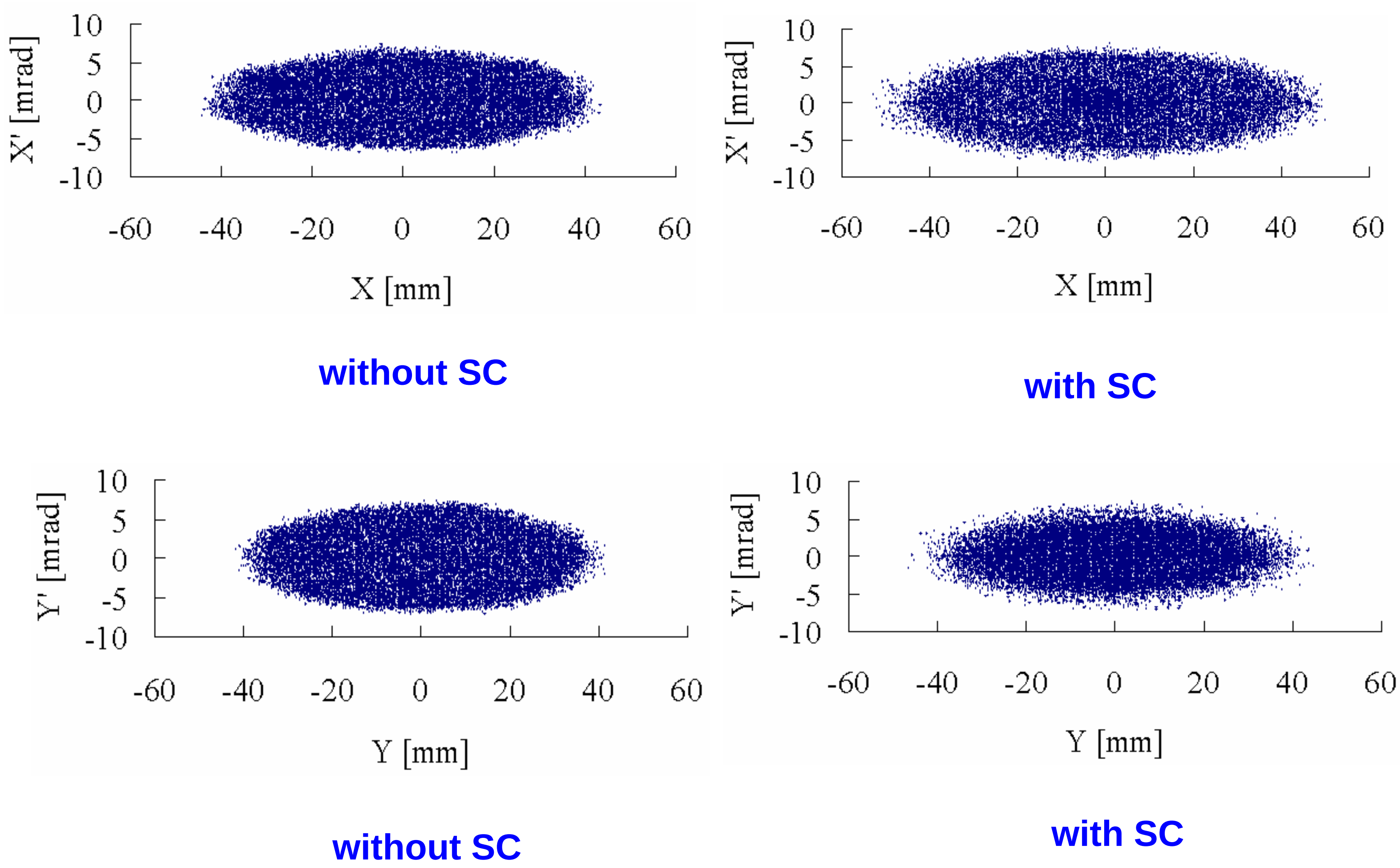
green:
4th order structure resonance

gray:
3rd deference structure resonance

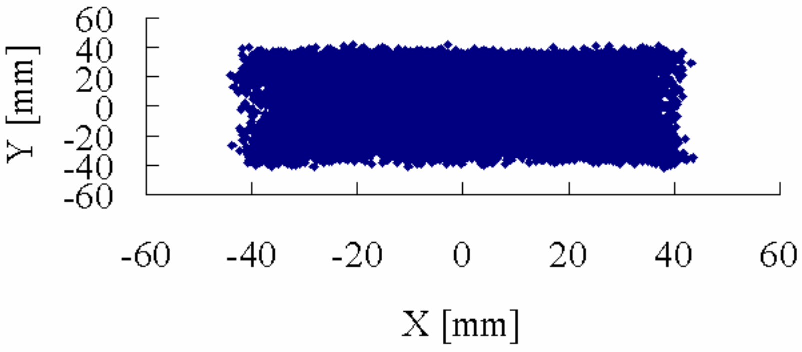
pink:
coupling resonance



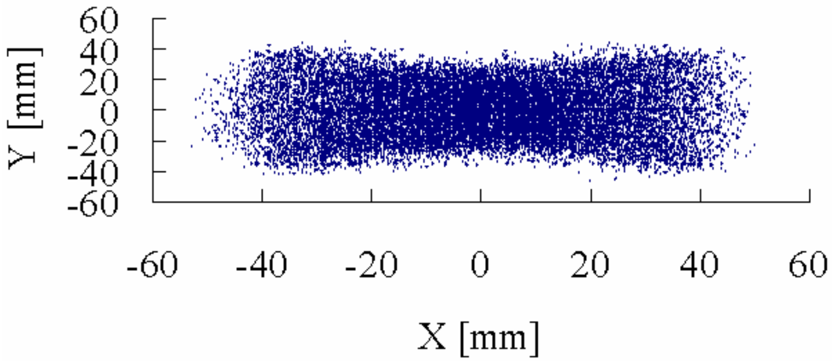
Correlated Painting with/without SC



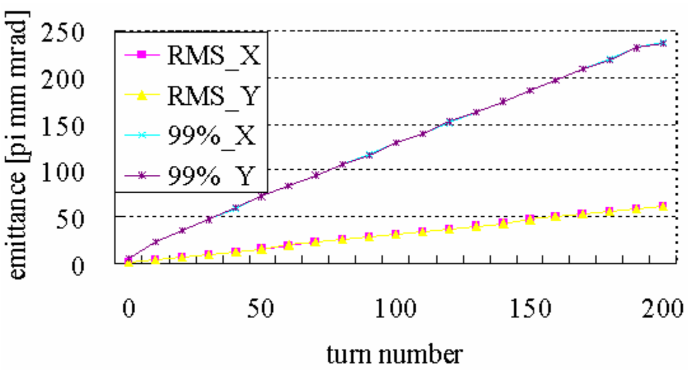
Correlated Painting with/without SC



without SC

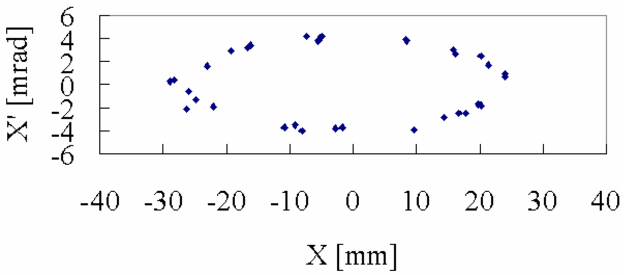


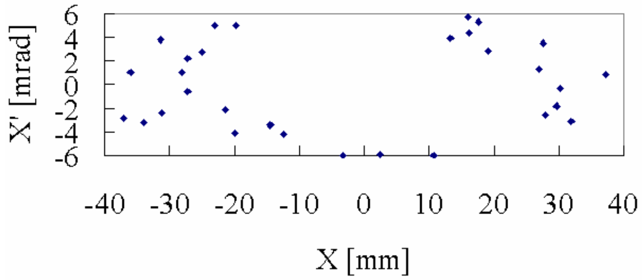
with SC

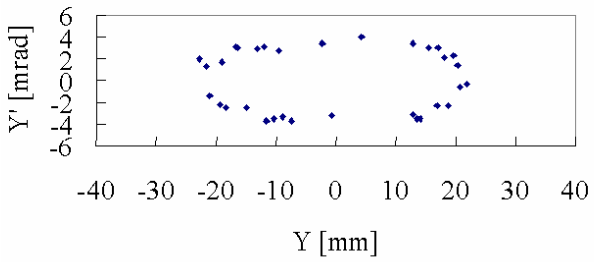


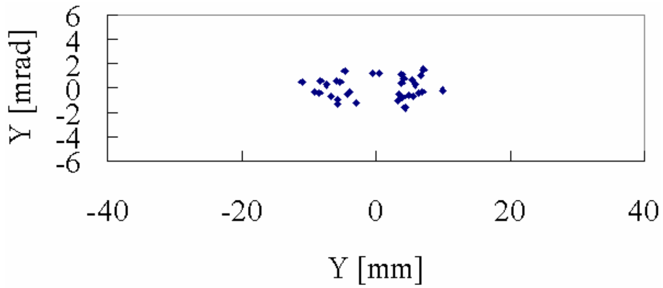
without SC

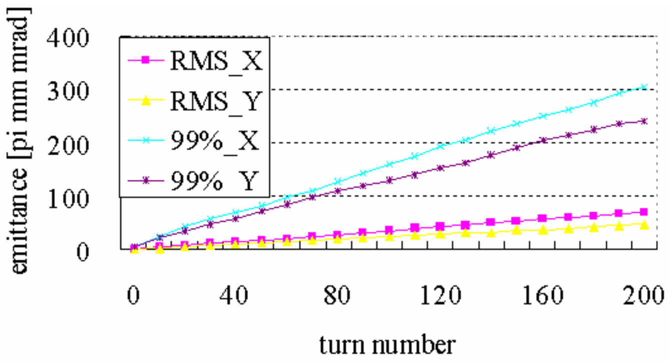
Transverse Coupling in Correlated Painting



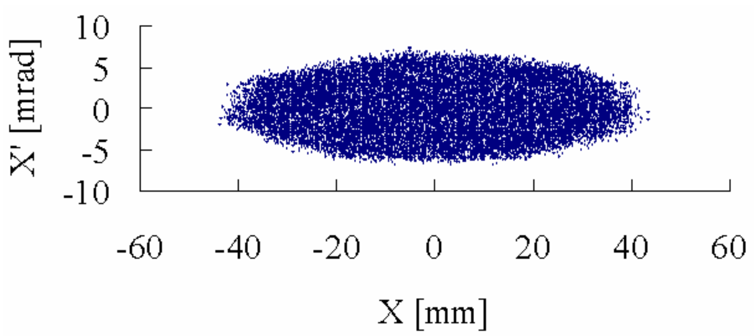




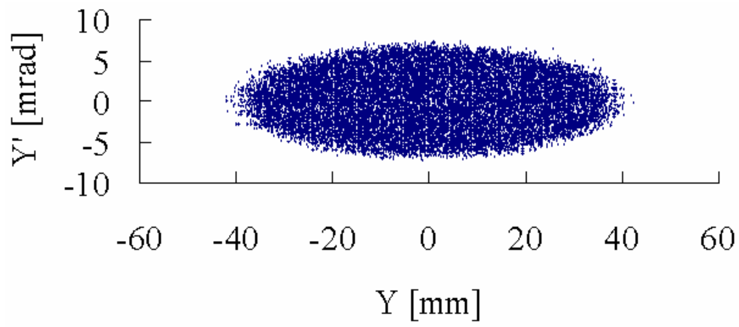




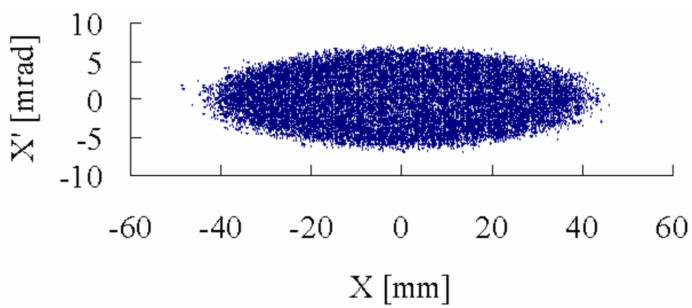
Anti-Correlated Painting with/without SC



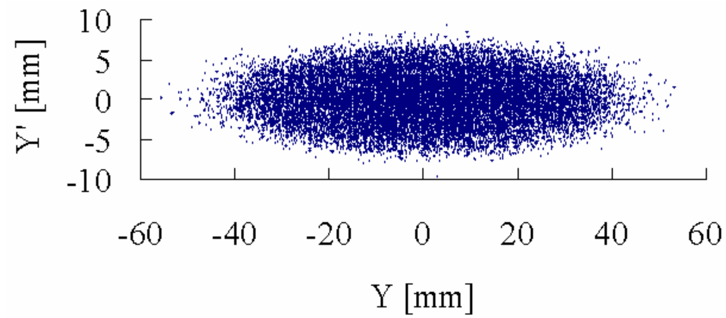
without SC



with SC



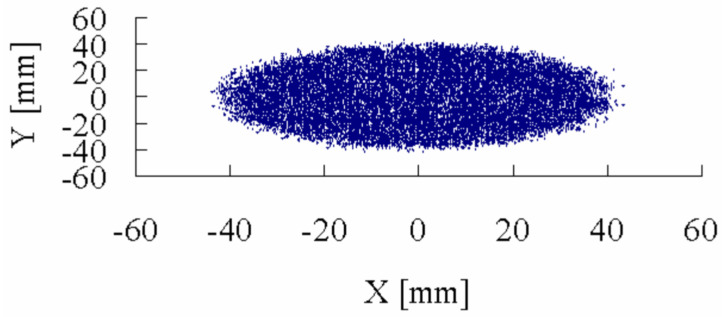
without SC

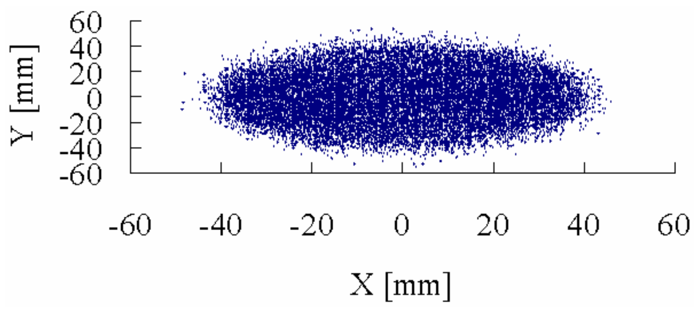


with SC

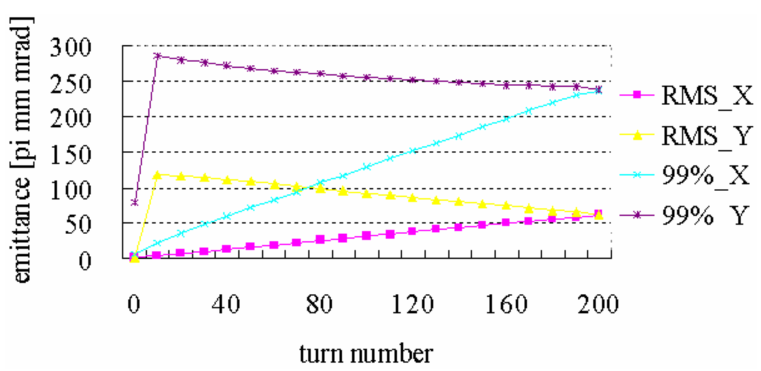
More halo in vertical direction

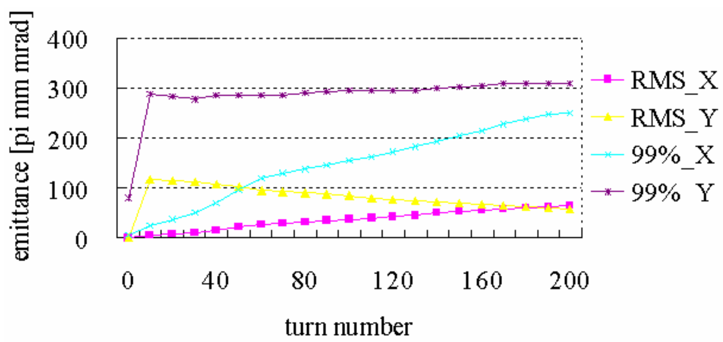
Correlated Painting with/without SC





without SC | **with SC**



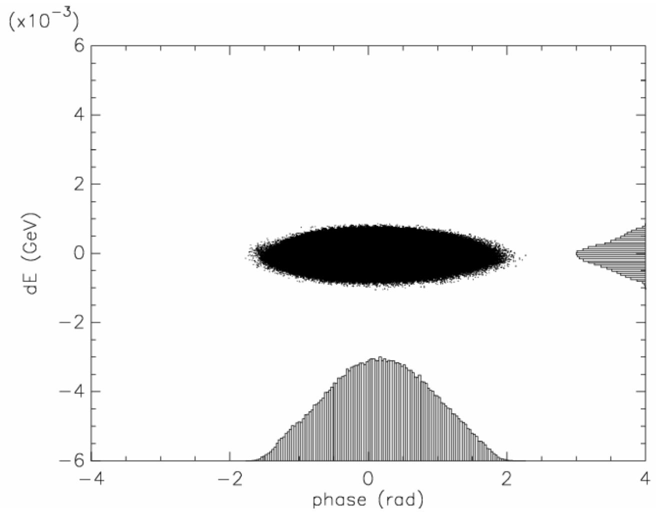


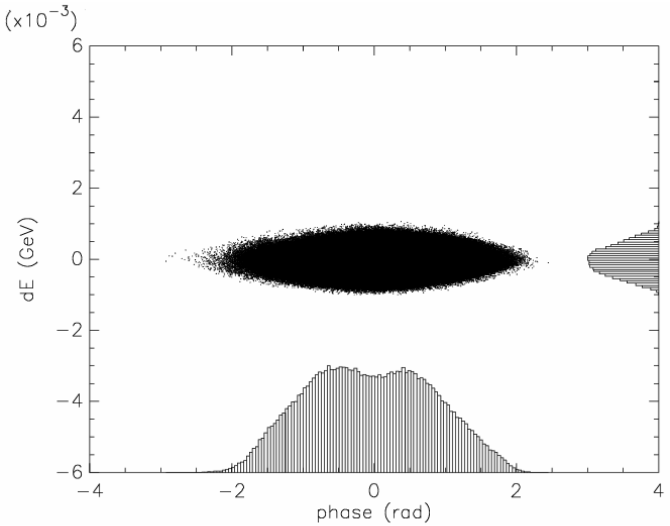
with SC

without SC

Without transverse coupling

Injection Optimization in Longitudinal Direction



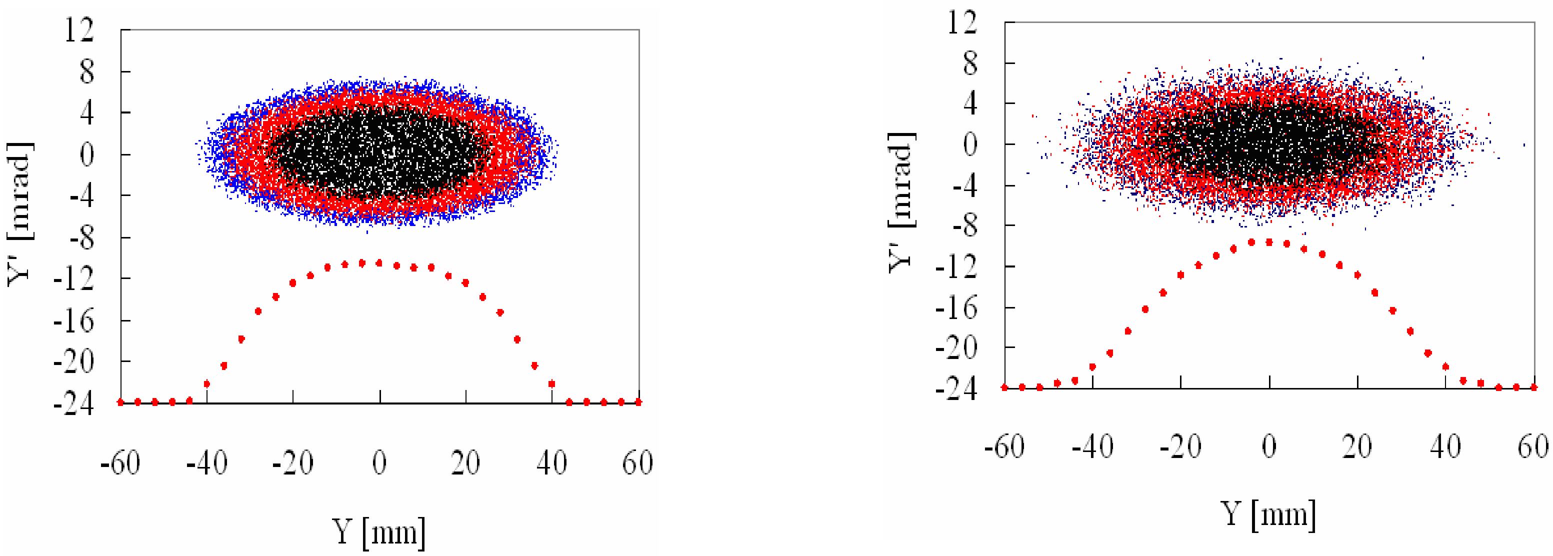


Without momentum offset

With momentum offset

Injection Optimization in Transverse Direction

- For anti-correlated painting, it does not have the capability of painting over the halo in one direction (vertical direction here).
- The injected particles on the effects of space charge expand towards inner and outer region of the emittance space.

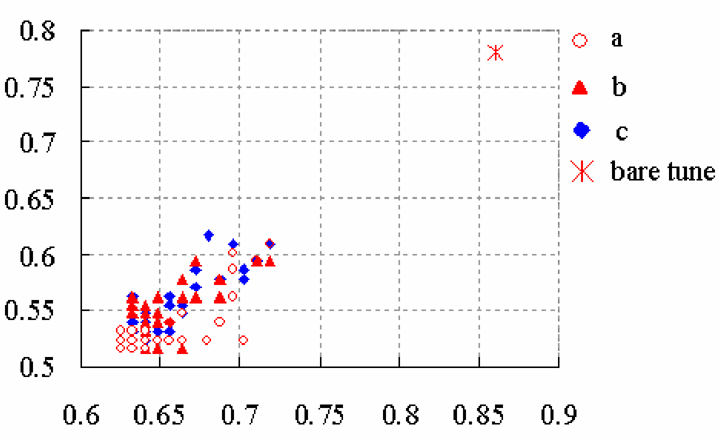


without SC — with SC

Particles distribution in (y, y') phase space after painting

Injection Optimization in Transverse Direction

- Injectling most particles a smaller emittance than the final target value to “reduce” halo production.
- Injecting less particles in the inner and outer region of the emittance space to produce a uniform transverse distribution and reduce halo production.

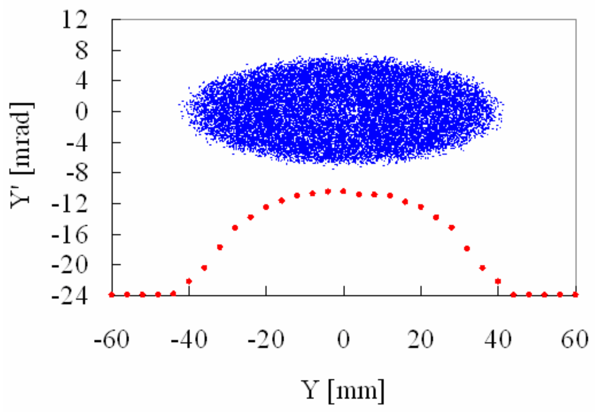


a: injecting particles a small emittance

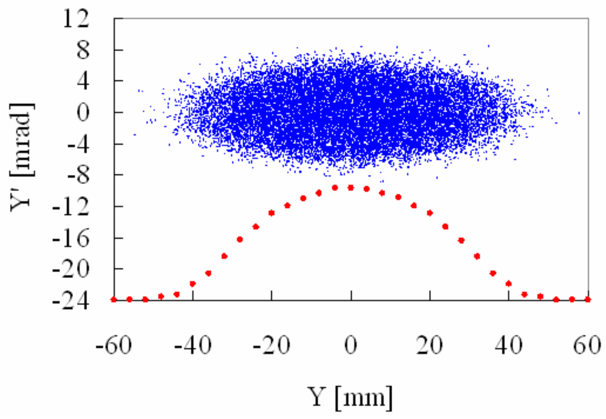
b: injecting less particles in the inner and outer region of the emittance space

c: bump in theory

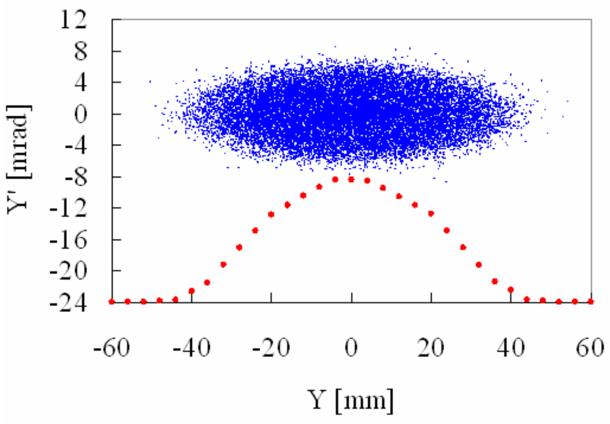
Particle distribution with Different Injection Orbit Bump



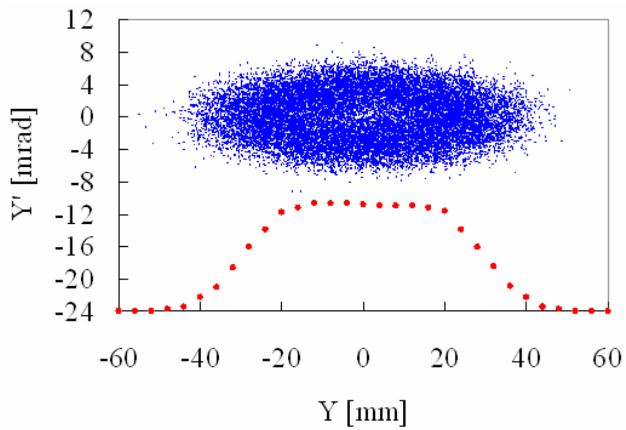
without SC



bump in theory

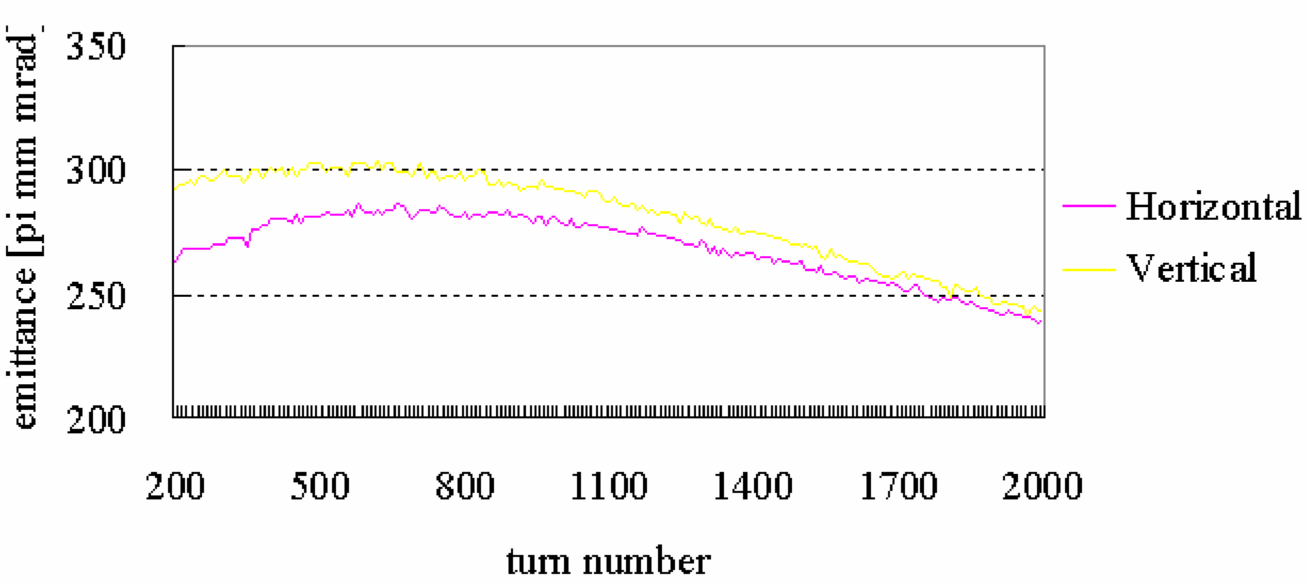


injecting particles a small emittance



injecting less particles in the inner and outer region of the emittance space

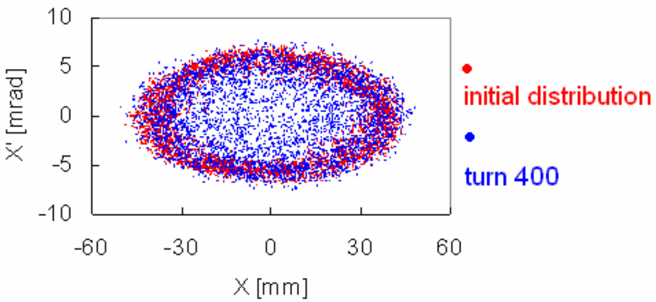
Space Charge Effects in Ramping



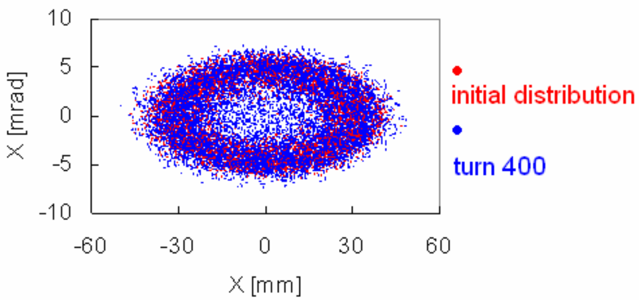
time evolution of the 99% emittance

Diffusion of Particles Among Different Parts

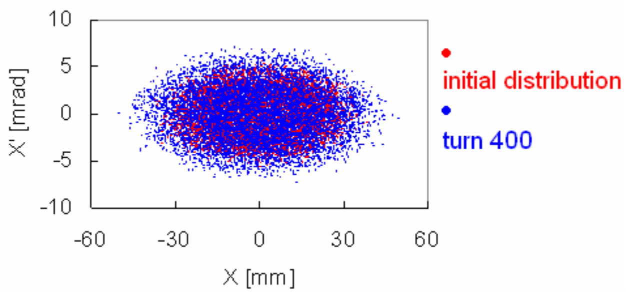
The initial distribution is produced by anti-correlated painting



particles in the outer region

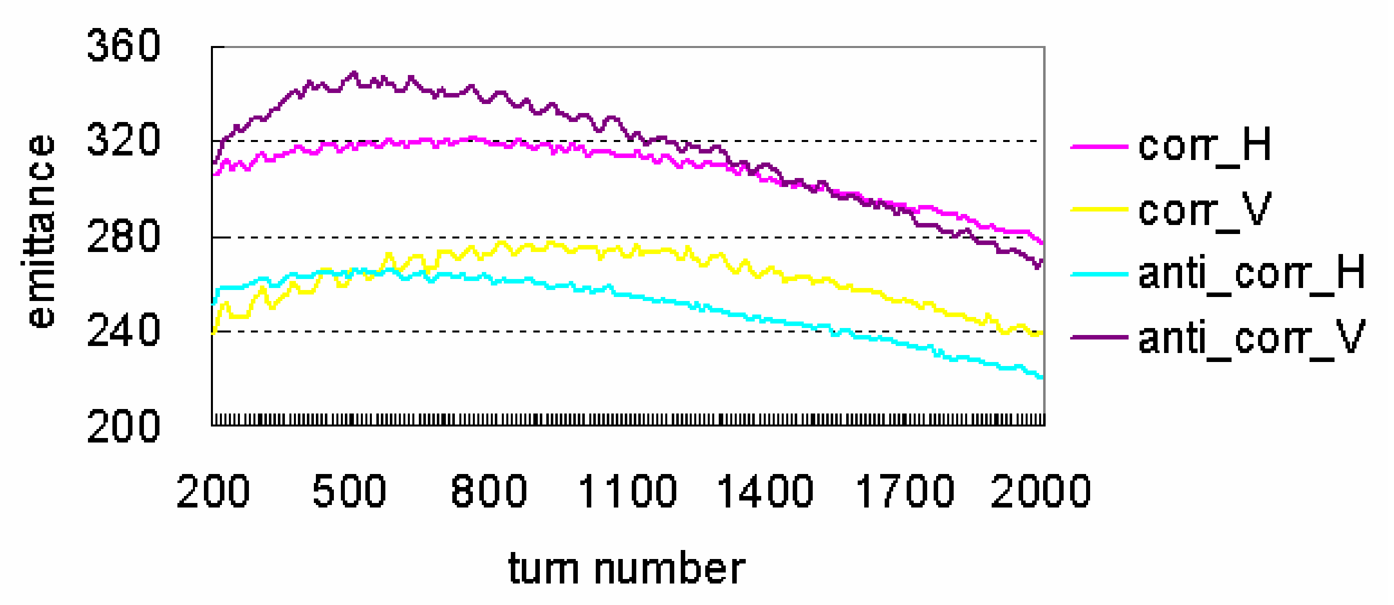


particles in the middle region



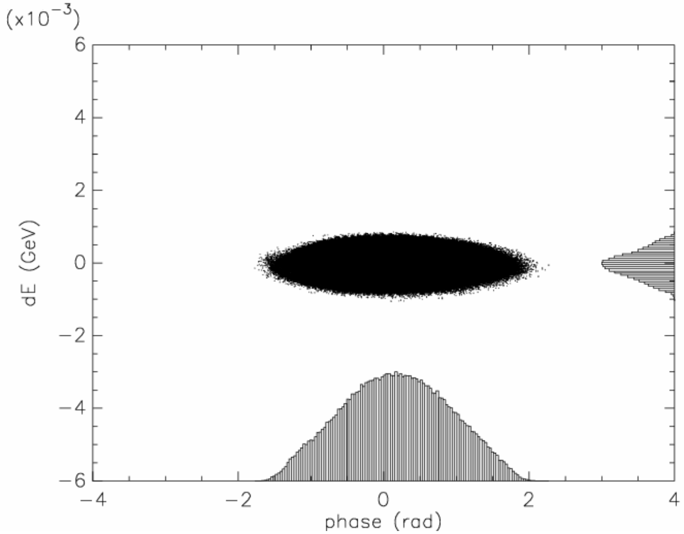
particles in the inner region

The Dependence of Emittance Growth on Painting Scheme

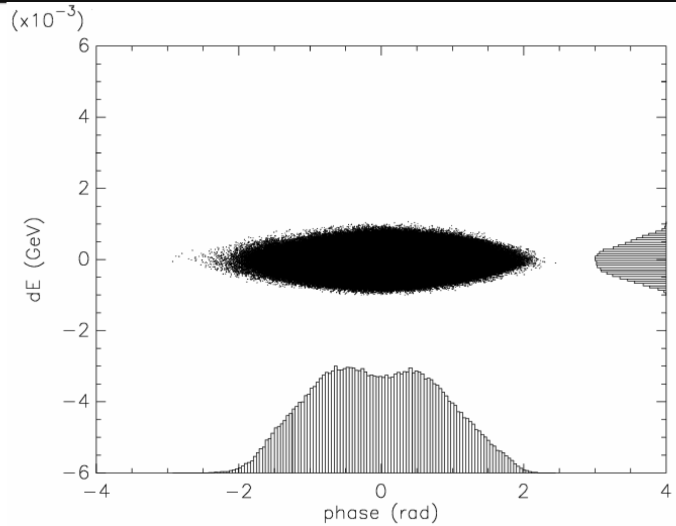


time evolution of the 99% emittance using different injection painting scheme

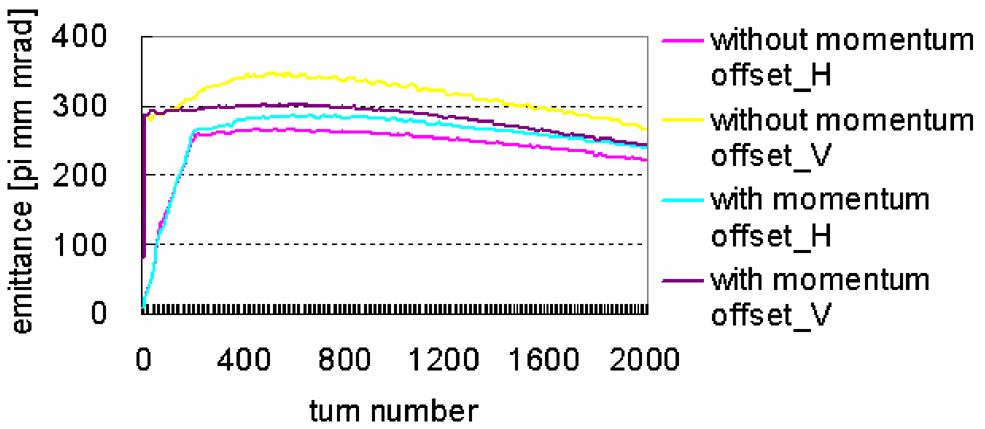
The Dependence of Emittance Growth on Initial Distribution



Without momentum offset

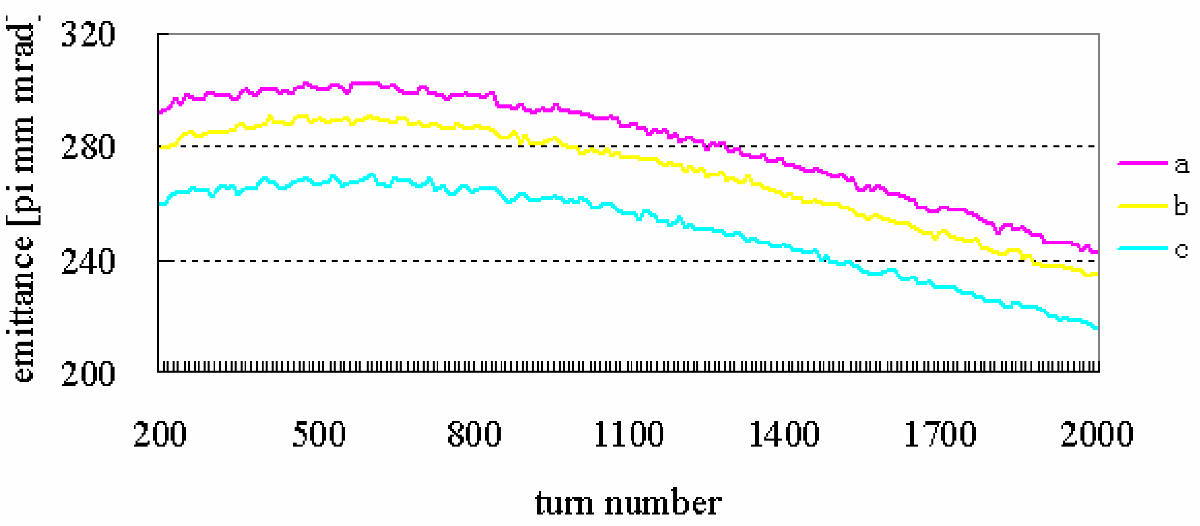


With a momentum offset



time evolution of the 99% emittance with and without momentum offset during injection

The Dependence of Emittance Growth on Initial Distribution



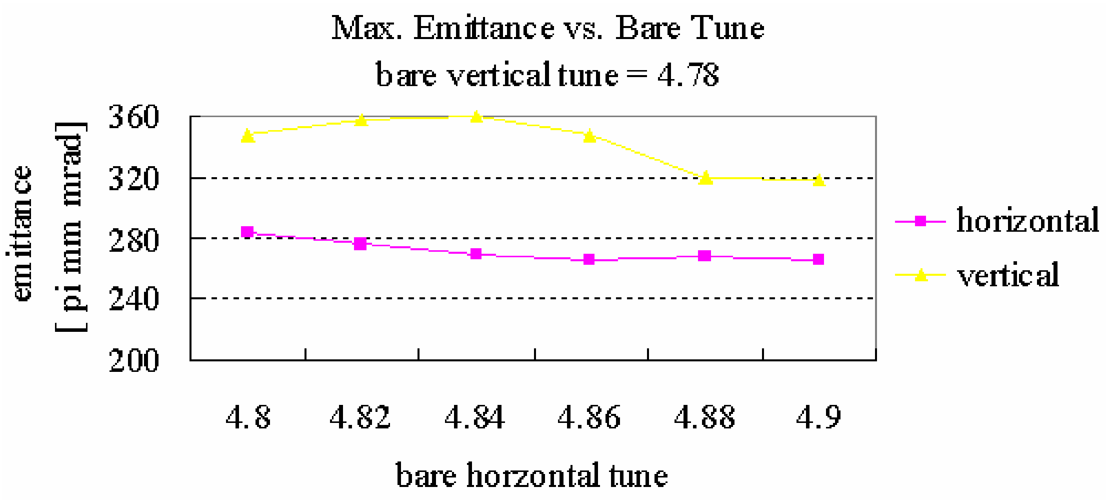
a: bump in theory

b: injecting less particles in the inner and outer region of the emittance space

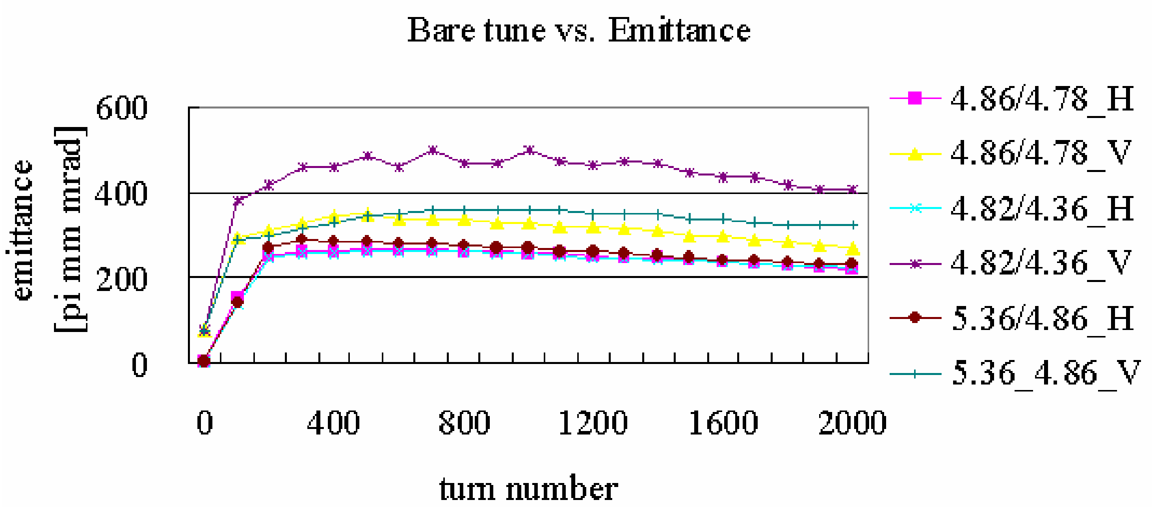
c: injecting all particles a smaller emittance than the final target

All the initial distributions show a similar trend of emittance growth without magnet errors.

The Dependence of Space Charge Effects on the Bare Tune



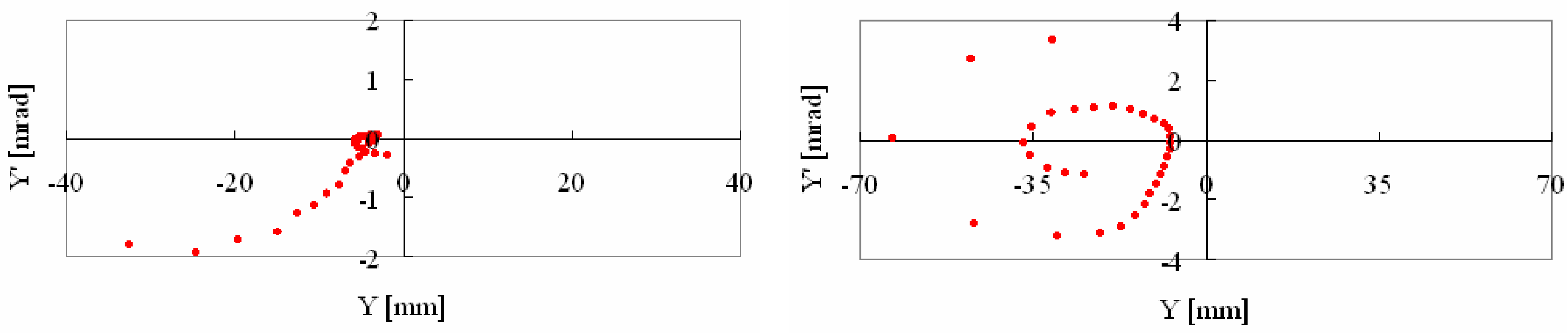
The maximum 99% vertical emittance during ramping vs. the bare horizontal tune



The time evolution of the 99% emittance with different bare tune

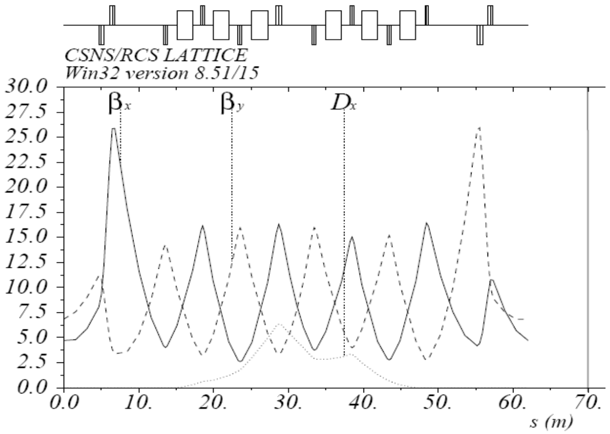
Space Charge Induced Structure Resonance

Poincaré maps of two test particles during ramping with the bare tune 4.82/4.36

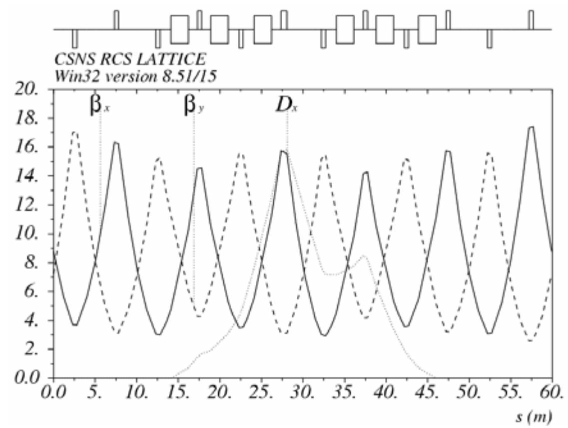


Structure resonance Q_y=4

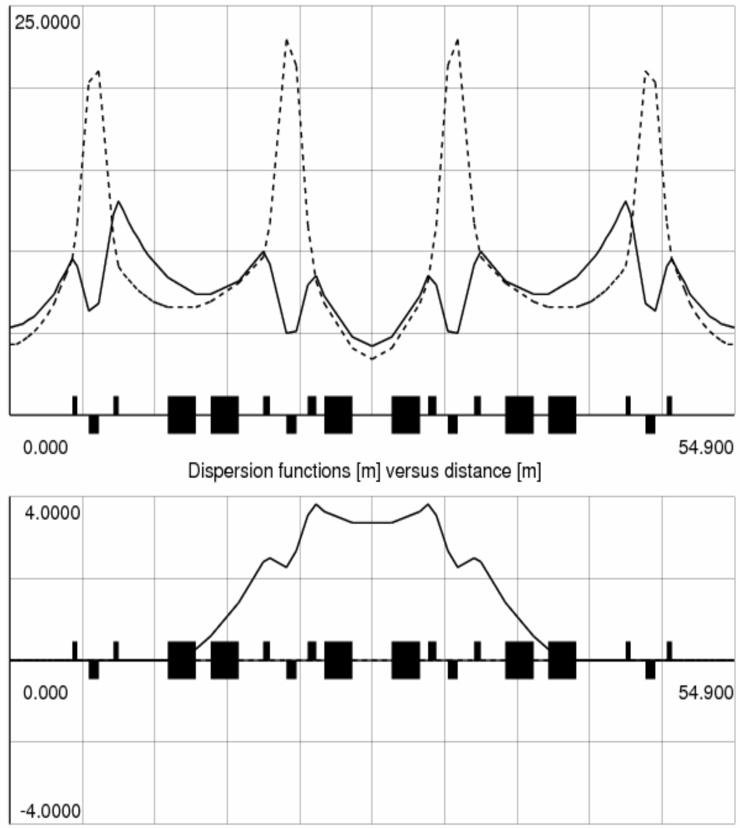
Lattice Type vs SC – Layout of Three Lattices



Hybrid



FODO



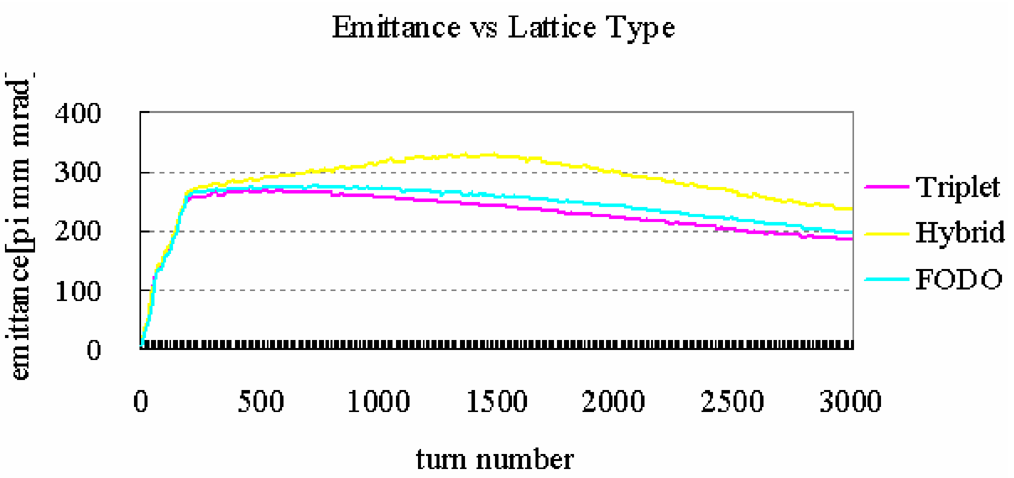
Triplet

Lattice Type vs SC – Parameters of Three Lattices

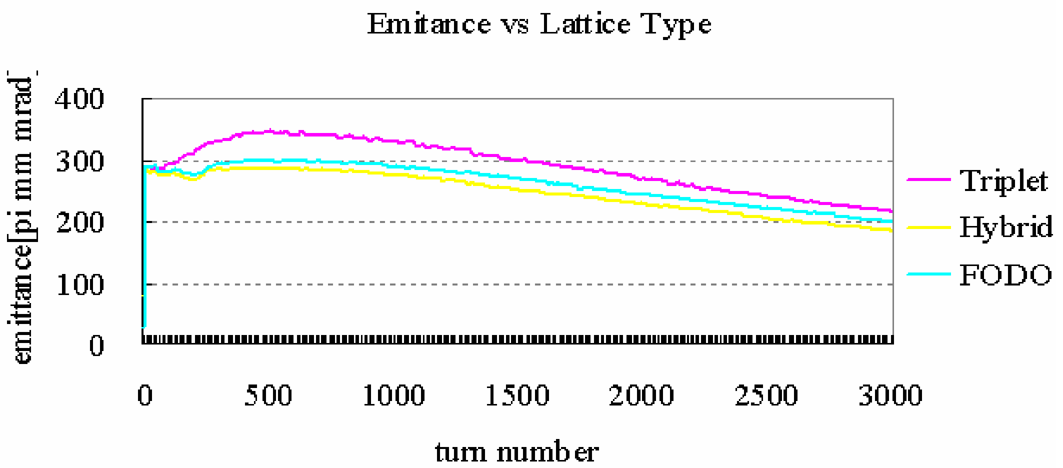
Structure	Triplet	FODO	Hybrid
Circumference (m)	228	240	248
Super-periods	4	4	4
Qx/Qy	4.86/4.78	5.86/5.78	5.86/5.78
Max. β_h/β_v (m)	11/26	17/17	24/25
Max. drift (m)	11	4.5	9.3

The lattice of the hybrid structure which is the early version consists of FODO cells in the arcs and doublet cells in the straight sections.

Lattice Type vs SC – 99% emittance



horizontal



vertical

Summary

- Many simulation work has been done for space charge effects study, including the space charge effects in painting, ramping and the dependence of space charge effects on the bare tune, lattice type.
- The choice of bare tune is very important, the lattice of FODO structure is the best, but it doesn't have long enough uninterrupted straight for injection.
- optimization of the injection scheme for minimum halo formation and small tune spread
- Further work will involve the study of space charge effects in the presence of magnet field errors.

Acknowledgment

The authors would like to thank Shinji Machida for providing us the SIMPSONS code and helps on test run

Thanks for your attention!