Simulation Studies for Inspection of the Benchmark Test with PATRASH

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3GeV ring simulation group (JKJ)

Agenda

1. Introduction
2. Calculation Condition of Benchmark Test
3. Results of benchmark test.
   (ACCSIM, SIMPSONS, PATRASH)
4. Focus on emittance growth at early stage
   for the inspection of the benchmark test. (PATRASH)
5. Summary

[Introduction]

○ 3GeV ring simulation group* has been established in the last fall.

Purpose: To Estimate quantitatively beam loss caused by

1. nonlinear space charge force
2. nonlinear components of magnetic fields
3. machine imperfection,

in a reliable manner.

↑

Important to justify the available simulation codes
by benchmark tests. (ACCSIM, SIMPSONS, PATRASH).

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[Simulation Codes for Benchmarking]

Characteristics of Simulation Codes

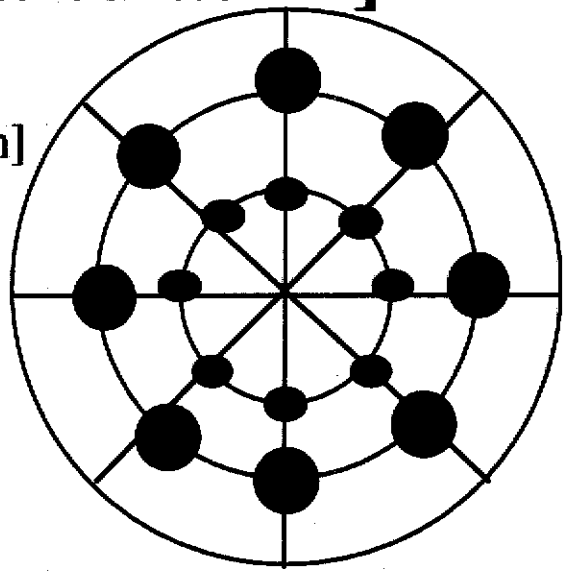
	ACCSIM	SIMPSONS	PATRASH
Development	TRIUMF G.	S.Machida	Y.Shimosaki
Space charge	Hybrid FMM[1)]	PIC[2)]	Hybrid TM[3)]
Dimension	2D,3D	2D, 3D	2D
Painting process	Yes	Yes	No
Tracking	Thick lens	Thin lens	Thick lens
Run	S.Igarashi	S.Machida	Y.Shimosaki

1) Fast Multipole Method
2) PIC with Multipole expansion
3) Tree Method

[Space Charge Force Calculation]

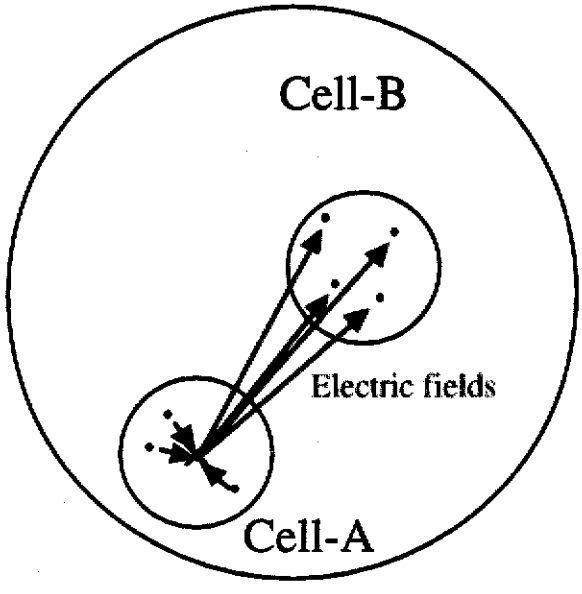
[SIMPSONS : PIC with Multipole expansion]

Space charge potential is expanded
by using PIC-charge
in the azimuthal direction .



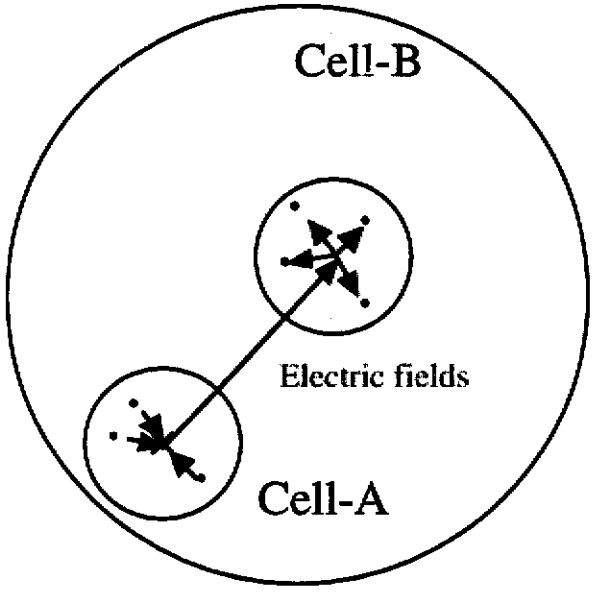
[PATRASH : Tree Method]

The particles in Cell-A
is transformed to one macro-particle
on the center of Cell-A.
Then the space charge force
from the center of Cell-A
to particles in Cell-B is calculated.



[ACCSIM : Fast multipole Method]

The space charge force
from the center of Cell-A
to the center of Cell-B is
calculated, then distributed
to particles in Cell-B.



[Calculation Condition]

1. 2D (x, x', y, y'), $\Delta p/p = 0$.

2. Initial beam distribution after painting process

3. Peak currents of 10A, 20A and 30A.

4. Longitudinal step size = 1.0m. 10000 particls. (Saturation of Calculation)

5. Injection energy (400.0MeV).

6. Space charge on.

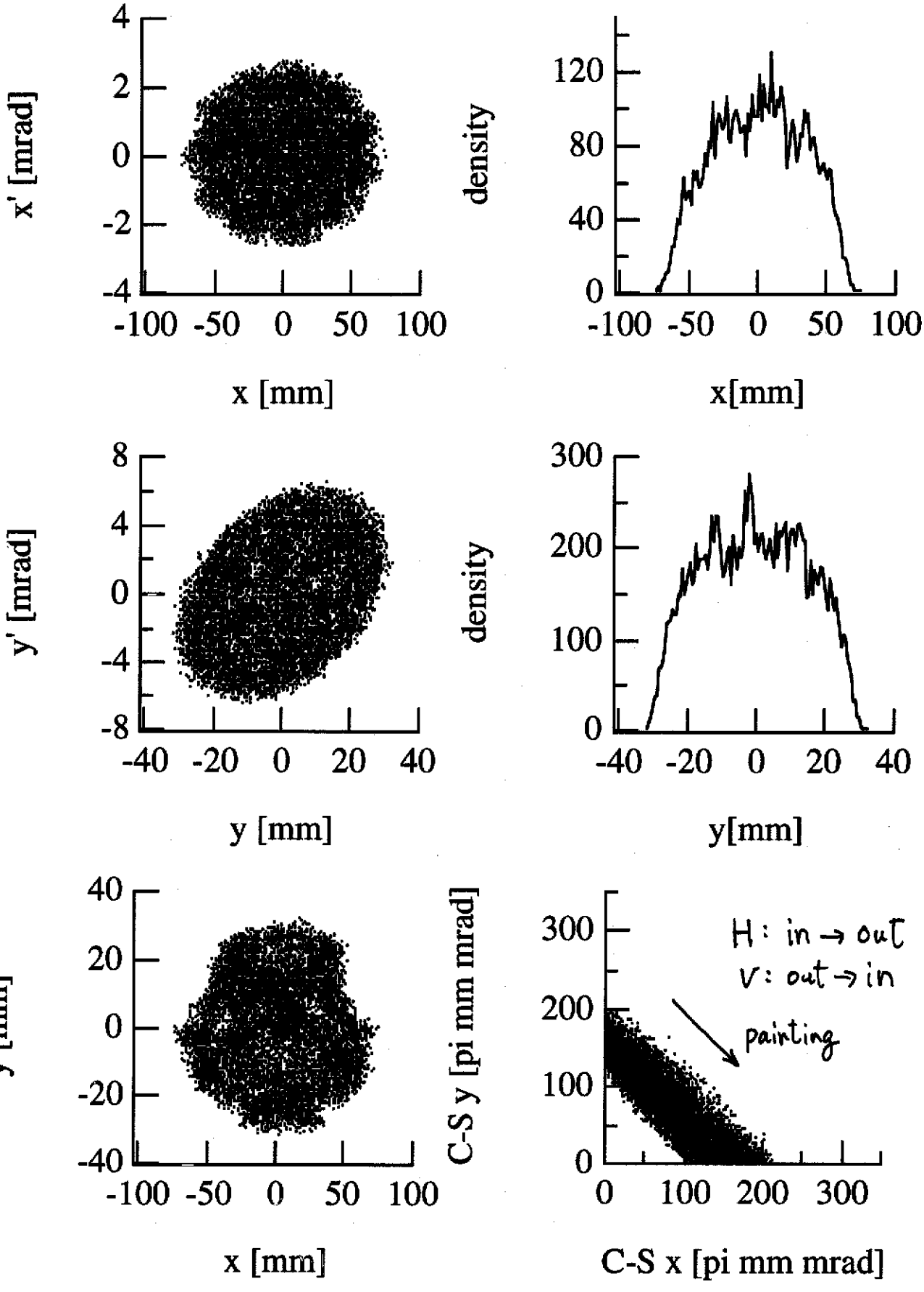
7. Sextupole magnet for chromaticity correction on/off.

8. 90%, 95% and 99% Courant-Snyder invariants were compared between each codes.

[Benchmark Test Initial Distribution]

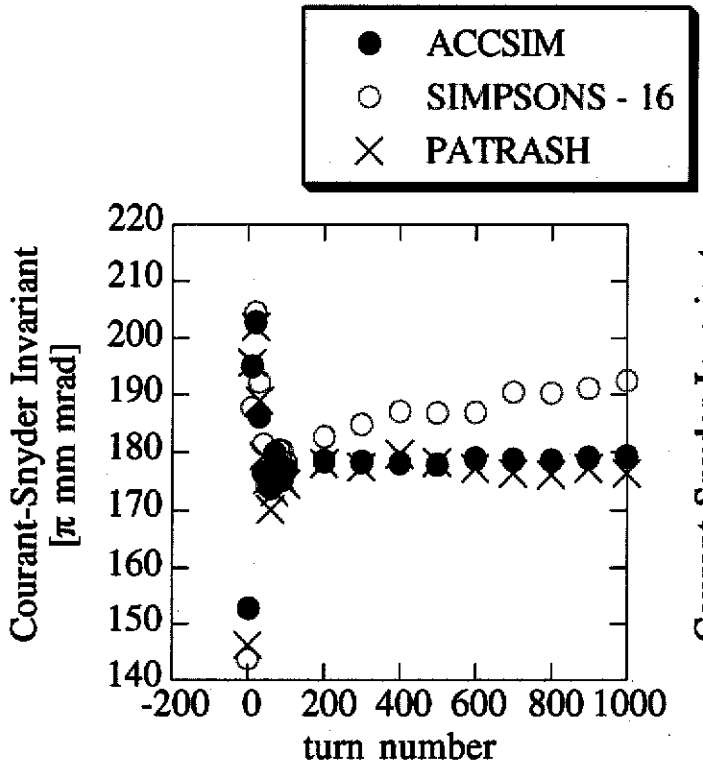
at foil

20A, (6.64, 6.27), RMS-matced beam (made by F.Noda)

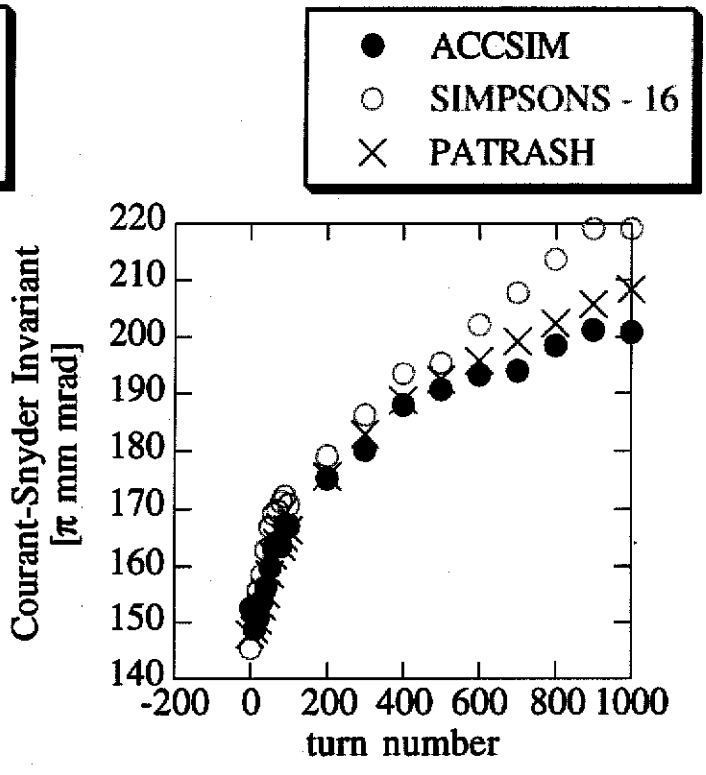


[Benchmark Test Result 20A part1]

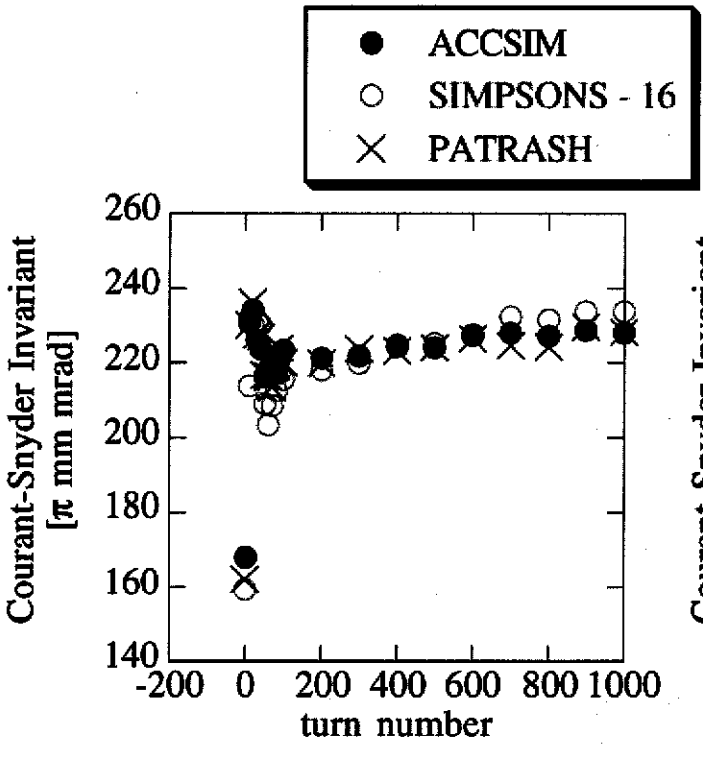
20A, (6.64, 6.27), Sextupole magnet on



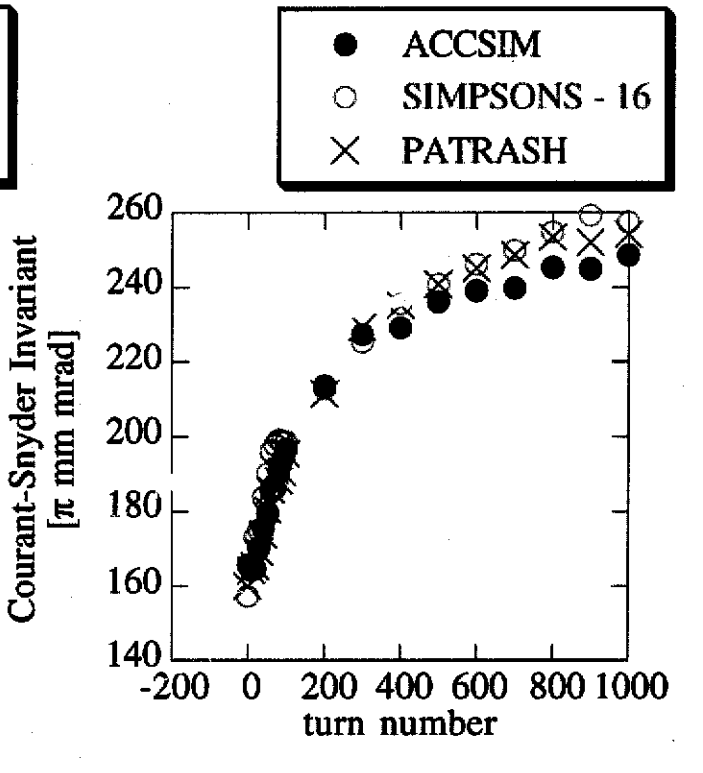
Horizontal 90% Courant-Snyder invariant



Vertical 90% Courant-Snyder invariant



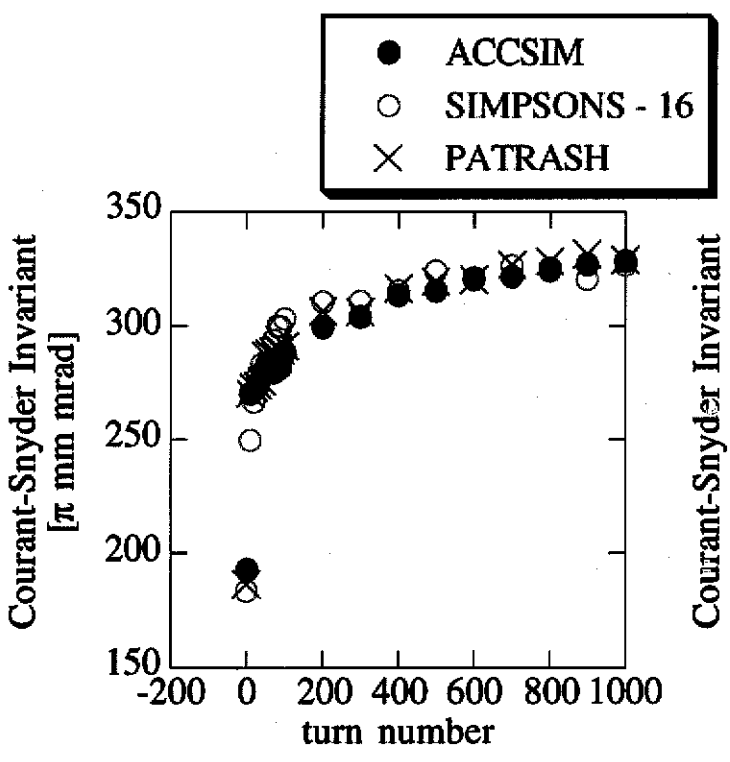
Horizontal 95% Courant-Snyder invariant



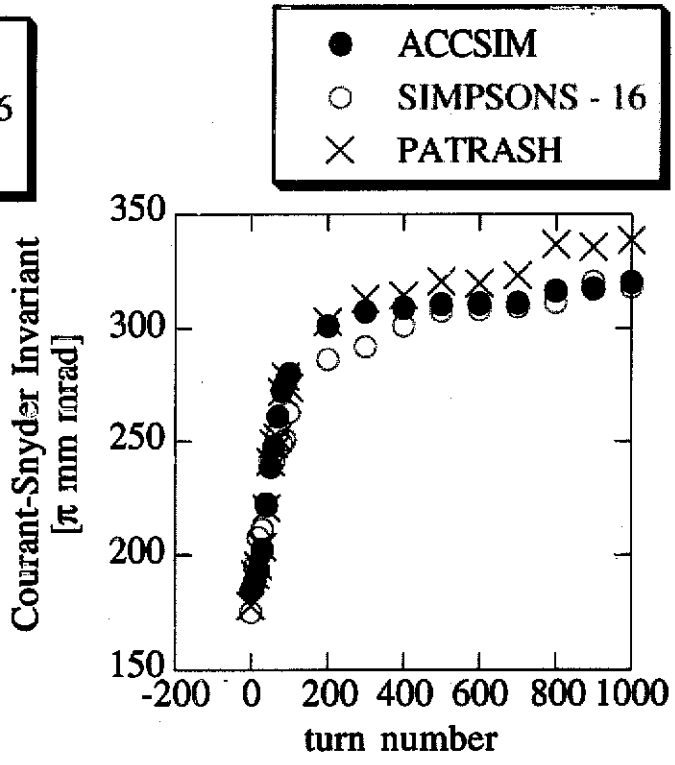
Vertical 95% Courant-Snyder invariant

[Benchmark Test Result 20A part2]

20A, (6.64, 6.27), Sextupole magnet on



Horizontal 99% Courant-Snyder invariant



Vertical 99% Courant-Snyder invariant

○ The results of ACCSIM, SIMPSONS and PATRASH were good agreement with each other.

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ACCSIM, SIMPSONS and PATRASH are reliable to estimate beam loss.

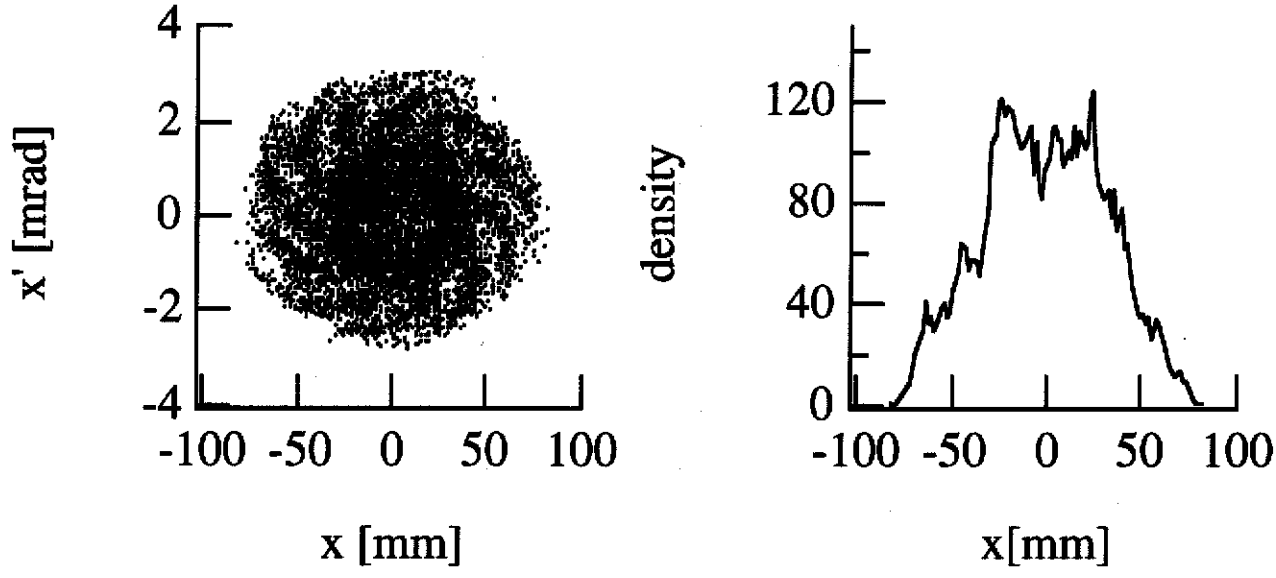
○ Why does the horizontal emittance glow up at the early stage of the injection, though the painted beam was injected?

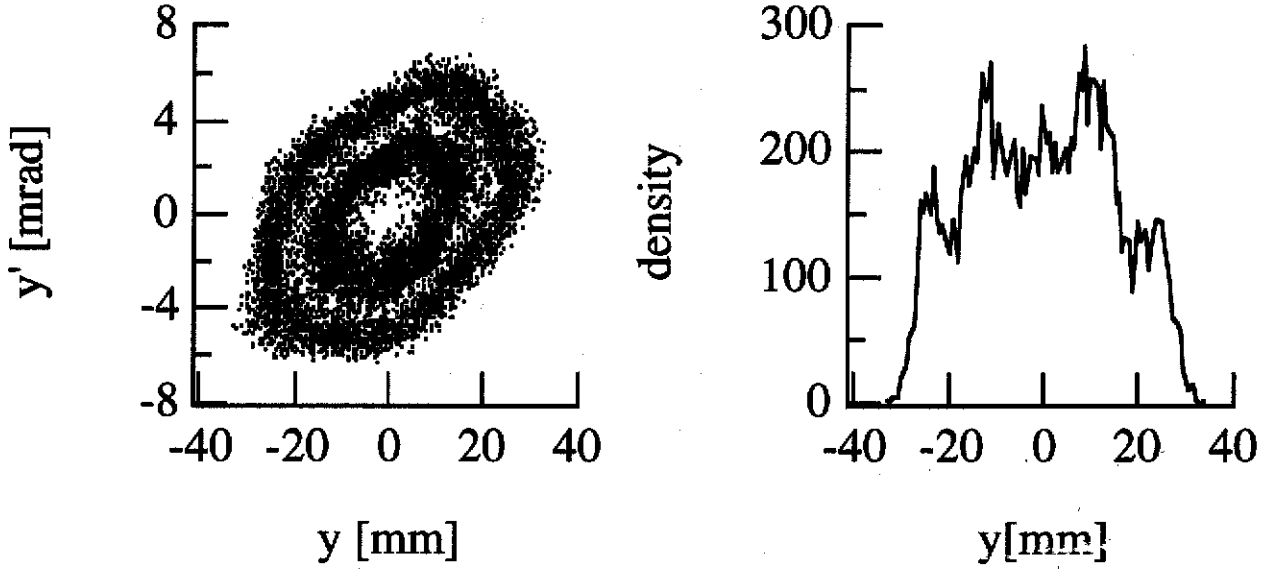
↓

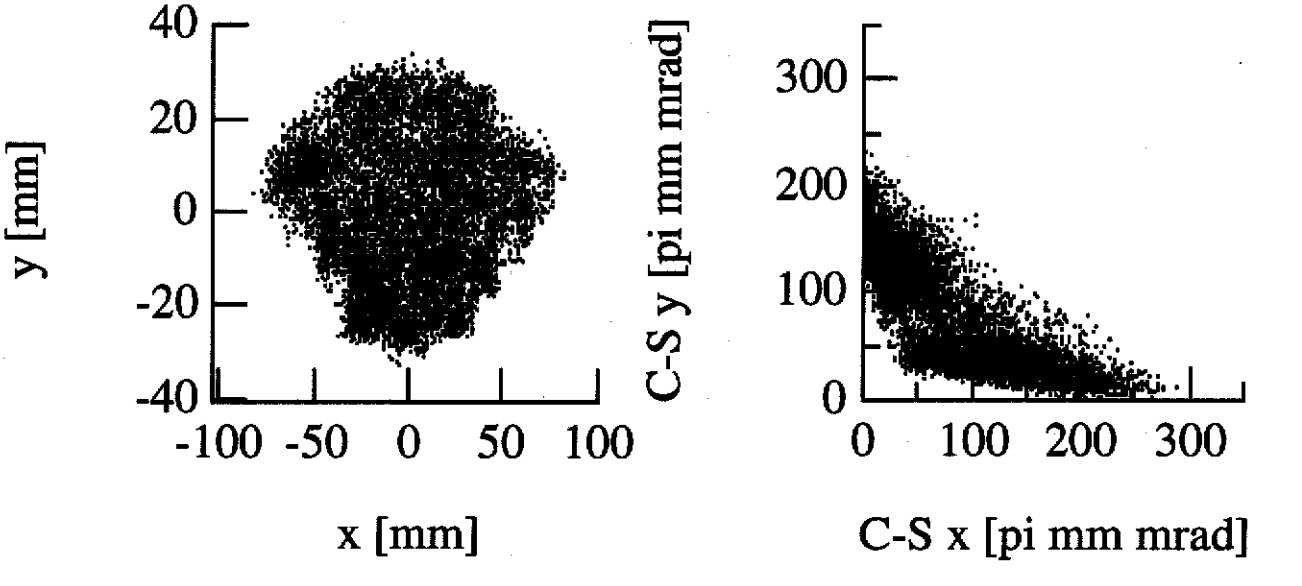
The behavior of particles in the initial 20turns has been studied by PATRASH for the inspection of the benchmark test from a beam-dynamics point of view.

[Beam Distribution 4turn] at foil

20A, (6.72, 6.35), Sextupole magnet off

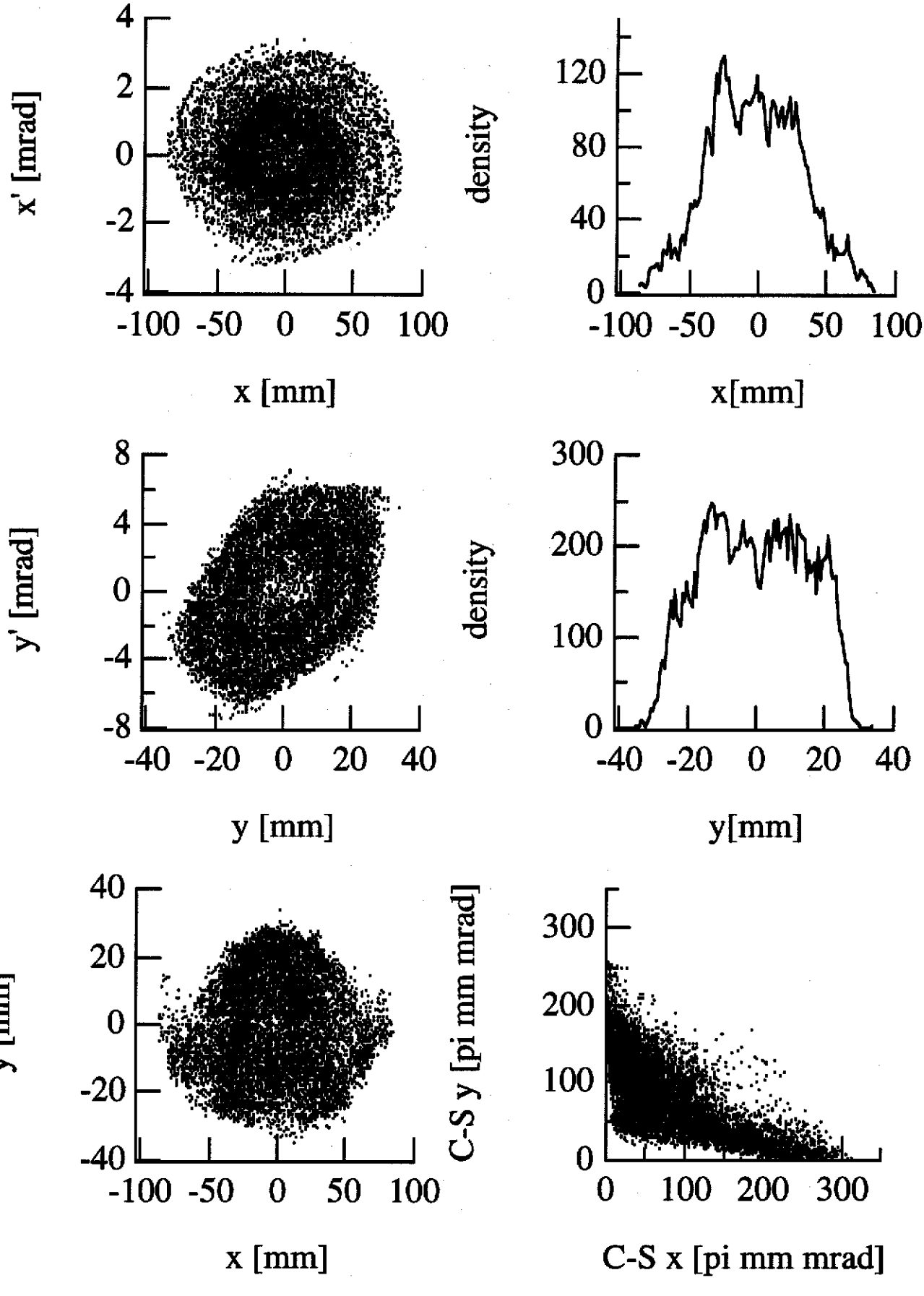






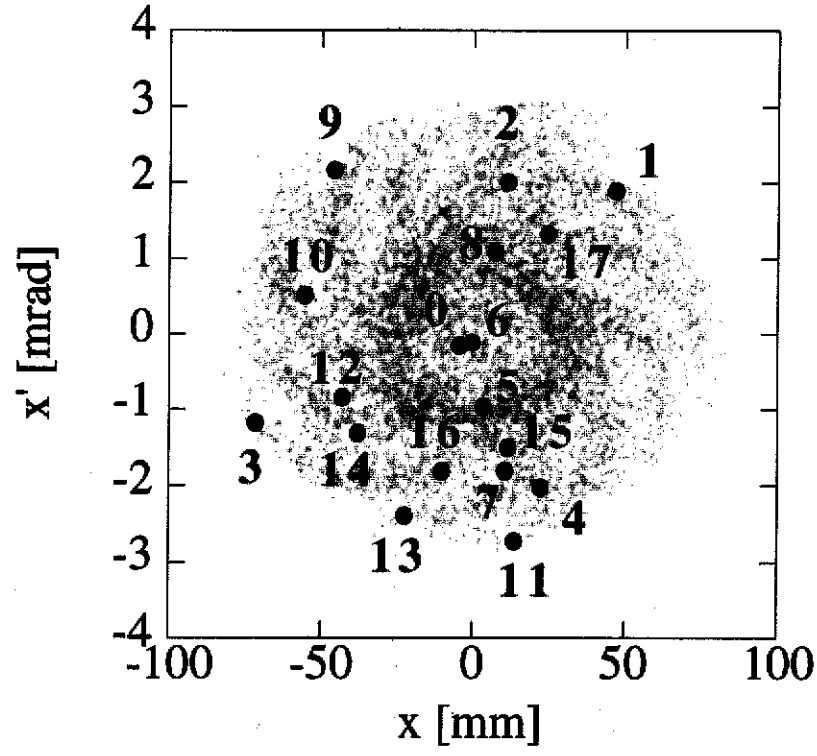
[Beam Distribution 8turn] at foil

20A, (6.72, 6.35), Sextupole magnet off

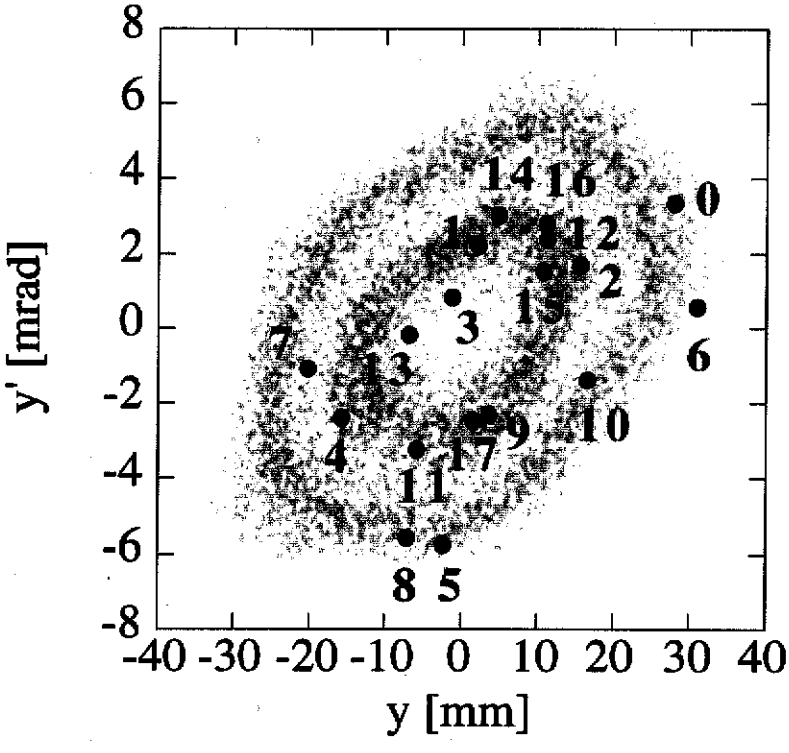


[Poincaré Map Analysis]

Put 18 test particles on the particular points of 4turn.

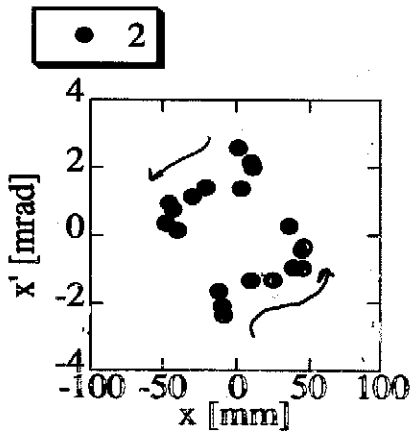


Horizontal, 4turn

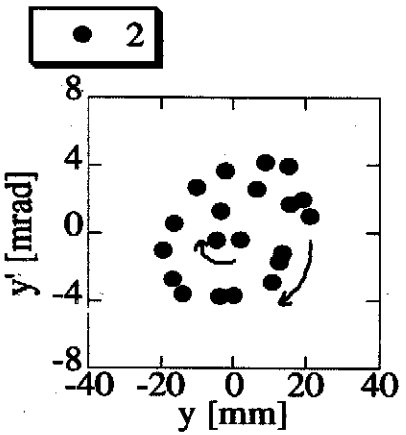


Vertical, 4turn

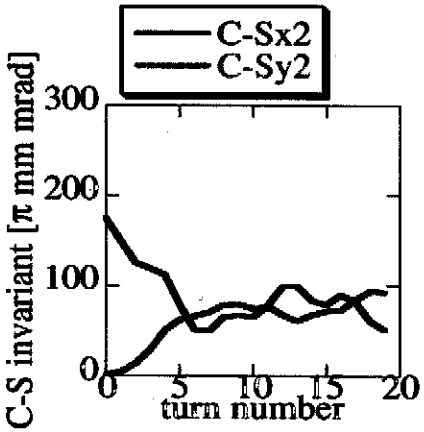
[Behavior of Test Particle ID:2, 4] at foil



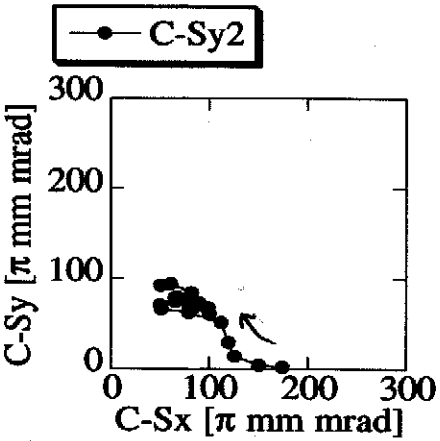
x' vs. x



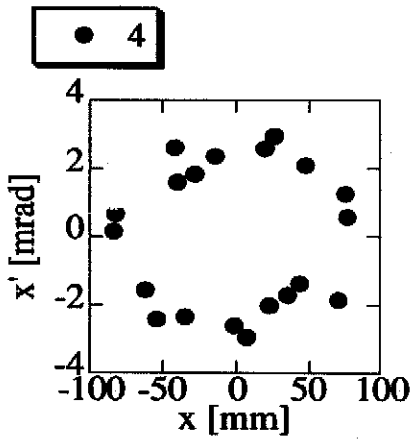
y' vs. y



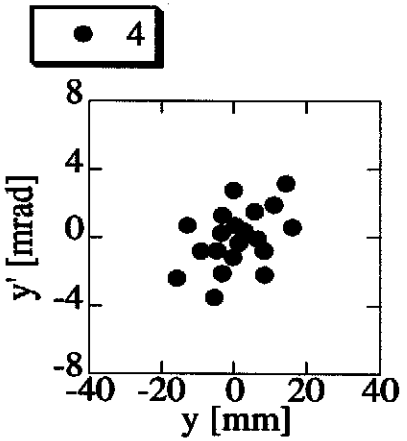
Courant Snyder invariant vs. turn



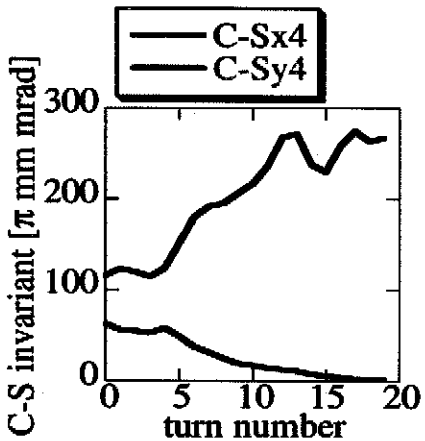
C-Sy vs. C-Sx



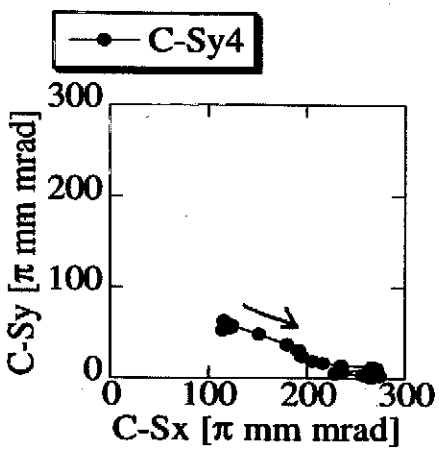
x' vs. x



y' vs. y

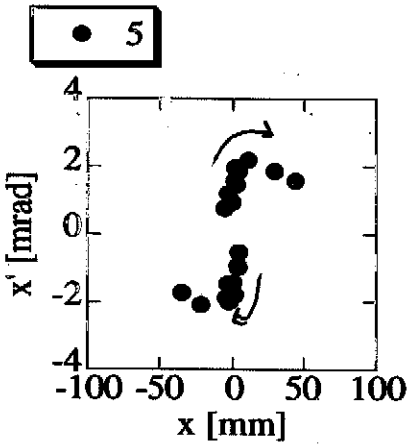


Courant-Snyder invariant vs. turn

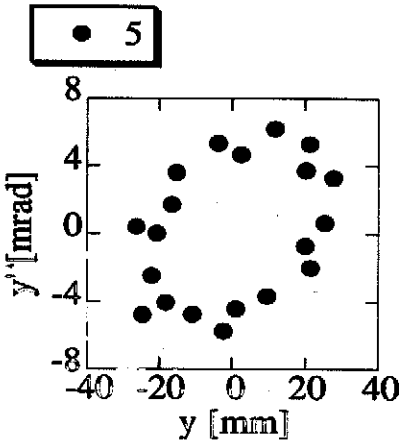


C-Sy vs. C-Sx

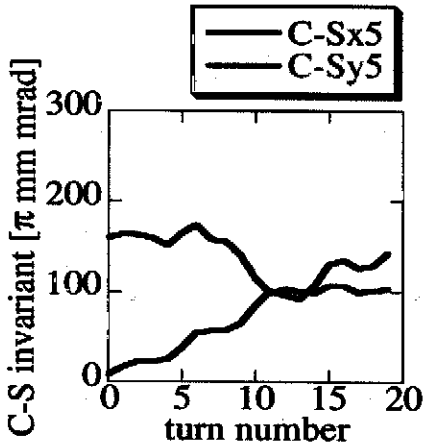
[Behavior of Test Particle ID:5, 7] at foil



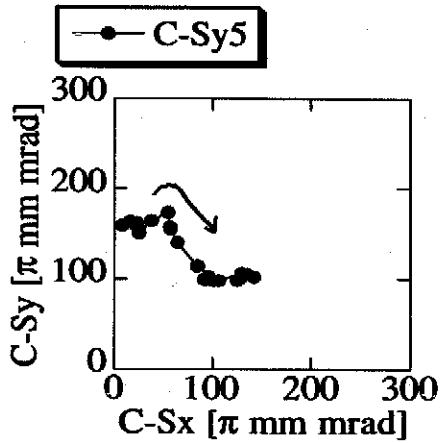
x' vs. x



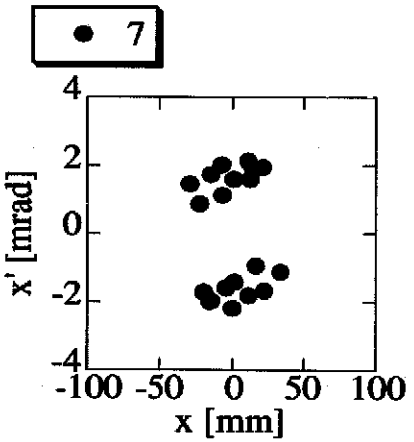
y' vs y



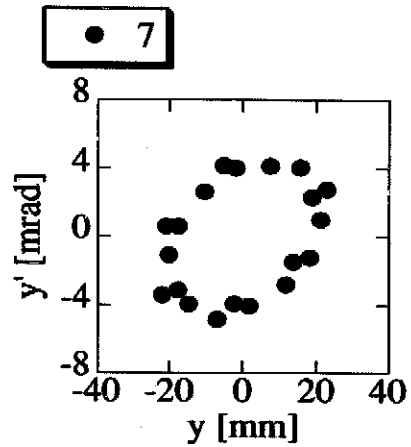
Courant-Snyder invariant vs. turn



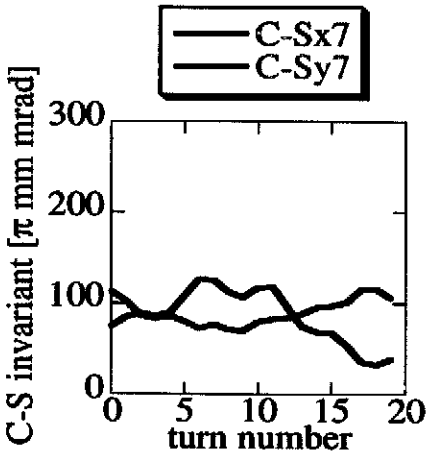
C-Sy vs. C-Sx



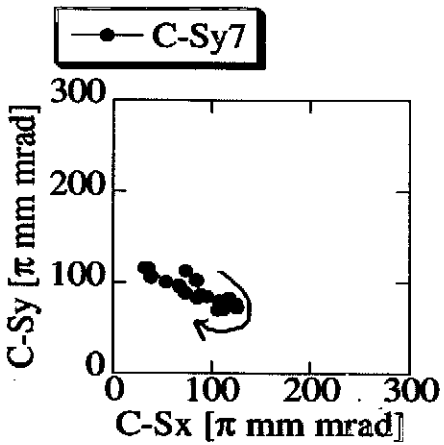
x' vs. x



y' vs y



Courant-Snyder invariant vs. turn



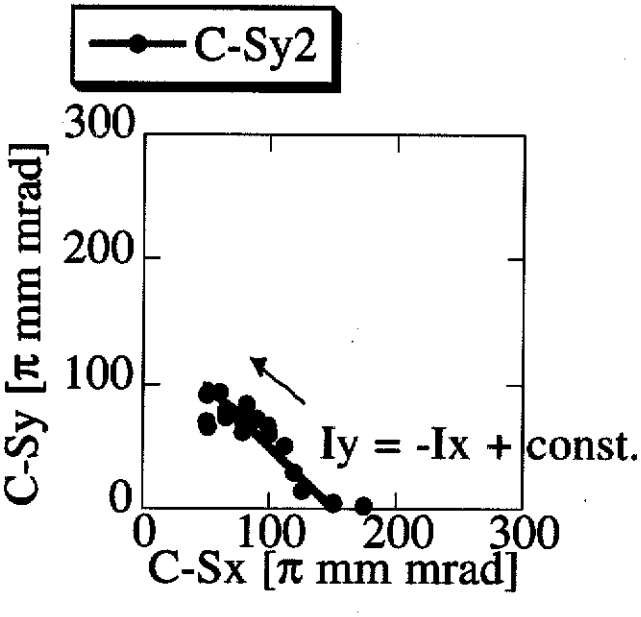
C-Sy vs. C-Sx

[Tune Analysis]

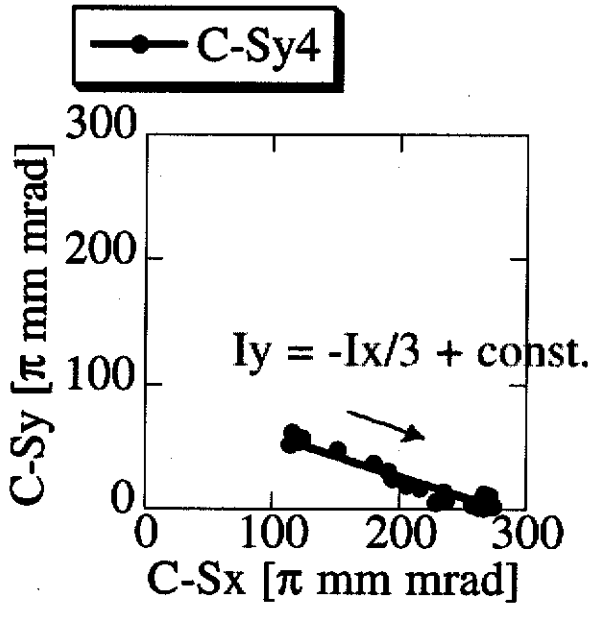
Bare tune (6.72, 6.35)
Max Incoherent tune shift
(0.25, 0.21)

ID: (νx, νy)

0 : (6.47, 6.14) I : Action variable = (C-S invariant)/2
1 : (6.48, 6.16)
2 : (6.47, 6.16) → $3\nu x - 3\nu y = 1$ → $Ix + Iy$ = const.of motion
3 : (6.55, 6.20)
4 : (6.55, 6.19) → $6\nu x - 2\nu y = 27$ → $Ix + 3Iy$ = const.of motion
5 : (6.53, 6.16)
6 : (6.52, 6.18)
7 : (6.48, 6.14)
8 : (6.48, 6.16)
9 : (6.56, 6.19) → $6\nu x - 2\nu y = 27$
10 : (6.52, 6.16)
11 : (6.56, 6.18) → $6\nu x - 2\nu y = 27$
12 : (6.48, 6.16) → $3\nu x - 3\nu y = 1$
13 : (6.52, 6.18)
14 : (6.53, 6.17)
15 : (6.48, 6.18)
16 : (6.48, 6.15)
17 : (6.48, 6.17) → $3\nu x - 3\nu y = 1$

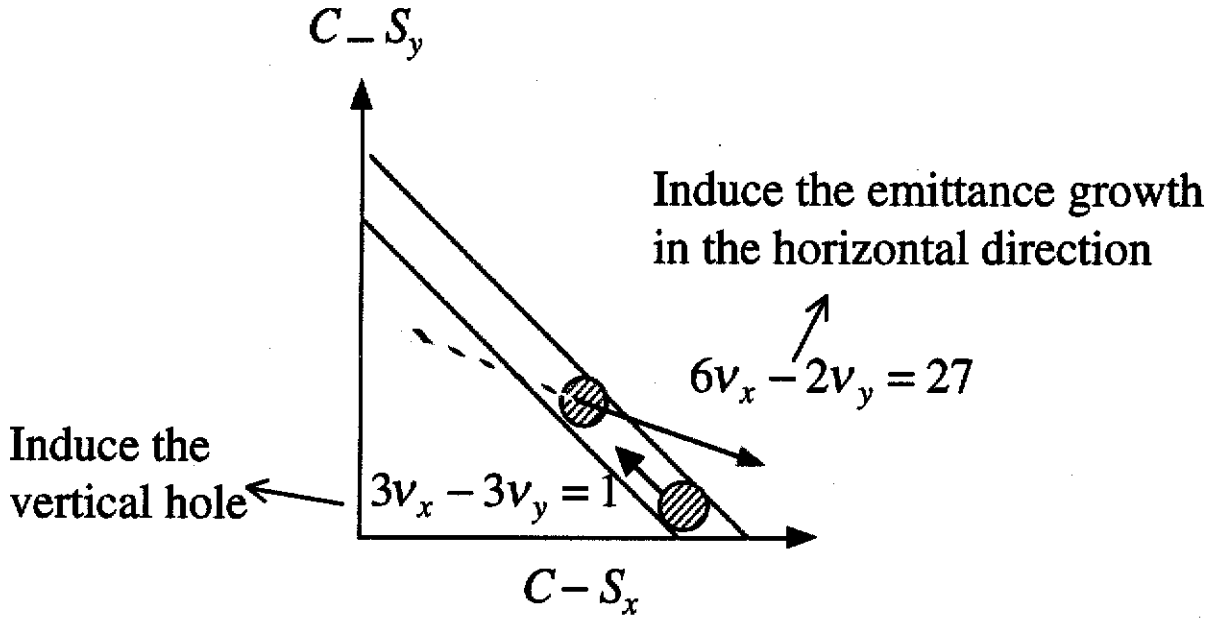


C-S invariant of test particle ID:2

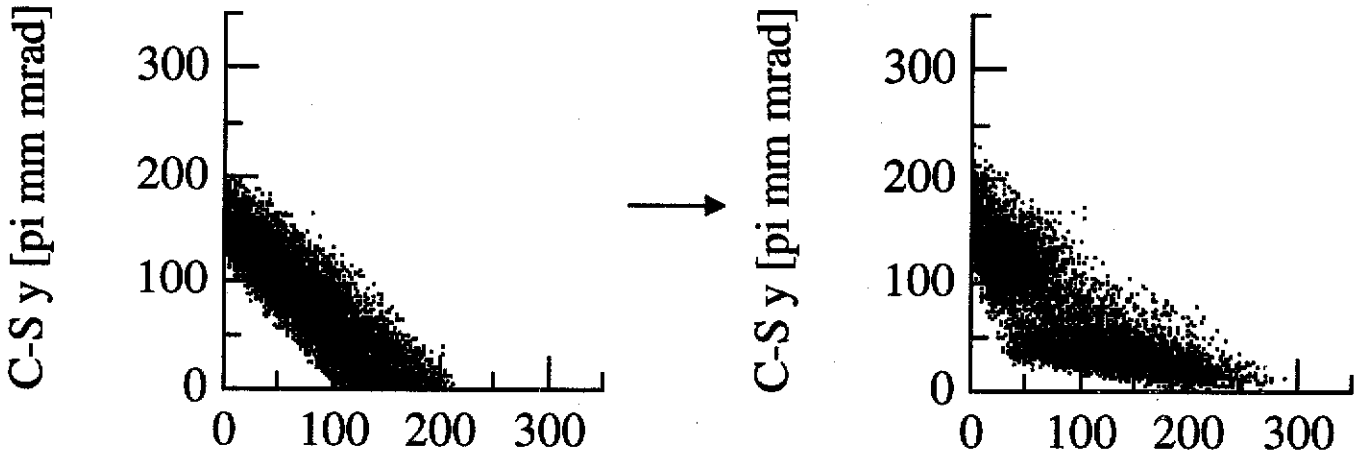


C-S invariant of test particle ID:4

[Behavior of Particles at the Early Stage]



Particles move along the each const. of motion.



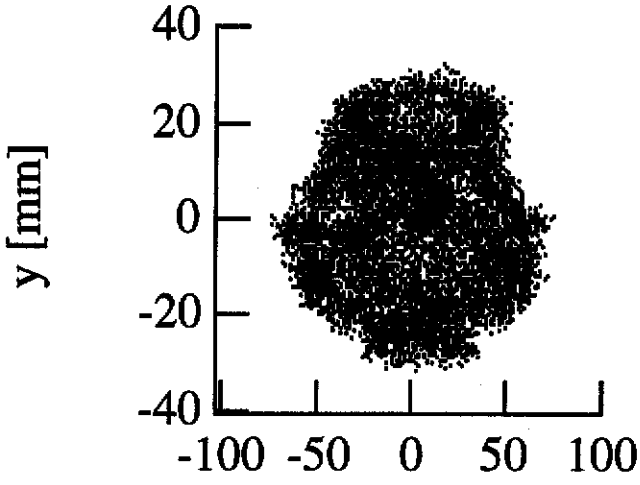
Motion of individual particles subject to nonlinear resonances in a micro scale.

↓

Redistribution of the beam in a global scale.

[What is a Source of Resonance?

Under studying]



Initial beam distribution
(after painting made by F.Noda)

○Space charge potential of
symmetric beam distribution

↓

$$\sum_{m,n} x^{2m} y^{2n}$$

○Space charge potential of
asymmetric beam distribution including offset

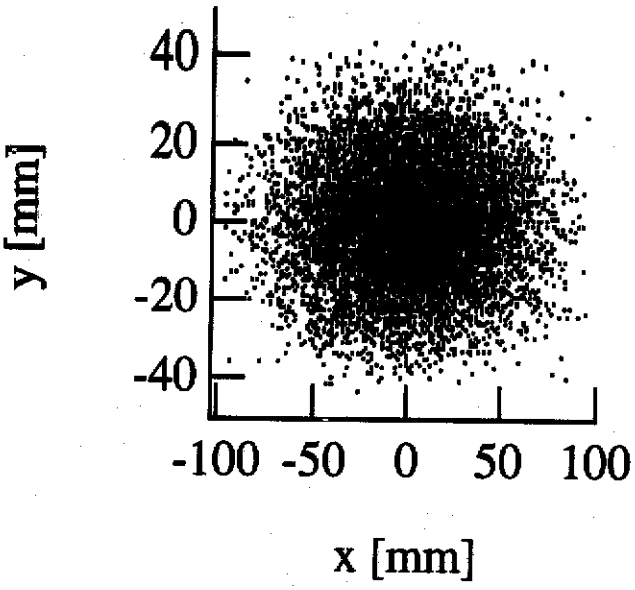
↓

$$\sum_{m,n} x^{2m} y^{2n} + \sum_{m,n} x^{2m+1} y^{2n+1}$$

↓

More sensitive to resonances than
symmetric beam distribution because
of the higher multipole components
and induced more harmonics.

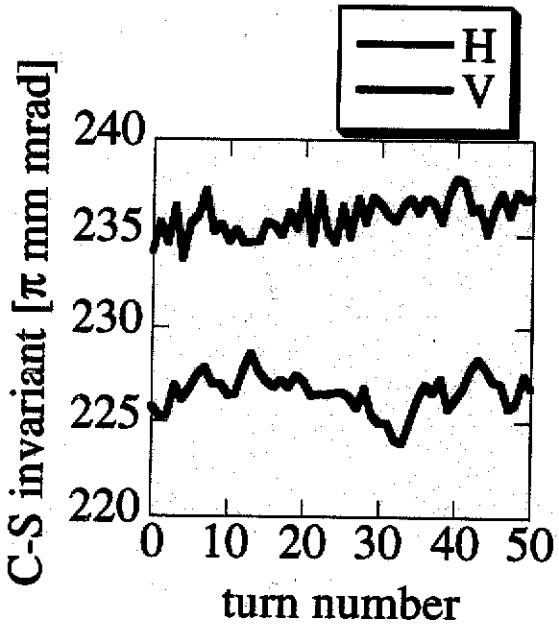
[Example Symmetric Gaussian]



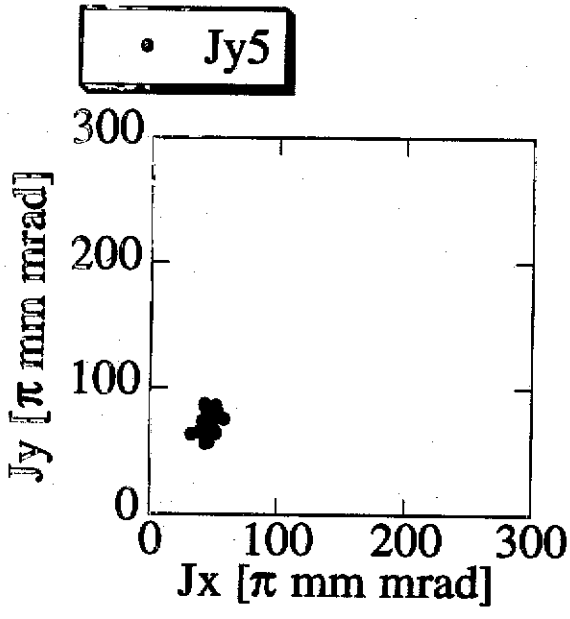
Symmetric RMS-matched beam (Gaussian)

→ Emittance growth is not shown.

Initial beam distribution
(RMS-matched Gaussian
made by S.Machida)



95% Courant-Snyder invariant



C-Sy vs. C-Sx, matched Gaussian
Test particle of ID:5

[Summary]

- The results of ACCSIM, SIMPSONS and PATRASH were in good agreement with each other!

- The rapid emittance growth at the early stage of the injection was shown in horizontal direction, though the painted beam was injected.

  ↓

  The behavior of particles in the initial 20turns has been studied by PATRASH for the inspection of the benchmark test.

- The emittance growth could be attributed to nonlinear resonances .

- It is suggested that these resonances are excited by the space charge force originating from the asymmetric beam distribution.

- In this study, the beam distribution after painting was used as an initial distribution. The same or other transient phenomena may also occur in asymmetric painting **process**.