Halo Simulation with Simpsons

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Halo workshop, Montauk
2003. 05. 19-23

Purpose of simulation:

- detailed study of single particle motion -

Coherent oscillations tell us the stability of a space charge detuned beam as a whole.

- coherent tune shift < incoherent tune shift
- Threshold of coherent resonance is higher than that of incoherent one.

In a high current machine, only a few percent (or even less) loss is tolerated. Need to understand particle behavior of those few particles.

- To what extent, coherent theory is useful?
- There might be a mixture of coherent and incoherent pictures.

Role of macro particles in multi-particle tracking

Usually it gives rms emittance and other moments.

What does trajectory of individual macro particle tells us?

Orbit of individual macro particle in multi-particle tracking does not have any useful information? Only emittance and other moments does?

In practice, single particle orbit strongly depends on grid size.
(HB2002 at Fermilab last year)

Improvement of code

For example,

In cylindrical coordinate,

Use area weighting to assign charge to the neighboring grids.

Use arithmetic weighting to obtain electric field inside grids.

Tracking parameters to see single particle behavior

In order to make a 3D simulation,

number of macro particles is around 1E5 or more

number of grids is around 50 in all directions

small enough time step, 10 kicks per focusing unit.

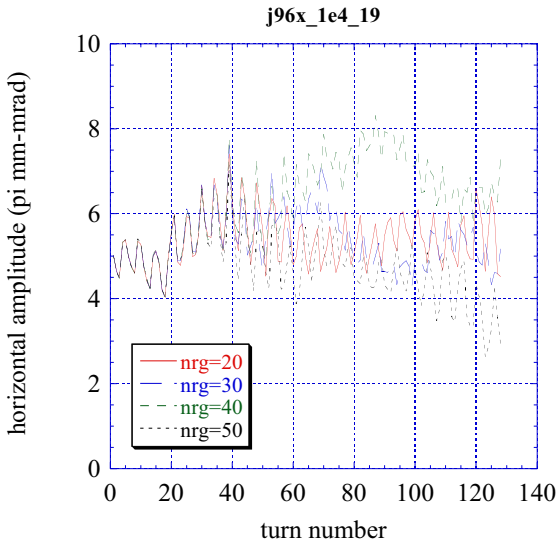
The code now gives the stable (does not depend on simulation parameter) single particle trajectory with those improvement and proper parameters.

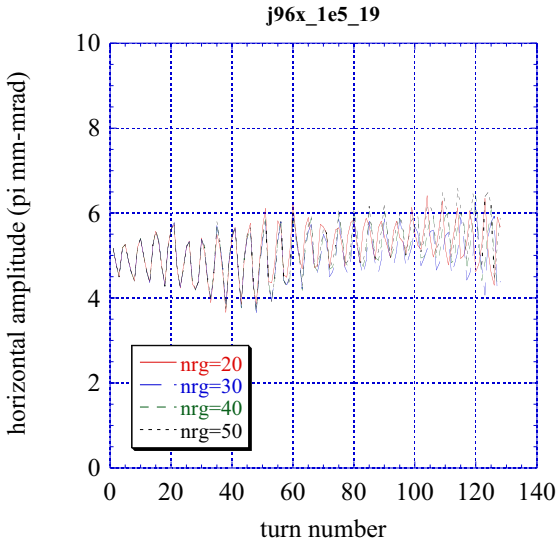
Stability of single particle

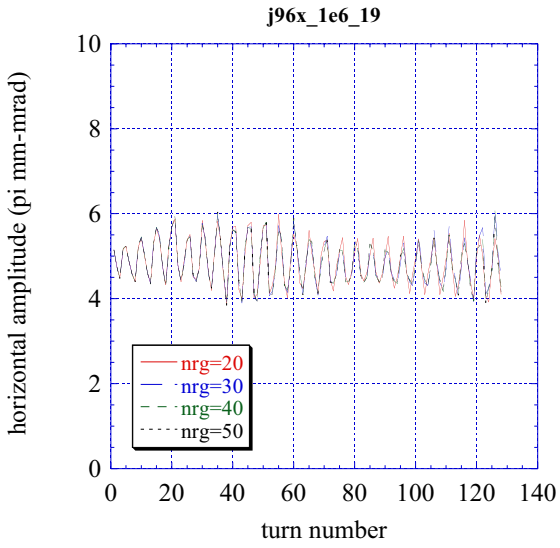
necessary number of macro particles, grid size, etc.

$1x10^4$ $1x10^5$ $1x10^6$

H







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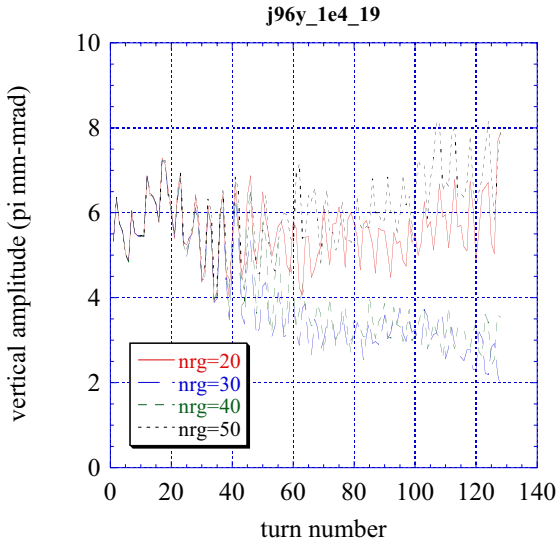

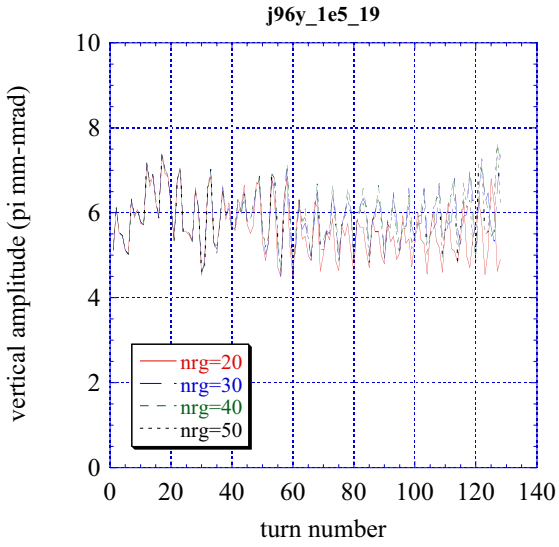

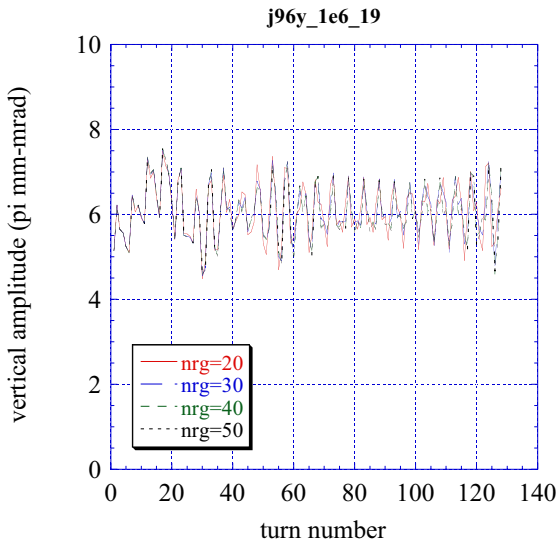

Longitudinal grid size vs. transverse amplitude

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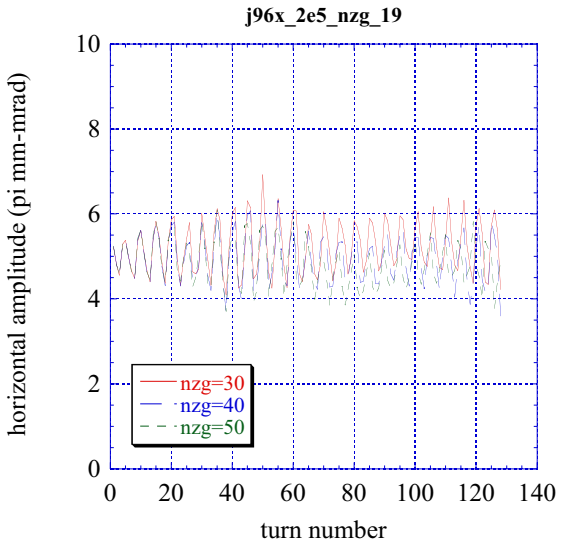

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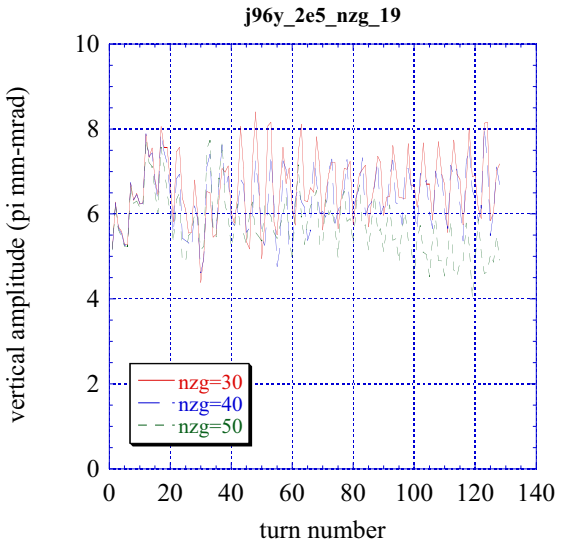


In addition, realistic modelling of aperture

Each lattice elements have a realistic cross section.

circular, elliptic, racetrack, rectangular, diamond, etc.

acceptance is more than 486 pi mmmrad.

Collimator has a rectangular shape with 324 pi.

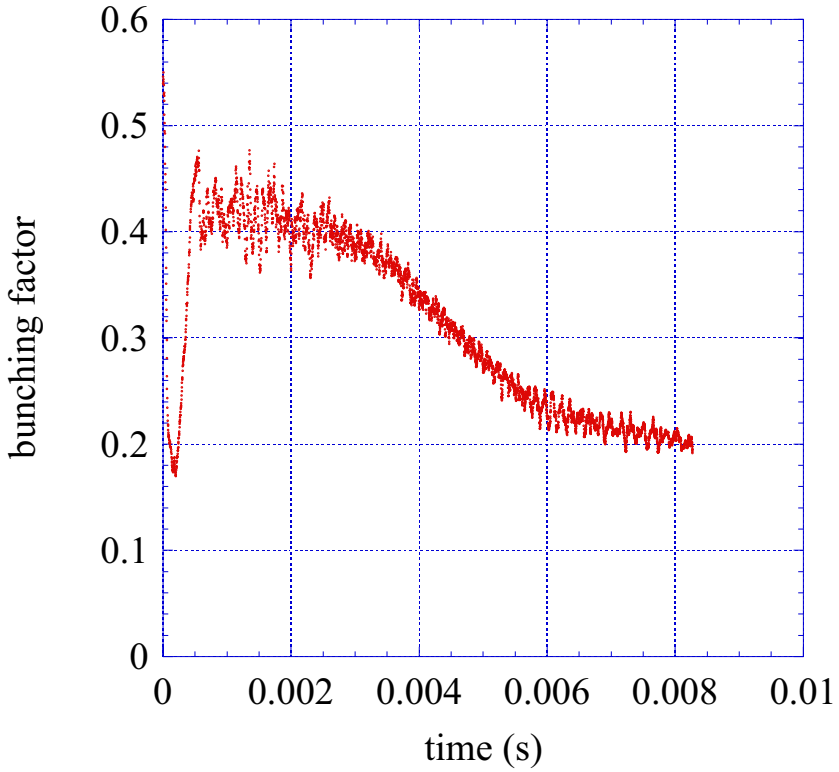
Beam emittance after correlated painting is 216 pi.

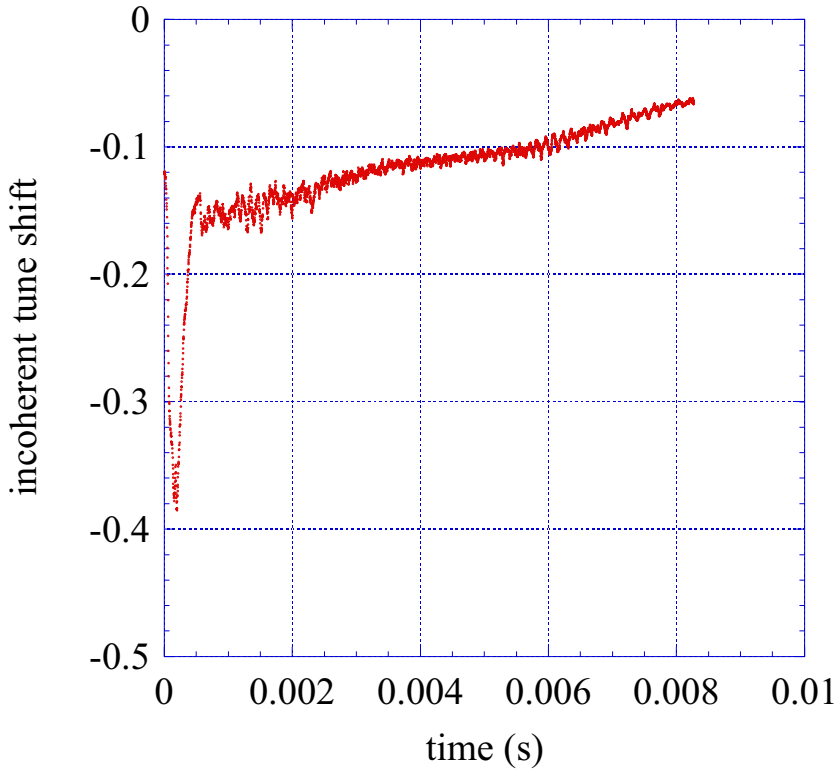
Bunching factor and tune shift

J-PARC RCS

181MeV injection, to 3 GeV in 20 ms.

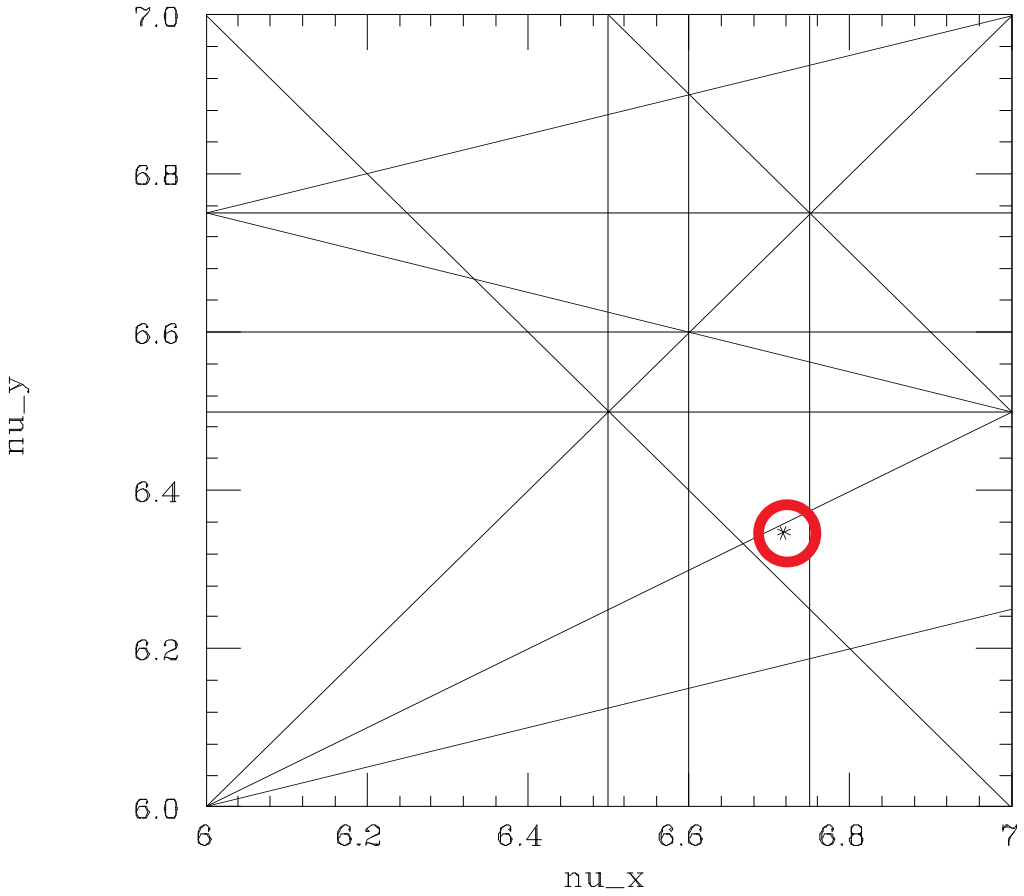
around 1GeV in 8ms.





Working point and resonances

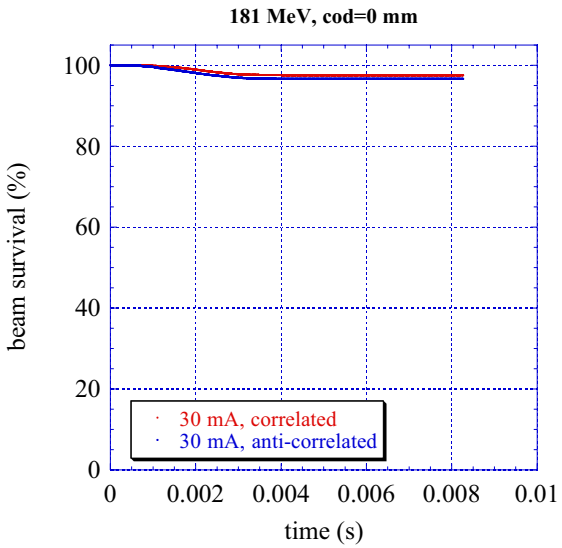
3 fold symmetry lattice



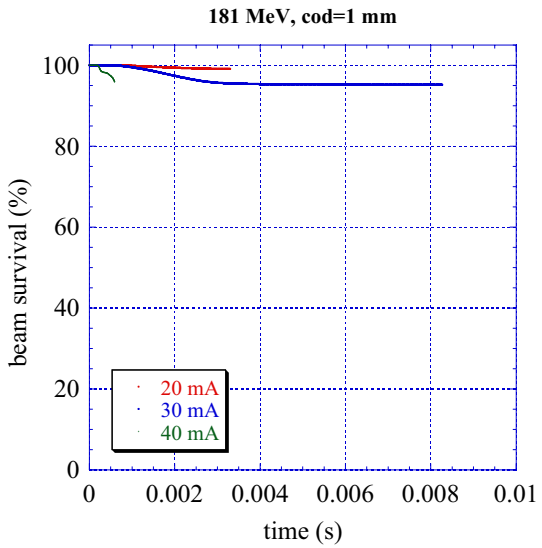
COD magnitude and beam loss

COD (RMS)

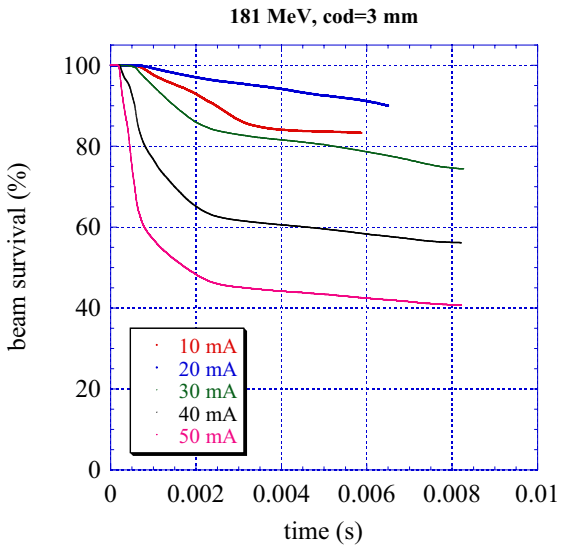
0 mm



1 mm



3 mm



beam loss

less than 5%

about 5%

more than10%

Orbit of lost particles

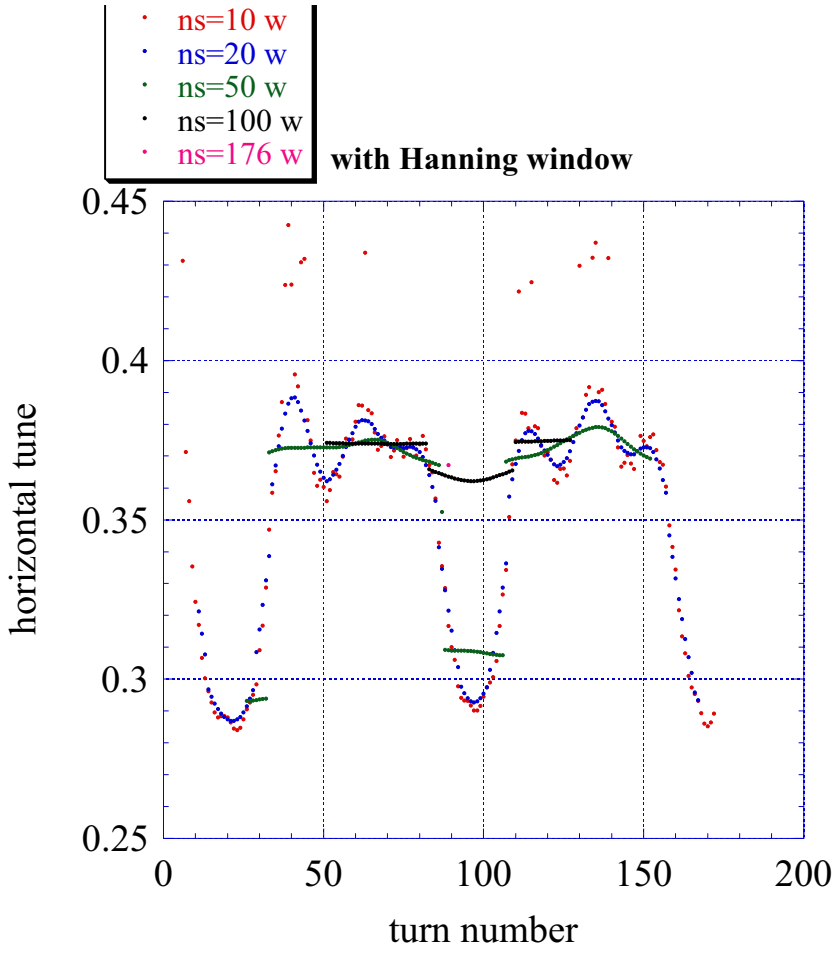
First, track all macro particles (~1E5). Identify the initial coodinates of some particles that eventually are lost.
Secondly, track the same macro particles with recording the coordinates turn by turn of the lost particles.

All the particle loss happens at collimator. Since the collimator has rectangular cross section, horizontal or vertical loss can be identified.

Instantenous tune measurement

Interpolated Fourier Transform with data windowing (Asseo, et.at.)

FT of 20 turns shows the tune modulation due to synchrotron oscillations.



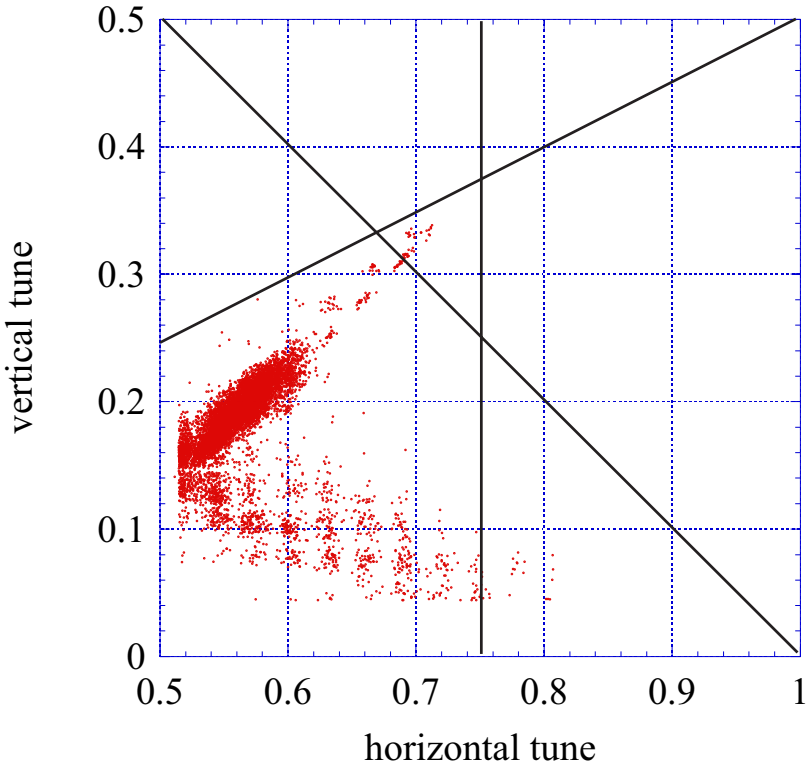
Tune footprint

for 34 turns just after painting injection

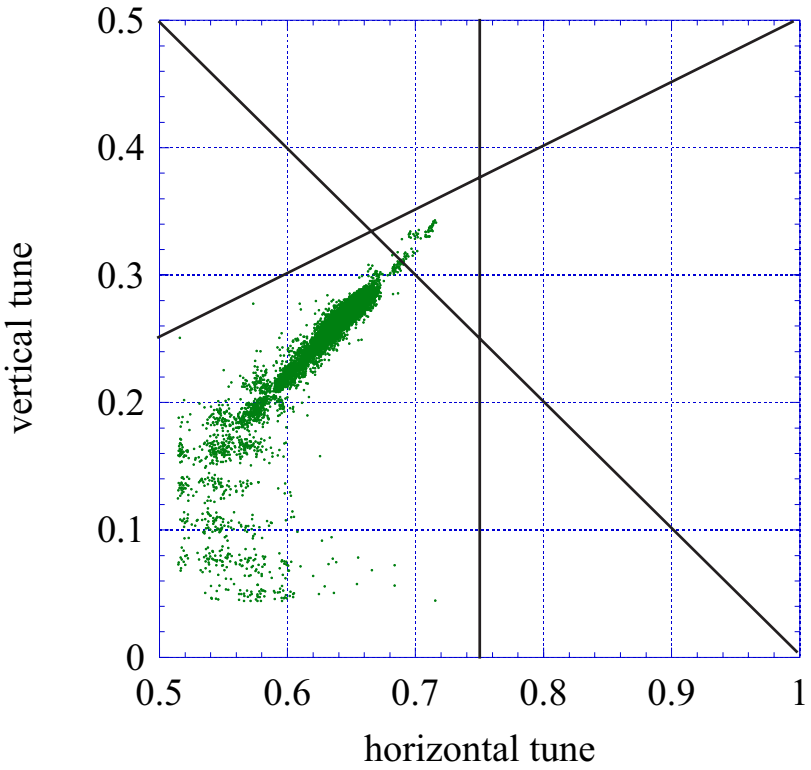
bare tune is (6.72,6.35).

181 MeV injection to 3GeV synchrotron

20mA



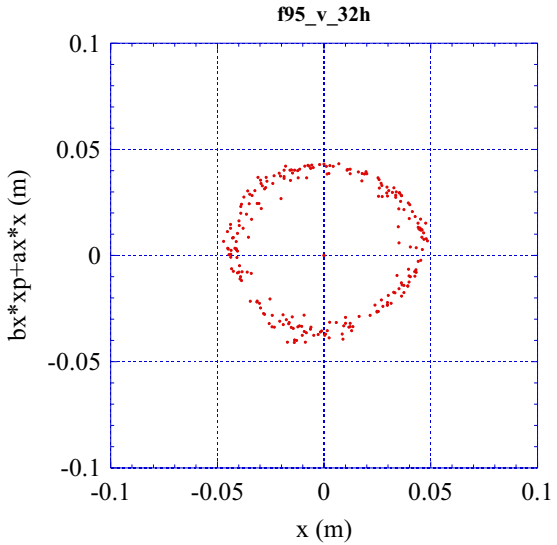
10 mA

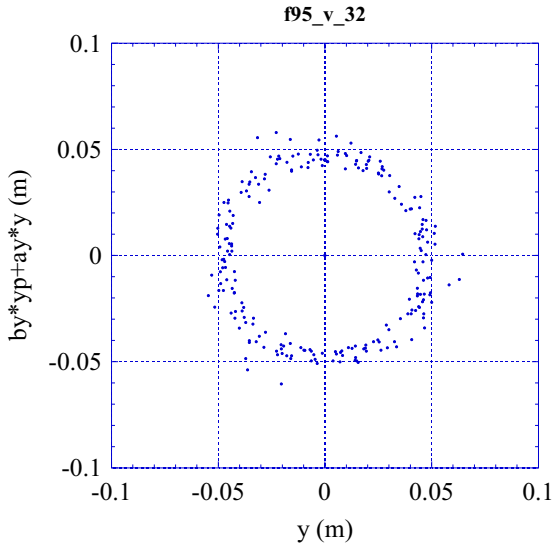


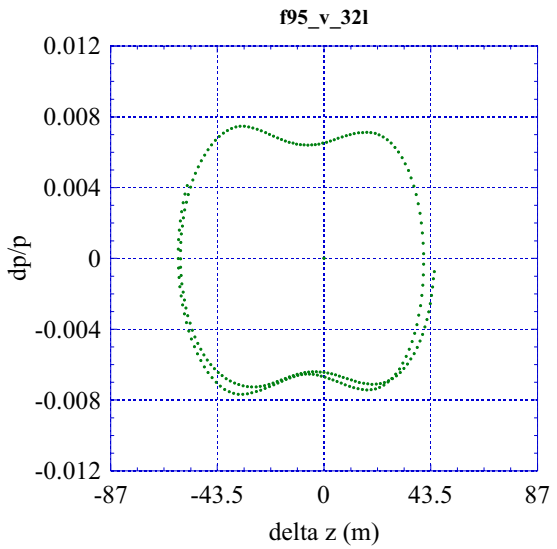
Particle trajectory of lost particle #32

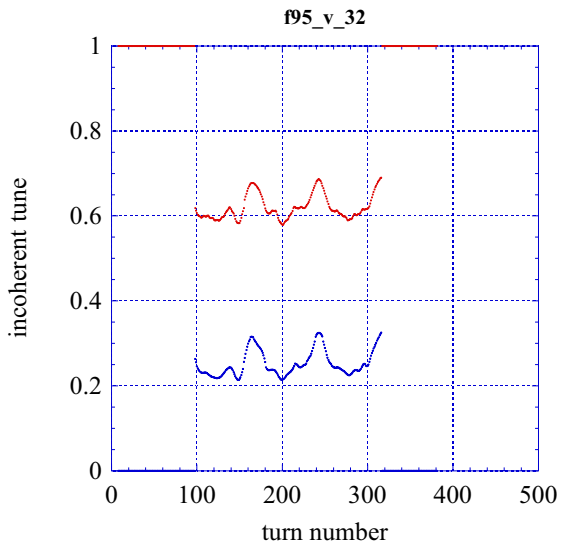
- dp/p is large
- tune modulation due to synchrotron oscillations

- longitudinal phase space is deformed by 2nd harmonics RF.





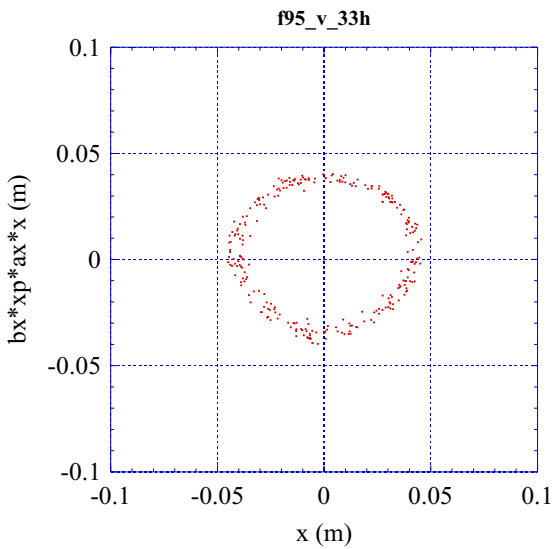


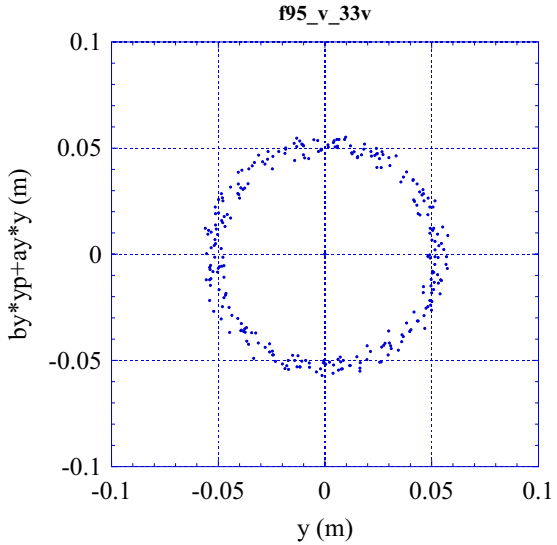


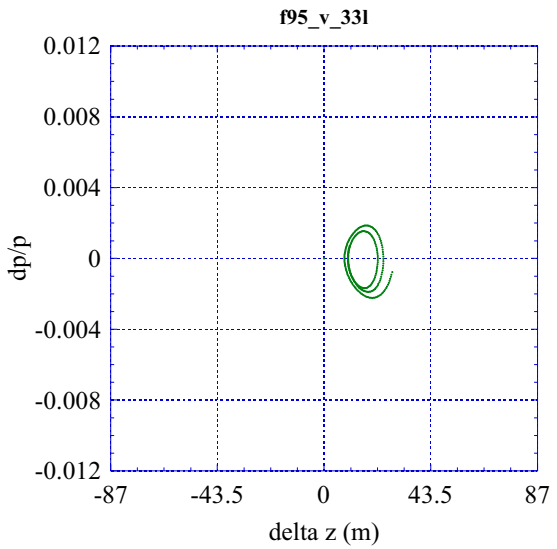
Particle trajectory of lost particle #33

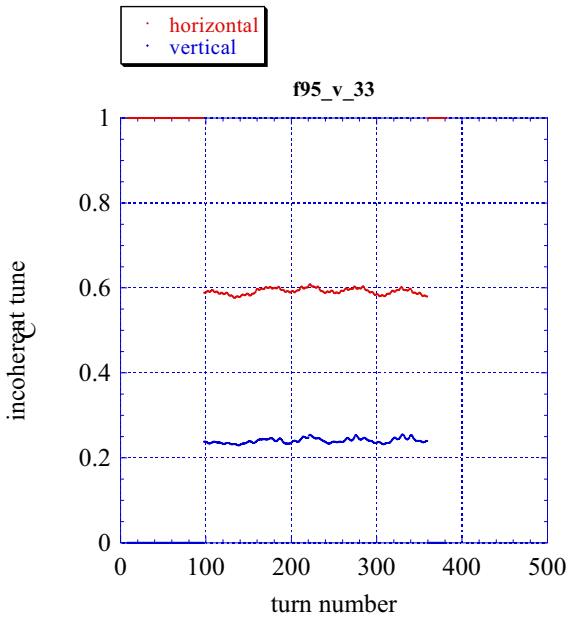
- dp/p small
- tune modulation due to synchrotron oscillations

- longitudinal phase space is deformed by 2nd harmonics RF (particle is trapped at one of fixed point).

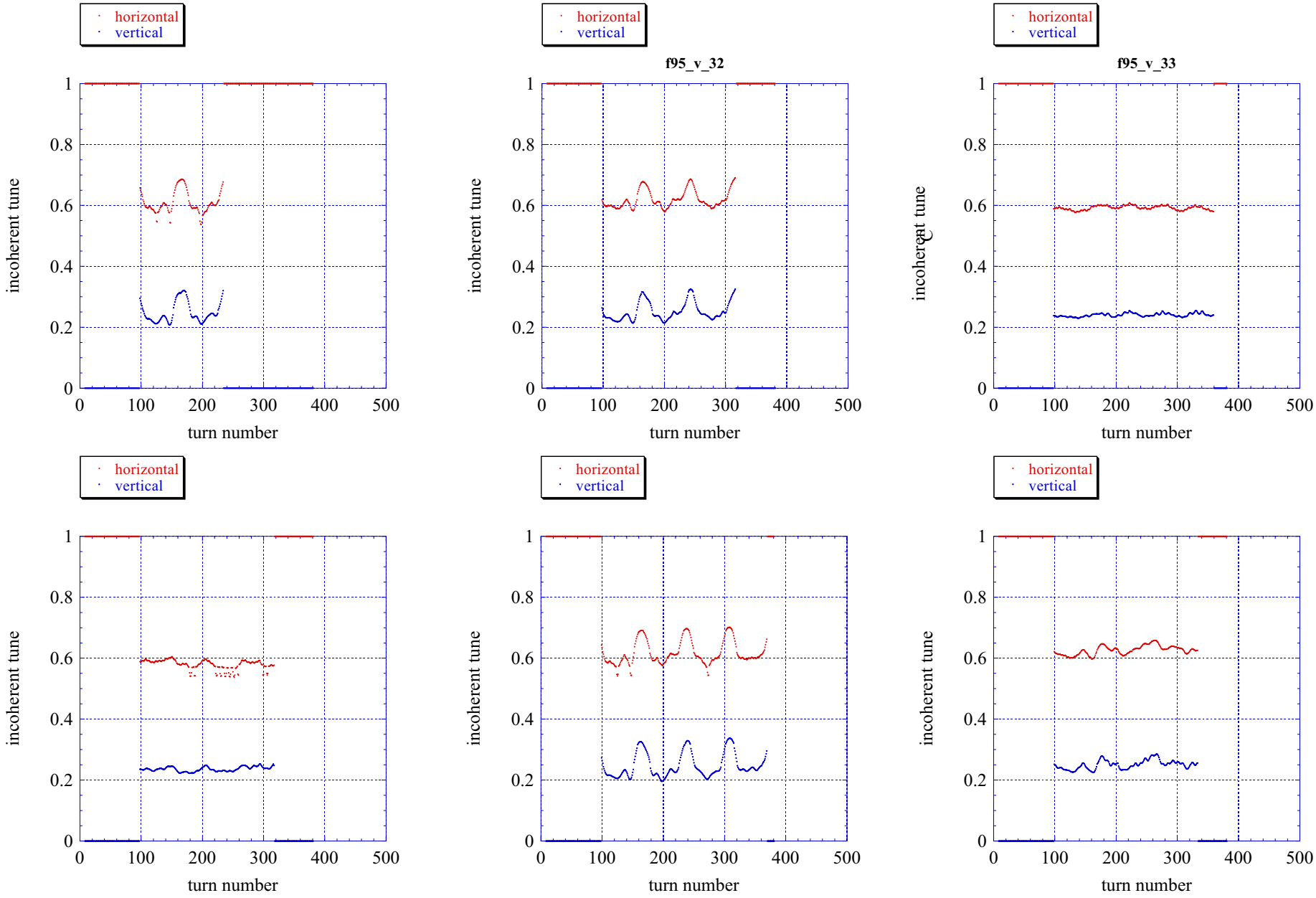




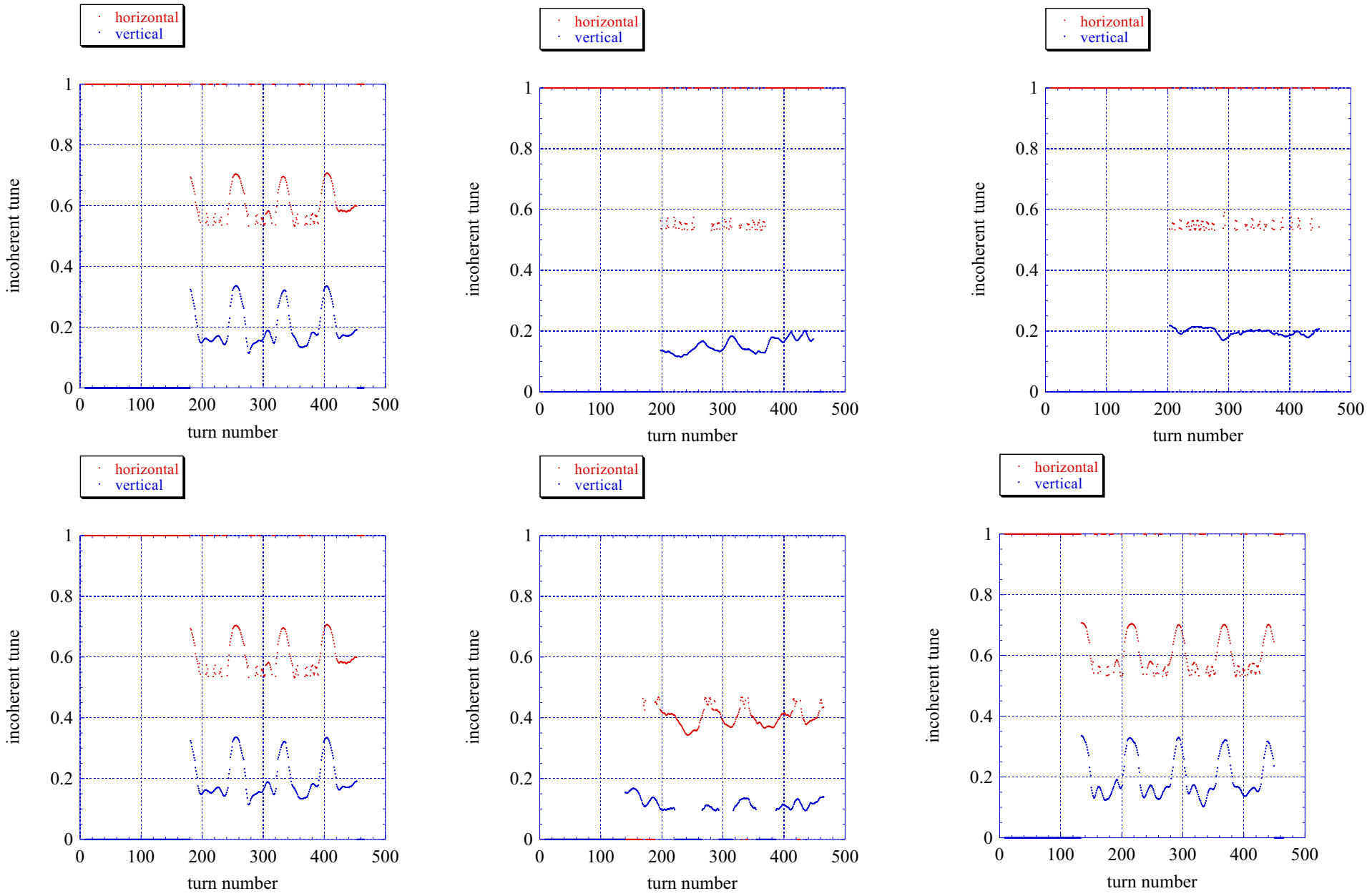




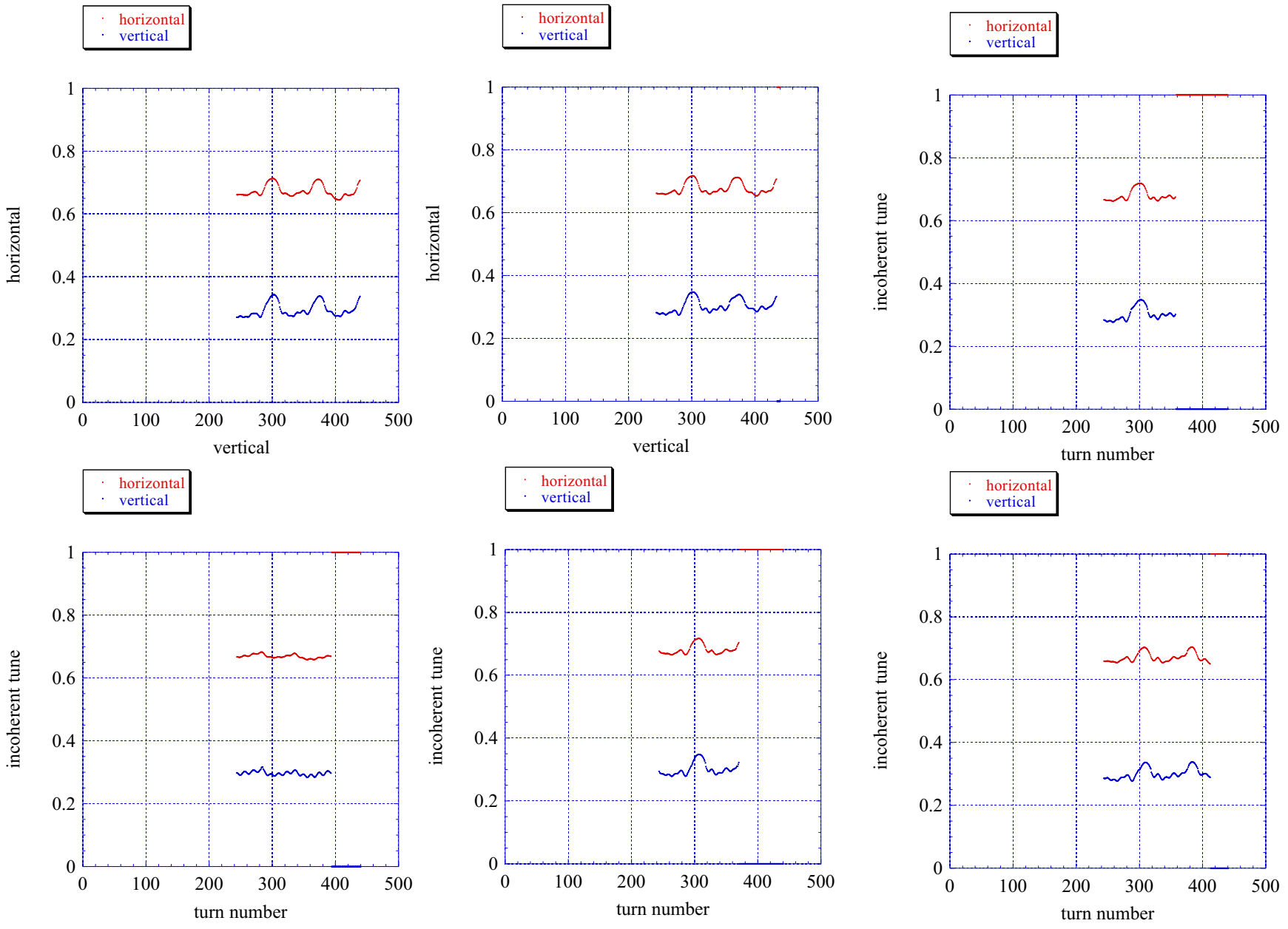
Tune evolution of lost particle (20mA)



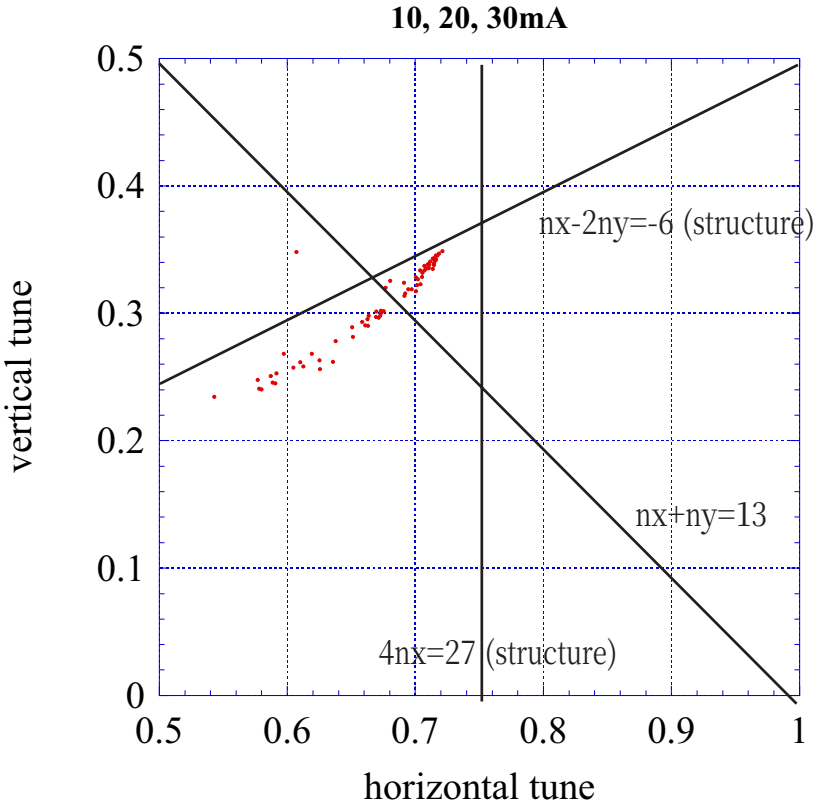
Tune evolution of lost particle (30mA)

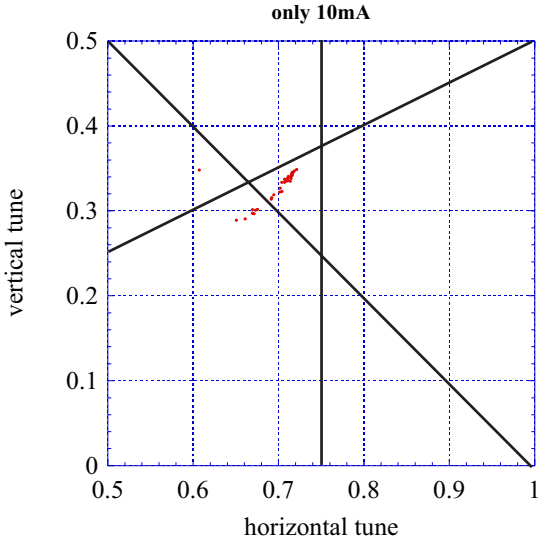


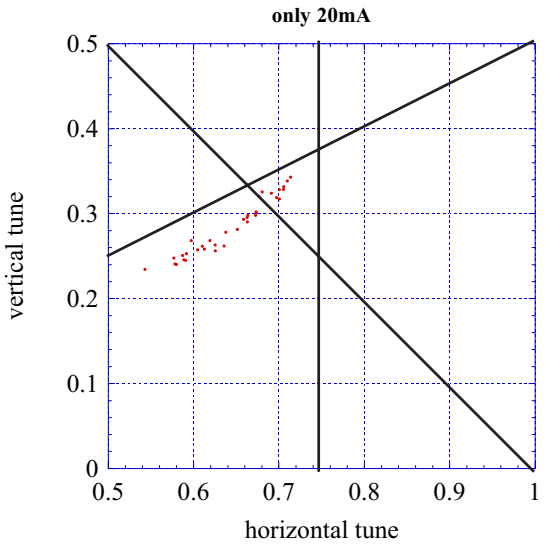
Tune evolution of lost particle (10mA)



Tune of lost particles (when it was lost)



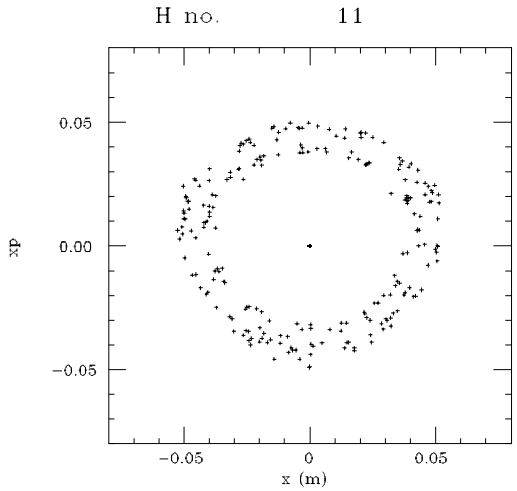


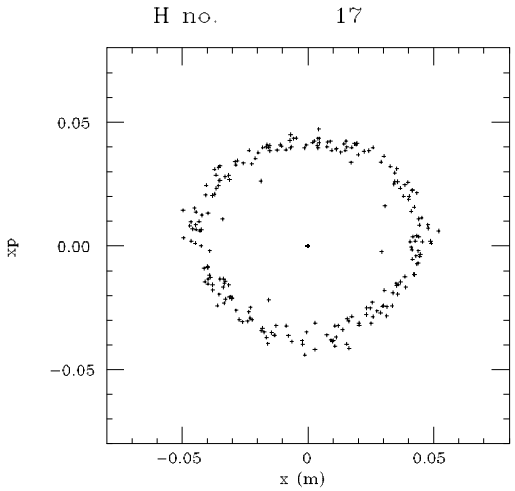


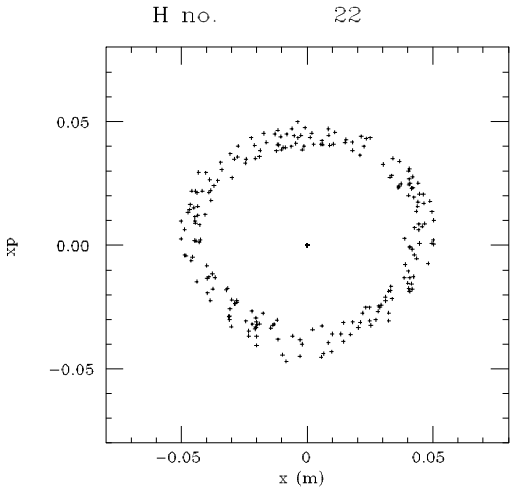
20mA, COD=1mm

transverse phase space (**partcile is lost at vertical aperture**)

H







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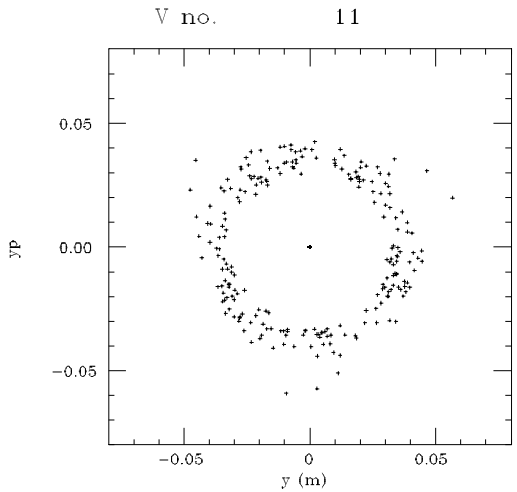
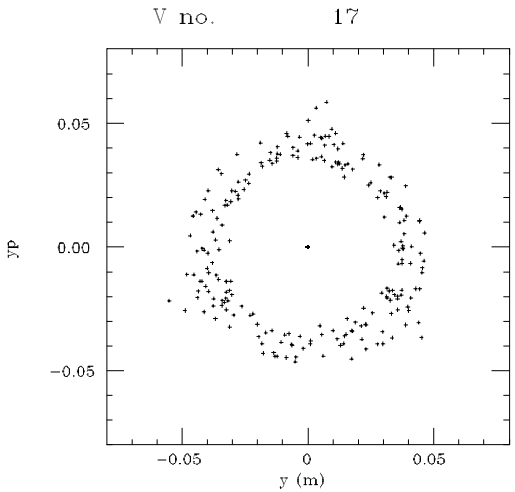
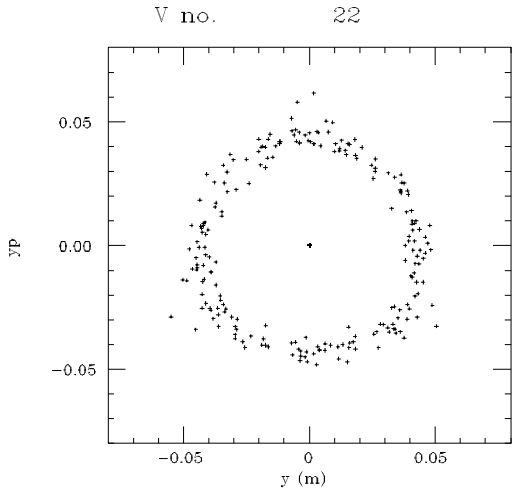
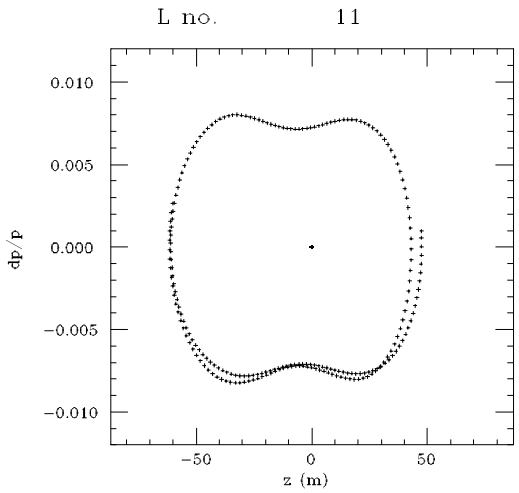


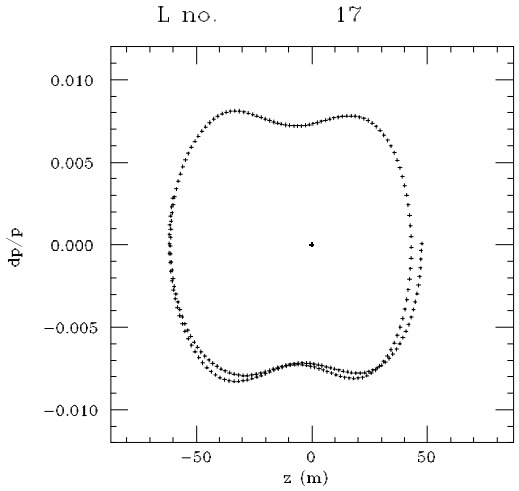


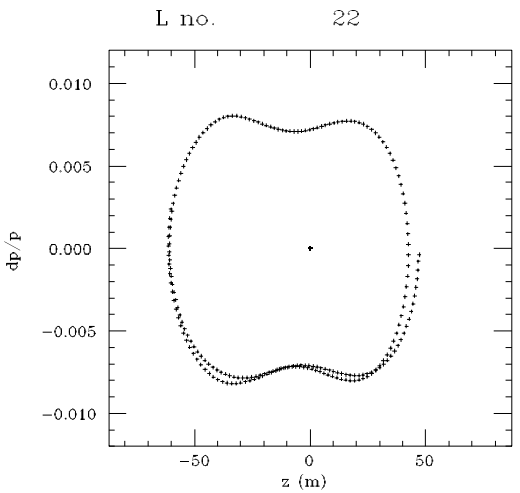


20mA, COD=1mm

longitudinal phase space







lost particle had large dp/p.

Summary

- Incoherent motions are studied to see mechanism of beam loss of a few percent.
- Code with optimized parameters gives reasonable single particle trajectory.
- Single particle tune (of lost particle) was observed for J-PARC RCS (3GeV) model.

Append. Simulation updates for one year

In cylindrical coordinate system, PIC method

- assign charge to the neighboring grids
- interpolate electric field by the neighboring values
- **optimization of grids and integration time step**
- **include realistic physical aperture limit including collimator**
- **beam loss estimate instead of rms emittance**

Example

- **3D simulation of J-PARC RCS**
  - **trans and long painting with acceleration**
- **COD effects with chromaticity correction sextupole**

Study of beam loss mechanism

- **phase space coordinates and instantaneous tune**

Append. Tune footprint (no COD)