Space charge simulation update (3)

Shinji Machida
ASTeC, STFC Rutherford Appleton Laboratory
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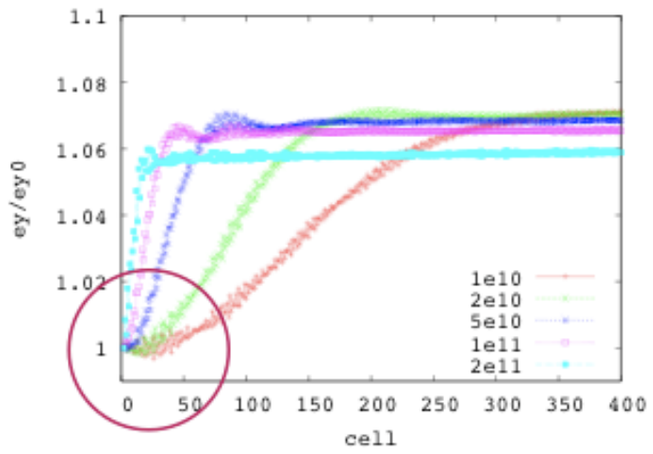
Contents

- Calculation of tune shift and spread
- Emittance growth
  - ideal lattice
  - alignment error of 2 mm (rms)
- Multi-turn injection

Slide from the last meeting

Perfect lattice (2)

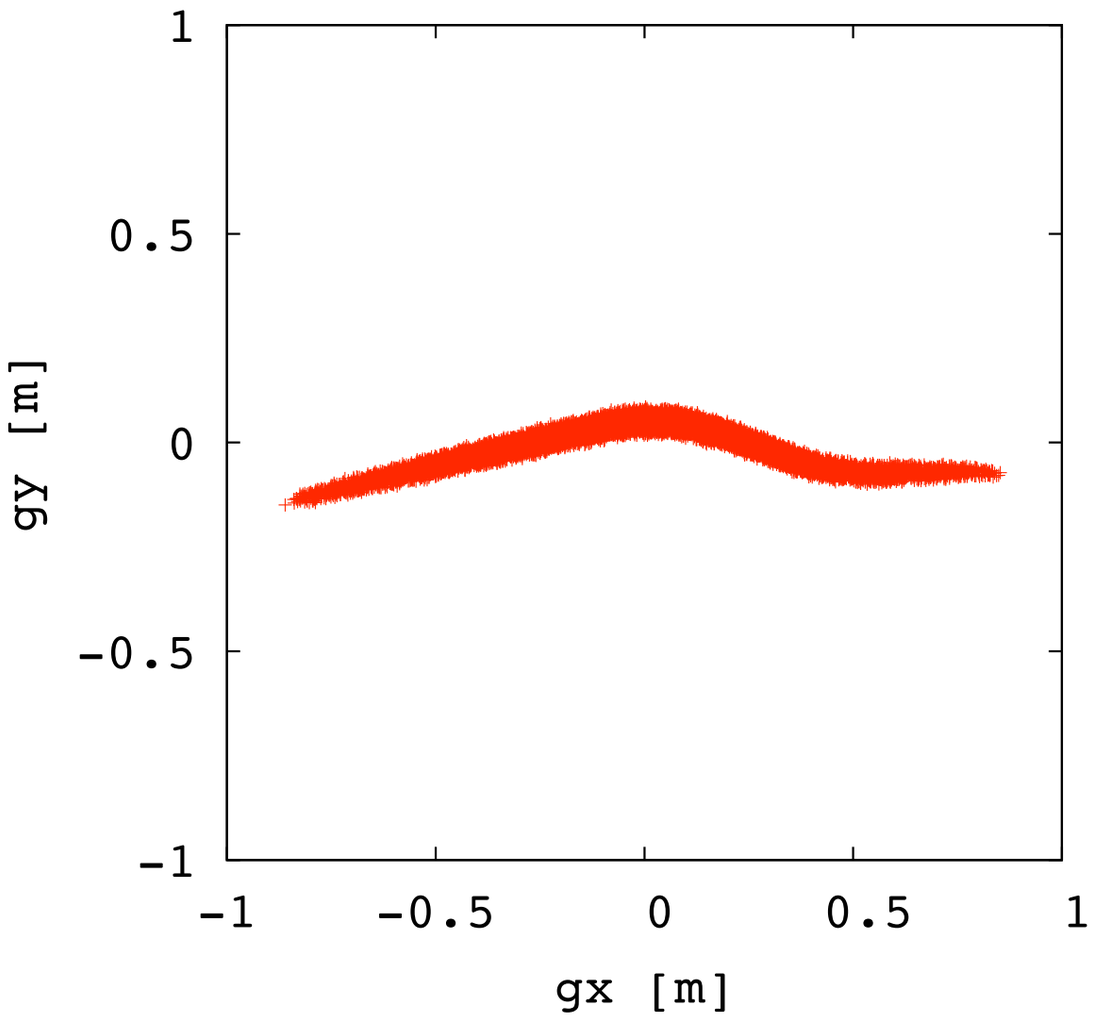
- Last time, I looked at only the first 5 turns (40 cells).
- "observation of parametric resonance at qy=0.25" may be wrong.



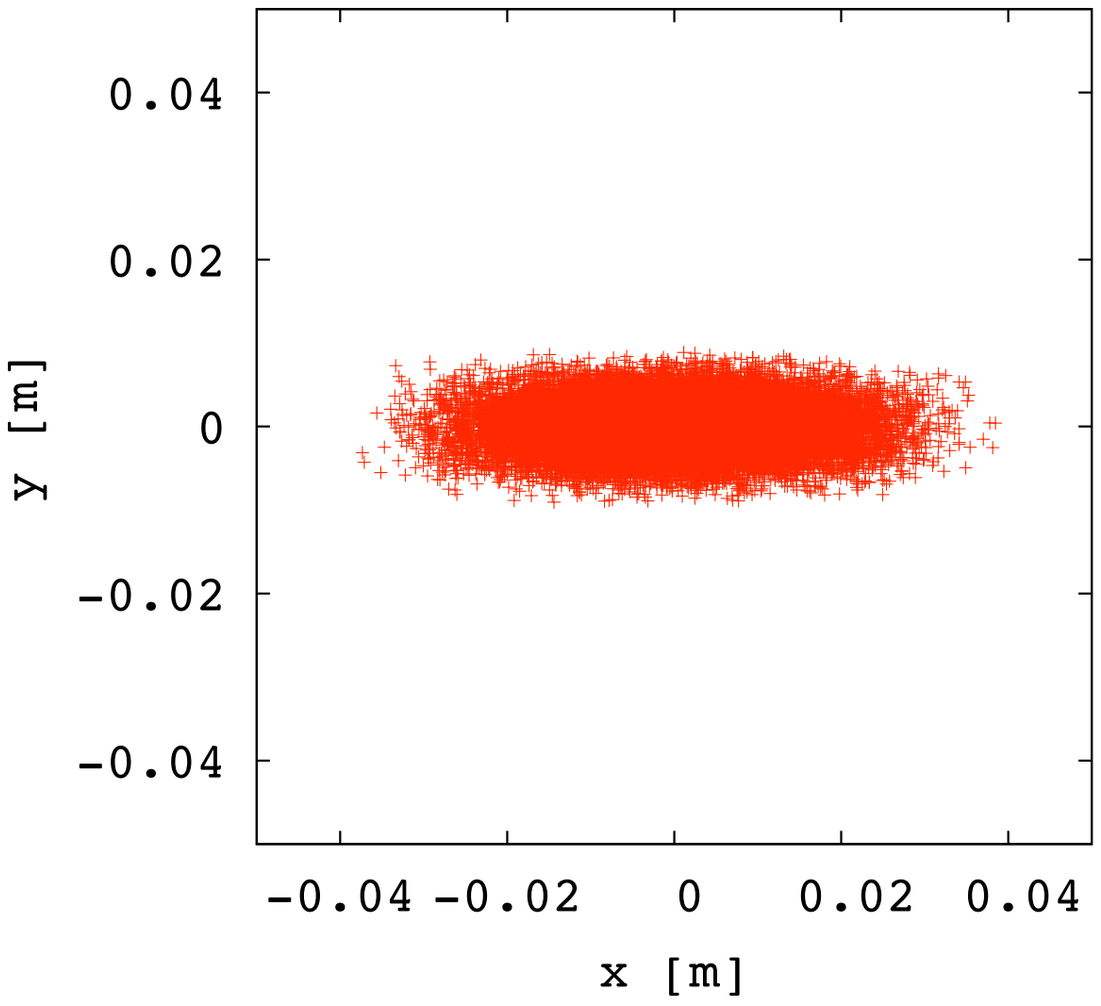
- Horizontal beam size was not calculated properly.
  - bunch has a large curvature in a small ring.
  - beam size due to dispersion and momentum spread.

Bunch (beam) shape

- Top view: a bunch does not have an ellipsoidal shape.



- Different size in H and V although beta function are similar.



Space charge tune shift

- Gaussian distribution in 3-D (cut at 2.5 sigma), the maximum tune shift is

$$\Delta Q_y = -\frac{r_p n_t}{2\pi\sqrt{\epsilon_{rms,y}}(\sqrt{\epsilon_{rms,x}}+\sqrt{\epsilon_{rms,y}})\beta^2\gamma^3 B_f}$$

- Beam size in horizontal is mainly determined by dispersion and momentum spread

$$\sqrt{\epsilon_x} = \sqrt{\epsilon_{\beta,x} + (D_x\delta)^2/\beta_x}$$
$$= \sqrt{11\times10^{-6} + 133\times10^{-6}}$$

b=1.3 m, e=8e-6
Dx=0.87 m, dp/p=0.0132

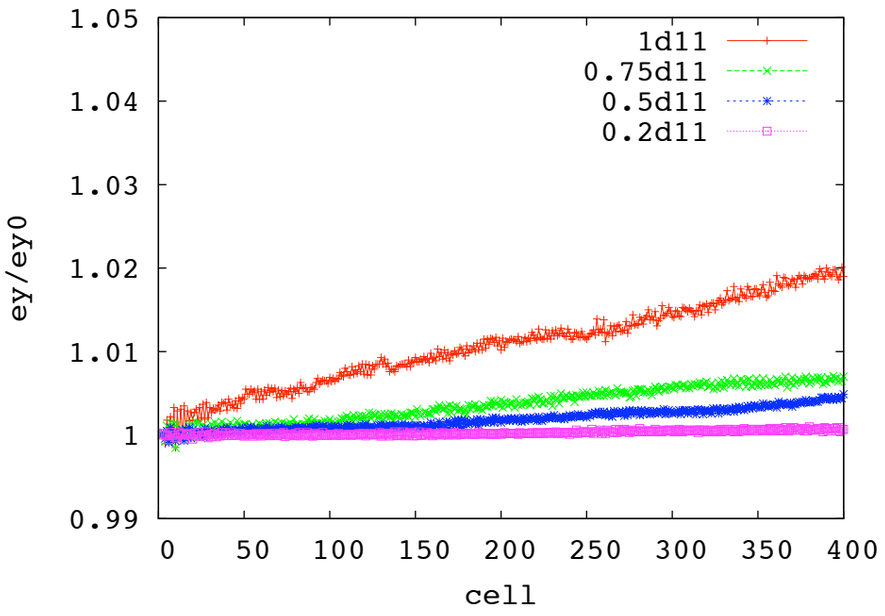
Intensity dependence

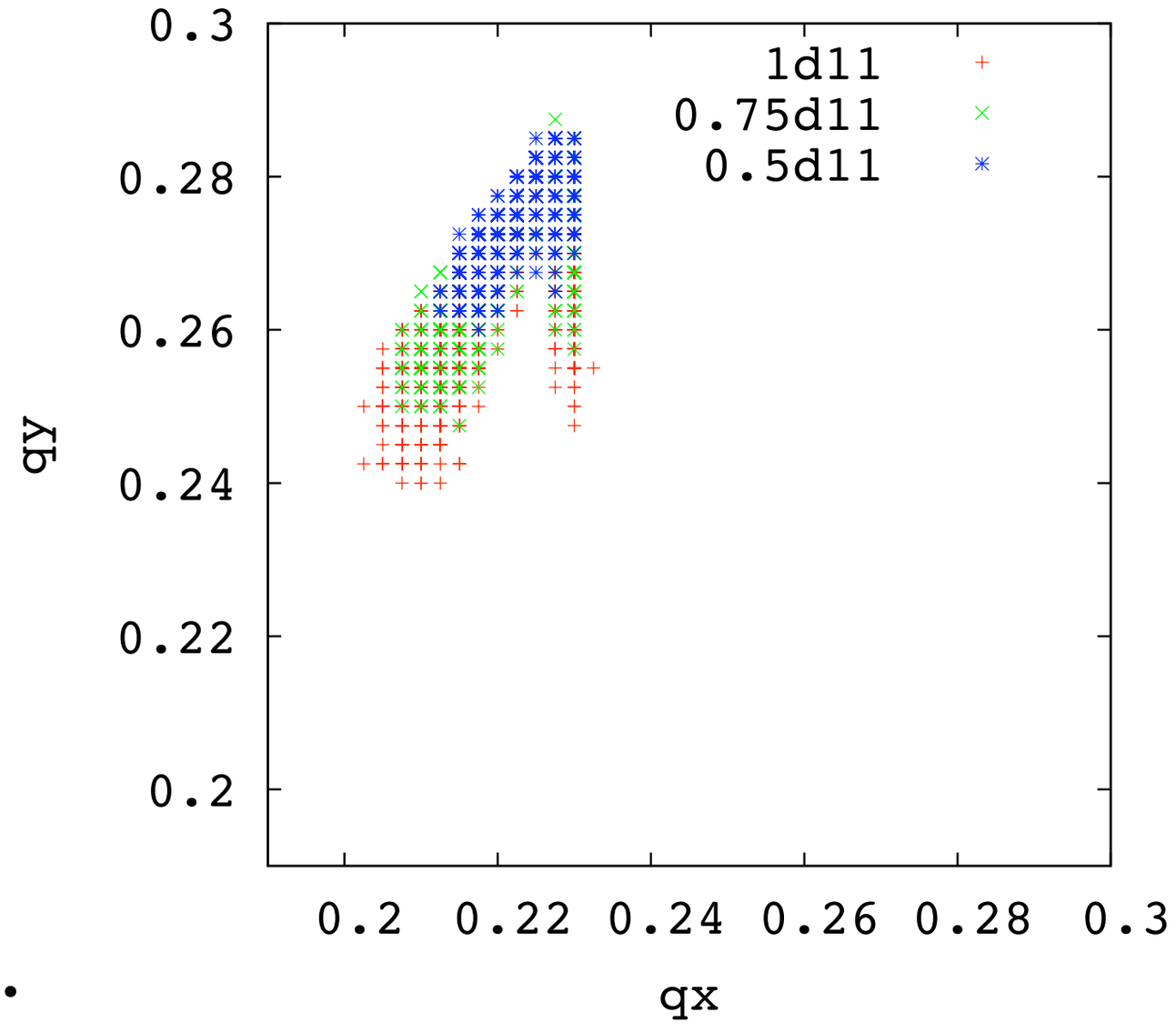
- Tune shift vs intensity

intensity in per bunch	cell dq_y (q_y=0.287)	cell dq_x (q_x=0.227)
0.2×10^{11}	-0.013 (0.274)	-0.004 (0.223)
0.5×10^{11}	-0.033 (0.254)	-0.009 (0.218)
1×10^{11}	-0.067 (0.220)	-0.019 (0.208)
1.5×10^{11}	-0.100 (0.187)	-0.028 (0.199)

Tune spread

- FFT of the first 50 turns (400 cells).

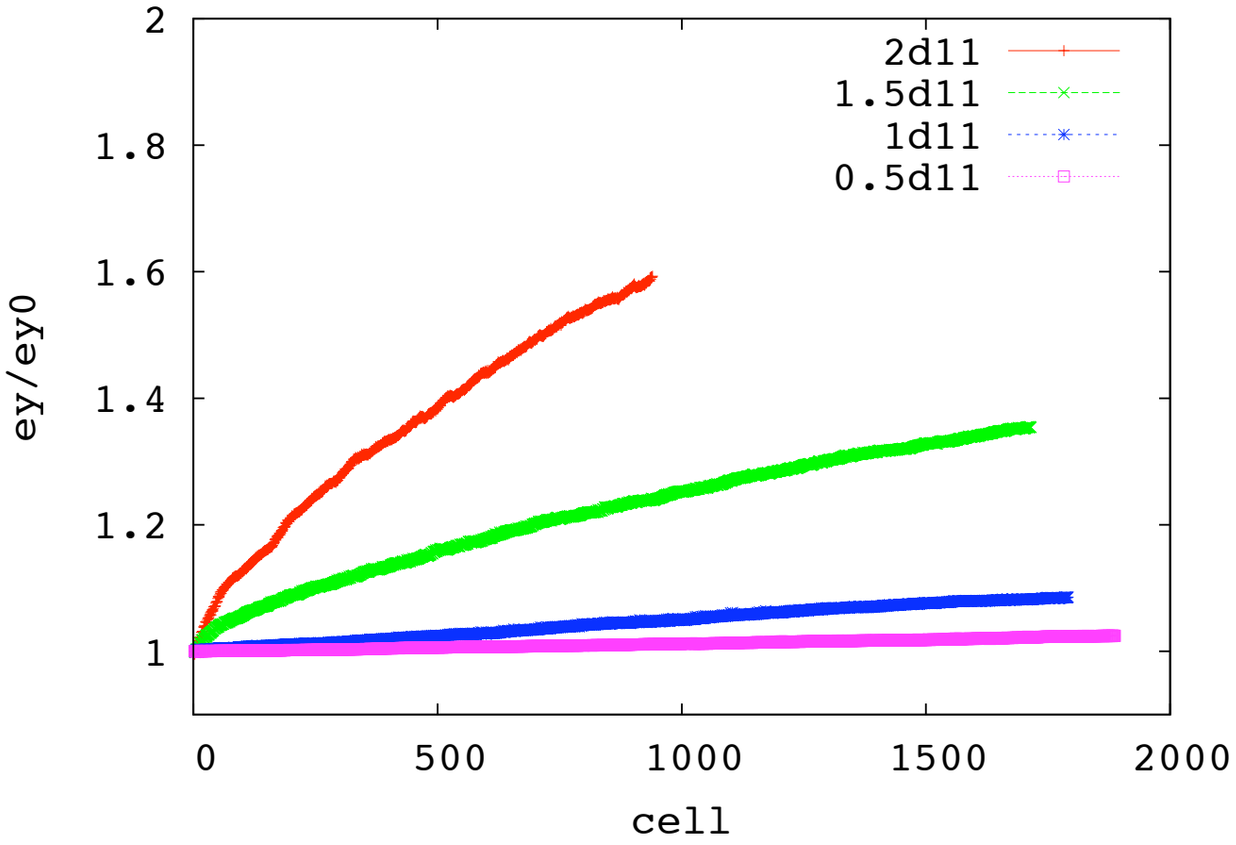




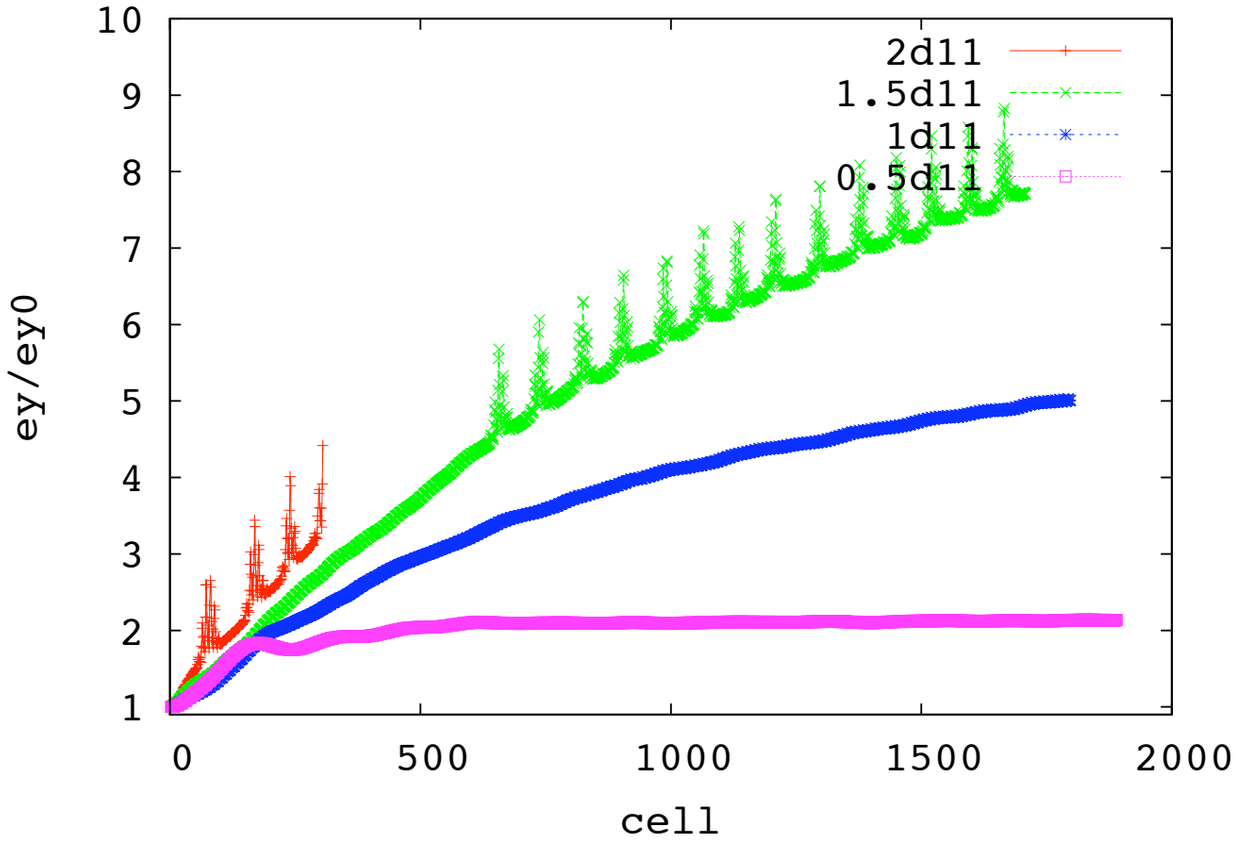
- Cell tune in the model lattice is (0.227, 0.287).

Long term behavior

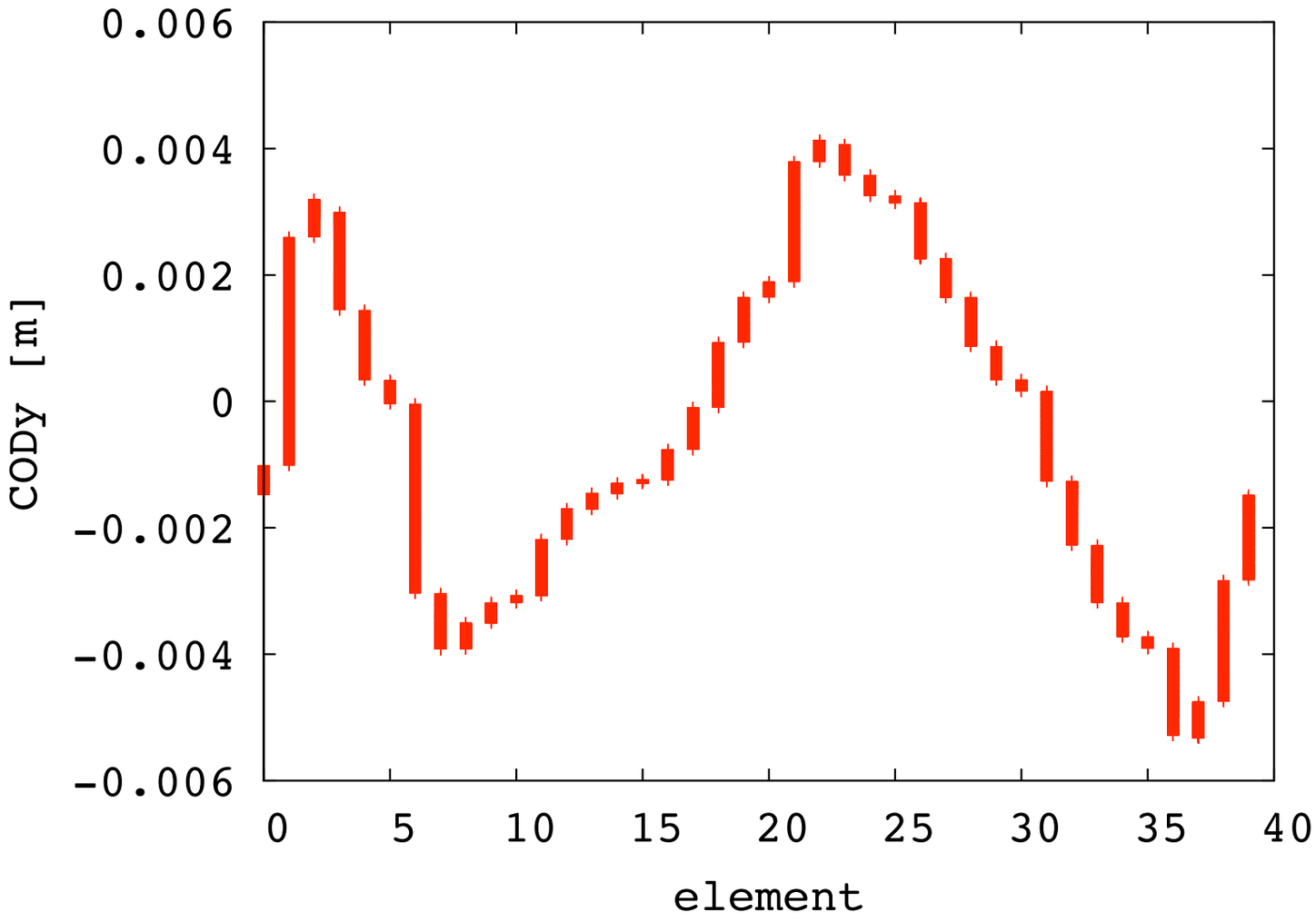
- Without error, primary source is qy=0.25.



- With alignment error, Qy=2 (qy=0.25).



COD with alignment error of +/- 2mm



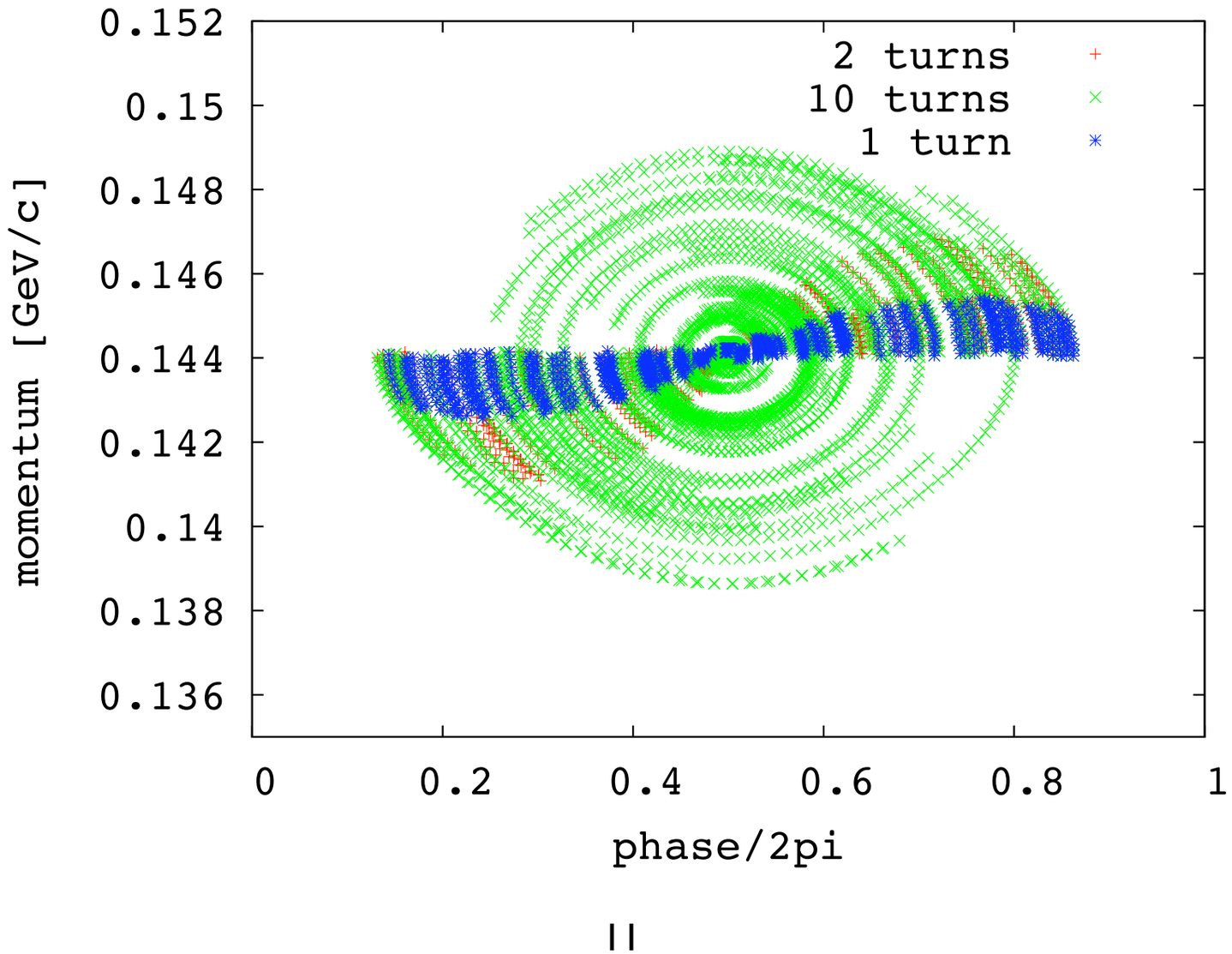
5 elements in one cell

Multi-turn injection

- In reality, a beam current is accumulated with many injection turns (~50 turns).
- dp/p of linac beam is small (0.001) and rf bucket height is much larger (0.042).
  - Mismatch in longitudinal phase space makes line density (or bunching factor) time dependent.

Longitudinal phase space

- Synchrotron tune is about 1/13.
- Keep injecting new particles.

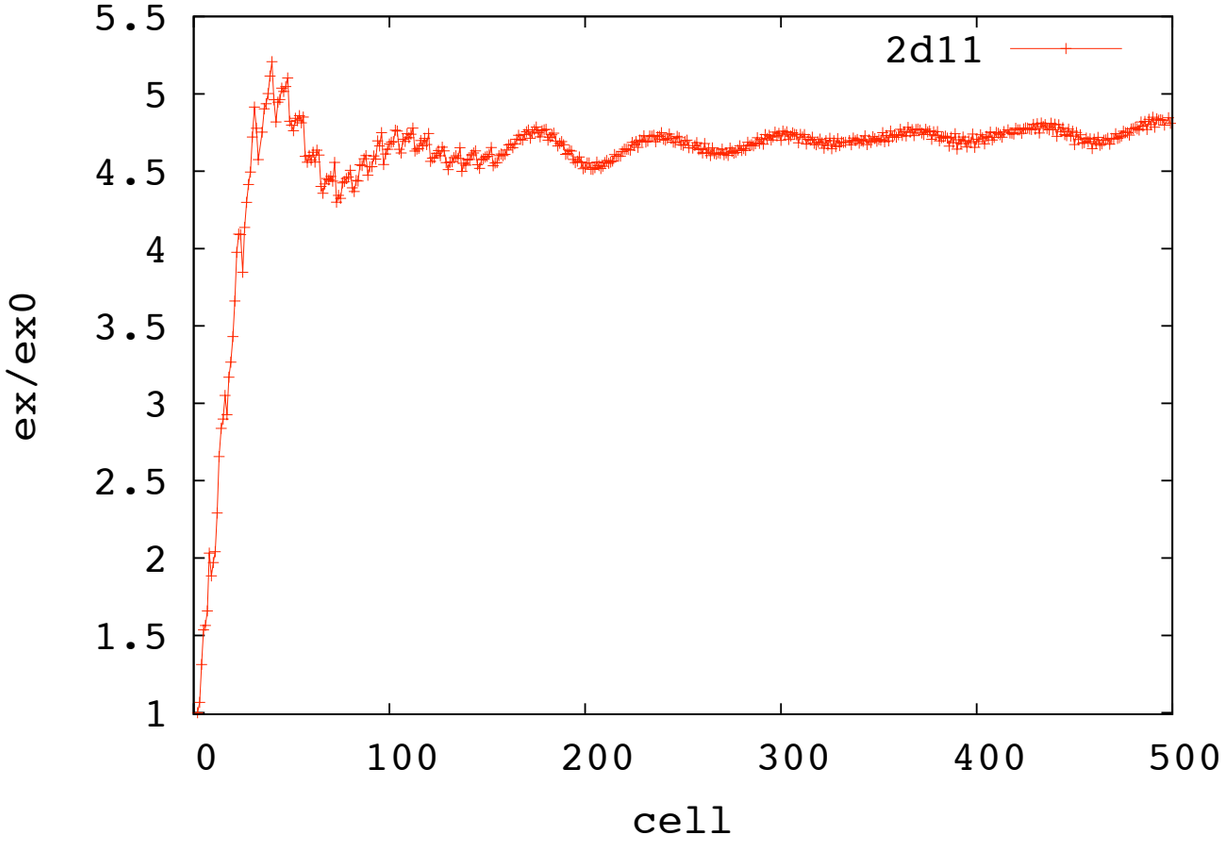


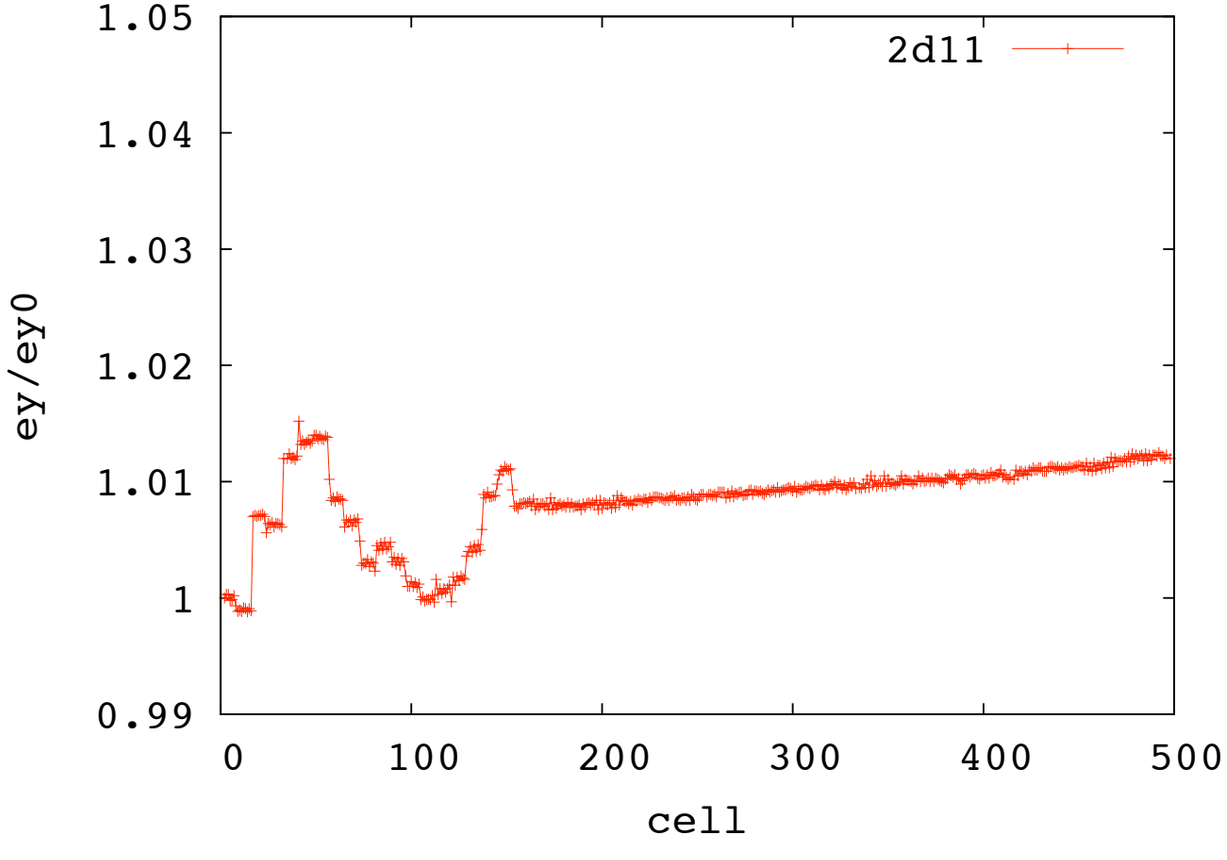
Multi-turn injection simulation

- 1st: inject N particles.
- 2nd: inject N particles and throw randomly selected N particles away. Increase charge per particle by 2.
- 3rd: inject N/2 particles and throw randomly selected N/2 particles away. Increase charge per particle by 3.
- n-th: inject N/(n-1) particles and throw randomly selected N/(n-1) particles away. Increase charge per particle by N.

Results with 30 turns injection

- Horizontal has rapid increase of ‘beam size’ due to dispersion.
- Not much ‘emittance’ growth in vertical.
  - Bunching factor is larger.





Summary

- Tune spread calculated in simulation seems reasonable.
- Larger emittance growth with higher current. Similar results in a synchrotron.
- Simulation with multi-turn injection shows
  - horizontal beam size is determined by dispersion and hard to separate from emittance growth.
  - space charge effects are weaker due to larger bunching factor at least at the beginning.