Space charge simulation update (4)

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Contents

- Quick review of tune shift (spread).

- Multi-turn injection.

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Space charge tune shift

- Gaussian distribution (cut at 2.5 sigma in simulation), 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

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

$$= \sqrt{11 \times 10^{-6} + 133 \times 10^{-6}}$$

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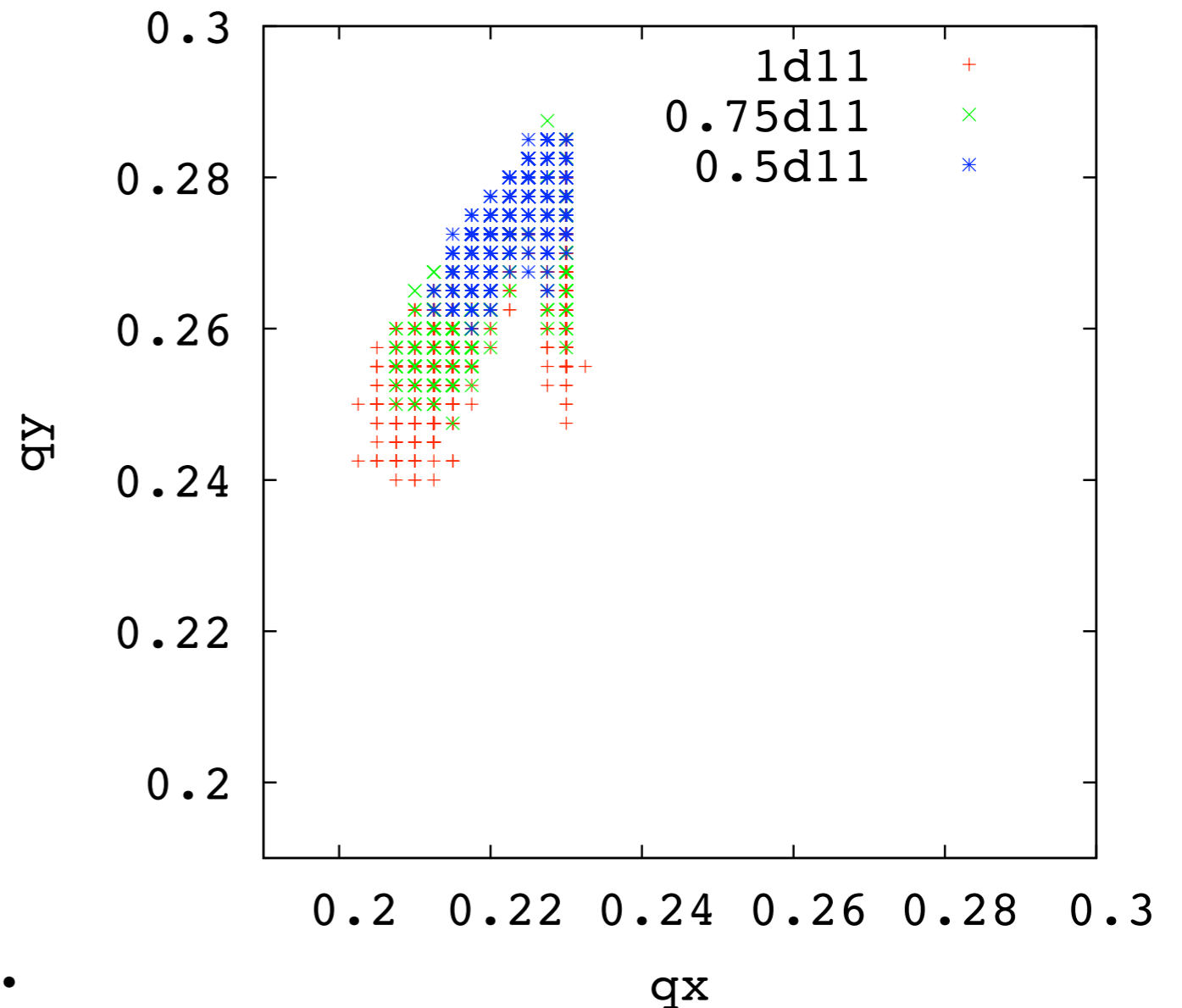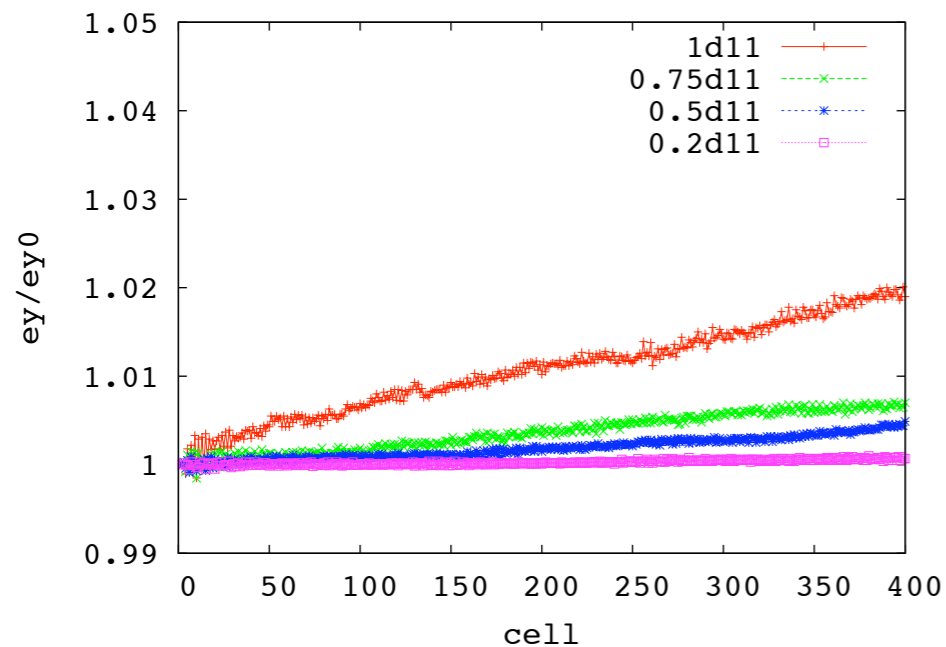
- Cell tune in the model lattice is (0.227, 0.287).

Multi-turn injection (1)

- In reality, a beam current is accumulated with many injection turns.

  - ~60 turns to accumulate 1E11 ppb or 6E11 ppp

- 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.

Multi-turn injection (2)

- Keep injecting the constant number of particles per turn.

- Increase intensity by injecting more number of turns (as in reality).

  - 1E11 ppb (6E11 ppp) by 60 turns.

  - 2E11 ppb (12E11 ppp) by 120 turns.

  - ...

Define "emittance" in the following way

- In vertical direction,

$$\epsilon_v = \sqrt{<y^2><y'^2> - <yy'>^2}$$

- In horizontal direction, it includes beam size from dispersion effects,

$$\epsilon_h = \sqrt{<x^2><x'^2> - <xx'>^2}$$

where

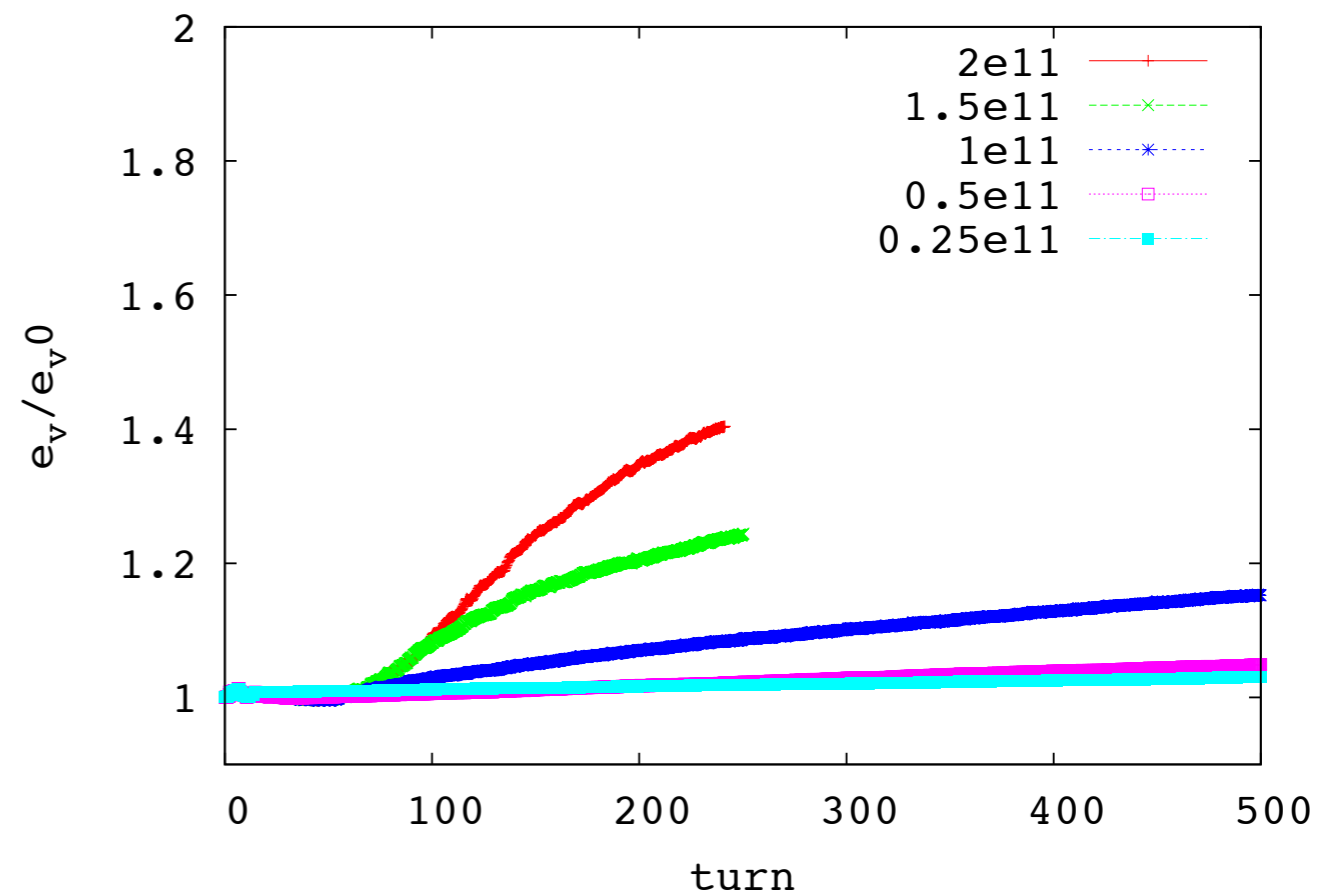$$x = x_\beta + \delta D \qquad\qquad x = x'_\beta + \delta D'$$
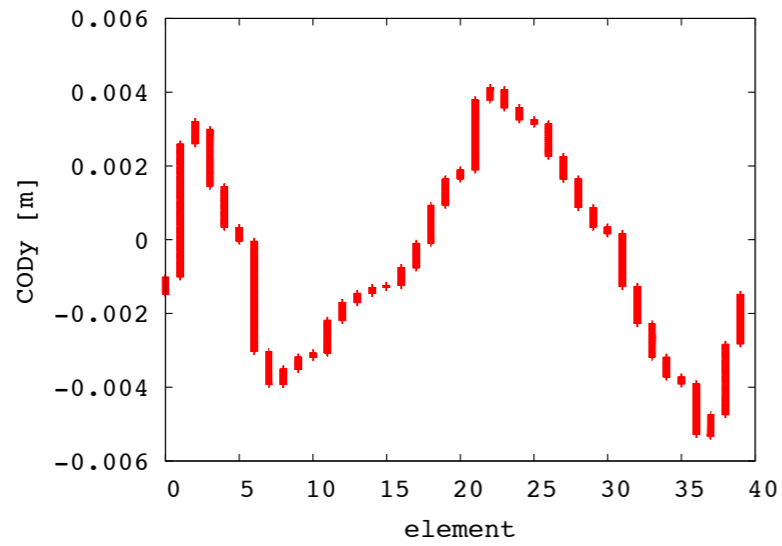
Intensity dependence
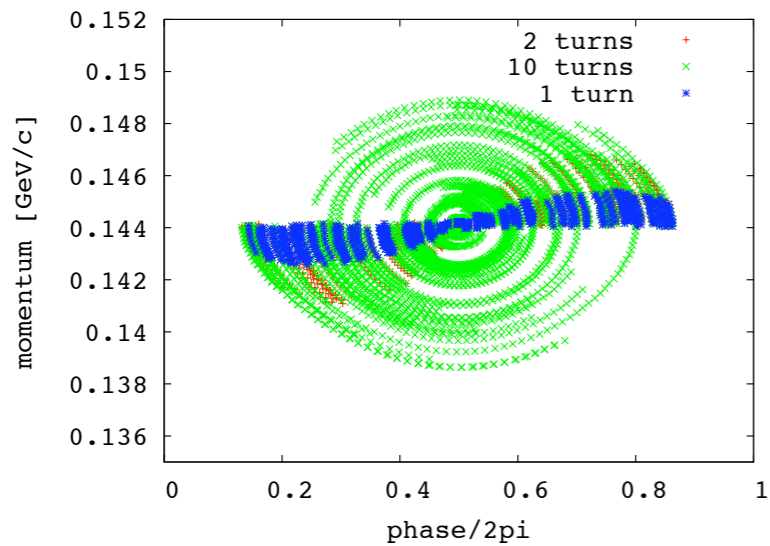
- **horizontal**
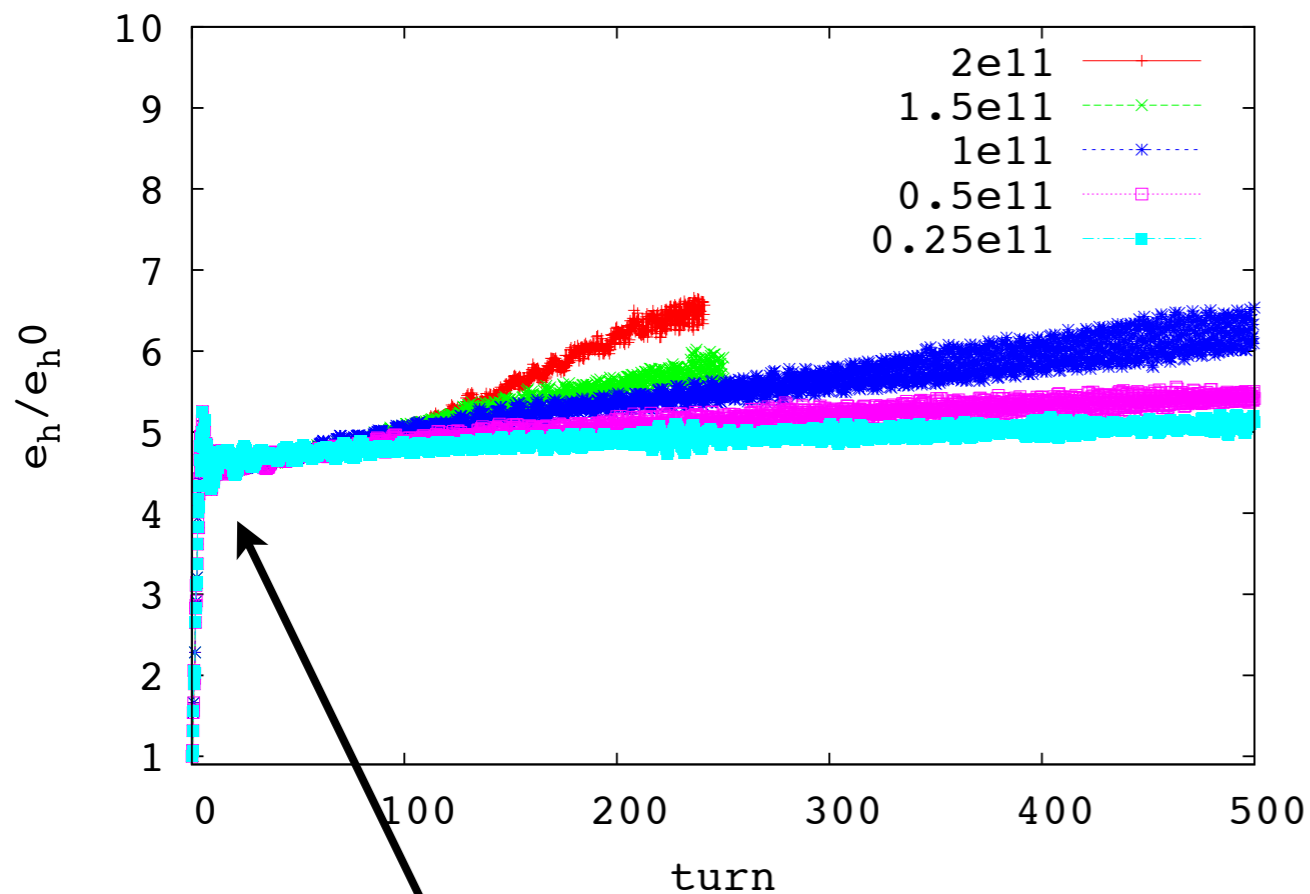
- **vertical**
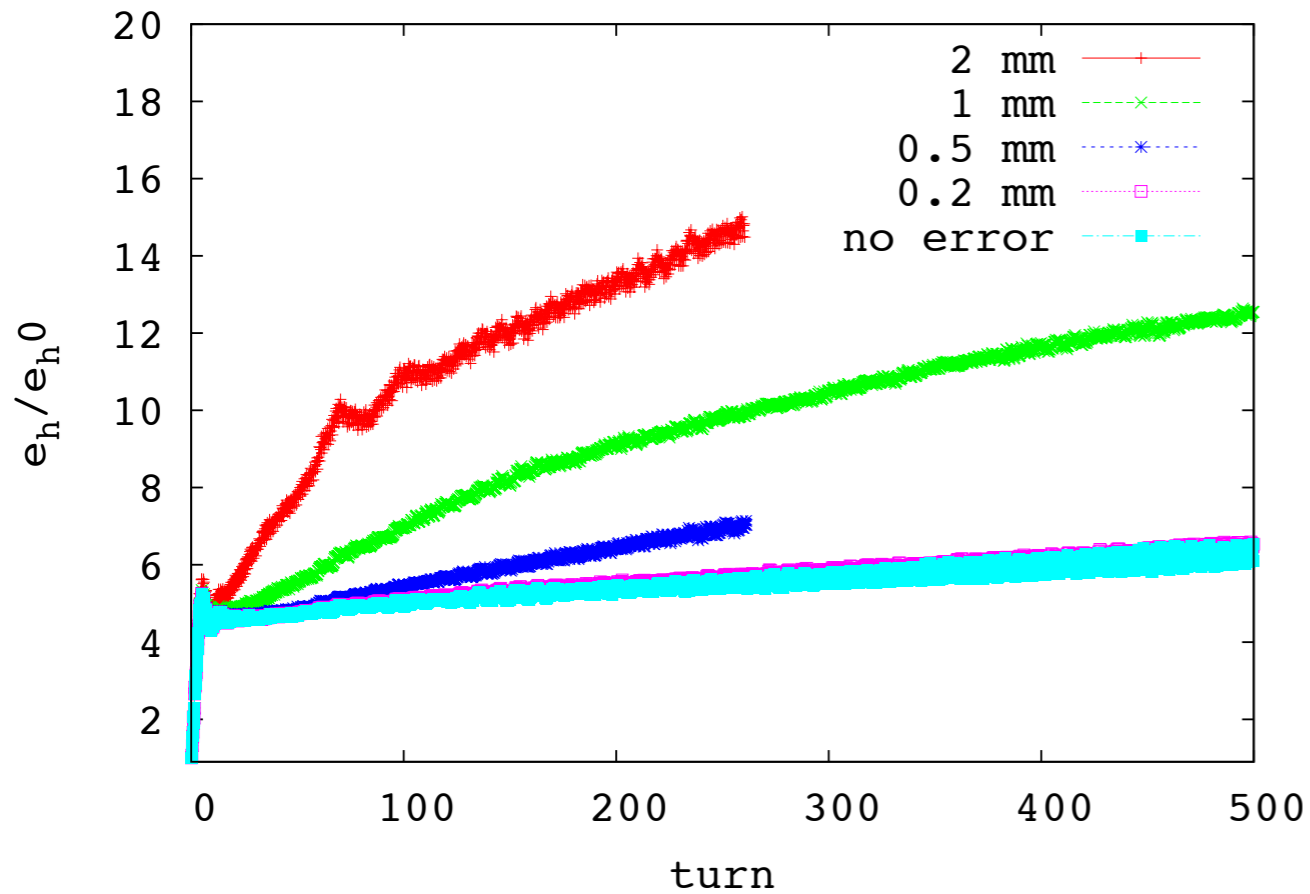

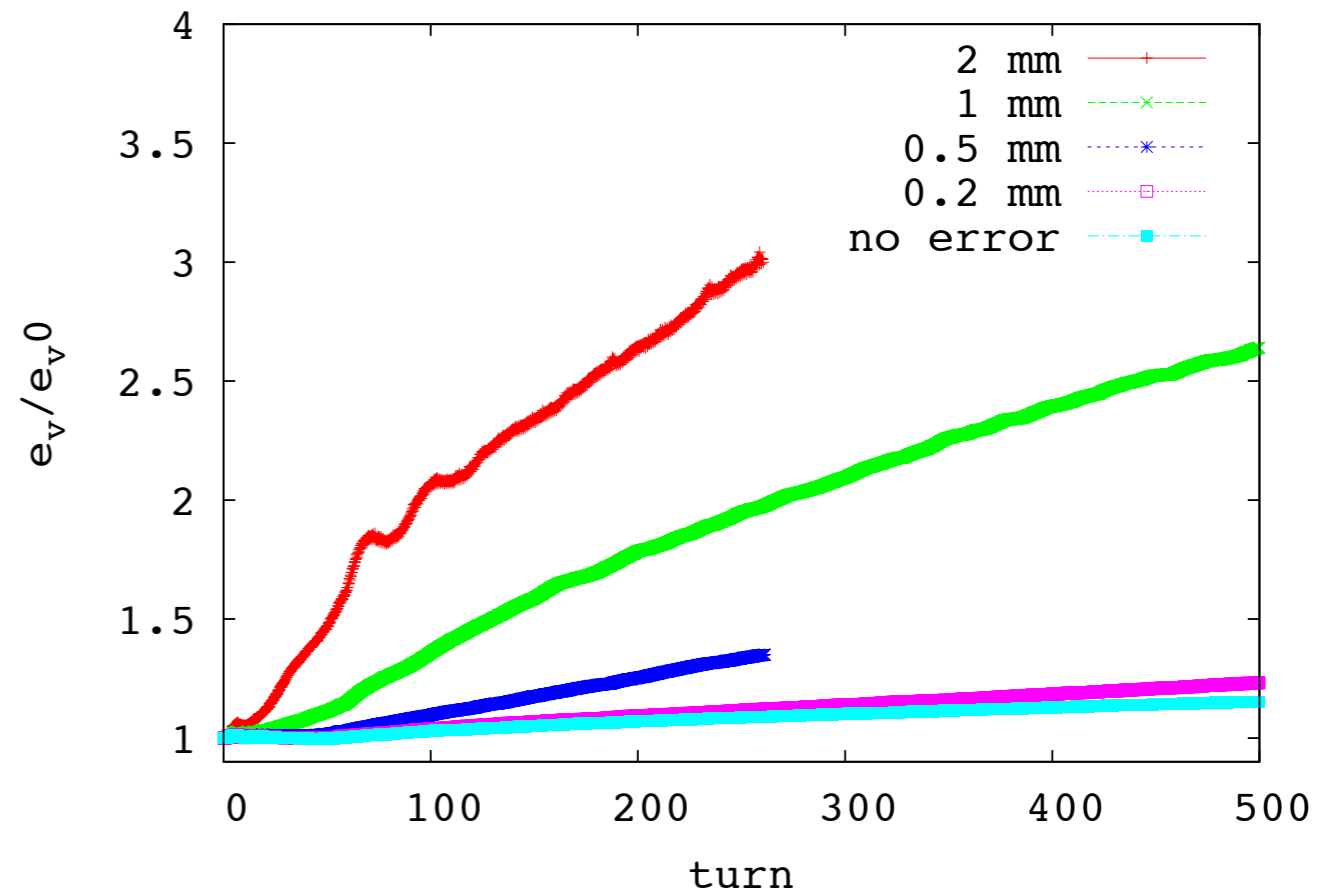- Big jump in the first few turns in H is due to the increase of momentum spread in a rf bucket.
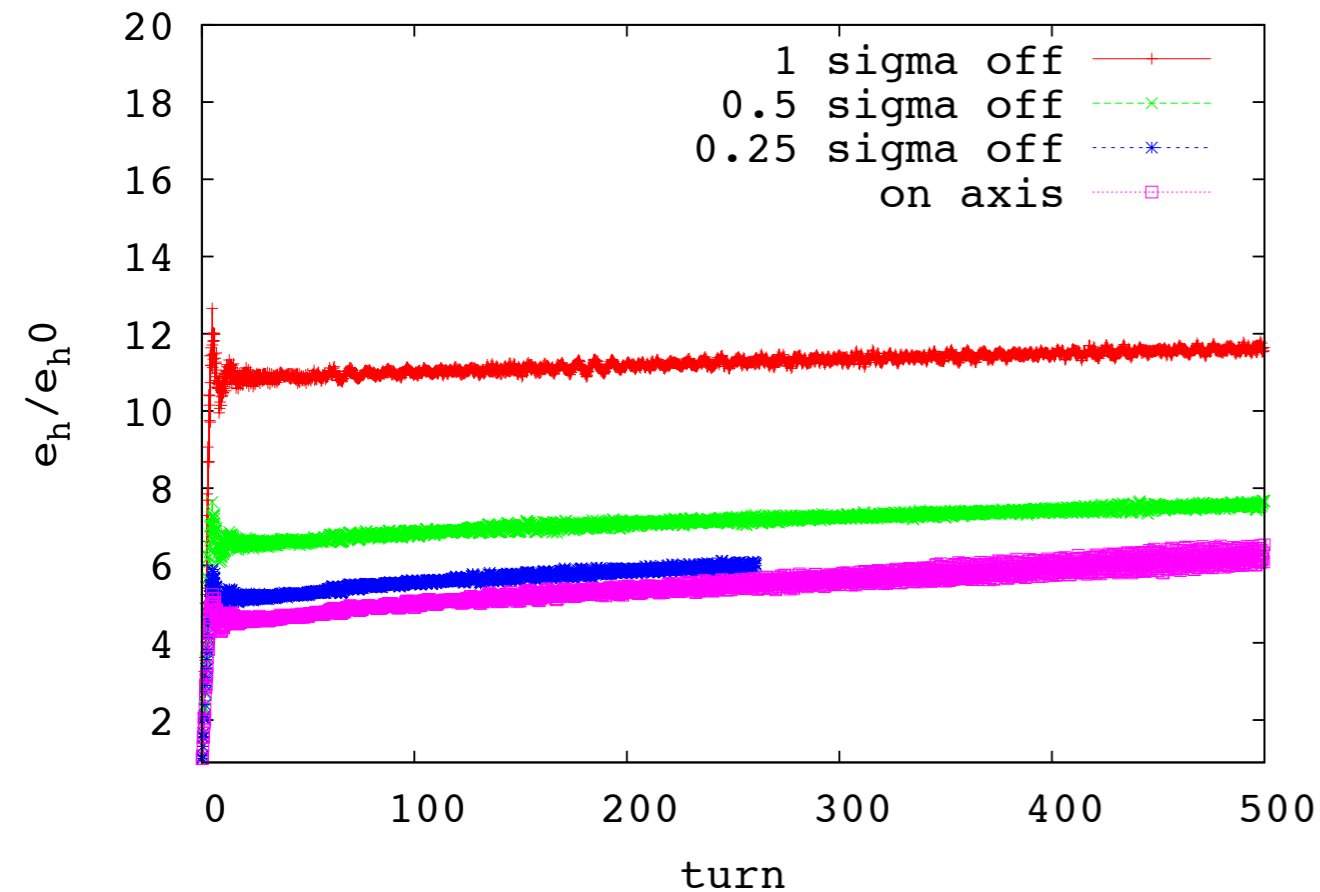
Alignment error

with 1E11 ppb
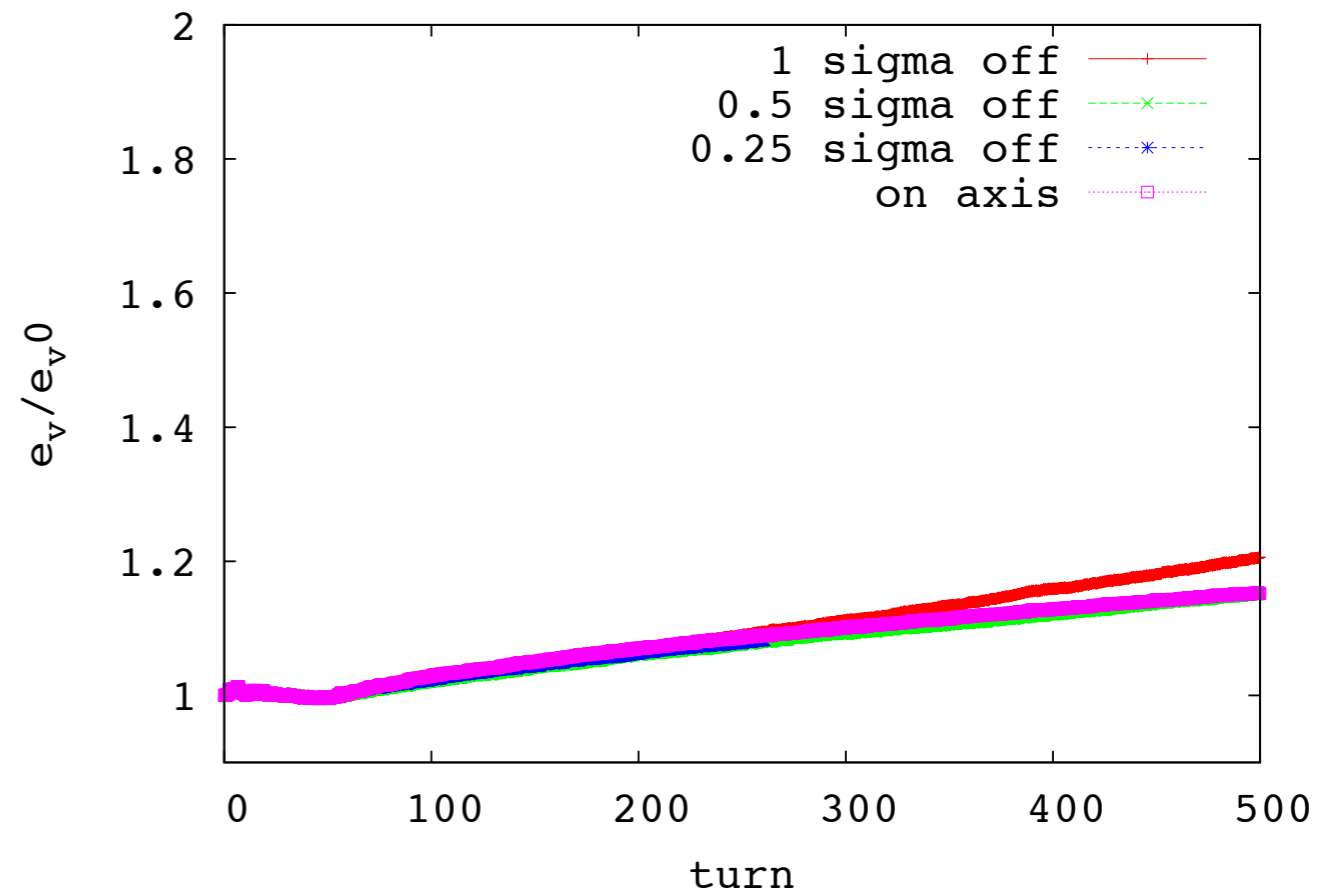

- **horizontal**

- **vertical**

Injection orbit error in horizontal
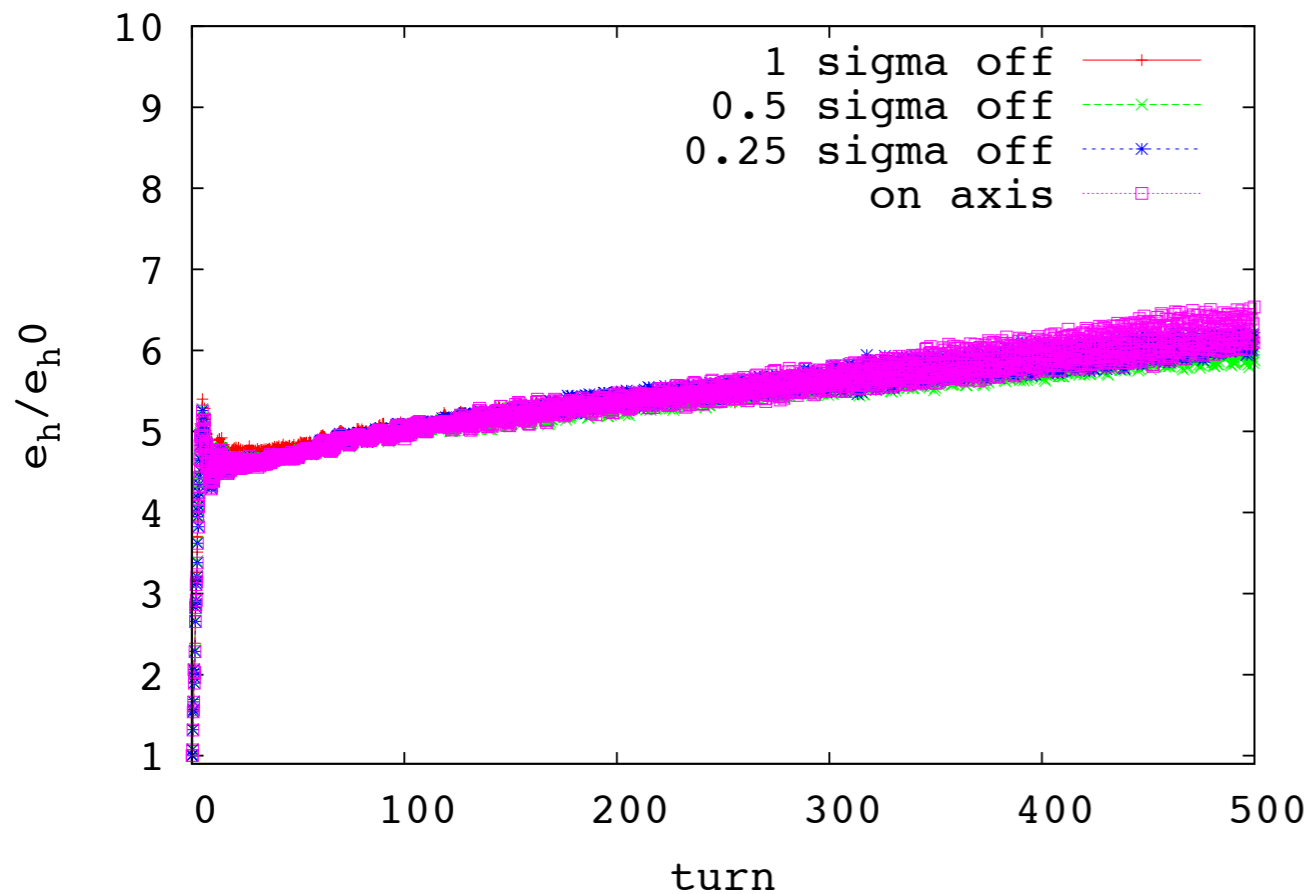## with 1E11 ppb
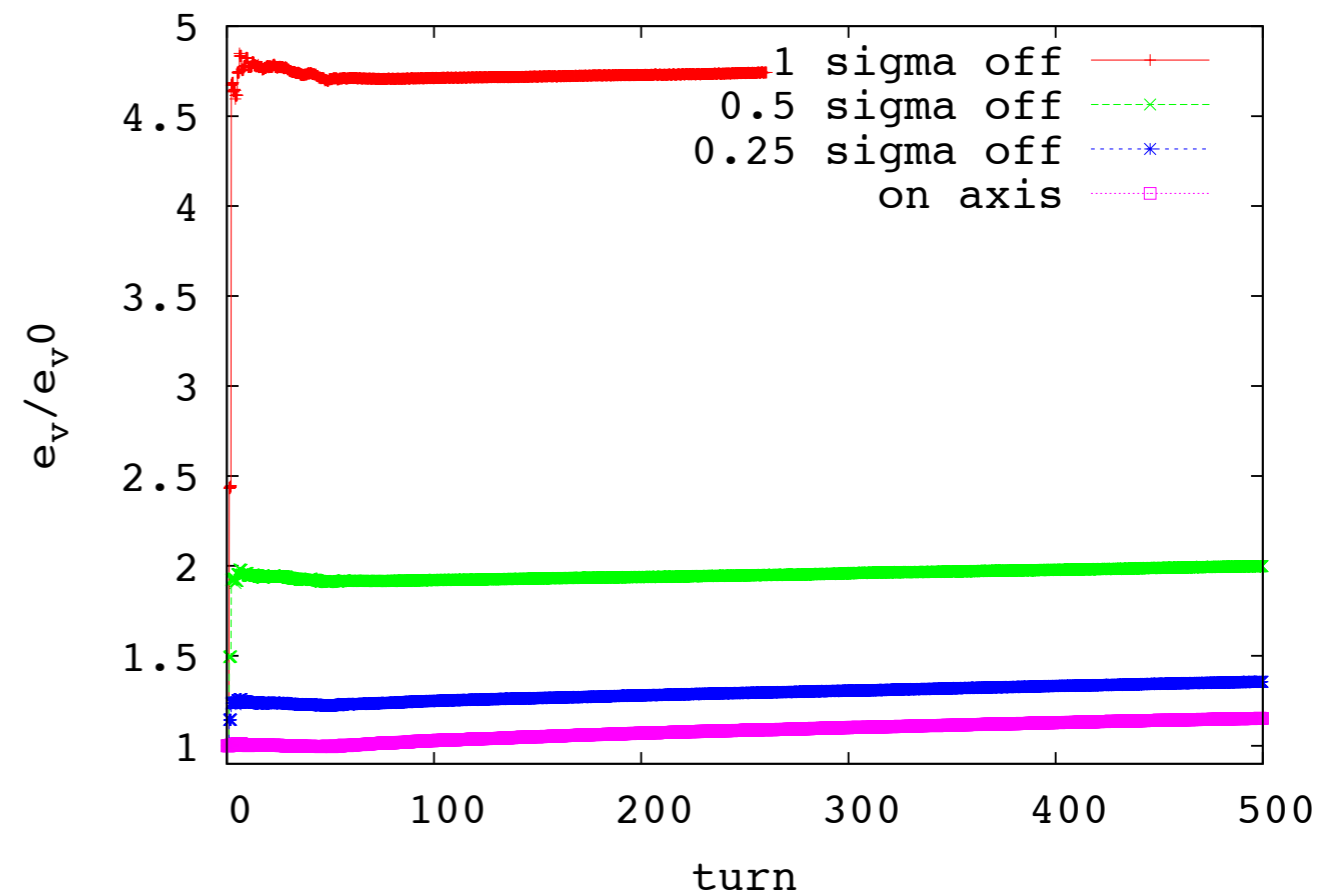
- horizontal

- vertical

- We should repeat this with alignment error.

Injection orbit error in vertical
with 1E11 ppb

- ### horizontal

- ### vertical

- ## We should repeat this with alignment error.

Conclusion

- As expected, emittance increase appears beyond 1E11 ppb.

- Alignment error of +/-0.5 mm makes the growth faster.

- 50% growth, or 20% in beam size, with +/-1 mm alignment error after ~120 turns (first 60 turns are injection period).

- Horizontal beam size is dominated by dispersion. We should use vertical beam size to see the space charge effects.

Next step

- Now we have a good idea how much and how fast the emittance growth by space charge occurs.

- Question is whether it is less or more than that by foil scattering.