Space charge simulation update

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Code development

- Space charge module of Simpsons (space charge simulation code for synchrotron)

plus

- Tracking module of S-code (FFAG tracking code).

Simpsons-FFAG?

Space charge module

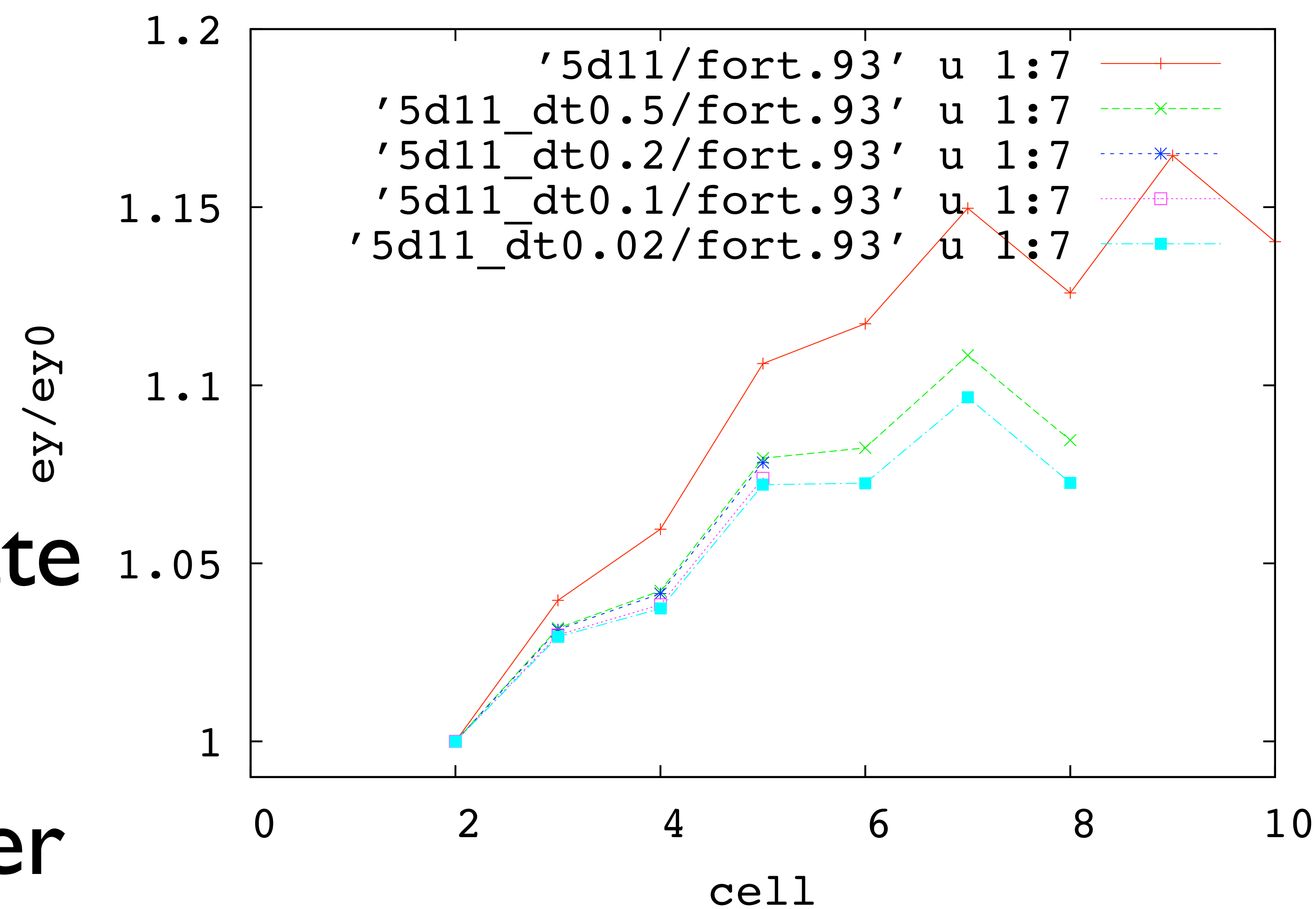
- n_s (=20) slices in longitudinal direction.
- Within a slice, <u>transverse</u> space charge is calculated using *r-theta* grids (cells) assuming no longitudinal variation.
- Density difference between cells in adjacent slice is used for <u>longitudinal</u> space charge.
- Model between 2.5-D and 3-D.

Optimization of tracking parameters (1)

- Number of space charge kicks per cell.
- Number of macro particles.
- Number of grids (cells in *r-z-theta*) for single bunch.

Optimization of tracking parameters (2)

- Number of space charge kicks per cell depends on space charge strength.
- Optimize it at moderate space charge strength.
- For simulation of higher current, increase # of kicks proportional to the strength.



red: 12 kicks per cell
green: 24 kicks
blue: 60 kicks
pink: 120 kicks
light blue: 600 kicks

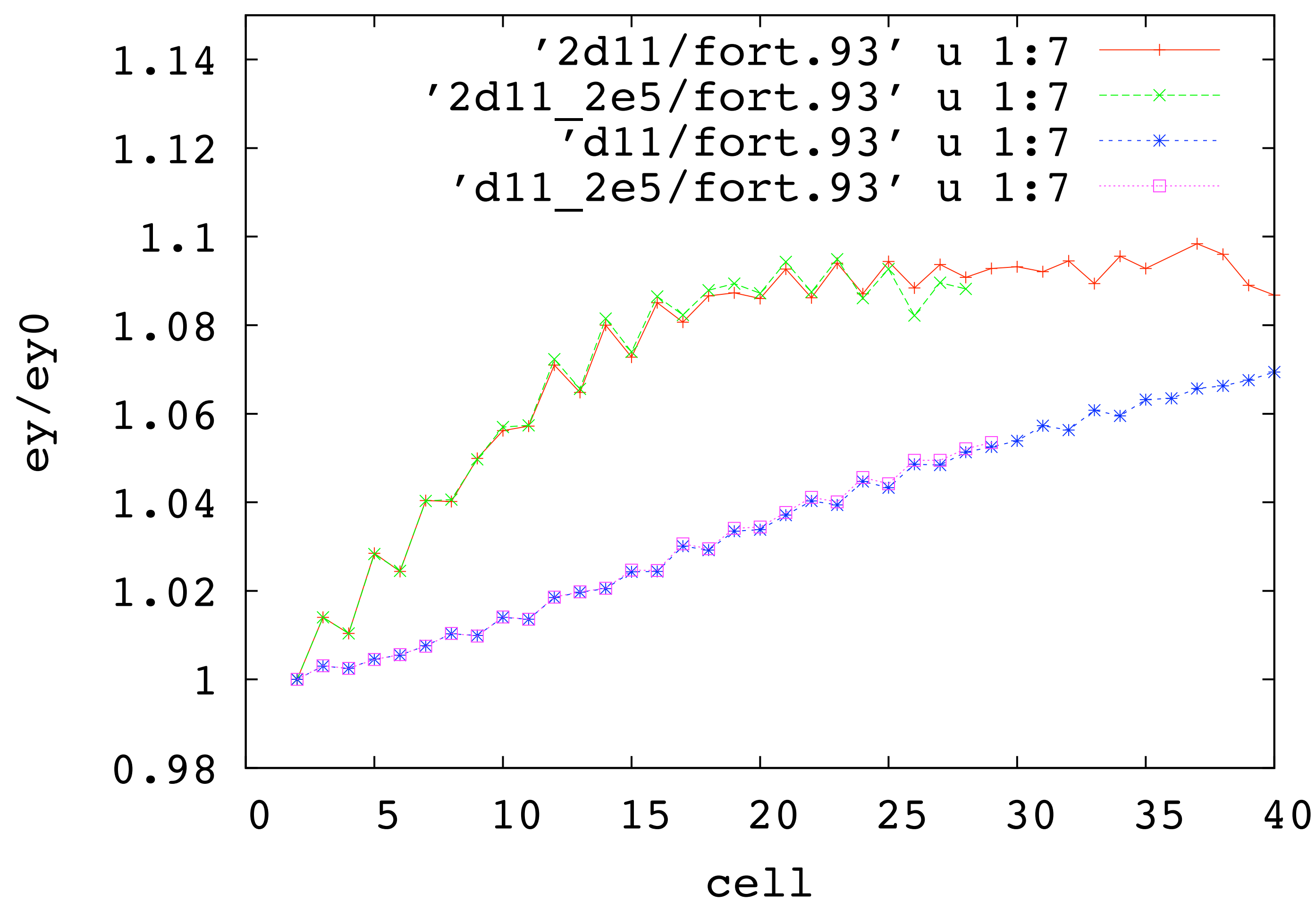
Optimization of tracking parameters (3)

- Number of macro particles depends on number of grids (cells).
- It does not depends on space charge strength.
- Once we have reasonable number of particles per cell, keep the same parameters.

Optimization of tracking parameters (4)

- Rule of thumb is 10 macro particles per cell.
  - if there are grids 20 in r and z, 16 in theta,
  - 20 (r) x 20 (z) x 16 (theta) x 10 = 64,000

Macro particles of 20,000 and 200,000 give almost identical results for two intensity cases.



Optimization of tracking parameters (5)

- Choice of number of cell is arbitrary at the moment.
  - 20 (r) x 20 (z) x 16 (theta) seems to be the minimum from previous experience.

Space charge tune shift

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

$$\Delta Q_y = -\frac{r_p n_t}{\pi(4\epsilon_{rms,un})(1+\sqrt{\epsilon_x/\epsilon_y})\beta^2\gamma^3}\frac{1}{B_f}$$

- $e_{y,\text{ rms, unnor}}$=1.3 x 10^{-6}, n_t=0.6 x 10^{11}, B_f=0.42 gives
  - Effectively, e_x ~ 10 e_y because of dispersion function.
  - \Delta Qy=-0.142

- Tune in the model lattice is (1.816, 2.292).

Observation expected (1)

- Without error fields, only systematic resonances affect a beam.
  - Q_y=2.0 is not a systematic integer resonance.
- However, because of 8-fold symmetry, Q_y=2.0 is quarter resonance (q_y=0.250) in each cell.
  - Cell tune without tune shift is (0.227, 0.286).
  - q_y=0.250 is second order (?) parametric resonance. (Okamoto and Yokoya, NIM A482 p.51 2002).

Observation expected (2)

- Tune shift vs intensity

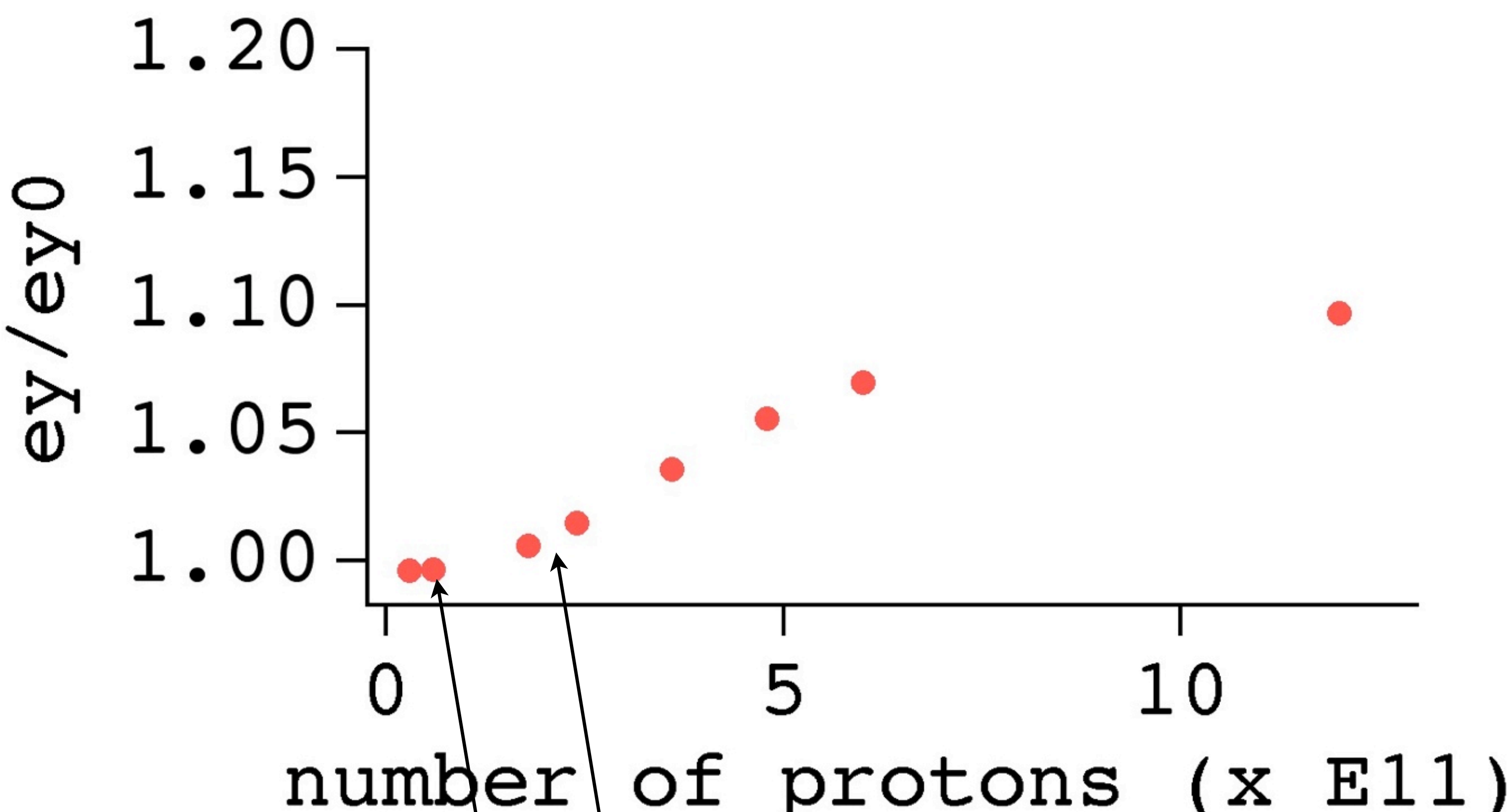
intensity in a ring	cell dq_y (q_y)	ring dQ_y (Q_y)
0.6×10^{11}	-0.018 (0.268)	-0.142 (2.150)
1.8×10^{11}	-0.053 (0.233)	-0.426 (1.866)
2.4×10^{11}	-0.071 (0.215)	-0.568 (1.724)
3.6×10^{11}	-0.107 (0.179)	-0.852 (1.440)

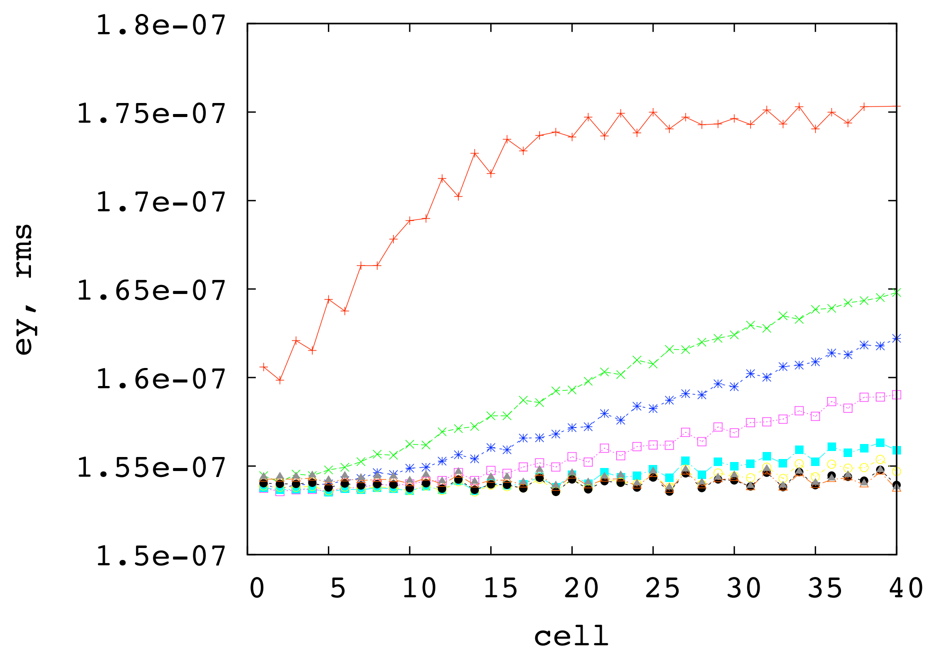
when maximum tune shift hits q_y=0.250

when coherent tune shift hits q_y=0.250.

Simulation results

- Emittance growth (5th turn) vs intensity.





when coherent tune shift hits q_y=0.250.

when maximum tune shift hits q_y=0.250

Summary

- New space charge simulation code for FFAG shows reasonable results.
- In the ideal lattice without errors, quarter resonance in each cell is the primary source of emittance growth.
- Next step
  - Multi-turn injection.
  - COD makes Q_y=2.0 another source of growth.
  - Comparison with growth from scattering.