Lifetrac vs. BBSS Benchmarks
(Updated Results)

D. Shatilov (BINP) and K. Ohmi (KEK)

10th FCC-ee Optics Design meeting
CERN, 11 Sep. 2015

❖ Weak-strong simulations

- ✓ Top and low energies, head-on and crossing angle, with and w/o beamstrahlung.
- ✓ Good agreement between Lifetrac and BBWS, as reported at FCC-ee meeting on 31/08/2015, **https://indico.cern.ch/event/438918/**

❖ Next step: quasi-strong-strong (Lifetrac) vs. strong-strong (BBSS)

- ✓ At low energy, due to weak damping, much more turns are required to converge to the equilibrium. It takes too long for strong-strong code, so we performed tests only at high energy.
- ✓ Head-on and crossing angle, with and w/o beamstrahlung.

The set of parameters for high energy (175 GeV), 2 IPs:

```
Perimeter = 100 km (50 km between IPs).
Crossing angle = 30 mrad (full)
gamma   = 342466
emitt_x = 1.3 nm          emitt_y = 2.6 pm
beta_x  = 50 cm           beta_y  = 2 cm
tune_x  = 0.56            tune_y  = 0.61        tune_s = 0.032724
sigma_z = 2.22 mm         sigma_e = 0.0016
Damping decrements = 0.0062 (x,y)
Energy acceptance  = 2% (synchrotron aperture 12.5 sigma)
```

Bunch population: 1.1*10^11 particles

Lifetrac (quasi-strong-strong)	BBSS (rms)
emitt_x => 1.46 nm (rms), 1.44 pm (Gauss-fitted)	1.55 nm
emitt_y => 4.17 pm (rms), 3.43 pm (Gauss-fitted)	4.71 pm
sigma_x => 24.3 um (rms), 24.0 um (Gauss-fitted)	25.1 um
sigma_y => 85.5 nm (rms), 77.1 nm (Gauss-fitted)	91.2 nm
sigma_z => 2.65 mm (rms), 2.61 mm (Gauss-fitted)	2.65 mm
sigma_e => 0.00191 (rms), 0.00188 (Gauss-fitted)	0.00190
Crabbing: 0.297 mrad	0.312 & 0.280 mrad
Luminosity = 7.44e31	7.11e31
Lifetime = 120 min	

Bunch population: 1.5*10^11 particles

Lifetrac (quasi-strong-strong)	BBSS (rms)
emitt_x => 1.51 nm (rms), 1.48 pm (Gauss-fitted)	1.65 nm
emitt_y => 4.84 pm (rms), 4.02 pm (Gauss-fitted)	5.84 pm
sigma_x => 24.5 um (rms), 23.9 um (Gauss-fitted)	25.7 um
sigma_y => 91.6 nm (rms), 82.6 nm (Gauss-fitted)	101.3 nm
sigma_z => 2.99 mm (rms), 2.91 mm (Gauss-fitted)	2.99 mm
sigma_e => 0.00215 (rms), 0.00209 (Gauss-fitted)	0.00214
Crabbing: 0.339 mrad	0.354 & 0.332 mrad
Luminosity = 11.85e31	11.01e31
Lifetime = 12 min	

Possible reason of discrepancy between quasi-strong-strong and strong-strong: bunch focusing by the opposite bunch. As a result, the opposite bunch’s beta-function dependence on azimuth is modified. This effect is accounted in strong-strong, but not accounted in quasi-strong-strong simulations.

This is a known problem, it can be solved in quasi-strong-strong model, but it would require software update.

Nevertheless, even now agreement between the two codes is quite satisfactory.

Situation giving qualitative difference between weak-strong and strong-strong

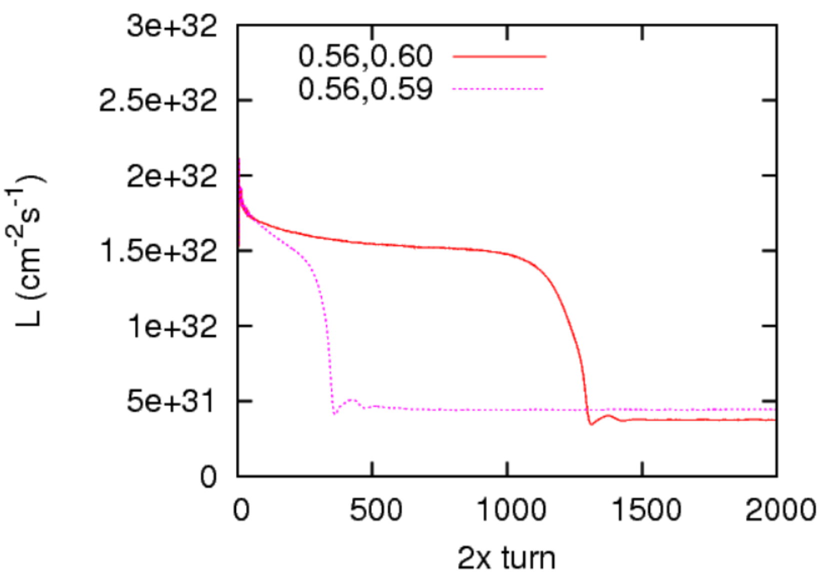
Head-on, without beamstrahlung, $(\nu_x, \nu_y) = (0.56, 0.60)$

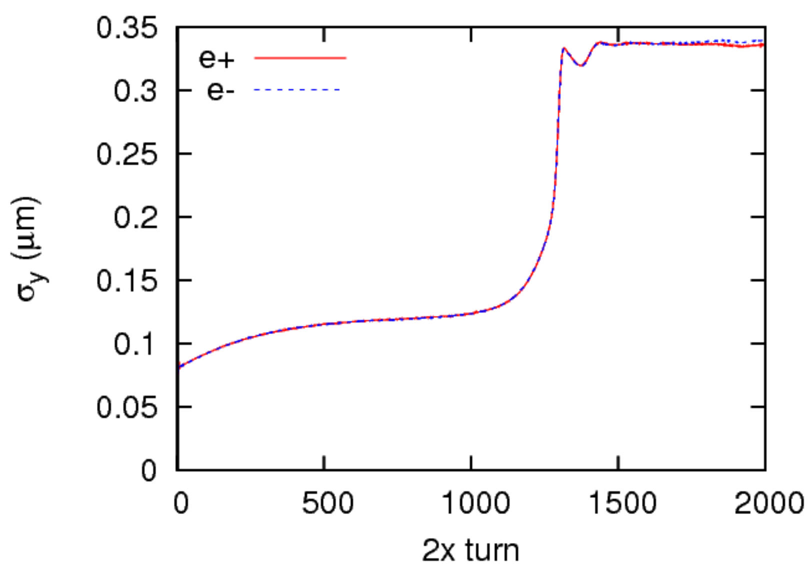
Lifetrac (quasi-strong-strong)	**BBSS** (rms)
emitt_x => 1.77 nm (rms), 1.74 pm (gf)	1.73 nm
emitt_y => 4.94 pm (rms), 3.15 pm (gf)	59.2 & 60.4 pm
sigma_x => 22.5 um (rms), 21.5 um (gf)	22.3 um
sigma_y => 95.3 nm (rms), 76.0 nm (gf)	336 & 340 nm
Luminosity = 1.58e32	3.77e31

K. Ohmi

About this phenomenon

- Two beams enlarged correctively.
- This phenomenon was studied in 2000. K.O et al, PRL92, 214801
- Gaussian beam did not give this result.
- PIC weak-strong gave the same result.
- 2 dimensional effect.
- Radiation excitation is important.
- x-y coupling is enhanced correctively.

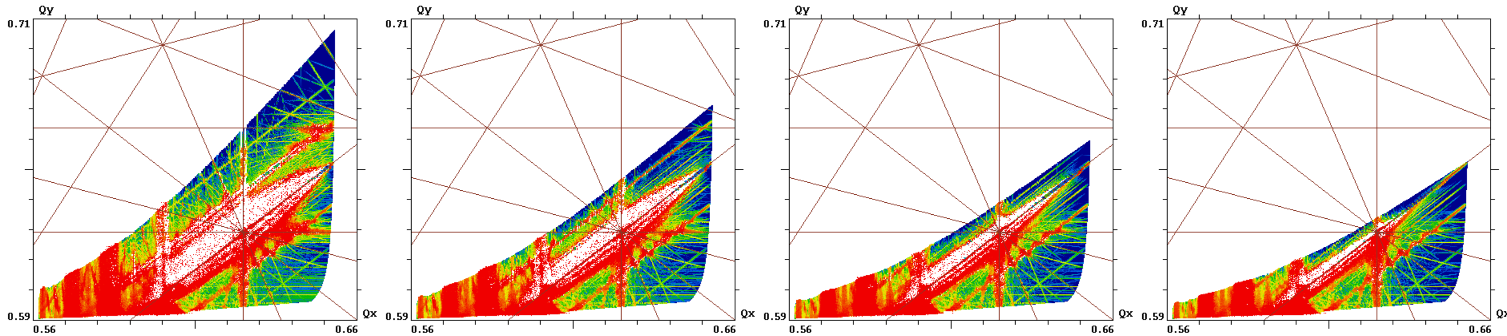




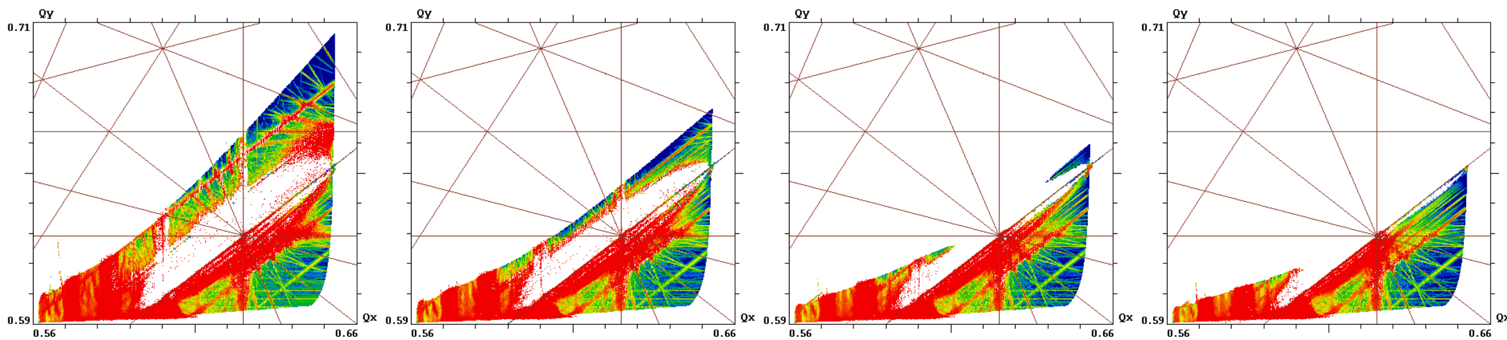
FMA Footprints vs. ε_y for $(\nu_x, \nu_y) = (0.56, 0.59)$

	ε_y = 5 pm	ε_y = 10 pm	ε_y = 15 pm	ε_y = 20 pm

Lattice without coupling



Weak skew added

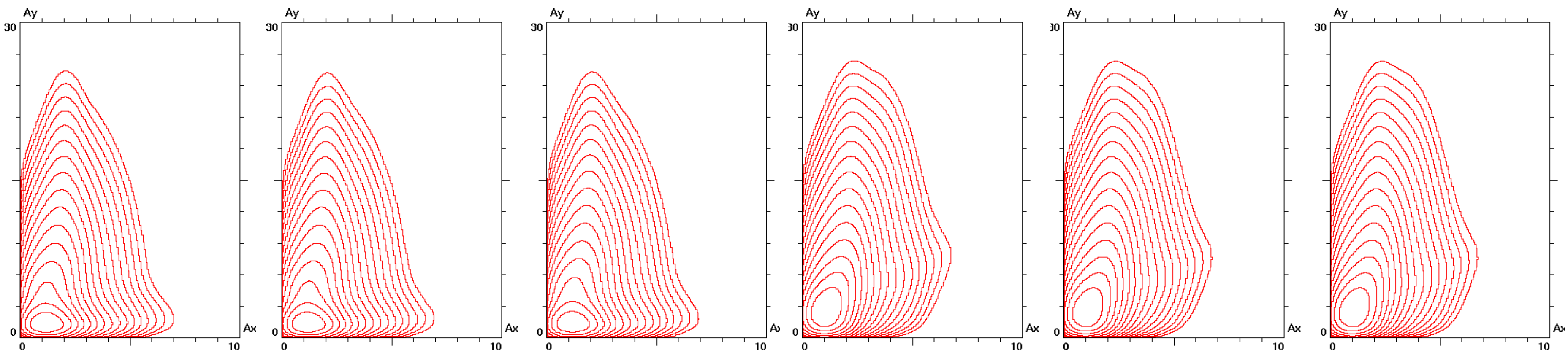


Without explicit coupling, quasi-strong-strong iterations always converge to $\varepsilon_y \sim 5$ pm

With small explicit coupling, quasi-strong-strong also produces such instability.

Example: ε_y = 9 pm => 27 pm

Step 0 | Step 5 | Step 10 | Step 15 | Step 20 | Step 25



ε_y = 9 pm | ε_y = 9.3 pm | ε_y = 10.3 pm | ε_y = 21.9 pm | ε_y = 27.6 pm | ε_y = 27.2 pm

Conclusions I

- When $\nu_x + \xi_x > \nu_y$ the footprint may cross the main coupling resonance, despite $\nu_x < \nu_y$ and $\xi_x < \xi_y$
- In most cases this does not affect the luminosity, but can affect the vertical beam tails.
- In some cases this leads to instability: both beams “move” toward the main coupling resonance and blow up. The instability threshold is model-depending. In strong-strong model (non-Gaussian opposite bunch) it is lower than in quasi-strong-strong model (Gaussian opposite bunch).
- To avoid such instability, one has to set the betatron tunes not too close to the main coupling resonance, especially when ξ_x is large, or use collision scheme with large Piwinski angle, where ξ_x is small.

Conclusions II

- Benchmark tests showed good agreement between quasi-strong-strong (Lifetrac) and strong-strong (BBSS) beam-beam codes.
- Some discrepancies exist, but they are not significant and their sources are (seem to be) known.
- Further development of quasi-strong-strong code towards non-Gaussian strong beams is possible.
- Current version of quasi-strong-strong code provides reliable results, and it is much faster. Direct calculation of beamstrahlung lifetime is not possible in strong-strong simulations. However, cross-check with strong-strong code would be desirable for the final results.