Beam-beam simulations with lattice for FCC-ee

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Acknowledgements:
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Outline

➤ Lattices for $t\bar{t}$ (by K. Oide)
  ● Compare two versions
    ✶ FCCee_t_82_by2_1a_nosol_DS_2
    ✶ FCCee_t_65_26_1_2
  ● Error seeds in vertical offsets of $S\{DF\}^*$ [sextupoles in arc sections) to generate vertical emittance

➤ FMA
  ● DA, beam-beam and lattice resonances

➤ Luminosity
  ● BBWS
  ● SAD: beam-beam + lattice

➤ Summary
## 1. Machine parameters (for half ring)

<table>
<thead>
<tr>
<th>Lattice version</th>
<th>82_by2*</th>
<th>65_26_1_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (km)</td>
<td>49988.8</td>
<td>49990.9</td>
</tr>
<tr>
<td>E (GeV)</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>Number of IPs</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(N_b)</td>
<td>81</td>
<td>78</td>
</tr>
<tr>
<td>(N_p(10^{11}))</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Full crossing angle (rad)</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>(\varepsilon_x) (nm)</td>
<td>1.26</td>
<td>1.3</td>
</tr>
<tr>
<td>(\varepsilon_y) (pm)</td>
<td>2.52</td>
<td>2.5</td>
</tr>
<tr>
<td>(\beta_x^*) (m) [optional]</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(\beta_y^*) (mm) [optional]</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>(\sigma_z) (mm)\textsuperscript{SR}</td>
<td>2.4</td>
<td>2.1</td>
</tr>
<tr>
<td>(\sigma_\delta(10^{-3})\textsuperscript{SR}</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Fractional betatron tune (\nu_x/\nu_y)</td>
<td>.56/.61</td>
<td>.54/.57</td>
</tr>
<tr>
<td>Synch. tune (\nu_s)</td>
<td>0.0329</td>
<td>0.0375</td>
</tr>
<tr>
<td>Damping rate/turn (10^{-2}) [x/y/z]</td>
<td>1.06/1.06/2.09</td>
<td>1.1/1.1/2.2</td>
</tr>
<tr>
<td>Lum./IP(10^{34}\text{cm}^{-2}\text{s}^{-1})</td>
<td>1.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Ref. K. Oide et al., “Design of beam optics for the FCC-ee collider ring”, Submitted to PRAB.*
1. Lattice properties

➤ Chromatic nonlinearity

- Similar except higher 3rd chromaticity in Ver. 82_by2

From K. Oide
1. Lattice properties

➤ Dynamic aperture

● 6D Tracking: 50 turns
● Element-by-element rad. damping

From K. Oide
1. Lattice properties

➢ Dynamic aperture

- 6D Tracking: 50 turns
- Turn-by-turn lumped rad. damping

From K. Oide
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ Effects of RF

- Strong X-Y to Z coupling
- Strong impact of synch. motion on FMA
- On-momentum DA decrease significantly due to SR

Conditions:
1) Bare lattice
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 1024 half turns
6) BB OFF
7) δ=0

RF OFF:

RF ON:
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

- Effects of RF
  - Strong X-Y to Z coupling
  - Strong impact of synch. motion on FMA

Conditions:
1) Bare lattice
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 1024 half turns
6) BB OFF
7) $\delta=2\sigma_p$
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ Effects of tracking turns

- Poor resolution of diffusion in FMA
- Weak impact on size of DA w/o BB

RF OFF:

RF ON:

Conditions:
1) Bare lattice
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 128 half turns
6) BB OFF
7) $\delta=2\sigma_p$
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ Beam-beam effects

- Extend footprint in tune space and drive resonances
- Reduce DA

$\delta=0$: [Graph Image]

$\delta=2\sigma_p$: [Graph Image]

Conditions:
1) Bare lattice
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 1024 half turns
6) RF & BB ON
7) Np=0.85E11
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

- Effects of errors in vertical offsets of S{DF}*
  - Modify footprint in tune space
  - Reduce DA

\[ \delta = 0: \]

\[ \delta = 2\sigma_p: \]

Conditions:
1) Error seed #25
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 1024 half turns
6) RF & BB ON
7) Np=0.85E11
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ Effects of errors in vertical offsets of S\{DF\}*
  ● Modify footprint in tune space
  ● Reduce DA
  ● Tracking in the order of damping time: Better surviving rate

\(\delta=0:\)

\(\delta=2\sigma_p:\)

Conditions:
1) Error seed #25
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 128 half turns
6) RF & BB ON
7) Np=0.85E11
3. Luminosity

➤ Weak-strong simulation w/ and w/o lattice

- Lum. loss due to interplay of BB+Lattice => a few per cent
- Lum. is sensitive to working point

Conditions:
1) Bare lattice
2) Lumped rad. damping/excitation, CW & BS ON
3) # of bunches: 78, $\sigma_{z0}=2.1$mm
3. Luminosity

- Weak-strong simulation w/ and w/o lattice

  - Errors in $S\{DF\}^*$ also generate dispersion at RF (longer bunch), and dispersion/linear coupling at IP
  - Lum. loss with errors in $S\{DF\}^*$ is not due to lattice nonlinearity
  - Local linear coupling at IP $\Rightarrow$ Additional lum. loss

Conditions:
1) Bare lattice + Errors
2) Lumped rad. damping/excitation, CW & BS ON
3) # of bunches: 78, $\sigma_{z0}=2.8\text{mm}$

![Graph showing specific luminosity vs. $I_{bunch}(e^+)+I_{bunch}(e^-)$ for different conditions.]
4. Lifetime

➤ Particle losses in tracking

- Mechanism: Beamstrahlung effects + Finite DA
- DA is determined by rad. damping/excitation, Lattice nonlinearity and BB

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4. Lifetime

➢ Particle losses in tracking
  ● Translate loss rate into lifetime
  ● CW improves lifetime via suppressing beam-beam tail
  ● Need more careful simulations: Larger number of macro-particles and tracking turns

4. Lifetime

➢ Effects of rad. damping/excitation

- Distributed (element-by-element) vs. Lumped (one-turn, to speed up simulation)
- Case: FCCee_t_82_by2_1a_nosol_DS_2 with Error seed #25
- Small effect if BB dominates DA (?)
5. Summary

➤ FMA

● Rad. damping/excitation: not considered in FMA but very important at FCC-ee

● SAD+NAFF+BB almost agree with D. Shatilov’s results except much worse resolution in my simulations

● Synch. motion (X-Y to Z coupling) is very important at FCC-ee

● Beam-beam is an important factor in determining DA

● Errors in vert. offsets of S{DF}* affect DA (w/ BB) [likely tolerable?]

➤ Luminosity and lifetime

● BB+Lattice causes lum. loss in the order of a few per cent

● Errors in vert. offsets of S{DF}*: almost no lum. loss, might affect lifetime with BB

● BS+DA defines lifetime, likely not serious