Weak-strong beam-beam simulations

Minimum crossing angle round/flat SixTrack/Lifetrac
Emittance blow-up and luminosity lifetime

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## HL-LHC baseline parameters

<table>
<thead>
<tr>
<th></th>
<th>LHC nominal</th>
<th>HL-LHC 25 ns</th>
</tr>
</thead>
<tbody>
<tr>
<td># Bunches</td>
<td>2808</td>
<td>2808</td>
</tr>
<tr>
<td>p/bunch [$10^{11}$]</td>
<td>1.15 (0.58A)</td>
<td>2.2 (1.11 A)</td>
</tr>
<tr>
<td>Energy in one beam [MJ]</td>
<td>360</td>
<td>690</td>
</tr>
<tr>
<td>$\gamma \varepsilon_{x,y}$ [µm]</td>
<td>3.75</td>
<td>2.5</td>
</tr>
<tr>
<td>$\sigma_z$ [cm], $\sigma_{\delta p/p}$ [$10^{-3}$]</td>
<td>7.5, 0.1</td>
<td>7.5, 0.1</td>
</tr>
<tr>
<td>$\beta^*$ [cm]</td>
<td>55</td>
<td>15</td>
</tr>
<tr>
<td>X-angle [µrad], separation</td>
<td>300, (10.0 $\sigma$)</td>
<td>590, (12.5 $\sigma$)</td>
</tr>
<tr>
<td>Geometrical luminosity loss factor</td>
<td>0.83</td>
<td>0.31</td>
</tr>
<tr>
<td>Peak lumi [$10^{34}$]</td>
<td>1.0</td>
<td>7.4</td>
</tr>
<tr>
<td>(with full Piwinsky angle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virtual lumi [$10^{34}$]</td>
<td>1.2</td>
<td>21.9</td>
</tr>
<tr>
<td>(w/o Piwinsky angle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_{\text{leveling}}$ [h] @ 5E34</td>
<td>n/a</td>
<td>9.0</td>
</tr>
<tr>
<td>#Pile up @5E34</td>
<td>25</td>
<td>140</td>
</tr>
</tbody>
</table>
Simulation parameters

• HLLHCV1.0 optics (SLHCV3.1b for flat case)
• DA tracking – $10^6$ turns
• FMA – $2^{13}$ turns
• Multiparticle tracking – 5,000 particles/bunch, weighted distribution, up to $2.5 \times 10^6$ turns
  • No IBS, gas scattering or other diffusion mechanisms. From experience, these usually mitigate (!) beam-beam resonances. However, they would enhance the rate of tail population
Luminosity Leveling at $5 \times 10^{34}$
Luminosity Leveling at $5 \times 10^{34}$
Minimum DA During Luminosity Leveling at $5 \times 10^{34}$

courtesy D. Banfi
FMA During Luminosity Leveling at $5 \times 10^{34}$

$\beta^* = 70\text{cm}$

No errors

$\beta^* = 42\text{cm}$
FMA During Luminosity Leveling at $5\times10^{34}$

$\beta^* = 30\text{cm}$  
No errors  
$\beta^* = 15\text{cm}$
FMA For Ultimate Case $\beta^*=15\text{cm}$, $N_p=2.2 \times 10^{11}$

No errors

Errors – Seed1
Macroscopic Beam Parameters
During Luminosity Leveling at $5 \times 10^{34}$

$\beta^* = 70\,\text{cm}$, $x=590\,\text{urad}$

$\tau_L = 50\,\text{h}$

IP8=on, CC=on
Macroscopic Beam Parameters During Luminosity Leveling at $5 \times 10^{34}$

$\beta^* = 42\,\text{cm}, x = 450\,\text{urad}$

IP8=on, CC=on
Macroscopic Beam Parameters During Luminosity Leveling at $5 \times 10^{34}$

$\beta^* = 15\text{cm}$, $x=450\text{ urad}$

IP8=on, CC=on
Macroscopic Beam Parameters
Ultimate Case $N_p=2.2 \times 10^{11}$

$\beta^* = 15\text{cm}$, $x=590\text{ urad}$
No errors, IP8=on, CC=on
Evolution of Tails
Ultimate Case Np=2.2×10^{11}

β* = 15cm, x=590 urad
No errors, IP8=on, CC=on
Macroscopic Beam Parameters
Ultimate Case $N_p = 2.2 \times 10^{11}$

$\beta^* = 15\text{cm}, x = 590\text{ urad}$
Error seed1, IP8=on, CC=on
Evolution of Tails
Ultimate Case $N_p = 2.2 \times 10^{11}$

$\beta^* = 15\text{cm, } x = 590\text{ urad}$
Error seed1, IP8=on, CC=on
Macroscopic Beam Parameters
Ultimate Case $N_p = 2.2 \times 10^{11}$

$\beta^* = 15\text{cm}, x=450 \text{ urad}$
No errors, IP8=on, CC=on
Evolution of Tails
Ultimate Case $N_p=2.2 \times 10^{11}$

$\beta^* = 15\text{cm}, x=450 \text{ urad}$
No errors, IP8=on, CC=on
Conclusions for round optics

Multiparticle tracking for HLLHCV1.0 shows:

1. No degradation of parameters in Nominal scenario (lumi leveled at 5E34 and constant x-angle 590 urad)
2. No degradation of parameters with reduced x-angle 450 urad at leveled lumi 5E34
3. Slight degradation of luminosity lifetime (\(\tau\sim 40\) hr) at full virtual lumi 2E35 at \(\beta^*\)=15 and x-angle 590 urad due to tail growth and particle losses
Flat Optics 30/7.5 cm

DA benchmarking with Sixtrack and Lifetrac:

![Graph showing dynamical aperture vs. crossing angle](graph.png)
Luminosity Leveling at $5 \times 10^{34}$ with Flat Optics $\beta_x/\beta_y=4$, CC=off, x-angle=350 urad
Flat Optics 30/7.5 cm

DA at minimum $\beta$-function (min separation):

![Graph showing dynamical aperture vs. crossing angle with two data points marked.](image-url)
Macroscopic Beam Parameters During Luminosity Leveling at $5 \times 10^{34}$

$\tau_L \sim 35$ hr

$\beta^* = 30/7.5\text{cm}$, $x=350\text{ urad}$

IP8=on, CC=off
Evolution of Tails

\[ \beta^* = 30/7.5 \text{cm}, \ x=350 \text{ urad} \]

IP8=on, CC=off
Macroscopic Beam Parameters During Luminosity Leveling at $5 \times 10^{34}$

$\beta^* = 30/7.5\text{cm, } x=320\text{ urad}$

IP8=on, CC=off

$\tau_L \sim 10\text{ hr}$

$\tau_L \sim 7\text{ hr}$
Evolution of Tails

\[ \beta^* = 30/7.5 \text{cm}, \, x=320 \text{ urad} \]

IP8=on, CC=off
FMA Flat Optics $\beta^*=30/7.5\text{cm}$, $N_p=1.2\times10^{11}$
Conclusions for flat optics

1. Minimum DA>5-6σ at β=30/7.5 is achieved at crossing angle > 350-380 urad

2. Slight reduction of luminosity lifetime (τ~35 hr) at x-angle 350 urad (DA=5σ)

3. Significant degradation of luminosity lifetime (τ~10 hr) at x-angle 320 urad (DA=3σ), significant tail growth (1-2 orders of magnitude)
   • Potentially can be used for BBC studies
Outlook

1. Although quantitative conclusions were shown to be robust by previous experience, quantitative results may be slightly affected by low statistics
   - 5,000 macro-particles averaged over 10,000 turns
   - $3 \times 10^6$ turns ~ 4 minutes
   - Work is being done to launch more massive studies at FermiGrid

2. It is essential to include other diffusion mechanisms
   - Noise smears resonances, but enhances population of tails
Appendix: error tables used

/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/IT_errortable_v65
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/D1_errortable_v1
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/D2_errortable_v4
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/Q4_errortable_v1
/afs/cern.ch/eng/lhc/optics/HLLHCV1.0/errors/Q5_errortable_v1