The FCC-ee booster synchrotron

Bastian Haerer (CERN) for the FCC-ee lattice design team
## Booster parameters

### 100 km top-up booster
- 20 GeV – 175 GeV

### 6 GeV linac & damping ring at 1.5 GeV

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>FCCee-Z</th>
<th>FCCee-W</th>
<th>FCCee-H</th>
<th>FCCee-tt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [GeV]</td>
<td>45.6</td>
<td>80</td>
<td>120</td>
<td>175</td>
</tr>
<tr>
<td>Type of filling</td>
<td>Full</td>
<td>Top-up</td>
<td>Full</td>
<td>Top-up</td>
</tr>
<tr>
<td>BR # of bunches</td>
<td>7100</td>
<td>35500</td>
<td>5260</td>
<td>60</td>
</tr>
<tr>
<td>BR cycle time [s]</td>
<td>26.75</td>
<td>97.75</td>
<td>68.6</td>
<td>7.1</td>
</tr>
<tr>
<td># of BR cycles</td>
<td>20</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Total number of bunches</td>
<td>71000</td>
<td>5260</td>
<td>780</td>
<td>62</td>
</tr>
<tr>
<td>Filling time (both species) [sec]</td>
<td>1070</td>
<td>391</td>
<td>548.8</td>
<td>84.6</td>
</tr>
<tr>
<td>Injected bunch population [$10^{10}$]</td>
<td>4.3</td>
<td>0.21</td>
<td>6.0</td>
<td>0.12</td>
</tr>
</tbody>
</table>

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Y. Papaphilippou
Circumference: $C = 97.75$ km
Bending radius: $\rho = 10.5$ km

2 experimental straight sections (A & G)
2 RF sections in points D and J

We would like to avoid “tapering”
$\rightarrow$ To be confirmed by 6D tracking studies
The layout of the booster follows the footprint of FCC-hh ➔ inside the experiments

Images from:

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FODO cell of the FCC-ee booster

B = bending magnet, Q = quadrupole, S = sextupole

0.5 m   11.0 m   1.5 m   0.775 m   0.65 m   0.15 m   54 m
Optics for 80-175 GeV*

FODO cell:
L = 54 m
φ = 90°/60°

* maximum beam energy in collider

2-cell half-bend dispersion suppressor
Optics for 45 GeV*

FODO cell:
L = 54 m
φ = 60°/60°

* maximum beam energy in collider
<table>
<thead>
<tr>
<th>Parameter</th>
<th>$60°/60°$</th>
<th>$90°/60°$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_x$</td>
<td>306.225</td>
<td>457.225</td>
</tr>
<tr>
<td>$Q_y$</td>
<td>304.290</td>
<td>304.290</td>
</tr>
<tr>
<td>$\xi_x$</td>
<td>-338.778</td>
<td>-507.658</td>
</tr>
<tr>
<td>$\xi_y$</td>
<td>-336.455</td>
<td>-420.928</td>
</tr>
<tr>
<td>$\alpha_c / 10^{-6}$</td>
<td>13.7</td>
<td>6.5</td>
</tr>
<tr>
<td>$\varepsilon_x (20 \text{ GeV})/\text{nm rad}$</td>
<td>0.045</td>
<td>0.015</td>
</tr>
<tr>
<td>$\varepsilon_x (45 \text{ GeV})/\text{nm rad}$</td>
<td>0.235</td>
<td>0.075</td>
</tr>
<tr>
<td>$\varepsilon_x (175 \text{ GeV})/\text{nm rad}$</td>
<td>3.540</td>
<td>1.124</td>
</tr>
</tbody>
</table>
Non-interleaved sextupole scheme

\[ \mu_x = \mu_y = 180^\circ \ (\rightarrow \text{-I transformation}) \]
Dynamic aperture (at 175 GeV)

Only linear chromaticity is compensated

±2% acceptance no problem
$60^\circ/60^\circ$ optics

\[
d = \log_{10} \left[ \sqrt{ (\nu_x^{(2)} - \nu_x^{(1)})^2 + (\nu_y^{(2)} - \nu_y^{(1)})^2 } \right]
\]

working point

\[
tune \ footprint
\]
90°/60° optics

interleaved sextupole scheme

work station

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Detuning with amplitude

- **Detuning in first order** given by
  \[ Q_x = Q_{x,0} + \alpha_{xx} J_x + \alpha_{xy} J_y \]
  \[ Q_x = Q_{x,0} + \alpha_{yx} J_x + \alpha_{yy} J_y \]

- \( \alpha_{ij} \) are the detuning coefficients, \( J \) the action

- **Detuning coefficients** (also higher orders) can be quickly calculated with PTC_normal
Tune footprints of 60°/60° optics

Analytic calculation based on first order PTC_normal results

Tracking results

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Summary and Outlook

• Sufficient dynamic aperture of more than 70 $\sigma$ achieved with the 60°/60° optics

• We are confident to find a suitable sextupole scheme for 90°/60° optics using the PTC normal form analysis
  → Multi-family sextupole scheme allows to modify higher orders of chromaticity and detuning with amplitude

• Future step: estimate the strength of instabilities and the emittance evolution during filling and ramp-up
Thank you for your attention!

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