e^+ e^- “Higgs Factory”
Parameter Relations

U. Wienands, with thanks to Y. Cai & M. Sullivan
In collaboration with A. Chao, Y. Nosochkov, J. Byrd (LBNL), F. Zimmermann (CERN).

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BASICs Recap

- Luminosity Equation:

\[ Lum0 := \frac{3}{8} \frac{P0 \rho (byIP \ xix + bxIP \ xiy)}{m_e \pi r_e^2 \gamma^3 e \ bxIP \ byIP} \]

- Beamstrahlung lifetime:

\[ \tau_{ng} := \frac{1}{6} \frac{\sqrt{C} \sqrt{2} \sqrt{3} m_e (byIP \ xix + bxIP \ xiy) \sqrt{nb} \sqrt{u} e^u}{\sqrt{Lum00} \sqrt{bxIP} \sqrt{byIP} c^{3/2} \sqrt{xiy} \sqrt{xix} \alpha^2 \hbar \text{MeVs}} \]

- where \( u \) is:

\[ u_{0\ ng} := \frac{1}{9} \frac{\eta m_e^{4/3} e^{1/3} 3^{2/3} (byIP \ xix + bxIP \ xiy)^{2/3} \text{sigz} \sqrt{nb}}{Lum00^{1/6} \pi^{1/6} r_e^{1/3} bxIP^{1/6} byIP^{1/6} P0^{1/3} \rho^{1/3} \sqrt{C} \sqrt{c} \sqrt{xiy} \sqrt{xix} \hbar \text{MeVs}} \]
Observations

- For the “free” parameters, beamstrahlung lifetime is proportional to...
  \[ \sqrt{\text{nb}}, \sqrt{\beta_x}, e^{\alpha z}, e^{\eta} \]
- and inversely proportional to
  \[ \sqrt{\xi_x} \]

- A starting parameter set was given by F. Zimmermann & modif. by Cai et al.:
  - P=50 MW, C=26700 m, r=2625 m, \( \beta_x = 0.05 \) m, \( \beta_y = 0.001 \) m, xix=0.035, xiy=0.07, eta=0.03, sigz=0.0015, nb=50, gammar=2.35E5 (120 GeV).
  - Lum=1.32E34 * 0.76; emitx=4.3E-9 mr; emity=21E-12 mr,
<table>
<thead>
<tr>
<th>Parameter</th>
<th>LEP2</th>
<th>LEP3</th>
<th>TTEV</th>
<th>TLEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy [GeV]</td>
<td>104.5</td>
<td>120</td>
<td>120</td>
<td>175</td>
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<tr>
<td>Circumference [km]</td>
<td>26.7</td>
<td>26.7</td>
<td>18.9</td>
<td>82.4</td>
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<tr>
<td>Beam current [mA]</td>
<td>4</td>
<td>7.2</td>
<td>5.0</td>
<td>6.4</td>
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<tr>
<td>Number of bunches</td>
<td>4</td>
<td>50</td>
<td>20</td>
<td>466</td>
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<tr>
<td>Bunch population [$10^{10}$]</td>
<td>57.5</td>
<td>8.0</td>
<td>10.0</td>
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<tr>
<td>Horizontal emittance [nm]</td>
<td>48</td>
<td>4.3</td>
<td>4.4</td>
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<td>Vertical emittance [nm]</td>
<td>0.25</td>
<td>0.02</td>
<td>0.022</td>
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<td>$\beta_x^*$ [mm]</td>
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<td>50</td>
<td>50</td>
<td>50</td>
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<td>$\beta_y^*$ [mm]</td>
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<td>1</td>
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<tr>
<td>Hourglass factor</td>
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<td>0.76</td>
<td>0.72</td>
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<td>SR power [MW]</td>
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<td>50</td>
<td>50</td>
<td>50</td>
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<td>Bunch length [mm]</td>
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<td>1.5</td>
<td>1.86</td>
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<td>Momentum acceptance [%]</td>
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<td>3.0</td>
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<td>Beam-beam parameter</td>
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<td>0.07</td>
<td>0.09</td>
<td>0.06</td>
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<tr>
<td>Luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$]</td>
<td>0.0125</td>
<td>1.01</td>
<td>0.77</td>
<td>1.16</td>
</tr>
</tbody>
</table>
# Bunches Scaling

![Graph showing scaling of bunches at 120 GeV, with lines for η=1%, η=2%, and η=3%.]
Emittance vs # of Bunches

120 GeV

Emittance (mr)

# of Bunches
$\beta x$ Scaling

120 GeV

$\tau$ (s) vs. $\beta_x$ (m)

- $\eta = 3\%$
- $\eta = 2\%$
- $\eta = 1\%$
$\xi_x$ Scaling

120 GeV

$\eta=3\%$

$\eta=2\%$

$\eta=1\%$
 Aspect Ratio

• Aspect ratio scales as:

\[
\frac{\mathcal{E}_y}{\mathcal{E}_x} = \frac{0.204081632653061}{\beta_x} x^2
\]

• Want \(\xi_x\) small, \(\beta_x\) large => extreme aspect ratio

• Note: changing \(\xi_y\) or \(\beta_y\) changes luminosity; not the beamstrahlung lifetime
$\sigma_z\text{ Scaling}$
Arc Lattice for 120 GeV in LEP Tunnel (Y. Cai)

90°/60° FODO Lattice

$$\beta \leq 50 \text{m}$$
$$D \leq 0.14$$

Dynamic Aperture

$$\eta > 4\%$$

Emittance:

$$\varepsilon_x = F_c \frac{C_q \gamma^2}{J_x} \theta^3$$

where $\theta$ is the bending angle in a cell.

Design: $\varepsilon_x = 4.3 \text{ nm}$ and cell length is 28.28 m
Beam-beam parameter

Bunch luminosity

There is no surprise. It simply confirms calculations.
Conclusion (so far)

- Increasing the # of bunches allows to maintain a reasonable aspect ratio of the beam
  - emittances do get very small.
  - for 150 bunches (2% energy acceptance needed); cell length approaches 20 m.
- $\beta_x$ and $\xi_x$ control beamstrahlung lifetime with little effect on luminosity.
- $\beta_y$ and $\xi_y$ control luminosity with little effect on beamstrahlung lifetime
- $\sigma_z$ has significant effect on beam lifetime
- Varying $\beta_x$ and/or $\xi_x$ allows to increase beam lifetime at the expense of beam aspect ratio.
  - may not be a route to success
• Expts. would like 4 m L*
  - $\beta_y > 22000$ m in the first quadrupole, for 2 m length. $\beta_x$ would be 7000 m
  - this requires 110 mm pole radius (15$\sigma$ BSC); 7.3T tip field.
  - such a quad throws about 12 kW of synch rad. at $E_c=10s$ of MeV.
    this will require a beam pipe radius of $\geq 20$ mm to avoid intercept.

• If we move the 1$^{st}$ quad in to 1.5 m:
  - 4400 m $\beta_y$ for a 1.5 m long magnet; $\beta_x \approx 2200$ m
  - 50 mm pole radius and 9.6 T tip field; 17 kW of s.r. power

• In either case a 20-mm-radius pipe may be too small to avoid intercepting.
IR Doublet (M. Sullivan)
Summary

• Simple scaling suggests a larger number of bunches will be beneficial to mitigate beamstrahlung effects on beam lifetime
  - Can we fit 100...150 in without having two rings??
• The s.r. power limits beam current and thus forces low emittance
• Aspect ratios of 1:200 or higher are highly desirable.
• S.R. from the IR quadrupoles will need to be watched carefully.