Some Alignment and Instrumentation Issues for CESR as a Damping Ring Test Facility

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Primary Goals

- Electron cloud measurements
  - $e^{-}$ cloud buildup in wigglers
  - $e^{-}$ cloud amelioration in wigglers
  - Instability thresholds
- Ultra-low emittance
  - Study emittance diluting effect of the $e^{-}$ cloud on the $e^{+}$ beam
  - Detailed comparisons between electrons and positrons
  - Also look at fast-ion instability issues for electrons
  - Alignment issues and emittance tuning algorithms
  - Beam dynamics issues (including energy dependence 1.5 to 5.5 GeV operation)

Secondary Goals

- ILC DR hardware testing
## Low Emittance Lattice Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wiggler</td>
<td>12 @ 2.1T</td>
<td></td>
</tr>
<tr>
<td>Beam Energy</td>
<td>2.0 GeV</td>
<td>Will explore low $\varepsilon$ designs in the 1.5-2.5 GeV range</td>
</tr>
<tr>
<td>$\sigma_{E/E}$</td>
<td>$8.6 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon_x$</td>
<td>3.0 nm</td>
<td>Wiggler-dominated value. Further reduction possible with $\beta$ function (in wigglers) and wiggler field tuning and/or fewer active wigglers</td>
</tr>
<tr>
<td>$\tau_{x,y}$</td>
<td>47 ms</td>
<td></td>
</tr>
<tr>
<td>$Q_x$</td>
<td>14.53</td>
<td></td>
</tr>
<tr>
<td>$Q_y$</td>
<td>9.59</td>
<td></td>
</tr>
<tr>
<td>$Q_z$</td>
<td>0.1</td>
<td>Requires higher RF voltage than we typically use</td>
</tr>
<tr>
<td>$\sigma_z$</td>
<td>6.9 mm</td>
<td></td>
</tr>
<tr>
<td>$\alpha_c$</td>
<td>$7.1 \times 10^{-3}$</td>
<td></td>
</tr>
</tbody>
</table>
Further Parameter Information

- **Energy:** 1.5 to 5.5 GeV

- **Bunch Spacing:**
  - Presently use 14 ns
  - Can use alternating 6ns, 8ns scheme with activation of existing parallel feedback systems
  - Intend to explore 2ns and/or 4ns option if needed for ILC DR studies

- **Touschek Lifetime**
  - In ultra-low emittance operation expect lifetimes of a few to several minutes
Low Emittance Lattice Functions

Wiggler Insert Regions

Note E-W Asymmetry
Vertical Emittance Estimates

- Beam-Beam Scan with low current 1-on-1 Collisions in 1.88 GeV HEP Conditions (with pretzel)
  - Differential vertical displacement controlled by phase advance between vertical separators in North
  - Fast Luminosity Monitor provides measurement of overlap
    Peak $\Rightarrow 8.4 \times 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$
- Measure $\sigma_y = 2.66 \mu$m
  (with $\beta_y^* = 11.2$ mm and $\varepsilon_h = 136$ nm)
  $\Rightarrow$ $\varepsilon_y = 0.63$ nm
  $\Rightarrow$ $\varepsilon_y / \varepsilon_x \sim 0.005$

Vertical Emittance Estimates from Coupling Contribution:
With $\varepsilon_x = 3.0$ nm $\Rightarrow \varepsilon_y \sim 15$ pm
With $\varepsilon_x = 2.0$ nm and $\varepsilon_y / \varepsilon_x \sim 0.0025$ $\Rightarrow \varepsilon_y \sim 5$ pm
Likely improvement without CLEO solenoid and pretzel!
South IR Extraction Line Option

~40 m available for possible extraction line and diagnostics

~18 m South insertion region for diagnostics and test devices
Emittance Measurement

• High resolution transverse size measurements
  – Laserwire
  – Also working on x-ray beam profile monitor

• Desired laserwire capabilities
  – Bunch-by-bunch capability
    • Possibly 2 ns to 14 ns bunch spacing
  – Fast measurement
    • Touschek lifetimes are short (minutes)
  – Resolution suitable for $\sigma_y \sim 10 \, \mu m$
• Expected beam sizes
  – Vertical assumes perfect dispersion correction
  – Values at center of South IR:
    • $\sigma_y \sim 11.6 \, \mu m$
    • $\sigma_x \sim 79 \, \mu m$
    • Compton scattering from the positron beam can be viewed through the present CESR-c luminosity monitor window
Luminosity Monitor Window

- Aluminum $\gamma$ Window
  - Faces into South IR
  - 1 in thick ($0.26 \times_0$)
  - 16.1 m from center of CesrTF insertion region
  - Looks at $e^+$ beam
  - Aperture (for 16.1 m):
    - $\pm 1.5$ mrad vertical
    - -5 to +2 mrad horizontal
      (negative is to inside of ring)
Radiative Bhabha $\gamma$ Detector

$\Rightarrow$ Compton $\gamma$ Detector?

- **Segmented Scintillator Detector**
  - Offers possibility of measuring the Compton photon angular distribution
  - Fast R7400 PMTs offer bunch-by-bunch response
  - Well-understood operation

![Diagram of Segmented Scintillator Detector]

**Vertical**
- $\sigma = 0.96$
- $\mu = 0.06$
- Rate = 28595

**Horizontal**
- $\sigma = 1.01$
- $\mu = 6.00$
- Rate = 6353
Some Laserwire Discussion Points

• Beam sizes are comparable to ATF
• ATF scanning times seem somewhat long given the short beam lifetime and questions of stability
  – 6 minutes for y scan
  – 15 minutes for x scan
  – Can we consider a system with sufficient power on the beam to complete a scan with $\Delta t < \tau_{\text{Touschek}}$?
• CW laser system with fast detector versus pulsed laser system
  – What are pros and cons?
  – What are the costs?
CesrTF Alignment Sensitivity Estimates

- Analytical estimates using CesrTF parameters
- Utilize A. Wolski’s procedures in his DR evaluation note
- Make rough sensitivity estimates for comparison purposes
- Some sources of vertical emittance
  - Vertical steering $\Rightarrow$ vertical dispersion
  - Betatron coupling from horizontal to vertical
  - Horizontal dispersion coupled into vertical
- Closed orbit errors from quadrupole misalignments
  - Sensitivity: RMS quad misalignment to give a vertical orbit distortion equal to the beamsize for the target emittance (5 pm in our case)

$$\frac{\langle y^2 \rangle}{\langle \sigma_y^2 \rangle} \approx \frac{\langle \Delta Y_q^2 \rangle}{8 \varepsilon_y \sin^2 \pi \nu_y} \sum_{1O}$$

$$\sum_{1O} = \sum_{\text{quads}} \beta_y (k_1 L)^2$$
Alignment Sensitivity Estimates (cont’d)

• Coupling and dispersion from quadrupole rotations
  – Sensitivity: RMS quadrupole rotation to generate the target vertical emittance

\[
\frac{\varepsilon_y}{\langle \Delta \Theta_q^2 \rangle} \approx \frac{J_x}{J_y} \frac{1 - \cos 2\pi \nu_x \cos 2\pi \nu_y}{(\cos 2\pi \nu_x - \cos 2\pi \nu_y)^2} \varepsilon_x \Sigma_{1C} + \frac{J_x}{J_x} \frac{\sigma^2_\delta}{\sin^2 \pi \nu_y} \Sigma_{1D}
\]

\[
\Sigma_{1C} = \sum_{\text{quads}} \beta_x \beta_y (k_1 L)^2 \quad \Sigma_{1D} = \sum_{\text{quads}} \beta_y \eta_x (k_1 L)^2
\]

• Coupling and dispersion from sextupole misalignments
  – Sensitivity: RMS sextupole misalignment to generate the target vertical emittance

\[
\frac{\varepsilon_y}{\langle \Delta Y_s^2 \rangle} \approx \frac{J_x}{J_y} \frac{1 - \cos 2\pi \nu_x \cos 2\pi \nu_y}{4(\cos 2\pi \nu_x - \cos 2\pi \nu_y)^2} \varepsilon_x \Sigma_{2C} + \frac{J_x}{J_x} \frac{\sigma^2_\delta}{4 \sin^2 \pi \nu_y} \Sigma_{2D}
\]

\[
\Sigma_{2C} = \sum_{\text{sexts}} \beta_y \beta_x (k_2 L)^2 \quad \Sigma_{2D} = \sum_{\text{sexts}} \beta_y \eta_x (k_2 L)^2
\]
### Lattice Comparisons

<table>
<thead>
<tr>
<th></th>
<th>CesrTF</th>
<th>ATF</th>
<th>TESLA</th>
<th>ILC 6 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference (m)</td>
<td>768</td>
<td>139</td>
<td>17000</td>
<td>6114</td>
</tr>
<tr>
<td>Energy (GeV)</td>
<td>2.0</td>
<td>1.28</td>
<td>5.0</td>
<td>5.066</td>
</tr>
<tr>
<td>Horizontal Emittance (nm)</td>
<td>2.5</td>
<td>1.0</td>
<td>5.1</td>
<td>5.5</td>
</tr>
<tr>
<td>Vertical Emittance (pm)</td>
<td>5.0 (target)</td>
<td>5.0</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Energy Spread (x10^{-3})</td>
<td>0.86</td>
<td>0.55</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>J_x</td>
<td>1.0</td>
<td>1.6</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>J_y</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Q_x</td>
<td>14.53</td>
<td>15.141</td>
<td>76.310</td>
<td>56.584</td>
</tr>
<tr>
<td>Q_y</td>
<td>9.59</td>
<td>8.759</td>
<td>41.180</td>
<td>41.618</td>
</tr>
</tbody>
</table>
Lattice Sensitivities

<table>
<thead>
<tr>
<th></th>
<th>CesrTF</th>
<th>ATF</th>
<th>TESLA</th>
<th>ILC 6km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrupole Alignment (nm)</td>
<td>756</td>
<td>241</td>
<td>80.7</td>
<td>198</td>
</tr>
<tr>
<td>Quadrupole Rotation (µrad)</td>
<td>245</td>
<td>825</td>
<td>40.5</td>
<td>58.3</td>
</tr>
<tr>
<td>Sextupole Alignment (µm)</td>
<td>227</td>
<td>45.6</td>
<td>11.3</td>
<td>40.4</td>
</tr>
</tbody>
</table>

- ATF / TESLA / ILC from A. Wolski
- Note: these are sensitivity estimates and *not* actual tolerances
- Alignment sensitivities tend to be significantly less for CesrTF!
- Nominal CESR alignment *resolutions* and *tolerances*
  - Quad Position: ~100 µm ~100-200 µm
  - Quad Rotation: ~100 µrad ~100 µrad
  - Sextupole Position: ~100 µm ~200-400 µm
- Local errors may be (are in a number of cases) larger
Presently at an early stage of evaluation

- As expected from sensitivity estimates, most critical item is quadrupole alignment errors
- Need to pursue improvements in both the starting point alignment and in correction methods
Machine Corrections

- Starting the study of machine corrections
- Plots at right show impact of closed orbit correction
  - Running average and standard deviation are plotted for a series of 200 seeds
  - Thus right edge gives expected value
- Still testing/evaluating the full suite of corrections
- Then will explore emittance tuning schemes
• Quadrupole alignment is a critical issue
  – Need a ring-wide improvement
    • Has major implications for the scope of the alignment upgrade
  – In order to have a starting point consistent with 5-10 pm vertical emittance goal, should aim for better than 100 µm initial alignment capability
  – We still need to review the impact of vibration/ground motion issues and magnet support stability (also magnet stability)
• Question: How much will upgrading the CesrTF alignment and survey capabilities benefit the alignment and survey R&D needed for the ILC damping rings?