Recent Results From CesrTA Intrabeam Scattering Investigations

Speaker: Michael Ehrlichman

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Overview

- Description of CESR and CesrTA program
- Intrabeam scattering (IBS) theory and our model
- Results of IBS experiments
  - Size vs. current at various energies and vertical beam sizes
  - Size vs. RF voltage
- Vertical data with puzzling current dependence
- Directions and conclusion
CesrTA Program

- CesrTA is a reconfiguration of CESR dedicated to studying the physics and technology of stored e+/e- beams
  - 768 m
  - Twelve 1.9 T damping wigglers
  - 1.8 to 5.3 GeV
  - ~3 nm·rad by ~10 pm·rad
  - Independently powered quadrupoles
  - Turn-by-turn, bunch-by-bunch instrumentation

- Multi-bunch studies
  - Electron Cloud
  - Fast Ion

- Single-Bunch Effects
  - Intrabeam Scattering (IBS)
  - Coherent Tune Shift
  - Incoherent Tune Shift
  - Optics Correction
• Machine Setup
  – 6 or 12 wigglers powered
    • 100 ms or 50 ms damping time (500 ms without wigglers)
  – 6.3 MV RF provided by four 500 MHz superconducting cavities
    • Adjustable down to ~1 MV
    • ~10 mm bunch lengths
  – Single-bunch charges from \( \sim 1 \times 10^9 \) up to \( \sim 1 \times 10^{11} \) particles
    • Lifetime dominated by Touschek scattering

• Beam Physics
  – Intrabeam Scattering
    • \( \varepsilon_x \) increase of \( \sim 300\% \) (~1 m horizontal dispersion)
    • \( \varepsilon_y \) increase of < 20\% (very low vertical dispersion and coupling)
  – Potential Well Distortion
  – Coherent Tune Shift -0.5 kHz/mA
    • Resonance lines up To 6\(^{th}\) order observed
  – Vertical Behavior is Puzzling
    • Anomalous blow up at high current
Multiple small-angle scattering events among the particles that compose a bunch couples single-particle emittances, and in the presence of dispersion can increase the total emittance of the beam.

Results in a current-dependent emittance
- A lower bound on beam size for a desired current, or an upper bound on current for a desired size

Limits:
- Luminosity lifetime in hadron machines
- Per-bunch luminosity in a linear collider
- Peak brilliance in a light source

IBS in e⁺/e⁻ accelerators, in contrast to hadron machines
- Fast rise time due to high density of short bunches
  - Increased equilibrium size
- Gaussian Core + Lightly Populated Tails (theory modified by tail-cut)
- Growth rates have γ⁻⁴ dependence
• Formalism by Kubo and Oide
  – Generalization of Bjorken & Mtingwa’s formalism
  – Uses eigen-decomposition of beam $\Sigma$-matrix, rather than Twiss parameters

$\Sigma = \begin{pmatrix}
\langle xx \rangle & \langle xy \rangle & \langle xz \rangle & \langle xp_x \rangle & \langle xp_y \rangle & \langle xp_z \rangle \\
\langle yz \rangle & \langle yy \rangle & \langle yz \rangle & \langle yp_x \rangle & \langle yp_y \rangle & \langle yp_z \rangle \\
\langle zx \rangle & \langle zy \rangle & \langle zz \rangle & \langle zp_x \rangle & \langle zp_y \rangle & \langle zp_z \rangle \\
\langle px \rangle & \langle px y \rangle & \langle px z \rangle & \langle p x p_x \rangle & \langle p x p_y \rangle & \langle p x p_z \rangle \\
\langle py \rangle & \langle py y \rangle & \langle py z \rangle & \langle p y p_x \rangle & \langle p y p_y \rangle & \langle p y p_z \rangle \\
\langle pz \rangle & \langle pz y \rangle & \langle pz z \rangle & \langle p z p_x \rangle & \langle p z p_y \rangle & \langle p z p_z \rangle 
\end{pmatrix}$

– Natural handling of coupling
  • Normal mode emittances
  • No “coupling” parameters

– Incorporates tail-cut
  • Central Limit Theorem
  • Excludes rare, large-angle scattering events ($< 1$ event/particle/$\tau_{\text{damp}}$)
Simulation Overview

• Cornell’s BMAD Simulation Suite (normal modes env.)
• Element-by-element model of CesrTA lattice including multipole terms and field-map wiggler models
• IBS blow up calculated by Kubo & Oide formalism
• Potential well distortion (PWD) calculated by Billing’s effective impedance formalism
  – Current-dependent effective RF voltage
• Beam sizes obtained from beam Σ-matrix
•Simulation has 3 significant free parameters
  1. Zero-current horizontal emittance
  2. Zero-current vertical emittance
  3. Effective longitudinal inductive impedance
• Working point is selected
  – Vertical coherent tune changes by ~4 kHz from low current to high current
• Apply optics corrections
  – Phase and Orbit
  – Dispersion and Coupling
• If desired, increase $\varepsilon_{y0}$ using closed coupling and dispersion bumps
• Charge single bunch to $>10^{11}$ particles
• Cut injection and take beam size measurements as the beam decays
  – Vertical by x-ray beam size monitor
  – Horizontal by visible light beam size monitor
  – Longitudinal by streak camera
• Decay due to Touschek lifetime
  – Experiment takes about 30 minutes
2.1 GeV Results

<table>
<thead>
<tr>
<th>Input Parameters</th>
<th>Result at high current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run ID</td>
<td>ε_y_0 (pm)</td>
</tr>
<tr>
<td>Low ε_y_0</td>
<td>12.7 - 17.9</td>
</tr>
<tr>
<td>Med ε_y_0</td>
<td>57.1 - 67.2</td>
</tr>
<tr>
<td>High ε_y_0</td>
<td>200.8 - 219.2</td>
</tr>
</tbody>
</table>

*7.5 \times 10^{10} part. \approx 12 \text{ nC} \approx 5 \text{ mA}
2.3 GeV Results

- IBS rates have $\gamma^{-4}$ dependence

<table>
<thead>
<tr>
<th>Run ID</th>
<th>$\varepsilon_{y0}$ (pm)</th>
<th>$\varepsilon_{x0}$ (nm)</th>
<th>$\varepsilon_x$ ($7.5 \times 10^{10}$) (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low $\varepsilon_{y0}$</td>
<td>7.01-11.2</td>
<td>5.7</td>
<td>9.41</td>
</tr>
<tr>
<td>High $\varepsilon_{y0}$</td>
<td>62.0-72.6</td>
<td>5.6</td>
<td>7.06</td>
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2.5 GeV Results

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<th>(\epsilon_{x0}) (nm)</th>
<th>(\epsilon_x (7.5 \times 10^{10})) (nm)</th>
</tr>
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<td>9.9 – 14.6</td>
<td>4.4</td>
<td>6.83</td>
</tr>
<tr>
<td>High (\epsilon_{y0})</td>
<td>47.6 – 56.9</td>
<td>4.5</td>
<td>5.62</td>
</tr>
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</table>
• ~1 m RMS horizontal dispersion leads to significant horizontal blow up
• IBS rise times have $\gamma^{-4}$ dependence

<table>
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<tr>
<th>Energy (GeV)</th>
<th>$\epsilon_y$ (pm)</th>
<th>$\epsilon_x$ (nm)</th>
<th>$\epsilon_x \times 10^{10}$ parts. (nm)</th>
</tr>
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*Note: 2.3 GeV lattice uses distinct horizontal optics

• 253% Blow Up
• 165% Blow Up
• 151% Blow Up
- Measurements at 0.5 and 1.0 mA
  - IBS seen in larger sizes at 1.0 mA
- Three Distinct Lattices (all ideal)
  1. Original CesrTA Lattice
  2. Lattice with $x$-$z$ tilt minimized
  3. Lattice with half the damping and no tilt
- See TUPME065 from this conference for more details on $x$-$z$ coupling studies
• For a given vertical emittance, current, and wiggler field what is the energy to minimize horizontal emittance?
  • $\varepsilon_{x0}$ goes as $\gamma^2$
  • IBS rates go as $\gamma^{-4}$
• Not consistent with IBS model
  – IBS size vs. current plot would be “log like”
• Species-independent
• Sensitive to betatron and synchrotron tunes
• Not sensitive to chromaticity
• FFT of vertical centroid and size does not show a strong signal above noise
• Energy spread measured to be constant, no threshold behavior seen in energy spread vs. current.
• Seen even in large beams
• Coupling (Cbar12) vs. current measured to be constant
• Coherent tune shift plays a part, but not the whole story
• Incoherent tune shift is a suspect, cannot be whole story
  – direct space charge
• Beam size vs. current with different damping rates.

• Measurements on beams with global coupling.
  – Significant vertical IBS growth rate.

• Measurements at 1.8 GeV.
  – Requires instrumentation development.

• Understanding vertical behavior at high current.
  – Model higher current behavior.

• Lower emittances.
• IBS data has been gathered over a range of energies, particle densities, and RF voltages.
• Model developed that gives good agreement with horizontal and longitudinal data.
  – IBS and PWD effects
• Model for high-current vertical data yet to be found.
  – Stop by TUPME065 if you have any ideas
• Directions: global coupling, various damping rates, 1.8 GeV, and lower vertical emittance