Session 3 summary: Particle Scattering

T. Demma (LAL), E. Karantzoulis (Elettra) and Y. Papaphilippou (CERN)
<table>
<thead>
<tr>
<th>Time</th>
<th>Session &quot;Particle Scattering&quot;</th>
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<tbody>
<tr>
<td>14:30 - 15:05</td>
<td>Review of Particle Scattering&lt;br&gt;Theo Demma (LAL)</td>
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<tr>
<td>15:05 - 15:25</td>
<td>Design of IBS dominated low emittance ring,&lt;br&gt;Fanouria Antoniou (CERN)</td>
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<tr>
<td>15:25 - 15:45</td>
<td>Intrabeam scattering studies at CESR-TA,&lt;br&gt;Suntao Wang (CESRTA)</td>
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The Intrabeam scattering effect

- Theoretical models calculate the IBS growth rates:
  - Complicated integrals averaged around the rings
    - Depend on optics and beam properties

- Classical models of Piwinski (P) and Bjorken-Mtingwa (BM)
  - Benchmarked with measurements for hadron beams but not so well for lepton beams

- High energy approximations Bane and CIMP
  - Integrals with analytic solutions

- Tracking codes SIRE and CMAD-IBStrack
  - Based on the classical approach

- Several theoretical models and their approximations developed over the years → three main drawbacks:
  - Gaussian beams assumed
  - Betatron coupling not trivial to be included
  - Impact on damping process? H. Bartosik for F. Antoniou
Comparison between theoretical models

- Comparison between the theoretical models for the SLS lattice
- All results normalized to the ones from BM
- Good agreement at weak IBS regimes
- Divergence grows as the IBS effect grows
  - Benchmarking of theoretical models and MC codes with measurements is essential
Energy choice for IBS reduction

- Broad minimum of the emittances around 2.5 GeV (left) while the IBS effect becomes weaker with energy (right).
- Higher energies are interesting for IBS but not for the emittance requirements.
- **Energy increase** (2.424 → 2.86 GeV) → **reduction of the IBS effect** by a factor of 2 (3 → 1.5).
- The scaling of the output emittance with energy reflects the domination of damping time or IBS growth time in each energy regime.

H. Bartosik for F. Antoniou
Scanning on the detuning factor (here DF=1..25), optimal phase advances can be found where chromaticity, IBS growth rates and space charge detuning are minimized.

Other interesting regions according to the requirements of the design also exist.
Algorithm for Macroparticle Simulation of IBS

- The lattice is read from a MAD (X or 8) files containing the Twiss functions and R transport matrices.
- 6-dim Coordinates of particles are generated (Gaussian distribution at S).
- The scattering routine is called:
  - Particles of the beam are grouped in cells.
  - Particles inside a cell are coupled
  - Momentum of particles is changed because of scattering.
  - Invariants of particles and corresponding growth rate are recalculated.
- Particles are tracked at next element a 6-dim R matrix.
- Radiation damping and excitation effects are evaluated at each turn.

T. Demma
IBS evaluation in SuperB

SuperB V12 LER lattice (~1800 IPs)
\[ \sigma_z = 5.0 \times 10^{-3} \text{ m} \]
\[ \delta p = 6.3 \times 10^{-4} \]
\[ \epsilon_x = 1.8 \times 10^{-9} \text{ m} \]
\[ \epsilon_y = 0.25 / 100 \epsilon_x \]
\[ ppb = 5.7 \times 10^{12} \]

MacroParticleNumber = 3 x 10^5
Grid size = 10\( \sigma_y \times 10 \sigma_x \)
# cells = 64 x 64
# slices = 64
# processors for this run = 64

Theoretical models compared with simulations for Super-B, using IBS-Track and C-MAD codes: one turn evolution of emittance with Intra-beam scattering.
Emittance Evolution in SuperB LER

Evolution of horizontal, vertical and longitudinal emittances under the influence of IBS as obtained by the tracking code for different values of the bunch population: $6 \times 10^9$ (blue), $60 \times 10^9$ (red) and $100 \times 10^9$ (green). Horizontal lines represent the steady state values predicted by Piwinski (full) and Bane (dashed) models for the considered bunch populations.
SIRE: IBS Distribution study

\[ p_k(\xi_k) = \frac{1}{\sqrt{2\pi\sigma_k}} e^{-\frac{\xi_k^2}{2\sigma_k^2}} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Confidence</th>
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<tbody>
<tr>
<td>(\Delta p/p)</td>
<td>3048.7</td>
<td>&lt;1e-15</td>
</tr>
<tr>
<td>X</td>
<td>1441.7</td>
<td>&lt;1e-15</td>
</tr>
<tr>
<td>Y</td>
<td>1466.9</td>
<td>&lt;1e-15</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Eq. (e_x) (m rad)</td>
<td>2.001e-10</td>
</tr>
<tr>
<td>Eq. (e_y) (m rad)</td>
<td>2.064e-12</td>
</tr>
<tr>
<td>Eq. (\sigma_0)</td>
<td>1.992e-3</td>
</tr>
<tr>
<td>Eq. (\sigma_2)</td>
<td>1.687e-3</td>
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There are several methods for calculating IBS growth rates.
As part of CesrTA, we have implemented and compared many of them.
Over a wide range of parameters, we find all give very similar predictions.
We treat the Coulomb Log the same for each method we have implemented.
  - Piwinski's formulas modified to take impact parameters.

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Combined Results vs. Energy

Low $\epsilon_y$ Conditions

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>Blowup Percentage</th>
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<tbody>
<tr>
<td>2.1</td>
<td>101% $\epsilon_x$</td>
</tr>
<tr>
<td>2.3</td>
<td>82% $\epsilon_x$</td>
</tr>
<tr>
<td>2.5</td>
<td>43% $\epsilon_x$</td>
</tr>
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</table>

~ 50 um Vertical Beam Size Conditions

<table>
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<tr>
<th>Energy (GeV)</th>
<th>Blowup Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>81% $\epsilon_x$</td>
</tr>
<tr>
<td>2.3</td>
<td>33% $\epsilon_x$</td>
</tr>
<tr>
<td>2.5</td>
<td>27% $\epsilon_x$</td>
</tr>
</tbody>
</table>
The tail-cut is a modification to IBS theory that excludes from the rise time those scattering events that occur less frequently than once per particle per damping period.

\[ \frac{1}{\tau_{\text{IBS}}} \propto \log \frac{b_{\text{max}}}{b_{\text{min}}} \]

- Weak application of the central-limit theorem.
- Significant in machines with strong damping.
- Without the tail-cut, IBS theory can significantly over-estimate the equilibrium beam size.

*M.P. Ehrlichman et al. PRSTAB 16 (2013) 104401*
Anomalous Vertical Blow-Up

- 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

S. Wang
Open Questions

- Beam profile modification due to scattering
  - Theory for non-Gaussian beams (B. Nash, PhD thesis)
  - Effect in core particles is “known” (Gaussian core?)
  - Scattering in tails is less evident (Touschek-like effect dominant?)
  - Influence of lattice non-linearities and other collective effects (space-charge, impedance,...)
- Agreement of IBS theories
  - Only a matter of including tail cuts?
  - Influence of optics (especially in high-energy approximations)
- IBS theory including vertical coupling
  - Kubo and Oide formalism, other ideas?
- Impact on damping process
- Effect of Scattering in polarisation and vice versa
Open Questions

• Full employment of particle scattering codes for shedding light in previous questions
  – Benchmarking with measurements

• Disentangling IBS with other collective effects (especially in measurements)
  – Accurate knowledge of machine model and its current dependence (optics distortion, coupling)

• Instrumentation for resolving tails in beam profiles

• Measuring energy spread
  – Especially in absence of good model on longitudinal profile evolution
THANK YOU!!!