IBS and cooling in RHIC, HE-LHC active emittance control

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1\textsuperscript{st} vertical stochastic cooling in RHIC

14 Jan 2010

cooling starts

15 October 2010
High-Energy LHC, Malta
1. LHC active emittance control
   - HE LHC damping times
   - Maximization of integrated luminosity

1. IBS and cooling in RHIC
   - Measurements and simulations for IBS
   - Au$^{79+}$ beam dynamics with stochastic cooling
# High Energy LHC parameters (from F. Zimmermann)

[R. Assmann et al, “First thoughts on a higher energy LHC”, CERN-ATS-2010-177]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal LHC</th>
<th>High energy HE-LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam energy [TeV]</td>
<td>7</td>
<td>16.5</td>
</tr>
<tr>
<td>peak luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$]</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>luminosity lifetime [h]</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>events per crossing</td>
<td>19</td>
<td>76</td>
</tr>
<tr>
<td># bunches / beam</td>
<td>2808</td>
<td>1404</td>
</tr>
<tr>
<td>bunch population [$10^{11}$]</td>
<td>1.15</td>
<td>1.3</td>
</tr>
<tr>
<td>Luminosity leveling</td>
<td>no</td>
<td>yes: $e_{x,y}$</td>
</tr>
<tr>
<td>initial transverse normalized emittance [mm]</td>
<td>3.75</td>
<td>3.75 (x) 1.84 (y) 2.59</td>
</tr>
<tr>
<td>number of IPs contributing to tune shift</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>maximum total beam-beam tune shift</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>IP beta function [m]</td>
<td>0.55</td>
<td>1.0 (x), 0.43 (y) 0.6</td>
</tr>
<tr>
<td>full crossing angle [mrad]</td>
<td>285 (9.5 $s_{x,y}$)</td>
<td>~180 (12 $s_{x0}$)</td>
</tr>
<tr>
<td>longitudinal SR emittance damping time [h]</td>
<td>12.9</td>
<td>0.98</td>
</tr>
<tr>
<td>horizontal SR emittance damping time [h]</td>
<td>25.8</td>
<td>1.97</td>
</tr>
<tr>
<td>initial long. IBS emittance rise time [h]</td>
<td>61</td>
<td>64</td>
</tr>
<tr>
<td>initial hor. IBS emittance rise time [h]</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>initial ver. IBS emittance rise time [h], (k=0.2)</td>
<td>~400</td>
<td>~400</td>
</tr>
</tbody>
</table>
Means of active emittance control during stores

Assume that initial beam parameters have been adjusted to acceptable values.

1. Adjust strength of active cooling (currently not an option in LHC)
   change of gain, power, average “system on” time
   changes equilibrium emittance

2. Increase transverse emittance
   random dipole kicks $\theta$ [M. Syphers, Handbook]
   \[
   \frac{d\varepsilon}{dt} = \frac{f_0}{2} (\beta \gamma) \beta_0 \theta_{rms}^2
   \]

3. Use x-y coupling to equalize transverse emittances
   when operating at beam-beam limit, maintains same bb parameter in both planes
   works well in RHIC without and with active cooling
   $\varepsilon_x = \varepsilon_y \Rightarrow \xi_x = \xi_y$

4. Increase bunch length to reduce peak currents
   random phase kicks $\delta \varphi$ [M. Syphers, Handbook]
   \[
   \frac{d\varepsilon_s}{dt} = \frac{f_0}{2} \frac{E_0}{\omega_{rf}} \sqrt{-\frac{\beta eV_{rf} \cos \varphi_s}{2 \pi h \eta E_0}} (\delta \varphi_{rms})^2
   \]
HE LHC emittances without and with heating

Heating condition: $\xi = 0.01$ (constant)
Constant crossing angle $\theta \sim 180$ mrad.

$\varepsilon_x$, $\varepsilon_y$ and $\varepsilon_s$ vs time for flat and round ($\beta^* = 0.6m$) beams

Courtesy of O. Dominiguez, F. Zimmermann, in CERN-ATS-2010-177.
HE LHC emittance without and with heating

Heating determined by: $\xi = 0.01$ (constant)

Same luminosity with round and flat beams.

Courtesy of O. Dominiguez, F. Zimmermann, in CERN-ATS-2010-177.
HE LHC luminosity with round beams

\[ L = \frac{f_c \gamma N \xi}{r_0 \beta^*} F \left( \frac{\sigma_s}{\beta^*}, \theta \right) \]

- Larger beam-beam parameter \( \xi \) allows for larger luminosity, or smaller \( N \) (and stored energy) for same luminosity
- Assumed beam-beam parameter (\( \xi_{\text{tot}} = 0.01 \)) is conservative, smaller than SppS, Tevatron, RHIC
- May be increased beyond 0.01 (and even further with electron lenses)

\( \xi \) evolution without heating, max = 0.02, (max = 0.035 for flat beams, \( \int L dt + 5 \degree \rightarrow \int L dt + 20 \% \))

Courtesy of O. Domininguez, F. Zimmermann in CERN-ATS-2010-177.
2 Tevatron electron lenses in operation (not operationally used for HOBBC).

2 RHIC electron lenses for head-on BB compensation under construction.
Relativistic Heavy Ion Collider
1 of 2 ion colliders, only polarized p-p collider

2 superconducting 3.8 km rings
2 large experiments
100 GeV/nucleon Au
250 GeV polarized protons

Performance defined by
1. Luminosity $L$
2. Proton polarization $P$
3. Versatility

Au-Au, d-Au, Cu-Cu, polarized p-p (so far)
12 different energies (so far)
Intrabeam scattering in RHIC

IBS leads to debunching and transverse emittance growth of heavy ion beams.

Comparison of measured and simulated $\varepsilon(t)$ and $\sigma_s(t)$ [A. Fedotov et al., proceedings HB2008.]

Beam: $\text{Au}^{79+}, 100\text{ GeV/nucleon, 95 deg/cell, } N_b=0.92\times10^9$

Simulation: BETACOOL
RHIC – 3D stochastic cooling for heavy ions

5-9 GHz, cooling times ~1 h

M. Brennan, M. Blaskiewicz, F. Severino, Phys. Rev. Lett. 100 174803 (2008); PRST-AB, PAC, EPAC
RHIC – bunched beam stochastic cooling for heavy ions

- Longitudinal cooling since 2007
- First transverse (vertical) cooling in 2010

- So far stochastic cooling increased average store luminosity by factor 2
- Expect another factor 2 with full 3D cooling

Issues being addressed:
- Vacuum leaks at feedthroughs
- Mechanical motion of long. kickers
- Cross-talk between Blue and Yellow vertical system (addressed by 100 MHz shift in Blue)
- Construction, installation, and commissioning of horizontal systems

M. Brennan
M. Blaskiewicz
K. Mernick et al.

14 Jan 2010
RHIC Au beams with vertical stochastic cooling

Emittance measurement with Ionization Profile Monitor (IPM).

[M. Blaskiewicz, J.M. Brennan, and K. Mernick, PRL 105, 094801 (2010).]
Cooling only one beam

Because of Blue-Yellow cross talk of vertical cooling systems in 2010, only one beam could be cooled at the time. Loss rate of other beam increased as a result (from unmatched beam sizes at the IP).

Initial beam-beam parameter
\[ \xi \sim 0.002/IP \text{ (2 IPs)} \]

HE LHC: Adjust heating to maintain same emittances in both beams.
(Known effect from SppS, HERA, RHIC.)
RHIC store evolution with 3D stochastic cooling

Simulation by M. Blaskiewicz

Longitudinal profiles with \( h_1 = 360 \, (360 \, \text{kV}) \) and \( h_2 = 7 \times 360 \, (4 \, \text{MV}) \)

Simulations have matched observable cases so far.

Au beam with
\( N_b = 0.5 \times 10^9 \)
\( N_b = 1.0 \times 10^9 \)
\( N_b = 1.5 \times 10^9 \)
RHIC store evolution with 3D stochastic cooling

Simulation by M. Blaskiewicz

Au beam with $N_b = 0.5 \times 10^9$
$N_b = 1.0 \times 10^9$
$N_b = 1.5 \times 10^9$

Expect ~3x larger $\Delta Q$ with 56 MHz SRF (under construction)

Then closer to LHC.

Wolfram Fischer
Summary

LHC

• LHC damping times of 1h (long.) and 2h (transv.) much shorter than IBS growth times (>50h)

• Heating required to maintain constant beam-beam parameter $\xi \sim 0.01$ (increase in $\xi$ allows for more luminosity or a reduction in intensity)

RHIC

• Observations and simulations of IBS induced emittance growth generally agree well, evolution of with stochastic cooling predictable.

• With cooled Au beams not yet operating at beam-beam limit (need new 56 MHz SRF to reduce debunching, $\geq 2013$)

• Even at relatively small beam-beam parameters, equal cooling in both beams (= equal heating in HE LHC) is necessary to maintain good beam lifetimes