Beam-beam Effects with high pile-up test in the LHC

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on the behalf of the beam-beam team

ICFA Mini-Workshop on Beam-Beam Effects in Hadron Colliders (BB2013)
OUTLINE

• Overview
• LHC commissioning > exploring the beam-beam parameters
  • High Pile-up tests at the LHC
  • SPS Q20, new scenarios for brightness
• Summary
Beam–beam limit at the LHC

Tolerance

Since the beginning it was unclear whether the beam-beam limitation for the LHC will come from Head On or Long Range Collisions

Identifying the limit is crucial for the luminosity optimization scenario:

- Increase Bunch Intensity $N$
- Increase Bunch emittance $\varepsilon$
- The ratio $\Delta Q$ is constant
  - Luminosity increase due to $N \uparrow$, $\beta^* \downarrow$
  - $\xi$ is unperturbed

$\Delta Q \propto \frac{N}{\varepsilon}$

Change in energy ($\gamma$)
- Implication of crossing
- $\Delta Q \propto \frac{N \cdot \varepsilon}{\alpha^2 \gamma}$

See W. Herr Talk #31: Long range beam-beam effects and experience in the LHC

Preferred scenario:
- Moderate $\beta^*$ along with high bunch number
From the Design Report of the LHC, the nominal HO tune shift:
\[ \xi = 0.0037 \]

**Caution:**

The nominal HO tune shift was derived from:
- SPS experience
- Possible contribution from lattice non linearity
- Significant LR contributions

in order to:
- Achieve the target of \(10^{34}\) luminosity
- With a coherent set of «safe» parameters
  
  \(N: 1.15 \times 10^{11} \text{ ppb}, \varepsilon: 3.75 \mu m\)

**Very Conservative, not an upper limit!!!**
Fill 1068-1069 (May 2010)

GOALS:
- check the feasibility of colliding high intensity bunches (HO)
- test whether such bunches can collide with static offset in IP2 (Low PileUP Test)
  - $E = 450$ GeV
  - $N \sim 1E11$ ppb

Setup:
- $\varepsilon \sim 3$ $\mu$m (slightly smaller than nominal)
- $\beta^* 10$ m in all IPs
- Q: collision tunes (.31 H .32 V)

Results:
- little problems with HO bb interactions
- small contribution from lattice non linearities which was expected to be important at 450 GeV
- no effects during transverse offset scan on lifetime and emittance

Conclusion:
- $\xi \sim 0.004$ per crossing achieved exceeding the nominal.
- intensity was pushed further to nominal earlier than expected for the luminosity runs.
Overview

\[ \Delta Q_h = +0.005 \] to bring lifetime to 25h

NOMINAL beam beam parameter is achieved !!!

<table>
<thead>
<tr>
<th></th>
<th>Beam 1</th>
<th>Beam 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>2.2</td>
<td>3.3</td>
</tr>
<tr>
<td>V</td>
<td>2.4</td>
<td>3.7</td>
</tr>
<tr>
<td>(μm)</td>
<td>Injection</td>
<td>After LumiScan</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>V</td>
</tr>
<tr>
<td>2.4</td>
<td>2.7</td>
<td>3.6</td>
</tr>
<tr>
<td>2.9</td>
<td>3.2</td>
<td>4.9</td>
</tr>
</tbody>
</table>
The Quest continues...

Fill 1765-1766 (May 2011)

**GOALS:**
- Check the feasibility of colliding high intensity bunches (HO) with a beam beam linear parameter greater than nominal
- \( E = 450 \text{ GeV} \)
- \( \beta^* \text{ 11 m in all Ips} \)

**Setup:**
- Nominal crossing angles and spectrometers off in IP2/IP8
- Q: collision tunes \(.31 \text{ H} \quad .32 \text{ V}\)
- ADT on at injection and off afterwards

**3 Tests:**
- 1 bunch/beam
- 2 bunches x beam
- 4 collisions x bunch

\( 1.6 \times 10^{11} \text{ emitt} 1.2 \text{ microns at injection} \rightarrow \text{blowup (mainly vertical) end up with average almost 2.2 microns} \)

\( \xi: 0.009/\text{IP} \), total 0.018 (collide only IP1,5)

Small tune scan, no lifetime effect, emittance blowup beam 2
Fill 1765-1766 (May 2011)

Test 2:

Beam 1: bunch 100 bunch 1885  
Beam 2: bunch 100 bunch 991

Collision scheme

IP 1/5: b100 - b100  
IP 2: b100 - b991  
IP 8: b1885 - b991
Test 3:

Part A

We wanted a symmetric filling scheme with 4 collisions per bunch.

Part B

To avoid 10\(^{th}\) order resonance tunes, the tunes were moved to .31H .31V.

With N=1.85E11 ppb and \(\varepsilon=1.3\) \(\mu\)m, the lifetime achieved was \(\zeta=0.017/IP\) -> total 0.034.
• To check whether the bright beams sent from the injectors can be digested by the experiments, 2 high pile up test were scheduled in october 2011.

• Parasitically, to these tests the beam parameters evolution were monitored in order to study the high HO tune shift regime and eventual limitations.

- Fill 2201 (10 October 2011)
  - Filling scheme
  - Emittances and Intensity Measurements.
  - Beam Losses Analysis.
  - Comparison with the simulations.

- Fill 2252 (25 October 2011)
  - Filling Scheme.
  - Beam Losses Observation.
  - Beams Separation and its effects on intensity and emittances.
Beam Emittances at FLATTOP

<table>
<thead>
<tr>
<th></th>
<th>Hor</th>
<th>Ver</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>3.6</td>
<td>2.8</td>
</tr>
<tr>
<td>B2</td>
<td>3.3</td>
<td>3.1</td>
</tr>
</tbody>
</table>

$\Xi \sim 0.025$
Burn-off/Total losses \(\approx 75\%\)

Burn-off/Total losses \(\approx 43\%\)

Burn-off/Total losses \(\approx 40\%\)

BEAM 2

BETTER LIFETIME AFTER TUNE SCAN??

-4.1E9 p/min

-6.6E9 p/min
Tevatron Luminosity Model
\[ \epsilon x, y, N, \sigma_P^2 \]
FILL 2252

**Filling** - Losses Observation - Separation Steps - Emitt. Observation

\[ N \approx 2.3 \times 10^{11} \text{ pbb} \]
\[ \varepsilon \approx 2.5 \mu m \]

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FILL 2252  Filling Losses Observation  - Separation Steps - Emitt. Observation

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FILL 2252  Filling - Losses Observation - Separation Steps - Emitt. Observation

3 HO Collisions (beam 1)

Beam 1 Bunches colliding only in IP 1&5
FILL 2252  Filling - Losses Observation  Separation Steps  Emitt. Observation

Beam 1

Beam 2

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Mid 2012 SPS passing to the Q20 optics...
Even brighter beams can be delivered to the LHC!
High pile up to be repeated with a goal of:
\[ \mu = 100 \]

Again, PARASITICALLY, beam parameters were monitored to study the HO b-b factor and its effects on these bright beams.

**Fill 2822-2823-2824-2825 (July 2012)**

**2822 ->** 1 bunch 3e11 ppb 2 um emittance reached stable beams with deteriorated beams. Pile-up 45

**2823 ->** same configuration + increase chromaticity by 3 units decided to dump before reached stable beams since the beams were unstable again

**2824 ->** After discovering the problem, 2 bunches 3e11ppb stayed 10 min in SB. Pile-up 58
B1 not cured yet, B2 reached collisions with 2.2 um emittance

**2825 ->** Longitudinal Blow-up issue solved, still instability observed during the squeeze causing losses and blow-up.
Pile-up 70 reached in IP1
Instability during the squeeze for Beam 1
SUMMARY

Commissioning
Nominal and beyond beam-beam tune shift was achieved without any particular problems

High Pile-up 1
Observed emittance growth at injection energy and more through the ramp. Vertical emittance growth observed twice in the vertical plane in beam 1 still under investigations for fill 1, since for fill 2 it corresponds to the separation of the beams.
Missing losses contribution to the Luminosity evolution model (not only beam-beam losses?)
Long Range effects in fill 2252 or just losses from tune resonances?

High Pile-up 2
Systematic studies (parallel separation, leveling and noise excitation) still to be done. The instabilities that showed up were independently present from the HO tune shift

Under the present conditions we do not consider the HO bb interaction as a limit for the LHC performance
Thank you for your attention
Fill 1765-1766 (May 2011)

Test 1:

FBCT Intensity and Beam Energy

Corrected Normalized Emittance $\varepsilon_N$ for fill 1765-B1

Collisions in ATLAS

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**Growth @ Inj:**
B1 ~ 12%
B2 ~ 8%

**Growth @ Ramp:**
B1H ~ 44%
B1V ~ 30%
B2H ~ 30%
B2V ~ 7%
Backup Slides

Parametric Ordinary Differential Equations (ODEs) in:

\[ \mathcal{E}_x, \mathcal{E}_y, N, \sigma_P^2 \]

- Beam Emittance
- Beam Intensity
- Rms Momentum Spread

- the emittance growth and the particle loss due to scattering on the residual gas;
- the particle loss and the emittance growth due to scattering in IPs;
- the transverse and longitudinal emittance growth due to intrabeam scattering;
- the bunch lengthening due to RF noise;
- The emittance growth predicted from the Transverse Feedback Systems (ADT) noise
- synchrotron radiation damping.
Backup Slides

BEAM 1
-4.12 p/min
-6.64 p/min

BEAM 2
-5.57 p/min

regimes separation

Beam 1

Tune Scans

Beam 2

Tune Scans

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Backup Slides

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Backup Slides

b101 - b101 (HO in IP1 IP5)
b101 - b992 (HO in IP2)
b995 - b101 (HO in IP8)

b995 - b992 (LR in IP 1 IP5)
Backup Slides

Colliding in: IP 2 with #101

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