Buch-by-bunch Luminosity Variations in LHC

Study of the BbyB Luminosity variations in Run 2

Correlations and impact for LHC & HL-LHC

I. Efthymiopoulos
Bunch-by-Bunch Luminosity Variation

Bunch Intensities

\[
\frac{N_1 N_2 f N_b}{4\pi \sigma_x \sigma_y} \sqrt{1 + \left( \frac{\sigma_s}{\sigma_x} \frac{\phi}{2} \right)^2} = \mathcal{L} = \frac{R}{\sigma}
\]

- Variations in the bunch intensity or luminous region size (transverse and/or long-emittance variations) result in Luminosity variations for the experiments or fluctuations to the event PU rate.
Luminosity Variations in LHC

- Luminosity (integrated over all bunches) evolution in SB
Luminosity Variations in LHC

• Bunch Luminosity evolution in SB

ATLAS Luminosity - Fill 7334

CMS Luminosity - Fill 7334

Time
Luminosity Variations in LHC

- Compare several fills in 2017 and 2018 with BCMS and 8b4e beams and different polarities for LHCb dipole
- Fills considered:

<table>
<thead>
<tr>
<th>Year</th>
<th>Fill</th>
<th>SB duration</th>
<th>LHCb polarity</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>BCMS</td>
<td>5848</td>
<td>~20h</td>
<td>NEG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5849</td>
<td>~1d2h</td>
<td>NEG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5976</td>
<td>~14h</td>
<td>POS</td>
</tr>
<tr>
<td></td>
<td>8b4e</td>
<td>6324</td>
<td>~15h</td>
<td>POS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6364</td>
<td>~15h</td>
<td>NEG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6385</td>
<td>~14h</td>
<td>POS</td>
</tr>
<tr>
<td>2018</td>
<td>BCMS</td>
<td>6919</td>
<td>~20h</td>
<td>NEG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7056</td>
<td>~1d2h</td>
<td>POS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7061</td>
<td>~14h</td>
<td>POS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7320</td>
<td>~15h</td>
<td>NEG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7314</td>
<td>~15h</td>
<td>NEG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7334</td>
<td>~14h</td>
<td>NEG</td>
</tr>
</tbody>
</table>
Fill 7334 – 2018 BCMS LHCb/neg

Bunch lumi vs time
• red line = mean luminosity
• Dashed line = +10%

ATLAS Luminosity - Fill 7334

CMS Bunch Lumi Variation - Fill 7334
Fill 7334 – 2018 BCMS LHCb/neg

End of x-sing angle lev.

CMS Bunch Lumi Variation - Fill 7334

ATLAS Bunch Lumi Variation - Fill 7334

# bunches vs time [min] for CMS and ATLAS

# bunches vs time [min] for larger rms values for CMS and ATLAS

# bunches vs time [min] for larger percentage values for CMS and ATLAS

CERN

ie - HL-LHC WP2 Meeting - June 11, 2019
Fill 7314 - BCMS/LHCb=NEG

End of x-sing angle lev.

SpecLumi

Beam 1*Beam 2 - Bunch Intensity Variation - Fill 7314

Beam 1 Bunch Variation - Fill 7314

Beam 2 Bunch Intensity Variation - Fill 7314

Beam 2 Bunch Length Variation - Fill 7314

Beam 1 Bunch Length Variation - Fill 7314

Blen1

Blen1

Blen1
Fill 7056 - BCMS/LHCb=POS

ATLAS Bunch Lumi Variation - Fill 7056

End of x-sing angle lev.

ATLAS Bunch Specific Lumi Variation - Fill 7056
The observed variations vs time in the bunch luminosity are mainly correlated to the beam intensity variations.
Fill 6919 - BCMS/LHCb=NEG

- ATLAS levelled at $0.7 \times 10^{34}$ for the whole fill
Fill 6919 - BCMS/LHCb=NEG

- Bunch luminosity variation
Fill 6919 - BCMS/LHCb=NEG

- Bunch luminosity variation
The fact that ATLAS was levelled (by separation) had marginal effect on the bunch luminosity variations for both experiments.

As for other fills, the major contribution comes from the beam intensity fluctuations with both beams having equal share.
Lumi leveling

ATLAS Bunch Lumi Variation - Fill 6324

relative spread [%]

0  20  40  60  80  100

0  10  20  30  40  50  60  70  80  90  100

rms  max/min  lumi level

# bunches

0  20  40  60  80  100

0  10  20  30  40  50  60  70  80  90  100

>2 rms  >2.5 rms

# bunches

0  100

0  200  400  600  800  1000

0  200  400  600  800  1000

>10pc  >20pc

Bunch Luminosity [Hz/ub]

0  5  10

0  60  120  180  240  300  360  420  480  540  600  660  720  780

time [min]

Lumi level

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Fill 6324 – 2017 8b4e

- CMS data

Lumi leveling
Fill 6324 - 8b4e/LHCb=POS

\[ I_{B1} \times I_{B2} \]

- ATLAS Bunch Beam Current Variation - Fill 6324
- Beam 1 Bunch Intensity Variation - Fill 6324
- Beam 2 Bunch Intensity Variation - Fill 6324
- Beam 1 Bunch Length Variation - Fill 6324
- Beam 2 Bunch Length Variation - Fill 6324
- ATLAS Bunch Specific Lumi Variation - Fill 6324

SpecificLumi_{ATLAS}
Intensity fluctuations in the cycle

Injection – beam intensity

Stable Beam – Intensity

B1 4.4%
B2 4.24%

Emittance

<table>
<thead>
<tr>
<th></th>
<th>B1H</th>
<th>B1V</th>
<th>B2H</th>
<th>B2V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inj</td>
<td>4.78%</td>
<td>4.6%</td>
<td>4.96%</td>
<td>5.1%</td>
</tr>
<tr>
<td>SB</td>
<td>6.54%</td>
<td>7.78%</td>
<td>13.64%</td>
<td>9.86%</td>
</tr>
</tbody>
</table>

From BSRT data – all fills without any selection!
Fill 7006 – 2018 BCMS

- “nominal” BCMS fill as all others in 2018, except of the missed last injection of B1
Fill 7006 – 2018 BCMS

- Compare colliding bunches with another fill
  - good agreement for the duration of the fill
Fill 7006 – 2018 BCMS

• No RMS growth of the non-colliding train bunches, while the colliding trains show the same increase as in all other BCMS fills.
Fill 7006 – 2018 BCMS

Intensity

S. Papadopoulou
Emittance

Non colliding train:
- E-growth in H-plane as expected
- No (or minimal) growth in the V-plane

Check with the lumi model ongoing…

S. Papadopoulou
Fill 7006 – 2018 BCMS

• Reminder: additional losses (above burn-off limit) observed in the 2018 for the BCMS beams, correlated to the e-cloud pattern in the trains

From fill 7006 it seems the non-colliding train that exhibits e-cloud, shows no(?) losses and no(?) e-growth

• Could be the source of the observed losses are around the IP (e-cloud in the triplets or combined effect of e-cloud + BBLR) – to investigate further
Bunch-by-Bunch Luminosity Variation

\[
\frac{N_1 N_2 f N_b}{4\pi \sigma_x \sigma_y} \left( \frac{1}{\sqrt{1 + \left( \frac{\sigma_s}{\sigma_x} \phi \right)^2}} \right) = \mathcal{L} = \frac{R}{\sigma}
\]

Impact to the experiments:

- Trigger limitations due to maximum event bandwidth
  - Would need to adjust trigger levels, trigger menu thresholds to remain optimal and at maximum read-out capacity during levelling

- Variable PU distribution, beyond the nominal from Poisson
  - Challenging to apply calibration factors globally

- First feedback from the experiments (EDQ WG meetings: a variation < 10% would be easily acceptable, further studies ongoing also for Run 3

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B. Petersen - 19th EDQ WG meeting (https://indico.cern.ch/event/790362/)
Bunch variations & PU

LHC

±10%

HL-LHC

±10%
Summary

• Highlight results from a study of **BbyB Luminosity fluctuation** in LHC for BCMS and 8b4e fills presented
  • the fluctuations manifest during SB while a small growth is observed during FB and the ramp

• A general growth of up to **20% RMS** observed for the BCMS fills of 2018, mainly due to fluctuations in the **bunch intensities**.
  • The maximum spread for the bunch luminosities goes up to **60%** for a sizeable fraction of the bunches in the fill, typically for the ~10 head bunches of the trains

• For **8b4e fills** that show no (major) signs of e-cloud, **no rms spread increase** (could even be a small dumping) is observed

• From fill 7006 having a **full non-colliding train during SB** no (sizeable) increase in BbyB rms is observed. This result points to the the intensity losses and thus fluctuations in BCMS beams originate mainly form the IP regions, where the e-cloud adds on top of the BB and BBLR effects. Further studies are ongoing to further understand it.

• If not mitigated, the BbyB luminosity fluctuations at the levels observed would have an impact to the overall strategy for the experiments to configure trigger rates and optimise the available bandwidth to maximise the recorded luminosity for Run 3 and HL-LHC
  • Further studies are ongoing, to follow in the EDQ WG meetings
Spare slides
Luminosity Variations in LHC

- Luminosity\textsuperscript{(integrated over all bunches)} evolution in SB