Specification of separation collapsing speed for HL-LHC

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Acknowledgments: E. Metral, L. Carver, W. Kozanecki

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Contents

• Minimum of Landau Damping during “adjust” beam process

• Observed issues:
  • 2012 Observations (Adjust beam process, IP8 bunches, offset leveling MD)
  • 2015 Observations (OP scans, losses in adjust)

• Separation bump speed

• HL-LHC rise time

• Summary
HL-LHC SD during adjust (Crab crossing off)

Evolution of the SD during collapse of separation (crab-crossing off):
LR+HO beam-beam in IP1 and IP5

Extended results:
“Joint HiLumi LHC-LARP Meeting 2015”
C. Tambasco et al.

Ultimate scenario

Parameters in:
“HL-LHC Operational Scenarios” E. Metral et al.

Negative LOF: two reductions at ~6σ and ~1.5σ
HL-LHC SD during adjust (Crab crossing on)

Evolution of the SD during collapse of separation (crab-crossing on):
LR+HO beam-beam in IP1 and IP5

Baseline scenario

Negative LOF: two reductions at \(\sim 6\sigma\) and \(\sim 1.5\sigma\)

Ultimate scenario

- 570A Oct current
Reduction at $6\sigma$ during collapse

**Baseline scenario**

- Larger reduction of SD for negative Landau octupole polarity
- Crab off: SD similar for positive Landau octupole polarity for single beam

**Ultimate scenario**

- Same considerations as baseline
Reduction at 1.5σ during collapse

SD strongly reduction for both polarities of the Landau Octupoles

Larger reduction of SD for positive Landau octupoles polarity

Positive worst than negative polarity

A minimum of stability diagram can not be avoided
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Instabilities were not observed during the adjust beam process (except bunch colliding in IP8 see next slide)

EOS instability observed (Evian 2014)

Only two fills were unstable at the minimum of stability during the intensity ramp up

Slow adjust beam process ~200 s

“Stability diagrams of colliding beams in the Large Hadron Collider” PRSTAB 2014
IP8 special bunches: luminosity leveling with separation

“Stability diagrams of colliding beams in the Large Hadron Collider” PRSTAB 2014

Density of the instability peaked around 1.5 $\sigma$ beam-beam separation (all physics fills of 2012, positive and negative octupole polarities)
Several minutes spent at minimum of stability
Comparable with minimum of Landau Damping
LHC 2012 offset leveling MD

Reduced damper gain during the MD

<table>
<thead>
<tr>
<th>Full separation [σ]</th>
<th>Rise time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>2.7</td>
</tr>
<tr>
<td>1.1</td>
<td>6.7</td>
</tr>
<tr>
<td>1.4</td>
<td>1.8</td>
</tr>
<tr>
<td>6</td>
<td>5.9</td>
</tr>
</tbody>
</table>

2-day internal review of LHC performance limitations (linked to transverse collective effects) during run I, X. Buffat: “Snow-flakes" instabilities and instabilities during adjust”

Summary of the 2012 collapse of separation observations:

- Offset of 1.5 σ is critical due to the minimum SD
- 2 beam dumps at the minimum of stability during the adjust beam process
- IP8 bunches unstable over all the year (+-LO) but with different magnitude 70-2% beam losses (could be related to chromaticity 2 vs 15 units?)
- Fastest instabilities during MD ~2s rise time damped with ADT

Not very good knowledge of ADT settings and chromaticity
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LHC 2015 leveling with offset

Evolution of the SD during **leveling with offset**: LR+HO beam-beam in IP1 and IP5

+550A Oct current

Speed during the collapse 1.2-1.3 $\sigma$/s  
($\sim$0.8 s/$\sigma$)  
40 s in total for the adjust process

**Positive LOF**

Never observed instabilities during the collapse, except for OP scans with a less effective ADT (or lower chromaticity)

Rise time of the instabilities observed at flat top: 10-15 s  
and faster during the squeeze (5 s)  
(L. Carver) $\rightarrow$ ramp rate already faster than the observed worst instability

Reduction around $\sim$1.5 $\sigma$
Example: fill 4363 (14th Sept)

Coherent oscillation observed $1.5-2\sigma$, the damper was less effective (similar case of the 2012 test)

ADT plays fundamental role in instabilities at $1.5-2\sigma$ separation
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Adjust process: Luminosity

Example: fill 4363 (14th Sept)

Corrected published luminosity delay by 2 s

\[ sep[\sigma] = \sqrt{-4 \ln \frac{L/(N_1 \times N_2)}{L^0/(N_1^0 \times N_2^0)}} \]
Adjust process: ramp rate

Example: fill 4363 (14th Sept)

For a beam separation $\sim 1.5-2\sigma$ correctors are already in the deceleration part of the ramp: will not gain from an increased ramp rate

ATLAS: 2-1$\sigma$ $\rightarrow$ 1.2 s
CMS: 2-1$\sigma$ $\rightarrow$ 2.3 s
Adjust process: losses

Example: fill 4363 (14th Sept)

\[ sep[\sigma] = \sqrt{-4 \ln \frac{L/(N_1 \cdot N_2)}{L^0/(N_1^0 \cdot N_2^0)}} \]

Strong losses for while bringing beams into collision around \(~2\,\text{to}\,3\sigma\) \(\rightarrow\) scraping of tails

Going faster might not be a good option
All fills during adjust had minimum beam lifetime above 1 hour. The fills below 1 hour lifetime were dumped during squeeze for other raison than losses. The lower lifetime is an artifact of the dump.

Adjust beam process worst beam loss lifetime: quench limit 0.2 h (6.5 TeV, 1.1 e11 ppb)
Adjust process: losses

Example: fill 4363 (14th Sept)

Rough estimates for HL-LHC:

2.2e11 ppb
7 TeV
Assuming same diffused tails
same ramp rate as LHC
Loss lifetimes of the order of 0.5 h

→ One might need to slower the separation bump knobs

(ongoing analysis with B. Salvachua)
OP scan: losses

Example: fill 4363 (14th Sept)

\[ sep[\sigma] = \sqrt{-4 \ln \frac{L/(N_1 \times N_2)}{L^0/(N_1^0 \times N_2^0)}} \]

1 order of magnitude less w.r.t. tail scraping while bringing the beam in collision
Adjust process: correctors and losses

Example: fill 4337 (9th Sept)

For a beam separation $\sim 1.5-2\sigma$ correctors are already in the deceleration part of the ramp.

CMS: $2-1\sigma \rightarrow 4.1$ s
ATLAS: $2-1\sigma \rightarrow 1.2$ s

Strong losses for while bringing beams into collision around $\sim 2-3\sigma$.
LHC 2015 separation bump speed

### Speed from 2σ to 1σ

<table>
<thead>
<tr>
<th>Fill #</th>
<th>ATLAS [s/σ]</th>
<th>CMS [s/σ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4332</td>
<td>1.428</td>
<td>3.822</td>
</tr>
<tr>
<td>4337</td>
<td>1.368</td>
<td>4.152</td>
</tr>
<tr>
<td>4363</td>
<td>1.248</td>
<td>2.280</td>
</tr>
<tr>
<td>4364</td>
<td>1.86</td>
<td>1.962</td>
</tr>
<tr>
<td>4384</td>
<td>2.016</td>
<td>1.836</td>
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<tr>
<td>4391</td>
<td>1.774</td>
<td>1.670</td>
</tr>
<tr>
<td>4398</td>
<td>1.417</td>
<td>1.787</td>
</tr>
<tr>
<td>4555</td>
<td>1.458</td>
<td>2.226</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>1.571</td>
<td>2.467</td>
</tr>
</tbody>
</table>
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Critical regions: 1.5-2.5 s rise time—> comparable with ATLAS and CMS speed (Average ATLAS: 1.571s/σ and CMS 2.476 s/σ)
HL-LHC impedance modes at the minimum of stability

Negative LOF

Some modes are unstable at the 1.5σ minimum for crab crossing Off while collapsing the beams.

The minimum at 6σ with the crab crossing On is worst than the one with the crab crossing Off.

At 6σ the collapse if faster.
• HL-LHC as LHC will have a minimum of SD at 1.5σ separation during the collapse of the separations bumps

• No observations of instabilities at the minimum of SD (1.5 σ) during the regular operational fills
  • Observations on 2012 fills during intensity ramp up (unknown ADT, Q’ setups)
  • Observations of instabilities at min SD for IP8 special bunches (minutes spent at the minimum)
  • Observations in 2015 OP scans: reduced ADT
  • Observed instabilities, ~5 s for LHC (N. Biancacci, L. Carver), always slower than the ramp rate

• The min of SD occurs at the deceleration part of the correctors: increasing the ramp rate will not help

• Going faster will have also bad impact on beam loss lifetimes
  • The LHC speed is ~1.5 s/σ (ATLAS) and ~2.5 s/σ (CMS) comparable with the HL-LHC rise time

• Modes are Landau damped at the minimum of stability for the case with crab crossing ON for 1.5 σ separation, however the minimum at 6σ has a smaller stability diagram w.r.t to crab crossing OFF

• MDs are planned to explore fast instability at the minimum of SD
Back up
Ramp rate during the HL-LHC collapse

Considering 40 s in total from 1 mm to 0 mm IP1 & 5 separations:

48-3 σ range: LHC 2015: 1.2-1.3 σ/s (0.83 s/σ)
3-0σ range: LHC 2015: 0.3 σ/s (3 s/σ)

48-3 σ range: LHC 2016: 1.7 σ/s (0.6 s/σ)
3-0σ range: similar to LHC 2015

HL-LHC (ε_n=2.5 μm, 7 TeV):

- BASELINE scenario with β*~70cm: 1.6 σ/s
- ULTIMATE scenario with β*~40cm: 2.0 σ/s
- FULLY SQUEEZED scenario with β*~15cm: 3.5 σ/s
HL-LHC beta squeeze summary

Negative polarity always preferred

Positive polarity gives larger SD from $\beta^* \sim 0.39m$

Correction applied at $\beta^* = 70cm$

Reduction can be compensated by increasing the beta in the arcs by a factor of 8% at $\beta^* = 70cm \rightarrow 650A$
LHC expected rise time

RT-vs-Qp d=50 turns planey M2748 Nb1.2e11 sigmaz-0.090m

N. Biancacci
LHC octupole current

SD-vs-Qp d=50 turns gaussian eps2.5um Nb2.2e11 sigmaz-0.081m oct-negative

N. Biancacci
LHC 2015 OP scan: losses

Example: fill 4363 (14th Sept)

Losses observed also for the OP scan in IP5
Critical area 1.5-2σ
Adjust process: correctors and Lumi

Example: fill 4337 (9th Sept)