LHC beam and luminosity lifetimes revisited

Author(s) / Department-Group: M. Lamont (BE/OP), O. Johnson (Oxford University)

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Summary

The single beam lifetimes and luminosity lifetime during LHC Stable Beams in 2012 for a large number of fills are considered. The evolution of single beam lifetime through a given fill is obtained from fits to BCT data and from the combination of luminosity losses and calibrated beam loss to collimation. A breakdown of the single beam lifetime into principle components is performed allowing a quantitative picture of component lifetime evolution during Stable Beams. The situation before and after the octupole polarity change and concomitant increase in chromaticity in August 2012 are compared.

The analysis is extended to the luminosity lifetime and an attempt to made to evaluate emittance growth from the luminous region size and luminosity evolution through the fill.

1 Introduction

2012 was a successful year for luminosity production. Machine set-up was characterized by:

• tight collimator settings which, by virtue of effectively shadowing the inner triplets, allowed a $\beta^*$ of 60 cm in the GPDs in physics;
• the delivery of 50 ns beam with high bunch population and low emittance from the injector complex.

There were a number of issues in the squeeze and adjust phases throughout the year associated with the chosen operational regime. At the beginning of August 2012 the lattice octupole polarity was changed. At the same time the chromaticity at the end of the ramp, in the squeeze and adjust phase was increased considerably. These maneuvers were aimed at suppressing a series of total beam losses driven by instabilities in the squeeze and, in particular, during the adjust phase. In the following these changes in operating conditions are referred to as “OPC”.

In general, Stable Beams was reasonably quiet from a beam dynamics perspective with head-on beam-beam providing sufficient Landau damping to counter coherent instabilities (although the transverse dampers remained firmly on).

The results of analyzing 2012 data from all fills with over 8 hours of Stable Beams are presented in this paper. Data was extracted from the logging database and the LPC AFS repository.

2 Single Beam Lifetime

Firstly a sliding exponential fit to the DCBCT measurements for beam 1 and beam 2 was performed. A window size of 10 minutes was used. The data was generally clean and good fit quality was obtained.

Secondly the beam loss measurements (running sum 12 – 83.9 s) from the beam loss monitors (BLMs) associated with the primary collimator TCPA slots for beam 1 and beam 2 were extracted from the logging database. The logging variable names are:

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These BLMs have been calibrated against the total beam loss by the collimation team [1] through the different phases of the nominal cycle. The resulting calibration factor from the analysis of the squeeze is used here to reconstruct the total beam loss into collimation sections in protons per second through the Stable Beam period. The squeeze calibration factor is used because this is uncontaminated by luminosity losses in the calibration process; the stable beam calibration factor given in [1] had knowingly not taken luminosity losses taken into account. (In the original analysis running sum 9 (1.3 s) was used. This, however, gives a rather noisy signal (and cluttered plots).

Initially the assumption is made that the loss rate given by the IR7 collimator BLM calibration factor represents all collimation losses. As will be seen below this assumption leads to excellent agreement in the assignment of losses. This is presumably due to the use of very tight settings in 2012 operation. The use of a similar calibration factor in IR3 would also be appropriate as will become apparent. Note also that the same calibration factor is used for both beam 1 and beam 2.

Thirdly the luminosity data from ATLAS, CMS and LHCb were extracted from the logging database. The beam loss rate due to luminosity through the fill from ATLAS, CMS and LHCb was calculated and summed. In the calculation an inelastic cross section of 75 mb was assumed [2]. The luminosity-independent elastic and inelastic cross sections given by TOTEM in [2] are $\sigma_{el} = (27.1 \pm 1.4)$ mb; $\sigma_{inel} = (74.7 \pm 1.7)$ mb. The total cross section is given as $(101.7 \pm 2.9)$ mb. Note that the inelastic cross-section here is total minus elastic and thus includes diffractive processes. The assumption made here is that elastically scattered protons remain within the beam. This assumption is quantified in the discussion on emittance growth below.

Given the above, it is possible to:

- reconstruct the beam lifetime from combination of beam loss to the collimators and to luminosity burn;
- compare the lifetime calculated from losses with that from the fit to the BCT data;
- compare the losses to collimation with those due to luminosity;
- and as a cross-check compare the beam current evolution given by the BCT with that derived as described above from subtracting the losses derived above from the initial beam current.

### 2.1 Loss breakdown

Typical examples of the development of single beam loss rates through a fill are shown in figures 1 and 2. Loss rates to luminosity (clearly the same for beam 1 and beam 2) and to collimation are displayed. Fill 2728 was relatively early in the year and fill 3363 after the OPC. One can quantify the division of losses in the fills shown over an eight hour period. The results are shown in table 1. Of note are:

- the significantly higher loss rates during the first hour or so of the fill – this is a feature of all fills;
- the fact that losses to collimation are comparable or greater than those to luminosity;
- the losses to collimation range from 44% to 60% of the total losses over 8 hours in the examples shown;
- the good agreement between the analysis and the actual losses given by the difference between the DCBCT at the start of fill and after 8 hours.
Figure 1: Beam 1 and beam 2 loss rates to luminosity and collimation (fill 2728)

Figure 2: Beam 1 and beam 2 loss rates to luminosity and collimation (fill 3363)

Table 1: Loss breakdown over 8 hours for two fills, one early in 2012, one later.

<table>
<thead>
<tr>
<th>Fill</th>
<th>Beam</th>
<th>Luminosity losses</th>
<th>Collimation losses</th>
<th>Total estimated losses (8 hrs.)</th>
<th>Collimation fraction of total</th>
<th>Total losses DCBCT</th>
<th>Estimate wrt BCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2728</td>
<td>1</td>
<td>$2.09 \times 10^{13}$</td>
<td>$1.63 \times 10^{13}$</td>
<td>$3.71 \times 10^{13}$</td>
<td>0.44</td>
<td>$3.89 \times 10^{13}$</td>
<td>0.96</td>
</tr>
<tr>
<td>2728</td>
<td>2</td>
<td>$2.09 \times 10^{13}$</td>
<td>$2.04 \times 10^{13}$</td>
<td>$4.13 \times 10^{13}$</td>
<td>0.49</td>
<td>$4.18 \times 10^{13}$</td>
<td>0.99</td>
</tr>
<tr>
<td>3363</td>
<td>1</td>
<td>$2.06 \times 10^{13}$</td>
<td>$2.77 \times 10^{13}$</td>
<td>$4.83 \times 10^{13}$</td>
<td>0.57</td>
<td>$4.68 \times 10^{13}$</td>
<td>1.03</td>
</tr>
<tr>
<td>3363</td>
<td>2</td>
<td>$2.06 \times 10^{13}$</td>
<td>$3.06 \times 10^{13}$</td>
<td>$5.12 \times 10^{13}$</td>
<td>0.60</td>
<td>$5.22 \times 10^{13}$</td>
<td>0.98</td>
</tr>
</tbody>
</table>
2.2 Single beam lifetime breakdown

An alternative way of viewing the same data is to decompose the overall single beam lifetime into its main components based on the calculated loss rates. This is illustrated in Figures 3 and 4. Also shown in the figures is the single beam lifetime extracted from sliding fits to the DCBCT for beam 1 and beam 2. The essential conclusion is, as expected, the same: losses to collimation is approximately equal to or greater than losses to luminosity.

![Figure 3: Single beam lifetime breakdown beam 1 (fill 2908)](image)

![Figure 4: Single beam lifetime breakdown beam 2 (fill 3323)](image)

2.3 Comparison of lifetimes derived from BCT and beam loss

The combined single beam lifetime from losses to collimation and luminosity are now compared with the single beam lifetime derived from the BCTs.

Examples showing comparison of lifetime calculated from combined losses and that calculated from the BCT fit are shown in figures 5 and 6. Of note:

- There is very good agreement between the BCT lifetimes and those reconstructed from the beam loss to collimation and luminosity burn. This implies that all significant losses are tracked well by the losses to collimation and to luminosity. Losses to beam-gas and IR3 may be assumed to be relatively low in 2012.
- The single beam lifetime typically starts at around 20 hours and increases to over 30 hours after 6 hours of Stable Beams
2.4 Comparison of integrated losses versus BCT

The validity of the assumption that the IR7 BLM calibration tracks well the total losses can be verified by integrating the loss rates to collimation and luminosity over time (equation 1) and comparing these result with the measured beam current.

\[ N(t) = N_0 - \int \frac{dN}{dt} dt \]  

(1)

The results of the comparison of the beam current evolution given by the BCT with that derived from subtracting the derived losses from the initial beam current is shown in figures 7 and 8. The figures show the measured beam current and the beam current reconstructed from the initial current with the calculated beam loss subtracted (see equation 1). Good agreement is observed supporting the assumption (for 2012) that all significant beam loss bar luminosity is concentrated in IR7 and is tracked well by the BLM calibration. After 8 hours the difference between the integrated losses from the DCBCT and the total derived from the estimated combined losses is typically about 1 to 4% for beam 1, and around 1 to 2 % for beam 2 (see also table 1).

Direct examination of the above figures show excellent agreement for beam 2. The agreement is less good for beam 1 in the example fills shown. This is a general feature. One possible reason for the discrepancy can be seen in figure 9 which shows the raw BLM readings from the primary collimators in both IR7 and IR3.
Figure 7: Beam current beam 1 - DCBCT and that reconstructed from losses.

Figure 8: Beam current beam 2 - DCBCT and that reconstructed from losses.

Note:

- The losses in IR3 track the discrepancies.
- The larger discrepancies for beam 1 are reflected in the higher losses in IR3.
- There were lower losses in IR3 (and IR7) before the OPC.
- These conclusions were subsequently confirmed by analysis of collimation losses in IR7/IR3 [6]. This analysis estimated 1 to 2% for beam 2 and around 4% for beam 1 of the total annual collimation losses went into IR3 during 2012.

3 Losses before and after octupole polarity change

The octupole polarity change (OPC) took place on 7th August 2012 and was followed by a few fills in which the octupole current and chromaticity were raised in a largely successful attempt to address instabilities. One necessary operational change was the use of high chromaticity (of order 15 units) in both planes to combat instabilities at the end of the ramp and in the squeeze. Although the octupole current and high chromaticity were brought down during the collision beam process and routinely lowered in Stable Beams, they remained higher than before the
OPC. There was an tacit acceptance of poorer lifetime conditions which not unsurprising given
the high bunch population and record luminosities. This presumably explains the worsening of
losses in Stable Beams. Work in progress is visible when comparing figures 11 and 12.

The situation before and after can be seen more explicitly by looking at the single beam
lifetime components as shown in figure 13. Examination of the beam loss versus intensity shows
a clear worsening after the OPC. Note that fills 2170 and 3192 had very similar initial luminosity
(fill 2710: peak luminosity 6.76e33 cm$^{-2}$s$^{-1}$; fill 3192: peak luminosity 6.66e33 cm$^{-2}$s$^{-1}$). In both
cases the high loss rates at the start of fill can be seen. Further optimization of octupoles and
chromaticity might well have been possible after the OPC. Any optimization would benefit by
allowing the first 30 minutes or so of the fill to pass; as noted above the first hour is a period of
high beam loss making optimization of parameters against lifetime less than obvious.

3.1 OPC: discussion

Considering the OPC and associated increase in chromaticity, the following may be noted.

- Before the octupole polarity change the losses for one beam on the collimators are com-
  parable to the losses to luminosity.
After the octupole polarity change the losses for any one beam on the collimators are greater than the losses to luminosity – there is a clear increase in beam loss after the OPC. It should also be noted that the bunch intensity also went up, as did the luminosity.

As noted above the chromaticity was not reduced as much as it could have been in Stable Beams. Additionally the positive tune shift introduced in the collision beam process was removed when the OPC was introduced following a tune scan on 7th August. This is perhaps not surprising given the change in direction of the octupole detuning.

In an attempt to quantify the effect of the OPC a global exponential fit to the luminosity over the first 8 hours of a fill for fills before and after the OPC was performed. These fits give:

- a mean luminosity lifetime of 12.4 before the OPC;
- a mean luminosity lifetime of 10.5 after the OPC.

Over 8 hours fill a drop in luminosity lifetime from 12 to 10 hours costs around 10.7 $\text{pb}^{-1}$ at 60 cm, 1.6e11, 4 TeV. This is not too excessive. There is a soft trade off possible here – reduce the losses by opening the collimators at the cost of an increase of $\beta^*$. (A back of the envelope calculation shows that a increase in luminosity lifetime of 4 hours is approximately equivalent to a reduction in $\beta^*$ of 10 cm. The essential message would appear to be that if losses are sustainable, then go for higher peak luminosity.)
4 Comparison with 2011

Losses during a typical fill in 2011 are shown in figure 14. Briefly, losses to collimation are clearly less than those to luminosity. Losses in IR3 are significantly higher, reflected in less good agreement between the sum of luminosity and IR7 losses, and the measured beam current. This evidently the result of the looser collimator settings deployed in IR7 in 2011.

Figure 14: Beam 1 and beam 2 loss rates to luminosity and collimation during fill 2195 (2011). The high losses at start of fill are again apparent.
5 Luminosity lifetime

The ATLAS luminosity as recorded on the logging database is used for this analysis. Again 2012 data from all fills with over 8 hours of stable beams are analyzed. For each fill:

- ATLAS’s luminosity data are read;
- a sliding window clean is applied to remove initial optimization and subsequent luminosity optimization scans;
- a sliding window fit to an exponential is performed to give the luminosity lifetime through the fill.

5.1 Luminosity lifetime through a fill

The luminosity lifetime (sliding 20 minute window) for typical fill in shown in figure 15.

![ATLAS luminosity lifetime vs time – Fill 3192](image)

**Figure 15:** Luminosity lifetime evolution fill 3192

On a short time scale it is noted that at the beginning of high performing fills towards the end of 2012, the luminosity lifetime was as low as 4 to 5 hours at the start of a fill. See for example figure 16.

The luminosity lifetime in the first hour or so of a fill is systematically lower than the rest of a fill. This is true before and after the OPC as illustrated in figures 17 and 18. It has already been noted that the beam loss can be markedly higher during the start of fill period. Another potential contribution to the luminosity lifetime is emittance blow-up and this is now considered.
Another potential contribution to the luminosity lifetime is emittance blow-up. Accurate beam size measurements during Stable Beams were not available. One potential source of information is the measurement of the luminous region size by the experiments. The data used here is that provided by ATLAS. The measurement has the disadvantage of not being able to distinguish beam 1 from beam 2 but does provide horizontal and vertical sizes of the overlap. An example fill is shown in figure 19. This is fairly typical in that:

- the luminous region size in approximately equal in the horizontal and vertical planes at

\[ \tau = 11.4 \]
Figure 18: Luminosity and fit for fill 3192 – after OPC

- the growth rate in horizontal plane is initially higher than the vertical;
- but the two equalize after three hours or so into the fill.

Naively converting the luminous region size into beam size and then normalized emittance gives typically what is seen in figure 20. The standard picture is that the horizontal and vertical emittances are similar at the start of fill (t=0) with a steeper increase in horizontal plane that then flattens out. The increase is almost linear in the vertical plane.

Figure 19: Typical luminous region size through a fill as reported by ATLAS (fill 3299)

One can also reconstruct an effective emittance from the luminosity. This is regularly used as a figure of merit but has the disadvantage of not distinguishing beam 1 and beam 2, or the transverse planes. Figures 21 and 22 shows the result of reconstructing the effective emittance through a fill. The implicit assumption here is that all luminosity reduction besides the loss of particles from the beam is due to emittance growth. This likely true in the first approximation.
but other mechanisms are present. These include: the effect of increasing bunch length on the geometric reduction factor, and the hour glass effect. The effect of orbit drifts on beam separation at the interaction point are also present.

**Figure 20:** Horizontal (red) and vertical (blue) normalized emittance calculated from ATLAS’s luminous region size (fill 3192). Fit to equation 2 in horizontal plane, linear fit in vertical plane.

Plotting emittance growth derived from the luminous region and that from the luminosity on the same plot for a given fill in shown in figure 23. It is clear from the figure that despite initial agreement the two derivations of emittance diverge as the fill progresses. One possible reason is the dependance of the accuracy of luminous region size estimate on event rate which decreases as the fill proceeds.

**Figure 21:** Effective normalized emittance from luminosity (fill 3192). The fit is to equation 2.
Concentrating on the effective emittance derived from luminosity, growth rates are extracted from a two stage linear fit in the horizontal plane, a single linear fit in the vertical plane, and via a global fit to:

$$\epsilon(t) = \epsilon_0 + B(1 - e^{-t/\tau}).$$

(2)

The results show:

- A short time scale linear fit and a global fit lifetime to equation 2 evaluated at $t = 0$ give a $\frac{d\epsilon}{dt}$ of approximately 0.15 micron/hour.
• The corresponding initial “lifetime” \((\epsilon/d\epsilon/dt)\) is around around 16 to 17 hours (see figure 25).

### 6.1 Emittance growth - discussion

Emittance growth mechanisms include:

• elastic scattering at the interaction points;
• elastic scattering from residual gas;
• intra-beam scattering;
• non-linear resonances;
• incoherent beam-beam;
• electron cloud;
• noise, for example, power supplies, phase and amplitude noise in the RF system, ground motion;
• long range beam-beam.

The emittance growth rate can be expressed via:

\[
\frac{d\epsilon}{dt} = \epsilon \frac{d\epsilon}{dt} = 2r_{\sigma} = \frac{2}{\sigma} \frac{d\sigma}{dt}
\]

The effective normalized emittance used is defined by:

\[
\epsilon_{\text{eff}}^{\text{N}} = \sqrt{\epsilon_{\text{Nx}} \epsilon_{\text{Ny}}}
\]

The effective normalized emittance growth rate follows naturally from equation 3.

IBS emittance growth [3] arises from the change in longitudinal momentum in a collision at a location of nonzero dispersion. This leads to an effective change in the transverse coordinates of the colliding particles with respect to off-momentum orbits. The larger the dispersion, the faster the IBS emittance growth from this effect. If the vertical dispersion is negligible, but there is some H-V coupling, we expect the horizontal IBS emittance growth to feed directly into the vertical plane. In the LHC the vertical dispersion is low but not zero and in presence of coupling H will drive V.

With good coupling correction, one would expect vertical IBS to be significantly lower than horizontal. This has been observed at 450 GeV where normalized emittance growth rates \((d\epsilon/dt)\) of approximately 0.45 micron/hour in the horizontal plane and 0.05 micron/hour in the vertical plane have been measured [4].

Considering IBS at 4 TeV and inputting the appropriate parameters into the IBS module of MADX (with crossing angles on, generating some vertical dispersion) one obtains emittance growth rates \((d\epsilon/dt)\) of 0.08 micron/hour in the horizontal plane and 0.019 micron/hour in the vertical plane for the fill shown in figure 21.

Considering elastic scattering at IP and following [5]:

\[
\frac{d\epsilon}{dt} = N_{ip} \beta^*_x L \sigma_{el}(\theta^2_x) / (N_b N_p)
\]

where \(N_{ip}\) is the number of interaction points, \(\beta^*_x\) is the horizontal beta function at the IP, \(L\) is the luminosity, \(\sigma_{el}\) is the elastic cross-section, \(\sqrt{\langle \theta_x^2 \rangle}\) is the rms proton-proton scattering angle, \(N_b\) is the number of bunches, \(N_p\) is the number of protons per bunch.

The rms scattering angle is given by:

\[
\sqrt{\langle \theta_x^2 \rangle} = (bS/2)^{-1/2}
\]

where \(b\) is the slope parameter and \(S\) is the Lorentz invariant. Using a \(b\) of \(\approx 19.9\) GeV\(^{-2}\), a \(\sigma_{el}\) of 27.1 mbarn at 4 TeV [2] one obtains a emittance growth rate \((d\epsilon/dt)\) of 0.028 micron/hour (in both planes of course). This represents around 20% of the initial growth rate.
Equation 5 shows a dependency of $d\epsilon / dt$ on luminosity and bunch population. Feeding in luminosity and bunch current as a function of time into equation 5, the normalized emittance contribution due to elastic scattering as a typical fill develops is shown in figure 24. More systematic study would be required but these numbers imply that around 70% of the observed growth rate might be attributed to elastic scattering and IBS. The fact that vertical growth rates are of the same order of magnitude as the horizontal growth rates suggests that coupling might be feeding IBS from the horizontal to the vertical plane.

If one assumes Gaussian beams, the observed emittance growth is not enough to explain the observed beam loss on the aperture limits defined by the collimators. In colliding beams there are processes driving diffusion – a significant percentage of the beam is being pushed into the tails and on to the collimators.

7 Luminosity lifetime breakdown

Having explored emittance growth, the luminosity lifetime may be revisited. The luminosity lifetime may be broken down into the following components:

- beam loss to luminosity;
- beam loss to collimators;
- beam loss to other mechanisms;
- emittance growth;
- changes to geometric reduction factor and hour glass factor;
- (parasitic separation at the IP due to orbit drifts).

In terms of the usual parametrization of luminosity:

$$\frac{1}{L} \frac{dL}{dt} = \frac{1}{I_1} \frac{dI_1}{dt} + \frac{1}{I_2} \frac{dI_2}{dt} + \frac{1}{\sigma_x} \frac{d\sigma_x}{dt} + \frac{1}{\sigma_y} \frac{d\sigma_y}{dt} + \frac{1}{\mathcal{H}} \frac{d\mathcal{H}}{dt} + \frac{1}{\mathcal{F}} \frac{d\mathcal{F}}{dt}$$  \hspace{1cm} (7)

where $I_1$ is the beam 1 current; $I_2$ is the beam 2 current; $\sigma_x$ is the horizontal beam size at the interaction point (assumed equal for beam 1 and beam 2); $\sigma_y$ is the horizontal beam size at the...
interaction point (assumed equal for beam 1 and beam 2); $H$ is the hour glass factor; and $F$ is the geometric luminosity reduction factor.

Given the above breakdown of the single beam lifetime, and derived emittance growth, the luminosity lifetime can now be broken down into components. The results for typical fills are shown in figures 25 and 26.

- The relative importance of emittance growth and beam loss to both luminosity and collimation and its evolution through a fill can be seen. Luminosity lifetime in 2012 was dominated by losses rather than emittance growth – particularly as a fill developed and the emittance growth rate fell. The main contributions to the luminosity lifetime can be combined via:

\[
\frac{1}{\tau_L} = \frac{1}{\tau_{loss}} + \frac{1}{\tau_{\epsilon\text{eff}}} 
\]

Here $\tau_{loss}$ is the combined single beam losses rates for both beams which as we have seen very well reproduces the single beam lifetimes. $\tau_{\epsilon\text{eff}}$ is the inverse effective emittance growth rate.

- Good agreement between the fit to luminosity and the combined components is observed.

- The shorter time resolution of the losses component also clearly shows the poor lifetime at start of fill.

\[\text{Table 2: Approximate luminosity lifetime breakdown for illustrated fills at start and after 2 hours of the fill. Fill 2710 (poor beam 2 lifetime at start of fill) and fill 3192. All numbers in hours.}\]

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{Fill} & \text{time in fill} & \text{Luminosity lifetime} & \text{Losses lifetime} & \text{Emittance lifetime} \\
\hline
2710 & 0 & 2.4 & 2.8 & 17.3 \\
2710 & 2 & 10.4 & 19.0 & 23.1 \\
3192 & 0 & 4.9 & 7.1 & 15.6 \\
3192 & 2 & 8.1 & 12.7 & 22.2 \\
\hline
\end{array}
\]
8 Conclusions

- Single beam lifetimes in Stable Beams were reconstructed from consideration of losses to luminosity and losses to collimation. To be clear this implies that the two principle components of single beam losses are losses in IR7 and losses to luminosity. The concentration of losses in IR7 are due to the tighter collimator settings used in 2012.

- In 2012 the losses in IR3 correlate with the discrepancy between the integral of combined losses, and the losses measured by the BCT.

- The breakdown of single beam lifetime shows that in 2012 the loss of protons to collimation ranged between 40 and 60% of the total losses in a fill, and thus were close to the total losses to luminosity.

- In 2011 losses to IR7 and indeed total losses were significantly lower, reflecting the more relaxed collimator settings. There were also relatively more losses in IR3 in 2011.

- Losses to collimation through a fill increased after the OPC suggesting less than ideal optimization of octupole and chromaticity settings in Stable Beams following the OPC.

- A sliding window fit to the GPD luminosity measurements show a luminosity lifetime that starts at around 5 to 6 hours at the beginning of a high luminosity fill, climbing to 10 to 15 hours as the fill develops. Besides luminosity burn, there are significant contribution to the luminosity lifetime due to losses on collimators and initially emittance growth. These are quantified.

- $\frac{d\epsilon}{dt}$ is calculated to be around 0.15 micron/hour at the start of fill. The growth rate falls as the fill progresses. Data from luminous region measurements shows similar rates of growth in both the horizontal and vertical planes. The contribution to emittance growth due to elastic proton-proton scattering at the high luminosity interaction points is estimated to be around 20% of the total emittance growth. The IBS growth rate evaluated using the MADX IBS module gives a contribution of around 50% to the total initial rate in the horizontal plane.

Together IBS and elastic scattering account for, of the order, 70% of the observed effective emittance growth in the horizontal plane. Assuming no coupling, the combined effect is around 30% in the vertical plane.
• Losses in the first hour were systematically high contributing to the low luminosity lifetime. Given that beam-beam limit phenomenon is observed in degradation of luminosity lifetime and/or beam lifetime in hadron colliders, one might conclude that this regime has been experienced and that the “beam-beam tolerance” observed in Run 1 was thanks to a remarkably efficient collimation system.

References

[1] B. Salvachua et al, Lifetime analysis at high intensity colliders applied to the LHC, Proceedings of IPAC2013, Shanghai, China.


