# THE HL-LHC OPERATIONAL SCENARIOS: MACHINE PARAMETERS

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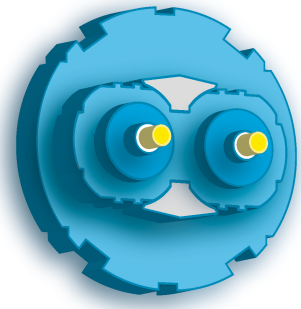

High Luminosity LHC

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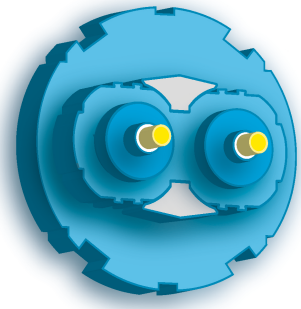

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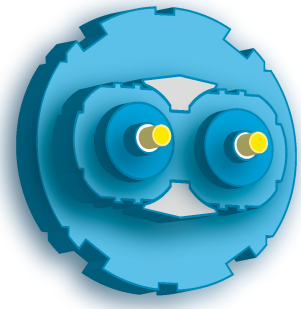

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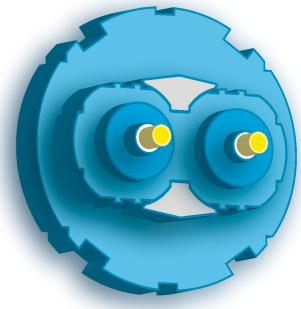

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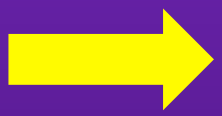

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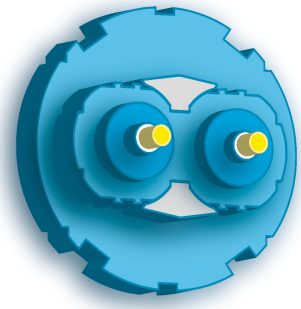

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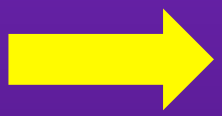

HL-LHC parameters page (PLC, 16/12/2014)

- The 2 baseline HL-LHC operational scenarios => Beam and machine parameters from injection till stable beams
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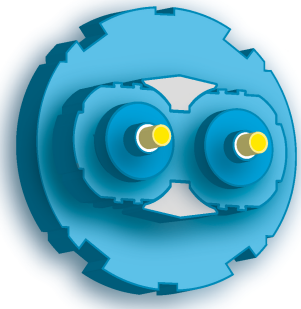

High Luminosity LHC

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  - **NOMINAL (pile-up of 140 events / crossing)**
  - **ULTIMATE (pile-up of 210 events / crossing)**

- ***The LHC physics programme will also provide lead collisions to ALICE & ATLAS & CMS (overall goal to accumulate 10 $nb^{-1}$ during the whole LHC operating period after Run 2)***

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- **Parameters assumed for HL-LHC performance estimates**

| | |
|---|---|
| Scheduled physics time for p-p luminosity production/year ($T_{phys}$) [days] | 160 |
| Minimum turn-around time [h] | 3 |
| Performance efficiency – goal [%] | 50 |
| Pile-up limit IP1/5 [events/crossing] | 140 / 200 |
| Pile-up density limit – IP1/5 [events/mm/crossing] | 1.3 |
| Visible cross-section IP1/5 [mb] | 85 |

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| | |
|---|---|
| Scheduled physics time for p-p luminosity production/year ($T_{phys}$) [days] | 160 |
| Minimum turn-around time [h] | 3 |
| Performance efficiency – goal [%] | 50 |
| Pile-up limit IP1/5 [events/crossing] | 140 / 200 |
| Pile-up density limit – IP1/5 [events/mm/crossing] | 1.3 |
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210

# HL-LHC parameters page as of 16/12/2014 (Parameters and Layout Committee)

| Parameter | Nominal LHC (design report) | HL-LHC 25ns (standard) | HL-LHC 25ns (BCMS) [9] | HL-LHC 50ns |
|---|---|---|---|---|
| Beam energy in collision [TeV] | 7 | 7 | 7 | 7 |
| $N_b$ | 1.15E+11 | 2.2E+11 | 2.2E+11 | 3.5E+11 |
| $n_b$ | 2808 | 2748 | 2604 | 1374 |
| Number of collisions in IP1 and IP5 [1] | 2808 | 2736 | 2592 | 1368 |
| $N_{tot}$ | 3.2E+14 | 6.0E+14 | 5.7E+14 | 4.9E+14 |
| beam current [A] | 0.58 | 1.09 | 1.03 | 0.89 |
| x-ing angle [µrad] | 285 | 590 | 590 | 590 |
| beam separation [σ] | 9.4 | 12.5 | 12.5 | 11.4 |
| $\beta^*$ [m] | 0.55 | 0.15 | 0.15 | 0.15 |
| $\varepsilon_n$ [µm] | 3.75 | 2.50 | 2.50 | 3 |
| $\varepsilon_L$ [eVs] | 2.50 | 2.50 | 2.50 | 2.50 |
| r.m.s. energy spread | 1.13E-04 | 1.13E-04 | 1.13E-04 | 1.13E-04 |
| r.m.s. bunch length [m] | 7.55E-02 | 7.55E-02 | 7.55E-02 | 7.55E-02 |
| IBS horizontal [h] | 80 -> 106 | 18.5 | 18.5 | 17.2 |
| IBS longitudinal [h] | 61 -> 60 | 20.4 | 20.4 | 16.1 |
| Piwinski parameter | 0.65 | 3.14 | 3.14 | 2.87 |
| Total loss factor R0 without crab-cavity | 0.836 | 0.305 | 0.305 | 0.331 |
| Total loss factor R1 with crab-cavity | (0.981) | 0.829 | 0.829 | 0.838 |
| beam-beam / IP without Crab Cavity | 3.1E-03 | 3.3E-03 | 3.3E-03 | 4.7E-03 |
| beam-beam / IP with Crab cavity | 3.8E-03 | 1.1E-02 | 1.1E-02 | 1.4E-02 |
| Peak Luminosity without crab-cavity [$cm^{-2}\ s^{-1}$] | 1.00E+34 | 7.18E+34 | 6.80E+34 | 8.44E+34 |
| Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [$cm^{-2}\ s^{-1}$] | (1.18E+34) | 19.54E+34 | 18.52E+34 | 21.38E+34 |
| Events / crossing without levelling and without crab-cavity | 27 | 198 | 198 | 454 |
| Levelled Luminosity [$cm^{-2}\ s^{-1}$] | - | 5.00E+34 [5] | 5.00E+34 | 2.50E+34 |
| Events / crossing (with leveling and crab-cavities for HL-LHC) [8] | 27 | 138 | 146 | 135 |
| Peak line density of pile up event [event/mm] (max over stable beams) | 0.21 | 1.25 | 1.31 | 1.20 |
| Leveling time [h] (assuming no emittance growth) [8] | - | 8.3 | 7.6 | 18.0 |
| Number of collisions in IP2/IP8 | 2808 | 2452/2524 [7] | 2288/2396 | 0 [4]/1262 |
| $N_b$ at LHC injection [2] | 1.20E+11 | 2.30E+11 | 2.30E+11 | 3.68E+11 |
| $n_b$ / injection | 288 | 288 | 288 | 144 |
| $N_{tot}$ / injection | 3.46E+13 | 6.62E+13 | 6.62E+13 | 5.30E+13 |
| $\varepsilon_n$ at SPS extraction [µm] [3] | 3.40 | 2.00 | < 2.00 [6] | 2.30 |

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1.08E-4

8.1 cm

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| $n_b$ / injection | 288 | 288 | 288 | 144 |
| $N_{tot}$ / injection | 3.46E+13 | 6.62E+13 | 6.62E+13 | 5.30E+13 |
| $\varepsilon_n$ at SPS extraction [µm] [3] | 3.40 | 2.00 | < 2.00 [6] | 2.30 |

1.08E-4

8.1 cm

# HL-LHC parameters page as of 16/12/2014 (Parameters and Layout Committee)

| Parameter | Nominal LHC (design report) | HL-LHC 25ns (standard) | HL-LHC 25ns (BCMS) [9] | HL-LHC 50ns |
|---|---|---|---|---|
| Beam energy in collision [TeV] | 7 | 7 | 7 | 7 |
| $N_b$ | 1.15E+11 | 2.2E+11 | 2.2E+11 | 3.5E+11 |
| $n_b$ | 2808 | 2748 | 2604 | 1374 |
| Number of collisions in IP1 and IP5 [1] | 2808 | 2736 | 2592 | 1368 |
| $N_{tot}$ | 3.2E+14 | 6.0E+14 | 5.7E+14 | 4.9E+14 |
| beam current [A] | 0.58 | 1.09 | 1.03 | 0.89 |
| x-ing angle [µrad] | 285 | 590 | 590 | 590 |
| beam separation [σ] | 9.4 | 12.5 | 12.5 | 11.4 |
| $\beta^*$ [m] | 0.55 | 0.15 | 0.15 | 0.15 |
| $\varepsilon_n$ [µm] | 3.75 | 2.50 | 2.50 | 3 |
| $\varepsilon_L$ [eVs] | 2.50 | 2.50 | 2.50 | 2.50 |
| r.m.s. energy spread | 1.13E-04 | 1.13E-04 | 1.13E-04 | 1.13E-04 |
| r.m.s. bunch length [m] | 7.55E-02 | 7.55E-02 | 7.55E-02 | 7.55E-02 |
| IBS horizontal [h] | 80 -> 106 | 18.5 | 18.5 | 17.2 |
| IBS longitudinal [h] | 61 -> 60 | 20.4 | 20.4 | 16.1 |
| Piwinski parameter | 0.65 | 3.14 | 3.14 | 2.87 |
| Total loss factor R0 without crab-cavity | 0.836 | 0.305 | 0.305 | 0.331 |
| Total loss factor R1 with crab-cavity | (0.981) | 0.829 | 0.829 | 0.838 |
| beam-beam / IP without Crab Cavity | 3.1E-03 | 3.3E-03 | 3.3E-03 | 4.7E-03 |
| beam-beam / IP with Crab cavity | 3.8E-03 | 1.1E-02 | 1.1E-02 | 1.4E-02 |
| Peak Luminosity without crab-cavity [$cm^{-2}\,s^{-1}$] | 1.00E+34 | 7.18E+34 | 6.80E+34 | 8.44E+34 |
| Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [$cm^{-2}\,s^{-1}$] | (1.18E+34) | 19.54E+34 | 18.52E+34 | 21.38E+34 |
| Events / crossing without levelling and without crab-cavity | 27 | 198 | 198 | 454 |
| Levelled Luminosity [$cm^{-2}\,s^{-1}$] | - | 5.00E+34 [5] | 5.00E+34 | 2.50E+34 |
| Events / crossing (with leveling and crab-cavities for HL-LHC) [8] | 27 | 138 | 146 | 135 |
| Peak line density of pile up event [event/mm] (max over stable beams) | 0.21 | 1.25 | 1.31 | 1.20 |
| Leveling time [h] (assuming no emittance growth) [8] | - | 8.3 | 7.6 | 18.0 |
| Number of collisions in IP2/IP8 | 2808 | 2452/2524 [7] | 2288/2396 | 0 [4]/1262 |
| $N_b$ at LHC injection [2] | 1.20E+11 | 2.30E+11 | 2.30E+11 | 3.68E+11 |
| $n_b$ / injection | 288 | 288 | 288 | 144 |
| $N_{tot}$ / injection | 3.46E+13 | 6.62E+13 | 6.62E+13 | 5.30E+13 |
| $\varepsilon_n$ at SPS extraction [µm] [3] | 3.40 | 2.00 | < 2.00 [6] | 2.30 |

1.08E-4

8.1 cm

# HL-LHC parameters page as of 16/12/2014 (Parameters and Layout Committee)

| Parameter | Nominal LHC (design report) | HL-LHC 25ns (standard) | HL-LHC 25ns (BCMS) [9] | HL-LHC 50ns |
|---|---|---|---|---|
| Beam energy in collision [TeV] | 7 | 7 | 7 | 7 |
| $N_b$ | 1.15E+11 | 2.2E+11 | 2.2E+11 | 3.5E+11 |
| $n_b$ | 2808 | 2748 | 2604 | 1374 |
| Number of collisions in IP1 and IP5 [1] | 2808 | 2736 | 2592 | 1368 |
| $N_{tot}$ | 3.2E+14 | 6.0E+14 | 5.7E+14 | 4.9E+14 |
| beam current [A] | 0.58 | 1.09 | 1.03 | 0.89 |
| x-ing angle [µrad] | 285 | 590 | 590 | 590 |
| beam separation [σ] | 9.4 | 12.5 | 12.5 | 11.4 |
| $\beta^*$ [m] | 0.55 | 0.15 | 0.15 | 0.15 |
| $\varepsilon_n$ [µm] | 3.75 | 2.50 | 2.50 | 3 |
| $\varepsilon_L$ [eVs] | 2.50 | 2.50 | 2.50 | 2.50 |
| r.m.s. energy spread | 1.13E-04 | 1.13E-04 | 1.13E-04 | 1.13E-04 |
| r.m.s. bunch length [m] | 7.55E-02 | 7.55E-02 | 7.55E-02 | 7.55E-02 |
| IBS horizontal [h] | 80 -> 106 | 18.5 | 18.5 | 17.2 |
| IBS longitudinal [h] | 61 -> 60 | 20.4 | 20.4 | 16.1 |
| Piwinski parameter | 0.65 | 3.14 | 3.14 | 2.87 |
| Total loss factor R0 without crab-cavity | 0.836 | 0.305 | 0.305 | 0.331 |
| Total loss factor R1 with crab-cavity | (0.981) | 0.829 | 0.829 | 0.838 |
| beam-beam / IP without Crab Cavity | 3.1E-03 | 3.3E-03 | 3.3E-03 | 4.7E-03 |
| beam-beam / IP with Crab cavity | 3.8E-03 | 1.1E-02 | 1.1E-02 | 1.4E-02 |
| Peak Luminosity without crab-cavity [$cm^{-2}\,s^{-1}$] | 1.00E+34 | 7.18E+34 | 6.80E+34 | 8.44E+34 |
| Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [$cm^{-2}\,s^{-1}$] | (1.18E+34) | 19.54E+34 | 18.52E+34 | 21.38E+34 |
| Events / crossing without levelling and without crab-cavity | 27 | 198 | 198 | 454 |
| Levelled Luminosity [$cm^{-2}\,s^{-1}$] | - | 5.00E+34 [5] | 5.00E+34 | 2.50E+34 |
| Events / crossing (with leveling and crab-cavities for HL-LHC) [8] | 27 | 138 | 146 | 135 |
| Peak line density of pile up event [event/mm] (max over stable beams) | 0.21 | 1.25 | 1.31 | 1.20 |
| Leveling time [h] (assuming no emittance growth) [8] | - | 8.3 | 7.6 | 18.0 |
| Number of collisions in IP2/IP8 | 2808 | 2452/2524 [7] | 2288/2396 | 0 [4]/1262 |
| $N_b$ at LHC injection [2] | 1.20E+11 | 2.30E+11 | 2.30E+11 | 3.68E+11 |
| $n_b$ / injection | 288 | 288 | 288 | 144 |
| $N_{tot}$ / injection | 3.46E+13 | 6.62E+13 | 6.62E+13 | 5.30E+13 |
| $\varepsilon_n$ at SPS extraction [µm] [3] | 3.40 | 2.00 | < 2.00 [6] | 2.30 |

**=> HL-LHC aims to achieve a "virtual" peak lumi much higher than the acceptable lumi from detectors (~ 20E34 $cm^{-2}s^{-1}$) and to control the instantaneous lumi by "luminosity leveling"**

# THE 2 BASELINE HL-LHC OPERATIONAL SCENARIOS

# THE 2 BASELINE HL-LHC OPERATIONAL SCENARIOS

=> See https://espace.cern.ch/HiLumi/WP2/task4/Shared%20Documents/HLLHC-OperationalScenarios-FinalVersion_06-05-2015_EM.pdf

# THE 2 BASELINE HL-LHC OPERATIONAL SCENARIOS

=> See https://espace.cern.ch/HiLumi/WP2/task4/Shared%20Documents/HLLHC-OperationalScenarios-FinalVersion_06-05-2015_EM.pdf

- **Main assumptions**

# THE 2 BASELINE HL-LHC OPERATIONAL SCENARIOS

=> See https://espace.cern.ch/HiLumi/WP2/task4/Shared%20Documents/HLLHC-OperationalScenarios-FinalVersion_06-05-2015_EM.pdf

- **Main assumptions**
  - **ATS optics**

# THE 2 BASELINE HL-LHC OPERATIONAL SCENARIOS

=> See https://espace.cern.ch/HiLumi/WP2/task4/Shared%20Documents/HLLHC-OperationalScenarios-FinalVersion_06-05-2015_EM.pdf

- **Main assumptions**
  - ATS optics
  - New Mo-Gr collimators with a 5 μm Mo coating are installed, in LSS7 only

# THE 2 BASELINE HL-LHC OPERATIONAL SCENARIOS

=> See https://espace.cern.ch/HiLumi/WP2/task4/Shared%20Documents/HLLHC-OperationalScenarios-FinalVersion_06-05-2015_EM.pdf

- **Main assumptions**
  - ATS optics
  - New Mo-Gr collimators with a 5 μm Mo coating are installed, in LSS7 only
  - Leveling with β* in IP1&5 and // separation in IP2&8

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  - ATS optics
  - New Mo-Gr collimators with a 5 μm Mo coating are installed, in LSS7 only
  - Leveling with β* in IP1&5 and // separation in IP2&8
  - Few non-colliding bunches for the experiments (for background studies)

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  - New Mo-Gr collimators with a 5 μm Mo coating are installed, in LSS7 only
  - Leveling with β* in IP1&5 and // separation in IP2&8
  - Few non-colliding bunches for the experiments (for background studies)
  - Crab Cavities are active providing full compensation of the crossing angle in IP1&5. Reduction of the impedance of the Crab Cavities to the required level (and good control of the impedance of new equipment, in particular at large β values)

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- **Main assumptions**
  - ATS optics
  - New Mo-Gr collimators with a 5 μm Mo coating are installed, in LSS7 only
  - Leveling with β* in IP1&5 and // separation in IP2&8
  - Few non-colliding bunches for the experiments (for background studies)
  - Crab Cavities are active providing full compensation of the crossing angle in IP1&5. Reduction of the impedance of the Crab Cavities to the required level (and good control of the impedance of new equipment, in particular at large β values)
  - All the existing circuits should operate at their nominal performance (e.g. non-conformities observed so far should be repaired by Run 4)

- **SPS extraction**
  - Q20 optics
  - Gamma transition = 17.951
  - 10 MV in the 200 MHz RF cavities + 1 MV in the 800 MHz RF cavities (in bunch shortening mode)

| Parameters at SPS[1] extraction [2] | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches | 288 | |
| $\varepsilon_n$ [μm] | 2.00 | 1.40 |
| $\varepsilon_L$ [eVs] | 0.66 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 2.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 13.7 | |

- **SPS extraction**
  - Q20 optics
  - Gamma transition = 17.951
  - 10 MV in the 200 MHz RF cavities + 1 MV in the 800 MHz RF cavities (in bunch shortening mode)

| Parameters at SPS[1] extraction [2] | HL-LHC (standard) | HL-LHC (BCMS) |
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- **SPS extraction**
  - Q20 optics
  - Gamma transition = 17.951
  - 10 MV in the 200 MHz RF cavities + 1 MV in the 800 MHz RF cavities (in bunch shortening mode)

In case of excessive emittance blow-up in HL-LHC

| Parameters at SPS[1] extraction [2] | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches | 288 | |
| $\varepsilon_n$ [μm] | 2.00 | 1.40 |
| $\varepsilon_L$ [eVs] | 0.66 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 2.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 13.7 | |

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 | |
| $\varepsilon_L$ [eVs] | 0.7 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -170 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | 1930 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [μm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 | |
| $\varepsilon_L$ [eVs] | 0.7 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| β* [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [μrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [μrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [μrad] | ±1259 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [μrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [μrad] | -170 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [μrad] | 1930 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [μrad] | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [μm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 | |
| $\varepsilon_L$ [eVs] | 0.7 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| β* [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [μrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [μrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [μrad] | ±1259 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [μrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [μrad] | -170 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [μrad] | 1930 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [μrad] | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 | |
| $\varepsilon_L$ [eVs] | 0.7 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| β* [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -170 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | 1930 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 | |
| $\varepsilon_L$ [eVs] | 0.7 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -170 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | 1930 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
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| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -170 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | 1930 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 | |
| $\varepsilon_L$ [eVs] | 0.7 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -170 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | 1930 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 | |
| $\varepsilon_L$ [eVs] | 0.7 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -170 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | 1930 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 | |
| $\varepsilon_L$ [eVs] | 0.7 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at th[illegible] [µrad] | -170 (H) | |
| Half crossing angle at | 1930 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

~ As used in 2012

| Parameters at the injection plateau after RF capture | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [μm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 | |
| $\varepsilon_L$ [eVs] | 0.7 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 | |
| β* [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[4] | |
| Tunes (H/V) | 62.28/60.31 | |
| Transition gamma (average B1/B2) | 53.83 | |
| Half crossing angle at the IP for ATLAS (IP1) [μrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [μrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [μrad] | ±1259 (V) | |
| Half parallel separation at th | ±2.0 (H) | |
| Half crossing | +295 (H) | |
| Half para | ±2.0 (V) | |
| Half exter | -170 (H) | |
| Half crossing a | 1930 (H) | |
| Half parallel angle at the I | ±30 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 [1,4] | |

**Negative sign => Better for 1-beam impedance induced instabilities. ± 6.5 A used in 2012**

| Parameters during ramp | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 - 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 (0.45 TeV) to 16 (7 TeV) linearly with time | |
| $\varepsilon_L$ [eVs] | 0.7 (0.45 TeV) to 2.5 (7 TeV) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 (0.45 TeV) to 1.08 (7 TeV) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 (0.45 TeV) to 8.1 (7 TeV) | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[6] (0.45 TeV) - HL-LHCV1.1 end of ramp[7] (7 TeV) | |
| Tunes (H/V) | 62.28/60.31 to 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.83 to 53.86 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) [5] | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (0.45 TeV) to ±240 (7 TeV) (V) scaling with p | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) [5] | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | 1930 (0.45 TeV) to -115 (7 TeV) (H) scaling with p | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (0.45 TeV) to 0 (7 TeV) (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 to ±2.0 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 (0.45 TeV) to -570[8] (7 TeV) scaling with ~ $p^2$ [1,4] | |

| Parameters during ramp | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 - 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 (0.45 TeV) to 16 (7 TeV) linearly with time | |
| $\varepsilon_L$ [eVs] | 0.7 (0.45 TeV) to 2.5 (7 TeV) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 (0.45 TeV) to 1.08 (7 TeV) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 (0.45 TeV) to 8.1 (7 TeV) | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[6] (0.45 TeV) - HL-LHCV1.1 end of ramp[7] (7 TeV) | |
| Tunes (H/V) | 62.28/60.31 to 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.83 to 53.86 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) [5] | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (0.45 TeV) to ±240 (7 TeV) (V) scaling with p | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) [5] | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | 1930 (0.45 TeV) to -115 (7 TeV) (H) scaling with p | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (0.45 TeV) to 0 (7 TeV) (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 to ±2.0 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 (0.45 TeV) to -570[8] (7 TeV) scaling with ~ $p^2$ [1,4] | |

| Parameters during ramp | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 - 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 (0.45 TeV) to 16 (7 TeV) linearly with time | |
| $\varepsilon_L$ [eVs] | 0.7 (0.45 TeV) to 2.5 (7 TeV) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 (0.45 TeV) to 1.08 (7 TeV) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 (0.45 TeV) to 8.1 (7 TeV) | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[6] (0.45 TeV) - HL-LHCV1.1 end of ramp[7] (7 TeV) | |
| Tunes (H/V) | 62.28/60.31 to 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.83 to 53.86 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) [5] | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (0.45 TeV) to ±240 (7 TeV) (V) scaling with p | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) [5] | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | 1930 (0.45 TeV) to -115 (7 TeV) (H) scaling with p | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (0.45 TeV) to 0 (7 TeV) (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 to ±2.0 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 (0.45 TeV) to -570[8] (7 TeV) scaling with ~ $p^2$ [1,4] | |

| Parameters during ramp | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 - 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 (0.45 TeV) to 16 (7 TeV) linearly with time | |
| $\varepsilon_L$ [eVs] | 0.7 (0.45 TeV) to 2.5 (7 TeV) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 (0.45 TeV) to 1.08 (7 TeV) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 (0.45 TeV) to 8.1 (7 TeV) | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[6] (0.45 TeV) - HL-LHCV1.1 end of ramp[7] (7 TeV) | |
| Tunes (H/V) | 62.28/60.31 to 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.83 to 53.86 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) [5] | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (0.45 TeV) to ±240 (7 TeV) (V) scaling with p | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) [5] | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | 1930 (0.45 TeV) to -115 (7 TeV) (H) scaling with p | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (0.45 TeV) to 0 (7 TeV) (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 to ±2.0 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 (0.45 TeV) to -570[8] (7 TeV) scaling with ~ $p^2$ [1,4] | |

| Parameters during ramp | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 - 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 (0.45 TeV) to 16 (7 TeV) linearly with time | |
| $\varepsilon_L$ [eVs] | 0.7 (0.45 TeV) to 2.5 (7 TeV) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 (0.45 TeV) to 1.08 (7 TeV) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 (0.45 TeV) to 8.1 (7 TeV) | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[6] (0.45 TeV) - HL-LHCV1.1 end of ramp[7] (7 TeV) | |
| Tunes (H/V) | 62.28/60.31 to 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.83 to 53.86 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) [5] | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (0.45 TeV) to ±240 (7 TeV) (V) scaling with p | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) [5] | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | 1930 (0.45 TeV) to -115 (7 TeV) (H) scaling with p | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | ±30 (0.45 TeV) to 0 (7 TeV) (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 to ±2.0 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 (0.45 TeV) to -570[8] (7 TeV) scaling with ~ $p^2$ [1,4] | |

| Parameters during ramp | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 - 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 (0.45 TeV) to 16 (7 TeV) linearly with time | |
| $\varepsilon_L$ [eVs] | 0.7 (0.45 TeV) to 2.5 (7 TeV) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 (0.45 TeV) to 1.08 (7 TeV) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 (0.45 TeV) to 8.1 (7 TeV) | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[6] (0.45 TeV) - HL-LHCV1.1 end of ramp[7] (7 TeV) | |
| Tunes (H/V) | 62.28/60.31 to 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.83 to 53.86 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) [5] | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (0.45 TeV) to ±240 (7 TeV) (V) scaling with p | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) [5] | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half cros | 1930 (0.45 TeV) to -115 (7 TeV) (H) scaling with p | |
| Half para | ±30 (0.45 TeV) to 0 (7 TeV) (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 to ±2.0 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 (0.45 TeV) to -570[8] (7 TeV) scaling with ~ $p^2$ [1,4] | |

Maximum available current

| Parameters during ramp | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 0.45 - 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 8 (0.45 TeV) to 16 (7 TeV) linearly with time | |
| $\varepsilon_L$ [eVs] | 0.7 (0.45 TeV) to 2.5 (7 TeV) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 3.7 (0.45 TeV) to 1.08 (7 TeV) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 10.4 (0.45 TeV) to 8.1 (7 TeV) | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 | |
| Optics | HL-LHCV1.1 injection[6] (0.45 TeV) - HL-LHCV1.1 end of ramp[7] (7 TeV) | |
| Tunes (H/V) | 62.28/60.31 to 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.83 to 53.86 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) [5] | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±1259 (0.45 TeV) to ±240 (7 TeV) (V) scaling with p | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) [5] | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | | |
| Half parallel separation at the IP for CMS (IP5) [mm] | | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | | |
| Half cros | 1930 (0.45 TeV) to V) (H) scaling with p | |
| Half para | ±30 (0.45 TeV) to V) (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±3.5 to ±2.0 (V) | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [1] | |
| Landau octupole Current (LOF) [A] | -20 (0.45 TeV) to -570[8] (7 TeV) scaling with ~ $p^2$ [1,4] | |

To keep the same tune spread

Maximum available current

**From here onwards, we have to distinguish between NOMINAL and ULTIMATE scenarios**

From here onwards, we have to distinguish between NOMINAL and ULTIMATE scenarios

# NOMINAL

| Parameters during pre-squeeze (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [μm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 to 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 end of ramp[9] to HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.86 to 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [μrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [μrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [μrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [μrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0(V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5][μrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][μrad] | -115(H) | |
| Half parallel angle at the IP for LHCb (IP8) [μrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters during pre-squeeze (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 to 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 end of ramp[9] to HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.86 to 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0(V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5][µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | -115(H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters during pre-squeeze (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 to 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 end of ramp[9] to HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.86 to 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0(V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5][µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | -115(H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

To limit luminosity

| Parameters during pre-squeeze (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 to 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 end of ramp[9] to HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.86 to 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0(V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5][µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | -115(H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters during pre-squeeze (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 to 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 end of ramp[9] to HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gar | 53.86 to 53.78 | |
| Half crossing a | ±295 (V) | |
| Half parallel se | ±2.0 (H) | |
| Half external cross | ±170 (V) | |
| Half crossing angle at the I | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0(V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5][µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | -115(H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

**Separation preserved => Better for stability diagram with octupoles (LOF < 0) and BBLR**

| Parameters during pre-squeeze (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 to 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 end of ramp[9] to HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.86 to 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0(V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5][µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5][µrad] | -115(H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters during pre-squeeze (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 to 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 end of ramp[9] to HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.86 to 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [ | +295 (H) | |
| Half parallel separation at the IP for | ±2.0(V) | |
| Half external crossing angle at the | -250(H) | |
| Half crossing angle at the IP for LHC | -115(H) | |
| Half parallel angle at the IP for LHCb (IP8) [ | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

To optimize the required octupole current and DA

| Parameters for the collision process (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ $cm^{-2}s^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit)[cm] | 8.1 | |
| β* [m] in IP1/2/5/8 | 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[12] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[13] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ $cm^{-2}s^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit)[cm] | 8.1 | |
| β* [m] in IP1/2/5/8 | 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[12] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[13] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ $cm^{-2}s^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit)[cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[12] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[13] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ $cm^{-2}s^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit)[cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[12] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[13] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit)[cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[12] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[13] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ $cm^{-2}s^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit)[cm] | 8.1 | |
| β* [m] in IP1/2/5/8 | 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[12] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[13] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ $cm^{-2}s^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit)[cm] | 8.1 | |
| β* [m] in IP1/2/5/8 | 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[12] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[13] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit)[cm] | 8.1 | |
| β* [m] in IP1/2/5/8 | 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[12] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[13] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit)[cm] | 8.1 | |
| β* [m] in IP1/2/5/8 | 0.7/10/0.7/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2.0 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[12] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2.0 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[13] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters in stable beams (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 (start of fill) | |
| $\varepsilon_n$ [µm] | 2.5 (start of fill) | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| Levelling method in IP1/2/5/8 | β*/separation/β*/separation | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 (start of fill) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 (start of fill) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 (start of fill) | |
| β* [m] in IP1/2/5/8 | 0.7 to 0.15/10/0.7 to 0.15/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) to HL-LHCV1.1 pre-squeeze (0.44 m)[14] to HL-LHCV1.1 collision round (0.15 m)[15] | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 to 53.73 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) [7] | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) [7] | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±0.138[16] to 0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) [7] | |
| Half parallel separation at the IP for CMS (IP5) [mm] | 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) [7] | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±0.043[17] to 0 (V) [1] | |
| Transverse damper damping time [turns] | 50[18] [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3[18] [6,8] | |
| Landau octupole Current (LOF) [A] | -570[18] [1,4,8] | |

| Parameters in stable beams (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 (start of fill) | |
| $\varepsilon_n$ [µm] | 2.5 (start of fill) | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| Levelling method in IP1/2/5/8 | β*/separation/β*/separation | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 (start of fill) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 (start of fill) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 (start of fill) | |
| β* [m] in IP1/2/5/8 | 0.7 to 0.15/10/0.7 to 0.15/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) to HL-LHCV1.1 pre-squeeze (0.44 m)[14] to HL-LHCV1.1 collision round (0.15 m)[15] | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 to 53.73 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) [7] | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) [7] | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±0.138[16] to 0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) [7] | |
| Half parallel separation at the IP for CMS (IP5) [mm] | 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) [7] | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±0.043[17] to 0 (V) [1] | |
| Transverse damper damping time [turns] | 50[18] [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3[18] [6,8] | |
| Landau octupole Current (LOF) [A] | -570[18] [1,4,8] | |

| Parameters in stable beams (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 (start of fill) | |
| $\varepsilon_n$ [µm] | 2.5 (start of fill) | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| Levelling method in IP1/2/5/8 | β*/separation/β*/separation | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 (start of fill) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 (start of fill) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 (start of fill) | |
| β* [m] in IP1/2/5/8 | 0.7 to 0.15/10/0.7 to 0.15/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) to HL-LHCV1.1 pre-squeeze (0.44 m)[14] to HL-LHCV1.1 collision round (0.15 m)[15] | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 to 53.73 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) [7] | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) [7] | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±0.138[16] to 0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) [7] | |
| Half parallel separation at the IP for CMS (IP5) [mm] | 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) [7] | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±0.043[17] to 0 (V) [1] | |
| Transverse damper damping time [turns] | 50[18] [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3[18] [6,8] | |
| Landau octupole Current (LOF) [A] | -570[18] [1,4,8] | |

| Parameters in stable beams (nominal) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 (start of fill) | |
| $\varepsilon_n$ [µm] | 2.5 (start of fill) | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 140/140/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 5.1/0.001/5.1/0.17 | 4.8/0.001/4.8/0.16 |
| Levelling method in IP1/2/5/8 | β*/separation/β*/separation | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 (start of fill) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 (start of fill) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 (start of fill) | |
| β* [m] in IP1/2/5/8 | 0.7 to 0.15/10/0.7 to 0.15/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.7 m) to HL-LHCV1.1 pre-squeeze (0.44 m)[14] to HL-LHCV1.1 collision round (0.15 m)[15] | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 to 53.73 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) [7] | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) [7] | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±0.138[16] to 0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) [7] | |
| Half parallel separation at the IP for CMS (IP5) [mm] | 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) [7] | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±0.043[17] to 0 (V) [1] | |
| Transverse damper damping time [turns] | 50[18] [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3[18] [6,8] | |
| Landau octupole Current (LOF) [A] | -570[18] [1,4,8] | |

# ULTIMATE

| Parameters during pre-squeeze (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 6/10/6/10 to 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 end of ramp to HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.86 to 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters during pre-squeeze (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| β* [m] in IP1/2/5/8 | 6/10/6/10 to 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 end of ramp to HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.86 to 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters during pre-squeeze (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.30 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Filling pattern | standard[2] | BCMS[3] |
| $\varepsilon_n$ [µm] | 2.0 | 1.6 |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| β* [m] in IP1/2/5/8 | 6/10/6/10 to 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 end of ramp to HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.86 to 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250 (H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) [3] | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 (V) [3] | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[19] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[20] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[19] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[20] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[19] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[20] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[19] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[20] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[19] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[20] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[19] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[20] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[19] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[20] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[19] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[20] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters for the collision process (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8 (at the end of the collision process)[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| $\varepsilon_n$ [µm] | 2.5 | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 | |
| $\beta^*$ [m] in IP1/2/5/8 | 0.46/10/0.46/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | ±2 to 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±2.0 to ±0.138[19] (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) | |
| Half parallel separation at the IP for CMS (IP5) [mm] | ±2 to 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±2 to ±0.043[20] (V) | |
| Delay in the start of the collision process in IP1/2/5/8 | Synchronised IP1 and IP5 to full head-on collision first, and then IP2 and IP8 | |
| Time to go in collision in IP1/5 (from 2 σ full separation to 0 σ) [s]. No time constraint for IP2/8 | < 1 | |
| Transverse damper damping time [turns] | 50 [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3 [6,8] | |
| Landau octupole Current (LOF) [A] | -570 [1,4,8] | |

| Parameters in stable beams (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 (start of fill) | |
| $\varepsilon_n$ [µm] | 2.5 (start of fill) | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ $cm^{-2}s^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| Levelling method in IP1/2/5/8 | β*/separation/β*/separation | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 (start of fill) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 (start of fill) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 (start of fill) | |
| β* [m] in IP1/2/5/8 | 0.46 to 0.15/10/0.46 to 0.15/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) to HL-LHCV1.1 pre-squeeze (0.44 m)[14] to HL-LHCV1.1 collision round (0.15 m)[15] | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 to 53.73 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) [7] | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) [7] | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±0.138[19] to 0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) [7] | |
| Half parallel separation at the IP for CMS (IP5) [mm] | 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) [7] | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±0.043[20] to 0 (V) | |
| Transverse damper damping time [turns] | 50[18] [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3[18] [6,8] | |
| Landau octupole Current (LOF) [A] | -570[18] [1,4,8] | |

| Parameters in stable beams (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 (start of fill) | |
| $\varepsilon_n$ [µm] | 2.5 (start of fill) | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| Levelling method in IP1/2/5/8 | β*/separation/β*/separation | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 (start of fill) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 (start of fill) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 (start of fill) | |
| β* [m] in IP1/2/5/8 | 0.46 to 0.15/10/0.46 to 0.15/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) to HL-LHCV1.1 pre-squeeze (0.44 m)[14] to HL-LHCV1.1 collision round (0.15 m)[15] | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 to 53.73 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) [7] | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) [7] | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±0.138[19] to 0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) [7] | |
| Half parallel separation at the IP for CMS (IP5) [mm] | 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) [7] | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±0.043[20] to 0 (V) | |
| Transverse damper damping time [turns] | 50[18] [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3[18] [6,8] | |
| Landau octupole Current (LOF) [A] | -570[18] [1,4,8] | |

| Parameters in stable beams (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 (start of fill) | |
| $\varepsilon_n$ [µm] | 2.5 (start of fill) | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| Levelling method in IP1/2/5/8 | β*/separation/β*/separation | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 (start of fill) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 (start of fill) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 (start of fill) | |
| β* [m] in IP1/2/5/8 | 0.46 to 0.15/10/0.46 to 0.15/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) to HL-LHCV1.1 pre-squeeze (0.44 m)[14] to HL-LHCV1.1 collision round (0.15 m)[15] | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 to 53.73 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) [7] | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) [7] | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±0.138[19] to 0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) [7] | |
| Half parallel separation at the IP for CMS (IP5) [mm] | 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) [7] | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±0.043[20] to 0 (V) | |
| Transverse damper damping time [turns] | 50[18] [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3[18] [6,8] | |
| Landau octupole Current (LOF) [A] | -570[18] [1,4,8] | |

| Parameters in stable beams (ultimate) | HL-LHC (standard) | HL-LHC (BCMS) |
|---|---|---|
| Beam total energy [TeV] | 7 | |
| Particles per bunch, $N$ [$10^{11}$] | 2.2 (start of fill) | |
| $\varepsilon_n$ [µm] | 2.5 (start of fill) | |
| Maximum number of bunches per beam | 2748 | 2604 |
| Number of colliding pairs in IP1/2/5/8[10] | 2736/2452/2736/2524 | 2592/2288/2592/2396 |
| Filling pattern | standard[2] | BCMS[3] |
| Levelled pile-up in IP1/5/8 | 210/210/4.5 | |
| Levelled luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$] in IP1/2/5/8[11] | 7.6/0.001/7.6/0.17 | 7.2/0.001/7.2/0.16 |
| Levelling method in IP1/2/5/8 | β*/separation/β*/separation | |
| Total RF voltage [MV] | 16 | |
| $\varepsilon_L$ [eVs] | 2.5 (start of fill) | |
| r.m.s. energy spread (Gaussian fit) [$10^{-4}$] | 1.08 (start of fill) | |
| r.m.s. bunch length (Gaussian fit) [cm] | 8.1 (start of fill) | |
| β* [m] in IP1/2/5/8 | 0.46 to 0.15/10/0.46 to 0.15/3 | |
| Optics | HL-LHCV1.1 pre-squeeze (0.46 m) to HL-LHCV1.1 pre-squeeze (0.44 m)[14] to HL-LHCV1.1 collision round (0.15 m)[15] | |
| Tunes (H/V) | 62.31/60.32 | |
| Transition gamma (average B1/B2) | 53.78 to 53.73 | |
| Half crossing angle at the IP for ATLAS (IP1) [µrad] | ±295 (V) [7] | |
| Half parallel separation at the IP for ATLAS (IP1) [mm] | 0 (H) | |
| Half external crossing angle at IP for ALICE (IP2) [µrad] | ±170 (V) | |
| Half crossing angle at the IP for ALICE (IP2)[5] [µrad] | ±240 (V) [7] | |
| Half parallel separation at the IP for ALICE (IP2) [mm] | ±0.138[19] to 0 (H) | |
| Half crossing angle at the IP for CMS (IP5) [µrad] | +295 (H) [7] | |
| Half parallel separation at the IP for CMS (IP5) [mm] | 0 (V) | |
| Half external crossing angle at the IP for LHCb (IP8)[5] [µrad] | -250(H) | |
| Half crossing angle at the IP for LHCb (IP8)[5] [µrad] | -115 (H) [7] | |
| Half parallel angle at the IP for LHCb (IP8) [µrad] | 0 (V) (1) | |
| Half parallel separation at IP for LHCb (IP8) [mm] | ±0.043[20] to 0 (V) | |
| Transverse damper damping time [turns] | 50[18] [1] | |
| Chromaticity Q' (dQ/(dp/p)) | +3[18] [6,8] | |
| Landau octupole Current (LOF) [A] | -570[18] [1,4,8] | |

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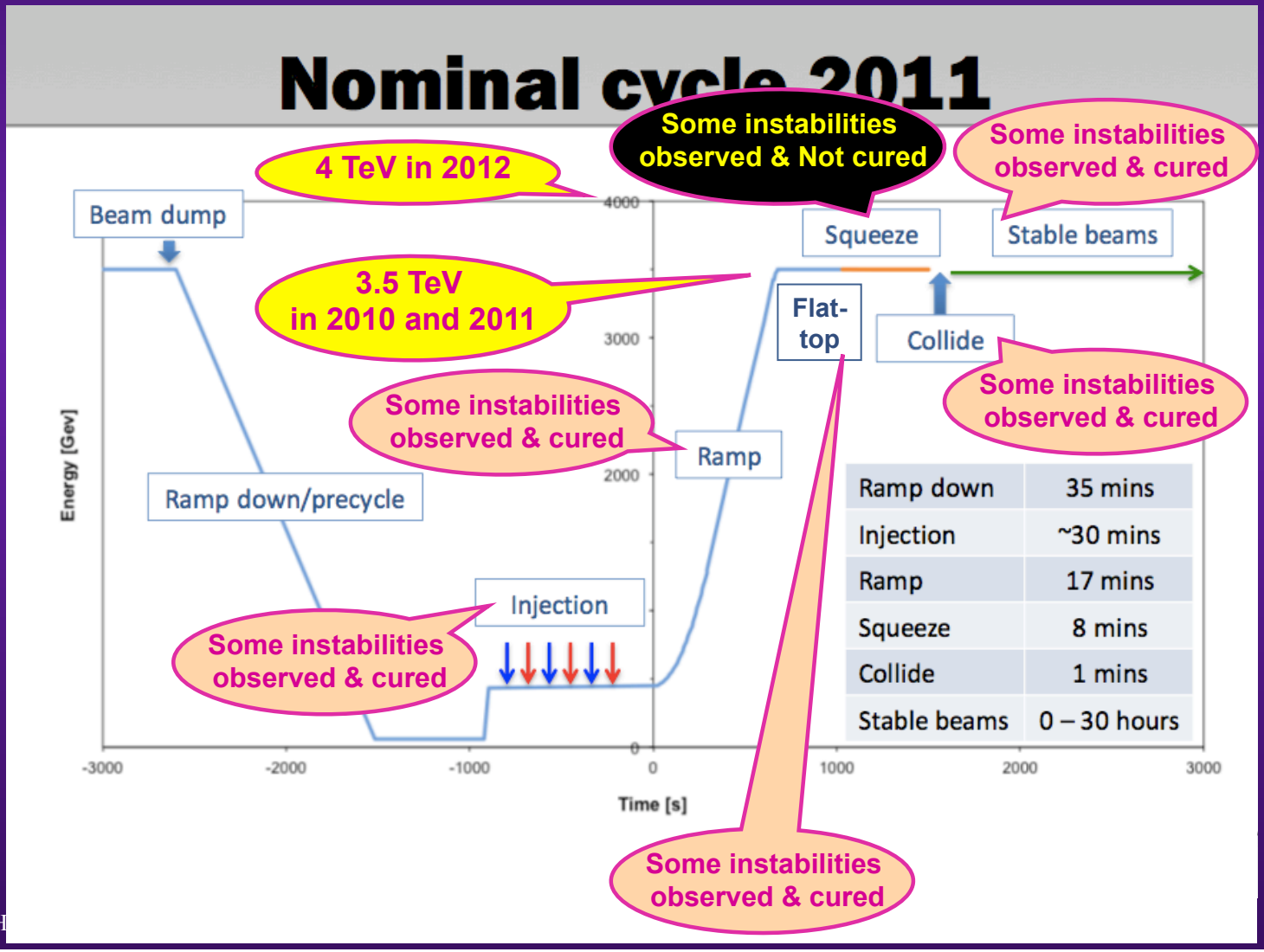

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  - **Others…**

# APPENDIX

# Footnotes for the PLC parameters

[1] Assuming one less batch from the PS for machine protection (pilot injection, TL steering with 12 nominal bunches) and non-colliding bunches for experiments (background studies…). Note that due to RF beam loading the abort gap length must not exceed the 3μs design value.

[2] An intensity loss of 5% distributed along the cycle is assumed from SPS extraction to collisions in the LHC.

[3] A transvere emittance blow-up of 10 to 15% on the average H/V emittance in addition to the 15% to 20% expected from intra-beam scattering (IBS) is assumed (to reach the 2.5 μm/3.0 μm of emmitance in collision for 25ns/50ns operation)

[4] As of 2012 ALICE collided main bunches against low intensity. satellite bunches (few per-mill of main bunch) produced during the generation of the 50ns beam in the injectors rather than two main bunches, hence the number of collisions is given as zero.

[5] For the design of the HL-LHC systems (collimators, triplet magnets,..), a design margin of 50% on the stated peak luminosity was agreed upon.

[6] For the BCMS scheme emittances down to 1.4 μm have already been achieved at LHC injection which might be used to mitigate excessive emittance blowup in the LHC during injection and ramp.

[7] The lower number of collissions in IR2/8 wrt to the general purpose detectors is a result of the agreed filling scheme, aiming as much as possible at a democratic sharing of collisions between the experiments.

[8] The total number of events/crossing is calculated with an inelastic cross-section of 85 mb (also for nominal), while 100 mb is still assumed for calculating the proton burn off and the resulting levelling time

[9] BCMS parameters are only considered for injection and as a backup parameter set in case one encounters larger than expected emittance growth in the HL-LHC during injection, ramp and squeeze