



## Performance of the new baseline (and other operational scenarios)

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## Unchanged parameters and assumptions

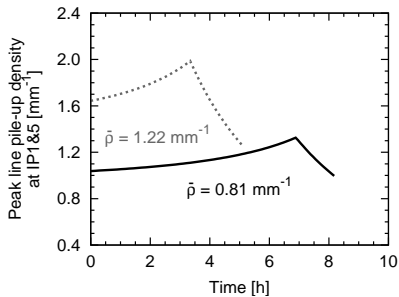
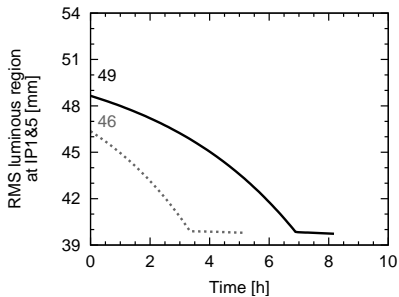
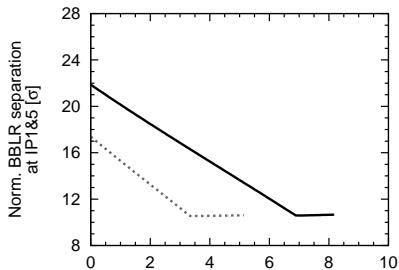
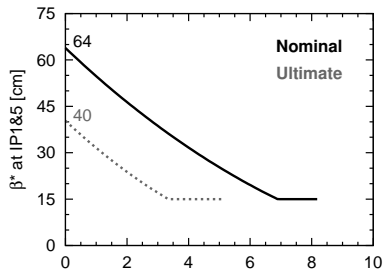
- ▶ 2 CCs for partial compensation of crossing angle ( $\sim 380 \mu\text{rad}$ ).
- ▶ Luminosity levelling with  $\beta^*$  at 2%.
- ▶ Crossing angle (in  $\mu\text{rad}$ ) is constant; norm. BBLR separation (in  $\sigma$ ) is reduced.
- ▶ Constant bunch length (7.6 cm q-Gaussian RMS, or FWHM of 21.2 cm).
  
- ▶ Evolution of emittance with intrabeam scattering and synchrotron radiation for both transverse planes (additional 40 h growth for vertical). No CC noise.
- ▶ Conservative cross section for burn-off: 111 mb (total).
- ▶ Cross-section for PU: 81 mb.

## Baseline: improved performance I

- ▶ Total number of bunches: **2760** (old: 2748).
- ▶ At IP1&5:
  - ▶ Number of colliding bunches: **2748** (old: 2736).
  - ▶ Minimum  $\beta^*$ : **15 cm** (old: 20 cm).
  - ▶ Minimum norm. BBLR separation:  **$10.6\sigma$**  (old:  $12.5\sigma$ ).
  - ▶ Full crossing angle: **500  $\mu$ rad** (old: 510  $\mu$ rad).
- ▶ At IP8: Number of colliding bunches: **2572** (old: 2524).
- ▶ Efficiency: **50 % for nom./ult.** (old: 50 % for nom., 58 % for ult.).
- ▶ Turn-around time: **145 min for nom., 150 min for ult.**  
(old: 3.12 h  $\approx$  187 min for nom./ult.).

| Parameter                             | Unit  | Baseline (Standard) |             |
|---------------------------------------|---|---------------------|-------------|
|                                       |   | Nominal             | Ultimate    |
| <i>At IP&amp;5:</i>                   |   |                     |             |
| Levelled luminosity                   | $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$            | 5.0                 | 7.5         |
| Levelled pile-up                      | 1   | 131                 | 197         |
| <b>Effective line pile-up density</b> | <b><math>\text{mm}^{-1}</math></b>                  | <b>0.81</b>         | <b>1.22</b> |
| Levelling time                        | h   | 7.0                 | 3.4         |
| Fill duration                         | h   | 8.2                 | 5.1         |
| <b>Yearly integrated luminosity</b>   | <b><math>\text{fb}^{-1}/160 \text{ days}</math></b> | <b>259</b>          | <b>321</b>  |
| Diff. w.r.t. base. std. nom.          | %   | ref.                | +24.0       |

## Baseline: improved performance II



## BCMS: Standard performance

- ▶ Total number of bunches: **2748** (old: 2604).
- ▶ At IP&5:
  - ▶ Number of colliding bunches: **2736** (old: 2604).
  - ▶ New baseline round optics.
  - ▶ Baseline levelled luminosities (they used to be smaller to match baseline pile-up).

| Parameter                             | Unit  | Baseline (Standard) |             | Baseline (BCMS) |             |
|---------------------------------------|---|---------------------|-------------|-----------------|-------------|
|                                       |   | Nominal             | Ultimate    | Nominal         | Ultimate    |
| <i>At IP&amp;5:</i>                   |   |                     |             |                 |             |
| Levelled luminosity                   | $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$            | 5.0                 | 7.5         | 5.0             | 7.5         |
| Levelled pile-up                      | 1   | 131                 | 197         | 132             | 197         |
| <b>Effective line pile-up density</b> | <b><math>\text{mm}^{-1}</math></b>                  | <b>0.81</b>         | <b>1.22</b> | <b>0.81</b>     | <b>1.22</b> |
| Levelling time                        | h   | 7.0                 | 3.4         | 6.8             | 3.3         |
| Fill duration                         | h   | 8.2                 | 5.1         | 8.1             | 5.1         |
| <b>Yearly integrated luminosity</b>   | <b><math>\text{fb}^{-1}/160 \text{ days}</math></b> | <b>259</b>          | <b>321</b>  | <b>258</b>      | <b>320</b>  |
| Diff. w.r.t. base. std. nom.          | %   | ref.                | +24.0       | -0.2            | +23.6       |
| Diff. w.r.t. base. std. ult.          | %   | -                   | ref.        | -               | -0.3        |

- ▶ BCMS optics, beam parameters, and performance, very similar to current HL-LHC Baseline Standard.

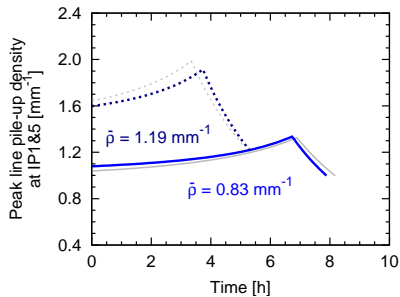
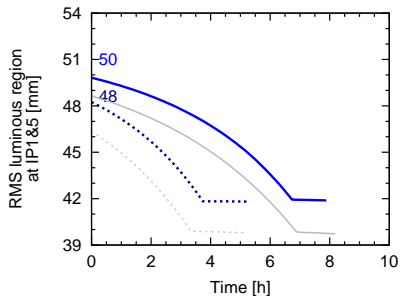
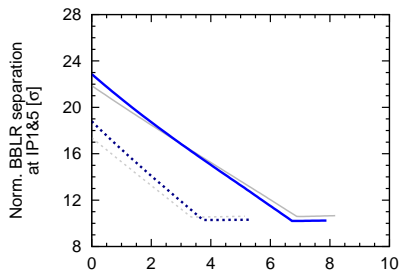
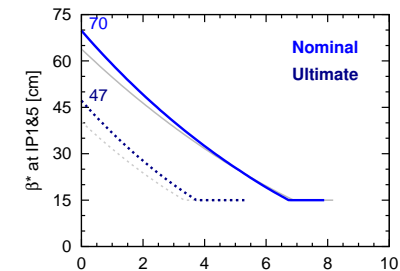
## 8b+4e: small performance change I

- ▶ Total number of bunches: **1972** (old: 1968).
- ▶ At IP&5:
  - ▶ Number of colliding bunches: **1967** (old: 1960).
  - ▶ New baseline round optics.
  - ▶ Full crossing angle: **470  $\mu$ rad** (old: 480  $\mu$ rad), due to smaller normalized transverse emittance (2.2  $\mu$ rad) w.r.t. baseline optics.

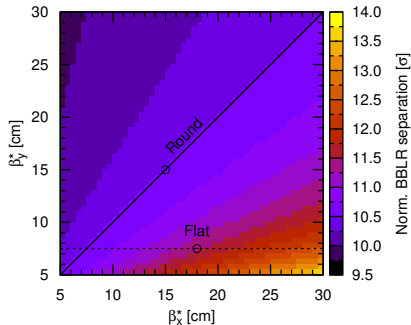
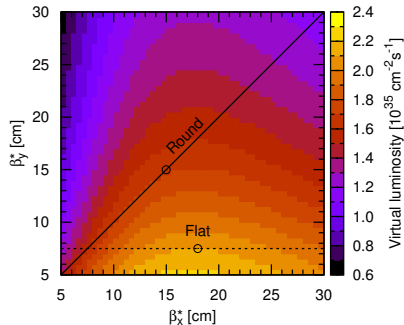
| Parameter                             | Unit  | Baseline (Standard) |             | 8b+4e       |             |
|---------------------------------------|---|---------------------|-------------|-------------|-------------|
|                                       |   | Nominal             | Ultimate    | Nominal     | Ultimate    |
| <i>At IP&amp;5:</i>                   |   |                     |             |             |             |
| Levelled luminosity                   | $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$            | 5.0                 | 7.5         | 3.8         | 5.5         |
| Levelled pile-up                      | 1   | 131                 | 197         | 140         | 200         |
| <b>Effective line pile-up density</b> | <b><math>\text{mm}^{-1}</math></b>                  | <b>0.81</b>         | <b>1.22</b> | <b>0.83</b> | <b>1.19</b> |
| Levelling time                        | h   | 7.0                 | 3.4         | 6.8         | 3.8         |
| Fill duration                         | h   | 8.2                 | 5.1         | 7.9         | 5.3         |
| <b>Yearly integrated luminosity</b>   | <b><math>\text{fb}^{-1}/160 \text{ days}</math></b> | <b>259</b>          | <b>321</b>  | <b>196</b>  | <b>239</b>  |
| Diff. w.r.t. base. std. nom.          | %   | ref.                | +24.0       | -24.2       | -7.6        |
| Diff. w.r.t. base. std. ult.          | %   | -                   | ref.        | -           | -25.4       |

- ▶ Performance remains 24 %–25 % lower than Baseline.

## 8b+4e: small performance change II



## Flat: larger performance than Baseline Standard I



- ▶ New flat optics is explored: for a minimum  $\beta_{||}^* = 7.5$  cm,  $\beta_x^*$  is found such that the virtual luminosity is maximized.
- ▶ Normalized BBLR separation is linearly extrapolated from the cases  $(\beta_x^*/\beta_{||}^*, d_{\text{BBLR}}) = (20 \text{ cm}/20 \text{ cm}, 10.5\sigma)$ , and  $(40 \text{ cm}/15 \text{ cm}, 12.5\sigma)$ .
- ▶ Partial crabbing (up to  $\sim 380 \mu\text{rad}$ ).



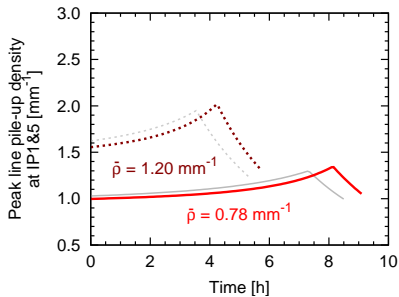
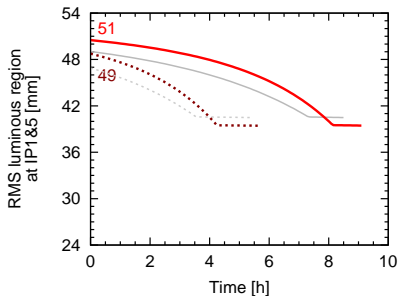
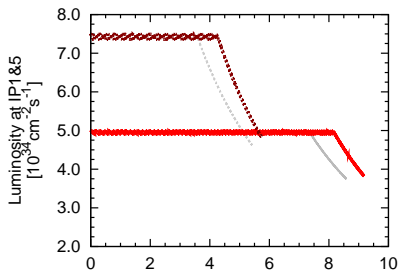
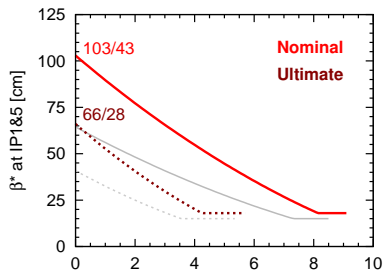
## Flat: larger performance than Baseline Standard II

- ▶ New baseline number of (total/colliding at IP1&5) bunches.
- ▶ At IP&5:
  - ▶ Minimum  $\beta^*$ : **18.0 cm/7.5 cm** (old: 40 cm/15 cm).
  - ▶ Minimum norm. BBLR separation: **11.4 $\sigma$**  (old: 12.5 $\sigma$ ).
  - ▶ Full crossing angle: **490  $\mu$ rad** (old: 360  $\mu$ rad).

| Parameter                             | Unit  | Baseline (Standard) |             | Flat        |             |
|---------------------------------------|---|---------------------|-------------|-------------|-------------|
|                                       |   | Nominal             | Ultimate    | Nominal     | Ultimate    |
| <i>At IP&amp;5:</i>                   |   |                     |             |             |             |
| Levelled luminosity                   | $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$            | 5.0                 | 7.5         | 5.0         | 7.5         |
| Levelled pile-up                      | 1   | 131                 | 197         | 131         | 197         |
| <b>Effective line pile-up density</b> | <b><math>\text{mm}^{-1}</math></b>                  | <b>0.80</b>         | <b>1.20</b> | <b>0.78</b> | <b>1.20</b> |
| Levelling time                        | h   | 7.4                 | 3.6         | 8.2         | 4.3         |
| Fill duration                         | h   | 8.5                 | 5.3         | 9.1         | 5.7         |
| <b>Yearly integrated luminosity</b>   | <b><math>\text{fb}^{-1}/160 \text{ days}</math></b> | <b>262</b>          | <b>326</b>  | <b>267</b>  | <b>340</b>  |
| Diff. w.r.t. base. std. nom.          | %   | ref.                | +24         | +2          | +30         |
| Diff. w.r.t. base. std. ult.          | %   | -                   | ref.        | -           | +4          |

- ▶ Performance w.r.t. Baseline Standard is 2% and 4% larger, for nominal and ultimate, respectively.
- ▶ Slight reduction of nominal effective pile-up density.

# Flat: larger performance than Baseline Standard III

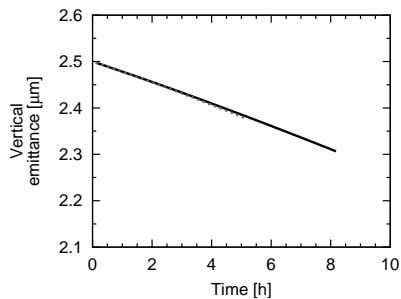
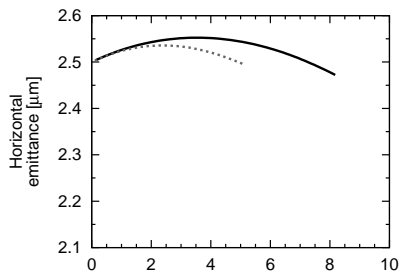
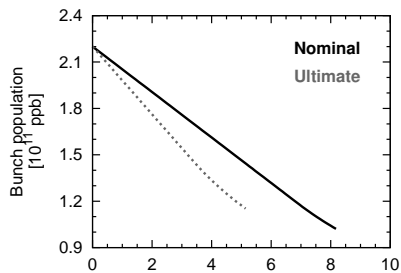


## Summary

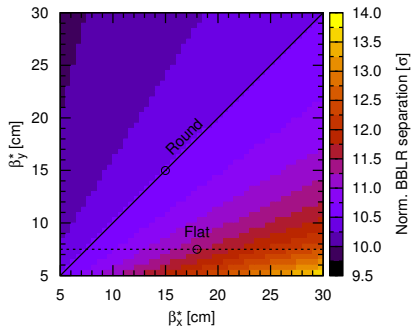
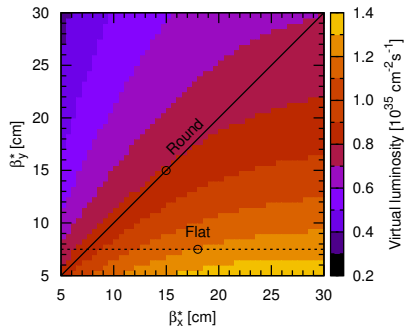
- ▶ **Baseline Standard:** Pushed optics with reduced  $\beta^*$  and crossing angle, as well as significantly lower turn-around time, have lead to performance beyond the project's goal for nominal operation ( $\sim 260 \text{ fb}^{-1}/160 \text{ days}$ ).
- ▶ An efficiency of 50 % is enough to reach an integrated performance of  $\sim 320 \text{ fb}^{-1}/160 \text{ days}$  for the Baseline Standard at ultimate operation.
- ▶ Current **BCMS parameters** deliver the **same performance than Standard**.
- ▶ Proportional performance reduction of the 8b+4e scenario w.r.t. Baseline remains similar after parameters update.
- ▶ A new **Flat scenario** has been envisioned ( $\beta^* = 18 \text{ cm}/7.5 \text{ cm}, 11.4\sigma$ ), and its performance surpasses that of the HL-LHC Baseline.  $\rightarrow$  to be validated.
- ▶ In the absence of CCs, new optimal flat optics have to be implemented  $\rightarrow$  to be done.

Back-up

## Baseline (Standard): Bunch population and emittances

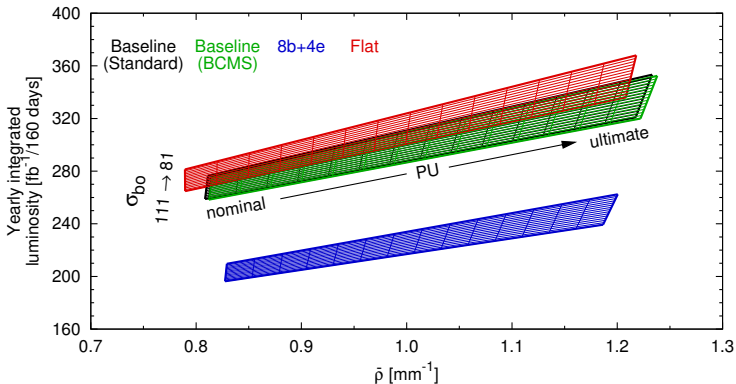


## No CC: new flat optics?



Peak luminosity and norm. BBLR separation for the case without CCs:  
a new optimal ratio  $\beta_x^*/\beta_y^*$  has yet to be found.

## Cross-section for burn-off: 81 mb



| Parameter                                    | Unit                      | Baseline (Std.) |          | Baseline (BCMS) |          | 8b+4e   |          | Flat    |          |
|--|---------------------------|-----------------|----------|-----------------|----------|---------|----------|---------|----------|
|  |                           | Nominal         | Ultimate | Nominal         | Ultimate | Nominal | Ultimate | Nominal | Ultimate |
| Yearly integrated luminosity                 | $\text{fb}^{-1}/160$ days | 276             | 353      | 276             | 352      | 210     | 262      | 284     | 373      |
| Diff. w.r.t. $\sigma_{\text{b.o.}} = 111$ mb | %                         | +6.8            | +10.1    | +6.9            | +10.1    | +6.8    | +9.8     | +6.4    | +9.7     |

| Parameter                           | Unit                                     | Baseline (Std.) |           | Baseline (BCMS) |           | 8b+4e     |           | Flat       |           |
|-------------------------------------|--|-----------------|-----------|-----------------|-----------|-----------|-----------|------------|-----------|
|                                     |  | Nominal         | Ultimate  | Nominal         | Ultimate  | Nominal   | Ultimate  | Nominal    | Ultimate  |
| $n_b$ bunches                       | 1  | 2760            | 2760      | 2748            | 2748      | 1972      | 1972      | 2760       | 2760      |
| $N_b$                               | $10^{11}$                                | 2.2             | 2.2       | 2.2             | 2.2       | 2.2       | 2.2       | 2.2        | 2.2       |
| $N_{tot}$                           | $10^{14}$                                | 6.07            | 6.07      | 6.05            | 6.05      | 4.34      | 4.34      | 6.07       | 6.07      |
| Beam current                        | A  | 1.10            | 1.10      | 1.10            | 1.10      | 0.79      | 0.79      | 1.10       | 1.10      |
| $\epsilon_n$                        | $\mu\text{m}$                            | 2.5             | 2.5       | 2.5             | 2.5       | 2.2       | 2.2       | 2.5        | 2.5       |
| $E$ spread                          | $10^{-4}$                                | 1.29            | 1.29      | 1.29            | 1.29      | 1.20      | 1.20      | 1.29       | 1.29      |
| RMS bunch length                    | cm                                       | 7.6             | 7.6       | 7.6             | 7.6       | 7.6       | 7.6       | 7.6        | 7.6       |
| FWHM                                | cm                                       | 21.2            | 21.2      | 21.2            | 21.2      | 21.2      | 21.2      | 21.2       | 21.2      |
| IBS horizontal                      | h  | 19.6            | 19.6      | 19.6            | 19.6      | 14.3      | 14.3      | 18.1       | 18.1      |
| IBS longitudinal                    | h  | 29.9            | 29.9      | 29.9            | 29.9      | 21.5      | 21.5      | 30.7       | 30.7      |
| <i>At IP1&amp;5</i>                 |  |                 |           |                 |           |           |           |            |           |
| No. collisions                      | 1  | 2748            | 2748      | 2736            | 2736      | 1967      | 1967      | 2748       | 2748      |
| Min. $\beta^*$                      | cm                                       | 15.0/15.0       | 15.0/15.0 | 15.0/15.0       | 15.0/15.0 | 15.0/15.0 | 15.0/15.0 | 18.0/7.5   | 18.0/7.5  |
| Full x-sing angle                   | $\mu\text{rad}$                          | 501             | 501       | 501             | 501       | 470       | 470       | 492        | 492       |
| Min. norm. BBLR sep.                | $\sigma$                                 | 10.6            | 10.6      | 10.6            | 10.6      | 10.6      | 10.6      | 11.4       | 11.4      |
| Piwinski parameter                  | 1  | 2.7             | 2.7       | 2.7             | 2.7       | 2.7       | 2.7       | 2.4        | 2.4       |
| Virt. lumi w/o CC                   | $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ | 8.04            | 8.04      | 8.00            | 8.00      | 6.54      | 6.54      | 11.09      | 11.09     |
| Virt. lumi w/ CC                    | $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ | 16.64           | 16.64     | 16.57           | 16.57     | 14.19     | 14.19     | 20.94      | 20.94     |
| Virt. pile-up w/o CC                | 1  | 211             | 211       | 211             | 211       | 239       | 239       | 291        | 291       |
| Virt. pile-up w/ CC                 | 1  | 436             | 436       | 436             | 436       | 520       | 520       | 549        | 549       |
| Virt. loss factor w/o CC            | 1  | 0.34            | 0.34      | 0.34            | 0.34      | 0.34      | 0.34      | 0.36       | 0.36      |
| Virt. loss factor w/ CC             | 1  | 0.70            | 0.70      | 0.70            | 0.70      | 0.74      | 0.74      | 0.68       | 0.68      |
| Levelled lumi                       | $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ | 5.0             | 7.5       | 5.0             | 7.5       | 3.8       | 5.5       | 5.0        | 7.5       |
| Levelled pile-up                    | 1  | 131             | 197       | 132             | 197       | 140       | 200       | 131        | 197       |
| $\beta^*$ (start)                   | cm                                       | 63.9/63.9       | 40.3/40.3 | 63.5/63.5       | 40.1/40.1 | 69.8/69.8 | 47.1/47.1 | 102.7/42.8 | 65.8/27.4 |
| Norm. BBLR sep. (start)             | $\sigma$                                 | 21.9            | 17.4      | 21.8            | 17.3      | 22.9      | 18.8      | 27.2       | 21.8      |
| RMS lum. region (start)             | mm                                       | 48.6            | 46.4      | 48.6            | 46.3      | 49.8      | 48.2      | 50.4       | 48.6      |
| Peak line PU dens. (start)          | $\text{mm}^{-1}$                         | 1.04            | 1.64      | 1.04            | 1.65      | 1.08      | 1.60      | 1.00       | 1.56      |
| RMS lum. region (end)               | mm                                       | 39.9            | 39.9      | 40.0            | 40.0      | 41.9      | 41.8      | 39.3       | 39.3      |
| Peak line PU dens. (end)            | $\text{mm}^{-1}$                         | 1.33            | 1.99      | 1.32            | 1.98      | 1.34      | 1.91      | 1.35       | 2.03      |
| <b>Eff. line pile-up dens.</b>      | $\text{mm}^{-1}$                         | 0.81            | 1.22      | 0.81            | 1.22      | 0.83      | 1.19      | 0.79       | 1.21      |
| Levelling time                      | h  | 7.0             | 3.4       | 6.8             | 3.3       | 6.8       | 3.8       | 7.8        | 4.1       |
| Fill duration                       | h  | 8.2             | 5.1       | 8.1             | 5.1       | 7.9       | 5.3       | 8.8        | 5.5       |
| <b>Yearly integrated luminosity</b> | $\text{fb}^{-1}/160 \text{ days}$        | 258.8           | 320.9     | 258.3           | 320.0     | 196.3     | 239.3     | 264.8      | 336.0     |
| Diff. w.r.t. base. std. nom.        | %  | ref.            | 24.0      | -0.2            | 23.6      | -24.2     | -7.6      | 2.3        | 29.8      |
| Diff. w.r.t. base. std. ult.        | %  | -               | ref.      | -               | -0.3      | -         | -25.4     | -          | 4.7       |