



High
Luminosity
LHC



8b+4e parameters

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P. Baudrenghien and E. Shaposhnikova

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8b+4e revived interest

Even after extended scrubbing, LHC operation with 25 ns beams still remains very challenging mainly due to electron cloud (heat load and preservation of beam quality).

Parameters table

[Parameter table link](#)

| Parameter | Nominal LHC | HL-LHC 25ns | HL-LHC 25ns | 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 [μ rad] | 285 | 590 | 590 | 590 |
| beam separation [σ] | 9.4 | 12.5 | 12.5 | 11.4 |
| β^* [m] | 0.55 | 0.15 | 0.15 | 0.15 |
| ε_n [μ m] | 3.75 | 2.50 | 2.50 | 3 |
| ε_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 [$\text{cm}^{-2} \text{s}^{-1}$] | 1.00E+34 | 7.18E+34 | 6.80E+34 | 8.44E+34 |
| Virtual Luminosity with crab-cavity: Lpeak*R1/R0 | (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 [$\text{cm}^{-2} \text{s}^{-1}$] | - | 5.00E+34 | 5 | 5.00E+34 |

8b+4e parameters at injection

Reference: [CERN-ACC-2014-0006](#)

| | |
|-----------------|----------------------|
| Emittance | $1.7 \mu\text{m}$ |
| Bunch intensity | 2.4×10^{11} |
| Energy spread | 3.5×10^{-4} |
| Bunch length | 10.5 cm |

These have been calculated with the LIU criteria (space charge, instability threshold and RF limitations throughout the injector chain) and assuming all the LIU upgrades, **but**

Baseline parameters (collision)

| | | | |
|-----|---|-----------------|----------------------|
| US2 | { | Emittance | 2.5 μm |
| | | Bunch intensity | 2.2×10^{11} |

HL-LHC baseline parameters are beyond what considered achievable in the LIU baseline. A new LIU-compatible scenario is defined for comparison:

| | | | |
|-----|---|-----------------|----------------------|
| LIU | { | Emittance | 2.3 μm |
| | | Bunch intensity | 1.9×10^{11} |

Turn-around time

Since Chamonix 2014 HL-LHC beams need a 7.2s longer SPS ramp (E. Shaposhnikova):

| Phase | Time [minutes] | G. Arduini et al |
|--------------------------------------|-------------------|------------------|
| Ramp down/precycle | 60 | |
| Pre-injection checks and preparation | 15 | |
| Checks with set-up beam | 15 | |
| Nominal injection sequence | 20 | 23'} |
| Ramp preparation | 5 | 28' @ inj. |
| Ramp | 25 | |
| Squeeze | 30 | |
| Adjust/collisions | 10 | |
| Total | 180 | 183' |

IBS blow-up at inj, ramp & squeeze

Some improvements to the the codes:

- ★ IBS uses MAD growth times instead of approximation formula
- ★ IP1 and IP5 with V and H crossing (before identical)
- ★ Future: General CC settings, flat leveling options, realistic granular leveling, etc.

IBS blow-up at inj, ramp & squeeze

| train | 30% long. blow-up | ϵ_x [μm] | ϵ_y [μm] |
|-----------------|----------------------|-----------------------------|-----------------------------|
| 1 st | no | 2.1 | 1.74 |
| last | no | 1.95 | 1.72 |
| average | no | 1.9 | |
| 1 st | yes | 2.0 | 1.73 |
| last | yes | 1.9 | 1.72 |
| average | yes | 1.8 | |

We keep $\epsilon_{x,y}=2.2\mu m$ at collision but there might be margin in the future for lower $\epsilon_{x,y}$.

Colliding bunches

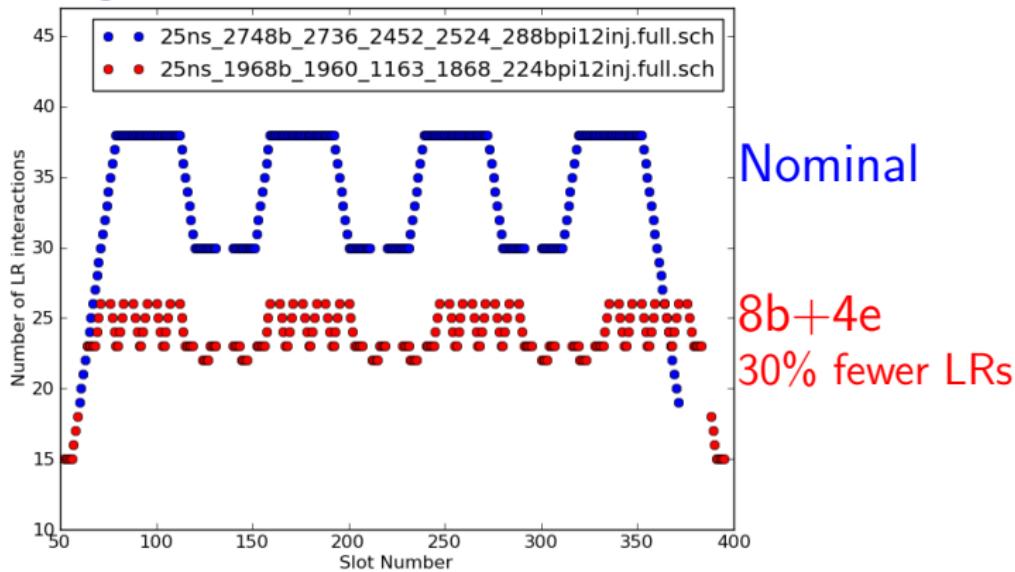
| case | IP1&5 | IP2 | IP8 | #SPS inj |
|--------------------|-------|------|------|-------------|
| nominal | 2736 | 2452 | 2524 | 12 |
| 8b+4e | 1960 | 1163 | 1868 | 12 |
| 8b+4e ⁺ | 2016 | 889 | 1168 | 9 |

Optimized filling scheme for IP1&5 ($8b+4e^+$)
discarded by experiments.

A loss of 5% intensity is assumed (2.3×10^{11} ppb).

Crossing angle with 8b+4e

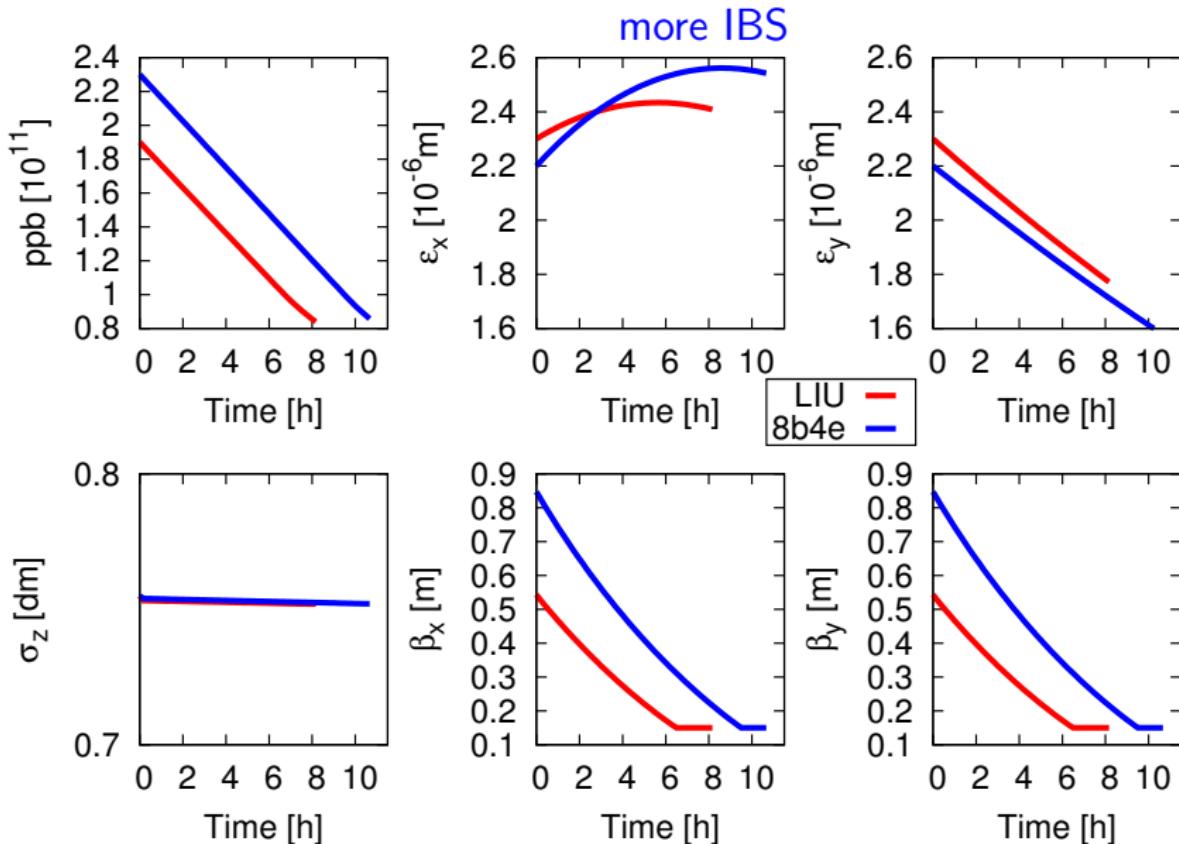
T. Pieloni
C. Tambasco



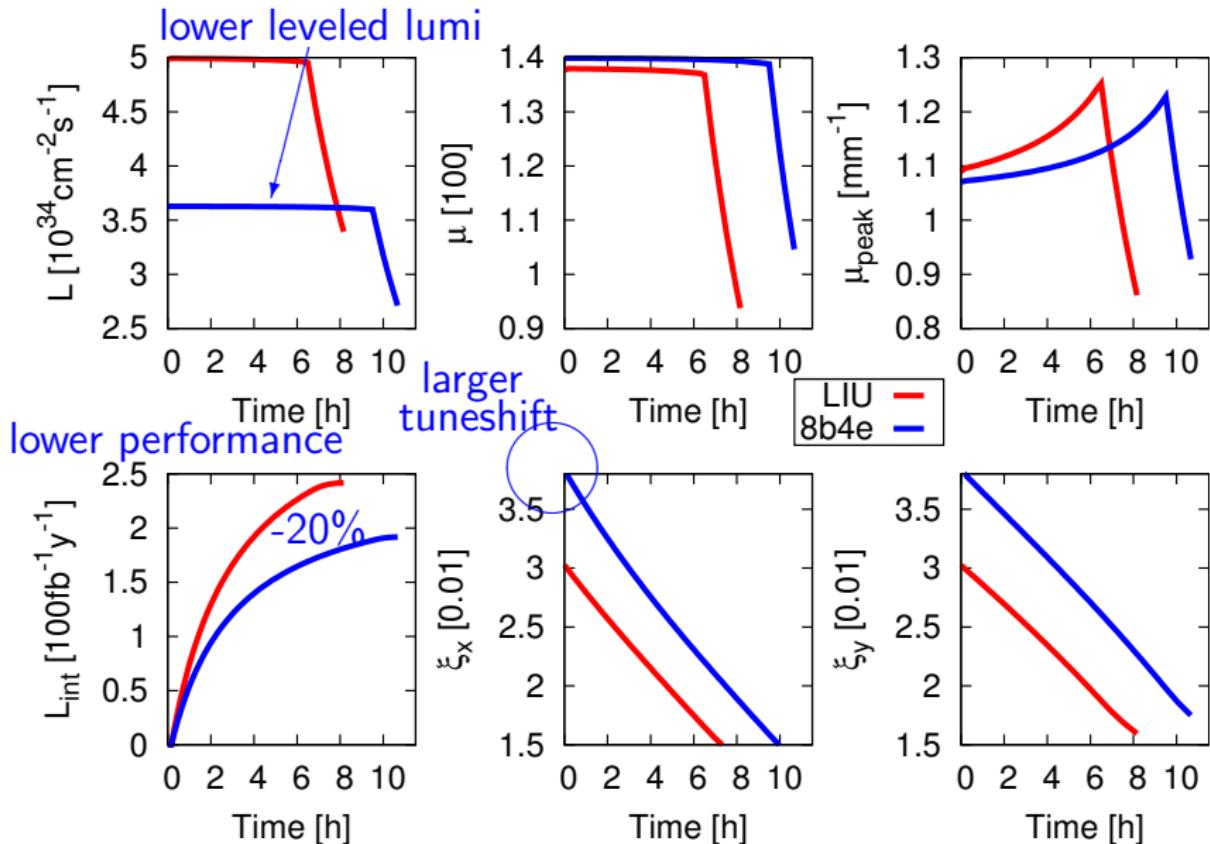
Lower number of long range encounters allows for smaller crossing angle and smaller β^* .

We take $\theta = 9\sigma$ to alleviate CC voltage and $\beta^* = 0.15\text{m}$ to be aligned with baseline.

8b+4e: Performance I



8b+4e: Performance II



8b+4e comparisons

| | N [10 ¹¹] | ϵ [μm] | $\beta_{x,y}^*$ [cm] | $L_{\text{year}} [fb^{-1}]$ Opt. fill | 6h fill | fill [h] | Pile-up | [$\frac{1}{\text{mm}}$] |
|------|--------------------------|---------------------------------|-------------------------|---|------------|-------------|---------|---------------------------|
| US2 | 2.2 | 2.5 | 15,15 | 258 | 226 | 9.8 | 138 | 1.3 |
| LIU | 1.9 | 2.3 | 15,15 | 242 | 226 | 8.0 | 138 | 1.3 |
| 8b4e | 2.3 | 2.2 | 15,15 | 192 | 164 | 10 | 140 | 1.2 |
| | 2.3 | 2.2 | 10,10 | 196 | 164 | 11 | 140 | 1.4 |
| | | 2.1 | 15,15 | 192 | 164 | 10 | 139 | 1.2 |

LIU case performance is 6% below HL-LHC baseline.

8b+4e performance is 20% below LIU-compatible case.

β^* and ϵ have little impact on 8b+4e performance.

8b+4e parameter table

| | US2a | 8b+4e |
|--------------------------------------|------|-------|
| E [TeV] | 7 | 7 |
| N _b [10 ¹¹] | 2.2 | 2.3 |
| n _{bunches} | 2748 | 1968 |
| IP1&5 colls | 2736 | 1960 |
| N _{tot} [10 ¹⁴] | 6.0 | 4.5 |
| beam current [A] | 1.09 | 0.82 |
| x-sing angle [μ rad] | 590 | 400 |
| beam separation [σ] | 12.5 | 9.0 |
| β^* [m] | 0.15 | 0.15 |
| ϵ_n [μ m] | 2.5 | 2.2 |
| ϵ_L [eVs] | 2.5 | 2.5 |
| E spread [10 ⁻⁴] | 1.13 | 1.13 |
| bunch length [cm] | 7.55 | 7.55 |
| IBS horizontal [h] | 18.0 | 13.1 |
| IBS longitudinal [h] | 21.4 | 17.6 |
| Piwinski parameter | 3.14 | 2.3 |

8b+4e parameter table

| | US2a | 8b+4e |
|---|-----------|-----------|
| Loss factor no CC | 0.305 | 0.406 |
| Loss factor with CC | 0.829 | 0.857 |
| beam-beam no CC [10^{-3}] | 3.3 | 5.1 |
| beam-beam with CC [10^{-2}] | 1.1 | 1.3 |
| Peak Lumi without CC [$cm^{-2}s^{-1}10^{34}$] | 7.18 | 8.52 |
| Virtual lumi with CC [$cm^{-2}s^{-1}10^{35}$] | 1.95 | 1.80 |
| Pile-up without lev CC | 198 | 328 |
| Leveled lumi [$cm^{-2}s^{-1}10^{34}$] | 5 | 3.63 |
| Pile-up with lev CC | 138 | 140 |
| Peak pile-up density | 1.26 | 1.23 |
| Leveling time [h] | 8.7 | 9.7 |
| Number of collisions IP2/IP8 | 2452/2524 | 1163/1868 |
| N_b at injection [10^{11}] | 2.3 | 2.4 |
| n_b per injection | 288 | 224 |
| N_{tot} per injection [10^{13}] | 6.6 | 5.4 |
| Emittance at injection [μm] | 2 | 1.7 |

Conclusions

- ★ Parameter table for 8b+4e released
- ★ 8b+4e performance is 20% below an LIU-compatible HL-LHC case
- ★ (LIU case performance is 6% below HL-LHC baseline)
- ★ There is some margin for future improvements of 8b+4e (batch-by-batch longitudinal blow-up, β^* , filling scheme, etc)