# Update of HI-Lumi Parameters (25 ns) following RLIUP

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Summarized in HL-LHC Deliverable Report D1.3: "BEAM PARAMETERS AT LHC INJECTION"

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# Outline

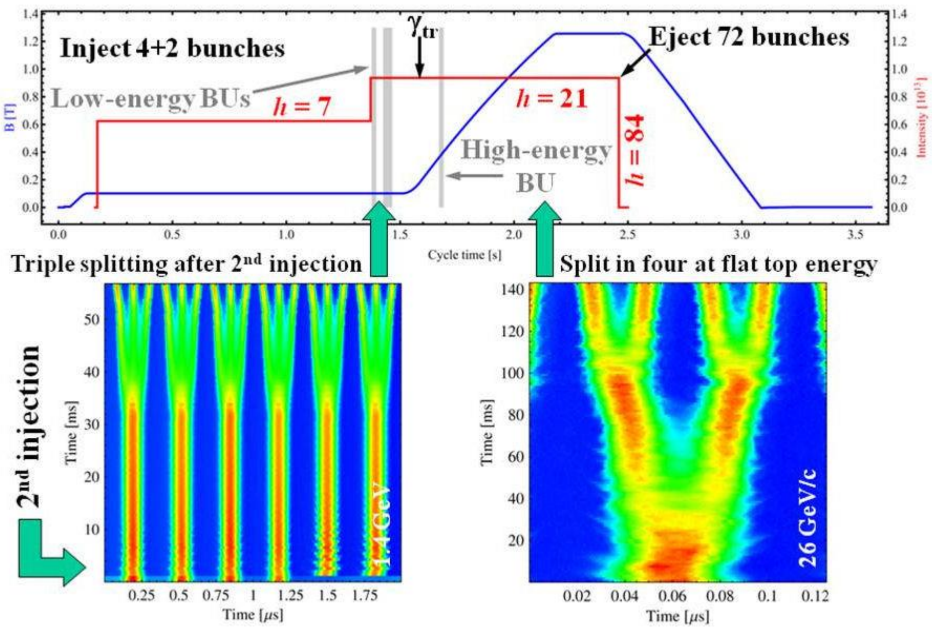
- Production schemes for nominal performance (Standard and BCMS) – 25 ns
  - Filling patterns
  - Parameters in collision
  - Integrated performance
  - Parameters at injection

- Alternative production scheme (8b+4e) – 25 ns
  - Motivation
  - Parameters at injection
  - Filling patterns
  - Parameters in collision
  - Integrated performance

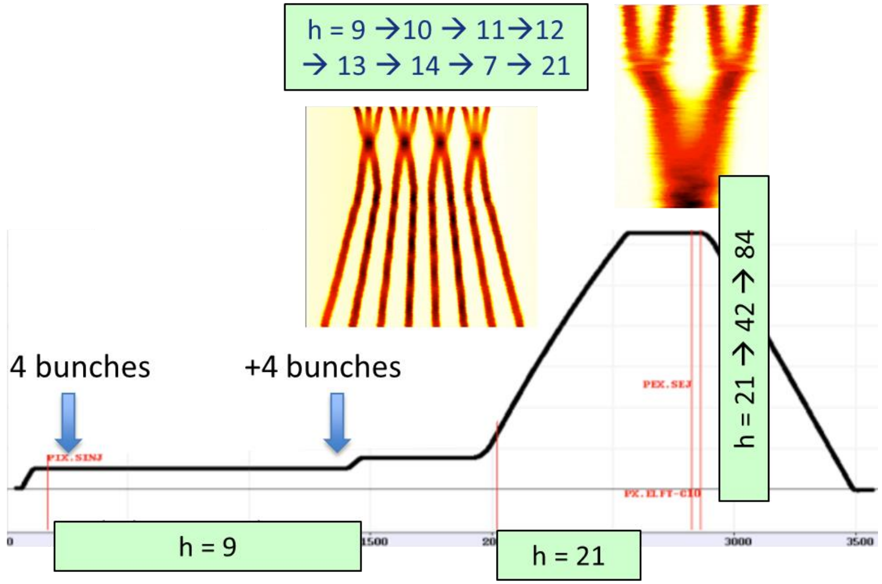
c/o LIU

# LHC beam production schemes (25 ns)

- Standard scheme:
  - 72 bunches/PS extraction starting from 6 PSB bunches (x 12)




- BCMS (Batch Compression Merging and Splittings):
  - 48 bunches/PS extraction starting from 8 PSB bunches (x 6)




- 2 x Brightness of the Standard beam

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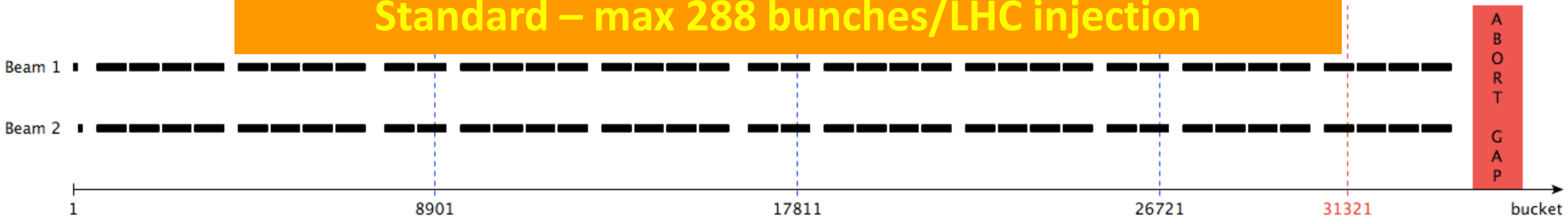
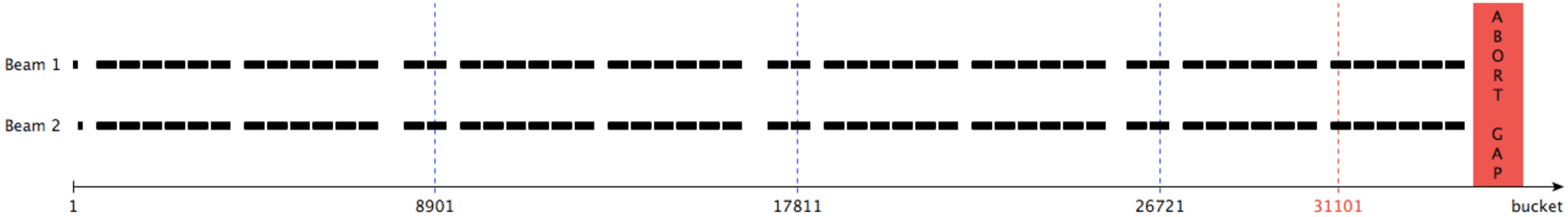
# Filling schemes

| Scheme | # bunches/beam | # Colliding IP1-5 | # Colliding IP2 | # Colliding IP8 |
|---|---|---|---|---|
| Standard | 2748 | 2736 | 2452 | 2524 |
| BCMS | 2604 | 2592 | 2288 | 2396 |

**Standard – max 288 bunches/LHC injection**




**BCMS – max 288 bunches/LHC injection**

# Filling schemes - assumptions

- Minimum rise-time of the SPS injection kicker: 225 ns.
- Minimum rise-time of the LHC injection kicker: 900 ns.
- Minimum pulse length of the SPS extraction/LHC injection kickers: 8200 ns
- Minimum rise-time of the LHC beam dump kicker: 3000 ns.

# Parameters in collision

| | $N_b$ $[10^{11}]$ | $\varepsilon^*_{n\ coll}$ [μm] | # colliding bunches IP1,5 | Crossing angle [μrad] | Beam-beam separation [σ] | $L_{virtual}$ $[10^{34} cm^{-2} s^{-1}]$ |
|---|---|---|---|---|---|---|
| Standard | 2.2 | 2.5 | 2736 | 590 | 12.5 | 21.3 |
| BCMS | 2.2 | 2.5 | 2592 | 590 | 12.5 | 20.2 |

**β*=15 cm and full crossing angle compensation by Crab Cavities**

| | |
|---|---|
| Total RF Voltage [MV] | 16 |
| $\varepsilon_L^*$[eV.s] at start of fill | 2.5 |
| Bunch length (4 σ)[ns]/ (r.m.s.) [cm] | 1/7.5 |

# Integrated performance - assumptions

| | |
|---|---|
| Scheduled Physics Time for p-p luminosity production/year ($T_{spt}$) [days] | 160 |
| Minimum Turn-Around Time ($T_{around\_min}$) [h] | 3 |
| Performance Efficiency ($\eta$) – goal [%] | 50 |
| Pile-up limit [events/crossing] | 140 |
| Pile-up Density limit – baseline (stretched) [events/mm/crossing] | 1.3 (0.7) |

$$\eta = \frac{L_{int}}{L_{fill}} \frac{T_{around\_min} + T_{fill}}{T_{spt}} \times 100$$

**~53 % in 2012**

$L_{fill}$ = luminosity integrated during one fill of duration $T_{fill}$;
$T_{spt}$= scheduled physics time, i.e. time scheduled for luminosity production;
$T_{fill}$= the optimum fill length maximizing the integrated luminosity taking into account the turn-around time and the luminosity lifetime;

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# Integrated performance – L(t)

- Beam intensity evolution taking into account:
  - Burn-off: total cross-section 110 mb.
  - Additional (unknown) source of intensity loss - lifetime of 200 h (2012 experience).
- Emittance evolution including:
  - Intra-Beam Scattering (IBS). No coupling assumed.
  - Radiation damping.
  - An additional (unknown) source of vertical emittance blow-up - lifetime of 40 h (observed during Run I).
- A finite difference method in time intervals of 5 minutes.

# Integrated performance

| | Levelling Time [h] | Opt. fill length [h] | η [%] | ϕ [%] | Integrated Luminosity [fb$^{-1}$/y] | Max. Mean Pile-up density/Pile-up [ev./mm]/[ev./xing] |
|---|---|---|---|---|---|---|
| Standard | 7.4 | 8.7 | 50 | 37 | 255 | 1.25/140 |
| BCMS | 7.4 | 8.7 | 50 | 37 | 241 | 1.25/140 |

$$\phi = \frac{L_{int}}{L_{fill}} \frac{T_{fill}}{T_{spt}} \times 100$$

**Smaller number of bunches penalizes BCMS at constant collision parameters**

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# Expected parameters at injection

- Beam intensity losses of few % to be expected during the cycle (2012)
  - At injection (e.g. satellite bunches preceding or following the SPS batch).
  - During the injection plateau and at the start of the ramp (e.g. uncaptured particles).
  - During the ramp when the collimators are closed.
  - When the two beams are brought in collision.
- An intensity loss of 5% distributed along the cycle is assumed during the LHC cycle from SPS extraction to collisions in the LHC.
- A transverse emittance blow-up of 10 to 15 % on the average of the H/V emittance in addition to that expected from Intra-Beam Scattering (IBS).
  - Might be optimistic but recent data on 2012 experience are encouraging

# Parameters at injection from SPS

| | SPS Extraction | | LHC collision (min. value – IBS) | LHC collision | | |
|---|---|---|---|---|---|---|
| | $N_b$ [$10^{11}$] | $\varepsilon_n$ (H/V) [μm] | $\varepsilon_n$ (H/V) [μm] | $N_b$ [$10^{11}$] | $\varepsilon_{n\ coll.}$ (H/V) [μm] | Blow-up from SPS ext. [%] |
| Standard | 2.3 | 2.0/2.0 | 2.3/2.0 | 2.2 | 2.5/2.5 | 25 |
| BCMS | 2.3 | 2.0/2.0 | 2.3/2.0 | 2.2 | 2.5/2.5 | 25 |

IBS emittance blow-up assuming constant r.m.s. bunch length of 10 cm with controlled longitudinal emittance blow-up during injection and ramp.
RF voltage linear ramp from 6 MV at injection to 16 MV at flat-top.
Typical cycle length.

**c/o LIU**

| | | LHC | | | | | |
|---|---|---|---|---|---|---|---|
| | | $N$ ($10^{11}$ p/b) | $\epsilon_{x,y}$ ($\mu$m) | $p$ (GeV/c) | $\epsilon_z$ (eVs/b) | $B_l$ (ns) | bunches/train |
| LIU | Standard | 2.00 | 1.88 | 450 | 0.60 | 1.65 | 4×(72b+8e) |
| | BCMS | 2.00 | 1.37 | 450 | 0.60 | 1.65 | 6×(48b+8e) |

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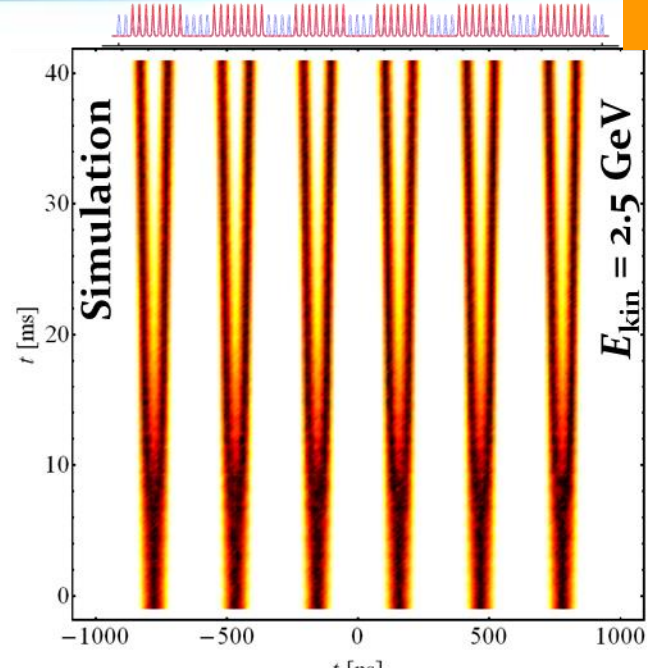
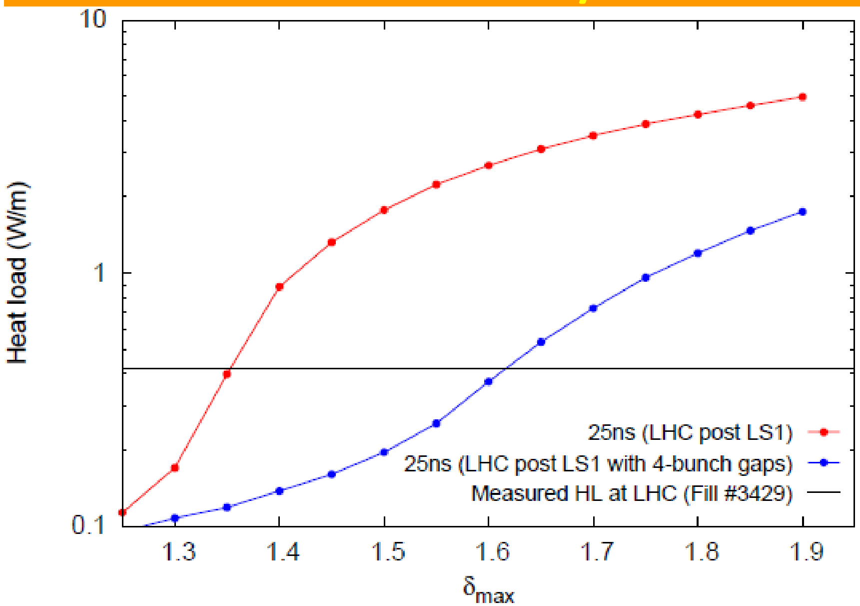
# Alternative scenario

- Detrimental e-cloud effects can be mitigated by using specially conceived filling patterns
- Flexibility of the injector complex to build bunch trains with long enough gaps interspersed
- So far a minimum SEY of ~1.4 has been achieved in the main dipole beam screens after scrubbing.




**Up to 7 PSB bunches could be injected in the PS → 56 bunches/PS extraction**



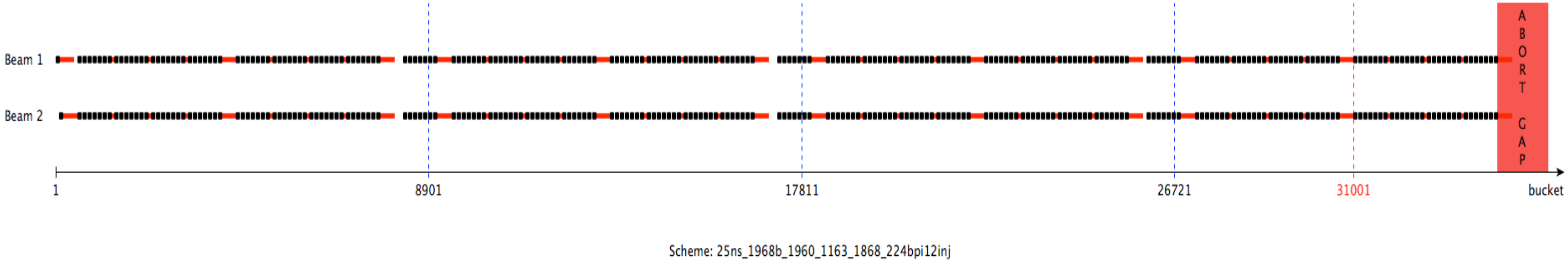
# Expected parameters

| | c/o LIU<br>SPS Extraction | | LHC collision<br>(min. value – IBS) | LHC collision | | |
|---|---|---|---|---|---|---|
| | $N_b$ [$10^{11}$] | $\varepsilon_n$ (H/V) [μm] | $\varepsilon_n$ (H/V) [μm] | $N_b$ [$10^{11}$] | $\varepsilon_{n\ coll.}$ (H/V) [μm] | Blow-up from SPS ext. [%] |
| 8b+4e | 2.4 | 1.7 | 2.1/1.7 | 2.3 | 2.2/2.2 | 30 |

- Assumed:
  - IBS blow-up and an additional transverse emittance blow-up of 15%.
  - an intensity loss of approximately 5% in the LHC.

# Filling scheme

| Scheme | # bunches/beam | # Colliding IP1-5 | # Colliding IP2 | # Colliding IP8 |
|---|---|---|---|---|
| 8b+4e | 1968 | 1960 | 1163 | 1868 |




- Assumptions:
  - 224 bunches per SPS extraction.
  - Increase of the SPS extraction/LHC injection kicker pulse length from 8200 ns to 8600 ns.

# Parameters in collision

| | $N_b$ $[10^{11}]$ | $\varepsilon^*_{n\ coll}$ [μm] | # colliding bunches IP1,5 | Crossing angle [μrad] | Beam-beam separation [σ] | $L_{virtual}$ $[10^{34}cm^{-2}s^{-1}]$ |
|---|---|---|---|---|---|---|
| 8b+4e | 2.3 | 2.2 | 1960 | 555 | 12.5 | 19.0 |

**β*=15 cm and full crossing angle compensation by Crab Cavities**

| | |
|---|---|
| Total RF Voltage [MV] | 16 |
| $\varepsilon_L^*$[eV.s] at start of fill | 2.5 |
| Bunch length (4 σ)[ns]/ (r.m.s.) [cm] | 1/7.5 |

# Expected integrated performance

| | Levelling Time [h] | Opt. fill length [h] | η [%] | ϕ [%] | Integrated Luminosity [$fb^{-1}$/y] | Max. Mean Pile-up density/Pile-up [ev./mm]/[ev./xing] |
|---|---|---|---|---|---|---|
| 8b+4e | 8.3 | 9.4 | 50 | 38 | 188 | 1.2/140 |

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# Conclusions

- A set of parameters has been defined for the 25 ns beam in the LHC to reach/approach HL-LHC target performance.
- Parameters at injection have been inferred for realistic filling schemes.
- These parameters are  very close to those expected at extraction from the SPS after the full upgrade of the injectors according to the LIU project.
- An alternative scenario based on beams with 25 ns spacing has been conceived to reduce the electron cloud effects in the LHC

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