# 80 bunch scheme in the LHC

R. Tomás and X. Buffat

Thanks to F. Antoniou, G. Arduini, H. Bartosik, O. Brüning, H. Damerau, S. Gilardoni, M. Giovannozzi, B. Goddard, V. Kain, R. de Maria, Y. Papaphilippou, G. Papotti, T. Pieloni, G. Rumolo, E. Shaposhnikova and J. Uythoven

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# Turn-around time

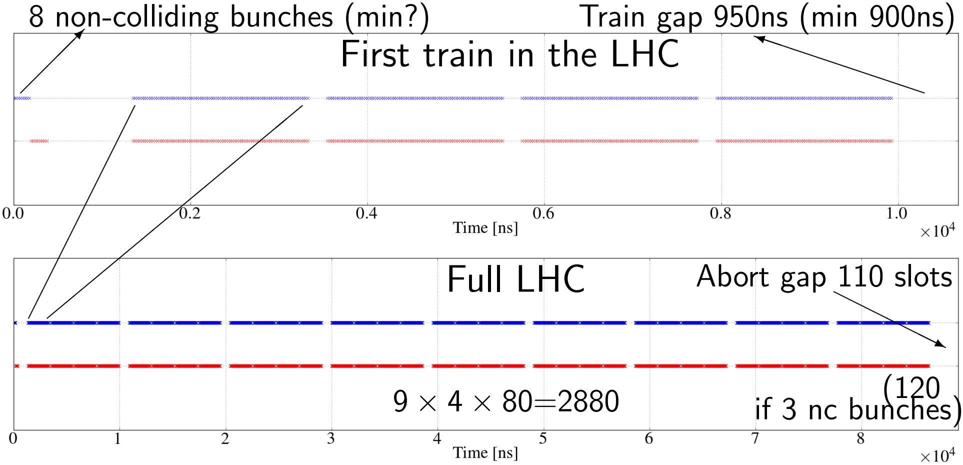
Since Chamonix 2014 HL-LHC beams need a 7.2s longer SPS ramp (E. Shaposhnikova):

G. Arduini et al

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

Maybe 80 bunch scheme helps with turn-around-time

# 80 bunch scheme and 4 PS batch trains



# Comparing to nominal (colliding bunches)

| # | IP1&5 | IP2 | IP8 | Abort gap | Non-Coll. | #SPS inj |
|---|---|---|---|---|---|---|
| 72 | 2736 | 2452 | 2524 | 120 | 12 | 12 |
| $72^+$ | 2808 | 2276 | 2232 | 120 | 12 | 11 |
| 80 | 2800 | 2727 | 2694 | 110 | 8 | 12 |
| $80^+$ | 2880 | 2380 | 2366 | 110 | 8 | 10 |

If 3 non-colliding bunches OK, abort gap=120 OK.
Else train gap can be shorter by 2 slots (950→900ns)
Saving 2 SPS injections shortens turn-around-time (183'→178') and decreases IBS emittance growth by ≈1% in first trains.

# Comparing to nominal (luminosity)

| # | IP1&5 | IP2 | IP8 | Abort gap | Non-Coll. | #SPS inj |
|---|---|---|---|---|---|---|
| 72 | 2736 | 2452 | 2524 | 120 | 12 | 12 |
| $72^+$ | +2.6% | -7.2% | -11% | 120 | 12 | 11 |
| 80 | +2.3% | +11% | +6.7% | 110 | 8 | 12 |
| $80^+$ | +5.2% | -3% | -6.2% | 110 | 8 | 10 → |

extra ≈0.5% from TAT not included

**With 80 everybody wins**

Does IP2 want it?

**$80^+$ is optimized for IP1&5**

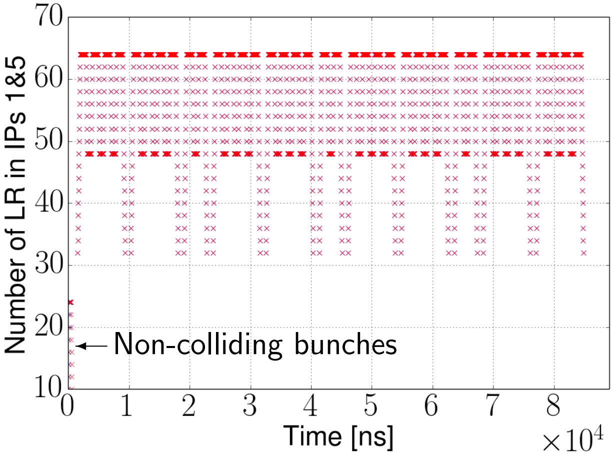
Is $80^+$ OK for LHCB? → Need input

# How to find the optimum?

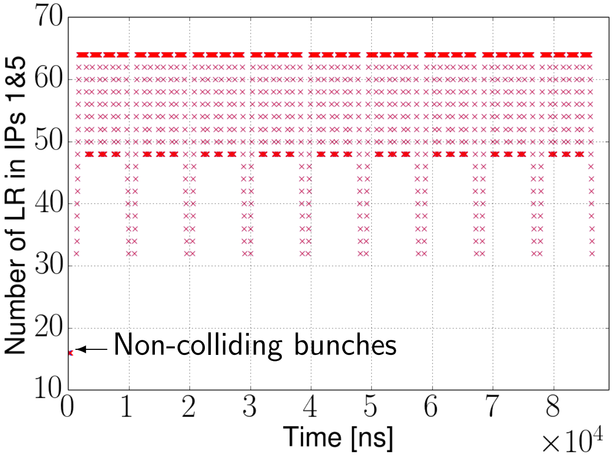
3 PS batch types: 72, 80, 81
SPS trains made of 1,2,3 or 4 PS batches
(120 different SPS trains)
with $\approx$10 possible train gaps (900-1150ns)
and between 10 and 15 SPS injections

This gives about $10^{40}$ possible LHC filling schemes
(symmetries are used to find good combinations)

# Long ranges in Nominal



# Long ranges in $80^+$




No differences other than fewer non-colliding bunches is better

# 80 bunches/4 trains merits and issues

Merits:

- ★ 5.2% more luminosity in IP1&5 (same pile-up)
- ★ with room for compromises with other IPs
- ★ Possibly faster turn-around
- ★ Potential to be a scrubbing beam

Issues:

- ★ SPS to LHC transfer with $4\times80=320$ bunches instead of $4\times72=288$
- ★ Injection protection devices (TDI, TCDI, etc) need to "survive" the extra charge
- ★ $\approx$10% larger heat load due to e-cloud

# Pushed 8b+4e

Merits:

- 7 PSB bunches can provide $56\times\mathbf{4}\times\mathbf{9}$=2016 bunches in the LHC
- Considerably lower e-cloud than 25 ns baseline
- Larger lumi than 50 ns or plain 8b+4e
- Smaller $\beta^*$ and smaller crossing angle thanks to fewer long ranges.

Issues:

- Lower luminosity than baseline
- with 10% more peak pile-up

# Pushed 8b+4e

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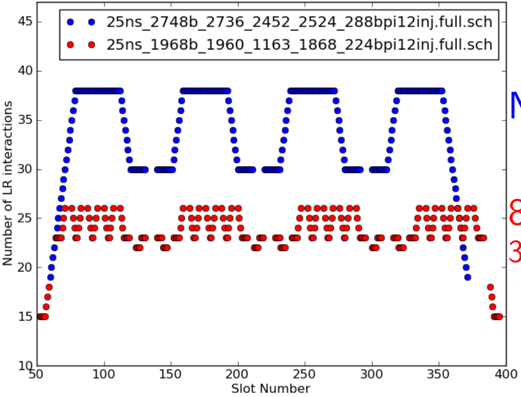
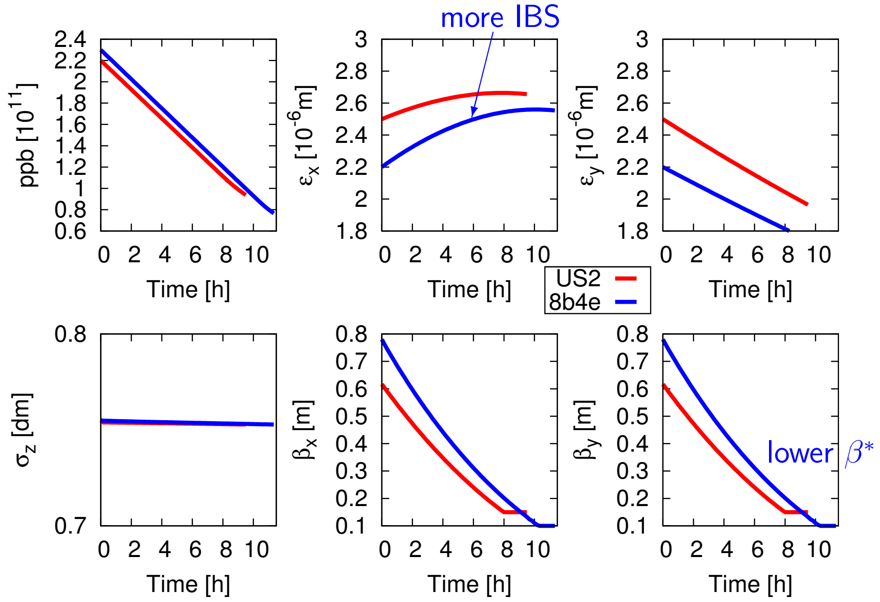



Nominal

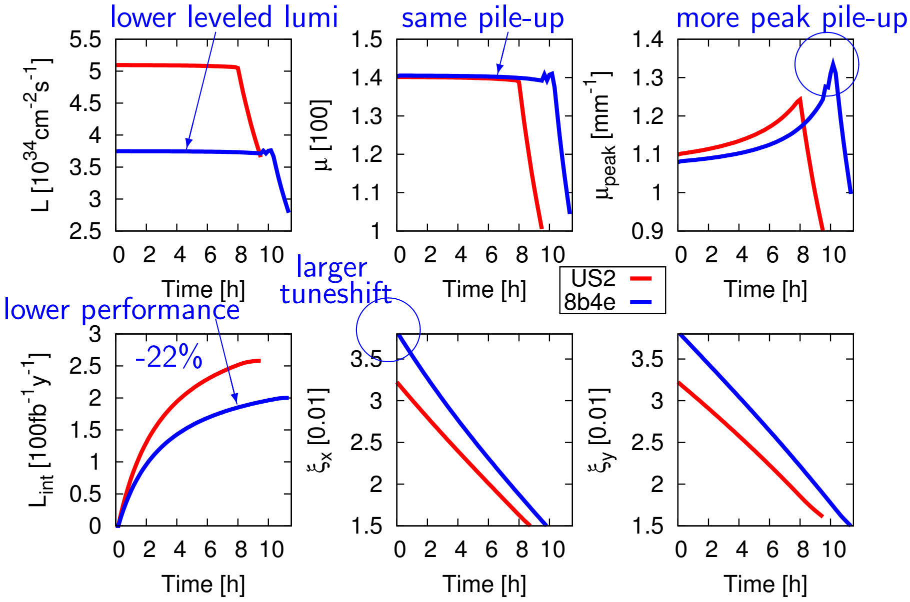
8b+4e
30% fewer LRs

Lower number of long range encounters allows for smaller crossing angle and smaller $\beta^*$ ($\beta^* = 10$cm, $\theta = 530\mu m$ ($9\sigma$) with crab cavities in the following)

# Pushed 8b+4e: Performance I (preliminary)



# Pushed 8b+4e: Performance II (preliminary)



# Conclusions

- 80 bunch scheme is promising for performance and flexibility: up to 5.2% in lumi, turn-around-time, scrubbing beam, 80bunch/3batches, etc
- Experimentally not yet demonstrated
- and full LHC potential not yet explored
- Need to know: minimum number of non-colliding bunches, figure of merit for luminosities in the IPs and abort gap margin.
- Risk of protection devices to be assessed.