Alternative bunch filling scheme

for the LHC

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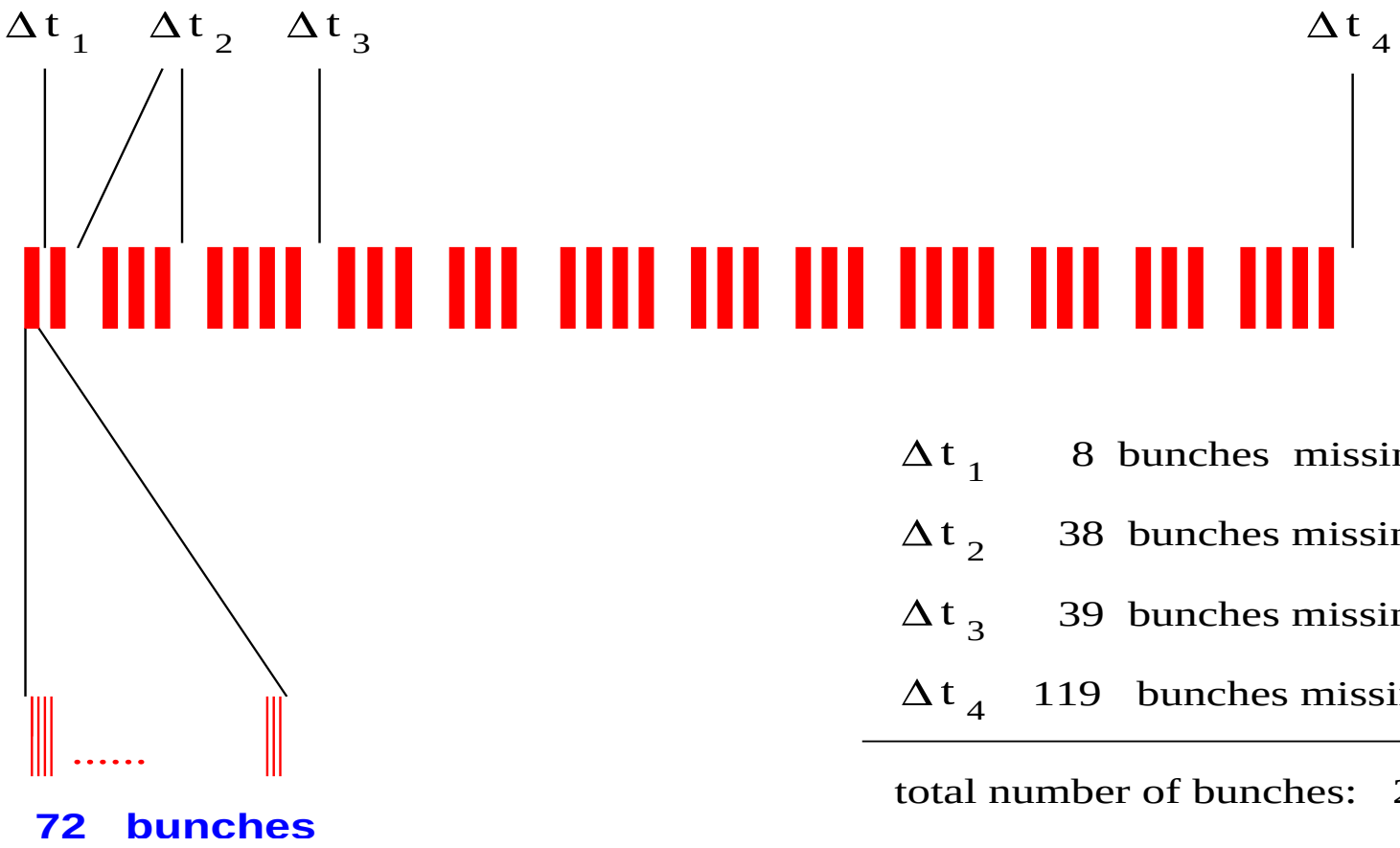
Present LHC filling scheme (25 ns):

- **Present scheme for high (nominal) luminosity with 25 ns spacing, with 72 bunches per batch**

$$\{[(72b+8e)*2+30e]+[(72b+8e)*3+30e]+[(72b+8e)*4+31e]\}$$
$$\{[(72b+8e)*3+30e]+[(72b+8e)*3+30e]+[(72b+8e)*4+31e]\}*3$$
$$+\quad \{80e\} \quad = \quad 3564$$

- **39 batches with 72 bunches each**
- **12 SPS supercycles**
- **Total: 2808 bunches (b), 756 empty spaces (e)**

Present LHC filling scheme (25 ns):



Δt_1	8	bunches missing
Δt_2	38	bunches missing
Δt_3	39	bunches missing
Δt_4	119	bunches missing

total number of bunches: 2808

Present LHC filling scheme (25 ns):

- **Present scheme for high (nominal) luminosity with 25 ns spacing, with 72 bunches per batch**

$$\{[(72b + 8e) * 2 + 30e] + [(72b + 8e) * 3 + 30e] + [(72b + 8e) * 4 + 31e]\}$$
$$\{[(72b + 8e) * 3 + 30e] + [(72b + 8e) * 3 + 30e] + [(72b + 8e) * 4 + 31e]\} * 3$$
$$+ \quad \{80e\} \quad = \quad 3564$$

- **Total 2808 bunches (b), 756 empty spaces (e)**
- **SPS injection kicker: 8 missing bunches, 0.225 μs.**
- **LHC injection kicker: 38/39 missing bunches, 0.975 μs.**
- **Abort gap: 119 missing bunches, 3 μs.**

Why alternatives ?

- In 2004: 4 batches of 72 bunches were transferred from PS to SPS
- Recently with 72 bunches instability was observed in PS (probably understood)
- Transferring 48 bunches was never a problem
- → Elias for details ...
- → Evaluate what can be done with 48 bunches per batch (for nominal beam, not ultimate, not ions)

Requirements for any filling scheme:

- keep injection and abort gaps at least as large
- maintain four-fold symmetry (for beam-beam)
- in SPS: keep $N_{tot} \leq 4 \cdot 10^{13}$
- last injection should be longest duration (synchronization of beam dump)
- maximize number of bunches (rather: collisions)

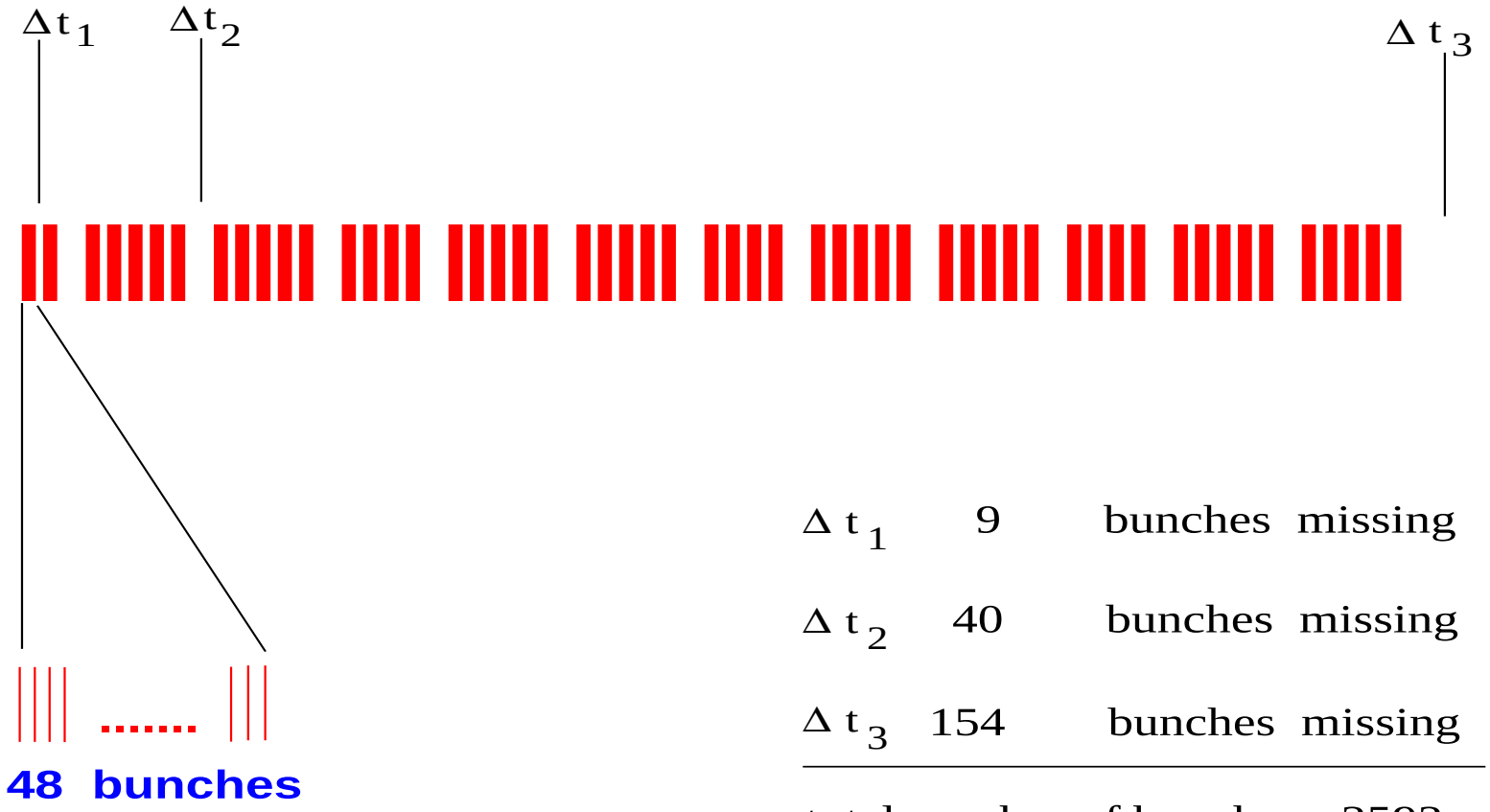
Alternative LHC filling schemes:

- **Our proposal with 48 bunches per batch:**

$$\begin{aligned} & \{[(48b + 9e) * 2 + 31e] * 1 + [(48b + 9e) * 5 + 31e] * 2\} \\ + \quad & \{[(48b + 9e) * 4 + 31e] * 1 + [(48b + 9e) * 5 + 31e] * 2\} * 3 \\ + \quad & \{114e\} \quad = \quad 3564 \end{aligned}$$

- **Total 2592 (old: 2808) bunches ($\approx$ 8 % less)**
- **SPS injection: 9 (old: 8) missing bunches, 0.25 μs.**
- **LHC injection: 40 (old: 38/39) missing bunches, 1.025 μs.**
- **Abort gap: 154 (old: 119) missing bunches, 3.875 μs.**

Proposed LHC filling scheme (25 ns):



Δt_1	9	bunches missing
Δt_2	40	bunches missing
Δt_3	154	bunches missing

total number of bunches: 2592

Some features:

- Same number of SPS supercyles (12)
- 54 batches of 48 bunches
- Lower maximum intensity per LHC injection ($\approx$ 17% lower)
- All gaps slightly larger than in nominal scheme
- Significantly larger abort gap (3.875 μs)

Implications for luminosity performance

- Slightly reduced number of collisions (luminosity):
  - 2808 $\rightarrow$ 2592 in IP1 and IP5 (8 %)
  - 2736 $\rightarrow$ 2496 in IP2 (protons) (9 %)
  - 2622 $\rightarrow$ 2340 in IP8 (11 %)
- Increased effect in IP2 and IP8 due to larger abort gap
- Is this reduction relevant ? (fluctuations etc.)

beam-beam and PACMAN numerology

	nominal	alternative
1 head-on collision missed	252	336
2 head-on collisions missed	3	6
min. number of long range	45	45
max. number of long range	120	120

- Fewer head on collisions in IP 2 and 8 (only)
- No change for long range interactions
- No additional problems expected

Implications for PS and SPS

- PS and SPS cycles, e-cloud, filling time

  ...

- → Elias for details

Operation without crossing angle

Without crossing angle: completely safe bunch distance is 600 ns

$$\begin{aligned} & \{[(1b + 56e) * 2 + 31e] * 1 + [(1b + 56e) * 5 + 31e] * 2\} \\ + \quad & \{[(1b + 56e) * 4 + 31e] * 1 + [(1b + 56e) * 5 + 31e] * 2\} * 3 \\ + \quad & \{114e\} \quad = \quad 3564 \end{aligned}$$

- **Derived from 48 bunch scheme:**
  1 batch = 1 bunch → 54 bunches
- **Difference to 43 bunch scheme: not equidistant**

Collisions in LHCb

- With 54 bunches: collisions in IP8 require longitudinal displacement of some bunches by 75 ns
- Two options:
  - Displace bunches in one beam only
  - Displace bunches symmetrically in both beams
  - Assume 5 displaced bunches →

Collisions in LHCb - numerology

	no bunches displaced	displaced in one beam	displaced in both beams
collisions in IP1	54	49	54
collisions in IP2	52	47	42
collisions in IP5	54	49	54
collisions in IP8	0	5	5

Summary

- Good alternative when 72 bunches per batch are difficult
- Almost the same luminosity
- Operational implications in PS/SPS → Elias
- Possibly interesting step on the way to 72 bunches