POST-LS1 25 NS & 50 NS OPTIONS FROM THE INJECTORS

Rende Steerenberg, Gianluigi Arduini, Theodoros Argyropoulos, Hannes Bartosik, Thomas Bohl, Karel Cornelis, Heiko Damerau, Alan Findlay, Roland Garoby, Brennan Goddard, Simone Gilardoni, Steve Hancock, Klaus Hanke, Wolfgang Höfle, Giovanni Iadarola, Elias Metral, Bettina Mikulec, Yannis Papaphilippou, Giovanni Rumolo, Elena Shaposhnikova,...

With thanks to the OP-teams and Machine supervisor teams

Scope:

- Protons only
- Multi-bunch beams only
- LHC Injectors
  - PSB
  - PS
  - SPS

Contents:

- LHC 50ns and 25ns evolution in 2012
- Limitations and difficulties encountered
- The menu for Post-LS1
- Potential issues/challenges
- Concluding remarks

- LHC 50ns and 25ns evolution in 2012
- Limitations and difficulties encountered
- The menu for Post-LS1
- Potential issues/challenges
- Concluding remarks

Classical 25ns & 50ns Beam Parameters

- Initial specifications:

Defined Characteristics 2004 (Source: LHC-OP-ES-0002 rev 1.0, EDMS: 487892)

	PSB extraction				PS extraction			SPS extraction			
	Ip / ring [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	nb bunches
LHC25	2.4 - 13.8	≤ 2.5	2	4 + 2	0.2 -1.15	≤ 3	72	0.2 -1.15	≤ 3.5	≤ 0.8	1 - 4 x 72
LHC50	1.2 - 6.9	≤ 2.5	2	4 + 2	0.2 -1.15	≤ 3	36	0.2 -1.15	≤ 3.5	≤ 0.8	1 - 4 x 36

- From Chamonix 2012:

Tentative Operational Characteristics 2012

	PSB extraction				PS extraction			SPS extraction			
	Ip / ring [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	nb bunches
LHC25	16	2.5	2	4 + 2	1.3	2.5	72	1.15	3.5	0.7	1 - 4 x 72
LHC50	11	1.6	2	4 + 2	1.8	1.9	36	**1.6**	**2**	≤ 0.8	1 - 4 x 36

- Performance end 2012:

Achieved Operational Characteristics 2012

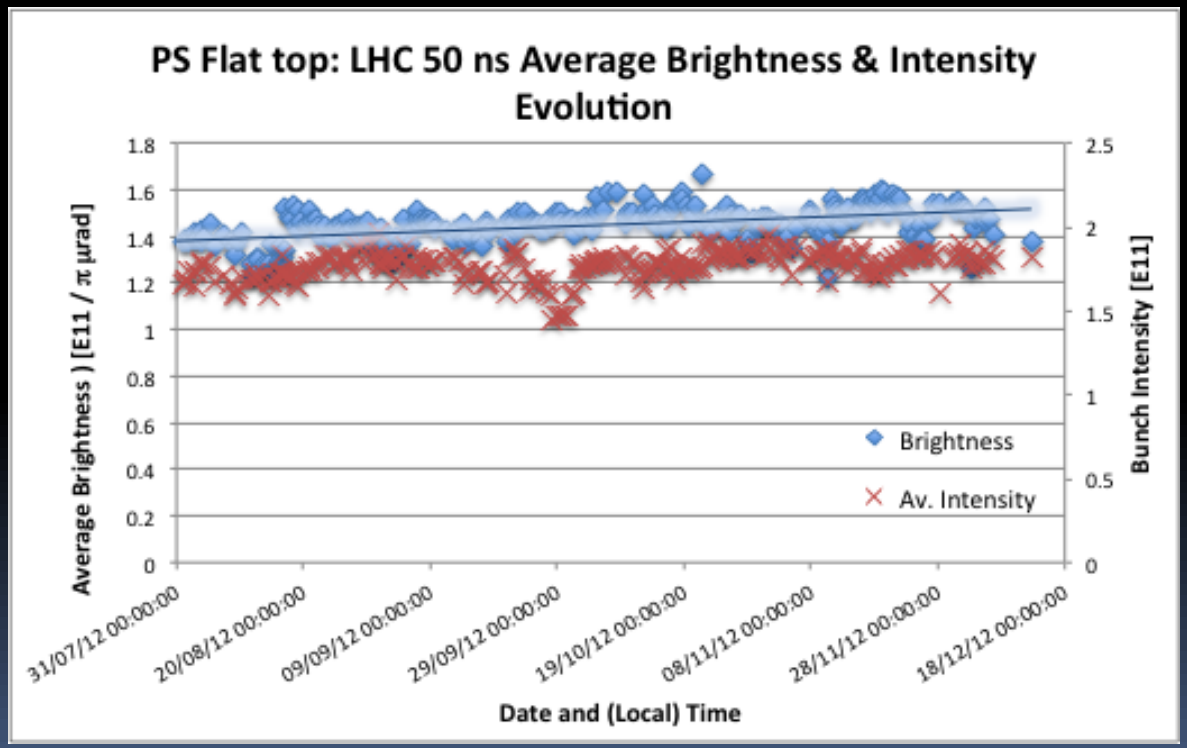
	PSB extraction				PS extraction			SPS extraction			
	Ip / ring [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	nb bunches
LHC25	16	2.3	2	4 + 2	1.3	2.4	72	1.35	~ 3	0.7	1 - 4 x 72
LHC50	12	1.35	2	4 + 2	1.9	1.5	36	**1.65**	**1.65**	≤ 0.8	1 - 4 x 36

Beam Brightness Evolution

- Continuous optimisation resulted in brighter beams.
- Systematic logging in PSB, PS and SPS started after the summer with at least 1 measurement per shift.

- SPS April:
  - $I_p = 1.4 \times 10^{11}$ ppb
  - $\varepsilon_{h/v} = 1.8$ µm rad

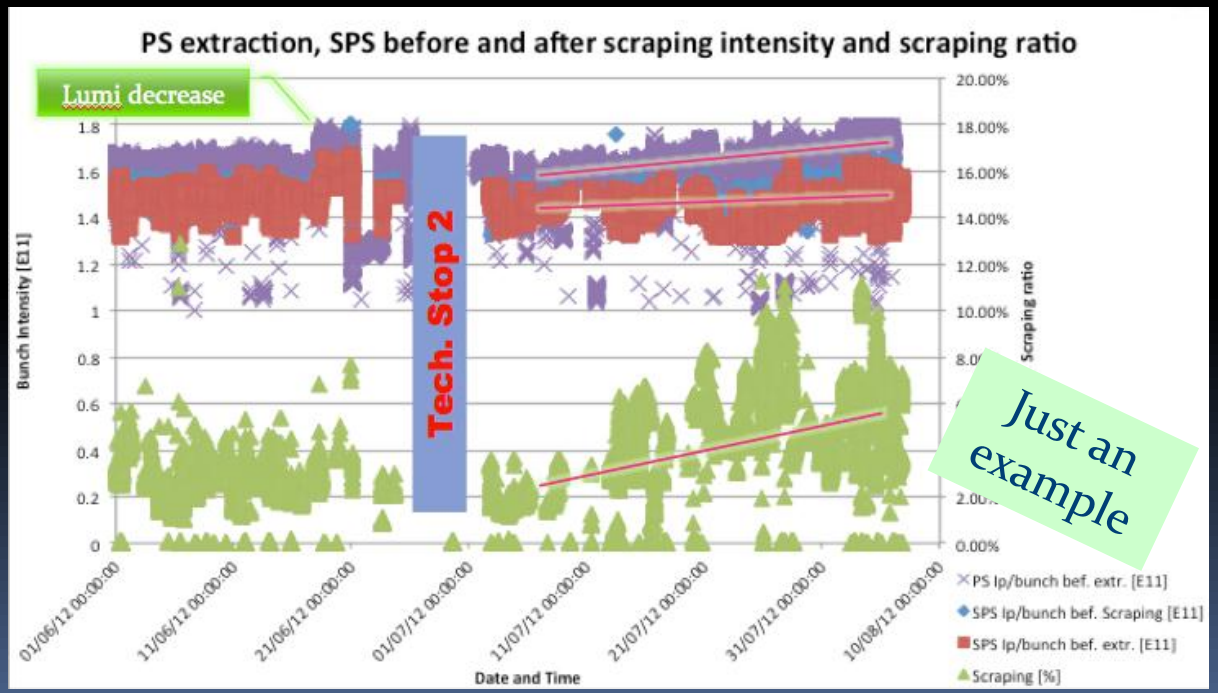
- SPS November:
  - $I_p = 1.65 \times 10^{11}$ ppb
  - $\varepsilon_{h/v} = 1.65$ µm rad



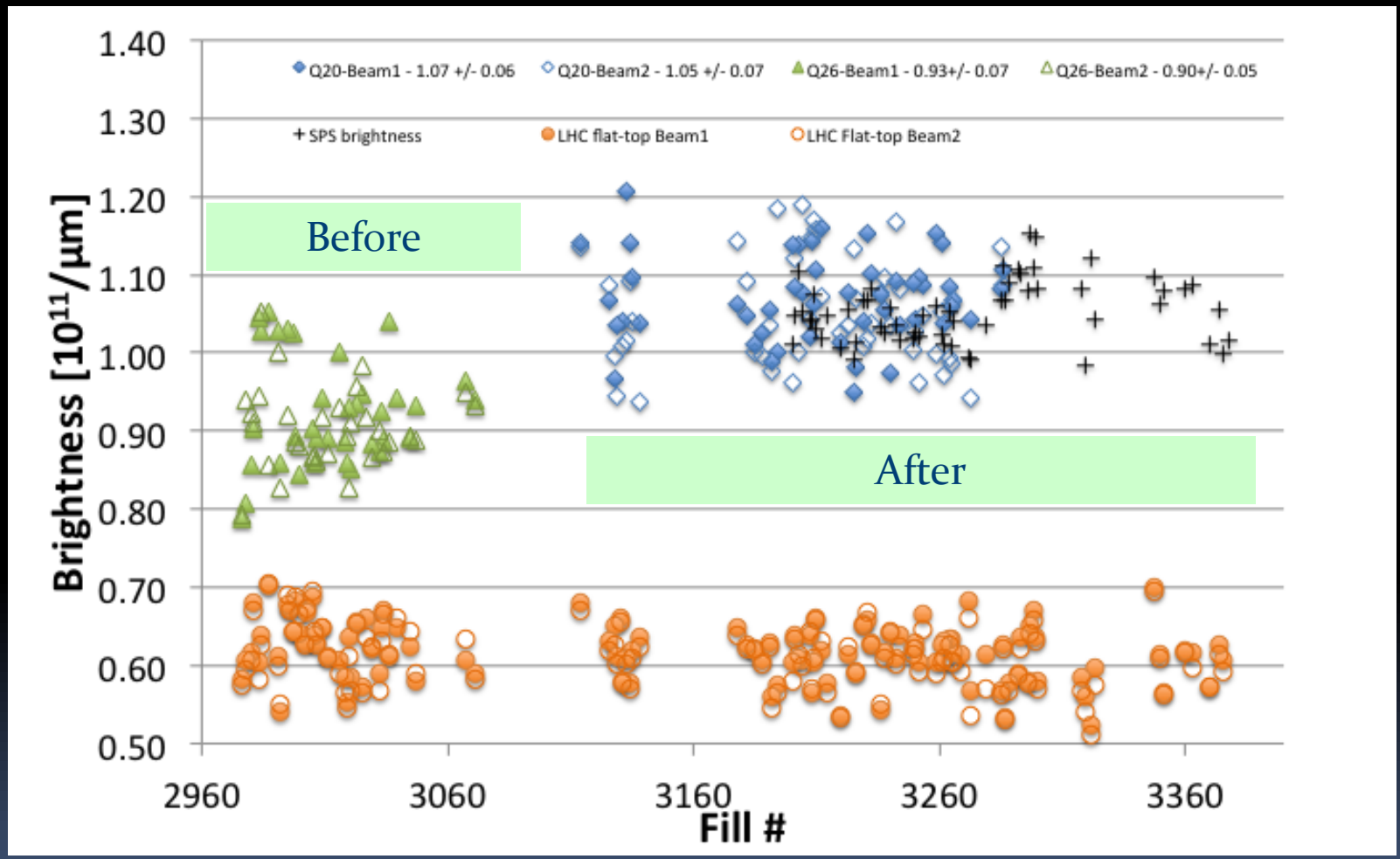
Some of the Optimisation

- PSB injection matching improvement
  - Provided brighter beams to the PS.
- PS working point
  - To be able to swallow the brighter PSB beam without transverse emittance blow up.

- Be aware of optimising, focusing on a single parameter.
- Each improvement should be checked throughout the entire injector chain.



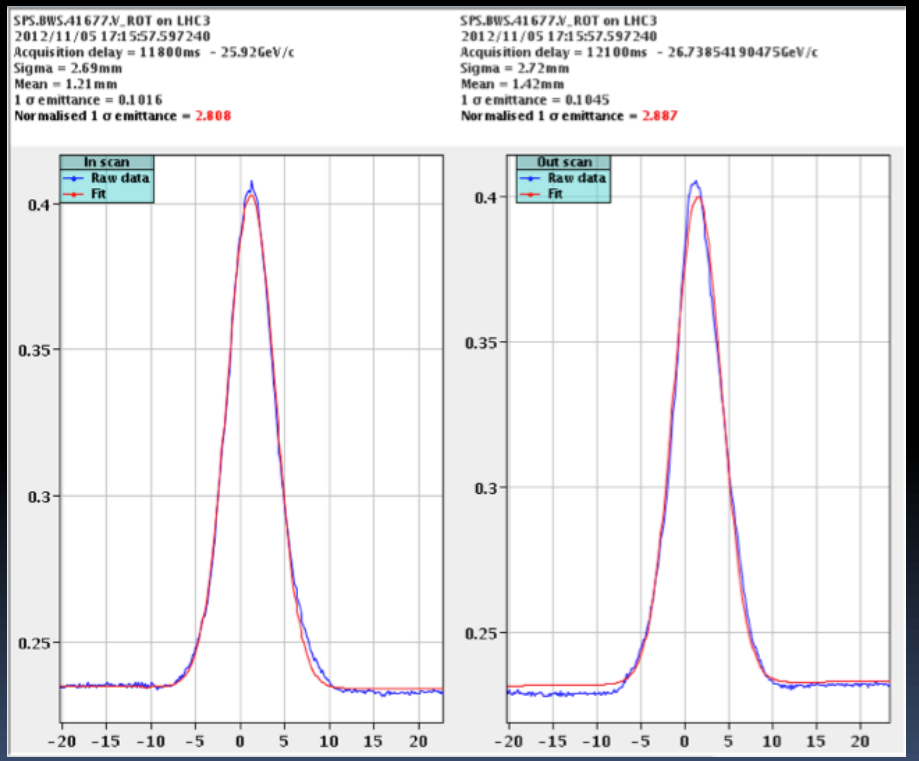
SPS Q20 deployment



Courtesy of Y. Papaphilippou

Some of the Optimisation

- LHC 25 ns classical
  - 1.5 x 10^{11} ppb in ~2.9 µm rad at flat bottom.
  - 1.35 x 10^{11} ppb at flat top.
  - No transverse emittance measurement available for flat top.
  - The wire scanner can only be used on flat bottom to remain within safe limit (BI).



- LHC 50ns and 25ns evolution in 2012
- Limitations and difficulties encountered
- The menu for Post-LS1
- Potential issues/challenges
- Concluding remarks

Just a Sub-set

- PSB:
  - Intensity changes require WP modification on the 4 rings to keep transverse emittances minimum.
- PS:
  - Injection oscillations from recombination for smaller emittances give larger relative transverse emittance blow up
  - More dense bunches increased space charge and required WP modification
  - Coupled bunch instabilities with higher intensities
  - For magnetic reasons an “empty” LHC cycle was put in front of the filling cycles in the super cycle.

Just a Sub-set

- SPS:
  - Transverse emittance measurements.
    - Impossible to use wire scanners at flat top, as this is beyond breakage limit.
    - The wire scanner measurements a the end of the SPS flat bottom and the LHC flat bottom show good agreement.
  - Orbit variation at flat top (shims and vacuum chamber grounding)
  - Longitudinal multi bunch instability
  - Sensitivity of SPS longitudinal blow up on PS bunch length and intensity.

- General:
  - Even though considerable effort was put on the wire scanner measurements along the chain, measuring the transverse emittances remain difficult with these small beam sizes.

- LHC 50ns and 25ns evolution in 2012
- Limitations and difficulties encountered
- The menu for Post-LS1
- Potential issues/challenges
- Concluding remarks

The Multi-bunch Menu for 2015

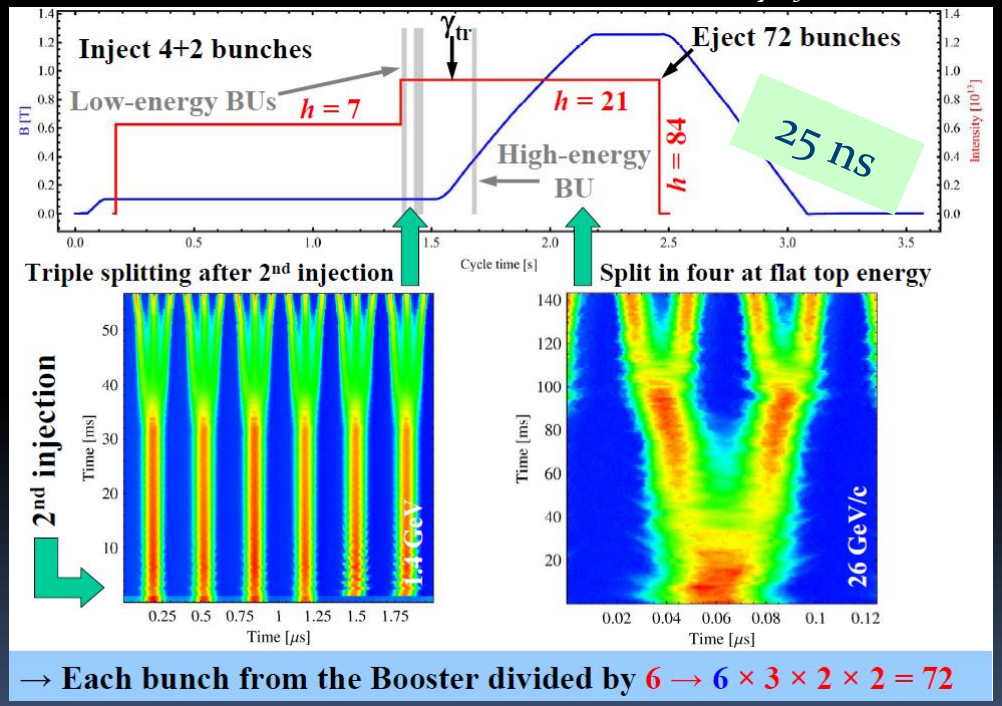
- The classical beams with end of 2012 beam parameters:
  - LHC50
  - LHC25
- Low emittance or high brightness beams (h=9 with batch compression, merging and splitting, called "BCMS"):
  - LHC50 BCMS
  - LHC25 BCMS

See: "LHC Injector Upgrade" by Heiko Damerau, Chamonix 2012

The Classical 25ns & 50 ns Beam Production

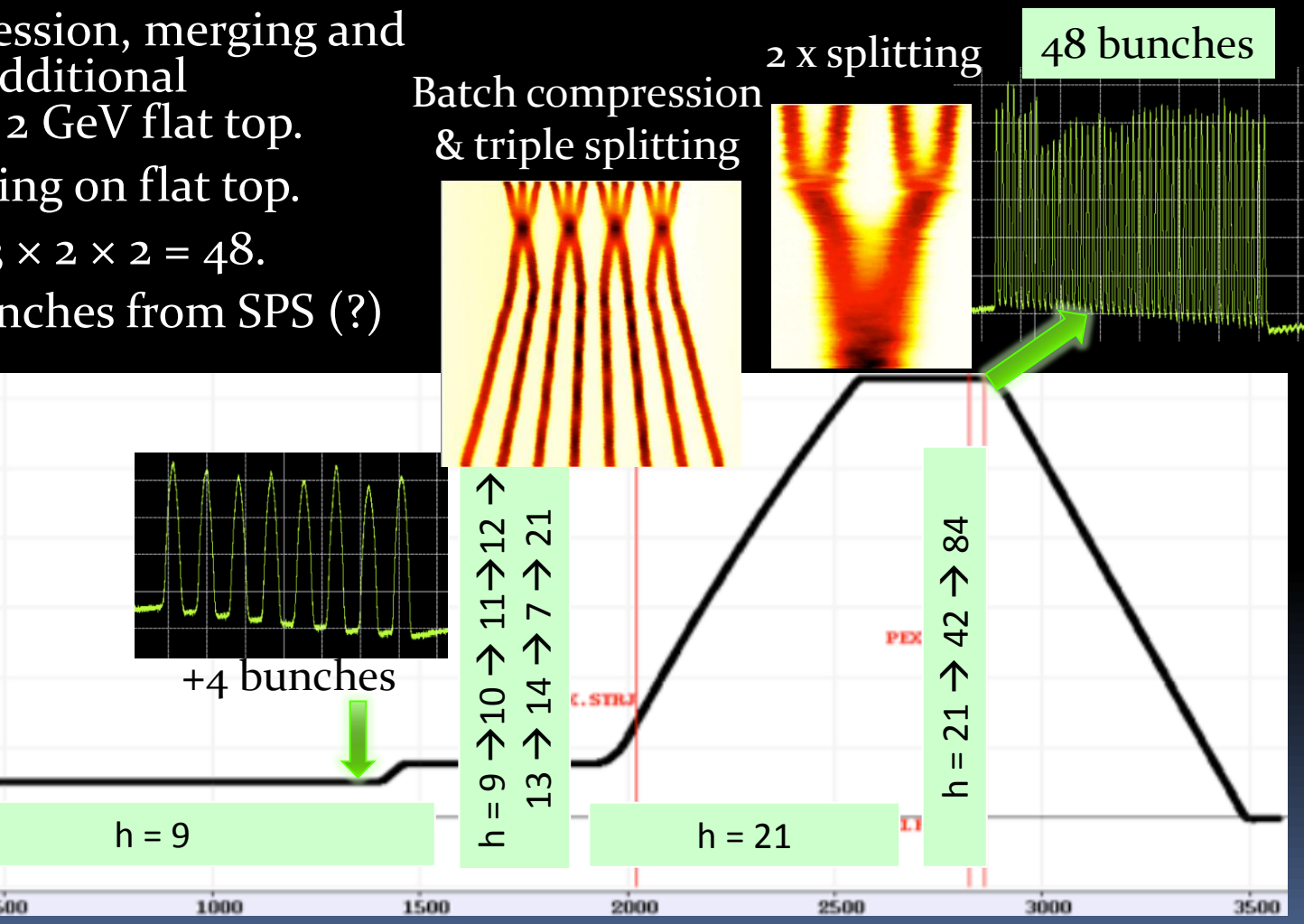
- The 25 ns:
  - Double batch injection from PSB (4 + 2 bunches).
  - Triple splitting at LE in PS.
  - Acceleration.
  - 2 x splitting at HE in PS.
  - Bunch rotation in PS.
  - Up to 4 batches to SPS.
  - 288 bunches out of SPS.
- The 50 ns:
  - Similar to 25ns at LE.
  - 1 x splitting at HE in PS.
  - Bunch rotation in PS.
  - Up to 4 batches to SPS.
  - 144 bunches out of SPS.

Courtesy of H. Damerau



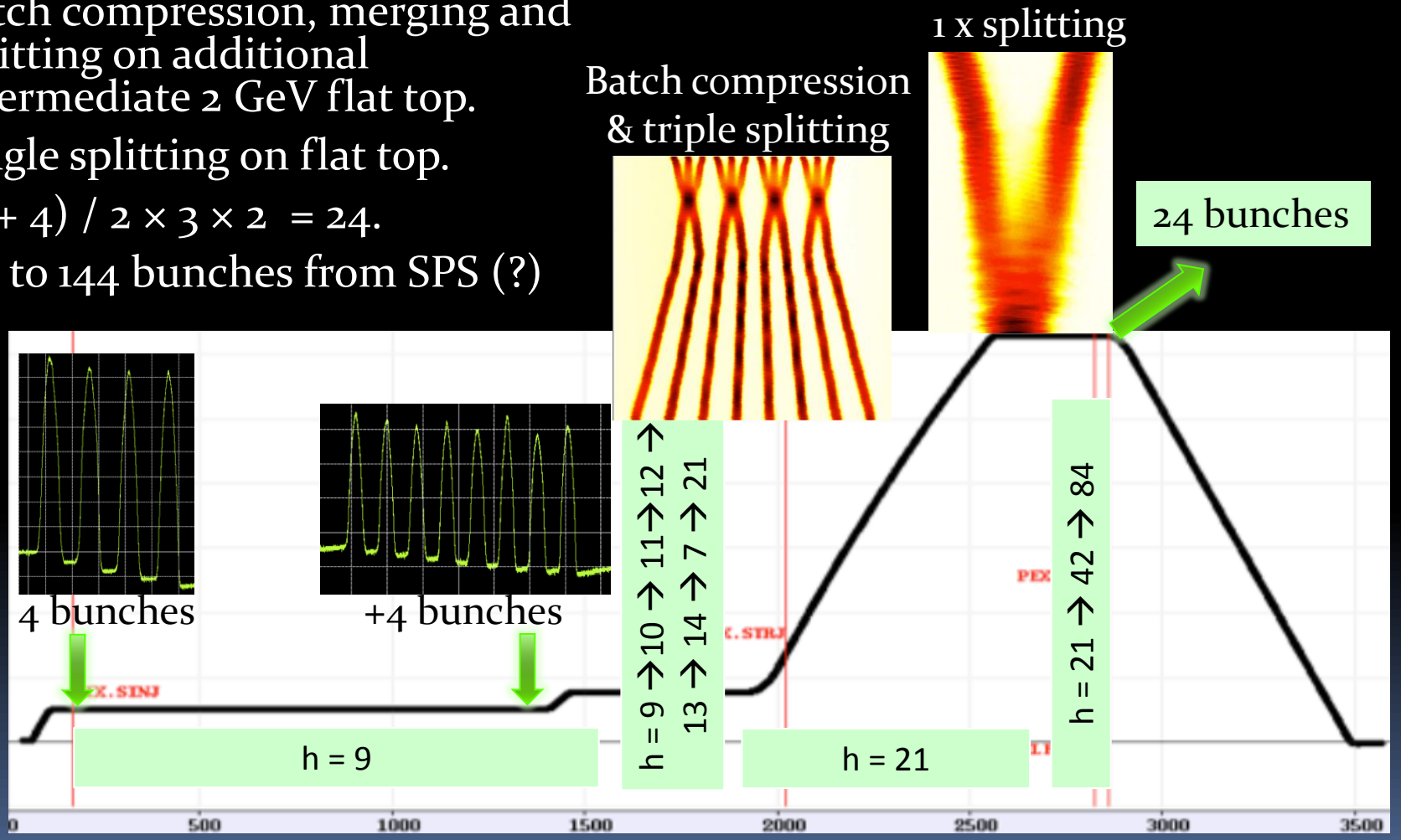
LHC 25ns BCMS Beam Production in PS

- Double batch injection with 8 bunches on h=9.
- Batch compression, merging and splitting on additional intermediate 2 GeV flat top.
- Double splitting on flat top.
- (4 + 4) / 2 × 3 × 2 × 2 = 48.
- Up to 288 bunches from SPS (?)



LHC 50ns BCMS Beam Production in PS

- Double batch injection with 8 bunches on h=9.
- Batch compression, merging and splitting on additional intermediate 2 GeV flat top.
- Single splitting on flat top.
- (4 + 4) / 2 × 3 × 2 = 24.
- Up to 144 bunches from SPS (?)



Achieved Beam Parameters 2012

- Performance achieved for classical and BCMS beams in 2012:

Achieved Operational Characteristics 2012											
	PSB extraction				PS extraction			SPS extraction			
	Ip / ring [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	nb bunches
Classical beams:											
LHC25	16	2.3	2	4 + 2	1.3	2.5	72	**1.35**	**~ 3**	0.7	1 - 4 x 72
LHC50	12	1.35	2	4 + 2	1.9	1.5	36	**1.65**	**1.65**	≤ 0.8	1 - 4 x 36
High Brightness beams											
LHC25 BCMS	7.5	1	2	4 + 4	1.2	1.2	48	**1.15**	**1.4**	0.7	1 - 4 x 48
LHC50 BCMS	6	0.9	2	4 + 4	1.9	1.1	24	**1.6**	**1.2**	≤ 0.8	1 - 4 x 24

- The BCMS (high brightness) beams are new and were only really commissioned autumn 2012:
  - Although there were 3 partial LHC physics fills, these beams were mainly used in an MD context and no operational experience is available.
  - Complicated and delicate production process in PSB and PS.
  - SPS working point fine with present brightness, beyond this adaptation is required.
  - Require maintenance.

25ns & 50ns Beam Parameters

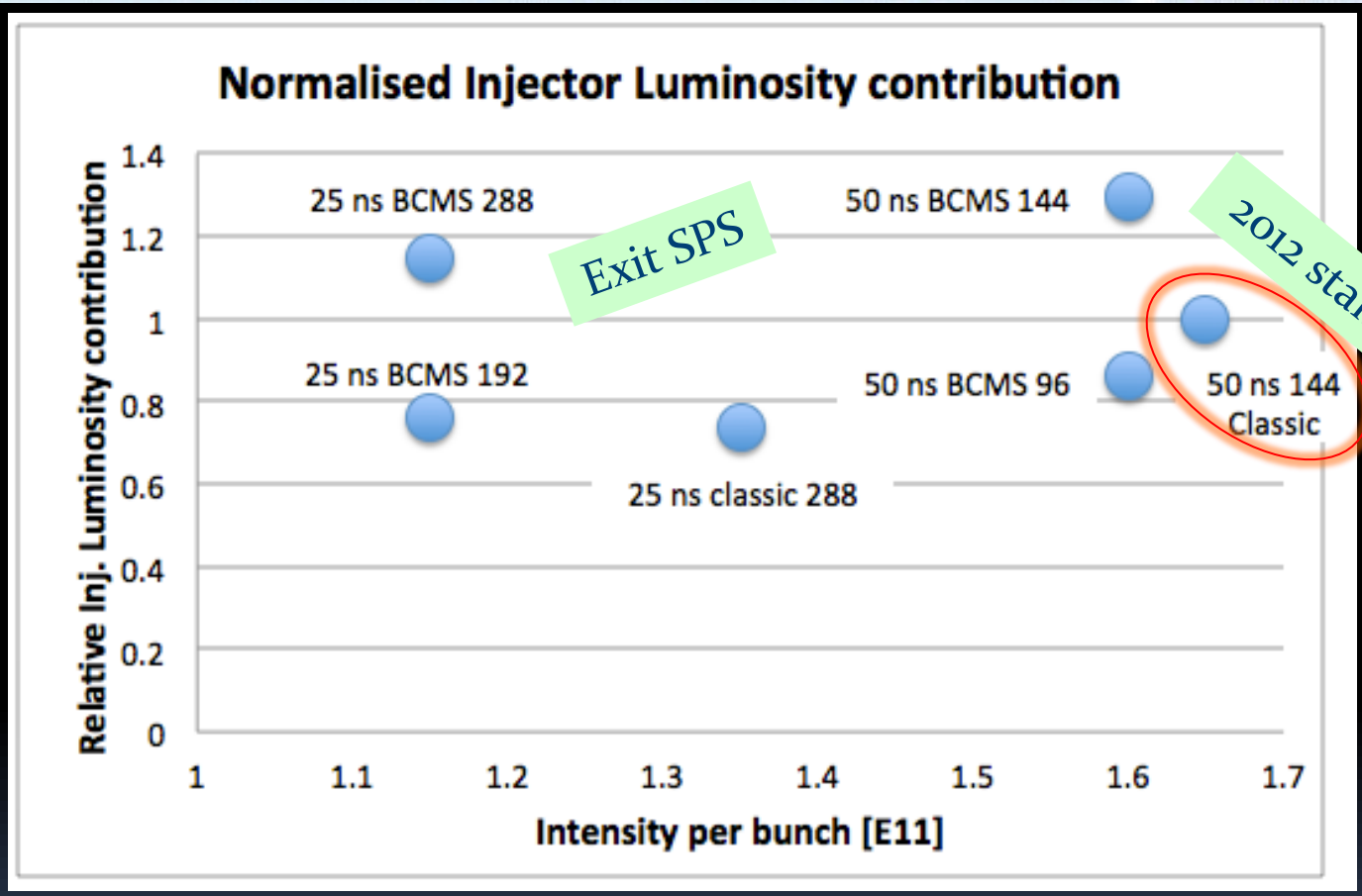
- The injectors contribution to the luminosity is:

$$L \mu \frac{N_b^2}{e} M$$

Where:

- N_b = number of protons per bunch
- M = number of bunches
- ε = average transverse emittance

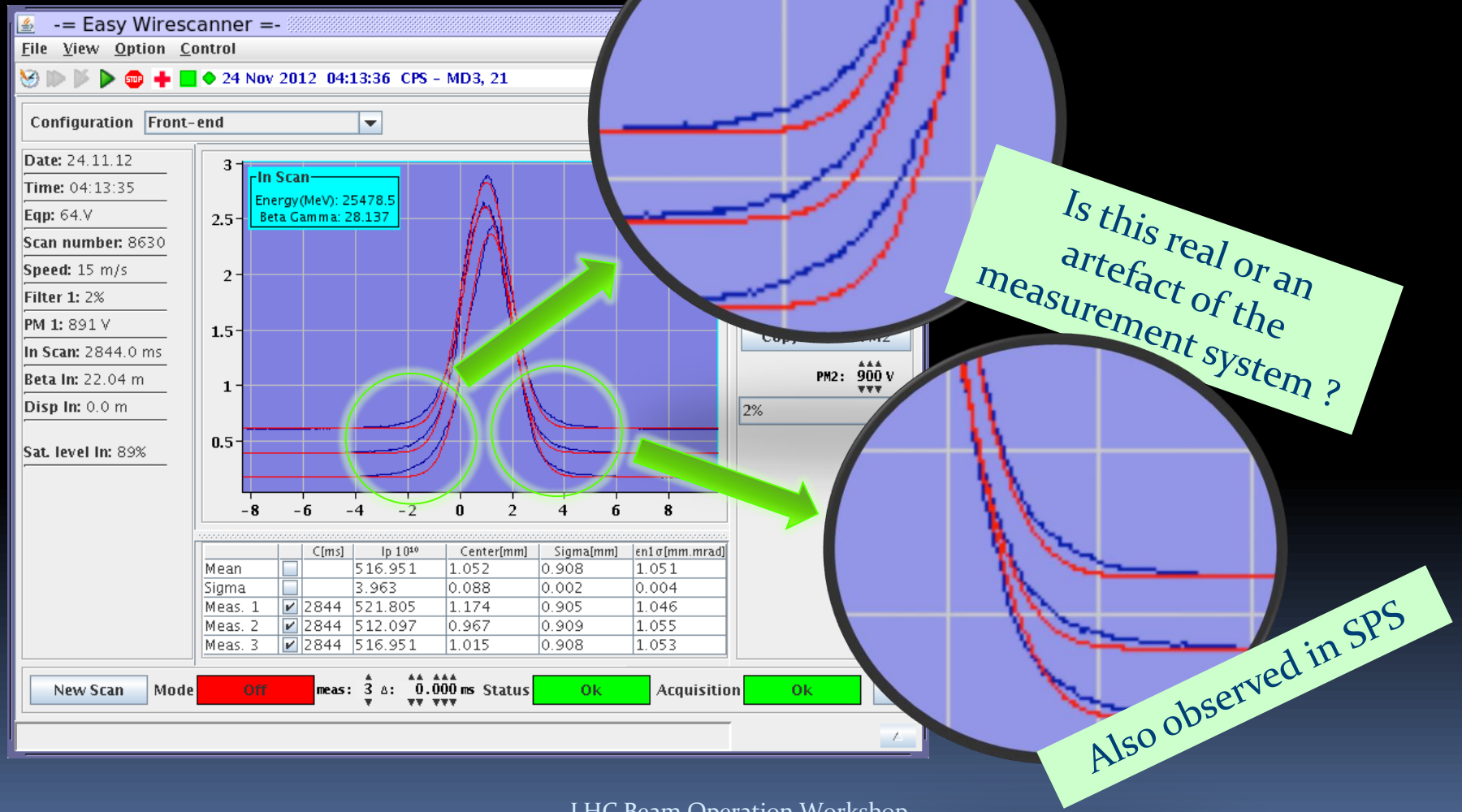
Injector Luminosity Contribution



- Can we maintain quality for 5 or 6 batch injection with BCMS in SPS ?
- No pile up considerations included

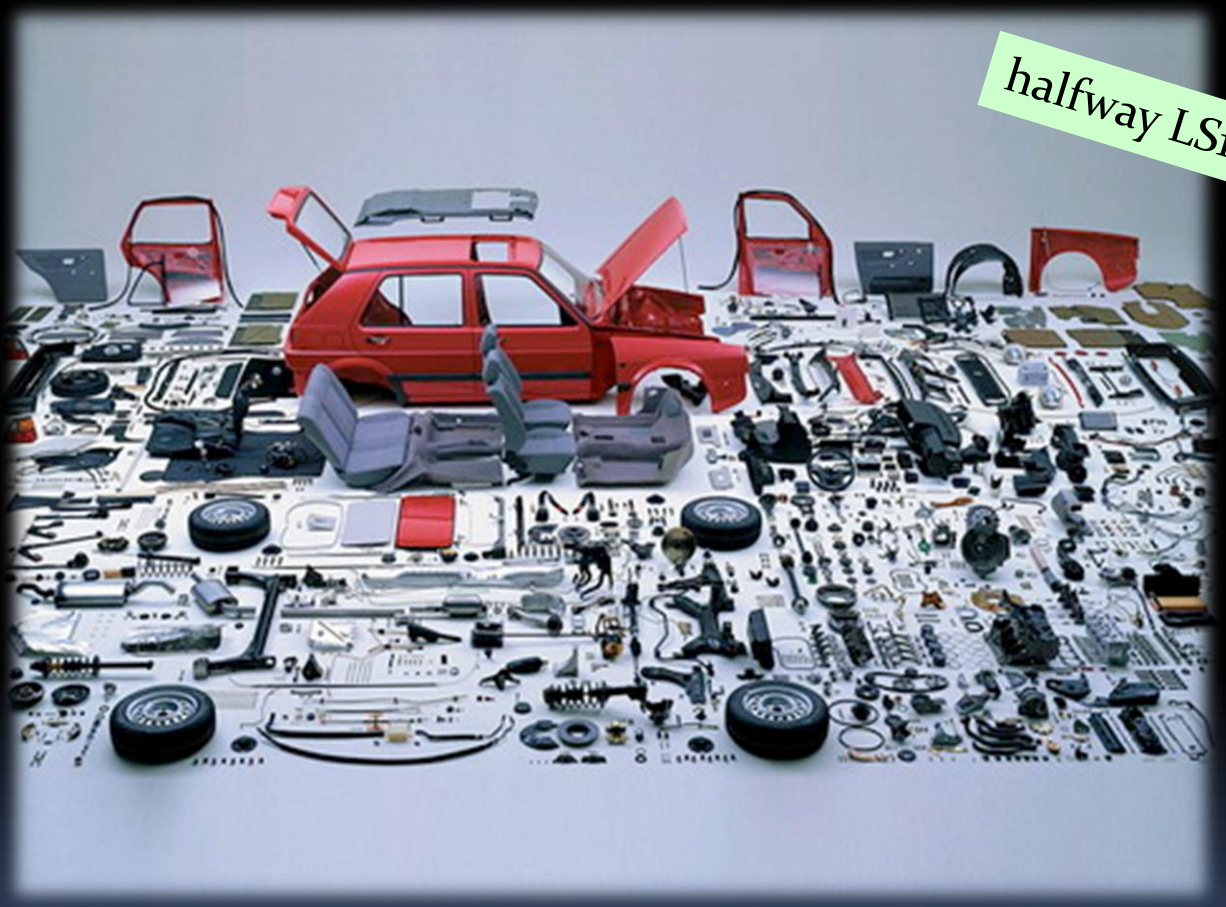
Example of Work that Remains

- Tails…



- LHC 50ns and 25ns evolution in 2012
- Limitations and difficulties encountered
- The menu for Post-LS1
- Potential issues/challenges
- Concluding remarks

LS1 for the Injectors



...will it ever work again ?

Potential LS1 PSB Improvements

- Complete realignment of the magnet stacks → Potentially improved orbit.
- New BPM's to be commissioned → turn-by-turn measurement.
- YASP for FGC3 orbit correctors in place and polarity corrections → active orbit correction possible.
- New digital beam control → but no operational experience.
- New transverse damper.
- New BPM's in the PSB injection line → potentially better injection steering.

Potential LS1 PS Improvements

- Complete realignment of the main magnets to be followed by beam based realignment at start up.
- Transverse damper in both planes → Less dependency on PSB recombination errors (promising results already in 2012).
- New 1-turn delay feedback on 10 MHz cavities.
- Increase of voltage available per 10 MHz cavity tuning group. (re-commission all beams)
- New longitudinal feedback kicker (Finemet cavity) → no experience at all in PS.
- Major RF controls renovation enabling RF controls on new beams.
- Major controls renovation

Potential LS1 SPS Improvements

- Re-matching TT2-TT10.
- 800 MHz SPS feedback (+more voltage).
- MKE kicker will be shielded (present heating limitation).
- Partial realignment of sector 6.
- ungrounded vacuum chambers to be corrected → orbit perturbation.
- Fix lose shims.
- High energy orbit for Q20 to be improved (including beam based realignment).
- Existing SPS transverse damper upgrade and development of high bandwidth system.

Post-LS1 Worries/Challenges

- All these changes and new systems etc. need to be commissioned, made operational and operational experience needs to be gained.
- SPS will have been opened virtually everywhere → e-cloud
  - Scrubbing, scrubbing, scrubbing and ….. !!!
  - Enhanced scrubbing beam is very promising.
- To gain operational experience we need the BCMS beams very often in the super cycles in 2014.
  - Dumping the beam in the SPS so often might be an issue.

- LHC 50ns and 25ns evolution in 2012
- Limitations and difficulties encountered
- The menu for Post-LS1
- Potential issues/challenges
- Concluding remarks

Concluding remarks

- After all the LS1 work in the injectors we should first find back the 2012 performance.
  - PS Complex beam operation mid-July 2014.
  - SPS beam operation mid-October 2014.
  - LHC beam Early 2015.
- Optimisation in the injectors provides more and more bright beams, scratching every percent.
  - What about the 30 - 40% transverse emittance blow up in the LHC ?

25ns & 50ns Beam Parameters

- Expected performance post-LS1:

	Expected Operational Characteristics 2015										
	PSB extraction				PS extraction			SPS extraction			
	Ip / ring [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	nb bunches
Classical beams											
LHC25	16	2.3	2	4 + 2	1.3	2.4	72	1.35	~ 3	0.7	1 - 4 x 72
LHC50	12	1.35	2	4 + 2	1.9	1.5	36	1.65	1.65	≤ 0.8	1 - 4 x 36
High brightness beams											
LHC25 BCMS	7.5	1	2	4 + 4	1.2	1.2	48	**1.15**	**1.4**	0.7	1 - 4 x 48
LHC50 BCMS	6	0.9	2	4 + 4	1.9	1.1	24	**1.6**	**1.2**	≤ 0.8	1 - 4 x 24

- The BCMS beams are promising, but new.
- They will undergo further development in 2014 and 2015 to improve quality.
- Performance limitations for the BCMS beams need to be fully explored.
- How many batches should the SPS inject, 4, 5, 6 ?
- Operational experience has to be gained, starting in 2013.

Thanks ?