



PERFORMANCE REACH OF THE INJECTOR COMPLEX IN 2012

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With the help of:

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Scope

- What is included:
 - This presentation will only deal with the protons in the injectors for the LHC.
 - It will treat only the performance reach in 2012.
 - It mainly concentrates on the 50 ns beam for physics, as the 25 ns in the present configuration does not seem to provide the required integrated luminosity for 2012.
- What is not included:
 - It will not treat LIU related project tasks.
 - Therefore it will not deal with the performance after LS₁.



Content

- Brief reminders of last years' Chamonix
- The 2011 injectors performance
- The 50 ns production and difficulties
- Are there margins for improvement left ?
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Chamonix 2011 Beam Characteristics

- Focusing on the most relevant beams:

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

Possible Characteristics 2011											
	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 (DB)	16	2.5	2	4 + 2	1.3	2.5	72	1.15	3.6	0.7	1 - 4 x 72
LHC50 (SB)	24	3.5	1	3 x 2	1.75	3.5	36	1.45	3.5	≤ 0.8	1 - 4 x 36
LHC50 (DB)	8	1.2	2	4 + 2	1.3	1.3	36	1.15 (?)	1.5 (?)	≤ 0.8	1 - 4 x 36

- The double batch 50 ns “high-performance” beam characteristics were not really known last time
 - They had been produced occasionally during MD’s, but not routinely.



A Mini-Evaluation

Possible improvements for 2011



- Higher current from LINAC2 (180mA instead of 160mA):
 - Advantage: Increase of intensity while keeping transverse emittance constant (LHC DR, Vol. III page 15)
 - Issue: Presently not done because of lack of spare amplifier tubes
- Double batch injection LHC50/75:
 - Will surely result in smaller transverse emittances
 - Could potentially allow for higher intensities, but **how far can we go with LHC50/75 double batch ?** (MD time needed)

D. Kuchler at IEFC 13/01/2012:

MD for peak performance pushed the current up to 177mA (mainly source and RFQ settings), but PSB could not really make use of it (insignificant decrease of LHC beam emittance).

Do we need to put more effort in this?

Many unknowns at Chamonix 2011

We went very far with the 50 ns double batch !

This beam had the biggest potential

The injectors did very well, but they are asked to do even better.



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What Was Provided in 2011

- LHC beam commissioning and first stable beams → Single batch 75 ns
- After the LHC scrubbing run, 1st week of April → Single batch 50 ns
- July 14th and beyond → Double batch 50 ns beam “work horse” of 2011

Final Operationally Produced Characteristics 2011

	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 (DB)	16	2.5	2	4 + 2	1.3	2.5	72	1.15	3.5	0.7	1 - 4 x 72
LHC50 (SB)	24	3.5	1	3 x 2	1.75	3.5	36	1.45	3.5	≤ 0.8	1 - 4 x 36
LHC50 (DB)	10	1.4	2	4 + 2	1.6	1.6	36	1.5	1.9	≤ 0.8	1 - 4 x 36

- Initially a controlled transverse blow-up was applied in the injectors.
- Once the double batch 50 ns beam was taken by the LHC the performance was pushed throughout the injector chain:
 - Gradual intensity increases resulted in ~30% more than anticipated
 - Keeping the transverse emittances as small as possible (+27%)
- The 25 ns beam was for the first time produced within nominal specifications.



Evolution of the LHC beam in 2011

Beam Brightness out of SPS 13/07/2011 - 30/10/2011



LHC 50 ns bunch intensity out of SPS 13/07/2011 - 30/10/2011



Based on data from SPS logbook for 36 bunches/batch



Improved Operability

- The 50 ns double batch beam only became really operational in 2011.
- Two dedicated users for 12 and 36 bunch version were introduced:
 - More cycles/beams to maintain (identical).
 - Improved stability/reproducibility.
 - Reduced switching time.
- The controlled SPS longitudinal blow-up became ppm.
- SPS also provided the controlled transverse blow-up.
- The Operations teams became more and more autonomous in adjustments and optimization.

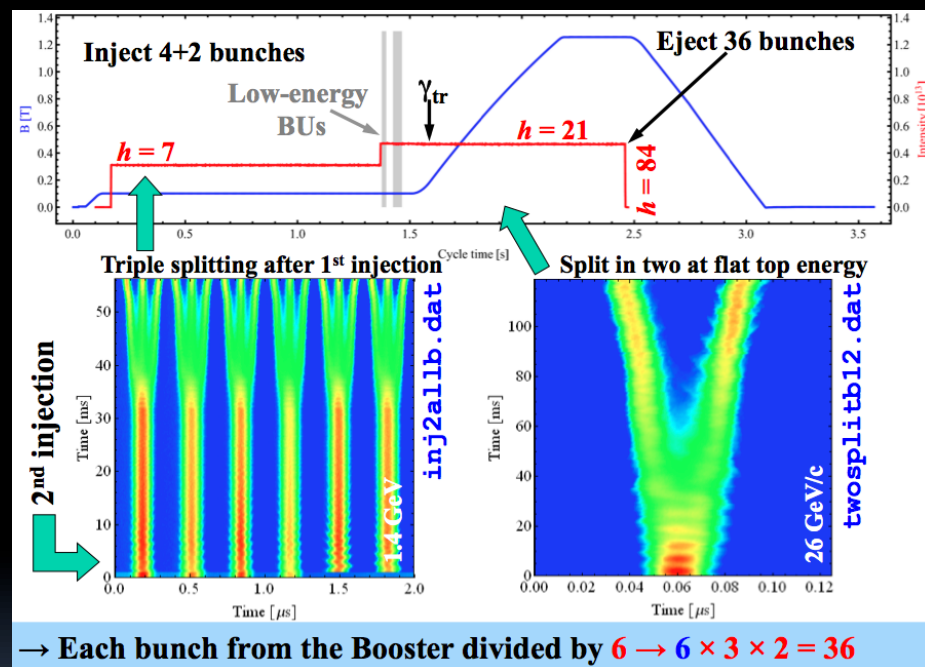


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LHC 50 ns Double Batch Production

- Multi-turn injection from LINAC2 into the PS Booster
- Double batch injection from PSB (4 + 2 bunches)
- Single Bunch per PSB ring
 - 1st batch → 4 bunches
 - 2nd batch → 2 bunches
- Triple splitting in PS
- Acceleration
- Double splitting in PS
- Bunch rotation in PS
- $\epsilon_{\text{Long final}} = \epsilon_{\text{Long init}} \times 2.33/6$
- $\epsilon_{h/v} < \epsilon_{\text{nom}}$ and well preserved
- Potential issues:
 - PSB: Space charge → $\epsilon_{h/v}$
 - PS: Space charge at injection and CBI after γ -jump → ϵ_{Long} , τ_{bunch} , bunch-to-bunch intensity variations (feedback available)
 - SPS: e-cloud → Instabilities → scrubbing required



Courtesy of H. Damerau



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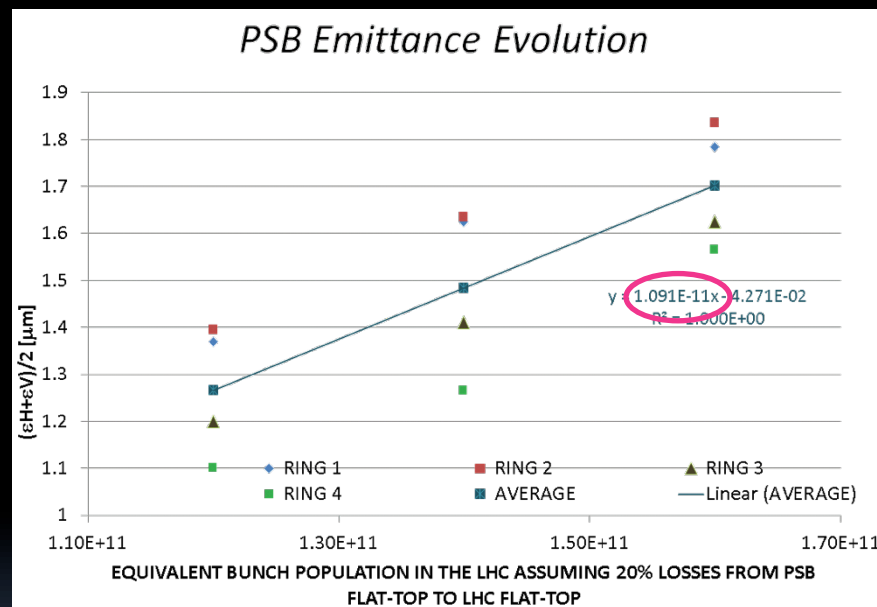


Where to gain

- Without making changes, as proposed by the LIU project, the only gain can come from intensity and emittance.
- We know that:

$$L \propto \frac{N^2}{\epsilon}, \text{ but}$$

- Therefore: $L \propto N$
- Provided the chain can handle brighter beams without blowing up the transverse emittance more.
- Should we only use the best performing rings ?



Courtesy of PSB team



Potential Issues Increasing Intensity

- PSB:
 - Increase of intensity to be done with care to preserve transverse emittance as much as possible
 - Differences between rings, worst one determines the final performance (Ring 1 & 2)
- PS:
 - Space charge limits → preserve transverse emittance on long flat bottom.
 - CBI → Feedback available.
 - Take care of splitting processes to minimize bunch to bunch intensity variations.
- SPS:
 - Scrubbing needed (with 25 ns beam)
 - Injection losses, requiring higher intensity from PS, resulting in larger transverse emittances.
 - Beam stability (longitudinally → bunch length)
 - For intensities $> 1.5 \times 10^{11}$ ppb ZS voltage needs to be lowered to at least ~ 110 kV, meaning no slow extraction (NA fixed target physics).
 - ZS issue prevents going to shorter (dedicated) filling super cycles.



Tentative 2012 Performance

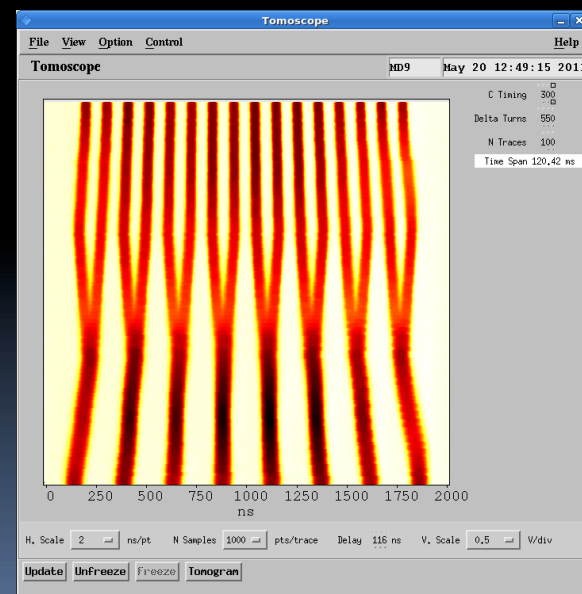
- Provided these potential issues are well taken care of a slight increase in intensity (+ emittance) should be feasible
- It will be a slow process of small increases and careful adjustments.

Tentative Operational Characteristics 2012											
	PSB extraction				PS extraction			SPS extraction			
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- Might already not be compatible with NA operation
 - No NA physics during preparation, filling and MD's ?
- For the 25 ns nominal characteristics will be delivered, unless more advanced ideas are implemented.
 - Only last year nominal parameters were reach for the very 1st time.

More advanced ideas (LIU nevertheless)

- A batch compression scheme, presented at Chamonix 2011:
 - Smaller transverse emittances for similar intensities.
 - Based on harmonic 9 at PS injection followed by batch compression and splitting.
 - Will become available to the PS and SPS later in 2011.
- LHC can most likely not profit from this new scheme before the end of the 2012 run
- More details:
 - “Performance potential of the injectors after LS1”
 - By Heiko Damerou
 - Thursday 09/02 at 8:30



Courtesy of H. Damerou and S. Hancock



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A few word of caution on Satellites

- Following discussions during the Evian workshop low luminosity collisions are foreseen using “natural” or “parasitic” satellites on main bunches and no enhanced satellites.
 - No means in the injectors to quantify and qualify satellites
 - Aim is/was to minimize satellites
 - Pushing main-bunch performance may alter satellite-bunch conditions
- At present there are no good diagnostic tools available to measure satellites
 - Take them as they come.



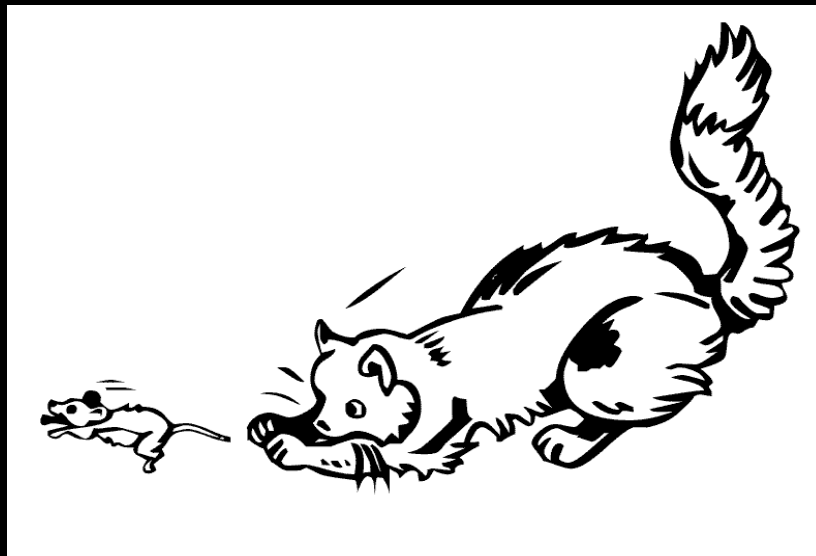
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Conclusions

- The 2011 performance has evolved and is much better than anticipated.
- Margins for further improvement on present scheme have been “squeezed” and leave little room for further performance increase.
- Best operational performance to LHC in 2011:
 - 1.5×10^{11} ppb in $1.9 \mu\text{mrad}$ \rightarrow Brightness 7.9×10^{10} ppb/ μmrad
- Anticipated operational performance to LHC in 2012:
 - 1.6×10^{11} ppb in $2 \mu\text{mrad}$ \rightarrow Brightness 8×10^{10} ppb/ μmrad
 - We will go as high as possible, but compromises will have to be made.....
- Will we produce more luminosity aiming for stable, but slightly reduced performance or by pushing the performance and accept less reproducibility ?
- For further performance improvement, radical changes, as proposed in the LIU project are needed, but only after LS1 and LS2.



What you want in life is sometimes just out of reach

On the other hand the famous Thomas Edison said:

"We shall have no better conditions in the future if we are satisfied with all those which we have at present."