Luminosity Increase in 2011 - Potential of the Injectors

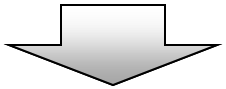
B. Mikulec @ Mini-Chamonix 2011

With extremely valuable input from many colleagues of
the LHC injector chain

Peak Luminosity

Injectors have influence on the following beam parameters for LHC to increase the peak luminosity:

- Brightness N/ε
- Total beam current $n_b f_{rev} N$



① Increase number of bunches (25 ns beam)

② Increase bunch intensity

③ Decrease transverse emittances

Bunch intensity increase theoretically most efficient parameter of the 3: $L \propto N^2$

PSB

- 50 ns double-batch (DB) beam
  - **Nominal** LHC bunch intensity: gain through transverse emittance decrease
  - Or/and: increase **bunch intensity**
- Other option for higher collision rate: 25 ns DB beam
  - Transverse emittances from PSB equivalent to 50 ns SB

General PSB recipe for small transverse emittances: inject the minimum number of turns!

PSB – Measured Performance

=equal in PSB to double intensity 50ns DB beam!

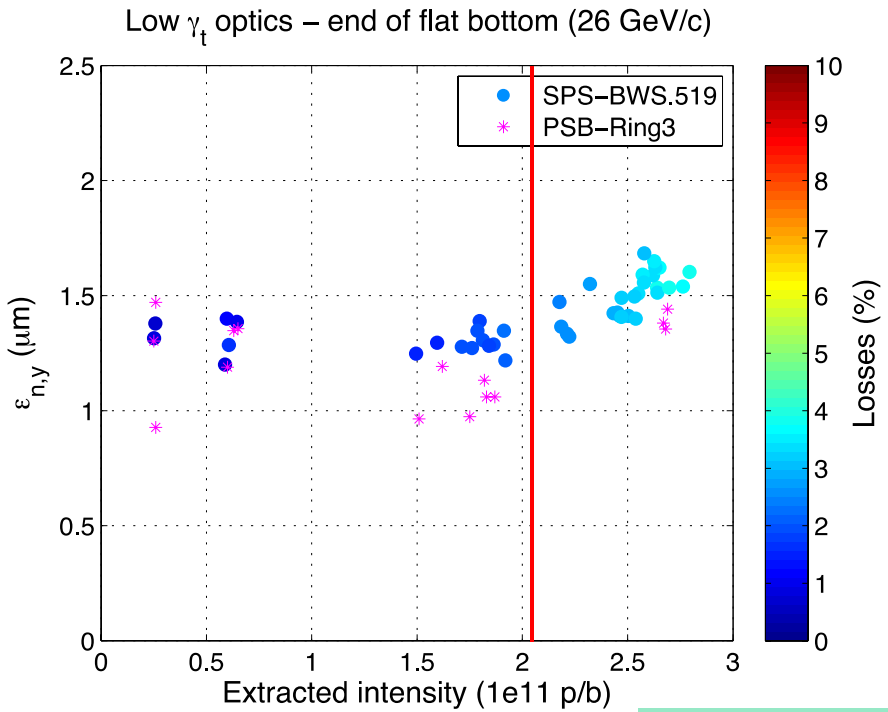
PSB ring intensity	8.5E11 **(50ns DB)**	11.5E11 **(50ns DB)**	16.5E11 **(25ns DB or 50ns SB)**
LHC bunch intensity (assume here 10% transfer losses from PSB extraction to SPS flat top before scraping)	**~1.27E11**	**~1.72E11**	**~1.24E11**
Hor./vert. 1σ norm. emittance	1.5/1 µm	~1.6/1.4 µm	2.5/1.9 µm
Sum of transv. emittances	2.5 µm	~3 µm	4.4 µm

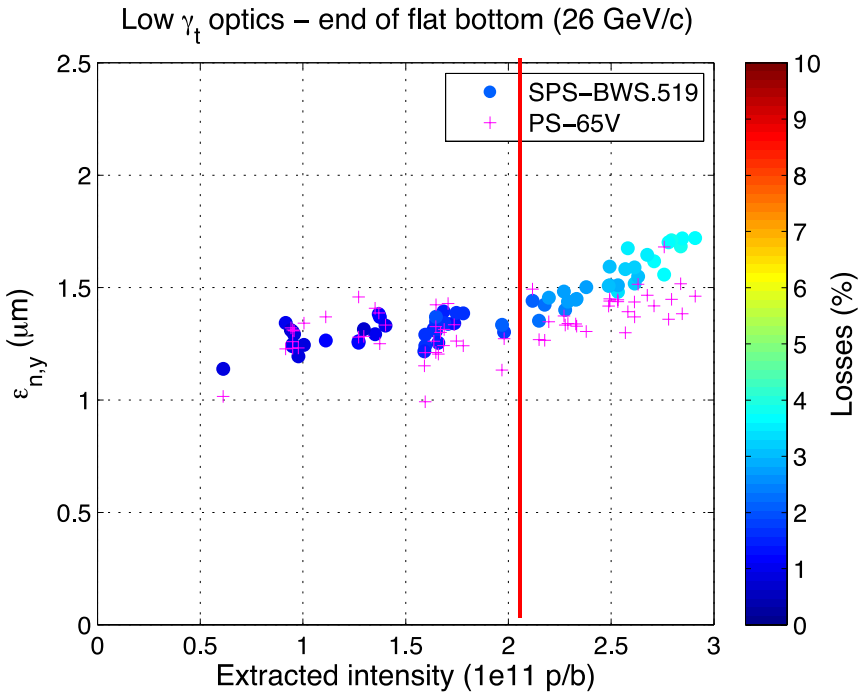
PS

- Use 50/25 ns beams with double-batch transfer from PSB
- Continue steady machine tuning to minimize transverse emittance blow-up
- Operational intensity limit of multi-bunch beams in the PS around **1.7E11 ppb**
  - Longitudinal beam quality degradation in terms of bunch length and bunch-to-bunch intensity with increasing bunch intensity
- Novel schemes to increase beam brightness are being investigated in MDs (batch compression scheme – see appendix), but no operational implementation for this year

Emittance Conservation of SINGLE BUNCH

- Vertical emittance conservation throughout the injectors (until end of SPS flat bottom) has been shown this year for a SINGLE BUNCH, at least up to ~2E11 ppb for the low γ_t optics



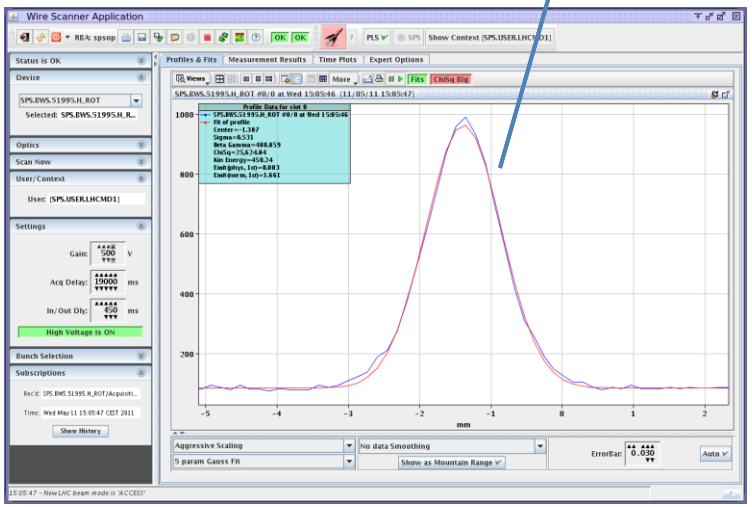


Courtesy of H. Bartosik et al.

Courtesy of G. Rumolo et al.

SPS – Measured Performance with nominal Q26 optics

Beam type	**50ns DB**	**50ns DB**	**50ns SB / 25 ns DB**
LHC bunch intensity	**~1.4E11**	**~1.6E11**	**~1.3E11**
Hor./vert. 1σ norm. emittance at flat top	1.7/1.7 μm (gated on 1st batch)	2/1.9 μm (gated on 1st batch)	2.5/2.7 μm
Sum of transv. emittances at FT	3.4 μm	3.9 μm (~3.5 μm at inj.)	~5.2 μm



Very little losses ~4%!

SPS

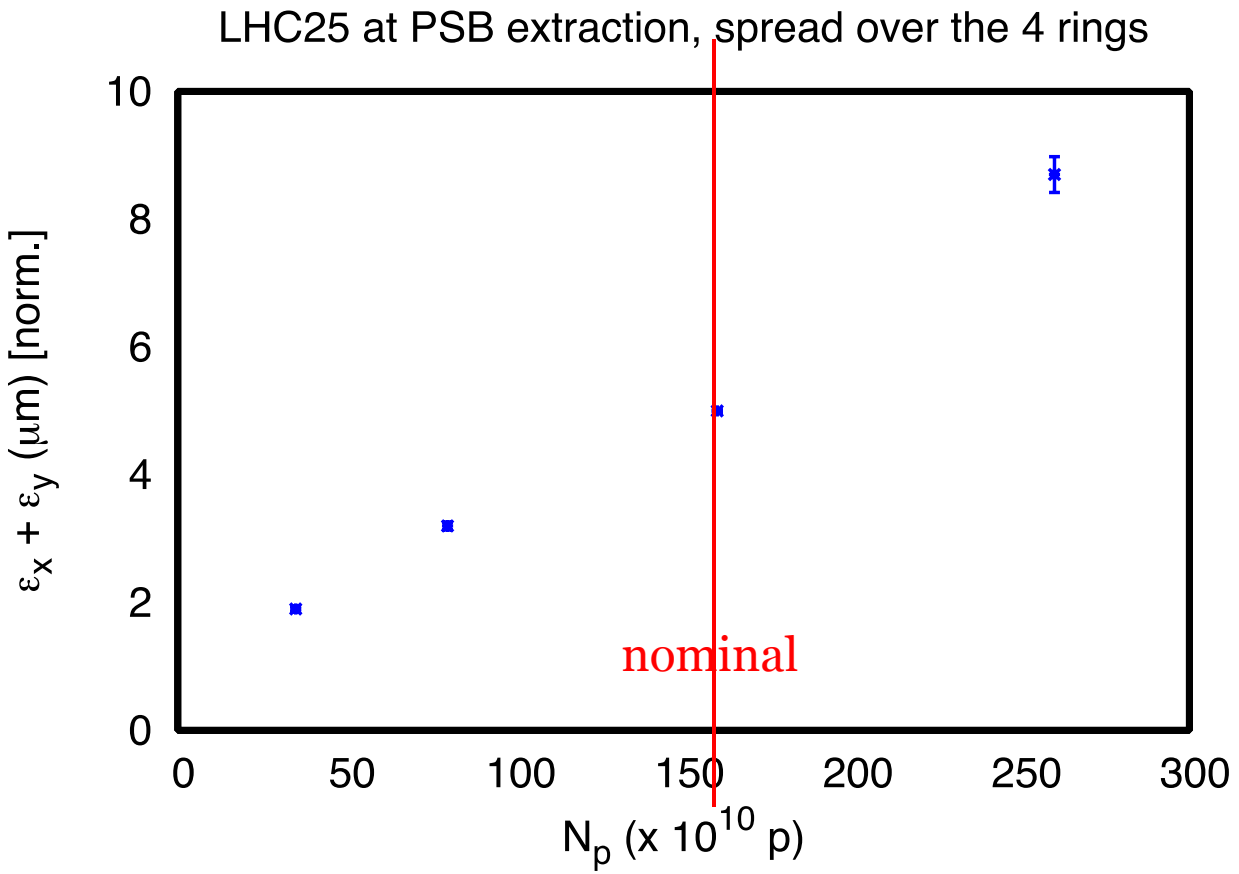
- Scrubbing has improved a lot machine performance (e.g. e^--cloud effects present for 25 ns beam, but no big influence)
  - Go in steps in case of increasing bunch intensity to avoid problems with kickers and electrostatic septum
- With the 800 MHz rf system on, **1.6E11 ppb** are stable with Q20 optics (50 ns 4 batches); for Q26 optics controlled long. emittance blow-up is required
  - For single-bunch instability margins → Q20 optics shows clear advantages
  - **Continue intense studies to make Q20 optics operational** (e.g. inject into LHC coming MD block; focus on multi-bunch multi-batch beams)
- Puzzling transverse emittance measurements during last MD → continue effort of machine inter-calibration of wire scanners, screens in the transfer lines and BI in the LHC

Conclusions and Outlook

- Strategies in the injectors have been presented that could help increase the LHC peak luminosity still this year
- Additional ideas are being investigated, but would be for the longer-term future
- **Double-batch transfer beams** currently highest potential (including 25 ns beam); overall operational intensity limit for 50 ns DB beam currently ~**1.6E11 ppb within ~2/2 µm**
- Continue push to make Q20 optics operational in SPS (MDs!) and slow step-wise intensity increase of existing beams
- Parameters tend to drift in the machines → steady effort to keep the performance of the injectors at maximum

Appendix

PSB transverse emittance of LHC 25ns beam



PS – Batch Compression Scheme

Presented by C. Carli at Chamonix 2011

- Applicable for 50 or 25 ns bunch spacing; **gain bunch intensity within same transverse emittances**
  - **Inject 8 PSB bunches (SB transfer of 4 rings)** into h_{PS}=9 buckets
  - Batch compression using h=10, bunch splitting and another batch compression (h=21); splitting or double splitting to reach 32 or 64 bunches (50/25ns beam)
  - 25ns beam: **5** injections to fill SPS (320 bunches; 8 μs OK for LHC inj. kickers)

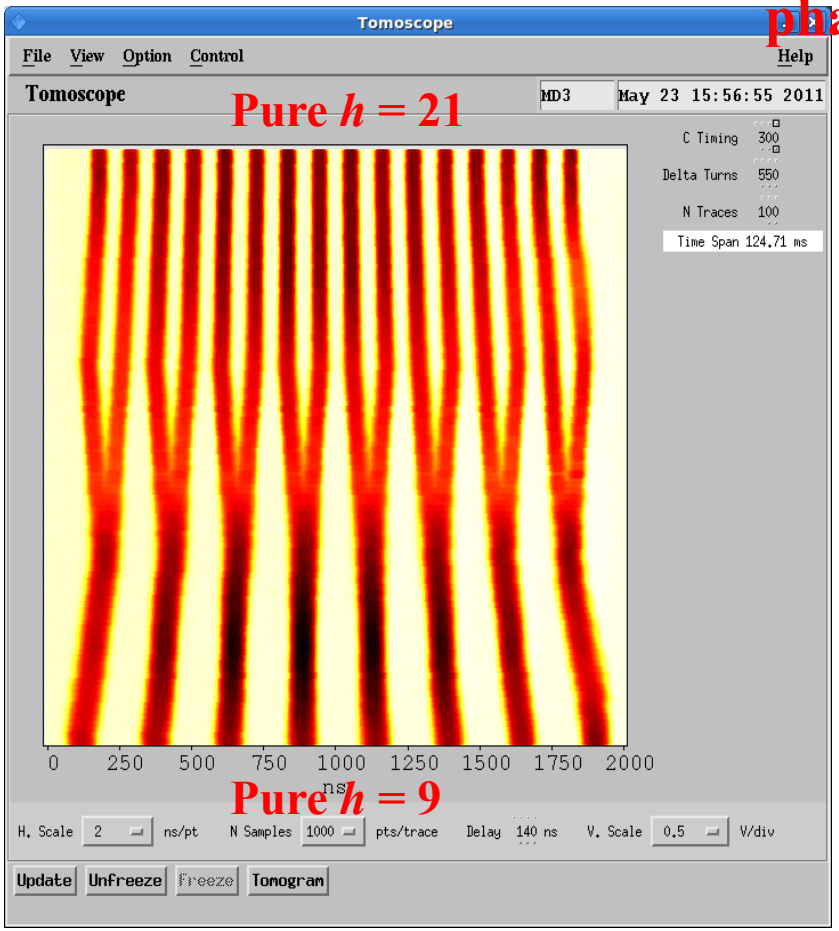
☺ Theoretical beam brightness increase by factor 1.5 (each PSB bunch split into 8 instead of 12)

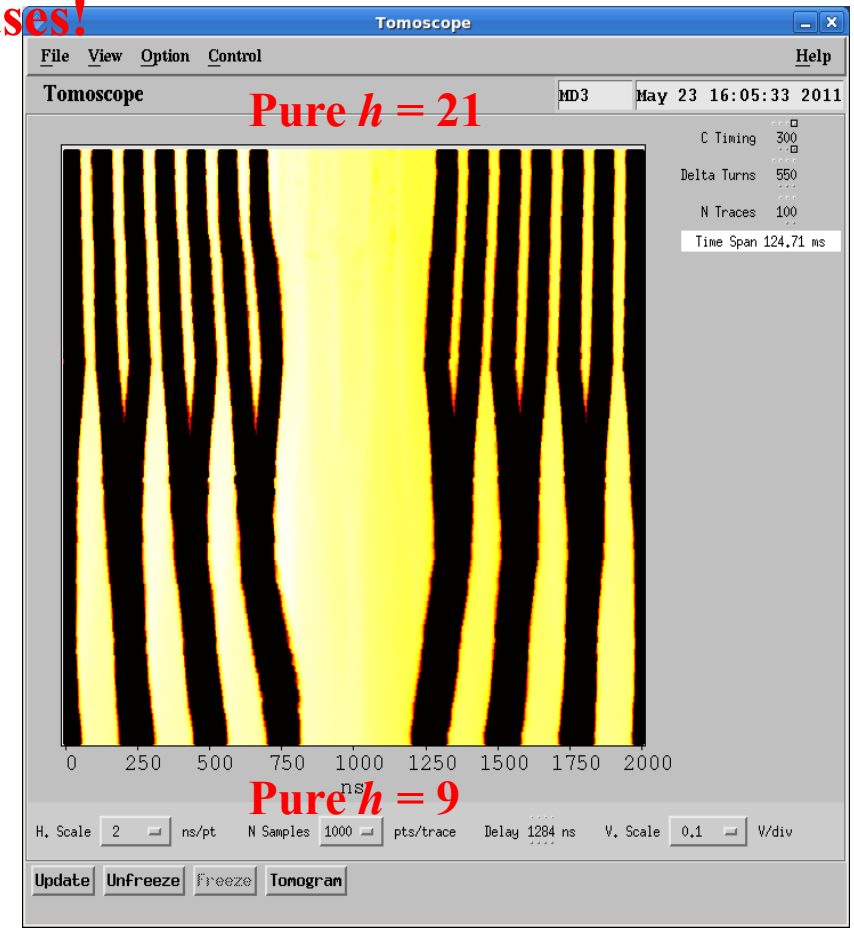
☹ Shorter bunch length at injection – space charge limitations?

☹ Requires additional hardware and development to change beam control

Observations at 1.4 GeV

Same RF manipulation at 1.4 GeV, without any change of forward phases!

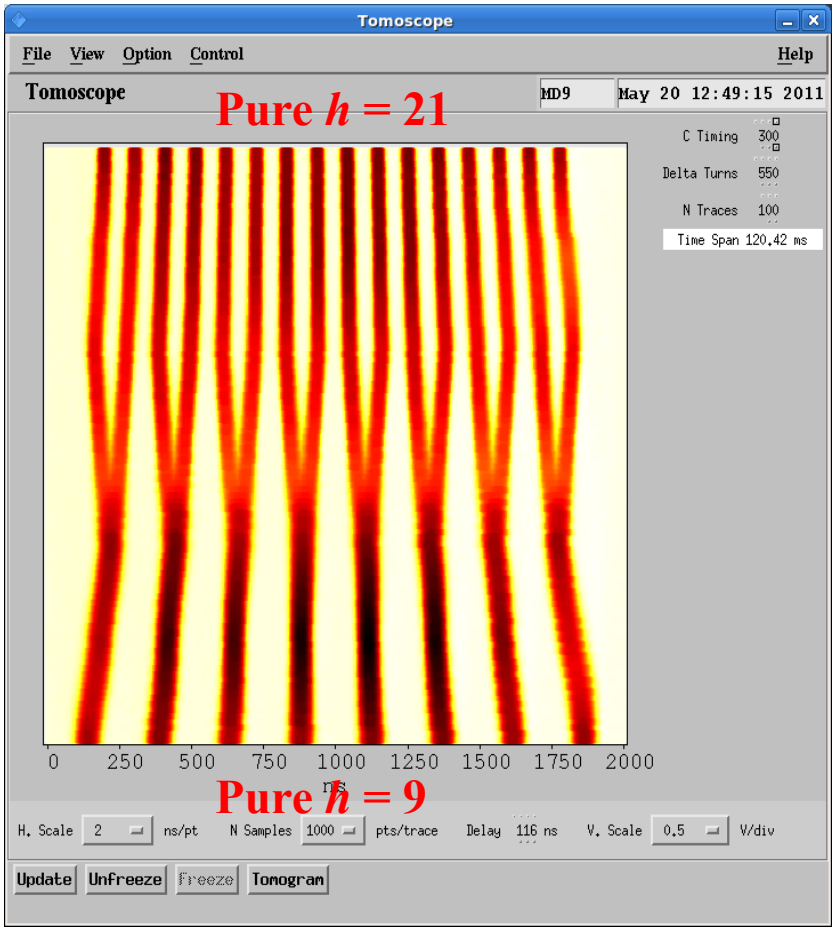




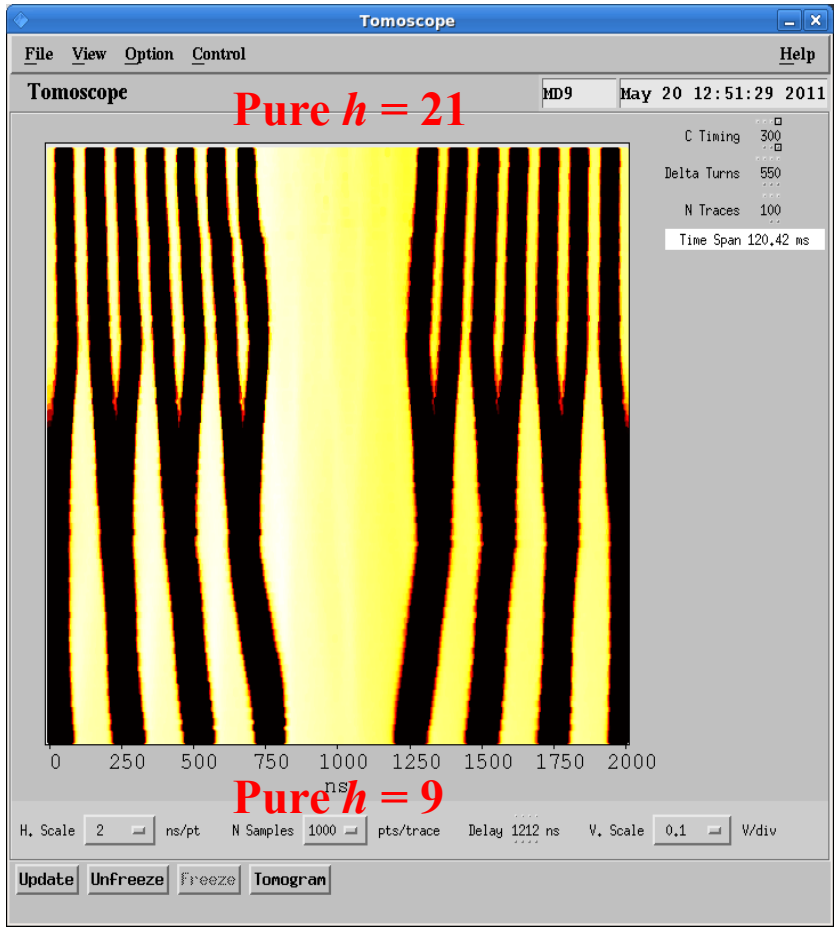
→ Fine up to $\varepsilon_{l,\max} = 0.8$ eVs (cf. full bucket at 0.94 eVs)

First observations at 2.0 GeV (*h*9 acceleration)

$h = 9 \rightarrow 21$



Evolution of empty bucket



→ Fine up to $\varepsilon_{l,\mathrm{max.}} = 1.2$ eVs (cf. full bucket at 1.43 eVs)