ALTERNATIVE BUNCH FILLING SCHEME FOR THE LHC - PART II (INJECTOR COMPLEX)

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Part I (LHC) by Werner

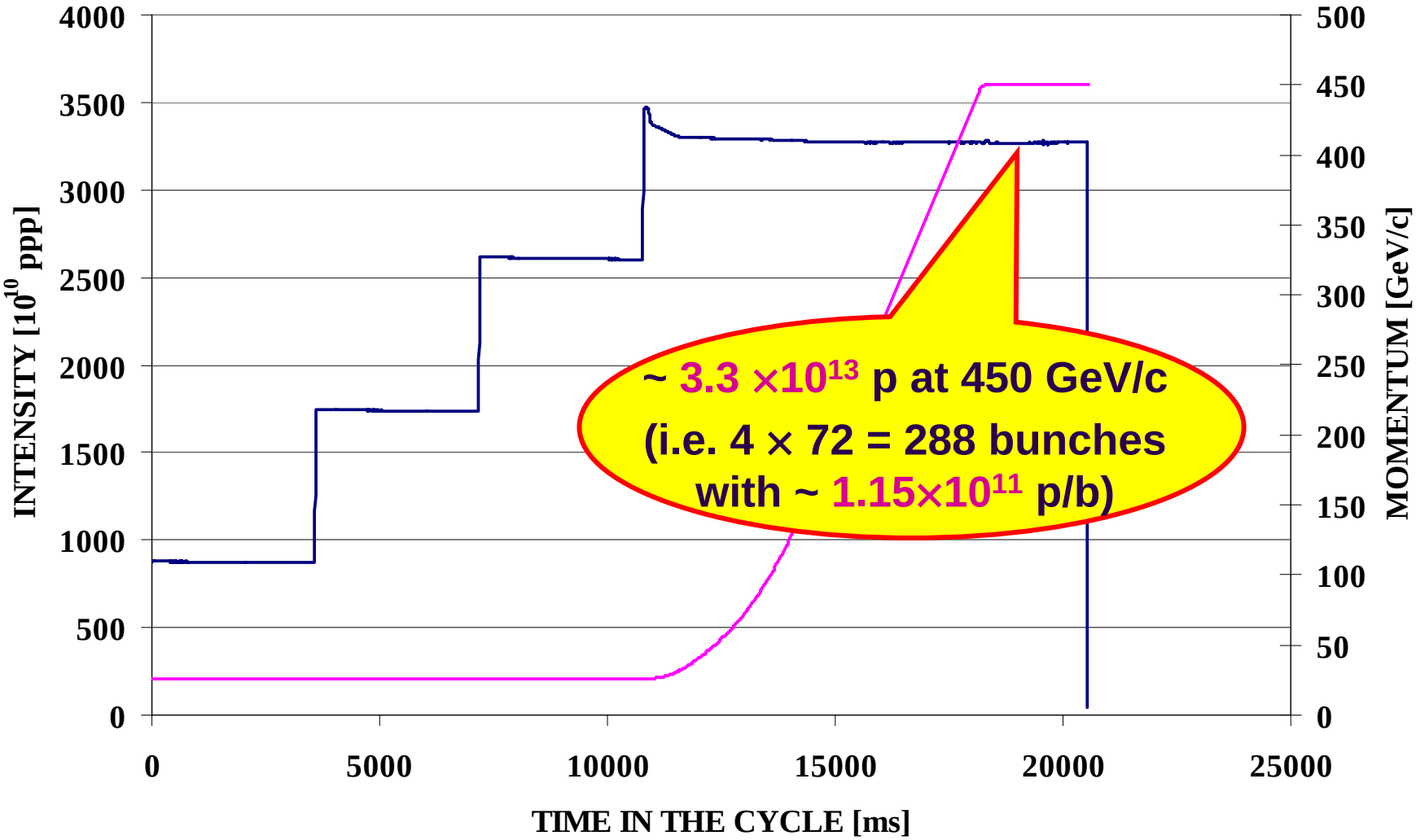
- **Introduction and motivation for the injector complex**
- **Review of the LHC ultimate filling schemes (M. Benedikt, LTC, 09/03/05)**
- **Implications & advantages for the**
  - **PSB, PS, SPS**
  - **LHC $\Longrightarrow$ See Werner's talk + reduced coupled-bunch instability from collimators**
- **LHC filling time**
- **MD on 17/10/06 $\Longrightarrow$ 5 injections of 48 bunches into the SPS**
- **Conclusion**

INTRODUCTION & MOTIVATION FOR THE INJECTOR COMPLEX (1/4)

- This is an "alternative" scheme for the nominal LHC beam with batches of 48 bunches (in 2.4 s) from the PS instead of 72 (in 3.6 s)
- No additional resources are required
- This 48-bunch scheme has nothing to do with the 48-bunch scheme proposed for ultimate LHC filling schemes

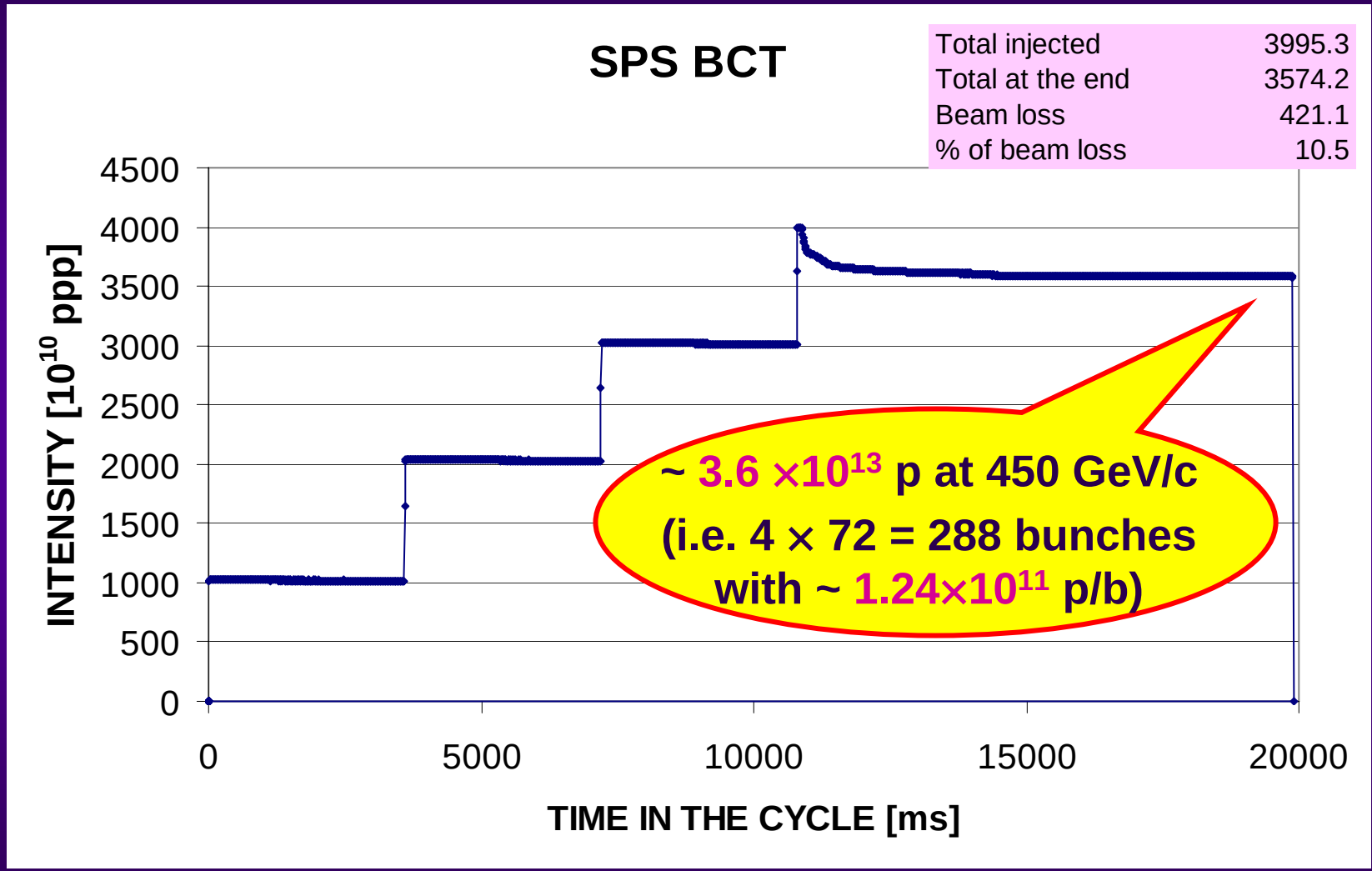
INTRODUCTION & MOTIVATION FOR THE INJECTOR COMPLEX (2/4)

LHC beam in the SPS in 2004 (supercycle length = 21.6 s)



INTRODUCTION & MOTIVATION FOR THE INJECTOR COMPLEX (3/4)

LHC beam in the SPS at the end of 2006 (15/11/06)



What about the transverse and longitudinal beam parameters?

INTRODUCTION & MOTIVATION FOR THE INJECTOR COMPLEX (4/4)

- **But, during almost the whole year 2006, only ~ half the nominal intensity was stable (due to a PS horiz. instability near extraction, never observed with 48 bunches!)**

- **Proposition for the collimator tests (see APC 13/10/06): $\underbrace{6 \times 48}_{= 4 \times 72} = 288$ bunches with 1.15 10^{11} p/b (~ 3.3 10^{13} p)**

- **This scheme was then proposed to be looked at as a possible alternative in RLC meeting 24/10/06**

- **Werner and Tatiana studied the implications in the LHC, and refined the scheme (5 batches only…) for beam-beam considerations**

LHC ULTIMATE FILLING SCHEME (M. Benedikt, LTC, 09/03/05)

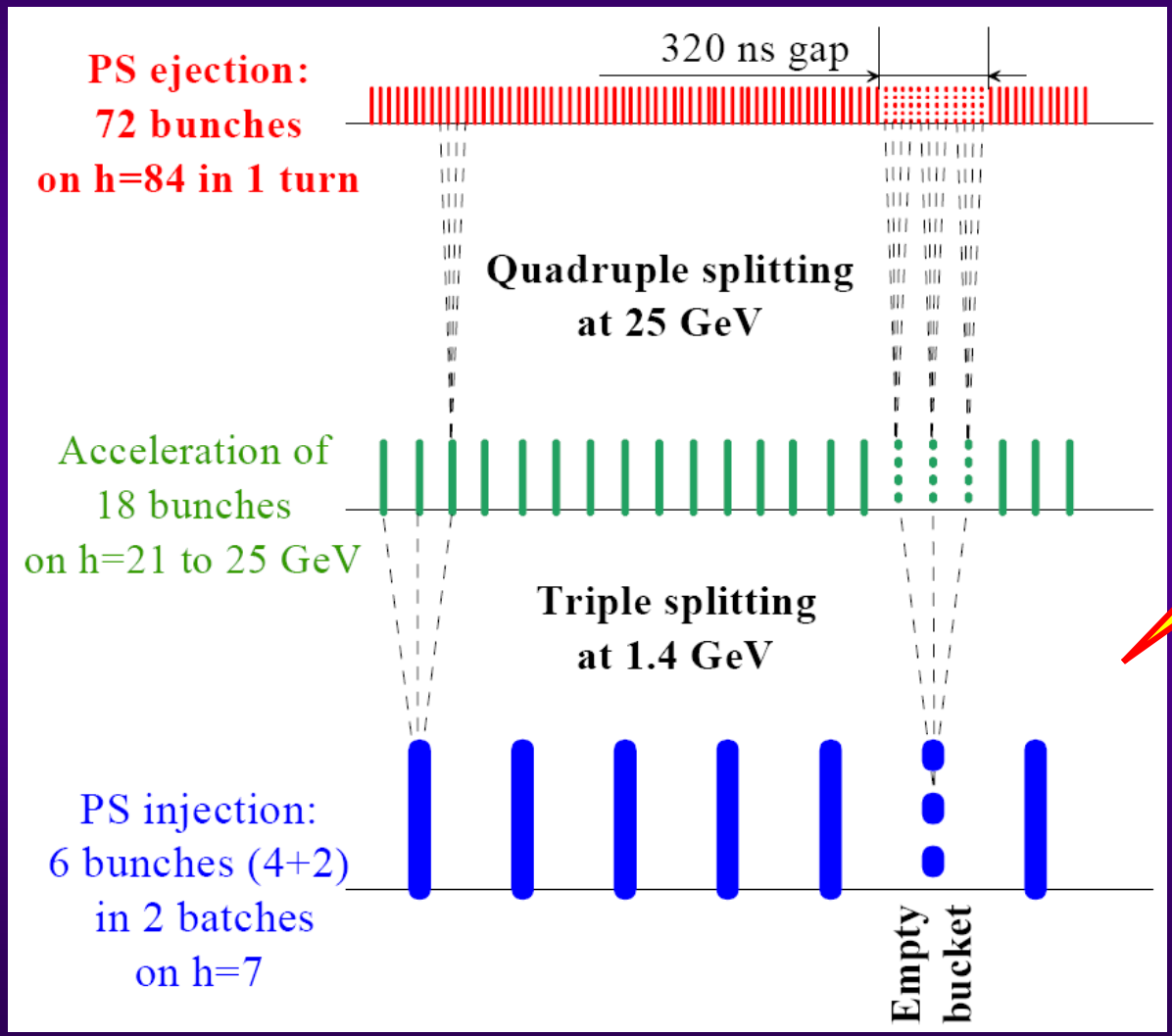
- Ultimate beam via batch compression in the PS (h=9,10,11,12,13,14,28,42,84 instead of h=7,21,42,84)
- A train of 42 or 48 bunches, spaced by 25 ns, is sent to the SPS every 3.6 s (double-batch injection from the PSB: 4+3(or4) bunches)
- 42 bunches preferred to 48 bunches (more bunches in LHC)
- 2 solutions with 42 bunches@25 ns in the PS
  - Solution 1: 266 466 466 466 $\Longrightarrow$ 2606 bunches (i.e. ~ - 7%)
  - Solution 2: 1444 3444 3444 3444 $\Longrightarrow$ 2436 bunches (i.e. ~ - 13%)
- LHC filling time with Solution 1 increased by 33%
- Manpower and machine time for MDs required

PSB

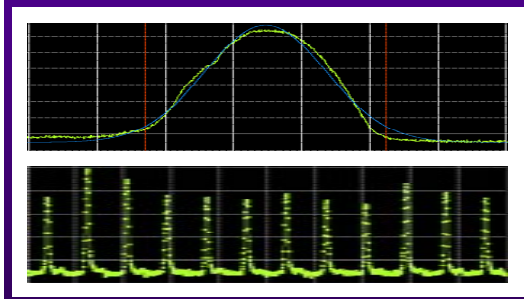
- **No modification**
- **Only 1 user required now (TSTLHC, 1 bunch / ring) instead of 2 before (TSTLHC, and LHC with 2 bunches on 2 rings only)**
- **Easier to maintain**

PS (1/11)

- Generation of the nominal bunch train for LHC (25 ns bunch spacing) $\Longrightarrow$ LHC Design Report, Ch. 7, p. 45

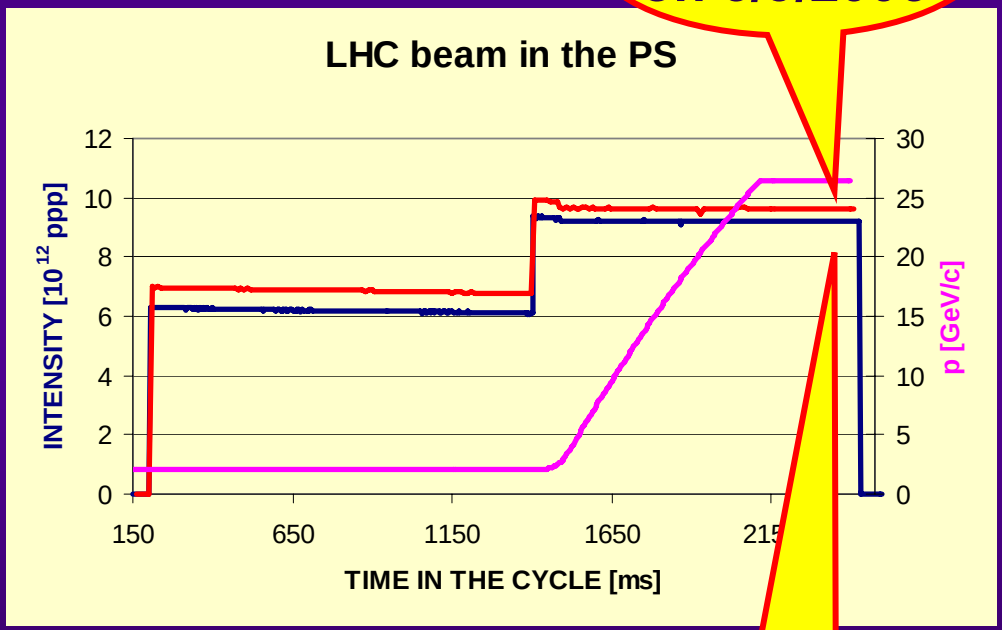


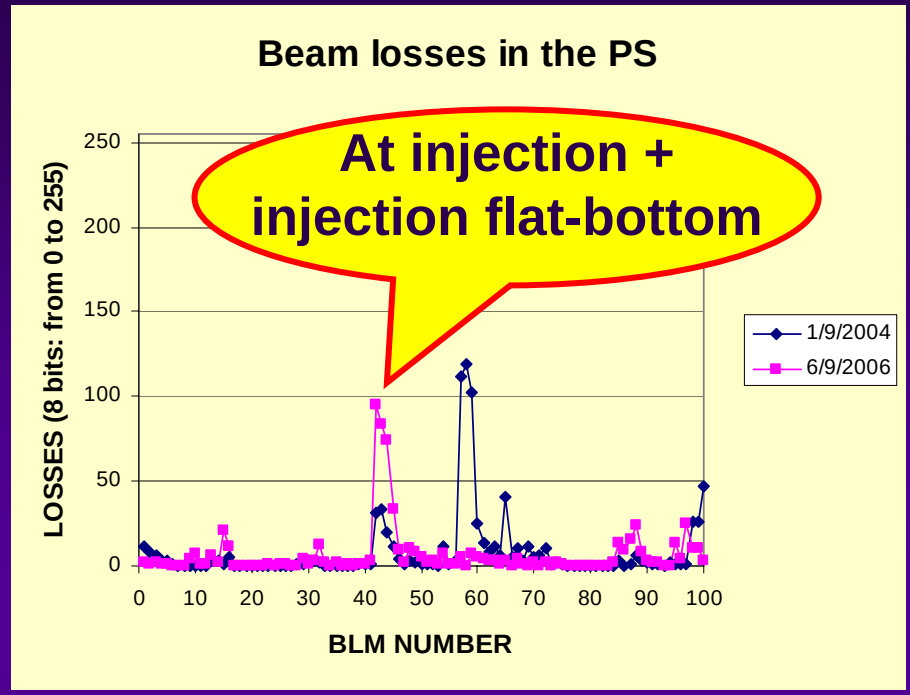
In the alternative scheme, only 1 batch of 4 bunches is needed

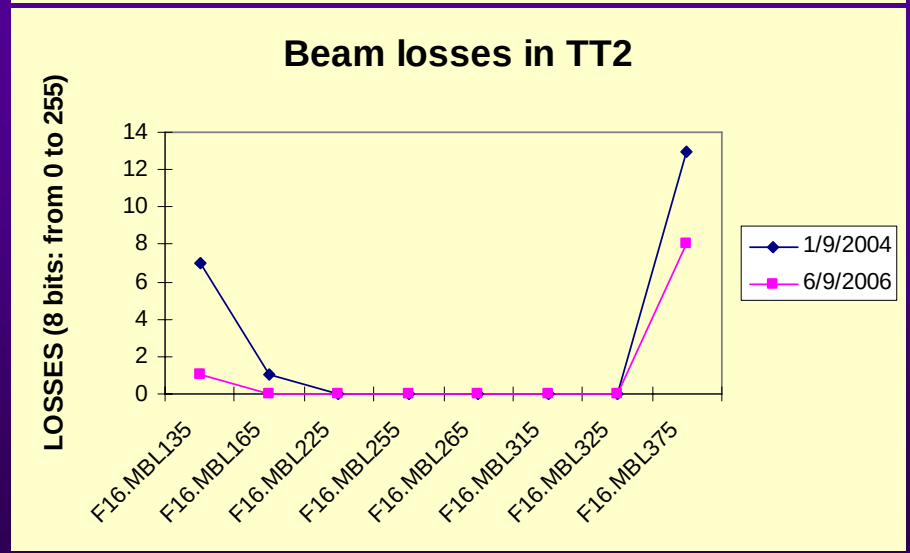


PS (2/11)

Polished LHC beam in the PS in 2004 and 2006

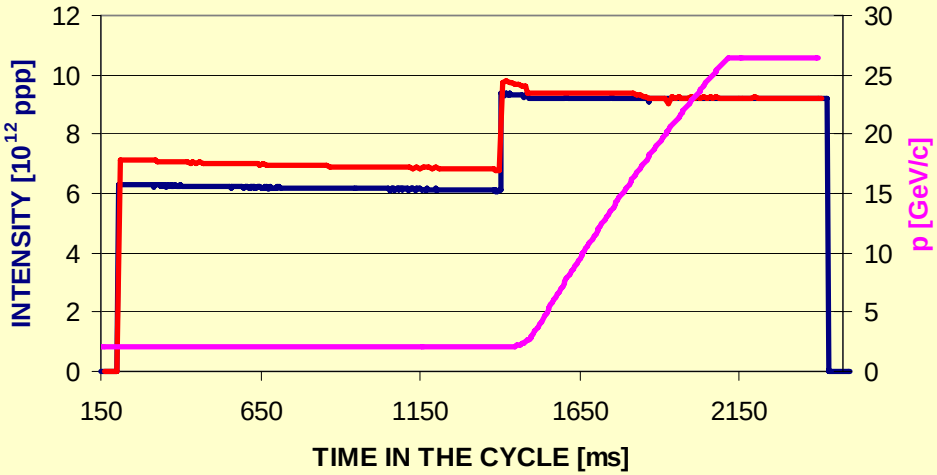


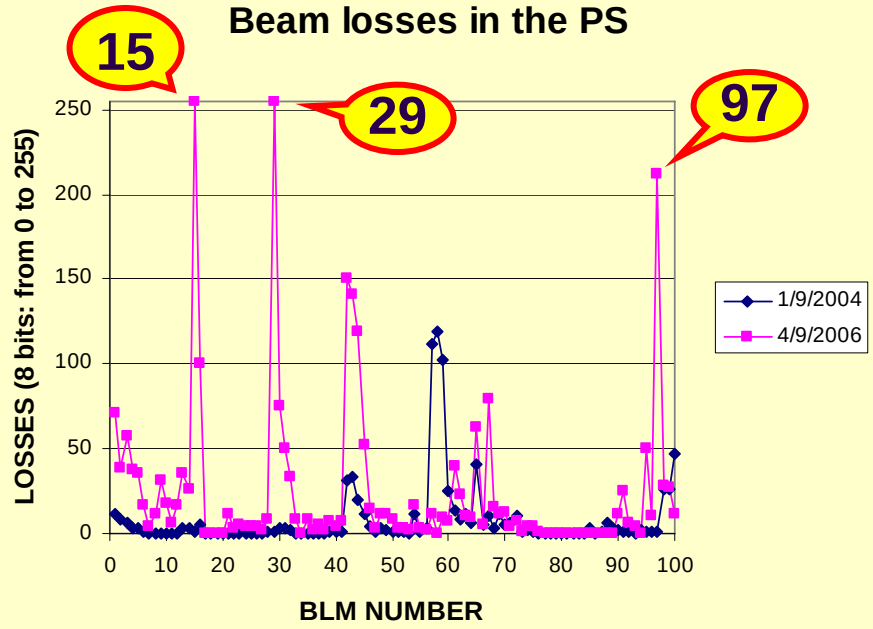


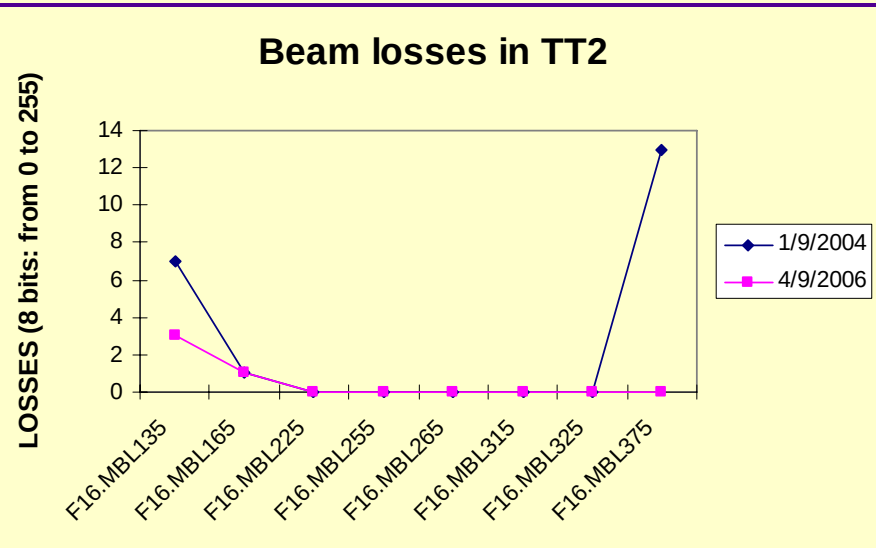


PS (3/11)

Un-polished LHC beam in the PS in 2006



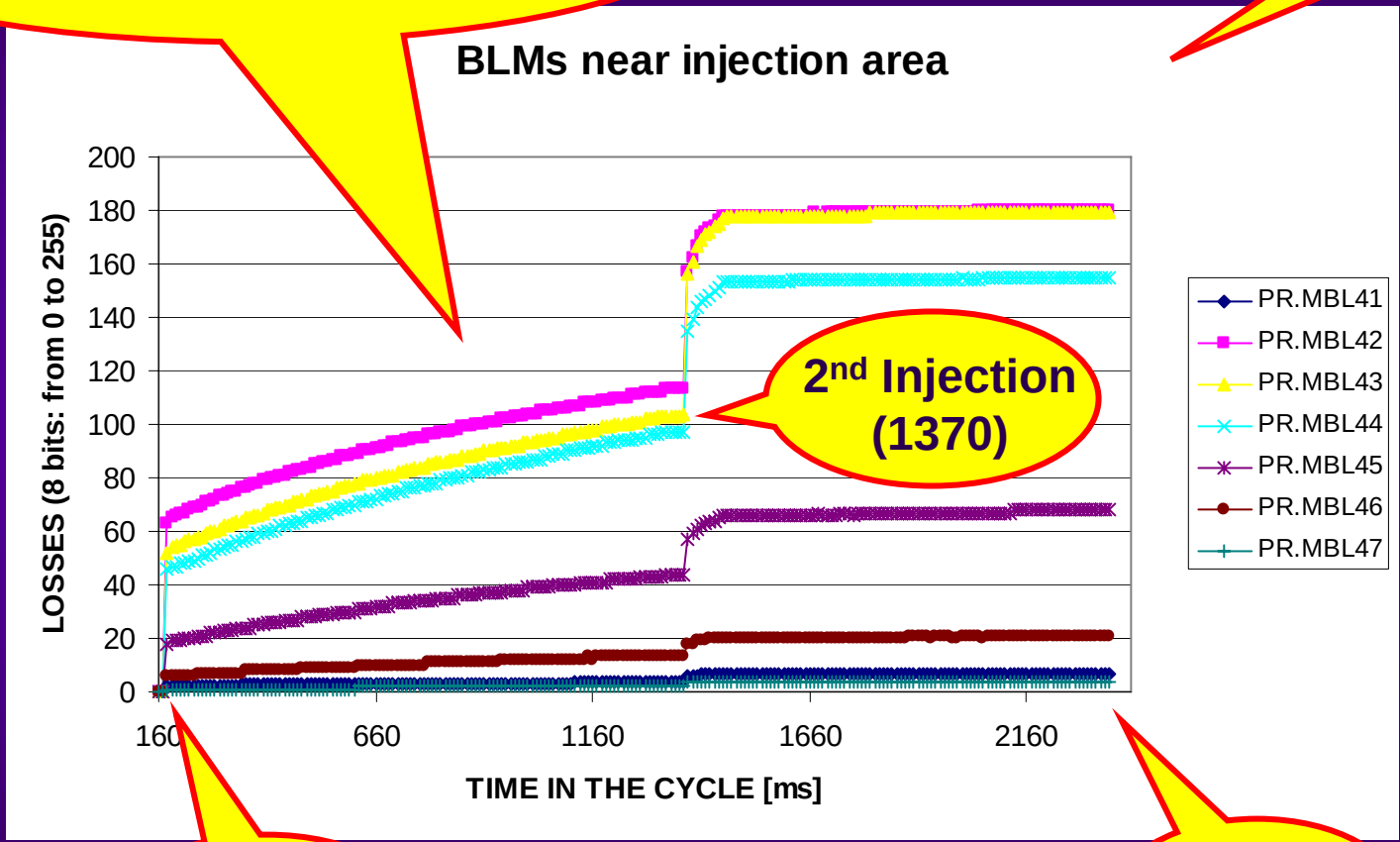




PS (4/11)

Activation problems have been encountered near the injection area, [M. Benedikt, ABOC, 07/11/06]

19/07/06



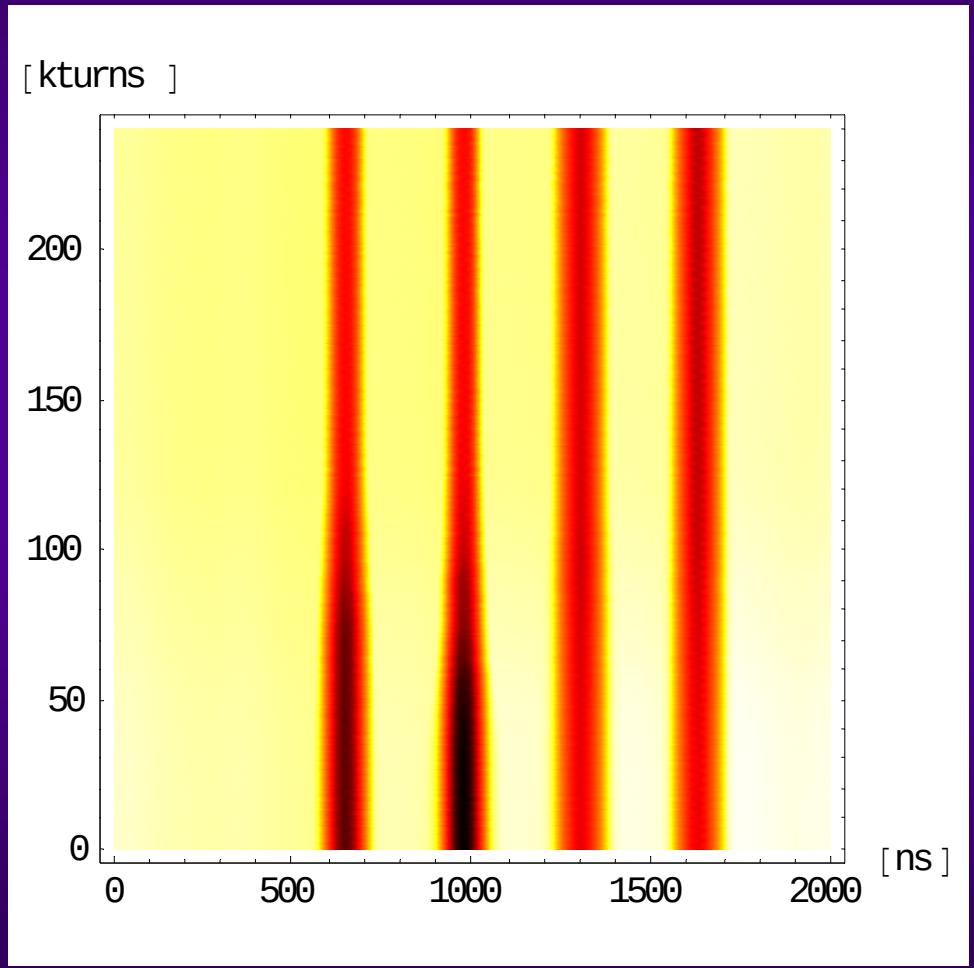
2nd Injection (1370)

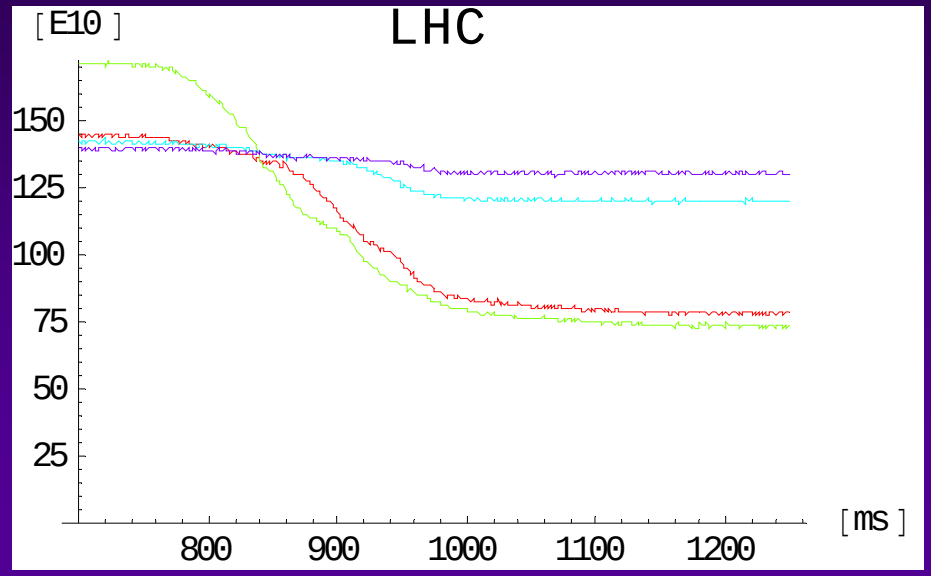
1st Injection (170)

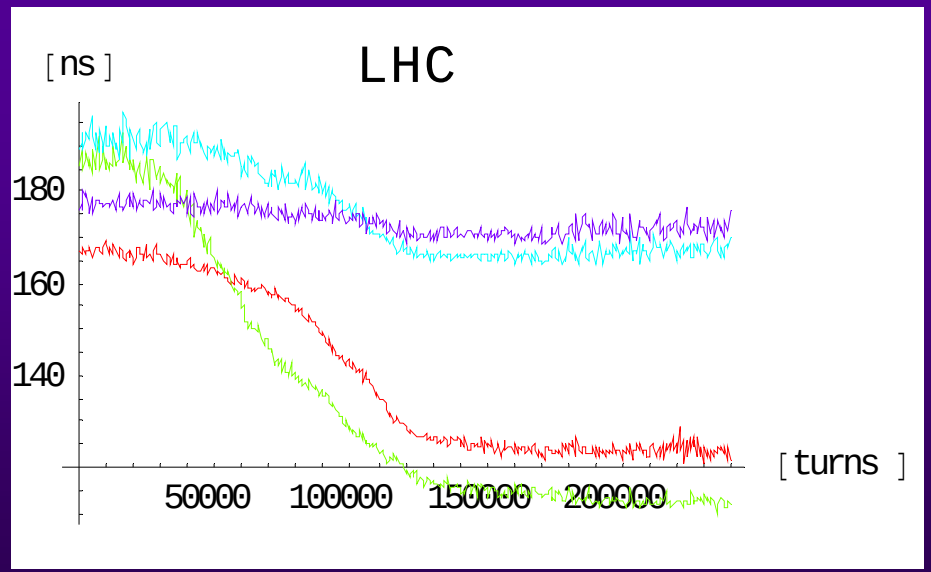
Ejection (2395)

PS (5/11)

Beam losses on the injection flat-bottom ⇒ Space charge driven resonance trapping phenomena





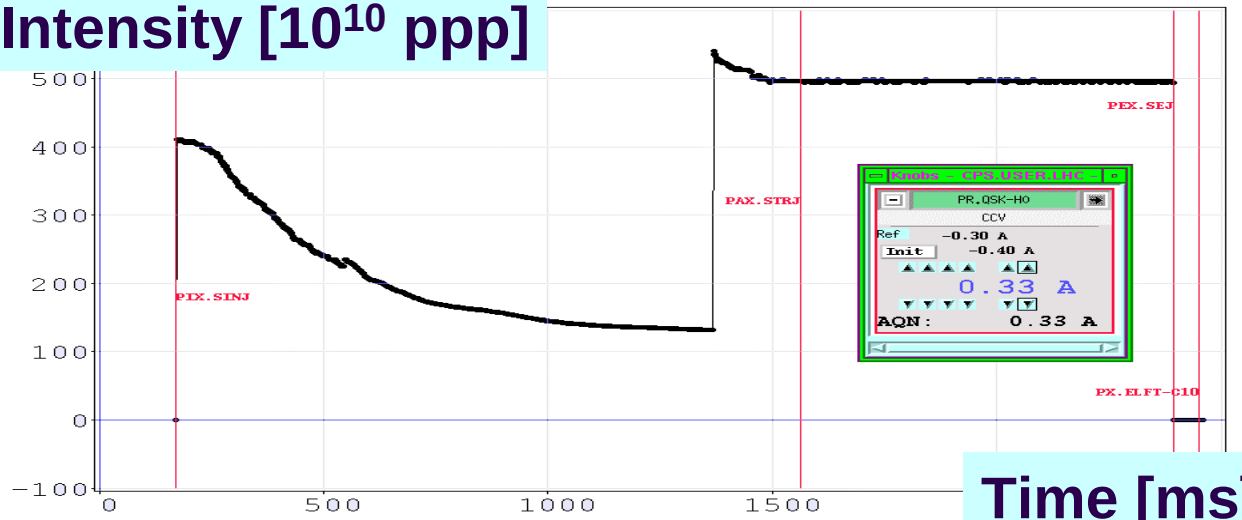


Courtesy S. Hancock

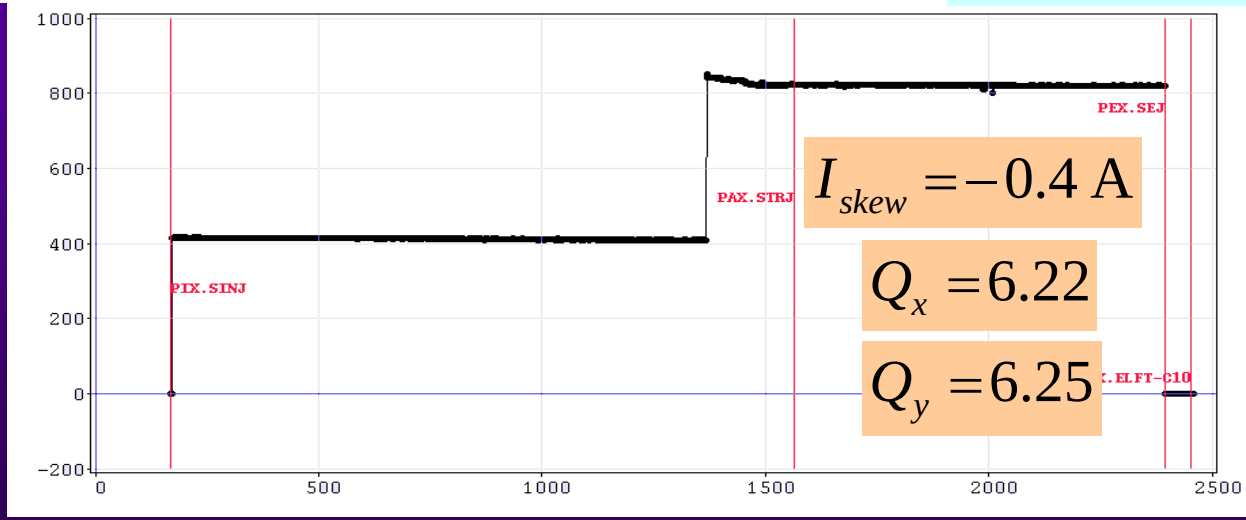
Stabilization of the PS beam for LHC by linear coupling only

Pictures from 2000

Intensity [10^{10} ppp]



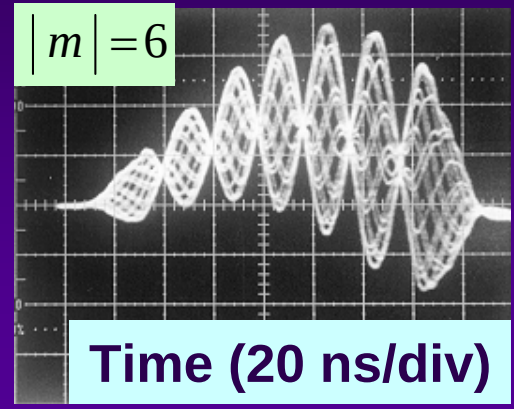
Time [ms]

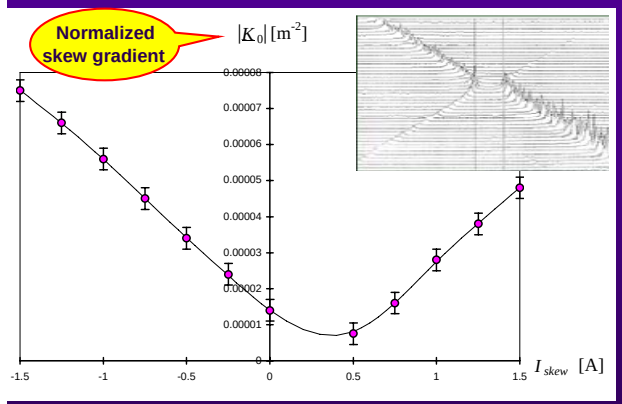


$I_{skew} = -0.4$ A

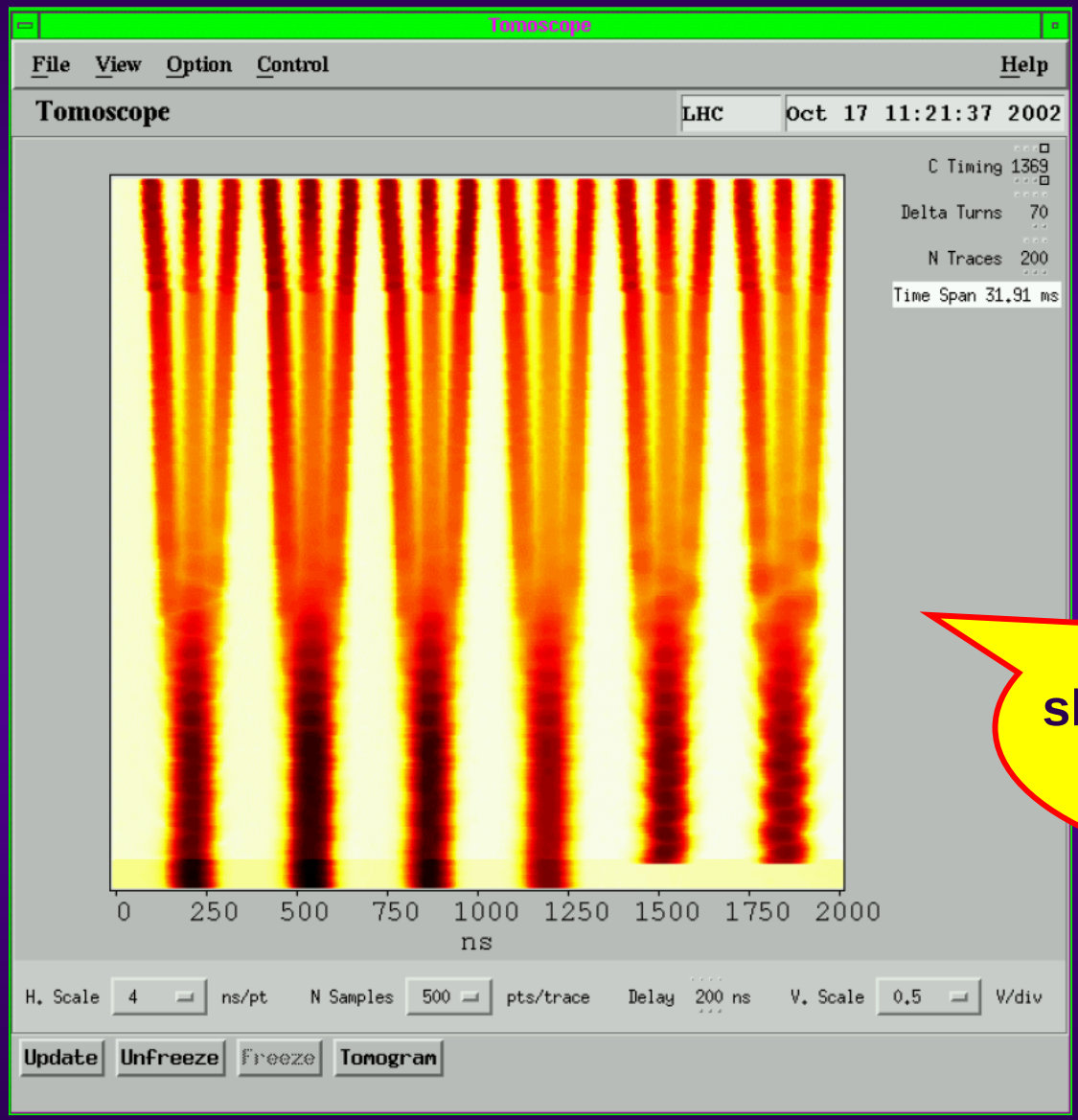
$Q_x = 6.22$

$Q_y = 6.25$





PS (7/11)



S. Hancock, Chamonix XII, 2003

Mountain range data showing the second batch injection and triple splitting

PS (8/11)

PS longitudinal issues for the LHC beam, S. Hancock, APC, 22/09/06

Reproducibility Issues

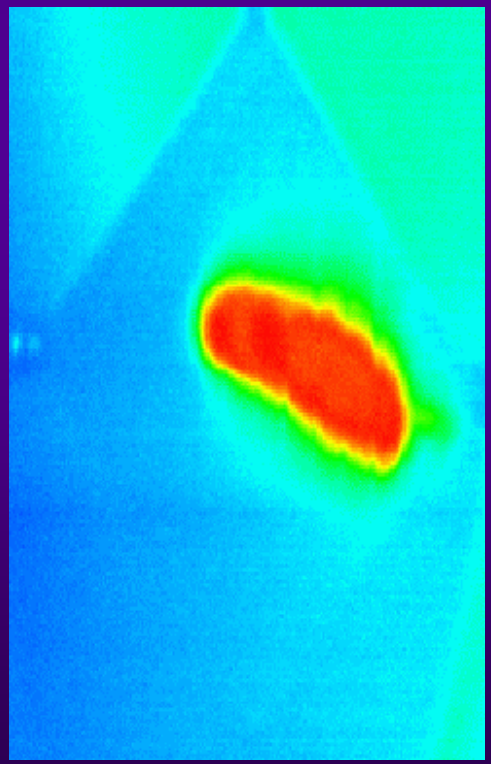
- LHC-type beams require up to 5 distinct rf systems in the same cycle.
- ~8 phases must be controlled to better than 1° (half of these are remote).
- There are a similar number of hardware delays – some of them critical at the 1ns level (and none of them remote).
- All these parameters are inter-related.
- There are 3 cascaded synchronization steps to lock onto the SPS – each of them entails up to half a dozen parameters (none of which are remote).
- The non-reproducibility of the PS magnetic field on the long injection plateau of the double-batch variants (and, we suspect, at the arrival on the flat-top of all LHC-type cycles) leads to shot-to-shot and day-to-day variations.
- We observe variations in cavity response according to the intensity per bunch and beam control effects according to the number of bunches in the machine.

PS (9/11)

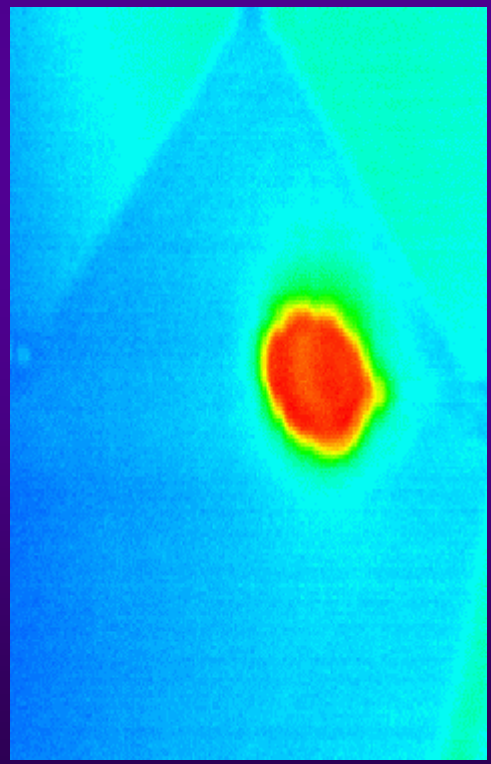
High-energy instability

- **At the beginning of the scrubbing run (19/07/06) the beam was seen to be much larger horizontally on the (first screen) F16.MTV107 in the TT2 line…**

Unstable



Stable



PS (10/11)

- During the whole year 2006, the beam was sometimes stable, sometimes unstable

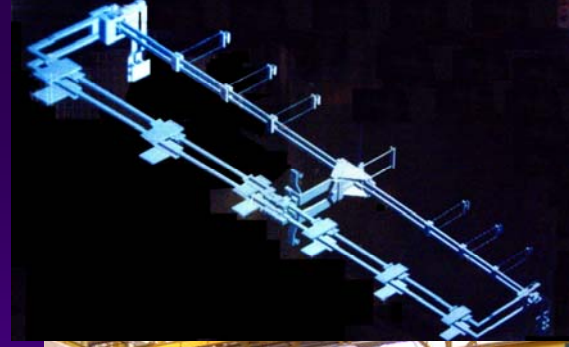
- It turned out (at the end of the year!) that when using the 40 MHz cavity in SS77 the beam was unstable and stable when the "spare" one in SS78 was used

- A more detailed study was started to investigate the reason for this difference

  - The fact that the beam was sometimes stable and unstable at other times was due to the alternate use of the two 40 MHz cavities that did not deliver the same voltage for an identical reference $\Longrightarrow$ Solved by re-calibration

  - There is a bunch length instability threshold at ~11.5 ns (bunch length before bunch rotation), most probably due to e-cloud as observed in 2001…

PS (11/11)



- **Rms current for the 8loop (potential problem raised at the OP Days, 7-8/02/07) ⟹ OK**
  - **SPS (new) supercyle length = 20.4 s (21.6 before)**
  - **Number of basic (1.2 s) periods = 17**
  - **8 loop rms current max = 560 A**

	Duration [s]	Basic period	rms current (per cycle) [A]
TSTLHC	2.4	2	680
EASTC	2.4	2	340
AD	2.4	2	607
nTOF	1.2	1	350

	Number of cycles	**rms current (per supercycle) [A]**
TSTLHC	5	
EASTC	1.8 (0)	
AD	0.2 (0)	
nTOF	0	
PS supercycle (in basic periods)	**14** (10)	**552** (522)

SPS (1/4)

- **Resistive-wall (with inductive-bypass) instability at 26 GeV/c (wake field from the previous bunches + from the previous turn only)**

Rise-time [in SPS turns]

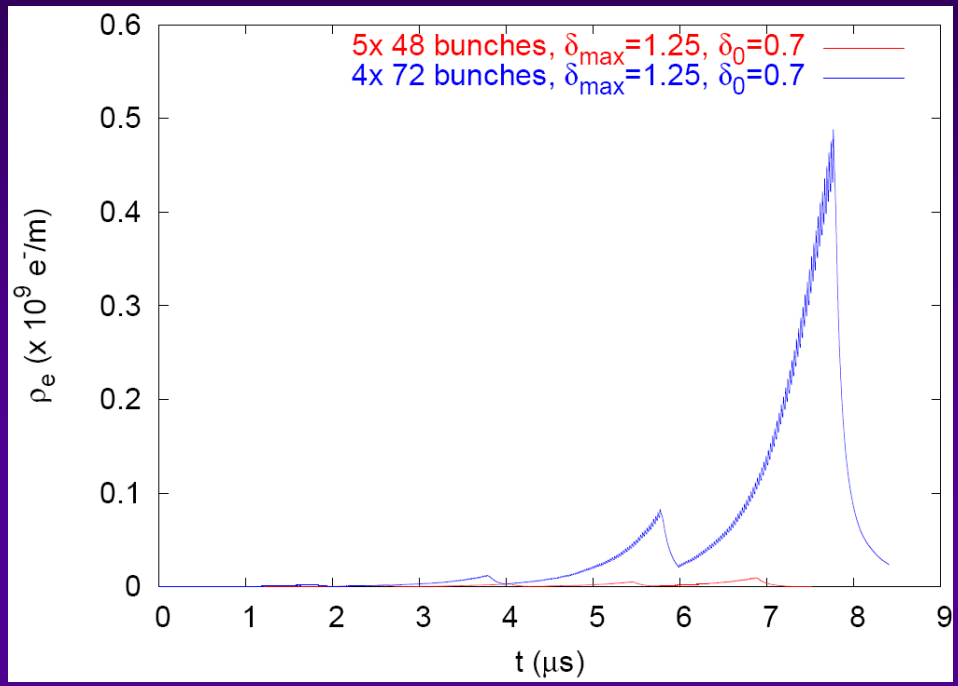
	72 bunches	48 bunches
1 batch	195	245 (+ 26%)
4 batches*	97	
5 batches**		110 (+ 13%)

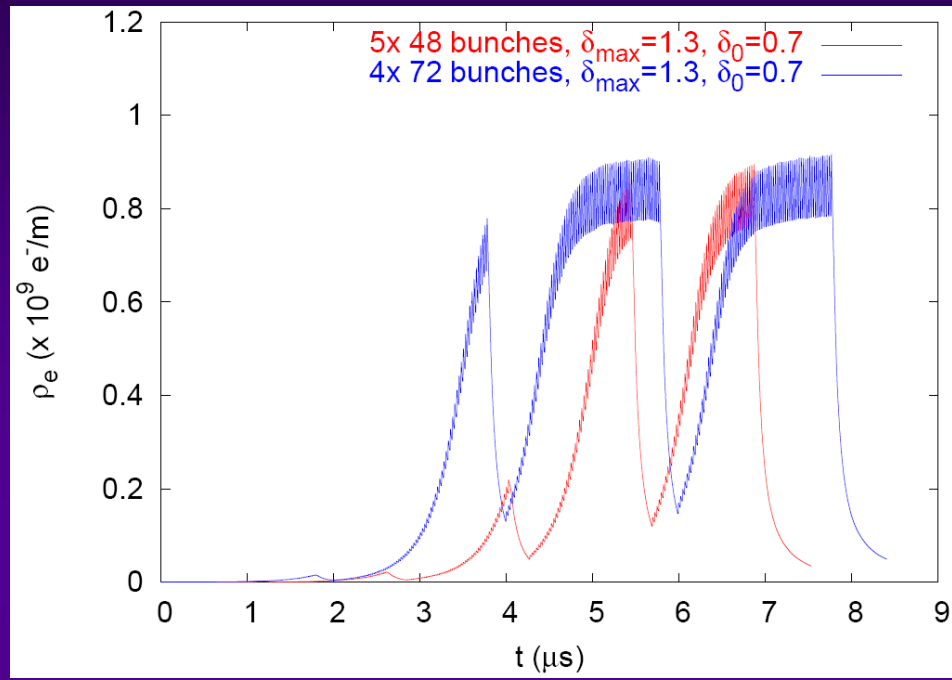
* The gap between the batches is 8 missing bunches, i.e. 225 ns

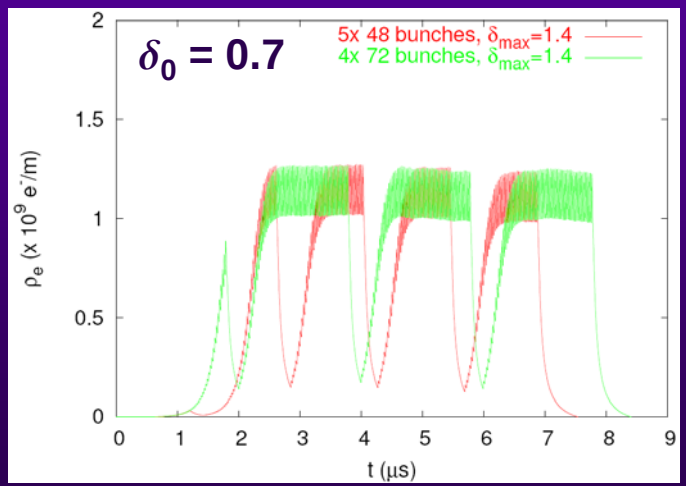
** The gap between the batches is 9 missing bunches, i.e. 250 ns

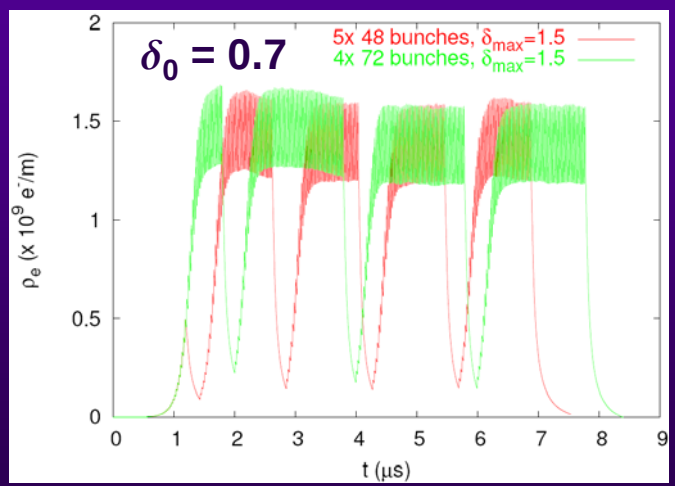
SPS (2/4)

- **Ecloud build-up (from G. Rumolo)**









Smaller ecloud effect ⟹ Vert. chromaticity could be lowered (⟹ less losses)

SPS (3/4)

- **Longitudinal plane (from E. Chapochnikova)**
  - **With the present "long" acceleration ramp RF voltage and power are not limitations up to ultimate bunch intensity**
  - **With 5 injections instead of 4, more transients in RF system can cause slightly more losses at injection $\Longrightarrow$ Some programming of different functions should be done (voltage, longitudinal damper...)**

SPS (4/4)

- A further advantage is the larger spacing between PS batches (9 missing bunches instead of 8, i.e. 250 ns instead of 225 ns) as the rise-time for the injection kickers is for the moment at the limit

- Finally, the reduced maximum intensity (240 bunches instead of 288) of each SPS extraction (LHC injection) is advantageous for the machine protection, both for the SPS and LHC

LHC FILLING TIME

Nominal (P. Collier, Chamonix XIII, 2004)

- 234 334 334 334.
- 12 SPS supercyles (of 21.6 s) per beam => 24 in total, i.e. a filling time of 24 × 21.6 s = 518.4 s = 8 min 38 s.

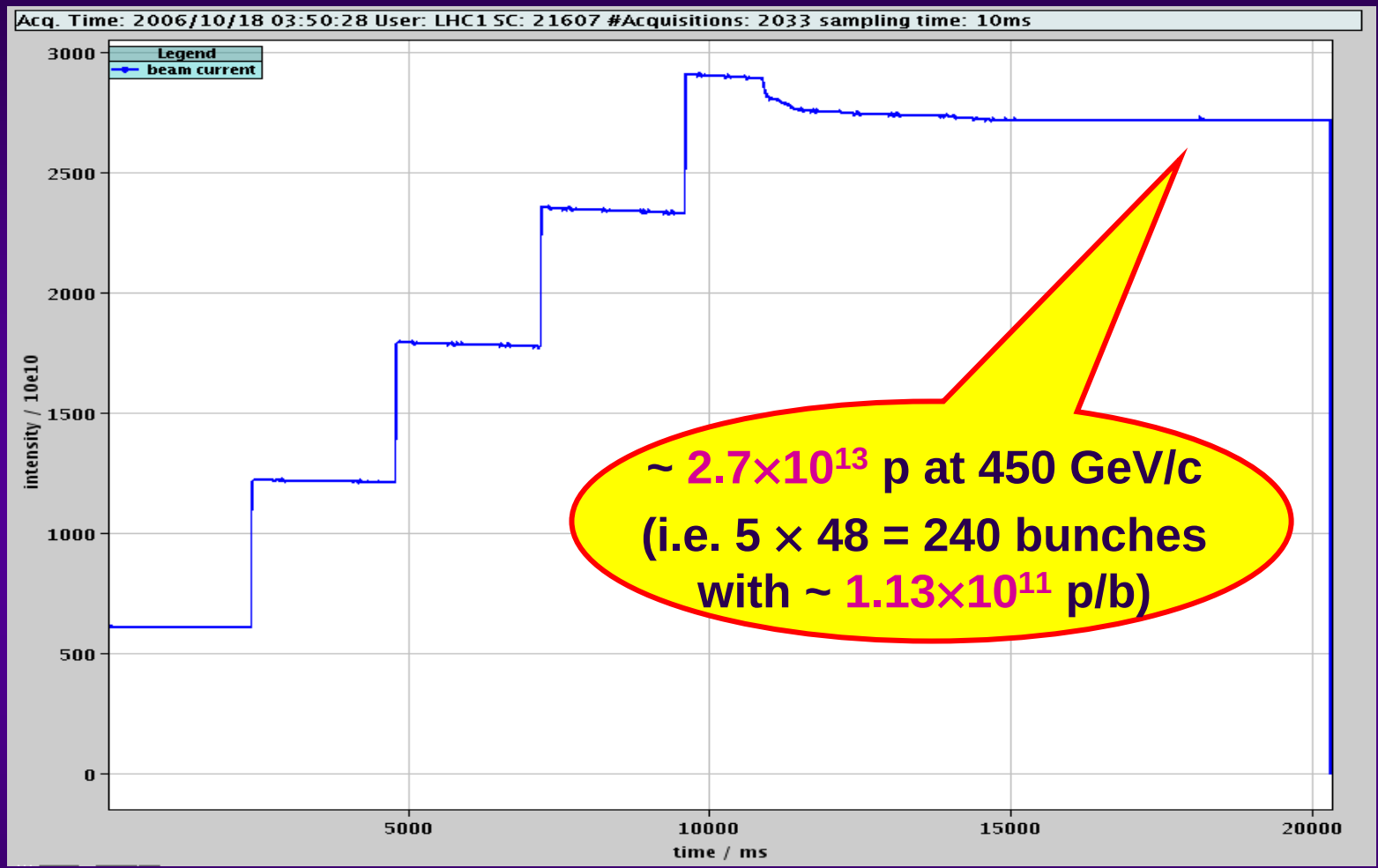
Ultimate scheme (M. Benedikt, LTC, 09/03/2005)

- 266 466 466 466.
- 12 SPS supercyles (of 21.6 s + 2 × 3.6 s = 28.8 s) per beam => 24 in total, i.e. a filling time of 24 × 28.8 s = 691.2 s = 11 min 31 s. The filling time is increased in this case by 33 %.

Proposed alternative (for the nominal)

- 255 455 455 455.
- 12 SPS supercyles (of 21.6 s - 3 × 3.6 s + 4 × 2.4 s = 20.4 s) per beam => 24 in total, i.e. a filling time of 24 × 20.4 s = 489.6 s = 8 min 10 s. The filling time is decreased in this case by 5.5 %.

MD performed on 17/10/06 $\Longrightarrow$ 5 injections of 48 bunches



- MD on 09/11/06 (see elogbook) $\Longrightarrow$ 6 injections of 48 bunches (used for the TT40 collimator tests)

CONCLUSION

- An “alternative” bunch filling scheme for the LHC is being proposed (in case of problems or as a possible step on the way to 72 bunches)

$\Longrightarrow$ Uses PS batches of 48 bunches in 2.4 s

  - Less bunches (2592 instead of 2808) and more gaps in the LHC $\Longrightarrow$ Better for the coupled-bunch instability induced by the collimators
  - 8 % less bunches $\Longrightarrow$ 8 % less luminosity
  - More robust through the injector chain (less losses…)
  - Only 4% more intensity per bunch is sufficient to compensate for the loss of luminosity (reminder: estimated intensity fluctuations $\approx$ 10%)
  - Filling time shorter by 5.5 % (SPS supercycle of 20.4 s instead of 21.6)
  - Larger gaps for the kickers…