Studies of the LHC beam loss in the SPS

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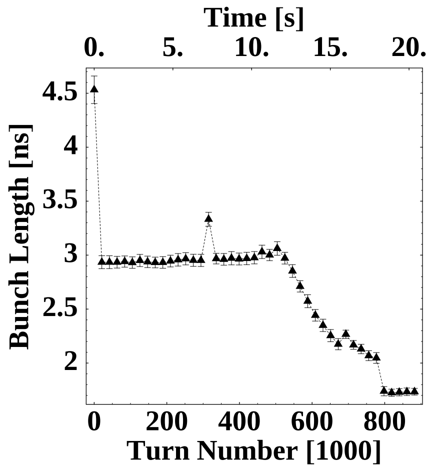
T. Bohl, T. Linnecar, E. Shaposhnikova and J. Tuckmantel

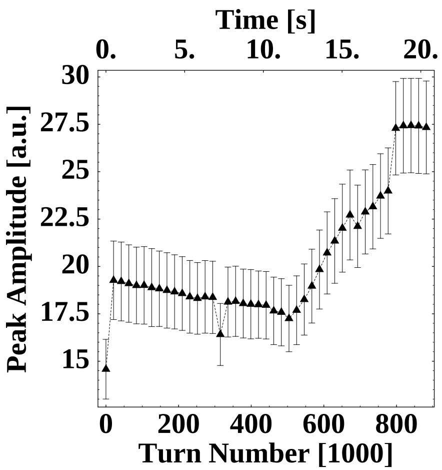
Acknowledgments: G. Arduini, S. Hancock, U. Wehrle and PS/SPS operation team

Remarks:

- Longitudinal plane
- Studies on the flat bottom
- Measurements in 2003-2004, still more data available

LHC beam in the SPS



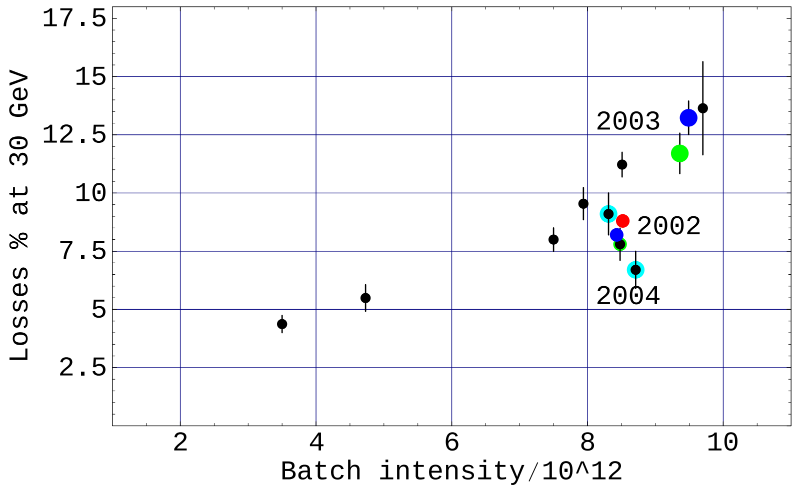


- **LHC beam:** 4 batches of 72 bunches with average longitudinal emittance of **0.35 eVs** at injection (26 GeV/c), **0.42 eVs** at the end of the flat bottom and **0.6 eVs** on the flat top (450 GeV)
- **Bunch intensity at injection:** 1.3×10^{11} in 2003 and 1.2×10^{11} in 2004
- Acceleration in the 200 MHz RF system. The 800 MHz RF system in BS-mode during the ramp to cure beam instabilities - **no effect on losses on the flat bottom**

Beam loss studies in 2003 - 2004

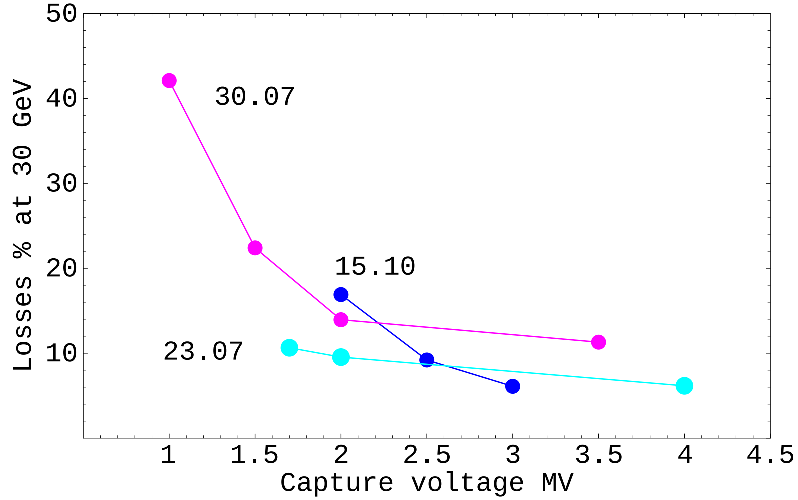
Dependence of relative loss on

batch intensity



V=2 MV

capture voltage

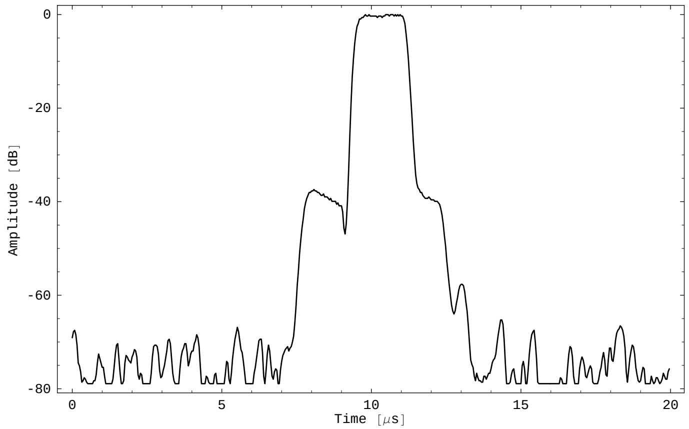


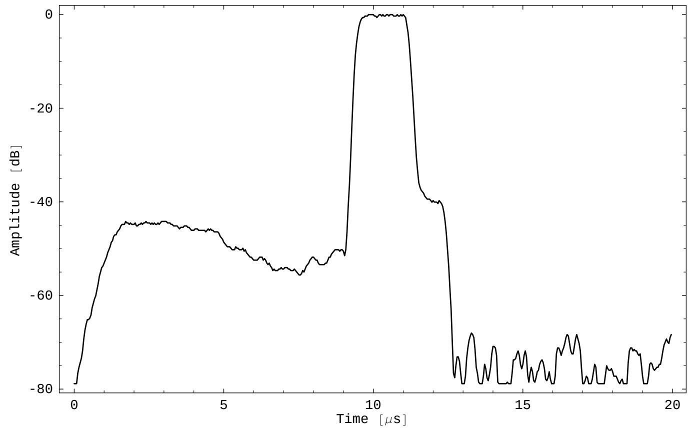
$N_b/10^{12}$= 7.8 (23.07), 9.7 (30.07), 9.4 (15.10)

- **Strong dependence on batch intensity, much less on total (number of batches) or bunch intensity (75 ns bunch spacing!)**
- **Beam losses are reduced for higher voltages (constant in this case)**
- **Reduction of losses at the end of 2004 due to new working point** (*G. Arduini et al.*) **and RF gymnastics**

Injection and flat bottom losses

200 MHz beam component at injection and 3 s later



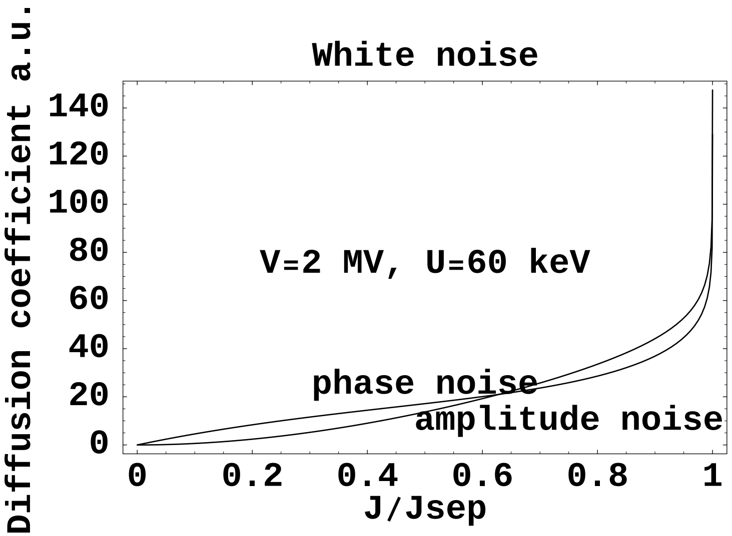


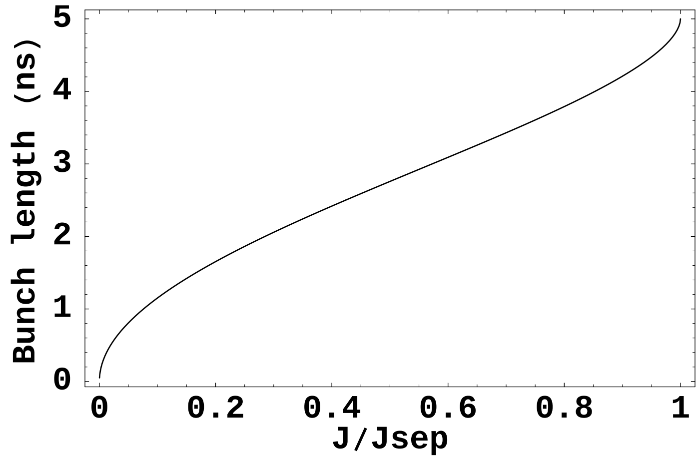
- **Uncaptured particles are moving to the left ⟶ negative energy deviation due to particle energy loss (observed not only at injection but also during the coast after voltage drop)**

- **Flux of uncaptured particles continues after injection! ⟶ noise?**

Diffusion due to white noise in accelerating bucket

$D(J)$ $\tau(J)$

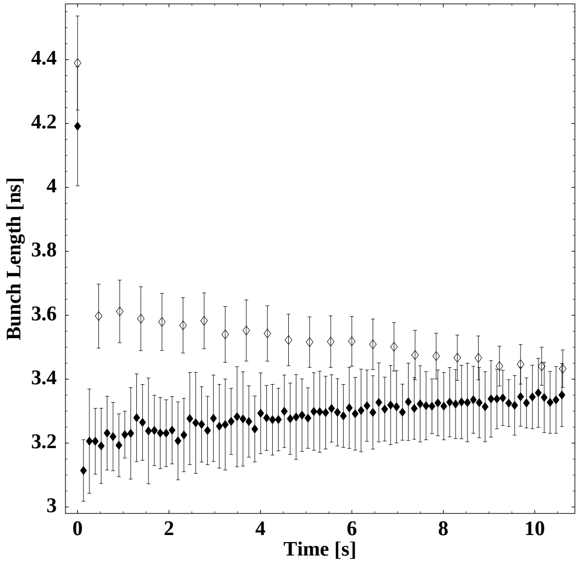




- **The diffusion coefficient sharply increases towards the separatrix $\longrightarrow$ bunch tails are more affected by the noise for longer bunches and also for a bucket reduced due to intensity effects (energy loss)**

Measurements and simulations with noise

- Bunch length on the flat bottom



Top curve: $V_{inj} = V_{fb} = 2$ MV. Bottom curve: $V_{inj} = 2$ MV, $V_{fb} = 3$ MV. $\bar{N}_{bunch} = 1.25 \times 10^{11}$.

- Losses are reduced when 2 MV injection voltage is raised after 100 ms to 3 MV in comparison with constant 2/3 MV
- Bunch peak amplitude decreases along the flat bottom in all cases, but less for higher voltages
- Simulations: a reduction in σ (Gaussian fit) for longer bunch in 2 MV and an increase for shorter bunch in 3 MV both for phase and amplitude noise, but amplitude noise doesn't change the bunch peak amplitude.

Noise studies

Aim of the test: **To check cavity and power amplifier noise levels (includes cavity amplitude and phase loops and one-turn feedback)**

Method: **Inject phase and/or amplitude noise until effect on beam is seen. Effect can be observed on peak detected signal as an increase in decay rate.**

Result: **One has to increase phase noise by $\sim$ 36 dB to lower peak amplitude lifetime to $\sim$ 150 s. Implies that without extra noise lifetime due to the existing noise is $\sim$ 180 h.**

Same result for amplitude noise: 95 h without extra noise

Conclusion: **Noise in cavity loops is unimportant for the present application (lifetime 10 min)**

Flat bottom beam loss and lifetime

Ongoing and future studies

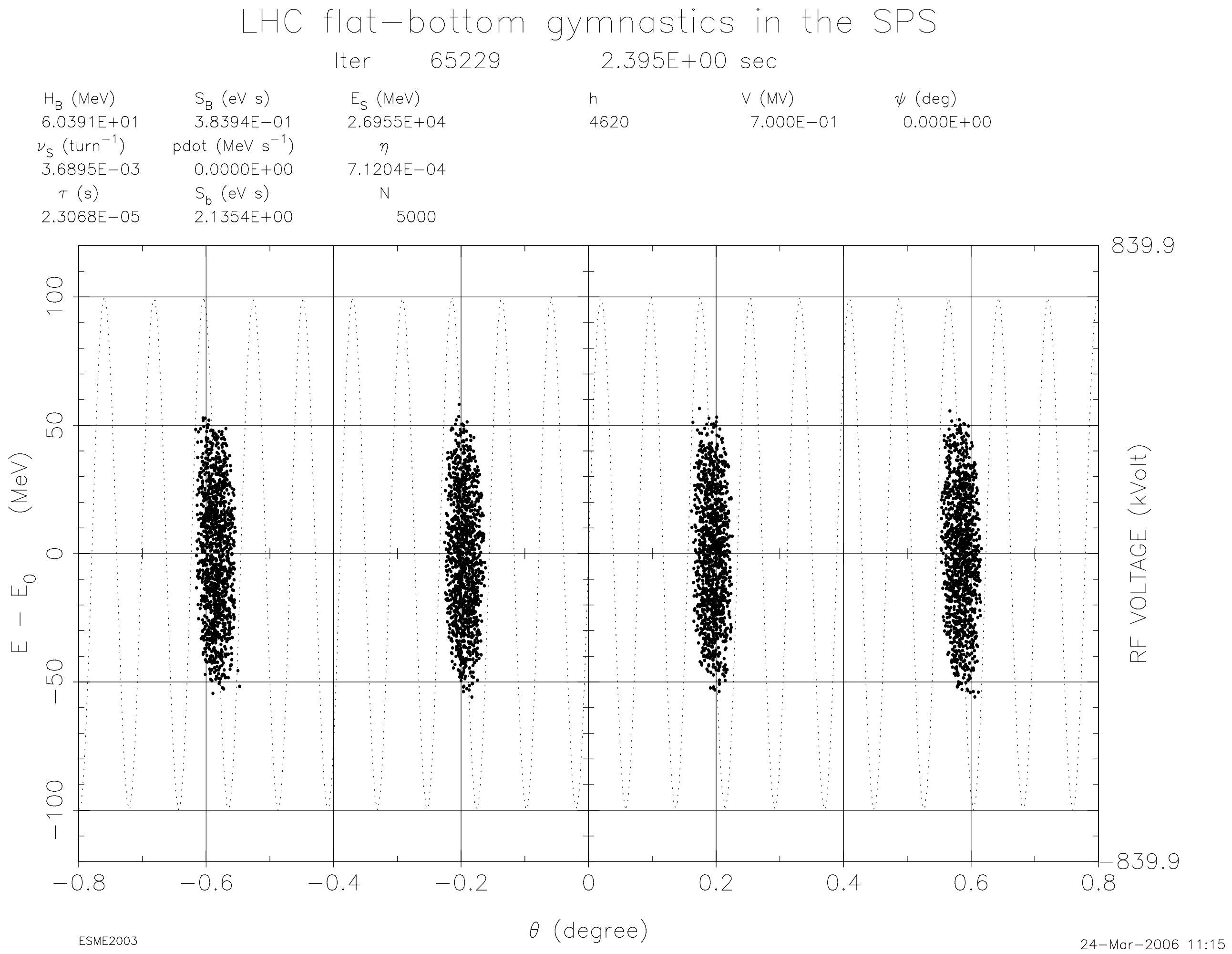
- Effect of new working point (WP)
- RF gymnastics: (2 MV increased to 3 MV after 10 ms during 100 ms) helps for one batch but less for 4 batches in the ring (voltage dip for each injection → loss → recapture of lost particle → satellite bunches...)
- Realistic bunch shape after splittings and rotation in the PS (studies by H. Damerau)
- Bunch length variation along the batch
- Injection phase drift up to 40 deg (to study in 2006)

Flat bottom losses with a new WP

beam type	V_{inj} MV	V_{fb} MV	N_{mean} 10^{10}	loss %	SD %
25 ns	1.0	2.0	34.59	7.3	0.4
25 ns	2.0	2.0	33.80	7.9	0.3
25 ns	2.0	3.0	35.03	6.6	0.4
short bunches	2.0	3.0	34.40	6.1	0.5
PS FB off	2.0	3.0	33.95	6.9	0.2
inj. phase corr.	2.0	3.0	34.09	5.6	0.2
eq. spaced batches	2.0	3.0	34.14	5.4	0.2
75 ns	2.0	3.0	12.51	2.6	0.2
75 ns	2.0	2.0	12.39	3.4	0.4
75 ns	3.0	3.0	12.41	4.7	0.2

Bunches at injection to the SPS (1/3)

ESME simulations (S. Hancock, H. Damerau)

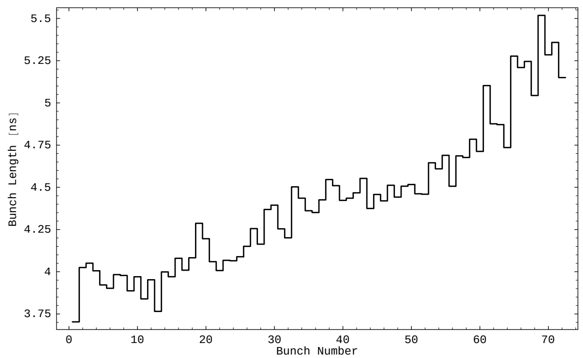


- **For "ideal" bunches some particle losses only for 700 kV**

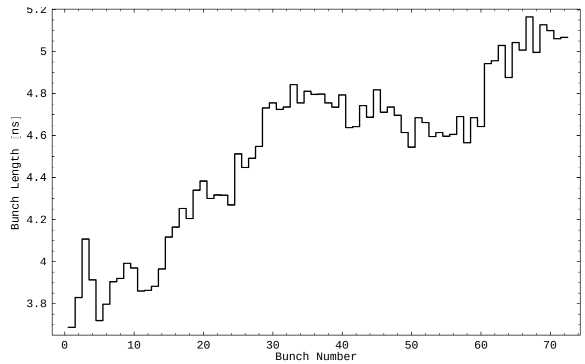
Bunches at injection to the SPS (2/3)

Bunch length (uncorrected - 0.4 ns) along the batch

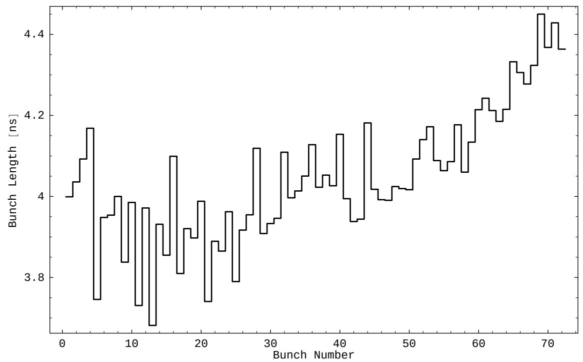
(A) min: 3.7 ns, max: 5.52 ns



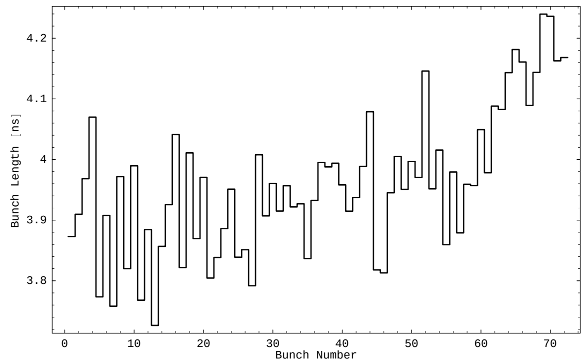
(B) min: 3.69 ns, max: 5.16 ns



(C) min: 3.68 ns, max: 4.45 ns



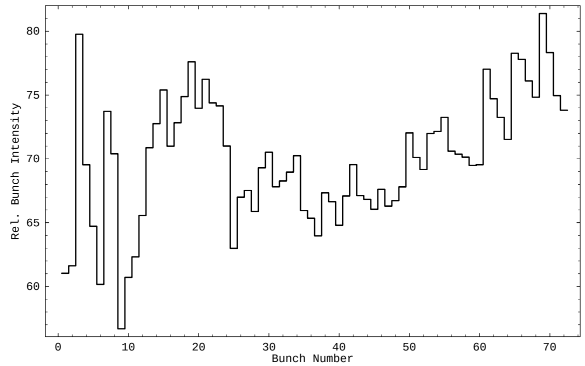
(D) min: 3.73 ns, max: 4.24 ns



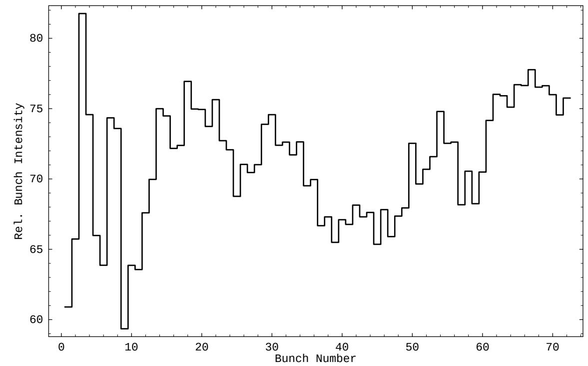
Bunches at injection to the SPS (3/3)

Bunch intensity (length x peak amplitude) variation along the batch

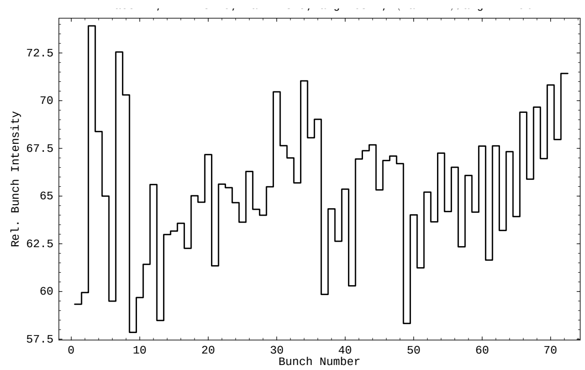
(A)



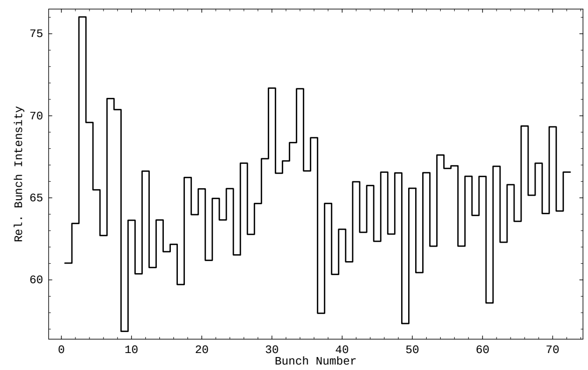
(B)



(C)



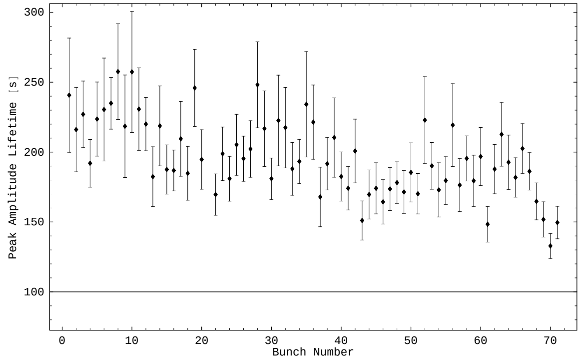
(D)



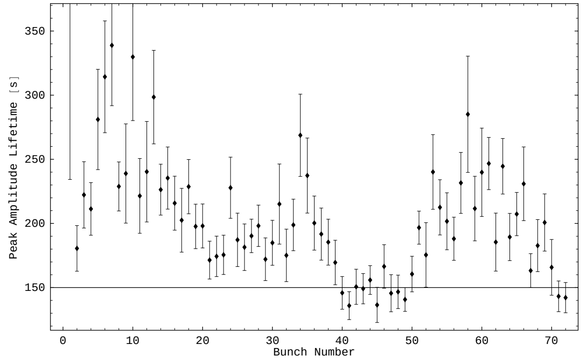
Beam lifetime on the flat bottom (1/2)

Peak amplitude lifetime along the batch

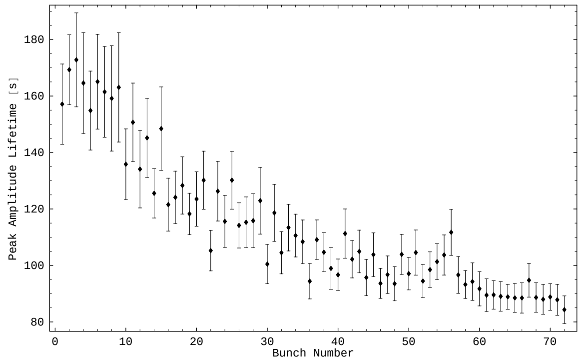
(A) 3 MV, new WP, 4.4 ns



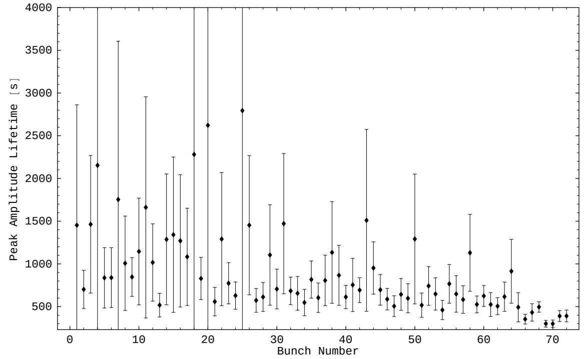
(B) 2 MV, new WP, 4.4 ns



(C) 2 ↗ 3 MV, old WP, 4 ns



(D) 2 ↗ 3 MV, new WP, 4 ns



Beam lifetime on the flat bottom (2/2)

The lifetime of the average bunch peak amplitude (0.5 - 10.5 s)

figure	Voltage		Bunch length		Lifetime T for	
	V_{inj} MV	V_{fb} MV	τ_{inj}^{av} ns	τ_{fb}^{av} ns	old WP s	new WP s
(A)	3	3	4.4	3.15	-	191
(B)	2	2	4.4	3.35	-	170
	2	2	4.0	3.25	-	394
	3	3	4.0	3.05	173	418
(C, D)	2	3	4.0	2.8	110	721

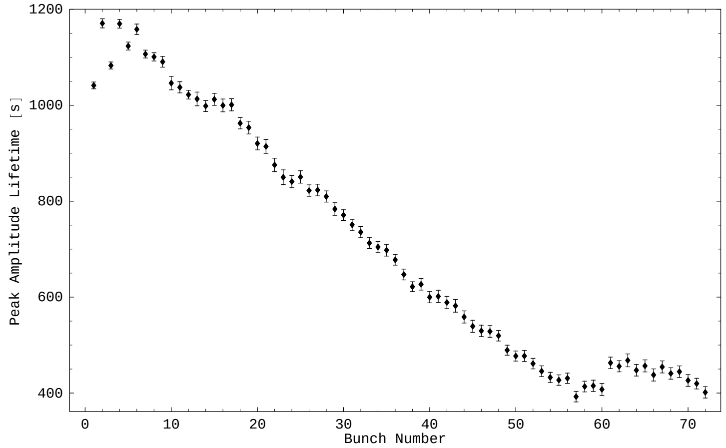
Summary

- **Beam losses were significantly reduced in 2004 ... but they are still too large for bunch-to-bucket transfer**
- **The exact loss mechanism is not yet clear**
- **RF manipulations in the SPS which help to reduce losses in fact aim to keep particles away from the separatrix**
- **Practical measures → improvement of phase-space distribution of injected bunches:**
  - **cure of beam loading and coupled bunch instabilities - longitudinal broad-band feedback system (in collaboration with GSI)**
  - **more voltage before extraction in the PS (short bunches)**
  - **correction of injection phase drift**
- **Studies of beam lifetime in the coast**

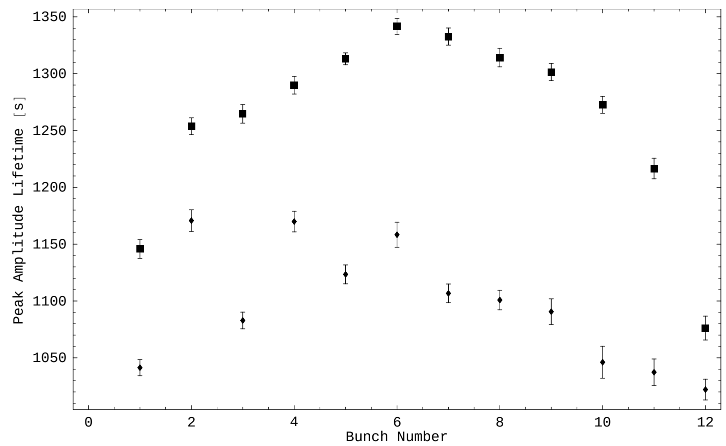
Beam observations during the coast (1/4)

Individual bunch peak amplitude lifetime (30 s $\leq t \leq$ 690 s)

72 bunches



12 bunches

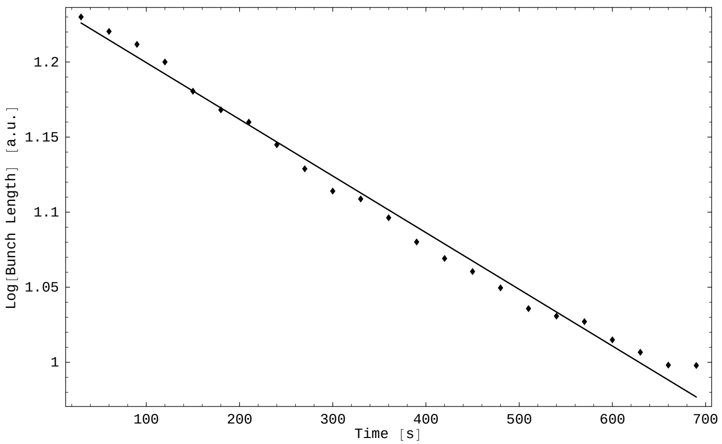


MD on 3.11.2004: 26 GeV, new WP, 2 MV at 200 MHz, 214 kV at 800 MHz (BSM), nominal intensity, 25 ns bunch spacing, 72 and 12 bunches

Beam observations during the coast (2/4)

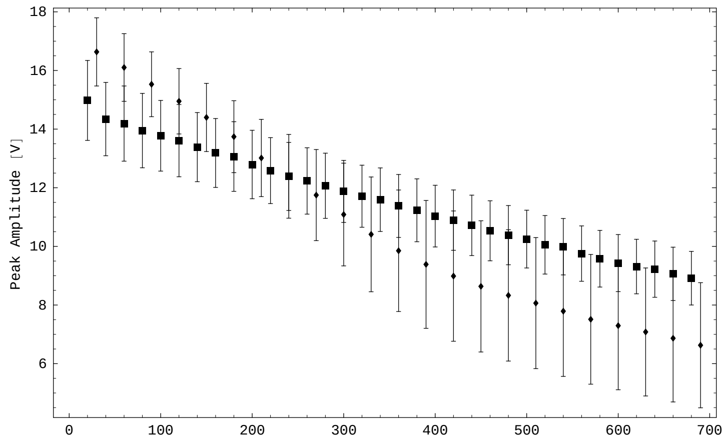
Average bunch length and peak amplitude versus time

log[bunch length]



72 bunches

peak amplitude



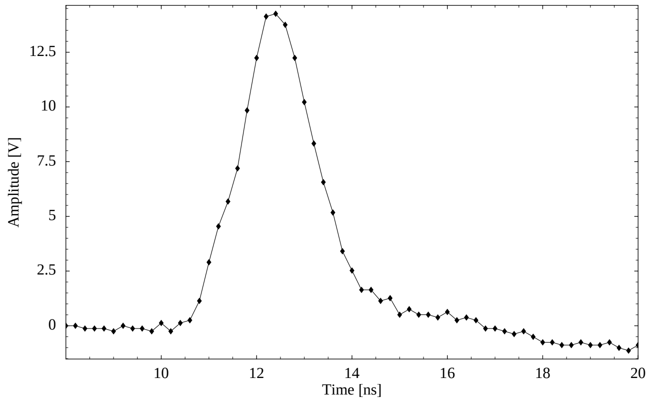
72&12 bunches

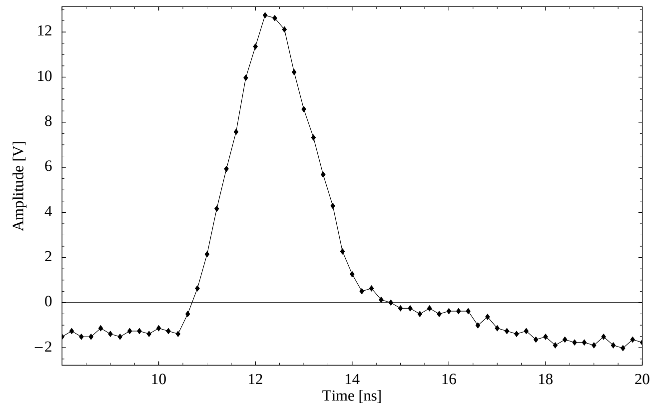
average life time (s)	72 bunches	12 bunches
bunch length	2650 ± 60	7280 ± 75
bunch peak amplitude	660 ± 12	1260 ± 10

Beam observations during the coast (3/4)

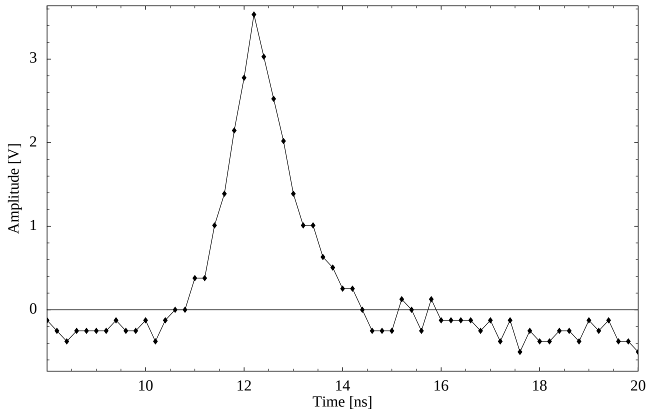
t=20 s

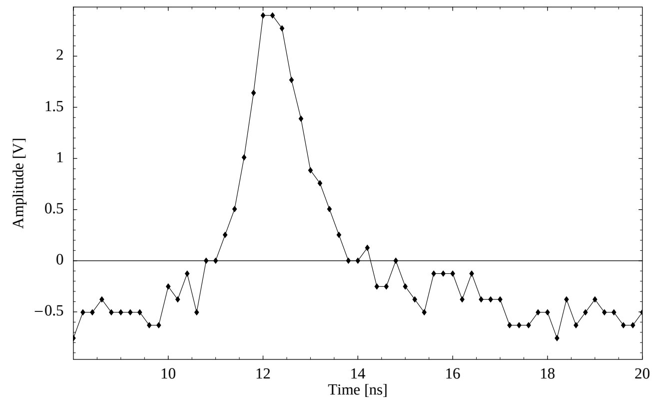
bunch 1/12 **bunch 12/12**





t=1580 s





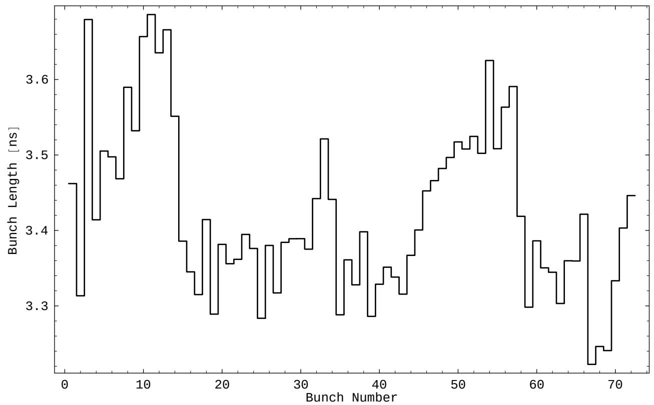
→ The first bunch is also affected!

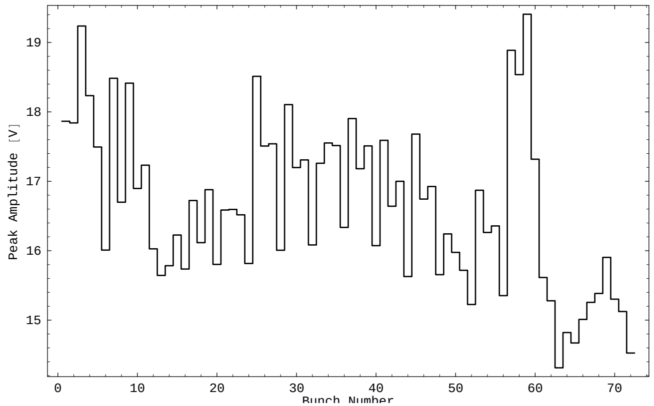
Beam observations during the coast (4/4)

t=30 s

bunch length

bunch peak amplitude





t=690 s