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SPS

RF studies of the high intensity CNGS beam in the SPS

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Run no.	Date
1	15/09/2004
2	21/09/2004
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5	28/09/2004
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Summary

Different steps taken during a high intensity CNGS run in September 2004 to improve machine performance and minimise beam losses in the SPS are described. Results of the PS-SPS transfer studies, in particular the effect of 200 MHz modulation, debunching and RF voltage harmonic and amplitude in the PS before extraction, on beam transmission in the SPS, are also presented.

1 Introduction

After the start-up of the CNGS programme [1] CERN must produce a Fixed Target (FT) type of beam with intensities of not less than 4.4×10^{13} at 400 GeV [2]. In September 2004 there was a special run with a high intensity FT beam to see the effect of the recent upgrades of accelerators in the chain (done mainly for LHC beam) and to determine the present intensity limitations and possible solutions to overcome them. A significant part of the run was also devoted to optimising the PS-SPS transfer.

During this run the supercycle CY-700 was used. The injection of the first batch is at time 0 and of the second batch at 1200 ms. The acceleration starts at 1260 ms. Transition crossing is at 1485 ms. Estimations of losses and beam transmission presented in this Note are based on beam intensity measured by a BCT (Beam Current Transformer) at different moments in the cycle, as shown in Table 1. Due to the dependence of the BCT signal on bunch length some of the loss measurements (especially at the beginning of the ramp) do not have meaning on their own and should be considered together with other readings.

Below all bunch length measurements correspond to 4σ length from a Gaussian fit to a bunch profile corrected for pick-up (PU) response, but not for cable transfer function (on average ~ 0.3 ns should be subtracted [3] from presented values of bunch length).

m	time ms	momentum GeV/c	intensity N_m	beam loss definition
0	0	14	N_0	
1	1260	14	N_1	$l_1 = 1 - N_1/N_0$
2	1470	20	N_2	$l_2 = 1 - N_2/N_1$
3	1530	27	N_3	$l_3 = 1 - N_3/N_2$
4	1740	50	N_4	$l_4 = 1 - N_4/N_3$
5	4320	400	N_5	$l_5 = 1 - N_5/N_4$

Table 1: Synchronous momentum of the beam at different times of the CNGS cycle corresponding to the standard (displayed on "Larger" video page) intensity measurements.

2 MD on 15.09

The main purposes of this MD were following:

- SPS transmission optimisation for this beam intensity,
- PS-SPS transfer studies.

We started with the voltage programme (V-1) shown in Fig. 1 (left) obtained by operators on shift by small trims from the one used normally in 2004 for the fixed target (FT) cycle, see Fig. 1 (right). The 200 MHz voltage at injection and on the flat bottom was $V_{inj} = 820$ kV and the 800 MHz RF system was off. Total intensity: $(4.3 - 4.7) \times 10^{13}$ injected, 4.4×10^{13} maximum accelerated.

Slow continuous beam losses after transition were already observed for these intensities. They were reduced by using the one-turn-delay feedback during acceleration (unlike the FT cycle).

We observed that with this capture voltage, after injection of the first batch, uncaptured beam moves towards the tail of the batch. At the beginning of acceleration this beam is recaptured creating a triangular batch shape and also populating the kicker gap, see Fig. 2 (left). The injection of the second batch cleans approximately half this gap. The beam which is left in the abort gap and recaptured at the beginning of ramp (less than 5×10^{10}), will be lost at the extraction from the SPS, where the limitation for the lost particles is $\sim 10^{11}$.

The second part of this MD was devoted to measurements of transmission efficiency in the SPS as a function of RF settings in the PS (voltage amplitude at 10 MHz, 200 MHz and debunching off/on). The results of these studies are presented in Table 2. After the SPS stop of 3 hours transverse settings in the SPS changed (unexplained). Measurements done at this time are shown in the last row in Table 2.

Summary:

- One-turn-delay feedback is necessary for these intensities during the whole acceleration cycle.
- A minimum 200 MHz modulation (24 kV) is absolutely necessary "to see" the beam in the SPS.
- For beam debunched in the PS before extraction to the SPS, the transmission in the SPS is better by approximately 0.5%.

Later we learned (Steve Hancock) that the poor bunch-to-bunch and shot-to-shot reproducibility was due to the absence of one of the controlled emittance blow-ups in the PS.

PS		SPS													
RF		intensity		relative loss measured at different time in cycle											
n		N_1 10^{13}	σ_N 10^{13}	l_1 %	σ_1 %	l_2 %	σ_2 %	l_3 %	σ_3 %	l_4 %	σ_4 %	l_5 %	σ_5 %	l_Σ %	σ_Σ %
7	d	2.85	0.05	0.8	0.08	0.28	0.32	3.43	0.34	0.45	0.24	0.55	0.1	5.5	0.77
7	d	4.50	0.17	-	-							-	-	5.79	0.51
0	d	4.60	0.05	1.54	0.11	0.63	0.21	4.91	0.23	0.61	0.1	0.58	0.11	8.27	0.31
0	b	4.63	0.07	1.69	0.11	0.73	0.37	4.84	0.18	0.87	0.24	0.81	0.32	8.93	0.48
1	b	4.43	0.13	1.83	0.13	0.89	0.24	4.87	0.34	0.74	0.36	0.63	0.13	8.99	0.51
1	b	4.39	0.08	-	-	0.7	0.23	5.93	0.5	0.21	0.15	-	-	6.83	0.6

Table 2: MD on 15.09. Transmission in the SPS for different RF settings in the PS. First line - measurements with FT beam at different cycle. In the second and last line $l_\Sigma = l_2 + l_3 + l_4$; σ_i is the standard deviation of measured l_i. The voltage at harmonic $h = 16$ is 4 kV in all cases except the last line where it was 2.5 kV, n is the number of the 200 MHz cavities in the PS with 24 kV each, "d" and "b" mean correspondingly debunched and bunched beam before extraction in the PS. The last line - measurements with new transverse settings after the SPS stop.

3 MD on 21.09

The purpose of this MD was the optimisation of the voltage programme in the SPS.

The voltage programme used for fixed target beam in 2004 and the first voltage programme used for CNGS beam (V-1), shown in Fig. 1, are different from the voltage programme used in the past (1997-1998), when a record intensity of 4.8×10^{13} was obtained and some reference measurements were taken [4]. In particular, the voltage is now higher before and after transition crossing by approximately 1 MV. The injected beam intensity was around 5.2×10^{13}. Typically 4.6×10^{13} were accelerated to 400 GeV. The distribution of transmission loss during the cycle for voltage programme (V-1) is shown in Table 3.

Some tests and their results from this MD are summarised below.

- For the voltage programme (V-1), the maximum voltage of 7.5 MV after 2000 ms could be reduced by 0.5 MV without visible BCT losses. Losses were seen with a voltage of 6.5 MV at 3500 ms.

- Variation of injection voltage. Increase from 0.8 MV to 1.1 MV and then to 1.4 MV (constant along the flat bottom) decreased the amount of uncaptured beam moving to the right, but did not give any improvement on the total beam transmission, see Table 3.

- We tried to reduce the voltage before transition. With the dip down to 3.7 MV (from 6 MV initial) at 1420-1430 ms we started to see small losses on the BCT signal. Finally we were able to reduce the maximum voltage before transition down to 5.7 MV (from 6.5 MV). At the same time we had some increase of injected intensity. The beam transmission for this voltage programme (V-2) and intensity is shown in Table 3.

- Around 14h30 4.87×10^{13} was accelerated to top energy - slightly more than the previous SPS record (1998).

- Radiation limitation due to the beam dumping at high energy. No acceleration to top energy. Beam dump after transition, at 1600 ms (in this case another beam dump can be used).

- Transition crossing studies (16h30). Observations of peak detected signal from different parts of the batch have shown strong quadrupole oscillations across transition for the head of the batch.

The voltage trim at transition (change in timing for voltage rise by 3 ms) based on observation of these signals (minimization of oscillation amplitude) allowed the transition losses to be decreased down to 5.5 %. As a result, for the increased injected intensity (5.6×10^{13}) around 5.1×10^{13} could now be accelerated through transition, see Table 3. The transmission losses during the ramp with this voltage programme (V-3) are shown in Table 3.

- The losses were reduced after adjustment of the injection RF frequency (corresponding to changes from 627.87 to 627.73 Gauss). The results are presented in the two last lines of Table 3.
- It was found out that in all cases (including the nominal voltage programme used for FT beam) the first and second batch were injected into different voltages due to the start of acceleration shortly after the second injection. As a result the second batch seemed to have more losses at transition. This was corrected (constant voltage of 0.8 MV till 1220 ms instead of till 1200 ms previously). The final voltage programme (V-4) after trims around transition is shown in Fig. 3 together with (V-1) for comparison. Other values have not been changed and are the same for both programmes, see Fig. 1 (right).

Voltage		intensity		relative loss measured at different time in cycle							
V_{inj} MV	ramp	N_1 10^{13}	σ_N 10^{13}	l_2 %	σ_2 %	l_3 %	σ_3 %	l_4 %	σ_4 %	l_Σ %	σ_Σ %
0.8	V-1	5.08	0.05	1.29	0.37	7.11	0.39	1.02	0.35	9.42	0.87
1.1	V-1	5.08								9.69	
1.4	V-1	5.10								10.05	
0.8	V-2	5.23	0.03	0.96	0.13	7.51	0.58	1.59	0.16	10.07	0.49
0.7	V-2	5.25	0.03	1.07	0.23	7.22	0.45	1.57	0.56	9.86	0.85
0.8	V-3	5.44	0.1	1.27	0.79	5.91	0.24	0.67	0.56	7.85	0.85
1.25	V-3	5.32	0.11	1.52	0.33	5.96	0.31	0.63	0.15	8.10	0.43
1.25	V-3	5.17	0.15	1.17	0.11	5.56	0.21	0.36	0.18	7.08	0.28
0.8	V-3	5.33	0.15	1.03	0.26	5.87	0.56	0.89	0.32	7.79	0.73

Table 3: MD on 21.09. Beam transmission for different voltage programmes in the SPS, see Fig. 3. For the 2nd and 3rd lines $l_\Sigma = l_2 + l_3 + l_4$. Two last lines - beam transmission after a correction of the RF frequency at injection.

Summary:

- Minimization of bunch oscillation after transition crossing allowed the losses at transition to be reduced.
- Triangular shape of the first batch is due to the recapture of particles at the beginning of the ramp. Batches were injected in different voltages and as a result the second batch had more losses through transition.

4 MD on 22.09

This MD was also devoted to the study of beam transmission in the SPS as a function of RF settings in the PS. In the SPS the voltage programme used was (V-4), see Fig. 3.

From the peak detected (PD) signal taken in different parts of the batch one could see that at the end of the cycle the beam was more stable for bunched mode (with V=2.5 kV at 10 MHz and 1 cavity of

24 kV at 200 MHz in the PS), than for unbunched, In bunched mode, it was more stable for the case with lower voltage in the PS before extraction.

It was not possible to measure losses l_1 and l_5 from the available display, but they were always there seen as a continuous slope on the BCT signal both on the flat bottom ($\sim 2\%$) and after transition ($\sim 5\%$), till approximately 3000 ms. For constant conditions in the SPS, losses increased with an increase of voltage at 10 MHz in the PS, see Table 4. At the same time more uncaptured beam was visible on the flat bottom with the fast BCT signal.

PS			SPS									
Voltage			intensity		relative loss measured at different time in cycle							
h=16 kV	V_{200} kV		N_1 10^{13}	σ_N 10^{13}	l_2 %	σ_2 %	l_3 %	σ_3 %	l_4 %	σ_4 %	l_Σ %	σ_Σ %
4.0	7x24	d	5.49	0.07	0.47	0.4	5.73	0.36	0.87	0.25	7.08	0.70
4.0	1x24	d	5.45	0.04	0.33	0.13	5.65	0.24	0.91	0.22	6.89	0.38
2.5	1x24	b	5.42	0.08	0.22	0.17	5.26	0.21	0.54	0.16	6.01	0.23
4.0	1x24	b	5.40	0.07	1.80	0.44	5.44	0.19	0.67	0.23	7.90	0.48
10.0	1x24	b	5.31	0.07	1.7	0.58	6.83	0.76	0.5	0.15	9.02	1.24
4.0	7x24	d	5.43	0.03	0.91	0.16	5.38	0.27	-	-	6.29	0.26
4.0	7x24	d	5.42	0.03	0.44	0.26	5.49	0.08	-	-	5.93	0.28

Table 4: MD on 22.09. Transmission in the SPS for different RF settings in the PS. The last line - new voltage programme in the SPS on the flat bottom in the SPS (0.8 MV increased to 2.5 MV in 50 ms after 50 ms.

Summary of observations:

- Best transmission in the SPS is for the lowest voltage in the PS (2.5 kV).
- For beam without debunching in the PS we observed the effect of stabilisation of coupled bunch instabilities at high energy due to the bunch-to-bunch intensity variation. More detailed analysis is required.
- The triangular shape of the first batch was corrected and the number of recaptured particles in the kicker gap was reduced by the voltage increase within 50 ms from 0.8 MV to 2.5 MV, 50 ms after the first injection, as shown in Fig. 4, (left). Reduction of voltage back to 0.8 MV for the second injection leads to losses from the first batch. Lost particles are partially recaptured again at the beginning of acceleration. On the other hand, high voltage (2.5 MV) at the moment of injection of the second batch causes emittance increase due to filamentation and therefore is not optimum for transition crossing of the second batch. For an identical capture of two batches voltage modulation within a revolution period is needed.

5 MDs on 27.09, 28.09 and 29.09

5.1 MD on 27.09

Over the weekend the injected intensity was further increased. As an example, around 15h00 in the SPS an intensity of 5.927×10^{13} was recorded at 1260 ms and 5.577×10^{13} at 1530 ms.

An increase of FB gain by 3 dB improved the transition crossing. Measurements of relative loss at transition crossing done around 13h30 with feedback gain lower than normal by 3 dB, normal and higher by 3 dB, gave average values of 6.82%, 6.22% and 5.26% at the corresponding average intensities of 5.60×10^{13}, 5.70×10^{13} and 5.65×10^{13}. Note that similar measurements done later (around 19h30) gave slightly higher loss for increased FB gain - probably due to some drift of settings. Around 15h00 there were frequent trips on TRX2 and as a result one tube was changed. Typical (for time period 19h26 - 19h40) loss distribution during the cycle for these intensities and increased FB gain is shown in Table 5.

Voltage		intensity		relative loss measured at different time in cycle							
V_{inj} MV	ramp	N_1 10^{13}	σ_N 10^{13}	l_2 %	σ_2 %	l_3 %	σ_3 %	l_4 %	σ_4 %	l_Σ %	σ_Σ %
0.8	V-4	5.68	0.05	0.09	0.07	5.97	0.48	0.81	0.13	6.87	0.55

Table 5: MD on 27.09.2004. Transmission in the SPS with increased FB gain by 3 dB. Voltage at injection (0.8 MV) is increased after 50 ms to 2.5 MV during 50 ms. Voltage programme for the rest of the cycle is (V-4).

A small increase (by 200 kV) of the minimum voltage of 3.03 MV during transition crossing increased losses from the previous average value of 6.0% to 7.2%.

For these intensities continuous losses seen after transition crossing were larger than before, Table 4, reaching ~ 7 %. Bunch length measurements taken on 22.09, Fig. 5, showed that approximately the first 100 bunches in the batch have significant emittance blow-up (factor two in bunch length) after transition crossing. This roughly corresponds to the filling time of the 200 MHz TW cavities (~ 620 ns) and probably can be explained by transient beam loading. However particle loss from these bunches alone, which contain ~ 5 % of total intensity, cannot explain ~ 5 % loss of total intensity above transition.

Sharp beam loss was observed from time to time at the beginning of acceleration.

Voltage rise after injection of the first batch on the flat bottom was varied. Injection into 0.8 MV, then, after 10 ms, rise to 2 MV or 2.5 MV during 40 ms gave losses at transition crossing (l_3) 6.13% and 6.15% correspondingly. The previous scheme (0.8 MV increased to 2.5 MV after 50 ms in 50 ms) gave practically the same (6.0%) loss at transition l_3.

5.2 MD on 28.09

In the morning large losses were observed at the beginning of acceleration in the SPS with the same machine settings as on 27.09. They were removed later by a sharp increase in voltage in the front porch (G. Arduini). The reason for this change was unclear at that time.

Measurements with different feedbacks on and off were performed, average intensity at 1260 ms was 5.87×10^{13}. The main conclusion was that with all feedbacks in operation transmission at transition is 0.8% better (loss of 4.7% in the last case and 5.5% with only feedbacks on cavities 1, 2 on and 3,4 - off). With all feedbacks off beam was lost.

With FT beam of nominal intensity a similar batch structure (emittance blow-up of first approximately 100 bunches) as for CNGS beam was observed.

5.3 MD on 29.09

The first part of the studies during this day, from 3h00 till 7h00 a.m., was a dedicated MD and was mainly devoted to the problem of high energy losses. The BCT signal showed typical decrease of the total intensity after transition till 400 GeV from 5.1×10^{13} to 4.8×10^{13} or from 5.3×10^{13} to 4.9×10^{13}, which corresponds to a relative beam loss of (6-7)%. These losses were the reason for a radiation interlock and early beam dump during acceleration. These losses occurred mainly between 1500 ms and 3000 ms, after 3000 ms the BCT signal was practically flat, see Fig. 9 (left). These losses seemed to be intensity dependent, so that for intensities after transition varying from 5.4×10^{13} to 5.2×10^{13}, the intensity at 400 GeV was around 5.0×10^{13}. A few per cent loss was also observed along the flat bottom.

We studied the effect of the variation of chromaticity (together with G. Arduini). Vertical chromaticity was increased by 0.2 units. No visible changes in the loss pattern. The same type of losses also occurred with the horizontal chromaticity increased by 0.25 units.

At 4h40 the injected beam had a bad structure, with bunch intensity increasing towards the end of each batch. We could see from the fast BCT signal that this part of the beam had more losses during transition crossing.

We introduced the new voltage programme after transition crossing, Fig. 4 (right), which corresponds to a constant bucket area of 0.4 eVs up to 4 s in the cycle. No additional losses were observed. With the 0.4 eVs programme after 4.0 s small losses were observed at the very end of the cycle.

The second part of this MD was from 19h00. We started with the tests which allowed the reason of sudden beam loss at the beginning of acceleration on 28.09 to be identified. When gains of all feedbacks were lowered by 3 dB we could use the previous voltage programme (V-4) without voltage increase in the front porch. It was the increase of feedback gain by 3 dB done on 27.09 which improved the transition crossing on the same day but led to strong losses at the beginning of the ramp on 28.09.

After the SPS stop (from 7h00 till 19h00) the problem with ZS sparking was seen again. It prevented acceleration to top energy. Strong losses were observed after transition which triggered the beam dump interlock. We corrected some transverse settings which were left from the one-batch operation in the morning, but the settings of transverse damper were still wrong, as was found later.

6 MDs on 30.09 and 1.10

These last two MDs were mainly devoted to measurements of beam transmission in the SPS with beam bunched at harmonic $h = 8$ in the PS. This beam needed special preparation in the PS, but could be interesting for possible future use in the PS with a new scheme for continuous beam transfer and reduction of the PS cycle length from 1.2 s to 0.9 s.

Measurements of bunch length along the first batch before and after transition crossing are presented in Fig. 6.

6.1 MD on 30.09

We started with reference measurements using beam bunched in the PS at harmonic $h = 16$ with $V = 2.5$ kV, first with full modulation at 200 MHz (24x7 kV) and then with one cavity only (24 kV). Amplitude of the signal from the wall-current monitor showing beam line density along the batch for these two cases can be seen in Fig. 7.

In the SPS we used voltage programme (V-5) shown in Fig. 4 (left). Measurements of bunch length along the first batch before and after transition crossing for injected beam with full modulation at 200 MHz (7x24 kV) are presented in Fig. 6. As can be seen, the bunch length after transition is strongly modulated along the batch at a frequency of ~ 1.3 MHz. This modulation becomes less pronounced later in the cycle probably due to particle loss from bunches with larger emittances. A different pattern along the batch appears at the end of the cycle due to coupled bunch instabilities, Fig. 6. Note also the initial bunch length modulation at the PS revolution frequency due to the intensity variation in the four Booster rings.

This part of the MD was finished at 19h00. The results for the beam transmission in the SPS are shown in Table 6.

PS			SPS										
Voltage			intensity		relative loss measured at different time in cycle								
h	V_h kV	V_{200} kV	N_1 10^{13}	σ_N 10^{13}	l_2 %	σ_2 %	l_3 %	σ_3 %	l_4 %	σ_4 %	l_Σ %	σ_Σ %
16	2.5	7x24	5.60	0.16	0.	0.	5.45	0.35	1.02	0.23	6.47	0.50
16	2.5	1x24	5.70	0.08	0.	0.	5.49	0.34	0.86	0.25	6.39	0.61
8	2.5	1x24	4.91	0.07	0.79	0.29	7.48	0.27	0.62	0.20	8.89	0.59
8	2.5	1x24	5.43	0.04	1.39	0.46	7.44	0.32	0.74	0.22	9.57	0.63
8	2.5	1x24	5.49	0.04	1.21	0.31	7.52	0.43	0.69	0.17	9.42	0.57

Table 6: MD on 30.09 (above line) and 1.10 (below line). Transmission in the SPS for different RF settings in the PS. No debunching in the PS in all cases. In the SPS voltage programme (V-5).

To produce beam bunched at harmonic $h = 8$ a different magnetic cycle had to be used in the PS (user EASTB). At 23h10 this beam was injected into the SPS, but the intensity was lower than before due to radiation problems in the PS. However even at this intensity losses at transition were 2% higher than for beam bunched at $h = 16$, Table 6. After losses at transition the continuous high energy loss after transition was smaller.

Measurements of the beam spectrum for future MKE kicker heating estimations were done for the beam with total intensity 4.4×10^{13} at 400 GeV and density modulation at $h = 8$.

6.2 MD on 1.10

Next day, 1.10, at 18h00 we continued measurements with this beam (bunched in the PS at $h = 8$) but with higher injected intensities. Beam transmission for two sets of measurements taken with the same PS and SPS settings, but at different moments, are presented in Table 6, last two lines. As can be seen, for these high intensities relative losses were also higher, mainly due to increased capture losses (l_2). Amplitude of the signal from the wall-current monitor showing beam line density along the batch for this situation can be seen in Fig. 8.

At 21h00 the cycle in the PS had been changed (to MD3) to get normal operation settings with $h = 16$, debunching and full modulation at 200 MHz (7 cavities with 24 kV). The purpose of this part of the MD was to try and reduce the continuous beam loss at high energy, which starts after transition crossing. The measurements of transmission with different gains of feedback and phase loop are shown in Table 7.

gain of		intensity		relative loss measured at different time in cycle							
feed-back	phase loop	N_1 10^{13}	σ_N 10^{13}	l_2 %	σ_2 %	l_3 %	σ_3 %	l_4 %	σ_4 %	l_Σ %	σ_Σ %
low	norm.	5.47	0.10	0.	0.	6.05	0.35	1.15	0.3	7.2	0.53
norm.	norm.	5.43	0.13	0.	0.	5.03	0.25	0.83	0.16	5.87	0.4
norm.	high	5.43	0.12	0.	0.	5.57	0.45	0.48	0.14	6.05	0.56

Table 7: MD on 1.10. Transmission in the SPS for different RF settings in the SPS. In the PS: h=16 with V=4 kV, 7x24 kV at 200 MHz and debunching in all cases.

We started by changing the feedback gain. Reducing the feedback gain made the average transmission worse by 1.3%. Increased gain (see MD on 27.09) improved transition crossing after careful set-up but required significantly increased voltage in the front porch.

Finally the high energy loss was reduced from $\sim 5\%$ to (1-1.5)% with the help of increased phase loop gain after transition (it is programmable through the cycle, unlike the gain of the feedback). The comparison of the beam transmission (BCT signal) with the nominal and increased phase loop gain is presented in Fig. 9. For these conditions measurements of bunch length and peak amplitude (averaged over 2000 bunches of the first batch) are shown in Fig. 10. The bunch length at 400 GeV is in the range of (1.65 – 2.0) ns. After the bunch length correction (-0.35 ns) for the cable length [3], with a voltage of 7.5 MV these values correspond to a longitudinal emittance in the range of (0.38 – 0.6) eVs with an average emittance of 0.5 eVs. The bunch length increase at the end of the cycle is caused by coupled-bunch instabilities, which can be cured by increasing the synchrotron frequency spread with the help of the 800 MHz RF system in bunch shortening mode through the cycle. The 800 MHz RF system was not used during this run due to lack of time, but it is used in the SPS to stabilise the LHC beam at high energies and it was also successfully used in the past (1998) with the same purpose for a fixed-target beam [5]. The average bunch length at 3.0 s (230 GeV/c) is 1.4 ns (1.75 ns - 0.35 ns) and corresponds to emittance of 0.3 eVs for a voltage of 7.5 MV.

The last day when high intensity CNGS beam was available, was 3.10. Slightly higher intensities were injected on 2.10 to see the effect of reduction of beam loss after transition on maximum intensity accelerated to top energy. Unfortunately these intensities were still below those injected on 27.09 and for them the maximum intensity of 5.3×10^{13} was finally obtained at 400 GeV.

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Figures

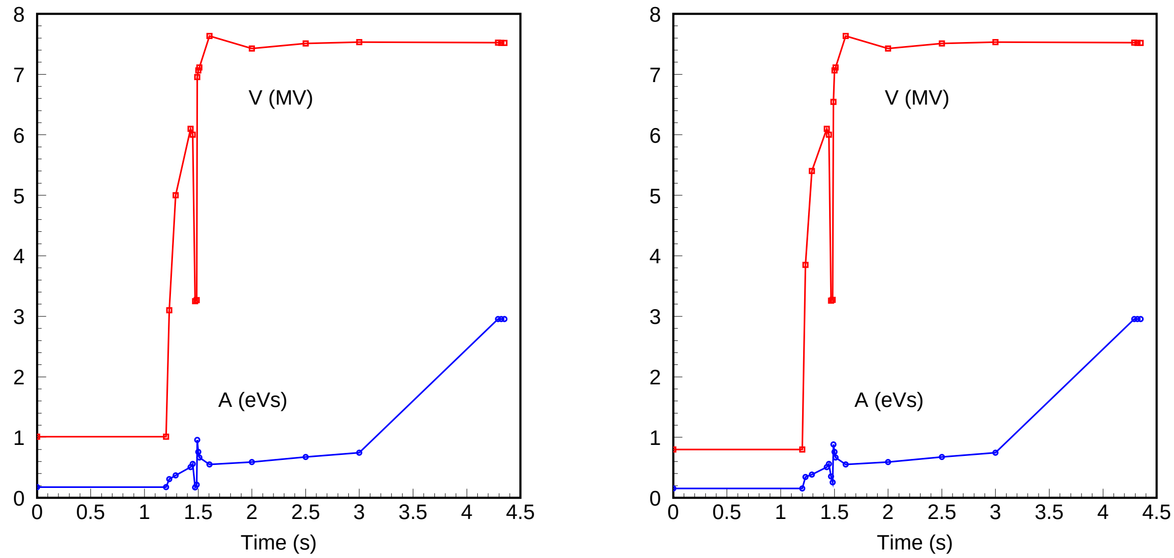

Figure 1: Voltage programme and corresponding bucket area at the beginning of the CNGS run (voltage program V-I), MD on 15.09 (left) and during normal operation, fixed target cycle (right).

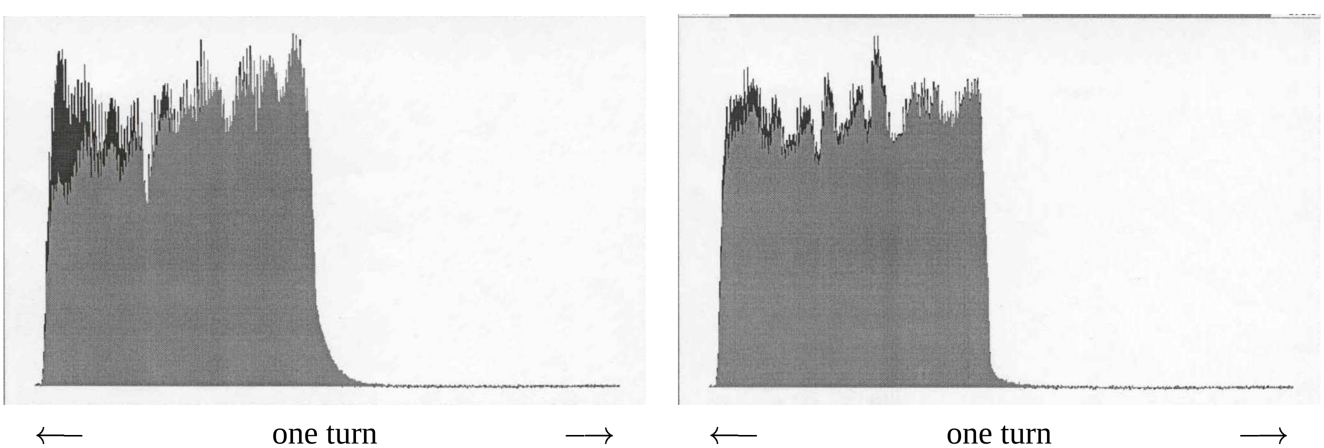

Figure 2: Fast BCT signal of the first batch at injection (black) and at the beginning of the ramp (gray) for the capture voltage of 800 kV constant (left) and increased after 50 ms to 2.5 MV in 50 ms (right). Note triangular batch shape and recaptured particles in the kicker gap for the first case. MD on 15.09 (left) and 22.09 (right).

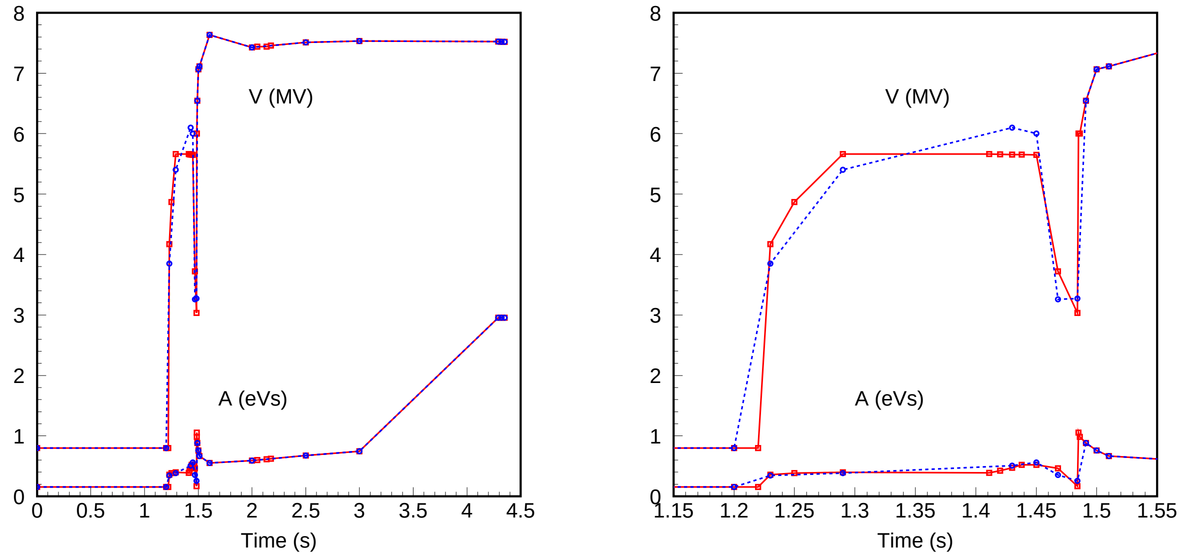

Figure 3: Voltage programme and corresponding bucket area before (V-1, dashed line) and after (V-4, solid line) trims during MD on 21.09. Whole cycle (left figure) and zoomed in around transition energy (right).

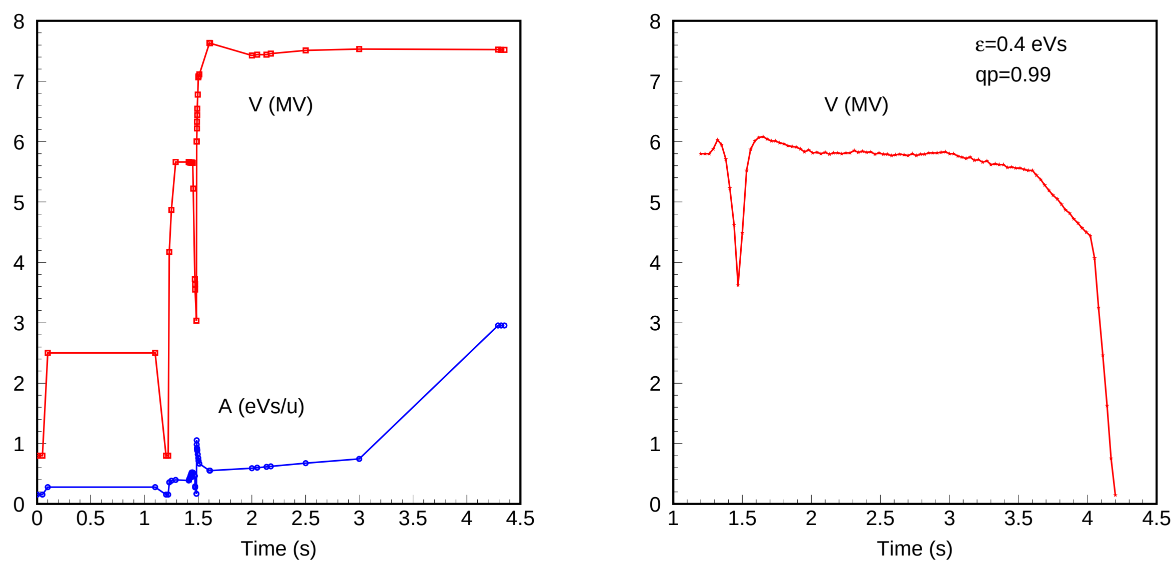

Figure 4: Left: voltage programme (V-5) and corresponding bucket area used as nominal from MD on 22.09. Right: calculated voltage programme for constant bucket area of 0.4 eVs used after transition crossing during MD on 29.09. No additional losses were observed from transition till 4 s in the cycle.

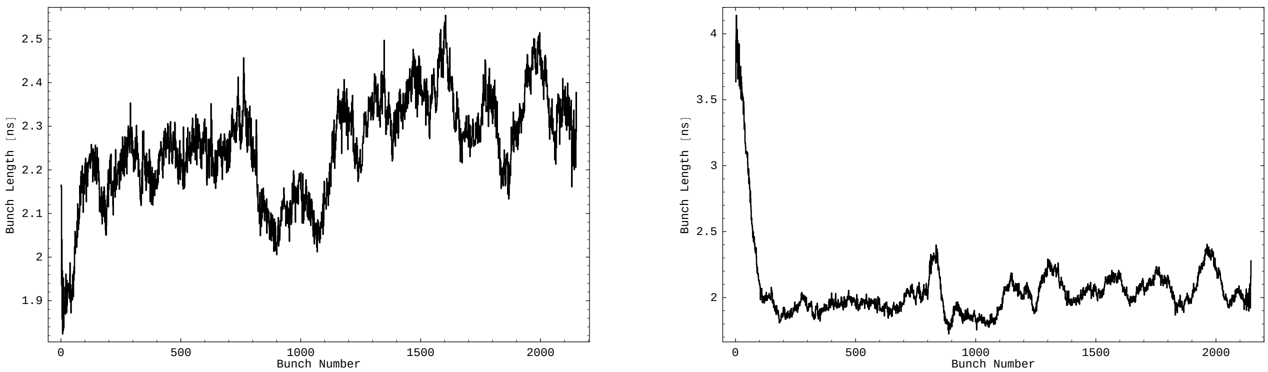

Figure 5: Bunch length as a function of bunch number in the first batch before, t=1.469 s, (left) and after, t=1.582 s, (right) transition crossing. Nominal conditions in the PS. At injection in the SPS 0.8 MV increased to 2.5 MV in 50 ms after 50 ms. MD on 22.09.

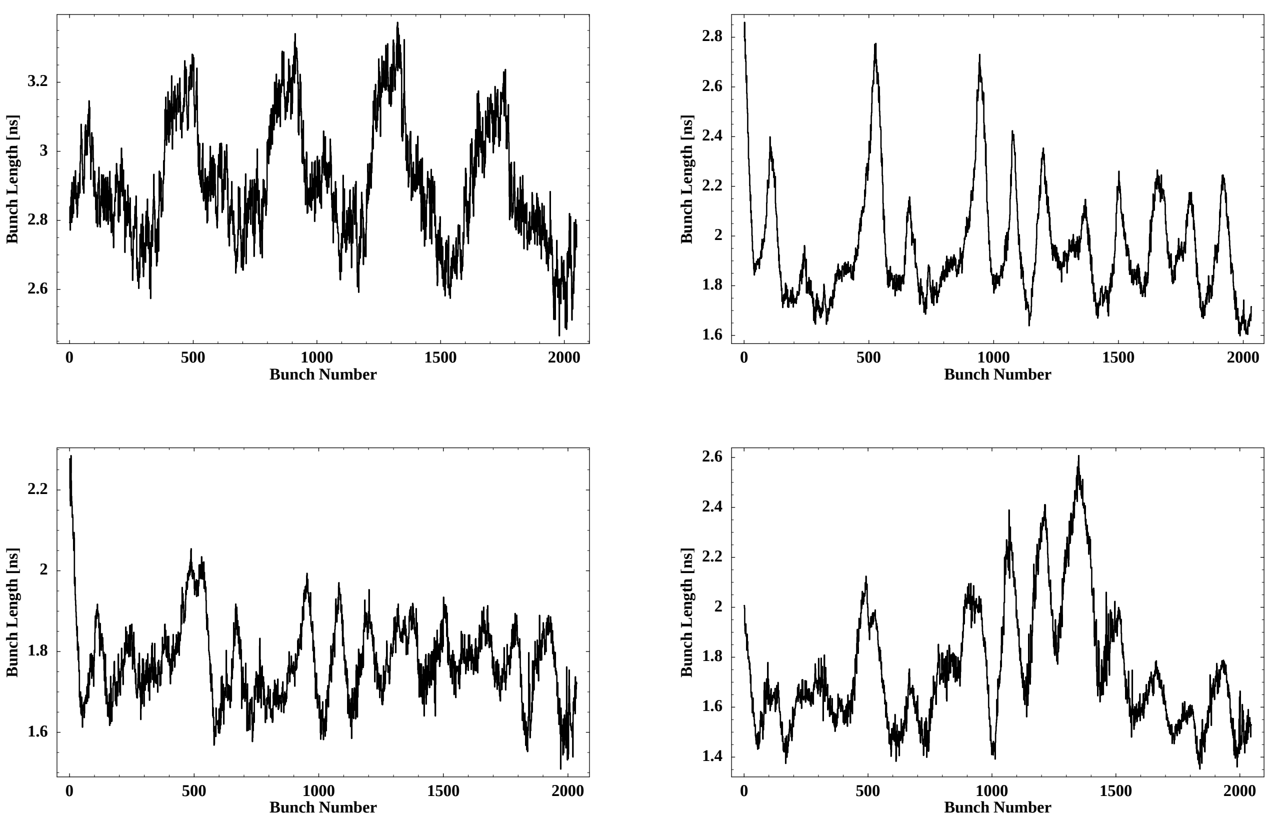

Figure 6: Bunch length as a function of bunch number in the first batch at different moments in the cycle: t=1.315 s - below transition, (top, left), t=1.534 s - after transition (top, right), t=3.286 s (bottom, left) and t=4.163 s (bottom, right). RF settings in the PS: 2.5 kV at $h = 16$, debunching on, full modulation at 200 MHz. MD on 30.09.

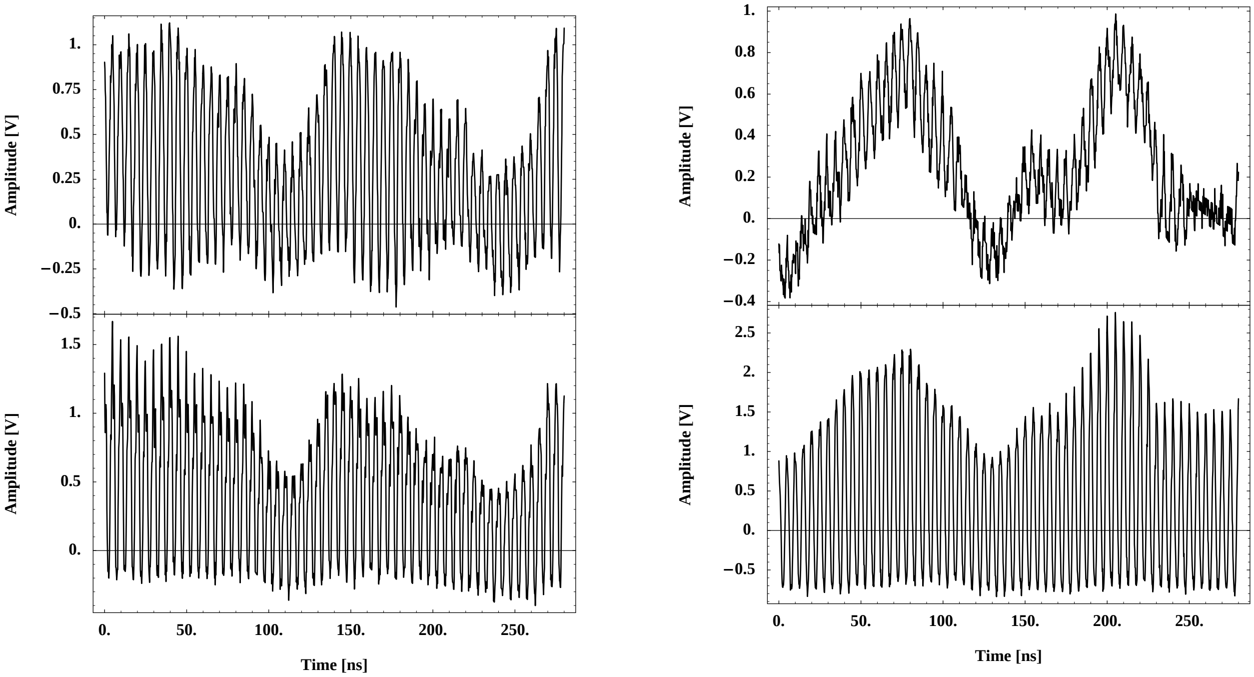

Figure 7: Bunch length along the first batch at injection (top) and 100 ms later (bottom). Conditions in the PS: beam is bunched at $h = 16$; left: debunching on, modulation with seven 200 MHz cavities (nominal scheme of PS-SPS transfer); right: debunching off, modulation with one 200 MHz cavity. MD on 22.09 (left) and 30.09 (right).

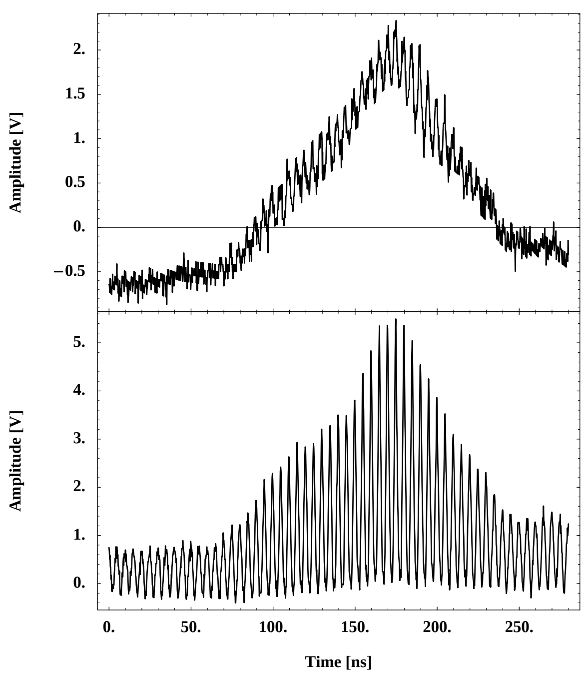

Figure 8: Bunch length along the first batch at injection (top) and 100 ms later (bottom). Conditions in the PS: beam is bunched at $h = 8$, debunching off, modulation with one 200 MHz cavity. MD on 1.10.

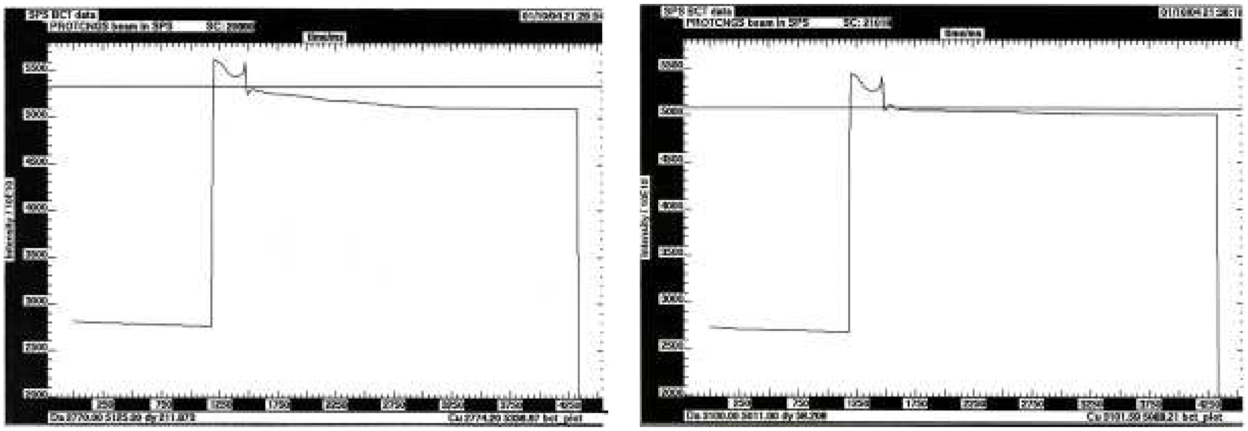

Figure 9: The BCT signal during the SPS cycle for the nominal (left) and increased (right) gain of the phase loop after transition. Note a reduction of the continuous beam loss at high energies in the second case. MD on 1.10.

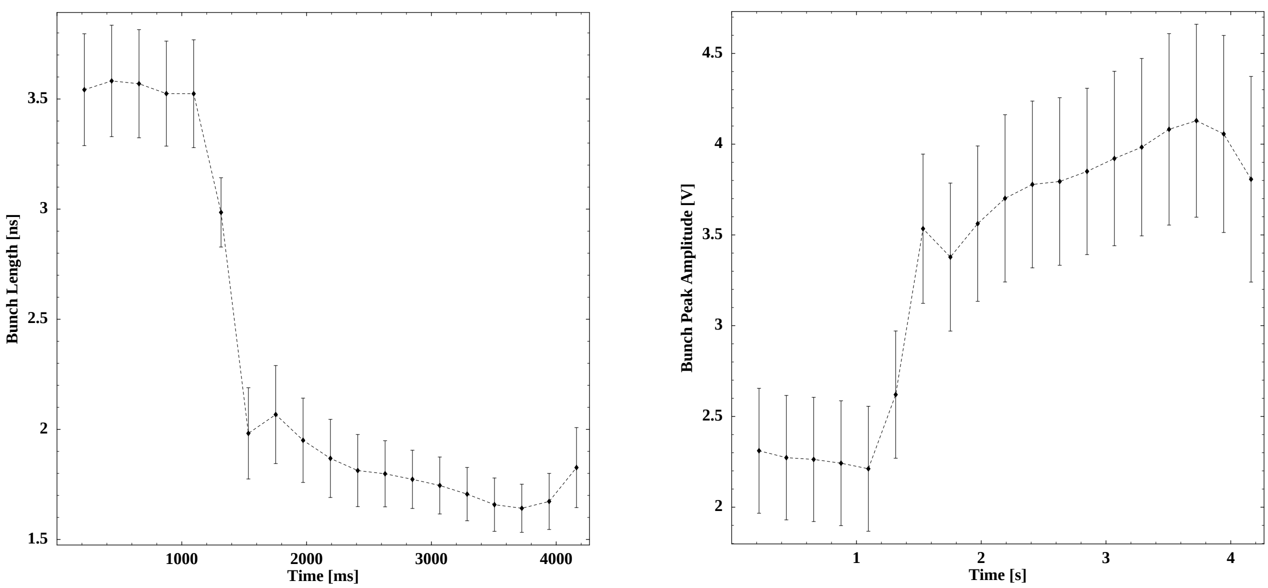

Figure 10: Bunch length (left) and peak amplitude (right) evolutions during the cycle (averaged for ~ 2000 bunches of the first batch). Nominal conditions in the PS (debunching on, full modulation at 200 MHz). Increased phase loop gain in the SPS after transition (reduced losses). Beam intensity at 400 GeV: 5.1×10^{13}. MD on 1.10.