EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN – AB DIVISION

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SPS Spill Quality

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Abstract

The SPS slow extraction spill is controlled by the servo-spill system, a closed loop feedback acting on dedicated quadrupoles to stabilize the extracted beam intensity. The harmonics of 50 Hz cannot be corrected by this system and must be corrected using a feed-forward system. The stability of the feed-forward correction was evaluated during the SPS proton and Indium runs in 2003. Significant drifts were observed over longer time spans, but also sudden changes over the time scale of 24 hours.

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1 Introduction

2 SPS Slow Extraction

The third order resonant extraction from the SPS can be briefly described in the following way.

A set of suitably located extraction sextupoles is used to create a stable area in radial phase space. Presently tree extraction sextupoles are powered during fixed target operation: LSE.224, LSE.406 and LSE.424. The strength of the first two are $K_2 l = -0.1248\ \mathrm{m}^{-2}$, while the strength of the third is $K_2 l = 0.1214\ \mathrm{m}^{-2}$. Initially the phase space area is somewhat larger than the area occupied by the beam for a tune $Q_H \cong 26.63$. A dedicated servo-quadrupole system consisting of 4 short QMS quadrupoles is used to gradually move the tune towards $Q_H = 26\frac{2}{3}$, leading to a reduction of the stable phase space towards zero. Protons or ions with coordinates outside the stable area move away from the beam core along the outward going separatrices (see Fig. 1). Eventually they enter the field of the electrostatic septa (ZS, 5 tanks) of the North or West extraction zone. The ZS deflect the particles into the extraction channel consisting of a thin (MST, 3 elements) and a thick (MSE, 5 elements) septum magnets. Figure 1 indicates the stability limit for a tune of 26.64 and the position of the North and West ZS. To allow simultaneous extraction to the North and West areas, the horizontal betatron phase advance between the West and North electrostatic septa is adjusted to match 9 betatron periods.

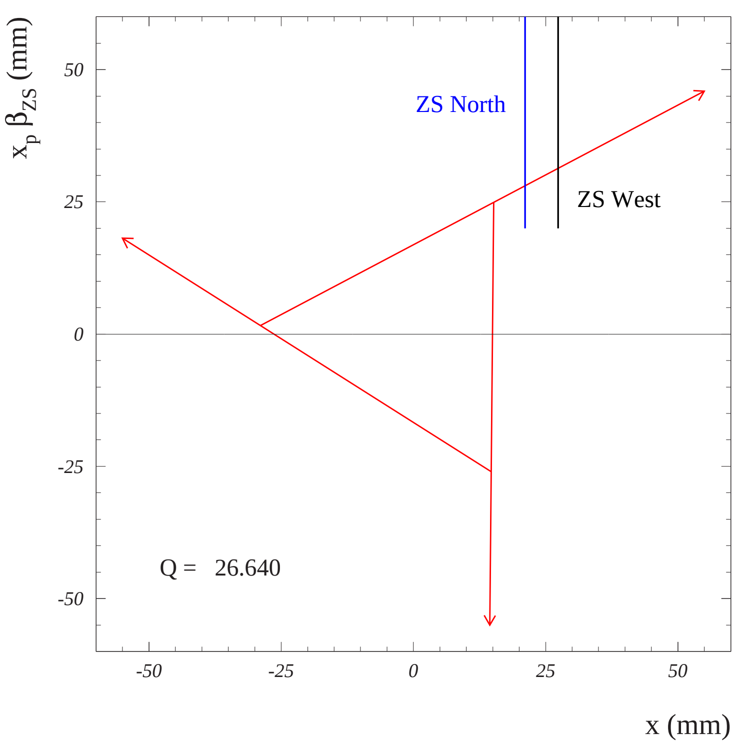

Figure 1: Stable phase space area for a tune of 26.64 just before extraction. The coordinates are given for the betatron-function of 66 m of the electrostatic septa.

The extraction septa are positioned outside the machine aperture, therefore the closed orbit

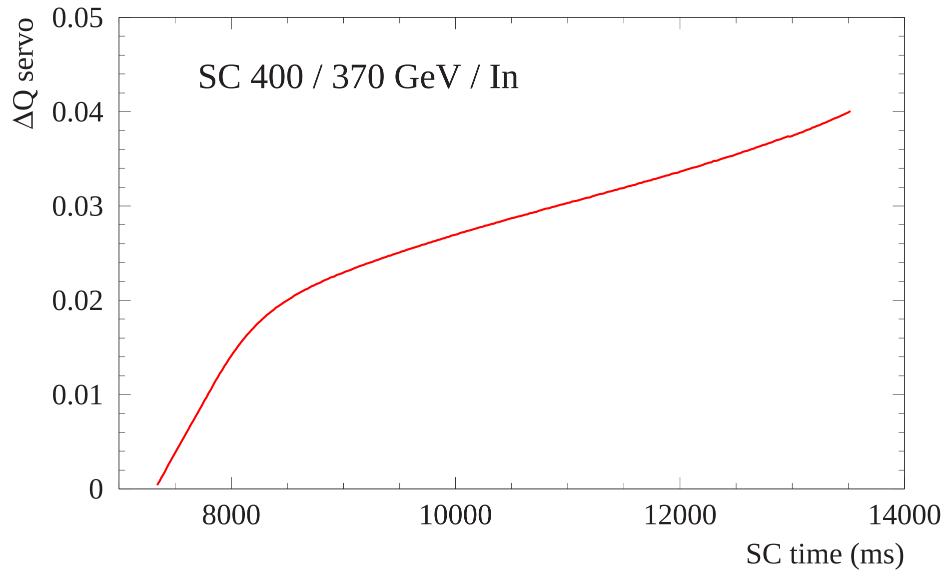

Figure 2: Tune change due to the action of the servo-spill quadrupoles for the SPS Indium run.

is bumped locally towards the ZS septa using a set of 4 fast horizontal bumper magnets. The West ZS is positioned further out than the North ZS, and the sharing of beam intensities between the two extraction zones is controlled by the horizontal bump amplitude of the West extraction zone.

2.1 Servo Spill Control

The servo-spill system controls the spill intensity via a set of 4 QMS quadrupoles installed in position 116. The intensity signal from the beam extracted to the North (default) or West area transfer lines is compared to a reference values and used to feedback on the spill intensity by adjusting the machine tune. A detailed description can be found in Reference [1]. An example for the tune change induced by the servo-spill quadrupoles is shown in Fig. 2. The total tune trim is typically ~ 0.03. Since the servo quadrupoles are installed between the West and North extraction channels, this tune change leads to a phase advance change of 10° between the two extraction points.

The loop gain of the servo-spill system is low, and it is not capable of correcting the residual 50 Hz (and its harmonics) tune ripple that is present on the beam. The correction is based on a feed-forward mechanisms. A 50 Hz modulation, with a determined phase relative to the mains (defined in PCR) and a defined amplitude is added to the servo-spill quadrupole current. The setting of the feed-forward signal are adjusted manually and as long as the ripple is stable in amplitude and phase, it is possible to perform a good correction of the 50 Hz harmonics. An example for a correction and uncorrected spill is shown in Figure 4 and 5.

For an ideal spill, the rate of particles dN/dt that are extracted should remain constant. The rate is controlled by a tune change. In the presence of tune ripple of amplitude δ at a frequency

f, the rate will be modulated according to

$$\frac{dN}{dt} \propto \dot{Q} + 2\pi f \delta cos(2\pi f t) \quad (1)$$

Here $\dot{Q}$ is the steady state tune change that is applied to obtain on average a constant rate dN/dt. The modulation amplitude of the spill at the frequency f intensity is therefore

$$A_m = \frac{2\pi f \delta}{\dot{Q}} \quad (2)$$

In the SPS the beam is typically extracted with $\dot{Q} \sim 0.005$ s^{-1}. For a 50 Hz noise a tune modulation amplitude of $\delta \simeq 1.510^{-6}$ is sufficient to generate a modulation of the spill rate of 10%. An example of the FFT spectrum for the current in the QF1 main quadrupole family is shown in Fig. 3. The harmonics of 50 Hz are at the level of a few ppm on the current.

2.2 Feed-Forward Calibration

The effect of the FF system has been calibrated for both proton and indium beams. For each harmonic the sensitivity was recorded for a normal spill in percent modulation per 1 mV amplitude change of the FF amplitude. The results are given in Table 1. Since the indium spill is 50% longer than the proton spill and $\dot{Q}$ is therefore 50% slower, one expects higher sensitivity of the Indium spill to the FF signals by the same amount. It turns out however the the sensitivity of the Indium spill is $\sim$ 3 times higher for the 50 Hz harmonic. Furthermore the sensitivity dependence on frequency is much steeper for the Indium spill. The difference is most likely

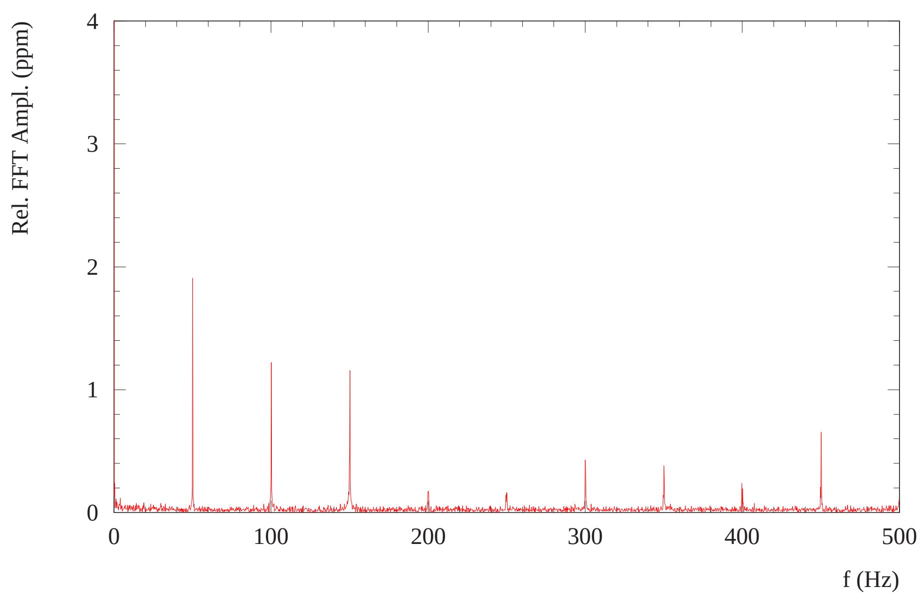

Figure 3: FFT of the QF1 main quadrupole PC current on the SPS extraction flat top. The amplitudes of the harmonics reach the level of a few part-per-million.

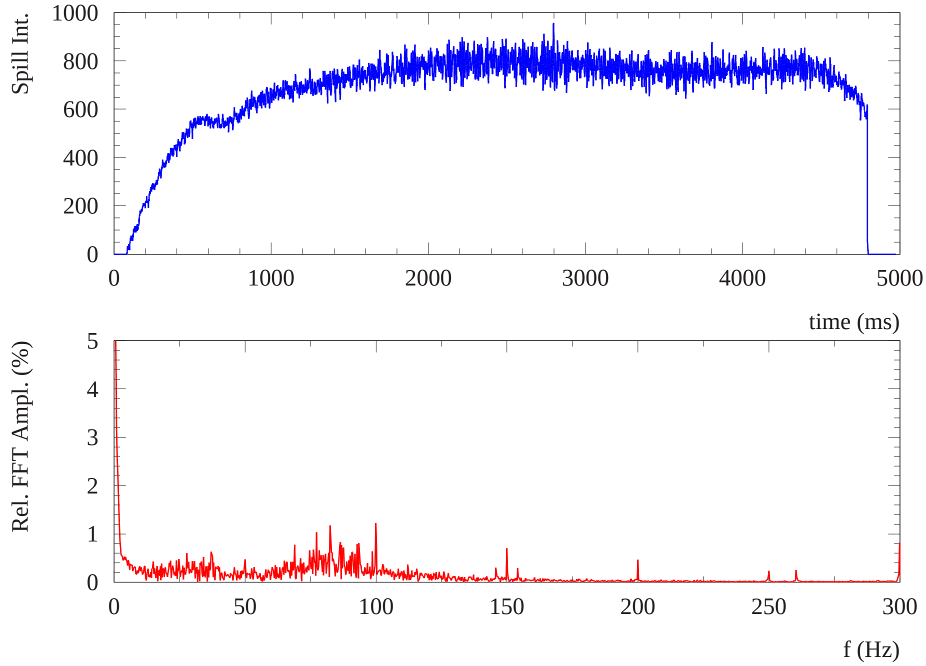

Figure 4: Slow extracted proton spill to the North targets at 400 GeV/c with well corrected mains harmonics (top : spill intensity, bottom : FFT of the spill intensity.

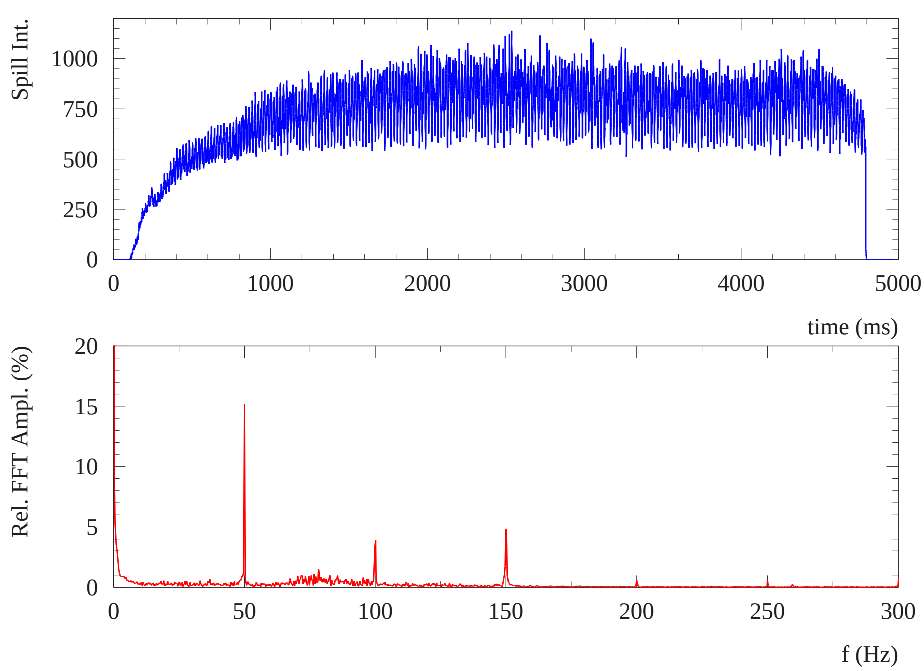

Figure 5: Slow extracted proton spill to the North targets at 400 GeV/c without correction of the mains harmonics (top : spill intensity, bottom : FFT of the spill intensity.

f (Hz)	Beam	κ (%/mV)
50	p	1.6 $\pm$ 0.2
100	p	1.0 $\pm$ 0.2
150	p	0.7 $\pm$ 0.2
50	In	5.1 $\pm$ 0.5
100	In	1.6 $\pm$ 0.4
150	In	0.3 $\pm$ 0.03
300	In	0.02 $\pm$ 0.01

Table 1: Calibration of the FF signal. For each mains harmonic and beam type, the sensitivity of the spill modulation is given in % per mV amplitude. One notes a large difference of sensitivity for the proton and the ion beams.

due to the effect of the closed-loop feedback on the spill that 'interacts' of course with the FF settings. In particular the gains were modified slightly between the proton and the Indium runs, and a higher (30-50%) proportional gain was used during the Indium run.

The transfer function for the slow extraction process was determined to be

$$G(s) = \frac{Ke^{-sT_0}}{(1+sT_1)^2} \tag{3}$$

where the delay T_0 varies between 60 and 100 turns (1-3 ms) and while $T_1 \simeq 70$ turns (1.5 ms) [2]. The implication of the delay T_0 is that the servo-spill system only reacts after a dead-time T_0, and it will take another equivalent to delay until the correction finally affects the beam.

Provided the closed loop system does not interfere significantly with the FF of the mains harmonics, then the sensitivity should follow the same transfer function. The calibrations are compared with the spill transfer function in Fig. 6 for the two different beams. While for the proton beam the frequency dependence matches the spill transfer function for $T_1 = 1.5$ ms, the indium data only fits the same second order transfer function for $T_1 = 7$ ms. Whether this difference is due to the interference with the closed loop system of has other origins is not understood. There is a priori no explanation for a difference in time constants for the 2 beams.

3 Proton spill

For the SPS fixed target beam with intensities of $2times10^{13}$ protons, the feedback signal for the servo-spill is provided by SEM grids. Examples for corrected and uncorrected spills are shown in Fig. 4 and 5. Without correction the modulation amplitude of the proton spill reaches 15-20% for the 50 Hz harmonic, and somewhat less at 100 Hz. This un-corrected modulation amplitude corresponds to a tune ripple at 50 Hz of $\delta Q \sim 2 10^{-6}$. The ripple at higher frequency is smaller.

4 Indium spill

For the Indium fixed target beam with intensities of up to 6×10^{10} charges, the feedback signal is provided by a fast scintillator. Example for a corrected spill is shown in Fig. 7. Without

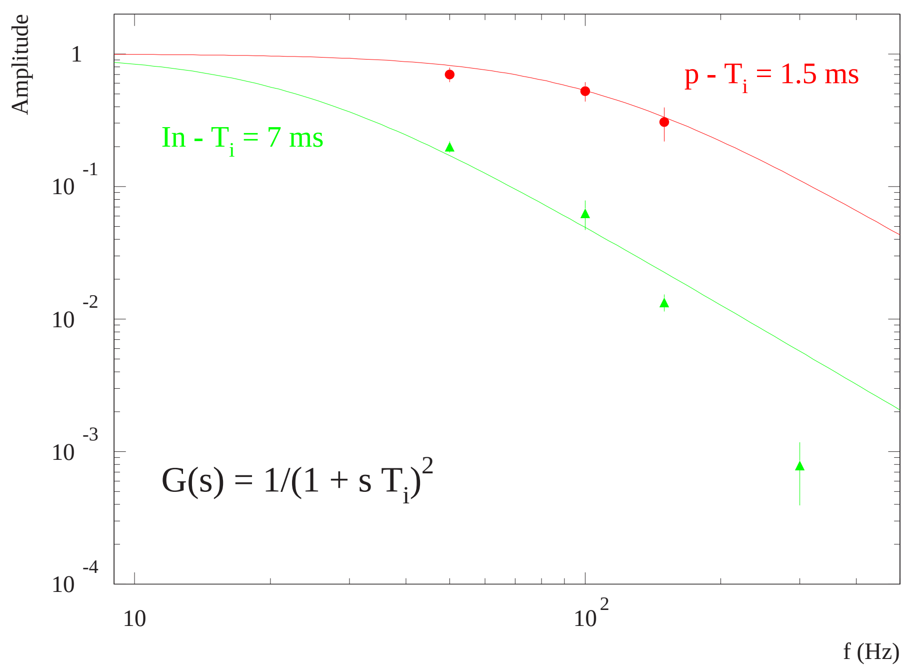

Figure 6: Transfer function for the spill harmonics measured for protons and for Indium ions. The points have been normalized to the 50 Hz point that was set on the transfer function. The proton measurements agree with the expected function and time constant, but for Indium the time constant T_1 must be increased to 7 ms to obtain a reasonable match.

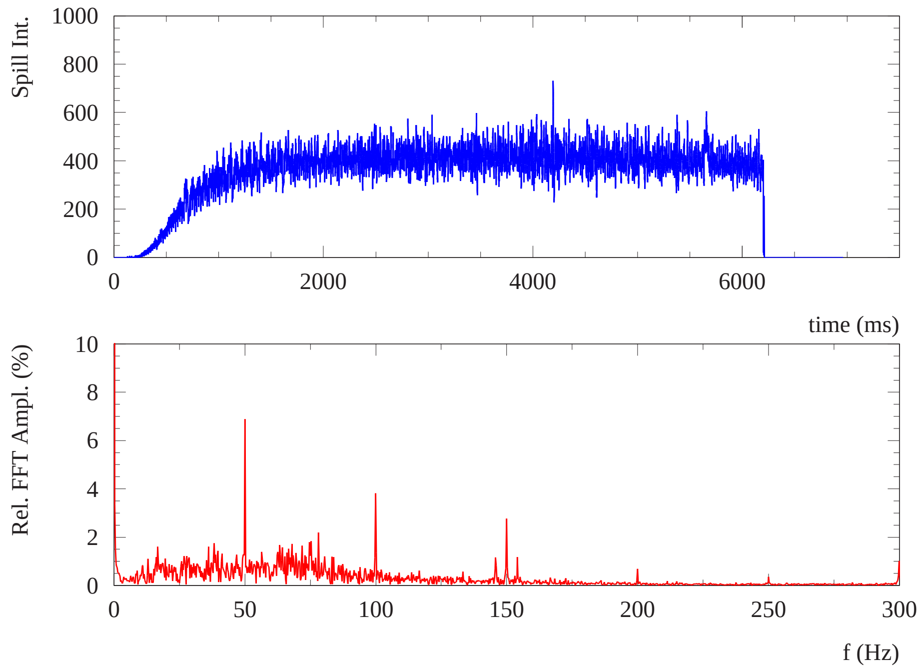

Figure 7: Slow extracted Indium spill to the North targets at 370 GeV/c with corrected mains harmonics (top : spill intensity, bottom : FFT of the spill intensity. Contrary to the proton case, it is very difficult to reduce the amplitudes below 5%.

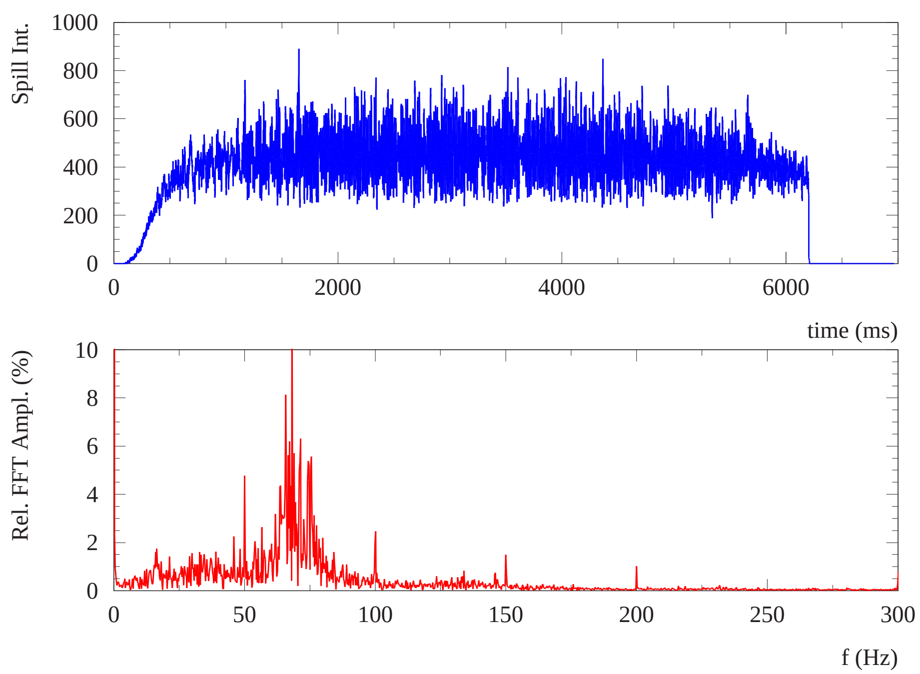

Figure 8: Slow extracted Indium spill to the North targets at 370 GeV/c under noisy conditions, with broad peaks in the 70 Hz region.

correction the modulation amplitude of the proton spill reaches 15-20% for the 50 Hz harmonic, and somewhat less at 100 Hz. This un-corrected modulation amplitude corresponds to a tune ripple at 50 Hz of $\delta Q \sim 2 10^{-6}$. The ripple at higher frequency is smaller.

5 Harmonics Evolution

The stability of the HFF correction was monitored between August and November for both proton and Indium runs. The corrections were adjusted regularly and the HFF settings recorded. Contrary to earlier statements, the corrections vary significantly over a run, as shown in Fig. 9 for the 50 Hz harmonic.

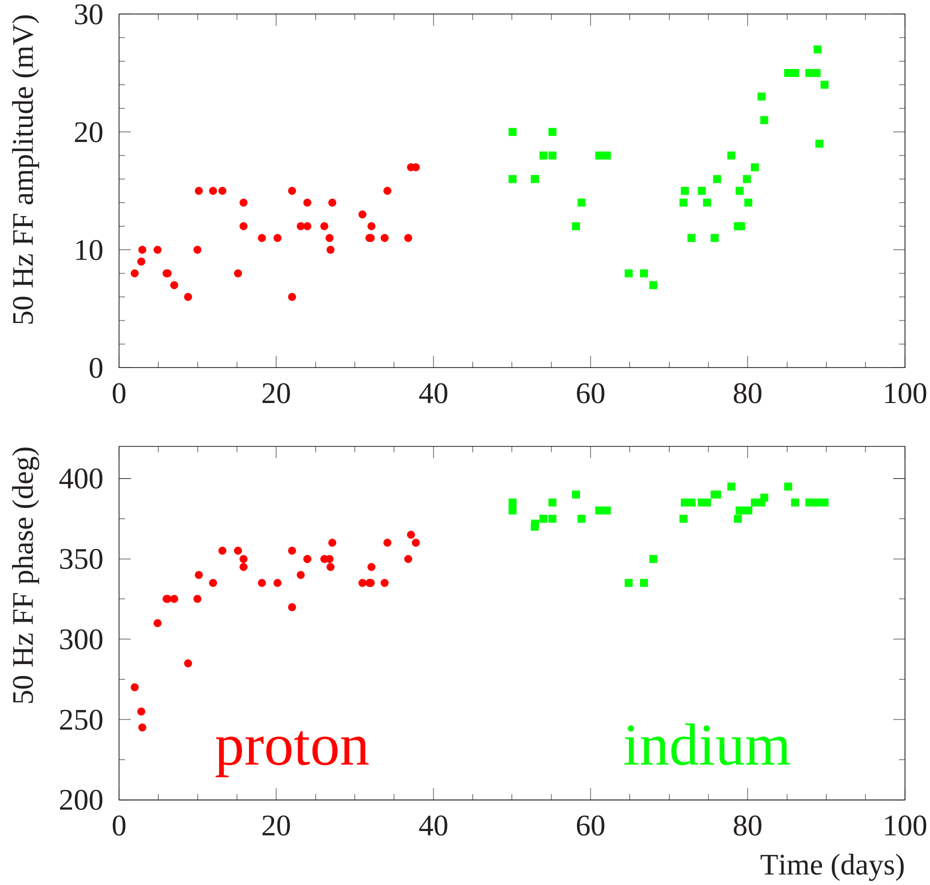

Figure 9: Feedforward settings for the 50 Hz harmonic for the SPS proton and Indium runs from August to November 2003. The amplitude is shown in the top figure, the phase on the bottom figure.

6 Discussion

Contrary to 'popular' belief, the 50 Hz harmonics for the spill FF system are not stable over a run, they can even vary significantly within 24 hours. A good correction of the harmonics requires a daily readjustment of the FF settings.

7 Conclusion

8 Acknowledgements

References

[1] M. Gyr, *Proposal for a new Servo-Spill System : Power Requirements for different Configurations, CERN / SL 95-103 (BT).*

[2] V. Rödel, *La dynamique de l'extraction lente su Synchrotron à Protons de 400 GeV du CERN en vue d'un asservissement*, Thèse N° 506 du Dept. de Mécanique de l'EPFL, 1983.