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DOUBLE BATCH FILLING IN THE PS

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PS-MD Report

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1. Introduction

Filling the LHC with the required intensity within the proper transverse emittance, as proposed in the nominal scheme, requires the use of the technique of "double batch filling" in the PS. It consists of 3 phases: (i) transfer of the PSB beam - made up of one bunch per ring - into only one half of the PS circumference, (ii) acceleration of a new beam in the PSB while keeping the 4 bunches coasting at injection energy in the PS, (iii) injection of the second beam into the remaining half of the PS circumference and then acceleration of the total beam of 8 bunches.

An initial test took place on October 23, 1993 mainly to check the timing implementation. During the "LHC test", on December 11, 1993 the scheme was fully tested (with only one PSB ring) at the raised transfer energy of 1.4 GeV .

2. Implementation

2.1 Magnetic cycle

A magnetic cycle of 3.6 s, with a 1.2 s injection plateau at 1.4 GeV, had already been set-up and used in previous machine developments. It was defined as cycle No 37 and loaded under label H. All details on its characteristics are given in Ref. [1)].

2.2 Triggering of pulsed elements

All timing pulses necessary to trigger pulsed PS injection elements and instrumentation devices are generated from a cascade of preset counters clocked either by the C train for coarse timing or by the PSB RF train for fine timing. The first of all these counters is reset by PX. C0, at the origin of the C train.

To generate the second burst of timing pulses, required for the second PSB to PS transfer, an additional reset pulse was produced 1200 ms after the first one, from an extra preset counter, as shown in Fig. 1.

With this simple modification, the injection kicker (KFA45) and the septum bumpers (BSM40, 42, 43, 44) were pulsed twice, at a 1.2 s interval, with the same Current Control Value (CCV).

2.3 Cycling of DC elements

As the PS injection septum (SMH42) could not stand a DC value 26% higher than nominal [2)], its current was ramped from 1665 A (corresponding to 800 MeV) to the value necessary for 1.4 GeV: 2450 A. The high current value was maintained for 1.2 s and then reduced back to 1665 A by means of a combination of consecutive CCVs gated by various PLS Users lines. The way this facility was implemented is explained elsewhere [3)]. An identical current shape powered the PSB extraction septa and a transfer quadrupole.

This programming allowed an independent adjustment of the septum current on the 2 consecutive batches (within a few tens of amperes).

2.4 PLS and Enable / Disable of the double batch

The second reset pulse, providing a second burst of timing pulses, was gated by the PLS line MD, and therefore was only generated during the 3.6 s cycle. Turning the double batch timing ON or OFF was achieved by loading a CCV of respectively 1200 or 0 in the relevant preset counter.

Disabling the second injection could also be manually achieved by disconnecting the output of the additional preset counter.

2.5 PSB/PS RF synchronisation

A synthesizer tuned at the PS frequency of 3.5 MHz (h=8) was used as a stable RF reference source. Division by 2 of this frequency provided a stable 1.75 MHz RF source to which the PSB beam was synchronised, prior to transfer. Further division by 4 provided the 437 KHz PS Revolution Frequency Train. Phasing of this PS Revolution Frequency Train with respect to the RF frequency to which the PSB beam is synchronised, was achieved, in steps of one PS RF bucket, by a new device implemented in the RF low level, the "bucket selector". The setting of this "bucket selector" is activated after injection of the first batch and allows positioning of the second PSB beam , with respect to the already circulating beam in the PS.

A synopsis of this PSB/PS RF synchronisation [4)] is shown in Fig. 2 and the use of the RF Train in the injection timing system is shown in Fig. 3.

3. Results

3.1 Constraints on injection kicker rise and fall times

In the nominal LHC filling scheme the PS beam is made up of twice 4 PSB bunches. To avoid transverse blow-up induced by horizontal coherent oscillations, the kicker must deflect the second incoming beam onto the closed orbit without affecting the circulating one. This can only be achieved if the kicker rise and fall times fit between 2 consecutive PS RF buckets (h=8) and if their positions in time, relative to the incoming bunches are precisely set by the fine delays (Fig.4a).

During the test, each of the 2 batches contained only one bunch, from one PSB ring. After the first injection, transfer of the second bunch could therefore be made into any of the 7 remaining PS RF buckets, by means of adjustment of the "bucket selector". Three cases were considered.

(i) Injection of the second bunch into one of the 5 buckets non adjacent to the first one. This leaves plenty of space for the injection kicker rise and fall times between the circulating bunch and the incoming one (Fig. 4b). In these conditions, the 2 bunches could be injected properly, with negligible coherent oscillations.

(ii) Injection of the second bunch into the bucket preceding the bucket of the circulating one. This leads to a more stringent situation where the kicker fall time (only) has to be precisely set, as in a standard single batch injection (Fig. 4c).

(iii) Finally, the choice of a second bucket right after the one of the circulating bunch imposes constraints on rise and fall times, as in the nominal scheme for LHC (fig. 4d). The fall time defines the "quality" of the first injection, whereas both rise and fall times are relevant for the second injection. This patterns requires a kick duration of nearly one machine turn and a "bucket selector" setting of 7. This situation, which is the most representative of the nominal scheme, was set-up during the test.

3.2 Beam oscillations and emittances

After careful adjustment of the injection kicker coarse and fine delays (respectively under remote and local control), the worst case situation, as presented in Fig. 4d, was obtained. Observation of bunch trajectories on the CODD were upset by the generation of trigger pulses at the second injection and could only be made with the help of CODD specialists. However, beam oscillations were observed on pick-ups analogue signals and are shown in Fig. 5. Amplitude of the oscillations could be evaluated.

The first bunch, injected at the far end of the kicker flat-top, suffers also at the second injection from both kick edges: from the leading part of the rise and from the trailing part of the fall. It made coherent oscillations of about 3 mm peak-to-peak at both injections.

The second bunch, injected at the beginning of the kicker flat-top, is in a better situation. It receives only one kicker deflection and at the second turn is far enough of the trailing edge of the injection kicker. It made a coherent oscillation of 2 mm p-p.

The 2 bunches were accelerated on harmonic 8 (Fig.6) and extracted at 26 GeV/c. Transverse emittances were measured before extraction and compared in both cases of single and double batch. With an intensity per bunch of 2.10^{10} p, they could be considered identical within the measurement precision:

Normalised emittances (1s)	Single batch	Double batch
ε^*_h [μm]	3.3	3.5
ε^*_v [μm]	3.7	3.7

4. Conclusions

The PS can now, on a single cycle, inject and accelerate beams from two consecutive PSB cycles, as proposed in the LHC nominal filling scheme.

Minimisation of injection oscillations should be made easier with remote and independent (on the 2 batches) control of the kicker fine delays.

Digital observation of bunch oscillations, with the CODD, requires a proper gating of instrumentation triggers which has still to be worked out and implemented.

References

1. N. Blazianu. Création et utilisation de cycles magnétiques dans le cadre du test LHC. PS/OP Note 94-09 (MD).
2. M. Thivent, Les septa DC du PSB et du PS utilisés à 1.4 GeV pour le "Test LHC", PS/PA Note 94-06 (MD).
3. G. Cyvoct, Test LHC 1.4 GeV : modulation des courants des septa et d'un quadrupole par PLS, PS/OP Note 94-12 (MD).
4. R. Garoby. PSB/PS synchronisation. Private communication.

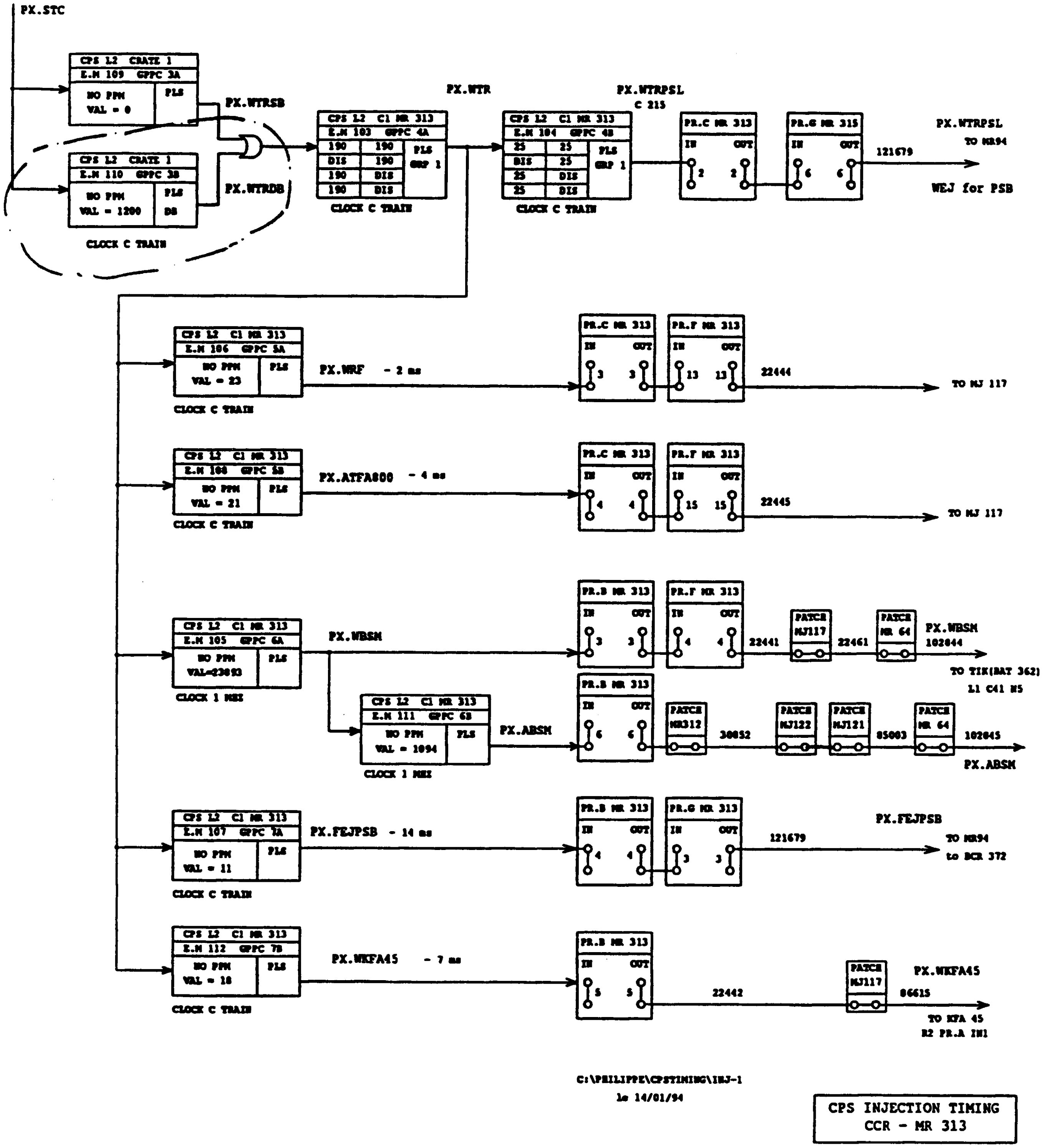

Fig. 1 Additional reset pulse in the injection timing, for double batch injection

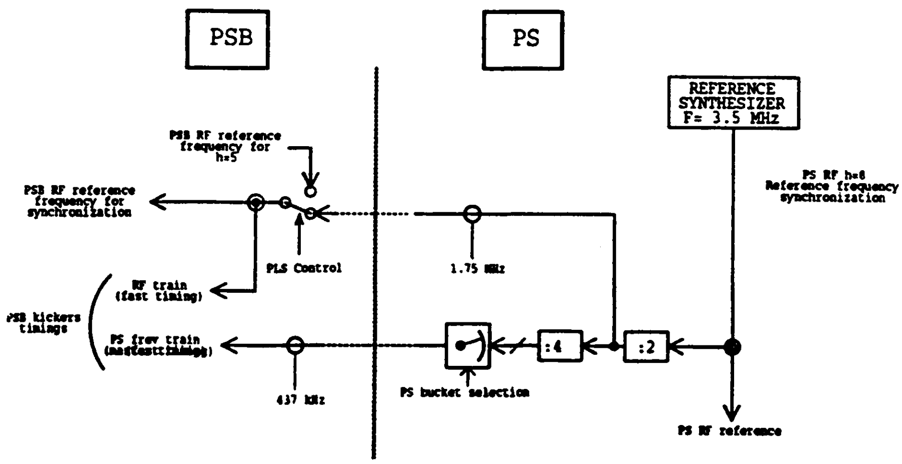

Fig. 2 PSB/PS RF synchronisation

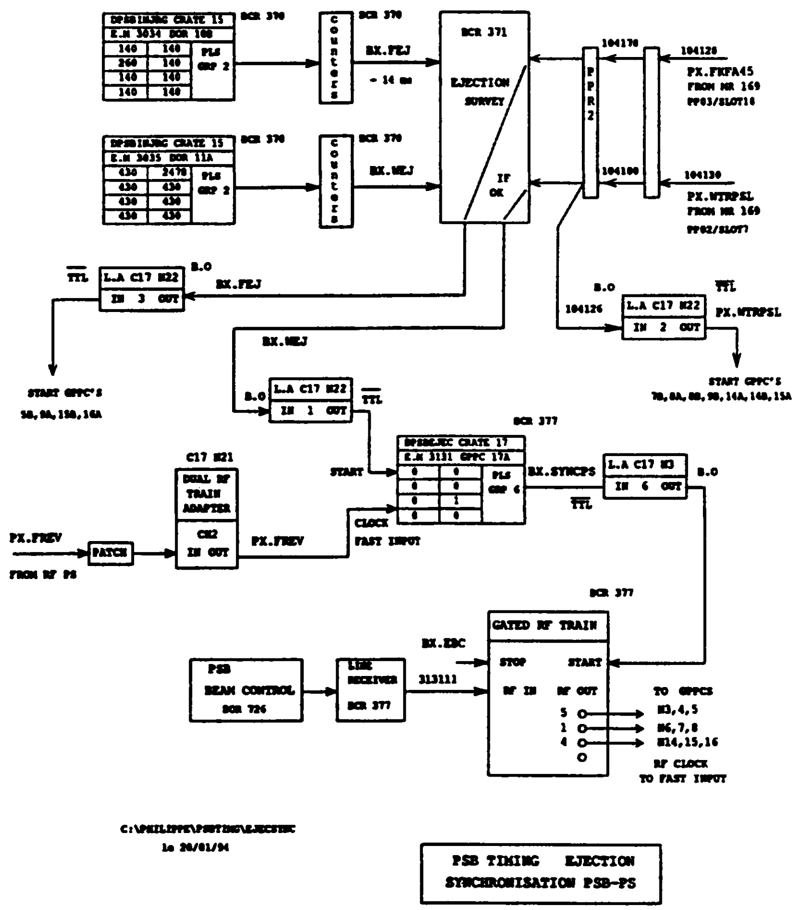

Fig. 3 RF Train gating for the PSB/PS injection timing

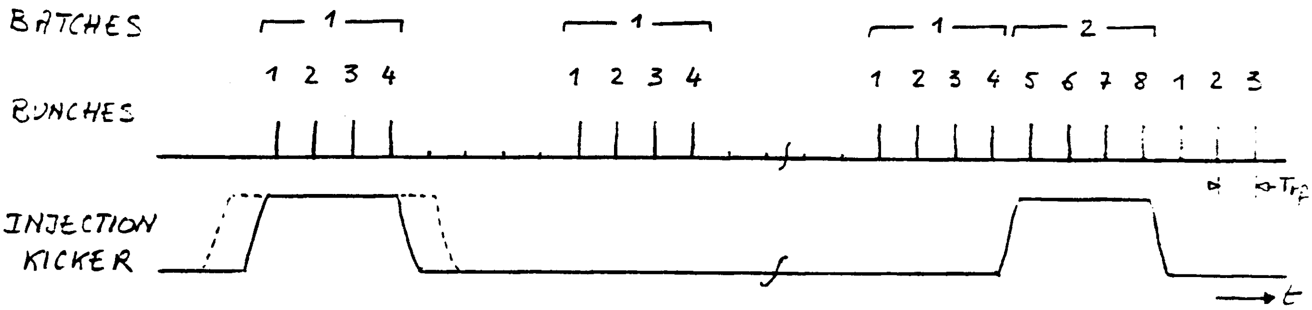

Fig. 4a: Double Batch as required for the LHC nominal scheme
Tight constraints on kicker rise, fall and flat-top times. (Different fine delay values could relax injection of the first batch)

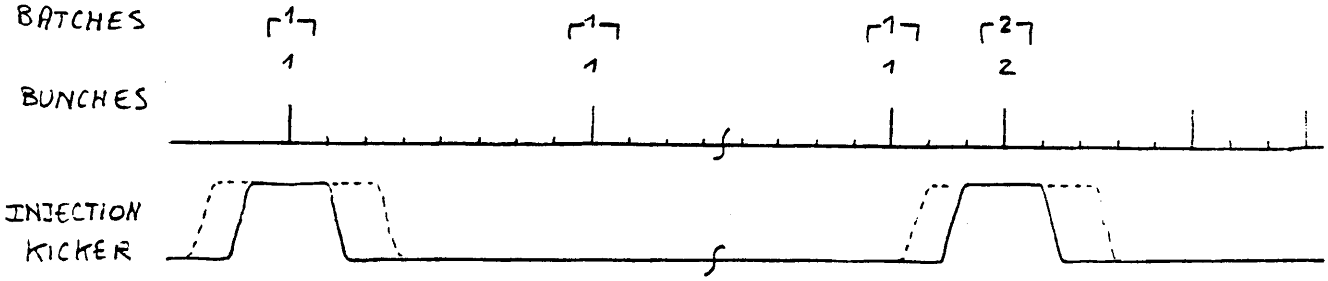

Fig. 4b: Double Batch in "LHC test" conditions. Injection of the 2 bunches in *non consecutive* buckets
Loose requirements on kicker rise, fall and flat-top times

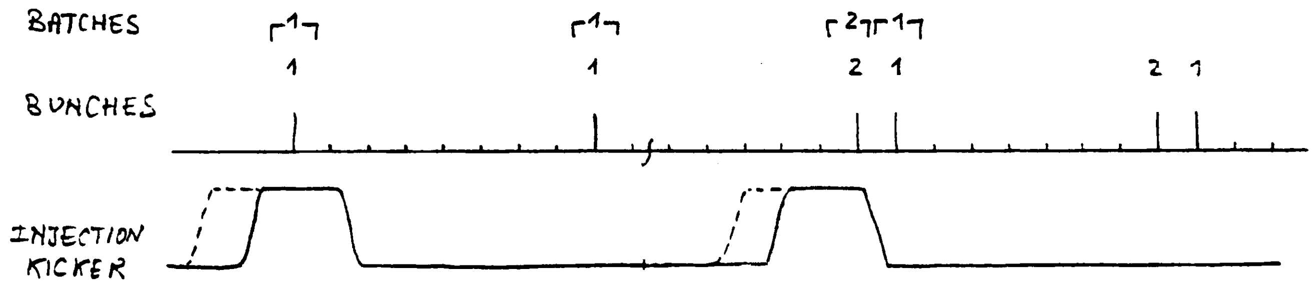

Fig. 4c: Double Batch in "LHC test" conditions. Injection of bunch 2 in the bucket *preceding* bunch 1
Tight requirements on kicker fall time only, as in a standard single batch injection

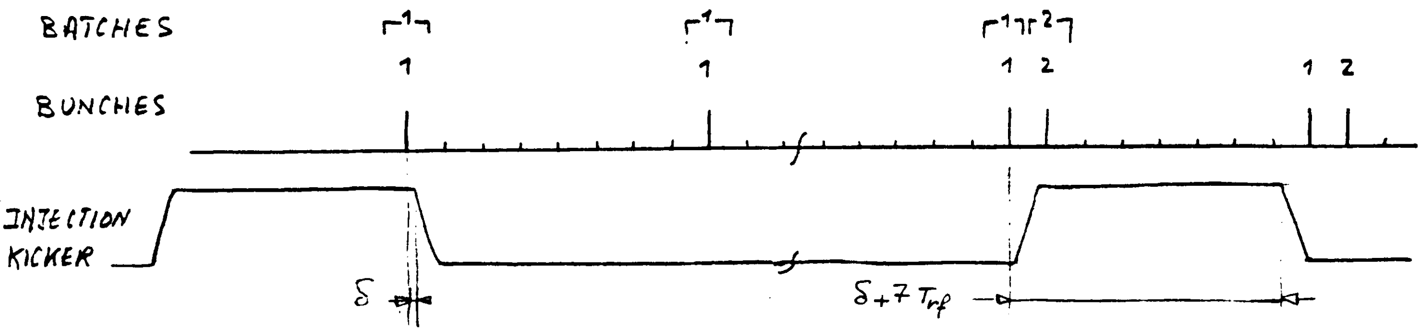

Fig. 4d: Double Batch as acheived in the "LHC test". Injection of bunch 2 in the bucket *following* bunch 1
Tight requirements on kicker rise and fall times, as in the LHC nominal scheme

Fig. 4 Relative position of beam and PS injection kicker pulse for double batch injection

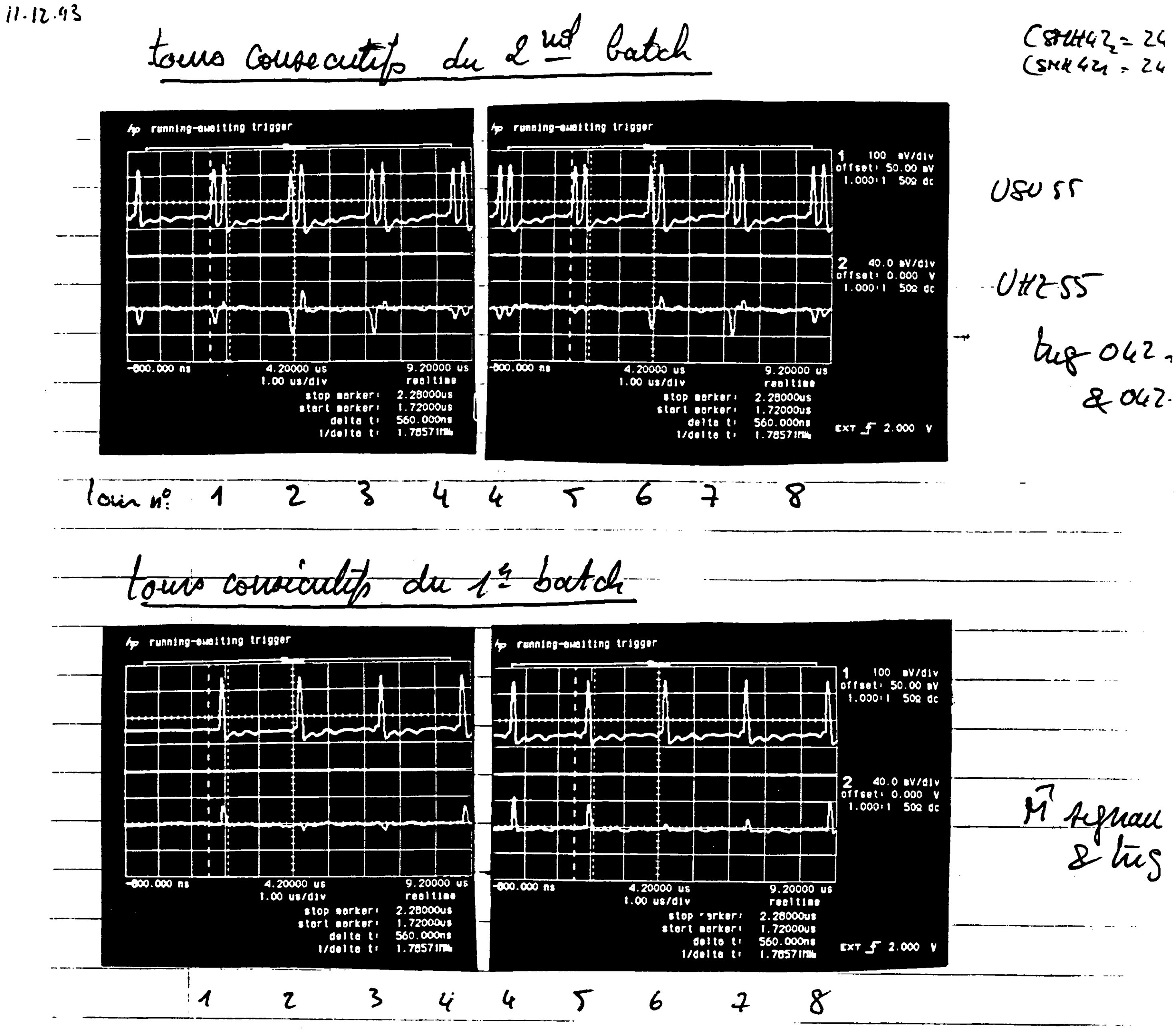

Fig. 5 Bunch trajectories at first and second injection

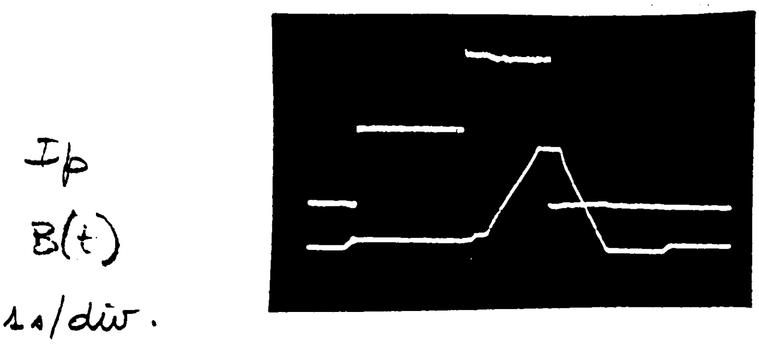

Fig. 6 Circulating beam in the PS with double batch filling