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Mr. Volker RODEL E-7

Resonant extraction from the SPS. Observations made during the start-up and the first operation period after the shut-down of January/February 1978.

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1. Introduction

During the shut-down most of the extraction quadrupoles, sextupoles and octupoles were removed to new lattice positions. These modifications had become necessary for the following reasons :

- The old lattice positions had been optimized for Q_H = 27.6. After the change of the working point to 26.6 these positions were rather unfavourable, in particular for resonant extraction to the North Area.

- Space had to be made available for the additional machine octupoles which will be installed in the future.

The present report shortly describes the experience made with the new lattice positions of the extraction lenses. Some observations concerning the first third-integer extraction from the SPS at 400 GeV/c are also reported. In Annex 1 the effect of two extraction quadrupoles on the machine tune is examined.

2. Third-integer extraction to the West Area

Three third-integer spills to the West Area were set up for period 1: a 25 ms spill SE1 around 195 GeV/c on the first ramp, a 1.4 sec spill SE2 on the 210 GeV/c flat top and another 25 ms spill SE3 around 225 GeV/c on the second ramp.

For the three extractions the resonance at Q_H = 26 2/3 was excited by the sextupoles LSE 2060, LSE 3240, LSE 5060 and LSE 6240. The normalized strength of each sextupole was + 4 m^{-1}.

still same layout in 9/81 ! and 3/82.

The horizontal machine chromaticity was uncorrected (i.e. $\sim$ -1) for all extractions. The strength of the Landau damping octupoles is of little importance for the present third-integer extractions, as long as the octupole polarity is negative.

SE1 and SE3 were controlled by the LQES servo, whereas SE2 was controlled by the RF servo as usual.

Fig. 1 shows the density distribution of the extracted proton beam SE2 at the electrostatic septum. The maximum jump of about 14 mm is in good agreement with the theoretically predicted 13 mm. As generally observed since we did the first third-integer extraction from the SPS (compare Commissioning Report No. 23), the "jump spread" is larger than expected.

3. Third-integer extraction to the North Area

During period 1 third-integer extraction to the North Area was set up at 400 GeV/c for tests of the beam transfer line TT20. A spill of about 400 ms length was successfully controlled by the LQES servo. The resonance at Q_H = 26 2/3 was excited by the sextupoles LSE 1060, LSE 2240, LSE 4060 and LSE 5240. This sextupole arrangement corresponds to the one used for West extraction.

With a normalized strength of + 4 m^{-1} per sextupole the density distribution shown in Fig. 2 was measured at the electrostatic septum.

This distribution is in reasonable agreement with theoretical predictions. The maximum jump is somewhat larger than expected, which may be partly due to an insufficient correction of the horizontal closed orbit. Fig. 3 shows the separation between the circulating and the extracted beam at the entrance of the thin septum magnet MST.

At the end of the 400 GeV/c spill an instability was observed resulting in a vertical blow-up of the extracted beam and in a horizontal displacement at the MST. This instability which is not yet understood caused considerable losses at the thin septum magnet. To reduce the effect of the instability, about 10^{11} protons had to be dumped 100 ms before the end of the flat top. A North extraction test at 210 GeV/c did not show such an instability. The density distribution measured at the electrostatic septum (Fig. 4) is in perfect agreement with the distribution observed at the same energy for West extraction (Fig. 1).

4. Fast half-integer extraction

The quadrupoles which drive the fast resonant spill and which permit to interrupt it, QE 3140 and QE 6080 respectively, are those already used before the shut-down. As outlined in Annex 1 the betatron phase-shift between the two quadrupoles must be situated within well defined limits to guarantee efficient spill interruption. An alternative position for QE 6080 which must give way to an LOFN, must therefore be chosen with care.

The octupoles needed for half-integer extraction were removed to new lattice positions during the shut-down. The following octupoles are now in use: LOE 1040, LOE 3300, LOE 6200 and LOE 6360.

On the first luminescent screen in TT60 a horizontal tail of the extracted beam was observed during the larger part of period 1. Whereas this tail was quite important at high intensities, it practically disappeared at low intensity. Towards the end of period 1 the normalized strength of the extraction octupoles was reduced from + 90 m^{-2} per LOE to + 60 m^{-2} per LOE. This reduction of octupole strength considerably reduced the length and the relative intensity of the tail of the extracted proton beam. The jumps at the electrostatic septum still remained largely sufficient, as shown in Fig. 5.

During the start-up it was found out that the fast spill can only be interrupted efficiently by the second or third trigger method described in SPS Improvement Report No. 116 (trigger for QE 6080 derived from BSI or BCT signals) if the spill is not shorter than about 2 ms. With a 2 ms spill stable and reliable operation was achieved deriving the trigger signal for QE 6080 from BSI 6103 (see Fig. 6).

5. Conclusions

During period 1 up to five resonant extractions were successfully performed during the same accelerator cycle. The new sextupole positions are more favourable than the previous positions and permit, in particular, to use the same extraction scheme at Q_H = 26 2/3 to the West and to the North Areas. The new octupole positions also proved to be suitable.

The main problem that has to be examined in the coming weeks seems to be the instability observed at the end of the slow spill on the 400 GeV/c flat top.

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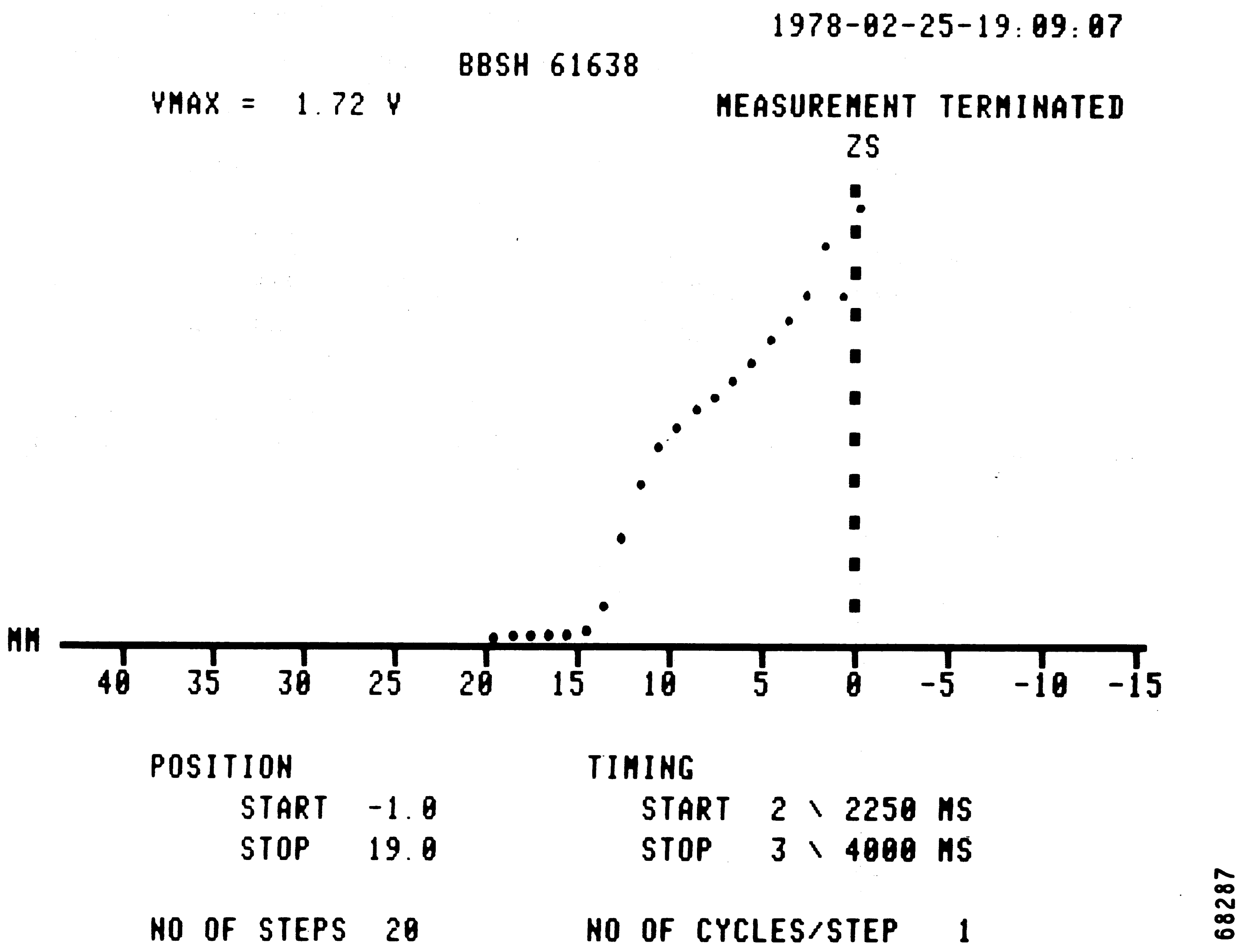

Fig. 1 Density distribution at the electrostatic septum ZS for third-integer extraction to the West Area at 210 GeV/c.

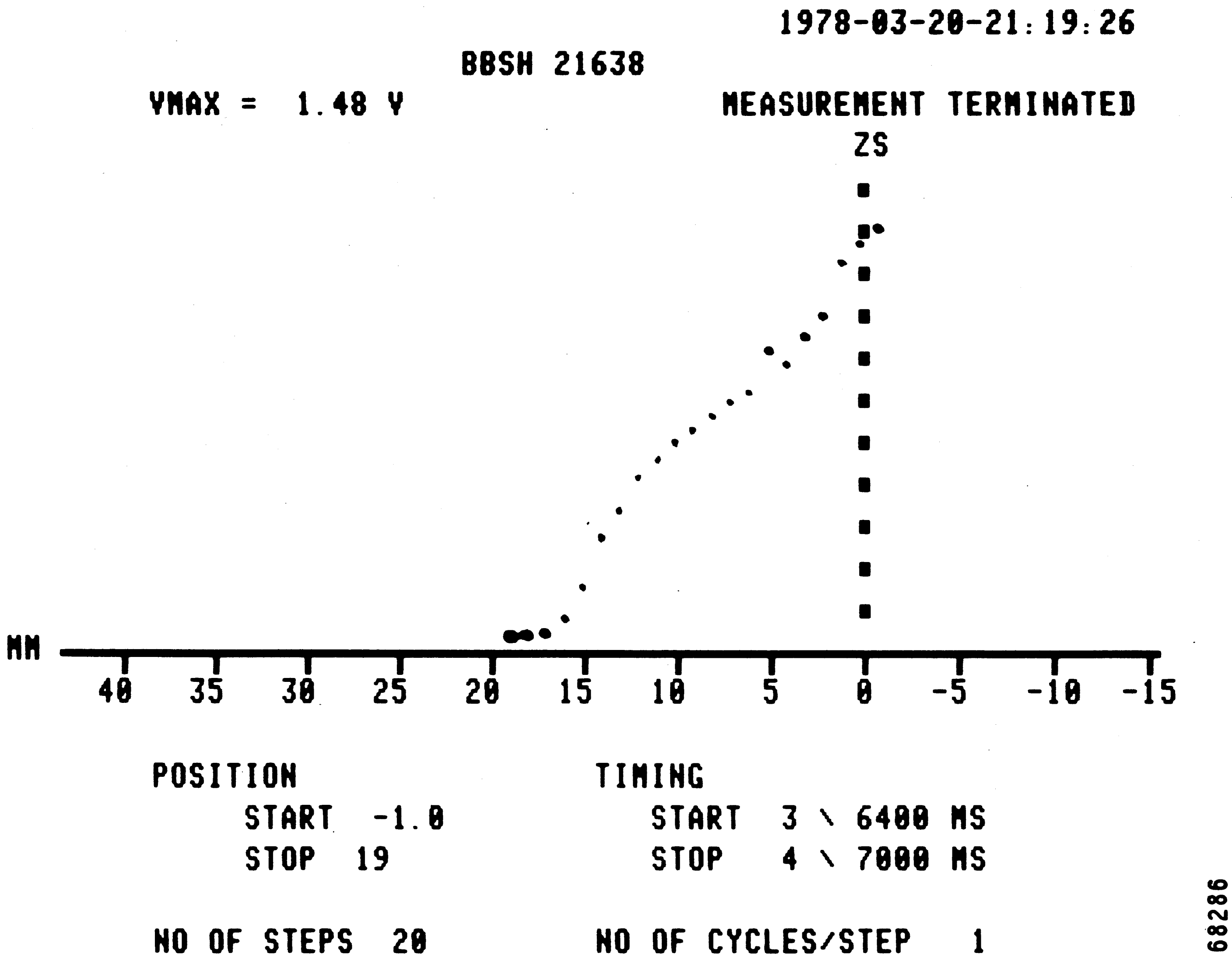

Fig. 2 Density distribution at ZS for third-integer extraction to the North Area at 400 GeV/c.

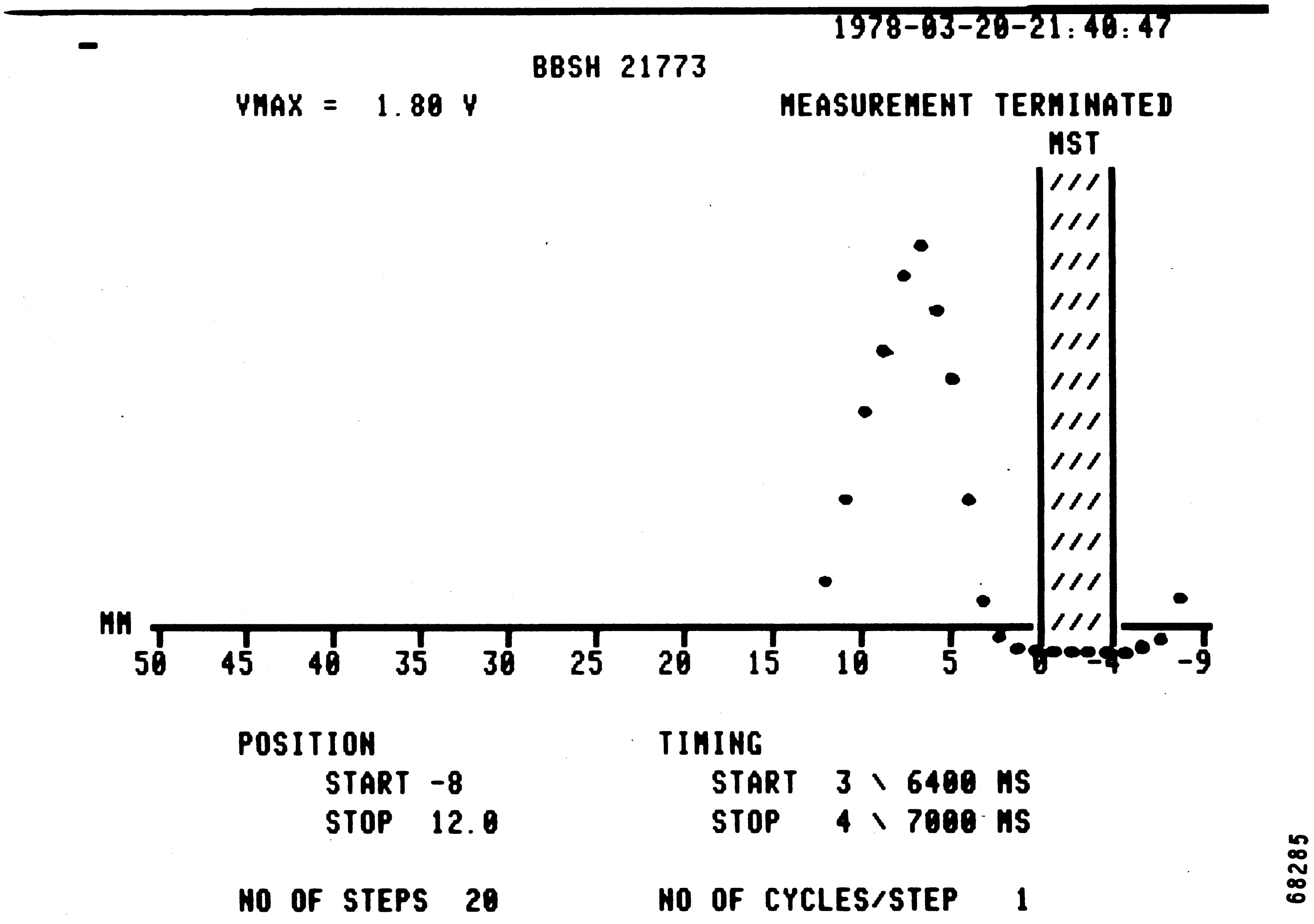

Fig. 3 Separation between the circulating beam and the extracted beam at the entrance of MST for 400 GeV/c extraction to the North Area.

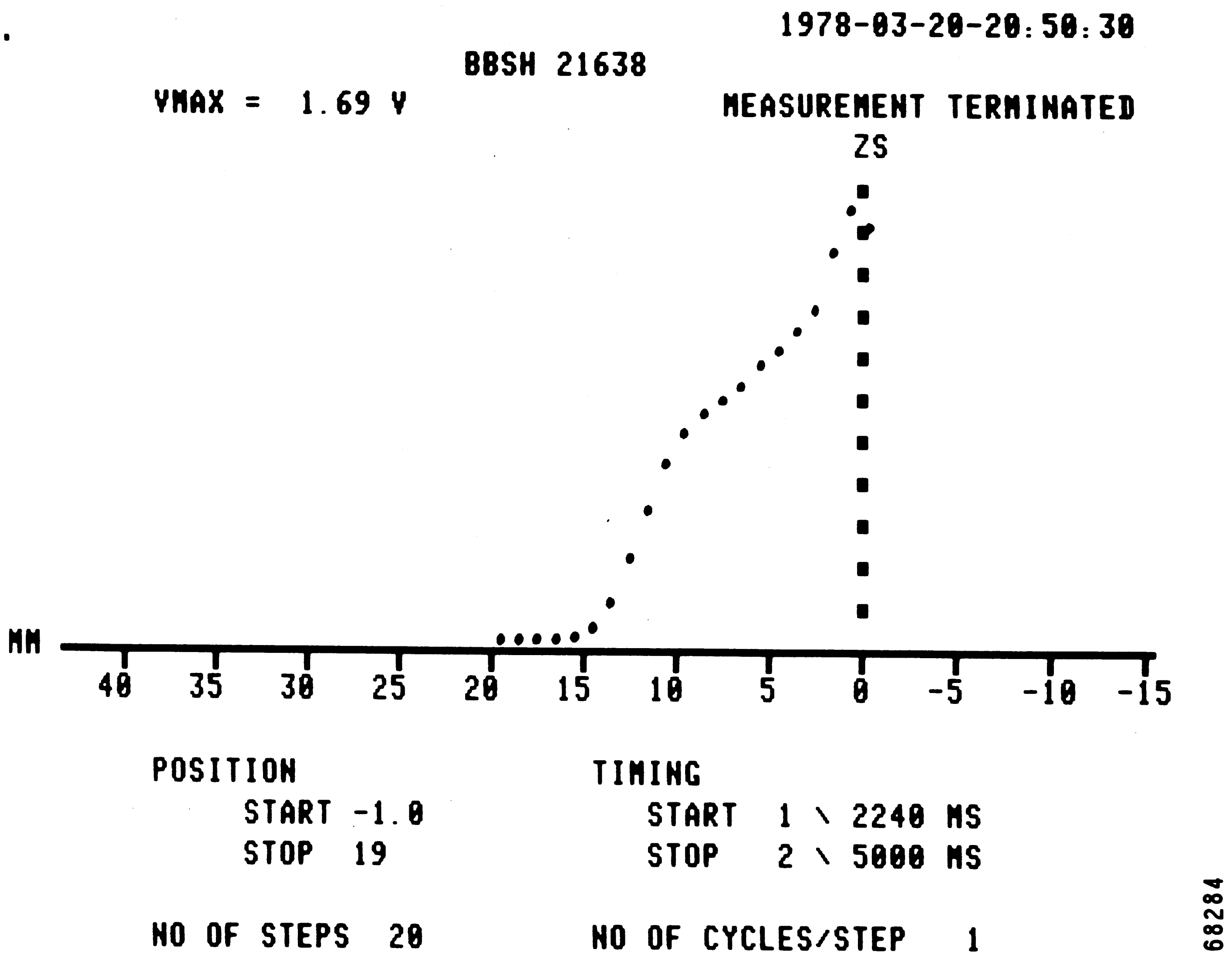

Fig. 4 Density distribution at ZS for third-integer extraction to the North Area at 210 GeV/c.

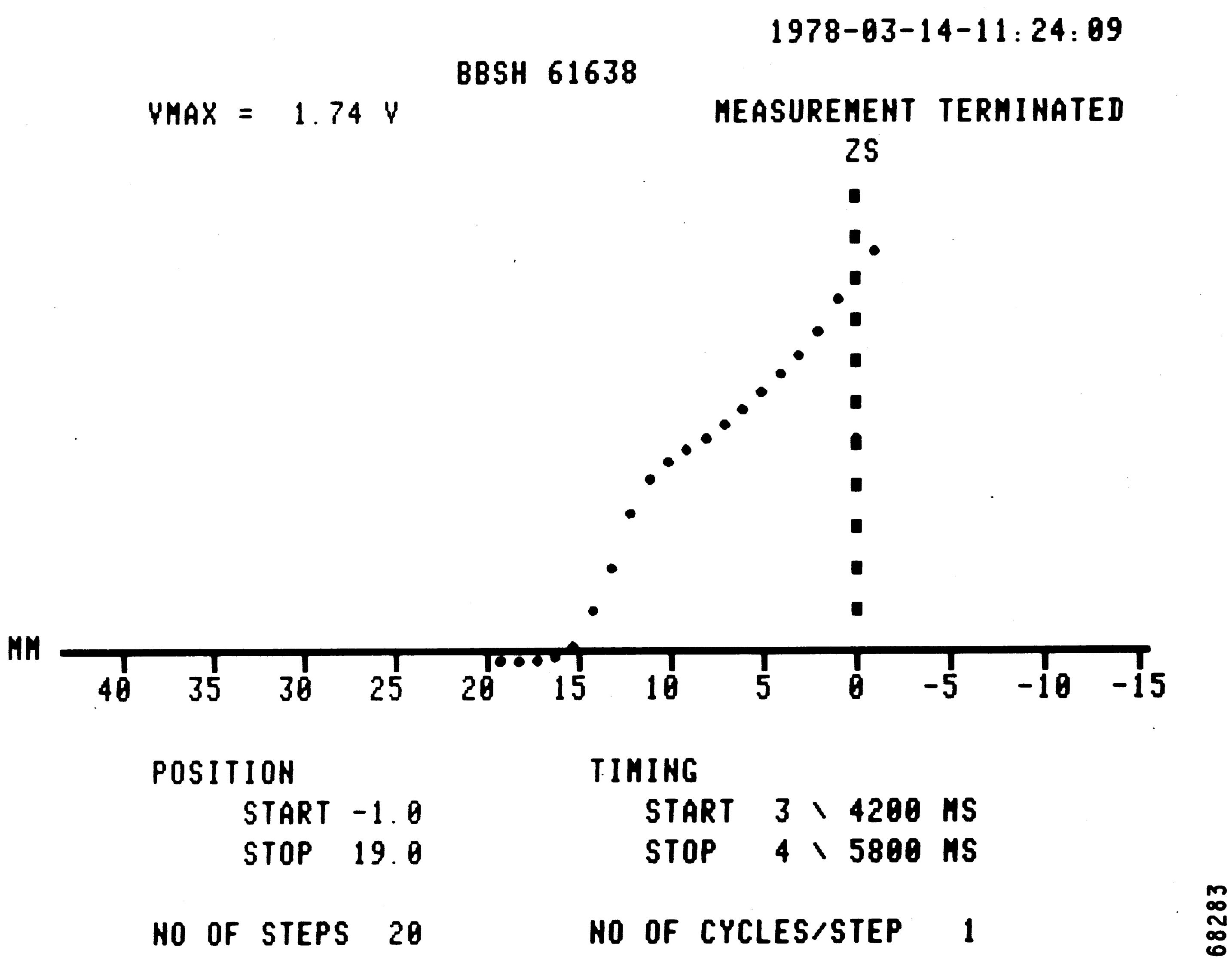

Fig. 5 Density distribution at ZS for fast half-integer extraction at 330 GeV/c.
$\bar{k}_{oct}$ = + 60 m^{-2} per LOE.

Cycle No.	I1(T=5600)	I2(T=5800)	I-EXTR.
1	377	51	326
2	421	53	368
3	425	76	349
4	391	46	345
5	378	48	330
6	405	49	356
7	385	54	331
8	418	58	360
9	369	44	325
10	380	54	326
11	421	75	346
12	411	54	357
13	377	43	334
14	408	68	340
15	410	61	349
16	419	74	345
17	420	67	353
18	399	63	336
19	390	48	342
20	416	79	337
21	410	66	344

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Fig. 6 Cycle to cycle stability of the residual intensity I_2 (in 10^{10} protons) after a fast resonant extraction. A 2 ms spill was stopped by a current pulse through QE 6080, triggered by a signal derived from BSI 6103.

Effect of two extraction quadrupoles in the SPS

If the one turn matrix including the two extraction quadrupoles is :

$$M = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$$

then the phase-shift per turn is given by :

$$\cos\psi = 1/2\ (a_{11} + a_{22})$$

and a comparison of this ψ with the value for the unperturbed machine will enable one to obtain the change of the machine tune due to the additional quadrupoles. The quantity $1/2\ (a_{11} + a_{22})$ is known as the half-trace of the matrix M. At the limit of stability of the machine (edge of the stopband) the half-trace is equal to ± 1.

With the following notations :

K_1, K_2 = normalized strengths of quadrupoles 1 and 2
θ = phase-shift from quadrupole 1 to quadrupole 2
μ = $2\pi Q$ (Q = tune of unperturbed machine)

one finds by a straightforward calculation :

$$\cos\psi = \cos\mu + \frac{K_1 + K_2}{2}\sin\mu + \frac{K_1 K_2}{2}\sin\theta\ \sin(\mu-\theta)$$

The formula is, of course, symmetrical in K_1 and K_2 ($\mu-\theta$ being the phase-shift from quadrupole 2 to quadrupole 1). If $K_2 = 0$, one obtains the well known formula for a single quadrupole :

$$\cos\psi = \cos\mu + \frac{K_1}{2}\sin\mu$$

or at the edge of the half-integer stopband ($\cos\psi = -1$) :

$$K_1 = 2 \text{ tg}\left(\frac{\pi}{2} + \frac{\mu}{2}\right)$$

<u>Example</u> With Q = 26.55 the beam becomes unstable for K_1 = +.31677 which at 400 GeV/c corresponds to a current of - 155.6 A through an extraction quadrupole.

Now we consider a machine tuned to Q = 26.55 and two quadrupoles of opposite polarity which rise simultaneously to the same amount of strength. If the quantity $\sin\theta \sin(\mu-\theta)$ is positive the machine tune moves towards the resonant tune, if it is zero the machine tune remains unchanged and if it is negative the machine tune moves away from the half-integer resonance. The condition :

$$\sin\theta \sin(\mu-\theta) \leq 0$$

is fulfilled for :

$$0^\circ \pm n*\pi \leq \theta \leq 18^\circ \pm n*\pi \; ; \quad n = 0, 1, 2, ..$$

More generally, if one wants to stop a fast half-integer spill at a time t_1, one must satisfy the condition :

$$\left[\frac{d(\cos\psi)}{dt}\right]_{t=t_1} \geq 0$$

In practice, t_1 is the time at which the second quadrupole is triggered, that is $K_2(t_1) = 0$ and one obtains :

$$0 \leq \sin\mu \left(\frac{dK_1}{dt} + \frac{dK_2}{dt}\right) + \sin\theta \sin(\mu-\theta)\, K_1 \frac{dK_2}{dt}$$

for $t = t_1$ and assuming a constant tune of the unperturbed machine.

In our present half-integer scheme $\sin\mu$ equals $-.309$ and K_1 and $\frac{dK_1}{dt}$ are both positive at the time the spill is stopped. If $\frac{dK_2}{dt}$ was equal to $-\frac{dK_1}{dt}$, the quantity $\sin\theta \sin(\mu-\theta)$ would again have to meet the requirement :

$$\sin\theta \sin(\mu-\theta) \leq 0$$

that is

$$0^o \pm n*\pi \leq \theta \leq 18^o \pm n*\pi .$$

As QE2 is somewhat delayed with respect to QE1 and as the currents through both extraction quadrupoles follow, up to their maxima, semi-sinusoidal functions of opposite polarity but equal shape (if the capacitor charging voltage has the same absolute value for both quadrupoles which is usually the case), the relation :

$$\frac{dK_1}{dt} + \frac{dK_2}{dt} < 0 \quad \text{at} \quad t = t_1$$

holds rather than :

$$\frac{dK_1}{dt} + \frac{dK_2}{dt} = 0$$

Therefore, the quantity $\sin\mu \left(\frac{dK_1}{dt} + \frac{dK_2}{dt}\right)$ is positive at $t = t_1$, which increases the interval into which the phase-shift θ must fall. A more detailed calculation shows that for present extraction parameters some 10^o might be added on either side of the interval, leading to the following condition :

$$-10^o \pm n*\pi \leq \theta \leq 28^o \pm n*\pi$$

It seems, however, indicated not to make use of this enlarged interval, but to take the additional 10^o on either side of the interval $0 \pm n*\pi \leq \theta \leq 18^o \pm n*\pi$ as a safety margin: to stop efficiently a fast half-integer spill it is probably favourable to rapidly move the tune away from the resonance, that is, to make $\frac{d(\cos\psi)}{dt}$ clearly larger than zero.

Finally, it should be mentioned that the phase-shift between the extraction quadrupoles used at present, QE 3140 and QE 6080, is $25*\pi + 13.5^o$ for Q = 26.55 which is well within the required interval.

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