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SPACE-CHARGE EFFECTS IN $p\bar{p}$ OPERATION

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Laslett space-charge detuning, head-tail and beam-beam effects must be carefully considered in setting up the machine at 26 GeV.

I. Incoherent Laslett Q shift [1]

$$\Delta Q_V = -\frac{N r_p}{\pi\gamma}\,\frac{2}{B\beta^2\gamma^2}\,\frac{\beta_v}{b(a+b)}$$

$$\Delta Q_H = -\frac{N r_p}{\pi\gamma}\,\frac{2}{B\beta^2\gamma^2}\,\frac{\beta_H}{a(a+b)}$$

where $B = \frac{\text{bunch length * number of bunches}}{\text{1.5 * machine circumference}}$ (for parabolic bunches)

a,b = horizontal and vertical beam half-width (2σ)

$$b = \sqrt{E_v\beta_v} \quad ; \quad a = \sqrt{E_v\beta_v + (\alpha p\,\frac{\Delta p}{p})^2}$$

Take the beam parameters measured in the 1981 $p\bar{p}$ run

$$E_V = E_H = \cdot 4\,\pi\,10^{-6} \qquad\qquad a = 8\ 10^{-3}$$

$$\longrightarrow$$

$$\frac{\Delta p}{p} = 3.5\ 10^{-3} \qquad\qquad b = 4\ 10^{-3}$$

bunch length : 2.7 ns

$N = 10^{11}$ per bunch

and calculate

$$\boxed{\begin{aligned}\Delta Q_{Vinc} &= -\ .05\\ \Delta Q_{Hinc} &= -\ .025\end{aligned}}$$

At 270 GeV, the vertical detuning is down to 7.10^{-4} and can be neglected.

II. Coherent Q shifts

1. Laslett Q shift from the perfect vacuum pipe:[1]

$$\Delta Q_{Vc} = - \frac{Nr_p}{\pi\gamma} \beta_V \left[\frac{\xi_1}{h_o^2 B\beta^2\gamma^2} + \frac{\varepsilon_1}{h_o^2} + \frac{\varepsilon_2}{g^2} \right]$$

$$\Delta Q_{Hc} = \frac{Nr_p}{\pi\gamma} \beta_H \left[\frac{-\xi_1^*}{W_o^2 B\beta^2\gamma^2} + \frac{1}{h_o^2} + \frac{2}{g^2} \right]$$

h_o and W_o are the chamber half-height and width,and g is the magnet gap half-height.

ξ_1, ξ_1^*, ε_1 and ε_2 are the Laslett coefficients.

The only significant term comes from ξ_1 in ΔQ_V, with the result:

$$\Delta Q_{VC} = - 1.10^{-3}$$

which can be neglected.

2. Head-tail Q shift:

This is due to the interaction of the dense single bunch with the imaginary part of the machine transverse coupling impedance arising from cavities and cross-section changes in the vacuum chamber. This effect has been evaluated during the $p\bar{p}$ workshop in 1980[2], using the standard broad-band model. At 26 GeV, the result can be written, for head-tail mode m = o:

$$\Delta Q_{HT} = .064 \times \frac{4}{\Delta t} \times \frac{Z_\perp}{125}$$

Δt = bunch length in ns

$Z_\perp$ = transverse coupling impedance at the resonance peak,(1.3 GHz) in $M\Omega m^{-1}$.

Following the same broad-band model, an estimate of the SPS transverse coupling impedance has already been derived from measurements of the head-tail instability growth rates at 270 GeV (3). One can use this result ($Z_{\perp}$ = 18 M m^{-1}) to predict the coherent tune shift of the N = 10^{11}p, 2.7 ns long bunch typical of the 1981 $p\bar{p}$ run.

One finds $\Delta Q = -.014$

whereas measurements give:

$$\boxed{\Delta Q_V = -.03}$$

(the horizontal effect was unfortunately not measured).

At 270 GeV, with a 2 ns long bunch, the effect should be 4.10^{-3}, not quite negligible!

III. Consequence for $p\bar{p}$ operation

It is important to know with great precision where in the tune diagram the individual particles which compose the beams, are sitting. In the present working region, it is imperative that they clear both 3rd and 4th order resonances from injection to storage.

If Q_o is the tune of the machine (single particle), what one measures by exciting the beam coherently is $Q_M = Q_o + \Delta Q_C + \Delta Q_{HT}$ whereas the individual protons are sitting at $Q_p = Q_o + \Delta Q_{inc.}$ When beams are in collision, the beam-beam effect must be added. For a small antiproton bunch colliding against 3 strong proton bunches (nominal intensity and emittances)

on has $$Q_{\bar{p}} = Q_o + \Delta Q_{bb}$$

with $\Delta Q_{bb} = 6 \times .003 = .018$.

This situation is described in fig. 1 where Q_M has been chosen close to the value actually used during period 8 of 1981. (The yet unknown ΔQ_{HC} has been ignored.)

Particles populate the shaded areas, with maximum density around the centre of the lozanges. They do clear 4th and 3rd order resonances, but straddle the coupling resonance.

Some comments are in order :

- the situation described (3 bunches with nominal parameters) seems to be the limit one can accommodate in this working area ;

- Q must be set to high precision.

Consequently:

  - no horizontal excursion is allowed during the early acceleration, as with the finite chromaticity this produces a Q change;

  - proton beam parameters (intensity, emittances) must be frozen: it is impossible to properly tune up the machine with intensity or emittances jittering by more than, say, 20%;

- in order to minimize these space-charge effects, the bunches must be maintained as long as possible at low energy: programming the RF voltage to the nominal values on the flat bottom (1.65 MV) and during the early rise is essential;

- the situation will have to be reconsidered when the antiproton intensity increases towards the nominal 5.10^{10} per bunch.

References

1) On intensity limitations imposed by transverse space-change effects in circular particle accelerators, L.J. Laslett. BNL 7534 (1963).

2) Workshop on $p\bar{p}$ in the SPS SPS $p\bar{p}$ 1, March 1980.

3) Improvement report No, 181, D. Boussard, J. Gareyte.

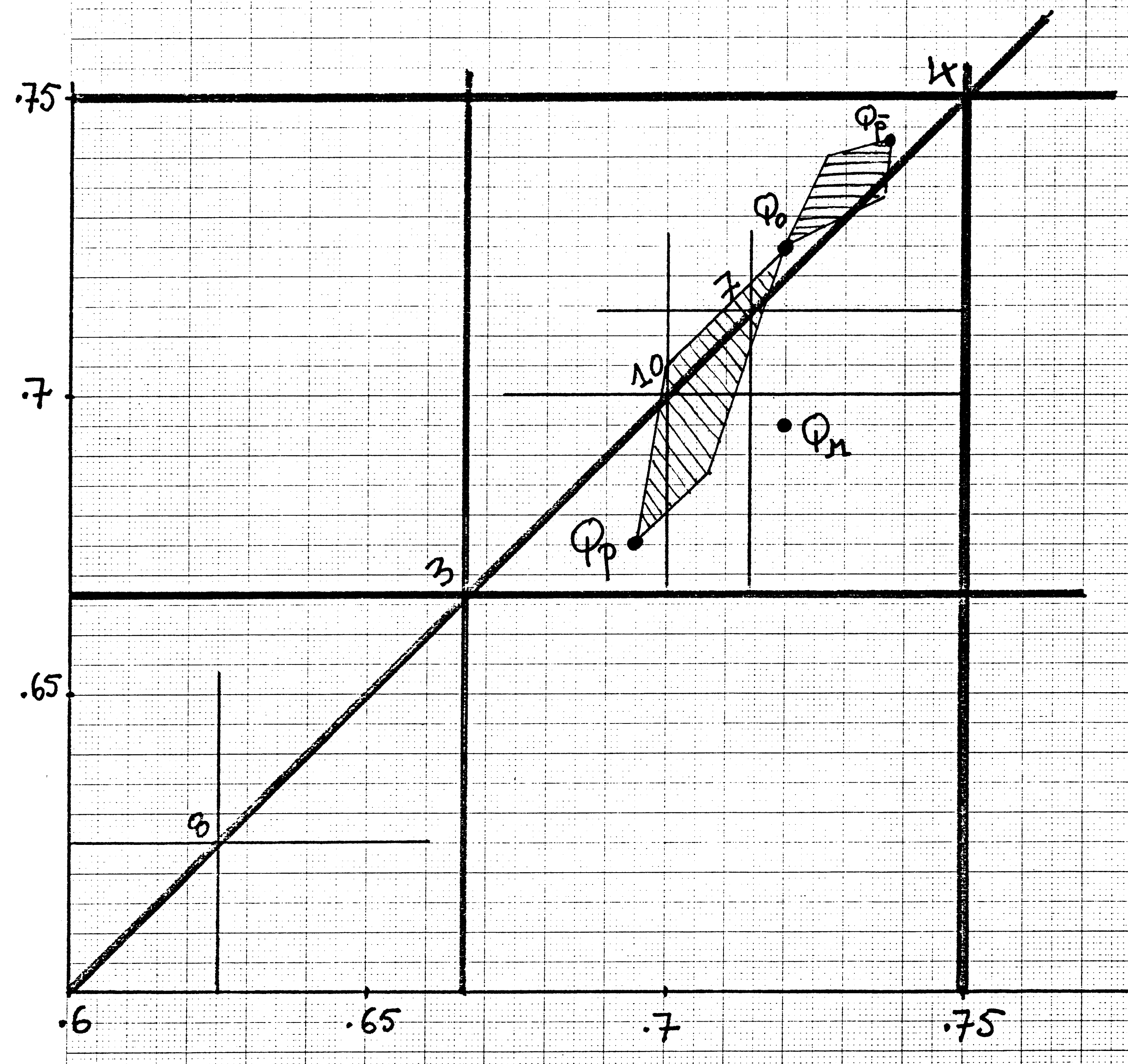

Fig. 1 Tune diagram at 26 GeV.

- 3 p bunches - nominal parameters
- small intensity $\bar{p}$ bunches

Q_0: single particle Q

Q_M: Q measured with protons

Q_P : Q of central proton

$Q_{\bar{P}}$: Q of central antiproton

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