

BEAM-BEAM EFFECTS IN THE SPS PROTON-ANTI PROTON COLLIDER

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Abstract

During the proton-anti proton collider run several experiments were carried out in order to understand the effect of the beam-beam interaction on backgrounds and lifetimes. In this talk a selection of these experiments will be presented. From these experiments, the importance of relative beam sizes and tune ripple could be demonstrated.

1 GENERAL LAYOUT OF SPS COLLIDER OPERATIONS

In the first collider runs, the SPS was operated with 3 proton bunches against 3 anti-proton bunches, colliding in 6 collision points. The proton bunch intensity at that time was close to $2 \cdot 10^{11}$ and the anti-proton intensities were about ten times less. In this configuration, total tuneshifts of 0.028 were sometimes obtained but the anti-proton lifetimes, in the beginning of the coast were poor. A horizontal pretzel scheme was introduced in order to separate the beams in the unwanted collision points (fig 1) and the SPS could then profit from the upgraded anti-proton accumulation facility, operating with 6 against 6 bunches. In this scheme the beams were separated in 9 of the 12 crossing points.

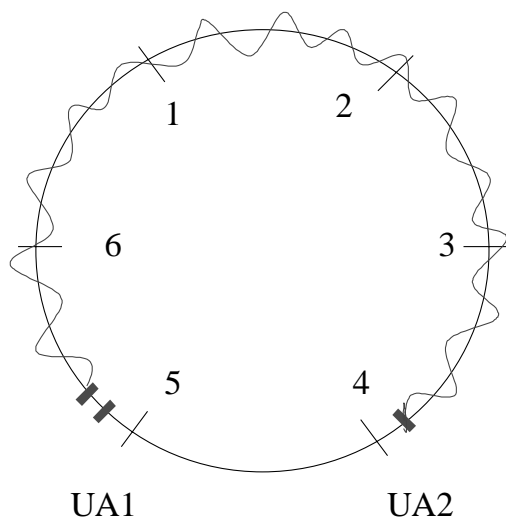


Fig 1 : Schematic layout of the SPS pretzel scheme

The beam separation was 6σ or better in all the crossing points, except for one, where the separation was only 3.5σ (fig 2.).

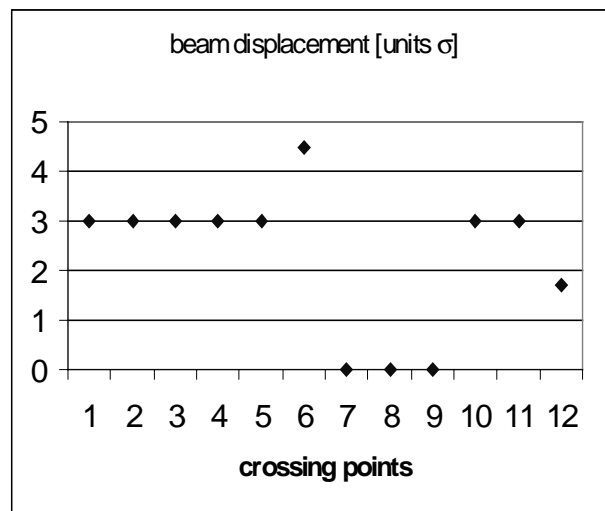


Fig 2 : beam half-separation in the 12 crossing points. .

The same electrostatic separators were used during injection to separate the beams in all crossing points, in order to keep emittances small during the injection and acceleration process.

The parameters of the SPS collider in the final 6 on 6 operation are listed in table 1.

Injection energy	: 26 GeV
Coast energy	: 315 GeV
Protons	: $1.7 \cdot 10^{11}$/bunch 6 bunches
Pbar	: $0.8 \cdot 10^{11}$/bunch 6 bunches
ϵ_x, ϵ_y (ϵ being defined as $4\gamma\sigma^2/\beta$)	: 15 to 20 mm mrad
$\xi_{x,y}$: 0.015 to 0.02 (total)

Table 1 : general parameters during the SPS collider run with 6 protons on 6 anti-protons.

The tune diagram with typical proton- and anti-proton footprints during physics is shown in fig 3. The tune difference between protons and antiprotons could be

trimmed with sextupoles, placed where the beams were separated. The core of the beam is at the higher tune values.

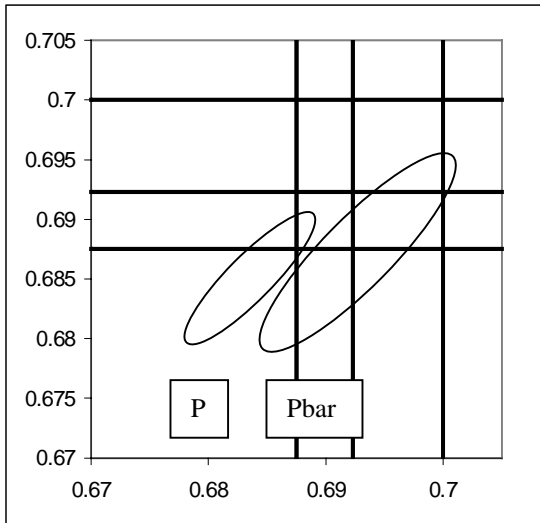


Fig 3 : Working point during physics. The horizontal and vertical lines represent respectively the 16th (.6875), the 13th (.6923) and the 10th (.700) order resonance.

2 THE INFLUENCE OF BEAM SIZE

In some of the runs, where the machine went into coast with substantial smaller pbar emittances, the protons had a very bad lifetime and gave a lot of proton background, and this in spite of the fact that the pbar intensity was ten times less than the proton intensity. This phenomenon could be artificially reproduced by scraping one of the beams with a collimator at a place where they are separated and observing the background and/or the lifetime of the other beam. In fig 4 a horizontal tune scan is shown looking at the proton background before and after the pbar emittance was reduced by 30%. Although the intensity of the

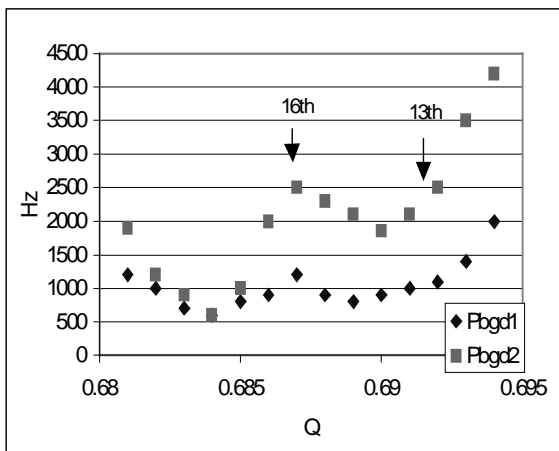


Fig 4 : proton background as function of tune, before (Pbgd1) and after (Pbgd2) the pbar emittance was reduced by 30%.

anti-protons was reduced by the scraping process, the protons seem to suffer much more from the beam-beam interaction. This experiment is showing that mainly the high amplitude particles (amplitude measured in units of sigma of the other beam) suffer from the high order resonances.

In fact it turned out to be very important for lifetime and background that the two beams had the same size. In case of unequal beam sizes, the bigger beam would lose all the particles sitting outside the other beam creating a low lifetime and high background in the beginning of the coast. This is illustrated in fig 5, where the evolution of the proton- and anti-proton emittances is plotted during a normal physics coast. By accident the protons are smaller than the anti-protons in the beginning, but throughout the coast the pbars lose mainly high amplitude particles and after three to four hours the anti-proton emittance is reduced and matches the proton emittance. The small growth of the proton emittance is due to intra beam scattering.

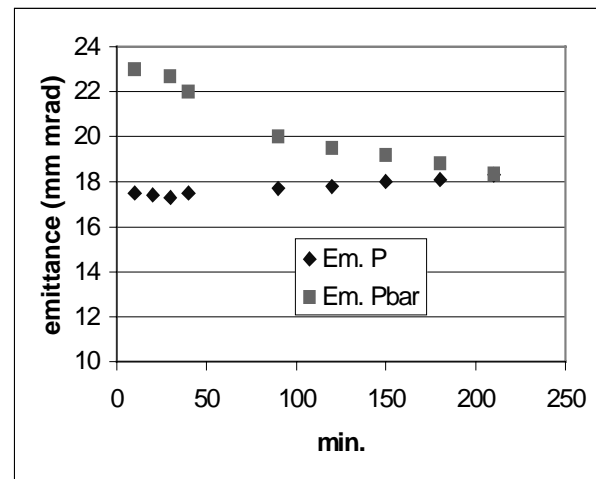


Fig 5 : Evolution of the proton and p-bar emittance during the first 200 minutes of a coast.

3 THE INFLUENCE OF SEPARATION

Tune scans were also performed for different separation. Reducing the separation in the parasitic crossing from 6σ to 3σ , increases the background on the 16th as well as on the 13th order resonance as can be seen in Fig 6.

In another experiment only one bunch of protons was colliding head-on with one bunch of anti-protons in two collision points. The beam was then separated in one of the two points in steps of 0.1σ . The result is shown in fig 7. The background rises very quickly as function of separation, reaching a maximum at 0.3σ . The background decreases then very slowly as function of further separation.

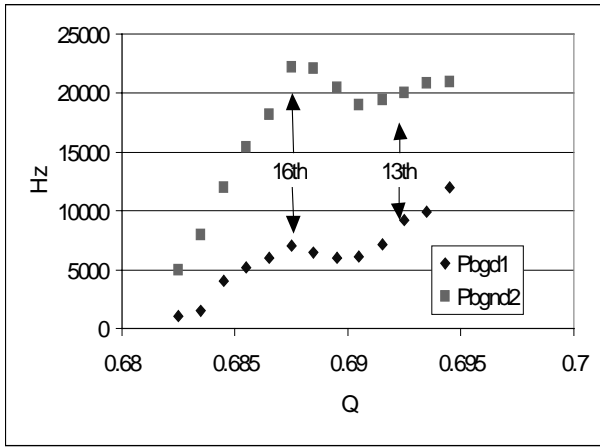


Fig 6 : Tune scans with full (Pbgd1) and half separation (Pbgnd2).

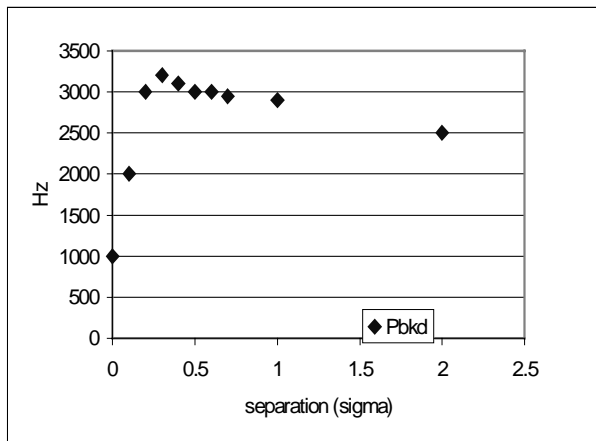


Fig 7 : Proton background as function of separation.

4 THE EFFECT OF TUNE MODULATION

High order resonances in non linear fields manifest themselves as stable islands in phase space. Most of the particles will have a varying amplitude but the motion stays periodic and stable. Tune modulation will make islands move in and outward. For small frequencies, the particles will stay trapped in the islands and they can be transported to very high amplitudes due to the tune variation. If the tune is varied fast enough there will be passages created between the islands through which the particles can move very quickly in or outward (cfr. empty bucket acceleration). At even higher frequencies the separatrices of the island become transparent. Particles can be trapped in an island at low amplitude and leave the island again at high amplitude. Whatever the mechanism, tune modulation, together with non-linear resonances, creates the possibilities for particles to move to higher amplitudes.

This could be very clearly observed in the SPS : in order to have good lifetimes with colliding beams, the

chromaticity had to be tuned as close as possible to zero. Also the noise on the main magnets had to be reduced to a minimum in order to preserve good lifetimes in collision.

The effect of tune modulation can be easily demonstrated with simulation. In fig 8 the results are shown of a simple simulation using a head-on beam-beam kick separated by a linear transfer matrix in which the phase advance is modulated with a frequency of 200Hz. In the first case the tune modulation is $5 \cdot 10^{-5}$ and in the second case it is $3 \cdot 10^{-4}$. What is shown is the diffusion rate (z-axis) as function of the unperturbed tune (x-axis) and the initial amplitude (y-axis) ranging from 0 to 10σ . In both cases the 16th and 10th order resonance can clearly be seen. In the first case, the particles on the 10th order resonance move out with a diffusion time constant of one minute or faster only from 4σ onwards and on the 16th order only from 7σ onwards. In the second case, with the stronger tune modulation, the particles on the 10th order move out with the same speed already at 2.5σ and on the 16th order already at 5σ .

5 CONCLUSIONS

- Experience with the SPS proton anti-proton collider showed that it is very important to have the same beam sizes for both beams in order to obtain good lifetimes and backgrounds.
- The high order resonances have almost no effect on the particles with small amplitudes.
- The “bad” effect of miss crossing reaches already a maximum at a separation 0.2 to 0.3 sigma.
- All tune modulation (chromaticity, power supply ripple etc.) should be reduced to a minimum

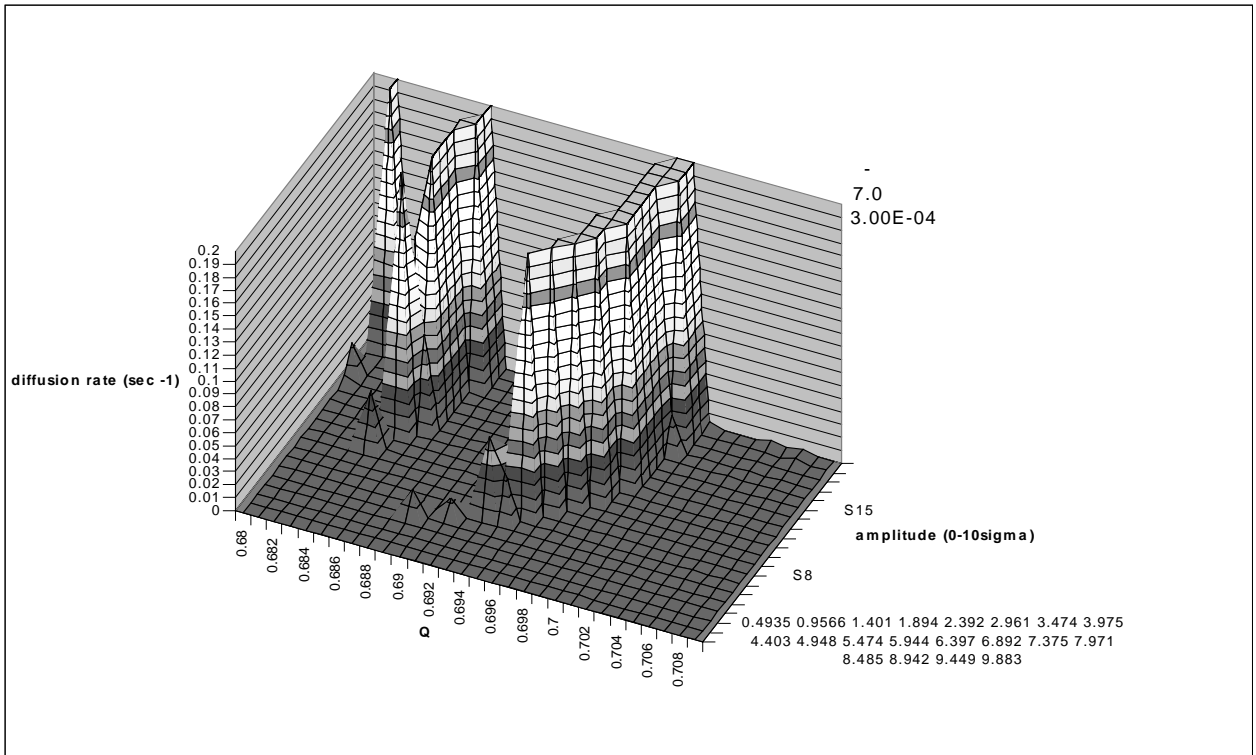
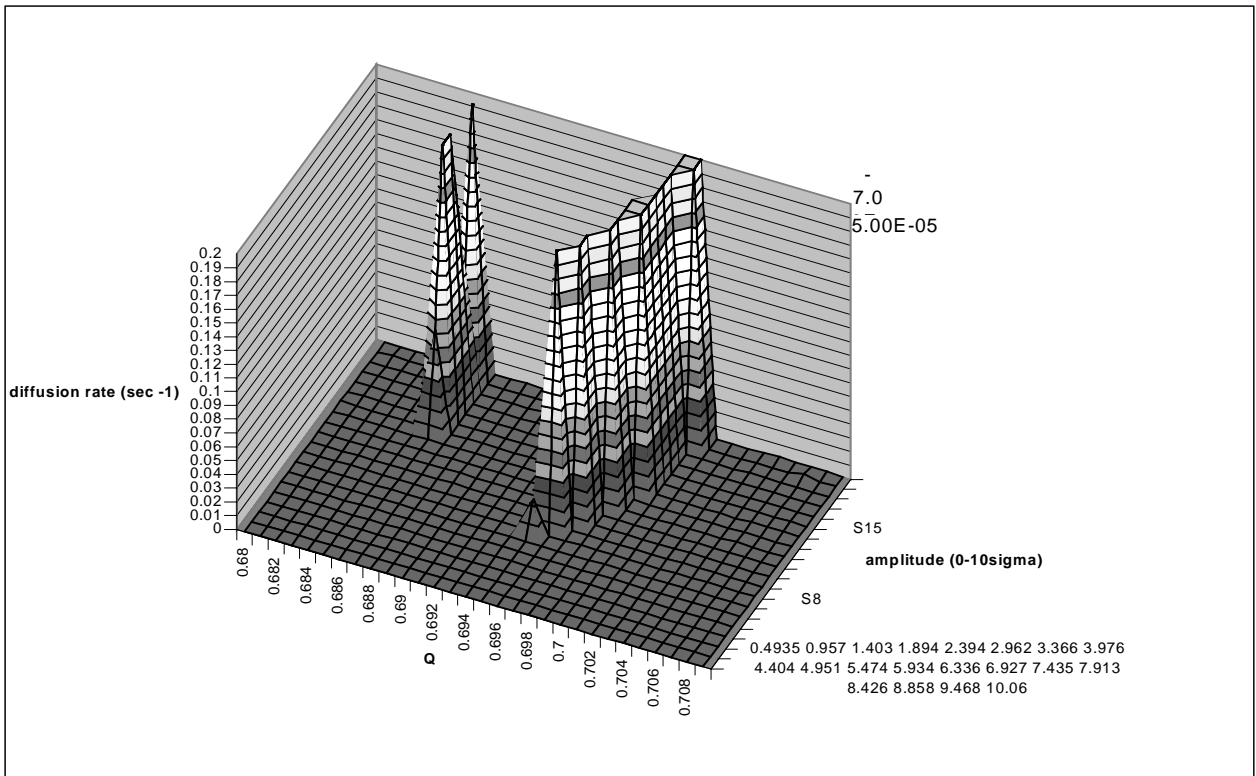


Fig 8 : diffusion rates (z) as function of tune(x) and initial amplitude (y : 0 to 10 σ). Total tune shift 0.012. Tune modulation 200 Hz, modulation amplitude 0.00005 (above) and 0.0003 (below).