0602E

SPS/DI-MST/Note/85-3 16th October, 1985

Possible performance of the SPS as an antiproton-heavy ion collider

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I. Introduction

In 1986 fully stripped ^{16}O ions will be injected into the SPS for acceleration up to 225 GeV/c per nucleon and used for fixed-target experiments through the normal SPS slow extraction systems and beam lines.

The possibility of storing these ions in the SPS together with an antiproton beam so as to produce collisions at high energy between these two species can therefore be contemplated. The purpose of this note is to show what performance could be reached in this case with minimal disturbance to the normal ppbar complex. As a second step, and should the physics interest justify some further development, a higher luminosity could be envisaged. A few ideas aiming in this direction are outlined.

II. Simultaneous acceleration of $^{16}O^{8+}$ and pbar beams

The SPS is equipped with four directional, travelling wave 200 MHz cavities, each capable of delivering an accelerating voltage of nearly 2 MV. While the machine is used as a ppbar collider, two of these cavities accelerate proton bunches while the other two, in which the direction of flow of the RF energy has been reversed, accelerate the antiprotons. Both systems are driven from a unique oscillator which is phase-locked onto one of the dense proton bunches, the master bunch. The fact that the cavities are directional is rather a drawback as far as the acceleration of protons and antiprotons is concerned, since it halves the RF voltage which would otherwise be available for each species. On the contrary, to simultaneously accelerate antiprotons and oxygen ions, which do not travel at exactly the same speed, two separate non-interacting systems are needed, and full use can be made of the directivity of the cavities.

The longitudinal acceptance of the SPS for oxygen ions at a momentum of 13 GeV/c per nucleon (26 GeV/c proton equivalent) and for a maximum voltage of 4 MV is .41 eVs. However, the ions must be accelerated through transition at 21.6 GeV/c per nucleon and this puts a more severe limitation on the maximum possible emittance which can be accepted in this machine. The dilemma is that one must go through transition fast enough not to lose the oxygen ions, but slowly enough to provide a sufficient acceptance for the antiprotons. A possible compromise is to choose at the oxygen transition energy (43.2 GeV/c for the antiprotons) a rate of rise of the magnetic field $\dot{B} = 0.4 Ts^{-1}$. This should allow the simultaneous acceleration of oxygen bunches with an emittance up to 0.15 eVs and of antiproton bunches with an emittance up to 0.25 eVs.

A faster rate would cause losses of antiprotons due to lack of acceptance while a slower rate would cause losses of oxygen at transition (Johnsen effect).

The deuteron beams which have been accelerated recently in the CPS had a longitudinal emittance of 0.2 eVs per bunch, but admittedly, no special care had been taken to reach lower values, as there has been no incentive up to now to do so[1]. Given the characteristics of the linac beam, values as low as 0.1 eVs could be hoped for[2] and this would fit the above mentioned SPS acceptance.

The number of oxygen ions accelerated per cycle in the CPS is supposed to be 3.10^8. These particles will be distributed in 15 bunches accelerated on harmonic 20[3].

The antiproton bunches are at present injected in the SPS with an emittance of 0.5 eVs. Clearly this value has to be halved either by distributing the particles among more bunches or by accepting a reduction of the intensity. The upgraded AA (with ACOL) will be capable of delivering up to 6 10^{11} pbars in a longitudinal emittance of 6 eVs. Therefore a bunch of 0.25 eVs could contain 2.5 10^{10} pbars.

III. Storage of counter-rotating $^{16}O^{8+}$ and pbar beams

The highest possible magnetic field which can be sustained at present in DC mode in the SPS corresponds to a momentum per nucleon of 315 GeV/c for the antiprotons and half this value for the oxygen ions. The relative difference in velocities between the two species under these circumstances is 1.3 10^{-5}. In order to produce collisions in well defined spots one can store debunched beams crossing at an angle. Another way is to use bunched beams circulating on different orbits in the machine arcs to give the same revolution frequencies but colliding head-on in the straight sections where the value of the dispersion is zero: in this way the difference in velocity is compensated by the difference in path length so as to maintain synchronism between the bunches of different particles. Let us examine the advantages and disadvantages of these two schemes.

1. Debunched beams crossing at an angle

Six batches containing each 15 bunches of oxygen ions, and extending over 1.6µs, could be injected in the SPS interleaved with six equispaced pbar batches. Each pbar batch would consist of two groups of bunches injected separately on two different CPS cycles and distant in the SPS by 700 ns to allow for the antiproton injection kickers' rise and fall time. Each group would originate from a single AA bunch of .5 eVs containing 5.10^{10} antiprotons. This bunch would be split in three adjacent bunches in the CPS and accelerated on harmonic 20. Allowing for some dilution in the process, the emittance of these small bunches would still be less than 0.25 eVs. The time available in between pbar batches is 2.7 μs, and this is sufficient to accommodate the 1.6 μs duration of the batch of ions plus 1 μs for the rise and fall time of the kickers (those normally used for proton injection). The bunches of ions as well as those of antiprotons would be compressed longitudinally in the CPS by the usual process on harmonic 20, as has been done routinely for years with protons.

This scheme would provide in the SPS beams of 6 10^{11}pbars and 1.8 10^{9} oxygen ions. The achievable luminosity depends on the minimum crossing angle possible, which in turn depends on the transverse emittances. With the present low beta insertion providing $\beta_H^* = 1$ m, $\beta_V^* = 0.5$ m at the crossing points, and assuming normalised emittances for both beams of 15 π 10^{-6} rad.m, the interaction diamond will have a length of 1 m for horizontal crossing angle $\psi = 0.84$ mrad.

The luminosity is given by the formula

$$L = \frac{f_{rev}}{2\pi R} \frac{N\bar{p}\ No}{h_{eff}\ \Psi/2}$$

where Npbar and No are respectively the number of antiprotons and of oxygen ions, R is the machine radius, f_{rev} the revolution frequency and h_{eff} the effective height of the beams at the crossing point ($h_{eff} = 2\sqrt{\pi}\sigma$ where σ is the r.m.s. amplitude of the particles).

For the above parameters this gives $L = 6.10^{24}$ $cm^{-2}s^{-1}$. This is a very modest value, and in addition, it is not possible to produce as large a crossing angle in the SPS low beta insertions. Therefore the only way to end up with reasonable numbers with debunched beams is to stochastically cool the transverse emittances. A moderate cooling by a factor 5 would allow a crossing angle of 0.38 mrad, comparable to what has already been achieved in the SPS experimentally with the electrostatic separators(4) and provide a luminosity of 3.10^{25} cm^{-2} s^{-1}.

S. v.d. Meer has shown[(5)] that with debunched beams in the SPS much larger cooling factors can be reached. For instance with a cooling factor of 100, a luminosity of 6.10^{26} is achievable with a crossing angle of .084 mrad.

A major drawback of debunched beams is the danger of positive ions trapping by the pbar beam potential. V.d. Meer[(5)] has shown that a clearing system is mandatory to get rid of these ions. However, his analysis was based on a residual pressure in the SPS vacuum chamber of 2.10^{-9} torr N_2 equivalent, whereas ten times lower values are now currently measured. This point therefore would deserve further scrutiny.

Another problem concerns the beam-beam tune shift. With the natural emittances the total beam-beam tune shift suffered by the oxygen ions is .039. This means that 10th order resonances cannot be avoided. Whereas this situation leads to a bad lifetime for bunched beams, it could possibly be tolerable for debunched beams. However, as soon as the beams are cooled, a scheme to separate them over most of the circumference must be devised. As the momentum spread of both beams will be as low as $\pm$ 3 10^{-4} a difference of 2 mm in the average radius of the orbits will provide a sufficient separation over 80% of the circumference. For a cooling factor larger than 5, separation must also be provided along the straight sections. A scheme using horizontal and vertical separators now being envisaged for ppbar[(6)] would have this capability.

2. Head-on collisions with bunched beams

In this scheme the major limitation comes from the fact that one cannot accelerate the full oxygen beam as it comes from the CPS, since single bunches are needed. Therefore the number of oxygen ions will be reduced to 1.2 10^{8} (in 6 bunches of 0.2 10^{8} each) and the number of antiprotons to 1.5 10^{11} (in 6 bunches of 0.25 10^{11} each).

Moreover, to ensure synchronism between bunches of the two species the antiprotons must be stored at an average radial position 7.2 mm outside and the oxygen ions 7.2 mm inside with respect to the central orbit. This is not possible with the low beta insertion used at present because of the too large chromatic aberrations it creates. However, a new chromaticity correction scheme including 5 sextupole circuits instead of the 4 circuits used a present is being studied with a view to increase the performance of the ppbar collider. If successful this scheme would provide enough momentum acceptance to accommodate the counter-rotating pbar and oxygen beams. The luminosity in this case would reach 1.3 10^{26} $cm^{-2}s^{-1}$. With the chromaticity correction as it is at present, enough momentum acceptance could be provided by "detuning" the low beta insertion up to $\beta_H^* = 3m$, $\beta_V^* = 1.5$ m (instead of $\beta_H^* = 1m$, $\beta_V^* = .5m$). But this would limit the luminosity to 4.3 $10^{25} cm^{-2}s^{-1}$.

In a few years the SPS collider could be equipped with a stochastic cooling system for bunched beams. Although cooling times for normal bunches of 10^{11} particles or so are calculated to be in the 30 hour range, the low intensity oxygen bunches could possibly be cooled to very low emittances in a few minutes. This would multiply the luminosity by a factor 2.

The acceleration of single bunches of oxygen of so low an intensity is likely to be problematic, especially in the presence of the counter-rotating dense antiproton bunches. One possibility could be to lock the oxygen RF system onto one or more batches of 15 bunches inserted in between the "useful" bunches and which would collide with the antiprotons far from the detectors.

<u>Remark</u>

In 1988 standing wave cavities will be installed in the SPS to accelerate electrons and positrons to 20 GeV/c and will provide an accelerating voltage up to 32 MV. Although these are non-directional devices, they can be used to create a directional accelerating system by feeding them in a special way ($\pi/2$ phase shift from cavity to cavity)[7]. This possibility would remove the restriction on the longitudinal acceptance for the pbar bunches and allow the acceleration of the full AA stack, in 6 bunches, thus increasing the luminosity by a factor 4 in the scheme with head-on collision of bunched beams. The oxygen bunches would not significantly profit from more voltage, because they have to pass transition where the possible momentum spread is severely limited.

IV. Conclusions and possible developments

The performance of the source of oxygen ions soon to be installed at CERN would allow colliding-beam experiments to be carried out in the SPS between these particles and antiprotons at a momentum up to 315 GeV/c for the antiprotons and 157.5 GeV/c per nucleon for the oxygen ions.

By using bunched beams colliding head-on, luminosities around $10^{26}cm^{-2}s^{-1}$ (and possibly up to $4.10^{26}cm^{-2}s^{-1}$ if the standing-wave cavities can be used) could be reached. This solution does not demand special developments but the problem of accelerating single bunches of ions of very low intensity together with counter-rotating antiproton bunches remains to be solved.

Using debunched beams crossing at an angle is another possibility, but a special transverse cooling system must be built in this case, and ion clearing might also prove necessary.

The most obvious way to increase the luminosity further would be to improve the performance of the source or replace it by a better one. A factor 5 to 10 increase in output current seems within reach[8]. Another route would be to debunch the beam in the CPS, apply stochastic momentum cooling and rebunch the cooled beam on harmonic one, thus increasing the single bunch intensity by a factor 15. Even more powerful, of course, would be the cooling and accumulation in a dedicated ring. But this is another story!

Due to the strong imbalance between the total energies of the colliding particles, experimenters may want to displace the collision point upstream of the detector in the direction of the incoming oxygen ions. While it presents no problem to displace the collision point, the geometry of the low beta insertion is fixed and this entails a loss of luminosity for non-centred collisions. The rule of thumb is that for a displacement of L meters the beta value at the new crossing point will be around 2L. For instance a displacement of 5 m means a loss of luminosity of a factor 20 for bunched beam collisions.

References

1. E. Brouzet, R. Cappi. Personal communication.
2. K.H. Schindl, Personal communication.
3. E. Brouzet, PS/DL/Min 85-1.1
4. L. Evans et al, CERN SPS 85-17.
5. S. van der Meer, CERN/PS/AA 79-42.
6. L. Evans et al, SPS/DI-MST/Note/85-2.
7. D. Eoussard, personal communication.
8. H. Hazeroth, Private communication.