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THE FEASIBILITY OF POLARIZED PROTONS IN THE SPS PROTON-ANTIPROTON COLLIDER

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Résumé. Nous résumons les études présentes et antérieures sur la réalisation pratique d'un faisceau de protons polarisés dans le collisionneur pp au SPS.

Abstract. Past and present studies on the feasibility of polarized protons in the SPS proton-antiproton collider are outlined.

1. Introduction

The purpose of this paper is to outline some of the problems associated with the storage of polarized protons in the SPS proton-antiproton collider. Some time ago 1] a detailed study of the feasibility of accelerating polarized protons throughout the SPS injector (PS) was made. The recent successful acceleration of polarized beams in the Brookhaven AGS 2] has shown that the problems anticipated in maintaining polarization in such strong focussing machines can be overcome with the appropriate hardware and with considerable care.

Recently, the feasibility of maintaining polarization through acceleration in a large proton synchrotron like the SPS has been assessed 3,4]. In such a machine the very large number of depolarizing resonances to be crossed makes the resonance jumping techniques used in the lower energy machines impractical. The solution proposed for the SPS was to install a Siberian Snake in order to make the spin tune equal to one half, independent of the energy. In this paper some of the additional constraints imposed by the requirements of colliding beam operation are examined.

2. Collider Performance

The luminosity in a hadron collider with head-on collisions between bunched beams is given by

\[ L = \frac{2N_pN_H}{\pi M} \left( \frac{\beta^*_H \beta^*_V}{\beta^*_H \beta^*_V (E_{Hp} + E_{H-}) (E_{Vp} + E_{V-})} \right)^{1/2} \]

where \( N_p, \bar{p} \) is the number of particles per bunch, \( f \) the revolution frequency (43.4 kHz for the SPS) \( M \) the number of bunches per beam, \( \beta^*_H, \beta^*_V \) the value of the horizontal and vertical betatron functions at the experimental crossing points and \( \beta^*_H, \beta^*_V \) the normalized horizontal and vertical emittances (2 sigma) divided by \( \pi \).

The following tables gives the design parameters relevant to equation 1), compared with the best achieved (November 1984).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \gamma )</td>
<td>288</td>
<td>336</td>
</tr>
<tr>
<td>( M )</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>( N_p(10^{11}) )</td>
<td>1</td>
<td>1.6</td>
</tr>
<tr>
<td>( N_p(10^{12}) )</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>( \beta^<em>_H(m), \beta^</em>_V(m) )</td>
<td>2 x 1</td>
<td>1 x 0.5</td>
</tr>
<tr>
<td>( \beta^<em>_H, \beta^</em>_V(\text{rad}) )</td>
<td>24 x 12</td>
<td>18 x 18</td>
</tr>
<tr>
<td>Peak luminosity ( (10^{29} \text{ cm}^{-2} \text{s}^{-1}) )</td>
<td>10</td>
<td>3.2</td>
</tr>
</tbody>
</table>
The preparation of both proton and antiproton bunches requires a complex series of manipulations in the PS. A single proton bunch can be transferred each PS cycle of 2.4 seconds duration. In order to allow the injection of three proton bunches followed by three antiproton bunches the SPS magnetic field is held constant at the injection level of 26 GeV/c for 14.4 seconds followed by 14.4 seconds for ramping to 315 GeV/c and then back to the injection level (Figure 1). Only on the cycle on which the antiprotons are transferred does the machine pass into storage mode.

![Injection Acceleration Low-β squeezing](image)

**Figure 1**

3. **Source Requirements**

It will be noticed that the required polarized proton intensity per CPS cycle is low (~ $10^{12}$), quite comparable with that already achieved with polarized beams at the AGS. The problem is to get all $10^{12}$ particles into a single 4 nanosecond bunch. With protons this is achieved by selecting only one of the 20 bunches accelerated in the CPS. Multiturn injection of polarized protons into the CPS at 50 MeV, supposing a 67 microsecond linac pulse with 50% injection efficiency would require $4 \times 10^{12}$ polarized protons per pulse, or nearly 10 mA out of the linac, clearly very difficult with state-of-the-art polarized sources. Obviously, more efficient ways of maximizing the bunch density must be used. One possibility is recombination of bunches in longitudinal phase space, a technique already under development at the PS.

For colliding beam operation the minimum possible transverse emittance is required in order to maximize the luminosity (equation 1). In this respect, negative ion injection into either the PS directly or via the PS booster should conserve the phase space density more efficiently than the multiturn process. However, here the rather low linac energy is a disadvantage in that the stripper foils must be extremely thin and delicate in order to avoid undue emittance blowup due to multiple traversals. In addition, present day polarized negative ion sources have considerably less peak current capability than H$^+$ sources.

4. **SPS Injection Energy**

The bunch line density in collider mode is about a factor of 20 higher than for fixed target physics. As a result a number of instability mechanisms have been identified which make it impossible to cross transition energy ($\gamma = 23.3$) without substantial loss [6]. In addition, Laslett space-charge detuning and the beam-beam interaction [7] require the highest possible injection energy (26 GeV/c) from the PS in order that both protons and antiprotons can be accelerated with good efficiency. This puts a tremendous charge on the PS, requiring acceleration through the very difficult high energy range above 20 GeV/c.

5. **Siberian Snakes**

A possible single Siberian Snake design for the SPS as as fixed target synchrotron has already been proposed [3]. However, in collider mode, where the
correct spin orientation must be achieved simultaneously at the injection point and in the two experimental areas, a double snake would be required. Almost certainly a lot of existing extraction equipment would have to be moved out in order to fit in a snake in straight section 2 as well as in straight section 5 of the SPS.

One positive aspect of the high injection energy is that the snake aperture requirement would be relaxed compared with the initial design.

6. Conclusions

The acceleration of polarized protons through the CPS/SPS complex presents many practical problems and requires a great deal of hardware and effort. Nevertheless, the only obvious technical limitation is that of the intensity of the polarized source. If sources for the milliampere range could be developed and if Siberian Snakes work as well as expected, it is not inconceivable that luminosities approaching those obtained with unpolarized protons could be achieved.

Acknowledgements

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References


Discussion

Prof. A.D. Krisch commented about trying to increase the intensity by using a booster and he mentioned that a programme to construct a booster is more or less approved at Brookhaven which is expecting to gain about a factor twenty in intensity.