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Abstract

The storage of antiprotons in the ISR for proton - antiproton physics is planned for 1981, using the 3.5 GeV/c, cooled, antiproton source, which is currently being built at CERN. Two schemes have been studied for achieving this aim. Firstly, the antiprotons could be injected at 3.5 GeV/c from the cooling ring and accelerated in the ISR or secondly, they could be injected into the ISR at 26 GeV/c after acceleration in the CERN Proton Synchrotron (PS). Although the latter scheme is more expensive, since it requires a new transfer line, it has been adopted as it is operationally more reliable and as it makes it possible to stack the antiprotons. With five full-intensity pulses, the circulating antiproton current would be 0.15 A, which, with a 30 A proton beam, would yield a luminosity of $1.3 \times 10^{29} \text{ cm}^{-2}\text{s}^{-1}$ in a standard intersection and $9.2 \times 10^{29} \text{ cm}^{-2}\text{s}^{-1}$ with the planned superconducting low- β scheme.

1. Introduction

The storage of antiprotons in the ISR was first discussed in 1962 by K. Johnsen¹ before the ISR were constructed. The idea was to collect antiprotons generated in a target by an ejected beam from the CERN-PS. Later, it was proposed to use antiprotons created from antihyperon decay^{2,3}. With the advent of the CERN 300 GeV/c Proton Synchrotron (SPS), a study was based on the use of a 200 GeV/c beam to produce the secondary antiprotons for the ISR either directly from a target or via antihyperon decay⁴. The estimated luminosity was in the range 10^{25} to $10^{26} \text{ cm}^{-2}\text{s}^{-1}$. The cooling of the antiprotons using an electron beam in a separate device is mentioned in this reference but not considered. The problem was re-examined in 1975⁵, this time with a 400 GeV/c primary beam. Electron cooling was again mentioned but not considered. Soon after, the possibility of electron cooling for antiproton beams produced from PS protons was studied⁶, but this was quickly followed by schemes based on stochastic cooling either in the ISR itself or in a separate ring⁷. For the latter case, a luminosity of $7 \times 10^{26} \text{ cm}^{-2}\text{s}^{-1}$ was estimated. Stochastic betatron cooling was first suggested by S. Van der Meer⁸ and stochastic momentum cooling is believed to have been first suggested by R.B. Palmer of Brookhaven National Laboratory during the 1975 ISABELLE Summer Study⁹. It was quickly recognized that, in order to achieve useful luminosities for physics, special cooling schemes would be essential and considerable work was carried out by the ISR Division in this field¹⁰. By this time, the idea of a separate accumulator ring operating with stochastic cooling at 3 to 4 GeV/c and using antiprotons made by PS protons on a target was well established. Achieving luminosities in the range 10^{29} to $10^{30} \text{ cm}^{-2}\text{s}^{-1}$ was thought to be possible¹¹. The emphasis then changed to using antiprotons in the SPS¹² following the work of C. Rubbia^{13,14} and the "Initial Cooling Experiment" (ICE) was set up in 1977 as a precursor of the Antiproton Accumulator¹⁵ which is currently under construction. Initially, it was foreseen to transfer the antiprotons from the AA ring to the SPS or the ISR at 3.5 GeV/c. However, for SPS operation, this scheme was abandoned in favour of having post-acceleration in the PS to 26 GeV/c¹⁶. Similarly, for ISR operation there are advantages in having post-acceleration to 26 GeV/c and following a final project study¹⁷, the proposal to build a new transfer line allowing 26 GeV/c injection was approved at the end of 1978. Although the 3.5 GeV/c injection option has been replaced by that for 26 GeV/c, it is briefly considered ISR Division, CERN, CH-1211 Geneva 23

here since if it were to be revived, it would be possible to have antiproton-antiproton collisions in the ISR.

2. 3.5 GeV/c Injection Option

Figure 1 shows the CERN site with the AA ring and the new transfer tunnels which are currently under construction. Originally, it was proposed to eject the antiprotons from the AA ring along TT2 into Ring 1 of the ISR at 3.5 GeV/c (dashed line in Fig. 1). For this mode of operation, the ISR must accelerate the antiprotons to their final energy in the range 11 to 31 GeV/c, which requires crossing transition. Not only would this have required a specially designed and installed transition jump, but it would have prevented the ISR from accelerating more than a single pulse of 30 mA, since no way is known for getting a coasting stack across transition. It would also raise problems of compatibility with low- β insertions and the question of whether it is better to ramp experimental magnets, such as the Split-Field Magnet, which has a 900 ton solid core, during the acceleration or to wait until the final energy is reached. When studied in detail¹⁷, these problems do not turn out to be impossible to solve but their concurrence leads to a long and complicated setting up procedure with poor reliability.

3. 26 GeV/c Injection Option

For post-acceleration, the antiprotons are returned to the PS via TTL2 and TT2 (Fig. 1). After acceleration, the particles can either be ejected to the SPS via a new line TT70 or to the ISR via a new line TT6 and the existing line TTL1. Thus, the ISR is relieved of the task of accelerating the beam from 3.5 GeV/c for which it is manifestly ill-suited and instead it is possible to exploit its excellent storage capabilities and stack antiproton pulses over several days so giving far higher luminosities than were possible with the 3.5 GeV/c injection scheme. These considerations led to the adoption of the 26 GeV/c injection scheme despite its higher cost and it is hoped, using this scheme, to have antiprotons circulating in the ISR in 1981.

4. Antiproton Operation and Estimated Luminosities

One important difference from normal operation will be the rarity of antiprotons. It will take 24 h of continuous accumulation to reach the design figure of 6×10^{11} antiprotons in the AA ring, which gives only 30 mA of circulating beam in the ISR. Thus, there will be a high premium on accurate and efficient steering and diagnostics in the transfer lines in order to avoid losses. TT2 and TTL2 can be tuned with protons travelling in the opposite direction to the antiprotons. This also applies to TT70 which can be tuned with protons ejected from the SPS, but the TT6 line can only be tuned with antiprotons and specially sensitive electromagnetic pick-ups will be installed in order to do this with low-intensity pre-pulses from the AA ring.

Somewhat arbitrarily, an operation cycle of stacking five pulses of 6×10^{11} antiprotons over four days followed by six days of stable beam conditions has been adopted (Fig. 2). The initial setting up time has been estimated at 8½ h after which the beams are available for physics except for brief interruptions of 1 h for the injection of new pulses.

Table 1 lists the peak and integrated luminosities in a standard ISR intersection and in the conventional

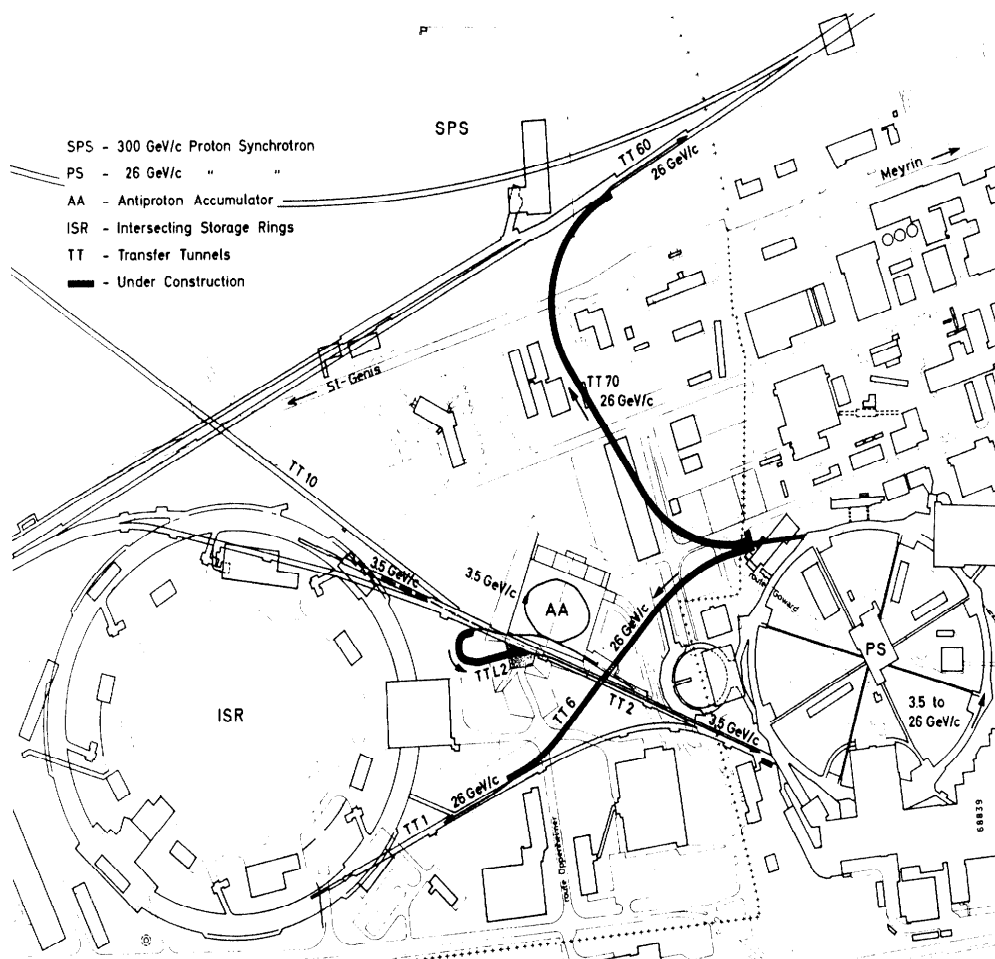


Fig. 1 The Transfer of Antiprotons Between the CERN Machines

and superconducting low- β schemes assuming a 30 A proton beam, 100 % survival and zero transverse emittance blow-up during transfer from the AA ring to the ISR and no stochastic cooling for either beam in the ISR. Table 1 is based on 26 GeV/c operation but operation at lower energies will be possible with the same operation cycle (Fig. 2). For the maximum ISR energy of 31.4 GeV/c, the stacking over the first four days will be at 26 GeV/c and only once the stacking has been completed will the coasting beams be accelerated by phase displacement to 31.4 GeV/c.

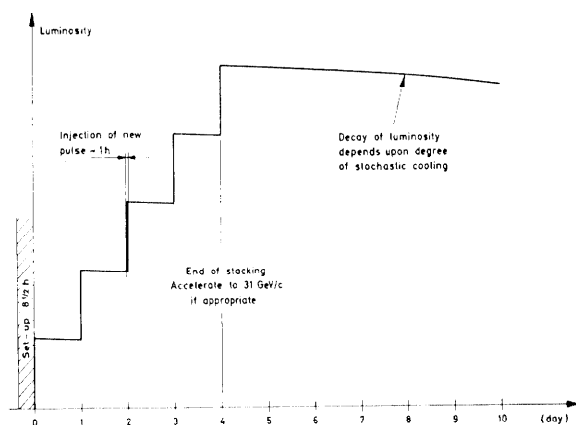


Fig. 2 Luminosity Profile During a 10-Day Physics Run With Stacking During the First 4 Days

TABLE 1

ISR Performance at 26.6 GeV/c

Conditions: $I_p = 30$ A, $I_{\bar{p}, \max} = 0.15$ A

Intersection		Standard	Steel low- β	SC low- β
Parameter		$\beta_V = 14$ m	$\beta_V = 3$ m	$\beta_V = 0.3$ m
σ_p	[mm]	1.18	0.55	0.17
$\sigma_{\bar{p}}$	[mm]	0.68	0.31	0.10
h_{eff}	[mm]	3.4	1.6	0.5
L_{max}	[cm ⁻² s ⁻¹]	1.3×10^{29}	2.8×10^{29}	9.2×10^{29}
$\frac{1}{L} \frac{dL}{dt}$	[s ⁻¹]	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}
$\int L dt$ (10 days)	[cm ⁻²]	5.7×10^{34}	1.2×10^{35}	4.0×10^{35}

5. Use of Stochastic Cooling in the ISR

It has been tacitly assumed above that it is best to collide the antiprotons with the highest possible intensity proton beam. However, for many experiments, a small loss in luminosity would be readily accepted if the current loss rates and hence the background could be reduced to zero. Stochastic cooling offers this possibility and furthermore the integrated luminosity may not in fact be lower than for the high-intensity, non-

cooled case. In order to evaluate the potential gain, some conservative assumptions were made and the highest proton beam current was computed¹⁸ at which a somewhat improved version of the existing experimental equipment for cooling in the ISR would balance the beam blow-up due to intra-beam scattering, gas scattering and coupling for a vertical emittance equal to that of the incoming antiproton beam. The antiproton beam is also assumed to have its emittance maintained constant by cooling. The results of these calculations are given in Table 2.

TABLE 2

Estimated 26 GeV/c Performance with Cooled Beams

Conditions: $I_p = 7.25$ A, $I_{\bar{p},\max} = 0.15$ A with cooling

Intersection		Standard	Steel low- β	SC low- β
Parameter		$\beta_V = 14$ m	$\beta_V = 3$ m	$\beta_V = 0.3$ m
σ_p	[mm]	0.68	0.31	0.10
$\sigma_{\bar{p}}$	[mm]	0.68	0.31	0.10
h_{eff}	[mm]	2.4	1.1	0.35
$L_{\max}$	[cm ⁻² s ⁻¹]	4.5×10^{28}	9.9×10^{28}	3.1×10^{29}
$\frac{1}{L} \frac{dL}{dt}$	[s ⁻¹]	0	0	0
$\int L dt$ (10 days)	[cm ⁻²]	3.1×10^{34}	6.8×10^{34}	2.1×10^{35}

Symbols Used in Tables

σ = standard deviation of the vertical particle distribution,

$$h_{\text{eff}} = \sqrt{2\pi} \sqrt{\sigma_p^2 + \sigma_{\bar{p}}^2},$$

L = luminosity,

I = current,

$p, \bar{p}$ = proton or antiproton parameters,

β_V = vertical betatron amplitude function,

t = time.

6. Experimental Magnets

The Split-Field Magnet spectrometer, the Superconducting Solenoid and the Open Axial Field Magnet substantially affect the circulating beams and since they are common to both beams, their fields cannot be simply reversed for antiproton operation. In the case of the Split-Field Magnet, this has made it necessary to accept a reduced horizontal aperture for the antiproton beam. The effect of the Superconducting Solenoid will be to separate the two beams vertically by ~ 17 mm. This will be corrected by adding vertical orbit bumps of ± 8.5 mm to each beam, for which new dipoles will be needed. Fortunately, the Open Axial Field Magnet has far less influence and the existing vertical orbit correctors are sufficient to bring the beams into head-on collision. All other experimental magnets can be used without any special considerations.

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