PROPOSED P-$\bar{P}$ COLLIDING BEAM FACILITY AT CERN

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I. Introduction

Following the proposal of Budker and Skrinsky in 1966 and the subsequent experimental studies of electron cooling, Rubbia suggested various schemes for collecting antiprotons, injecting them in the SPS, accelerating them together with protons and colliding the beams at energies up to 270 GeV.

During 1976, working groups examined these possibilities and as a result a cooling experiment (ICE) and a study group were initiated. In the course of these studies, important advances were made in the theory of stochastic cooling. This technique, proposed by van der Meer in 1968 had seemed too slow for our application. However, some new techniques were proposed which, combined with the theoretical advances, indicated the feasibility of a fast pre-cooling of each injected pulse in momentum space before adding it to the stack.

Consequently, the initial proposal for a two-ring solution based on electron cooling was abandoned in favor of the present proposal. This decision has now been confirmed by the outstanding results of stochastic cooling tests on ICE.

II. Basic Parameters

A fundamental requirement on any proposed scheme was that its construction, testing, and operation should have a minimum impact on the existing research programs of the SPS and ISR. This alone indicates the need to use protons at PS energy for producing the antiprotons.

The basic scheme consists in directing 26 GeV/c protons from the PS on to a target. The antiprotons produced will be focussed and injected into a fixed-field cooling ring. Each injected pulse undergoes a rapid pre-cooling to reduce its momentum spread, after which it will be deposited by the rf system at the top of the stack. The stack is cooled continuously, both longitudinally and transversely so that particles slowly migrate to the bottom of the stack. The overall layout proposed is shown in Fig. 1.

To achieve the design luminosity of 10^{30} cm^{-2} sec^{-1} at 270 GeV/c it is necessary to collect, cool, and stack antiprotons for many hours. Studies of lifetimes in the SPS and feasible improvements to the average vacuum indicated that a luminosity lifetime of about 24 hours could be expected at 270 GeV/c. Consequently, the present design is based on collecting sufficient antiprotons in ~24 hours to reach luminosities of ~10^{30}.

Initial experiments with intense single bunches in the SPS indicate that about 10^{11} protons per 200 MHz bunch can be captured and accelerated, within invariant emittances of about 10π μrm. A low-beta insertion was designed which leaves free the space between two existing SPS quadrupoles (29m) and gives beta values of 4.7m horizontally and 1m vertically.

If we assume similar emittances for the antiprotons, applying the luminosity formula indicates a requirement to accumulate ~10^7 $\bar{p}$'s per second. With the present PS intensity of 10^{13} ppp, a cycle time of 2.6 secs, and collecting $\bar{p}$'s of 3.5 GeV/c, this can be attained within a momentum bite of ±0.75% and transverse emittances of 100π μrm.

III. Cooling Ring

The ring diameter must be as small as possible to minimize the stochastic cooling requirements. Since means exist to confine the protons in one quarter of the PS circumference, the cooling ring can have one quarter the diameter of the PS. At 3.5 GeV/c this allows a design with adequate space for injection, extraction, cooling, and diagnostic equipment.

To provide adequate "mixing" of particles η must be at least 0.1 (i.e., $\gamma_{tr} < 2.45$) which in a ring of average radius 25m implies an average $\alpha_p \simeq 4.2$m. However, injection of the large emittance, large momentum spread beam requires α_p close to zero at the septum to minimize the "kick" strength required. Also the stacked beam must be screened from the injection kicker by means of a moveable shutter. To minimize the momentum separation required to achieve this, α_p at the injection kicker should be large. For similar reasons, the pre-cooling kickers have shutters and must be located at large α_p. In addition, to avoid blow-up of betatron oscillations the pre-cooling kickers are located in two regions of equal α_p separated by half a betatron wavelength. The focussing lattice designed to satisfy these conditions is shown in Fig. 2. The aperture requirements are based on the need to have a stacked beam with a total momentum width of 2.5%, an injected beam of 1.5%, both with horizontal and vertical emittances of 100π μrm and separated by a momentum "gap" of 1.8% (Fig. 3). The corresponding apertures are shown in Fig. 4 and the overall layout of the ring in Fig. 5.

IV. Some Limitations

In order to make use of the extracted beam line TT 60 for reverse injection to the SPS, a vertical emittance limit of $E_V = 1\pi$ μrm is imposed. With 6×10^{11} antiprotons in the cooled stack within this emittance, evaluation of intra-beam scattering following Piwinski's theory shows that the beam blow-up can be overcome by the stochastic cooling for a final horizontal emittance, $E_H = 1.4\pi$ μrm and a total momentum spread of $\delta p/p = 3\times10^{-3}$. This corresponds to a total bunch area of 5.63 eV sec.

The SPS rf system has a nominal frequency of 200 MHz and will be able to supply a peak voltage/turn of 8.8 MV. The traveling-wave structures accelerate only in one direction so that connecting half the cavities in the opposite sense allows the p and $\bar{p}$ beams to be treated separately with up to 4.4 MV/turn. For stationary buckets at 270 GeV/c this provides a bucket area of about 2 eV sec. This leaves no margin for dilution of the antiproton bunches unless the number of bunches is 4 or more. The number of bunches proposed is 6, which leaves open the possibility of utilizing more than one of the 6 long straight sections for colliding-beam physics. Although this leaves some margin in the bucket area at 270 GeV/c, the area available near transition energy in the SPS is insufficient. Consequently it is proposed to accelerate each of the 6 bunches in 4 adjacent 200 MHz buckets up to high energy. There the 4 adjacent bunches will be coalesced into a single 200 MHz bucket.

V. Injection and Initial Acceleration Into the SPS

Many options exist for the detailed scheme of capturing the antiproton and proton bunches in the SPS and for their initial acceleration without incurring excessive Laslett Q shift. These are being studied both theoretically and experimentally at present.

The scheme proposed initially is to trap 1/6 of the stack in the cooling ring in a small bucket (h = 1), accelerate it to the injection/ejection orbit and then eject it along TT2A and down TT60 thence into the SPS.

The 6 bunches thus formed would be captured by a subsidiary rf system in the SPS running at 2.6 MHz (h = 60) with an initial bunch length of 80m. Subsequently, the shortened bunches would be recaptured and rotated at h = 210 in larger buckets. After this, each 5.7m long bunch is captured into the four adjacent 200 MHz buckets. Both proton and antiproton beams are then accelerated by the normal SPS rf system up to the required collision energy.

The main parameters of the proposed scheme are shown sequentially in Fig. 6.

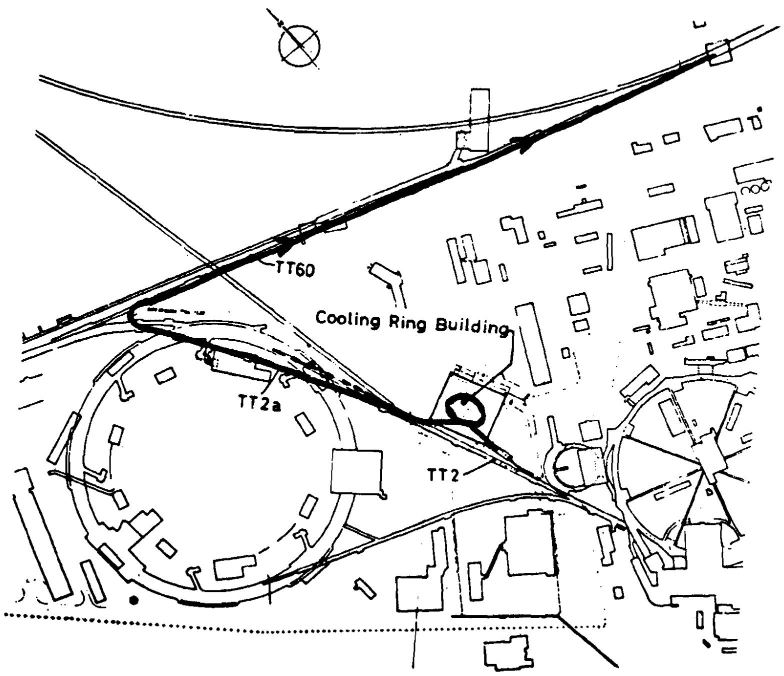

Fig. 1. Overall site layout

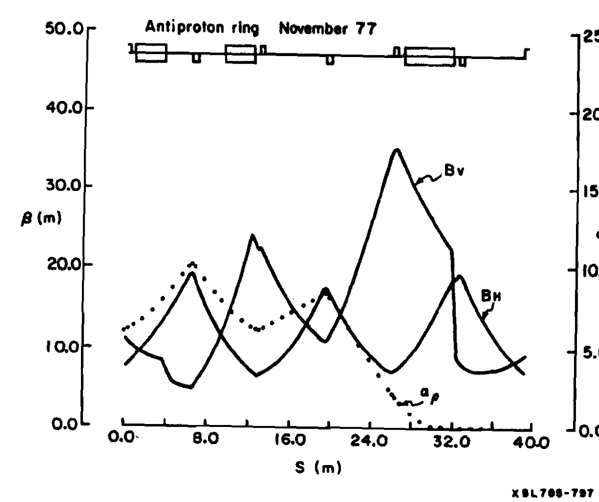

Fig. 2. Focussing lattice

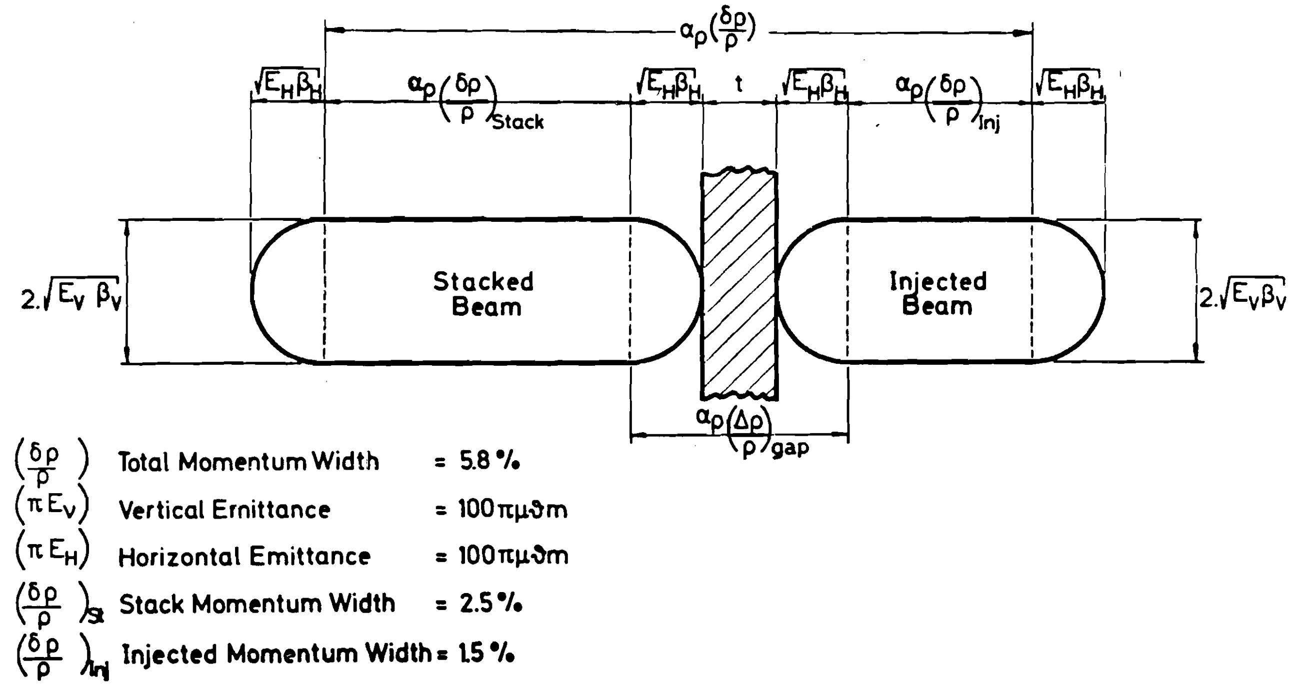

Fig. 3. Machine acceptance

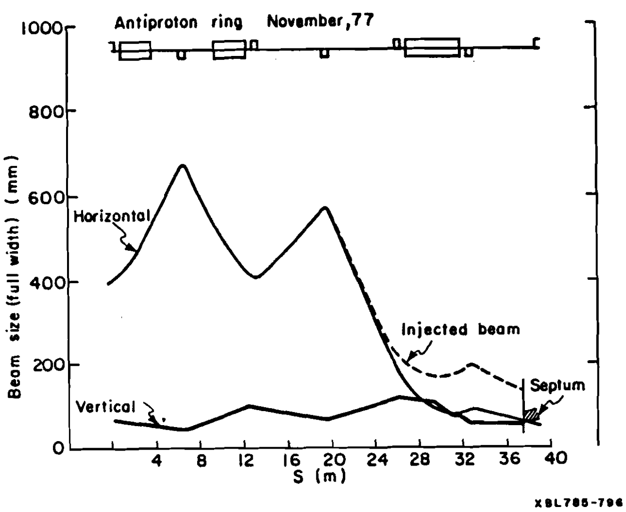

Fig. 4. Apertures

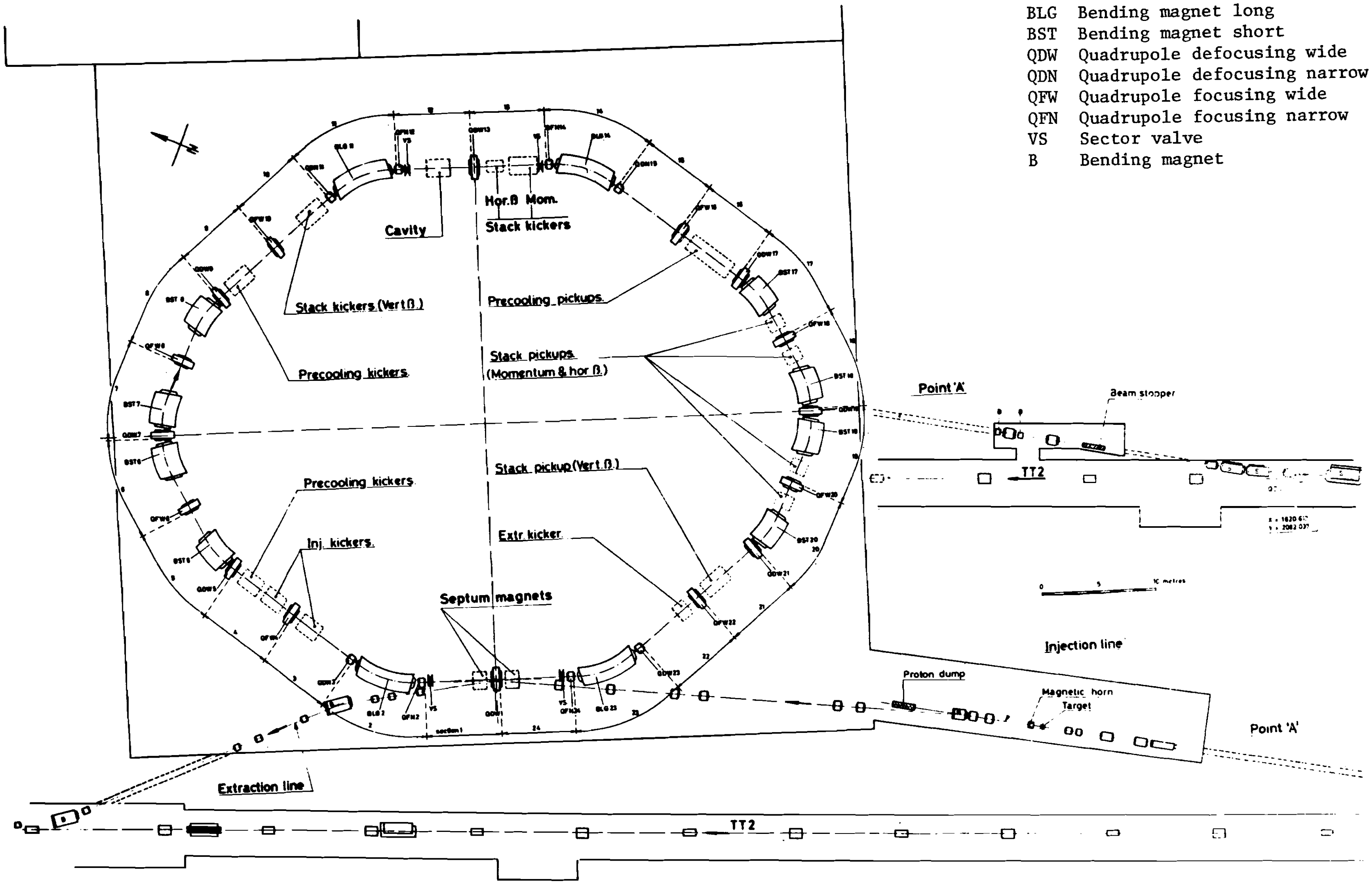

Fig. 5. General layout of the antiproton accumulator

MAIN PARAMETERS

10^{13} protons at 26 GeV/c each 2.6 secs.

$\Downarrow$

2.5×10^{7} $\bar{p}$'s at 3.5 GeV/c within: -

$$\frac{\delta p}{p} = \pm 7.5\%$$

$$E_{\gamma} = 100\pi\mu\text{rm}$$

Pre-Cooling $\frac{\delta p}{p}$ from ± 7.5‰ to ± 1‰ in 2 secs.

$\Downarrow$ X 24,000 in 18 hours.

Stack $\frac{\delta p}{p} = \pm 12.5‰$: $E_H = 100\pi\mu\text{rm}$: $E_{\gamma} = 100\pi$

$\Downarrow$

6×10^{11} $\bar{p}$ in $\frac{\delta p}{p} = \pm 1.5‰$: $E_H = 1.4\pi\mu\text{rm}$: $E_{\gamma} = 1\pi\mu\text{rm}$.

$\Downarrow$

Colliding Beams at 270 GeV/c

6 bunches p, $\bar{p}$ each 10^{11} and 1.5m long.

Interaction Region $\beta_H = 4.7\text{m}$: $\beta_V = 1.0\text{m}$

Emittances (E_H, E_V): $\left.\begin{array}{ll} \text{protons} & 6.9 \times 3.5 \\ \text{antiprotons} & 3.8 \times 1.9 \end{array}\right\} \times 10^{-8}\pi$ rad m.

Luminosity: 10^{30} cm^{-2} sec^{-1}

L. Lifetime 24 hrs at 2×10^{-9} Torr.

Fig. 6. Main parameters of the proposed scheme