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ON THE FEASIBILITY OF ANTIDEUTERON PRODUCTION AND STORAGE AT CERN

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ABSTRACT

The new Antiproton Accumulator Complex is now in operation at CERN. We consider the possibility of using this facility to create and store antideuterons and conclude all that we could achieve an accumulation rate of about $2 \cdot 10^6$ particles/day. No major rebuild of the rings is envisaged, but it is thought that modification to existing components and becoming operational would take about 5 to 6 months. We stress, however, that the operation of such a facility and the use of any stack of antideuterons for particle physics would be extremely taxing.

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1. INTRODUCTION

From the beginning of the Antiproton Accumulator, AA, project and then subsequently the Low Energy Antiproton Ring, LEAR, there has been a certain interest, extending beyond simple curiosity, in examining the possibilities of producing, collecting and storing other light anti-nuclei, particularly antideuterons. Their production rates in the collision of accelerated protons with target nuclei were estimated by Hagedorn in the early sixties [1], and antideuterons from this source were experimentally observed at Brookhaven [2] and at CERN [3] in 1965. Production ratios with respect to negative pions were measured in these experiments.

A separated antideuteron beam has since been set up at IHEP, Serpukhov [4], where a proton beam of 70 GeV/c and below is used with an external target (beryllium, aluminium and iron) to produce secondary antideuterons at 12 GeV/c into a solid angle of 18 μ sr and a momentum bite of $\pm 1\%$. The rate is given as just below one antideuteron per 10^{12} primary protons.

The successful production and storage of cooled beam of antiprotons [5] led to a proposal [6] to produce low-energy antideuterons from colliding beams of antiprotons via the reaction $\bar{p} + \bar{p} \rightarrow \bar{d} + \pi^-$. A schematic double-ring collider has been proposed by Möhl et al. [7]. The conversion efficiency would be $5\bar{d}$ per $10^4 \bar{p}$ and the $\bar{d}$ yield about 0.5 $\bar{d}/s$.

CERN has just completed the Antiproton Collector Project, AAC, with the aim to increase the previous AA accumulation rate by a factor of 10. It is, therefore, a suitable time to review the possibilities of collecting antideuterons in the new machine complex.

2. THE ANTIPROTON ACCUMULATOR COMPLEX, AAC

The ACOL project added the Antiproton Collector, AC to the AA, which was itself modified, and provided a new Antiproton Production, AP, area, in which is housed the production target and the parts of the transfer lines subject to high radiation levels. Some estimations of the ultimate performance of the AAC are given in another report at this symposium [8]. The ACOL design goal was to collect antiprotons at a rate of $6 \cdot 10^{10} \bar{p}/h$ and the ultimate value is about double this rate, allowing for some technological optimism. For the estimates of antideuteron production we shall use the ACOL design values.

The 26 GeV/c production beam is focused onto an iridium target, from which negative secondaries of 3.5 GeV/c in a 6% momentum bite are transported to the AC. Very close to the target is the 20 mm diameter lithium lens, which is the first element in the transport line. This lens collects secondaries into a transverse acceptance of 200π mm.mrad corresponding to laboratory production angles up to 73 mrad (5.3×10^{-3} sr). The present best antiproton yield is 5×10^{-6} $\bar{p}/p$, and this should rise during 1988 to 7×10^{-6} $\bar{p}/p$. That would give a production rate of 5×10^{10} $\bar{p}/h$ (assuming 10^{13} p/pulse and 50% of the PS cycles). The accumulation rate would be lower due to inefficiencies in the collection, transfer and cooling.

The AC accepts the bunched beam from the target, reduces the momentum spread by bunch rotation and then by momentum stochastic cooling, while at the same time cooling in both transverse planes. After 4.8 s (later to be 2.4 s) the beam has a momentum spread of a few per mil and transverse emittances of 25π mm.mrad.

The cooled beam from the AC is transferred to the stack tail in the AA and then cooled into the stack. The AA was modified to cope with the expected higher stack intensities, and the transverse acceptances were reduced to 25π mm.mrad.

3. ANTIDEUTERON PRODUCTION

The experimental ratios of $\bar{d}/\bar{p}$ production cross sections for production beams of 70 GeV/c momentum and below are plotted in Fig. 1. The secondary momentum, production angle, or transverse momentum, and target materials are also indicated. The point at 70 GeV/c, for 13.3 GeV/c secondary momentum, corresponds to the peak of the experimental curve relating $\bar{d}/\bar{p}$ to $\bar{d}$ momentum (the $\bar{p}$ cross section is that for antiprotons of one half the $\bar{d}$ momentum). The other data points are for secondary momenta below the production peaks at the respective primary momenta as will be the case for $\bar{d}$ production at the AAC. Koch [9] has, by interpolation, estimated the $\bar{d}/\bar{p}$ ratio for 26 GeV/c primary, 3.5 GeV/c secondary, in the forward direction to be 4×10^{-6} $\bar{d}/\bar{p}$. This leads us to expect 200 $\bar{d}$ per pulse (10^{13} p) in the AC.

Source		p_{inc} (GeV/c)	p_{sec} (GeV/c)	p_T (GeV/c)	Lab. angle
● Antipov et Al. [10]	p-Al	70	13.3	0.6	
○ Binon et Al. [11]	p-Al	52	18.7		0°
○ Binon et Al.	p-Al	43	15.5		0°
▼ Dorfman et Al. [2]	p-Be	30	5	0.4	
X Massam et Al. [3]	p-Be	19.2	2.5		6°

Fig. 1 - Experimental antideuteron/antiproton production ratios, R_d/R_p , where $R_d = \bar{d}/w^-$ and $R_p = \bar{p}/w^-$.

4. ACCUMULATION OF ANTIDEUTERONS

Antideuterons cannot be accumulated in the Antiproton Accumulator Complex as it presently stands, due mainly to their lower velocity in the accumulator ring when it is operating at normal (maximum) magnetic field levels. The velocity of antideuterons is 0.88 c compared with 0.96 c for antiprotons with the same magnetic rigidity. There is a great demand for the antiproton source over the next few years, for both SPS collider physics and the LEAR program, so that the conversion to antideuterons seems excluded in the near future. However, we did ask the following questions. When we are no longer required to furnish antiprotons, what changes would be required (excluding a complete rebuild of the rings themselves) in order to be able to accumulate antideuterons; would we be able to maintain the same accumulation efficiency as for antiprotons; what limits would arise from operational aspects (i.e. low intensity beams) and what would be the length of time to achieve such a transformation. As we will see, the effort would be largely one of manpower and although we have not made any cost estimates, it should not be very expensive in materials. However, we must stress that even if we see no theoretical barriers, the program may be impracticable from an operational point of view.

The first problem encountered is the operation of debunching cavities in the Collector ring. These cavities convert the short incoming bunches which have a 6% energy spread to essentially a continuous beam with the energy spread reduced to be within the capacity of the collector ring momentum cooling system and which contribute a factor 4 to the accumulation yield. It would be necessary to retune and operate them at the new revolution frequency which would be 9% lower than at present. This appears possible but would probably require that they must be dismantled so that the tuning system could be modified. A further problem, which may be more serious, is that the spacing of the incoming bunches will correspond to the frequency of the protons in the PS before these are ejected onto the target. The circumference of the collector ring was designed so that the frequency given by

$$\text{Harmonic number} = \text{particle velocity/ring circumference}$$

is the same for the PS and the Collector ring. At present the harmonic

numbers for the PS and the Collector are 20 and 6, respectively. The length of the Collector corresponds to 6 rf periods allowing it to receive 5 bunches at the PS frequency and leaving one period for the falling edge of the injection kicker.

We can partially correct for the lower antideuteron velocity by using harmonic number 18 in the PS, reducing the error in the bunch spacing to 1%. If the centre bunch of the five coming from the PS is timed correctly this gives a phase error at the debuncher cavity of 7.2° for the first and last bunches. We guess that the accumulation yield needs to be derated by a factor of 0.7.

The next problem lies with the stochastic cooling systems, first in the Collector and then in the Accumulator ring. All filters in the feedback system have to be recalculated and rebuilt to allow for the new revolution frequencies. The notch filter for the momentum cooling in the Accumulator has to be lengthened. The power combining systems for cooling pick-up and kickers have to be rebuilt because of the change in particle velocity. All this is possible - the time required for this work (assuming all preparations are made in advance) is estimated to be about 3 months and is determined mainly by the need to rebuild the Collector ring pick-up system which is housed inside the pick-up vacuum tanks.

There will be a mismatch between the particle and wave velocities in the pick-up and kicker structures for the Accumulator stack cooling system but it is expected that adequate cooling times can be achieved. The antideuterons will be injected into the Collector ring along with about 10^5 as many antiprotons. Although the revolution frequencies for the two types of particles are different, about half of the harmonic will overlap. The signal from the antiprotons will act as noise for these overlapping harmonics. This noise power will be comparable to the already existing amplifier noise and one might estimate that this effect would reduce cooling rates by a factor of 2 as only a half of the bandwidth would be effective. Otherwise, cooling rates would be limited by amplifier noise to about those obtained for antiprotons.

Should the contaminating antiprotons interfere with the cooling of antideuterons in the Collector ring, it would be possible to remove a considerable number of them by capturing them with the rf system, sweeping them into the chamber wall. It is hard to see that many of the

uncooled antiprotons could survive the transfer between rings, the rf transfer to the stack tail region and the stochastic transfer into the Accumulator stack core but if any should survive, they could be removed by sweeping the stack with empty rf buckets at the antiproton frequency.

Operational difficulties arise because of the very low number of particles we are dealing with. Fortunately we have the possibility of tuning up the cooling systems by injecting a 3.5 GeV/c deuteron beam directly from the PS while operating the AAC in reversed magnet polarity. The time needed to become ready for operation would be 1 to 2 months after all modifications had been completed. Observation of antideuterons in the Collector ring, during accumulation, would not be possible with the existing equipment. Today's state of operation with antiprotons emphasizes the difficulty of maintaining peak performance over a period of days although, after a year or so of operation, we expect that this will become easier. This would be essential for antideuteron operation as we can only expect a maximum stacking rate of 2×10^6 particles/day with 100% utilisation of the PS. This estimate for the stacking rate includes a factor of 0.5 because neither bunch rotation or cooling are expected to be as efficient as for antiprotons.

The use of the accumulated deuterons for particle physics poses further problems. With the low, maximum accumulation rate, it would not be possible to consider beam transfer to LEAR via the PS, as the minimum intensity required in the PS for beam control for deceleration is about 10^9 particles i.e. about 140 days of uninterrupted stacking. This limit might be reduced to a few 10^8 with today's equipment, but to decelerate a smaller number of particles considerable development is required. There is always the possibility of using the simultaneous deceleration of deuterons and with the invisible antideuterons, but at present, there is no satisfactory method to handle a smaller number of antideuterons in the PS. Although one could envisage the insertion of an internal target in the Accumulator ring, it is hard to see how any useful experiment could be mounted in the space available, especially at small angles. It is of course quite straightforward to make a fast extraction of a portion of the stack and send it down the 3.5 GeV/c transfer line towards the PS.

We wish to acknowledge the useful comments on accumulating antideuterons from our colleagues in the PS Division.

REFERENCES

- [1] R. Hagedorn, *Nuovo Cimento* 25 (1962) 1017.
- [2] D.E. Dorfan et al., *Phys. Rev. Letters* 14 (1965) 1003.
- [3] T. Massam et al., *Nuovo Cimento* 39 (1965) 6574.
- [4] V.V. Vasiliev et al., 11th Int. Conf. on High Energy Accelerators, Geneva, 1980, Ed. W.S. Newman (Birkhäuser Verlag, Basel, 1980) p. 369.
- [5] S. van der Meer, *Trans. on Nuclear Sci.* NS-28 (1981) 1994.
- [6] H. Pilkuhn and H. Poth, CERN $\bar{p}$ LEAR Note 86 (1980).
- [7] D. Möhl et al., *Nucl. Inst. and Methods* 202 (1982) 427.
- [8] C.D. Johnson, This symposium, (1987).
- [9] H. Koch, CERN $\bar{p}$ LEAR Note 42 (1979), and this symposium (1987).
- [10] Yu.M. Antipov et al., *Soviet Journal Nuc. Phys.* 13 (1971) p. 78.
- [11] F. Binon et al., *Phys. Letters* 30B (1969) p.510.