Presented at Workshop on Polarized Antiproton Sources
April 18-21, 1985 - Bodega Bay, California

SUMMARY OF WORKSHOP

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I will try to briefly summarize the activities and conclusions of this Workshop on how to produce a source of spin-polarized antiprotons. I want to stress that the opinions presented here are purely my own. I am sure that some of the participants will not exactly agree with my evaluation of some of the ideas; but that is the danger that accompanies the fun of summarizing a workshop on such a forefront and speculative subject.

I would like to begin by thanking Owen Chamberlain who is even more responsible than me for this workshop. The Workshop grew out of discussions which we had at the Marseille Spin Symposium, last September, in which he expressed amazement at the successful operation of the CERN antiproton collider. He recalled that in the 1950's he and Segre had to wait a long time for a single antiproton and they certainly did not think that one would ever store, manipulate and collide antiproton beams. In view of this progress and both of our long term interests in spin-polarization we decided that we might encourage another "impossible dream" by hosting a workshop on how to polarize antiprotons.

The idea was to invite a number of clever physicists from rather different areas of physics which might impact on this formidable problem. Our hope was that a short but intense interaction between these people who normally do not interact would be constructive and that some new and workable ideas for polarizing antiprotons might emerge. We purposely held the Workshop in this very isolated village to insure that there would be no distractions and to maximize the interactions between the participants.

The workshop opened with review lectures by two experts who defined our present knowledge of the two fields which the workshop hoped to unite. W. Haeberli of Wisconsin reviewed the status of polarized proton ion sources[1] and S. van der Meer of CERN reviewed the storage of antiprotons[2]. Since both of these distinguished gentlemen have given similar lectures many times we agreed that they did not have to again write up these lectures which can be found in the literature[1,2].

The majority of the workshop was spent in parallel working groups of about 5 to 10 people which were presided over by a Coordinator. One could attain the status of Coordinator by proposing an idea for polarizing antiprotons either before or during the workshop. The critical evaluation of these ideas was fairly rapid and sharp, thus the tenure of most Coordinators was fairly brief. I will describe in some detail all of the suggested ideas which I can recall, even those which were quickly rejected. This is because of my concern that we may have been too critical in dispatching some of the ideas. Moreover it has been difficult to get detailed manuscripts from Coordinators whose proposals were rejected in 15 minutes with statements such as "...it is impractical because the signal to background ratio is 10^{-42}."

1. Polarization of Antiprotons from Antihyperon Decay (Coordinator A. Yokosawa)

Antihyperons are produced when a Multihundred-GeV proton beam strikes a target. The antihyperons decay into antiprotons, which should have the same polarization as the protons from hyperon decay. A polarized proton/antiproton beam of this type is being built at Fermilab. The antiprotons should have a polarization of about 50%. The low intensity and large phase space may make it difficult to store and accelerate these polarized antiprotons; however it should certainly be possible to scatter them from a polarized or unpolarized proton target. This Fermilab beam should begin operation by early 1987.

2. Polarization of Antiprotons Using a Spin Filter (Coordinator D. Cline)

The Spin Filter technique uses a polarized proton gas jet which is placed inside an antiproton ring. One then accelerates or decelerates the antiprotons to some energy where the proton-antiproton total cross section is different when the spins are parallel and antiparallel. The antiprotons in one spin state are then scattered more often and disappear more quickly from the storage ring. After perhaps 10 or 20 hours the remaining antiprotons should have a significant spin polarization. Fortunately several groups are already developing polarized atomic hydrogen jets for various reasons. Niinikoski (CERN) described some of these efforts including his own at CERN and the Michigan-MIT effort at Brookhaven.

This Spin Filter technique appeared practical and quite promising provided some energy is found at which the total cross section for antiproton-proton scattering depends markedly on whether the colliding particles have parallel or antiparallel spins. There are no data on the total cross sections for polarized antiprotons colliding with polarized protons. Hopefully a significantly spin-dependent total cross section will be found in the energy region below 1 GeV, where the proton-proton spin dependence is so large that some physicists feel that it indicates the existence of dibaryon resonances or bound states. A low energy beam of antiprotons can be polarized by elastically scattering them at certain angles. By scattering these upon a polarized proton target one can measure the spin dependence of the antiproton-proton total cross section. This measurement should be made both with the spins parallel to the beam direction and then transverse to the beam direction. A number of participants, especially W. Haeberli, E. Steffens[3] and D. Cline are considering such measurements possibly at LEAR or Fermilab. The larger the spin cross-section difference the easier it will be to polarize a coasting beam of antiprotons.

3. Polarization of Antiprotons Using Stochastic Techniques (Coordinator O. Chamberlain)

By analogy to the Stochastic Cooling technique used at CERN to increase the brightness of a particle beam, one would attempt to enhance the parts of a beam with high polarization and deplete those with a low polarization. The crucial element in this scheme is a polarization sensitive detector, which could transmit an appropriate signal to another part of the ring before the polarized beam reached that part. The difficulty is the small size of the electrical signals available from the proton's magnetic moment in comparison to the signals due to the proton's charge. It was hoped that with a narrow band filter one might concentrate on the frequency range near the proton's NMR frequency. But S. van der Meer calculated that the signal to noise ratio had the very discouraging value of about 10^{-42}.

4. Polarization of Antiprotons Using Dynamic Nuclear Polarization (Coordinator A.D. Krisch)

This technique is analogous to the Dynamic Nuclear Polarization technique in a polarized proton target where microwave power is used to induce hyperfine interactions which transfer the polarization of some polarized electrons to some nearby protons in the target beads. For antiprotons the idea is to inject some unpolarized antiprotons into an interaction region with a high longitudinal B-Field along with some polarized electrons moving at the same velocity. Microwave radiation could then induce spin transfer interactions with the polarized electrons near to the antiprotons. D. Kleppner and C. Jeffries concluded that with the present maximum polarized electron density of about $10^{10}/\text{cm}^3$, the polarization transfer rate to each antiproton would be about $10^{-5}/\text{sec}$, which is somewhat long. However if considerably high polarized electron densities could be achieved, such as the $10^{16}/\text{cm}^3$ or so hoped for at SLC, then the technique might be reconsidered.

5. Polarization of Antiprotons from Spontaneous Synchrotron Radiation Emission
(Coordinator L.C. Teng)

It is well known that circulating beams of electrons acquire a transverse polarization because synchrotron radiation emission is a few per cent more probably in one transverse spin state than in the other. In about one hour electron beams at PETRA and HERA will acquire polarizations of 80% or more. Unfortunately, as Teng calculated prior to the workshop, the polarization depends on γ^4/R and the magnetic moment. Thus even at the 20 TeV of SSC it would take antiprotons or protons about 10^7 years to acquire a useful polarization.

6. Polarization of Antiprotons from Induced Synchrotron Radiation
(Coordinators L.C. Teng, H. Steiner)

It was hoped that the synchrotron radiation emission polarization might be enhanced by shining a circularly polarized laser onto the beam. Calculations indicated that for SSC energies the laser would need a frequency in the X-ray region. No X-ray lasers are presently available.

7. Polarization of Directly Produced Antiprotons
(Coordinator B.E. Bonner)

It is well known that the particles produced when a high energy proton beam strikes a target have some polarization at some production angles. Unfortunately the polarization generally seems to be larger at larger production angles where the cross sections are smaller. Thus it appears difficult to simultaneously obtain a high polarization and a high intensity. However more experimental work might produce some interesting results.

8. Polarization of Antiprotons Using the Repeated Stern-Gerlach Effect
(Speaker T. Niinikoski)

A paper by Niinikoski and Rossmanith was presented which uses the small spacial separation given to particles of different longitudinal spin states when they pass through a quadrupole magnet. Since alternate quadrupoles in a storage ring alternate in sign, the spin must be rotated by 180° after each quadrupole to use this effect to get a macroscopic separation of the two spin states. This novel idea has several problems, such as unusual requirements on phase stability, which were stressed by many participants, but the proponents remain enthusiastic about this new idea.

9. Polarization of Antiprotons by Antihydrogen Formation (Coordinator K. Imai)

This technique, which might result in some interesting Atomic Physics, started as a plan to pass beams of positrons and antiprotons together with the same velocity into a drift region, where they could form atoms of antihydrogen. One could then polarize the antihydrogen atoms using the same atomic beam techniques used in polarized proton ion sources. Using the magnetic moment of antihydrogen atoms, it would be possible to store them in a Nestor-type ring where quadrupoles provide the bending and sextupoles provide the focusing. The formation rate for antihydrogen atoms was estimated by C. Jeffries and D. Kleppner to be about 10^3 per second. This is clearly too low to be useful for high energy accelerator experiments. However, it soon emerged that so far no one has ever produced one single atom of antihydrogen, polarized or unpolarized. With even a very weak beam of antihydrogen it would be possible to do some very interesting experiments such as comparing the Lamb shift for antihydrogen with that for hydrogen. A number of the participants, especially K. Imai and A. Rich plan to begin antihydrogen experiments.

10. Polarization of Antiprotons in a Penning Trap (Speaker G. Gabrielse)

We received a lecture on the beautiful technique developed at the University of Washington for holding a single particle in a Penning Trap for many hours. Since it is a single particle which is trapped, it is certainly polarized. It should be possible to capture an antiproton, just as one has captured other particles and to do experiments such as a comparison p and $\overline{p}$ masses. Since the typical $\overline{p}$ "processing" rate in a Penning trap is one per day this did not seem interesting as a source of polarized antiprotons.

There were a few other ideas proposed during a roundtable, but I have only sketchy notes and do not recall who proposed them so I will just list them briefly.

11. Polarization by Channeling

Pass an antiproton beam through a thin metal foil in the hope that one $\overline{p}$ spin state will pass more frequently. Perhaps use a magnetized iron foil.

12. Try to polarize antiprotons through interactions with the polarized high energy photons from a diamond.

In summary the workshop was more successful than Owen Chamberlain and I had hoped for when we planned it. Many of the ideas are clearly not presently practical, but I believe that our studies of them have given us more understanding of polarized antiprotons. We have also established valuable links between experts in atomic physics, condensed matter physics, nuclear physics, and high energy physics which might produce some important results outside of this workshop. Two of the ideas for polarizing antiprotons look quite promising; Antihyperon Decay and Spin Filter, and might actually lead to high energy polarized antiproton beams in the next few years.

1. W. Haeberli in High Energy Physics with Polarized Beams and Polarized Targets, Lausanne, 1980; Ed. C. Joseph and J. Soffer, (Birkhauser Verlag, Basel, 1981), p. 199.
2. S. van der Meer in CERN Accelerator School, Antiprotons for Colliding Beam Facilities, 1983; Ed. P. Bryant and S. Newman, CERN 84-15, p. 183.
3. E. Steffens et al., Lecture at 3rd LEAR Workshop Tignes France, January 1985.