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ABSTRACT

Polarization experiments in low-energy $\bar{p}p$ physics are highly desirable in order to investigate the rich system of quantum numbers and annihilation channels. It is planned to use high quality $\bar{p}$ beams from LEAR for a first generation of polarization studies in two-body channels on polarized external targets. Internal polarized jet targets could further increase the experimental possibilities and the precision in $\bar{p}p$ physics.

1. INTRODUCTION

Within less than two years from now, a low-energy antiproton ring (LEAR)¹ will start operation at CERN. LEAR will provide $\bar{p}$ beams between 0.1 and 2 GeV/c of high intensity ($> 10^6 \text{ s}^{-1}$) and quality. Improvements to be expected are illustrated in Table 1 by comparison at 400 MeV/c with a standard $\bar{p}$ beam. At low energies, where the resolution limits the target thickness, luminosities will still be sufficient to perform systematic $\bar{p}p$ studies^{2,3} even on polarized proton targets. Figure 1 shows some landmarks in the momentum range of LEAR.

Table 1: Comparison of $\bar{p}$ beams at 400 MeV/c

	Standard beam	LEAR with cooling	Gains in precision
Duty cycle	~ 0.1	~ 1.0	} trigger purity
$\pi/\bar{p}$	$\sim 10^2:1$	0:1	
$\Delta p/p$	$\sim 1.5 \times 10^{-2}$	$< 10^{-3}$	energy resolution
$\bar{p}/s$	$< 10^3$	$> 10^6$	statistical accuracy
ϵ { divergence	$\sim 10 \text{ mrad}$	$\sim 1 \text{ mrad}$	} angular resolution
diameter	$\sim 1 \text{ cm}$	$\sim 0.1 \text{ cm}$	

Most of the information on hadronic interactions come from baryon-baryon (BB) interactions and from meson-baryon (MB) interactions. The two other hadronic channels, meson-meson (MM) and antibaryon-baryon ($\bar{B}B$), are less well studied owing to obvious experimental problems. Owing to crossing symmetry, the amplitudes for pairs of reactions are described by a common analytical function (e.g. $pp \rightarrow pp$ and $\bar{p}p \rightarrow \bar{p}p$ ⁴, or $\bar{p}p \rightarrow MM$ and $p\bar{p} \rightarrow p\bar{p}$ ⁵ or $pe \rightarrow pe$ and $\bar{p}p \rightarrow e^+e^-$ ⁵). New $\bar{p}$ experiments at LEAR will greatly improve our knowledge of the amplitudes in the low-energy region. In a one-boson exchange model the same bosons contribute to BB and $\bar{B}B$ interactions with a change in sign if the G-parity of the exchanged boson is odd. This situation should allow the extraction of information on the nature of the baryon interaction⁶. There is, however, the unique process of annihilation in the $\bar{B}B$ system, which cannot be described in boson exchange terms. There is also no satisfactory quark model description. Annihilation probably is intimately related to the internal structure of

Fig. 1 Momentum range of LEAR together with some relevant resonances and thresholds accessible with transmission targets.

the baryon, to the dynamics of quarks in hadrons, and (in terms of potential descriptions) to the short-range effects in $\bar{B}B$ and BB interactions. The very large annihilation cross-sections at low energy, however, lead to the conclusion that annihilation has to be quite long range as well. Annihilation couples $\bar{B}B$ to a large variety of quasi-particle and particle channels with a large choice of quantum numbers. Annihilation is strongest at low energies. Here in fact it dominates the $\bar{p}p$ interaction and it appears cleanest since no inelastic channels compete below 800 MeV/c (Fig. 1). At very low energies one can take advantage of the restricted complexity of quantum numbers. Pure s-wave annihilation might be investigated, offering a chance for a unique analysis. There has been a lot of excitement in connection with the possible existence of narrow baryonium states⁷ (systems with hidden baryon number where substructures of B and $\bar{B}$ should resist annihilation). The experimental situation in this field is controversial⁸.

The importance of polarization experiments in $\bar{p}$ physics is evident when we compare them with the experience obtained over more than 20 years in nucleon-nucleon (NN) scattering. The short range of the interaction leads to a truncation of angular momentum and restricts the number of necessary parameters in a phase-shift analysis. However, polarization experiments were needed in order to disentangle the spin dependences⁹.

The BB system has the same spin structure and probably a similar range. Therefore a phase-shift parametrization should also be appropriate for BB scattering. Polarization experiments are necessary and at least of similar importance since there are additional complications. In $\bar{p}p$ no generalized Pauli principle acts and consequently the full set of partial waves has to be fitted. Inelasticities are probably very high in every partial wave and as a result all phases may have large complex components.

This could further double the number of important parameters. Under these conditions it is clear that one needs a solid data base. Since $\bar{p}$ beams will always be weaker than proton (or neutron) beams, the unpolarized data will be of lower statistics. All this points to the importance of sophisticated polarization measurements at LEAR. There are sizeable polarization effects in $\bar{p}p$ scattering measured above 910 MeV/c¹⁰ and in $\pi^+\pi^-$ annihilation¹¹. Recently a partial wave analysis of $2\pi^0$ and $\pi^+\pi^-$ was performed¹² which demonstrates the importance of $\pi^+\pi^-$ asymmetry data on a polarized proton target and which underlines the chances to piece together a picture of annihilation. In a contribution to this conference, J.M. Richard predicts polarization effects in $\bar{p}p \rightarrow \bar{p}p$ and $\bar{p}p \rightarrow \bar{n}n$ using an OBE model¹³. Spectacular spin-flip effects in the charge-exchange channels should occur owing to the dominance of pure $I = 1$ (long-range pion) exchange. In case one should have not only polarized proton targets but also polarized anti-proton beams, then annihilation channels which couple to singlet or triplet $\bar{p}p$ states alone could be switched on and off at will. (Annihilation into two 0^- particles or quasi-particles can only occur from $\bar{p}p$ triplet states, for example). This could be a very powerful way to disentangle different channels.

2. THE LEAR FACILITY

LEAR is a small storage and stretcher synchrotron for antiprotons (Fig. 2). The antiprotons will be obtained from an "antiproton factory" which has already entered into its first test stage. This factory consists of the CERN 26 GeV PS and an antiproton accumulator synchrotron (AA)¹⁴. The AA accepts $\bar{p}$ produced by PS protons at their production optimum of 3.5 GeV/c. This ensures that one always gets the maximal possible $\bar{p}$ flux for a given load on the PS. In the AA, for every PS cycle the $\bar{p}$ burst is compressed in phase space by fast stochastic momentum cooling and shifted onto a storage orbit. Here the $\bar{p}$ stack is piled up and is further compressed continuously by cooling. High-density $\bar{p}$ beams,

Fig. 2 LEAR in the PS South Hall with the transfer line from the PS and a sketch of the experimental areas.

Table 2: Some LEAR parameters

Momentum range:	0.1-2 GeV/c
Circumference:	78.54 m
Free length of long straight sections between quadrupoles:	8 m
Approximate working point:	$Q_H = 2.3; Q_V = 2.7; \gamma_c^2 = -(14.5)^2$
Maximum acceptances (in π mm·mrad):	$E_H = 240; E_V = 48; \Delta p/p = 1.1\%$

free of any contamination, can be peeled off from the AA stack with a time average up to nearly 10^7 $\bar{p}$ /s. Antiprotons will be ejected in batches, decelerated in the PS down to fixed momentum of 0.6 GeV/c ($\beta \approx 0.5$), and then injected into LEAR. Each batch must contain more than 10^9 $\bar{p}$, the lower limit of safe operation of the PS instrumentation. Antiprotons will be shared between different users (SPS collider, ISR) so that the average number available for LEAR physics will be $> 10^6$ s⁻¹. This, together with the lower limit of 10^9 $\bar{p}$ per injection, imposes a $\bar{p}$ beam spill-out time of $\approx 10^3$ s from LEAR for operation with good duty cycle. Ultrahigh vacuum is needed in order to keep the beam losses down at low energies, and a superslow stochastic extraction¹⁵ has to be developed.

LEAR is a strongly focusing synchrotron with four laminated dipoles and a separate focusing structure with two quadrupole doublets in each straight section. Parameters are shown in Table 2. The detailed design characteristics can be found elsewhere¹. The return yoke of the bending magnets will be inside the ring in order to allow easy extraction of particles which may be produced with the internal beam. A 20 kV RF system will decelerate or accelerate the stored beam to the desired working momentum. The construction of LEAR foresees various modes of operation.

In a stretcher ring mode the stochastic extraction system feeds an external beam which can be split and directed to different experimental areas (Fig. 2).

In storage ring mode the internal strongly cooled beam is used up in interactions with an internal hydrogen gas jet target¹⁶. Space for gas targets is foreseen in one straight section and in the centres of two bending magnets (for $\bar{n}$ production). Eventually a polarized atomic beam¹⁷ could be used as well. This approach allows extreme precision in energy and angular resolution and makes the most economic use of the available antiprotons. Also studies at very low relative $\bar{p}p$ energies using co-rotating H⁻¹⁸, and studies at very high relative $\bar{p}p$ energies using stored protons in a collider mode¹⁹, are envisaged.

3. A PROPOSED EXPERIMENT

Six experimental groups with experience in polarization physics have submitted a proposal²⁰ for a first generation of investigations of spin effects in $\bar{p}p$ two-body interactions. Their aim is to measure $d\sigma/d\Omega$ and P in the three channels $\bar{p}p \rightarrow \pi^+\pi^-$, $\bar{p}p \rightarrow K^+K^-$, and $\bar{p}p \rightarrow \bar{p}p$, over the momentum range 0.3-2 GeV/c, using a conventional polarized target. The statistics aimed at is $> 10^4$ recorded events per momentum at 15 momenta for the K^+K^- channel (which has the smallest branching ratio). The apparatus is sketched in Fig. 3. The target magnet is used for momentum analysis and

Fig. 3 a) The planned beam line. b) The experimental set-up with a polarized target.

for particle identification, exploiting the two-body kinematics. The full angular range can be measured in the mesonic channels, while the elastic scattering can be studied over that angular interval where $\bar{p}$ and p have sufficient range to escape from the target and reach the MWPCs. At those beam energies and angles where elastically scattered p have sufficient energy (> 120 MeV) a measurement of their polarization with a carbon polarimeter (Fig. 3b) can be made parasitically to determine the Wolfenstein parameter $D = I(0,n,0,n)$. Provided carbon has sufficient analysing power for antiprotons, the parameter $D_t = I(0,n,n,0)$ will also be obtained. A calculation using Glauber theory indicates that 10-20% polarization on carbon may be expected in the range $5-7^\circ$ at around $1 \text{ GeV}/c$ ²¹. The determination of the analysing power of carbon (or other nuclei) for $\bar{p}$ at a few momenta is planned. It will decide whether polarized $\bar{p}$ beams can be made with a set-up as shown in Fig. 3a. With magnets (M1 and M2) the scattering angle θ of $\bar{p}$ on the polarizing target placed in an intermediate focus (normally used for degraders) can be optimized. Scattered $\bar{p}$ can be re-focused downstream into the polarized target set-up.

If a polarized $\bar{p}$ beam of reasonable intensity proves to be feasible, measurements of $\Delta\sigma_L$ and $\Delta\sigma_T$ and of spin-correlation parameters would be possible. If any narrow baryonium states can be confirmed or found, then polarization measurements of the two-body channels would be concentrated on these mass ranges in an attempt to determine quantum numbers.

4. FUTURE POSSIBILITIES

Phase-space cooling which avoids multiple scattering blow-up and losses of stored $\bar{p}$ in LEAR will allow the running of experiments even with low-energy $\bar{p}$ on an internal gas jet target^{16,3}. While the $\bar{p}$ economy (strong interaction efficiency) of an external target is related to the energy resolution (through target thickness), the $\bar{p}$ economy on a jet target can be much better (Fig. 4). It depends on the acceptance of the

Fig. 4 Target efficiencies: a) on an external hydrogen transmission target with a thickness chosen to give a certain resolution; b) on an internal hydrogen gas target with perfect phase-space cooling.

storage ring. On a jet, moreover, the energy resolution is determined by the small $\Delta p/p$ of the circulating cooled beam (e.g. for $\Delta p/p = 10^{-3}$, $\Delta\sqrt{s} = 5$ keV at 100 MeV/c and $\Delta\sqrt{s} = 700$ keV at 2 GeV/c).

Of course one has to provide sufficiently strong cooling, or a thin enough scatterer. A polarized atomic beam target¹⁷ with a thickness of $d \approx 10^{12}$ protons per cm^2 , should be perfectly suitable for polarization studies. With 10^{11} $\bar{p}$ circulating in LEAR, this internal target would produce $\sim 3 \times 10^4$ strong $\bar{p}p$ interactions per second. Above 500 MeV/c this target can be operated in a parasitic mode. Further advantages of this scheme are: small interaction volume, very good angular resolution, purity and absence of windows, free choice of polarization, perfect transparency for low-energy particles, and low background (no beam dump).

Besides "standard" polarization studies, physics otherwise not accessible could also become feasible with a polarized jet. Both $d\sigma/d\Omega$ and P could be studied even in the elastic channel over the full angular range down to 100 MeV/c (5 MeV). Here good data are needed in order to determine singlet and triplet s-wave contributions. Threshold phenomena could be studied in an optimal way owing to the high resolution³. The relatively high interaction rate allows the study of channels with branching ratios far below 10^{-4} . The hyperon antihyperon channels ($\bar{\Lambda}\Lambda$, $\bar{\Lambda}\Sigma^0$, $\bar{\Sigma}^+\Sigma^-$, $\Sigma^0\Sigma^0$, $\bar{\Sigma}^-\Sigma^-$) play the role of model reactions for ambitious polarization studies, since the weak decays are very efficient analysers for the hyperon polarization. Correlation parameters are obtainable, and with a polarized target three spin measurements are possible with good statistics.

In the case of Λ , the light quarks u and d combine to form a "diquark" with spin-isospin $S = I = 0$, while for Σ this "diquark" has $S = I = 1$. Therefore the polarization of the strange quark s is always equal to the polarization of a Λ , and always opposite to the polarization of a Σ . The

same situation holds for antihyperons. In $\bar{p}p \rightarrow \bar{Y}Y$ polarization studies one can therefore observe selectively the $\bar{s}s$ quark pair creation and the dynamics of both the strange and antistrange valence quarks.

Bubble-chamber data for $\bar{p}p \rightarrow \bar{Y}Y$ exist²² which show (with some 100 events) large polarization effects, opposite for Λ and Σ . A striking similarity to polarization effects in $\pi^-p \rightarrow Y\bar{K}$ appears²³. I would like to stress that there is also a striking similarity to polarization effects observed in inclusive hyperon production (e.g. $p + Be \rightarrow Y + X$) at high energy²⁴. A semiclassical model²⁵ developed for the inclusive data might be applicable for the two-body reactions $\bar{p}p \rightarrow \bar{Y}Y$ and $\pi^-p \rightarrow Y\bar{K}$ as well. All these reactions contain as the main ingredient $\bar{s}s$ creation, probably under similar kinematical conditions. At LEAR the $\bar{Y}Y$ production and polarizations could be studied with very high accuracy on a polarized internal jet, and with large momentum transfers [$|t| < 15 \text{ (GeV/c)}^2$] in the collider mode.

For complete $\bar{p}p$ studies on a polarized proton reaction target (jet or external) polarized $\bar{p}$ are necessary. Complementary to scattering, a method to polarize $\bar{p}$ could be to pass $\bar{p}$ stored in LEAR through an internal polarized "filter" target. If, for example, $\sigma_{\uparrow\uparrow} \neq \sigma_{\uparrow\downarrow}$ then transverse polarization could be enriched at the expense of intensity. This scheme was discussed some time ago for protons in the ISR²⁶. Phase-space cooling offers a chance to realize it at LEAR. Open questions are however whether singlet and triplet cross-sections are sufficiently different, and how to get reasonable time constants to build up polarization. With a transversely oriented polarized jet, more than 10^7 s would be needed at least. One might increase the filter thickness by injecting the polarized H_0 in the direction of one of the 12 m long straight sections. (The method could be tested with low-energy protons. For them the following holds: $\sigma_{\uparrow\uparrow} \approx 0$ and $\sigma_{\uparrow\downarrow} \approx \sigma_t$ ⁹.)

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