ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Trieste

INFN/AE-90/09

14 Settembre 1990

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EXPERIMENTAL TRENDS IN $\bar{N}N$ SCATTERING

Servizio Documentazione
dei Laboratori Nazionali di Frascati

EXPERIMENTAL TRENDS IN $\bar{N}N$ SCATTERING

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ABSTRACT

Recent antiproton-proton data, mostly on spin observables, are illustrated and their trend discussed. The data are compared with one-boson-exchange models to extract the global behaviour of annihilation. Some ideas for future measurements and developments are presented.

Invited Talk at the
First Biennial Conference on Low Energy Antiproton Physics (LEAP 90)
Stockholm, 2-6 July 1990

1. INTRODUCTION

The contribution of LEAR, the Low-Energy-Antiproton-Ring at CERN to the study of $\bar{N}N$ scattering is by now impressive. Although in the past several laboratories contributed to this field, and to quote only recent results I should like to recall the work done in Brookhaven and at KEK in the early 80's, by now the quality of the LEAR beam is so superior that CERN is the only laboratory where this physics is pursued. This situation is summarized in Table 1. Most of the measurements listed in the table had been presented and discussed at the previous LEAR Workshop in Villars[1], and by now have been published[2-18]. The new results, mostly on spin observables, come mainly from PS198 and PS199, the two esperiments installed after the commissioning of ACOL, the new CERN Antiproton Collector. All the cross-section data in Table 1 can be described surprisingly well by a large variety of potential models[19]. A recent detailed comparison of the cross-section data with potential models calculations can be found in Ref. 20.

The basic ingredients of these models are

- meson exchanges at large distances ($r \gtrsim 0.8$ fm). These are assumed to be the same as determined in the NN interaction, and the sign of each contribution is obtained from the *G*-parity rule[21]:

$$V_{N\bar{N}} = \sum_{\pi\rho\omega\sigma\ldots} (-1)^G V_{NN}(\mathrm{OBE});$$

- annihilation at short range, usually parametrized as an optical potential, eventually state and energy dependent. This is the new part, to be compared to the results of microscopic calculations.

TABLE 1

	Experiment	Measured Momenta (MeV/c)	Reference
Cross Sections:			
$\sigma_{tot}(\bar{p}p)$	PS 172	220 ⟼ 600, 74 momenta	2, 3
$\sigma_{ann}(\bar{p}p)$	PS 173	180 ⟼ 600, 53 momenta	4
$\sigma_{tot}(\bar{n}p)$	PS 178	100 ⟼ 350 MeV/c	
$\bar{p}p \rightarrow \bar{p}p$ Elastic scattering:			
ρ	PS 172	233, 272, 550, 800, 1100	5, 6
	PS 173	181, 219, 239, 261, 287, 505,590	7, 8
$d\sigma/d\Omega$	PS 173	181, 287, 505	9
	PS 172	529 ⟼ 1550, 15 momenta	10, 11
	PS 198	439, 544, 697	12, 13
A_{on}	PS 172	529 ⟼ 1550, 15 momenta	10, 11
	PS 198	439, 544, 697	12, 13
D_{onon}	PS 172	988, 1089, 1291, 1359	14
	PS 198	697	
$\bar{p}p \rightarrow \bar{n}n$ Charge exchange:			
$d\sigma/d\Omega$	PS 173	183, 287, 505, 590	15
	PS 199	600, ⟼ 1300, 8 momenta	16, 17
A_{on}	PS 199	600, ⟼ 1300, 8 momenta	16, 18
D_{onon}	PS 199	600, 900 [near future]	
K_{noon}	PS 199	?	

Since the annihilation cross-section is very large, to reproduce the data the annihilation potential has to act up to large distances, so that it is difficult to separate the contributions of the two parts from the cross-section data alone. As a matter of fact, only π-exchange and a suitably parametrized annihilation potential, with an annihilation radius of ~ 0.8 fm, already give a satisfactory description of the data. For instance, a Woods-Saxon type annihilation potential, with

$$\mathrm{Rc}\ V_{ann} = -c_0/1 + \exp[(r - r_0)/\alpha_0]$$
$$\mathrm{Im}\ V_{ann} = -c_1/1 + \exp[(r - r_1)/\alpha_1],$$

and no energy, spin, or isospin dependence, already gives very good fits with

$c_0 = c_1 = 500$ MeV, $r_0 = r_1 = 0.74$ fm, and $\alpha_0 = \alpha_1 = 0.2$ fm[22].

Disentangling annihilation from meson exchange is to my mind a very important step forward in understanding hadron dynamics. $N\bar{N}$ physics offers the unique opportunity of studying the process of the quark annihilation, but the complications of a four-fermions system demand for good measurements of spin observables.

2. THE ELASTIC $\bar{p}p \rightarrow \bar{p}p$ CHANNEL

Experiment PS198 has measured A_{0n} over the entire angular range at 497, 523 and 697 MeV/c. The data at 697 MeV/c are already published[12]: new results[13] at the two lowest momenta are shown in Fig. 1, together with previous data from experiment PS172[10] and predictions from the Paris[23], the Dover-Richard[24], and the Nijmegen[25] models.

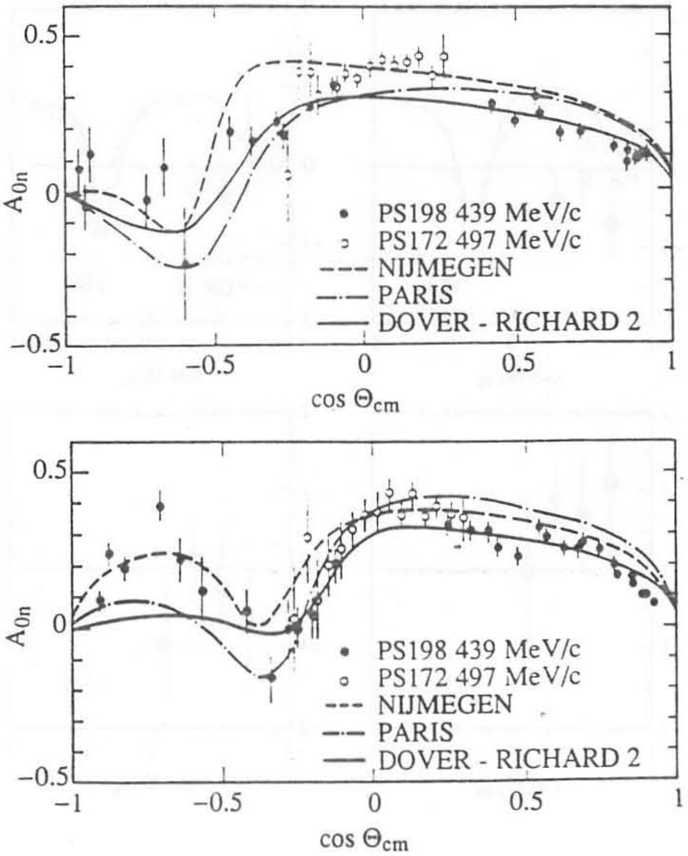

Fig. 1 Analysing power for $\bar{p}p$ elastic scattering at two momenta. The curves are predictions from potential models, Dover-Richard [24], Paris [23], Nijmegen [25].

The analysing power exhibits a lot of structure with angle and momentum, with a typical diffraction pattern, already observed at higher momenta[26]. This pattern is only poorly reproduced by the potential models. There is good agreement between the two sets of new data, which anyway represent either a vast improvement over previous measurements, or cover a region where data did not exist (momenta smaller than 910 MeV/c).

By analysing the polarization of the scattered proton with a carbon polarimeter, experiment PS172 could obtain some D_{0n0n} data in the backward hemisphere and in the higher momentum range (from 1000 to 1550 MeV/c). Some of these data[14] are shown in Fig. 2: although the error bars are large, the result is interesting because it suggests either zero or negative values for D_{0n0n} (except at 1291 MeV/c), while the potential models would like this parameter to be close to 1. Data on D_{0n0n} have been collected also by experiment PS198 at 700 MeV/c, but the analysis is still in progress.

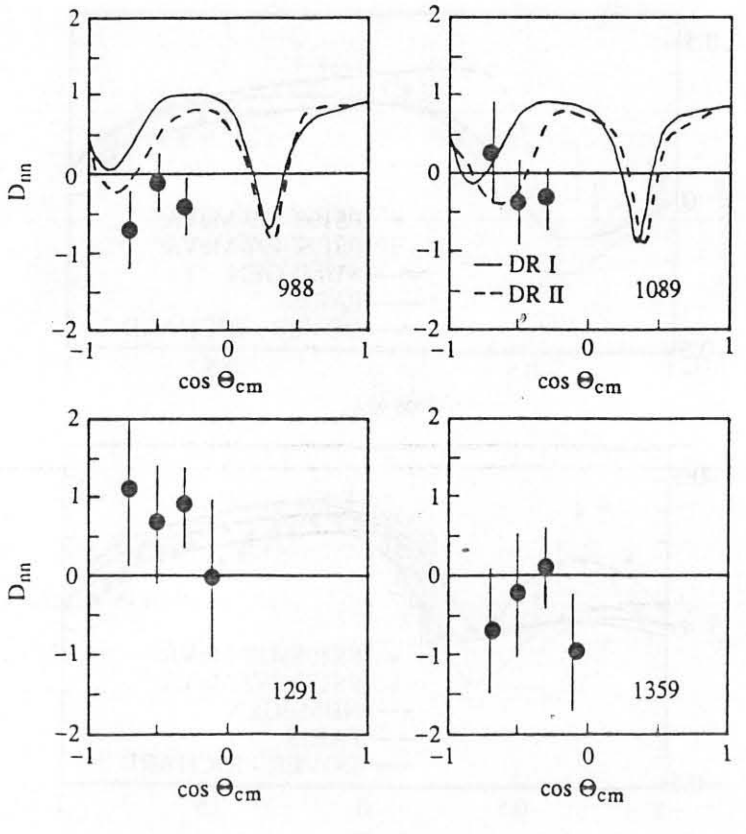

Fig. 2 D_{nn} results for $\bar{p}p$ elastic scattering at 988, 1089, 1291, and 1359 MeV/c. Theoretical predictions are from the models of Ref. 24: Dover-Richard I (full curve) and Dover-Richard II (dashed curve).

3. THE CHARGE-EXCHANGE CHANNEL

The charge-exchange reaction is expected to be a particularly sensitive channel to probe the antinucleon-nucleon force. On the one hand, the long-range part should be dominated by pion exchange, a 'classical' term in any OBEP model. On the other hand, since its amplitude is given by difference of the $I = 0$ and $I = 1$ amplitudes, it should provide a good test of isospin independence.

The analysing power of the charge-exchange $\bar{p}p \rightarrow \bar{n}n$ reaction has been measured for the first time at low momentum (a previous measurement[27] exists at 8 GeV/c) by experiment PS199. Data have been collected at eight different incident $\bar{p}$ momenta, ranging from 600 to 1300 MeV/c. First results[16,18] at 656 MeV/c are shown in Fig. 3, and compared with potential model calculations[23,24,25,28,29].

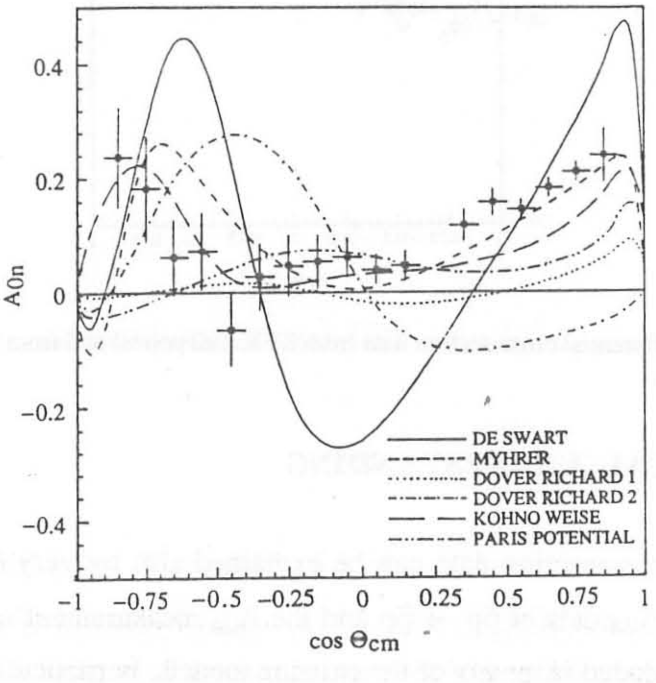

Fig. 3 Analysing power for $\bar{p}p \rightarrow \bar{n}n$ at 656 MeV/c, as measured by experiment PS199, compared with potential model calculations.

The data exhibit an interesting pattern, with backward and forward peaks of similar strengths, and possibly a flat minimum in the central region. This simple pattern is reproduced only poorly by the theoretical predictions, apart from the prediction of Ref. 29. In particular, there are very big differences in the predictions of the various models also in the forward angles, where π-exchange is expected to dominate the reaction. The same experiment has measure also, with high statistics, the differential cross-section. The data at 693 MeV/c[16,17] are compared with previous KEK data[30] in Fig. 4. The agreement between the two sets of data is good, at variance with the data at lower momenta from PS173[15] and from KEK[30], which show large differences both in the forward and in backward directions.

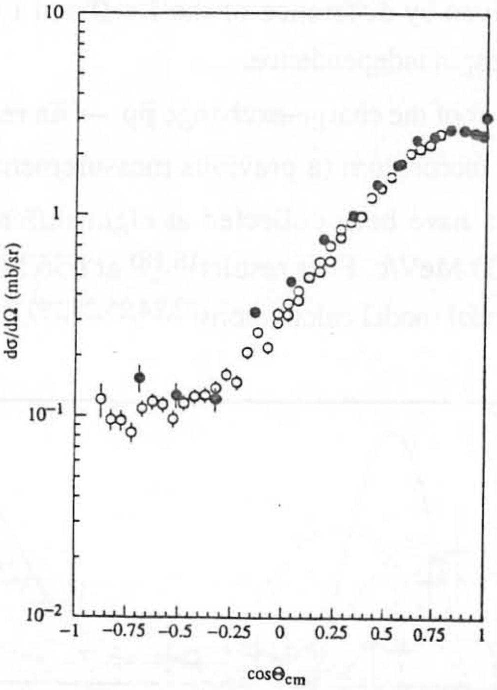

Fig. 4 $\bar{p}p + \bar{n}n$ differential cross-section data from KEK (full points) and from LEAR (open points) at 690 MeV/c.

4. THEORETICAL UNDERSTANDING

While the cross-section data can be explained also by very 'simple' models, at present the set of A_{0n} data of $\bar{p}p \rightarrow \bar{p}p$ and the A_{0n} measurement of $\bar{p}p \rightarrow \bar{n}n$ at 656 MeV/c are not reproduced by any of the existing models. In particular, it does not seem possible to reproduce any of the A_{0n} data with an OBE potential model in which only a π is exchanged[31].

The availability of the new LEAR data has stimulated theoretical work on the models, where, so far, several parameters were only loosely constrained. This is the case, for instance, for the Paris model[32], where a slight readjustment of the core parameters of both the real and the imaginary parts of the potential could improve the calculation of both the charge-exchange cross-section and the analysing power of the elastic channel.

This is true also in the case of the Dover-Richard model. In order to enhance the spin effects, namely the difference in the strength of the singlet and the triplet part of the meson-exchange potential, they reduced[31)] somewhat r_{cut}, the radius at which they regularize the Yukawa potentials. Changing r_{cut} from 0.8 to 0.74 fm, they could obtain a substantial improvement in their calculation of A_{0n} for charge exchange (Fig. 5a) and at the same time a good agreement for the elastic channel (Fig. 5b).

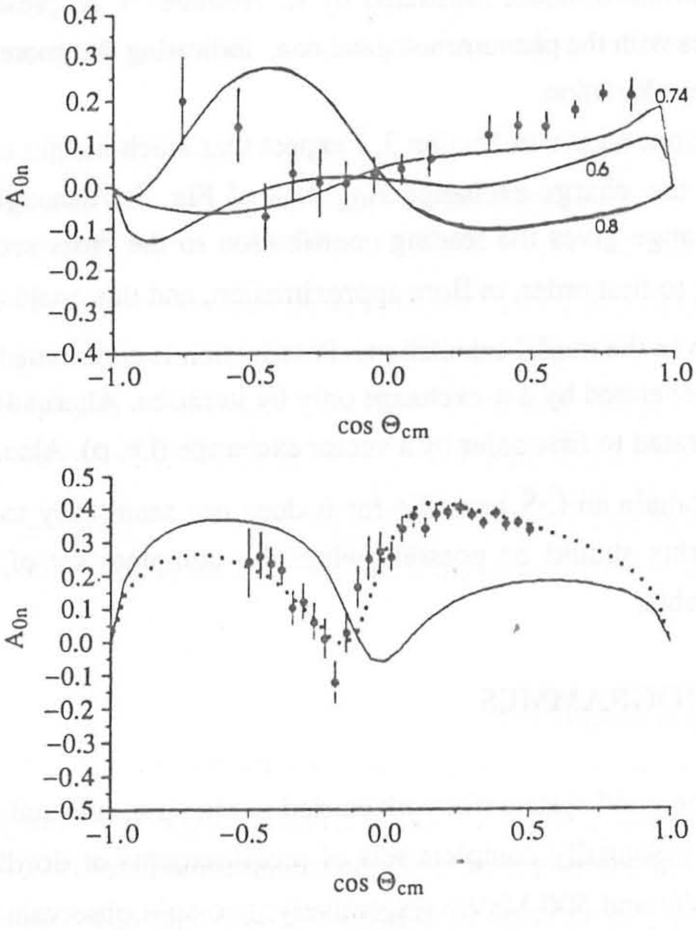

Fig. 5 Comparison of modified Dover-Richard model with A_{0n} data from Experiments PS199 and PS172. (a): $\bar{p}p + \bar{n}n$ data at 656 MeV/c compared with model calculations with $r_{cut} = 0.8, 0.6$, and 0.74 fm; (b): $\bar{p}p \rightarrow \bar{p}p$ data at 679 MeV/c with the modified Dover-Richard model (dotted curve) and with a calculation using only (full curve).

Excellent fits to the $\bar{p}p$ data has been provided by the Nijmegen group[33)], using a coupled channel model. It will be of great interest to compare simultaneously the elastic and the charge exchange channels.

Improving the models by taking into account the new data is surely a very important and necessary programme. Still, to me the main motivation for studying $N\bar{N}$ scattering is

- to extract the global properties of annihilation;
- to learn about the s-channel effects.

In this respect, the amount of theoretical work to be done is still considerable. A very interesting attempt to evaluate the annihilation potential in a consistent way is the two-meson annihilation model illustrated by K. Holinde$^{34)}$. At present the computed potential disagrees with the phenomenological one, indicating that more diagrams have to be included in the calculation.

For the reasons I gave in Section 3, I expect that much insight could be gained if one understood the charge-exchange A_{0n} data of Fig. 3. Although in the forward direction π-exchange gives the leading contribution to the cross-section, it does not contribute to A_{0n} to first order, in Born approximation, and this could explain the broad range of variation in the model calculations. Polarization is contributed by an $\bar{L}\cdot\bar{S}$ term, which could be generated by a π-exchange only by iteration. Alternatively, a spin-orbit term can be generated to first order by a vector exchange (i.e. ρ). Also, the annihilation potential could contain an $\bar{L}\cdot\bar{S}$ term. So far it does not seem easy to draw a definite conclusion, but this should be possible when the complete set of A_{0n} data, at all momenta, is available.

5. FUTURE PROGRAMMES

In spite of the good systematic work carried out in $\bar{p}p$ elastic and $\bar{p}p \rightarrow \bar{n}n$ charge exchange, where essentially complete sets of measurements of $d\sigma/d\Omega$ and A_{0n} exist down to 180 MeV/c and 500 MeV/c respectively, two-spin observables are needed to constrain the models. I do not think a systematic programme of measurements, similar to the one performed on the NN channel, should be started: a phase-shift analysis in the $N\bar{N}$ system would require 20 parameters per partial wave, so it is absolutely ruled out. Also, the dibaryon experience would surely stop, from the beginning, any attempt to go in that direction. On the contrary, in the $N\bar{N}$ case I believe that, after adjustment to the existing data, the potential models should be tested against a few specific measurements, which can select some basic properties of the theory.

Ideally this programme requires polarized $\bar{p}$'s on a polarized target. Two-spin correlation measurements would then also be possible in some very important annihilation channels, such as $\bar{p}p \rightarrow \pi^+\pi^-$, K^+K^-, where spectacular spin effects have been seen[35,36]. Work is going on in the direction of polarizing the LEAR beam: this is what I call the far future. On the other hand, some measurements can be performed already in the next three years or so, using unpolarized $\bar{p}$'s, polarized proton and neutron targets, and analysing the polarization of one of the particles in the final state; I will start with this topic.

5.1 Near-future programmes

Experiment PS199 is the only experiment presently installed at LEAR working on $N\bar{N}$ scattering (not to mention the experiment PS185, dedicated to $\bar{p}p \rightarrow \bar{Y}Y$). In the second half of this year, it is scheduled to measure D_{0n0n} at two momenta (600 and 900 MeV/c), by measuring the neutron polarization in $\bar{p}p \rightarrow \bar{n}n$: at the same time data for K_{n00n} will be collected by analysing the $\bar{n}$ polarization by $\bar{n}p$ scattering. The $\bar{n}p$ analysing power is not known yet, but the same Collaboration plans to measure it in the future.

The Collaboration has proposed[37,38] to extend the present program and perform four measurements, some of which have also technical implications:

a. Measurement of A_{0n} for $\bar{p}n \rightarrow \bar{p}n$;

b. Measurement of K_{k00k} for $\bar{p}p \rightarrow \bar{n}n$;

c. Measurement of D_{0n0n} for $\bar{p}p \rightarrow \bar{p}p$;

d. Measurement of $\Delta\sigma_T$ for $\bar{p}p$

Each of these measurements should typically be carried out at three momenta. I will only comment on the second measurement, which is a test of the prediction, put forward ten years ago[39], that the $\bar{n}$ produced in the forward direction in a charge-exchange reaction on longitudinally polarized protons should be almost fully polarized (K_{k00k} should be close to 1). This prediction is expected to be very firm, being based on the tensor character of the long-range π-exchange. If verified, it suggests a way to produce a polarized $\bar{n}$ beam.

5.2 Far-future programmes

A major advance for all future programmes would be achieved if the $\bar{p}$ beam circulating in LEAR could be polarized. Two projects are presently been pursued.

The first is the project that the FILTEX collaboration is carrying on, to develop and install in LEAR a gas target of polarized hydrogen$^{40)}$. The target would act as a spin filter, by absorbing in a different way the beam component with spin parallel or antiparallel to the target. Also, the gas target will allow one-spin measurements (A_{0n}) in $\bar{p}p$ elastic, charge-exchange, and possibly in some annihilation channels at very low momenta. For the circulating $\bar{p}$ beam to be polarized, three conditions must be verified: a minimum density for the target (~ 10^{14} atoms per cm^2) thus requiring the use of a storage cell, a minimum difference in the absorption cross-section for parallel and antiparallel spins ($\Delta\sigma_T/\sigma_T \sim 0.10$), and the absence of depolarizing effects over the time (10 h) the beam polarization builds up. A test experiment with protons is at present installed at the Test Storage Ring in Heidelberg$^{41)}$.

An alternative way to polarize the circulating $\bar{p}$ beam in LEAR has been proposed$^{42)}$, which relies on the possibility of spatially separating the two spin components of the beam by means of repeated Stern-Gerlach kicks provided by the so-called spin-splitter, an arrangement of two quadrupoles with a solenoid in between, inserted in a straight section of LEAR. The feasibility of the method is not clear, since the effect is very small (particles with opposite spin directions are separated at a speed of ~ 2 mm/h) and the integration of the spin-splitter in the lattice of LEAR is not straightforward. A test experiment has been approved at the Indiana cooler ring, and a feasibility test is going on at present$^{43)}$.

6. CONCLUSIONS

The LEAR/ACOL complex ha enabled to perform precise measurements in $N\bar{N}$ scattering.

In the $\bar{p}p \to \bar{p}p$ elastic, the $\bar{p}p \to \bar{n}n$ charge-exchange, and in the two-meson annihilation $\bar{p}p \to \pi^+\pi^-$ and $\bar{p}p \to K^+K^-$ channels, complete sets of differential cross-section and analysing power data exist down to 200 and 500 MeV/c respectively. These data are only poorly reproduced by the existing potential models, whose parameters were adjusted essentially for cross-section data before the 1980's. Theoretical work has now started, to extract from the interaction the part which is specific to the $N\bar{N}$ system, namely annihilation. This work will greatly benefit from the two-spin measurements which are planned over the next few years.

In the future the main goal will be to dispose of polarized $\bar{p}$ and $\bar{n}$ beams. In the case of $\overline{\mathrm{p}}$'s, two different techniques seem promising, and are now under test at proton storage rings. By the time of our next conference, we should know wether polarization might really be a sophisticated option for the LEAR beams, and an essential ingredient of $\mathrm{N}\bar{\mathrm{N}}$ physics.

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