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First Results for the Two-Spin Parameter A_{LL} in π^0 Production by 200-GeV Polarized Protons and Antiprotons *

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First Results for the Two-Spin Parameter A_{LL} in π^0 Production by 200-GeV Polarized Protons and Antiprotons*

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Abstract

The two-spin parameter A_{LL} in inclusive π^0 production by longitudinally-polarized protons and antiprotons on a longitudinally-polarized proton target has been measured at the 200-GeV Fermilab spin physics facility, for π^0s at $x_F = 0$ with $1 \le p_t \le 3$ Gev/c. The results exclude, at the 95% confidence level, values of $A_{LL}(PP) > 0.1$ and < -0.1, for π^0s produced by protons, and values of $A_{LL}(\bar{P}P) > 0.1$ and < -0.2 for incident antiprotons. The relevance of $A_{LL}(PP)$ for the gluon spin density is discussed. The data are in good agreement with "conventional", small or zero, gluon polarization.

We report on a first measurement of the two-spin parameter A_{LL} for inclusive π^0 production by longitudinally-polarized protons and antiprotons on a longitudinally-polarized proton target. This parameter is of particular interest because it is related to the fundamental spin-properties of the parton scattering amplitudes [1] and to the spin-weighted parton-helicity distributions, when measured in hadronic reactions that reflect the interactions between gluons and/or quarks. The hadron asymmetry A_{LL} is defined as the relative difference between the cross sections for beam and target hadrons of equal or opposite helicities,

$$A_{LL} = (\sigma_{\Leftrightarrow} - \sigma_{\Rightarrow}) / (\sigma_{\Leftrightarrow} + \sigma_{\Rightarrow}) = P_B^{-1} \cdot \langle P_T \rangle^{-1} \cdot (N_{\Leftrightarrow} - N_{\Rightarrow})/(N_{\Leftrightarrow} + N_{\Rightarrow}), \qquad (1)$$

where $\sigma(s, x_F, p_t)$ are the invariant cross sections for inclusive π^0 production in antiparallel ($\Leftrightarrow$) and parallel ($\Rightarrow$) spin states of the beam and target particles. Since the incident hadrons have opposite momenta in the C.M. of the interaction, the helicities are equal when the spin directions are antiparallel. The quantities $N(s, x_F, p_t)$ are the corresponding normalized event rates measured in the experiment, P_B is the beam polarization, and $\langle P_T \rangle$ is the target polarization averaged over polarized and unpolarized nucleons.

Assuming factorization, A_{LL} is given by the convolution of the asymmetries $\hat{A}_{LL}$ for parton-parton scattering with the spin-weighted parton distribution functions. If a hadronic reaction reflects the properties of the lowest-order PQCD amplitudes, a measurement of A_{LL} can be used to obtain information on the spin distributions of the constituents involved in the interaction.

The experiment was carried out at the Fermilab spin physics facility, which consists of a 200-GeV polarized proton or antiproton beam incident on a polarized proton target. The design and performance of the beam, arising from lamda or antilambda decays, is described in Ref. [2]. Three phase space regions of the beam are defined, with average beam polarization of P_B = 0.45 and -0.45 in two of these regions, representing together about one-half of the total beam intensity. The third region, with an average beam polarization of zero, is used to study instrumental effects that could introduce systematic errors. A set of 12 magnets in the beam line rotates the beam-particle spin from the transverse-horizontal into the longitudinal direction at the polarized target. These magnets reverse the sign of the polarization 5 times per hour to cancel possible geometric bias and to minimize the effects of time-dependent drifts in the apparatus. The size of the beam spot at the experimental target is 2.6 cm (FWHM) with horizontal and vertical divergences of less than 1 mrad.

The 3-cm diameter polarized proton target [3] of length 20 cm consists of 2-mm diameter beads of frozen Pentanol ($C_5H_{12}O$) doped with Chromium-V. Pentanol contains one polarizable, free proton for about six unpolarizable, bound protons and neutrons. The effective polarization-dilution factor, including the target windows, is $D = P_T/<P_T> = (8 \pm 1)$. The free protons are polarized to typically either $P_T = 0.75$ or $P_T = -0.80$ in 3 to 4 hours at a temperature of 0.4 K, using microwaves of appropriate frequencies near 70 GHz. When maximum polarization is reached and microwave power is turned off, the ^3He-^4He dilution refrigerator cools the Pentanol beads down to < 80 mK. The proton spin relaxation time at this temperature is more than 50 days and allows the target solenoid to be moved upstream, giving an unobstructed solid angle of 130 mrad with respect to the beam axis at the exit of the target. The target polarization is reversed about once per day to reduce possible systematic errors related to beam polarization reversal.

Decay photons from π^0s produced by interactions of beam particles with the target are detected in two lead-glass photon calorimeters as shown in Fig.1. The layout of the beam and detectors is the same as that described in Ref.[4]. Each calorimeter ("Central Electromagnetic Calorimeters CEMC-1 and CEMC-2") consists of 504 lead-glass counters [5] in an array of 21 columns by 24 rows. The dimensions of the individual lead-glass blocks are 3.81 cm x 3.81 cm x 18 radiation lengths. A p_t threshold signal from the CEMCs, generated by summing the individual counter signals with weights proportional to their transverse distance from the beam line, is required in the trigger to avoid saturation by low-p_t events. The trigger rate was about 800 events for the full beam intensity of 2 x 10^7 protons per 20-sec spill, with a trigger threshold corresponding to p_t = 1.6 GeV/c. The antiproton beam intensity was about twenty times less. Most of the data were taken simultaneously with other experiments requiring reduced beam intensity.

The signals from the lead-glass counters were recorded for each trigger, providing information on energy and position of all electromagnetic showers. Photon pairs in the CEMC that had generated the p_t threshold signal were selected as π^0 candidates according to the criteria described in Ref.[4]. The analysis yielded 560,000 inclusive π^0 events with $1 \leq p_t \leq 3$ GeV/c from P-P interactions and 350,000 events from $\bar{P}$-P interactions. The two-photon invariant-mass distributions are similar to those given in Ref.[4] and show π^0 peaks with a mass resolution of ± 5 % expected from the calibration of the detectors with 30 GeV positrons. The background from uncorrelated photon pairs and from π^0s produced outside the target volume decreases from 20 % at p_t = 1 GeV/c to 10 % at p_t = 3 GeV/c.

The results for A_{LL} measured for incident protons and antiprotons, as functions of p_t, are shown in Table I and Fig.2. Only statistical errors are given. Each value for A_{LL} in the p_t interval covered by these measurements is consistent with zero, within the statistical errors. The results averaged over the entire p_t regions exclude, at the 95 % confidence level, values of $A_{LL}(PP) > 0.1$ and < -0.1, for π^0 production by protons, and $A_{LL}(\bar{P}P) > 0.1$ and < -0.2 for incident antiprotons.

The asymmetry calculated for events produced by the part of the beam with average polarization of zero, provides an estimate of ΔA_{LL} = 0.03 as an upper limit for possible false asymmetries. The relative systematic uncertainties proportional to A_{LL} are estimated to be 15 % and correspond to possible errors in the beam and target polarizations, and in the background subtraction under the π^0 peaks in the two-photon mass distributions. The statistical precision of the measurements using the proton beam is limited because most of the data were taken at reduced beam intensity. Using the full beam intensity, the present statistics could have been reached in about one week.

A QCD-based hard-scattering model [6] has been used to predict the expected values of $A_{LL}(PP)$ for different values of the spin-weighted gluon distribution functions. The aim of the model was to demonstrate that a measurement of A_{LL} in π^0 production can support or rule out the idea of very strong gluon polarization. The calculation also showed that only future high precision experiments might attain the precision necessary to distinguish between different assumptions covering the range of "conventional" dynamical mechanisms for gluon polarization. In Fig.2 we compare the results for $A_{LL}(PP)$ with the predictions for "unconventional" (large) and for "conventional" (small or zero) gluon polarization. We observe good consistency with small or zero values of the spin-weighted gluon distribution function, but not with the prediction that assumes very large gluon polarization in longitudinally-polarized protons.

Ref.[6] also shows that, in principle, it is possible to determine experimentally, by measuring the "valence spin observable" $A_{LL}{}^{DV}$, if a particular reaction, such as π^0, direct photon or jet production, obeys the spin rules of lowest-order PQCD in a given kinematical region. This observable is essentially given by the known valence-quark spin distributions because it combines proton and antiproton data to cancel the unknown gluon distribution by subtraction. However, the test is based on small differences between the measured quantities and would therefore also require very precise data.

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FIGURE CAPTIONS

Fig. 1 The layout of the experimental apparatus.

Fig. 2 The two-spin parameter A_{LL} in the reactions (a) $P + P \Rightarrow \pi^0 + X$ and (b) $\bar{P} + P \Rightarrow \pi^0 + X$ at 200 GeV, for $-0.1 < x_F < 0.1$. The curves are predictions for different values of the spin-weighted gluondistribution function (see Ref. [6]).

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TABLE I. The asymmetry parameter A_{LL} measured in the reactions, $p\uparrow + p \rightarrow \pi^0 + X$ and $\overline{p}\uparrow + p \rightarrow \pi^0 + X$ at 200 GeV, for $-0.1 < x_F < 0.1$.

p_T (GeV/c)	A_{LL} Protons (%)	A_{LL} Antiprotons (%)
1.0 – 1.5	1 ± 5	-9 ± 6
1.5 – 2.0	-1 ± 5	0 ± 8
2.0 – 3.0	-1 ± 6	-7 ± 15
3.0 – 4.0	-31 ± 27	...

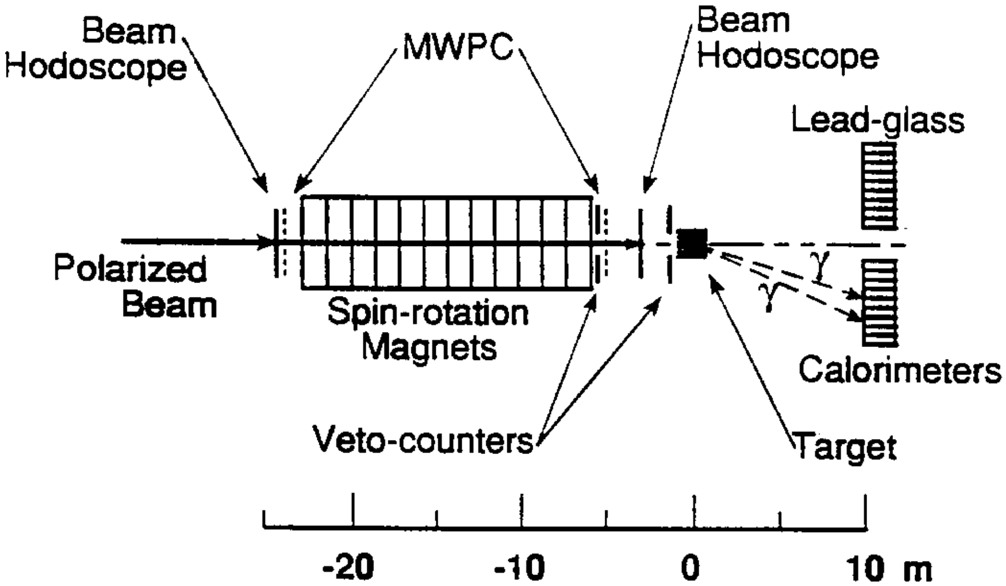

Figure 1

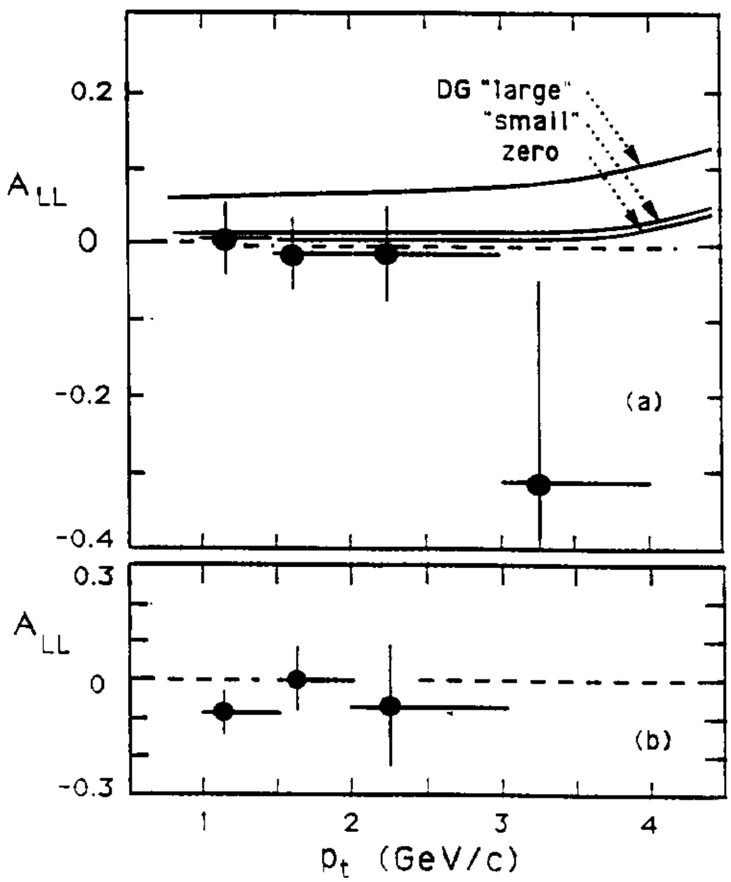

Figure 2