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Measurements of $\Delta\sigma_L(pp)$ and $\Delta\sigma_L(\bar{p}p)$ at 200 GeV/c*

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A measurement was made at Fermilab of the difference in the total cross sections between states with beam and target polarizations aligned antiparallel and parallel, $\Delta\sigma_L = \Delta\sigma(\vec{\downarrow}) - \Delta\sigma(\vec{\uparrow})$, using 200-GeV/c, polarized proton and antiproton beams and a polarized proton target. This measurement explores the spin dependence of particle interactions and the constituent dynamics. A difference in the spin-dependent total cross sections has been observed in previous experiments at lower energies [1], and this experiment was the first to explore possible spin effects in $\Delta\sigma_L$ at much higher energies.

The polarized proton beam is produced from parity-nonconserving decays of the Λ^0 hyperon, where protons emitted from these decays have their spins aligned along the direction of their momenta [2]. The Λ hyperons are produced, along with other particles, when unpolarized, 800-GeV/c protons strike a beryllium target. A virtual source of protons is produced at the target from these decays and the proton polarization is correlated to the transverse distance from the target. A beam of polarized antiprotons can be produced in an analogous manner using $\bar{\Lambda}^0$ decays. The beam transport system goal was to produce no net spin precession and to preserve the correlation between the beam particle polarization and the transverse position at the virtual source. The beam transport used four sets of quadrupole magnets to focus the beam at intermediate and final focal points. An electronic, particle-tagging system was located at the intermediate focus, while the polarized target was near the final focus. A detailed description of the polarized beam is given in Ref. 3.

Because this beam is produced from decays, the polarization of each beam particle was determined through a tagging system. The momentum and polarization of each beam particle is measured using a series of overlapping scintillator hodoscopes and look-up electronics. Signals from the tagging system were then sent to the experimental trigger. Plus and minus polarization magnitudes were in bins of 10% between 25% and 64%, while those particles tagged with polarizations between -25% and +25% were as-

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signed zero polarization. An absolute calibration of the beam polarization was performed using two polarimeters: one using the Primakoff effect [4] and the other Coulomb-nuclear interference (CNI) [5]. These measurements gave an absolute measurement of the beam polarization to about 15%.

A series of twelve spin-rotation (snake) dipole magnets rotated the particle spin direction from the transverse horizontal (S) to the longitudinal (L) direction. The particle spin direction was changed by reversing the magnet polarity, and was reversed every 10 spills, with about 5 reversals per hour. Two beam Čerenkov counters detected the pion contamination, which for the polarized proton beam was about 13%, while the polarized antiproton beam contained five times more π^- 's than \bar{p} 's. Typical intensities for this experiment were 1.2×10^7 and 8.5×10^6 per 20-second spill for the polarized p and \bar{p} beams, respectively. The average beam polarization was 0.42 for polarization values between 25% and 55%.

The polarized proton target was a frozen spin target and produced a polarization of about 75% through the dynamic nuclear polarization process. The target material was pentanol, with a 13% hydrogen fraction and a target constant of 1040 ± 38 mb. The target size was a 3-cm-diameter cylinder, 20 cm in length. A ^3He - ^4He dilution refrigerator was used to cool the target to about 40 mK and a superconducting solenoid, capable of a 6.5 T magnetic field, was used to align the spin direction. The spins of the target protons were reversed approximately every 24–36 hours to reduce systematic effects.

The apparatus used to measure the particle scattering consisted of several overlapping scintillator hodoscopes. Two of these, one upstream and one downstream of the snake magnets, measured the beam particle trajectory on to the polarized target. A third transmission hodoscope located 13 m downstream of the target measured the amount of scatter from the beam-target collisions. Each hodoscope could locate the hit position within a 2 mm segment size in both the vertical and horizontal directions. The amount of scattering was found by calculating the difference between the undeflected particle trajectory projected to a segment on the transmission hodoscope and the segment actually struck. A t value was calculated from $t \approx -(p\theta)^2 = -p^2(\Delta x^2 + \Delta y^2)/d^2$, where p is the beam particle momentum, Δx and Δy the amount of deflection in the horizontal and vertical directions, respectively, and d is the distance between the polarized target and the transmission hodoscope. This calculation was performed online using memory-lookup electronics. The number of particles scattered into each t bin for each beam polarization bin was then counted; no single events were recorded, and hence large number events could be counted rapidly. Corrections adjusted the number of counts in each t bin due to the grid geometry.

The value of $\Delta\sigma_L$ per t bin is given by: $\Delta\sigma_L = -2A\epsilon/P_B \cdot P_T$, where ϵ is the asymmetry of the number of particles transmitted for beam and target spin aligned antiparallel (+) or parallel (-), $\epsilon = (N_T^+/N_0^+ -$

$N_T^-/N_0^-) / (N_T^+/N_0^+ + N_T^-/N_0^-)$, where N_T is the number of transmitted particles and N_0 is the total number of particles, A is the target constant, P_B is the average beam polarization, and P_T is the average target polarization. The statistical accuracy scales as the inverse square root of the total number of particles, $1/\sqrt{N_0}$. Three quantities were periodically reversed to reduce systematic errors: (1) the polarization state of the beam particle, (2) the spin rotation direction by the snake magnets, and (3) the spin direction of the protons in the polarized target. A total of eight quantities were then summed appropriately to determine the number of particles in each of the parallel and antiparallel states. From the data, the first t bin contains about 97% of the transmitted number of particles to about 3% background counts. The transmitted asymmetry can be found from the formula, $\epsilon_{Trans} = (1 + B/N) \epsilon_{T1} - (B/N) \epsilon_{Back}$, where B is the total number of background particles, N is the total number of particles measured, ϵ_{T1} is the asymmetry calculated from the first t bin, and ϵ_{Back} is the asymmetry due to the background particles. The value of ϵ_{Back} was found by making a fit of the asymmetries formed from the number of particles scattered into each t bin, excluding the first one, as a function of t . The value of ϵ_{Back} is fairly insensitive to the value of B . The preliminary result for $\Delta\sigma_L(pp)$, along with the values of ϵ_{T1} , ϵ_{Back} , and ϵ_{Trans} , are given in Table I for the polarization values between 35 and 55% and for the expanded polarization values between 25 and 55%. These same quantities are given for $\bar{p}p$ scattering in Table II. Both sets of results are consistent with zero and the errors given are statistical only. A second detector system also gave results consistent with zero.

TABLE I. $\Delta\sigma_L(pp)$ results for 2 different beam polarization bins.

Quantity	Beam Pol 35-55%	Beam Pol 25-55%
ϵ_{T1}	0.000000 ± 0.000006	-0.000001 ± 0.000005
ϵ_{Back}	0.000026 ± 0.000061	0.000046 ± 0.000053
ϵ_{Trans}	-0.000001 ± 0.000006	-0.000003 ± 0.000006
$\Delta\sigma_L(pp)$	$-4 \pm 40 \mu\text{b}$	$-18 \pm 38 \mu\text{b}$

TABLE II. $\Delta\sigma_L(\bar{p}p)$ results for 2 different beam polarization bins.

Quantity	Beam Pol 35-55%	Beam Pol 25-55%
ϵ_{T1}	-0.000031 ± 0.000016	-0.000025 ± 0.000014
ϵ_{Back}	0.000051 ± 0.000150	0.000074 ± 0.000131
ϵ_{Trans}	-0.000034 ± 0.000017	-0.000029 ± 0.000015
$\Delta\sigma_L(\bar{p}p)$	$-199 \pm 99 \mu\text{b}$	$-183 \pm 94 \mu\text{b}$

Many systematic effects such as beam motion, momentum and polarization distributions, geometrical effects, and snake magnet effects have been studied. False asymmetries such as adding + and - polarization states to produce a "fake zero" polarization and summing every other spill together, have also been calculated in an analogous manner to $\Delta\sigma_L$. As a cross check of the data, a CNI-like measurement was made using a vertically-aligned (N) beam polarization. The measured left-right asymmetry was found to be $+0.002491 \pm 0.000183$, a 13σ effect, while the up-down asymmetry is consistent with zero. Calculating left-right and up-down asymmetries using the longitudinally-polarized beam gives nonzero contributions, which may correspond to a S- or N-type component. Similar results were found in studies of the \bar{p} beam. At present, the systematic errors have not been included in the $\Delta\sigma_L$ result, but are not expected to be dominant.

There are currently two different theoretical predictions for $\Delta\sigma_L$. One [6] of these predictions is based on conventional Regge phenomenology, where $\Delta\sigma_L(pp; s) \sim s^{-1.15}$, and s is the square of the energy. For $\sqrt{s} = 20$ GeV, $\Delta\sigma_L \approx -19 \mu\text{b}$. The other prediction [7] is based on phenomenology from jet physics, where $\Delta\sigma_L(pp; s)$ is divided into two parts, one from coherent hadronic dynamics and the other, $\Delta\sigma_L^{jet}$, is the contribution from constituent parton scattering. A measurement of $\Delta\sigma_L^{jet}$ can provide information on the spin-dependent gluon contribution, ΔG , since the gluon processes are dominant in this kinematic region. For a large ΔG , $\Delta\sigma_L^{jet} \approx 26 \mu\text{b}$, and for no ΔG contribution, $\Delta\sigma_L^{jet} \approx 2 \mu\text{b}$. Figure 1 shows the comparison of theoretical predictions and results of this experiment.

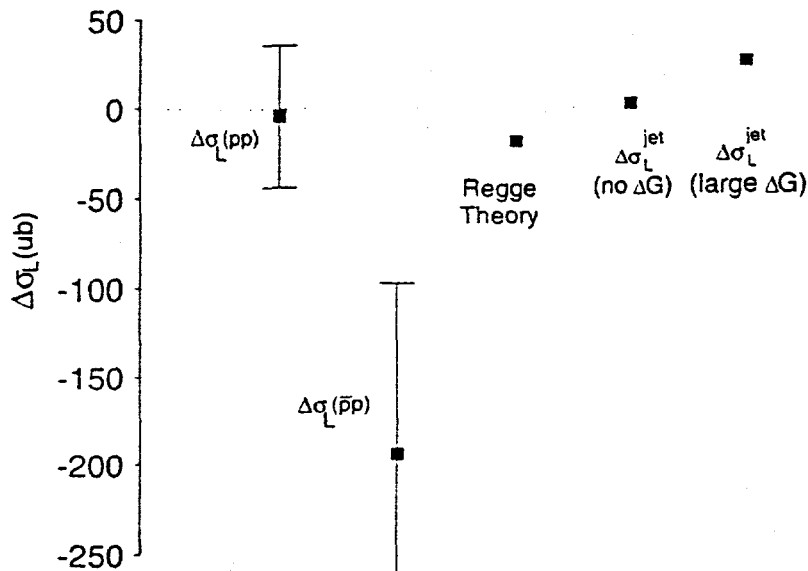


FIGURE 1. Comparison of theoretical predictions with results from this experiment.

The measurements of $\Delta\sigma_L(pp)$ and $\Delta\sigma_L(\bar{p}p)$ at 200 GeV/c are both consistent with zero, within statistical errors. The current results are not able to distinguish between theoretical models and predictions.

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