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Transverse spin effect in inclusive hadron - hadron interactions

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TRANSVERSE SPIN EFFECTS IN INCLUSIVE HADRON – HADRON INTERACTIONS

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Abstract

An experimental overview of transverse spin asymmetries in inclusive pion and Λ^0 production by intermediate and high energy transversely polarized proton and antiproton beams is presented. Preliminary results from Fermilab E-704 experiment are also discussed. The considerable polarization P_0 of hyperons produced at high x_F has been known for a long time. More recently large values of the analyzing power A_N and depolarization D_{NN} were also found in inclusive Λ^0 production at 200 GeV/c. Pions produced by polarized protons and antiprotons show also large values of the analyzing power A_N increasing with x_F. These spin asymmetries are found to be large in the beam fragmentation region (large x_F) and at moderate p_T ($p_T \sim 1$ GeV/c). The similarity between the kinematical dependence of the hyperon polarization and the pion and Λ^0 analyzing power, in which A_N increases almost linearly with x_F above a certain p_T threshold, suggests a common origin and interpretation for these phenomena. These results can further test the current ideas on the underlying mechanisms for the hyperon polarization and the spin dependence in meson and hyperon production.

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[1] Preliminary results from the Fermilab E-704 experiment are presented on behalf of the collaboration.

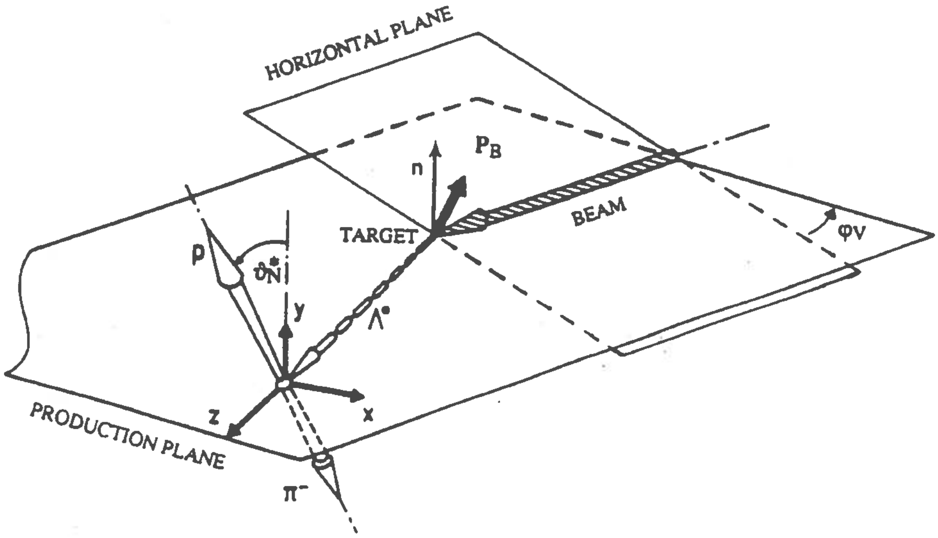

Figure 1: Transverse spin observables: definition of beam and scattered particle polarization vector directions.

1. Introduction

Spin effects in hadronic collisions at high energy have been observed in a variety of experiments over the last 20 years, yet conventional Perturbative QCD calculations predict that they should be very small. Sensitive tests of models of the strong interaction dynamics are provided by polarization measurements since they give insight into the spin dependence of the underlying partonic sub-processes. The role of the *spin* has been fundamental in the understanding of atomic and particle spectra (for instance the hyperfine splitting of atomic levels). With the devolopment of polarized beams and targets in the last few decades it has become possible to study the spin dependence of the structure and interaction dynamics in nuclear and particle physics.

The discovery of a large negative polarization, transverse to the production plane, at 300 GeV/c in inclusive Λ^0 production in 1976 at Fermilab [1] came as a surprise and showed our lack of understanding of the hadronic reaction mechanisms as far as spin observables are involved. This discovery renewed interest in spin as an important factor in high-energy hadron interactions. It set the stage for a systematic and detailed study of polarization effects in inclusive hyperon production over wide energy and kinematical ranges with a variety of beam particles and nuclear targets, both unpolarized, which showed that most hyperons are produced polarized. Large polarizations were found up to the highest measured energies ($\sqrt{s} = 60$ GeV) and transverse momenta ($p_T \sim 4.5$ GeV/c). The observed persistence of large polarizations at relatively high transverse momenta contradicts the widespread idea that such effects should disappear at large enough p_T. The question, however, of what is a large enough p_T and high enough energy still remains.

Previous expectations, based on Regge theory and QCD predictions, were that spin effects would vanish at high energies, since the smallness of spin-flip amplitudes, the large multiplicity of final states, and the contribution of several inelastic production channels to an inclusive process, make it unlikely to have the coherent interference between spin non-flip and spin flip amplitudes that leads to sizeable polarization effects. After decades of being regarded as an inessential complication to the strong interaction at high energy, spin has thus come again to the attention of the physics community.

Transverse single spin asymmetries are difficult to accommodate in a Perturbative QCD framework, but might be a clue for higher twist and non perturbative and confinement effects. Presently, these spin asymmetries can be taken into account only via model approaches [17, 18, 19, 20, 21, 22, 23].

A natural extension of these measurements is the study of transverse spin asymmetries in inclusive meson and hyperon production by high energy polarized proton and antiproton beams. An important role in such studies is being played by the Fermilab E-704 experiment, which is completing its data analysis.

Experiments using polarized beams and/or polarized targets at intermediate and high energies have been actively pursued during the past four decades at various laboratories in the world. Many different asymmetry measurements in a number of scattering processes have been carried out, and many unexpected results have been observed in hadron-hadron and lepton-nucleon scattering. However, the most complete piece of information comes from a large set of experiments where the beams and the targets were both unpolarized, but the polarization of produced hyperons was measured through their self analyzing parity violating decays. To this day this remains an intriguing and surprising branch of research.

The study of spin effects gives more complete information on the dynamics of particle interactions than the study of spin averaged observables. Since both quarks and gluons possess spin, and the forces between them are spin dependent, we can expect important information on these forces and on the nucleon structure to be obtained through the study of the spin dependent aspects of the hadron interactions, as has been the case before in atomic and nuclear physics. Studies of (inclusive) particle production are especially relevant, since the spin asymmetries result from the spin dependence of the underlying parton sub-processes as well as the parton spin wave-functions.

In an inclusive measurement $p\uparrow + N \rightarrow C + X$ (Fig. 1) with the beam polarized transverse to the reaction plane one can measure the analyzing power A_N, the depolarization D_{NN}, and by avaraging over opposite beam polarization states the polarization P_0:

$$A_N = \frac{1}{P_B} \cdot \frac{\sigma(i=\uparrow) - \sigma(i=\downarrow)}{\sigma(i=\uparrow) + \sigma(i=\downarrow)}$$

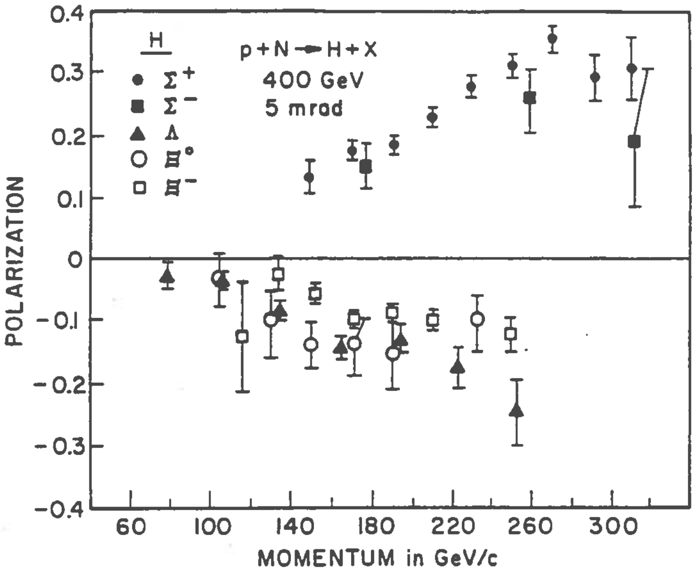

Figure 2: Polarization of different hyperons in $p + N \to Y + X$ as a function of their momentum p_Y [2]. The hyperons were produced at a fixed angle of 5 mrad with 400 GeV/c proton beams ($\langle x_F \rangle \approx p_Y/p_B$ and $\langle p_T \rangle \approx p_Y \times 0.005$).

$$P_0 = \frac{\sigma(f =\uparrow) - \sigma(f =\downarrow)}{\sigma(f =\uparrow) + \sigma(f =\downarrow)}$$

$$D_{NN} = \frac{1}{P_B} \cdot \frac{\sigma(i = f) - \sigma(i \neq f)}{\sigma(i = f) + \sigma(i \neq f)}$$

P_B is the effective beam polarization normal to the production plane, σ is the spin dependent differential cross section and i (f) refers to the initial (final) state polarization (the arrows ↑, ↓ indicate the polarization direction). Usually, these observables are expressed in terms of three independent kinematical variables, the center of mass energy $\sqrt{s}$, the fraction of the beam momentum carried by the outgoing particle x_F (Feynman x), and the transverse momentum with respect to the beam direction p_T.

In a simple quark-parton fragmentation/recombination model, these spin observables can be thought of in terms of the spins of the valence quarks. A_N then measures the valence quarks memory of the beam particle's spin and polarization, P_0 gives the magnitude and direction of the polarization of the sea quarks produced in the interaction, and D_{NN} measures the probability that leading valence quark(s) from the beam particle has its spin flipped in the interaction.

2. Hyperon Polarization

20 years ago in the reaction $p + N \to \Lambda^0 + X$ at 300 GeV/c it was found, that Λ^0 hyperons are produced with large negative polarization [1] with respect to the normal

to the production plane $\vec{n}$ ($\vec{n} = \vec{p_B} \times \vec{p_\Lambda} / |\vec{p_B} \times \vec{p_\Lambda}|$), and that the polarization increases in magnitude with x_F and p_T. After this unexpected discovery a detailed study of the hyperon polarization in inclusive processes has been pursued at various laboratories in the world, which showed that most hyperons are produced polarized [2] (Fig. 2). For a more complete review of these polarization phenomena see Refs. [2, 3, 4].

Since the first results on hyperon polarization, the origin of this polarization is attributed to some mechanism, based on semiclassical arguments [17, 18] or inspired by QCD [19, 20], by which *strange* quarks produced in the fragmentation process acquire a large negative polarization. In these models a hyperon is formed from a fragment of the incident proton which couples with one or more polarized *strange* quarks, resulting thus in a polarized hyperon. In the LUND model [18], an $s\bar{s}$ quark pair from the sea is produced polarized by a soft tunnelling process through a classically forbidden region in the color field. In the model of DeGrand and Miettinen [17] the polarization origins from the Thomas precession of the quark's spin in the recombination process, when accelerated from rest in the sea to the fast moving fragment of the incident proton. Szwed [19] proposes that the polarization arises from the multiple scattering of the *strange* quark in the gluonic field before hadronization. Experimental data are qualitatively consistent with the simple expectations based on these models.

Hyperon polarization experiments have covered a wide kinematic range of $0 \leq p_T \leq 4.5$ GeV/c over a large incident beam momentum range from 1.5 GeV/c to 800 GeV/c in fixed target and from $\sqrt{s} = 31$ to 62 GeV in colliding beam experiments (equivalent up to 2000 GeV/c in the fixed target mode), using different unpolarized hadron beams and nuclear targets.

The Λ^0 polarization data show a striking kinematical dependence with almost no energy dependence: the polarization increases linearly in magnitude with the beam momentum fraction x_F carried by the hyperon for p_T below 1 GeV/c, and grows in magnitude with the hyperon transverse momentum p_T and eventually reaches a plateau around $0.7 - 1.0$ GeV/c (Fig. 3). While the data on other hyperons (Fig. 2) are not nearly as extensive, they are consistent with a similar kinematic behavior with differing signs and magnitudes of the polarization. As the energy range has increased, and the variety and amount of data has increased as well, these features have become more striking and suggestive of some simple underlying dynamical mechanism.

The hyperon polarization was studied also with proton and meson beams. The meson nucleon interaction differs from the proton one in that, in a simple constituent quark model, the latter is a direct *strange* quark pick up in both fragmentation regions, whilst the former may require, in addition, quark rearrangement for the Λ^0 production. Among the mesons there is also a difference, since the kaons themselves carry the *strange* quark, which must become polarized, but doesn't need to be created in the collision. In general, the polarizations are found to be much larger. For instance, in the process $K + p \rightarrow \Lambda^0 + X$ the polarization is twice as large as for $p + p \rightarrow \Lambda^0 + X$.

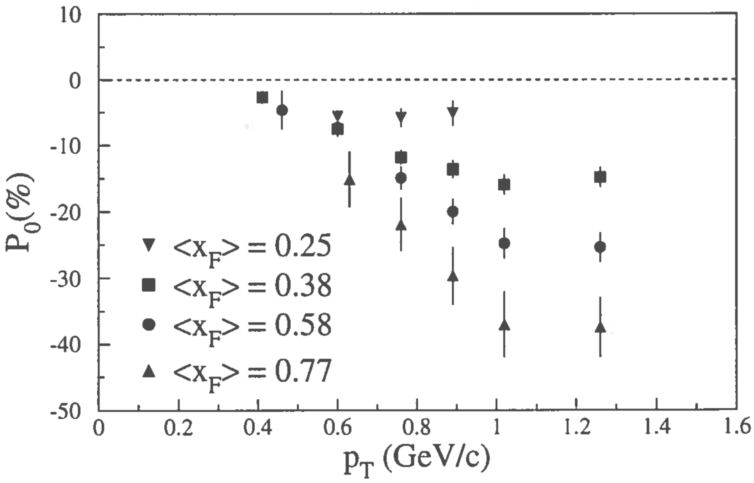

Figure 3: Kinematical dependence of the Λ^0 polarization.

In addition a sizeable, non-negligible, dependence of the Λ^0 polarization on the target type has been observed: the polarization diminishes in magnitude for heavier targets (like Cu or W) by about 25 % when compared to light targets (like Be).

The polarization of anti-Λ^0's produced in the same way and in the same kinematic region has been found to be consistent with zero (Fig. 4) [5]. This fact has led to the idea that polarization is primarily a leading particle effect, that is, the polarization is a consequence of the beam proton fragmentation mechanism. Thus there should be no polarization for particles that do not share any quarks with the incoming projectile, such as Ω^- and anti-hyperons. As a consequence of this leading particle effect, it is expected that anti-Λ^0 produced by antiproton beams be polarized essentially in the same way as Λ^0 produced in pp collisions with opposite polarization, as it has indeed been found. On the contrary, the recent observation of relatively large polarizations for anti-Σ^+ and anti-Ξ^- [5] hyperons produced with proton beams ($P_{\bar{Y}} \approx 10\%$) (Fig. 4), goes against the idea that anti-baryons produced by proton beams should not be polarized, since they don't share any valence quark with the incident proton beam.

The main features of the experimental results on hyperon polarization, therefore, can be summarized as follows:

1. The magnitude of the polarization increases linearly with p_T up to 0.7–1.0 GeV/c ($P_Y = 0$ at $p_T = 0$), after that it remains constant.
2. The magnitude of the polarization increases linearly with x_F.
3. The Λ^0 polarization is almost energy independent over the large measured range from 10 to 2000 GeV/c.
4. Almost all hyperons are found to be polarized in the proton fragmentation region: $P_{\Lambda^0} \sim -P_{\Sigma^0} \sim -P_{\Sigma^+} \sim -P_{\Sigma^-} \sim P_{\Xi^-} \sim P_{\Xi^0}$ and $P_{\Omega^-} \sim 0$

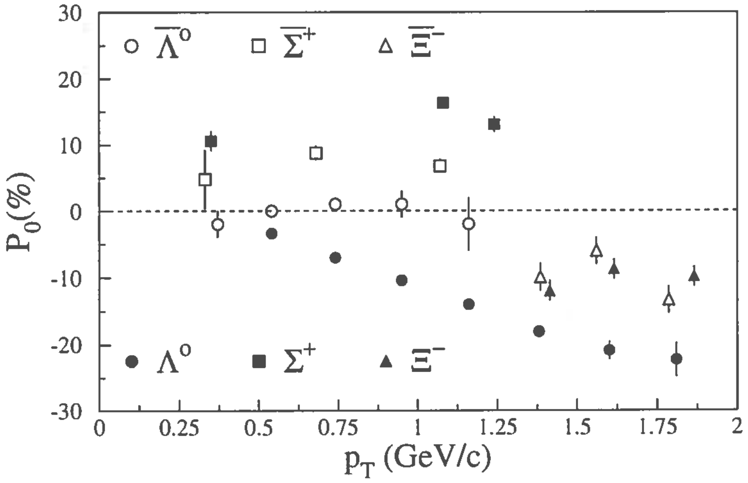

Figure 4: Polarization of antihyperons produced with proton beams (open symbols): $\bar{\Lambda}^0$, $\bar{\Sigma}^+$, and $\bar{\Xi}^-$ [5]. For comparison are also shown the polarizations of the relative hyperons (closed symbols).

5. Anti-hyperons produced by proton beams show large (unexpected) polarizations: $P_{\bar{\Lambda}^0} = 0$ but $P_{\bar{\Sigma}} \approx +10\%$ and $P_{\bar{\Xi}} \approx -10\%$

6. There is a small dependence of the polarization on the target type.

3. Experiments with Polarized Proton Beams (Intermediate Energies)

The first polarized low energy proton beams were obtained via scattering more than 35 years ago. In the 1970's, after the development of polarized ion sources, the acceleration of polarized protons became possible, and a beam of polarized protons at 6 GeV/c momentum was thus obtained at the Zero Gradient Synchrotron at Argonne National Laboratory. Later, polarized protons were accelerated up to 12 GeV/c. About 15 years ago, the Alternating Gradient Synchrotron at Brookhaven National Laboratory successfully accelerated polarized protons to a momentum of 22 GeV/c, after solving the problem of intrinsic depolarizing resonances by jumping them.

In inclusive processes, as well as in elastic scattering, large spin effects have been observed using polarized beams and/or targets. In these experiments one measures the right–left production asymmetry (analyzing power A_N) with respect to the direction of the beam polarization. For instance, a value of 33 % of the asymmetry corresponds to a ratio in the cross section of 2:1 i.e. with spin-up beams twice as many particles are produced to the left of the beam than to the right of the beam in the plane orthogonal to the beam polarization direction.

Several experiments have studied the transverse spin asymmetry A_N in inclusive pion, kaon and proton production using either polarized proton beams or polarized targets. The results have shown small asymmetries in the beam fragmentation region

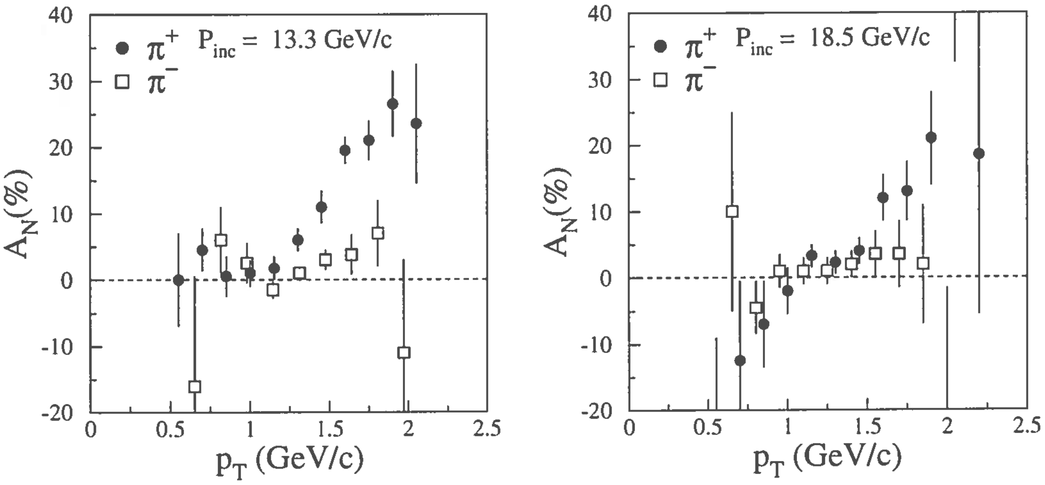

Figure 5: Analyzing power in inclusive pion production as a function of p_T at two different beam energies [7].

when the beam was unpolarized and the target polarized. This suggests a strong leading effect for A_N similar to that observeded for the hyperon polarization.

Large positive asymmetries have been observed in inclusive π^+ production in the forward beam fragmentation direction (large x_F) at different energies at ANL [6] and BNL [7, 8], while for the π^-'s the data from the same experiments are negative and small or compatible with zero. Figure 5 shows the analyzing power A_N for the inclusive charged pion production from [7] at BNL as a function of p_T at two different incident beam momenta. These results were obtained at relatively low values of x_F, $\langle x_F \rangle \sim 0.2$. Similar measurements were performed also by [8] at much larger x_F and similar p_T with the same polarized proton beam, but their results indicate much smaller values for A_N. A_N in K_S^0 production was also measured by [10, 8]. The data indicate a sizeable asymmetry of about 10 % in the central x_F region and medium p_T ($p_T \sim 1$ GeV/c).

First measurements of the Λ^0 spin parameters with a 6 GeV/c polarized proton beam were carried out at ANL about 20 years ago [9]. These results do not show large spin effects, and the observed spin asymmetries, including the Λ^0 polarization, are basically compatible with zero. However, this energy is still too small to compare these measurements with the results on the Λ^0 polarization obtained at much higher energies and discussed in the previous section.

More recently the Λ^0 spin parameters have been measured at the AGS with a 13.8 and 18.5 GeV/c polarized proton beam incident on a Be target in the central and small x_F region ($x_F < 0.5$), where generally spin effects are expected to be small, but at large p_T's up to 2 GeV/c [10]. In Fig. 6 are shown the A_N data measured in inclusive Λ^0 production at 18.5 Gev/c and the D_{NN} data as a function of x_F for different p_T intervals. These measurements are compatible with zero, and no p_T

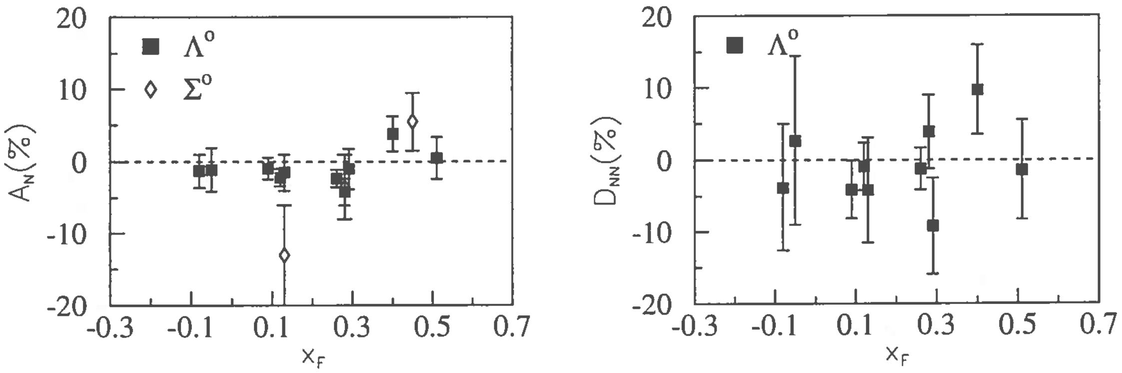

Figure 6: Analyzing power (left plot) and depolarization (right plot) in inclusive Λ^0 production at 18.5 GeV/c [10].

dependence is observed. On the contrary, D_{NN} in Σ^0 production was found to be as large as 25 % [10]. These results are combatible with fragmentation/recombination models for hyperon polarization [17, 18] based on SU(6) wave functions.

4. The Fermilab E-704 Experiment (High Energy)

During the 1990 fixed target run, the E704 group at Fermilab carried out several measurements using this polarized beam facility, and presently the data analysis is being completed. The $\pi^{\pm}$ and π^0 analyzing power A_N at large x_F, the difference in the parallel and anti-parallel total cross sections for pure helicity states $\Delta\sigma_{LL}$, the large p_T production of π^0 in the central region ($x_F \sim 0$), and the production of Λ^0 hyperons and K_S^0 mesons at large x_F have been measured.

For the first time high energy polarized proton and antiproton beams were obtained at 200 GeV/c at Fermilab from the parity violating decay of Λ^0 and anti-Λ^0 hyperons [11]. The polarized proton beam was obtained by selecting protons from the weak decay of Λ^0 particles produced in a primary target by the 800 GeV/c Tevatron extracted proton beam. Decay protons are longitudinally polarized in the Λ^0 decay rest frame, and acquire a transverse polarization when Lorentz-boosted to the laboratory frame: larger the angle between the proton momentum vector and the Λ^0 direction in the decay frame, larger the transverse proton polarizaiton in the laboratory frame (Fig. 7). Those emitted near ±90 in the Λ^0 rest frame have a transverse polarization of ±64 % in the laboratory frame. The protons polarization, on average, was determined by tagging their trajectory in the horizontal plane at an intermediate focus of the beamline, where also their momentum was tagged. The tagged polarization values ranged from -0.65 to $+0.65$, allowing thus the use of protons of opposite polarization signs simultaneously, which significantly supressed systematic effects. Events with tagged polarization values from 0.35 to 0.65 (-0.65 to -0.35) were considered to have positive (negative) polarization and were used in the anal-

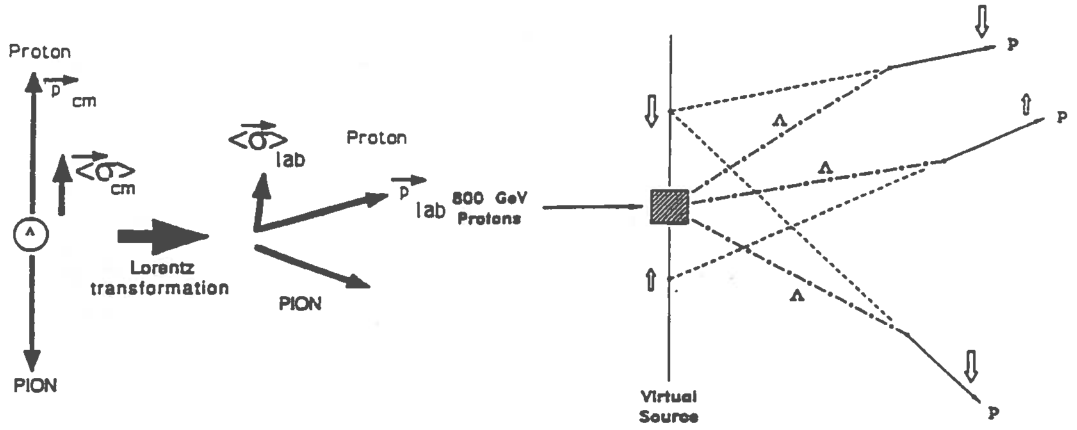

Figure 7: Polarized proton production: protons from Λ^0 decays are longitudinally polarized in the Λ^0 decay rest frame and acquire a transverse polarization when boosted to the laboratory frame; the proton transverse polarization is then correlated to the proton virutal source position.

ysis. The average polarization was 0.46 for both signs. A set of 12 dipole magnets rotated the transverse beam polarization direction from the horizontal to the vertical direction at the experimental target. In order to further suppress systematic errors, the polarity of the spin rotator magnets was reversed every 15 Tevatron spills. The polarized antiproton beam was obtained in a complementary way from the decay of anti-Λ^0 hyperons. Typical beam intensities were of 2×10^7 polarized protons and 2×10^5 polarized antiprotons per 20 second Tevatron spill.

5. Pion Asymmetries

The analyzing power A_N in inclusive pion (π^+, π^-, and π^0) production has been measured with 200 GeV/c transversely polarized proton and antiproton beams over a wide x_F range ($0.2 \leq x_F \leq 1.0$) and at moderate p_T ($0.2 \leq p_T \leq 2.0$ GeV/c). Large asymmetries have been found in all these processes, in which A_N increases in magnitude with x_F to large values above a threshold of about 0.5 GeV/c in p_T.

The $\pi^\pm$ asymmetry obtained with the polarized proton beam is presented in Fig. 8 [12], and shows a striking mirror symmetric dependence in x_F where A_N increases with increasing x_F to large positive values for π^+'s and decreases with increasing x_F to large negative values for π^-'s. A threshold for the onset of the asymmetry is observed around $p_T \sim 0.5$ GeV/c, below which A_N is essentially zero, and above which A_N increases (decreases) with p_T up to $p_T \sim 1.0$ GeV/c for π^+'s (π^-'s) in the covered p_T range.

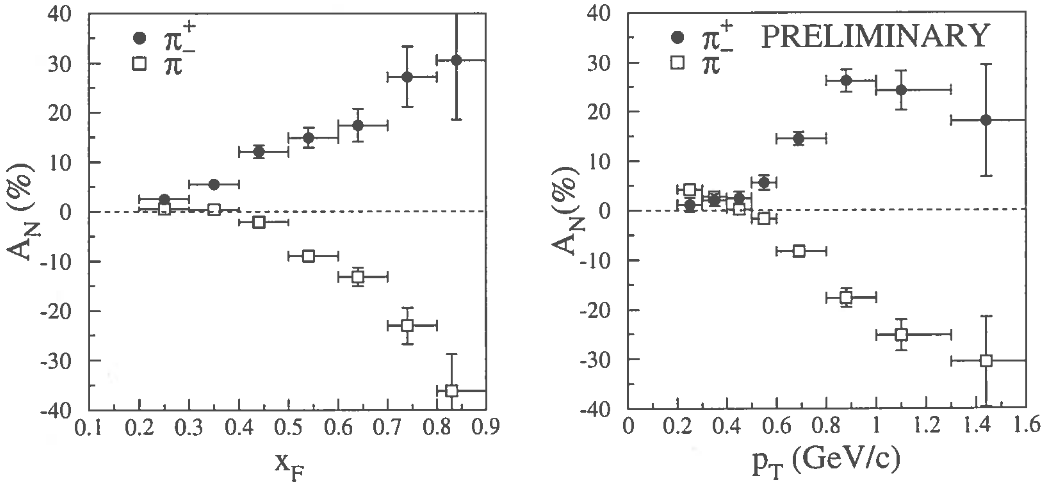

Figure 8: Analyzing power in inclusive pion production as a function of x_F [12] and p_T (preliminary results).

A charge symmetric behavior is found for $\pi^{\mp}$'s produced with the polarized antiproton beam (Fig. 9) [14]. Here A_N increases with increasing x_F to large positive values for π^-'s and decreases with increasing x_F to large negative values for π^+'s. The covered p_T range for these data is slightly smaller than for proton data ($p_T \leq 1.5$ GeV/c). The data show a similar p_T dependence as in the proton beam case, in particular also here a threshold for the onset of the asymmetry is observed around $p_T \sim 0.5$ GeV/c.

A_N was also measured in inclusive π^0 production over a similar x_F and p_T kinematical region. The asymmetry shows a similar behavior as for $\pi^{\pm}$ data, but is only half as large. The results obtained with polarized protons and antiprotons ($0.5 \leq p_T \leq 2.0$ GeV/c for these data) are presented in Fig. 10 [13]. In particular the sign of the π^0's A_N produced either by polarized protons or antiprotons is the same.

Preliminary results were obtained also for K^0_S's produced with the polarized proton beam. This asymmetry indicates a similar kinematical dependence as the π^0's A_N, with the same magnitude but opposite sign.

The A_N results in inclusive meson production show a similar kinematical x_F and p_T dependence and for any fixed x_F and p_T data point they can be summarized as follows:

$$A_N(p\uparrow p \to \pi^+ + X) \approx -A_N(p\uparrow p \to \pi^- + X) \approx \tfrac{1}{2}A_N(p\uparrow p \to \pi^0 + X) > 0$$

$$A_N(\bar{p}\uparrow p \to \pi^- + X) \approx -A_N(\bar{p}\uparrow p \to \pi^+ + X) \approx \tfrac{1}{2}A_N(\bar{p}\uparrow p \to \pi^0 + X) > 0$$

$$A_N(p\uparrow p \to \pi^+ + X) \approx A_N(\bar{p}\uparrow p \to \pi^- + X) > 0$$

$$A_N(p\uparrow p \to \pi^- + X) \approx A_N(\bar{p}\uparrow p \to \pi^+ + X) < 0$$

$$A_N(p\uparrow p \to \pi^0 + X) \approx A_N(\bar{p}\uparrow p \to \pi^0 + X) > 0$$

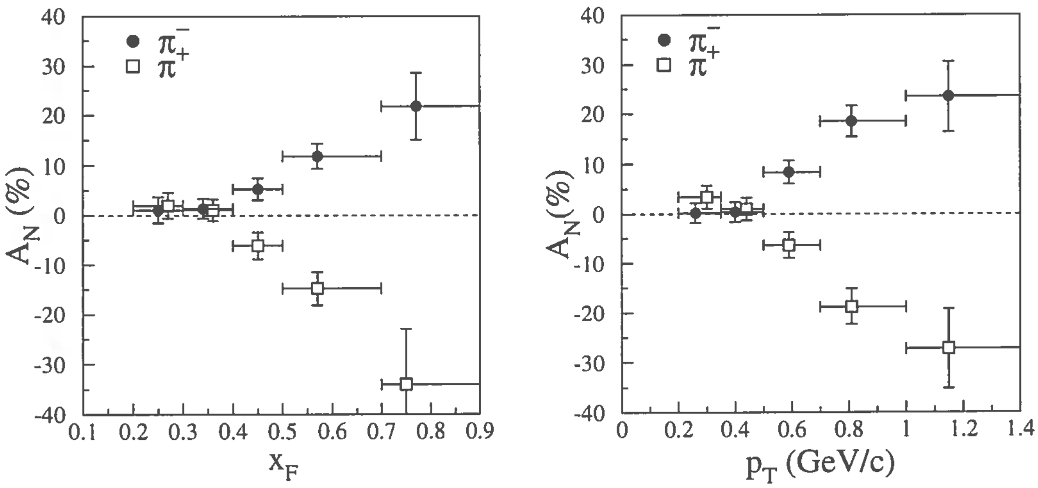

Figure 9: Analyzing power in inclusive pion production by transversely polarized antiprotons at 200 GeV/c from E-704 experiment as a function of x_F (left plot) and p_T (right plot) [14]).

6. Λ^0 Spin Observables

A natural extension of the high energy hyperon polarization measurements, performed with unpolarized beams and targets, is the study of the hyperon production mechanism with polarized proton beams at similar energies, and several spin observables can be measured in these processes, like the production asymemtry A_N and the polarization transfer D_{NN}.

The Λ^0 spin observables are obtained from the angular distribution of the decay proton in the Λ^0 rest frame, given, up to a normalization factor, by:

$$\frac{dN^{\pm}}{d\,(\cos\theta_N^*)} = \left(1 \pm P_B\langle\cos\phi_V\rangle A_N\right)\left(1 + \frac{\left(P_0 \pm P_B\langle\cos\phi_V\rangle D_{NN}\right)\alpha_\Lambda\cos\theta_N^*}{1 \pm P_B\langle\cos\phi_V\rangle A_N}\right) g\,(\cos\theta_N^*)\ .$$

P_B is the proton beam polarization, ϕ_V is the angle between the beam polarization axis directed upward and the normal to the production plane, and the $+(-)$ sign refers to positively (negatively) polarized beam particles (see Fig. 1). $\alpha_\Lambda = 0.642$ is the Λ^0 decay asymmetry, θ_N^* is the proton decay angle with respect to the normal to the production plane, and $g\,(\cos\theta_N^*)$ is an acceptance function. Integrating over ϕ_V or $\cos\theta_N^*$ or avaraging over opposite beam polarizations different spin observables can be extracted.

The Λ^0 analyzing power data are presented in Fig. 11 [15] as a function of x_F and p_T. They indicate a substantial negative values of the analyzing power in which A_N increases in magnitude with x_F and p_T, and reaches values larger than -15 % at large x_F and p_T, while at low x_F ($x_F < 0.5$) and/or low p_T ($p_T < 0.5$ GeV/c) these results are combatible with zero. The trend of these results shows similar behavior as the existing Λ^0 polarization data, thus suggesting a common interpretation.

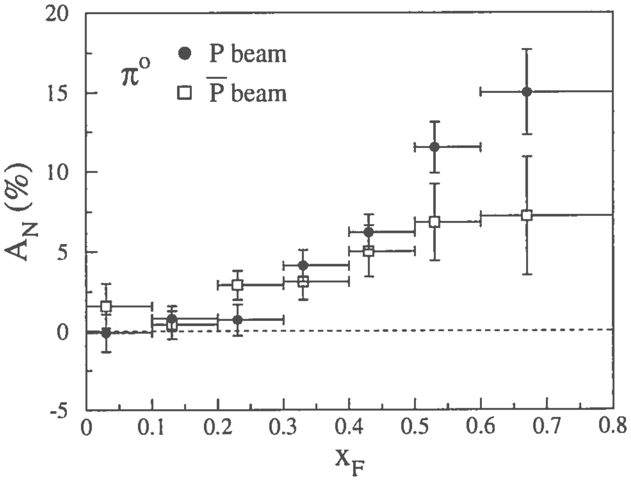

Figure 10: Analyzing power in inclusive π^0 production as a function of x_F [13].

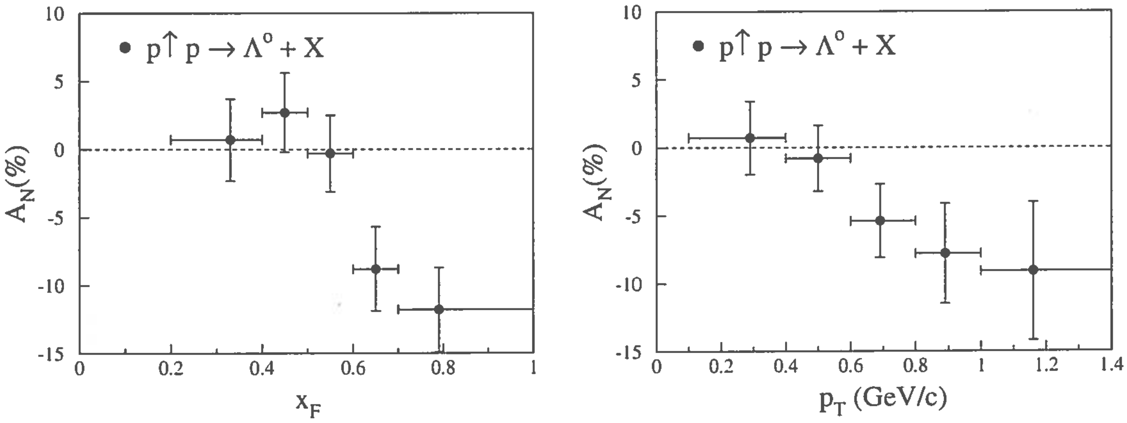

Figure 11: Analyzing power in inclusive Λ^0 production as a function of x_F and p_T [15].

The depolarization D_{NN} is shown in Fig. 12 [16]. At large x_F values (x_F approaching 1) D_{NN} reaches positive values as large as 30 % at $p_T \sim 1$ GeV/c, while almost no dependence in x_F is observed for $x_F < 0.6$, where D_{NN} is slightly positive. D_{NN} grows to significantly large positive values with increasing p_T and a saturation in p_T is observed around 1.0 GeV/c, while at low p_T values D_{NN} is compatible with zero. Also these data show a kinematical behavior similar to the polarization and A_N results.

7. Outlook

No quantitative theoretical explanation for these phenomenon exists at this point. In fact the prevailing theory of hadronic structure and interactions, QCD, predicts zero polarization at high energies and transverse momenta. The PQCD calculations,

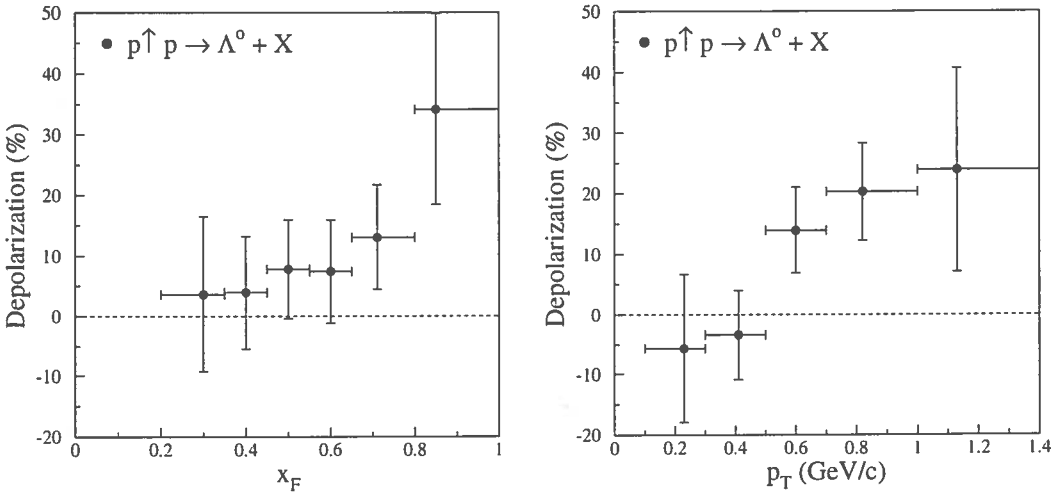

Figure 12: D_{NN} in inclusive Λ^0 production [16].

however, to be applicable requires that the products of the reaction have large p_T. Most of the current high energy experiments have measured spin effects at p_T below 2.0 GeV/c and PQCD calculations may not be directly applicable to them. The question, however, of what constitutes high enough transverse momenta remains, but no trend toward zero polarization is observed in the present data.

Different quark parton models were proposed to interpret these polarization effects by introducing spin dependent asymmetries into the quark and di-quark production and scattering amplitudes [17, 18]. Since the first results on hyperon polarization, the origin of this polarization has been discussed in terms of polarized *strange* quarks, based on semiclassical arguments [17, 18] or inspired by QCD [20], which highly polarizes the *strange* quark produced in the fragmentation process. In these models the Λ^0 spin is carried solely by its constituent *strange* quark since the ud di-quark is in a spin and isospin singlet state. Therefore, no correlation with the incident proton polarization is expected in Λ^0 production, since the ud di-quark propagates unperturbed as a spectator in the interaction, and spin asymmetries related to the beam polarization should vanish. The large negative Λ^0 production asymmetry A_N [15] and the large positive D_{NN} [16] are difficult to integrate in this picture and cannot be attributed to an effect similar to that proposed to explain the Λ^0 polarization, where a highly polarized *strange* quark produced in the fragmentation process recombines with an unpolarized ud spectator di-quark from the incident proton independently of its polarization. It appears that also the spectator di-quarks play a more active role in the production process, which was underestimated if not completely neglected [25].

The pion A_N results can be explained qualitatively as an effect similar to that proposed to explain the hyperon polarization [17], in which $q\bar{q}$ pairs produced in fragmentation processes become transversely polarized and at large x_F the transverse spin of the (anti)protons is correlated to its (anti)quark constituents. To produce a spin-zero meson, the polarized produced $(q)\bar{q}$ will couple with the spectator (anti)*up* or (anti)*down* quark from the polarized (anti)proton beam only in an antiparallel configuration. The reflected sign of π^-'s with respect to π^+'s (and between $\bar{p}$ and p beams) may originate from the fact that the *up* (anti)quark spin is almost fully aligned with that of the (anti)proton for x_F approaching one, wheras that of the *down* (anti)quark is oppositely aligned. This conclusion is consistent with recent SMC results [24] on semi-inclusive deep inelastic scattering, which probed the polarization of valence quarks in the nucleon.

Recent models based on non-perturbative approaches and peripheral mechanisms with an underlying quasi-binary sub-process, such as the *soft* π exchange mechanism [21], or resonance-decay interference between real and virtual channels [22], were proposed to explain the Λ^0 polarization and might more easily accommodate the Λ^0 results. These models seem also to be able to explain at least qualitatively the pion A_N data. A recent model, based on the idea of rotating constituents in polarized protons [23], appears to be moderately successful in accounting for the observed A_N in Λ^0 production, and should provide clear predictions for the D_{NN} data and appears to be in good qualitative agreement with the features of the data on the pion production asymmetry measured with both polarized protons and antiprotons.

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