ANALYZING POWER MEASUREMENT IN INCLUSIVE π^0 PRODUCTION AT HIGH x_F

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Abstract

We present first results for the analyzing power A_N in inclusive π^0 production obtained using the new 185 GeV/c Fermilab polarized proton beam. We obtain a value $A_N = 0.10 \pm 0.03$ for π^0's in the kinematic region $0.2 < x_F < 0.8$ and $0.3 < p_T < 1.2$ GeV/c. An interpretation of this result using a simple parton recombination model suggests that the spin of the proton is carried by its valence quarks.

New polarized proton and antiproton beams were successfully tested during the last fixed target run at Fermilab[1], making a wide range of high energy spin effects available for investigations. Here, we present preliminary results of a measurement that was performed during this first test run, along with the performance and polarization tests of the beam. A spin dependence in the cross section for inclusive production of neutral pions is expected naively due to non-vanishing similar effects in the production of π^-, π^+ and K_s at lower energies, high values of Feynman x (x_F) and moderate values of

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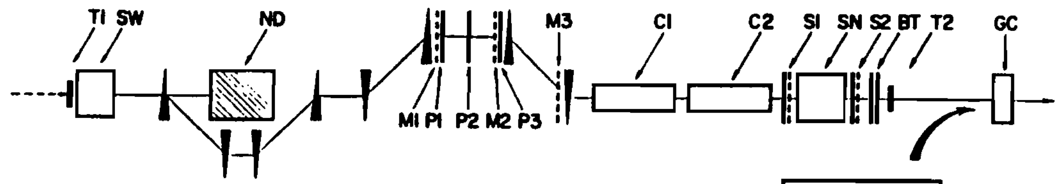
transverse momentum.[2,3] Related effects can be found in the production of hyperons with proton or meson beams[4] and of ρ mesons produced in meson nucleon collisions[5], where large polarization values have been measured. A perturbative QCD calculation is however not possible, since these effect already appear at low values of transverse momenta ($p_T \sim 1$ GeV/c) and are therefore due to soft processes. However, the pattern of results of all those measurements is qualitatively well reproduced by a model[6] that describes these production processes through the recombination of beam fragments with sea quarks. In this framework, spin dependent asymmetries are introduced, by means of small parameters, in the quark and diquark production and scattering amplitudes. Spin observables are then calculated using static SU(6) wave functions, under the assumption that the spins of the beam particle fragments are preserved in the scattering and recombination processes.

We have investigated the analyzing power A_N for the inclusive production of π^0's, which is given, for a fully polarized beam, by the asymmetry of the cross sections for π^0 production between positive and negative transverse polarization. The interesting feature of an analyzing power measurements is that it allows to test all the features of a model, since not only the existence of a polarization mechanism is involved, but also the spin flavor structure of the wavefunctions and the conservation of spin during fragmentation and recombination. In addition, such an effect might allow a relatively simple monitoring of the beam polarization during other experiments. Absolute measurements of the beam polarization are possible, based e.g. on Coulomb-Nuclear interference in proton proton scattering or Coulomb dissociation of beam protons into proton-π^0 pairs (inverse Primakoff effect).[1] Although these measurements were performed during our first test run, they require a complex experimental arrangement and an elaborate analysis that makes them hardly suitable for a continuous on line polarization monitoring.

The polarized beam for the experiment was produced selecting protons arising from the weak decay of Λ hyperons produced in a primary target. Protons emitted at an angle near $\pm 90^0$ in the Λ rest frame are transversely polarized with respect to their path in the laboratory; those emitted near 0^0 are longitudinally polarized. Therefore, it is possible to determine their polarization by tagging their trajectories. Along any direction in space, the polarization distribution has values from -0.64 to 0.64.[7] The



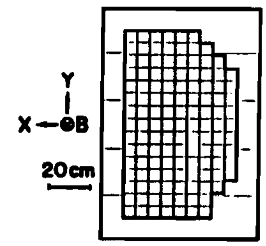


FIG. 1. Elevation view (not to scale) of the secondary MP line and of the experimental arrangement, and front view of the electromagnetic calorimeter.

secondary beamline is shown in Fig. 1, together with the experimental setup. The performance of this beam production scheme is presented in detail in Ref. 1. After the primary target T1, the selection of Λ-decay protons was achieved with a sweeper system SW, deflections in magnetic fields and the elimination of neutrals in the beam dump ND. A deflection along the vertical direction observed in hodoscopes M1-M3 allowed momentum determination. Together with the transverse position information of hodoscopes P1-P3, a full reconstruction of the kinematics was possible, as required to determine the beam polarization. The tagged transverse polarization component was in the horizontal plane. Vertical polarization at the π^0 production target was obtained through rotation by means of a spin rotator ("Siberian snake") SN, consisting of 8 dipoles.[8] To supress systematic errors, the polarity of the spin rotator, and therefore the correlation between each beam ray incident on the target and its polarization sign, was reversed every 10 Tevatron spills. For the present measurement we used only protons with tagged polarization magnitudes between 0.30 and 0.55, representing 47% of the total beam flux, with an average nominal polarization magnitude of 0.44. During this symposium we have presented already[1] first results, that test this value along with the validity of the polarized beam production scheme and the performance of the spin rotator system using the inverse Primakoff effect. For protons with a tagged polarization magnitude between 0.35 and 0.55 the measured polarization was 0.40 ± 0.12. We selected a proton beam with average momentum of 185 GeV/c and $\pm 9\%$ momentum spread.

The threshold Čerenkov counters C1 and C2 identified pions, about 13% of the beam. Because the mean beam phase space was 2 mrad·cm, each beam particle track was reconstructed by means of segmented hodoscopes placed at each end of the rotator magnet system, to accurately determine the transverse momentum of the produced pions. With one pair of X,Y hodoscopes, S1, placed 23.8 m upstream of the target, and a seco l | ui, S2, placed 2.45 n upstream, we obtained a precision in the reconstruction of the .ngle of incidence of 0.1 mr.

The layout of the experiment consisted of an electromagnetic calorimeter GC for the detection of the $\pi^0 \rightarrow \gamma\gamma$ decay products. It was placed on one side of the beam axis B, 50.5 m downstream of the target T2, and the active surface area was 0.5 m^2. The calorimeter had two sequential sections: upstream were 124 leadglass modules (6.35 cm . 6.35 cm, $13X_o$), which provided the necessary position resolution; downstream was a lead-s:intillator sandwich ($\sim 20X_o$). The modules were stacked in the shape of a semicircle, placed symmetrically with respect to the horizontal plane, to have a homogeneous acceptance for pions with the same transverse momentum. The inner, straight edge of the detector was at a distance of 30 cm from the nominal beam axis, to reduce noise and enhance the acceptance for high transverse momentum π^0's. The Pb-scintillator calorimeter allowed the total absorption of the γ-energy from the observed $\pi^0 \rightarrow \gamma\gamma$ decay. This detector was segmented vertically into 5 rectangular parts (76.0 cm wide by 25.2 cm high), each one consisting of 16 layers of 0.64 cm lead and 1.3 cm scintillator. The light produced in the scintillator of each segment was collected along top and bottom of each scintillator plate in wavelengthshifter bars running at each end into a photomultiplier. Having four photomultipliers at the "corners" of each segment allowed separation of the contributions to the energy deposition coming from different showers, due to the dependence of the light collection efficiency on the position of the shower in the calorimeter. These calorimeters were calibrated during an immediately preceding calibration run with 30 GeV positrons. At these energies the response of an electromagnetic calorimeter to γ's and electrons or positrons can be considered identical. The energy loss even for this particle energy through the leadglass made it necessary to calibrate this calorimeter having the previously calibrated lead-scintillator calorimeter in behind, to determine the leakage energy E_{SW}. The leadglass calibration energy

E_{LG} was determined event by event from the difference between the positron beam energy and E_{SW}. An iterative procedure as described in Ref.9 was used for the calibration of the leadglass modules. The calorimeter stability was mantained continuously through the calibration and the physics run using a monitoring system consisting of a LED-light source (7 high intensity HLMP-3950 diodes)[10] coupled to the modules via quartz-fiberoptics[11]. Three reference light sources of ^{241}Am-doped scintillator viewed by photomultipliers were used for an absolute monitoring of coherent gain shifts in the whole system.

The high-x_F π^0 trigger consisted of energy deposition in the leadglass of more than 30 GeV in anticoincidence with a charged particle veto counter upstream of the leadglass. We required the interaction to be initiated by a beam particle with momentum and polarization tagged successfully, in coincidence with a beam telescope BT placed immediately upstream of the target, and in anticoincidence with the two threshold beam Čerenkov counters C1 and C2. The data acquisition was performed with a PDP11/45 and standard CAMAC electronics; for the calorimeter photomultiplier readout we used a charge sensitive LeCroy 2280 ADC-system. Before each accelerator spill (repetition rate of about one 20 sec spill/minute) LED data as well as one pedestal measurement

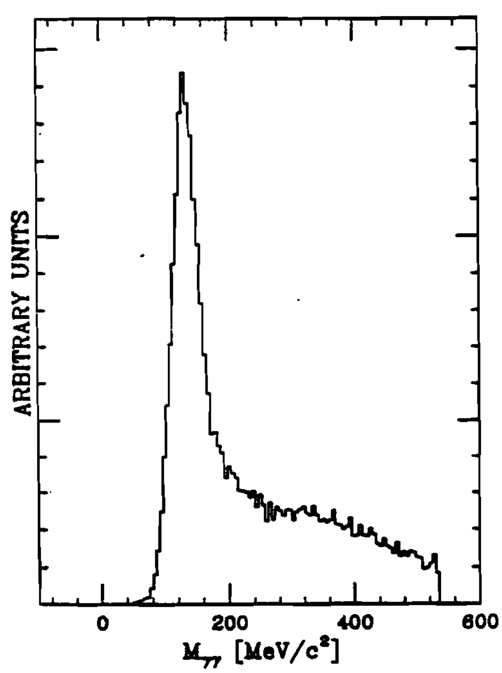


FIG. 2. $\gamma\gamma$ invariant mass.

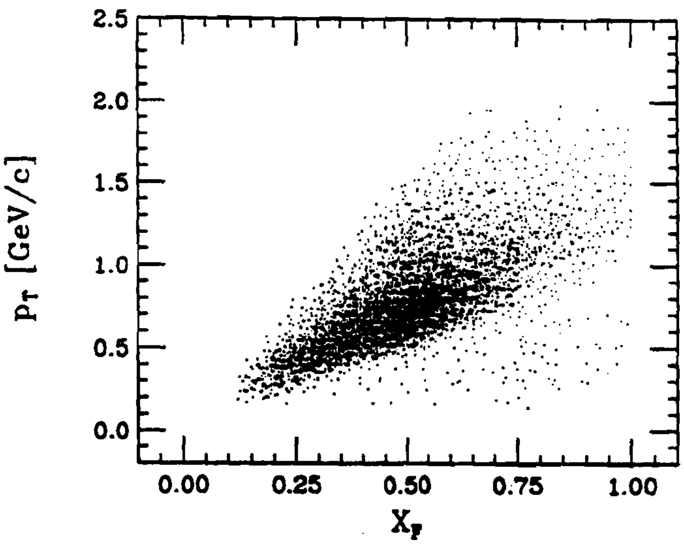


FIG. 3. Scatter plot of the $x_F - p_T$ distribution for reconstructed π^0's.

were acquired.

A total of 285000 triggers were collected, for a beam flux of 1.17x10^{10} protons. Half the data were obtained with a 10 cm thick polyethylene target, and half with a 7 mm scintillator target. The average beam rate of 10^7 particles/Tevatron spill produced typically 300 triggers, 7% of which reconstructed to a π^0. The reconstructed mass resolution was typically ± 17 MeV/c^2 (see Fig. 2), as expected from the finite position resolution of the leadglass and the overall energy and sampling resolution of the calorimeter. The range of x_F and transverse momentum covered by the data is shown in Fig.3.

We have determined the analyzing power A_N for π^0 production taking the average of the results obtained with the two spin rotator polarities evaluated separately. For positive rotator sign, A_N is given by

$$A_N = -\frac{1}{P_B cos\phi} \cdot \frac{N_\uparrow(\phi) - N_\downarrow(\phi)}{N_\uparrow(\phi) + N_\downarrow(\phi)} \quad (1)$$

The azimuthal angle ϕ is that between the beam polarization direction and the normal to the π^0 production plane. $N_{\uparrow,(\downarrow)}$ is the number of π^0's produced for beam spin tagged as positive (negative), normalized to the beam flux. P_B is the average beam polarization. The negative sign in front of the equation is due to the fact that the detector was placed to the right of the beam. For negative rotator polarity A_N is given by expression (2) reversed in sign. The data were binned into 4 regions of Feynman x. The results are presented in Fig. 4. The average analyzing power we observe for $< x_F >= 0.52$ and $< p_T >= 0.8$ Gev/c is 0.10 ± 0.03. Systematic effects on the result are negligible. Their magnitude, which is determined as the contribution to the measured analyzing power that does not reverse sign under reversal of rotator polarity, is 0.03 ± 0.03. The error in the absolute magnitude of the beam polarization determination, which is the same for all data points, has not been included. The analyzing power of the events constituting the background was also determined to be consistent with zero. The background underneath the π^0 peak was fitted and the measured asymmetry scaled accordingly. However, we are not only relying on the suppression of systematic errors obtained through the reversal of the spin rotator polarity. The major possible sources of systematic errors were additionally investigated through particular tests of our data and calculations. For one spin rotator polarity, the intensity modulation between beam particles with a polarization tagged as positive versus those tagged as negative is of the order of 14%. Taking the average for this effect between the two rotator polarity leaves a residual intensity modulation of less than 1%. Another source of systematic errors could arise from a position dependence of the beam polarization at the target together with the p_T dependence[12] of the pion production cross section. We have calculated that this effect is negligible, being of the order 10^{-3}.

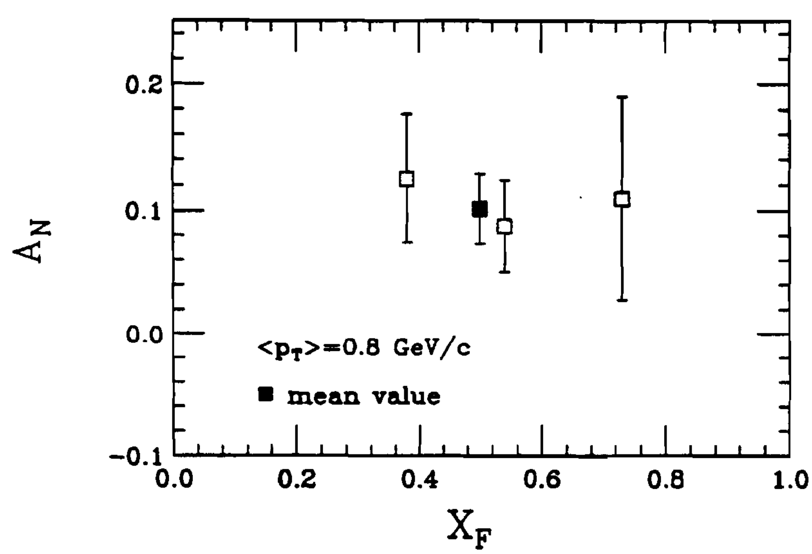


FIG. 4. The analyzing power A_N for π^0 production by polarized protons.

To compare our results with the predictions that can be obtained from the model described in Ref.6, we have evaluated the expectations for the analyzing power following the same assumptions. For pion production we obtain

$$A_N(\pi^+) = \frac{2}{3}\frac{(\epsilon+\epsilon')}{(1+\epsilon\epsilon')}, \quad A_N(\pi^0) = \frac{1}{3}\frac{(\epsilon+\epsilon')}{(1+\epsilon\epsilon')}, \quad A_N(\pi^-) = -\frac{1}{3}\frac{(\epsilon+\epsilon')}{(1+\epsilon\epsilon')} \qquad (2)$$

where ϵ and ϵ' reflect the different spin-orbit couplings of slow sea partons and fast valence quarks respectively. They can be extracted from polarization measurements of Λ production from proton[13] and kaon[14] beams. The predictions are expected to be valid at high x_F, where the ratio of π^+ to π^- production follows the u- and d-quark structure functions.[15] The resulting prediction is $A_N(\pi^0) = 0.19 \pm 0.02$. The error contains only the statistical uncertainties on the polarization measurement results used, not however those intrinsic to the model. We disagree in this calculation with respect to Ref.16, were a value of 10% is predicted. We have also taken into account indirect π^0 production through ρ meson decays, and we calculate a slight increase in the expected value for A_N. However, inclusion of a spin-spin term in the model[6] based on other measurements on hyperon production[17,18] improves the agreement with the data.

Our non-vanishing result for $A_N(\pi^0)$ suggests that fast quarks remember the transversity of the incident proton. In addition, despite the simplicity of the phenomenological description we find an agreement in sign and in order of magnitude between measurement and the expectation of the parton-recombination model[6], based on the results of polarization measurements in hyperon production. The same is true for lower energy data on charged pion production.[2]

During the same run, for a very short period a polarized antiproton beam was produced. We obtained 10^6 $\bar{p}$/spill arising from $\bar{\Lambda}$ decays, and roughly a factor of 5 more pions than antiprotons in the beam. We collected a small sample of π^0 triggers (4300 events) for a total beam flux of 8.5x10^7 antiprotons; we obtain $A_N = -(0.26 \pm 0.19)$ for $< x_F >= 0.38$ and $< p_T >= 0.6$ Gev/c.

Our results encourage us to extend such kind of measurements to other mesons and hyperons, to provide a more complete picture of the mechanisms involved in these processes. The issue is very interesting, especially since the relationship of the spin of the nucleons to that of the underlying constituents has recently been questioned.[19] For example, similar measurements for π^+ and π^- production are already planned for the next E704 running period (a 80 ft threshold Čerenkov counter that will serve this purpose was already tested). Additional measurement for Λ and Σ production in a similar kinematical range, as well as π^0 production at high p_T are also being prepared.

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