Final-State Interaction Effects in Inclusive γ and V^0 Production from pd Interactions at 18 GeV/c*

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Direct evidence is presented for final- (and/or initial-) state interaction effects in 18 GeV/c pd reactions involving inclusive γ and V^0 production. This evidence is manifested as an excessive number of protonlike events as compared to the number of neutronlike events; an asymmetric distribution in center-of-mass longitudinal V^0 momentum for the protonlike events; and strong spectator-proton production-angle asymmetry correlated with high-momentum spectators.

In this paper we present clear direct evidence for effects due to the interaction of final-state particles (or possibly the initial-state beam particle) with the spectator nucleon in pd interactions at 18.3 GeV/c. The data come from film taken at the Brookhaven National Laboratory 80-in. bubble chamber and were collected to study the following inclusive reactions:

$$p+d \to \gamma + \text{anything}, \quad p+d \to K_s^0 + \text{anything},$$

$$p+d \to \Lambda + \text{anything}, \quad p+d \to \bar{\Lambda} + \text{anything}.$$

A detailed presentation of these events is being published elsewhere[1] and in that publication a discussion of the experimental procedure is presented. Briefly, the data come from 50 000 pictures which were scanned for events associated with a visible V^0 (or γ). For each event, the production charged-prong multiplicity was recorded, and the beam track, any stopping proton track, one outgoing track if necessary, and the V^0 decay tracks were measured. The measurements were processed with TVGP-SQUAW and after the selection procedure[1] a sample of 8315 accepted events was obtained.

To classify events into neutron-target or proton-target categories, the definition of a spectator proton was taken to be a stopping proton with momentum less than 300 MeV/c. Even-pronged events with no spectator were designated protonlike, while odd-pronged events or even-pronged events which have a spectator as one of the prongs were designated neutronlike.

Because proton-target events *can* generate a spectatorlike prong, this separation procedure overestimates the number of neutron-target events. However, such proton events are mostly two-pronged,[2,3] a large proportion of which are presumably elastic scattering events. Our sample is only one quarter two-pronged events, none of which are elastic scatters, since each event has at least one V^0.

Examination of the protonlike and neutronlike samples revealed two effects. Firstly, the number of protonlike events is 4997, considerably in excess of the number of neutronlike events, 3318. It is evident from these numbers that any correction for the aforementioned overestimate of neutronlike events would only enhance this effect. Such an effect has been seen before[2] and is usually explained by a presumed interaction between the spectator proton and another particle, which gives the proton extra momentum and makes it appear as a *bona fide* prong. Thus genuine neutron-target events are supposed to contaminate the protonlike sample. Anomalous spectator distributions have been observed in other deuterium experiments.[3]

The second effect is that the distribution in V^0 c.m. system longitudinal momentum $P_L{}^*$ for the protonlike events is not symmetric. Examination of the Λ and K^0 lifetime distributions reveals that in addition to the loss for decay outside the chamber there is also a loss of about 10% of fast Λ events and about 5% of fast K^0 events. These are events for which the V decays a long distance from the production vertex. Apart from this small loss of events, the lifetime distributions for backward ($P_L{}^* < 0$) and forward V's are consistent with each other and the Λ and K_s^0 lifetimes are in good agreement with the present world average. In any case, such $\lesssim$ 10% scanning loss effects of fast hadronic V's are not sufficiently large to account for the observed asymmetries.

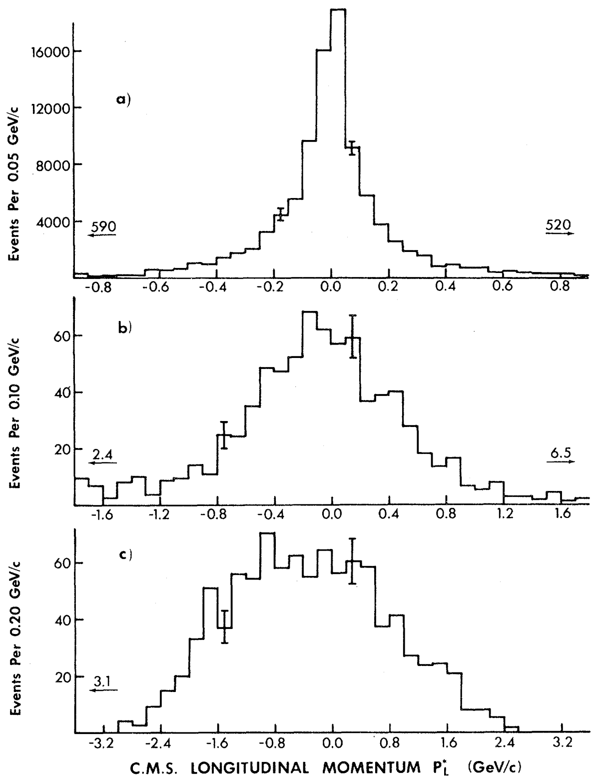

FIG. 1. Center-of-mass longitudinal momentum distributions for all protonlike events associated with a visible (a) γ; (b) K_s^0; (c) Λ. All distributions are corrected for geometrical losses. (The large numbers quoted for the γ events are due to the weighing procedure.)

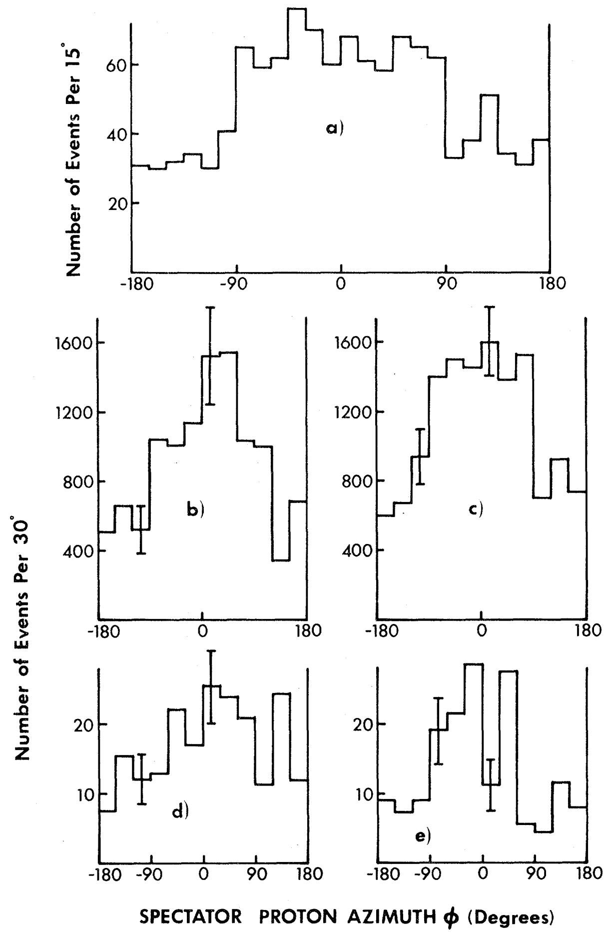

FIG. 2. Spectator-proton azimuthal angular distributions for all neutronlike events associated with a visible spectator proton. (a) All γ, K_s^0, and Λ events not corrected for geometrical losses; (b) all γ events with c.m. system longitudinal momentum $P_L^* < 0$; (c) all γ events with $P_L^* > 0$; (d) all $K_s^0 + \Lambda$ events with $P_L^* < 0$; (e) all $K_s^0 + \Lambda$ events with $P_L^* > 0$. (b)–(e) are corrected for geometrical losses.

After making standard corrections for geometrical losses, including a short-distance cutoff on the V flight path, the P_L^* distribution for the γ events is nearly symmetric as is clearly seen in Fig. 1(a); however, for the K_s^0 and Λ events the asymmetry persists. This is demonstrated in Figs. 1(b) and 1(c)—in particular Fig. 1(c) shows a striking asymmetry.

In order to investigate the causes of the above effects we have looked in some detail at the neutronlike events for which a visible spectator proton was detected and measured. This sample consists of 1198 events and the remaining discussion concerns only these events. Figure 2(a) shows the azimuthal distribution of spectator protons in the chamber. The azimuthal angle φ is defined in the usual way with the beam direction being the x axis and the normal to the bubble chamber window (pointing out) the z axis. Thus the beam direction corresponds to $\varphi = 0$. There is a large difference between the number of spectators in the forward ($|\varphi| < 90°$) and backward ($|\varphi| > 90°$) hemispheres, whereas a uniform distribution would be expected for true spectator protons. Defining a forward-backward asymmetry parameter as $a = (F - B)/(F + B)$, we obtain $a = 0.29 \pm 0.03$ for these events. There is a weak correlation between this asymmetry and the asymmetry of the V^0 c.m. system longitudinal momentum distribution. Figures 2(d) and 2(e) show the spectator azimuth distributions for the $K_s^0 + \Lambda$ events, where (d) has $P_L^* < 0$ and (e) has $P_L^* > 0$. The azimuthal asymmetry is less pronounced in those events with $P_L^* < 0$ ($a = 0.19 \pm 0.07$) than those with $P_L^* > 0$ ($a = 0.40 \pm 0.07$). The γ events seen in Figs. 2(b) and 2(c) show no such correlation and for the samples with $P_L^* < 0$

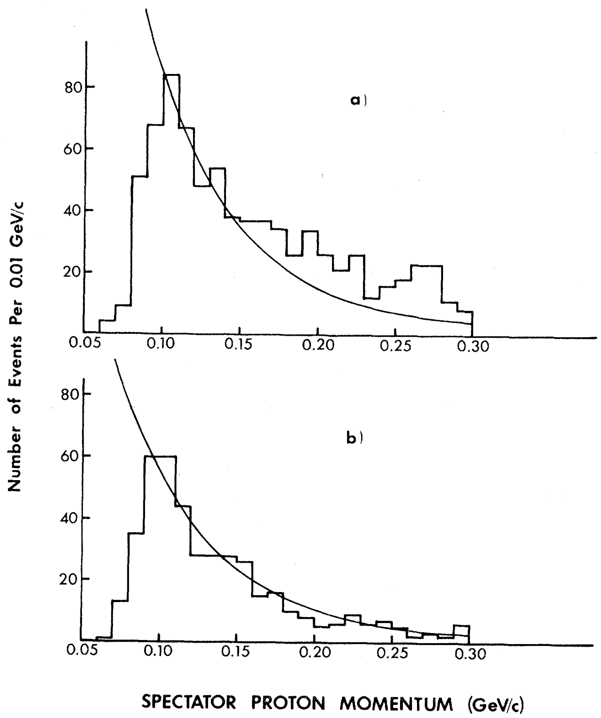

FIG. 3. Spectator-proton momentum distributions for all neutronlike events with visible spectator proton for (a) events with spectator in the forward hemisphere and (b) events with spectator in the backward hemisphere. The solid curves show the predictions of the Hulthén wave function (Ref.4) normalized to the number of events with spectator momenta between 0.10 and 0.15 GeV/c. The events are not weighted for geometrical losses; these corrections do not change the shapes of the distributions.

and $P_L^* > 0$, we find $a = 0.33 \pm 0.06$ and $a = 0.32 \pm 0.04$, respectively.

The momentum spectra for the forward and backward spectators are shown in Figs. 3(a) and 3(b). The momentum spectrum for the backward spectators follows the Hulthén distribution[4] more closely than that for the forward spectators (the solid curves show the predictions of the Hulthén wave function normalized to the number of events with spectator momenta between 0.10 and 0.15 GeV/c).

All of these experimental observations can be explained in terms of an interaction of the spectator proton with final-state particles (or the beam particle). This interaction imparts momentum to the spectator proton and knocks spectators preferentially from the backward to the forward hemisphere. Thus the forward spectator momentum distribution has an excess of high-momentum spectators. The backward events follow the Hulthén distribution because spectators are kicked uniformly out of the backward into the forward hemisphere. This statement is supported by quantitative agreement between the difference in the numbers of protonlike and neutronlike events and the departure from uniformity of the spectator azimuth distribution. Some of the spectator protons gain enough momentum to be classified as prongs and the neutron-target sample contaminates the protonlike sample. The fact that the azimuthal distribution of spectators shows a great deficiency in the backward hemisphere lends credence to this explanation.

Furthermore, because the spectator proton is a fast backward projectile in the overall c.m. system, a collision with an outgoing particle can only decrease the forward momentum of the outgoing particle. Thus, if the scattering cross section is sufficiently large, this process must contribute to the observed asymmetry of the P_L^* distributions. This effect should be (and is) more pronounced for Λ events than K_s^0 events than γ events. In fact one would expect the effect to be washed out in the γ events because it is a π^0 that is actually scattering off the spectator and the observed γ is simply a decay product. Also the γ Lorentz transformation characteristics are such than an interaction with a spectator will not scatter it so readily from $P_L^* > 0$ to $P_L^* < 0$. It should be noted that the reverse process, involving a spectator neutron, will rarely alter the classification of an event as protonlike. However, it will alter the momentum of the outgoing particles in approximately the same manner as for the neutron-target events.

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[1]W. R. Butler, S. Reucroft, J. W. Waters, and M. S. Webster, "Inclusive V^0 and γ Production in pd Interactions at 18 GeV/c" (to be published).

[2]A. Sheng *et al.*, Phys. Rev. D 12, 1219 (1975).

[3]R. Poster *et al.*, Phys. Rev. Lett. 33, 1625 (1974). Also see D. P. Sidhu and C. Quigg, Phys. Rev. D 7, 755 (1973); G. Alberi, L. P. Rosa, and Z. D. Thomé,

Phys. Rev. Lett. 34, 503 (1975); D. R. Harrington, Nucl. Phys. B87, 413 (1975).

[4]L. Hulthén and M. Sugawara, in *Handbuch der Physik*, edited by S. Flügge (Springer, Berlin, 1957), Vol. 39, p. 1; T. B. Borak, Ph.D. thesis, Vanderbilt University, 1971 (unpublished).

Search for a Difference between the Strange and Nonstrange Quarks of the K^+ Meson

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A tendency for the π^- to peak at small negative rapidity in the center-of-mass system for the reaction $K^+ + p \rightarrow \pi^- + X$ at 100 GeV may be related to a difference in the momentum spectra for the strange quark and the nonstrange quark in the K^+ meson, as may anomalies in the average multiplicity of charged particles and in the $p_T^{\max}$ of events as a function of π^- rapidity.

In general one might expect the strange and the nonstrange quarks of the K meson to share the momentum of the parent particle differently.[1] We may attempt to understand these differences by parametrizing them in terms of quark masses.[2-4] However, independently of the details of effective quark masses, one can address the phenomenological question of whether there are effects in Kp interactions which are not present in πp and pp interactions. In particular, in the light of the above ideas, one might hope to distinguish in K^+p interactions two different kinds of collisions, one involving the strange quark which on the average carries most of the K^+ momentum and one involving the nonstrange quark which carries only a small fraction of the K^+ momentum.

For its heuristic value, we use a model where the hadron-hadron collision is dominated by a single quark-quark collision, and the $\bar{s}$ and u quarks in the K^+ share the average momentum in the ratios $1-\alpha \approx 1$ and $\alpha \ll 1$, respectively.[5] We identify two cases and their consequences:

Reaction I.—The $\bar{s}$ quark from the K^+ collides with one of the three quarks in the proton. (a) The quark-quark center-of-mass energy, $(s_{qq})^{1/2}$, is relatively large. (b) The particle production will be symmetric in the quark-quark center-of-mass system and centered about a positive value of y, the rapidity in the K^+p center-of-mass system. (c) Because of the large s_{qq} the average number of particles produced, as measured by the average number of charged particles, $\langle n_c \rangle$, is relatively large. (d) The range in y of the particles produced will be relatively large, because of the large s_{qq}. (e) The transverse momentum distribution of the particles produced should reflect the large s_{qq} by exhibiting an increase in the tail at large p_T.[6]

Reaction II.—The u quark from the K^+ collides with one of the three quarks in the proton. (a) s_{qq} is relatively small. (b) The particle production is centered about a negative value of y. (c) $\langle n_c \rangle$ will be relatively small. (d) The particles produced will have a relatively narrow range of y values. (e) There should be fewer events having particles of large p_T.

Given the relative values of the K^+p, π^+p, and pp total cross sections, one expects that the cross section for Reaction I is about one half the cross section for Reaction II. At energies of several hundred GeV or lower, there will be a background in the central region in both cases, consisting of particles from fragmentation of the beam and projectile, or in alternative language, from the reclothing of the spectator quark(s) in the incident K^+ and proton.

The K^+p data we will examine were extracted from a large sample of pp and π^+p events at 100 GeV/c obtained in the Fermilab 30-in. hydrogen bubble chamber.[7] The solid histogram in Fig. 1 shows the inclusive rapidity spectrum for the π^- produced in the K^+p interactions. Negative pions are selected since they are relatively likely to originate directly in quark collisions, whereas positive pions are relatively more likely to originate from the fragmentation of the incident K^+