Observation of Preequilibrium Pion Evaporation from Excited Hadrons?

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Properly selected pions peripherally produced in the reaction $K^-p \to K^-p\pi^+\pi^-$ at 14 GeV/c exhibit an asymmetry in a particular reference frame designed to check a conjecture by Weiner that such pions may be evaporated from an excited hadron before thermodynamical equilibrium is reached. This is the first observation of localization in hadronic interactions.

It has been conjectured by Weiner[1] that in high-energy peripheral reactions pions may be evaporated from a hadron after a localized excitation has started to propagate, but before the energy transferred is evenly spread over this excited hadron. Such a mechanism should produce an asymmetric angular distribution of the radiated pions, depending on the energy conductivity properties of hadronic matter.

This effect has been searched for in a sample of about 16 000 events of the reaction $K^-p \to K^-p\pi^+\pi^-$ at 14 GeV/c. Results on this reaction studied by the Rutherford–Saclay–Ecole Polytechnique collaboration have already been published[2] and it is quite satisfactorily described by more conventional models.[3]

It is, however, possible to define a subsample of events which may be good candidates to study the conductivity effect: They would include pions which may have been radiated by the incident kaon (projectile) or proton (target) some time after they hit, assuming that the hit point may be located. If one follows Weiner, a first request is that the outgoing proton and kaon should have undergone a peripheral interaction, which is found to be insured by selecting events for which the center-of-mass rapidities satisfy $Y_K > 1.5$ and $Y_p < -1.2$. The localization condition $m_\pi \ll q \ll p_{\text{inc}}$ where q is the momentum transferred to the excited hadron is found to be satisfied by such events. It is then found that a convenient criterion to correlate pions with hadrons that may have radiated them is to keep only those for which the rapidity ratio $\rho = Y_\pi / Y_H$ satisfies $0.7 < \rho < 1.5$. This cut is obtained by examination of the correlation of ρ with two angles specifying the direction of the pion in the reference frame used to study the asymmetry.

For clarity, the frame is defined for a pion associated to the excited proton. Four vectors are defined in the rest frame of the excited proton (proton plus pion system). Let $\hat{K}_{\text{in}}$ be a unit vector defining the Y axis along the incoming kaon, $\hat{K}_{\text{out}}$ along the scattered kaon, and $\hat{\pi}$ along the pion. Let the *pseudovector* $\vec{\text{N}} = \hat{K}_{\text{in}} \times \hat{K}_{\text{out}}$ define the X axis, and the *true vector* $\vec{\text{Z}} = \vec{\text{N}} \times \hat{K}_{\text{in}}$ define the Z axis. The direction of the pion is thus defined by its polar angle θ with OZ and its azimuth φ around OZ (Fig. 1). It should readily be noted that *the definition is such that the scattered kaon is always in the upper half of the YZ plane;* this remark is essential for interpretation of the asymmetry.

Figures 2(a) and 2(b), respectively, display the correlation of $\cos\theta$ and φ with ρ (for the case of a π^+ tentatively associated with the proton). Negative values of ρ (pions emitted in the other hemisphere) are correlated to a 180° azimuth (beam direction) and to a 90° polar angle. Likewise, large values of ρ (well above 1) are associated with a 0° azimuth and 90° polar angle pinching, less dramatic because not *all* the events in this hemisphere accumulate at the end. Around $\rho = 1$, in the selected range (0.7–1.5), the events are more widely spread. The distributions of $\cos\theta$ and φ for such events are respectively dis-

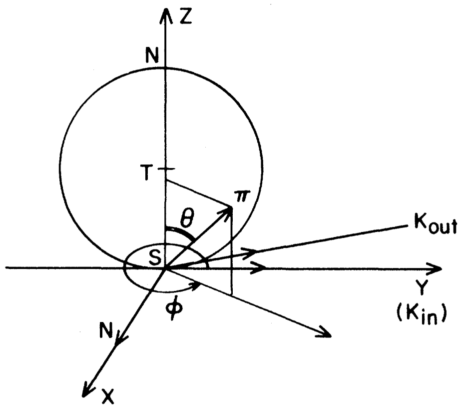

FIG. 1. Definition of axes in the excited-hadron reference frame. The definition explicitly assumes that the kaon is attracted by the proton. The pion momentum is shifted to the origin.

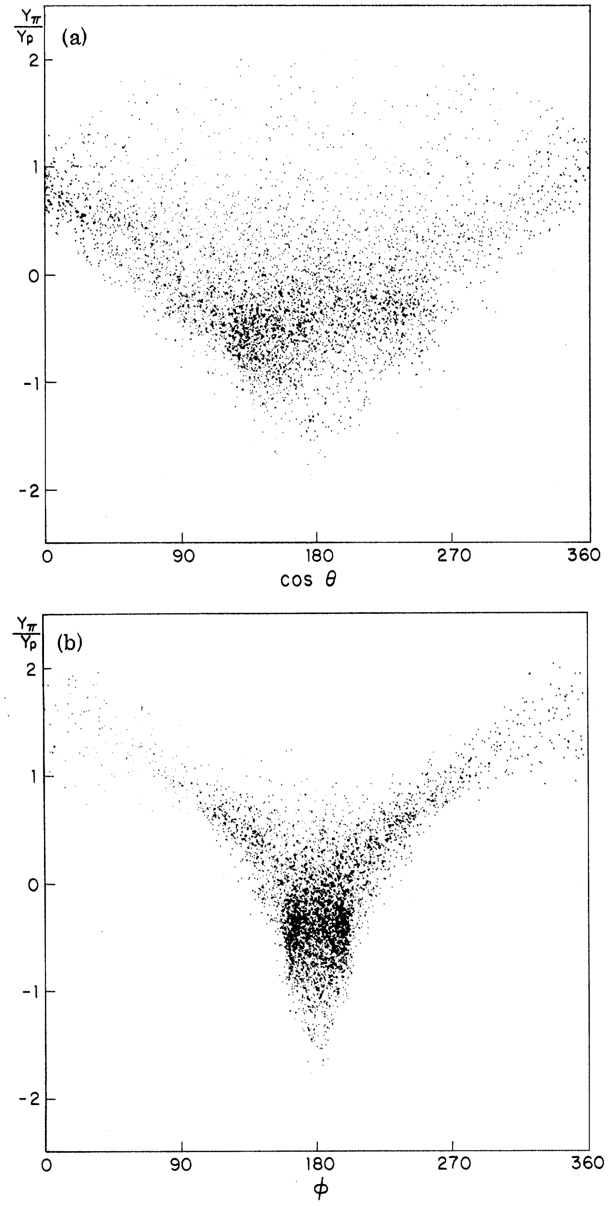

FIG. 2. Correlation diagrams (a) of the polar angle $\cos\theta$ and (b) of the azimuth φ of positive pions assumed associated to the proton with the rapidity ratio $\rho = Y_{\pi^+}/Y_p$.

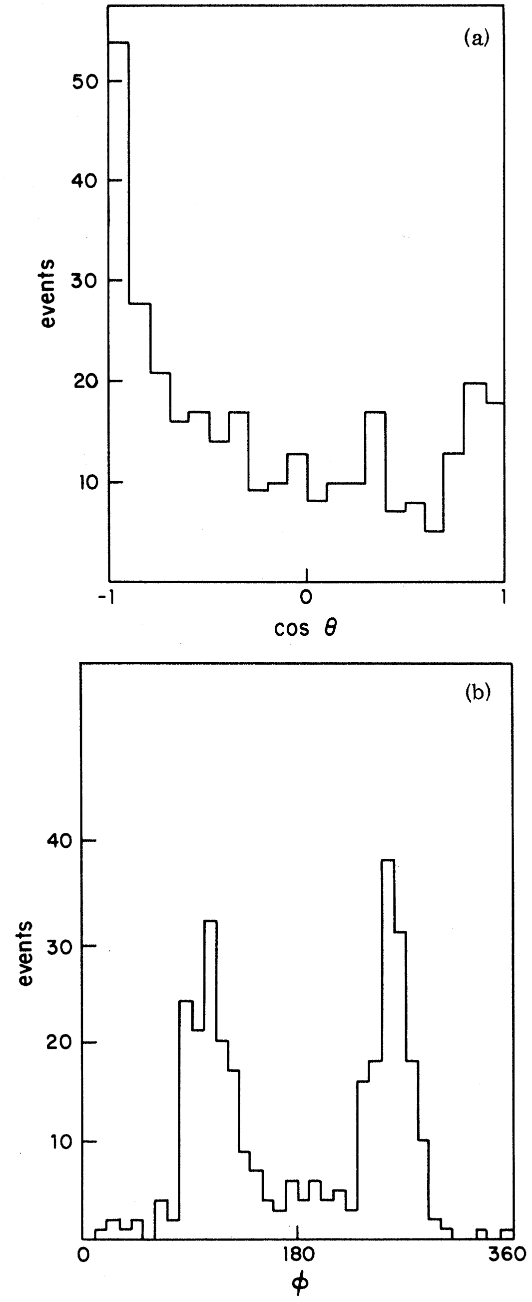

FIG. 3. Distributions (a) of the polar angle $\cos\theta$ and (b) of the azimuth φ of positive pions associated to the proton which satisfy $0.7 < Y_{\pi^+}/Y_p < 1.5$.

played in Figures 3(a) and 3(b). The φ distribution is not isotropic (even after correction of acceptance loss due to the cut in ρ), but no significant asymmetry is observed. *The $\cos\theta$ distribution, however, is obviously asymmetric.*

The asymmetries observed for each of the four cases (π^+ or π^- associated to K or p) are summarized in Table I. The reported asymmetry is not dependent on any model, and proceeds only from the particular choice of axes and event selection. No cut in ρ was found giving an opposite effect, and the use of a wider interval only smears out the effect.

This effect is obviously not an apparent parity-conservation violation, as the polar axis is a true vector. It is not consequence of momentum con-

TABLE I. Summary of asymmetry observation for the various possible pion-hadron associations. Asymmetry is reported as an up/down ratio for comparison with Ref. 1, and as an average of $\cos\theta$.

Radiated particle	Associated hadron	$\frac{N_{up}-N_{down}}{N_{up}+N_{down}}$	$\langle\cos\theta\rangle$
π^+	p	-0.24 ± 0.06	-0.19 ± 0.04
π^+	K^-	-0.26 ± 0.06	-0.18 ± 0.03
π^-	p	-0.10 ± 0.08	-0.04 ± 0.03
π^-	K^-	-0.20 ± 0.04	-0.10 ± 0.02

servation: Randomly generated phase space or double-resonance (ΔK^*) events do not exhibit any asymmetry. Current nonthermodynamical models cannot account for the observation as they do not distinguish between the emission point and the excitation point (they have no localization hypothesis).[4] On the contrary, the interpretation of the effect as due to preequilibrium radiation, as predicted by Weiner,[1] is straightforward. Referring back to Fig. 1, the excited hadron is represented by a sphere of center T, with its south pole, S, at the hit point (now a hot point). The observed asymmetry shows that there are more pions emitted with $\cos\theta < 0$ (south end) than with $\cos\theta > 0$ (north end). According to Weiner, when at least some pions are radiated before the energy transferred in the collision is uniformly distributed over the sphere, the south pole is still warmer than the north pole, in good agreement with the experimental result of we assume that more pions emerge where more energy is available.

Of course, the agreement depends on the assumption that the excited hadron indeed lies in the upper YZ half-plane. As the K^- proton interaction is attractive at low energies, and the Coulomb interference keeps the same sign at 14 GeV/c as found by Carnegie *et al.* and Baillon *et al.*,[5] the drawing of Fig. 1 is indeed correct, and consistent with the explanation proposed for the observed asymmetry. Therefore, a consistent observation using a K^+ beam would assess the effect and its interpretation (thus providing an alternate method to Coulomb interference to learn if an interaction is attractive or repulsive, valid for neutral particles as well).

Further support for the result is found by noting that for the selected events the modes of the azimuthal distribution around the X axis (not shown) are shifted in the direction, and by an amount (around 15 degrees), that may be expected from an angular momentum of a few times $\hbar$ (obtained by multiplying the momentum transfer by a proton radius) applied during a few times 10^{-23} sec. Indeed, the observed asymmetry yields a value of about 0.5 for the D parameter of Weiner,[1] corresponding to a relaxation time about twice as long as the excitation time.

Finally, three possible sources of *underestimation* can be found for the asymmetry reported: (1) The kinematical criteria enhance low effective masses. Products of cascade decays with low effective mass are incorporated, smearing the peripheral sample (this is particularly evident in the $p\pi^-$ combination). (2) Pion evaporation need not be normal to the surface of a spherical excited hadron. (3) The slight rotation around OX discussed above also smears the effect. The asymmetry reported here should thus be taken as a lower bound for comparison with theory.

To summarize, in a particular reference frame we see a significant asymmetry in pion production, which needs a localization hypothesis and has a natural interpretation in the framework of the model developed by Weiner (it might well be that other hypotheses may lead to localization, such as that suggested by Chou and Yang,[6] although the latter still deals with the t dependence of amplitudes).

I should like to thank the Rutherford-Saclay-Ecole Polytechnique collaboration and in particular Dr. Roland Barloutaud for the permission to perform the present analysis on their data, under my own responsibility. This work would not have progressed without Professor Richard Weiner's continuous advice and stimulation.

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[1] R. M. Weiner, Phys. Rev. Lett. 32, 630 (1974), and Phys. Rev. D 13, 1313 (1976).

[2] R. Barloutaud *et al.*, Nucl. Phys. B59, 374 (1973).

[3] D. Denegri, Nucl. Phys. B67, 518 (1973), and B91, 54 (1975).

[4] Reggeized models, e.g., predict the t dependence of the amplitude. In the present frame, two events where the pions would have the same momentum and the same φ, but opposite θ, would have the same four-momentum t. Regge models, although not contradicted by the present observation, cannot unfold the θ distribution.

[5] R. K. Carnegie *et al.*, Phys. Lett. B59, 308 (1975); P. Baillon *et al.*, Nucl. Phys. B107, 189 (1976).

[6] T. T. Chou and C. N. Yang, Phys. Rev. 175, 1832 (1968).