PROCEEDINGS OF SCIENCE

Measurement of Collins asymmetries for kaons and pions at BABAR

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Inclusive hadron production cross sections and angular distributions in e^+e^- collisions shed light on fundamental questions of fragmentation processes. Here are presented measurements of the Collins azimuthal asymmetries in inclusive production of hadron pairs, in the $e^+e^- \to h_1 h_2 X$ annihilation process, where the two hadrons, h_1 and h_2, either kaons or pions, are produced in opposite hemispheres. The data collected by the *BABAR* detector allow the determination of the Collins fragmentation function dependence on hadron fractional energy for the up, down and, for the first time, strange quarks.

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1. Motivation

Fragmentation, the process through which quarks or gluons hadronize into colourless hadrons, is described via fragmentation functions. Those universal functions contain non-perturbative information and have to be determined by experiments. A fragmentation function gives the probability for a quark to produce a given hadron carrying an energy E_h equal to a certain fraction $z = 2E_h/\sqrt{s}$ of half the total available energy $\sqrt{s}$.

In case of a transversely polarized quark $q\uparrow$, with spin s_q and momentum direction k_q, fragmenting into a spinless hadron of mass M_h and transverse momentum $P_\perp$ with respect to k_q, the fragmentation function can be expessed as:

$$D_1^{q\uparrow}(z,P_\perp;s_q) = D_1^q(z,P_\perp) + \frac{1}{zM_h} H_1^{q\uparrow}(z,P_\perp)\, s_q.(k_q \times P_\perp). \tag{1.1}$$

It is divided into two parts: an unpolarized fragmentation function D_1^q and a term dependent on a spin-orbit coupling, expressed through the mixed product $s_q.(k_q \times P_\perp)$, which leads to an asymmetry in the azimuthal angular distribution of the final states particles around the quark direction [1]. This behaviour is called the Collins effect. The polarized fragmentation function $H_1^{q\uparrow}$ present in this term gives the amplitude of the effect. It is also called the Collins fragmentation function.

The Collins effect is an azimuthal modulation, which can be studied either in semi-inclusive deep inelastic scattering, by sending an unpolarized lepton beam on polarized targets, or in e^+e^- annihilation followed by the hadronization of the produced $q\bar{q}$ pair. In the latter case, the directions of the q spin and $\bar{q}$ spin are unknown, but they have to be the same. Thus by studying the azimuthal correlation between two hadrons h_1 and h_2 produced in opposite hemispheres in the $e^+e^- \to h_1h_2X$ inclusive annihilation process, the azimuthal modulation can be observed, which leads to the measurement of the product of two Collins fragmentation functions, one for the fragmenting quark and one for the fragmenting antiquark.

2. Analysis

Two different reference frames have been used in the analysis to describe the process. Ideally the direction of the quark-antiquark pair in the centre of mass sholud be used. However, this direction is not known experimentally, but it can be approximated by the thrust axis of the event. In the thrust reference frame shown in figure 1, the scattering plane is defined by the beam axis and the thrust axis, with θ_{th} being the angle between the two axes. The modulation of the cross section is a cosine function of the sum of the azimuthal angles ϕ_1 and ϕ_2 of the two hadrons with respect to this plane:

$$\sigma \sim 1 + \frac{\sin^2\theta_{th}}{1+\cos^2\theta_{th}} \cos(\phi_1+\phi_2)\, \frac{H_1^{\uparrow}(z_1)\bar{H}_1^{\uparrow}(z_2)}{D_1(z_1)\bar{D}_1(z_2)}. \tag{2.1}$$

In the other hadron reference frame, one of the two hadrons, for example h_2, is taken as reference. The scattering plane is defined by the beam axis and the direction of h_2. The modulation of the cross section is a cosine function of twice the azimuthal angle ϕ_0 of h_1. The latter reference frame is simpler from an experimental point of view. However it leads to a more difficult theoretical

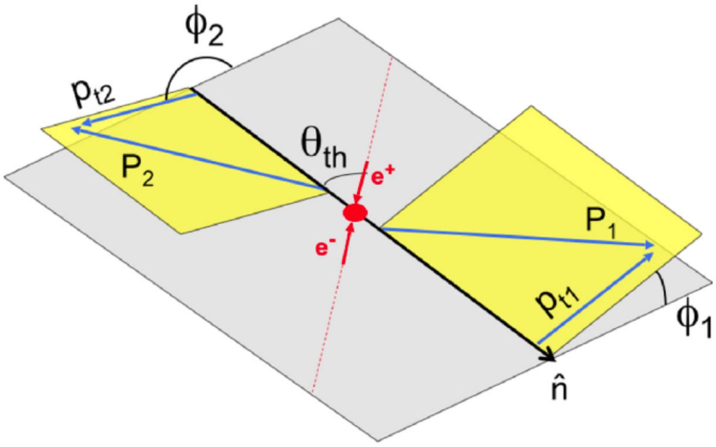

Figure 1: Definition in the thrust reference frame of the azimuthal angles ϕ_1 and ϕ_2 of the two hadrons as the angles between the scattering plane and their transverse momenta p_{t1} and p_{t2} around the thrust axis $\hat{n}$.

interpretation due to the entanglement of the involved fragmentation functions in the cross section dependence unlike the simple product of two fragmentation functions present in equation 2.1 in the former reference frame.

The analysis is based on the study of pairs of charged hadrons (C). Unlike sign pairs (U) and like sign pairs (L) are considered separately. These subsamples have indeed a different mix of favoured and disfavoured terms, where favoured means that the fragmenting quark matches one of the valence quark of the produced hadron, for example a u quark fragmenting into a π^+. The *BABAR* collaboration has extended its analysis published in 2014 measuring Collins asymmetries for pion pairs [2] with a new analysis published at the end of 2015, where the hadrons can be either pions or kaons [3]. It is the first such study involving kaons, thus giving information on the fragmentation of the strange quark. Both *BABAR* analyses are based on the total data sample of 468 fb^{-1} taken around 10.6 GeV centre of mass energy.

The analysis needs events with inclusive pairs of charged hadrons in opposite jets. Hadronic events are selected by requiring strictly more than two tracks in the event. The two jets topology is enhanced by requiring the thrust value to be greater than 0.8, which removes most of the $b\bar{b}$ background. A cut on the event visible energy removes most of the τ pair background. Tracks are identified as pions or kaons through ionization and Cherenkov radiation measurements. Tracks whose fractional energy lies between 0.15 and 0.9 are considered. This range is divided into four bins in the analysis.

As illustrated by the left plot of figure 2 in the case of kaon pairs in the thrust reference frame, the yields present a cosine dependence. In fact there are other effects, such as the detector acceptance, which may be responsible for a cosine dependence. The Collins effect manifests itself by the difference between the distributions for unlike sign pairs with like sign pairs or with all charged pairs. To remove most of the other effects, double ratios are calculated. They are shown on the right plot of figure 2, for unlike sign over like sign pairs (U/L) and for unlike sign over charged pairs (U/C). The modulation as the function of the angle in these double ratios is mostly due to the Collins effect. Its amplitude is obtained by a fit on the data samples.

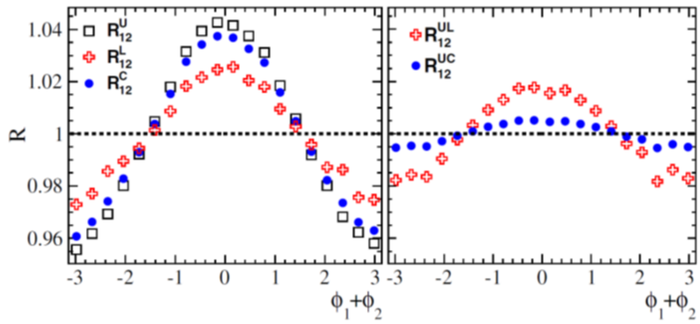

Figure 2: Distributions in the thrust reference frame as a function of the sum of azimuthal angles of (left) normalized yields for (white quares) unlike sign, (red crosses) like sign, and (blue circles) any charge combination of KK pairs and (right) their double ratios, (red crosses) unlike sign over like sign and (blue circles) unlike sign over any charge combination.

In order to extract the asymmetry on *uds* events from the measured raw asymmetry simultaneously for $\pi\pi$, $K\pi$, and KK pairs, we have to correct for both kaon-pion misidentification and backgrounds. The misidentification correction factors are obtained from Monte Carlo. They are smaller than 10%. The main background is from charm. It is about 30% on average and is estimated on a control sample enhanced with D^*.

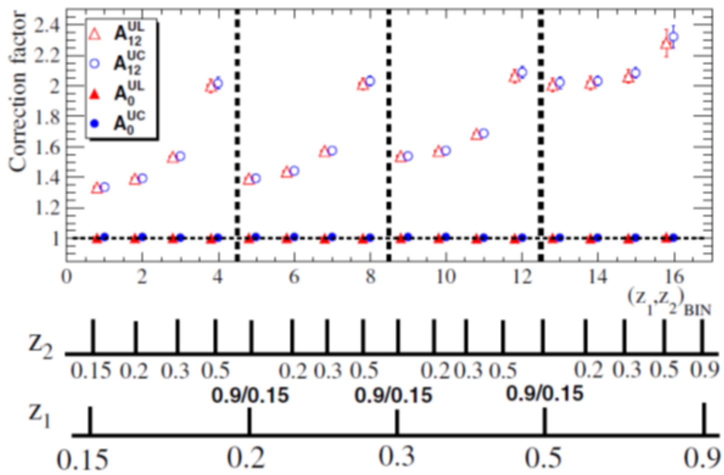

Figure 3: Correction factors for the dilution of the asymmetry due to the difference between the thrust axis and the $q\bar{q}$ direction. They are given by the open (full) markers, red triangles for the U/L and blue circles for the U/C double ratios, in the thrust (other hadron) frame.

Various systematic effects are taken into account. A major one is the dilution of the asymmetry due to the difference between the thrust axis and the $q\bar{q}$ direction. It is relevant only in the thrust reference frame. The correction factors, shown in figure 3, for all bins in the fractional energies z_1 and z_2 of the two hadrons, are determined from Monte Carlo and applied to all data samples. They range from 1.3 to 2.3. Overall, in this analysis, the total relative systematic errors does not exceed 10%.

3. Results

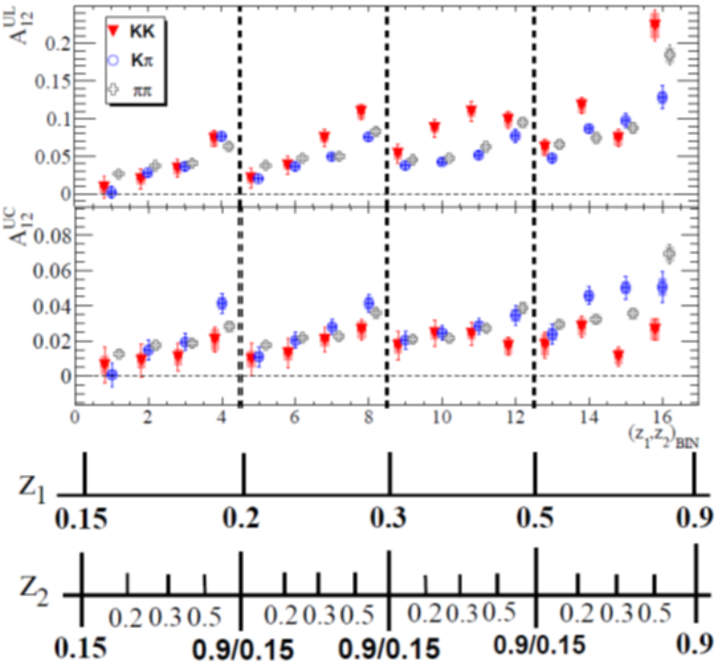

Figure 4: Comparison of (top) U/L and (bottom) U/C Collins asymmetries in the thrust reference frame for (red triangles) KK, (blue circles) $K\pi$, and (white cross) $\pi\pi$ pairs.

Figure 4 presents the results of the Collins asymmetries in the thust reference frame, as a function of z_1 and inside each bin of z_1 as a function of z_2. A significant asymmetry, which is increasing as a function of the fractional energies, is observed. It is consistent with the expected symmetry between z_1 and z_2. The results for $\pi\pi$ are in agreement with previous results from Belle [4] and BABAR [2]. Results for $K\pi$ and KK pairs are obtained for the first time. The asymmetries are of the same magnitude in all channels. The unlike sign to like sign pair asymmetry tends to be higher for kaon pairs at high fractional energy, thus giving an indication on the magnitude of the favored Collins fragmentation function for the strange quark.

The same trends are observed in the second hadron reference frame, as shown in figure 5. In particular, there is again in all modes a significant asymmetry, increasing as a function of z_1 and z_2.

4. Conclusion

In summary, BABAR has measured Collins asymmetries for charged hadron pairs in two jet events from e^+e^- annihilations in two reference frames. The Collins asymmetries are increasing with fractional energy, in agreement with theoretical expectations. The results for pion pairs agree with previous ones. First measurements have been produced for pairs involving kaons, which give information on the fragmentation of the strange quark.

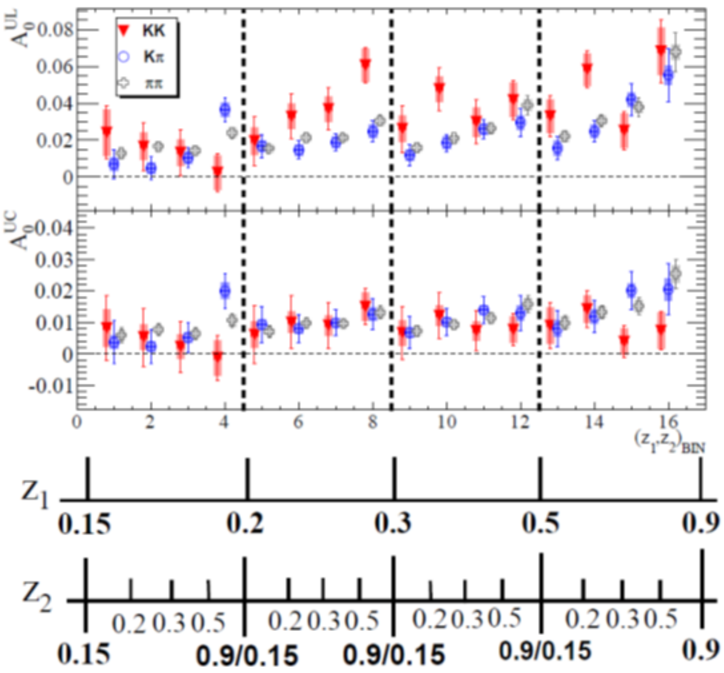

Figure 5: Comparison of (top) U/L and (bottom) U/C Collins asymmetries in the other hadron reference frame for (red triangles) KK, (blue circles) $K\pi$, and (white cross) $\pi\pi$ pairs.

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