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Measurement of Collins asymmetries in inclusive production of pion pairs in e^+e^- interactions at BaBar

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Summary. — We present a preliminary measurement of Collins asymmetries in inclusive production of charged pions for the process $e^+e^- \to q\bar{q} \to \pi\pi X$, at the center-of-mass energy near 10.6 GeV. We use a data sample corresponding to 468 fb^{-1} integrated luminosity collected by the BaBar experiment, and we consider pairs of charged pions produced in opposite jets in hadronic events. We measure azimuthal asymmetries in the pions distributions as a function of pion fractional energies, pion transverse momenta, and polar angle of the analysis axis. We confirm a non-zero Collins effect as observed by previous experiments.

PACS 13.66.Bc – Hadron production in e^-e^+ interactions.
PACS 13.87.Fh – Fragmentation into hadrons.

1. – Introduction

Transverse spin effects in fragmentation processes were first discussed by Collins [1], who introduced the chiral-odd polarized fragmentation function $H_1^\perp$, also called the Collins function, which describes the distribution of the final state hadrons relative to the momentum direction of the fragmenting quark.

Direct information on the Collins function can be obtained from e^+e^- annihilation experiments via the study of the semi-inclusive processes $e^+e^- \to q\bar{q} \to \pi\pi X$, where two charged pions coming from the fragmentation of a $q\bar{q}$ pair (where $q = u, d, s$) with opposite transverse spin are detected simultaneously. In e^+e^- annihilation, the measurement of the Collins asymmetry can be performed in two reference frames [2], as described in fig. 1. We refer to them as the thrust reference frame or RF12 (fig. 1(a)), and the second hadron reference frame or RF0 (fig. 1(b)).

The cross section in the e^+e^- center of mass frame is proportional to

$$\sigma \sim 1 + \sin^2\theta \cos\phi \frac{H_1^\perp(z_1, \mathbf{p}_{\perp 1})\overline{H}_1^\perp(z_2, \mathbf{p}_{\perp 2})}{D_1^\perp(z_1, \mathbf{p}_{\perp 1})\overline{D}_1^\perp(z_2, \mathbf{p}_{\perp 2})}, \quad (1)$$

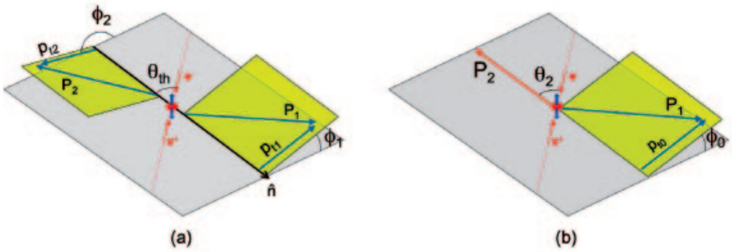

Fig. 1. – (a) Thrust reference frame or RF12: $\theta = \theta_{th}$ is the angle between the e^+e^- axis and the thrust axis ($\hat{n}$) [3], $\phi_{1,2}$ are the azimuthal angles between the scattering plane and the momentum transverse to the thrust axis, $\mathbf{p}_{t1,t2}$. Note that the thrust axis provides a good approximation to the $q\bar{q}$ axis, so that $\mathbf{p}_{ti} \simeq \mathbf{p}_{\perp i}$ in eq. (1). (b) Second hadron frame or RF0: θ_2 is the angle between the beam axis and the second hadron momentum P_2; ϕ_0 is the azimuthal angle between the plane defined by the beam axis and P_2, and the first hadron's transverse momentum $\mathbf{p}_{t0}$. All tracks are boosted to the e^+e^- center of mass frame.

where D_1 is the unpolarized fragmentation function, the bar denotes the $\bar{q}$ fragmentation, z is the pion fractional energy, $\mathbf{p}_\perp$ is the transverse momentum of the pions with respect to the $q\bar{q}$ direction, θ is the polar angle of the analysis axis, and ϕ is a proper combination of the pion azimuthal angles ($\phi_1 + \phi_2$ in the RF12 frame, or $2\phi_0$ in the RF0 frame).

The $\cos\phi$ modulation in eq. (1) produces an azimuthal asymmetry around the quark momentum, called the Collins effect or the Collins asymmetry. The first independent measurement of the Collins effect was performed by the Belle Collaboration [4]. We present here the preliminary results on Collins asymmetries obtained at BaBar.

2. – Analysis strategy

Assuming the thrust axis [3] to define the $q\bar{q}$ direction, and selecting pions in opposite hemispheres with respect to the thrust axis, we measure the azimuthal angles ϕ_1, ϕ_2, and ϕ_0. In order to select the two-jet topology, an event thrust value larger than 0.8 is required. Only pions coming from the primary vertex with a fractional energy $z = 2E_\pi/\sqrt{s}$ in the range between 0.15 to 0.9 are selected, where E_π and $\sqrt{s}/2$ are, respectively, the pion and beam energy in the center-of-mass system. The Collins asymmetry can be accessed by measuring the $\cos(\phi)$ modulation of the normalized distributions of the selected pion pairs, and performing suitable ratios of these distributions in order to eliminate detector induced asymmetries. We construct these ratios by selecting combinations of pions with same charge (L), opposite charge (U), and the sum of the two samples (C), which are fitted with a function linear in $\cos(\phi)$:

$$\frac{N^U(\phi_i)/\langle N^U \rangle}{N^{L(C)}(\phi_i)/\langle N^{L(C)} \rangle} = B_i + A_i \cdot \cos\phi_i. \tag{2}$$

The A_i parameter in eq. (2) is sensitive to the Collins effect, $i = 12$ or $i = 0$ identifies the reference frame (RF12 or RF0), $\phi_{12} = \phi_1 + \phi_2$ or $\phi_0 = 2\phi_0$, $N(\phi_i)$ is the di-pion yield, and $\langle N \rangle$ is the average bin content. Thanks to the large amount of data, corresponding to about 10^9 events, we are able to choose a 6×6 (z_1, z_2) matrix of intervals, with boundaries $z_i = 0.15$, 0.2, 0.3, 0.4, 0.5, 0.7, and 0.9, and the following p_t intervals: $p_t < 0.25\,\mathrm{GeV}/c$, $0.25 < p_t < 0.5\,\mathrm{GeV}/c$, $0.5 < p_t < 0.75\,\mathrm{GeV}/c$, and $p_t > 0.75\,\mathrm{GeV}/c$.

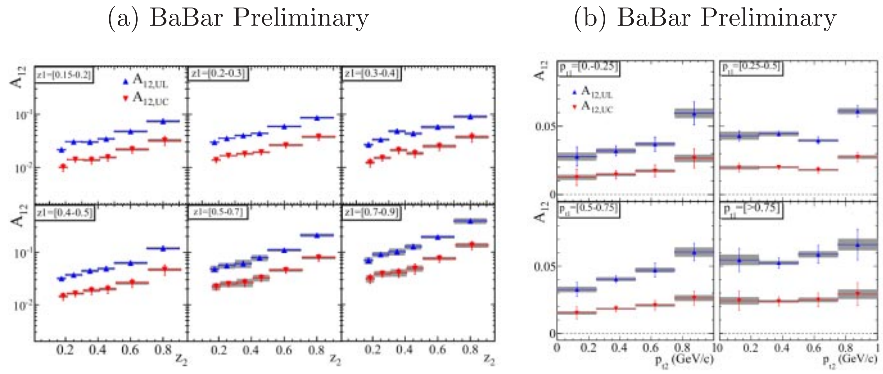

Fig. 2. – RF12 frame: (a) Collins asymmetries for light quarks as a function of (z_1, z_2), and (b) as a function of (p_{t1}, p_{t2}) intervals. Blue triangles refer to the ratio U over L (UL), while red triangles to the UC ratio. Statistical and systematic errors are shown as error bars and bands around the points, respectively.

3. – Study of systematic effects

A crucial point for the measurement of the Collins asymmetry is the identification of all systematic effects that can influence the azimuthal distributions of the pion pairs. We test the double ratio method on a Monte Carlo (MC) sample, and we evaluate the dilution of the measured asymmetry due to the approximation of the thrust axis as the $q\bar{q}$ direction. In addition, we study the influence of particle identification, the uncertainties due to the fit procedure, and other minor effects. When the effects are sizable we correct the measured asymmetries for them and assign appropriate systematic errors. All systematic uncertainties and/or corrections are evaluated for each interval of fractional energy z and transverse momentum p_t.

3·1. *Contribution of background events to the asymmetries.* – The presence of background processes can introduce azimuthal modulations not related to the Collins effect. The background sources giving a significant contribution after the selection procedure are: $e^+e^- \to \tau^+\tau^-$, $e^+e^- \to c\bar{c}$, and $e^+e^- \to \Upsilon(4S) \to B\overline{B}$, and we refer to them as τ, charm, and bottom backgrounds, respectively. The asymmetry measured (A^{meas}) by fitting the double ratio of eq. (2) includes also the azimuthal dependence of the above

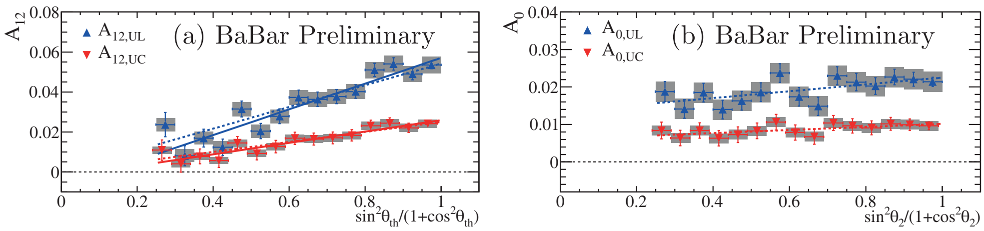

Fig. 3. – Collins asymmetries *vs.* polar angle θ_{th} (a), and θ_2 (b). Blue and red triangles indicate the UL and UC double ratio, respectively, while systematic uncertainties are shown by the gray bands. The linear fit to $p_0 + p_1 \cdot x$ is represented by a dotted line for each double ratio.

processes, and can be written as:

$$A^{meas} = \left(1 - \sum_i F_i\right) \cdot A^{uds} + \sum_i F_i \cdot A^i, \tag{3}$$

where F_i and A^i are respectively the fraction of pion pairs and the asymmetry due to the i^{th} background component, with $i = \tau$, charm or bottom. The fraction F_{bottom} is very low (less than 2%), while F_τ is relevant only for very energetic tracks. In addition, we measured A_τ in a τ-enhanced data sample, and found that the asymmetry is consistent with zero. For these reasons we set A_τ and A_{bottom} equal to zero. The charm contribution is the dominant background, with $F_{charm} \sim 30\%$ on average; both fragmentation processes and weak decays can introduce an azimuthal modulation. To estimate this contribution we select a charm-enhanced data sample requiring at least one D^* candidate from the decay $D^{*\pm} \to D^0\pi^\pm$. Given A^{meas} in the full data sample and A^{D^*} in the D^*-enhanced sample, we can extract the real contribution from light quarks (A^{uds}) to the Collins asymmetry.

4. – Preliminary results and conclusion

We study the behavior of the Collins asymmetries in the RF12 and RF0 frames as a function of pion fractional energy z, pion transverse momentum p_t, and as a function of the polar angle of the analysis axis. Figure 2 shows the corrected asymmetries in the RF12 frame, as an example. We observe a strong increase of the asymmetry as a function of pion fractional energy z (fig. 2(a)), which is in overall good agreement with previous Belle results [4]. No previous data from e^+e^- annihilation are available for the asymmetries as a function of p_t. Our data combined with previous data at low $|Q^2|$ ($\sim 2.4\,(\mathrm{GeV}/c)^2$) [5] in the space-like region can be used to investigate the evolution of Collins function. Finally, the Collins asymmetries are shown in fig. 3 as a function of the polar angle of the thrust axis θ_{th} in RF12, and the polar angle of the momentum of the second pion θ_2 in RF0. The dotted lines represent the results of the fit of a linear function to the data points. In the case of RF12 the fitted lines extrapolate rather close to the origin, consistently with the expectation. In contrast, the fits favor a non-zero constant parameter for the asymmetries in RF0; this behavior may be explained by the fact that θ_2 is more weakly correlated to the original $q\bar{q}$ direction than is the thrust axis.

In summary, we have reported preliminary BaBar results on the pion Collins asymmetries, extending our analysis to the study of the asymmetry behavior as a function of p_t. This may help to shed light on the evolution of the Collins fragmentation function. These data can also be valuable for improving global analyses, such as that of ref. [6].

REFERENCES

[1] Collins J. C., *Nucl. Phys. B*, **396** (1993) 161.
[2] Boer D., *Nucl. Phys. B*, **806** (2009) 23.
[3] Farhi E., *Phys. Rev. Lett.*, **39** (1977) 1587.
[4] Seidl R. *et al.* (Belle Collaboration), *Phys. Rev. Lett.*, **96** (2006) 232002; *Phys. Rev. D*, **78** (2008) 032011.
[5] Airapetian A. (HERMES Collaboration), *Phys. Rev. Lett.*, **94** (2005) 012002. Ageev E. (COMPASS Collaboration), *Nucl. Phys. B*, **765** (2007) 31.
[6] Anselmino M. *et al.*, *Phys. Rev. D*, **75** (2007) 054032.