Spin dependent fragmentation functions at BELLE

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Abstract. The measurement of the so far unknown chiral-odd quark transverse spin distribution in either semi-inclusive DIS(SIDIS) or inclusive measurements in pp collisions at RHIC has an additional chiral-odd fragmentation function appearing in the cross section. This chiral-odd fragmentation functions (FF) can for example be the so-called Collins FF or the Interference FF. HERMES has given a first hint that these FFs are nonzero, however in order to measure transversity one needs these FFs to be precisely known. At the Belle e^+e^- collider at the KEK-B factory a data set of 29.0 fb^{-1} has been used to obtain the Collins function.

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INTRODUCTION

At leading twist 3 quark distribution functions (DF) in the nucleon exist; the well known unpolarized quark DF, the somewhat known quark helicity DF and the so far unknown transversity DF. The latter cannot be measured in inclusive DIS due to its chiral-odd nature, since all possible interactions are chiral-even for nearly massless quarks. Therefore one needs an additional chiral-odd function in the cross section to access transversity. This can be either achieved by an anti quark transversity DF in double transversely polarized Drell-Yan processes or one can have a chiral-odd fragmentation function in SIDIS or hadroproduction.

THE BELLE EXPERIMENT

The Belle [2] experiment at the asymmetric e^+e^- collider KEK-B at Tsukuba, Japan, is mainly dedicated to study CP violation in B meson decays. Its center of mass energy is tuned to the $\Upsilon(4S)$ resonance at $\sqrt{s} = 10.58$ GeV and part of the data was recorded 60 MeV below the resonance. These off-resonance events are studied in order to measure spin dependent and also to perform precise measurements of spin independent fragmentation functions. At present an integrated luminosity of 29.0 fb^{-1} has been accumulated in the off-resonance data sample. The aerogel Čerenkov counter (ACC) , time-of-flight (TOF) detector and the central drift chamber (CDC) enable a good particle identification and tracking, which is crucial for these measurements. Using the information from the silicon vertex detector (SVD), one selects tracks originating from the interaction region and thus reducing the contribution of hadrons from heavy meson decays.

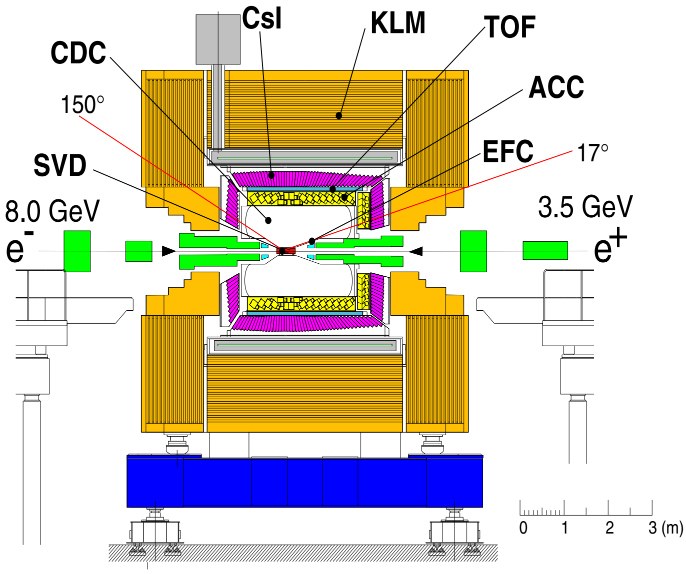

FIGURE 1. A schematic side view of the Belle detector.

To reduce the amount of hard gluon radiative events a cut on the kinematic variable thrust of $T > 0.8$ is applies. This enhances the typical 2-jet topology and the thrust axis is used as approximation of the original quark direction. To ensure that the pions did not originate in the decay of a vector meson and might be mistakenly put in the wrong hemisphere a lower cut on the fractional energy of 0.2 is performed.

COLLINS FF

The Collins effect occurs in the fragmentation of a transversely polarized quark with polarization $\mathbf{S_q}$ and 3-momentum $\mathbf{k}$ into an unpolarized hadron of transverse momentum $\mathbf{P}_{h\perp}$ with respect to the original quark direction. According to the Trento convention [3] the number density for finding an unpolarized hadron h produced from a transversely polarized quark q is defined as:

$$D_{hq^\uparrow}(z,P_{h\perp}) = D_1^q(z,P_{h\perp}^2) + H_1^{\perp q}(z,P_{h\perp}^2)\frac{(\hat{\mathbf{k}}\times\mathbf{P}_{h\perp})\cdot\mathbf{S}_q}{zM_h}, \tag{1}$$

where the first term describes the unpolarized FF $D_1^q(z,P_{h\perp}^2)$, with $z \stackrel{CMS}{=} \frac{2E_h}{Q}$ being the fractional energy the hadron carries relative to half of the CMS energy Q. The second term, containing the Collins function $H_1^{\perp q}(z,P_{h\perp}^2)$, depends on the spin of the quark and thus leads to an asymmetry as it changes sign under flipping the quark spin. The vector product can accordingly be described by a $\sin(\phi)$ modulation, where ϕ is the

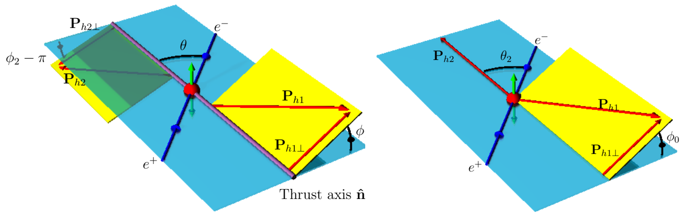

FIGURE 2. Description of the azimuthal angles ϕ_0, ϕ_1 and ϕ_2 relative to the scattering plane defined by the lepton axis and either the thrust axis $\hat{n}$ or the momentum of the 2^{nd} hadron P_{h2}.

azimuthal angle spanned by the transverse momentum and the plane defined by the quark spin and its momentum. In e^+e^- hadron production the Collins effect can be observed by a combined measurement of a quark and an anti quark fragmentation. Combining two hadrons from different hemispheres in jetlike events, with azimuthal angles ϕ_1 and ϕ_2 as defined in Fig. 2, would result in a $\cos(\phi_1+\phi_2)$ modulation. In the CMS these azimuthal angles are defined between the transverse component of the hadron momenta with regard to the thrust axis $\hat{n}$ and the plane spanned by the lepton momenta and $\hat{n}$. The comparison of the thrust axis calculations using reconstructed and generated tracks in the MC sample shows an average angular separation between the two of 75 mrad with a a root mean square of 74 mrad. Due to that small biases in one of the reconstruction methods used could arise and were studied as discussed later. Following reference[4] one either computes the azimuthal angles of each pion relative to the thrust axis which results in a $\cos(\phi_1+\phi_2)$ modulation or one calculates the azimuthal angle relative to the axis defined by the 2^{nd} pion which results in a $\cos(2\phi_0)$ modulation 2. While the first method directly accesses moments of the Collins functions the second method also contains a convolution integral of the Collins FF over possible transverse momenta of the hadrons.

Measured asymmetries

We measure the azimuthal asymmetries $N(2\phi)/N_0$, where $N(2\phi)$ denotes the number of hadron pairs in bins of either $2\phi_0$ or $\phi_1+\phi_2$ and N_0 is the average number of hadron pairs in the whole angle interval. The main background, producing similar azimuthal asymmetries as the Collins effect, is the radiation of soft gluons. This gluonic contribution is proportional to the unpolarized FF and is independent of the charge of the hadrons. Consequently taking the ratio of the normalized distributions for unlike-sign over like-sign pairs the gluonic distributions drop out in leading order:

$$R := \frac{\frac{N(2\phi_0)}{N_0}|_{unlikesign}}{\frac{N(2\phi_0)}{N_0}|_{likesign}}$$
$$\approx 1+\frac{\sin^2\theta}{1+\cos^2\theta}\left(F\left(\frac{H_1^{\perp,fav}}{D_1^{fav}},\frac{H_1^{\perp,disfav}}{D_1^{disfav}}\right)+\mathscr{O}f(Q_T,\alpha_S)^2\right)\cos(2\phi_0) \quad , \quad (2)$$

where θ is the angle between the colliding leptons and the produced hadron. Favored and disfavored FF describe the fragmentation of a light quark into a pion of same or opposite charge sign. A similar relation also holds for the $\cos(\phi_1+\phi_2)$ method. Those double ratios are then fit by the sum of a constant term and a $\cos(2\phi_0)$ or $\cos(\phi_1+\phi_2)$ modulation. Preliminary results for the cosine fits to the double ratios can be seen in Fig.3 for charged pion pairs, where the combined z-bins are obtained by adding the symmetric bins of the 4×4 $z \in [0.2, 0.3, 0.5, 0.7, 1.0]$ bins. A clear nonzero asymmetry is visible. Additionally the data shows a rising behavior with rising fractional energy z. The systematic errors are obtained by taking the differences of the double ratio results compared with results obtained by subtracting the unlike from the like sign asymmetries. Also the constant fit to the double ratios obtained in MC (without a Collins contribution) together with its statistical error and a similar fit to double ratios of positively charged over negatively charged pion pair data were assigned as systematic error. Also the differences to the results when fitting the double ratios also with higher order azimuthal modulations were added to the systematic errors.

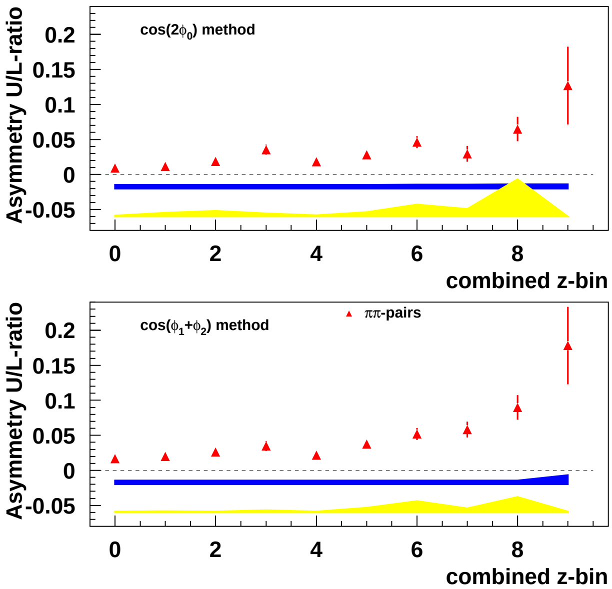

FIGURE 3. Double ratio results for the $\cos(2\phi_0)$ and the $\cos(\phi_1+\phi_2)$ method. The upper error bars correspond to systematic errors, the lower error bars to possible contributions by charm quarks.

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