Kaon Collins Fragmentation Function Measurement at BELLE

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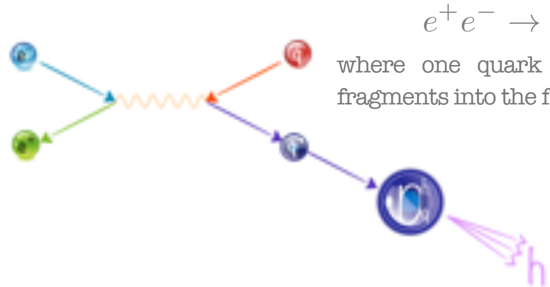
Fragmentation Function Measurements in e^+e^-

Fragmentation Functions (FFs) parametrize the non-perturbative process of hadronization of partons into colorless hadrons

The cleanest way to access fragmentation is via the reaction

$$e^+e^- \to q\bar{q} \to h\,X,$$



where one quark (q) or anti-quark ($\bar{q}$) fragments into the final observed hadron h

The fragmentation process is not only interesting because it provides information on parton confinement, but also because, as the FFs are universal, it can be used to study the nucleon structure in SIDIS and hadron reactions, where they enter the cross sections convoluted with parton distribution functions (PDFs).

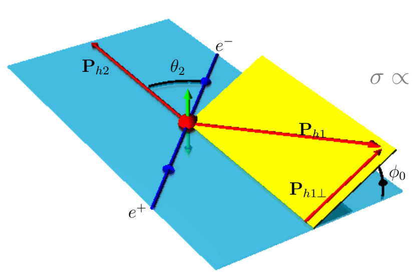
Collins Mechanism

In the Collins fragmentation mechanism the final state hadron is generated with a transverse momentum (with respect to the $q\bar{q}$ axis) correlated with the transverse spin of the fragmenting quark

The Collins FF ($H_1^\perp$) in e^+e^- can be accessed observing two hadrons fragmented from the quark and the anti-quark

$$e^+e^- \to q\bar{q} \to h_1\,h_2\,X$$

The cross section for this reaction is proportional to the convolution $\mathcal{F}$ over the quark/anti-quark transverse momenta of two Collins FFs:



$$\sigma \propto \left(1 + cos(2\phi_0)\mathcal{F}\left[\frac{H_1^\perp(z_1)\bar{H}_1^\perp(z_2)}{D_1^\perp(z_1)\bar{D}_1^\perp(z_2)}\right]\right)$$

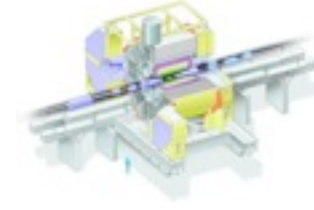
z_1 (z_2) is the first (second) hadron energy fraction with respect to fragmenting parton

Thus, in e^+e^- to access the Collins FFs one needs to measure the azimuthal modulation $cos2\phi_0$ of the cross section for two hadron production, where ϕ_0 is azimuthal angle of the first hadron with respect to the second hadron.

BELLE experiment

The measurements presented here are extracted from ~790 fb^{-1} data collected at the asymmetric (8 GeV electron, 3.5 GeV positron) e^+e^- collider KEKB by the BELLE spectrometer in Japan. Both data collected on the Y(4S) resonance energy ($\sqrt{s}$ =10.58 GeV) and in the continuum region ($\sqrt{s}$ =10.52 GeV) have been included in the analysis, after assuring that the two data sample yielded compatible results.

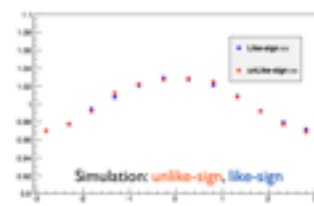
BELLE is a large solid angle spectrometer with good tracking capabilities for $17^0 < \Theta < 150^0$, and excellent particle identification.

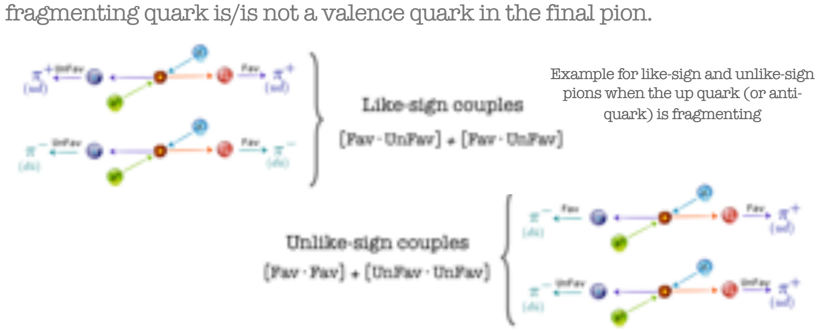


Double ratios: Unlike-sign over like-sign hadrons

To correct for the fake azimuthal modulations generated by acceptance effects and for gluon radiation modulation, which are charge-independent, the Collins amplitudes are measured from the ratio of unlike-sign and like-sign hadrons.

The cross-section for like- and unlike-sign hadrons is proportional to different combination of Collins FF; for instance, in case the two hadrons are both pions, like-sign pion cross section is related to the sum of convolutions of a favored and an unfavored Collins FF, where 'favored'/'unfavored' refer to the fact that the fragmenting quark is/is not a valence quark in the final pion.





In the limit of small $cos2\phi_0$ amplitudes for both the unlike-sign and like-sign couples, the double ratio of unlike-sign over like-sign couples is proportional to $\mathcal{B}_0(1 + \mathcal{A}_0\cos(2\phi_0))$, where

$$A_0 \propto \mathcal{F}\left[\frac{H_1^\perp(z_1)\bar{H}_1^\perp(z_2)}{D_1^\perp(z_1)\bar{D}_1^\perp(z_2)}\right]$$

Results for $\pi\pi$ have been published by BELLE (PRL 96,232002, (2006), PRD 78, 032011 (2008)). Here, pairs of hadrons involving a kaon are considered: πK and KK, and their amplitudes are compared with the amplitudes for pion pairs $\pi\pi$.

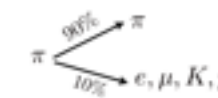
Measurements and Corrections

The use of double ratios assure that all non-Collins charge-independent effects are corrected for, and this has also been checked via the use of simulation.

PID correction

Belle has very high-performance particle identification detectors and algorithm, with efficiencies:

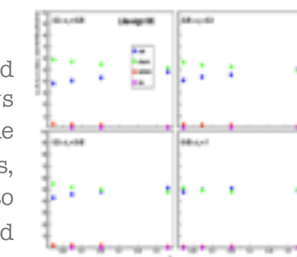
$$\varepsilon(\pi) \geq 90\% \quad \varepsilon(K) \geq 85\%$$



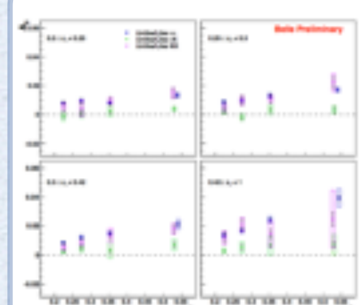
To correct for the remaining inefficiencies to correctly identify pions and kaons a 2-dimensional (momentum, polar angle) unfolding procedure has been performed: the probabilities for a track to be correctly/un-correctly identified are encoded into a smearing matrix, and have been extracted with a data-driven procedure that make use of known hadron decays. For instance the D* decay has been used, where the only negative hadron is known to be a kaon.

Various contributions

Major contributions are from u, d, s, charm and bottom fragmentations and tau decays (background). For pairs like $\pi\pi$ and πK the major contributions are from light quark u-d-s, while for KK the charm contributions is also significant. The Collins mechanism is expected to be sizable only for the light quarks u, d and s.



Results



A_0 amplitudes for $\pi\pi$ (blue), πK (green) and KK (violet) versus binning in

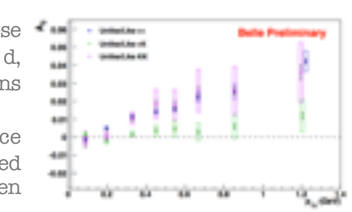
left: z_1 and z_2

bottom: p_{T0}, the first hadron transverse momentum

non-zero positive amplitudes with similar size and increasing with z and p_{T0} are observed for $\pi\pi$ and KK, while πK amplitudes are consistent with zero.

The extraction of the Collins functions from these amplitudes is not trivial: if we limit ourselves to u, d, s contributions we have a total of 12 possible Collins FFs for pions and 12 for kaons.

Some assumptions are needed, for instance consider only one favored and one unfavored fragmentation for u, d and the same for s, and then distinguish for the final state hadron itself.



Still: a lot of parameters! A full phenomenological study is needed to extract Collins FFs!

$$D^{\frac{U_{KK}}{L_{KK}}} \propto 1 + \cos 2\phi_0 \frac{\sin^2\theta}{1+\cos^2\theta}\left(\frac{4H_{1K}^{fav}H_{2K}^{fav} + 6H_{1K}^{dis}H_{2K}^{dis} + H_{1s\to K}^{dis}H_{2s\to K}^{dis} + H_{1s\to K}^{fav}H_{2s\to K}^{fav}}{4D_{1K}^{fav}D_{2K}^{fav} + 6D_{1K}^{dis}D_{2K}^{dis} + D_{1s\to K}^{dis}D_{2s\to K}^{dis} + D_{1s\to K}^{fav}D_{2s\to K}^{fav}} - \frac{4H_{1K}^{fav}H_{2K}^{dis} + 4H_{1K}^{dis}H_{2K}^{fav} + 2H_{1K}^{dis}H_{2K}^{dis} + H_{1s\to K}^{dis}H_{2s\to K}^{fav} + H_{1s\to K}^{fav}H_{2s\to K}^{dis}}{4D_{1K}^{fav}D_{2K}^{dis} + 4D_{1K}^{dis}D_{2K}^{fav} + 2D_{1K}^{dis}D_{2K}^{dis} + D_{1s\to K}^{dis}D_{2s\to K}^{fav} + D_{1s\to K}^{fav}D_{2s\to K}^{dis}}\right)$$