Measurement of Collins Asymmetries in the inclusive production of hadron pairs

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Outline

- Physics introduction
- Analysis reference frame
- Analysis strategy
- Raw asymmetries and Double Ratio
- Plans and Conclusion
Unpolarized distribution, helicity distribution and transversity distribution functions contain basic and necessary information for a full understanding of the quark structure at leading twist order.

Transversity ($h_1$) remains the less know distribution due to its chiral odd nature → it appears with another chiral-odd function in semi inclusive DIS experiment.

The most promising approach is the double transverse spin asymmetries in Drell-Yan $p\bar{p}$ interaction but, at present, the antiproton polarization efficiency is very low.
Collins FF in $e^+e^- \text{ annihilation}$

**SIDIS: Semi Inclusive Deep Inelastic Scattering**

$$e^+ e^- \rightarrow h_1 h_2 X$$

**Factorization theorem:**

$$\sigma^{e_p \rightarrow ehX} = \sum_q DF \times \sigma(eq \rightarrow eq) \times FF$$

**Transversity Distribution Function**

**Collins Fragmentation Function**

**Transverse Single Spin Asymmetries:**

$$A_T \propto h_1 \times H_1$$

**Collins Effect:**

Fragmentation of a quark $q$ with Spin $S_q$ into a spinless hadron $h$ carries an azimuthal dependence

$$\propto (k \times p_{h,\perp})^* S_q$$

**The Collins Asymmetries are proportional to:**

$$H_1 \perp (z_1) \times H_1 \perp (z_2)$$

where $H_1$ is the Collins FF

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Anselmino et al: Phys.Rev. D75,054032
hep-ex 0701006

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Collins FF at BaBar

\[ e^+e^- \rightarrow \pi\pi X \]

Number density for finding an hadron h produced from a transversely polarized quark.

\[
D_{hq}^{\uparrow} = D_1^q(z, P_{h\perp}^2) + H_1^q(z, P_{h\perp}^2) \frac{\hat{k} \times \vec{P}_{h\perp} \cdot \vec{S}_q}{z M_h}
\]

• Quark spin direction unknown: measurement of Collins function in one hemisphere is not possible;

• Correlation between two hemispheres results in \( \cos(\phi_1 + \phi_2) \) (or \( \cos(2\phi_0) \)) modulation of the observed di-hadron yield.
RF12: Thrust Reference Frame

$\phi_1 + \phi_2$ or thrust reference frame

$\theta_1$: angle between the lepton axis and the thrust axis;
$\phi_1,2$: azimuthal angles of the two hadrons between the scattering plane and the transverse hadrons momenta $P_{hiT}$.

$$d\sigma(e^+e^- \rightarrow h_1h_2X) = \sum_{q,q} \frac{3\alpha^2}{Q^2} \frac{e_q^2}{4} z_1^2 z_2^2 \left[ (1 + \cos^2 \theta) D_1^{q,(0)}(z_1) \bar{D}_1^{q,(0)}(z_2) + \sin^2(\theta) \cos(\phi_1 + \phi_2) H_1^{1,(1),q}(z_1) \bar{H}_1^{1,(1),q}(z_2) \right]$$
$\theta_2$: angle between the lepton axis and the second hadron momenta
$P_{h2}$;
$\phi_0$: angle between the plane spanned by one hadron momentum and the lepton momenta and the transverse momentum of the second hadron respect to the first hadron momentum

$$
\frac{d\sigma(e^+e^- \rightarrow h_1 h_2 X)}{d\Omega dz_1 dz_2 d^2q_T} = \frac{3\alpha^2}{Q^2} z_1^2 z_2^2 \left\{ A(y) \mathcal{F}[D_1 \bar{D}_2] + B(y) \cos(2\phi_0) \mathcal{F} \left[ \left( 2\hat{h} \cdot \vec{k}_T \hat{h} \cdot \vec{p}_T - \vec{k}_T \cdot \vec{p}_T \right) \frac{H_1^+ \bar{H}_2^+}{M_1 M_2} \right] \right\}
$$
Accessing the Collins Asymmetries: measurement of \( \cos(\phi_1 + \phi_2) \) (or \( \cos(2\phi_0) \)) normalized modulation of hadron pair \( (N(\phi_1 + \phi_2), N(2\phi_0)) \).

Normalized distribution:

\[
R_\alpha = \frac{N(\phi_\alpha)}{\langle N_\alpha \rangle} = a + b \cdot \cos(\phi_\alpha)
\]

where \( \phi_\alpha = \phi_1 + \phi_2 \) or \( \phi_\alpha = 2\phi_0 \)

Collins asymmetries

In the two hemispheres, we can detect two pions with the same sign \( (\pi^+\pi^+ \text{ or } \pi^-\pi^-) \) or with opposite sign \( (\pi^+\pi^- \text{ or } \pi^-\pi^+) \) → The favored fragmentation process describes the fragmentation of a quark of flavor \( q \) into an hadron with a valence quark of the same flavor \( (u \rightarrow \pi^+, d \rightarrow \pi^- \ldots) \) and unfavored for \( u \rightarrow \pi^-, d \rightarrow \pi^+ \ldots \):

UnLike-sign \( \pi \) pair (UL) \[ R_{UL} \]

Like-sign \( \pi \) pair (L) \[ R_L \]

Charged-sign \( \pi \) pair (C) \[ R_C \]

\( (\text{fav x fav}) + (\text{dis x dis}) \) \( (\text{fav x dis}) + (\text{dis x fav}) \) \( (\text{fav + dis}) x (\text{fav + dis}) \)
1) Preselection:
   a) Multi-hadron events (number of tracks > 2);
   b) Visible energy: $E_{\text{vis}} > 7$ GeV;
   c) Two jets events:
      → Thrust$>0.8$ eliminate the $\Upsilon$(4S) contribution;
      → $z=2E_h/Q >0.2$ (fractional energy of pions);
      → Select tracks from primary vertex;
Analysis strategy

2) assume the thrust axis as qq direction;
3) separate events in two hemispheres according to thrust axis;
4) select pions in opposite hemispheres;
5) measure the corresponding azimuthal angles ($\phi_i$);
6) Fit the raw asymmetries taking care of the detector acceptance.

\[
\cos(\theta) = \frac{(P_x n_x + P_y n_y + P_z n_z)}{|P|}
\]

![Diagram showing the analysis strategy with a figure illustrating the thrust axis and the angles $\theta_1$ and $\theta_2$.]
Raw Asymmetries: RF12

CM simulation: $R_L$ and $R_{UL}$ distributions

DATA: $R_L$ and $R_{UL}$ distributions

Run1-Run6
OffPeak
uds events

**Fit function:**

$$a + b \cos(\phi_1 + \phi_2)$$

- $a \rightarrow$ is consistent with 1
- $b \rightarrow$ is the raw asymmetry parameter (acceptance effects and radiative effects are included)

MC: Collins Asymmetry not implemented.

**Very Preliminary data**

$L \sim 45 \text{ fb}^{-1} @ 10.54 \text{GeV}$

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In order to eliminate the acceptance effects and the first order radiative effects, we can construct a double ratio, e.g. $\frac{R_L}{R_{UL}}$ (the asymmetries generated by QCD radiative events and acceptance effects do not depend on the charge combination of pion pair):

\[
\frac{R_L}{R_{UL}} = \frac{N^L(\phi)/<N^L_{12}>}{N^{UL}(\phi)/<N^{UL}_{12}>} \rightarrow P_0 + P_1 \cdot \cos(\phi)
\]

It will be consistent with unity within the statistical error

It contains only the Collins asymmetry and higher order radiative effects.

The same parametrization is true for other double ratio (e.g: $R_L/R_C$).
Double Ratio: thrust RF

Collins asymmetries not implemented in MC simulation ⇒ we expect $P_1$ consistent with zero.

Preliminary data: $cc$ and $\tau\tau$ contributions not subtracted; errors due to systematic effects not included.

The acceptance effects and the first order radiative effects cancel.
mc binned asymmetries

\[ \sigma_{\text{light } q} \approx 2.09 \text{ nb} \]
\[ \sigma_{cc} \approx 1.30 \text{ nb} \]
\[ \sigma_{bb} \approx 1.05 \text{ nb} \]

The Babar detector collected about 432 fb\(^{-1}\) at \(\Upsilon(4S)\) and 45 fb\(^{-1}\) below the \(\Upsilon(4S)\) resonance (10.54 GeV)

(\(\approx 10^9\) events for light quark);

Measurement of the Collins FF \((H(z))\) in small \(z_i\) intervals.

**Monte Carlo:**
we expect zero asymmetry in each \(z\) bin.
The competing sources for the azimuthal correlation are:

- **γ-Z interference**: does not lead to any significant additional $\phi$ dependence (it only modifies the $\theta$ distribution with a forward-backward asymmetry of a few percent) (hep-ph/0804.2408v2);

- **week decay**: parity violation can lead to azimuthal correlation between hadrons in opposite hemispheres, e.g. $\tau \rightarrow \pi \nu$ ($E_{\text{vis}}>7\text{GeV}$);

- **GLUON RADIATIVE EFFECTS**: It is the dominant Collins-like background contribution. It originates from low energetic gluon radiation $e^+e^-\rightarrow q\bar{q}g$ which does not manifest itself in a third jet but creates azimuthal asymmetries $\rightarrow$ The differenzial cross section is proporzional to $D_1(z)$ and $\overline{D}_1(z)$ for a given combination of hadrons $\rightarrow$ it’s necessary to construct quantities in which the gluon radiation component is largely absent (Double Ratio).
Outlook

- Measurement of charm contribution to the asymmetries and correction of data ($\text{e}^+\text{e}^-\rightarrow\text{cc} \sim 40\%$ of the total cross section);
- $\tau^+\tau^-$ contribution;
- Bottom background;

Evaluate the systematic effects which influence the asymmetry, e.g.:
- Estimate higher order radiative effects;
- Possible charge dependence of the detector response;
- Beam polarization measurements;
We have shown that this measurement is also feasible with BaBar data and we expect the first results for pions ready in a few months.

Thanks for your attention
Backup slides
The B-factories, PEPII and KEK, consist of asymmetric electron-positron beams. The center of mass energy is selected to be on the peak on the \( \Upsilon(4S) \) meson (10.58 GeV/c\(^2\)), which decay more than 96% into B\( \bar{B} \) meson pairs.

**Physics program:**
- The principal physics goal of the B-factories is to test the Kobayashi-Maskawa picture of CP violation by measuring the angle of the unitary triangle;
- precision measurements of decays of bottom and charm mesons of the \( \tau \) lepton;
- search for rare processes;
- the very clean environment make BaBar suitable also for inclusive studies of hadron production:

**Study of the azimuthal asymmetries in the inclusive production of two back-to-back hadron in the reaction:** \( e^+e^- \rightarrow h_1h_2X \)
PEP-II B-Factory

SLAC: Stanford Linear Accelerator Center (California, USA)

- PEP length 2219.3m;
- HER (High Energy Ring): 9.0 GeV e⁻;
- LER (Low Energy Ring): 3.1 GeV e⁺;
- Project Luminosity: $3 \times 10^{33}$ cm⁻²s⁻¹

BaBar detector
BaBar detector

**1.5T Solenoid**

**ElectroMagnetic Calorimeter**
6580 CsI(Tl) crystals

**DIRC**
144 quartz bars

**Drift CHamber**
40 stereo layers

**e^- (9GeV)**

**e^+ (3.1GeV)**

**Instrumented Flux Return**
19 RPCs layers (Run1-Run3)
12 LSTs layers (Run4-Run7)

**Silicon Vertex Tracker**
5 layers of double sided silicon strips
Accelerator parameters:
\[ e^+ \rightarrow 3.1 \text{ GeV} \]
\[ e^- \rightarrow 9.0 \text{ GeV} \]
\[ \sqrt{s} = 10.58 \text{ GeV} \]
\[ \beta_\gamma = 0.56 \]

Integrated Luminosity:
\[ 432.89/\text{fb} @ \gamma(4S) \]
\[ 53.74/\text{fb} @ 10.54 \text{ GeV} \]