The Transverse Spin Effects in Kaon Production at HERMES

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Outline

- Appetiser
- The RICH Detector
- The Measured Azimuthal Asymmetry Moments for Kaons
- Conclusions
Fit to the Sivers moments of charged pions by Anselmino et al.
Appetiser

→ predictions for the kaon Sivers moments neglecting sea quarks

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$\sigma^{ep\rightarrow eh} \sim \sum_q e_q^2 \cdot DF_q \otimes FF_{q\rightarrow h}$

Distribution Functions and Fragmentation Functions

- quark content:
  - proton: $uud$
  - $\pi^+: u\bar{d}$, $\pi^-: \bar{u}d$, $K^+: u\bar{s}$, $K^-: \bar{u}s$

- quark charge is additional factor

$\rightarrow$ unpol. scattering off a proton is dominated by scattering off a $u$ quark

- favoured unpolarised FF is much larger than unfavoured FF

(e.g. $u \rightarrow \pi^+, \bar{d} \rightarrow \pi^+, u \rightarrow K^+, \bar{s} \rightarrow K^+$
$\bar{u} \rightarrow \pi^+, d \rightarrow \pi^+, \bar{u} \rightarrow K^+, s \rightarrow K^+$)

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The HERMES Spectrometer

Hadron identification with the RICH detector
The RICH Detector

Dual radiator Ring Imaging Čerenkov detector
The RICH Detector

Dual radiator Ring Imaging Čerenkov detector

Aerogel: $n = 1.03$

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The RICH Detector

Dual radiator Ring Imaging Čerenkov detector

Aerogel: \( n = 1.03 \)

\( C_4F_{10} \): \( n = 1.0014 \)
The RICH Detector

Dual radiator Ring Imaging Čerenkov detector

Aerogel: \( n = 1.03 \)

\( \text{C}_4\text{F}_{10} : \ n = 1.0014 \)

PMT matrix with 1934 PMTs

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The RICH Detector

Dual radiator Ring Imaging Čerenkov detector

Aerogel: \( n = 1.03 \)

\( C_4F_{10} \): \( n = 1.0014 \)
opening angle:

$$\cos \Theta_c = \frac{1}{\beta n}$$

threshold momentum:

$$p = \frac{m \beta c}{\sqrt{1 - \beta^2}}$$

real $\pi$ $K$ event
Hadron Identification

opening angle:

\[ \cos \Theta_c = \frac{1}{\beta n} \]

threshold momentum:

\[ p = \frac{m \beta c}{\sqrt{1 - \beta^2}} \]
opening angle:

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Azimuthal Asymmetries

Measurement of cross section asymmetries depending on the azimuthal angles $\phi$ and $\phi_S$:

$$A_{\text{UT}}(\phi, \phi_S) = \frac{1}{S_\perp} \frac{N^\uparrow(\phi, \phi_S) - N^\downarrow(\phi, \phi_S)}{N^\uparrow(\phi, \phi_S) + N^\downarrow(\phi, \phi_S)}$$

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Azimuthal Asymmetries

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$$\sim \cdots \sin(\phi + \phi_S) \frac{\sum_q e_q^2 I \left[ \cdots \delta q(x, \vec{p}^2_T) \cdot H_{1T}^q(z, \vec{k}^2_T) \right]}{\sum_q e_q^2 q(x) \cdot D_1^q(z)}$$

$$+ \cdots \sin(\phi - \phi_S) \frac{\sum_q e_q^2 I \left[ \cdots f_{1T}^q(x, \vec{p}^2_T) \cdot D_1^q(z, \vec{k}^2_T) \right]}{\sum_q e_q^2 q(x) \cdot D_1^q(z)}$$

$$+ \cdots$$

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How to Disentangle . . .

distribution and fragmentation functions?

Assume a Gaussian distribution for $\vec{p}_T$ and $\vec{k}_T$ dependence:

$$A_{UT}(\phi, \phi_S) \sim \ldots \sin(\phi + \phi_S) \sum_q e_q^2 \cdot \delta q(x) \cdot H_{1}^{(1/2)}(z)$$

$$+ \ldots \sin(\phi - \phi_s) \sum_q e_q^2 \cdot f_{1T}^{(1/2)}(x) \cdot D_{1}^{q}(z)$$

$$+ \ldots$$

$(1/2)$: $|\vec{p}_T|$, $|\vec{k}_T|$ moment of distribution / fragmentation function
How to Disentangle . . .

distribution and fragmentation functions?

Assume a Gaussian distribution for \( \vec{p}_T \) and \( \vec{k}_T \) dependence:

\[
A_{UT}(\phi, \phi_S) \sim \sin(\phi + \phi_S) \sum_q e_q^2 \cdot \delta q(x) \cdot H_1^{(1/2)} q(z) \\
+ \sin(\phi - \phi_S) \sum_q e_q^2 \cdot f_{1T}^{(1/2)} q(x) \cdot D_q(z) \\
+ . . .
\]

asymmetry amplitudes

\( A_{UT}^{\sin(\phi+\phi_S)} \) and \( A_{UT}^{\sin(\phi-\phi_S)} \)

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Extraction of the Asymmetry Amplitudes

- Pions with large statistics:
  bin $A_{UT}(\phi, \phi_S)$ in $12 \times 12 \phi \times \phi_S$ bins, perform least-squares fit
Extraction of the Asymmetry Amplitudes

- pions with large statistics:
  bin $A_{UT}(\phi, \phi_S)$ in $12 \times 12 \phi \times \phi_S$ bins, perform least-squares fit

- kaons with low statistics:
  perform maximum-likelihood fit $\Rightarrow$ no azimuthal binning
  probability density function:

$$F_{\uparrow(\downarrow)}(A_{UT}^{\sin(\phi \pm \phi_S)}, \ldots, \phi, \phi_S) =$$

$$\epsilon \cdot \sigma_{UU} \cdot \frac{1}{2} \left(1 + (-) A_{UT}^{\sin(\phi \pm \phi_S)} \sin(\phi \pm \phi_S) + (-) \ldots \right)$$

acceptance $\epsilon$ and cross section $\sigma_{UU}$ independent of $A_{UT}^{\sin(\phi \pm \phi_S)}, \ldots$
Extraction of the Asymmetry Amplitudes

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- kaons with low statistics:
  perform maximum-likelihood fit $\Rightarrow$ no azimuthal binning
  - probability density function:

$$F_{\uparrow(\downarrow)} (A_{UT}^{\sin(\phi \pm \phi_S)}, \ldots, \phi, \phi_S) = \frac{1}{2} \left( 1 + (-)A_{UT}^{\sin(\phi \pm \phi_S)} \sin(\phi \pm \phi_S) + (-) \ldots \right)$$

  acceptance $\epsilon$ and cross section $\sigma_{UU}$ independent of $A_{UT}^{\sin(\phi \pm \phi_S)}, \ldots$
  - maximise $\log \mathcal{L}$, i.e., logarithm of the likelihood function:

$$\mathcal{L}(A_{UT}^{\sin(\phi \pm \phi_S)}, \ldots) = \frac{1}{\mathcal{N}} \prod_{i=1}^{N_{\uparrow}} F_{\uparrow i}^{N_{\uparrow}} \prod_{i=1}^{N_{\downarrow}} F_{\downarrow i}^{N_{\downarrow}}$$
$P_{h\perp}$–distributions

\begin{figure}
\centering
\includegraphics[width=\textwidth]{ph_perp_distributions}
\end{figure}

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Kaon Collins Amplitudes

\[ A_{\text{UT}}^{\sin(\phi+\phi_S)} \sim \delta q \cdot H_1^{(1/2)} \]

- no significant non-zero kaon amplitudes
- systematic uncertainty: PID, acceptance, smearing, unpolarised cosine moments
- overall scale uncertainty 6.6 %

Kaon Collins Amplitudes

\[ A_{UT} \sin(\phi + \phi_s) \sim \delta q \cdot H_1^{1/2} \]

- \( K^+ \) amplitudes consistent to \( \pi^+ \) amplitudes
- \( u \)-quark dominance

\( \Rightarrow \) Collins FF seems to be similar for pions and kaons?
Kaon Sivers Amplitudes

\[ A_{UT}^{\sin(\phi - \phi_S)} \sim f_{1T}^{(1/2)} \cdot D_1 \]

- **positive** \( K^+ \) amplitude
- **\( K^- \)** amplitude consistent with zero
- systematic uncertainty: PID, acceptance, smearing, unpolarised cosine moments
- overall scale uncertainty 6.6 %
Kaon Sivers Amplitudes

\[ A_{UT}^{\sin(\phi - \phi_S)} \sim f_{1T}^{(1/2)} \cdot D_1 \]

- \( K^+ \) amplitudes in some bins larger than \( \pi^+ \) amplitudes
- \( u \)-quark dominance
- sea quark contribution to Sivers moment important?

Kaon Sivers Amplitudes

\[ A_{UT} \sin(\phi - \phi_S) \sim f_{1T}^{(1/2)} \cdot D_1 \]

- fit to pion amplitudes by Anslemino et al.
- prediction for \( K^+ \) amplitudes slightly too small
- sea quark contribution to Sivers moment important?
Conclusions

- First measurement of Collins and Sivers moments for kaons in semi–inclusive DIS.
- Sea–quark contribution to the Sivers moments might be not negligible.
- Data taken in 2005 will double the statistics.
- We are working on the extraction of the Sivers function.
- Belle results will allow transversity extraction.
- The determination of $P_{h\perp}$–weighted asymmetry amplitudes is under study.
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Extraction of the Asymmetry Amplitudes

likelihood function:

\[ \mathcal{L}(A_{UT}^{\sin(\phi \pm \phi_S)}, \ldots) = \frac{1}{N} \prod_{i=1}^{N_{\uparrow}} F_{\uparrow i} \prod_{i=1}^{N_{\downarrow}} F_{\downarrow i} \]

with normalisation:

\[
\mathcal{N} = \mathcal{N}_{\uparrow}^{N_{\uparrow}} \cdot \mathcal{N}_{\downarrow}^{N_{\downarrow}} \\
\mathcal{N}_{\uparrow(\downarrow)} = \sum_{i=1}^{N_{\uparrow(\downarrow)}} N_{\uparrow(\downarrow)} + \left(1+(-)A_{UT}^{\sin(\phi \pm \phi_S)} \sin(\phi_i \pm \phi_{S_i})+(-)\ldots\right)
\]
Vector Meson Contribution

![Graph showing the vector meson contribution with plots for different particles and kinematic variables.](image)