Azimuthal asymmetries in SIDIS off unpolarized targets at COMPASS

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On behalf the COMPASS collaboration
Outline

- Introduction
- The COMPASS experiments
- Analysis and extraction of the asymmetries
- Results
- Conclusions
Azimuthal modulations in $l_p \rightarrow l'hX$ measured by

- EMC
- E665

Large modulations up to 40% for $\cos \phi$, while $\cos 2\phi \sim 5$

(with $\phi$ or $\phi_h$ the hadron azimuthal angle in GNS)

More recently ZEUS in the high-pT (pQCD region)

Since last year, new data from COMPASS and HERMES
Cahn effect – just a reminder

The unpolarized SIDIS cross section is:

\[ d\sigma^{lp\rightarrow l'hX} = \sum_q f_q(x,Q^2) \otimes d\sigma^{lp\rightarrow l'q} \otimes D^h_q(z,Q^2) \]

with \( f \) the PDF and \( D \) the FF

In collinear PM than the elementary xSection is

\[ d\sigma^{lp\rightarrow l'q} \propto \hat{s}^2 + \hat{u}^2 \propto x \left( 1 + (1-y)^2 \right) \]

i.e. no dependence on \( \phi_h \). Taking into account the parton transverse momentum in the kinematics leads to:

\[
\hat{s} = s x \left[ 1 - \frac{2k_T}{Q} \sqrt{1-y} \cdot \cos \phi \right] + O \left( \frac{k_T^2}{Q} \right) \\
\hat{u} = s x (1-y) \left[ 1 - \frac{2k_T}{Q \sqrt{1-y}} \cdot \cos \phi \right] + O \left( \frac{k_T^2}{Q} \right)
\]

Resulting in the \( \cos \phi_h \) and \( \cos 2\phi_h \) modulations observed in the azimuthal distributions
Unpolarised target SIDIS cross-section

\[
\frac{d\sigma}{dx \, dy \, d\psi \, dz \, d\phi_h \, dP_{h \perp}^2} = \frac{\alpha^2}{x y Q^2} \frac{y^2}{2 \left(1 - \varepsilon\right)} \left(1 + \frac{\gamma^2}{2x}\right) \left\{ F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2 \varepsilon(1 + \varepsilon)} \cos \phi_h F^{\cos \phi_h}_{UU} \right. \\
+ \varepsilon \cos(2\phi_h) F^{\cos 2\phi_h}_{UU} + \lambda_c \sqrt{2 \varepsilon(1 - \varepsilon)} \sin \phi_h F^{\sin \phi_h}_{LU} \right\}
\]

\[
F^{\sin \phi_h}_{LU} = \frac{2M}{Q} \mathcal{C} \left[ -\frac{\hat{h} \cdot k_T}{M_h} \left( x e H_1^1 + \frac{M_h}{M} f_1 \frac{\hat{G}^\perp}{z} \right) + \frac{\hat{h} \cdot p_T}{M} \left( x g_1^D_1 + \frac{M_h}{M} h_1^1 \frac{\hat{E}}{z} \right) \right]
\]

Cahn effect + Boer-Mulders DF

\[
F^{\cos \phi_h}_{UU} = \frac{2M}{Q} \mathcal{C} \left[ -\frac{\hat{h} \cdot k_T}{M_h} \left( x h H_1^1 + \frac{M_h}{M} f_1 \frac{\hat{D}^\perp}{z} \right) - \frac{\hat{h} \cdot p_T}{M} \left( x f_1^D_1 + \frac{M_h}{M} h_1^1 \frac{\hat{H}}{z} \right) \right]
\]

Boer-Mulders DF

\[
F^{\cos 2\phi_h}_{UU} = \mathcal{C} \left[ -\frac{2 (\hat{h} \cdot k_T) (\hat{h} \cdot p_T) - k_T \cdot p_T}{M M_h} h_1^1 H_1^1 \right]
\]

Cahn effect + Boer-Mulders x Collins FF + Cahn effect
Czech Republic, Finland, France, Germany, India, Israel, Italy, Japan, Poland, Portugal, Russia

Bielefeld, Bochum, Bonn, Burdwan, Calcutta, CERN, Dubna, Erlangen, Freiburg, Heidelberg, Helsinki, Lisbon, Mainz, Miyazaky, Moscow, Munich, Prague, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw, Yamagata

28 Institutes, ~230 physicists
luminosity: \( \sim 5 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \)
beam intensity: \( 2 \cdot 10^8 \mu^+ \text{/spill (4.8s/16.2s)} \)
beam momentum: \( 160 \text{ GeV/c} \)

longitudinally polarised muon beam
longitudinally or transversely polarised target
calorimetry
particle identification
The Spectrometer for the Muon Programme

- Trigger-hodoscopes
- ECAL & HCAL
- \( \mu \) Filter
- RICH
- SM1
- SM2
- TWO STAGE SPECTROMETER:
  \[ 0.003 < x < 0.5 \]
  \[ 10^{-3} < Q^2 < 10 \text{ (GeV/c)}^2 \]
- 6LiD Target
- Gems
- Drift chambers
- Micromegas
- Silicon
- SciFi
- MWPC
- Straws

\( 60 \text{ GeV} \mu \rightarrow \)
Data used for this analysis

- part of the 2004 ($^6$LiD target) data collected with longitudinal (L) and transverse (T) polarization
- with both target orientation configurations to cancel possible polarization effects

Event selection:
DIS events...
- $Q^2 > 1$ (GeV/c)$^2$
- $0.1 < y < 0.9$
- $W > 5$ (GeV/c$^2$)

Hadrons
- $0.2 < z < 0.85$
- $0.1 < p_T < 1.5$ (GeV/c)

Statistics of this analysis:
Mean kinematical values
unpolarised target SIDIS cross-section

to extract the asymmetries the azimuthal distributions have to be corrected by the apparatus acceptance

Final distributions fitted with the following function:

\[
N_{\text{corr}}(\phi) = N_0 + A_{\cos \phi} \cos \phi + A_{\cos 2\phi} \cos 2\phi + A_{\sin \phi} \sin \phi
\]

\[\text{(0.63}<z<0.85)\]

final azimuthal distribution

corrected azimuthal distribution (0.63<z<0.85)
The systematic error is evaluated from:

- compatibility of results with L and T target polarization (different experimental conditions, different MCs)
- comparison of results obtained using two different MCs with different settings for each data set (LEPTO default, standard COMPASS high pt; ~extreme cases)
- compatibility of results from subsamples corresponding to:
  - different periods
  - different geometrical regions for the scattered muon
Results: $\sin \phi$ modulation

\[
A_{\sin \phi} / \varepsilon_s
\]

\[
\varepsilon_s = \frac{2y\sqrt{1-y}}{1+(1-y)^2}
\]

error bars: statistical errors
bands: systematical errors

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Results: $\cos \phi$ modulation

\[ A_{\cos \phi} / \varepsilon_c = \frac{2(2 - y)\sqrt{1 - y}}{1 + (1 - y)^2} \]

COMPASS 2004 data ($^6$LiD)

\[ h^+ \]

\[ h^- \]
What was expected

\[ A_{D}^{\cos \phi} \]

\[ h^{+} \]

COMPASS 2004 $^6$LiD (part)

preliminary

M. Anselmino, M. Boglione, A. Prokudin, C. Türk
does not include Boer – Mulders contribution
results: \( \cos 2\phi \) modulation

\[ A_{\cos 2\phi} / \varepsilon_2 \]

\[ \varepsilon_2 = \frac{2(2-y)}{1+(1-y)^2} \]
Predictions

COMPASS 2004 LiD (part)

\[ \frac{A_D}{\cos^2 \phi} \]

- \[ h^+ \]
- \[ h^- \]

V. Barone, A. Prokudin, B. Q. Ma
Summary of the results

[Graph showing data points and curves for different variables, with labels and axes indicating measurements in terms of x, z, and p^T [GeV/c].]

preliminary
Summary

First results on unpolarized asymmetries:

- Results obtained separately for + and - hadrons
- $\sin \phi$ modulation compatible with 0
- $\cos \phi$ modulation up to 20% (for large $z$ or $p_T$) and the overall trend is reproduced by the predictions
- $\cos 2\phi$ modulation smaller (10% at most). Overall good agreement with the predictions
- There is a difference between $+h$ and $-h$ asymmetries on $\cos \phi / \cos 2\phi$

All in all: new input for deeper understanding of the nucleon structure
Thank You