Status Report of HERMES

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(on behalf of HERMES Collaboration)

• First measurement of transversity
• Exotic baryons: the pentaquark
• The spectrometer and the data taking

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Even they were puzzled ...
DIS + SIDIS cross section

\[ d\sigma = d\sigma_{UU} + \cos 2\phi d\sigma_{UU} + \frac{1}{Q} \cos \phi d\sigma_{UU} + \lambda \frac{1}{Q} \sin \phi d\sigma_{LU} \]

\[ + S_L \left[ \sin 2\phi d\sigma_{UL} + \frac{1}{Q} \sin \phi d\sigma_{UL} \right] + \lambda S_L \left[ d\sigma_{LL} + \frac{1}{Q} \cos \phi d\sigma_{LL} \right] \]

\[ + S_T \left[ \sin(\phi + \phi_S) d\sigma_{UT} + \sin(\phi - \phi_S) d\sigma_{UT} + \sin(3\phi - \phi_S) d\sigma_{UT} + \frac{1}{Q} \sin(2\phi - \phi_S) d\sigma_{UT} \right] \]

\[ + \lambda S_T \left[ \cos(\phi - \phi_S) d\sigma_{LT} + \frac{1}{Q} \cos(2\phi - \phi_S) d\sigma_{LT} + \sin(3\phi - \phi_S) d\sigma_{UT} \right] + ....... \]
Operator decomposition of the Correlation Function at Twist-2

\[ \Phi_{\text{Corr}}^{Tw \ 2} (x) = \frac{1}{2} \left\{ f_1(x) + S_L g_1(x) \gamma_5 + h_1(x) \gamma_5 \gamma S_T \right\} \gamma^- \]

\[ f_1 = \]
Unpolarized quark in unpolarized nucleon

\[ g_{1L} = \]
Helicity difference

Extremely well known function

Function measured by HERMES (EMC, SMC, E142-143-154-155)
Operator decomposition of the Correlation Function at Twist-2

$$\Phi_{Corr}^{Tw_2} (x) = \frac{1}{2} \left\{ f_1 (x) + S_L g_1 (x) \gamma_5 + h_1 (x) \gamma_5 \gamma S_T \right\} \gamma^-$$

$$h_1 = \begin{array}{c}
\text{Single helicity flip} \\
q_R \\
q_L
\end{array} \quad - \quad \begin{array}{c}
\text{Single helicity flip} \\
p_+
\end{array}$$

NOT ALLOWED IN E.M. INTERACTIONS
Operator decomposition of the Correlation Function at Twist-2

\[ \Phi_{TwCorr}^{2}(x) = \frac{1}{2} \{ f_1(x) \} \]

Peculiarity of transversity

Relativistic nature of quark.
In absence of relativistic effects \( h_1(x) = g_1(x) \)

\( Q^2 \) -evolution. Unlike for \( g_1^p(x) \), the gluon doesn’t mix with quark in \( h_1^p(x) \)

High sensitivity to the valence quark polarization \( q \) and \( \bar{q} \) have opposite sign.

Tensor charge: first moment of \( h_1 \).
Calculable by lattice QCD.
DIS + SIDIS cross section

\[ d\sigma = d\sigma_{UU} + \cos 2\phi d\sigma_{UU} + \frac{1}{Q} \cos \phi d\sigma_{UU} + \lambda \frac{1}{Q} \sin \phi d\sigma_{LU} \]

\[ + S_L \left[ \sin 2\phi d\sigma_{UL} + \frac{1}{Q} \sin \phi d\sigma_{UL} \right] + \lambda S_L \left[ d\sigma_{LL} + \frac{1}{Q} \cos \phi d\sigma_{LL} \right] \]

\[ + S_T \left[ \sin(\phi + \phi_S) d\sigma_{UT} + \sin(\phi - \phi_S) d\sigma_{UT} + \sin(\phi - \phi_S) d\sigma_{UT} \right] \]

Peculiarity of \( f_{1t}^\perp \)

- Chiral-even naïve T-odd DF
- Related to parton orbital momentum
- Violates naïve universality of PDF
- Different sign of \( f_{1t}^\perp \) in DY
Definition of Angles and Asymmetries

\[(\phi - \phi_S)\]
Angle of hadron relative to initial quark spin (Sivers)

\[(\phi + \phi_S)\]
Angle of hadron relative to final quark spin (Collins)

• Sivers-Collins effects can be distinguished only with transverse polarised target.

• Large asymmetry has been measured in inclusive \(\pi\) production (\(p \uparrow p \rightarrow \pi X\)) \(\rightarrow\) jet axis not known. Both mechanisms involved.
Definition of Angles and Asymmetries

\[ A_{\text{UT}}^h (\phi, \phi_S) = \frac{1}{|S_T|} \frac{N_{h\uparrow}^\uparrow(\phi, \phi_S) - N_{h\downarrow}^\downarrow(\phi, \phi_S)}{N_{h\uparrow}^\uparrow(\phi, \phi_S) + N_{h\downarrow}^\downarrow(\phi, \phi_S)} = A_{\text{UT}}^{\text{Collins}} \sin(\phi + \phi_S) + A_{\text{UT}}^{\text{Sivers}} \sin(\phi - \phi_S) \]

\[ A_{\text{UT}}^{\text{Collins}} = \left\langle \frac{p_{\perp}}{|M_h \cdot \sin(\phi + \phi_S)|} \right\rangle_{\text{UT}} = |S_T| \left( \sum_q e_{1q}^2 H_{1q}^{(1), q\rightarrow h} \right) \cdot \frac{1-y}{1-y + y^2/2} \]

\[ A_{\text{UT}}^{\text{Sivers}} = \left\langle \frac{p_{\perp}}{|M_p \cdot \sin(\phi - \phi_S)|} \right\rangle_{\text{UT}} = |S_T| \left( \sum_q e_{1q}^2 f_{1q} D_{1q}^{q\rightarrow h} \right) \]

\[ = \sum_q e_{1q}^2 H_{1q}^{(1), q\rightarrow h} \cdot \frac{1-y}{1-y + y^2/2} \]

\[ = \sum_q e_{1q}^2 f_{1q} D_{1q}^{q\rightarrow h} \]
Transverse asymmetry for $\pi^+$, $\pi^-$, $\pi^0$

Sivers Moments

- First measurement of naïve T-odd DF in DIS (orbital mom)
- Opposite sign from RHIC DY?

Collins Moments

- Much of plausible value ranges of transversity and disfavoured Collins function are excluded.
Hadron spectroscopy

• **Standard Quark Model**
  – allows hadrons as
    • mesons \((q\bar{q})\)
    • baryons \((qqq)\)
  – also allows “non-standard” or exotic hadron states
    • multiquark mesons \((qq\bar{q}\bar{q})\)
    • multiquark baryons \((qqq\bar{q}\bar{q})\)
      -> appear as baryon resonances
    • hybrid states \((\bar{q}g\) or \(qq\bar{g}\))
    • dibaryons \((qqqqqq)\)
    • glueballs
Search for Exotic Baryon States

Predictions:
Bag models (Jaffe ‘77; De Swart ‘80): 1.8-1.9 GeV
Skyrme model (Praszalowicz ‘87, Walisser ‘92): 1.3 – 1.8 GeV
Chiral-Soliton Model (Diakonov, Polyakov ‘97)

New anti-decuplet

\[ \Xi^{-}\pi^{-} \text{ or } \Sigma^{-}K^{-} \]
\[ \Xi^{0}\pi^{+} \text{ or } \Sigma^{+}\bar{K}^{0} \]

The 3 corners are exotics
Complete Particle Identification with high efficiency: 98% ($\pi$), 88% (K), 85% (p)

Direct reconstruction: detection of each decay ptc, Inv mass reconstruction (other exp. missing mass)

Excellent invariant mass systematics: ± 2 MeV
Event Reconstruction

\[ e^+ d \rightarrow K_S^0 p X \rightarrow \pi^+ \pi^- p X \]

- RICH ID: 1-15 GeV for \( \pi \), 4-9 GeV for \( p \)
- \( K_S \) decay length > 7 cm
- Distance cut: \( \pi^+ \pi^- \), \( K_S \) \( p \), \( \theta^+ \) beam
- Collinearity \( K_S \) \( \pi \pi \) < 45 mrad
- \( 485 < K_S \)-mass < 509 MeV
- No \( \Lambda \)
Particle Identification Proof

Good identification of $\Lambda$ means clear identification of $p$. Good $K_S$ identification within the kinematical cuts of this analysis.
Detector Mass calibration

ρ⁰(770)

φ(1020)

Λ*(1520)

Λ(1116)
Detector Mass calibration

$\rho^0(770)$

$\phi(1020)$

$\bar{\Lambda}(1116)$

$\Lambda^*(1520)$
Detector Mass calibration

$\rho^0(770)$

$\phi(1020)$

Masses in agreement with PDG values $\pm 2$ MeV

$\Lambda(1116)$

$\Lambda^*(1520)$
Measured Invariant Mass

Excess at 1526 MeV

Background approximated by a polynomial

Width dominated by detector resolution

\( \frac{N_s}{N_b} = 71.7/163.6 \) in 2\( \sigma \) interval

Fit Gauss+P4

\( \chi^2 = 1.4 \)

\( M = 1526 \quad \text{2(stat) 2(sys) MeV} \)

\( \sigma = 7.5 \quad 2.4(\text{stat}) \text{ MeV} \)
Monte Carlo Simulation

- Simulated resonance at 1540 MeV
- Simulated $\Gamma=2$ MeV
- Decay in $K_{sp}$
- Full detector simulation

- Recons. Mass at 1540 ± 0.3 MeV
- Recons. $\sigma=7 \pm 0.2$ MeV
Status of the Spectrometer
Status of the Spectrometer

Spectrometer fully debugged after the shutdown
Each single detector is operative!
80K DIS collected in 2003-runII with transverse polarized hydrogen target
Conclusions

🌟 First observation of non-zero Sivers effect

🌟 Sizeable Collins asymmetries measured for $\pi^0$ and $\pi^-$

🌟 A kind of brain storm is underway for model interpretation

2003: milestone from HERMES transverse asymmetries
>2004: results from HERMES, COMPASS, BELLE (RHIC-rIII, CLAS)
Conclusions

- First observation of non-zero Sivers effect
- Sizeable Collins asymmetries measured for $\pi^0$ and $\pi^-$
- A kind of brain storm is underway for model interpretation
- A narrow exotic baryon resonance has been directly reconstructed
- Most precise determination of the mass $M=1526 \pm 2 \pm 2$ MeV, $\sigma=7.5 \pm 2.4$ MeV
- Background description and Monte Carlo simulation

Taking data for physics