Electroproduction of single π^+ mesons on transversely polarised protons

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DESY

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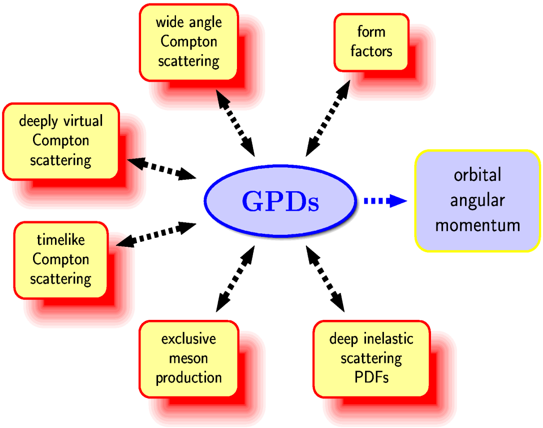
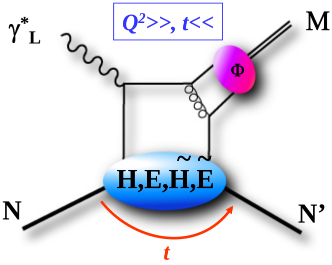
- Generalised Parton Distributions (GPDs)
- Exclusive π^+ production at HERMES
  - Analysis framework
  - Preliminary study of transverse spin asymmetry

Generalised parton distributions



- how to access GPDs?



- exclusive production of

$$\begin{array}{lcl} \gamma & \to & H, E, \widetilde{H}, \widetilde{E} \\ \rho, \omega, \phi & \to & H, E \\ \pi, \eta & \to & \widetilde{H}, \widetilde{E} \end{array}$$

$\Rightarrow$ Ji's relation [X.Ji, PRL78(1997)610]

$$J_q^3 = \lim_{t \to 0} \frac{1}{2} \int_{-1}^{1} dx\, x \,[H_q + E_q]$$

- tool to quantify aspects of hadron structure in QCD in terms of quarks and gluons [PRep388(2003)41]
- transverse spatial distribution of partons
- orbital angular momentum inside the nucleon

Framework for studying $ep \to e' n \pi^+$ and $\gamma^* p \to n\pi^+$

[M.Diehl, S.Sapeta; EPJC41(2005)515]

e'
l', E'

e
l, E

θ

γ^* $q = (l - l')$
$\nu = (E - E')$

polarisation vector ϵ_m, ϵ_n

$m, n = 0 : \gamma^*_L$

$m, n = -1, +1 : \gamma^*_T$

$\varepsilon = \frac{\Gamma_L}{\Gamma_T} = \frac{1}{1 + 2\frac{\nu^2 + Q^2}{4EE' - Q^2}}$

π^+
p_{π^+},
E_{π^+}

?

kinematic variables

$Q^2 = -q^2$

$x_B = \frac{Q^2}{2M_p \nu}$

$t = (q - p_{\pi^+})^2$
$\quad = (P - P')^2$

polarised photoabsorption
cross sections and interference terms

$\sigma_{mn}^{ij\ \gamma^* p \to n\pi^+}(x, Q^2, t) \propto \sum_{spins} (\mathcal{A}^i_m)^* \mathcal{A}^j_n$

$\sigma_{mn} = \sum_{ij} \rho_{ji} \sigma^{ij}_{mn} \propto \epsilon^{\mu *}_m W_{\mu\nu} \epsilon^\nu_n \propto L^{\nu\mu} W_{\mu\nu}$

hadronic tensor

$W_{\mu\nu} = \sum_{ij} \rho_{ji}\, \delta^{(4)} \sum_{spins} \langle p(i) | J_\mu(0) | n\pi^+ \rangle \langle n\pi^+ | J_\nu(0) | p(j) \rangle$

?

p
P, M_p

n
P', E'_n
$M_X = M_n$

target spin density matrix

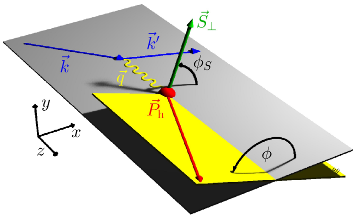
$\rho_{ji} = \frac{1}{2}(\delta_{ji} + \vec{S} \cdot \vec{\sigma}_{ji})$

$i, j = +\frac{1}{2}, -\frac{1}{2}$

$\sigma^{ep \to e' n\pi^+} \propto L^{\nu\mu} W_{\mu\nu} \frac{d^3 l'}{2E'} \frac{d^3 p_{\pi^+}}{2E_{\pi^+}} \frac{d^3 P'}{2E'_n}$

Cross section for $ep^{\uparrow} \to e' n\pi^{+}$: $[\sigma_{mn}^{ij\ \gamma^* p \to n\pi^+}] \times [f(\phi, \phi_S)]$

$$\frac{d\sigma(x, Q^2, t, \phi, \phi_S)}{dx\, dQ^2\, dt\, d\phi\, d\phi_S} = d\sigma_{UU} + \mathcal{P}_T\, d\sigma_{UT}$$



$$\mathcal{P}_T = \frac{P_T}{\sqrt{1 - \sin^2\theta \sin^2\phi_S}}$$

$$\begin{aligned} d\sigma_{UU}(\phi) &= \frac{1}{2}(\sigma_{++}^{++} + \sigma_{++}^{--}) + \varepsilon\sigma_{00}^{++} \\ &\quad - \varepsilon\cos(2\phi)\mathrm{Re}\,\sigma_{+-}^{++} \\ &\quad - \sqrt{\varepsilon(1+\varepsilon)}\cos\phi\,\mathrm{Re}\,(\sigma_{+0}^{++} + \sigma_{+0}^{--}) \end{aligned}$$

$$\begin{aligned} d\sigma_{UT}(\phi, \phi_S) &= A_{UT}^{\sin(\phi-\phi_S)}\sin(\phi-\phi_S) + A_{UT}^{\sin(\phi+\phi_S)}\sin(\phi+\phi_S) \\ &\quad + A_{UT}^{\sin\phi_S}\sin\phi_S + A_{UT}^{\sin(2\phi-\phi_S)}\sin(2\phi-\phi_S) \\ &\quad + A_{UT}^{\sin(3\phi-\phi_S)}\sin(3\phi-\phi_S) + A_{UT}^{\sin(2\phi+\phi_S)}\sin(2\phi+\phi_S) \end{aligned}$$

Fourier amplitude:

$$A_{UT}^{\sin(\phi-\phi_S)} = \cos\theta\,\mathrm{Im}\,(\sigma_{++}^{+-} + \varepsilon\sigma_{00}^{+-}) + \frac{1}{2}\sin\theta\sqrt{\varepsilon(1+\varepsilon)}\mathrm{Im}\,(\sigma_{+0}^{++} - \sigma_{+0}^{--})$$

QCD factorisation theorem for $\gamma_L^* p \to n\pi^+$

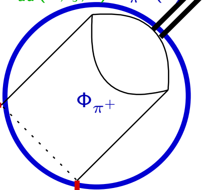
! valid in the limit of $Q^2 \gg$ at x_B, t fixed

! no precocious scaling at $Q^2 \geq 1\,\mathrm{GeV}^2$

e, e', θ, γ_L^*, π^+, E_{π^+}

$$\mathcal{A}^{\gamma_L^* p \to n\pi^+}(\xi, t) \equiv \langle \pi^+(p_{\pi^+}) n(P') | J_{\mathrm{em}} \cdot \epsilon_0 | p(P) \rangle$$

$$= \frac{1}{Q} \int_{-1}^{1} dx \int_0^1 dz \; T_{ud}(x, \xi, z)\, F_{ud}(x, \xi, t)\, \Phi_{\pi^+}(z)$$



kinematic variables

Q^2, x_B, t

$z = \frac{E_{\pi^+}}{\nu}$

$x \approx x_B$

$\xi = \frac{x}{2-x}$

$x + \xi$, $x - \xi$

hard scattering kernel

$$T_{ud} \propto \frac{e_u}{z\left(x + \frac{\xi}{2}\right) - i0} + \frac{e_d}{(1-z)\left(x - \frac{\xi}{2}\right) + i0}$$

pion distribution amplitude

asymptotic form $\quad \Phi_{as}(z) = \frac{3}{4}(1 - z^2)$

generalised parton distributions

$$F_{ud} = \bar{u}_n(P') \left[\gamma^+ \gamma_5 \widetilde{H}_{u-d}(x, \xi, t) + \frac{\gamma_5 \Delta^+}{2M_p} \widetilde{E}_{u-d}(x, \xi, t) \right] u_p(P)$$

p, P — n, P'

$$\sigma_{00}^{+-} \propto \sqrt{1 - \xi^2} \frac{\sqrt{t_0 - t}}{M_p} \xi \, \mathrm{Im}\left(\widetilde{\mathcal{E}}^* \widetilde{\mathcal{H}} \right)$$

Theoretical prediction for $A_{UT}^{\sin(\phi-\phi_S)}$

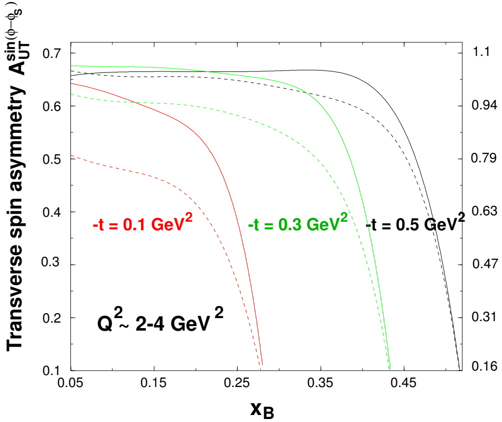
$$A_{UT}^{\sin(\phi-\phi_S)} \propto \frac{\mathrm{Im}\,(\widetilde{\mathcal{E}}^*\widetilde{\mathcal{H}})}{|\widetilde{\mathcal{H}}|^2 - t|\widetilde{\mathcal{E}}|^2 - \mathrm{Re}\,(\widetilde{\mathcal{E}}^*\widetilde{\mathcal{H}})}$$

$\widetilde{H}$, $\widetilde{E}$: chiral quark-soliton model of GPDs

asymptotic and Chernyak-Zhitnitsky DA

[**Frankfurt et al.; PRD60(1999)014010**]

[**Polyakov, Stratmann; hep-ph/0609045**]

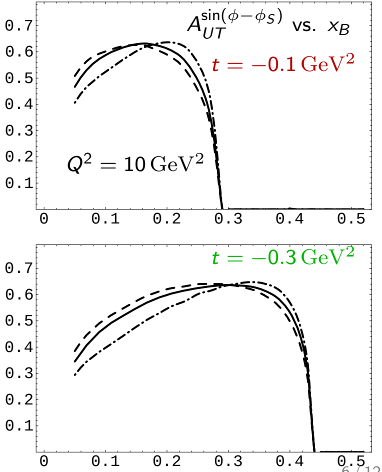


$\widetilde{H}$: double distribution ansatz

$\widetilde{E}$: pion pole-dominated ansatz

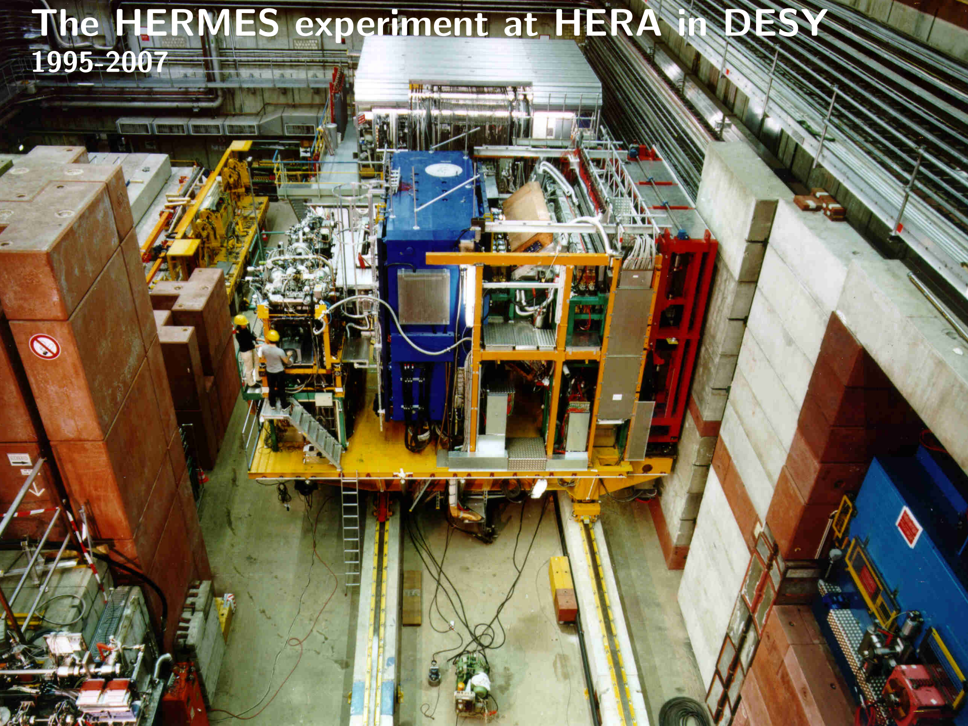
small LO and NLO corrections

[**Belitsky, Müller; PLB513(2001)349**]

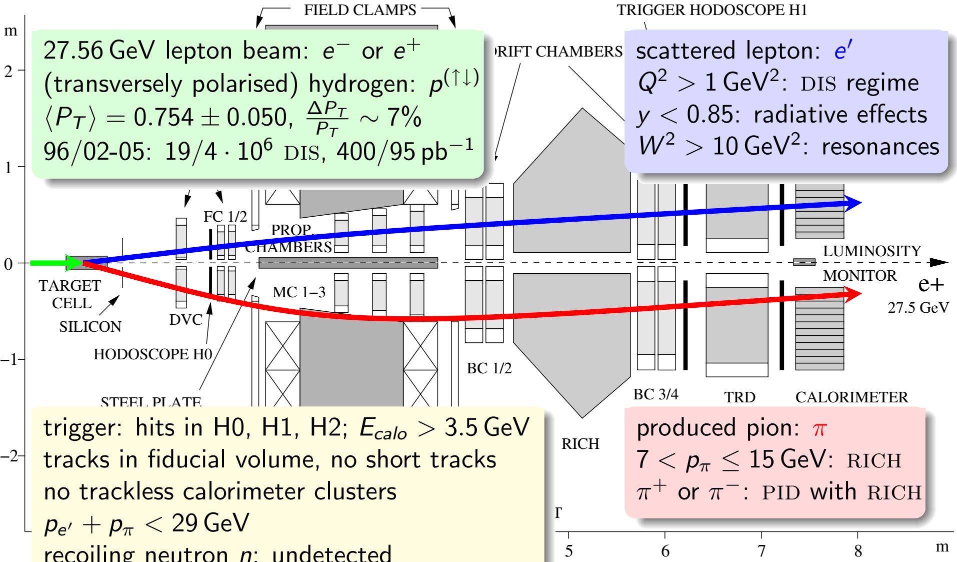


The HERMES experiment at HERA in DESY

1995-2007



Exclusive-event selection for $ep \rightarrow e' n \pi^+$



27.56 GeV lepton beam: e^- or e^+
(transversely polarised) hydrogen: $p^{(\uparrow\downarrow)}$
$\langle P_T \rangle = 0.754 \pm 0.050$, $\frac{\Delta P_T}{P_T} \sim 7\%$
96/02-05: $19/4 \cdot 10^6$ DIS, $400/95\,\text{pb}^{-1}$

scattered lepton: e'
$Q^2 > 1\,\text{GeV}^2$: DIS regime
$y < 0.85$: radiative effects
$W^2 > 10\,\text{GeV}^2$: resonances

trigger: hits in H0, H1, H2; $E_{calo} > 3.5\,\text{GeV}$
tracks in fiducial volume, no short tracks
no trackless calorimeter clusters
$p_{e'} + p_\pi < 29\,\text{GeV}$
recoiling neutron n: undetected
$\Rightarrow M_X^2 = M_n^2 = 0.88\,\text{GeV}^2$

produced pion: π
$7 < p_\pi \leq 15\,\text{GeV}$: RICH
π^+ or π^-: PID with RICH

Exclusivity for $ep \to e'n\pi^+$ at HERMES

- no recoil detection

$\Rightarrow$ missing mass technique:

$M_X^2 = (q_e + q_p - q_{e'} - q_{\pi^+})^2$

for $(N_{\pi^+} - N_{\pi^-})^{\text{data}}$

for $(N_{\pi^+} - N_{\pi^-})^{\text{PYTHIA}}$

$\Rightarrow$ $N_{\pi^+}^{excl}$ obtained as a double difference

PYTHIA Monte Carlo generator:
-no nucl.res. and excl.π^+ processes
-tuned to HERMES SIDIS and VM prod.

- kinematic requirements

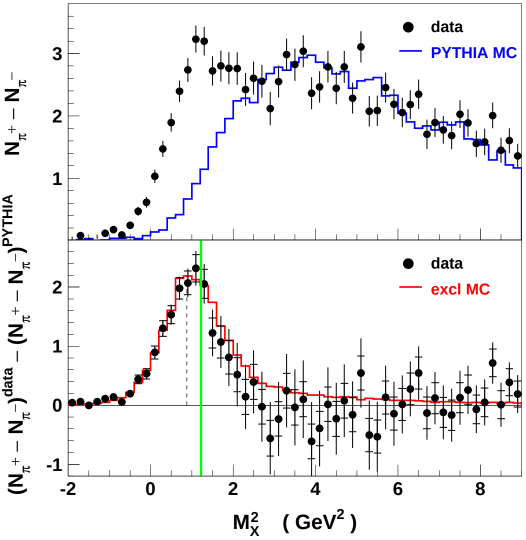
$Q^2 > 1\,\text{GeV}^2$

$W^2 > 10\,\text{GeV}^2$

$y < 0.85$

$p_\pi > 7\,\text{GeV}$

- $M_X^2 < 1.2\,\text{GeV}^2$
- $t' = t - t_0$



Exclusive peak clearly centred at the neutron mass

Mean and width in agreement with exclusive MC

Extraction of the six Fourier amplitudes of $d\sigma_{UT}$

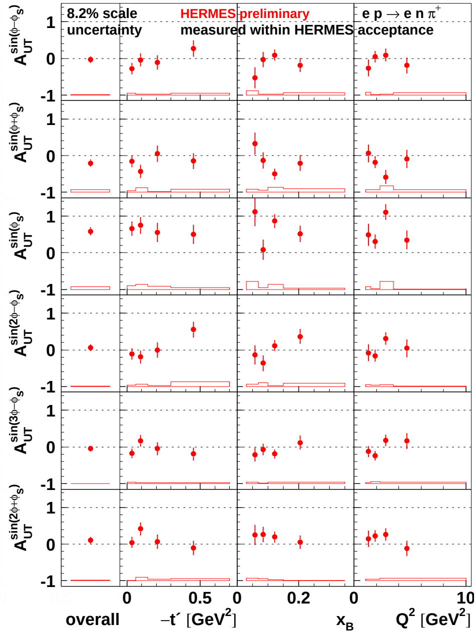
- unbinned maximum likelihood fit (UML) [**Jeroen Dreschler, July 2006**]
- probability density function

$$f_{\pm}(\phi, \phi_S; \theta_k) = 1 \pm \mathcal{P}_T \sum_{k=1}^{6} \theta_k \sin(\mu\phi + \lambda\phi_S)_k$$

- $\theta_k = A_{UT,meas}^{\sin(\mu\phi+\lambda\phi_S)_k}$ maximising the likelihood function

$$L(\theta_k) = \prod_{i=1}^{N^+} f_+(\phi^i, \phi_S^i; \theta_k) \prod_{j=1}^{N^-} f_-(\phi^j, \phi_S^j; \theta_k)$$

Results for the kinematic dependences of A_{UT}



$\langle -t' \rangle = 0.18\,\mathrm{GeV}^2,\ \langle x_B \rangle = 0.13,\ \langle Q^2 \rangle = 2.38\,\mathrm{GeV}^2$

$$A_{UT}^{\sin(\phi-\phi_S)} \propto \cos\theta\,\mathrm{Im}\,(\sigma_{++}^{+-} + \varepsilon\sigma_{00}^{+-}) + \frac{1}{2}\sin\theta\sqrt{\varepsilon(1+\varepsilon)}\mathrm{Im}\,(\sigma_{+0}^{++} - \sigma_{+0}^{--})$$

$$A_{UT}^{\sin(\phi+\phi_S)} \propto \frac{1}{2}\cos\theta\,\varepsilon\,\mathrm{Im}\,\sigma_{+-}^{+-} + \frac{1}{2}\sin\theta\sqrt{\varepsilon(1+\varepsilon)}\mathrm{Im}\,(\sigma_{+0}^{++} - \sigma_{+0}^{--})$$

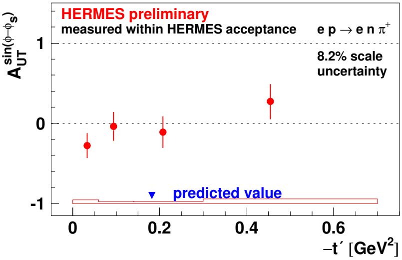
$$A_{UT}^{\sin\phi_S} \propto \cos\theta\sqrt{\varepsilon(1+\varepsilon)}\mathrm{Im}\,\sigma_{+0}^{+-}$$

$$A_{UT}^{\sin(2\phi-\phi_S)} \propto \cos\theta\sqrt{\varepsilon(1+\varepsilon)}\mathrm{Im}\,\sigma_{+0}^{-+} + \frac{1}{2}\sin\theta\,\varepsilon\mathrm{Im}\,\sigma_{+-}^{++}$$

$$A_{UT}^{\sin(3\phi-\phi_S} \propto \frac{1}{2}\cos\theta\,\varepsilon\,\mathrm{Im}\,\sigma_{+-}^{-+}$$

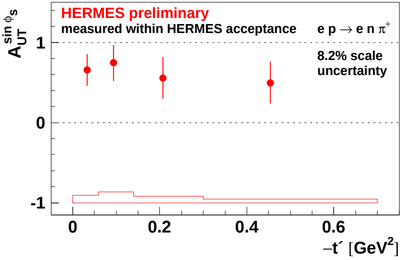
$$A_{UT}^{\sin(2\phi+\phi_S)} \propto \frac{1}{2}\sin\theta\,\varepsilon\,\mathrm{Im}\,\sigma_{+-}^{++}$$

The $-t'$ dependence of two Fourier amplitudes



- $A_{UT}^{\sin(\phi-\phi_S)}$: a sign change or consistency with zero vs. $-t'$
- consistent with dominance of $\widetilde{E} \gg \widetilde{H}$

$$A_{UT}^{\sin(\phi-\phi_S)} \propto -\frac{\sqrt{-t'}}{M_p} \frac{\mathrm{Im}(\widetilde{\mathcal{E}}^* \widetilde{\mathcal{H}})}{|\widetilde{\mathcal{E}}|^2}$$



- $A_{UT}^{\sin\phi_S}$: unexpectedly large
- does not vanish at $-t' = 0$

$$A_{UT}^{\sin\phi_S} \propto \sigma_{+0}^{+-}$$

- sizeable interference between contributions from γ_L^* and γ_T^*

Summary and outlook

Summary

- This is the first attempt to measure the asymmetry A_{UT} in exclusive π^+ production on transversely polarised protons.

Outlook

- Study of the influence of the $cos\phi$ and $cos(2\phi)$ contribution on the extracted amplitudes:

$$A_{UT}(\phi, \phi_S) = \frac{1}{|\mathcal{P}_T|} \frac{d\sigma(\phi, \phi_S) - d\sigma(\phi, \phi_S + \pi)}{d\sigma(\phi, \phi_S) + d\sigma(\phi, \phi_S + \pi)}$$

$$d\sigma = 1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos(2\phi)} \cos(2\phi) + \mathcal{P}_T [A_{UT}^{\sin(\phi-\phi_S)} \sin(\phi - \phi_S)$$
$$+ A_{UT}^{\sin(\phi+\phi_S)} \sin(\phi + \phi_S) + A_{UT}^{\sin\phi_S} \sin\phi_S + A_{UT}^{\sin(2\phi-\phi_S)} \sin(2\phi - \phi_S)$$
$$+ A_{UT}^{\sin(3\phi-\phi_S)} \sin(3\phi - \phi_S) + A_{UT}^{\sin(2\phi+\phi_S)} \sin(2\phi + \phi_S)]$$

- Estimate of the systematic uncertainty due to acceptance, resolution smearing, misalignment, and kinematic bin width.