Exclusive π^+ cross sections and asymmetry at HERMES

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on behalf of the HERMES Collaboration

DESY

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- Generalised Parton Distributions
- Exclusive π^+ production at HERMES
  - Spin-averaged cross section
  - Transverse spin asymmetry

Generalised Parton Distributions

- in the limit of $Q^2 \gg$ at x_B, t fixed, $\gamma^* p$ amplitude factorises

- contributions to the cross section

γ_L^*	leading-twist, QCD factorisation theorem
γ_L^*-γ_T^*	$\frac{1}{Q}$ suppressed
γ_T^*	$\frac{1}{Q^2}$ suppressed

- for exclusive π^+ production $\gamma^* p \to \pi^+ n$

$$\sigma_L \propto (1-\xi^2)|\widetilde{H}|^2 - \xi^2\, t|\widetilde{E}|^2 - \xi^2 \mathrm{Re}(\widetilde{E}^* \widetilde{H})$$

ξ: skewness

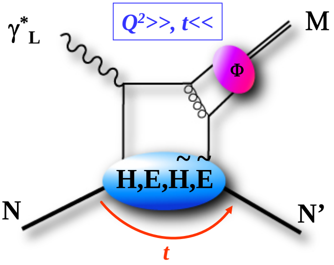
- relation to PDFs and FFs

$\widetilde{H}(x,0,0) = \Delta q(x)$ for $t \to 0$

$\int_{-1}^{1} dx\, \widetilde{H}(x,\xi,t) = g_A(t)$

$\int_{-1}^{1} dx\, \widetilde{E}(x,\xi,t) = g_P(t)$

- how to access GPDs?



- exclusive production of

γ	$\to$	$H, E, \widetilde{H}, \widetilde{E}$
ρ, ω, ϕ	$\to$	H, E
π, η	$\to$	$\widetilde{H}, \widetilde{E}$

! no precocious scaling at $Q^2 \geq 1\,\mathrm{GeV}^2$ for hard exclusive meson production

Exclusivity for $ep \rightarrow e'\pi^+ n$ 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 $(N_{\pi^+} - N_{\pi^-})^{\text{PYTHIA}}$

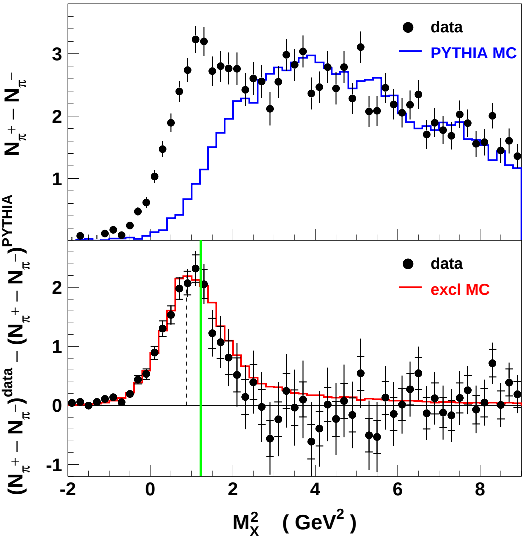
$\Rightarrow$ $N_{\pi^+}^{excl}$ obtained as a double difference

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

Cross section determination

- $ep \leftrightarrow \gamma^* p$: $\frac{d\sigma^{\gamma^* p \to \pi^+ n}(x_B, Q^2, t', \phi)}{dt'\, d\phi} = \frac{1}{\Gamma_V(x_B, Q^2)} \frac{d\sigma^{ep \to e' \pi^+ n}(x_B, Q^2, t', \phi)}{dx_B\, dQ^2\, dt'\, d\phi}$
- Hand convention: $\Gamma_V(x_B, Q^2) = \frac{\alpha}{8\pi} \frac{1}{M_p^2 E^2} \frac{Q^2}{x_B^3} \frac{1-x_B}{1-\epsilon}$, ϵ: γ^* polarisation parameter

$$\frac{d\sigma^{\gamma^* p \to \pi^+ n}(x_B, Q^2, t')}{dt'} = \frac{1}{\Gamma_V(\langle x_B \rangle, \langle Q^2 \rangle)} \frac{N_{\pi^+}^{excl}}{\mathcal{L}\, \Delta x_B\, \Delta Q^2\, \Delta t'\, \kappa(x_B, Q^2)\, \eta}$$

$N_{\pi^+}^{excl}$	π^+ events after background subtr.	κ	detection probability
Γ_V	virtual-photon flux factor	η	radiative correction factor
$\mathcal{L}$	integrated luminosity	Δ	bin size

For the data sample 1996-2005:

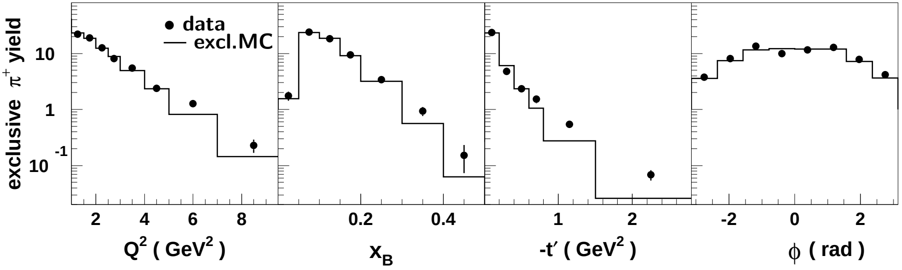
- $N_{\pi^+}^{excl} = 4510$ events, $[2-20\%]_{syst}$ $\mathcal{L} = 0.4\,\mathrm{fb}^{-1}$ $[5\%]_{syst}$
- kinematic range

$1 < Q^2 < 11\,\mathrm{GeV}^2 \quad \rightarrow \quad$ four Q^2 bins

$0.02 < x_B < 0.55 \quad \rightarrow \quad$ three x_B bins

$0 < -t' < 3\,\mathrm{GeV}^2 \quad \rightarrow \quad$ six $-t'$ bins

Exclusive distributions: Monte Carlo comparison



exclusive MC (GPD models):

- • Vanderhaeghen,Guichon,Guidal PRD60(1999)094017

  or
- ○ Mankiewicz,Piller,Radyushkin EPJC10(1999)307

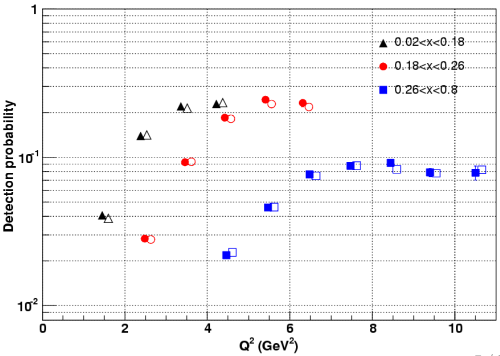
$$\kappa = \frac{N^{rec}_{\pi^+}}{N^{gen}_{\pi^+}} = [0.04 - 0.28]$$

acc. [0.1-0.7]
cuts [0.4-0.5]

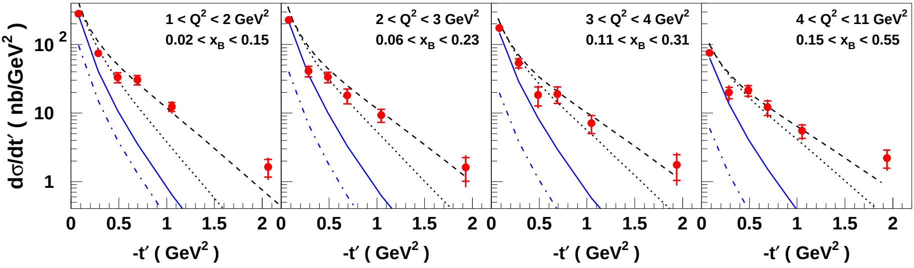
κ: probability to detect e' and π^+ (generated in 4π) in the HERMES spectrometer; $[\sim 15\%]_{syst}$

$$\eta = \frac{\sigma^{obs}}{\sigma^{Born}} = 0.77, \text{ at } M_X^2 < 1.2\,\mathrm{GeV}^2$$

-dominated by vertex&loop corrections
-independent of kinematics

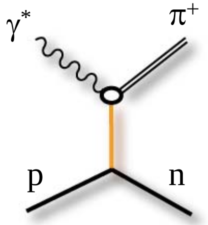


Results: the differential cross sections PLB659(2008)486



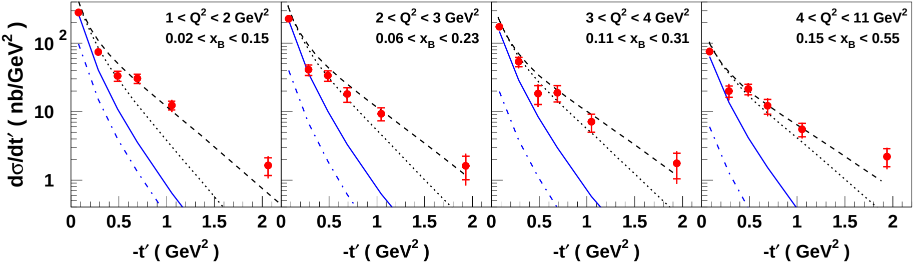
Regge model J.M.Laget PRD70(2004)054023	— — —	$\frac{d\sigma}{dt}$
	......	$\frac{d\sigma_L}{dt}$

- π^+ production described by exchange of π and ρ Regge trajectories
- Q^2- and $-t'$-dependent FFs for $\pi\pi\gamma$ and $\pi\rho\gamma$
- σ_T predicted to be 15-25% of σ (about 6% at low $-t'$)



good description of the magnitude, and $-t'$, Q^2 dependences of the data

Comparison with theory PLB659(2008)486



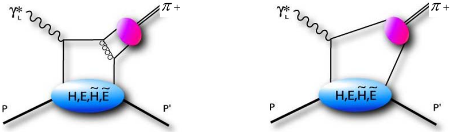
GPD model for $\frac{d\sigma_L}{dt'}$ — · — leading-order calculations

——— with power corrections

Vanderhaeghen,Guichon,Guidal PRD60(1999)094017

- $\widetilde{E}$ dominated by pion-pole, F_π
- $\widetilde{H}$ neglected
- Regge-inspired t dependence for $\widetilde{E}$
- power corrections due to intrinsic k_T

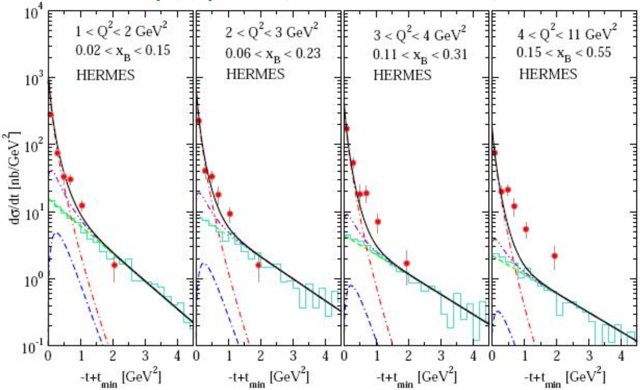
and soft-overlap contribution



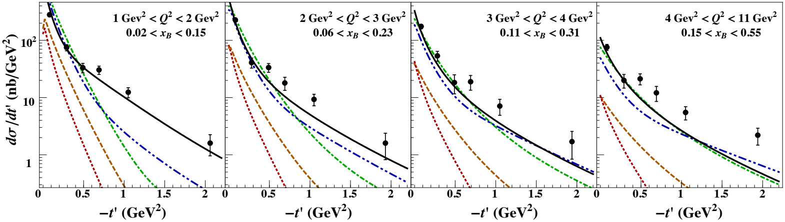
fair agreement with data at lower $-t'$ if power corrections are included

Comparison with recent theoretical models

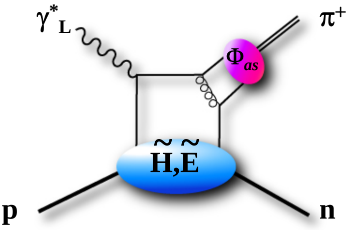
M. Kaskulov, U. Mosel arXiv:0904.4442 [hep-ph]: two-component model, soft and hard partonic reactions



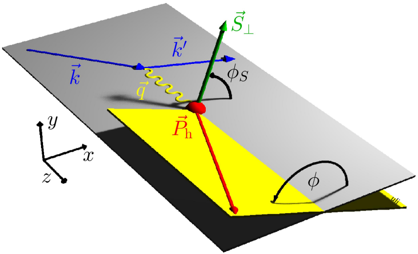
Ch. Bechler and D. Müller arXiv:0906.2571 [hep-ph]: Regge inspired arguments and counting rules



Transverse spin asymmetry



unp. cross section	$\sigma_{UU} \propto \lvert\widetilde{H}\rvert^2 - t\lvert\widetilde{E}\rvert^2 - \mathrm{Re}(\widetilde{E^*}\widetilde{H})$
spin asymmetry	$\propto \mathrm{Im}(\widetilde{E}^*\widetilde{H})/\sigma_{UU}$
	higher order corrections cancel
	scaling reached at lower Q^2



For transversely polarised target:
$\sigma_{UT} \propto \lvert\vec{S}_T\rvert \sin(\phi - \phi_S)\, \mathrm{Im}(\widetilde{E}^*\widetilde{H}) + \dots$

$\Rightarrow$ extract $A_{UT,\ell}^{\sin(\phi-\phi_S)}$ plus additional five sine amplitudes,
ℓ: $\vec{S}_T \to \vec{P}_T$ with respect to $\vec{k}$

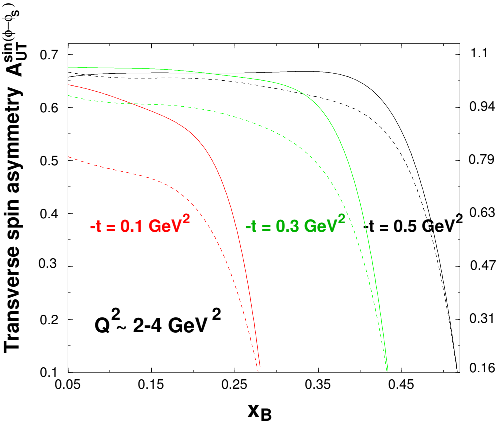
M. Diehl, S. Sapeta EPJC41(2005)515

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

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

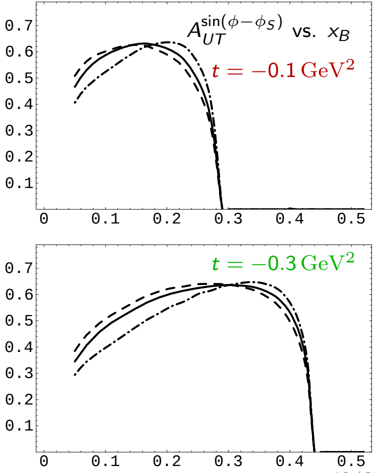
$\widetilde{H}$, $\widetilde{E}$: chiral quark-soliton model of GPDs
asymptotic and Chernyak-Zhitnitsky DA

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



$\widetilde{H}$: double distribution ansatz
$\widetilde{E}$: pion pole-dominated ansatz
small LO and NLO corrections

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

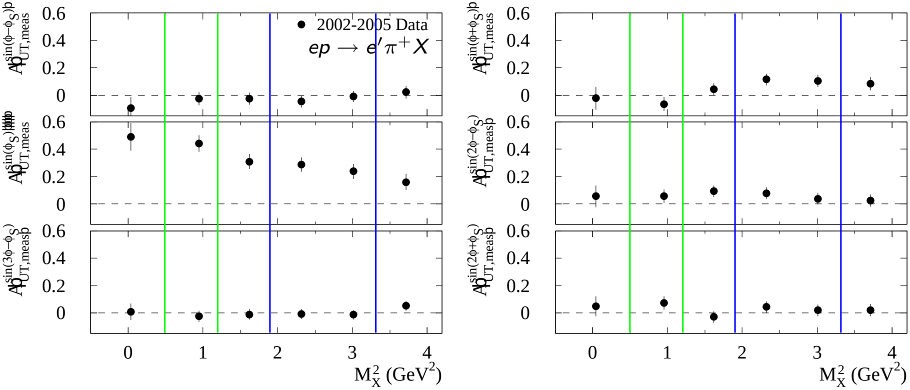


Measured asymmetry $A_{UT,\ell}$ vs. squared missing mass

measured = exclusive signal $f_{\pi^+}^{excl} = \frac{N_{\pi^+}^{excl}}{N_{\pi^+}^{data}} \approx \frac{1}{2}$ plus background $1 - f_{\pi^+}^{excl}$

A_{UT} in $M_X^2 = [0.5 - 1.2]\,\mathrm{GeV}^2$

$A_{UT,bg}$ in $M_X^2 = [1.9 - 3.3]\,\mathrm{GeV}^2$



- background correction → extract exclusive asymmetry

$$A_{UT,\ell}^{excl} \equiv A_{UT,bg.corr} = \frac{1}{f_{\pi^+}^{excl}} A_{UT} - \frac{1 - f_{\pi^+}^{excl}}{f_{\pi^+}^{excl}} A_{UT,bg}$$

Kinematic dependences of $A_{UT,\ell}^{excl}$

$ep \to e'\pi^+ n$

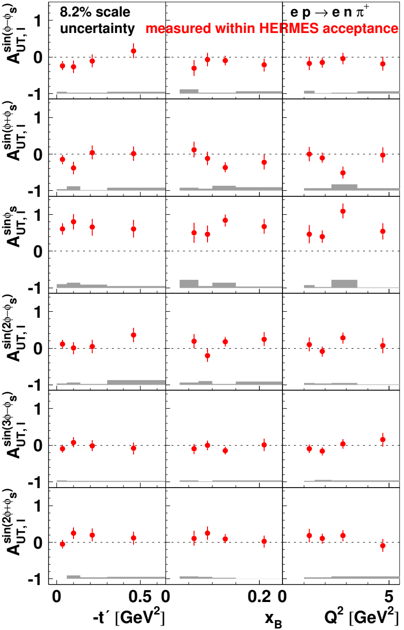
$-t \equiv -t'$

$\langle -t\rangle = 0.182\,\mathrm{GeV}^2$
$\langle x\rangle = 0.126$
$\langle Q^2\rangle = 2.38\,\mathrm{GeV}^2$

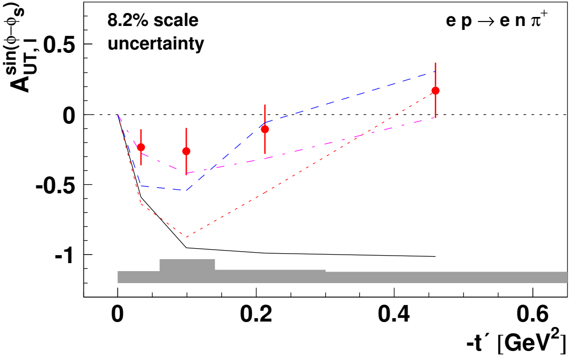
helicity amplitude
$\mathcal{M}_{\pi^+ n,\gamma^* p}$

$A_{UT,\ell}^{\sin(\phi-\phi_S)} \propto \mathcal{M}_{0+,0+}$

$A_{UT,\ell}^{\sin\phi_S} \propto \mathcal{M}_{0-,++}$

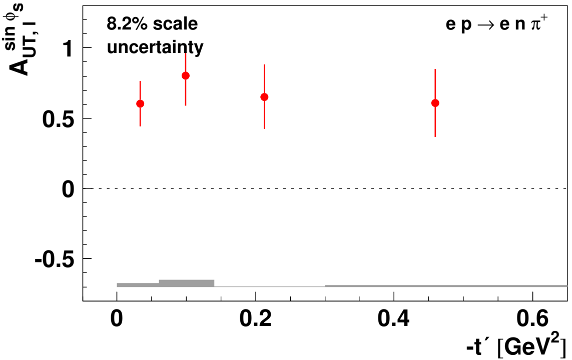


Results: leading asymmetry amplitude $A_{UT,\ell}^{\sin(\phi-\phi_S)}$



S. Goloskokov and P. Kroll arXiv:0906.0460 [hep-ph]	– – –	handbag/modified perturbative approach
Ch. Bechler and D. Müller arXiv:0906.2571 [hep-ph]	– · –	"Regge-ized" model for $\widetilde{\mathcal{E}}$
	. . . . . .	GPD model for $\widetilde{\mathcal{E}}$
	———	pion-pole dominance for $\widetilde{\mathcal{E}}$

Results: subleading asymmetry amplitude $A_{UT,\ell}^{\sin\phi_S}$



- $A_{UT,\ell}^{\sin\phi_S}$ expected to be suppressed by $1/Q$ compared to $A_{UT,\ell}^{\sin(\phi-\phi_S)}$
- arXiv:0906.0460 [hep-ph]: data require
  - quark helicity-flip twist-3 GPD H_T
  - twist-3 pion wave function ϕ_π

$A_{UT,\ell}^{\sin\phi_S}$ found to be surprisingly large

Summary and conclusions

Exclusive π^+ cross section

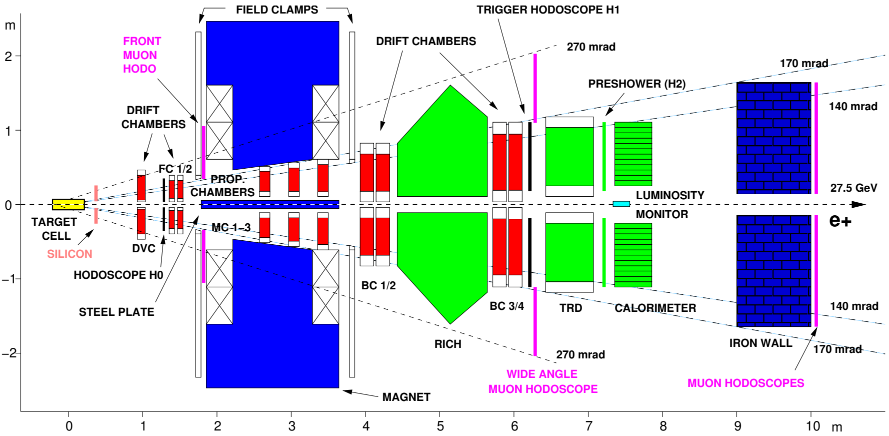
- results from recent paper PLB 659 (2008) 486
- GPD model in fair agreement with data at low values of $-t$;
  data support the order of magnitude of power corrections
- Regge model provides good description of the kinematic dependences

Transverse spin asymmetry

- results ready for publication DESY 09-106, arXiv:0907.2596 [hep-ex]
- first experimental attempt to study this observable
- larger statistics required for more detailed studies of the kinematic dependences, for example @ JLab

Backup slides

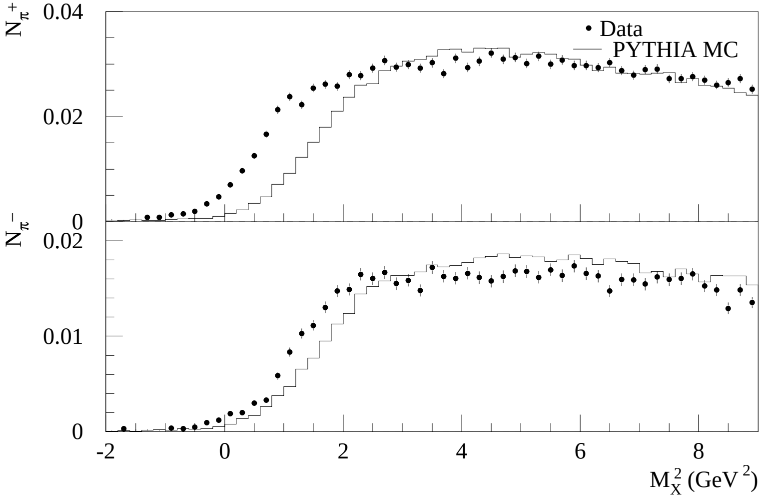
The HERMES experiment at DESY



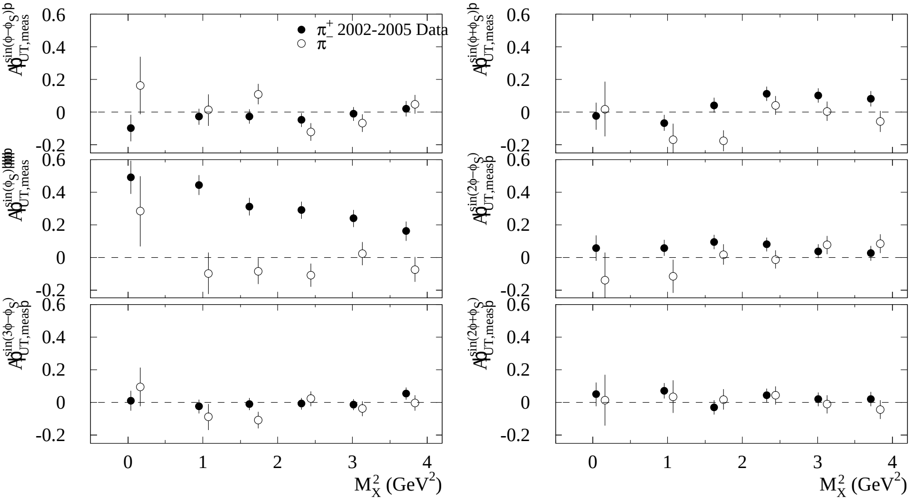
- internal (polarised) hydrogen fixed target, 27.6 GeV (polarised) $e^{\pm}$ beam
- tracking system: drift chambers $\Delta\Theta = 0.6\,\mathrm{mrad}$, vertical dipole magnet $1.5\,\mathrm{T\,m}$, $\frac{\Delta p}{p} = 0.5\%$
- lepton-hadron separation: $> 99\%$ efficiency; particle identification: π, $p_{\pi} = 1\text{-}15\,\mathrm{GeV}$

Data-to-PYTHIA comparison of yields

- PYTHIA processes: 95,99 (DIS); 91,92,94 (VMD)

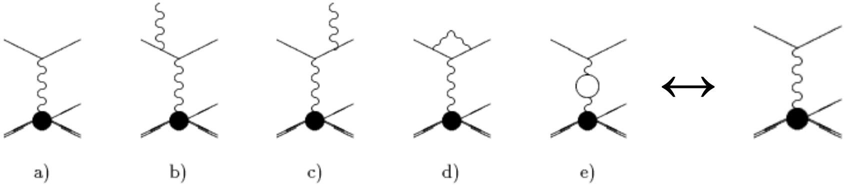


Raw amplitudes vs. M_X^2 for π^+ and π^-



Radiative effects for exclusive π^+ production

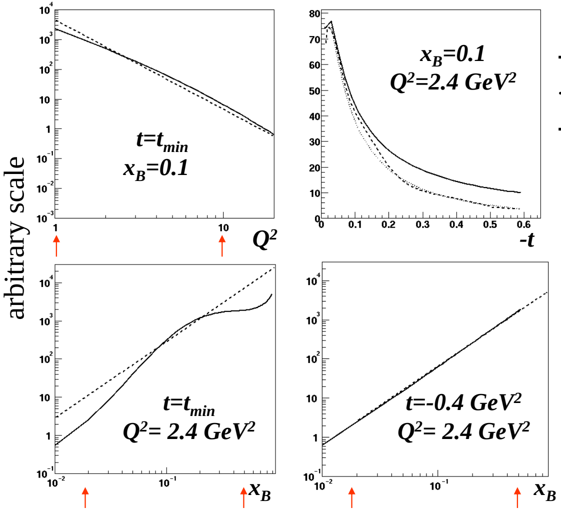
$$\sigma^{obs}(x_B, Q^2) \longleftrightarrow \sigma^{Born}(x_B, Q^2)$$



- correct the measured cross section by $\eta = \dfrac{\sigma^{obs}}{\sigma^{Born}} = 0.77$
- RADGEN adapted to exclusive processes with VGG GPD model as input

  Akushevich, Böttcher, Ryckbosch hep-ph/9906408, A. Ilyichev
- little variation of η ($< 3\%$) as a function of x_B, Q^2, or t' for $M_X^2 < 1.2\,\mathrm{GeV}^2$
- compute at Born level $\langle x_B \rangle$, $\langle Q^2 \rangle$, $\langle t' \rangle$, $\Gamma_V(\langle x_B \rangle, \langle Q^2 \rangle)$
- corrections applied for smearing $12/15\%(< 25/35\%)$, bin size $\delta = 1.08(< 1.2)$

GPD models



— VGG model

...... Tuned VGG ($\tilde{E}$*e^t)

- - Piller model

↑↑ Hermes kinematics

→ different dependence for VGG and Piller

- ▶ VGG model: Vanderhaeghen, Guichon, Guidal PRD 60 (1999) 094017
- ▶ Piller model: Mankiewicz, Piller, Radyushkin EPJC 10 (1999) 307

Transverse spin asymmetry

Hard exclusive pion electroproduction

$$ep^{\uparrow} \longrightarrow en\pi^{+}$$

Single-spin azimuthal asymmetry

$$A_{UT,\ell}(\phi,\phi_S) = \frac{1}{|P_T|}\frac{\mathrm{d}\sigma^{\uparrow}(\phi,\phi_S) - \mathrm{d}\sigma^{\downarrow}(\phi,\phi_S)}{\mathrm{d}\sigma^{\uparrow}(\phi,\phi_S) + \mathrm{d}\sigma^{\downarrow}(\phi,\phi_S)} = \frac{d\sigma_{UT,\ell}}{d\sigma_{UU}}$$

$$\mathrm{d}\sigma_{UU} = 1 + 2\langle\cos\phi\rangle\cos\phi + 2\langle\cos(2\phi)\rangle\cos(2\phi)$$

$$\begin{aligned}\mathrm{d}\sigma_{UT,\ell} = {} & 2\langle\sin(\phi-\phi_S)\rangle\sin(\phi-\phi_S) + 2\langle\sin(\phi+\phi_S)\rangle\sin(\phi+\phi_S) \\ & + 2\langle\sin\phi_S\rangle\sin\phi_S + 2\langle\sin(2\phi-\phi_S)\rangle\sin(2\phi-\phi_S) \\ & + 2\langle\sin(3\phi-\phi_S)\rangle\sin(3\phi-\phi_S) + 2\langle\sin(2\phi+\phi_S)\rangle\sin(2\phi+\phi_S)\end{aligned}$$

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

$$\Longrightarrow A_{UT,\ell}^{\sin(\phi-\phi_S)} = \frac{2\langle\sin(\phi-\phi_S)\rangle}{\mathrm{d}\sigma_{UU}}$$