Implementation of the Goloskokov-Kroll model pseudoscalar meson production in PARTONS

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Goloskokov-Kroll Model

- Factorization for electroproduction of mesons has been proven only for longitidunally polarized photons [Collins-Frankfurt-Strikman '97]
- For transversely polarized photons, cross section is power suppressed by $1/Q$ [Collins-Frankfurt-Strikman '97]
- But in some kinematics, it is apparent that transversely polarized photons contributes substantially [HERMES Collaboration, arXiv:0907.2596[hep-ex]]

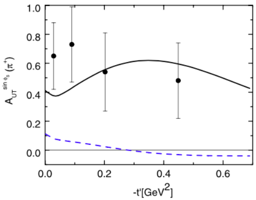


Fig. 2 (Color online) The $\sin\phi_s$ moment for a transversely polarized target at $Q^2 \simeq 2.45$ GeV^2 and $W = 3.99$ GeV. The prediction from our handbag approach is shown as a *solid line*. The *dashed line* is obtained disregarding the twist-3 contribution. Data are taken from [10]

Figure: [Goloskokov-Kroll '10]

Goloskokov-Kroll Model

- Contributions from transversely polarized photons can be computed as a twist-3 effect in the handbag mechanism [Goloskokov-Kroll '10]
- In pseudoscalar meson production, the following amplitudes are relevant in GK model

$$\mathcal{M}_{0+,0+} = \sqrt{1-\xi^2}\frac{e}{Q}[\langle\tilde{H}\rangle - \frac{\xi^2}{1-\xi^2}\langle\tilde{E}\rangle]$$

$$\mathcal{M}_{0-,0+} = \frac{e}{Q}\frac{-t'}{2m}[\xi\langle\tilde{E}\rangle]]$$

$$\mathcal{M}_{0-,++} = \sqrt{1-\xi^2}e\,\langle H_T\rangle$$

$$\mathcal{M}_{0+,\mu+} = -\frac{e}{4m}\sqrt{-t'}\langle\bar{E}_T\rangle$$

Goloskokov-Kroll Model

- Generically, $\langle F \rangle$ represents a convolution of a GPD F with an appropriate subprocess amplitude

$$\langle F \rangle = \sum_{\lambda} \int_{-1}^{1} dx \, \mathcal{H}_{\mu'\lambda,\mu\lambda}(x, \xi, Q^2) \, F(x, \xi, t)$$

  where λ denotes unobserved helicities of the partons.
- Subprocesses are calculated in the so-called modified perturbative approach: Transverse momenta of the quark and the anti-quark in the meson are kept and gluon radiations are taken into account through Sudakov factor
- GPDs appear in the following combination

$$F^0(x, \xi, t) = \frac{1}{\sqrt{2}} \Big(e_u \, F^u(x, \xi, t) - e_d \, F^d(x, \xi, t) \Big)$$

$$F^+(x, \xi, t) = F^u(x, \xi, t) - F^d(x, \xi, t)$$

Goloskokov-Kroll Model

- In impact space

$$\mathcal{H}_\pi = \int d\tau d^2\vec{b}\,\hat{\Psi}_\pi(\tau, -\vec{b})\hat{\mathcal{F}}^i_\pi(\bar{x}, \xi, \tau, Q^2, \vec{b})\alpha_s(\mu_R)\ exp\big(-S(\tau, \vec{b}, Q^2)\big)$$

- Hard scattering kernels has the following forms in momentum space

$$\mathcal{F}^q_{\pi^0} = \frac{N_c^2-1}{2N_c}\sqrt{\frac{2}{N_c}}\frac{Q}{\xi}\Big[\frac{1}{k_\perp^2 + \tau(\bar{x}+\xi)Q^2/(2\xi) - i\epsilon} - \frac{1}{k_\perp^2 - \bar{\tau}(\bar{x}-\xi)Q^2/(2\xi) - i\epsilon}\Big]$$

$$\mathcal{F}^q_{\pi^+} = \frac{N_c^2-1}{2N_c}\sqrt{\frac{2}{N_c}}\frac{Q}{\xi}\Big[\frac{e_d}{k_\perp^2 + \tau(\bar{x}+\xi)Q^2/(2\xi) - i\epsilon} - \frac{e_u}{k_\perp^2 - \bar{\tau}(\bar{x}-\xi)Q^2/(2\xi) - i\epsilon}\Big]$$

- A Gaussian meson wave function is used at twist-2

$$\Psi_\pi(\tau, \vec{b}) \sim \tau(1-\tau)exp\Big[\frac{\tau(\tau-1)}{4}\frac{\vec{b}^2}{a_\pi^2}\Big]$$

Goloskokov-Kroll Model

- Sudakov factor has the form

$$S(\tau, b, Q) = s(\tau, b, Q) + s(\bar{\tau}, b, Q) - \frac{4}{\beta_0}\, ln\, \frac{ln(\mu_R/\Lambda_{QCD})}{\hat{b}}$$

where

$$s(\tau, b, Q) = \frac{8}{3\beta_0}\Big(\hat{q}\, ln\Big(\frac{\hat{q}}{\hat{b}}\Big) - \hat{q} + \hat{b}\Big) + NLL$$

$$\hat{b} = -ln(b\, \Lambda_{QCD})$$

$$\hat{q} = ln\big(\tau Q/(\sqrt{2}\Lambda_{QCD})\big)$$

- Twist-3 meson wave function

$$\Psi_\pi(\tau, \vec{b}) \sim exp\Big[-\frac{\vec{b}^2}{8a_\pi^2}\Big]\, I_0(\frac{\vec{b}^2}{8a_\pi^2})$$

Goloskokov-Kroll Model GPDs

- GPDs are constructed from double distribution ansatz

$$F_i^a(\bar{x}, \xi, t) = \int_{-1}^{1} d\rho \int_{-1+|\rho|}^{1-|\rho|} d\eta \, \delta(\rho + \xi\eta - \bar{x}) f_i^a(\rho, \eta, t)$$

where for valence-quark GPDs;

$$f_i(\rho, \eta, t) = exp[(b_i - \alpha_i' \, ln \, \rho)t] \, F_i^a(\rho, \xi = t = 0) \, \frac{3}{4} \frac{(1-\rho)^2 - \eta^2}{(1-\rho)^3} \Theta(\rho)$$

- Parameters of the forward limits

$\tilde{H}$: DSSV, Phys. Rev. D **80**, 034030 (2009)

H_T: ABM, Phys. Rev. D **86**, 054009 (2012) and DSSV, Phys. Rev. D **80**, 034030 (2009)

$\tilde{E}$: LHPC Collaboration, Phys. Rev. D **77**, 094502 (2008)

$\bar{E}_T$: QCDSF and UKQCD Collaborations, Phys. Rev. Lett. **98**, 222001 (2007)

Goloskokov-Kroll Model

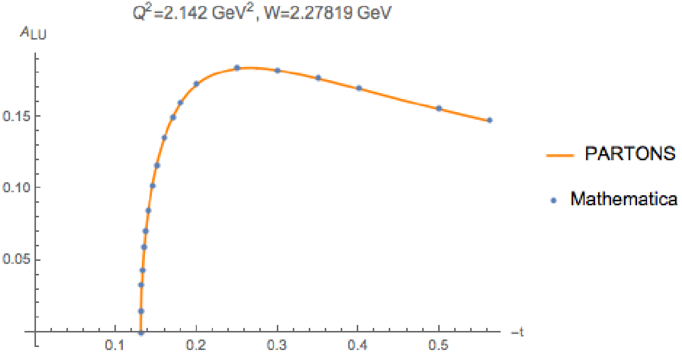
- To compute the longitudinal cross section, we need: Twist-2 meson wave function, kernel, running coupling, Sudakov factor and GPDs $\tilde{H}$ and $\tilde{E}$.
- To compute the transverse cross section, we need: Twist-3 meson wave function, kernel, running coupling, Sudakov factor and GPDs H_T and $\bar{E}_T$.
- 3 dimensional integrals, over $\bar{x}, \tau$ and b, are performed in impact space
- π^+ electroproduction also receives a pion pole contribution, besides the handbag contribution

Goloskokov-Kroll Model

- $3D$ integrals are time consuming
- Standard integration routines take hours to compute an observable at a single point
- To speed up, we use VEGAS Monte Carlo integration implemented in gsl library
  - can choose number of evaluations
  - can choose χ^2 range
- As a result, an observable can be computed at a single point within a minute or two with a good accuracy

PARTONS vs. Mathmematica

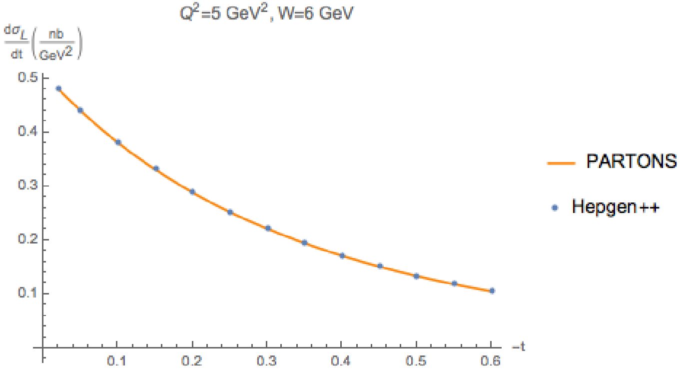
Comparison between PARTONS and Mathmematica codes in π^+ electroproduction



PARTONS $\approx$ 35 min, whereas Mathematica $\approx$ 5 days

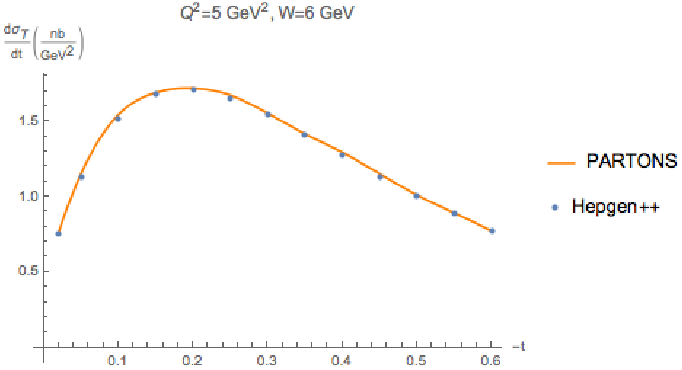
PARTONS vs. Hepgen++

Comparison between the PARTONS and Hepgen++ in π^0 electroproduction



PARTONS vs. Hepgen++

Comparison between the PARTONS and Hepgen++ in π^0 electroproduction



Comparison between the *PARTONS* and *Hepgen*++ in π^0 electroproduction