Hard Exclusive Electroproduction of Pseudoscalar Mesons at JLAB

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- Introduction & Physics Goals
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Hard Exclusive Scattering

The QCD factorization theorem has been generalized to a large group of hard exclusive processes,

$$\gamma^*(q) + T(p) \rightarrow M(q\,') + T'(p\,')$$

The amplitude of this reaction can be written as:

$$\sum_{i,j} \int_0^1 dz \int dx_1 f_{i/p}(x_1, x_1 - x_B; t, \mu)\, H_{ij}(Q^2 x_1/x_B, Q^2, z, \mu)\, \phi_j(z, \mu)$$

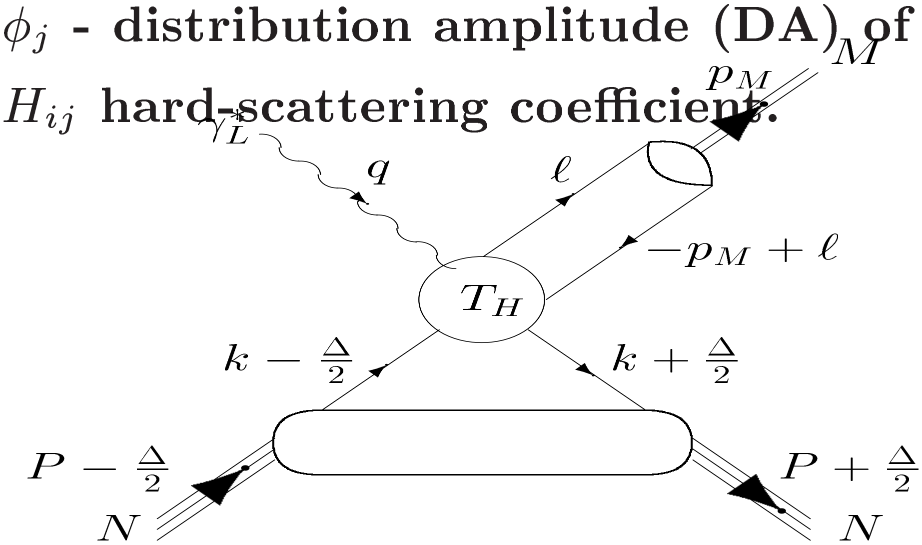
+power-suppressed corrections,

where $f_{i/p}$ **is a GPD for partons of type** i **in hadron** p

x_1 **- fraction of the target momentum ,**

ϕ_j **- distribution amplitude (DA) of the meson**

H_{ij} **hard-scattering coefficient.**



Physics Goals

Polarized parton densities can be probed in unpolarized collisions.

In hard exclusive meson production we access:

- quark momentum distributions (f_1) with longitudinally polarized vector mesons
- quark helicity distributions (g_1) with pseudo-scalar mesons.

Note:

- GPD based calculations were performed only for longitudinally polarized virtual photon
- The dominance of hard-gluon exchange processes can only be confirmed theoretically for sufficiently large values of Q^2 ($Q^2 > 10$)

The onset of the hard regime can be established via study of the change of the t ($t = (p - p')^2 = \Delta^2$) dependence with an increase of Q^2

Leading order amplitudes

The pion electroproduction (hard scattering) amplitude $\mathcal{M}_\pi^L$ for a longitudinal virtual photon in leading order in Q in terms of GPDs (ignoring $\widetilde{E}$) could be written in the form:

$$\mathcal{M}_\pi^L \approx -ie\,\frac{4}{9}\,\frac{1}{Q}\left[\int_0^1 dz\,\frac{\Phi_\pi(z)}{z}\right]\frac{1}{2}\,(4\pi\alpha_s)\,A_{\pi N}\,\bar{N}(p')\not{n}\gamma_5\,N(p)$$

where $\Phi_\pi(z)$ is the pion distribution amplitude, and where α_s is the strong coupling constant.
For π^0 and η on proton, the amplitudes are defined as:

$$A_{\pi^0 p} = \int_{-1}^{1} dx\,\frac{1}{\sqrt{2}}\left(e_u\,\widetilde{H}^u - e_d\,\widetilde{H}^d\right)\left\{\frac{1}{x-\xi+i\epsilon}+\frac{1}{x+\xi-i\epsilon}\right\}$$

$$A_{\pi^+ n} = -\int_{-1}^{1} dx\left(\widetilde{H}^u - \widetilde{H}^d\right)\left\{\frac{e_u}{x-\xi+i\epsilon}+\frac{e_d}{x+\xi-i\epsilon}\right\}$$

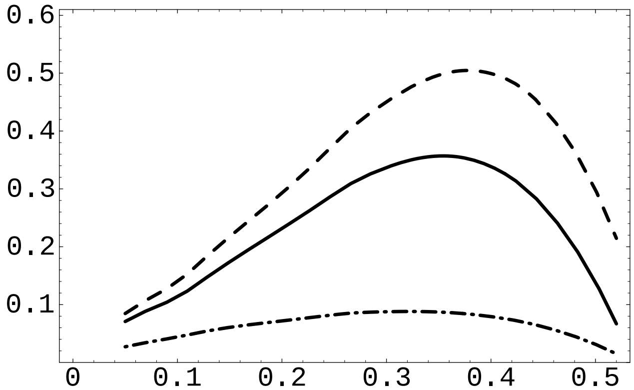
$$A_{\eta p} = \int_{-1}^{1} dx\,\frac{1}{\sqrt{6}}\left(e_u\,\widetilde{H}^u + e_d\,\widetilde{H}^d - 2\,e_s\,\widetilde{H}^s\right)\left\{\frac{1}{x-\xi+i\epsilon}+\frac{1}{x+\xi-i\epsilon}\right\}$$

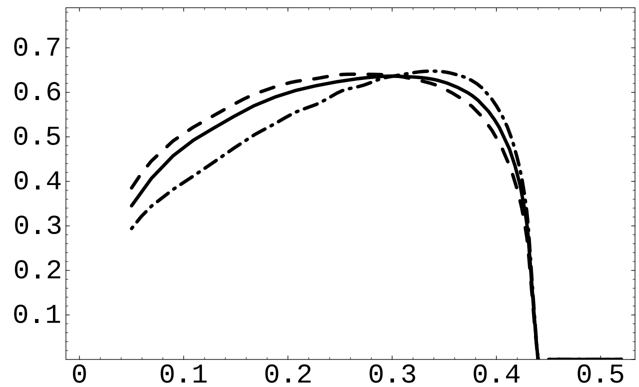
In the forward limit for $\widetilde{H}^q(x,\xi,t)$:

$$\tilde{H}^q(x,0,0) = \begin{cases} \Delta q(x), & x > 0\,, \\ \Delta\bar{q}(-x), & x < 0\,. \end{cases}$$

Hard exclusive production

→ A.Belitsky et al (2001).





The leading twist predictions for the unpolarized photoproduction cross section $d\sigma_L^{\pi^+}/d\Delta^2$ at $Q^2 = 10GeV^2$ for $\Delta^2 = -0.3GeV^2$.

The transverse proton single spin asymmetry $A_\perp$ for $\Delta^2 = -0.3\ GeV^2$.

The solid, dashed and dash-dotted curves represent the LO and NLO with 2 different scale setting prescriptions.

Cross section observables are unstable, but ratios are not affected significantly by NLO corrections.

Observables

Probe hard exclusive processes in electroproduction of pseudoscalar mesons off the proton and deuterium in a wide kinematical range

- ratios of π^+, π^0, η on deuteron and proton
- ratios for η and π^0 off nucleons
- shape of the t dependence of the coherent scattering off the proton and deuteron
- the t dependence of the π^+ π^0 and η production for different Q^2
- the Q^2 dependence of the π^0 and η production for fixed x_{Bj}

Processes:

$$e + p = e' + n + \pi^+ \quad (1)$$

$$e + p = e' + p' + 2\gamma \quad (2)$$

$$e + d = e' + d' + 2\gamma \quad (3)$$

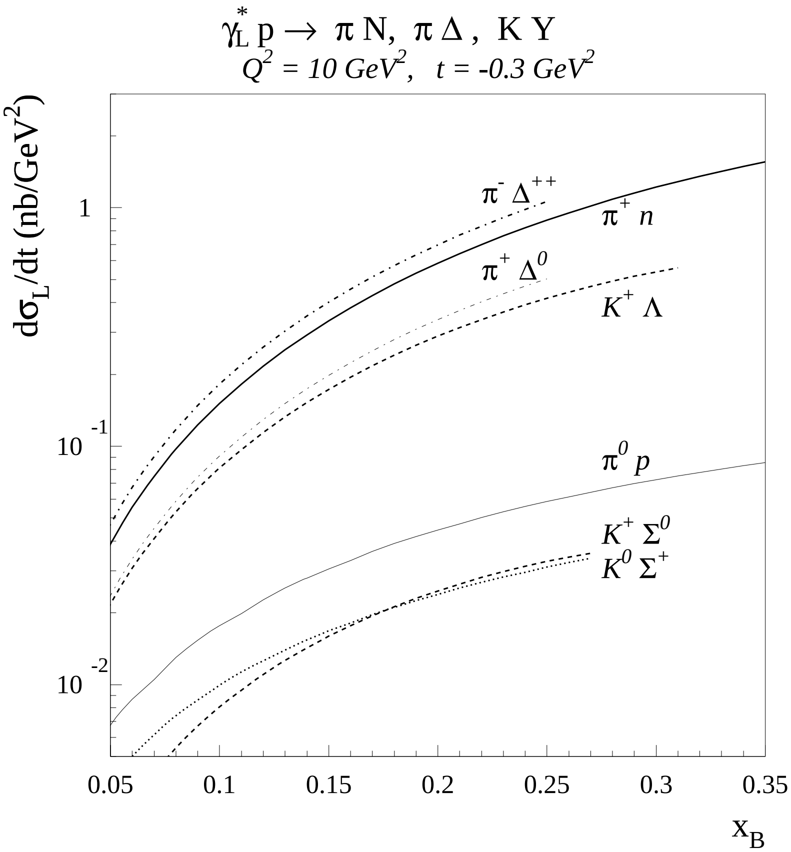
$$e + d = e' + [N] + 2\gamma \quad (4)$$

$$e + d = e' + p' + 2\gamma \quad (5)$$

Precocious scaling of the spin asymmetries and of the ratios of the cross sections is possible already at $Q^2 \sim 5GeV$ (PRD60,014010).

Pion Ratios

Mankiewicz et al. (1998)



Leading order predictions for the πN, $\pi\Delta$ and KY longitudinal electroproduction cross sections at $t =$ -0.3 GeV^2, as function of x_B.

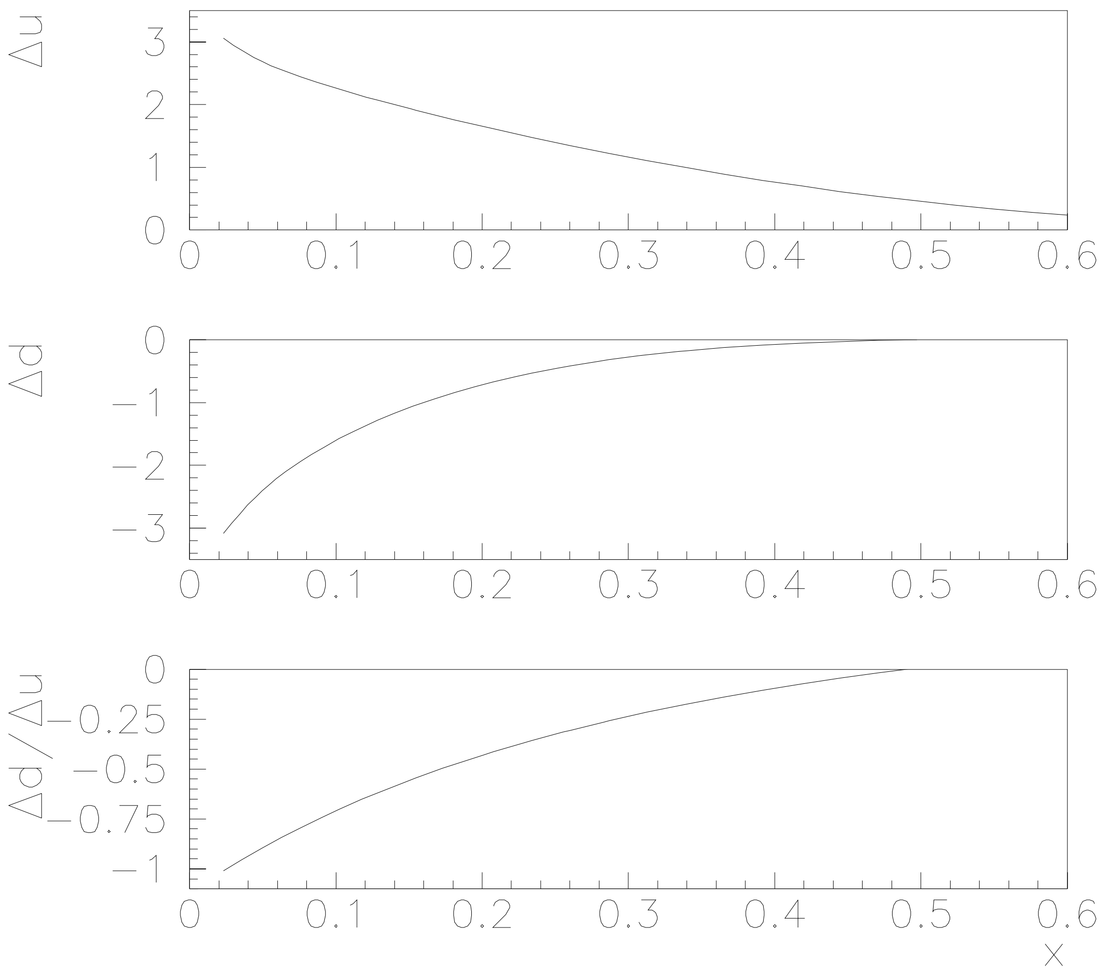
$$\pi_p^0 : \pi_p^+ \sim \left(\frac{2\Delta u + \Delta d}{2\Delta u - \Delta d}\right)^2$$

At large $x_{\rm Bj}$ ($x_{\rm Bj} \sim 0.3$) contribution from the pion cloud, (pseudoscalar part) add further to the cross section ratio of π^+ to π^0 .

π^0 ratios

The π^0 ratio on proton and neutron is proportional to the ratio of polarized distribution functions $\frac{\Delta d}{\Delta u}$:

$$\pi_n^0 : \pi_p^0 \approx \left(\frac{2\frac{\Delta d}{\Delta u} + 1}{2 + \frac{\Delta d}{\Delta u}} \right)^2$$



Polarized distribution functions from Brodsky, Burkardt and Schmidt (BBS).

Leading order amplitudes

In the limit of exact $SU(3)$ symmetry($f_\pi = f_\eta$) amplitudes for proton:

$$< 0|j^5_\mu|\pi^0 >\sim \frac{f_\pi}{\sqrt{2}}(\frac{2}{3}\Delta u + \frac{1}{3}\Delta d),$$

$$< 0|j^5_\mu|\eta >\sim \frac{f_\eta}{\sqrt{6}}(\frac{2}{3}\Delta u - \frac{1}{3}\Delta d + \frac{2}{3}\Delta s)$$

For the π^0, η ratio on proton:

$$\pi^0 : \eta = \frac{1}{2}\left(\frac{2}{3}\Delta u + \frac{1}{3}\Delta d\right)^2 : \frac{1}{6}\left(\frac{2}{3}\Delta u - \frac{1}{3}\Delta d + \frac{2}{3}\Delta s\right)^2$$

For the π^0, η ratio on proton with account of axial anomaly and the $SU(3)$ breaking:

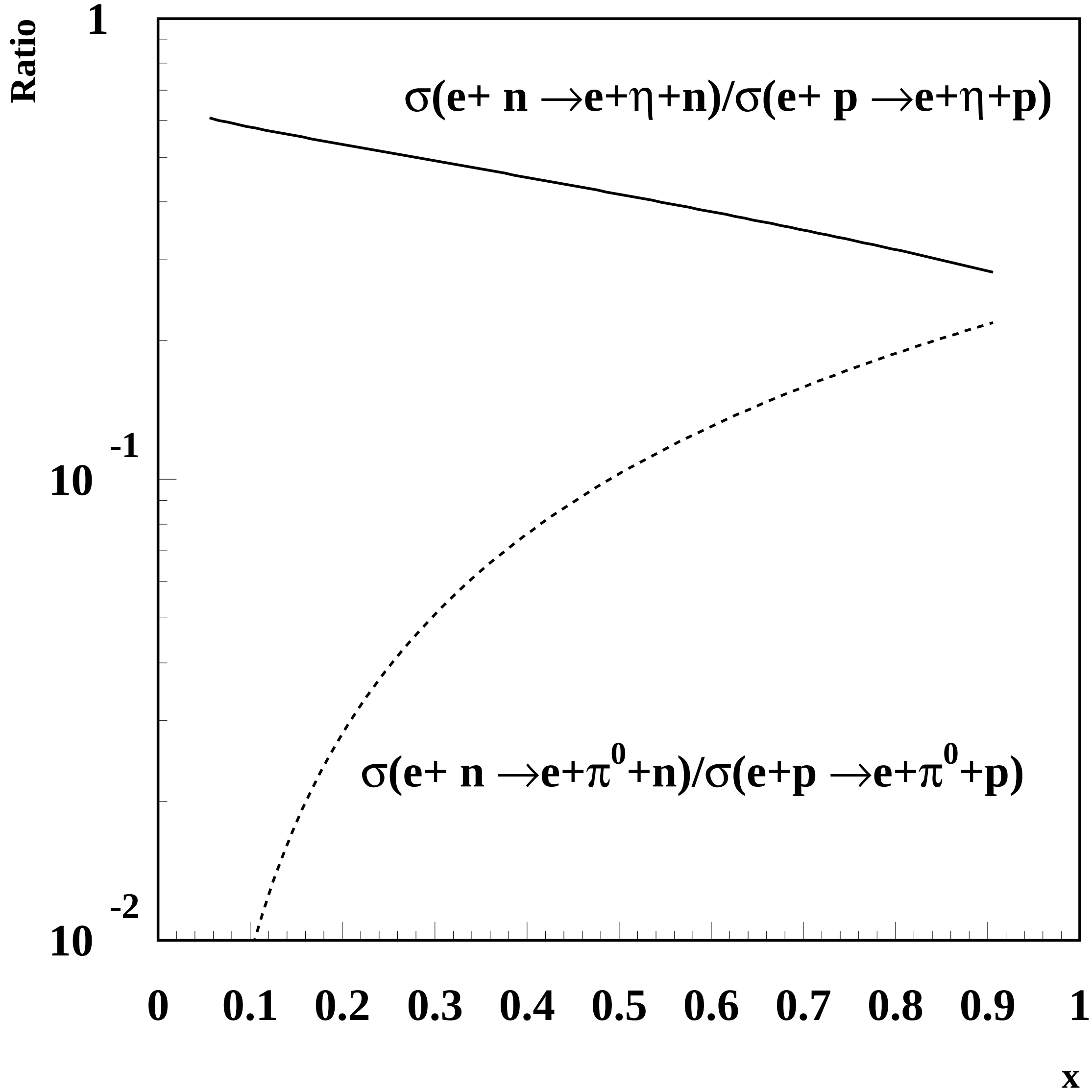
$$\pi^0 : \eta = \frac{1}{2}\left(\frac{2}{3}\Delta u + \frac{1}{3}\Delta d\right)^2 : \frac{1}{6}\left(\frac{2}{3}1.27\Delta u - \frac{1}{3}1.27\Delta d + \frac{2}{3}1.14\Delta s\right)^2$$

The η production rate is increasing a factor of 1.61 with respect to π^0.

Note:

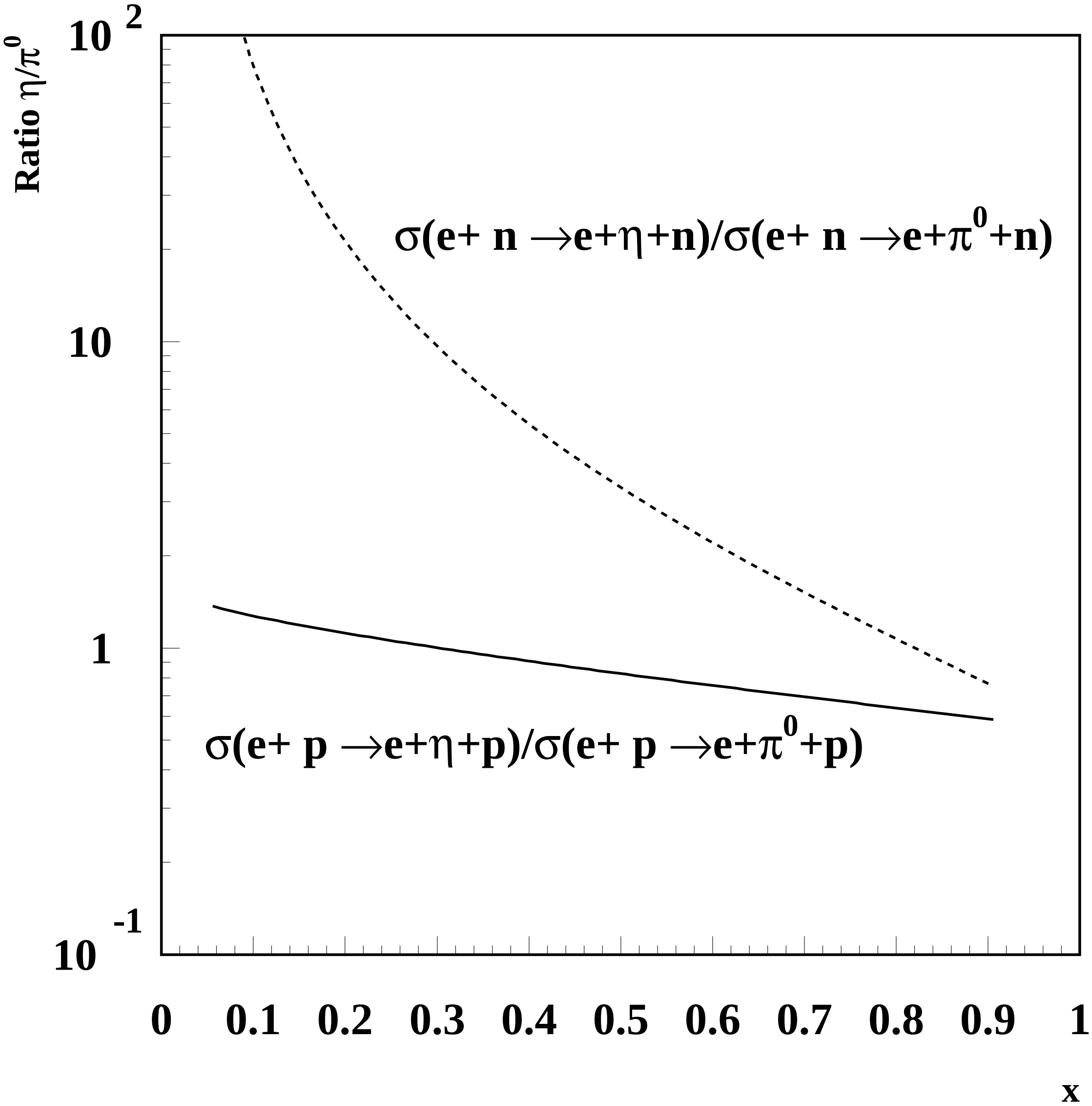
- **because of mass difference between π^0 and η higher twist effects would be different.**

π^0 and η ratios



Neutron to proton ratios for π^0 and η from Strikman et. al.

π^0 and η ratios

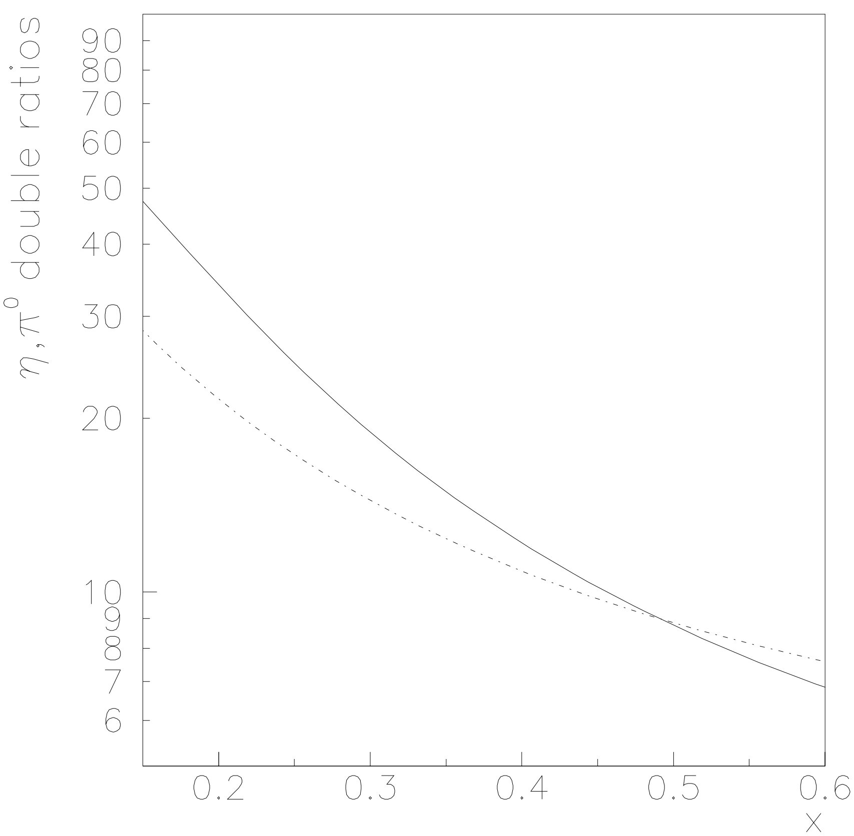


η to π^0 ratios for neutron and proton from Strikman et. al.

π^0 and η double ratios

For the π^0 to η ratio on deuteron (coherent case):

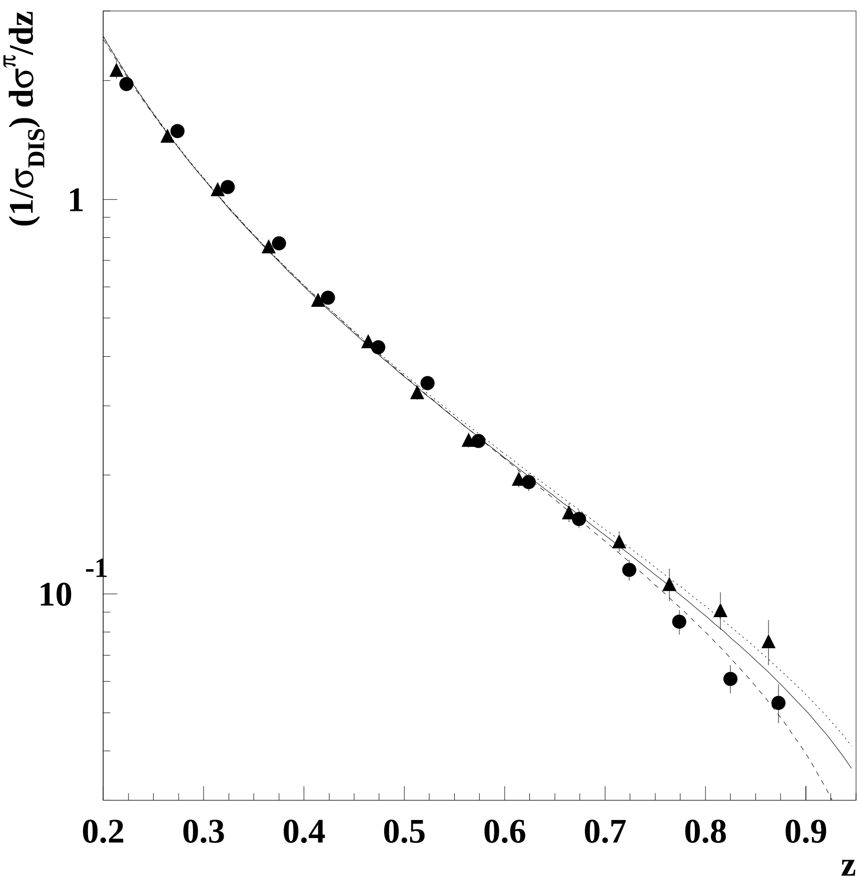
$$\pi^0_D : \eta_D \approx \frac{27}{\left(1 + \frac{4\Delta s}{(\Delta u + \Delta d)}\right)^2} \approx 27 : 1$$



The $\sigma(\gamma_L + D \to \pi^0 + D)/\sigma(\gamma_L + D \to \eta + D)$ **to** $\sigma(\gamma_L + D \to \pi^0 + N)/\sigma(\gamma_L + N \to \eta + N)$ **(solid line) and** $\sigma(\gamma_L + p \to \pi^0 + p)/\sigma(\gamma_L + p \to \eta + p)$ **(dashed line).**

Pion multiplicities

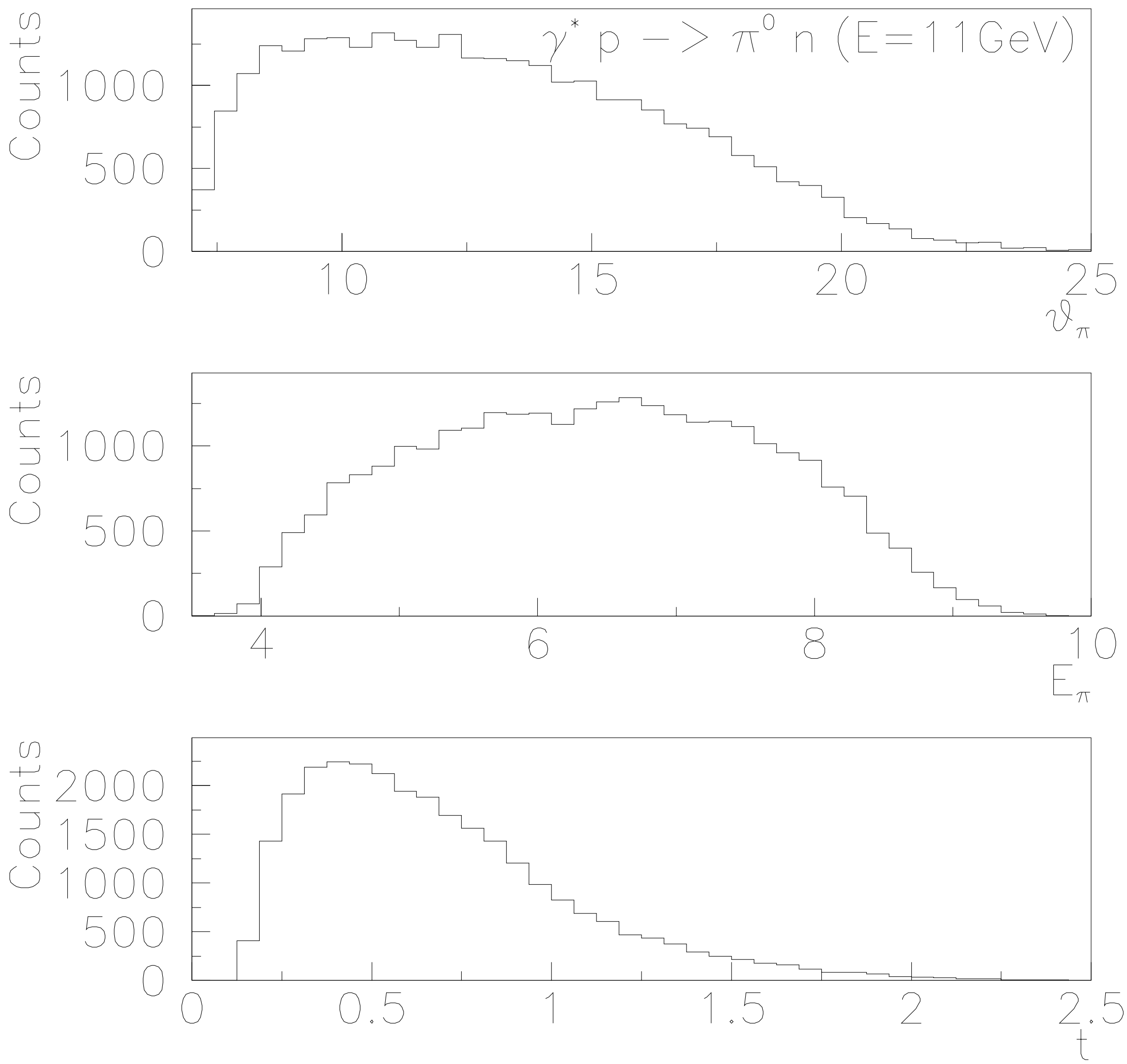
HERMES Eur.Phys.J.C21 (2001)



Filled circles for π^0 and triangles for $\frac{1}{2}(\pi^+ + \pi^-)$. Curves are fits to $\frac{1}{2}(\pi^+ + \pi^-)$ to BKK formula.

In the exclusive limit the relative number of π^+ is increasing with respect to π^0.

Kinematics at 11 GeV



Kinematic distributions of $11GeV$ exclusive pi-0s.
$Q^2 > 5GeV^2, W^2 > 4GeV^2, \theta_\gamma > 10^o$

Required resolution of π^0 mass reconstruction $\approx 10\%$

Outlook

- **Significant suppression predicted in hard exclusive production of pseudoscalar mesons on neutrons compared to protons and in relative rates of π^0 and η in the case of free protons and neutrons compared to coherent production off the deuteron.**
- **Significant suppression predicted in hard exclusive production of π^0 compared to π^+.**
- **The extraction of σ_L/σ_T ratio at HALL-A or HALL-C in addition to measurements over a wide kinematic range at HALL-B will provide a test of GPD based predictions for production of pseudoscalar mesons at JLAB energies.**