Access Quark Information Through semi-Inclusive Deep-Inelastic Scattering Experiments at JLab-12 GeV

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- Opportunities of SIDIS at JLab-12GeV.
- How do we know when we hit a quark ?
- Cross sections of SIDIS π production at NLO.
- Ratios of multiplicities carry quark information.
- My list of interesting SIDIS physics topics at JLab-12GeV.

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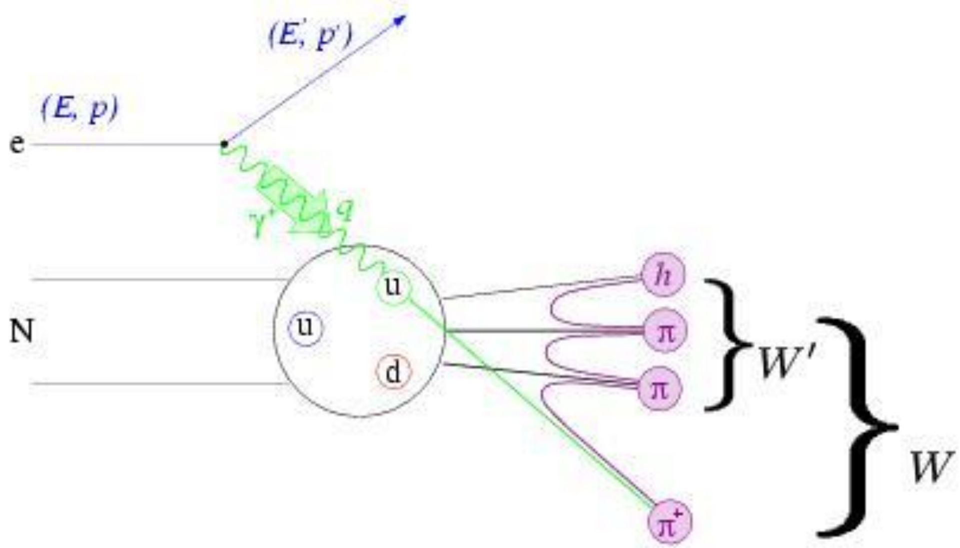
SIDIS Program at JLab-12 GeV

- A_{UT} trans. target SSA, Collins and Sivers asymmetries to access quark transversity and Sivers distribution function. $\pi^{+/0/-}$, $K^{+/-}$ etc.
- A_{LL} long. target double-spin asymmetries for quark spin-flavor decomposition, $\Delta u, \Delta d, \Delta \bar{u} - \Delta \bar{d}$
- Hadron azimuthal distribution in SIDIS, like cos(2φ), access transverse momentum dependent parton distributions. and more…



$z = E_\pi / \nu$

Three underline assumptions:

- Hard scattering at the vertex.
- Independent fragmentation (soft).
- Universality of Frag. Func.

Can we access quark information at JLab-12 GeV?

- Hard scattering. How do we know when we hit a quark ?
- Fragmentation. Quark information carried out by hadron ?
- Universality of Frag. Func. Agree with e^+e^-, p+p data ?

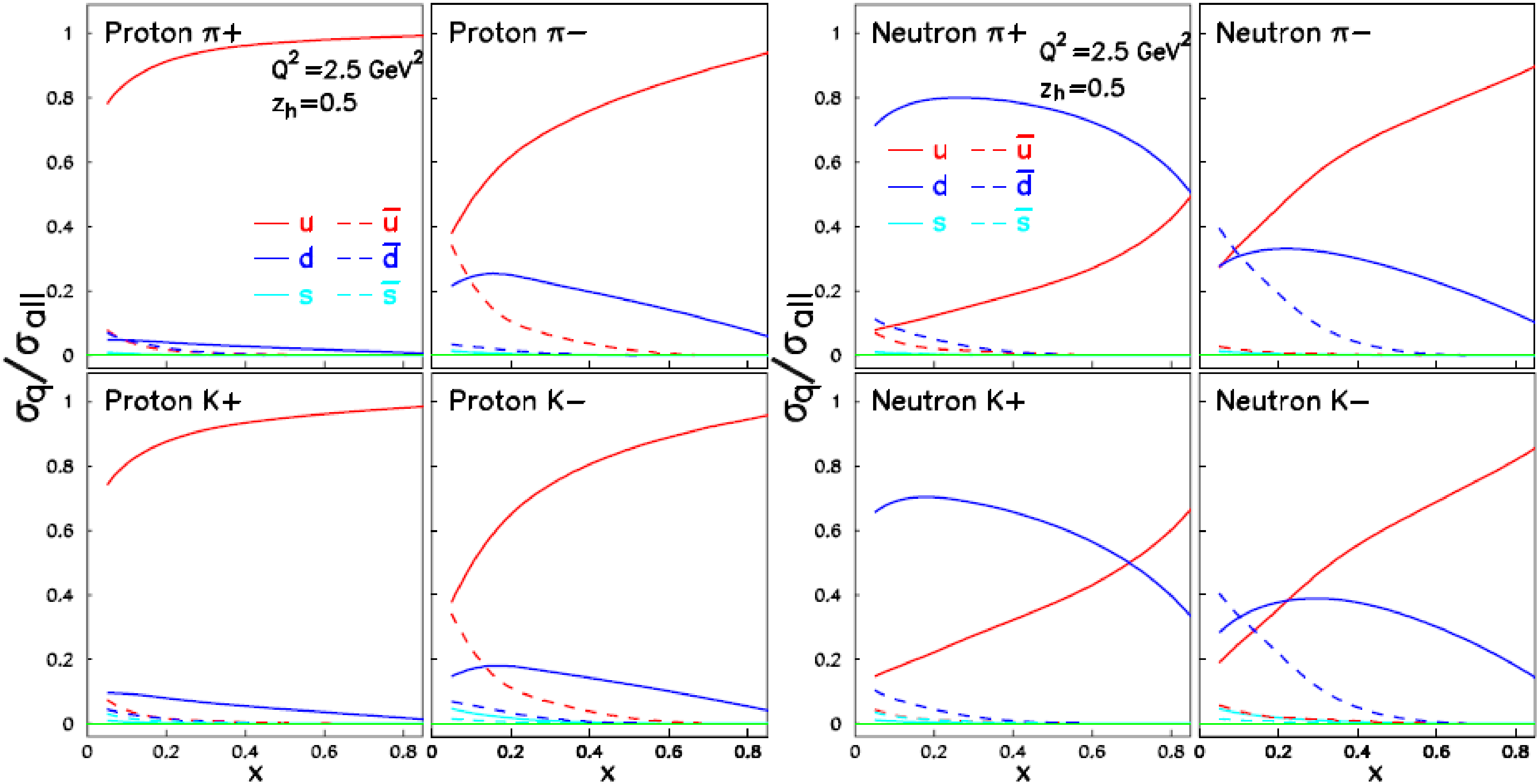
Do we understand the fundamental cross sections in SIDIS, to Next-Leading-Order ?

Do we understand their relative relations, Q^2, z, p_t and φ-dependencies ?

The first step of SIDIS program at JLab-12 GeV is to firmly establish the baseline of interpretation.

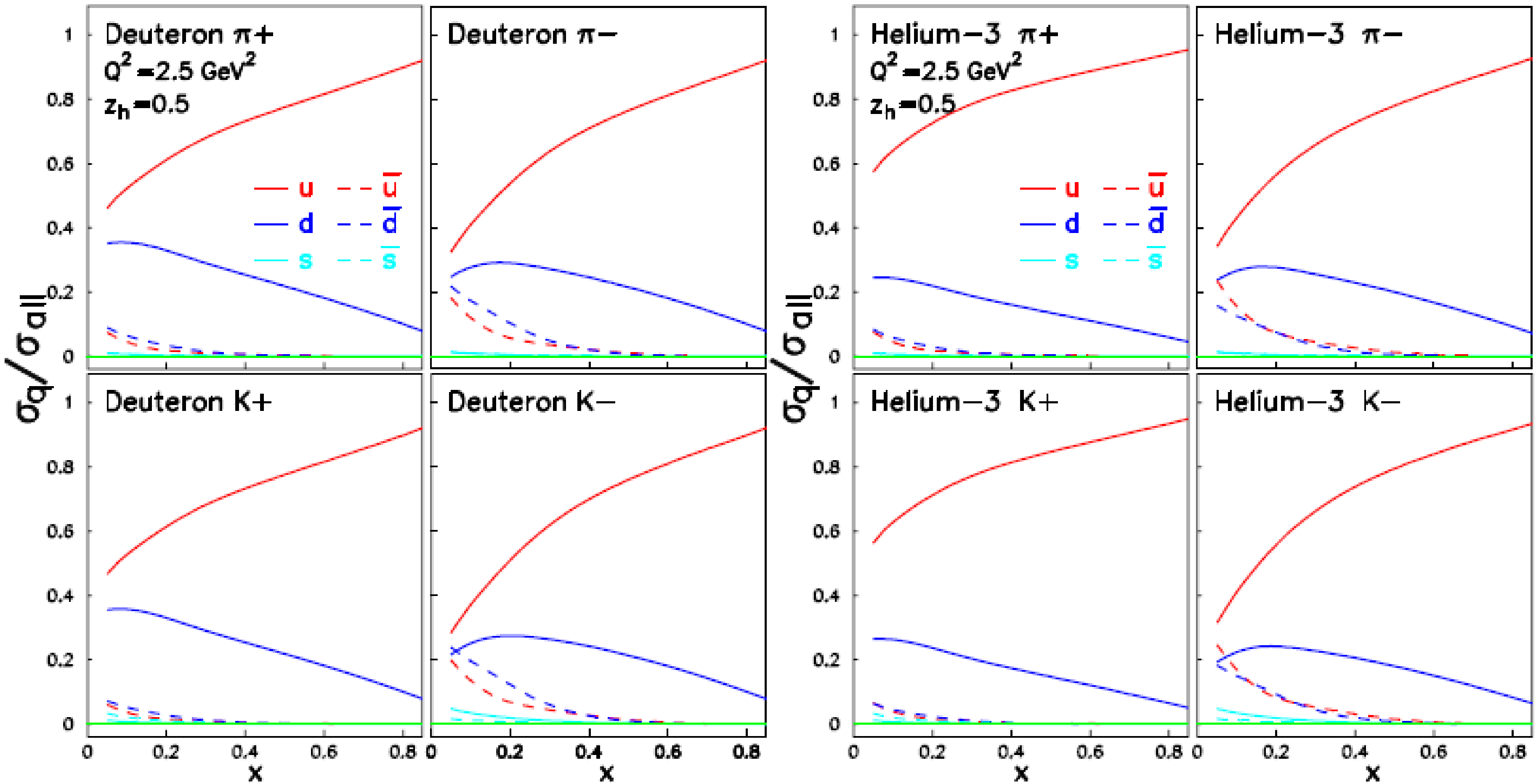
What is the best evidence ?

Leading Order Cross Sections, contributions from each quark flavor



$$\sigma_q/\sigma_{all} = e_f^2 q_f \cdot D_f^h / \sum_i e_i^2 q_i \cdot D_i^h \qquad (@z_h = 0.5)$$

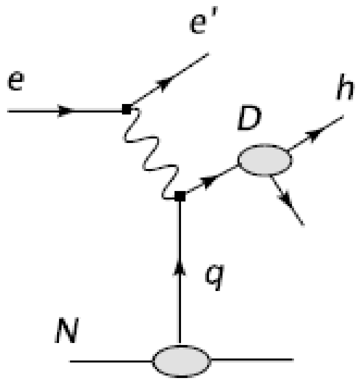
LO contributions from each quark flavor, on Deuteron and ^{3}He



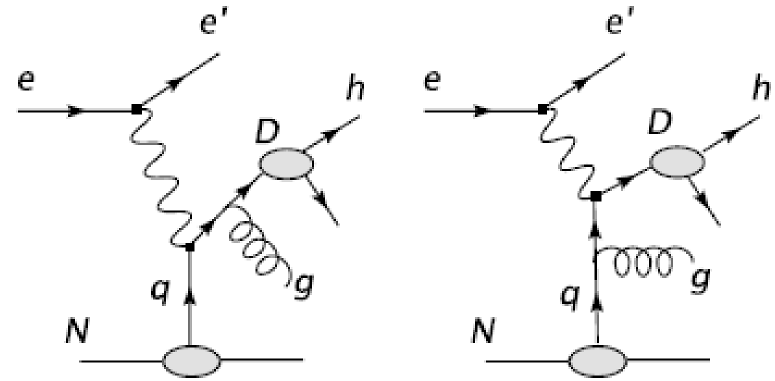
$$\sigma_q/\sigma_{all} = e_f^2 q_f \cdot D_f^h / \sum_i e_i^2 q_i \cdot D_i^h$$

SIDIS cross sections at NLO

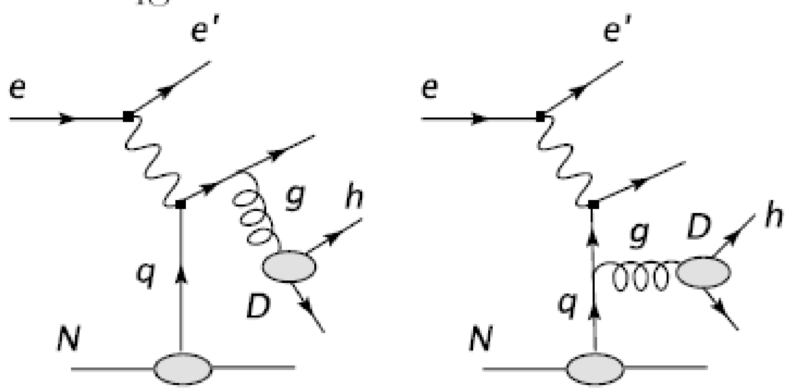
LO:



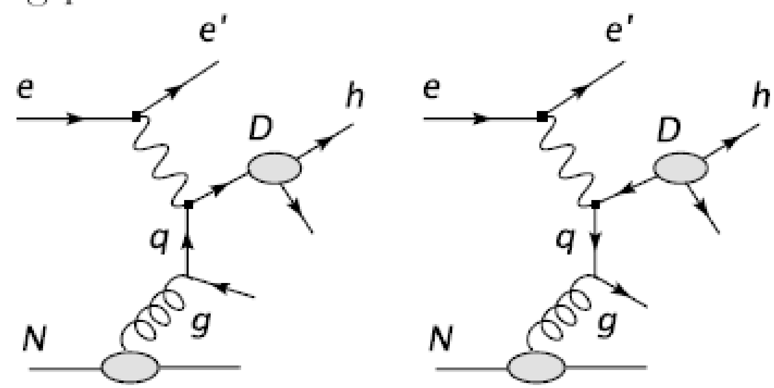
NLO-qq:



NLO-qg:



NLO-gq:



$$q(x,Q^2)\cdot D(z,Q^2) \Rightarrow \int \frac{dx'}{x'}\int \frac{dz'}{z'}\, q\left(\frac{x}{x'}\right) C(x',z')\, D\left(\frac{z}{z'}\right)$$

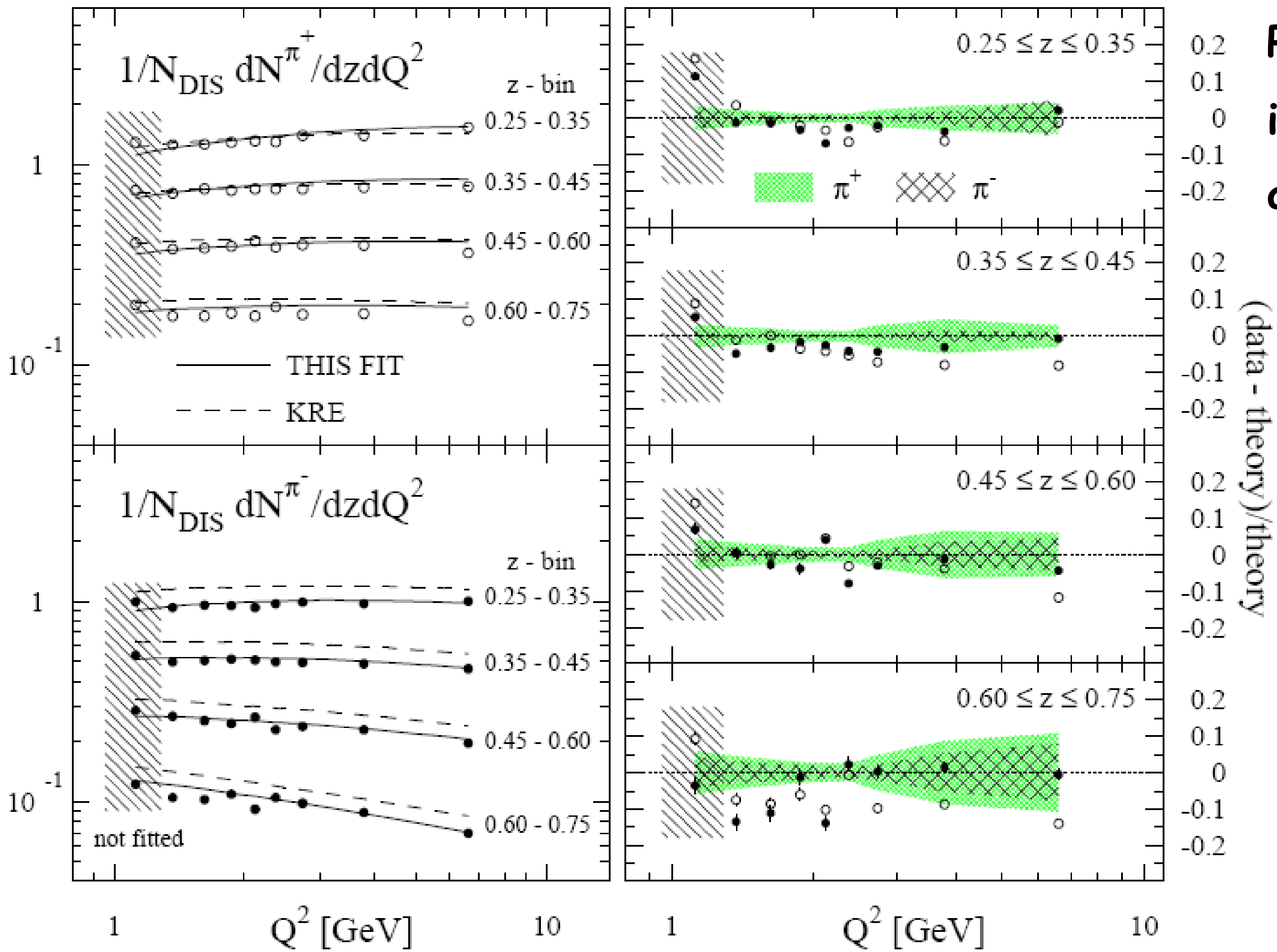
$$\sigma^h(x,z) = \sum_f e_f^2 q_f \left[1 + \otimes \frac{\alpha_s}{2\pi} \mathcal{C}_{qq} \otimes \right] D_{q_f}^h$$

$$+ \left(\sum_f e_f^2 q_f\right) \otimes \frac{\alpha_s}{2\pi} \mathcal{C}_{qg} \otimes D_G^h + G \otimes \frac{\alpha_s}{2\pi} \mathcal{C}_{gq} \otimes \left(\sum_f e_f^2 D_{q_f}^h\right)$$

Wilson co-efficiencies $C_{ij}(x,z)$ are well-known.

At NLO, gluon Frag. Func. are involved, limited number of unknowns. Many independent measurements help to constrain these unknowns within the framework of a global NLO-QCD fit.

NLO global fits of Fragmentation Functions



Pion multiplicities, integrated over Pt and φ

Global fit to e^+e^-, SIDIS and p+p data, to predict cross sections at NLO for JLab-12GeV

Fit compare with HERMES SIDIS data, R. Sassot et al. 2007.

For example, a measurement with CLAS12:

SIDIS π^+, π^-, π^0 production on proton and deuteron targets

$$ep \rightarrow e' \pi X \qquad e(p+n) \rightarrow e' \pi X$$

Form ratios from measured yields N_{π^+}, N_{π^-}

$$\frac{(N_{\pi^+} + N_{\pi^-})^p}{(N_{\pi^+} + N_{\pi^-})^d} \qquad \frac{(N_{\pi^+} - N_{\pi^-})^p}{(N_{\pi^+} - N_{\pi^-})^d}$$

Check kinematic dependence on Q^2, x_{bj}, z_π, P_t

High Luminosity $10^{35} cm^{-2} s^{-1}$

	E_0=11 GeV	E_0=8.8 GeV	E_0=6.6 GeV
Beam on LH_2	1000 hours	250 hours	250 hours
Beam on LD_2	1000 hours	250 hours	250 hours

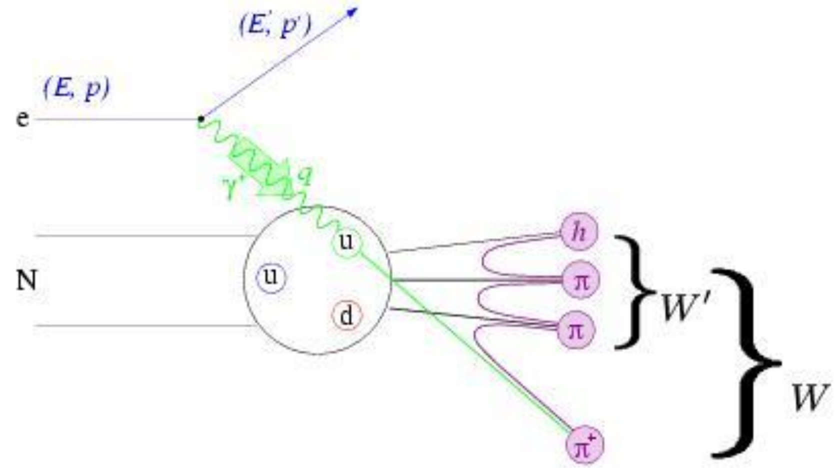
Definition and cuts

$$x_{bj} = \frac{Q^2}{2\nu M}$$

$$z_\pi = \frac{E_\pi}{\nu}$$

$$x_F = \frac{2p^*_{//}}{W}$$

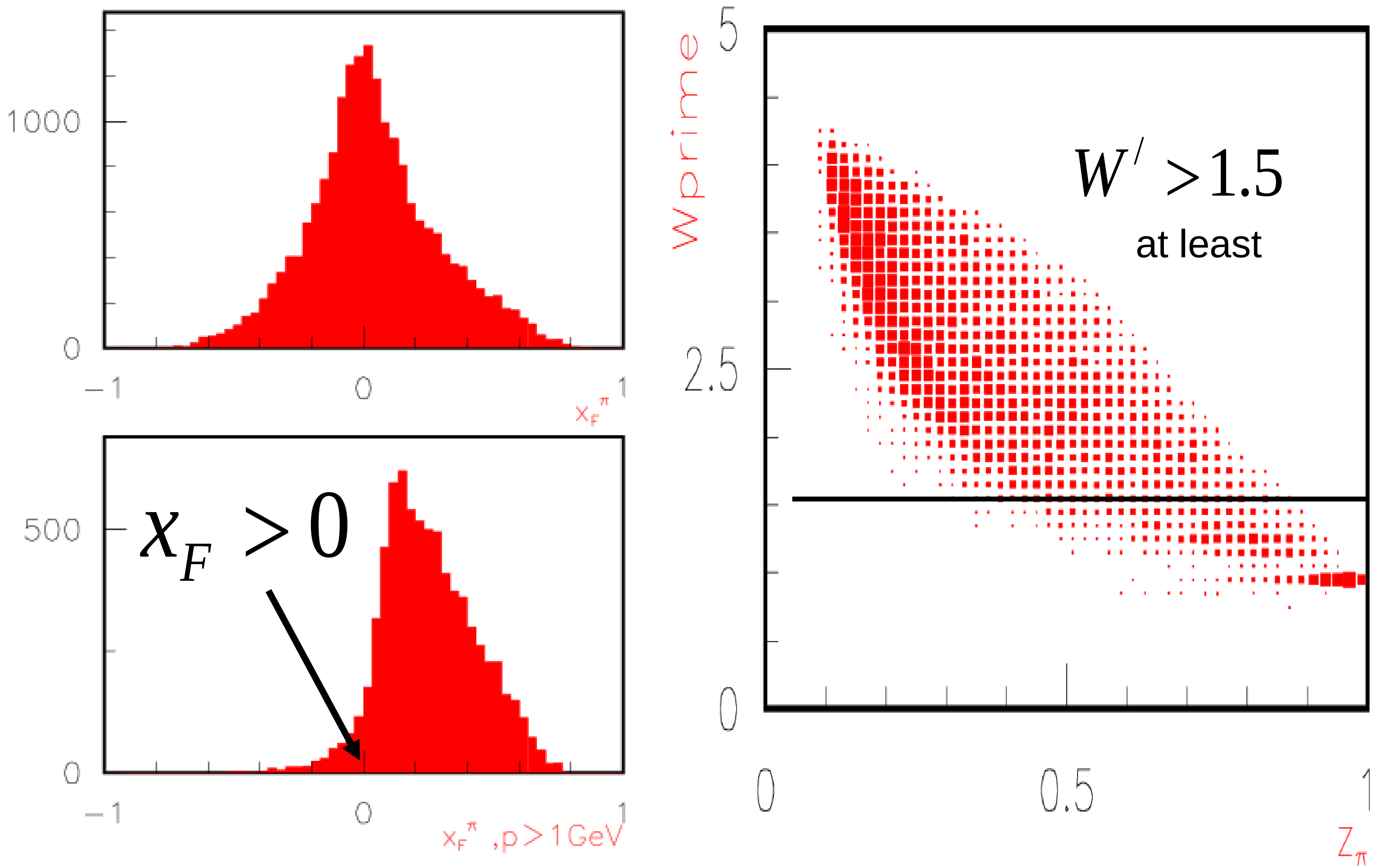
* Virtual-photon nucleon CM



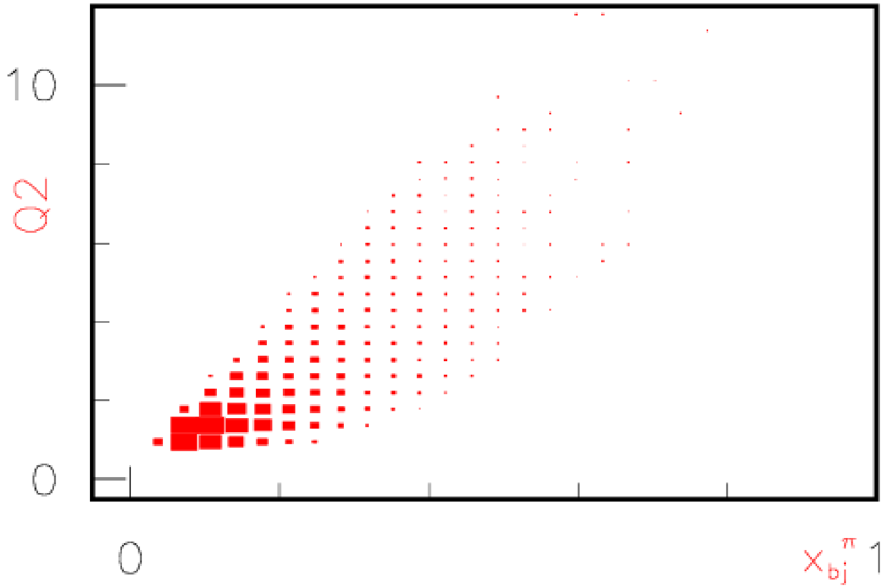
$z = E_\pi/\nu$

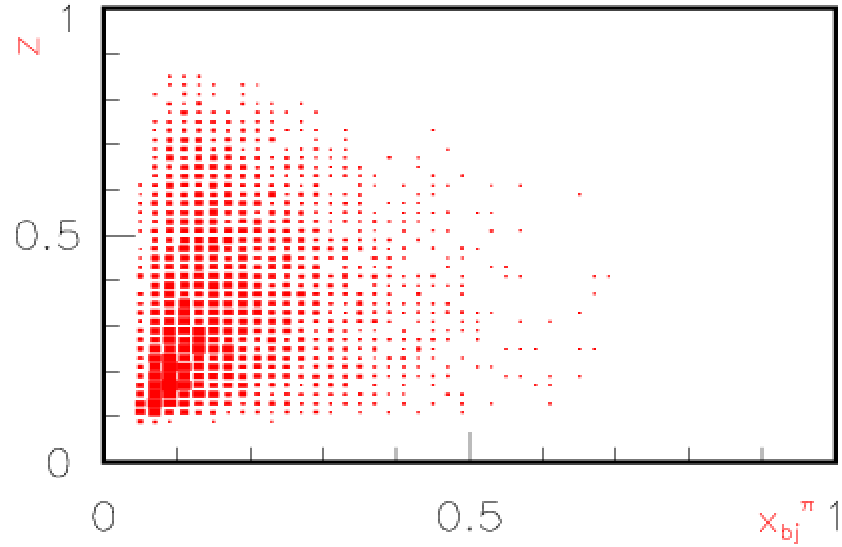
$$Q^2 > 1GeV^2, W > 2GeV, x_F > 0$$

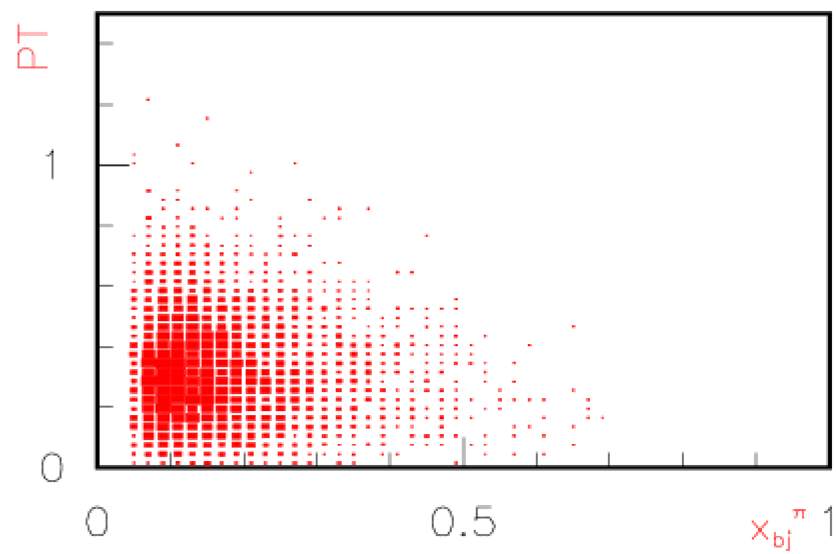
Cuts for pion on x_F, W'



Q2 vs. x, z vs. x, Pt vs. x





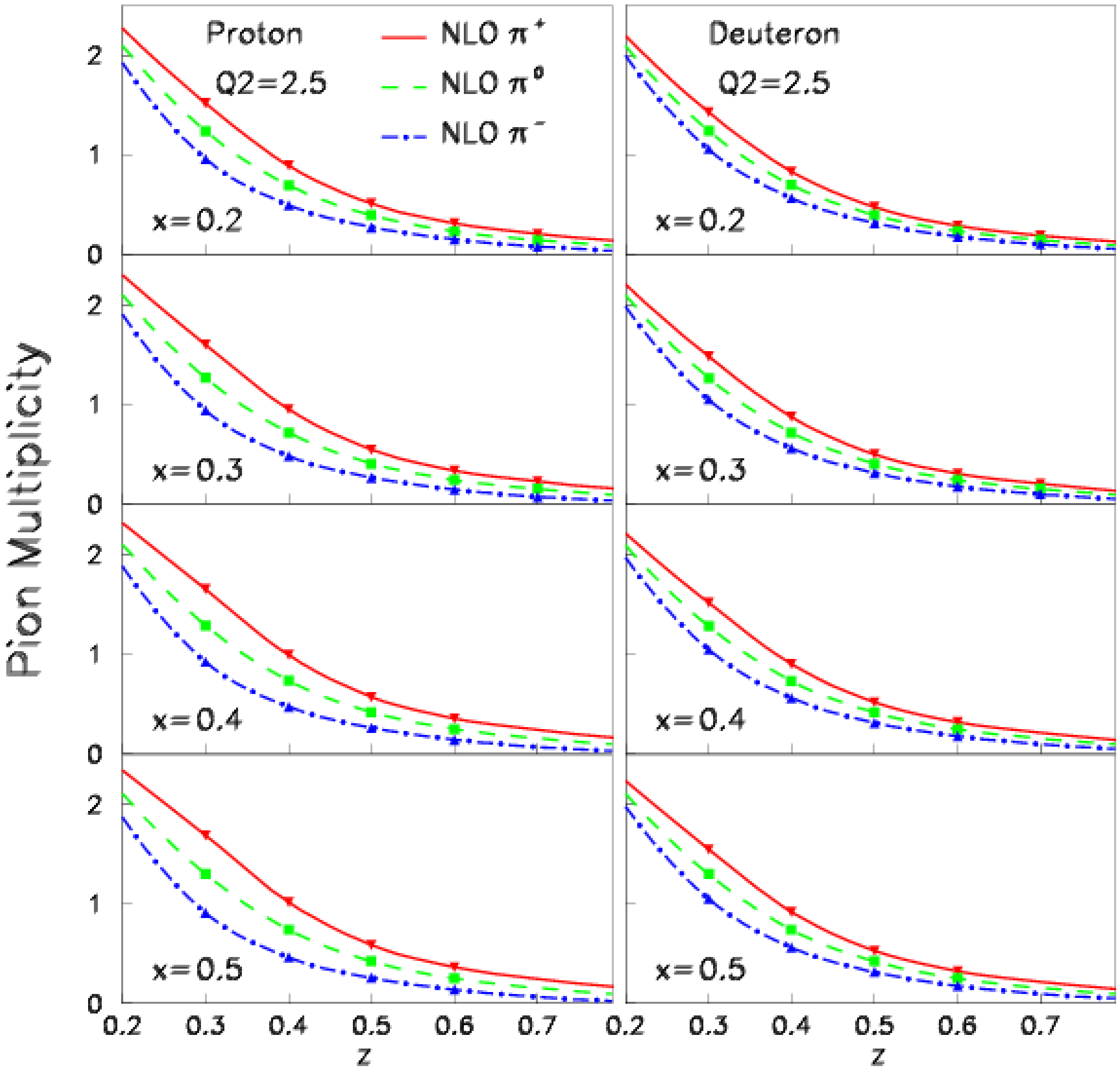


Check Q^2 dependence for a given z and x

Check z dependence for a given Q^2 and x

Check P_t dependence for a given Q^2 and x

Expected results: z-dependence



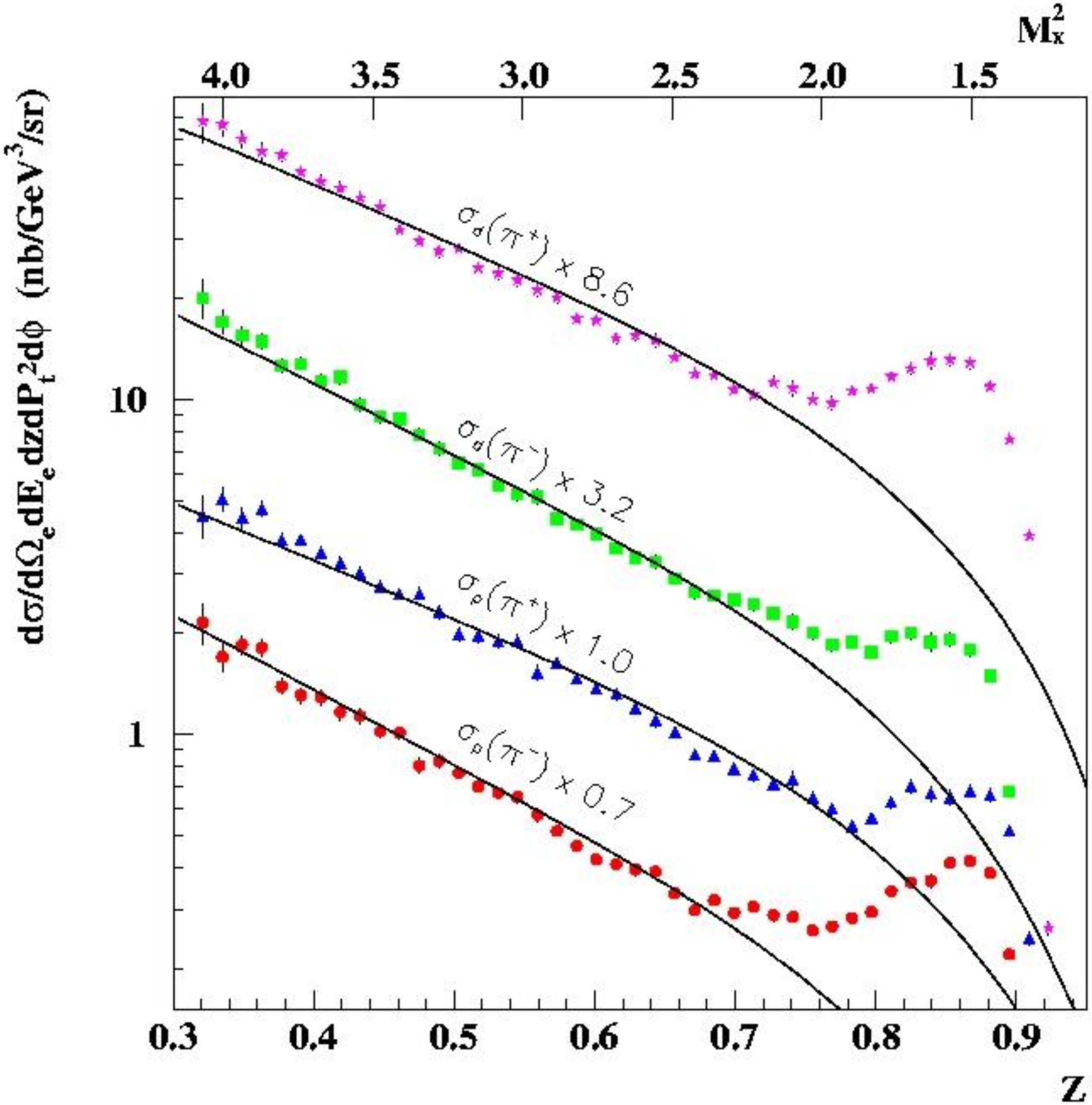
Curve: Prediction in NLO from R. Sassot .

Q2=2.5,
x=0.2,0.3,0.4,0.5

SU(2) symmetry in the fragmentation process ?

$$\pi^0 = (\pi^+ + \pi^-)/2$$

Hall C data at 5.5 GeV: cross sections

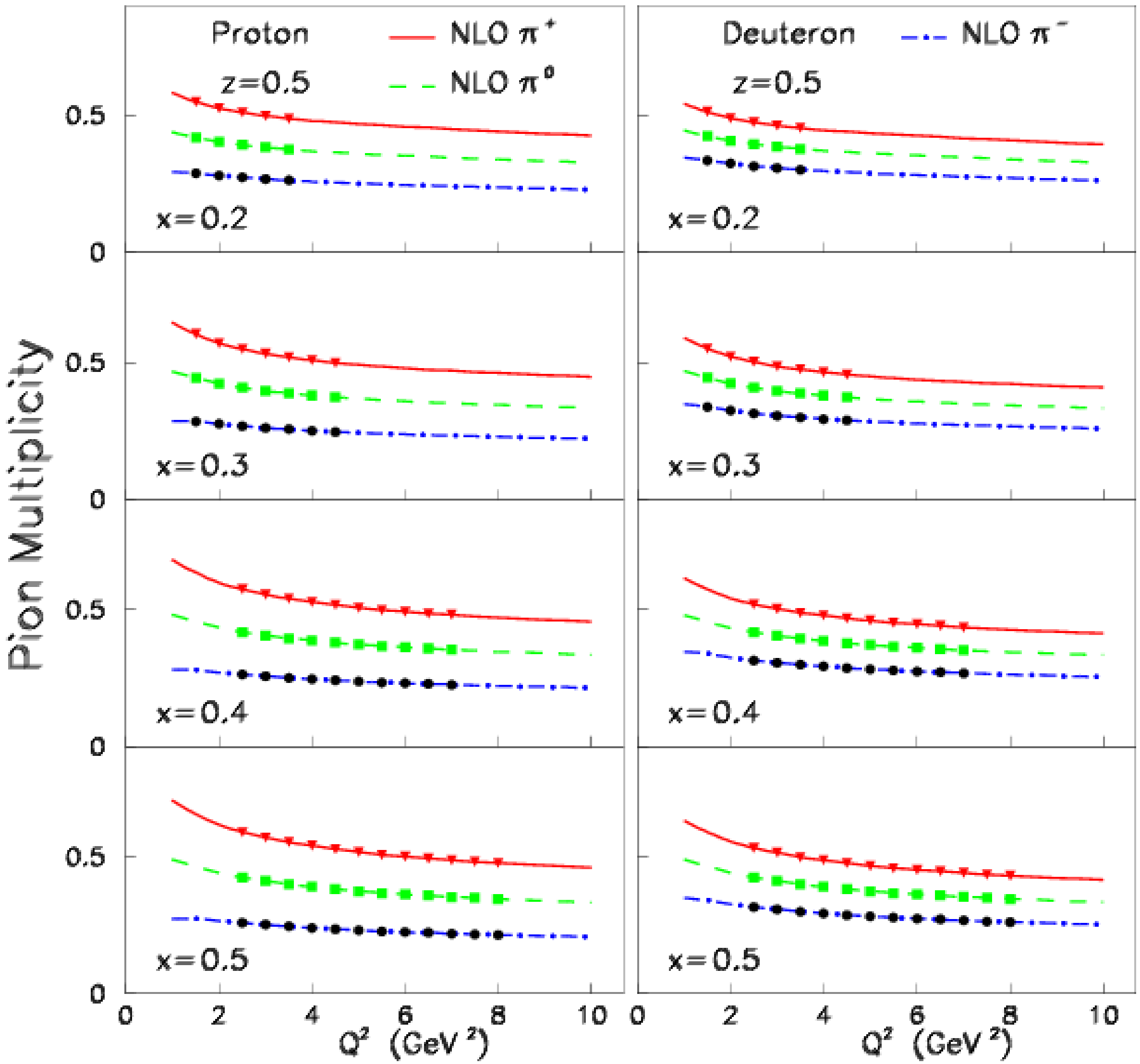


$x=0.32$, $Q^2=2.3$ GeV^2.

smooth in $0.4<z<0.65$

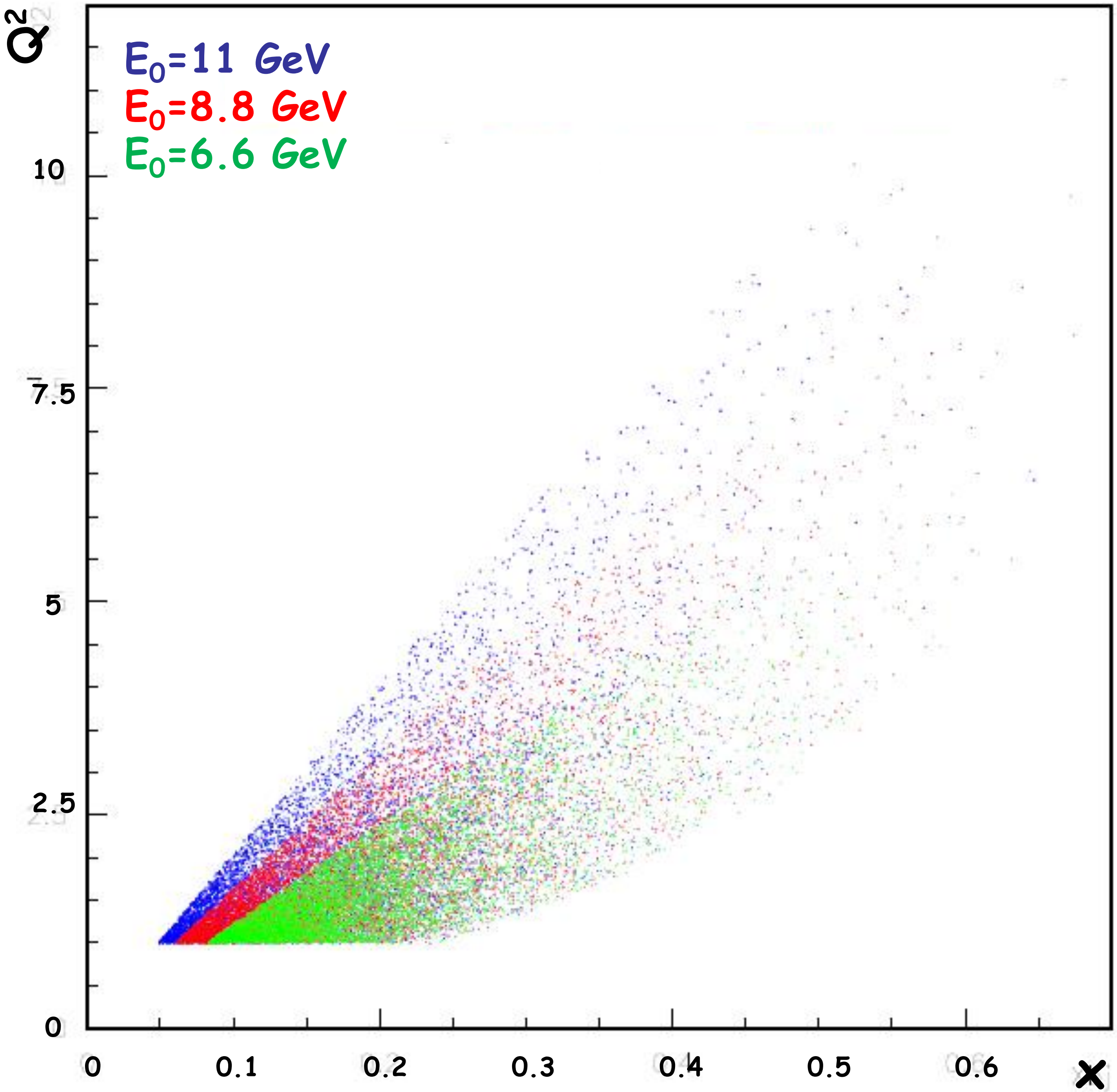
agree with LO calculations.

Expected results: Q2 dependence



Curves: predictions from NLO, R. Sassot et al.

z=0.5,
x=0.2,0.3,0.4,0.5



(x, Q^2) coverage.

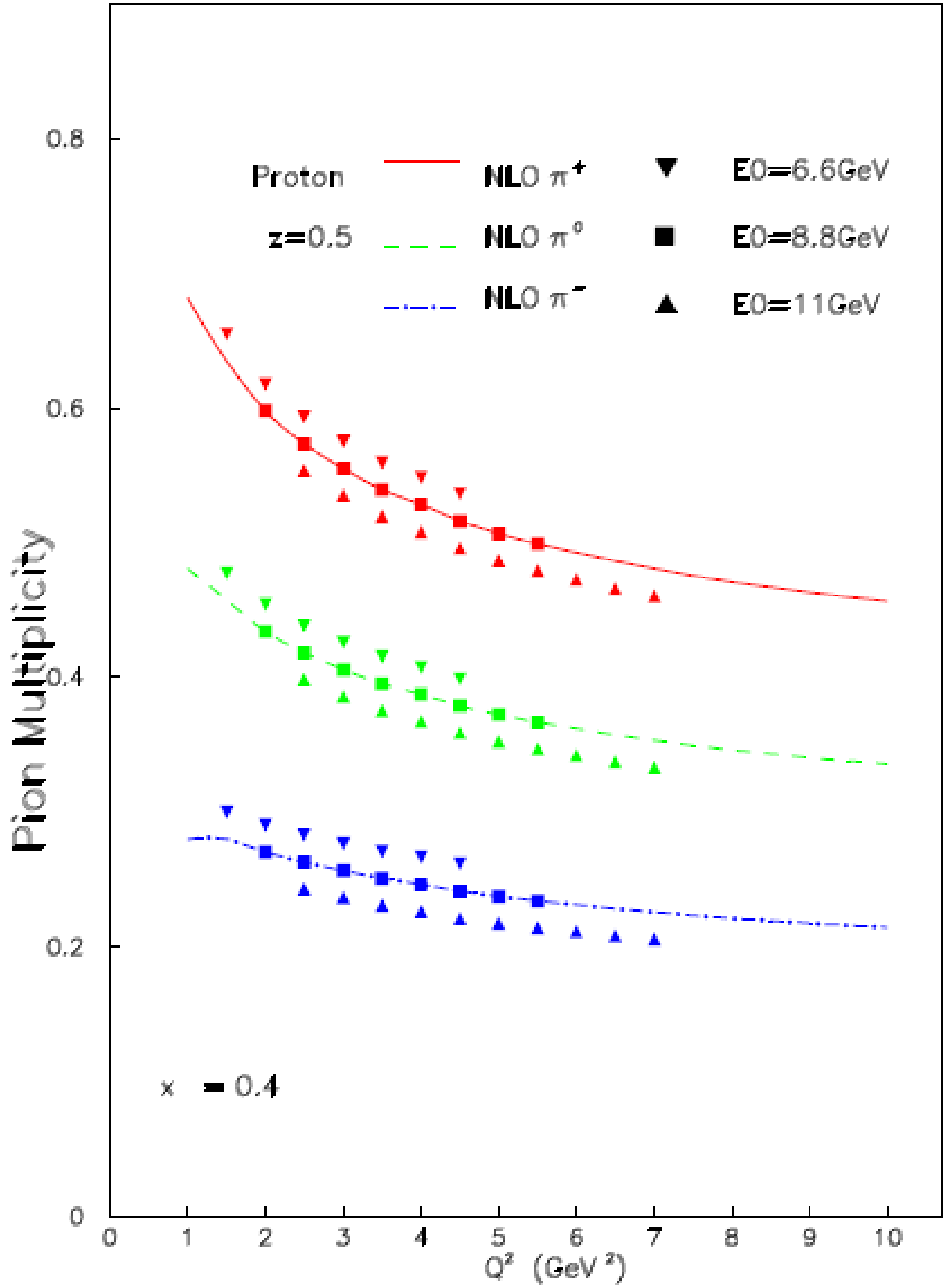
with beam energy 11,8.8 and 6.6 GeV

$Q^2 > 1.0$ GeV^2

$W > 2.0$ GeV

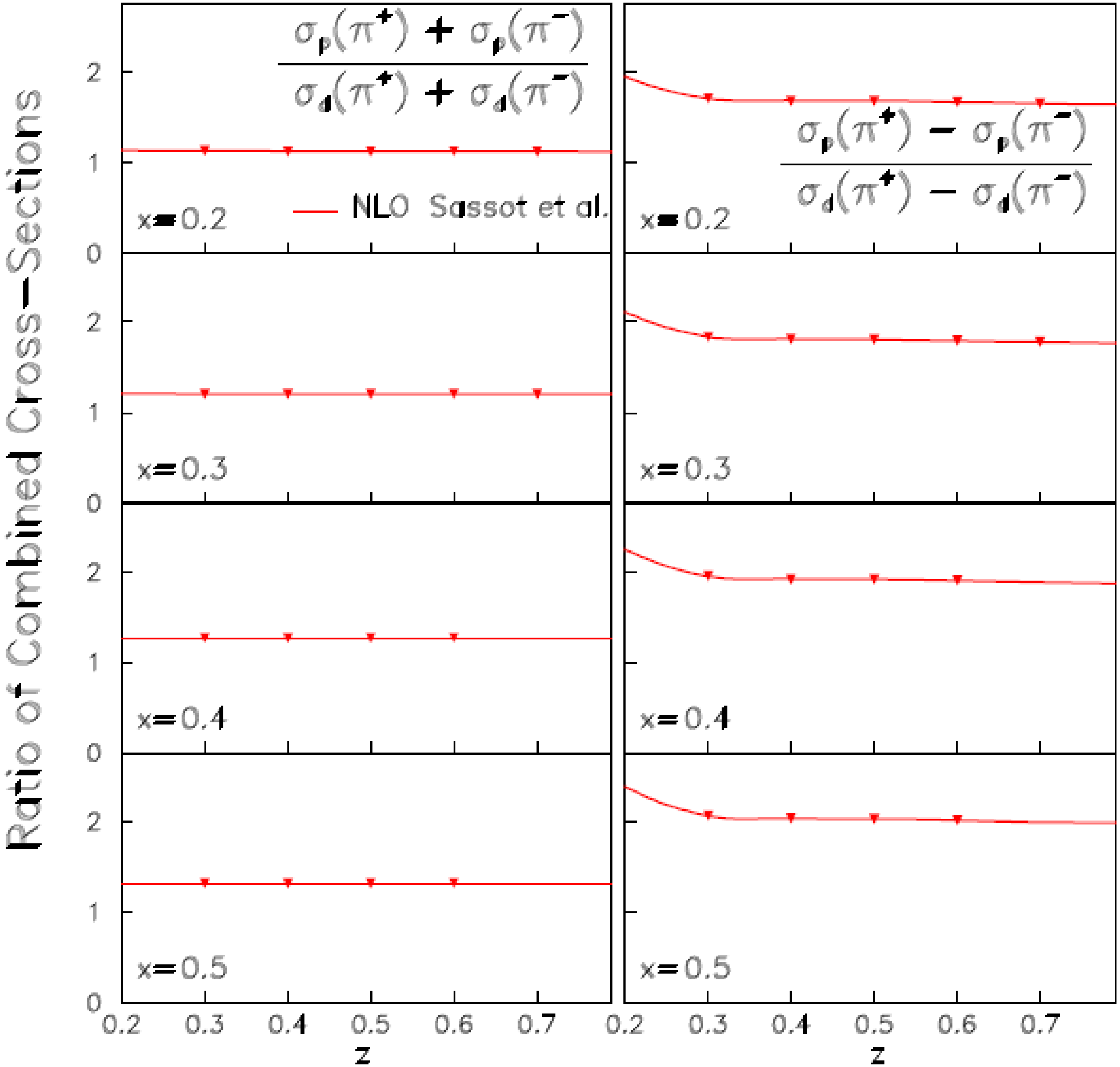
$W' > 1.5$ GeV

$X_F > 0$



Q^2-dependence , same Q^2 point covered by different beam energy.

Combined-ratio of multiplicities



At LO no z-dependency. SU(2) symmetry in pdf and F.F.

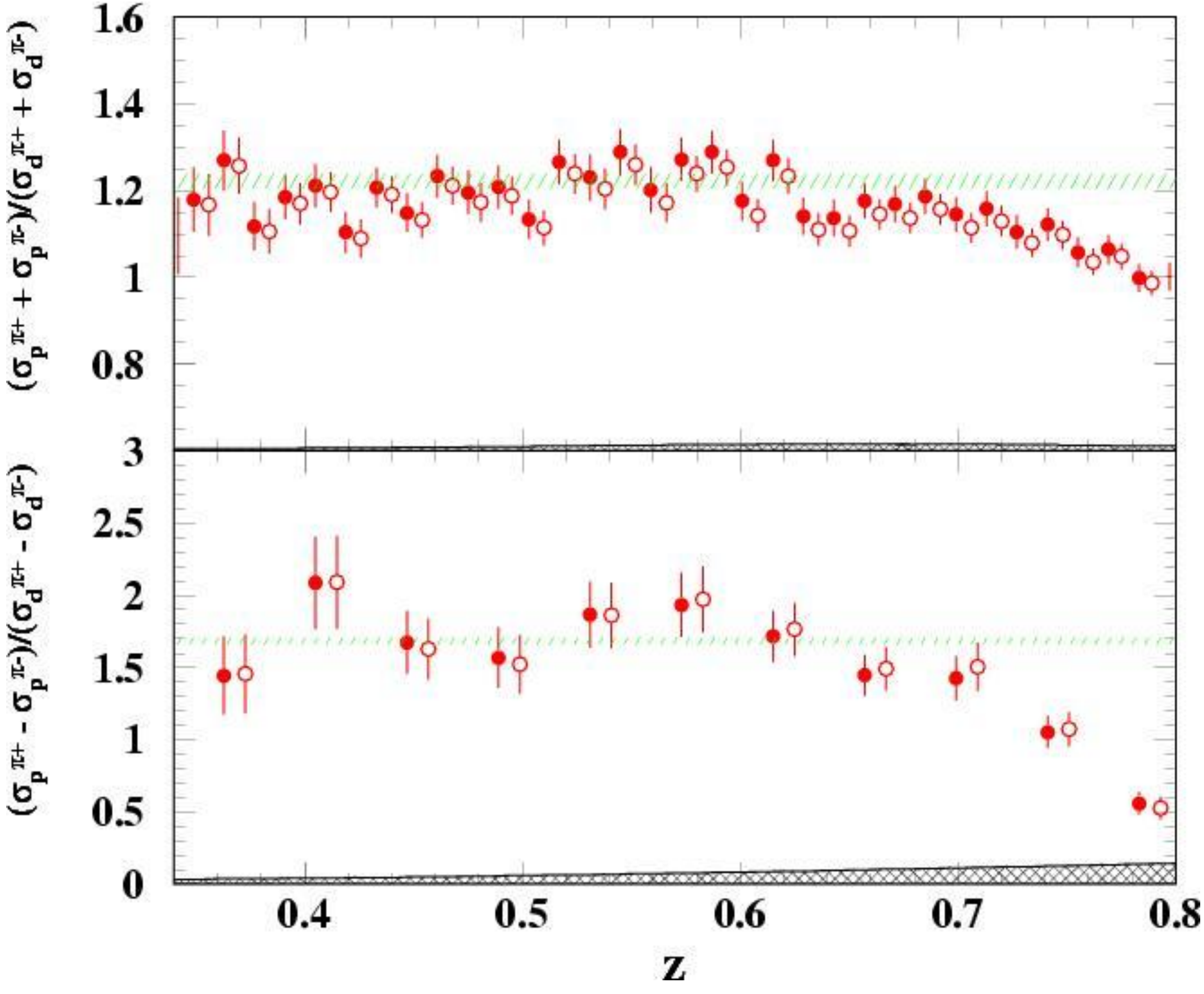
Even at NLO, z-dependency mostly canceled in the ratio.

ratios become completely determined by parton distributions.

A clear evidence to prove that parton information is preserved in the fragmentation process.

At 5.5 GeV, we already know from Hall C data …

Hall C data at 5.5 GeV: combined-ratio of multiplicities



X=0.32, Q^2=2.3 GeV^2.

Flat in 0.4<z<0.7

Agree with LO parton distribution ratios.

and the reason is …

Neglect sea quarks and assume no p_t dependence of parton distribution functions

→ Fragmentation functions drop out at Leading Order, due to SU(2) symmetry.

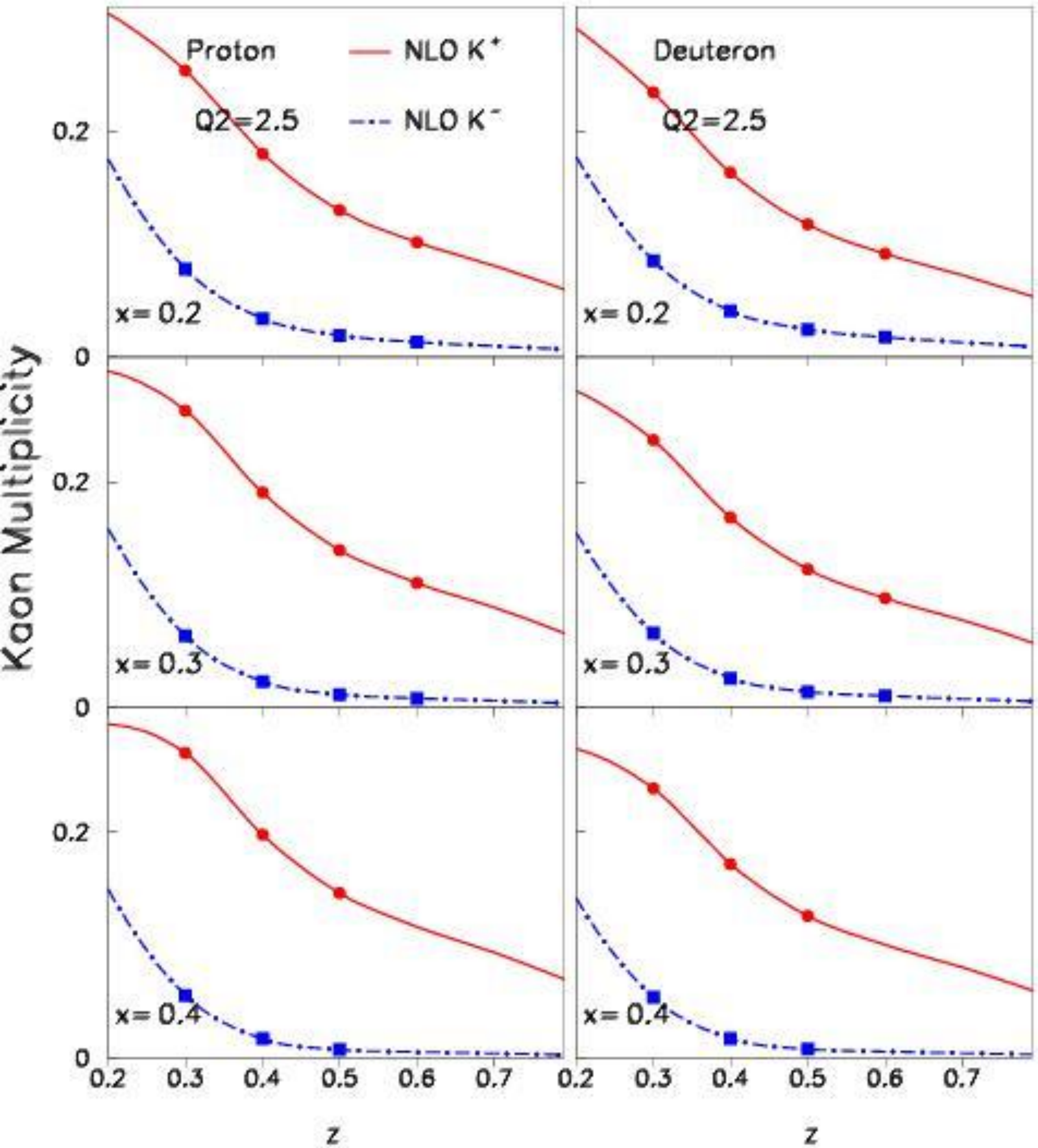
→ $[\sigma_p(\pi^+) + \sigma_p(\pi^-)]/[\sigma_d(\pi^+) + \sigma_d(\pi^-)]$

$= [4u(x) + d(x)]/[5(u(x) + d(x))]$ *independent of z.*

→ $[\sigma_p(\pi^+) - \sigma_p(\pi^-)]/[\sigma_d(\pi^+) - \sigma_d(\pi^-)]$

$= [4u(x) - d(x)]/[3(u(x) + d(x))]$ *independent of z .*

Kaon multiplicities



Cut on P_K<3.0 GeV/c, no RICH.

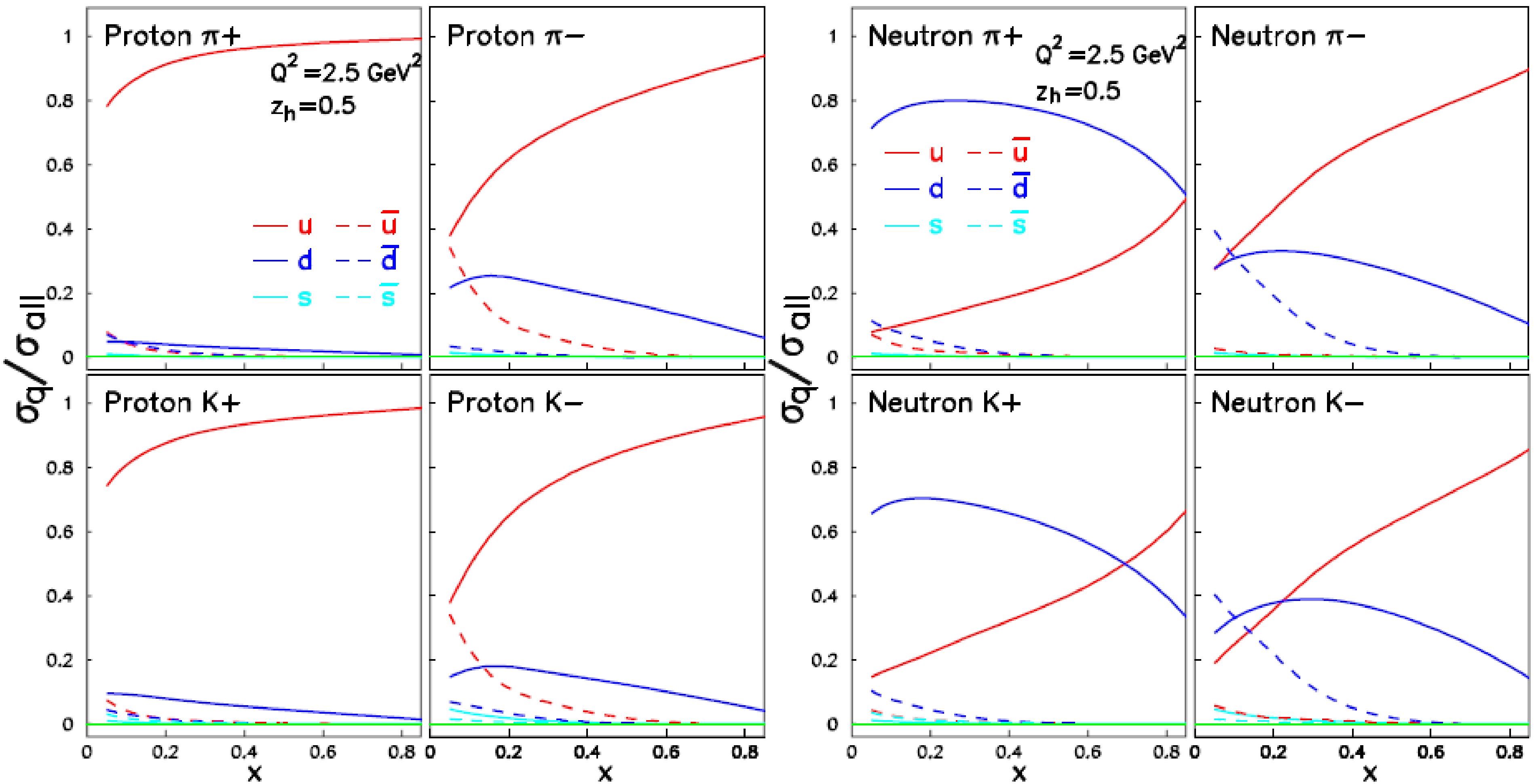
A planned RICH detector helps in:

1. Eliminate π contamination.
2. Expand coverage to high-z, to study the transition to exclusive KY channels.

Kaon from the hit-quark ?
Any hope to access s-quark information ?

Need a detailed understanding of cross sections to ~2% level.

Recall LO Cross Sections, contributions from each quark flavor.



$$\sigma_q/\sigma_{all} = e_f^2 q_f \cdot D_f^h / \sum_i e_i^2 q_i \cdot D_i^h \qquad (@z_h = 0.5)$$

A list of questions in SIDIS

- π Frag. Func. agree with e^+e^-, p+p data ?
- Fragmentation to other mesons: η, K_s^0, ρ, ω and ϕ. Ratio π^0/η.
- Connection between Frag. Func. to hadron structure.
- ϕ(s-sbar) in SIDIS carry information of s-quarks ? What about spin asymmetries, Sivers asymmetries ?
- Transition from SIDIS to the exclusive limit, a theory picture ?
- Λ production and Λ polarization. Spin-transfer, induced polarization, transverse spin asymmetry to access quark transversity.

Summary

- SIDIS@JLab-12GeV offers many new physics opportunities.
- Firmly establish the baseline of interpretation is the critical step.

- Understanding cross sections of π-production to NLO level is the first step.