The longitudinal double-spin asymmetries in semi-inclusive deep-inelastic scattering of electrons and positron by protons and deuterons

Polina Kravchenko
on behalf of HERMES collaboration

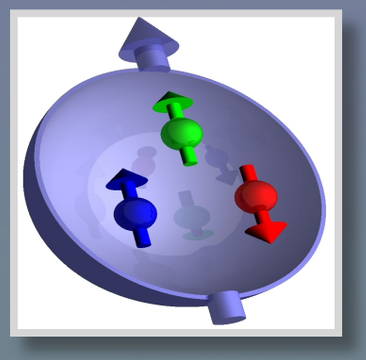
Motivation

DSA as an observable for helicity distribution extraction

Experimental results

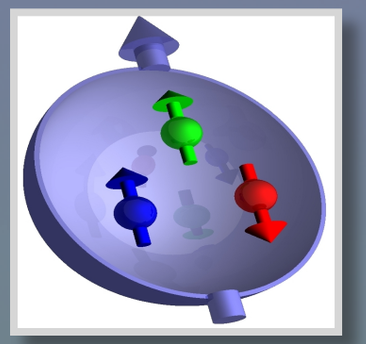
Summary

Proton structure



- looks simple in static quark model

Proton structure



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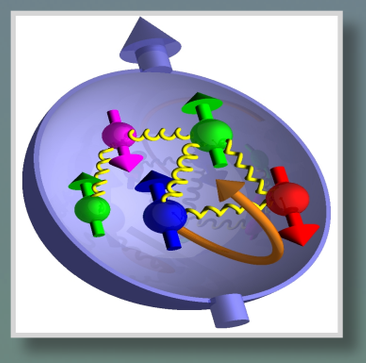

- much more complicated in QCD

See talk J.Qiu on Monday

Motivation I

Where does the Nucleon Spin come from?

$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$

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Motivation II

Polarization-depedent structure of the nucleon

- unpolarized $q(x)$, $g(x)$
- helicity $\Delta q(x)$, $\Delta g(x)$
- transversity $\Delta_T q(x)$
- Transverse Momentum dependent (TMD) distributions
- Generalized Parton (GPDs) distributions

Focus in this talk: nucleon helicity structure

Helicity distributions

- What do we know? $\Delta\Sigma \sim 0.3$
- But how do the different $\Delta q(x)$, $q=u,d,s,...$ look like?
- How they can be measured?

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Find a process where one probes
interaction with quark of a given polarization
with respect to the parent nucleon

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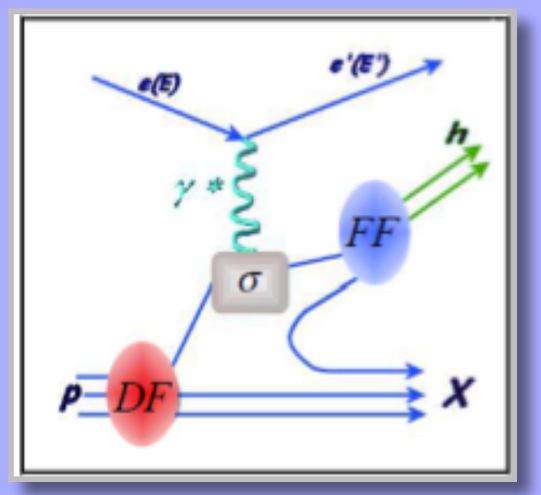

Semi-inclusive Deep-Inelastic Scattering

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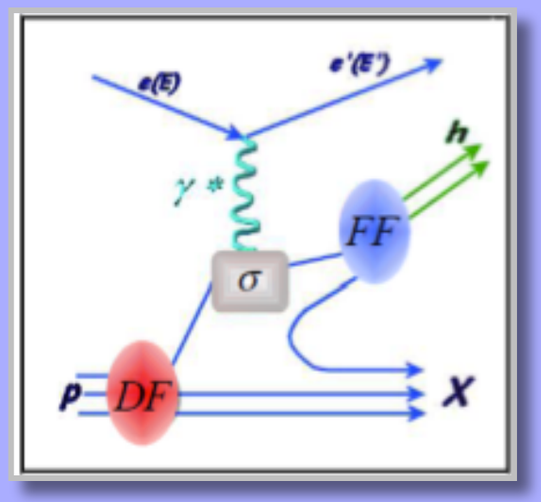

Semi-inclusive Deep-Inelastic Scattering

The possible contributions to the DIS cross section in the semi-inclusive measurement

$$\sigma^h = \sigma^h_{UU} + \lambda_l \sigma^h_{LU} + S_L \sigma^h_{UL} + \lambda_l S_L \sigma^h_{LL} + S_T \sigma^h_{UT} + \lambda_l S_T \sigma^h_{LT}$$

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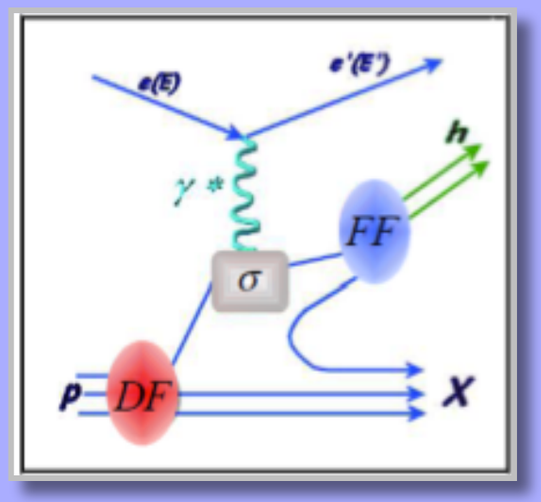

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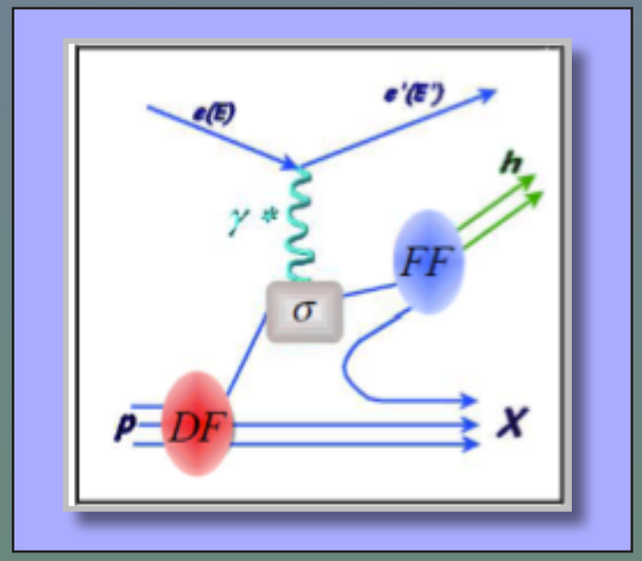
two structure functions appear

$$S_L \lambda_l \left[\sqrt{1-\epsilon^2} F_{LL} + \sqrt{2\epsilon(1-\epsilon)} cos(\phi) F^{cos\phi}_{LL} \right.$$

HERMES experiment

See talk G.Schnell on Wednesday



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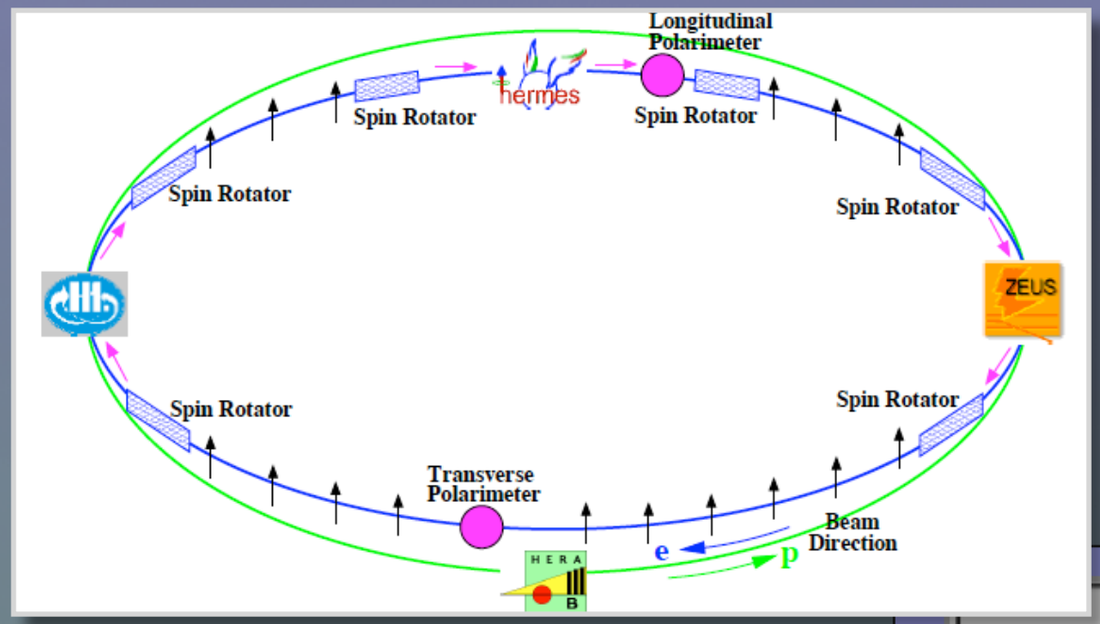
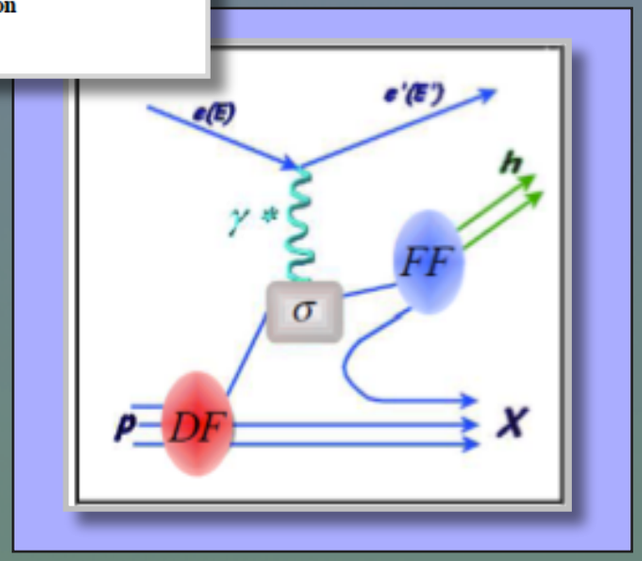
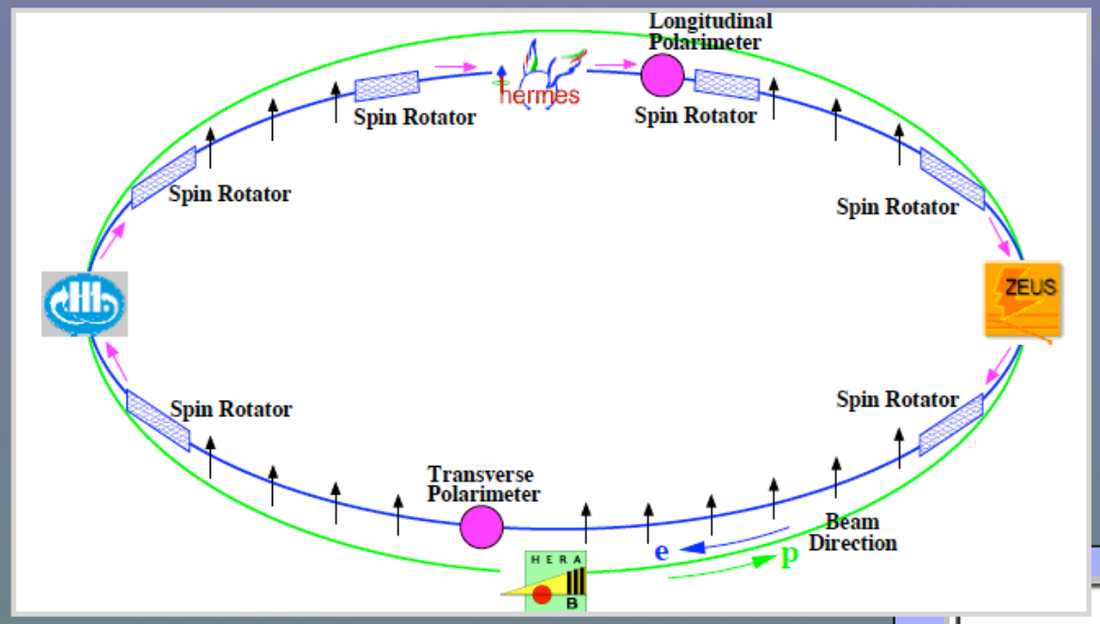


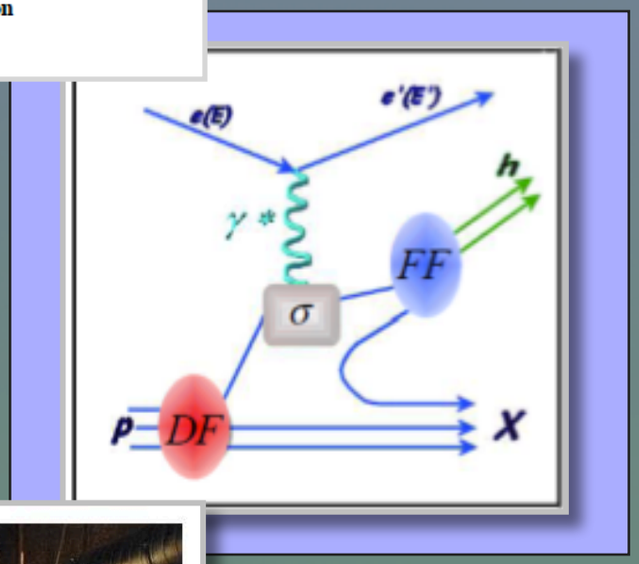


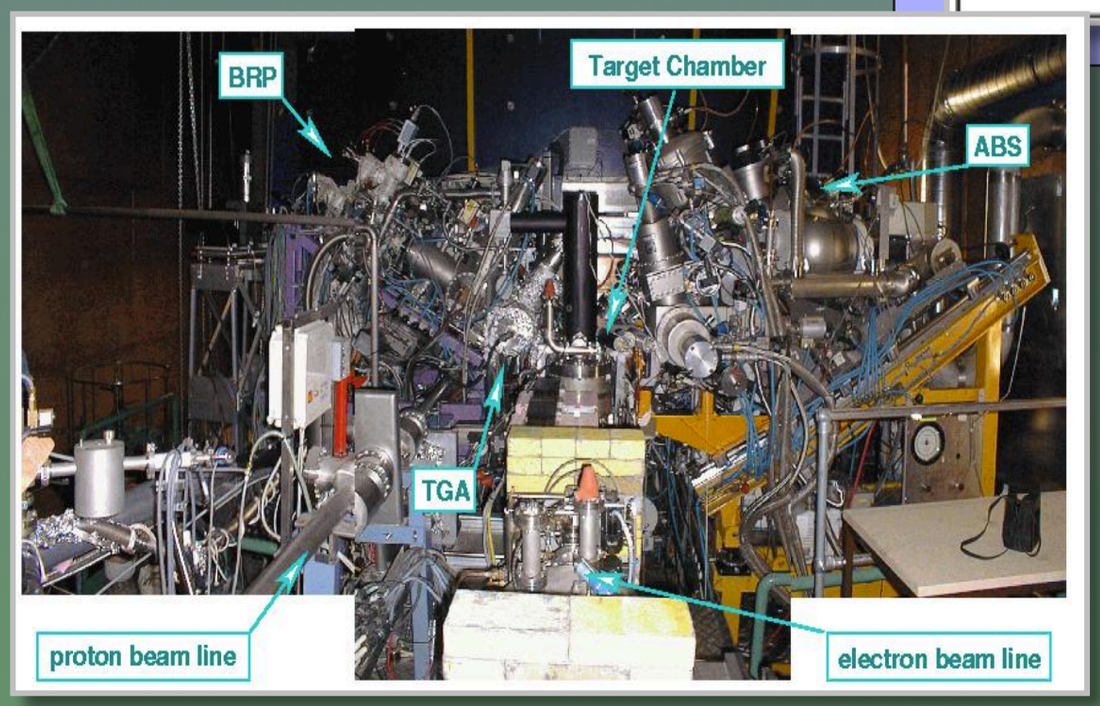
HERA positron beam properties:

- E_e=27.6GeV, I_e<50mA, P_b=0.55
- lifetime=12-14h
- transversely polarized e± in storage ring
- polarization build-up by emission of synchrotron radiation (Sokolov-Ternov effect)
- Spin rotators around HERMES IP

HERMES experiment





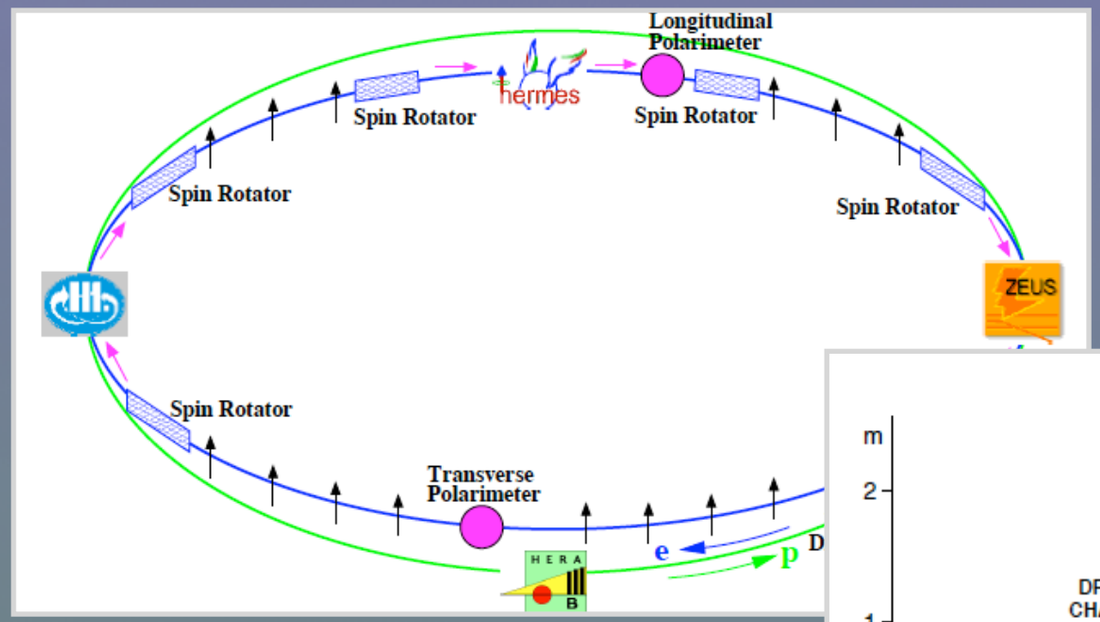


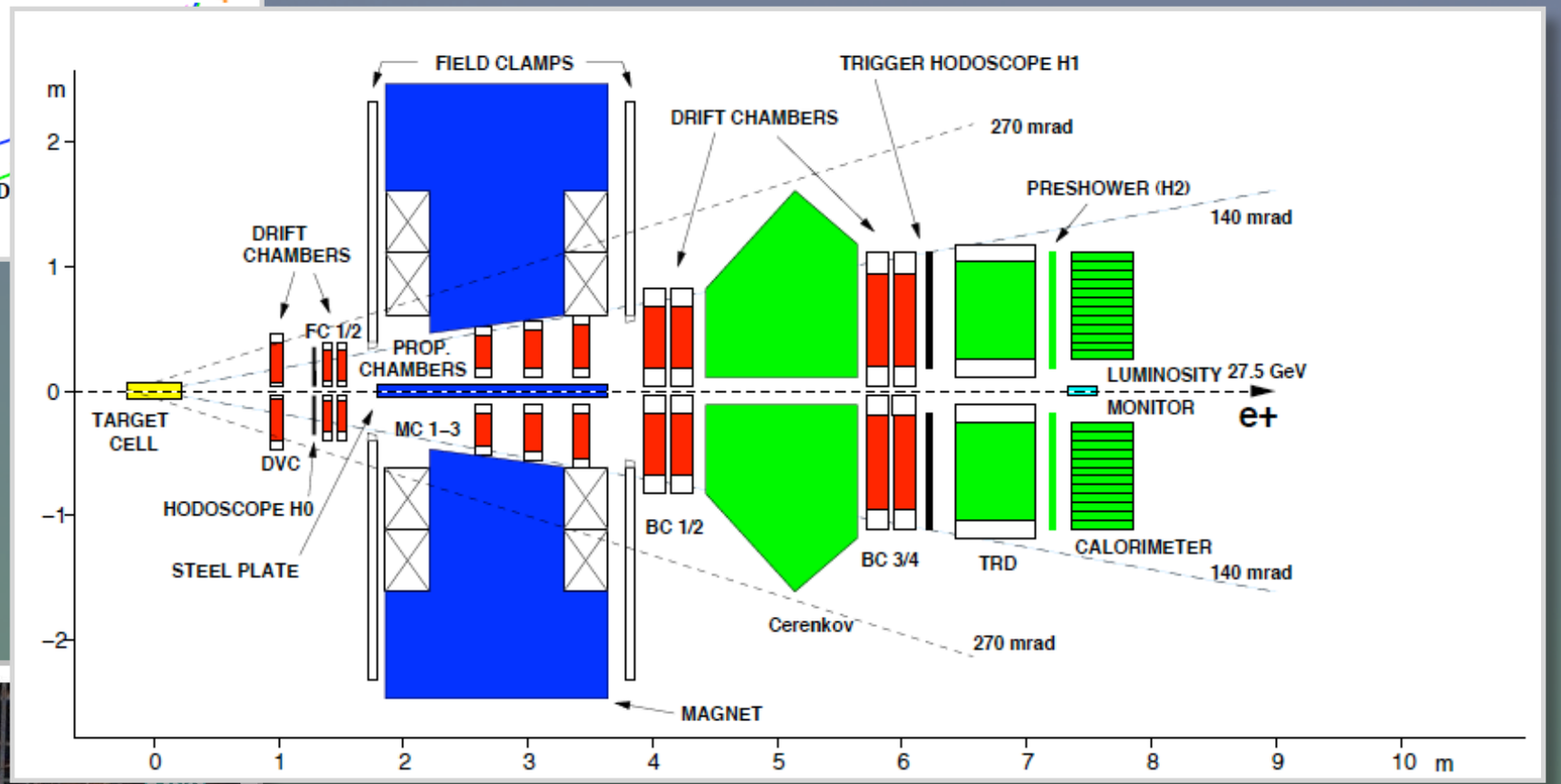
Typical HERMES target properties :

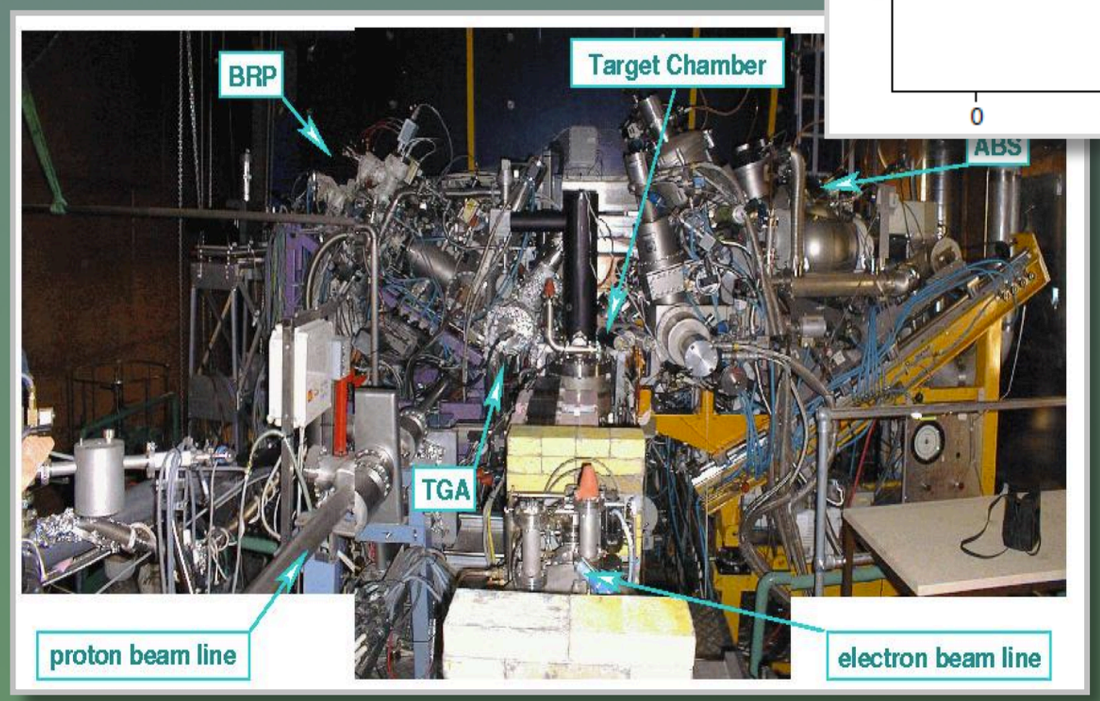
- P_t~0.85; polarized $H^{\uparrow\rightarrow}$, $D^{\rightarrow}$
- dilution factor=1
- Thickness =10^{14}-10^{15} nucl/cm^2
- Temperature=100K

internal to the HERA storage ring

HERMES experiment

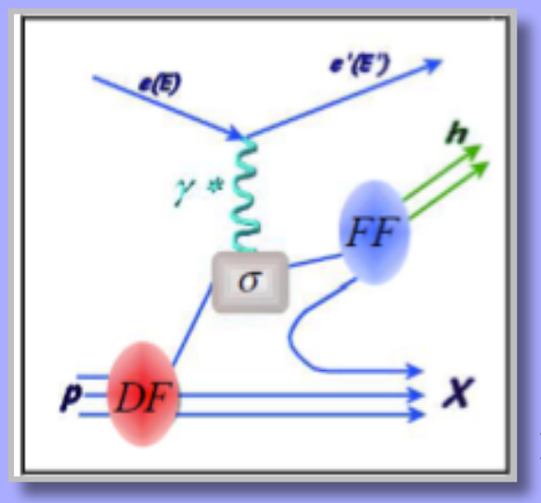




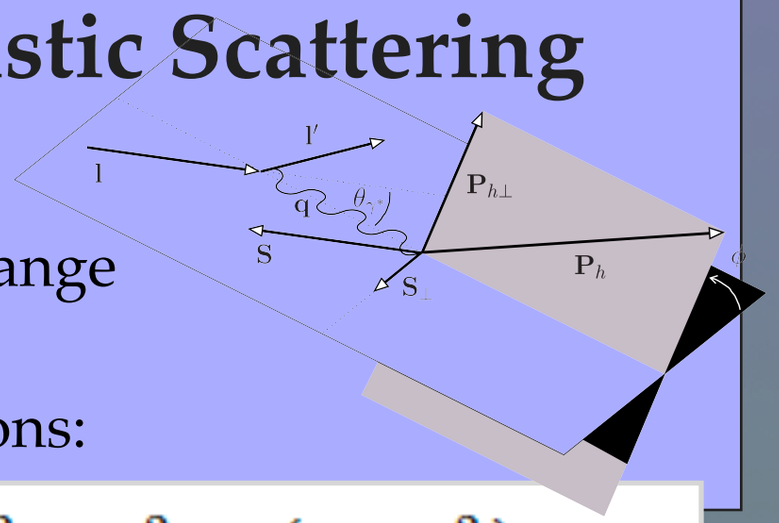


- **Tracking:** Drift Vertex Chambers, Front Chambers, Magnet Chambers, Back Chambers
- **Particle Identification:**

Čerenkov (RICH) Detector, Transition Radiation Detector, Preshower, Calorimeter
Luminosity Monitor (Bhabha / Møller scattering)



Semi-inclusive Deep-Inelastic Scattering



SIDIS cross section in the one-photon-exchange approximation
in term of moments of azimuthal modulations:

$$\frac{\mathrm{d}\sigma^h}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}P_{h\perp}^2\,\mathrm{d}\phi} = \frac{2\pi\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$
$$\Big\{F_{UU,T}^h + \epsilon F_{UU,L}^h + \lambda\Lambda\sqrt{1-\epsilon^2}F_{LL}^h$$
$$+\sqrt{2\epsilon}\left[\lambda\sqrt{1-\epsilon}\,F_{LU}^{h,\sin\phi} + \Lambda\sqrt{1+\epsilon}\,F_{UL}^{h,\sin\phi}\right]\sin\phi$$
$$+\sqrt{2\epsilon}\left[\lambda\Lambda\sqrt{1-\epsilon}\,F_{LL}^{h,\cos\phi} + \sqrt{1+\epsilon}\,F_{UU}^{h,\cos\phi}\right]\cos\phi$$
$$\ldots\phi + \epsilon\,F_{UU}^{h,\cos 2\phi}\cos 2\phi\Big\}$$

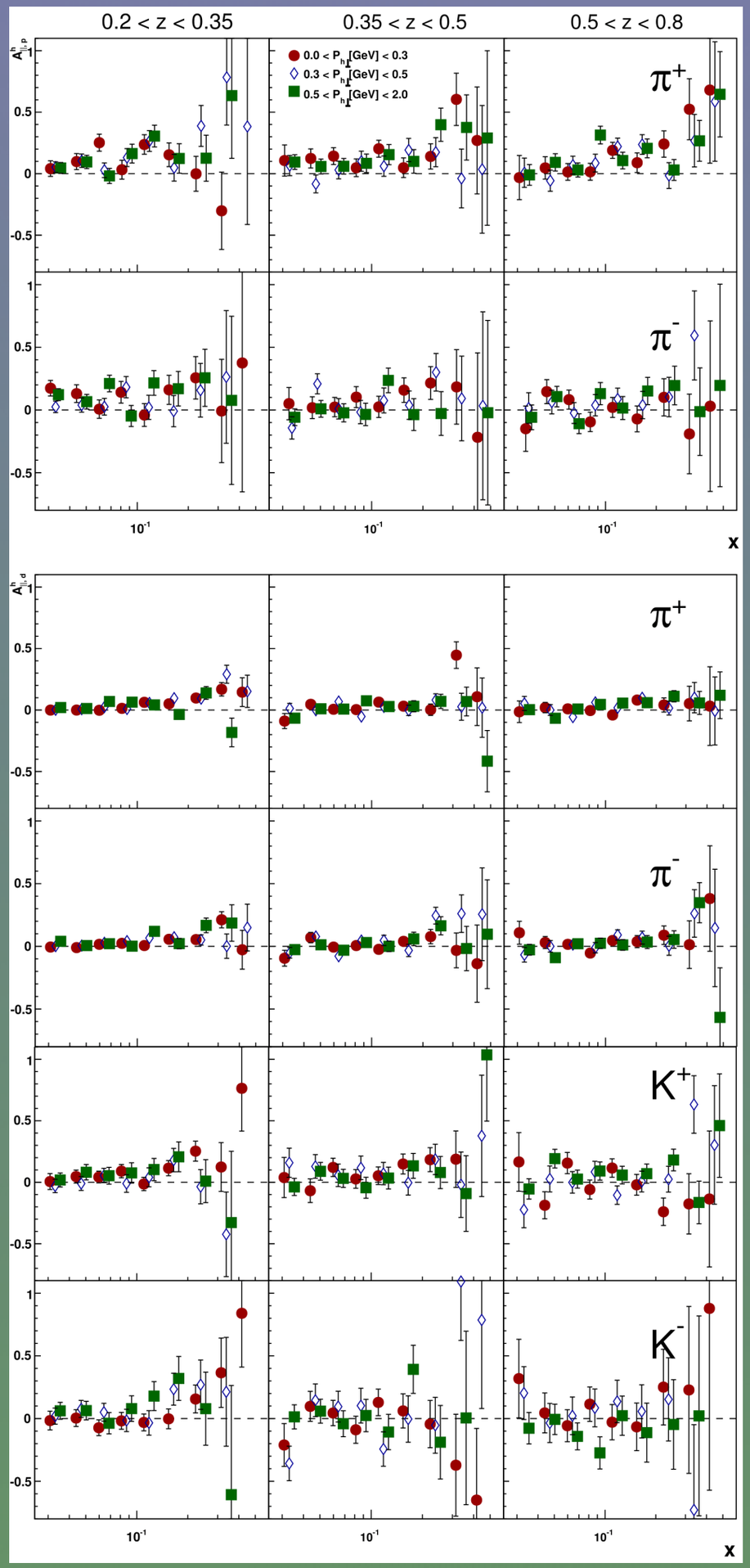
In the limit of small hadron momentum $P_{h\perp} \ll zQ$

$$F_{LL}^h \propto \sum_q e_q^2 [g_{1L}^q(x,p_T^2) \otimes \mathcal{W}_1 D_1^{q\to h}(z,k_T^2)]$$

$$A_{LL}^h = \frac{1}{\lambda_l S_L}\frac{d\sigma_h^{\vec{\Leftarrow}}(\phi) - d\sigma_h^{\vec{\Rightarrow}}(\phi)}{d\sigma_h^{\vec{\Leftarrow}}(\phi) + d\sigma_h^{\vec{\Rightarrow}}(\phi)}$$

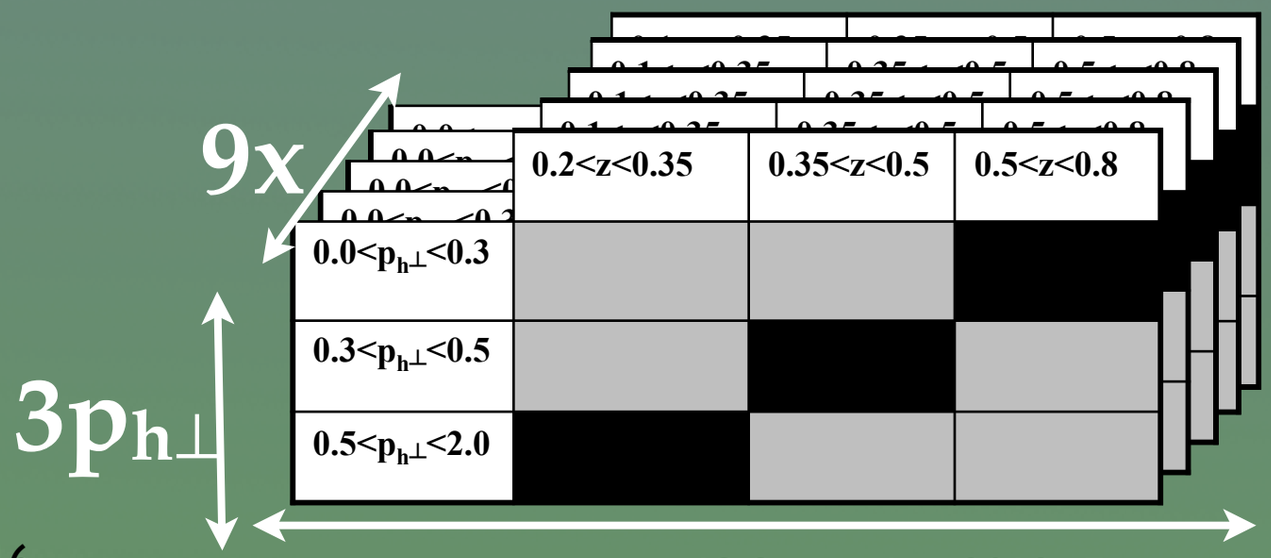
Helicity distributions $\Delta q(x)$

3D binned asymmetry $A_1(x,z,p_{h\perp})$

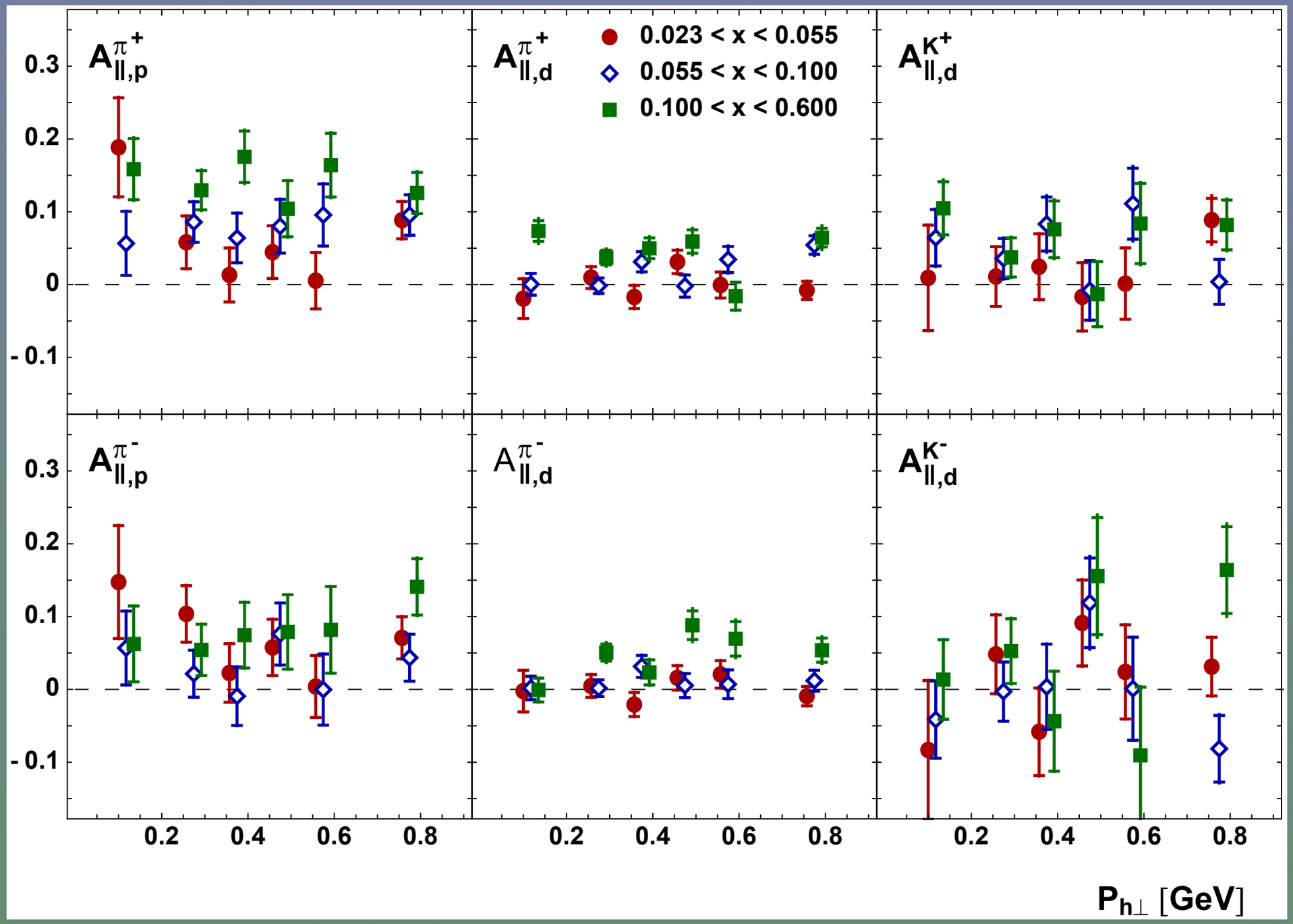


Provide a dataset of semi-inclusive asymmetries binned simultaneously in x, z, and $p_{h\perp}$

to better isolate different regions of fragmentation

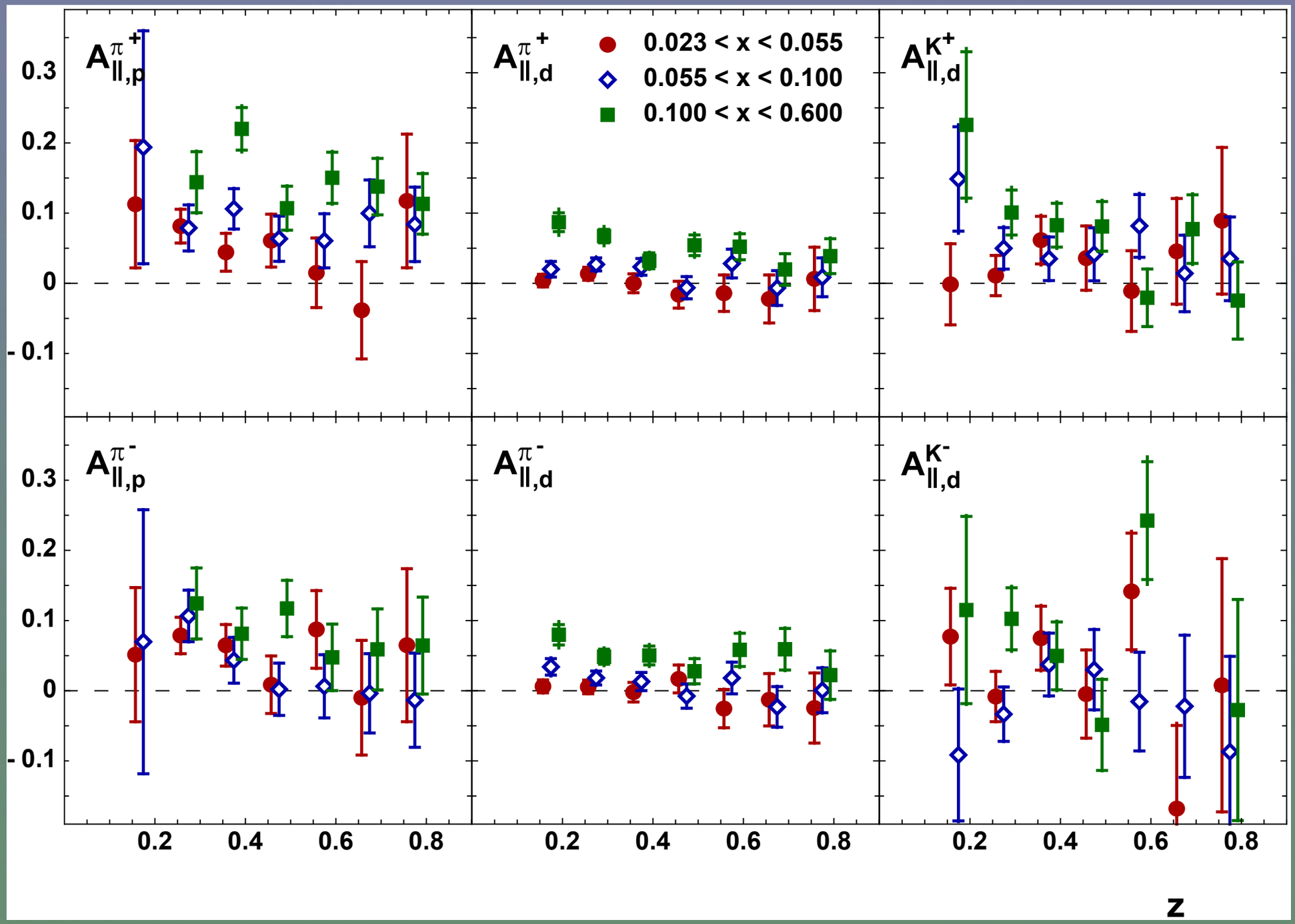


2D binned asymmetry $A_1(x, p_{h\perp})$

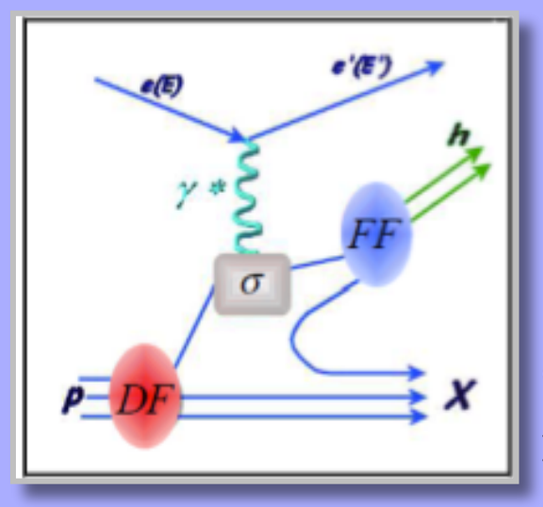


No significant $p_{h\perp}$ dependence observed

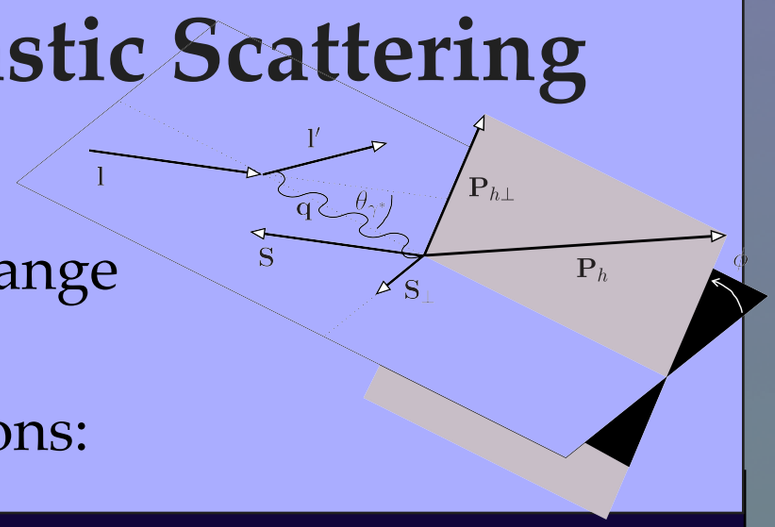
2D binned asymmetry $A_1(x,z)$



No significant z dependence observed



Semi-inclusive Deep-Inelastic Scattering



SIDIS cross section in the one-photon-exchange approximation
in term of moments of azimuthal modulations:

ϕ angle is the azimuthal angle of the hadron plane around the virtual-photon direction

Taking the Wandzura-Wilczek approximation

$$F_{LL}^{h,cos\phi} \propto \frac{M}{Q} \sum_q e_q^2 [g_{1L}^q(x, p_T^2) \otimes \mathcal{W}_2 D_1^{q \to h}(z, k_T^2)]$$

Unintegrated helicity distributions $\Delta q(x,k_\perp)$

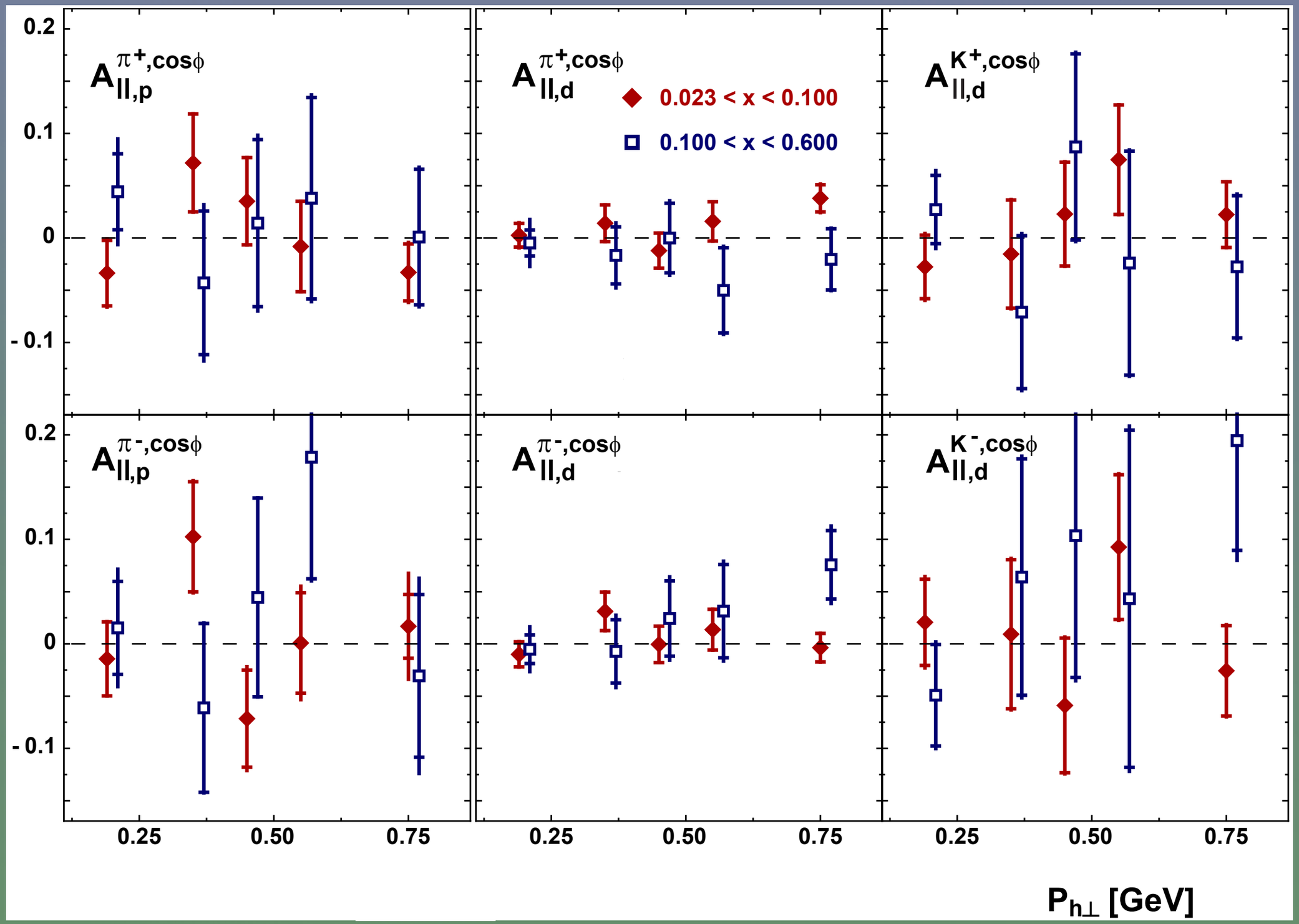
$$\frac{\mathrm{d}\sigma^h}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}P_{h\perp}^2\,\mathrm{d}\phi} = \frac{2\pi\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\left.\begin{aligned} &+\sqrt{2\epsilon}\left[\lambda\sqrt{1-\epsilon}\,F_{LU}^{h,\sin\phi} + \Lambda\sqrt{1+\epsilon}\,F_{UL}^{h,\sin\phi}\right]\sin\phi \\ &+\sqrt{2\epsilon}\left[\lambda\Lambda\sqrt{1-\epsilon}\,F_{LL}^{h,\cos\phi} + \sqrt{1+\epsilon}\,F_{UU}^{h,\cos\phi}\right]\cos\phi \\ &+\Lambda\epsilon\,F_{UL}^{h,\sin 2\phi}\sin 2\phi + \epsilon\,F_{UU}^{h,\cos 2\phi}\cos 2\phi \end{aligned}\right\}. \quad (1$$

To access

$$A_{LL}^h = \frac{1}{\lambda_l S_L}\frac{d\sigma_h^{\vec{\Leftarrow}}(\phi) - d\sigma_h^{\vec{\Rightarrow}}(\phi)}{d\sigma_h^{\vec{\Leftarrow}}(\phi) + d\sigma_h^{\vec{\Rightarrow}}(\phi)} = A_{LL}^h(x,y,z,p_{h\perp}) + cos\phi A_{LL}^{cos\phi}(x,y,z,p_{h\perp})$$

cos ϕ moments of semi-inclusive double spin asymmetry $A_{LL}(p_{h\perp}, x)$

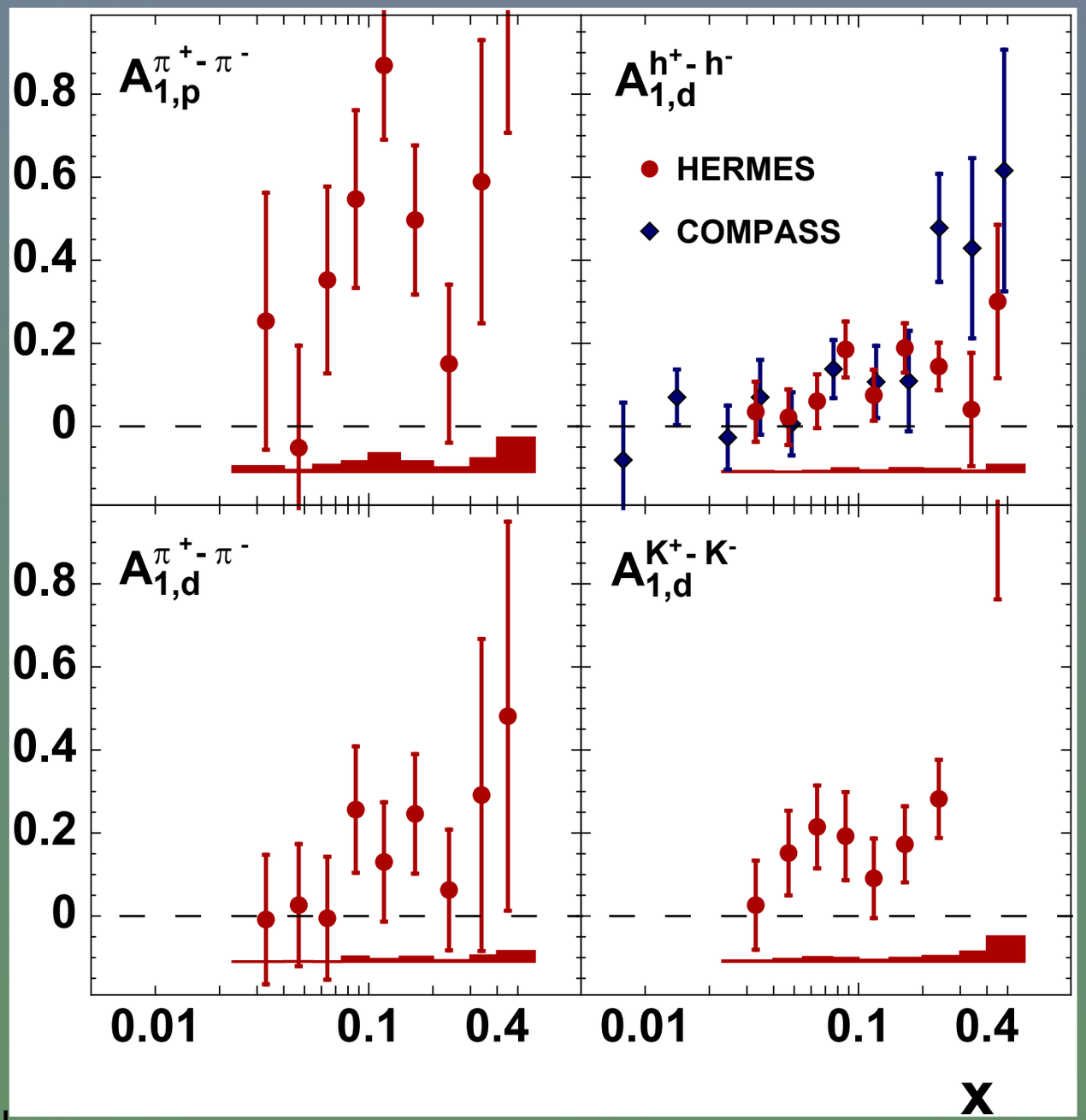


Hadron charge difference asymmetry

$$A_1^{h^+-h^-} = \frac{(d\sigma^{\rightarrow}_{h^+\Leftarrow} - d\sigma^{\rightarrow}_{h^-\Leftarrow}) - (d\sigma^{\rightarrow}_{h^+\Rightarrow} - d\sigma^{\rightarrow}_{h^-\Rightarrow})}{(d\sigma^{\rightarrow}_{h^+\Leftarrow} - d\sigma^{\rightarrow}_{h^-\Leftarrow}) + (d\sigma^{\rightarrow}_{h^+\Rightarrow} - d\sigma^{\rightarrow}_{h^-\Rightarrow})}$$

Provides additional spin-structure information

Smaller error bars on the kaon sample due to larger difference in kaon yields



Valence helicity distributions

Assuming charge conjugation symmetry

$$D_1^{q\to h^+} = D_1^{\bar{q}\to h^-}$$

and isospin symmetry

$$D_1^{u\to \pi^+} = D_1^{d\to \pi^-} \qquad D_1^{u\to \pi^-} = D_1^{d\to \pi^+}$$

Valence helicity distributions

Assuming charge conjugation symmetry

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Deuteron target

$$A_{1,d}^{h^+-h^-} \underset{=}{LO\ LT} \frac{g_1^{u_v} + g_1^{d_v}}{f_1^{u_v} + f_1^{d_v}}$$

helicity valence-quark distribution

$$g_1^{q_v} \equiv g_1^q - g_1^{\bar{q}}$$

and isospin symmetry

$$D_1^{u\to\pi^+} = D_1^{d\to\pi^-} \qquad D_1^{u\to\pi^-} = D_1^{d\to\pi^+}$$

Proton target

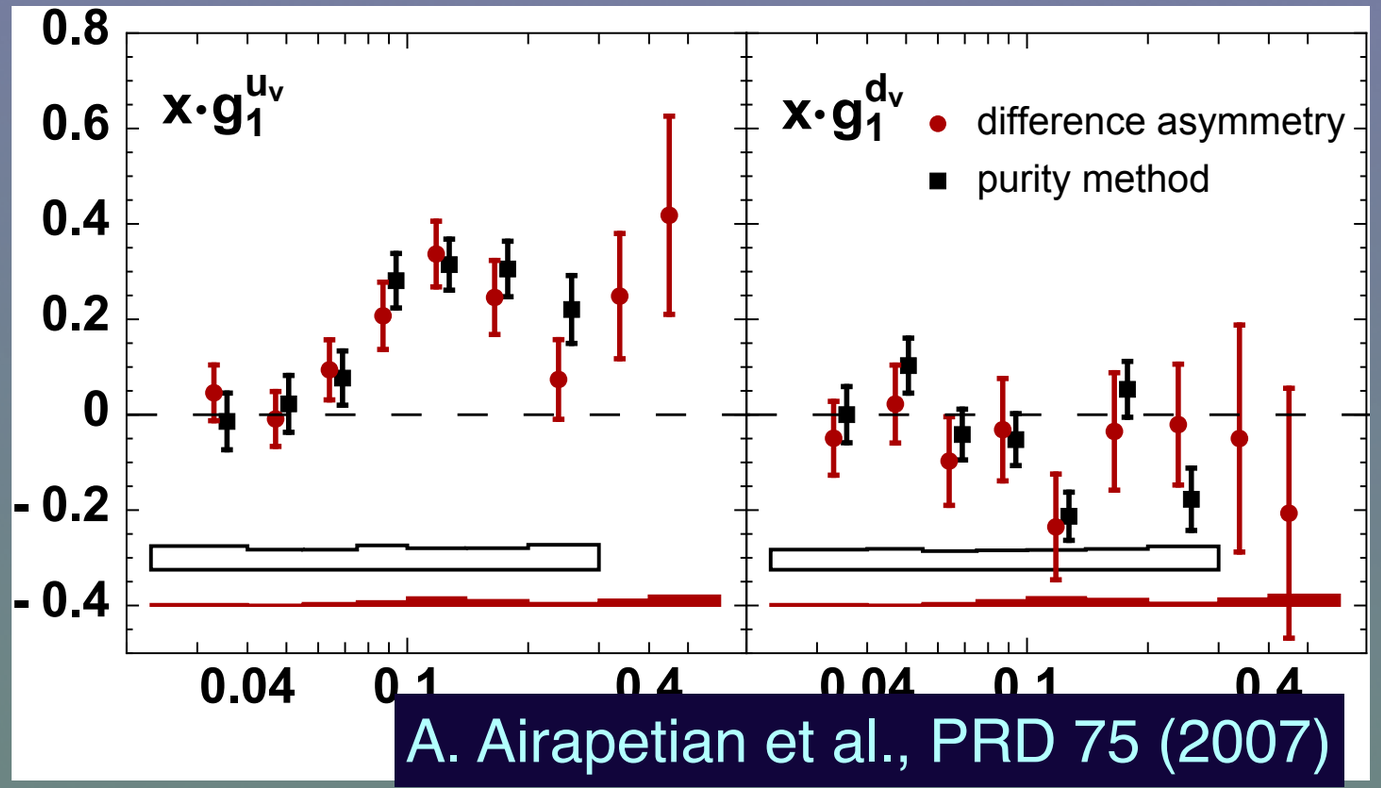
$$A_{1,p}^{h^+-h^-} \underset{=}{LO\ LT} \frac{4g_1^{u_v} - g_1^{d_v}}{4f_1^{u_v} - f_1^{d_v}}$$

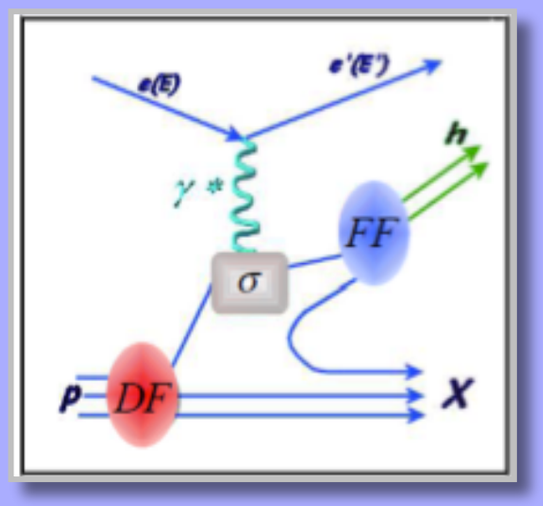
polarization average valence-quark distribution

$$f_1^{q_v} \equiv f_1^q - f_1^{\bar{q}}$$

Valence helicity distributions

- LO parton model
- Charge conjugation
- Isospin symmetry
- No MC usage
- The contribution of FF drop out





Semi-inclusive Deep-Inelastic Scattering

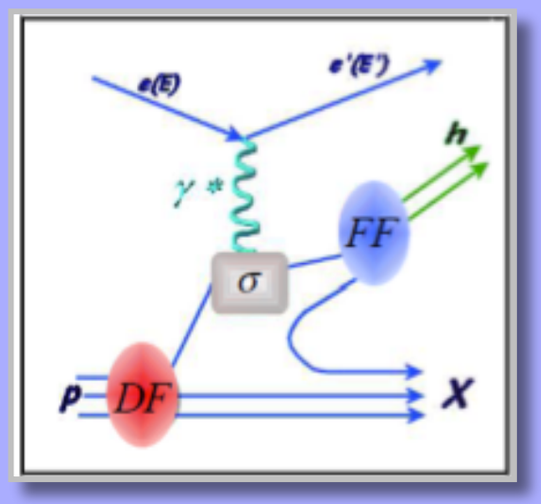
Method (Flavor tagging):
Use correlation between detected hadron and struck quark → **'LO Purity method'**

Observable: semi-inclusive double-spin asymmetry

A. Airapetian et al., PRD 75 (2007)

$$A_1^h(x,Q^2) \overset{LO}{\sim} \frac{\sum_q e_q^2 \Delta q(x,Q^2) \int dz D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) \int dz D_q^h(z,Q^2)}$$

$$\sim \sum_q \underbrace{\frac{e_q^2 q(x) \int dz D_q^h(z)}{\sum_{q'} e_{q'}^2 q' \int dz D_{q'}^h(z)}} \cdot \underbrace{\frac{\Delta q(x)}{q(x)}} \sim P_q^h \frac{\Delta q}{q}$$



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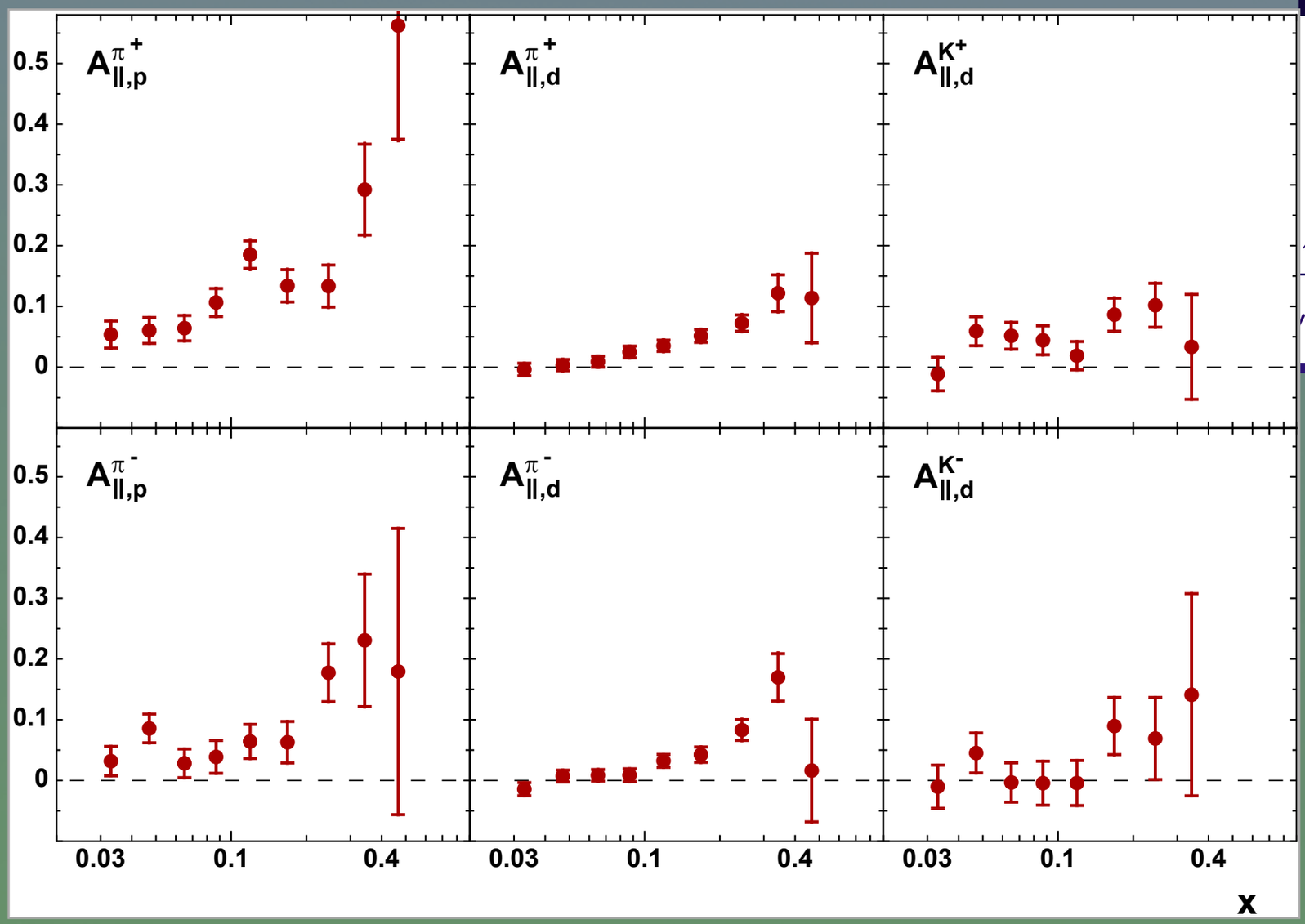
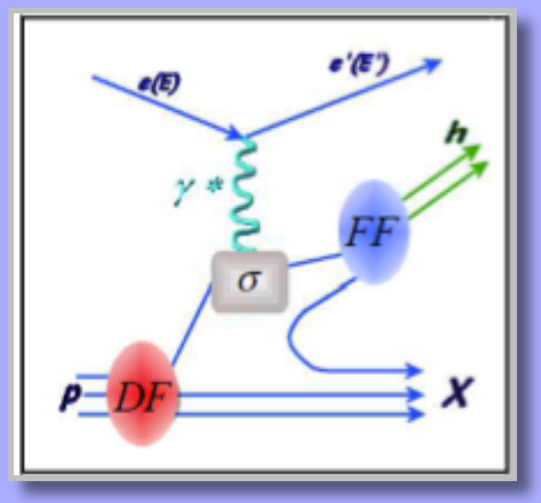


$$\frac{D_q^h(z)}{D_q^h(z)} \cdot \frac{\Delta q(x)}{q(x)} \sim P_q^h \frac{\Delta q}{q}$$



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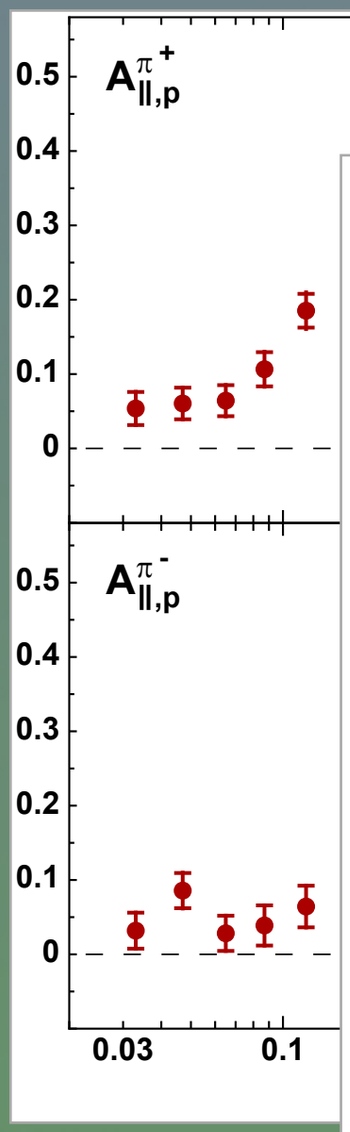
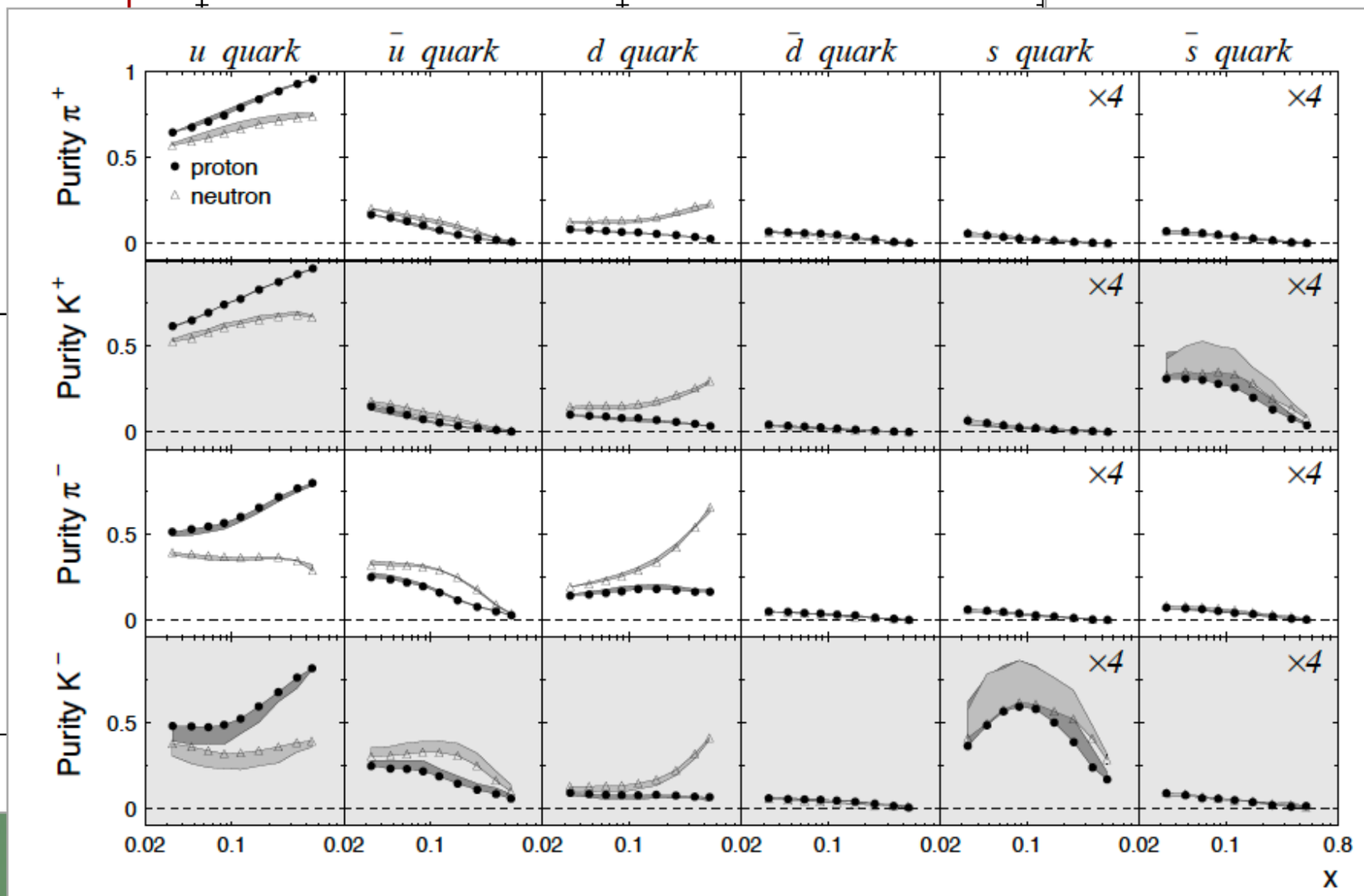
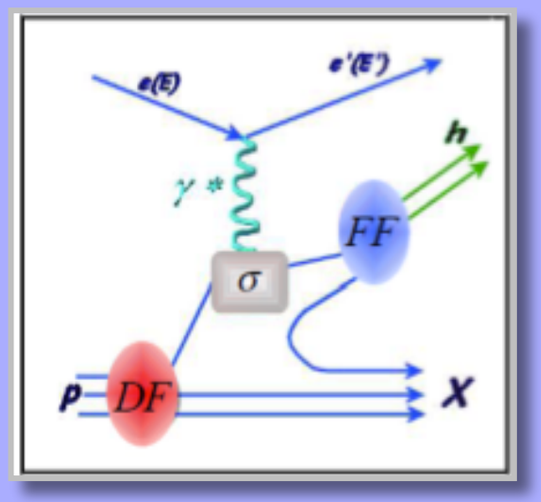




$$\sum_q e_q^2 \frac{\Delta q}{q}$$



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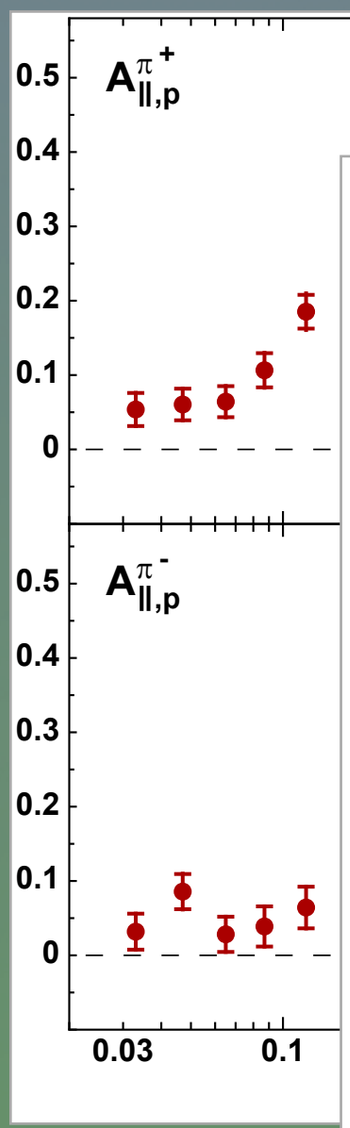

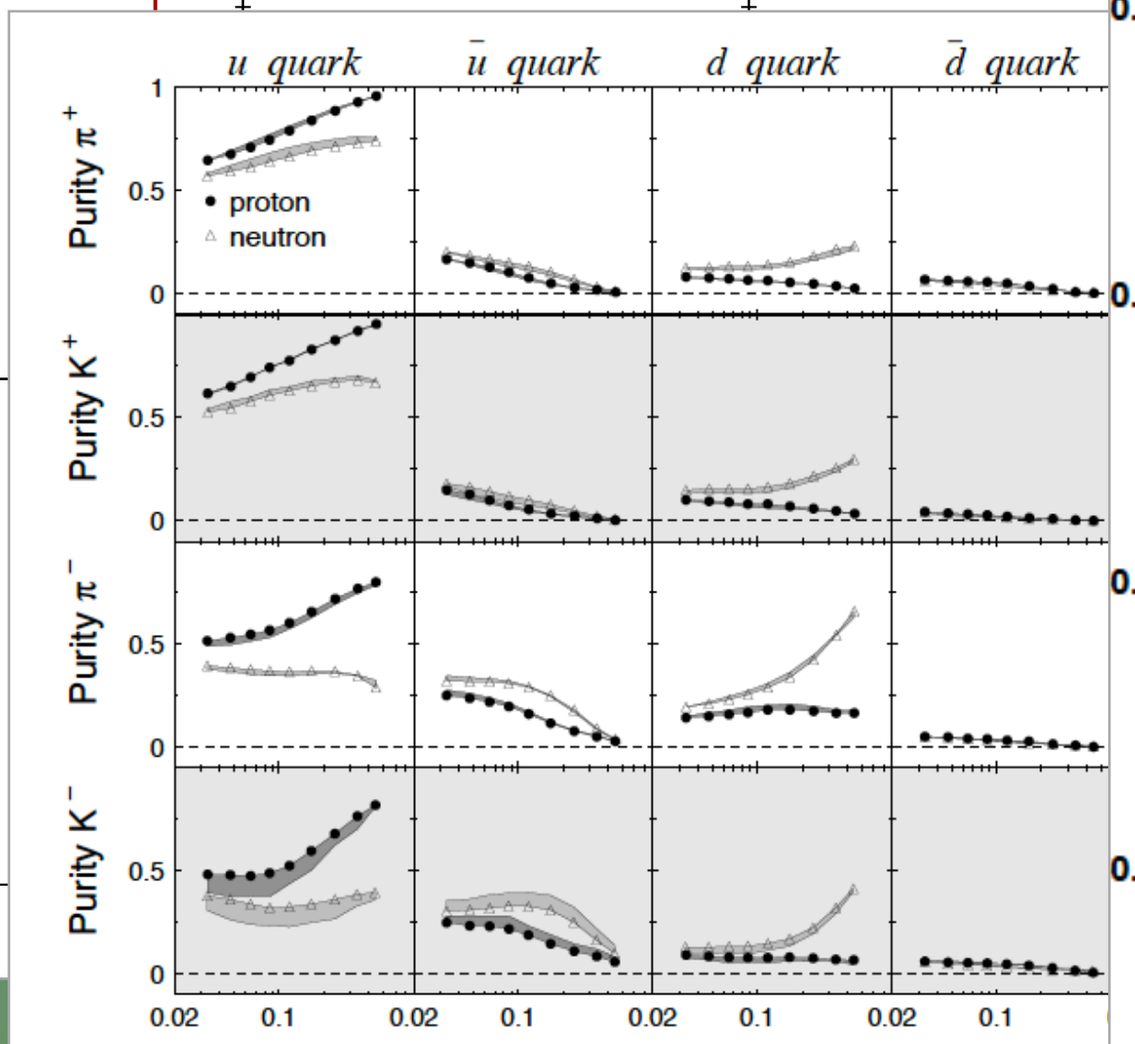

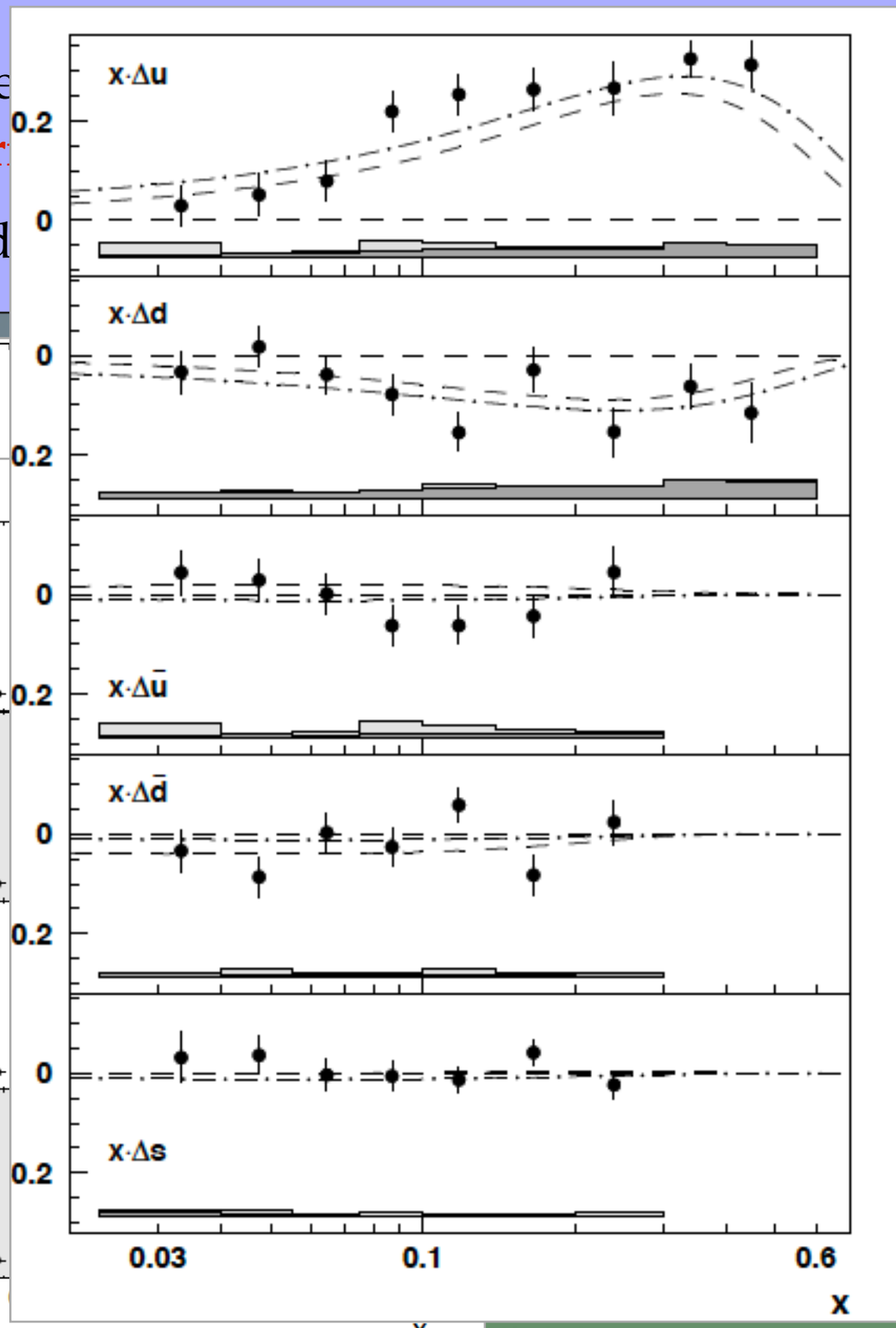

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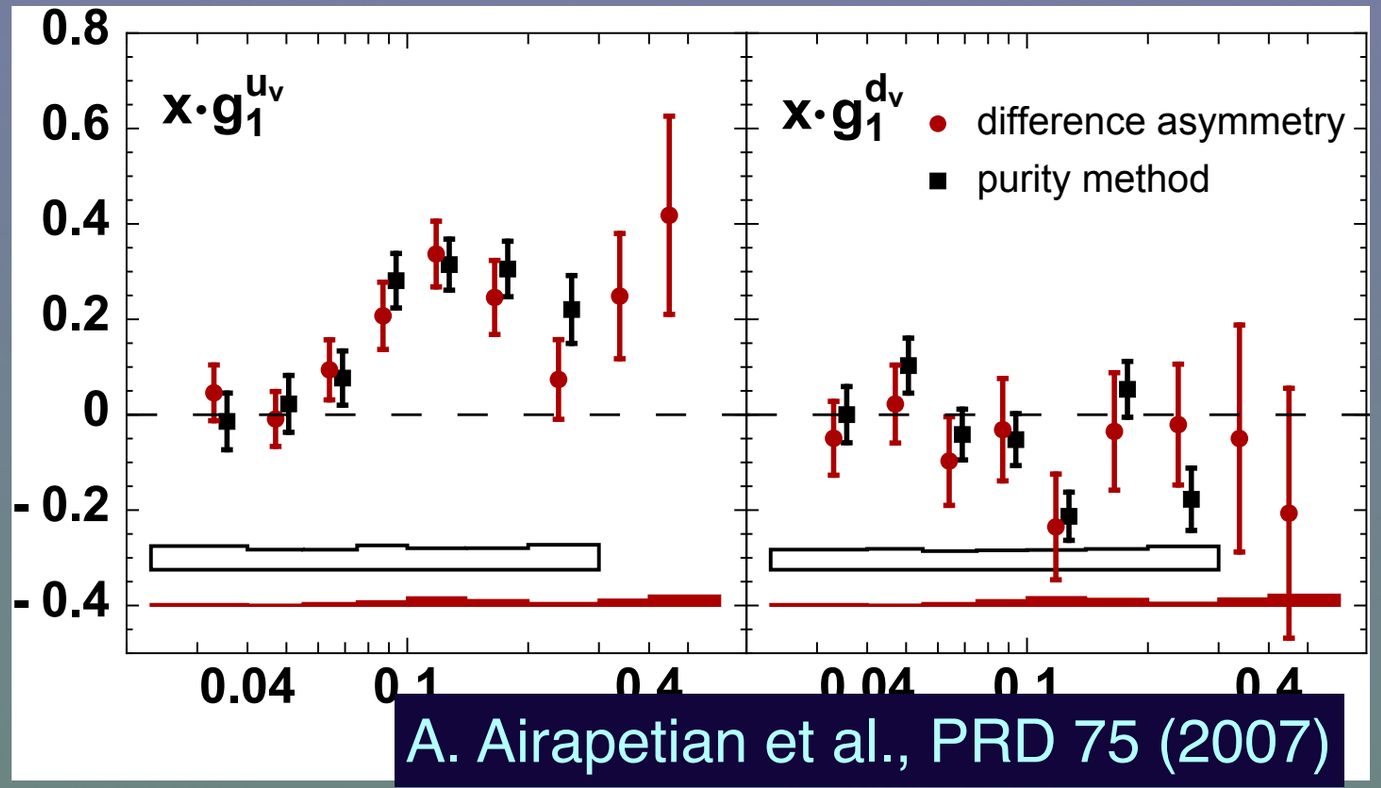
- Isospin symmetry
- No MC usage
- The contribution of FF drop out



A. Airapetian et al., PRD 75 (2007)

- LO parton model
- Purity from MC
- Theoretical model for FF

Summary

Several longitudinal double-spin asymmetries in SIDIS have been presented. The extend the analysis of the previous HERMES publication to include also transverse-momentum dependence.

With the precision of the measurements, the virtual-photon-nucleon asymmetries display no significant dependence on **z, $p_{h\perp}$**.

The **cos** ϕ moments of semi-inclusive double spin asymmetry as a function $p_{h\perp}$ are shown and compatible with zero.

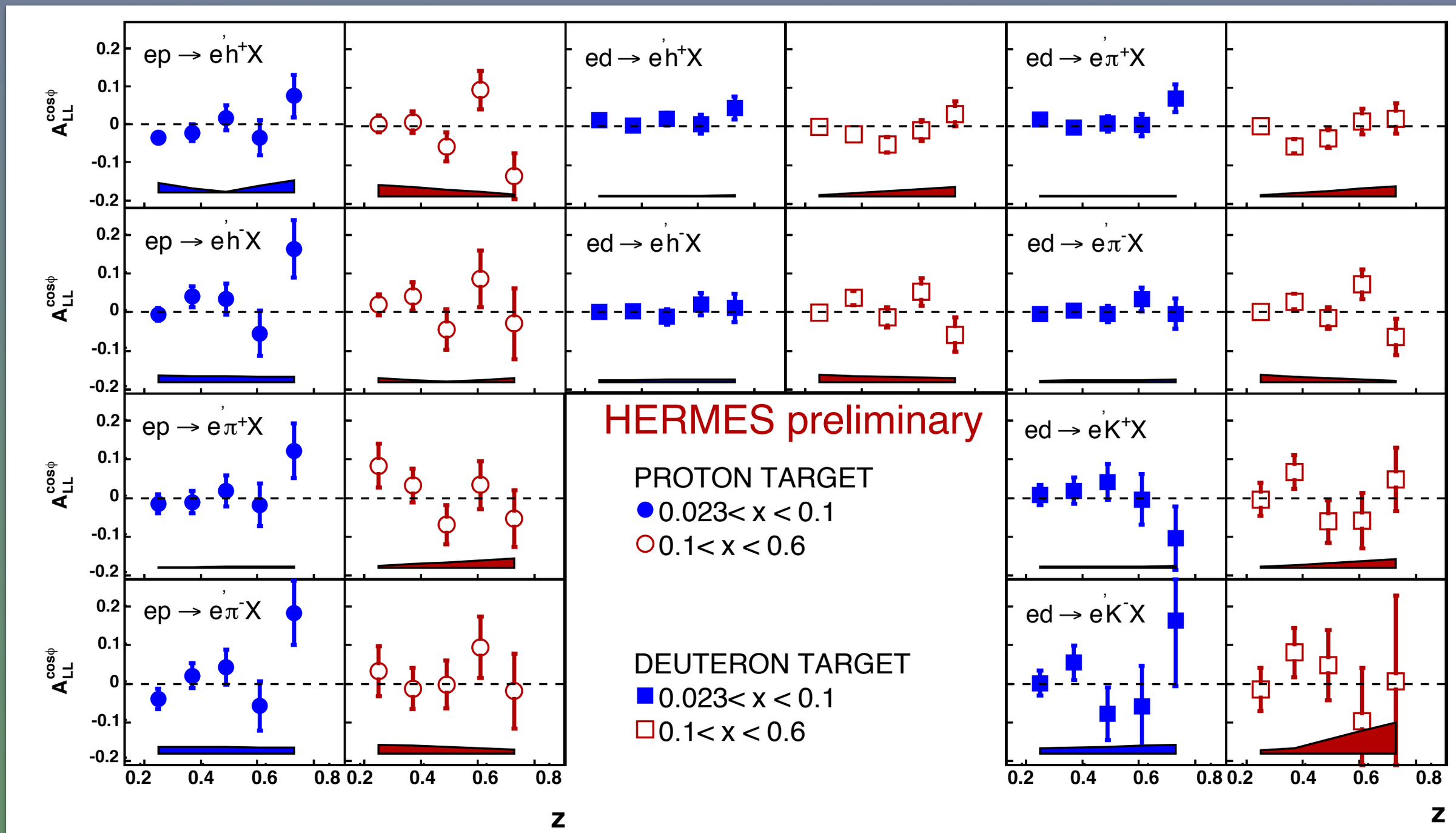
Hadron charge difference asymmetries have been measured . Valence helicity densities are presented in comparison with the same quantities from previous HERMES purity extraction.

These data are expected to provide an essentially model-independent constrain for theory and parametrization as they provide **the first even longitudinal double-spin semi-inclusive dataset** binned in three kinematic variables simultaneously.

Backup slides

NEW!!

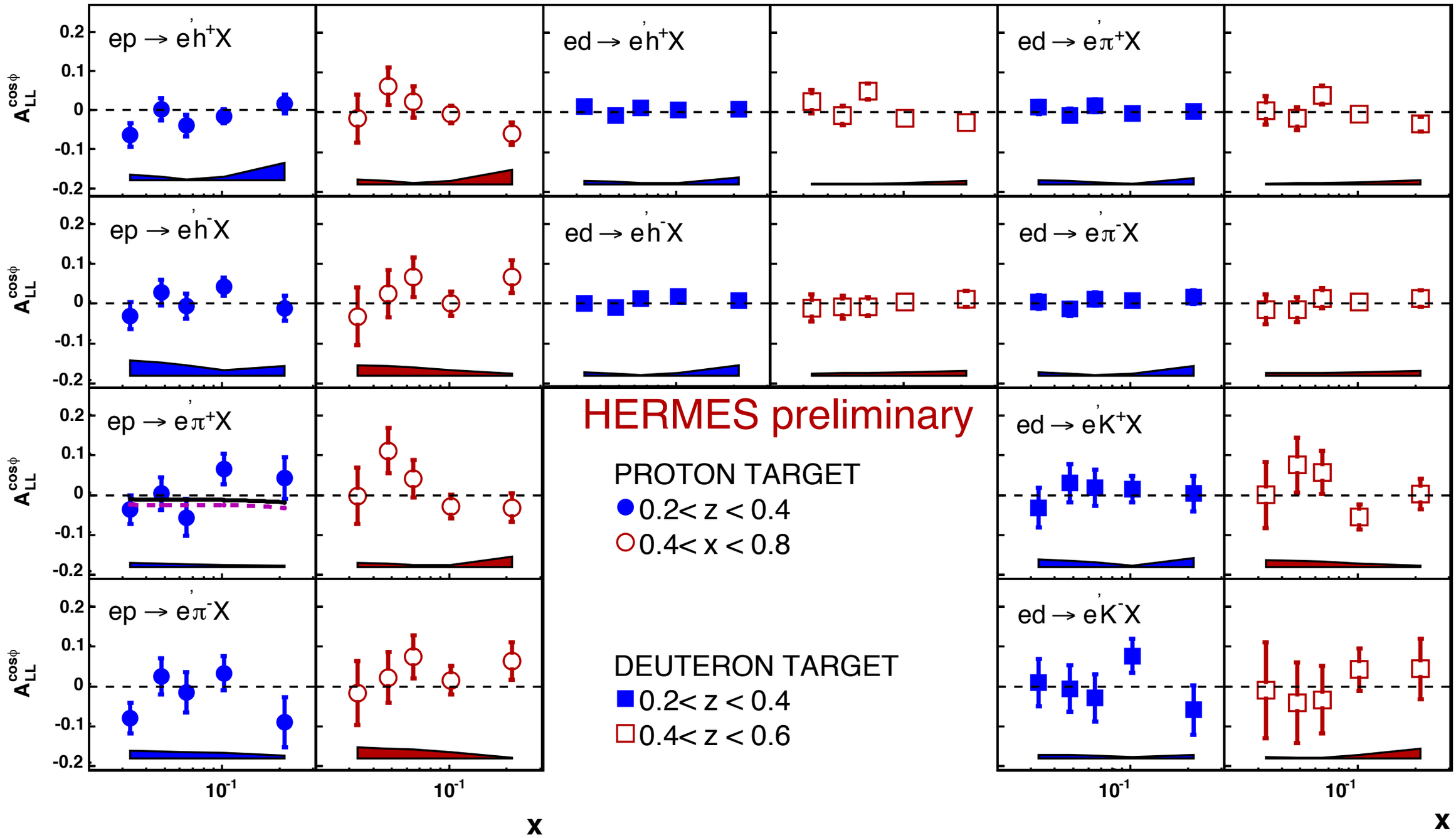
$\cos\phi$ moments of semi-inclusive double spin asymmetry $A_{LL}(z, x)$



Theoretical prediction M. Anselmino et al., PRD 74, 074015 (2006)

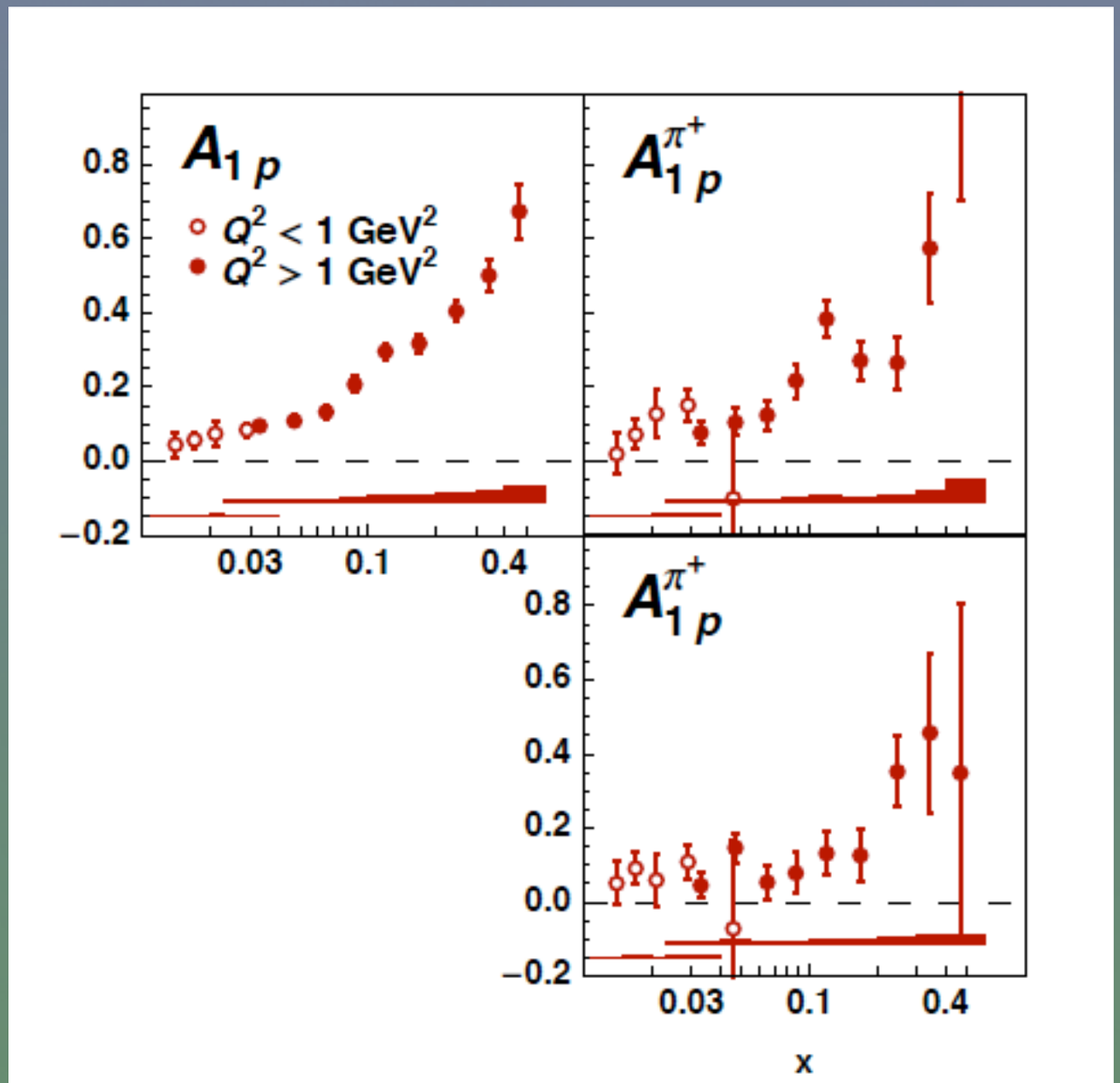
NEW!!

$\cos\phi$ moments of semi-inclusive double spin asymmetry $A_{LL}(x, z)$



Theoretical prediction M. Anselmino et al., PRD 74, 074015 (2006)

Longitudinal semi-inclusive double-spin asymmetries at HERMES.



Longitudinal semi-inclusive double-spin asymmetries at HERMES.