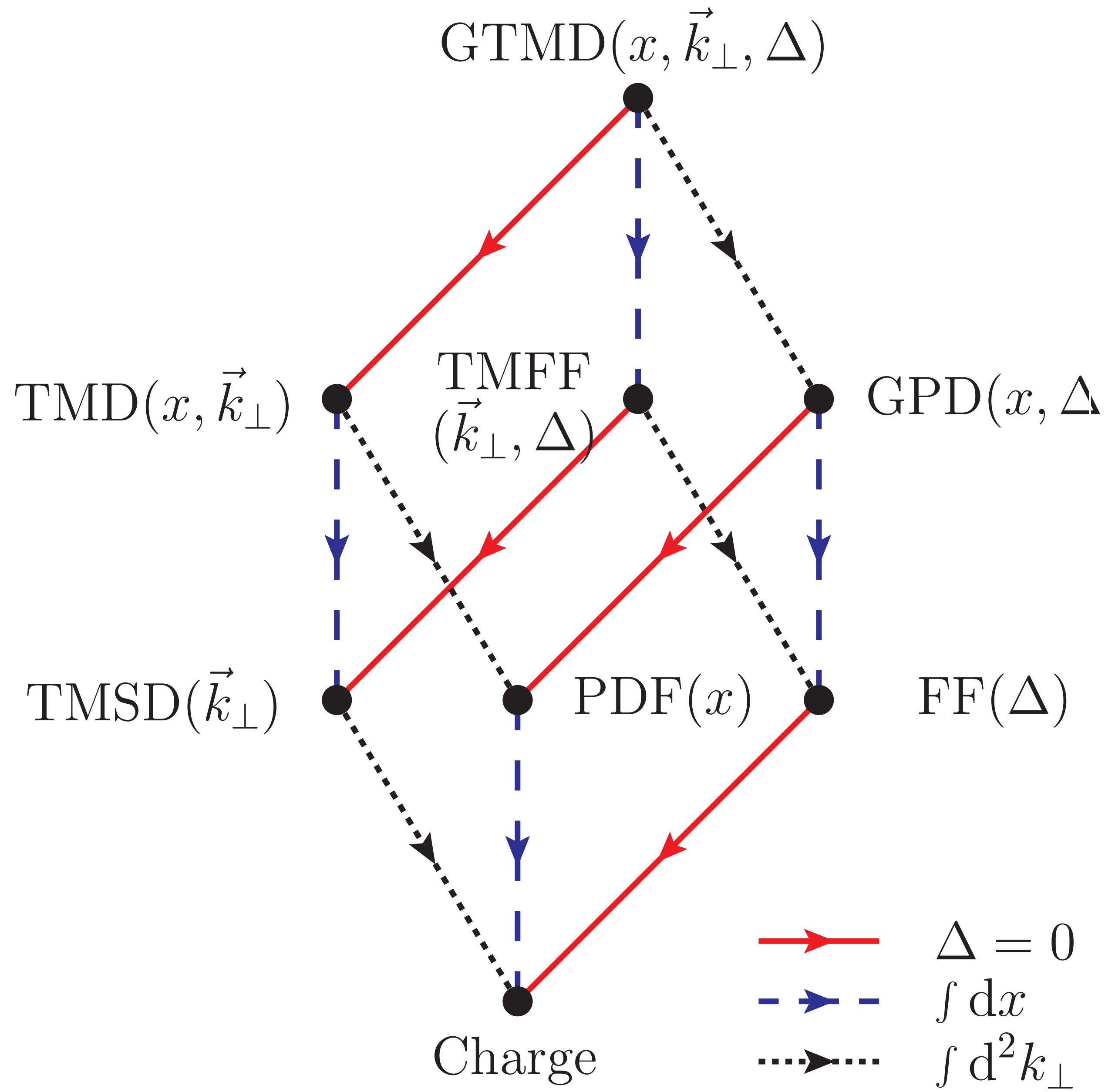
Recent results from hermes

Eduard Avetisyan

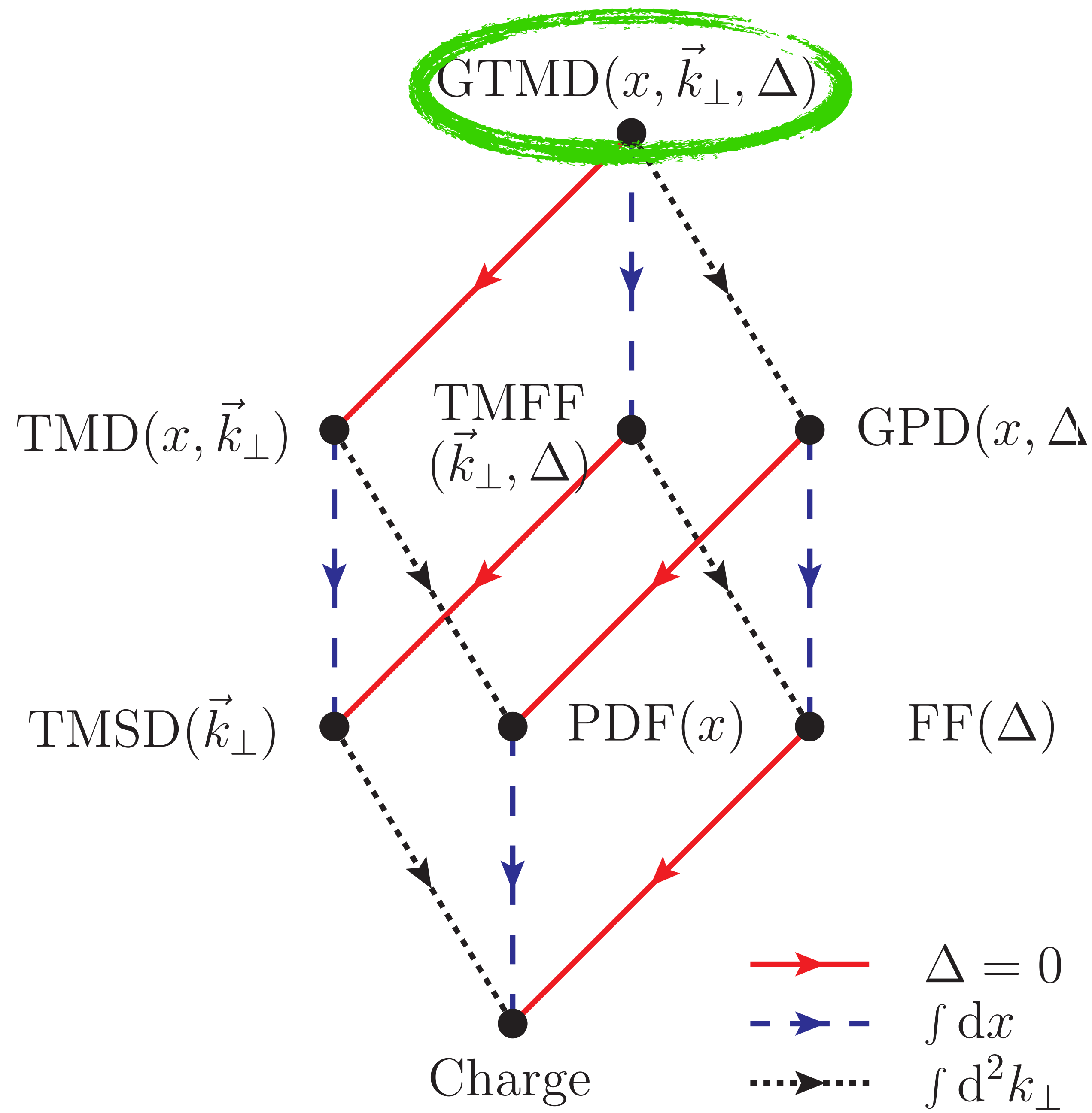
DESY PRC73 Open Session
April 2012

The Nucleon structure in 3D



The Nucleon structure in 3D

➡ **Most complete up to date: GTMDs**



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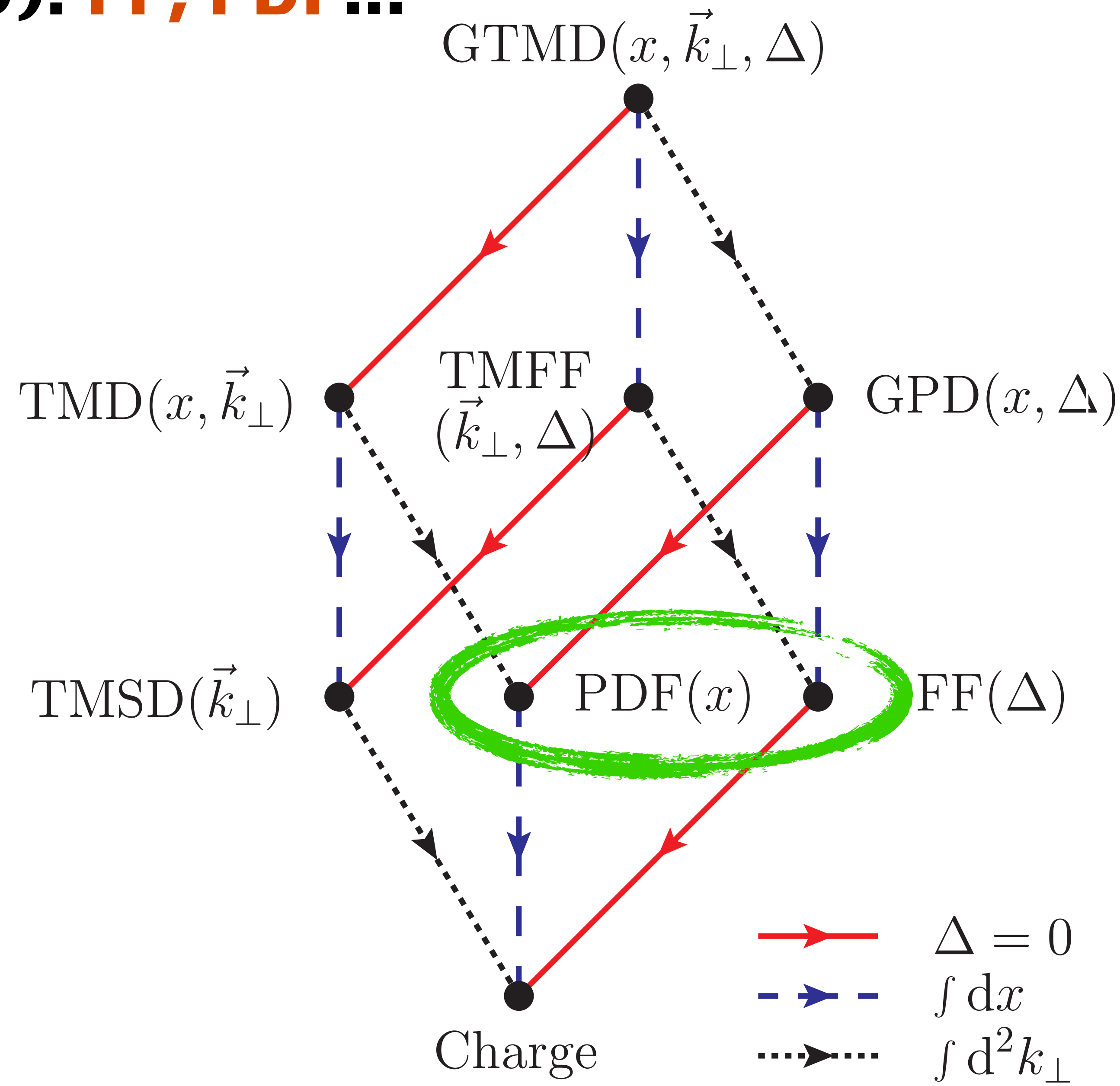
- ➡ **Inclusive measurements(1D): FF, PDF...**



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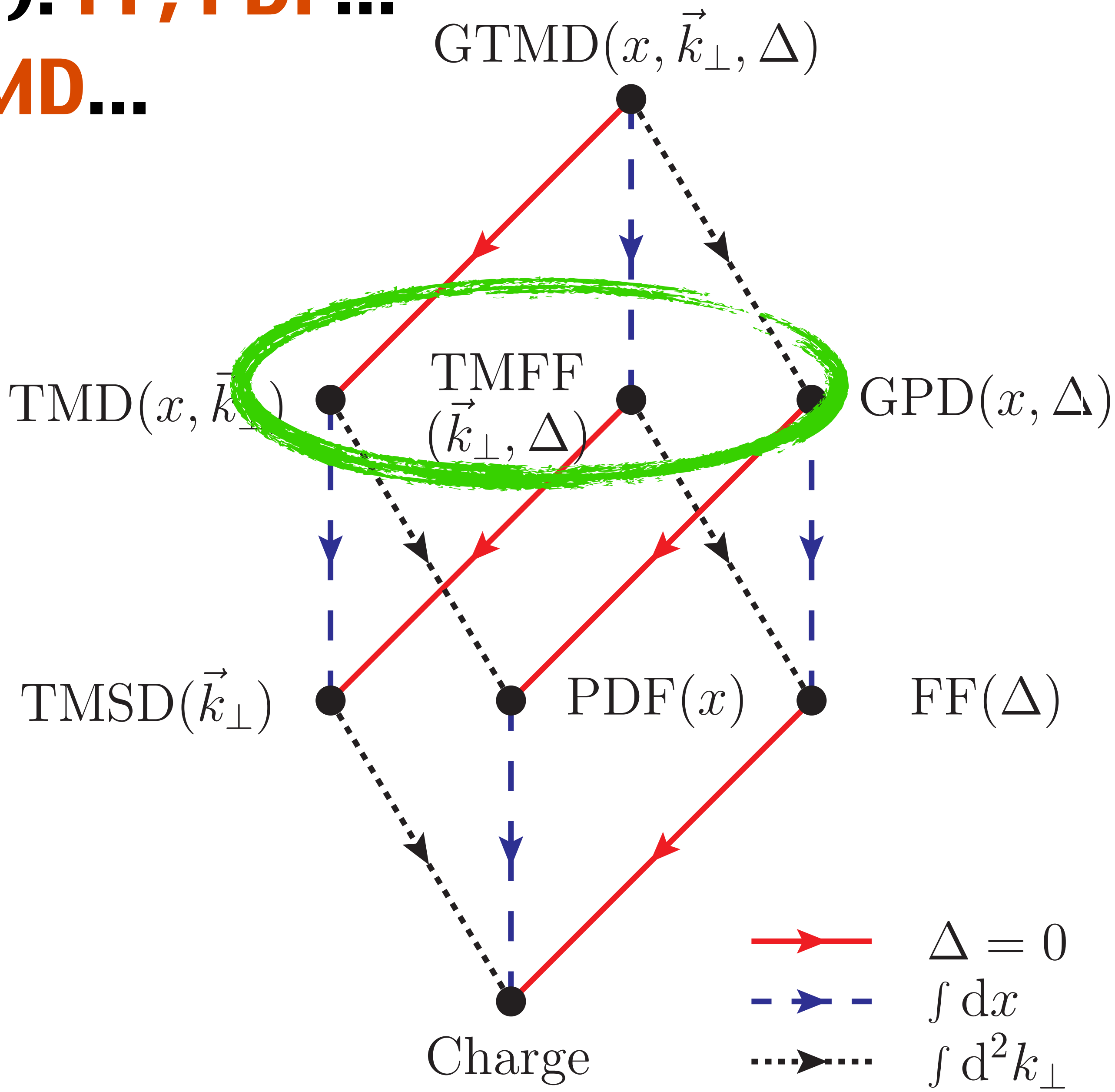

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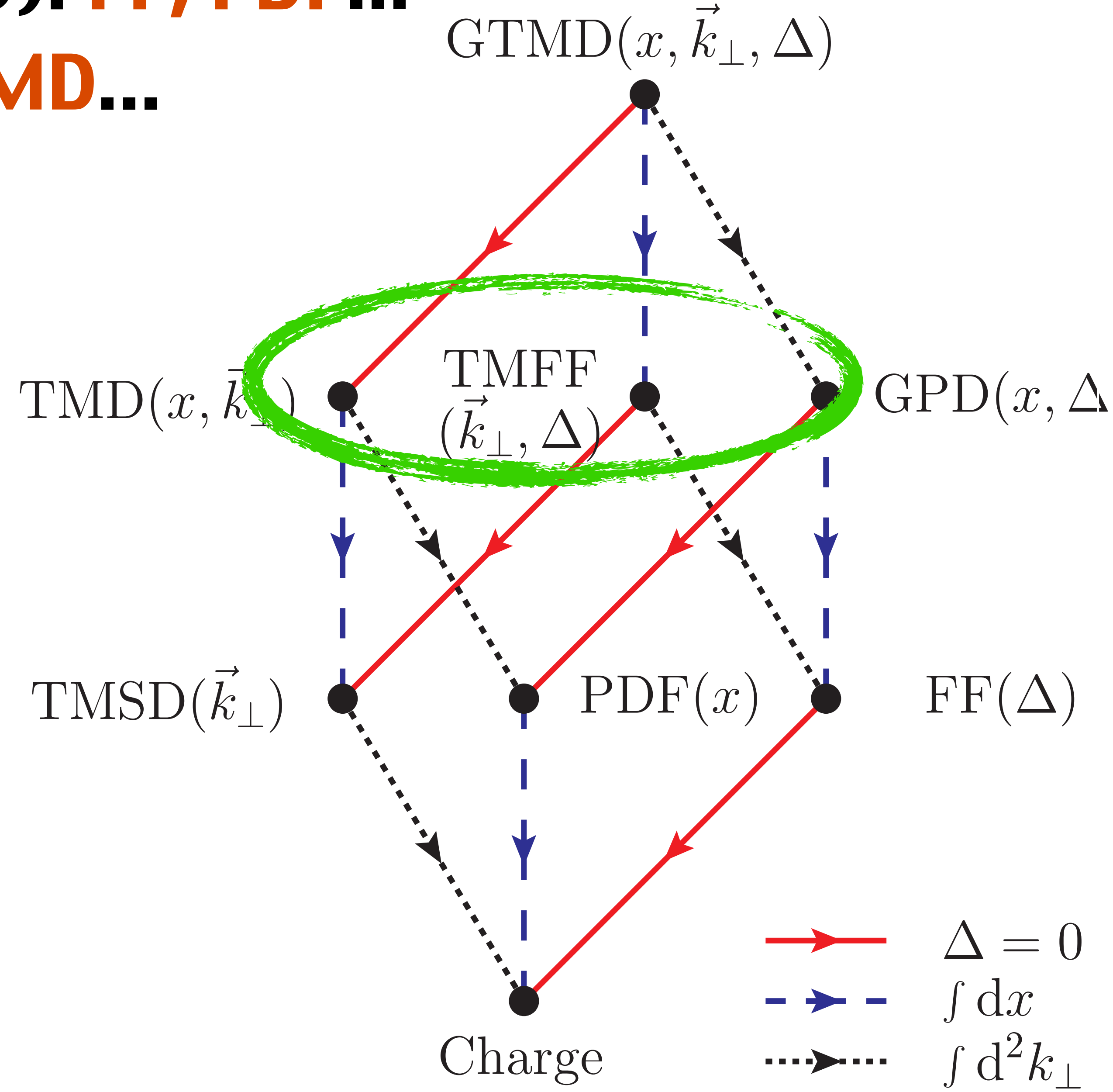
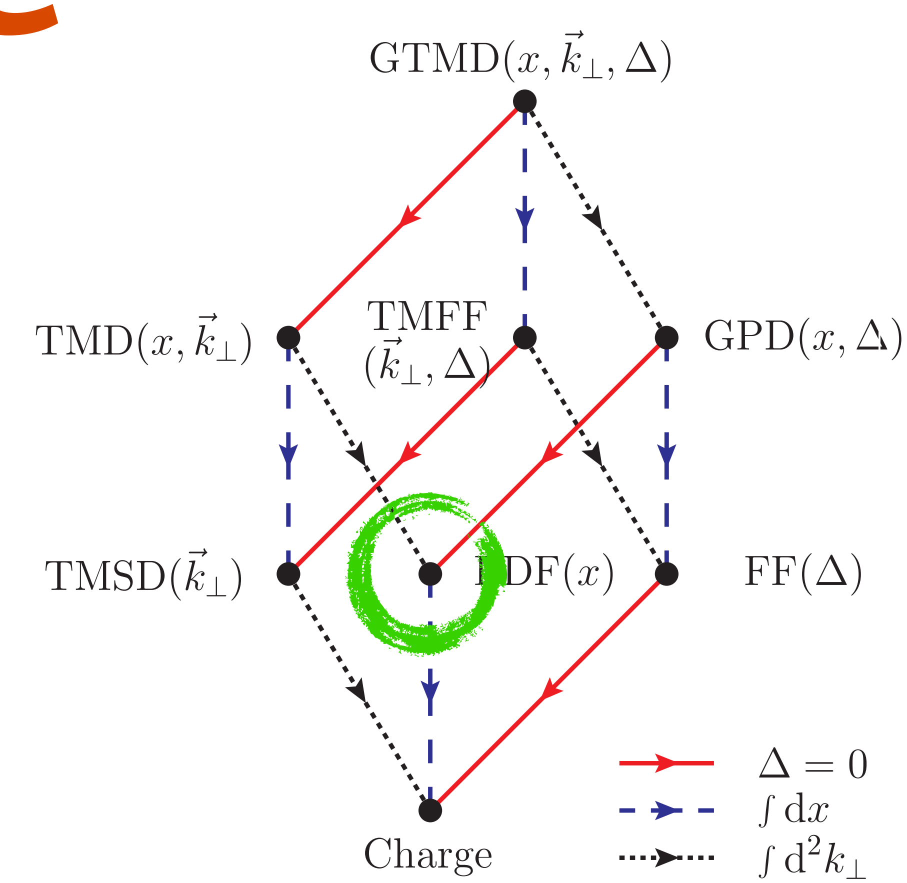


- ➡ **Complicated:**
- ➡ **Beam polarization**
- ➡ **Target polarization**
- ➡ **Complete kinematics**
- ➡ **…**

Inclusive



GTMD$(x, \vec{k}_\perp, \Delta)$
TMD$(x, \vec{k}_\perp)$
TMFF
$(\vec{k}_\perp, \Delta)$
GPD(x, Δ)
TMSD$(\vec{k}_\perp)$
PDF(x)
FF(Δ)
Charge
$\Delta = 0$
$\int \mathrm{d}x$
$\int \mathrm{d}^2 k_\perp$

Inclusive DIS (A_2,g_2)

$$
\begin{aligned}
\frac{d^3\sigma}{dx\,dy\,d\phi} \quad \propto \quad & \frac{y}{2}F_1(x,Q^2) + \frac{1-y-\gamma^2y^2/4}{2xy}F_2(x,Q^2) \\
& -S_l S_N \cos\alpha\left[\left(1-\frac{y}{2}-\frac{\gamma^2y^2}{4}\right)g_1(x,Q^2) - \frac{\gamma^2 y}{2}g_2(x,Q^2)\right] \\
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Inclusive DIS (A_2,g_2)

HERA

$$\frac{d^3\sigma}{dx\,dy\,d\phi} \propto \frac{y}{2}F_1(x,Q^2) + \frac{1-y-\gamma^2y^2/4}{2xy}F_2(x,Q^2)$$
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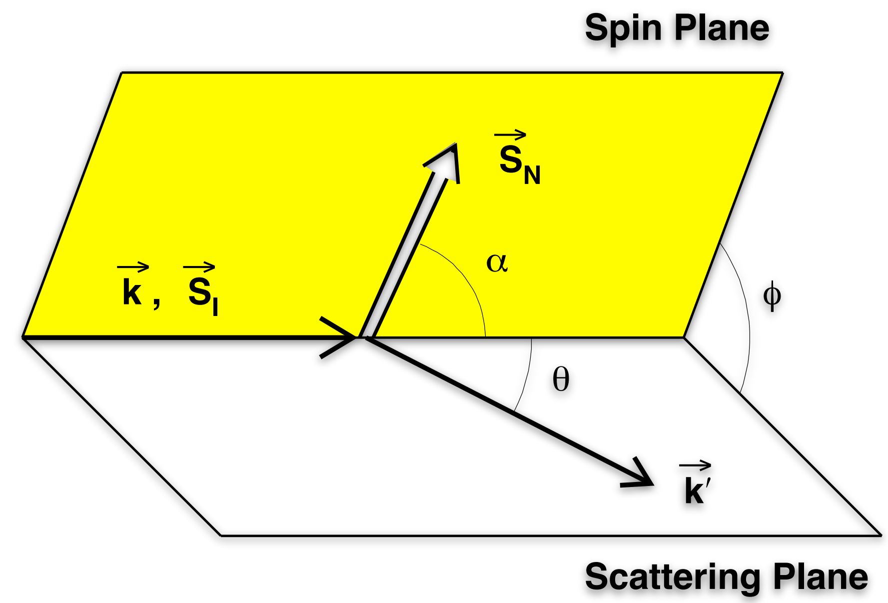

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hermes

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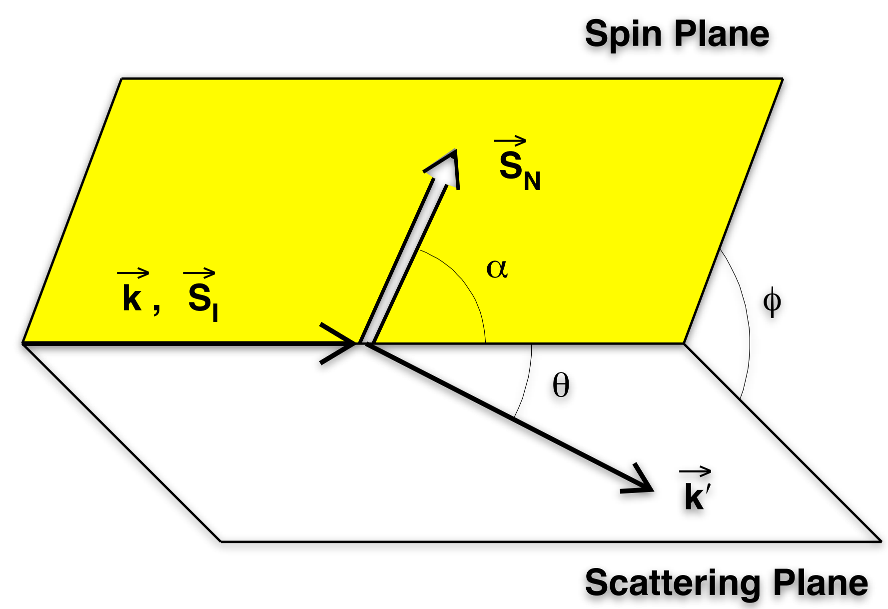

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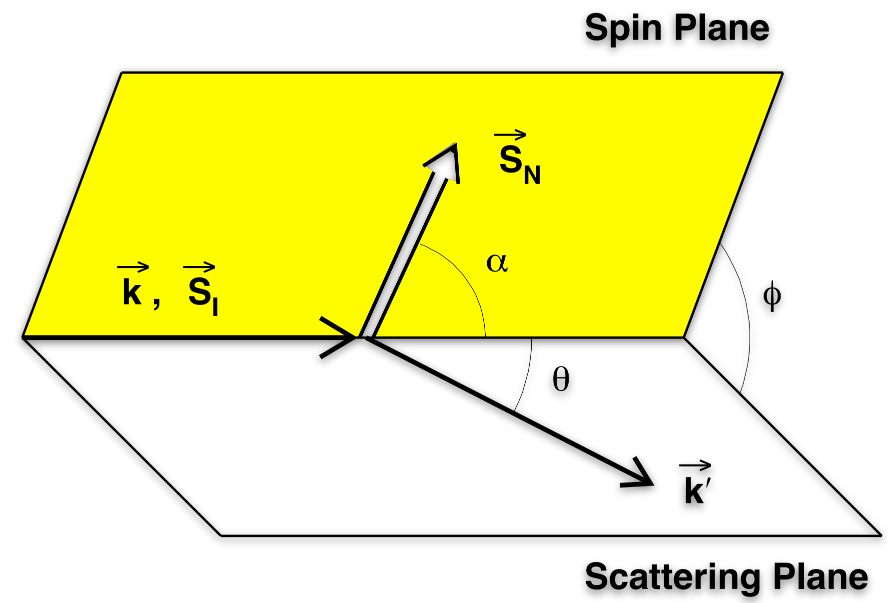

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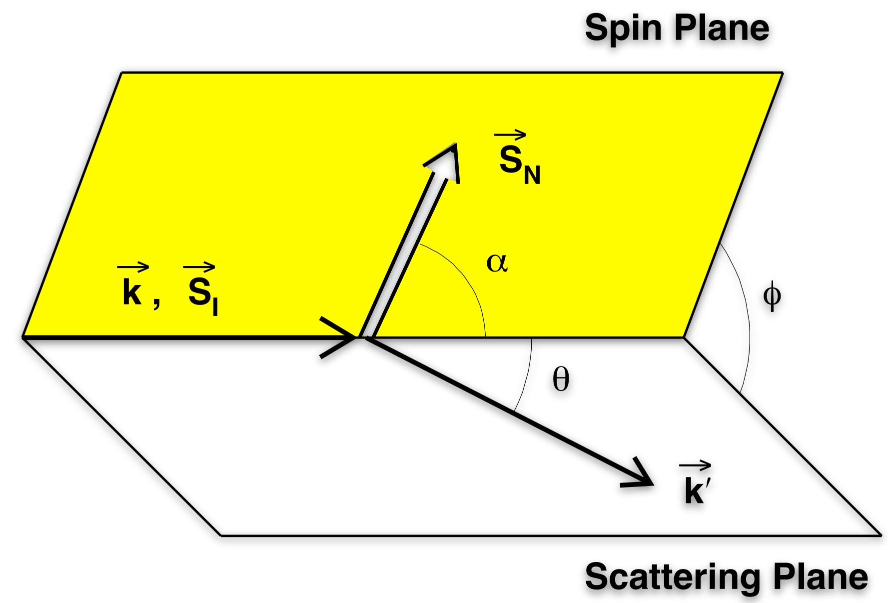
NEW



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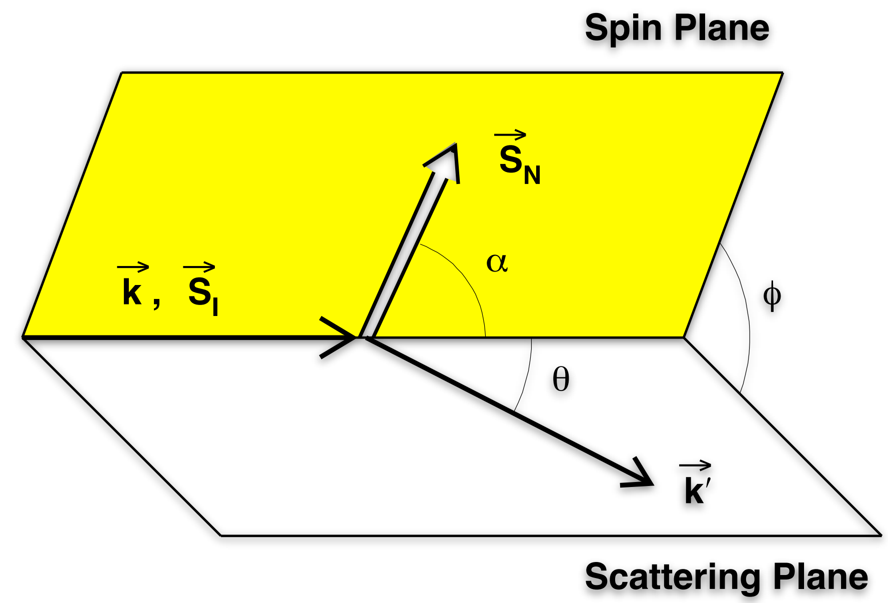

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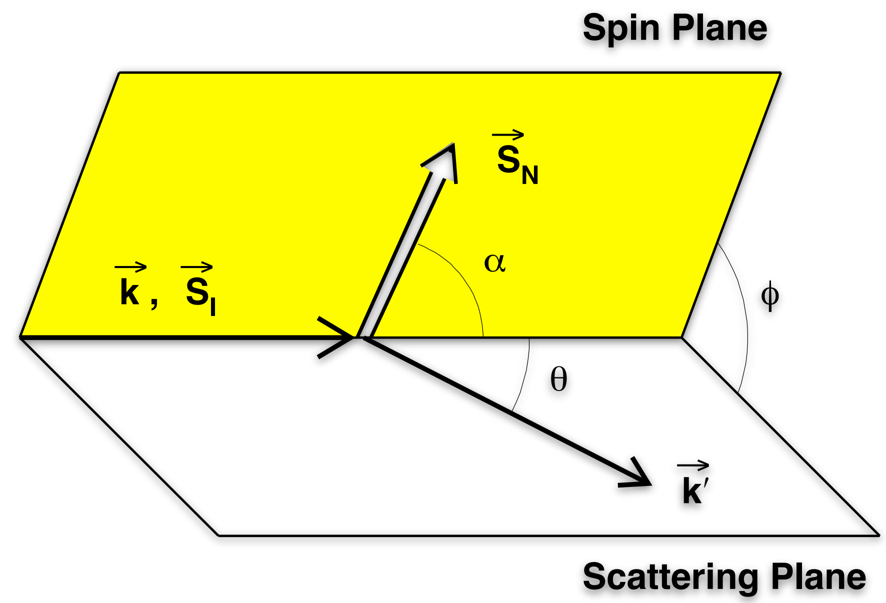
NEW

hermes

$$\frac{\sigma^{\rightarrow\Downarrow}-\sigma^{\rightarrow\Uparrow}}{\sigma^{\rightarrow\Downarrow}+\sigma^{\rightarrow\Uparrow}} = \frac{\Delta\sigma_T}{\bar{\sigma}}$$

$$= \frac{-\gamma\sqrt{1-y-\frac{\gamma^2y^2}{4}}\left(\frac{y}{2}g_1(x,Q^2)+g_2(x,Q^2)\right)}{\left[\frac{y}{2}F_1(x,Q^2)+\frac{1}{2xy}\left(1-y-\frac{\gamma^2y^2}{4}\right)F_2(x,Q^2)\right]}\cos\phi = A_T\cos\phi$$

Inclusive DIS (A_2, g_2)



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NEW

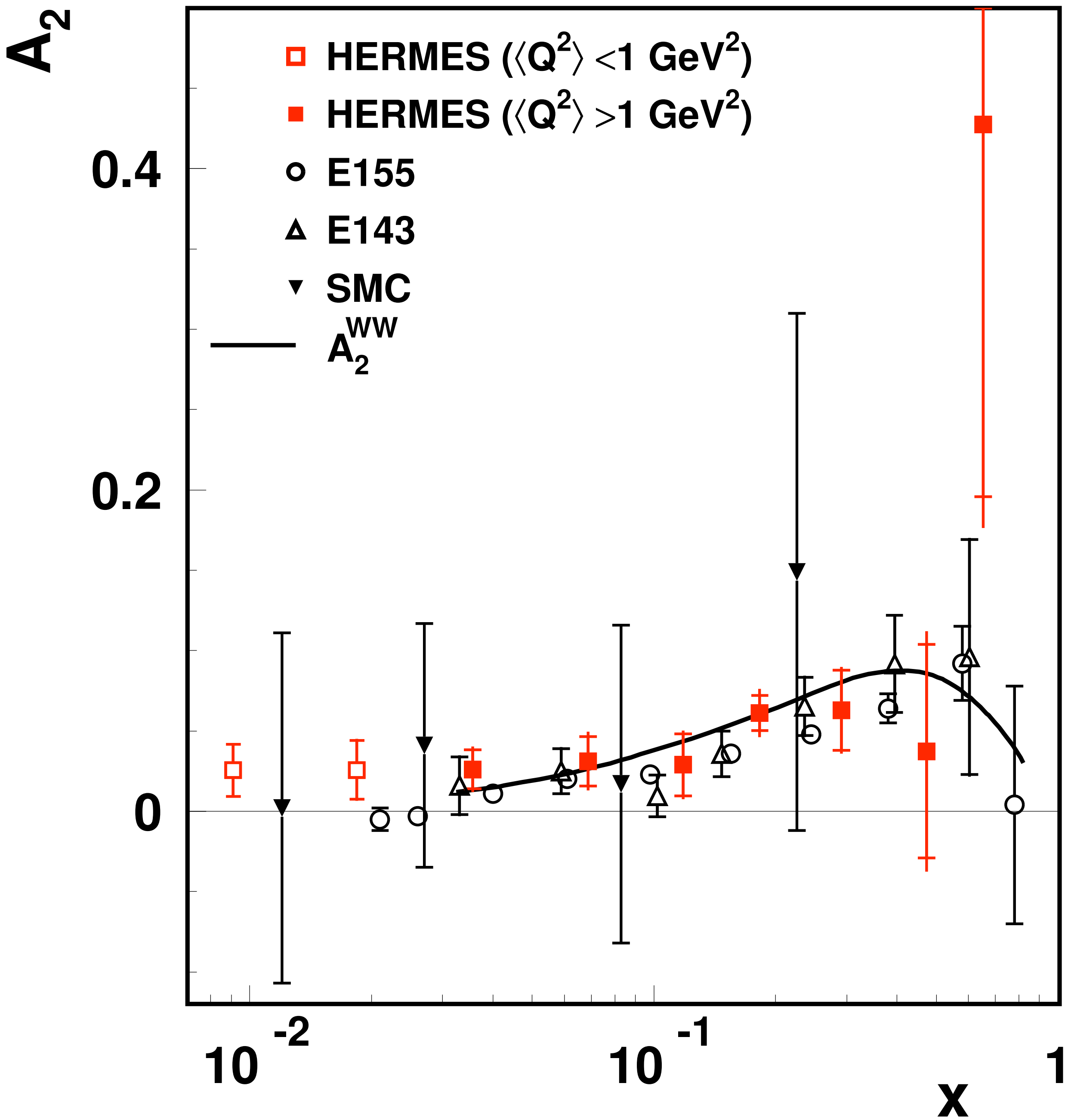
hermes

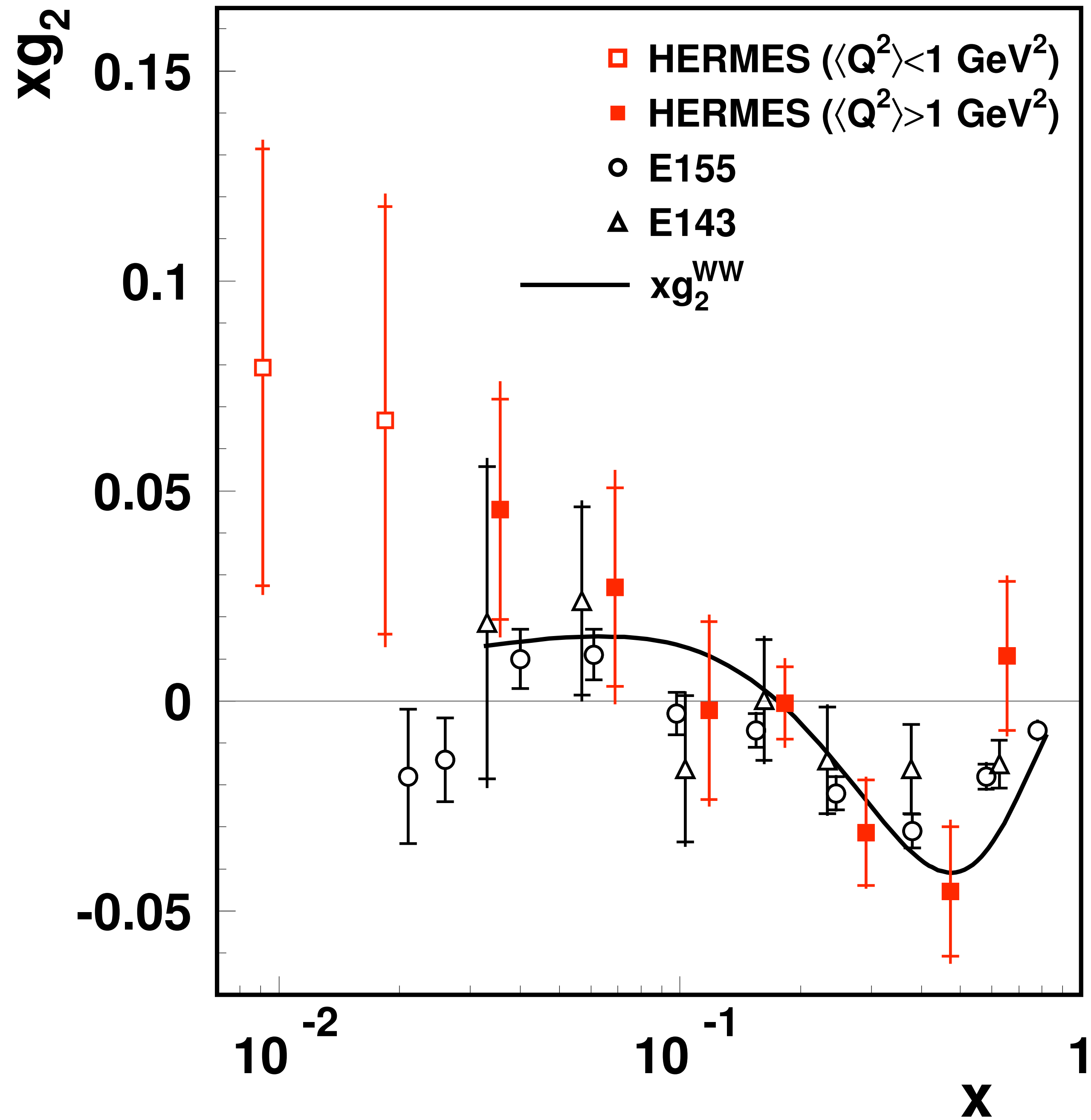
parameterizations

$$\mathbf{A_2} = \frac{1}{\mathbf{d}(1+\gamma\xi)} \mathbf{A_T} + \frac{\xi(1+\gamma^2)}{1+\gamma\xi} \frac{\mathbf{g_1}}{\mathbf{F_1}}$$

$$\mathbf{g_2} = \frac{\mathbf{F_1}}{\gamma \mathbf{d}(1+\gamma\xi)} \mathbf{A_T} - \frac{\mathbf{F_1}(\gamma - \xi)}{\gamma(1+\gamma\xi)} \frac{\mathbf{g_1}}{\mathbf{F_1}}$$

A. Airapetian et al. [HERMES], EPJ C 72 (2012) 1921





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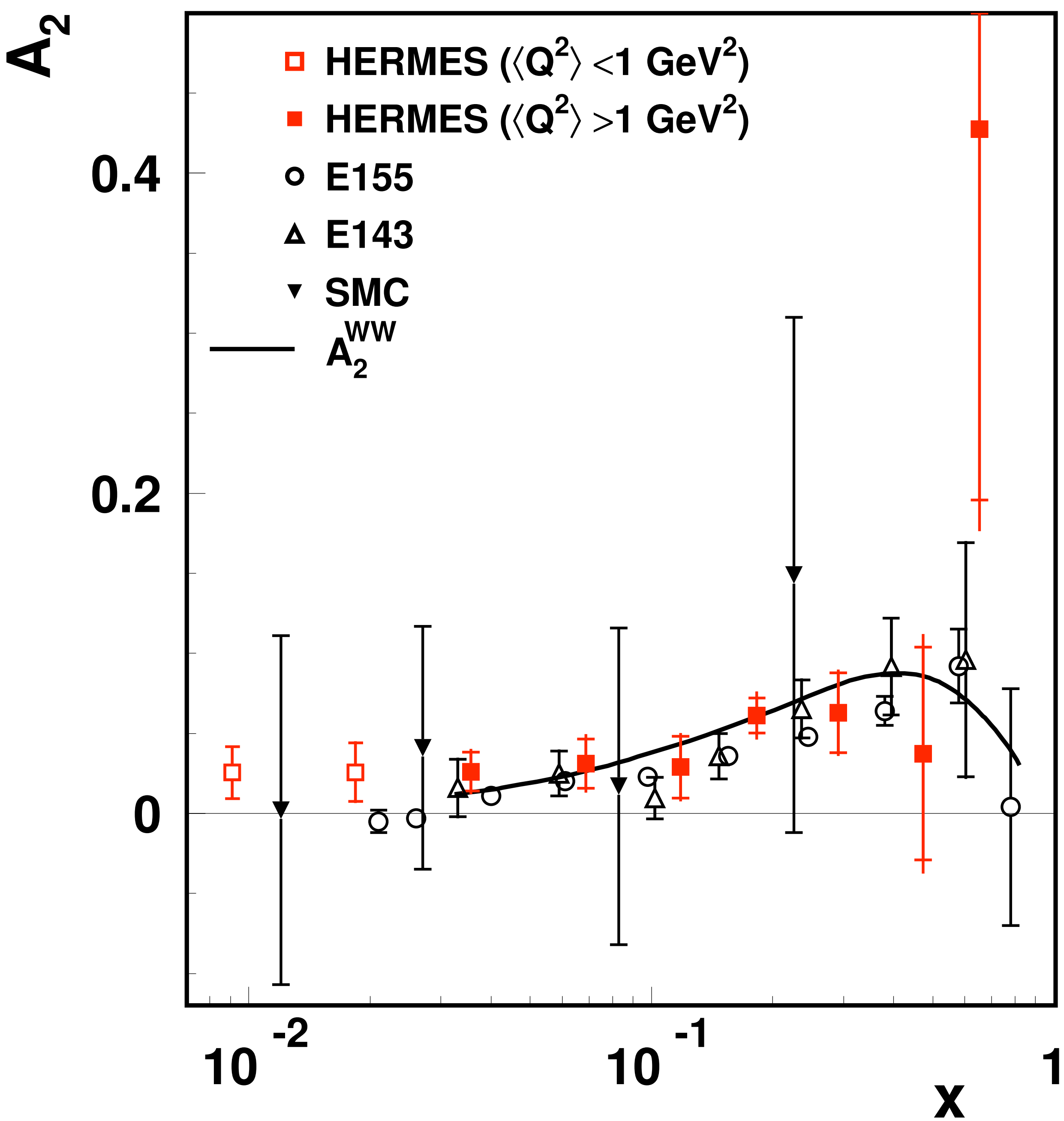

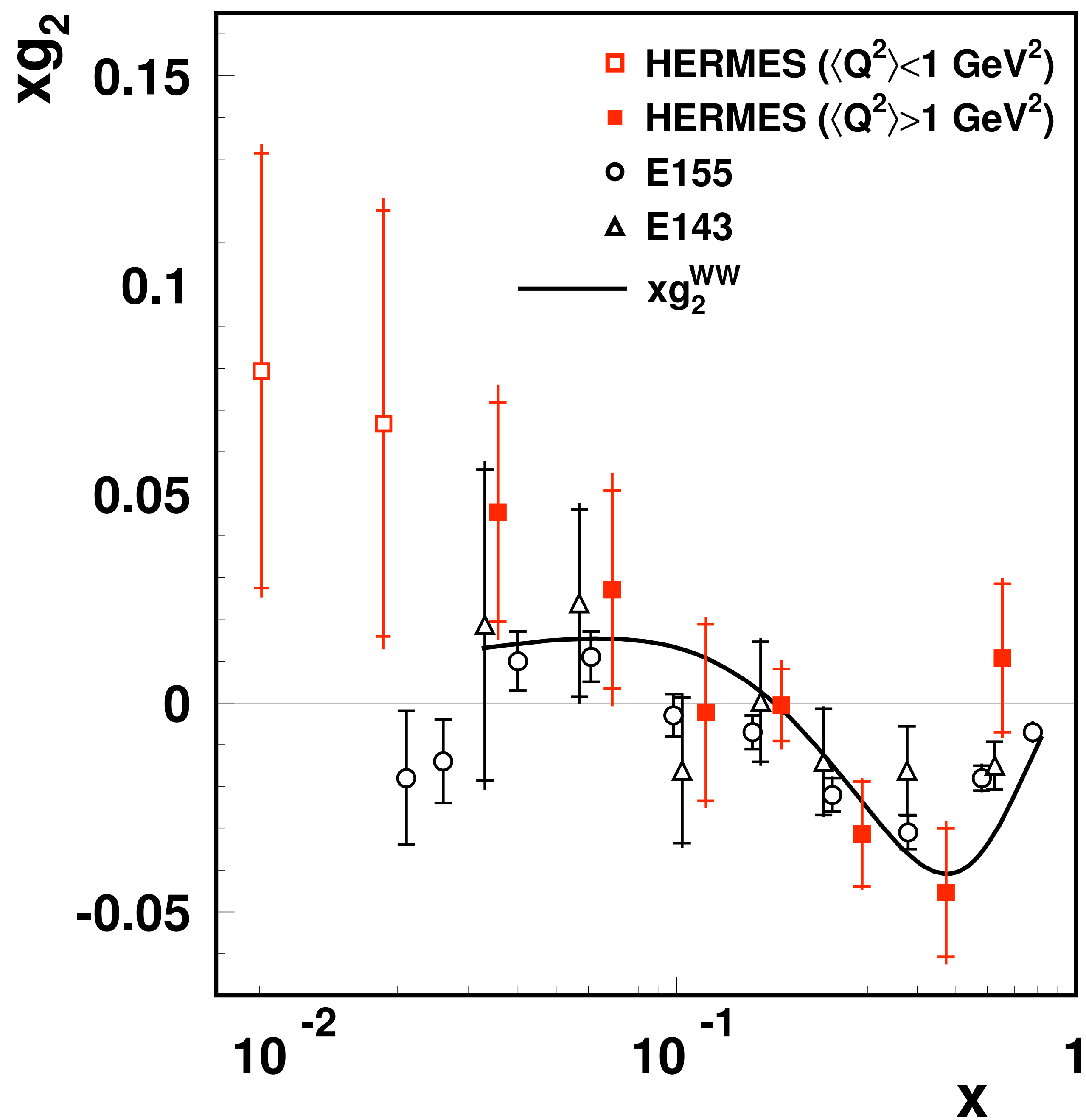

Unique measurement:

- ➡ Pure hydrogen target (no dilution, low systematics)
- ➡ Full unfolding (no systematic correlations)

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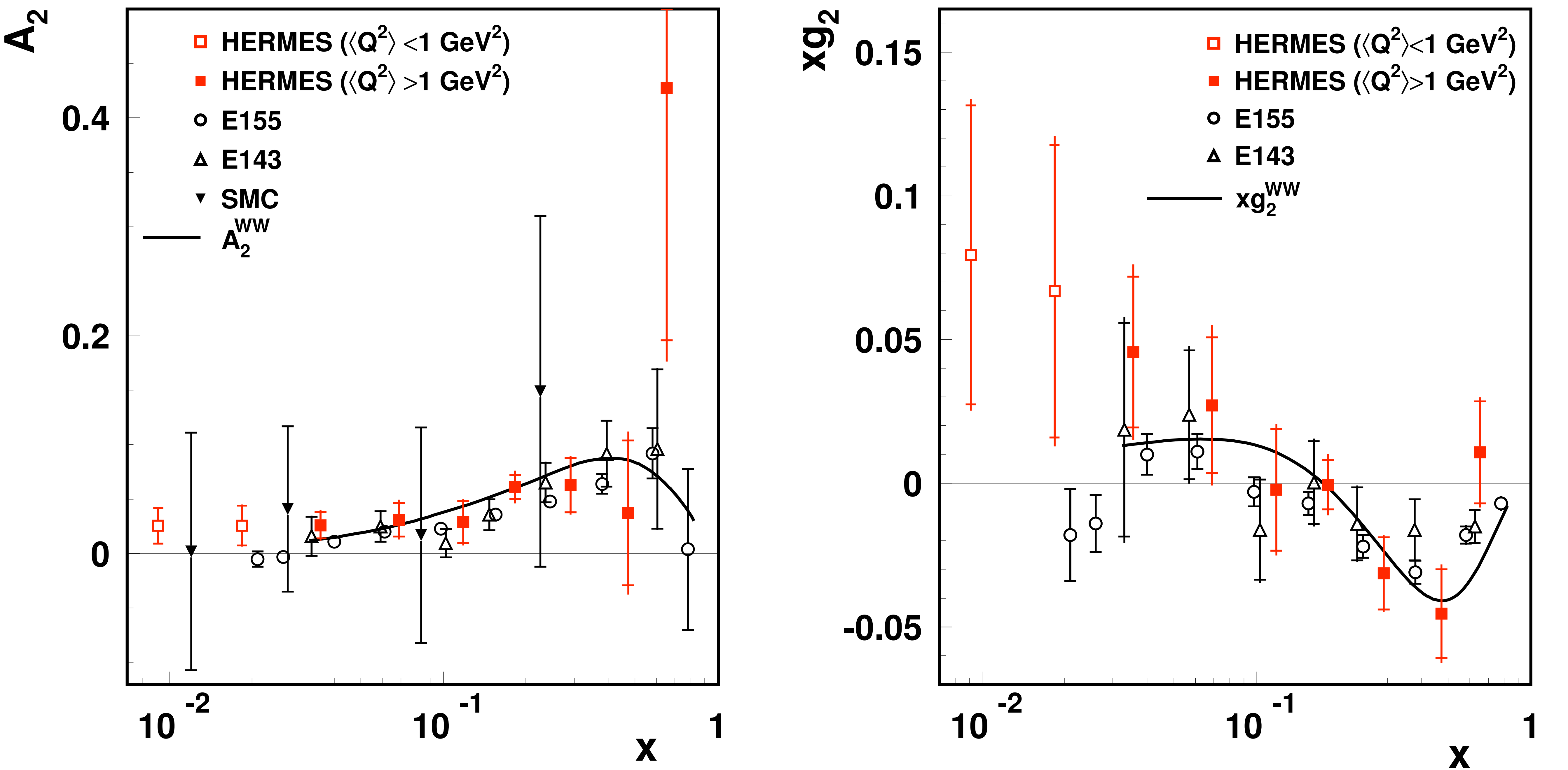

➡ **Burkhardt-Cottingham sum-rule test**

$$\int_{0.023}^{0.9} g_2(x,Q^2)\,dx = \mathbf{0.006} \pm \mathbf{0.024}_{\rm stat} \pm \mathbf{0.017}_{\rm syst}$$

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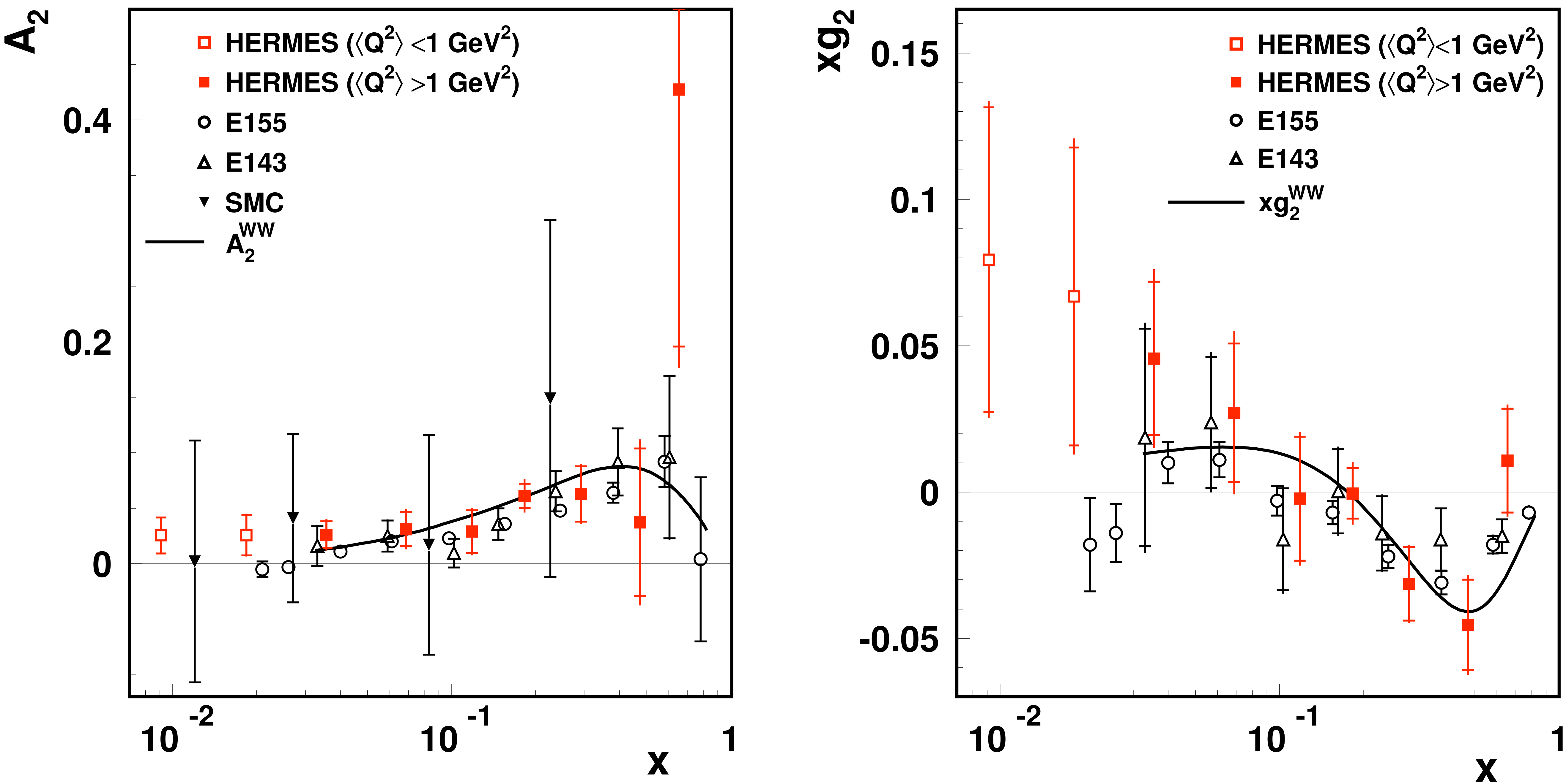
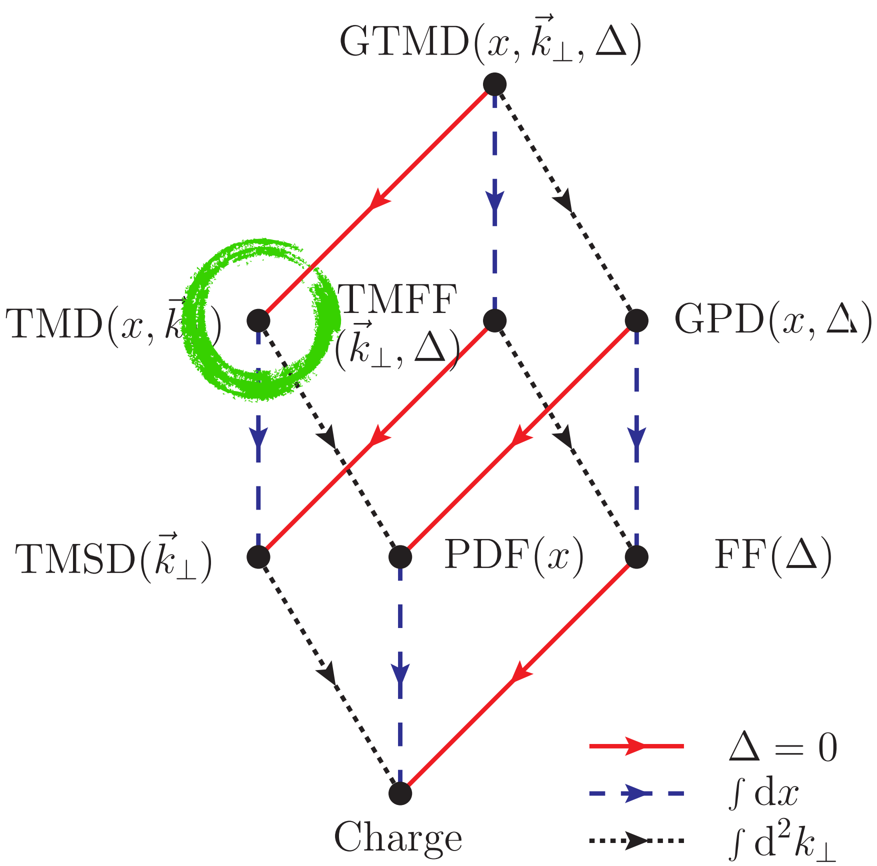


➡ **twist-3 moment, related to quark-quark-gluon correlations**

$$\mathbf{d_2(Q^2)} \equiv 3\int_0^1 x^2\,\bar{g}_2(x,Q^2)\,dx = \mathbf{0.0148} \pm \mathbf{0.0096}_{\rm stat} \pm \mathbf{0.0048}_{\rm syst}$$

Semi-inclusive



Semi-inclusive unpolarized asymmetries

$$\frac{d^4\sigma}{dx\,dy\,dz\,dP_{h\perp}^2} \propto \left(1+\frac{\gamma^2}{2x}\right)\{F_{UU,T}+\epsilon F_{UU,L}\}$$

target polarization

$$F_{XY,Z} = F_{XY,Z}(x,y,z,P_{h\perp})$$

beam polarization

virtual-photon polarization

Semi-inclusive unpolarized asymmetries

Inclusive limit: F_T

Inclusive limit: F_L

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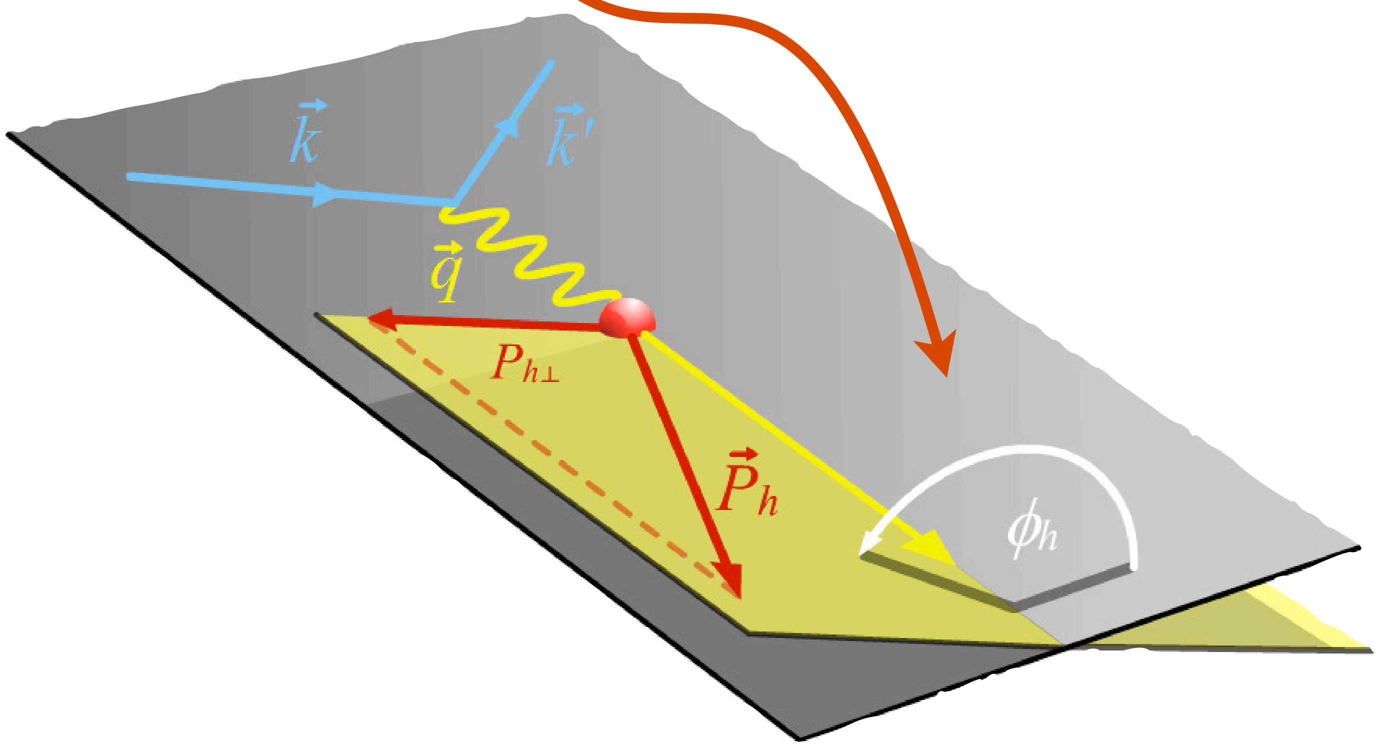
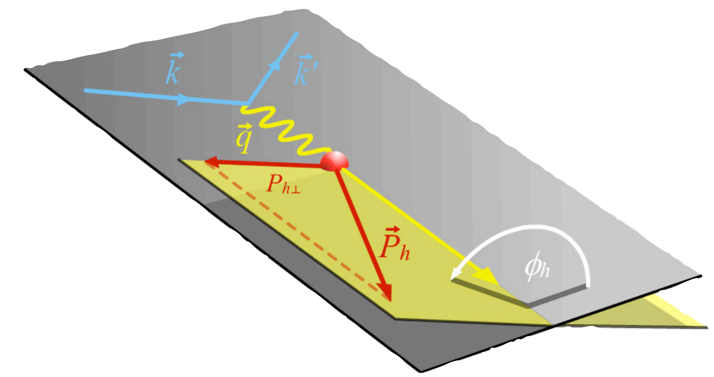
$$+\sqrt{2\epsilon(1-\epsilon)}F_{UU}^{\cos\phi_h}\cos\phi_h+\epsilon F_{UU}^{\cos 2\phi_h}\cos 2\phi_h\}$$



Semi-inclusive unpolarized asymmetries



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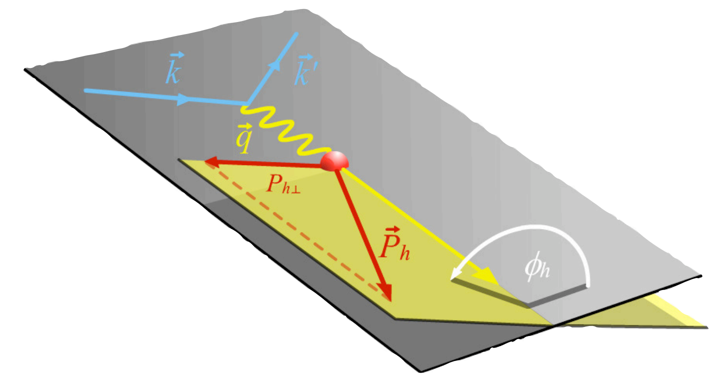
➡ **Extract azimuthal moments:**

$$2\langle\cos n\phi\rangle_{UU} \overset{n=1,2}{\equiv} 2\frac{\int d\phi_h \cos n\phi\, d\sigma}{\int d\phi_h d\sigma} = \frac{\epsilon F_{UU}^{\cos n\phi}}{F_{UU,T}+\epsilon F_{UU,L}}$$

Semi-inclusive unpolarized asymmetries



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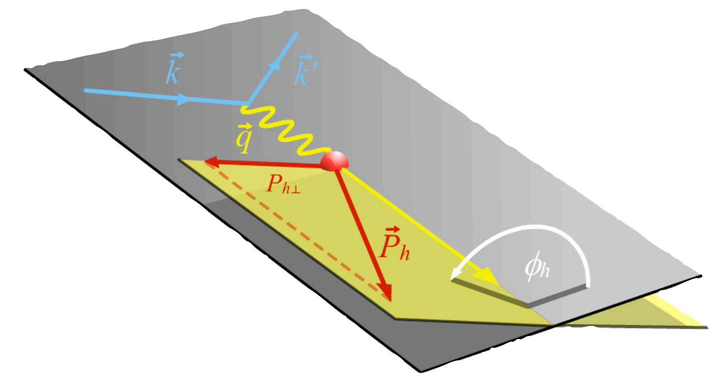

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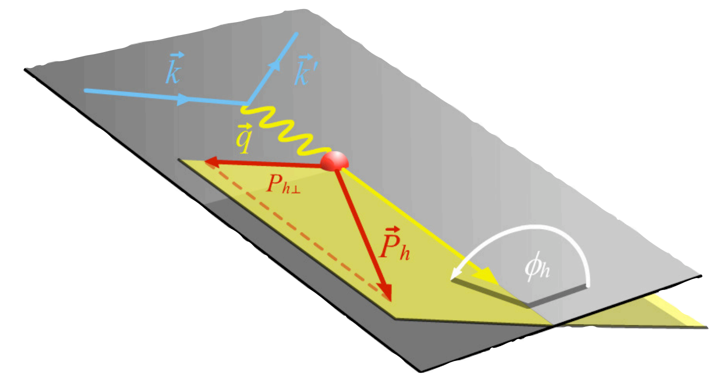

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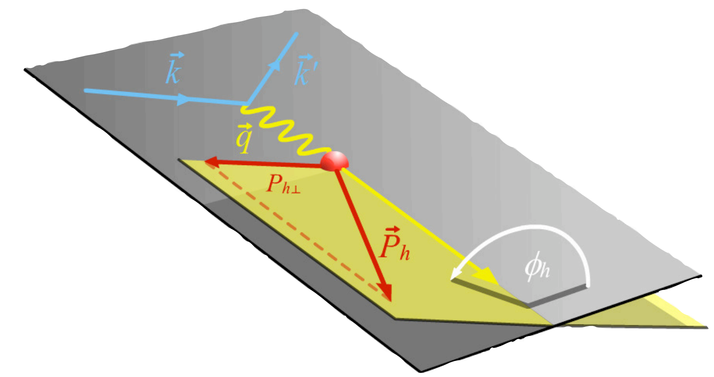
spin-orbit correlations
(Boer-Mulders effect)

Semi-inclusive unpolarized asymmetries



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➡ **Extrac ... thal moments:**

Boer-Mulders DF

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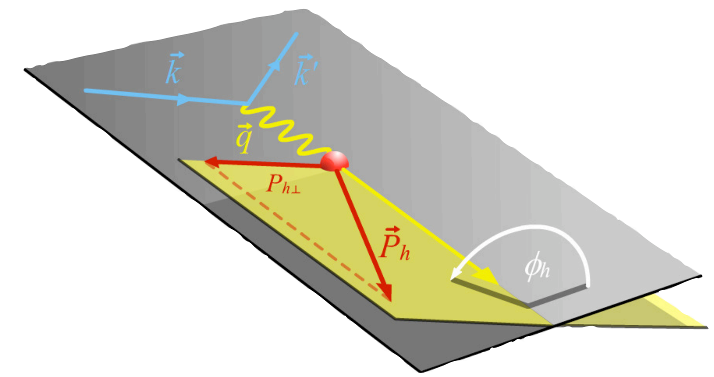

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➡ **Extrac** **thal mo**

Boer-Mulders DF

Collins FF

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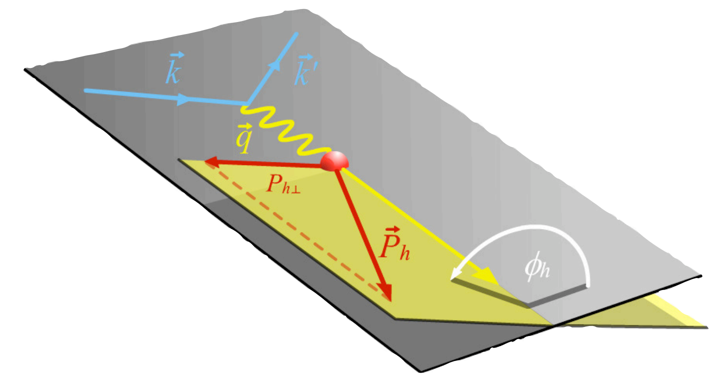

$$\frac{d^5\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} \propto \left(1+\frac{\gamma^2}{2x}\right)\{F_{UU,T}+\epsilon F_{UU,L}$$

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➡ **Extrac**... **thal mo**...

Boer-Mulders DF

Collins FF

$$2\frac{\int d\phi_h \cos n\phi\, d\sigma}{\int d\phi_h d\sigma} = \frac{\epsilon F_{UU}^{\cos n\phi}}{F_{UU,T}+\epsilon F_{UU,L}}$$

twist-2 (leading)

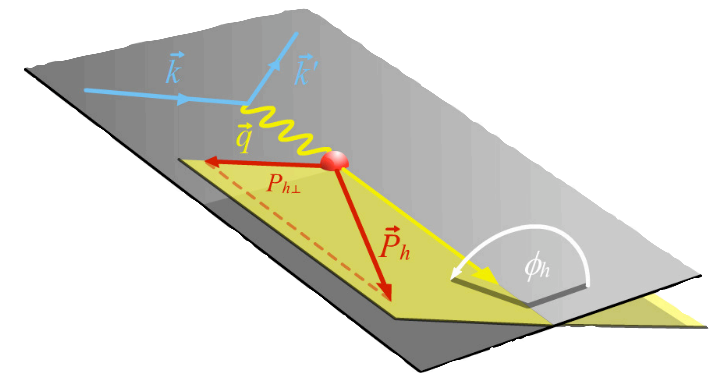
$$F_{UU}^{\cos 2\phi} \propto -\sum_q h_1^{\perp,q}(x,p_T^2)\otimes H_1^{\perp,q\to h}(z,K_T^2)$$

$$+\left(\frac{M}{Q}\right)^2\sum_q f_1^q(x,p_T^2)\otimes D_1^q(z,K_T^2)$$

twist-4

spin-orbit correlations
(Boer-Mulders effect)

Semi-inclusive unpolarized asymmetries



$$\frac{d^5\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} \propto \left(1+\frac{\gamma^2}{2x}\right)\{F_{UU,T}+\epsilon F_{UU,L}$$

$$+\sqrt{2\epsilon(1-\epsilon)}F_{UU}^{\cos\phi_h}\cos\phi_h+\epsilon F_{UU}^{\cos 2\phi_h}\cos 2\phi_h\}$$

➡ **Extrac... thal mo...**

$$2\frac{\int d\phi_h \cos n\phi \, d\sigma}{\int d\phi_h d\sigma} = \frac{\epsilon F_{UU}^{\cos n\phi}}{F_{UU,T}+\epsilon F_{UU,L}}$$

Boer-Mulders DF

Collins FF

twist-2 (leading)

$$F_{UU}^{\cos 2\phi} \propto -\sum_q h_1^{\perp,q}(x,p_T^2)\otimes H_1^{\perp,q\to h}(z,K_T^2)$$

$$+\left(\frac{M}{Q}\right)^2\sum_q f_1^q(x,p_T^2)\otimes D_1^q(z,K_T^2)$$

twist-4

spin-orbit correlations (Boer-Mulders effect)

kinematic correlation (Cahn effect)

A. Airapetian et al, submitted to PRD (arXiv:1204.4161)

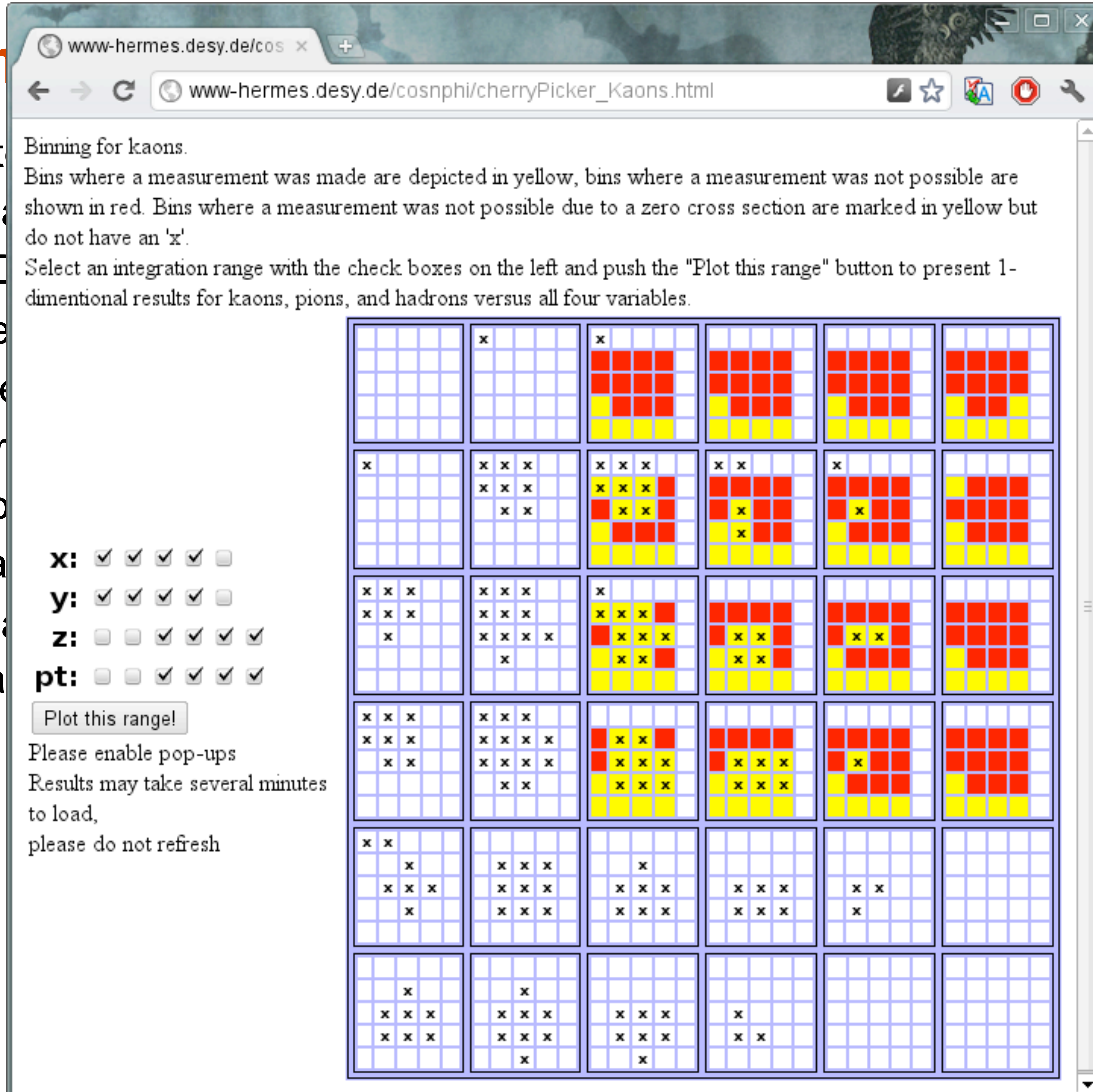
A. Airapetian et al, submitted to PRD (arXiv:1204.4161)

- ➡ most complete data up to date
- ➡ fully differential 4D extraction (in 900 bins!)
- ➡ employ full 5D unfolding
- ➡ requires large statistics!
  - ➡ includes the data taken in 2006/2007
  - ➡ even larger MC sample needed (20x data, generated on GRID)
  - ➡ available for pions, kaons (RICH) and unidentified hadrons
  - ➡ hydrogen and deuterium targets
- ➡ fully differential results available online with a tool to integrate the moments in an arbitrary kinematic range:

http://www-hermes.desy.de/cosnphi/

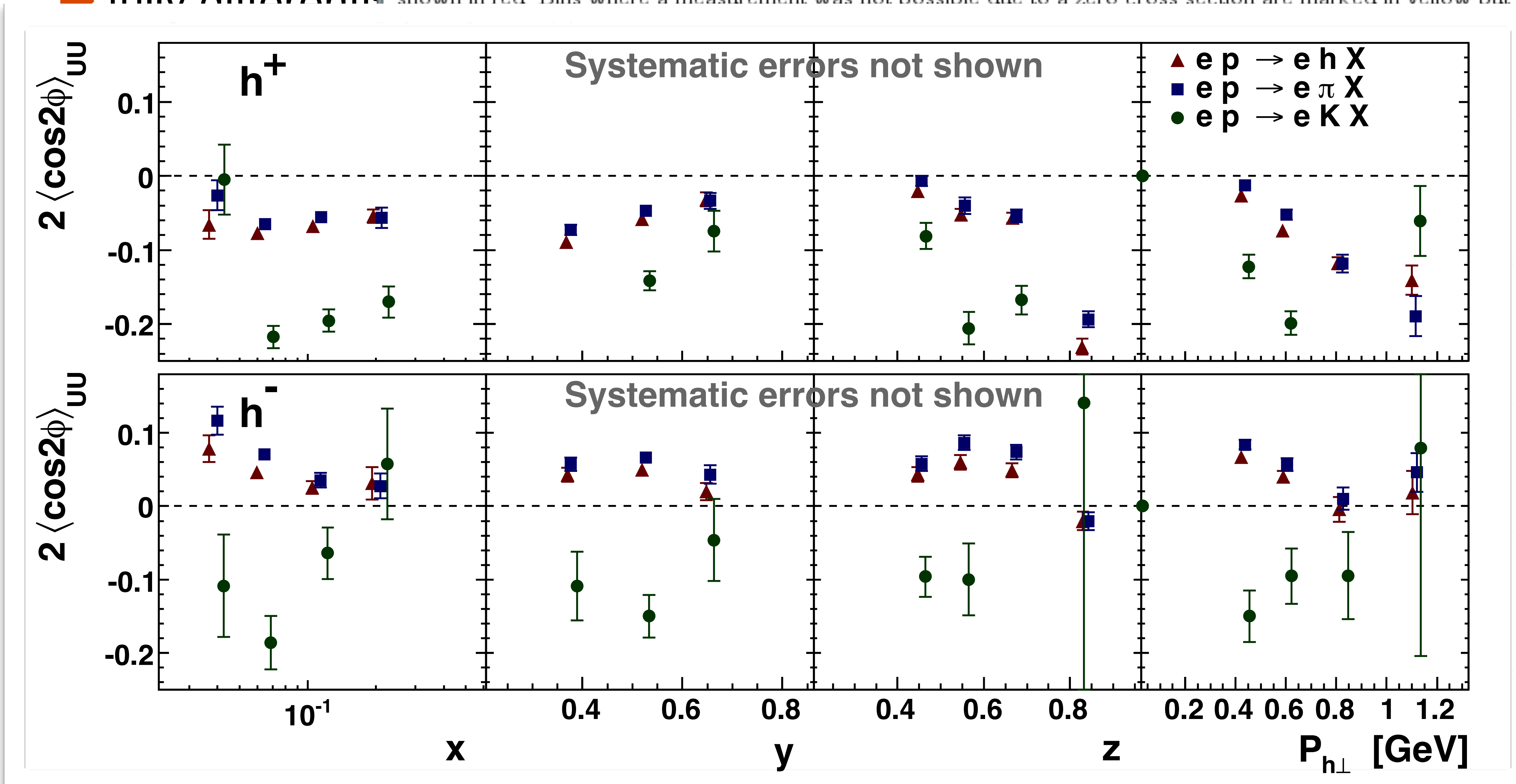
A. Airapetian

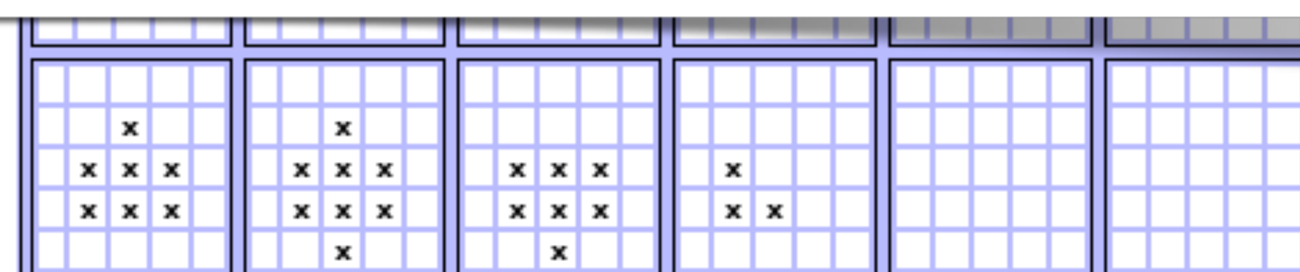
- most complet
- fully differenti
- employ full 5D
- requires large
  - includes the
  - even larger
  - available fo
  - hydrogen a
- fully differenti
  moments in a



A. Airapetian

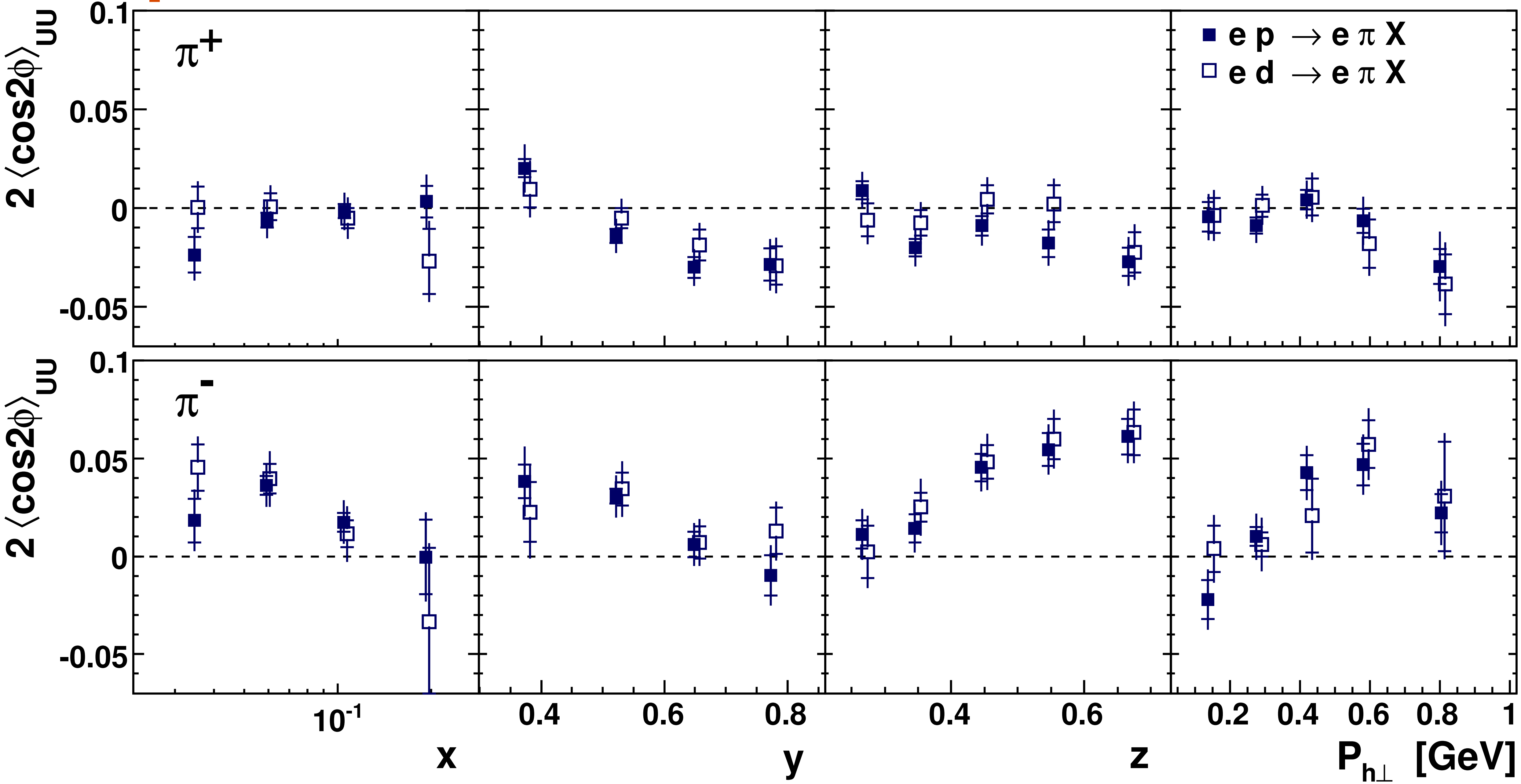
- most complet
- fully differenti





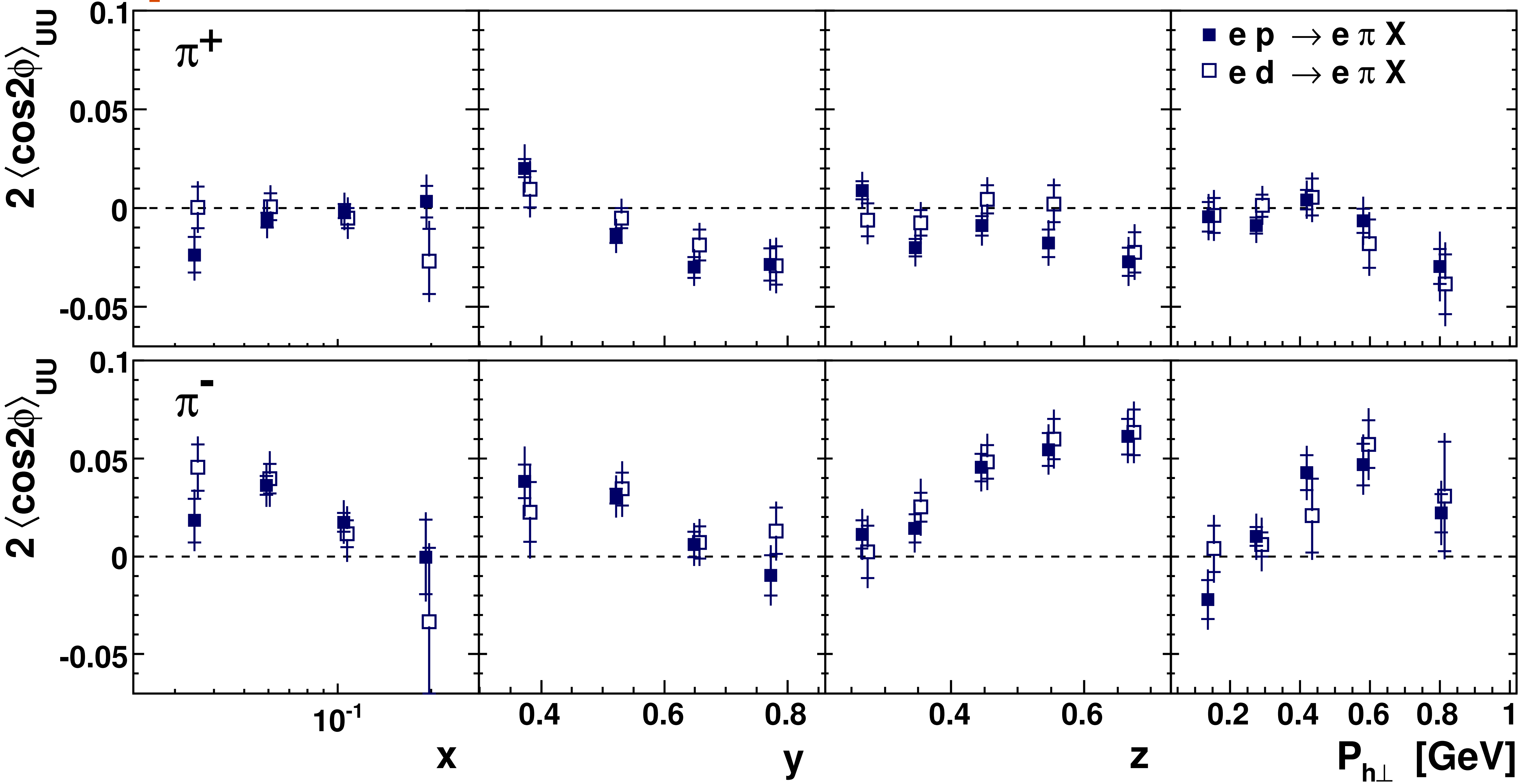
cos2ϕ Modulation

[arXiv:1204.4161]



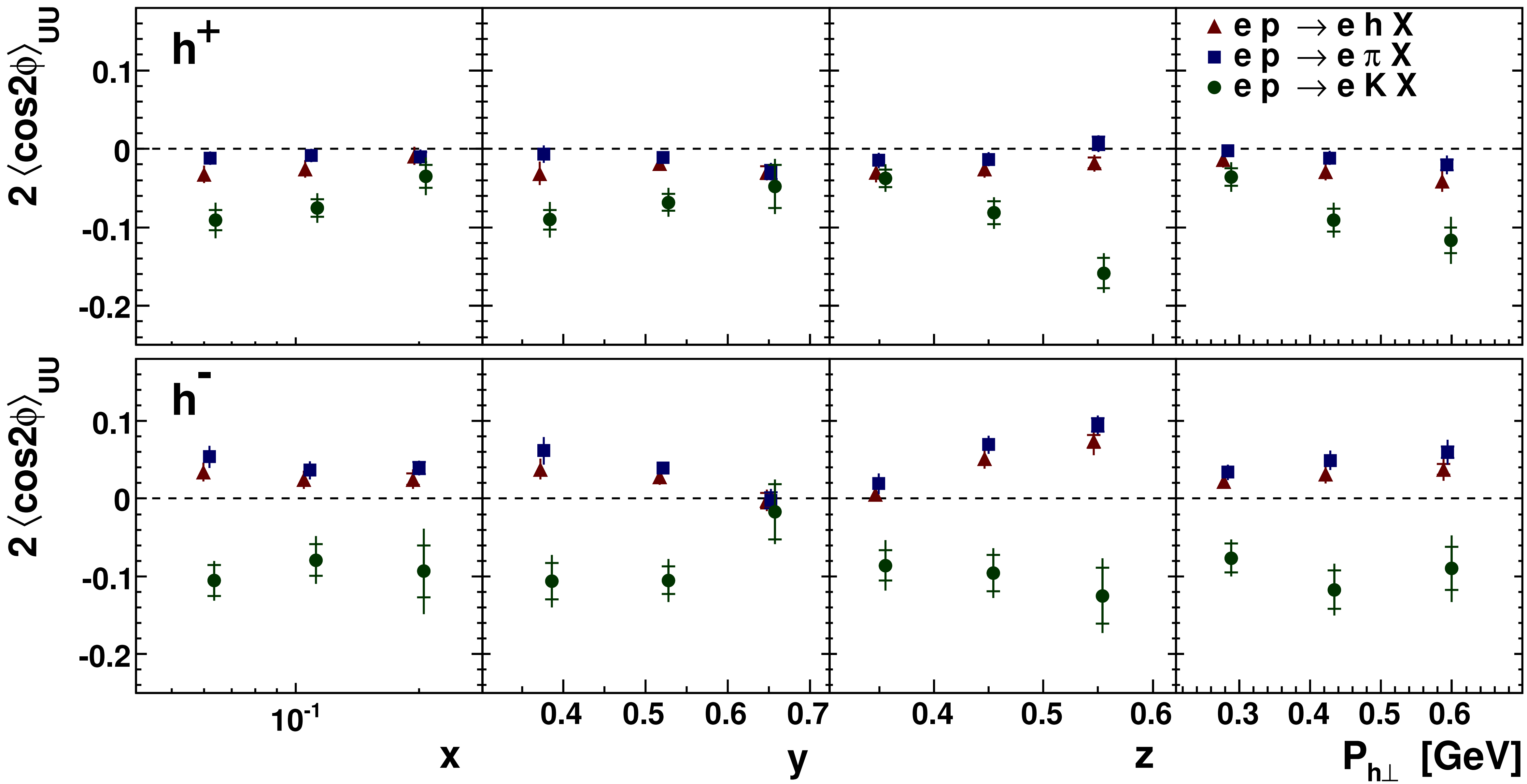
cos2ϕ Modulation

[arXiv:1204.4161]

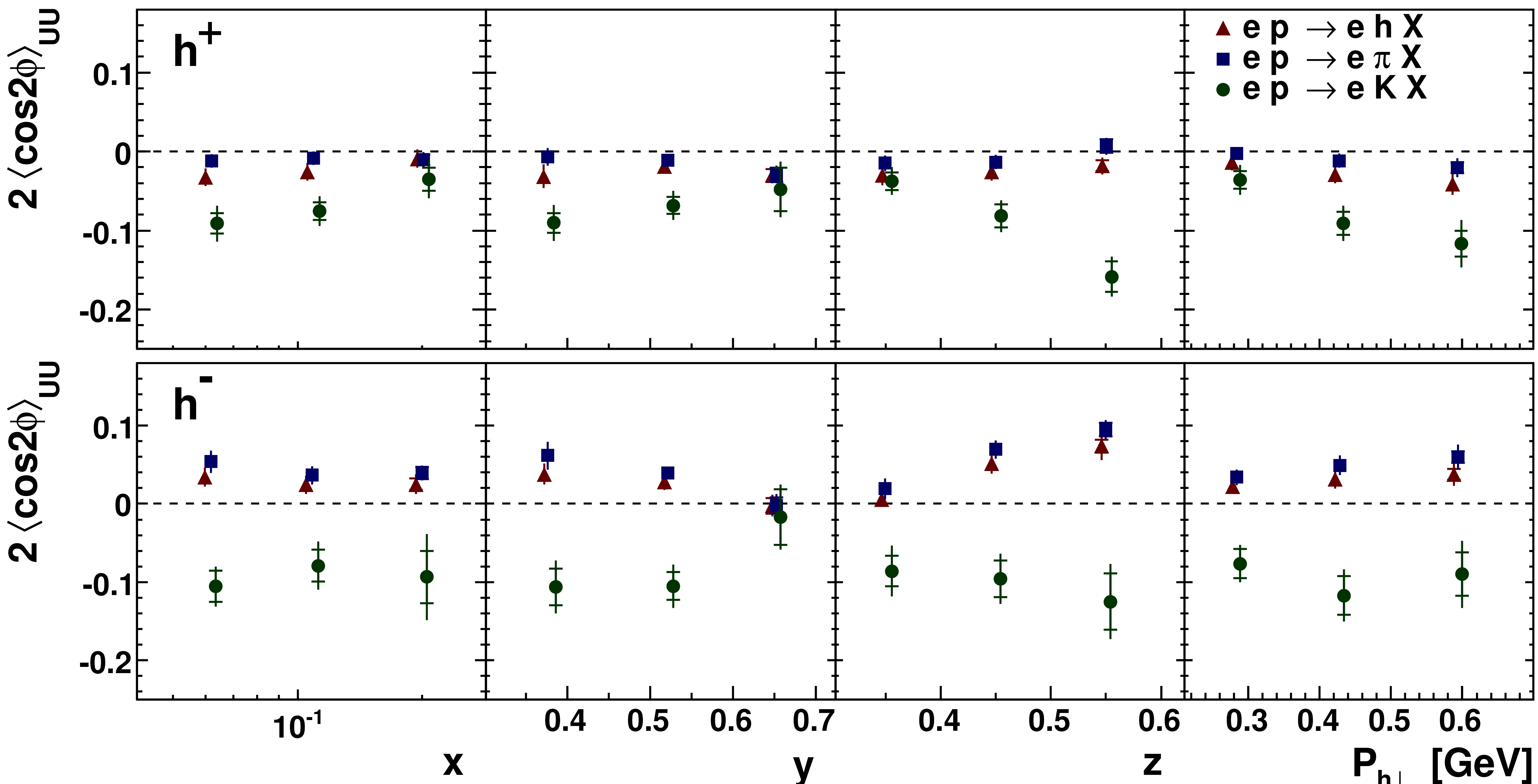


- ➡ flavor-dependence indicates **significant** Boer-Mulder-Collins effect
- ➡ Cahn effect (expected to be) **flavor-blind** in first approximation
- ➡ hardly any difference between H and D targets

Strange Kaons cos2ϕ



Strange Kaons cos2ϕ



- ➡ Kaons: larger magnitude than pions
- ➡ Same sign for K^+ and K^-
- ➡ Boer-Mulders function expected similar for pions and kaons - Collins function role important
- ➡ K^- opposite sign to π^- - pure sea object

cosϕ moment of A_{LL} asymmetry

$$\frac{d^5\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} \propto \left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\epsilon F_{UU,L}$$

$$+\sqrt{2\epsilon(1-\epsilon)}F_{UU}^{\cos\phi_h}\cos\phi_h+\epsilon F_{UU}^{\cos 2\phi_h}\cos 2\phi_h$$

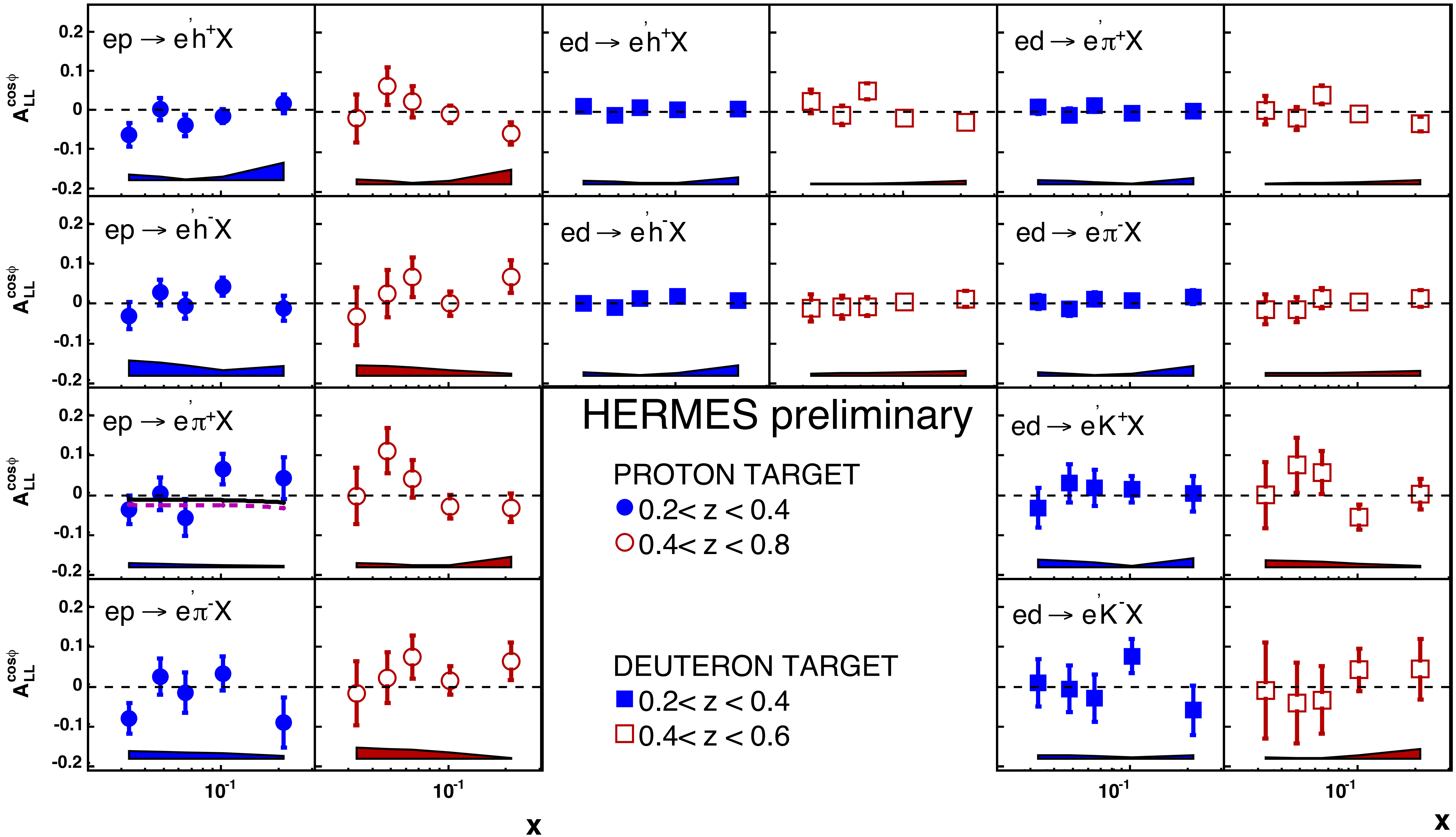
$$+\lambda_e S_{||}\left[\sqrt{1-\epsilon^2}F_{LL}+\sqrt{2\epsilon(1-\epsilon)}\cos\phi_h F_{LL}^{\cos\phi_h}\right]\Big\}$$

Target: long.
Beam: long.

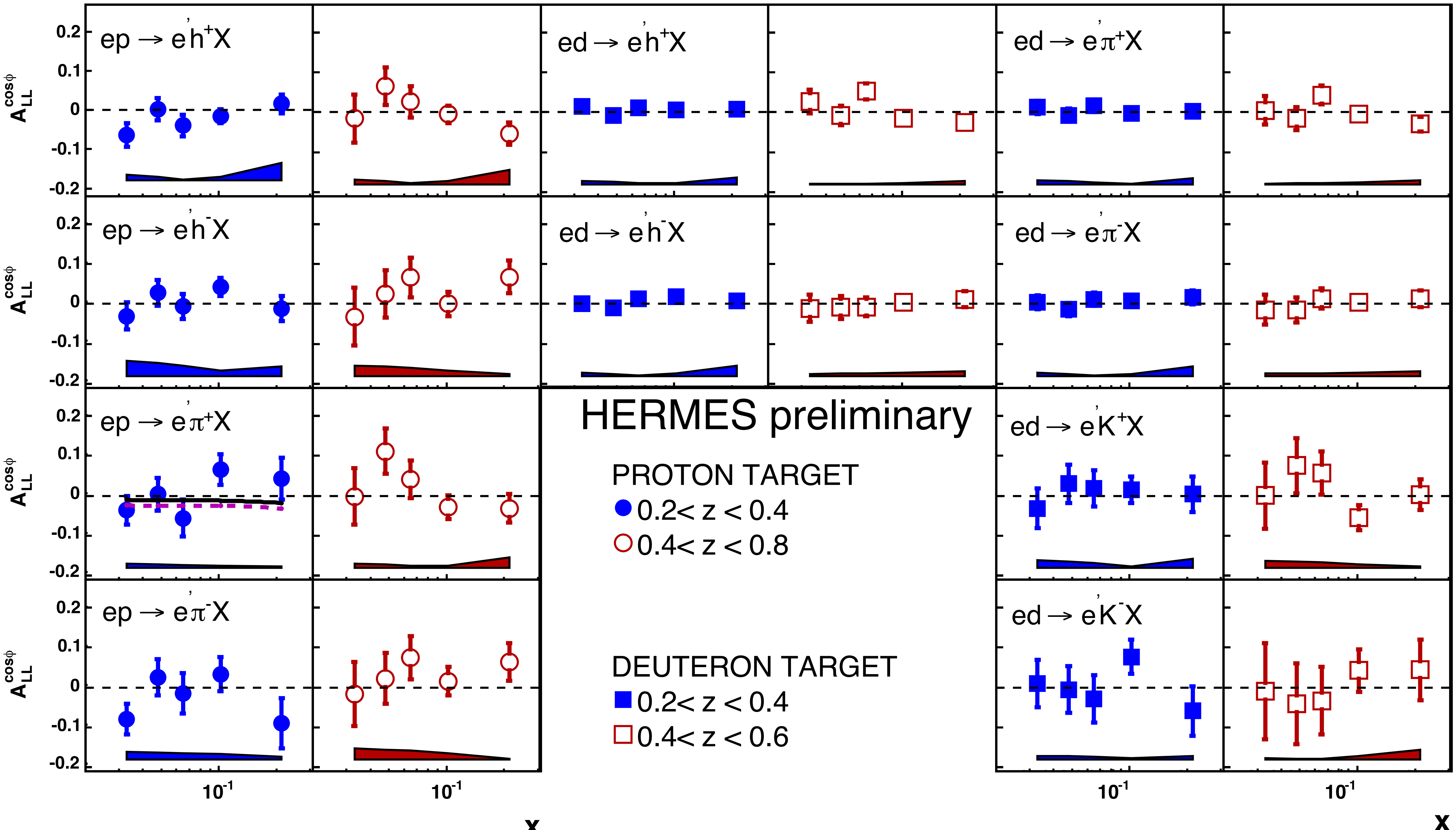
inclusive limit: $g_1(x)$

twist-3

cosϕ moment of A_{LL} asymmetry

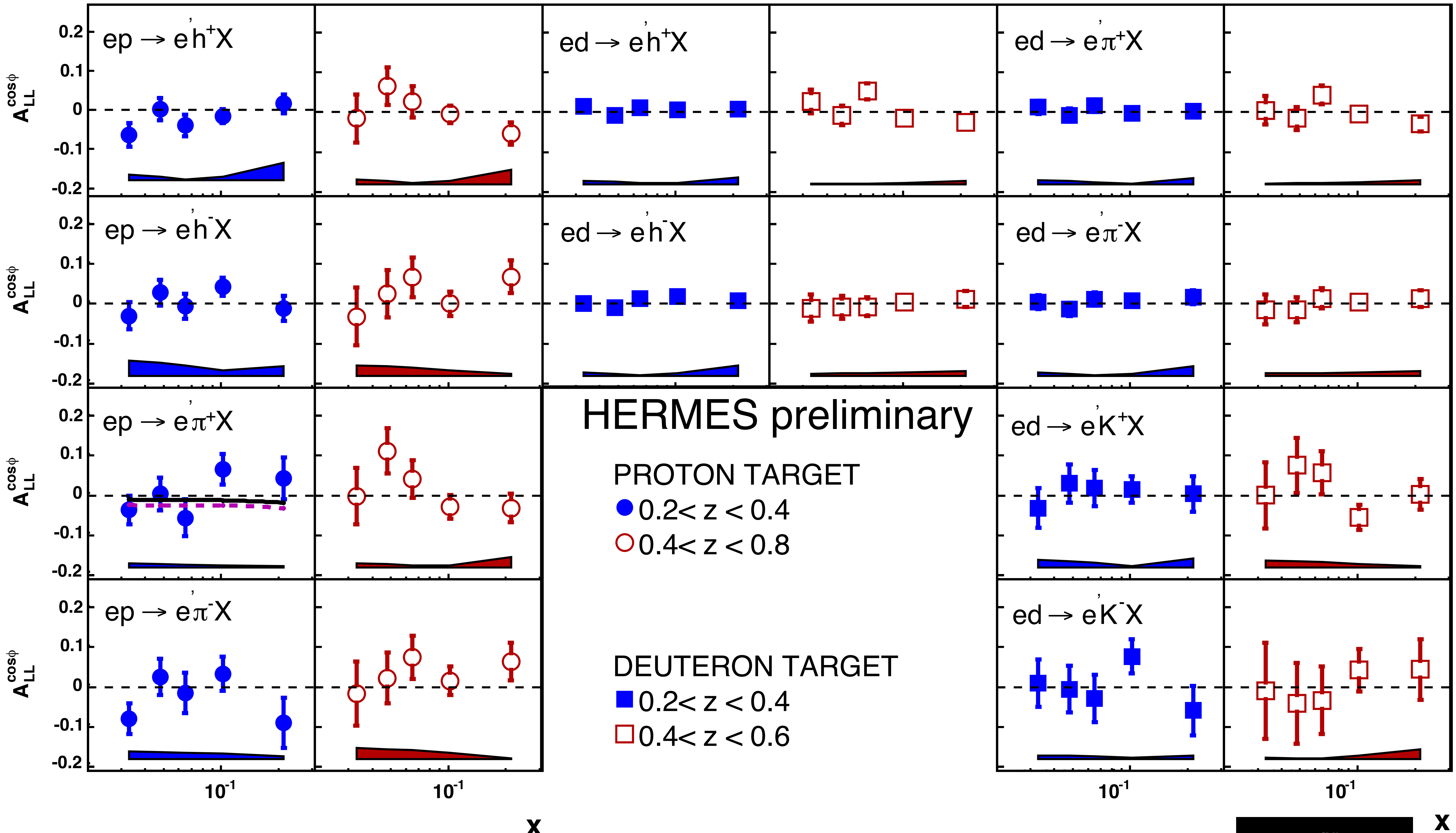


cosφ moment of A_{LL} asymmetry



- Consistent with zero
- Compatible within hydrogen and deuterium targets
- No significant kinematic dependence observed

cosφ moment of A_{LL} asymmetry



- Consistent with zero
- Compatible within hydrogen and deuterium targets
- No significant kinematic dependence observed

SIDIS Amplitudes Summary @HERMES:

$$
\begin{aligned}
d\sigma \;=\;& d\sigma^{0}_{UU} + \cos(2\phi)\, d\sigma^{1}_{UU} + \frac{1}{Q}\cos(\phi)\, d\sigma^{2}_{UU} \;+\; P_l\, \frac{1}{Q}\sin(\phi)\, d\sigma^{3}_{LU} \\
+\;& S_L\left[\sin(2\phi)\, d\sigma^{4}_{UL} + \frac{1}{Q}\sin(\phi)\, d\sigma^{5}_{UL} \;+\; P_l \left(d\sigma^{6}_{LL} + \frac{1}{Q}\cos(\phi)\, d\sigma^{7}_{LL}\right)\right] \\
+\;& S_T\left[\sin(\phi-\phi_s)\, d\sigma^{8}_{UT} + \sin(\phi+\phi_s)\, d\sigma^{9}_{UT} + \sin(3\phi-\phi_s)\, d\sigma^{10}_{UT} + \frac{1}{Q}\sin(2\phi-\phi_s)\, d\sigma^{11}_{UT} + \frac{1}{Q}\sin(\phi_s)\, d\sigma^{12}_{UT}\right. \\
&\qquad \left. + P_l \left(\cos(\phi-\phi_s)\, d\sigma^{13}_{LT} + \frac{1}{Q}\cos(\phi_s)\, d\sigma^{14}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_s)\, d\sigma^{15}_{LT}\right)\right]
\end{aligned}
$$

SIDIS Amplitudes Summary @HERMES:

published

published, update with higher statistics pending

$$
\begin{aligned}
d\sigma \;=\;& \boxed{d\sigma^0_{UU}} + \cos(2\phi)d\sigma^1_{UU} + \frac{1}{Q}\cos(\phi)d\sigma^2_{UU} + P_l \boxed{\frac{1}{Q}\sin(\phi)d\sigma^3_{LU}} \\
&+ S_L\left[\boxed{\sin(2\phi)d\sigma^4_{UL} + \frac{1}{Q}\sin(\phi)d\sigma^5_{UL}} + P_l\left(\boxed{d\sigma^6_{LL}} + \frac{1}{Q}\cos(\phi)d\sigma^7_{LL}\right)\right] \\
&+ S_T\left[\boxed{\sin(\phi-\phi_s)d\sigma^8_{UT} + \sin(\phi+\phi_s)d\sigma^9_{UT}} + \sin(3\phi-\phi_s)d\sigma^{10}_{UT} + \frac{1}{Q}\sin(2\phi-\phi_s)d\sigma^{11}_{UT} + \frac{1}{Q}\sin(\phi_s)d\sigma^{12}_{UT}\right. \\
&\quad \left. + P_l\left(\cos(\phi-\phi_s)d\sigma^{13}_{LT} + \frac{1}{Q}\cos(\phi_s)d\sigma^{14}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_s)d\sigma^{15}_{LT}\right)\right]
\end{aligned}
$$

published

published

SIDIS Amplitudes Summary @HERMES:

published, update with higher statistics pending

published

$$
\begin{aligned}
d\sigma \;=\;& d\sigma^0_{UU} + \cos(2\phi)\,d\sigma^1_{UU} + \frac{1}{Q}\cos(\phi)\,d\sigma^2_{UU} \;+\; P_l\;\frac{1}{Q}\sin(\phi)\,d\sigma^3_{LU}\\
&+\; S_L\left[\sin(2\phi)\,d\sigma^4_{UL} + \frac{1}{Q}\sin(\phi)\,d\sigma^5_{UL} \;+\; P_l\left(d\sigma^6_{LL} + \frac{1}{Q}\cos(\phi)\,d\sigma^7_{LL}\right)\right]\\
&+\; S_T\left[\sin(\phi-\phi_s)\,d\sigma^8_{UT} + \sin(\phi+\phi_s)\,d\sigma^9_{UT} + \sin(3\phi-\phi_s)\,d\sigma^{10}_{UT} + \frac{1}{Q}\sin(2\phi-\phi_s)\,d\sigma^{11}_{UT} + \frac{1}{Q}\sin(\phi_s)\,d\sigma^{12}_{UT}\right.\\
&\qquad\left. +\, P_l\left(\cos(\phi-\phi_s)\,d\sigma^{13}_{LT} + \frac{1}{Q}\cos(\phi_s)\,d\sigma^{14}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_s)\,d\sigma^{15}_{LT}\right)\right]
\end{aligned}
$$

published

published

paper in preparation

SIDIS Amplitudes Summary @HERMES:

paper submitted

published

published, update with higher statistics pending

$$\begin{aligned}
d\sigma &= d\sigma^0_{UU} + \cos(2\phi)d\sigma^1_{UU} + \frac{1}{Q}\cos(\phi)d\sigma^2_{UU} + P_l\,\frac{1}{Q}\sin(\phi)d\sigma^3_{LU} \\
&+ S_L\left[\sin(2\phi)d\sigma^4_{UL} + \frac{1}{Q}\sin(\phi)d\sigma^5_{UL} + P_l\left(d\sigma^6_{LL} + \frac{1}{Q}\cos(\phi)d\sigma^7_{LL}\right)\right] \\
&+ S_T\Big[\sin(\phi-\phi_s)d\sigma^8_{UT} + \sin(\phi+\phi_s)d\sigma^9_{UT} + \sin(3\phi-\phi_s)d\sigma^{10}_{UT} + \frac{1}{Q}\sin(2\phi-\phi_s)d\sigma^{11}_{UT} + \frac{1}{Q}\sin(\phi_s)d\sigma^{12}_{UT} \\
&\quad + P_l\left(\cos(\phi-\phi_s)d\sigma^{13}_{LT} + \frac{1}{Q}\cos(\phi_s)d\sigma^{14}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_s)d\sigma^{15}_{LT}\right)\Big]
\end{aligned}$$

published

published

paper in preparation

SIDIS Amplitudes Summary @HERMES:

paper submitted

published

published, update with higher statistics pending

released

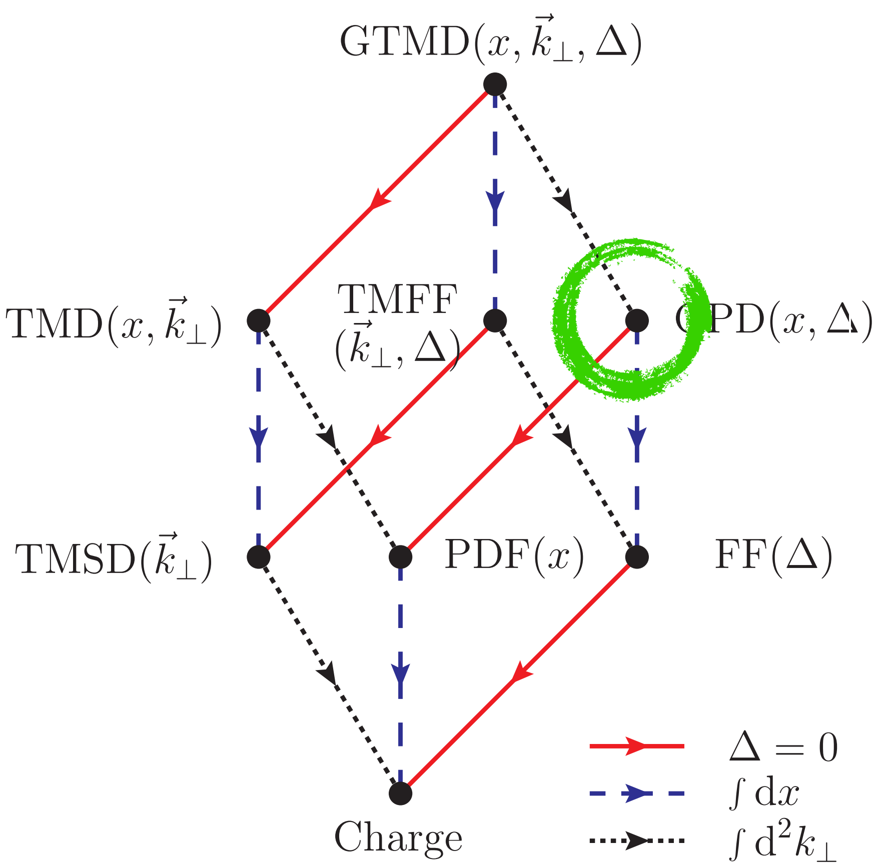
$$
\begin{aligned}
d\sigma \; = \; & d\sigma^0_{UU} + \cos(2\phi)d\sigma^1_{UU} + \frac{1}{Q}\cos(\phi)d\sigma^2_{UU} \; + \; P_l \; \frac{1}{Q}\sin(\phi)d\sigma^3_{LU} \\
+ \; S_L & \left[\sin(2\phi)d\sigma^4_{UL} + \frac{1}{Q}\sin(\phi)d\sigma^5_{UL} \; + \; P_l \left(d\sigma^6_{LL} + \frac{1}{Q}\cos(\phi)d\sigma^7_{LL} \right) \right] \\
+ \; S_T & \left[\sin(\phi-\phi_s)d\sigma^8_{UT} + \sin(\phi+\phi_s)d\sigma^9_{UT} + \sin(3\phi-\phi_s)d\sigma^{10}_{UT} + \frac{1}{Q}\sin(2\phi-\phi_s)d\sigma^{11}_{UT} + \frac{1}{Q}\sin(\phi_s)d\sigma^{12}_{UT} \right. \\
& \left. + P_l \left(\cos(\phi-\phi_s)d\sigma^{13}_{LT} + \frac{1}{Q}\cos(\phi_s)d\sigma^{14}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_s)d\sigma^{15}_{LT} \right) \right]
\end{aligned}
$$

published

published

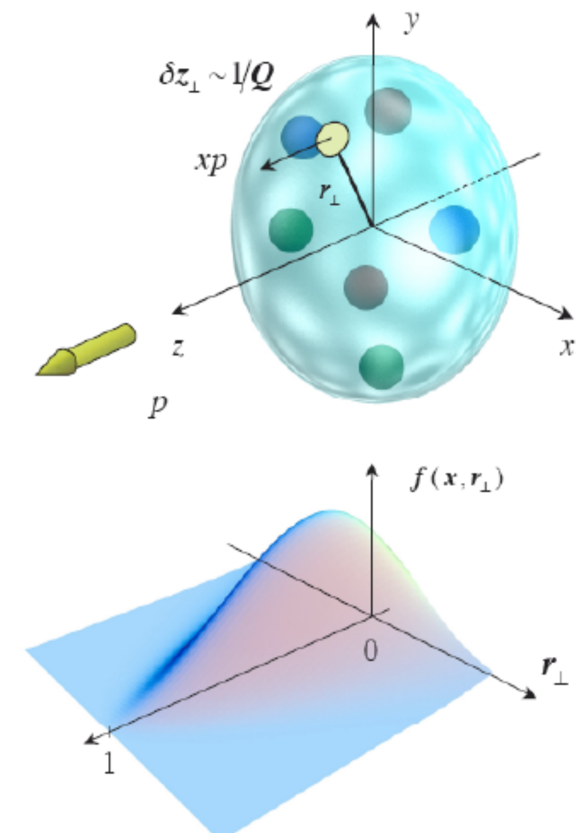
paper in preparation

Exclusive



$\mathrm{GTMD}(x, \vec{k}_\perp, \Delta)$
$\mathrm{TMD}(x, \vec{k}_\perp)$
TMFF
$(\vec{k}_\perp, \Delta)$
$\mathrm{GPD}(x, \Delta)$
$\mathrm{TMSD}(\vec{k}_\perp)$
$\mathrm{PDF}(x)$
$\mathrm{FF}(\Delta)$
Charge
$\Delta = 0$
$\int \mathrm{d}x$
$\int \mathrm{d}^2 k_\perp$

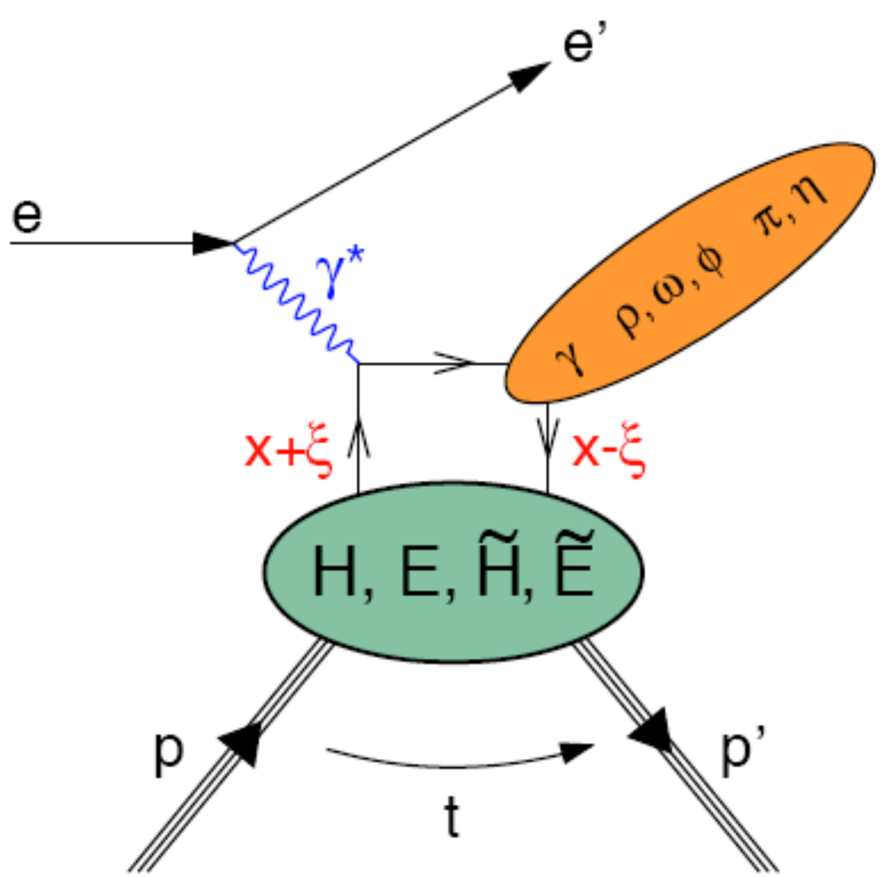
Exclusive measurement: GPDs



Simultaneous access to

➡longitudinal momentum fraction (PDF)

➡position in transverse direction (FF)

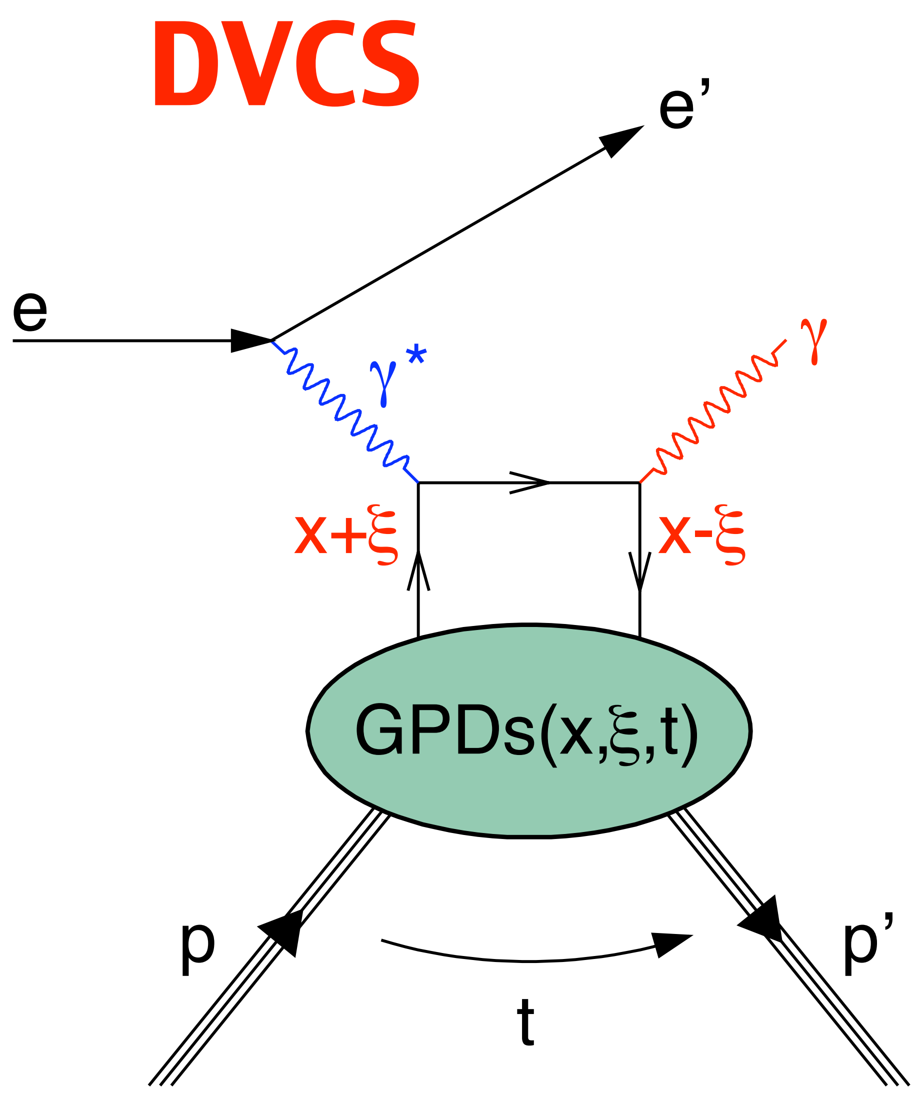


Quantum numbers of produced particle

combination of GPDs involved

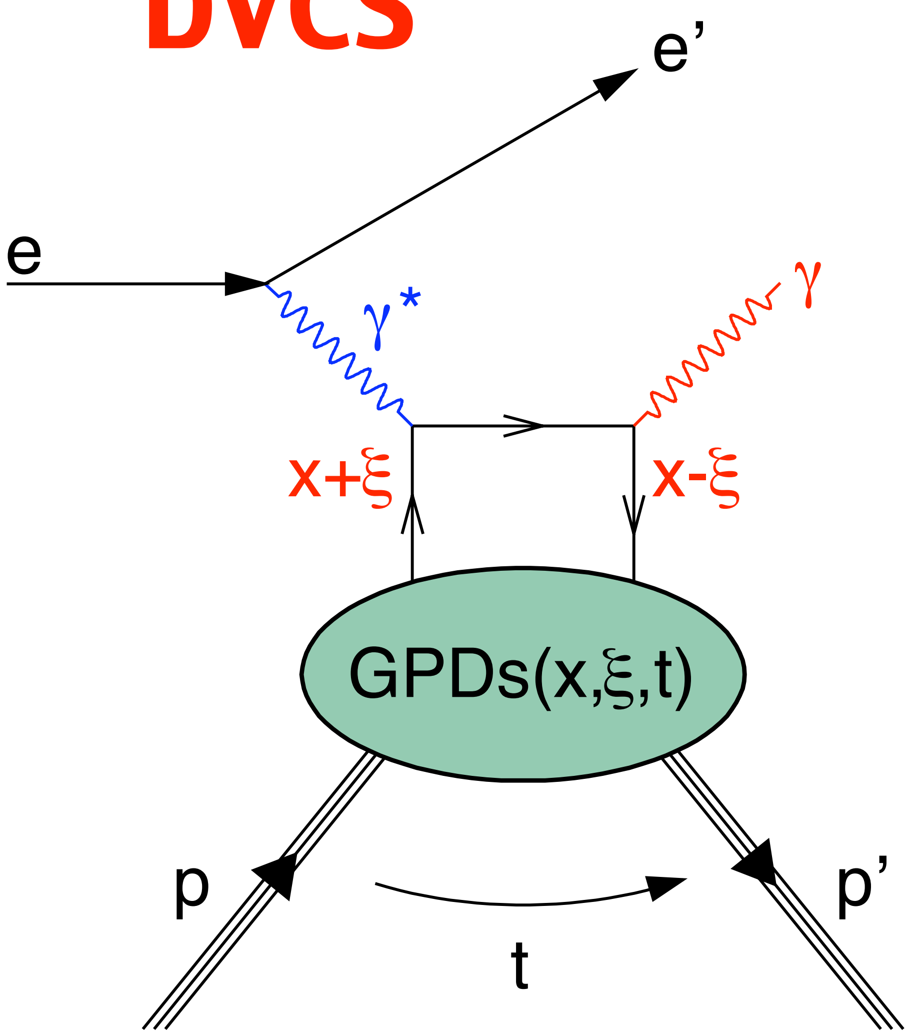
- DVCS(γ) $H, E, \widetilde{H}, \widetilde{E}$
- Vector mesons(ρ ϕ) H, E
- Pseudoscalar mesons(π η) $\widetilde{H}, \widetilde{E}$

Real-photon production

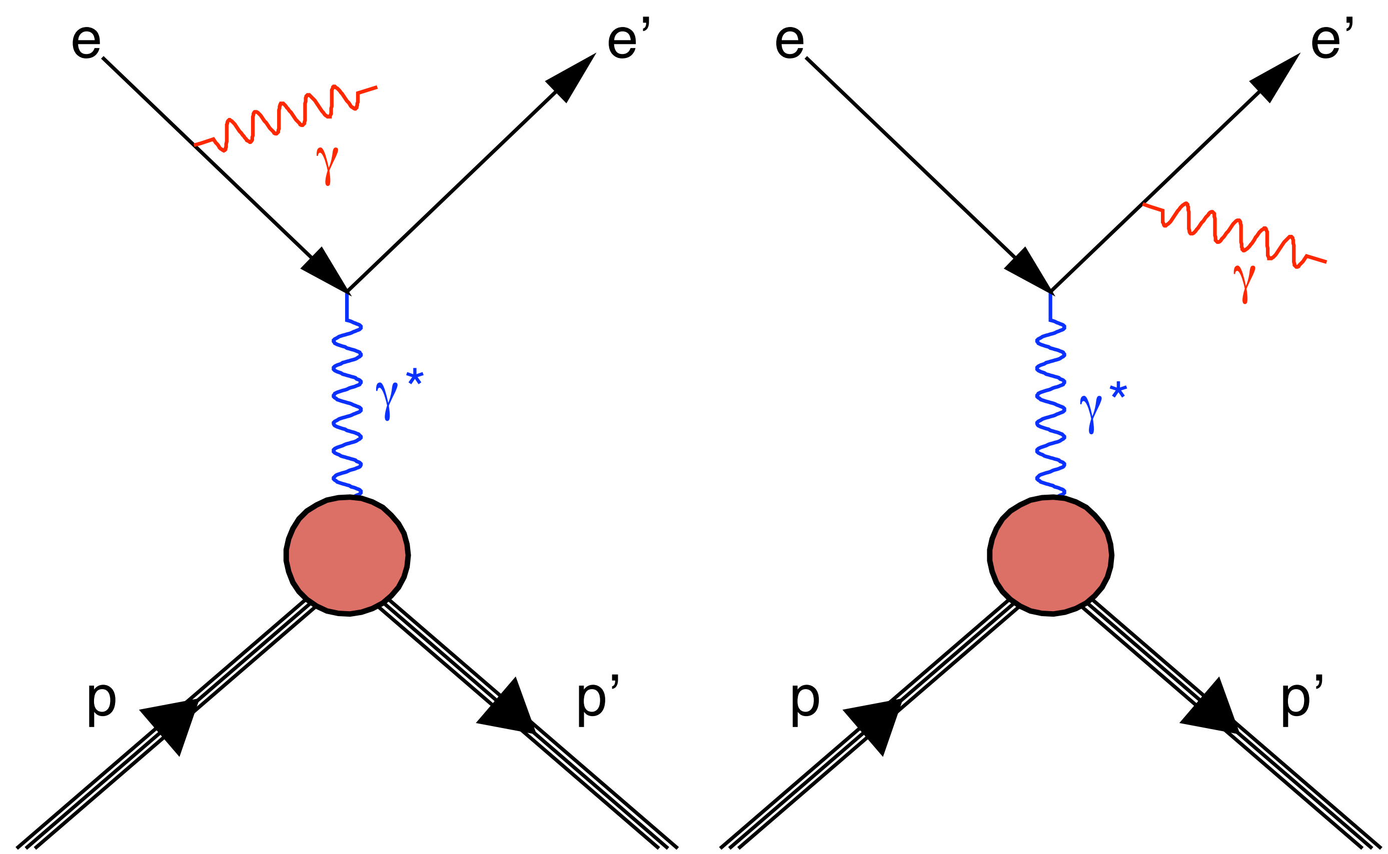


Real-photon production

DVCS

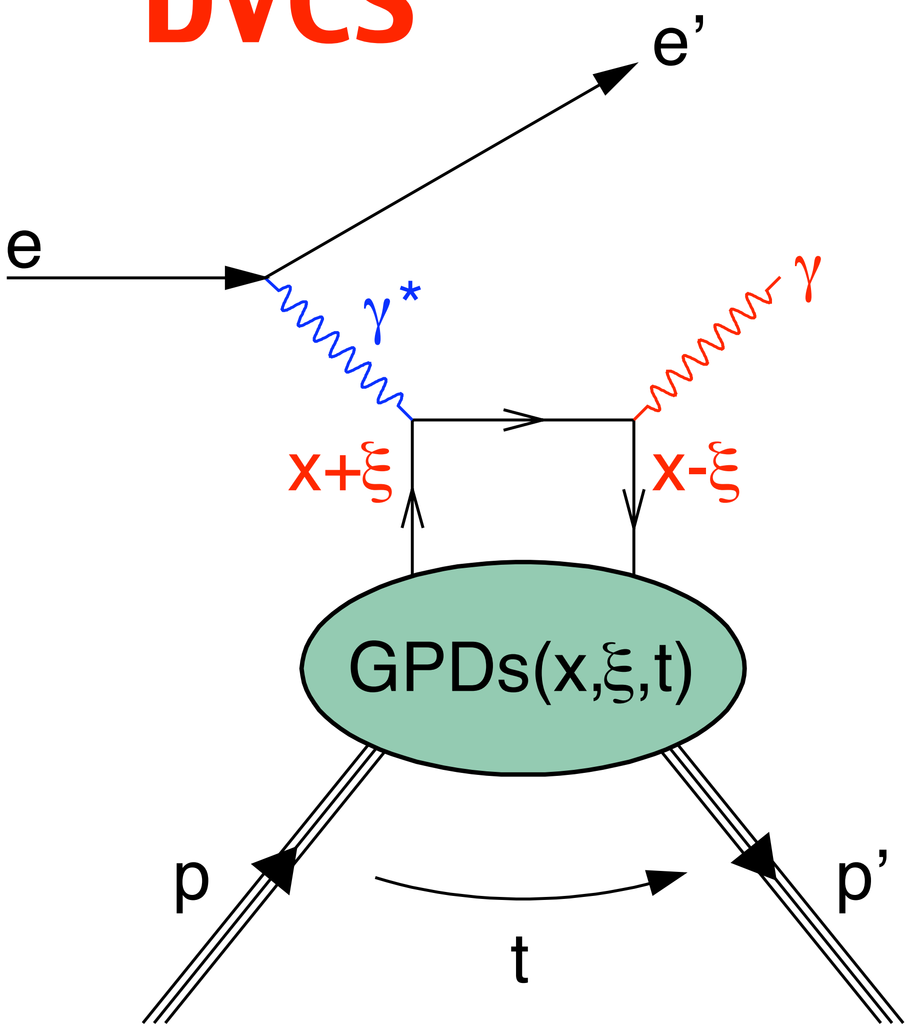


Bethe-Heitler

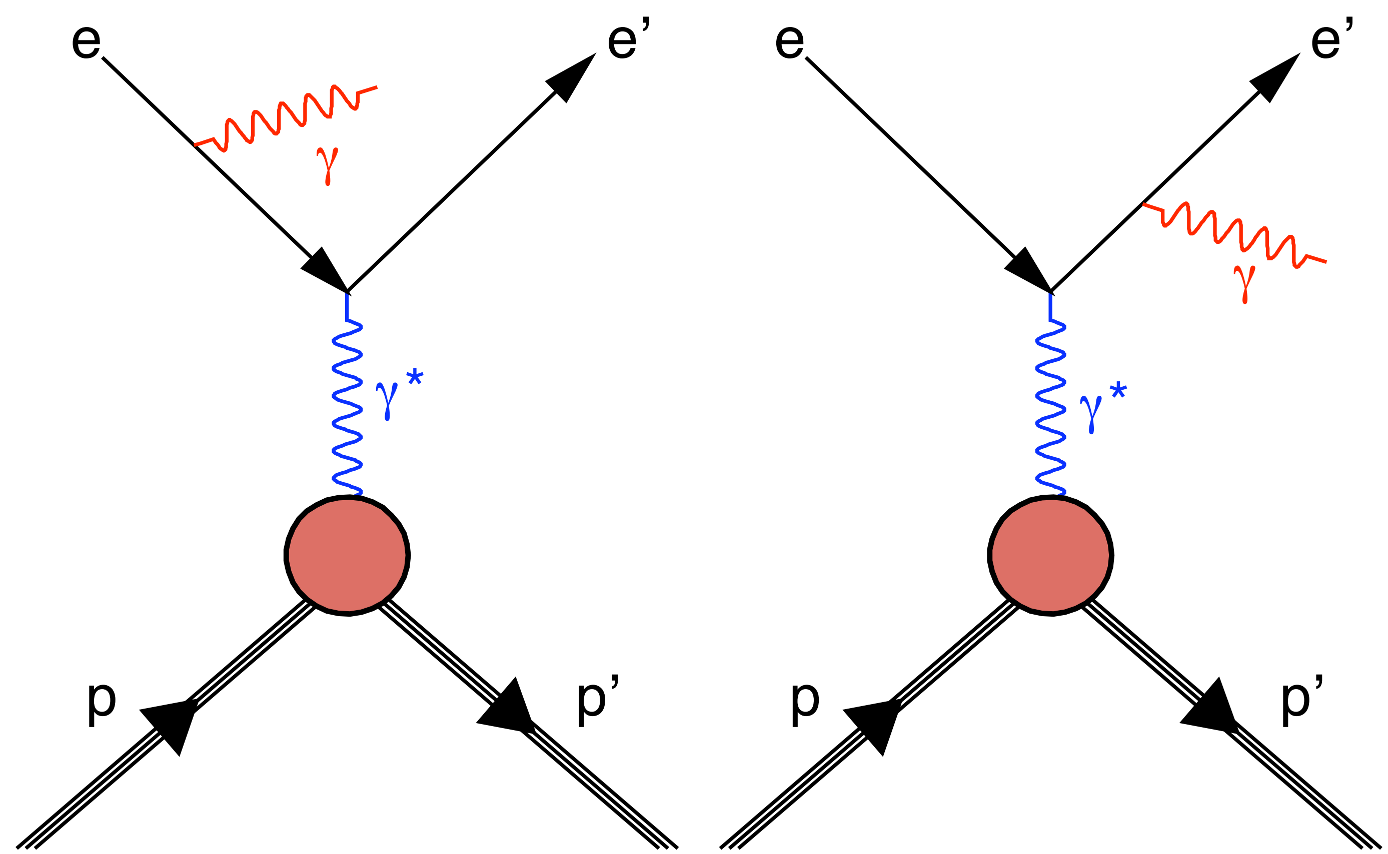


Real-photon production

DVCS

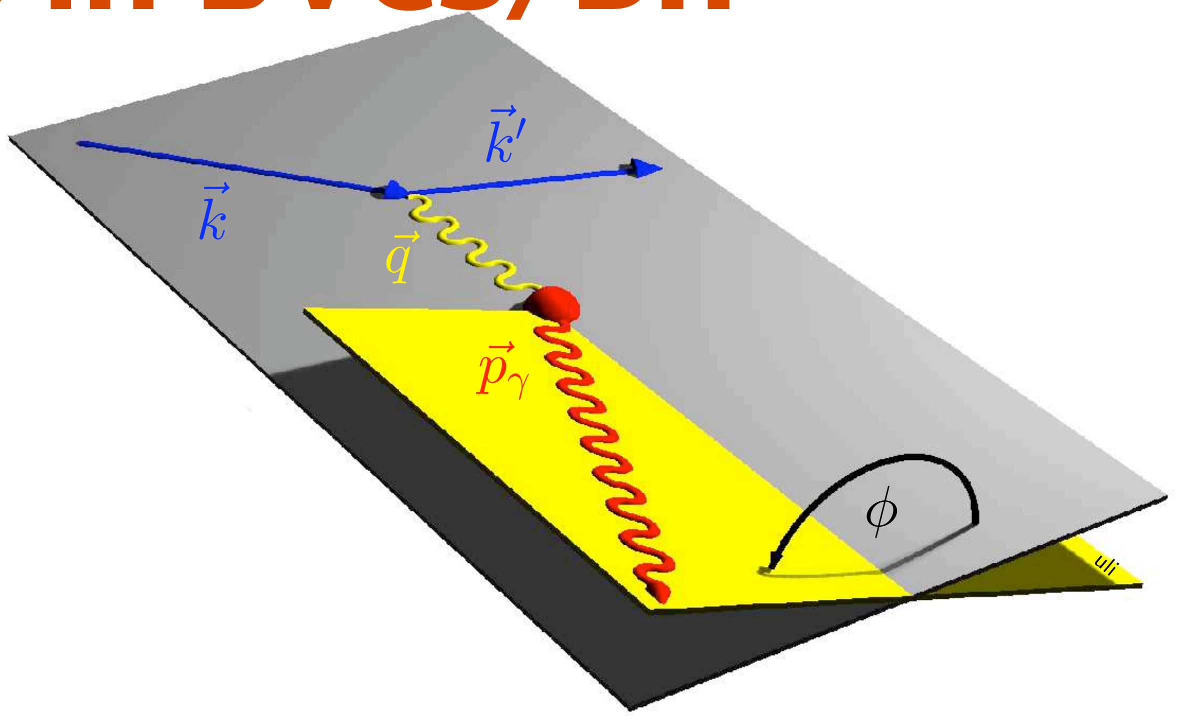


Bethe-Heitler



$$\frac{d^4\sigma}{dQ^2\,dx_B\,dt\,d\phi} = \frac{y^2}{32(2\pi))^4\sqrt{1+\frac{4M^2x_B^2}{Q^2}}}\left(|\mathcal{T}_{\mathrm{DVCS}}|^2 + |\mathcal{T}_{\mathrm{BH}}|^2 + \mathcal{I}\right)$$

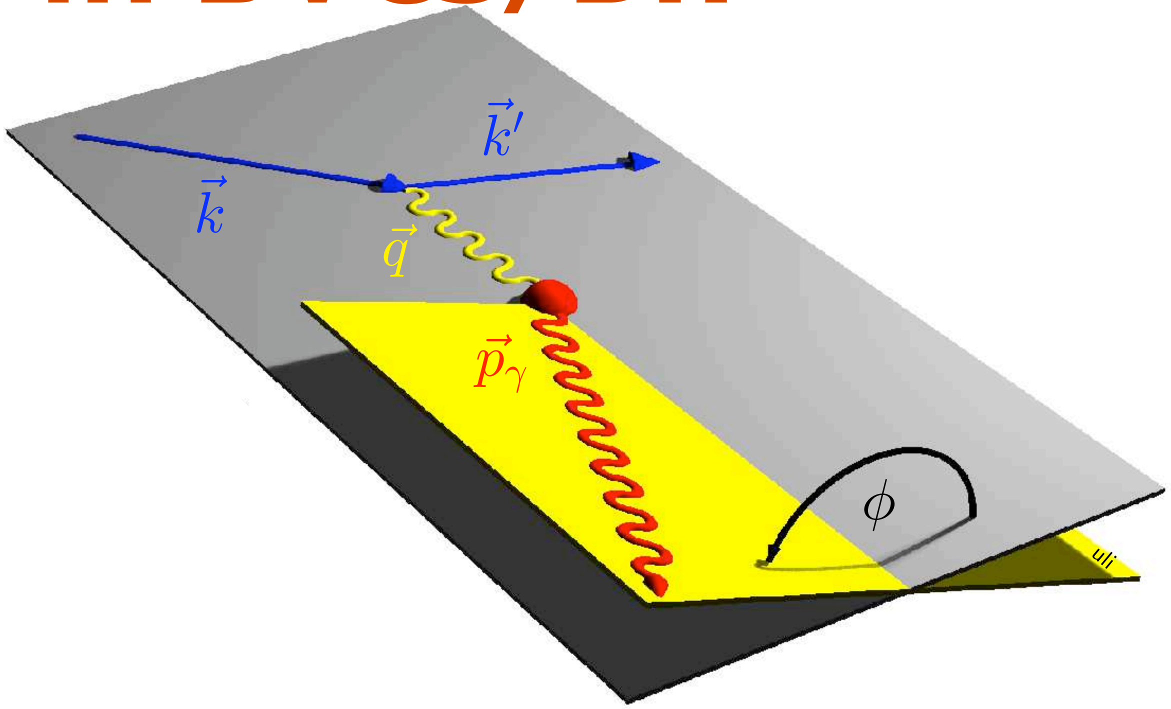
Azimuthal dependences in DVCS/BH
with unpolarized target



- **beam polarization P_B**
- **beam charge C_B**

Fourier expansion in ϕ:

Azimuthal dependences in DVCS/BH
with unpolarized target

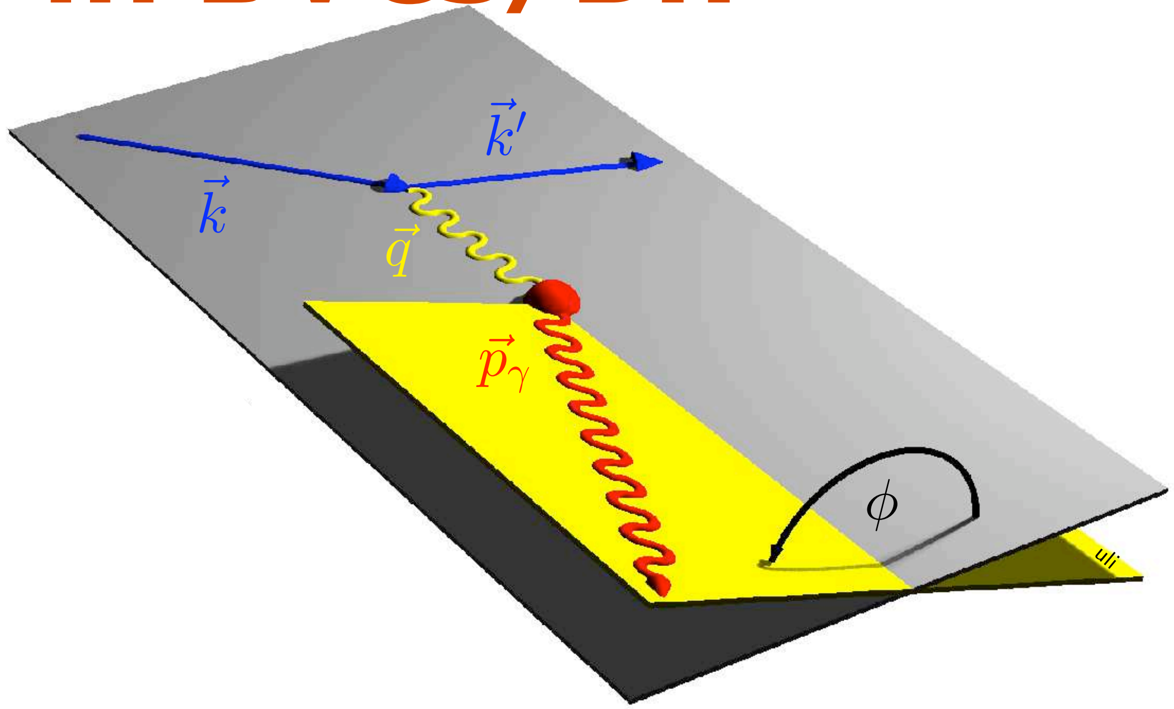


- **beam polarization P_B**
- **beam charge C_B**

Fourier expansion in ϕ:

$$|\mathcal{T}_{\mathrm{BH}}|^2 = \frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \sum_{n=0}^{2} c_n^{\mathrm{BH}} \cos(n\phi)$$

Azimuthal dependences in DVCS/BH
with unpolarized target



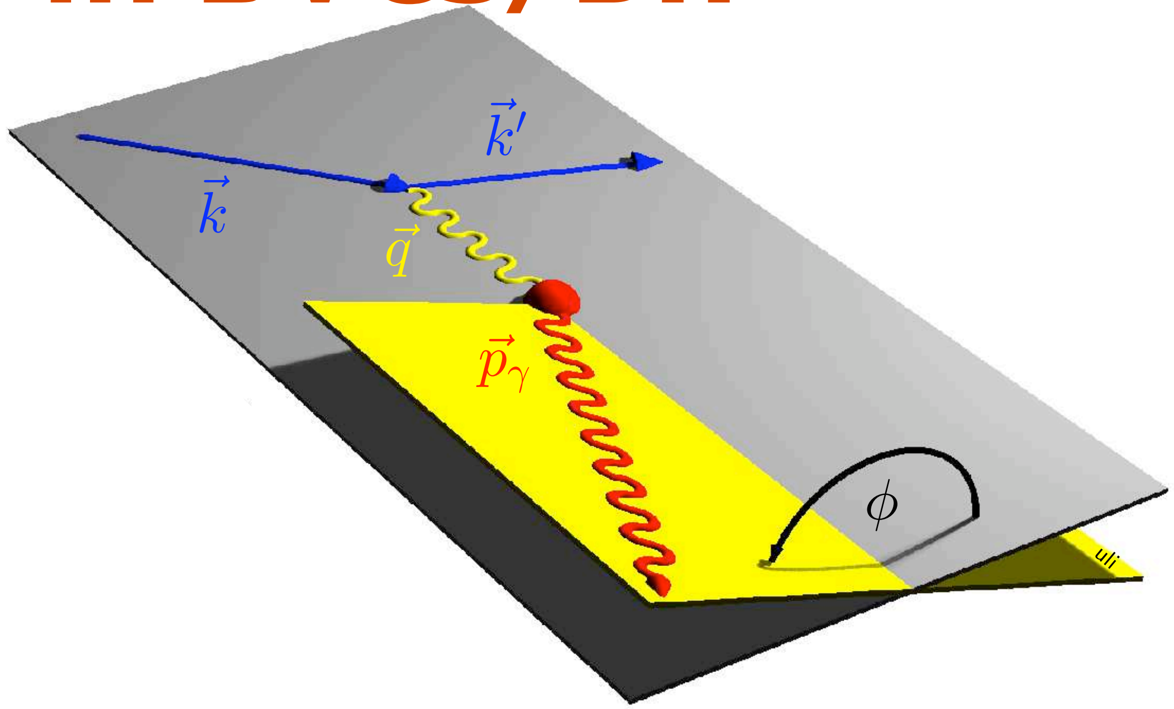
- **beam polarization P_B**
- **beam charge C_B**

Fourier expansion in ϕ:

$$|\mathcal{T}_{\mathrm{BH}}|^2 = \frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \sum_{n=0}^{2} c_n^{\mathrm{BH}} \cos(n\phi)$$

$$|\mathcal{T}_{\mathrm{DVCS}}|^2 = K_{\mathrm{DVCS}} \left[\sum_{n=0}^{2} c_n^{\mathrm{DVCS}} \cos(n\phi) + P_B \sum_{n=1}^{1} s_n^{\mathrm{DVCS}} \sin(n\phi) \right]$$

Azimuthal dependences in DVCS/BH
with unpolarized target



- **beam polarization P_B**
- **beam charge C_B**

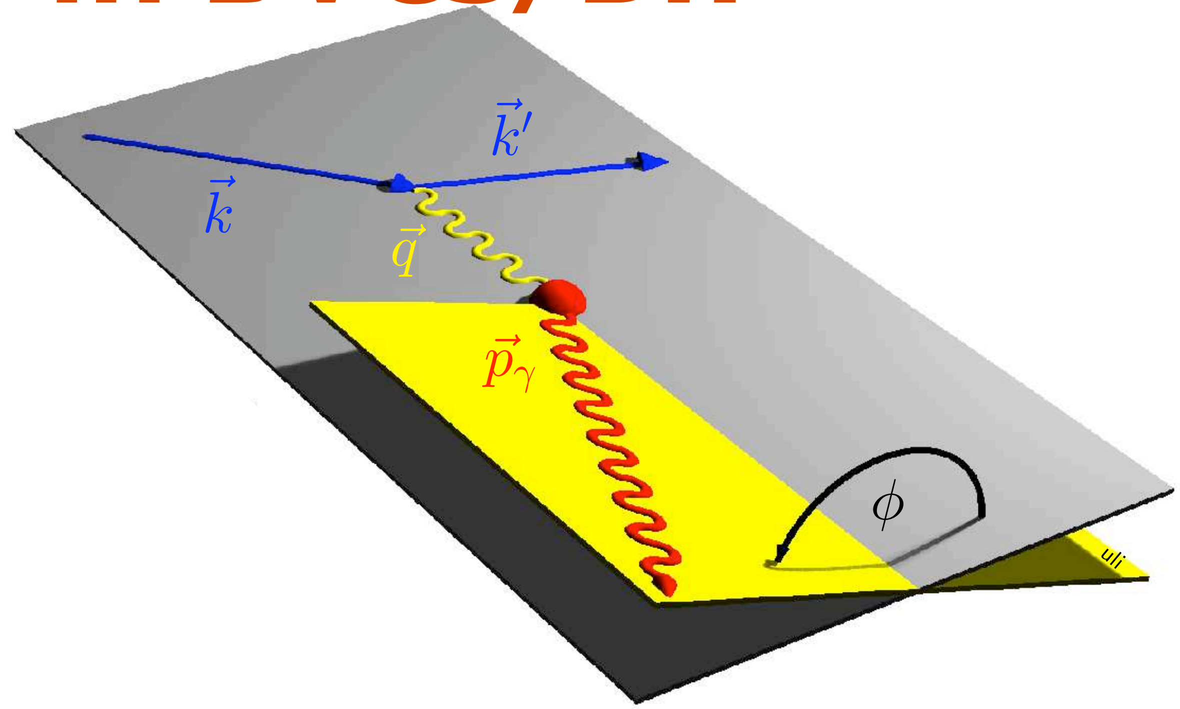
Fourier expansion in ϕ:

$$|\mathcal{T}_{\mathrm{BH}}|^2 = \frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \sum_{n=0}^{2} c_n^{\mathrm{BH}} \cos(n\phi)$$

$$|\mathcal{T}_{\mathrm{DVCS}}|^2 = K_{\mathrm{DVCS}} \left[\sum_{n=0}^{2} c_n^{\mathrm{DVCS}} \cos(n\phi) + P_B \sum_{n=1}^{1} s_n^{\mathrm{DVCS}} \sin(n\phi) \right]$$

$$\mathcal{I} = \frac{C_B K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[\sum_{n=0}^{3} c_n^{\mathcal{I}} \cos(n\phi) + P_B \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi) \right]$$

Azimuthal dependences in DVCS/BH
with unpolarized target



- **beam polarization P_B**
- **beam charge C_B**

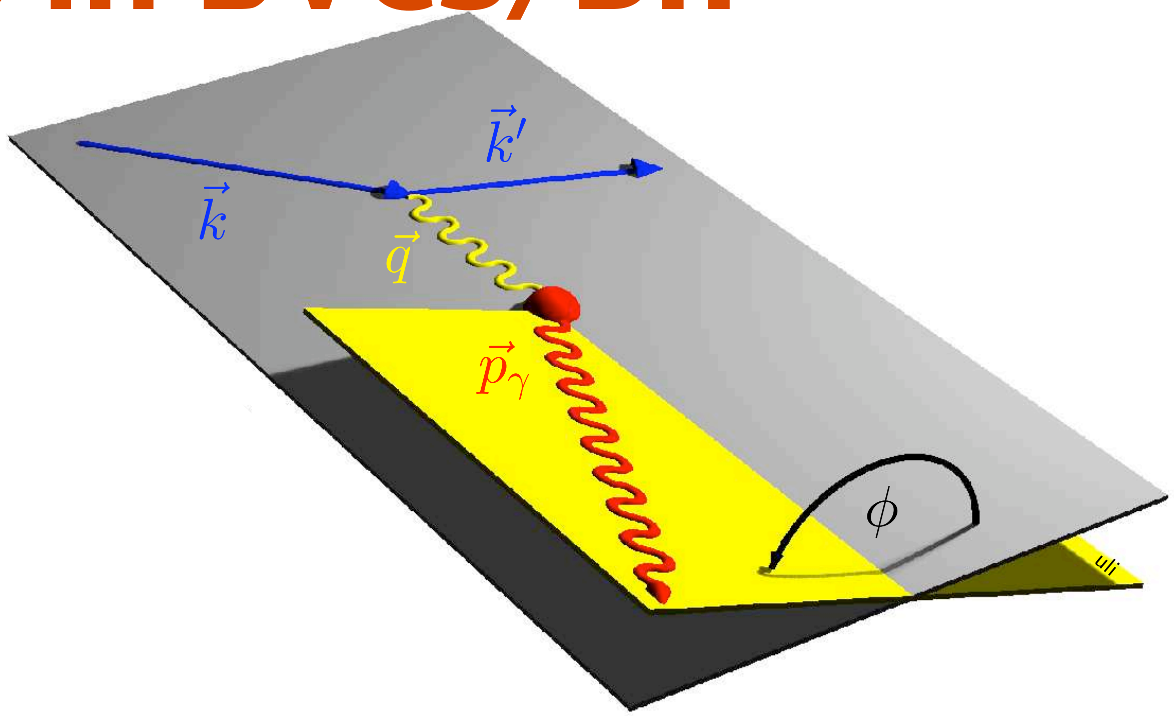
Fourier expansion in ϕ:

$$|\mathcal{T}_{\text{BH}}|^2 = \frac{K_{\text{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \sum_{n=0}^{2} c_n^{\text{BH}} \cos(n\phi)$$

$$|\mathcal{T}_{\text{DVCS}}|^2 = K_{\text{DVCS}} \left[\sum_{n=0}^{2} c_n^{\text{DVCS}} \cos(n\phi) + P_B \sum_{n=1}^{1} s_n^{\text{DVCS}} \sin(n\phi) \right]$$

$$\mathcal{I} = \frac{C_B K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[\sum_{n=0}^{3} c_n^{\mathcal{I}} \cos(n\phi) + P_B \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi) \right]$$

Azimuthal dependences in DVCS/BH
with unpolarized target



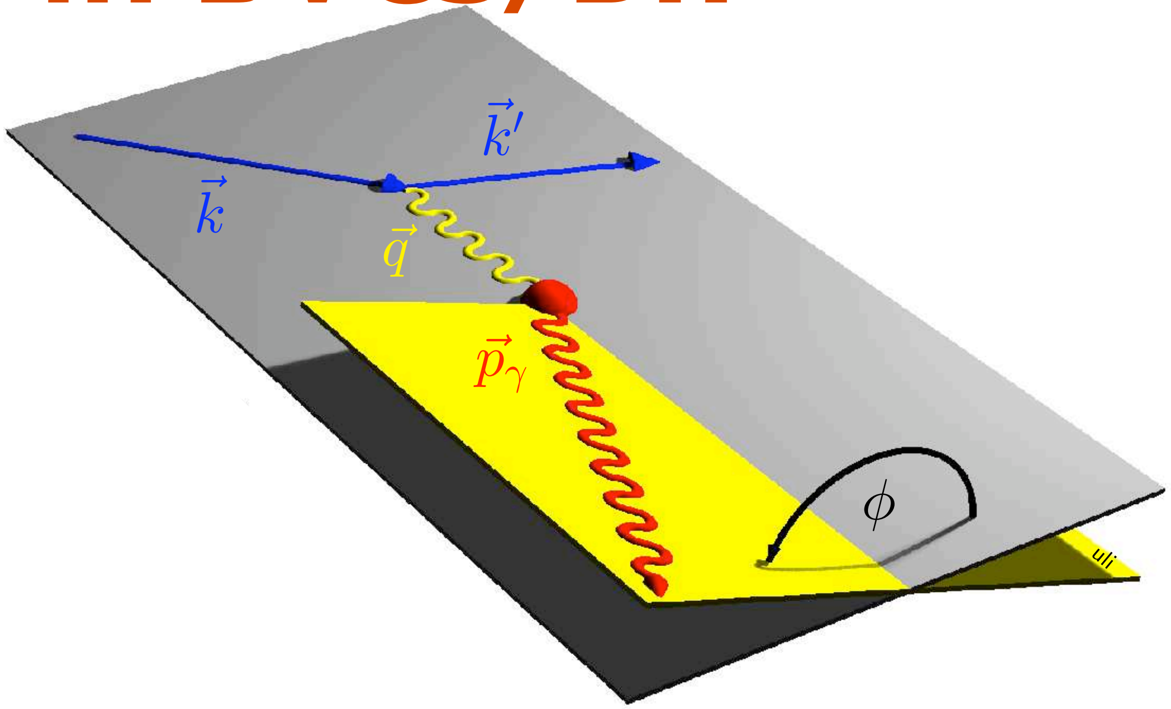
- **beam polarization P_B**
- **beam charge C_B**

Fourier expansion in ϕ:

$$\sigma(\phi, P_B, C_B) = \sigma_{\mathrm{UU}}(\phi) \cdot \left[1 + P_B \mathcal{A}_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) + C_B P_B \mathcal{A}_{\mathrm{LU}}^{\mathcal{I}}(\phi) + C_B \mathcal{A}_{\mathrm{C}}(\phi)\right]$$

Azimuthal dependences in DVCS/BH

with unpolarized target



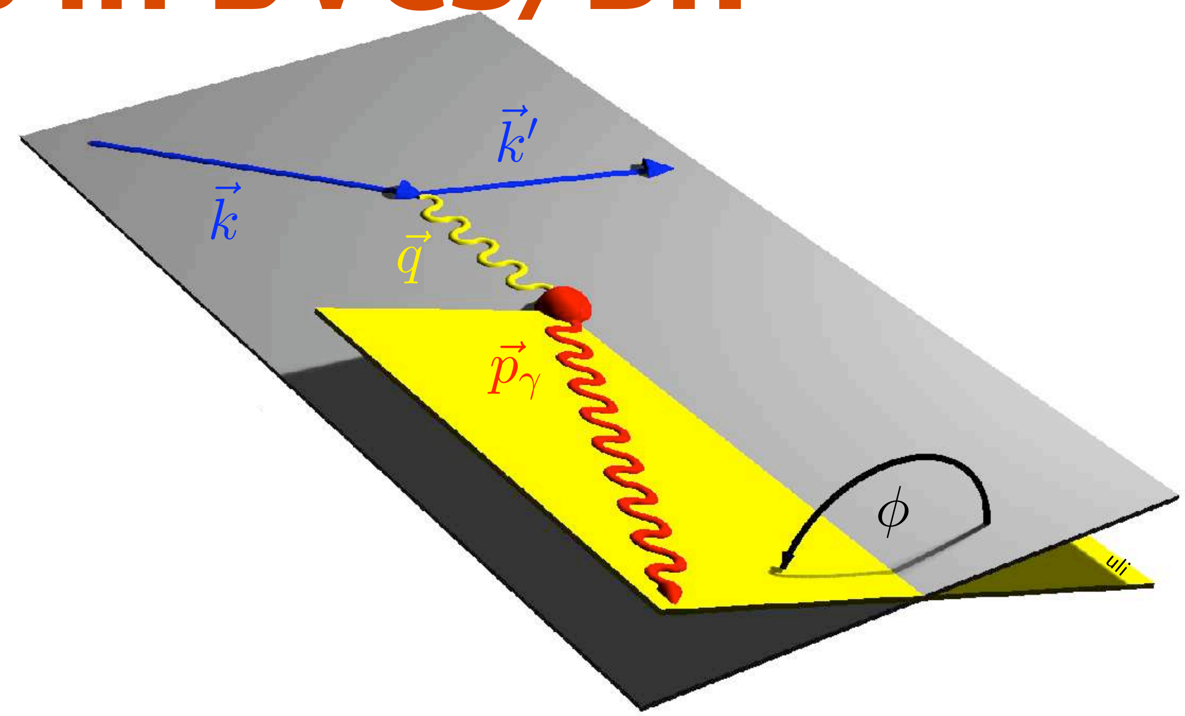
- **beam polarization P_B**
- **beam charge C_B**

Fourier expansion in ϕ:

$$\sigma(\phi, P_B, C_B) = \sigma_{\mathrm{UU}}(\phi) \cdot \left[1 + P_B \mathcal{A}_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) + C_B P_B \mathcal{A}_{\mathrm{LU}}^{\mathcal{I}}(\phi) + C_B \mathcal{A}_{\mathrm{C}}(\phi)\right]$$

$\mathrm{Re}[F_1 \mathcal{H}]$

Azimuthal dependences in DVCS/BH
with unpolarized target



- **beam polarization P_B**
- **beam charge C_B**

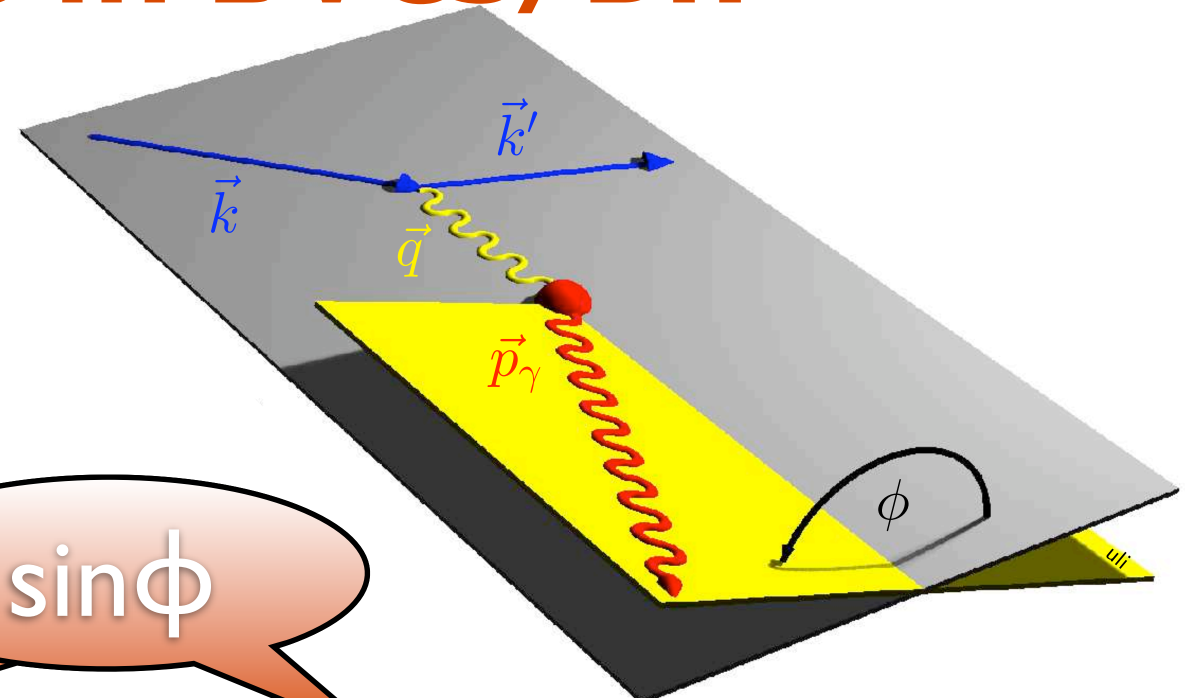
Fourier expansion in ϕ:

$$\sigma(\phi, P_B, C_B) = \sigma_{\mathrm{UU}}(\phi) \cdot \left[1 + P_B \mathcal{A}_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) + C_B P_B \mathcal{A}_{\mathrm{LU}}^{\mathcal{I}}(\phi) + C_B \mathcal{A}_{\mathrm{C}}(\phi)\right]$$

$\mathrm{Im}[F_1 \mathcal{H}]$

$\mathrm{Re}[F_1 \mathcal{H}]$

Azimuthal dependences in DVCS/BH
with unpolarized target



- **beam polarization P_B**
- **beam charge C_B**

Fourier expansion in ϕ:

sinφ

$$\sigma(\phi, P_B, C_B) = \sigma_{\mathrm{UU}}(\phi) \cdot \left[1 + P_B \mathcal{A}_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) + C_B P_B \mathcal{A}_{\mathrm{LU}}^{\mathcal{I}}(\phi) + C_B \mathcal{A}_{\mathrm{C}}(\phi)\right]$$

twist-3

$\mathrm{Im}[F_1 \mathcal{H}]$

$\mathrm{Re}[F_1 \mathcal{H}]$

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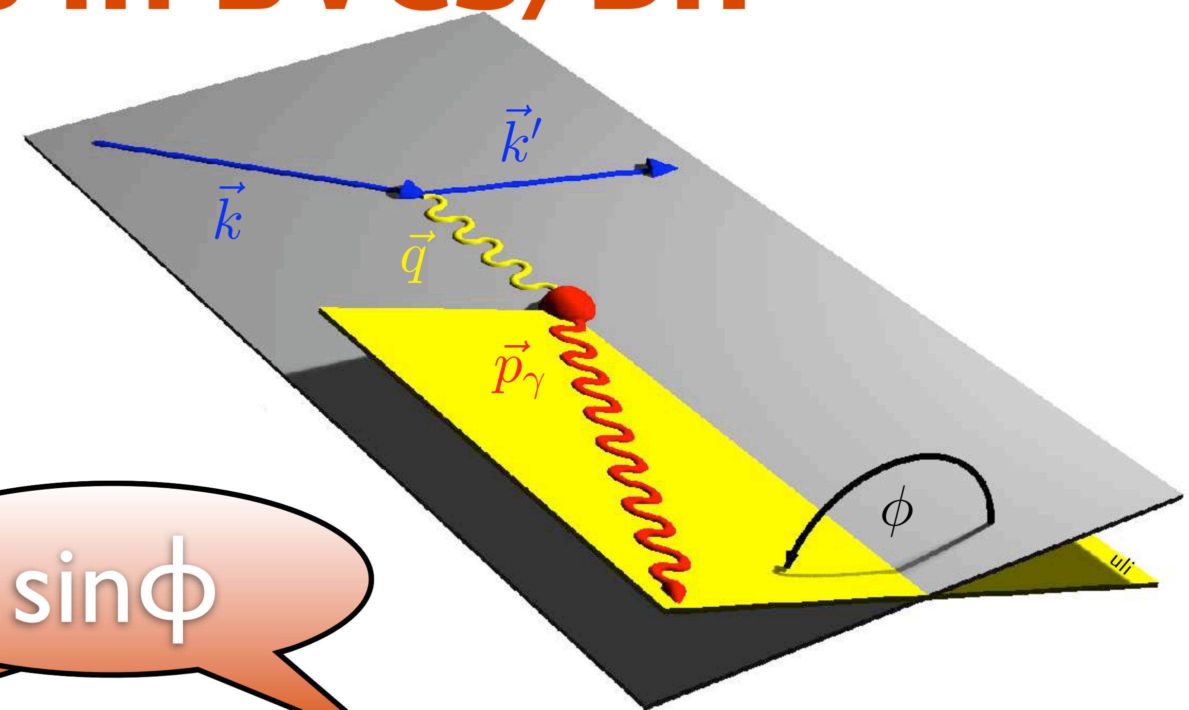

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twist-3

$\mathrm{Im}[F_1 \mathcal{H}]$

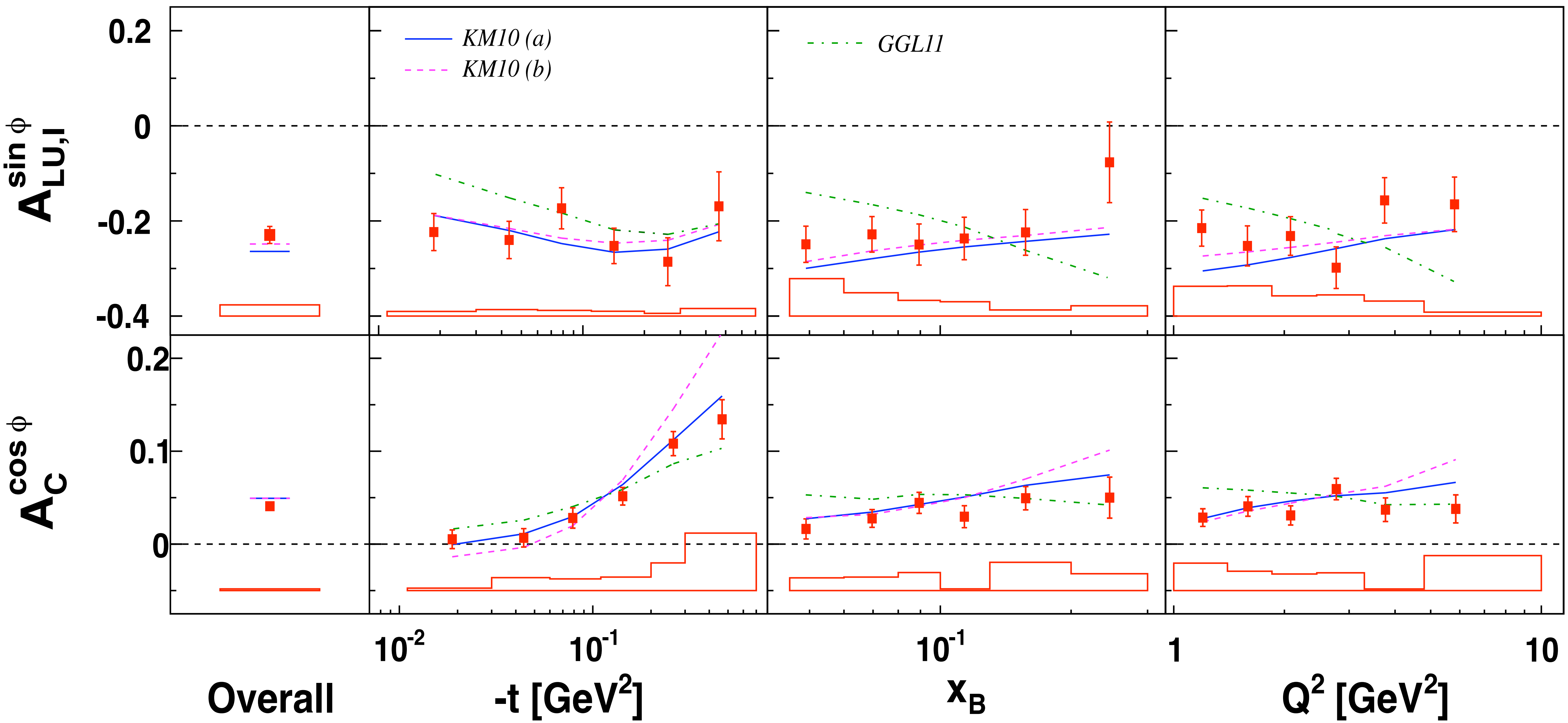
$\mathrm{Re}[F_1 \mathcal{H}]$

beam charge allow to decouple from twist-3

(F_1 is the Dirac form factor)

($\mathcal{H}$ is Compton form factor involving GPD H)

Airapetian et al, submitted to JHEP [arXiv:1203.6287]



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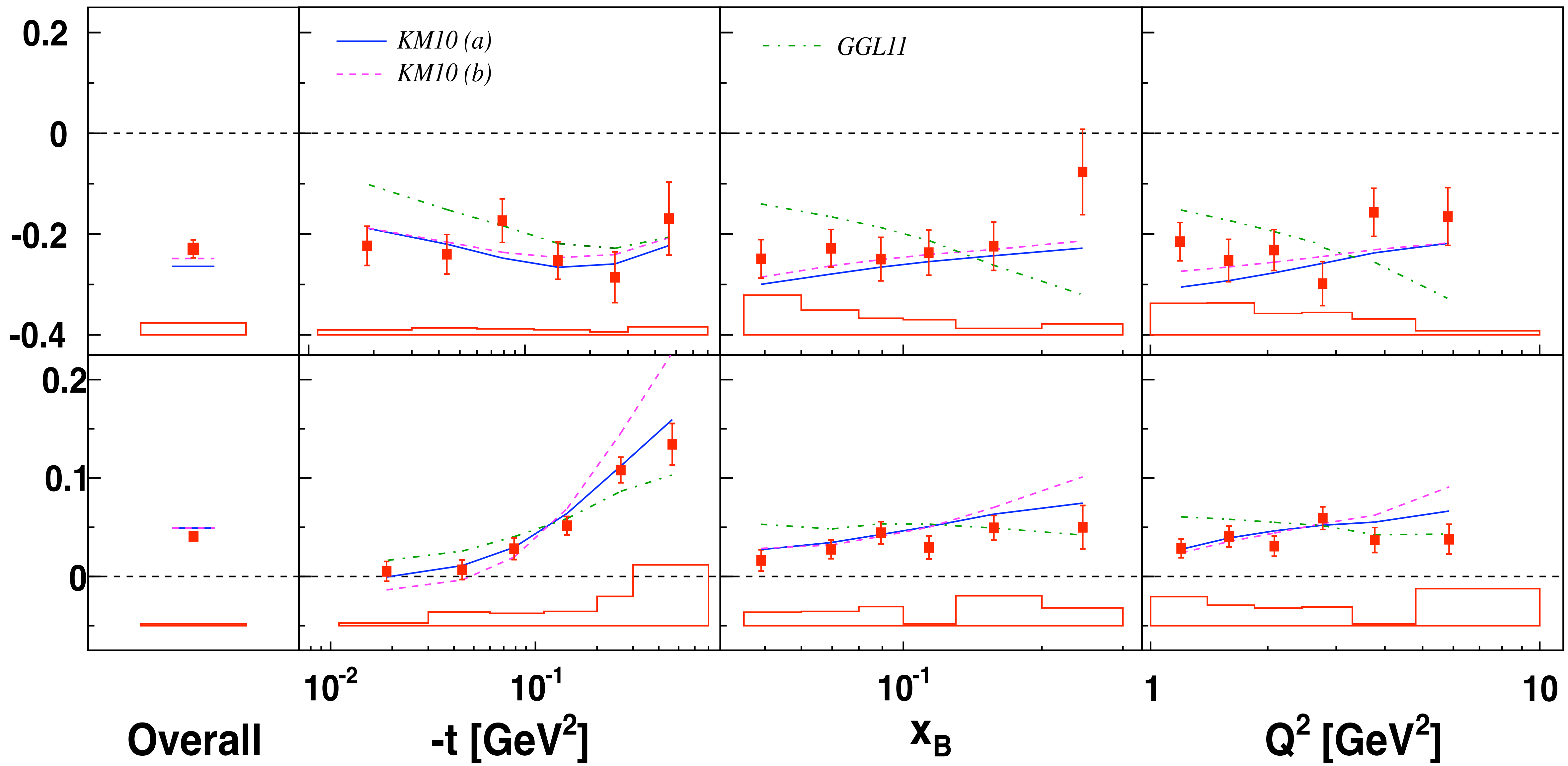
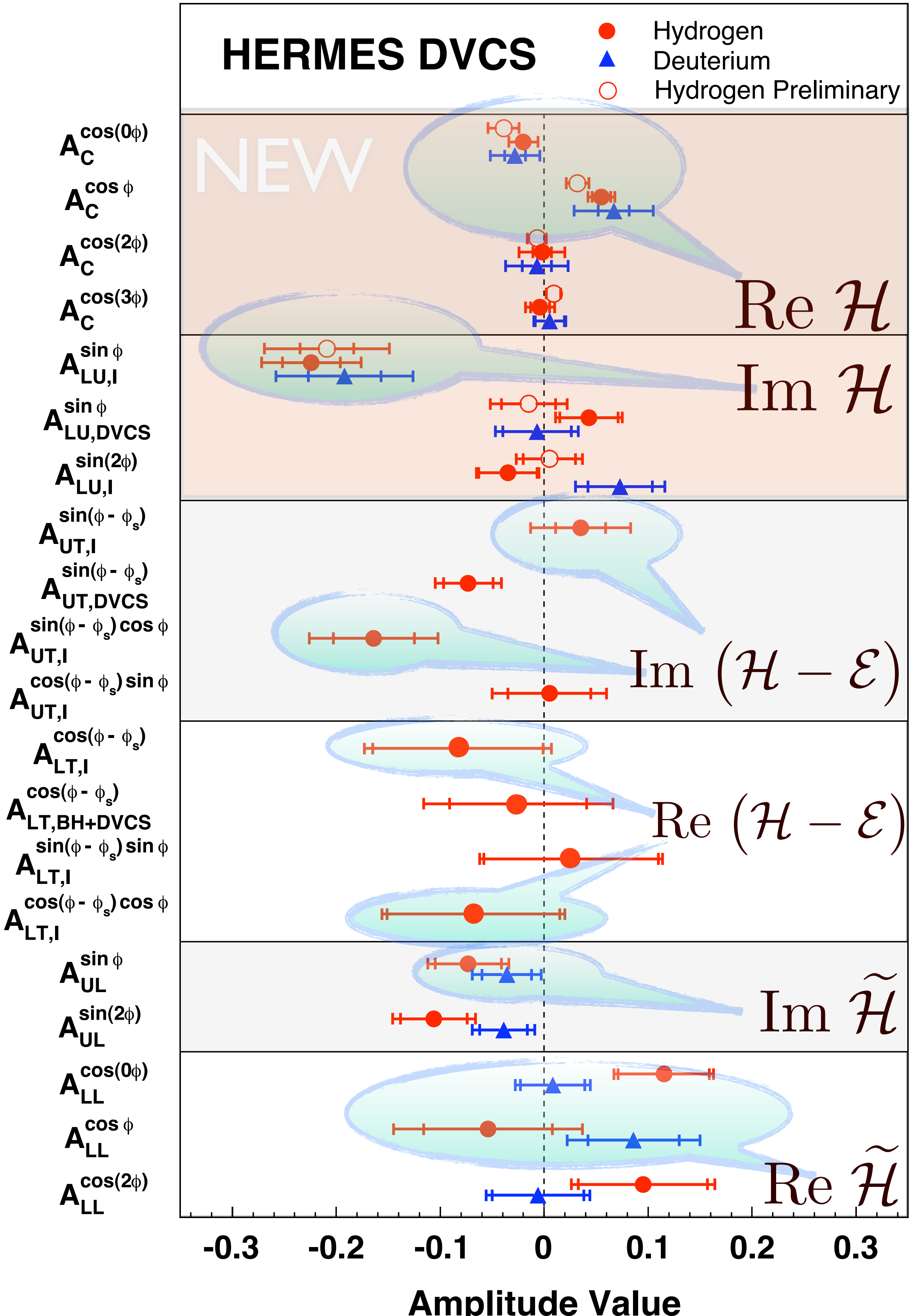


- Full hydrogen dataset used (incl. 2006/2007 data)
- More than double statistics w.r.t. previous publication (JHEP11 (2009) 083)
- Sensitivity to Re and Im parts of CFF $\mathcal{H}$

Full set of DVCS Asymmetries



Beam-charge asymmery

Beam-helicity asymmetry

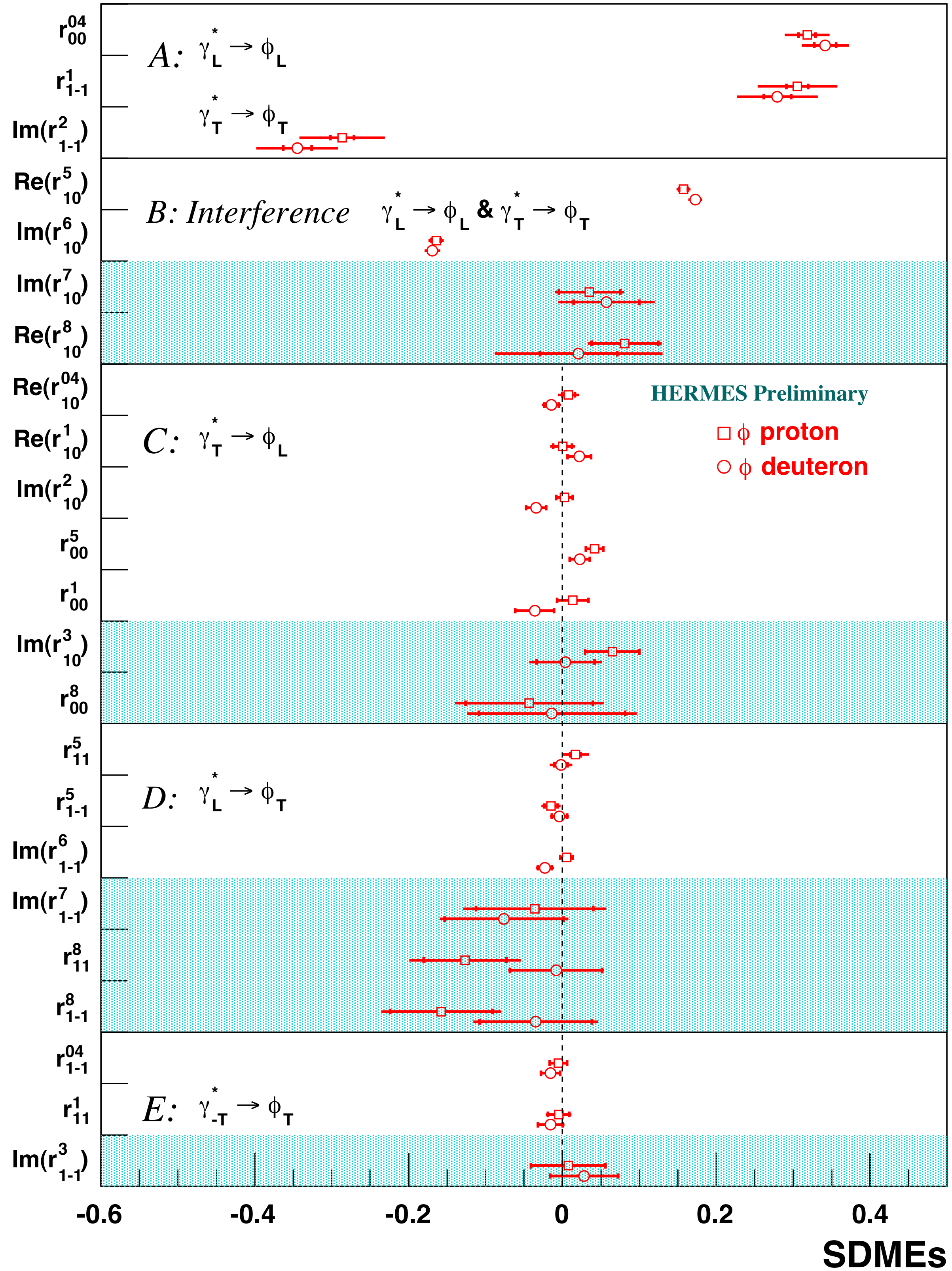
Transverse target-spin asymmetry

Double transverse target-spin asymmetry

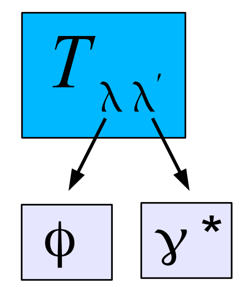
Longitudinal target-spin asymmetry

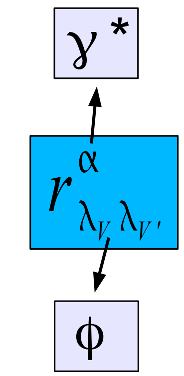
Double longitudinal target-spin asymmetry

SDMEs of exclusive φ meson production



production and decay angular distributions W parametrized by helicity amplitudes T or alternatively by SDMEs r:





$\gamma^*_L \to \phi_L$ access to GPD $\mathcal{H}$

$\gamma^*_T \to \phi_T$ access to GPD $\widetilde{\mathcal{H}}$

➡ **SDMEs of A and B classes are significantly nonzero**

➡ **C,D,E mostly consistent with zero**

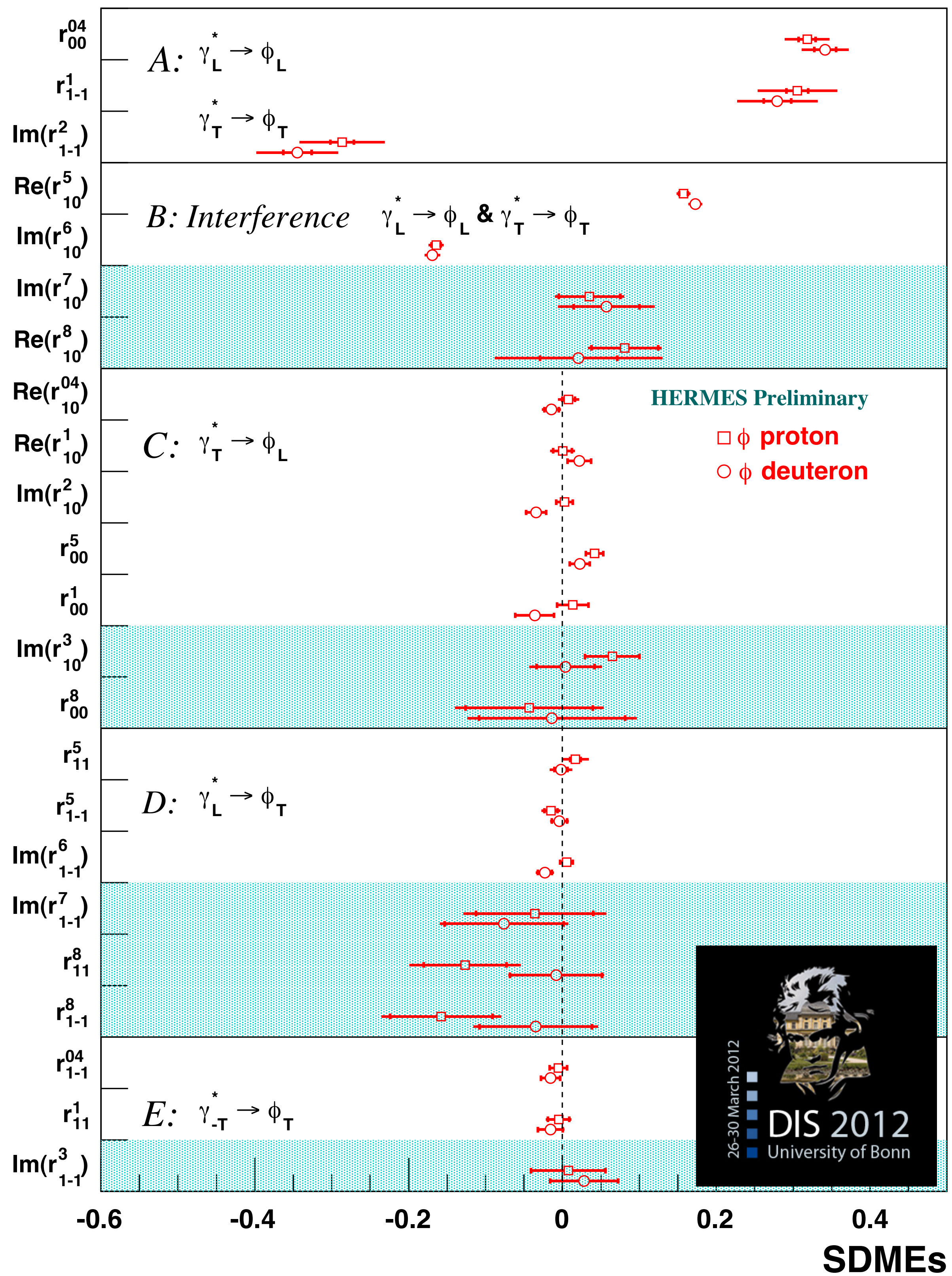
➡ **SCHC mainly conserved**

➡ **helicity amplitude hierarchy tested:**

A	B	C	D	E

$$|T_{00}|^2 \sim |T_{11}|^2 \gg |T_{01}|^2 > |T_{10}|^2 \sim |T_{-11}|^2$$

SDMEs of exclusive ϕ meson production



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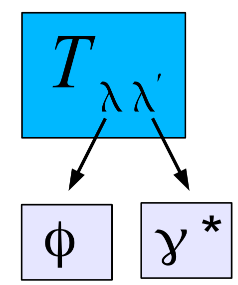

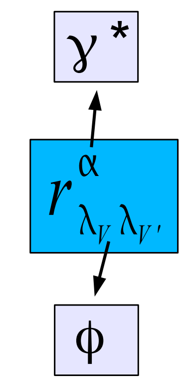

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Summary

➡HERMES continues actively publishing papers

Publications since last PRC

- ➡ Inclusive A_2, g_2 measurements EPJ C 72 (2012) 1921
- ➡ Cosine moments in semi-inclusive unpolarized asymmetry measurement arXiv:1204.4161
- ➡ Beam-helicity and beam-charge asymmetries in DVCS arXiv:1203.6287

Released results

- ➡ Semi-inclusive asymmetry $A_{LL} \cos\phi$ amplitude
- ➡ Exclusive ϕ meson production SDMEs

Ongoing activities

- ➡ 10 papers in preparation

➡Data preservation activity crucial for ongoing and future analyses/publications (see Michael's talk)

Backups

cosϕ Modulation

$$
\begin{aligned}
F_{UU}^{\cos\phi} \quad \propto \quad & -\frac{M}{Q}\sum_q h_1^{\perp,q}(x,p_T^2)\otimes H_1^{\perp,q\to h}(z,K_T^2) \\
& -\frac{M}{Q}\sum_q f_1^q(x,p_T^2)\otimes D_1^q(z,K_T^2)
\end{aligned}
$$

cosϕ Modulation

twist-3

$$F_{UU}^{\cos\phi} \propto -\frac{M}{Q}\sum_q h_1^{\perp,q}(x,p_T^2)\otimes H_1^{\perp,q\to h}(z,K_T^2)$$
$$-\frac{M}{Q}\sum_q f_1^q(x,p_T^2)\otimes D_1^q(z,K_T^2)$$

cosϕ Modulation

$$F_{UU}^{\cos\phi} \propto -\frac{M}{Q}\sum_q \underbrace{h_1^{\perp,q}(x,p_T^2)\otimes H_1^{\perp,q\to h}(z,K_T^2)}_{\text{twist-3}}$$

$$-\frac{M}{Q}\sum_q \underbrace{f_1^q(x,p_T^2)\otimes D_1^q(z,K_T^2)}_{\text{twist-3}}$$

cosϕ Modulation

$$F_{UU}^{\cos\phi} \propto -\frac{M}{Q}\sum_q \boxed{\overset{\text{twist-3}}{h_1^{\perp,q}(x,p_T^2)\otimes H_1^{\perp,q\to h}(z,K_T^2)}}$$

Boer-Mulders effect

$$-\frac{M}{Q}\sum_q \boxed{\underset{\text{twist-3}}{f_1^q(x,p_T^2)\otimes D_1^q(z,K_T^2)}}$$

cosϕ Modulation

$$F_{UU}^{\cos\phi} \propto -\frac{M}{Q}\sum_q \underbrace{h_1^{\perp,q}(x,p_T^2)\otimes H_1^{\perp,q\to h}(z,K_T^2)}_{\text{twist-3}} -\frac{M}{Q}\sum_q \underbrace{f_1^q(x,p_T^2)\otimes D_1^q(z,K_T^2)}_{\text{twist-3}}$$

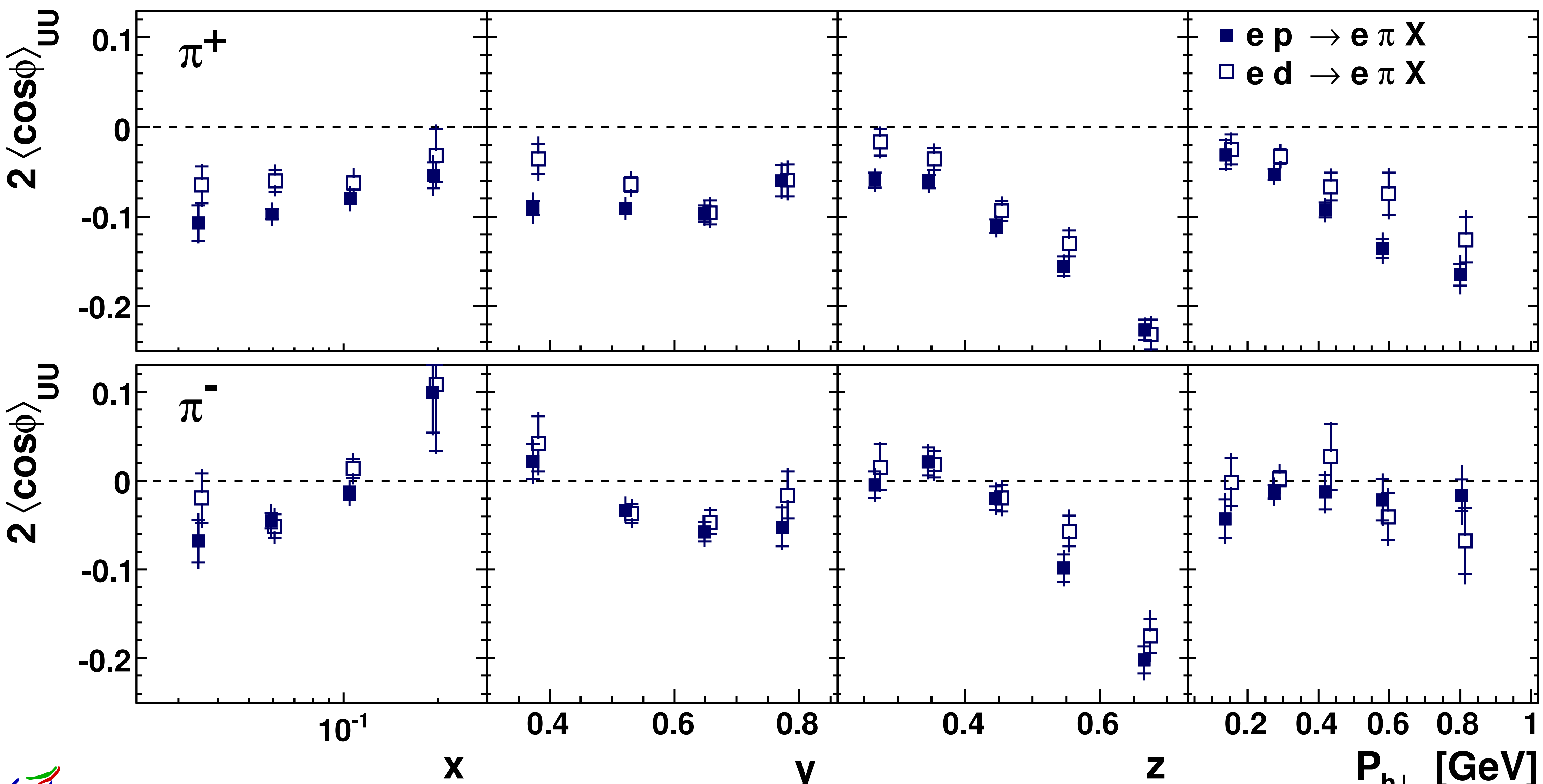
← Boer-Mulders effect

← Cahn effect

cosϕ Modulation

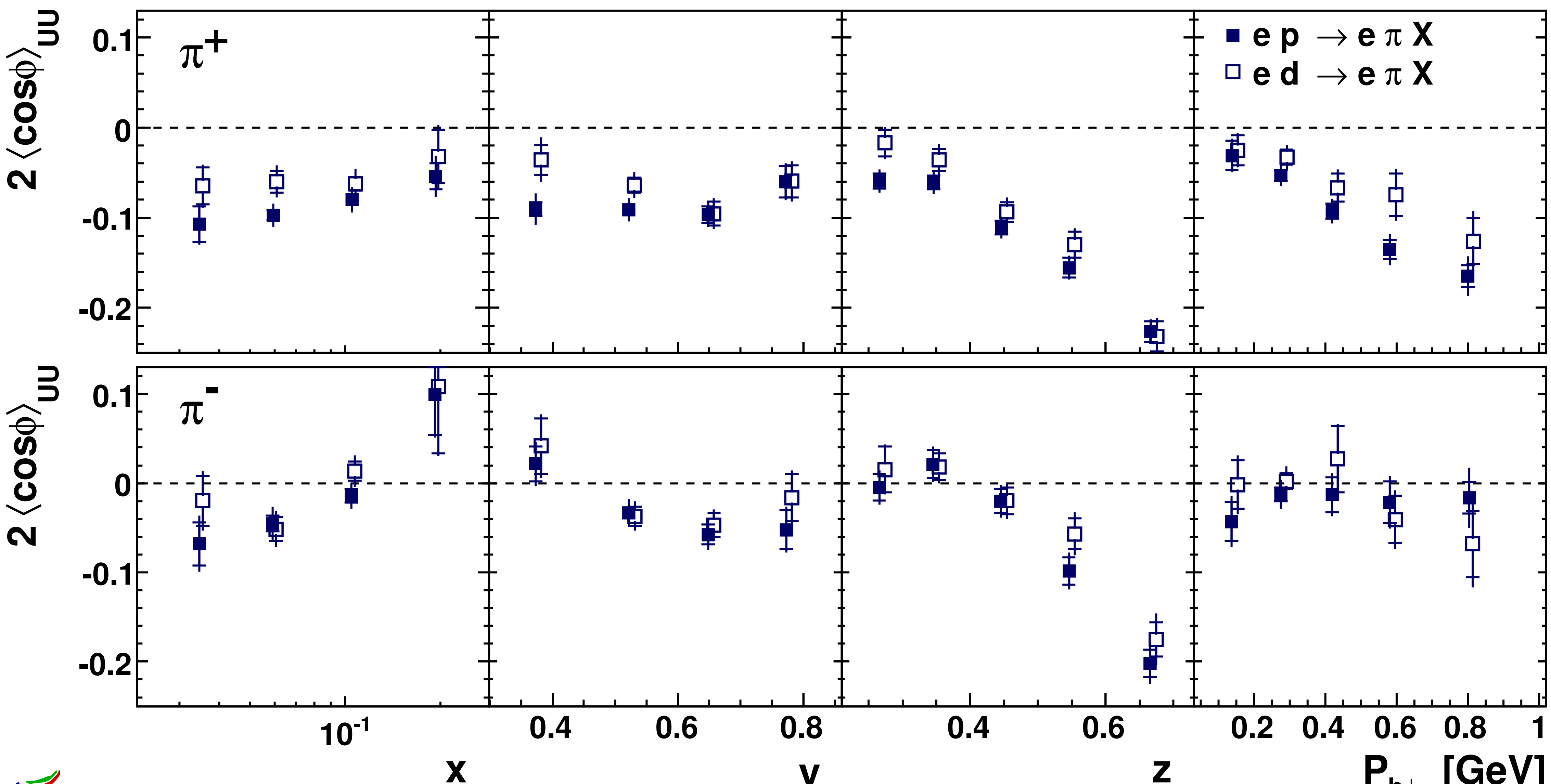
$$F_{UU}^{\cos\phi} \propto -\frac{M}{Q}\sum_q \underbrace{h_1^{\perp,q}(x,p_T^2)\otimes H_1^{\perp,q\to h}(z,K_T^2)}_{\text{twist-3}} \quad \leftarrow \text{Boer-Mulders effect}$$

$$-\frac{M}{Q}\sum_q \underbrace{f_1^q(x,p_T^2)\otimes D_1^q(z,K_T^2)}_{\text{twist-3}} \quad \leftarrow \text{Cahn effect}$$

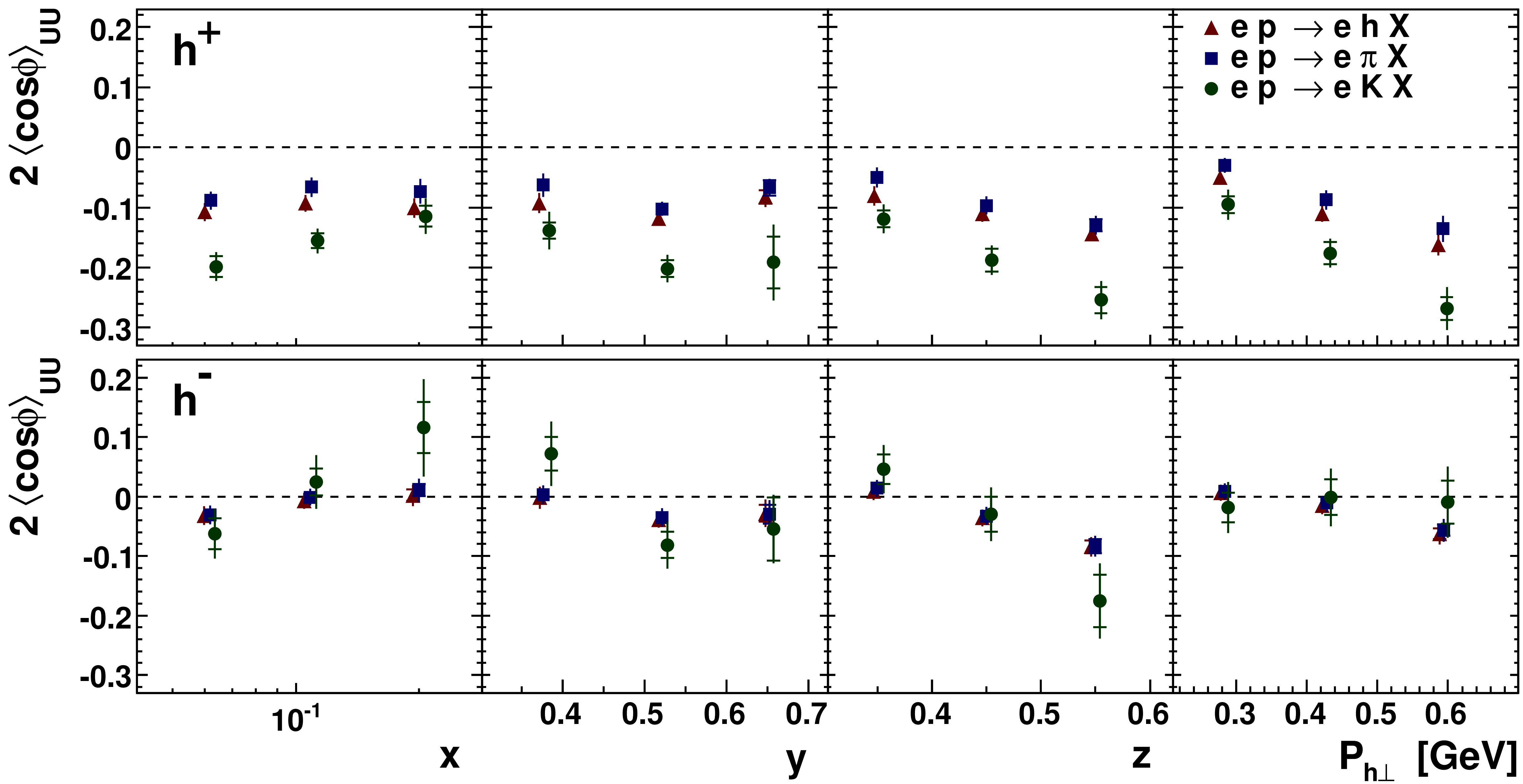


cosϕ Modulation

➡ increase in **z**, no flavor dependence: Cahn-effect dominance
➡ transverse momentum dependence: Boer-Mulders contribution



Strange Kaons cosϕ



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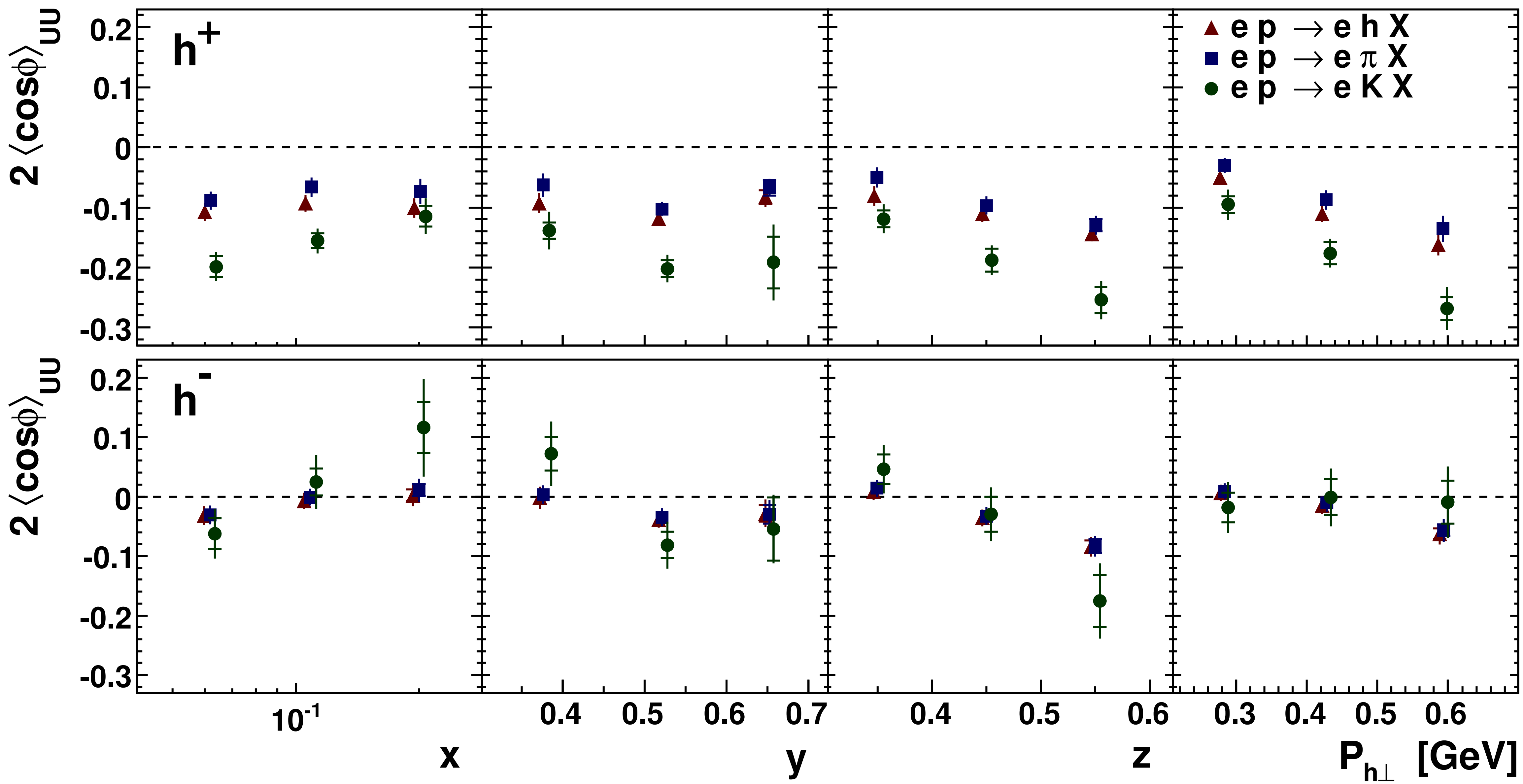
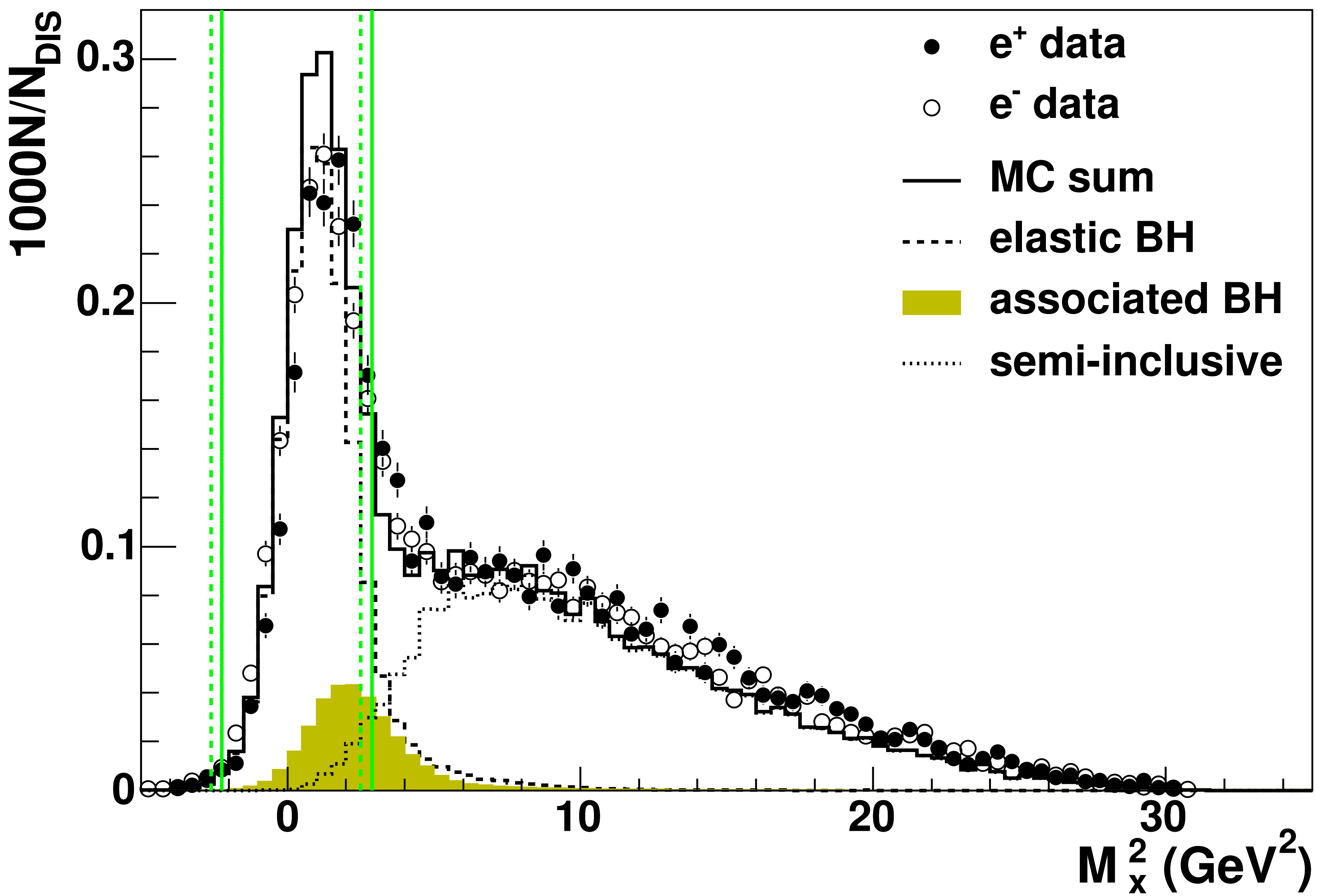


- ➡ Kaons: larger magnitude than pions
- ➡ K+ cos2phi similar to K+ cosphi - Boer-Mulders role important
- ➡ K+ difference from K- attributed to Cahn effect

Exclusivity: missing-mass technique



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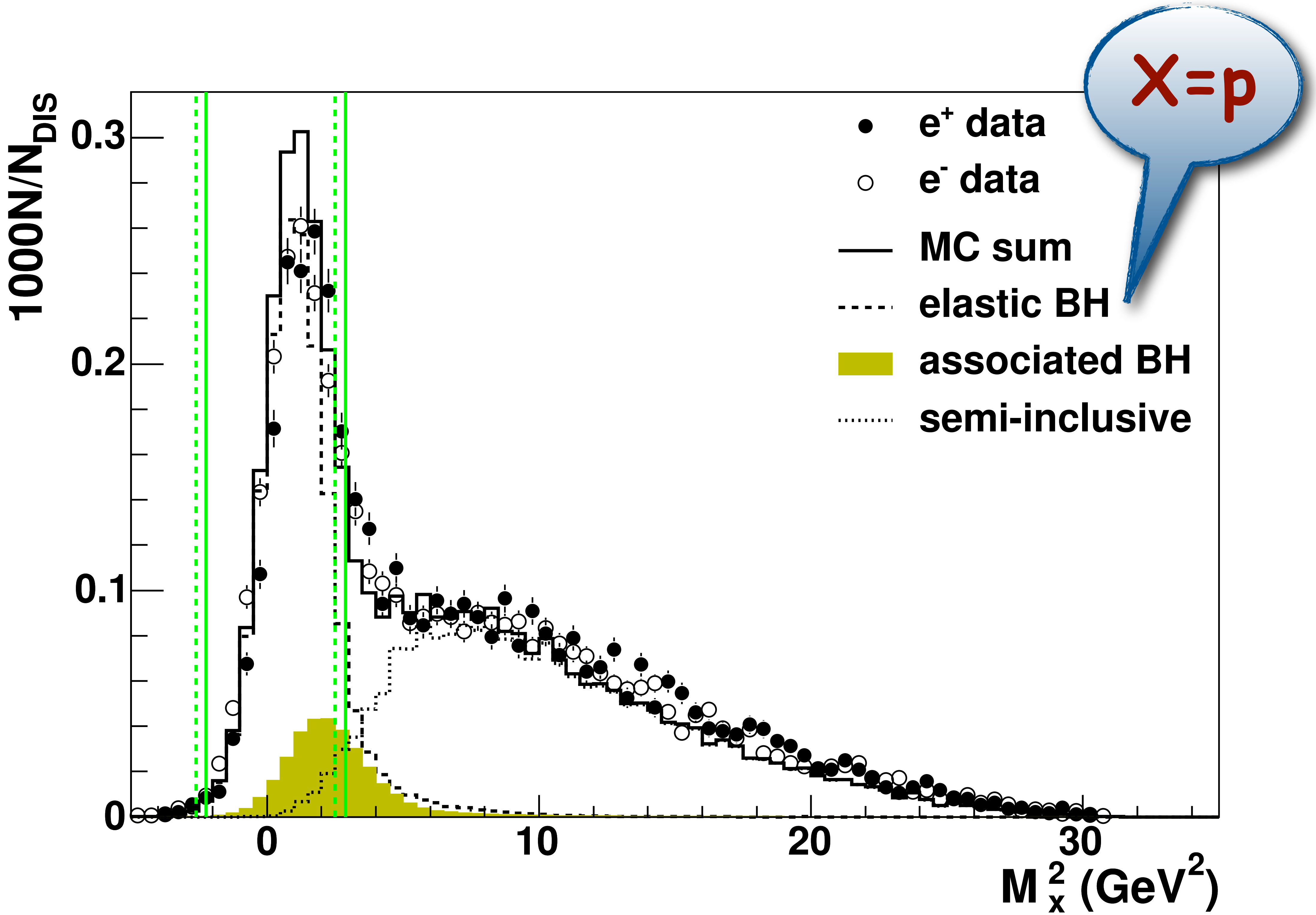

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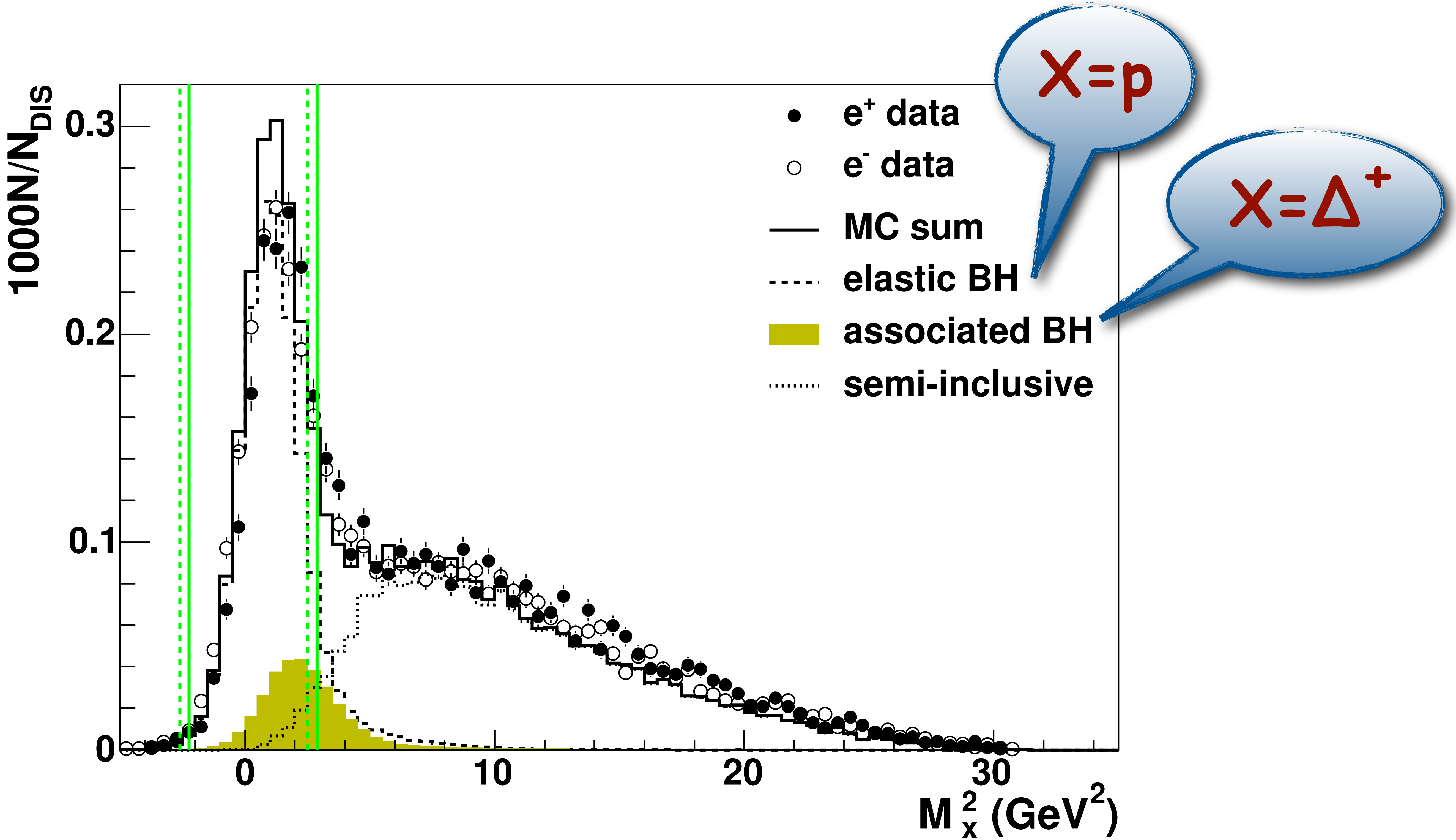

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