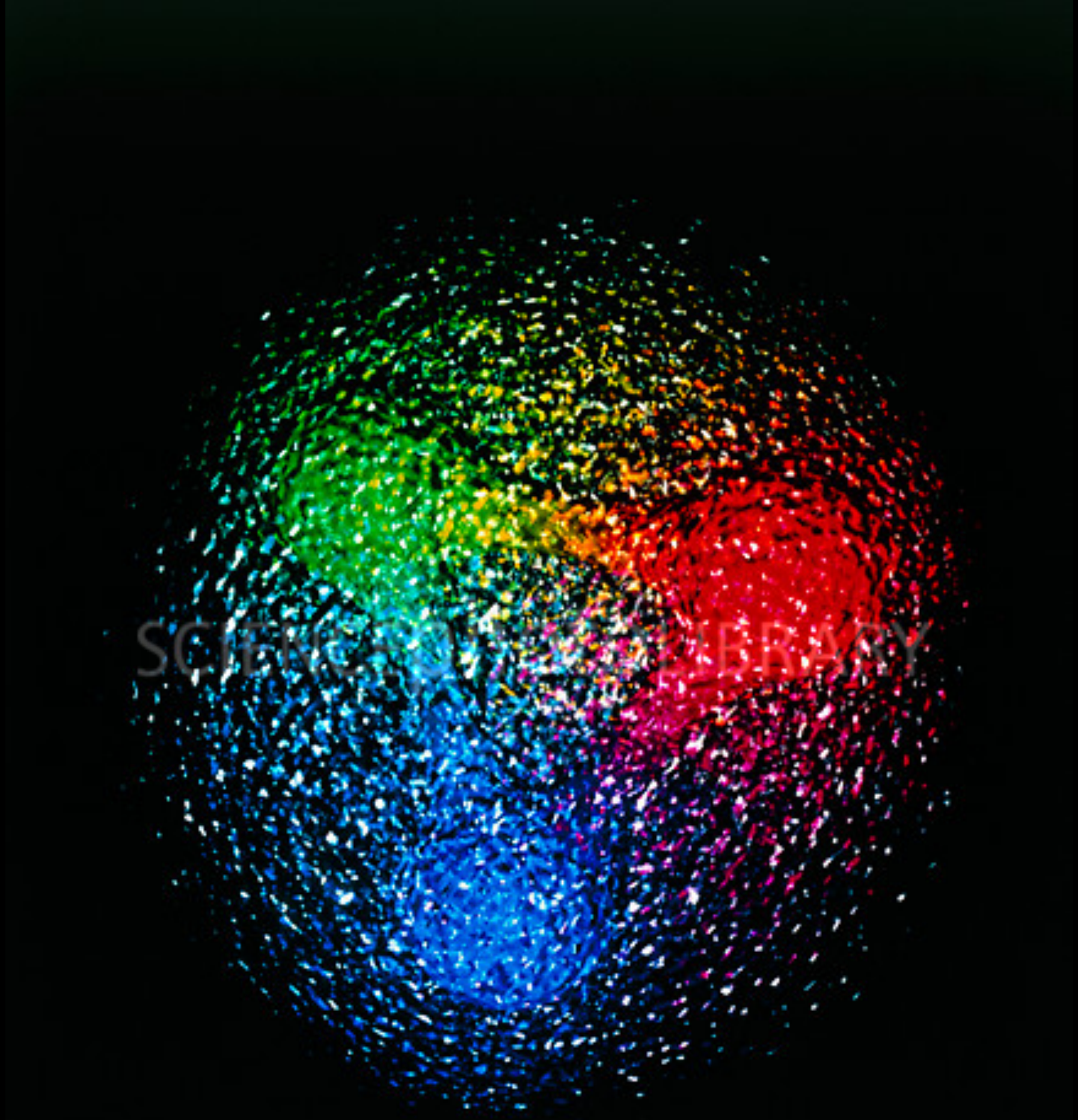

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hermes

Transverse Momentum Distributions: Recent News from HERMES

Dr Bjoern Seitz, University of Glasgow

INSPIRING PEOPLE

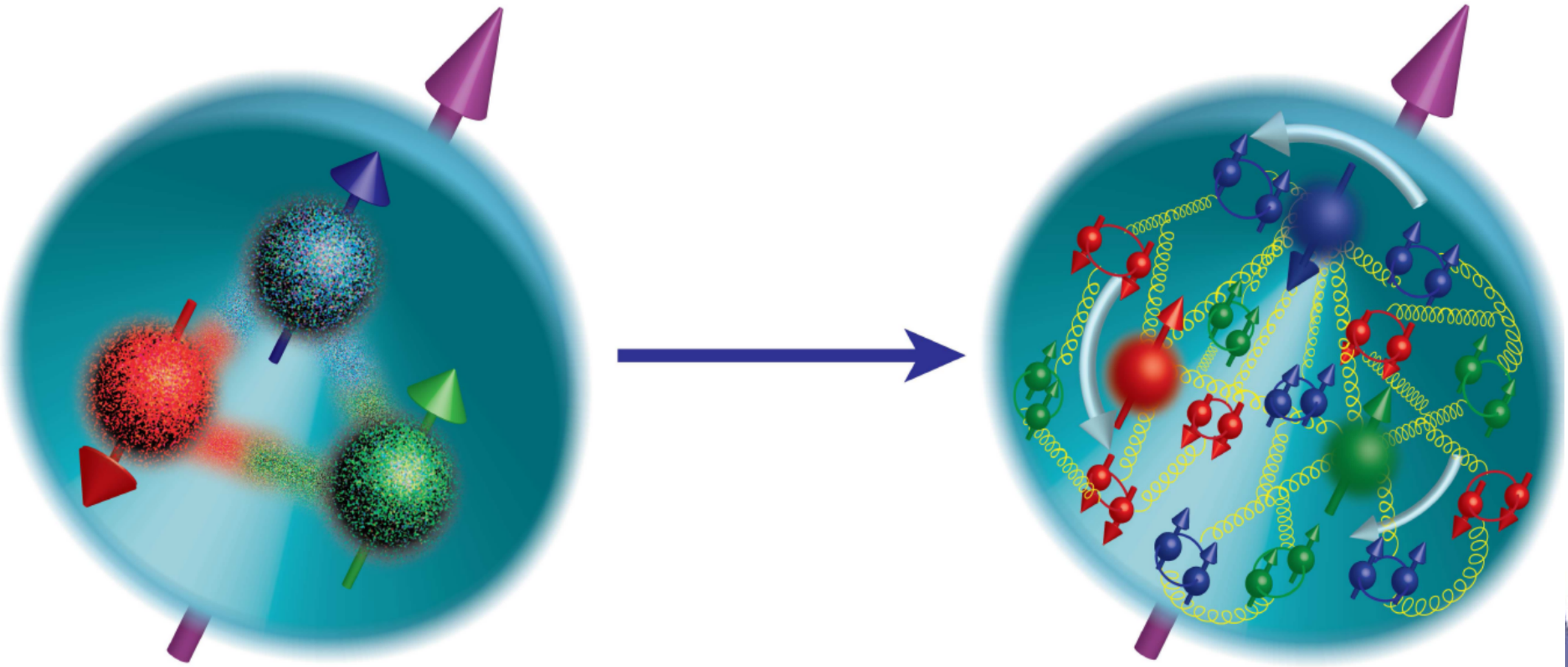


image taken from INT Program INT–17–3

Spatial and Momentum Tomography of Hadrons and Nuclei

Wigner Distributions

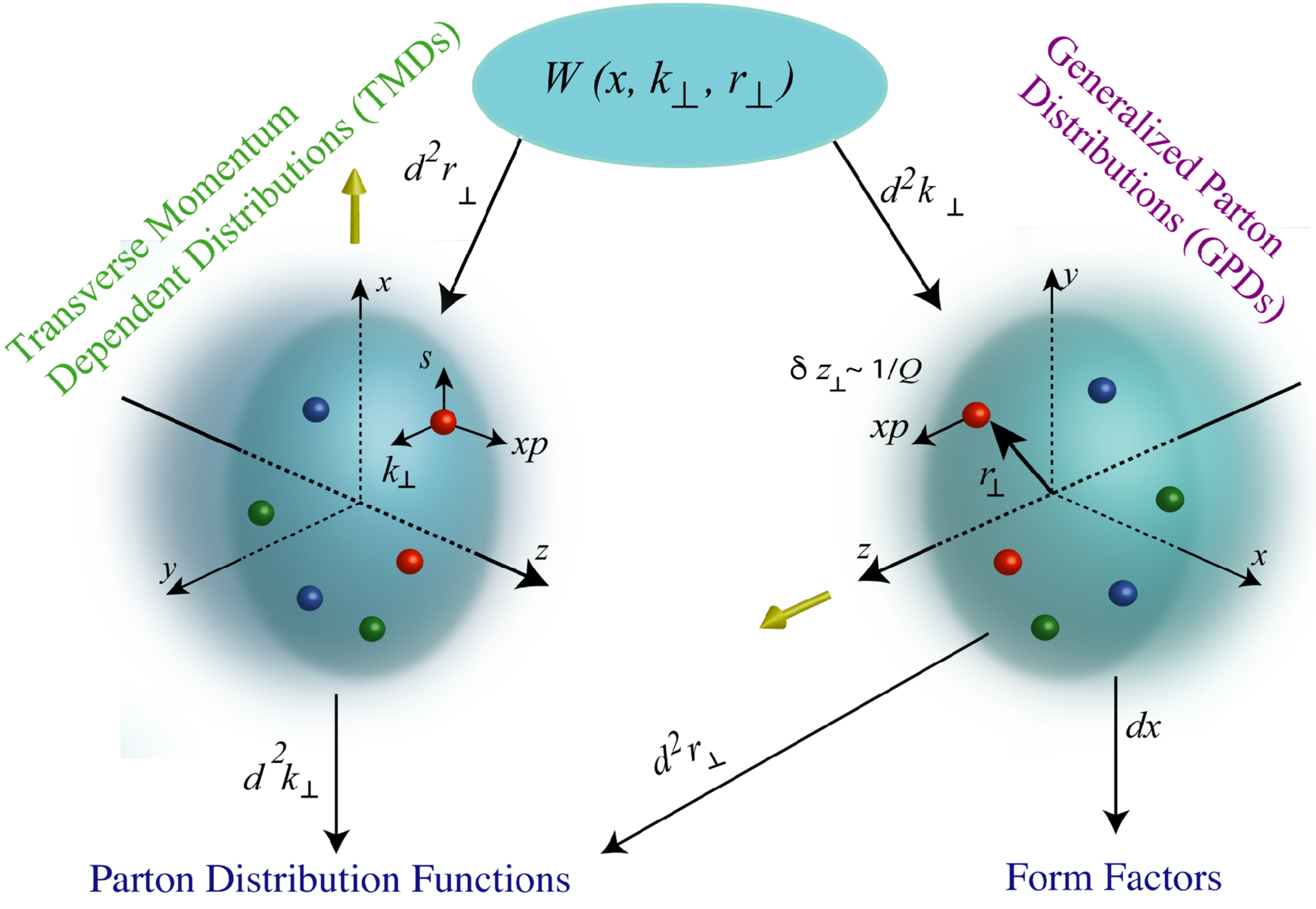


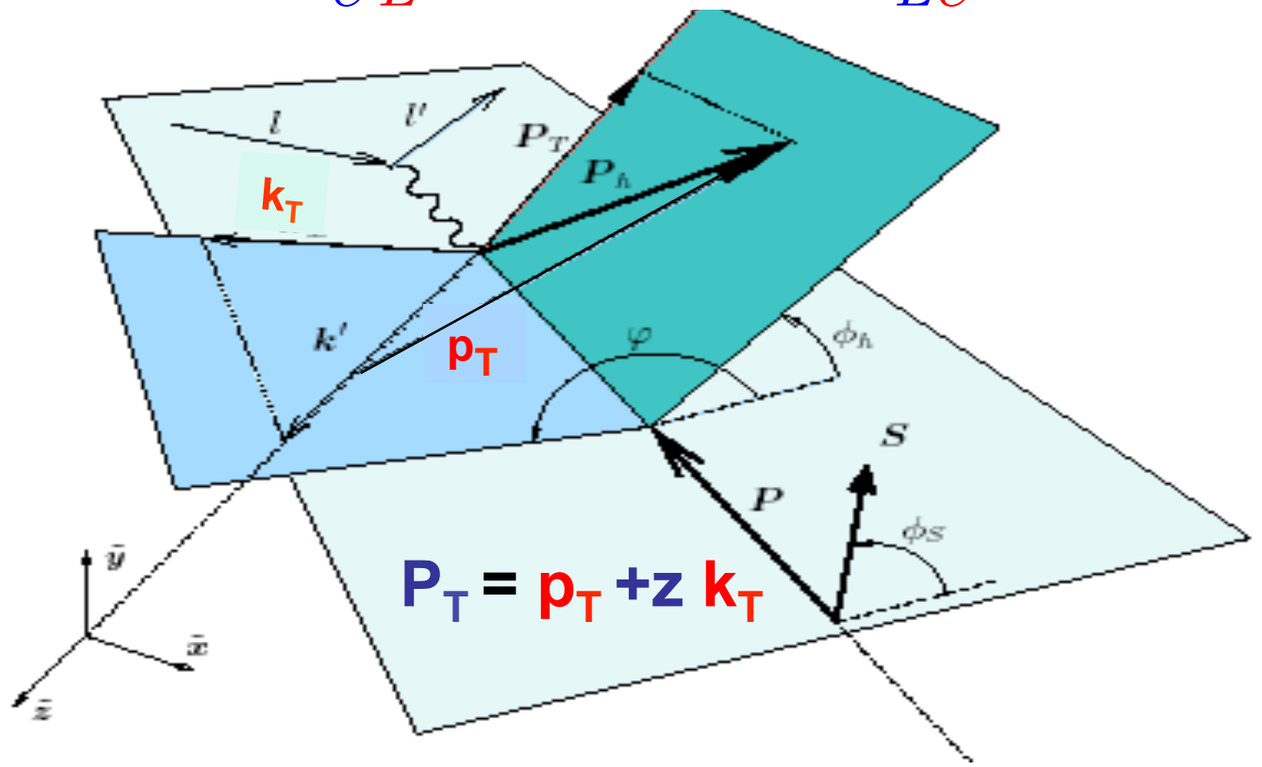
image taken from INT Program INT–17–3

Spatial and Momentum Tomography of Hadrons and Nuclei

SIDIS: Partonic Cross Section and Kinematics

$$\nu = (qP)/M$$
$$Q^2 = (k-k')^2$$
$$y = (qP)/(kP)$$
$$x = Q^2/2(qP)$$
$$z = (qP_h)/(qP)$$

$$\sigma = F_{UU} + P_t F_{UL}^{\sin\phi} \sin 2\phi + P_b F_{LU}^{\sin\phi} \sin\phi \ldots$$



Azimuthal moments in hadron production in SIDIS provide access to different structure functions and underlying transverse momentum dependent distribution and fragmentation functions.

$$\int d^2\vec{k}_T d^2\vec{p}_T \delta^{(2)}(z\vec{k}_T + \vec{p}_T - \vec{P}_T)$$

$$F_{XY}^h(x,z,P_T,Q^2) \propto \sum H^q \times f^q(x,k_T,..) \otimes D^{q\to h}(z,p_T,..) + Y(Q^2,P_T) + \mathcal{O}(M/Q)$$

beam polarization — target polarization

corrections for the region of large $k_T \sim Q$

slide from H. Avakian

Azimuthal Moments in SIDIS

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]$$

$$+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

$$+|\boldsymbol{S}_\perp|\left[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)\right.$$

$$+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$\left.+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\right]$$

$$+|\boldsymbol{S}_\perp|\lambda_e\left[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}\right.$$

$$\left.+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\right]\Big\},$$

quark polarization

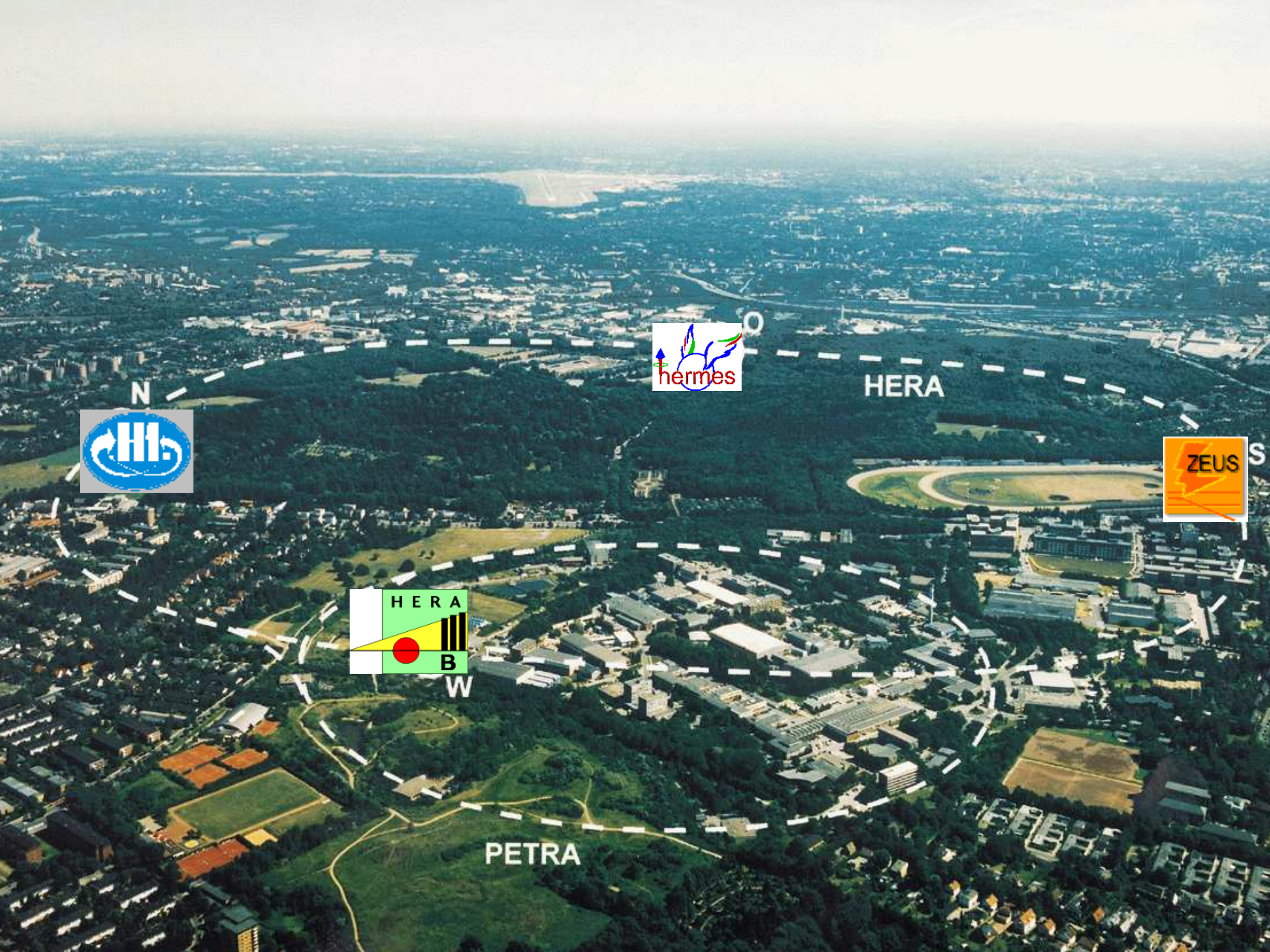
N/q	U	L	T
U	$\mathbf{f_1}$		$h_1^\perp$
L		$\mathbf{g_1}$	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$\mathbf{h_1}$ $h_{1T}^\perp$

Higher Twist PDFs

N/q	U	L	T
U	$f^\perp$	$g^\perp$	$h, \mathbf{e}$
L	$f_L^\perp$	$g_L^\perp$	$\mathbf{h_L}, e_L$
T	$f_T, f_T^\perp$	$\mathbf{g_T}, g_T^\perp$	$h_T, e_T, h_T^\perp, e_T^\perp$

Experiment for a given target polarization measures all moments simultaneously

slide from H. Avakian


N
O
S
W
HERA
PETRA
hermes
H1
ZEUS
HERA
B

Recipe for a successful experiment: azimuthal asymmetries in SIDIS

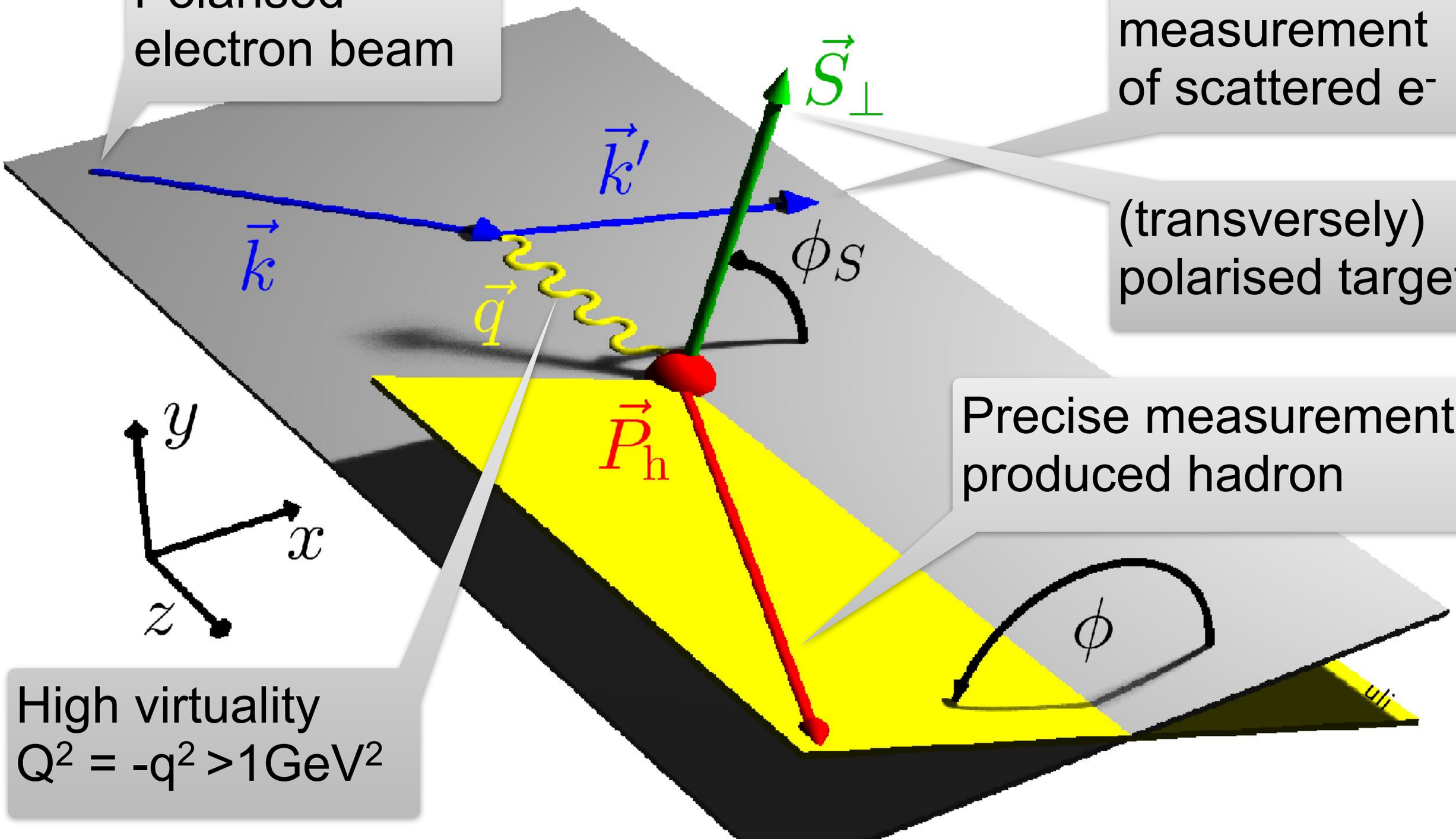
Polarised electron beam

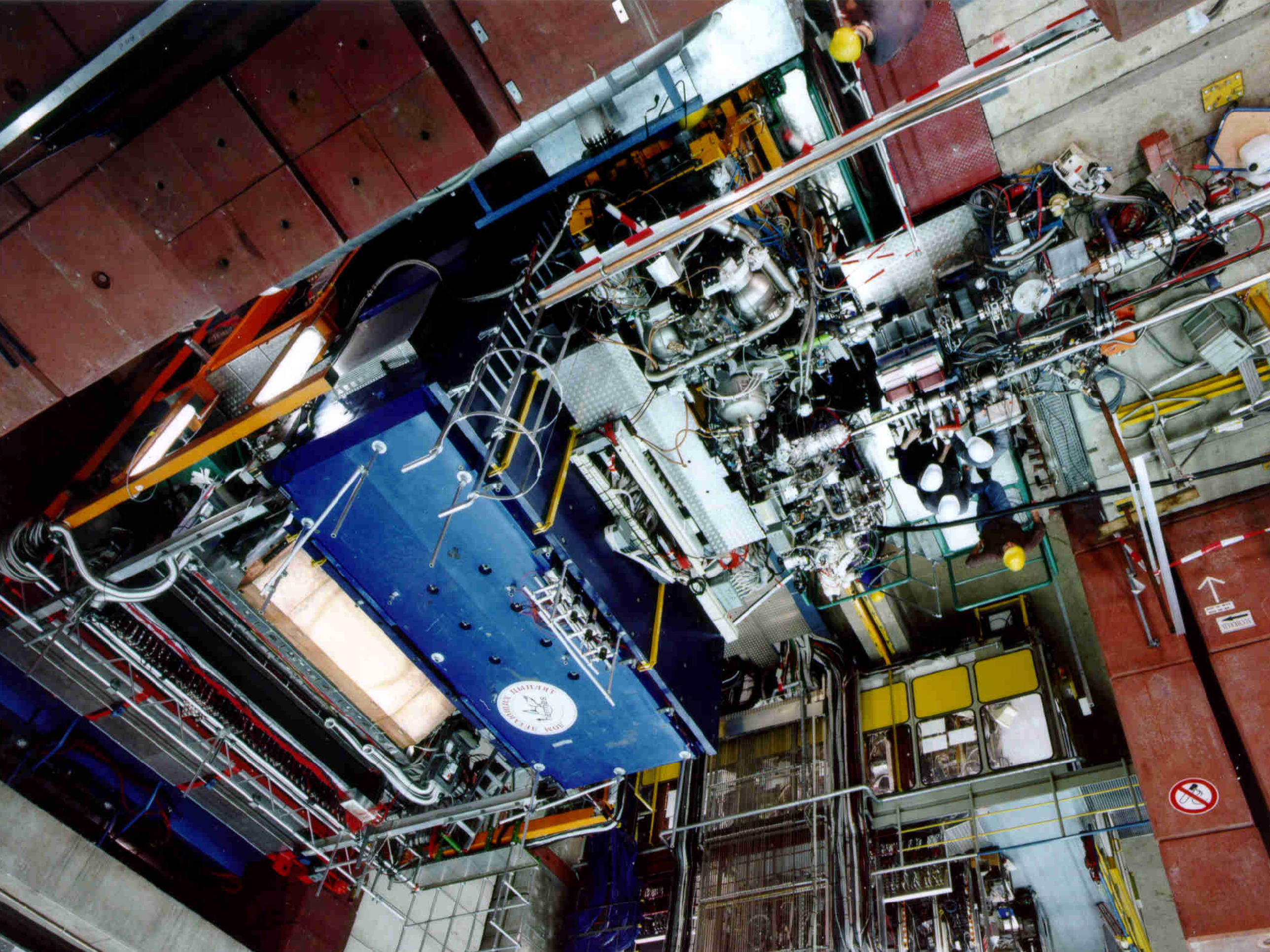
Precise measurement of scattered e^-

(transversely) polarised target

Precise measurement produced hadron

High virtuality
$Q^2 = -q^2 > 1 GeV^2$

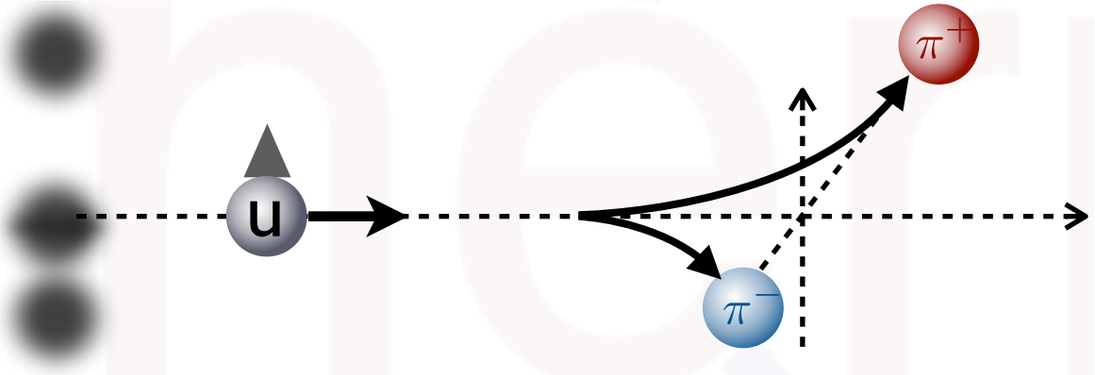




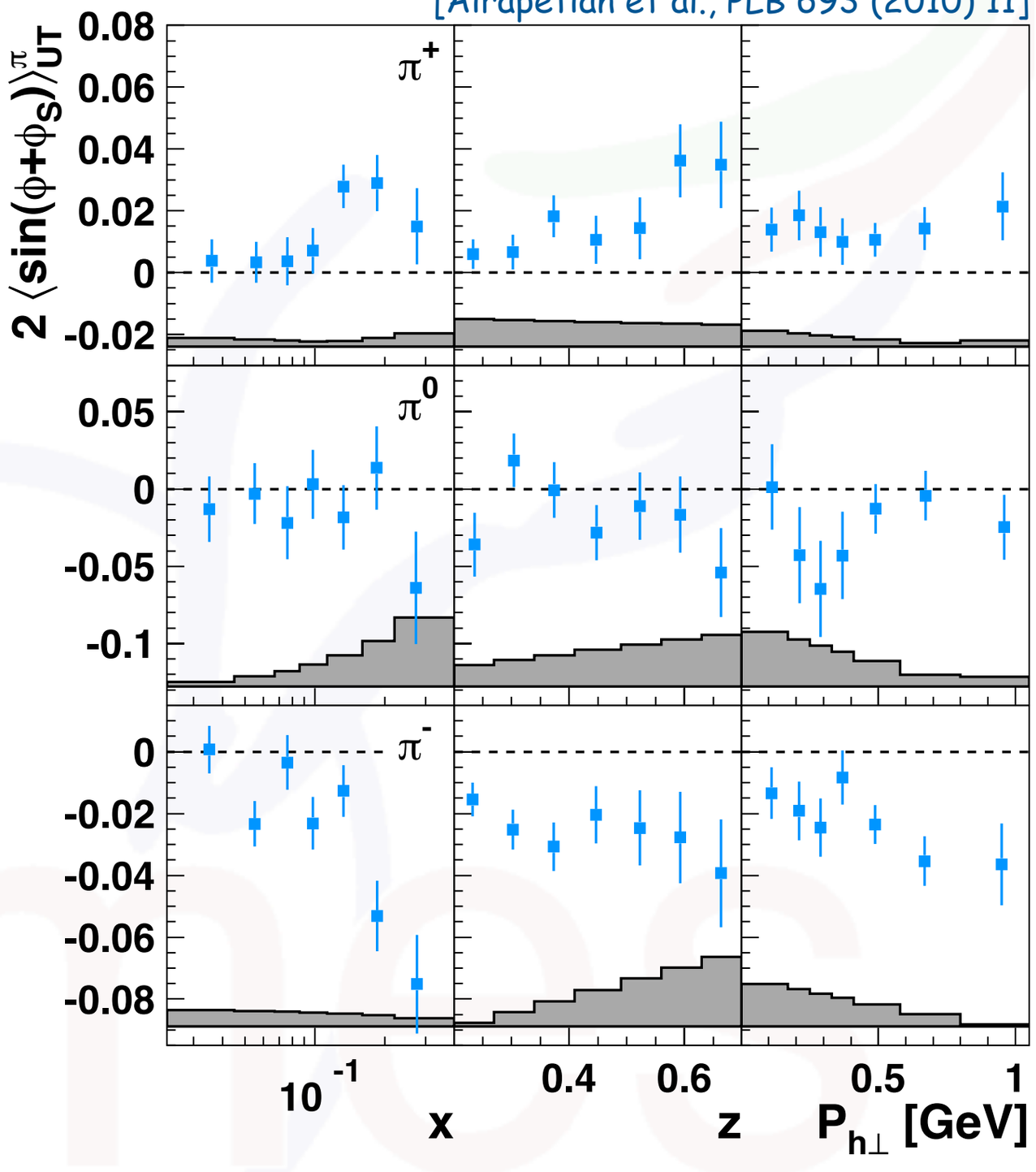
Collins Effect

	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

- transverse polarization of quarks leads to large effects!
- opposite in sign for charged pions
- disfavoured Collins FF large and opposite in sign to favoured one
- Non-zero transversity
- Non-zero Collins function

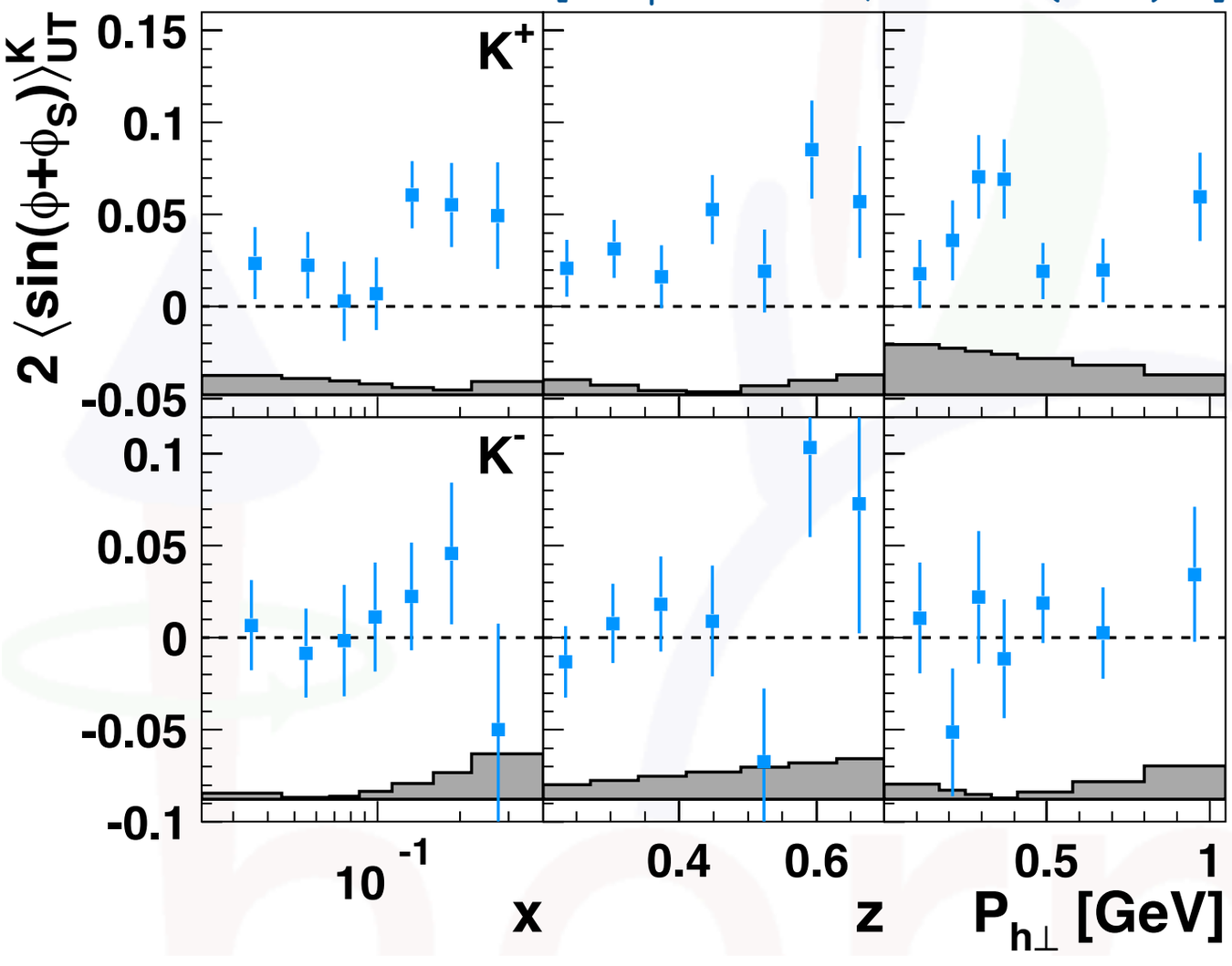


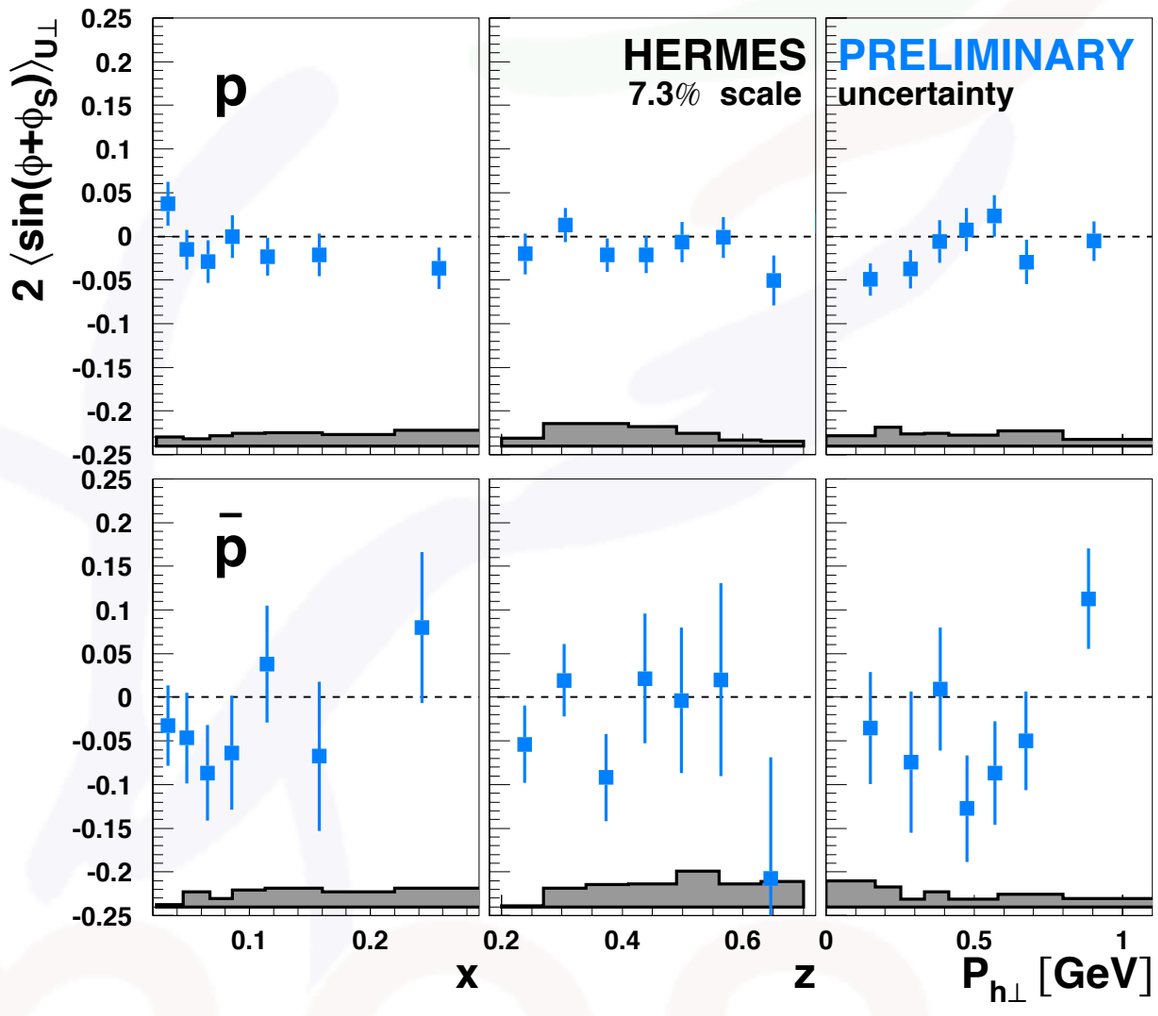
[Airapetian et al., PLB 693 (2010) 11]



Collins Effect - part II

[Airapetian et al., PLB 693 (2010) 11]





- positive Collins SSA amplitude for positive kaons
- consistent with zero for negative kaons and (anti)protons

➡️vanishing sea-quark transversity and baryon Collins effect?

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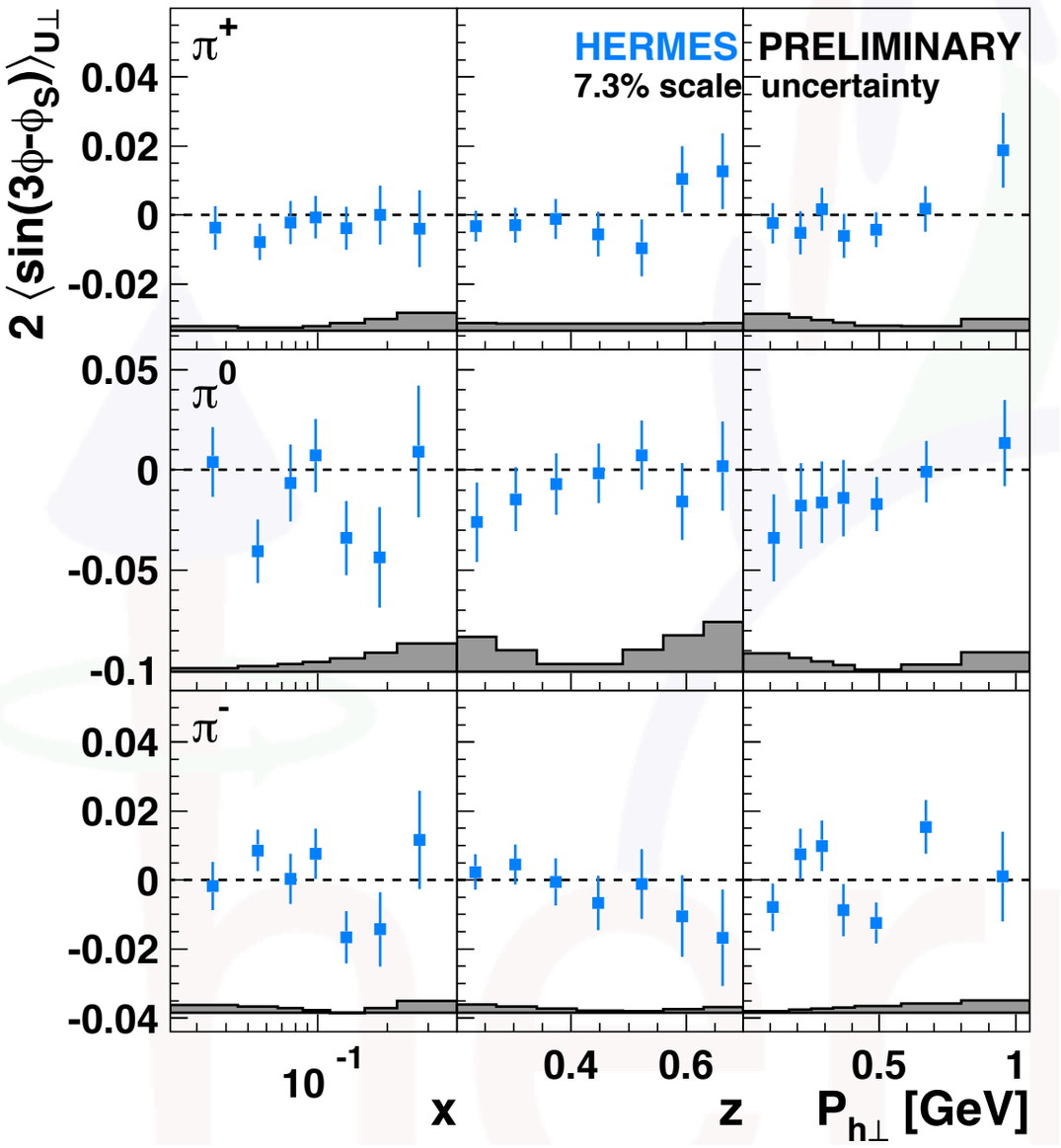
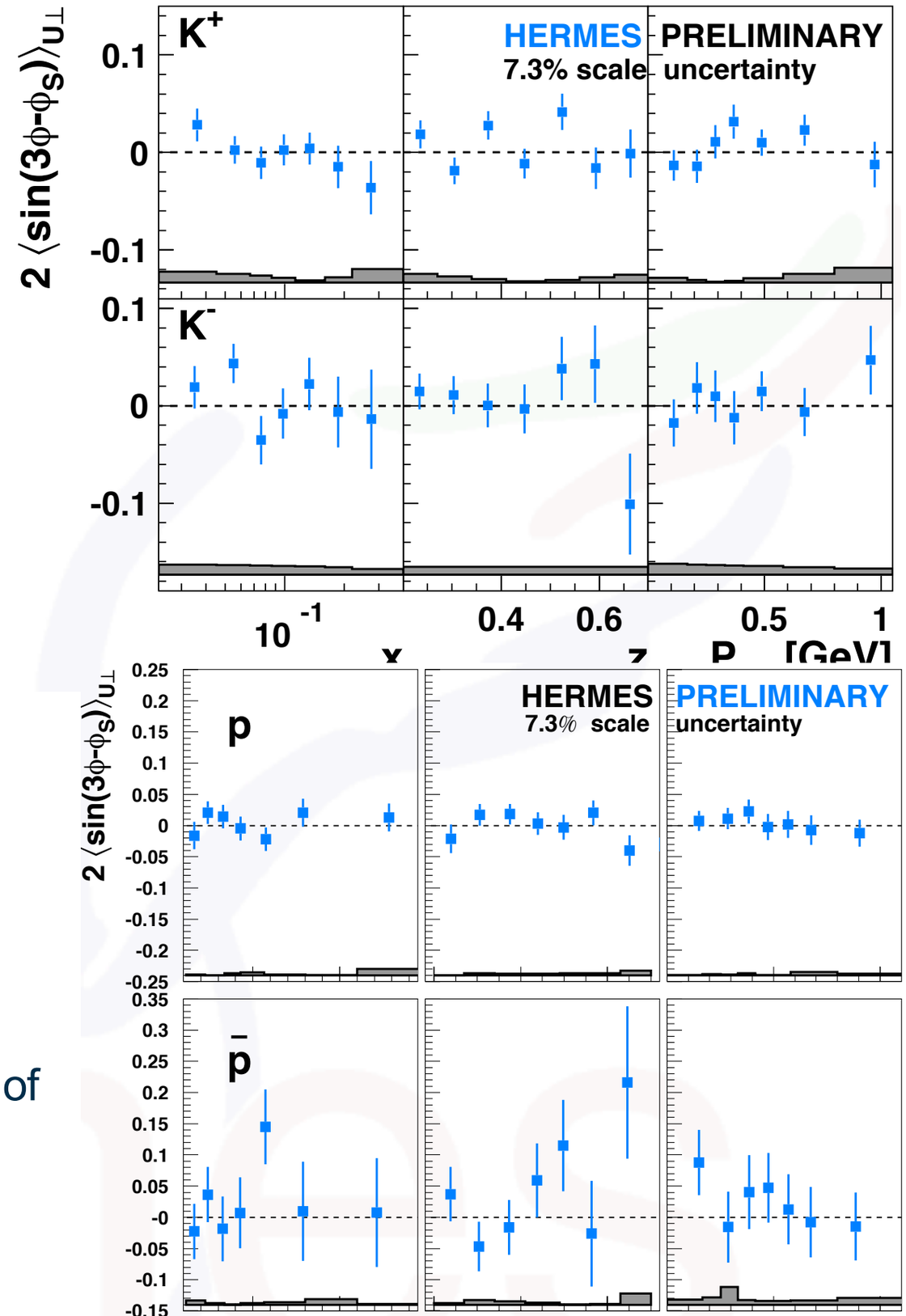
	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

Pretzelosity





Consistent with zero; but suppressed by two powers of $P_{h\perp}$ with respect to transversity and Collins

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	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

Boer-Mulders Effect

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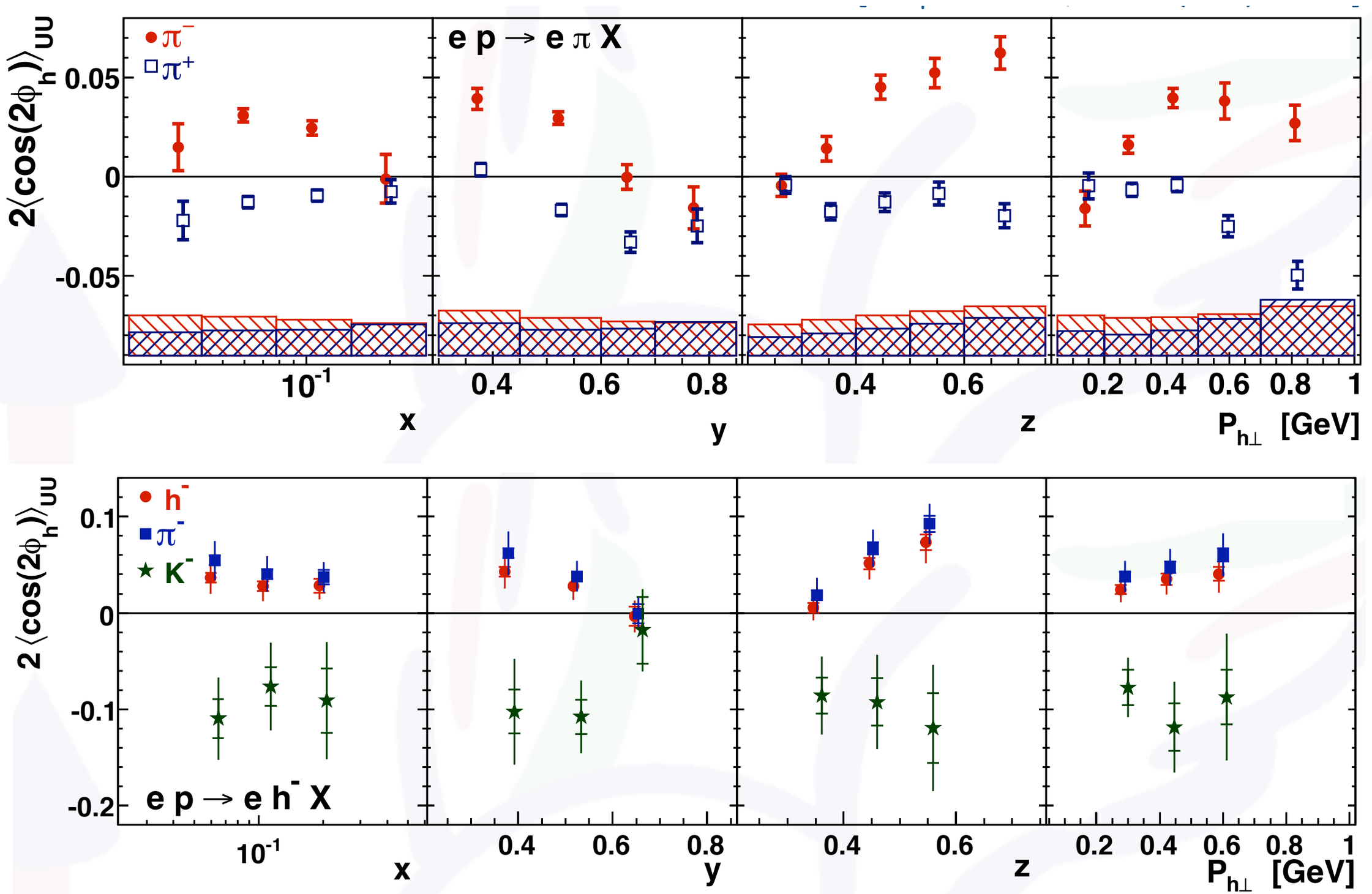

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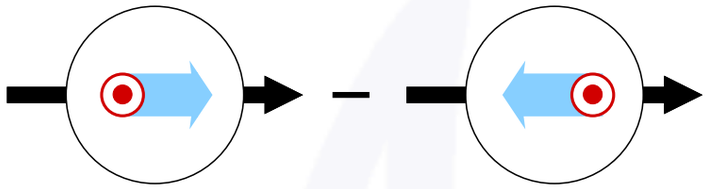
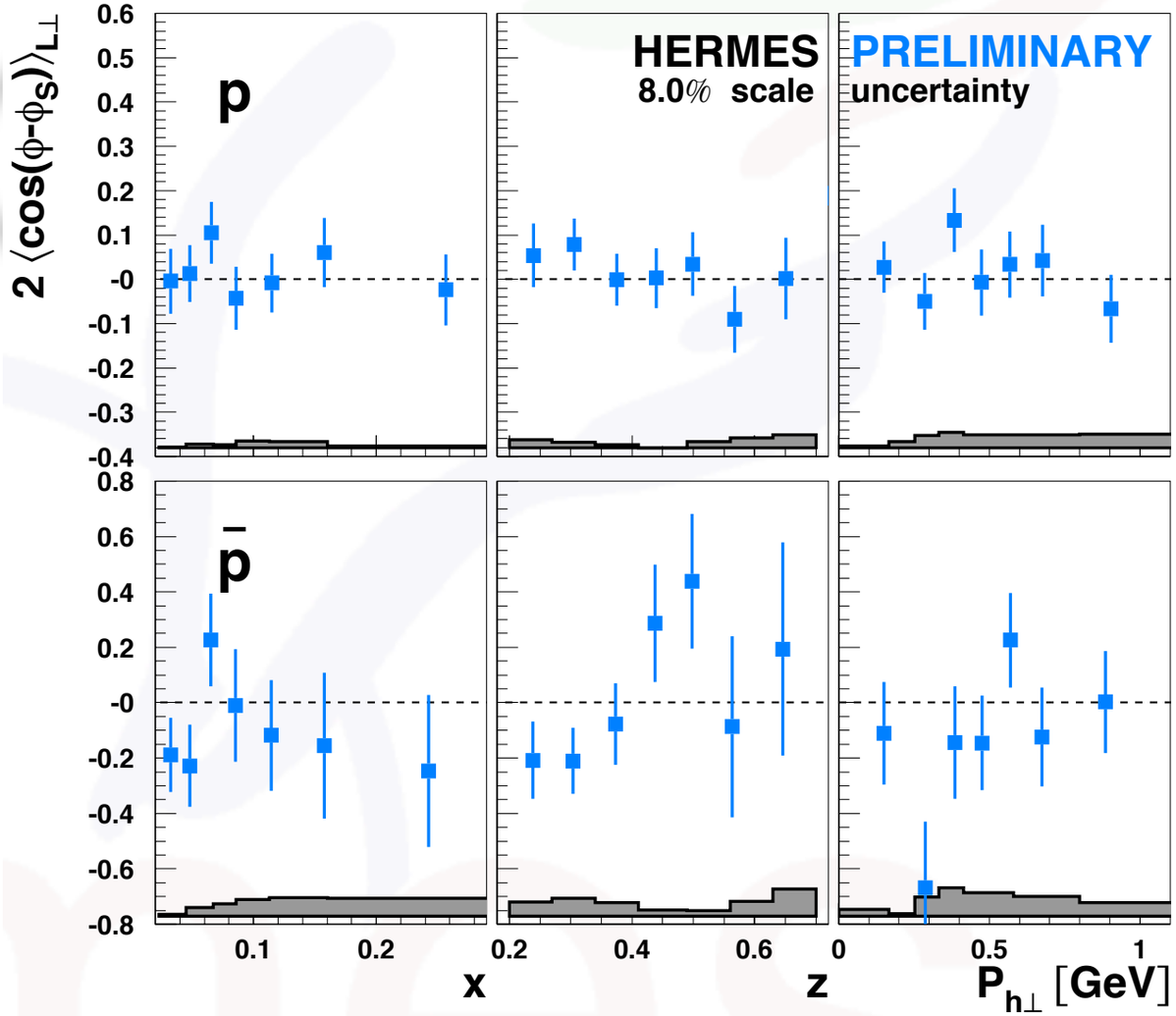
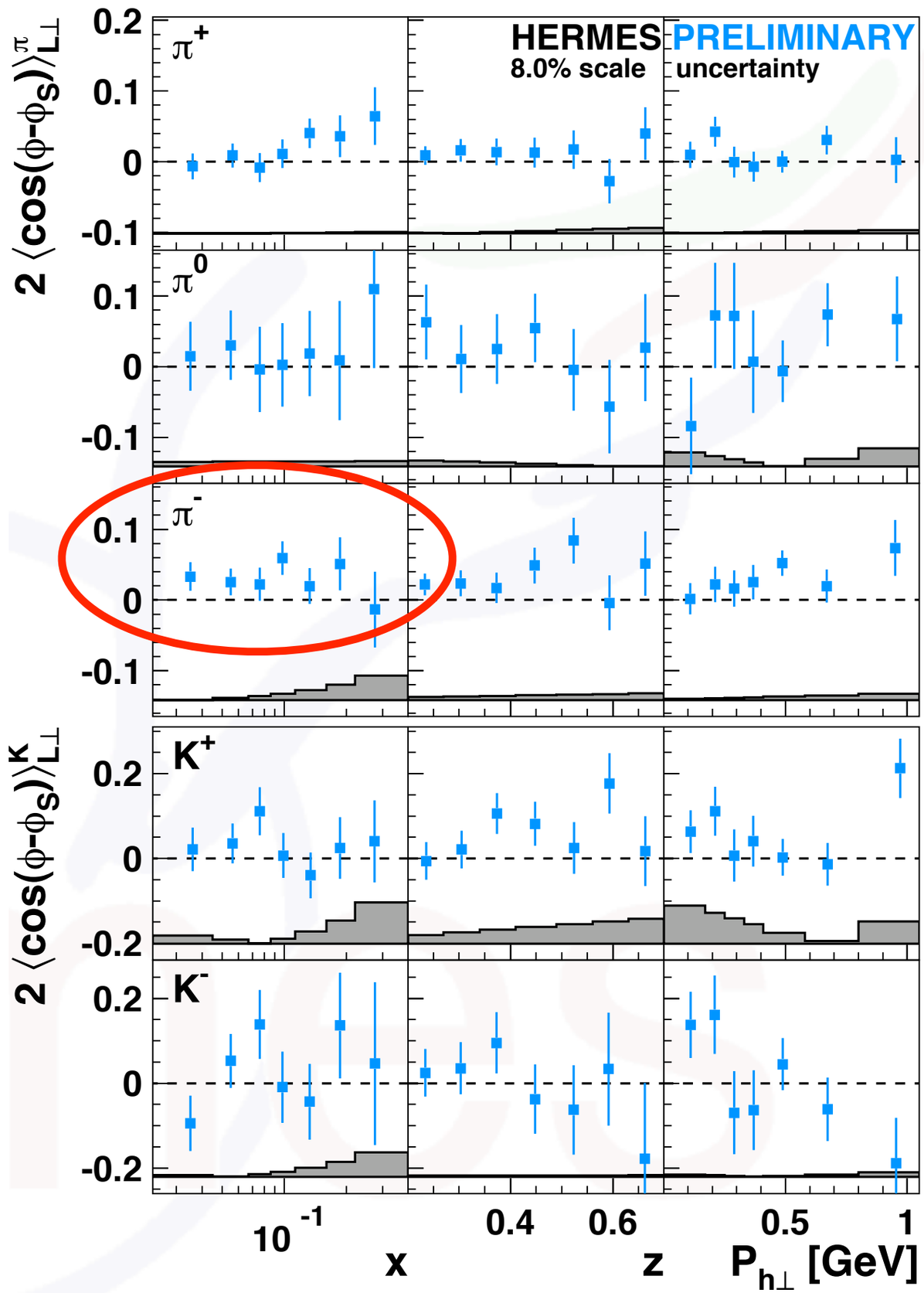
	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1,\ h_{1T}^\perp$





Worm Gear



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	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

Sivers effect

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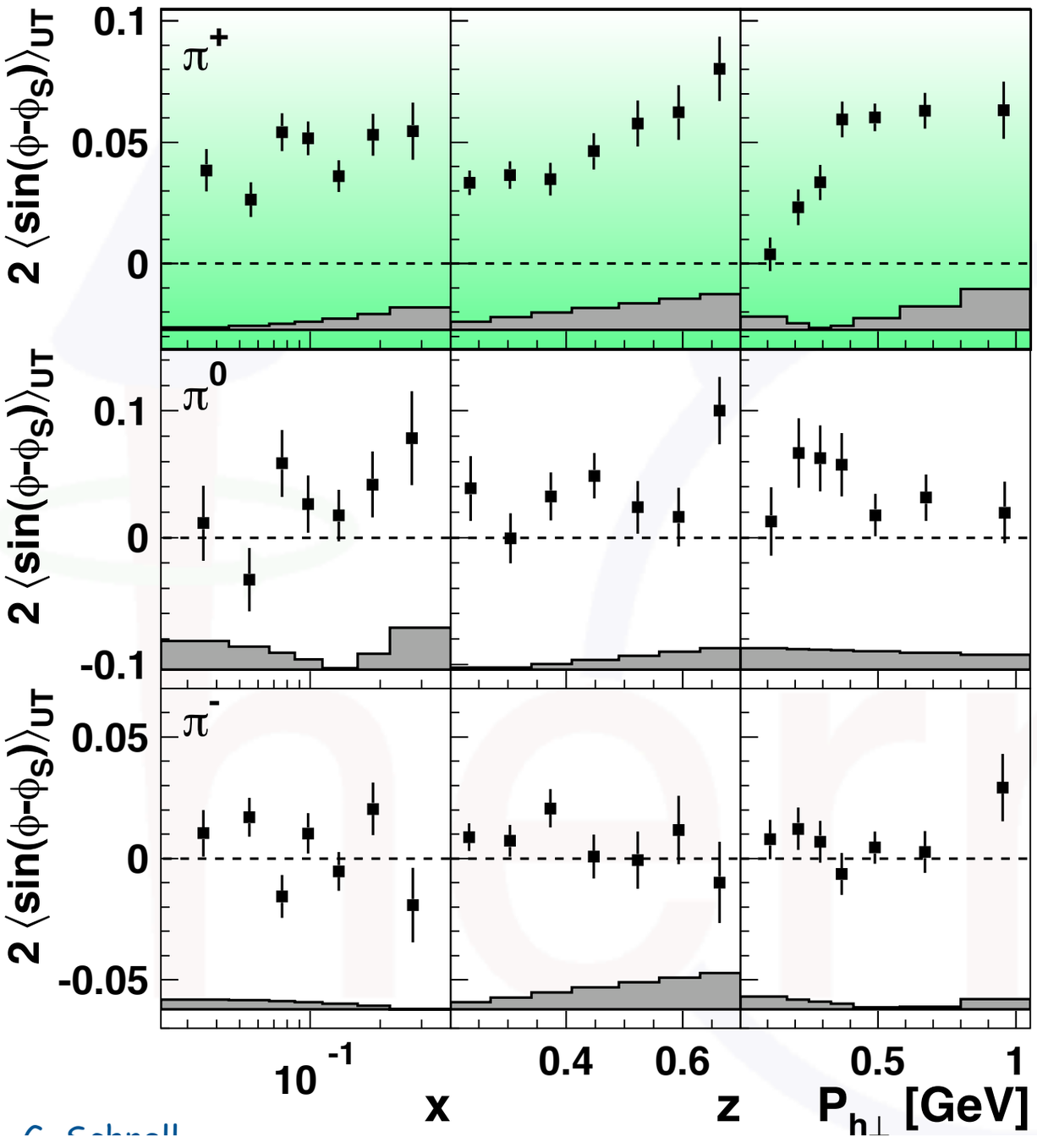

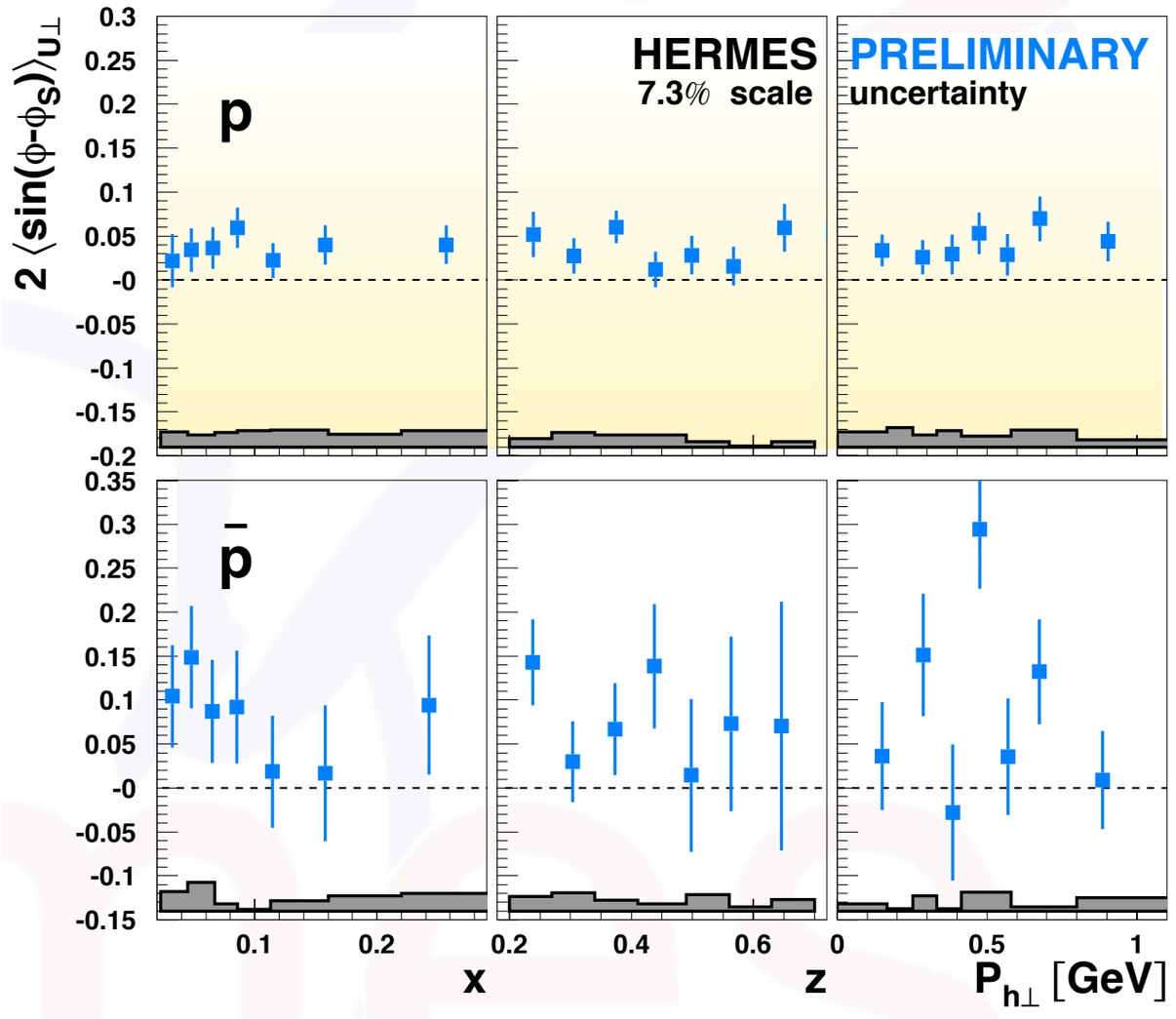

similar amplitudes for positive pions and protons

☛ u-quark dominance (and not a FF effect)?

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All things longitudinal - a new analysis of A_{LL}

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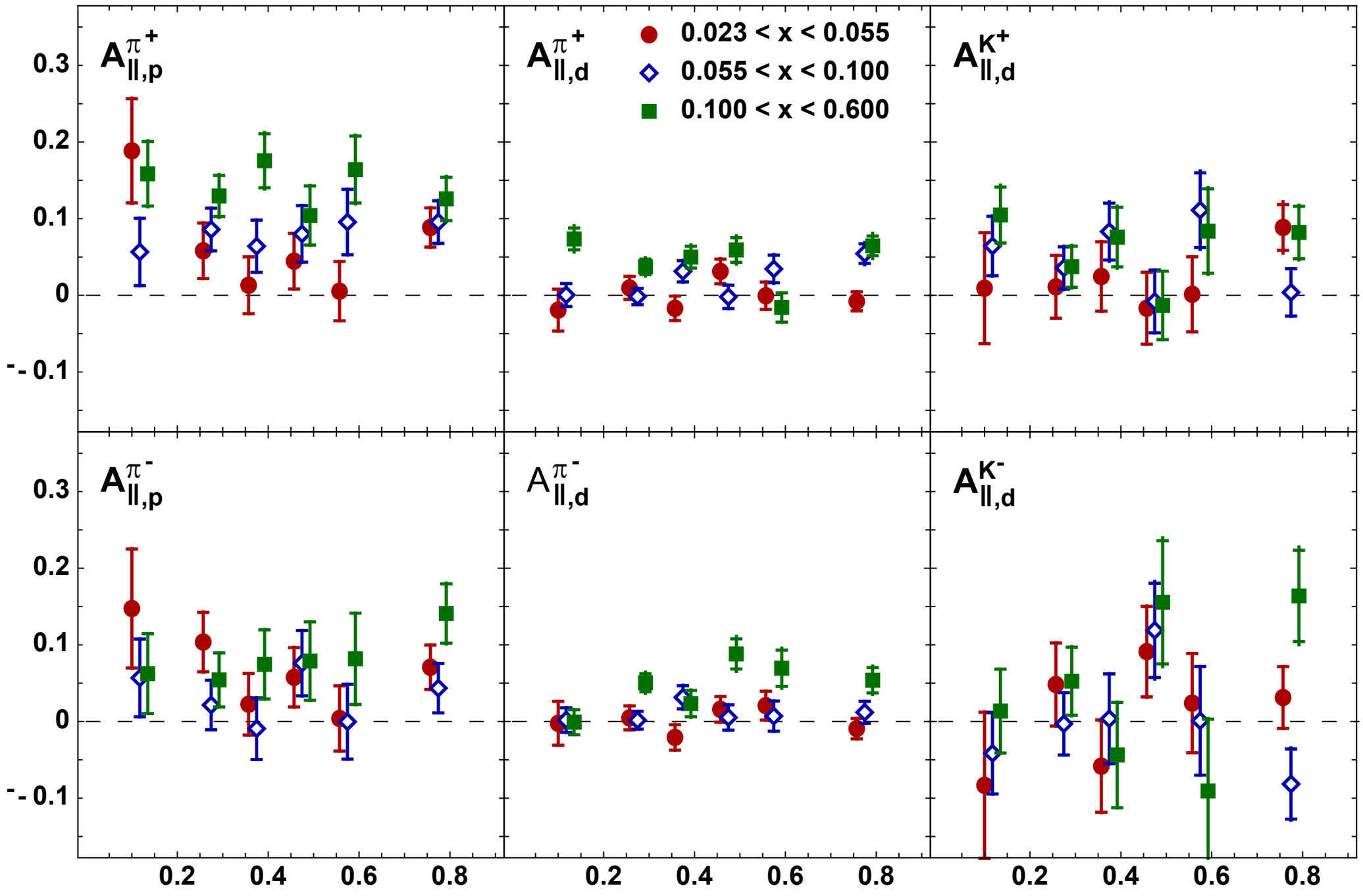
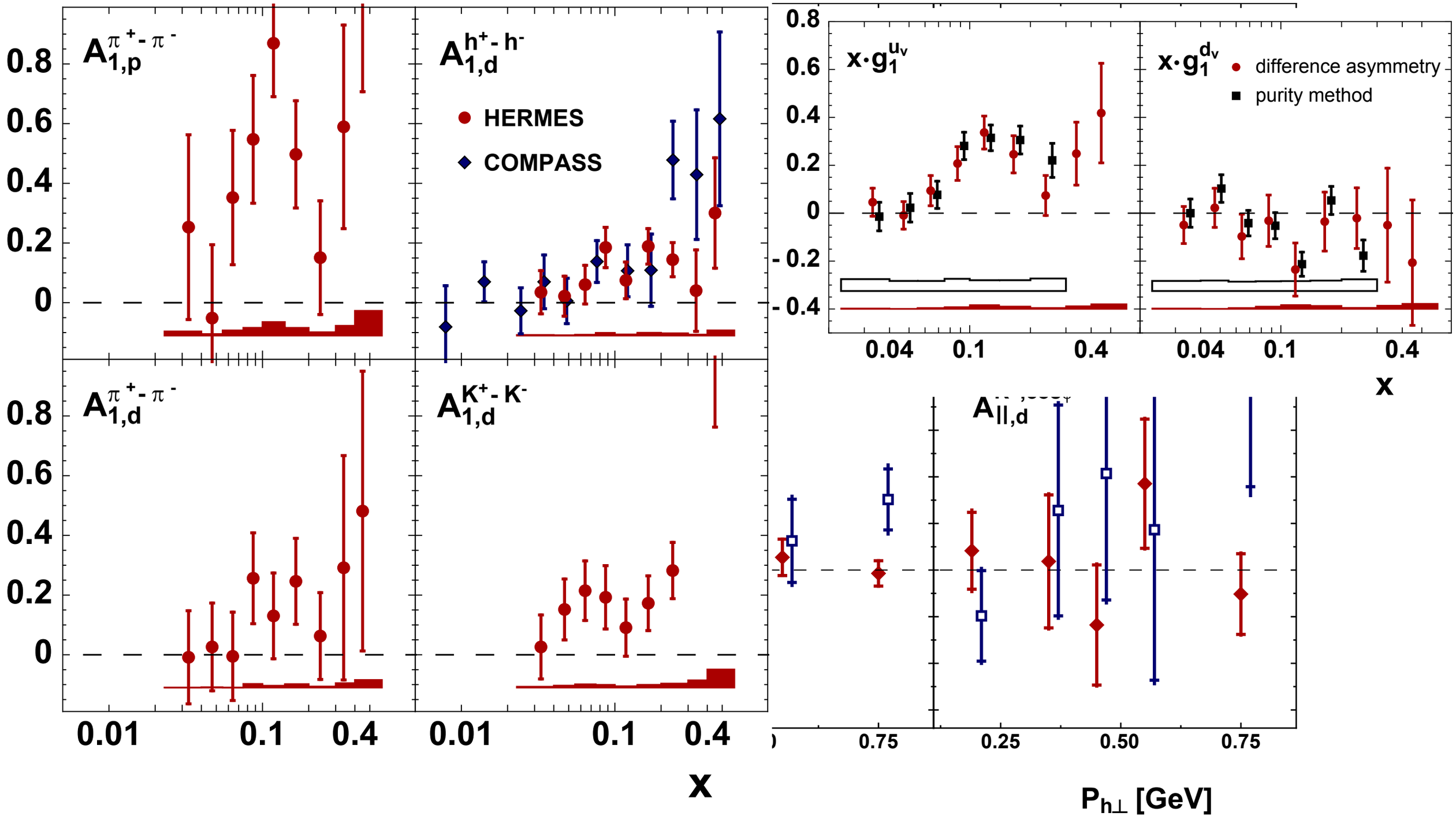
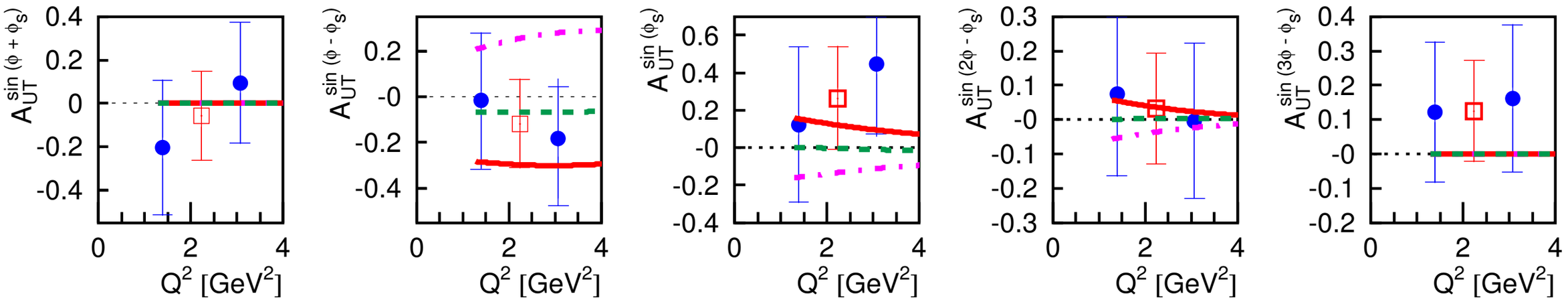


All things longitudinal - a new analysis of A_{LL}



Going vector - the ω



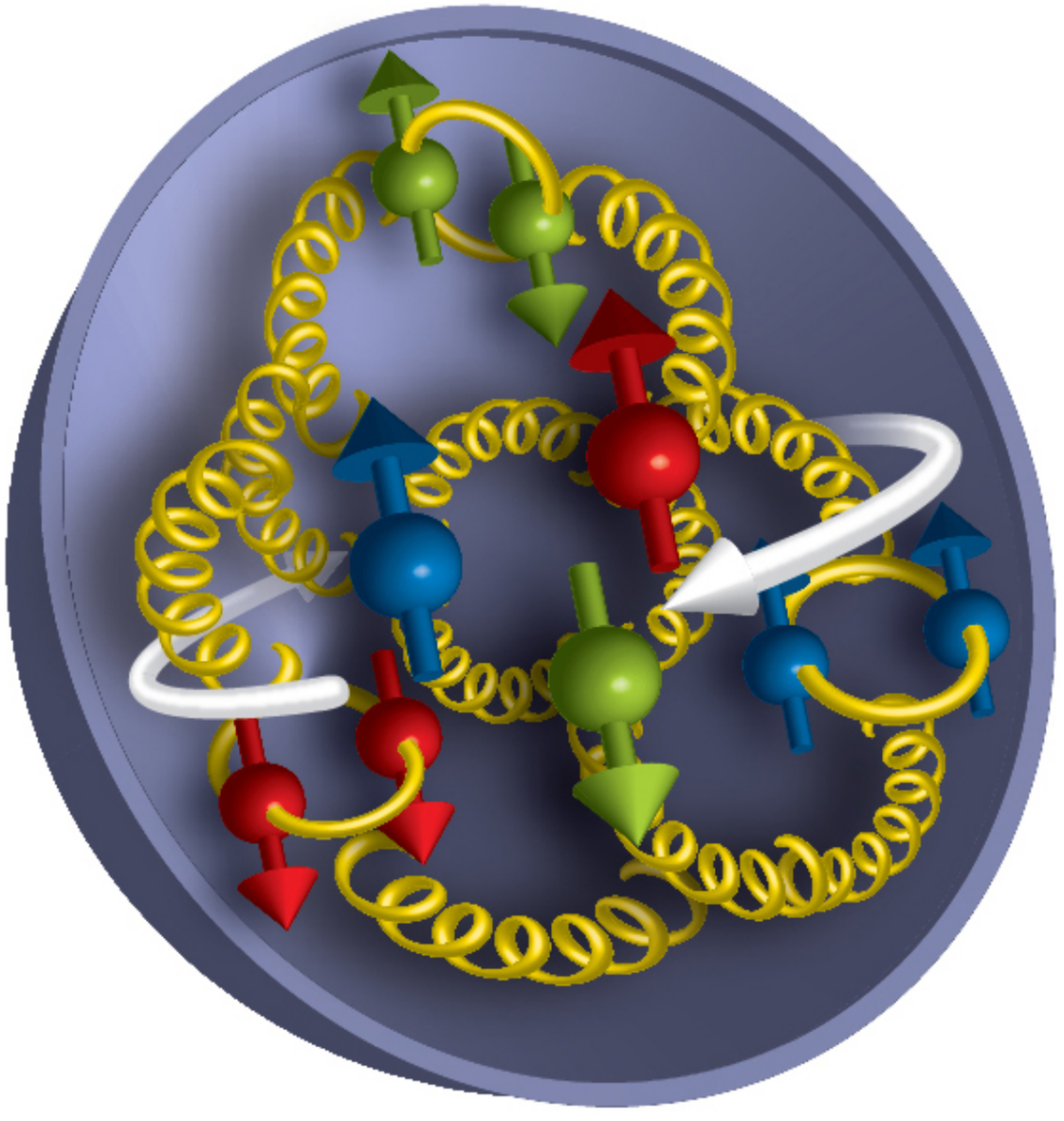
Lines are model predictions from S. Goloskov & P. Kroll Eur. Phys. J. A50 (2014) 146

Dashed lines without π-pole contribution

Solid and dash-dotted lines show positive and negative πω transition form factor

Summary

- HERMES conceived to solve the ‘spin puzzle’
- Semi Inclusive Deep Inelastic Scattering with hadron identification key to success
- Versatile experiment design opened avenue to access new physics:
  - Transversity and Transverse Momentum distributions
  - Evidence for Boer-Mulders, Collins, Sivers, Pretzelosity, Worm-Gears …
  - Hard exclusive reactions and Generalised Parton Distributions
- Be prepared to be surprised …



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Thank you very much for your attention

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