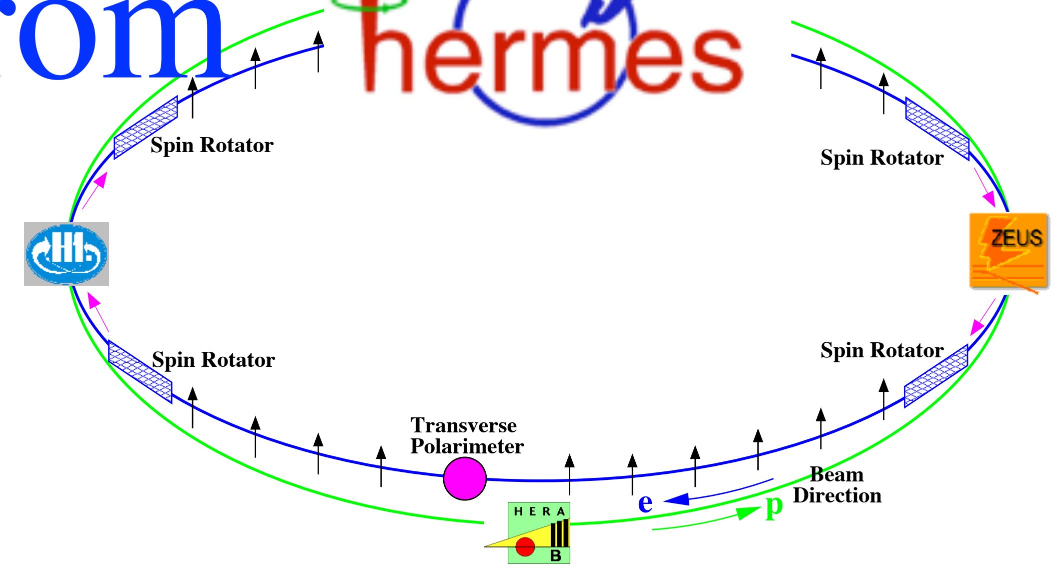
Highlights from hermes



HERA Symposium

Hamburg, June 18, 2013

Ami Rostomyan

(on behalf of the HERMES collaboration)

spin and hadronization

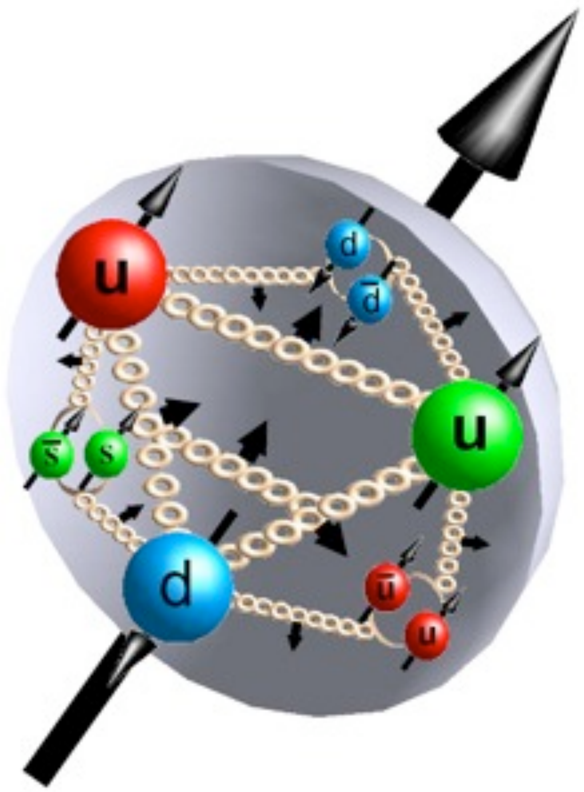
HERMES main research topics:

✓ **origin of nucleon spin**

- ☛ longitudinal spin/momentum structure
- ☛ transverse spin/momentum structure

✓ **hadronization/fragmentation**

spin and hadronization



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☛ momentum: quarks carry ~ 50 % of the proton momentum

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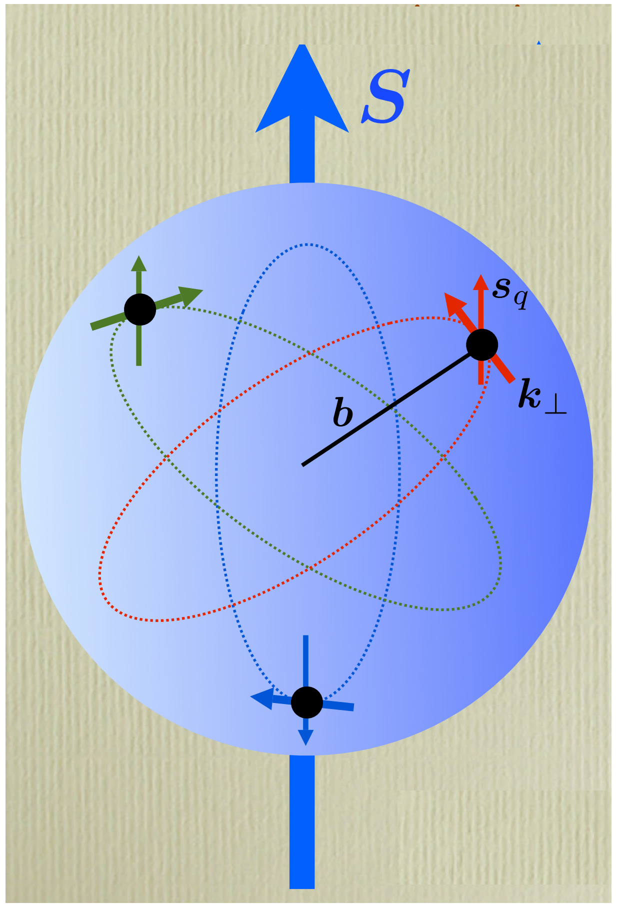
quantum phase-space "tomography" of the nucleon

Wigner functions: $W^q(\mathbf{k}, \mathbf{b})$

probability to find a quark in a nucleon with a certain polarization in a position **b** and momentum **k**



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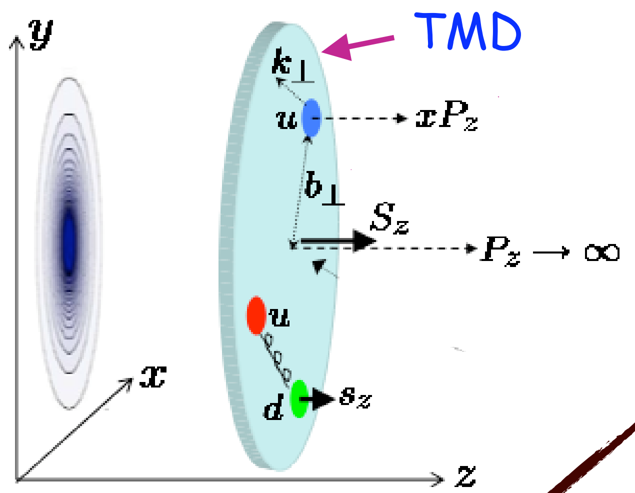
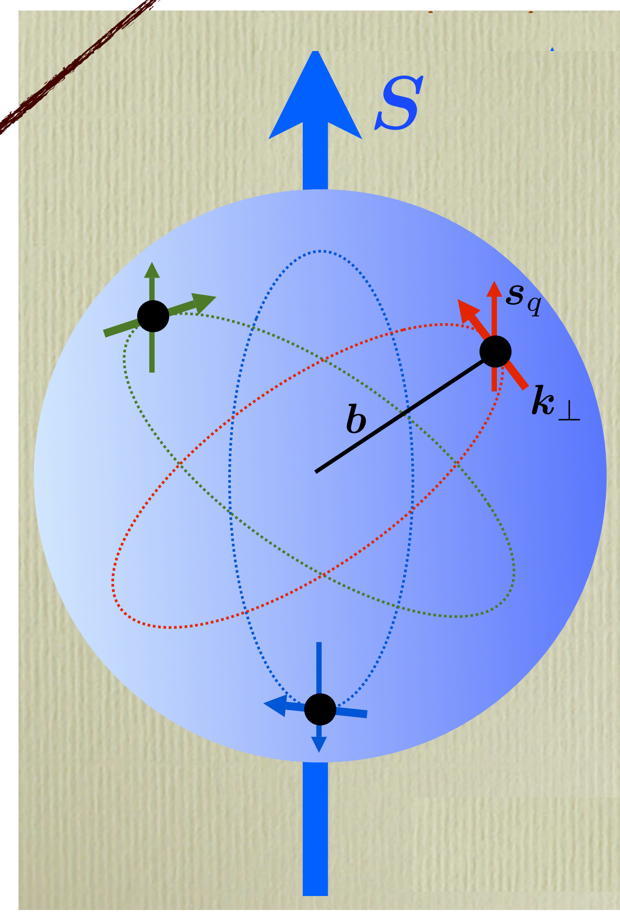
$\int d^3\mathbf{b}$



$q(x,\mathbf{k_T})$

Transverse Momentum Dependent
(**TMDs**) distribution functions (DF)



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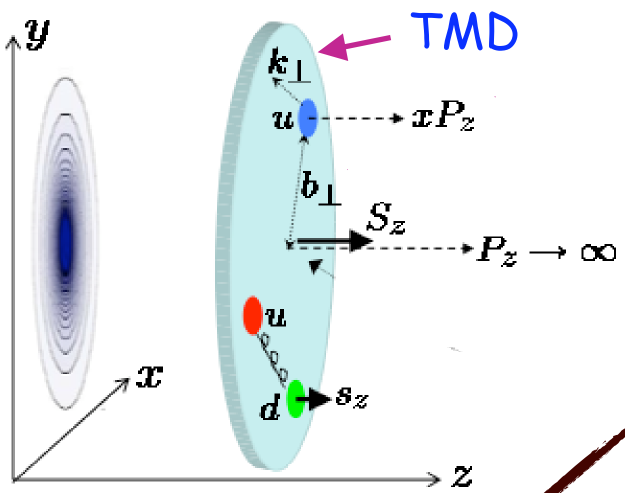

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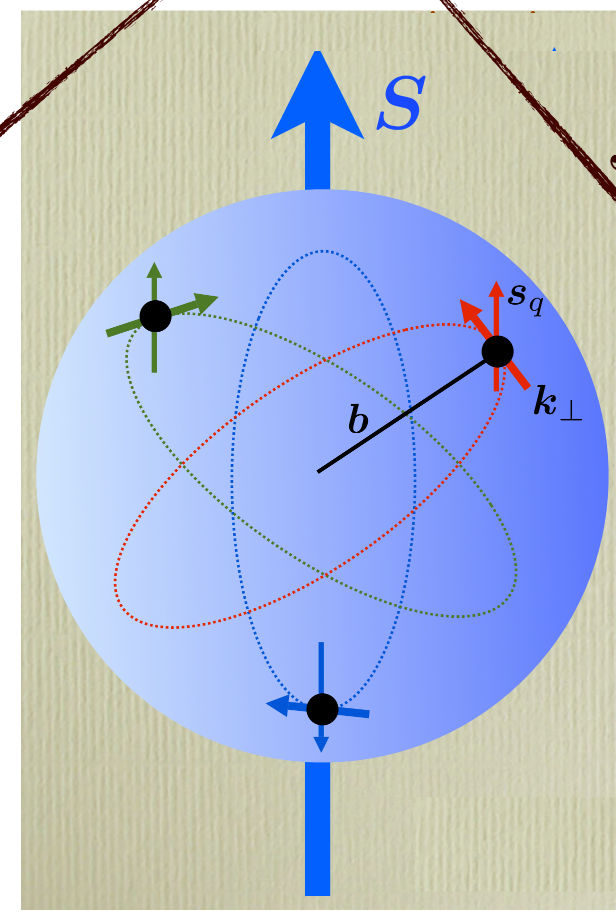
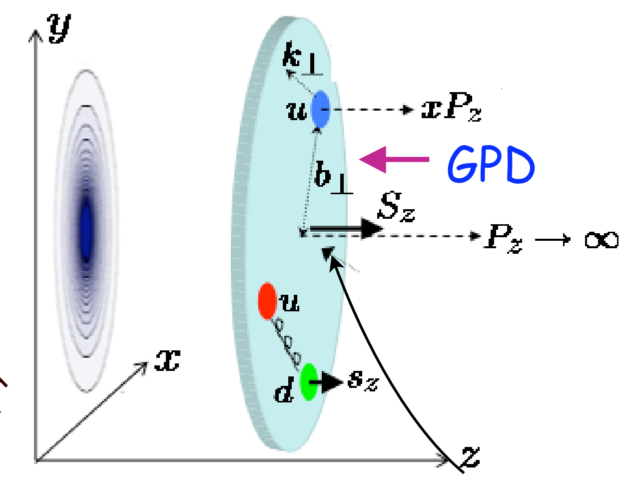


$\int d^2\mathbf{k_T}\, d\mathbf{b_L}$



center of momentum

$R_\perp = \sum x_i r_{\perp_i}$

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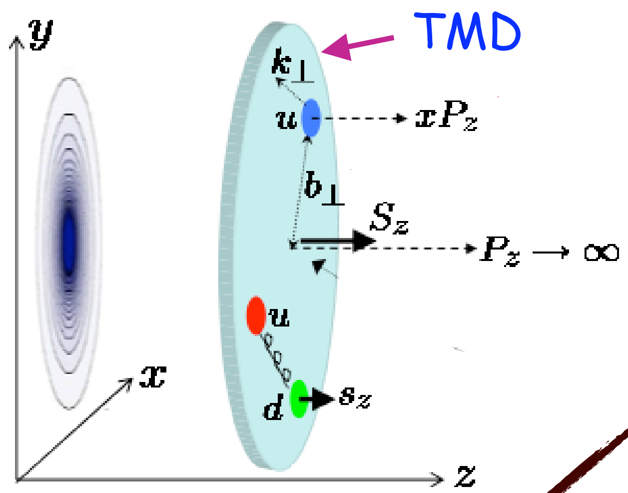

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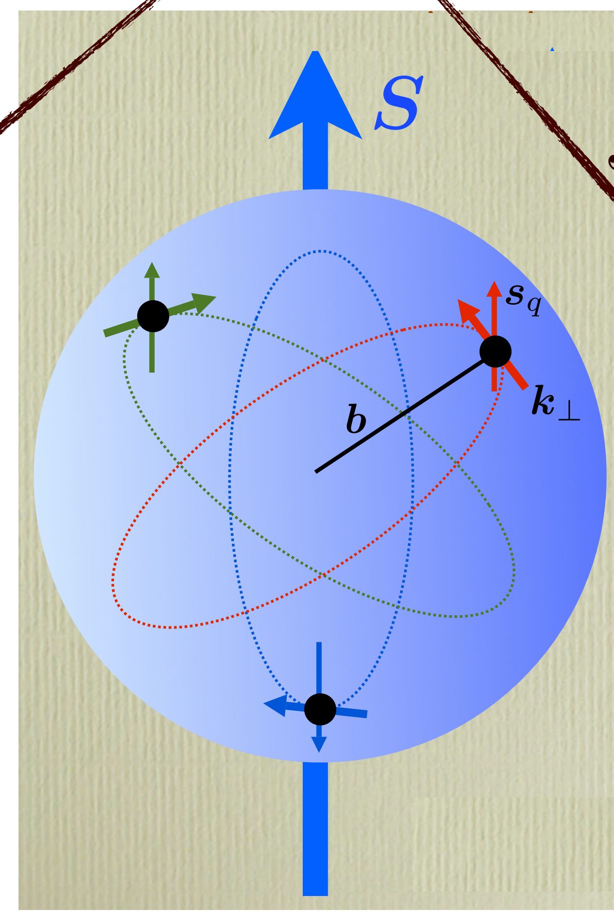

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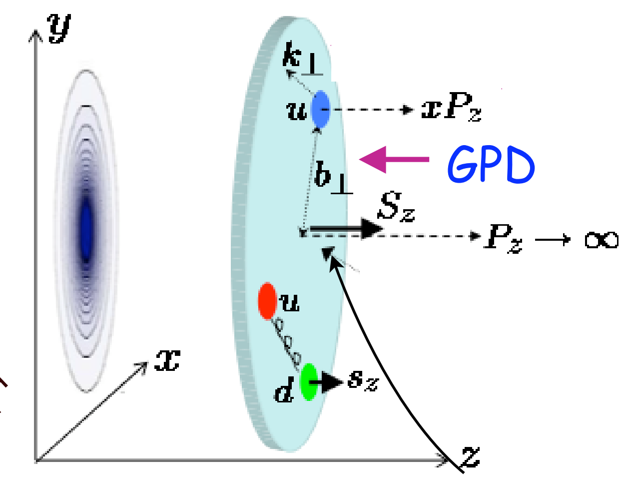

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transve osition dependent
d bution functions

FT

$H(x, \xi, t)$

Generalized Parton Distributions
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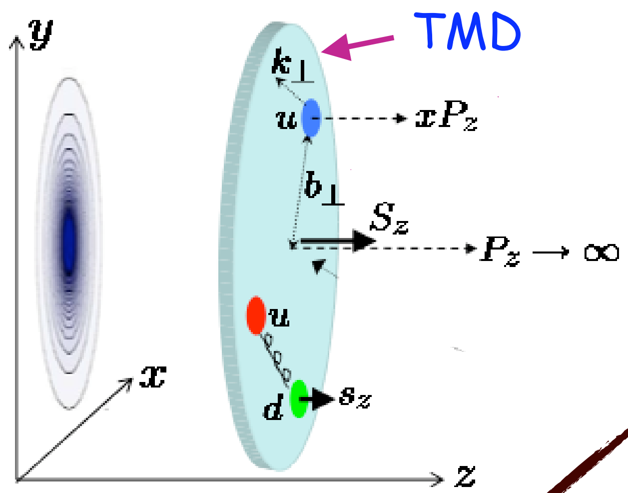

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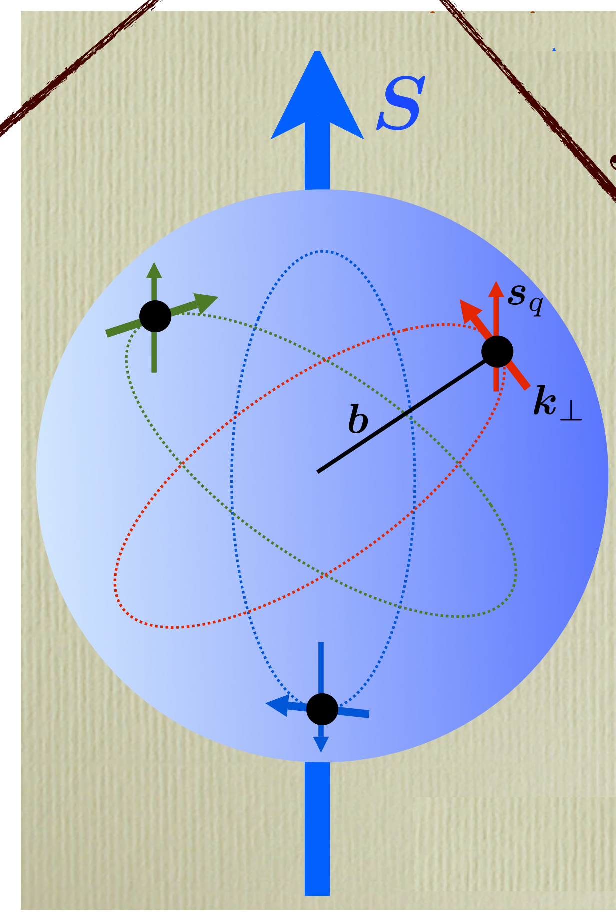

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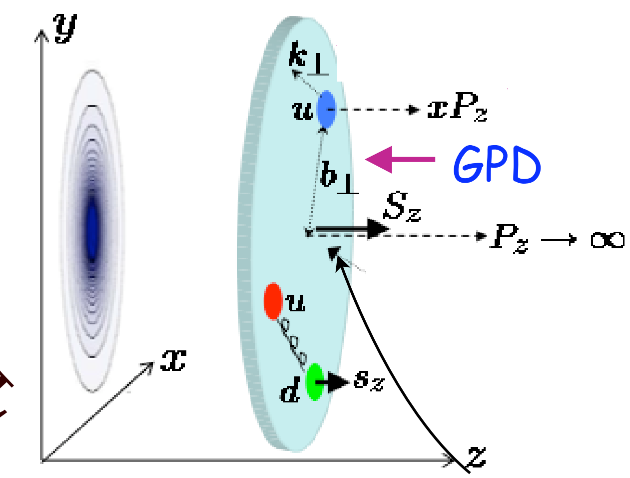

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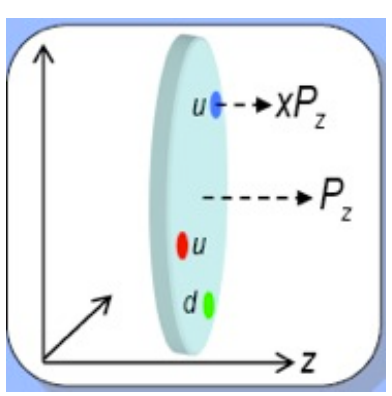
Generalized Parton Distributions (**GPDs**)

$\int d^2\mathbf{k_T}$

$\xi = 0,\ t = 0$

$f^q(x)$



Parton Distribution Functions (**PDFs**)

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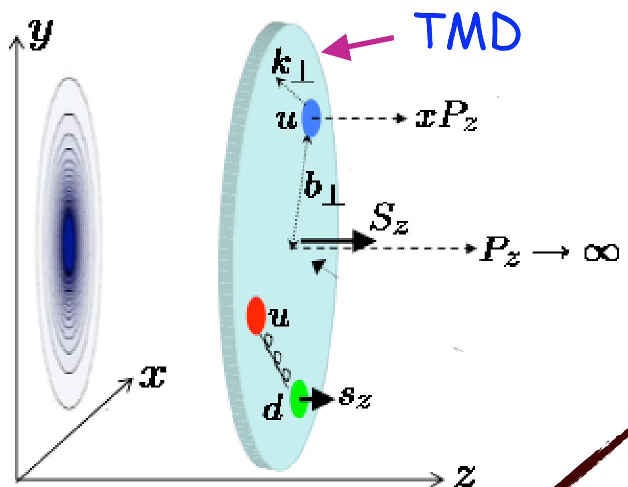

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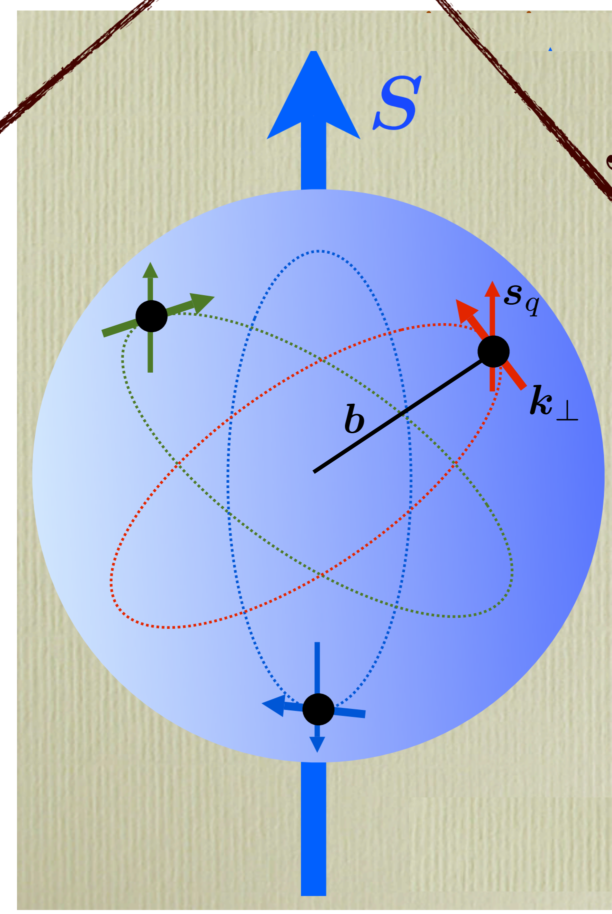

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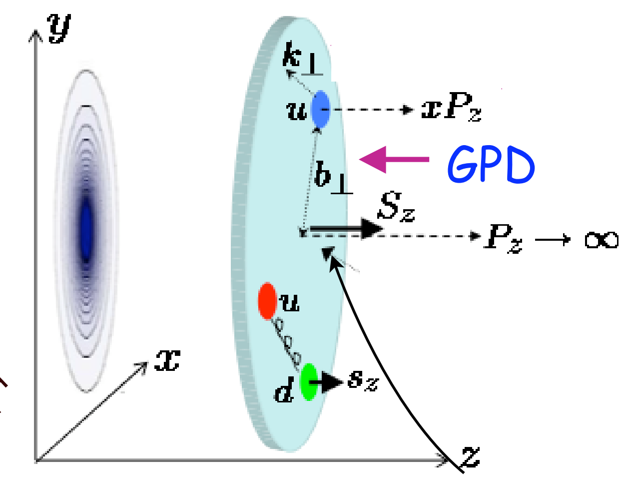

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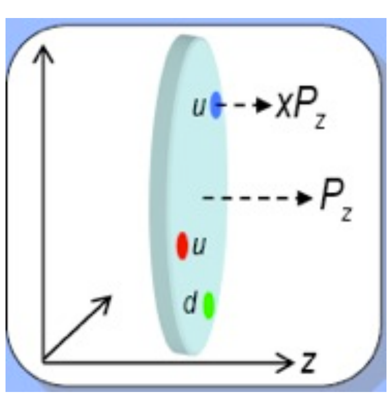

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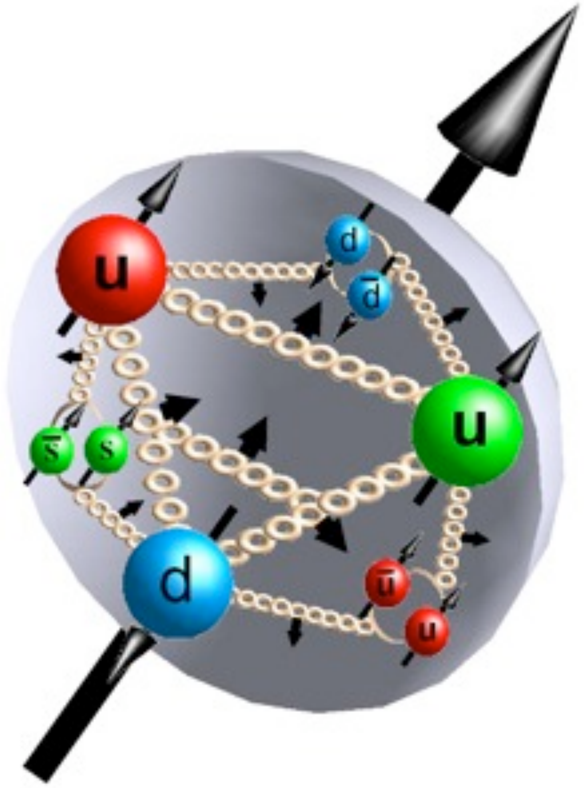
spin and hadronization



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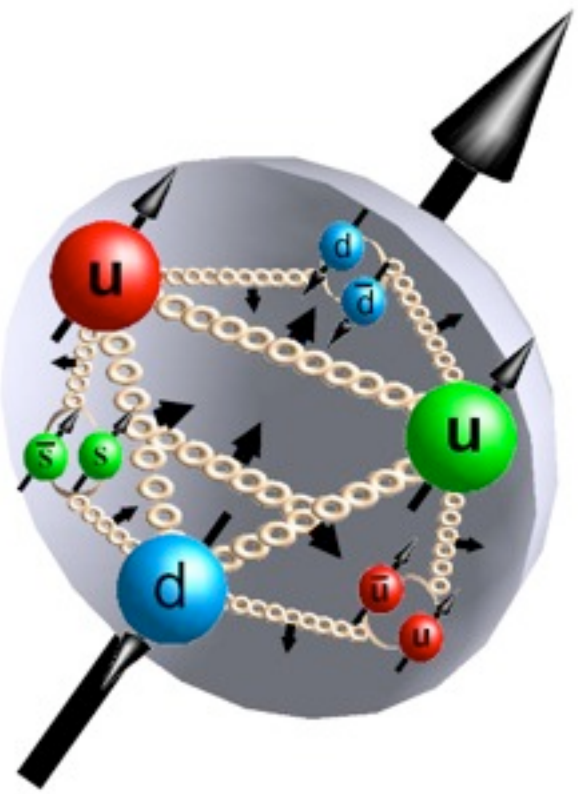

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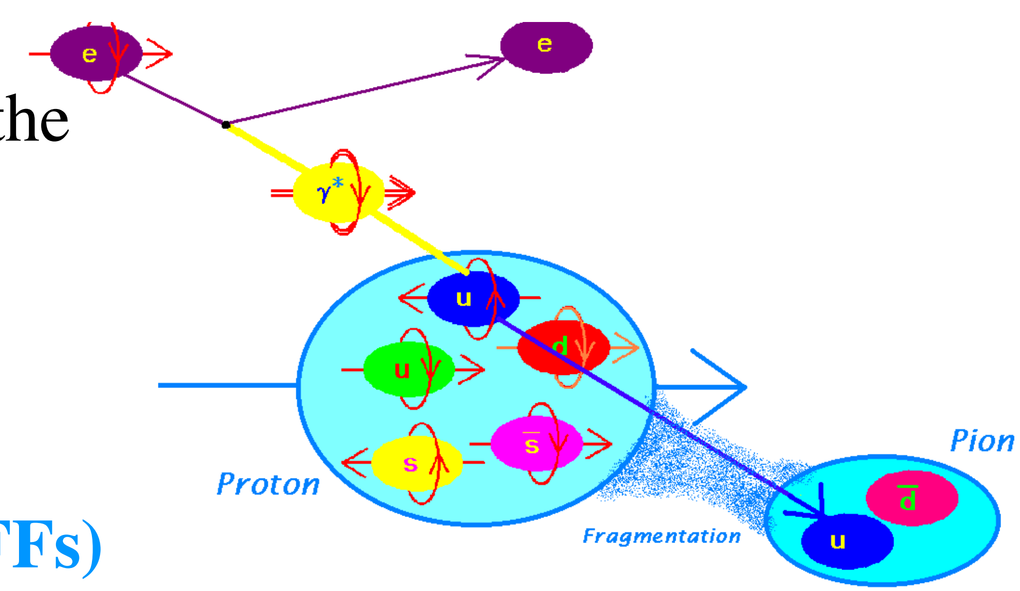
- ➡ **study of TMD DFs and GPDs**

✓ isolated quarks have never been observed in nature

✓ fragmentation functions were introduced to describe the hadronization

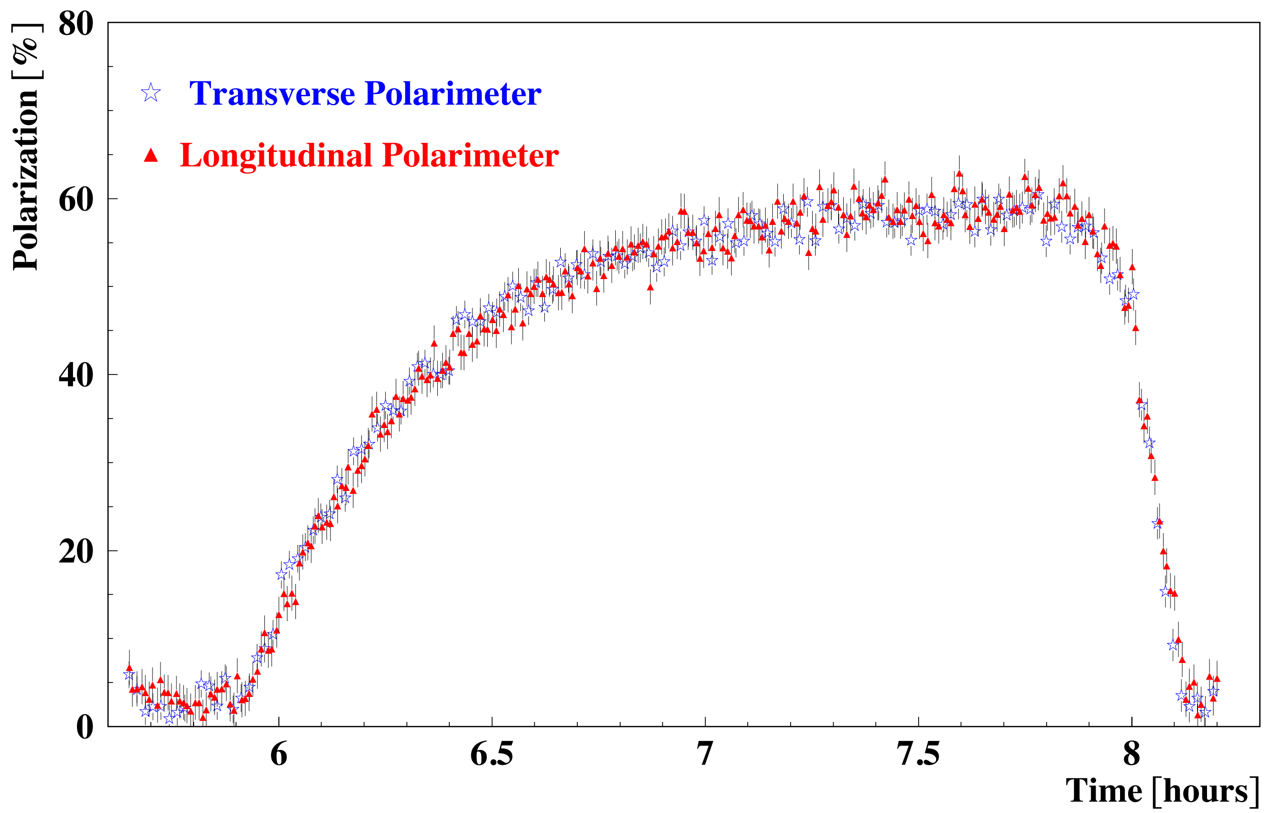
- ☛ non-pQCD objects
- ☛ universal but not well known functions
- ➡ **advantage of lepton-nucleon scattering data → flavour separation of fragmentation functions (FFs)**



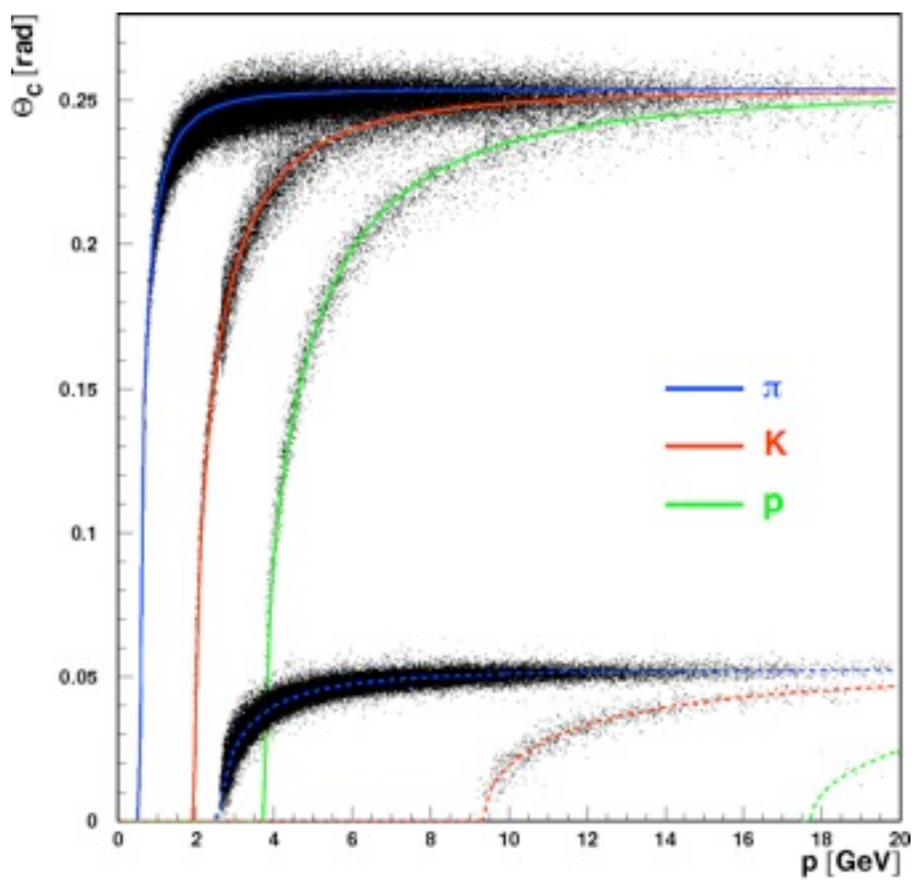
advantages of the experiment

The HERMES experiment, located at HERA, with its pure gas targets and advanced particle identification (π, K, p) is well suited for TMD and GPD measurements.

self-polarized e^+/e^- beam



hadron identification with RICH detector



- **longitudinal** target polarization (H, D, ^{3}He)
- **transverse** target polarization (H)
- **unpolarized** targets: H, D, ^{4}He, ^{14}N, ^{20}Ne, ^{84}Kr, ^{131}Xe
- **unpolarized** H, D targets with **recoil detector**

semi-inclusive measurements (probing TMDs)

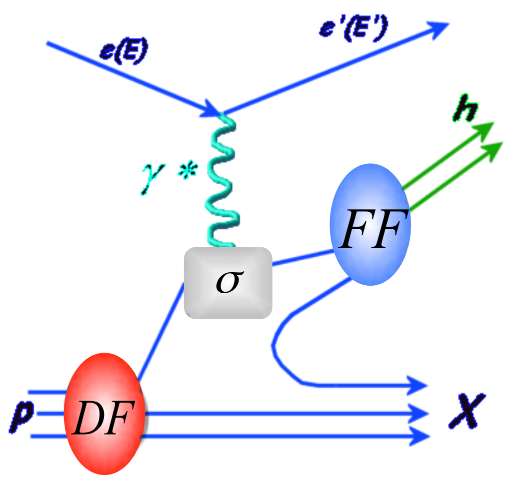
semi-inclusive DIS cross section and TMDs

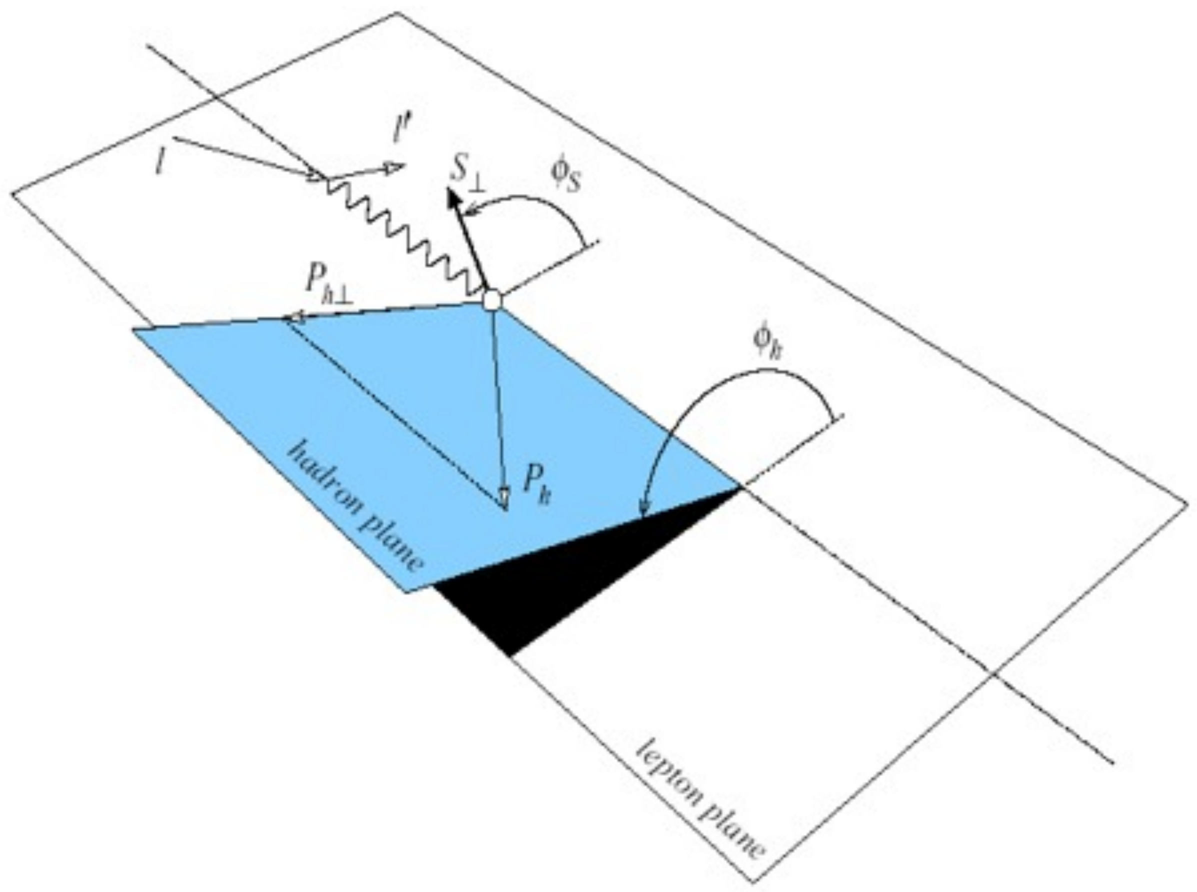
F_{XY}

beam λ_e | target $S_\perp, S_{||}$

$$\frac{d^4\sigma}{dx\, dy\, dz\, d\phi_s} \propto F_{UU} + S_{||}\lambda_e\sqrt{1-\epsilon^2}F_{LL} + S_\perp\{...\}$$

$f_1 \otimes D_1$





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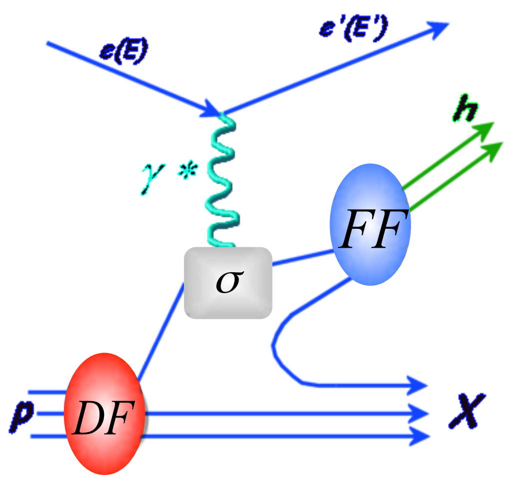
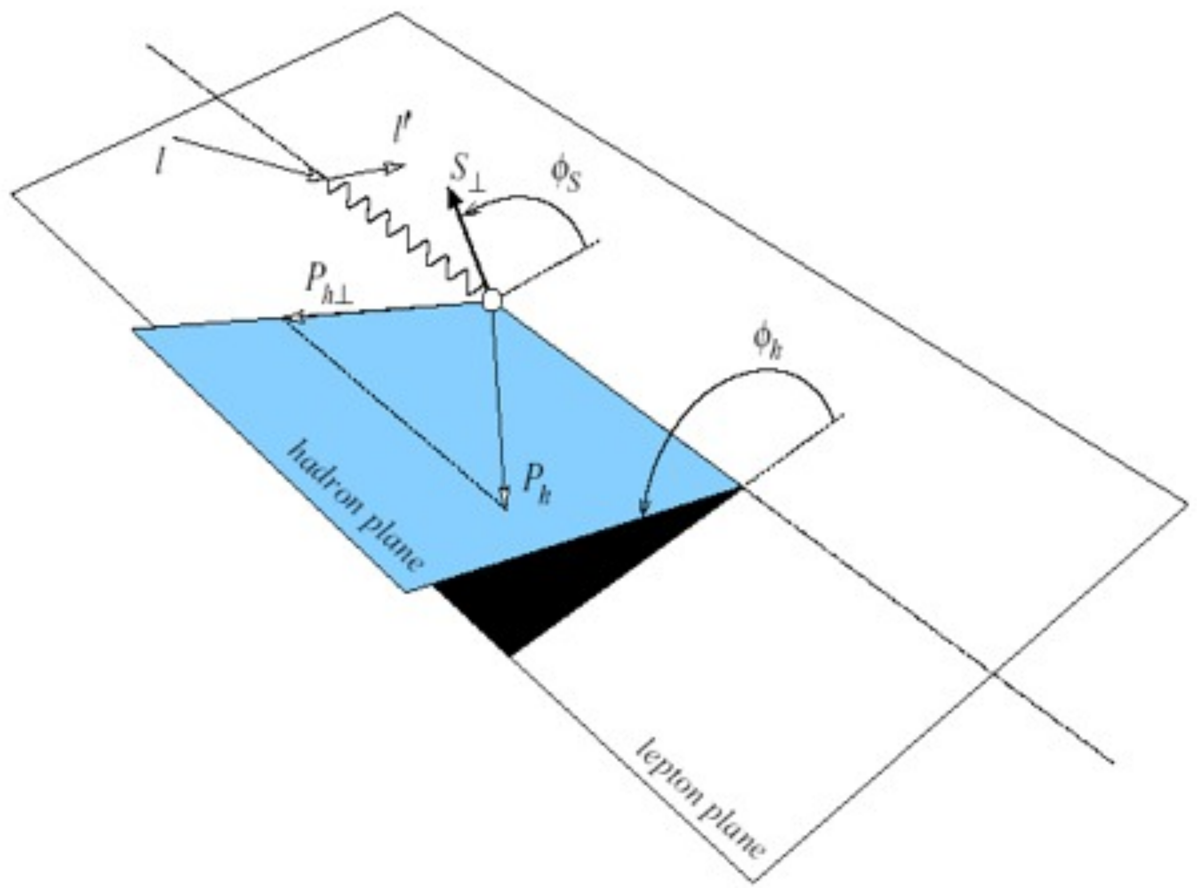
$$+ \quad \lambda_e\left\{\sqrt{2\epsilon(1-\epsilon)}F^{\sin\phi}_{LU}\sin\phi\right\} + S_{||}\left\{\ldots\right\} + S_\perp\left\{\ldots\right\}$$





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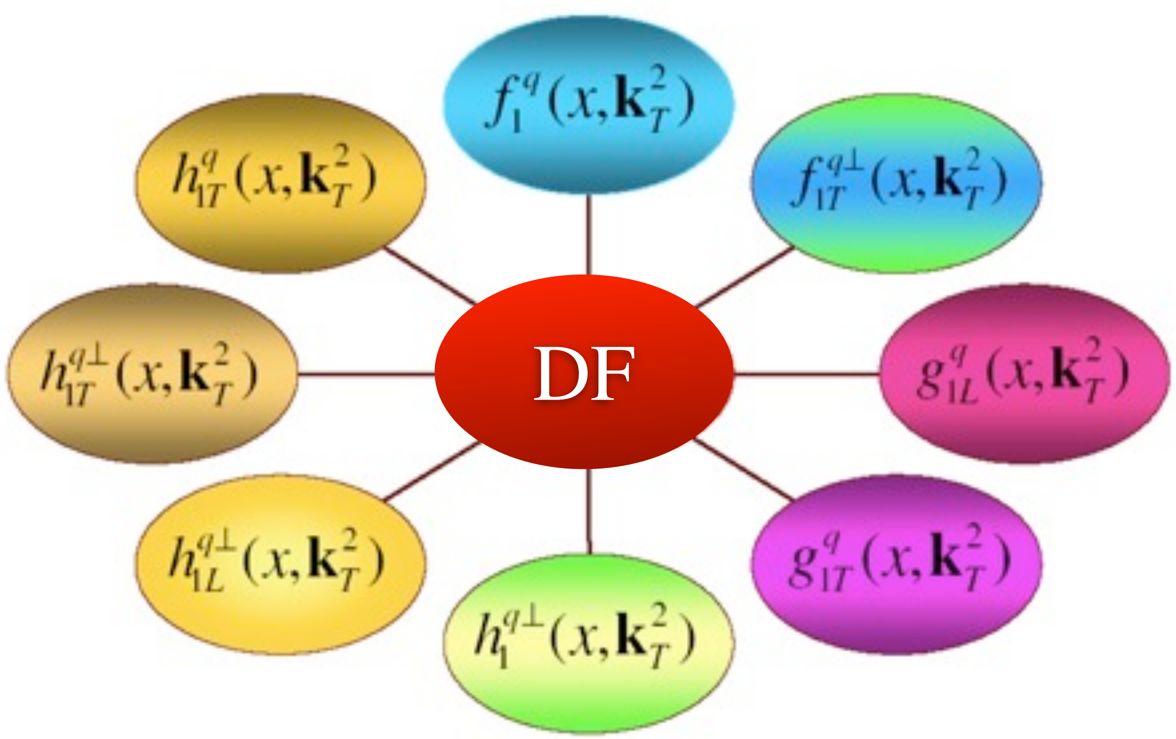
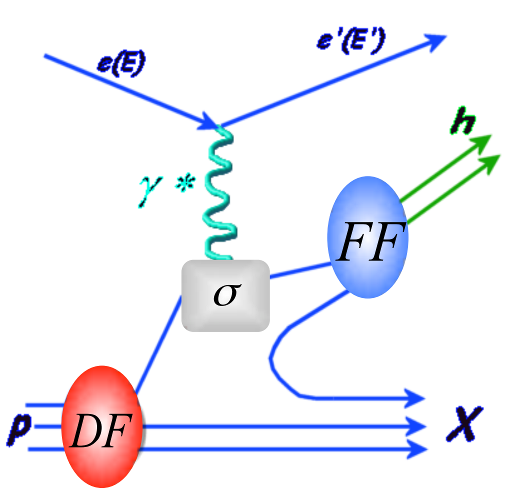
leading twist TMD DF:
parameterize the quark-flavor
structure of the nucleon





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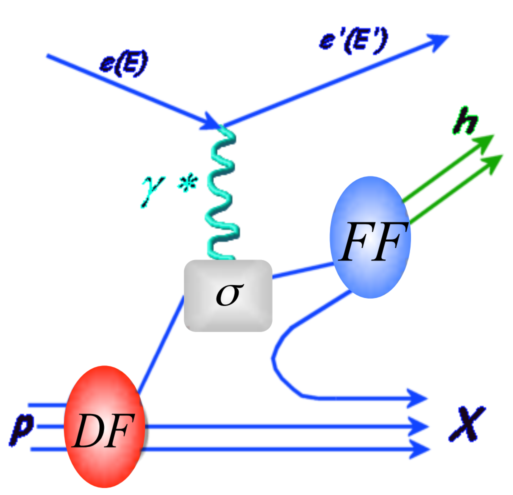
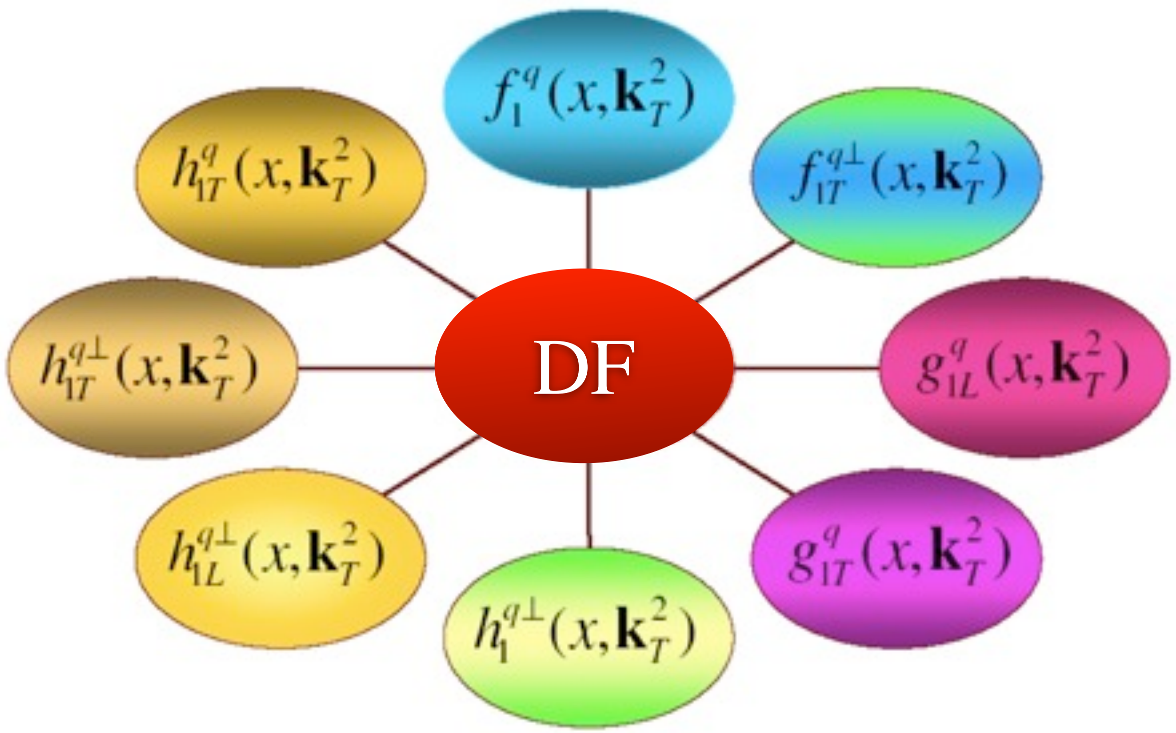
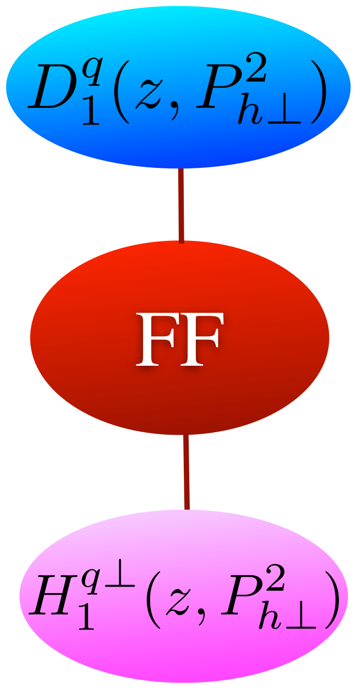
leading twist TMD FF:
number densities for the conversion of a quark of a certain type to a specific hadron







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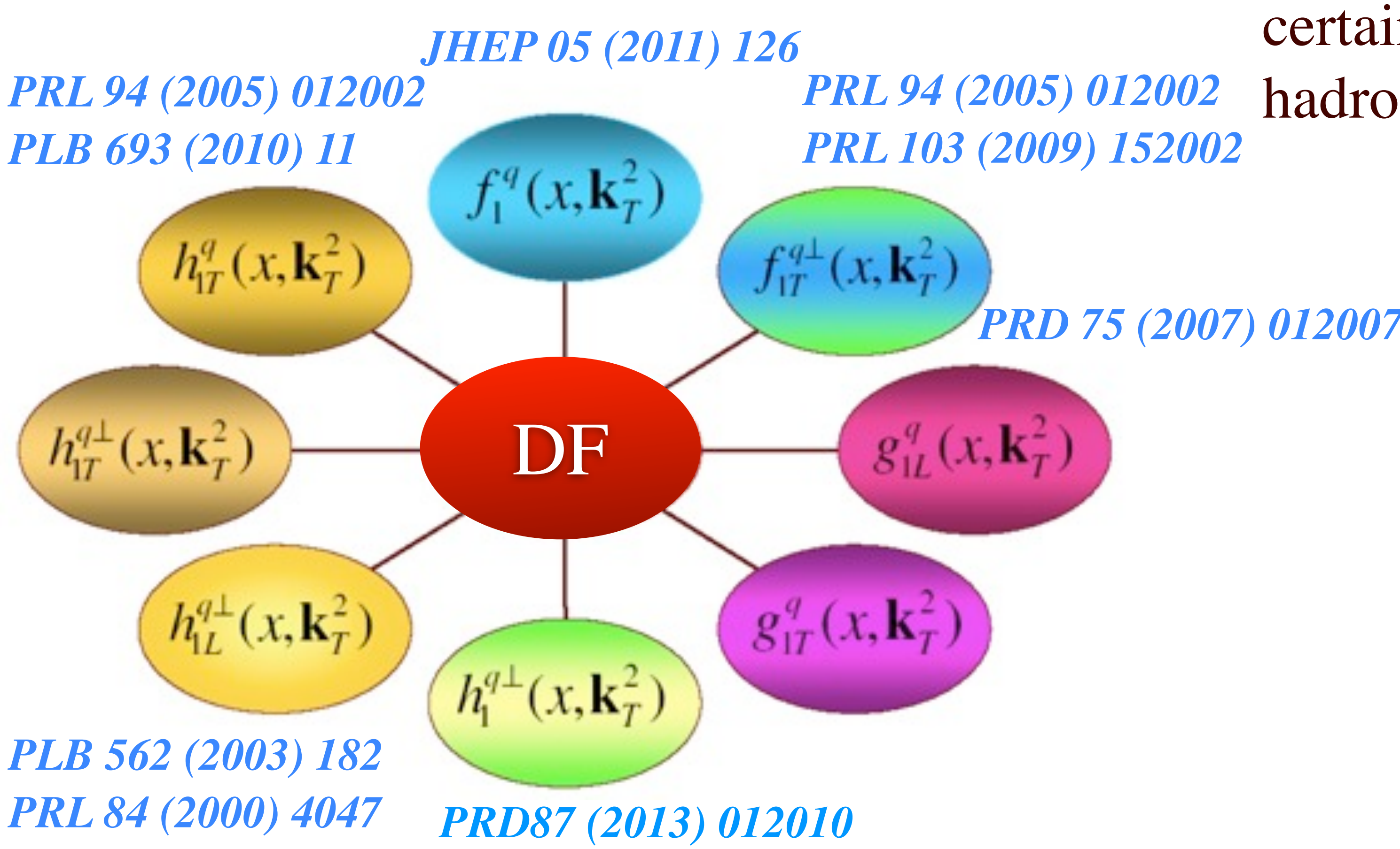

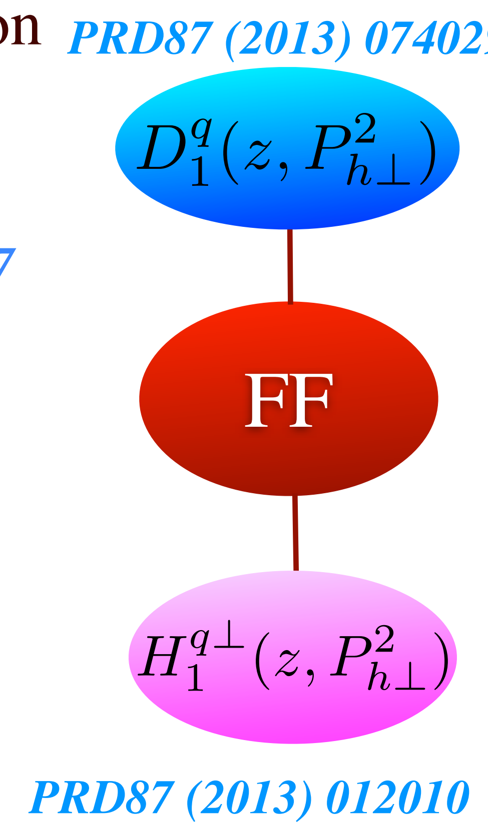

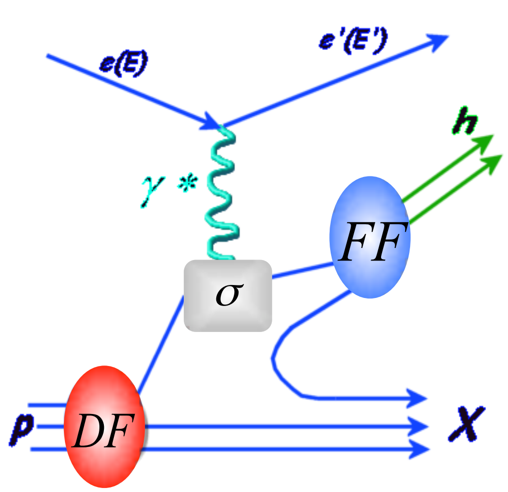

HERMES: access to all TMDs thanks to the polarized beam and target

semi-inclusive DIS cross section and TMDs

$f_1 \otimes D_1$ | twist-3 | $h_1^\perp \otimes H_1^\perp$

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twist-3

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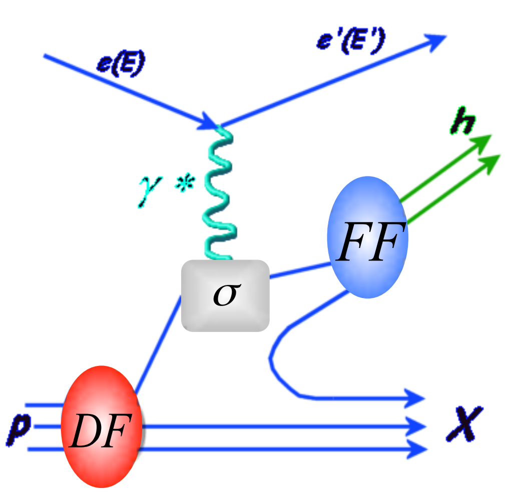

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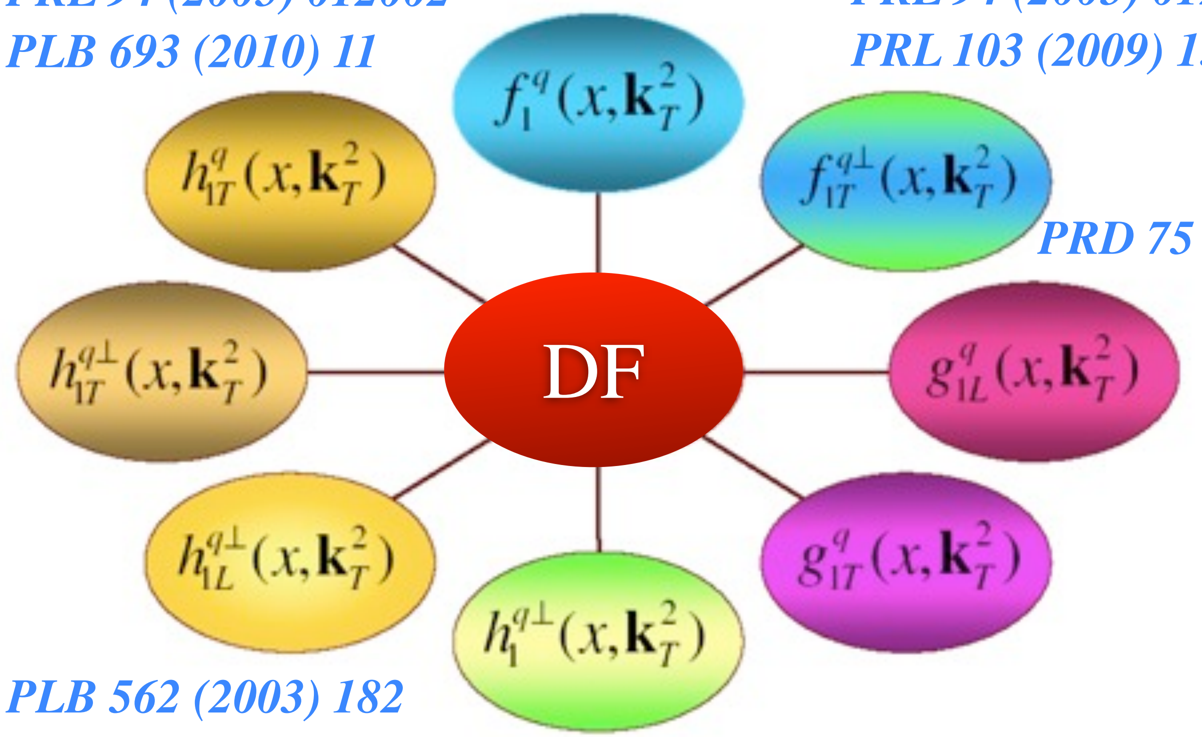

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PRL 84 (2000) 4047

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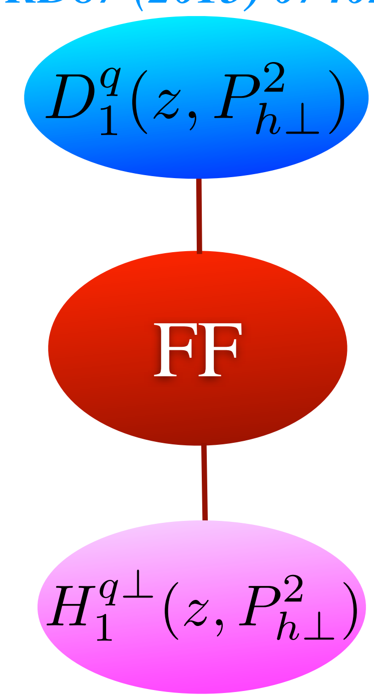
PRD87 (2013) 074029



PRD87 (2013) 012010

HERMES: access to all TMDs thanks to the polarized beam and target

unpolarized quarks

$$\sigma_{UU} \propto f_1 \otimes D_1$$

$f_1 =$ 

unpolarized quarks

$$\sigma_{UU} \propto f_1 \otimes D_1$$

$$f_1 =$$ 

$$M^h = \frac{d\sigma^h_{SIDIS}(x, Q^2, z, P_{h\perp})}{d\sigma_{DIS}(x, Q^2)}$$

unpolarized quarks

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LO interpretation of multiplicity results (integrated over $\mathbf{P}_{h\perp}$):

$f_1 =$ 

$$M^h \propto \frac{\sum_q e_q^2 \int dx\, f_{1q}(x, Q^2) D_{1q}^h(z, Q^2)}{\sum_q e_q^2 \int dx\, f_{1q}(x, Q^2)}$$

$$M^h = \frac{d\sigma^h_{SIDIS}(x, Q^2, z, P_{h\perp})}{d\sigma_{DIS}(x, Q^2)}$$

✓charge-separated multiplicities of pions and kaons sensitive to the individual quark and antiquark flavours in the fragmentation process

unpolarized quarks

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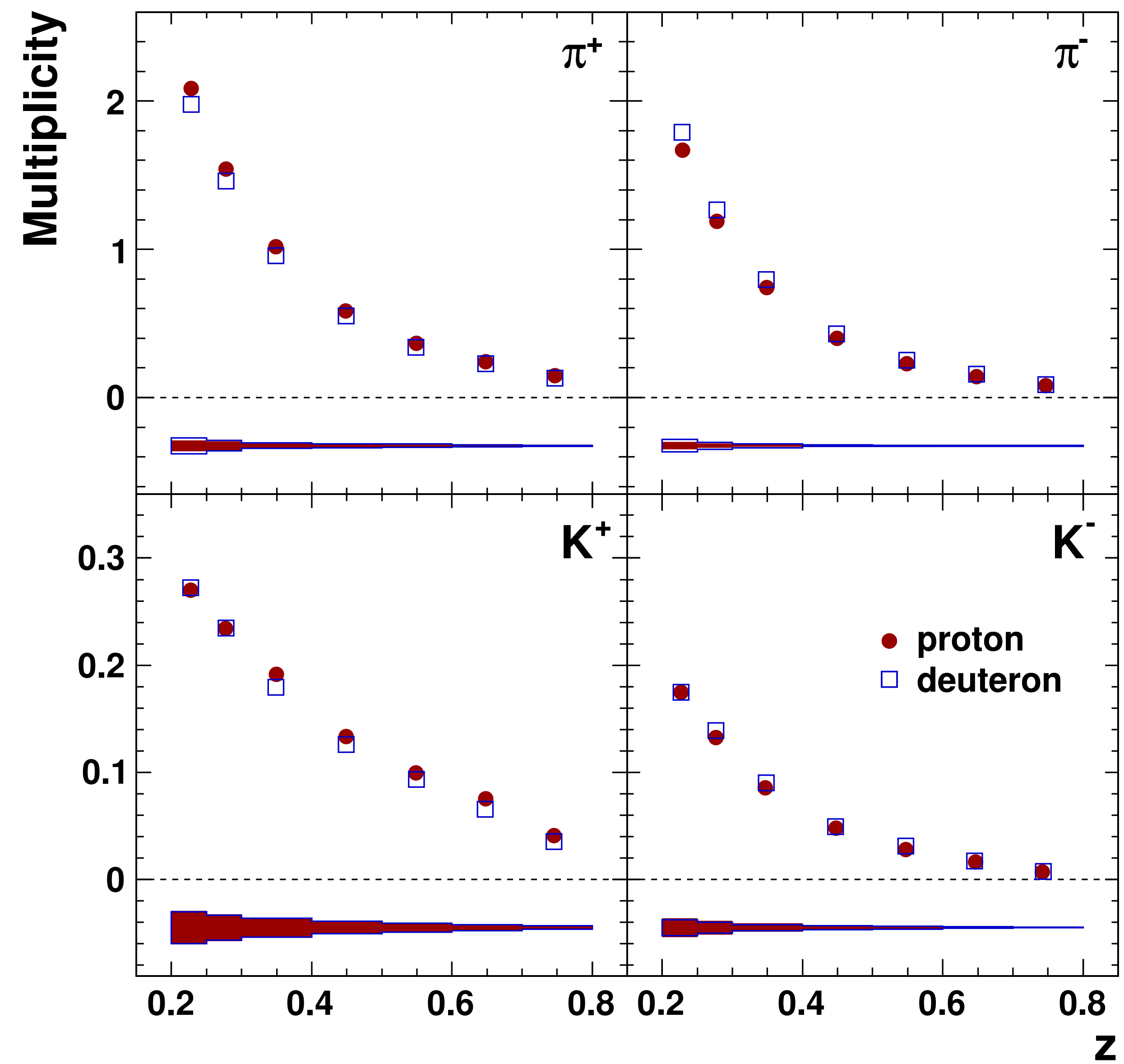

π^+ and K^+:

☛ favoured fragmentation on proton

π^-:

☛ increased number of d-quarks in D target and favoured fragmentation on neutron

K^-:

☛ cannot be produced through favoured fragmentation from the nucleon valence quarks

unpolarized quarks

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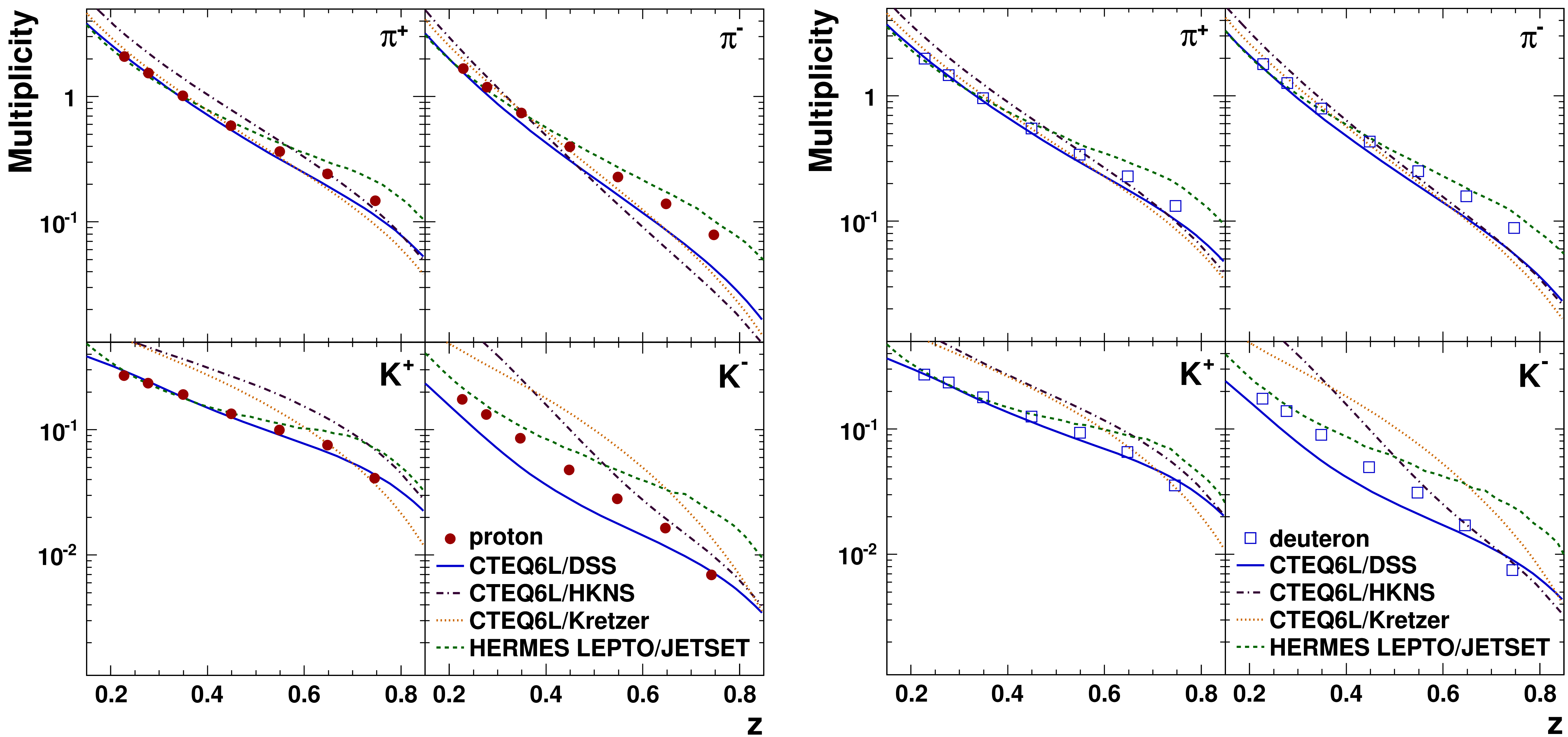
$$\sigma_{UU} \propto f_1 \otimes D_1$$



✓calculations using DSS, HNKS and Kretzer FF fits together with CTEQ6L PDFs

proton:

- fair agreement for positive hadrons
- disagreement for negative hadrons

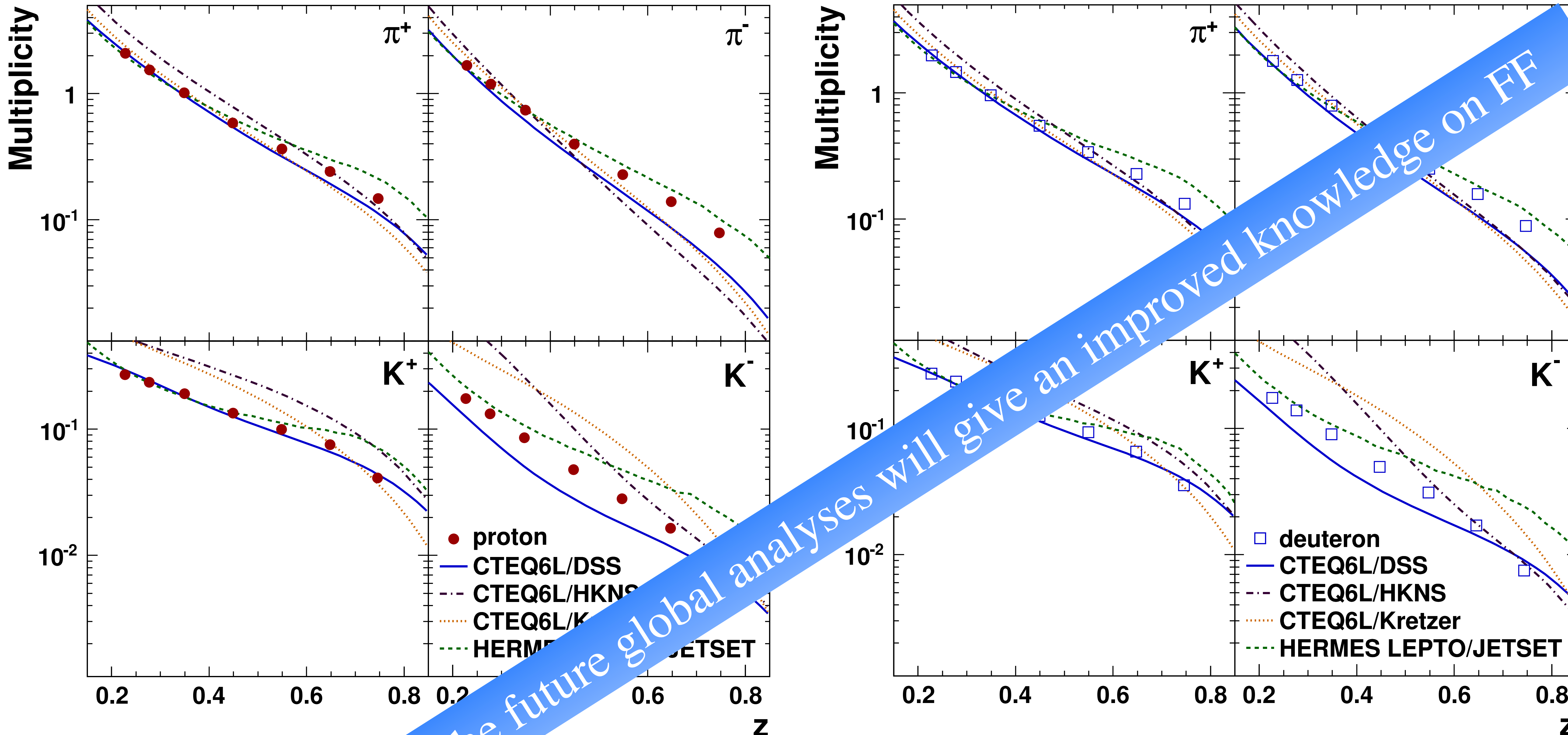
deuteron:

- results are in general in better agreement with the various predictions

unpolarized quarks

$\sigma_{UU} \propto f_1 \otimes D_1$

- Phys.Rev. D87 (2013) 074029



✓ inclusion of the data in the future global analyses will give an improved knowledge on FF

✓calculations using D KS and Kretzer FF fits together with CTEQ6L PDFs

proton:

- fai nt for positive hadrons
- ement for negative hadrons

d

- results are in general in better agreement with the various predictions

evaluation of strange quark PDFs

✓ in the absence of experimental constraints, many global QCD fits of PDFs assume

$$s(x) = \bar{s}(x) = r[\bar{u}(x) + \bar{d}(x)]/2$$

✓ isoscalar extraction of $S(x)\mathcal{D}_{\mathcal{S}}^{\mathcal{K}}$ based on the multiplicity data of K^+ and K^- on D

$$S(x)\int \mathcal{D}_S^K(z)dz \simeq Q(x)\left[5\frac{\mathrm{d}^2N^K(x)}{\mathrm{d}^2N^{DIS}(x)} - \int \mathcal{D}_Q^K(z)dz\right]$$

$$\begin{aligned}
S(x) &= s(x) + \bar{s}(x) \\
Q(x) &= u(x) + \bar{u}(x) + d(x) + \bar{d}(x) \\
\mathcal{D}_{\mathcal{S}}^{\mathcal{K}} &= D_1^{s\to K^+} + D_1^{\bar{s}\to K^+} + D_1^{s\to K^-} + D_1^{\bar{s}\to K^-} \\
\mathcal{D}_{\mathcal{Q}}^{\mathcal{K}} &= D_1^{u\to K^+} + D_1^{\bar{u}\to K^+} + D_1^{d\to K^+} + D_1^{\bar{d}\to K^+} + \ldots
\end{aligned}$$

evaluation of strange quark PDFs

✓ in the absence of experimental constraints, many global QCD fits of PDFs assume

$$s(x) = \bar{s}(x) = r[\bar{u}(x) + \bar{d}(x)]/2$$

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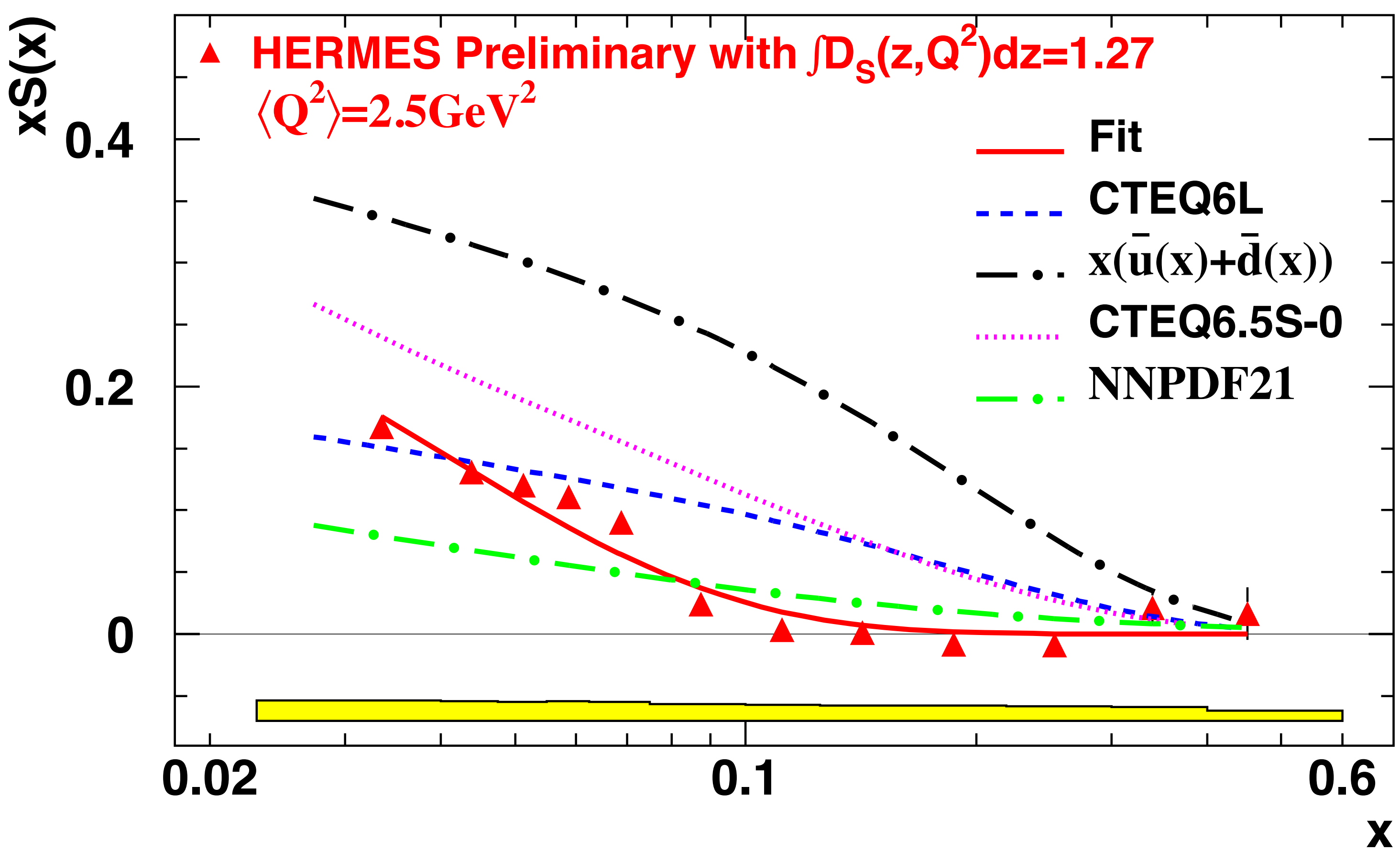
$$\begin{aligned} S(x) &= s(x) + \bar{s}(x) \\ Q(x) &= u(x) + \bar{u}(x) + d(x) + \bar{d}(x) \\ \mathcal{D}_S^{\mathcal{K}} &= D_1^{s\to K^+} + D_1^{\bar{s}\to K^+} + D_1^{s\to K^-} + D_1^{\bar{s}\to K^-} \\ \mathcal{D}_Q^{\mathcal{K}} &= D_1^{u\to K^+} + D_1^{\bar{u}\to K^+} + D_1^{d\to K^+} + D_1^{\bar{d}\to K^+} + \ldots \end{aligned}$$



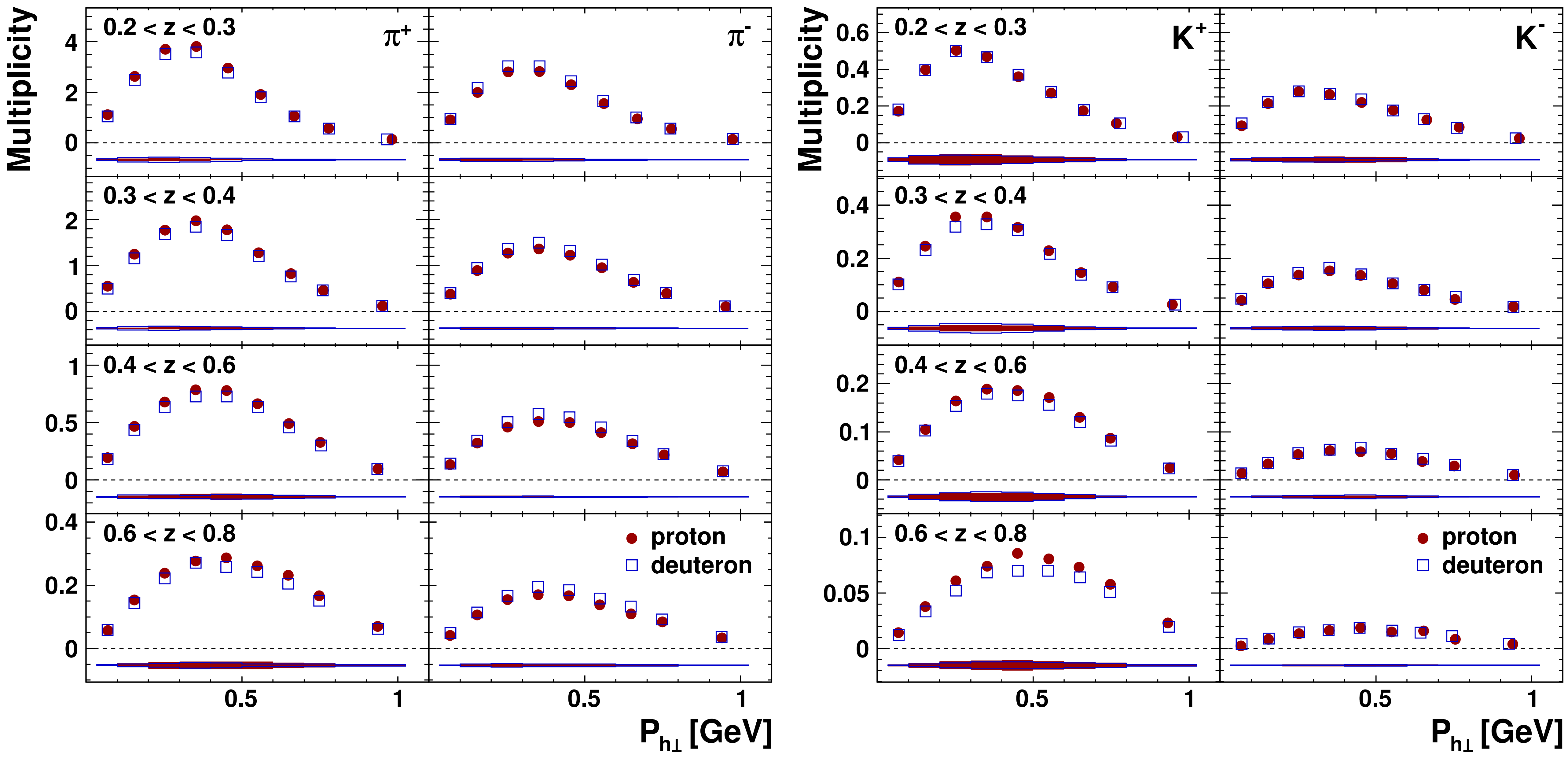
✓ the distribution of S(x) is obtained for a certain value of $\mathcal{D}_S^{\mathcal{K}}$

✓ the normalization of the data is given by that value

✓ whatever the normalization, the shape is incompatible with the predictions

beyond the collinear factorization

- Phys.Rev. D87 (2013) 074029

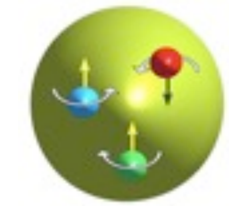


✓ multi-dimensional analysis allows exploration of new kinematic dependences

✓ broader $P_{h\perp}$ distribution for K^-

quark's transverse degrees of freedom

$$\sigma_{UU} \propto h_1^\perp \otimes H_1^\perp$$

$h_1^\perp =$ 

quark's transverse degrees of freedom

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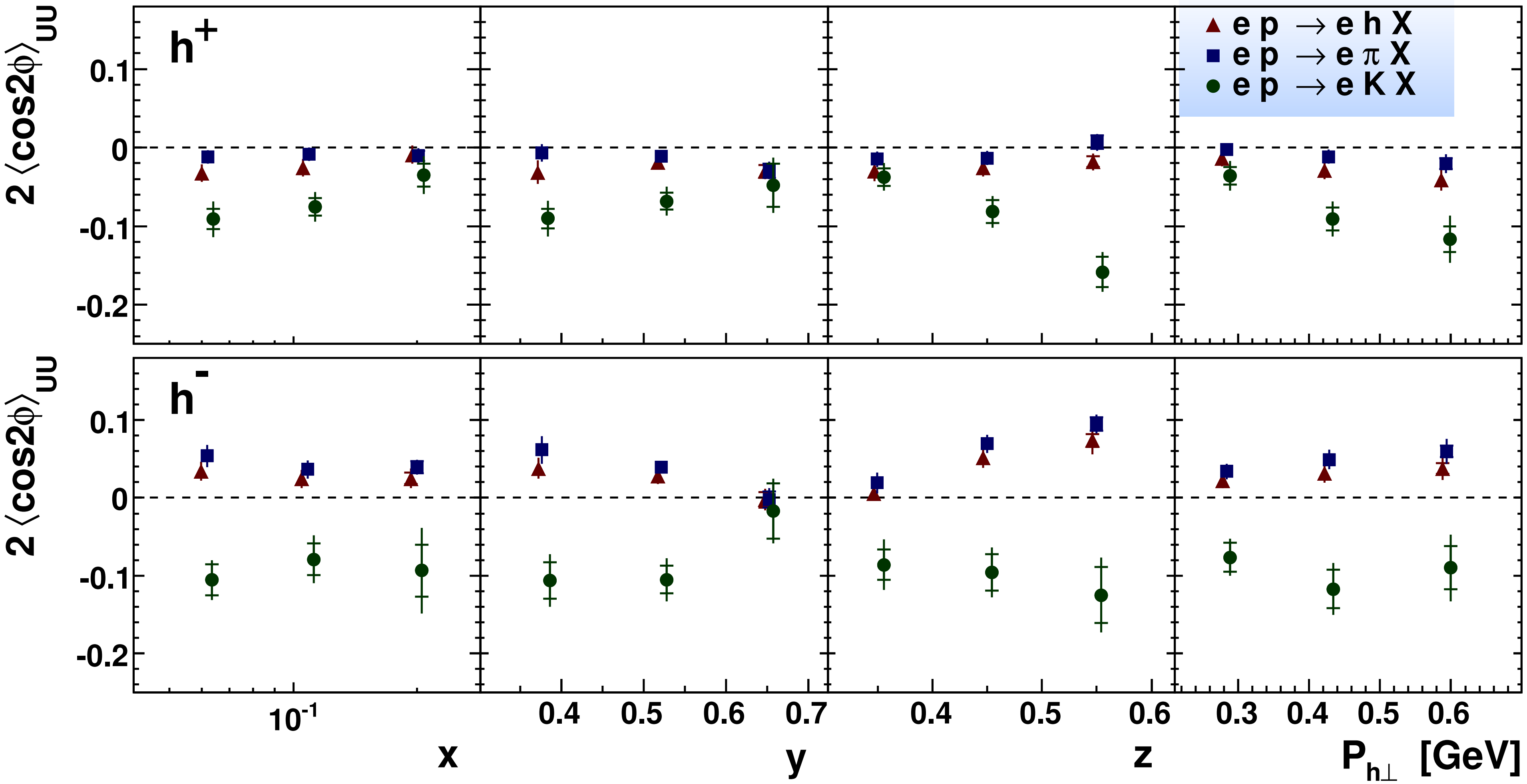
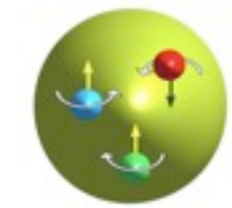
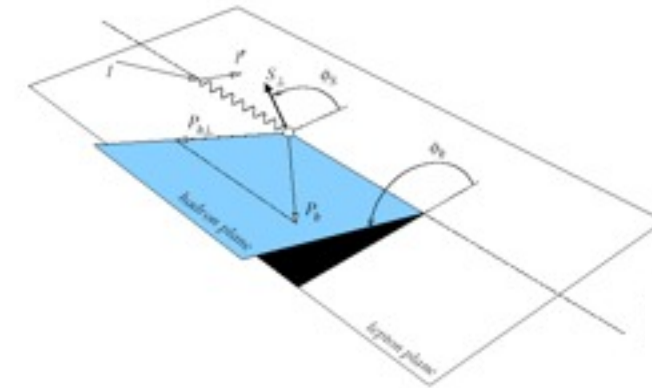


$$h_1^{\perp} =$$





Phys.Rev. D87 (2013) 012010

- ✓ negative asymmetry for π^+ and positive for π^-
  - ☛ from previous publications (*PRL 94 (2005) 012002, PLB 693 (2010) 11-16*):

$$H_1^{\perp,u\rightarrow\pi^+} = -H_1^{\perp,u\rightarrow\pi^-}$$

  - ☛ **data support Boer-Mulders DF $h_1^{\perp}$ of same sign for u and d quarks**
- ✓ K^- and K^+ : striking differences w.r.t. pions
  - ☛ role of the sea in DF and FF

beyond the leading twist

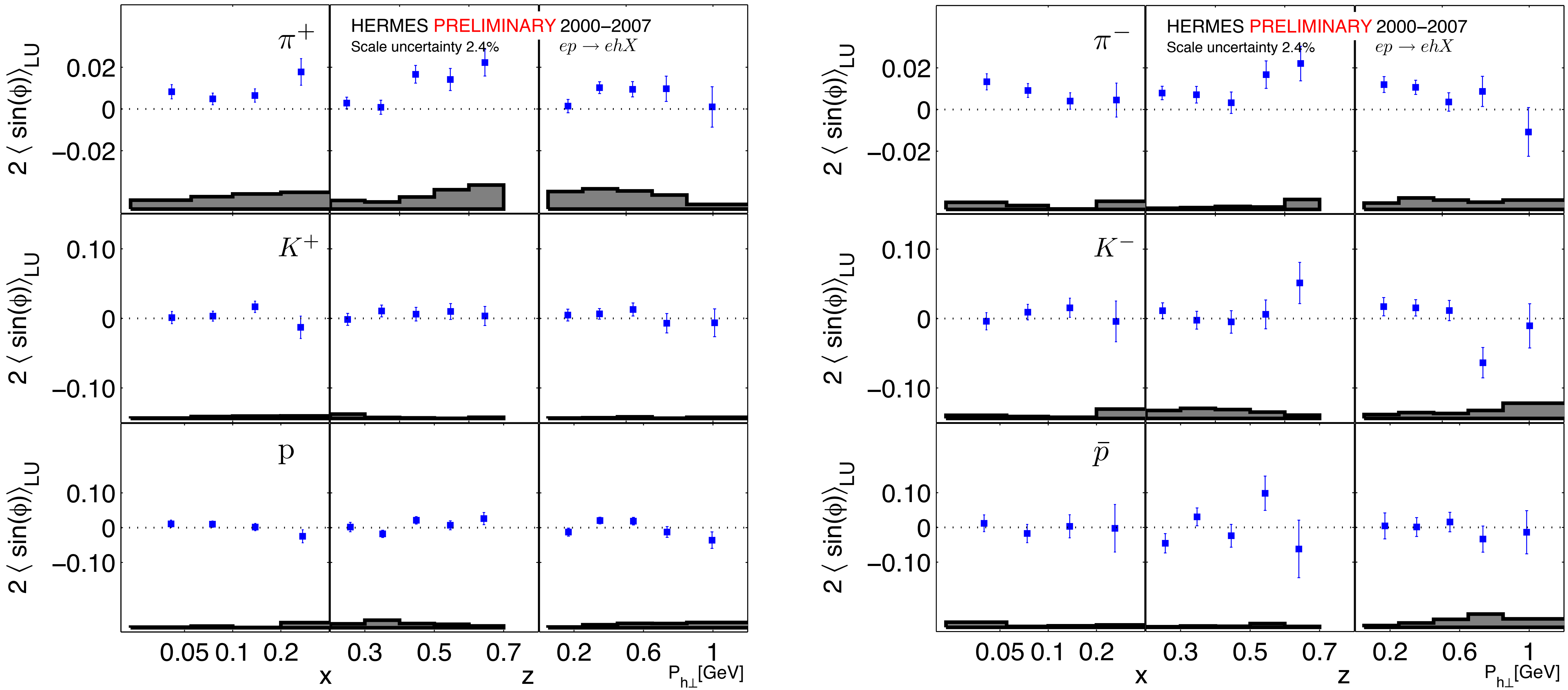
$$\frac{d^6\sigma}{dx\; dy\; dz\; dP^2_{h\perp} d\phi\; d\phi_s} \propto \Big\{ F_{UU} + \ldots + \lambda_e \Big\{ \sqrt{2\epsilon(1-\epsilon)} F_{LU}^{\sin\phi} \sin\phi \Big\} + \ldots$$

convolutions of twist-2 and twist-3 functions

beyond the leading twist

$$\frac{d^6\sigma}{dx\, dy\, dz\, dP_{h\perp}^2\, d\phi\, d\phi_s} \propto \left\{F_{UU} + \ldots + \lambda_e\left\{\sqrt{2\epsilon(1-\epsilon)}F_{LU}^{\sin\phi}\sin\phi\right\} + \ldots\right.$$

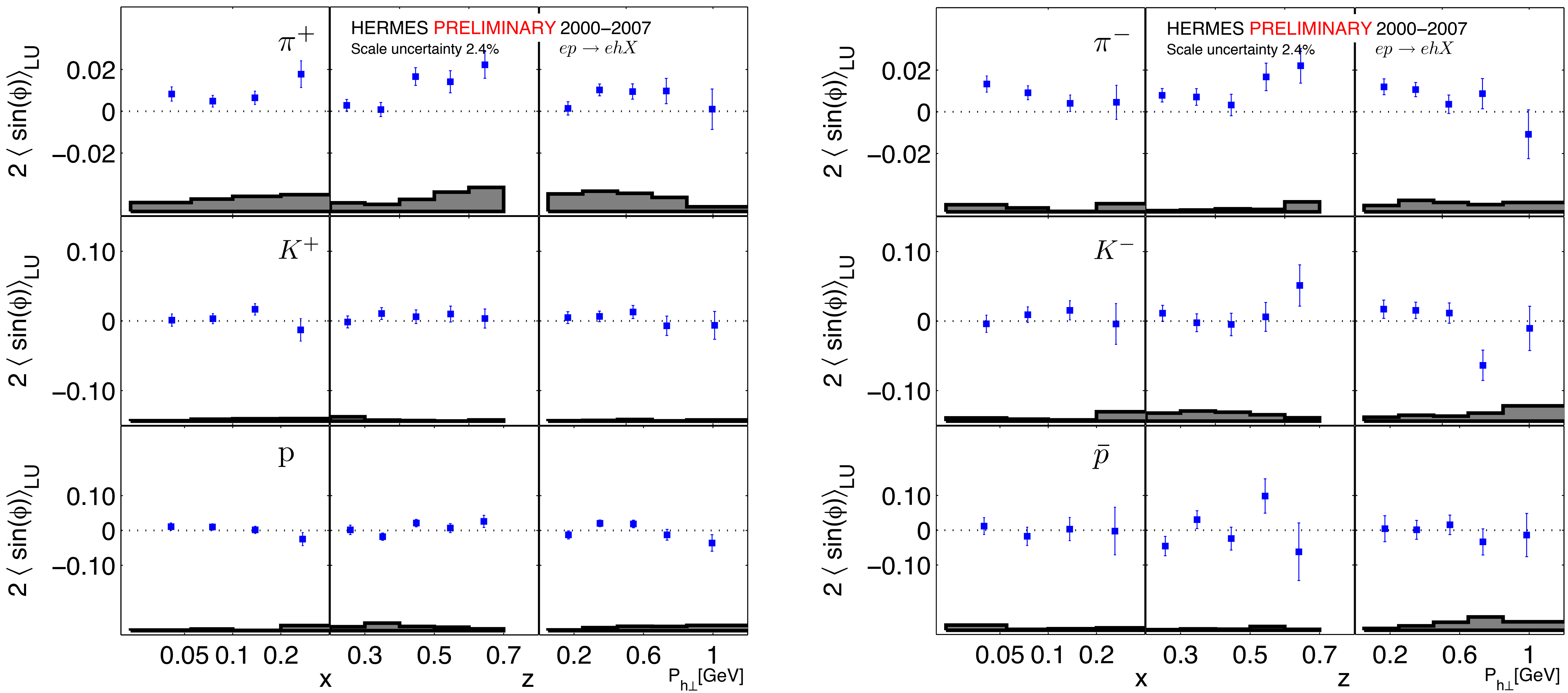
convolutions of twist-2 and twist-3 functions



beyond the leading twist

$$\frac{d^6\sigma}{dx\,dy\,dz\,dP_{h\perp}^2\,d\phi\,d\phi_s} \propto \left\{F_{UU} + \ldots + \lambda_e\left\{\sqrt{2\epsilon(1-\epsilon)}F_{LU}^{\sin\phi}\sin\phi\right\} + \ldots\right.$$

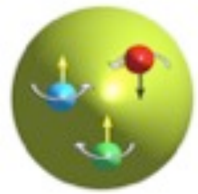
convolutions of twist-2 and twist-3 functions



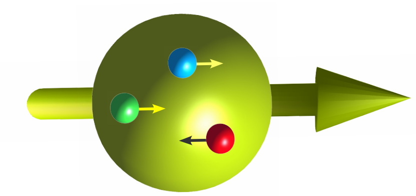
π^+ and π^-

☛ the role of the twist-3 DF or FF is sizeable

halftime report



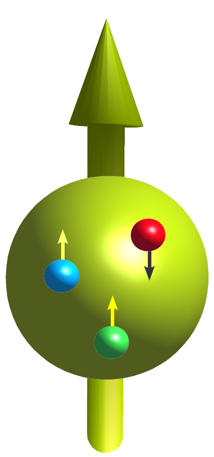
$$d\sigma = d\sigma^0_{UU} + \cos(2\phi)d\sigma^1_{UU} + \frac{1}{Q}\cos(\phi)d\sigma^2_{UU} + P_l \frac{1}{Q}\sin(\phi)d\sigma^3_{LU}$$

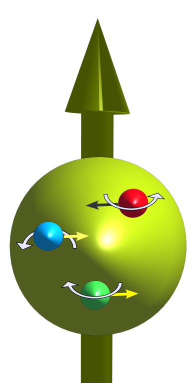


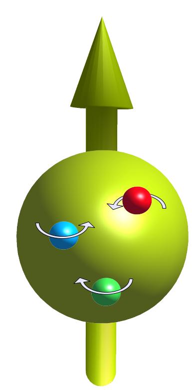
$$+ S_L\left[\sin(2\phi)d\sigma^4_{UL} + \frac{1}{Q}\sin(\phi)d\sigma^5_{UL} + P_l\left(d\sigma^6_{LL} + \frac{1}{Q}\sin(\phi)d\sigma^7_{LL}\right)\right]$$

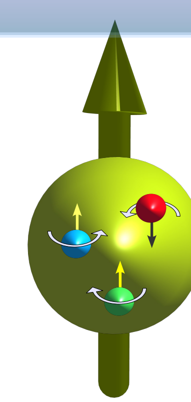
$$+ S_T\Big[\sin(\phi-\phi_s)d\sigma^8_{UT} + \sin(\phi+\phi_s)d\sigma^9_{UT} + \sin(3\phi-\phi_s)d\sigma^{10}_{UT} + \frac{1}{Q}\sin(2\phi-\phi_s)d\sigma^{11}_{UT} + \frac{1}{Q}\sin(\phi_s)d\sigma^{12}_{UT}$$

$$+ P_l\left(\cos(\phi-\phi_s)d\sigma^{13}_{LT} + \frac{1}{Q}\cos(\phi_s)d\sigma^{14}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_s)d\sigma^{15}_{LT}\right)\Big]$$









halftime report

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

published

published

published

published

published

paper coming out soon

paper coming out soon

published

published

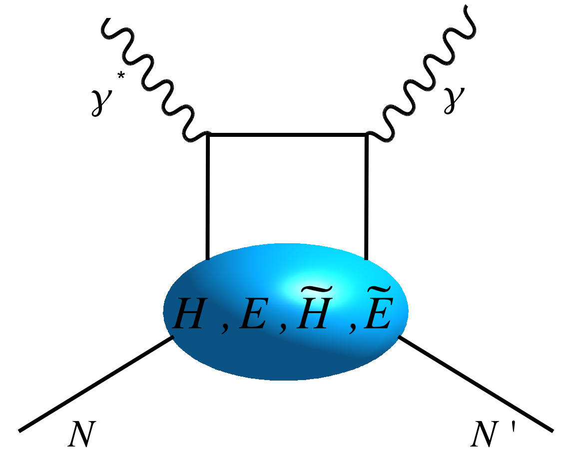
paper coming out soon

exclusive measurements (probing GPDs)

DVCS

- theoretically the cleanest probe of GPDs

$$\gamma^* N \to \gamma N : H, E, \widetilde{H}, \widetilde{E}$$



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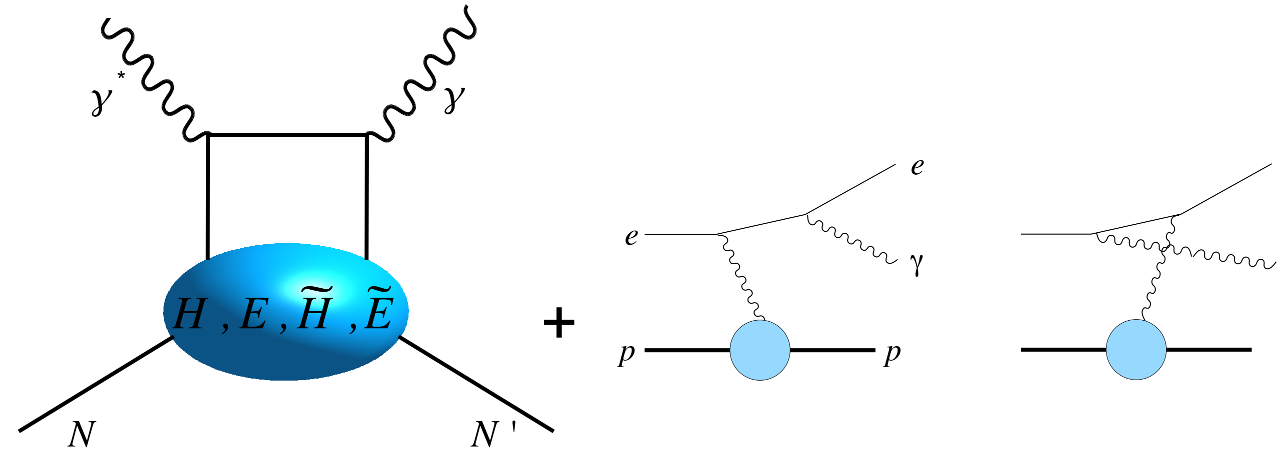

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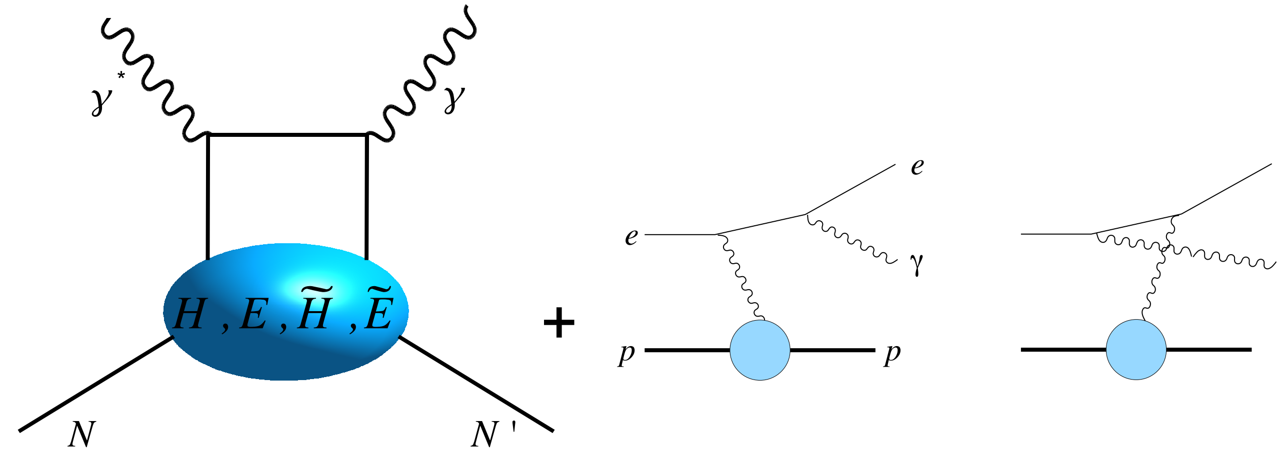


σ_{xy}

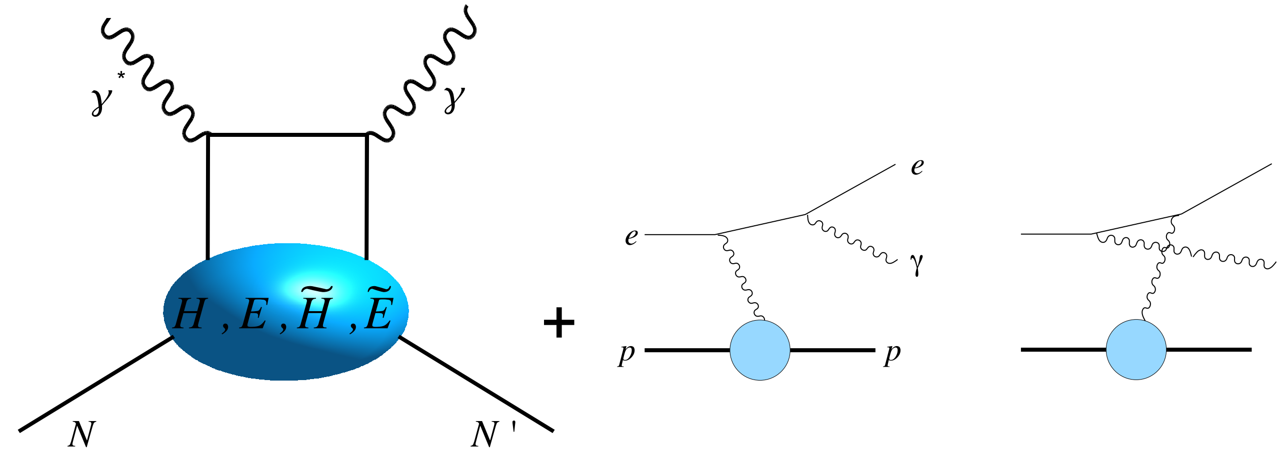
beam: λ_l

target: $S_\perp, S_{||}$

Bethe–Heitler | interference | DVCS

$$
\begin{array}{lclcl}
d\sigma \sim d\sigma^{BH}_{UU} & + & e_\ell d\sigma^{I}_{UU} & + & d\sigma^{DVCS}_{UU} \\
 & + & e_\ell \lambda_\ell d\sigma^{I}_{LU} & + & \lambda_\ell d\sigma^{DVCS}_{LU} \\
 & + & e_\ell S_{||} d\sigma^{I}_{UL} & + & S_{||} d\sigma^{DVCS}_{UL} \\
 & + & e_\ell S_\perp d\sigma^{I}_{UT} & + & S_\perp d\sigma^{DVCS}_{UT} \\
+\lambda_\ell S_{||} d\sigma^{BH}_{LL} & + & e_\ell \lambda_\ell S_{||} d\sigma^{I}_{LL} & + & \lambda_\ell S_{||} d\sigma^{DVCS}_{LL} \\
+\lambda_\ell S_\perp d\sigma^{BH}_{LT} & + & e_\ell \lambda_\ell S_\perp d\sigma^{I}_{LT} & + & \lambda_\ell S_\perp d\sigma^{DVCS}_{LT}
\end{array}
$$

DVCS



- theoretically the cleanest probe of GPDs

$$\gamma^* N \to \gamma N : H, E, \widetilde{H}, \widetilde{E}$$

σ_{xy}

beam: λ_l

target: $S_\perp, S_{||}$

Bethe–Heitler

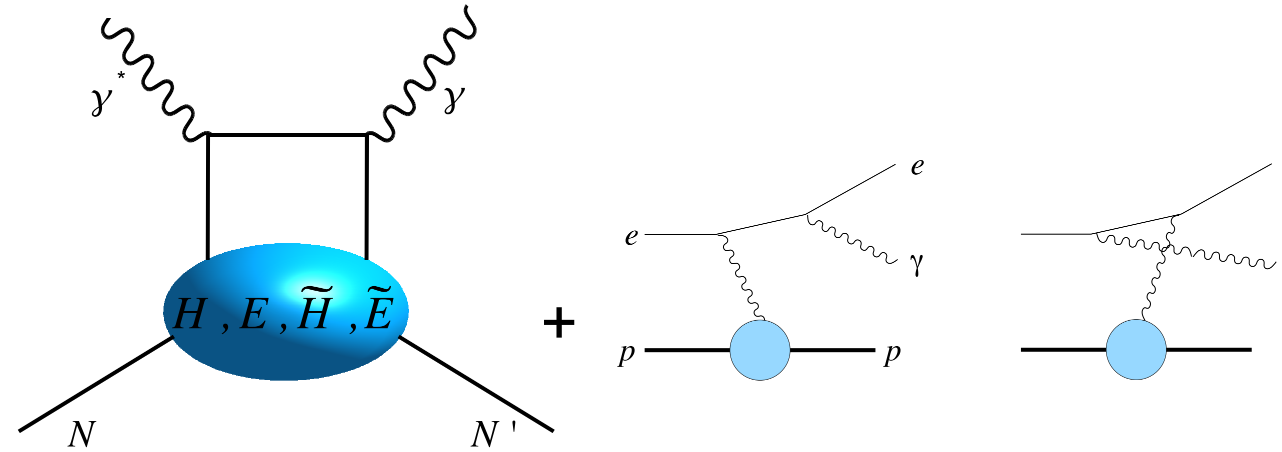
beam charge: e_ℓ

interference

DVCS

$$\begin{aligned}
d\sigma \sim d\sigma^{BH}_{UU} \quad &+ \quad e_\ell d\sigma^{I}_{UU} &&+ \quad d\sigma^{DVCS}_{UU}\\
&+ \quad e_\ell \lambda_\ell d\sigma^{I}_{LU} &&+ \quad \lambda_\ell d\sigma^{DVCS}_{LU}\\
&+ \quad e_\ell S_{||} d\sigma^{I}_{UL} &&+ \quad S_{||} d\sigma^{DVCS}_{UL}\\
&+ \quad e_\ell S_\perp d\sigma^{I}_{UT} &&+ \quad S_\perp d\sigma^{DVCS}_{UT}\\
+\lambda_\ell S_{||} d\sigma^{BH}_{LL} \quad &+ \quad e_\ell \lambda_\ell S_{||} d\sigma^{I}_{LL} &&+ \quad \lambda_\ell S_{||} d\sigma^{DVCS}_{LL}\\
+\lambda_\ell S_\perp d\sigma^{BH}_{LT} \quad &+ \quad e_\ell \lambda_\ell S_\perp d\sigma^{I}_{LT} &&+ \quad \lambda_\ell S_\perp d\sigma^{DVCS}_{LT}
\end{aligned}$$

DVCS



☛ theoretically the cleanest probe of GPDs

$$\gamma^* N \to \gamma N : H, E, \widetilde{H}, \widetilde{E}$$

σ_{xy} → beam: λ_l ; target: $S_\perp, S_{||}$

Bethe-Heitler | beam charge: e_ℓ | interference | DVCS

$$\begin{aligned}
d\sigma \sim d\sigma^{BH}_{UU} &+ e_\ell d\sigma^{I}_{UU} &+ d\sigma^{DVCS}_{UU} \\
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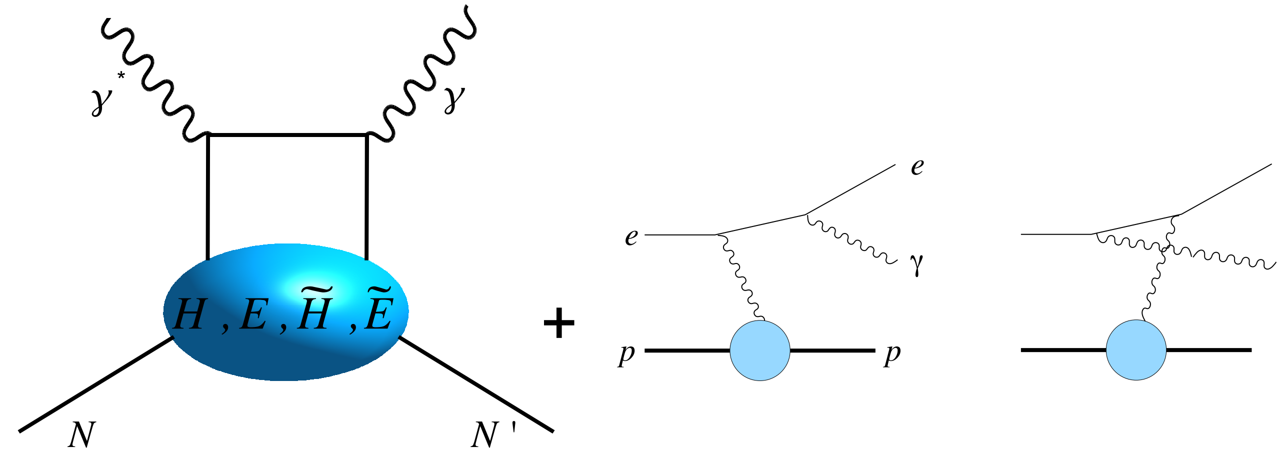
&+ e_\ell S_\perp d\sigma^{I}_{UT} &+ S_\perp d\sigma^{DVCS}_{UT} \\
+\lambda_\ell S_{||} d\sigma^{BH}_{LL} &+ e_\ell \lambda_\ell S_{||} d\sigma^{I}_{LL} &+ \lambda_\ell S_{||} d\sigma^{DVCS}_{LL} \\
+\lambda_\ell S_\perp d\sigma^{BH}_{LT} &+ e_\ell \lambda_\ell S_\perp d\sigma^{I}_{LT} &+ \lambda_\ell S_\perp d\sigma^{DVCS}_{LT}
\end{aligned}$$

✓HERMES measured complete set of beam helicity, beam charge and target polarization asymmetries

DVCS



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$$\gamma^* N \to \gamma N : H, E, \widetilde{H}, \widetilde{E}$$

Bethe–Heitler | beam charge: e_ℓ | interference | DVCS | $\sigma_{\rm xy}$ → beam: λ_l, target: $S_\perp, S_{||}$

$$
\begin{aligned}
d\sigma \sim d\sigma^{BH}_{UU} &+ e_\ell d\sigma^{I}_{UU} &&+ d\sigma^{DVCS}_{UU} \\
&+ e_\ell \lambda_\ell d\sigma^{I}_{LU} &&+ \lambda_\ell d\sigma^{DVCS}_{LU} \\
&+ e_\ell S_{||} d\sigma^{I}_{UL} &&+ S_{||} d\sigma^{DVCS}_{UL} \\
&+ e_\ell S_\perp d\sigma^{I}_{UT} &&+ S_\perp d\sigma^{DVCS}_{UT} \\
+\lambda_\ell S_{||} d\sigma^{BH}_{LL} &+ e_\ell \lambda_\ell S_{||} d\sigma^{I}_{LL} &&+ \lambda_\ell S_{||} d\sigma^{DVCS}_{LL} \\
+\lambda_\ell S_\perp d\sigma^{BH}_{LT} &+ e_\ell \lambda_\ell S_\perp d\sigma^{I}_{LT} &&+ \lambda_\ell S_\perp d\sigma^{DVCS}_{LT}
\end{aligned}
$$

☛ unpolarized target

$$F_1 \mathcal{H} + \frac{x_B}{2-x_B}(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E}$$

☛ longitudinally polarized target

$$\frac{x_B}{2-x_B}(F_1+F_2)\left(\mathcal{H} + \frac{x_B}{2}\mathcal{E}\right) + F_1 \widetilde{\mathcal{H}} - \frac{x_B}{2-x_B}\left(\frac{x_B}{2}F_1 + \frac{t}{4M^2}F_2\right)\widetilde{\mathcal{E}}$$

☛ transversely polarized target

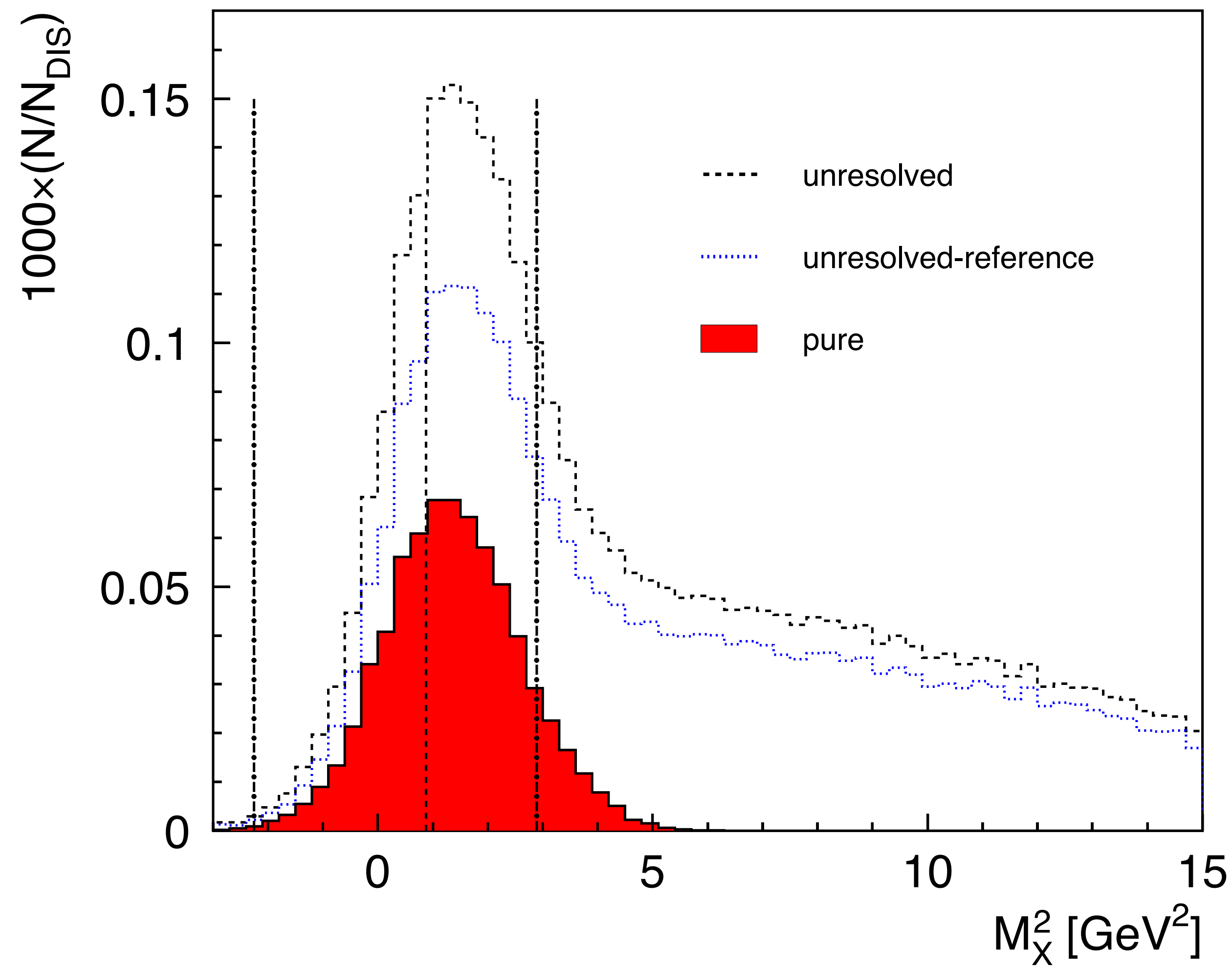
$$\frac{t}{4M^2}\left[(2-x_B)F_1 \mathcal{E} - 4\frac{1-x_B}{2-x_B}F_2 \mathcal{H}\right]$$

✓HERMES measured complete set of beam helicity, beam charge and target polarization asymmetries

DVCS measurements with the recoil detector

$ep \to e'\gamma p'$

(recoil data)



✓ unresolved and unresolved-reference samples: $ep \to e'\gamma X$

- ☛ use missing mass technique
- ☛ for comparison only

✓ pure sample: $ep \to e'\gamma p'$

- ☛ all particles in the final state are detected
- ☛ kinematic event fit
- ☛ BH/DVCS events with 83% efficiency
- ☛ background contamination from semi-inclusive and associated processes less than 0.2%

GPD H: unpolarized hydrogen target

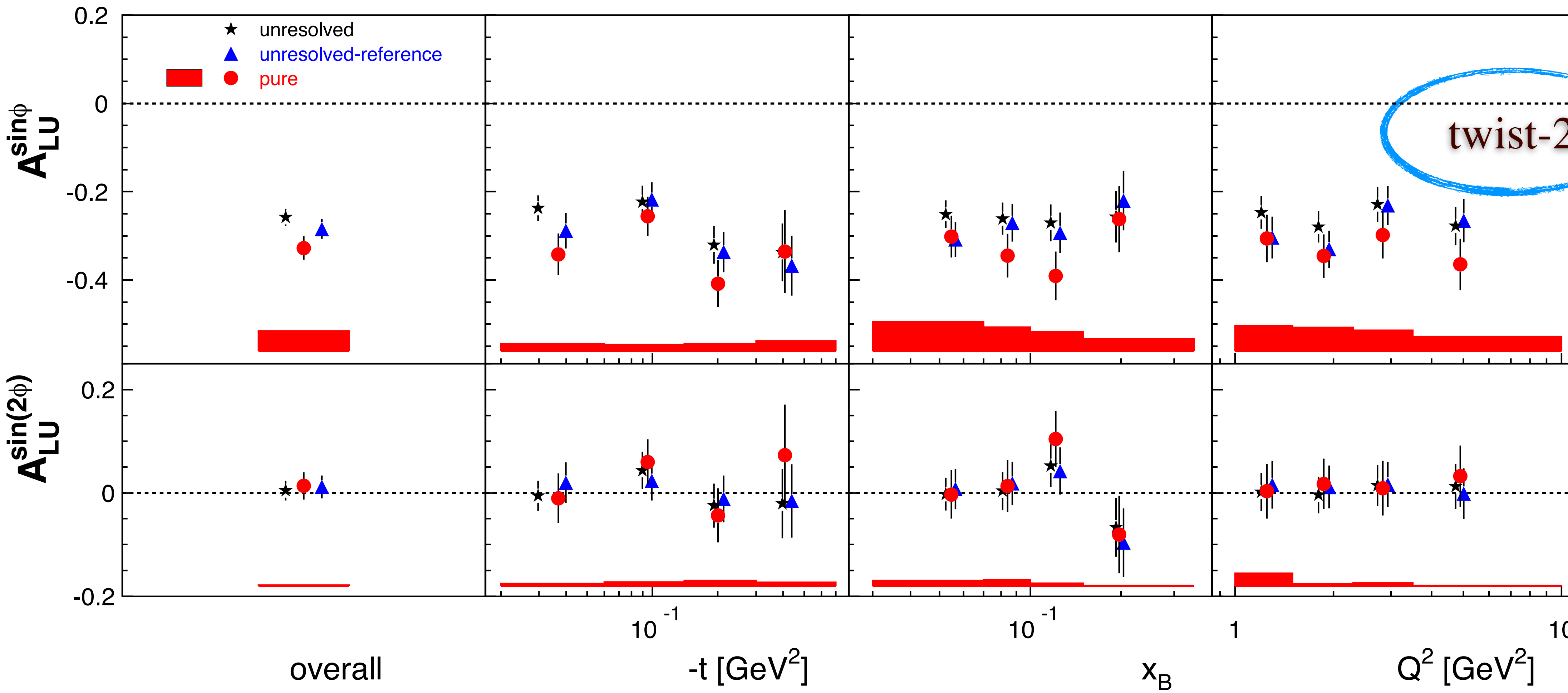
$ep \rightarrow e'\gamma p'$

(recoil data)

$$\sigma(\phi, P_\ell, e_\ell) = \sigma_{UU}(\phi) \times \left[1 + P_\ell \mathcal{A}_{LU}^{DVCS}(\phi) + e_\ell P_\ell \mathcal{A}_{LU}^{I}(\phi) + e_\ell \mathcal{A}_C(\phi)\right]$$

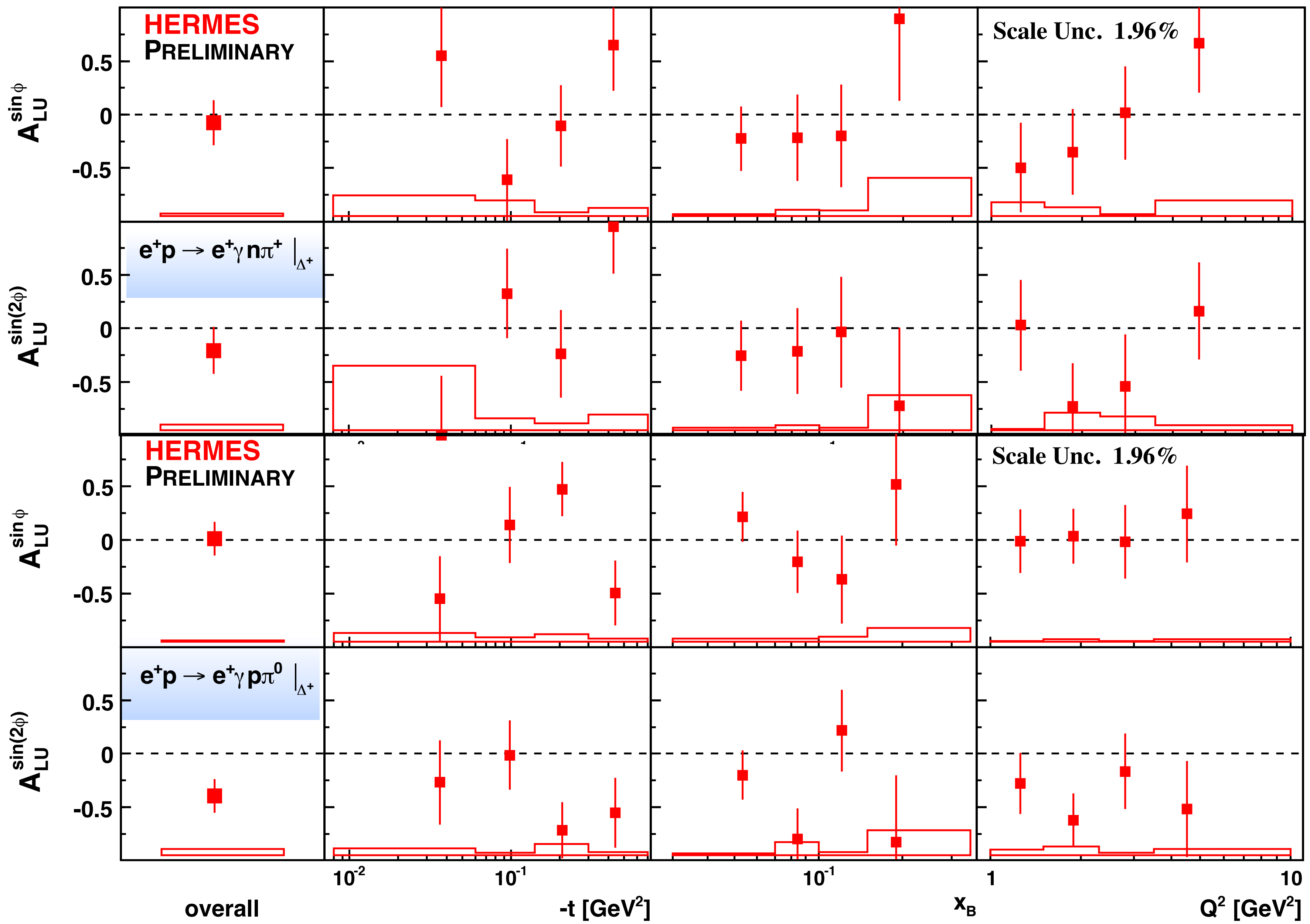
$$\mathcal{A}_{\rm LU}(\phi) \simeq \sum_{n=1}^{2} A_{\rm LU}^{\sin(n\phi)} \sin(n\phi)$$

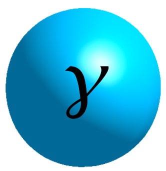
☛ extraction of single-charge beam-helicity asymmetry amplitudes for elastic (pure) data sample



☛ indication for slightly larger magnitude of the leading amplitude for elastic process compared to the one in the recoil detector acceptance (unresolved-reference)

associated DVCS



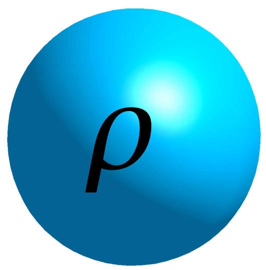


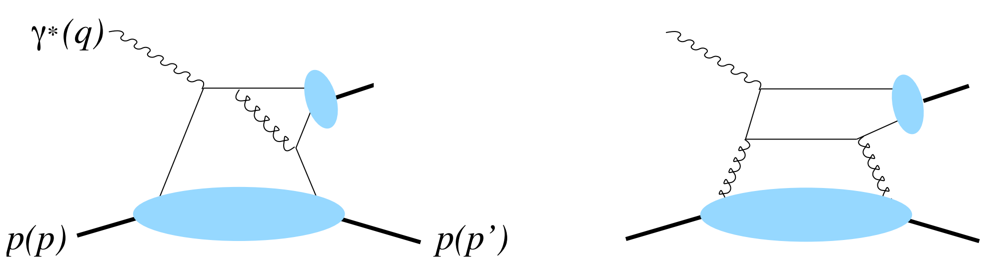
$ep \rightarrow e'\gamma\Delta$

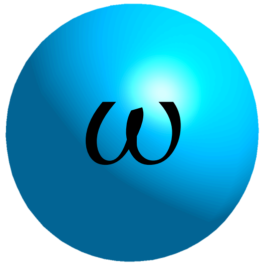
(recoil data)

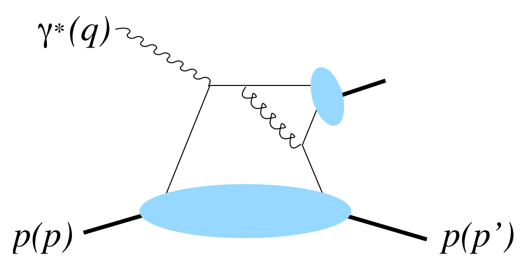
- consistent with zero result for both channels
- associated DVCS is mainly dilution in the analysis using the missing mass technique
- in agreement with the DVCS results on pure sample

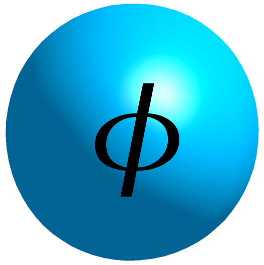
given channel probes specific GPD flavour

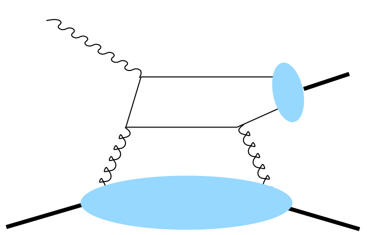


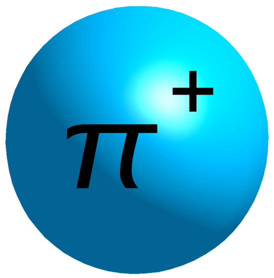








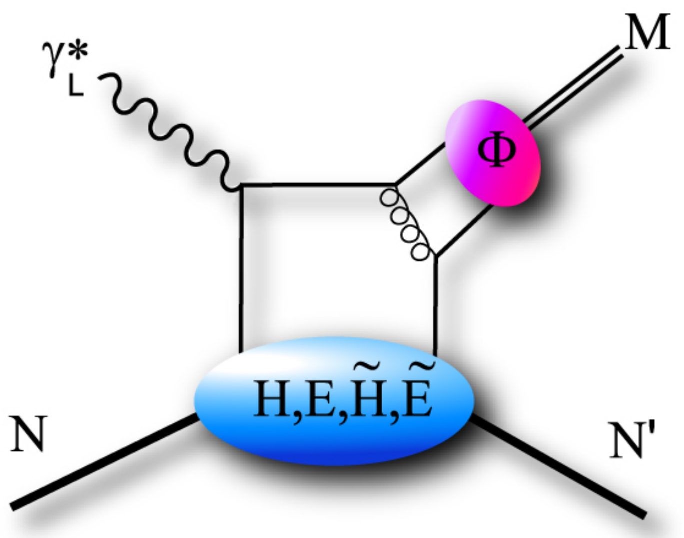




exclusive vector-meson production

☛ factorization in collinear approximation for σ_L(and ρ_L, ω_L, ϕ_L) only

$$\mathcal{A} \propto F(x,\xi,t;\mu^2) \otimes K(x,\xi,z;\log(Q^2/\mu^2) \otimes \Phi(z;\mu^2)$$



exclusive vector-meson production

☛ factorization in collinear approximation for $\sigma_L($ and $\rho_L, \omega_L, \phi_L)$ only

$$\mathcal{A} \propto F(x,\xi,t;\mu^2) \otimes K(x,\xi,z;\log(Q^2/\mu^2) \otimes \Phi(z;\mu^2)$$

-Goloskokov, Kroll (2006)-

☛ power corrections: $k_\perp$ is not neglected

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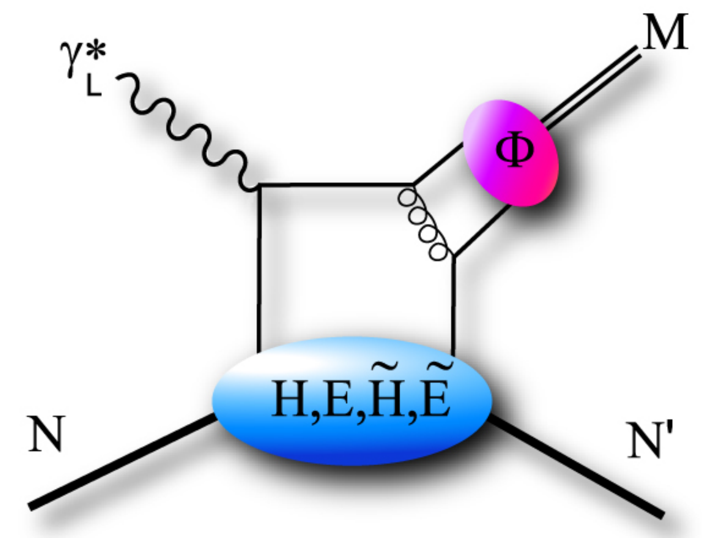
☛ $\gamma_T^* \to \rho_T^0$ transitions can be calculated



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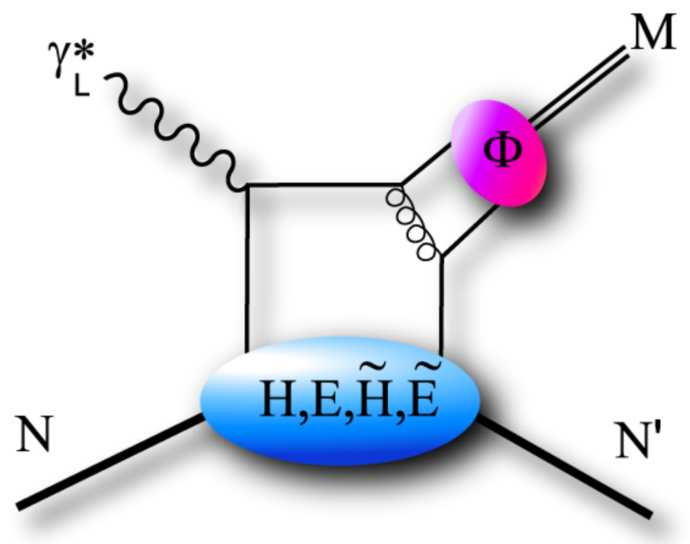

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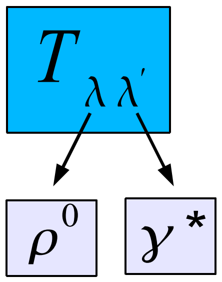
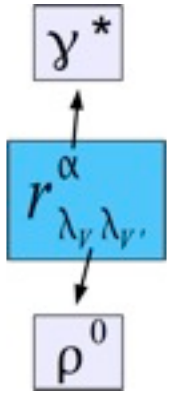
☛ $\gamma^*_T \rightarrow \rho^0_T$ transitions can be calculated

$$\frac{d\sigma}{dx_B\, dQ^2\, dt\, d\phi_s\, d\phi\, d\cos\vartheta\, d\varphi} \sim \frac{d\sigma}{dx_B\, dQ^2\, dt} W(x_B, Q^2, t, \phi_s, \phi, \cos\vartheta, \varphi)$$

☛ production and decay angular distributions W decomposed:

$$W = W_{UU} + P_l W_{LU} + S_L W_{UL} + P_l S_L W_{LL} + S_T W_{UT} + P_l S_T W_{LT}$$





☛ parametrized by helicity amplitudes or alternatively by SDMEs:
- ☛ the helicity transfer from virtual photon to the vector meson (s-channel helicity conservation)
- ☛ the parity of the diffractive exchange process
  - ☛ natural parity is related to H and E
  - ☛ unnatural parity is related to $\widetilde{H}$ and $\widetilde{E}$

GPD H: SDMEs on unpolarized target

ρ^0 ω

$ep \to e' \rho^0 p'$

$ep \to e' \omega p'$

$T_{\lambda\lambda'}$ → ρ^0, γ^*

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

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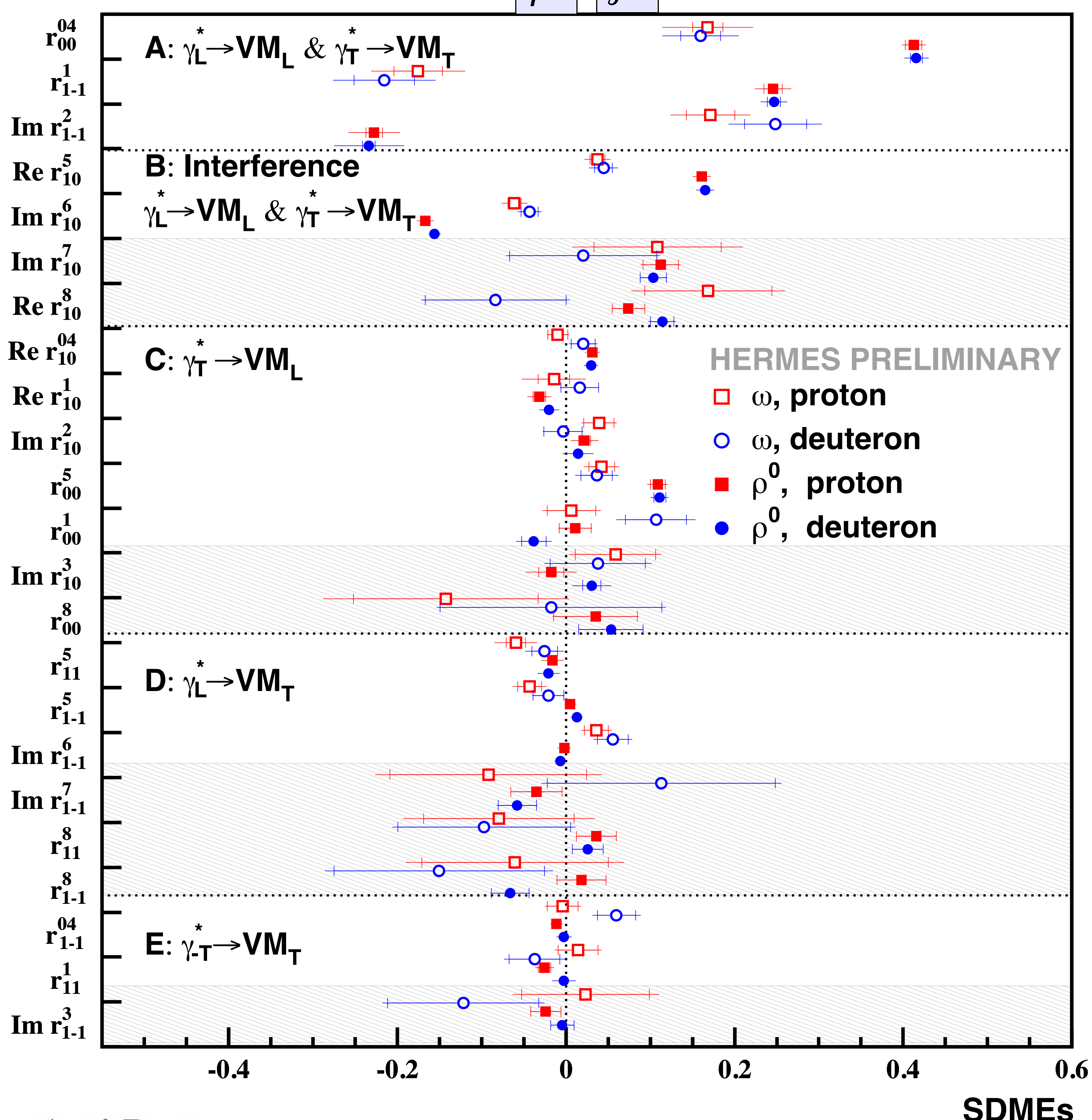


$\gamma^*_L \to \omega_L$ $\gamma^*_T \to \omega_T$

- ☛ SDMEs are significantly different from zero
- ☛ the magnitude of ω meson SDMEs is smaller than that of ρ^0

$\gamma^*_L \to \omega_T$ $\gamma^*_T \to \omega_L$ $\gamma^*_T \to \omega_{-T}$

- ☛ hardly any s-channel helicity violation for ω meson in contrast to ρ^0

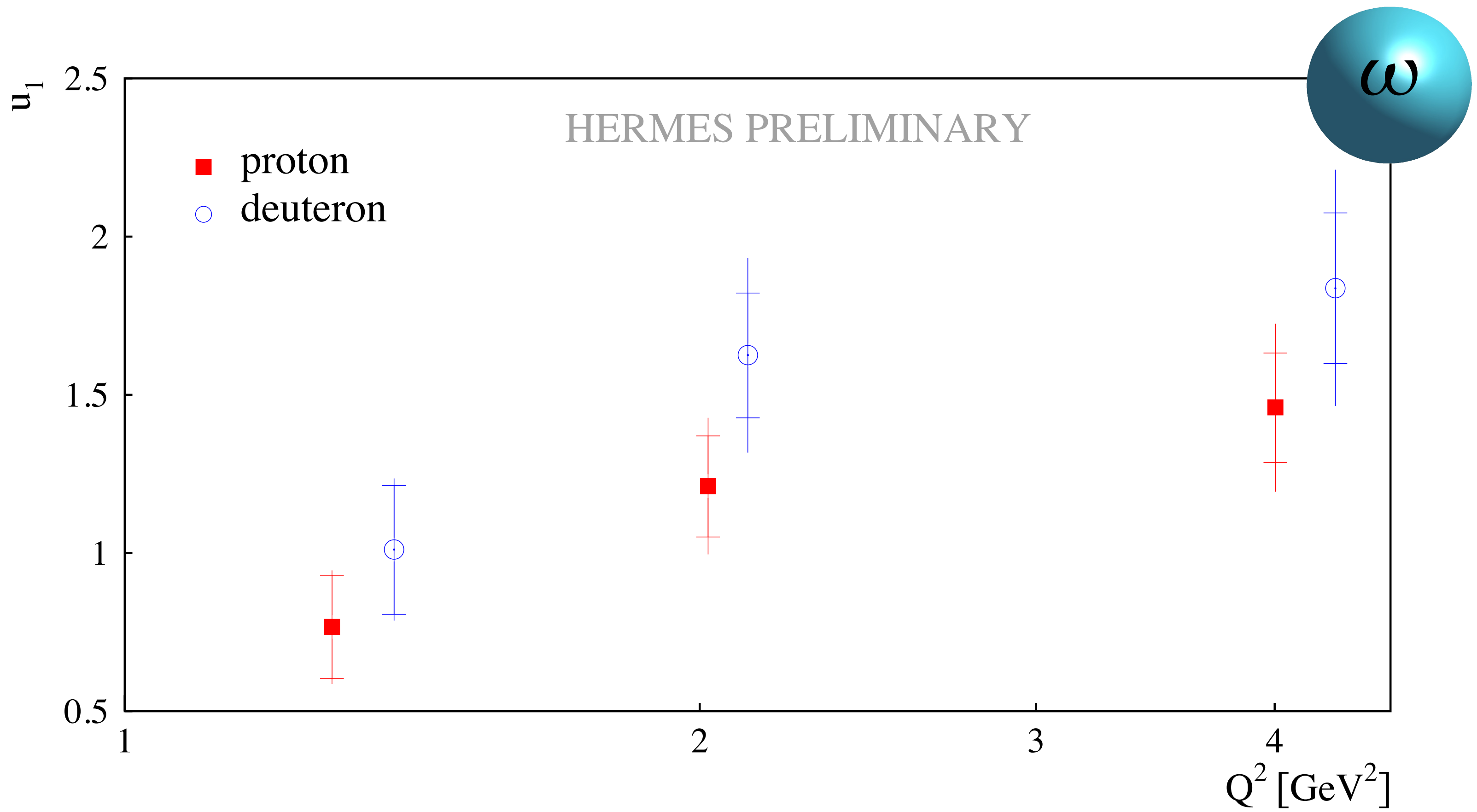
observation of unnatural-parity exchange contribution

- give information about $\widetilde{H}$
- at large W and Q^2, this transition should be suppressed by a factor of M_V/Q
- the combinations of SDMEs expected to be zero in case of natural parity exchange dominance

$$u_1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^1_{11} - 2r^1_{1-1}$$

$$u_2 = r^5_{11} + r^5_{1-1}$$

$$u_3 = r^8_{11} + r^8_{1-1}$$



✓ large signal of unnatural parity exchange

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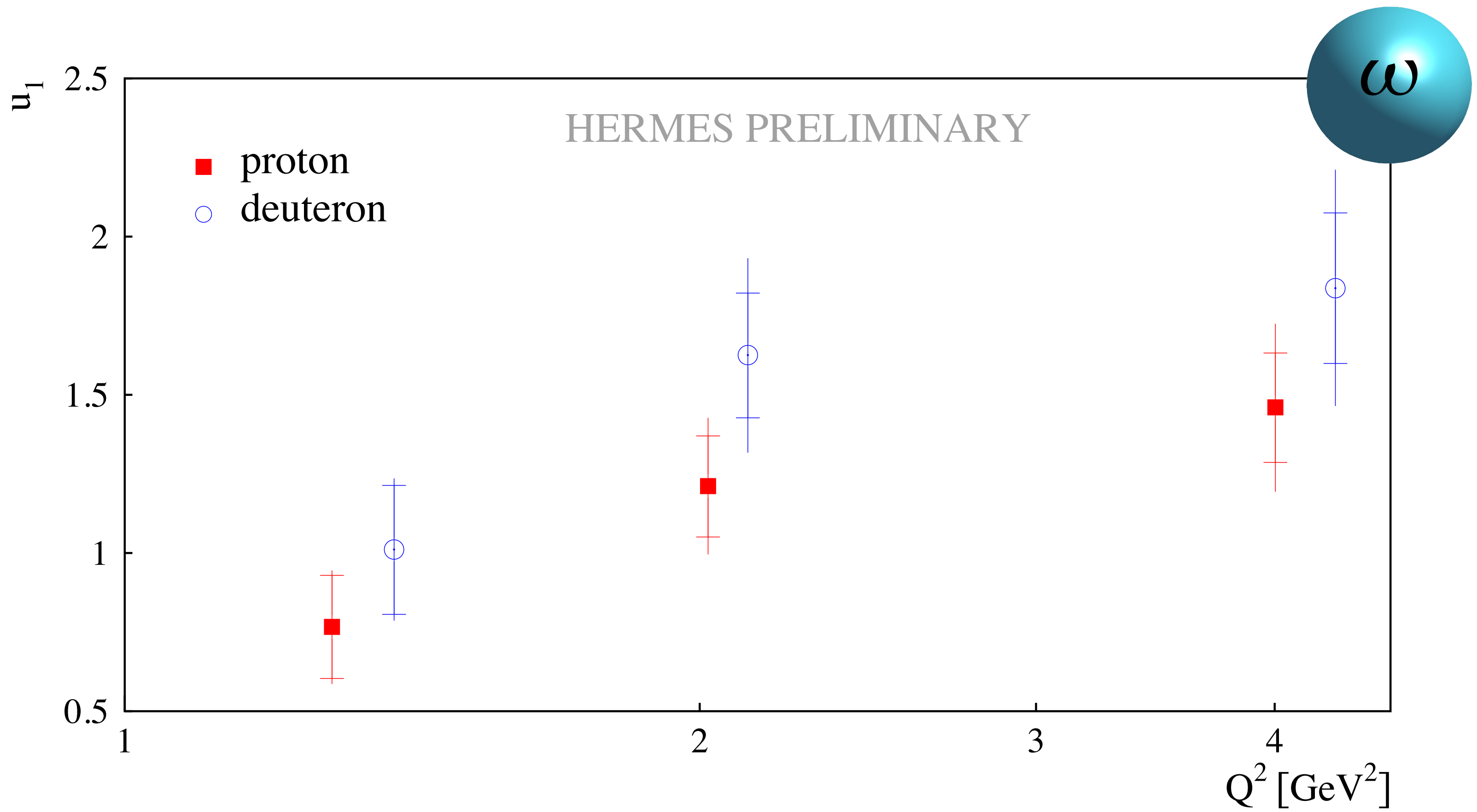

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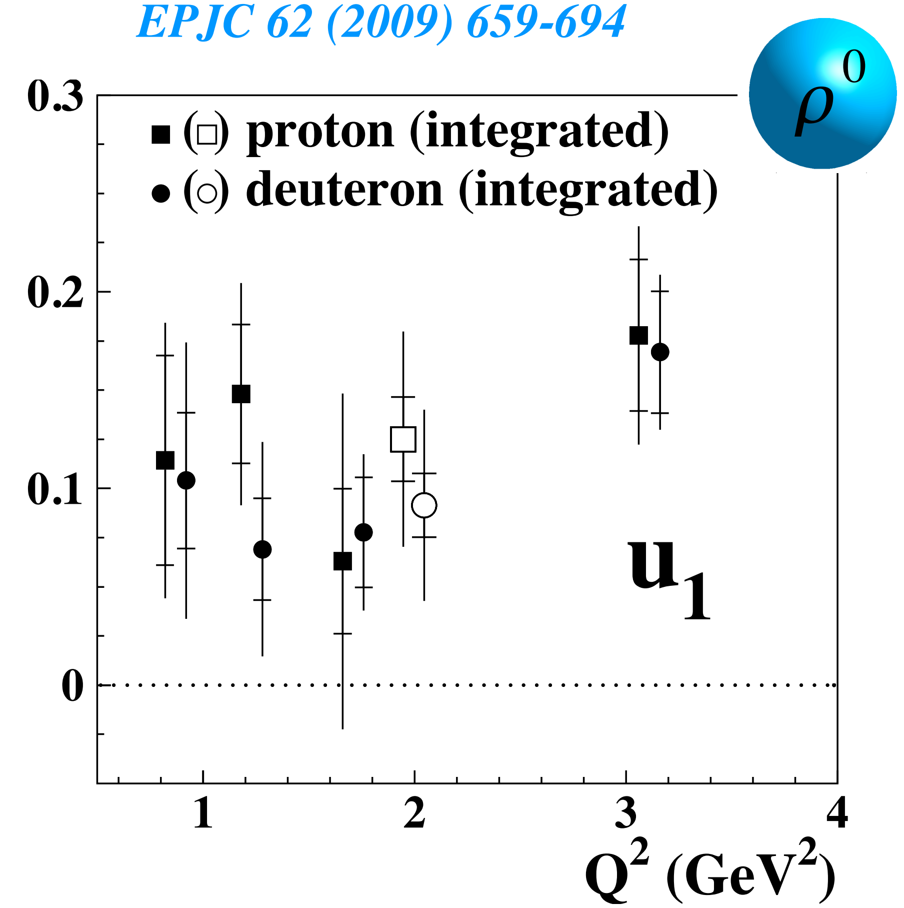
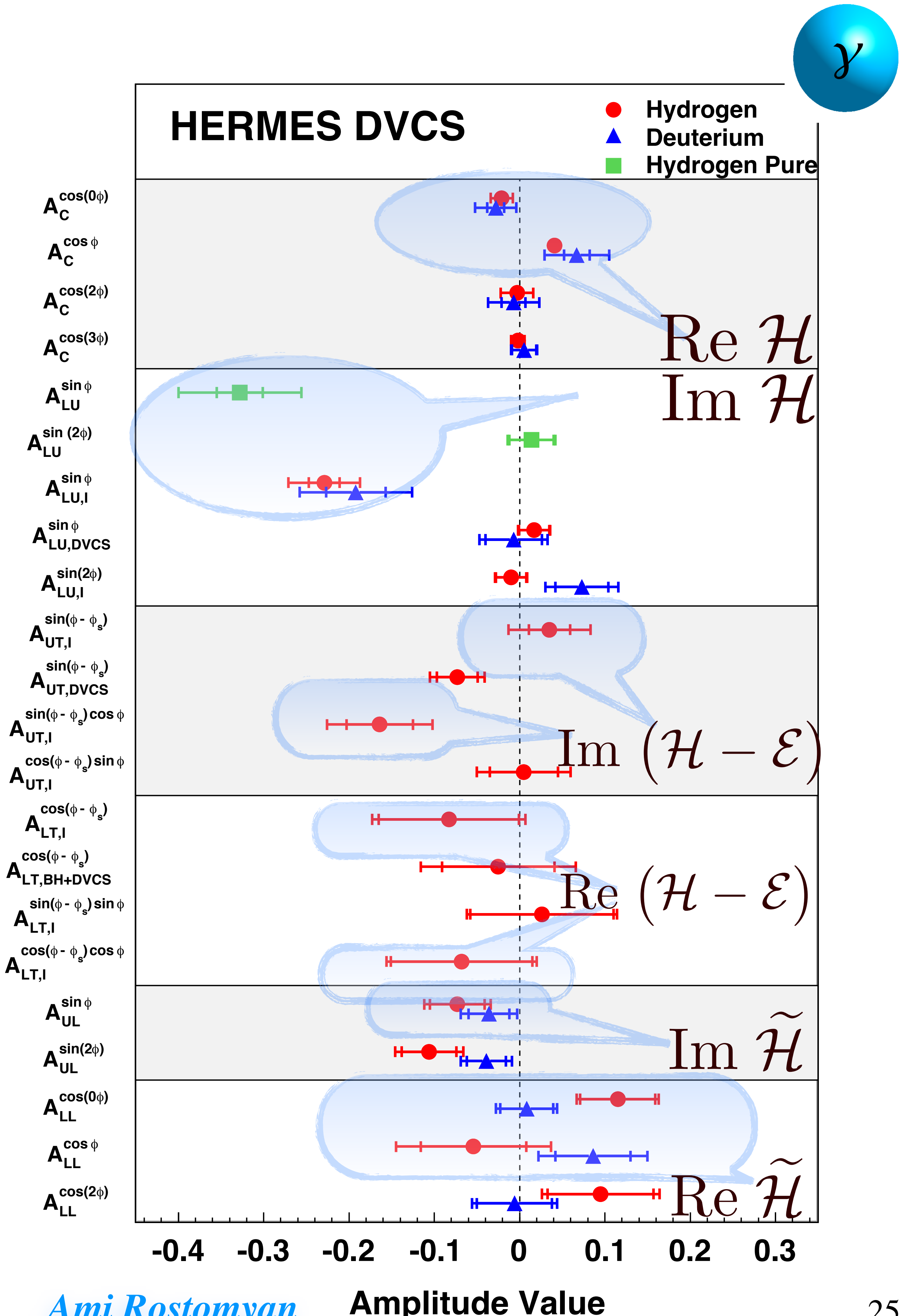
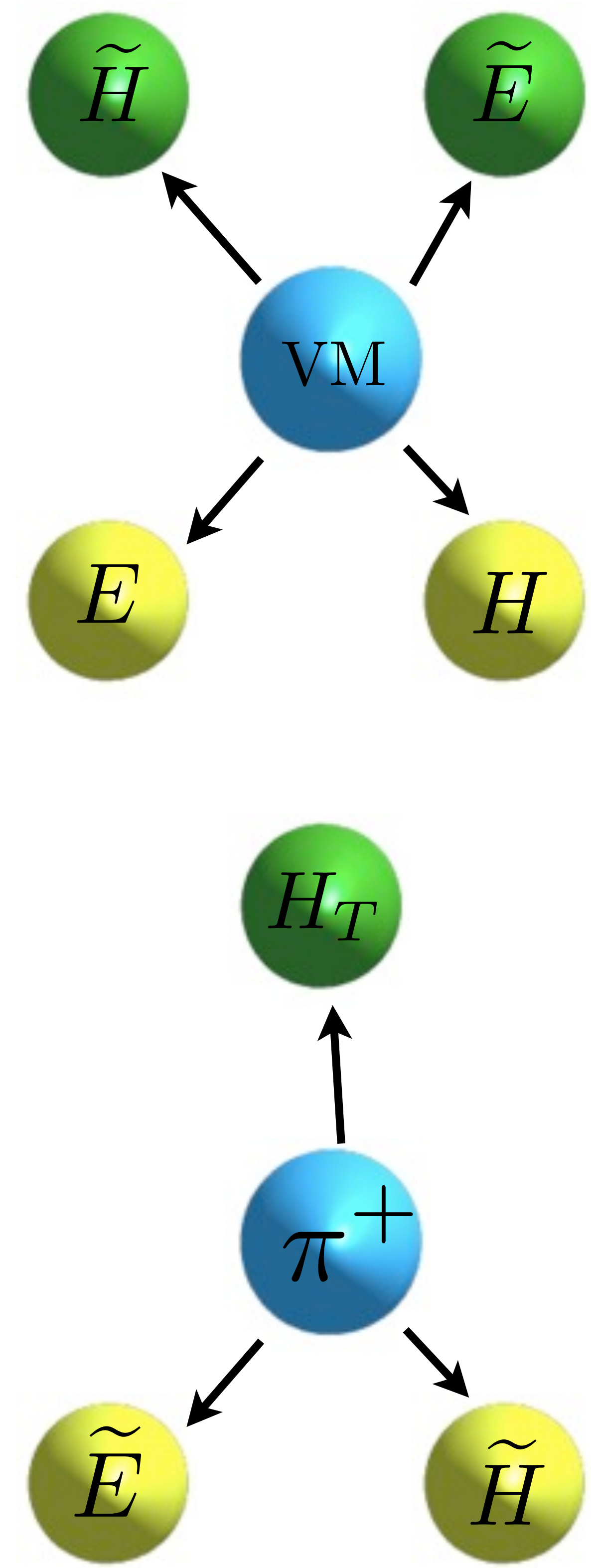


✓ large signal of unnatural parity exchange

halftime report





The Spin Community And The World

- HERMES has been the pioneering collaboration in TMD and GPD fields
- still very important player in the field of nucleon (spin) structure
  - polarized $e^{+/-}$ beams
  - pure gas target
  - good particle identification
  - recoil detector