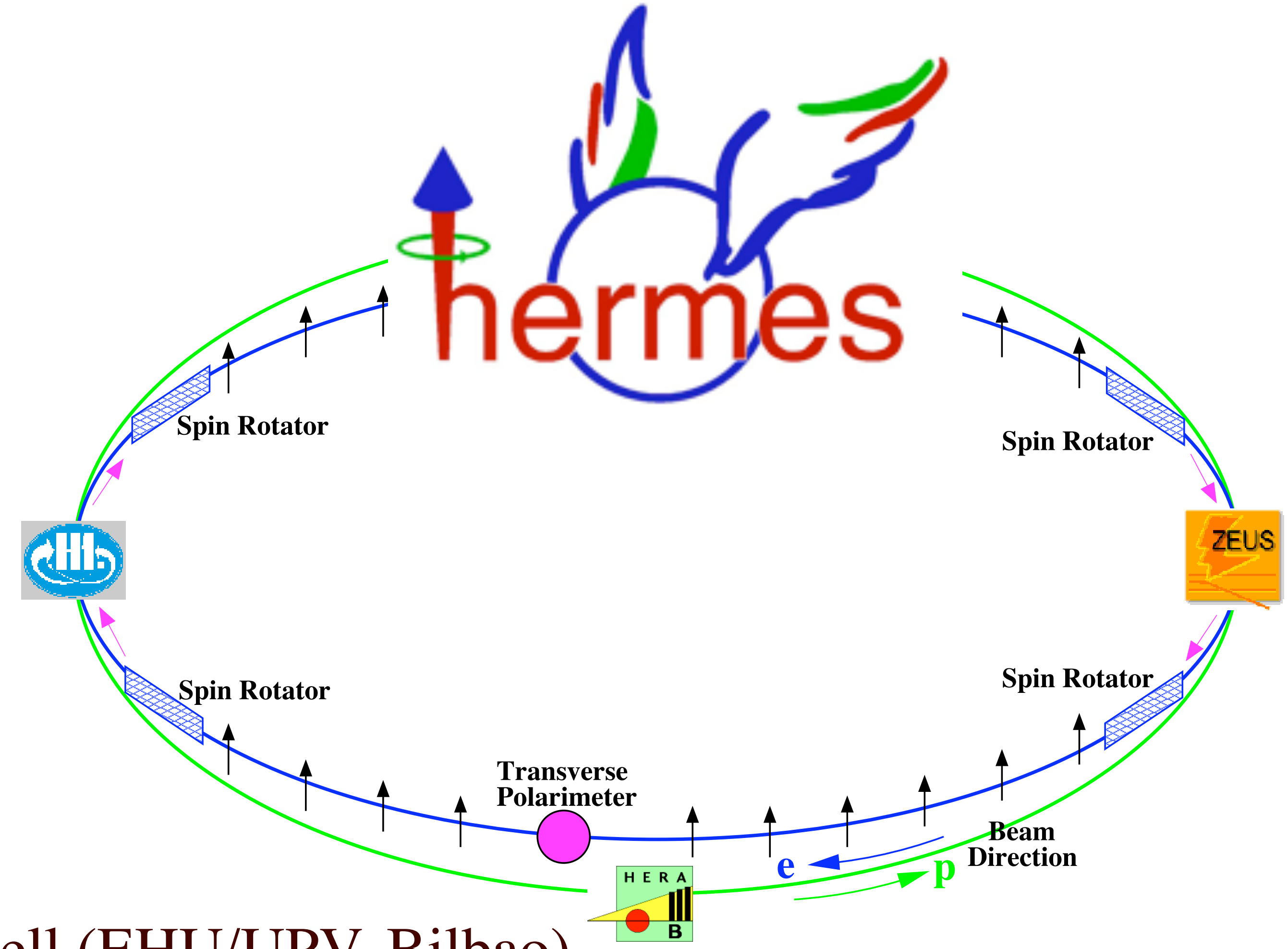
Report for Physics Research Committee from



Spokesperson: G. Schnell (EHU/UPV, Bilbao)
Analysis coordinator: M. Contalbrigo (INFN, Ferrara)
Deputy analysis coordinator: **A. Rostomyan** (DESY, Hamburg)

Open session
DESY PRC 72

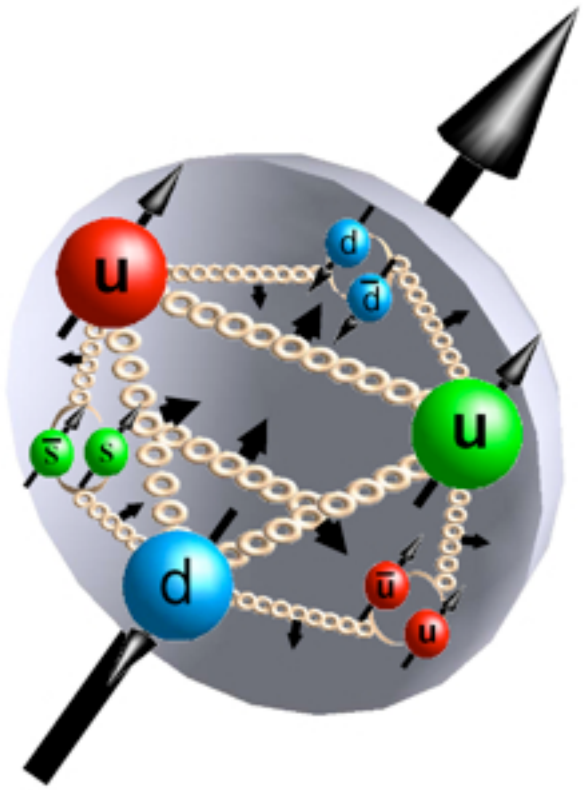
October 25-26, 2011
DESY Hamburg

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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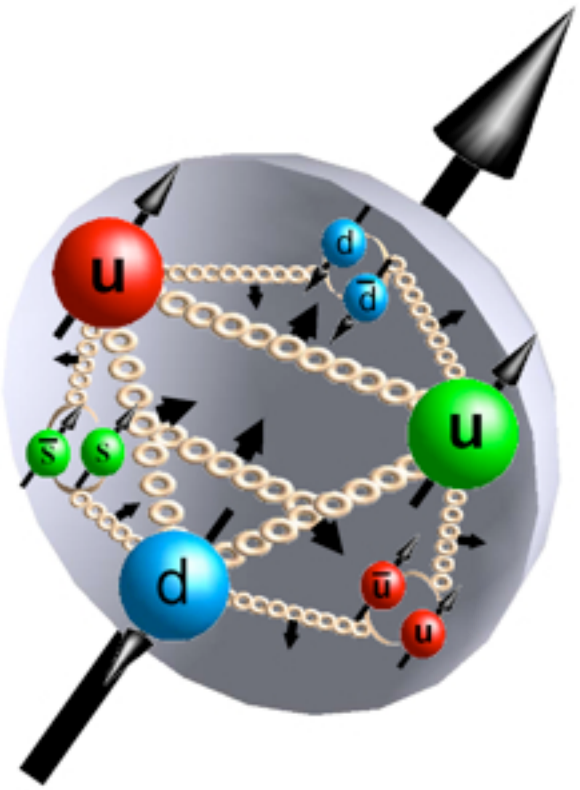
spin-1/2 particles (quarks, leptons, proton, neutron…)

- ☛ are the fundamental constituents of matter
- ☛ are responsible for stability of matter (Pauli-principle)
  - ☛ no two spin-1/2 particles can occupy a state with identical quantum numbers

spin and hadronization



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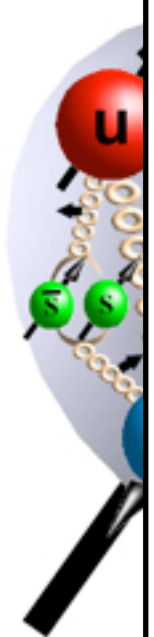
nucleon properties (charge, momentum, magnetic moment, spin...) should be explained by its constituents

- ☛ momentum: quarks carry ~ 50 % of the proton momentum
- ☛ spin: total quark spin contribution only ~30%



David Gross' presentation on HEP 2011

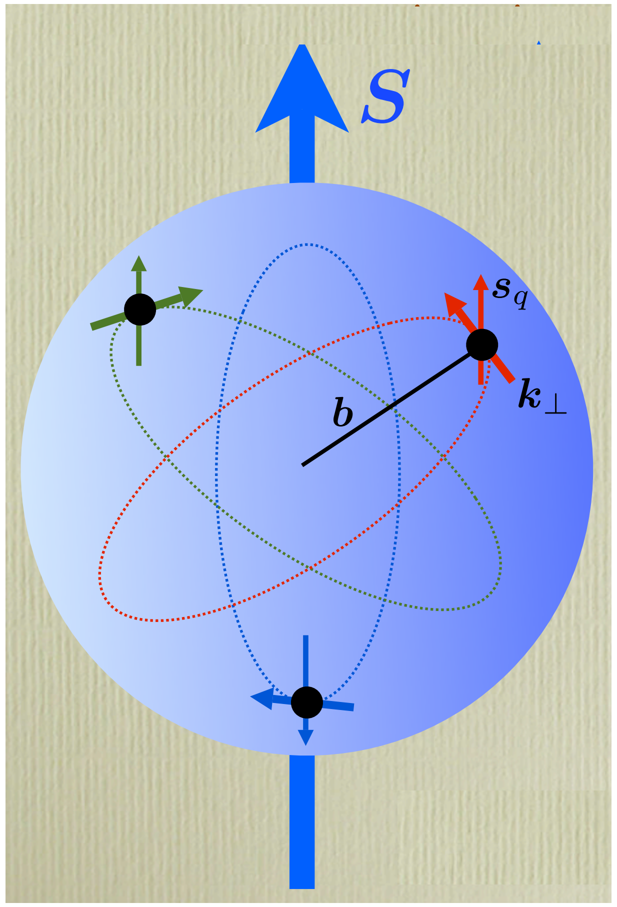
NEW PREDICTIONS (10 years)

1. QCD tests & applications will greatly improve, incorporating NLO, NNLO,...and a theory of fragmentation and hadronization.
2. Atlas and CMS will discover a candidate Higgs particle.
3. There will be convincing evidence for Susy particles.
4. Plans will be underway to build a LC (at Cern) to explore the superworld and the US will join CERN.
5. There will be direct detection of the Dark Matter wind.
6. Alice will see a crossover to the perturbative quark-gluon plasma.
7. Some new Z mesons will be discovered.
8. Gravitational waves and B modes will be observed.
9. String theory will start to be a **theory** with predictions.
10. We will have a plausible explanation of why Λ is so small.

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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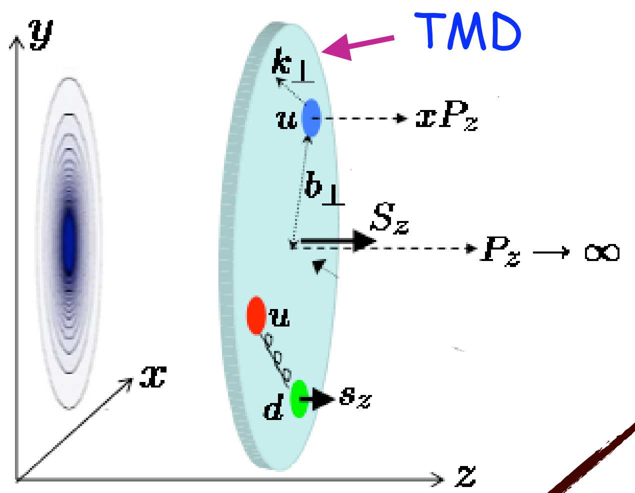
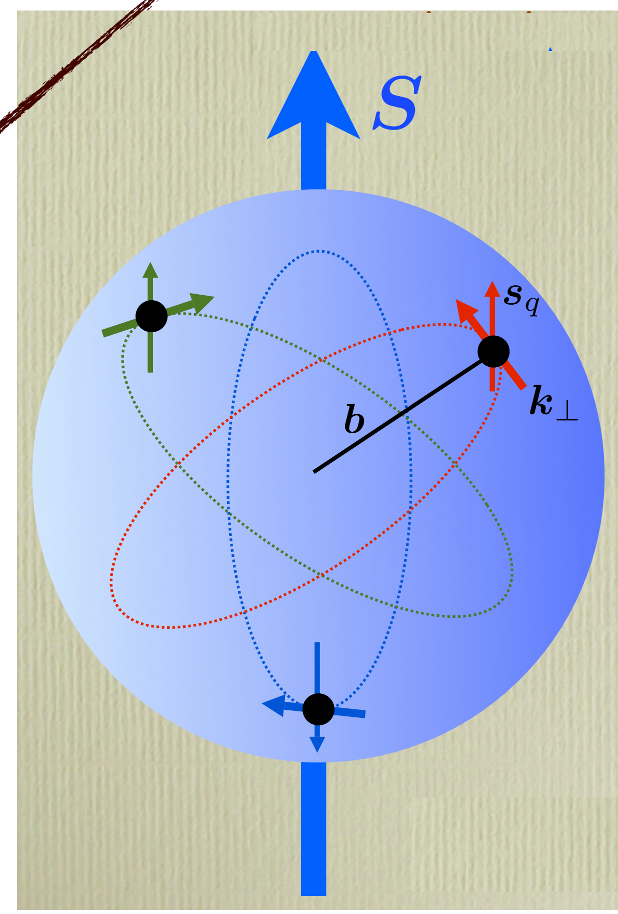


$$\int d^3\mathbf{b}$$



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

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

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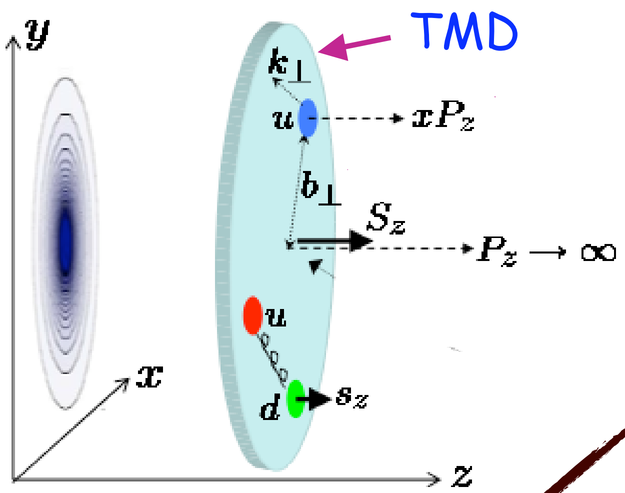
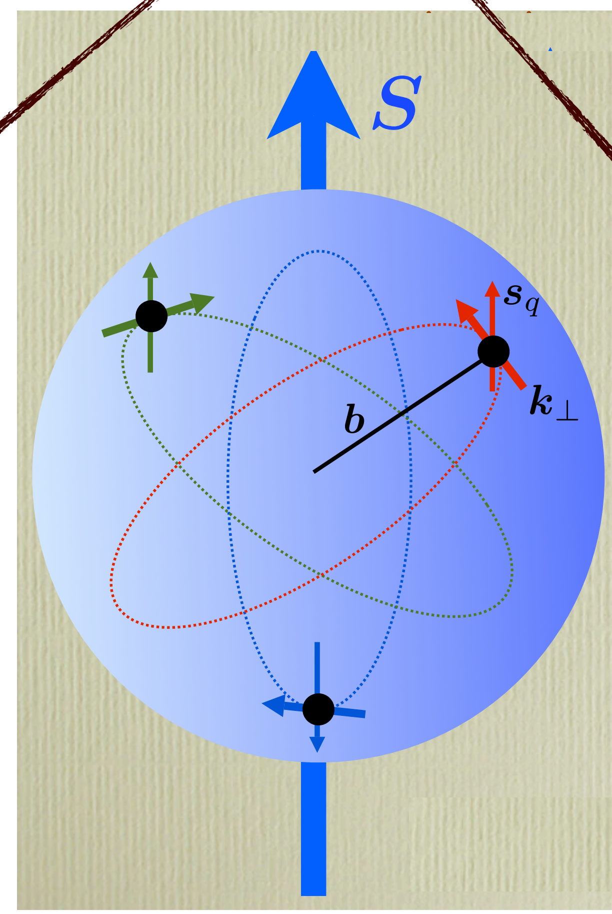
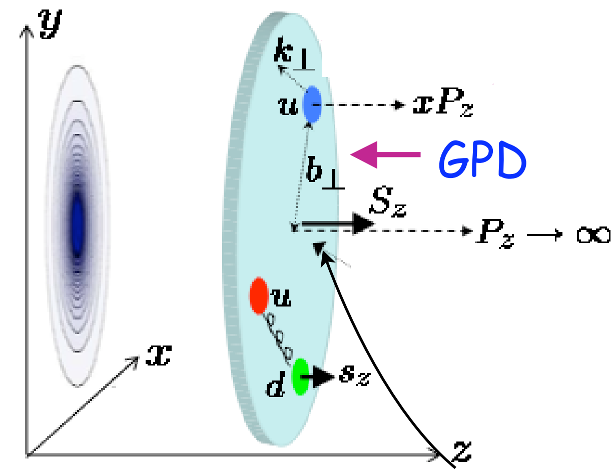
$\int d^3\mathbf{b}$

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







center of momentum

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

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

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

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space dependent distribution functions

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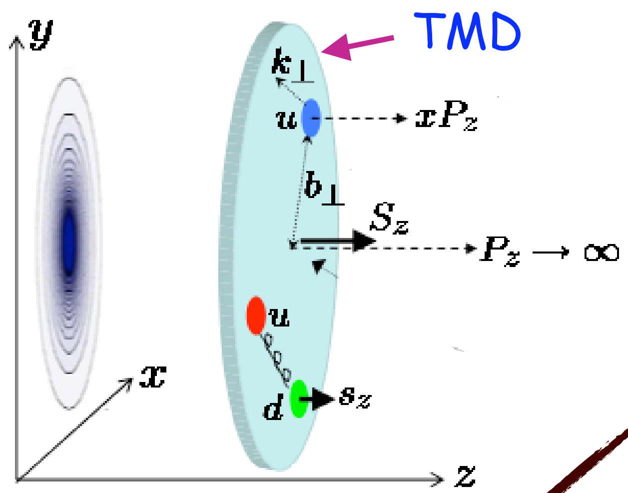

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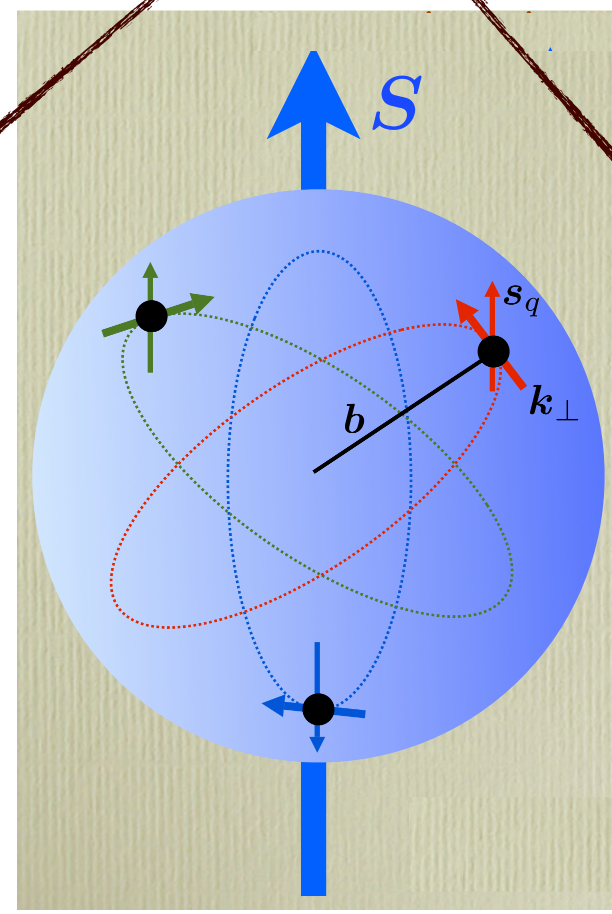

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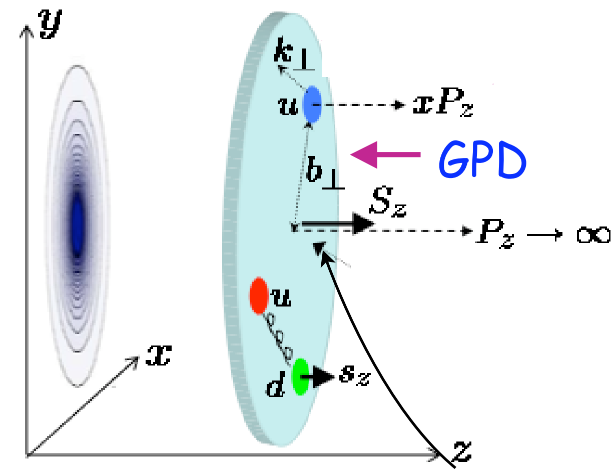

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Transverse Momentum Dependent (**TMDs**) distribution functions

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

$\xleftrightarrow{\text{FT}}$

space dependent distribution functions

$H(x, \xi, t)$

Generalized Parton Distributions (**GPDs**)

quantum phase-space "tomography" of the nucleon

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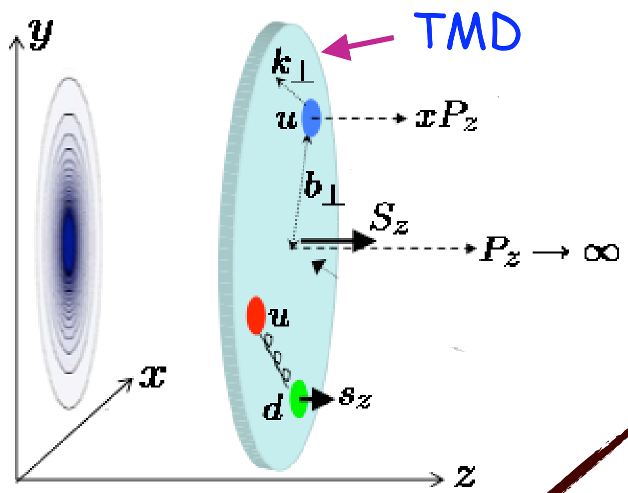

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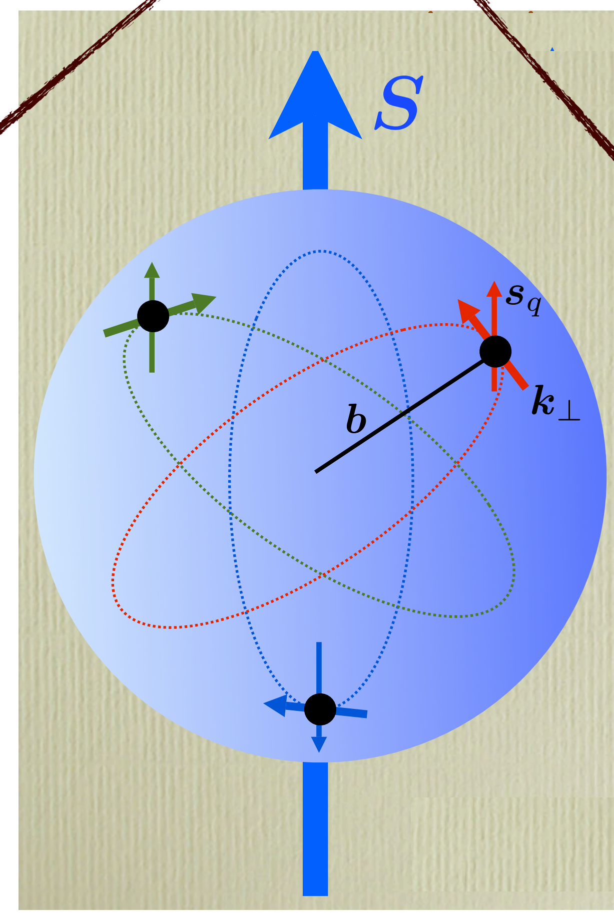

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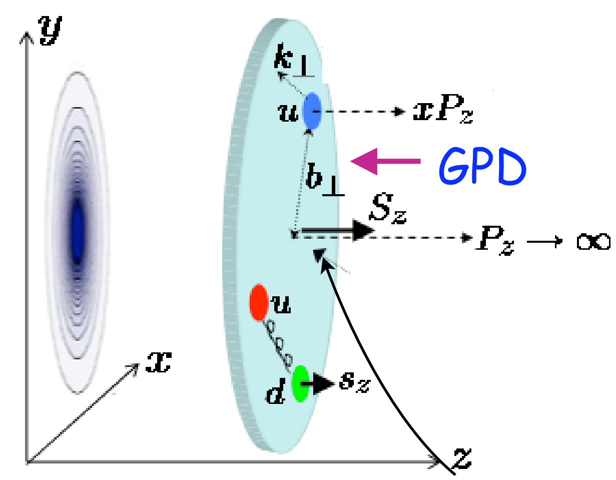

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FT

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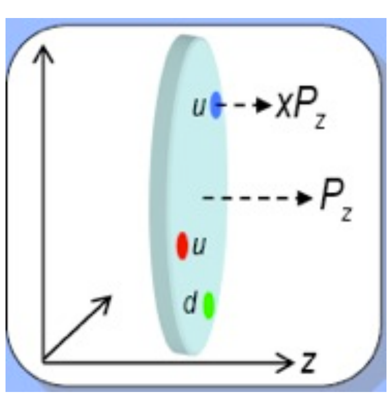
Generalized Parton Distributions (**GPDs**)

$\xi = 0,\ t = 0$

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

$f^q(x)$



Parton Distribution Functions (**PDFs**)

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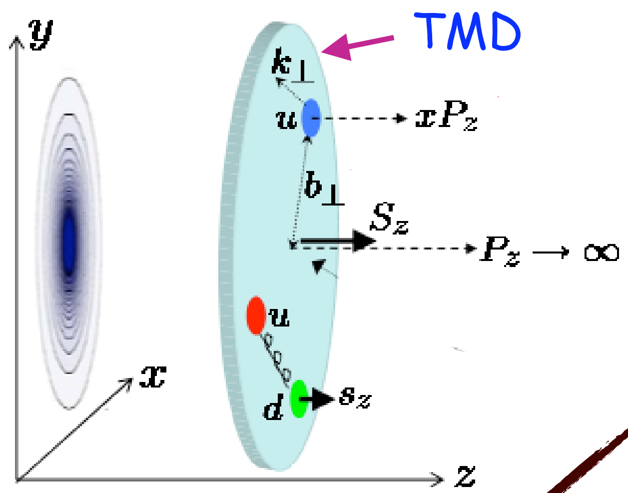

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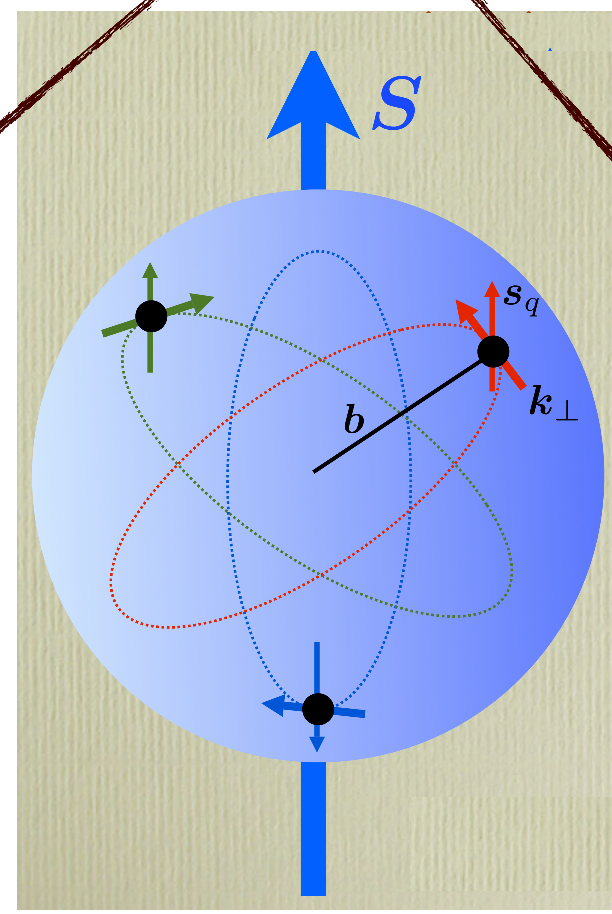

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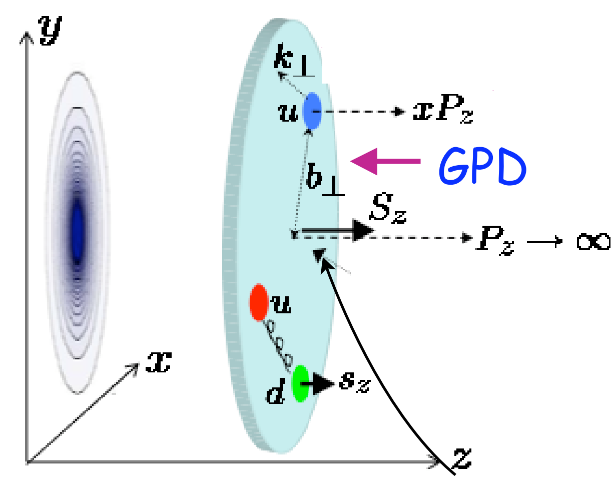

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☛**semi-inclusive measurements**

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☛ **exclusive measurements**

$\xi=0,\ t=0$

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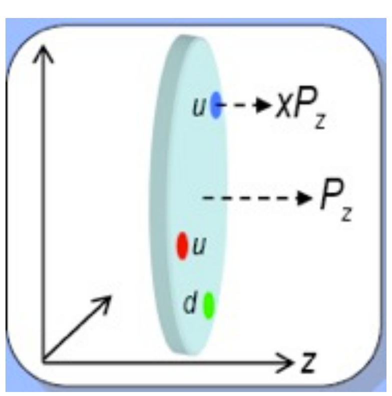

Parton Distribution Functions **(PDFs)**

☛ **inclusive measurements**

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.

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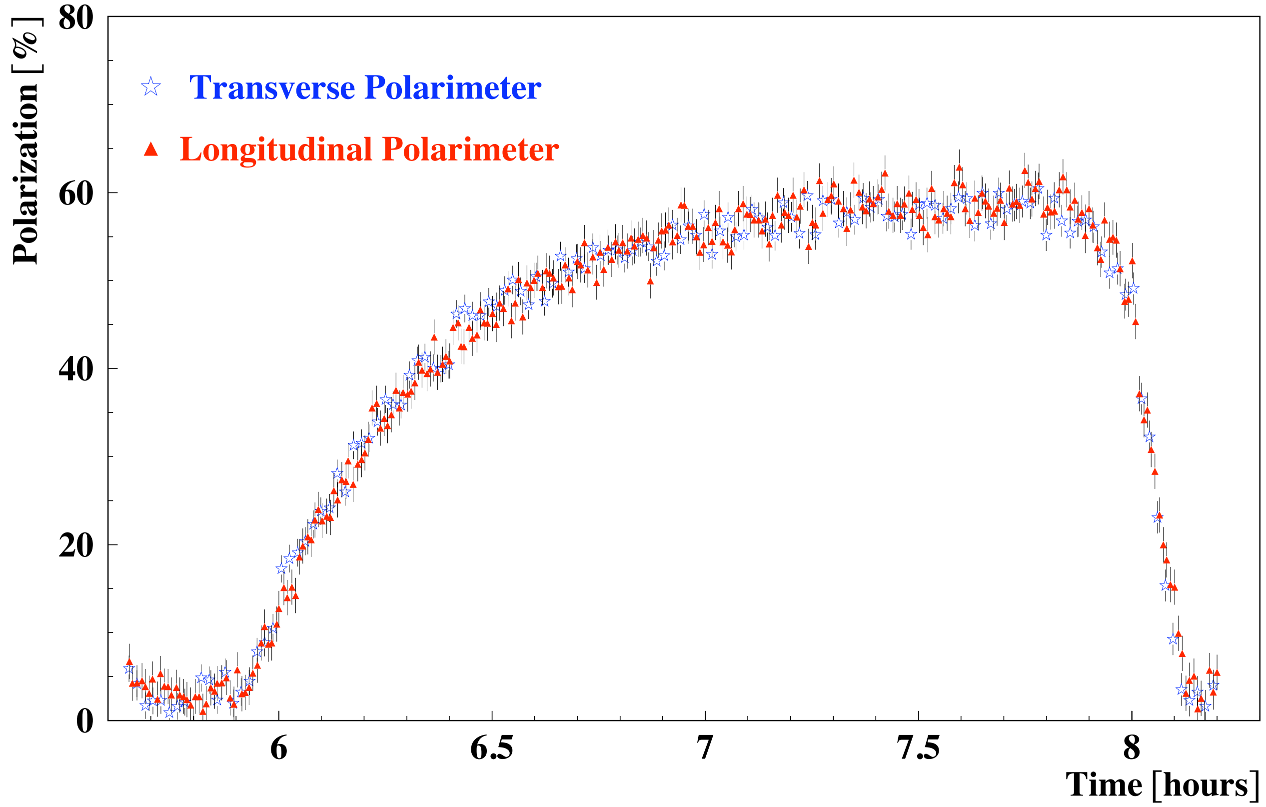

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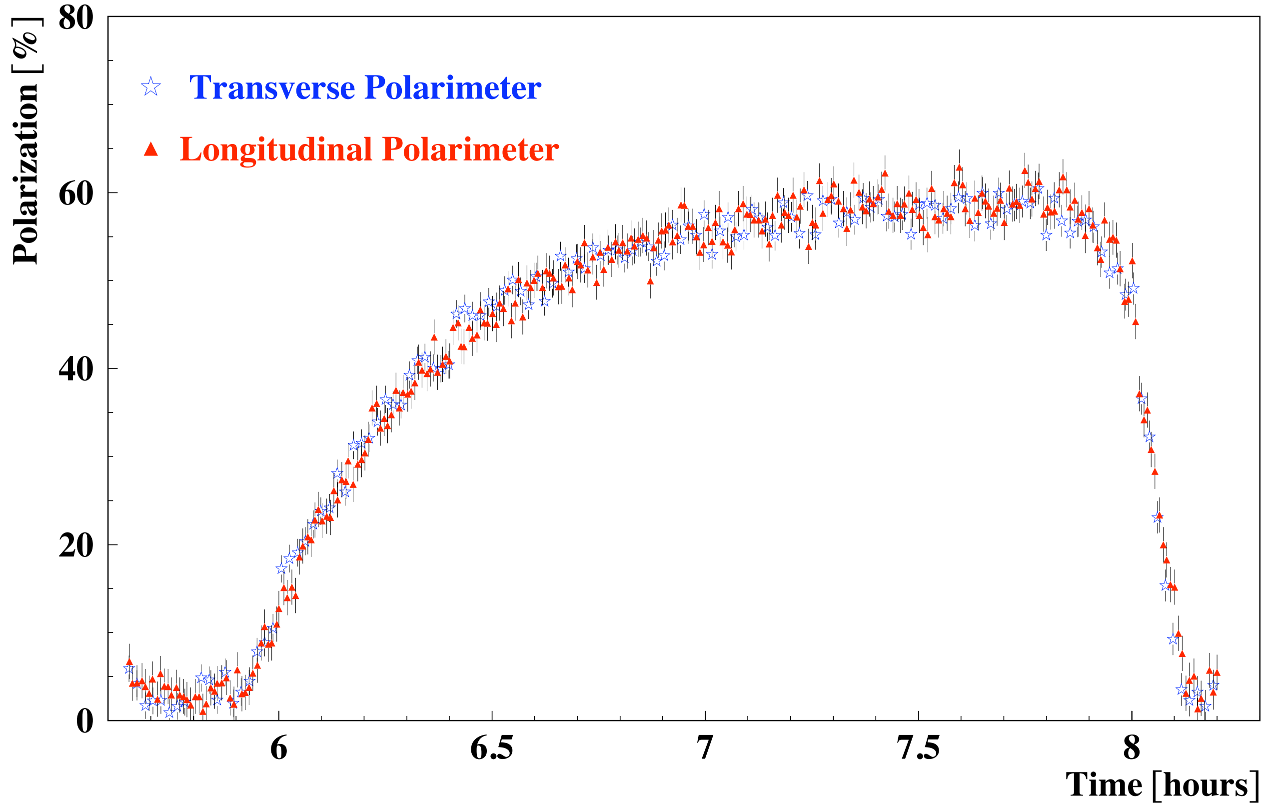

- **longitudinal** target polarization (H, D, ^{3}He)
- **transverse** target polarization (H)
- **unpolarized** targets: H, D, ^{4}He, ^{14}N, ^{20}Ne, ^{84}Kr, ^{131}Xe
- **unpolarized** H, D targets with **recoil detector**

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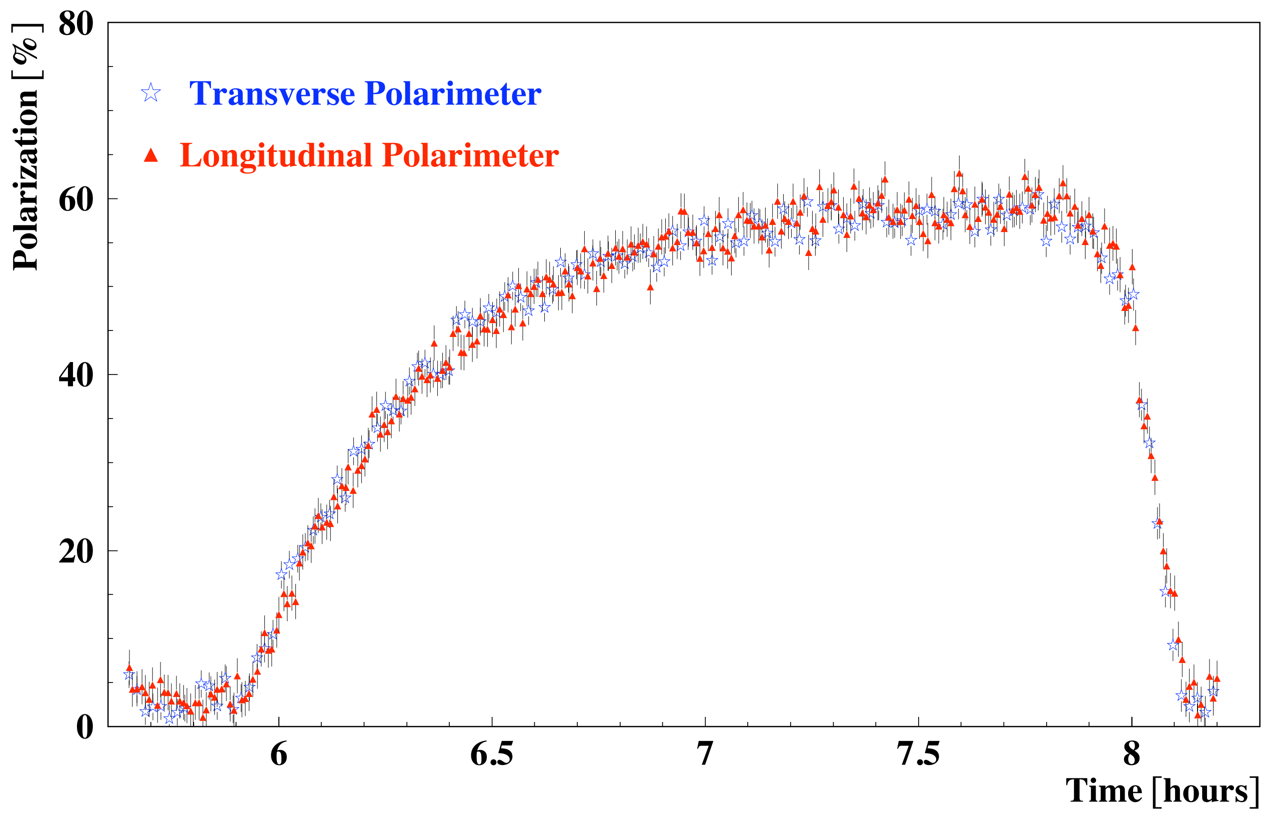
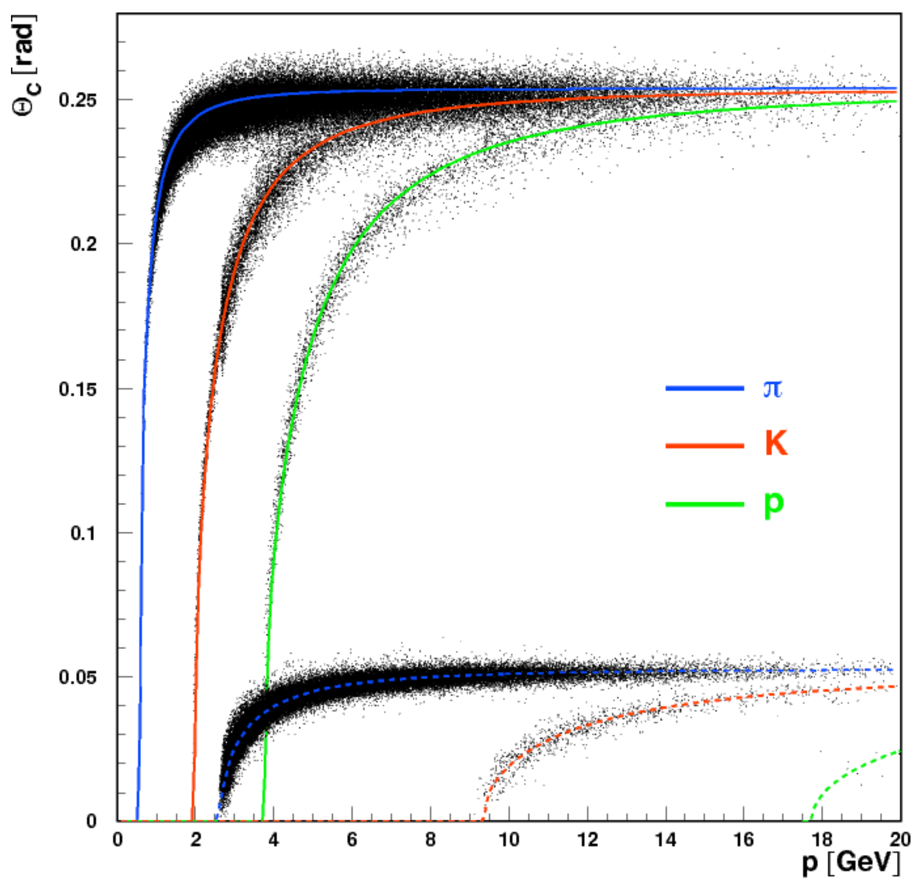


hadron identification with RICH detector



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inclusive measurements

inclusive DIS cross section and structure function F_2

$$\frac{d^2\sigma}{dxdQ^2} = \frac{4\pi\alpha_{em}^2}{Q^4}\frac{F_2(x,Q^2)}{x}\left[1 - y - \frac{Q^2}{4E^2} + \frac{y^2 + Q^2/E^2}{2\left[1 + R(x,Q^2)\right]}\right] \qquad F_2(x) = x\sum_q e_q^2 f_1^q(x)$$

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- HERMES collaboration - JHEP 05 (2011) 126

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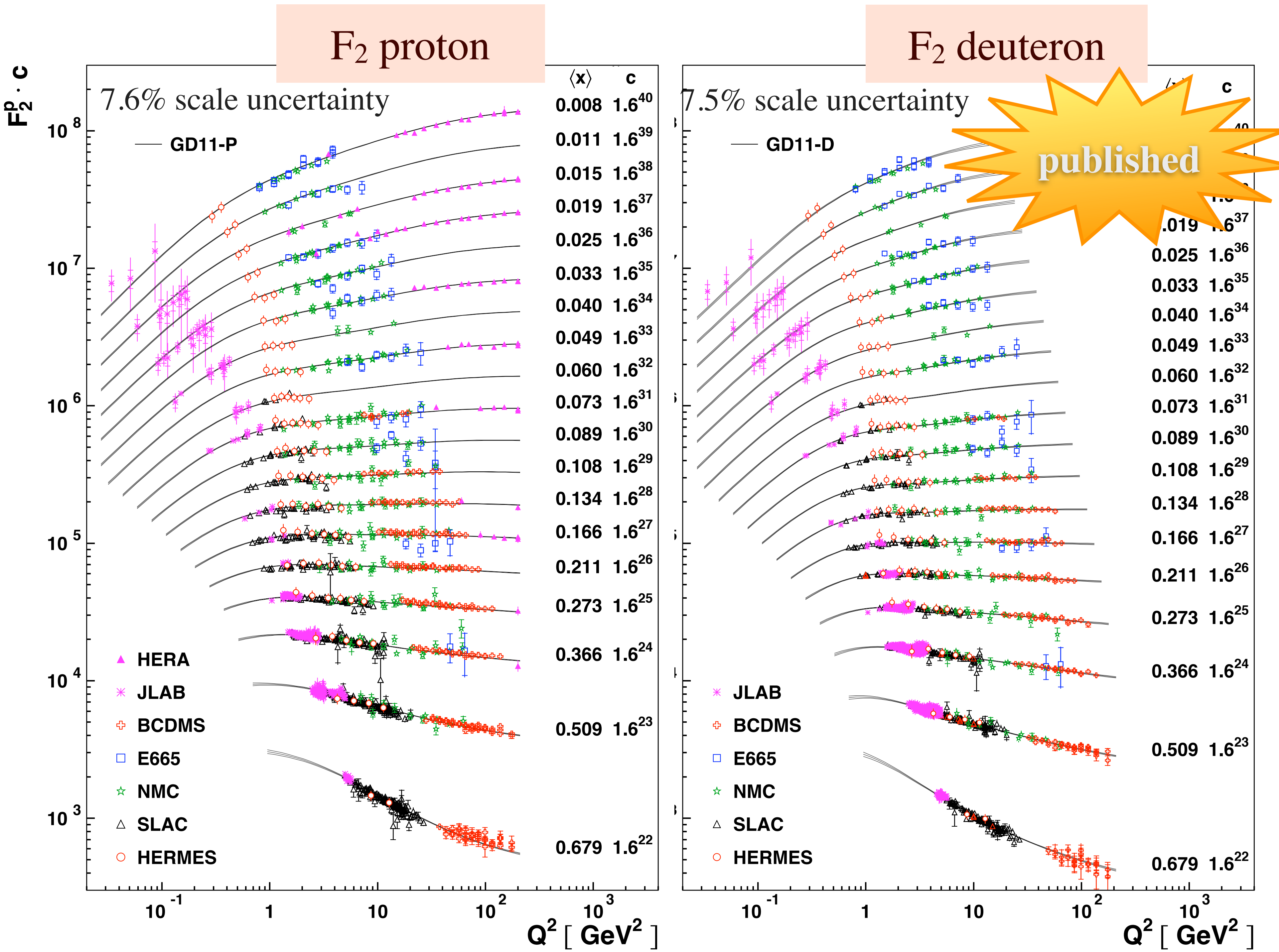

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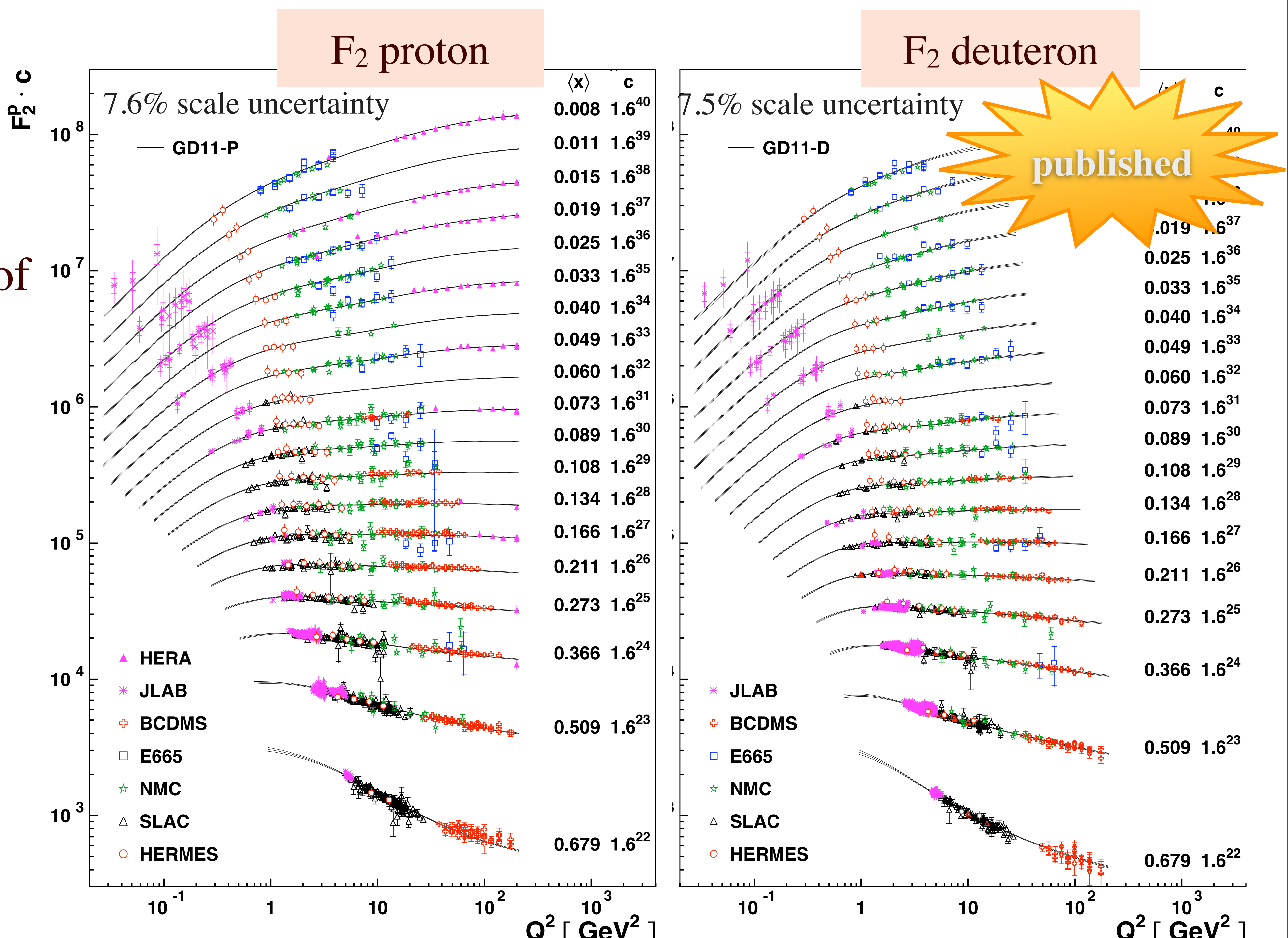
HERMES data

☛ cover the transition region between the perturbative and non-perturbative regimes of QCD



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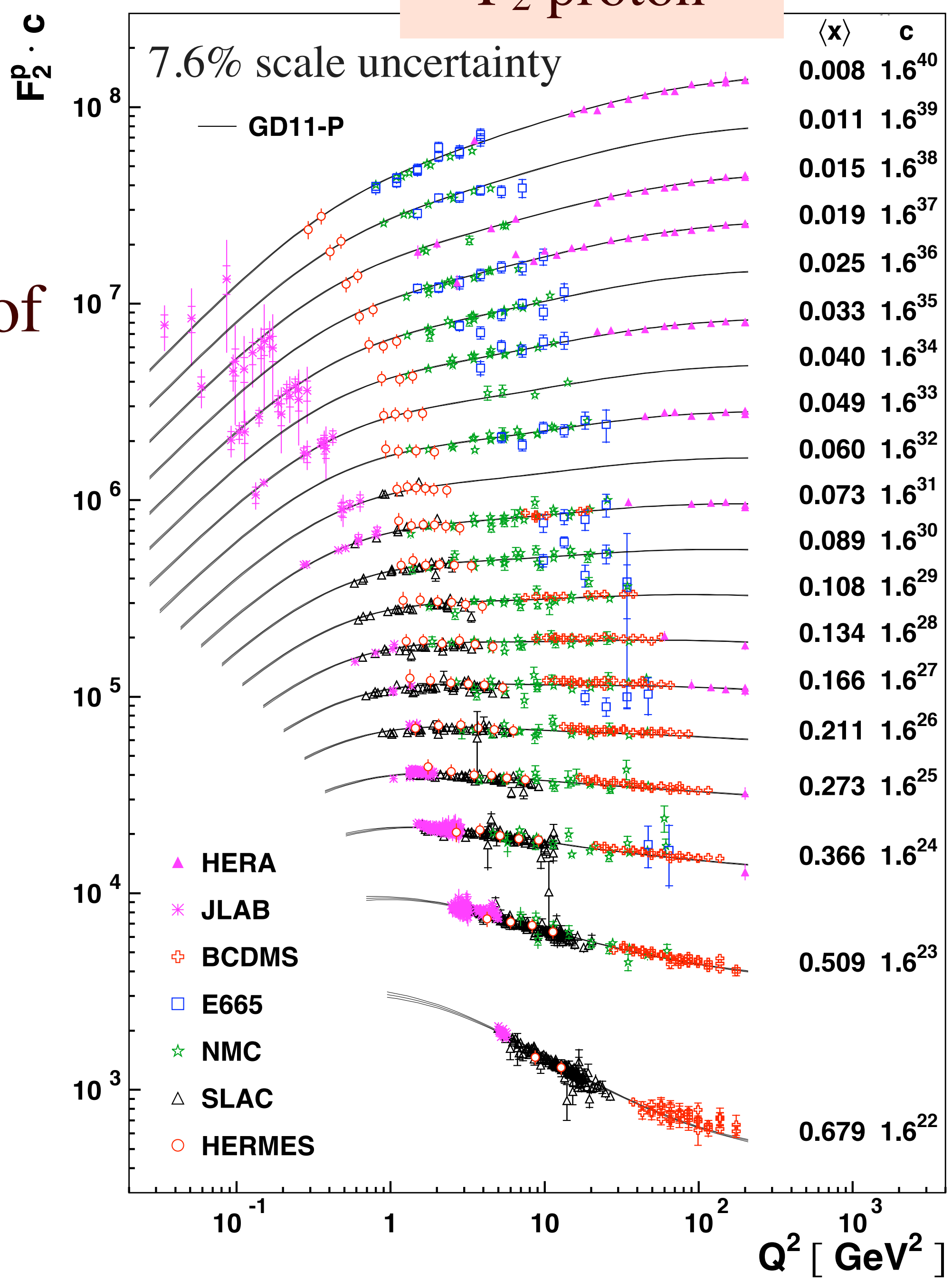
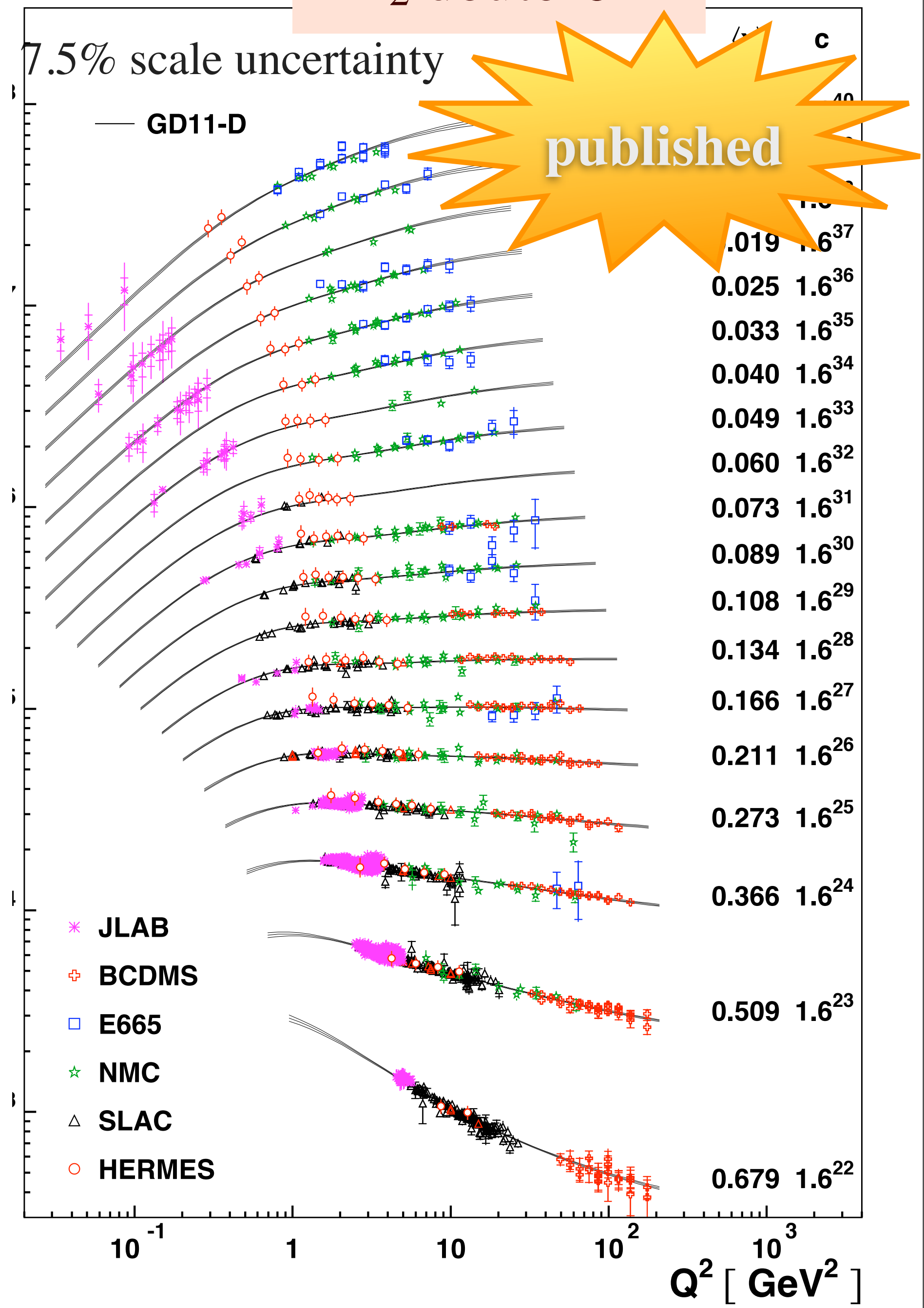
F_2 proton



F_2 deuteron



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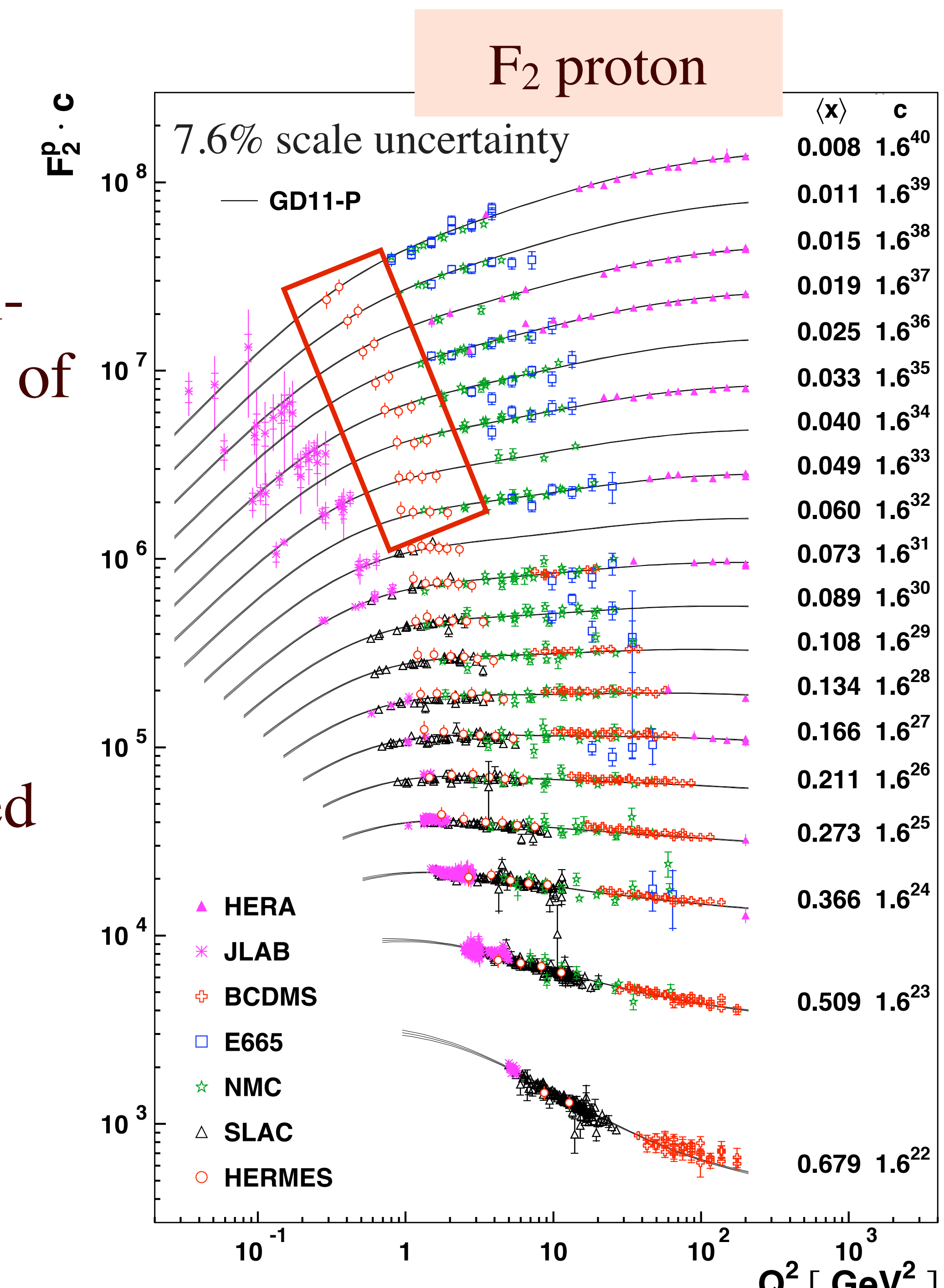

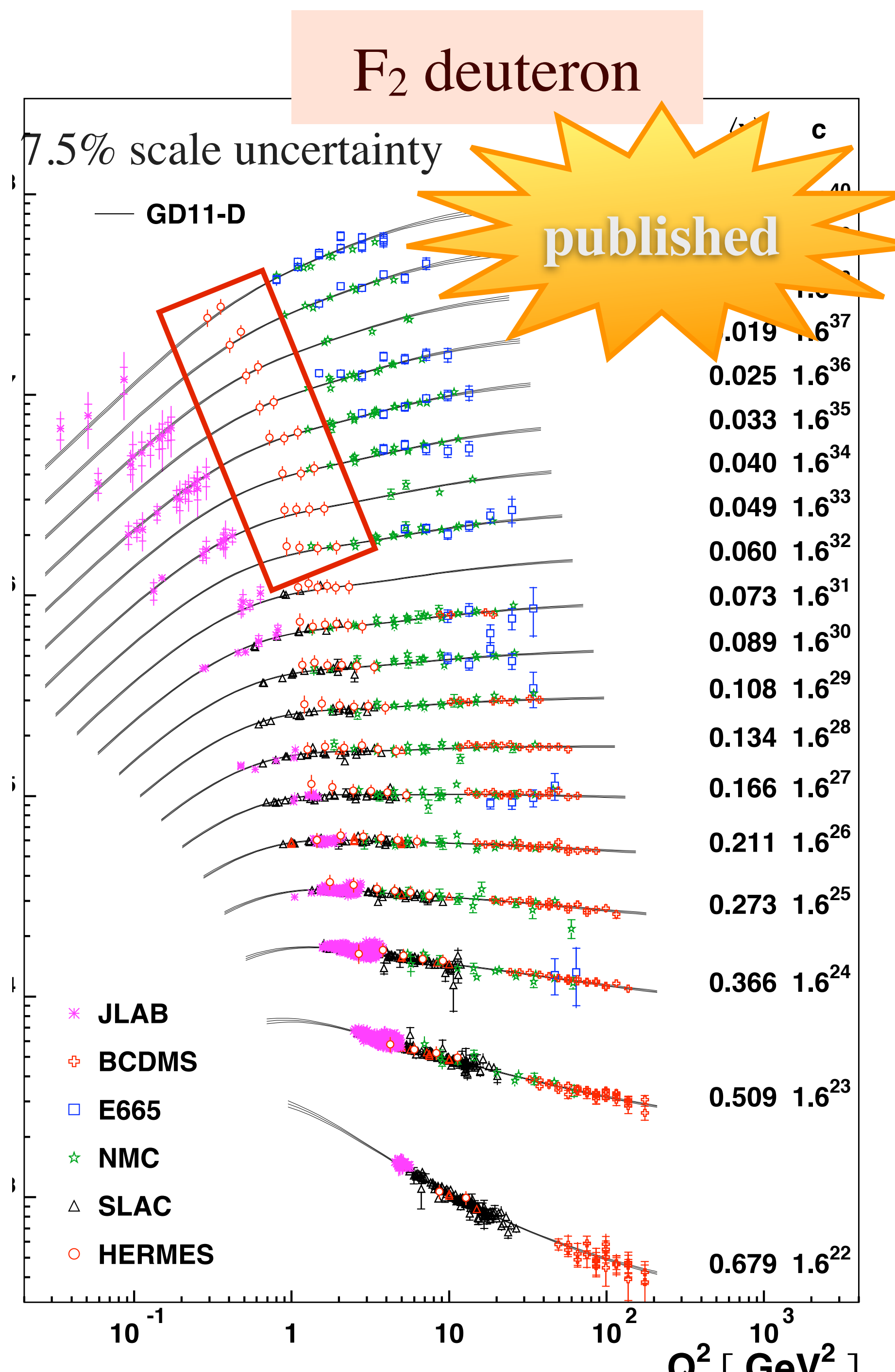

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GD11-P: fits to world data

- ☛ HERMES relative normalization 1.5% (p) and 2.2 % (d)

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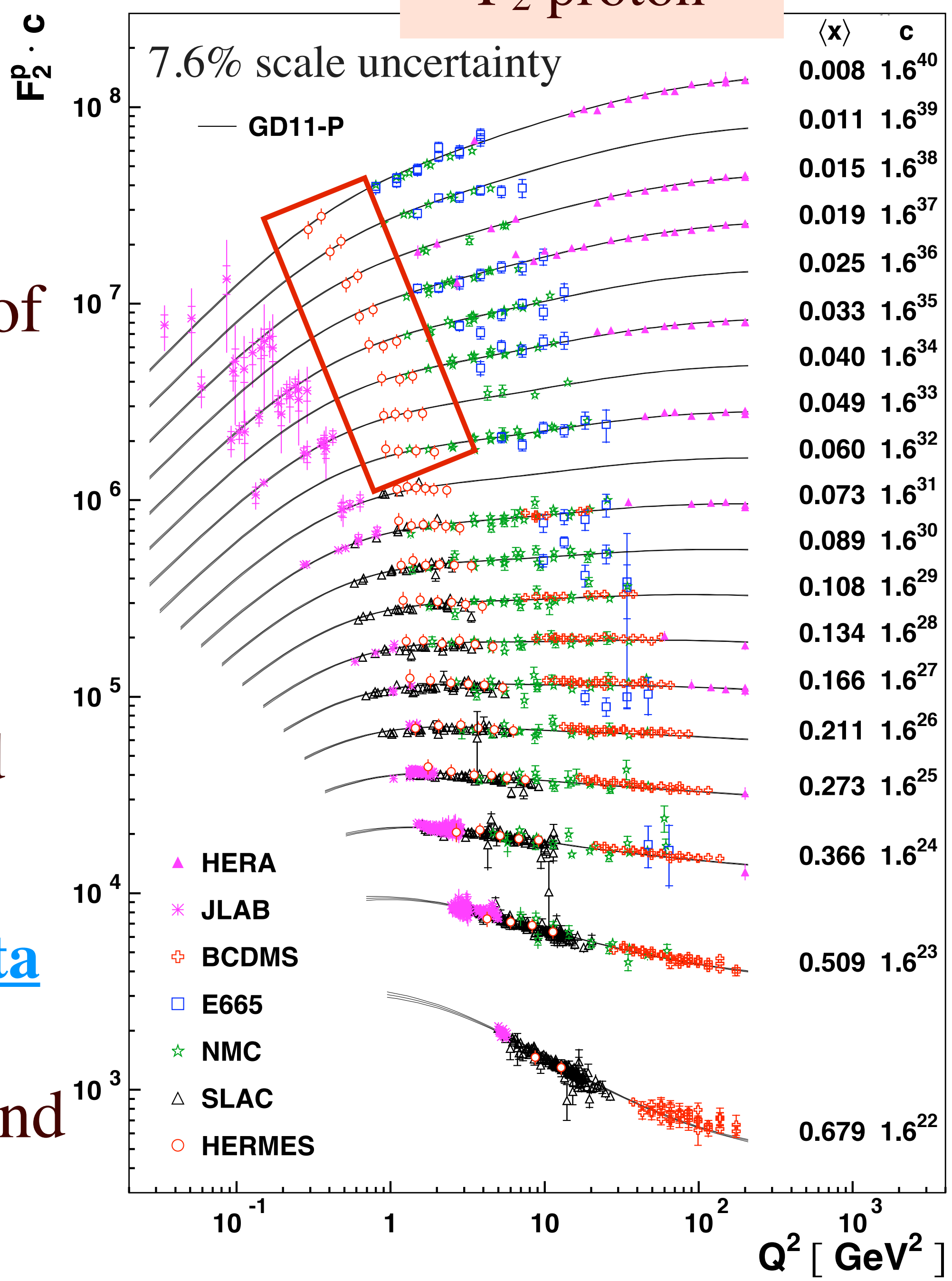
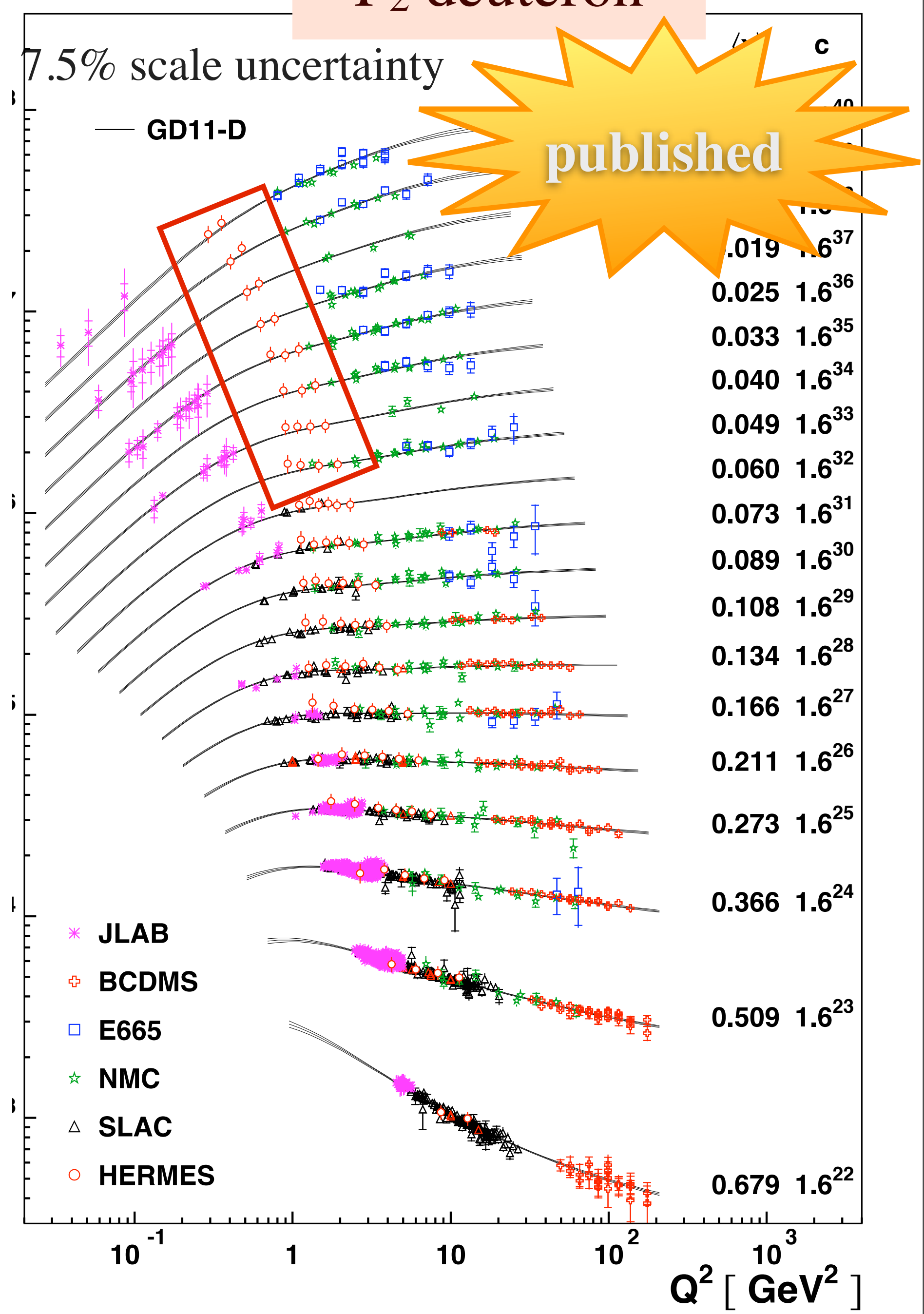


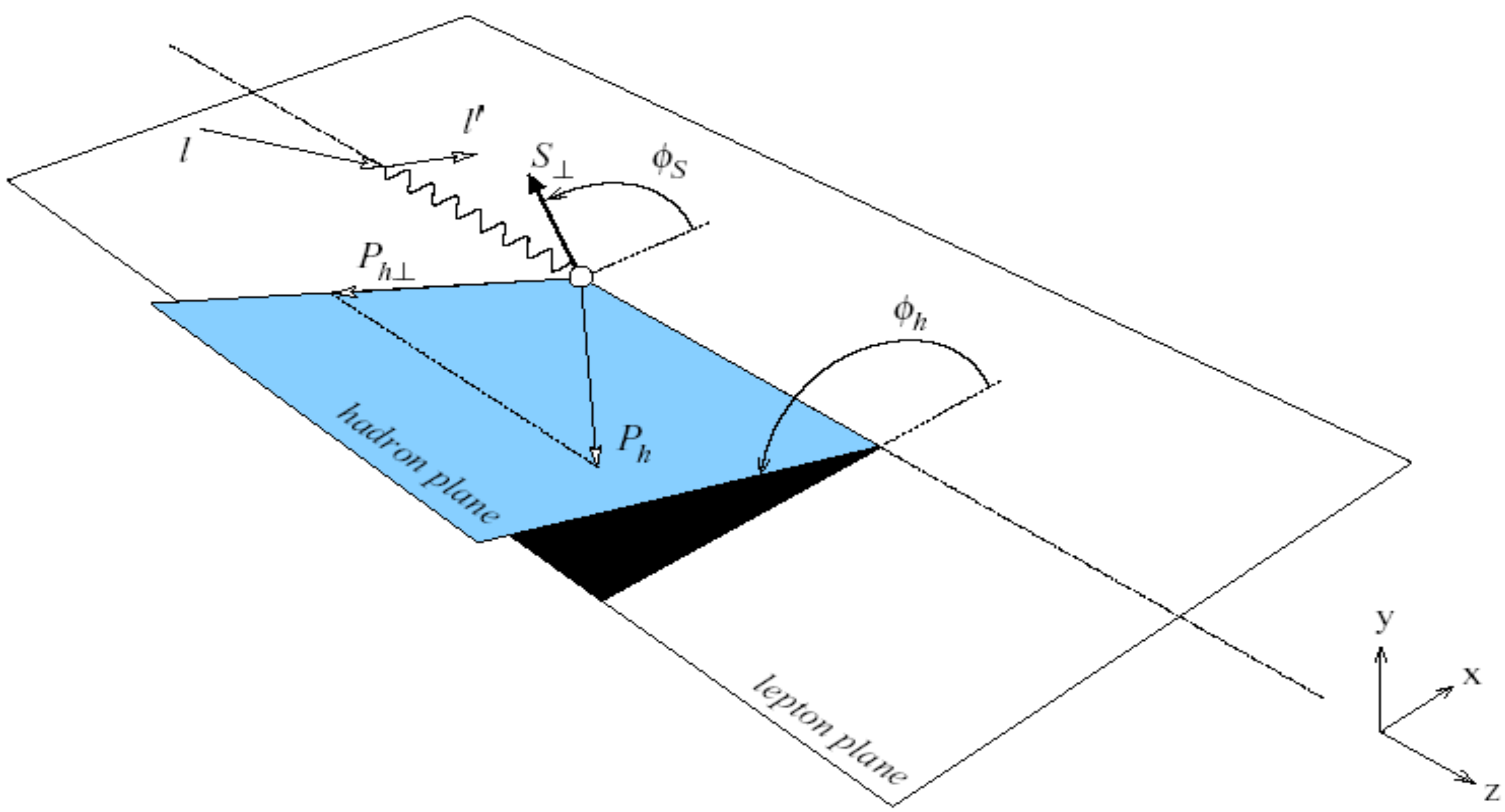
F_2 deuteron



semi-inclusive measurements

semi-inclusive DIS cross section and TMDs

$$\frac{d^6\sigma}{dx\;dy\;dz\;dP_{h\perp}^2\,d\phi\;d\phi_s} \overset{\text{leading}}{\underset{\text{twist}}{\propto}} \Big\{ F_{UU} + \epsilon\, F_{UU}^{\cos 2\phi} \cos 2\phi \Big\} + S_{||}\lambda_e \Big\{ \sqrt{1-\epsilon^2} F_{LL} \Big\} + S_\perp \Big\{ ... \Big\} + ...$$



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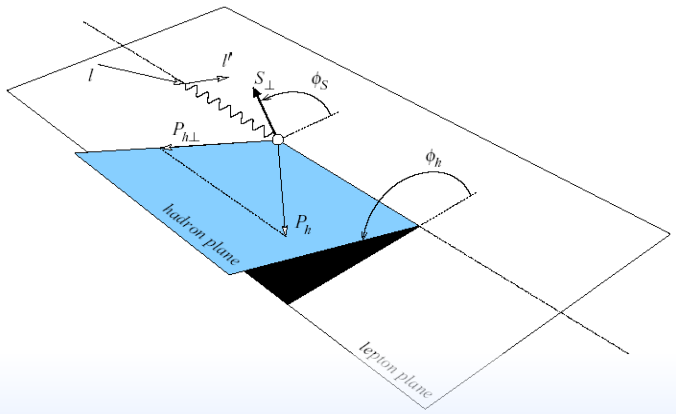

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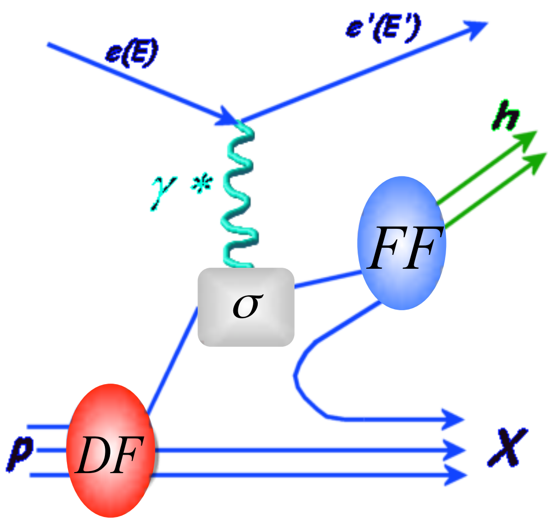

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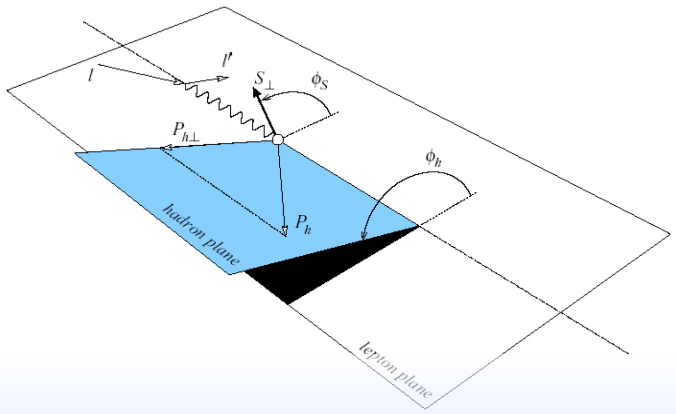

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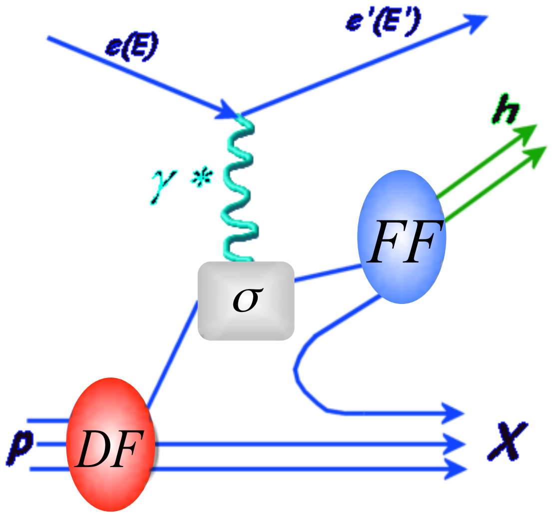
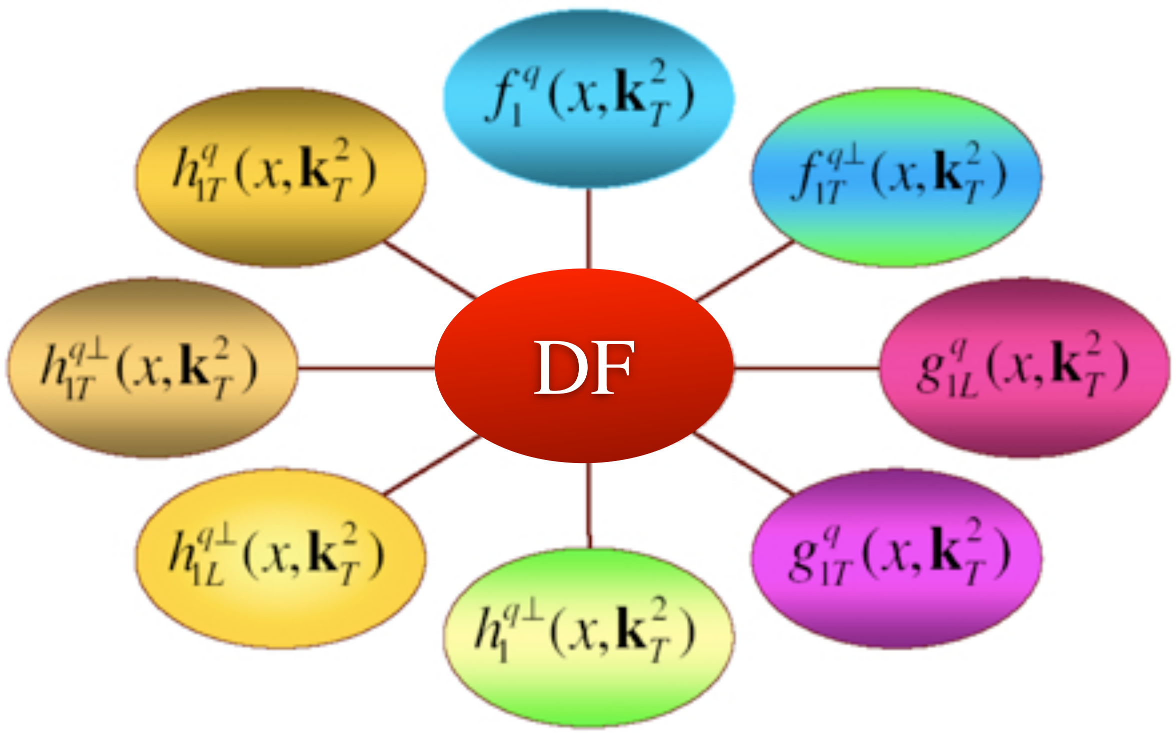


leading twist TMD DF:
parameterize the quark-flavor structure of the nucleon



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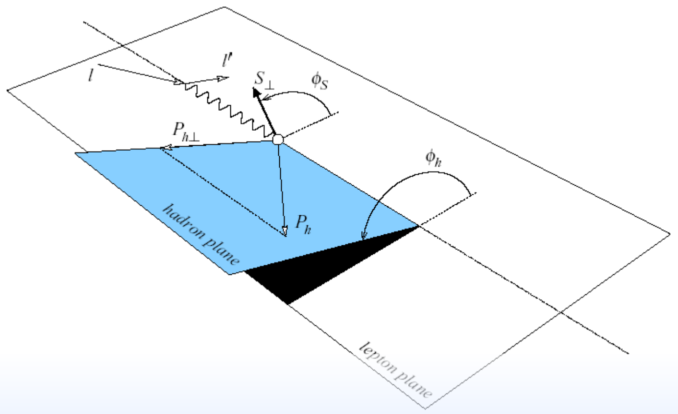

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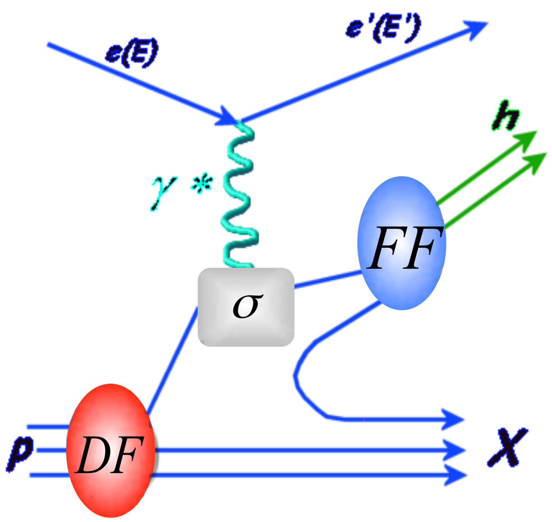
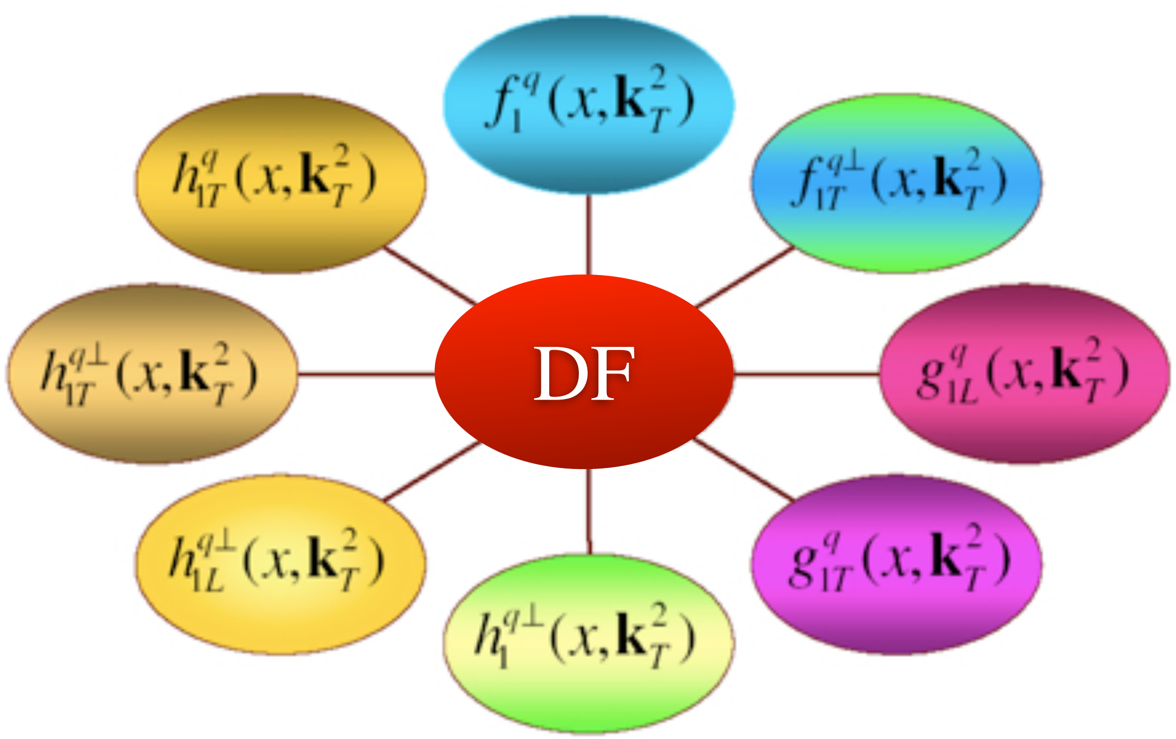
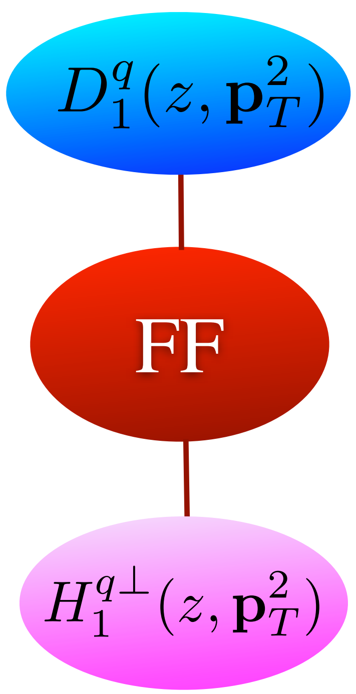


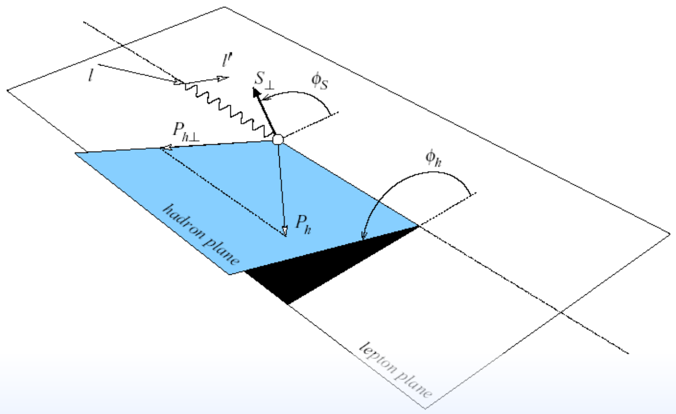
leading twist TMD DF:
parameterize the quark-flavor structure of the nucleon

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

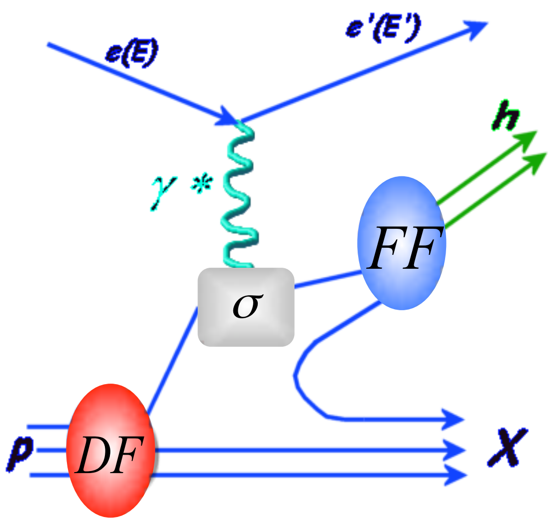




semi-inclusive DIS cross section and TMDs



$$\frac{d^6\sigma}{dx\, dy\, dz\, dP_{h\perp}^2\, d\phi\, d\phi_s} \overset{\text{leading}}{\underset{\text{twist}}{\propto}} \left\{ F_{UU} + \epsilon\, F_{UU}^{\cos 2\phi} \cos 2\phi \right\} + S_{||}\lambda_e \left\{ \sqrt{1-\epsilon^2} F_{LL} \right\} + S_{\perp}\left\{ ... \right\} + ...$$



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

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number densities for the conversion of a quark of a certain type to a specific hadron

JHEP 05 (2011) 126

PRL 94 (2005) 012002
PLB 693 (2010) 11

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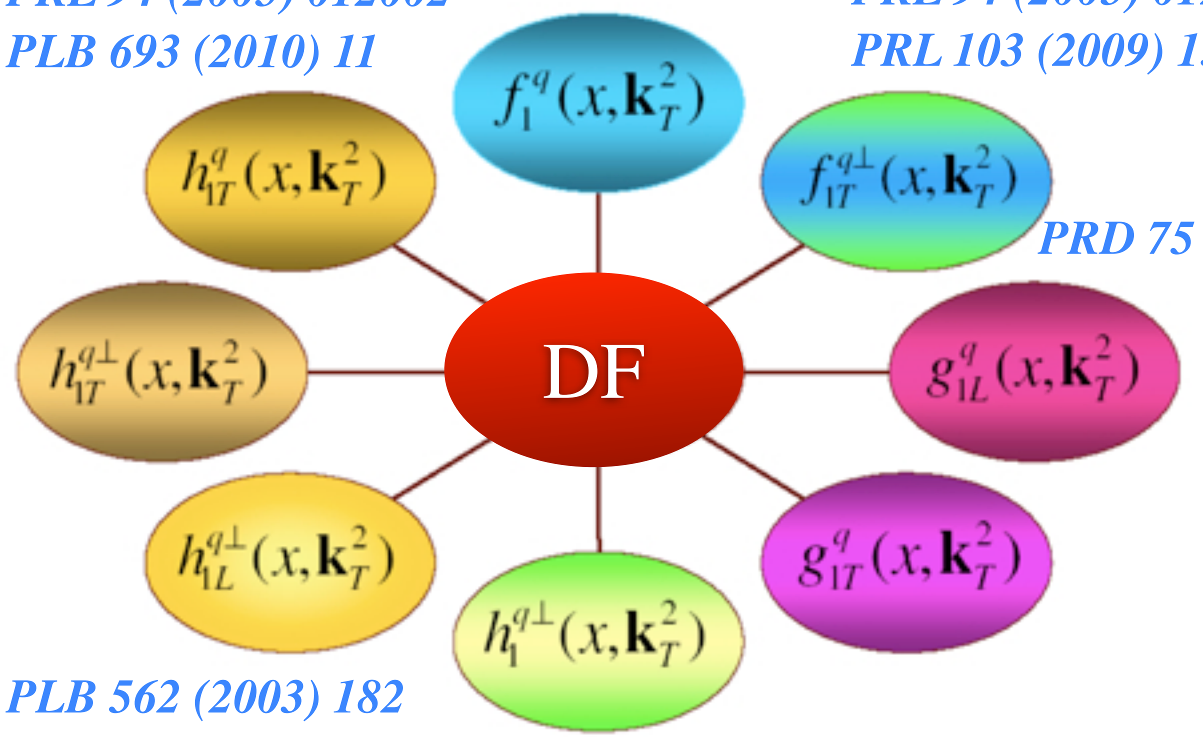
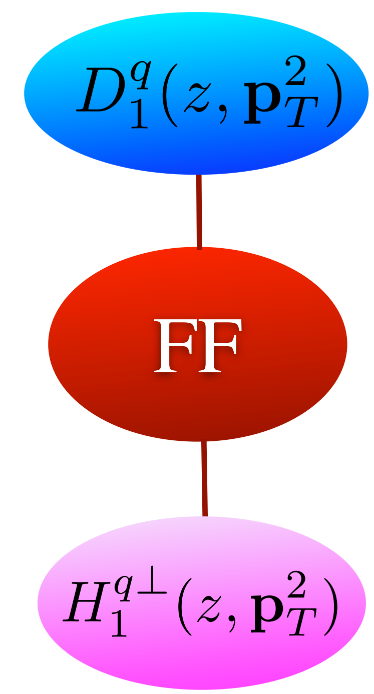
PRL 103 (2009) 152002

PRD 75 (2007) 012007

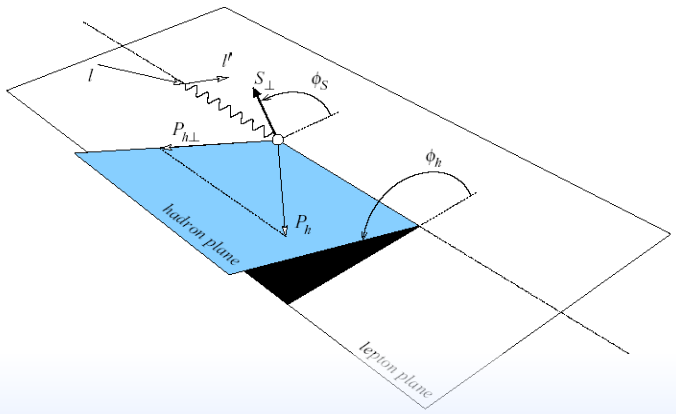




PLB 562 (2003) 182
PRL 84 (2000) 4047

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

semi-inclusive DIS cross section and TMDs



$f_1 \otimes D_1$ $\quad h_1^\perp \otimes H_1^\perp$ $\quad g_{1L} \otimes D_1$

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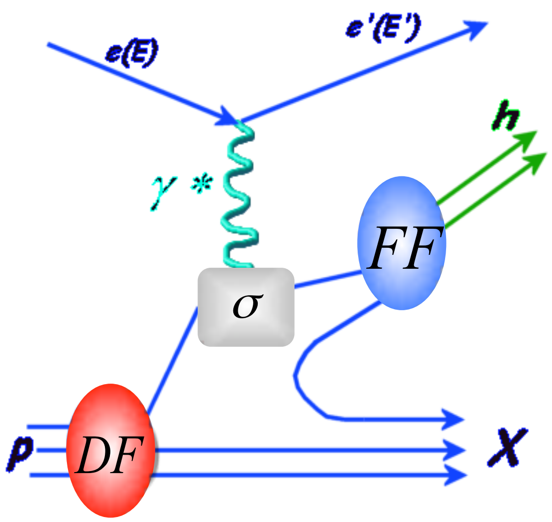

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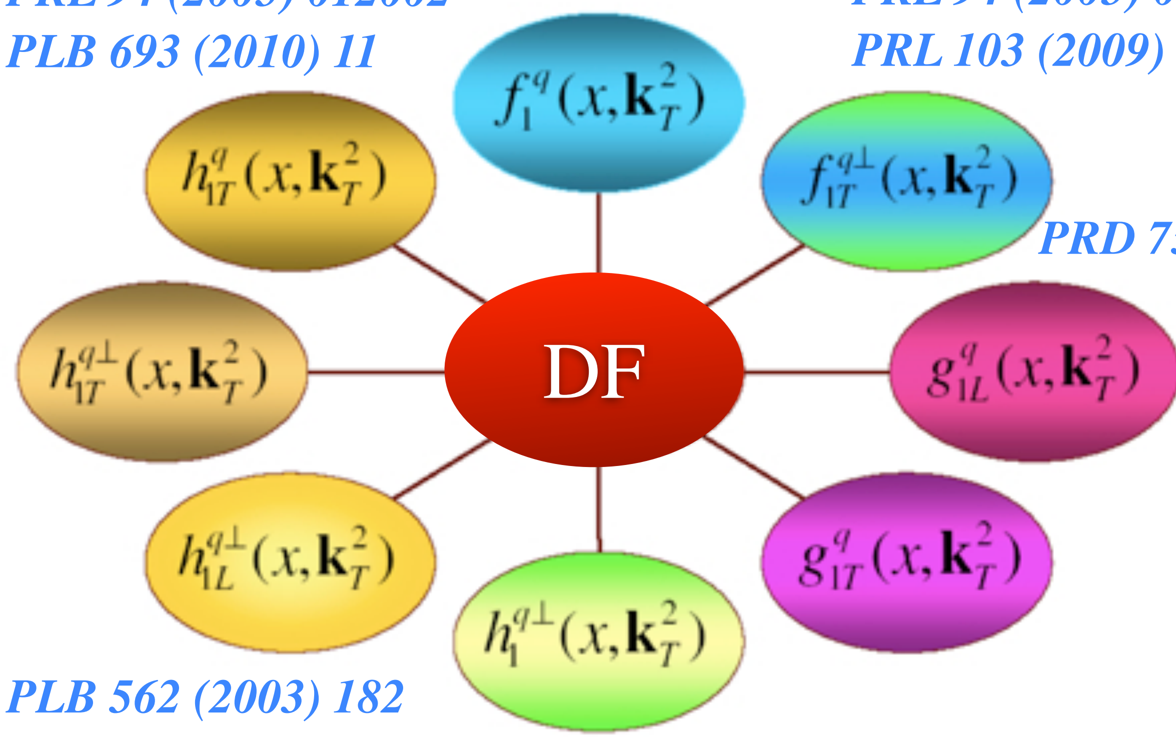

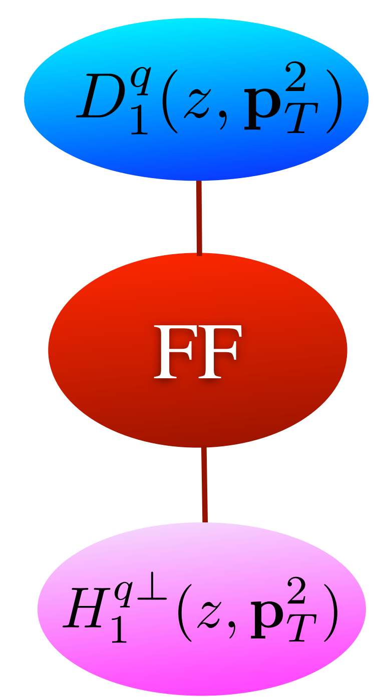

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HERMES: access to all TMDs thanks to the polarized beam and target

fragmentation in vacuum

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

$$f_1 =$$ 

fragmentation in vacuum

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

$$f_1 =$$ 

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

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

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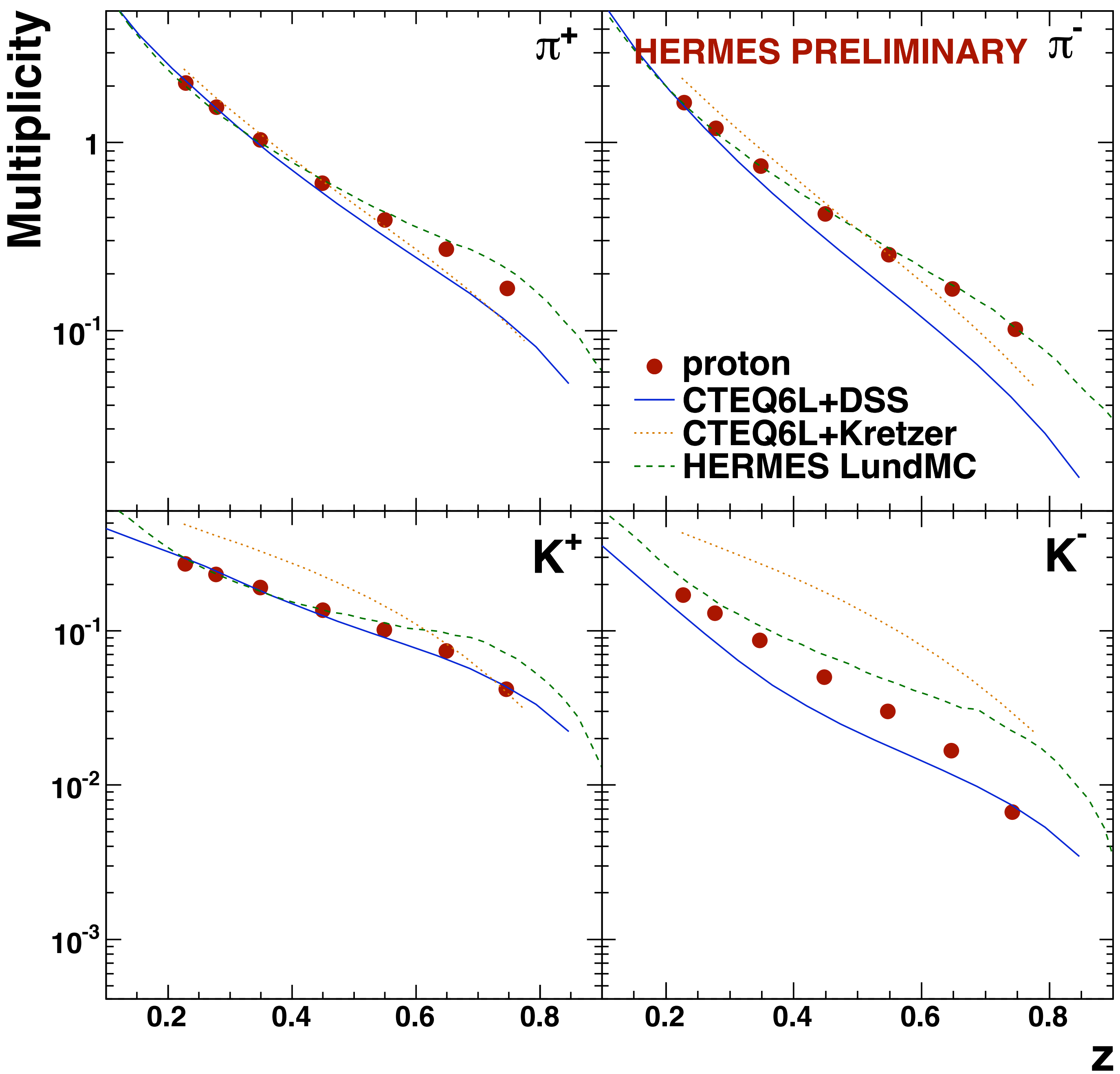
- ☛ fair agreement for positive hadrons
- ☛ disagreement for negative hadrons



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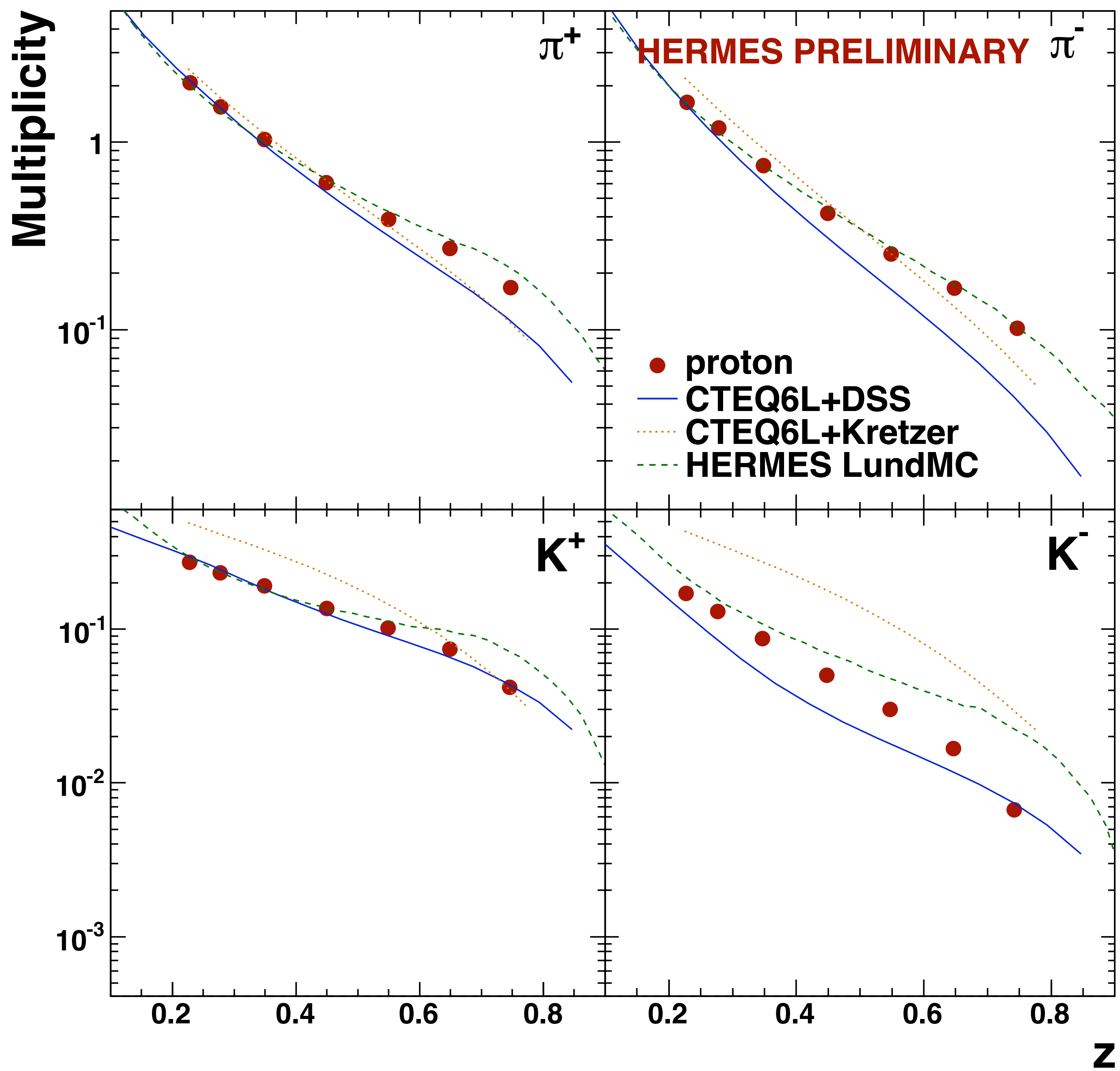
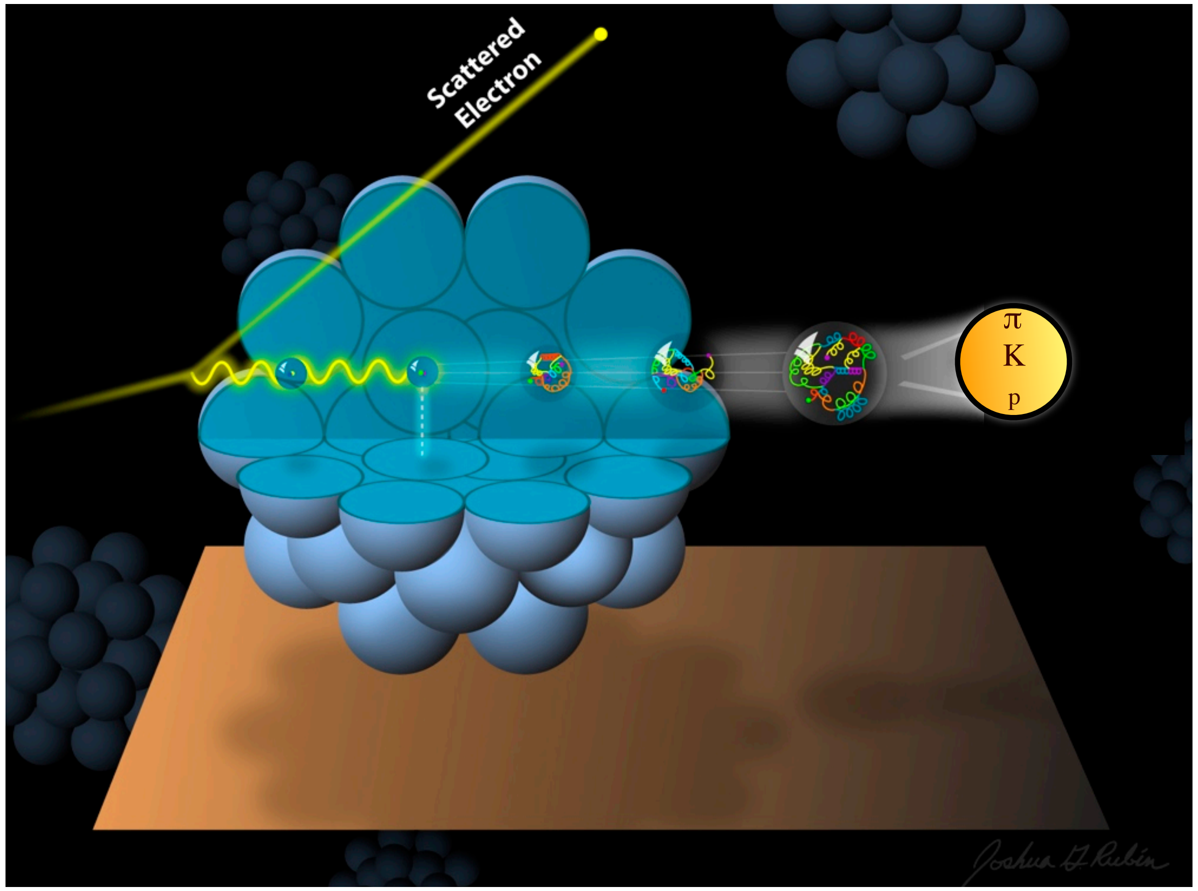
✓ inclusion of the data in the future global analyses can give an improved knowledge on FF



fragmentation in nuclear matter



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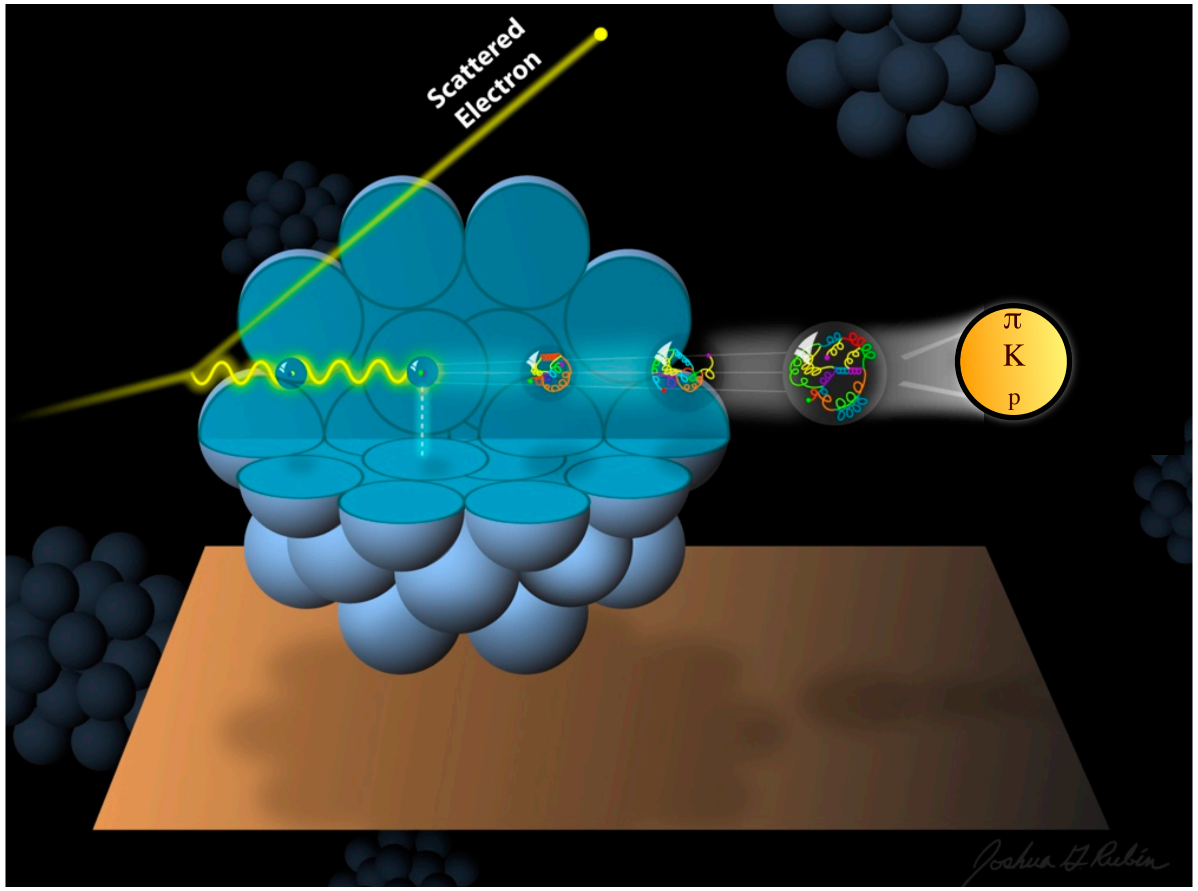

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☛ the struck quark or the $q\bar{q}$ pair propagate through a “cold” nuclear medium

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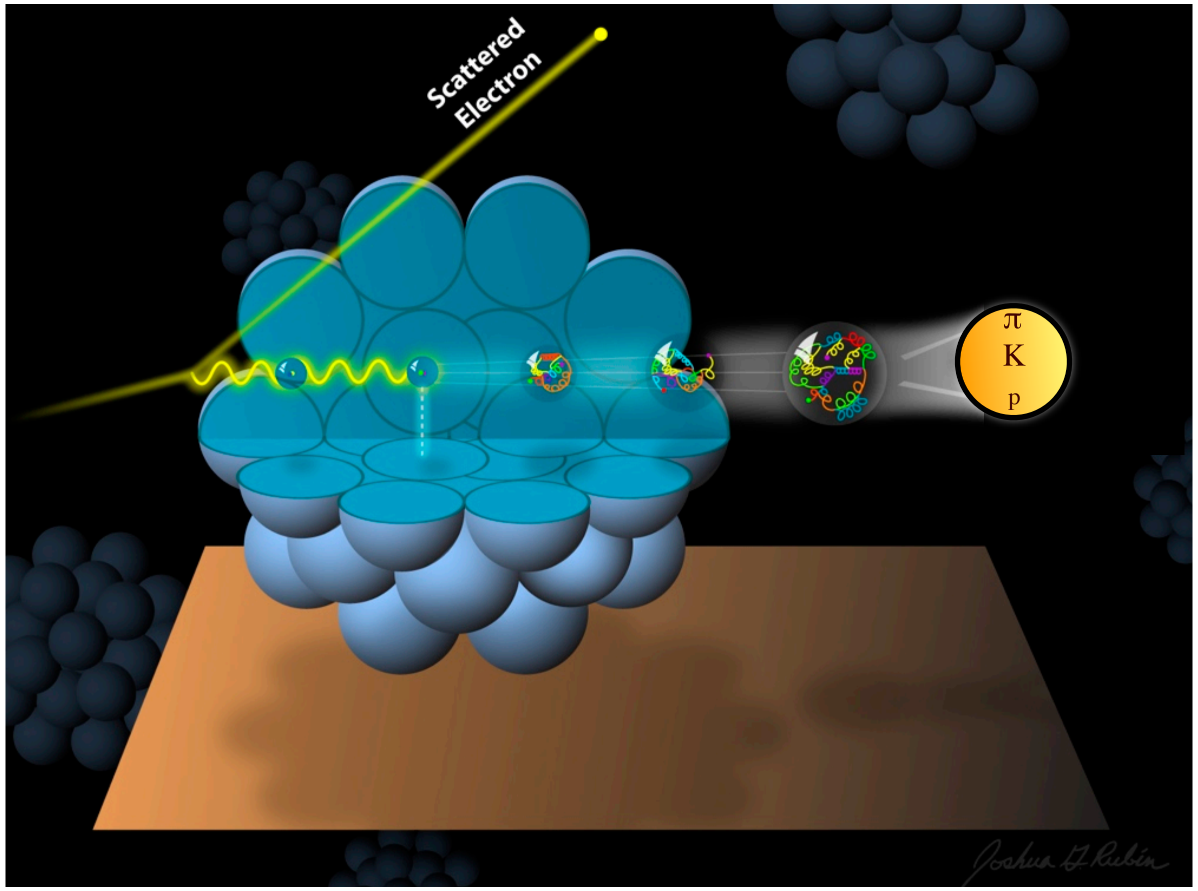

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☛ interaction signature: reduction of the number of hadrons per DIS event and per nucleon

$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu, Q^2, z, p_t^2)}{N^e(\nu, Q^2)}\right)_A}{\left(\frac{N^h(\nu, Q^2, z, p_t^2)}{N^e(\nu, Q^2)}\right)_D}$$

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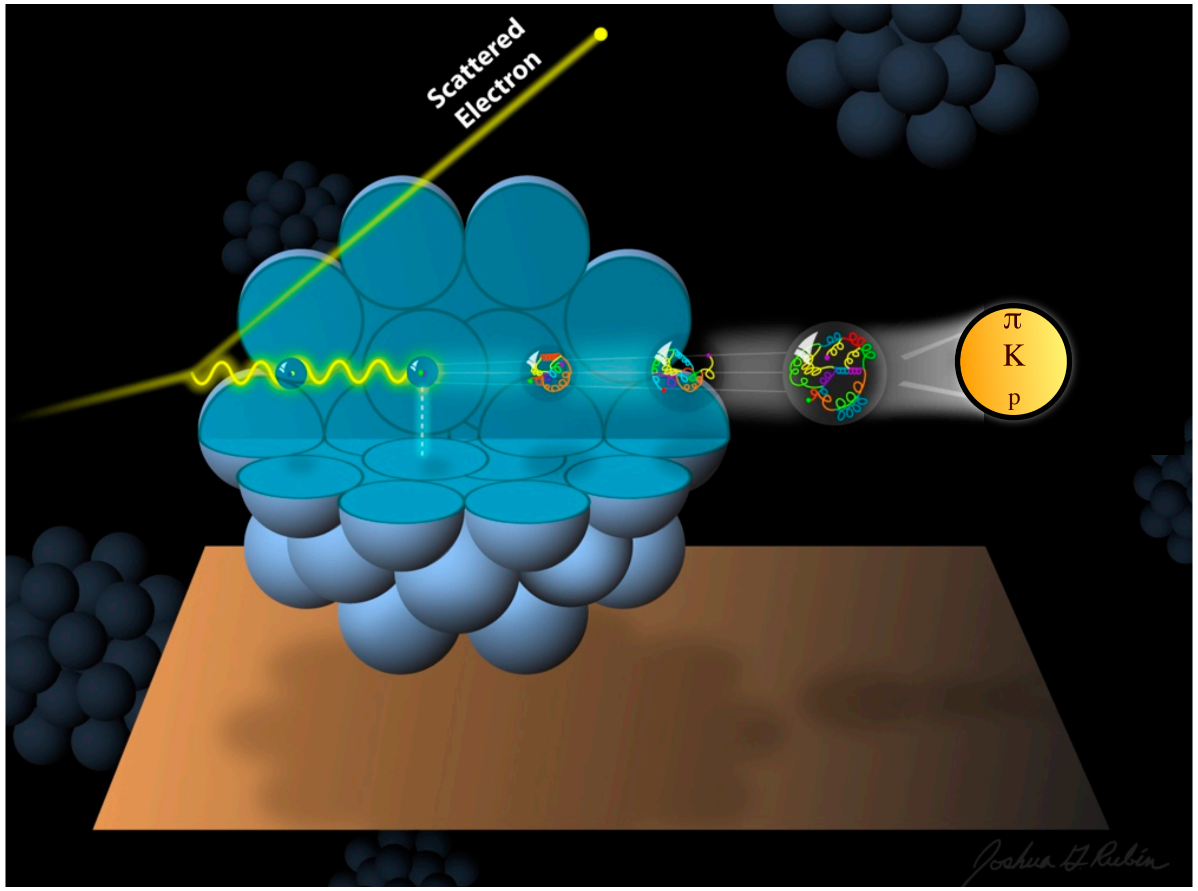

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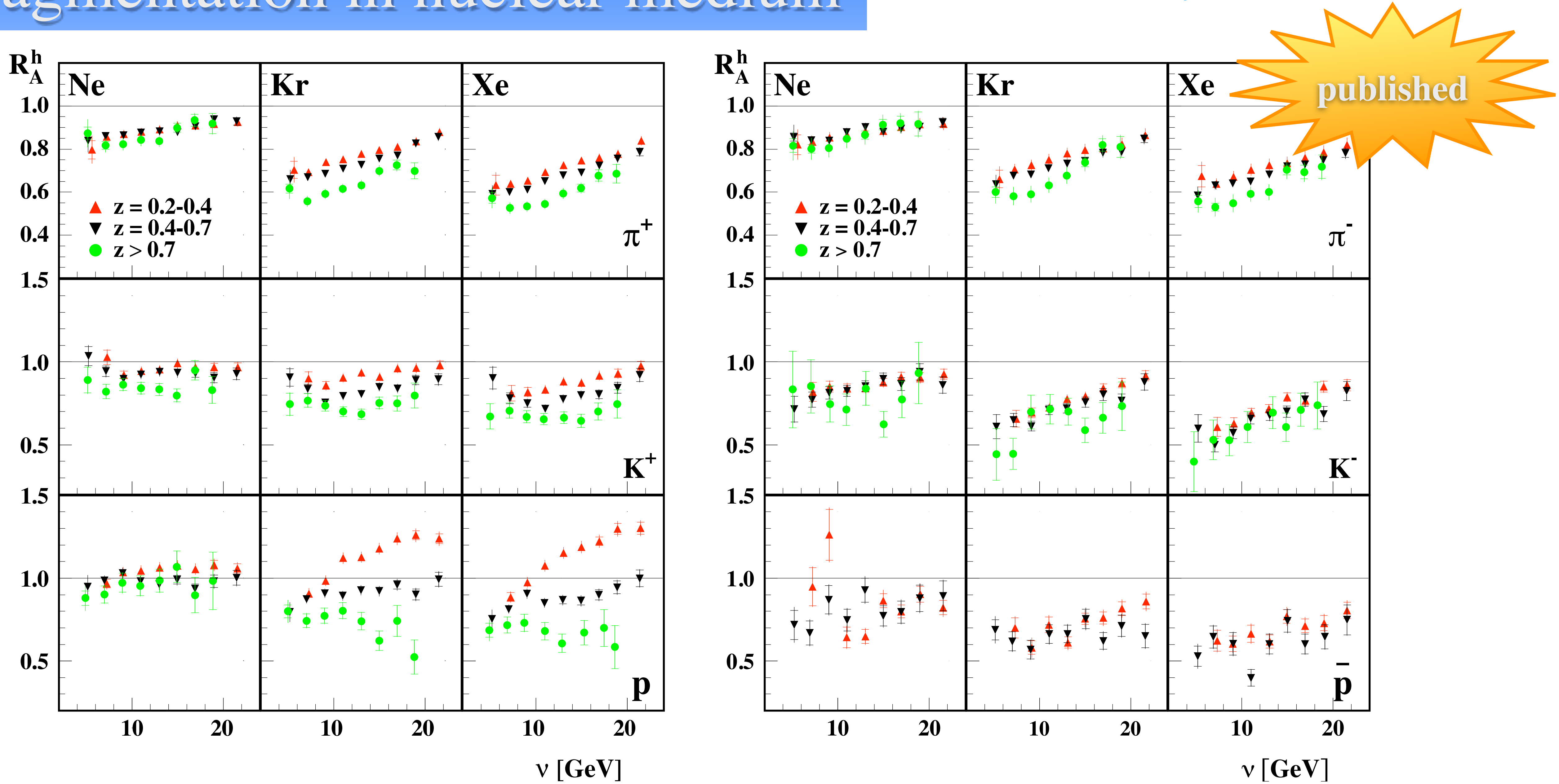
✓ leptonic probes: well determined energy and momentum transferred to the quark

✓ useful for understanding the fundamental aspects of hadronization

✓ input for calculation of nuclear parton distributions

fragmentation in nuclear medium

- Eur. Phys. J. A 47 (2011) 113



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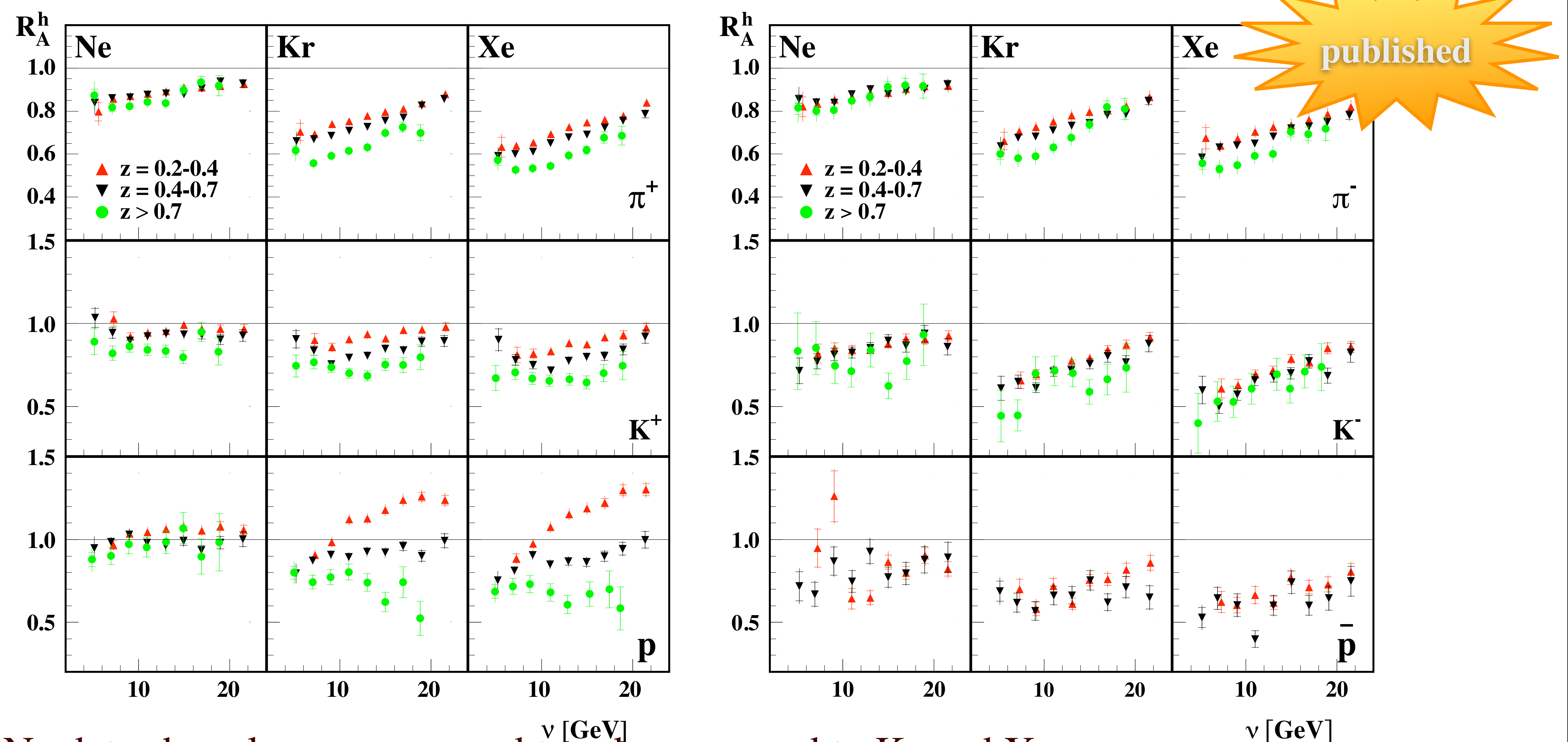
- Eur. Phys. J. A 47 (2011) 113



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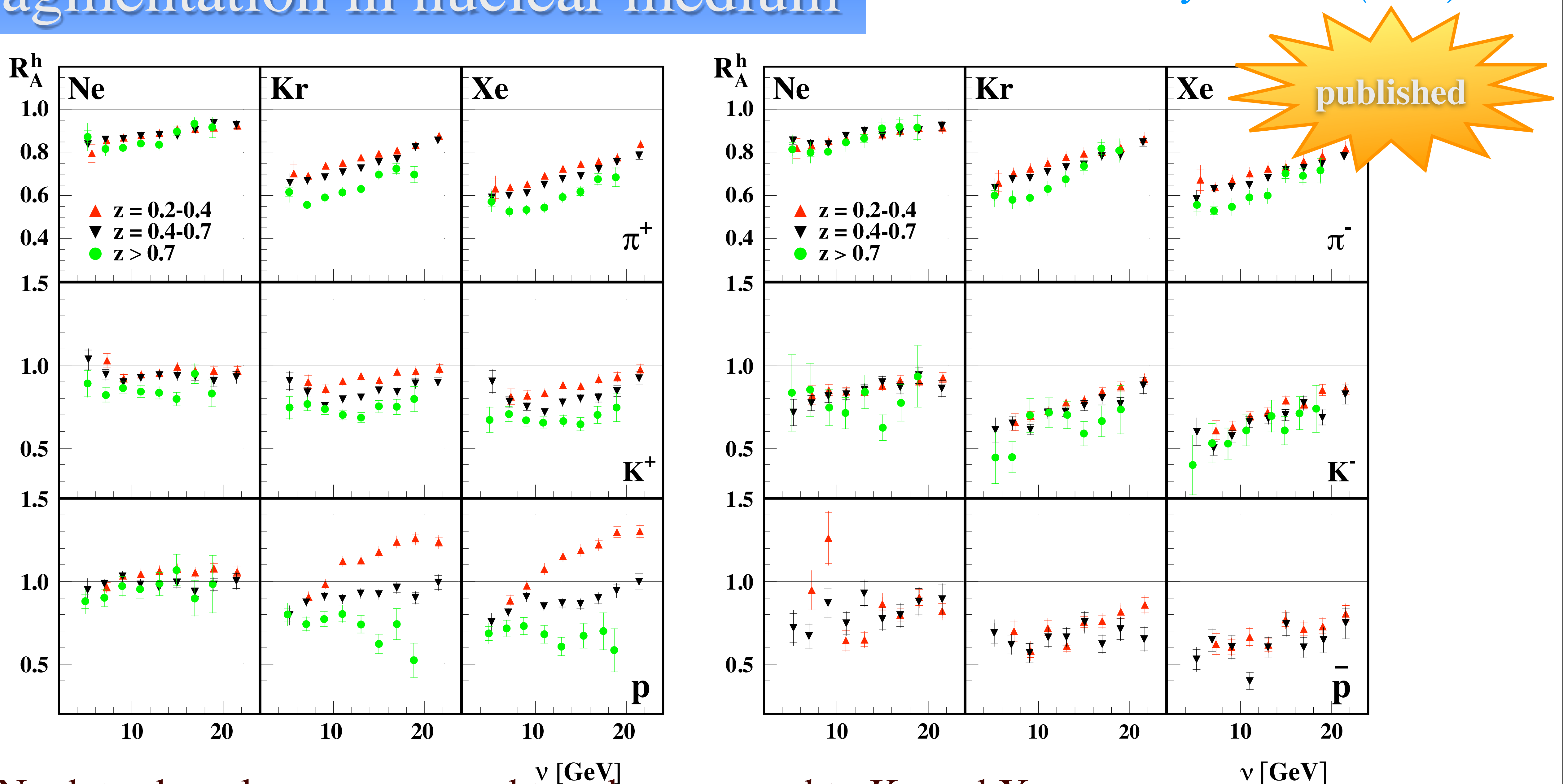
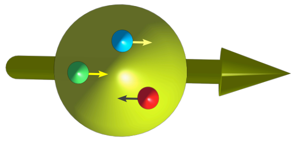
- Eur. Phys. J. A 47 (2011) 113



- Ne data show less pronounced trends compared to Kr and Xe
- π^+, π^-, K^-: increase of R_A with virtual photon energy ν
- K^+ : clear increase of R_A with ν for the lowest z-slice and flatter behavior for higher z
- $\bar{p}$: weak ν-dependence
- p: R_A exceeding unity at higher values of ν and low **z** (apart from hadronization, different production mechanisms contribute)

hadron-charge difference asymmetry A_1

$\sigma_{LL} \propto g_{1L} \otimes D_1$

$g_{1L} =$ 

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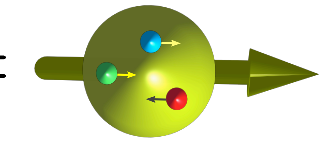
$g_{1L} =$ 

H

$$A_{1p}^{h^+-h^-} = \frac{4\Delta u_v(x) - \Delta d_v(x)}{4u_v(x) - d_v(x)}$$

D

$$A_{1d}^{h^+-h^-} = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$$

- ☛ assumption: charge conjugation symmetry in fragmentation: $D_q^h(z) = D_{\bar{q}}^h(z)$
  - ☛ cancellation of fragmentation functions in the charge difference asymmetry

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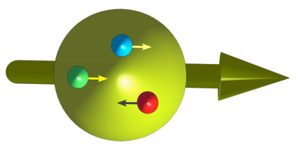
$g_{1L} =$ 

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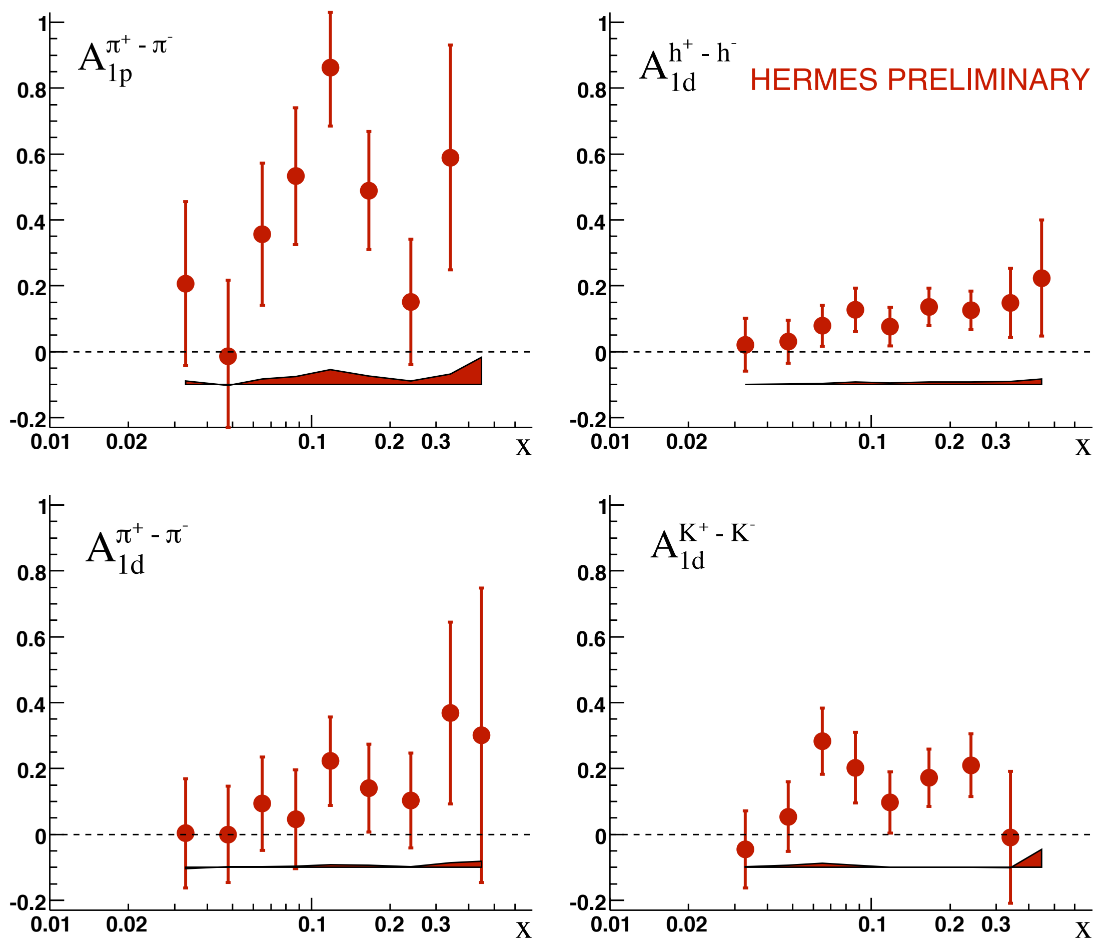

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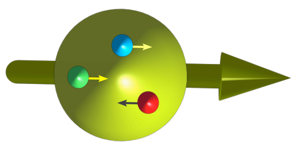
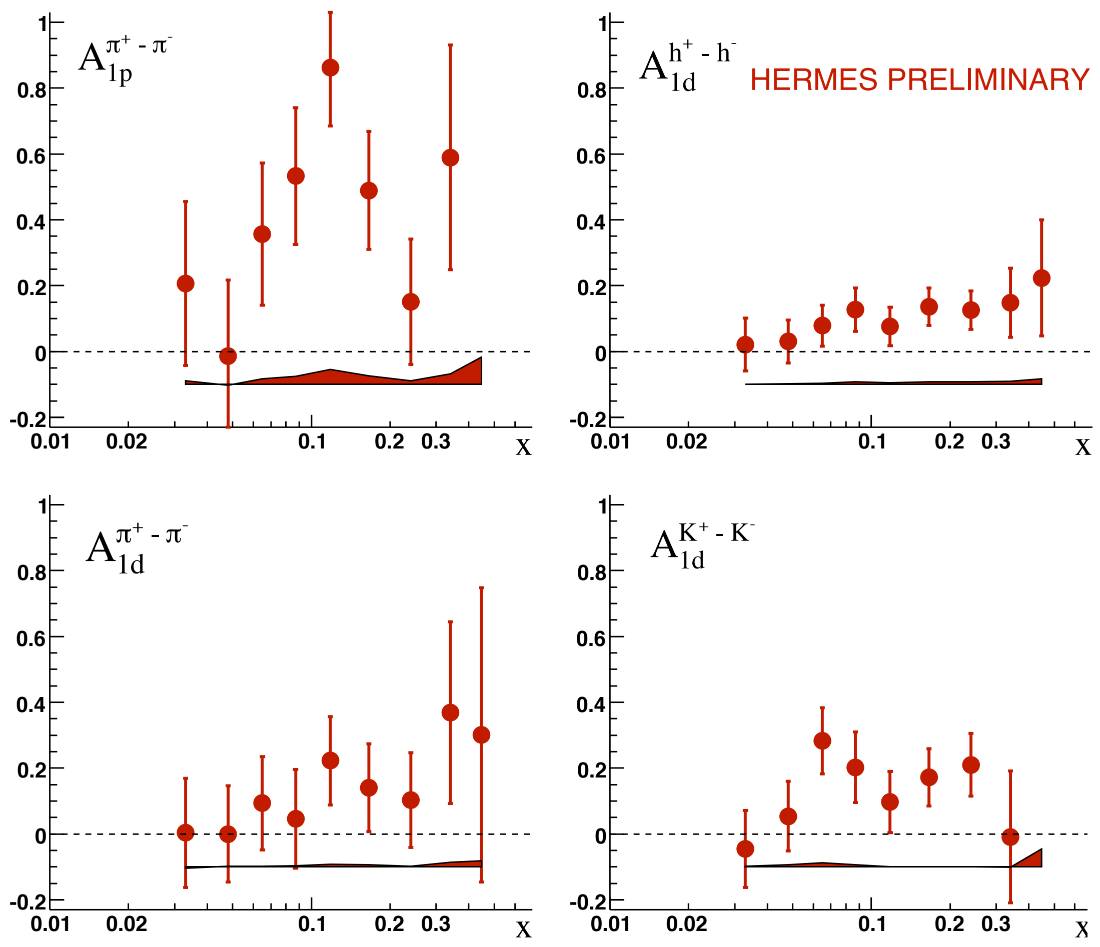
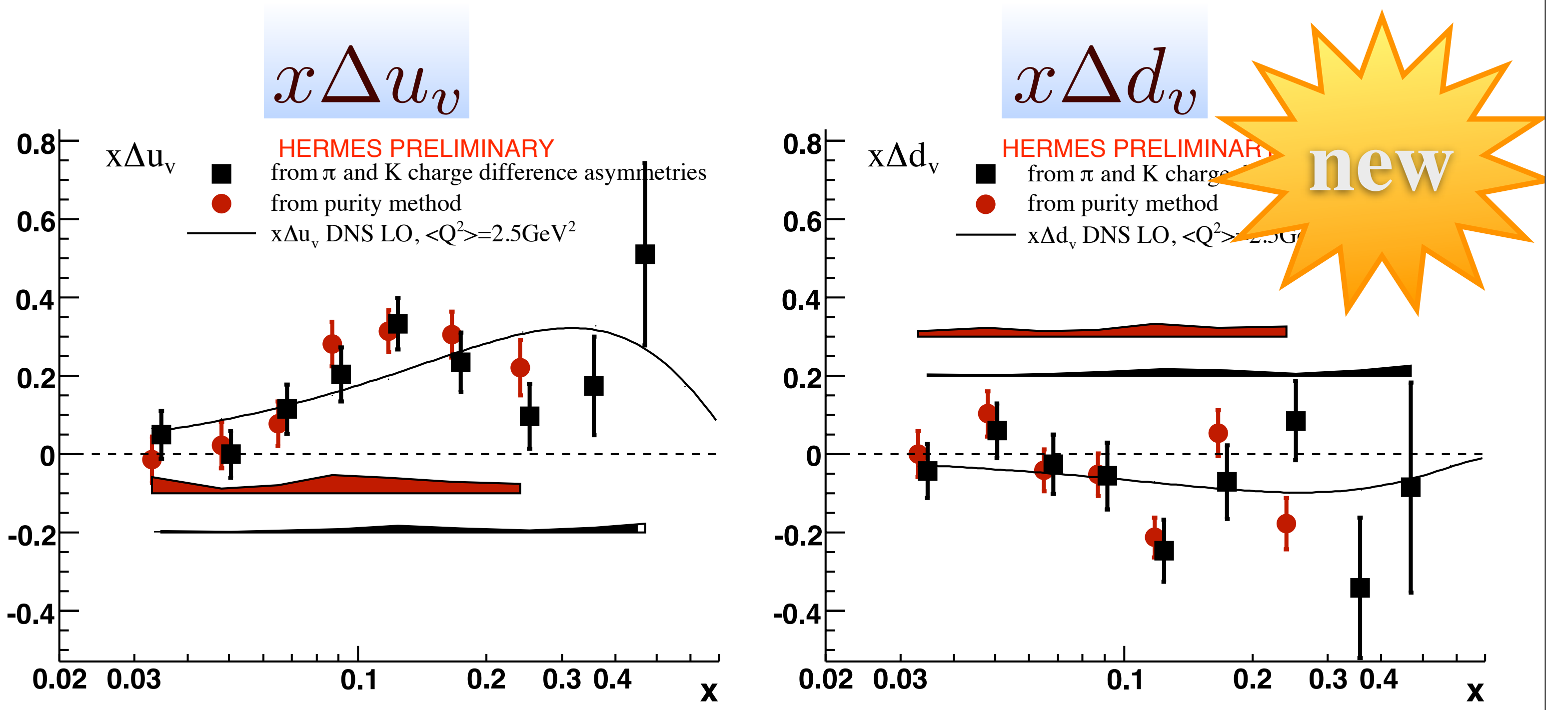
$g_{1L} =$ 



- **assumption**: charge conjugation symmetry in fragmentation: $D_q^h(z) = D_{\bar{q}}^h(z)$
  - cancellation of fragmentation functions in the charge difference asymmetry
- these equations can be solved for the flavor separated polarized valence quark densities

$x\Delta u_v$ $x\Delta d_v$



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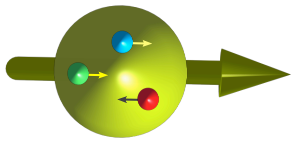
$g_{1L} =$ 

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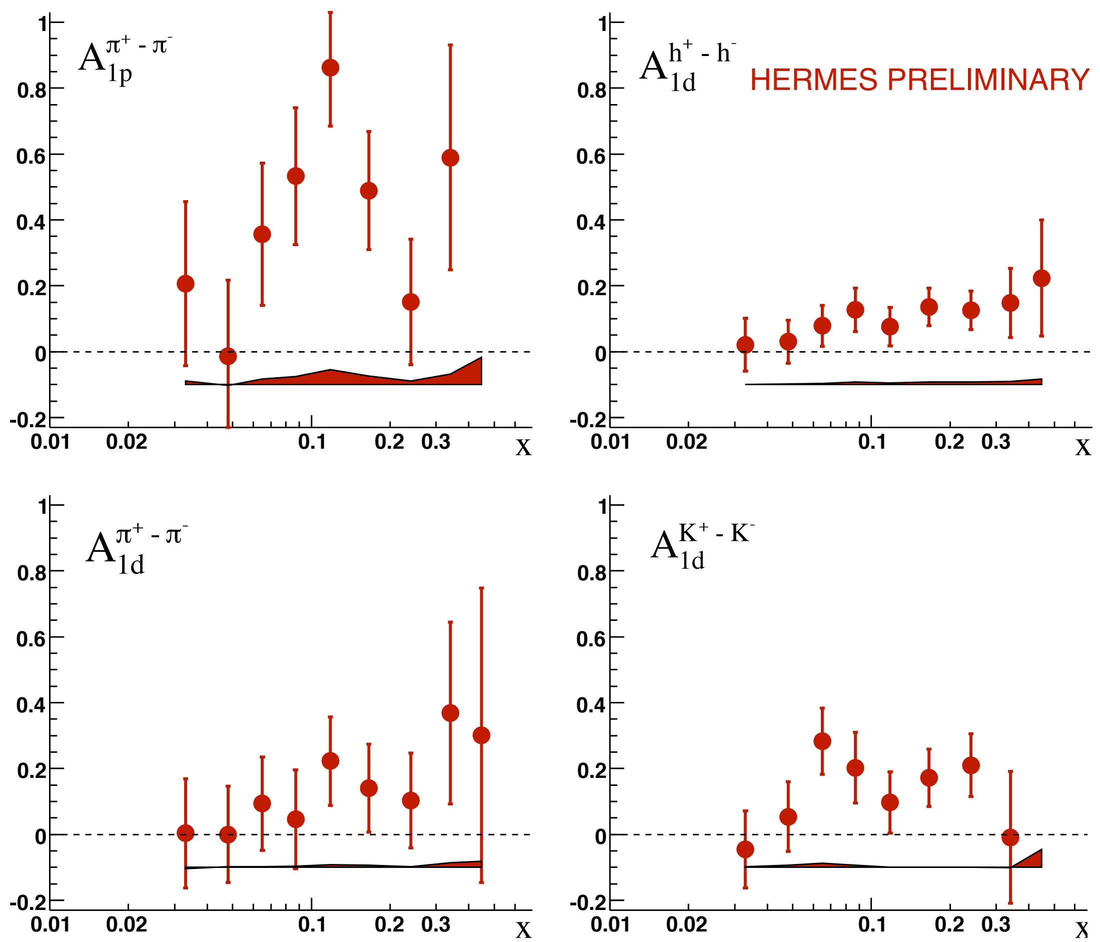

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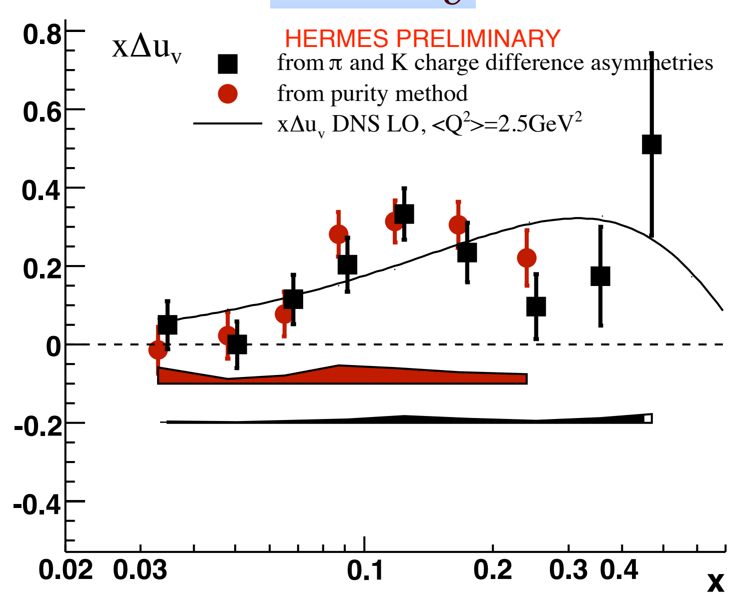
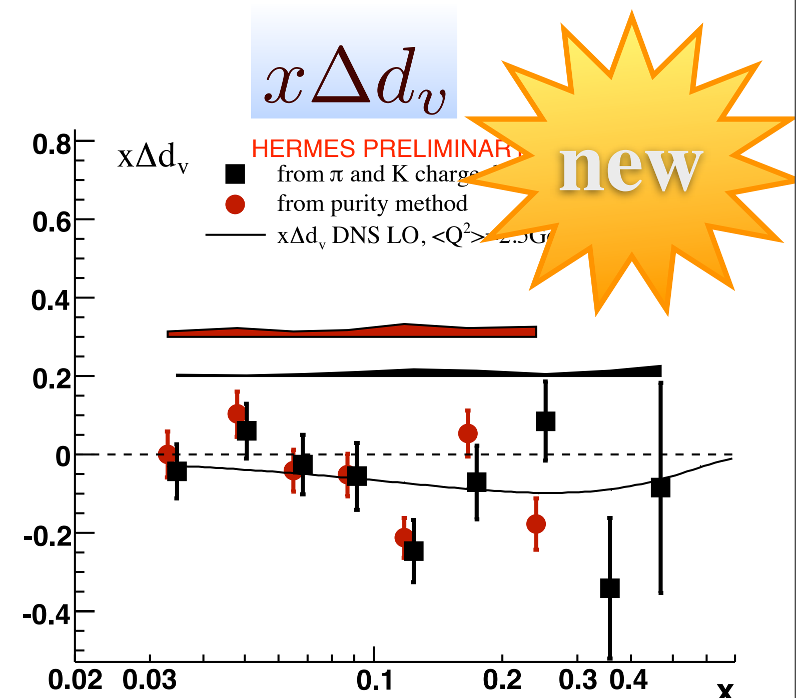
✓good agreement between results from current analysis and purity method (- HERMES collaboration - *Phys. Rev. D 71 (2005) 012003*) involving different assumptions

$x\Delta u_v$



$x\Delta d_v$



fragmentation involving quark's transverse degrees of freedom

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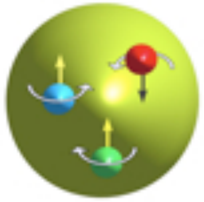
$h_1^{\perp} =$ 

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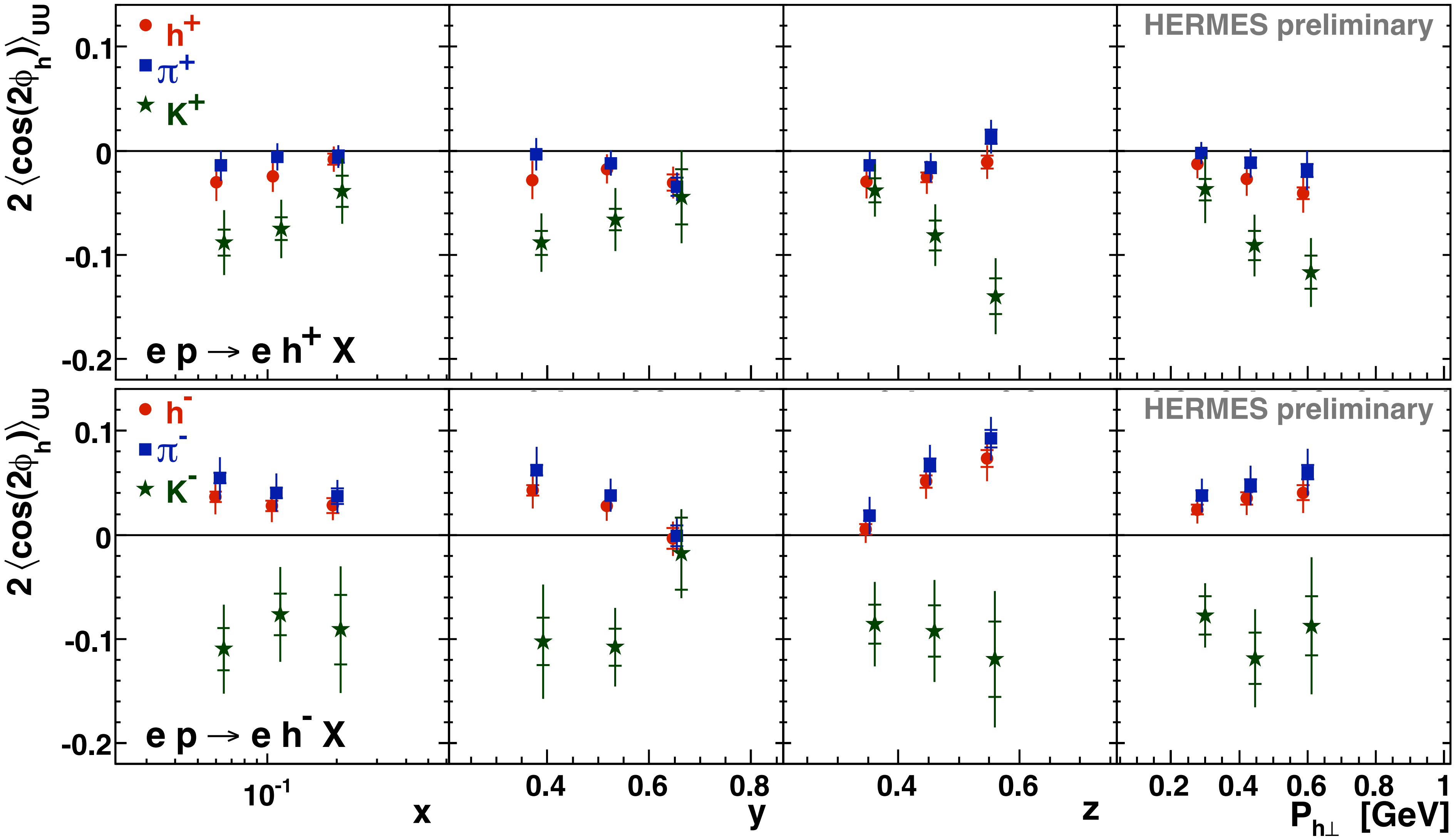

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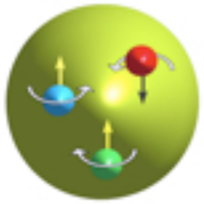
$h_1^\perp =$ 

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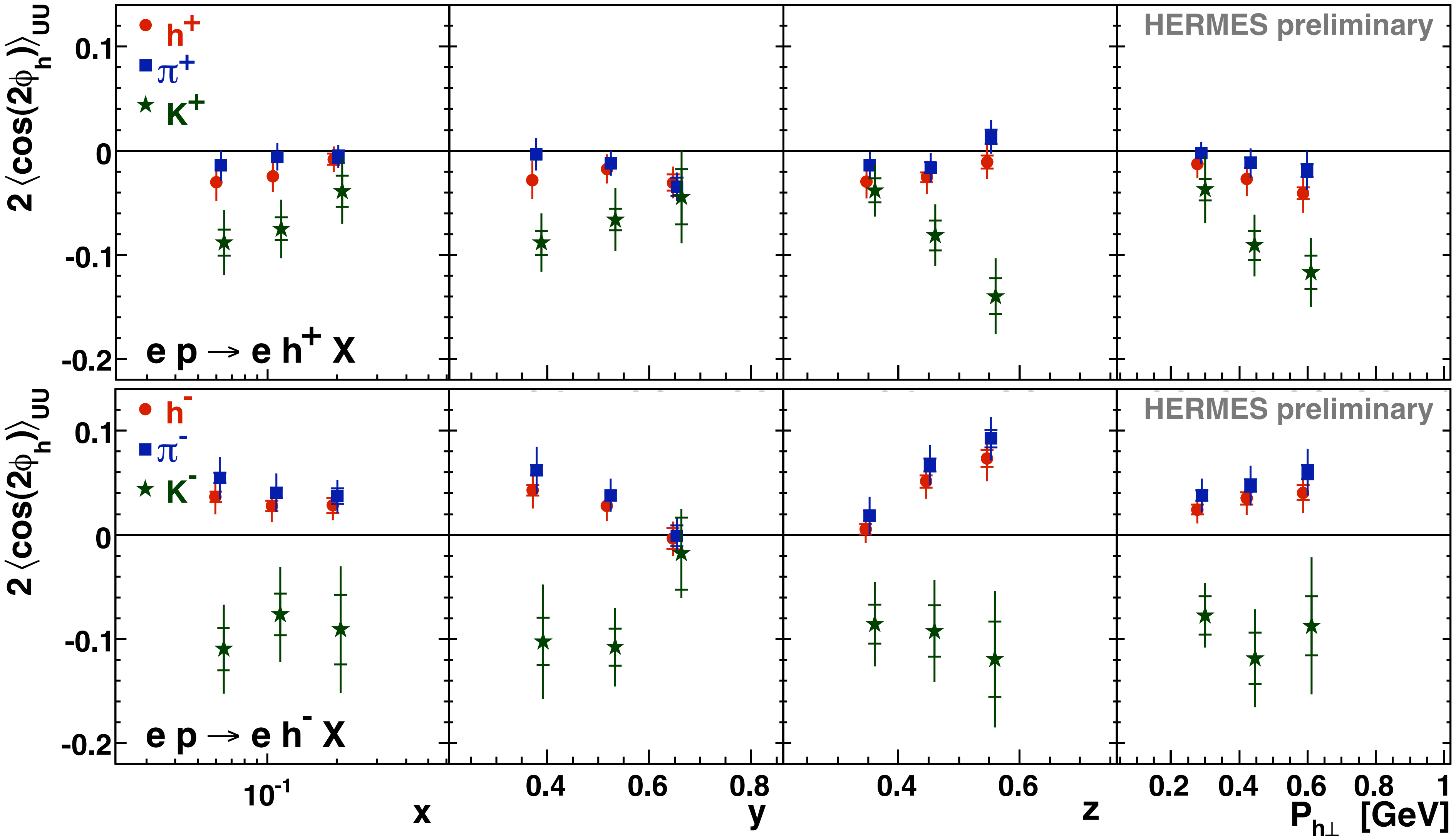

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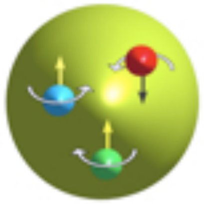
$h_1^{\perp} =$ 

✓ negative asymmetry for π+ and positive for π-

☛ from previous publications (*PRL 94 (2005) 012002, PLB 693 (2010) 11-16*):

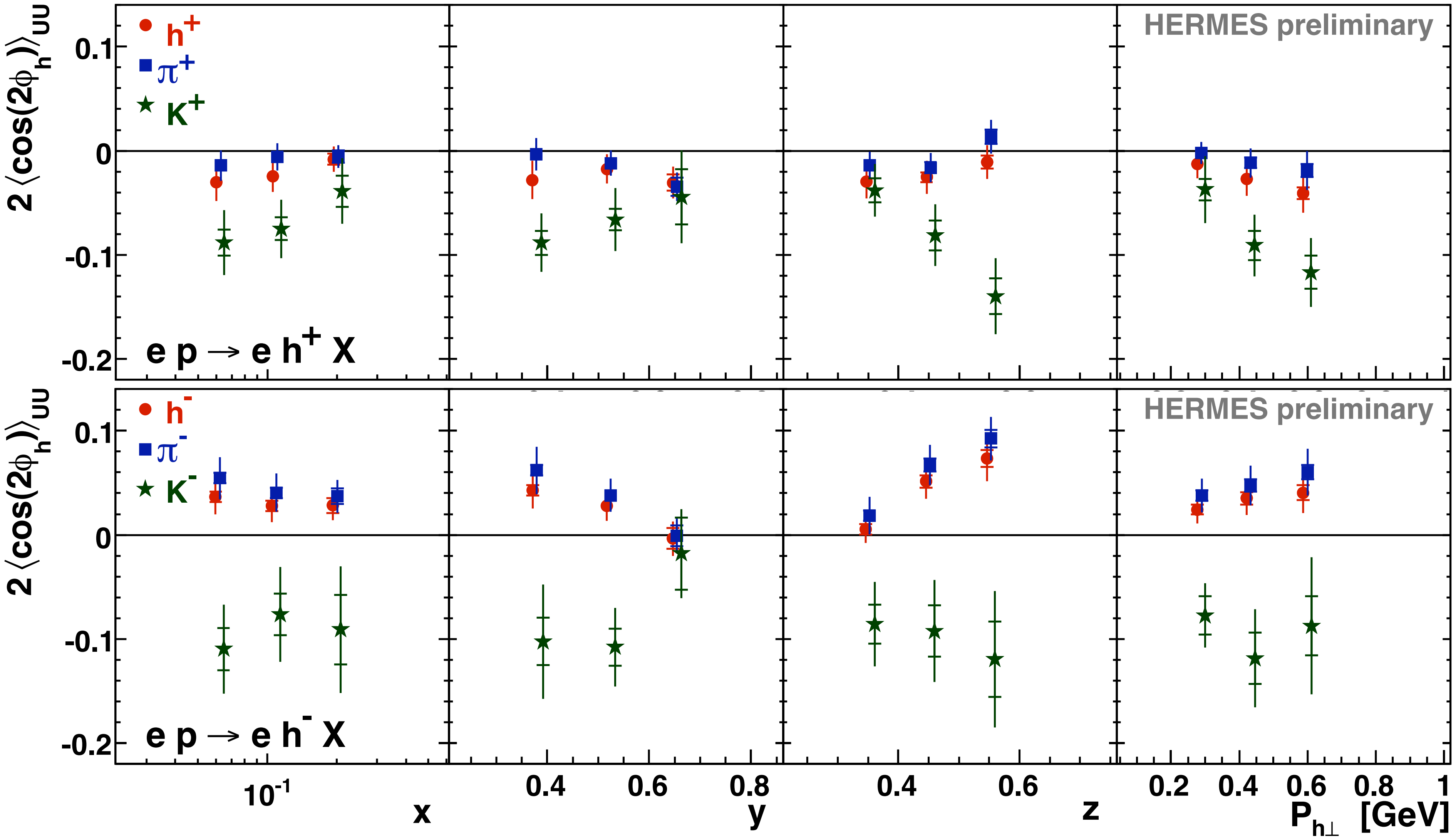
$$H_1^{\perp,u\to\pi^+} = -H_1^{\perp,u\to\pi^-}$$

☛ data support Boer-Mulders DF $h_1^{\perp}$ of same sign for u and d

✓ K- and K+ : striking differences w.r.t. pions

☛ role of the sea in DF and FF

fragmentation involving quark's transverse degrees of freedom



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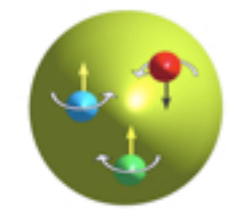
$h_1^{\perp} =$ 

close to submission

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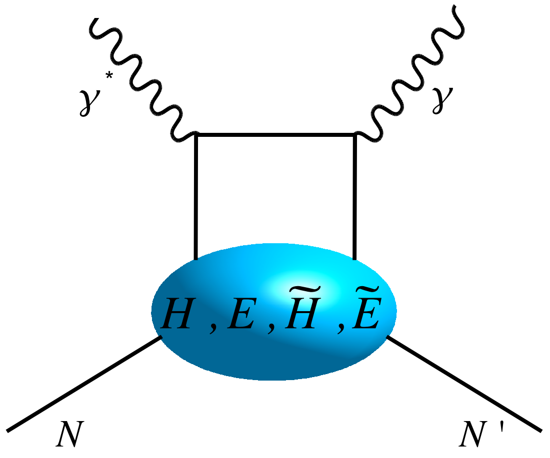
exclusive measurements

DVCS

- theoretically the cleanest probe of GPDs

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



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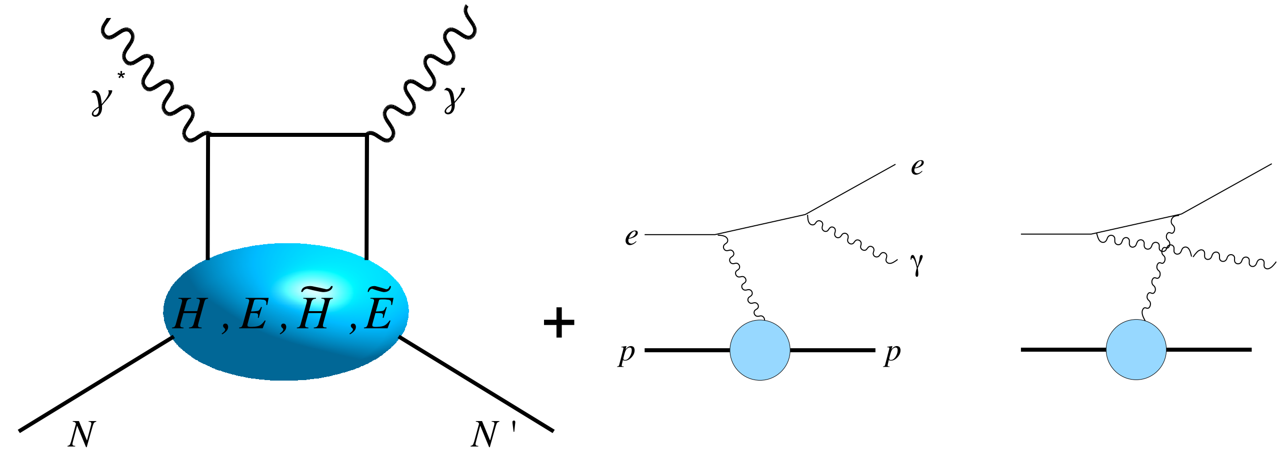

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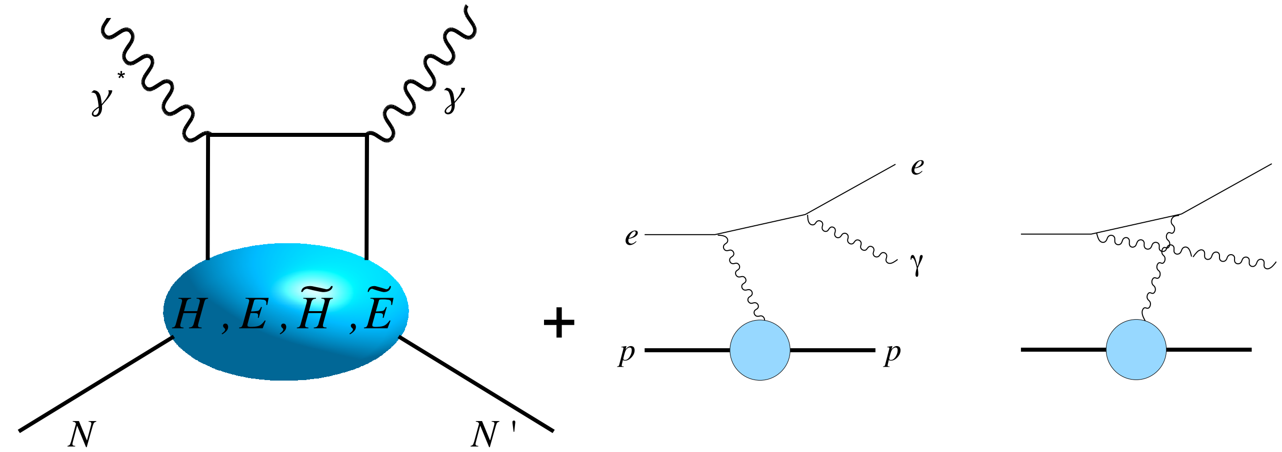

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$\sigma_{\rm xy}$

beam: λ_l

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

Bethe–Heitler   interference   DVCS

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

DVCS

- ☛ theoretically the cleanest probe of GPDs

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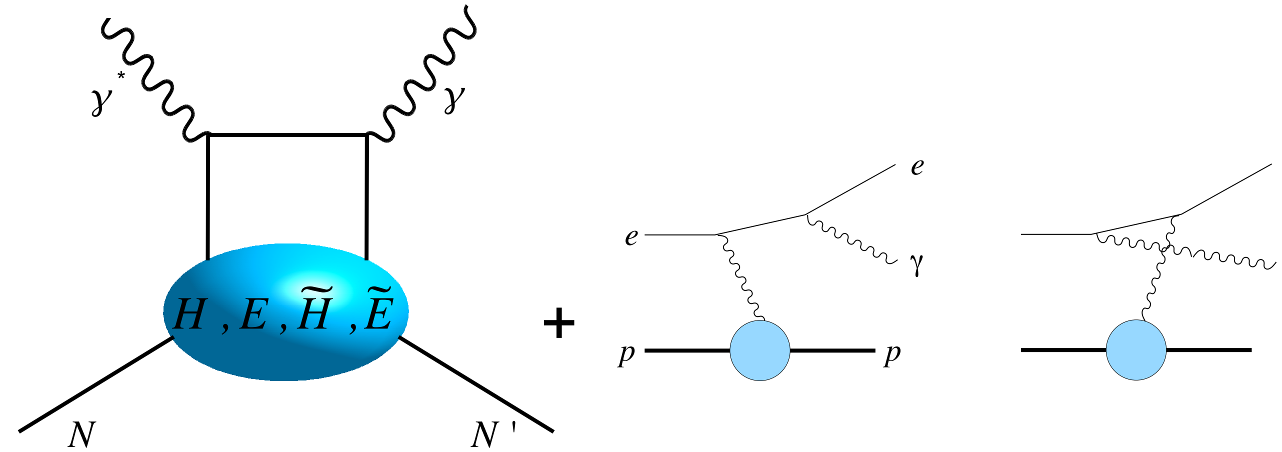


$\sigma_{\rm xy}$

beam: λ_l

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

Bethe–Heitler

beam charge: e_ℓ

interference

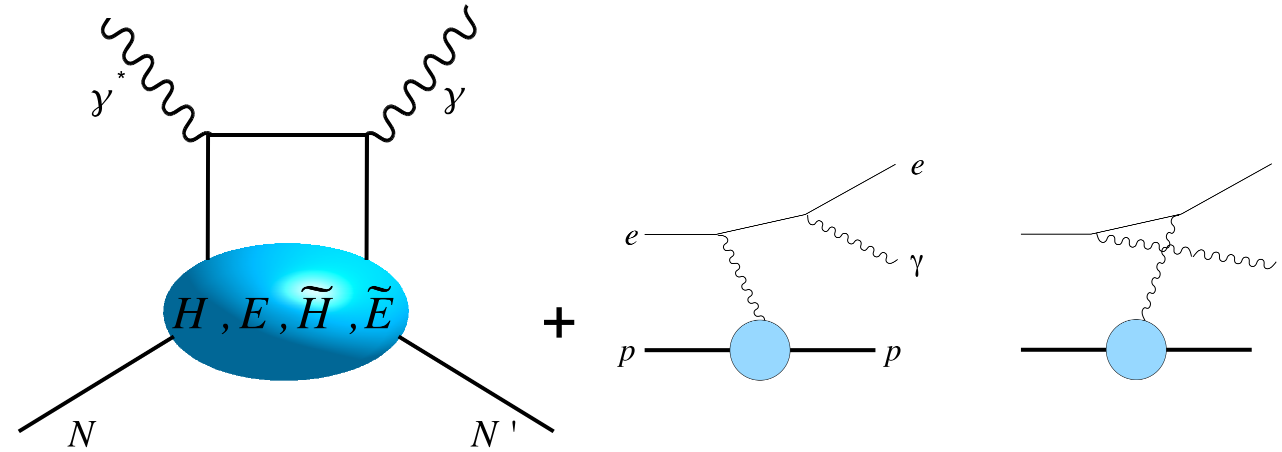
DVCS

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

DVCS

☛ theoretically the cleanest probe of GPDs

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



Bethe–Heitler

beam charge: e_ℓ

interference

DVCS

σ_{xy}

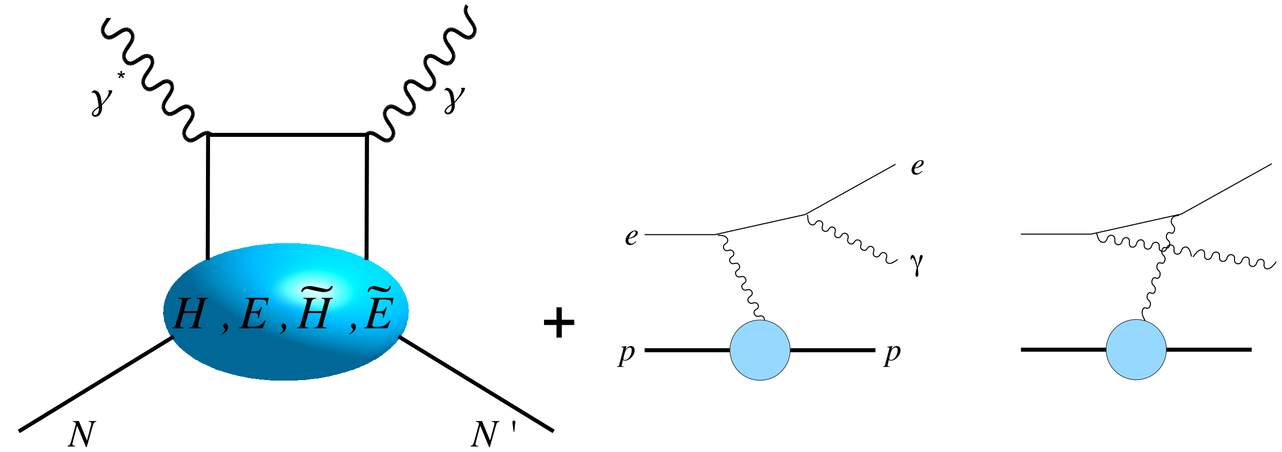
beam: λ_l

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

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

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

DVCS



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Bethe-Heitler

beam charge: e_ℓ

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

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

☛ 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

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

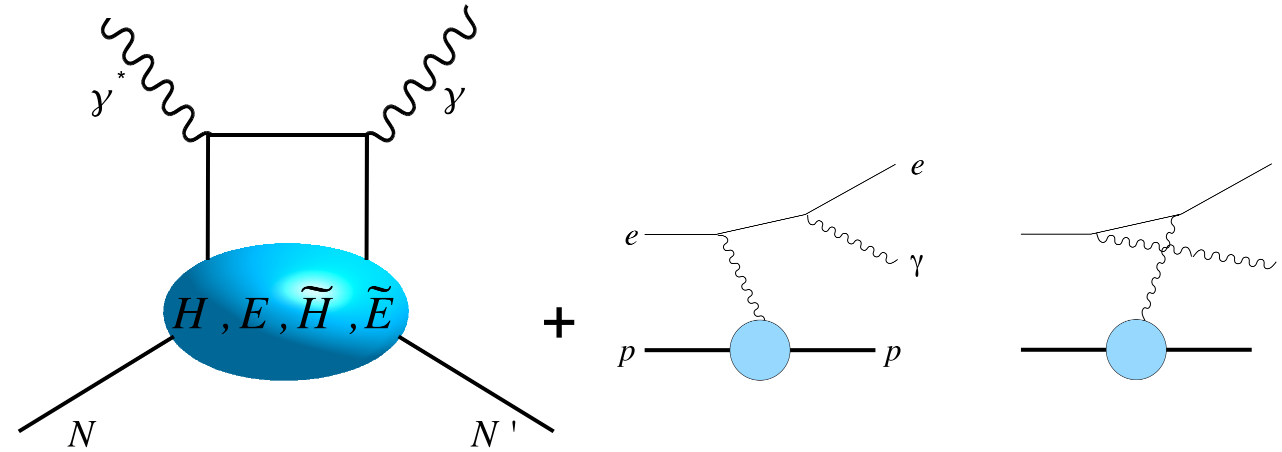
☛ transversely polarized target

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

DVCS

☛ theoretically the cleanest probe of GPDs

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



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

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

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

☛ 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

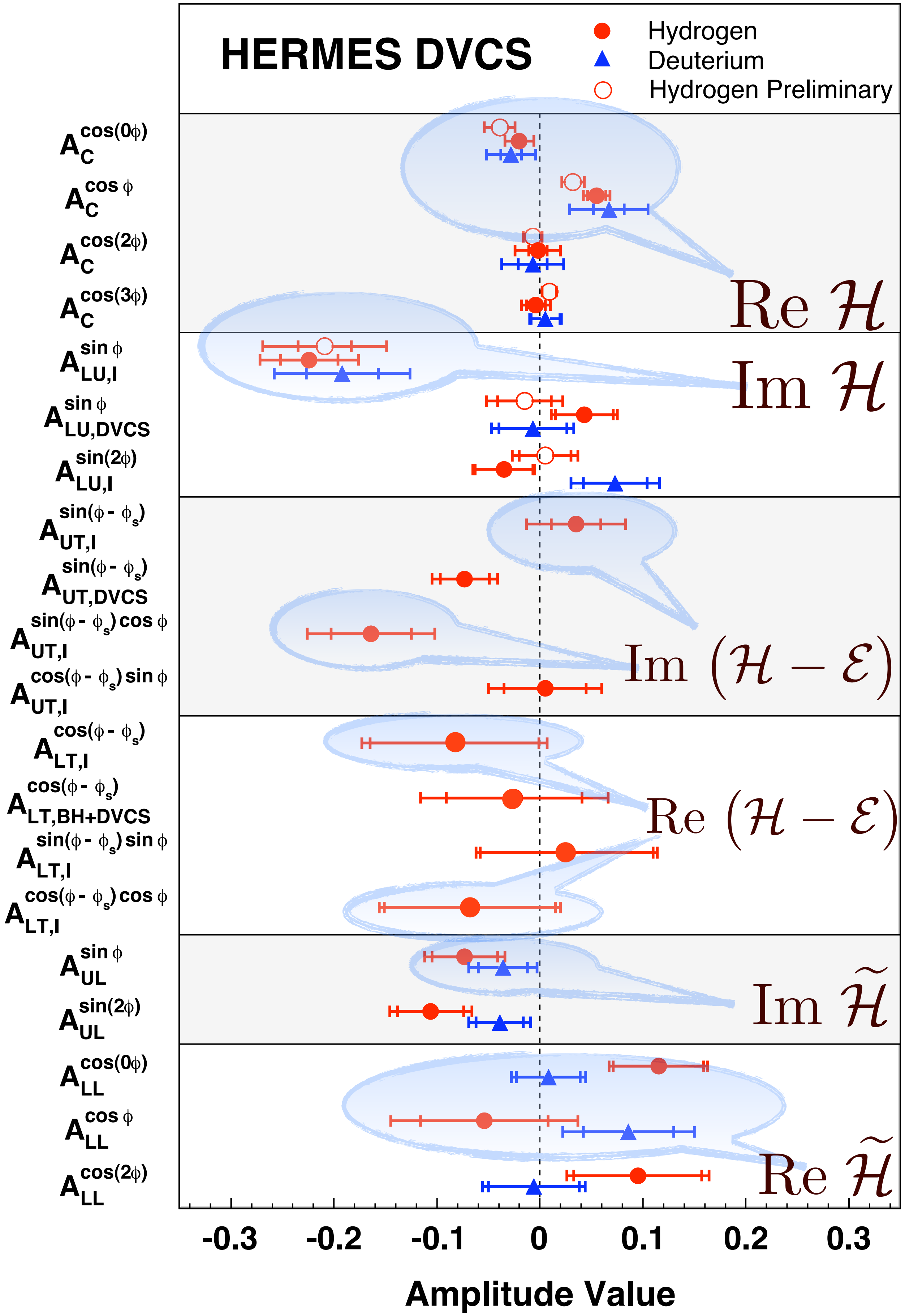
$$\frac{x_B}{2-x_B}(F_1+F_2)\left(\mathcal{H} + \frac{x_B}{2}\mathcal{E}\right) + F_1 \widetilde{\mathcal{H}} - \frac{x_B}{2-x_B}\left(\frac{x_B}{2}F_1 + \frac{t}{4M^2}F_2\right)\widetilde{\mathcal{E}}$$

☛ transversely polarized target

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

✓need information about GPDs E and H

$$J_q = \frac{1}{2} \lim_{t\to 0} \int_{-1}^{1} dx\, x\, [H_q(x,\xi,t) + E_q(x,\xi,t)]$$

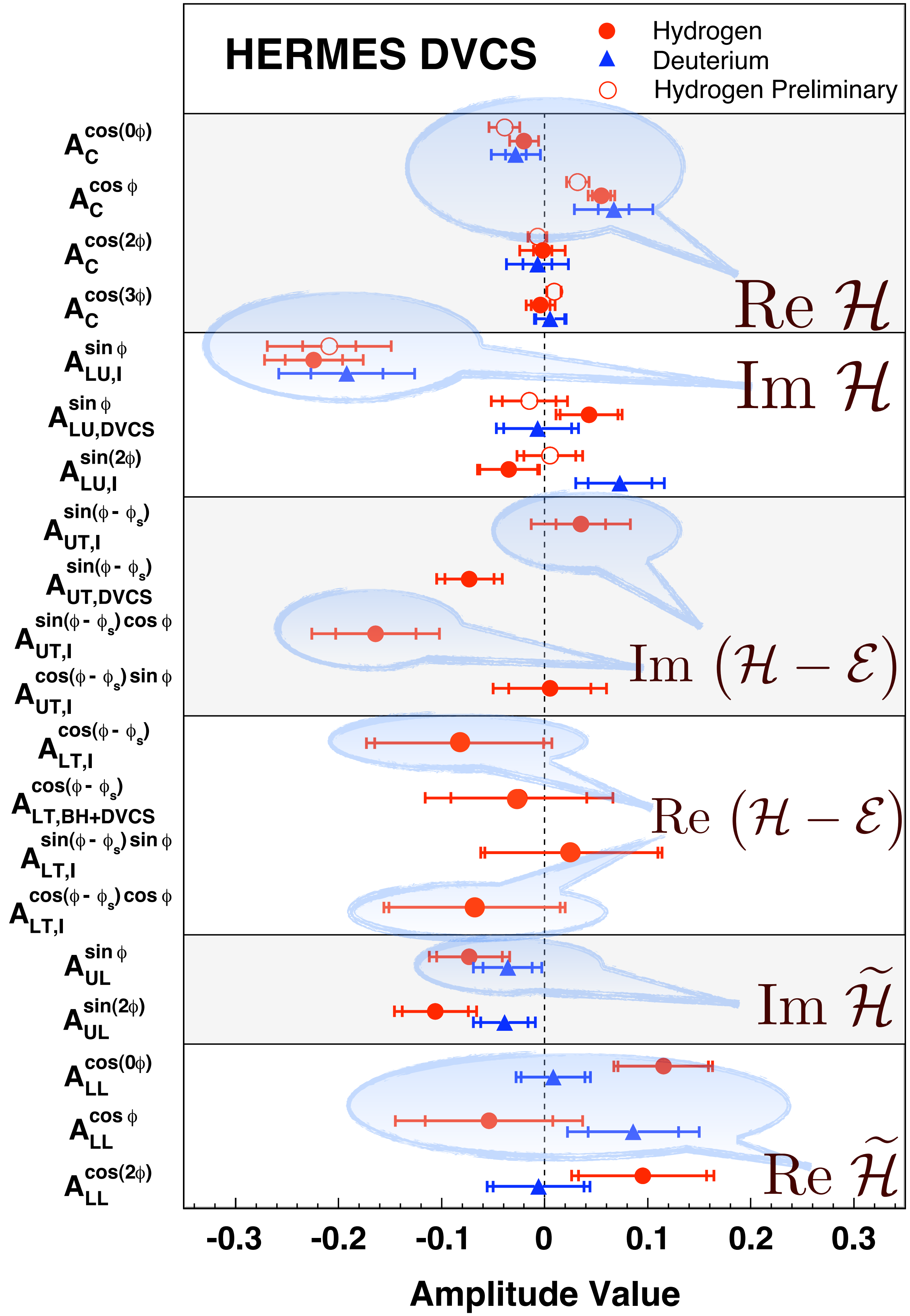


unique and complete set of DVCS asymmetries

$$\gamma^* N \to \gamma N : F\left(H, E, \widetilde{H}, \widetilde{E}\right)$$

$$\mathcal{F}(\xi, t) = \sum_q \int_{-1}^{1} dx\, C_q(\xi, x)\, F^q(x, \xi, t)$$

unique and complete set of DVCS asymmetries



(pre-recoil publications)

- JHEP 11 (2009) 083 -
- Nucl. Phys. B 829 (2010) 1-27 -

- JHEP 11 (2009) 083 -
- Nucl. Phys. B 829 (2010) 1-27-

$$\gamma^* N \to \gamma N : F\left(H, E, \widetilde{H}, \widetilde{E}\right)$$

$$\mathcal{F}(\xi, t) = \sum_q \int_{-1}^{1} dx\, C_q(\xi, x)\, F^q(x, \xi, t)$$

- JHEP 06 (2008) 066 -

new

- Phys. Lett. B 704 (2011) 15-23 -

-JHEP 06 (2010) 019 -
- Nucl. Phys. B 842 (2011) 265-298 -

- JHEP 06 (2010) 019 -
- Nucl. Phys. B 842 (2011) 265-298 -

double -spin asymmetries

γ

$ep \rightarrow e'\gamma X$

(pre-recoil data)

$$\sigma(\phi, \phi_s, e_\ell, S_\perp, \lambda_l) = \sigma_{\mathrm{UU}}(\phi)\Big\{1 + e_\ell \mathcal{A}_C(\phi) + \lambda_l \mathcal{A}_{LU}^{DVCS}(\phi) + e_\ell \lambda_l \mathcal{A}_{LU}^{I}(\phi)$$
$$+S_\perp \mathcal{A}_{UT}^{DVCS}(\phi, \phi_S) + e_\ell S_\perp \mathcal{A}_{UT}^{I}(\phi, \phi_S)$$
$$+ \lambda_l S_\perp \mathcal{A}_{LT}^{BH+DVCS}(\phi, \phi_S) + e_\ell \lambda_l S_\perp \mathcal{A}_{LT}^{I}(\phi, \phi_S)\Big\}$$

double -spin asymmetries

$ep \to e'\gamma X$

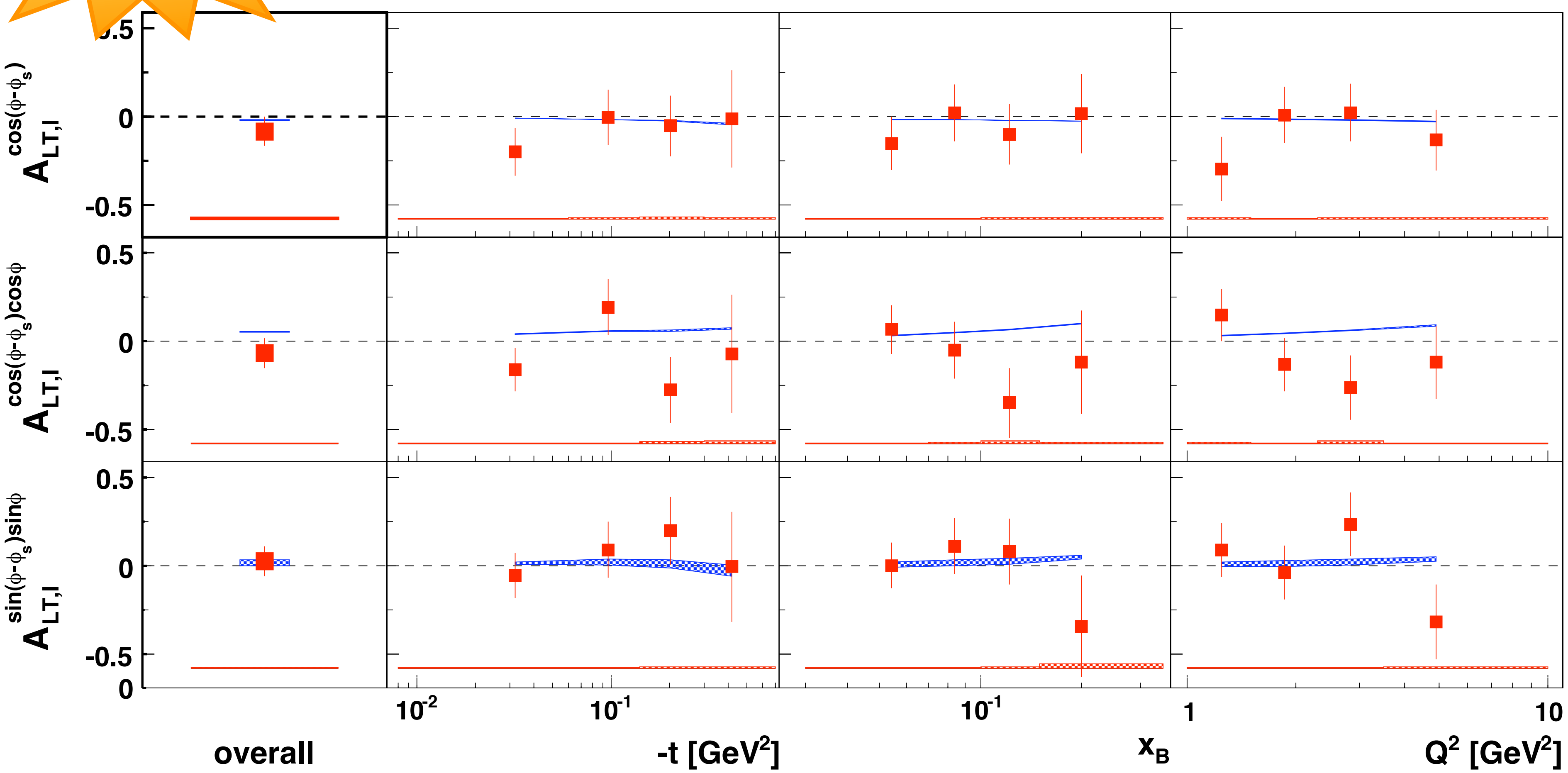
(pre-recoil data)

published

$$\sigma(\phi,\phi_s,e_\ell,S_\perp,\lambda_l) = \sigma_{\rm UU}(\phi)\Big\{1 + e_\ell\mathcal{A}_C(\phi) + \lambda_l\mathcal{A}_{LU}^{DVCS}(\phi) + e_\ell\lambda_l\mathcal{A}_{LU}^{I}(\phi) + S_\perp\mathcal{A}_{UT}^{DVCS}(\phi,\phi_S) + e_\ell S_\perp\mathcal{A}_{UT}^{I}(\phi,\phi_S) + \lambda_l S_\perp\mathcal{A}_{LT}^{BH+DVCS}(\phi,\phi_S) + e_\ell\lambda_l S_\perp\mathcal{A}_{LT}^{I}(\phi,\phi_S)\Big\}$$

- HERMES Collaboration- Phys. Lett. B 704 (2011) 15-23

✓ extracted for the first time



$\propto A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi}$

$\propto \mathrm{Re}\big(F_2\widetilde{H} - (F_1 + F_2\xi)\widetilde{E}\big)$

$\propto \mathrm{Re}[F_2\mathcal{H} - F_1\mathcal{E}]$

double -spin asymmetries

$ep \to e'\gamma X$

(pre-recoil data)

published

$$\sigma(\phi,\phi_s,e_\ell,S_\perp,\lambda_l) = \sigma_{\mathrm{UU}}(\phi)\Big\{1 + e_\ell\mathcal{A}_C(\phi) + \lambda_l\mathcal{A}_{LU}^{DVCS}(\phi) + e_\ell\lambda_l\mathcal{A}_{LU}^{I}(\phi)$$
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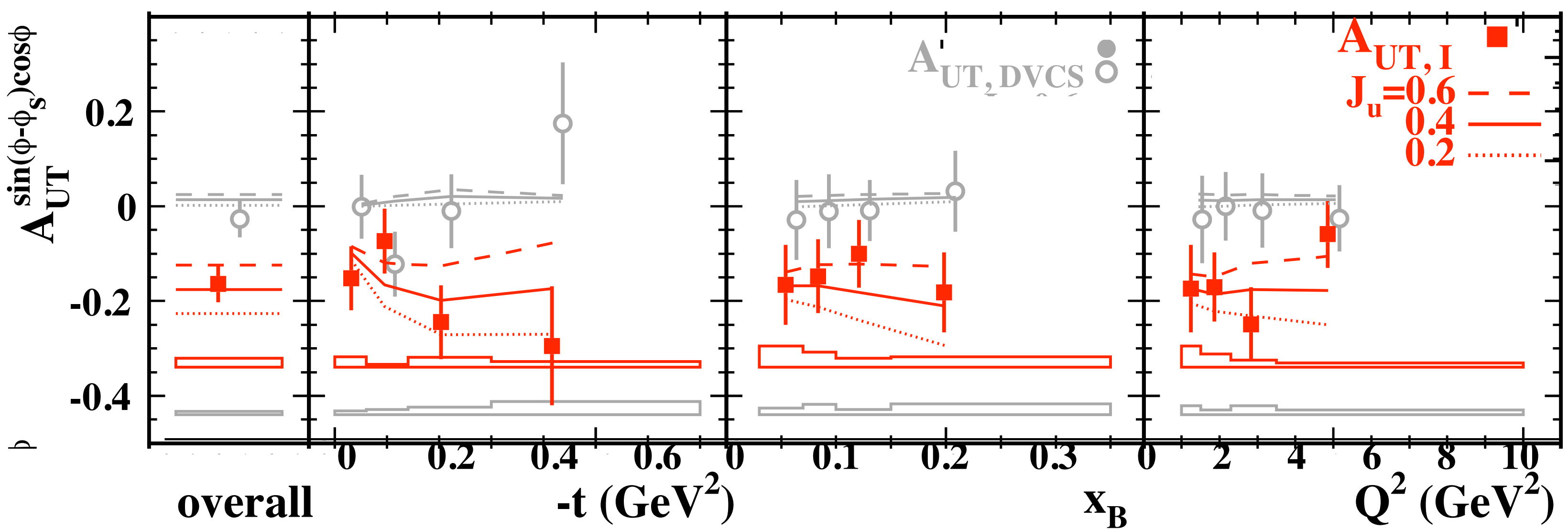
$$+\lambda_l S_\perp\mathcal{A}_{LT}^{BH+DVCS}(\phi,\phi_S) + e_\ell\lambda_l S_\perp\mathcal{A}_{LT}^{I}(\phi,\phi_S)\Big\}$$

- HERMES Collaboration- Phys. Lett. B 704 (2011) 15-23

- HERMES Collaboration- : JHEP 06 (2008) 066, 24



$\propto \; \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}]$

$\propto \; \mathrm{Im}[\mathcal{H}\mathcal{E}^* - \mathcal{E}\mathcal{H}^* + \xi\widetilde{\mathcal{E}}\widetilde{\mathcal{H}}^* - \widetilde{\mathcal{H}}\xi\widetilde{\mathcal{E}}^*]$

☛ $A_{\mathrm{UT,I}}^{\sin(\phi-\phi_s)\cos\phi}$ found much more sensitive to GPD E than others, and thus to J_u

double -spin asymmetries

$ep \to e'\gamma X$

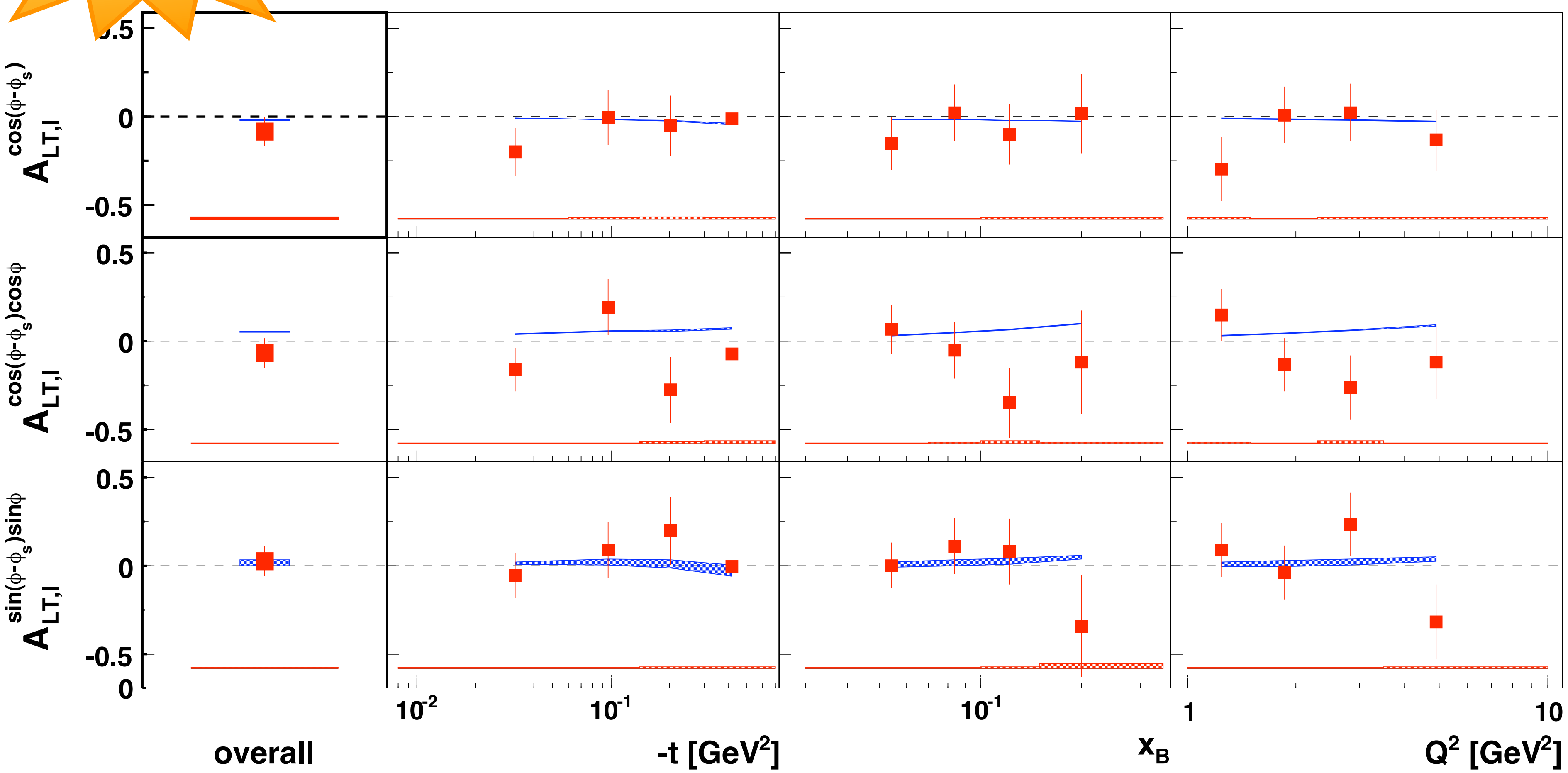
(pre-recoil data)

published

$$\sigma(\phi,\phi_s,e_\ell,S_\perp,\lambda_l) = \sigma_{\mathrm{UU}}(\phi)\Big\{1 + e_\ell\mathcal{A}_C(\phi) + \lambda_l\mathcal{A}_{LU}^{DVCS}(\phi) + e_\ell\lambda_l\mathcal{A}_{LU}^{I}(\phi)$$
$$+S_\perp\mathcal{A}_{UT}^{DVCS}(\phi,\phi_S) + e_\ell S_\perp\mathcal{A}_{UT}^{I}(\phi,\phi_S)$$
$$+\lambda_l S_\perp\mathcal{A}_{LT}^{BH+DVCS}(\phi,\phi_S) + e_\ell\lambda_l S_\perp\mathcal{A}_{LT}^{I}(\phi,\phi_S)\Big\}$$

- HERMES Collaboration- Phys. Lett. B 704 (2011) 15-23

✓ extracted for the first time



$\propto A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi}$

$\propto \mathrm{Re}\big(F_2\widetilde{H} - (F_1 + F_2\xi)\widetilde{E}\big)$

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double -spin asymmetries

$ep \rightarrow e'\gamma X$

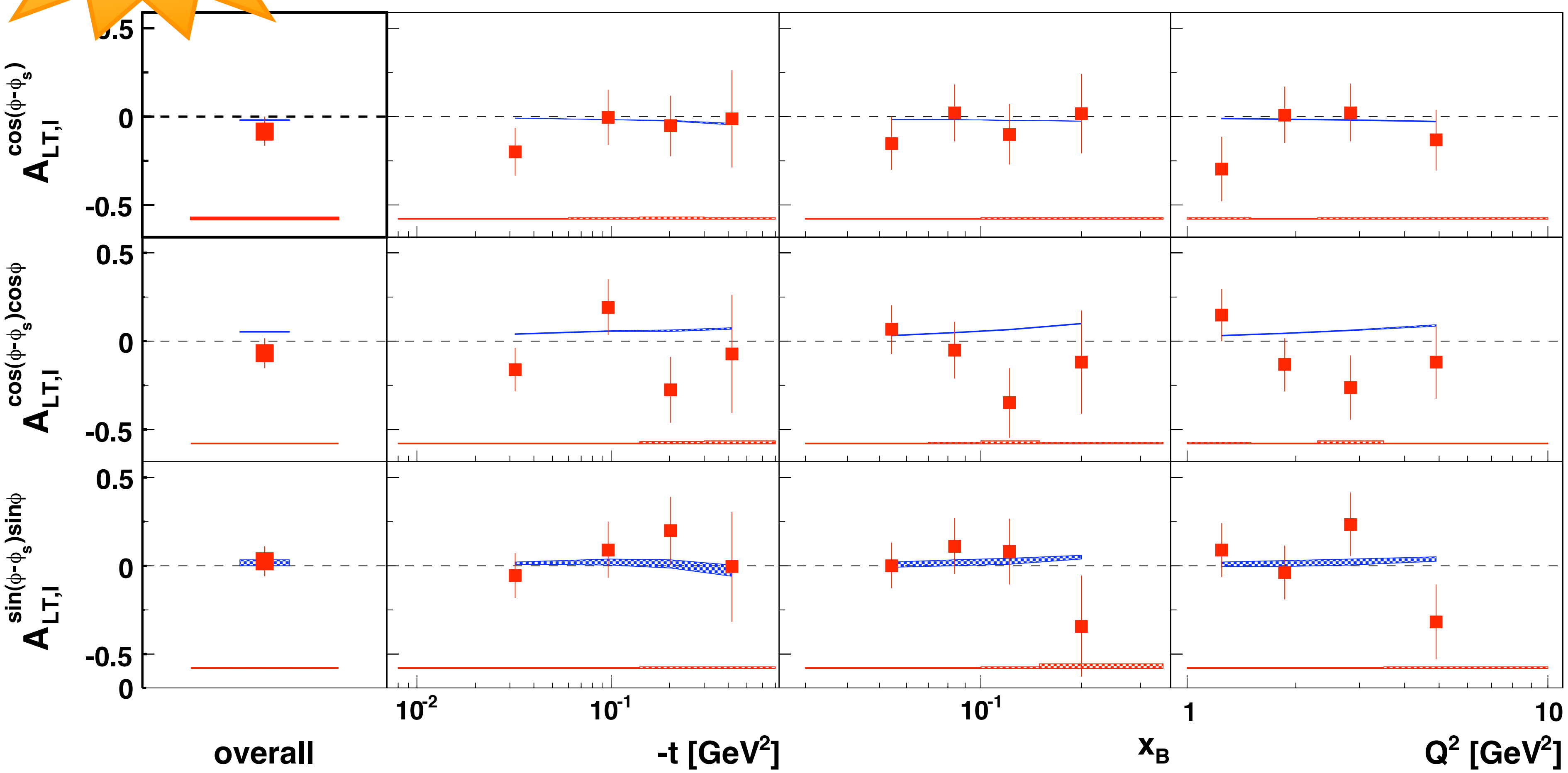
(pre-recoil data)

$$\sigma(\phi,\phi_s,e_\ell,S_\perp,\lambda_l) = \sigma_{\mathrm{UU}}(\phi)\Big\{1 + e_\ell \mathcal{A}_C(\phi) + \lambda_l \mathcal{A}_{LU}^{DVCS}(\phi) + e_\ell\lambda_l\mathcal{A}_{LU}^{I}(\phi) + S_\perp \mathcal{A}_{UT}^{DVCS}(\phi,\phi_S) + e_\ell S_\perp \mathcal{A}_{UT}^{I}(\phi,\phi_S) + \lambda_l S_\perp \mathcal{A}_{LT}^{BH+DVCS}(\phi,\phi_S) + e_\ell\lambda_l S_\perp \mathcal{A}_{LT}^{I}(\phi,\phi_S)\Big\}$$

- HERMES Collaboration- Phys. Lett. B 704 (2011) 15-23

published

✓ extracted for the first time



$\propto A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi}$

$\propto \mathrm{Re}\big(F_2\widetilde{H} - (F_1 + F_2\xi)\widetilde{E}\big)$

$\propto \mathrm{Re}[F_2\mathcal{H} - F_1\mathcal{E}]$

- ☛ $A_{LT,I}^{\sin(\phi-\phi_s)\sin\phi}$ could provide a similar constraint to the real part of $\mathrm{Re}\,\mathcal{E}$
- ☛ due to different kinematic pre-factors, this amplitude is suppressed

double -spin asymmetries

γ

$ep \to e'\gamma X$

(pre-recoil data)

published

$$\sigma(\phi, \phi_s, e_\ell, S_\perp, \lambda_l) = \sigma_{\mathrm{UU}}(\phi)\Big\{1 + e_\ell \mathcal{A}_C(\phi) + \lambda_l \mathcal{A}_{LU}^{DVCS}(\phi) + e_\ell \lambda_l \mathcal{A}_{LU}^{I}(\phi)$$
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- HERMES Collaboration- Phys. Lett. B 704 (2011) 15-23

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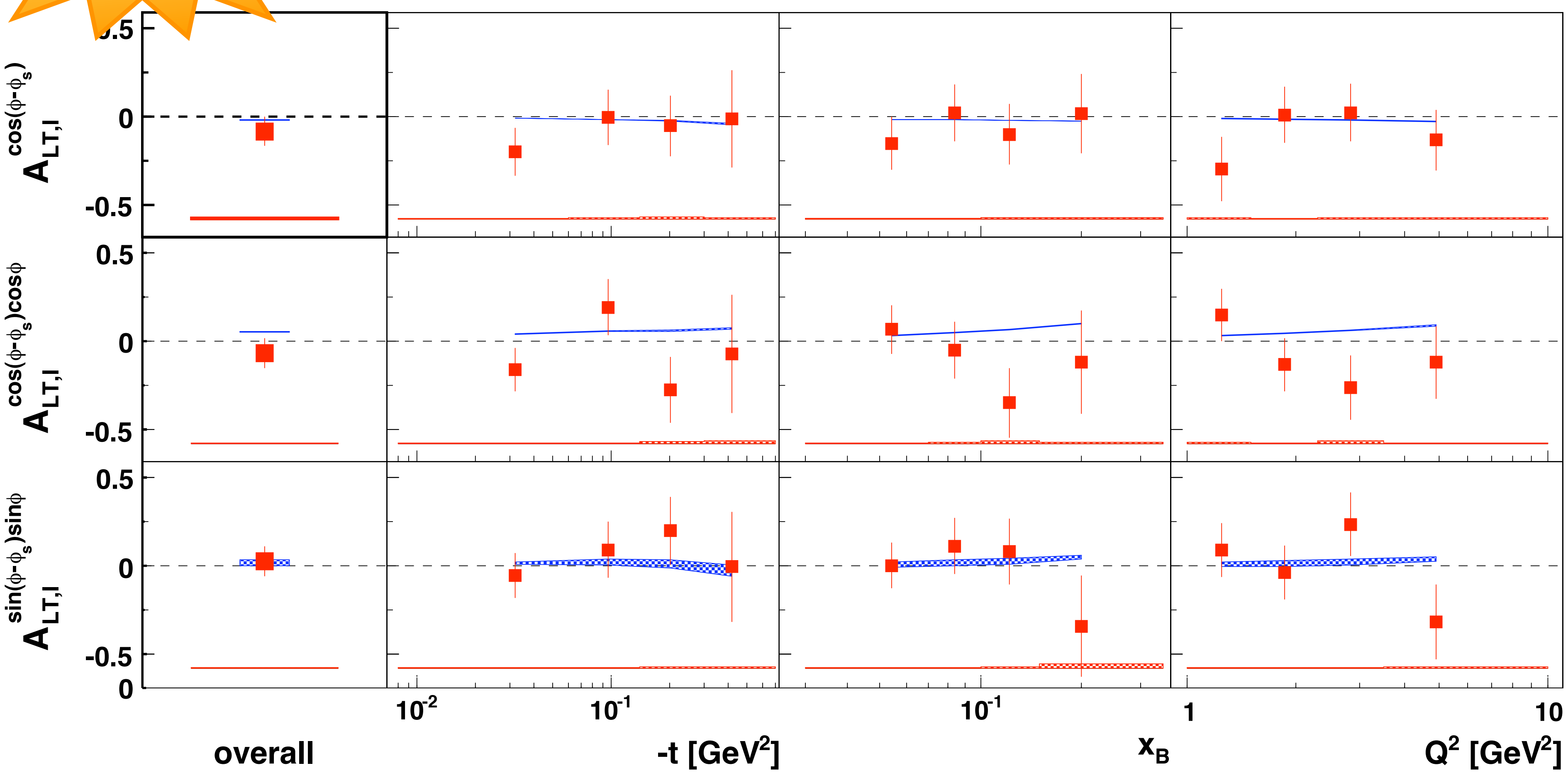


$\propto A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi}$

$\propto \mathrm{Re}\big(F_2\widetilde{H} - (F_1 + F_2\xi)\widetilde{E}\big)$

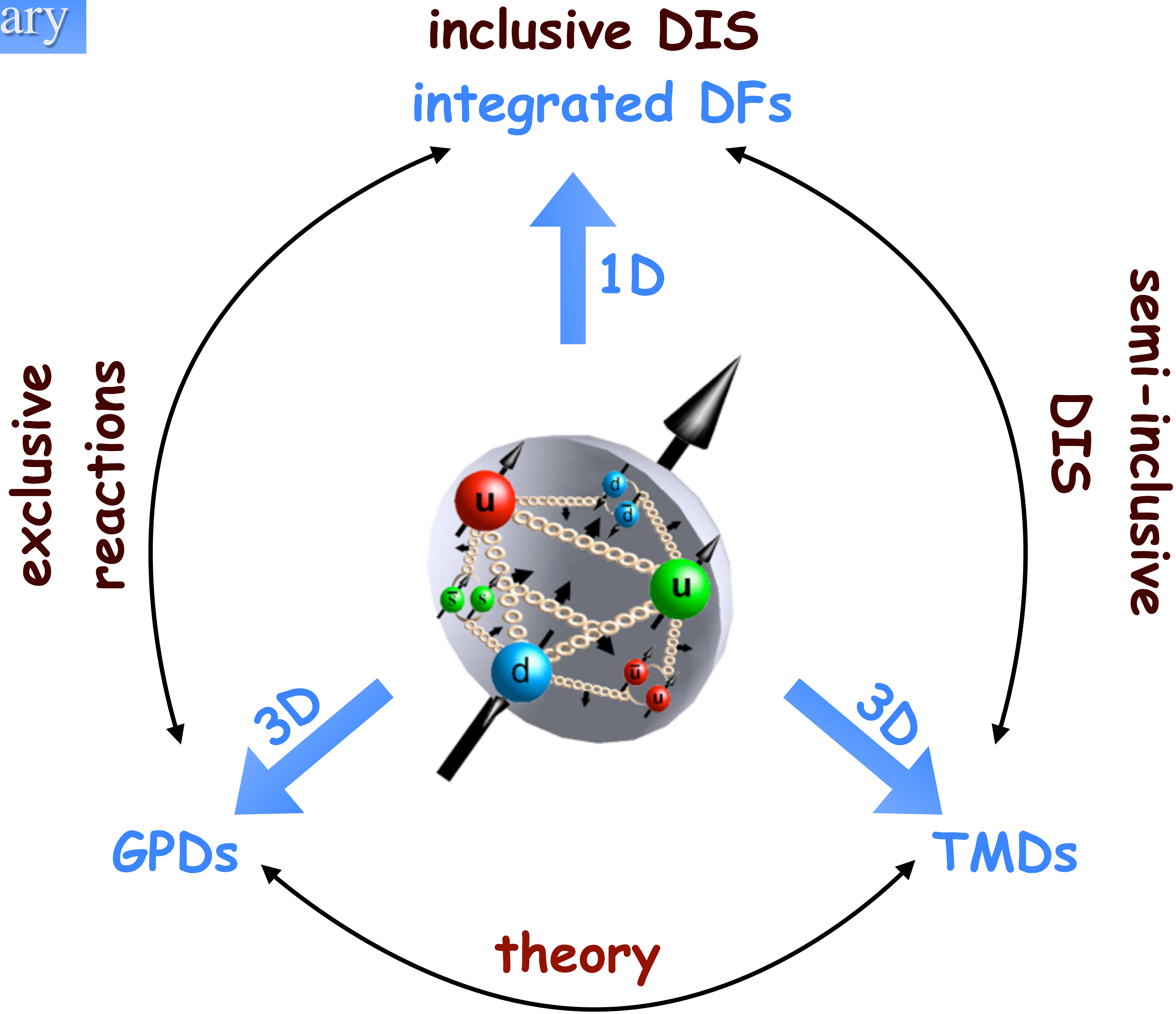
$\propto \mathrm{Re}[F_2\mathcal{H} - F_1\mathcal{E}]$

☛ $A_{LT,I}^{\sin(\phi-\phi_s)\sin\phi}$ could provide a similar constraint to the real part of $\mathrm{Re}\,\mathcal{E}$

☛ due to different kinematic pre-factors, this amplitude is suppressed

✓ nevertheless, may serve as additional constraints in global fits

summary


inclusive DIS
integrated DFs
1D
exclusive reactions
semi-inclusive DIS
3D
3D
u
u
d
GPDs
TMDs
theory

publications in 2011

before PRC 71

- *Nucl. Phys. B842 (2011) 265-298*
- *Eur. Phys. J. C 71 (2011) 1609*

after PRC 71

- *JHEP 05 (2011) 126*
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☛ **in total 5 publications so far in 2011**

☛ 3 more publications are expected

☛ 8 more in circulation within collaboration

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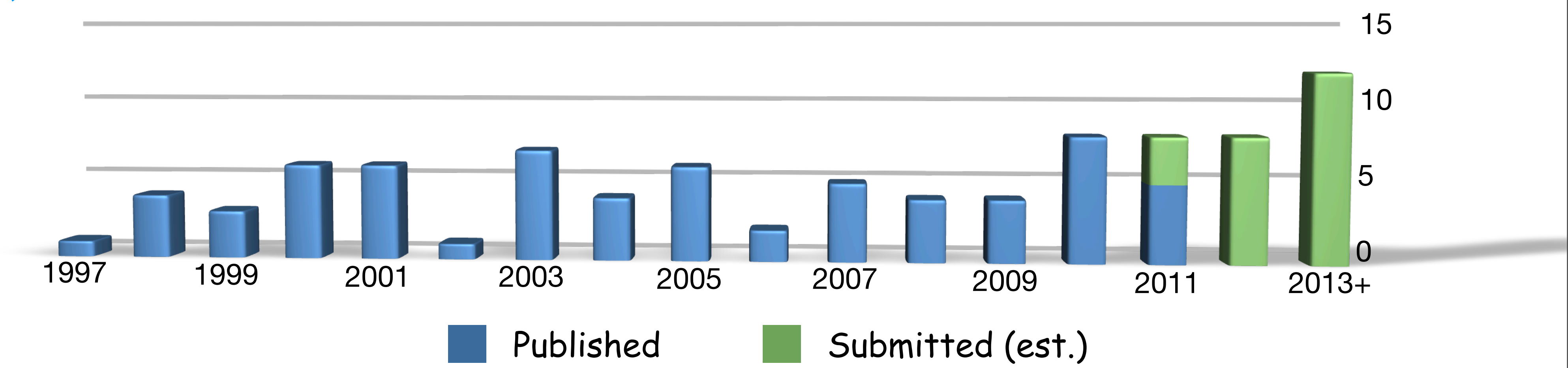

average citations per paper: 69

publications in 2011

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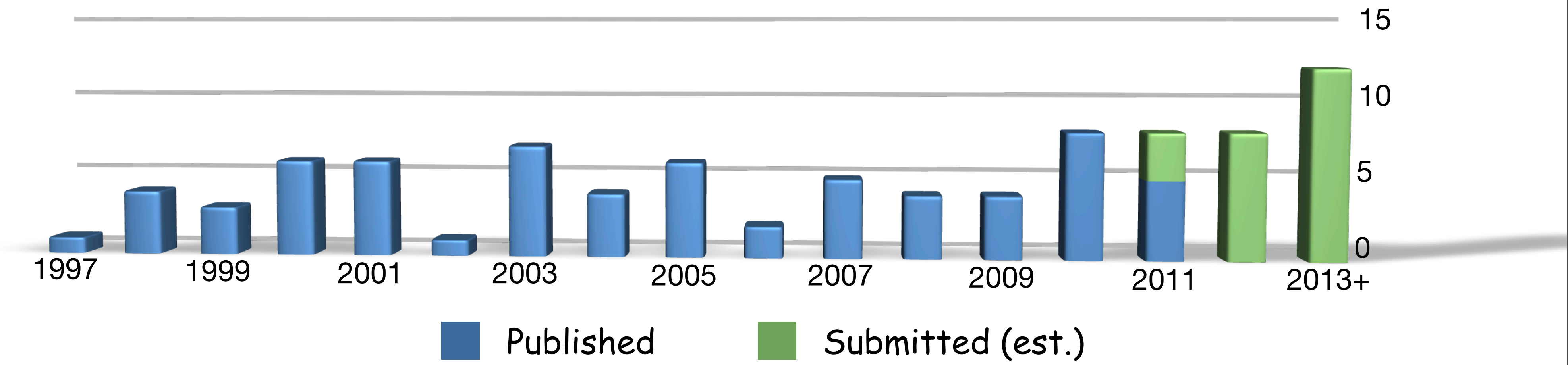

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HERMES clearly in publication phase

publications in 2011

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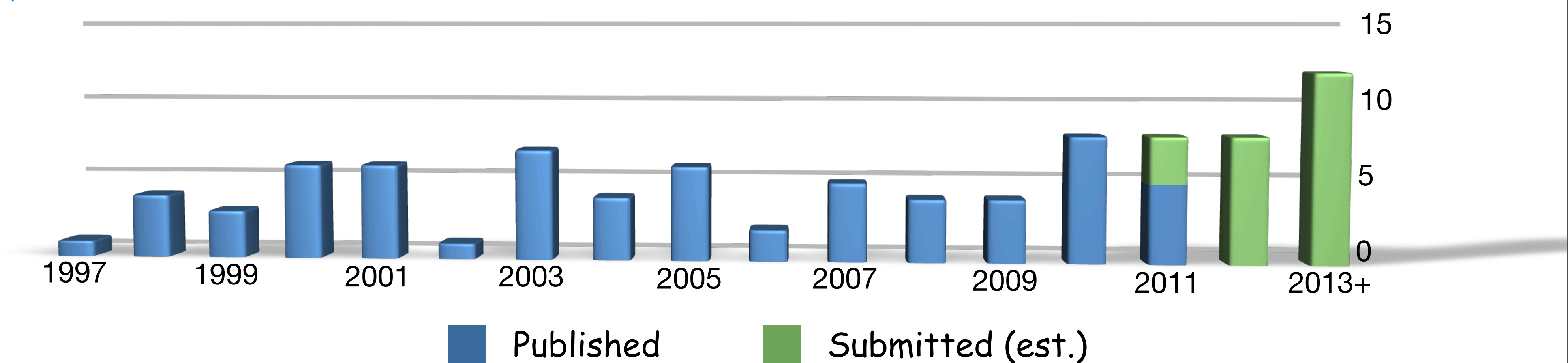


average citations per paper: 69

HERMES clearly in publication phase

☛ major conferences (PANIC, HEP, EINN'11 etc.): 17

☛ major workshops (DIS, EDS-Blois, etc.): 30+

data preservation

status of data preservation

✓ **HERMES participates in DPHEP initiative**

data

✓ **long term storage space requirements**

☛ slow access ~150 TB (raw data)

☛ fast access ~50 TB (uDST, MC)

✓ **hardware**

☛ planned to run the current batch nodes as long as possible

☛ selected the DESY batch (BIRD) as an alternative for future HERMES analysis (migration and testing underway)

software

✓ **software**

☛ final migration to SLD5 at the end of the year

✓ **software validation**

☛ participating in IT-developed SP-system

☛ validation tests under development

documentation

✓ **digital documentation**

☛ all internal notes and additional information moved to inSpire into a password protected area

✓ **non-digital documentation**

☛ some shelves already filled in the library, digitizing under consideration

✓ **web pages**

☛ analysis pages migrated to wiki

☛ static web-pages served locally, evaluating the ZMS-based IT web-service

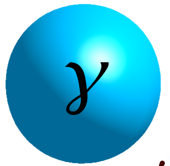
The Spin Community And The World

- 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

Thanks!

backup slides

GPD H: unpolarized hydrogen target



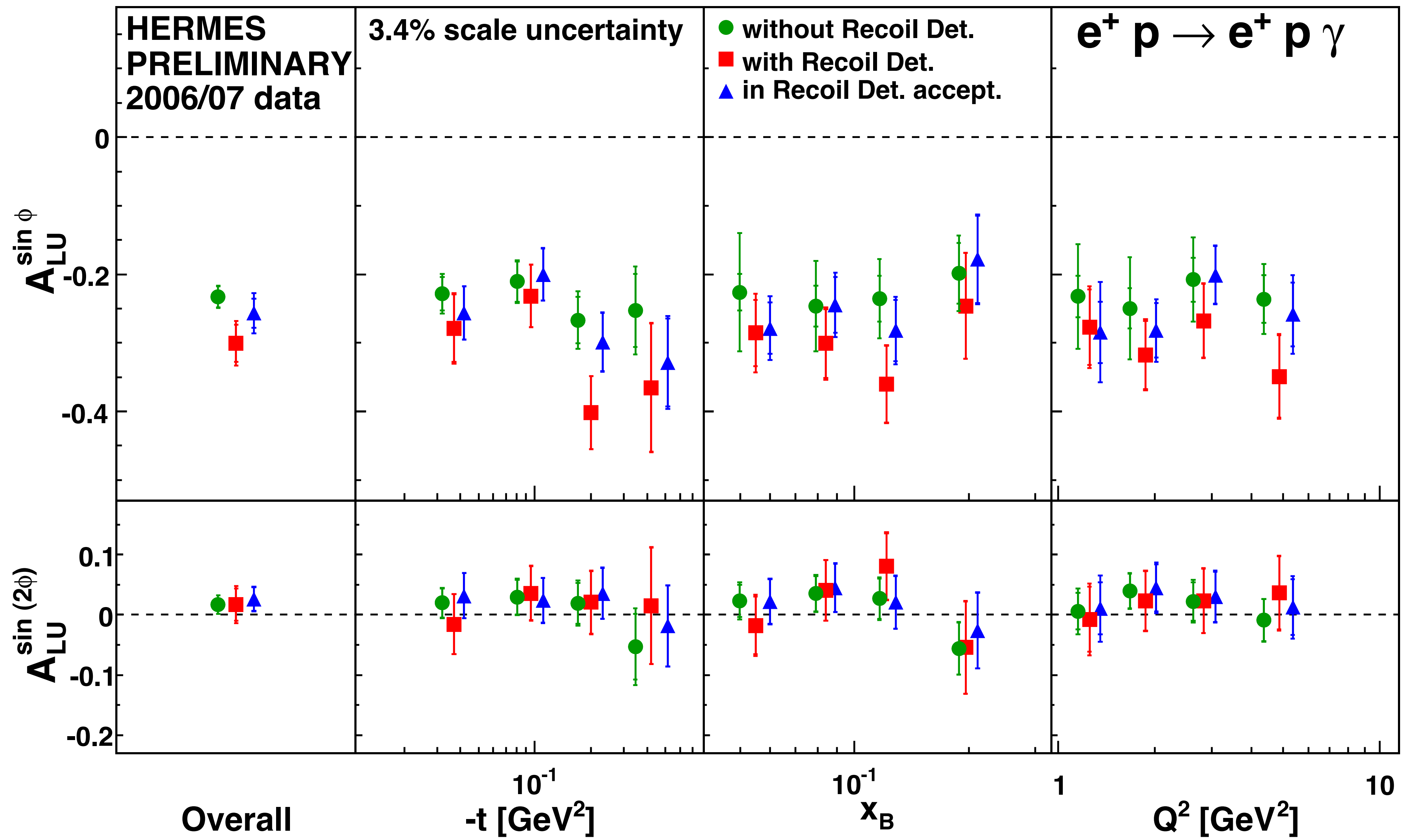
$ep \to e'\gamma p'$

(recoil data)

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

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

☛ extraction of single-charge beam-helicity asymmetry amplitudes for elastic data sample (background < 0.1%)



☛ indication for slightly larger magnitude of the leading amplitude for elastic process compared the one in the recoil detector acceptance