Recent results from the HERMES collaboration

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University of the Basque Country UPV/EHU - Spain

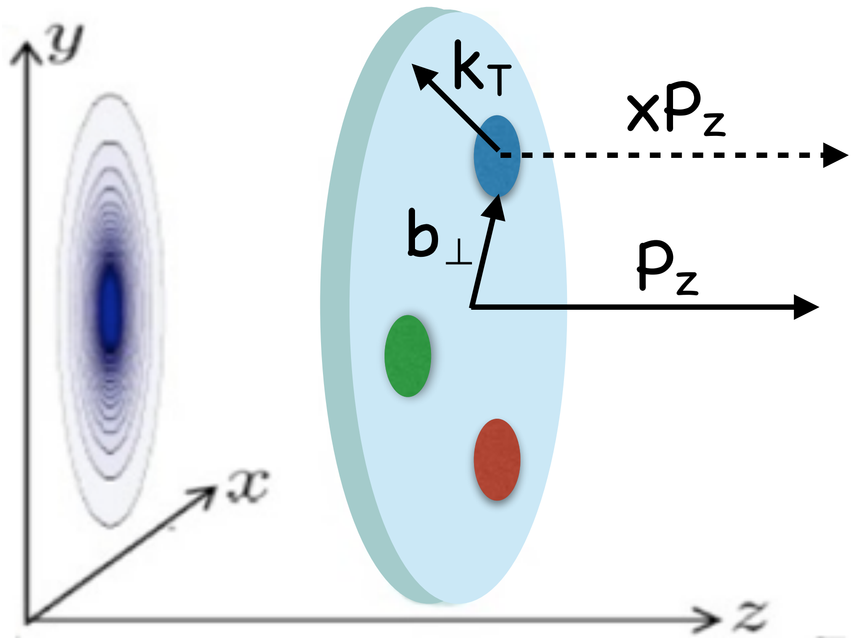
IWHSS
Suzdal, 18-20 May 2015

Outline

- 3D picture of the nucleon:
  - ω SDMEs from exclusive DIS
  - A_{UT} and A_{LT} in semi-inclusive DIS
  - A_{UT} in inclusive DIS
- Bose-Einstein correlations in DIS
- Λ polarization in quasi-real photoproduction
- Searching again for the pentaquark in quasi-real photoproduction

3D pictures of the nucleon

Wigner distributions $W(x, \vec{k}_T, \vec{b}_\perp)$

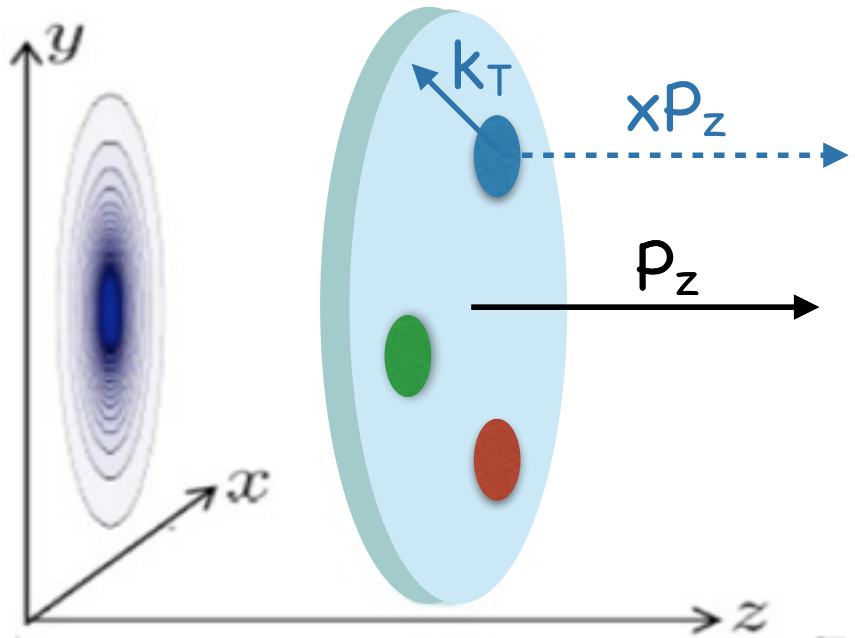


3D pictures of the nucleon

Wigner distributions $W(x, \vec{k}_T, \vec{b}_\perp)$

$\int d^2\vec{b}_\perp$

transverse-momentum dependent PDFs (TMD PDFs)



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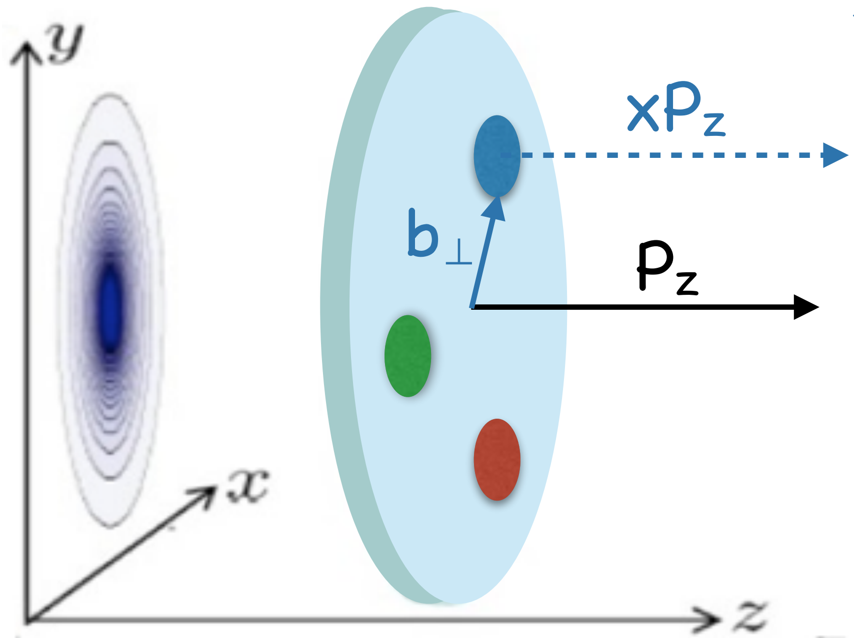

$\int d^2\vec{k}_T$

impact-parameter distributions

3D pictures of the nucleon

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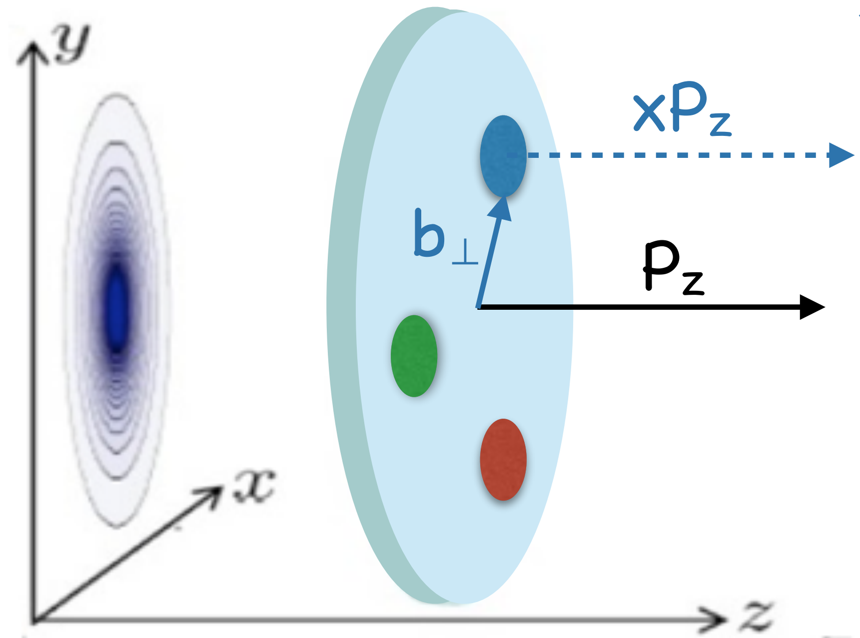

$\int d^2\vec{k}_T$

impact-parameter distributions

Fourier transform

generalized parton distributions (GPDs)

3D pictures of the nucleon

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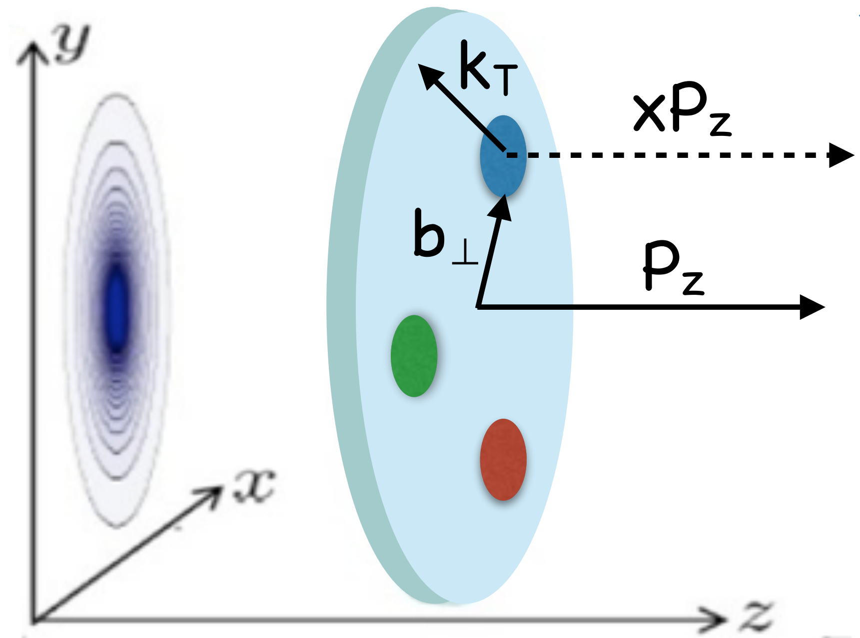


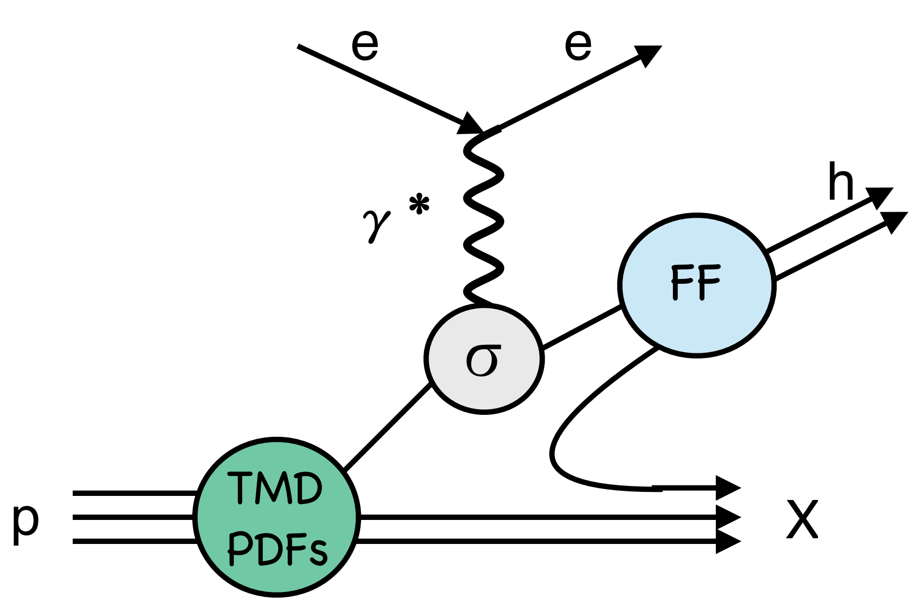
$\int d^2\vec{k}_T$

impact-parameter distributions

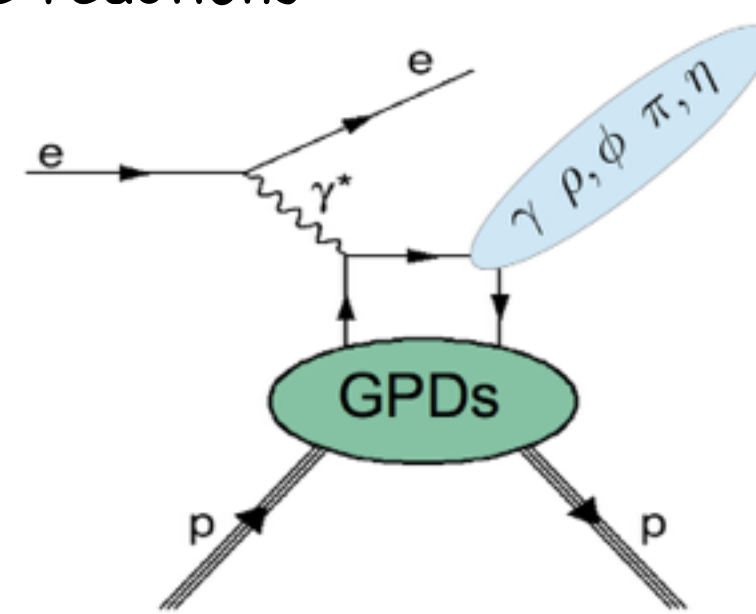
Fourier transform

generalized parton distributions (GPDs)

semi-inclusive DIS



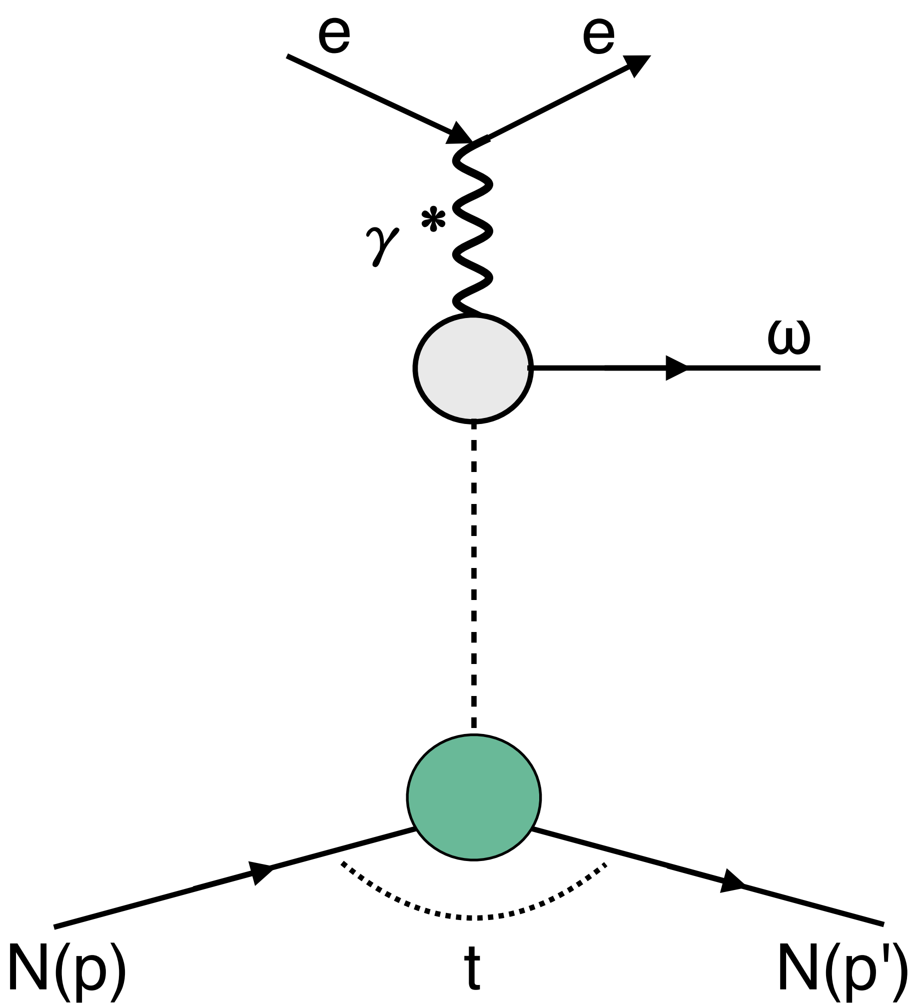
hard exclusive reactions



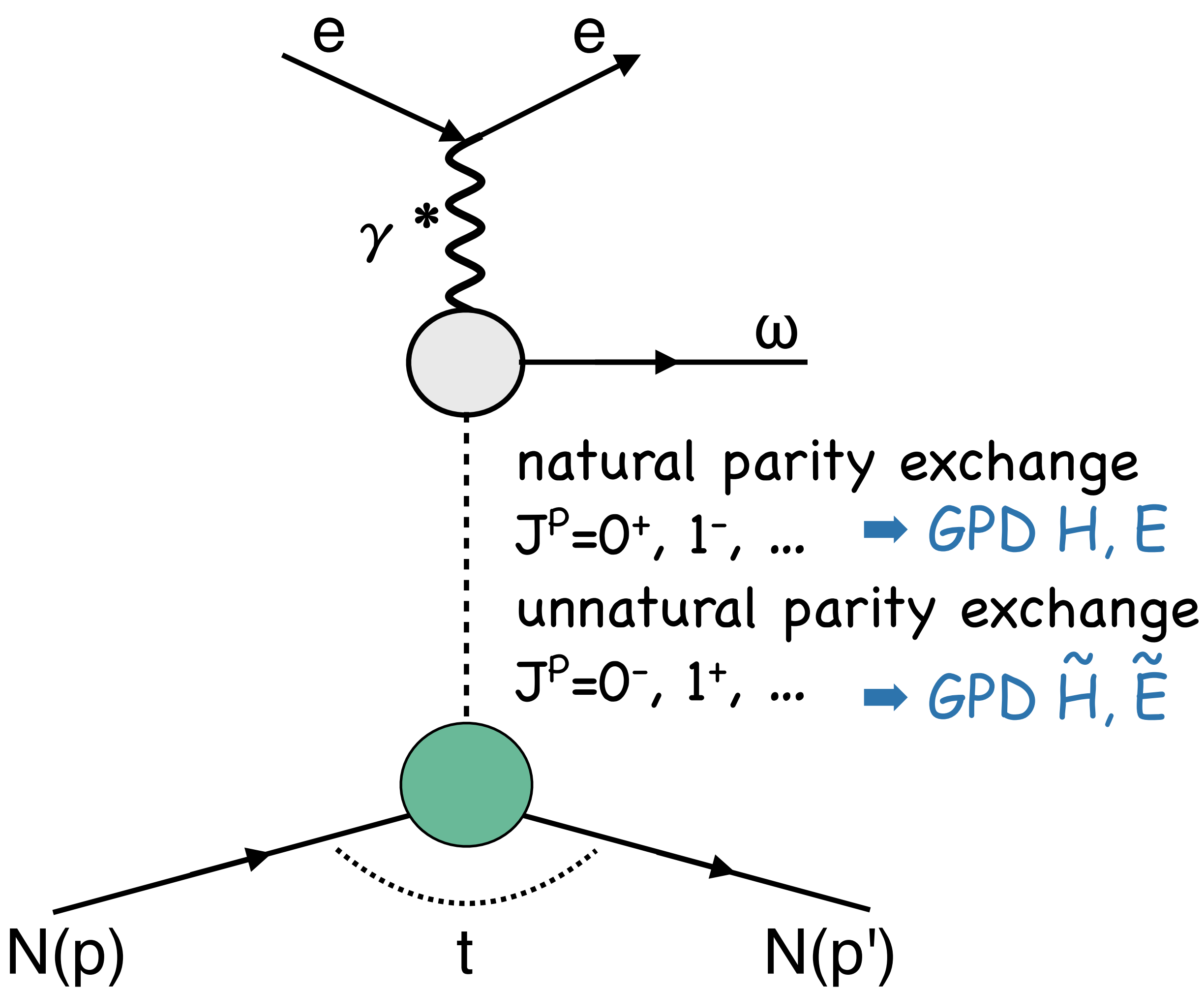
SDMEs from exclusive ω production

- unpolarized & longitudinally polarized e^+/e^- beam
- unpolarized H & D target

Exclusive ω production



Exclusive ω production



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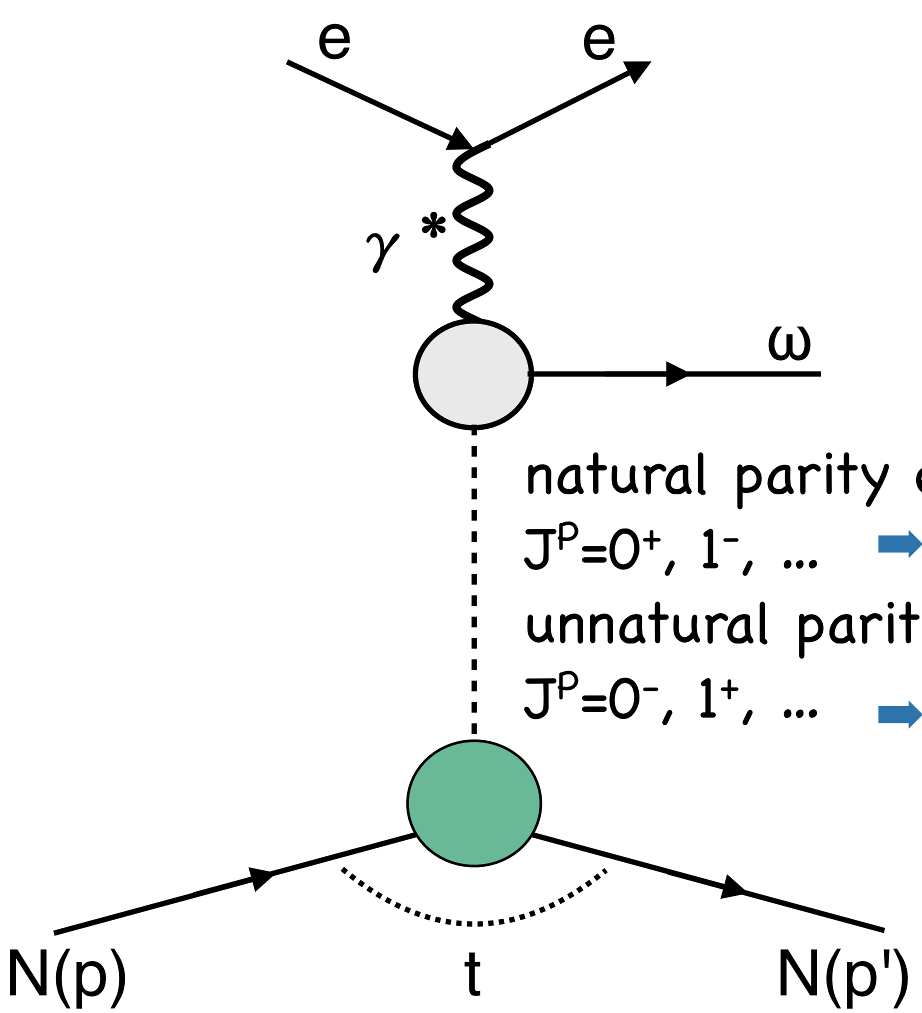


natural parity exchange

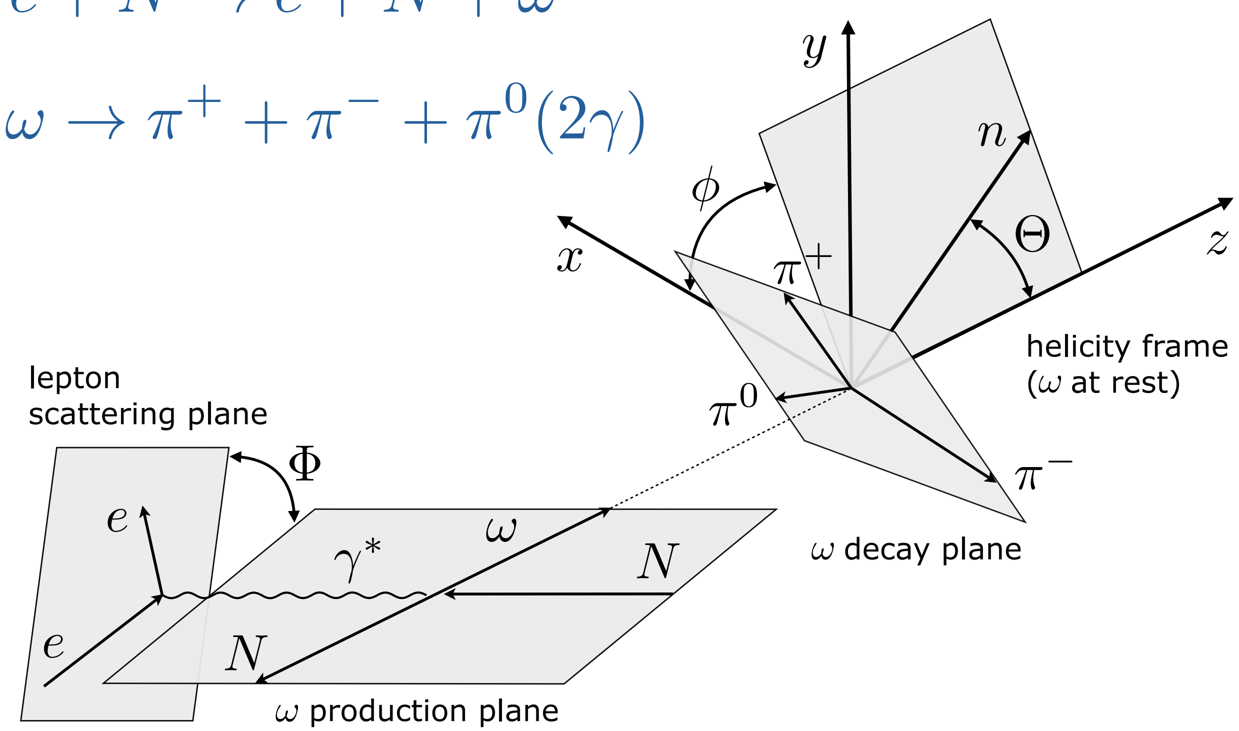
J^P=0^+, 1^-, … ➡ GPD H, E

unnatural parity exchange

J^P=0^-, 1^+, … ➡ GPD $\tilde{H}$, $\tilde{E}$

$$e + N \rightarrow e + N + \omega$$

$$\omega \rightarrow \pi^+ + \pi^- + \pi^0(2\gamma)$$

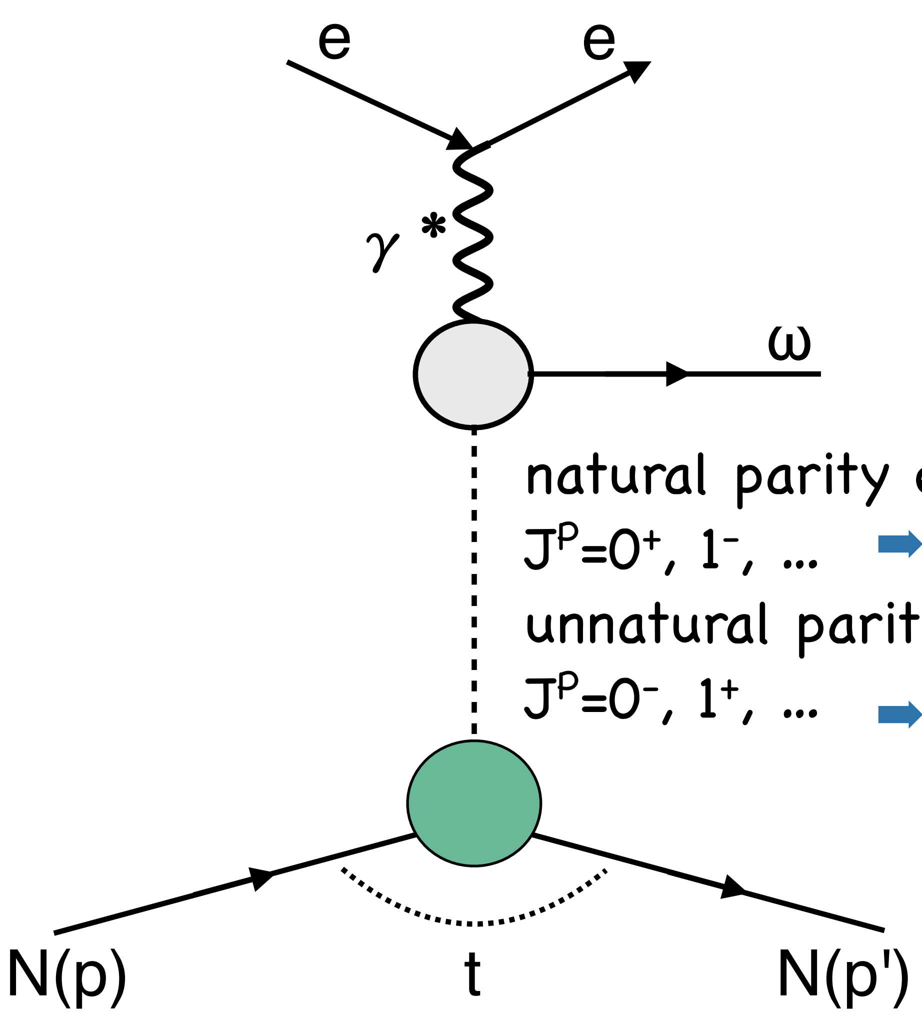


Fit angular distribution $\mathcal{W}(\Phi, \phi, \Theta)$ of ω decay pions

⇓

Spin density matrix elements (SDMEs) describing final spin state of ω

Exclusive ω production



natural parity exchange

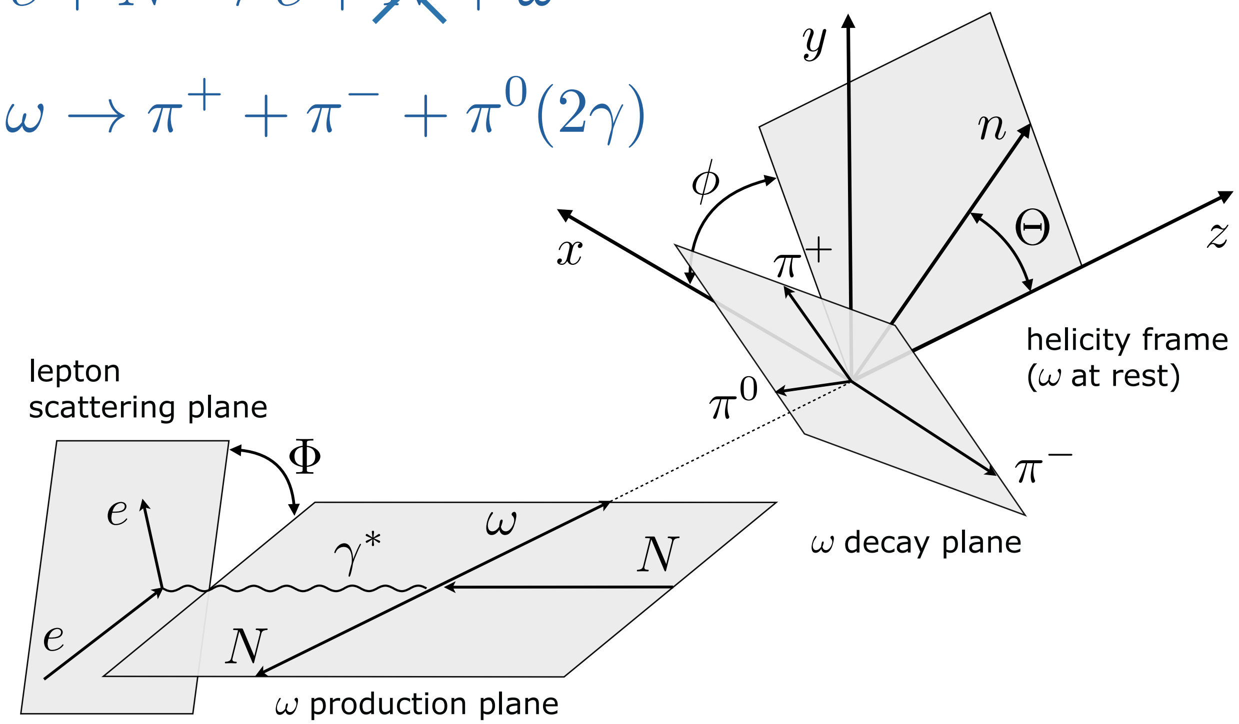
$J^P = 0^+, 1^-, \ldots$ ➡ GPD H, E

unnatural parity exchange

$J^P = 0^-, 1^+, \ldots$ ➡ GPD $\tilde{H}$, $\tilde{E}$

$e + N \rightarrow e + \cancel{X} + \omega$

$\omega \rightarrow \pi^+ + \pi^- + \pi^0(2\gamma)$



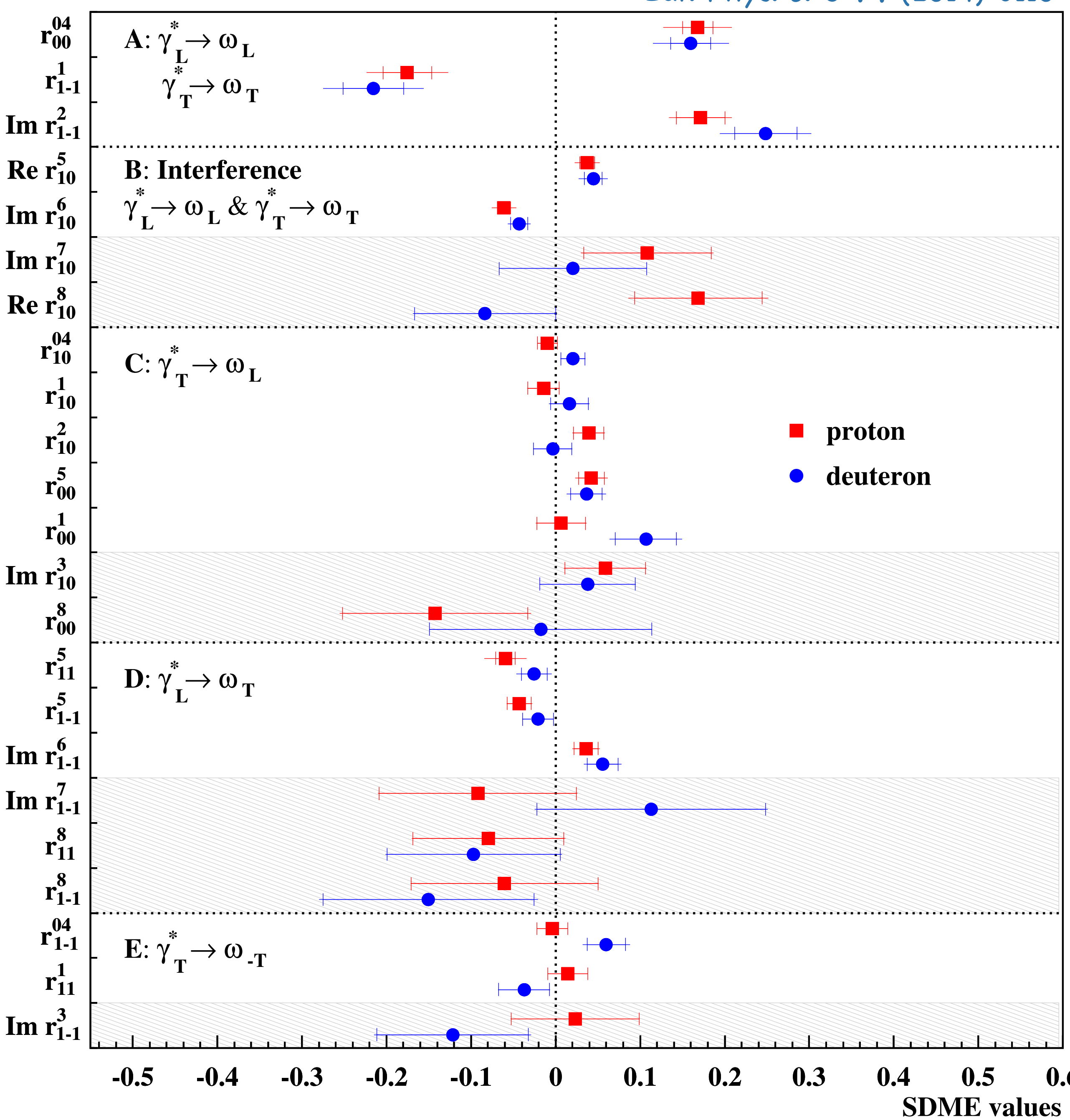
Fit angular distribution $\mathcal{W}(\Phi, \phi, \Theta)$ of ω decay pions

⇩

Spin density matrix elements (SDMEs)
describing final spin state of ω

Results ω SDMEs

Eur. Phys. J. C **74** (2014) 3110



- 5 classes of SDMEs
- unpolarized and polarized SDMEs
- proton & deuteron similar

Results ω SDMEs

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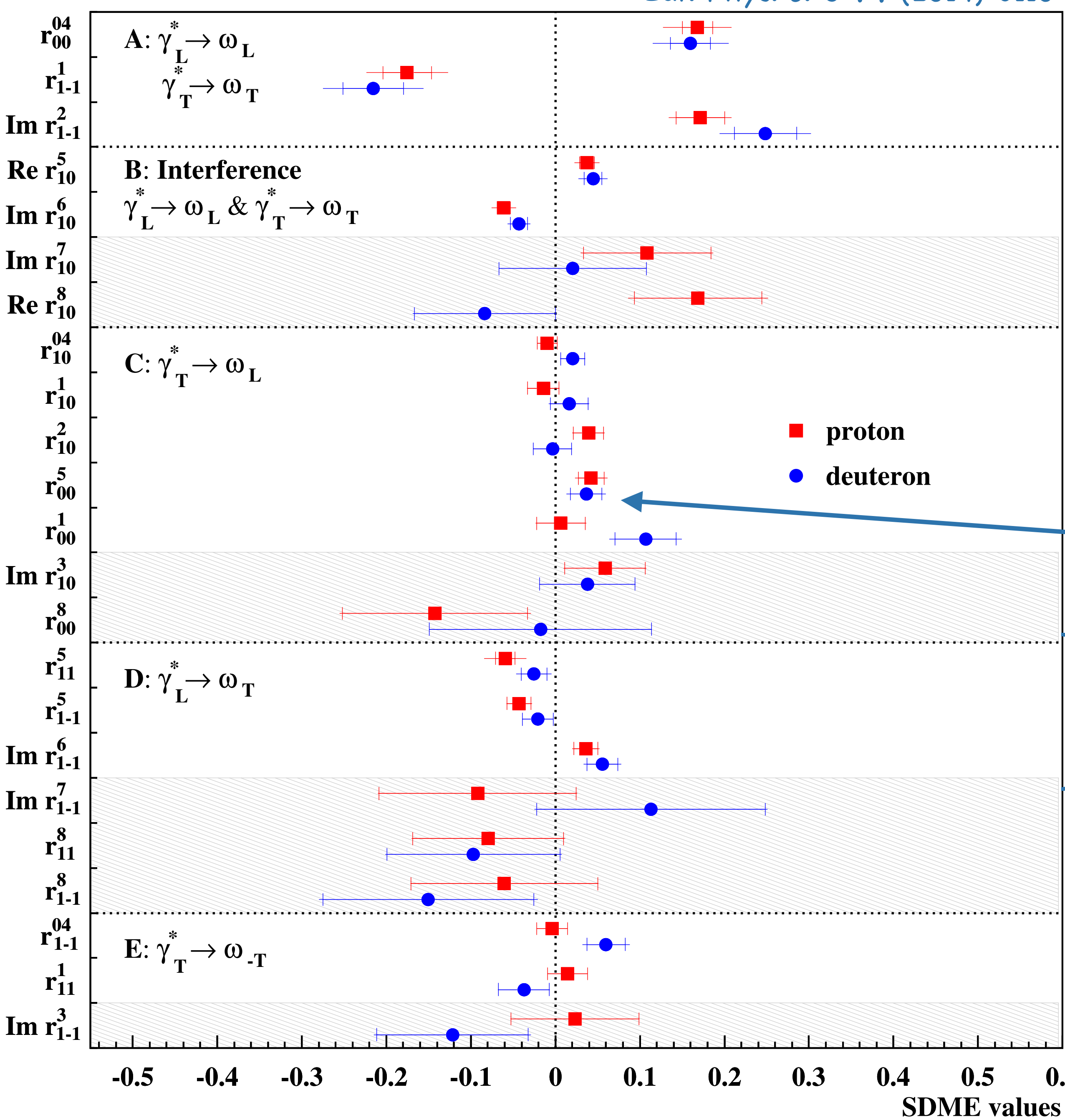


- 5 classes of SDMEs
- unpolarized and polarized SDMEs
- proton & deuteron similar

- s-channel helicity conservation ($\lambda_{\gamma^*} = \lambda_\omega$):
  - fulfilled for class A & B
  - class C - slight violation:

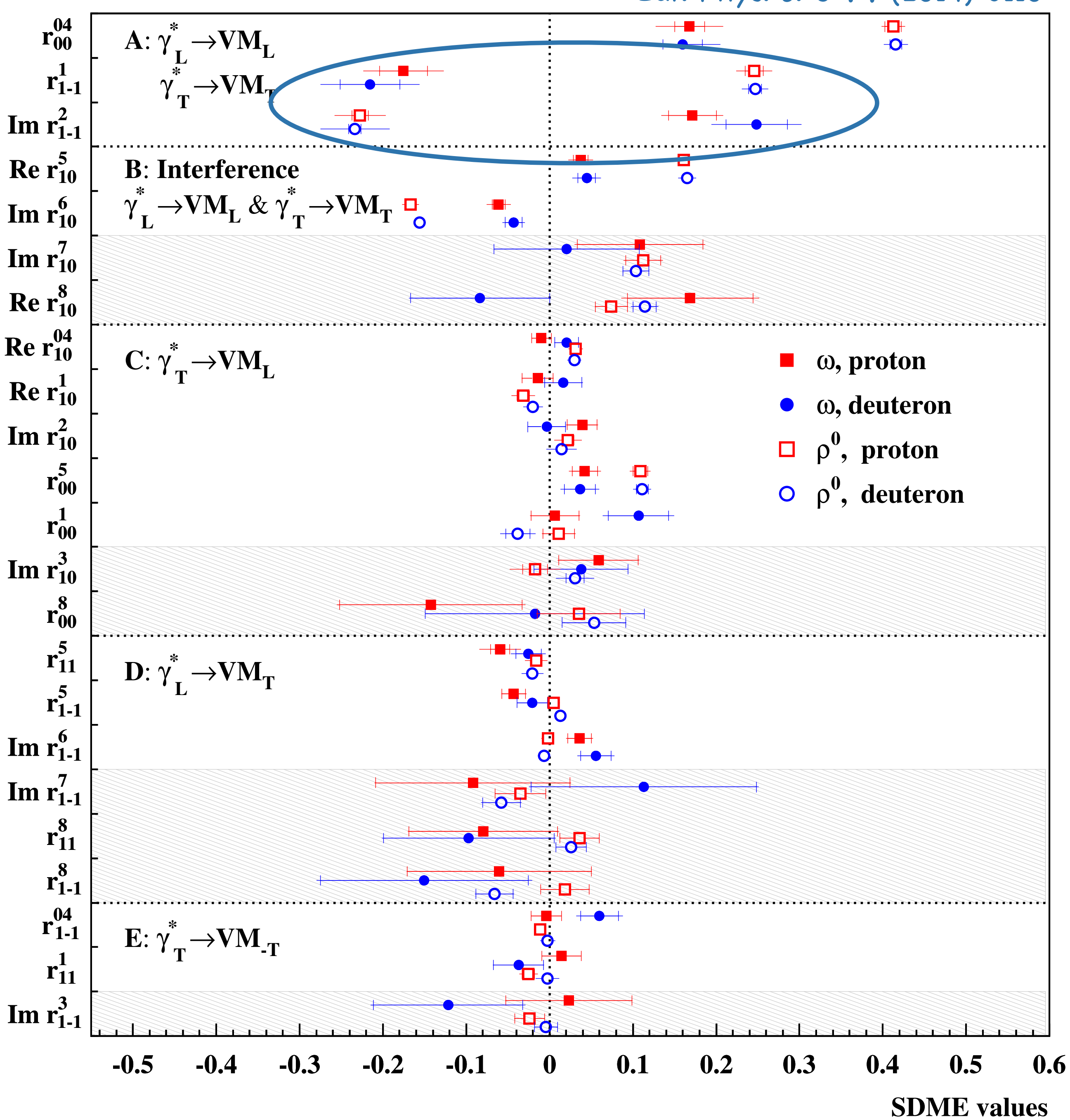
    $r^5_{00} \neq 0$ by $3(2)\,\sigma$ for p(d)

  - class D - slight violation:

    $r^5_{11} + r^5_{1-1} - \Im r^6_{1-1} \neq$ by $3(2.5)\,\sigma$ for p(d)

Results ω and ρ SDMEs

Eur. Phys. J. C **74** (2014) 3110



- ω: $r^1_{1-1} < 0$ and $\Im r^2_{1-1} > 0$
- ρ: $r^1_{1-1} > 0$ and $\Im r^2_{1-1} < 0$

⇩

- ω: large unnatural parity exchange
- ρ: large natural parity exchange

exclusive ρ^0: Eur. Phys. J. C **62** (2009) 659

Test of unnatural-parity exchange

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

$$\propto 2\,\epsilon|U_{10}|^2 + |U_{11} + U_{-11}|^2$$ (U=unnatural-parity amplitude)

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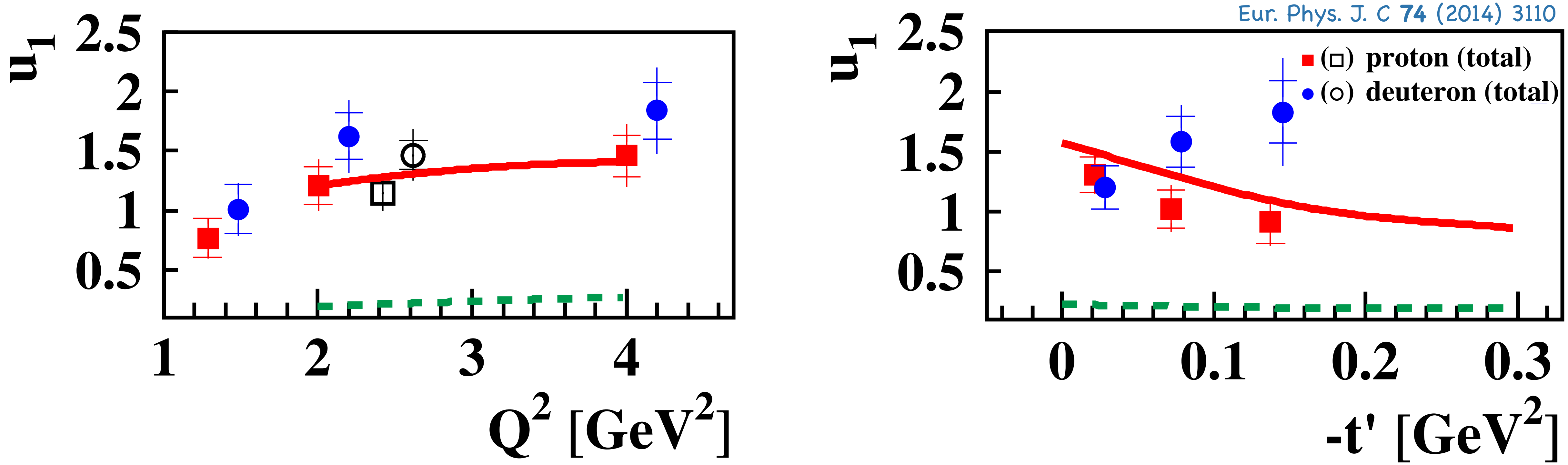

- large unnatural parity exchange seen

Test of unnatural-parity exchange

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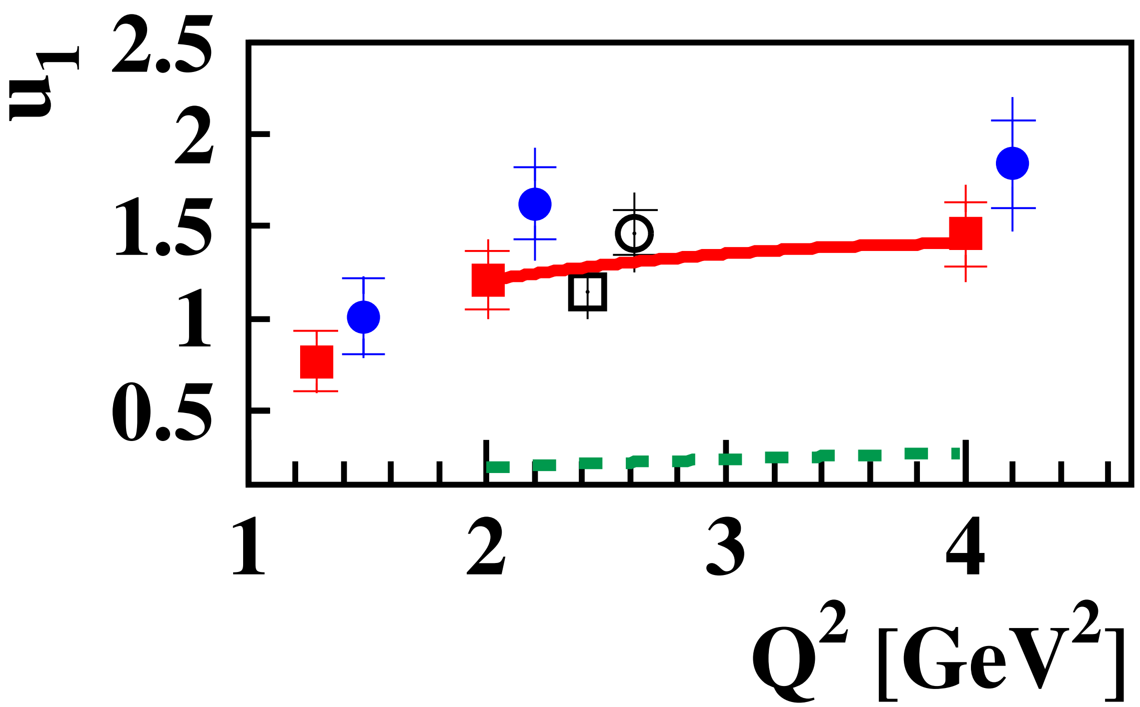
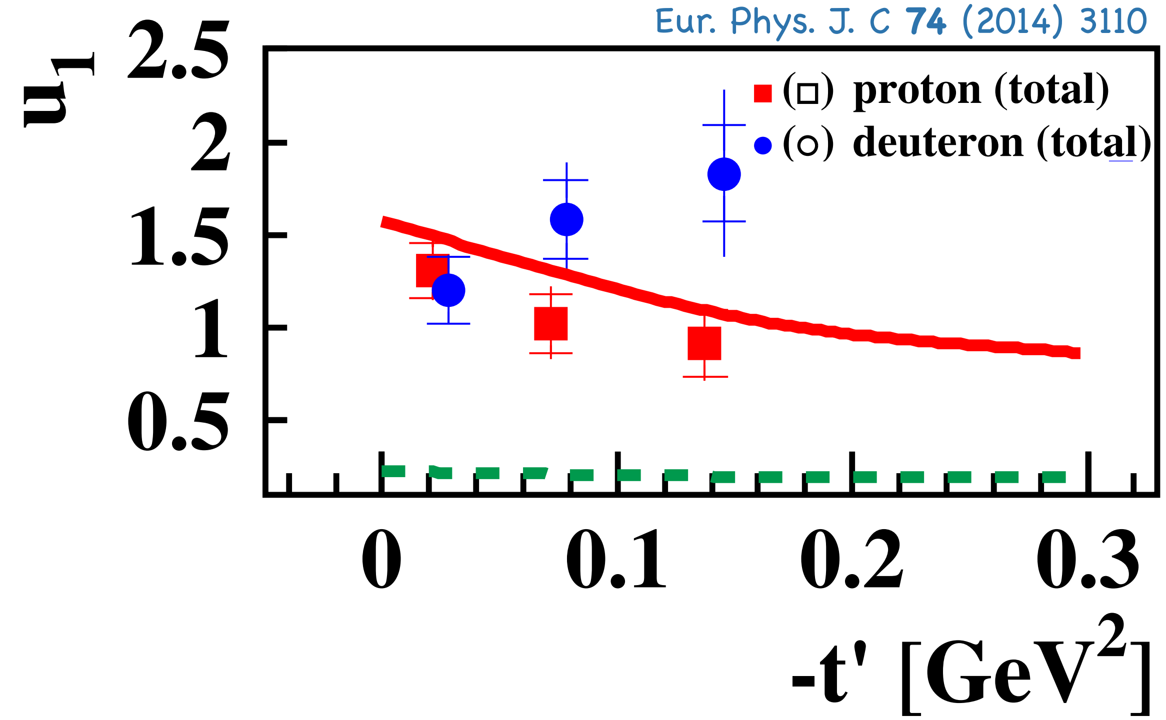
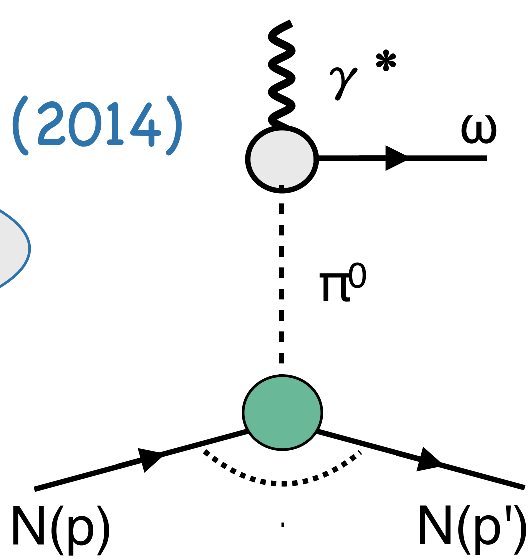




- large unnatural parity exchange seen
- model for protons - S. Goloskokov and P. Kroll, Eur. Phys. J A **50** 146 (2014)
  without pion-pole contribution
  with pion-pole contribution
  pion-pole contribution seems to account completely
  for unnatural-parity exchange

talk Tue 09h40
by S. Goloskokov



Kinematic dependencies

class A: $\gamma^*_L \to \omega_L$ and $\gamma^*_T \to \omega_T$

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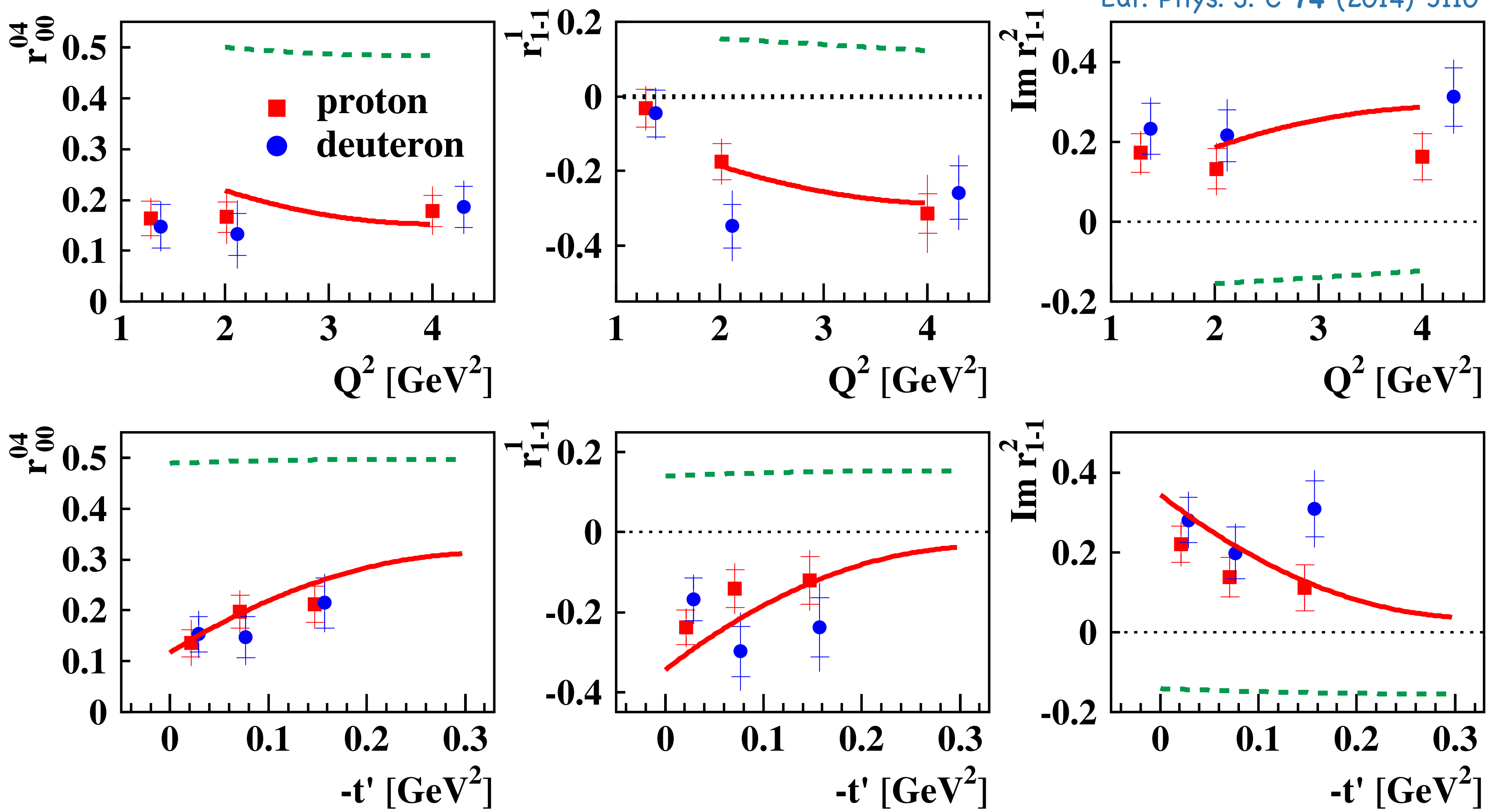

- no pronounced kinematic dependence observed
- again, need for pion-pole contribution observed

Kinematic dependencies

class B: interference $\gamma^*_L \to \omega_L$ and $\gamma^*_T \to \omega_T$

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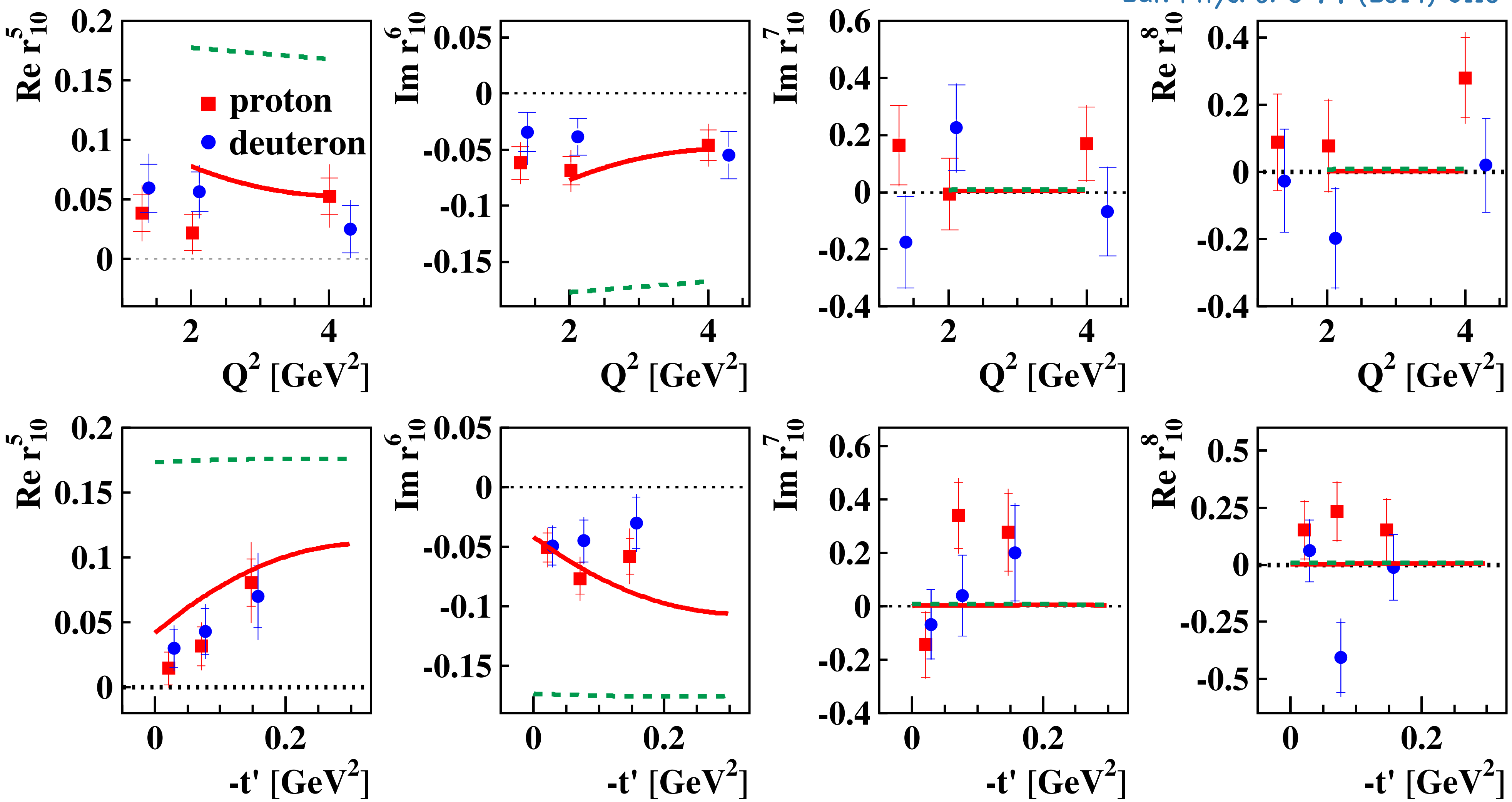

- no pronounced kinematic dependence observed
- need for pion-pole contribution observed for unpolarized SDMEs

Longitudinal-to-transverse cross-section ratio

$$R = \frac{d\sigma(\gamma^*_L \to \omega)}{d\sigma(\gamma^*_T \to \omega)} \approx \frac{1}{\epsilon}\frac{r^{04}_{00}}{1 - r^{04}_{00}}$$

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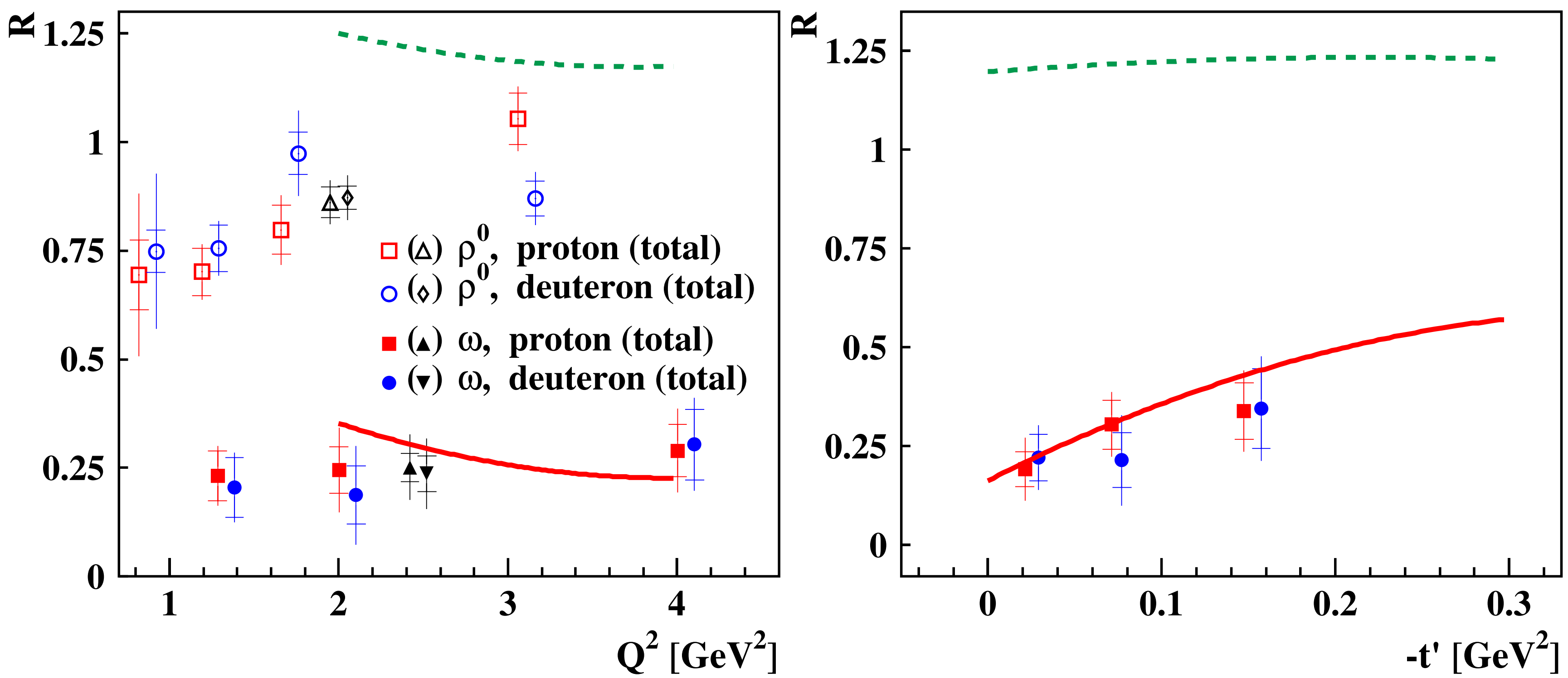
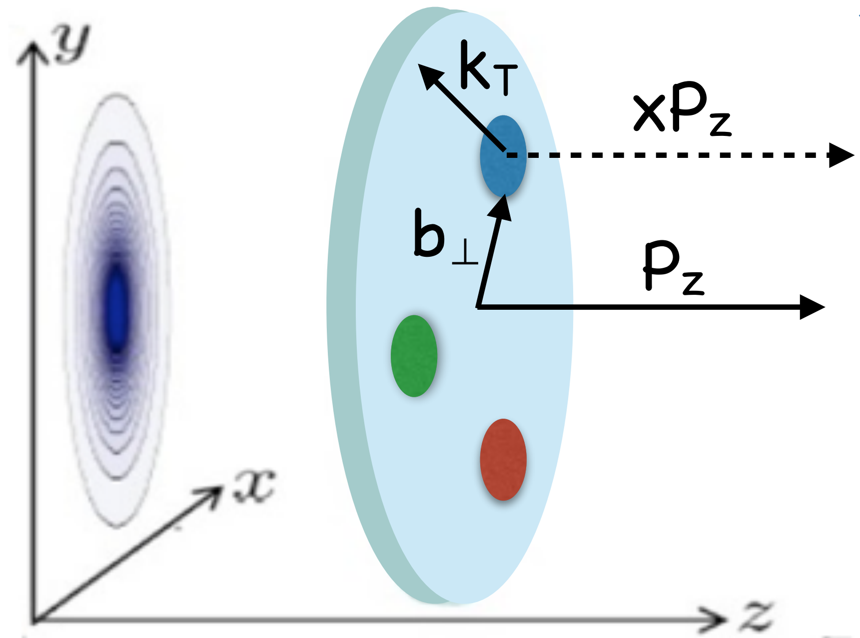


- R(ω) 4 times smaller than R(ρ)
- no pronounced kinematic dependence observed
- need for pion-pole contribution

3D pictures of the nucleon

Wigner distributions $W(x, \vec{k}_T, \vec{b}_\perp)$

$\int d^2\vec{b}_\perp$ → transverse-momentum dependent PDFs (TMD PDFs)

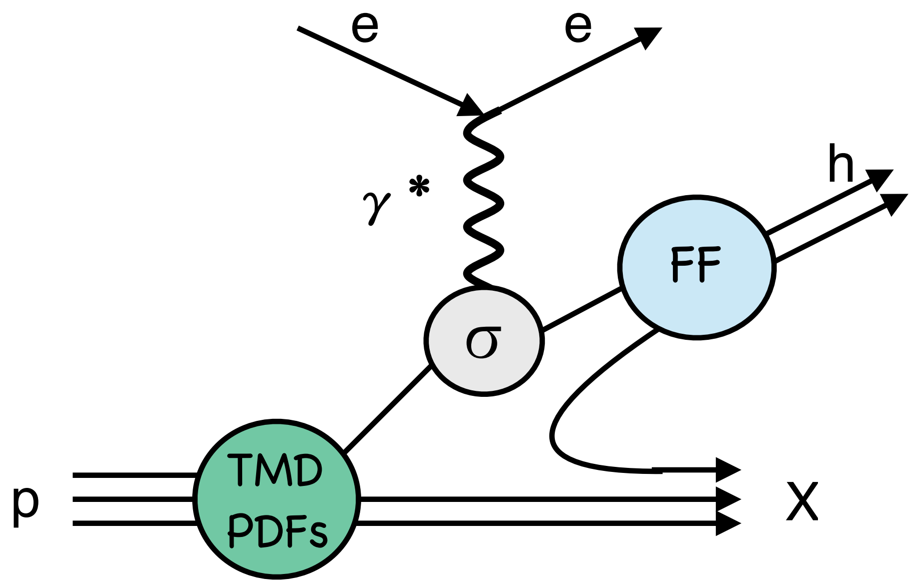


$\int d^2\vec{k}_T$ → impact-parameter distributions

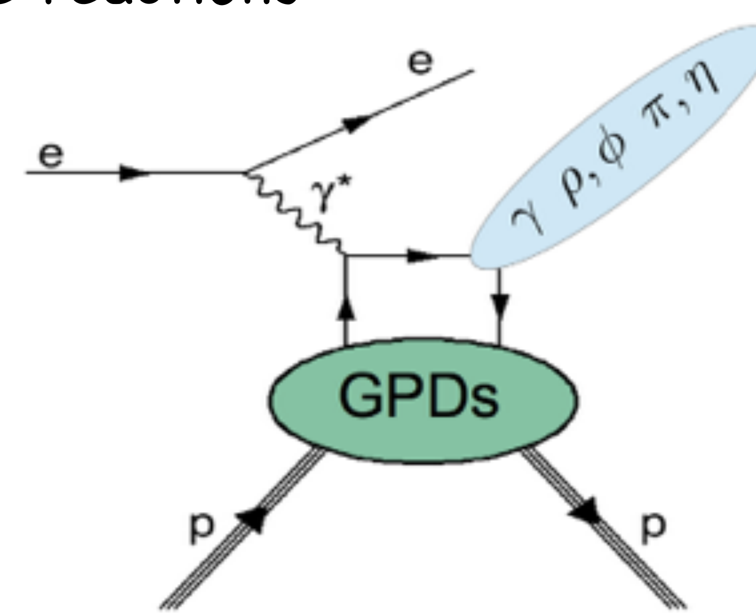
↓ Fourier transform

generalized parton distributions (GPDs)

semi-inclusive DIS



hard exclusive reactions



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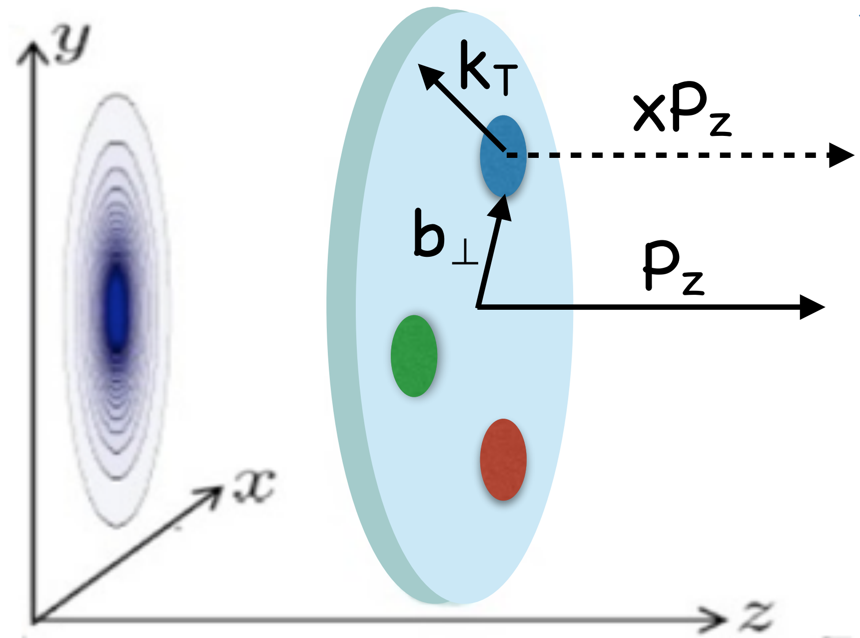


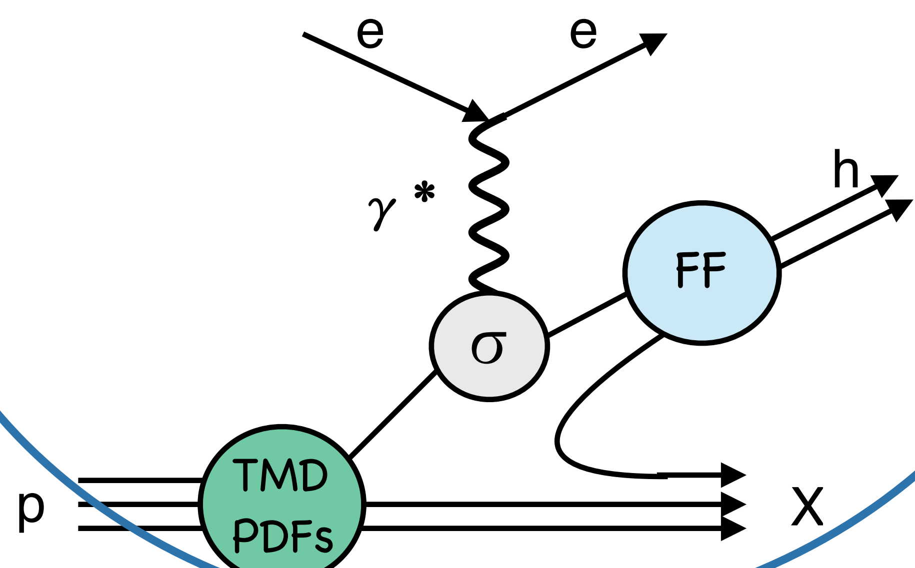
$\int d^2\vec{k}_T$

impact-parameter distributions

Fourier transform

generalized parton distributions (GPDs)

semi-inclusive DIS



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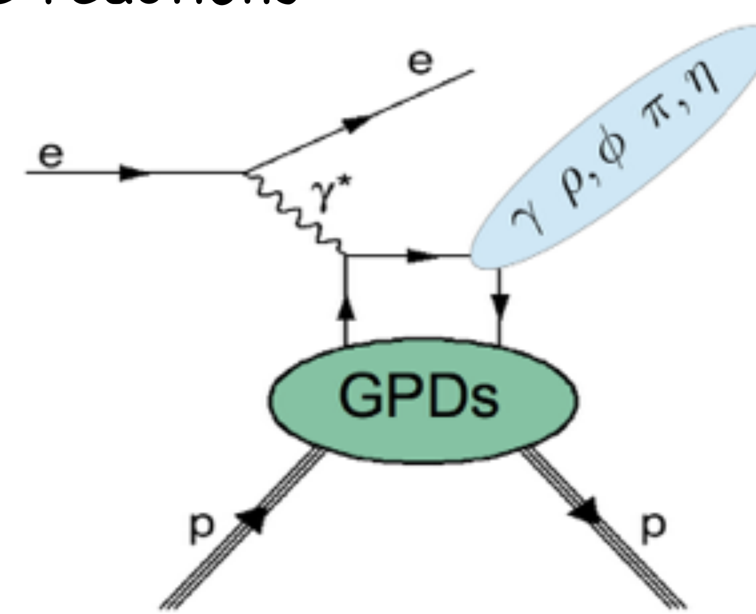


A_{UT} and A_{LT} in semi-inclusive DIS

- unpolarized & longitudinally polarized e^+/e^- beam
- transversely polarized H target

Semi-inclusive DIS cross section

$$\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2\,d\phi_S} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\Big\{F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi_h)F_{UU}^{\cos(\phi_h)} + \epsilon\cos(2\phi_h)F_{UU}^{\cos(2\phi_h)}$$

beam polarization

$$+\lambda_e\sqrt{2\epsilon(1-\epsilon)}\sin(\phi_h)F_{LU}^{\sin(\phi_h)}$$

longitudinal target polarization

$$+S_L\left[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi_h)F_{UL}^{\sin(\phi_h)} + \epsilon\sin(2\phi_h)F_{UL}^{\sin(2\phi_h)}\right]$$

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

transverse target polarization

$$+S_T\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

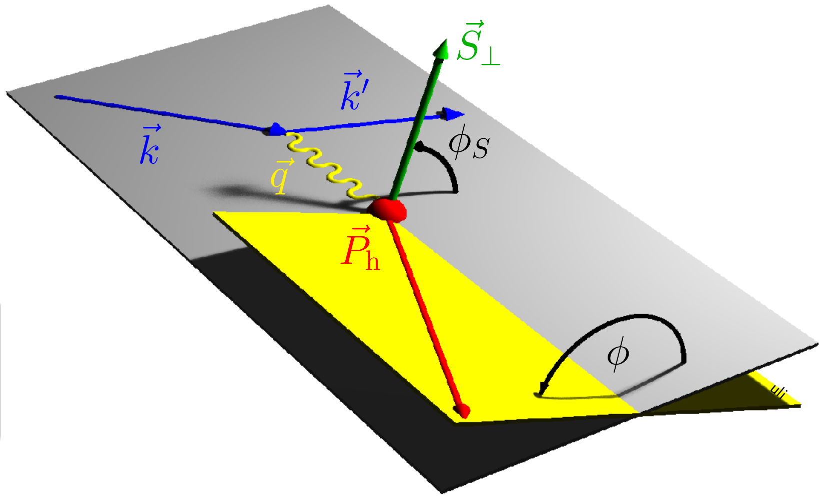
$$+\quad \epsilon\sin(\phi_h+\phi_S)F_{UT}^{\sin(\phi_h+\phi_S)} + \epsilon\sin(3\phi_h-\phi_S)F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\quad \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S)F_{UT}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi_h-\phi_S)F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+S_T\lambda_e\Big[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S)F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S)F_{LT}^{\cos(\phi_S)}$$

$$+\quad \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi_h-\phi_S)F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}$$

- structure function $F_{XY(,Z)}$
  X=beam, Y=target, Z=γ^* polarization



Semi-inclusive DIS cross section

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$$\Big\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi_h)F_{UU}^{\cos(\phi_h)} + \epsilon\cos(2\phi_h)F_{UU}^{\cos(2\phi_h)}$$

beam polarization

$$+\lambda_e\sqrt{2\epsilon(1-\epsilon)}\sin(\phi_h)F_{LU}^{\sin(\phi_h)}$$

longitudinal target polarization

$$+S_L\left[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi_h)F_{UL}^{\sin(\phi_h)} + \epsilon\sin(2\phi_h)F_{UL}^{\sin(2\phi_h)}\right]$$

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

transverse target polarization

$$+S_T\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

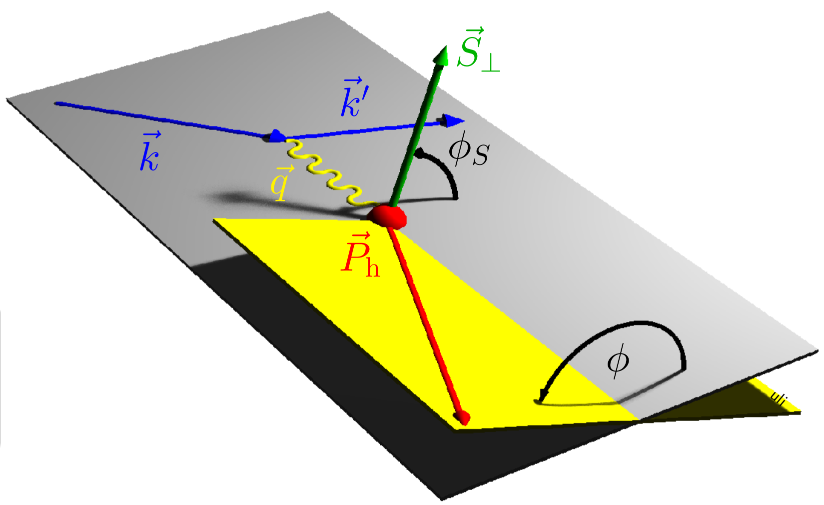
$$+ \epsilon\sin(\phi_h+\phi_S)F_{UT}^{\sin(\phi_h+\phi_S)} + \epsilon\sin(3\phi_h-\phi_S)F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+ \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S)F_{UT}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi_h-\phi_S)F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+S_T\lambda_e\Big[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S)F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S)F_{LT}^{\cos(\phi_S)}$$

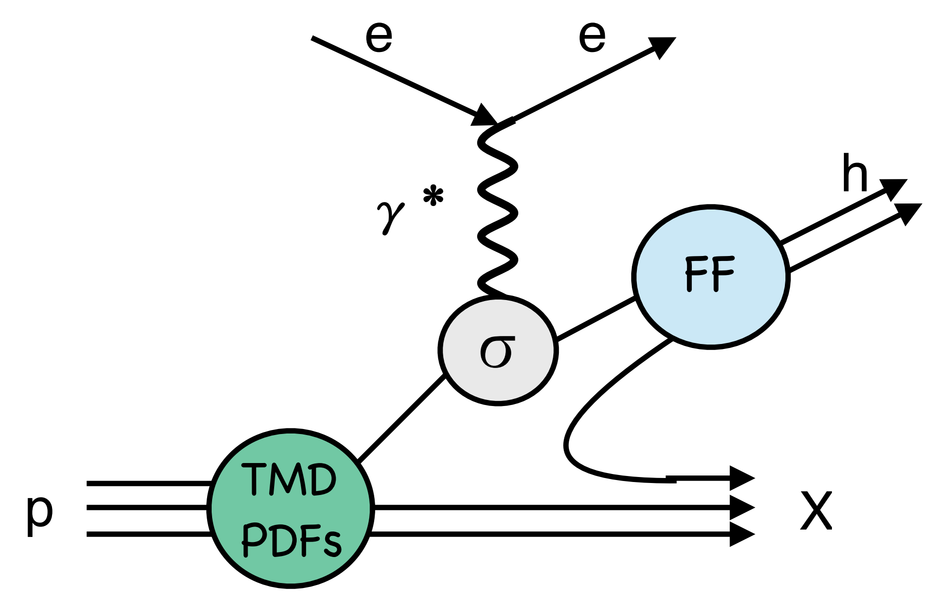
$$+ \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi_h-\phi_S)F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}$$

- structure function $F_{XY(,Z)}$
  X=beam, Y=target, Z=γ^* polarization
- leading twist



Transverse-momentum-dependent PDFs and FFs

structure function $F_{XY(,z)} \propto$ TMD PDF $\otimes$ FF



parton distribution functions (PDFs)

		quark		
		U	L	T
nucleon	U	f_1		$h_1^\perp$
	L		g_1	$h_{1L}^\perp$
	T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1, $h_{1T}^\perp$

fragmentation functions (FFs)

		quark		
		U	L	T
h	U	D_1		$H_1^\perp$

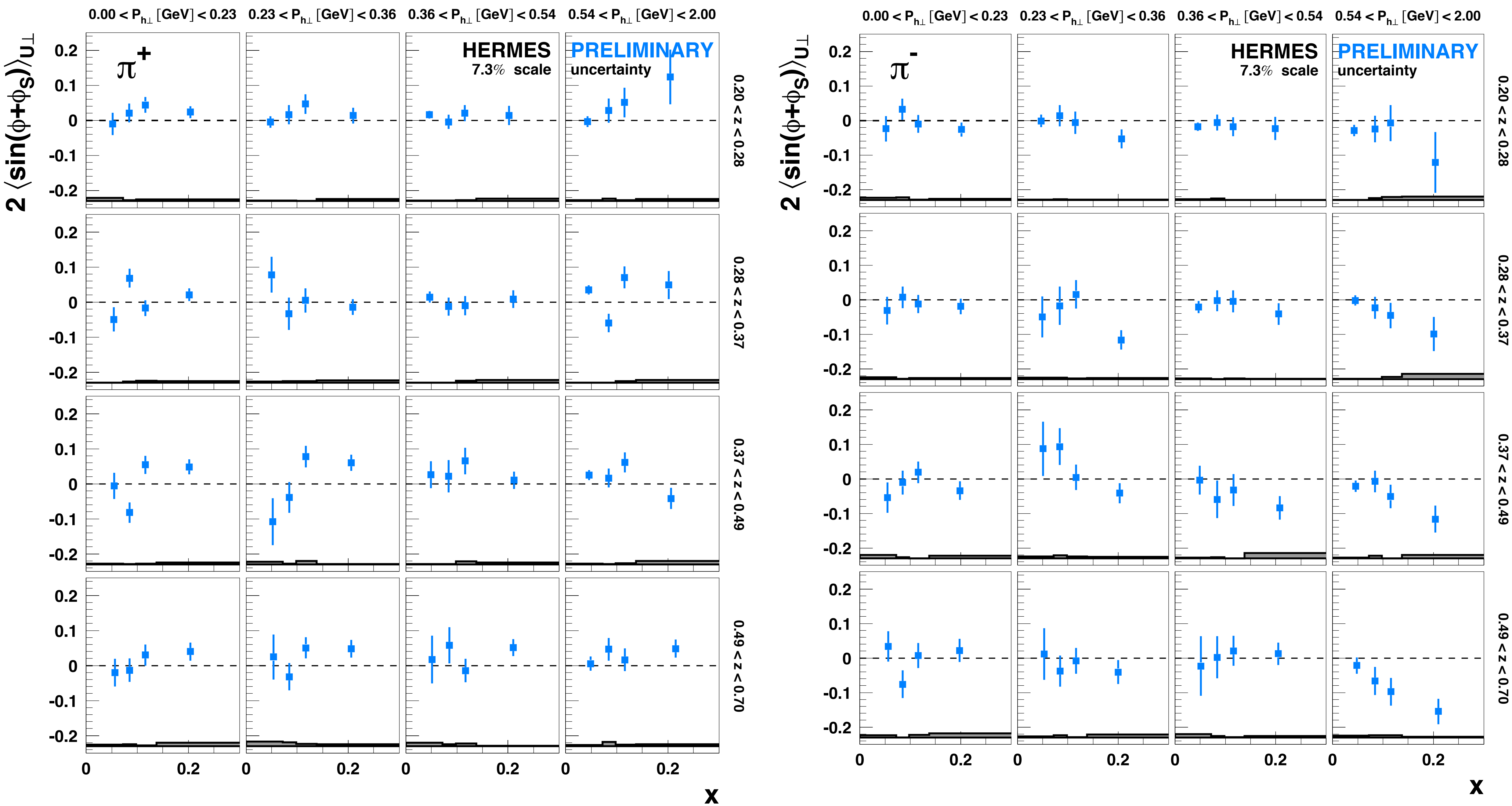
nucleon with transverse/longitudinal spin

quark with transverse/longitudinal spin

quark transverse momentum

Collins amplitudes

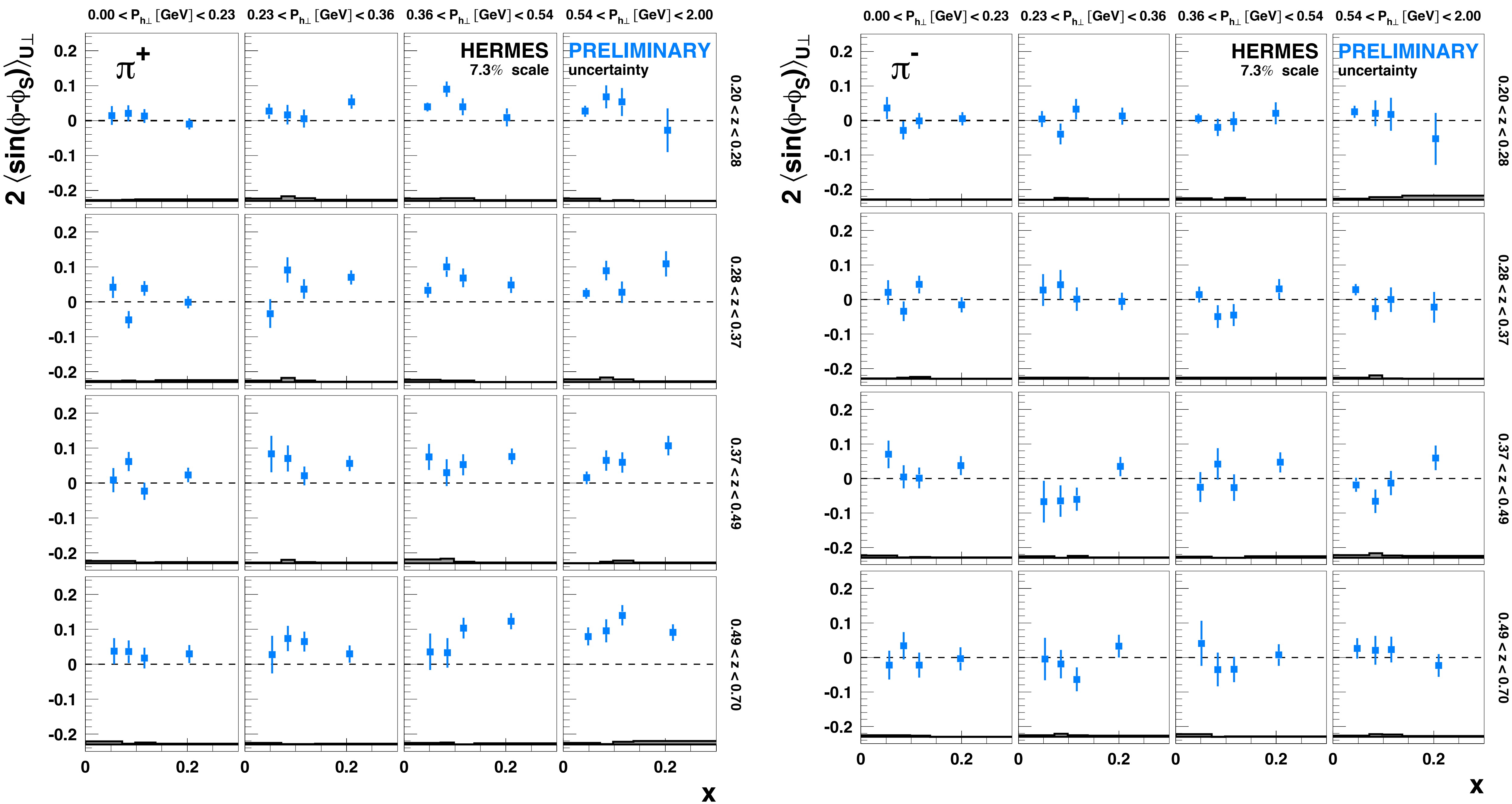
$$F_{UT}^{\sin(\phi_h+\phi_S)} \propto h_{1T} \otimes H_1^{\perp}$$



- π^+ amplitudes positive; π^- amplitudes negative
- π^- amplitudes increasing with x at large $P_{h\perp}$

Sivers amplitudes

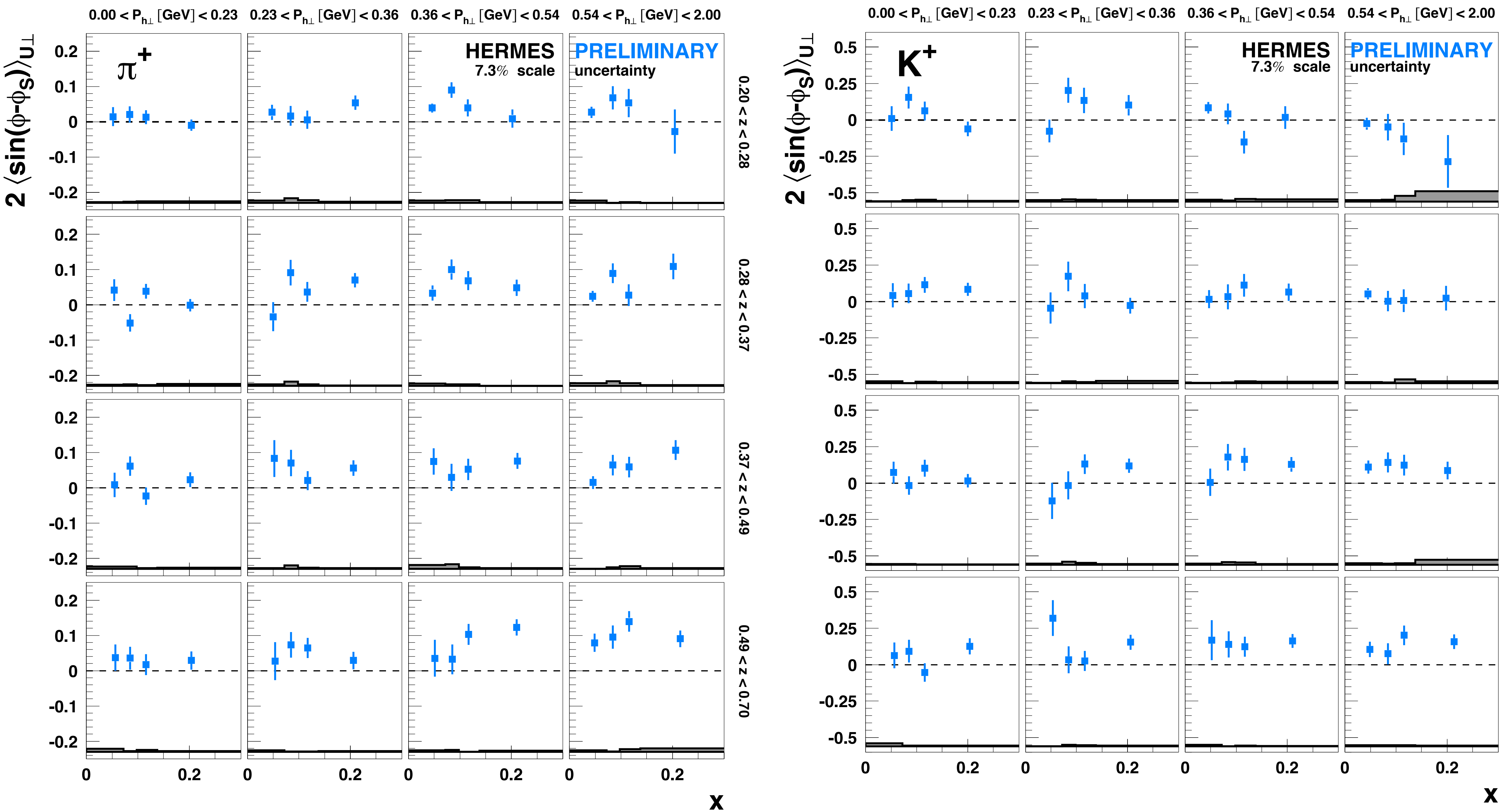
$$F_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp} \otimes D_1$$



- π^+ amplitudes positive; π^- amplitudes≈0
- π^+ amplitudes increasing with x at large $P_{h\perp}$

Sivers amplitudes

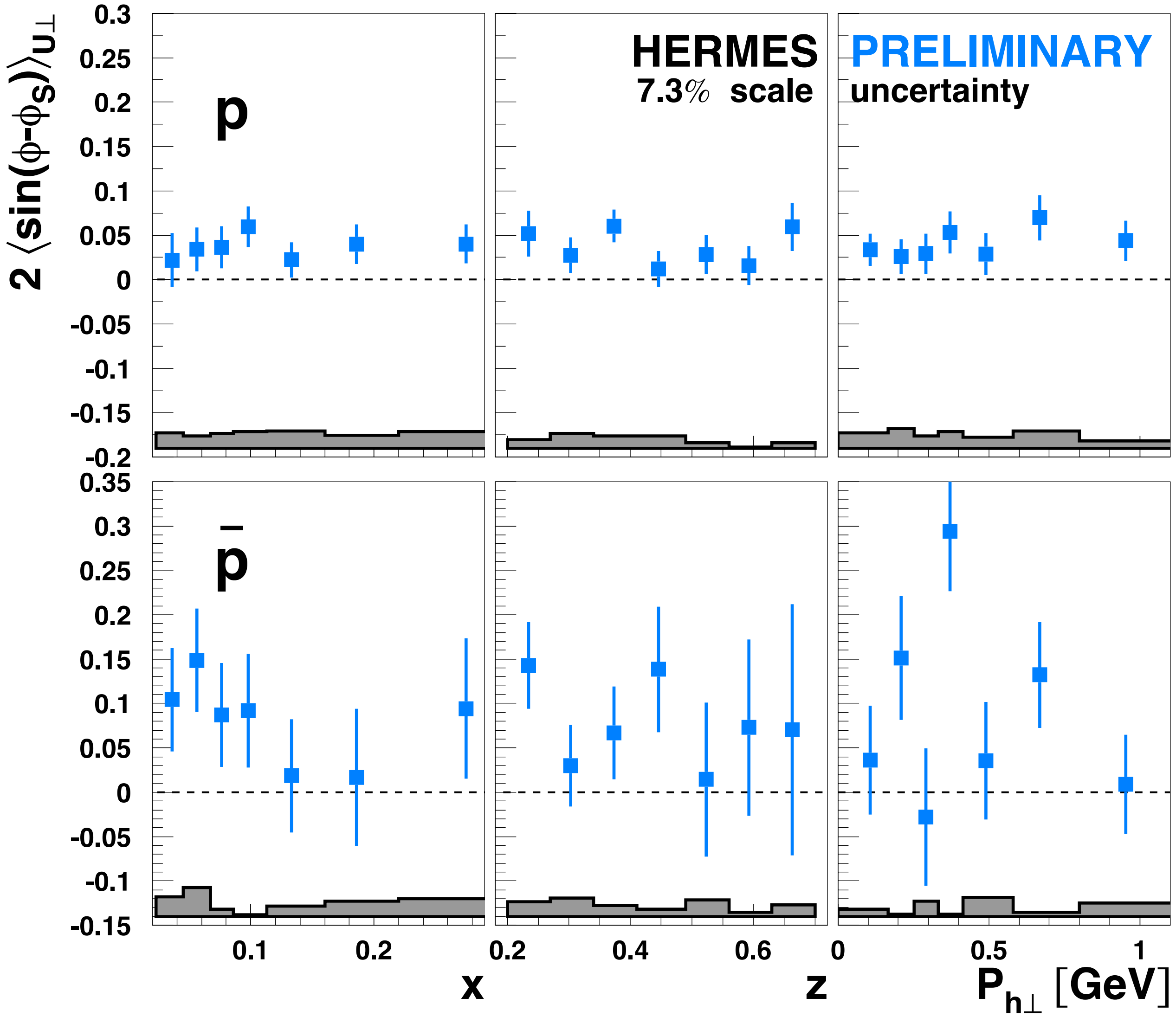
$$F_{UT}^{\sin(\phi_h - \phi_S)} \propto f_{1T}^{\perp} \otimes D_1$$

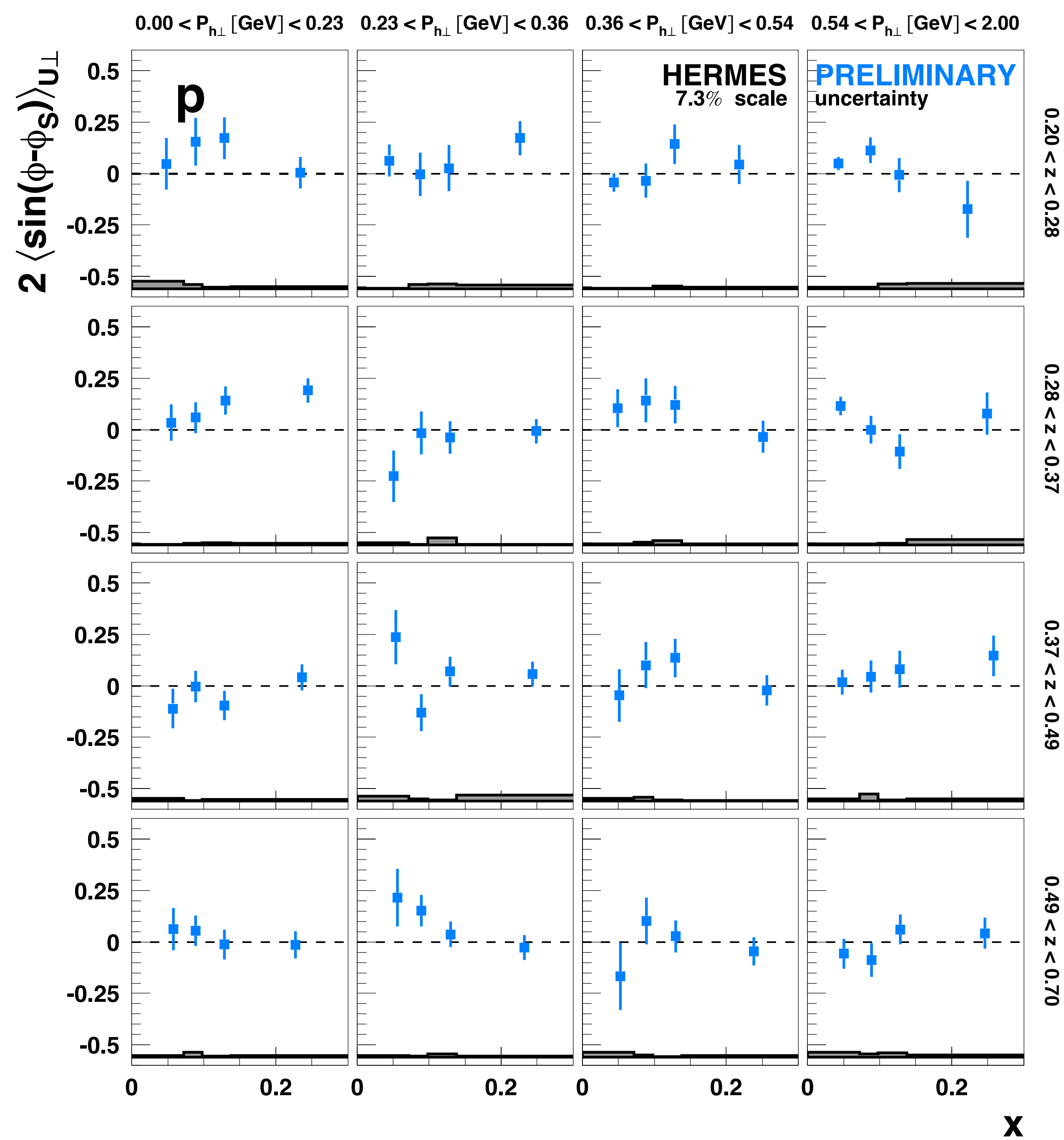


- K⁺ amplitudes positive, larger than π⁺ ⟶ non-trivial role of sea quarks?

Sivers amplitudes

$$F_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp} \otimes D_1$$

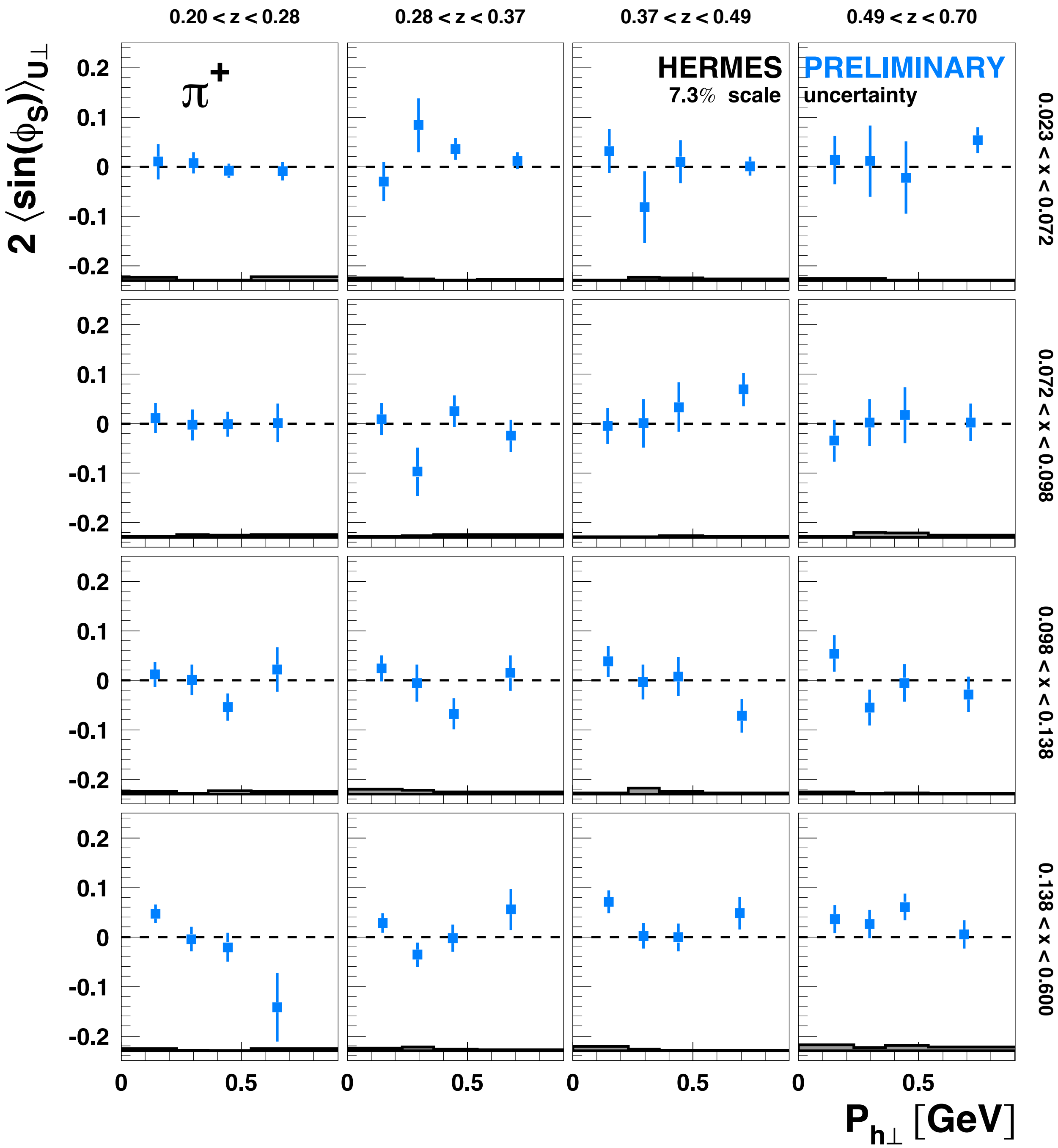


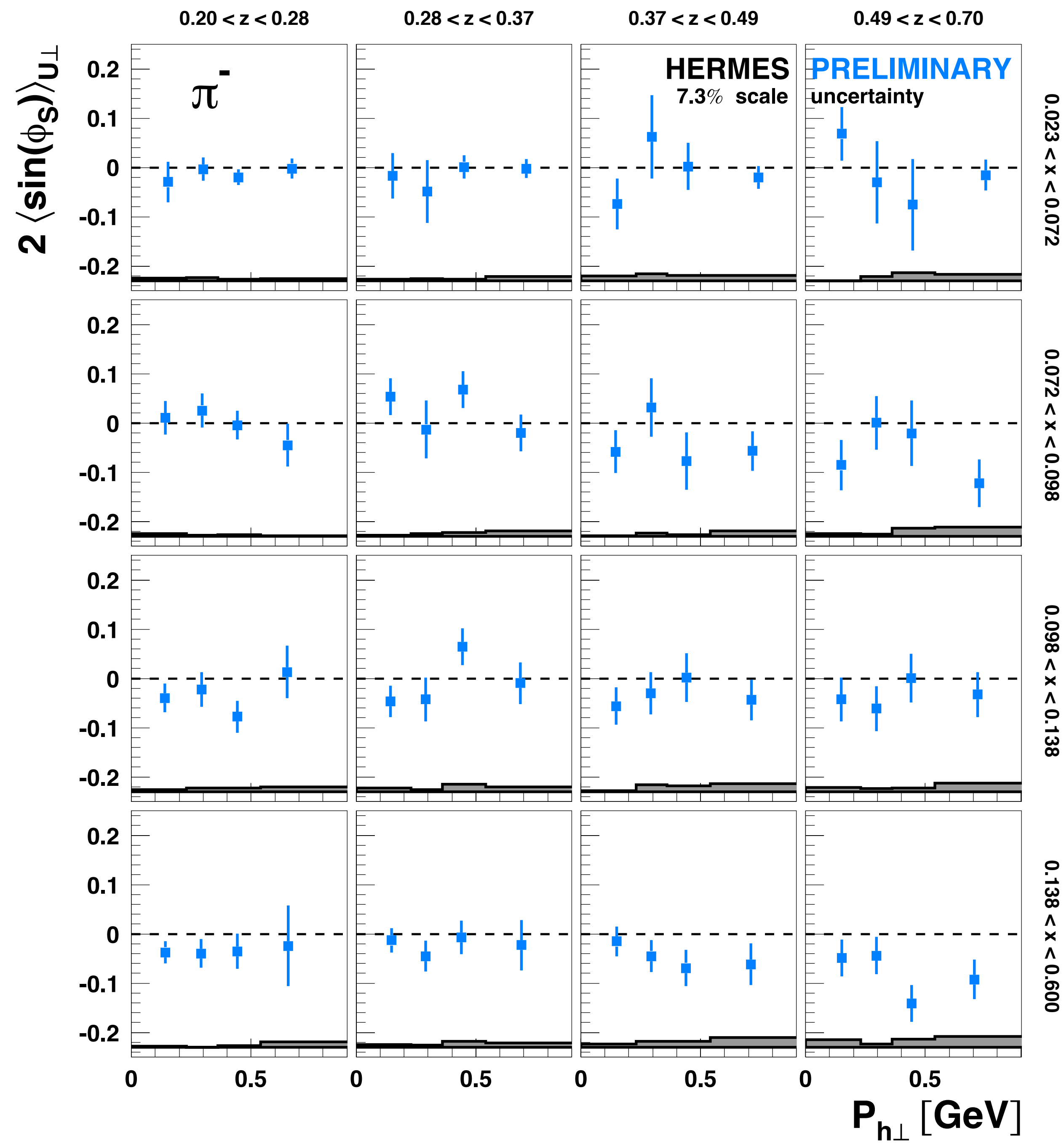


- positive proton amplitudes

$\sin(\phi_S)$

higher twist!

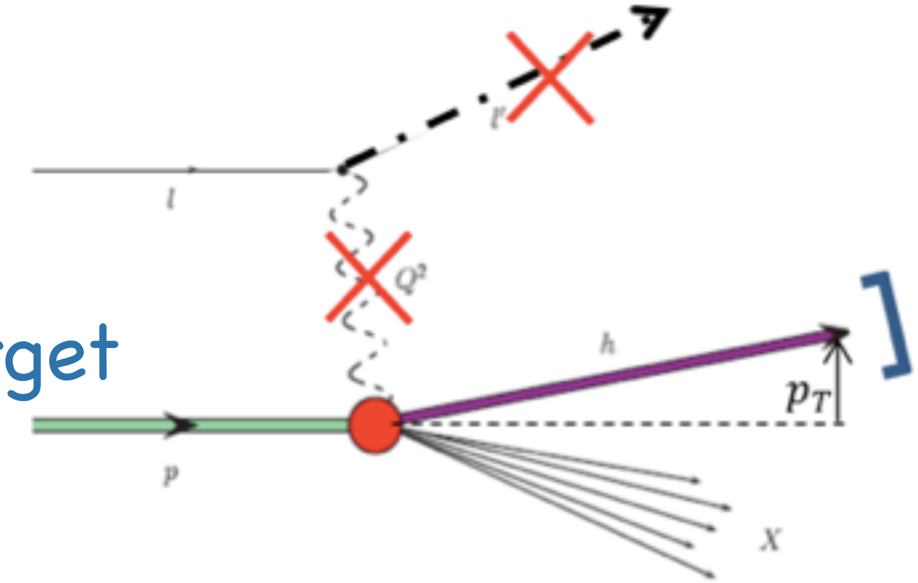




- π^- amplitudes negative

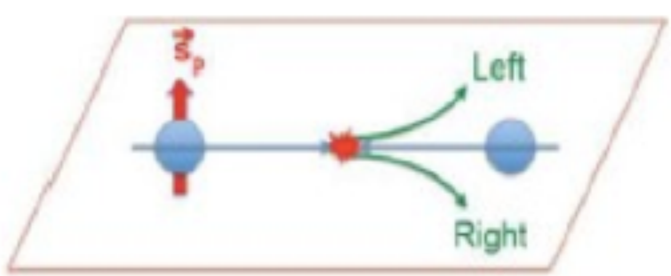
A_{UT} in inclusive DIS

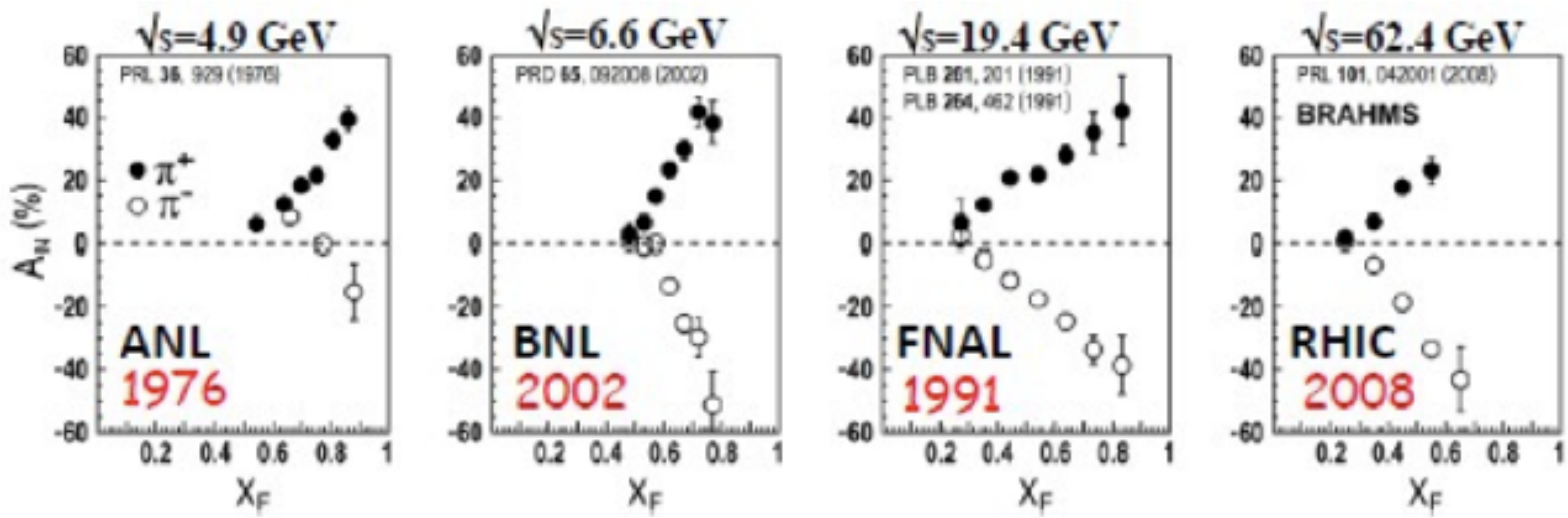
- unpolarized e^+/e^- beam
- transversely polarized H target



Motivation

- Large left-right asymmetries (A_N) observed in $p^{\uparrow}p \rightarrow hX$ for $\sqrt{s}$ from 4.9 to 500 GeV

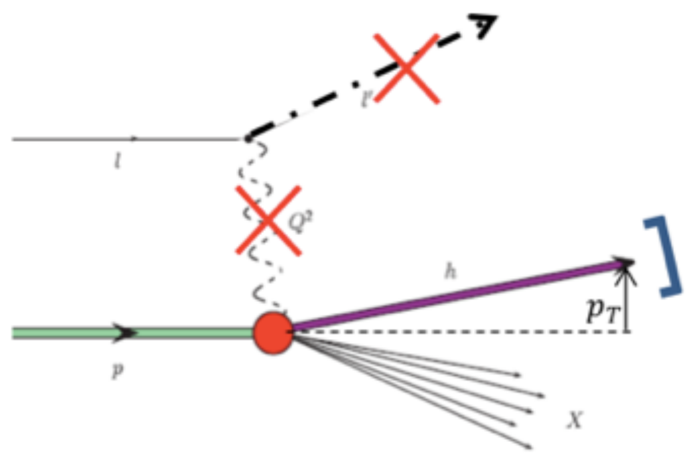




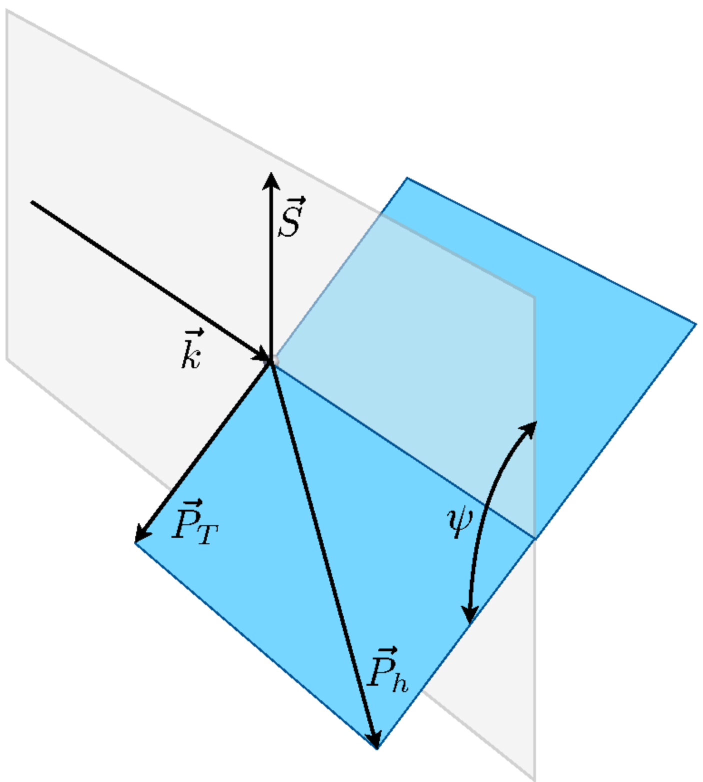
- Not interpretable based on collinear factorisation in leading twist
- Possible interpretations are based on
  - TMD PDFs and FFs - mainly Sivers and Collins effect
  - collinear with higher-twist multiparton correlations

Transverse target spin asymmetry at HERMES

- Inclusive hadron electroproduction $e^{\pm}p^{\uparrow} \to hX$



- P_T wrt. lepton beam
- $x_F=P_L/P_{L,max}$ in ep CMS



- Azimuthal asymmetry

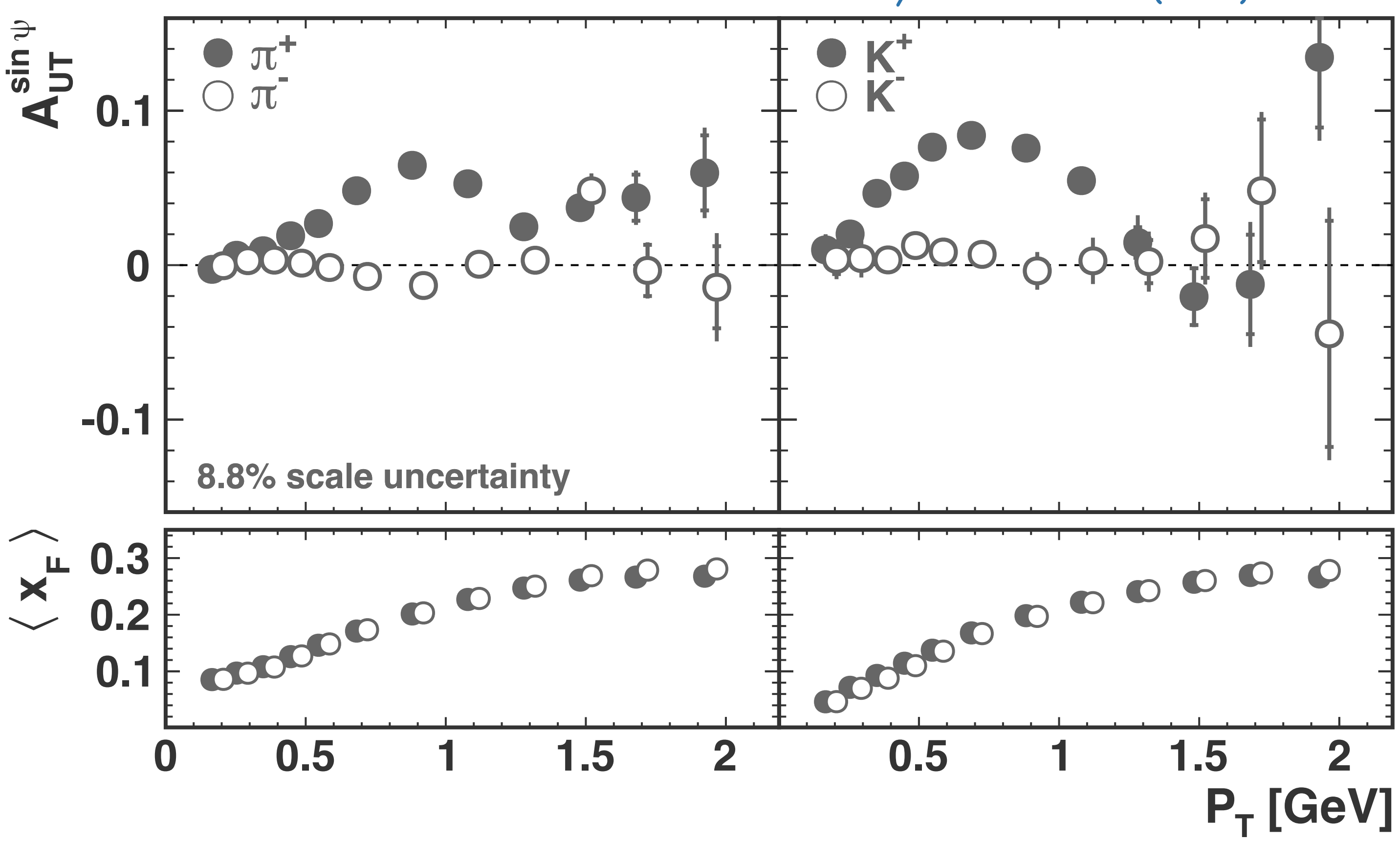
$$A_{UT}(x_F, P_T) = A_{UT}^{\sin\psi}(x_F, P_T)\,\sin\psi$$

$$A_{UT}^{\sin\psi} = \frac{\pi}{2} A_N$$

- at HERMES $\psi \approx \phi - \phi_S$ (Sivers angle)

P_T dependence

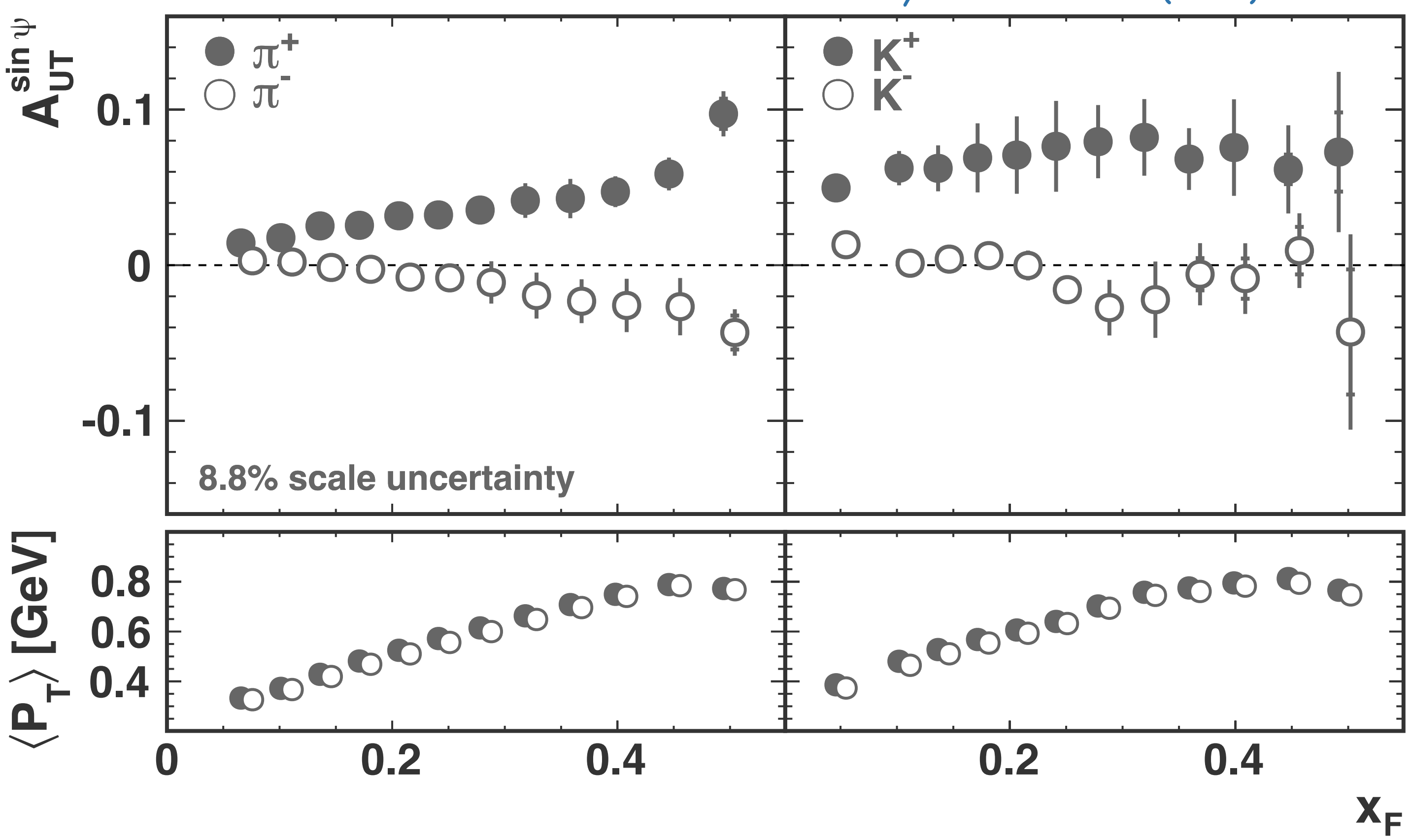
Phys. Lett. B **728** (2014) 183-190



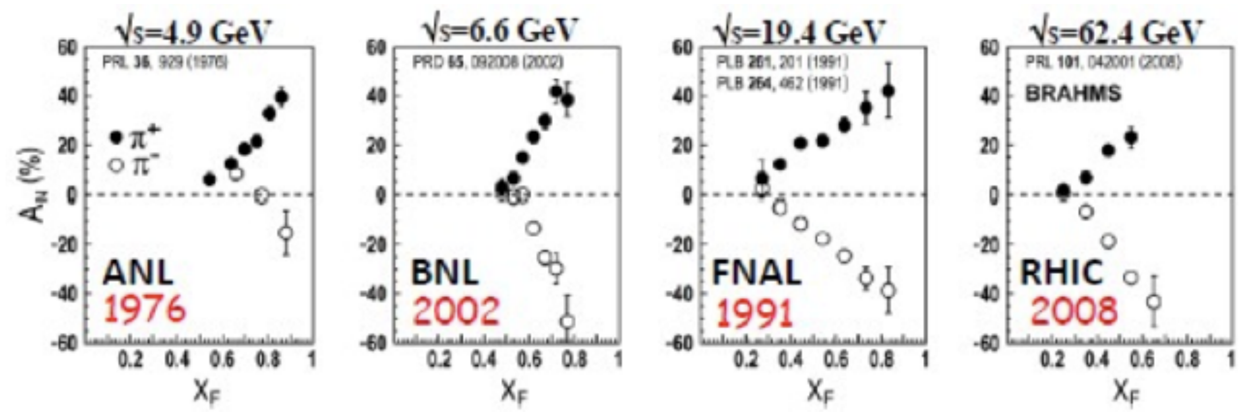
- π^+ and K^+
  - positive
  - larger for K^+ than for π^+
  - varying with P_T
- π^- and K^-
  - small amplitudes

x_F dependence

Phys. Lett. B **728** (2014) 183-190



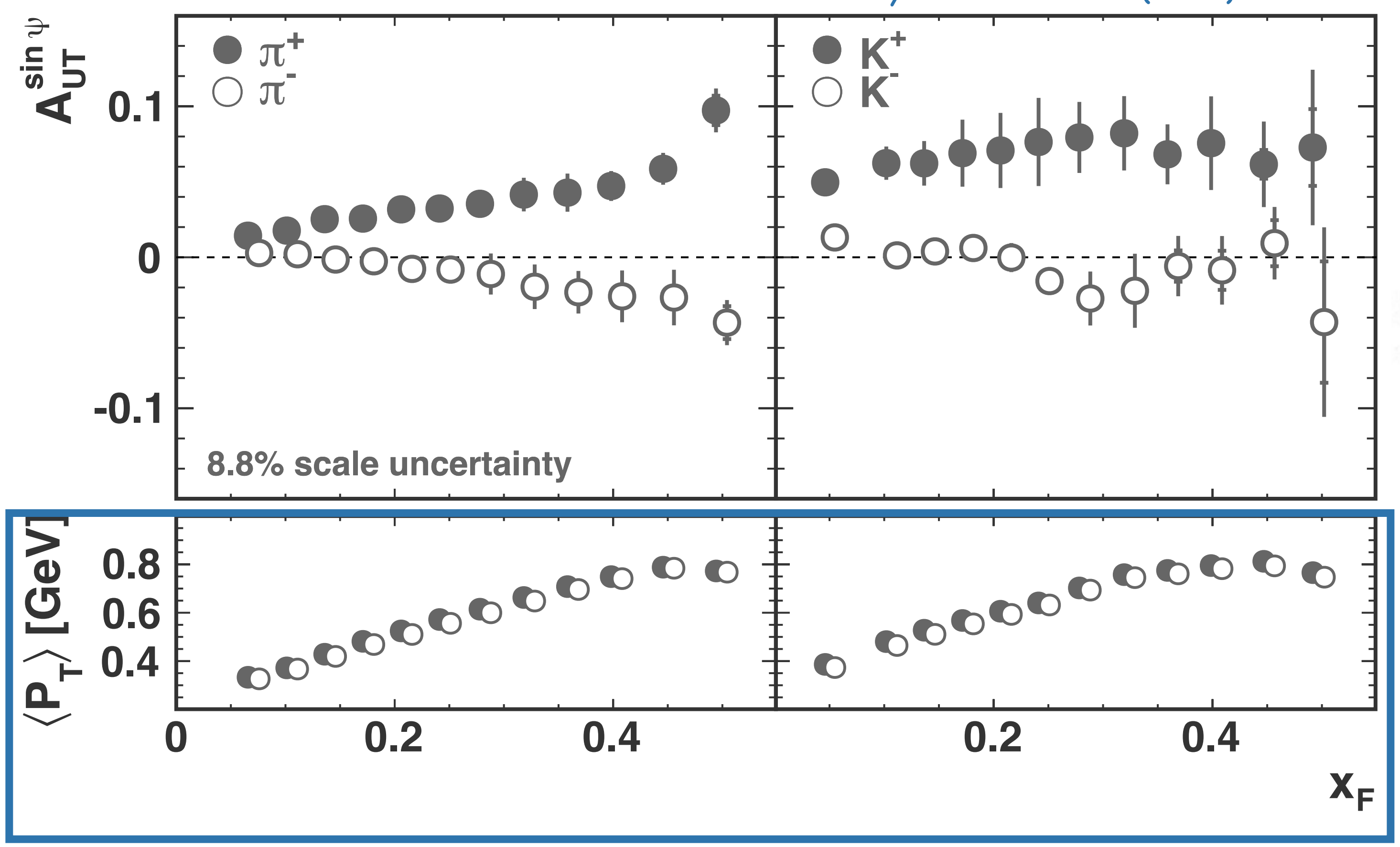
- π^+: >0, increasing linearly with x_F
- π^-: <0, decreasing linearly with x_F
- π^+ and π^- behave as $p^\uparrow p \to hX$



- K^+: >0, constant with x_F
- K^-: ≈0

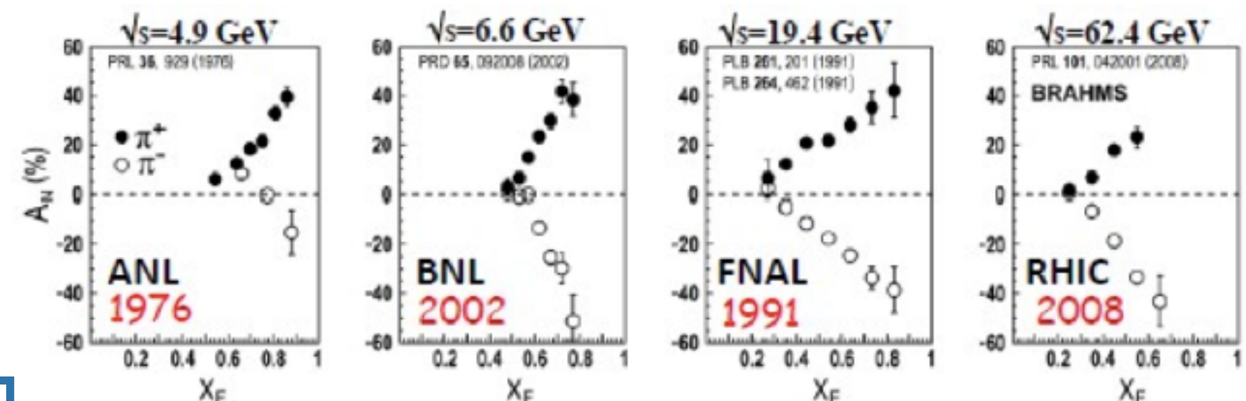
x_F dependence

Phys. Lett. B **728** (2014) 183–190



x_F-P_T correlation → 2D extraction

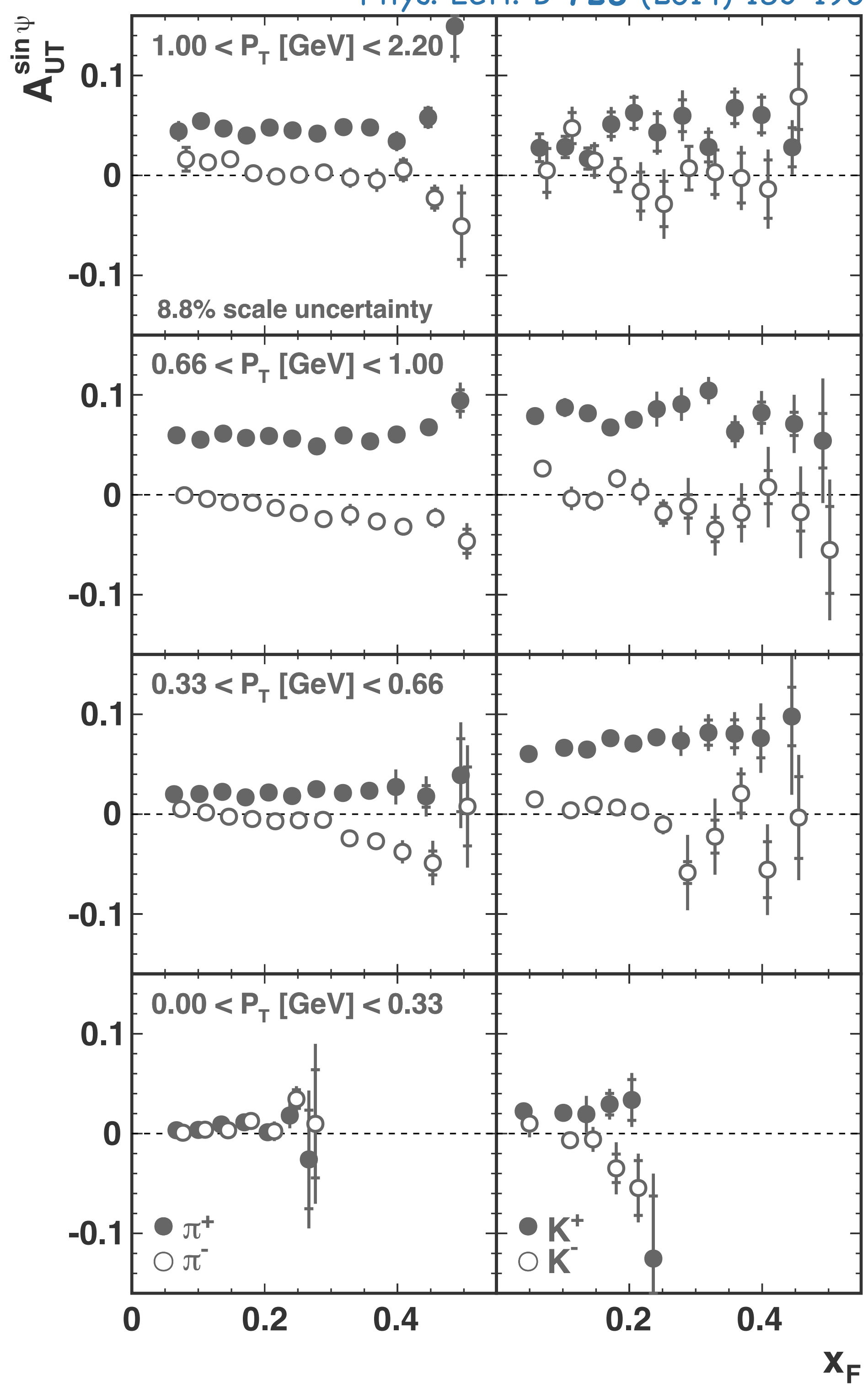
- π^+: >0, increasing linearly with x_F
- π^-: <0, decreasing linearly with x_F
- π^+ and π^- behave as $p^\uparrow p \to hX$



- K^+: >0, constant with x_F
- K^-: ≈0

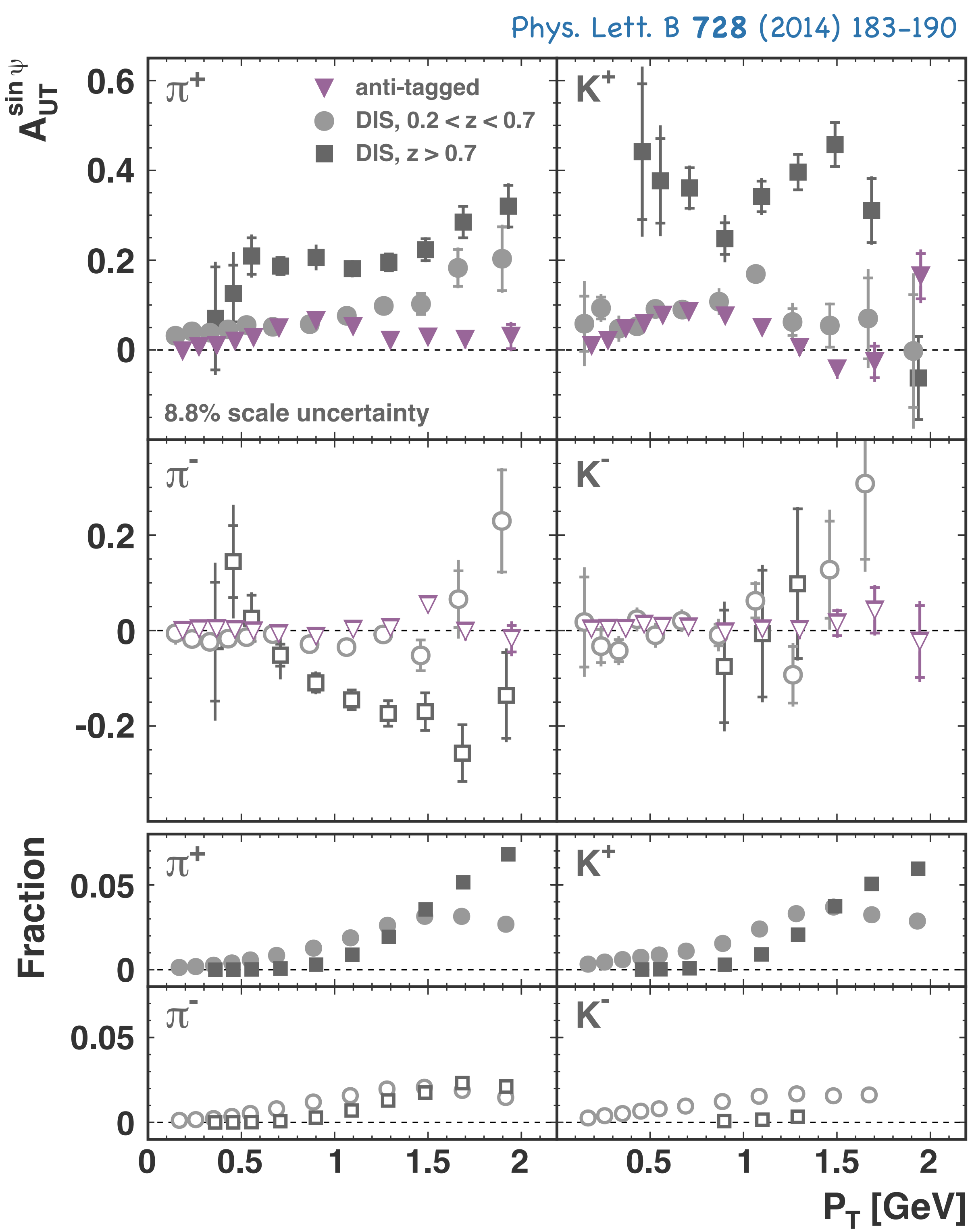
Disentanglement of x_F & P_T dependence

Phys. Lett. B **728** (2014) 183-190



- π^+: independent of $x_F \longrightarrow$ 1D x_F dependence from P_T correlation
- π^-: decreasing linearly with x_F, as for 1D
- note: π^- and π^+ from $p^\uparrow p \to hX$ linear dependence on x_F remains after slicing in P_T
- K^+: constant/slightly increasing with x_F
- K^-: constant/slightly decreasing with x_F

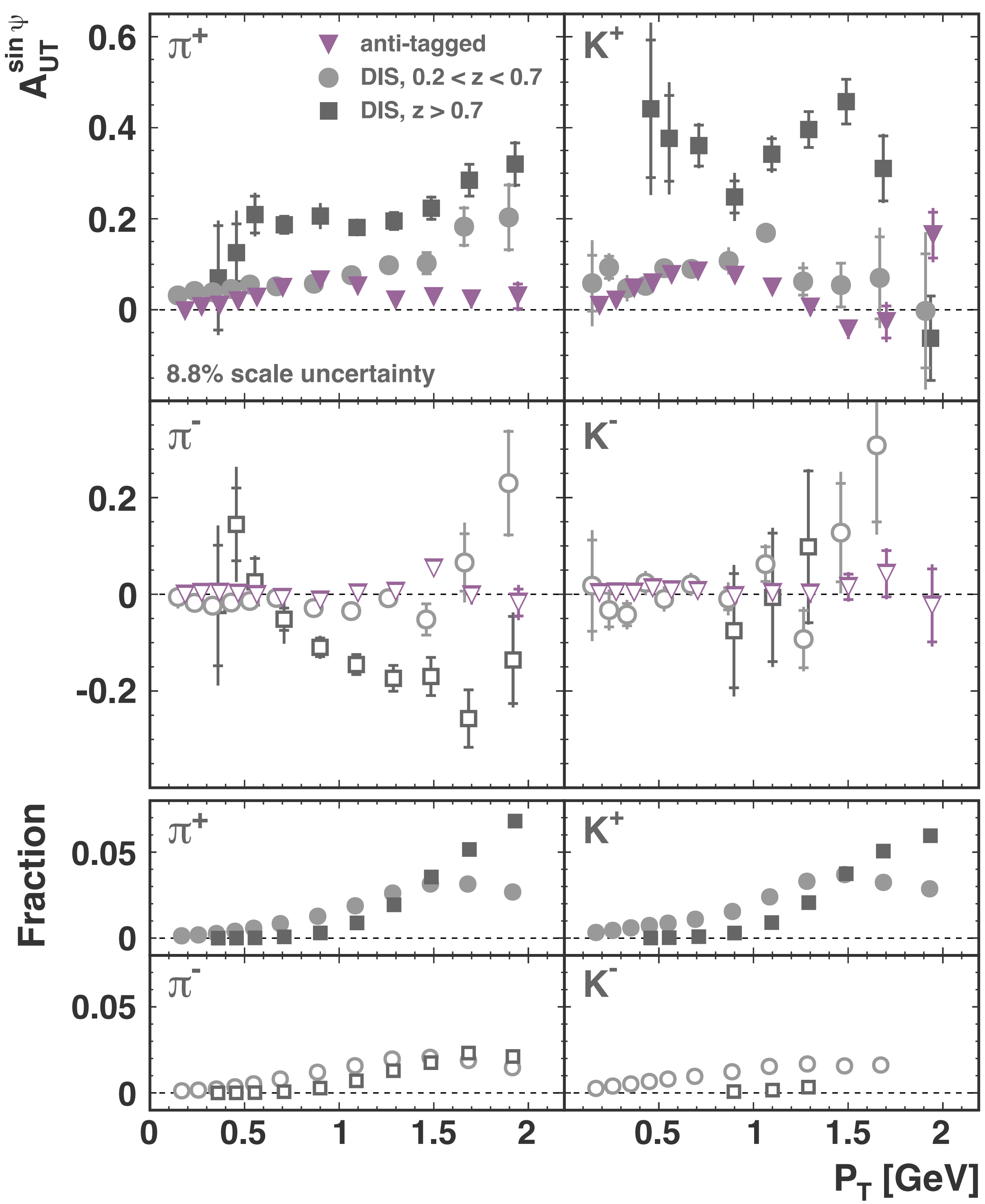
Disentanglement of sub-samples



- anti-tagged
  - no scattered $e^{\pm}$ detected
  - mainly $Q^2 \approx 0$
  - hard scale P_T
  - $P_T > \Lambda_{QCD}$: higher twist
  - $P_T \approx \Lambda_{QCD}$: no theory predictions
  - ≈ overall results, 98% of statistics

Disentanglement of sub-samples

Phys. Lett. B **728** (2014) 183-190



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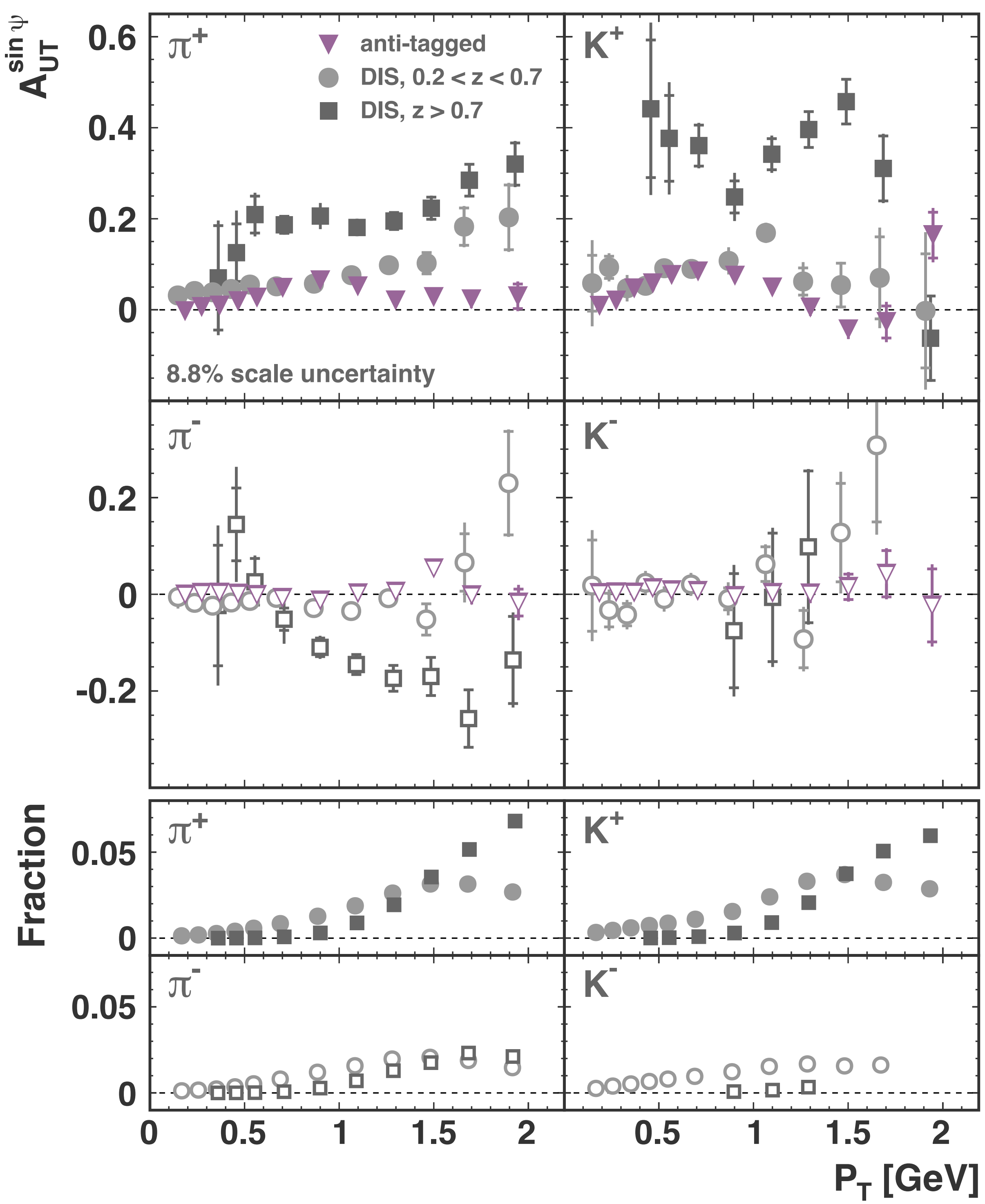
  - ≈ overall results, 98% of statistics
- DIS with 0.2<z<0.7
  - mainly $\langle Q^2 \rangle > \langle P_T \rangle$
  - TMD PDF and FF description
  - similar to Sivers amplitudes

Disentanglement of sub-samples

Phys. Lett. B **728** (2014) 183-190



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- DIS with 0.2<z<0.7
  - mainly $\langle Q^2 \rangle > \langle P_T \rangle$
  - TMD PDF and FF description
  - similar to Sivers amplitudes
- DIS with z>0.7
  - $\langle Q^2 \rangle > \langle P_T \rangle$
  - TMD PDF and FF description
  - large asymmetries for $\pi^{\pm}$, K^+
  - exclusive processes (ρ,φ)
  - favoured fragmentation

Bose-Einstein correlations in DIS

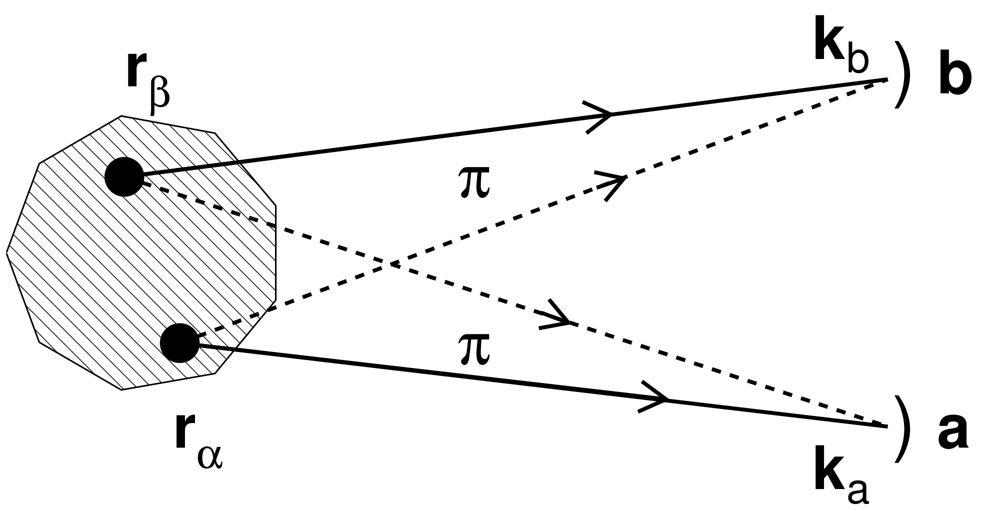
- unpolarized e^+/e^- beam
- H, D, ^3He, ^4He, N, Ne, Kr, Xe target

Bose-Einstein correlations

- incoherent source of identical bosons
- symmetry of wave function under exchange of identical bosons

⇓

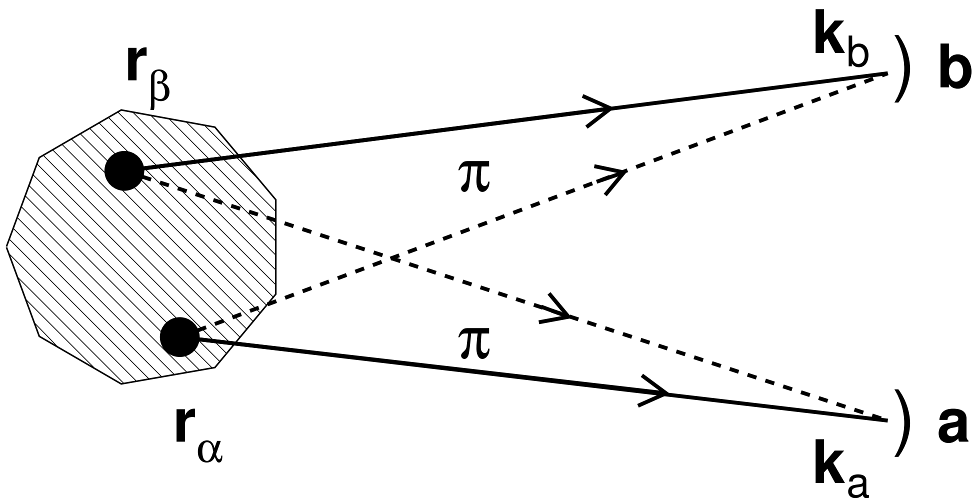
constructive interference



Measurement of source distribution

- measurements of stelar radii by Hanbury Brown and Twiss
- first in particle physics: $p\bar{p}$ collisions
- heavy-ion collisions, study of fireball source distribution
- e^+e^- annihilation
- measurements in DIS are far less abundant

Bose-Einstein correlations



Two-point sources:

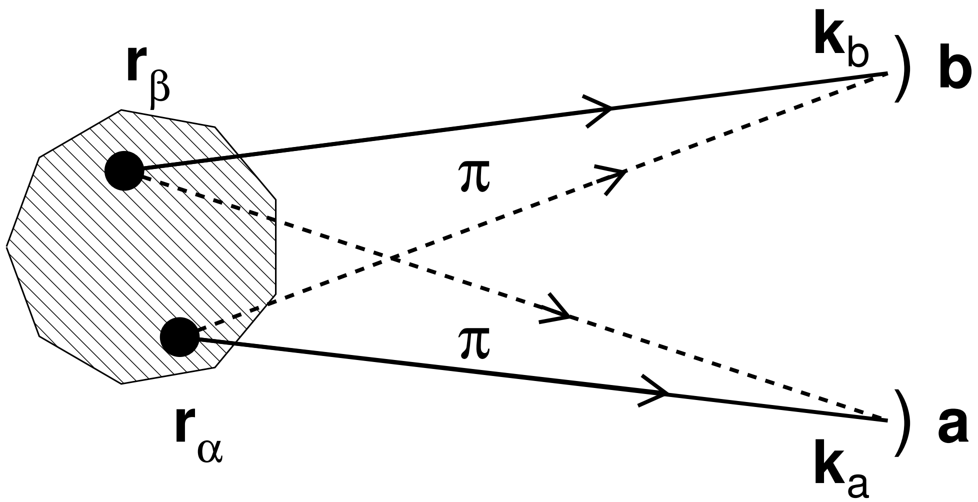
$$R(\mathbf{k}_\alpha, \mathbf{k}_\beta) \propto 1 + \cos(\delta\mathbf{k}.\delta\mathbf{r})$$

Bose-Einstein correlations

Goldhaber parametrisation of continuous space-time distribution of sources

$$R(T) = 1 + \lambda \exp(-T^2 r_G^2)$$

- Gaussian shape of source
- r_G: size of source
- $T^2 = -(p_1 - p_2)^2$
- λ = 0 -> coherent sources; no correlation
  λ = 1 -> completely incoherent sources



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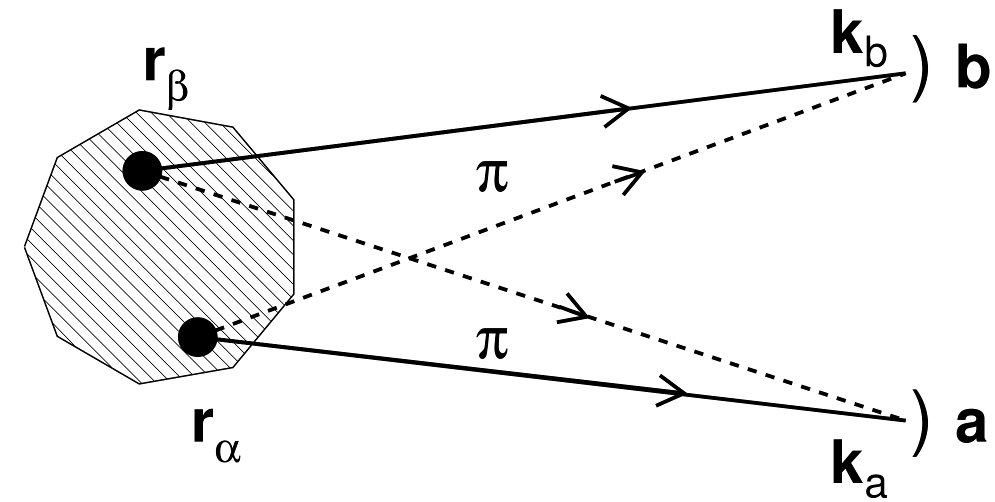


Two-point sources:

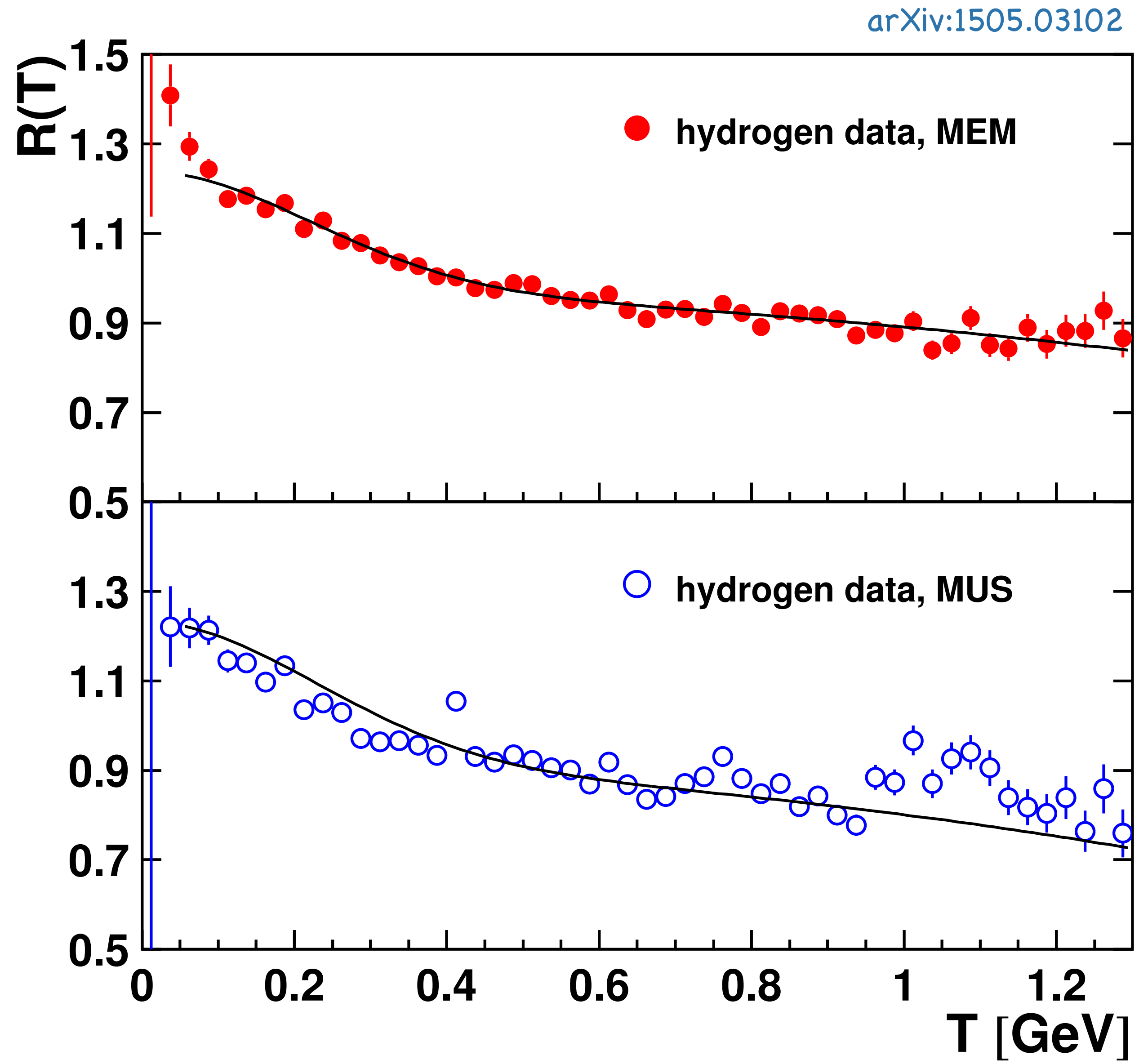
$$R(\mathbf{k}_\alpha, \mathbf{k}_\beta) \propto 1 + \cos(\delta\mathbf{k}.\delta\mathbf{r})$$

Extraction from experimental correlation function from like-sign unidentified hadrons

$$R(p_1, p_2) = D(p_1, p_2)/D_r(p_1, p_2)$$

- reference sample free from BEC, built from
  - unlike-sign pairs (MUS)
  - event mixing (MEM)

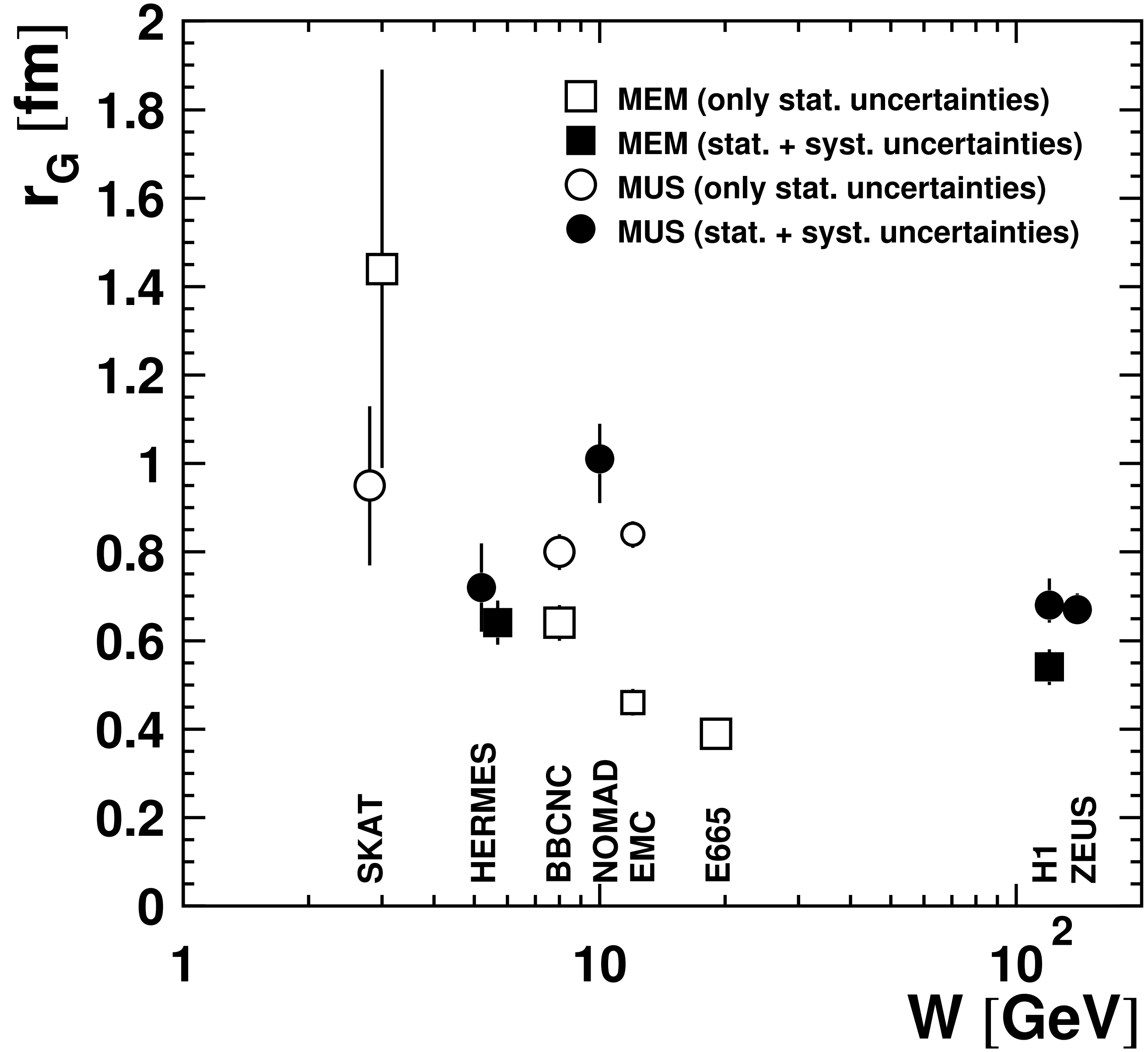
Results



MEM	MUS
$r_G = 0.64 \pm 0.03(\mathrm{stat})^{+0.04}_{-0.04}(\mathrm{sys})\ \mathrm{fm}$	$r_G = 0.72 \pm 0.04(\mathrm{stat})^{+0.09}_{-0.09}(\mathrm{sys})\ \mathrm{fm}$
$\lambda = 0.28 \pm 0.01(\mathrm{stat})^{+0.00}_{-0.05}(\mathrm{sys})\ \mathrm{fm}$	$\lambda = 0.28 \pm 0.02(\mathrm{stat})^{+0.02}_{-0.04}(\mathrm{sys})\ \mathrm{fm}$

Comparison to other experiments

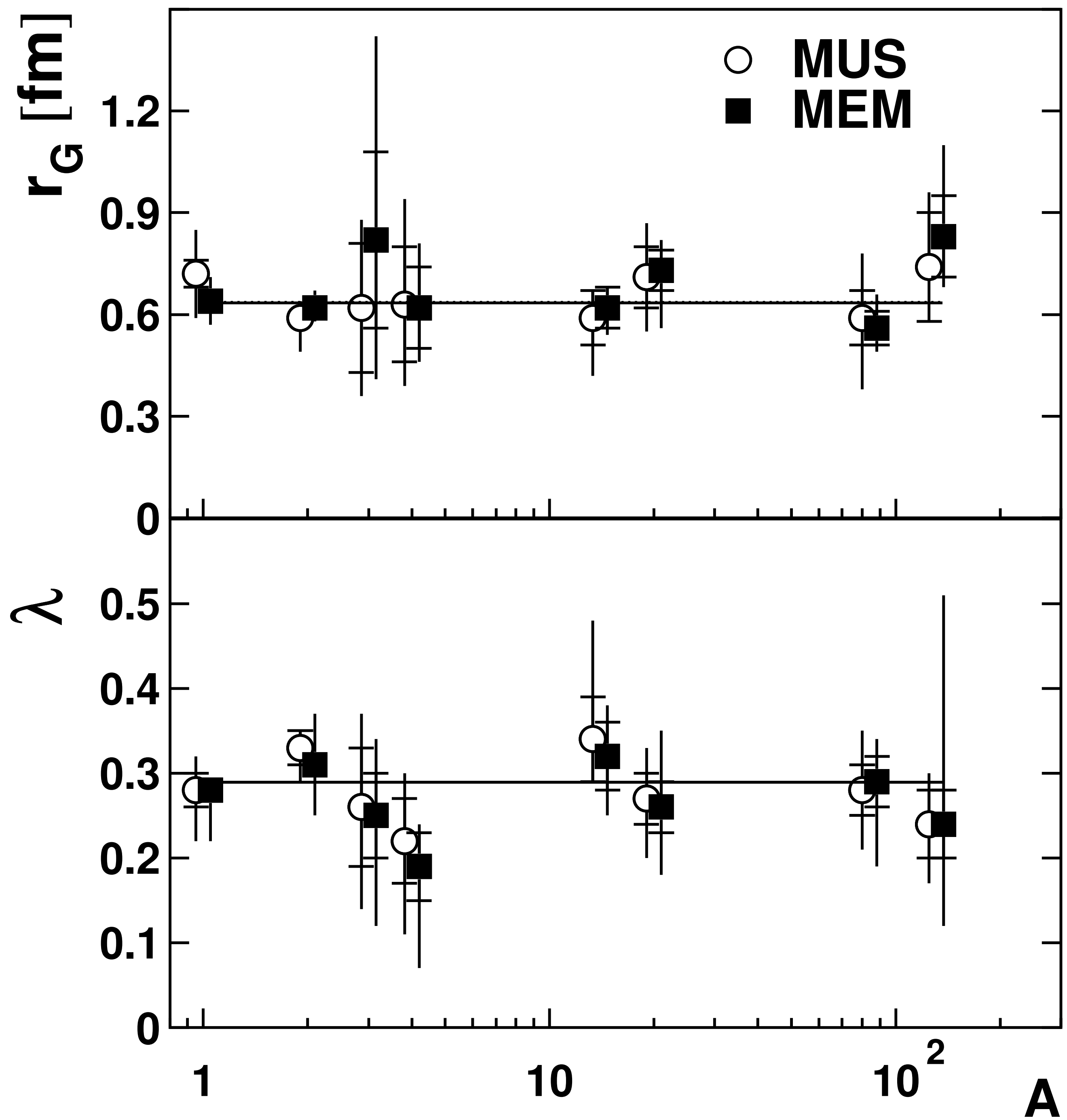
arXiv:1505.03102



- general agreement between experiments, with $0.4 \text{ fm} < r_G < 1.0 \text{ fm}$
- HERMES and BBCNC agree well
- MUS values higher than MEM values

Nuclear-mass dependence

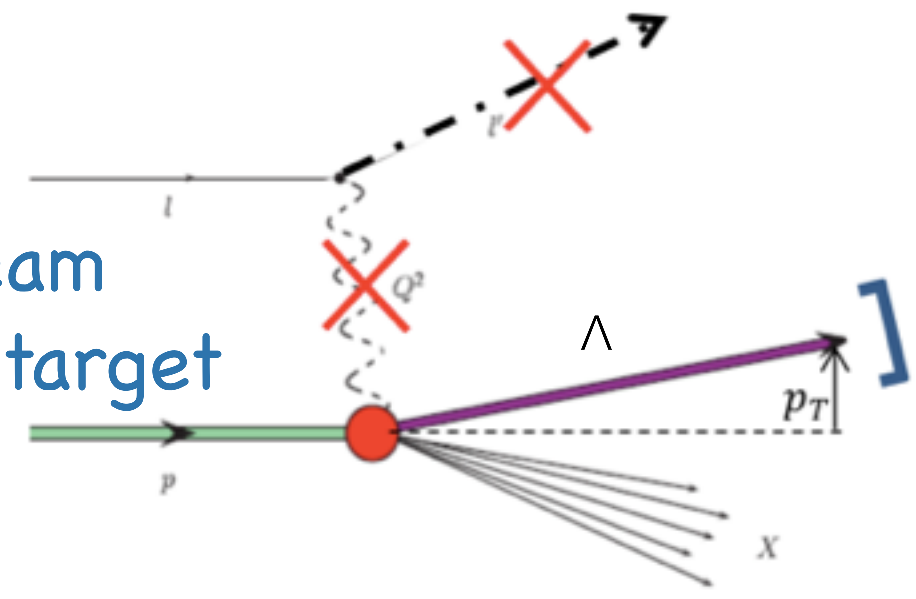
arXiv:1505.03102



- no dependence on nuclear mass A observed

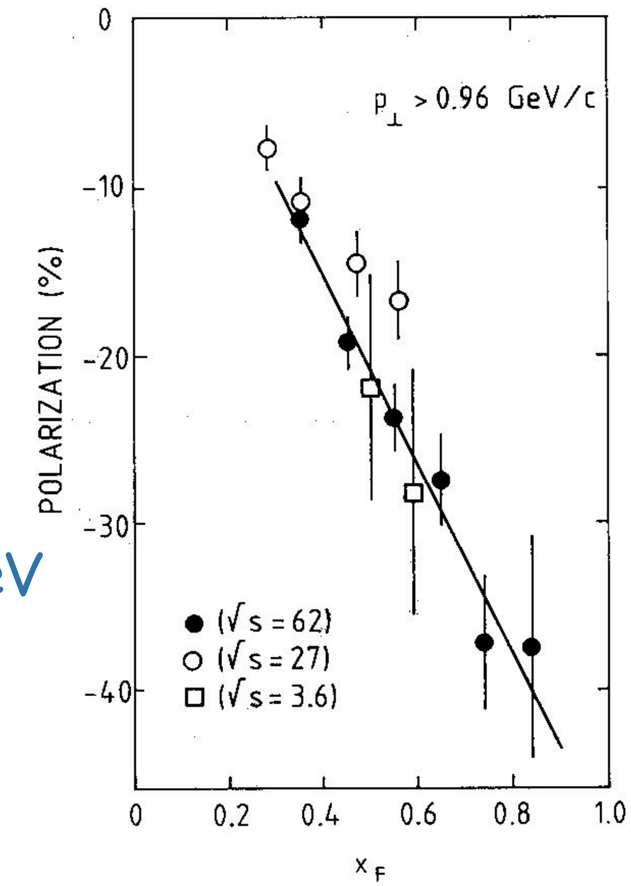
Λ polarization in quasi-real photo-production

- unpolarized e^+/e^- beam
- H, D, He, Ne, Kr, Xe target



Motivation

- Large transverse Λ polarization P^{Λ} observed in unpolarized hadron scattering experiments
- Vast majority: negative polarization values observed, except positive for $K^{-}p$ and $\Sigma^{-}N$
- Magnitude increases with x_F and p_T, reaching plateau for p_T=1 GeV



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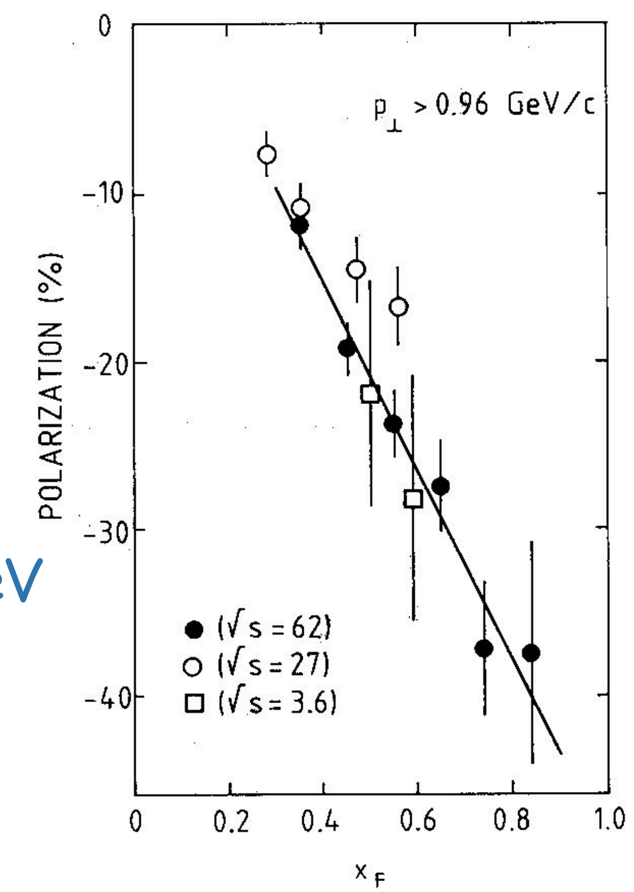
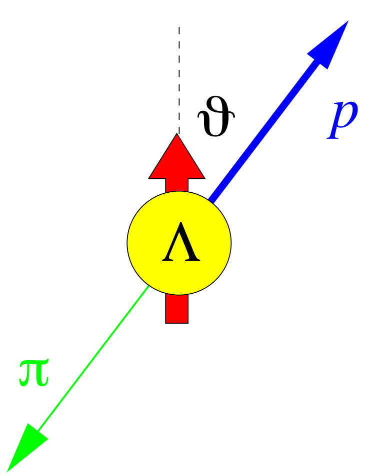


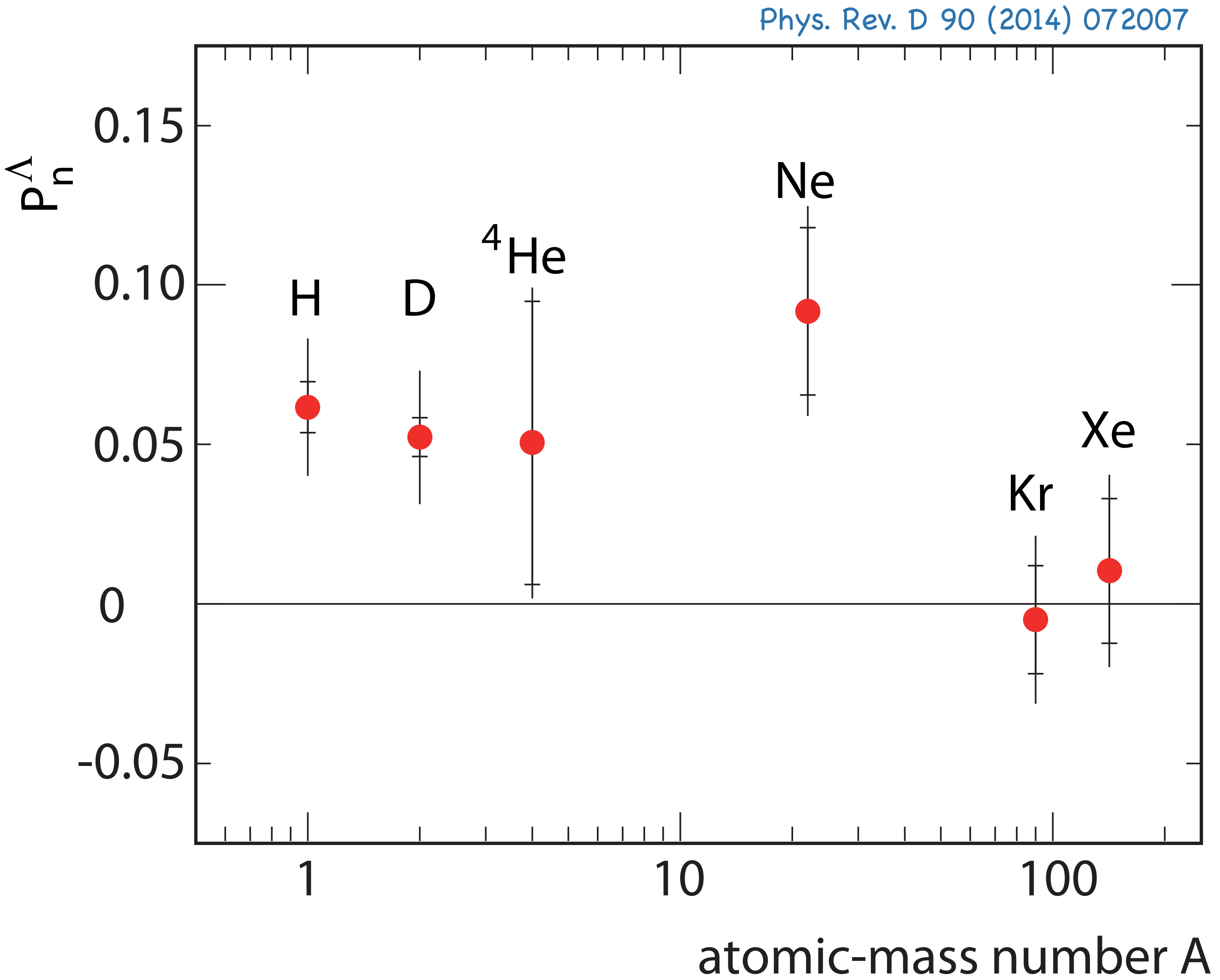
- $ep \rightarrow \Lambda^{\uparrow} X$ scattering?
- SIDIS (high Q^2) $P^{\Lambda} \propto D_{1T}^{\perp}$, polarising FF
- current measurement: inclusive ($Q^2 \approx 0$)



parity-violating weak decay of Λ: in Λ rest frame, proton preferably emitted along Λ spin direction

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}(1 + \alpha P^{\Lambda} \cos\theta_p)$$

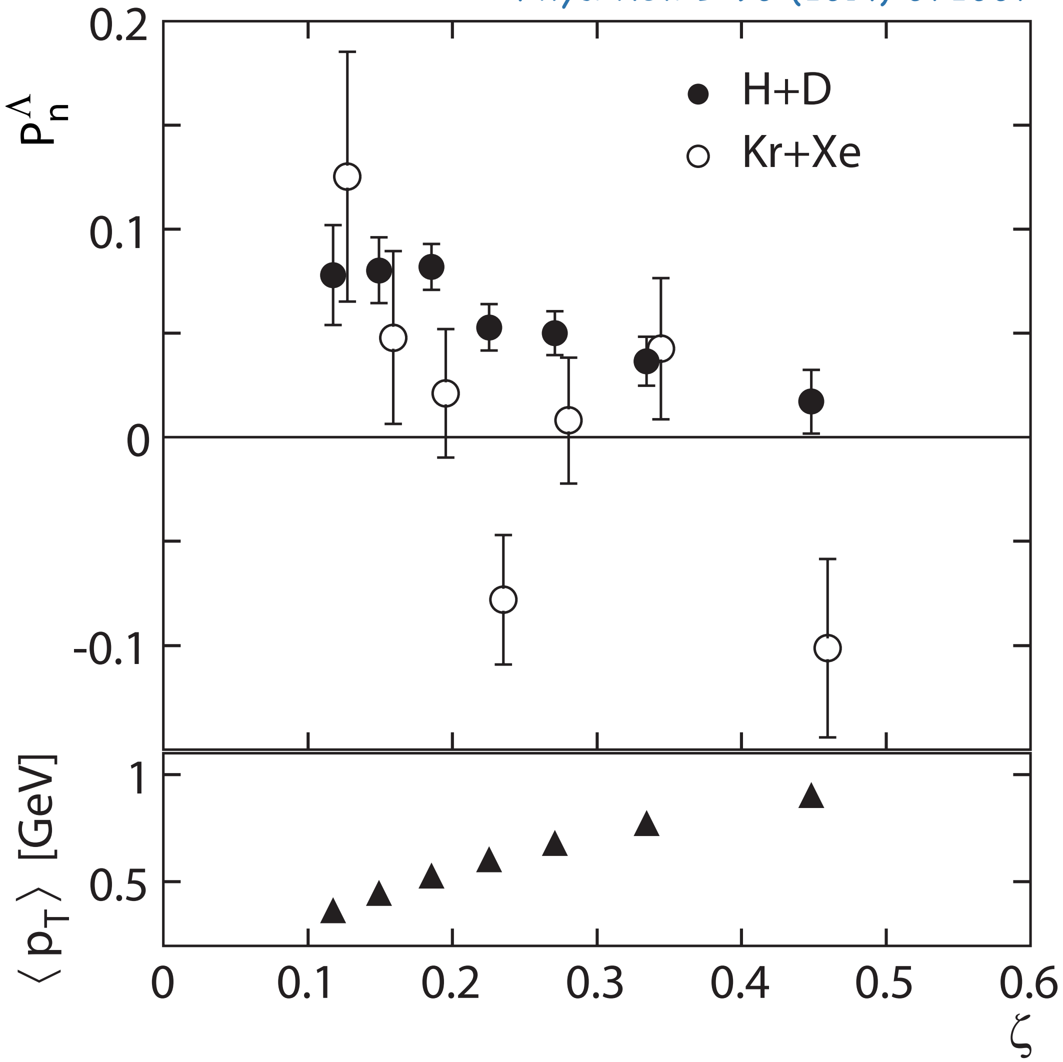
Atomic-mass dependence



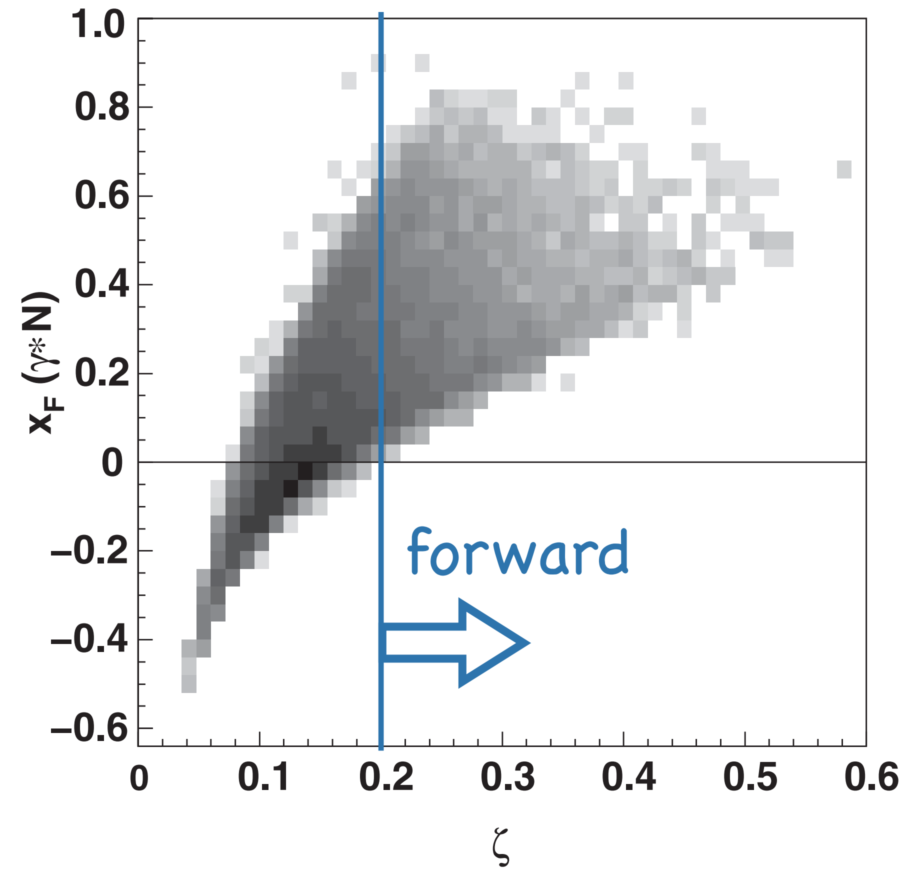
- positive P^Λ for light nuclei
- P^Λ consistent with zero for heavier nuclei

Kinematic dependence

Phys. Rev. D 90 (2014) 072007

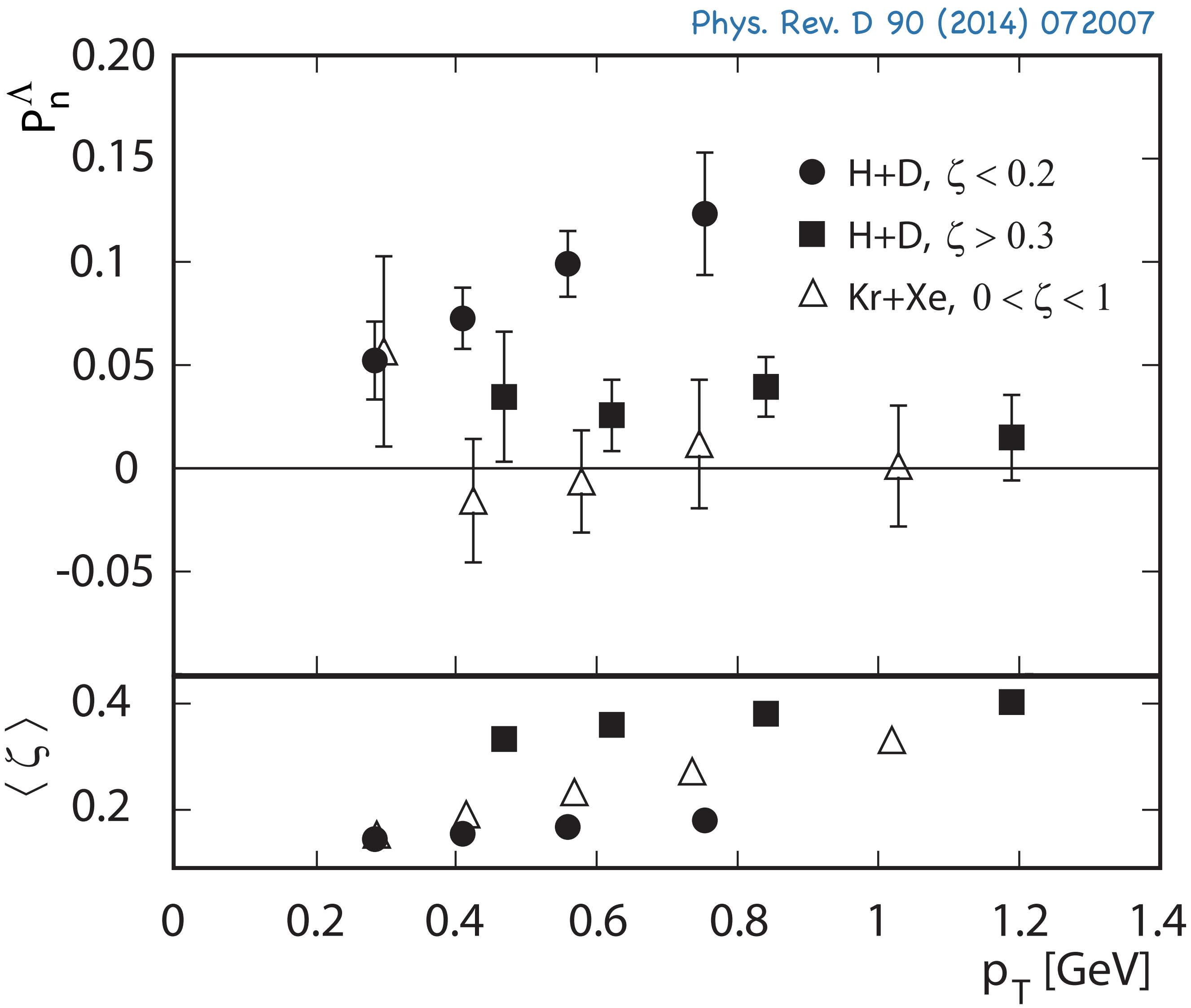


$$\zeta = (E_\Lambda + p_{z\Lambda})/(E_e + p_e)$$



- H+D: P^Λ larger in backward region ⟶ possibly influence of current and target fragmentation

Kinematic dependence



- H+D: P^Λ increases with p_T in backward region, while constant in forward region

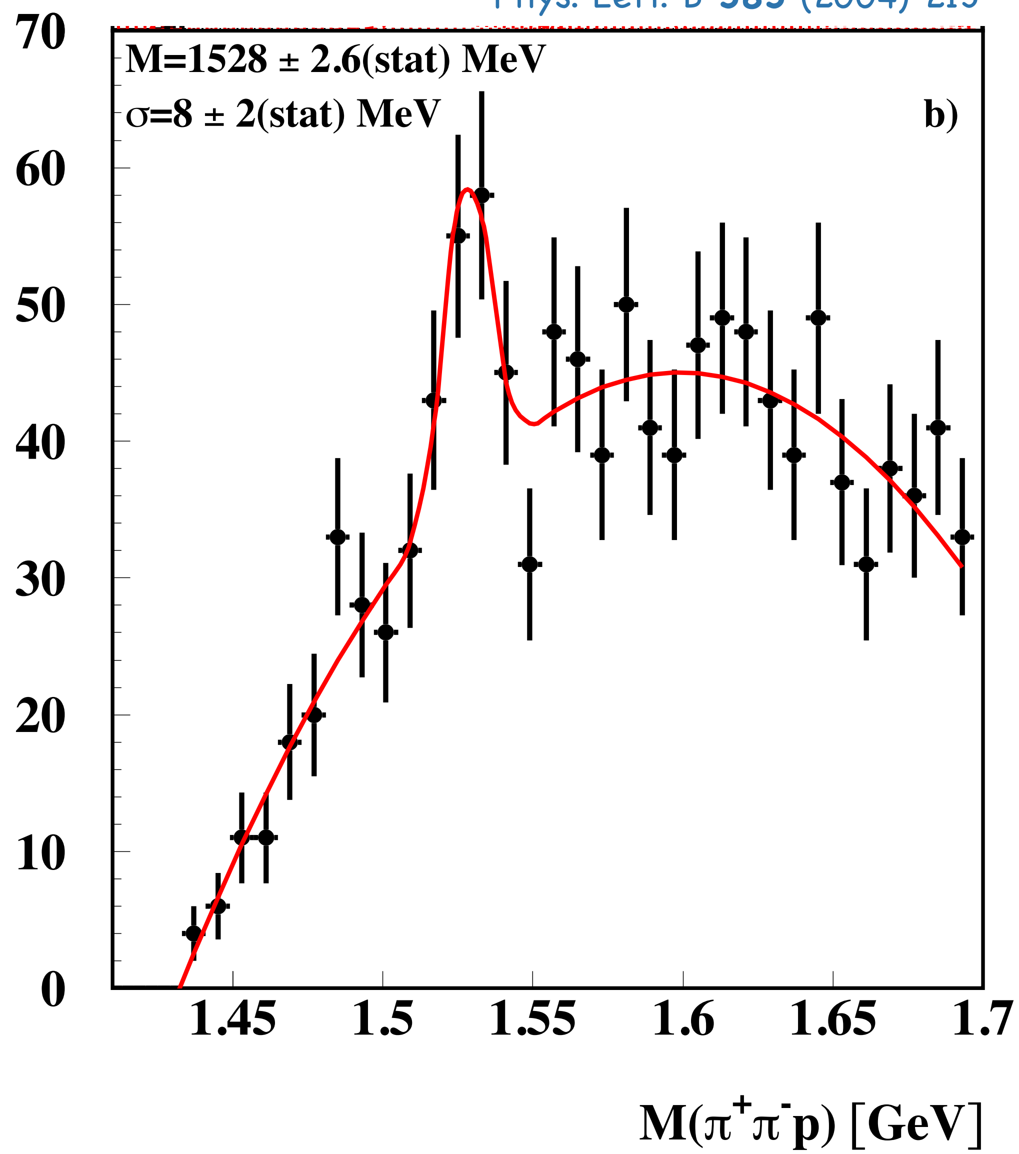
Searching for the pentaquark in quasi-real photoproduction

- unpolarized e^+/e^- beam
- H, D target

Searching for the pentaquark in '04

$$eD \to \Theta^+ X \to p\, K^0_S\, X \to p\, \pi^+ \pi^-\, X$$

Phys. Lett. B **585** (2004) 213

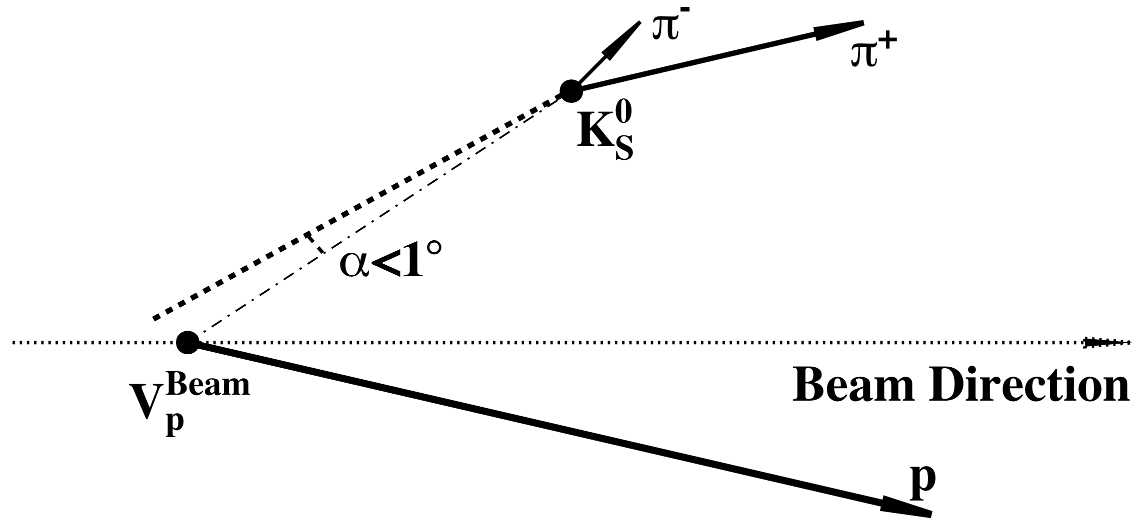


significance=3.7 σ

Searching for the pentaquark in '15

$$eN \to \Theta^+ X \to p\, K_S^0\, X \to p\, \pi^+ \pi^-\, X$$

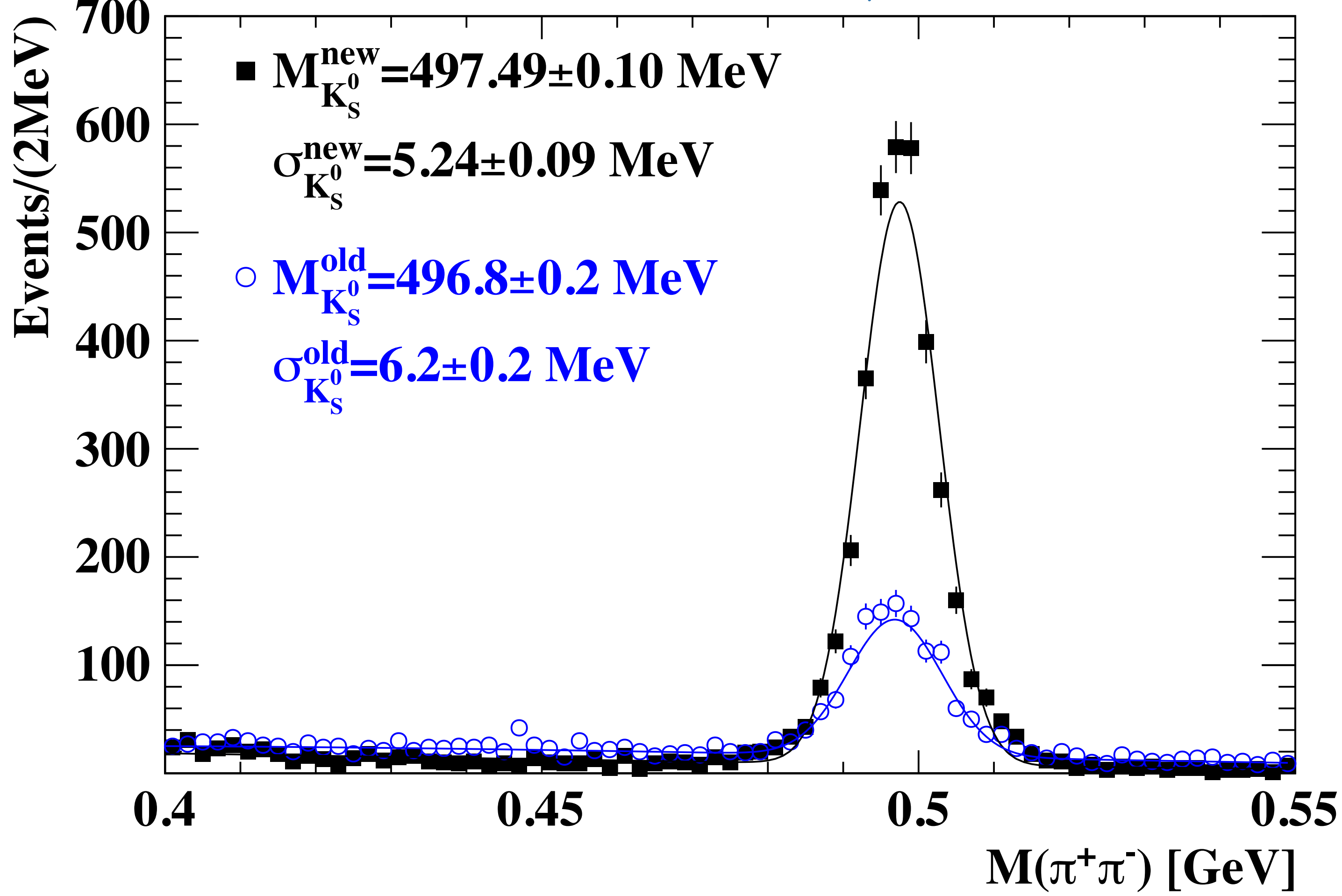
- Major modifications compared to previous publication Phys. Lett. B **585** (2004) 213:
  - increased statistics
  - event-level algorithm for PID from RICH, compared to track-level algorithm
  - improved event-level fitting track reconstruction, based on Kalman-filter algorithm
  - K_S^0 reconstruction based on track geometry, not on PID



Searching for the pentaquark in '15

K^0_S spectra

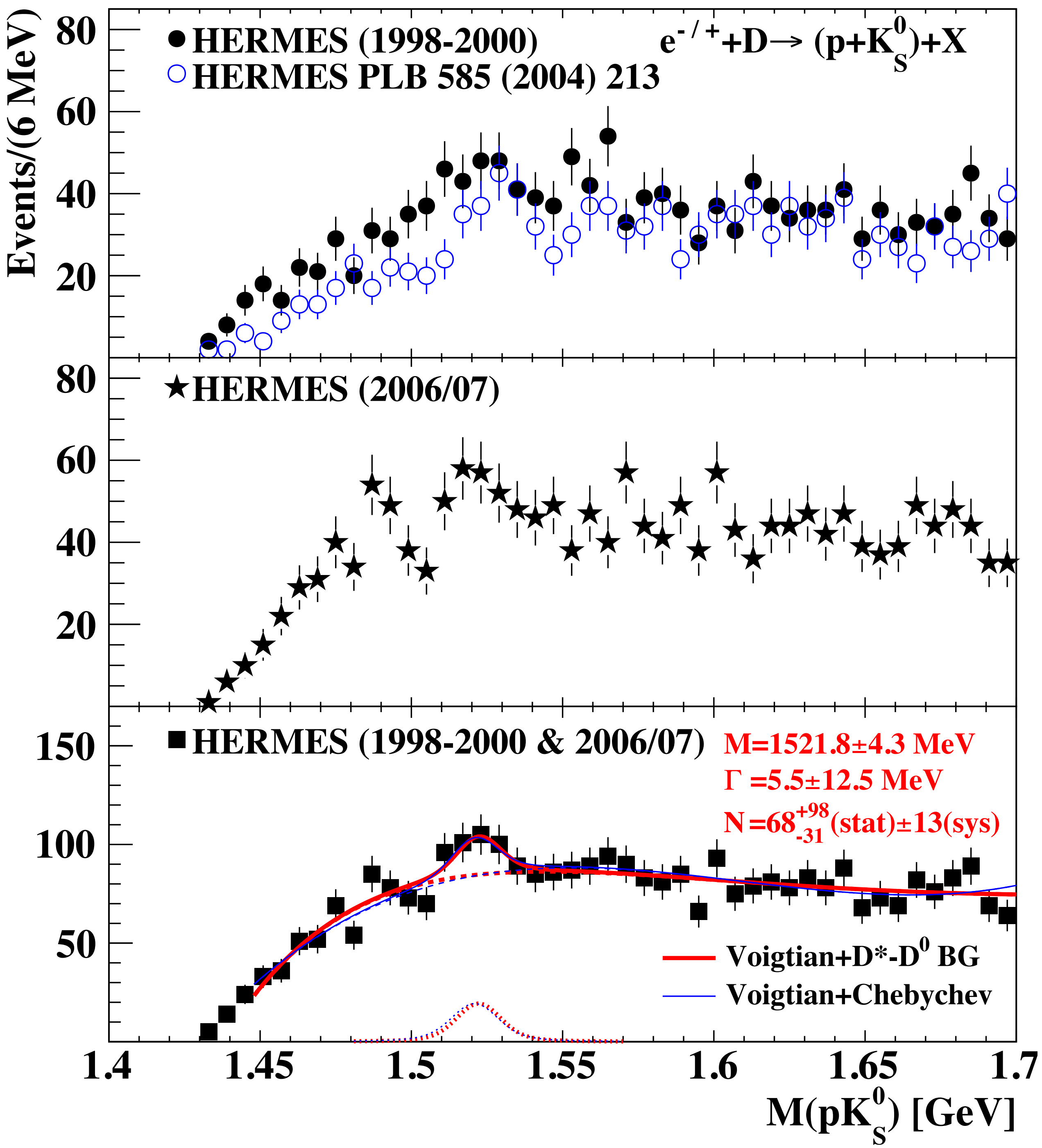
Phys. Rev. D **91** (2015) 057101



2004	2015
963±38 K^0_S	3311±60 K^0_S
180±15 background events	87±11 background events

Searching for the pentaquark in '15

Phys. Rev. D **91** (2015) 057101



- peak at 1521.8 ± 4.3 MeV
- Num of signal events=68^{+98}_{-31} (stat)± 13 (sys)
- significance=2 σ
- no evidence for a resonance on H

Summary

- 3D picture of the nucleon:
  - ω SDMEs from exclusive DIS: good model description with inclusion of pion pole.
  - A_{UT} and A_{LT} in semi-inclusive DIS: 3D extraction, including protons: contribute to understanding of various TMD PDFs @ twist 2 and twist 3.
  - A_{UT} in inclusive DIS: complement $p^{\uparrow}p \rightarrow hX$ data; contribute to understanding of higher twist and/or TMD PDF & FF formalism.
- Bose-Einstein correlations in DIS: clear signals observed, without evidence for target-mass dependence.
- Λ polarization in quasi-real photoproduction: positive for light nuclei; compatible with zero for Kr and Xe.
- Searching again for the pentaquark in quasi-real photoproduction: no evidence for pentaquark resonance.

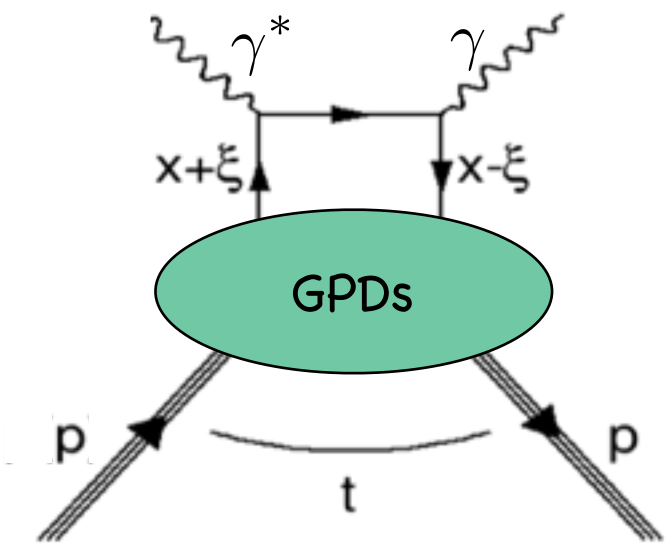
Thank you

Back up

A_{LU} from associated deeply virtual Compton scattering

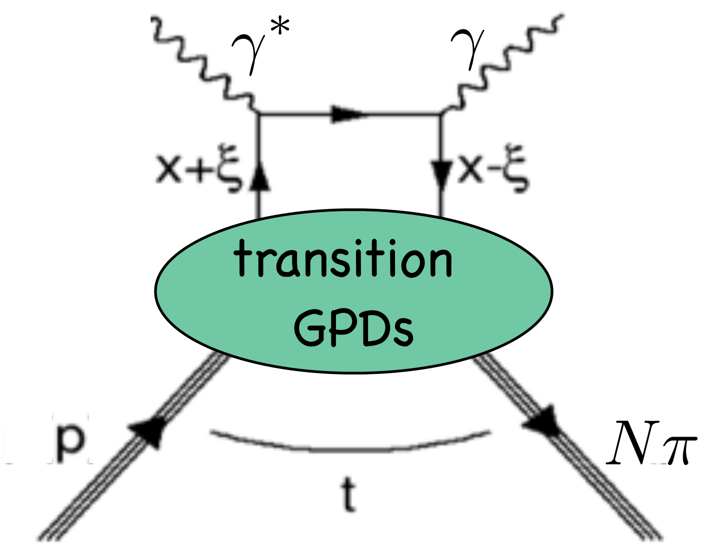
- longitudinally polarized e^+ beam
- unpolarized H target

Beam-helicity asymmetry in $ep \longrightarrow e\gamma\pi N$ in Δ-resonance region



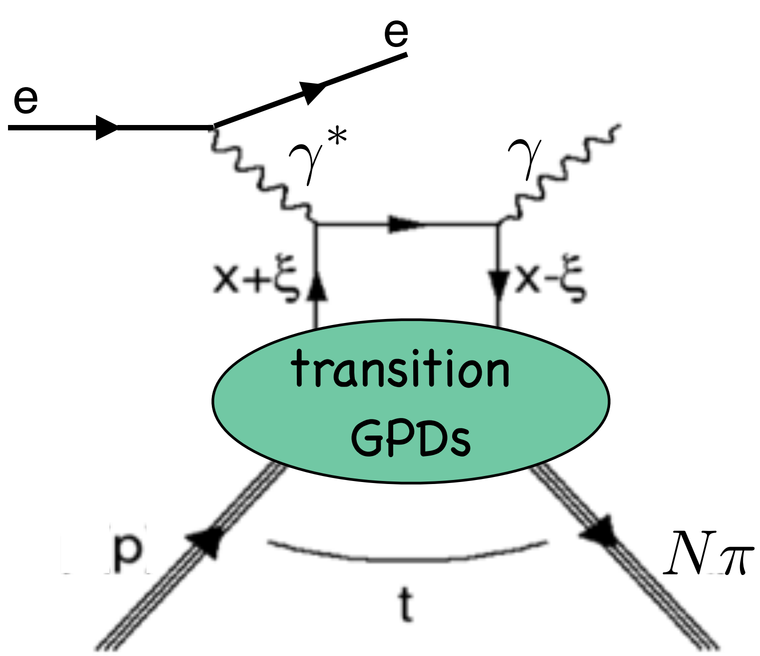
DVCS

Beam-helicity asymmetry in ep⟶eγπN in Δ-resonance region



associated DVCS

Beam-helicity asymmetry in $ep \longrightarrow e\gamma\pi N$ in Δ-resonance region



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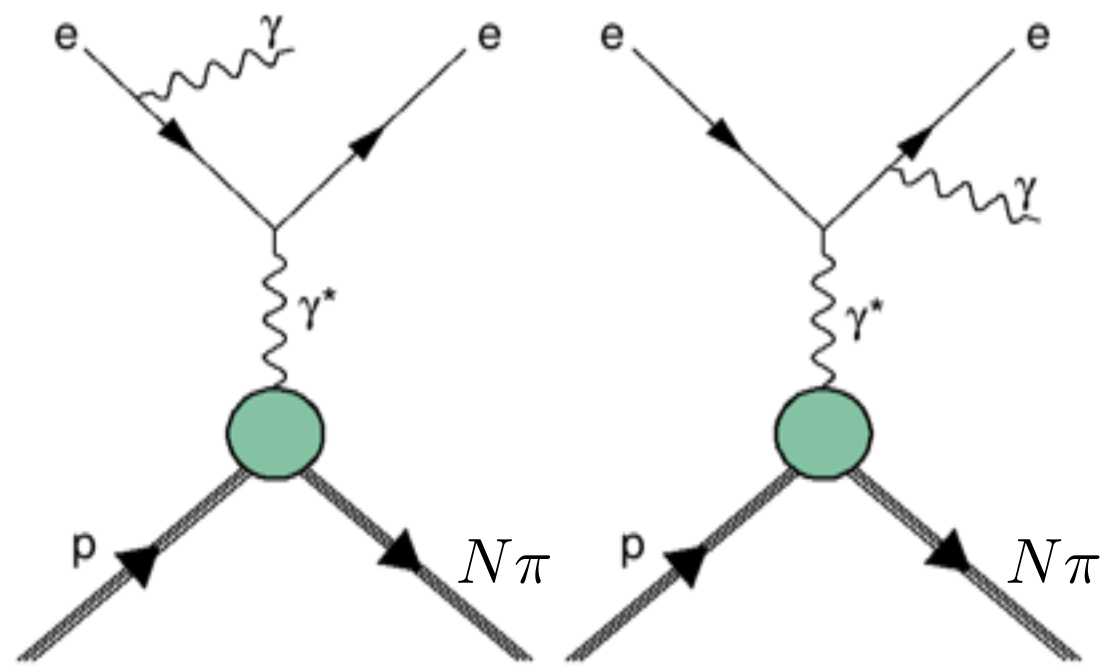
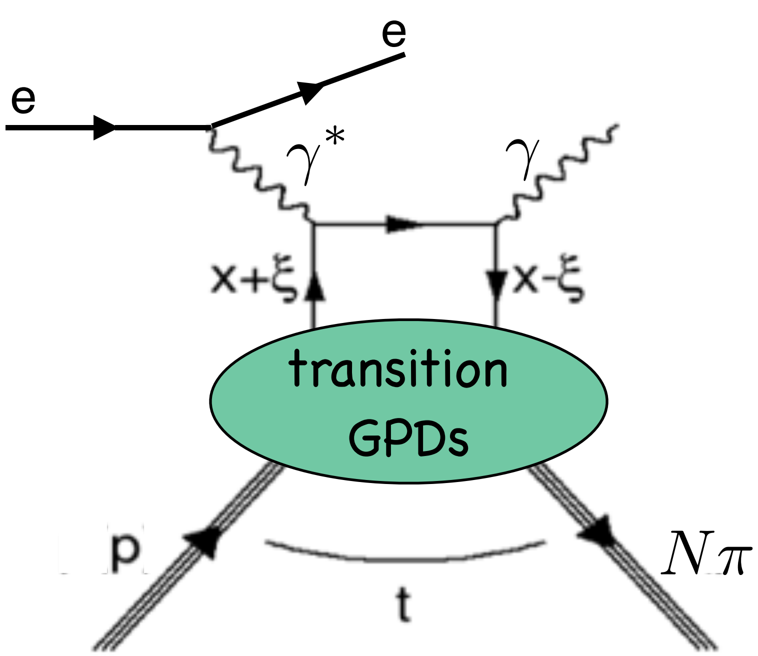


associated Bethe-Heitler

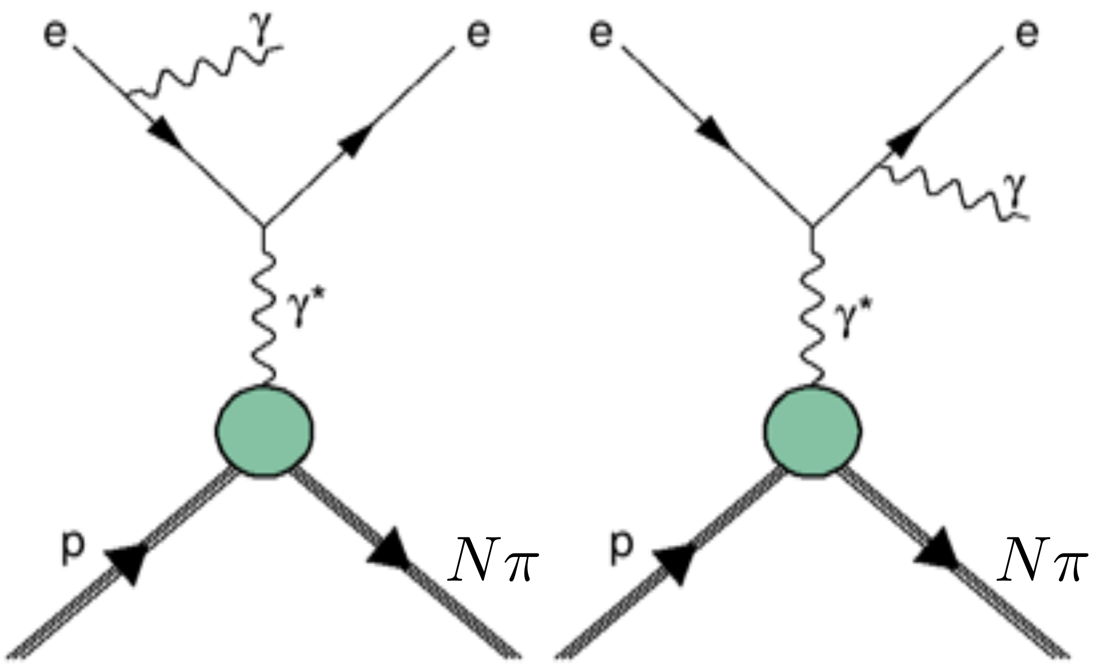
$$d\sigma \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \tau_{BH}\tau^*_{DVCS} + \tau_{DVCS}\tau^*_{BH}$$

access through azimuthal asymmetries ←

Beam-helicity asymmetry in $ep \longrightarrow e\gamma\pi N$ in Δ-resonance region



associated DVCS



associated Bethe-Heitler

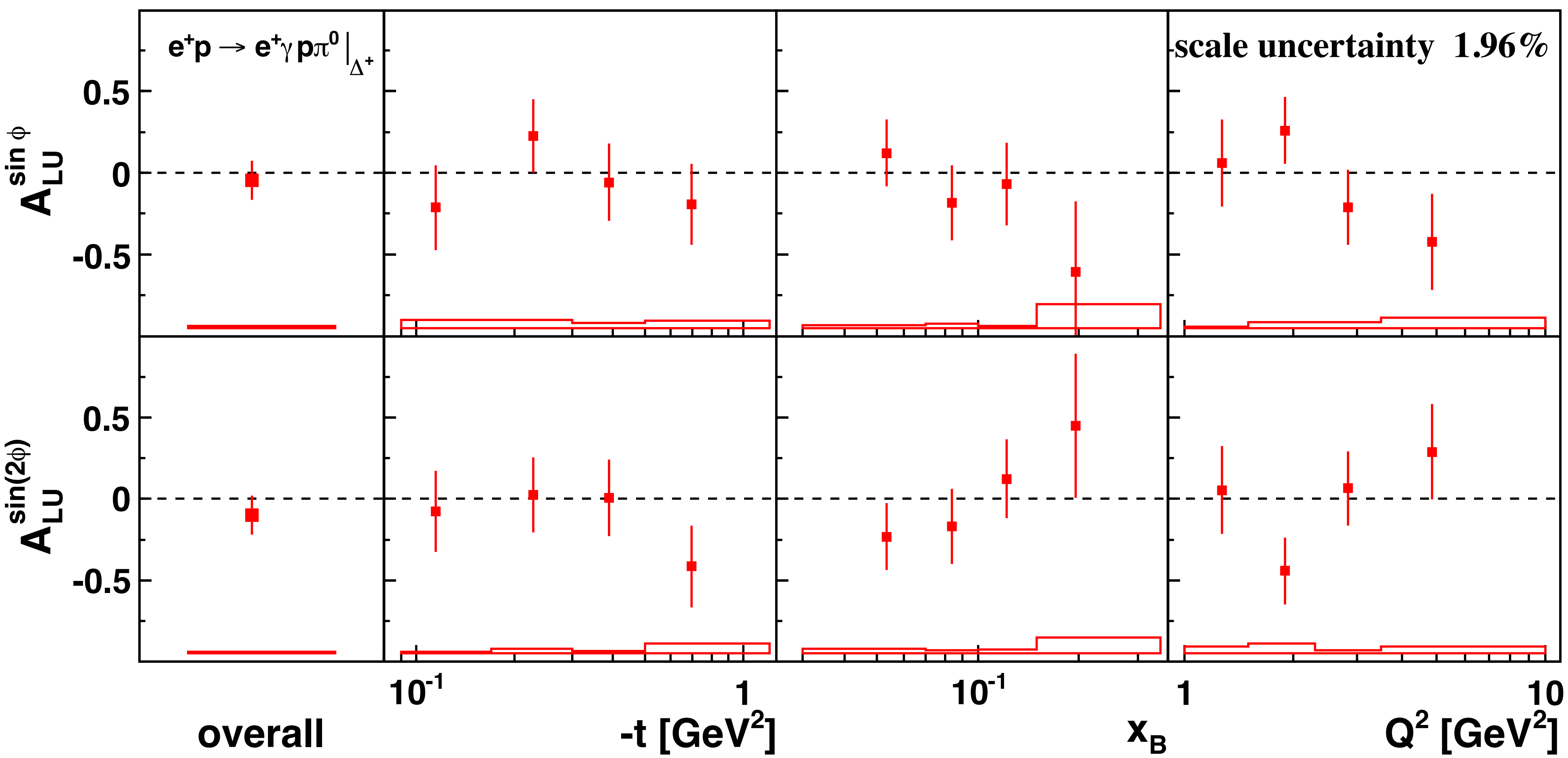
$$d\sigma \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \tau_{BH}\tau^*_{DVCS} + \tau_{DVCS}\tau^*_{BH}$$

access through azimuthal asymmetries

- channels $ep \longrightarrow e\gamma p\pi^0$ and $ep \longrightarrow e\gamma n\pi^+$
- detection of e,γ (spectrometer) and p,π^+ (recoil detector); π^0,n undetected
- kinematic fitting with selection of region around Δ resonance

Beam-helicity asymmetry in ep⟶eγπN in Δ-resonance region

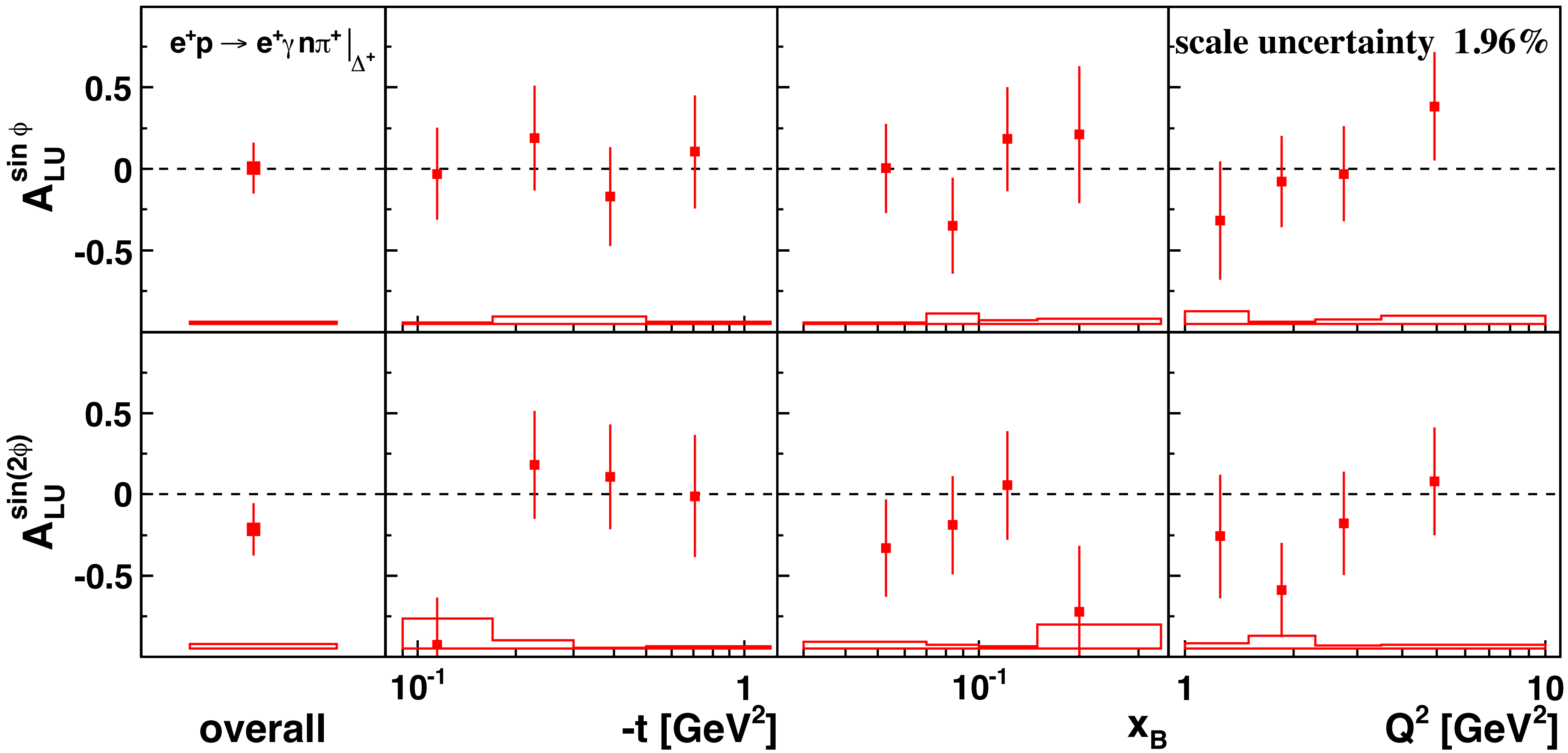
JHEP **01** (2014) 077



- asymmetry background correction SIDIS (11%) and ep⟶eγp (4.6%)
- leading asymmetry consistent with zero

Beam-helicity asymmetry in ep⟶eγπN in Δ-resonance region

JHEP **01** (2014) 077



- asymmetry background correction SIDIS (23%) and ep⟶eγp (0.2%)
- leading asymmetry consistent with zero