HERMES overview

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(DESY)

for the hermes collaboration

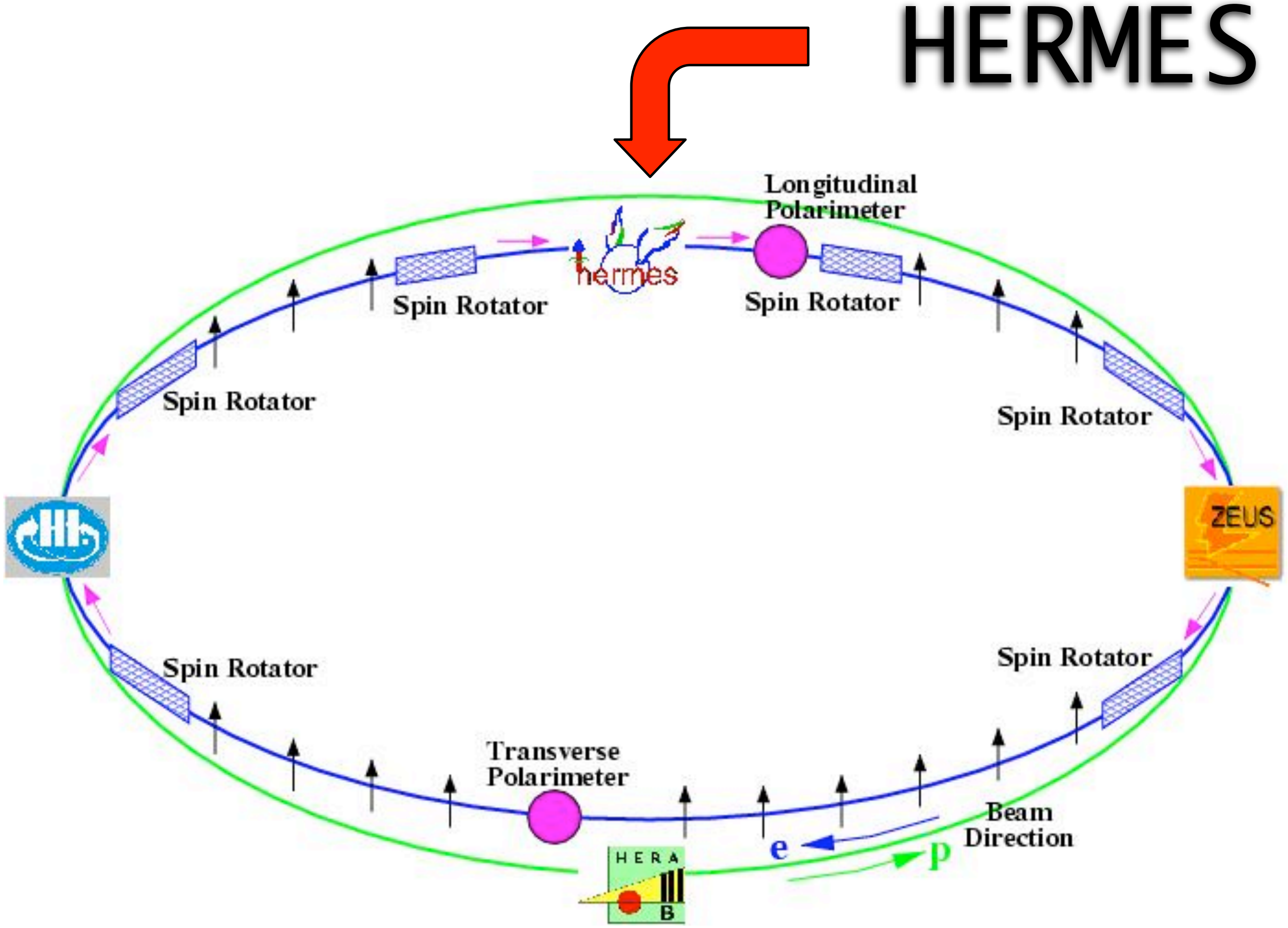
The 7th
Circum-Pan-Pacific Symposium on
High Energy Spin Physics
Sept. 15th - Sept. 18th, 2009
Yamagata, Japan

Overview

- HERMES experiment
- longitudinal nucleon structure
  - strange quark distribution $s(x)$ and $\Delta s(x)$
- transverse structure of the nucleon
  - transversity and transverse momentum dependent distribution functions
- 3D picture of the nucleon

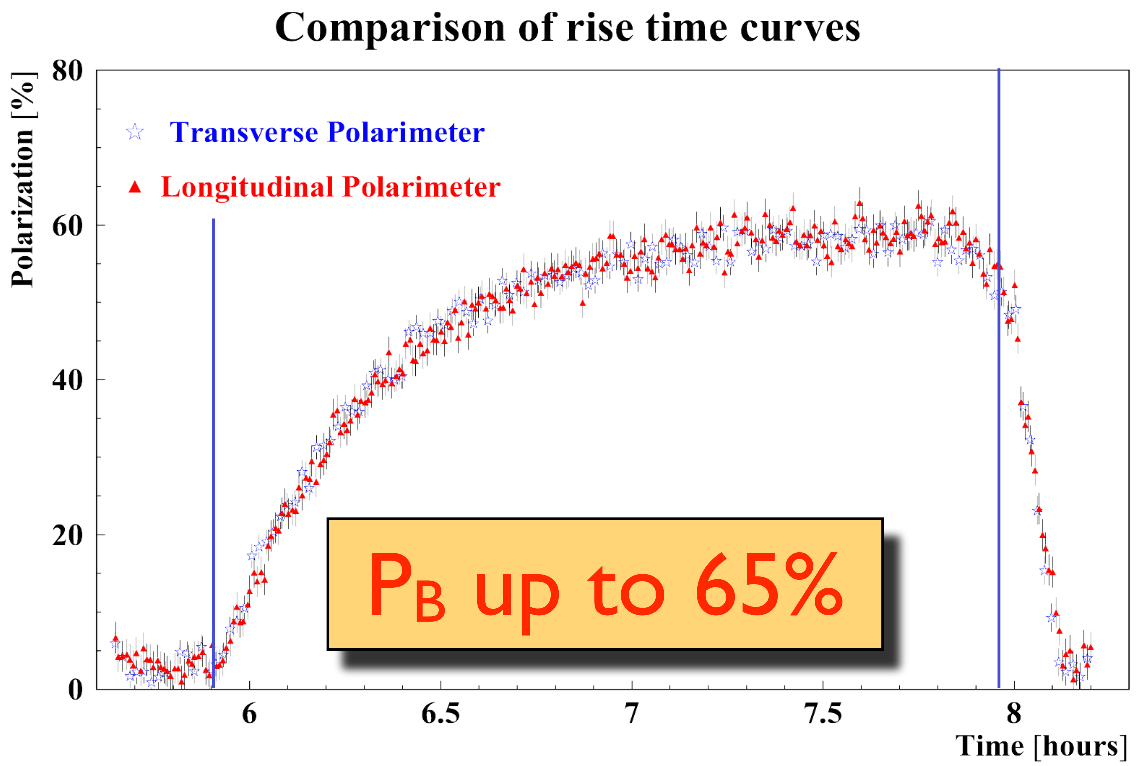
  Accessing generalized parton distributions via
  - deeply virtual Compton scattering
  - exclusive meson production
- search for 2-photon exchange signal

HERMES @ HERA



- Fixed target experiment
  ➡ only using HERA lepton (e^+/e^-) beam
- HERA lepton beam self-polarizing
  ➡ cross section asymmetry in synchrotron radiation emission leads to build-up of transverse polarization (Sokolov-Ternov effect)
- Beam polarization measured by two independent polarimeters
- Spin-rotators ➡ longitudinal polarization at HERMES interaction region

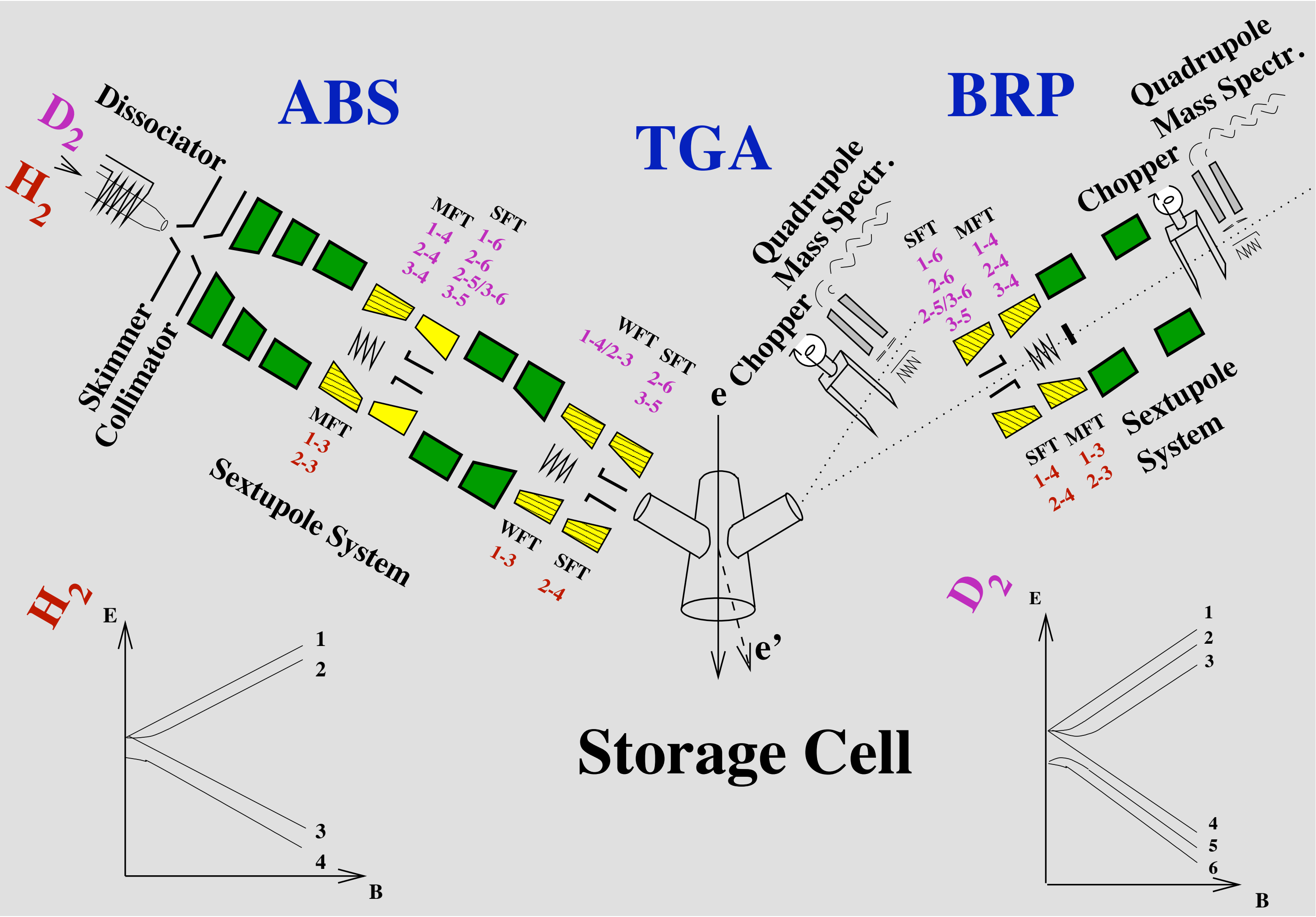
Comparison of rise time curves



P_B up to 65%

The HERMES Target

Gaseous target in storage cell aligned with lepton beam

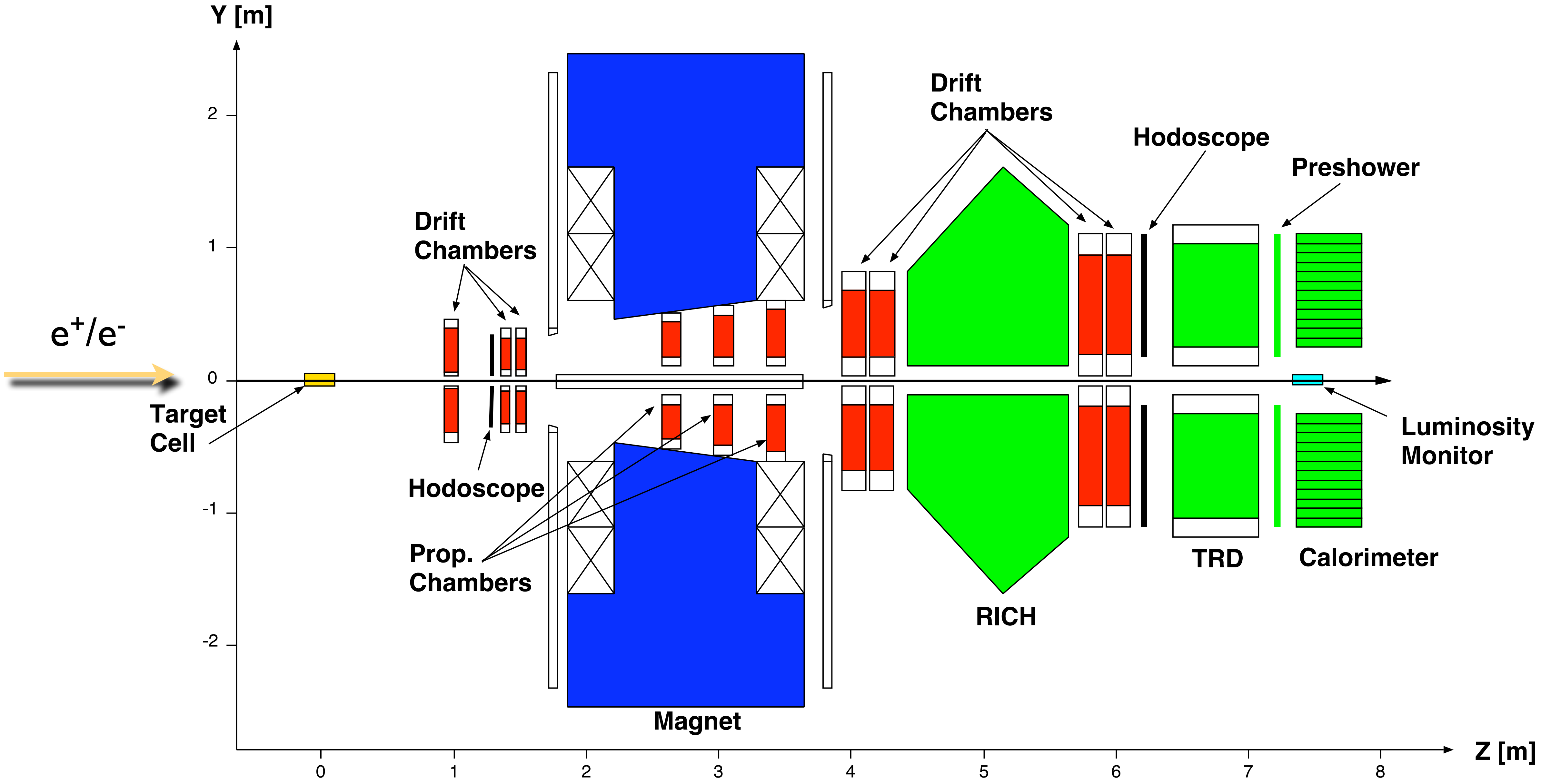


Polarization:
longitudinal: ~85%
transversal: ~75%

Features:

- Pure target (no dilution)
- Unpolarized targets:
  variety of nuclear targets
  - H, D, He, Ne, Kr, ...
- Polarized targets:
  - Longitudinal pol. (1995-2000)
    H, D, He
  - Transverse pol. (2002-2005)
    H
  - Rapid reversal of polarization direction within 0.5s (every 90s)

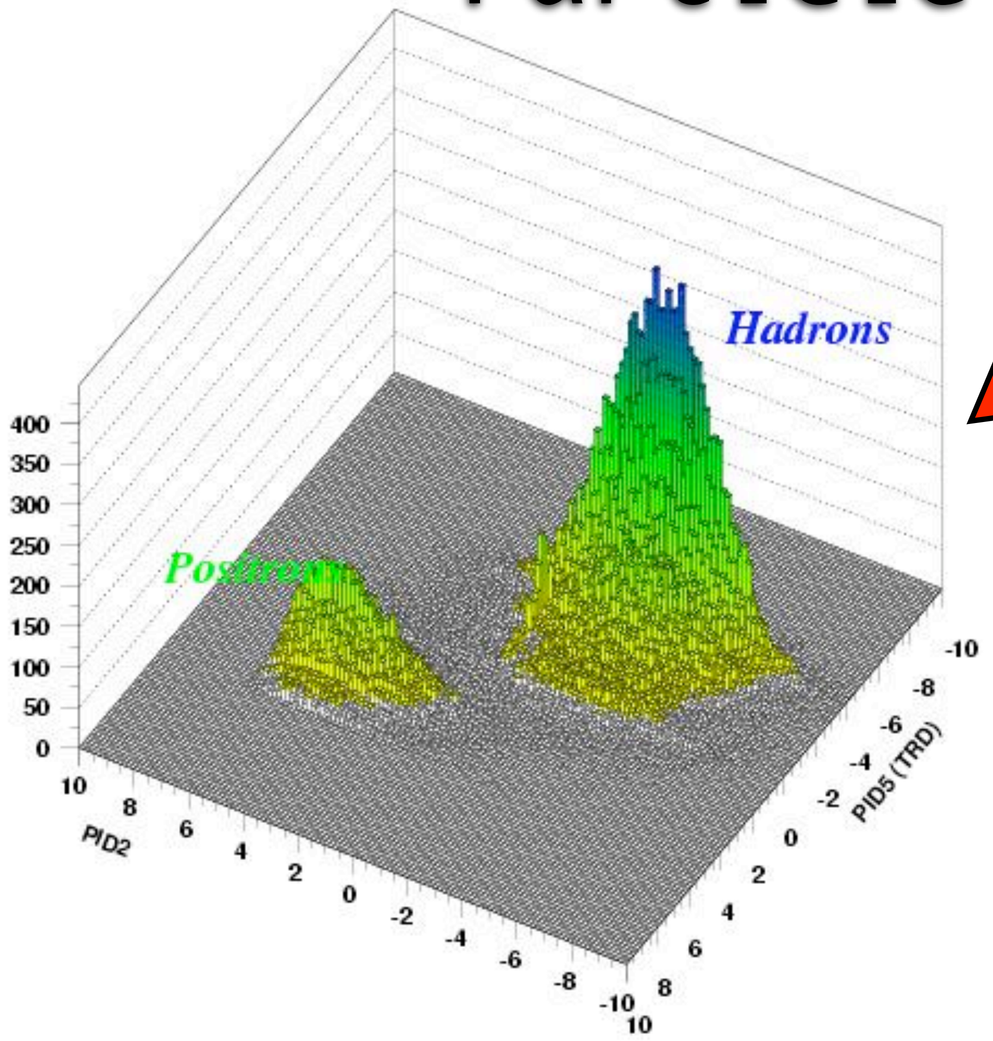
HERMES Spectrometer



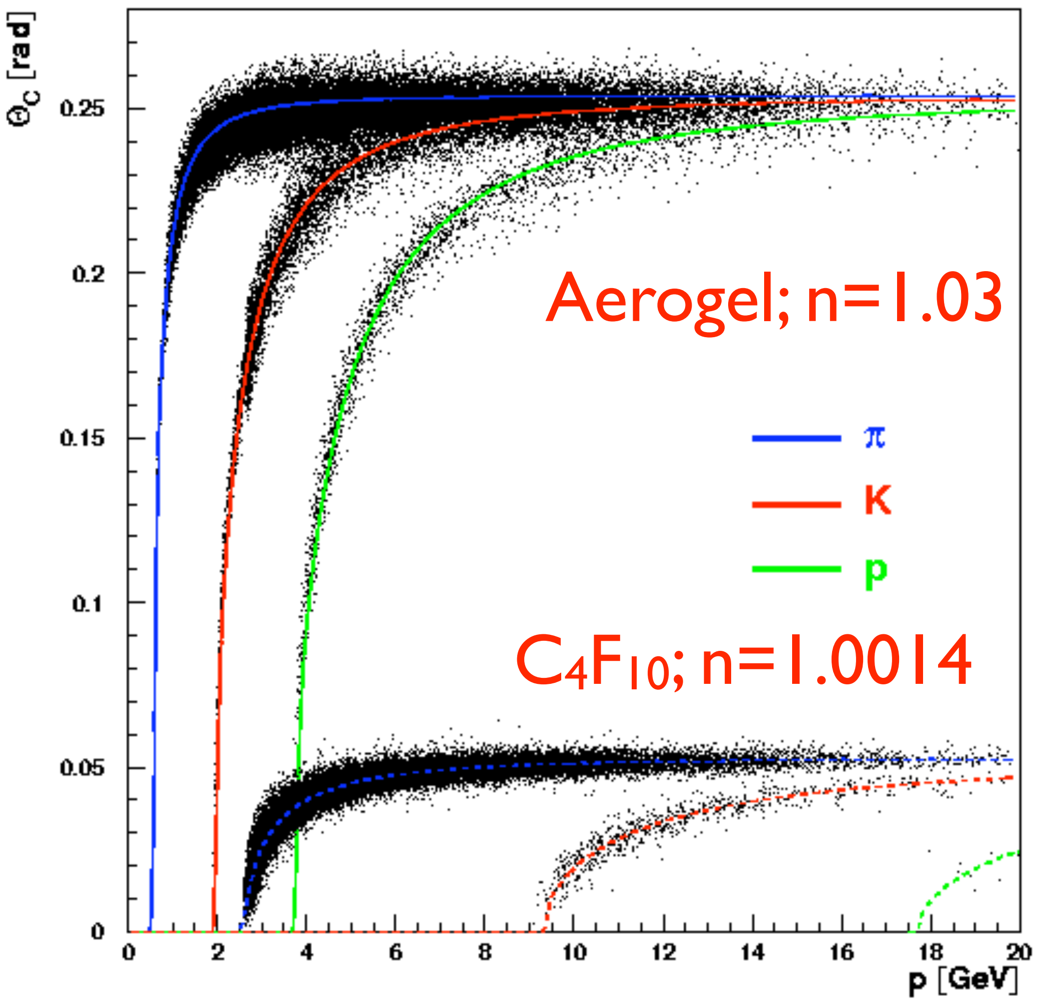
- Forward acceptance spectrometer: 40 mrad $\leq \Theta \leq$ 220 mrad
- Kinematic coverage: $0.02 \leq x_{Bj} \leq 0.8$ for $Q^2 > 1$ GeV^2 and W > 2 GeV
- Tracking: $\delta P/P$ = 0.7% - 2.5%, $\delta\Theta \leq 1$ mrad
- PID: TRD, Preshower, Calorimeter, RICH (Cherenkov before 1998)

Particle Identification

excellent lepton/hadron separation



RICH: two radiators allow hadron separation between 2-15 GeV

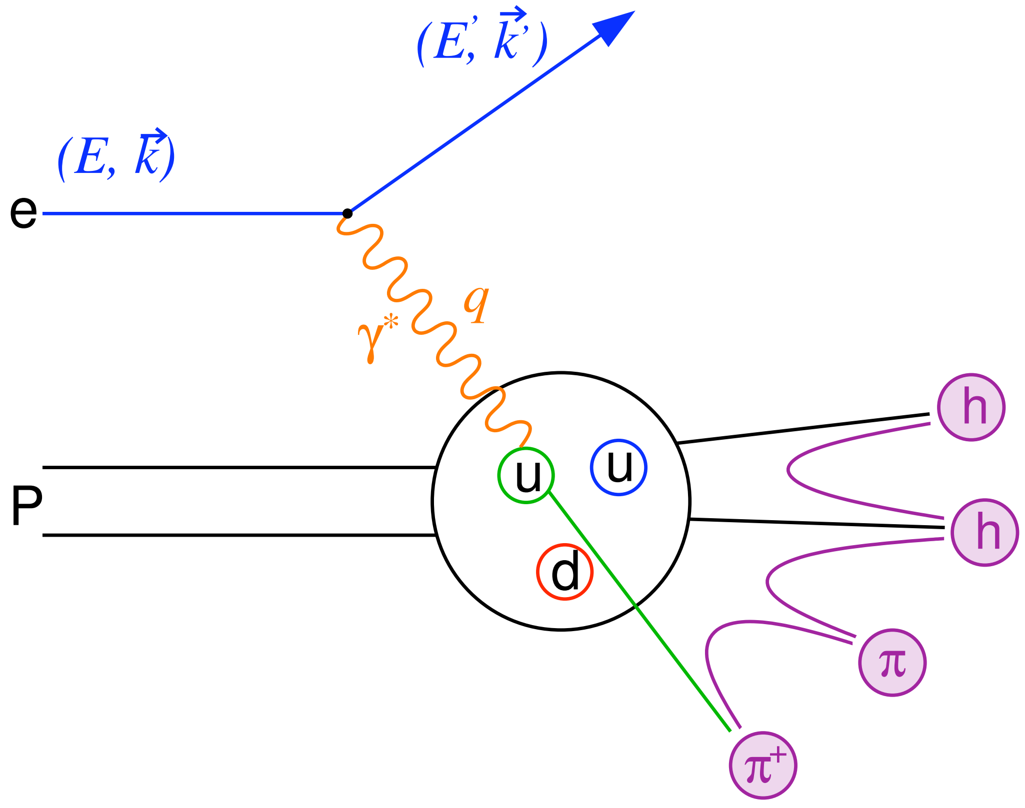


Aerogel; n=1.03

C_4F_{10}; n=1.0014

Quark helicity distributions from longitudinal double-spin asymmetries

Deep-inelastic scattering



$$
\begin{aligned}
Q^2 &= -q^2 = -(k-k')^2 \\
\nu &\overset{lab}{=} E - E' \\
x &= \frac{Q^2}{2M\nu} \\
z &\overset{lab}{=} \frac{E_{\text{had}}}{\nu}
\end{aligned}
$$

Cross section contains Distribution Functions and Fragmentation Functions:

$$\sigma^{ep\to eh} \sim \sum_q \mathrm{DF}^{p\to q} \otimes \sigma^{eq\to eq} \otimes \mathrm{FF}^{q\to h}$$

DF: distribution of quarks in the nucleon

FF: fragmentation of (struck) quark into hadronic final state

Inclusive DIS

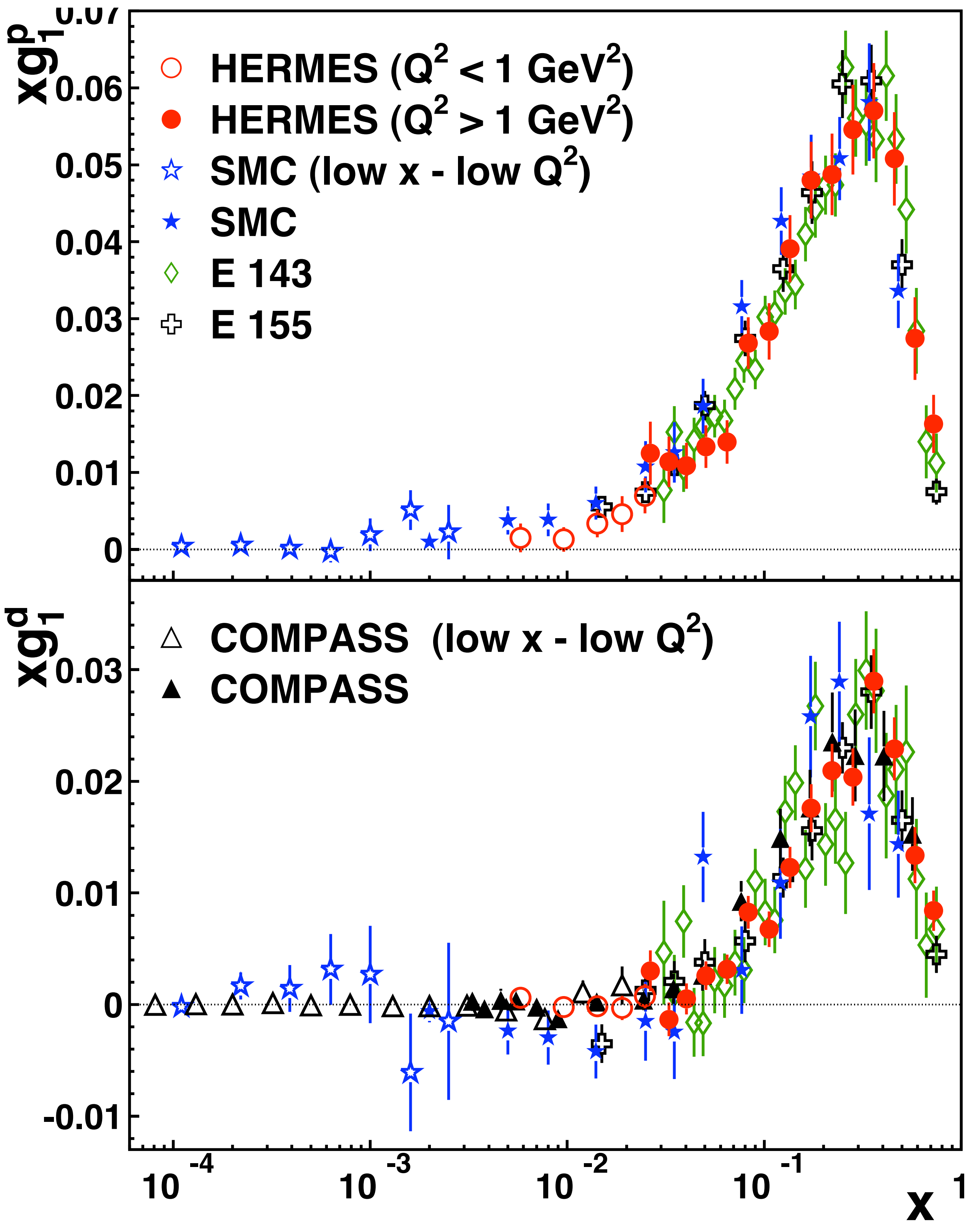
- inclusive DIS ⟹ spin dependent structure function g_1

$$A_{||} = \frac{\sigma^{\overset{\rightarrow}{\Leftarrow}} - \sigma^{\overset{\rightarrow}{\Rightarrow}}}{\sigma^{\overset{\rightarrow}{\Leftarrow}} + \sigma^{\overset{\rightarrow}{\Rightarrow}}}$$

- first moment $\Gamma_1^d = \int dx\, g_1^d$ saturates towards low x

in NNLO	central value	uncertainties theor.	uncertainties exp.	uncertainties evol.
$\Delta\Sigma = a_0$	0.330	0.011	0.025	0.028
$\Delta u + \Delta\bar{u}$	0.842	0.004	0.008	0.009
$\Delta d + \Delta\bar{d}$	-0.427	0.004	0.008	0.009
$\Delta s + \Delta\bar{s}$	-0.085	0.013	0.008	0.009

Phys. Rev. D 75 (2007) 012007



Semi-inclusive DIS

- semi-inclusive DIS ⟹ disentangle quark-antiquark helicities (flavor tagging)
- needs information about the fragmentation process, either from FF parameterizations or Monte Carlo models
- first moment for Δs

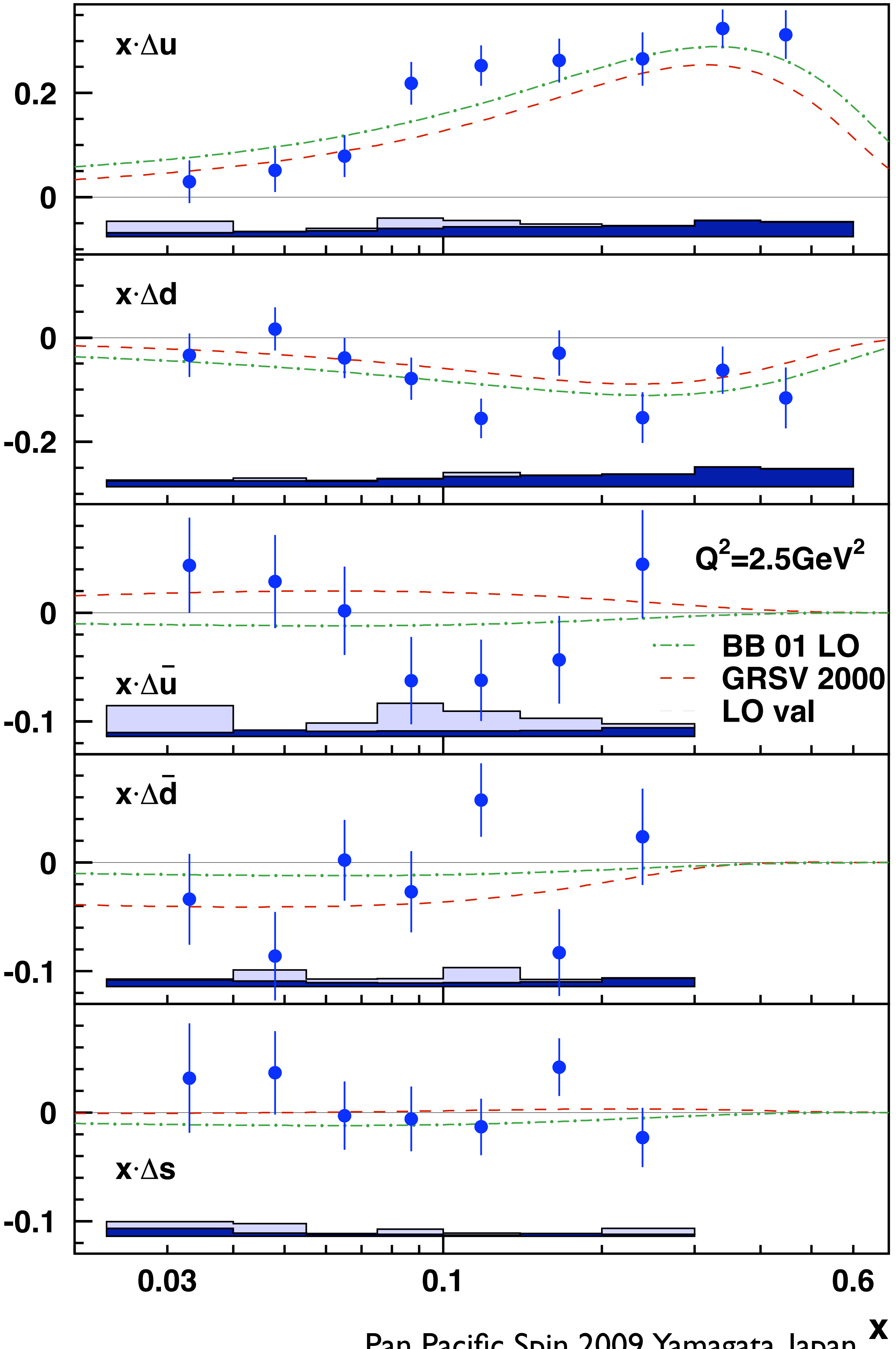
$$\Delta s = 0.028 \pm 0.033 \pm 0.009$$

in the measured range

$$0.023 < x_{\mathrm{B}} < 0.3$$

- no sensitivity to $\Delta\bar{s}$

Phys. Rev D 71 (2005) 012003



Strange PDFs with isoscalar target

Assumptions:
- isospin symmetry between proton and neutron
- charge conjugation invariance in fragmentation

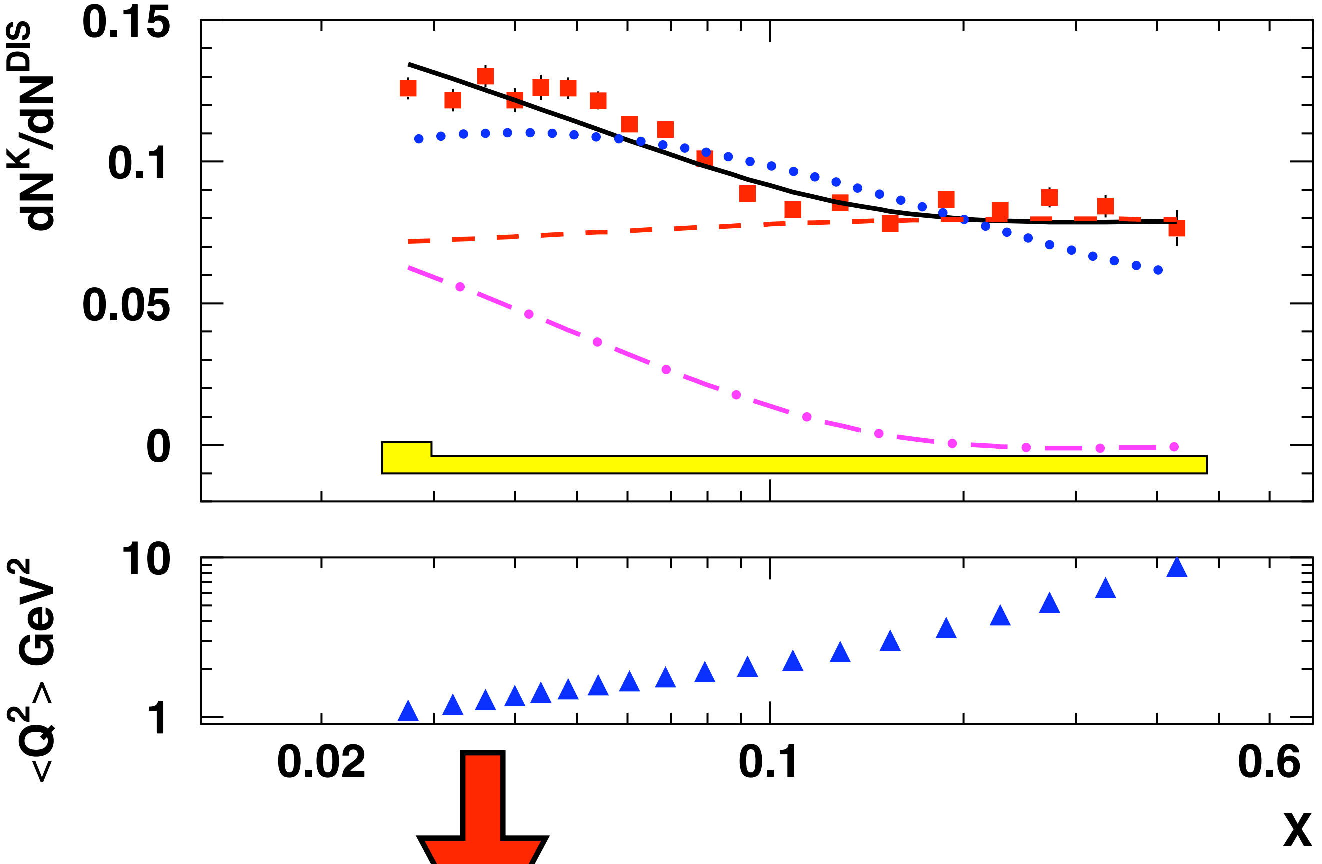
- strange quarks carry no isospin ⇒ $S(x)_{\text{Proton}} = S(x)_{\text{Neutron}}$
- deuteron target (isoscalar!):
  fragmentation process in DIS can be described by isospin independent FFs
- charged kaon multiplicity in LO:

$$\frac{dN^{\mathrm{K}}(x)}{dN^{\mathrm{DIS}}(x)} = \frac{Q(x)\int D_Q^{\mathrm{K}}(z)dz + S(x)\int D_S^{\mathrm{K}}(z)dz}{5Q(x)+2S(x)}$$

$$Q(x) \equiv u(x) + \bar{u}(x) + d(x) + \bar{d}(x) \qquad D_Q^{\mathrm{K}} \equiv 4D_u^{\mathrm{K}}(z) + D_d^{\mathrm{K}}(z)$$

$$S(x) \equiv s(x) + \bar{s}(x) \qquad D_S^{\mathrm{K}}(z) \equiv 2D_s^{\mathrm{K}}(z)$$

Fitting $dN^{K}(x)/dN^{DIS}(x)$



Assuming S(x)=0 for x>0.15:

$$\int_{0.2}^{0.8} D_Q^{\mathrm{K}}(z)dz = 0.398 \pm 0.010$$

de Florian et al., PRD75, 114010 (2007):

$$\int_{0.2}^{0.8} D_Q^{\mathrm{K}}(z)dz = 0.435 \pm 0.044$$

$$\frac{dN^{\mathrm{K}}(x)}{dN^{\mathrm{DIS}}(x)} = \frac{Q(x)\int D_Q^{\mathrm{K}}(z)dz + \boxed{S(x)\int D_S^{\mathrm{K}}(z)dz}}{5Q(x) + \cancel{2S(x)}}$$

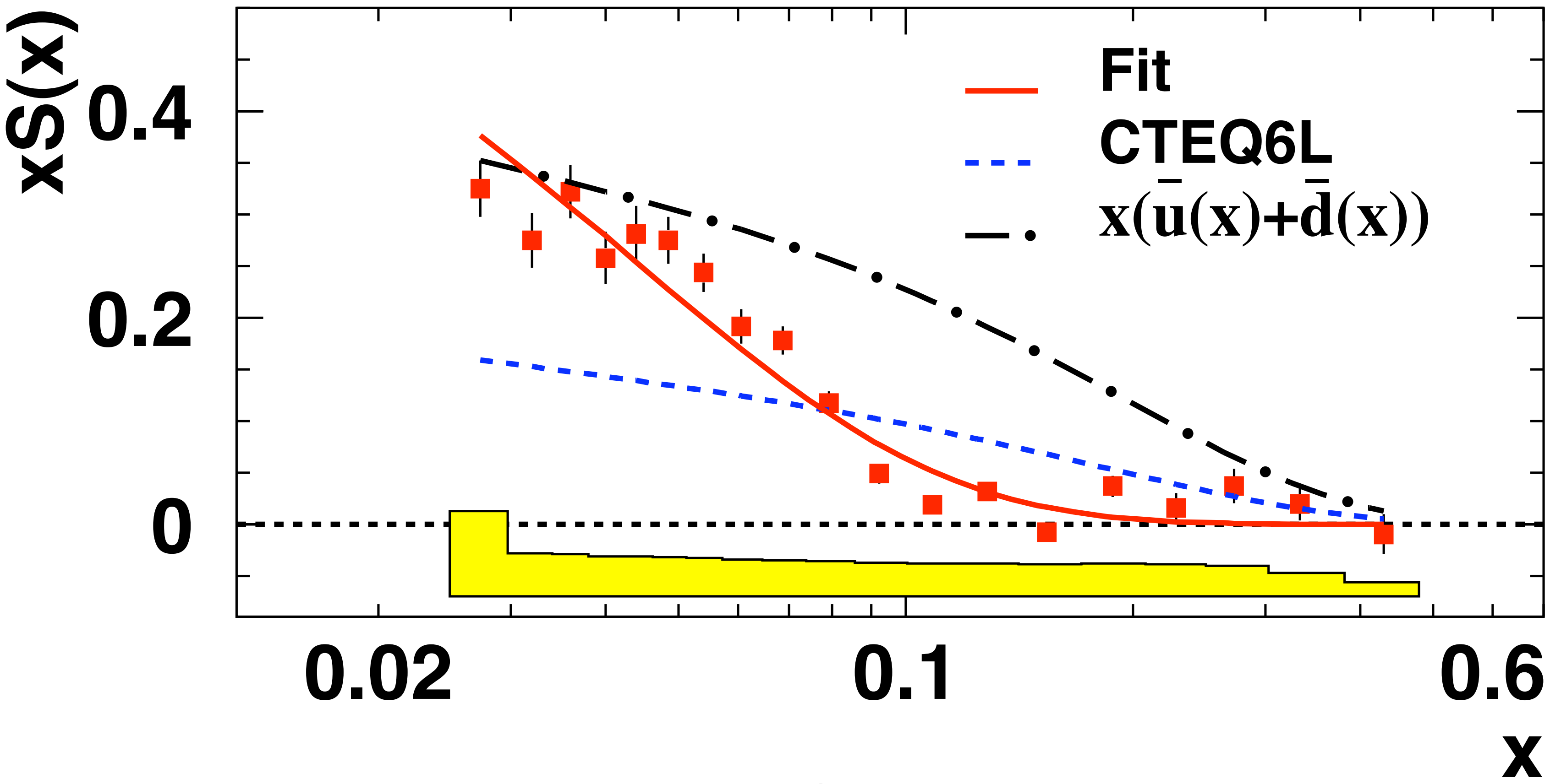
CTEQ6L

S(x) at Q^2=2.5 GeV^2

- xS(x) obtained by evolution of data to Q^2=2.5 GeV^2 using

$$\int_{0.2}^{0.8} D_S^{\mathrm{K}}(z)dz = 1.27 \pm 0.13$$

de Florian et al., PRD75, 114010 (2007)

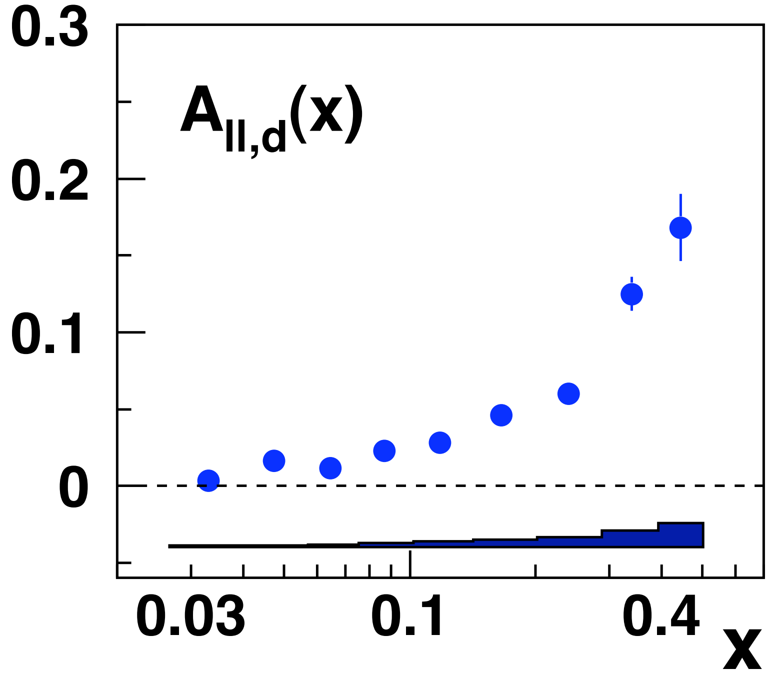


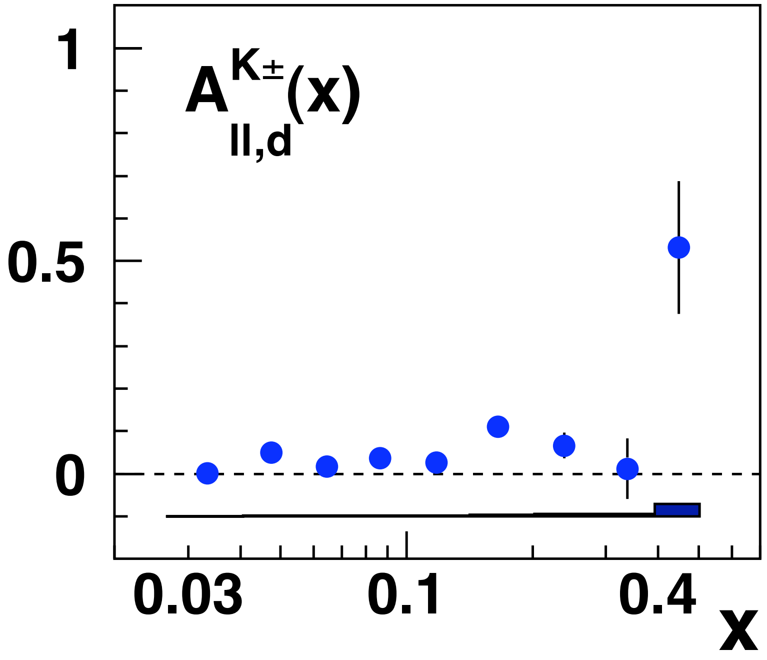
- shape incompatible with CTEQ6L and with average of the isoscalar non-strange sea

Extraction of ΔQ(x) and ΔS(x)

Double spin asymmetries from long. pol. deuteron target

$$A_{||}^{(h)} = \frac{\sigma^{\overrightarrow{\Leftarrow},(h)} - \sigma^{\overrightarrow{\Rightarrow},(h)}}{\sigma^{\overrightarrow{\Leftarrow},(h)} + \sigma^{\overrightarrow{\Rightarrow},(h)}}$$





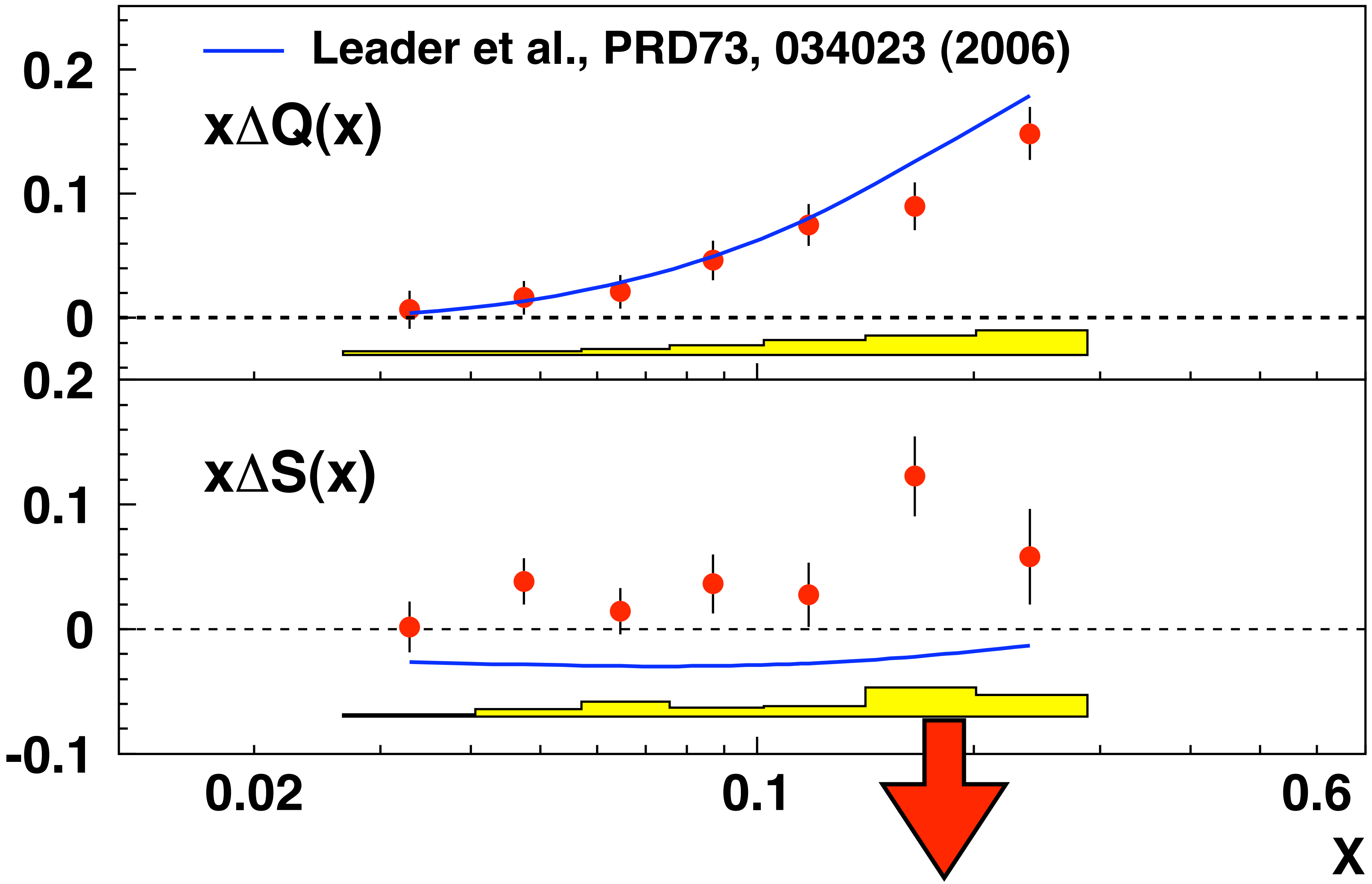
$$A_{||,d}(x)\frac{d^2N^{\rm DIS}(x)}{dx\,dQ^2} = \mathcal{K}_{LL}(x,Q^2)\,[5\Delta Q(x) + 2\Delta S(x)]$$

$$A^{\rm K}_{||,d}(x)\frac{d^2N^{\rm DIS}(x)}{dx\,dQ^2} = \mathcal{K}_{LL}(x,Q^2)\left[\Delta Q(x)\int D_Q^{\rm K}(z)dz + \Delta S(x)\int D_S^{\rm K}(z)dz\right]$$

(from S(x) extraction)

$$\Delta Q(x) = \Delta u(x) + \Delta\bar{u}(x) + \Delta d(x) + \Delta\bar{d}(x)$$
$$\Delta S(x) = \Delta s(x) + \Delta\bar{s}(x)$$

Helicity distributions at Q^2=2.5 GeV^2



$0.02 < x_B < 0.6$

$$\Delta S = 0.037 \pm 0.019 \pm 0.027$$

Phys. Lett.. B 666 (2008) 446

$\Delta\bar{s} = 0$ →

$$\Delta s = 0.028 \pm 0.033 \pm 0.009$$

$$\Delta S = 0.129 \pm 0.042 \pm 0.129$$

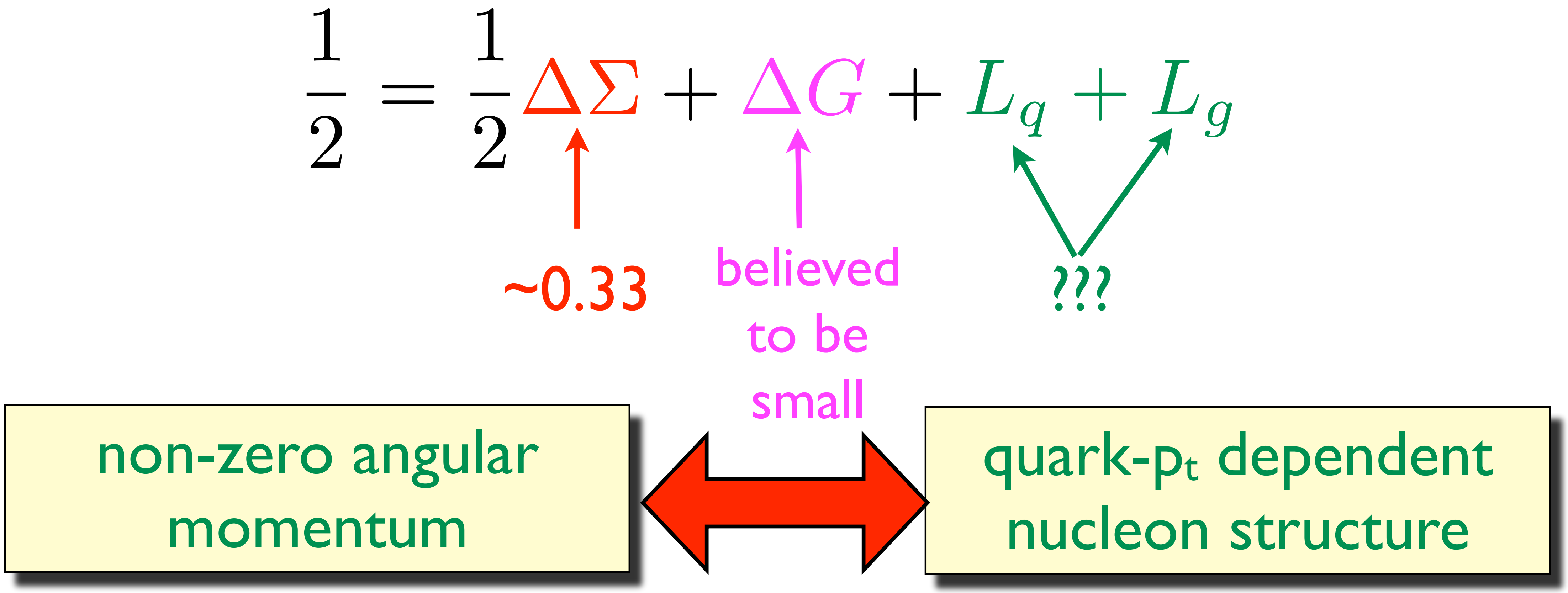
$0.02 < x_B < 0.3$

Phys. Rev D 71 (2005) 012003

Transverse Structure
of
the Nucleon

Single spin asymmetries and transverse structure

Nucleon spin puzzle:



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

non-zero angular momentum

quark-p_t dependent nucleon structure

Measurement of azimuthal asymmetries in the one-hadron production cross section

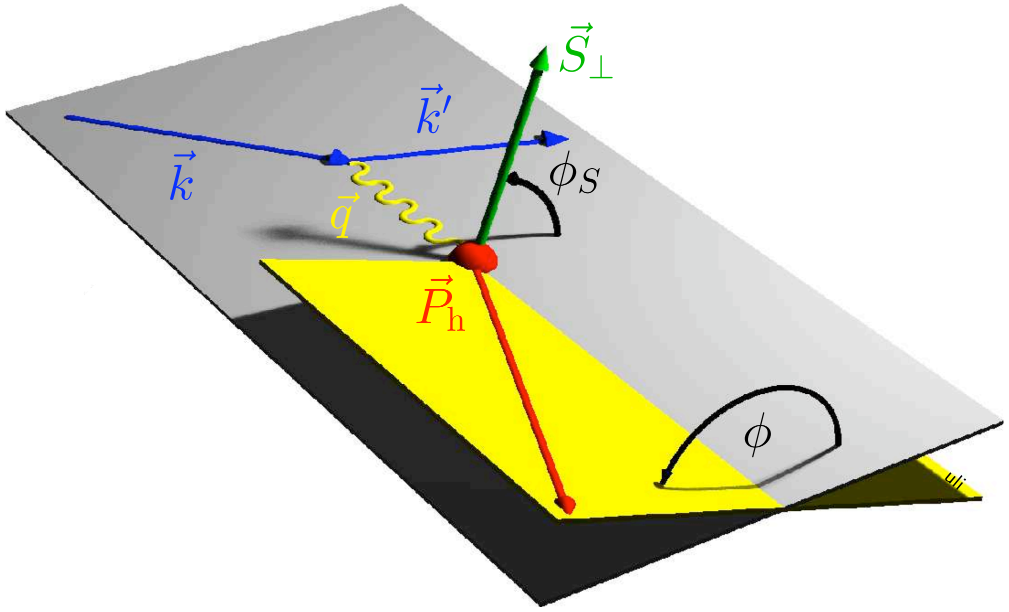
1-Hadron Production (ep→ehX)

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

σ_{XY}

Beam Target

Polarization



1-Hadron Production (ep→ehX)

$$d\sigma = d\sigma^0_{UU} + \boxed{\cos 2\phi\, d\sigma^1_{UU}}$$

$$+ \quad S_L \left\{ \sin 2\phi\, d\sigma^4_{UL} + \frac{1}{Q} \sin\phi \right.$$

$$+ \quad S_T \left\{ \boxed{\sin(\phi - \phi_S)\, d\sigma^8_{UT}} + \boxed{\sin(\phi + \phi_S)\, d\sigma^9_{UT}} + \sin(3\phi - \phi_S)\, d\sigma^{10}_{UT} \right.$$

$$+ \frac{1}{Q} \left(\sin(2\phi - \phi_S)\, d\sigma^{11}_{UT} + \sin\phi_S\, d\sigma^{1}_{UT} \right)$$

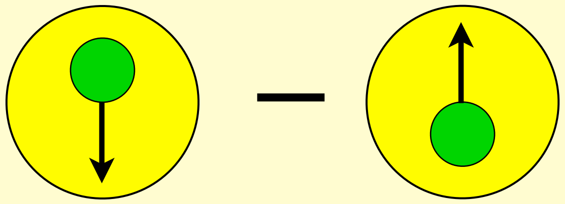
$$+ \frac{1}{Q} \left(\mathrm{c} \quad d\sigma^{15}_{LT} \right) \Big] \Big\}$$

σ_{XY}

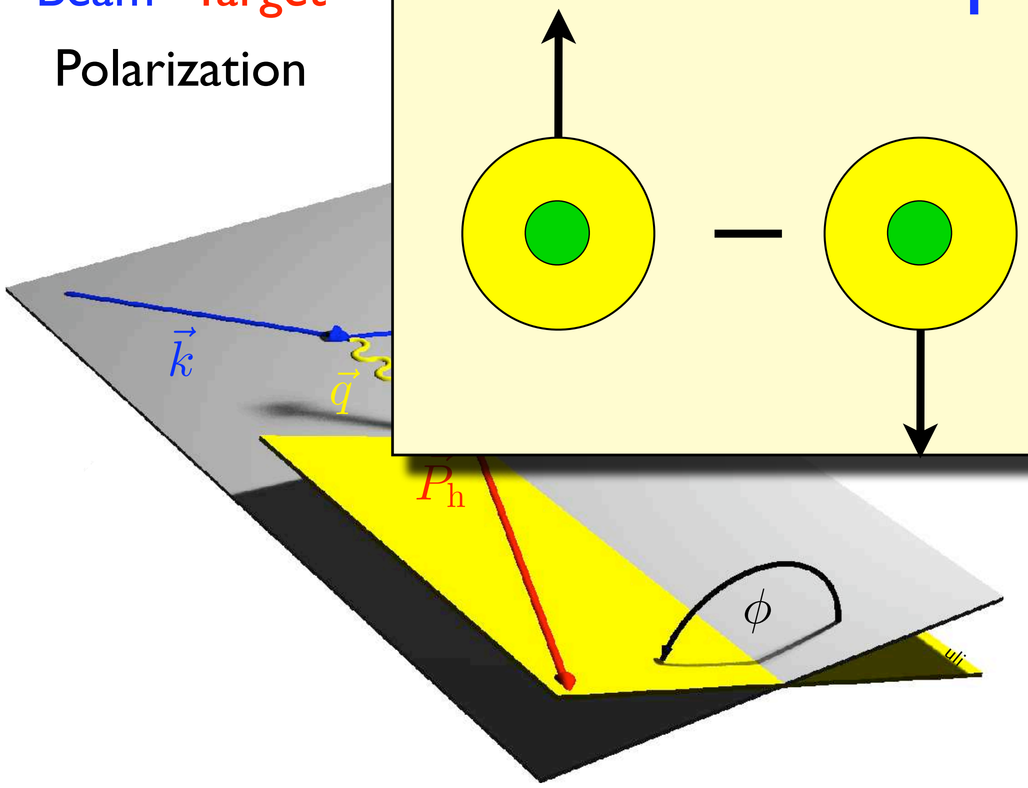
Beam Target

Polarization

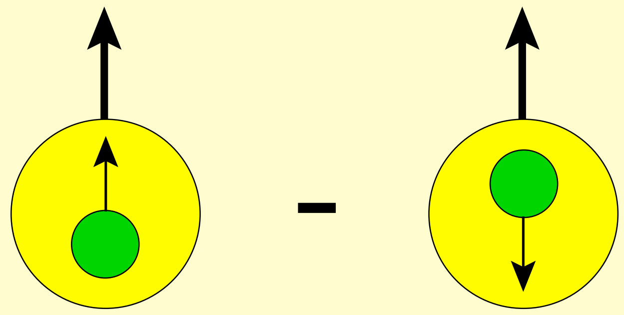
Boer-Mulders-DF ⊗ Collins-FF



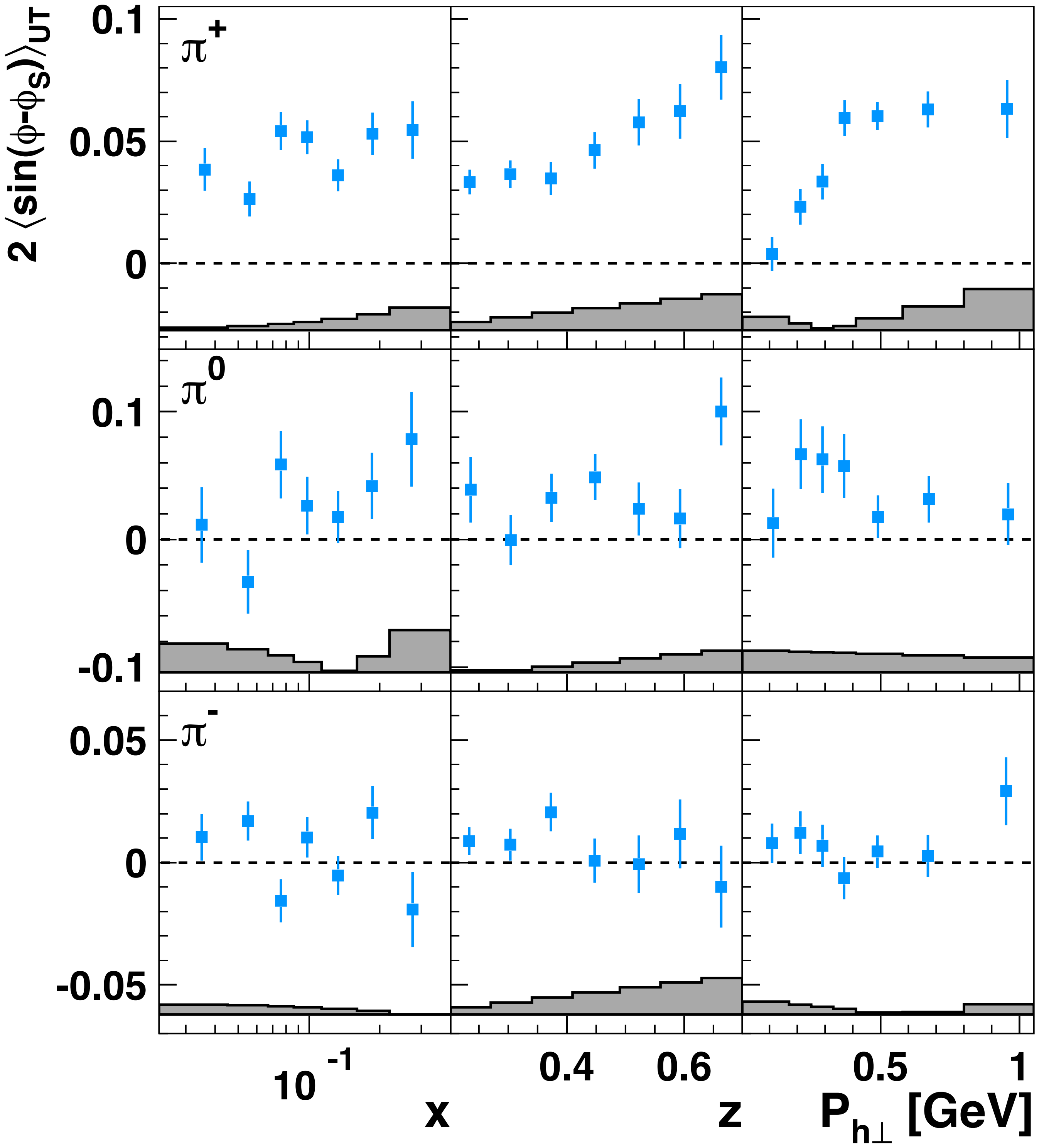
Sivers-DF ⊗ unpol FF



δq-DF ⊗ Collins-FF



Sivers Amplitudes for Pions

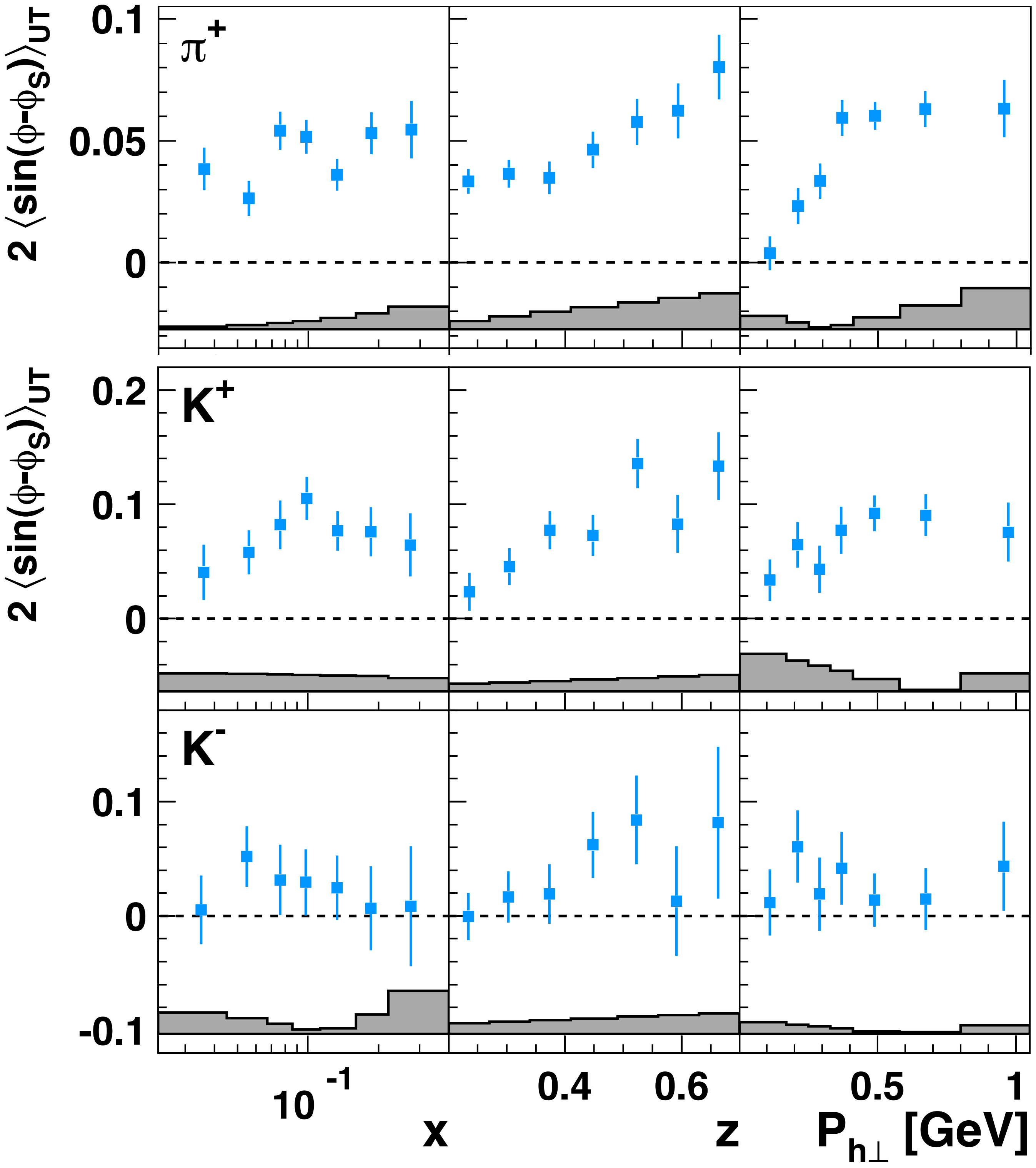


$$A_S \propto f_{1T}^{\perp} \otimes D_1^q$$

- positive, except for π-
- implies non-zero orbital angular momentum of quarks
- isospin symmetry of π-mesons fulfilled

A. Airapetian et al., arXiv:0906.3918

Sivers Amplitudes for Pions & Kaons



$$A_S \propto f_{1T}^{\perp} \otimes D_1^q$$

- positive, except for π^-
- implies non-zero orbital angular momentum of quarks
- isospin symmetry of π-mesons fulfilled
- π^+, K^+:
  - saturation at $P_{h\perp} > 0.4$ GeV
  - consistent with predicted linear decrease $P_{h\perp} \rightarrow 0$
- difference between K^+ and π^+ suggests significant role of non-u-quarks

A. Airapetian et al., arXiv:0906.3918

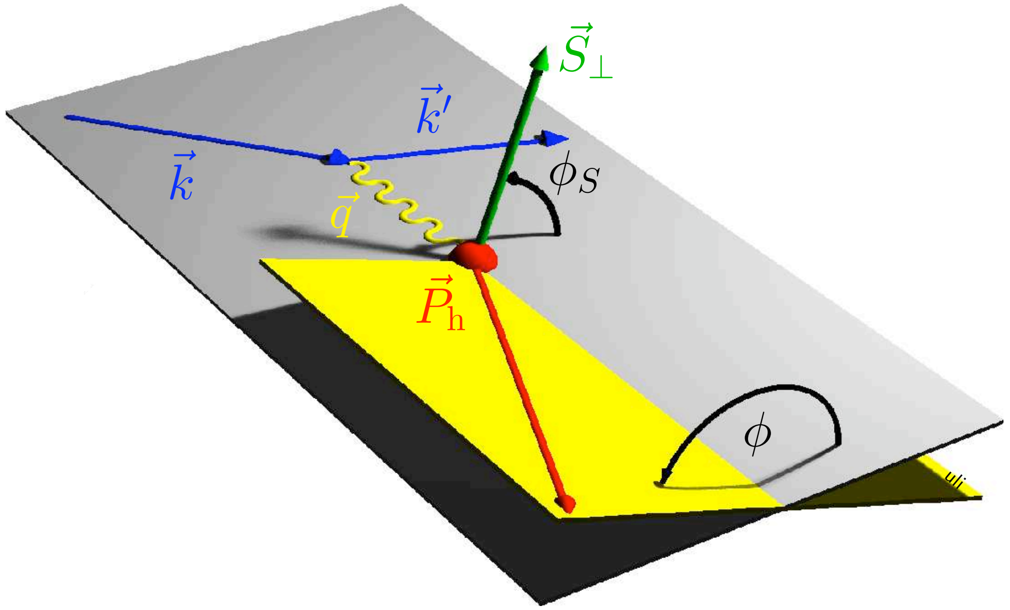
1-Hadron Production (ep→ehX)

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

σ_{XY}

Beam Target

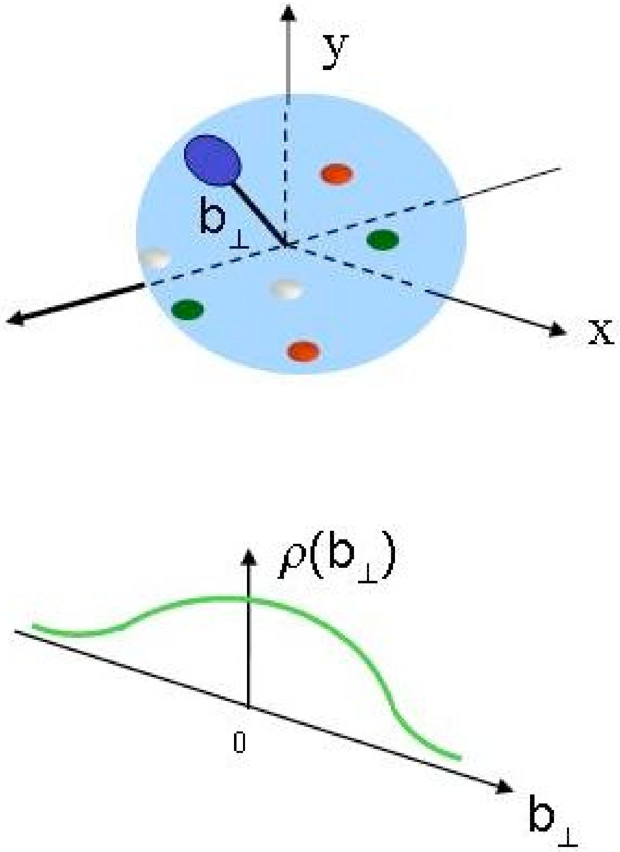
Polarization



See talk by
F. Giordano
tomorrow @ 10:05

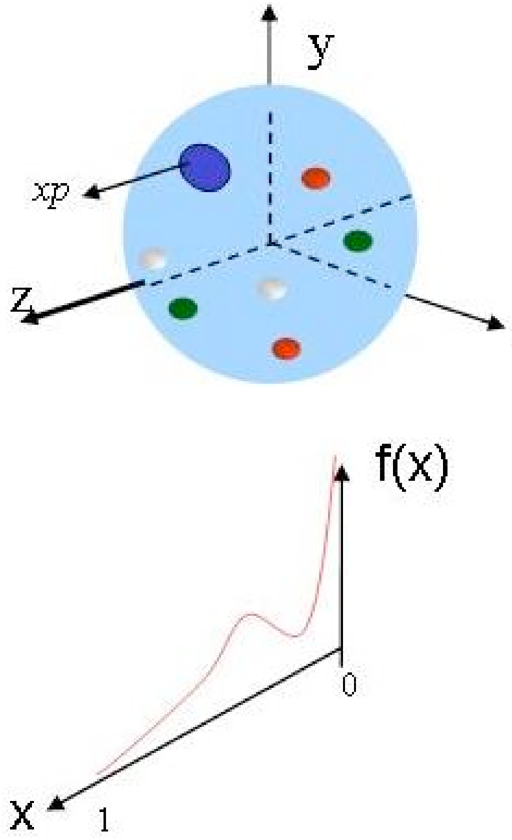
Accessing Generalized Parton Distribution Functions (GPDs)
via
Deeply Virtual Compton Scattering (DVCS)
and
exclusive meson production

GPDs



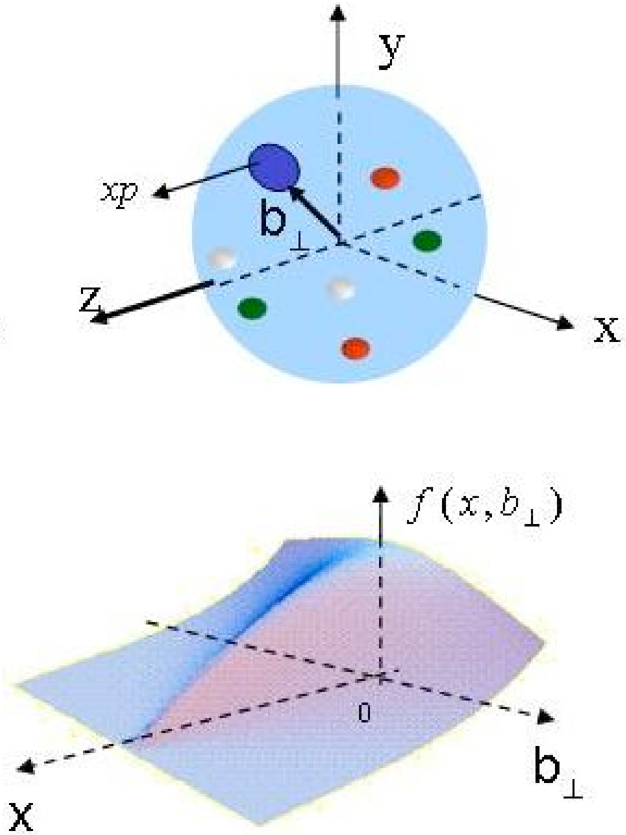
Form factors

Transverse distribution of quarks in space coordinates



Parton Distribution Functions

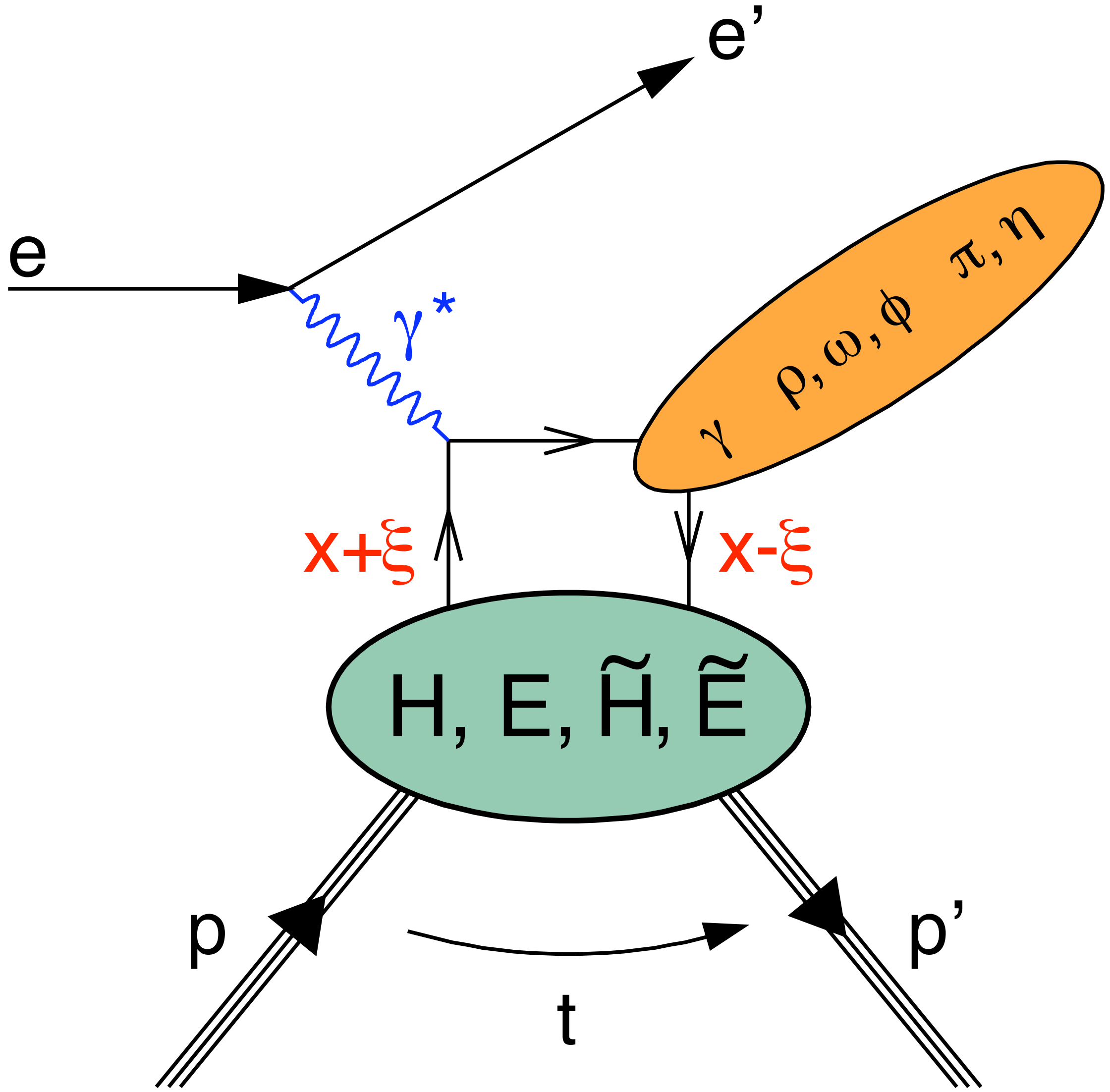
Quark longitudinal momentum fraction distribution in the nucleon



GPDs

Correlation between transverse position and longitudinal momentum fraction of quark in the nucleon

Probing GPDs in Exclusive Reactions



Form factors

⇒ moments:

$$\int dx H^q(x,\xi,t) = F_1^q(t)$$

$$\int dx E^q(x,\xi,t) = F_2^q(t)$$

PDFs:

⇒ limits:

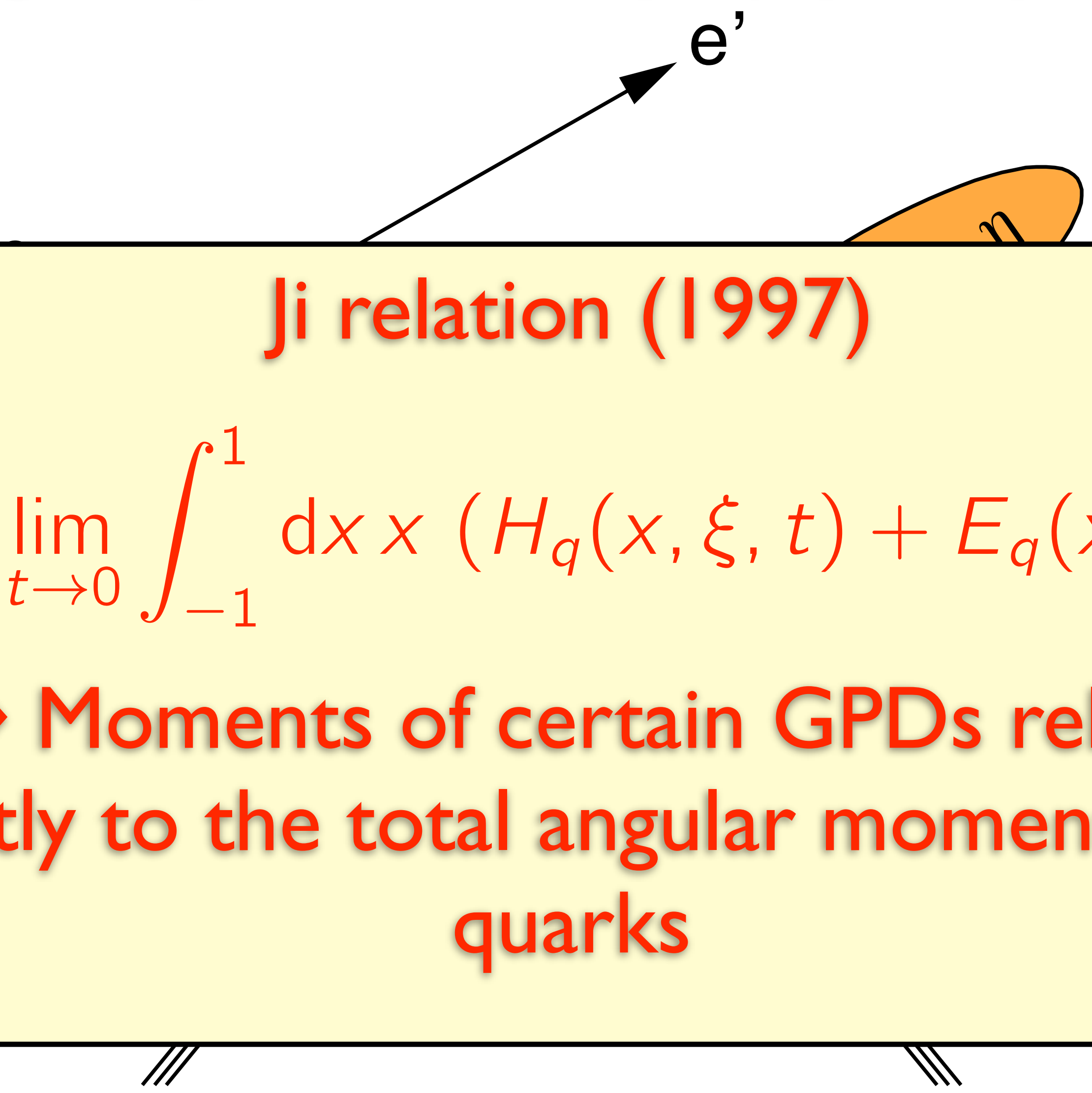
$$H^q(x,\xi=0,t=0) = q(x)$$

$$\widetilde{H}^q(x,\xi=0,t=0) = \Delta q(x)$$

	unpolarized	polarized
no nucleon hel. flip	H	$\widetilde{H}$
nucleon hel. flip	E	$\widetilde{E}$

(+ 4 more chiral-odd functions)

Probing GPDs in Exclusive Reactions



Ji relation (1997)

$$J_q = \lim_{t\to 0}\int_{-1}^{1} \mathrm{d}x\, x\, \left(H_q(x,\xi,t) + E_q(x,\xi,t)\right)$$

➜ Moments of certain GPDs relate directly to the total angular momentum of quarks

Form factors
⇒ moments:

$$\int \mathrm{d}x H^q(x,\xi,t) = F_1^q(t)$$
$$\int \mathrm{d}x E^q(x,\xi,t) = F_2^q(t)$$

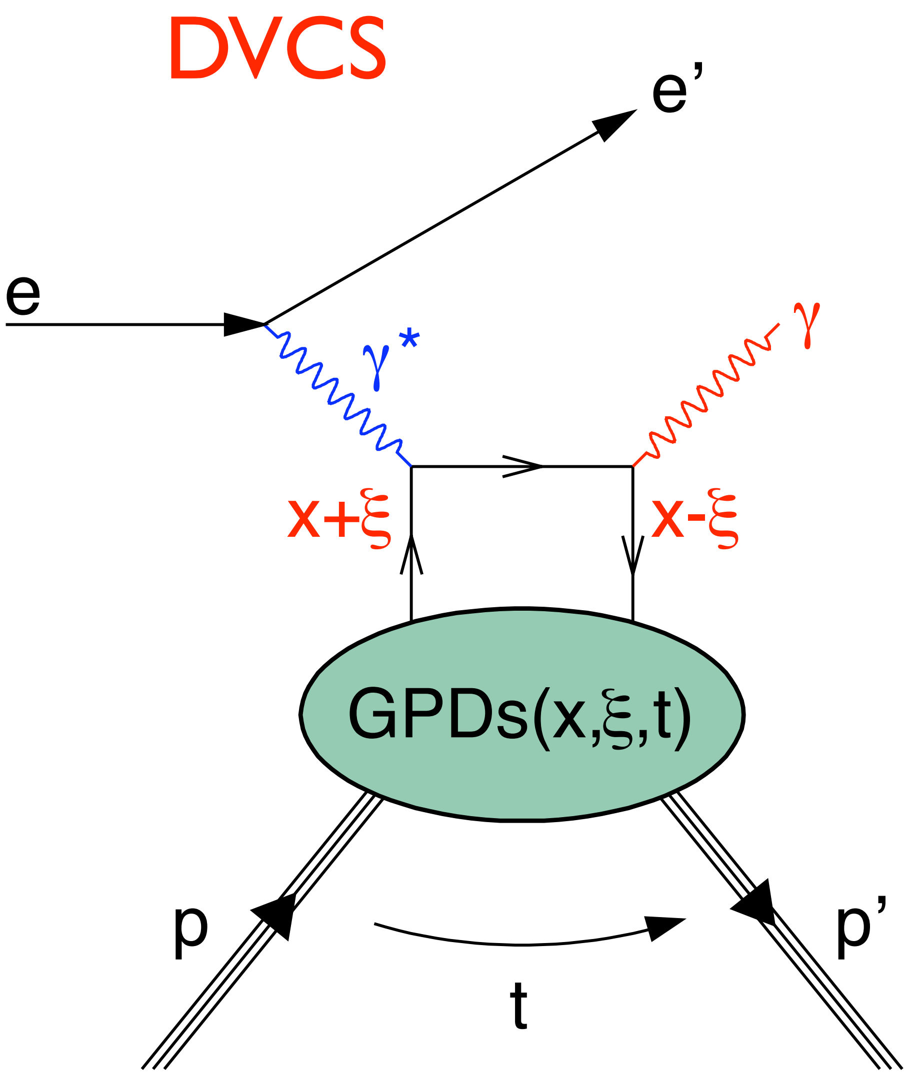
PDFs:
⇒ limits:

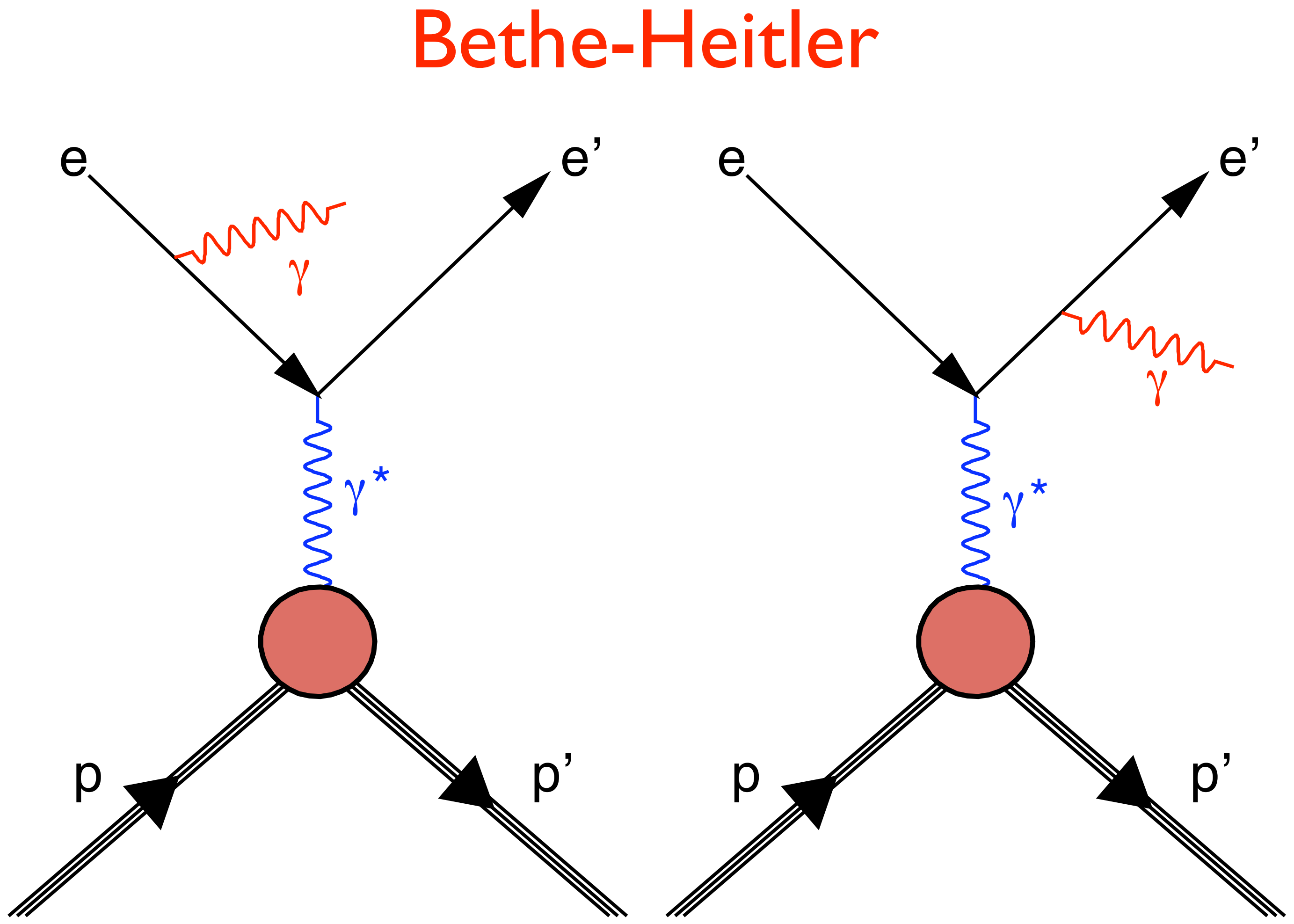
$$H^q(x,\xi=0,t=0) = q(x)$$
$$\widetilde{H}^q(x,\xi=0,t=0) = \Delta q(x)$$

	unpolarized	polarized
no nucleon hel. flip	H	$\widetilde{H}$
nucleon hel. flip	E	$\widetilde{E}$

(+ 4 more chiral-odd functions)

DVCS/Bethe-Heitler Interference


DVCS

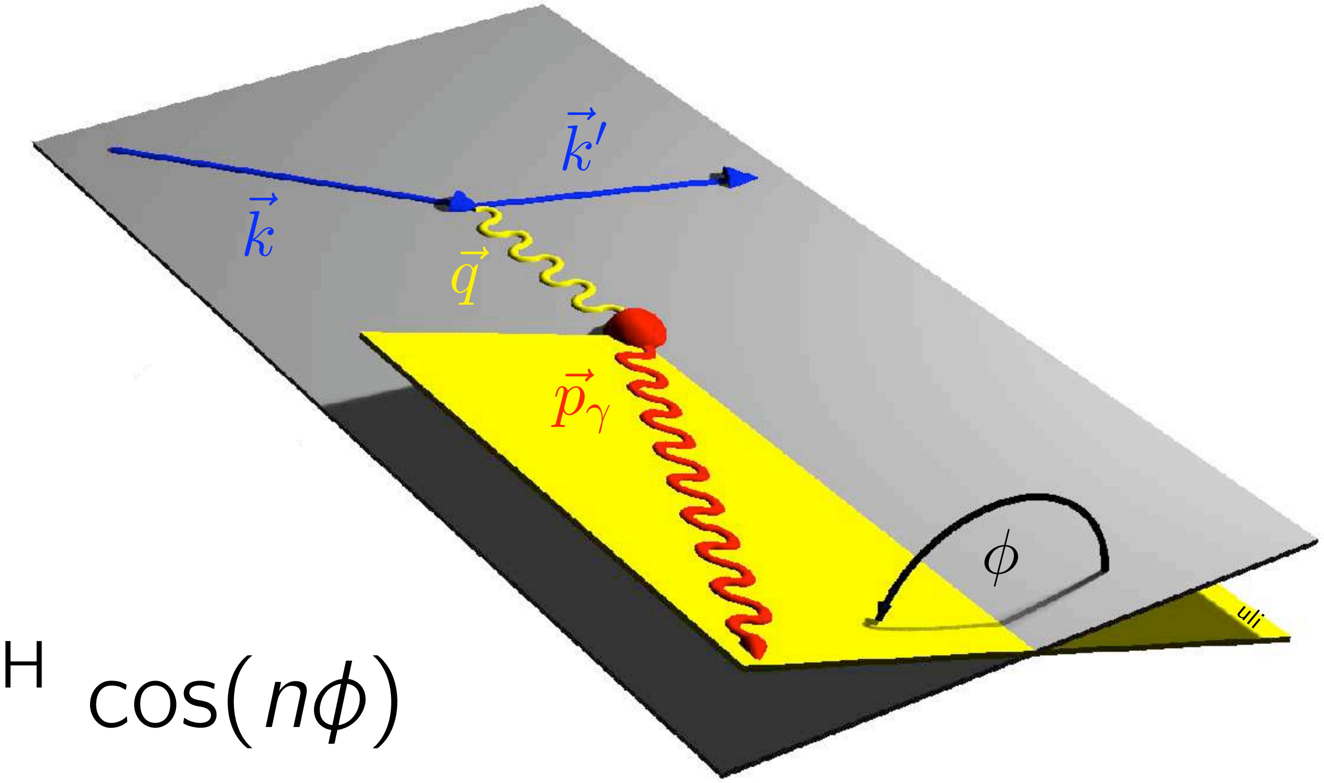

Bethe-Heitler

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

Azimuthal Dependences in DVCS

Fourier expansion for Φ:

- beam polarization P_B
- beam charge C_B
- unpolarized target



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

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

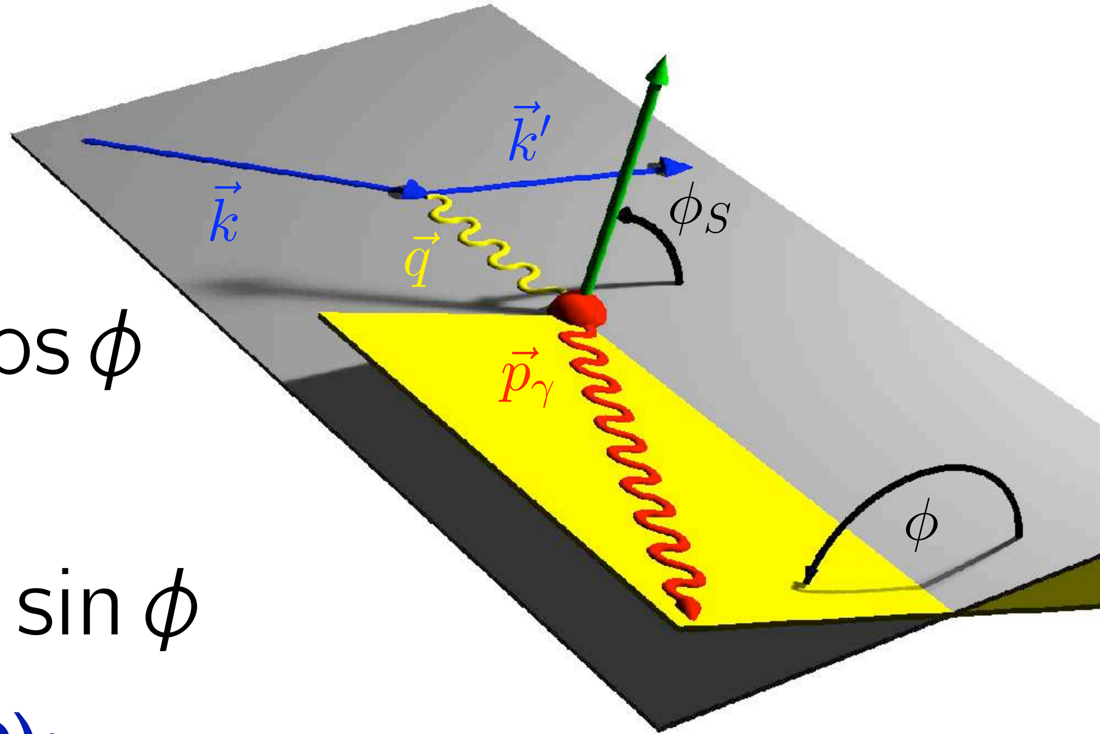
$$\mathcal{I} = \frac{C_B K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[\sum_{n=0}^{3} c_n^{\mathcal{I}} \cos(n\phi) + P_B \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi) \right]$$

Azimuthal Asymmetries in DVCS

Cross section:

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

Azimuthal asymmetries:



- Beam-charge asymmetry $A_C(\Phi)$:

$$d\sigma(e^+, \phi) - d\sigma(e^-, \phi) \propto \mathrm{Re}[F_1 \mathcal{H}] \cdot \cos\phi$$

- Beam-helicity asymmetry $A_{LU}(\Phi)$:

$$d\sigma(e^{\rightarrow}, \phi) - d\sigma(e^{\leftarrow}, \phi) \propto \mathrm{Im}[F_1 \mathcal{H}] \cdot \sin\phi$$

- Transverse target-spin asymmetry $A_{UT}(\Phi)$:

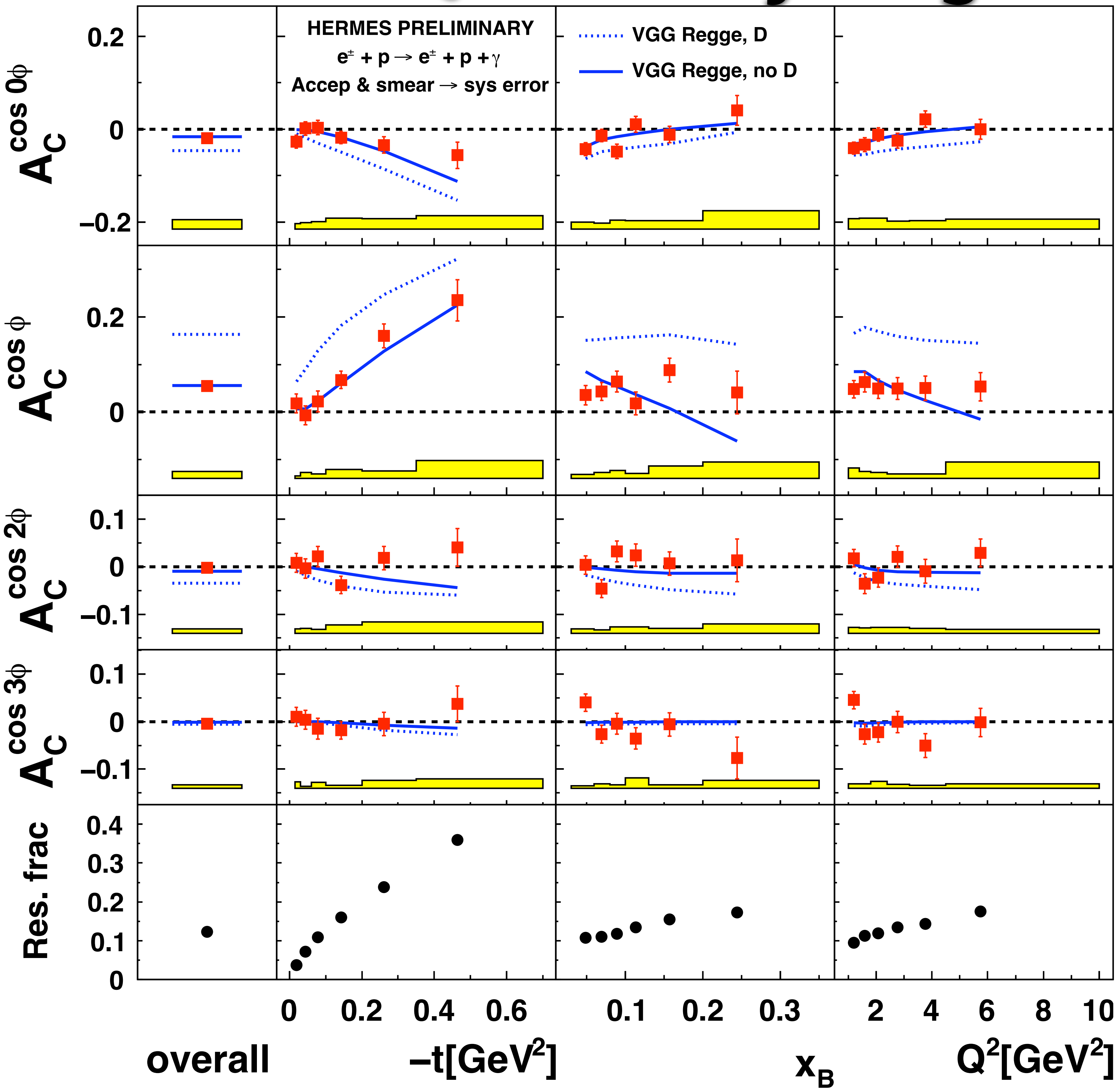
$$d\sigma(\phi, \phi_S) - d\sigma(\phi, \phi_S + \pi) \propto \mathrm{Im}[F_2 \mathcal{H} - F_1 \mathcal{E}] \cdot \sin(\phi - \phi_S) \cos\phi$$
$$+ \mathrm{Im}[F_2 \widetilde{\mathcal{H}} - F_1 \xi \widetilde{\mathcal{E}}] \cdot \cos(\phi - \phi_S) \sin\phi$$

(F_1, F_2 are the Dirac and Pauli form factors)

($\mathcal{H}$,$\mathcal{E}$ … Compton form factors involving GPDs H, E, …)

A_C on a hydrogen target

All data
1996-2005



constant term

$\propto -A_C^{\cos\phi}$

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

[higher twist]

[gluon leading twist]

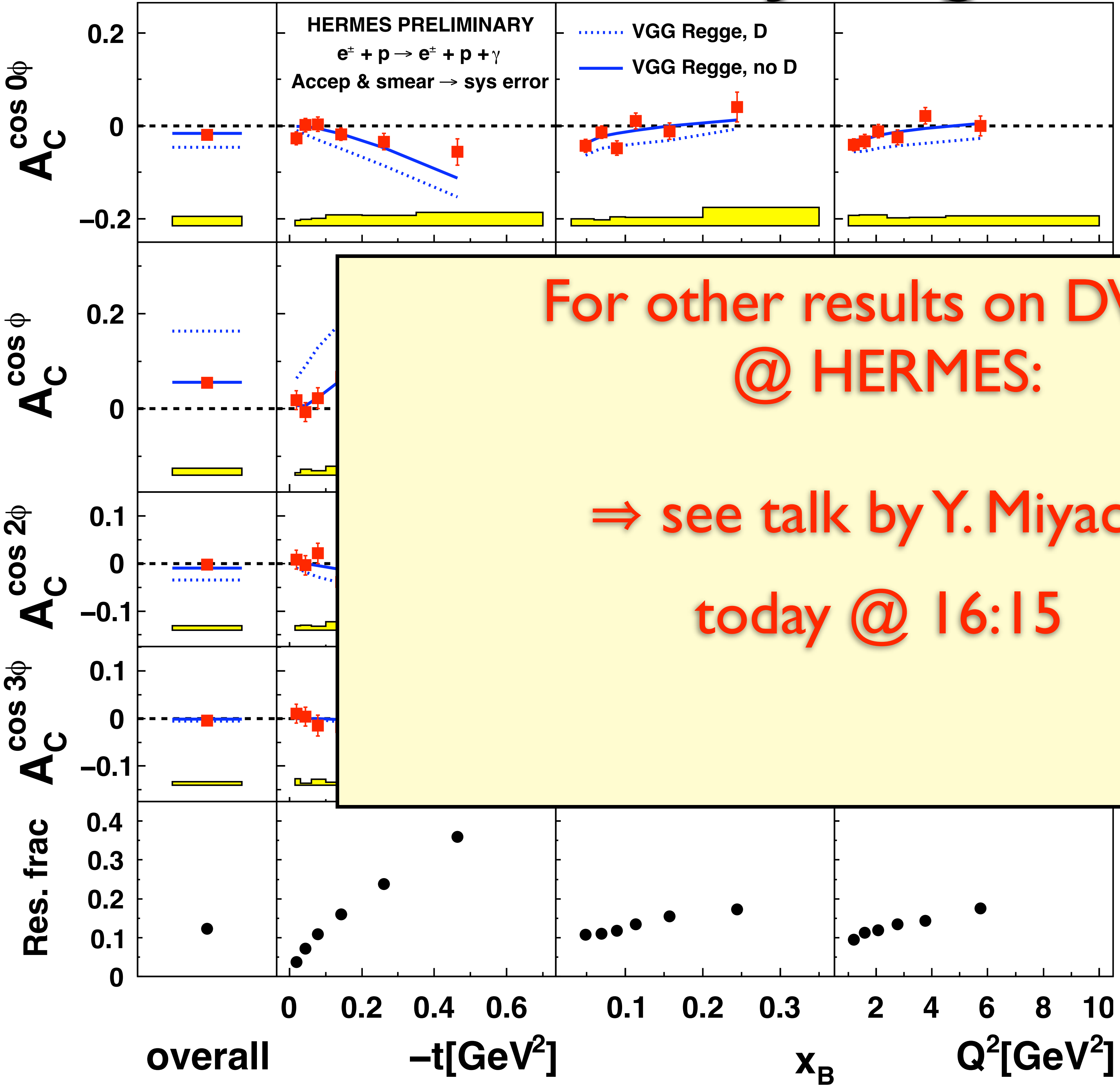
resonant fraction:

$ep \rightarrow e\Delta^+\gamma$

GPD model:VGG Phys. Rev. D60 (1999) 094017 & Prog. Nucl. Phys. 47 (2001) 401

A_C on a hydrogen target

All data
1996-2005



For other results on DVCS
@ HERMES:

⇒ see talk by Y. Miyachi

today @ 16:15

constant term

$\propto -A_C^{\cos\phi}$

$\mathcal{H}]$

ist]

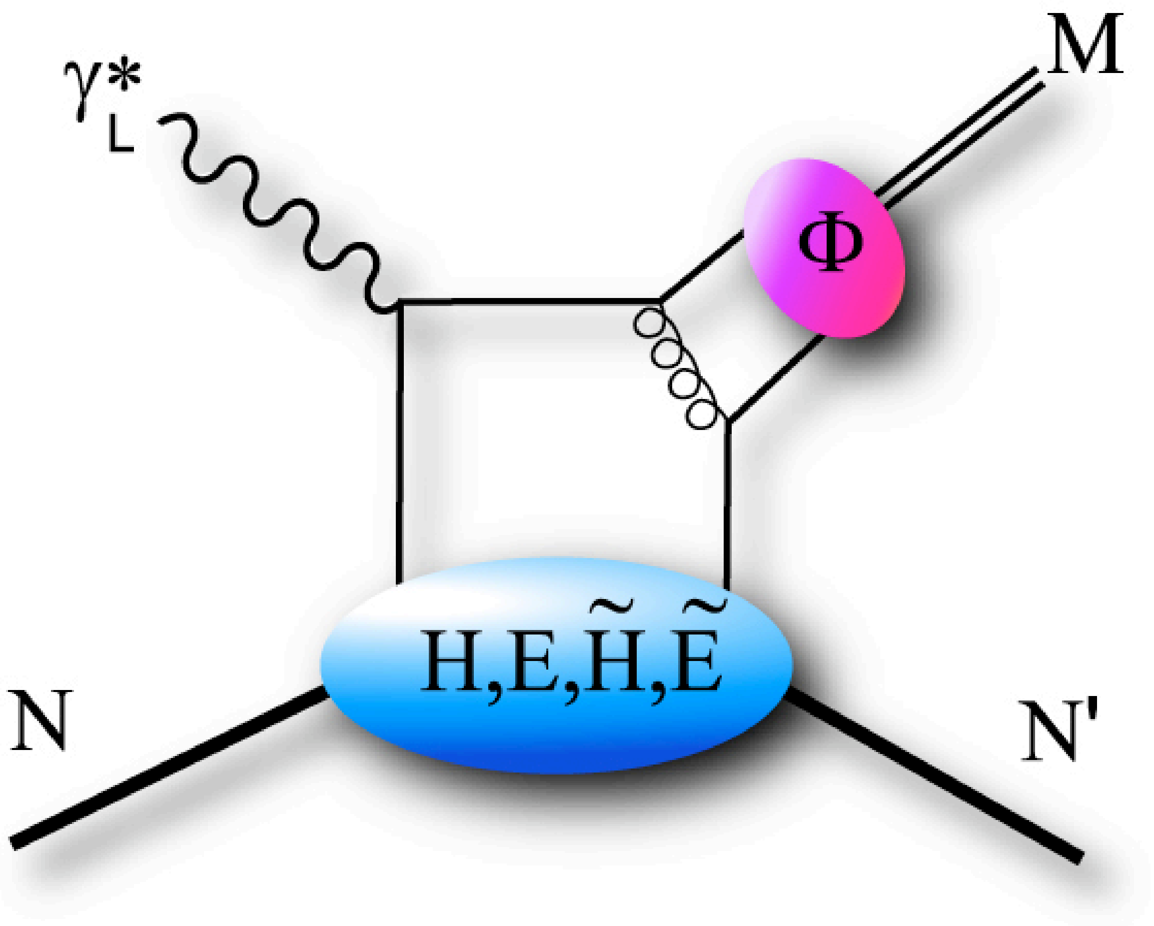
ding twist]

resonant fraction:

$ep \rightarrow e\Delta^+\gamma$

GPD model: VGG Phys. Rev. D60 (1999) 094017 & Prog. Nucl. Phys. 47 (2001) 401

Beyond DVCS: exclusive meson production

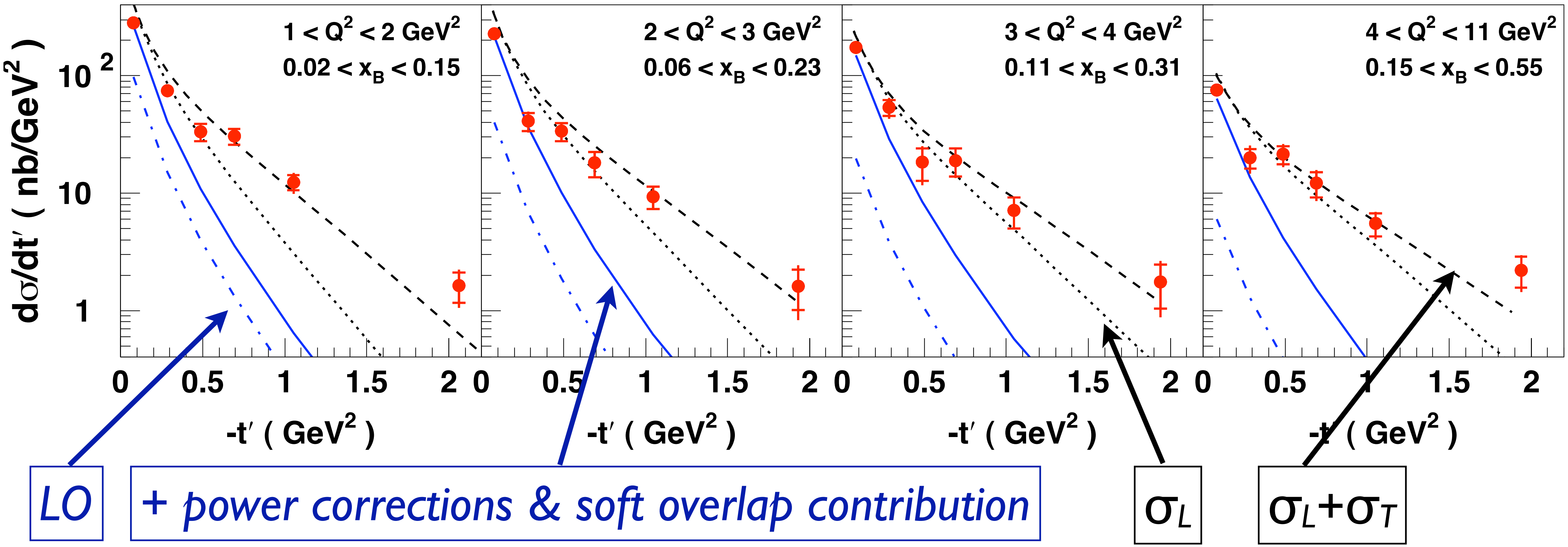


- Quantum number of final state selects different GPDs:
  - vector mesons:

    H, E
  - pseudo-scalar mesons:

    $\tilde{H}, \tilde{E}$

$ep \rightarrow e' \pi^+ (n)$: $d\sigma/dt'$



LO

+ power corrections & soft overlap contribution

σ_L

$\sigma_L + \sigma_T$

- GPD model: VGG, Phys. Rev. D60 (1999) 094017
  - model only describes σ_L
  - GPD $\tilde{E}$ expected to dominate (⇒GPD $\tilde{H}$ neglected)
  - at large -t' data may receive significant contribution from the σ_T
- Regge model calculations: Laget, Phys. Rev D 70 (2004) 054023

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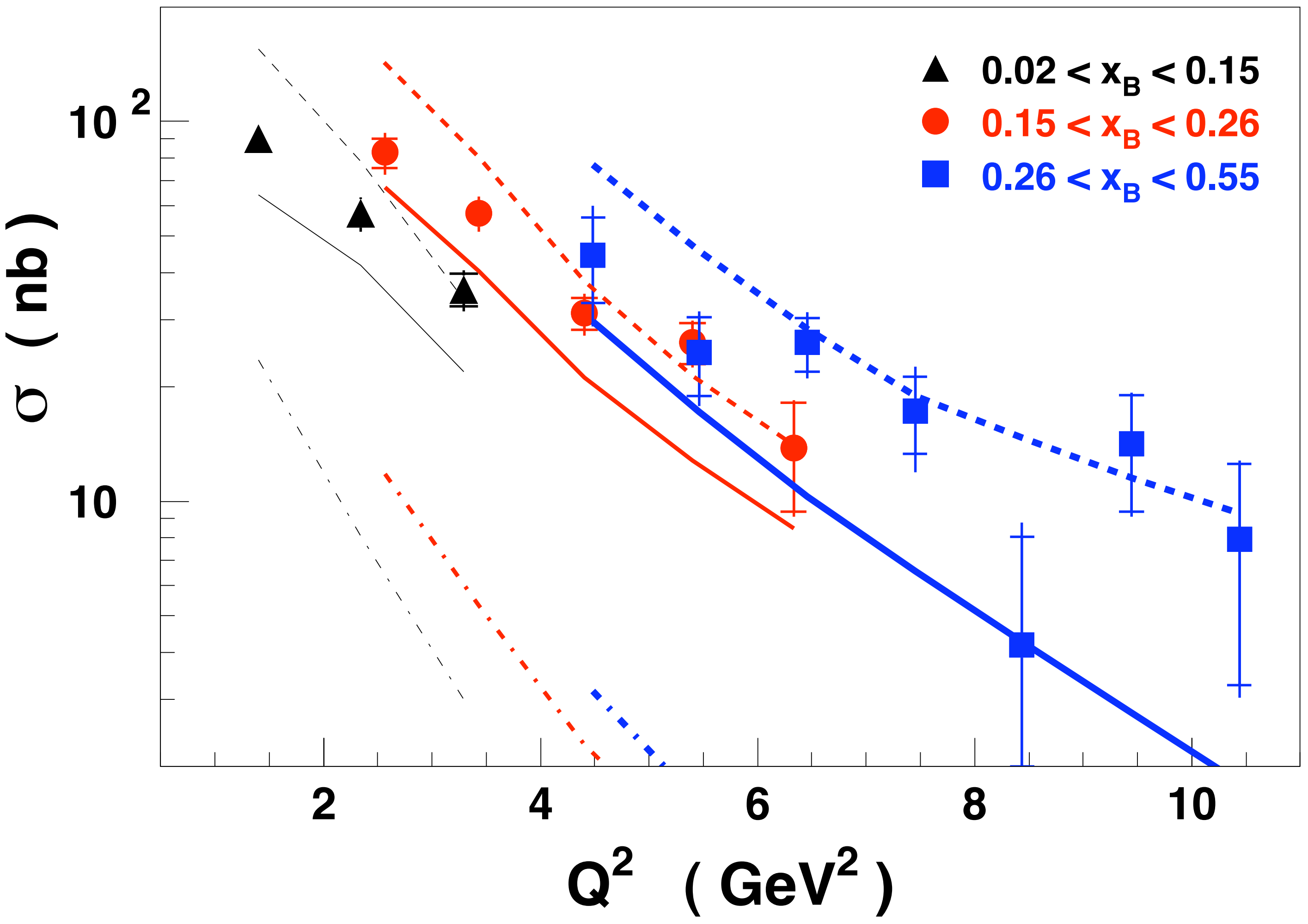
$ep \rightarrow e'\pi^+(n)$: $d\sigma/dQ^2$



VGG model:

┅ LO

— LO+power correction

Regge model:

┅ $\sigma_L + \sigma_T$

- Q^2 dependence well described by the GPD model including corrections

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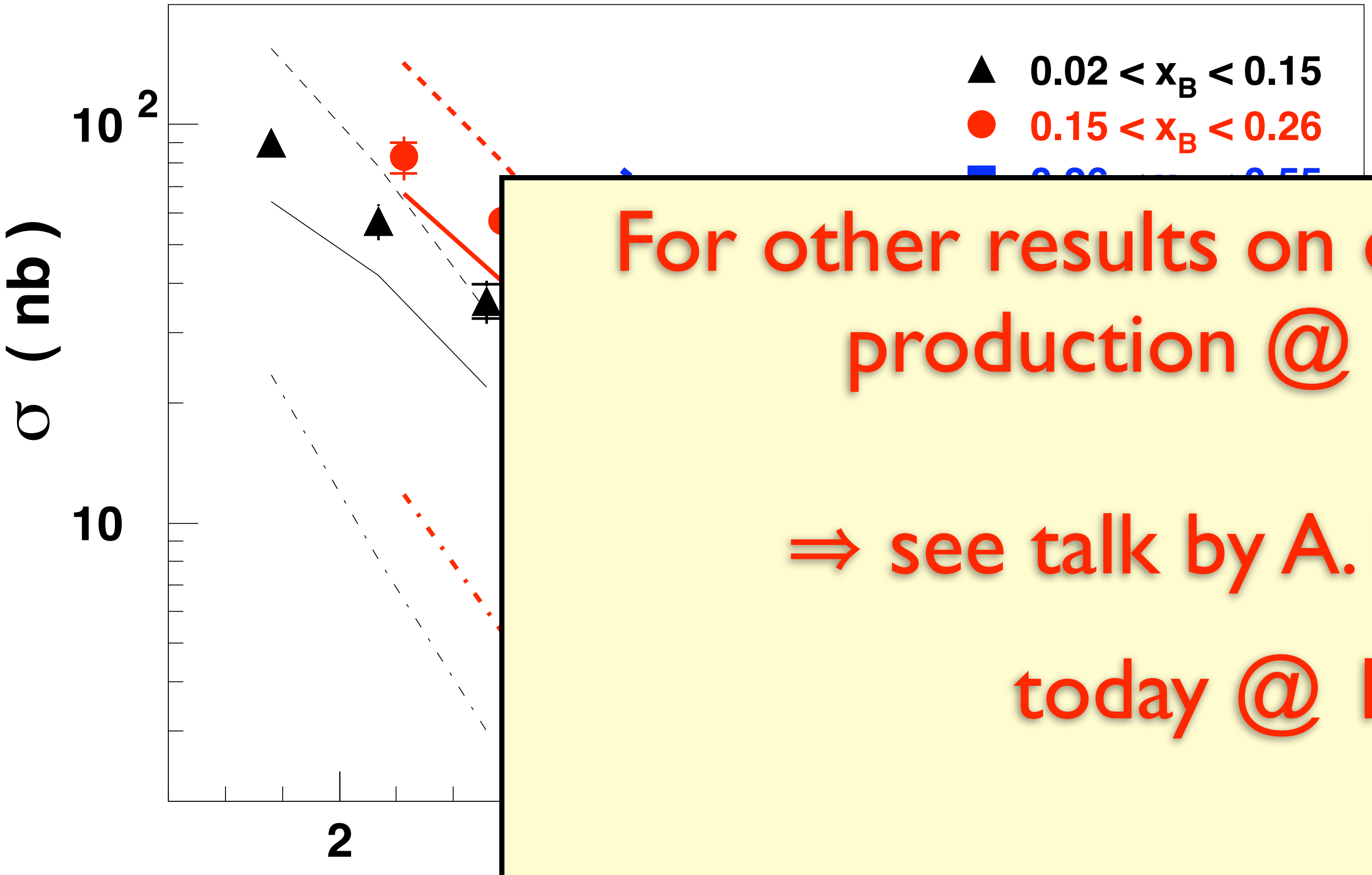
$ep \to e'\pi^+(n)$: $d\sigma/dQ^2$



VGG model:

LO

correction

For other results on exclusive meson production @ HERMES:

⇒ see talk by A. Rostomyan

today @ 16:40

- Q^2 dependence well described by the GPD model including corrections

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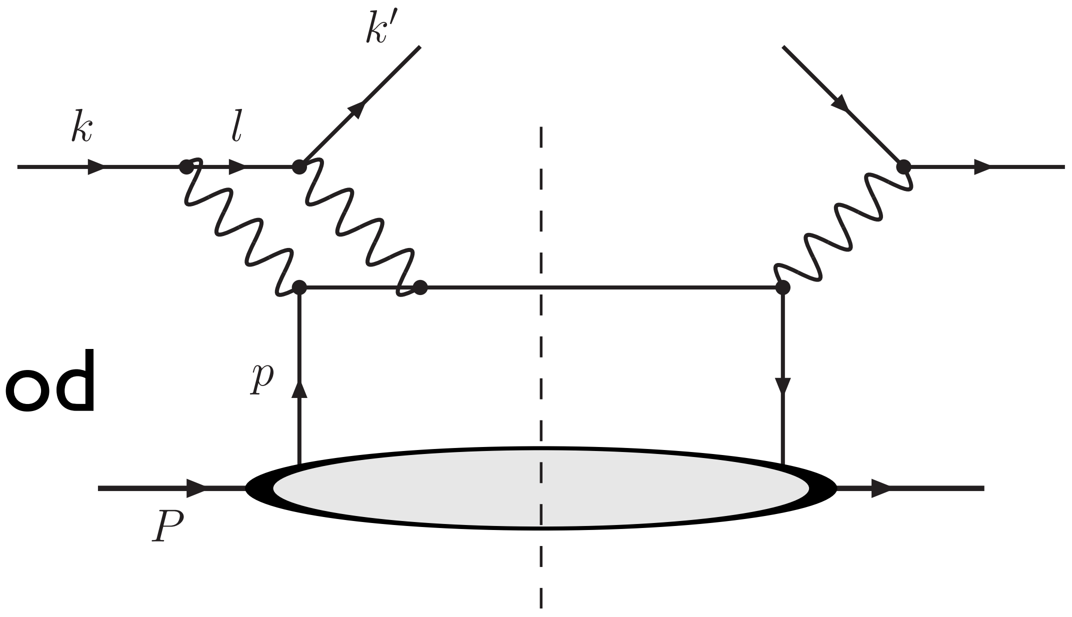
Two-photon exchange

Two-photon Exchange

Elastic scattering:

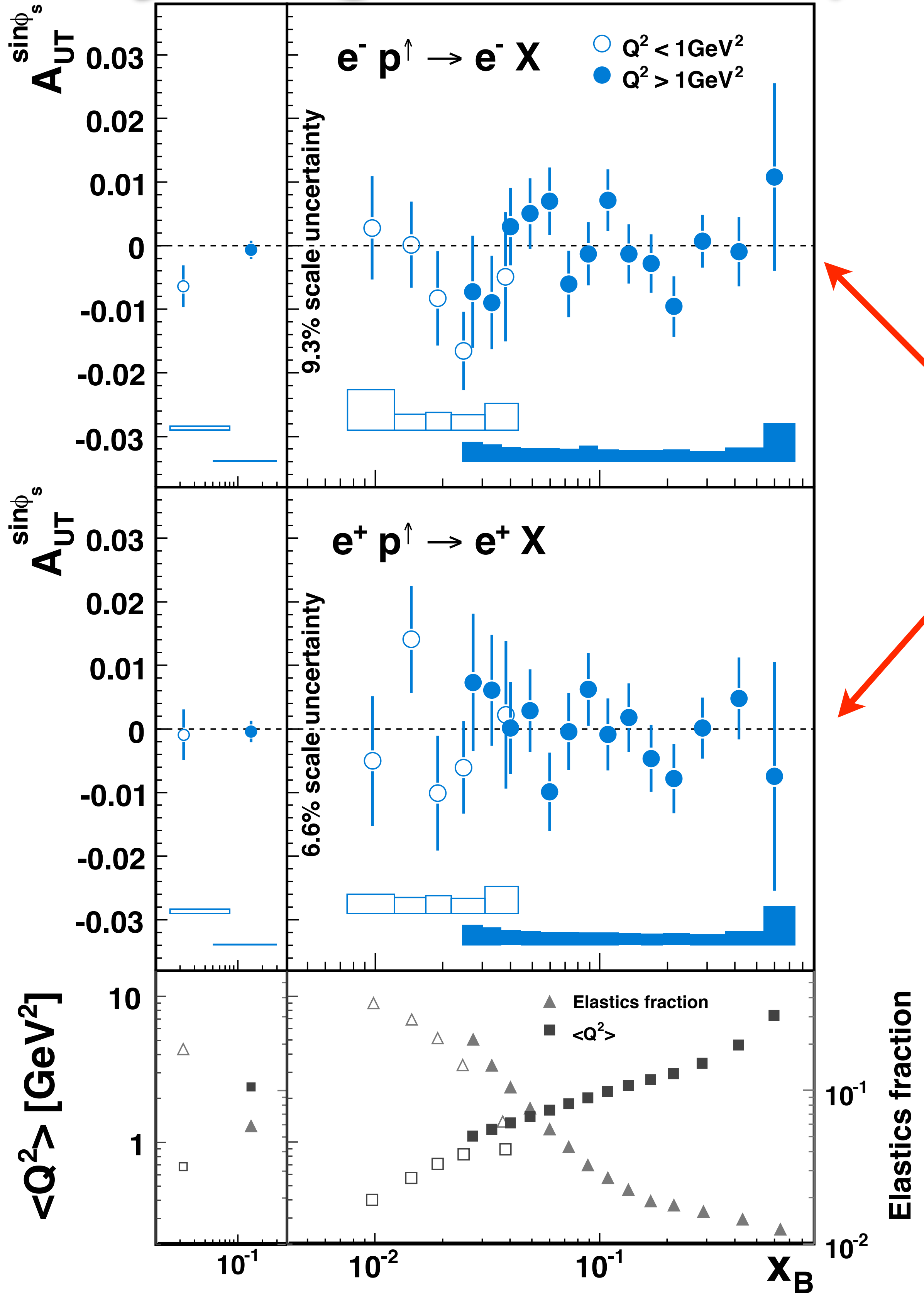
- two-photon exchange best candidate to explain discrepancy of proton G_E/G_M measurement from Rosenbluth method and polarization transfer method



DIS:

- interference between one- and two-photon exchange could lead to SSAs in inclusive DIS off transversely polarized targets
- Interference sensitive to the beam charge (odd number of e.m. couplings to the beam)
- Proportional to $S \cdot (\vec{k} \times \vec{k}')$ → either measure left-right asymmetries or $\sin(\Phi_S)$ modulation

Any sign of two-photon exchange in DIS?



Consistent with zero on the 10^{-3} level

A. Airapetian et al., arXiv:0907.5369

Achim Hillenbrand

Pan Pacific Spin 2009, Yamagata, Japan

Conclusions

- Quark helicity distributions:
  - New extraction of $\Delta s(x)$ (and $s(x)$) from isoscalar D target
  - Shape of $s(x)$ much softer than that of the light isoscalar sea
  - ΔS consistent with zero
- Transverse momentum dependent distributions (TMDs)
  - Rich set of information available from unpolarized and transversely polarized data ➠ Talk by F. Giordano
  - final results on Sivers amplitudes imply non-zero orbital angular momentum
- Generalized Parton Distributions (GPDs)

  ⇒ Access via DVCS and exclusive meson production

  ➠ Talk by Y. Miyachi ➠ Talk by A. Rostomyan
- There is no signal for 2-photon exchange in DIS at HERMES at 10^{-3} level

Backup

Measured Inclusive Asymmetries

$\boxed{P_{zz} = 0.83 \pm 0.03}$ $\boxed{A_{zz} \sim 0.01}$ $\Rightarrow \dfrac{b_1^d}{F_1^d} = -\dfrac{3}{2} A_{zz}$

(measured by HERMES)

$$\sigma = \sigma_{\mathrm{unpol}} \left[1 + P_B P_z A_\parallel + \underbrace{\frac{1}{2} P_{zz} A_{zz}}_{\text{Deuterium}} \right]$$

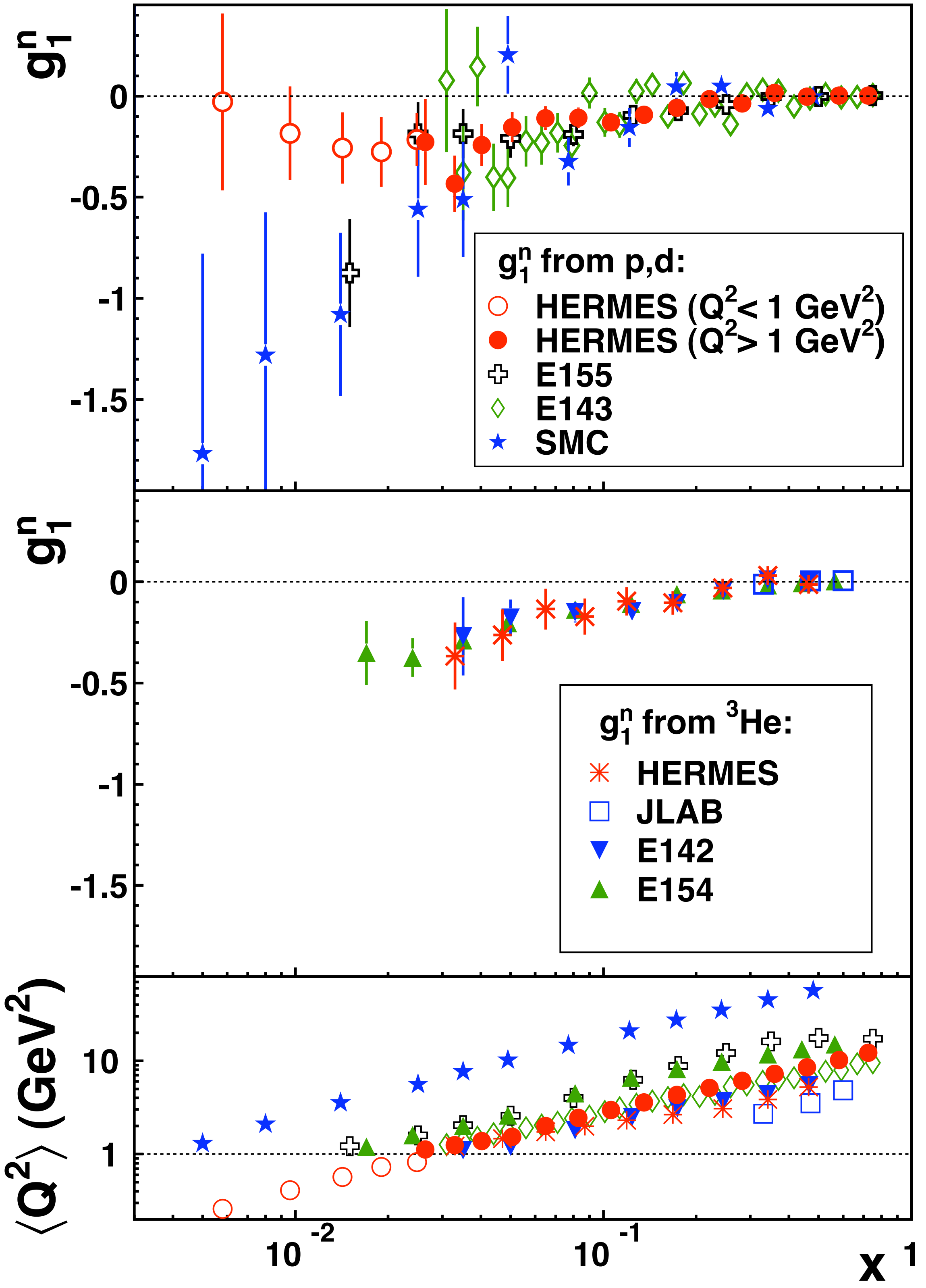
measured DIS cross section

inclusive asymmetry:

$$A_\parallel = \frac{\sigma^{\overset{\rightarrow}{\Leftarrow}} - \sigma^{\overset{\rightarrow}{\Rightarrow}}}{\sigma^{\overset{\rightarrow}{\Leftarrow}} + \sigma^{\overset{\rightarrow}{\Rightarrow}}} = \frac{1}{P_B P_z} \cdot \frac{\frac{N^{\overset{\rightarrow}{\Leftarrow}}}{L^{\overset{\rightarrow}{\Leftarrow}}} - \frac{N^{\overset{\rightarrow}{\Rightarrow}}}{L^{\overset{\rightarrow}{\Rightarrow}}}}{\frac{N^{\overset{\rightarrow}{\Leftarrow}}}{L^{\overset{\rightarrow}{\Leftarrow}}} + \frac{N^{\overset{\rightarrow}{\Rightarrow}}}{L^{\overset{\rightarrow}{\Rightarrow}}}}$$

$$g_1(x, Q^2) = \underbrace{\frac{1}{1 - \frac{y}{2} - \frac{1}{4} y^2 \gamma} \Bigg[\frac{Q^4}{8\pi\alpha^2 y}}_{\text{kinematic factors}} \underbrace{\frac{\partial^2 \sigma_{\mathrm{unpol}}}{\partial x \partial Q^2}}_{\text{param.}} \underbrace{A_\parallel(x, Q^2)}_{\text{meas.}} + \underbrace{\frac{y}{2}\gamma^2}_{\text{kin. fac.}} \underbrace{g_2(x, Q^2)}_{\text{param.}} \Bigg]$$

g_1 : Neutron results

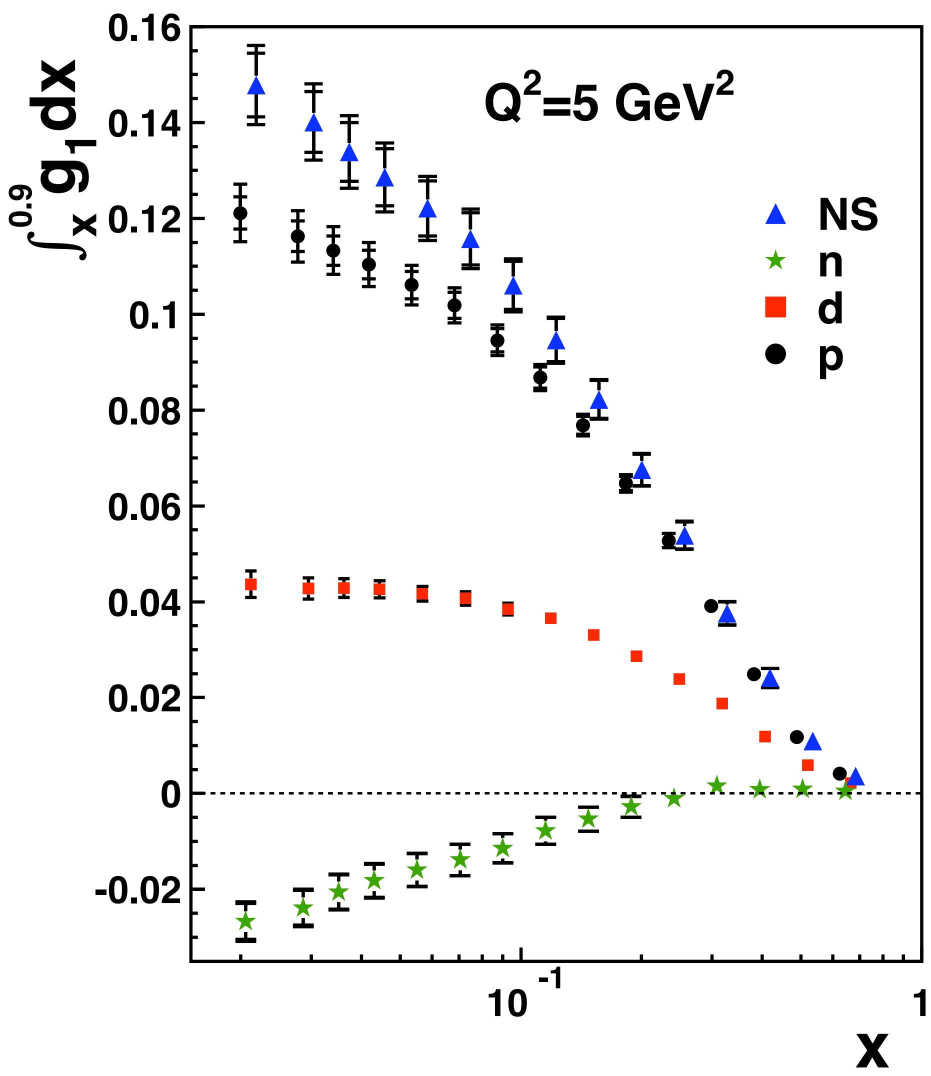


$$g_1^n = \frac{2}{1 - \frac{3}{2}\omega_D} \cdot g_1^d - g_1^p$$

$\omega_D = 0\ 05 \pm 0\ 01$

- g_1^n negative everywhere except at very high x
- Low-Q^2 data tends to zero at low x
  - Contrary to SMC data at higher Q^2

g_1 : Integrals



$$\Gamma_1^d = \int dx\, g_1^d$$

Assuming saturation in the deuteron integral:

➡ Use only deuteron data!

$$\Gamma_1^d = \left(1 - \frac{3}{2}\omega_D\right) \frac{1}{36} \left[4 a_0 \underbrace{\Delta C_S^{\overline{MS}}}_{\text{theory}} + a_8 \underbrace{\Delta C_{NS}^{\overline{MS}}}_{\text{theory}}\right]$$

from hyperon beta decay
(a_8=0.586±0.031)

$$a_0 \overset{\overline{MS}}{=} \Delta\Sigma$$

$$\boxed{\begin{aligned} \Delta u + \Delta\bar{u} \\ \Delta d + \Delta\bar{d} \\ \Delta s + \Delta\bar{s} \end{aligned}} \begin{aligned} &= \frac{1}{6}[2a_0 + a_8 + 3a_3] \\ &= \frac{1}{6}[2a_0 + a_8 - 3a_3] \\ &= \frac{1}{3}[\ a_0 - a_8] \end{aligned}$$

from neutron beta decay
(a_3=1.269±0.003)

in NNLO	central value	uncertainties		
		theor.	exp.	evol.
a_0	0.330	0.011	0.025	0.028
$\Delta u + \Delta\bar{u}$	0.842	0.004	0.008	0.009
$\Delta d + \Delta\bar{d}$	-0.427	0.004	0.008	0.009
$\Delta s + \Delta\bar{s}$	-0.085	0.013	0.008	0.009

$Q^2 = 5\text{GeV}^2$, NNLO in $\overline{\text{MS}}$ scheme

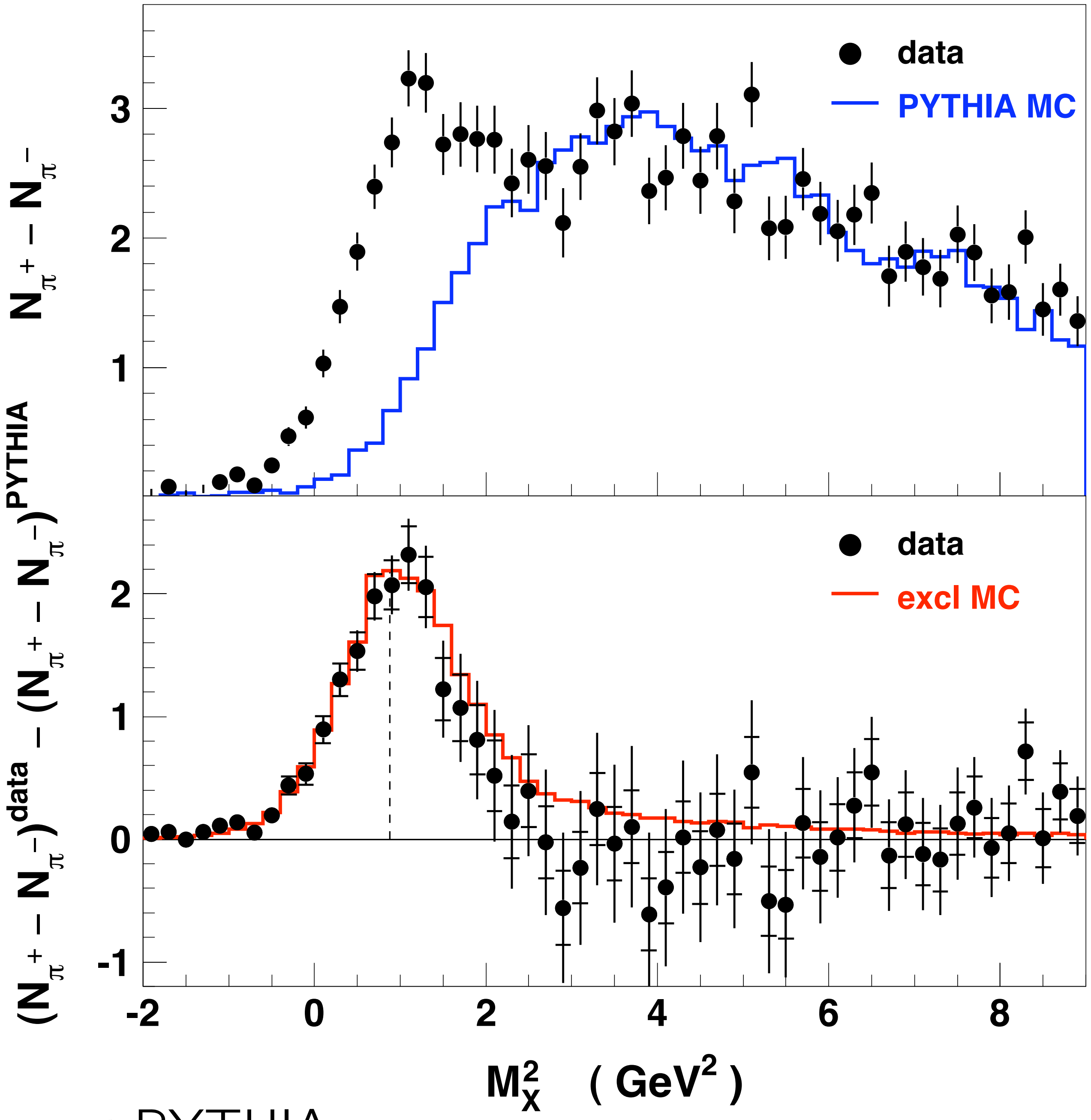
$ep \rightarrow e'\pi^+(n)$

no recoil nucleon detection
⇒select events via missing mass

Background:

- background channels:
  - $ep \rightarrow e'\pi^+(n\pi)$
  - $ep \rightarrow e'\pi^+(n\pi\pi)$
- BKG from excl. ρ^0 production
- SIDIS background

Double difference:



$$N_{\pi^+}^{\text{excl}} = (N_{\pi^+} - N_{\pi^-})^{\text{data}} - (N_{\pi^+} - N_{\pi^-})^{\text{PYTHIA}}$$

⇒ peak centered at squared neutron mass