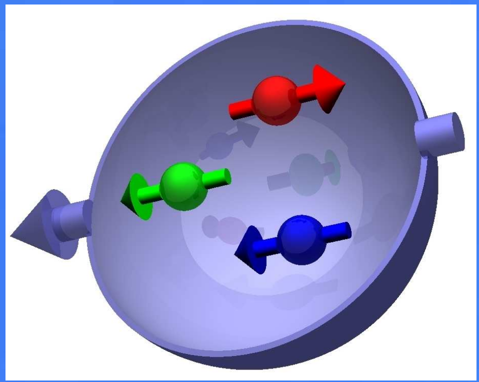
Where is the Spin of the Nucleon hidden?

E.C. Aschenauer

DESY-ZEUTHEN

The Spin Structure of the Nucleon



Naive Parton Model:

$$\Delta u_v + \Delta d_v = 1$$

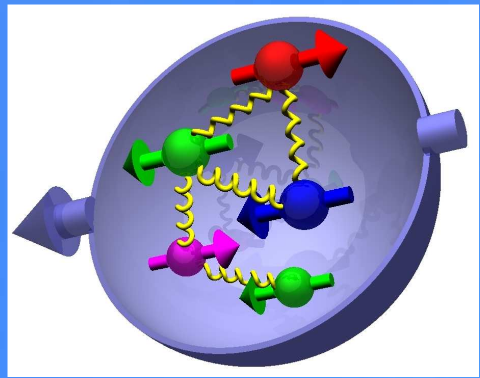
$$\Longrightarrow \Delta u_v = \frac{4}{3}, \Delta d_v = \frac{-1}{3}$$

BUT

1988 EMC measured:

Σ_q **= 0.123 $\pm$ 0.013 $\pm$ 0.019**

$\Longrightarrow$ **Spin Puzzle**



F_2 from HERA tells:

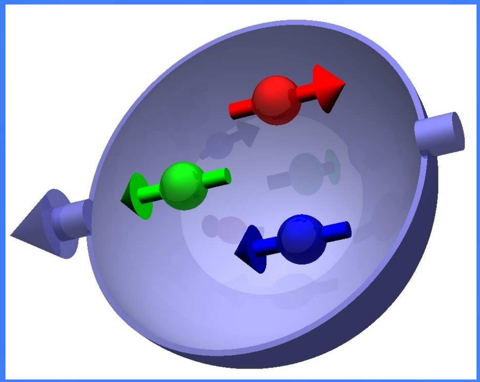
Gluons are important !

$\Longrightarrow$ **sea quarks Δq_s**

$\Longrightarrow$ ΔG

$$\frac{1}{2} = \frac{1}{2}\underbrace{(\Delta u_v + \Delta d_v + \Delta q_s)}_{\Delta\Sigma = 0.201 \pm 0.103} + \underbrace{\Delta G}_{> 0} + L_q + L_g$$

The Spin Structure of the Nucleon



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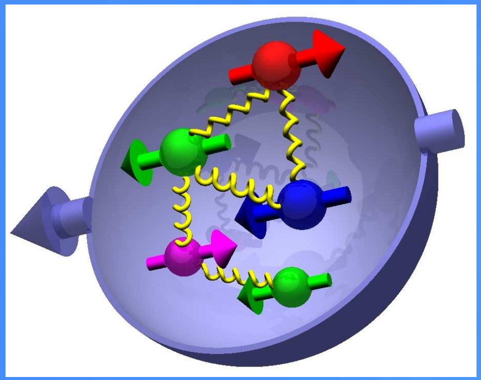

F_2 from HERA tells:

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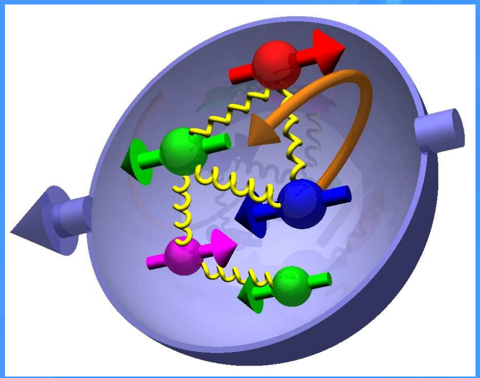
$\Longrightarrow$ **sea quarks** $\mathbf{\Delta q_s}$

$\Longrightarrow \mathbf{\Delta G}$



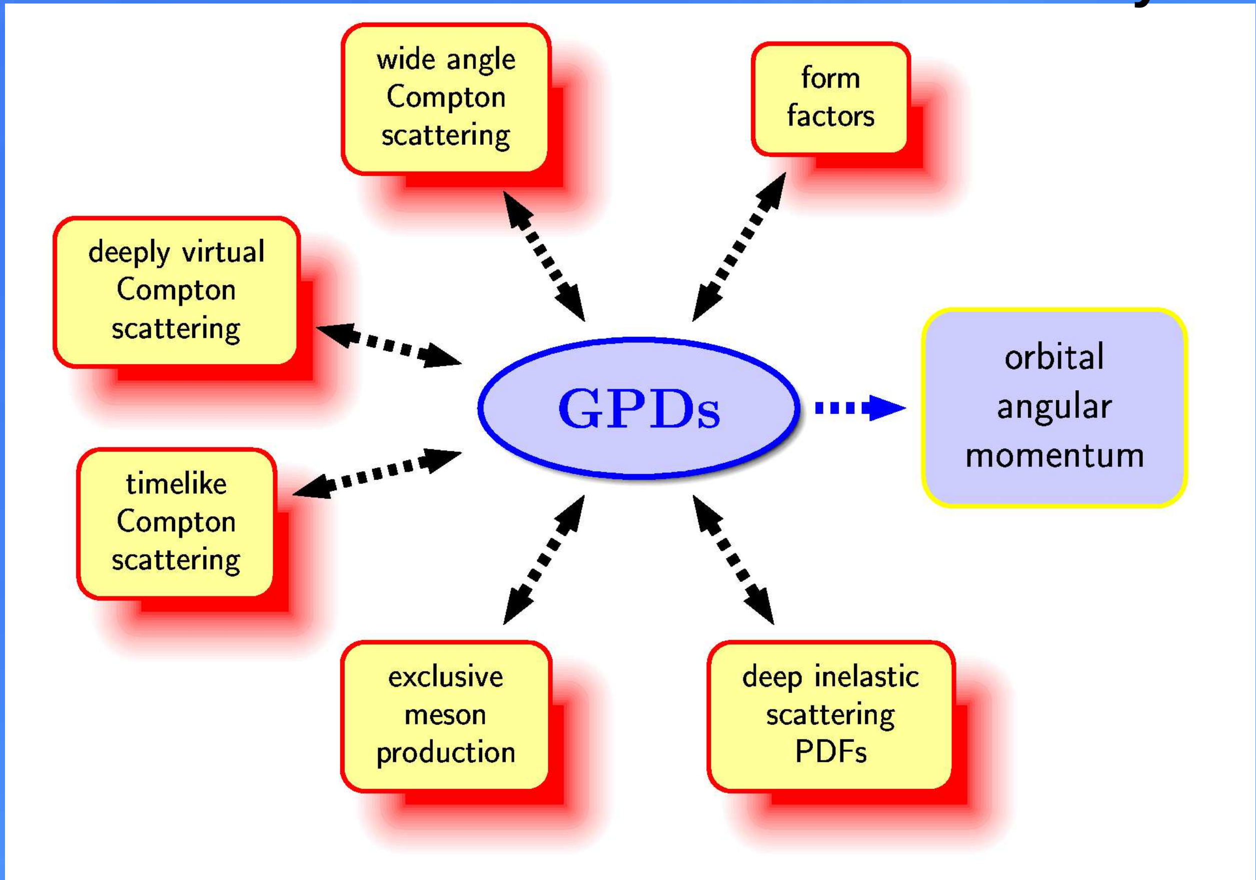
Full description of J_q & J_g

needs

orbital angular momentum

$$\frac{1}{2} = \frac{1}{2}(\Delta u_v + \Delta d_v + \Delta q_s) + \Delta G + \underbrace{L_q + L_g}_{?}$$

The Hunt for $\mathrm{L_q}$



Study of hard exclusive processes leads to a new class of PDFs

Generalised Parton Distributions

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

$\Rightarrow$ possible access to orbital angular momentum

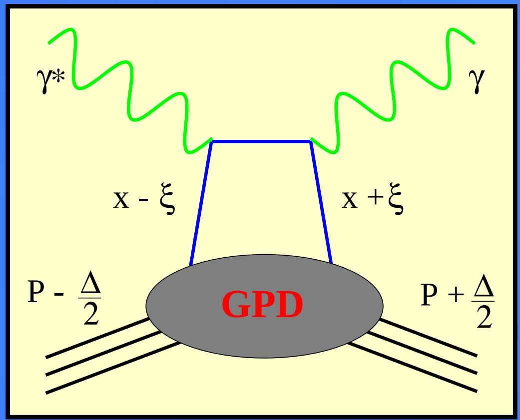
$$\frac{1}{2}\left(\int_{-1}^{1} x\,\mathrm{d}x\,(H^q + E^q)\right)_{t\to 0} = J_q$$

exclusive processes: all products of a reaction are detected

$\Longrightarrow$ missing energy ($\Delta\mathrm{E}$) and missing Mass ($\mathrm{M_x}$) = 0

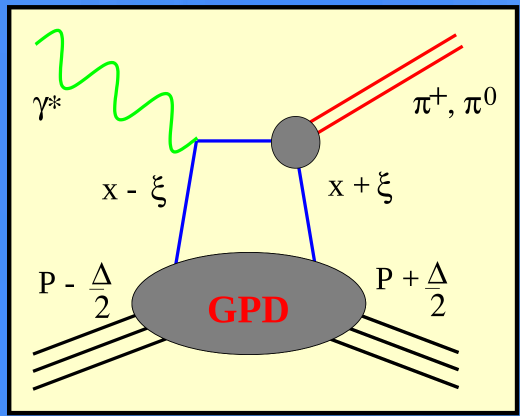
GPDs Introduction

quantum numbers of final state $\Rightarrow$ select different GPDs



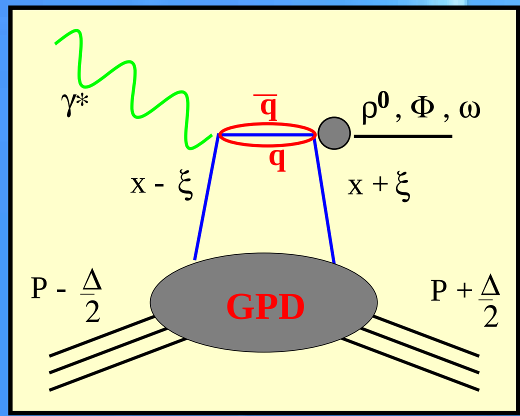
DVCS:

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



pseudo-scalar mesons

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



vector mesons

H^q, E^q

What does GPDs characterize?

unpolarized	polarized	
$H^q(x,\xi,t)$	$\tilde{H}^q(x,\xi,t)$	**conserve nucleon helicity**
$E^q(x,\xi,t)$	$\tilde{E}^q(x,\xi,t)$	**flip nucleon helicity**

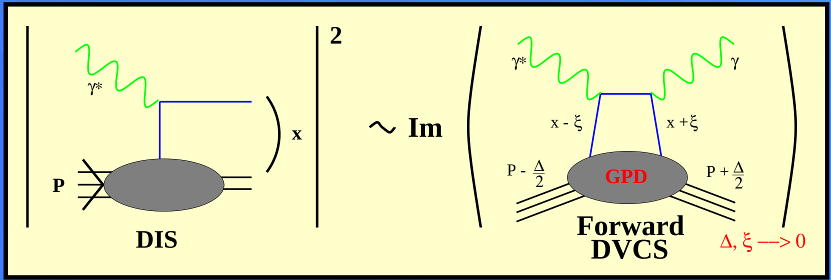
x, t, ξ **defined on the light cone**

x: **longitudinal momentum fraction** t: **momentum transfer** ($t = \Delta^2$)

ξ: **exchanged longitudinal momentum fraction** ($\xi = \frac{x_{Bj}/2}{1-x_{Bj}/2}$)

GPDs Introduction II

- **Link to DIS:**



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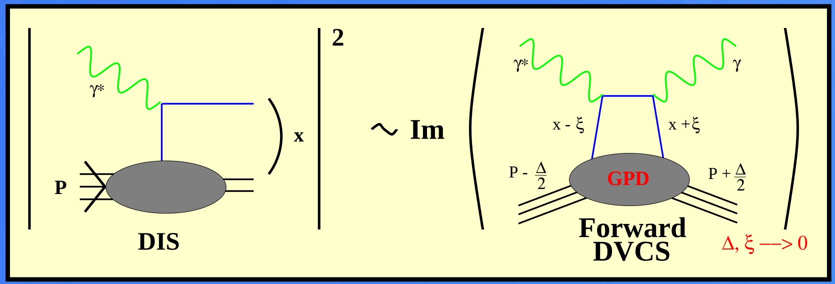

- **standard PDFs**
  $\Longrightarrow \xi = 0$ **and** $t = 0$
  $\mathbf{H}(\mathbf{x}, \xi = \mathbf{0}, \mathbf{t} = \mathbf{0}) = \mathbf{q}(\mathbf{x})$
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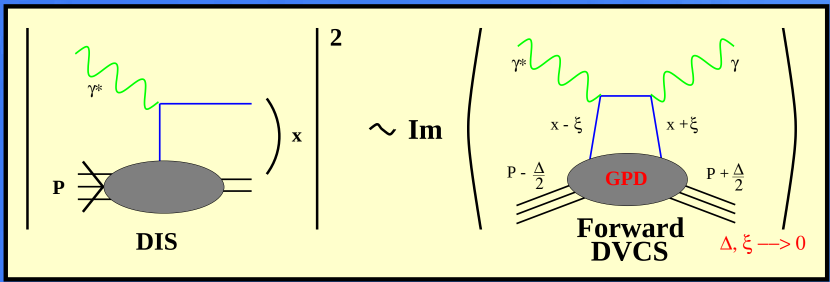

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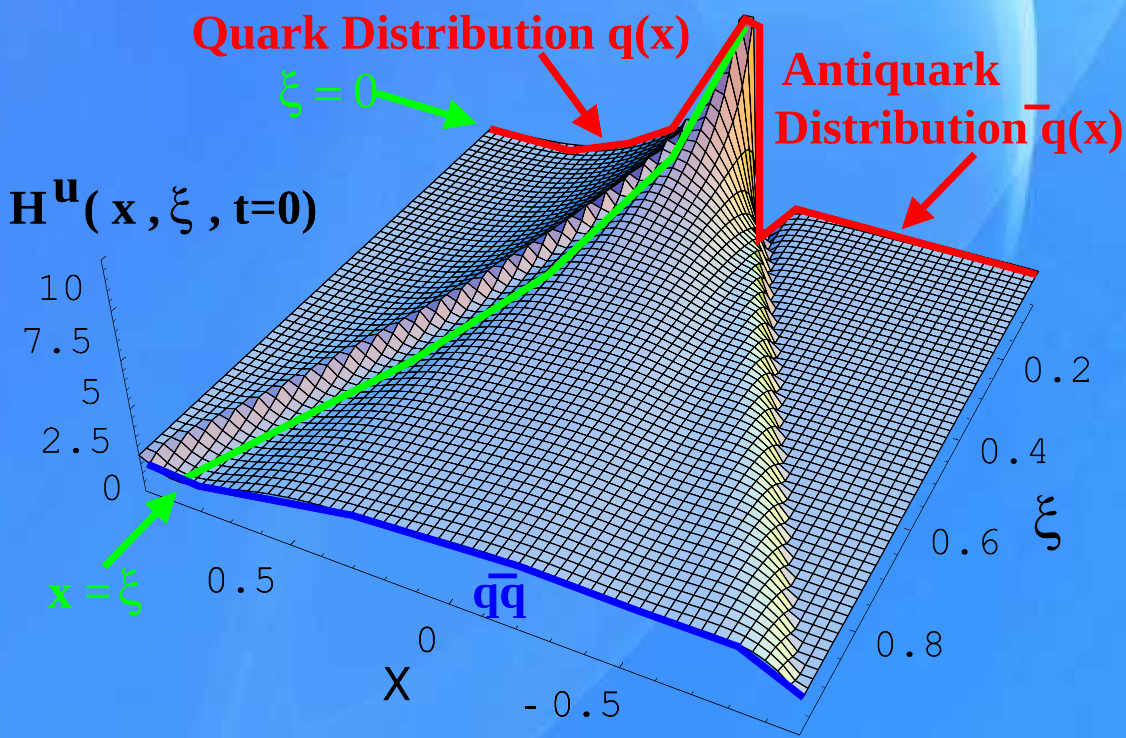
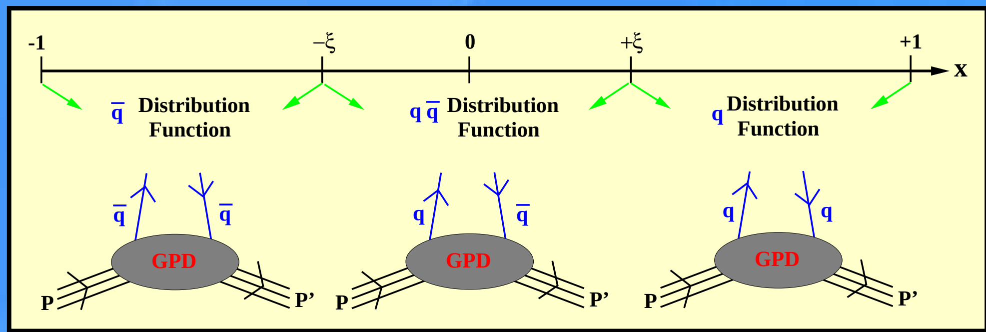
- $\mathbf{E}, \mathbf{\tilde{E}}$ **do NOT appear in DIS**
  $\Longrightarrow$ **New Info !**





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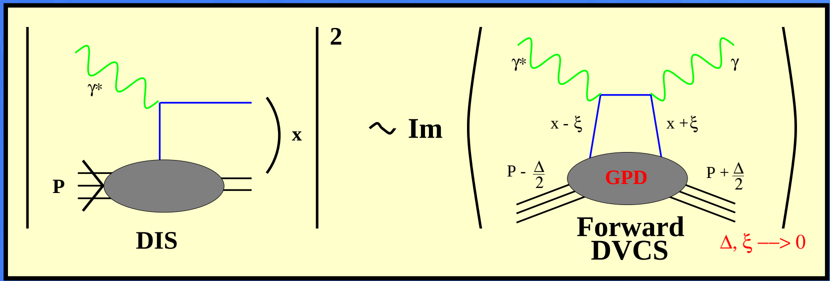

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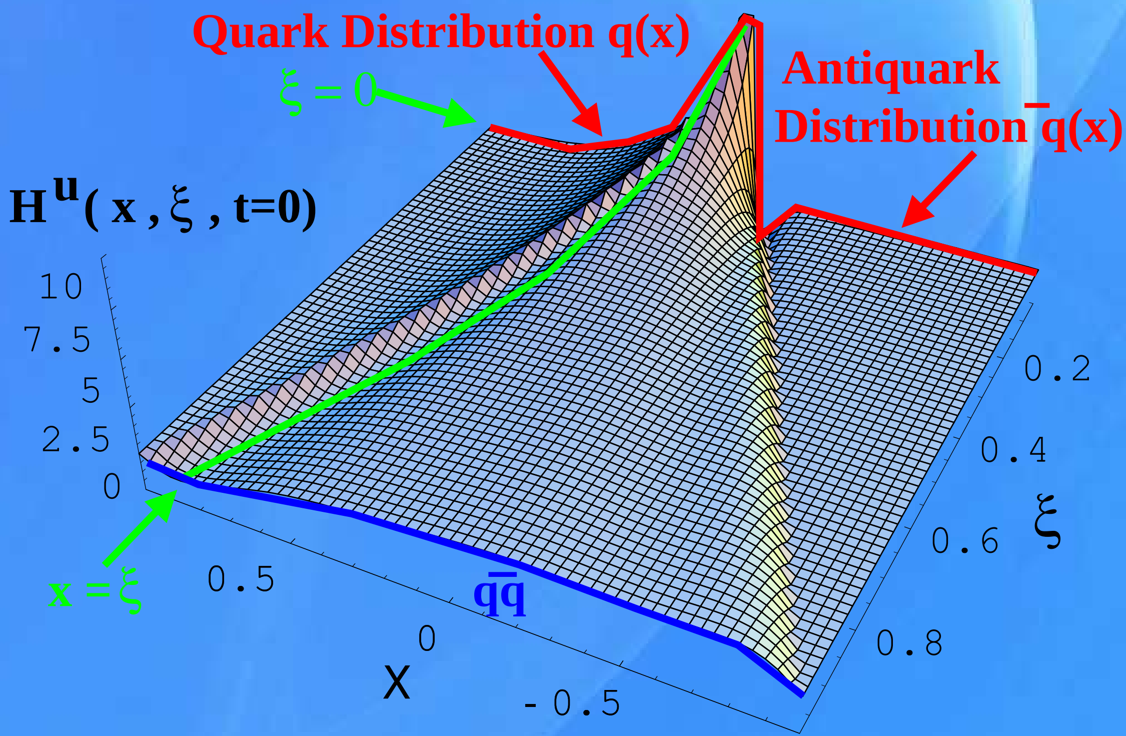
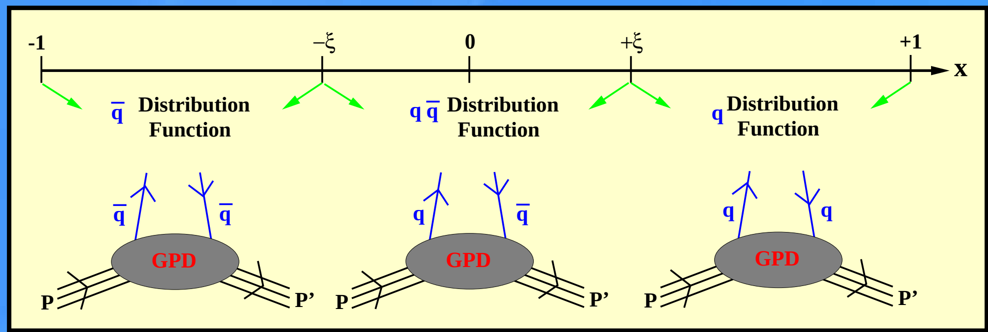
- **Study GPDs**





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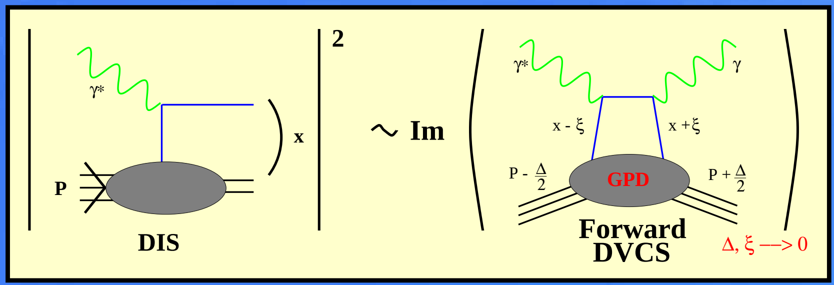

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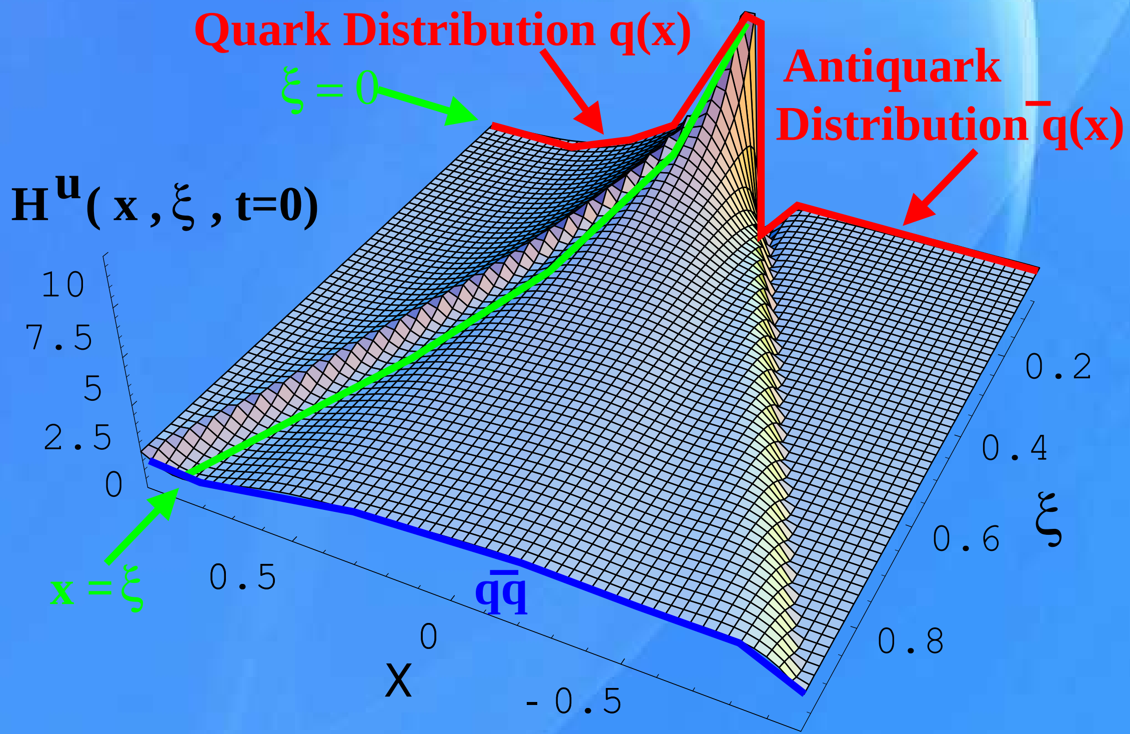
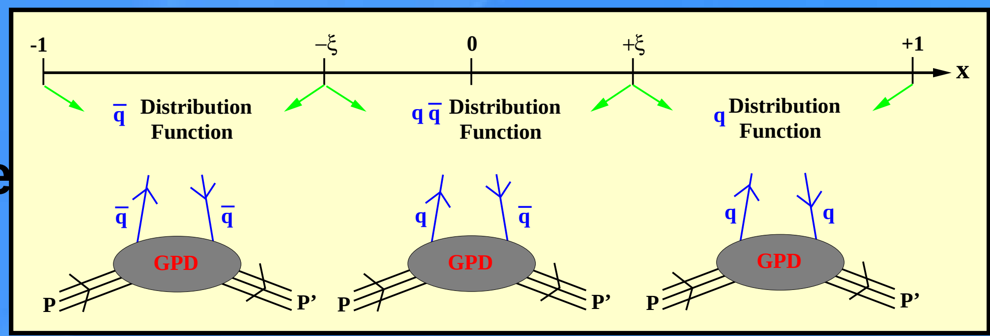
- **Study GPDs**
  - **with spin observables**
    single spin azimuthal asymme





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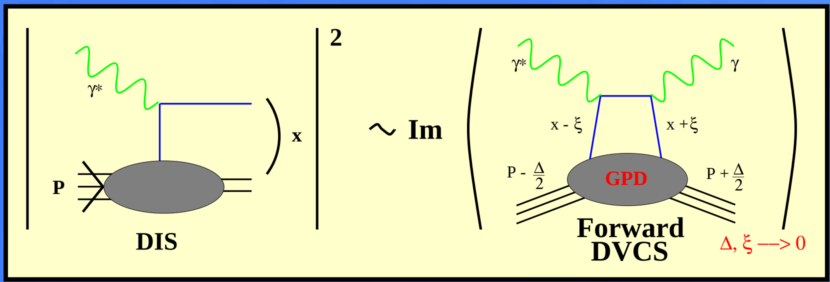

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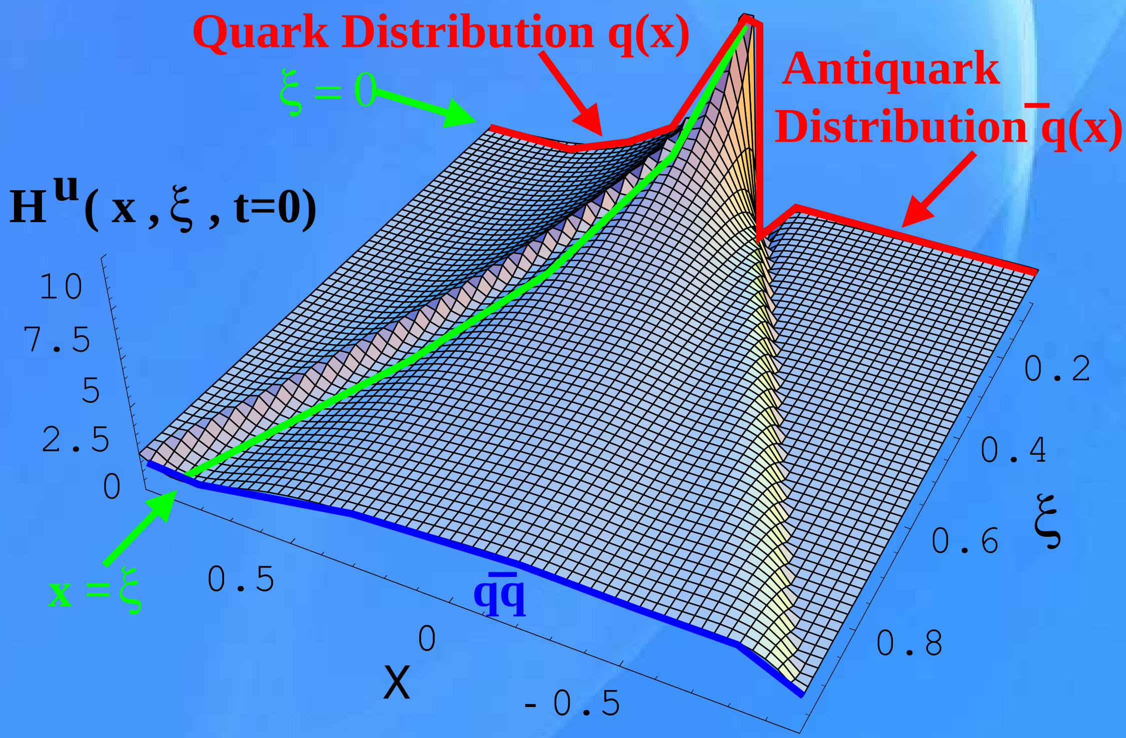

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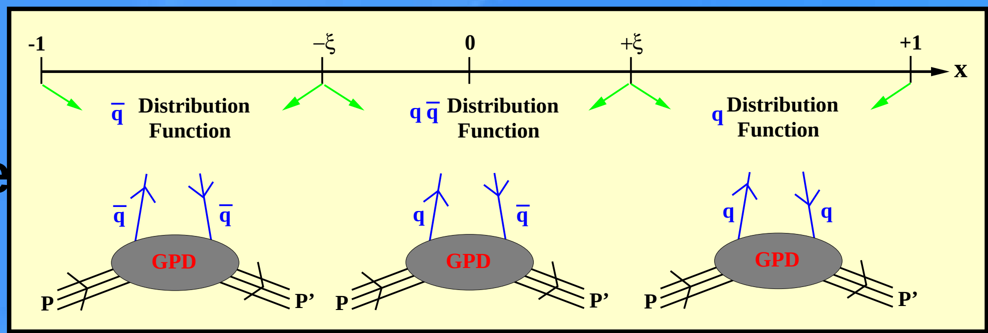
  - **azimuthal asymmetries**



GPDs Introduction II

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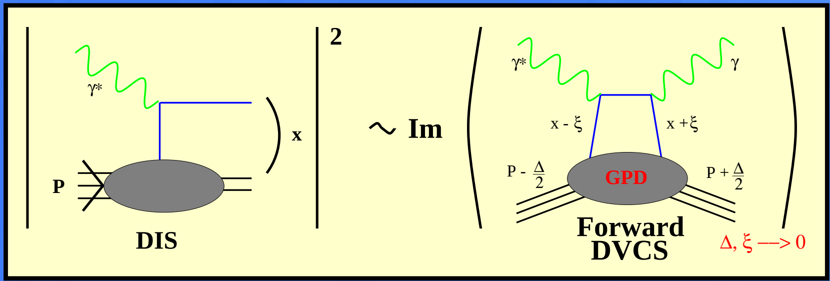

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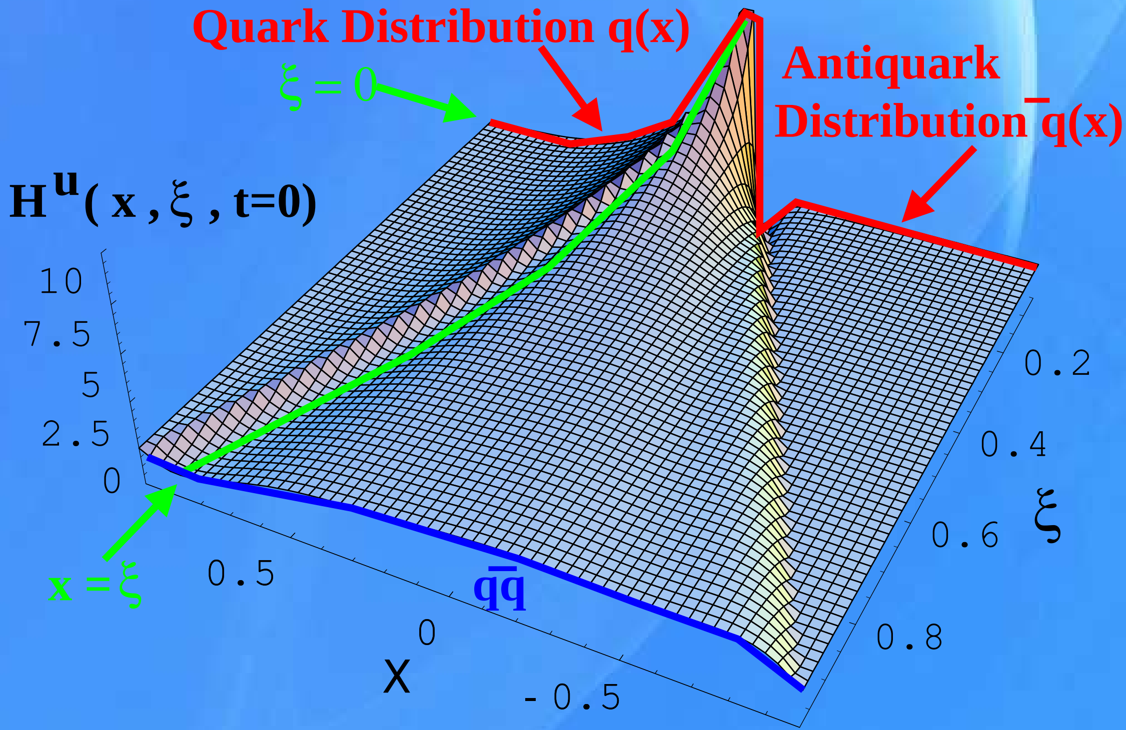
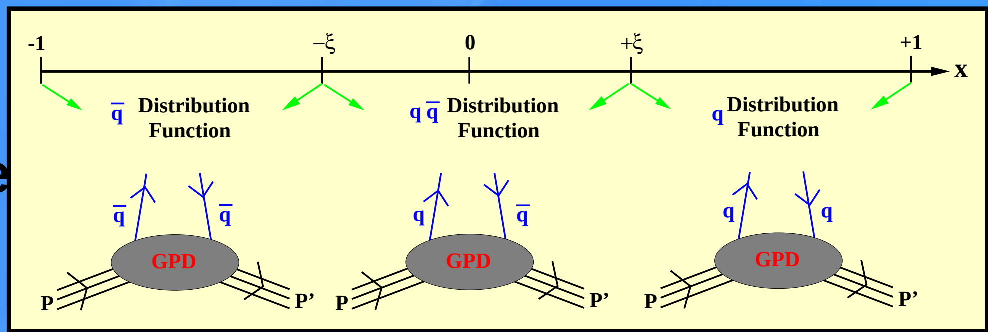
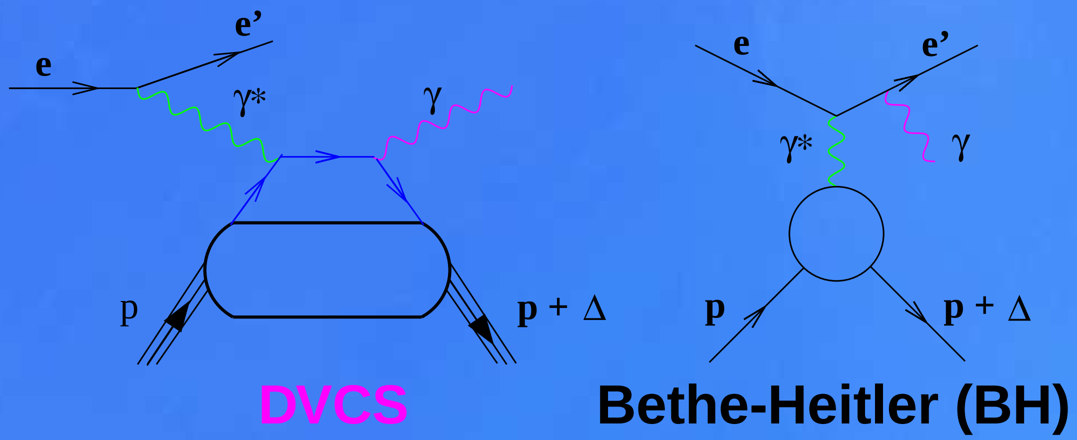
- **Study GPDs**
  - **with spin observables single spin azimuthal asymme**
  - **azimuthal asymmetries**
  - **via cross sections**





DVCS $ep \to e'\gamma p$

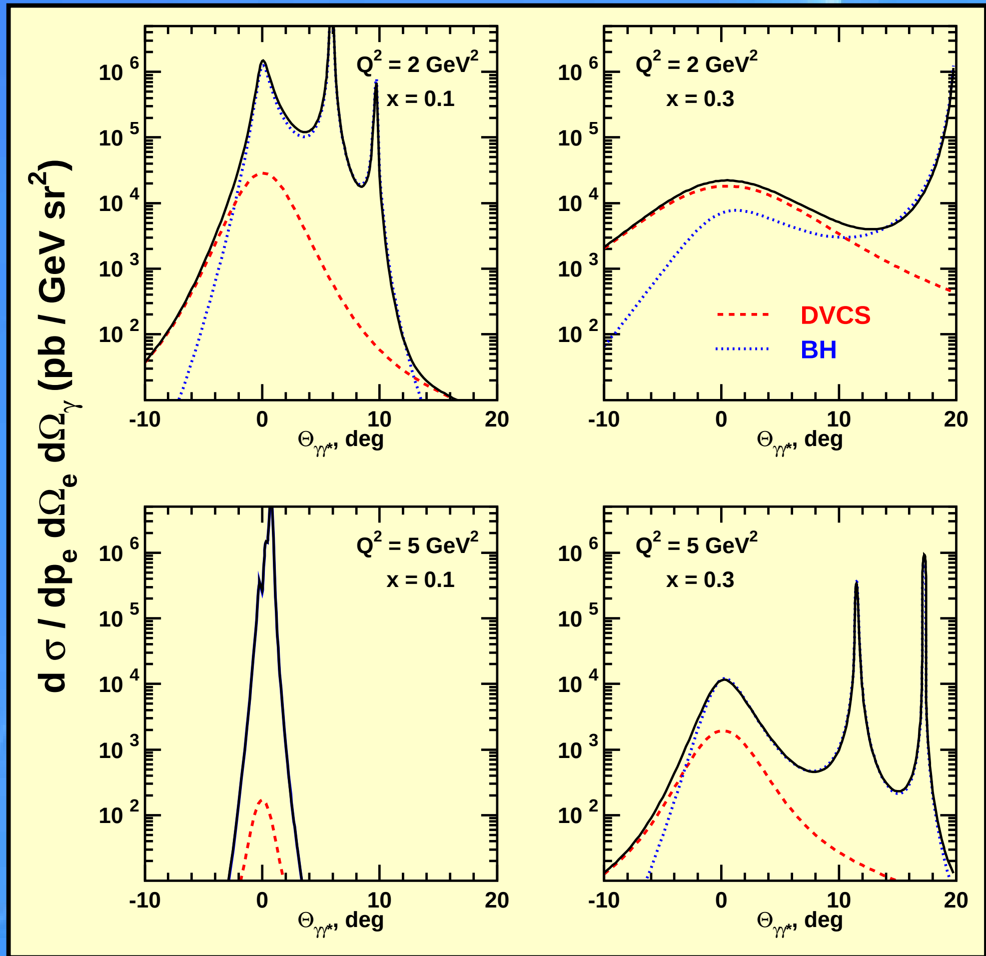


$$d\sigma \quad \propto \quad |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2$$
$$+ \quad (\mathcal{T}^*_{BH}\mathcal{T}_{DVCS} + \mathcal{T}^*_{DVCS}\mathcal{T}_{BH})$$

HERMES, JLAB:
DVCS-BH interference:
$\Longrightarrow$ **use BH as a vehicle to study DVCS**

H1, ZEUS:
measure DVCS cross section directly

HERMES / JLAB kinematics:
BH cross section larger than DVCS



[Korotkov, Nowak, hep-ph/0108077]

DVCS azimuthal asymmetries

$$d\sigma \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + (\mathcal{T}^*_{BH}\mathcal{T}_{DVCS} + \mathcal{T}^*_{DVCS}\mathcal{T}_{BH})$$

isolate BH-DVCS interference term $\Longrightarrow$ non-zero azimuthal asymmetries

- **imaginary part $\propto$ beam helicity asymmetry:**

$$d\sigma_{\overleftarrow{e^+}} - d\sigma_{\overrightarrow{e^+}} \propto \mathrm{Im}\,(\mathcal{T}_{BH}\mathcal{T}_{DVCS})$$
$$\propto \sin\phi \Longrightarrow H^u(x,\xi,t)$$

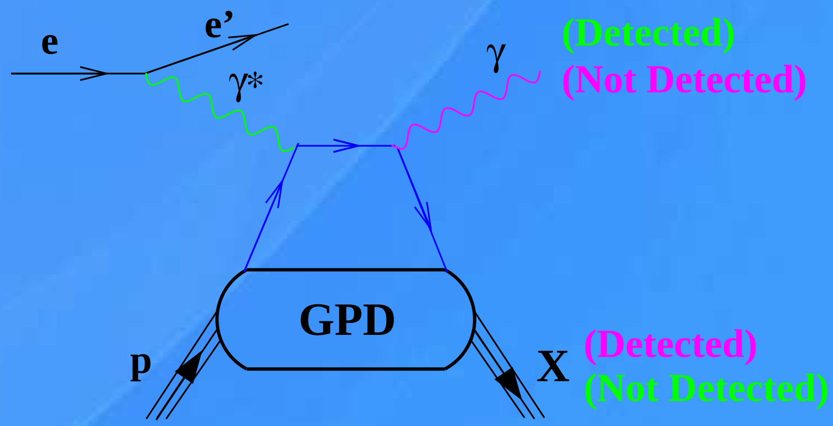
$\Rightarrow$ asymmetry measured by HERMES and JLAB

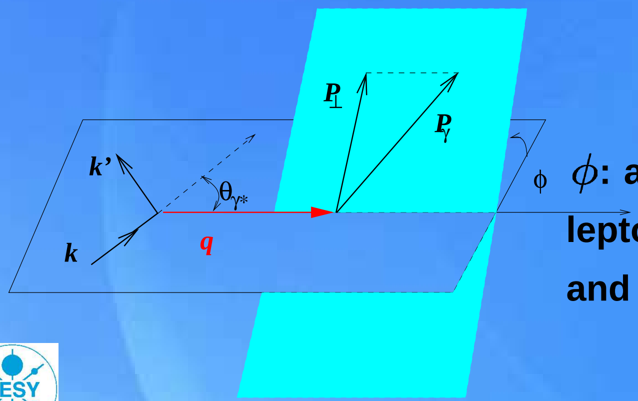
- **real part $\propto$ beam charge asymmetry:**

$$d\sigma_{e^+} - d\sigma_{e^-} \propto \mathrm{Re}\,(\mathcal{T}_{BH}\mathcal{T}_{DVCS})$$
$$\propto \cos\phi \Longrightarrow H^u(x,\xi,t)$$

$\Rightarrow$ asymmetry measured by HERMES

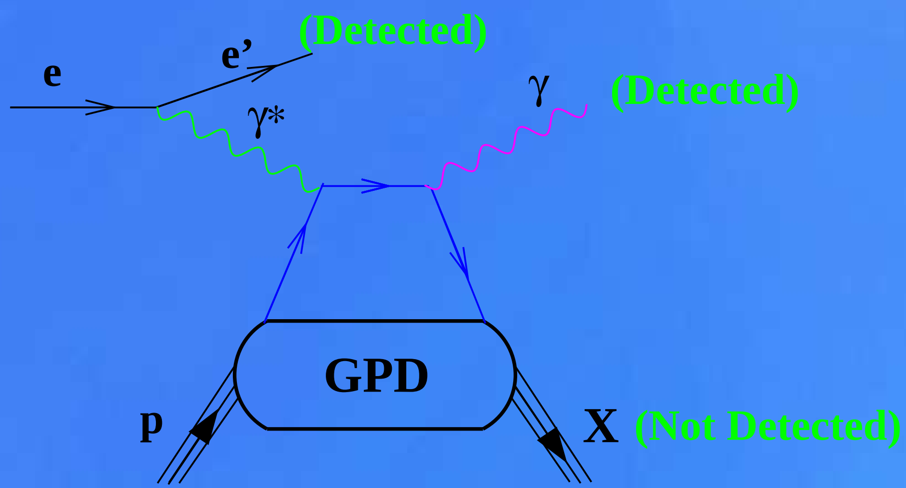
- **no polarized target needed**



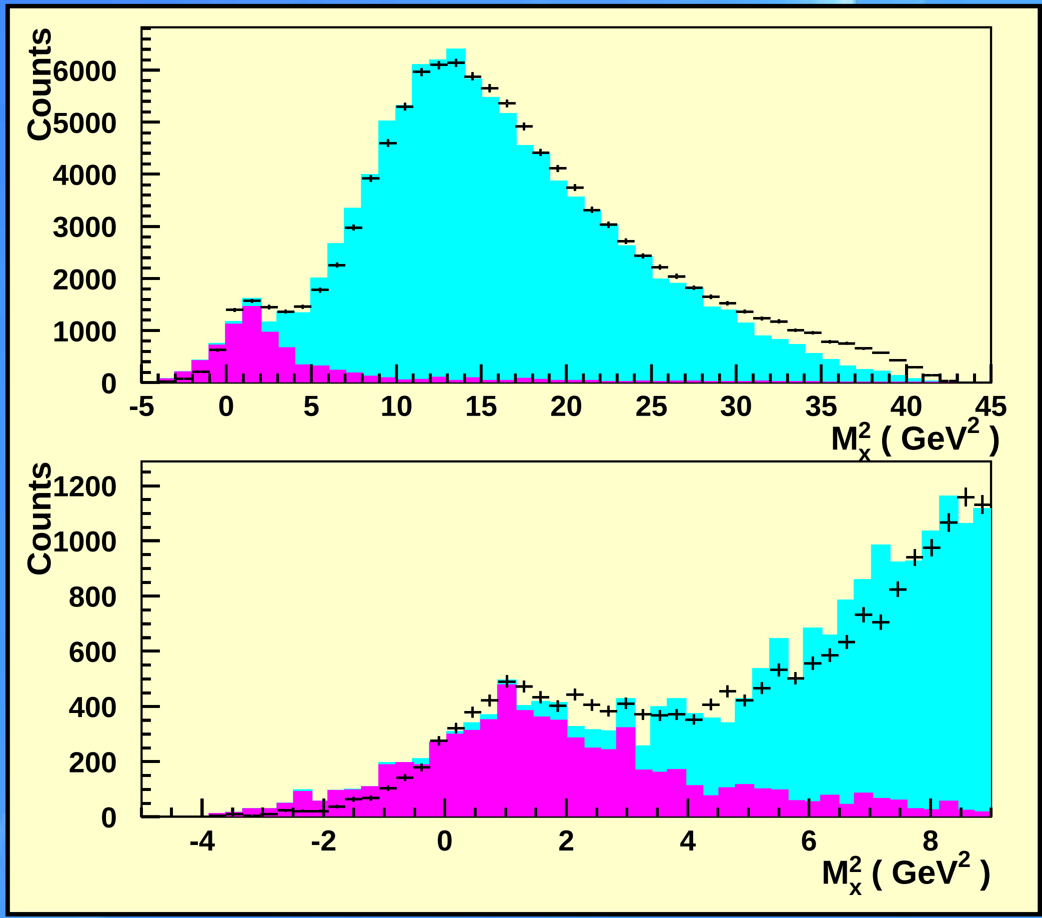


ϕ: azimuthal angle between lepton scattering plane and the $\gamma^*\gamma$ - plane

DVCS at HERMES



$$\mathbf{M_x}(\mathbf{ep} \longrightarrow \mathbf{e}'\gamma + \mathbf{X})$$



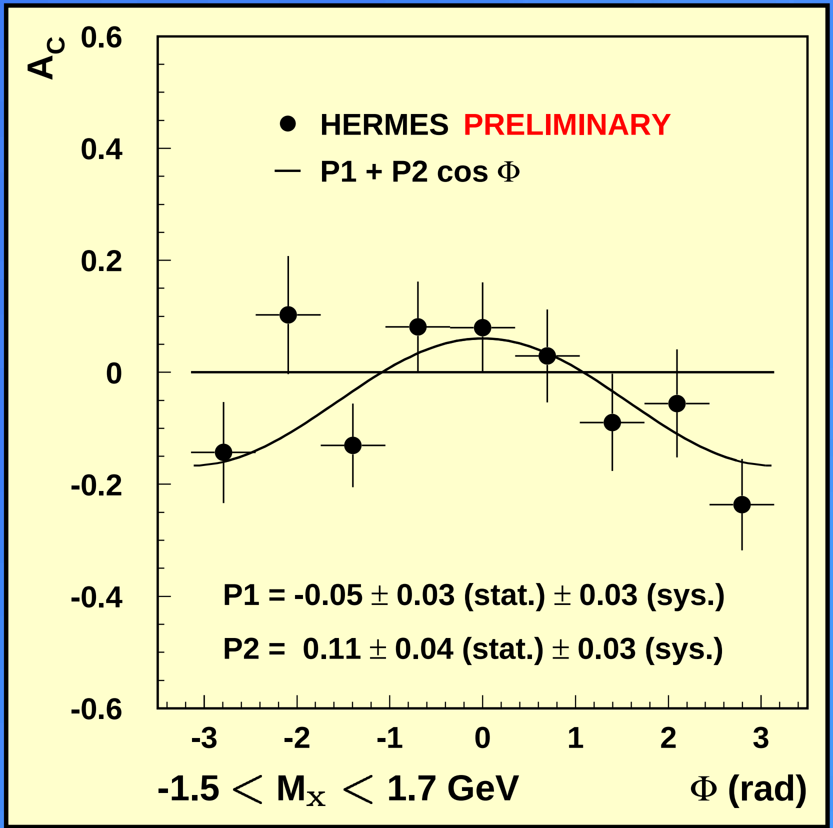
$\Longrightarrow$ **Exclusivity has to be ensured by missing mass:** $M_x^2 = (q + p - p_\gamma)^2 = M_p^2$

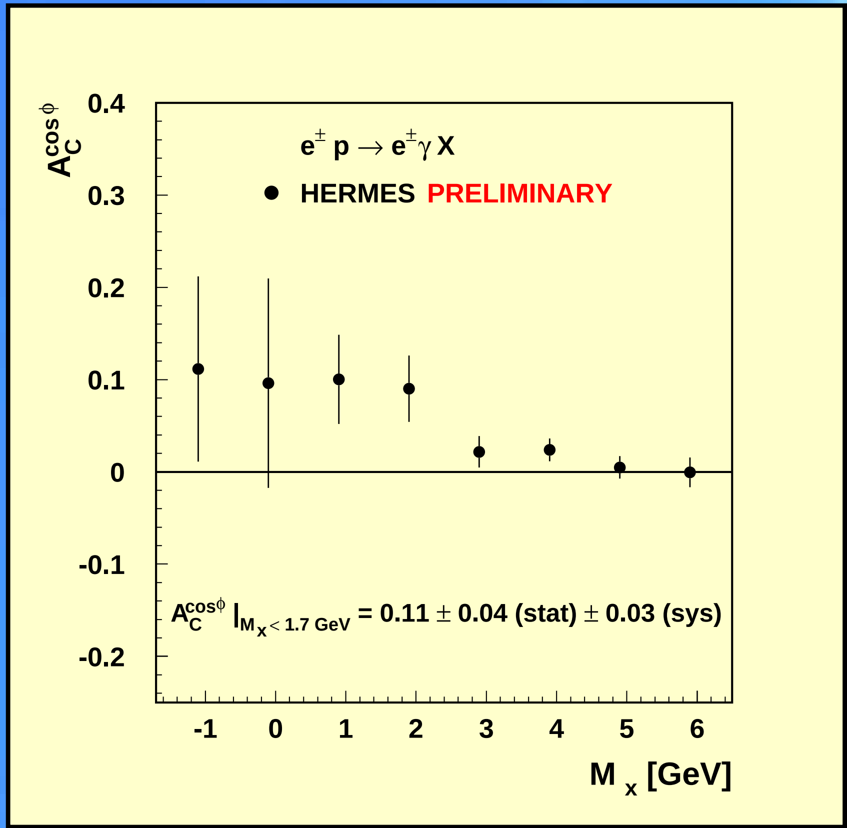
Energy resolution in exclusive region:
$\Longrightarrow \sigma(M_x) \approx$ **0.8 GeV**

Improve Exclusivity: **detect recoil proton** $\Rightarrow$ **planned for 2005/2006 data taking**

DVCS beam charge asymmetry (BCA)

- $d\sigma_{e^+} - d\sigma_{e^-}$ **sensitive to** $\mathrm{Re}\,(\mathcal{T}_{BH}\mathcal{T}_{DVCS}) \Longrightarrow \cos\phi$



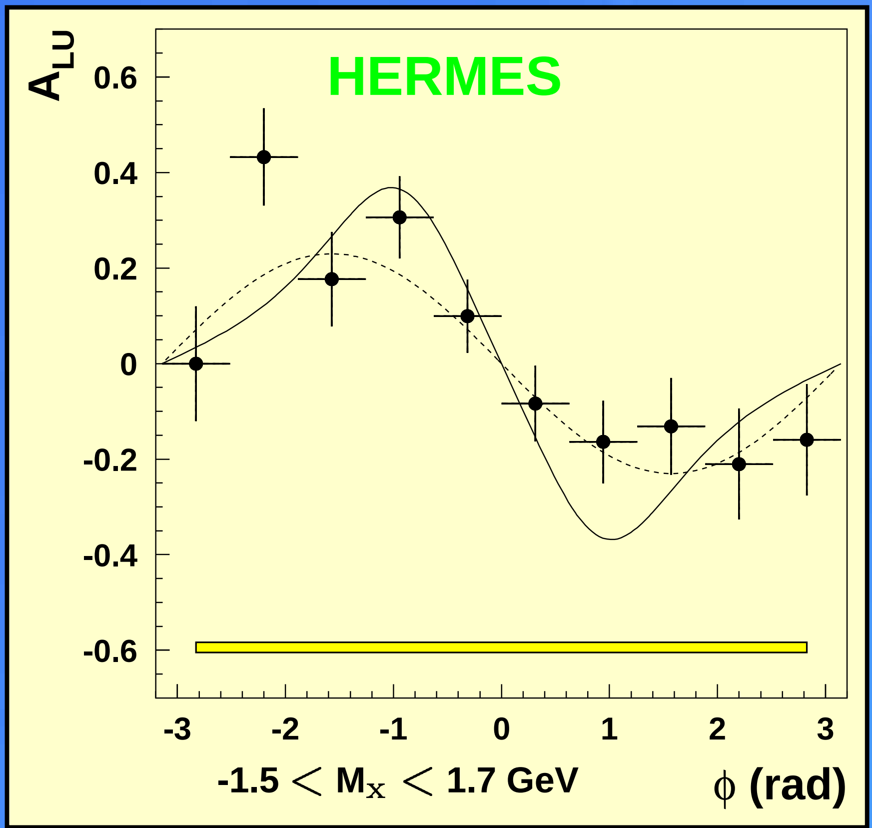


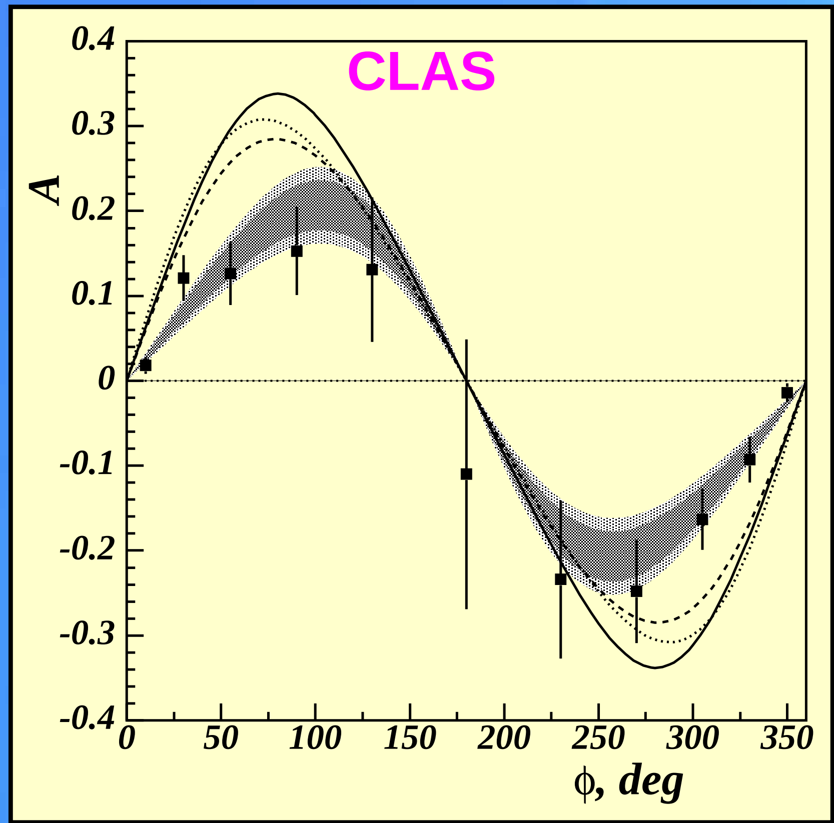
$$\mathbf{A_C}(\phi) = \frac{\mathbf{N_{e^+}}(\phi) - \mathbf{N_{e^-}}(\phi)}{\mathbf{N_{e^+}}(\phi) + \mathbf{N_{e^-}}(\phi)}$$

- **azimuthal asymmetry appears at** $\mathbf{M_x \sim M_p}$

DVCS single beam-spin asymmetry (BSA)

- $d\sigma_{\overleftarrow{e^+}} - d\sigma_{\overrightarrow{e^+}}$ **sensitive to** $\text{Im}\left(\mathcal{T}_{BH}\mathcal{T}_{DVCS}\right) \Longrightarrow \sin\phi$





96/97: **[PRL87 (2001), 182001]**

$$A_{LU}^{\sin\phi}(\phi) = -0.18 \pm 0.03 \pm 0.03$$

at $\langle x\rangle = 0.11$, $\langle Q^2\rangle = 2.5$ **GeV^2**, $\langle -t\rangle = 0.27$ **GeV^2**

[PRL87 (2001), 182002]

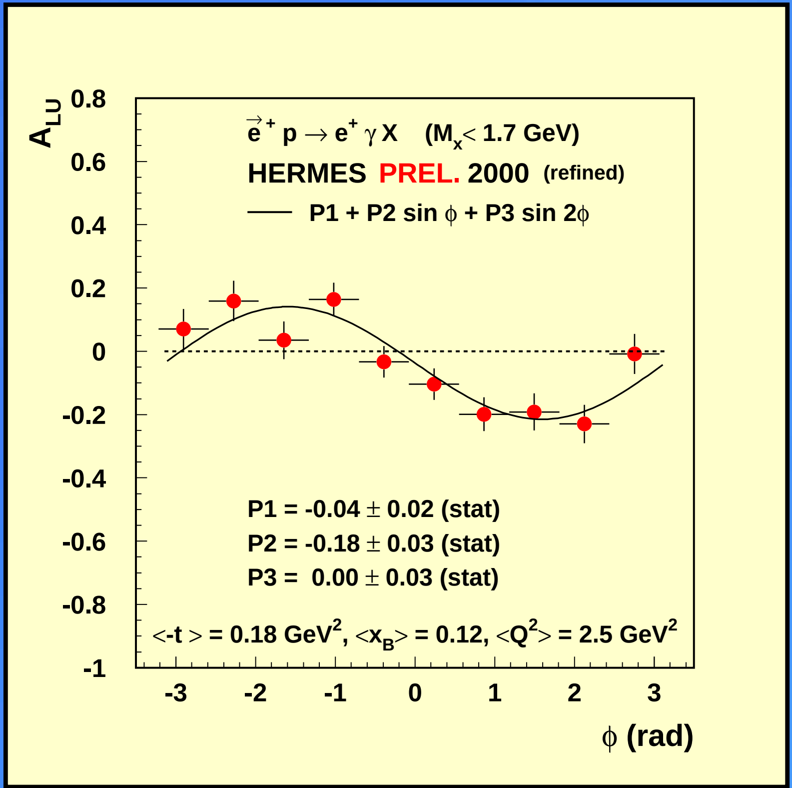
$$A_{LU}^{\sin\phi}(\phi) = -0.202 \pm 0.021 \pm 0.009$$

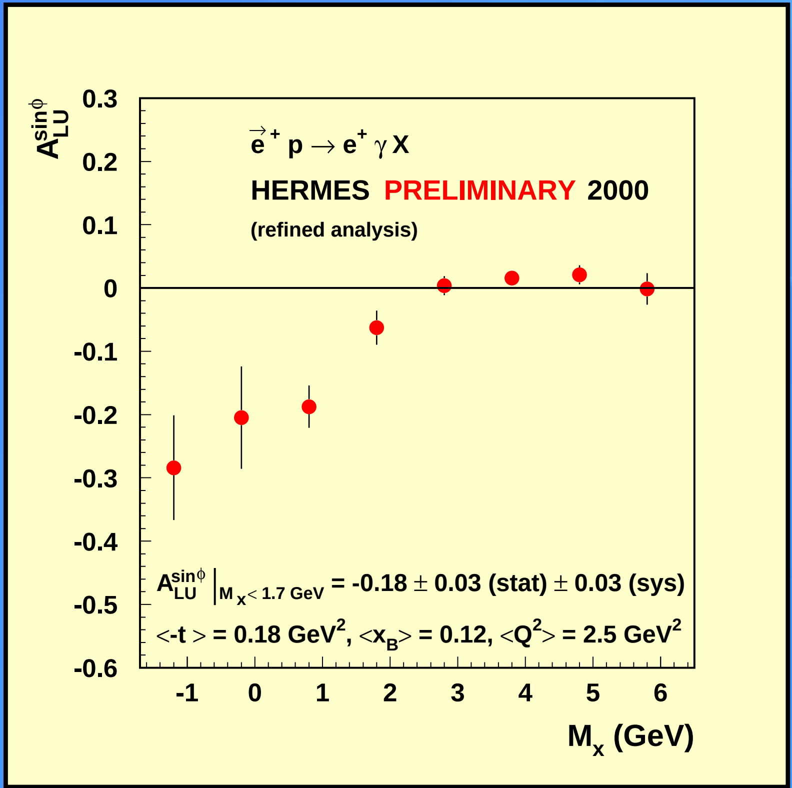
at $x = 0.15 - 0.25$, $Q^2 = 1 - 1.5$ **GeV^2**, $-t = 0.1 - 0.25$ **GeV^2**

GPD-calculation: [Kivel et al. Phys. Rev. D 63 (2001), 114014]

Much more data!

- $d\sigma_{\overleftarrow{e^+}} - d\sigma_{\overrightarrow{e^+}}$ **sensitive to** $\mathrm{Im}\,(\mathcal{T}_{BH}\mathcal{T}_{DVCS}) \Longrightarrow \sin\phi$

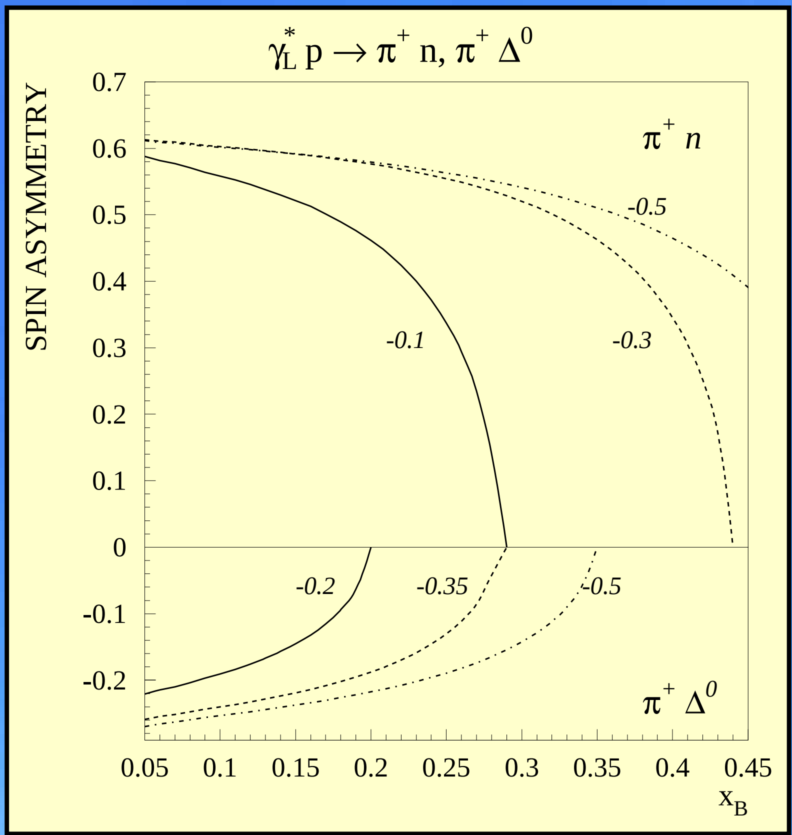




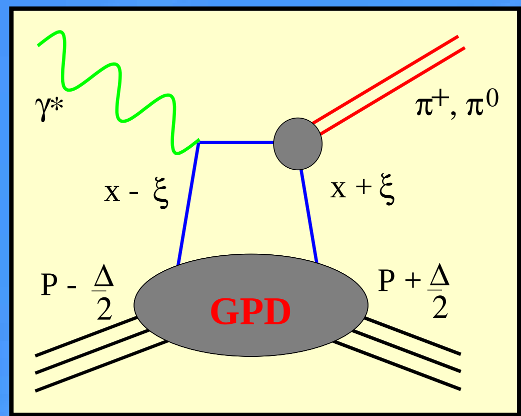
- **all azimuthal asymmetries (BCA & BSA) appear at** $\mathbf{M_x \sim M_p}$
- **enough statistics to study kinematic dependencies of GPDs**
- **DVCS data on polarized proton / deuterium target** $\Longrightarrow$ **access to** $\tilde{\mathrm{H}}, \tilde{\mathrm{E}}$
- **DVCS data on nuclear targets (D, ^{3}He, Ne, Kr)**
  $\Longrightarrow$ **coherent scattering on a nucleus ?!**

Exclusive PS meson production e p $\rightarrow$ e' n π^+

- **cross section:** $\sigma \propto |\mathbf{S_T}| \sin\phi \cdot \tilde{\mathbf{E}} \cdot \tilde{\mathbf{H}}$
- σ **has an interference between pole and non-pole amplitudes:**
  $\tilde{\mathbf{E}} \Longleftarrow \pi$ **- FF** $\tilde{\mathbf{H}} \Longrightarrow \mathbf{\Delta q}$
  $\Longrightarrow$ **large single spin asymmetry expected for transverse polarized H-target**



[K. Goeke et al., hep-ph/0106012]



Lets see what the data say !

How to extract exclusive π^+

- **Production mechanismen:** $e\vec{p} \rightarrow e' \underbrace{n}_{\text{not detected}} \pi^+$

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- **no exclusive π^- production at a proton target**

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  not detected

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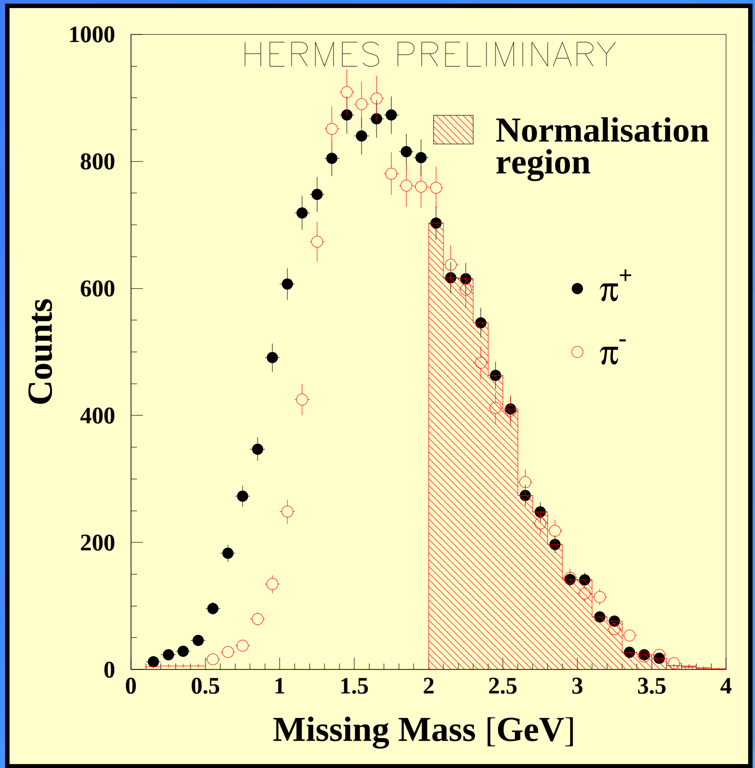
$\Longrightarrow$ **Trick: exclusive $\pi^+ \sim M_x(\pi^+) - M_x(\pi^-)$**



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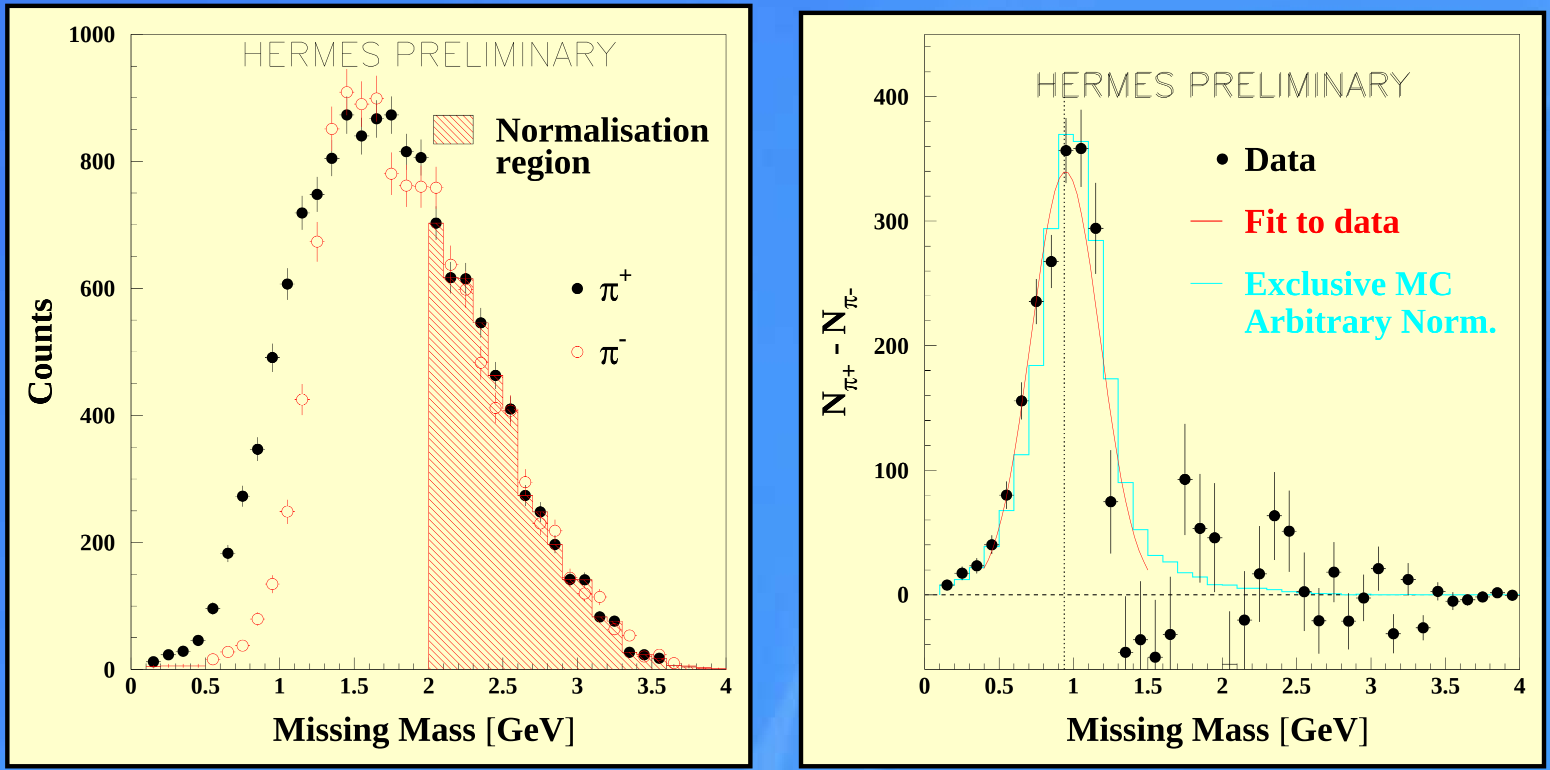

clear peak at missing mass $\approx \mathrm{M_n}$

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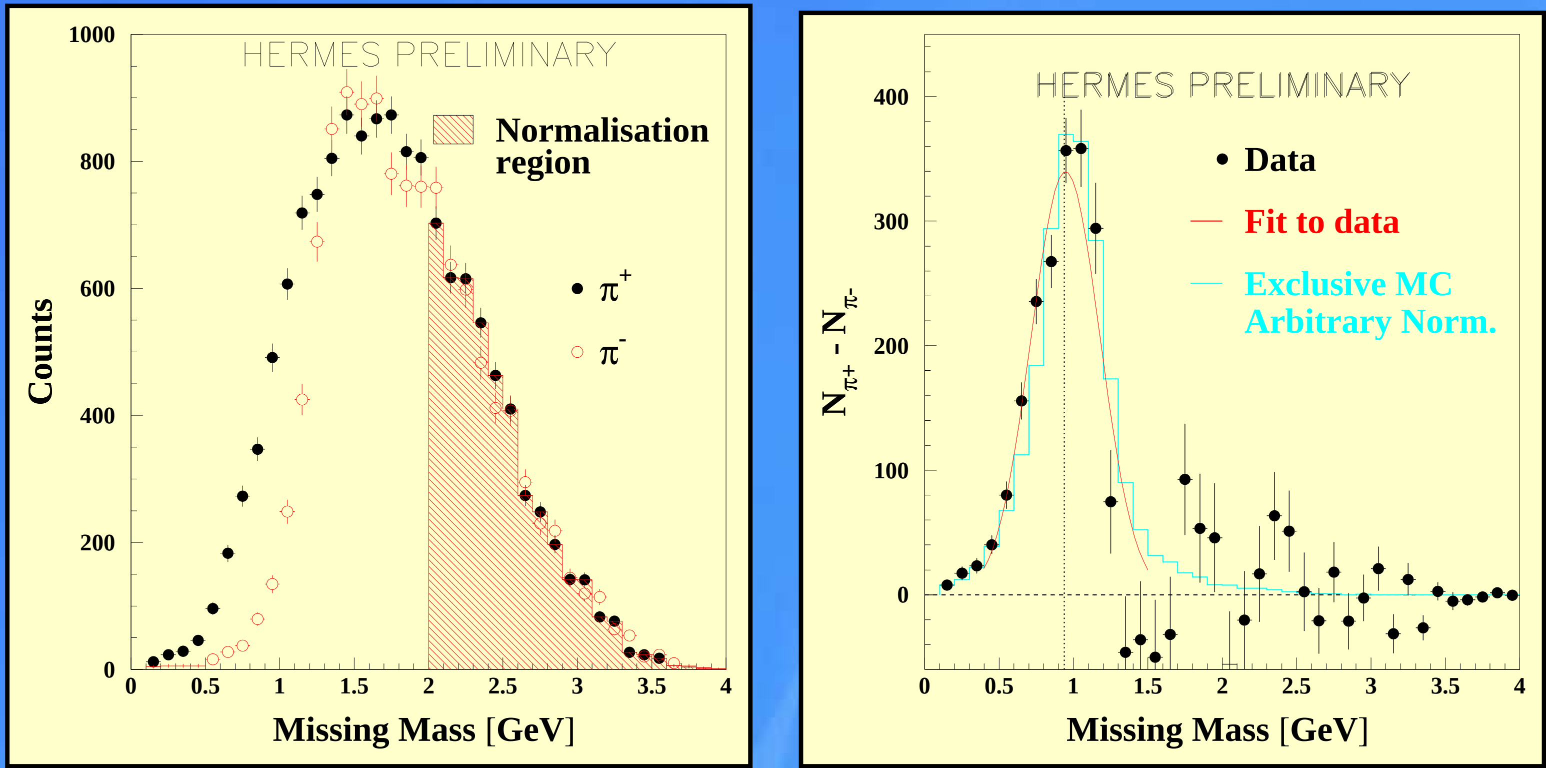

clear peak at missing mass $\approx \mathrm{M_n}$

$\Rightarrow$ **Problematic: difference in relative contribution of resonant and non-resonant channels to π^+, π^- yield**

Exclusive π^+ target - SSA

- **until 2001 no data with transverse polarized proton target available**
  $\Longrightarrow$ **use longitudinal polarized proton target**

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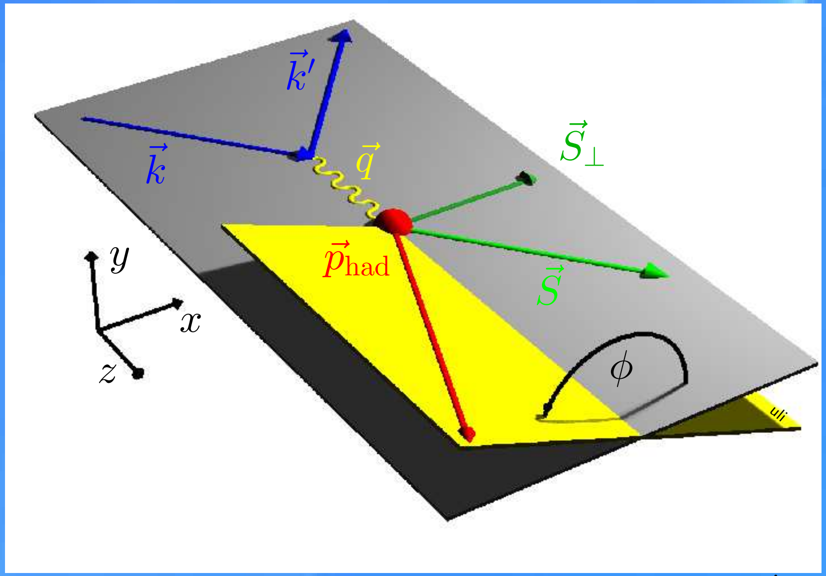

$\Longrightarrow$ **transverse component to γ^***

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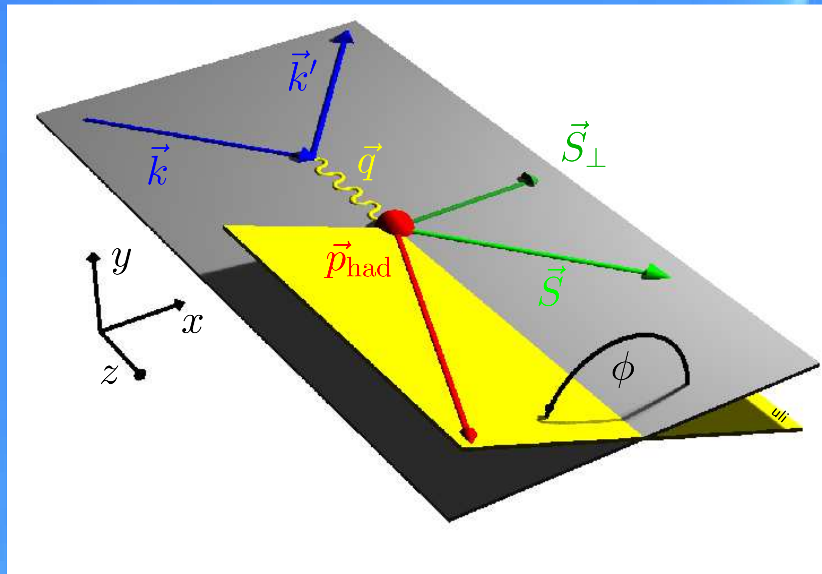
$$\sigma_S \sim [S_\perp \sigma_L + S_{||} \sigma_{LT}] \cdot A_{UL}^{\sin\phi} \sin\phi$$

unpolarized beam ↙ ↘ **polarized target**



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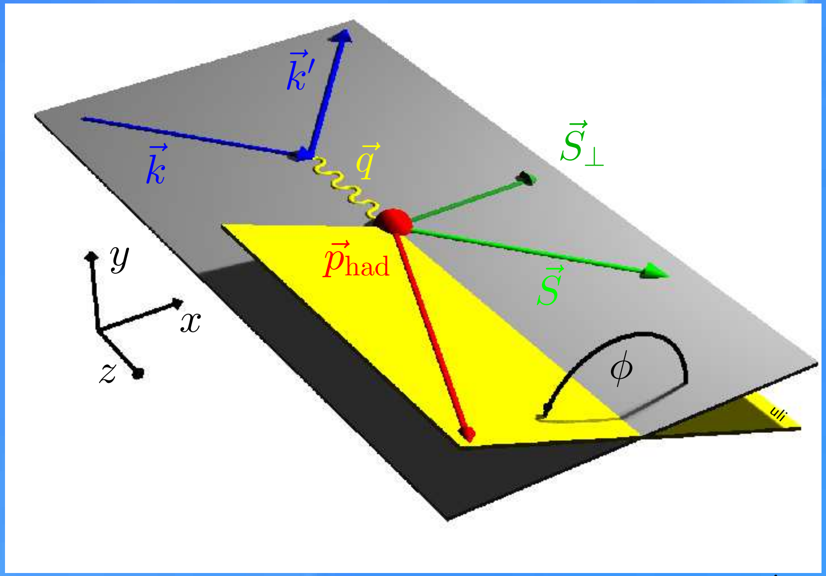
HERMES: $S_\perp / S \sim$ **0.17**



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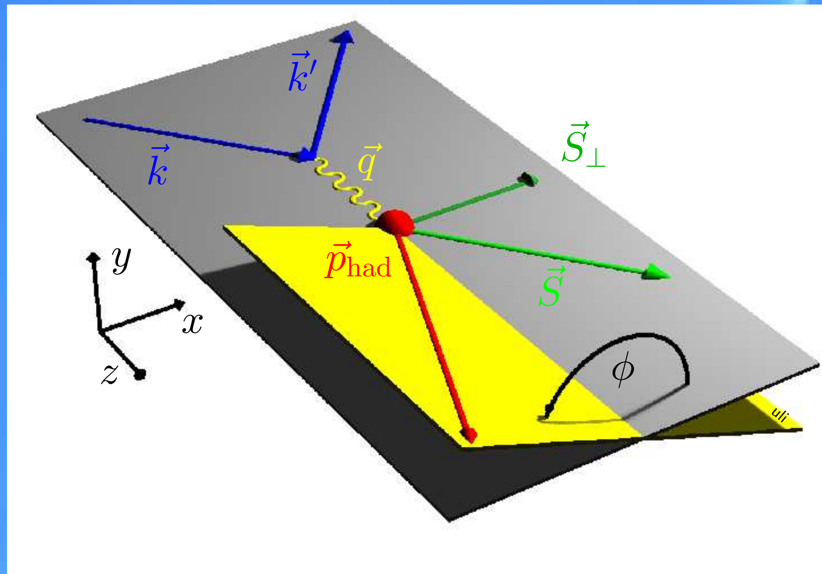

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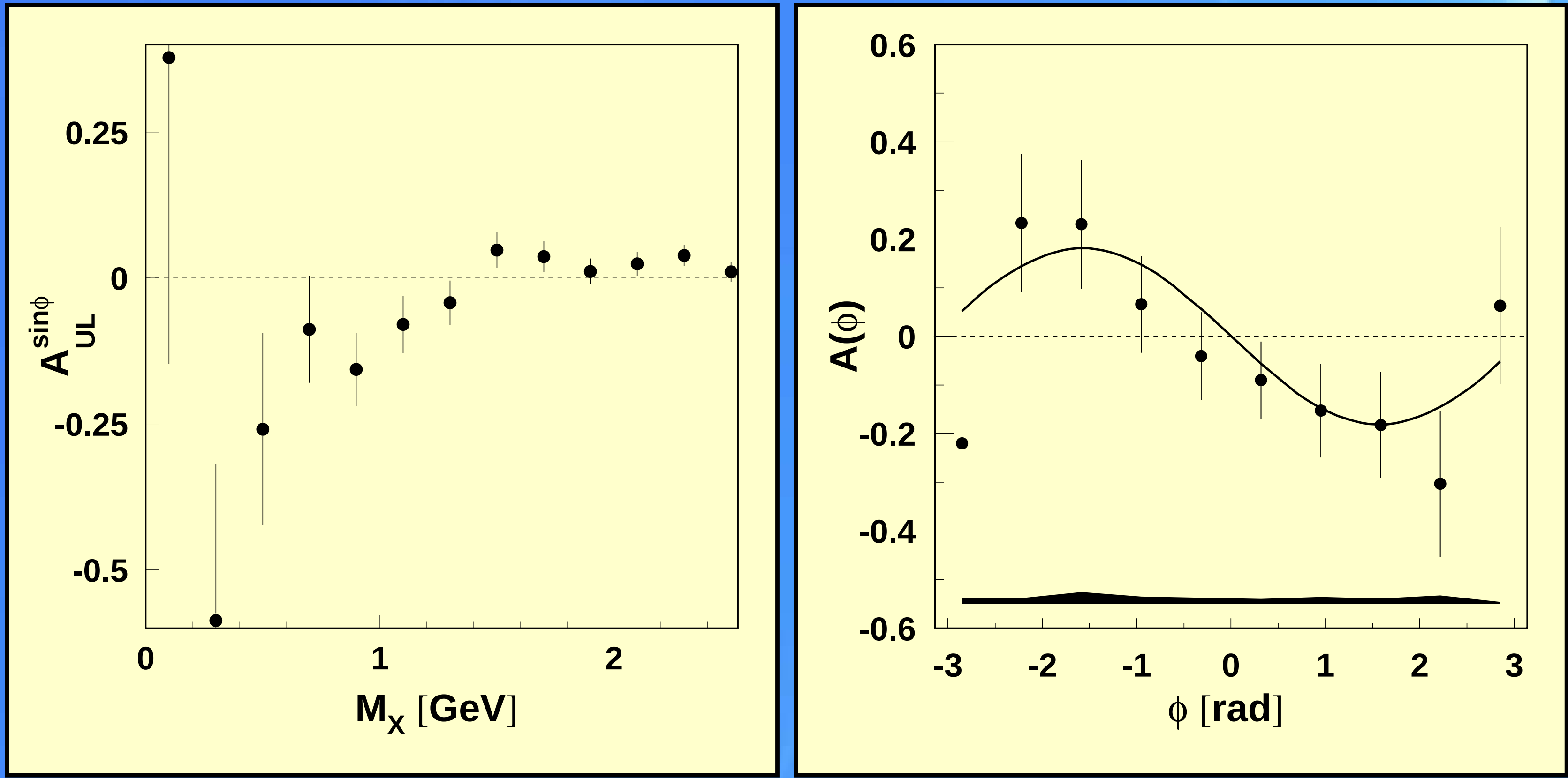
HERMES: $S_\perp/S \sim$ **0.17**

$\Longrightarrow$ **transverse component to** γ^*

- **Target Spin Asymmetry:**

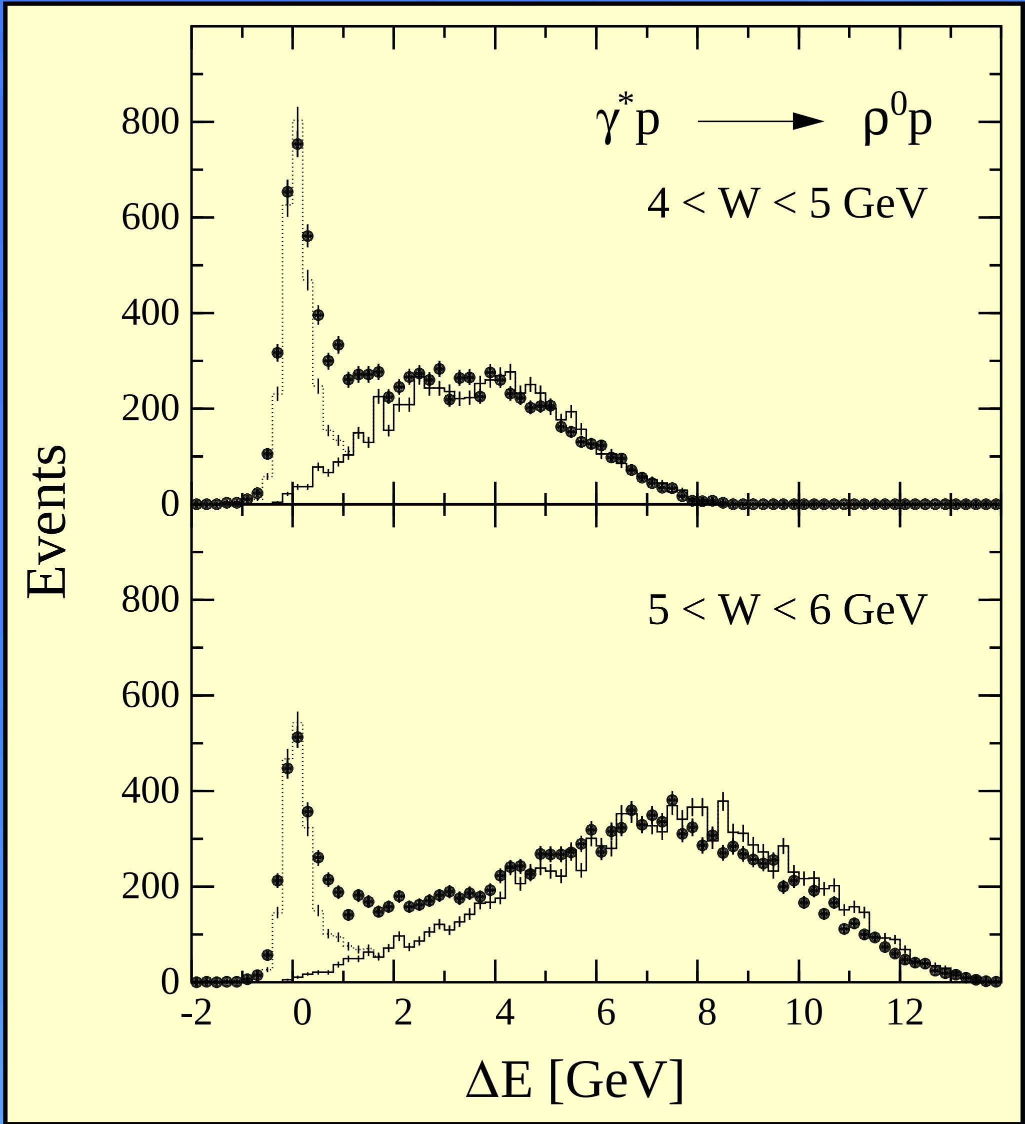
$$A_{UL}(\phi) = \frac{1}{\langle|P_t|\rangle} \cdot \frac{\sigma^{\leftarrow}(\phi) - \sigma^{\rightarrow}(\phi)}{\sigma^{\leftarrow}(\phi) + \sigma^{\rightarrow}(\phi)} = \frac{1}{\langle|P_t|\rangle} \cdot \frac{N^{\leftarrow}(\phi) - N^{\rightarrow}(\phi)}{N^{\leftarrow}(\phi) + N^{\rightarrow}(\phi)} \stackrel{\text{fit}}{=} A_{UL}^{\sin(\phi)} \cdot \sin(\phi)$$

Exclusive π^+ target - SSA-Results



- **Asymmetry appears at $\mathrm{M_x}$ = Nucleon mass**
- $\mathbf{A_{UL}^{\sin\phi} = -0.18 \pm 0.05 \pm 0.02}$ **at** $\mathbf{\langle x\rangle = 0.15, \langle Q^2\rangle = 2.2GeV^2, \langle t\rangle = -0.46GeV^2}$
- **more data needed** $\Longrightarrow$ **transverse polarized target to study** $\tilde{E}, \tilde{H}$

Exclusive VM-production $ep \to e'\rho^0/\phi p$

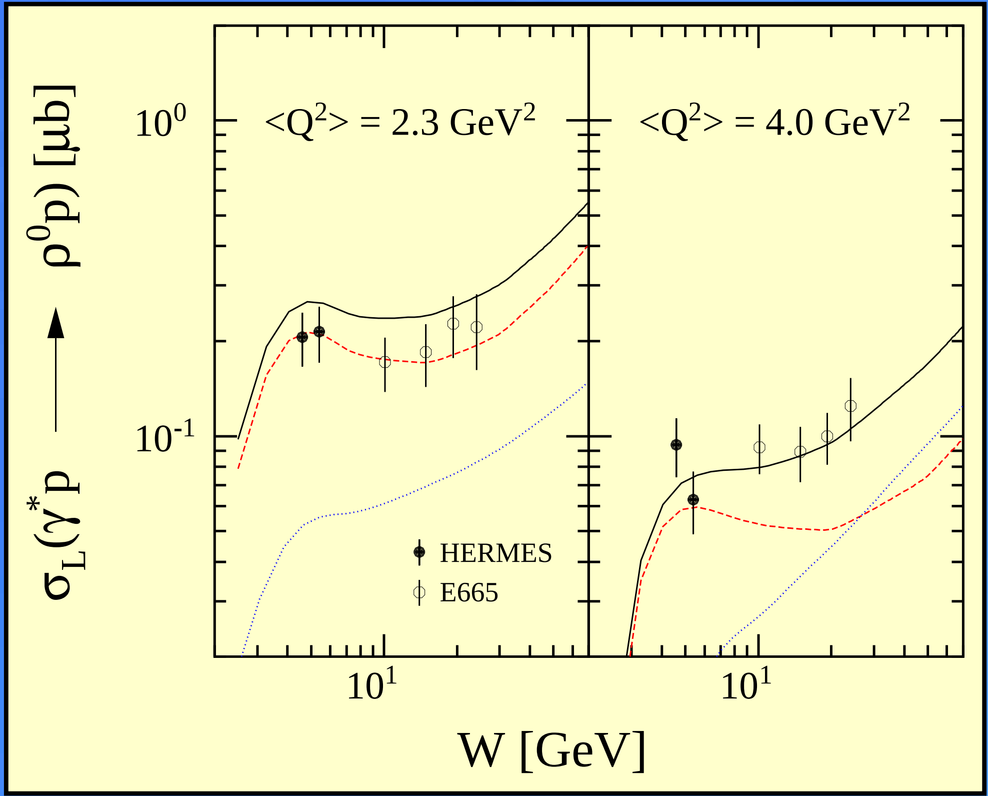


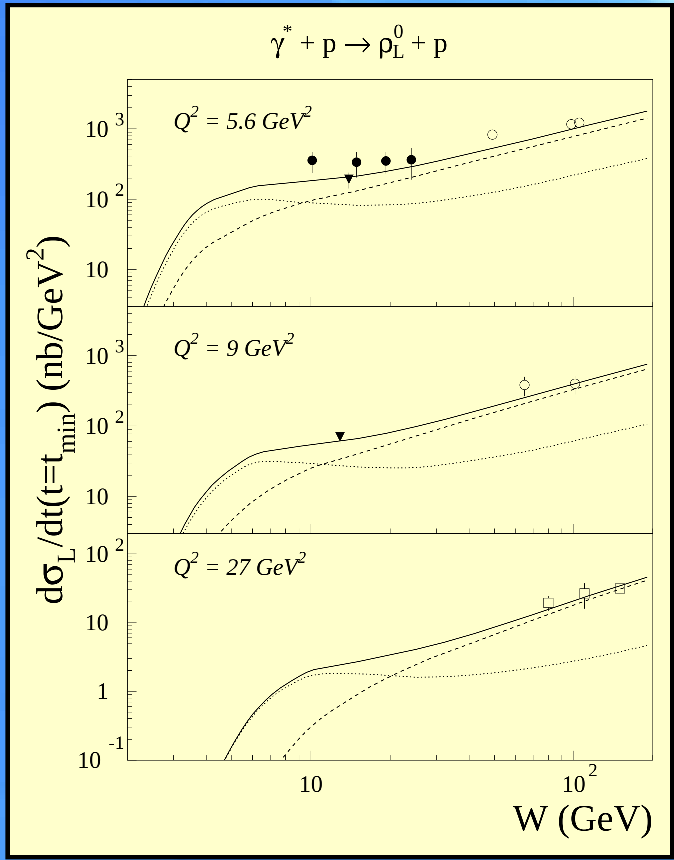
$$\rho^0 \to \pi^+\pi^-$$
$$\phi \to K^+K^-$$

- $\Rightarrow$ **Recoiling proton is not detected**
- $\Rightarrow$ **good determination of exclusive channel using $\mathbf{\Delta E}$**
- $\Rightarrow$ **DIS-'background' well described by Monte Carlo**
- $\Rightarrow$ **deduce longitudinal cross section from decay angular distributions σ_L^P**

$$\sigma_L^P \sim \frac{1}{2}\left(\frac{2}{3}H^u + \frac{1}{3}H^d\right)$$

Exclusive σ_L for ρ^0-Production





[K. Goeke et al., hep-ph/0106012]

GPD calculations:

- **quark exchange mechanism dominates**
  $\sigma_L(\gamma^* p \rightarrow \rho^0 p)$ **at low W^2**
- **2-gluon exchange mechanism dominates**
  $\sigma_L(\gamma^* p \rightarrow \rho^0 p)$ **at high W^2 and in** $\sigma_L(\gamma^* p \rightarrow \phi p)$

Deep Inelastic Scattering Cross Section

Cross Section: $$\frac{d^2\sigma}{d\Omega dE^2} = \frac{\alpha^2 E'}{Q^2 E} \underbrace{L_{\mu\nu}(k,q,s)}_{\text{leptonic}} \underbrace{W^{\mu\nu}(P,q,S)}_{\text{hadronic}}$$

$L_{\mu\nu}$: **purely electromagnetic $\Longrightarrow$ calculable in QED**

$$W^{\mu\nu} = -g^{\mu\nu} F_1\left(x,Q^2\right) + \frac{p^\mu p^\nu}{\nu} F_2\left(x,Q^2\right) + i\epsilon^{\mu\nu\lambda\sigma}\frac{q_\lambda}{\nu}\left(S_\sigma g_1\left(x,Q^2\right) + \frac{1}{\nu}\left(p\cdot q S_\sigma - S\cdot q p_\sigma\right) g_2\left(x,Q^2\right)\right)$$

(for spin 1) **+ quadrupole terms** (b_1, b_2, b_3, b_4)

F_1, F_2 g_1, g_2 $\Longrightarrow$ **Un- / Polarized Structure Functions**

BUT

Quarks are relativistic, have intrinsic k_T, masses and correlations

DIS and SIDIS Cross Section

$$d\sigma = d\sigma^0_{UU} + \frac{p_T}{Q}\cos\phi\, d\sigma^1_{UU} + \lambda\frac{1}{Q}\sin\phi\, d\sigma^2_{LU}$$

$\searrow f_1$

$$+S_L[\sin 2\phi\, d\sigma^3_{UL} + \frac{1}{Q}\sin\phi\, d\sigma^4_{UL}] + \lambda S_L[\sigma^5_{LL} + \frac{1}{Q}\cos\phi\, d\sigma^6_{LL}]$$

$\searrow h^{\perp}_{1L}$ $\qquad$ $\searrow g_{1L}$

$$+S_T[\sin(\phi+\phi_S)d\sigma^7_{UT} + \sin(3\phi-\phi_S)d\sigma^8_{UT} + \frac{1}{Q}\sin(2\phi-\phi_S)d\sigma^9_{UT}]$$

$\searrow h_1$ $\qquad$ $\searrow h^{\perp}_{1T}$

$$+\lambda S_T[\cos(\phi-\phi_S)d\sigma^{10}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_S)d\sigma^{11}_{LT}]$$

$\searrow g_{1T}$

$\Longrightarrow$ **non zero Single Spin Azimuthal Asymmetries**

σ_{LT}

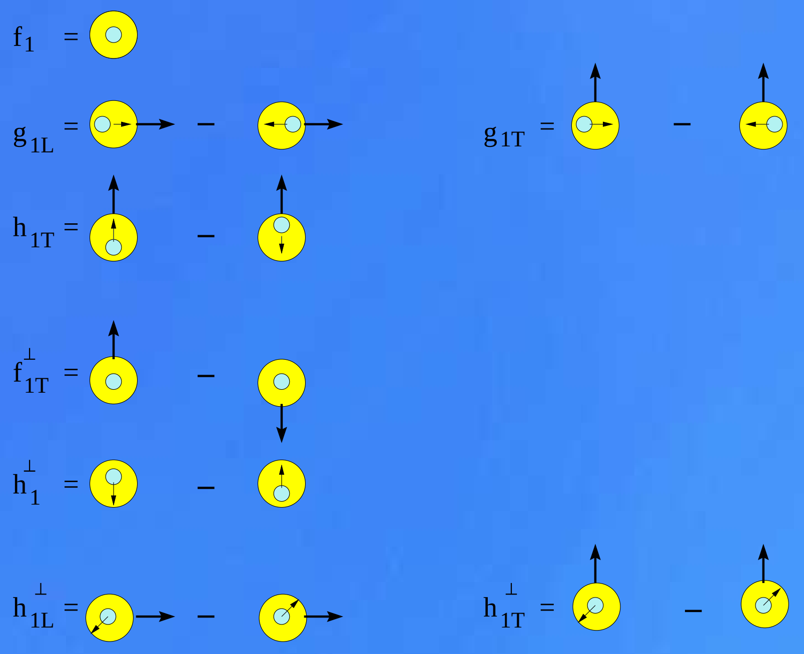
$\swarrow \searrow$

Beam Target polarization

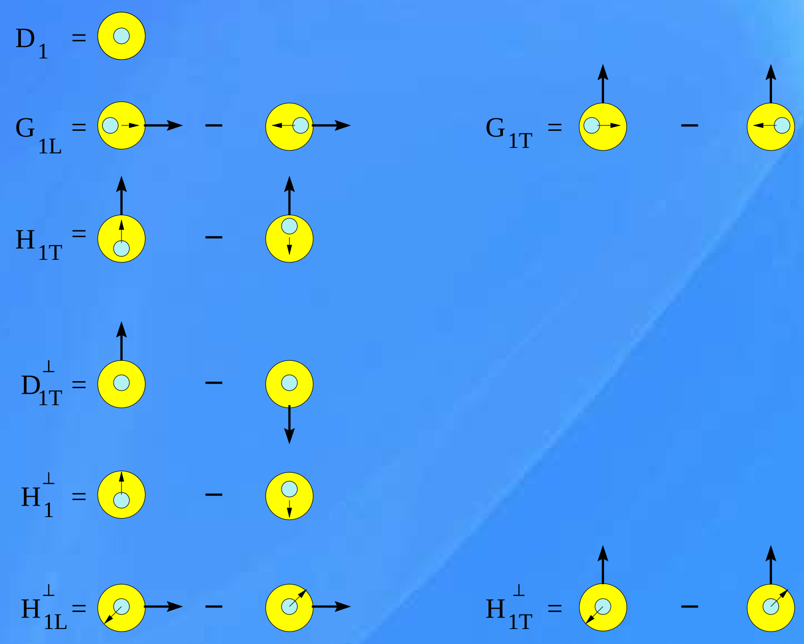
Mulders and Tangermann (NP B 461 (1996) 197)

Twist-2 Quark DF & FF

Distribution Functions (DF)



Fragmentation Functions (FF)



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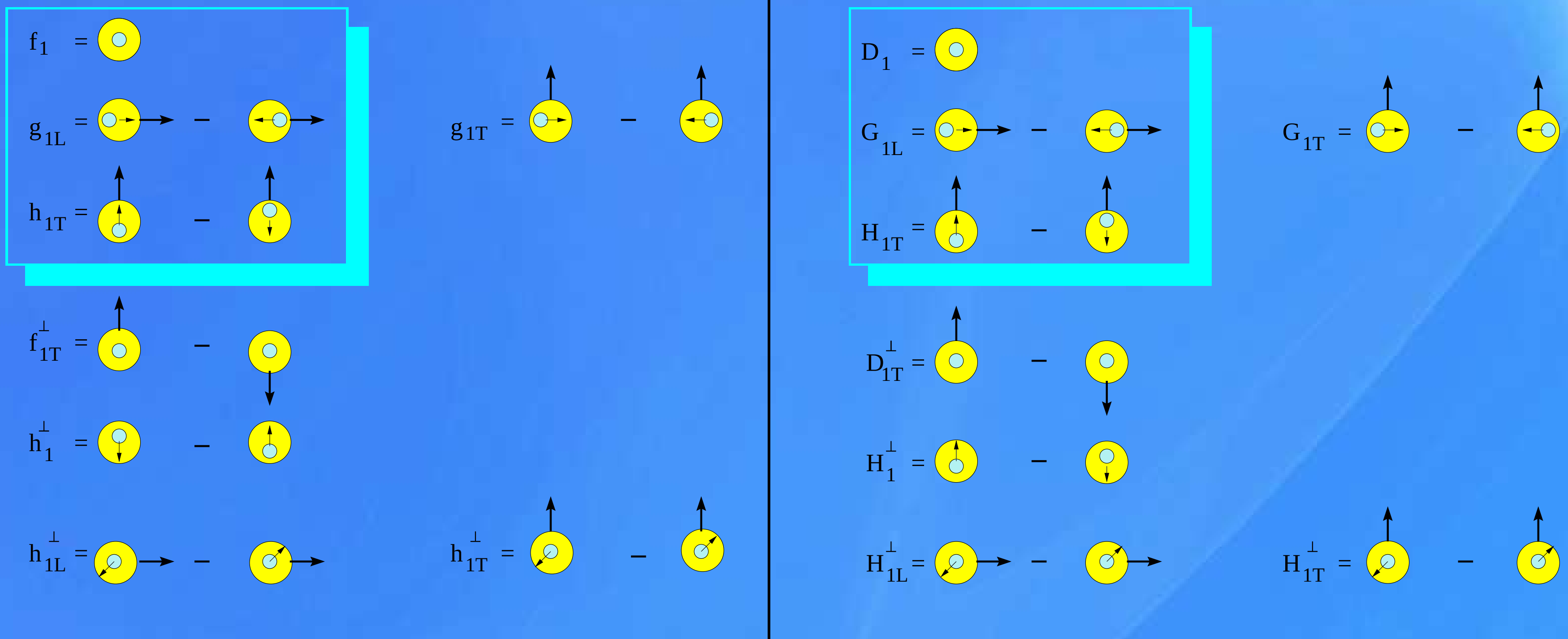

- survive k_t integration
- **The others are sensitive to intrinsic $< k_t >$ in the nucleon & in the fragmentation process**

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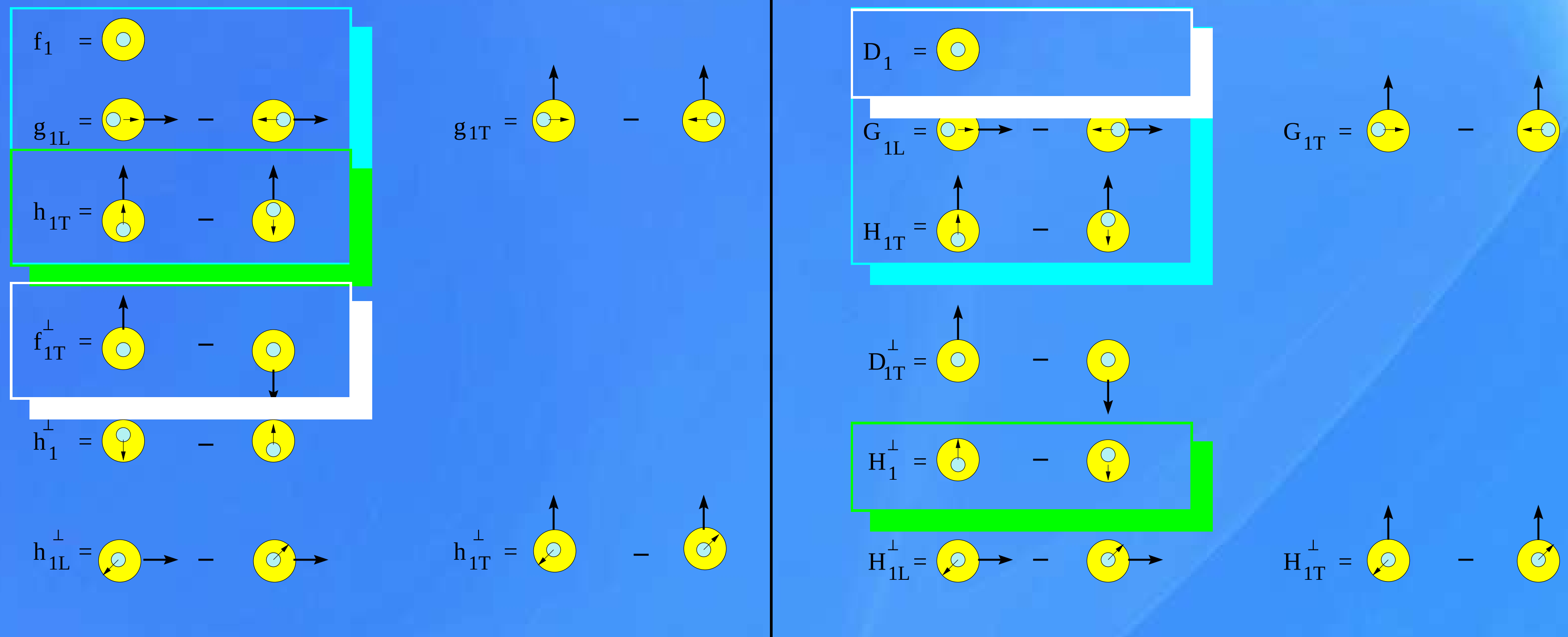
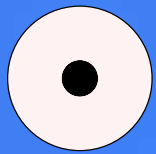
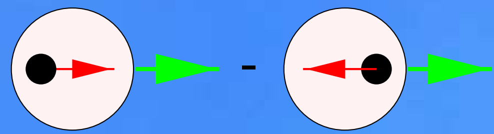
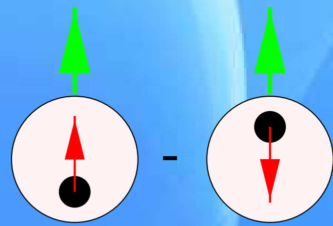


- survive k_t integration
- The others are sensitive to intrinsic $< k_t >$ in the nucleon & in the fragmentation process
- $f_{1T}^{\perp}$: Sivers DF D_1: std. unpol FF
- h_{1T}: transversity $H_1^{\perp}$: Collins FF

... surviving $k_\perp$ integration

$f_1^q =$ 

$g_1^q =$ 

$h_1^q =$ 

$\downarrow$

Unpolarized quarks and nucleons

vector charge:

$< PS|\bar{\psi}\gamma^\mu\psi|PS >=$

$\int_0^1 dx(q(x) - \bar{q}(x))$

q(x): spin averaged

well known

H1, ZEUS

$\downarrow$

Longitudinally polarized quarks and nucleons

axial charge:

$< PS|\bar{\psi}\gamma^\mu\gamma_5\psi|PS >=$

$\int_0^1 dx(\Delta q(x) + \Delta\bar{q}(x))$

Δq(x): helicity difference

known

SMC, HERMES, COMPASS, RHIC

$\downarrow$

Transversely polarized quarks and nucleons

tensor charge :

$< PS|\bar{\psi}\sigma^{\mu\nu}\gamma_5\psi|PS >=$

$\int_0^1 dx(\delta q(x) - \delta\bar{q}(x))$

δq(x): helicity flip

unmeasured

SMC, HERMES, COMPASS, RHIC

Characteristics of Transversity

- **Non-relativistic quarks:** $\Delta q(x) = \delta q(x)$
  $\Rightarrow$ δq **probes relativistic nature of quarks**
- **Angular momentum conservation**
  $\Rightarrow$ **Transversity has no gluon component**
  $\Rightarrow$ **different** Q^2 **evolution than** $\Delta q(x)$
- q **and** $\bar{q}$ **contribute with opposite sign to** $\delta q(x)$
  $\Rightarrow$ **predominantly sensitive to valence quark polarization**
- **Bounds:**
  $\Rightarrow |\delta q(x)| \leq q(x)$
  $\Rightarrow$ **Soffer bound:** $|\delta q(x)| \leq \frac{1}{2}[q(x) + \Delta q(x)]$

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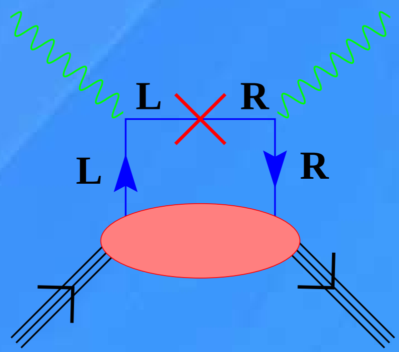

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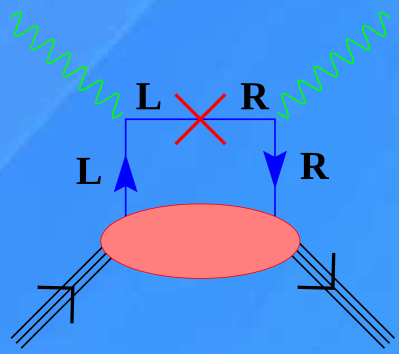

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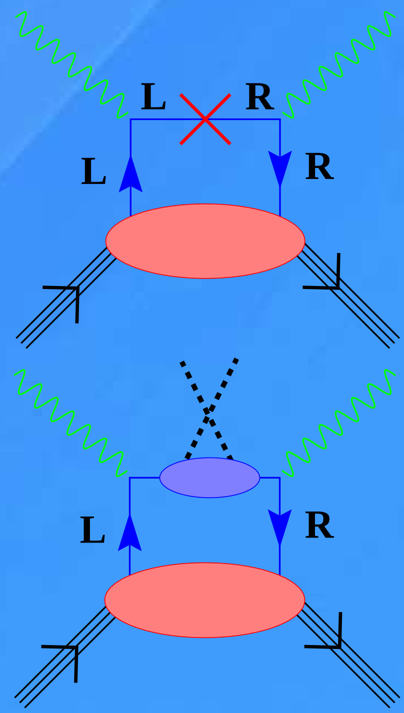

- **Transversity distribution CHIRAL ODD**

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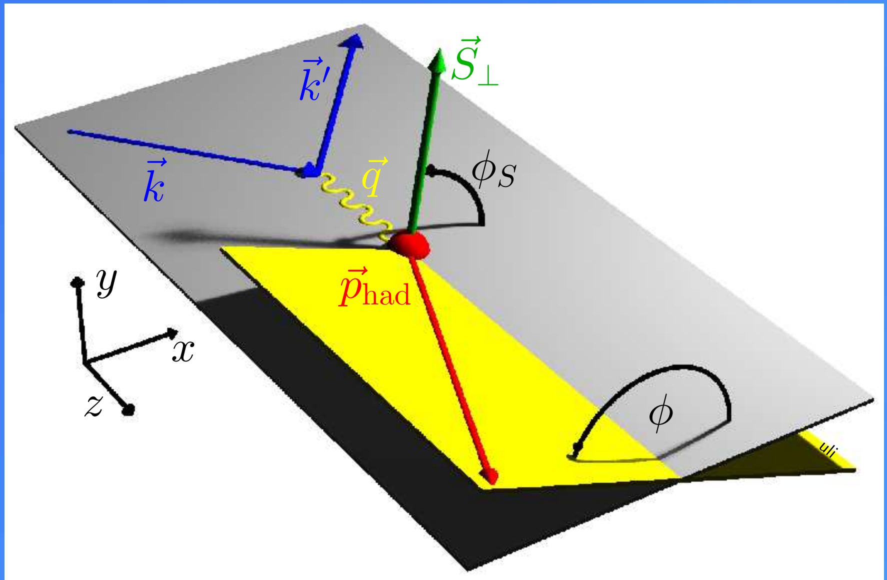
NEED another chiral-odd object!

$\Rightarrow$ **semi-inclusive DIS** $\Rightarrow$ $H_1^{\perp}$ **Collins FF**

How can one measure Transversity

Single spin azimuthal asymmetries with a transverse polarized target

$$ep^{\uparrow} \longrightarrow e'\pi X$$



$\Phi = \phi + \phi_s$ **Collins angle**

$$\sigma^{ep\to ehX} = \sum_q f^{H\to q} \otimes \sigma^{eq\to eq} \otimes D^{q\to h}$$

$\Downarrow$ **chiral-odd** **DF**

$\Downarrow$ **chiral-odd** **FF**

$$A_{UT}^{\sin\Phi} \propto \frac{\sum_{i=1}^{N^\uparrow} \sin\Phi - \sum_{i=1}^{N^\downarrow} \sin\Phi}{\frac{1}{2}(N^\uparrow + N^\downarrow)}$$

$$A_{UT}^{\sin\Phi} \propto \frac{\sum_q e_q^2 \delta q(x) H_1^{\perp,q}(z)}{\sum_q e_q^2 q(x) D_1^q(z)}$$

Can only measure $\delta \mathbf{q}(\mathbf{x}) \cdot \mathbf{H}_1^{\perp,\mathbf{q}}(\mathbf{z})$

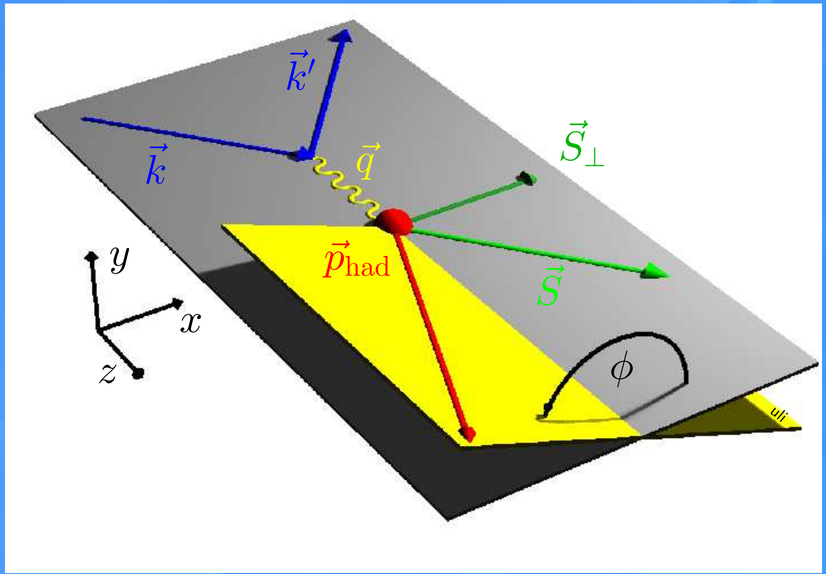
$\mathbf{H}_1^{\perp,\mathbf{q}}(\mathbf{z})$ from e^+e^- collider experiments, like Belle

First glimpse on Transversity?!

HERMES:

- until 2001 no data with transverse polarized proton target available
  $\Longrightarrow$ like for exclusive pion production
  $\Longrightarrow$ use longitudinal polarized proton and deuterium target

$$\mathbf{A_{UL}}(\phi) = \frac{\mathbf{1}}{\langle \mathbf{P} \rangle} \cdot \frac{\mathbf{N}^{\leftarrow}(\phi) - \mathbf{N}^{\rightarrow}(\phi)}{\mathbf{N}^{\leftarrow}(\phi) + \mathbf{N}^{\rightarrow}(\phi)}$$



S_T transverse component of target spin w.r.t. virtual photon:

$$\mathbf{S}_\perp \propto \sin \mathbf{\Theta}_\gamma \simeq \frac{\mathbf{2Mx}}{\mathbf{Q}} \sqrt{\mathbf{1 - y}} \sim \mathbf{0.15}$$

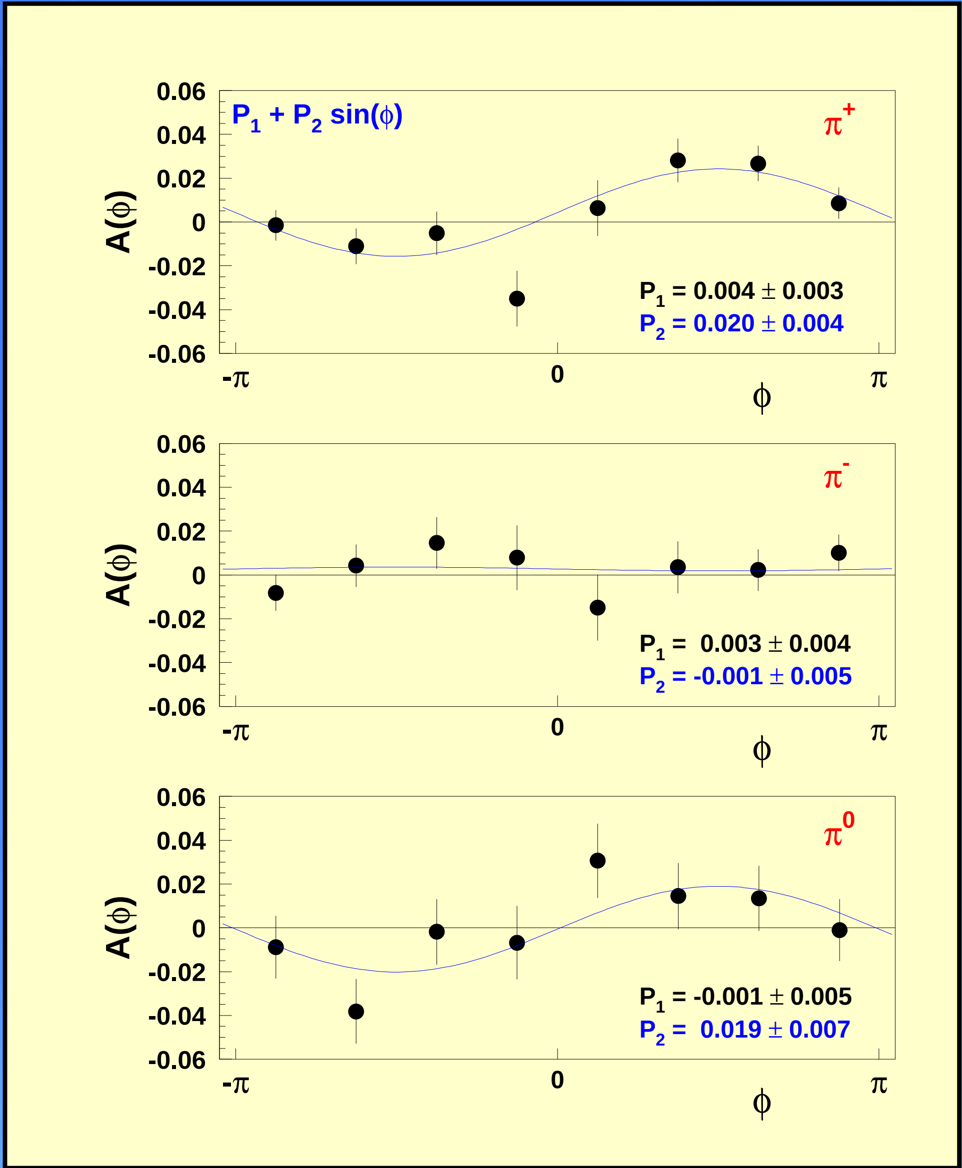
$$\mathbf{A_{UL}^{sin(\phi)}} - \mathbf{S}_{||} \cdot \frac{\mathbf{1}}{\mathbf{Q}} \mathbf{sin}(\phi)_{\mathbf{UL}} - \mathbf{S}_\perp \mathbf{sin}(\phi)_{\mathbf{UT}}$$

$\Longrightarrow$ transverse component to γ^*

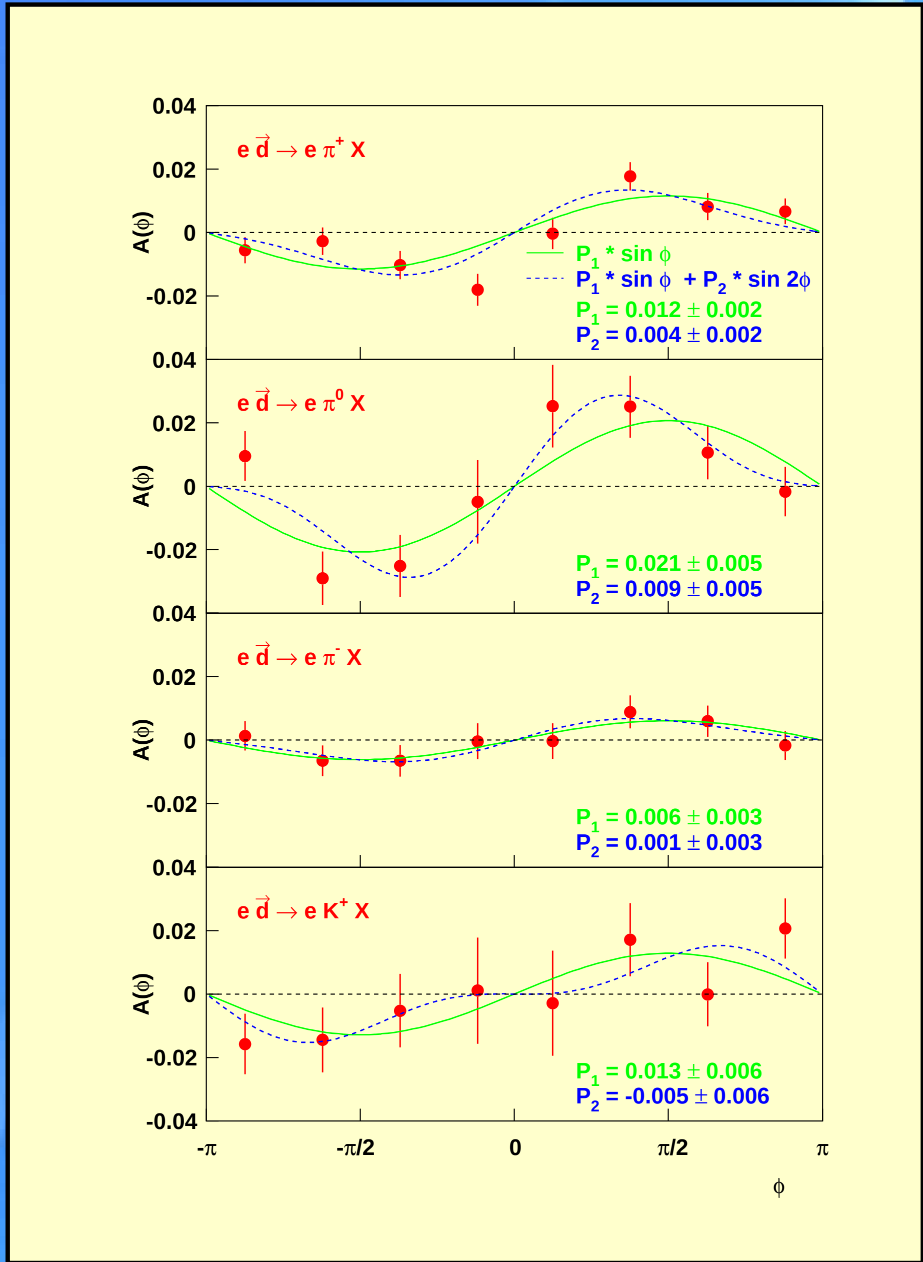
$$\mathbf{A_{UL}^{sin(\phi)}} = \mathbf{S}_{||} \frac{\mathbf{1}}{\mathbf{Q}} \sum_{\mathbf{q},\bar{\mathbf{q}}} \mathbf{e_q^2 x} \underbrace{h_L^a(x)}_{\text{sub-leading order}} \mathbf{H_1^{\perp q}}(\mathbf{z}) - \mathbf{S}_\perp \sum_{\mathbf{q},\bar{\mathbf{q}}} \mathbf{e_q^2 x} \underbrace{h_1^a(x) H_1^{\perp q}(z)}_{\text{transversity} \cdot \text{Collins FF}}$$

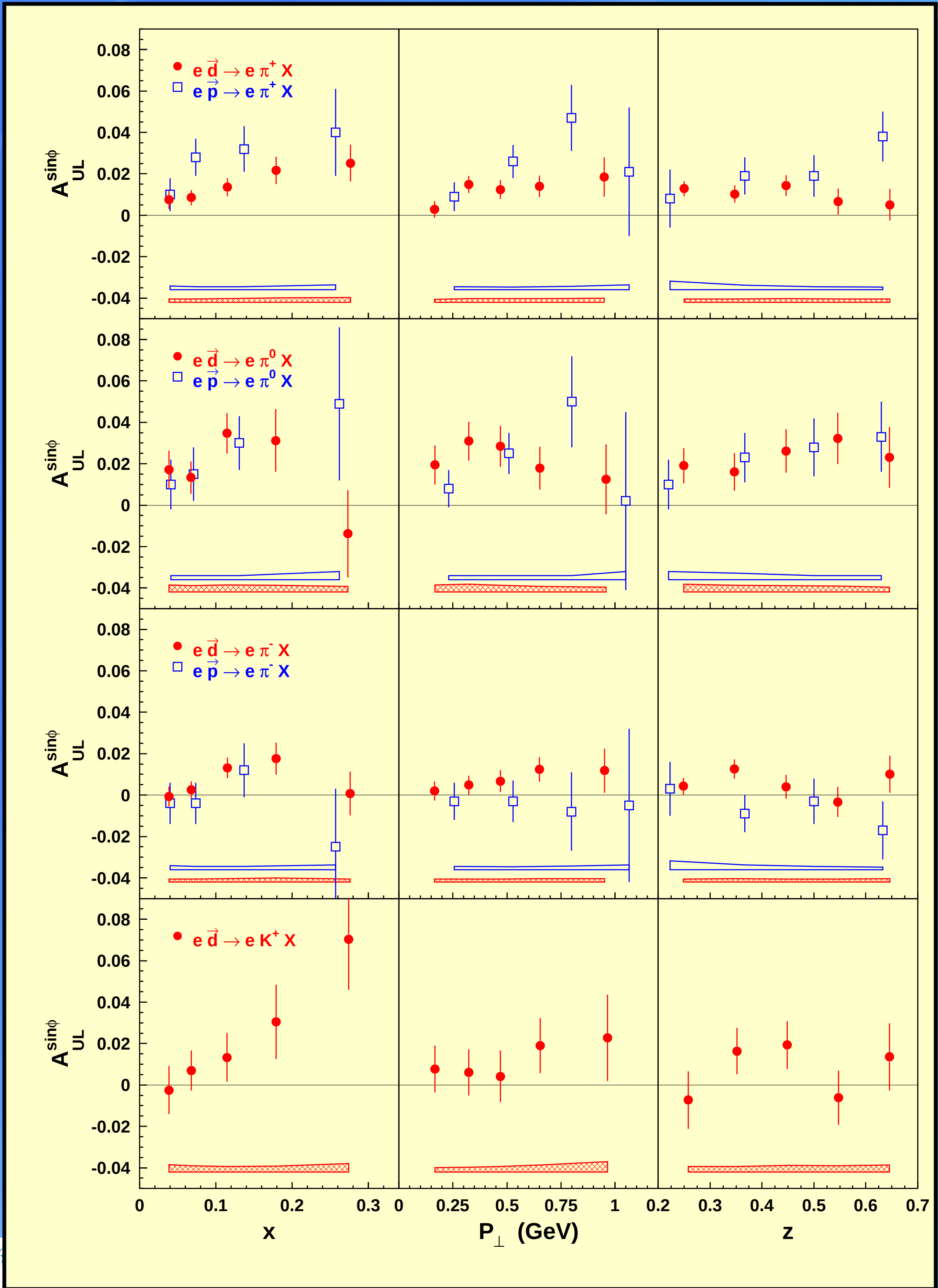
Results

PROTON



DEUTERON

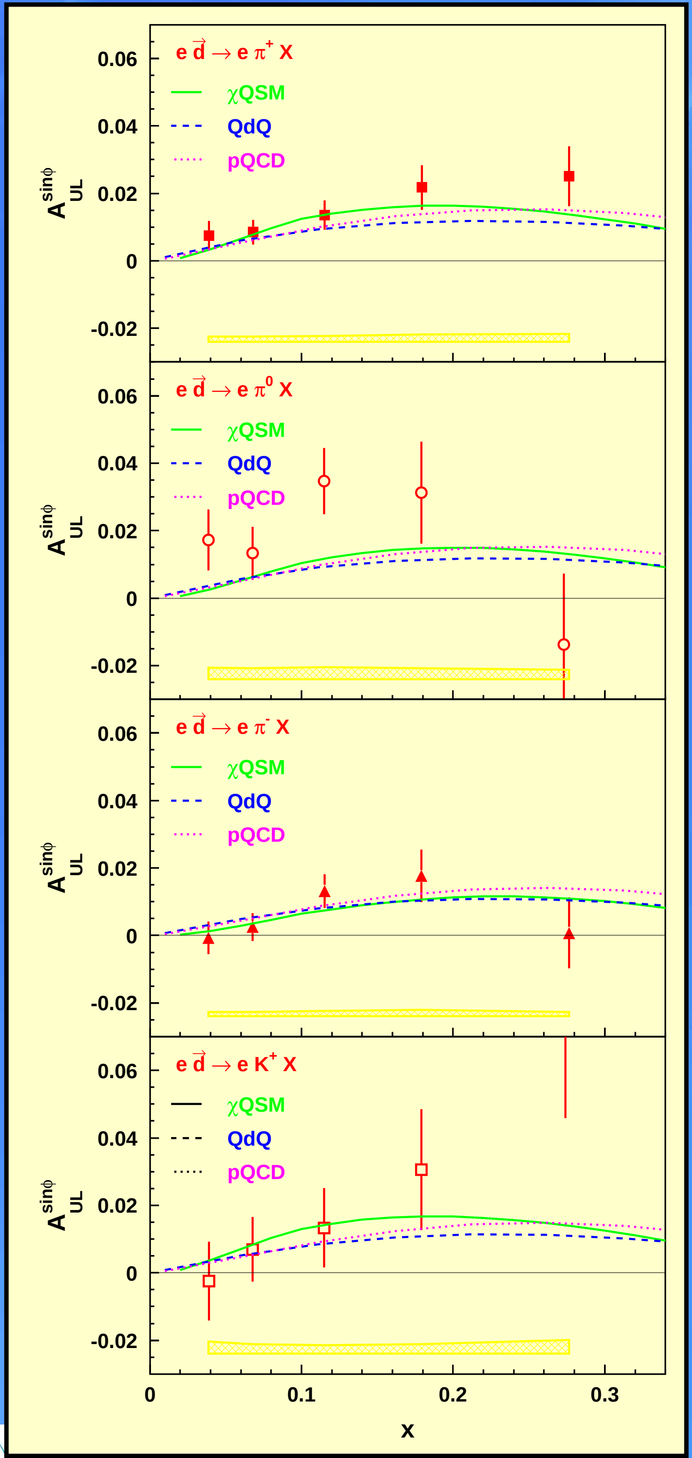




$A_{UL}^{sin\phi}$

Original predictions by Collins:

- **Proton Target**
  Larger for π^+, π^0 than for π^-
  (u-quark dominance)
- **Rise with x$_{bj}$**
  (valence quark dominance)
- **Grow with $p_\perp$, peak around 1 GeV**
  ($\frac{H_1^\perp}{D_1} \propto \frac{M_c M_h}{M_c^2+p_\perp^2}$ with $M_c \simeq$1 GeV)
- **First SSA for Kaons**



What does theory tell?

- h_1 **calculated in: χQSM, QdQ, pQCD models**
- **sub-leading order terms $\sim$ 0**
- **Collins FF $H_1^\perp$:**

  χQSM: $|\frac{\langle \mathbf{H_1^\perp} \rangle}{\langle \mathbf{D_1} \rangle}| = \mathbf{12.5 \pm 1.4\%}$

  QdQ, pQCD: 'Collins guess'

Challenges in Interpretation

Problem:

- **have neglected the Sivers - DF**

$$\mathbf{A_{UL}^{\sin(\phi)} \sim S_\perp \sum_{f,\bar{f}} e_f^2 x f_{1T}^{\perp q}(x) \cdot D_1(z)}$$

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longitudinally polarized target

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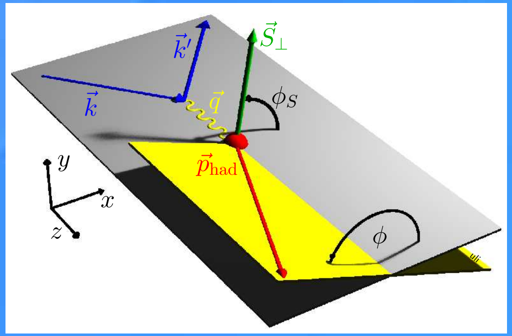
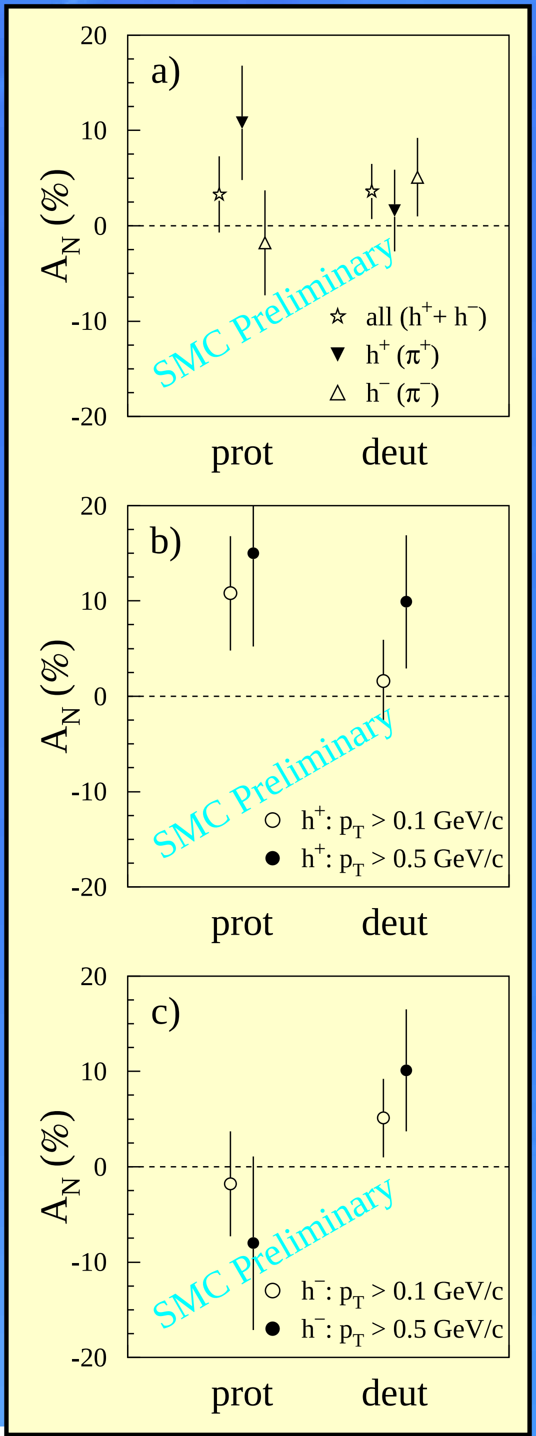
Transversely polarized target needed



- $\langle \sin\phi \rangle_{UT}$ **becomes dominant**
- **Sivers and Collins distinguishable**

$\langle \sin(\phi_h - \phi_S) \rangle$ **moment** $\langle \sin(\phi_h + \phi_S) \rangle$ **moment**

$$A_{UT}^{\sin(\phi_h - \phi_S)} \sim S_\perp \sum_{f,\bar{f}} e_f^2 x f_{1T}^{\perp q}(x) \cdot D_1(z) \qquad A_{UT}^{\sin(\phi_h + \phi_S)} \sim S_\perp \sum_{f,\bar{f}} e_f^2 x h_{1T}^{q}(x) \cdot H_1^{\perp q}(z)$$

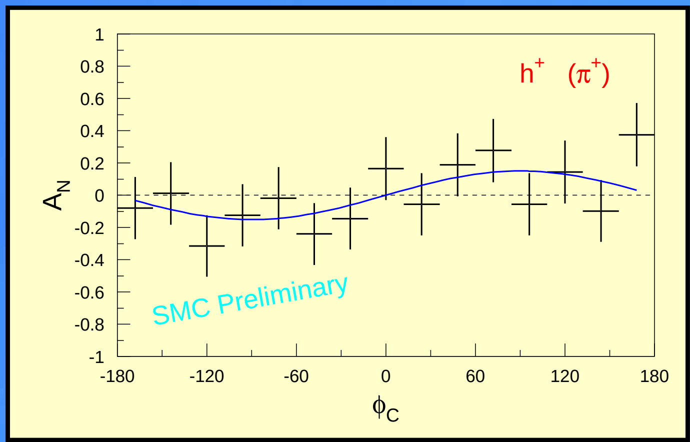


Results from SMC

Data with transversely polarized target

$$\mathbf{d\sigma \sim (1 + A_N \sin(\phi_C))d\phi_C}$$

$$\mathbf{A_N = \frac{1}{P_T f D_{NN}} \frac{1}{\langle \sin(\phi_C) \rangle} \frac{N(\phi_C) - N(\phi_C + \pi)}{N(\phi_C) - N(\phi_C + \pi)}}$$



Need more data $\Longrightarrow$ COMPASS, HERMES, RHIC

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Summary

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  - nothing definite known till now

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  - nothing definite known till now
  - data from longitudinally polarized targets suggest
    $\delta\mathbf{q} \neq \mathbf{0}$ $\mathbf{H_1^{\perp q}} \neq 0$
    BUT: Collins versus Sievers

- Orbital Angular Momentum $\mathbf{L_q}$
  - GPDs: new avenue to study the structure of the nucleon
  - exclusive reactions are experimentaly established
    $\Longrightarrow$ many different processes can and have been studied
    BUT: not yet enough data to
    - deduce kinematic dependences of GPDs
    - determine GPDs as accurate as standard PDFs
- The transverse spin structure of the nucleon
  - nothing definite known till now
  - data from longitudinally polarized targets suggest
    $\delta \mathbf{q} \neq \mathbf{0}$ $\quad\quad$ $\mathbf{H_1^{\perp q}} \neq 0$
    BUT: Collins versus Sievers
  - need data with transversely polarised targets
    $\Longrightarrow$ COMPASS, HERMES, RHIC