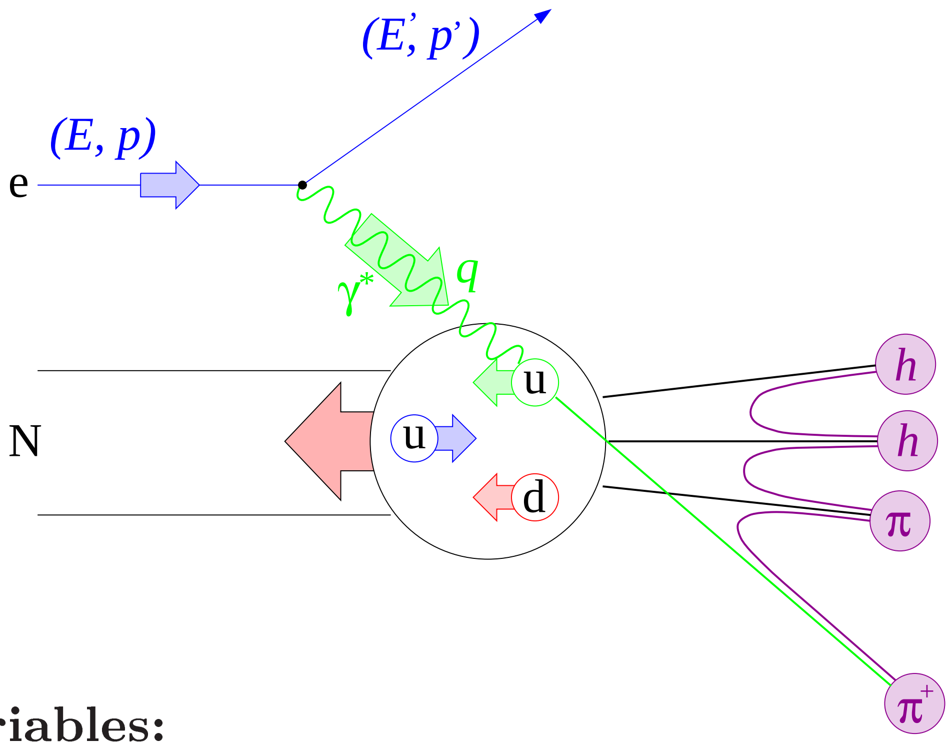
Recent Spin Physics Results from HERMES

Eric Thomas, INFN/LNF
On behalf of HERMES collaboration

- Polarized DIS
- The HERMES Experiment
- Double-Spin Asymmetries
  - ▷ inclusive ⇒ Polarized SF g_1
  - ▷ semi-incl $h^{\pm}$ ⇒ Polarized PDF Δq
  - ▷ High p_t $h^{\pm}$ ⇒ Gluon polarization $\Delta G/G$
- Single-Spin Asymmetries
  - ▷ semi-incl $\pi^{\pm}$⇒ New polarised SF and FF
- Summary-outlook

Polarized Deep Inelastic Scattering



DIS Variables:

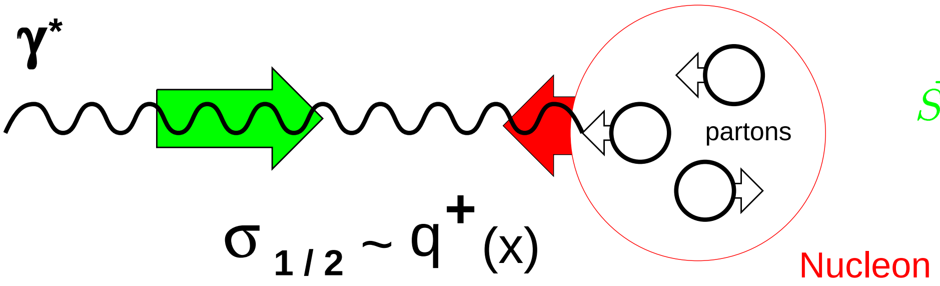
$$
\begin{aligned}
Q^2 &\overset{lab}{=} 4EE'\sin^2(\tfrac{\theta}{2}) \\
\nu &\overset{lab}{=} E - E' \\
x &\overset{lab}{=} \frac{Q^2}{2m\nu} \\
y &\overset{lab}{=} \frac{\nu}{E} = \frac{p\cdot q}{p\cdot k} \\
z &\overset{lab}{=} \frac{E_h}{\nu}
\end{aligned}
$$

- **Inclusive: detect E'**
- **Semi-Inclusive: detect E' and h**

flavour tagging

Virtual Photon Asymmetry

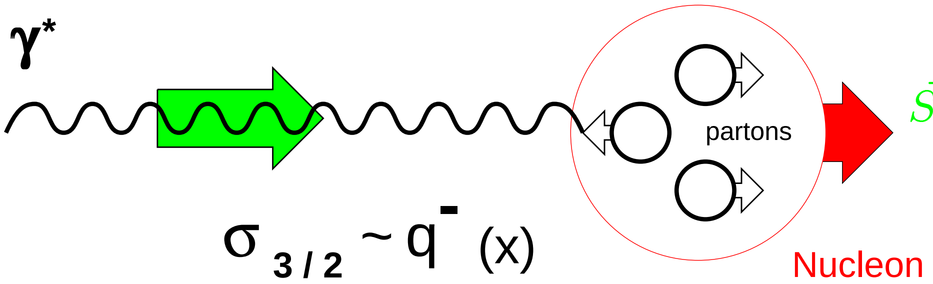
polarized Photon (Spin 1) can only probe quarks with spin opposite to its own:



$\vec{S_\gamma} + \vec{S_N} = 1/2$

$\sigma_{1/2} \sim q^{+}(x)$

$+$ means: quark spin parallel to **Nucleon spin**



$\vec{S_\gamma} + \vec{S_N} = 3/2$

$\sigma_{3/2} \sim q^{-}(x)$

$-$ means: quark spin opposite to **Nucleon spin**

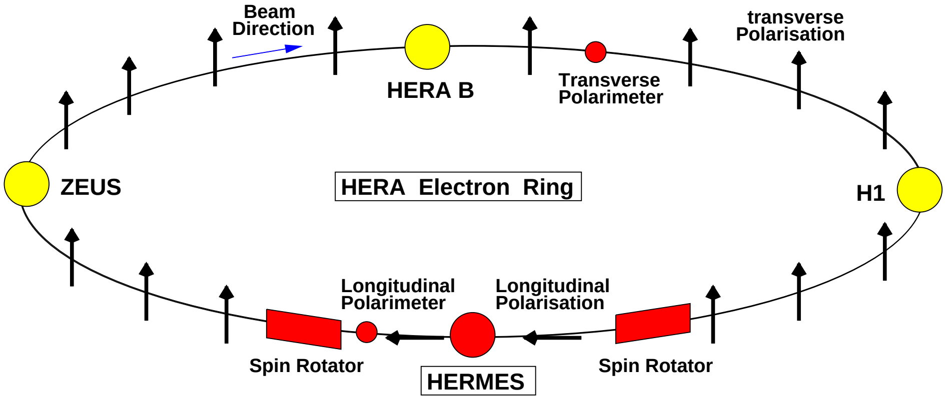
$\Rightarrow$ flipping spin of target $\Rightarrow$ **Quark Spin Distributions:**

$$\boxed{\Delta q_f(x) := q_f^+(x) - q_f^-(x)}$$

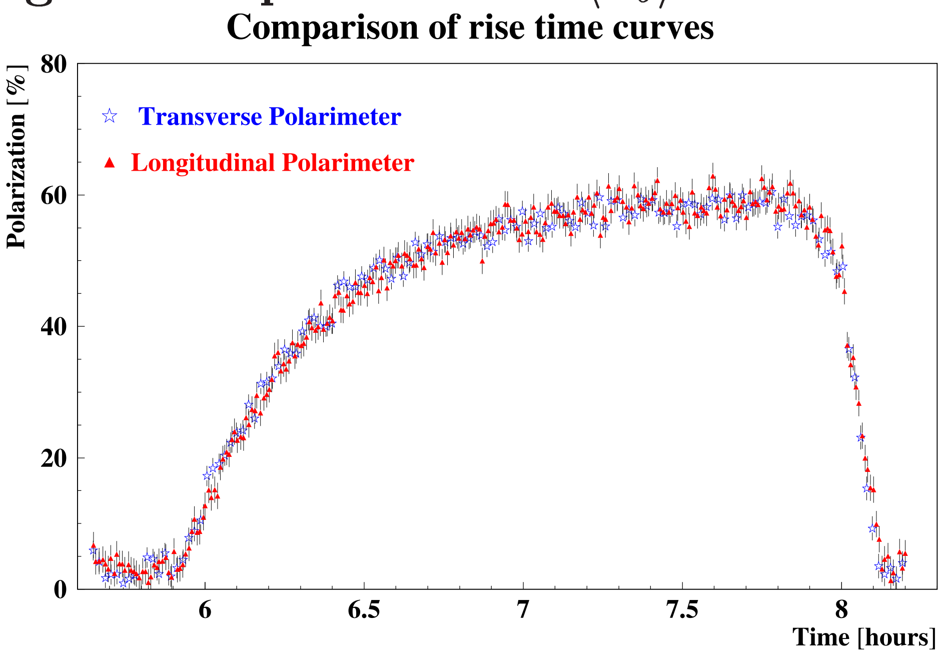
$$(\ f = u, d, s, \overline{u}, \overline{d}, \overline{s}\ )$$

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \simeq \frac{g_1}{F_1} = \frac{\sum_f e_f^2\, \Delta q_f(x, Q^2)}{\sum_f e_f^2\, q_f(x, Q^2)}$$

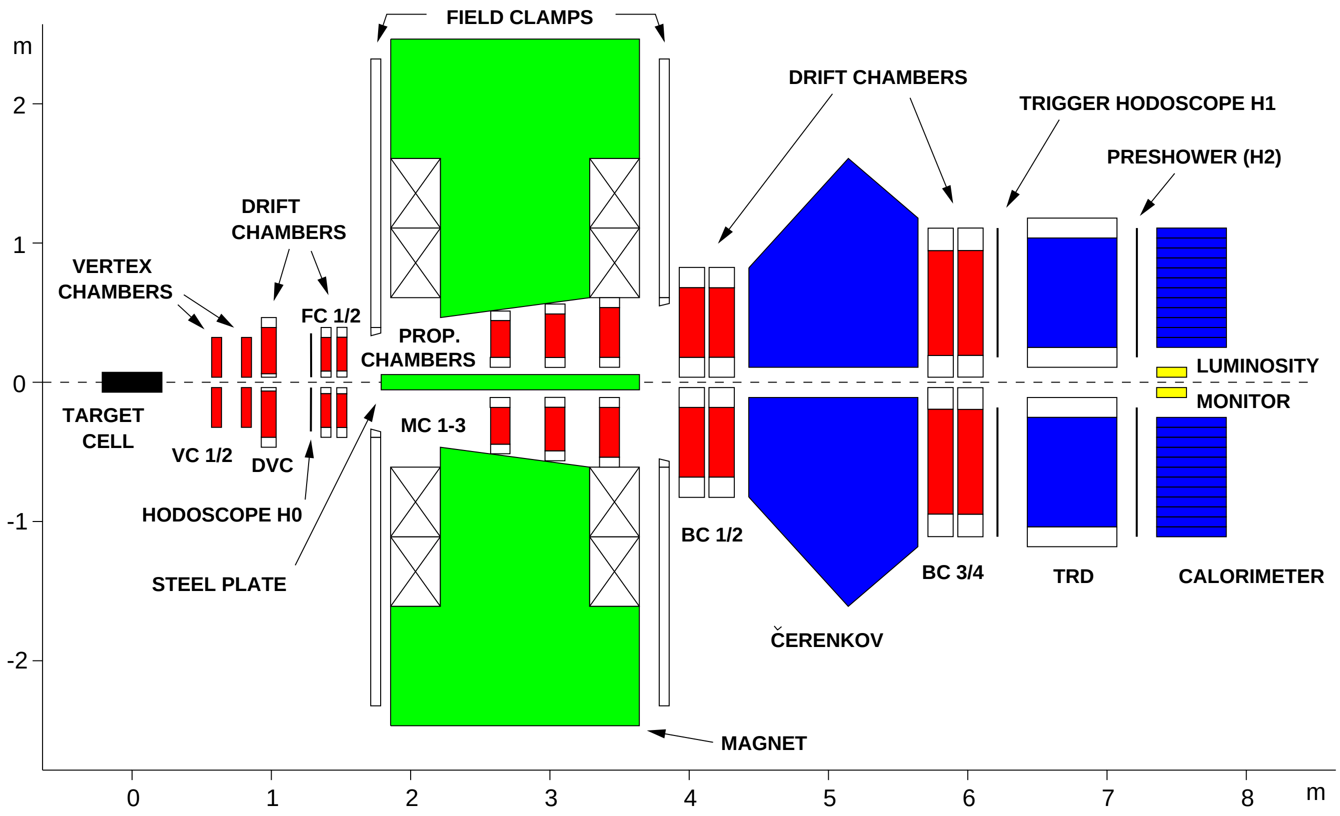
The Polarized Positron Beam at HERA



- **27.5 GeV e^+.**
- **Self-polarization by emission of synchrotron radiation, $P_b(t) = p_b^{max}[1 - exp(t/\tau)]$**
- **Spin rotators $\rightarrow$ longitudinal polarization at HERMES IP**
- **2 Polarimeters**
- **average beam polarization $\langle P_b \rangle \approx 55\%$**



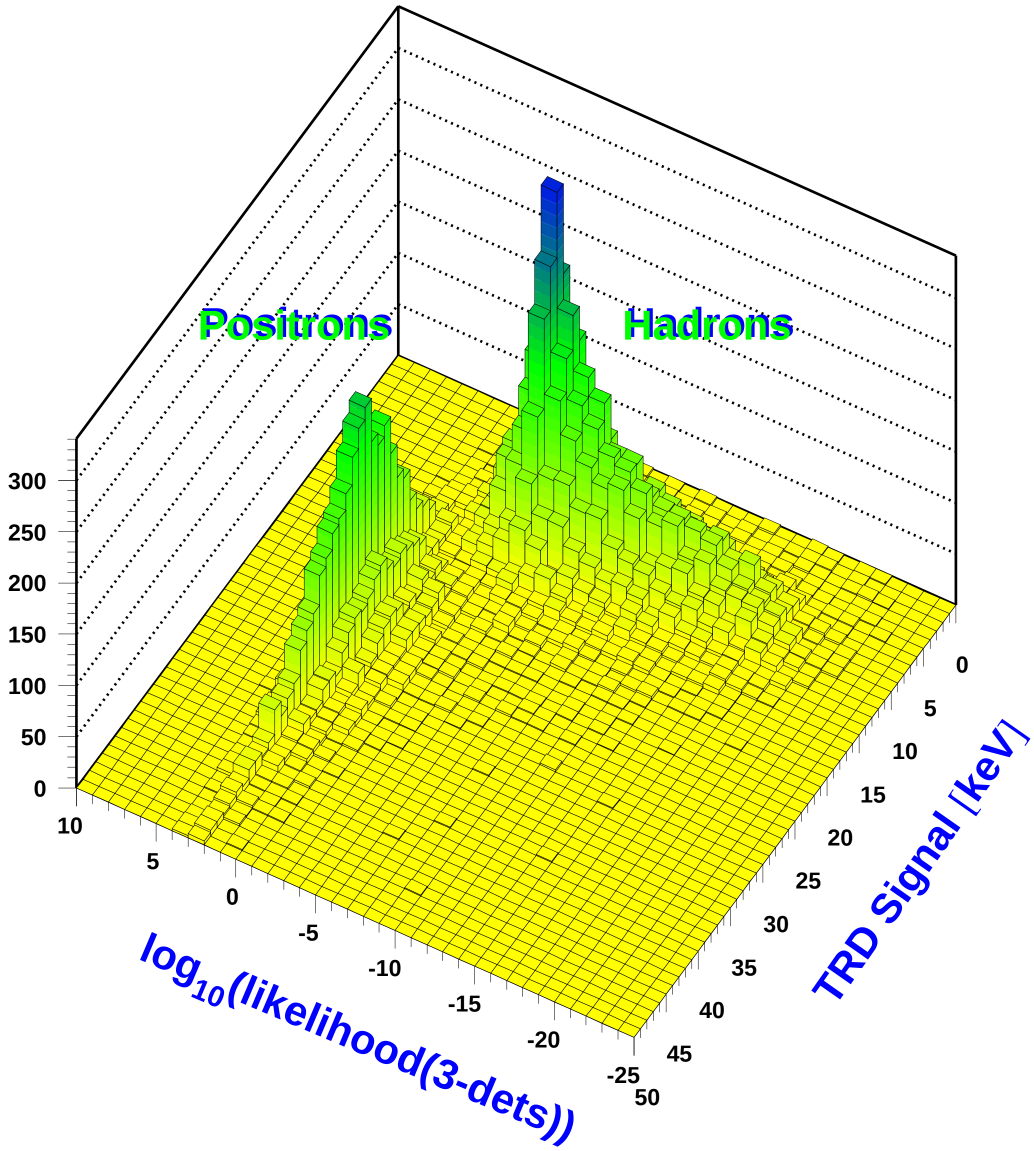
The HERMES Experiment



- **Target**: Internal storage cell gas target, density $(0.7-3)\times 10^{14}$ atoms/cm^2, $P_{\vec{H}} \approx 86\%$
- **kinematic:** $0.02 < x < 0.8$ for $Q^2 > 1$ and $W^2 > 4$
- **Tracking**: 57 tracking planes, $\delta P/P = (0.7-1.3)\%$, $\delta\theta < 0.6$ mrad
- **Particle identification**: Čerenkov (RICH98), TRD, Preshower, Calorimeter.

Particle Identification

- Lepton hadron separation, from Čerenkov , TRD, Preshower and Calo: e^+ contamination $< 1\%$



- $\pi^\pm$ identification: Čerenkov threshold detector

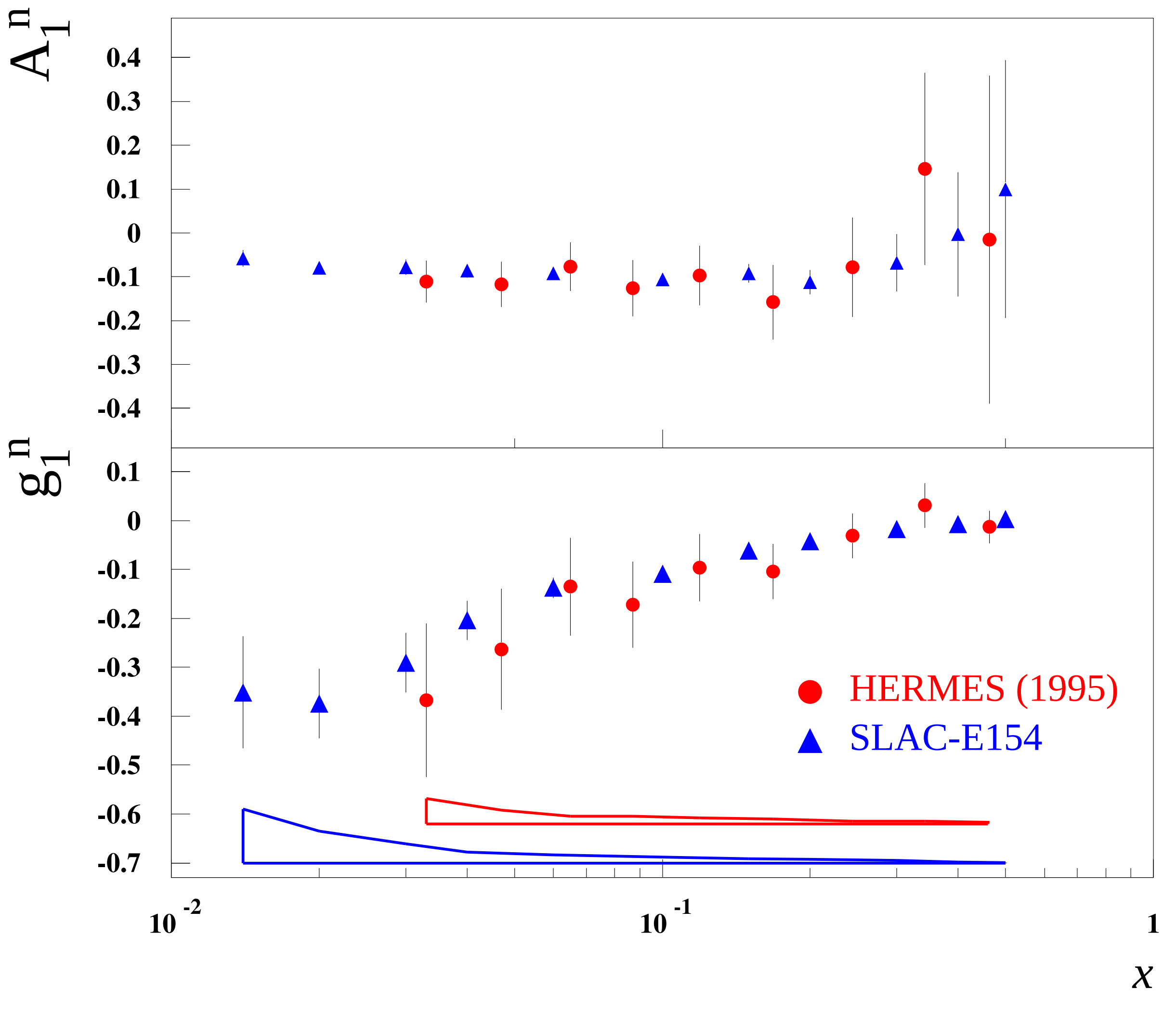
$$4.5GeV < P_\pi^\pm < 13.5GeV$$

Neutron Spin Structure Function $g_1^n(x)$

Target: $^3\overrightarrow{\mathrm{He}}$, **2 protons paired with spin 0**

$$A_1^{^3\mathrm{He}} \xrightarrow{Nucl.Corr.} A_1^n$$

$$g_1^n \simeq A_1^n \cdot F_1^n = A_1^n \cdot \frac{F_2^n}{2x(1+R)}$$

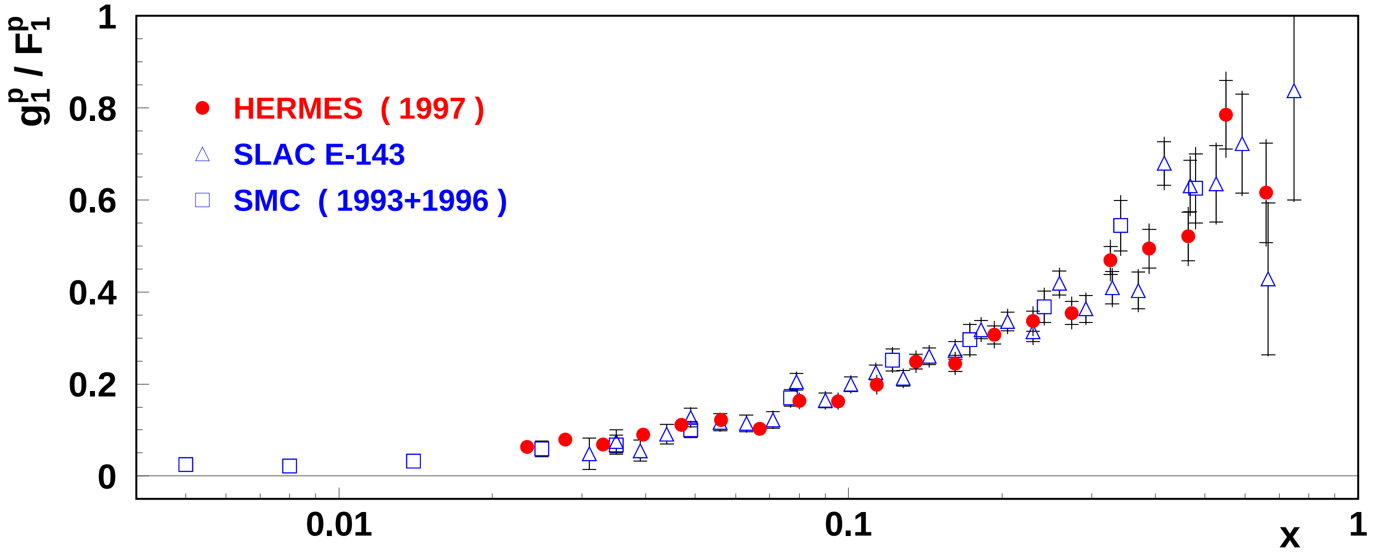


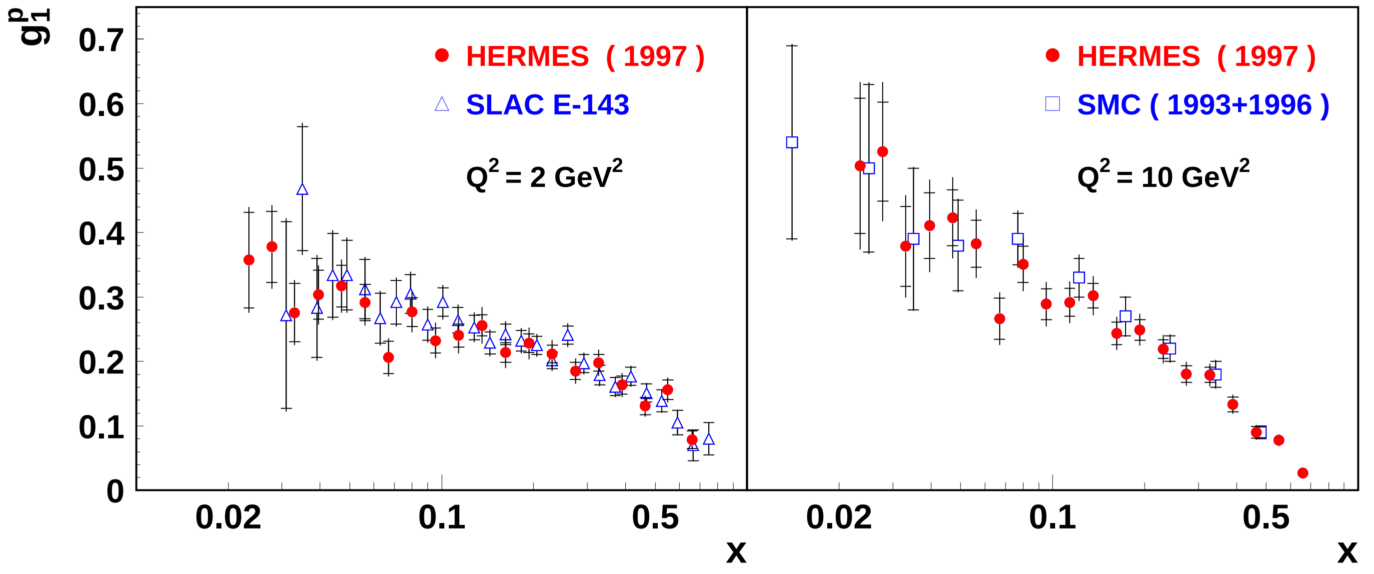
K. Ackerstaff et al., Phys. Lett. B404 (1997) 383-389.

Proton Spin Structure Function $g_1^{\rm p}(x)$

Target: $\overrightarrow{\rm H}$

$$A_1^{\rm p} \simeq g_1^{\rm p}/F_1^{\rm p} \Rightarrow g_1^{\rm p} \simeq A_1^{\rm p} \cdot F_1^{\rm p} = A_1^{\rm p} \cdot \frac{F_2^{\rm p}}{2x(1+R)}$$





A. Airapetian et al, Phys. Lett. B442 (1998) 484-492.

GDH integral:

K. Ackerstaff et al, Phys. Lett. B444 (1998) 531-538.

Semi-inclusive Asymmetries

Flavor - Tagging:
Correlation between struck q_f and detected h.

In LO-QCD:

$$\boxed{A_1^{\mathrm{h}}(x,Q^2) \simeq \frac{g_1^{\mathrm{h}}(x,Q^2)}{F_1^{\mathrm{h}}(x,Q^2)} = \frac{\int dz \sum_f e_f^2 \Delta q_f(x,Q^2) D_f^{\mathrm{h}}(z,Q^2)}{\int dz \sum_f e_f^2 q_f(x,Q^2) D_f^{\mathrm{h}}(z,Q^2)}}$$

- A_1^{h} **Measured semi-inc. asymm.**
- Δq_f (q_f) **Polarized (unpolarized) quark distributions**
- $D_f^{\mathrm{h}}(z)$ **fragmentation functions**

Unpolarized inputs:

▷ $q_f(x,Q^2)$ **parameterization**

▷ $D_f^{\mathrm{h}}(z,Q^2)$ **from LUND MC**

Assumptions:

▷ **Factorization (deep-inelastic scattering, hadronisation)**

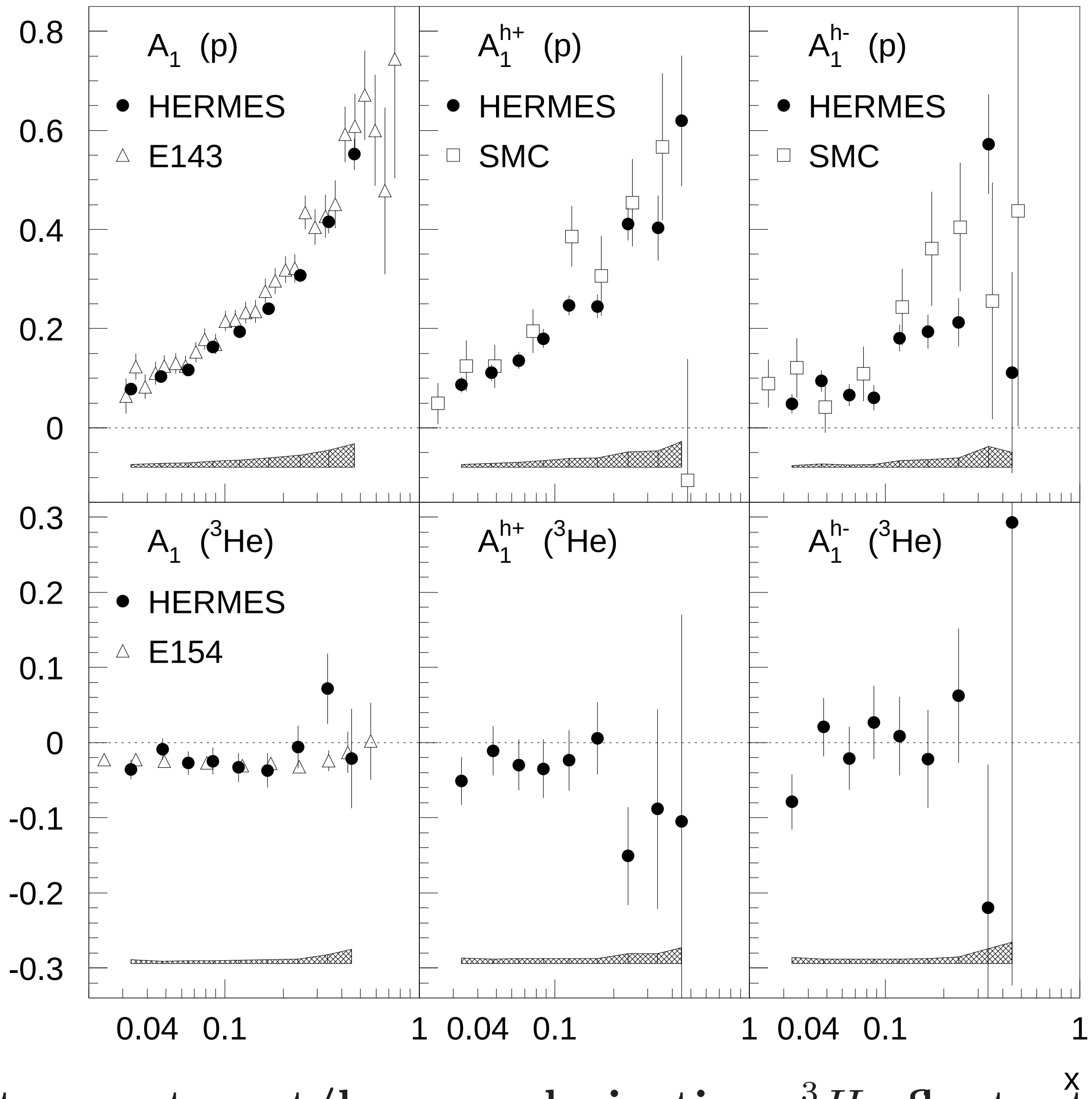
▷ **Fragmentation functions spin-independent**

Hadron Asymmetries

HERMES Data on $^3\overrightarrow{\mathrm{He}}$ (1995) $\overrightarrow{\mathrm{H}}$ (1996+1997)

To distinguish between current and target fragments, require:

$z = E_h/\nu \geq 0.2$ **and** $x_F \geq 0.1$ **and** $W^2 \geq 10GeV^2$



Syst. err: target/beam polarization, ^3He fluctuation, R.

K. Ackerstaff et al., Phys. Lett. B464 (1999) 123-134

Δq-Extraction

Global fit of inclusive and semi-inclusive p and n asymmetries.

- **Define Purities**

$$A_1^{\mathrm{h}}(x,Q^2) = \underbrace{\sum_q \frac{e_q^2 q(x) D_q^{\mathrm{h}}(z)}{\sum_{q'} e_{q'}^2 q'(x) D_{q'}^{\mathrm{h}}(z)}}_{P_q^h(x,z)} \frac{\Delta q(x)}{q(x)}$$

Purity $P_q^h(x,z)$ gives probability that a quark q(x) was struck when a hadron h(z) is detected.

- **Solve**

$$\vec{\mathcal{A}} = \mathcal{P}\vec{\mathcal{Q}}$$

$$\vec{\mathcal{A}} = \begin{pmatrix} A^{h_1}(x) \\ \dots \\ A^{h_m}(x) \end{pmatrix}, \vec{\mathcal{Q}} = \begin{pmatrix} \Delta q_1(x)/q_1(x) \\ \dots \\ \Delta q_n(x)/q_n(x) \end{pmatrix}, \mathcal{P} = \left[P_q^h(x)\right]$$

where $P_q^h(x) = \int_{z_{min}}^1 P_q^h(x,z)dz$

- **by minimizing**

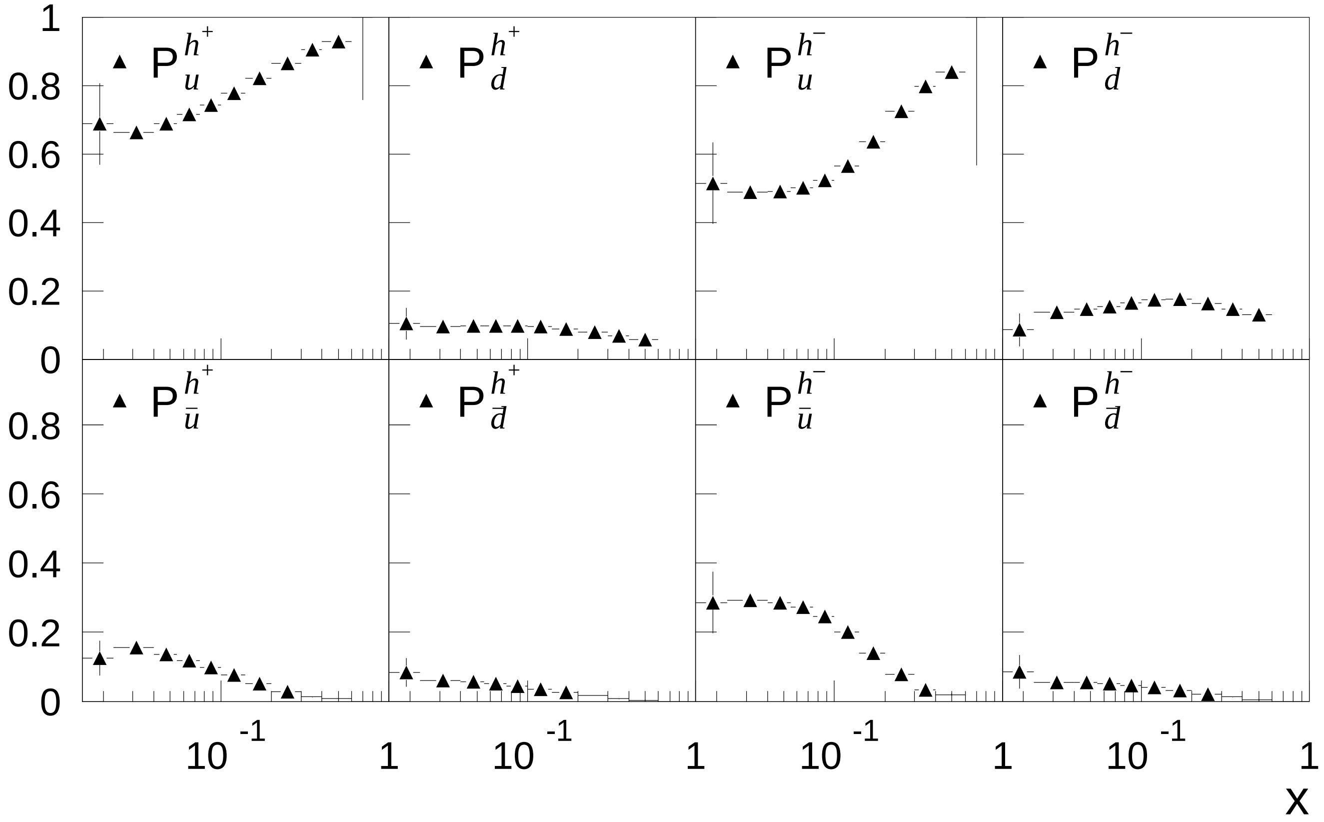
$$\chi^2 = (\vec{\mathcal{A}} - \mathcal{P}\cdot\vec{\mathcal{Q}})^T \nu_{\vec{\mathcal{A}}}^{-1} (\vec{\mathcal{A}} - \mathcal{P}\cdot\vec{\mathcal{Q}})$$

Proton Purity Functions

Purities are *spin-independent* quantities, determined by MC (LUND, $q_f(x)$ param.)

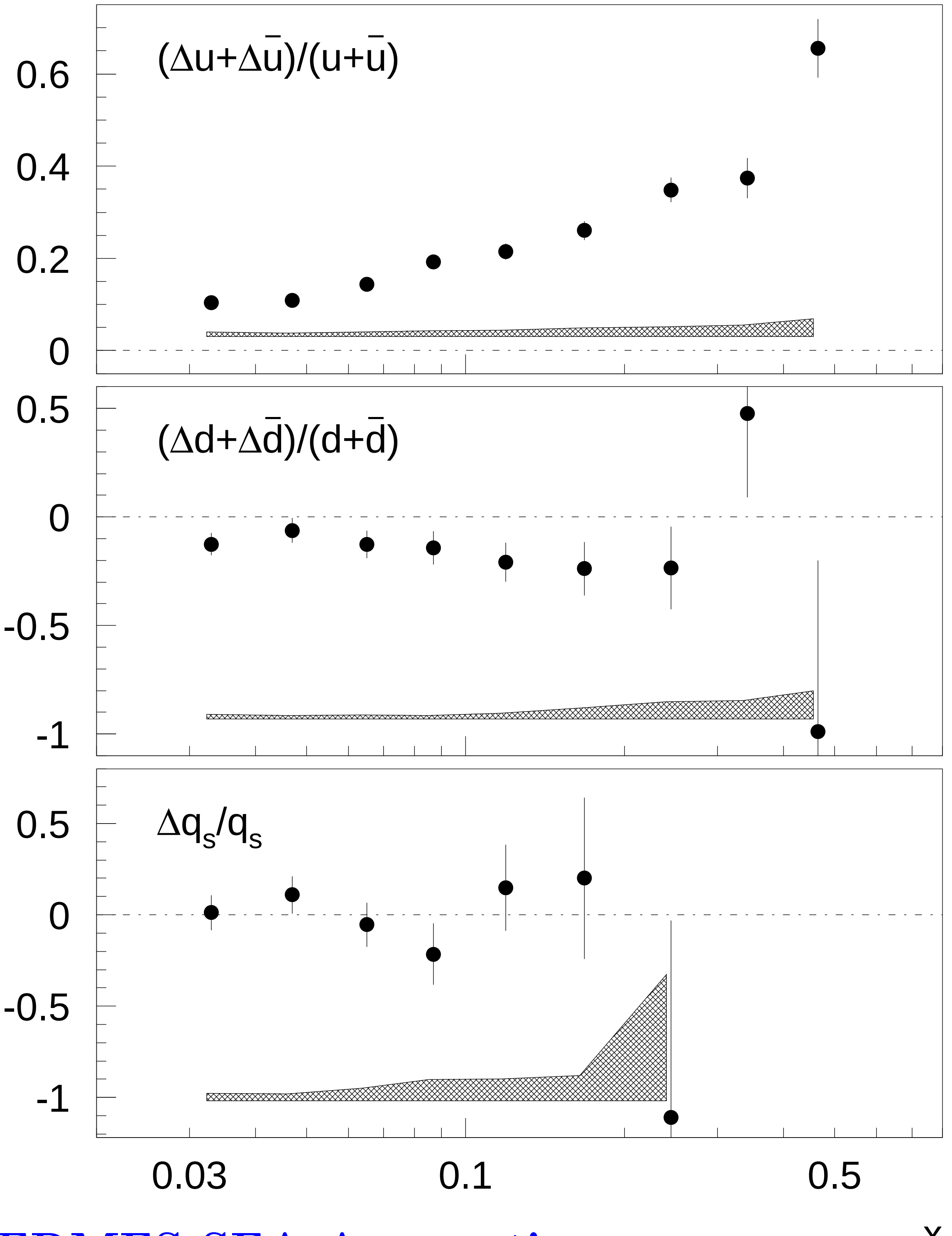
For proton target

positive hadrons negative hadrons



- h^+, h^- asymmetries on the proton dominated by $\Delta u(x)$
- Sensitivity to $\Delta d(x) = \Delta u_n(x)$ via neutron (^{3}He-data)
- Sensitivity to $\Delta \bar{u}(x)$ & $\Delta \bar{d}(x) \sim 10\%$ for $x \leq 0.2$

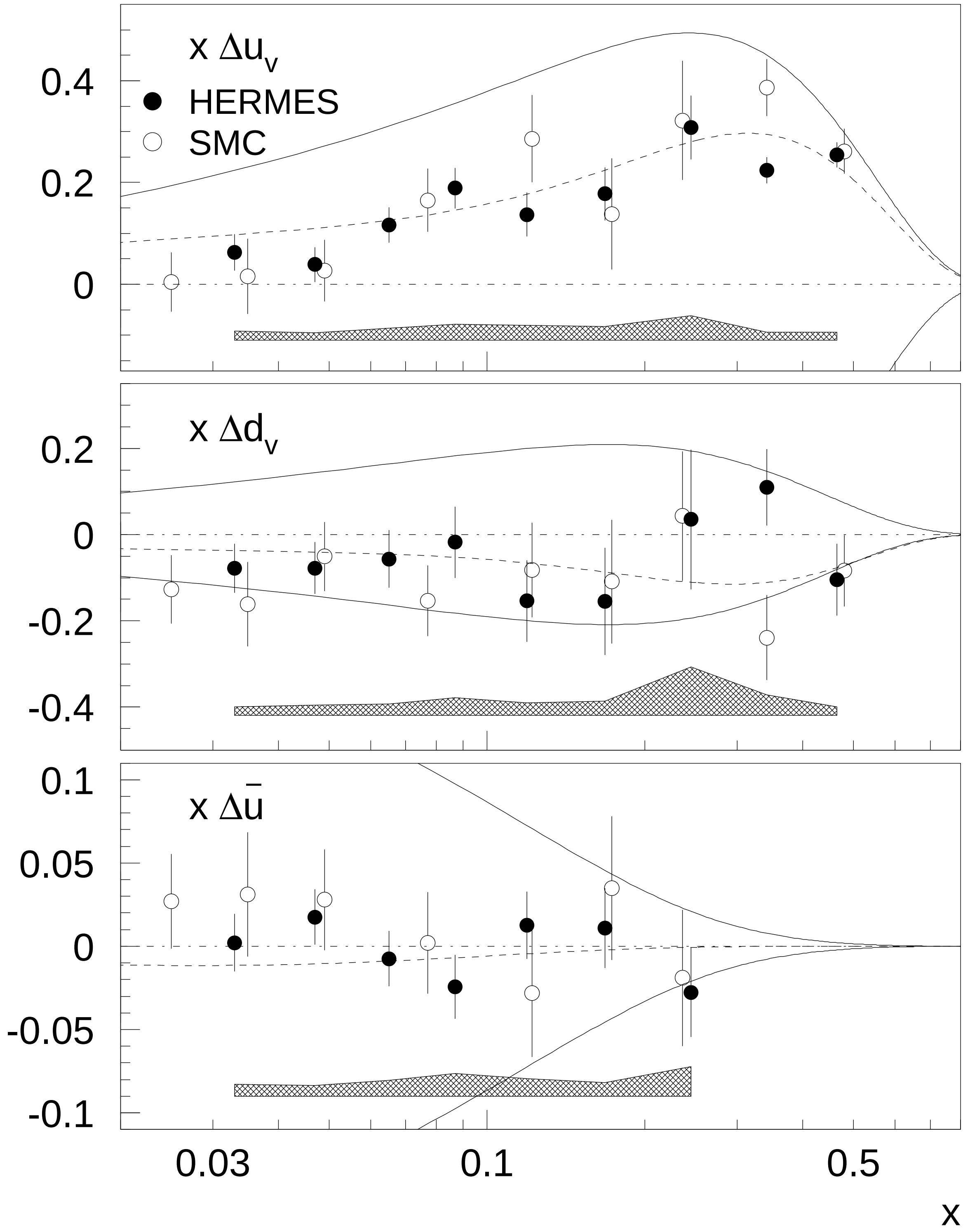
Flavor Decomposition



HERMES SEA Assumption:

$$\frac{\Delta u_s(x)}{u_s(x)} = \frac{\Delta d_s(x)}{d_s(x)} = \frac{\Delta s(x)}{s(x)} = \frac{\Delta\overline{u}(x)}{\overline{u}(x)} = \frac{\Delta\overline{d}(x)}{\overline{d}(x)} = \frac{\Delta\overline{s}(x)}{\overline{s}(x)}$$

Valence and Sea Quark Distributions



Remark: SMC has different SEA Assumption:
$\Delta u_s = \Delta d_s = \Delta s = \Delta \bar{u} = \Delta \bar{d}$

HERMES flavor decomposition

$$Q^2 = 2.5\ \mathbf{GeV}^2$$

	Direct measurement total integral[1]	prediction[2] inclus. $SU(3)$	NQPM
$\Delta u + \Delta\bar{u}$	$0.57 \pm 0.02 \pm 0.03$	0.66 ± 0.03	$\frac{4}{3}$
$\Delta d + \Delta\bar{d}$	$-0.25 \pm 0.06 \pm 0.05$	-0.35 ± 0.03	$-\frac{4}{3}$
$\Delta s + \Delta\bar{s}$	$-0.01 \pm 0.03 \pm 0.04$	-0.08 ± 0.02	0
$\Delta\Sigma$	$0.30 \pm 0.04 \pm 0.07$	0.23 ± 0.04	0

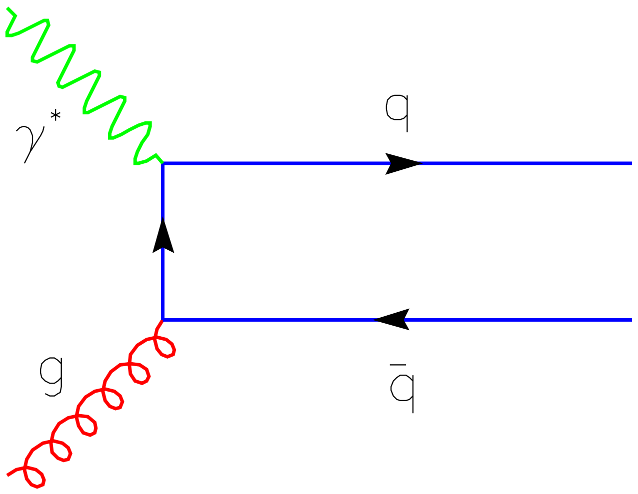
[1] **Low-x extrapolation via Regge parameterization.**
[2] **J. Ellis and M. Karliner, Phys. Lett. B 341 (1995) 397; hep-ph/9601280**

Remark:
Neither results represents direct measurement of Δ_S
$\triangleright$ **HERMES Dual-radiator RICH (1998) offers possibility of direct measurement through Kaon identification.**

K. Ackerstaff et al, Phys. Lett. B464 (1999) 123-134.

High p_t

- Photon gluon fusion process probe $G(x_G)$
- Spin asymmetry in Photon gluon fusion probe $\Delta G/G$



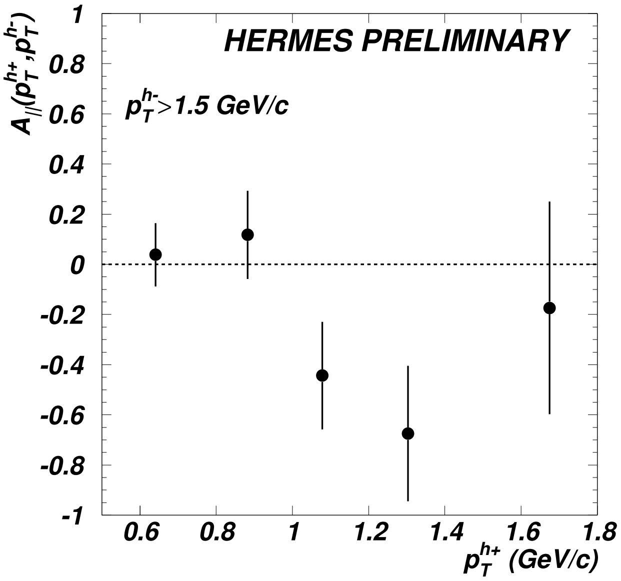
HERMES:
→ Measure asym of high p_T hadron pairs
→ Choose phase space where $(\gamma g \to q\bar{q})$ dominates
Require:

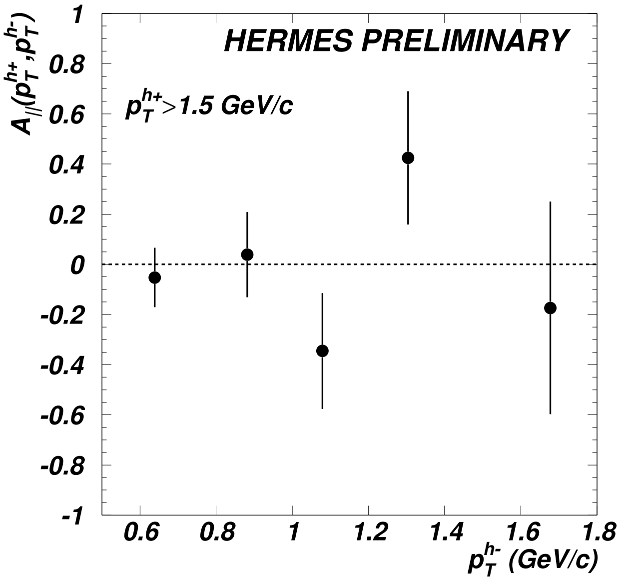
- at least **one h^+ and one h^-.**
- high momentum ($p_{h^\pm}$ >4.5 GeV) and high p_T (p_T >0.5 GeV).
- $M(2h) > 1.0$ **GeV**, to remove ρ and ϕ resonances.
- do not require scattered e^+ in the spectrometer $\Rightarrow$ Photoproduction $Q^2 \approx 0$ (maximize cross sect.)

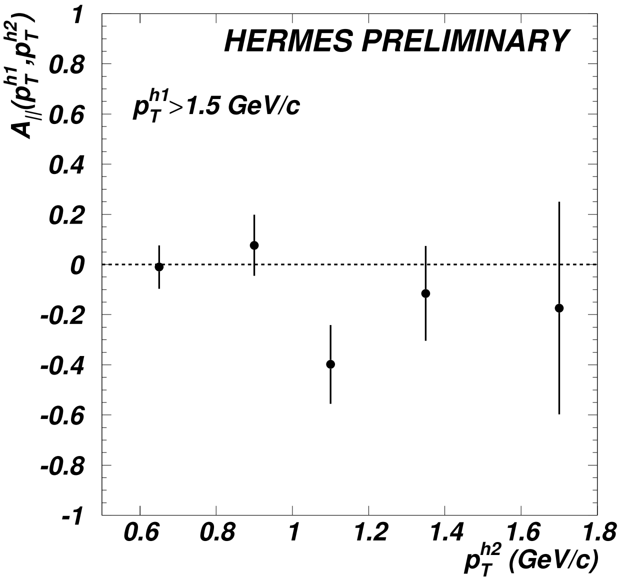
Data $A_{||}(p_T^{h^+}, p_T^{h^-})$

Cross section asymmetry:

$$A_{||} = \frac{N^{\uparrow\downarrow}L^{\uparrow\uparrow} - N^{\uparrow\uparrow}L^{\uparrow\downarrow}}{N^{\uparrow\downarrow}L_P^{\uparrow\uparrow} + N^{\uparrow\uparrow}L_P^{\uparrow\downarrow}}$$







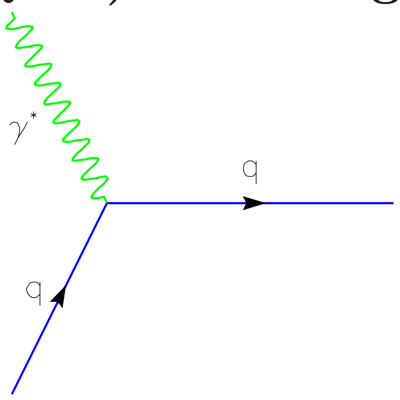
$p_T^{h_1} > 1.5,\ p_T^{h_2} > 1\text{GeV}$

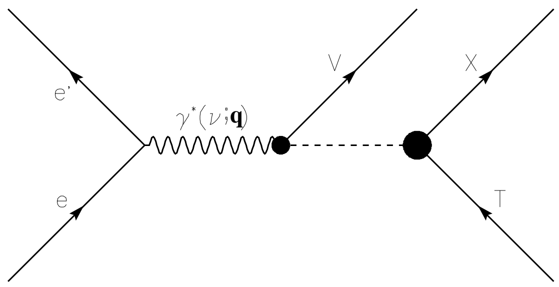
$\boxed{\langle A_{||} \rangle = -0.28 \pm 0.12 \pm 0.02}$

Negative asymmetry, ($\leftrightarrow$ to DIS asymmetry.)

Interpretation

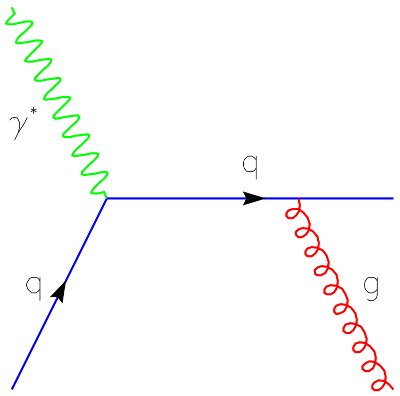
Assume four different processes may contribute (in LO QCD) to the high p_T h$^{\pm}$ pair production:

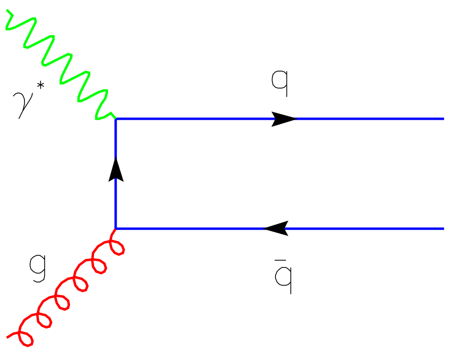




DIS
negligible contribution

VMD
assume $\mathbf{A}_{VMD} = \mathbf{0}$





QCDC
$A_{QCDC} \sim \frac{\Delta q}{q}$

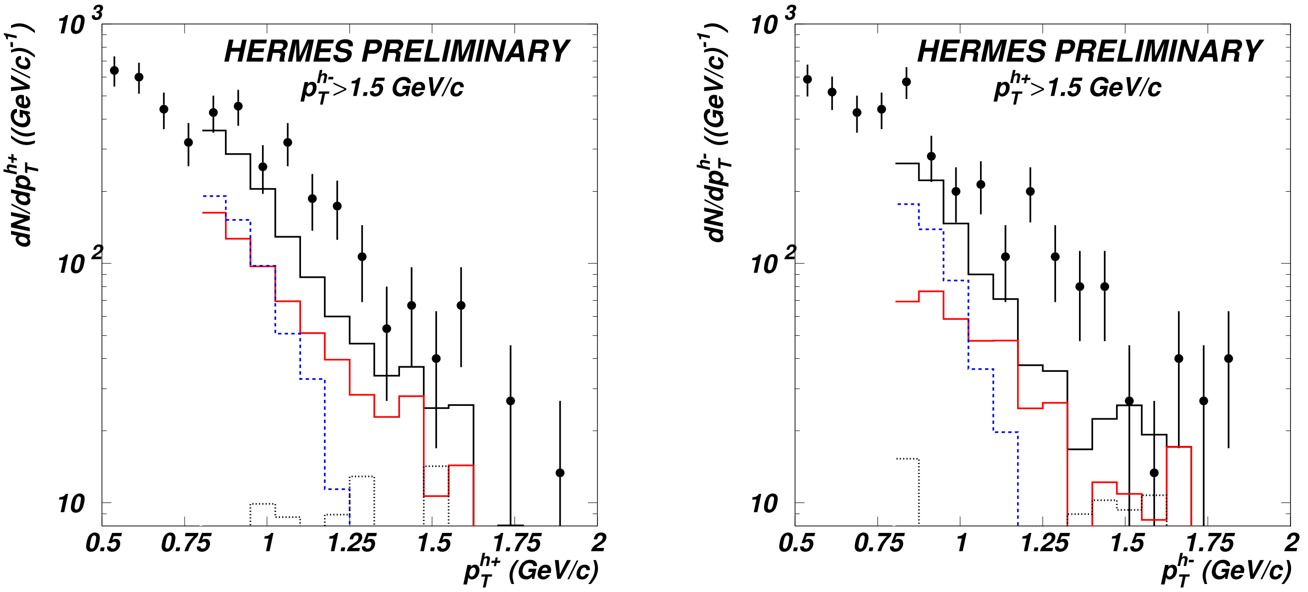
PGF
$A_{PGF} \sim \frac{\Delta G}{G}$

Their spin asymmetries can contribute to the measured asymmetry:

$A_{||} = A_{\mathrm{QCDC}} f_{\mathrm{QCDC}} + A_{\mathrm{PGF}} f_{\mathrm{PGF}} + A_{\mathrm{DIS}} f_{\mathrm{DIS}} + A_{\mathrm{VMD}} f_{\mathrm{VMD}}$

.. estimate their relative contributions.

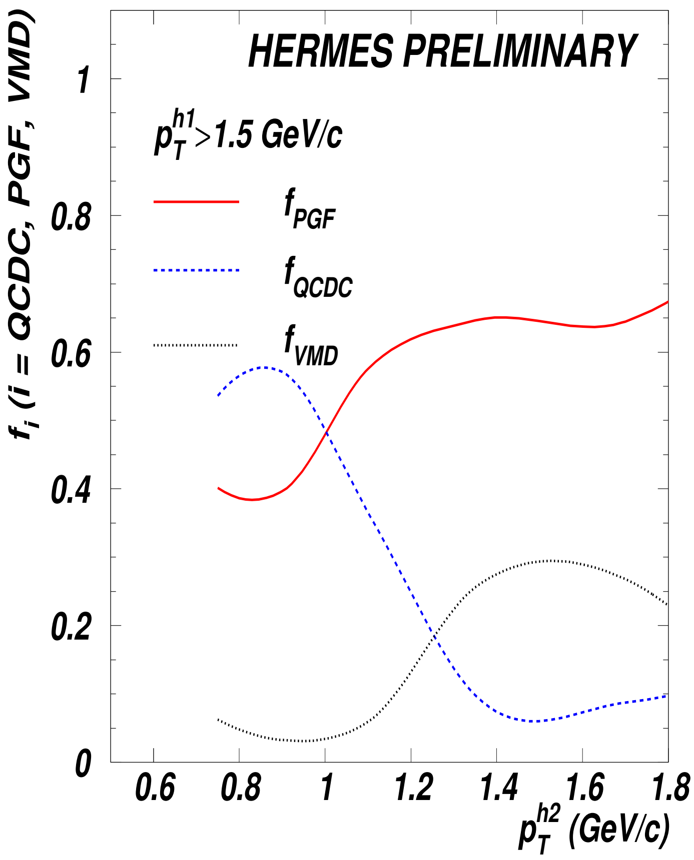
Contributions from PYTHIA model



black = total, red = PGF, blue = QCDC, dotted black = VMD

Process fractions f_i:
($f_{DIS} \approx 0$ from LEPTO)

$\Rightarrow$ PGF dominates where negative asymmetry is observed.



Model For $A_\parallel$ Interpretation

- **Use Pythia (LO QCD) to determine the unpolarized fractions f_i of the assumed four cross section contributions**

$$A_\parallel = D \sum_{i=1}^{4} f_i \cdot A_i$$

$i =$ **dis, vmd, qcdc, and pgf.**

- **LEPTO** $f_{\mathrm{DIS}} \approx 0$ **at** $\langle Q^2 \rangle = 0.06\ \mathrm{GeV}^2$
- **assume** $A_{\mathrm{VMD}} \approx 0$
- **calculate** $\langle D(y) \rangle = 0.9$ **depolarization factor**

$$A_\parallel \approx D(f_{\mathrm{QCDC}} A_{\mathrm{QCDC}} + f_{\mathrm{PGF}} A_{\mathrm{PGF}})$$

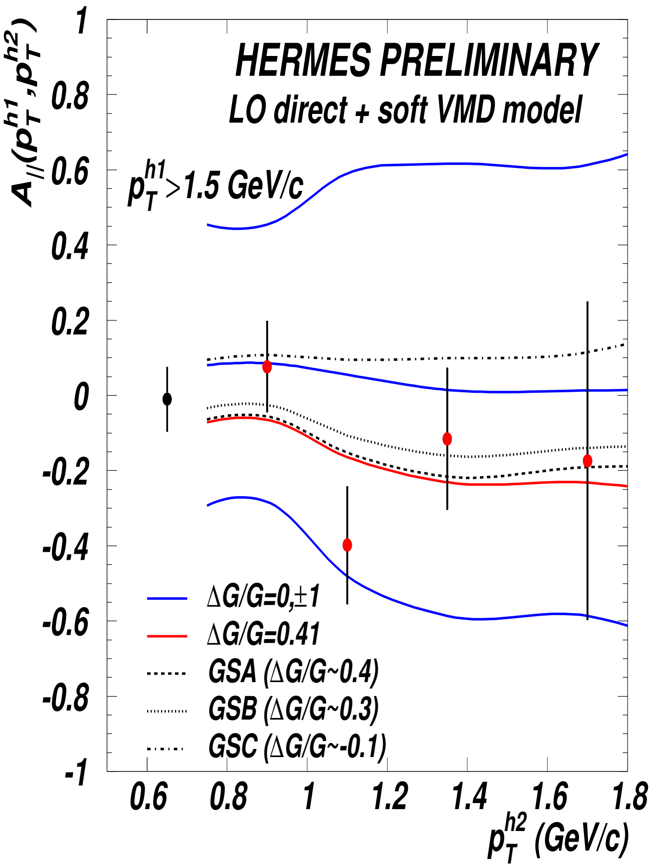
in small region of phase space one can write:

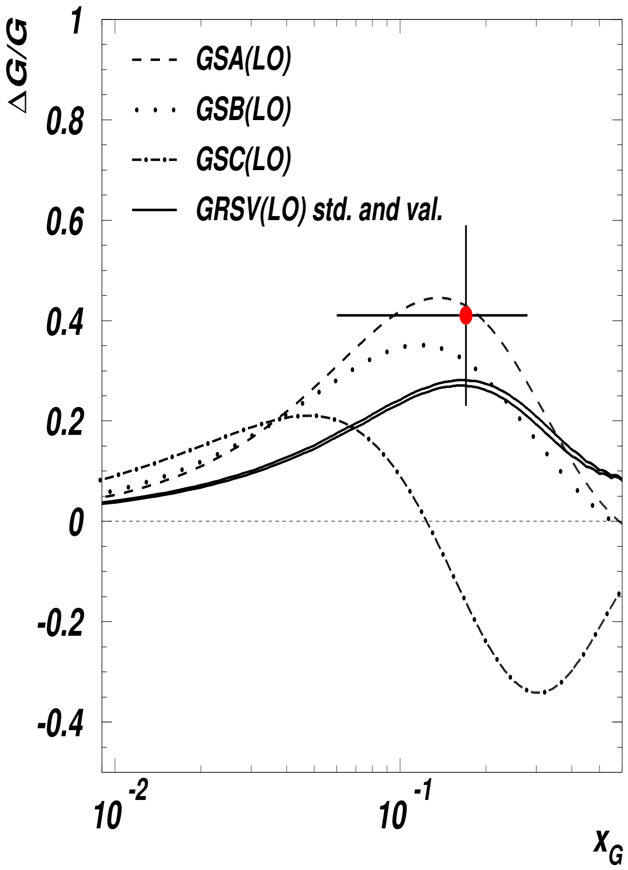
$$A_{\mathrm{PGF}} \approx \langle \hat{a}(\gamma g \to q\bar{q}) \rangle \left\langle \frac{\Delta G}{G} \right\rangle = \langle \hat{a}_{\mathrm{PGF}} \rangle \left\langle \frac{\Delta G}{G} \right\rangle$$
$$A_{\mathrm{QCDC}} \approx \langle \hat{a}(\gamma q \to qg) \rangle \left\langle \frac{\Delta q}{q} \right\rangle = \langle \hat{a}_{\mathrm{QCDC}} \rangle \left\langle \frac{\Delta q}{q} \right\rangle$$

- **LO QCD:** $\langle \hat{a}_{\mathrm{PGF}} \rangle = -1$
  $\langle \hat{a}_{\mathrm{QCDC}} \rangle = +1/2$

Result Using PYTHIA Model

$$\Delta G/G = +0.41 \pm 0.18 \text{ (stat.)} \pm 0.03 \text{ (exp.syst.)}$$
$$\textbf{at } \langle x_G \rangle = 0.17 \textbf{ and } \langle \hat{p}_T^2 \rangle = 2.1 \textbf{ GeV}^2$$





$\Delta G/G$ is positive

A. Airapetian et al, Phys. Rev. Lett. (in press)
hep-ex/9907020 **and** *DESY-99-071*

Single Spin Asymmetries.

HERMES: Spin structure of the nucleon

- Double Spin Asymmetries:

  Polarized Beam and Target.

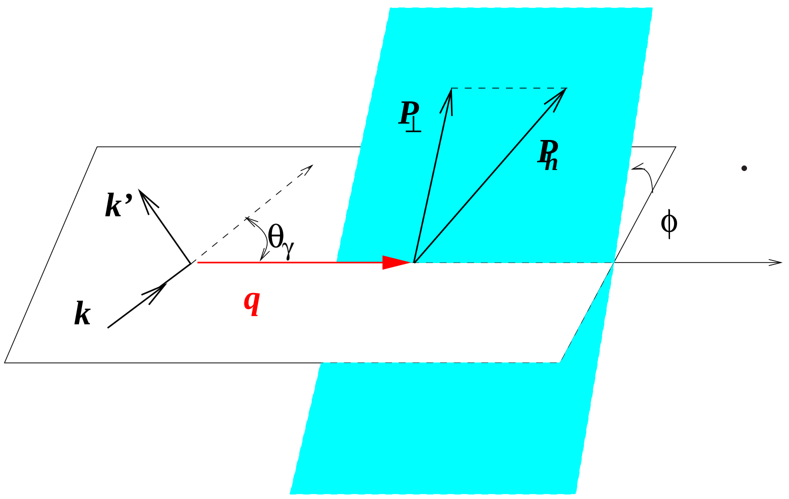
  $g_1^n \; g_1^p \; \Delta q \; \cdots$

  Longitudinal quark polarization densities.

- Single Spin Asymmetry (SSA):

  Polarized Beam or Target.

  Transverse quark polarization densities,



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Chiral odd DF

$\Downarrow$

Time-odd Collins FF

$\Downarrow$

SSA

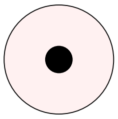
Naive parton models, non interacting collinear parton
Parity, Angular momentum, Helicity conservation

$$\Rightarrow \; \text{SSA} = 0$$

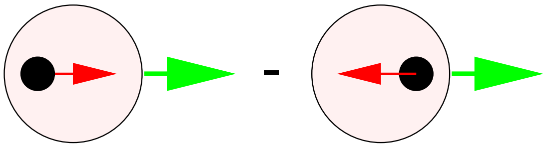
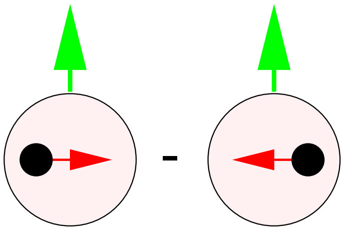
SSA originates from multi-parton correlation and vanish when PQCD becomes effective.

Interpretation of distribution functions.

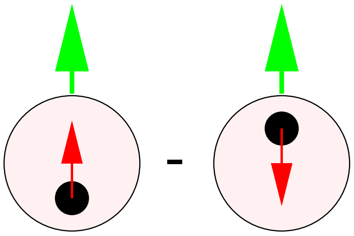
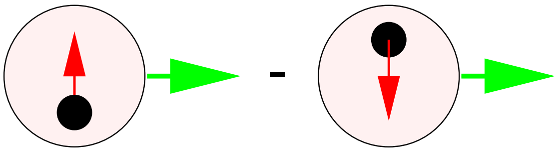
Recent classification by Mulders & Co.

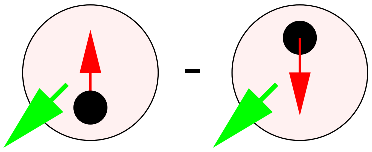
$f_1 =$ 

Unpolarized quark in unpolarized nucleon.

$g_{1L} =$  $g_{1T} =$ 

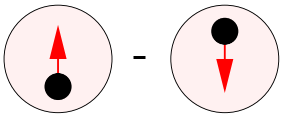
Longitudinall quark in longitudinal and transverse nucleon.

$h_1 =$  $h_{1L}^{\perp} =$ 

$h_{1T}^{\perp} =$ 

Transverse quark in longitudinal and transverse nucleon.

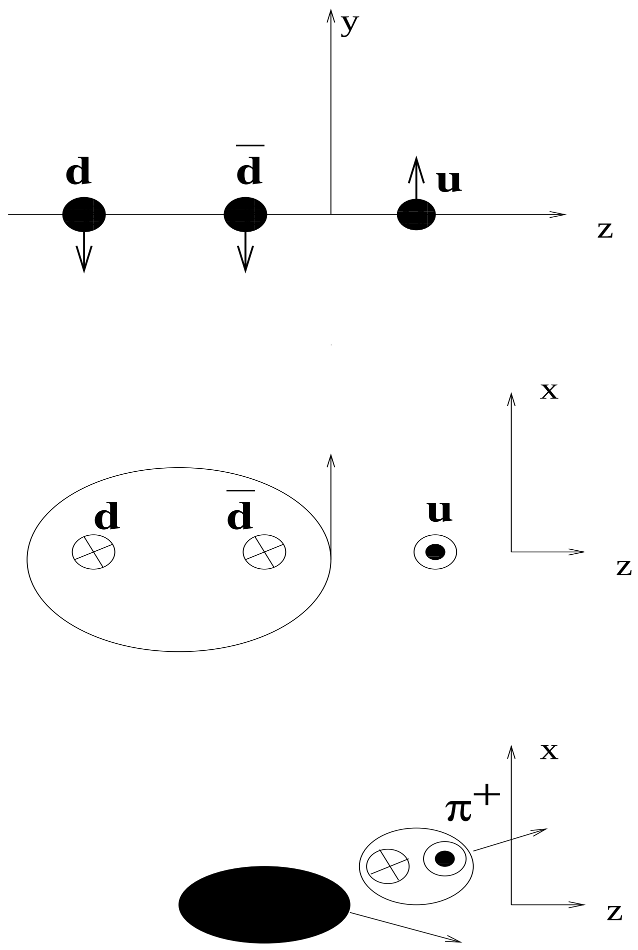
COLLINS FF:

$H_1^{\perp} =$ 

COLLINS FF

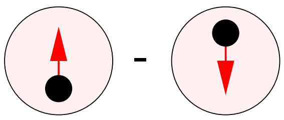
transverse quark polarimeter

Simple interpretation by Artru (Semi classical string model). `X. Artu et al.  hep-ph/9508239`



Correlation between the spin of the valance quark and the transverse momentum of the outgoing $\bar{q}$ (pion).

COLLINS FF:

$H_1^{\perp} =$ 

Contributions to $\sin\phi$

$$\mathcal{A}_{UL}^{\sin\phi} = \frac{\frac{L^+}{L_P^+}\int_0^{2\pi}\sin\phi\;\mathrm{d}N_+ \;-\; \frac{L^-}{L_P^-}\int_0^{2\pi}\sin\phi\;\mathrm{d}N_-}{\frac{1}{2}[\int_0^{2\pi}\mathrm{d}N_+ \;+\; \int_0^{2\pi}\mathrm{d}N_-]}$$

P. Mulders and R. Tangerman, Nucl. Phys. B461 (1996) 197

- Chirality structure of DF $\otimes$ FF : even
- Time reversal structure of DF $\otimes$ FF : odd

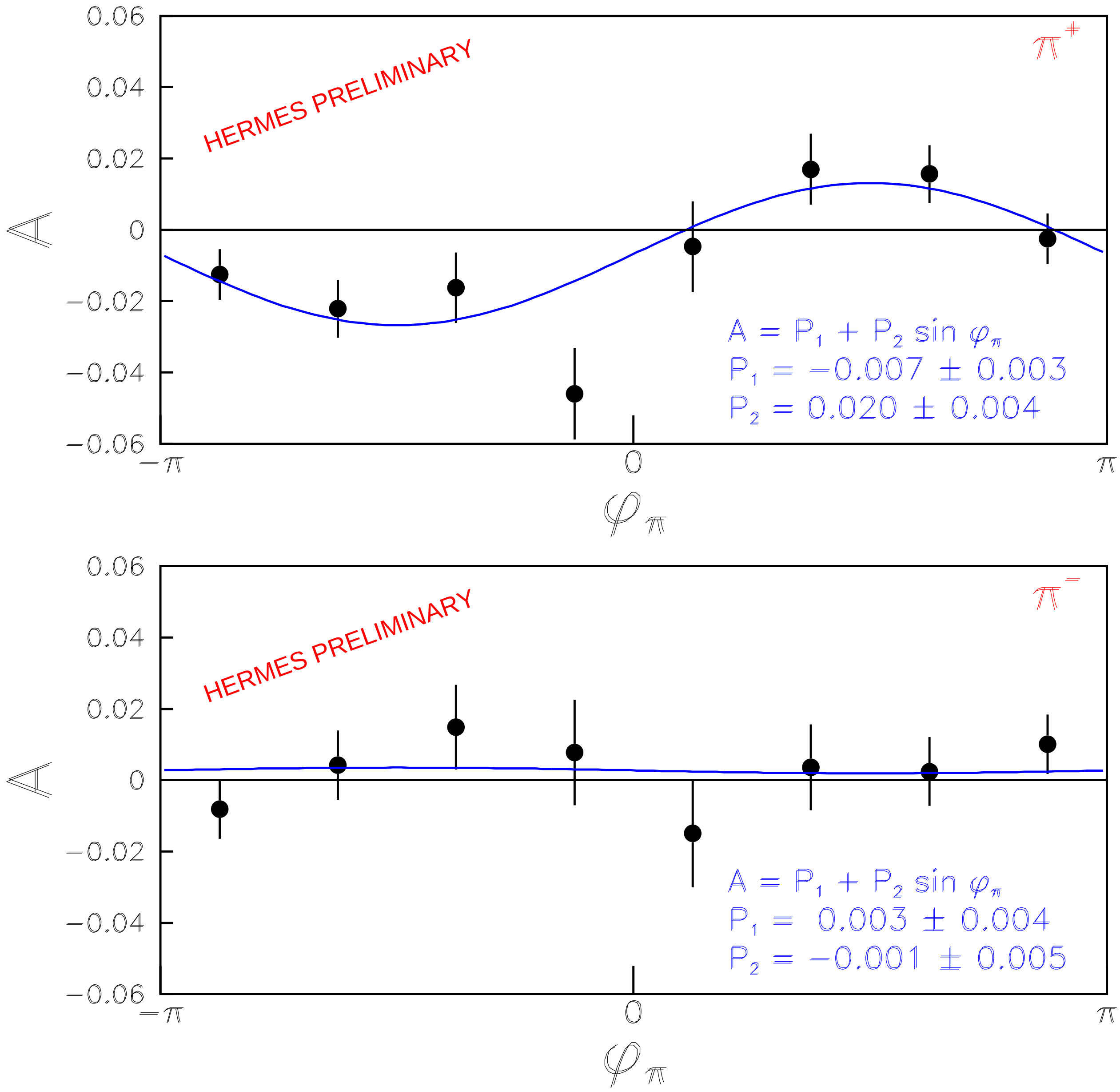
		T-even DF		T-odd FF	
		chirality		chirality	
		even	odd	even	odd
twist 2	U	$\mathbf{f}_1$			$H_1^\perp$
	L	$\mathbf{g}_{1L}$	$h_{1L}^\perp$		
	T	g_{1T}	$\mathbf{h}_1$ $h_{1T}^\perp$	$D_{1T}^\perp$	
twist 3	U	$f^\perp$	$\mathbf{e}$		$\mathbf{H}$
	L	$g_L^\perp$	$\mathbf{h}_L$	$D_L^\perp$	E_L
	T	$\mathbf{g}_T$ $g_T^\perp$	h_T $h_T^\perp$	$\mathbf{D_T}$	E_T

$$\begin{aligned} < \sin\phi >_{UL} \quad &\propto \quad S_L \sum_{a,\bar{a}} e_a^2 x h_L^a(x) H_1^{\perp a}(z) \\ &+ \quad S_T \sum_{a,\bar{a}} e_a^2 x h_1^a(x) H_1^{\perp a}(z) \end{aligned}$$

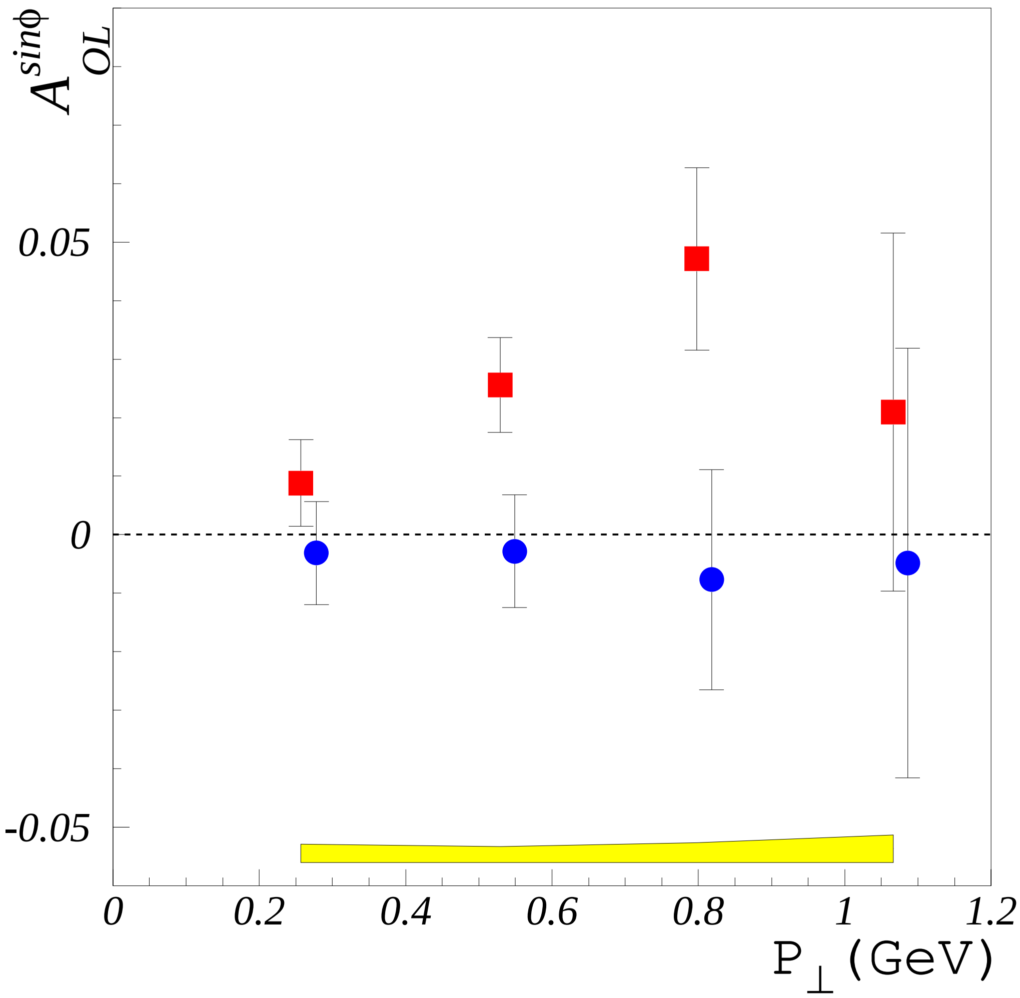
HERMES, Longitudinally polarized target:
$S_T << S_L$

Cross section Asymmetry

Asymmetry in the cross section $A(\phi) = \frac{1}{P_H} \frac{N^+ - N^-}{N^+ + N^-}$.



SSA $\mathcal{A}_{UL}$: $P_\perp$ dependence



$$\pi^+ \quad \mathcal{A}_{UL}^{sin\phi} \quad = \quad 0.022 \pm 0.005(stat) \pm 0.003(syst)$$

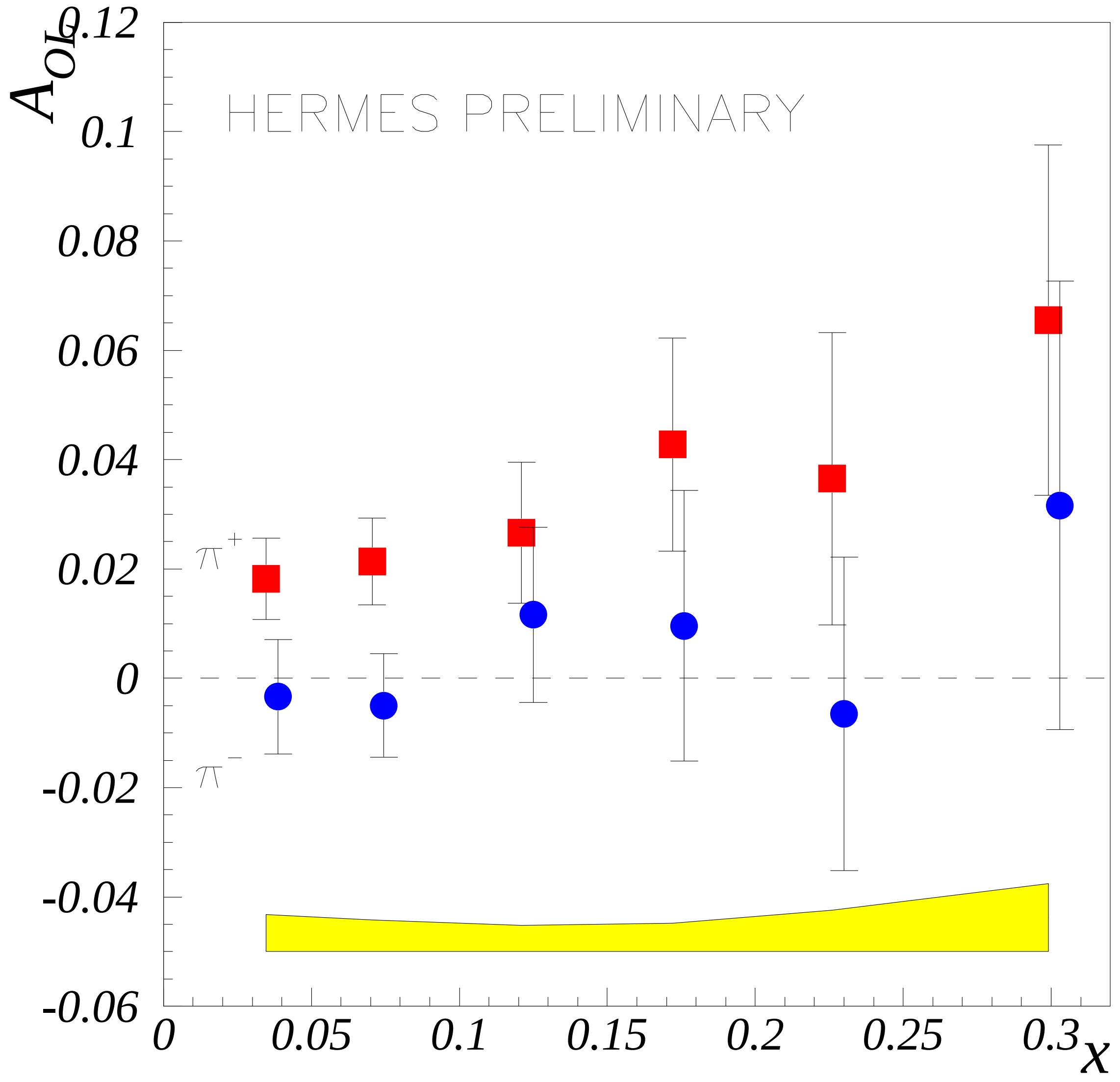
$$\pi^- \quad \mathcal{A}_{UL}^{sin\phi} \quad = \quad -0.005 \pm 0.008(stat) \pm 0.004(syst)$$

$$\pi^+ \quad \mathcal{A}_{UL}^{sin\phi} \quad \propto \quad \frac{4}{9} h_L^u \mathbf{H_1^{\perp u \rightarrow \pi^+}} + \frac{1}{9} h_L^d H_1^{\perp d \rightarrow \pi^+}$$

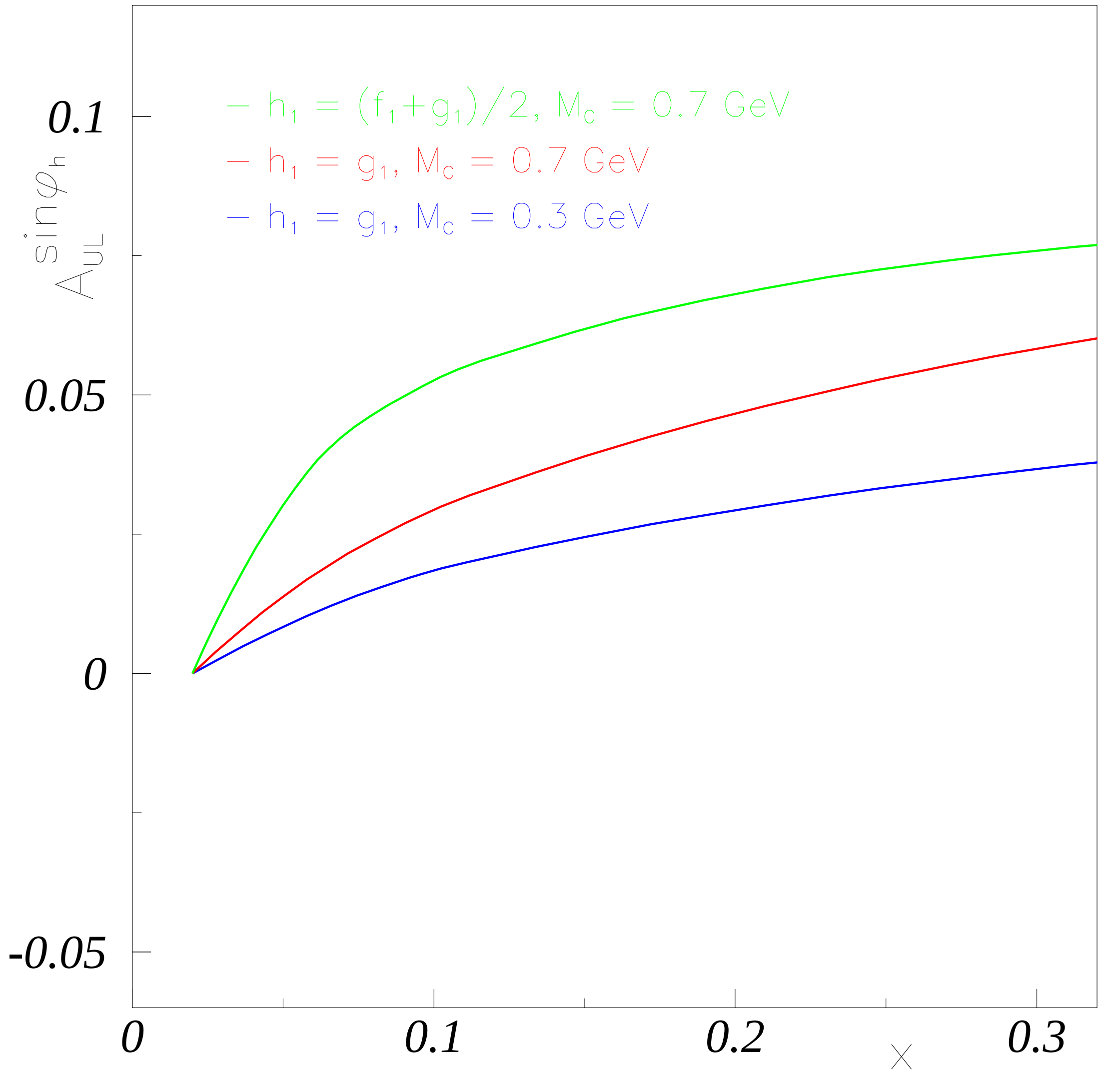
$$\pi^- \quad \mathcal{A}_{UL}^{sin\phi} \quad \propto \quad \frac{4}{9} h_L^u H_1^{\perp u \rightarrow \pi^-} + \frac{1}{9} h_L^d \mathbf{H_1^{\perp d \rightarrow \pi^-}}$$

A. Airapetian et al, submitted to Phys. Rev. Lett.
hep-ex/9910062 and *DESY-99-149*

SSA $\mathcal{A}_{UL}$: x dependence



SSA $\mathcal{A}_{UL}$, x dependence: THEORY



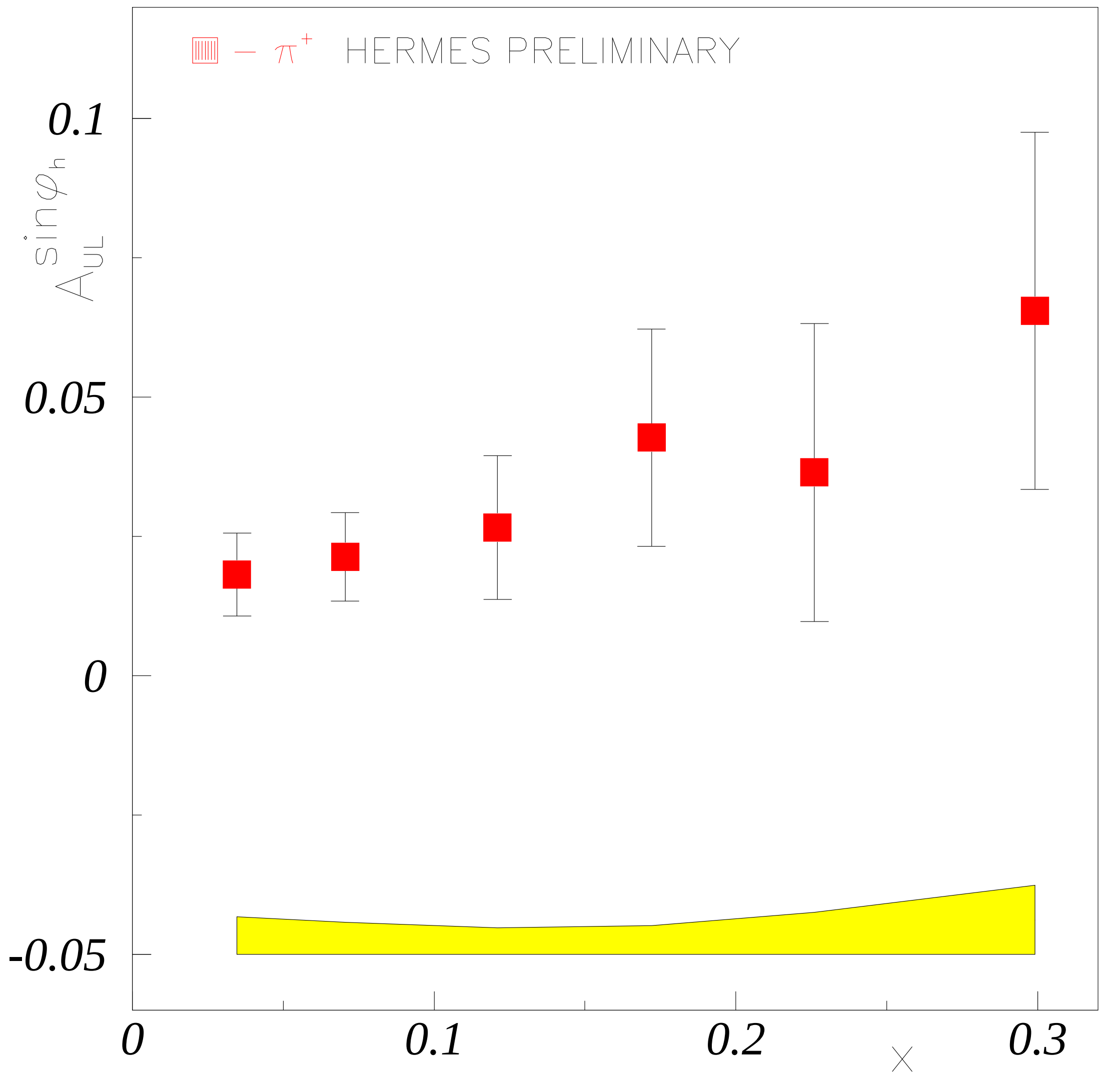
Curves: *A.M. Kotzinian et al., Proc. Nucleon99, hep-ph/9908466*

Assuming:

$$h_{1L}^{\perp}(x) \sim h_L(x) \approx h_1(x) \approx g_1(x)$$

$$\Rightarrow \frac{\sigma_{UL}}{\sigma_{OO}} \propto x \frac{g_1(x)}{f_1(x)}$$

SSA $\mathcal{A}_{UL}$, x dependence: π^+



Polarized results not presented

Polarized Physics Program

- **Longitudinal Spin Transfer to Λ**
- **Spin asymmetries in diffractive Vector Meson Production**

Unpolarized Physics Program

- **longitudinal and transverse polarization of Λ**
- $\bar{u}/\bar{d}$
- **Fragmentation Functions for light quarks $\longrightarrow \pi$, K, P, Λ**
- **Diffractive Vector Meson Production (coherence length effect).**
- $\mathbf{F_2}^{N/He/Kr}/\mathbf{F_2}^{D} \longrightarrow$ **nuclear effects on σ_L/σ_T**

Summary and outlook

Flavor Decomposition

- Δu **positive**
- Δd **negative**
- Δq_{Sea} **compatible with** 0
- $\rightarrow$ **2000 longitudinal** $\vec{D}$ **target**
  - ▷ $\Delta d_v(x)$, $\Delta u_v(x)$
- **Dual RICH**
  - ▷ **Direct measurement of sea polarization** $\Delta s(x)$,$\Delta \bar{u}(x)$, $\Delta \bar{d}(x)$

High p_T

- $\Delta G/G$ **positive at** $\langle x_G \rangle = 0.17$
- $\rightarrow$ **2000 longitudinal** $\vec{D}$ **target**
  - ▷ **enhanced stat, diff.** *signal/background*
- **Dual RICH +** μ **walls**
  - ▷ **Open charm,** J/ψ $\frac{\Delta G}{G}$ @ $x_G \sim 0.3$

Single Spin Asymmetries

- $\pi^+ \quad \mathcal{A}_{UL}^{sin\phi} \simeq 2\%$
- $\pi^- \quad \mathcal{A}_{UL}^{sin\phi} \simeq 0$
- **2001 Transversely polarized target ?**
  - ▷ **transversity,** h_1