Spin Structure of Nucleons

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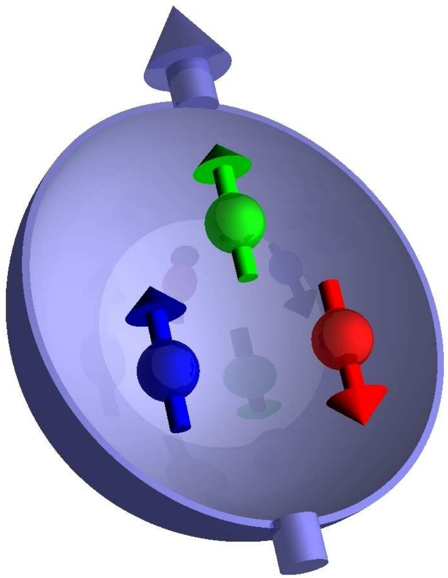
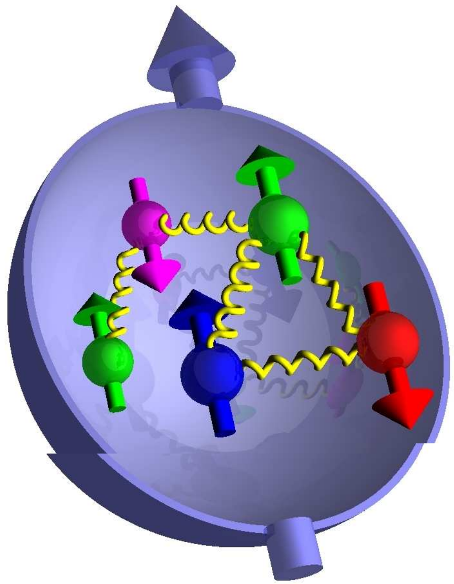
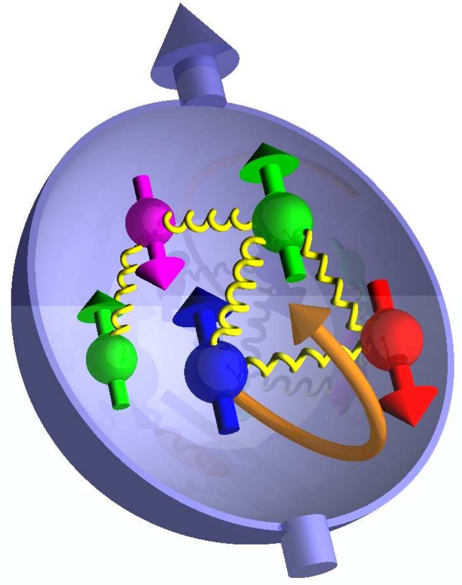






Naive Quark-Parton Model:

- $\Delta q_u = \frac{4}{3} \quad \Delta q_d = -\frac{1}{3}$

$\Delta\Sigma = \Delta q_u + \Delta q_d + \Delta q_s = 1$

Relat. Quark-Parton Model:

- Quark spin: $\Delta\Sigma \approx 0.6$

EMC [PLB206(1988)364]:

$\Delta\Sigma = 0.060 \pm 0.047 \pm 0.069$

HERA collider results:

- Gluons are important

$\Longrightarrow$ Measure ΔG!

at: COMPASS, HERMES, RHIC

Since: $\Delta q_f = \Delta q_f^{val} + \Delta q_f^{sea}$

$\Longrightarrow$ Measure Δq_f^{sea}!

at: HERMES, polar. RHIC

Proton spin budget:

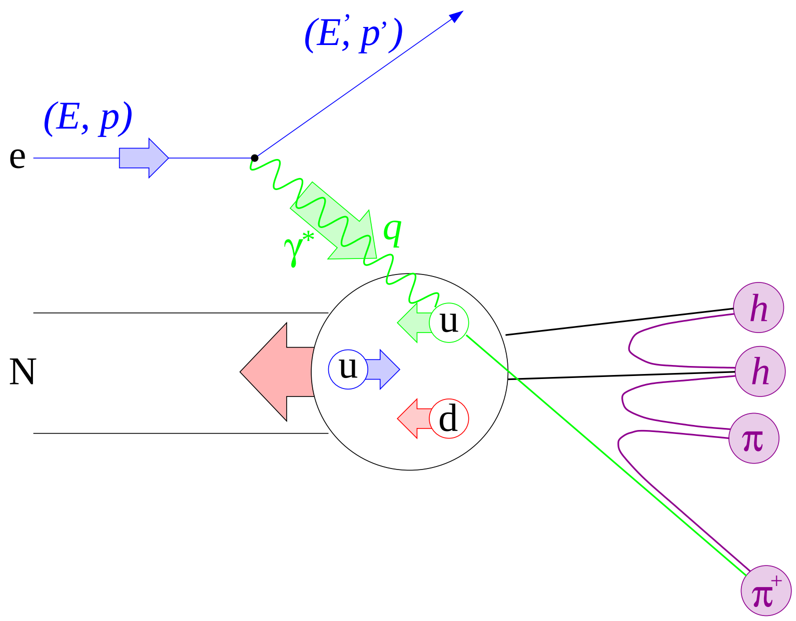
- $J = \frac{1}{2} = J^Q(\mu) + J^G(\mu)$
- $J^G = \Delta G + L^G$
- $J^Q = \frac{1}{2}\Delta\Sigma + L^Q$

L^Q : Quark orb. ang. mom.

$\Longrightarrow$ Measure J^Q : DVCS!

at: HERMES, JLAB

DIS: Kinematics, Cross Sections, Asymmetry



Virtual-photon kinematics:

$$Q^2 = -q^2 \qquad \nu = E - E'$$

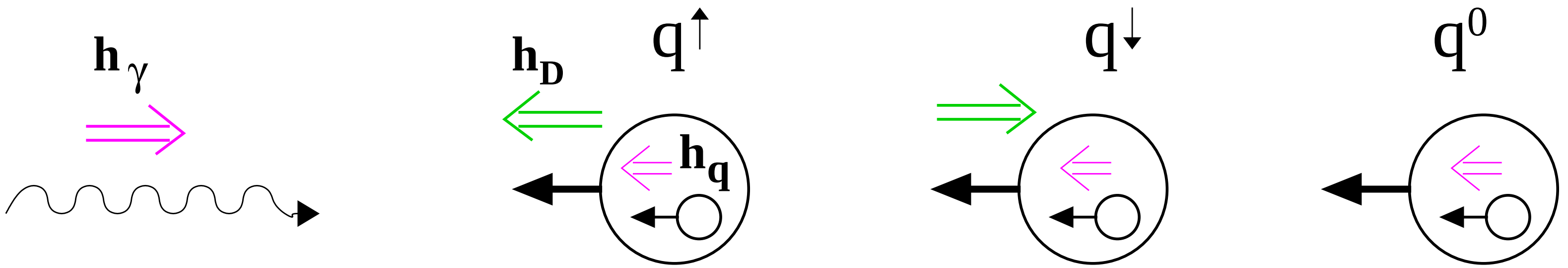
Fraction of nucleon momentum carried by struck quark: $x = \frac{Q^2}{2M\nu}$

fraction of virtual-photon energy carried by produced hadron h: $z = \frac{E_h}{\nu}$

Hadron transverse momentum: $P_{h\perp}$

- Unpolarized cross section: $\sigma_{UU} \equiv \frac{1}{2}(\sigma^{\overleftarrow{\Leftarrow}} + \sigma^{\overrightarrow{\Rightarrow}})$
- Cross section (helicity) difference: $\sigma_{LL} \equiv \frac{1}{2}(\sigma^{\overleftarrow{\Leftarrow}} - \sigma^{\overrightarrow{\Rightarrow}})$
- Double-spin asymmetry: $A_{||} \equiv \frac{\sigma_{LL}}{\sigma_{UU}} \simeq \frac{g_1}{F_1}$ (neglecting small g_2 contribution)
- Measured asymmetry: $A_{||} = \frac{1}{\langle P_T \rangle \langle P_B \rangle} \frac{(\frac{N}{L})^{\overleftarrow{\Leftarrow}} - (\frac{N}{L})^{\overrightarrow{\Rightarrow}}}{(\frac{N}{L})^{\overleftarrow{\Leftarrow}} + (\frac{N}{L})^{\overrightarrow{\Rightarrow}}}$

DIS Structure Functions in Quark-Parton Model



Spin-$\frac{1}{2}$ Nucleon	Spin-1 Deuteron
$F_1^{p,n} = \frac{1}{2}\sum_f e_f^2 \left(q_f^{\rightarrow} + q_f^{\leftarrow}\right) = \frac{1}{2}\sum_f e_f^2 q_f$	$F_1^d = \frac{1}{3}\sum_f e_f^2 \left(q_f^{\rightarrow} + q_f^{\leftarrow} + q^0\right)$
$g_1^{p,n} = \frac{1}{2}\sum_f e_f^2 \left(q_f^{\rightarrow} - q_f^{\leftarrow}\right) = \frac{1}{2}\sum_f e_f^2 \Delta q_f$	$g_1^d = \frac{1}{2}\sum_f e_f^2 \left(q_f^{\rightarrow} - q_f^{\leftarrow}\right)$
	$b_1^d = \frac{1}{2}\sum_f e_f^2 \left(2q_f^0 - (q_f^{\rightarrow} + q_f^{\leftarrow})\right)$

- g_1 measures a **certain combination of quark + anti-quark** helicity distributions $\Delta q_f = \Delta q_f^{val} + \Delta q_f^{sea}$

$\Rightarrow$ No new g_1 data published by HERMES or COMPASS during last 12 months

- b_1^d measures nuclear effects that make the deuteron look different from just the most simple proton-neutron system

Tensor Asymmetry in DIS on Deuteron

$$\frac{d^2\sigma_{\rm meas}}{dx dQ^2} = \frac{d^2\sigma_{\rm unpol}}{dx dQ^2}\left[1 - P_z P_B D A_1 + \frac{1}{2} P_{zz} A_{zz}\right]$$

- $\sigma_{\rm unpol} = \sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow} + \sigma^0$
- $P_{zz} = \frac{n^+ + n^- - 2n^0}{n^+ + n^- + n^0}$

$$A_{zz} = \frac{(\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}) - 2\sigma^0}{3\sigma_{\rm unpol} P^0_{zz}}$$

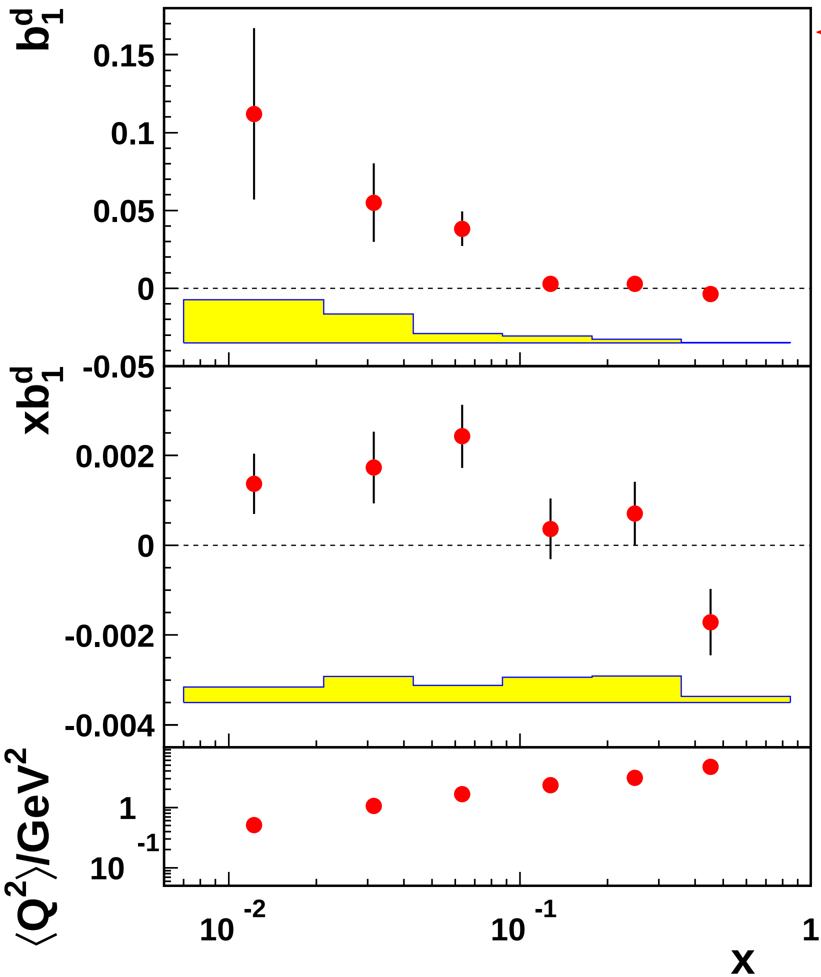
	vector term	tensor term
$\sigma^{\uparrow\uparrow}$	$+\lvert P_z \cdot P_B\rvert$	$+P^0_{zz}$
$\sigma^{\uparrow\downarrow}$	$-\lvert P_z \cdot P_B\rvert$	$+P^0_{zz}$
σ_0	< 0.01	$-2P^0_{zz}$

$$\lvert P_z \cdot P_B\rvert = 0.45 \pm 0.04$$
$$P^0_{zz} = 0.83 \pm 0.03$$

Tensor structure function b_1 from tensor asymmetry A_{zz}:

$$b_1^d = -\frac{3}{2} A^d_{zz} F^d_1 \qquad F^d_1 = \frac{1 + Q^2/\nu^2) F^d_2}{2x(1+R)}$$

Tensor Structure Function $b_1^d(x)$



$\Leftarrow$ HERMES result [PRL95 (2005) 242001]

Theory work < 1997:

- binding&Fermi motion effects at $x \geq 0.2$

Theory ≥ 1997: Double scattering

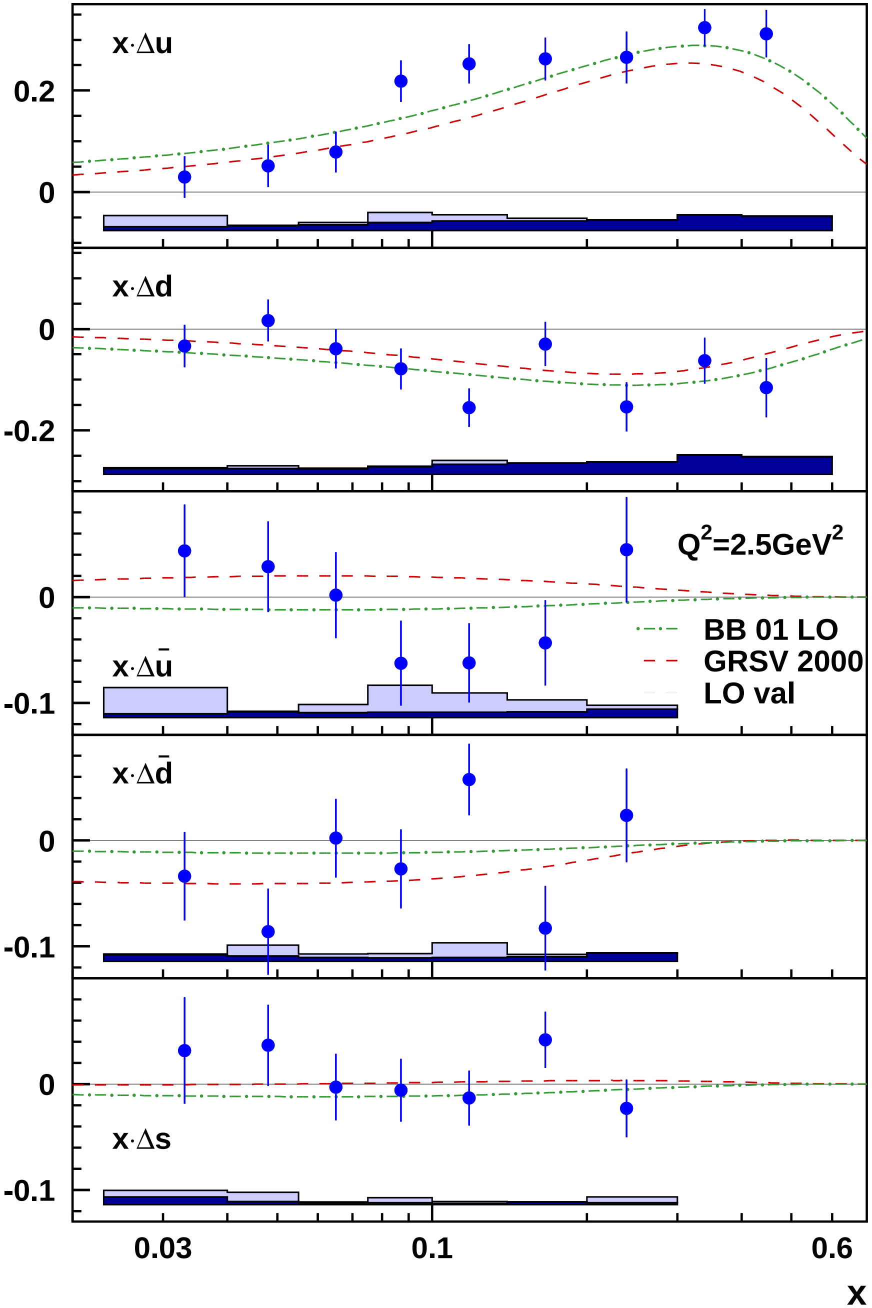
- diffr.nucl.shadowing+pion excess mech.
  Nikolaev et al., PLB 398, 245 (1997)
- coherent double scattering
  Edelmann et al., PRC 57, 3392 (1998)
- double scattering through VMD
  Bora & Jaffe, PRD 57, 6906 (1998)

$\hookrightarrow$ observe significant enhancement of b_1 at small x_B:

$\triangleright$ Close-Kumano sum rule $\int dx\, b_1(x, Q^2) = 0$ violated ??

$\triangleright$ interpretable as tensor polarization of the quark sea ?

Sea Quark Flavor Asymmetry



⇐ HERMES: 5-parameter flavor separation [PRD 71(2005) 012003]: semi-inclusive pion & kaon and inclusive asymmetries:

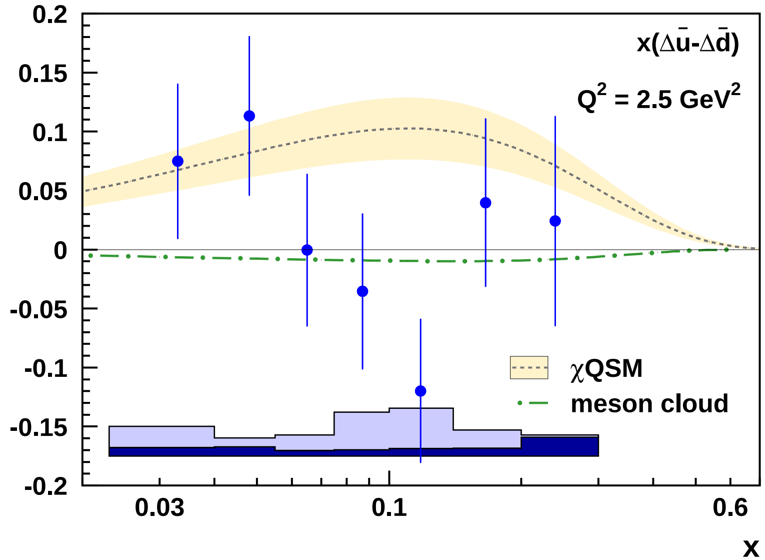
$$A_1^h(x,z) \propto \frac{\sum_f e_f^2 \Delta q_f(x) D_f^h(z)}{\sum_f e_f^2 q_f(x) D_f^h(z)}$$

with $D_f^h(z)$: Fragmentation function

- HERMES: Sea quark flavor asymmetry:

$$\int_{0.023}^{0.3} (\Delta q_u(x) - \Delta q_d(x))\, dx = 0.05 \pm 0.06 \pm 0.03$$

[PRL 92 (2004) 012005]



Spin Contribution of Strange Quarks

HERMES 'isoscalar' extraction method uses only deuterium data:

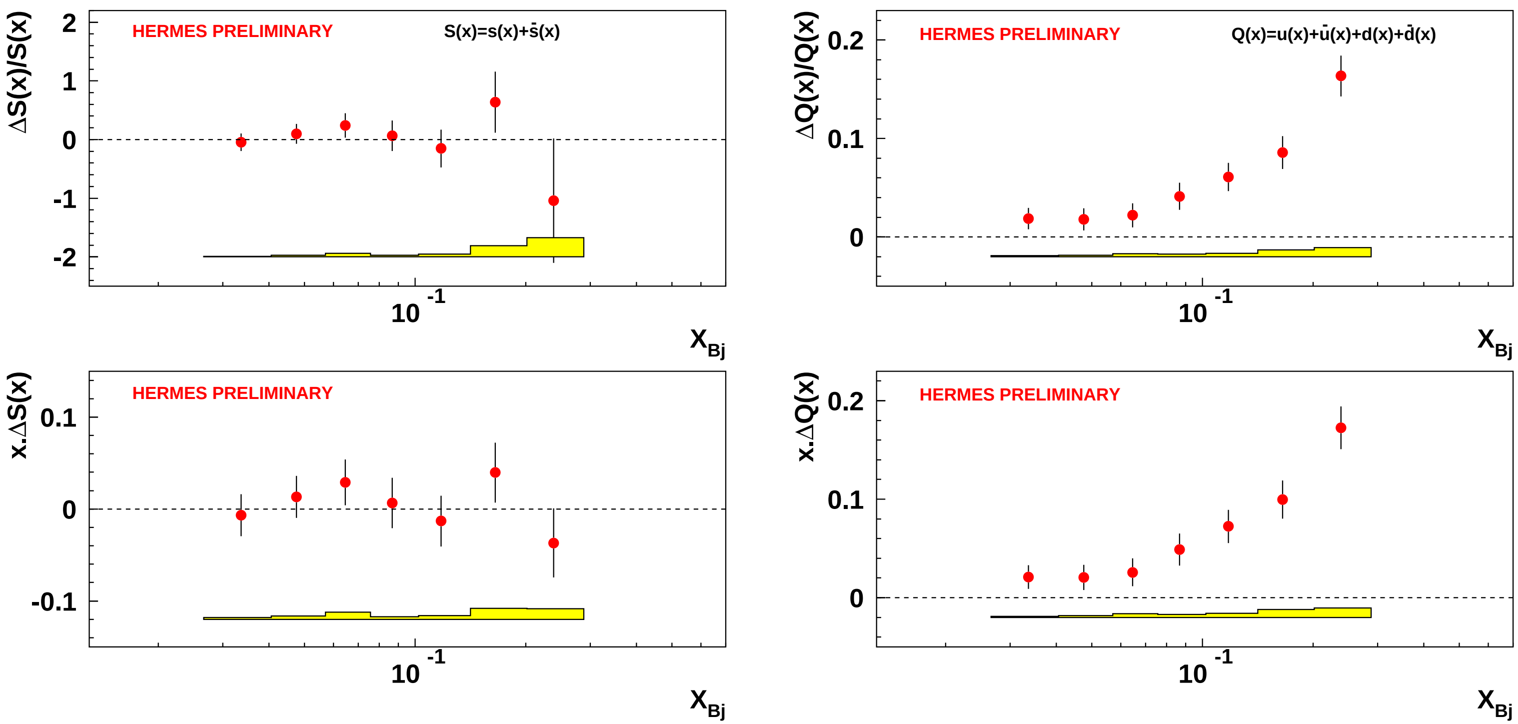
- K^+&K^- multiplicities, inclusive asymmetry A_1^d, kaon asymmetries $A_1^{K^+}$, $A_1^{K^-}$

⇒ Fit parameters: $\Delta S(x) = q_s(x) + \bar{q}_s(x)$; $\Delta Q(x) = q_u(x) + \bar{q}_u(x) + q_d(x) + \bar{q}_d(x)$

$\int_{0.02}^{0.6} \Delta S(x)\, dx = 0.006 \pm 0.029 \pm 0.007$ [preliminary 2005]

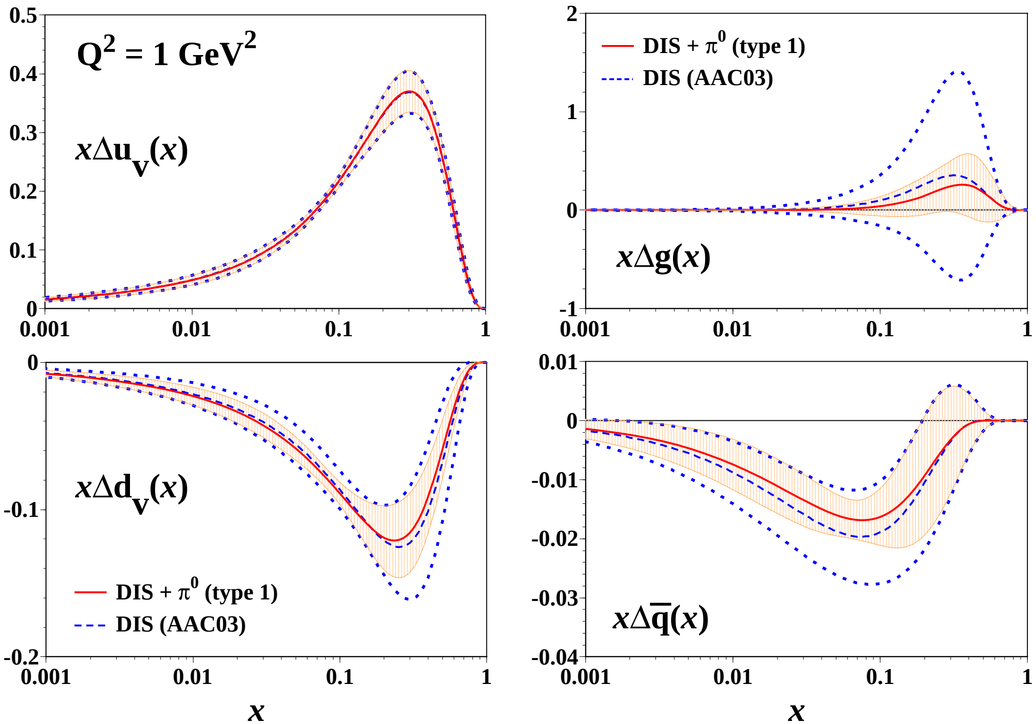
⇒ small ΔG? (suggested:gluon splitting into strange sea through axial anomaly)

- Note: uncertainties very sensitive to fragmentation function input



Next-to-leading Order QCD Fits

Typical (and most recent) results by AAC [hep-ph/0603213]: NLO in α_s, $\overline{MS}$ scheme



Assumptions:

- Flavor-symmetric Δq_{sea}
- Integrals of Δq_u^{val} and Δq_d^{val} fixed by weak decay constants F and D

Input experimental data:

- $A_1^{p,d}$ from COMPASS,JLAB,HERMES
- $A_{LL}^{\pi^0}$ from PHENIX

Results at $Q^2 = 1$ GeV^2: $\Delta\Sigma = 0.25 \pm 0.10$

$\Delta G = 0.47 \pm 1.08$ (DIS alone); $\Delta G = 0.31 \pm 0.32$ (DIS+PHENIX)

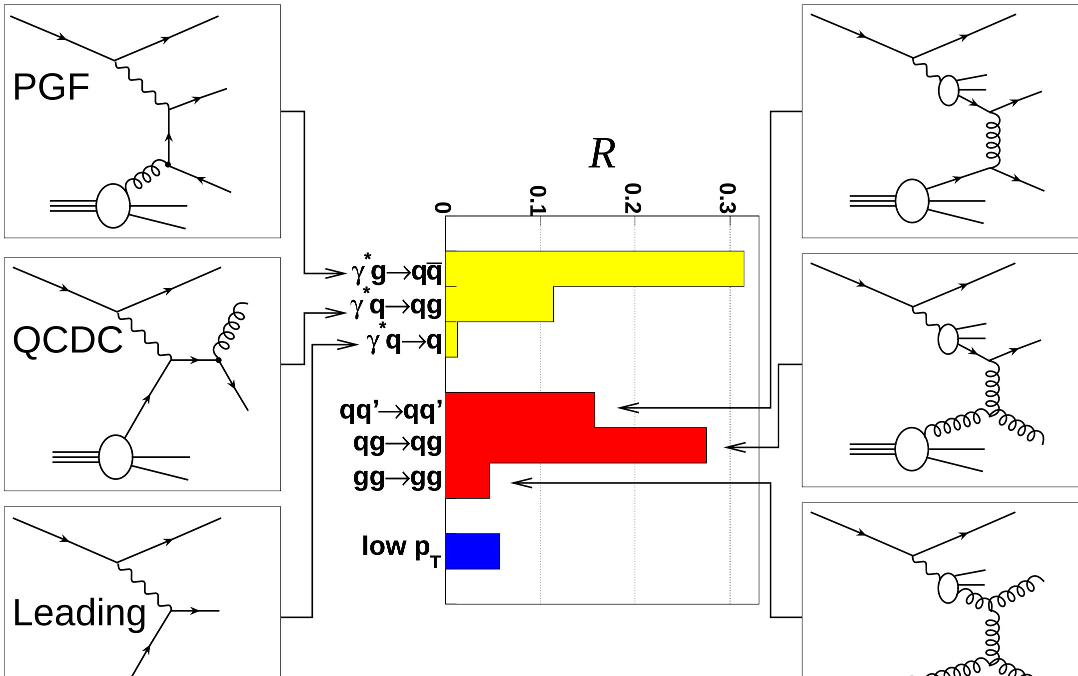
NOTE: From g_d^1 : $\Delta\Sigma^{exp}_{0.01<x<1} \approx 0.35 \pm 0.03$, while $\Delta\Sigma^{fit}_{0<x<0.01} \approx -0.13 \pm 0.11$ is obtained for low-x 'extrapolation' (due to stiff shape of PDF parameterizations)

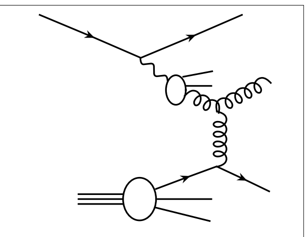
ALSO: low-x data urgently needed to constrain $g_1^{p,d}$ (E-RHIC,ELIC)

Determination of Gluon Contribution to Nucleon Spin

- Process: High-p_t hadron pairs in quasi-real photoprod.: $\langle Q^2 \rangle \approx 0.1$ GeV^2
- Sensitivity through $\gamma^* g$ 'direct' hard scattering or 'resolved-photon' process

left graphs: direct processes; right graphs: resolved-photon processes [COMPASS analysis]





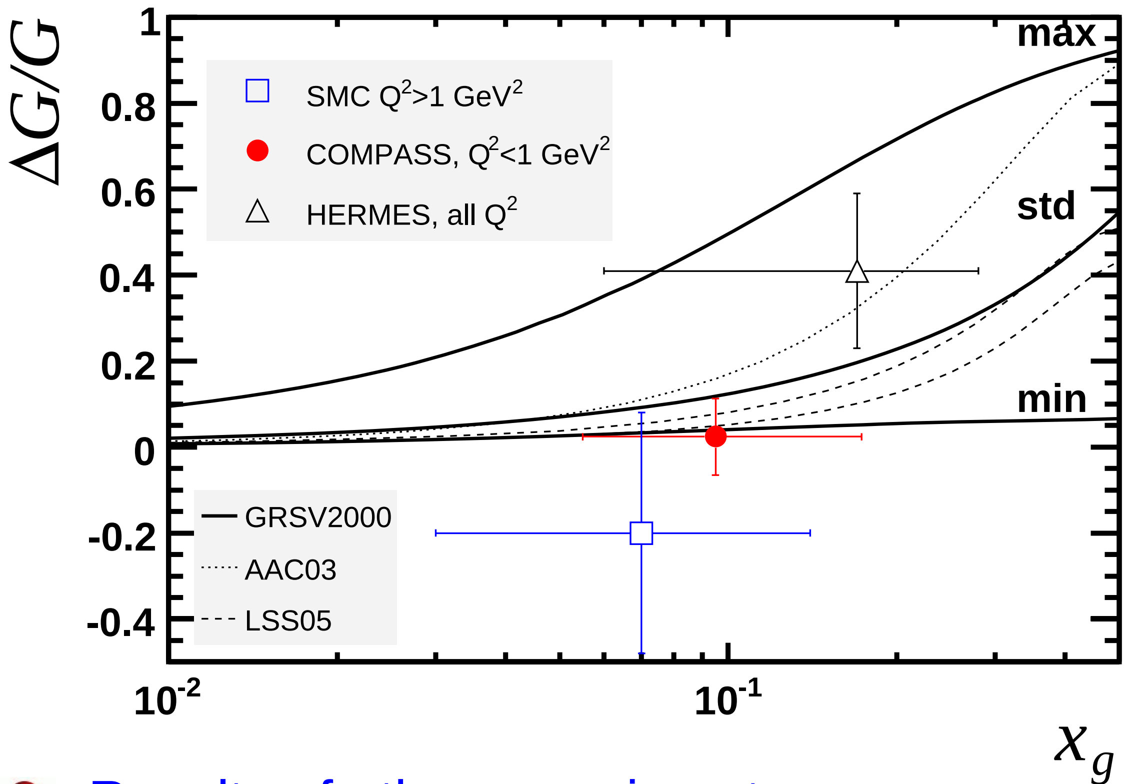
Other processes:

- Extraction heavily relies on PYTHIA simulation (LO only !)
- Hard scale $\mu^2 \simeq 3$ GeV^2 only 'loosely' correlated with x_g ($\langle x_g \rangle \simeq 0.1$)

- COMPASS: Open-charm production ($\gamma^* g \to c\bar{c}$)
- HERMES: Quasi-real photoproduction of single high-p_t hadrons
- RHIC: A_{LL} in inclusive direct γ & π^0 production, inclusive jet production

Results on Gluon Distribution $\frac{\Delta g}{g}(x_g)$

- Most precise result from high-p_t hadron pairs ⇓ COMPASS ⇓



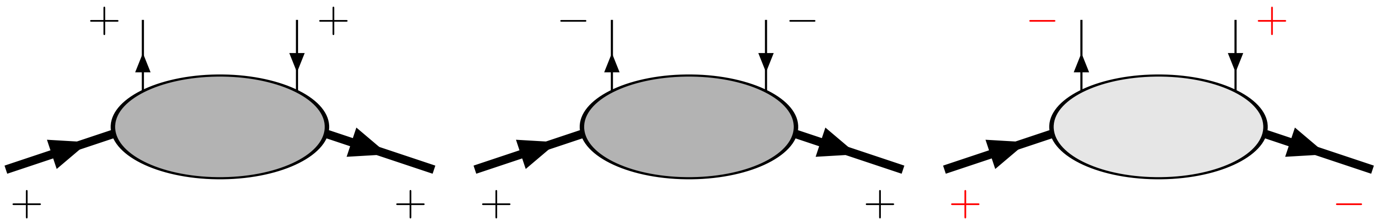
$Q^2 < 1$ GeV^2 ($\langle x_g \rangle \simeq 0.085$):
$\frac{\Delta g}{g} = 0.016 \pm 0.058_{stat} \pm 0.055_{syst}$
[PLB 612,154 (2005)]

$Q^2 > 1$ GeV^2 ($\langle x_g \rangle \simeq 0.13$) [prel.]:
$\frac{\Delta g}{g} = 0.06 \pm 0.31_{stat} \pm 0.06_{syst}$

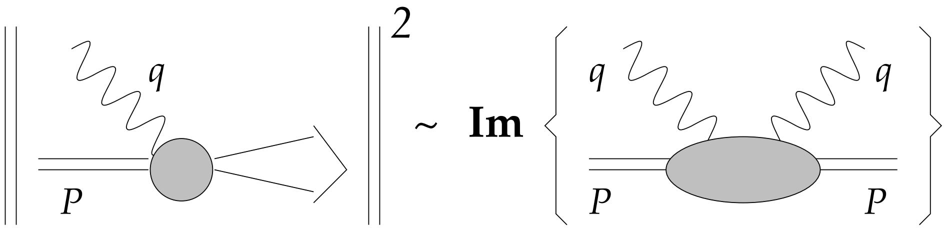
Open charm ($\langle x_g \rangle \simeq 0.15$) [prel.]:
$\frac{\Delta g}{g} = -0.57 \pm 0.31_{stat}$

- Results of other experiments:
  - HERMES high-p_t hadron pairs (all Q^2, $\langle x_g \rangle \simeq 0.17$) [PRL84 (2000) 2584]
    $\frac{\Delta g}{g} = 0.41 \pm 0.18_{stat} \pm 0.03_{exp-syst}$
  - PHENIX: Presently only confidence limits for different $\frac{\Delta g}{g}$ assumptions [PANIC05 talk]

The third twist-2 PDF: Transversity



Optical theorem:



$$q_f(x) = \quad q_f^{\stackrel{\rightarrow}{\Rightarrow}}(x) + q_f^{\stackrel{\rightarrow}{\Leftarrow}}(x) \quad \sim Im(\mathcal{A}_{++,++} + \mathcal{A}_{+-,+-})$$

$$\Delta q_f(x) = \quad q_f^{\stackrel{\rightarrow}{\Rightarrow}}(x) - q_f^{\stackrel{\rightarrow}{\Leftarrow}}(x) \quad \sim Im(\mathcal{A}_{++,++} - \mathcal{A}_{+-,+-})$$

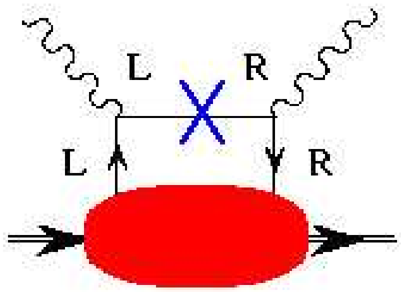
$$\delta q_f(x) \quad alias \quad h_1(x) \quad \sim Im\, \mathcal{A}_{+-,-+}$$

Positivity limit & Soffer bound:

$$|\delta q_f(x)| < q_f(x)$$

$$|\delta q_f(x)| < \frac{1}{2}\left(q_f(x) + \Delta q_f(x)\right)$$

How to Measure Transversity?



- Hard interactions conserve chirality

$\Leftarrow$ In DIS:chirality-flip diagram suppressed by quark mass

- The transversity distribution function is chiral-odd
  $\Rightarrow$ not accessible in DIS!

Semi-inclusive DIS: $$\sigma^{\mathrm{eH}\to\mathrm{ehX}} \propto \sum_{\mathrm{q}} \mathcal{D}^{\mathrm{H}\to\mathrm{q}} \otimes \sigma^{\mathrm{eq}\to\mathrm{eq}} \otimes \mathcal{F}^{\mathrm{q}\to\mathrm{h}}$$

where $\mathcal{D}$ denotes a distribution function and $\mathcal{F}$ a fragmentation function

(Factorization not yet proven for transv.-mom.-dependent subleading 1/Q terms)

Need another chiral-odd object: **Collins fragmentation function $\mathbf{H}_1^\perp$**

- also 'T-odd' (=odd under naive time reversal)
- represents interference of 2 amplitudes with different imaginary parts

  $\Rightarrow$ $\mathbf{H}_1^\perp$ can generate a single-spin asymmetry

NOTE: SIDIS alone can not independently determine δq and $\mathbf{H}_1^\perp$ (only shapes!)

- Collins function from BELLE $\mathrm{e}^+\mathrm{e}^-$ data: 1st result ! [hep-ex/0507063, acc. by PRL]
- Drell-Yan can yield transversity: upgraded RHIC, PAX? (only large x, 2012 ?)

SIDIS: Two contrasting T-odd Phenomena

A single-spin asymmetry can arise from some (naive) T-odd mechanism

With transverse target polarization two mechanisms become distinguishable

Transversity + T-odd Collins FF

- **Transversity:** polarizations of quark and nucleon correlated
- Photoabsorption flips quark polarization component in lepton scattering plane
- Quark polarization correlates with fragmentation $k_T \rightarrow \mathbf{P}_{h\perp}$ i.e. hadron production plane

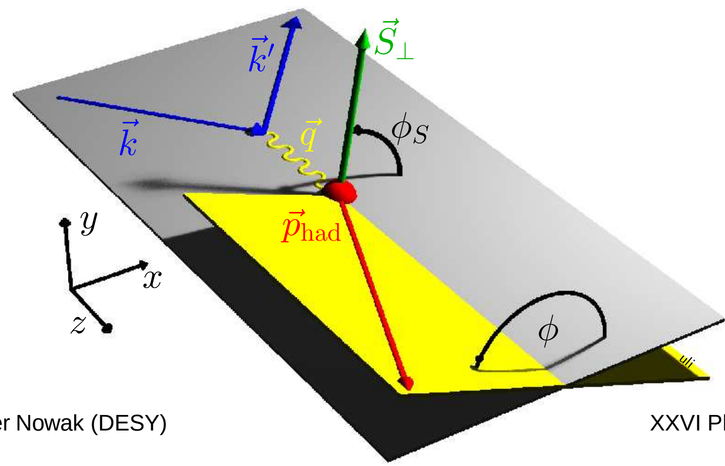
$\Rightarrow$ Single Target Spin Asymmetry $\propto \sin(\phi + \phi_S)$

T-odd Sivers distrib. function $f_{1T}^{\perp}$

- p_T of UNpolarized struck quark correlated with target polariz.
- p_T survives fragmentation, inherited by hadron $\mathbf{P}_{h\perp}$

$\Rightarrow$ Orientation of lepton scattering plane is irrelevant

$\Rightarrow$ Single Target Spin Asymmetry $\propto \sin(\phi - \phi_S)$



Extraction of Sivers & Collins Azimuthal Moments

Study azimuthal distributions of hadrons in: $\mathbf{e^{\pm}\, p^{\uparrow} \longrightarrow e^{\pm}\, \pi^{\pm} + X}$

unpol. beam (U), transv. pol. target (T)

$$A^{\ell}_{UT}(\phi,\phi_S) = \frac{1}{\langle S_T\rangle}\frac{N^{\Uparrow}_{\pi}(\phi,\phi_S) - N^{\Downarrow}_{\pi}(\phi,\phi_S)}{N^{\Uparrow}_{\pi}(\phi,\phi_S) + N^{\Downarrow}_{\pi}(\phi,\phi_S)}$$

$$\sim \sin(\phi-\phi_S)\sum_q e_q^2\,\mathcal{I}\left[w_{Siv}(p_T,P_{h_\perp})f_{1T}^{\perp,q}(x,p_T^2)\;D_1^q(z,k_T^2)\right]$$

$$+ \sin(\phi+\phi_S)\sum_q e_q^2\,\mathcal{I}\left[w_{Coll}(k_T,P_{h_\perp})h_{1T}^{q}(x,p_T^2)\;H_1^{\perp,q}(z,k_T^2)\right] + \ldots$$

$\mathcal{I}[\ldots]$: convol. integral over initial (p_T) and final (k_T) quark transverse momenta

$\Rightarrow$ can NOT DIRECTLY extract transverse-momentum-dependent functions !

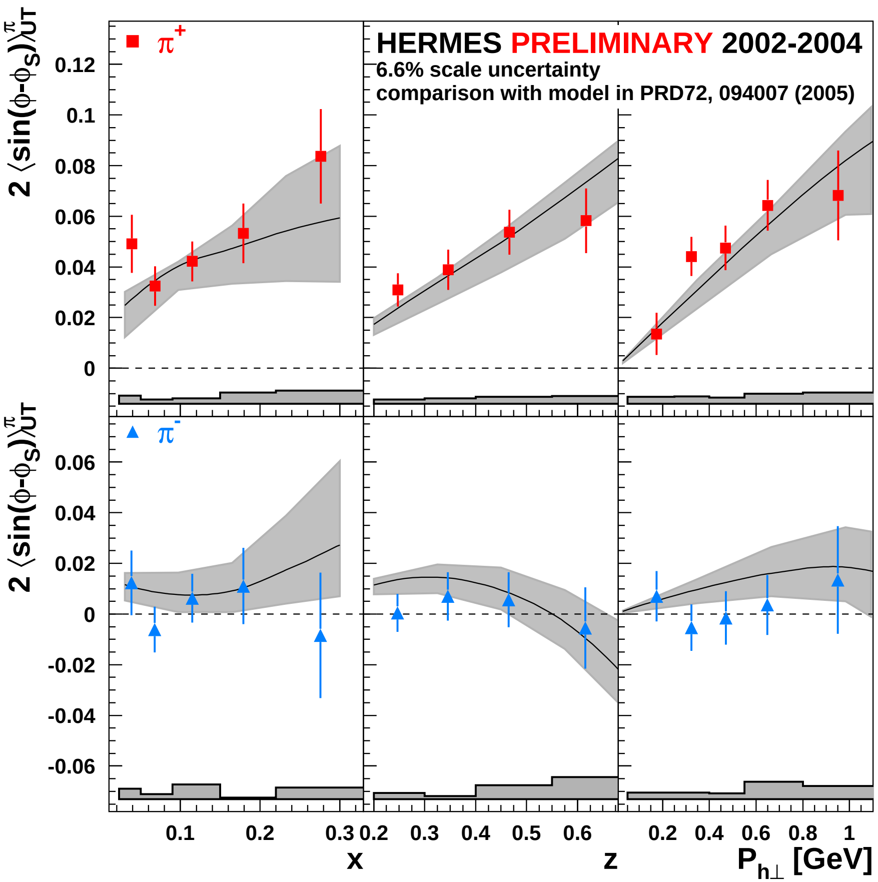
$\Rightarrow$ **Determine (simultaneously)** Sivers and Collins convolution integrals by a fit:

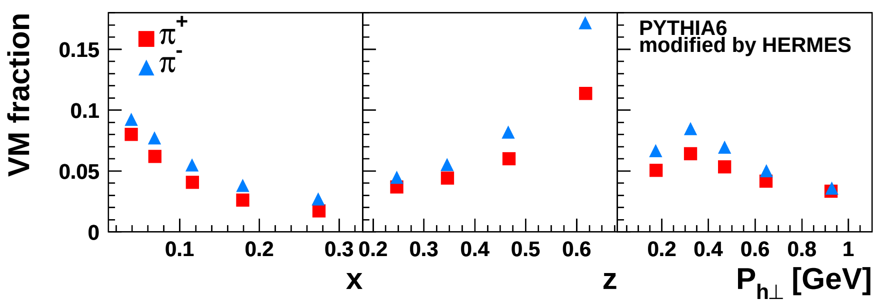
$$A^{\ell}_{UT}(\phi,\phi_S) = 2\left\langle \sin(\phi-\phi_S)\right\rangle^{\ell}_{UT}\sin(\phi-\phi_s) + 2\left\langle \sin(\phi+\phi_S)\right\rangle^{\ell}_{UT}\sin(\phi+\phi_s)$$

NOTE: asymmetry weighting by $P_{h_\perp}/(zM_h)$ makes convolution integral calculable (involves acceptance dependence)

Results on Sivers Moments from 2002-2004 data

$$2\left\langle \sin(\phi-\phi_S)\right\rangle_{UT}^{\ell} \approx 2\left\langle \sin(\phi-\phi_S)\right\rangle_{UT}^{\gamma^*} \propto -\sum_q e_q^2\, \mathcal{I}\left[w_{Siv}\; f_{1T}^{\perp,q}(x,p_T^2)\; D_1^q(z)\right.$$

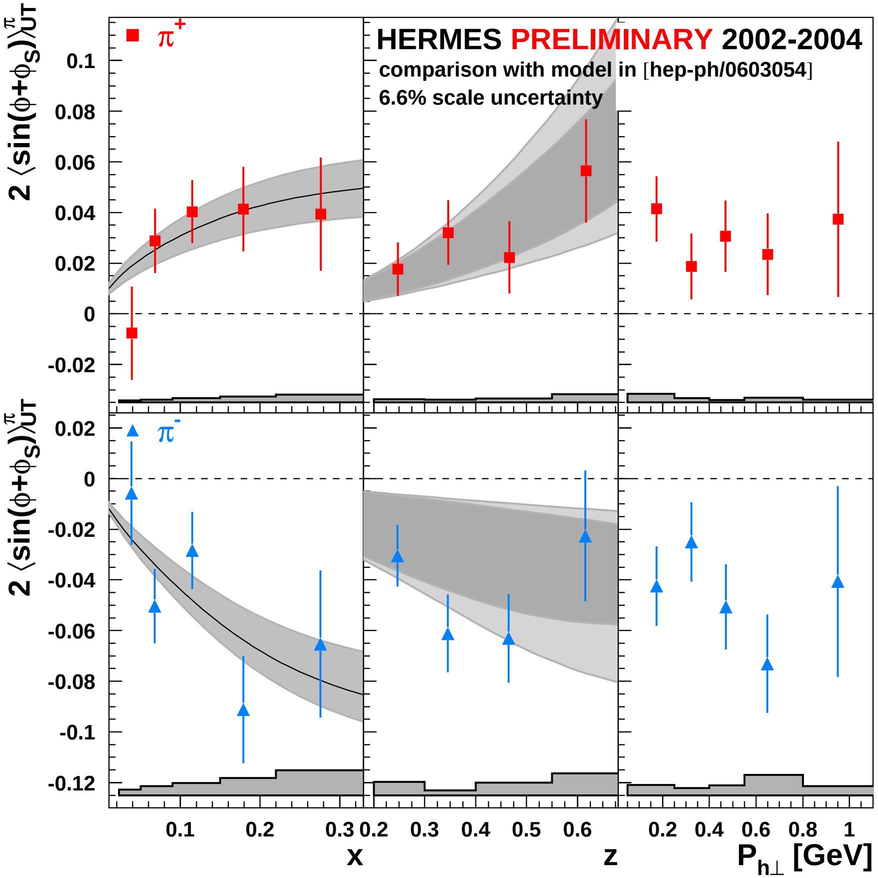


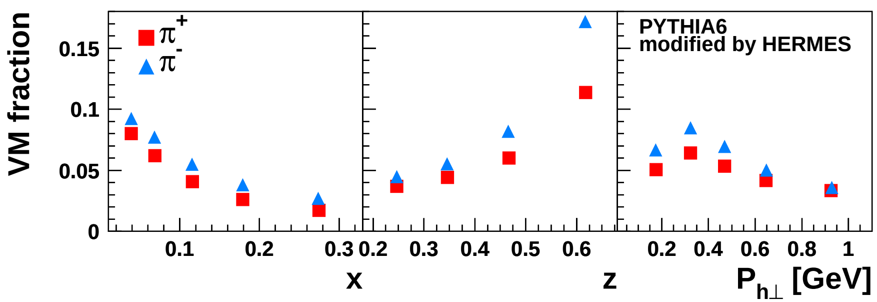


- ⇐ 1st measurement: HERMES (proton target)
- π^+: positive; π^-: consistent with zero
- ⇐ well described by phenomenol. model
- first unambigous evidence for a non-zero T-odd distribution fct. in DIS !
- ⇒ a signature for quark orbital angular momentum
- $f_{1T}^{\perp,u}$ negative (using Trento convention)
- ⇒ consistent with Burkhardt's picture of 'Chromodynamic lensing' !
- COMPASS: 'zero' results (deuteron target!)
- ⇐ NOTE: Contamination (2-16%) by decay of exclusively produced vector mesons

Results on Collins Moments from 2002-2004 data

$$2\langle \sin(\phi+\phi_S)\rangle^{\ell}_{UT} \approx 2\langle \sin(\phi+\phi_S)\rangle^{\gamma^*}_{UT} \propto \sum_q e_q^2\ \mathcal{I}\,\Big[w_{Coll}\ h^q_{1T}(x,p_T^2)\ H_1^{\perp,q}(z,k_T^2$$





- pos. HERMES π^+ results – no surprise: u-quark domin. and $\delta q > 0$ as $\Delta q > 0$
- negative HERMES π^- results were a surprise – now understood to require disfavored Collins function be large and opposite in sign (Artru fragm. model)

$\Leftarrow$ grey bands: predictions [hep-ph/0603054] of chiral quark soliton model:

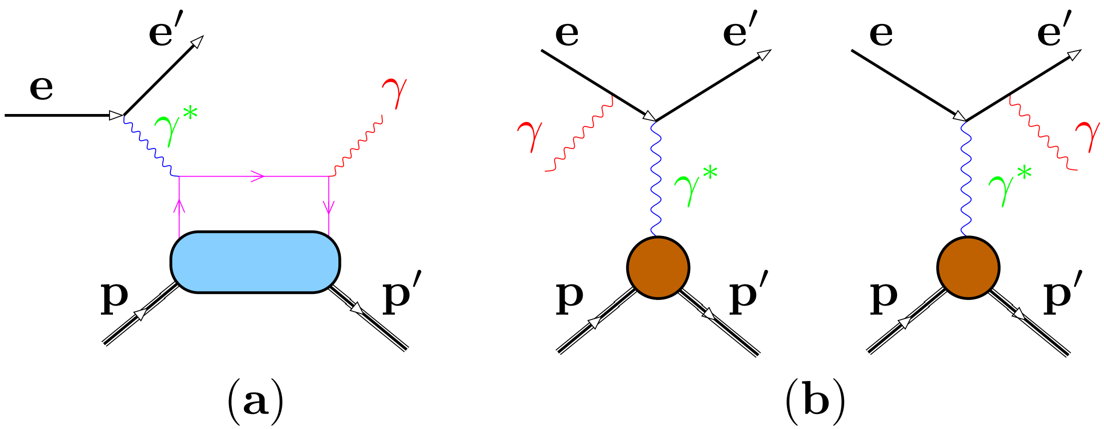
- ▷ x-dependence: mean Collins function fitted and found to be x-independent
- ▷ z-dependence: Collins fct. extracted from BELLE e^+e^- data [hep-ex/0507063]

- COMPASS: ‘zero’ results (on deuteron!)

$\Rightarrow$ HERMES, COMPASS and BELLE compatible

- COMPASS will take proton data in 2006

Deeply Virtual Compton Scattering

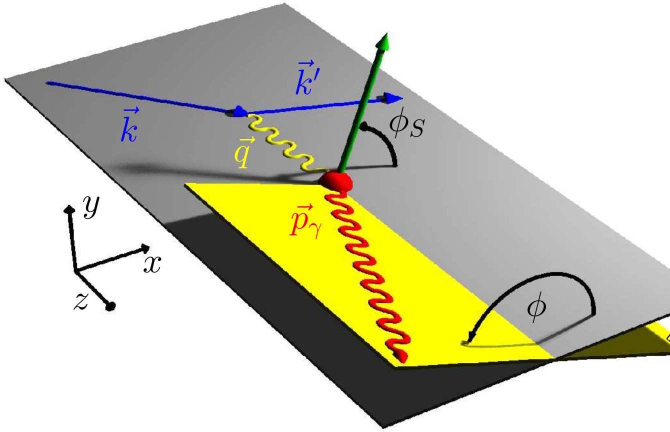


- Same final state in DVCS and Bethe-Heitler ⇒ Interference!
  $$d\sigma(\mathrm{eN} \to \mathrm{eN}\gamma) \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \underbrace{\mathcal{T}_{BH}\mathcal{T}^*_{DVCS} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}}_{\mathcal{I}}$$
- $\mathcal{T}_{BH}$ is calculable in QED and parameterized in terms of Dirac and Pauli Form Factors F_1, F_2
- $\mathcal{T}_{DVCS}$ is parameterized in terms of Compton form factors $\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}$ (which are convolutions of resp. GPDs $H, E, \widetilde{H}, \widetilde{E}$)
- (Certain Parts of) interference term $\mathcal{I}$ can be filtered out by forming certain cross section differences (or asymmetries)

⇒ GPDs $H, E, \widetilde{H}, \widetilde{E}$ **indirectly** accessible via interference term $\mathcal{I}$

Azimuthal Asymmetries in DVCS

DVCS–Bethe-Heitler Interference term $\mathcal{I}$
induces azimuthal asymmetries in cross-section:



- Beam-charge asymmetry $A_C(\phi)$ [BCA] :
  $d\sigma(e^+,\phi) - d\sigma(e^-,\phi) \propto \mathrm{Re}[F_1\mathcal{H}] \cdot \cos\phi$
- Beam-spin asymmetry $A_{LU}(\phi)$ [BSA] :
  $d\sigma(\overrightarrow{e},\phi) - d\sigma(\overleftarrow{e},\phi) \propto \mathrm{Im}[F_1\mathcal{H}] \cdot \sin\phi$
- Long. target-spin asymmetry $A_{UL}(\phi)$:
  $d\sigma(\overset{\Leftarrow}{P},\phi) - d\sigma(\overset{\Rightarrow}{P},\phi) \propto \mathrm{Im}[F_1\widetilde{\mathcal{H}}] \cdot \sin\phi$ [LTSA]
- Transverse target-spin asymmetry $A_{UT}(\phi,\phi_s)$ [TTSA]:

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

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

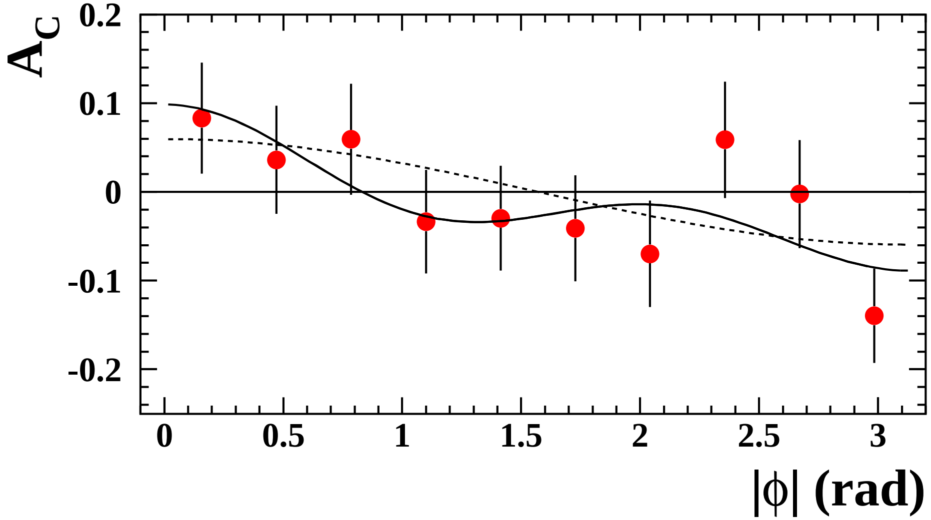
First Data on Beam-charge Asymmetry

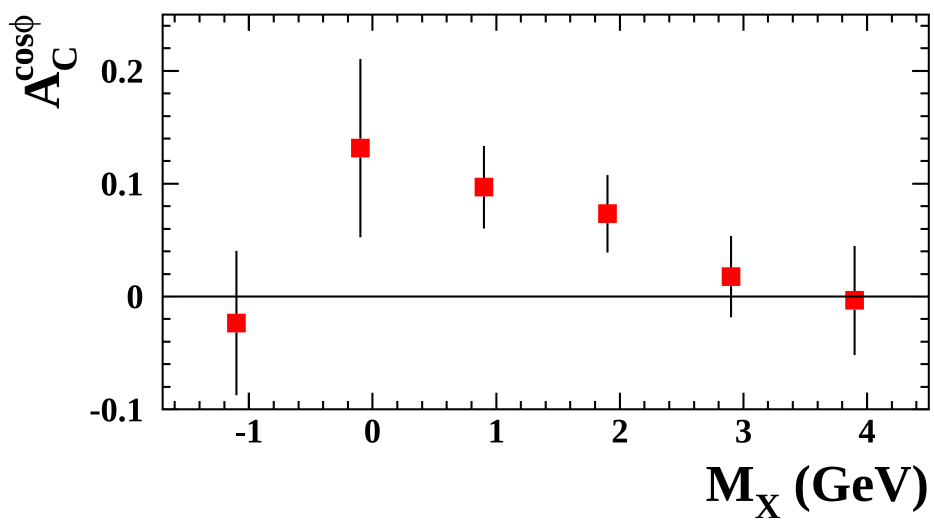
$$A_C(\phi) = \frac{d\sigma^+(\phi) - d\sigma^-(\phi)}{d\sigma^+(\phi) + d\sigma^-(\phi)} \propto \mathrm{Im} F_1 \mathcal{H} \cdot \cos\phi + \ldots$$

$\Rightarrow$ extract 'amplitudes' by fitting in every ϕ-bin

$$A_C(\phi) = const. + A_C^{\cos\phi} \cos\phi + A_C^{\cos 2\phi} \cos 2\phi + A_C^{\cos 3\phi} \cos 3\phi$$

- First measurement by HERMES (*un*polar. proton target) **[hep-ex/0605108, subm. to PRL]**:

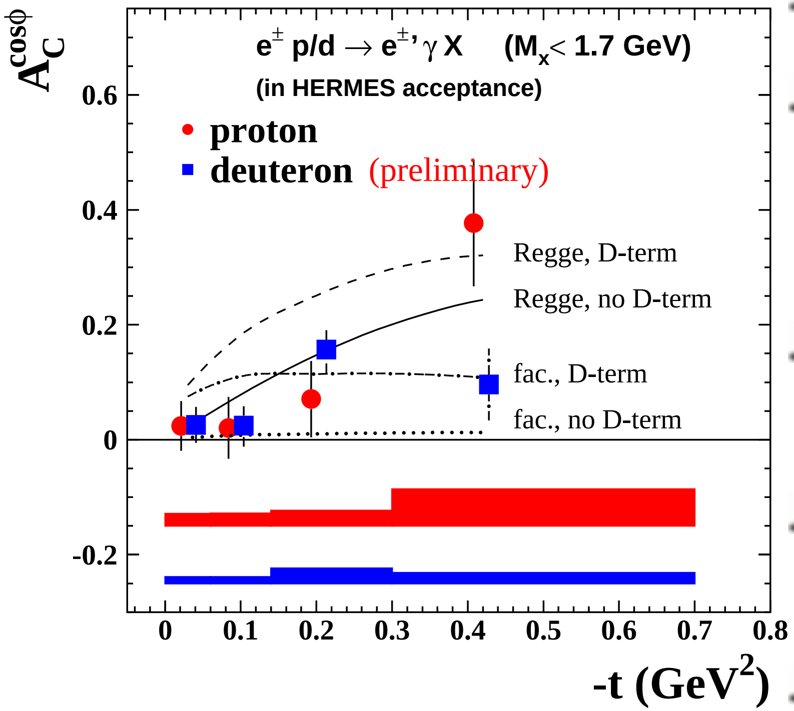




- use *symmetrization* ($\phi \to |\phi|$) to get rid of sinusoidal terms
- $A_C^{\cos\phi} = 0.060 \pm 0.027$, other contributions insignificant (dashed = pure $\cos\phi$)
- asymmetry only in exclusive and 'associate' M_X region ($\to$ resol. smearing)
- preliminary deuteron data (not shown) completely consistent

First Conclusion on GPD Models ?

BCA t-dependence can distinguish different GPD model versions:



- $A_C^{\cos\phi}$: elastic + associated production
- d-data: contributions per t-bin of associated production: 5,11,18,29% $\Rightarrow$ highest t-bin mostly affected
- GPD H dominates, $\tilde{H}$ and E suppressed [Goeke,Polyakov,Vanderhaeghen,PPNP 47(2001)401]
- Curves (code [Vanderhaeghen,Guichon,Guidal]) calculated for 4 different parameter sets
- BCA insensitive to profile fct. parameters

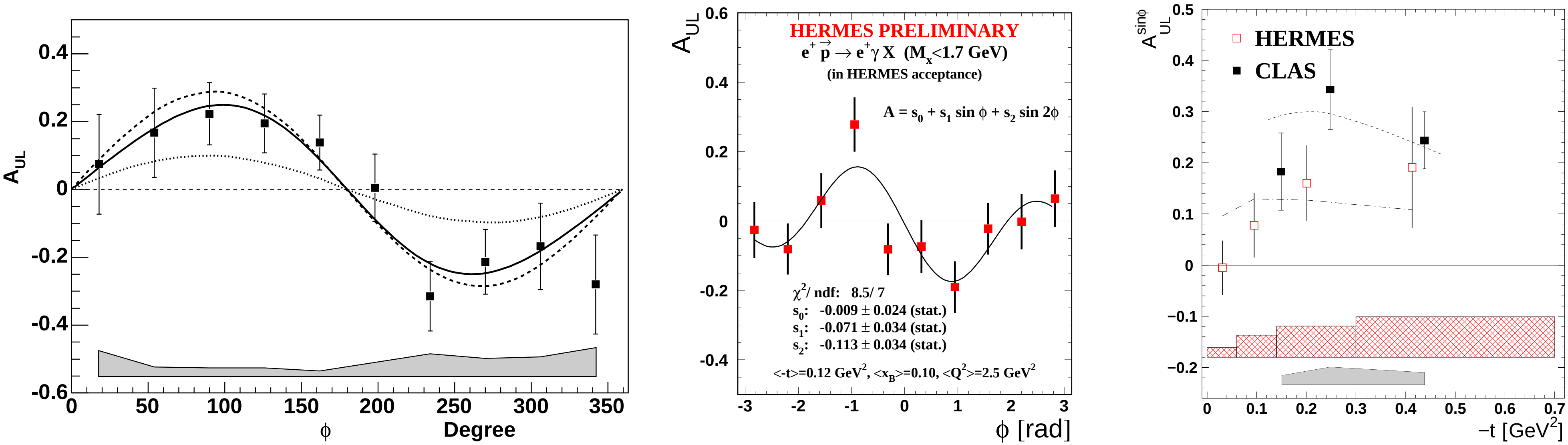
- HERMES HERA-I data disfavor Regge-inspired t-dependence with D-term
- 5 times more precise BCA data on HERMES disk from HERA-II

  (this data may benefit from recoil detector, presently being commissioned)
- Further BCA data only in far future (COMPASS> 2010 ?, JLAB> 2015 ???)

Longitudinal Target-spin Asymmetry

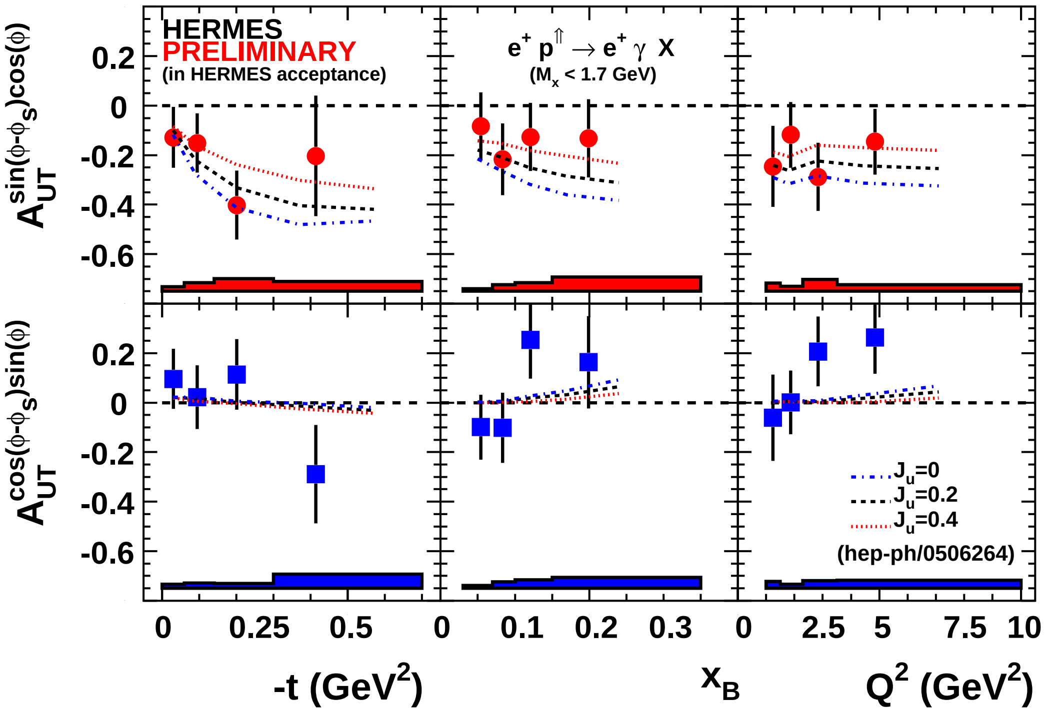
$$A_{UL}(\phi) = \frac{1}{\langle |P_L| \rangle} \cdot \frac{d\sigma^{\Rightarrow}(\phi) - d\sigma^{\Leftarrow}(\phi)}{d\sigma^{\Rightarrow}(\phi) + d\sigma^{\Leftarrow}(\phi)} \propto \mathrm{Im}\{F_1 \widetilde{\mathcal{H}} + \xi(F_1 + F_2)\mathcal{H} + \ldots\} \sin\phi$$

$\Rightarrow$ extract 'amplitudes' fitting per ϕ-bin $A_{UL}(\phi) = c + A_{UL}^{\sin\phi} \sin\phi + A_{UL}^{\sin 2\phi} \sin 2\phi$



- 1st published measurement: CLAS 2000-01 proton data [hep-ex/0605012]
- May 2005 prel. HERMES results (1996-2000 proton and deuteron data)
- both data sets have similar statistics and show expected $\sin\phi$ behaviour
- HERMES can approach lower t-values
- CLAS vs GPD model [PRD60,094017(1999)]: large contribution from GPD $\widetilde{H}$!

Transverse Target-spin Asymmetry: Sensitivity to J_u



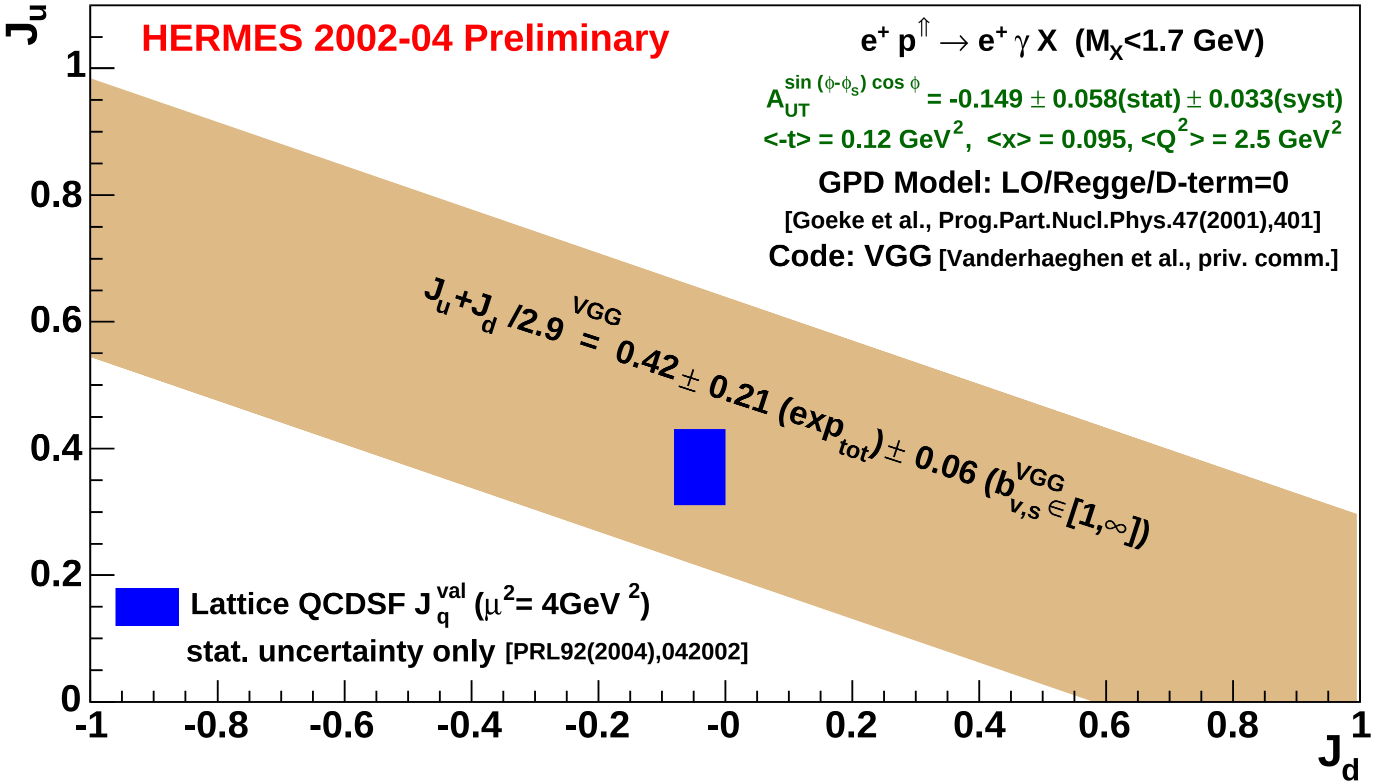
$$A_{UT}(\phi,\phi_S) = \frac{1}{\langle|P_T|\rangle} \cdot \frac{d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi)}{d\sigma(\phi,\phi_S) + d\sigma(\phi,\phi_S+\pi)} =$$

$$A_{UT}^{\sin(\phi-\phi_S)\cos\phi} \cdot \sin(\phi-\phi_S)\cos\phi + A_{UT}^{\cos(\phi-\phi_S)\sin\phi} \cdot \cos(\phi-\phi_S)\sin\phi$$

- First A_{UT} measurement by HERMES (U:*un*polar. beam, T:*transv.* pol. target) (twice more HERMES statistics on disk)
- JLAB: transv. target ≥ 2008 ?, COMPASS: plans for 2010
- GPD E can be modeled in forward limit by $e(x) = Aq_{val}(x) + B\delta(x)$ acc. to χQSM model [Prog.Part.Nucl.Phys.47(2001)401]
- $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ sensitive to J_u, not to the other parameters [hep-ph/0506264]

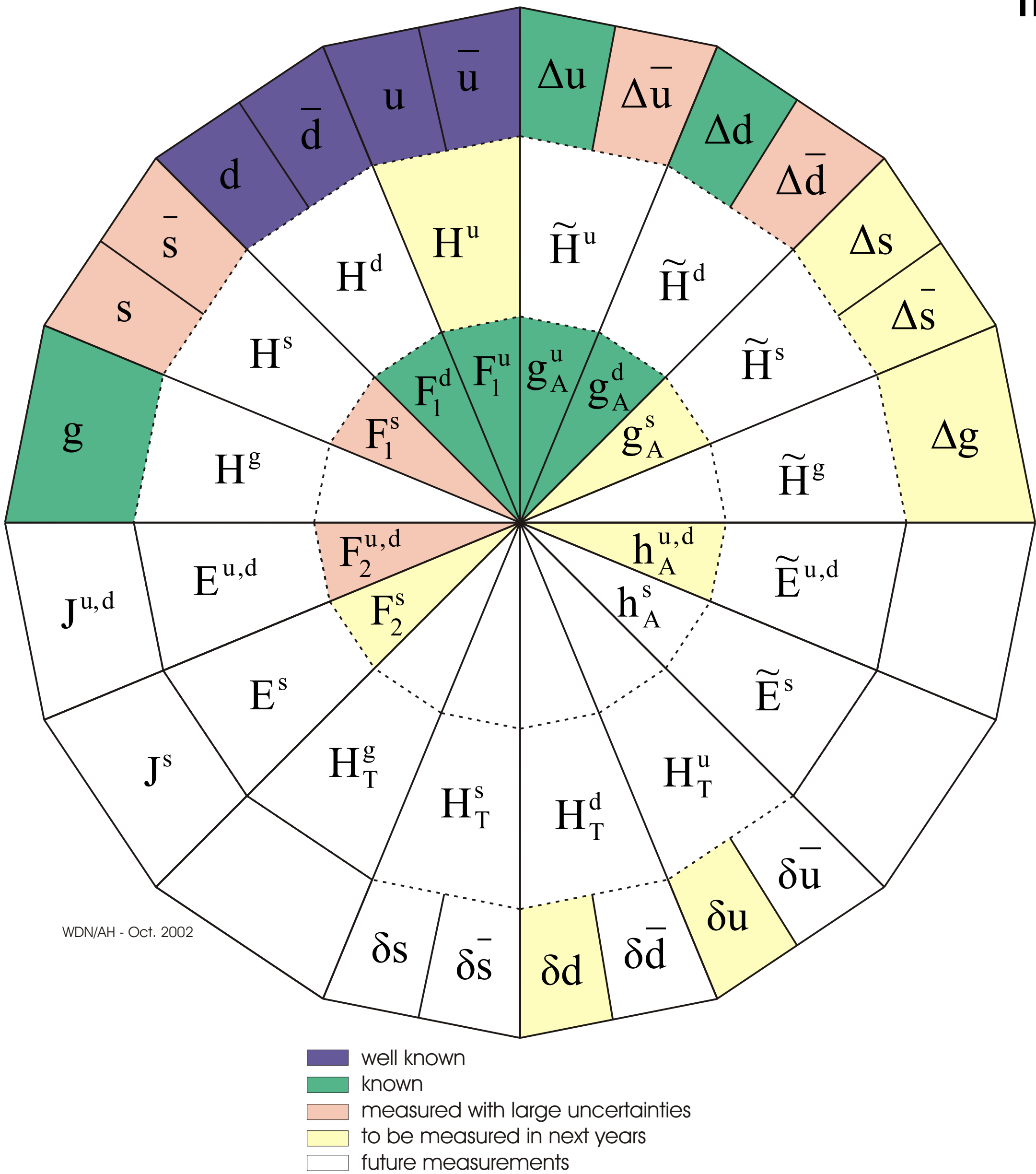
Model-dependent Constraint on J_u vs J_d

Unbinned maximum likelihood fit to $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ at average kinematics (fitting prel. HERMES data against VGG-model based calculations), leaving J_u and J_d as free parameters $\Rightarrow$ model-dependent 1-σ constraint on J_u vs. J_d:



- Quenched lattice calculation done with pion masses 1070, 870, and 640 MeV, and then extrapolated linearly in m_π^2 to the physical value
- Uncertainties on VGG model parameters shown as separate uncertainty (± 0.06)

Summary and Outlook



Improvement over last 4 years:

- Spin-independent & helicity PDFs
  - COMPASS: $\frac{\Delta g}{g}$
  - HERMES: $\Delta q_u, \Delta q_d, \Delta q_s$
  - JLAB: $\Delta q_u, \Delta q_d$ at large x
  - $\Rightarrow$ more: COMPASS,HERMES,RHIC
- Transversity & TMD-PDFs:
  - HERMES: Sivers function
  - BELLE: Collins (fragm.) function

$\Rightarrow$ more: BELLE,COMPASS,HERMES

transversity, Sivers & Boer-Mulders fct., ...

- GPDs:

finishing pioneering phase ...

$\Rightarrow$ **much more to come:**

HERMES,JLAB,COMPASS,JLAB-12 GeV