Single Spin Asymmetries and "Transversity" measured at HERMES

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on behalf of the hermes Collaboration

The Spin Structure of the Nucleon

$$\frac{1}{2} = \underbrace{\frac{1}{2}(\Delta u + \Delta d + \Delta s)}_{\downarrow} + \underset{\downarrow}{\Delta G} + \underbrace{L_q + L_g}_{\downarrow}$$

inclusive: g_p^1, g_n^1 $\rightarrow \Delta\Sigma$

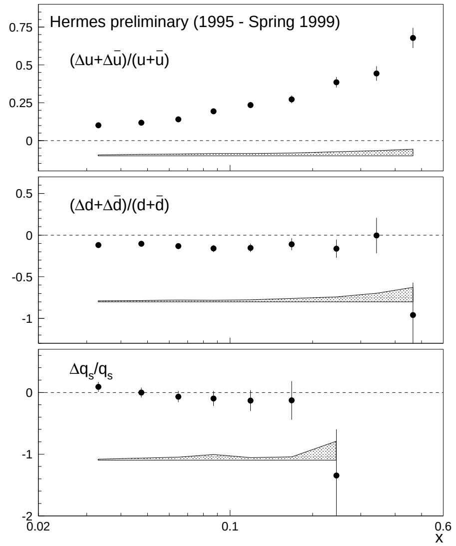
semi-incl.: flavor separation

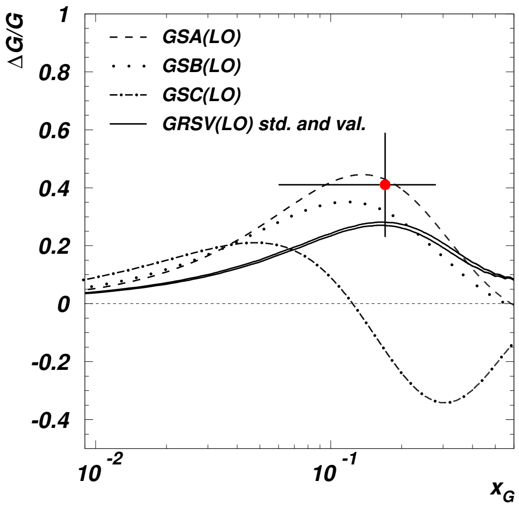
isolate PGF

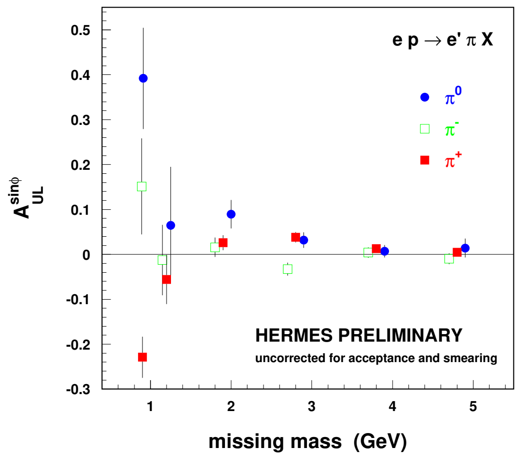
high-p$_t$ hadron pairs

exclusive: π, γ

Production







Deep Inelastic Scattering Cross Section

DIS - Cross Section:

$$\frac{d^2\sigma}{d\Omega dE^2} = \frac{\alpha^2 E'}{Q^2 E} L_{\mu\nu} W^{\mu\nu}$$

$$L_{\mu\nu} = 2[k_\mu k'_\nu + k_\nu k'_\mu - \left(k \cdot k' - m_e^2\right) g_{\mu\nu} + i m_e \epsilon_{\mu\nu\alpha\beta} S^\alpha \left(k - k'\right)^\beta]$$

Where: $S^\alpha = \frac{1}{2}\overline{u}\,(k,s)\,\gamma^\alpha \gamma_5 u\,(k,s)$

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

(for spin 1) + **quadrapole 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

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

$\searrow f_1$

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

$\searrow h_{1L}^{\perp}$ $\quad\quad \searrow g_{1L}$

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

$\searrow h_1$ $\quad\quad \searrow h_{1T}^{\perp}$

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

$\searrow g_{1T}$

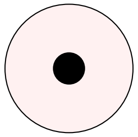
$\Longrightarrow$ **non zero Single Spin Asymmetries**

σ_{LT}

$\swarrow \searrow$

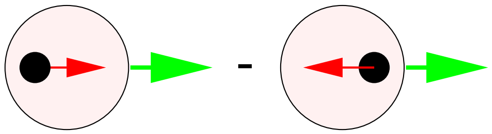
Beam Target polarization

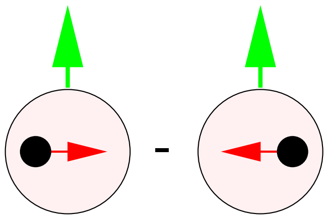
Mulders and Tangermann (NP B 461 (1996) 197)

f_1 =  **Unpolarized quarks in unpolarized nucleons**

$\Longrightarrow$ **q(x): spin averaged (well known)**

Longitudinal quarks in ...

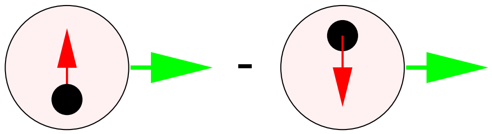
g_{1L} = 

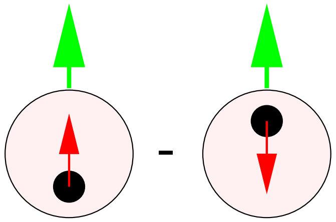
g_{1T} = 

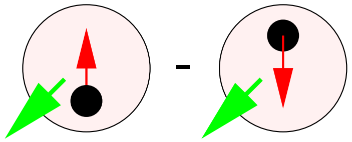
longitudinal **and** **transverse nucleons**

$\Longrightarrow$ **Δq(x): helicity difference (well known)**

Transverse quarks in ...

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

h_1 = 

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

longitudinal **and** **transverse nucleons**

$\Longrightarrow$ **δq(x): helicity flip (unknown)**

Characteristics of "Transversity" $\delta q(x)$

- in the absence of relativistic effects $\delta q(x) = \Delta q(x)$
- q and $\bar{q}$ contribute with opposite sign to $\delta q(x)$
  $\rightarrow$ predominantly sensitive to valence quark polarization
- unlike for g_1, gluon and quark polarization do not mix
  $\rightarrow$ different Q^2 evolution
- sum rule: first moment $\rightarrow$ tensor charge
  $\rightarrow$ reliably calculable in Lattice-QCD
  $\delta\Sigma = \sum_f \int_0^1 dx(\delta q_f(x, Q^2) - \delta\bar{q}_f(x, Q^2)) = 0.562 \pm 0.088$ at $Q^2 = 2GeV^2$
- Bounds:
  $f_1(x) \geq 0$ and $|g_1(x)| \leq f_1(x)$ $\qquad$ $|h_1(x)| \leq \frac{1}{2}(f_1(x) + g_1(x))$ (Soffer Bound)
- $h_1(x)$ is CHIRAL ODD
  can only be measured in combination with another chiral odd function

$\delta q(x)$ accessible in semi-inclusive DIS

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

chiral-odd — chiral-odd

DF — FF

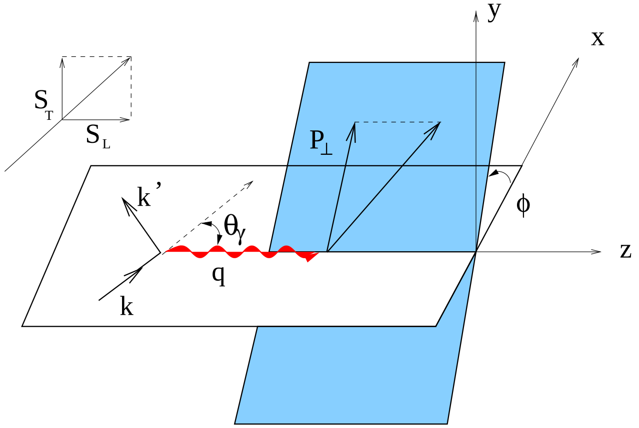
DISTRIBUTIONS			FRAGMENTATION		
	chirality			chirality	
	even	odd		even	odd
U	f_1		**U**	D_1	$H_1^\perp$
L	g_{1L}	$h_{1L}^\perp$	**L**	G_{1L}	$H_{1L}^\perp$
T	g_{1T}	h_1 $h_{1T}^\perp$	**T**	G_{1T} $D_{1T}^\perp$	H_1 $H_{1T}^\perp$

integrated over transverse momenta

P.J. Mulders nucl-th/9611040

Single Spin azimuthal Asymmetry

Kinematics:



$P_\perp$: pion transverse momentum

ϕ: azimuthal angle of π around γ^*

Asymmetry:

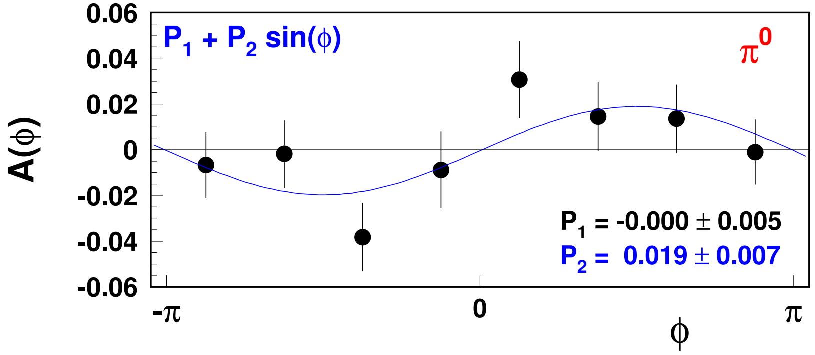
$$A(\phi)_{UL} = \frac{1}{<P_t>} \cdot \frac{(N^+(\phi) - N^-(\phi))}{(N^+(\phi) + N^-(\phi))}$$

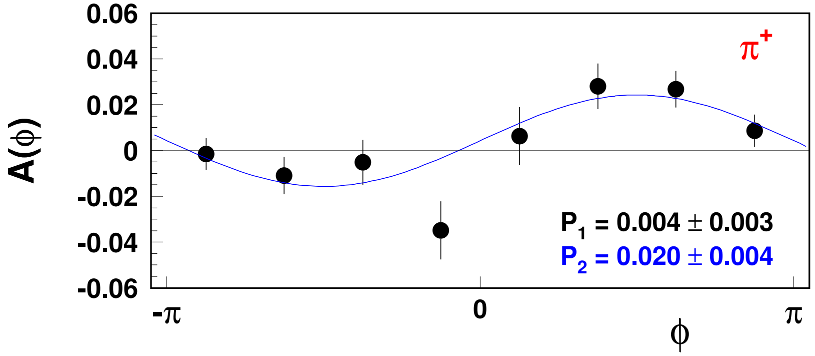
+ / -: target polarization direction

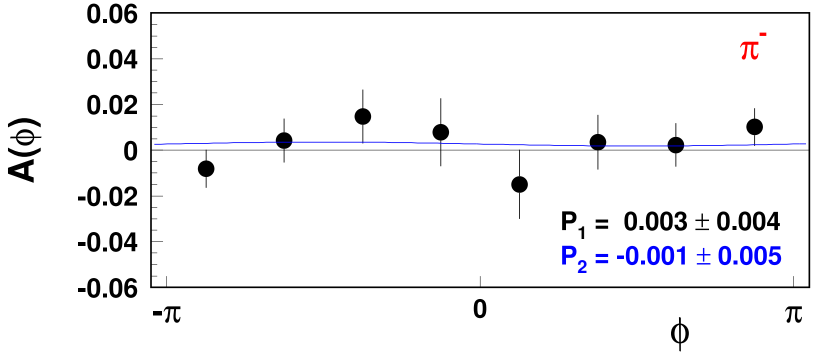
longitudinal polarized proton target:

$S_T \sim sin\Theta_\gamma \sim \frac{2Mx}{Q}\sqrt{1-y} \sim 15\%$

π^0: hep-ex/0104005, $\pi^\pm$: hep-ex/9910062

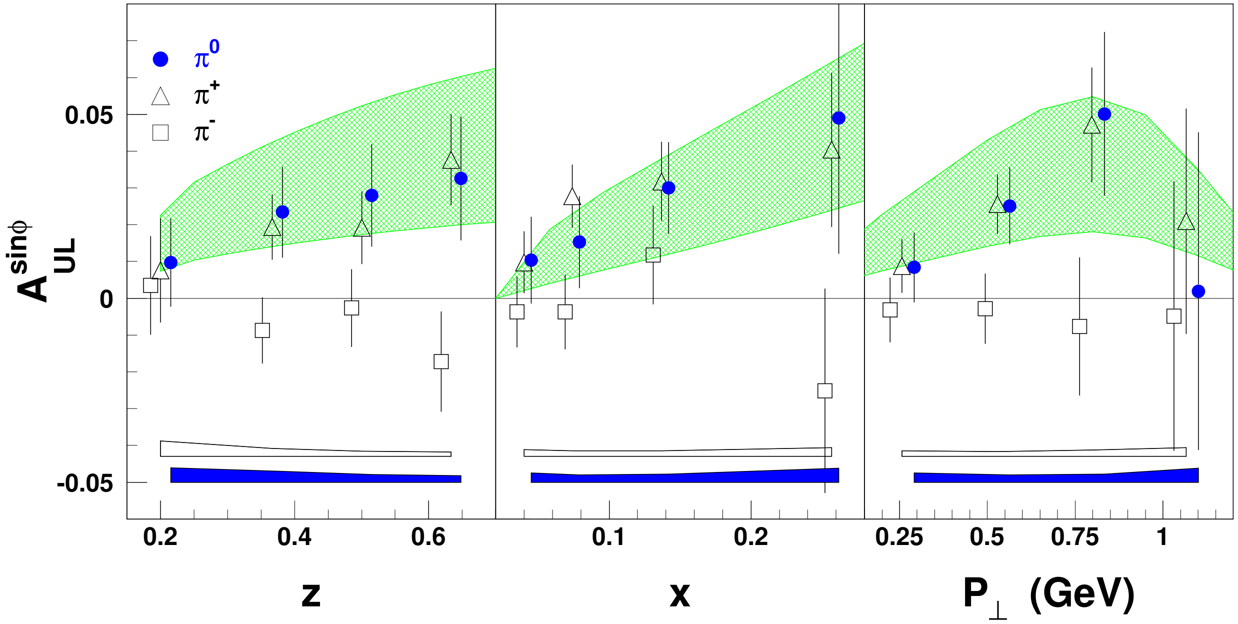






Azimuthally weighted Asymmetries

$$A_{UL}^{sin(\phi)} = \frac{\frac{L^+}{L_p^+}\sum_{i=1}^{N^+} sin(\phi_i^+) - \frac{L^-}{L_p^-}\sum_{i=1}^{N^-} sin(\phi_i^-)}{\frac{1}{2}(N^+ + N^-)}$$



- **x-dependence of** $A_{UL}^{sin(\phi)}$
  valence quarks dominance
- **$P_\perp$-dependence of** $A_{UL}^{sin(\phi)}$
  dominant role of intrinsic $k_\perp$
- $\pi^- \sim 0$:
  u**-quark dominance in proton**

$$< \frac{P_T}{zM_h} sin\phi >_{UL} \sim S_L \frac{2(2-y)}{Q\sqrt{1-y}} \sum_{f,\bar{f}} e_f^2 x h_L^f(x) H_1^{\perp f}(z) + S_T(1-y) \sum_{f,\bar{f}} e_f^2 x h_1^f(x) H_1^{\perp f}(z)$$

Interpretation

$$< \frac{P_T}{z M_h} sin\phi >_{UL} \sim S_L \frac{2(2-y)}{Q\sqrt{1-y}} \sum_{f,\bar{f}} e_f^2 x h_L^f(x) H_1^{\perp f}(z) + S_T (1-y) \sum_{f,\bar{f}} e_f^2 x h_1^f(x) H_1^{\perp f}(z)$$

$$h_L(x) = h_1(x) - \underbrace{\frac{d}{dx} h_{1L}^{\perp(1)}(x)}_{\sim 0 \to h_L(x) \sim h_1(x)}$$

$H_1^{\perp f}(z)$: spin dependent time-odd fragmentation function

'Collins effect': the transverse spin of quarks can be transformed into orbital angular momentum during the fragmentation

Produces particles with transverse momentum orthogonal to the spin direction of the fragmenting quark

Calculation with a good description of $A_{UL}^{sin(\phi)}$

- **lower bound on $h_1(x)$: $h_1(x) = g_1(x)$ non relativistic quarks**
  upper bound: $h_1(x) = \frac{1}{2}(f_1(x) + g_1(x))$
- **Parameterization for $H_1^{\perp u}(z)$**

Good promise measuring h_1

Future Measurements of $\delta q(x)$ with HERMES

Single Target-Spin Asymmetries in pion electro-production A_{UT}
$\rightarrow$ unpolarized beam + transversely polarized hydrogen target

Access to 'Transversity' via weighted asymmetry:

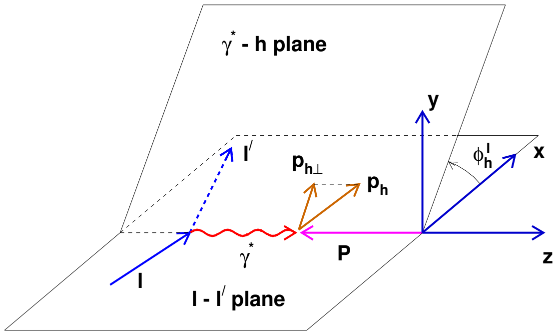
$$A_T(x,y,z) \equiv \frac{\int d\phi^\ell \int d^2 P_{h\perp} \frac{|P_{h\perp}|}{z M_h} \sin(\phi_s^\ell + \phi_h^\ell)\left(d\sigma^\uparrow - d\sigma^\downarrow\right)}{\int d\phi^\ell \int d^2 P_{h\perp}(d\sigma^\uparrow + d\sigma^\downarrow)}$$

Factorization w.r.t. x and z:

$$A_T(x,y,z) = P_T \cdot D_{nn} \cdot \frac{\sum_q e_q^2 \delta q(x) H_1^{\perp(1)q}(z)}{\sum_q e_q^2 q(x) \; D_1^q(z)}$$

$D_{nn} = (1-y)/(1-y+y^2/2)$ **- transverse spin transfer coefficient.**

P_T **transverse target polarization**



Assume:

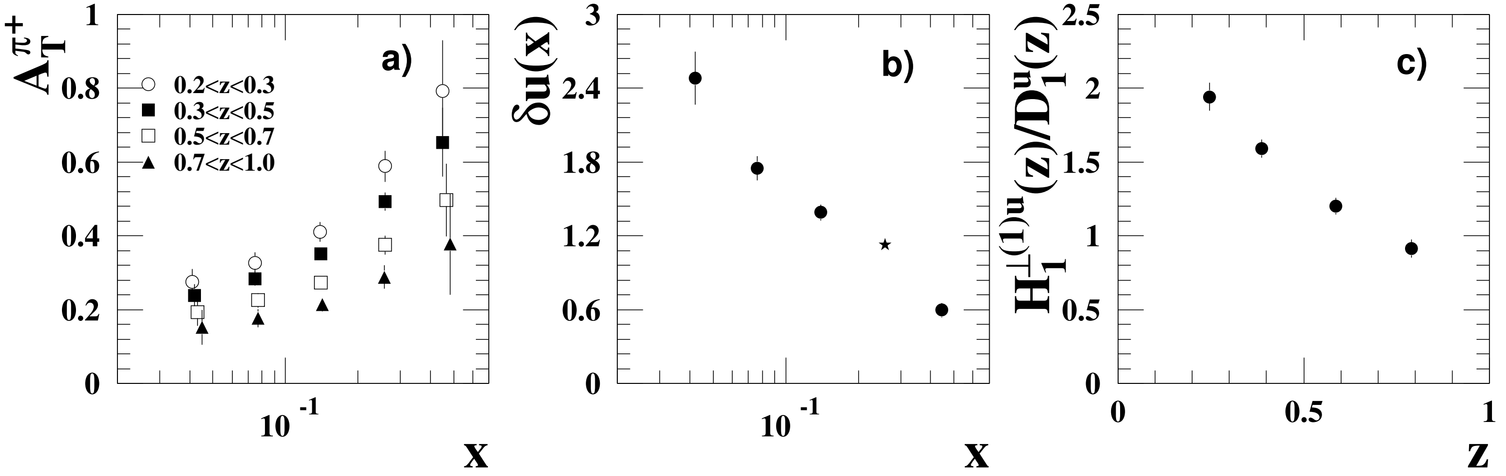
- **u-quark dominance**
- **$P_T = 0.75$**
- **Normalization:**

$\delta q(x_0) = \Delta q(x_0)$ **with $x_0 = 0.25$**

Predictions for HERMES

$$A_p^{\pi^+}(x,y,z) = P_T \cdot D_{nn} \cdot \frac{\delta u(x)}{u(x)} \cdot \frac{H_1^{\perp(1)}(z)}{D_1(z)}$$

Statistics: 7 Million DIS collected with a transverse polarized proton target:



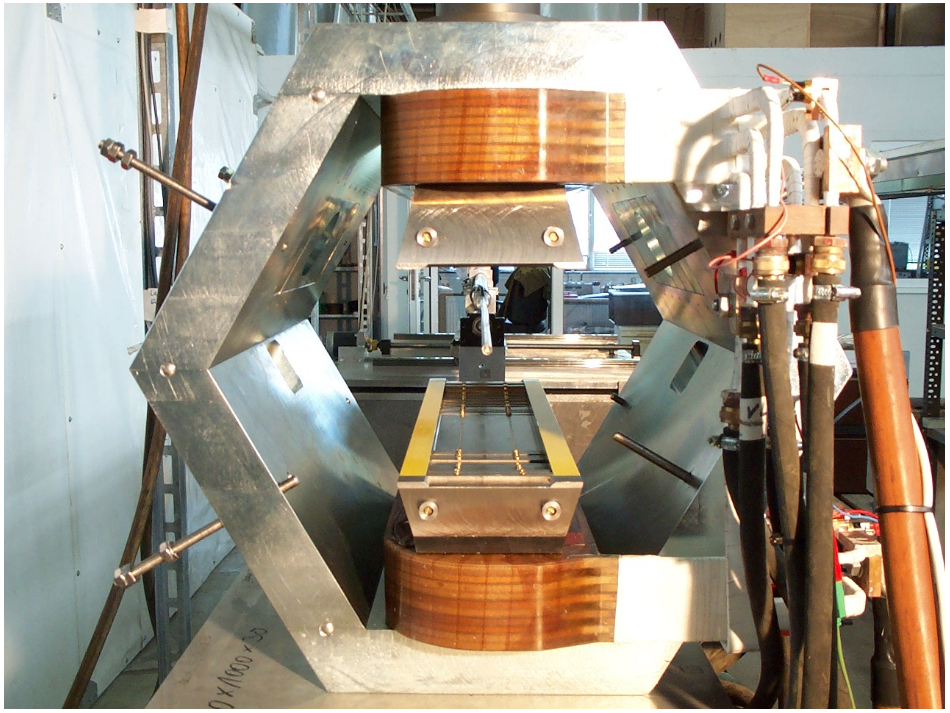
$\delta u(x) + \delta d(x)$: $\longrightarrow$ **transverse polarized deuterium target**

$H_1^{\perp(1)q}(z)$ **can be also measured at e^+e^- (LEP, BELLE)**

hep-ph / 0002268

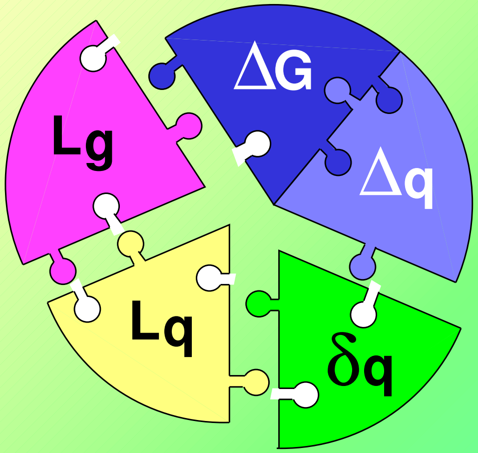
Ready for Beam

The new transverse target magnet



- B = 0.295 T
- Design-Uniformity: $\frac{\Delta B}{B} = 1.4 \cdot 10^{-4}$ over whole volume
- Uniformity along beam direction: $\frac{\Delta B}{B} = 4.5 \cdot 10^{-5}$
- Uniformity along $x-/y-$direction: $\frac{\Delta B}{B} = 6.5 \cdot 10^{-4}$
- Correction coil is already designed, if it will become at all necessary

The Spin Puzzle in 2000



and in 2003