The transverse spin structure of the nucleon

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October 7, 2008
Exploring the transverse structure of the nucleon (not only spin)

Transverse Momentum Dependent distribution functions (TMDs)

\[ q(x, k_\perp; Q^2) \]

Space dependent distribution functions

\[ q(x, b; Q^2) \]
(talk by M. Burkardt)
.... beyond the longitudinal structure which is "simple" (and studied for almost 40 years) ...
essentially $x$ and $Q^2$ degrees of freedom ....
The nucleon, as probed in DIS, in collinear configuration: 3 distribution functions

\[
\Phi_{ij}(k; P, S) = \sum_X \int \frac{d^3 P_X}{(2\pi)^3 2E_X} \frac{1}{(2\pi)^4} \delta^4(P - k - P_X) \langle PS | \bar{\Psi}_j(0) | X \rangle \langle X | \Psi_i(0) | PS \rangle
\]

\[
= \int d^4 \xi e^{ik\cdot\xi} \langle PS | \bar{\Psi}_j(0) \Psi(\xi) | PS \rangle
\]

\[
\Phi(x, S) = \frac{1}{2} \left[ f_1(x) \gamma^\nu n^\mu + S_L g_{1L}(x) \gamma^5 \gamma^\nu n^\mu + h_{1T} i\sigma_{\mu\nu} \gamma^5 n^\mu S_T^\nu \right]
\]
Transversity distribution

\[ \Delta_T q(x) = q_+^\uparrow(x) - q_-^\uparrow(x) \]

\( \Delta_T q \) also denoted as \( h_{1q} \) or \( \delta q \)

\( q(x, Q^2) \), \( \Delta q(x, Q^2) \) and \( \Delta_T q(x, Q^2) \)

are all fundamental, and different, leading-twist quark distributions, equally important

\[ \Delta_T q = \Delta q \text{ only for a proton at rest} \]
\[ \Delta q(x, Q^2) \]

\[ \Delta_T q(x, Q^2) \]

\[ |\uparrow, \downarrow\rangle = \frac{1}{\sqrt{2}}(|+\rangle \pm i|-\rangle) \]

\[ \Delta_T q(x, Q^2) \text{ in helicity basis} \]
No way of flipping helicity in DIS

possible access in SIDIS

or in Drell-Yan processes ....

"golden channel"
Partonic intrinsic motion

Plenty of theoretical and experimental evidence for transverse motion of partons within nucleons and of hadrons within fragmentation jets

uncertainty principle $\Delta x \simeq 1 \text{ fm} \Rightarrow \Delta p \simeq 0.2 \text{ GeV}/c$

primordial intrinsic motion
orbital motion

resummation of soft gluon emission
How and where do we learn about the transverse spin distribution and the partonic motion inside a nucleon? Are they correlated?

**TMDs in SIDIS**

**Single Spin Asymmetries (SSA) in SIDIS:** Collins and Sivers functions

Collins function from $e^+e^-$ unpolarized processes (Belle) and first extraction of transversity

SSA and TMDs in hadronic processes

Future measurements (Drell-Yan)
The leading-twist correlator, with intrinsic $k_{\perp}$, contains several other functions ..... 

$$
\Phi(x, k_{\perp}) = \frac{1}{2} \left[ f_1 h_+ + f_1^{\perp} \epsilon_{\mu\nu\rho\sigma} \gamma^\mu n_+^\nu k_+^\rho S_T^\sigma M + \left( S_L g_{1L} + \frac{k_+ \cdot S_T}{M} g_{1T}^{\perp} \right) \gamma^5 \gamma_+ ^5 \right]
$$

$$
+ \left( h_1^{\perp} \sigma_{\mu\nu} k_+^\mu n_+^\nu \right)
$$

$$
+ \left( h_1 \sigma_{\mu\nu} k_+^\mu n_+^\nu \right)
$$

$$
+ \left( h_1^{\perp} \sigma_{\mu\nu} k_+^\mu n_+^\nu \right)
$$
... with partonic interpretation

One can introduce spin-$k_{\perp}$ correlation in the Parton Distribution Functions (PDFs) and in the parton Fragmentation Functions (FFs)

Only possible (scalar) correlation is

$$ S \cdot (p \times k_{\perp}) $$
TMDs: Sivers function

\[ f_{q/p, S}(x, k_{\perp}) = f_{q/p}(x, k_{\perp}) + \frac{1}{2} \Delta^N f_{q/p}^\uparrow (x, k_{\perp}) \mathbf{S} \cdot (\hat{p} \times \hat{k}_{\perp}) \]

\[ = f_{q/p}(x, k_{\perp}) - \frac{k_{\perp}}{M} f_{1T}^\perp (x, k_{\perp}) \mathbf{S} \cdot (\hat{p} \times \hat{k}_{\perp}) \]

Boer-Mulders function

\[ f_{q, S_{q/p}}(x, k_{\perp}) = \frac{1}{2} f_{q/p}(x, k_{\perp}) + \frac{1}{2} \Delta^N f_{q}^\uparrow (x, k_{\perp}) \mathbf{s}_q \cdot (\hat{p} \times \hat{k}_{\perp}) \]

\[ = \frac{1}{2} f_{q/p}(x, k_{\perp}) - \frac{k_{\perp}}{2M} h_{1T}^\perp (x, k_{\perp}) \mathbf{s}_q \cdot (\hat{p} \times \hat{k}_{\perp}) \]
Spin-$p_\perp$ correlations in fragmentation process (case of final spinless hadron)

Collins function

\[
D_{h/q, s_q}(z, p_\perp) = D_{h/q}(z, p_\perp) + \frac{1}{2} \Delta^N D_{h/q}^\uparrow(z, p_\perp) s_q \cdot (\hat{p}_q \times \hat{p}_\perp)
\]

\[
= D_{h/q}(z, p_\perp) + \frac{p_\perp}{z M_h} H_{1/q}^\perp(z, p_\perp) s_q \cdot (\hat{p}_q \times \hat{p}_\perp)
\]
Spin-$p_\perp$ correlations in fragmentation process (case of final spin 1/2 hadron)

$$ D_{\Lambda,S_{\Lambda}/q}(z,p_\perp) = \frac{1}{2} D_{\Lambda/q}(z,p_\perp) + \frac{1}{2} \Delta^N D_{\Lambda^\uparrow/q}(z,p_\perp) \cdot S_{\Lambda} \cdot (\hat{p}_q \times \hat{p}_\perp) $$

$$ = \frac{1}{2} D_{\Lambda/q}(z,p_\perp) + \frac{p_\perp}{z M_{\Lambda}} D_{1T}^{-q}(z,p_\perp) \cdot S_{\Lambda} \cdot (\hat{p}_q \times \hat{p}_\perp) $$
where so that, finally, the SIDIS cross section (20) can be written

This is an exact expression at all orders in \((\pi\alpha_s)\), and the hadronic plane, Fig. 3. This azimuthal dependence introduces a dependence on the azimuthal angle \(\phi\).

Let us now consider again the issue discussed at the end of Sec. 5, \((\pi\alpha_s)\)-order terms of the production of a hadron. Such a dependence is integrated over in Eq. (31), as in the model treatment; it can be recovered at fixed \((\pi\alpha_s)\) by computing the fragmentation probability, by comparing Eqs. (19) and (31). The former equation describes the cross section for jet production and fragmentation, while the latter describes the cross section for the production of a hadron. Therefore, there cannot be any dependence in physical observables as:

Two scales: \(P_T \ll Q^2\)

\[
\frac{d^6 \sigma}{dx_B dQ^2 dz_h d^2 P_T d\phi_S} = \frac{d^6 \sigma}{\ell p^+ \rightarrow \ell h X} \left( x \right) f_q(x, k_{\perp}; Q^2) \otimes d\hat{\sigma}_{\ell q \rightarrow \ell q}(y, k_{\perp}; Q^2) \otimes D_q^h(z, p_{\perp}; Q^2)
\]

(Collins, Soper, Ji, J.P. Ma, Yuan, Qiu, Vogelsang)
many spin asymmetries

many spin asymmetries

Kotzinian, NP B441 (1995) 234
Mulders and Tangermann, NP B461 (1996) 197
Boer and Mulders, PR D57 (1998) 5780
Bacchetta et al., PL B595 (2004) 309
Bacchetta et al., JHEP 0702 (2007) 093

\[ d\sigma = d\sigma^{0}_{UU} + \cos 2\Phi_h d\sigma^{1}_{UU} + \frac{1}{Q} \cos \Phi_h d\sigma^{2}_{UU} + \lambda \frac{1}{Q} \sin \Phi_h d\sigma^{3}_{LU} \]

\[ + S_L \left\{ \sin 2\Phi_h d\sigma^{4}_{UL} + \frac{1}{Q} \sin \Phi_h d\sigma^{5}_{UL} + \lambda \left[ d\sigma^{6}_{LL} + \frac{1}{Q} \cos \Phi_h d\sigma^{7}_{LL} \right] \right\} \]

\[ + S_T \left\{ \sin(\Phi_h - \Phi_S) d\sigma^{8}_{UT} + \sin(\Phi_h + \Phi_S) d\sigma^{9}_{UT} + \sin(3\Phi_h - \Phi_S) d\sigma^{10}_{UT} \right. \]

\[ + \frac{1}{Q} \left[ \sin(2\Phi_h - \Phi_S) d\sigma^{11}_{UT} + \sin \Phi_S d\sigma^{12}_{UT} \right] \]

\[ + \lambda \left[ \cos(\Phi_h - \Phi_S) d\sigma^{13}_{LT} + \frac{1}{Q} \left( \cos \Phi_S d\sigma^{14}_{LT} + \cos(2\Phi_h - \Phi_S) d\sigma^{15}_{LT} \right) \right] \} \]

\[ d\sigma^n_{SBST} \text{ contains the TMDs} \]
EMC data, $\mu p$ and $\mu d$, $E$ between 100 and 280 GeV

$\cos \Phi_h$ dependence induced by quark intrinsic motion

$\langle k_\perp^2 \rangle = 0.28 \ (\text{GeV})^2 \quad \langle p_\perp^2 \rangle = 0.25 \ (\text{GeV})^2$

M.A., M. Boglione, U. D’Alesio, A. Kotzinian, F. Murgia and A. Prokudin
Sivers effect in SIDIS

\[ d\sigma^{\uparrow, \downarrow} = \sum_q \left( f_{q/p^{\uparrow, \downarrow}}(x, k_\perp; Q^2) \otimes d\hat{\sigma}(y, k_\perp; Q^2) \otimes D_{h/q}(z, p_\perp; Q^2) \right) \]

\[ f_{q/p^{\uparrow, \downarrow}}(x, k_\perp) = f_{q/p}(x, k_\perp) \pm \frac{1}{2} \Delta^N f_{q/p^\uparrow}(x, k_\perp) S \cdot (\hat{p} \times \hat{k}_\perp) \]

\[ d\sigma^\uparrow - d\sigma^\downarrow = \]

\[ \sum_q \Delta^N f_{q/p^\uparrow}(x, k_\perp) S \cdot (\hat{p} \times k_\perp) \otimes d\hat{\sigma}(y, k_\perp) \otimes D_{h/q}(z, p_\perp) \]

\[ \sin(\varphi - \Phi_S) \]

\[ 2\langle \sin(\Phi - \Phi_S) \rangle = A_{UT}^{\sin(\Phi - \Phi_S)} \]

\[ \equiv \frac{\int d\Phi d\Phi_S (d\sigma^\uparrow - d\sigma^\downarrow) \sin(\Phi - \Phi_S)}{\int d\Phi d\Phi_S (d\sigma^\uparrow + d\sigma^\downarrow)} \]
Brodsky, Hwang, Schmidt model for Sivers function

\[ S \cdot (p \times P_T) \propto P_T \sin(\Phi_\pi - \Phi_S) \]

needs $k_\perp$ dependent quark distribution in $p^\uparrow$ and final state interactions
\[ 2 \langle \sin(\phi - \phi_S) \rangle = A^\text{sin(\phi - \phi_S)}_{UT} \]

\[ \equiv 2 \int \int d\phi d\phi_S [d\sigma^\uparrow - d\sigma^\downarrow] \sin(\phi - \phi_S) \]

\[ \int \int \int d\Phi_h d\Phi_S [d\sigma^\uparrow + d\sigma^\downarrow] \]
New kaon data, large $K^+$ asymmetry!
Sivers asymmetry: COMPASS vs HERMES, problems?  
( COMPASS talks )

COMPASS 2007 proton data (part.)

preliminary

Sivers asymmetry: COMPASS vs HERMES, problems?  
( COMPASS talks )

COMPASS 2007 proton data (part.)

preliminary

courtesy of F. Bradamante
Collins effect in SIDIS

\[ D_{h/q, s_q}(z, p_\perp) = D_{h/p}(z, p_\perp) + 1/2 \Delta^N D_{h/q}(z, p_\perp) \cdot s_q \cdot (\hat{p}_q \times \hat{p}_\perp) \]

\[ d\sigma^\uparrow - d\sigma^\downarrow = \sum_q h_{1q}(x, k_\perp) \otimes d\Delta^\hat{\sigma}(y, k_\perp) \otimes \Delta^N D_{h/q}(z, p_\perp) \]

\[ A_{UT}^{\sin(\phi + \phi_S)} \equiv 2 \frac{\int d\phi d\phi_S [d\sigma^\uparrow - d\sigma^\downarrow] \sin(\phi + \phi_S)}{\int d\phi d\phi_S [d\sigma^\uparrow + d\sigma^\downarrow]} \]

\[ d\Delta^\hat{\sigma} = d\hat{\sigma}^\ell q^\uparrow \rightarrow \ell q^\uparrow - d\hat{\sigma}^\ell q^\uparrow \rightarrow \ell q^\downarrow \]

Collins effect in SIDIS couples to transversity
\[ 2 \langle \sin(\phi + \phi_S) \rangle = A_{UT}^{\sin(\phi + \phi_S)} \]
\[ \equiv 2 \frac{\int d\phi d\phi_S [d\sigma^\uparrow - d\sigma^\downarrow] \sin(\phi + \phi_S)}{\int d\phi d\phi_S [d\sigma^\uparrow + d\sigma^\downarrow]} \]
COMPASS data on Collins asymmetry, proton target
Collins function from $e^+e^-$ processes

(spinn effects without polarization, D. Boer)

$e^+e^- \rightarrow q\bar{q} \rightarrow h_1 h_2 X$

measure a correlation:

$$A_{12} \propto \sum_q \Delta^N D_{h_1/q\uparrow}(z_1, p_{\perp 1}) \otimes \Delta^N D_{h_2/\bar{q}\uparrow}(z_2, p_{\perp 2})$$
Belle data: \( A_{12} \propto \sum_q \Delta^N D_{\pi/q} \uparrow (z_1) \otimes \Delta^N D_{\pi/\bar{q}} \uparrow (z_2) \)
Extraction of Sivers, Transversity and Collins functions from SIDIS + BELLE data

u and d Sivers functions rather well determined

talk by A. Prokudin
extracted transversity distributions
(blue lines = Soffer's bound)
extracted Collins functions

M.A., M. Boglione, U. D’Alesio, A. Kotzinian, S. Melis, F. Murgia, A. Prokudin, C. Türk
TMDs and SSAs in hadronic processes

Cross section for $p p \rightarrow \pi^0 X$ in pQCD, only one scale, $P_T$

based on factorization theorem
(in collinear configuration)

$$d\sigma = \sum_{a,b,c,d=q,q,g} f_{a/p}(x_a) \otimes f_{b/p}(x_b) \otimes d\hat{\sigma}^{ab\rightarrow cd} \otimes D_{\pi/c}(z)$$

PDF

pQCD elementary interactions

$\pi^0$
Polarization-averaged cross sections at $\sqrt{s}=200$ GeV
(talk of C. Aidala at Transversity 2008, May 2008, Ferrara)

good pQCD description of data at 200 GeV, at all
rapidities, down to $p_T$ of 1-2 GeV/c
rather good agreement even at $\sqrt{s}=62.4$ GeV

Comparison of NLO pQCD calculations with BRAHMS $\pi$ data at high rapidity. The calculations are for a scale factor of $\mu=p_T$, KKP (solid) and DSS (dashed) with CTEQ5 and CTEQ6.5.

mid-rapidity pions
\[ d\sigma^\uparrow - d\sigma^\downarrow = \sum_{a,b,c,d=q,\bar{q},g} \Delta_T f_a \otimes f_b \otimes [\hat{d}\sigma^\uparrow - \hat{d}\sigma^\downarrow] \otimes D_{\pi/c} \]

was considered almost a theorem
but, .... where it all started from

$E704 \sqrt{s} = 20 \text{ GeV} \quad 0.7 < p_T < 2.0$
Unifying 62.4 and 200 GeV, BRAHMS + E704
(C. Aidala talk at transversity 2008, Ferrara)

BRAHMS Preliminary

\[ A_N(\pi) \]

\[ 0.5 < p_T(\pi) < 0.8 \text{ GeV/c} \]

E704 data - all \( p_T \) (small stars); \( p_T > 0.7 \text{ GeV/c} \) (large stars)
SSA in hadronic processes: TMDs, higher-twist correlations?

Two main different (?) approaches

1. Generalization of collinear scheme
   (assuming factorization)

\[
\frac{d\sigma}{d^4q} = \sum_{a,b,c=q,\bar{q},g} f_{a/P}(x_a, \mathbf{k}_{\perp a}) \otimes f_{b/P}(x_b, \mathbf{k}_{\perp b}) \otimes d\hat{\sigma}^{ab\to cd}(\mathbf{k}_{\perp a}, \mathbf{k}_{\perp b}) \otimes D_{\pi/c}(z, \mathbf{p}_{\perp\pi})
\]

single spin effects in TMDs

M.A., M. Boglione, U. D’Alesio, E. Leader, S. Melis, F. Murgia, A. Prokudin, ...

Field-Feynman
2. Higher-twist partonic correlations

(Efremov, Teryaev; Qiu, Sterman; Kouvaris, Vogelsang, Yuan; Bacchetta, Bomhof, Mulders, Pijlman; Koike ...)

contribution to SSA \((A^\uparrow B \rightarrow h X)\)

\[
d\Delta\sigma \propto \sum_{a,b,c} T_a(k_1, k_2, S_\perp) \otimes f_{b/B}(x_b) \otimes H^{ab\rightarrow c}(k_1, k_2) \otimes D_{h/c}(z)
\]

twist-3 functions

hard interactions

courtesy of W. Vogelsang
SSA in \( pp \rightarrow \text{jet} + \text{jet} + X, \ H_1 H_2 \rightarrow h_1 h_2 X \)

Bacchetta, Bomhof, Mulders, Pijlman; Boer, Vogelsang, Yuan; Teryaev

\[ k^\perp = \text{jet pair transverse momentum} \]

Sivers contribution to SSA \( (T_a \propto f_{1T}^{\perp (1)}) \)

\[
d\Delta\sigma \propto \sum_{a,b,c} f_{1T}^{\perp (1)}(x_1) \otimes f_{b/H_2}(x_2) \otimes d\hat{\sigma}_{[a]b \rightarrow cd} \otimes D_{h_1/c}(z_1) \ D_{h_2/d}(z_2)
\]

gluonic pole cross sections take into account gauge links

\[
d\hat{\sigma}_{[a]b \rightarrow cd} = \sum_D C_G^{[D]} \ d\hat{\sigma}_{ab \rightarrow cd} \quad C_G^{[D]} \quad \text{Diagram dependent Gauge link Colour factors}
\]

(breaking of factorization?)
Gluonic pole cross sections and SSA in $H_1 H_2 \to h_1 h_2 X$

\[
\frac{d\hat{\sigma}_{[q]q \to qq}}{dt} = \frac{1}{2} + \frac{1}{2} + \frac{3}{2} + \frac{3}{2}
\]

\[
= \frac{4\pi \alpha_S^2}{9\hat{s}^2} \left\{ \frac{\hat{s}^2 + \hat{u}^2}{2\hat{t}^2} + \frac{\hat{s}^2 + \hat{t}^2}{2\hat{u}^2} + \frac{\hat{s}^2}{\hat{t}\hat{u}} \right\}
\]

to be compared with the usual cross section

\[
\frac{d\hat{\sigma}_{qq \to qq}}{dt} = \frac{4\pi \alpha_S^2}{9\hat{s}^2} \left\{ \frac{\hat{s}^2 + \hat{u}^2}{\hat{t}^2} + \frac{\hat{s}^2 + \hat{t}^2}{\hat{u}^2} - \frac{2}{3} \frac{\hat{s}^2}{\hat{t}\hat{u}} \right\}
\]

\[
d\hat{\sigma}_{[\ell]q \to \ell q} = d\hat{\sigma}_{\ell q \to \ell q} \quad d\hat{\sigma}_{[q]q \to \ell^+ \ell^-} = -d\hat{\sigma}_{q\bar{q} \to \ell^+ \ell^-}
\]
TMDs and SSAs in Drell-Yan processes
(talk by A. Metz)

\[ \sigma^{D-Y} = \sum_a f_q(x_1, k_{\perp 1}; Q^2) \otimes f_{\bar{q}}(x_2, k_{\perp 2}; Q^2) d\sigma_{q\bar{q} \to \ell^+ \ell^-} \]

3 planes: plane \( \perp \) to polarization vectors,\( p - \gamma \) * plane, \( l^+ - l^- \) plane
no fragmentation process

recent paper by
Arnold, Metz, Schlegel
Unpolarized cross section already very interesting

$$\frac{1}{\sigma} \frac{d\sigma}{d\Omega} = \frac{3}{4\pi} \frac{1}{\lambda + 3} \left( 1 + \lambda \cos^2 \theta + \mu \sin 2\theta \cos \phi + \frac{\nu}{2} \sin^2 \theta \cos 2\phi \right)$$

Collins-Soper frame

naive collinear parton model: $\lambda = 1$ $\mu = \nu = 0$
Decay angular distributions in pion-induced Drell-Yan

E615 Data 252 GeV $\pi^- + W$  

Phys. Rev. D 39 (1989) 92

\[ m_{\mu\mu}(\text{GeV/c}^2) \]

\[ x_\pi \]

\[ p_T(\text{GeV/c}) \]

$\lambda \neq 1, \mu, \nu \neq 0, 1 - \lambda - 2\nu \neq 0$

(Jen-Chieh Peng talk at transversity 2008, Ferrara)
TMDs help: for example, the $\cos 2\phi$ term can be originated by the Boer-Mulders effect

$$d\sigma \propto \frac{d\sigma^0}{1 + \cos^2 \theta} + \sum_q h_{1q}^\perp (x_1, k_\perp) \otimes h_{1\bar{q}}^\perp (x_2, k_\perp) \otimes (d\hat{\sigma}^{\uparrow\uparrow} - d\hat{\sigma}^{\uparrow\downarrow}) \sin^2 \theta \cos 2\phi$$

Polarized D-Y processes with intrinsic $k_\perp$ have a rich structure, similar to SIDIS (D-YLAND contains 48 terms ...)

SSA in D-Y has a contribution from the coupling of the transversity distribution to B-M function

$$d\sigma^{\uparrow} - d\sigma^{\downarrow} \propto \sum_q h_{1q} (x_1) \otimes h_{1\bar{q}}^\perp (x_2, k_\perp) \otimes (d\hat{\sigma}^{\uparrow\uparrow} - d\hat{\sigma}^{\uparrow\downarrow}) \cos 2\phi$$

B-M 

$$f_{q,s_{q/p}}(x, k_\perp) = \frac{1}{2} f_{q/p}(x, k_\perp) - \frac{k_\perp}{2M} h_{1q}^\perp (x, k_\perp) s_q \cdot (\hat{p} \times \hat{k}_\perp)$$
Sivers effect in D-Y processes

By looking at the $d^4 \sigma / d^4 q$ cross section one can single out the Sivers effect in D-Y processes

$$d\sigma^\uparrow - d\sigma^\downarrow \propto \sum_q \Delta^N f_{q/p}^\uparrow(x_1, k_\perp) \otimes f_{\bar{q}/p}(x_2) \otimes d\hat{\sigma}$$

$q = u, \bar{u}, d, \bar{d}, s, \bar{s}$

$$A_{N}^{\sin(\phi_S - \phi_\gamma)} \equiv \frac{2\int_{0}^{2\pi} d\phi_\gamma [d\sigma^\uparrow - d\sigma^\downarrow] \sin(\phi_S - \phi_\gamma)}{\int_{0}^{2\pi} d\phi_\gamma [d\sigma^\uparrow + d\sigma^\downarrow]}$$

(p-p c.m. frame)
Crucial role of gauge-links in TMDs

- Profound implication: process-dependence of Sivers functions

\[ f_{\text{DY}}^{\text{Sivers}}(x, k_{\perp}) = - f_{\text{DIS}}^{\text{Sivers}}(x, k_{\perp}) \]

DIS: “attractive”

DY: “repulsive”

- Hugely important in QCD -- tests a lot of what we know about description of hard processes

W. Vogelsang’s talk at Beijing, June 2008
Predictions for $A_N$ (S. Melis)

Sivers functions as extracted by M.A., M. Boglione, U. D’Alesio, A. Kotzinian, S. Melis, F. Murgia, A. Prokudin and C. Türk from SIDIS data, with opposite sign

large Sivers SSA expected
Not all spin problems have been solved, but enormous progress has been made.

The spin-orbiting structure of quarks in nucleons begins to emerge.

Theory. Unintegrated PDF and FF play a crucial role; their $Q^2$ evolution is needed. Factorization and universality issues must be clarified, ...

Experiment. New data from COMPASS (proton target), JLab, RHIC, GSI, JPARK. D-Y processes very promising ...

Many interesting talks and much more information in next days ....

thank you!