OUTLINE

Dihadron Fragmentation Functions

Fragmentation
- Asymmetries at Belle
- Multiplicities at CLAS12

SIDIS with Dihadron

Confinement
- Transversity
- Higher-twist PDFs
Hadronization of the quark into a hadron $h$

$$D_1^{q ightarrow h}(z, \kappa_T^2)$$
Hadronization of the quark into a hadron $h$

$D_{1}^{q\rightarrow h} (z, \kappa_{T}^{2})$
Hadronization of the quark into a hadron $h$

$$D_1^{q\rightarrow h} (z, \kappa_T^2)$$

Hadronization of the quark into a hadron $h$

$$D_1^{q\rightarrow h_1 h_2} (z_1, z_2, R_T^2)$$

$\kappa_T$

$2R_T$
SINGLE-HADRON & DIHADRON SIDIS

Transverse mmt dep.

\[ d\sigma \propto \sum_q [PDF^q \otimes FF^q] (x, z, P_{h_\perp}^2) \]

Collinear

\[ d\sigma \propto \sum_q PDF^q(x) \times DiFF^q (z, M_h) \]
SINGLE-HADRON & DIHADRON SIDIS

Transverse mmt dep.

Collinear

\[ d\sigma \propto \sum_q [\text{PDF}^q \otimes \text{FF}^q] (x, z, P_{h\perp}^2) \]

\[ d\sigma \propto \sum_q \text{PDF}^q(x) \times \text{DiFF}^q(z, M_h) \]

TMD Fragmentation and Distribution functions

Collinear Distribution functions
SINGLE-HADRON & DIHADRON SIDIS

Transverse mmt dep.

Collinear

\[ d\sigma \propto \sum_{q} [PDF^q \otimes FF^q](x, z, P_{h\perp}^2) \]

\[ d\sigma \propto \sum_{q} PDF^q(x) \times DiFF^q(z, M_h) \]

TMD Fragmentation and Distribution functions
Convolution

Collinear Distribution functions
Simple product
SINGLE-HADRON & DIHADRON SIDIS

**Transverse mmt dep.**

\[ d\sigma \propto \sum_q [PDF^q \otimes FF^q] (x, z, P_{h\perp}^2) \]

**Collinear**

\[ d\sigma \propto \sum_q PDF^q(x) \times Diff^q(z, M_h) \]

- TMD Fragmentation and Distribution functions
- Convolution
- More Lorentz structures
- Collinear Distribution functions
- Simple product
SINGLE-HADRON & DIHADRON SIDIS

Transverse mmt dep.

\[ d\sigma \propto \sum_q [\text{PDF}^q \otimes \text{FF}^q] (x, z, P_{h\perp}^2) \]

Collinear

\[ d\sigma \propto \sum_q \text{PDF}^q (x) \times \text{DiFF}^q (z, M_h) \]

- TMD Fragmentation and Distribution functions
- Convolution
- More Lorentz structures
- 3D "tomography"

- Collinear Distribution functions
- Simple product
- 1D "tomography"
SINGLE-HADRON & DIHADRON SIDIS

Transverse mmt dep.

\[ d\sigma \propto \sum_q [PDF^q \otimes FF^q] (x, z, P_{h\perp}^2) \]

Collinear

\[ d\sigma \propto \sum_q PDF^q(x) \times DiFF^q (z, M_h) \]

- TMD Fragmentation and Distribution functions
- Convolution
- More Lorentz structures
- 3D "tomography"

- Collinear Distribution functions
- Simple product
- 1D "tomography"
- 2pion physics
SI PION PAIRS PRODUCTION @ BELLE

\[ A_{e^+e^-}(z, M_h^2, \bar{z}, \bar{M}_h^2) \propto \frac{\sum_q e_q^2 H_{1,sp}^q (z, M_h^2) H_{1,sp}^{\pi^+\pi^-} (\bar{z}, \bar{M}_h^2)}{\sum_q e_q^2 D_{1}^{\pi^+\pi^-} (z, M_h^2) D_{1}^{\pi^+\pi^-} (\bar{z}, \bar{M}_h^2)} \]

\[ R(z, M_h) = \frac{\left| R \right|}{M_h} \frac{H_{1,sp}^{\pi^+\pi^-} (z, M_h^2; Q_0^2)}{D_{1}^{\pi^+\pi^-} (z, M_h^2; Q_0^2)} \]

[A.C., Bacchetta, Radici, Bianconi, Phys.Rev. D85]
[Radici, A.C., Bacchetta, Radici, Guagnelli, JHEP 1505]
MULTIPlicITIES

Improve knowledge on Dihadron FF
→ think reduce uncertainty

\[ M^h(z, m_{\pi\pi}, x; Q^2) = \frac{\sum_q e_q^2 f_1^q(x; Q^2) D_1^q(z, m_{\pi\pi}; Q^2)}{\sum_q e_q^2 f_1^q(x; Q^2)} \]

Based on [A.C., Bacchetta, Radici, Bianconi, Phys.Rev. D85]

- exp. input at lower Q²
- test PWE & higher twists
- better knowledge on (z, Mₓ)-dependence
Higher-twist collinear structure of the nucleon through di-hadron SIDIS on unpolarized hydrogen and deuterium

A 12 GeV Research Proposal to Jefferson Lab (PAC 42)

E12-06-112B
Silvia Pisano & A.C.

Pavia
PEPSI gen.
\[ A_{UT}^{\sin(\phi_R+\phi_S) \sin \theta}(x, y, z, M_h; Q) = -\frac{B(y)}{A(y)} \left| \mathbf{R} \right| \sum_q e_q^2 h_1^q(x; Q^2) \frac{H_{1,sp}^q(z, M_h; Q^2)}{M_h} \sum_q e_q^2 f_1^q(x; Q^2) D_1^q(z, M_h; Q^2) \]

\[ A_{LU}^{\sin \phi_R \sin \theta}(x, y, z, M_h, Q) = -\frac{W(y)}{A(y)} \frac{M}{Q} \left| \mathbf{R} \right| \sum_q e_q^2 \left[ x e_q(x) H_{1,sp}^q(z, M_h) + \frac{M_h}{z M} f_1^q(x) \tilde{G}_{sp}^q(z, M_h) \right] \frac{M_h}{2} \sum_q e_q^2 f_1^q(x) D_1^{q,ss+pp}(z, M_h) \]

\[ A_{UL}^{\sin \phi_R \sin \theta}(x, y, z, M_h, Q) = -\frac{V(y)}{A(y)} \frac{M}{Q} \left| \mathbf{R} \right| \sum_q e_q^2 \left[ x h_L^q(x) H_{1,sp}^q(z, M_h) + \frac{M_h}{z M} g_1^q(x) \tilde{G}_{sp}^q(z, M_h) \right] \frac{M_h}{2} \sum_q e_q^2 f_1^q(x) D_1^{q,ss+pp}(z, M_h) \]

[Jaffe, Jin, Tiang, PRL 80]
[Radici, Jakob & Bianconi, PRD65]
[Bacchetta & Radici, PRD69]
DIHADRON SIDIS

\[ A_{UT}^{\sin(\phi_R+\phi_S) \sin \theta}(x, y, z, M_h; Q) = -\frac{B(y)}{A(y)} \frac{|R|}{M_h} \sum_{q} e_{q}^2 h_{1}^{q}(x; Q^2) \frac{H_{1,sp}^{<q}(z, M_h; Q^2)}{D_{1}^{q}(z, M_h; Q^2)} \]

\[ A_{LU}^{\sin \phi_R \sin \theta}(x, y, z, M_h, Q) = -\frac{W(y)}{A(y)} \frac{M}{2} \frac{|R|}{M_h} \sum_{q} e_{q}^2 \left[ x e_{q}(x) H_{1,sp}^{<q}(z, M_h) + \frac{M_h}{z M} f_{1}^{q}(x) G_{sp}^{<q}(z, M_h) \right] \]

\[ A_{UL}^{\sin \phi_R \sin \theta}(x, y, z, M_h, Q) = -\frac{V(y)}{A(y)} \frac{M}{2} \frac{|R|}{M_h} \sum_{q} e_{q}^2 \left[ x h_{L}^{q}(x) H_{1,sp}^{<q}(z, M_h) + \frac{M_h}{z M} g_{1}^{q}(x) G_{sp}^{<q}(z, M_h) \right] \]

[Jaffe, Jin, Tiang, PRL 80]
[Radici, Jakob & Bianconi, PRD65]
[Bacchetta & Radici, PRD69]
A_DIS(x, z, M_h^2, Q^2) = -C_y \left( \sum_q e_q^2 h_1^q(x, Q^2) \frac{|\tilde{R}|}{M_h} H_{1,sp}^{q \to \pi^+ \pi^-}(z, M_h^2, Q^2) \right) \left( \sum_q e_q^2 f_1^q(x, Q^2) D_{1}^{q \to \pi^+ \pi^-}(z, M_h^2, Q^2) \right)
DIHADRON SIDIS ON PROTON & DEUTERON

\[ A_{\text{DIS}}(x, z, M^2_h, Q^2) = -C_y \left( \sum_q e_q^2 h_1^q(x, Q^2) H_{1,sp}^{q \rightarrow \pi^+ \pi^-}(z, M^2_h, Q^2) \right) \left( \sum_q e_q^2 f_1^q(x, Q^2) D_1^{q \rightarrow \pi^+ \pi^-}(z, M^2_h, Q^2) \right) \]
Therefore, like in the case of the Collins asymmetry, the small asymmetries observed for the deuteron is proportional to yields.

A naive interpretation of our data, based on Eq. (7) and on isospin symmetry and charge conjugation, a possible dilution due to contributions from target fragmentation.

identified system; both agree reasonably well when including
lates asymmetries in the photon-nucleon system, while HERMES published them in the lepton-nucleon of the asymmetries the phase
not be directly compared for several reasons: (1) The opposite sign is due to the fact that in the extraction
When comparing the results on the NH
asymmetry is negative and shows no strong dependence on these variables.

The resulting asymmetries are shown in Fig. 4 as a function of

\[ A_{\text{DIS}}(x, z, M_h^2, Q^2) = -C_y \sum_q e_q^2 \frac{h_1^q(x, Q^2)}{f_1^q(x, Q^2)} \frac{\hat{R}}{M_h} \frac{H_{1, sp}^{q \rightarrow \pi^+ \pi^-}}{D_1^{q \rightarrow \pi^+ \pi^-}}(z, M_h^2, Q^2) \]

\[ (z, M_h)\text{-dependence determined by DiFF from Belle} \]

[\text{A.C., Bacchetta, Radici, Bianconi, Phys.Rev. D85}]
STATE-OF-THE-ART TRANSVERSITY

Discrepancy in the d distribution
New proton data don't change that!

[Radici, A.C., Bacchetta, Radici, Guagnelli, JHEP 1505]
STATE-OF-THE-ART TRANSVERSITY

Discrepancy in the d distribution
New proton data don't change that!

Kang et al central value

[Radici, A.C., Bacchetta, Radici, Guagnelli, JHEP 1505]
FUTURE OF THE TRANSVERSITY

Proposal for CLAS12

A 12 GeV Research Proposal to Jefferson Lab (PAC 39)

Measurement of transversity with dihadron production in SIDIS with transversely polarized target

Analysis Proposal for SoLID

Dihadron Electroproduction in DIS with Transversely Polarized $^3$He Target at 11 and 8.8 GeV

June 2, 2014

(A Proposal to Jefferson Lab (PAC 42))
FUTURE OF THE TRANSC 结

Proposal for CLAS12 PR12-12-009

A 12 GeV Research Proposal to Jefferson Lab (PAC 39)

Measurement of transversity with dihadron production in SIDIS with transversely polarized target

Analysis Proposal for SoLID

Dihadron Electroproduction in DIS with Transversely Polarized $^3$He Target at 11 and 8.8 GeV

June 2, 2014

(A Proposal to Jefferson Lab (PAC 42))

Improve determination of tensor charge!

$$\int_0^1 dx \, h_{1}^{qv}(x) = \delta q$$
FUTURE OF THE TRANSVERSITY

Proposal for CLAS12

A 12 GeV Research Proposal to Jefferson Lab (PAC 30)

Measurement of the transversity with dihadron production
in SIDIS experiment with a transversely polarized target.

Beam Request

A transversely polarized proton would allow precision measurements of flavor
statistics SIDIS experiment with a transversely polarized target.

The measurement of the target SSA in hadron pair production on
a hydrog

Underlying transversity PDF.

SoLID Proposal for CLAS12

Dihadron Electroproduction in DIS with Transversely
Polarized \(^3\)He Target at 11 and 8.8 GeV

June 2, 2014

(A Proposal to Jefferson Lab (PAC 42))

Improve determination of tensor charge!

\[
\int_0^1 dx \ h_1^{qV}(x) = \delta q
\]
DIHADRON SIDIS

@ HERMES & COMPASS
@ CLAS12 & SoLID

\[ A_{UT}^\sin(\phi_R+\phi_S) \sin \theta(x, y, z, M_h; Q) = -\frac{B(y)}{A(y)} \frac{\left| R \right|}{M_h} \sum_q e_q^2 h_1^q(x; Q^2) H_1^{\langle q} (z, M_h; Q^2) \]

\[ A_{LU}^\sin \phi_R \sin \theta(x, y, z, M_h, Q) = -\frac{W(y)}{A(y)} \frac{M}{Q} \frac{1}{2} \frac{\left| R \right|}{M_h} \sum_q e_q^2 \left[ x e^q(x) H_1^{\langle q} (z, M_h) + \frac{M_h}{z M} f_1^q(x) \tilde{G}_1^{\langle q} (z, M_h) \right] \]

\[ A_{UL}^\sin \phi_R \sin \theta(x, y, z, M_h, Q) = -\frac{V(y)}{A(y)} \frac{M}{Q} \frac{1}{2} \frac{\left| R \right|}{M_h} \sum_q e_q^2 \left[ x h_L^q(x) H_1^{\langle q} (z, M_h) + \frac{M_h}{z M} g_1^q(x) \tilde{G}_1^{\langle q} (z, M_h) \right] \]

[Jaffe, Jin, Tiang, PRL 80]
[Radici, Jakob & Bianconi, PRD65]
[Bacchetta & Radici, PRD69]
DIHADRON SIDIS

A_{UT} @ HERMES & COMPASS
@ CLAS12 & SoLID

$$A_{UT}^{\sin(\phi_R + \phi_S)} \sin \theta(x, y, z, M_h; Q) = -\frac{B(y)}{A(y)} \frac{|R|}{M_h} \sum_q e_q^2 h_1^q(x; Q^2) \frac{H_{1,sp}^q(z, M_h; Q^2)}{\sum_q e_q^2 f_1^q(x; Q^2) D_1^q(z, M_h; Q^2)}$$

A_{LU} @ CLAS

$$A_{LU}^{\sin \phi_R \sin \theta}(x, y, z, M_h, Q) = -\frac{W(y)}{A(y)} \frac{M}{Q} \frac{|R|}{2 M_h} \sum_q e_q^2 \left[ x e_q(x) H_{1,sp}^q(z, M_h) + \frac{M_h}{z M} f_1^q(x) \tilde{G}_{sp}^{q, q}(z, M_h) \right]$$

A_{UL} @ CLAS

$$A_{UL}^{\sin \phi_R \sin \theta}(x, y, z, M_h, Q) = -\frac{V(y)}{A(y)} \frac{M}{Q} \frac{|R|}{2 M_h} \sum_q e_q^2 \left[ x h_1^q(x) H_{1,sp}^q(z, M_h) + \frac{M_h}{z M} g_1^q(x) \tilde{G}_{sp}^{q, q}(z, M_h) \right]$$

[Jaffe, Jin, Tiang, PRL 80]
[Radici, Jakob & Bianconi, PRD 65]
[Bacchetta & Radici, PRD 69]
Dihadron SIDIS

\[ A_{UT} \sin(\phi_R + \phi_S) \sin \theta(x, y, z, M_h; Q) = \frac{-B(y)}{A(y)} \frac{|R|}{M_h} \sum_q e_q^2 h_1^q(x; Q^2) H_{1,sp}^{q}(z, M_h; Q^2) \]

\[ A_{LU} \sin \phi_R \sin \theta(x, y, z, M_h, Q) = \frac{-W(y)}{A(y)} \frac{M}{Q} \frac{1}{2 M_h} \sum_q e_q^2 \left[ x e_q(x) H_{1,sp}^{q}(z, M_h) + \frac{M_h}{z M} f_1^q(x) \tilde{G}_{sp}^{q}(z, M_h) \right] \]

\[ A_{UL} \sin \phi_R \sin \theta(x, y, z, M_h, Q) = \frac{-V(y)}{A(y)} \frac{M}{Q} \frac{1}{2 M_h} \sum_q e_q^2 \left[ x h_L^q(x) H_{1,sp}^{q}(z, M_h) + \frac{M_h}{z M} g_1^q(x) \tilde{G}_{sp}^{q}(z, M_h) \right] \]

[Jaffe, Jin, Tiang, PRL 80]
[Radici, Jakob & Bianconi, PRD65]
[Bacchetta & Radici, PRD69]

\[ \text{HERMES} \ & \ COMPASS \]
\[ @ \ CLAS12 \ & \ SoLID \]

\[ \text{CLAS} \ & \ CLAS12 \]
GOAL: extract $e(x)$ from CLAS data

For the longitudinal polarization of the beam, pair production. The relevant spin asymmetry can be built as ratios of structure functions.

The invariant mass squared of the hadron pair is $F_{\mathrm{LL}} = LU$. The cross section for two particle SIDIS can be written in terms of modulations in the azimuthal angle identified by the vector $A_{\mathrm{LL}} = LU$ is the ratio of longitudinal and transverse photon flux and can be expressed in terms of

$$ A_{\mathrm{LU}}^{\sin \phi_R} (x, z, m_{\pi\pi}; Q, y) = - \frac{W(y) M}{A(y) Q} \frac{|\mathbf{R}|}{m_{\pi\pi}} \sum_q e_q^2 \left[ x e_q^q (x, Q^2) H_{1,sp}^{\zeta,q} (z, m_{\pi\pi}, Q^2) + \frac{m_{\pi\pi}}{z M} f_1^q (x, Q^2) \tilde{G}_{sp}^{\zeta,q} (z, m_{\pi\pi}, Q^2) \right] \frac{\sum_q e_q^2 f_1^q (x, Q^2) D_{1,ss+pp}^q (z, m_{\pi\pi}, Q^2)}{\sum_q e_q^2} $$

...from CLAS data

Silvia Pisano's analysis

$e1-f$
GOAL: extract e(x) from CLAS data

For the longitudinal polarization of the beam, pair production. The relevant spin asymmetry can be built as ratios of structure functions.

\[ A_{LU}^{\sin \phi_R} (x, z, m_{\pi \pi}; Q, y) = -\frac{W(y)}{A(y)} \frac{M}{Q} \sum_q e_q^2 \left[ xe_q^2 (x, Q^2) H_1^{<,q} (z, m_{\pi \pi}, Q^2) + \frac{m_{\pi \pi}}{zM} f_1^q (x, Q^2) \tilde{G}_sp^{<,q} (z, m_{\pi \pi}, Q^2) \right] \]

...from CLAS data

higher-twist PDF e(x) unknown

Silvia Pisano's analysis e1-f
GOAL: extract e(x) from CLAS data

The longitudinal polarization of the beam, pair production. The relevant spin asymmetry can be built as ratios of structure functions. For the longitudinal polarization of the beam, the structure function can be written in terms of modulations in the azimuthal angle identified by the vector. The kinematics and the definition of the angles can be found in, by the kinematic variables: the invariant mass squared of the hadron pair is $F_{LL} = \cos \theta_{UU} \cos \theta_{LL}$.

Combining Eqs. (10,12), to leading-order in $x$, the structure functions of interest can be written in terms of PDFs higher-twist PDF $e(x)$ unknown

leading-twist DiFFs known

...from CLAS data

Silvia Pisano's analysis $e1-f$
For the longitudinal polarization of the beam, we now consider the structure function with the first subindex of the structure function corresponding to the beam polarization, the second to the target. We can identify the azimuthal angle by the kinematic variables:

\[ Q = \sqrt{m_{\pi\pi}^2 + \vec{p}_{\pi}^2} \]

The invariant mass squared of the hadron pair is

\[ x = \frac{Q^2}{4m_{\pi\pi}^2} \]

The kinematics and the definition of the angles can be be found in, e.g., the Wakamatsu model [3].

The particle SIDIS can be written in terms of modulations in the azimuthal angle identified by the vector \( \vec{r} \) we mention the azimuthal angle

\[ \phi_R = \frac{1}{2} \ln \left( \frac{1 + x}{1 - x} \right) \]

In the limit. Combining Eqs. (10,12), to leading-order in higher-twist PDF \( e(x) \) unknown, higher-twist DiFFs unknown

\[ A^\sin \phi_R (x, z, m_{\pi\pi}; Q, y) = \frac{W(y)}{A(y)} M |R| \sum_q e^2_q \left[ xe^q(x, Q^2) \left( H^L_{1,sp}(z, m_{\pi\pi}, Q^2) + \frac{m_{\pi\pi}}{Q^2} f^q(x, Q^2) \left( G^L_{sp}(z, m_{\pi\pi}, Q^2) + \sum_{sp} D^q_{1,ss+pp}(z, m_{\pi\pi}, Q^2) \right) \right) \right] \]

Silvia Pisano's analysis e1-f

...from CLAS data

Total Systematics

CLAS at 6 GeV on H

LFCQM

Bag model

Wakamatsu model
First Try Extraction

Assume no dynamical higher-twist in the fragmentation part

\[ A_{LU}^{\sin \phi} (x_i, m_{\pi \pi i}, z_i; Q_i, y_i) = \frac{W(y_i)}{A(y_i)} \frac{M}{Q_i} x_i \left[ \frac{4}{9} e_{uv} (x_i, Q_i^2) - \frac{1}{9} e_{dv} (x_i, Q_i^2) \right] \sum_{q=u,d,s} e_q^2 f_1^q (x_i, Q_i^2) n_{u,i}^\uparrow (Q_i^2) / n_{q,i} (Q_i^2) \]

Higher-twist collinear structure of the nucleon through di-hadron SIDIS on unpolarized hydrogen and deuterium

A 12 GeV Research Proposal to Jefferson Lab (PAC 42)

$e(x)$
- related to the scalar charge
- quark-gluon correlation
- quark mass term

$A_{L_R \sin \phi}$ dependence of the moment

- 12 GeV data projections for proton
- 6 GeV measurement on $H_2$ ($e1f$)
- bag model
- spectator model

$0.005$ $0.01$ $0.015$ $0.02$ $0.025$ $0.03$

$0.05$ $0.1$ $0.15$ $0.2$ $0.25$ $0.3$ $0.35$ $0.4$

$A_{L_R \sin \phi}$
Example: New fundamental interaction from beta decay?

\[ \Delta L_{\text{eff}} = G_F V_{ud} \sqrt{2} \epsilon_S g_S \bar{p}n \cdot \bar{e}(1 - \gamma_5)\nu_e \]

\[ -4G_F V_{ud} \sqrt{2} \epsilon_T g_T \bar{p}\sigma_{\mu\nu} n \cdot \bar{e}\sigma^{\mu\nu}(1 - \gamma_5)\nu_e \]

[AC,Baessler,Gonzalez-Alonso,Liuti, PRL 115]

\[ \int_{-1}^{1} dx \ h_1^u V - dV(x) = g_T \]

[Collins extraction]

[DVMP GGL]

Present DiFF extraction
Future DiFF extraction

[AC,Baessler,Gonzalez-Alonso,Liuti, PRL 115]
Example: New fundamental interaction from beta decay?

\[
\Delta L_{\text{eff}} = G_F V_{ud} \sqrt{2} \epsilon_S g_S \bar{p}n \cdot \bar{e}(1 - \gamma_5)\nu_e \\
-4G_F V_{ud} \sqrt{2} \epsilon_T g_T \bar{p}\sigma_{\mu\nu}n \cdot \bar{e}\sigma^{\mu\nu}(1 - \gamma_5)\nu_e
\]

[Cirigliano et al., NPB 830]

Could we do the same with \( g_S \)?

[AC,Baessler,Gonzalez-Alonso,Liuti, PRL 115]
BSM FUNDAMENTAL INTERACTIONS?

$\varepsilon_T$ vs. $\varepsilon_S$ plane from beta decay observables

with $\varepsilon_S = 0.0011(21)$ at 90% CL from Gonzalez & Camalich, PRL112.

with $\langle g_T \rangle = 0.839(357)$ from GGL & Pavia new

1σ errors
Hessian in blue & pink
Rfit method in red
Scatter plot in blue
MC 1D gives $\langle \varepsilon_T \rangle = 0.0012$

[AC, Baessler, Liuti, in progress]
✓ Vector, axial OK from first principles

• Dihadron SIDIS is a good tool to
  • access to scalar, tensor structures
  • glimpse of quark-gluon correlations

• Get more info on DiFF from CLAS12 as well
Proposal

Figure 14: $Q^2$ vs. $x_B$ for the final di-hadron sample.
SIDIS CROSS SECTION

\[
\frac{d\sigma}{dx\,dy\,dz\,d^2P_{h\perp}} \propto \frac{4\pi\alpha^2_{em}s}{Q^4} \sum_a e^2_a x \left\{ \cdots + (1-y)\frac{|P_{h\perp}|}{M_h} |S\perp| \sin(\phi_S + \phi_h) h_1(x) H_{1\perp}(z, P_{h\perp}^2) + \cdots \right\}
\]

1 process
a convolution

\[ \leftrightarrow \]

2 nonperturbative functions
• \( h_1 \) for the parton distribution
• \( H_{1\perp} \) for the fragmentation

No clean extraction of DISTRIBUTION part without INDEPENDENT process for the FRAGMENTATION PART!!
SIDIS CROSS SECTION

\[
\frac{d\sigma}{dxdydzd^2p_{h\perp}} \propto \frac{4\pi\alpha^2_{elms}}{Q^4} \sum_a e^2_a x \left\{ \cdots + (1 - y) \left| \frac{p_{h\perp}}{M_h} \right| |S| \sin(\phi_S + \phi_h) \right. h_1(x) H_1(z, P^2_{h\perp}) + \cdots \right\}
\]

1 process a convolution \leftrightarrow 2 nonperturbative functions

- \( h_1 \) for the parton distribution
- \( H_{1\perp} \) for the fragmentation

No clean extraction of DISTRIBUTION part without INDEPENDENT process for the FRAGMENTATION PART!!

FRAGMENTATION FUNCTIONS are accessed in e+e- annihilation
FRAGMENTATION IN ELECTRON-POSITRON ANNIHILATION

Transverse mmt dep.

\[ d\sigma \propto \sum_q \left[ FF^q \otimes \bar{FF}^{\bar{q}} \right] (z_1, z_2, P_{1\perp}, P_{2\perp}) \]

Collinear

\[ d\sigma \propto \sum_q FF^q(z_1, M_{h1}) \otimes \bar{FF}^{\bar{q}}(z_2, M_{h2}) \]

Courtesy of Anselm Vossen
SIDIS

$\gamma^*P$-frame
here projected on lepton plane for 2D view

Semi-inclusive
$\rightarrow X$ section sensitive to transverse mmt

$k_\perp$ correlations

Transverse spin-motion correlations
INTERPLAY & COLLABORATION BETWEEN TWO FIELDS

- **2007**: first success of a great collaboration
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- **2011-now**: fits for valence distributions, improvement of statistical techniques, proposals for more measurements, ...

[Bacchetta,AC,Radici, PRL107]
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- **2011-now**: fits, improvement of statistical techniques, proposals for more measurements
- **2013-now**: subleading-twist
  - first EXTRACTION of a subleading PDF
  - e(x) related to the nuclear SCALAR CHARGE & Sigma pion-nucleon
- **2015-6?**: publish CLAS analysis & extraction!

MANPOWER LIMITING PROGRESS

- Very FEW Belle members dedicated to hadronic physics (~5-6)
- Same for BaBar (~1-2)
- Lack of interest from the $e^+e^-$ community
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Study of Fragmentation Functions in e+e- Annihilation

Mauro Anselmino,1 Harut Avakian,2 Alessandro Bacchetta,3 Aurore Courtoy,4 Abhay Deshpande,5 Renee Fatemi,6 Leonard Gamberg,7 Haiyan Gao,8 Matthias Grosse Perdekamp,9 Zhong-Bo Kang,10 Sebastian Kuhn,11 John Lajoie,12 Hrayr Matevosyan,13 Andreas Metz,14 Zein-Eddine Meziani,14 Akio Ogawa,15 Silvia Pisano,16 Alexei Prokudin,2 Marco Radici,17 Ted Rogers,18 Patrizia Rossi,2 Ami Rostomyan,19 Peter Schweitzer,20 Anselm Vossen,21 and Feng Yuan22

NSAC white paper
SCALAR CHARGE

\[ \int_{-1}^{1} dx \, e^{q}(x, Q^2) = \int_{-1}^{1} dx \, e^{q}_{\text{loc}}(x, Q^2) = \frac{1}{2M} \langle P | \bar{\psi}_q(0) \psi_q(0) | P \rangle (Q^2) = \sigma_q(Q^2) \]

\[
\sigma_u(Q^2) + \sigma_d(Q^2) = \frac{\sigma_{\pi N}}{(m_u(Q^2) + m_d(Q^2)) / 2}
\]

pion-nucleon sigma-term

\[ \sigma_{\pi N} = \Sigma_{\pi N} = 79 \pm 7 \text{MeV} - 15 \text{MeV} \]

GWU (2002) result

Future:
theoretically interpret & apply
to models for scalar interactions!
D. Delepine & E. Peinado

LFCQ model: Lorcé et al. [arXiv:1411.2550]
but is related to the scale of the 1D projections. We show the result on Fig. 2 for that in principle depends on. Within that approximation, the respective values of bins for the WW scenario. The error bars correspond to the propagation of the experimental and DiFF errors.

FIG. 1: On the left panel, the $A_{LU}(x)$, $A_{LU}(z)$, and $A_{LU}(m_{\pi\pi})$ distributions. The results are given in Tab. I and shown in Fig. 1. Notice that the range of integration in $x$ goes beyond the range of known validity of the DiFF data set. However, since the behavior of these results indicates that the $\cos x$ integral of $x$ dependence twist contributions. The crucial observation is that the order of magnitude of the ratio $A^{\sin \phi_R}_{LU,fit}(x_i, m_{\pi\pi}, i, z_i; Q_i, y_i) = \frac{W(y_i)}{A(y_i)} A_{LU} \frac{m_{\pi\pi}}{Q_i} \int_{z_{\min, i}}^{z_{\max, i}} dz \int_{(m_{\pi\pi}, \min)_i}^{(m_{\pi\pi}, \max)_i} \frac{|R|}{m_{\pi\pi}} H_1^{<, u}(z, m_{\pi\pi}, Q_i^2) \frac{D_1^u(z, m_{\pi\pi}, Q_i^2)}{H_1^{<, u}(z, m_{\pi\pi}, Q_i^2)}$ known from PAVIA fit

integral of $x$ dependence guessed here $\sim 0.2$ leading-twist DiFFs known from PAVIA fit
Beyond WW

\[ A_{LU}^{\sin \phi_R} (x, m_{\pi i}, z_i; Q_i, y_i) = -\frac{W(y_i)}{A(y_i)} \frac{M x_i}{Q_i} \left[ e^V(x_i, Q_i^2) n_{u,i}^+(Q_i^2) + [f_1^V(x_i, Q_i^2)] / z_i n_{u,i}^G(Q_i^2) \right] \sum_{q=u,d,s} e_q^2 f_1^q(x_i, Q_i^2) n_{q,i}(Q_i^2) \]

Twist-3 DiFFs from DSA?

\[ F_{LL}^{\cos \phi_R} = -\sum_q e_q^2 x \frac{|R| \sin \theta}{Q} \tilde{D}^{\alpha q}(z, \cos \theta, m_{hh}) \]

\[ n_u^{\tilde{G}^q} (Q_i^2) \text{ arrump.} \quad n_u^{\tilde{D}^q} (Q_i^2) \cong \kappa n_u^+(Q_i^2) \]

From DSA we estimate an upper limit with \( \kappa = 0.2 \)

- PDF part /z \sim 0.7
- Q x D1 part \sim 1.
- Hi^c part \sim 0.2

Sergio's analysis of cosΦ modulation of DSA
Twist-3 DiFFs from DSA?

\[ A_{LU}^{\sin \phi_R}(x_i, m_{\pi i}, z_i; Q_i, y_i) = \frac{W(y_i)}{A(y_i)} M \frac{x_i [e^V(x_i, Q_i^2)] + f_1^V(x_i, Q_i^2)}{Q_i} \sum_{q=u,d,s} e_q^2 n_{u,i}(Q_i^2) n_{q,i}(Q_i^2) \]

\[ F_{LL}^{\cos \phi_R} = - \sum_q e_q^2 x |R| \sin \theta \frac{1}{Q} g_1^q(x) \tilde{D}^{q q}(z, \cos \theta, m_{hh}) \]

\[ n_{u}^{\tilde{G}^{q q}}(Q_i^2) \quad \text{assump.} \quad n_{u}^{\tilde{D}^{q q}}(Q_i^2) \cong \kappa n_{u}(Q_i^2) \]

From DSA we estimate an upper limit with \( \kappa = 0.2 \)
\[ A_{LU, \text{leading}}^{\sin \phi_R} (x_i, m_{\pi\pi}, z_i; Q_i, y_i) = \frac{W(y_i) \ M}{A(y_i) \ Q_i} \left[ x_i e^V(x_i, Q_i^2) + \kappa f_i^V(x_i, Q_i^2) / z_i \right] \sum_{q=u,d,s} e_q^2 f_1^q (x_i, Q_i^2) n_{q,i}(Q_i^2) \]