WG6
Spin and 3D Structure
Report

XVII International Workshop on Deep Inelastic Scattering and Related Subjects
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WG6: Spin and 3D Structure

Spin-orbit correlations (transverse momentum)
- Particle multiplicities
- Fragmentation functions
- Transverse spin asymmetries

Generalized parton distribution functions (coordinate space)
- Deeply virtual Compton scattering
- Exclusive reactions

Polarized parton distribution functions (longitudinal momentum)
- Helicity asymmetries
- Transverse spin asymmetries

The Proton

List of Speakers WG6, WG6/7

TUESDAY
April 9

Gunar Schnell
Matt Posik
Nick Lukow
Gunar Schnell
Stefan Diehl

Jan Matousek
Andrea Moretti
Nobuo Sato
J. Osvaldo Gonzalez H.
Andrea Simonelli
Alexey Vladimirov

Marcin Stolarski
Nicolas Pierre
Ralf Seidl
Aram Kotzinian
Alberto Accardi
Christopher Dilks

Albi Kerbizi
Franco Bradamante
Marco Radici
Nicole Lewis
Ken Barish

WEDNESDAY
April 10

Bakur Parsamyan
Xiaoyu Wang
Riccardo Longo
Wen-Chen Chang
Maxim Nefedov
Oleg Teryaev

Leonard Gamberg
Ignazio Scimemi
Kemal Tezgin
Christian Pisano
Abhiram Kaushik
Elliot Leader

Piet Mulders
Sergio Leal Gomez
Florent Scarpa
Sookhyun Lee
Shohini Bhattacharya

Felix Hekhorn
Chandan Mondal
Wei Yang
Wenjuan Mao
Arturo Amor

THURSDAY
April 11

Pawel Sznajder
Antoine Vidon
Francesco Bossu
Kemal Tezgin
Aleksandra Pedrak
Simone Rodini

Anna Martin
Harut Avakian
Yuxiang Zhao
Zhenyu Ye
Daniel Boer
Helicity Asymmetries in SIDIS

- RPD 71 (2005) 012003 → new multidimensional analysis of $A_1$
  \[ A^n_1 = \frac{C^n_\phi}{f_D} \left[ \frac{L_{++}N^h_{++} + L_{--}N^h_{--}}{L_{P,++}N^h_{++} + L_{P,--}N^h_{--}} \right] \]
  - Multidimensional analysis important, but statistically limited
  - Also charge difference asymmetry and $\cos \phi$ moments (twist-3)
  - arxiv:1810.07054
  - Beam helicity asymmetries $A^n_{LU} \rightarrow$ arxiv:1903.08544
$$\frac{d\sigma}{d\sigma_0} = 1 + A_{UU}^{\cos \phi} \cos \phi + A_{UU}^{\cos 2\phi} \cos 2\phi + \lambda_e A_{LU}^{\sin \phi} \sin \phi$$

- Charged and neutral pions
- Currently only 2% of approved data analyzed
- Detailed systematics study necessary
W-Boson Production and Sea Quark Polarization

- Parity violating single-spin asymmetries
  \[ A_L(l^-) = \frac{\Delta \bar{u}(x_1)d(x_2)(1 - \cos \theta)^2 - \Delta d(x_1)\bar{u}(x_2)(1 + \cos \theta)^2}{\Delta \bar{u}(x_1)d(x_2)(1 - \cos \theta)^2 + \Delta d(x_1)\bar{u}(x_2)(1 + \cos \theta)^2} \]

- Final results from the RHIC W-program (2009-2013)
  - PRD 99 (2019) 051102
  - PRD 98 (2018) 032007

- Also: status and outlook of gluon polarization from jet and dijet double helicity measurements
Unpolarized Azimuthal Modulations in SIDIS

- Acceptance corrected (LEPTO)
- Significant contributions from vector meson decays
- Planned 4D binning \((x, Q^2, z, p_T)\) and vector meson subtraction \((\rightarrow ^6LiD\ data)\)
- Currently only 4% of available data analyzed (2016+2017)

\(\mu^\pm\) at 160 GeV/c
\(H_2\) target

Jan Matousek
Charged Hadron Multiplicities

\[
\frac{d^4 \sigma}{dx dQ^2 dz dP_T^2} = \frac{2\pi^2 \alpha^2}{(xy)^2} [1 + (1 - y)^2] F_{UU}(x, Q^2, z, P_T^2)
\]

\[
M_{\text{meas}}(x, Q^2, z, P_T^2) = \frac{N(x, Q^2, z, P_T^2)}{N_{\text{DIS}}(x, Q^2) \Delta z \Delta P_T^2 \text{acc}(x, Q^2, z, P_T^2)}
\]

- Acceptance corrected (LEPTO, flat in $P_T^2$ and hadron charge)
- Diffractive vector meson contamination <2% (not corrected yet)
- No radiative corrections
- Currently only 10% of available data analyzed (2016)

\[
\mu^\pm \text{ at 160 GeV/c} \\
H_2 \text{ target}
\]

\[
\chi^2/\text{n.d.f.} > 0.98
\]

\[
P_T^2 < 3 \text{ (GeV/c)}^2 \\
0.4 < z < 0.6
\]
Kaon Multiplicities

\[ \frac{dM^h(x, Q^2, z)}{dz} = \frac{d^3\sigma^h(x, Q^2, z) / dx dQ^2 dz}{d^2\sigma^{DIS}(x, Q^2) / dx dQ^2} \]

- \( \mu^\pm \) at 160 Gev/c
- \( H_2 \) target

- 300 multidimensional bins \((x, y, z)\)
- Fully corrected for acceptance, efficiencies, resolution and reconstruction
- Radiative corrections (DJANGOH, 0% - 20%)
- Diffractive vector meson corrections (<10% in most bins)
- ¼ of available data analyzed
Hadron Multiplicities: Ratios

$\mu^{\pm}$ at 160 Gev/c $^6\text{LiD}$ target

$R_h = \frac{dM_{h^-}(x, Q^2, z)/dz}{dM_{h^+}(x, Q^2, z)/dz}$

- Strong $M_X$ dependence indicates the limited phase space can explain discrepancy with HERMES.
- PLB 786 (2018) 390
- The region of applicability of factorized pQCD in SIDIS should be revisited (high-$z$).
Fragmentation Functions

\[ \frac{d^2\sigma}{dz dP_T^h}(P_T^h) \]

- \(e^- (8 \text{ GeV}) e^+ (3.5 \text{ GeV}) > 1000 \text{ fb}^{-1}\)

- arxiv:1902.01552
- Transverse momentum dependence from thrust axis Correction chain and systematics: particle mis-ID, p-smearing, non \(q\bar{q}\) background, acceptance, weak decay, ISR
- New proposed \(q_T\)-weighted asymmetries for DiFF in SIDIS and SIA, access different STMD FF, flavor decomposition

Aram Kotzinian
Dihadron Fragmentation

- Access $G_1^{\perp a}$ beam and target spin asymmetries
- Results previously shown from CLAS-6
- CLAS-12 preliminary results based on 10% of the full projected statistics

$M_{\pi\pi} > 0.9$ GeV/$c^2$
Transversity from Difference Asymmetries

Avoid the use of FFs in the extraction of the PDFs (helicity asymmetries):

\[ A^{h_+ - h_-} = \frac{(\sigma_{\uparrow \downarrow}^{h_+} - \sigma_{\uparrow \downarrow}^{h_-}) - (\sigma_{\uparrow \uparrow}^{h_+} - \sigma_{\uparrow \uparrow}^{h_-})}{(\sigma_{\uparrow \downarrow}^{h_+} - \sigma_{\uparrow \downarrow}^{h_-}) + (\sigma_{\uparrow \uparrow}^{h_+} - \sigma_{\uparrow \uparrow}^{h_-})} \approx \frac{\Delta u_v + \Delta d_v}{u_v + d_v} \]

Transverse (Collins) asymmetries:

\[ \begin{align*}
A_{D,t} &= \frac{\sigma_{C,t}^+ - \sigma_{C,t}^-}{\sigma_{0,t}^+ + \sigma_{0,t}^-} \\
A'_{D,t} &= \frac{\sigma_{C,t}^+ - \sigma_{C,t}^-}{\sigma_{0,t}^+ - \sigma_{0,t}^-} \quad \text{and} \quad A_{C,t}^\pm = \sigma_{C,t}^\pm / \sigma_{0,t}^\pm
\end{align*} \]

“The method we applied is interesting and simple, and does not require any knowledge of the Collins fragmentation functions.”

Results from \( A_{D,t} \) and \( A'_{D,t} \) are essentially identical with standard transversity extractions using SIDIS and \( e^+ e^- \) data.

arxiv:1902.08445
Simulating Spin Dependent Fragmentation

$F_{q'hq} = \left| C_{q'hq} \right|^2 \left( \frac{1-Z}{\epsilon_h^2} \right) \frac{a \exp(-b_L \epsilon_h^2/Z) \ b_T^2 \ exp(-b_T k'_T^2)}{Na(\epsilon_h^2) \pi} \frac{||\mu||^2 + k'_T^2 - 2Im(\mu)S \cdot (\hat{z} \times k'_T)}{1 + b_T ||\mu||^2}$

- Extension of string breaking in Lund Model: $q\bar{q}$ pair in $^3P_0$ ($L=1, S=1, J=0$)
- Formalism defined in PRD 97 (2018) 074010 and arxiv: 1903.01736
- Implemented for DIS
- Currently:
  - Parton showers and multiple interactions switched off
  - Primordial $k_T$ switched off
  - Only pseudoscalar mesons produced
- Comparison for COMPASS kinematics, transversity and Collins effect ($p$, $d$)
Gluon Spin-Orbit Correlations

- Improved transverse asymmetries at mid-rapidity for $\eta$ mesons
- Background corrected
- Consistent with zero (similar to $\pi^0$)
- $\Lambda$ angular decay parameters consistent with previous measurements (200, 510 GeV)
Transverse Single Spin Asymmetries

- Inclusive charged hadrons
- Observe nuclear suppression of transverse spin asymmetries
- arxiv:1903.07442

\[ f(A^{1/3}) = \frac{A^0_N}{(A^{1/3})^\alpha} \]

\[ \alpha = 1.21^{+1.00\text{(stat)}+0.09\text{(sys)}}_{-0.42\text{(stat)}-0.07\text{(sys)}} \]
Universality of Sivers TMD

- First polarized DY measurements: PRL 119 (2017) 112002
- $q_T$ weighted asymmetries consistent with extraction from SIDIS (assuming sign-change)
- 50% of 2018 data is analyzed

$\pi^-$ at 190 Gev/c

$NH_3$ target

- Different evolution schemes
- Description consistent with COMPASS data
- PRD 97 (2018) 054005
Exclusive Single-Photon in Muonproduction

- Studied in 2012 pilot run, arxiv:1802.02739
- Combination of beam charge and helicity:
  - t-slope: $d\sigma^{+,+} + d\sigma^{-,-}$
  - d-term: $d\sigma^{+,+} - d\sigma^{-,-}$
- Invisible $\pi^0$ to be removed
- 1/8 of available 2016 data analyzed

$\pi^-$ at 190 GeV/c $H_2$ target

Antoine Vidon
Exclusive Single-Photon in Electroproduction

\[ A_{LU} = \frac{1}{P} \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)} \]

- From beam spin asymmetries
- Main background from \( ep \rightarrow ep\pi^0 \)
- Currently 2% of projected statistics (40% on disk)