TMD Studies at CLAS12

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TMDs Studies: from JLab to EIC  -  6-7 May 2021
Large acceptance spectrometer. Operative since 02/18
Luminosity up to $10^{35}$ cm$^{-2}$ s$^{-1}$; Wide rapidity coverage
Valence region
Several $Q^2$

Extended $p_T$ range
Weak correlation with $z$

Goal: explore quark dynamic effects in an extended phase-space matching various compelling regimes

Leverage in:
- $Q^2$ leverage: higher-twists
- $p_T$ leverage: perturbative vs non-perturbative
- $\eta$ leverage: target fragmentation

TMD study prescription
Particle Identification

\[ \pi^0 \rightarrow \gamma \gamma \]
reconstruction from Forward Calorimeter
\[ \sigma \sim 11.5 \text{ MeV} \]

\[ \pi^0 \rightarrow \gamma \gamma \]
reconstruction from Forward Tagger
\[ \sigma \sim 4.4 \text{ MeV} \]

TOF particle identification

RICH particle identification

Contalbrigo M.  
TMDs @ Jlab & EIC, 7th May 2021
## CLAS12 Program

<table>
<thead>
<tr>
<th>Year</th>
<th>Period</th>
<th>Run</th>
<th>Target</th>
<th>Polarization</th>
<th>Beam</th>
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<tr>
<td>2018</td>
<td>Spring-Fall</td>
<td>RGA</td>
<td>Proton</td>
<td>-</td>
<td>10.6 GeV</td>
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<td>Spring-Fall</td>
<td>RGB</td>
<td>Deuteron</td>
<td>-</td>
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<tr>
<td>2020</td>
<td>Spring-Fall</td>
<td>RGF</td>
<td>Deuteron</td>
<td>-</td>
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<td>Fall</td>
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<td>Nuclear</td>
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<td>RGG</td>
<td>⁷LiD, ⁶LiH</td>
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<td>10.6 GeV</td>
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</tbody>
</table>

++ Increased luminosity, extended energy range, additional targets
Beam Spin Asymmetry ($\pi^+$)

CLAS12 proton data (RGA)
S. Diehl et al., e-Print: 2101.03544

$$F_{LU}^{\sin \phi} = \frac{2M}{Q} C \left[ -\frac{\hbar \cdot k_T}{M_h} \left( x_B e H_1^\perp + \frac{M_h}{M} f_1 \tilde{G}^\perp \right) + \frac{\hbar \cdot P_T}{M} \left( x_B g^\perp D_1 + \frac{M_h}{M} h_1^\perp \tilde{E} \right) \right]$$

86.9±2.6 %
Opening the multi-state & multi-dimensional study

Beam Spin Asymmetry (pion)

\[ \langle P_T \rangle = 0.15 \text{ GeV} \quad \langle P_T \rangle = 0.37 \text{ GeV} \quad \langle P_T \rangle = 0.57 \text{ GeV} \]

\[ Q^2 = 4.8 \text{ GeV}^2 \]
\[ x_B = 0.39 \]
Beam Spin Asymmetry (di-hadron)

CLAS12 proton data (RGA)
T.B. Hayward et al., PRL 126 (2021) 152501

\[ d\sigma_{LU} \propto C\lambda_e \sin(\phi_h - \phi_{R\perp}) I[f_1 G_1^\perp] \]

\[ W\lambda_e \sin(\phi_{R\perp}) \left( x e(x) H_1^<(z, M_h) + \frac{1}{z} f_1(x) \tilde{G}^<(z, M_h) \right) \]

\[ 0.06 \]

\[ 0.04 \]

\[ 0.02 \]

\[ 0.00 \]

\[ -0.02 \]

\[ -0.04 \]

\[ -0.06 \]

\[ 0.06 \]

\[ 0.04 \]

\[ 0.02 \]

\[ 0.00 \]

\[ -0.02 \]

\[ -0.04 \]

\[ -0.06 \]

\[ M_h \leq 0.63 \text{ GeV} \]

\[ M_h > 0.63 \text{ GeV} \]
Multiplicity (pion)

Collinear study

$\text{ep} \rightarrow \text{e} \pi + \chi$

$\sum_q e_q f_1^q D_1^q$

$f_1 \text{ (CTEQ)}$

$D_1 \text{ (Sassot)}$

$\text{ep} \rightarrow \text{e} \pi - \chi$

$\sum_q e_q f_1^q D_1^q$

$f_1 \text{ (CTEQ)}$

$D_1 \text{ (Sassot)}$

PRELIMINARY
Multiplicity ($\pi+$)

Transverse momentum dependence and phase space

$ep \rightarrow e\pi^+X$

Color legend

- 0.2 < $z$ < 0.3
- 0.3 < $z$ < 0.4
- 0.4 < $z$ < 0.5
- 0.5 < $z$ < 0.6
- 0.6 < $z$ < 0.7

COMPASS, EPJC 73 (2013) 8, 2531

$<x> = 0.2$

$<x> = 0.29$
Example of precision & validation

**Monte Carlo** study

Transverse momentum dependence and role vector meson decays & phase space
TMD Asymmetries

$A_{UU}$ Pion channel:

$A_{UT}$ Single-hadron channel:

$A_{UT}$ Di-hadron channel:
Conclusions

CLAS12 is entering the 12 GeV production era

First beam-spin asymmetry published

Comprehensive program with

- polarized beam and targets
- nuclear targets

Large luminosity, wide acceptance, excellent PID

Important synergy & complementarity with EIC

Working for precision and new approaches

- to exploit existing infrastructure
- to boost the physics program