NEW RESULTS FROM E1206107 COLOR TRANSPARENCY (CT) EXPERIMENT IN PROTONS @ JLAB

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Hall C Users Meeting
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OUTLINE

➢ Color Transparency (CT) : Background / Introduction
➢ Past Experiments Status
➢ Need of The Experiment E1206107
➢ Hydrogen Normalization Result
➢ Systematic Study
➢ Carbon Result
➢ What’s Next?
➢ Summary
Mapping the transition from the nucleon-meson degrees of freedom to the quark-gluon degrees of freedom of QCD.

**Exclusive processes** (processes with completely determined initial and final states), are used to study the transition region.
NUCLEAR TRANSPARENCY

- Nuclear Transparency $T$ is a useful observable in studying CT.

- Ratio of cross-sections for exclusive processes from nuclei to nucleons is termed as Nuclear Transparency.

$$T = \frac{(\sigma_A/A)}{\sigma_N}$$

- $\sigma_A$ - Nuclear cross section
- $\sigma_N$ - Free nucleon cross section
- $\sigma_A/A$ - Bound nucleon cross section

$\sigma_A$ is parameterized as $\sigma_A = \sigma_N A^\alpha$

Experimentally: $\alpha = 0.72 - 0.78$, for $\pi$, $\kappa$, $p$
Traditional nuclear physics calculations (Glauber calculations) predict transparency to be energy independent.

**Ingredients**

- $\sigma_{hn}$ (h-N cross-section)
- Glauber multiple scattering approximation
- Correlations and FSI effects
Color transparency (CT) refers to the disappearance of initial and final state interactions in exclusive scattering at large 4-momentum transfer squared $Q^2$.

Introduced by Mueller and Brodsky in 1982. It arises in picture of quark-gluon interactions only.

CT takes place in the following 3 steps:

1. **Squeezing**
   The formation of a small-sized wavepacket PLC of quarks with small transverse size ($b$).

2. **Reduced interactions**
   Reduced interaction between the PLC and the nuclear medium ($\sigma \sim b^2$).

3. **Freezing**
   The PLC escapes the nucleus while small, or reduced FSI.
CT PAST EXPERIMENTS

CT Experiments

\[
\begin{align*}
\text{Baryon} & \quad \text{Meson} \\
A(p, 2p): & \quad A(\pi, \text{di-jet}): \text{FNAL} \\
A(e, e'p): & \quad A(\gamma, \pi^- p): \text{JLab} \\
\text{SLAC, JLab} & \quad A(e, e'\pi^+): \text{JLab} \\
\end{align*}
\]

A(e, e'\rho^0): DESY & JLab
CT PAST RESULTS - $A(e,e'p)$

Electron beam incident on various nuclear targets

Previous measurements consistent with Glauber prediction up to 8.0 (GeV/c)$^2$.

Perhaps we haven’t gone high enough in $Q^2$?

Plateau consistent with conventional calculations ...

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CT PAST RESULTS - MESONS

CT is well established at high energies. Onset of CT has been measured in Mesons but not in Baryons.

PION - \( A(e, e'\pi^+) \)

RHO - \( A(e, e'\rho^0) \)

Hall C E01-107 pion electroproduction

CLAS E02-110 rho electroproduction

X. Qian et al. PRC81:055209 (2010)

L. El Fassi et al. PLB 712,326 (2012)
CT This EXPERIMENT: E12-06-107

- E12-06-107 was the first experiment in the 12 GeV era
- Ran in Hall C at JLab in Spring 2018
- Coincidence trigger
- Targets: 10 cm LH₂, 6% rl ¹²C, ²⁷Al
- ~20 days of data taking
- E⁰ of 6.4 GeV and 10.6 GeV
- Beam current up to 65 μA

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<tr>
<td>6.4 GeV Beam</td>
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<tr>
<td>8.0</td>
<td>17.1</td>
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<td>10.6 GeV Beam</td>
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HYDROGEN NORMALIZATION

Parameterization of the known ep-elastic scattering cross section through a Monte Carlo simulation of the experiment


$E_{\text{miss}} < 65 \text{ MeV}$

$P_{\text{miss}} < 65 \text{ MeV/c}$
## SYSTEMATIC UNCERTAINTY

<table>
<thead>
<tr>
<th>Source</th>
<th>$Q^2$ dependent uncertainty (%)</th>
<th>Normalization uncertainty (%)</th>
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<td>Spectrometer acceptance</td>
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<td>Tracking efficiency</td>
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<td>Radiative corrections</td>
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<tr>
<td>Live time &amp; Det. efficiency</td>
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</tr>
<tr>
<td></td>
<td>Total</td>
<td>4.0</td>
</tr>
</tbody>
</table>
**TRANSPARENCY**

**Carbon Transparency**

- $E_{\text{miss}} < 80 \text{ MeV}$
- $P_{\text{miss}} < 300 \text{ MeV/c}$

Systematic Uncertainty 4%

(Model Dependent Uncertainty of 3.9% not included)
ASYMMETRY ($A_{LT}$) STUDY

$$A_{LT} = \frac{N_+ - N_-}{N_+ + N_-}$$

$Q^2$ [(GeV/c)$^2$]
ASYMMETRY VS MISSING MOMENTUM

\[ Q^2 = 8 \text{ (GeV/c)}^2 \]

\[ \frac{N \cdot N}{N' \cdot N'} \]

\[ A_L = \frac{N - N'}{N + N'} \]

\[ \text{Missing Momentum [MeV/c]} \]

\[ Q^2 = 9.4 \text{ (GeV/c)}^2 \]

\[ \frac{N \cdot N}{N' \cdot N'} \]

\[ A_L = \frac{N - N'}{N + N'} \]

\[ \text{Missing Momentum [MeV/c]} \]

\[ Q^2 = 11.4 \text{ (GeV/c)}^2 \]

\[ \frac{N \cdot N}{N' \cdot N'} \]

\[ A_L = \frac{N - N'}{N + N'} \]

\[ \text{Missing Momentum [MeV/c]} \]

\[ Q^2 = 14.2 \text{ (GeV/c)}^2 \]

\[ \frac{N \cdot N}{N' \cdot N'} \]

\[ A_L = \frac{N - N'}{N + N'} \]

\[ \text{Missing Momentum [MeV/c]} \]
ASYMMETRY VS MISSING ENERGY

\[ Q^2 = 8 \text{ (GeV/c)}^2 \]

\[ Q^2 = 9.4 \text{ (GeV/c)}^2 \]

\[ Q^2 = 11.4 \text{ (GeV/c)}^2 \]

\[ Q^2 = 14.2 \text{ (GeV/c)}^2 \]
SHELL STUDY


Spectrometer resolution of ~0.1%  2-5.5 MeV resolution

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SHELL STUDY – CONT'D.

\[ aS + bP = \text{data}, \quad 2a + 4b = 6 \]

SIMC S-shell when P-shell is turned off

SIMC P-shell when S-shell is turned off

\[ aS + bP = \text{data}, \quad 2a + 4b = 6 \]

SIMC S+P
SHELL STUDY – CONTD.

\[ \frac{\sigma_{\text{meas}}}{\sigma_{\text{PWIA}}} \]

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

- p-Shell
- s-Shell
- combined
SHELL STUDY – CONTD.

\[ \frac{T_{1s_{1/2}}}{T_{1p_{3/2}}} \]

\[ \chi^2 / \text{ndf} \quad 8.175 / 3 \]

\[ p_0 \quad 0.7401 \pm 0.01474 \]

\[ Q^2 \left[ (\text{GeV/c})^2 \right] \]
SUMMARY

➢ First experiment to take data using High Momentum Spectrometer and new Super High Momentum Spectrometer in 12 GeV era in Jefferson Lab.

➢ Hydrogen normalization result agrees with world’s ep elastic scattering data confirming that Hall C apparatuses are well-understood and well calibrated, and Monte Carlo Simulation is a good simulation of elastic scattering.

➢ Our results DO NOT SHOW the onset of Color transparency in protons up to 14.2 (GeV/c)^2, covering all kinematics of previous BNL results (proton momentum, Q^2).

➢ An article has been published in Physical Review Letters (D. Bhetuwal et al., Phys. Rev. Lett., 126(8), 082301 (2021)).

➢ A long paper is being finalized to send to Collaboration for review and then to Physical Review C.

➢ Future experiments will measure CT effects with different reaction mechanisms and precision.
ACKNOWLEDGEMENTS

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