Photodisintegration of Light Nuclei

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for the CLAS Collaboration

• Motivation
• Two-body photodisintegration of deuteron
• Two-body photodisintegration of $^3\text{He}$

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Photodisintegration of Few-Nucleon Systems at Medium Energies

Large Momentum Transfer Exclusive Processes
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Large Momentum Transfer Exclusive Processes

Short-range dynamics

Three-body mechanisms

T=0

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Large Momentum Transfer Exclusive Processes

Short-range dynamics

Transition from hadronic to partonic degrees of freedom
Dimensional Scaling Laws in Nuclear Physics

Brodsky, Farrar (1973): from dimensional analysis and perturbative QCD

- At high $t$ and high $s$, power-law behavior of the invariant cross section of an exclusive process $A + B \rightarrow C + D$ at fixed CM angle:

$$\frac{d\sigma}{dt} = \frac{1}{s^{n-2}} f(t / s)$$

where $n$ is the total number of the initial and final elementary fields.

- The energy dependence of the scattering amplitude given by the 'hard-scattering amplitude' $T_H$ for scattering collinear constituents from the initial to the final state:

$$pp \rightarrow pp \equiv 3q3q \rightarrow 3q3q$$

$$\frac{d\sigma}{dt} \sim \frac{|M|^2}{s^2},$$

where $[M] = [T_H] = (\sqrt{s})^{4-n}$

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Dimensional Scaling Laws: Examples

\[ pp \rightarrow pp \]

\[ n - 2 = (4 \times 3) - 2 = 10 \]

\[ \frac{d\sigma}{dt} \sim \frac{1}{s^{10}} f(t / s) \]
**Dimensional Scaling Laws: Examples**

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\[ \gamma^3 \text{He} \rightarrow pd \]

\[ n - 2 = (1 + 9 + 3 + 6) - 2 = 17 \]

\[ \frac{d\sigma}{dt} \sim \frac{1}{s^{17}} f(t / s) \]
Extensive Studies of Two-Nucleon Systems

\[ \gamma d \rightarrow pn \]

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Figure from R. Gilman, talk given at High-Energy Nuclear Physics and QCD, FIU, Miami, FL, 2010
What is the dynamical origin of scaling at medium energies?

Models for $\gamma d \rightarrow pn$

- **Quark Gluon String Model (QGSM)**
  - Three quark exchange with arbitrary number of gluon exchanges
  - Nonlinear *Regge* trajectories

- **Hard Rescattering Model (HRM)**

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$E_\gamma=2.0$ GeV
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Onset of quark-gluon dynamics through dimensional scaling: What have we learned?

- Overwhelming experimental evidence for success at momentum transfer as low as 1 GeV. Kinematics depends on the exclusive process.

- $p$QCD interpretation ruled out.

- Determination of the onset of quark-gluon dynamics generally limited to kinematics above the resonance region.

- Onset of quark-gluon dynamics in $A > 2$ nuclei expected at much higher energies than 1 GeV.
Dimensional Scaling Laws: Where do we stand?

• A comprehensive theoretical description of exclusive processes in the non-perturbative regime has proved difficult (pQCD, models).

• Overwhelming evidence for dimensional scaling, yes, but no general framework for interpretation across all processes.
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What is the origin of the scale-invariance of the underlying non-perturbative dynamics in the regime of confinement?
Photodisintegration of Light Nuclei with the CEBAF Large Acceptance Spectrometer CLAS

- Measured beam-spin asymmetry of two-body photodisintegration of $^1\text{H}$ at $E_{\gamma}=1.1 - 2.3 \text{ GeV}$, $\theta_{p,c.m.}=35^\circ - 145^\circ$ with linearly polarized photon beam (JLab E06-103)

- Measured differential cross sections of two-body photodisintegration of $^3\text{He}$ at $E_{\gamma}=0.4 - 1.4 \text{ GeV}$, $\theta_{p,c.m.}=30^\circ - 140^\circ$ (JLab E93-044)
Two-Body Photodisintegration of $d$

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$E_\gamma = 1.1 - 1.3$ GeV

$E_\gamma = 1.5 - 1.7$ GeV

$E_\gamma = 1.7 - 1.9$ GeV

$E_\gamma = 1.9 - 2.1$ GeV

$E_\gamma = 2.1 - 2.3$ GeV

CLAS Preliminary

QGSM
What can we learn about the onset of quarks and gluons in nuclear dynamics from two-body photodisintegration of $^3\text{He}$ at $E_v = (0.4 - 1.4) \text{ GeV}$?
Dimensional Scaling Laws: A New Insight

• QCD is not conformal, however it has manifestations of a scale-invariant theory (dimensional scaling, Bjorken scaling)

• AdS/CFT Correspondence between string theories in Anti de Sitter space-time and conformal field theories in physical space-time

• Allows to treat confinement at large distances and conformal symmetry at short distances

• Non-perturbative derivation of Dimensional Scaling Laws!

Dimensional Scaling Laws: A New Insight

- At short distances, dimensional scaling laws reflect the scale independence of $\alpha_s$ (asymptotic freedom)

- At large distances, dimensional scaling laws reflect the existence of infrared fixed point of QCD: $\alpha_s$ is large but scale-independent

- Scale-invariance is broken in the transition between these two dynamical regimes
Dimensional Scaling Laws: Our Approach
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• The nucleus is an ideal laboratory.
Two-Body Photodisintegration of $^{3}\text{He}$

$E_{\gamma} = (0.4 - 1.4)$ GeV

Advantages for Study of Dimensional Scaling

- Significant contribution of three-body mechanisms, especially at 0.6-0.8 GeV
- Resonance contribution to the cross section is suppressed.

Two-Body Photodisintegration of $^3$He

Scaling of invariant cross sections at 90°

- Extracted value from fits to JLab data:
  \[ N = 17 \pm 1 \]
- $|t|_{\text{thr}}$ and $p_{\perp \text{thr}}$ are too low to support hard scattering hypothesis:
  \[ |t|_{\text{thr}} = 0.64 \text{ (GeV/c)}^2 \]
  \[ p_{\perp \text{thr}} = 0.95 \text{ GeV/c} \]
- Our data are consistent with the hypothesis of conformal window from AdS/CFT

\[ \frac{d\sigma}{dt} \sim s^{-N} \]

Data fitted by: \[ \frac{d\sigma}{dt} = As^{-N} \]

Two-Body Photodisintegration of $^3$He

Scaling of invariant cross sections

$$s^{17} \frac{d\sigma}{dt} \sim \text{const.}$$

- Indication that above $\sim 0.7 \text{ GeV}$ data consistent with scale invariance for all CM angles
- Onset of dimensional scaling depends on the momentum transfer to individual constituents: supports AdS/CFT hypothesis


I. Pomerantz et al., private communication
Summary

✓ Two-body photodisintegration of d, $\gamma d \rightarrow pn$
  - Beam-spin asymmetry measured over a large kinematic range
  - Sensitivity to reaction mechanisms
  - Work in progress with theorists

✓ Two-body photodisintegration of $^3$He, $\gamma ^3$He $\rightarrow$ pd
  - First systematic study of dimensional scaling of an exclusive nuclear process involving $A>2$ nucleus at low $s$ and $t$.
  - Solid experimental evidence for onset of dimensional scaling at CM angles of 90°.
  - Indication for onset of dimensional scaling at other CM angles.
  - Observed scaling is qualitatively consistent with the hypothesis of conformal window at very low momentum transfer.
The END