Study of the Few Nucleon Systems

Yordanka Ilieva for the CLAS Collaboration
University of South Carolina

Hadronic Final States and QCD
XVII International Workshop on Deep-Inelastic Scattering and Related Subjects
27 April 2009, Madrid, Spain

Outline

- Searches for Short-Range Correlations in Nuclei.
- Searches for onset of scaling of invariant cross sections of exclusive processes: transition between hadronic and partonic degrees of freedom.
- Searches for onset of Color Transparency.

Why Few-Nucleon Systems?

How nuclear physics emerges from QCD?

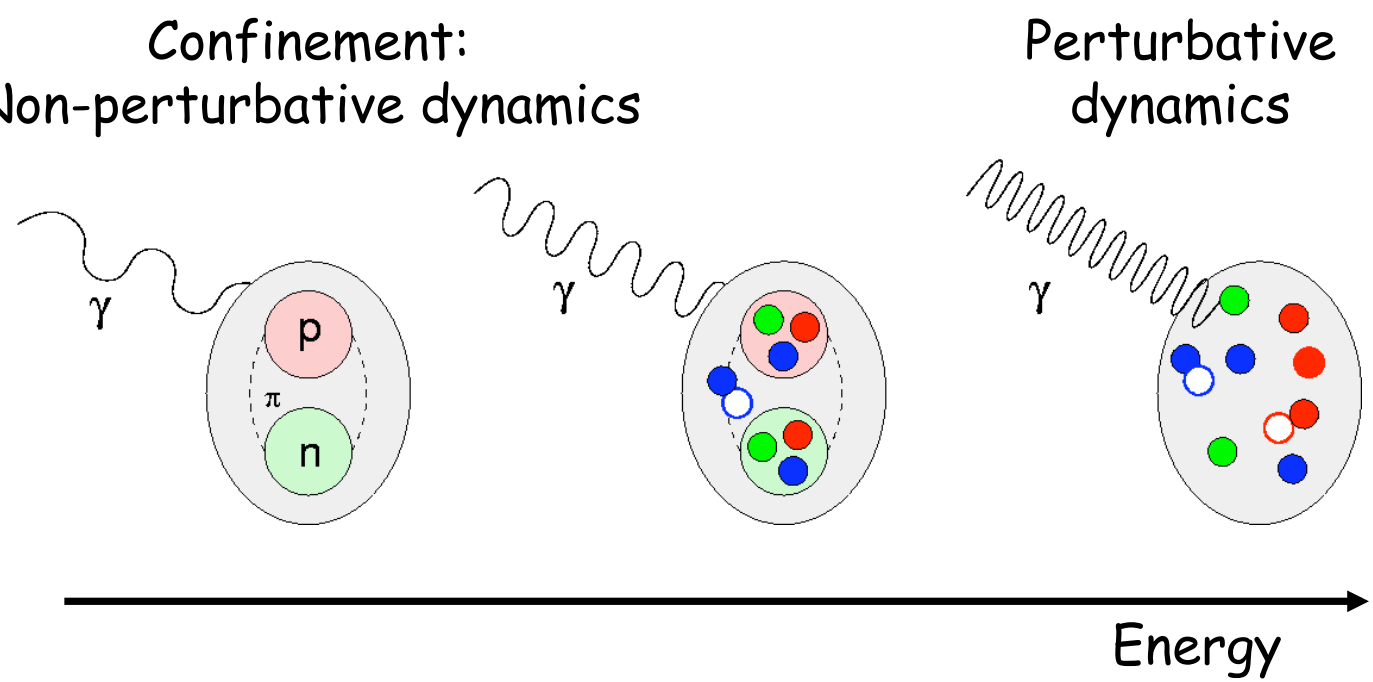
- How to derive the nuclear force from the fundamental quark-gluon interaction?
- What is the short-range structure of nuclei?
- How to connect the quark-gluon and the meson-nucleon regimes (long-range to short-range dynamics), what is the theoretical framework describing this transition?

Scales in Nuclear Physics

- Low-energy: Effective Field Theory, Lattice QCD, χPT
- Medium energy: nuclear, quark models, pQCD extensions? Relevant degrees of freedom?
- High energy: pQCD
- Lattice QCD

$$\lambda = \frac{h}{p}$$

p = 1 GeV/c
probes 1.2 fm

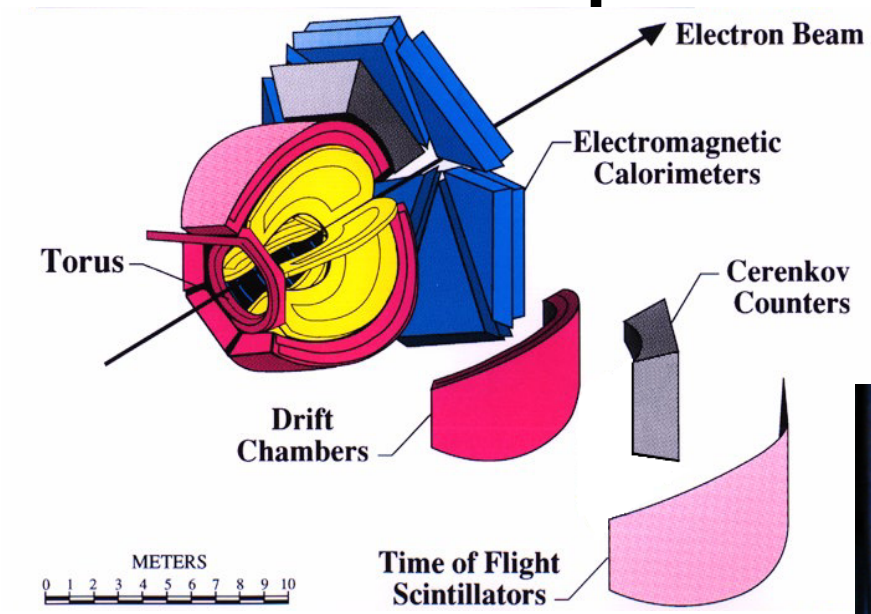


Thomas Jefferson National Accelerator Facility

JLab in Newport News, VA

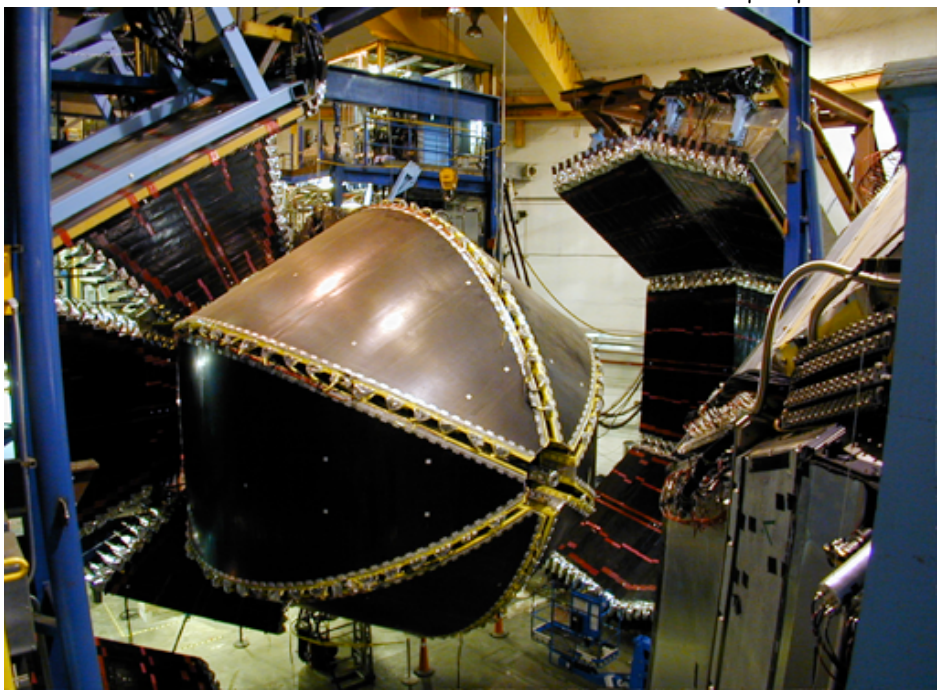
- Electron-beam accelerator
- Polarized c.w. electron beam
- Beam energies up to E_0 = 6 GeV
- Three experimental Halls A, B, and C

The CEBAF Large Acceptance Spectrometer CLAS

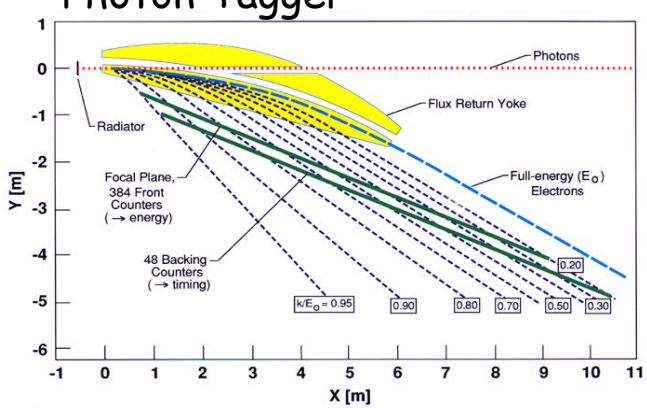


Performance

- $L = 10^{34}\ cm^{-2}\ s^{-1}$
- $\int B\ dl = 2.5$ T m
- $\Delta p/p \sim 0.5$–1 %
- $\sim 4\pi$ acceptance
- Best suited for multiparticle final states
- Bremsstrahlung Photon Tagger ($\Delta E_\gamma/E_\gamma \sim 10^{-3}$)

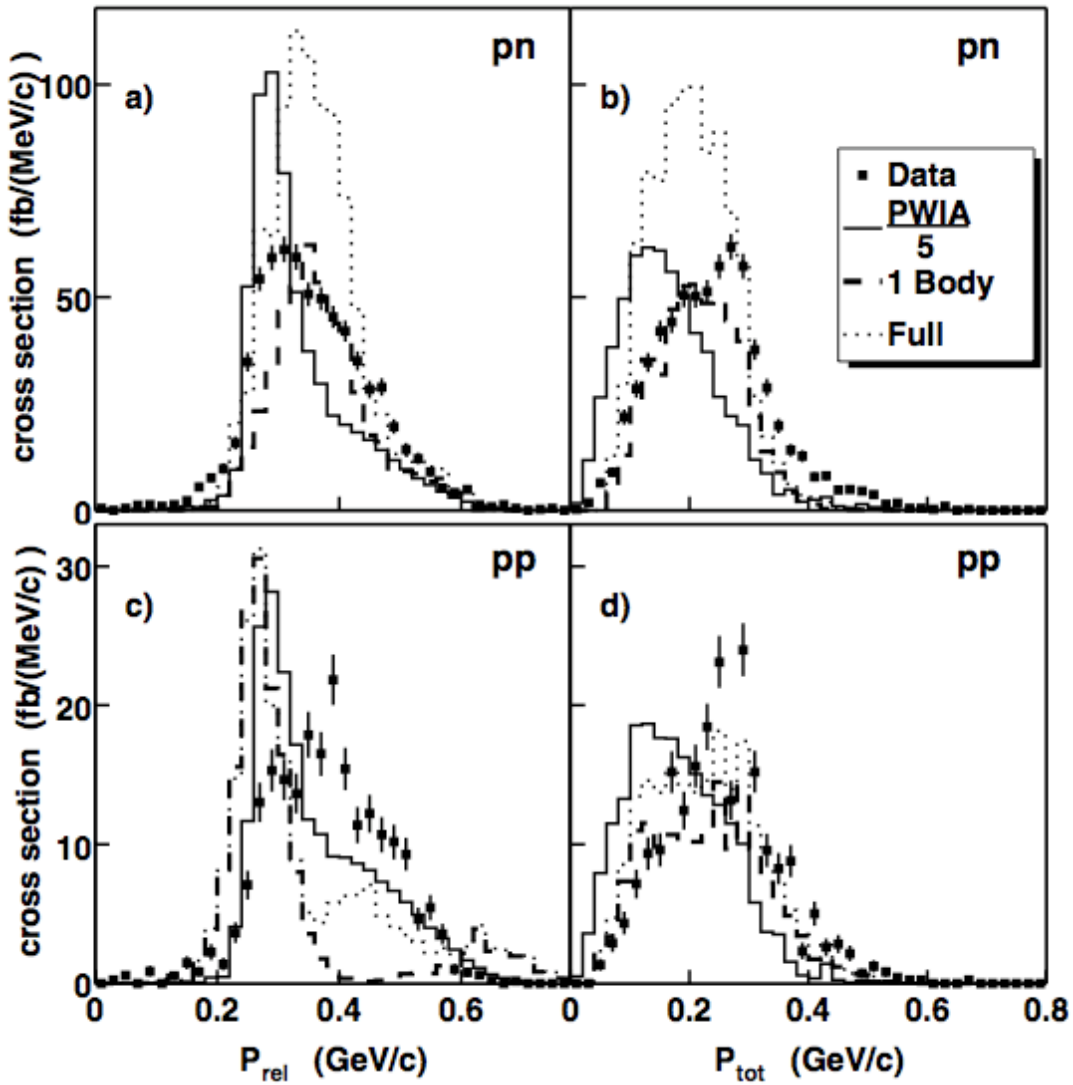


Photon Tagger



Nuclear Structure at Short Distances: SRC

^{3}He(e,e'pp)n



R. A. Niyazov **et al**, Phys. Rev. Lett , **92**, 052303 (2004)

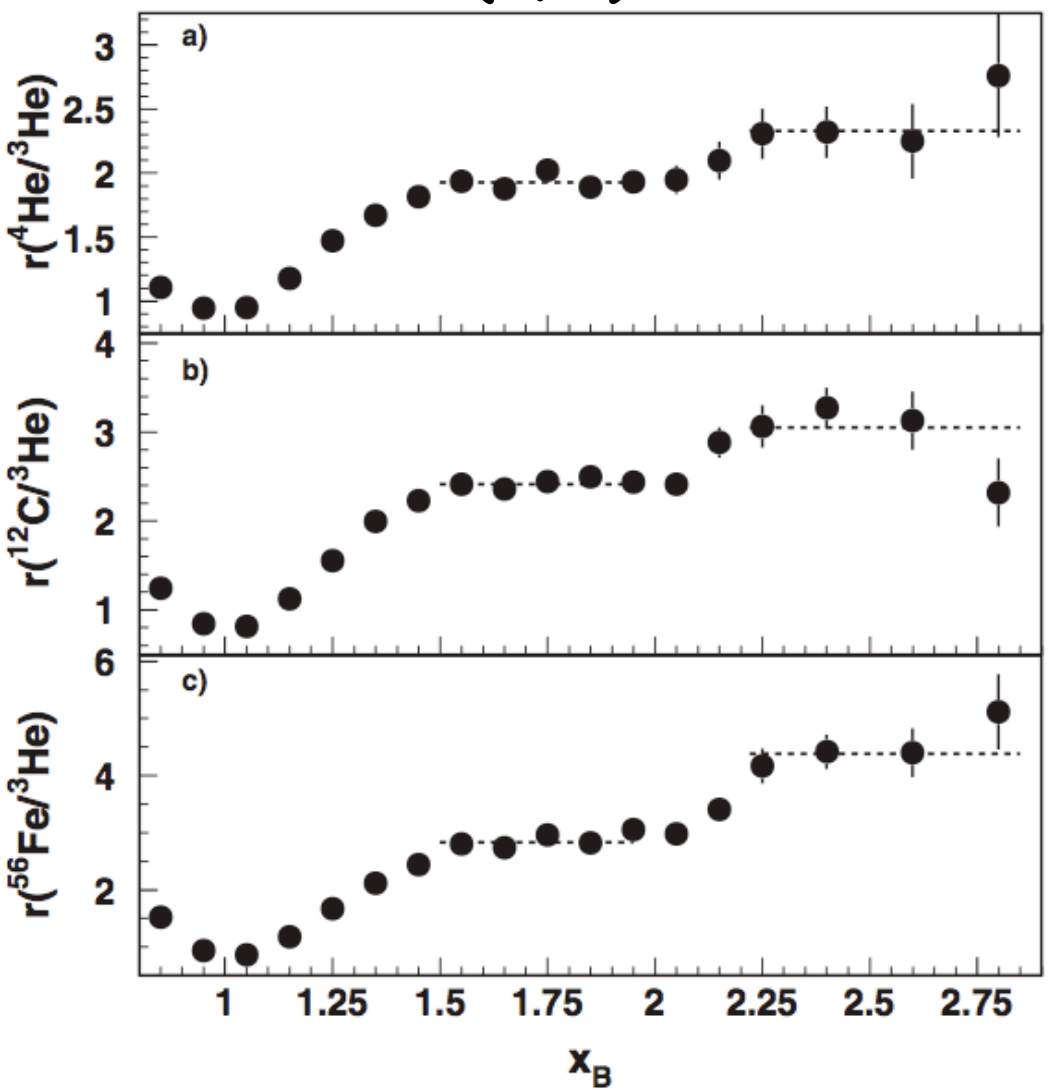
High-momentum components of the nuclear wf

- measured fast **pn**, **pp**; back-to-back nucleons
- reduced FSI: leading nucleon p_T<300 MeV/c
- pair momentum along **q**: very small
- little Q^2 or isospin dependence

measured spectator correlated NN pairs

Nuclear Structure at Short Distances: SRC

A(e,e')



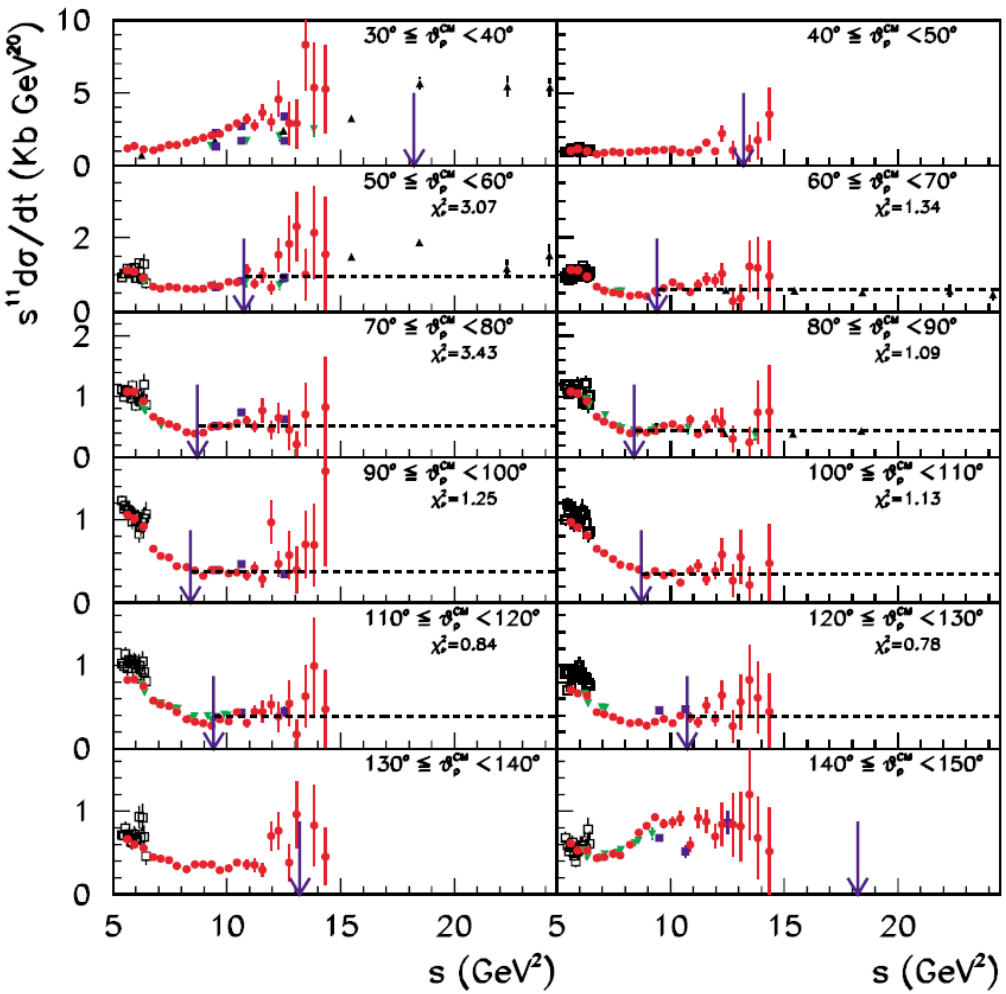
- quantified NN and NNN SRC probabilities
- > 90% of all nucleons with k≥300 MeV/c belong to NN SRC
- NN SRC build of 6q, ΔN, ΔΔ < 10 – 20% of the NN SRC
- NNN SRC present in nuclei with significant probability

K. S. Egiyan **et al**, Phys. Rev. Lett , **96**, 082501 (2006)

M. Strikman, arXiv:0903.1941 (2009)

Transition from Hadronic to Partonic Degrees of Freedom: Onset of Scaling

$\gamma d \rightarrow pn$

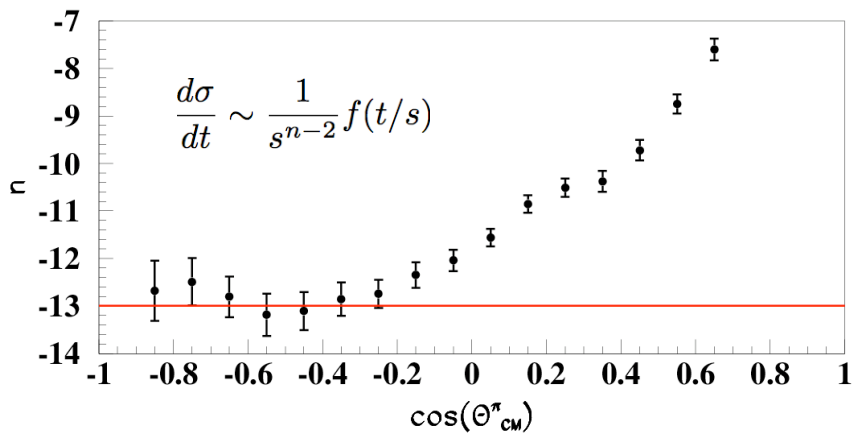


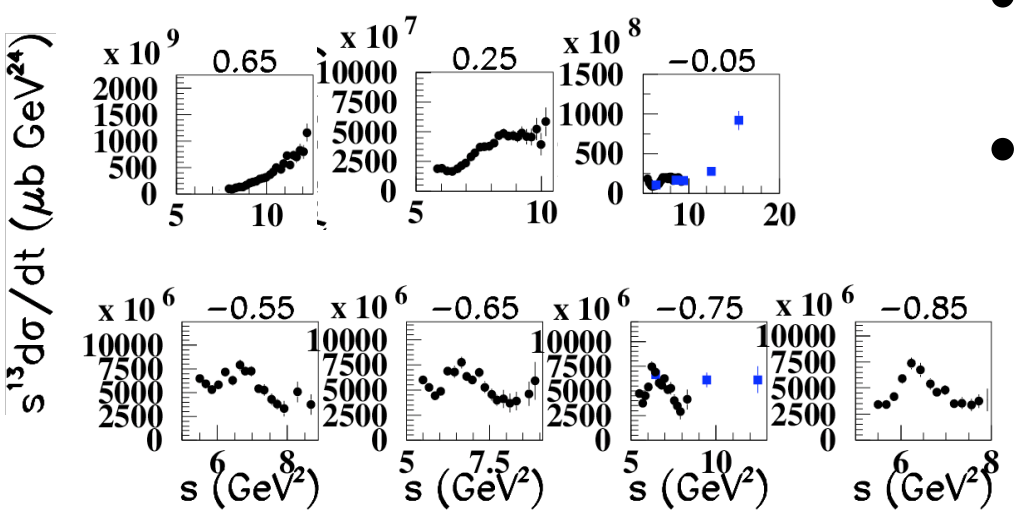
- $$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}} f(t/s)$$
- Data show scaling is reached for $p_T > 1.1$ GeV/c
- No model describes all the data

M. Mirazita **et al.**, Phys. Rev. C **70**, 014005 (2004); P. Rossi **et al.**, Phys. Rev. Lett. **94**, 012301 (2005)

Transition from Hadronic to Partonic Degrees of Freedom: Onset of Scaling

$\gamma d \rightarrow \pi^0 d$





- CLAS data generally consistent with scaling for cos θ_π < -0.25. This is consistent with the results of Meekins.
- Oscillating scaling.
- Existing meson-nucleon models do not reproduce the scaling of the invariant cross sections.

Oscillating Scaling

Theoretical explanations:

- The opening of new flavor channels
  [Brodsky, De Teramond, Phys. Rev. Lett. **60**, 1924 (1988)]
- Interference between pQCD and sizeable long-range effects
  [Brodsky, Carlson, Zipkin, Phys. Rev. D **20**, 2278 (1979); Miller, Phys. Rev. C **66**, 032201(R) (2002), Belitsky, Ji, and Yuan, Phys. Rev. Lett. **91**, 092003 (2003)]
- Quark orbital angular momenta
- Quark-hadron duality

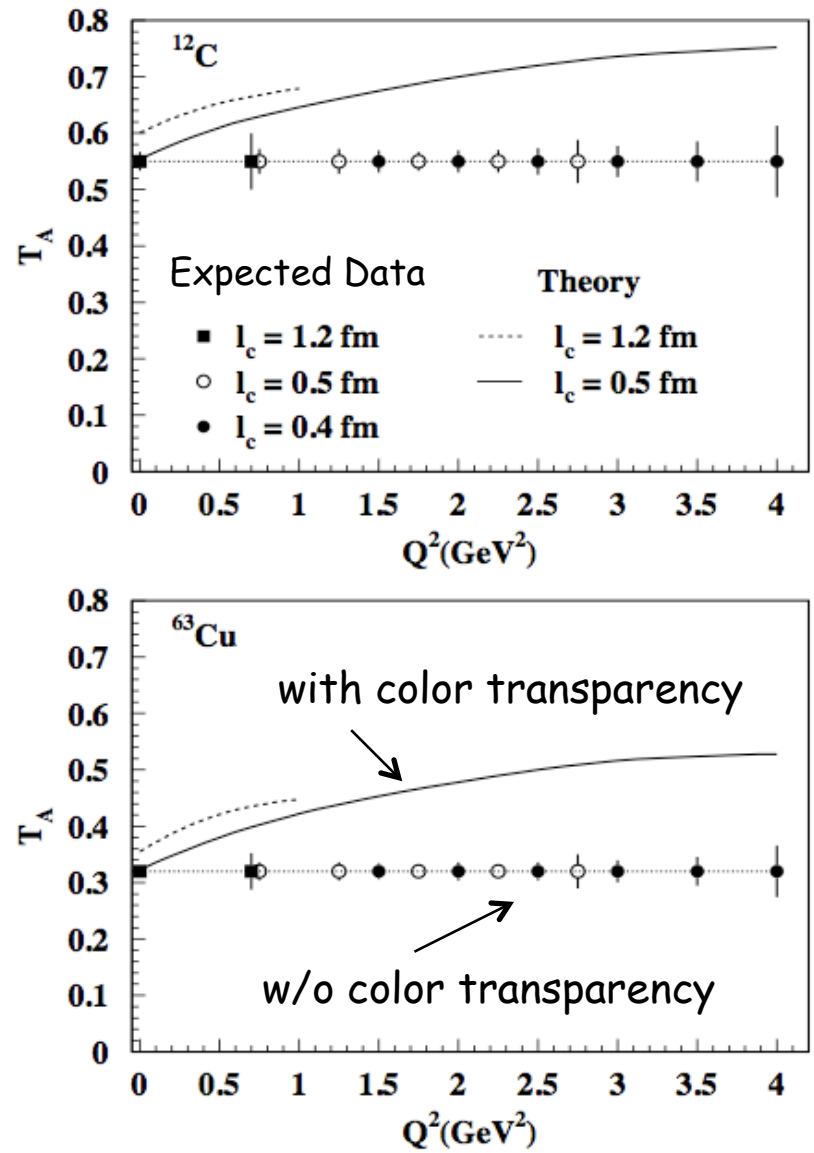
Search for the Onset of Color Transparency

- Small-size color-neutral object formed in a high-momentum transfer nuclear reaction. Object propagates through nuclear medium with reduced interactions.
- Study of the small-trasverse-separation hadron wave function components.
- Can be used to map the transition from quark-gluon to meson-nucleon degrees of freedom.
- Necessary condition for factorization of meson electroproduction to occur.

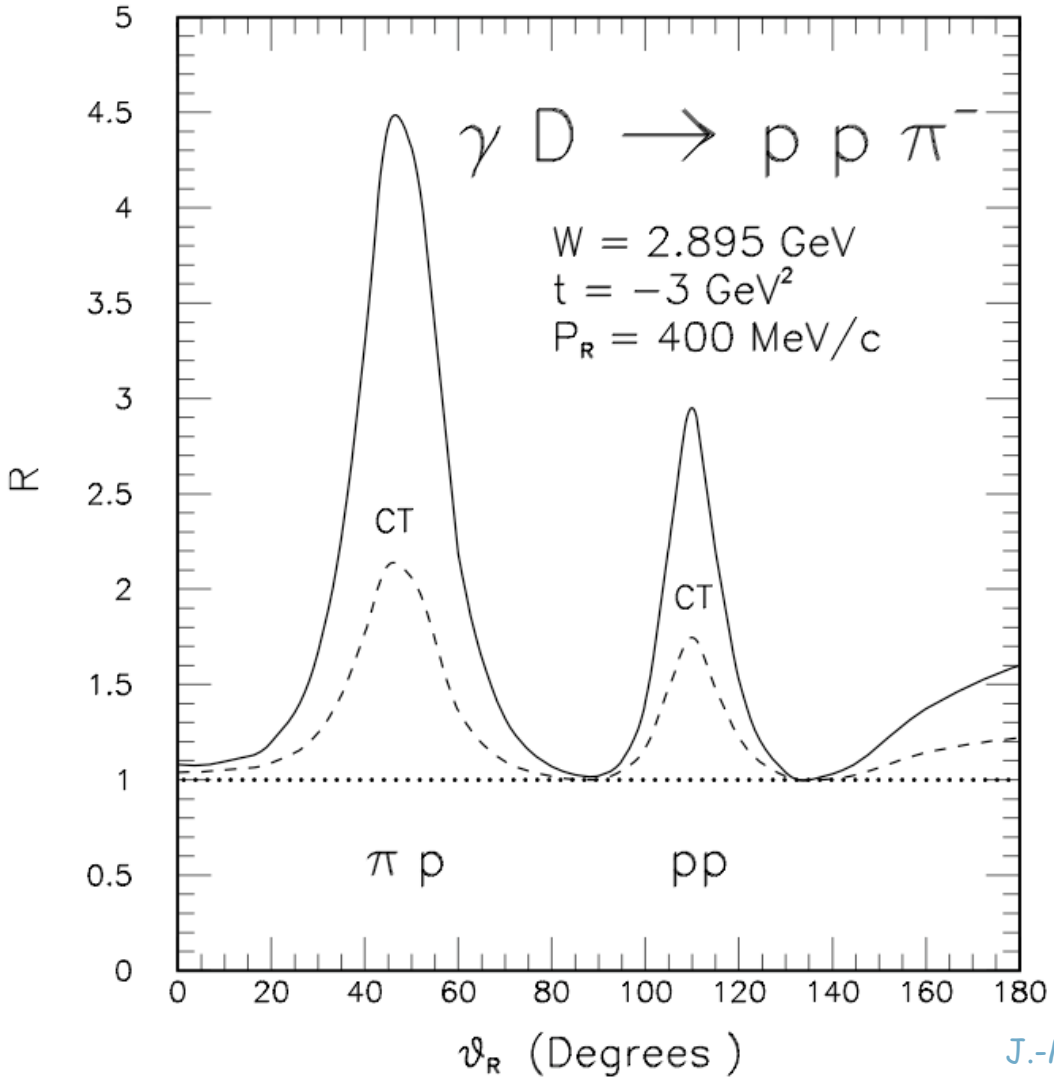
Search for Onset of Color Transparency

$A(e,e'p^0)$

- JLab E-02-110 (Hafidi et al.)
- Nuclear Transparency $T_A=\sigma_A/(A\sigma_N)$
- Targets: ^2H, ^{12}C, ^{56}Fe
- Q^2 = 1-2.5 $(GeV/c)^2$
- Fixed coherence length
- Corrections
- Results being finalized
- Extension of study with CLAS12: PR12-06-106 (Hafidi et al.)



Search for Onset of Color Transparency
$d(\gamma,\pi^- p)p$

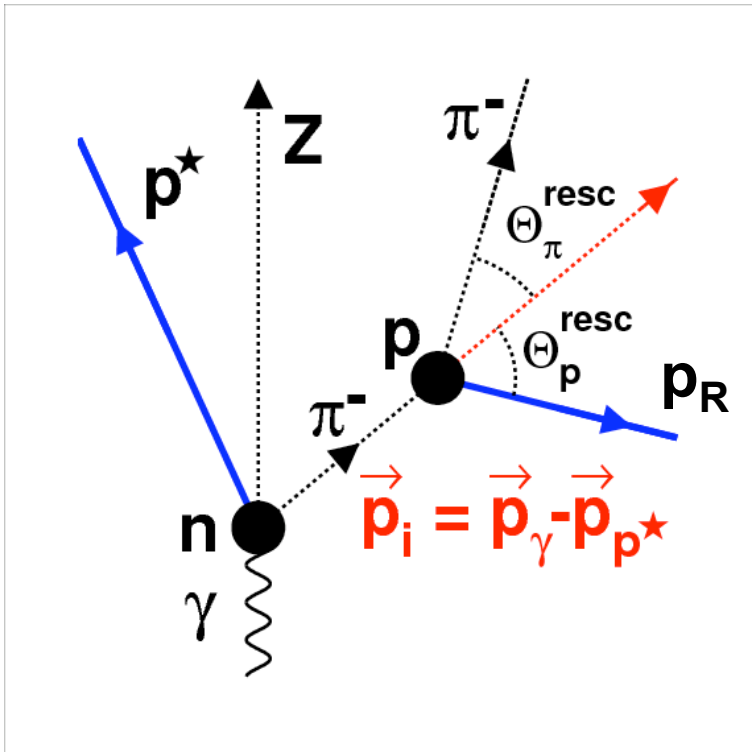


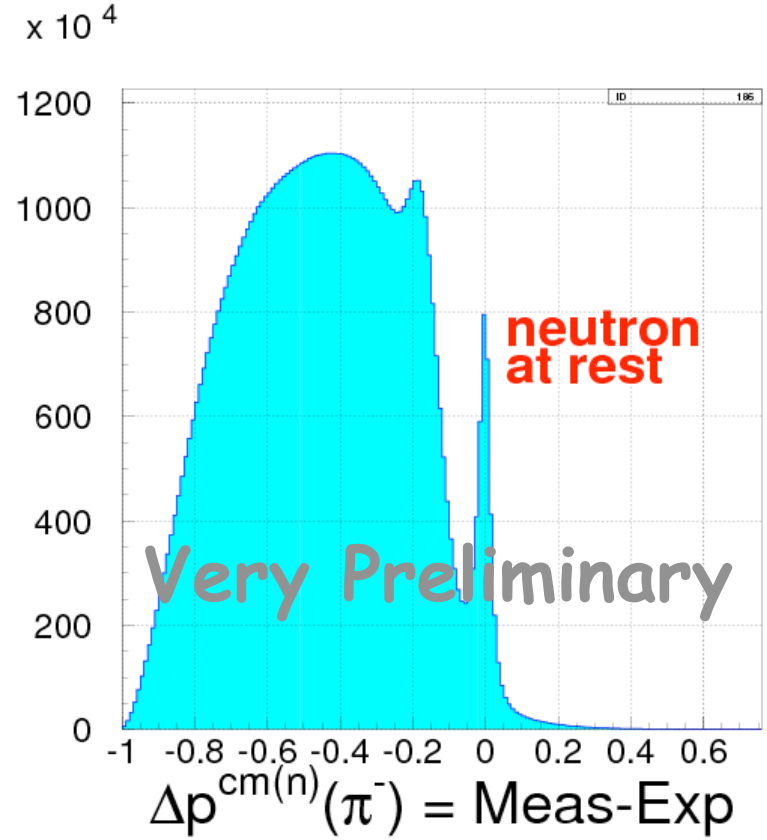
- Measure the **t** evolution of the ratio R of $\pi^- p$ rescattering and quasifree cross sections.
- Select $\pi^- p$ rescattering events.
- Select kinematics where rescattering is maximal: large t, large $\mathbf{P_R}$.
- CT signal: suppression of the $\pi^- p$ rescattering peak as **t** increases.

J.-M. Laget, Phys. Rev. *C*, **73**, 044003 (2006)

Search for Onset of Color Transparency

d(γ,π^-p)p feasibility of π^-p scattering-event selection





- Ongoing effort to extend the study to E_γ=5.7 GeV; Determine polarization observables.

Figures from N. Pivnyuk, ITEP, CLAS Collaboration Meeting, October (2008)

Conclusions

- The CLAS Collaboration has established a rich program in nuclear physics at intermediate energies both in photo- and electroproduction.
- Selected topics:
  - Solid experimental evidence and quantification of SRC in light nuclei.
  - Solid experimental evidence for onset of scaling in exclusive photoreactions at medium energies.
  - Ongoing searches for onset of Color Transparency.
  - Study of three-body mechanisms in real-photon experiments.
- Extension of program to 12 GeV: Color Transparency, Nuclear GPD, Quark Propagation and Hadron Formation.