Study of the Short-Range Properties of Nucleons at $Q^2 < 12$ GeV^2 using d(e,e'p)n with CLAS12

Spokespersons:

K. Egiyan, N. Gevorkyan, K. Griffioen, S. Stepanyan, L. Weinstein

PR12-06-115

PAC30

23 August 2006

Keith Griffioen for Kim Egiyan

and the CLAS Collaboration

INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

J. Phys. G: Nucl. Part. Phys. **29** (2003) R1–R45 PII: S0954-3899(03)54926-X

TOPICAL REVIEW

Hadrons in the nuclear medium

M M Sargsian[1], J Arrington[2], W Bertozzi[3], W Boeglin[1], C E Carlson[4], D B Day[5], L L Frankfurt[6], K Egiyan[7], R Ent[8], S Gilad[3], K Griffioen[4], D W Higinbotham[8], S Kuhn[9], W Melnitchouk[8], G A Miller[10], E Piasetzky[6], S Stepanyan[8,9], M I Strikman[11] and L B Weinstein[9]

Abstract: Quantum chromodynamics (QCD), the microscopic theory of strong interactions, has not yet been applied to the calculation of nuclear wavefunctions. However, it certainly provokes a number of specific questions and suggests the existence of novel phenomena in nuclear physics which are not part of the traditional framework of the meson–nucleon description of nuclei. Many of these phenomena are related to high nuclear densities and the role of colour in nucleonic interactions. Quantum fluctuations in the spatial separation between nucleons may lead to local high-density configurations of cold nuclear matter in nuclei, up to four times larger than typical nuclear densities. We argue here that experiments utilizing the higher energies available upon completion of the Jefferson Laboratory energy upgrade will be able to probe the quark– gluon structure of such high-density configurations and therefore elucidate the fundamental nature of nuclear matter. We review three key experimental programmes: quasi-elastic electro-disintegration of light nuclei, deep inelastic scattering from nuclei at $x > 1$ and the measurement of tagged structure functions. These interrelated programmes are all aimed at the exploration of the quark structure of high-density nuclear configurations.

Sound Bite

If JLab12 is to be a QCD laboratory, then QCD nuclear physics must play a significant role, and d(e,e'p)n --- for its simplicity, kinematic completeness, and discovery potential --- must be the nuclear flagship.

d(e,e'p)n

- Study the reaction e + d ---> e' + p + n using CLAS12 to detect e' and p at 11 GeV
- Study all processes at high Q^2 that yield p+n alone in the final state
- Search for point-like configurations (PLC) of the struck proton and modifications to the proton form factor in short-range correlations (SRC)
- Reconstruct neutron recoil momenta $0<p_n<650$ MeV/c for $Q^2<12$ GeV^2 from missing mass
- 32 days of beam time, d target, L= 2×10^{35}/cm^2/s

Variables and Cross Sections

$d^6\sigma/d^3E'd^3p_s$

$d^3E' \Rightarrow dx\, dQ^2\, d\phi_e$

$d^3p_s \Rightarrow dp_s\, d\theta_{\gamma s}\, d\phi_s$

Unpolarized --> one ϕ is arbitrary --> 5-fold differential

4-momentum conservation --> 4-fold differential

$(x, Q^2, \alpha_s, \phi_{\gamma s})$

$d^6\sigma \sim P_1(\phi_e)P_2(\phi_s)P_3(x)P_4(Q^2)P_5(p_s)$

works to 10% for 6 GeV data

with $\theta_{\gamma s}$ determined by 4-momentum conservation

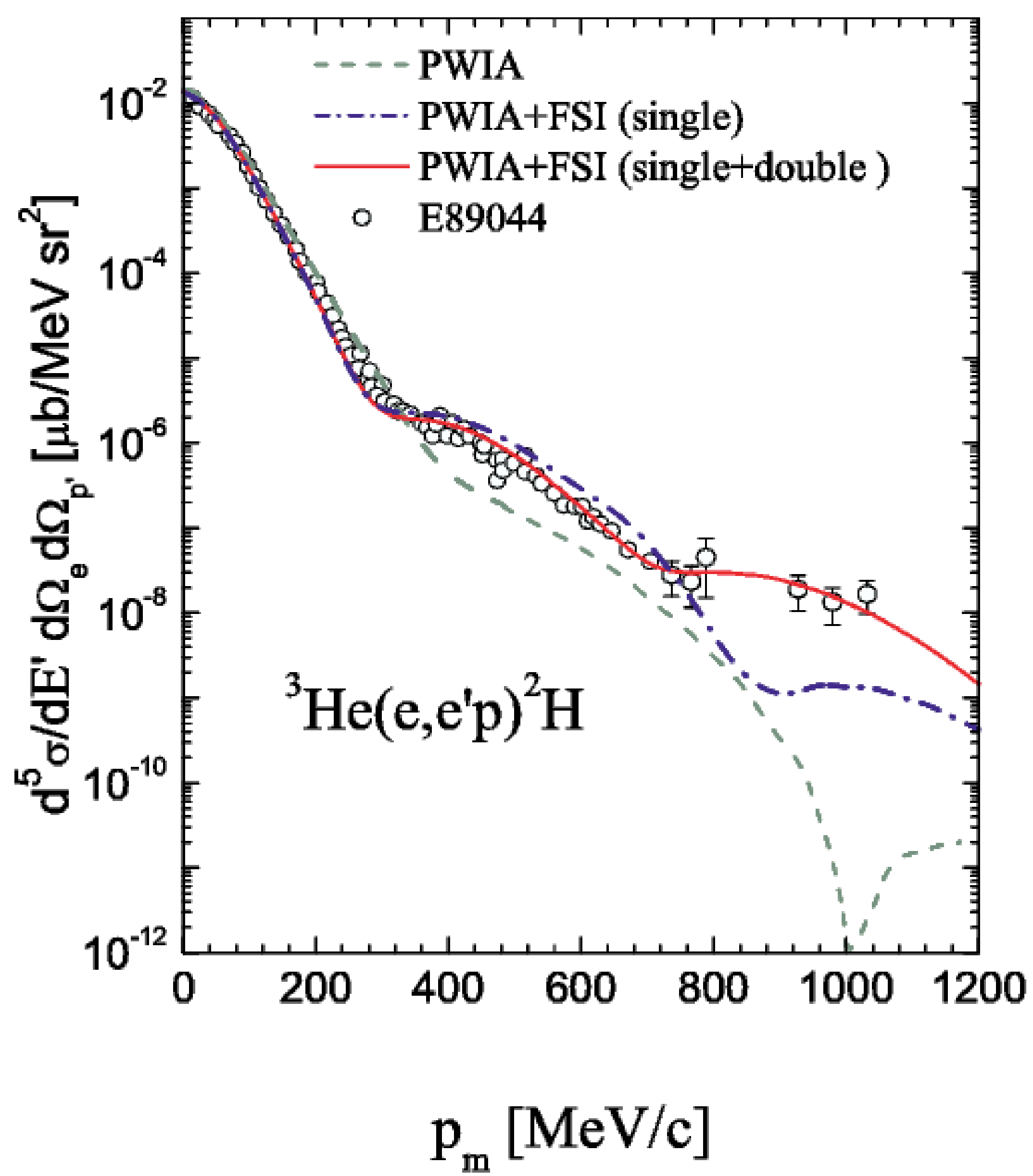
P_1 and P_2 are uniform distributions

This factorization must break down at large Q^2

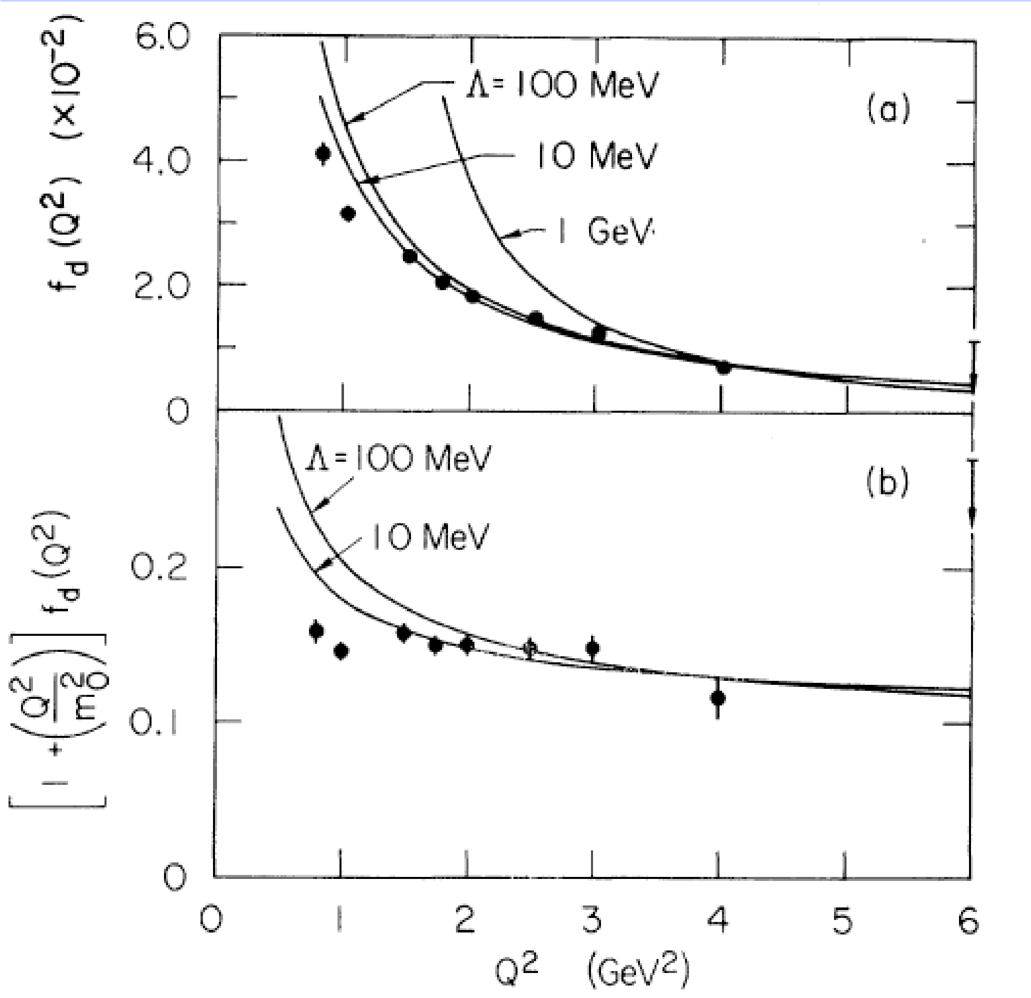
Generalized Eikonal Approximation (GEA)

Ciofi degli Atti
PRL95(05)052502

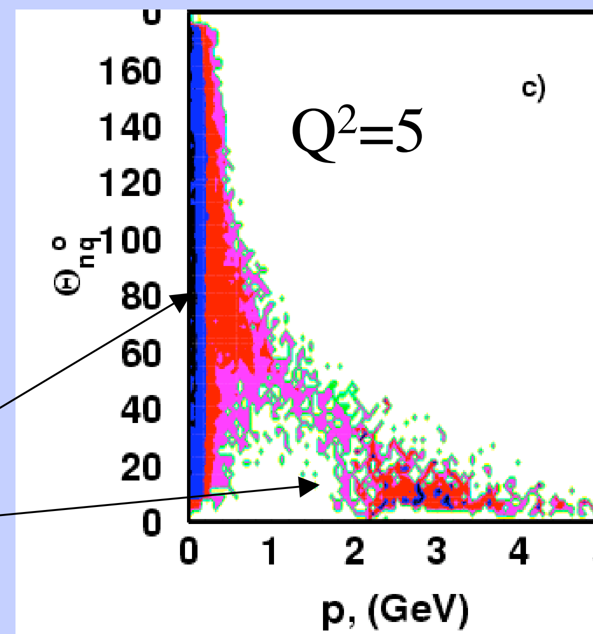
- Glauber Approx.:
  - NN scat. in Eikonal approx.
  - Frozen approx. (A-1) stationary
  - only perp. momentum transfer
- GEA:
  - Relaxed frozen approx. with (A-1) excitations
  - Longitudinal momentum transfer



pQCD for the Deuteron



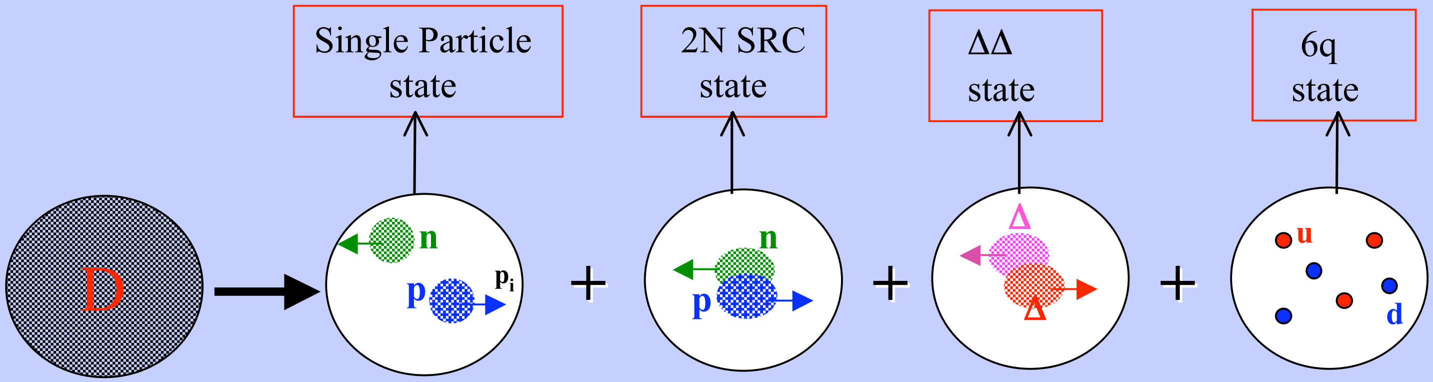
- $f_d(Q^2) =$ $F_d(Q^2)/F_N^{\,2}(Q^2/4) =$ $(\alpha_s/Q^2)[\ln(Q^2/\Lambda^2)]^{-\gamma}$
- $-\gamma = -(2/5)C_F/\beta =$ 8/145 for $n_f=2$
- 80% hidden color for large Q^2

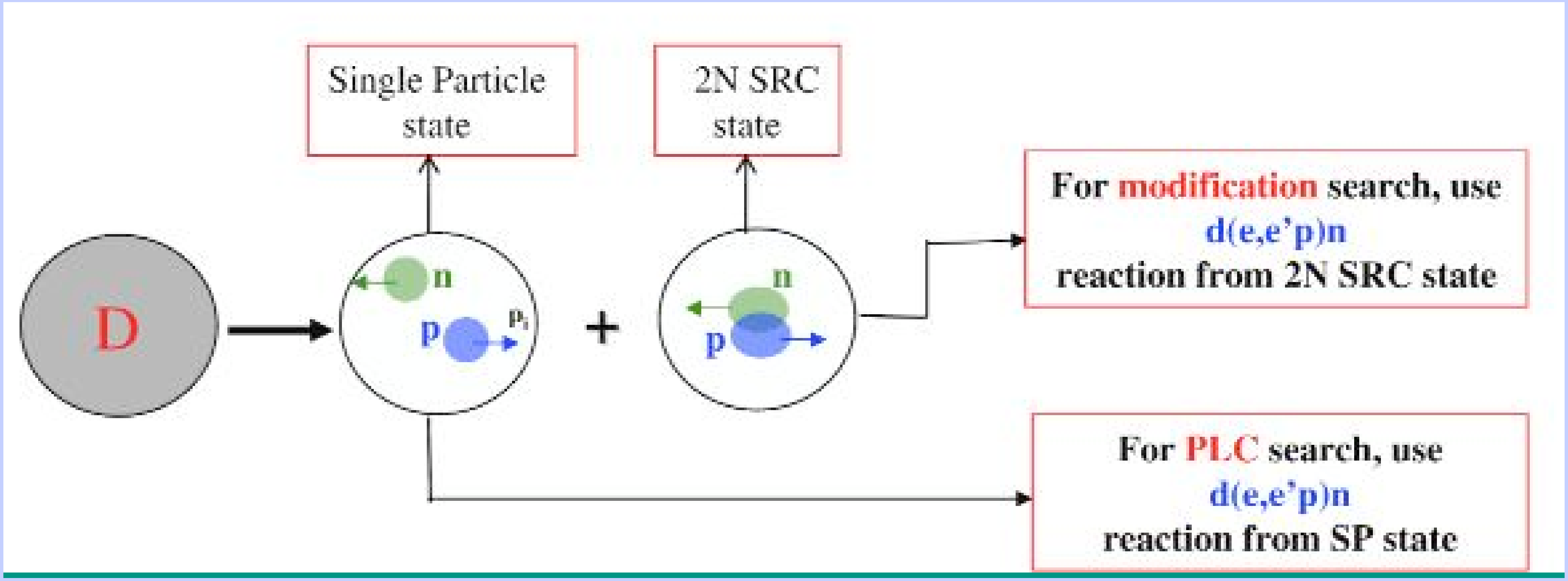


Target frag.
Current frag.

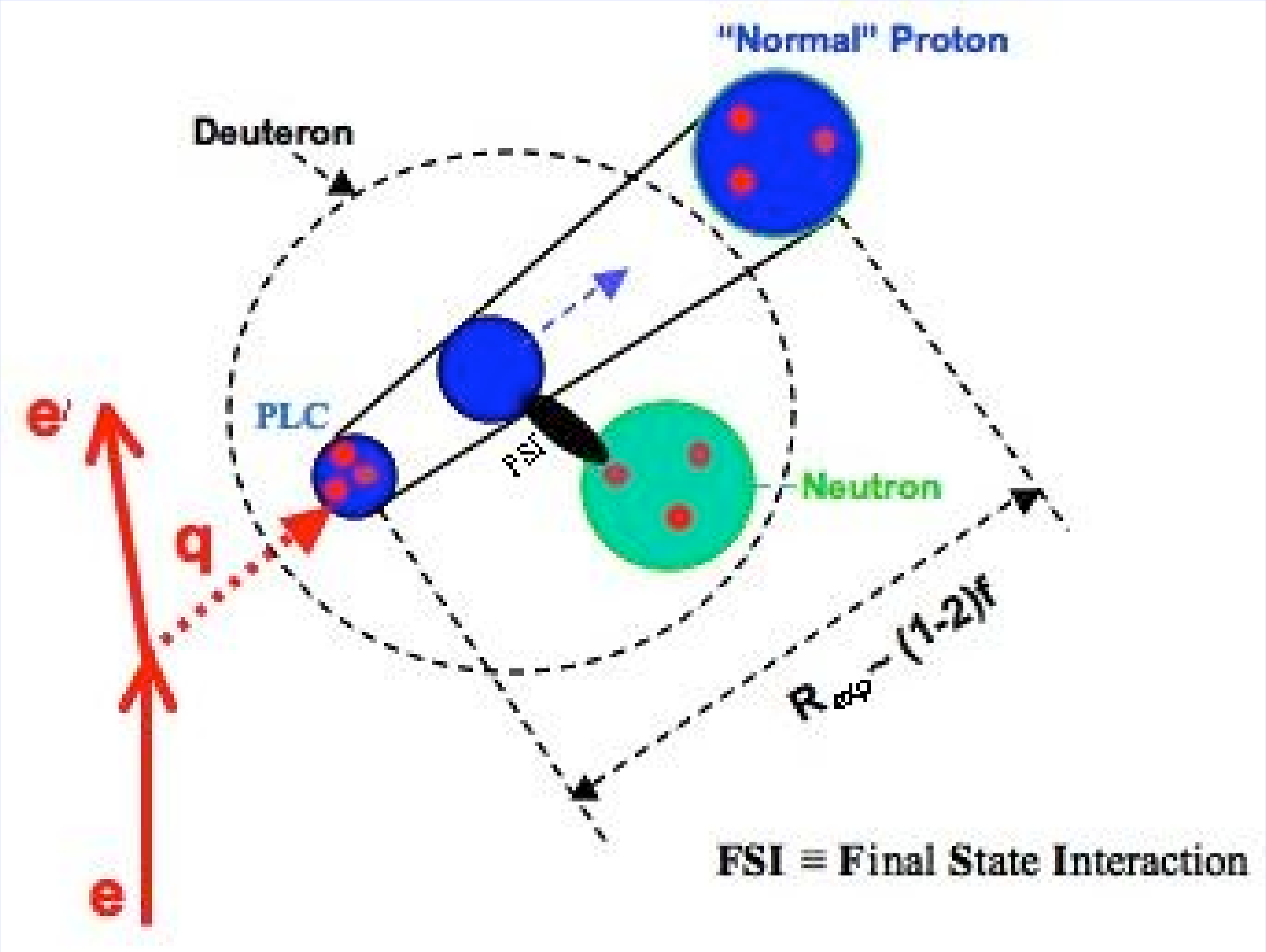
- Brodsky PRL51(83)83
- pQCD OK for $Q^2>2\ GeV^2$

Components of the Deuteron Wavefunction





Reduced FSI of a PLC



Transparency Ratios

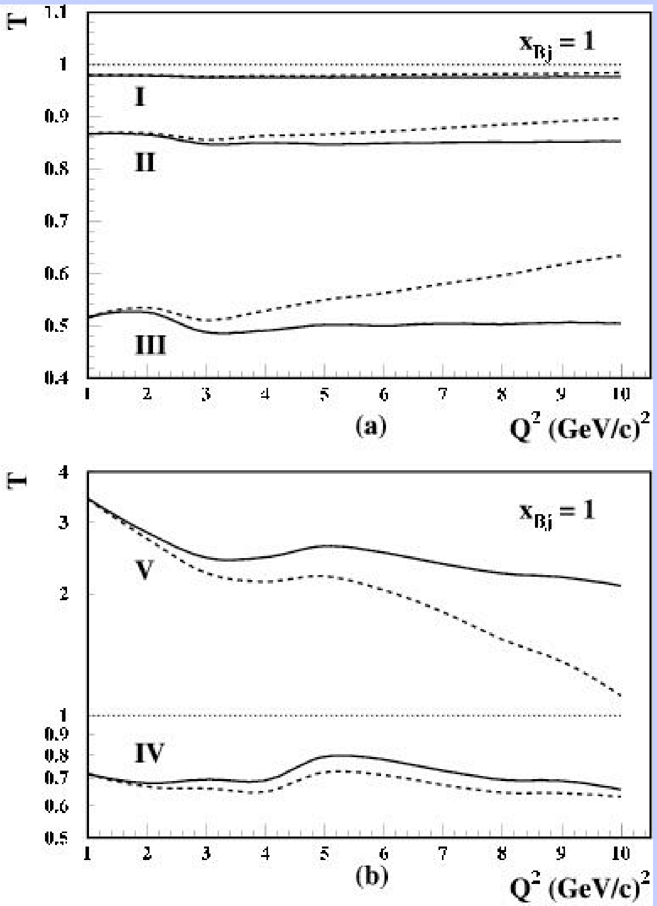
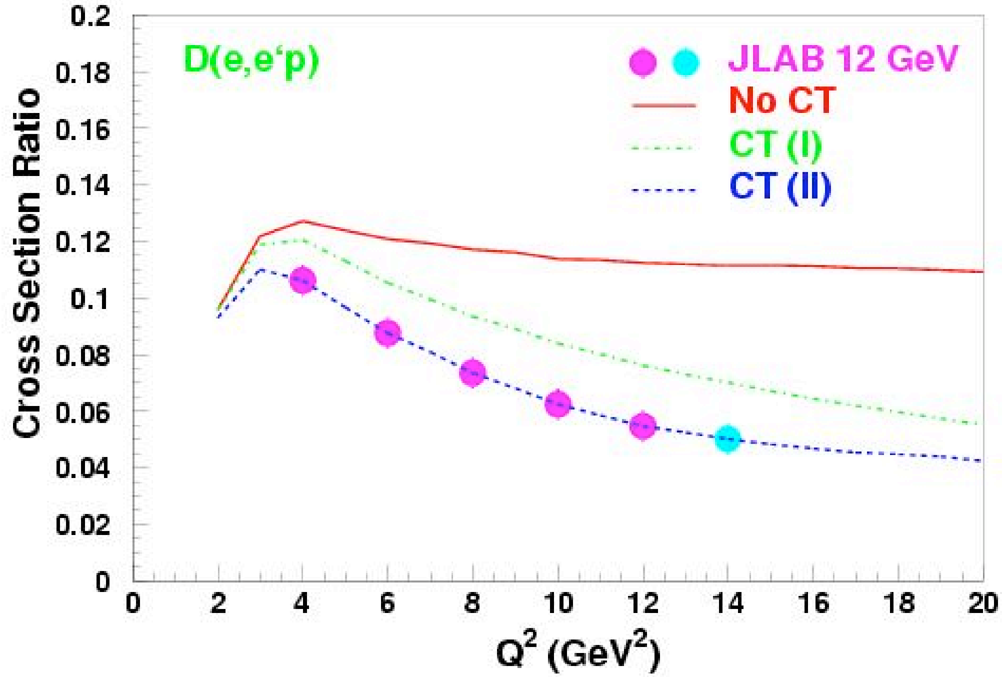


Fig.3

ZPhys A352(95)97
Frankfurt, Strikman, Sargsian

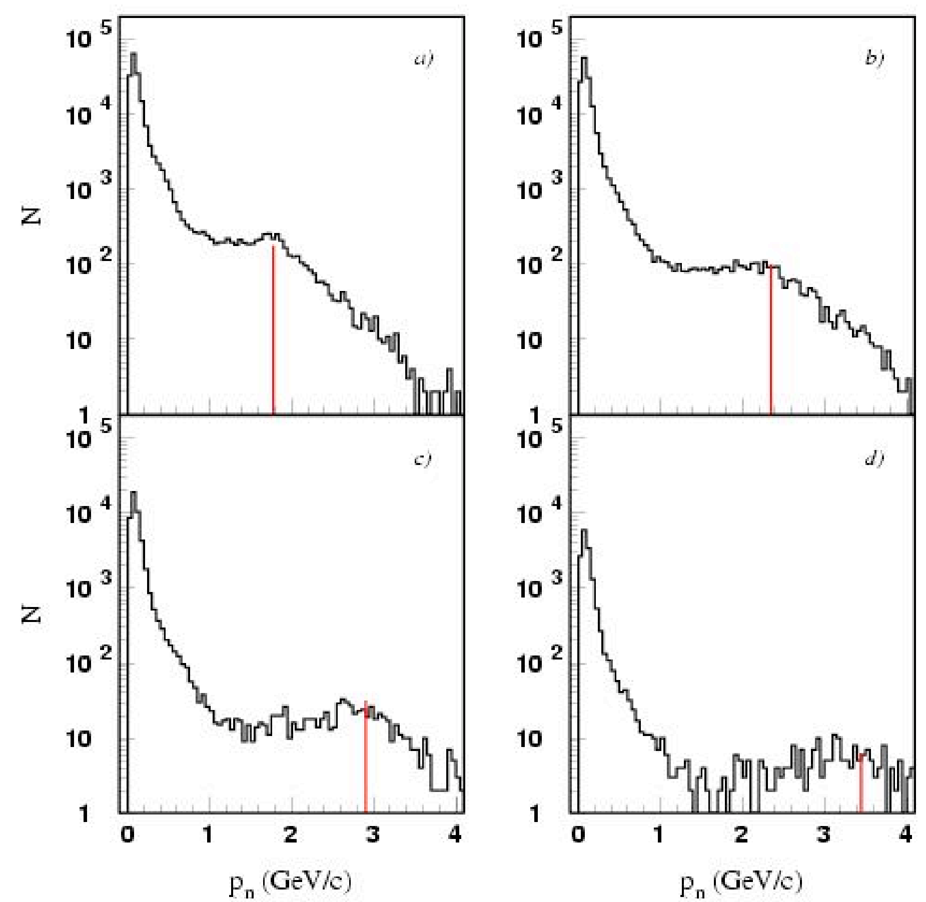
Sargsian, JPhys G29(03)R1



Left: T=exp/PWIA p_n=0, 100, 200, 300, 400 MeV/c (I-IV)
Right: T= exp(p_n=400)/exp(p_n=200)

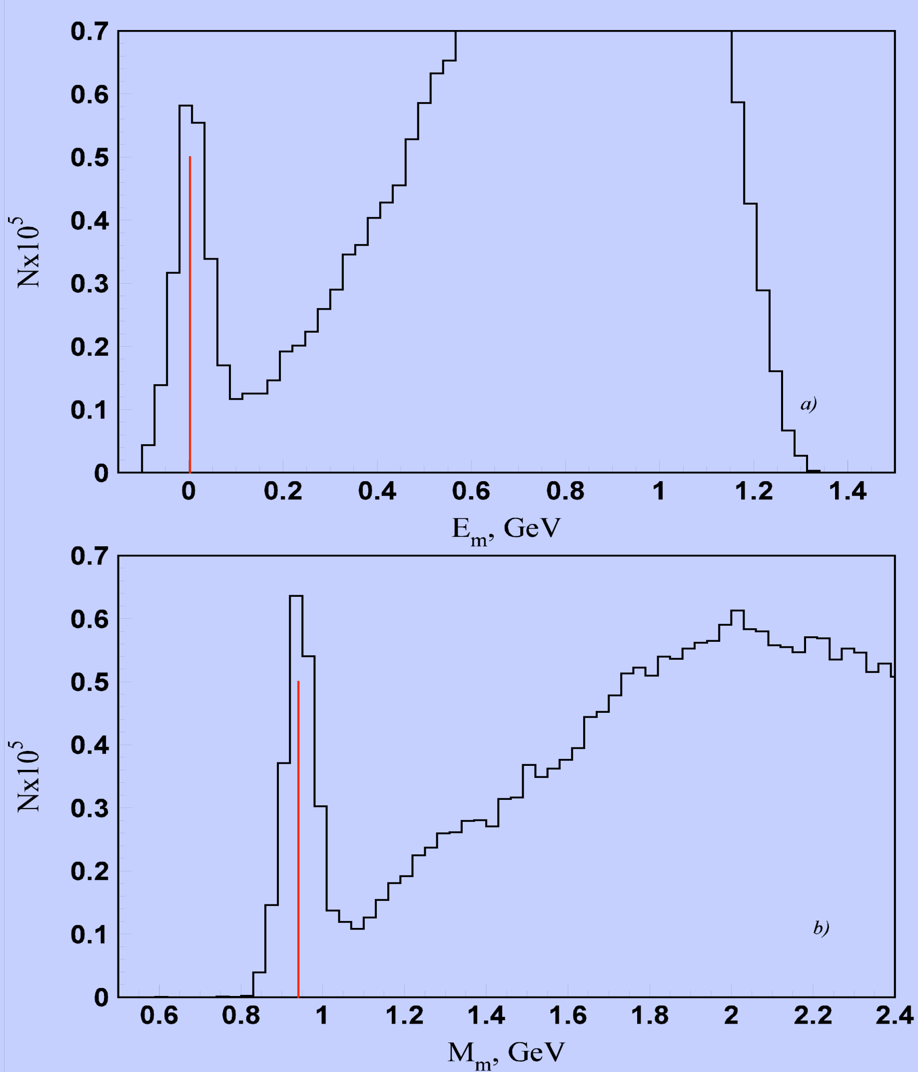
Momentum Distributions at 6 GeV

- Reconstructed p_n distributions for $Q^2 = 2, 3, 4, 5$ GeV^2 at E_{beam}=5.7 GeV (E6 CLAS)
- e n elastic (red)
- Region of interest is $p_n < 0.7$ GeV/c
- Proof of principle for 11 GeV



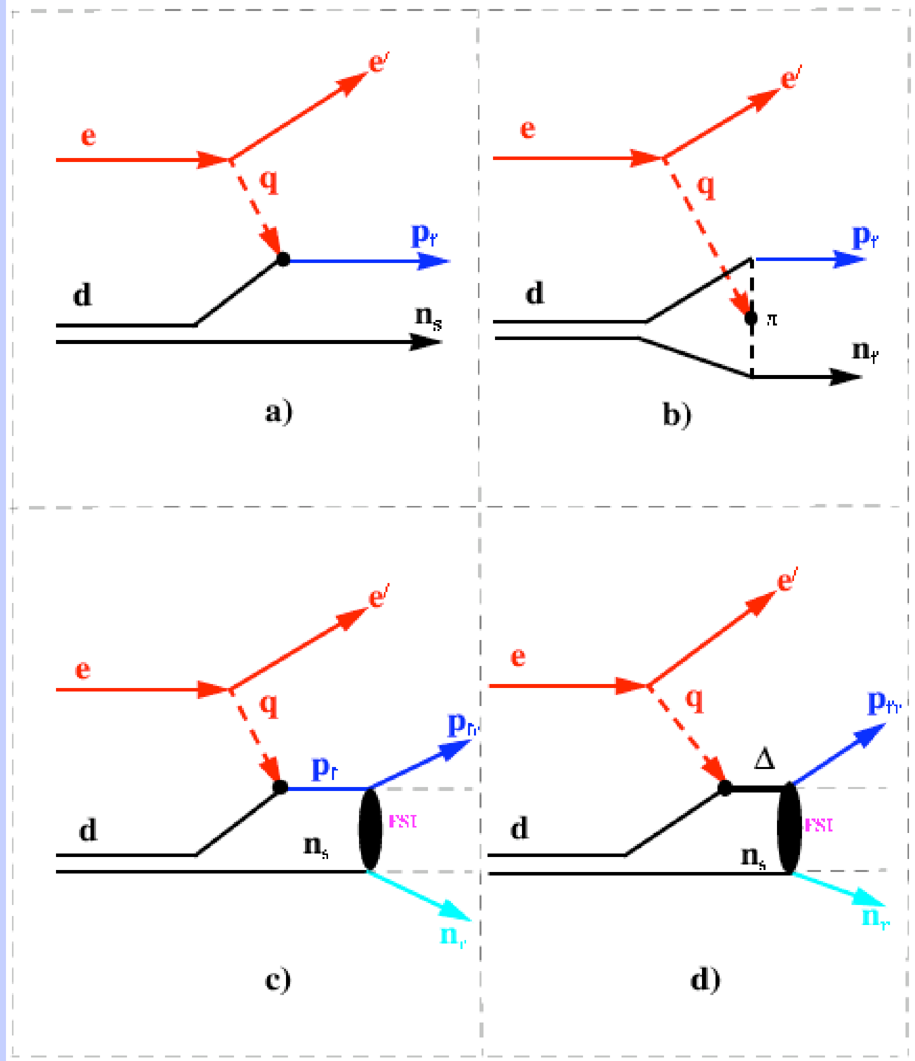
Missing Mass Technique

- E6 data with 50 MeV MM resolution
- CLAS12 expected MM resolution will be much better
- Clean separation of elastic and inelastic



Feynman Diagrams

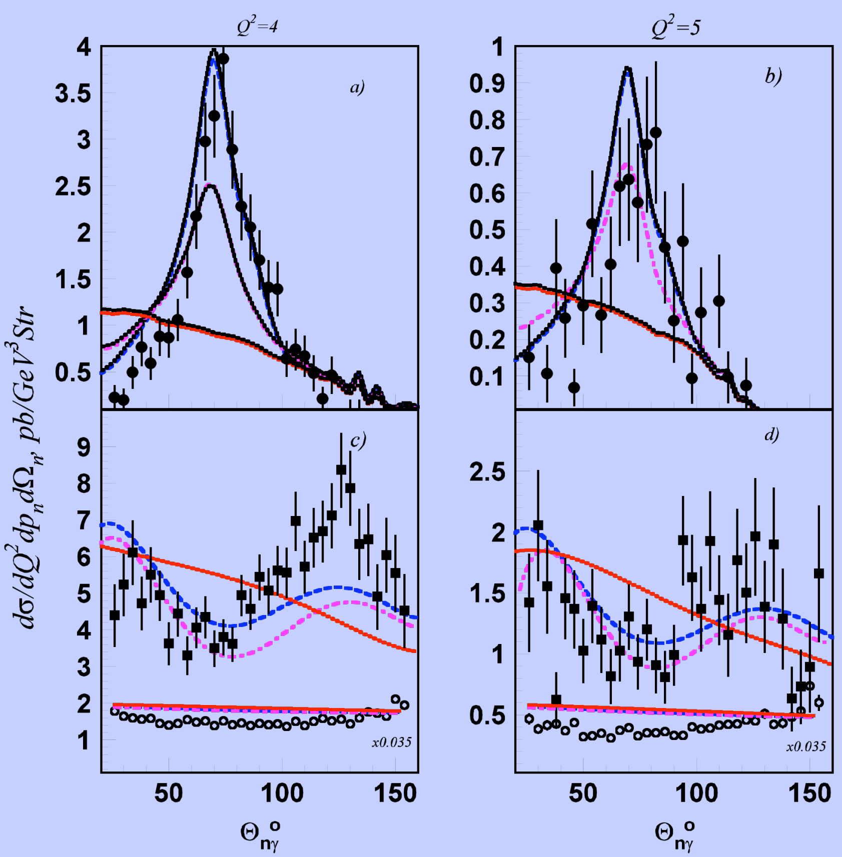
- (a) PWIA
- (b) Meson Exchange Currents (MEC)
- (c) FSI
- (d) Isobar Configuration (IC)
- Calculations by Laget

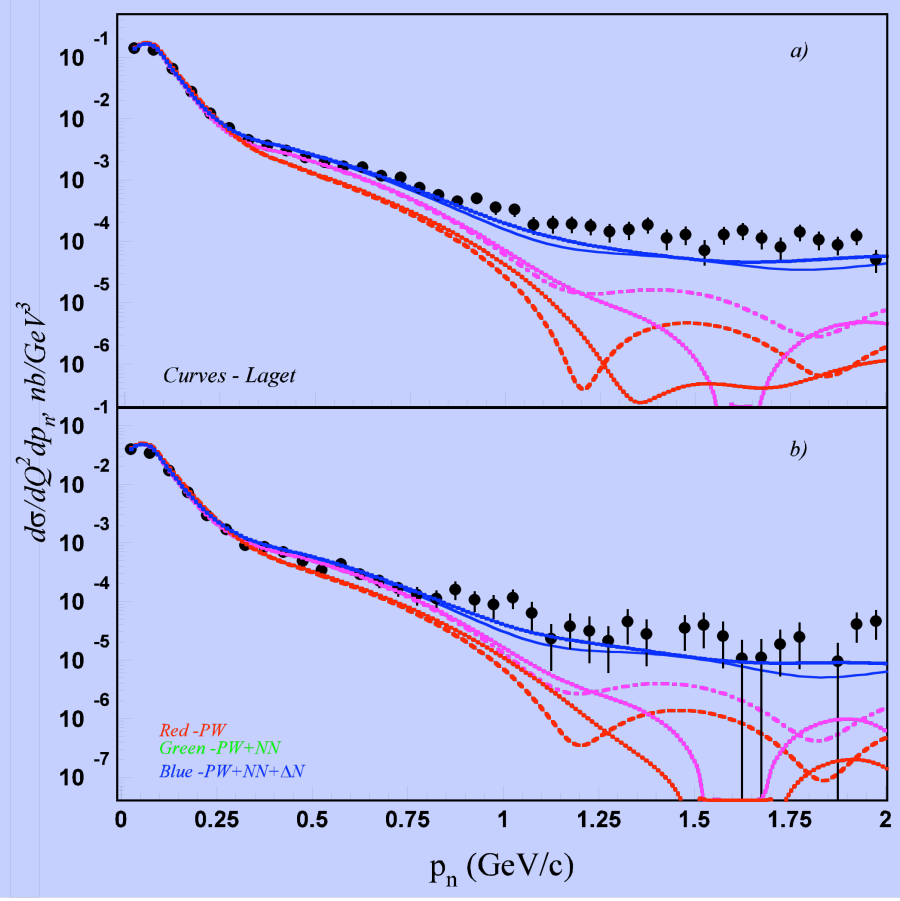


Diagrammatic Description of 6 GeV Data

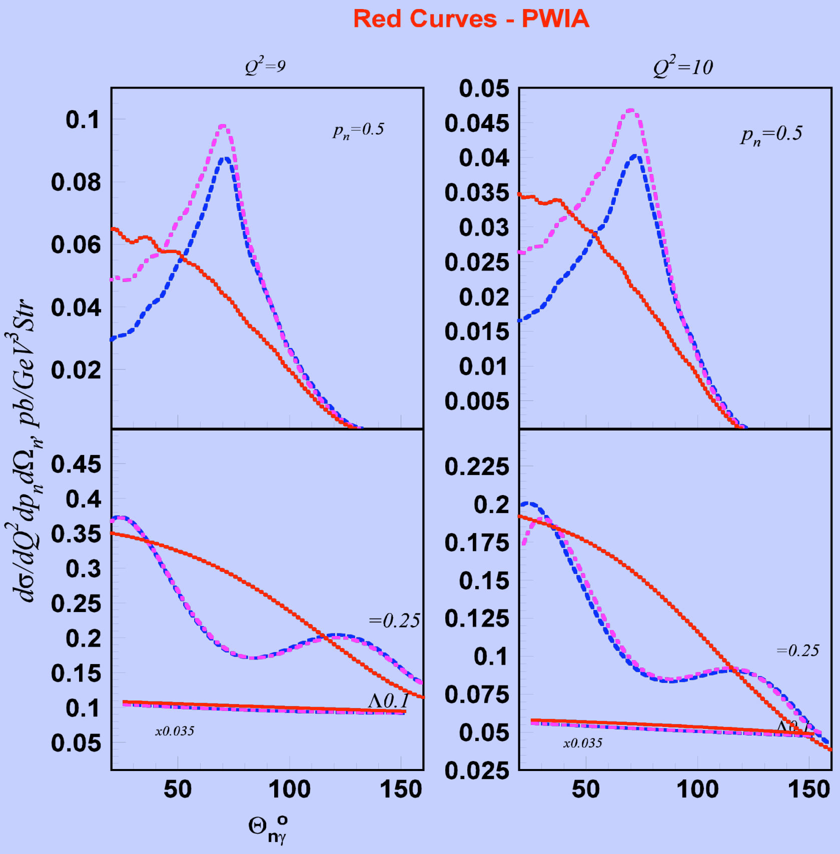
- Red: PWIA
- Magenta: with FSIs
- Blue: with FSIs and IC

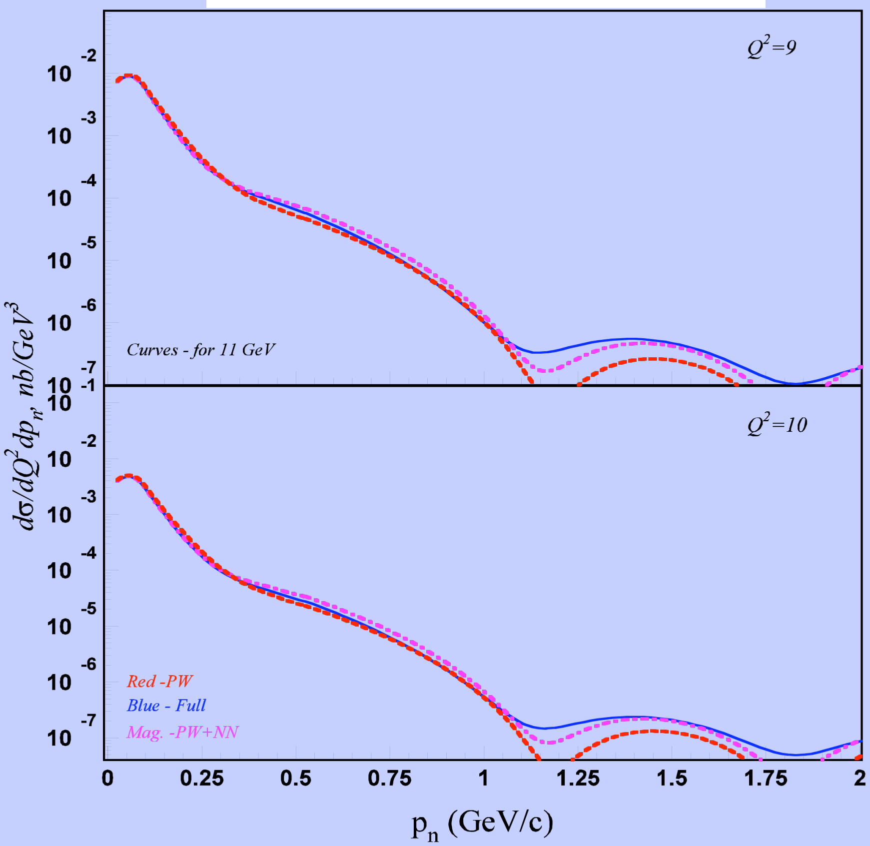
- Generalized Eikonal Approximation (GEA) in near future to confirm this





11 GeV Projections

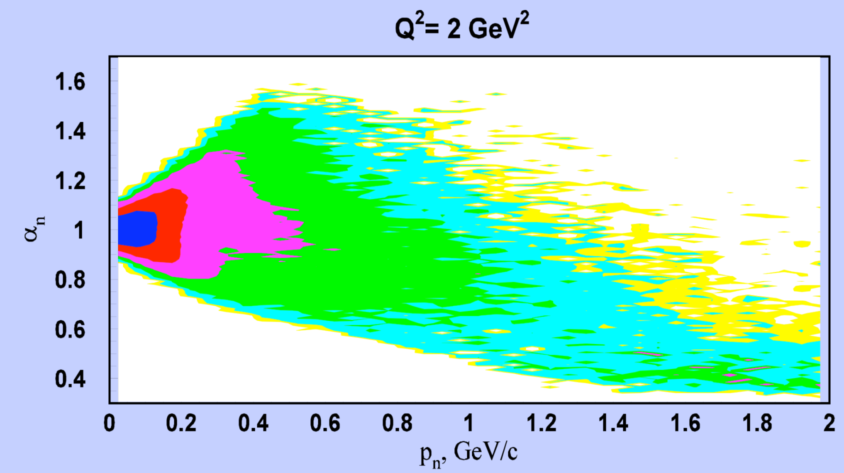


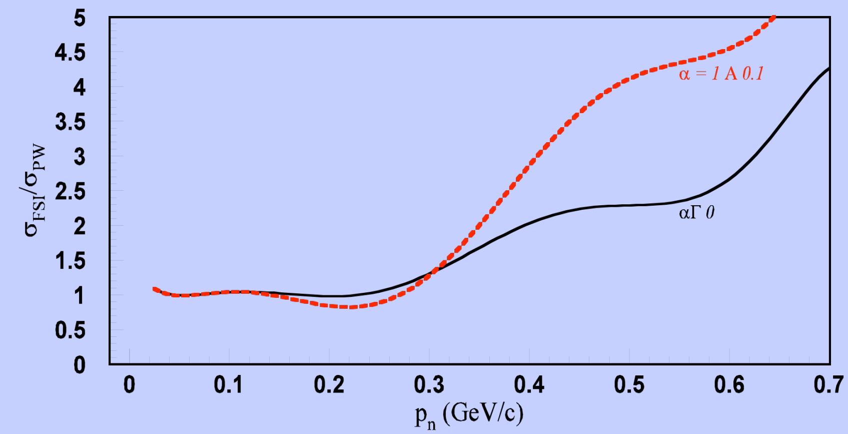


Light-Cone Fraction α_s

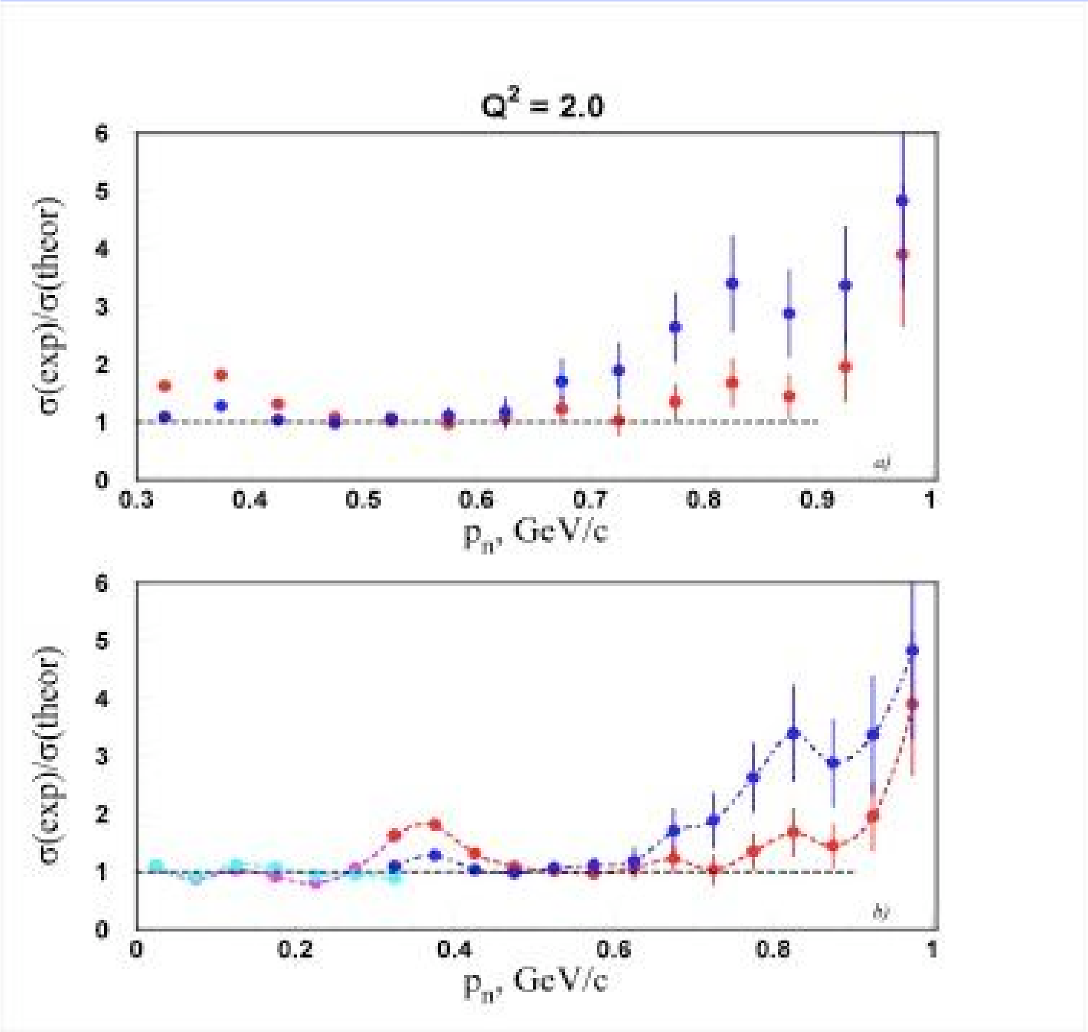
$$\alpha_n = \frac{E_n - p_n \cos\theta_{\gamma n}}{m_n}$$

- α_s = fraction of d momentum carried by spectator nucleon; $\alpha_s = 1$: internal momentum transverse is to **q**
- Red: $\alpha_s = 1$
- Black: $\alpha_s > 0$
- $\sigma_{FSI}/\sigma_{PWIA}$ vs p_n
- For $\alpha_s = 1$: screening for $0.2<p_n<0.3$ and double scattering for $p_n>0.3$





Where the FSIs Are

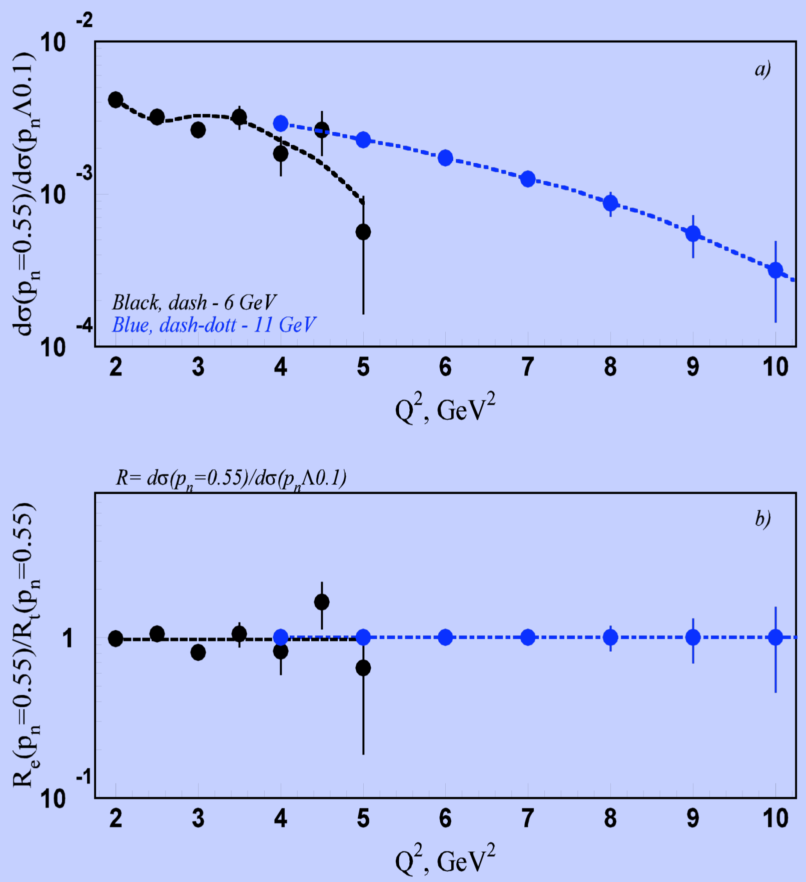


- Top: $\alpha_s > 1.23$; blue = full calculation; red = PWIA
- Bottom: $\alpha_s = 1$ (cyan) below p_n=0.3 GeV/c; same as upper curve for p_n>0.3 GeV/c
- FSI absent for p_n<0.2 GeV/c and for 0.45<p_n<0.55 GeV/c

Nuclear Modification of Form Factors

- $T_{e/e}$ is the ratio for $0.45<p_n<0.65$ and $\alpha_s > 1.23$ to $p_n<0.1$ and $\alpha_s = 1$
- $T_{t/t}$ is the same ratio for PWIA

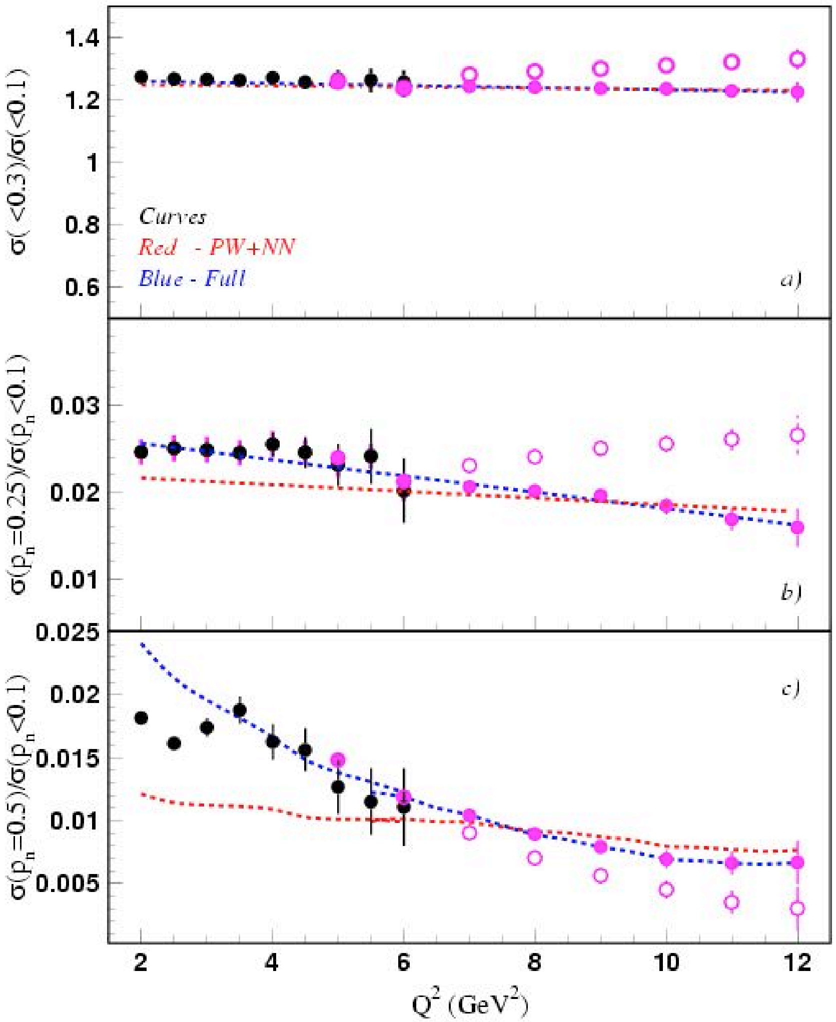
$$FF_{nm} = \frac{1}{\left(1+\frac{Q^2}{r}\right)^2}$$



$$\frac{T_{e/e}}{T_{t/t}} = \frac{1/\left(1+\frac{Q^2}{r}\right)^4}{1/\left(1+\frac{Q^2}{0.7\mathrm{GeV}^2}\right)^4}$$

CT Results

- Experimental ratios: σ(<0.3)/ σ(0.1), σ(0.25)/ σ(0.1) and σ(0.5)/ σ(0.1)
- Black points: E6 6 GeV data already taken
- Magenta points: solid: without CT; open: with CT
- Dotted red: PWIA
- Dashed blue: Laget PWIA+FSI+IC



Summary

- e+ d -> e' + n + p
  - simple, rigorously defined, easily measured reaction channel
  - nearly complete kinematics of a rare process at high Q^2
  - the best first place to start in understanding pQCD nuclear physics
  - small commitment of beam time
- Solid theoretical description
  - GEA is the generally accepted description of this reaction for hadronic degrees of freedom.
  - pQCD is the generally accepted description of this reaction for quark degrees of freedom at high Q^2
- The physics
  - potential for discovery of PLCs and modifications of the nucleon form factor in SRCs
  - CT is established in meson sector; onset is still unknown for baryons; this is the best way to find CT for the proton at Jlab