

Probing super-fast quarks in $e+A$ processes

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Short-range Nuclear Correlations at an Electron-Ion Colliders
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#motivations:

- Understanding the Nuclear – Repulsive Core
- Hadron–Quark transition in Cold Nuclear Matter
 - Superfast quarks in nuclei
 - Gluonic content of NN core
 - Color non-singlet/hidden color states
- Probing Three–Nucleon Forces at High Densities

#Theory of High Energy eA Scattering:

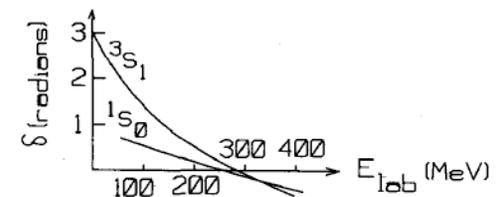
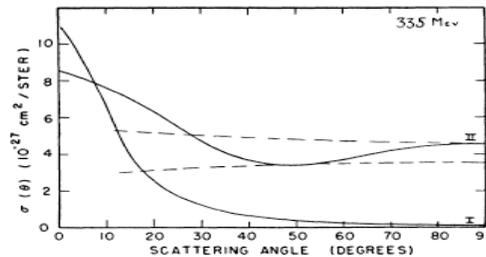
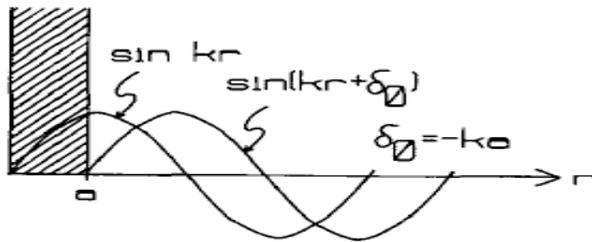
- Emergence of high-energy dynamics.
- High-Energy approximations
- Light-Front Wave Function of Nucleus
- From Schroedinger Equation to Feynman Diagrams

1. Probing NN Repulsive Core

"If the two-body forces are everywhere attractive and if many-body forces are neglected then the nucleon pairs are sufficiently close to take advantage of attractive interactions and a collapsed state of nuclear matter results "

G. Breit and E.P. Wigner, Phys. Rev. 53, 998 (1938).

Jastrow 1951 assumed the existence of the infinite hard core to explain the angular distribution of pp cross section at 340 MeV ($r_0=0.6\text{fm}$)



Non-monotonic NN central potential with the repulsive core was introduced: Brueckner & Watson 1953 to obtain nuclear density saturation.

Modern NN Potentials

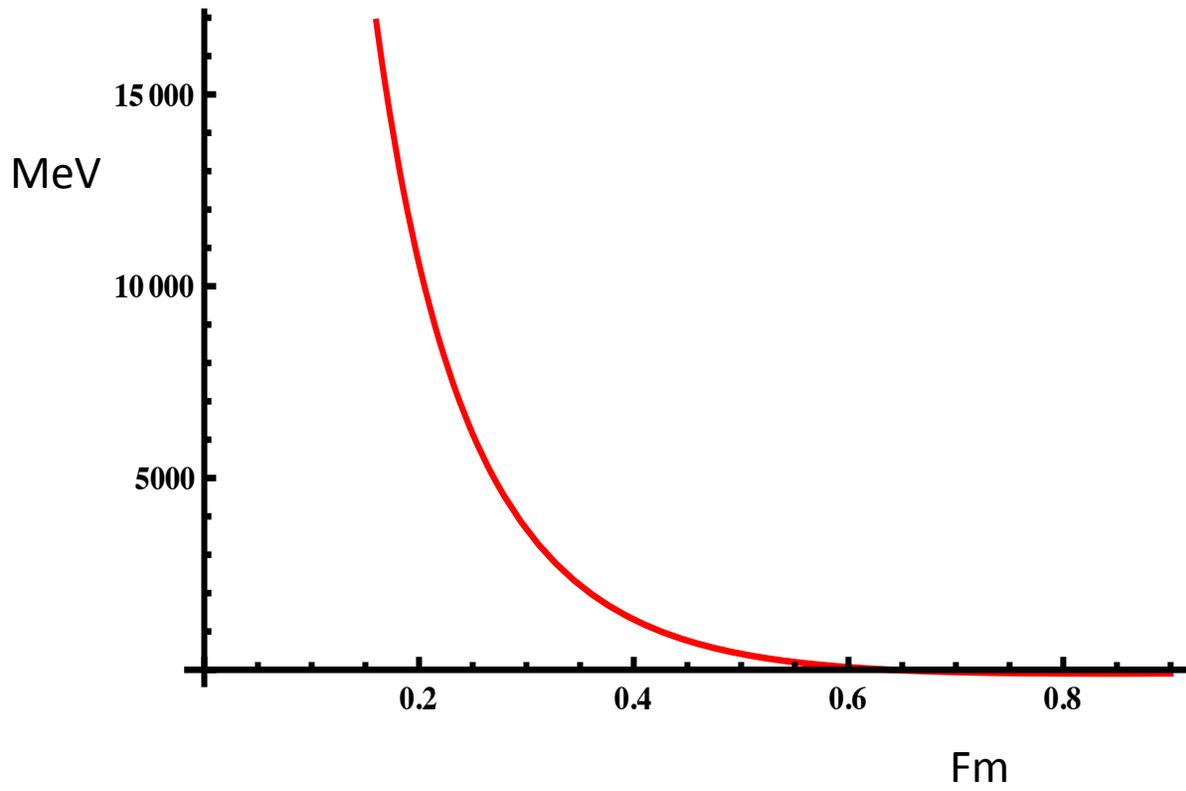
$$V^{2N} = V_{EM}^{2N} + V_{\pi}^{2N} + V_R^{2N}$$

$$V_R^{2N} = V^c + V^{l^2} L^2 + V^t S_{12} + V^{ls} L \cdot S + v^{ls^2} (L \cdot S)^2$$

$$V^i = V_{int,R} + V_{core}$$

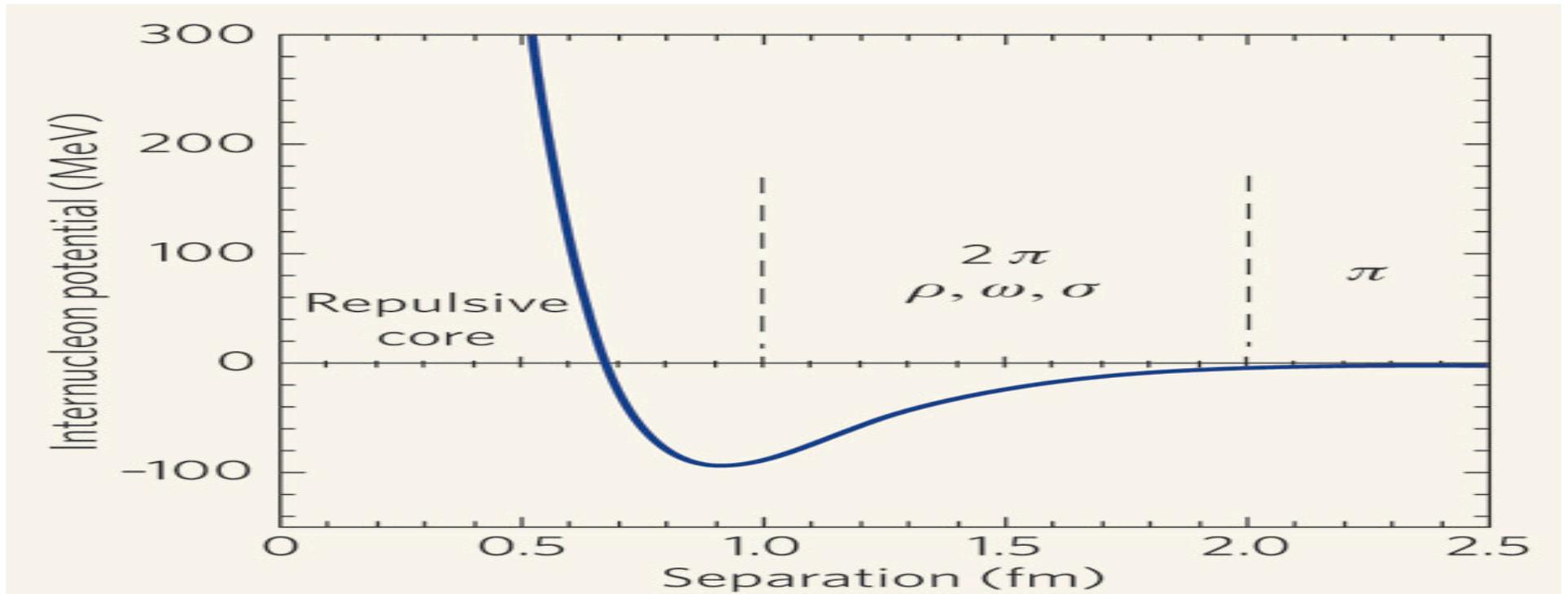
$$V_{core} = \left[1 + e^{\frac{r-r_0}{a}} \right]^{-1}$$

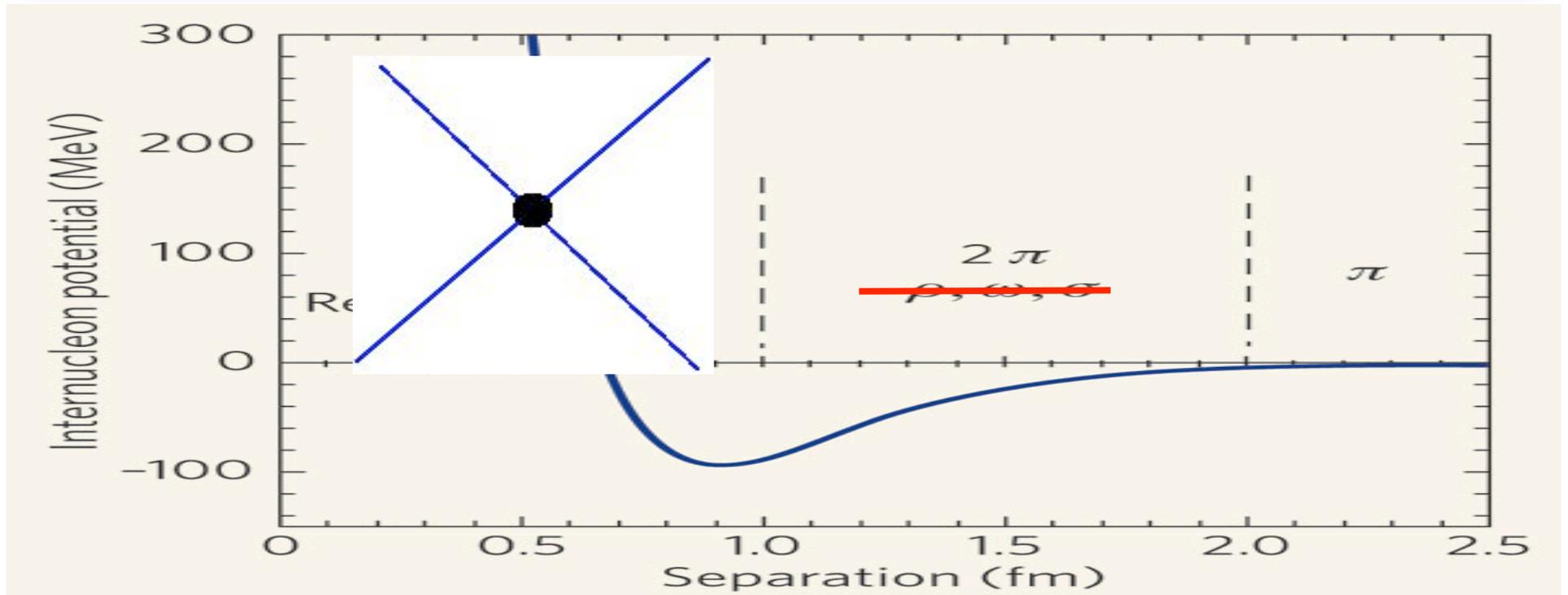
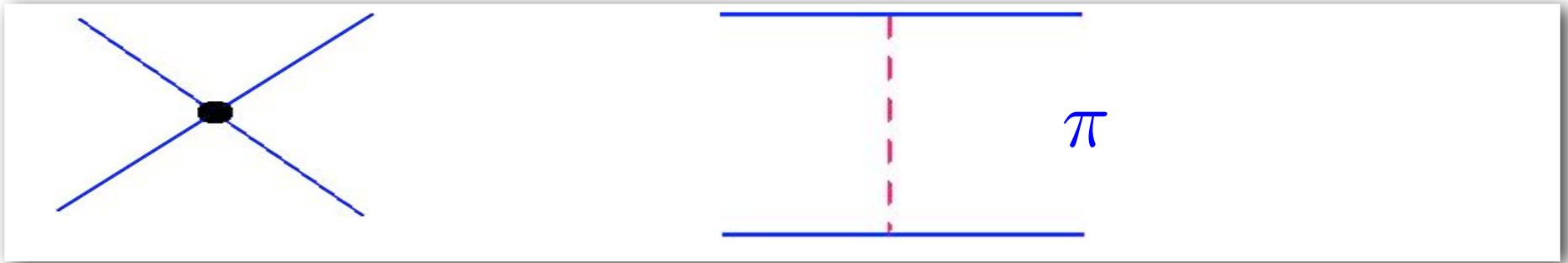
60's



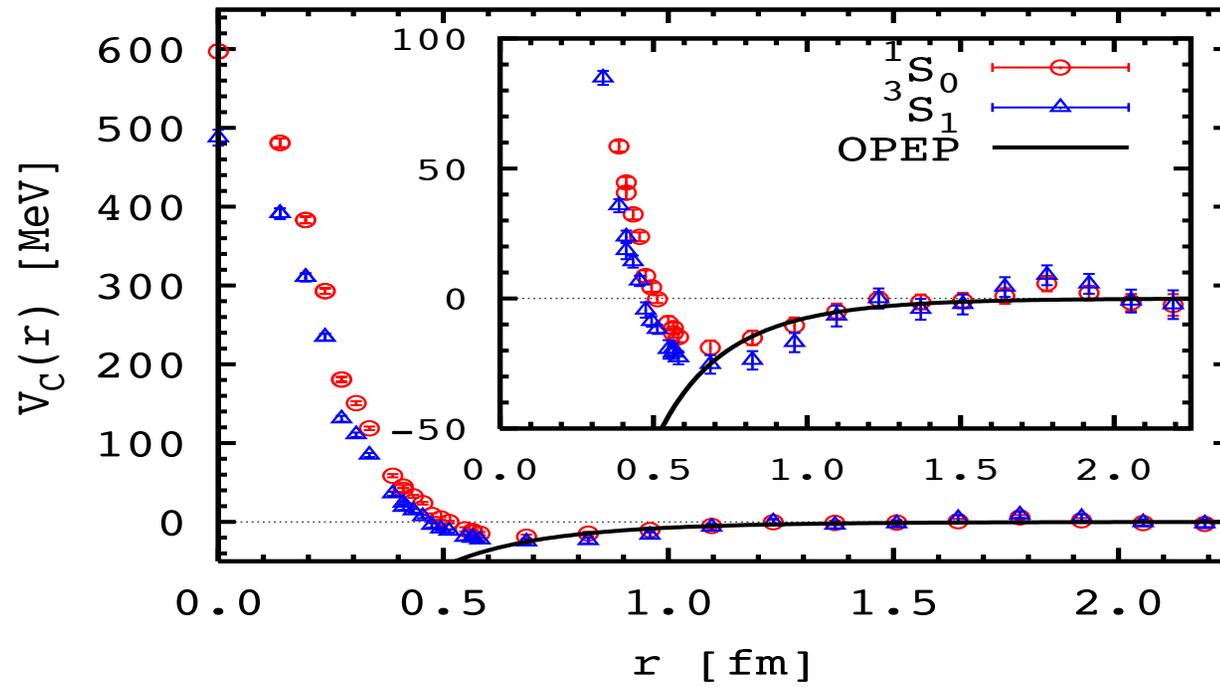


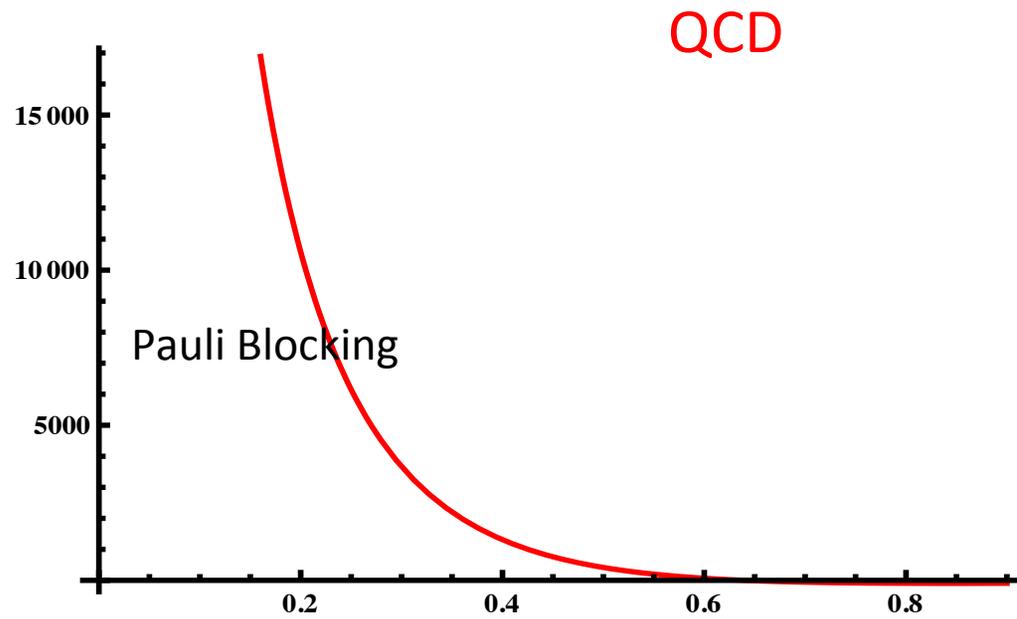
$\sigma, \pi, \rho, \omega, \dots$



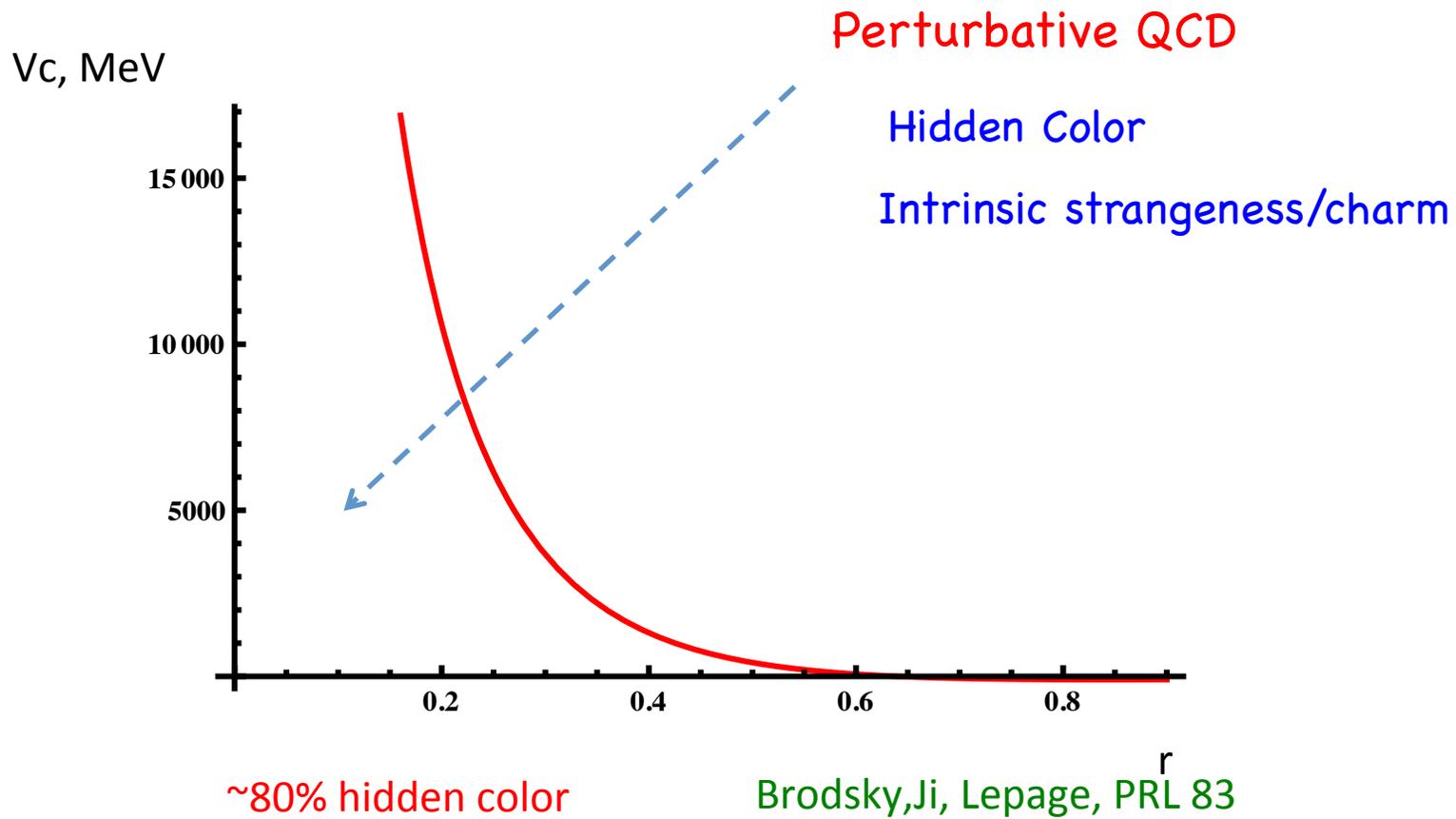


Lattice Calculations





Contradicts Neutron Star Observations:
will predict masses not more than 0.1 - 0.6 Solar mass



Probing the Deuteron at Short Distances

$$\Psi_d = \Psi_{pn} + \Psi_{\Delta\Delta} + \Psi_{NN^*} + \Psi_{hc} \dots$$

$$\Psi_{hc} = \Psi_{N_c, N_c}$$

The NN core can be due to the orthogonality of

$$\langle \Psi_{N_c, N_c} | \Psi_{N, N} \rangle = 0$$

Conceptually: How to probe nuclei at short nucleon separations

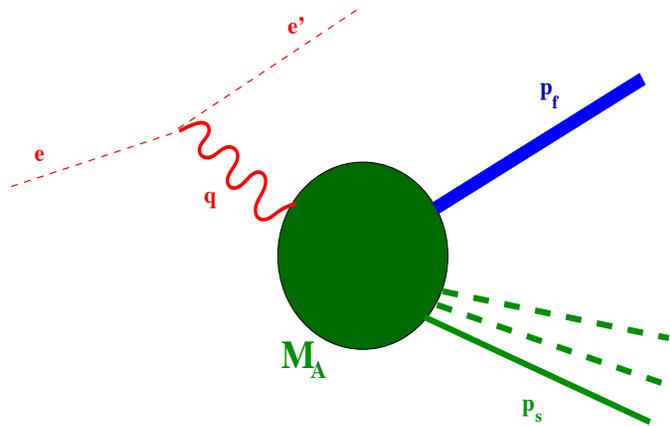
- Probe bound nucleons at large internal momenta
- Need high energy probes to resolve such nucleons in nuclei

#Theory of High Energy eA Scattering:

Emergence of High Energy Dynamics

- Short Range Nucleon Correlations(SRCs) are important feature of Nuclear Dynamics
- Transition from hadronic to quark-gluon degrees of freedom in cold-nuclei "should happen" through SRCs
- Internal momenta relevant to SRCs $p \sim M_N$ - Relativistic
- Such states are probed in high energy processes: high energy approximations can be applied in description of SRC dynamics

High Energy Approximations:



$$|\vec{q}| = q_3 \sim p_{f3} \gg p \sim M_N$$

$$Q^2 \geq \text{few GeV}^2$$

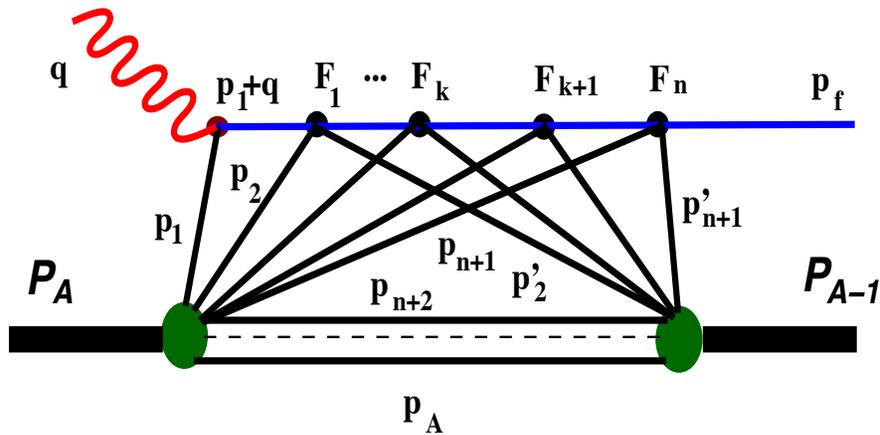
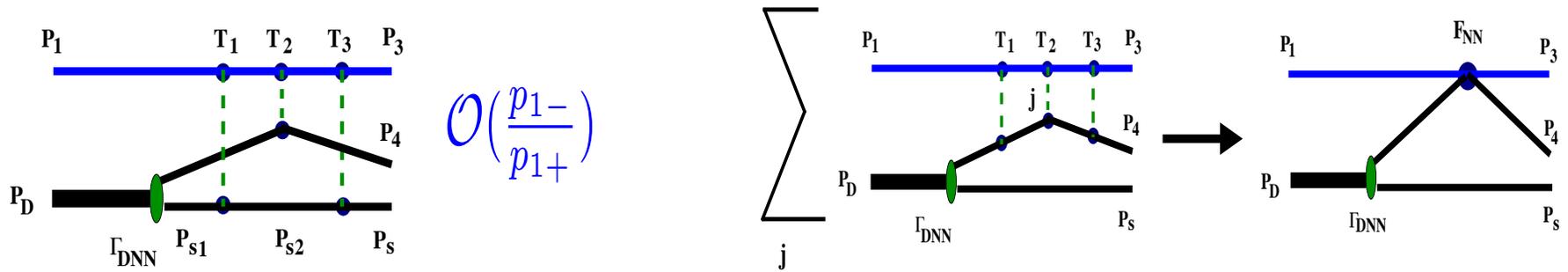
Both for QE/DIS

- Emergence of the **small parameter**

$$\frac{q_-}{q_+} = \frac{q_0 - q_3}{q_0 + q_3} \ll 1 \quad \mathcal{O}\left(\frac{q_-}{q_+}\right)$$

$$\frac{p_{f-}}{p_{f+}} = \frac{E_f - p_{f3}}{E_f + p_{f3}} \ll 1 \quad \mathcal{O}\left(\frac{p_{f-}}{p_{f+}}\right)$$

Emergence of "effective" theory



Effective Feynman Diagrammatic Rules

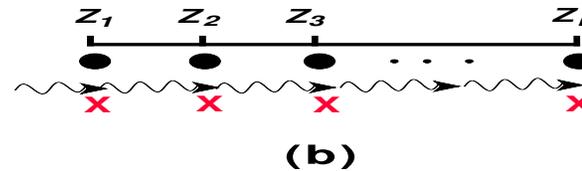
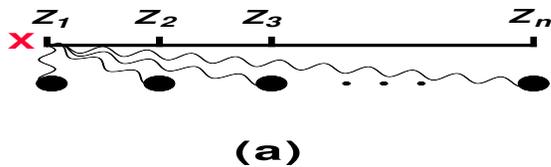
M.S. IJMS 2001

Wave function?

Light-Front Wave Function of the Nucleus

- Emergence of the light- front dynamics

$$\tau = t - z \sim \frac{1}{q_+} \rightarrow 0$$



- non relativistic case: due to Galilean relativity
 observer X can probe all n-nucleons at the same time

$$\Psi(z_1, z_2, z_3, \dots, z_n, t)$$

- relativistic case: observer X probes all n-nucleons at different n times

$$\Psi(z_1, t_1; z_2, t_2; z_3, t_3 \dots ; z_n, t_n)$$

- observer riding the light-front X probes all n-nucleons at same light-cone time:

$$\Psi_{LF}(Z_1, Z_2, Z_3, \dots, Z_n, \tau)$$

$$\tau = t_1 - z_1 = t_2 - z_2 = \dots = t_n - z_n \quad Z_i = t_i + z_i$$

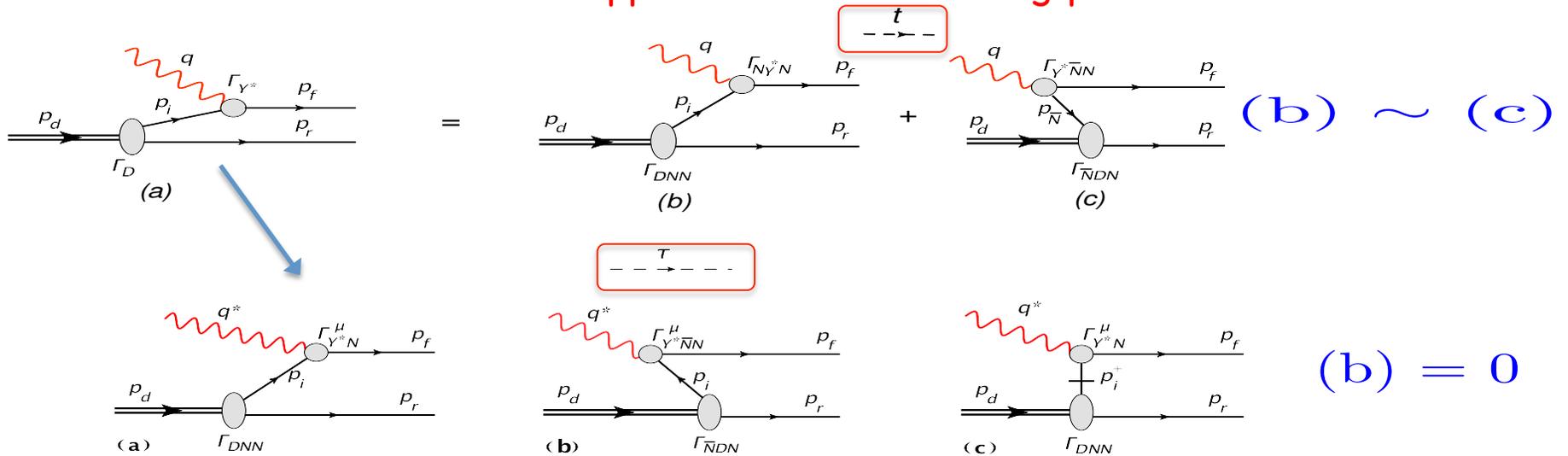
Light-Front wave function of the Nucleus

$$\Psi_{LF}(\mathcal{Z}_1, \mathcal{Z}_2, \mathcal{Z}_3, \dots, \mathcal{Z}_n, \tau)$$

- in the momentum space

$$\Psi_{LF}(\alpha_1, p_{1\perp}; \alpha_2, p_{2\perp}; \alpha_3, p_{3\perp}; \dots, \alpha_n, p_{n\perp}) \quad \alpha_i = \frac{p_{i-}}{p_{A-}/A}$$

- How the LF wave function appears in the scattering process



From Schroedinger Equation -> Feynman Diagrams-> Light-Front Wave Function

Schroedinger eq. \rightarrow

$$\left[-\sum_i \frac{\nabla_i^2}{2m} + \frac{1}{2} \sum_{i,j} V(x_i - x_j) \right] \psi(x_1, \dots, x_A) = E\psi(x_1, \dots, x_A)$$

Lipmann-Schwinger Eq.

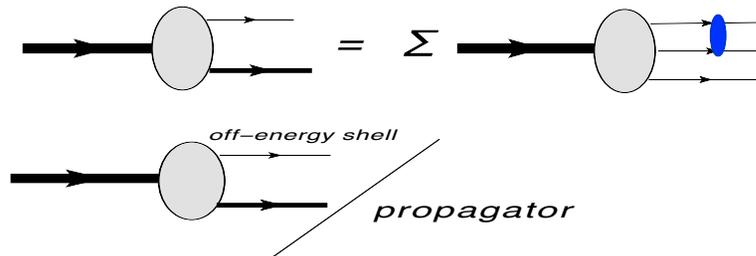
$$\left(\sum_i \frac{k_i^2}{2m} - E_b \right) \Phi(k_1, \dots, k_A) = -\frac{1}{2} \sum_{i,j} \int U(q) \Phi(k_1, \dots, k_i - q, \dots, k_j + q, \dots, k_A) d^3q$$

Lipmann-Schwinger Eq \rightarrow

$$\left(\sum_i \frac{k_i^2}{2m} - E_b \right) \Phi(k_1, \dots, k_A) = -\frac{1}{2} \sum_{i,j} \int U(q) \Phi(k_1, \dots, k_i - q, \dots, k_j + q, \dots, k_A) d^3q$$

$$\Phi(k_1, \dots, k_A) = \frac{1}{\sum \frac{k_i^2}{2m} - E_b} \Gamma_{A \rightarrow N, A-1}$$

t - ordered diagrammatic method

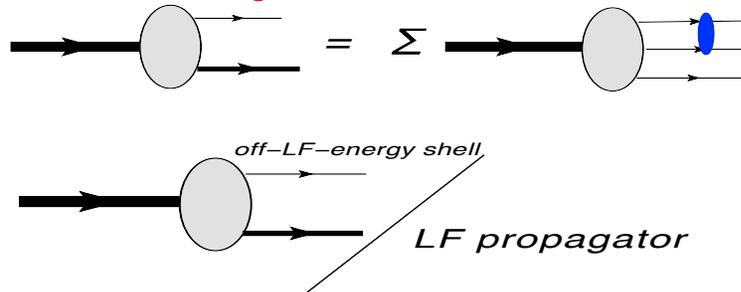


Weinberg Eq \rightarrow

$$\left(\sum \frac{k_{i\perp}^2 + m^2}{\alpha_i} - M_A^2 \right) \Phi_{LF}(k_1, \dots, k_A) = \frac{1}{2} \sum_{i,j} \int U_{LF}(q) \Phi_{LF}(k_1, \dots, k_A) \prod \frac{d\alpha_i}{\alpha_i} d^2k_{i\perp}$$

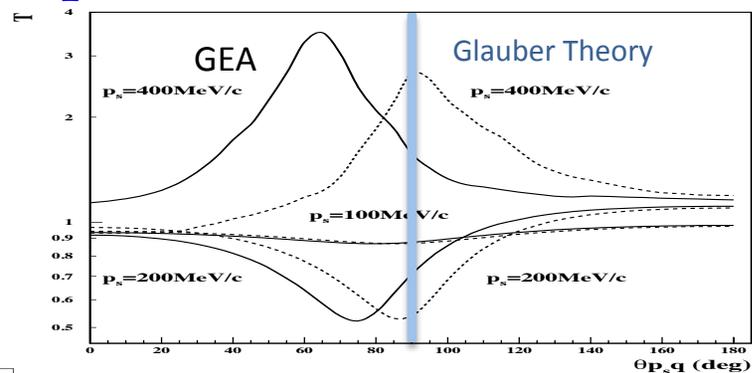
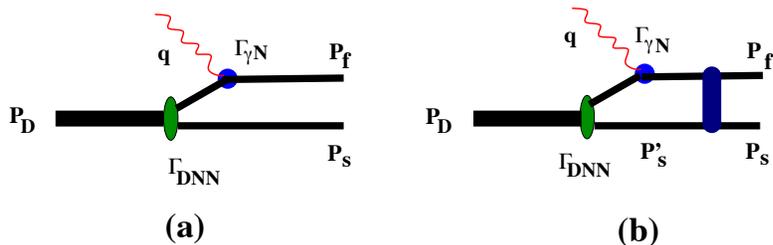
$$\Phi_{LF}(k_1, \dots, k_A) = \frac{1}{\sum \frac{k_{i\perp}^2 + m^2}{\alpha_i} - M_A^2} \Gamma_{A \rightarrow N, A-1}$$

\mathcal{T} - ordered diagrammatic method

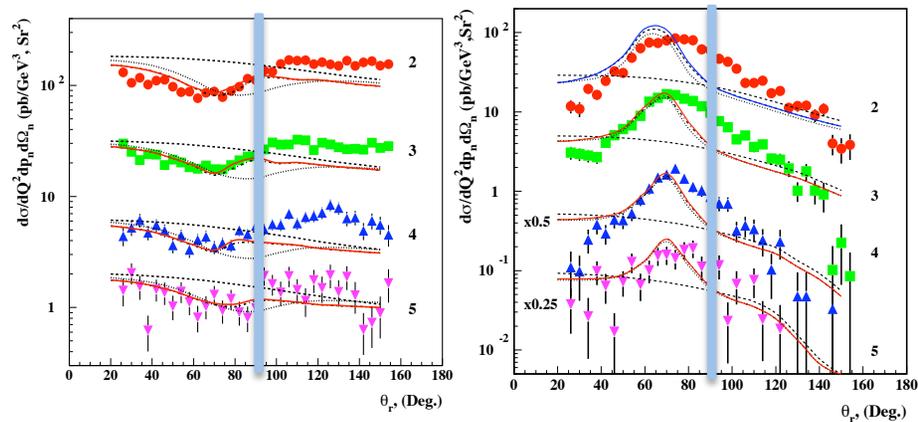


Some Results: $e + d \rightarrow e' + p + n$

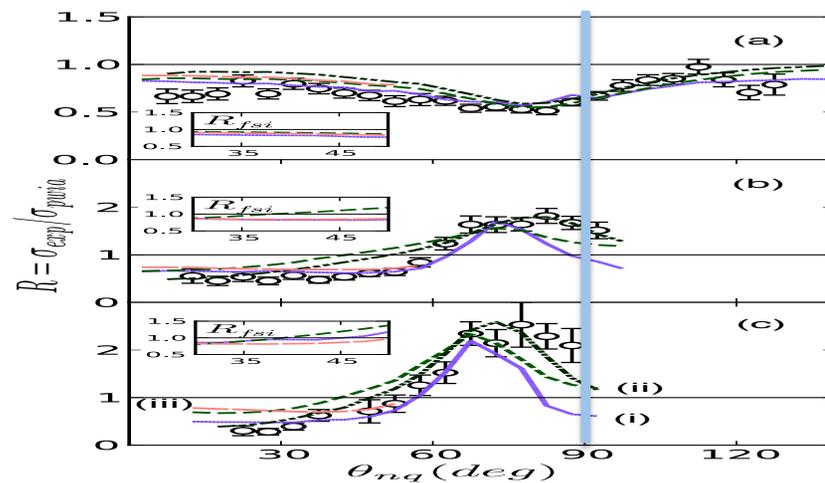
Frankfurt, M.S., Strikman, PRC 1997



K. Egiyan et al PRL 2008

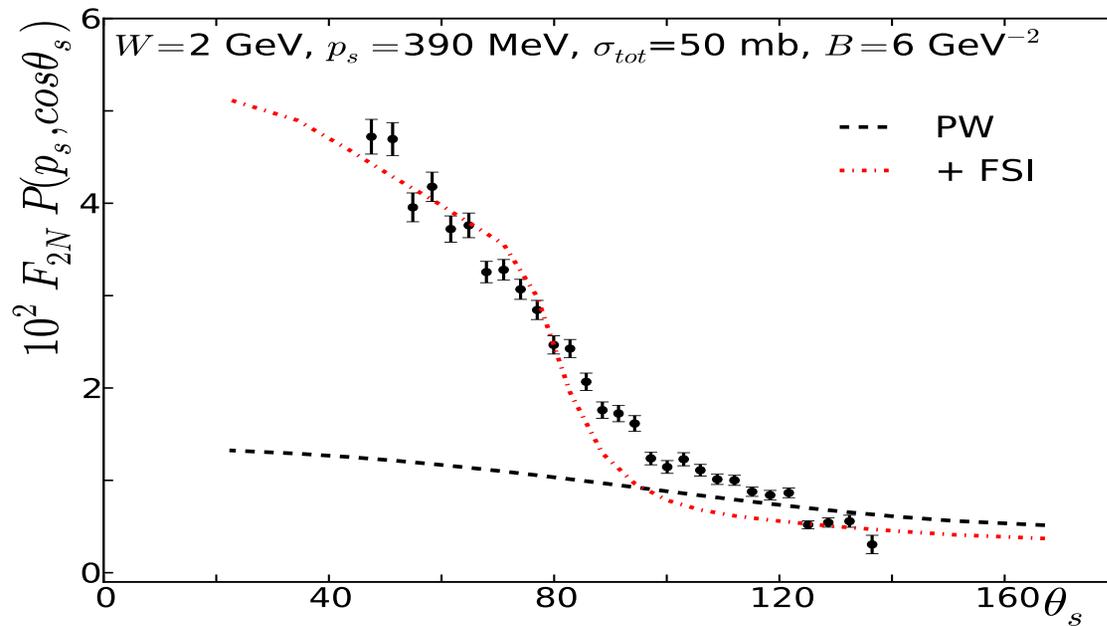


W. Boeglin et al PRL 2011

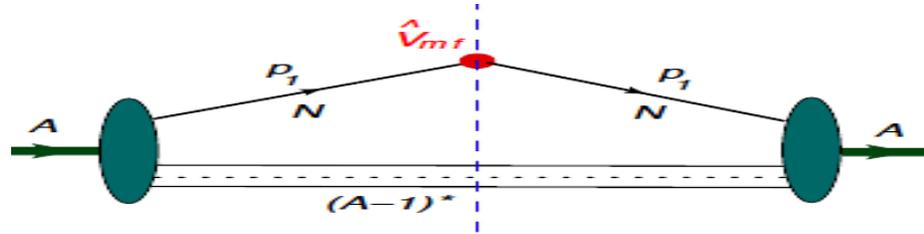


Extension to DIS: $e + d \rightarrow e' + p_s + X$

W.Cosyn & M.Sargsian, PRC 2011



Spectral Function Calculations



$$S_A^{MF} = -Im \int \chi_A^\dagger \Gamma_{A,N,A-1}^\dagger \frac{p_1 + m}{p_1^2 - m^2 + i\varepsilon} \hat{V}^{MF} \frac{p_1 + m}{p_1^2 - m^2 + i \times \varepsilon} \left[\frac{G_{A-1}(p_{A-1})}{p_{A-1}^2 - M_{A-1}^2 + i\varepsilon} \right]^{on} \Gamma_{A,N,A-1} \chi_A \frac{d^4 p_{A-1}}{i(2\pi)^4}$$

$$\hat{V}^{MF} = ia^\dagger(p_1, s_1) \delta^3(p_1 + p_{A-1}) \delta(E_m - E_\alpha) a(p_1, s_1)$$

$$\psi_{N/A}(p_1, s_1, s_A, E_\alpha) = \frac{\bar{u}(p_1, s_1) \Psi_{A-1}^\dagger(p_{A-1}, s_{A-1}, E_\alpha) \Gamma_{A,N,A-1} \chi_A}{(M_{A-1}^2 - p_{A-1}^2) \sqrt{(2\pi)^3 2E_{A-1}}}$$

$$S_A^{MF}(p_1, E_m) = \sum_{\alpha} \sum_{s_1, s_{A-1}} |\psi_{N/A}(p_1, s_1, s_A, E_\alpha)|^2 \delta(E_m - E_\alpha)$$

Short-Range Correlations

for large $k > k_{Fermi}$

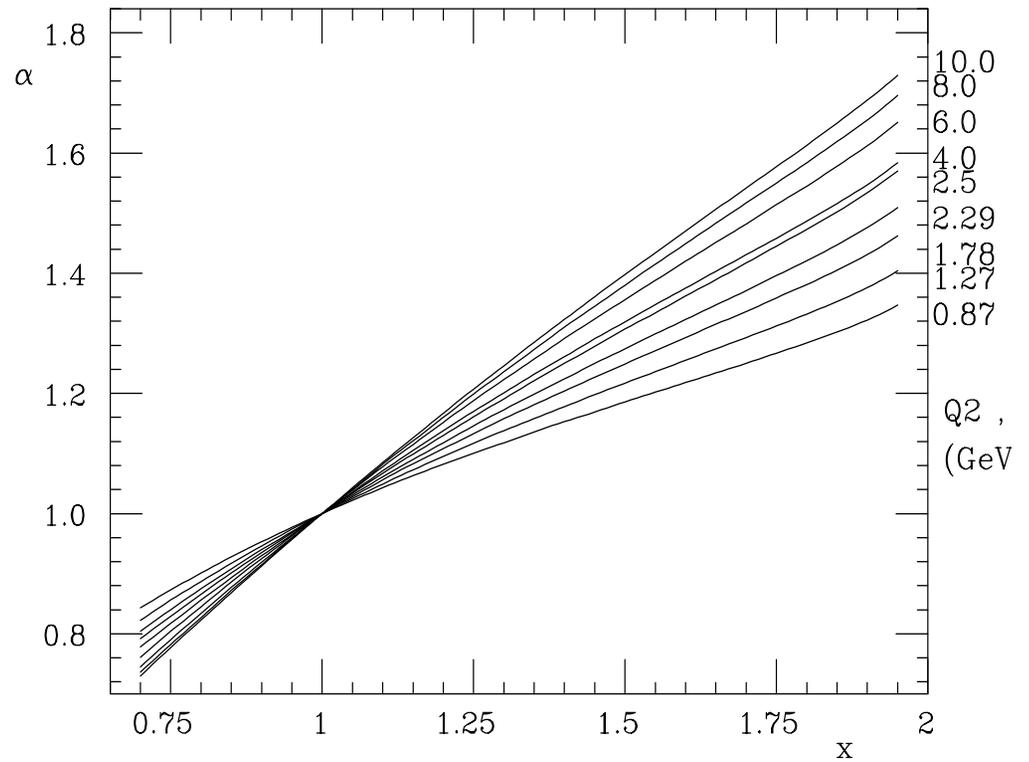
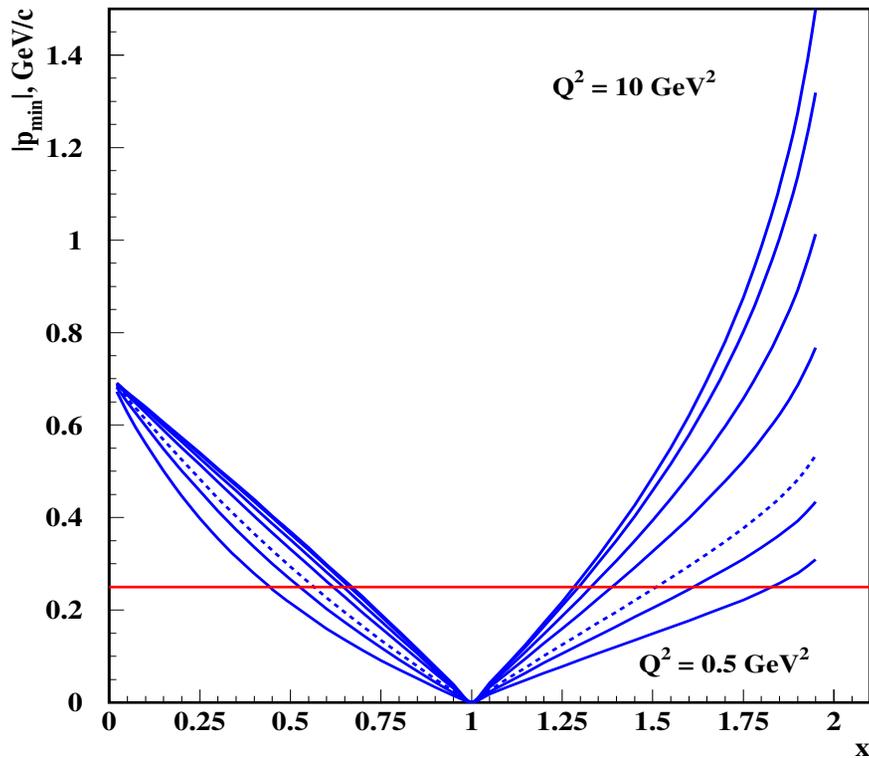
$$n_A(k) \approx a_{NN}(A)n_{NN}(k)$$

- Experimental observations

Frankfurt, Strikman Phys.
Rep, 1988
Day, Frankfurt, Strikman,
MS, Phys. Rev. C 1993

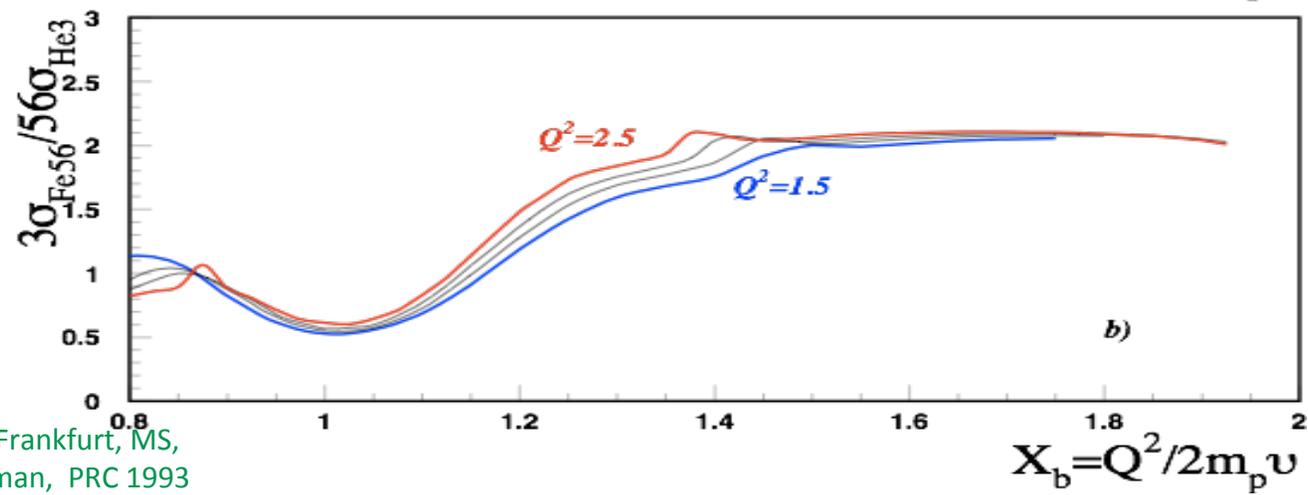
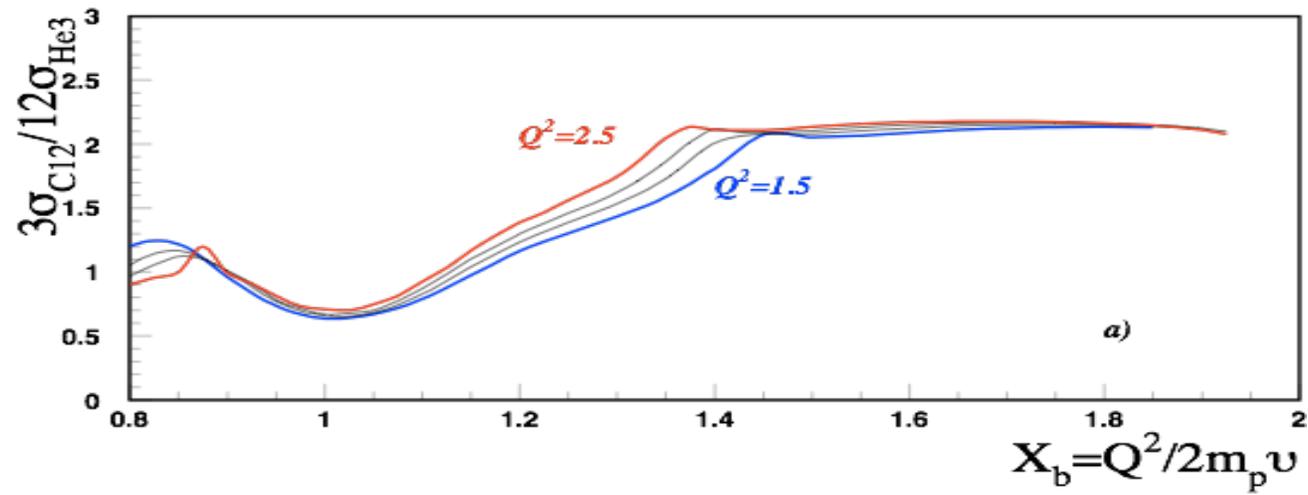
Egiyan et al, 2002,2006
Fomin et al, 2011

Nuclear Scaling in QE Inclusive $A(e,e')X$ reaction at $x > 1$ region



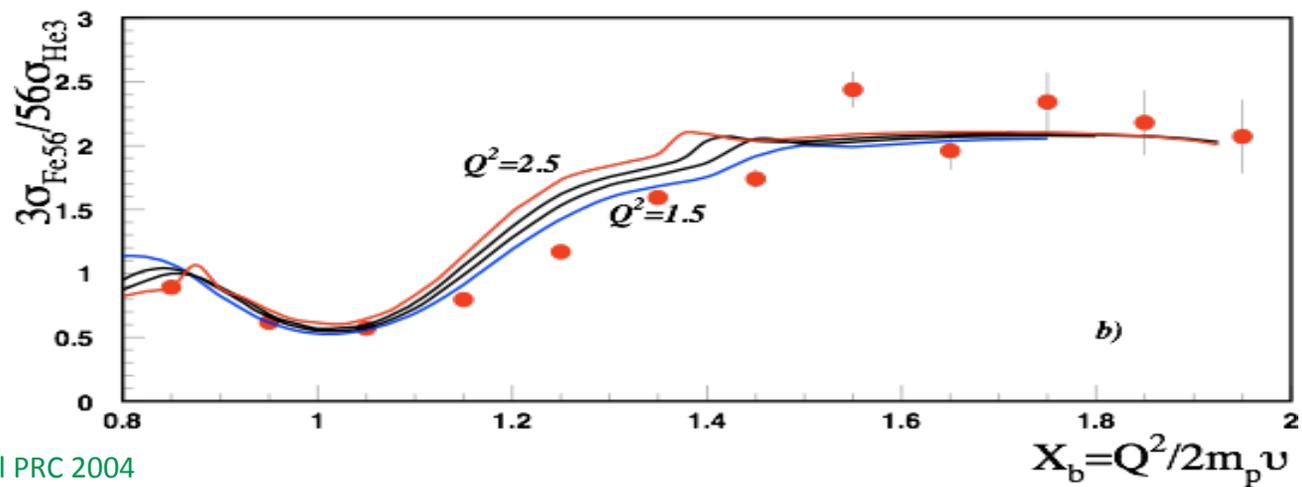
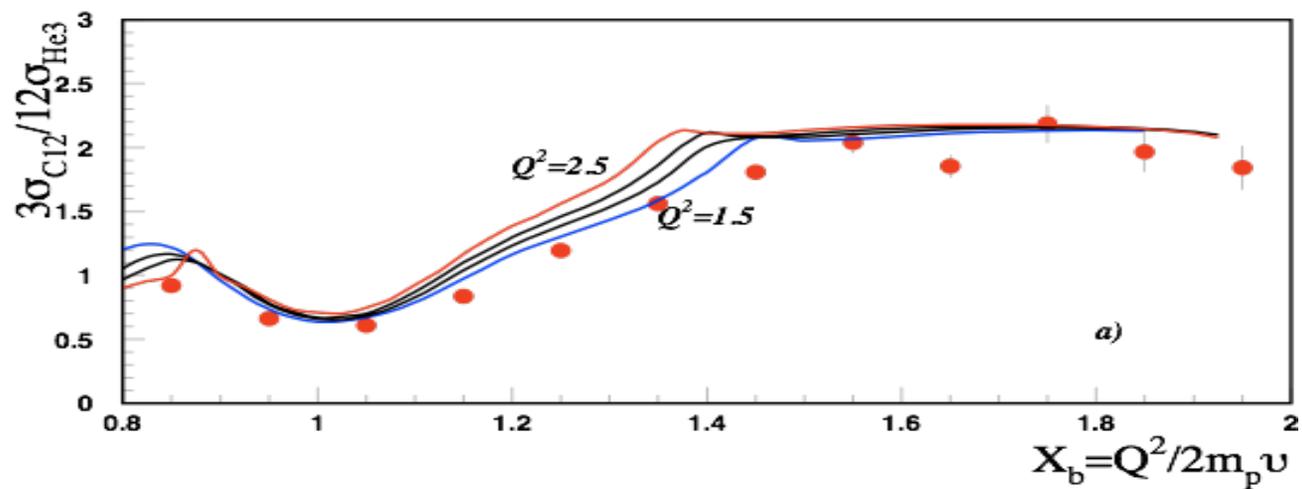
Day, Frankfurt, MS, Strikman,
PRC 1993

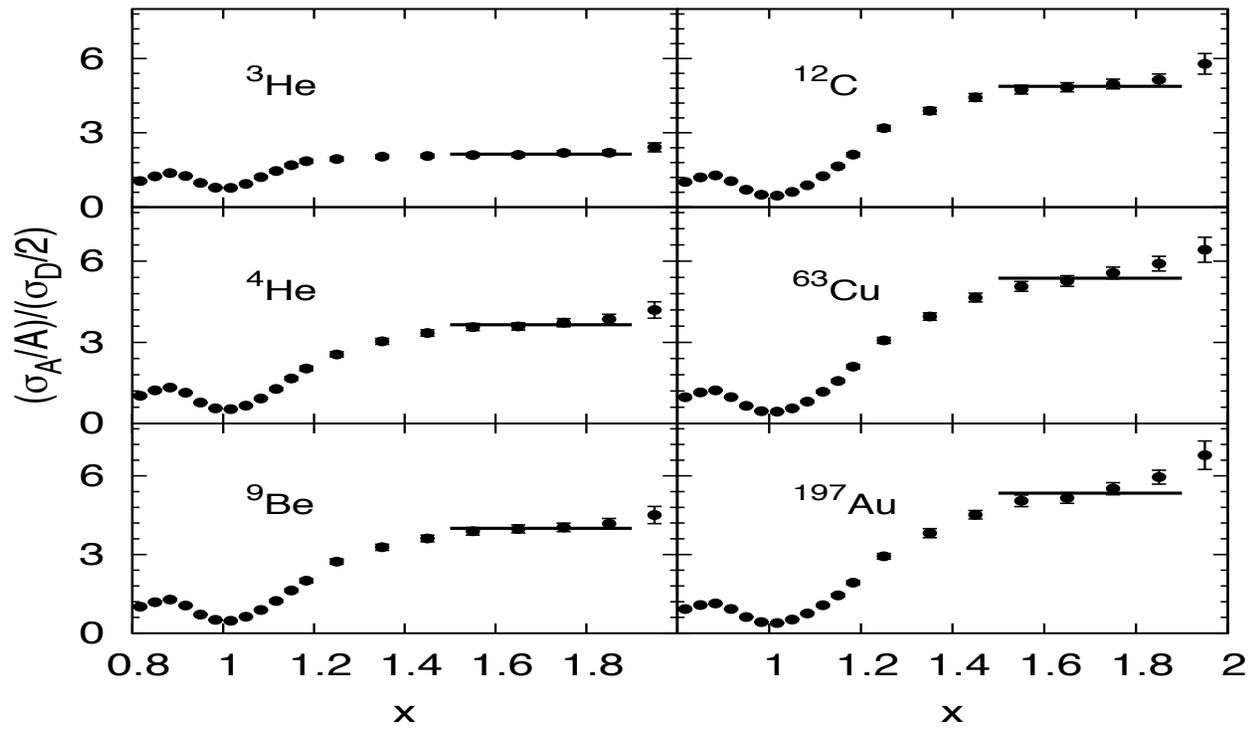
$A(e, e')$



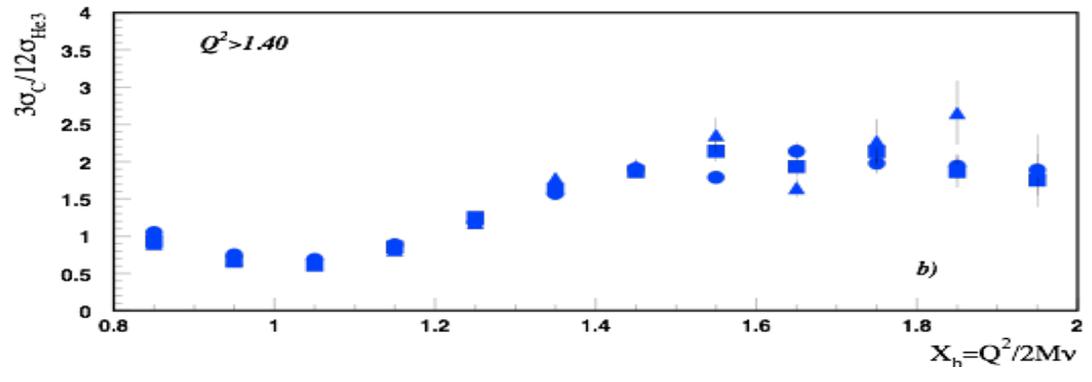
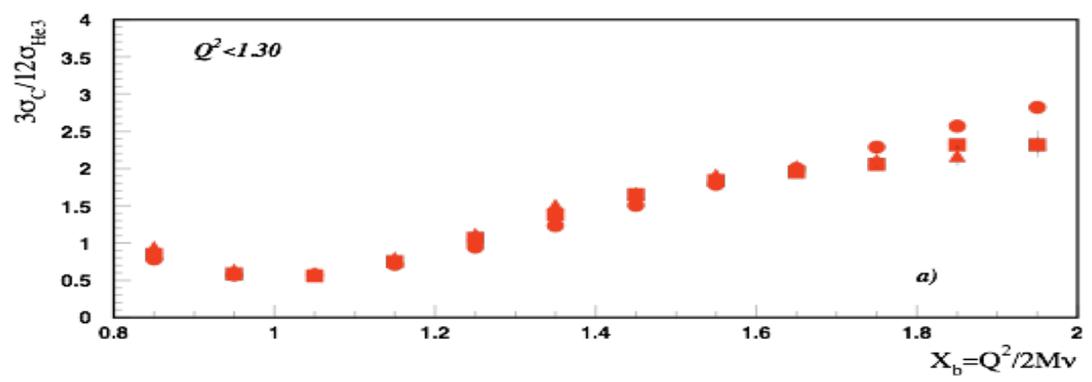
Day, Frankfurt, MS,
Strikman, PRC 1993

$A(e,e')$





$A(e,e')$



Meaning of the scaling values

Day, Frankfurt, MS,
Strikman, PRC 1993

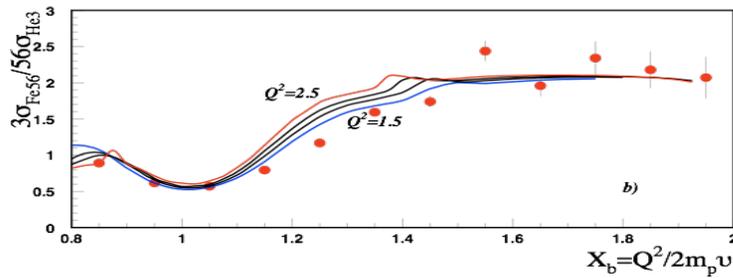
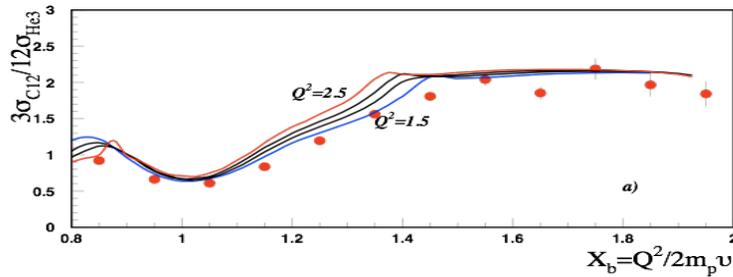
Frankfurt, MS, Strikman,
IJMP A 2008

Fomin et al PRL 2011

$$R = \frac{A_2 \sigma[A_1(e, e')X]}{A_1 \sigma[A_2(e, e')X]}$$

For $1 < x < 2$ $R \approx \frac{a_2(A_1)}{a_2(A_2)}$

$A(e, e')$



Egiyan, et al PRL 2006, PRC 2004

a2's as relative probability of 2N SRCs

Table 1: The results for $a_2(A, y)$

A	y	This Work	Frankfurt et al	Egiyan et al	Famin et al
^3He	0.33	2.07 ± 0.08	1.7 ± 0.3		2.13 ± 0.04
^4He	0	3.51 ± 0.03	3.3 ± 0.5	3.38 ± 0.2	3.60 ± 0.10
^9Be	0.11	3.92 ± 0.03			3.91 ± 0.12
^{12}C	0	4.19 ± 0.02	5.0 ± 0.5	4.32 ± 0.4	4.75 ± 0.16
^{27}Al	0.037	4.50 ± 0.12	5.3 ± 0.6		
^{56}Fe	0.071	4.95 ± 0.07	5.6 ± 0.9	4.99 ± 0.5	
^{64}Cu	0.094	5.02 ± 0.04			5.21 ± 0.20
^{197}Au	0.198	4.56 ± 0.03	4.8 ± 0.7		5.16 ± 0.22

2. Dominance of the (pn) component of SRC

for large $k > k_{Fermi}$

$$n_A(k) \approx a_{NN}(A)n_{NN}(k)$$

$$P_{pn/pX} = 0.92^{+0.08}_{-0.18}$$

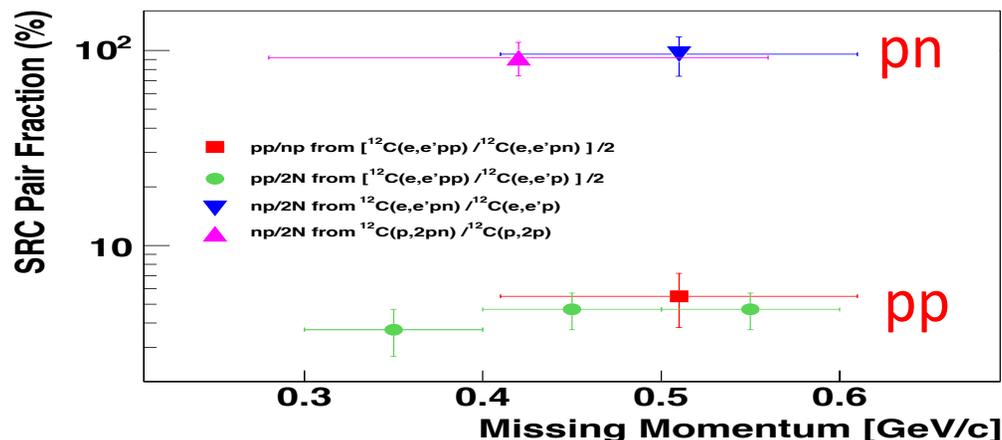
Theoretical analysis of BNL Data $A(p, 2p)X$ reaction

$$\frac{P_{pp}}{P_{pn}} \leq \frac{1}{2}(1 - P_{pn/pX}) = 0.04^{+0.09}_{-0.04}$$

E. Piasetzky, MS, L. Frankfurt,
M. Strikman, J. Watson PRL, 2006

$$P_{pp/pn} = 0.056 \pm 0.018$$

Direct Measurement at JLab R.Subedi, et al Science, 2008



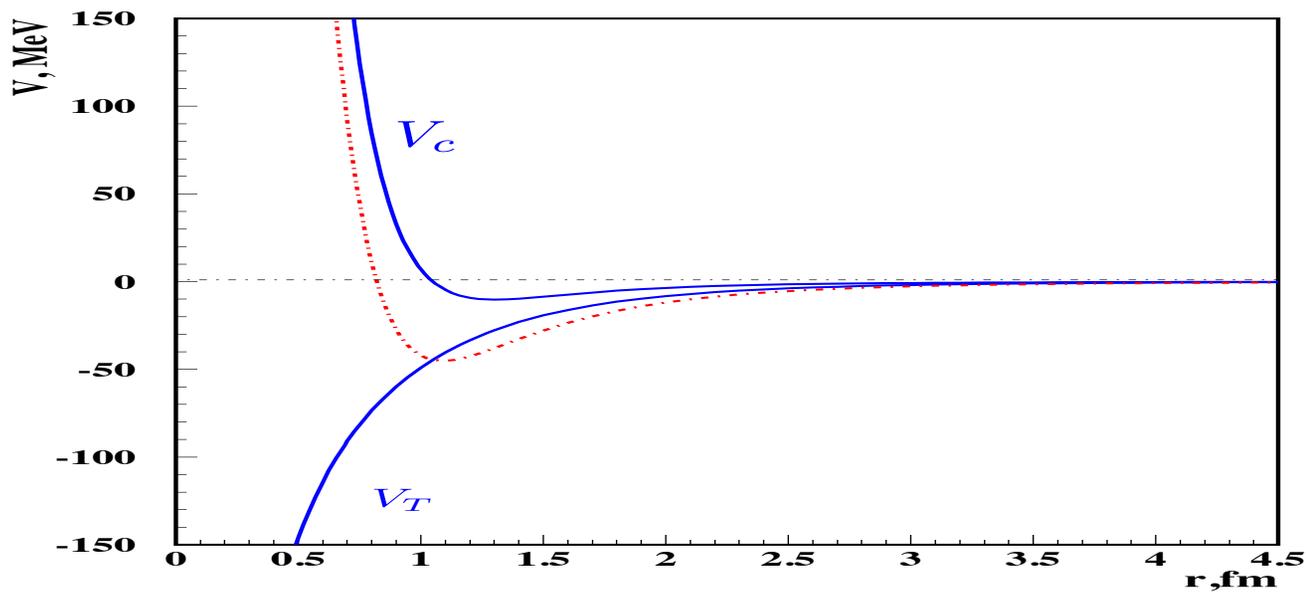
Factor of 20

Expected 4
(Wigner counting)

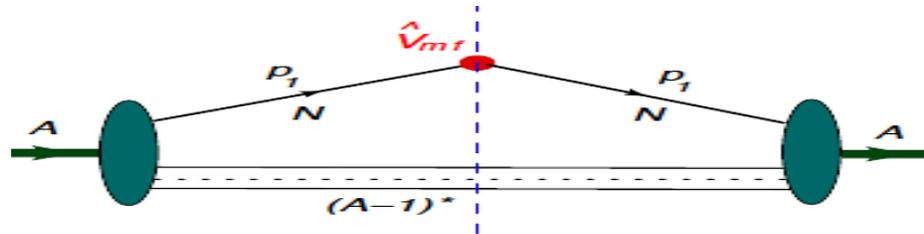
Theoretical Interpretation

$$\phi_A^{(1)}(k_1, \dots, k_i = p, \dots, k_j \approx -p, \dots, k_A) \sim \frac{V_{NN}(p)}{p^2} f(k_1, \dots, \dots)$$

$$n_A(k) \approx a_{NN}(A) n_{NN}(k)$$



Spectral Function Calculations



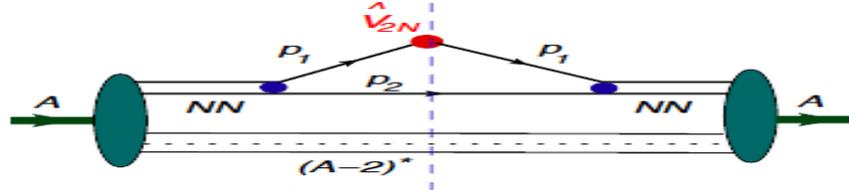
$$S_A^{MF} = -Im \int \chi_A^\dagger \Gamma_{A,N,A-1}^\dagger \frac{p_1 + m}{p_1^2 - m^2 + i\varepsilon} \hat{V}^{MF} \frac{p_1 + m}{p_1^2 - m^2 + i \times \varepsilon} \left[\frac{G_{A-1}(p_{A-1})}{p_{A-1}^2 - M_{A-1}^2 + i\varepsilon} \right]^{on} \Gamma_{A,N,A-1} \chi_A \frac{d^4 p_{A-1}}{i(2\pi)^4}$$

$$\hat{V}^{MF} = ia^\dagger(p_1, s_1) \delta^3(p_1 + p_{A-1}) \delta(E_m - E_\alpha) a(p_1, s_1)$$

$$\psi_{N/A}(p_1, s_1, s_A, E_\alpha) = \frac{\bar{u}(p_1, s_1) \Psi_{A-1}^\dagger(p_{A-1}, s_{A-1}, E_\alpha) \Gamma_{A,N,A-1} \chi_A}{(M_{A-1}^2 - p_{A-1}^2) \sqrt{(2\pi)^3 2E_{A-1}}}$$

$$S_A^{MF}(p_1, E_m) = \sum_{\alpha} \sum_{s_1, s_{A-1}} |\psi_{N/A}(p_1, s_1, s_A, E_\alpha)|^2 \delta(E_m - E_\alpha)$$

2N SRC model



$$\begin{aligned}
 P_{A,2N}^N(\alpha_1, p_{1,\perp}, \tilde{M}_N^2) &= \sum_{s_2, s_{NN}, s_{A-2}} \int \chi_A^\dagger \Gamma_{A \rightarrow NN, A-2}^\dagger \chi_{A-2}(p_{A-2}, s_{A-2}) \\
 &\times \frac{\chi_{NN}(p_{NN}, s_{NN}) \chi_{NN}^\dagger(p_{NN}, s_{NN})}{p_{NN}^2 - M_{NN}^2} \Gamma_{NN \rightarrow NN}^\dagger \frac{u(p_1, s_1) u(p_2, s_2)}{p_1^2 - M_N^2} \\
 &\times \left[2\alpha_1^2 \delta(\alpha_1 + \alpha_2 + \alpha_{A-2} - A) \delta^2(p_{1,\perp} + p_{2,\perp} + p_{A-2,\perp}) \delta(\tilde{M}_N^2 - \tilde{M}_N^{(2N),2}) \right] \frac{\bar{u}(p_1, s_1) \bar{u}(p_2, s_2)}{p_1^2 - M_N^2} \\
 &\times \Gamma_{NN \rightarrow NN} \frac{\chi_{NN}(p_{NN}, s_{NN}) \chi_{NN}^\dagger(p_{NN}, s_{NN})}{p_{NN}^2 - M_{NN}^2} \chi_{A-2}^\dagger(p_{A-2}, s_{A-2}) \Gamma_{A, NN, A-2} \chi_A \\
 &\times \frac{d\alpha_2}{\alpha_2} \frac{d^2 p_{2,\perp}}{2(2\pi)^3} \frac{d\alpha_{A-2}}{\alpha_{A-2}} \frac{d^2 p_{A-2,\perp}}{2(2\pi)^3}.
 \end{aligned} \tag{1}$$

O. Artiles & M.S. Phys. Rev. C 2016

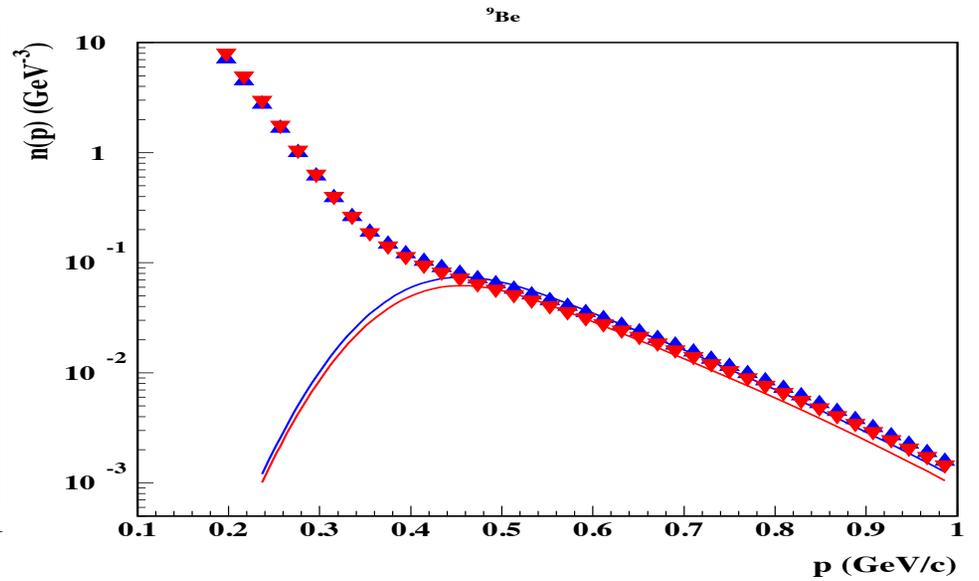
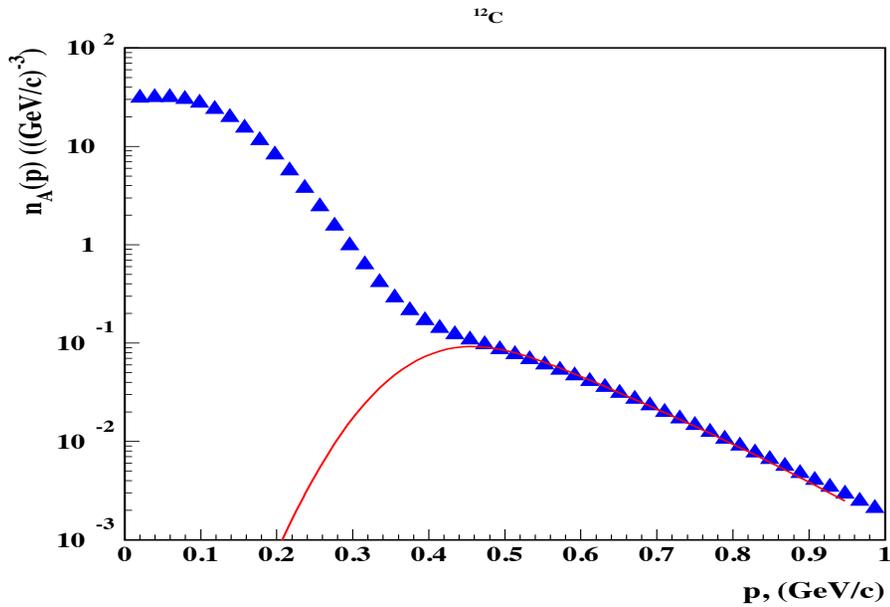
$$\rho_A(\alpha_N, p_{N,\perp}) = \int P_A(\alpha_N, p_{N,\perp}, \tilde{M}_N^2) \frac{1}{2} d\tilde{M}_N^2$$

$$\psi_{pn}^{LF}(\alpha, p_\perp) \approx C \psi_d^{LF}(\alpha, p_\perp)$$

$$\psi_{2N}^{s_{NN}}(\beta_1, k_{1,\perp}, s_1, s_2) = -\frac{1}{\sqrt{2(2\pi)^3}} \frac{\bar{u}(p_1, s_1) \bar{u}(p_2, s_2) \Gamma_{NN \rightarrow NN} \cdot \chi_{NN}(p_{NN}, s_{NN})}{\frac{1}{2} [M_{NN}^2 - 4(M_N^2 + k_1^2)]}$$

$$\psi_{CM}(\alpha_{NN}, k_{NN,\perp}) = -\frac{1}{\sqrt{\frac{A-2}{2}}} \frac{1}{\sqrt{2(2\pi)^3}} \frac{\chi_{NN}^\dagger(p_{NN}, s_{NN}) \chi_{A-2}^\dagger(p_{A-2}, s_{A-2}) \Gamma_{A \rightarrow NN, A-2} \chi_A^{s_A}}{\frac{2}{A} [M_A^2 - s_{NN, A-2}(k_{CM})]}$$

2N SRC model Non Relativistic Approximation



2N SRCs:

Proper Variables of 2N SRC are

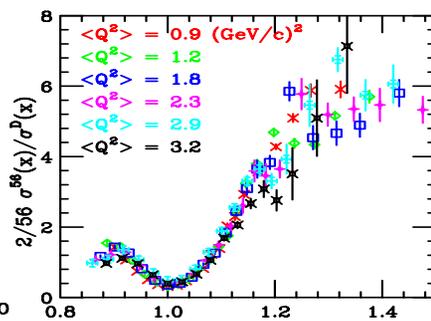
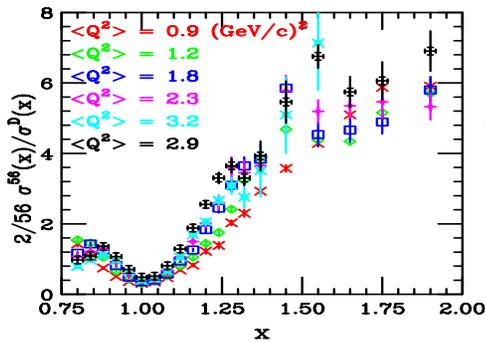
- the Light Front Momentum Fraction: $\alpha = \frac{p_N^+}{p_{NN}^+}$
- transverse momentum: p_{\perp}

Back to inclusive $A(e,e')X$ scattering

$$\sigma_{eA} = \sum \sigma_{eN} \cdot \rho_A(\alpha) \quad \text{where} \quad \rho_A(\alpha) = \int \rho_A(\alpha, p_{\perp}) d^2 p_{\perp}$$

$$1.3 \leq \alpha_{2N} \leq 1.5$$

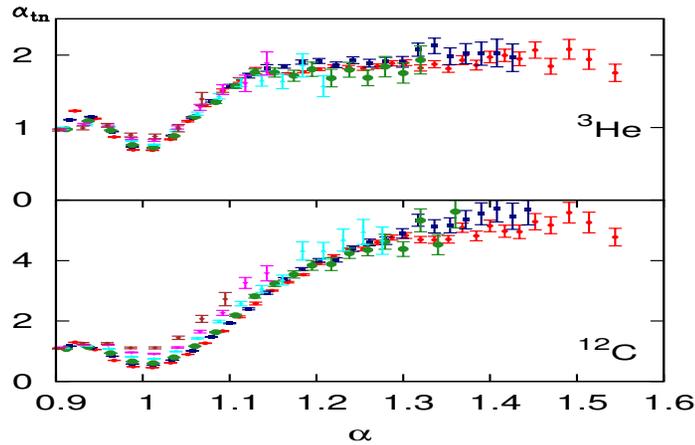
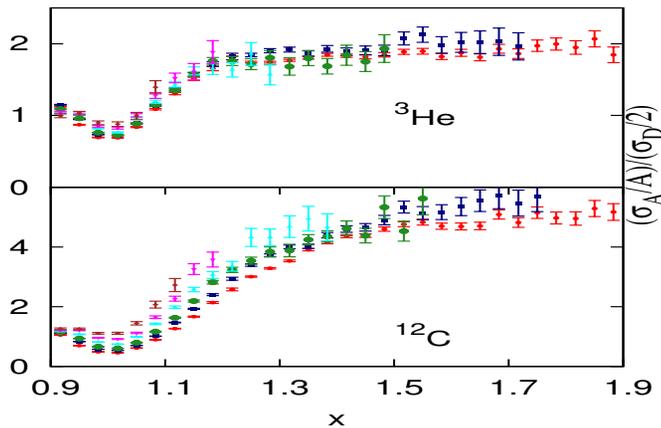
$$\alpha_{2N} = 2 - \frac{q_{-} + 2m_N}{2m_N} \left(1 + \frac{\sqrt{W_{2N}^2 - 4m_N^2}}{W_{2N}} \right)$$



$$\alpha \mid Q^2 \rightarrow \infty \rightarrow x$$

$$\alpha \mid x \rightarrow 1 \rightarrow 1$$

J.Arrington, D.Higinbotham
G.Rosner, M.S. Prog. PNP 2012

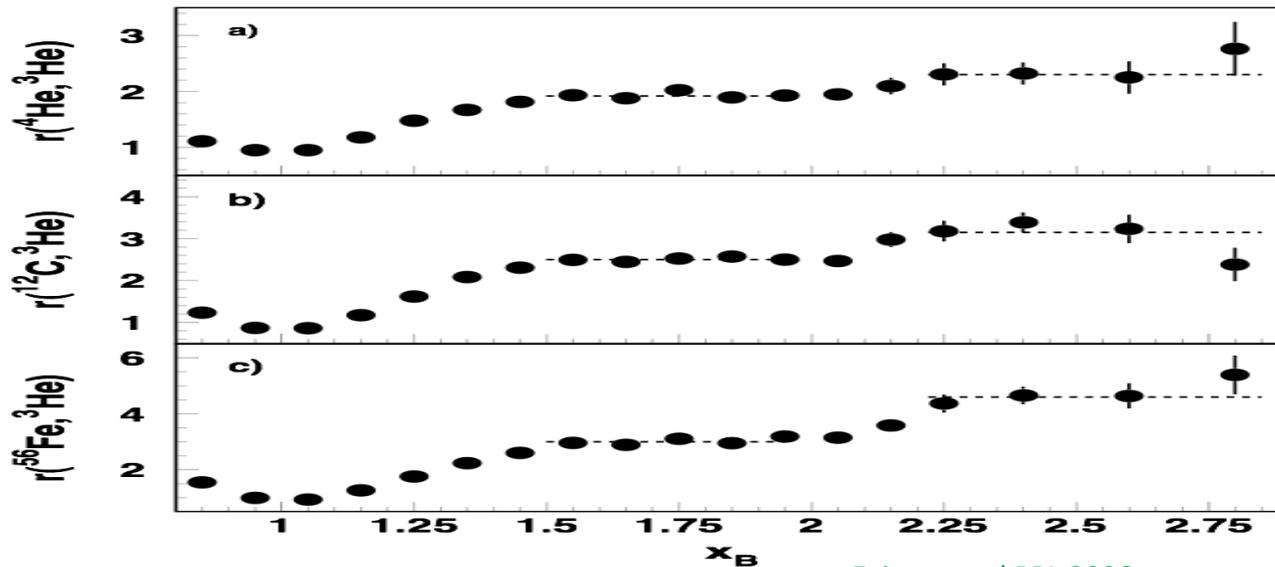


N.Fomin, D.Higinbotham
M.S., P.Sovignon ARNPS, 2017

Towards Three Nucleon Short Range Correlations

Looking for the Plateau in Inclusive Cross Section Ratios $x > 2$

For $1 < x < 2$ $R \approx \frac{a_2(A_1)}{a_2(A_2)}$ For $2 < x < 3$ $R \approx \frac{a_3(A_1)}{a_3(A_2)}$

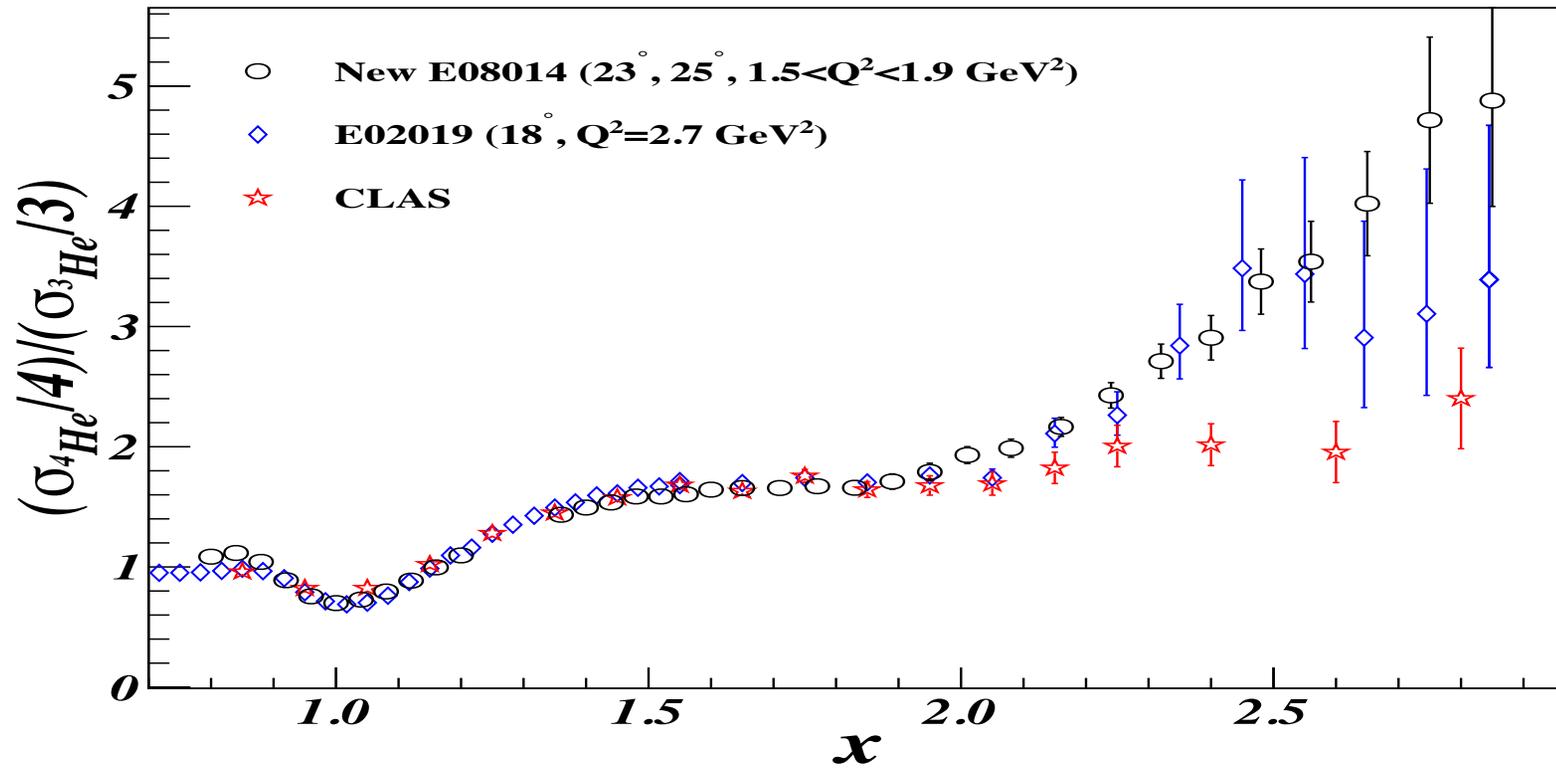


Egiyan, et al PRL 2006

Three Nucleon Short Range Correlations

Z. Ye, et al, 2017

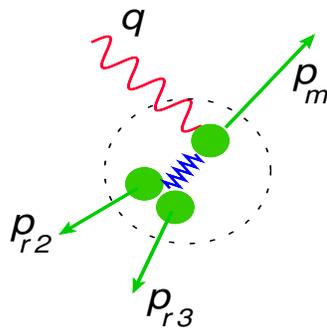
Looking for the Plateau in Inclusive Cross Section Ratios $x > 2$



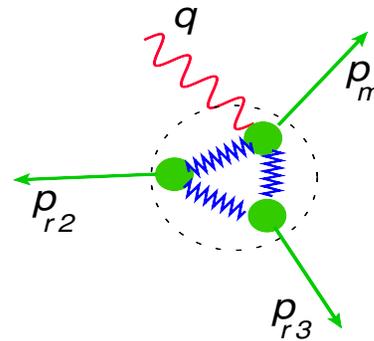
3N SRCs:

Proper Variables of 3N SRC are

- the Light Front Momentum Fraction: $\alpha = \frac{p_N^+}{p_{3N}^+}$
- transverse momentum: p_{\perp}



(a)

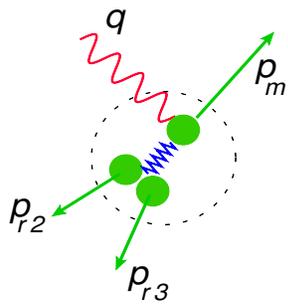


(b)

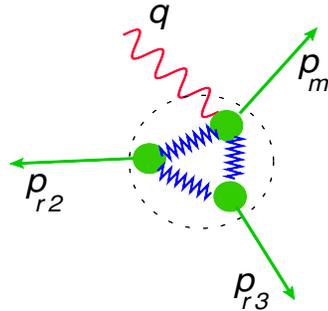
3N SRCs in Inclusive $A(e,e')X$ Reactions

Day, Frankfurt, M.S. Strikman, ArXiv 2018

$$\sigma_{eA} = \sum \sigma_{eN} \cdot \rho_A(\alpha) \quad \text{where} \quad \rho_A(\alpha) = \int \rho_A(\alpha, p_{\perp}) d^2 p_{\perp}$$

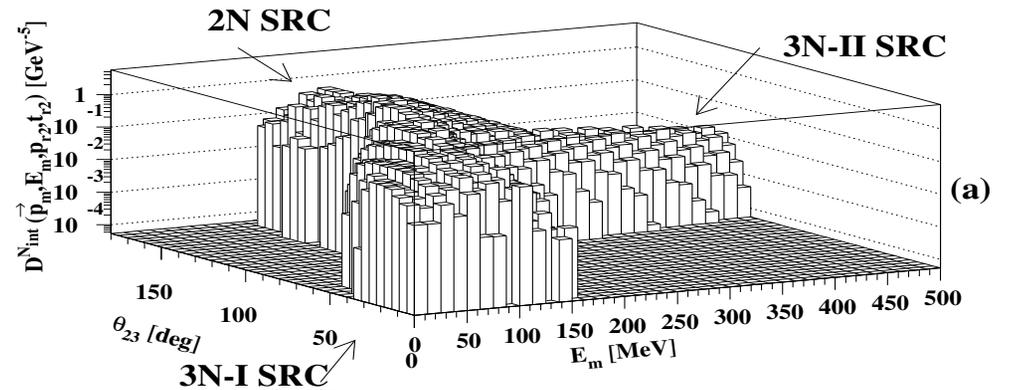


(a)

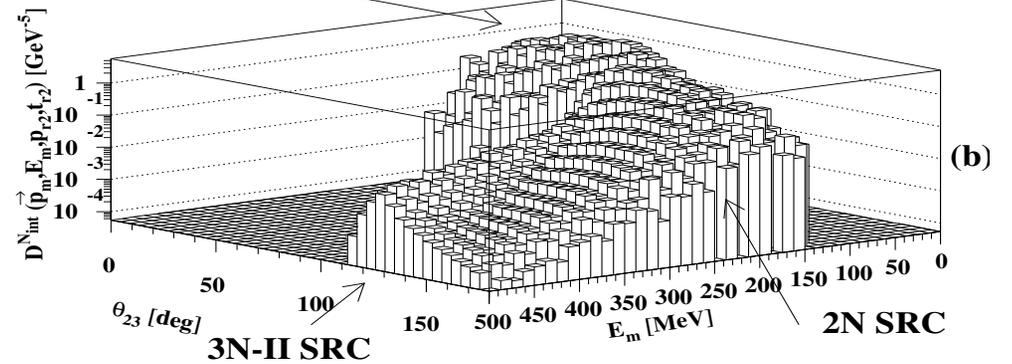


(b)

M.S. Abrahamyan, Frankfurt,
Strikman, Phys. Rev. C 2005



(a)



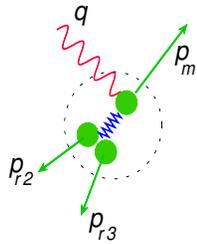
(b)

3N SRC model $\sigma_{eA} = \sum \sigma_{eN} \cdot \rho_A(\alpha)$ where $\rho_A(\alpha) = \int \rho_A(\alpha, p_{\perp}) d^2 p_{\perp}$

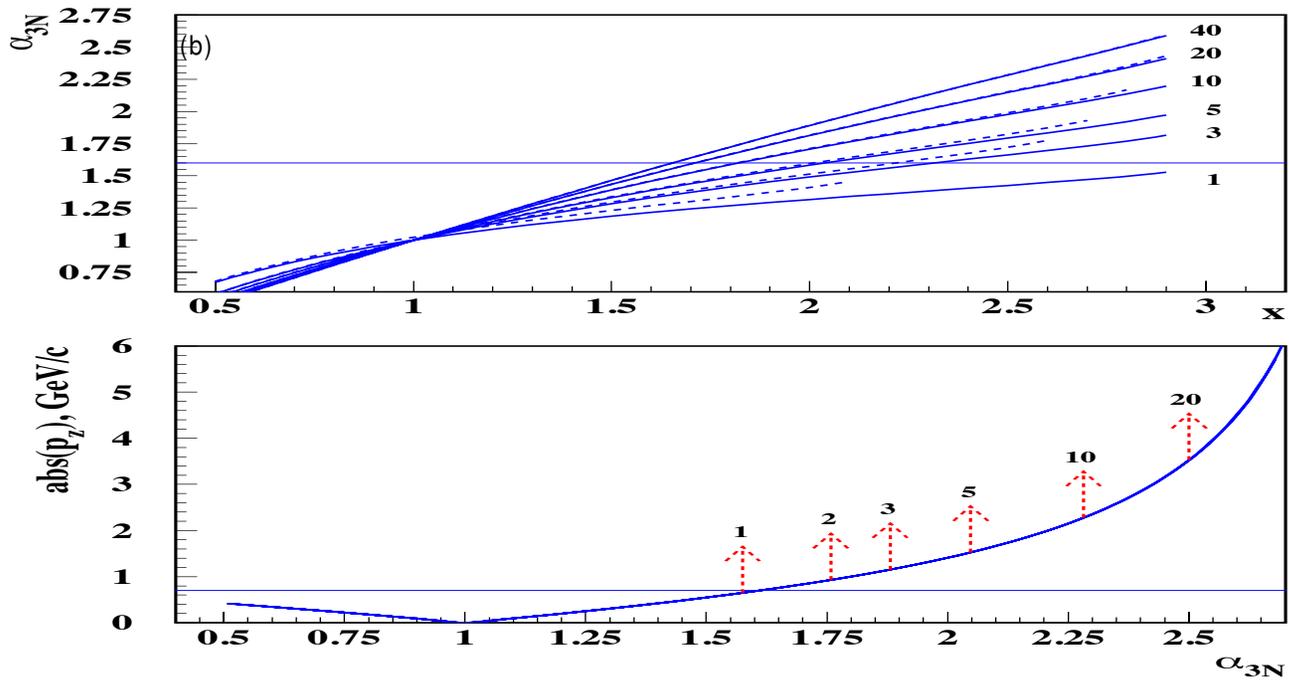
$$1.6 \leq \alpha_{3N} < 3$$

$$q + 3m_N = p_f + p_s$$

$$\alpha_{3N} = 3 - \frac{q_{-} + 3m_N}{2m_N} \left[1 + \frac{m_S^2 - m_N^2}{W_{3N}^2} + \sqrt{\left(1 - \frac{(m_S + m_n)^2}{W_{3N}^2}\right) \left(1 - \frac{(m_S - m_n)^2}{W_{3N}^2}\right)} \right]$$



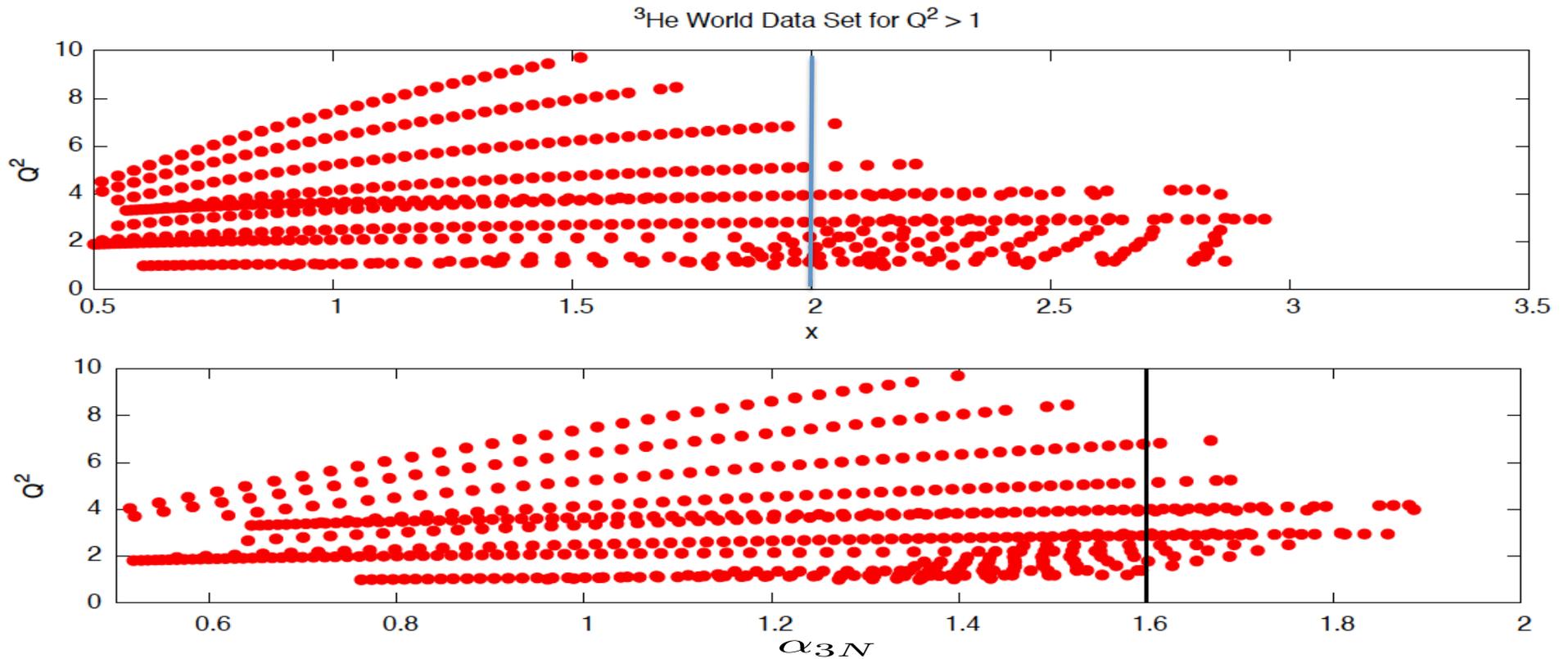
(a)



3N SRC model $\sigma_{eA} = \sum \sigma_{eN} \cdot \rho_A(\alpha)$ where $\rho_A(\alpha) = \int \rho_A(\alpha, p_{\perp}) d^2 p_{\perp}$

$$1.6 \leq \alpha_{3N} < 3$$

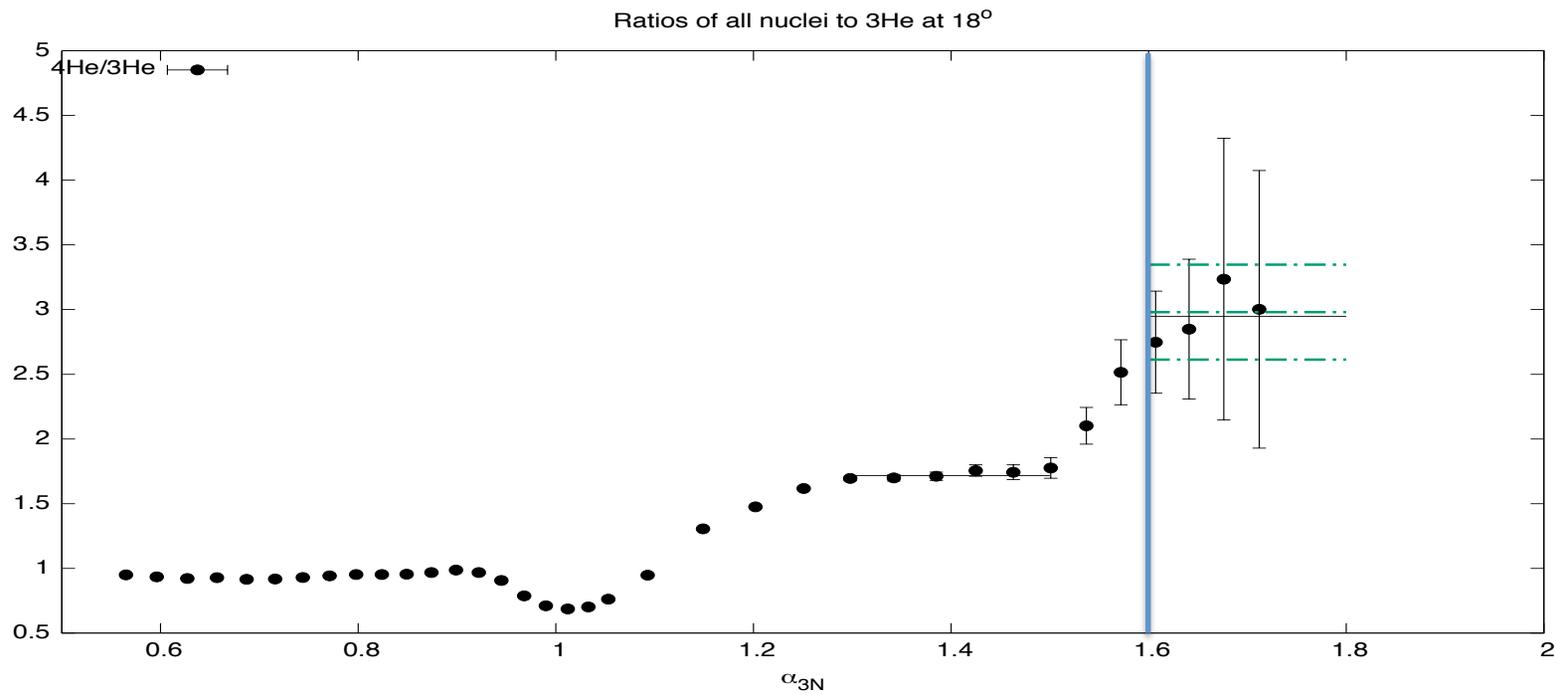
Donal Day, 2018



3N SRCs

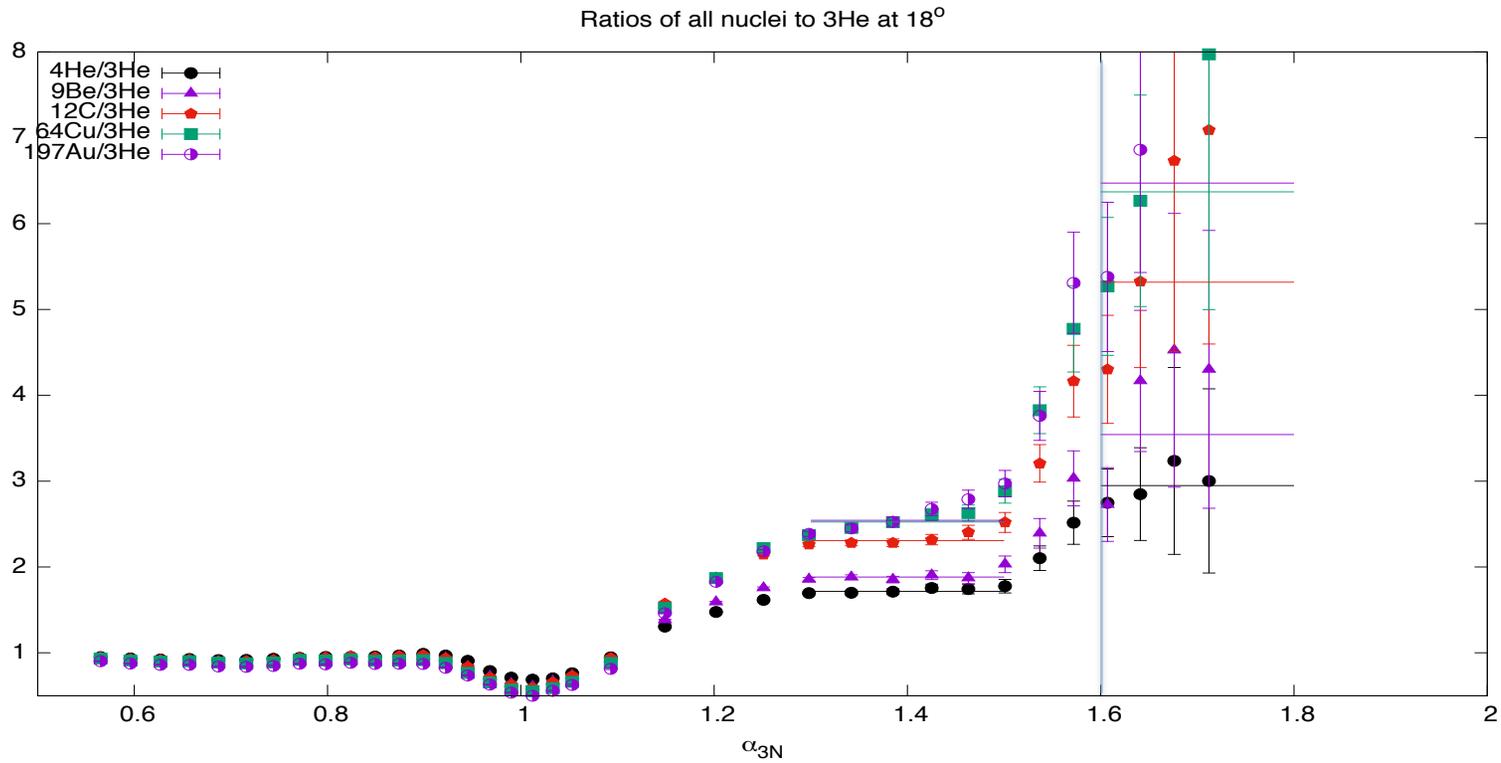
$$\sigma_{eA} = \sum \sigma_{eN} \cdot \rho_A(\alpha) \quad \text{where} \quad \rho_A(\alpha) = \int \rho_A(\alpha, p_{\perp}) d^2 p_{\perp}$$

$$1.6 \leq \alpha_{3N} < 3$$



JLab - E02019 - Data

3N SRC model $\sigma_{eA} = \sum \sigma_{eN} \cdot \rho_A(\alpha)$ where $\rho_A(\alpha) = \int \rho_A(\alpha, p_{\perp}) d^2 p_{\perp}$
 $1.6 \leq \alpha_{3N} < 3$

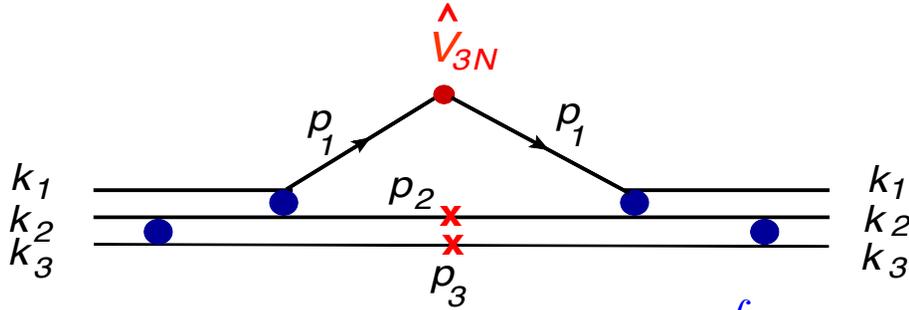


JLab - E02019 - Data

3N SRC: Light-Cone Momentum Fraction Distribution

A.Freese, M.S., M.Strikman, Eur. Phys. J 2015

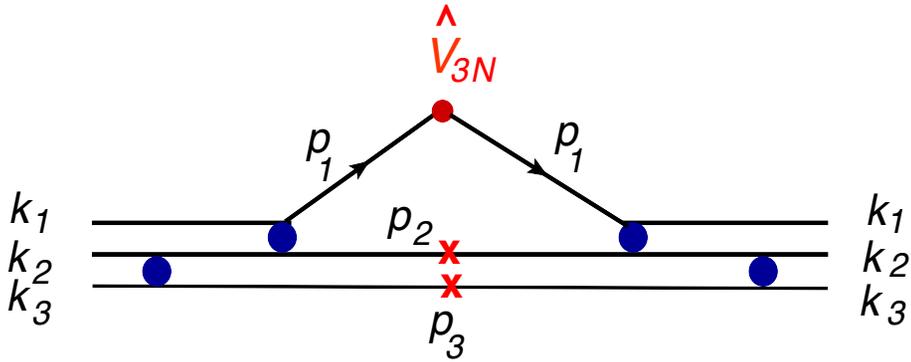
O. Artiles M.S. Phys. Rev. C 2016



$$\begin{aligned}
 P_{A,3N}^N(\alpha_1, p_{1,\perp}, s_1, \tilde{M}_N) &= \sum_{s_2, s_3, s_{2'}, \tilde{s}_{2'}} \int \bar{u}(k_1) \bar{u}(k_2) \bar{u}(k_3) \Gamma_{NN \rightarrow NN}^\dagger \frac{u(p_{2'}, \tilde{s}_{2'}) \bar{u}(p_{2'}, \tilde{s}_{2'})}{p_{2'}^2 - M_N^2} \\
 &\times \Gamma_{NN \rightarrow NN}^\dagger \frac{u(p_1, s_1)}{p_1^2 - M_N^2} u(p_2, s_2) \left[2\alpha_1^2 \delta(\alpha_1 + \alpha_2 + \alpha_3 - 3) \delta^2(p_{1\perp} + p_{2\perp} + p_{3\perp}) \delta(\tilde{M}_N^2 - M_N^{3N,2}) \right] \\
 &\times \bar{u}(p_2, s_2) \frac{\bar{u}(p_1, s_1)}{p_1^2 - M_N^2} \Gamma_{NN \rightarrow NN} \frac{u(p_{2'}, s_{2'}) \bar{u}(p_{2'}, s_{2'})}{p_{2'}^2 - M_N^2} u(p_3, s_3) \bar{u}(p_3, s_3) \Gamma_{NN \rightarrow NN}^\dagger u(k_1) u(k_2) u(k_3) \\
 &\times \frac{d\alpha_2}{\alpha_2} \frac{d^2 p_{2\perp}}{2(2\pi)^3} \frac{d\alpha_3}{\alpha_3} \frac{d^2 p_{3\perp}}{2(2\pi)^3}, \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 P_{A,3N}^N(\alpha_1, p_{1,\perp}, \tilde{M}_N) &= \int \frac{3 - \alpha_3}{2(2 - \alpha_3)^2} \boxed{\rho_{NN}(\beta_3, p_{3\perp}) \rho_{NN}(\beta_1, \tilde{k}_{1\perp})} 2\delta(\alpha_1 + \alpha_2 + \alpha_3 - 3) \\
 &\delta^2(p_{1\perp} + p_{2\perp} + p_{3\perp}) \delta(\tilde{M}_N^2 - M_N^{3N,2}) d\alpha_2 d^2 p_{2\perp} d\alpha_3 d^2 p_{3\perp}, \quad (1)
 \end{aligned}$$

3N SRC: Light-Cone Momentum Fraction Distribution

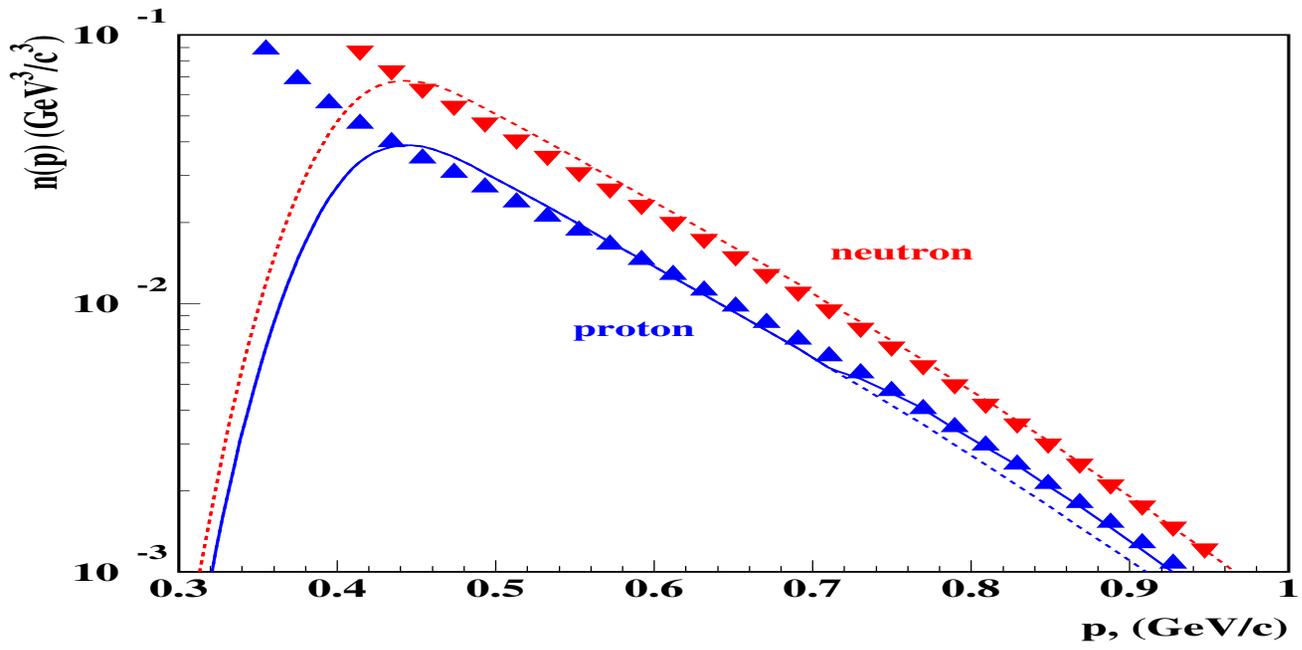
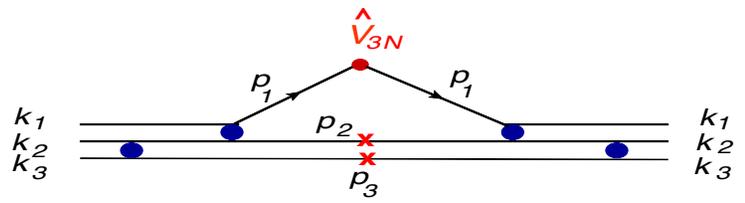


$$\rho_{3N}(\alpha_1) = \int \frac{1}{4} \left[\frac{3 - \alpha_3}{(2 - \alpha_3)^3} \rho_{pn}(\alpha_3, p_{3\perp}) \rho_{pn} \left(\frac{2\alpha_2}{3 - \alpha_3}, p_{2\perp} + \frac{\alpha_1}{3 - \alpha_3} p_{3\perp} \right) + \frac{3 - \alpha_2}{(2 - \alpha_2)^3} \rho_{pn}(\alpha_2, p_{2\perp}) \rho_{pn} \left(\frac{2\alpha_3}{3 - \alpha_2}, p_{3\perp} + \frac{\alpha_1}{3 - \alpha_2} p_{2\perp} \right) \right] \delta \left(\sum_{i=1}^3 \alpha_i - 3 \right) d\alpha_2 d^2 p_{2\perp} d\alpha_3 d^2 p_{3\perp}, \quad (1)$$

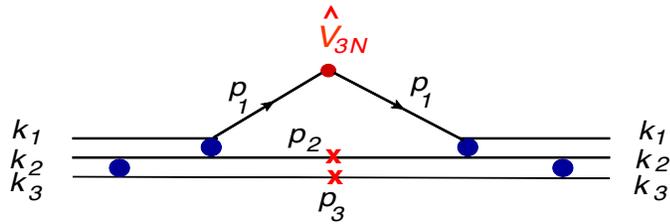
$$\rho_{pn}(\alpha, p_{\perp}) \approx a_2(A) \rho_d(\alpha, p_{\perp})$$

3N SRC: Light-Cone Momentum Fraction Distribution

O. Artiles M.S. Phys. Rev. C 2016



3N SRC: Light-Cone Momentum Fraction Distribution



$$-\rho_{3N} \sim a_2(A, z)^2$$

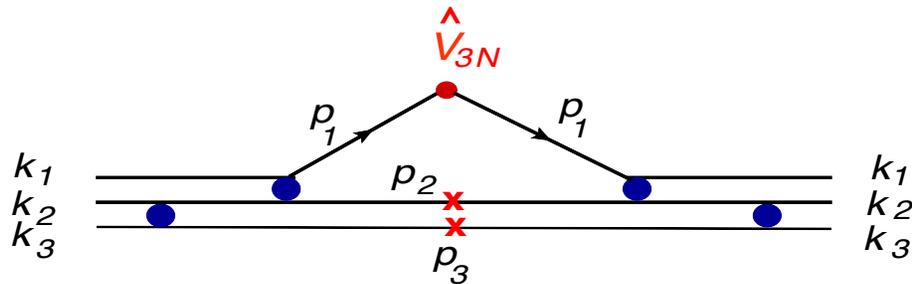
- For $A(e, e')$ X reactions: $\sigma_{eA} = \sum_N \sigma_{eN} \rho_{3N}(\alpha_{3N})$

- Defining: $R_3(A, Z) = \frac{3\sigma_{eA}}{A\sigma_{e^3He}} \Big|_{\alpha_{3N} \geq \alpha_{3N}^0}$

- We predict: $R_3(A, Z) = \frac{9}{8} \frac{(\sigma_{ep} + \sigma_{en})/2}{(2\sigma_{ep} + \sigma_{en})/3} \left(\frac{a_2(A, Z)}{a_2(^3He)} \right)^2 = \frac{9}{8} \frac{(\sigma_{ep} + \sigma_{en})/2}{(2\sigma_{ep} + \sigma_{en})/3} R_2^2(A, Z),$

- Where: $R_2(A, Z) = \frac{3\sigma_{eA}}{A\sigma_{e^3He}} \Big|_{1.3 \leq \alpha_{3N} \leq 1.5}$ where: $\alpha_{3N} \approx \alpha_{2N}$

3N SRC: Light-Cone Momentum Fraction Distribution



- $\rho_{3N} \sim a_2(A, z)^2$
- ppp and nnn strongly suppressed compared with ppn or pnn
- pp/nn recoil state is suppressed compared with pn

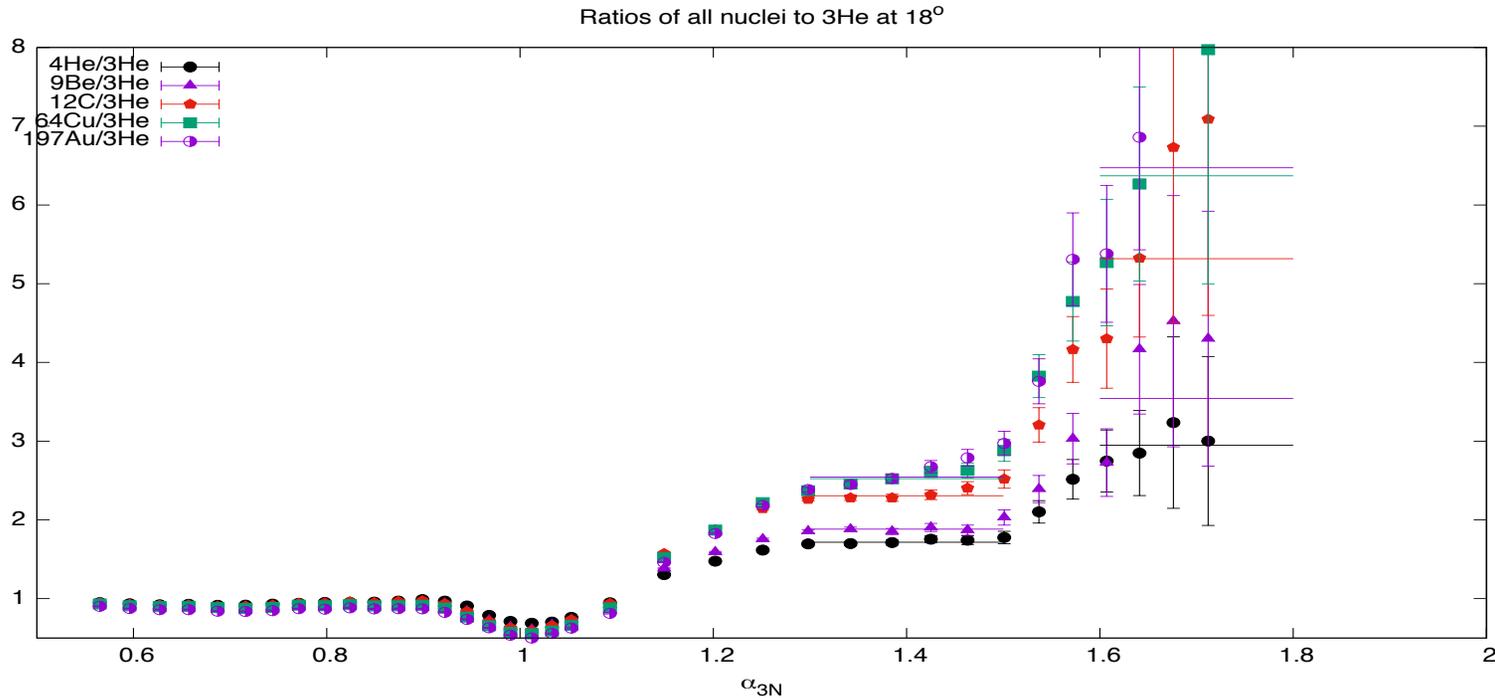
$$R_3(A, Z) = \frac{9}{8} \frac{(\sigma_{ep} + \sigma_{en})/2}{(2\sigma_{ep} + \sigma_{en})/3} \left(\frac{a_2(A, Z)}{a_2(^3He)} \right)^2 = \frac{9}{8} \frac{(\sigma_{ep} + \sigma_{en})/2}{(2\sigma_{ep} + \sigma_{en})/3} R_2^2(A, Z),$$

3N SRC model

$$R_2 = \frac{3\sigma_{eA}(\alpha_{3N})}{A\sigma_{3A}(\alpha_{3N})} \quad 1.3 \leq \alpha_{3N} \leq 1.5 \quad 1.6 \leq \alpha_{3N} < 3$$

$$R_3 = \frac{3\sigma_{eA}(\alpha_{3N})}{A\sigma_{3A}(\alpha_{3N})} \quad 1.6 \leq \alpha_{3N} \leq 1.8$$

$$R_3(A, Z) \approx R_2(A, Z)^2$$



3N SRC model

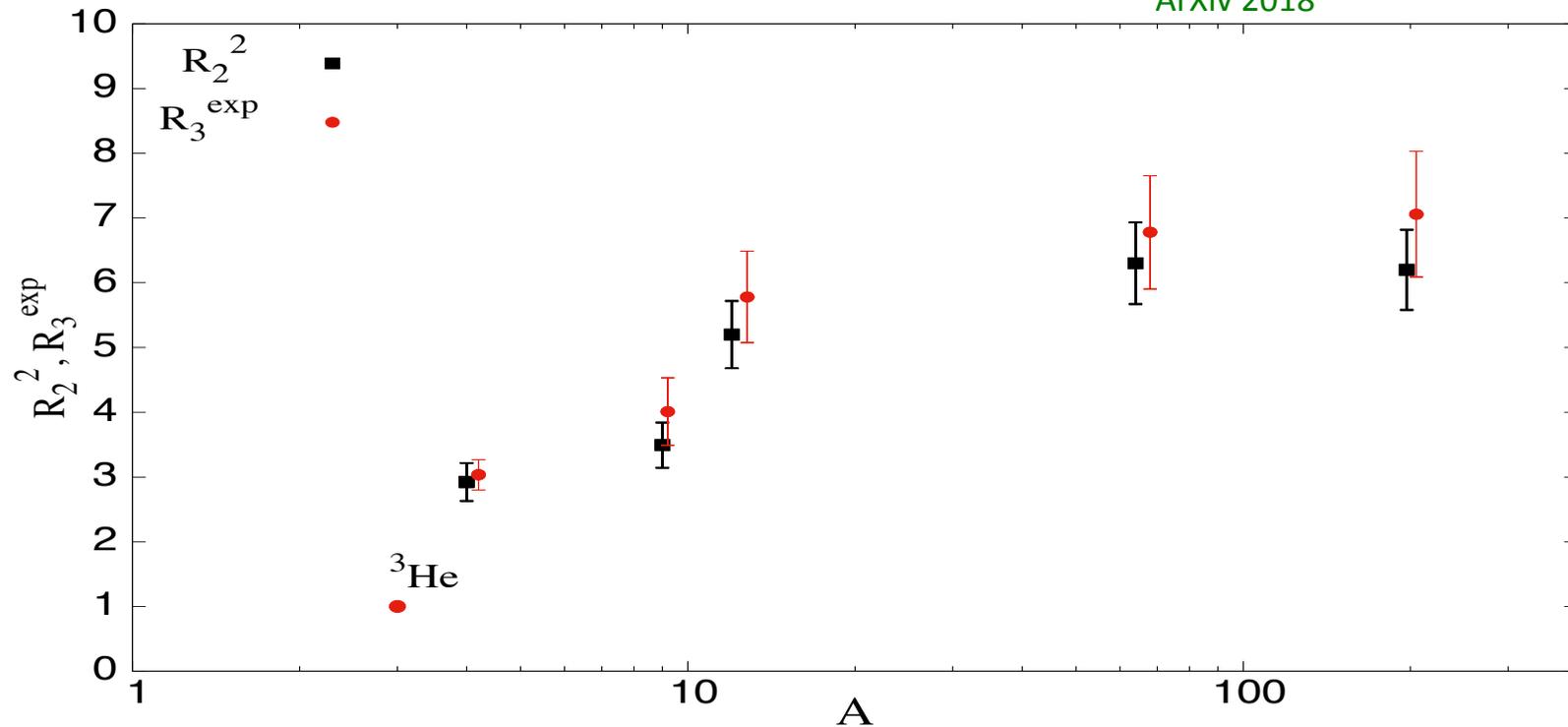
$$R_2 = \frac{3\sigma_{eA}(\alpha_{3N})}{A\sigma_{3A}(\alpha_{3N})} \quad 1.3 \leq \alpha_{3N} \leq 1.5$$

$$1.6 \leq \alpha_{3N} < 3$$

$$R_3 = \frac{3\sigma_{eA}(\alpha_{3N})}{A\sigma_{3A}(\alpha_{3N})} \quad 1.6 \leq \alpha_{3N} \leq 1.8$$

$$R_3(A) = R_2(A)^2$$

D.Day, L.Frankfurt, M.S, M.Strikman
ArXiv 2018



3N SRC model

Defining: $a_3(A, Z) = \frac{3}{A} \frac{\sigma_{eA}}{(\sigma_{e3He} + \sigma_{e3H})/2}$

One relates: $a_3(A, Z) = \frac{(2\sigma_{ep} + \sigma_{en})/3}{(\sigma_{ep} + \sigma_{en})/2} R_3(A, Z)$

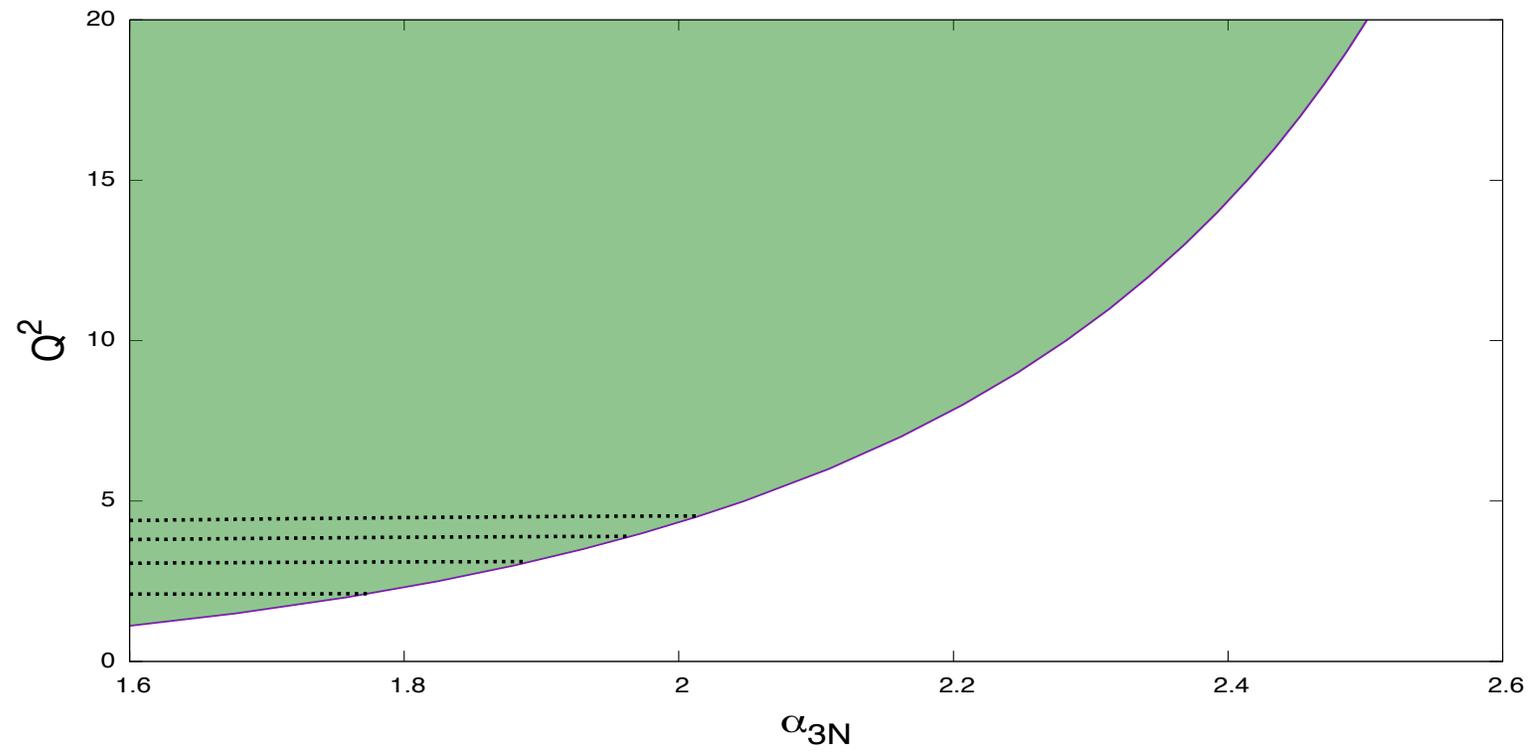
A	a_2	R_2	R_2^{exp}	R_2^2	R_3^{exp}	a_3
3	2.14 ± 0.04	NA	NA	NA	NA	1
4	3.66 ± 0.07	1.71 ± 0.026	1.722 ± 0.013	2.924 ± 0.29	3.034 ± 0.23	4.55 ± 0.35
9	4.00 ± 0.08	1.84 ± 0.027	1.878 ± 0.018	3.38 ± 0.38	4.01 ± 0.52	6.0 ± 0.78
12	4.88 ± 0.10	2.28 ± 0.027	2.301 ± 0.021	5.2 ± 0.5	5.78 ± 0.71	8.7 ± 1.1
27	5.30 ± 0.60	NA	NA	NA	NA	NA
56	4.75 ± 0.29	NA	NA	NA	NA	NA
64	5.37 ± 0.11	2.51 ± 0.027	2.502 ± 0.024	6.3 ± 0.63	6.780 ± 0.875	10.2 ± 1.3
197	5.34 ± 0.11	2.46 ± 0.028	2.532 ± 0.026	6.05 ± 0.6	7.059 ± 0.970	10.6 ± 1.5

D.Day, L.Frankfurt,M.S, M.Strikman
ArXiv 2018

3N SRC Summary & Outlook

- Proper variable for studies of 2N and 3N SRS are Light-Cone momentum fractions: α_{2N}, α_{3N}
- It seems we observed first signatures of 3N SRCs in the form of the “scaling”
- Existing data in agreement with the prediction of: $R_3(A, Z) \approx R_2(A, Z)^2$
- Unambiguous verification will require larger Q^2 data to cover larger α_{3N} region
- Reaching $Q^2 > 5 \text{ GeV}^2$ will allow to reach: $\alpha_{3N} > 2$

3N SRC Outlook



II. Probing SuperFast Quarks in Nuclei

Studies of nuclear partonic distributions at $x > 1$

Bjorken $x = \frac{Q^2}{2m_N \nu}$

- $x > 1$ requires a momentum transfer from the nearby nucleon or the quark from the nearby nucleon.
- $x > 1$ "super-fast quarks"

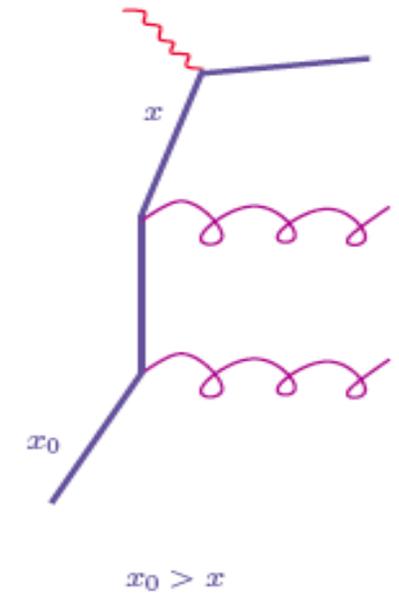
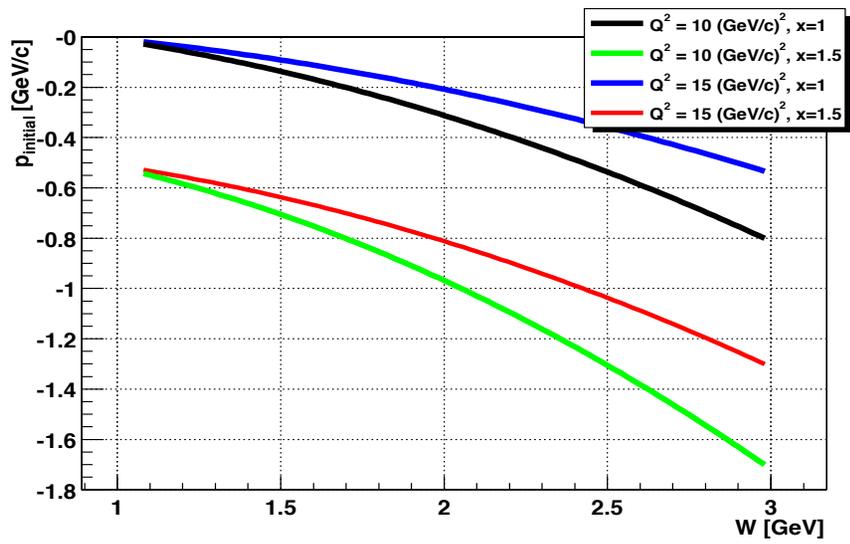
SuperFast quarks – short distance probes in nuclei

$$x = \frac{Q^2}{2m_N q_0} > 1$$

Two factors driving nucleons close together

Kinematic $p_{min} \equiv p_z = m_N \left(1 - x - x \left[\frac{W_N^2 - m_N^2}{Q^2} \right] \right)$

Dynamical: QCD evolution



Existing Experiments:

1. BCDMS Collaboration 1994 (CERN): $52 \leq Q^2 \leq 200 \text{ GeV}^2$
2. CCFR Collaboration 2000 (FermiLab): $Q^2 = 120 \text{ GeV}^2$
3. E02-019 Experiment 2010 (JLab) $Q_{AV}^2 = 7.4 \text{ GeV}^2$
4. Approved Experiments at JLab12: $e + A \rightarrow e' + X, Q^2 \geq 10 \text{ GeV}^2$
5. Alternative Studies at LHC: $p+A \rightarrow 2 \text{ jets} + X$
6. Electron Ion Collider: $\gamma + A \rightarrow e' + X, x_{Bj} > 1, Q^2 \geq 20 \text{ GeV}^2$
 $e + A \rightarrow e' + jet/N/h + X, x_h > 1$
 $\gamma + A \rightarrow jet_f/h_f + jet_b/h_b + X$

1. BCDMS Collaboration 1994 (CERN): Z.Phys C63 1994

Structure function of Carbon in deep-inelastic scattering of 200GeV muons

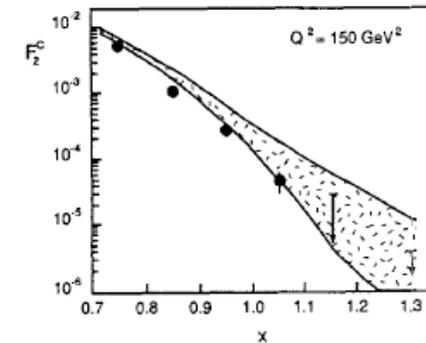
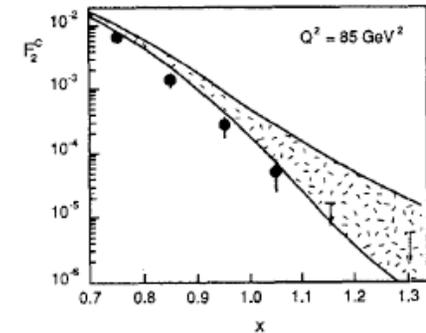
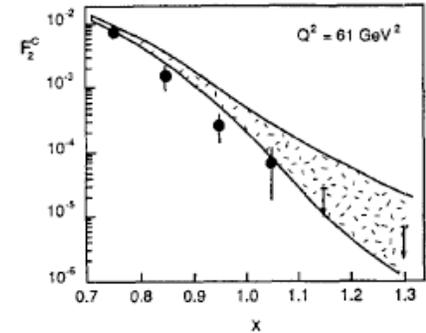
$$Q^2 = 61, 85 \text{ and } 150 \text{ GeV}^2$$

$$x = 0.85, 0.95, 1.05, 1.15 \text{ and } 1.3$$

$$F_{2A}(x, Q^2) = F_{2A}(x_0 = 0.75, Q^2) e^{-s(x-0.75)}$$

$$s = 16.5 \pm 0.6$$

More than Fermi Gas but very marginal high momentum component



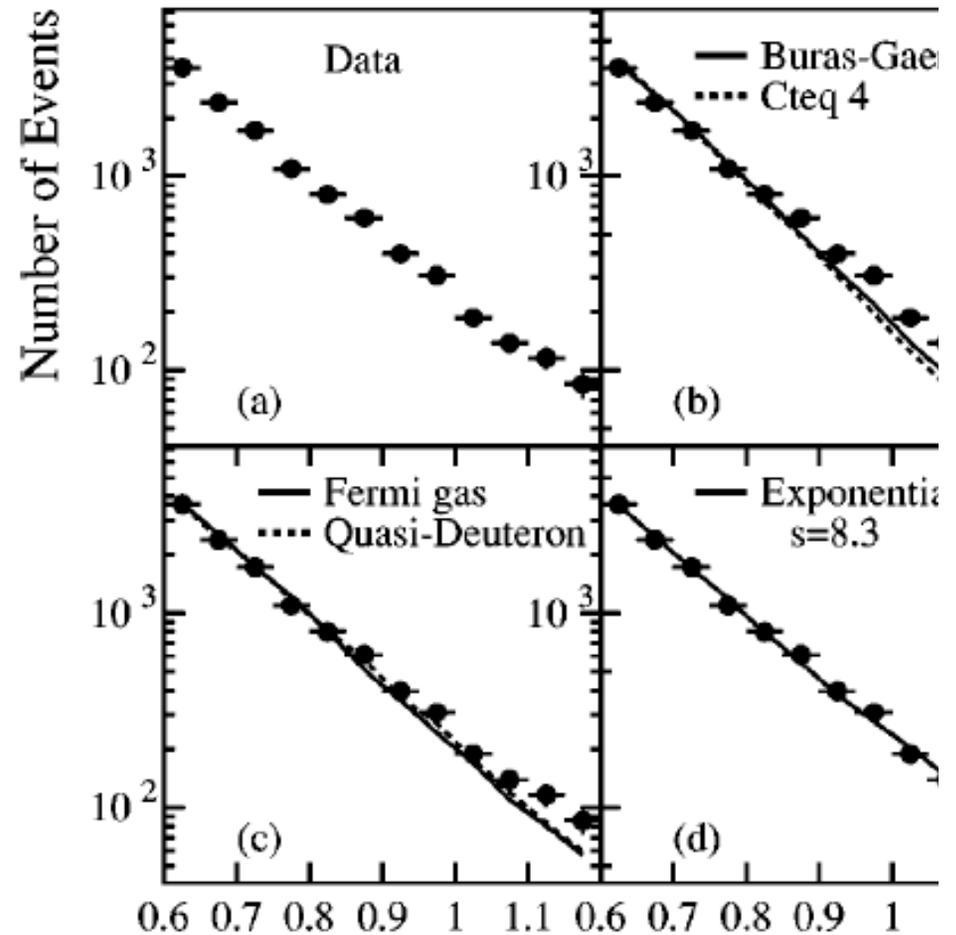
2. CCFR Collaboration 2000 (FermiLab):
 Phys. Rev. D61 2000

Using the neutrino and antineutrino beams in which structure function of Iron was measured in the charged current sector for average

$$Q^2 = 120 \text{ GeV}^2 \text{ and } 0.6 \leq x \leq 1.2.$$

$$F_{2A} \sim e^{-s(x-x_0)}$$

$$s = 8.3 \pm 0.7(\text{stat}) \pm 0.7(\text{sys})$$



3. E02-019 Experiment 2010 (JLab)

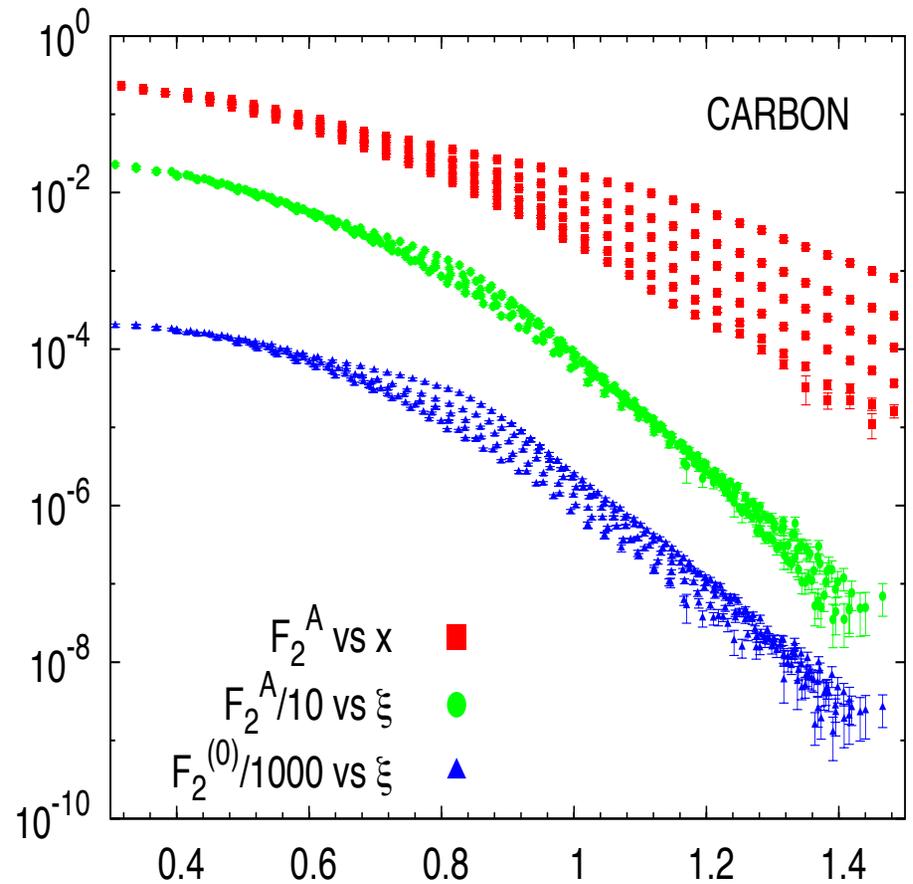
Fomin, Arrington, *phys.Rev.Lett* 204 2010

(ee') scattering of

2H , 3He , 4He , 9Be , ^{12}C , ^{64}Cu and ^{197}Au

$$6 < Q^2 < 9 \text{ GeV}^2$$

$$\xi = \frac{2x}{(1+r)} \text{ where } r = \sqrt{1 + \frac{4M_N^2 x^2}{Q^2}}$$



QCD Evolution Equation for Nuclear Partonic Distributions

Adam Freese, Wim
Cosyn, MS 2018

$$\frac{dq_{i,A}(x, Q^2)}{d \log Q^2} = \frac{\alpha_s}{2\pi} \left\{ 2 \left(1 + \frac{4}{3} \log\left(1 - \frac{x}{A}\right) \right) q_{i,A}(x, Q^2) + \frac{4}{3} \int_{x/A}^1 \frac{dz}{1-z} \left(\frac{1+z^2}{z} q_{i,A}\left(\frac{x}{z}, Q^2\right) - 2q_{i,A}(x, Q^2) \right) + \int_{x/A}^1 dz \frac{(1-z)^2 + z^2}{2z} G_A\left(\frac{x}{z}, Q^2\right) \right\}$$

$$F_{2A}(x, Q^2) = \sum_i e_i^2 x q_{i,A}(x, Q^2),$$

$$\frac{dF_{2A}(x, Q^2)}{d \log Q^2} = \frac{\alpha_s}{2\pi} \left\{ 2 \left(1 + \frac{4}{3} \log\left(1 - \frac{x}{A}\right) \right) F_{2,A}(x, Q^2) + \frac{4}{3} \int_{x/A}^1 \frac{dz}{1-z} \left(\frac{1+z^2}{z} F_{2A}\left(\frac{x}{z}, Q^2\right) - 2F_{2A}(x, Q^2) \right) + \frac{f_Q}{2} \int_{x/A}^1 dz [(1-z)^2 + z^2] \frac{x}{z} G_A\left(\frac{x}{z}, Q^2\right) \right\}$$

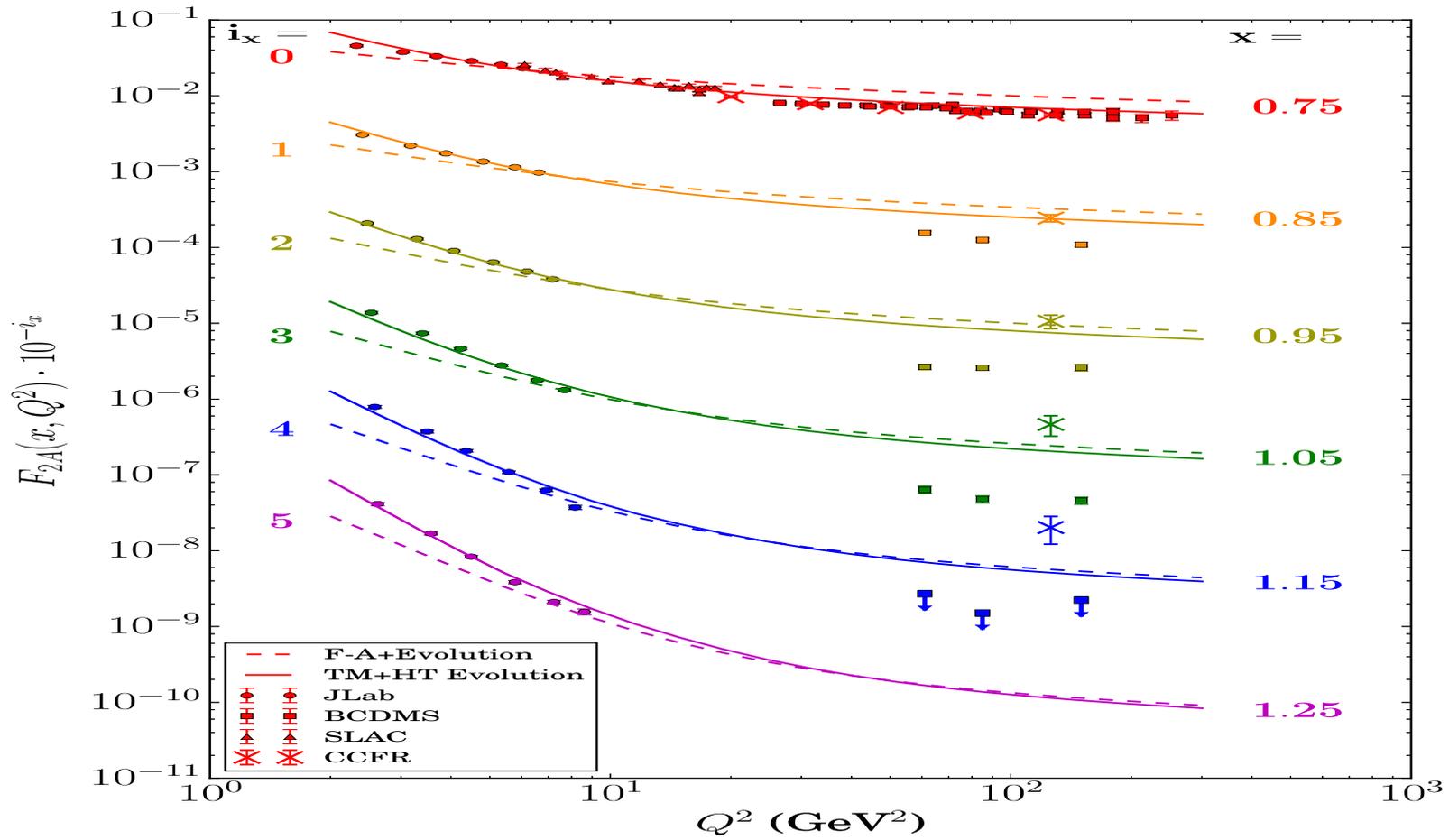
Neglecting $G_A(x, Q^2)$

$$\frac{dF_{2A}(x, Q^2)}{d \log Q^2} = \frac{\alpha_s}{2\pi} \left\{ 2 \left(1 + \frac{4}{3} \log\left(1 - \frac{x}{A}\right) \right) F_{2,A}(x, Q^2) + \frac{4}{3} \int_{x/A}^1 \frac{dz}{1-z} \left(\frac{1+z^2}{z} F_{2A}\left(\frac{x}{z}, Q^2\right) - 2F_{2A}(x, Q^2) \right) \right\}$$

Using input $F_{2A}^{(0)}(\xi, Q^2)$ from JLab analysis at $Q^2 = 7.4 \text{ GeV}^2$

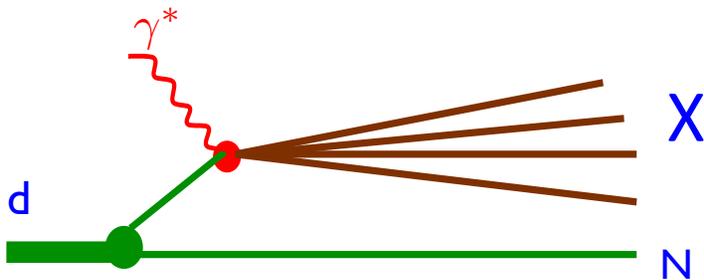
and calculate the evolution to Q^2 region of CCFR and BCDMS

$$Q^2 = 120 \text{ GeV}^2 \quad 52 \leq Q^2 \leq 200 \text{ GeV}^2$$



- Dynamics of generation of superfast quarks in nuclei

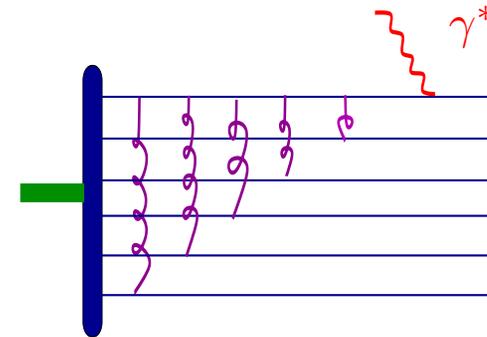
1. Convolution Model



$$F_{2d} = \int_x^2 \rho_d^N(\alpha, p_t) F_{2N}\left(\frac{x}{\alpha}, Q^2\right) \frac{d^2\alpha}{\alpha} d^2p_t$$

$$x_N = \frac{x}{\alpha}$$

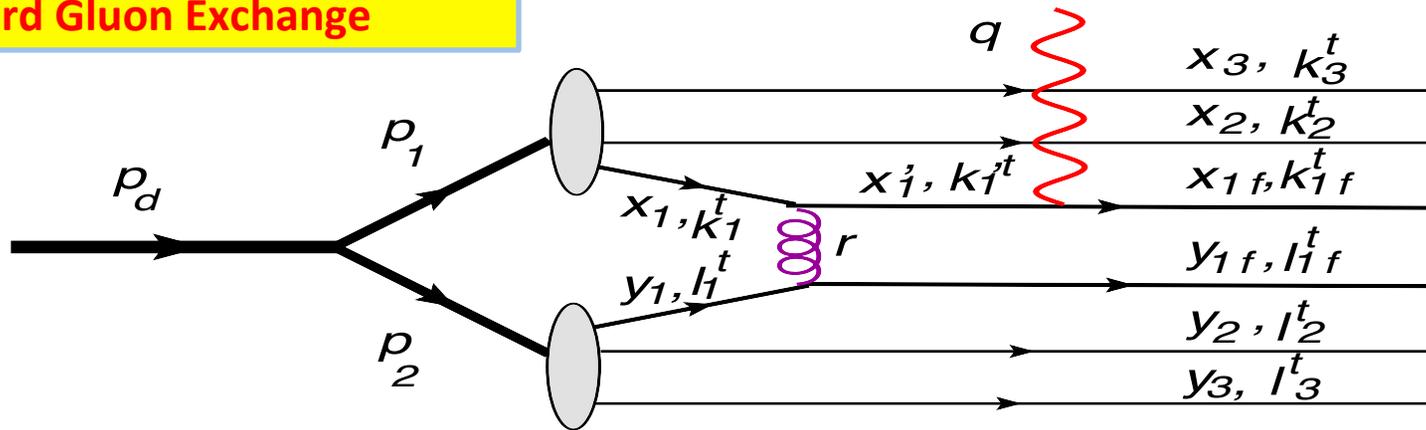
2. Six-Quark Model



$$F_{2D} = F_{2,(6q)} \sim \left(1 - \frac{x}{2}\right)^{10}$$

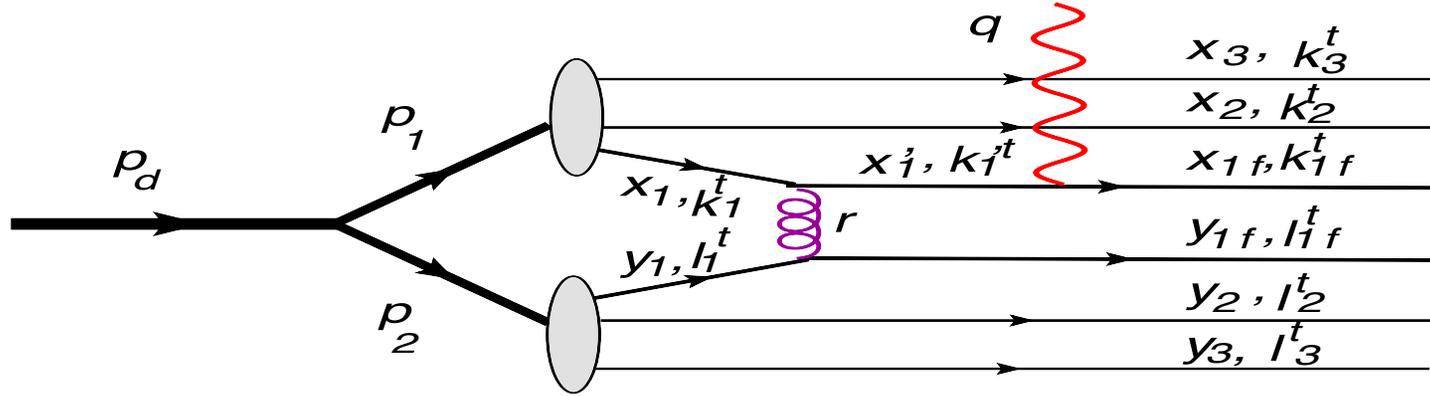
3. Hard Gluon Exchange

MS in progress



$$A^\sigma = \sum_{h_1, h_2} \int \frac{d\alpha}{\alpha} \frac{d^2 p_2}{2(2\pi)^3}$$

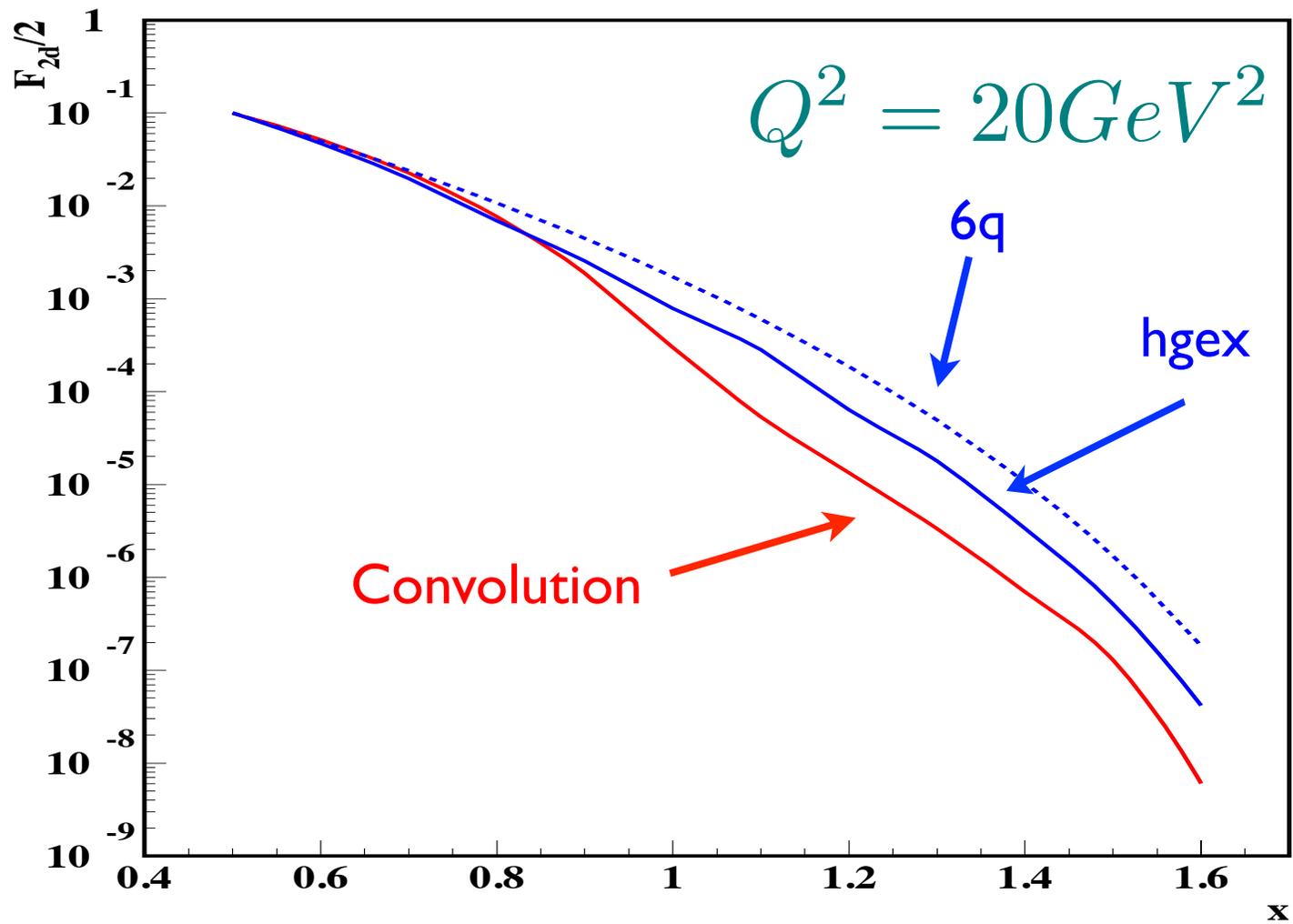
$$\left\{ \sum_{\eta_1, \lambda_1} H_{(\eta_{1f}, \eta_1), (\lambda_{1f}, \lambda_1)}^\sigma \frac{\psi_N^{h_1}(k_1, \eta_1; k_2, \eta_2; k_3, \eta_3)}{x_1 \sqrt{2(2\pi)^3}} \frac{\psi_N^{h_2}(l_1, \lambda_1; l_2, \lambda_2; l_3, \lambda_3)}{y_1 \sqrt{2(2\pi)^3}} \right\} \frac{\Psi_d^{h_1, h_2, m_d}(p_1, p_2)}{(1 - \alpha) \sqrt{2(2\pi)^3}}$$

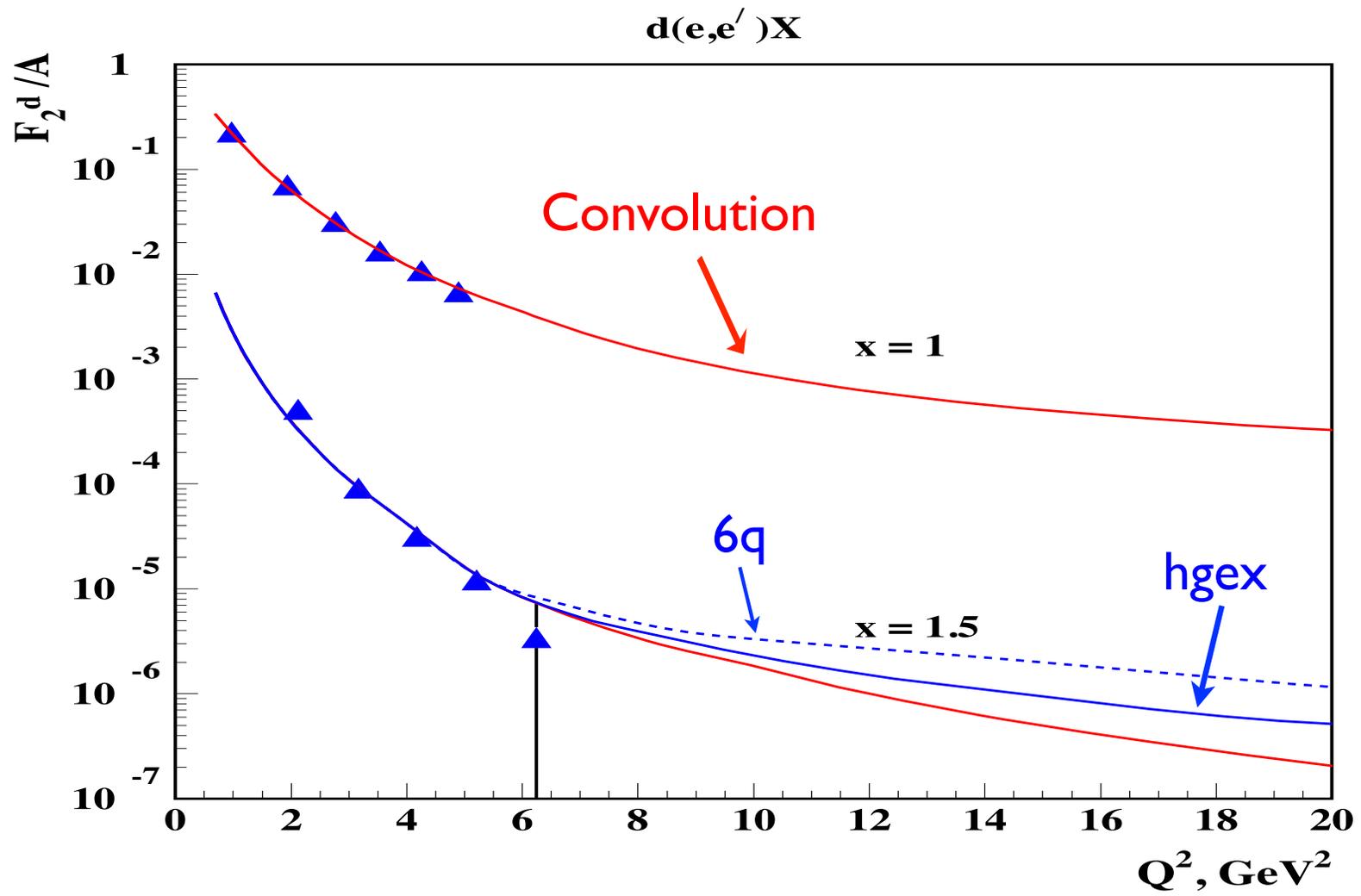


$$F_{2d}(x_{Bj}, Q^2) = \sum_{i,j} x_{Bj} e_i^2 \int dx_1 dy_1 \frac{d^2 l_{1f,t}}{2(2\pi)^3} \frac{8\alpha_{QCD}}{l_{1f,t}^4} f_i(x_1, Q^2) f_j(y_1, l_{1f,t}^2) \times$$

$$\frac{1}{y_1^2} \left[1 - \frac{x_{Bj}}{x_1 + y_1} \right]^2 \Theta(x_1 + y_1 - x_{Bj}) \left[\sum_{h_1, h_2} \int \frac{\Psi_d(\alpha, p_t)}{\alpha(1-\alpha)} \frac{d\alpha}{\sqrt{2(2\pi)^3}} \frac{d^2 p_t}{(2\pi)^2} \right]^2$$

where $x_{Bj} = \frac{Q^2}{2m_N \nu}$.



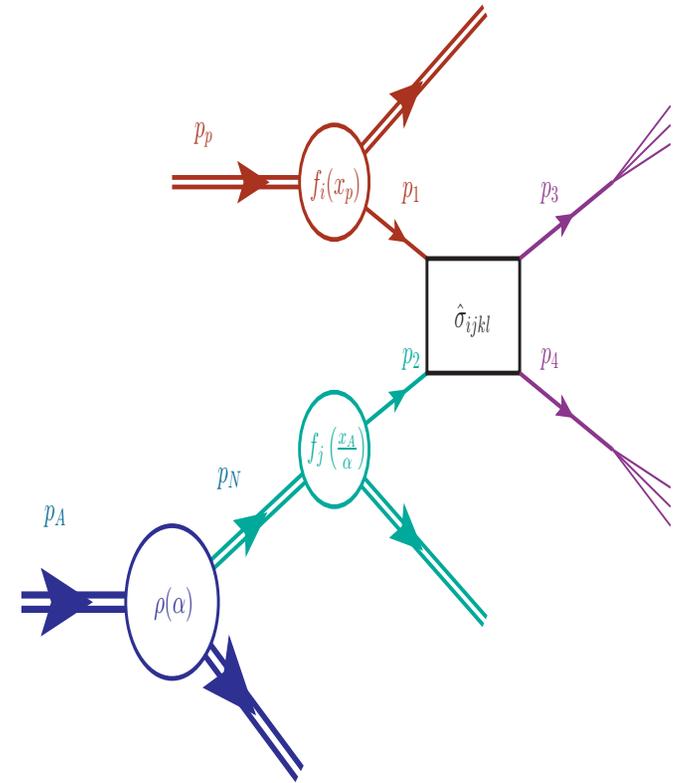


5. Probing Superfast quarks in $p+A \rightarrow 2 \text{ jets} + X$ reaction

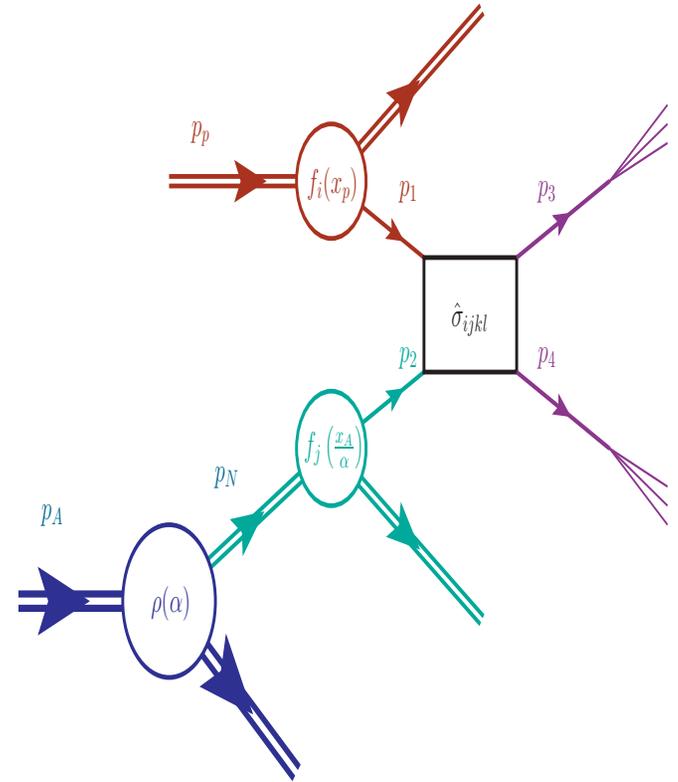
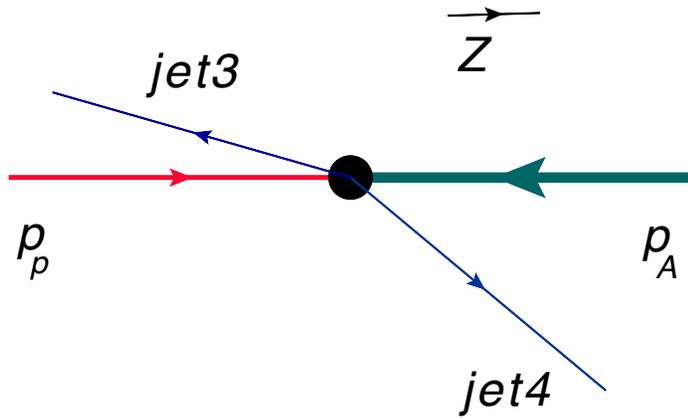
Adam Freese, M.S.
M.Strikman, EPJ 2015

$$p + A \rightarrow \text{dijet} + X$$

- Reaction is treated in Leading Twist Approximation
- Jets are produced in two-body parton-parton scattering
- one parton from the probe – other from the nucleus
- nuclear parton originated from the bound nucleon



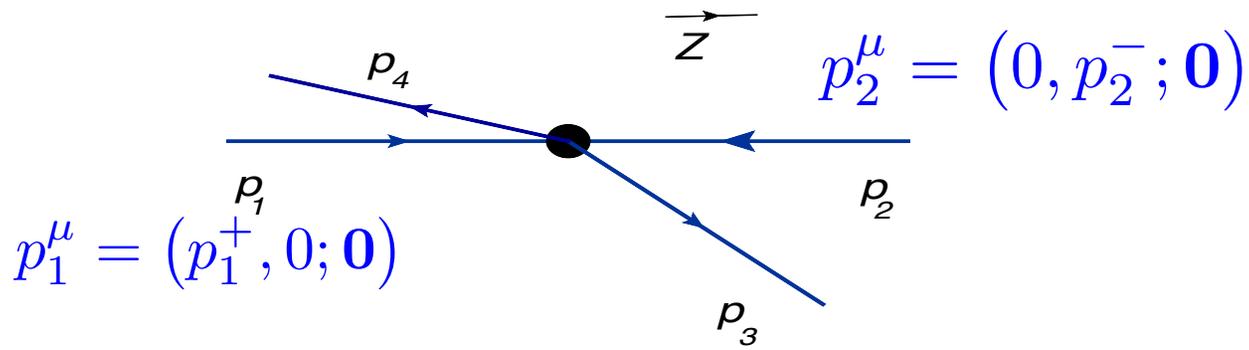
Jet - kinematics



$$p_p^\mu = \left(p_p^+, \frac{m_p^2}{p_p^+}, \mathbf{0}_T \right) = (2E_0, 0, \mathbf{0}_T) = \left(\sqrt{\frac{As_{NN}^{avg.}}{Z}}, 0, \mathbf{0}_T \right)$$

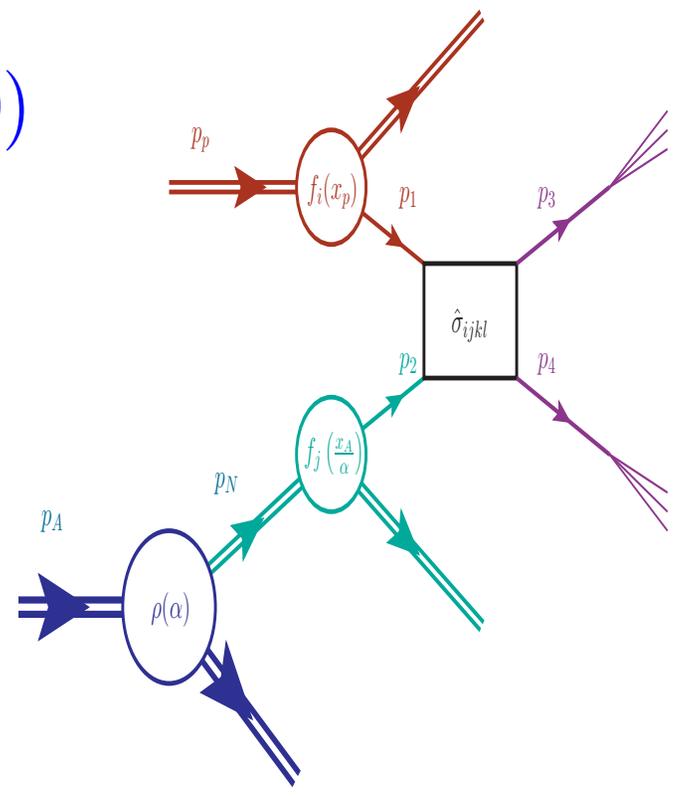
$$p_A^\mu = \left(\frac{M_A^2}{p_A^-}, p_A^-, \mathbf{0}_T \right) = (0, 2ZE_0, \mathbf{0}_T) = \left(0, \sqrt{AZs_{NN}^{avg.}}, \mathbf{0}_T \right)$$

Parton - kinematics



$$x_p = \frac{p_1^+}{p_p^+} = \sqrt{\frac{Z}{A}} \frac{p_1^+}{\sqrt{s_{NN}^{\text{avg.}}}}$$

$$x_A = A \frac{p_2^-}{p_A^-} = \sqrt{\frac{A}{Z}} \frac{p_2^-}{\sqrt{s_{NN}^{\text{avg.}}}}$$



$$p_1^\mu = (p_1^+, 0; \mathbf{0}) \quad x_p = \frac{p_1^+}{p_p^+}$$

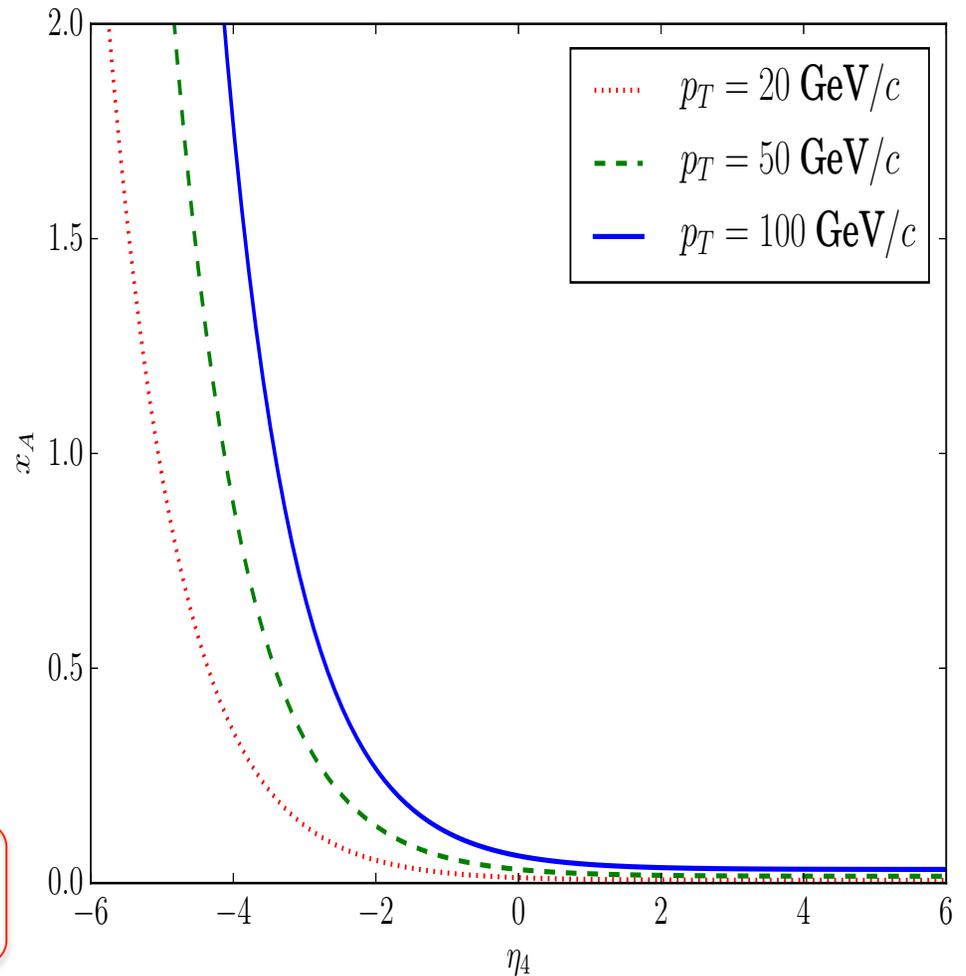
$$p_2^\mu = (0, p_2^-; \mathbf{0}) \quad x_A = A \frac{p_2^-}{p_A^-}$$

$$p_1^\mu + p_2^\mu = p_3^\mu + p_4^\mu$$

$$\eta = \frac{1}{2} \log \left(\frac{p^+}{p^-} \right)$$

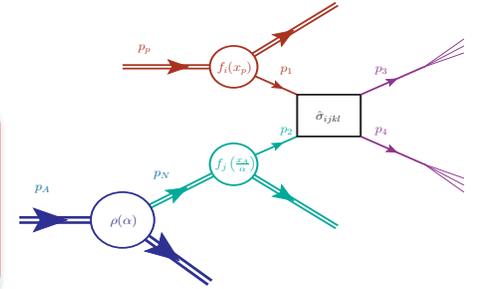
$$x_p = \sqrt{\frac{Z}{A}} \frac{p_T}{\sqrt{s_{NN}^{\text{avg.}}}} (e^{\eta_3} + e^{\eta_4})$$

$$x_A = \sqrt{\frac{A}{Z}} \frac{p_T}{\sqrt{s_{NN}^{\text{avg.}}}} (e^{-\eta_3} + e^{-\eta_4})$$



Differential Cross Section of the Reaction

$$\frac{d^3\sigma}{d\eta_3 d\eta_4 dp_T^2} = \sum_{ijkl} \frac{1}{16\pi (s_{NN}^{\text{avg.}})^2} \frac{f_{i/p}(x_p, Q^2)}{x_p} \frac{f_{j/A}(x_A, Q^2)}{x_A} \frac{|\overline{\mathcal{M}}_{ij \rightarrow kl}|^2}{1 + \delta_{kl}}$$



$$s_{NN}^{\text{avg}} = \frac{p_p^+ p_A^-}{A}$$

$$Q^2 = -(p_1 - p_3)^2 \approx p_T^2$$

$$f_{i/p}(x_p, Q^2)$$

$$f_{j/A}(x_A, Q^2)$$

Subprocess	$\frac{ \overline{\mathcal{M}} ^2}{g_s^4}$
$q_j + q_k \rightarrow q_j + q_k$	$\frac{4}{9} \frac{s^2 + u^2}{t^2}$
$q_j + q_j \rightarrow q_j + q_j$	$\frac{4}{9} \left(\frac{s^2 + u^2}{t^2} + \frac{s^2 + t^2}{u^2} \right) - \frac{8}{27} \frac{s^2}{ut}$
$q_j + \bar{q}_j \rightarrow q_k + \bar{q}_k$	$\frac{4}{9} \frac{t^2 + u^2}{s^2}$
$q_j + \bar{q}_j \rightarrow q_j + \bar{q}_j$	$\frac{4}{9} \left(\frac{s^2 + u^2}{t^2} + \frac{t^2 + u^2}{s^2} \right) - \frac{8}{27} \frac{u^2}{st}$
$q_j + \bar{q}_j \rightarrow g + g$	$\frac{32}{27} \frac{u^2 + t^2}{ut} - \frac{8}{3} \frac{u^2 + t^2}{s^2}$
$g + g \rightarrow q_j + \bar{q}_j$	$\frac{1}{6} \frac{u^2 + t^2}{ut} - \frac{3}{8} \frac{u^2 + t^2}{s^2}$
$q_j + g \rightarrow q_j + g$	$-\frac{4}{9} \frac{u^2 + s^2}{us} + \frac{8}{3} \frac{u^2 + s^2}{t^2}$
$g + g \rightarrow g + g$	$\frac{9}{2} \left(3 - \frac{ut}{s^2} - \frac{us}{t^2} - \frac{st}{u^2} \right)$

Nuclear Partonic Distributions

$$f_{i/A}(x_A, Q^2) = \sum_N \int_{x_A}^A \frac{d\alpha}{\alpha} \int d^2\mathbf{p}_T f_{N/A}(\alpha, \mathbf{p}_T) f_{i/N}^{(b)}\left(\frac{x_A}{\alpha}, \alpha, \mathbf{p}_T, Q^2\right)$$

$f_{N/A}(\alpha, \mathbf{p}_T)$ Light-Front fractional distribution of nucleon in the nucleus

$f_{i/N}^{(b)}\left(\frac{x_A}{\alpha_N}, \alpha_N, \mathbf{p}_{N,T}, Q^2\right)$ i-parton distribution in the bound nucleon N

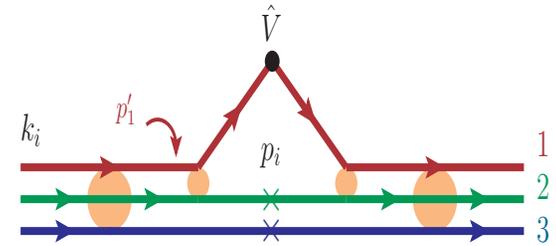
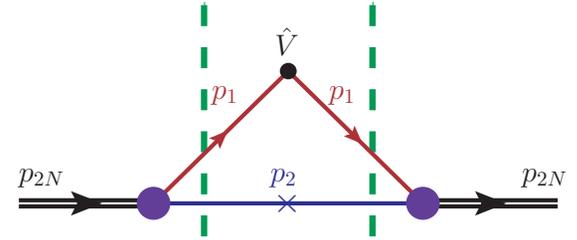
Light-Front Distribution of Nucleon in the Nucleus

$$f_{N/A}(\alpha, \mathbf{p}_T) = f_{N/A}^{(MF)}(\alpha, \mathbf{p}_T) + f_{N/A}^{(2)}(\alpha, \mathbf{p}_{NT}) + f_{N/A}^{(3)}(\alpha, \mathbf{p}_{NT}) \cdots$$

$$f_{N/A}^{(MF)}(\alpha, \mathbf{p}_T) = \frac{m_A}{A} \left| \Psi_{MF}^{(N)}(p) \right|^2$$

$$f_{N/A}^{(2)}(\alpha, \mathbf{p}_T) = \frac{a_2(A)}{2\chi_N} \frac{|\psi_d(k)|^2}{\alpha(2-\alpha)} \Theta(k - k_F)$$

$$f_{N/A}^{(3)}(\alpha, \mathbf{p}_T) = \frac{\{a_2(A)\}^2}{\alpha} \int \frac{d\alpha_3 d^2\mathbf{p}_{3T}}{\alpha_3(3-\alpha-\alpha_3)} \left\{ \frac{3-\alpha_3}{2(2-\alpha_3)} \right\}^2 \frac{|\psi_d(k_{12})|^2 \Theta(k_{12} - k_F)}{|\psi_d(k_{23})|^2 \Theta(k_{23} - k_F)}$$



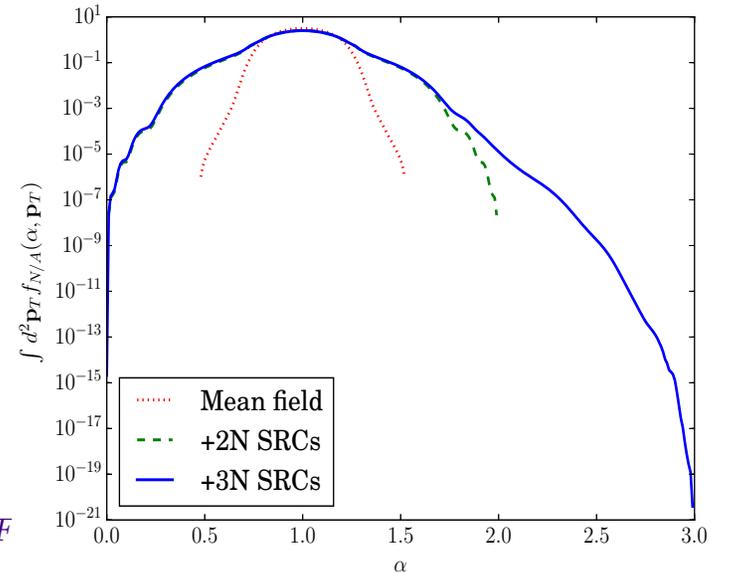
Light-Front Distribution of Nucleon in the Nucleus

$$f_{N/A}(\alpha, \mathbf{p}_T) = f_{N/A}^{(MF)}(\alpha, \mathbf{p}_T) + f_{N/A}^{(2)}(\alpha, \mathbf{p}_{NT}) + f_{N/A}^{(3)}(\alpha, \mathbf{p}_{NT}) \cdots$$

$$f_{N/A}^{(MF)}(\alpha, \mathbf{p}_T) = \frac{m_A}{A} \left| \Psi_{MF}^{(N)}(p) \right|^2$$

$$f_{N/A}^{(2)}(\alpha, \mathbf{p}_T) = \frac{a_2(A)}{2\chi_N} \frac{|\psi_d(k)|^2}{\alpha(2-\alpha)} \Theta(k - k_F)$$

$$f_{N/A}^{(3)}(\alpha, \mathbf{p}_T) = \frac{\{a_2(A)\}^2}{|\psi_d(k_{12})|^2} \frac{1}{\alpha} \int \frac{d\alpha_3 d^2\mathbf{p}_{3T}}{\alpha_3(3-\alpha-\alpha_3)} \left\{ \frac{3-\alpha_3}{2(2-\alpha_3)} \right\}^2 \frac{|\psi_d(k_{23})|^2}{\Theta(k_{12} - k_F)} \Theta(k_{23} - k_F)$$

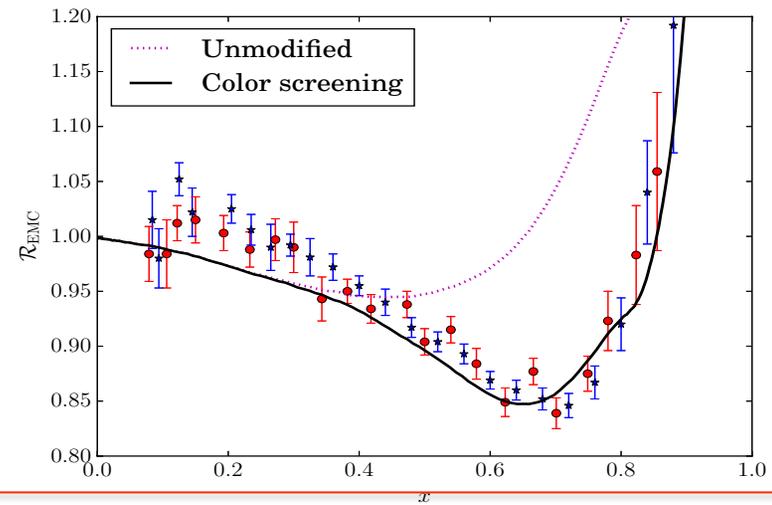
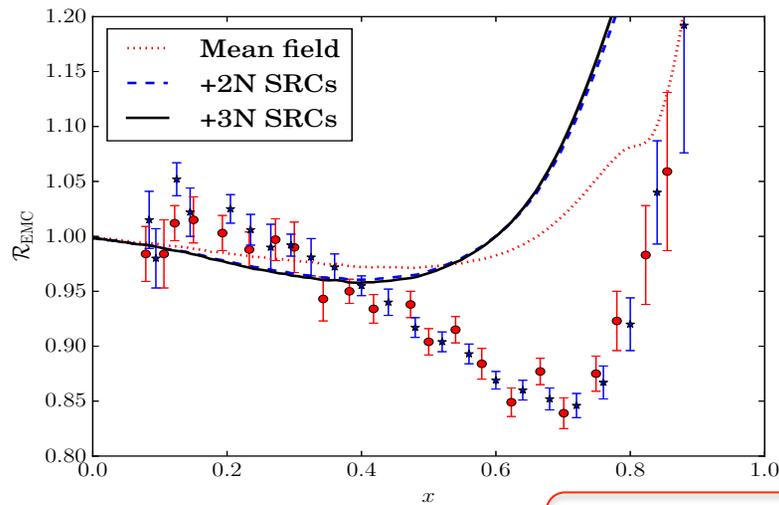


Partonic distribution in the bound nucleon: Medium Modification effects

$$F_2^{(A)}(x, Q^2) = \sum_N \int_x^A d\alpha \int d^2\mathbf{p}_T f_{N/A}(\alpha, \mathbf{p}_T) F_2^{(N,b)}\left(\frac{x}{\alpha}, \alpha, \mathbf{p}_T, Q^2\right)$$

$$\mathcal{R}_{\text{EMC}}(x, Q^2) = \frac{2}{A} \frac{\sigma_{eA}}{\sigma_{ed}} f_{\text{iso}} \approx \frac{2}{A} \frac{F_2^{(A)}(x, Q^2)}{F_2^{(d)}(x, Q^2)} f_{\text{iso}}$$

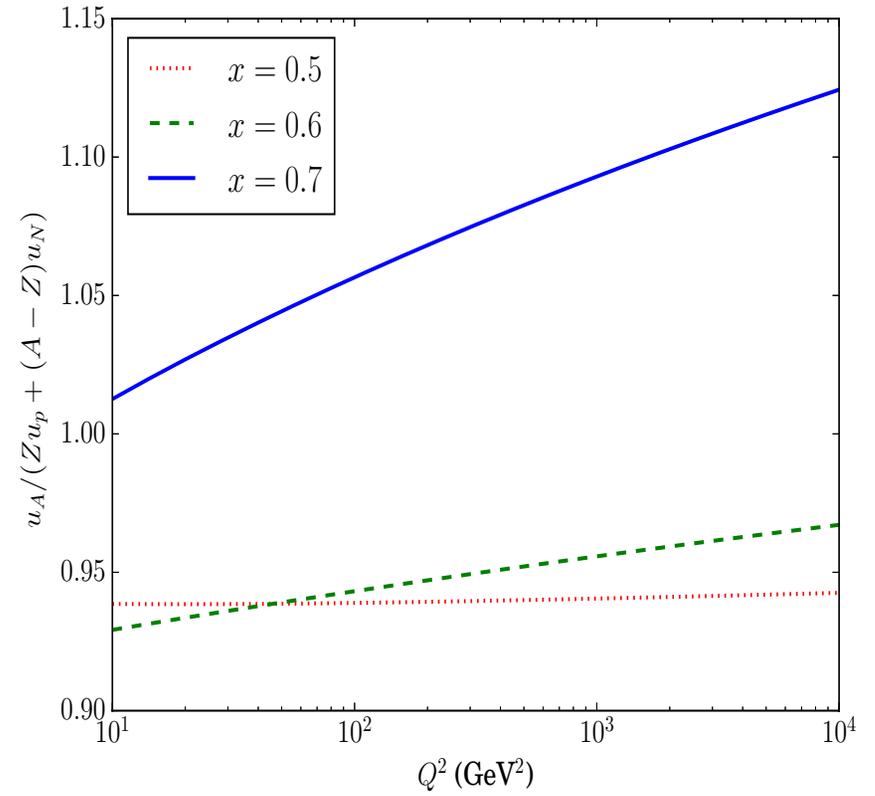
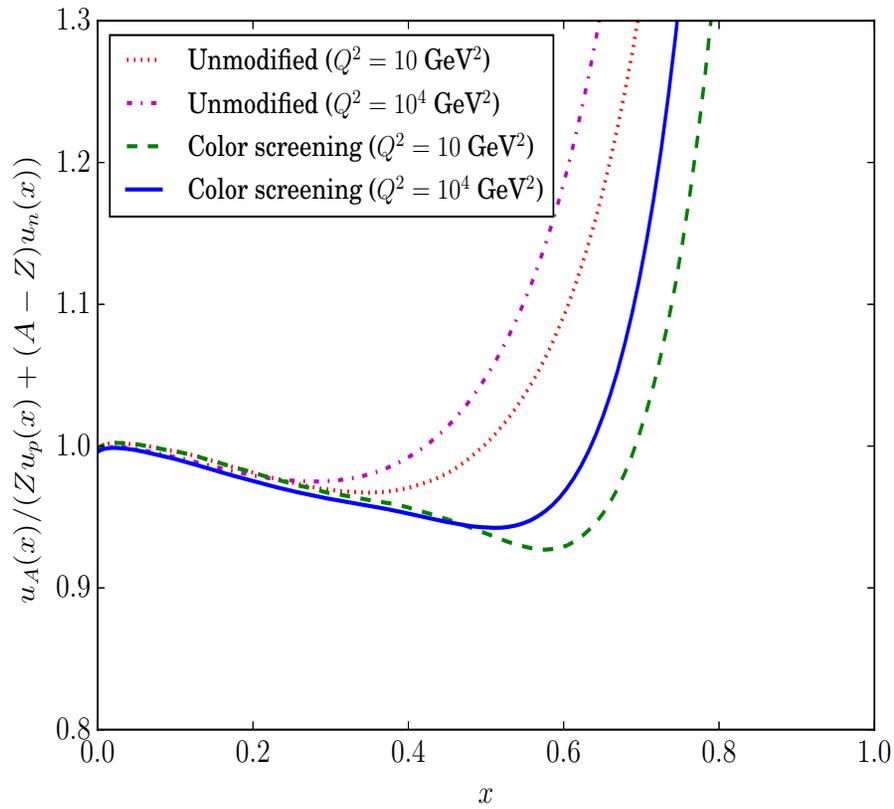
$$Q^2 = 10 \text{ GeV}^2$$



Color Screening Model ->

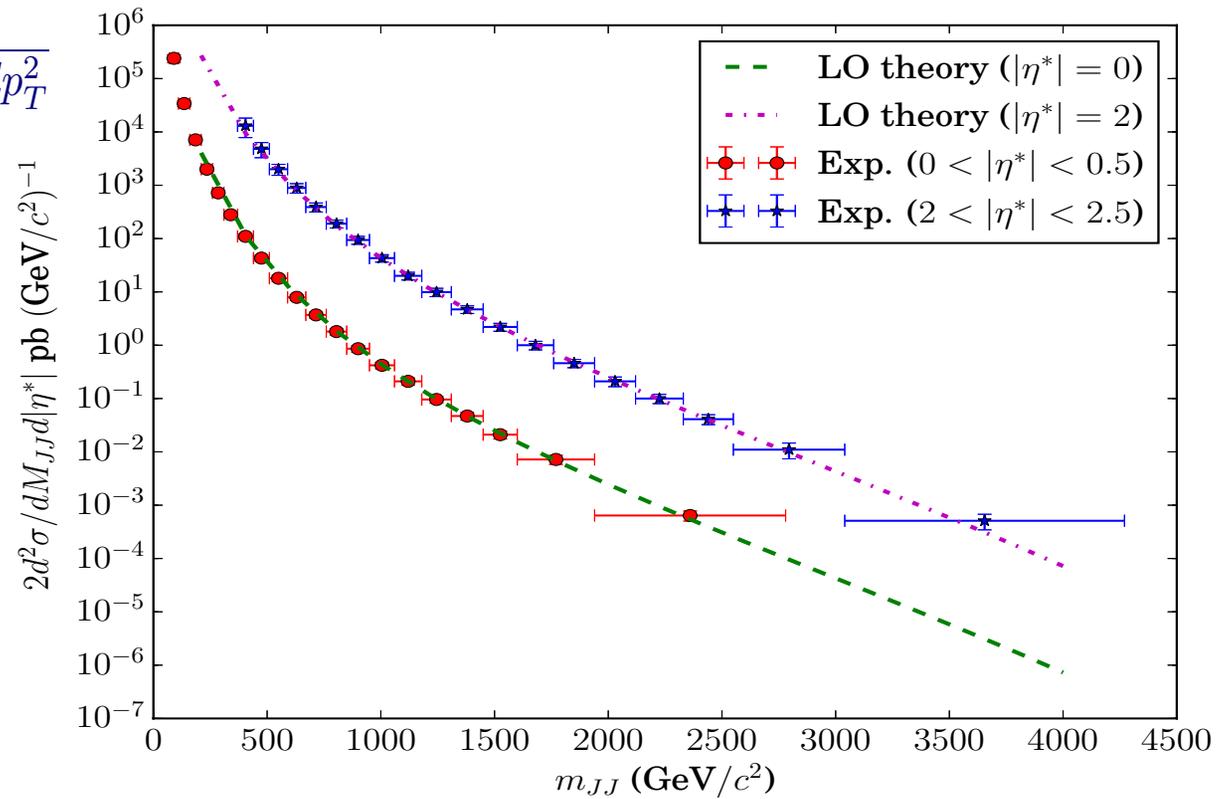
$$F_2^{(N,b)}\left(\frac{x}{\alpha}, \alpha, \mathbf{p}_T, Q^2\right) = F_2^{(N)}\left(\frac{x}{\alpha}, Q^2\right) \delta\left(k^2(\alpha, \mathbf{p}_T), \frac{x}{\alpha}\right)$$

QCD Evolution of Medium Modifications

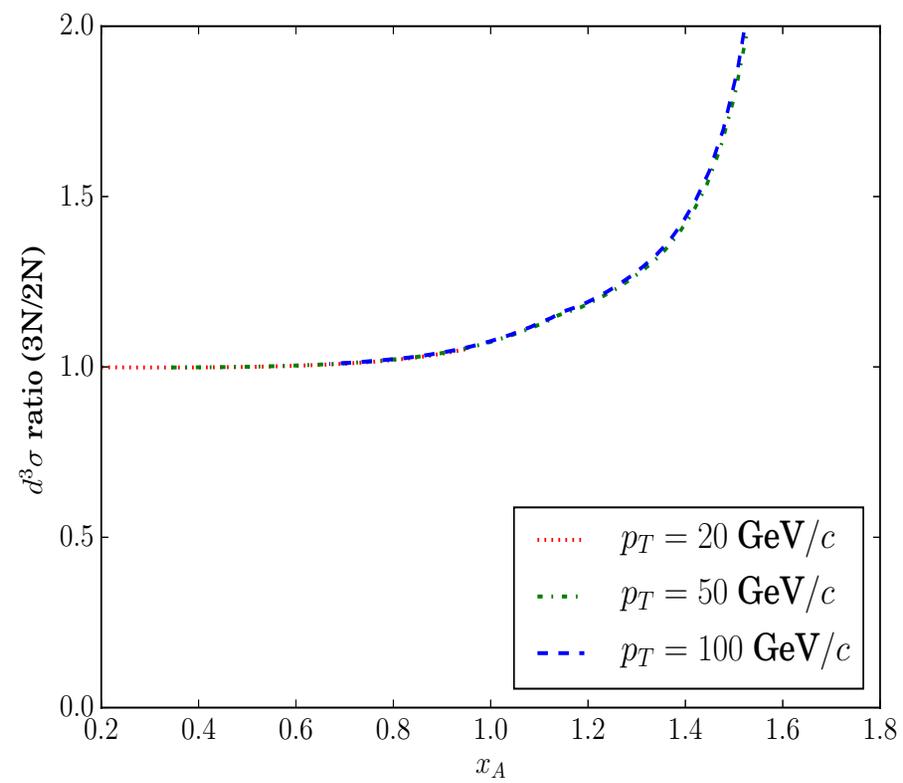
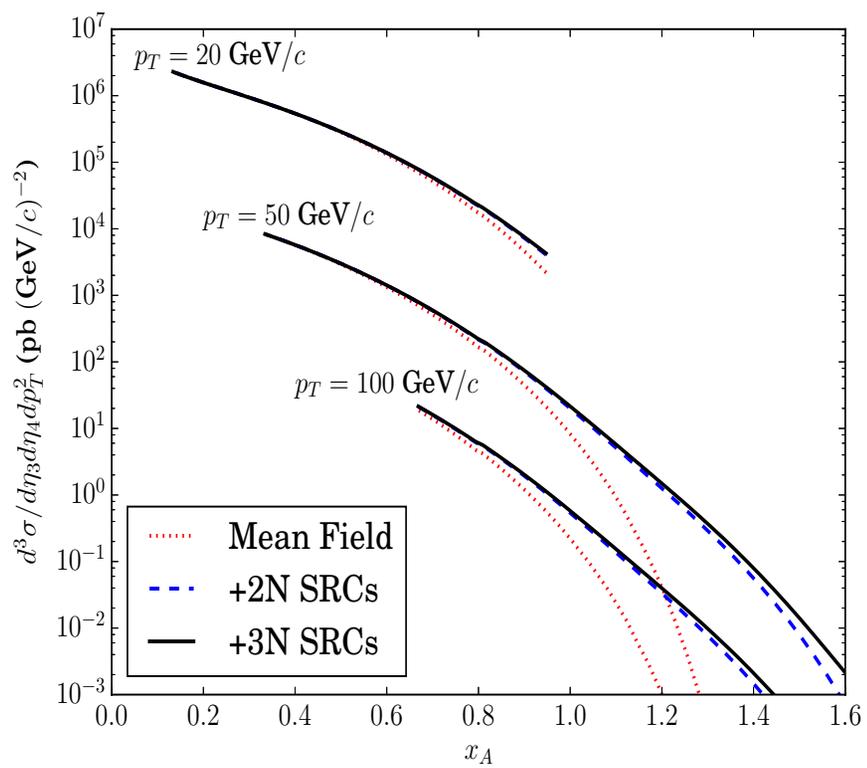


Checking Calculation for "Conventional" kinematics

$$\frac{2d^2\sigma}{dm_{JJ}d\eta^*} = \frac{4p_T}{\cosh(\eta^*)} \int d\bar{\eta} \frac{d^3\sigma}{d\eta_3 d\eta_4 dp_T^2}$$



G. Aad et al. (ATLAS Collaboration), Phys. Rev. D 86, 014022(2012).



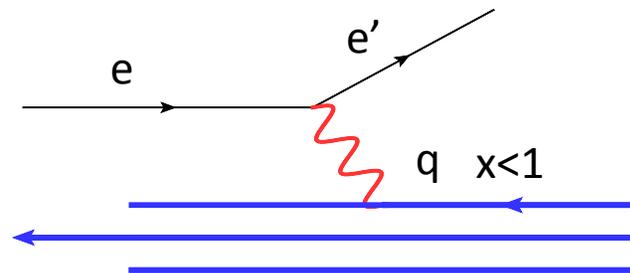
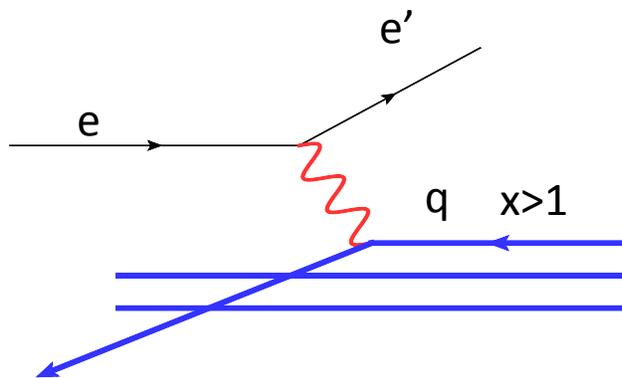
6. Electron Ion Collider:

$$\gamma + A \rightarrow e' + X, \quad x_{Bj} > 1, Q^2 \geq 20 \text{ GeV}^2$$

- For A=2 - core physics

- For A>2 - 3N physics

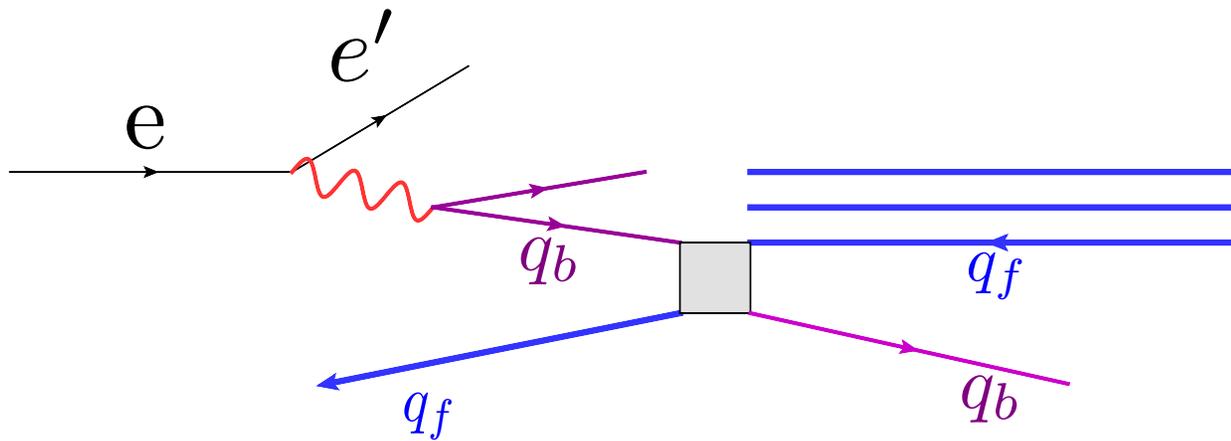
$$e + A \rightarrow e' + \text{jet}/N/h + X, \quad x_h > 1$$



$$x = \frac{p_T}{2E_n} e^\eta + \frac{Q^2}{4E_i E_n}$$

6. Electron Ion Collider:

$$\gamma + A \rightarrow jet_f/h_f + jet_b/h_b + X$$



$$x = \frac{p_T}{2E_n} (e^{\eta_f} + e^{-\eta_b})$$

Summary & Outlook

- Our theoretical approach allows to calculate nuclear reactions relevant To EIC kinematics – taking into account final state reinteractions

- Set of reactions such as: $\gamma + A \rightarrow e' + X$,

$$e + A \rightarrow e' + jet/N/h + X,$$

$$\gamma + A \rightarrow jet_f/h_f + jet_b/h_b + X$$

Will allow to reach practically unexplored $x > 1$ region

- Cross section in these kinematics is sensitive to the nuclear structure at very short distances: deuteron case for core studies, $A > 2$ case for 3N SRCs

Probing Deuteron at Core Distances at large Q^2

$$\Psi_d = \Psi_{pn} + \Psi_{\Delta\Delta} + \Psi_{NN^*} + \Psi_{hc} \dots$$

$$e + d \rightarrow e' + \Delta_{backward} + X$$

$$e + d \rightarrow e' + N_{backward}^* + X$$

