Probing 3N-SRCs Using Inclusive and Exclusive Reactions

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#motivations:

- High Density Fluctuations in Nuclei

Can such fluctuations be probed? – 2N, 3N SRCs

What they tell us about the nuclear forces at short distances

QCD/ Hadron transitions

Partons in the nuclear medum/EMC effects

Nature of the nuclear core

Nature of 3N forces

- Astrophysical Implications

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

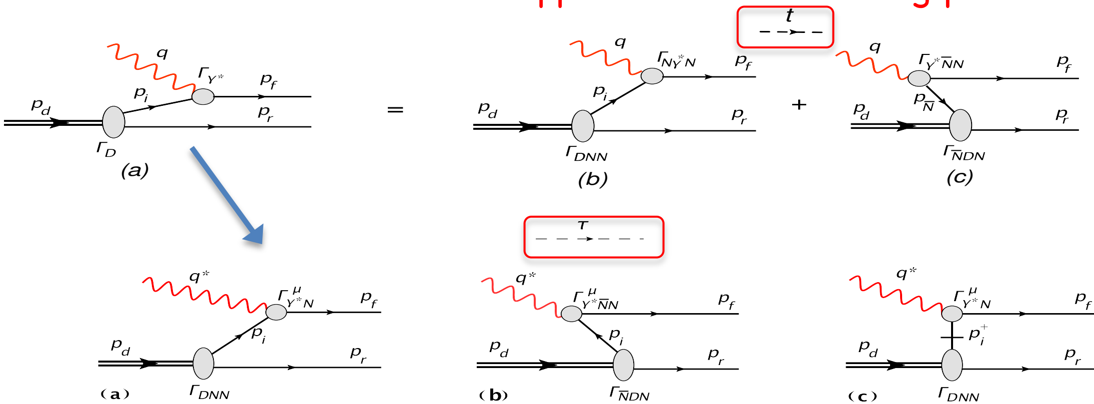
Light-Front wave function of the Nucleus

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

- in the momentum space

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

- How the LF wave function appears in the scattering process

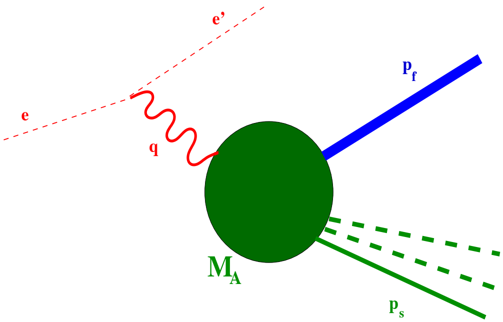


$$(b) \sim (c)$$

$$(b) = 0$$

Frank Vera, M.S. ArXiV 2018

High Energy Approximations:



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

$$Q^2 \geq few \quad \mathrm{GeV}^2$$

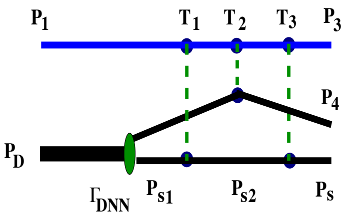
Both for QE/DIS

- Emergence of the small parameter

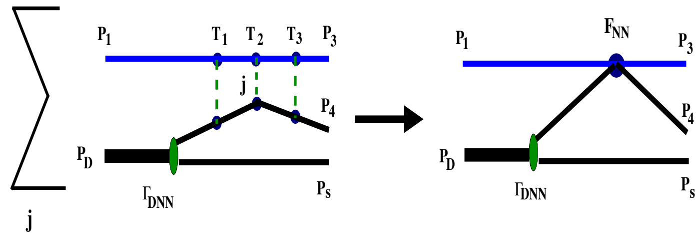
$$\frac{q_-}{q_+} = \frac{q_0 - q_3}{q_0 + q_3} \ll 1 \quad \mathcal{O}(\frac{q_-}{q_+})$$

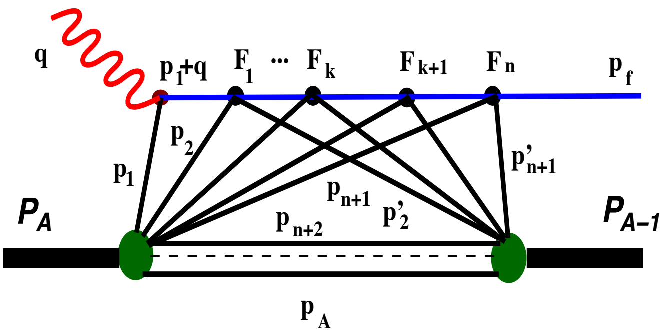
$$\frac{p_{f-}}{p_{f+}} = \frac{E_f - p_{f3}}{E_f + p_{f3}} \ll 1 \quad \mathcal{O}(\frac{p_{f-}}{p_{f+}})$$

Emergence of “effective” theory



$$\mathcal{O}\left(\frac{p_{1-}}{p_{1+}}\right)$$



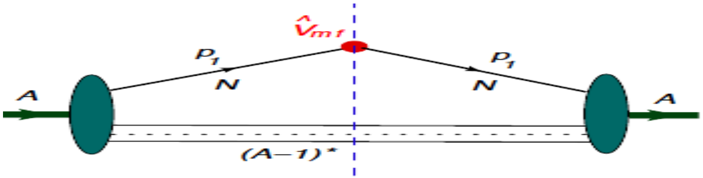


Effective Feynman Diagrammatic Rules

M.S. IJMS 2001

Wave function?

Spectral Function Calculations



$$S_A^{MF} = -Im \int \chi_A^\dagger \Gamma^\dagger_{A,N,A-1} \frac{\not{p}_1 + m}{p_1^2 - m^2 + i\varepsilon} \hat{V}^{MF} \frac{\not{p}_1 + m}{p_1^2 - m^2 + i \times \varepsilon} \left[\frac{G_{A-1}(p_{A-1})}{p_{A-1}^2 - M_{A-1}^2 + i\varepsilon} \right]^{on} \Gamma_{A,N,A-1} \chi_A \frac{d^4 p_{A-1}}{i(2\pi)^4}$$

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

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

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

1.Short-Range Correlations

for large $k > k_{Fermi}$

$$n_A^{LC}(\alpha, p_t) \approx a_{NN}(A,z) n_{NN}^{LC}(\alpha, p_t)$$

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

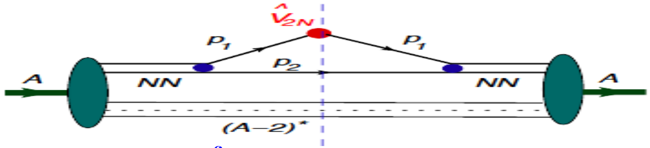
- Experimental observations

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

$$n_A^{LC}(\alpha, p_t) \approx a_{pn}(A,z) n_d^{LC}(\alpha, p_t)$$

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

2N SRC model



$$P^N_{A,2N}(\alpha_1, p_{1,\perp}, \tilde{M}_N^2) = \sum_{s_2, s_{NN}, s_{A-2}} \int \chi_A^\dagger \Gamma^\dagger_{A\to NN, A-2} \chi_{A-2}(p_{A-2}, s_{A-2})$$
$$\times \frac{\chi_{NN}(p_{NN}, s_{NN})\chi^\dagger_{NN}(p_{NN}, s_{NN})}{p_{NN}^2 - M_{NN}^2} \Gamma^\dagger_{NN\to NN} \frac{u(p_1, s_1)u(p_2, s_2)}{p_1^2 - M_N^2}$$
$$\times \left[2\alpha_1^2 \delta(\alpha_1 + \alpha_2 + \alpha_{A-2} - A)\delta^2(p_{1,\perp} + p_{2,\perp} + p_{A-2,\perp})\delta(\tilde{M}_N^2 - \tilde{M}_N^{(2N),2})\right] \frac{\bar{u}(p_1, s_1)\bar{u}(p_2, s_2)}{p_1^2 - M_N^2}$$
$$\times \Gamma_{NN\to NN} \frac{\chi_{NN}(p_{NN}, s_{NN})\chi^\dagger_{NN}(p_{NN}, s_{NN})}{p_{NN}^2 - M_{NN}^2} \chi^\dagger_{A-2}(p_{A-2}, s_{A-2})\Gamma_{A,NN,A-2}\chi_A$$
$$\times \frac{d\alpha_2}{\alpha_2} \frac{d^2 p_{2,\perp}}{2(2\pi)^3} \frac{d\alpha_{A-2}}{\alpha_{A-2}} \frac{d^2 p_{A-2,\perp}}{2(2\pi)^3}. \quad (1)$$

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

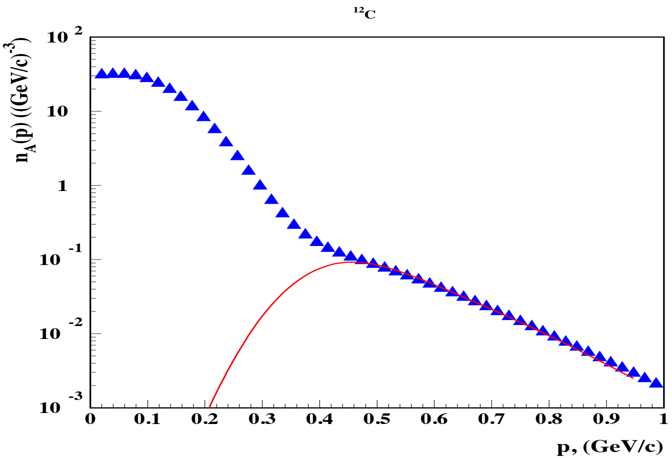
$$\rho_A(\alpha_N, p_{N,\perp}) = \int P_A(\alpha_N, p_{N,\perp}, \tilde{M}_N^2)\tfrac{1}{2} d\tilde{M}_N^2$$

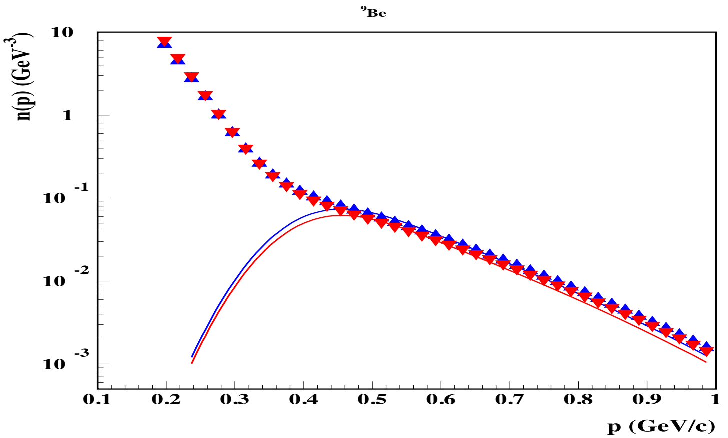
$$\psi^{LF}_{pn}(\alpha, p_\perp) \approx C\psi^{LF}_d(\alpha, p_\perp)$$

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

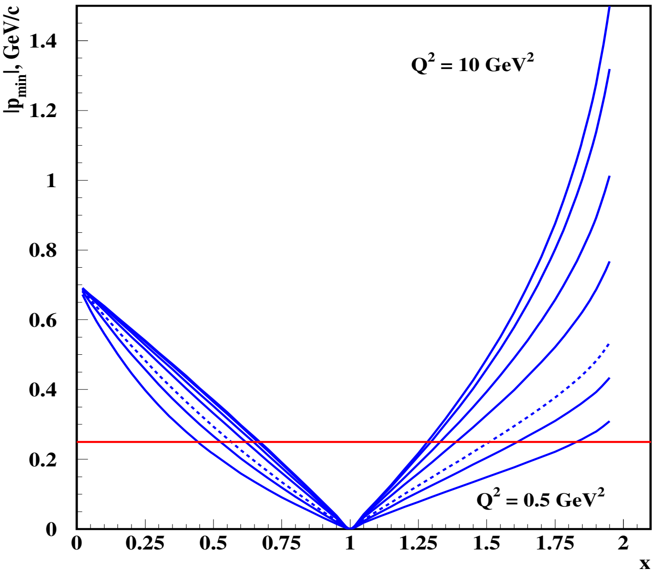
$$\psi_{CM}(\alpha_{NN}, k_{NN,\perp}) = -\frac{1}{\sqrt{\frac{A-2}{2}}} \frac{1}{\sqrt{2(2\pi)^3}} \frac{\chi^\dagger_{NN}(p_{NN},s_{NN})\chi^\dagger_{A-2}(p_{A-2},s_{A-2})\Gamma_{A\to NN,A-2}\chi_A^{s_A}}{\frac{2}{A}[M_A^2 - s_{NN,A-2}(k_{CM})]}$$

2N SRC model Non Relativistic Approximation

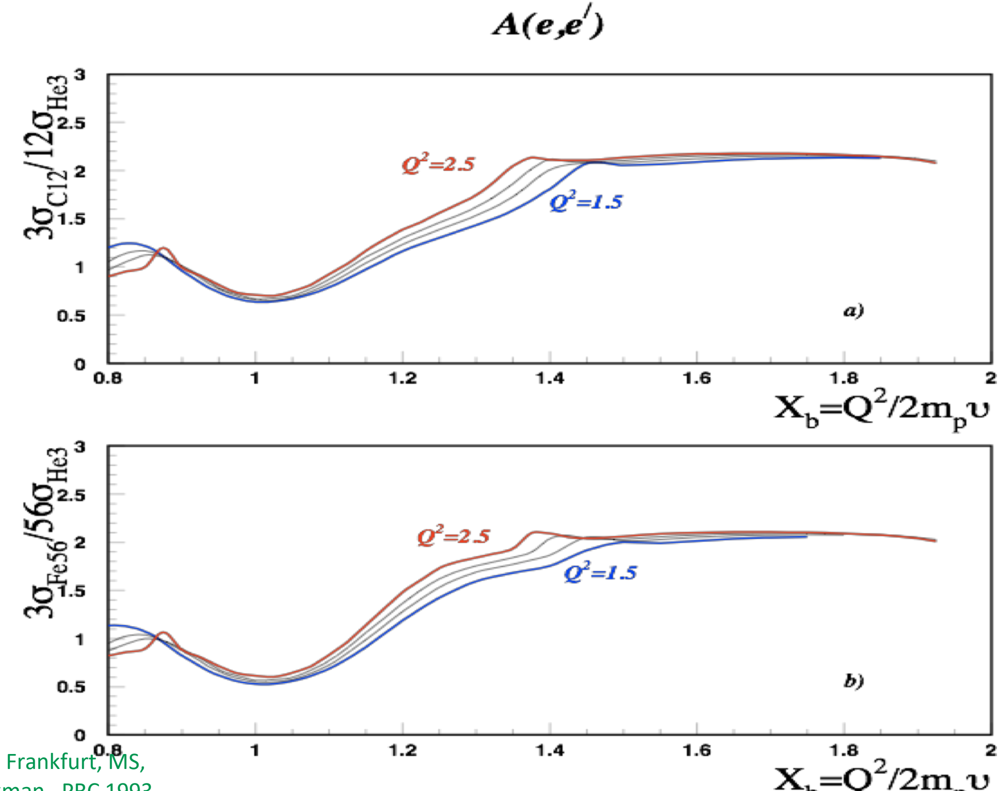




Nuclear Scaling in QE Inclusive A(e,e')X reaction at x>1 region



Day, Frankfurt, MS,
Strikman, PRC 1993



Day, Frankfurt, MS,
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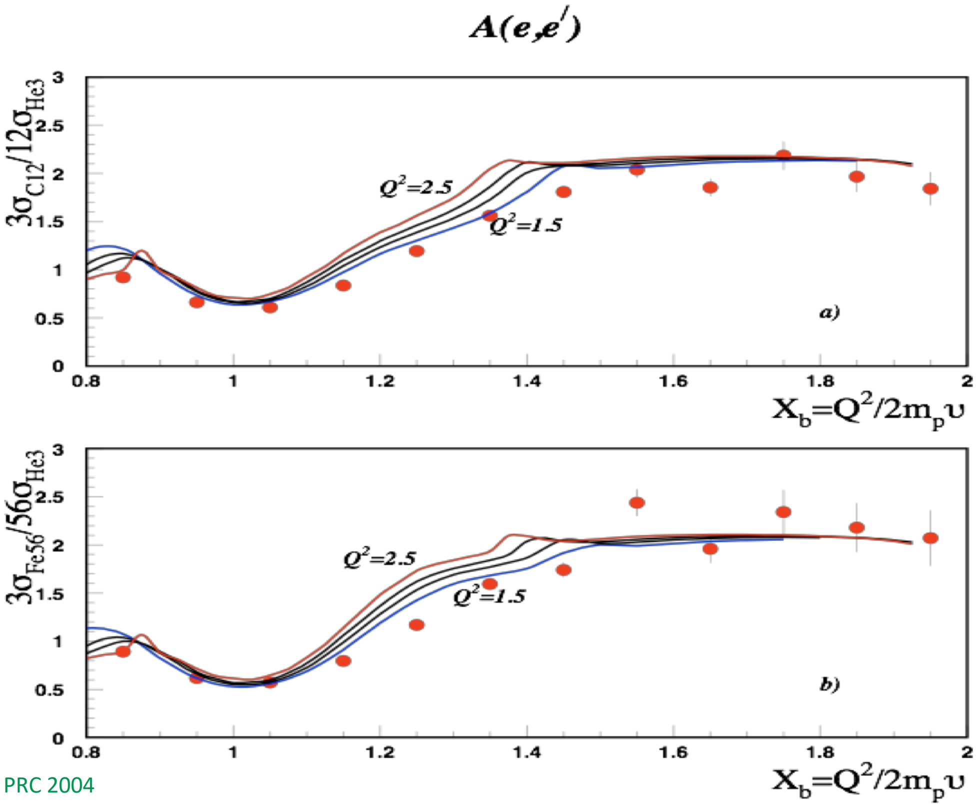
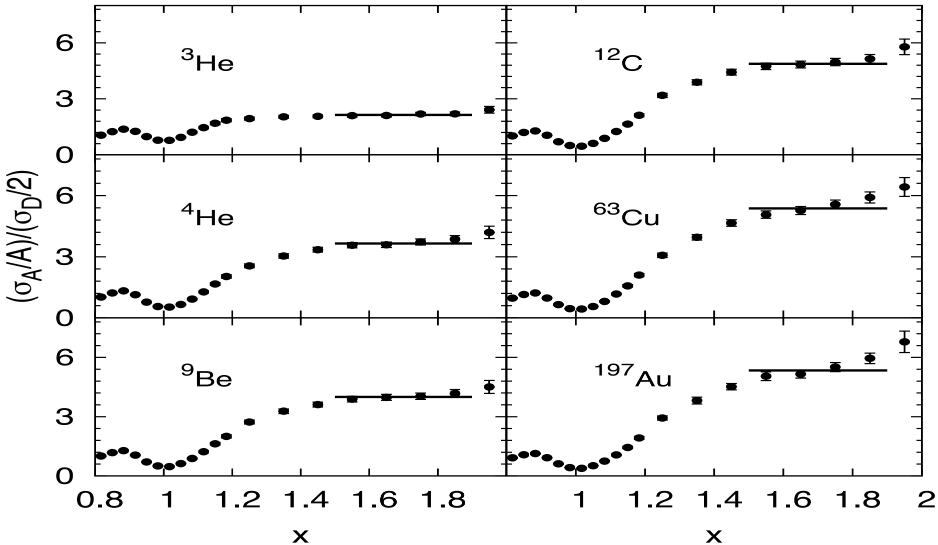
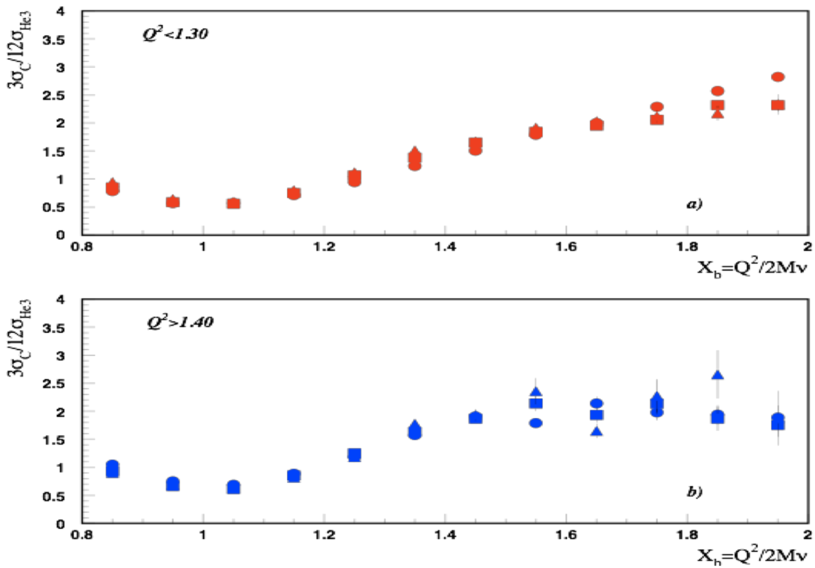


Egiyan, et al PRC 2004



Fomin et al PRL 2011

$A(e,e')$



$3\sigma_C/12\sigma_{He3}$
$Q^2<1.30$
a)
$X_b=Q^2/2M\nu$
$3\sigma_C/12\sigma_{He3}$
$Q^2>1.40$
b)
$X_b=Q^2/2M\nu$

Meaning of the scaling values

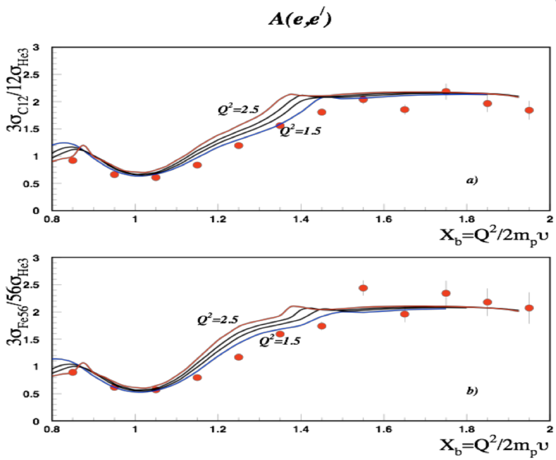
Day, Frankfurt, MS, Strikman, PRC 1993

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



Egiyan, et al PRL 2006, PRC 2004

a2's as relative probability of 2N SRCs

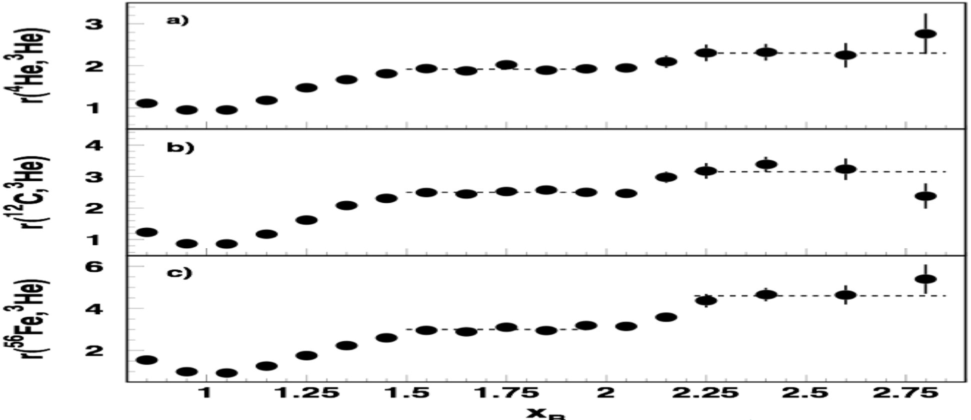
Table 1: The results for $a_2(A, y)$

A	y	This Work	Frankfurt et al	Egiyan et al	Famin et al
^{3}He	0.33	2.07±0.08	1.7±0.3		2.13±0.04
^{4}He	0	3.51±0.03	3.3±0.5	3.38±0.2	3.60±0.10
^{9}Be	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

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

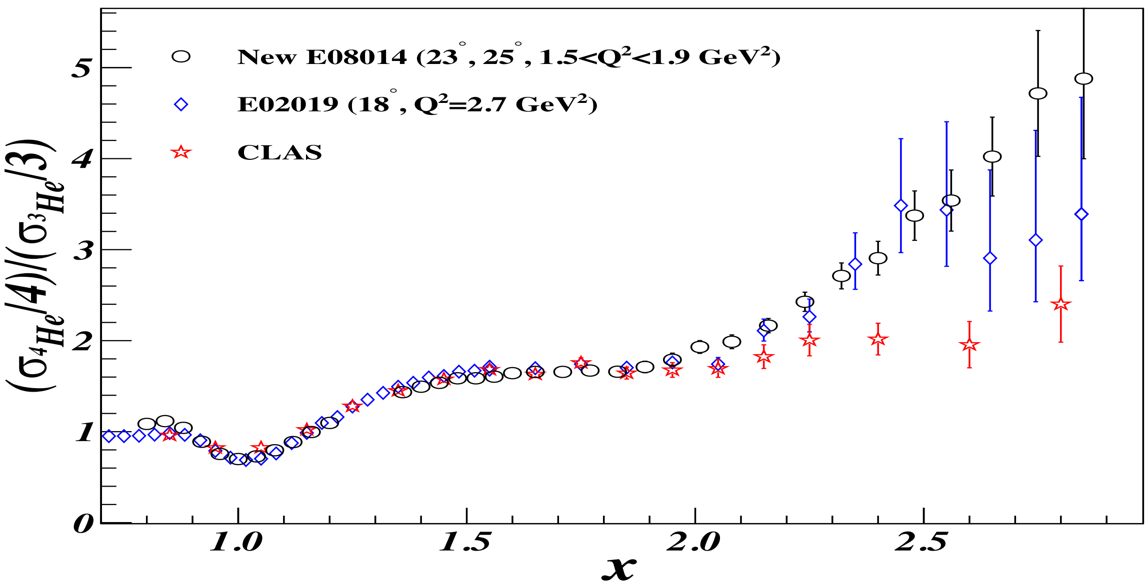


Egiyan, et al PRL 2006

3N SRCs

Z. Ye, at al, 2017

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



Egiyan, et al PRL 2006

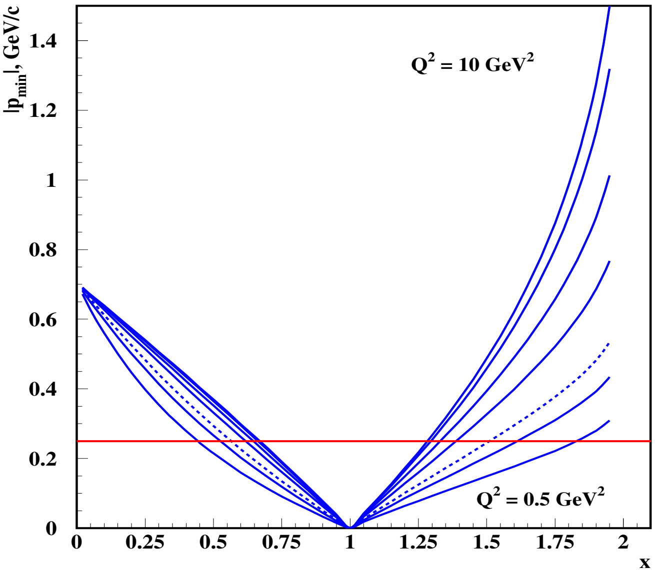
Egiyan, et al PRC 2004

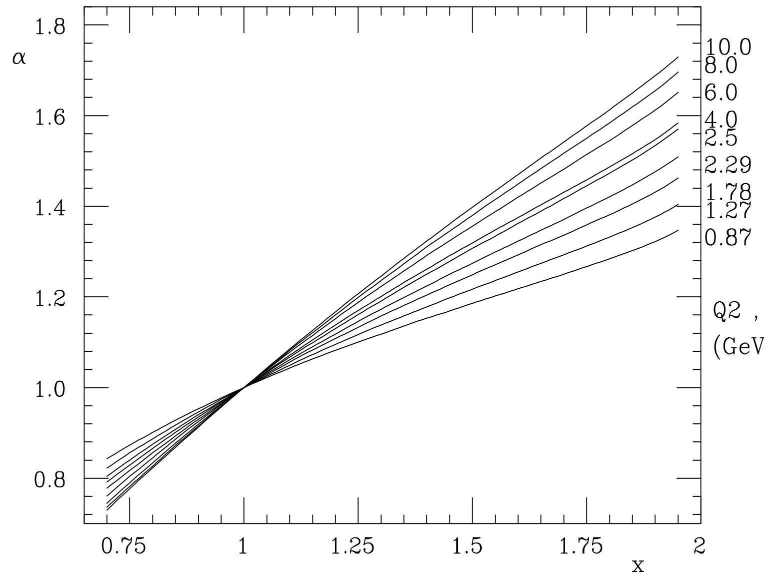
2N SRCs:

Proper Variables of 2N SRC are

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

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





Day, Frankfurt, MS,
Strikman, PRC 1993

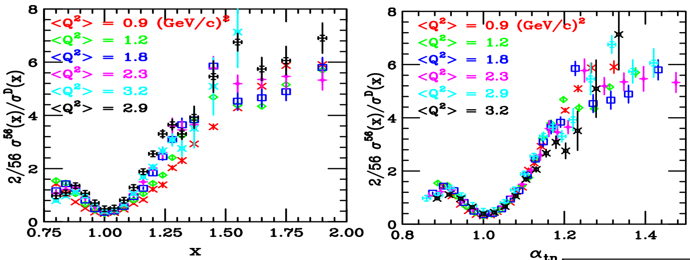
Back to inclusive A(e,e')X scattering

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

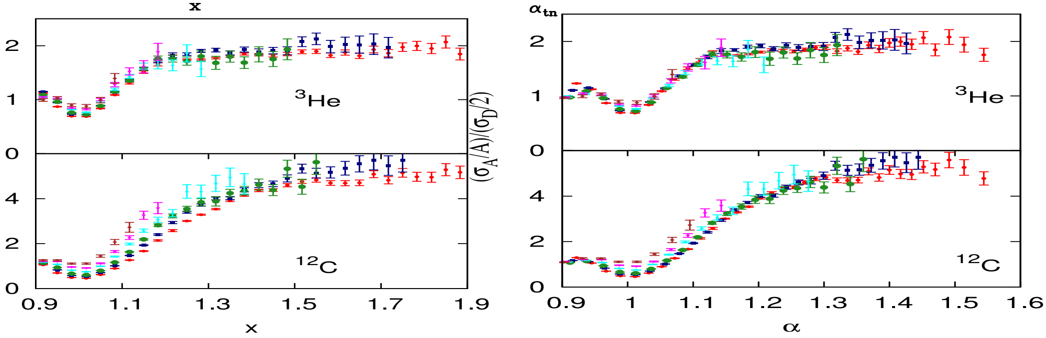
$$1.3 \le \alpha_{2N} \le 1.5$$

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

$$\alpha \Big|_{Q^2 \to \infty} \to x$$
$$\alpha \Big|_{x \to 1} \to 1$$



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

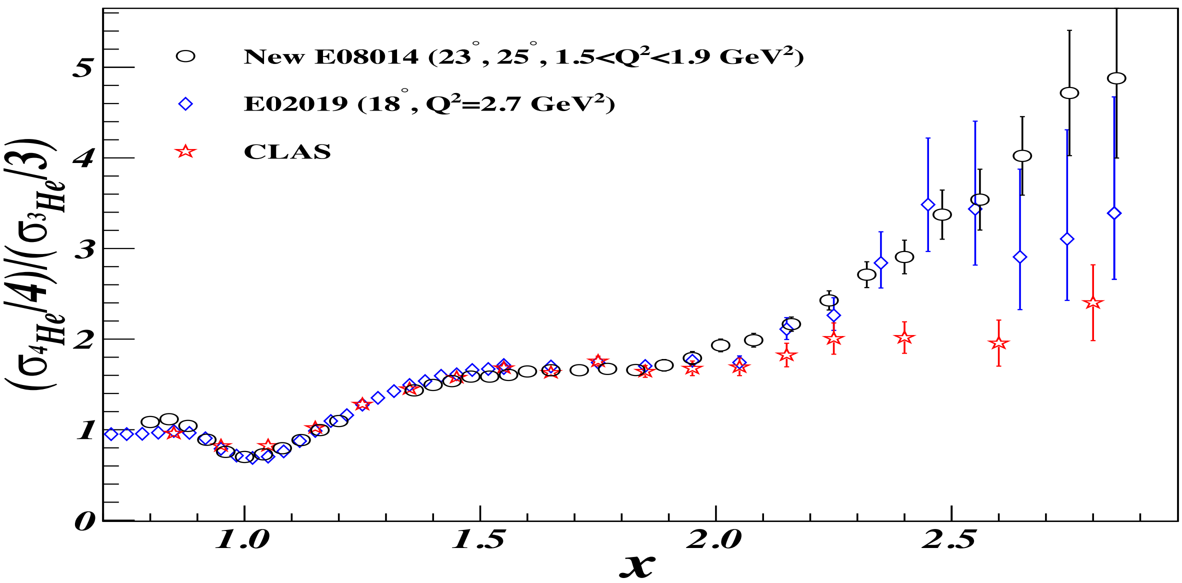


N.Fomin, D.Higinbotham
M.S., P.Sovignon ARNPS, 2017

Three Nucleon Short Range Correlations

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

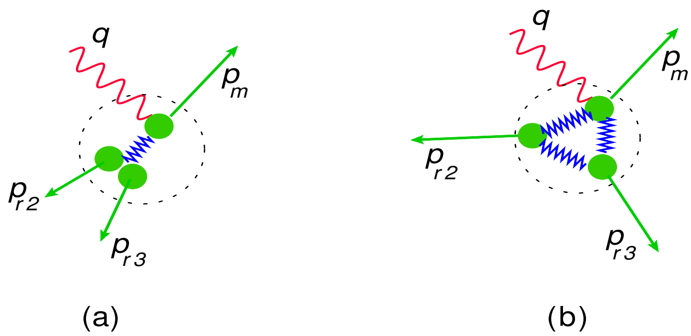
Z. Ye, at al, 2017



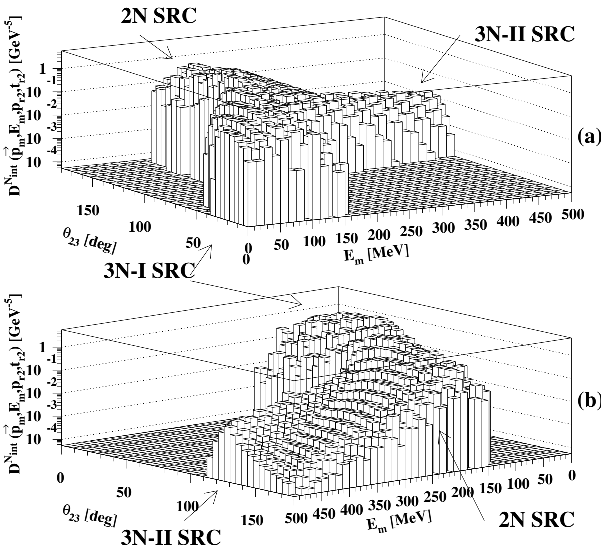
3N SRCs:

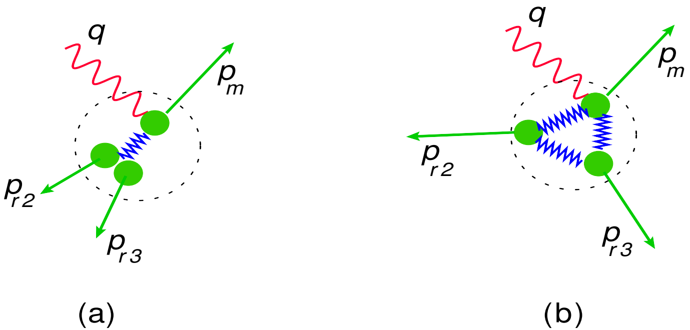
Proper Variables of 3N SRC are

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



3N SRCs:


2N SRC
3N-II SRC
(a)
θ23 [deg]
Em [MeV]
3N-I SRC
(b)
3N-II SRC
2N SRC


q
pm
pr2
pr3
(a)
(b)

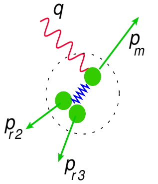
3N SRC model

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

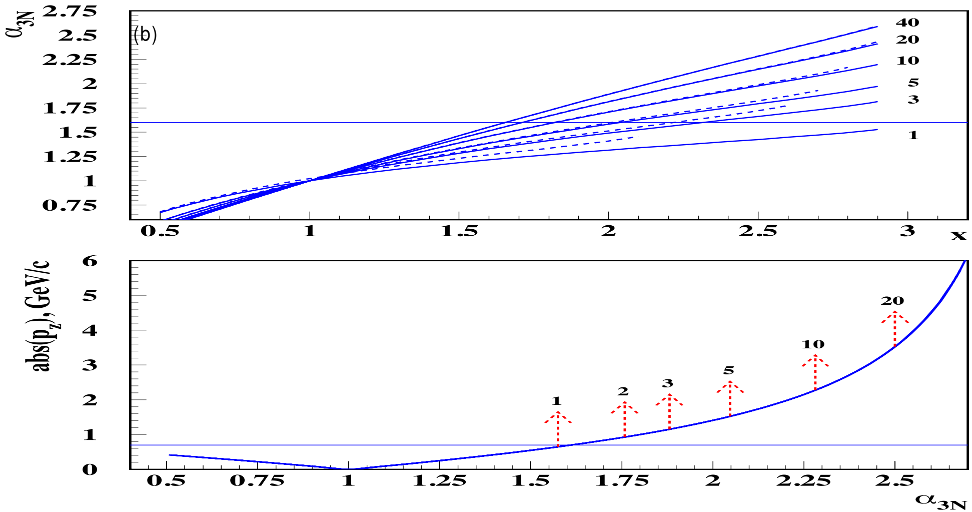
$$1.6 \leq \alpha_{3N} < 3$$

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

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



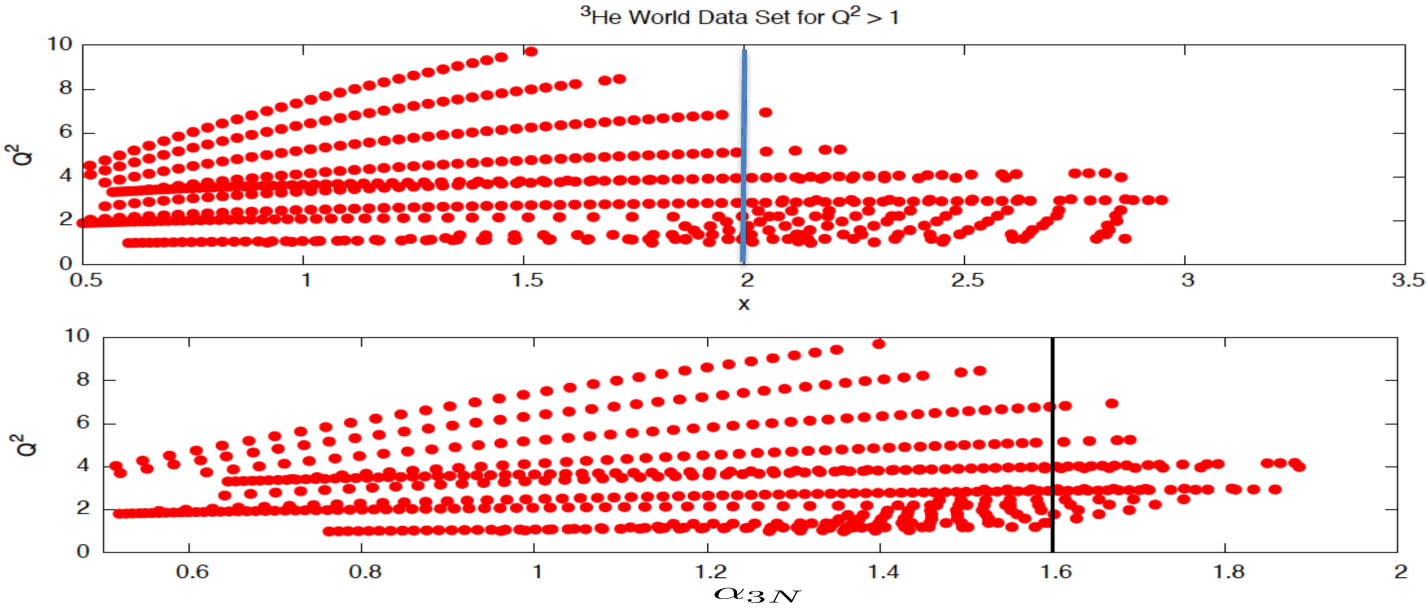
(a)



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, M.S., Frankfurt, Strikman 2018



3N SRCs

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

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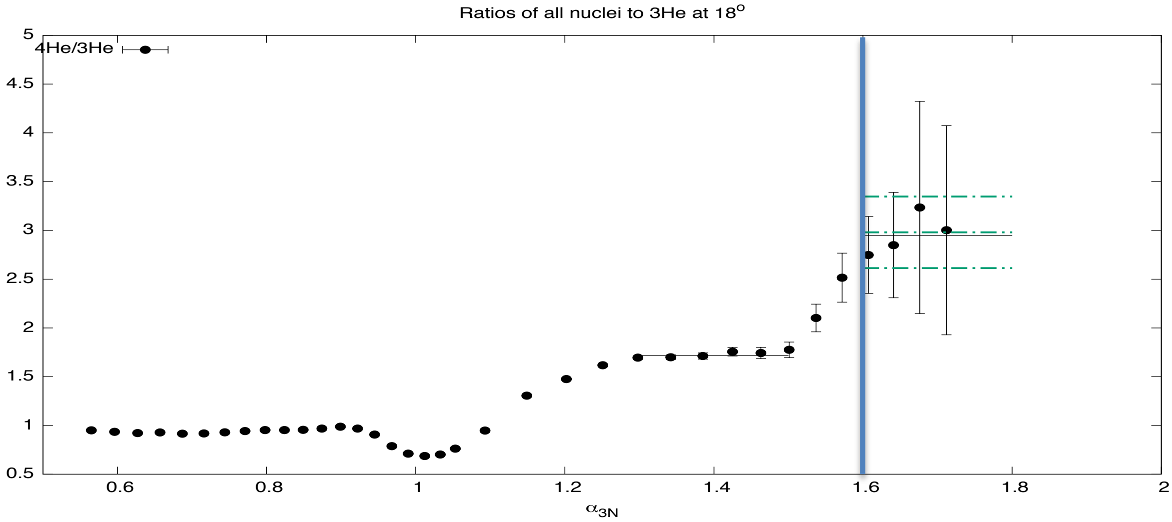
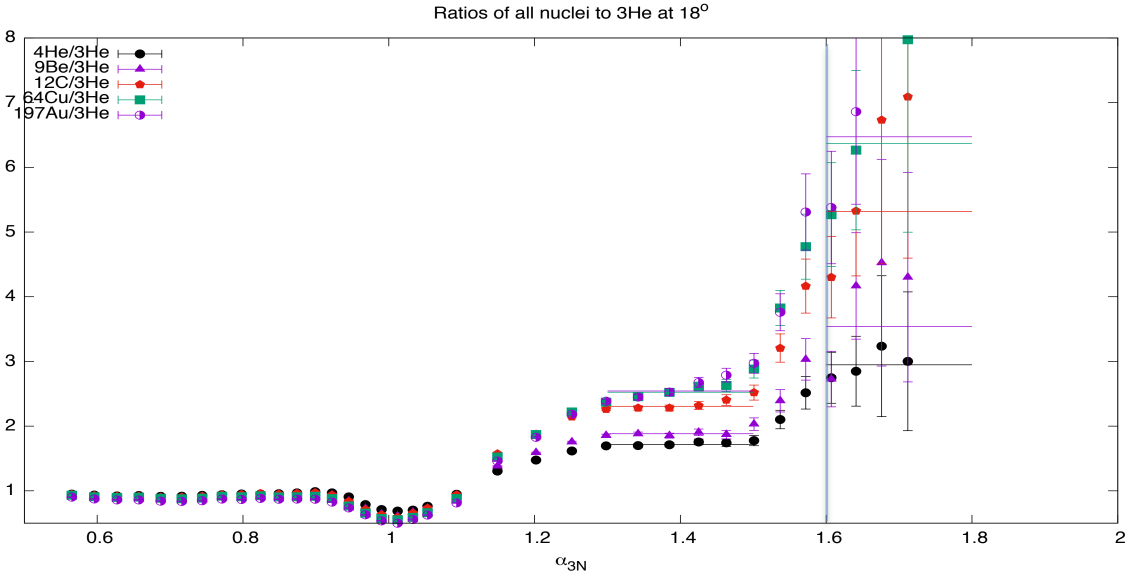


JLab - E02019 - Data

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

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

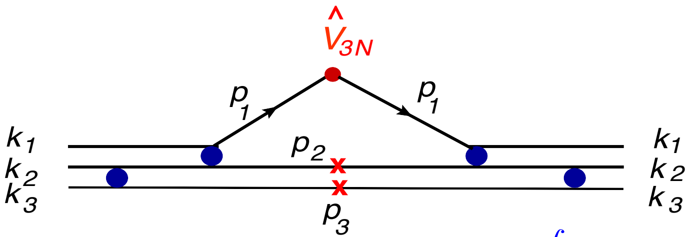


JLab - E02019 - Data

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



$$P^N_{A,3N}(\alpha_1, p_{1,\perp}, s_1, \tilde{M}_N) = \sum_{s_2,s_3,s_{2'},\tilde{s}_{2'}} \int \bar{u}(k_1)\bar{u}(k_2)\bar{u}(k_3)\Gamma^\dagger_{NN\to NN}\frac{u(p_{2'},\tilde{s}_{2'})\bar{u}(p_{2'},\tilde{s}_{2'})}{p^2_{2'} - M^2_N}$$

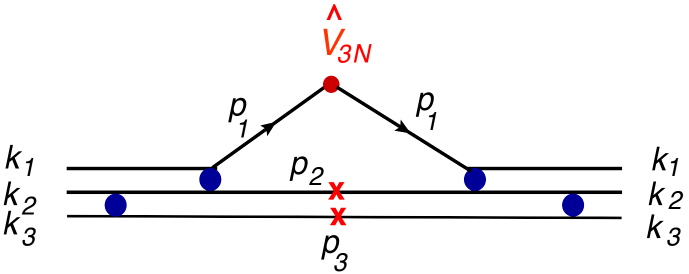
$$\times\ \Gamma^\dagger_{NN\to NN}\frac{u(p_1,s_1)}{p_1^2 - M_N^2}u(p_2,s_2)\left[2\alpha_1^2\delta(\alpha_1+\alpha_2+\alpha_3-3)\delta^2(p_{1\perp}+p_{2\perp}+p_{3\perp})\delta(\tilde{M}_N^2 - M_N^{3N,2})\right]$$

$$\times\ \bar{u}(p_2,s_2)\frac{\bar{u}(p_1,s_1)}{p_1^2 - M_N^2}\Gamma_{NN\to NN}\frac{u(p_{2'},s_{2'})\bar{u}(p_{2'},s_{2'})}{p^2_{2'} - M^2_N}u(p_3,s_3)\bar{u}(p_3,s_3)\Gamma^\dagger_{NN\to NN}u(k_1)u(k_2)u(k_3)$$

$$\times\ \frac{d\alpha_2}{\alpha_2}\frac{d^2p_{2\perp}}{2(2\pi)^3}\frac{d\alpha_3}{\alpha_3}\frac{d^2p_{3\perp}}{2(2\pi)^3}, \qquad (1)$$

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

3N SRC: Light-Cone Momentum Fraction Distribution



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

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

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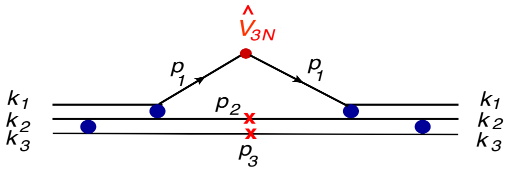


$$-\rho_{3N} \sim a_2(A,z)^2$$

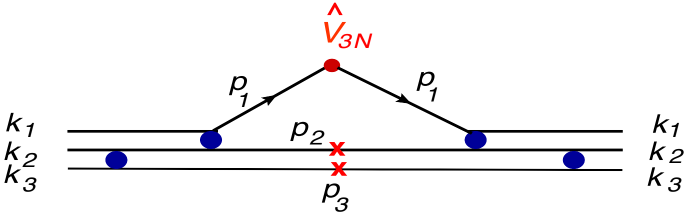
- For A(e,e') X reactions: $\sigma_{eA} = \sum_N \sigma_{eN}\rho_{3N}(\alpha_{3N})$

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

- 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: $R_2(A,Z) = \frac{3\sigma_{eA}}{A\sigma_{e^3He}}\Big|_{1.3\leq\alpha_{3N}\leq1.5}$ 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

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

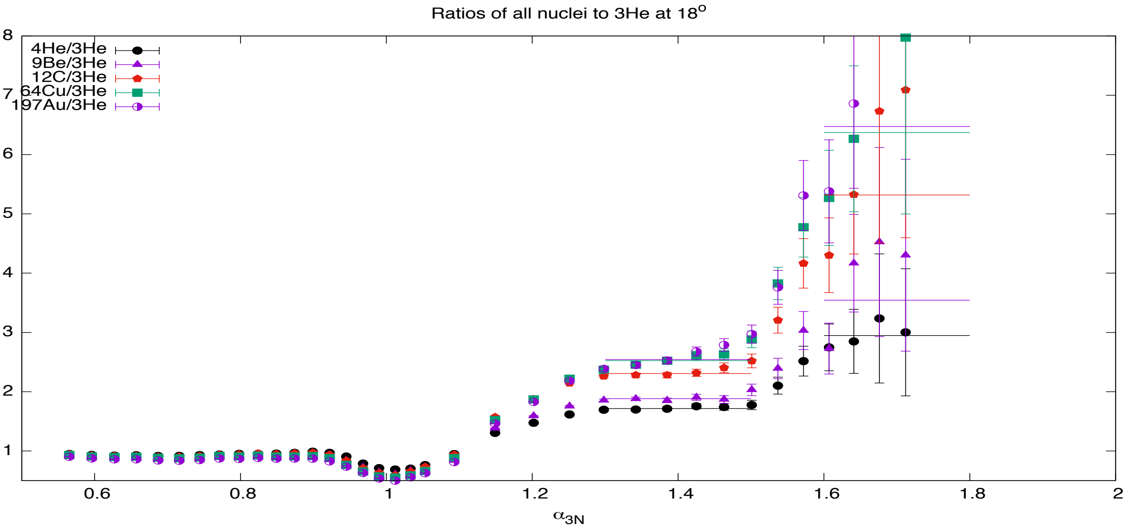
3N SRC model

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

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

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

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



3N SRC model

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

$$R_3 = \frac{3\sigma_{eA}(\alpha_{3N})}{A\sigma_{3A}(\alpha_{3N})} \quad 1.6 \leq \alpha_{3N} \leq 1.8 \qquad R_3(A) = R_2(A)^2$$

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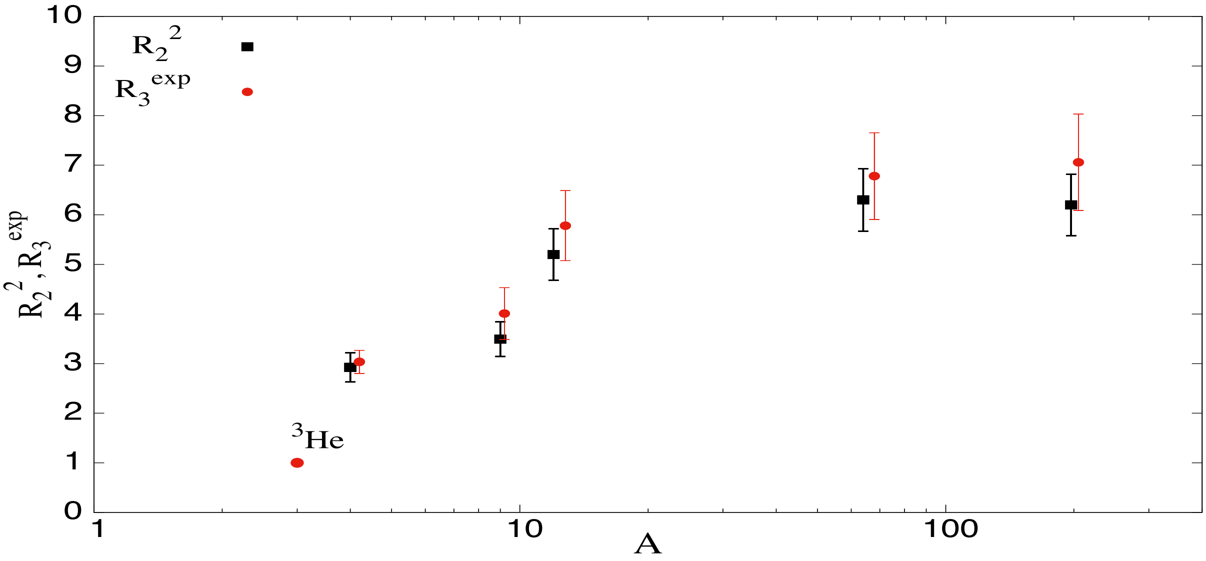

3N SRC model

Defining: $a_3(A,Z) = \frac{3}{A}\frac{\sigma_{eA}}{(\sigma_{e^3He}+\sigma_{e^3H})/2}$

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

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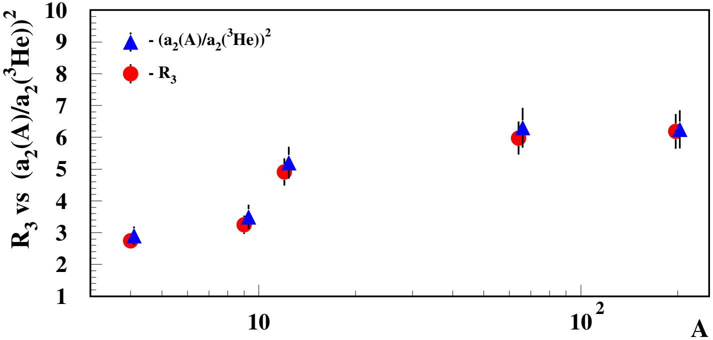
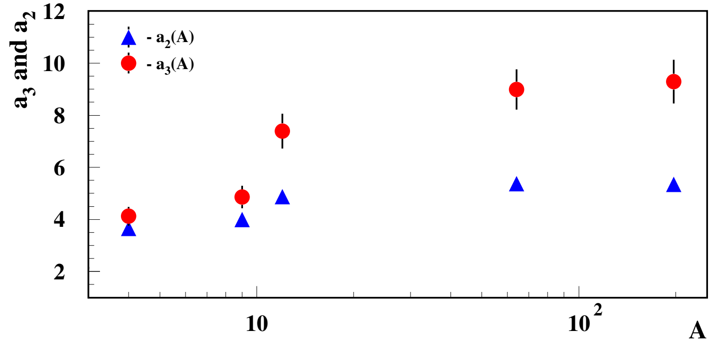
3N SRC model

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

$$R_3 = \frac{3\sigma_{eA}(\alpha_{3N})}{A\sigma_{3A}(\alpha_{3N})} \quad 1.6 \leq \alpha_{3N} \leq 1.8 \qquad R_3(A) = R_2(A)^2$$





3N SRC Summary & Outlook

- Proper variable for studies of 2N and 3N SRS are Light-Cone momentum fractions: α_{2N}, α_{3N}

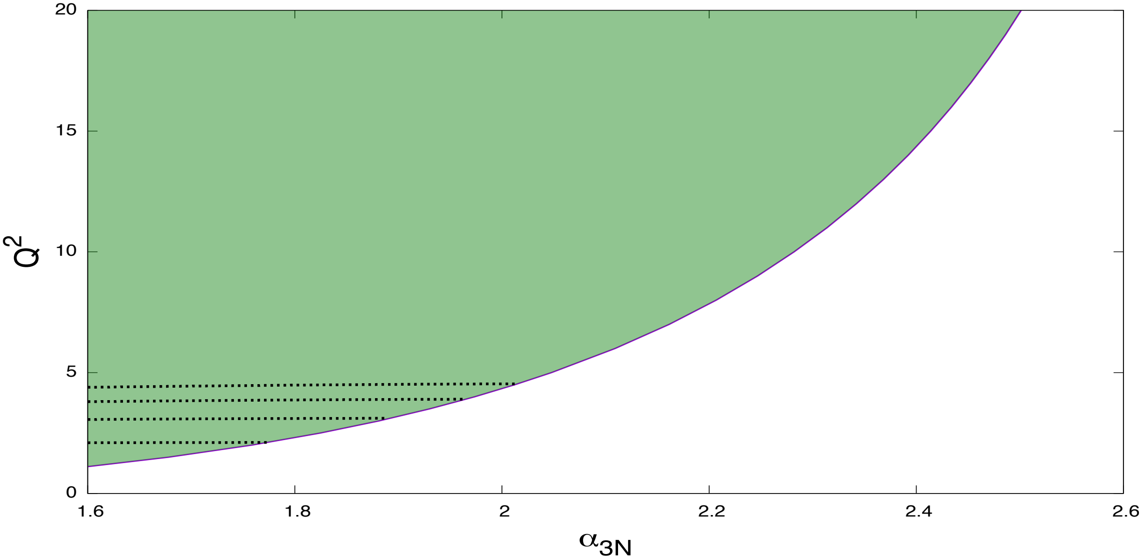
- It seems we observed first signatures of 3N SRCs in the form of the "scaling"

- Existing data in agreement with the prediction of: $R_3(A,Z) \approx R_2(A,Z)^2$

- Unambiguous verification will require larger Q2 data to cover larger α_{3N} region

- Reaching Q2 > 5 GeV2 will allow to reach: $\alpha_{3N} > 2$

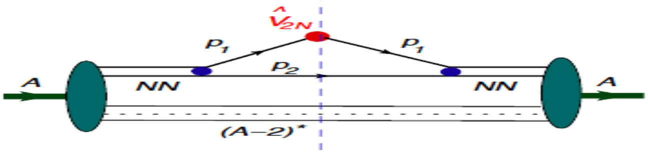
3N SRC Outlook



3N SRCs in Exclusive Processes: A(e,e′pp)X

Genuine pp-2NSRC vs pnp 3NSRC

Considering A(e,e'pp)X process: looking for apparent pp short range correlations

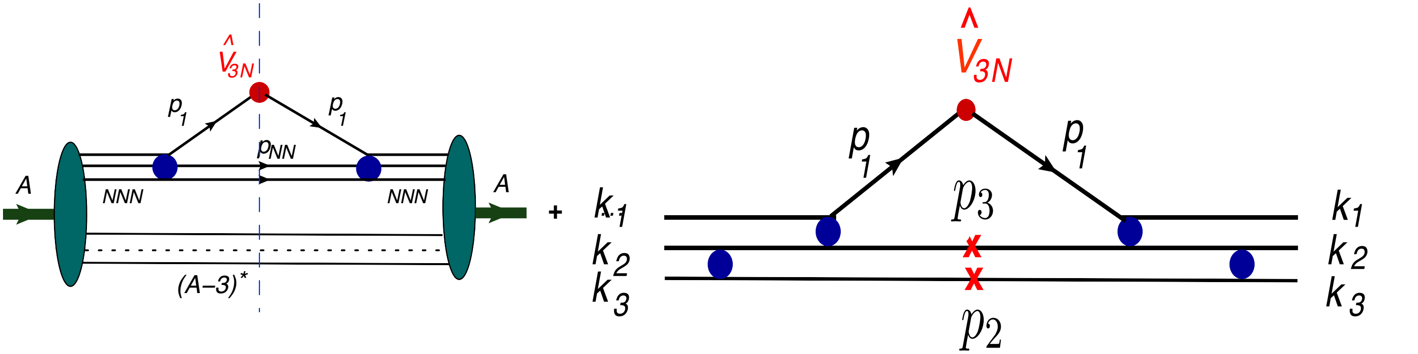


$$D_{A,2N}(\alpha_1, p_{1\perp}, \alpha_2, p_{2\perp}) = \rho_{pp}(\beta_1, k_{1\perp})\rho_{CM}(\alpha_{cm}, p_{cm,\perp})\frac{\alpha_2}{\alpha_{cm}}$$

$$\beta_1 = \frac{2\alpha_1}{\alpha_{cm}} \qquad \beta_2 = \frac{2\alpha_2}{\alpha_{cm}}$$

$$k_{1\perp} = p_{1\perp} - \frac{\beta_1}{2} p_{cm,\perp}$$

Considering A(e,e'pp)X process: looking for apparent pp short range correlations

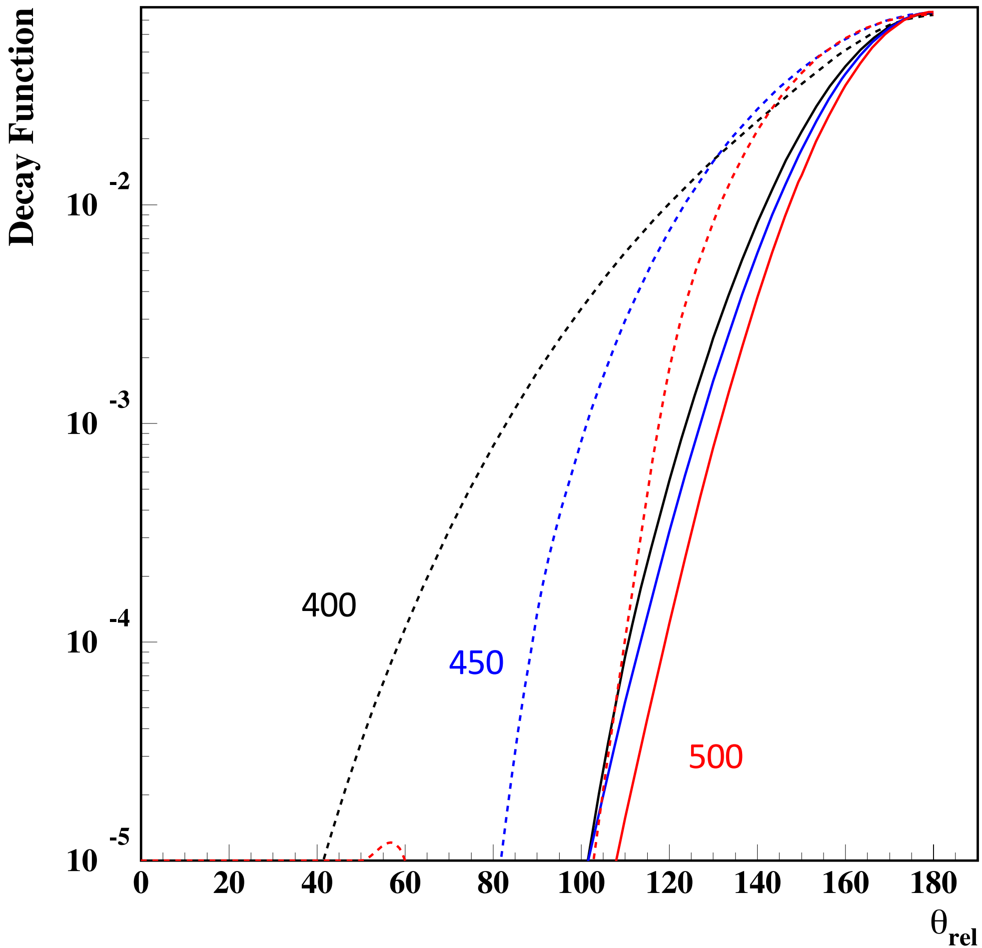


$$D_{A,3N}(\alpha_1, p_{1\perp}, \alpha_2, p_{2\perp}) = \frac{3-\alpha_2}{2(2-\alpha_3)^2}\rho_{pn}(\beta_3', k_{3\perp}')\rho_{pn}(\beta_1, k_{1,\perp})\alpha_3$$

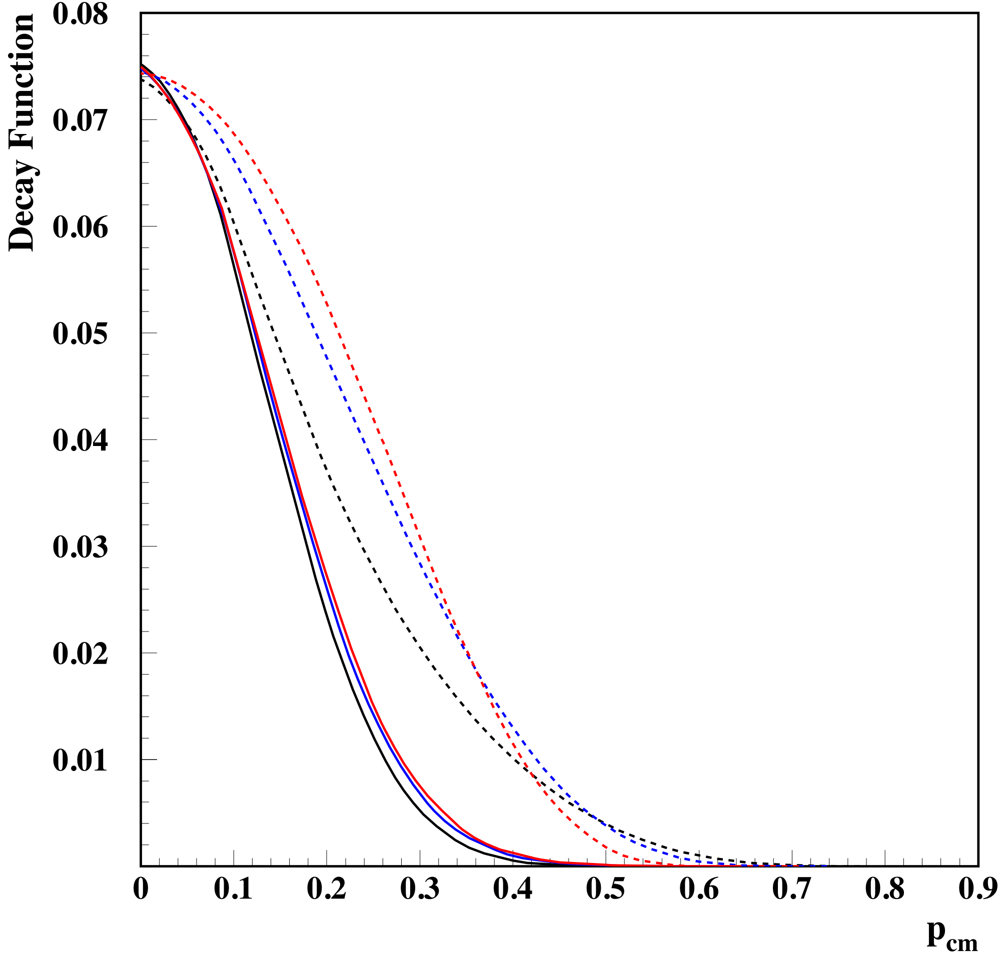
$$\alpha_2 = 3 - \alpha_1 - \alpha_3 \qquad \beta_3' = 2 - \beta_2$$

$$\beta_1 = \frac{2\alpha_1}{3-\alpha_2} \qquad \beta_2 \approx \alpha_2$$

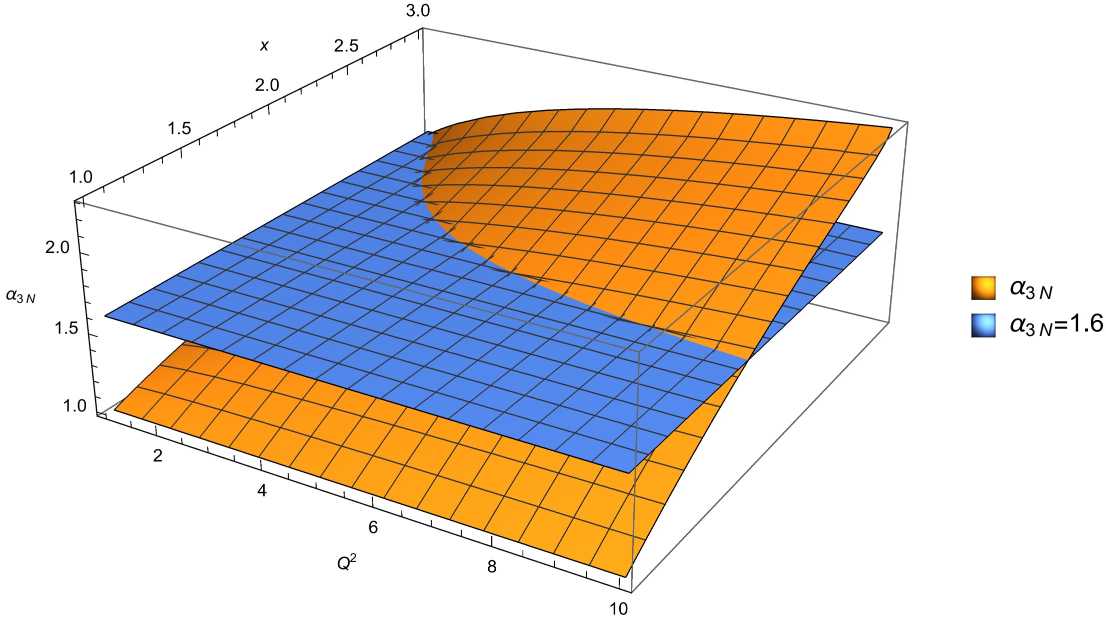
$$k_{1\perp} = p_{1\perp} + \frac{\beta_1}{2} p_{2\perp} \qquad k_3' \approx -p_{2\perp}$$



Decay Function
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
20
40
60
80
100
120
140
160
180
θ_{rel}
400
450
500



Decay Function
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
p_{cm}



x
1.0
1.5
2.0
2.5
3.0
α_{3N}
1.0
1.5
2.0
Q^2
2
4
6
8
10
α_{3N}
α_{3N}=1.6