Possible Topics for Inclusive/Sem-Inclusive eA scattreing

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I. Inclusive x > 1

1. Extraction of a2(A,Z) for wide range of Nuclei

2. Extraction of Light-Front Momentum Distribution of Nuclei

3. Possible Medium Modification Effects in Quasi-Elastic Region

4. Probing Polarized Structure of the Deuteron at $x > 1$

5. Probing Superfast Quarks - Setting up Studies of nuclear partonic distributions at $x>1$

6. Probing superfast quarks in jet production at LHC/EIC

II. Inclusive x > 2

1. Looking for the Plateau in Inclusive Cross Section Ratios

2. Understanding Transition from 2N to 3N SRCs

3. Extraction of Momentum Distribution in 3N SRC Region

4. Center of mass motion effects in 3N SRCs Semi-Inclusive Reactions

III. Semi-Inclusive Processes

1. Probing Deuteron & Extracting Nuclear TMDs

2. Looking for the Plateaus? in (e,e'N) Reactions

3. Probing $x - \alpha$ correlations in fast backward production off nuclei

4. Probing Non-nucleonic Components in Nuclei in Backward Production of Resonances

Trident Experiments

Emergence of Short-Range Correlations

- start with A-body Schroedinger equation interacting by two body potential only

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

- Introducing

$$\psi(x_1, \cdots, x_A) = \int \Phi(k_1, \cdots k_A) e^{i\sum_i k_i x_i} \prod_i \frac{d^3 k_i}{(2\pi)^{3/2}}$$

$$V(x_i - x_j) = \int U(q) e^{iq(x_i - x_j)} d^3 q$$

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

- Assume: system is dilute

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

- then the k dependence of the wave function for $k^2/2m_N \gg |E_B|$

Amado, 1976

$$\Phi^{(1)}(k_1,\cdots,k_c,\cdots,-k_c,\cdots,k_A) \approx \frac{U_{NN}(k_c)}{k_c^2} F_A(k_1,\cdots'\cdots',\cdots,k_A)$$

- Assume: $U_{NN}(q) \sim \frac{1}{q^n}$ with $n > 1$

$$\Phi^{(2)}(\cdots k_c,\cdots) \sim \frac{1}{k_c^{2+n}}\int \frac{1}{q^n}dq \sim \frac{U_{NN}(k_c)}{k_c^2}\int_{q_{min}} \frac{1}{q^n}dq$$

- For large k_c $\Phi^{(2)}(k_c) \ll \Phi^{(1)}(k_c)$

Frankfurt, Strikman 1981

- 3N SRCs are parametrically smaller than 2N SRC

- The same is true for relativistic equations as:

Bethe-Salpeter or Weinberg Light Cone Equations

- From $\Phi^{(1)}(k_1,\cdots,k_c,\cdots,-k_c,\cdots,k_A) \approx \frac{U_{NN}(k_c)}{k_c^2} F_A(k_1,\cdots'\cdots',\cdots,k_A)$ follows

for large $k > k_{Fermi}$

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

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

- Experimental observations

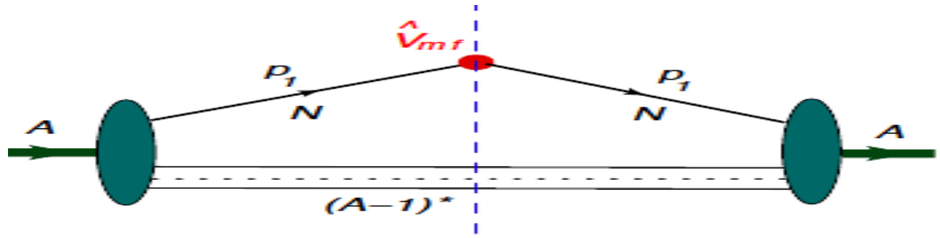
Egiyan et al, 2002,2006
Fomin et al, 2011

Modeling High Momentum and Missing Energy Nuclear Spectral Functions

- All best models are nonrelativistic

- SRC model allows to derive relativistic spectral functions if we know how to treat 2N SRCs relativistically

Mean Field Approximation



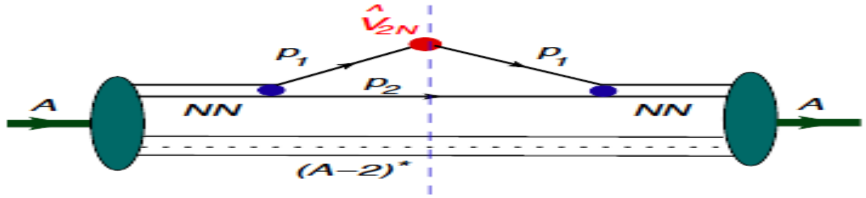
$$S_A^{MF} = -Im \int \chi_A^\dagger \Gamma^\dagger_{A,N,A-1} \frac{\not p_1 + m}{p_1^2 - m^2 + i\varepsilon} \hat{V}^{MF} \frac{\not p_1 + m}{p_1^2 - m^2 + i \times \varepsilon} \left[\frac{G_{A-1}(p_{A-1})}{p_{A-1}^2 - M_{A-1}^2 + i\varepsilon} \right]^{on} \Gamma_{A,N,A-1} \chi_A \frac{d^4 p_{A-1}}{i(2\pi)^4}$$

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

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

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

2N SRC model



$$S_A^{2N} = Im\int \chi_A^\dagger \Gamma^\dagger_{A,NN,A-2} \frac{G(p_{NN})}{p_{NN}^2 - M_{NN}^2 + i\varepsilon} \Gamma^\dagger_{NN\to NN} \frac{\not p_1 + m}{p_1^2 - m^2 + i\varepsilon} \hat{V}^{2N} \frac{\not p_1 + m}{p_1^2 - m^2 + i\varepsilon} \left[\frac{\not p_2 + m}{p_2^2 - m^2 + i\varepsilon}\right]^{on} \times$$

$$\Gamma_{NN\to NN} \frac{G(p_{NN})}{p_{NN}^2 - M_{NN}^2 + i\varepsilon} \left[\frac{G_{A-2}(p_{A-2})}{p_{A-2}^2 - M_{A-2}^2 + i\varepsilon}\right]^{on} \Gamma_{A,NN,A-2}\chi_A \frac{d^4p_2}{i(2\pi)^4} \frac{d^4p_{A-2}}{i(2\pi)^4}, \quad (1$$

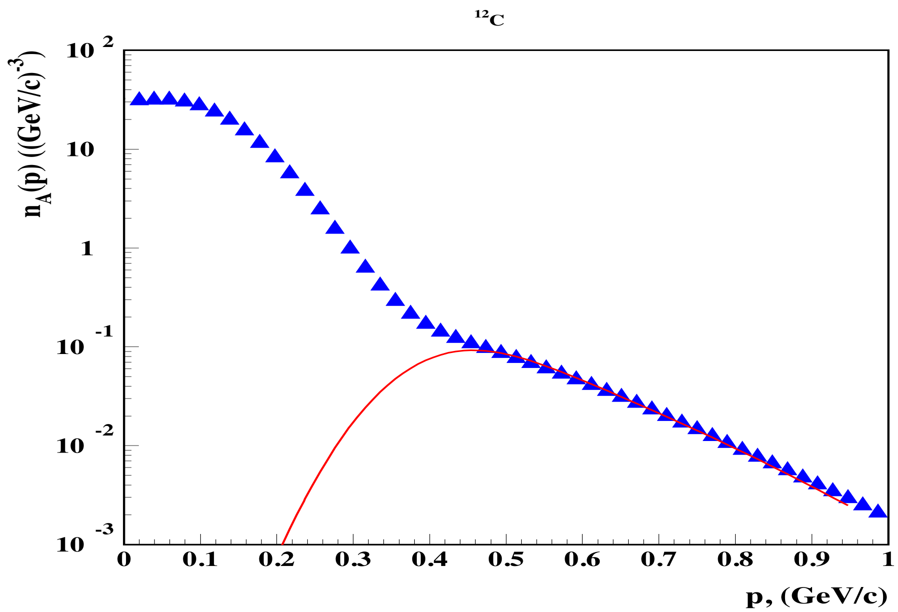
- Light-Front Approximation

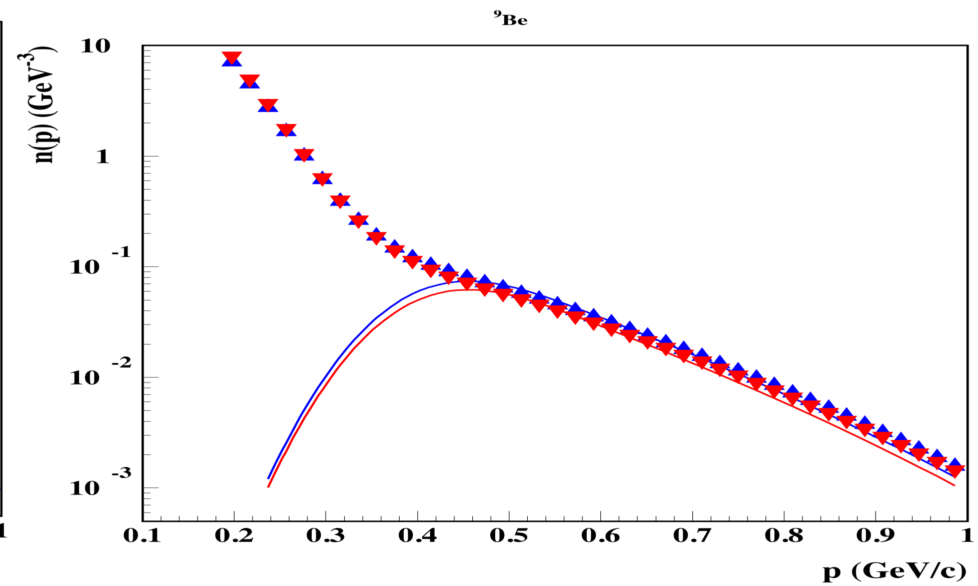
$$n_{CM}(p_{NN}) = N_0(A) e^{-\alpha(A) p_{NN}^2}$$

O.Artiles & M.S. 2016

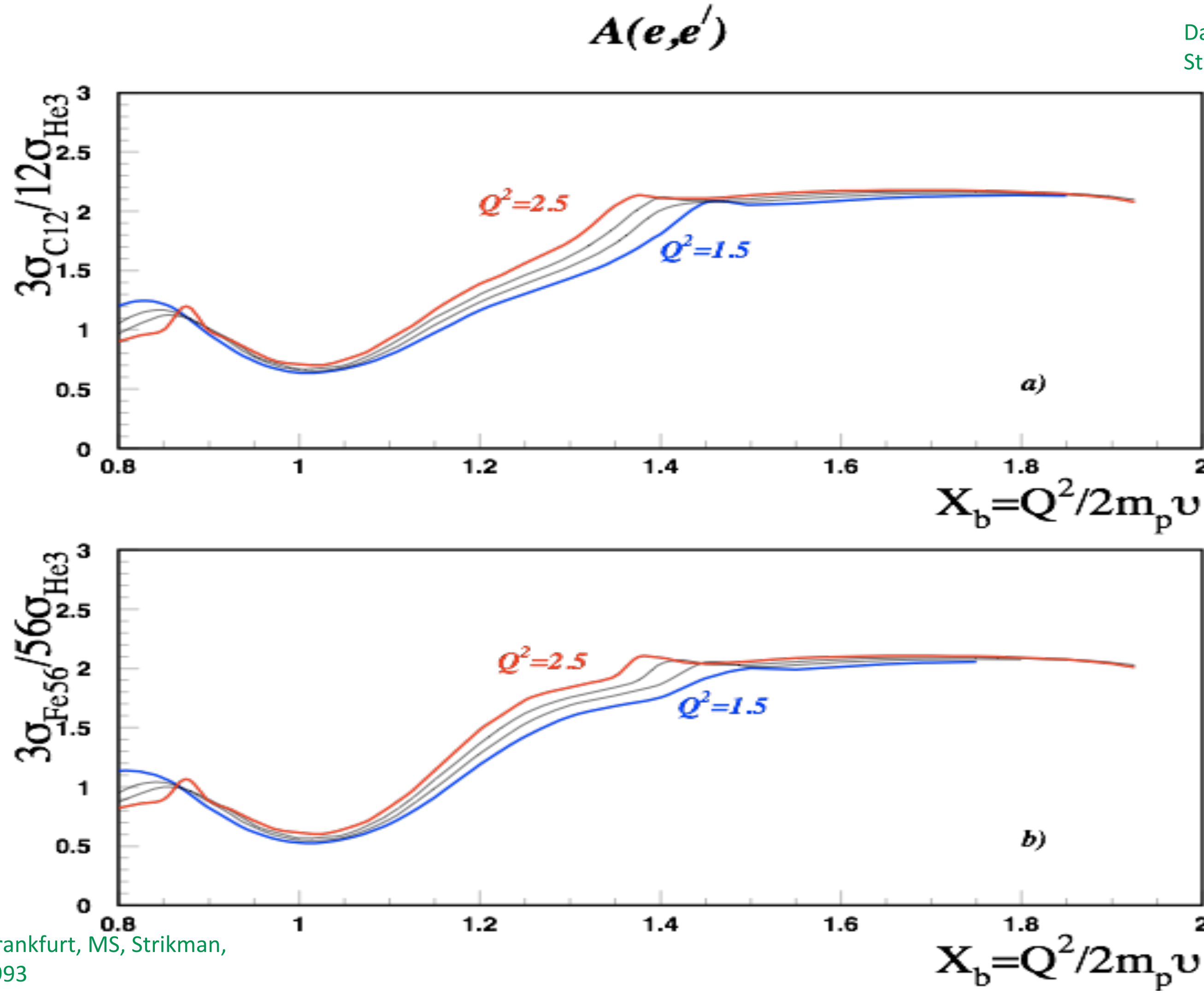
$$n_{NN}^N(p_{rel}) = \frac{a_2(A)}{(2x_N)^\gamma} n_d(p_{rel}) \qquad x_N = \frac{N}{A}$$

2N SRC model Non Relativistic Approximation



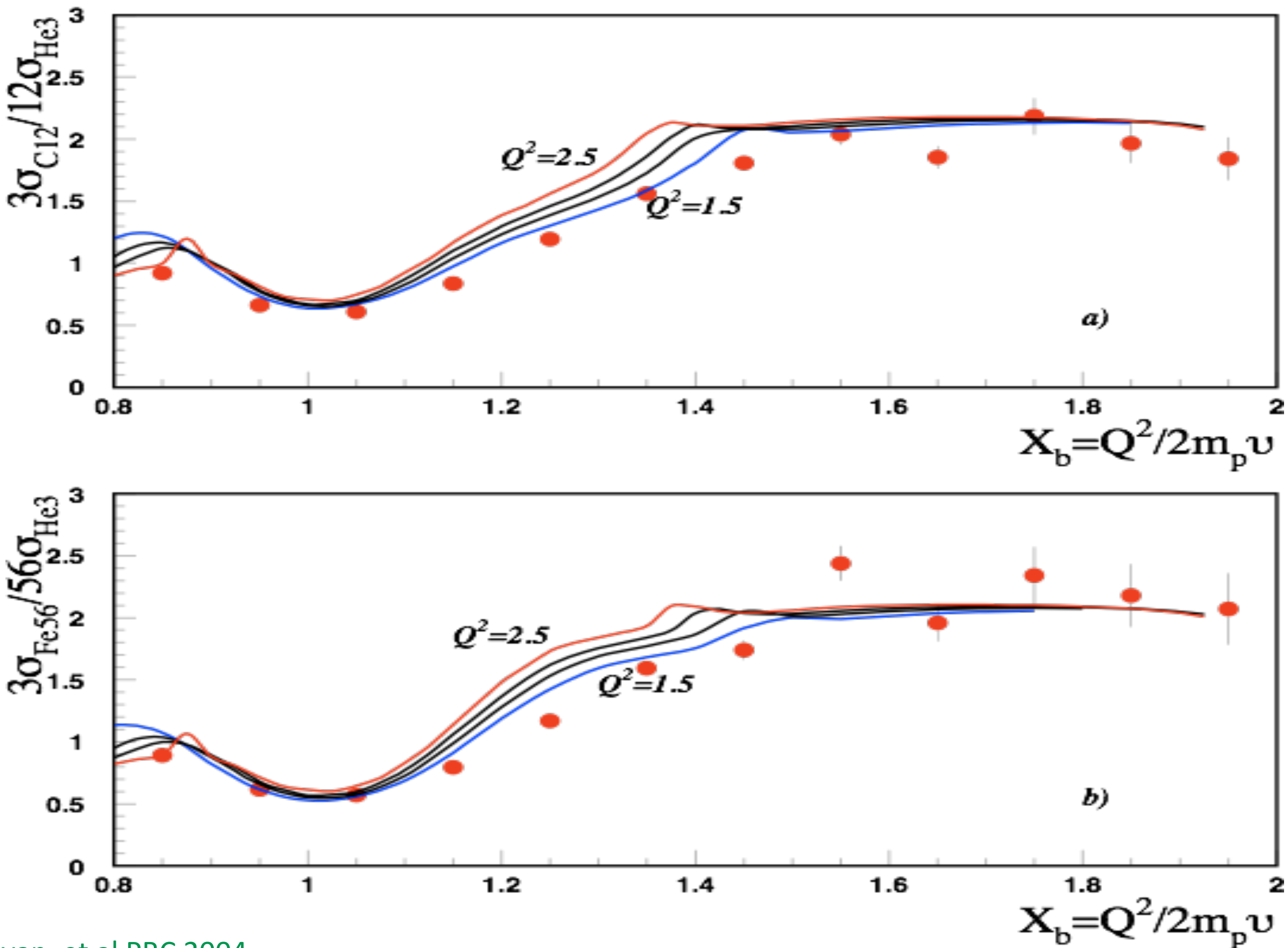


Day, Frankfurt, MS, Strikman, PRC 1993



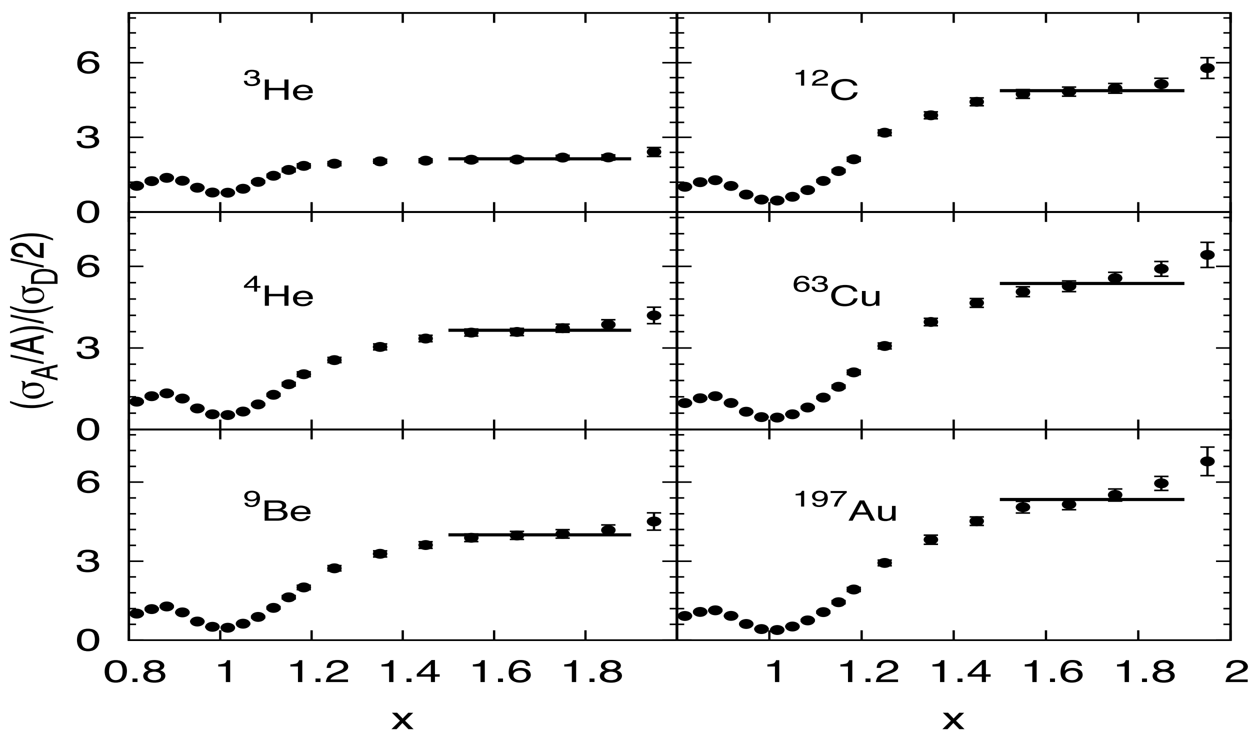
Day, Frankfurt, MS, Strikman, PRC 1993

$A(e,e')$

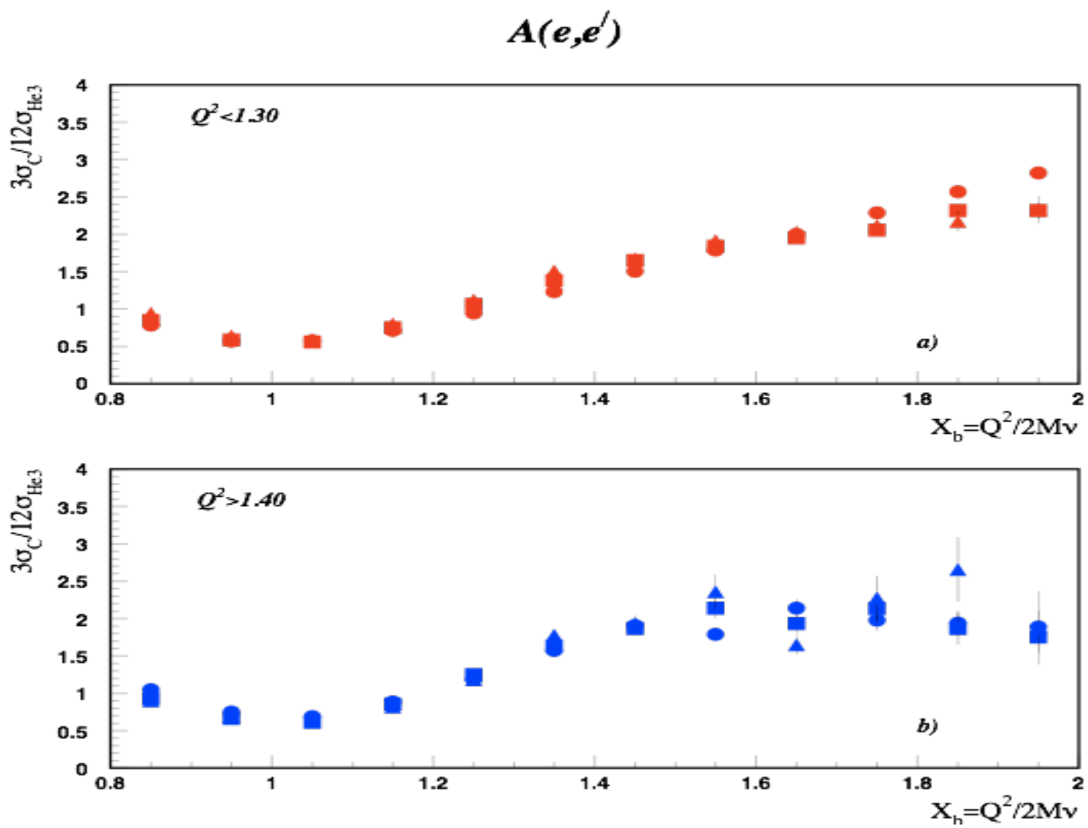


Fomin et al PRL 2011

Egiyan, et al PRC 2004



Fomin et al PRL 2011

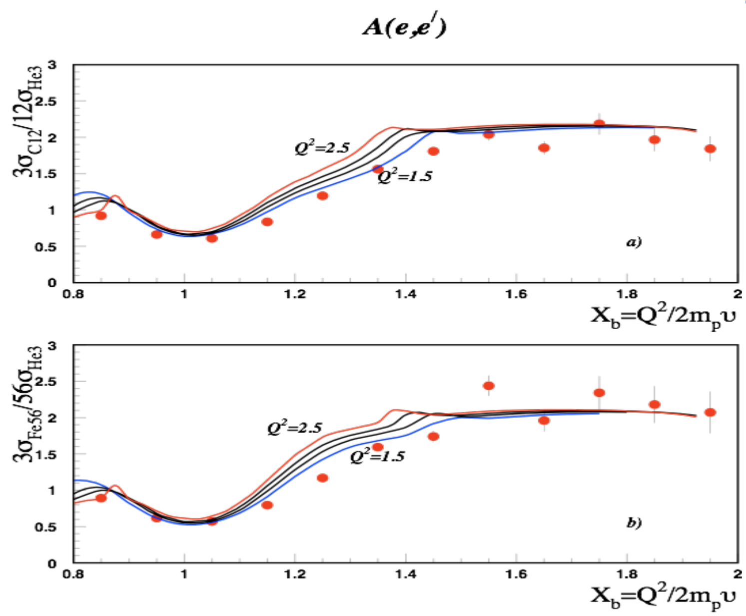


A(e,e′)
3σC/12σHe3
Q²<1.30
a)
Xb=Q²/2Mν
Q²>1.40
b)
Xb=Q²/2Mν

1. Extraction of a2(A,Z) for wide range of Nuclei

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

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



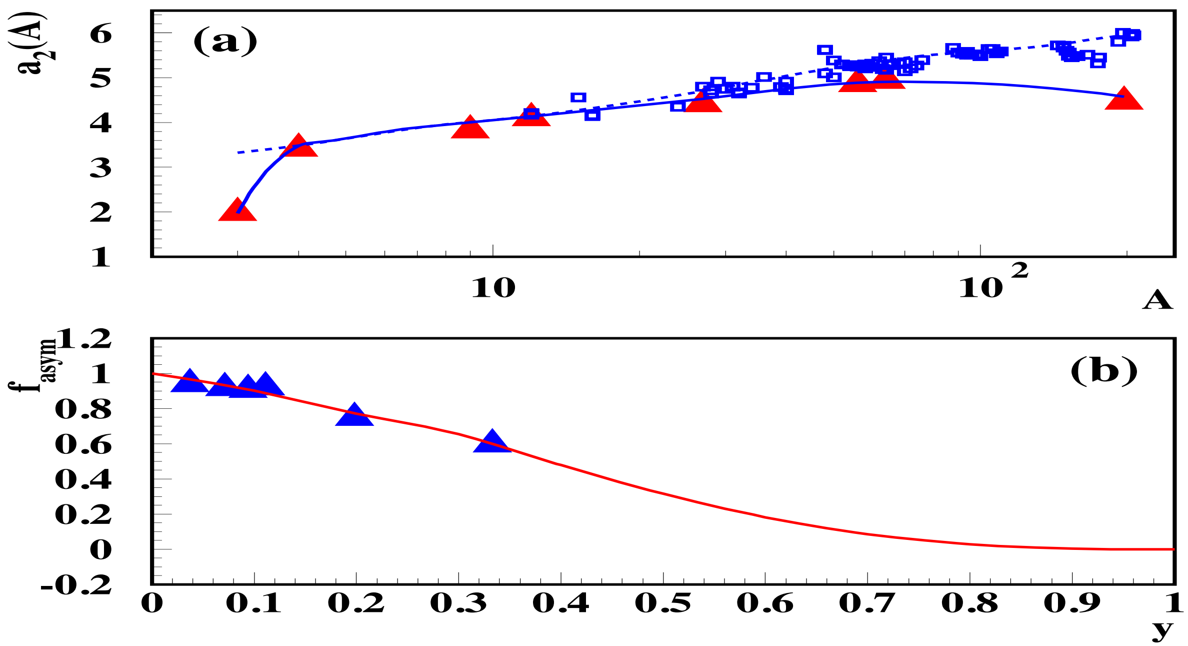
a2's as relative probability of 2N SRCs

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

Implications: For Nuclear Matter

$$a_2(A,y) = a_2(A,0)f(y)$$



Fitting $f(y)$

- 4 data points
- 2 boundary conditions due to the neglection of pp/nn SRCs
  $f(0) = 1$ and $f(1) = 0$
- 2 more boundary conditions due to
  $y \to 1$ and $y \to 0$ corresponds to $A \to \infty$
  $f'(0) = f'(1) = 0$
- 1 more positiveness of f(y)

$$f(y) \approx (1 + (b-3)y^2 + 2(1-b)y^3 + by^4) \qquad b \approx 3$$

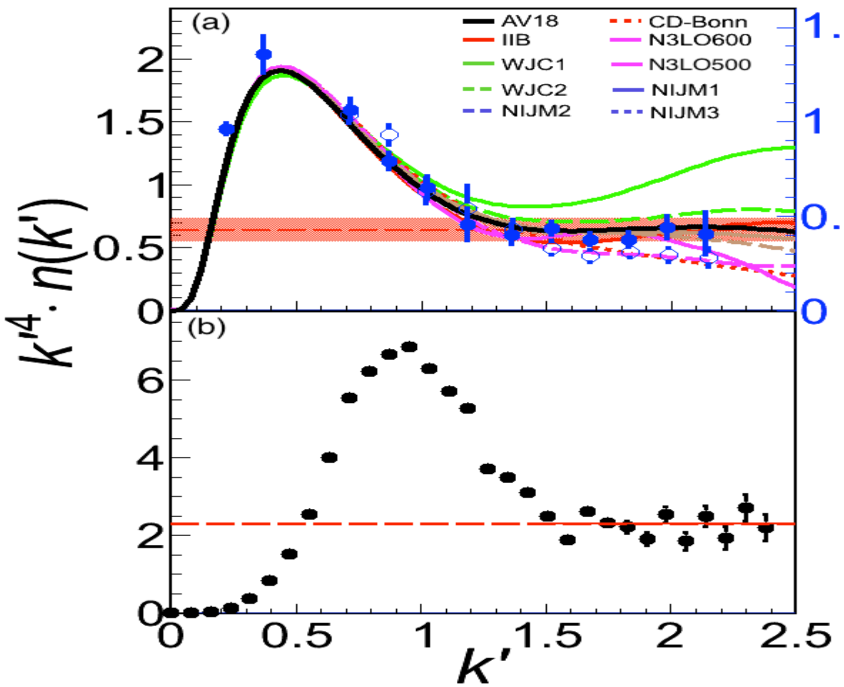
2. Extraction of Light-Front Momentum Distribution of Nuclei

$$F_{2A} = K\alpha f_A(\alpha)$$

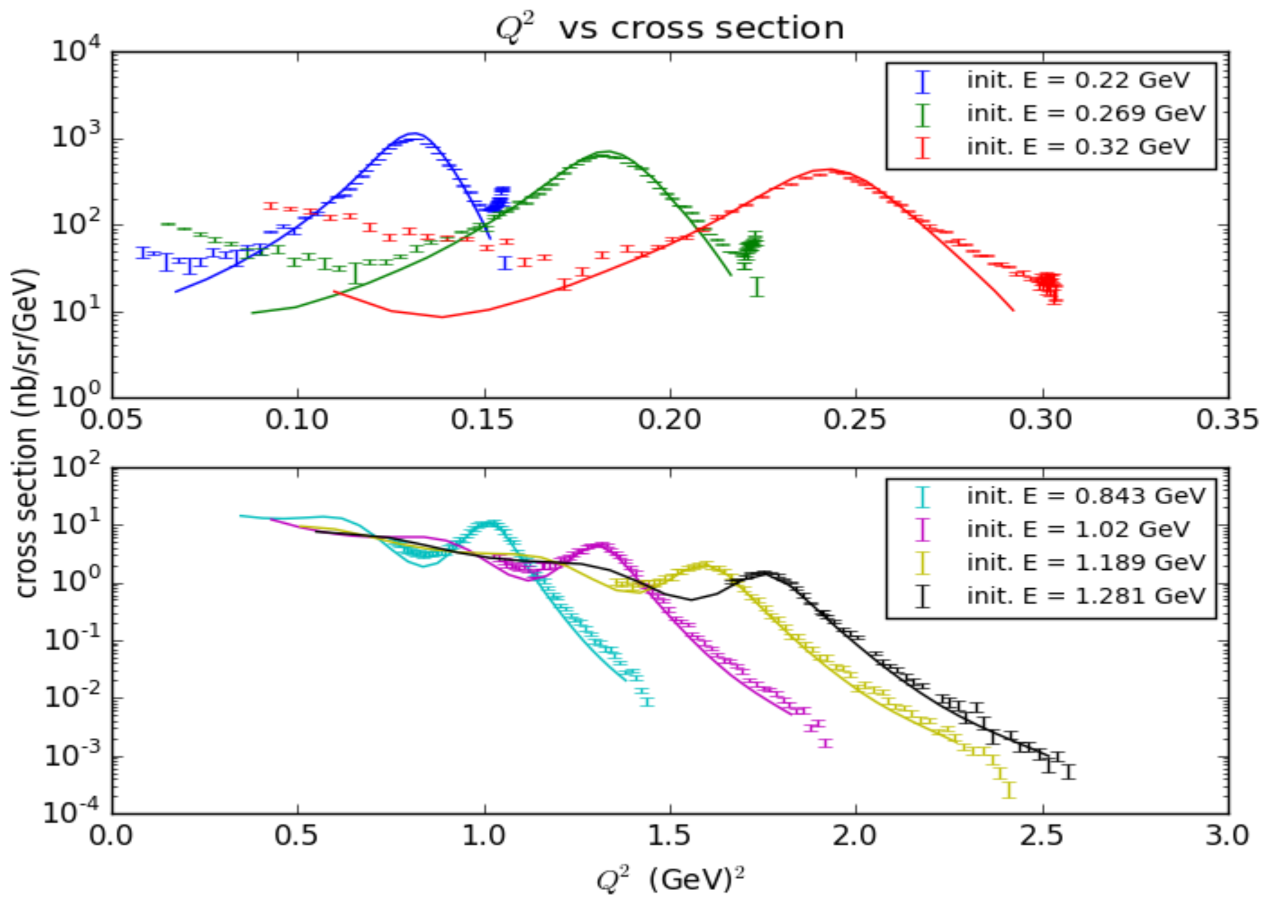
$$K \sim \sigma_{eN}^{LF}$$

$$f_A(\alpha) = \int \frac{1}{\alpha}\rho_A(\alpha, p_t) d^2 p_t$$

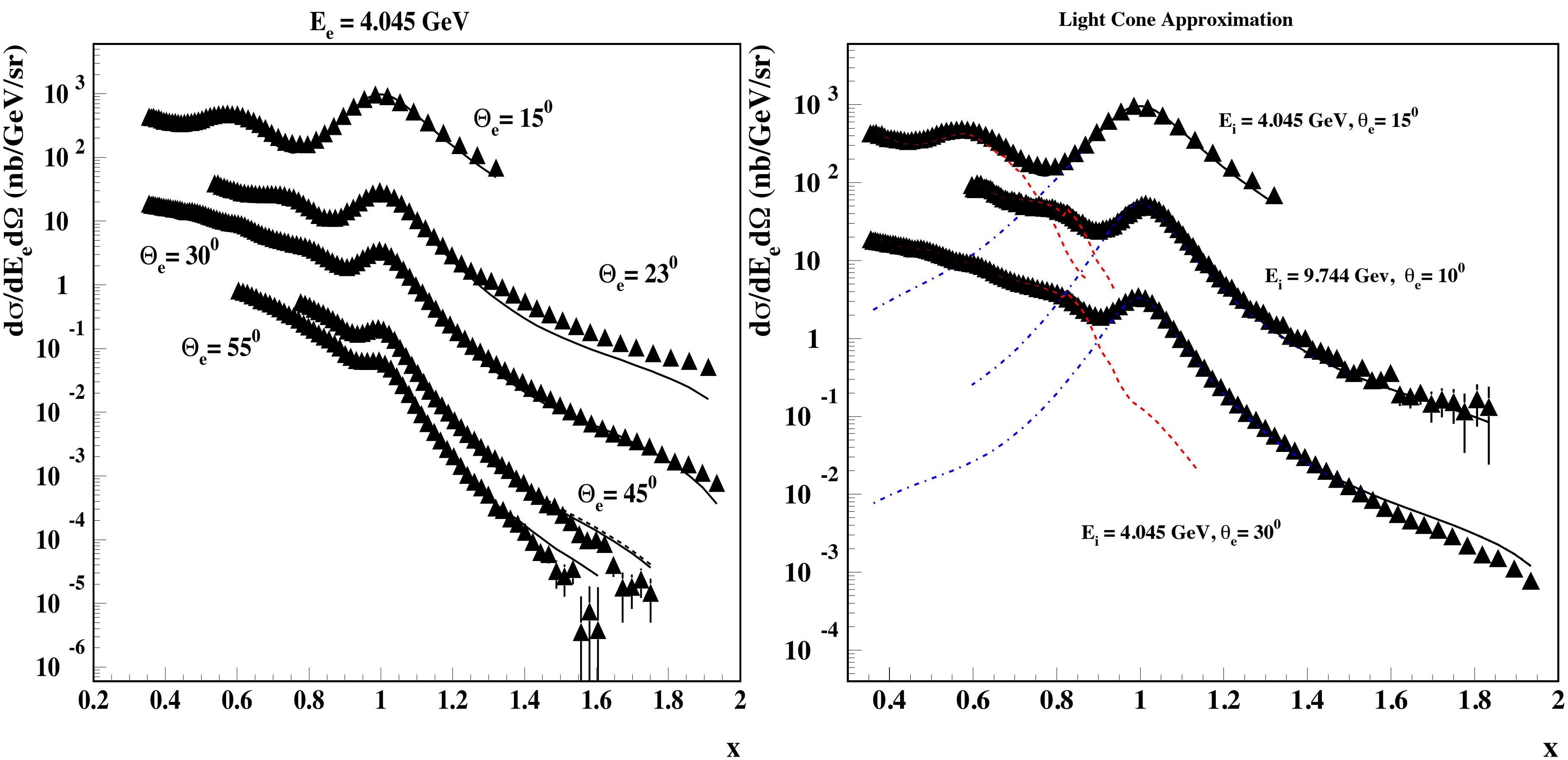
$$\alpha_{2N} = 2 - \frac{q_- + 2m_N}{2m_N}\left(1 + \frac{\sqrt{W_{2N}^2 - 4m_N^2}}{W_{2N}}\right)$$



3. Possible Medium Modification Effects in Quasi-Elastic Region



D.Day Data Base



E_e = 4.045 GeV
$d\sigma/dE_e d\Omega$ (nb/GeV/sr)
$\Theta_e = 15^0$
$\Theta_e = 23^0$
$\Theta_e = 30^0$
$\Theta_e = 45^0$
$\Theta_e = 55^0$
x
Light Cone Approximation
$d\sigma/dE_e d\Omega$ (nb/GeV/sr)
E_i = 4.045 GeV, $\theta_e = 15^0$
E_i = 9.744 Gev, $\theta_e = 10^0$
E_i = 4.045 GeV, $\theta_e = 30^0$
x

4. Probing Polarized Structure of the Deuteron at $x > 1$

- Tensor Polarized Deuteron = Compact Deuteron

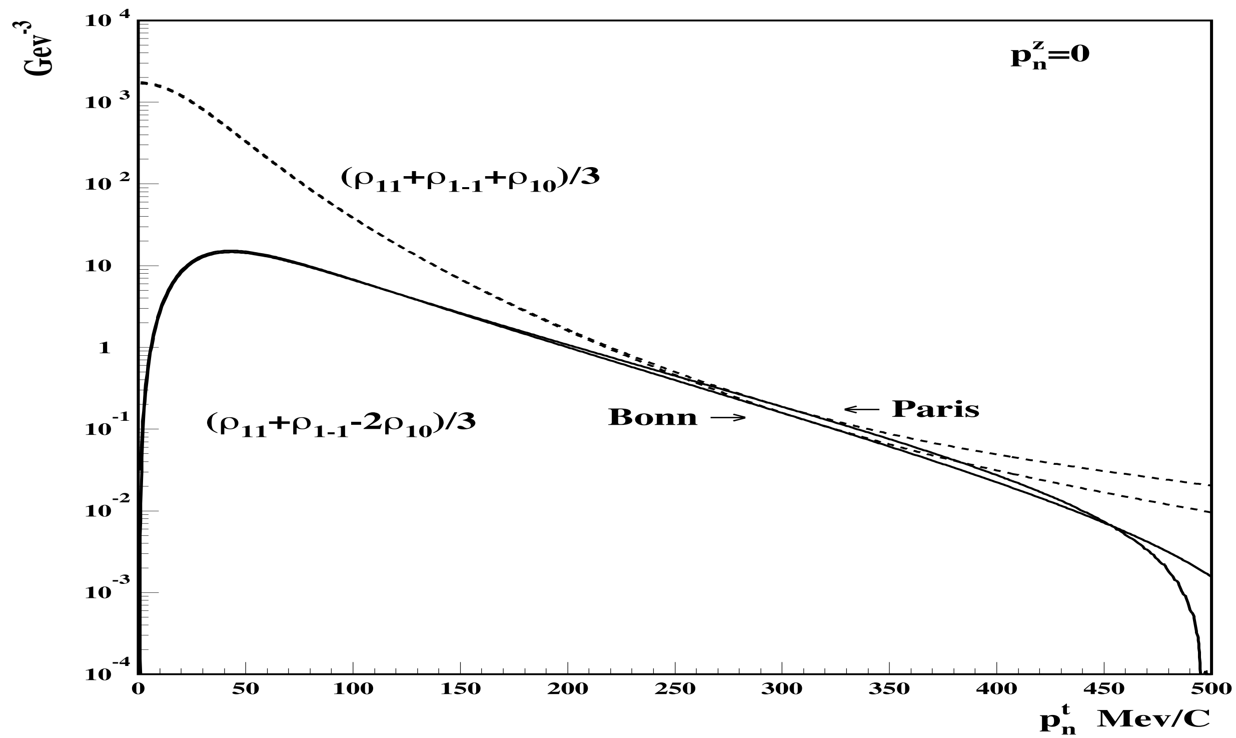
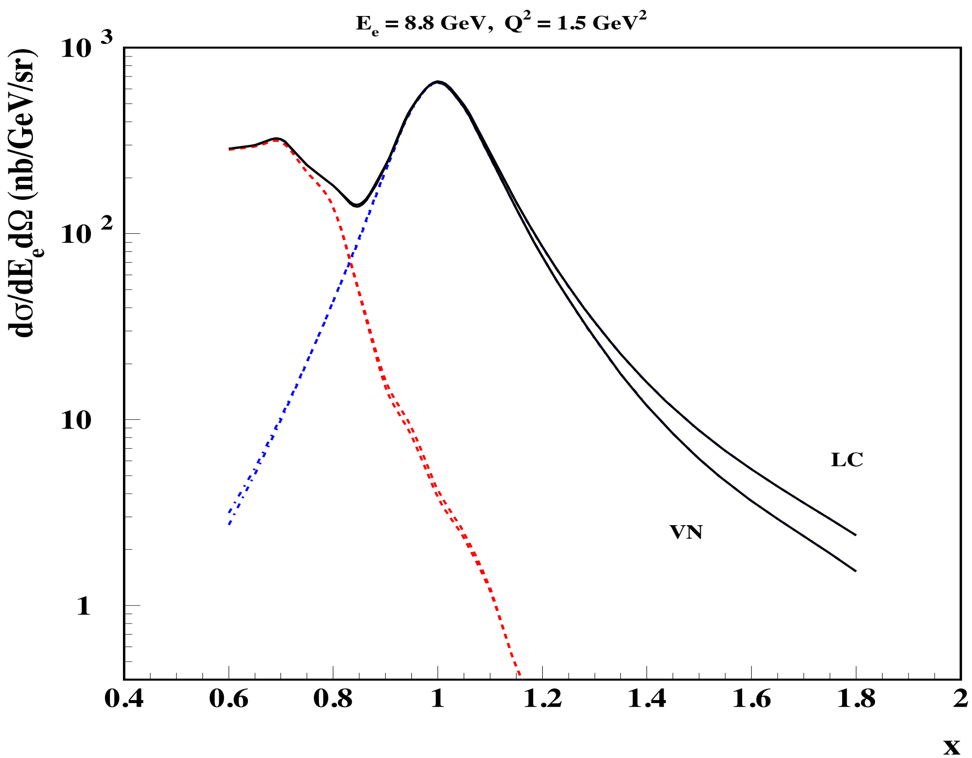
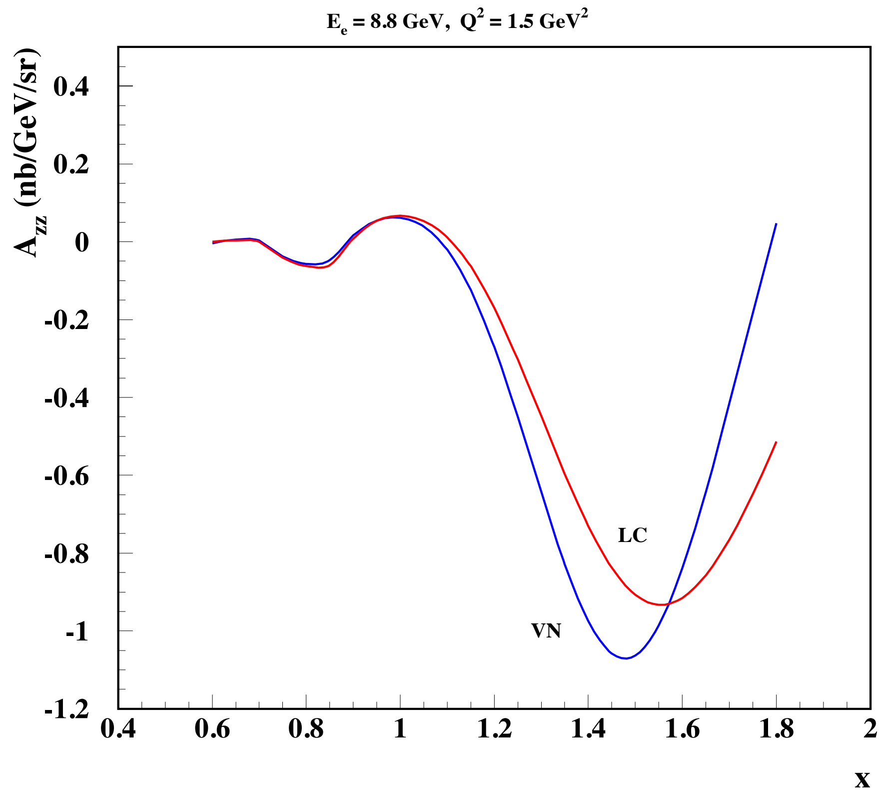


Fig.6

4. Probing Polarized Structure of the Deuteron at x > 1

- Tensor Polarized Deuteron = Compact Deuteron





5. Probing Superfast Quarks – Setting up 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"

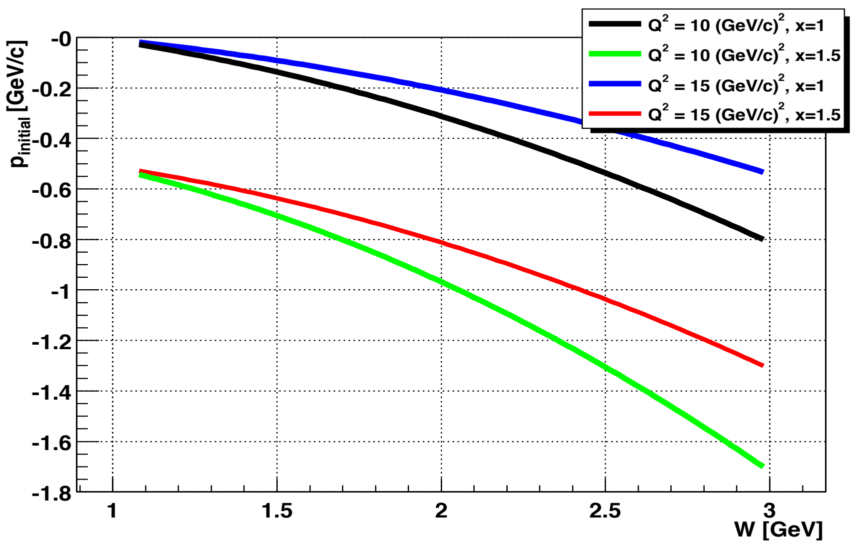
SuperFast quarks - short distance probes in nuclei

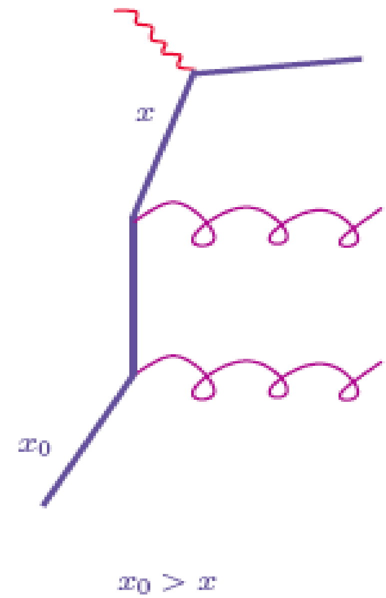
$$x = \frac{Q^2}{2m_N q_0} > 1$$

Two factors driving nucleons close together

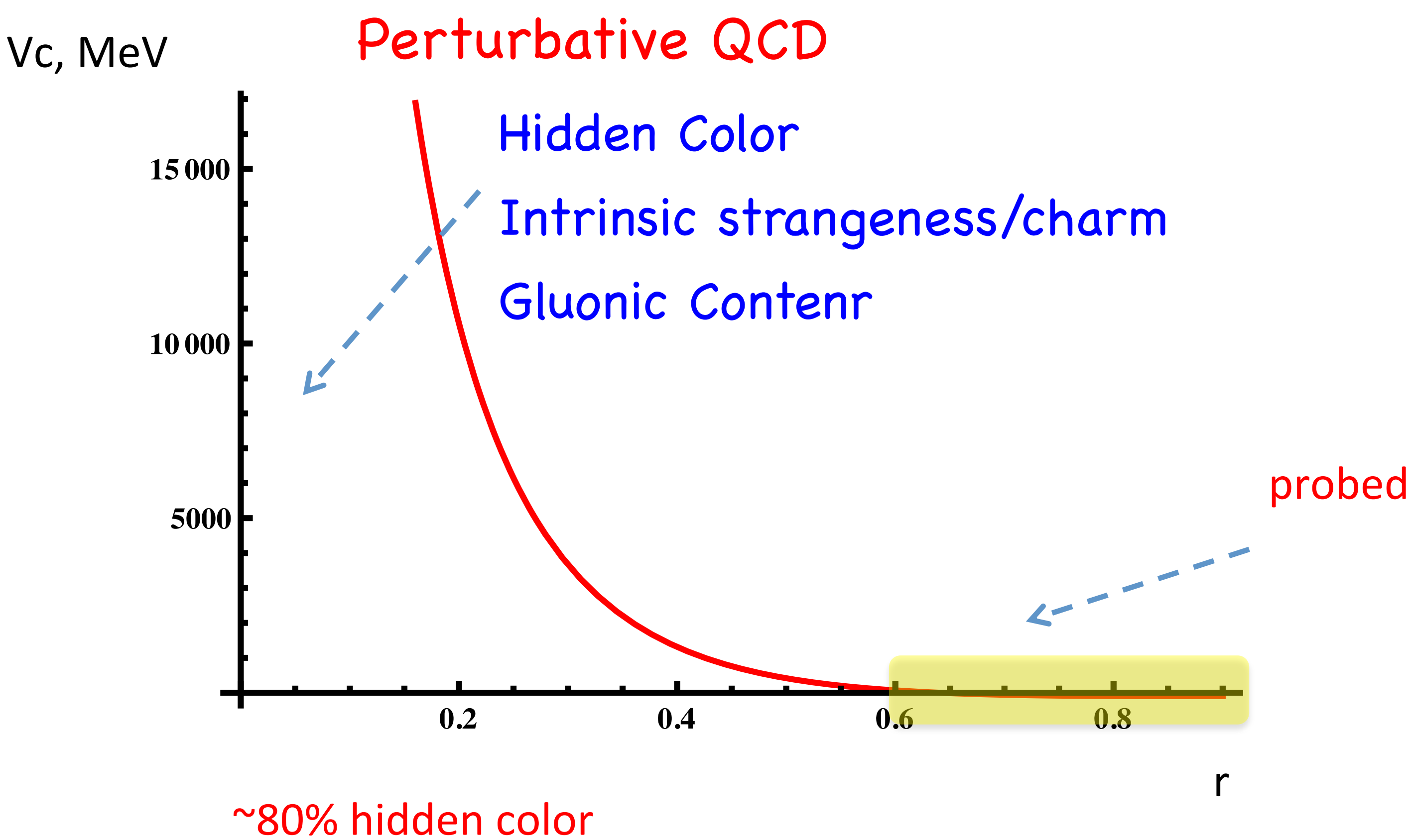
Kinematic $p_{min} \equiv p_z = m_N \left(1 - x - x\left[\frac{W_N^2 - m_N^2}{Q^2}\right]\right)$

Dynamical:QCD evolution



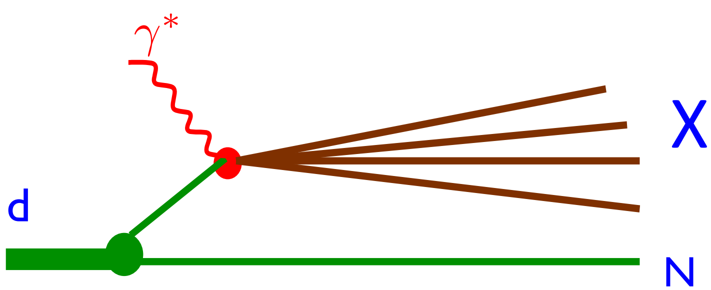


NN Interactions



- Probing F2 of the Deuteron at x > 1 (Jlab12,EIC)

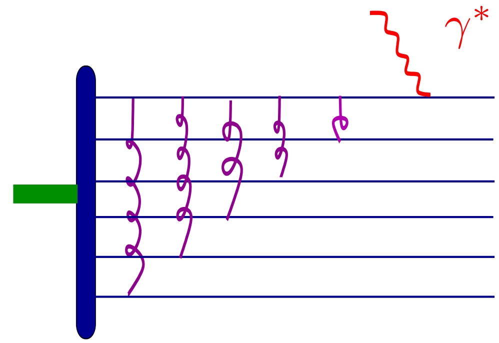
1. Convolution Model



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

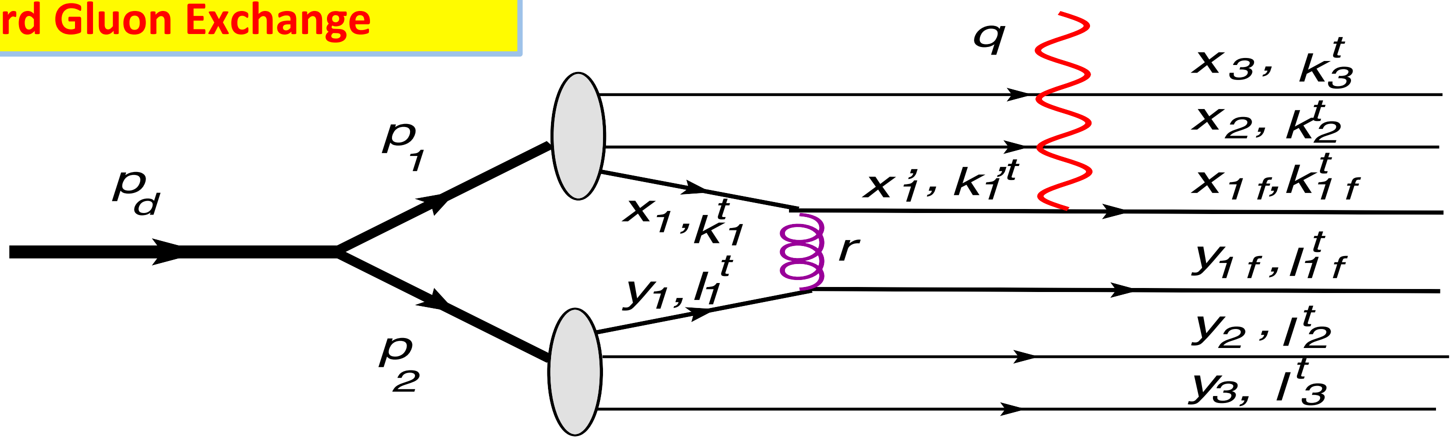
$$x_N = \frac{x}{\alpha}$$

2. Six-Quark Model



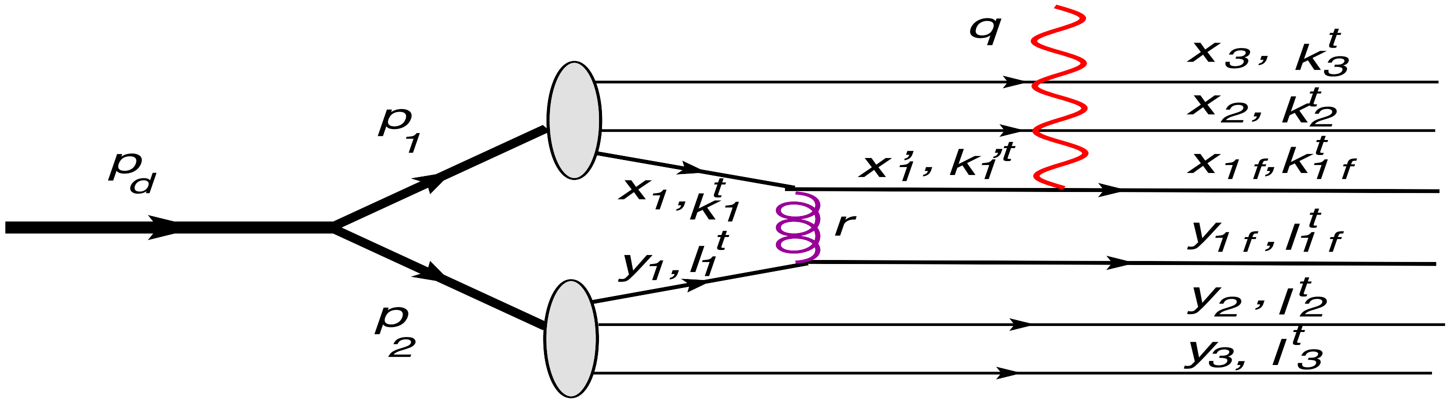
$$F_{2D} = F_{2,(6q)} \sim \left(1 - \frac{x}{2}\right)^{10}$$

3. Hard Gluon Exchange



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

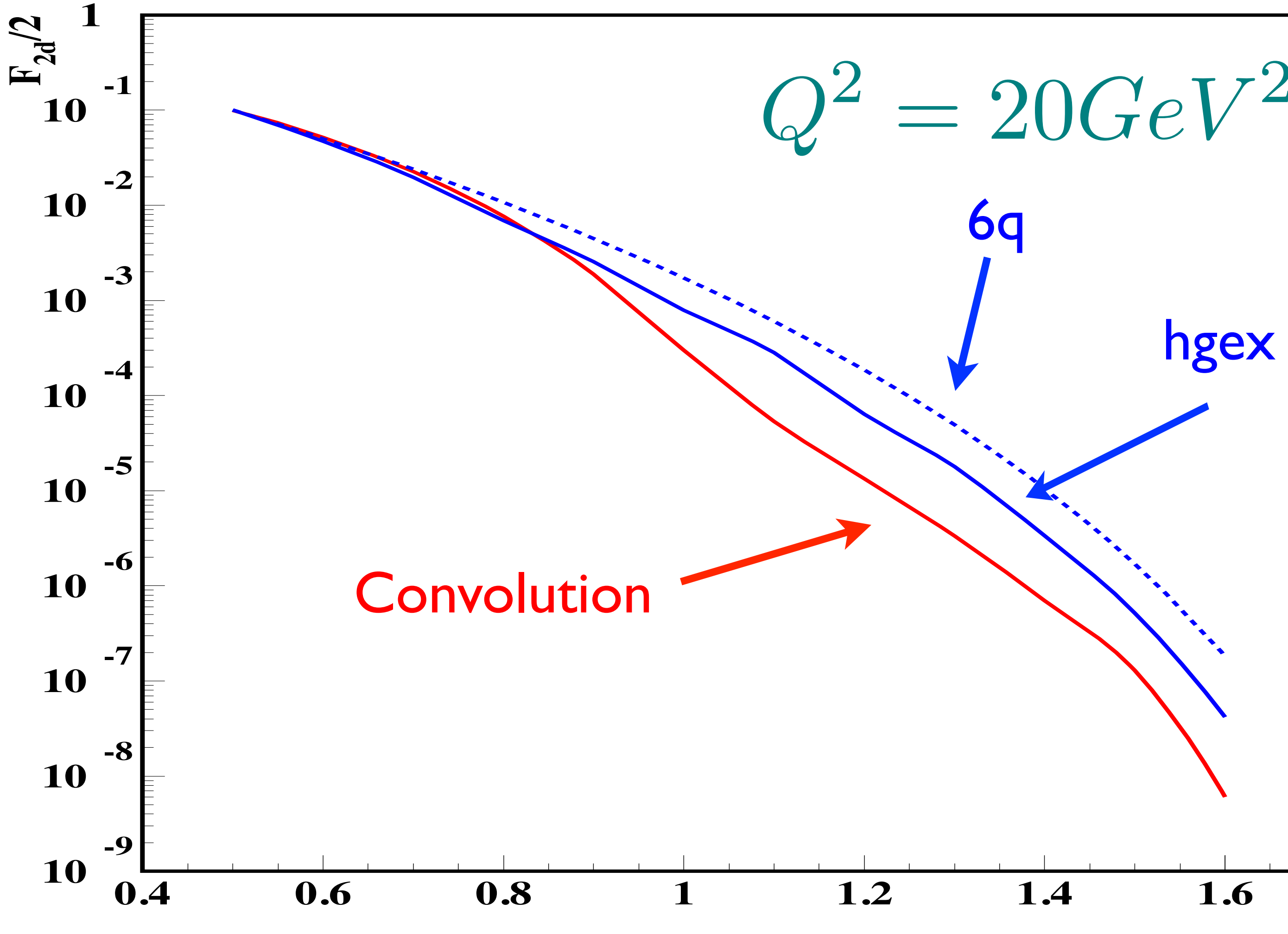
$$\left\{ \sum_{\eta_1,\lambda_1} H^\sigma_{(\eta_{1f},\eta_1),(\lambda_{1f},\lambda_1)} \frac{\psi_N^{h_1}(k_1,\eta_1;k_2,\eta_2;k_3,\eta_3)}{x_1\sqrt{2(2\pi)^3}} \frac{\psi_N^{h_2}(l_1,\lambda_1;l_2,\lambda_2;l_3,\lambda_3)}{y_1\sqrt{2(2\pi)^3}} \right\} \frac{\Psi_d^{h_1,h_2,m_d}(p_1,p_2)}{(1-\alpha)\sqrt{2(2\pi)^3}}$$



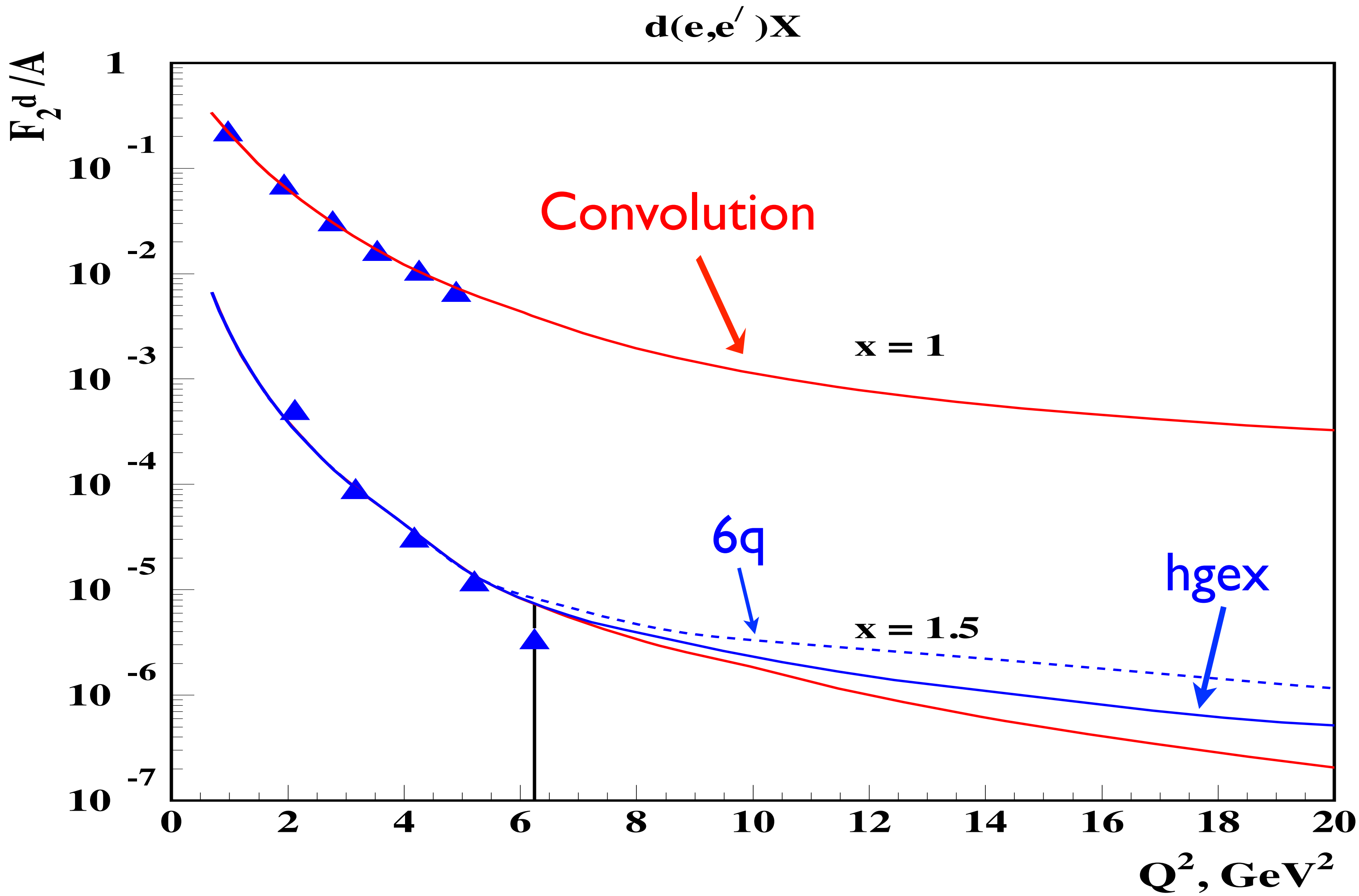
$$F_{2d}(x_{Bj},Q^2) = \sum_{i,j} x_{Bj} e_i^2 \int dx_1 dy_1 \frac{d^2 l_{1f,t}}{2(2\pi)^3} \frac{8\alpha_{QCD}}{l_{1f,t}^4} f_i(x_1,Q^2) f_j(y_1, l_{1f,t}^2) \times$$

$$\frac{1}{y_1^2}\left[1 - \frac{x_{Bj}}{x_1+y_1}\right]^2 \Theta(x_1+y_1-x_{Bj}) \left[\sum_{h_1,h2} \int \frac{\Psi_d(\alpha,p_t)}{\alpha(1-\alpha)} \frac{d\alpha}{\sqrt{2(2\pi)^3}} \frac{d^2 p_t}{(2\pi)^2}\right]^2$$

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



$F_{2d}/2$
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0.4
0.6
0.8
1
1.2
1.4
1.6
x
$Q^2 = 20GeV^2$
6q
hgex
Convolution



d(e,e′)X
F_2^d/A
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
2
4
6
8
10
12
14
16
18
20
Q^2, GeV^2
Convolution
x = 1
6q
hgex
x = 1.5

II. Probing the F2 of medium/heavy nuclei at x > 1

(CERN,, FermiLab,Jlab6 - Jlab12,EIC)

Existing Experiments:

1. BCDMS Collaboration 1994 (CERN): $52 \leq Q^2 \leq 200\ \mathrm{GeV}^2$

2. CCFR Collaboration 2000 (FermiLab): $Q^2 = 120\ \mathrm{GeV}^2$

3. E02-019 Experiment 2010 (JLab) $Q^2_{AV} = 7.4\ \mathrm{GeV}^2$

1. BCDMS Collaboration 1994 (CERN):

Z.Phys C63 1994

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

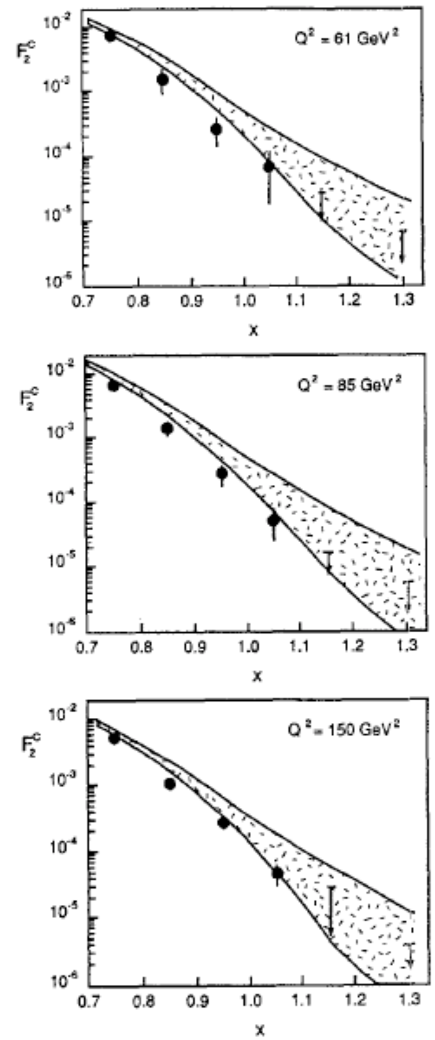
$$Q^2 = 61, 85 \text{ and } 150 \text{ GeV}^2$$

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

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

$$s = 16.5 \pm 0.6$$

More than Fermi Gas but very marginal high momentum component



2. CCFR Collaboration 2000 (FermiLab):

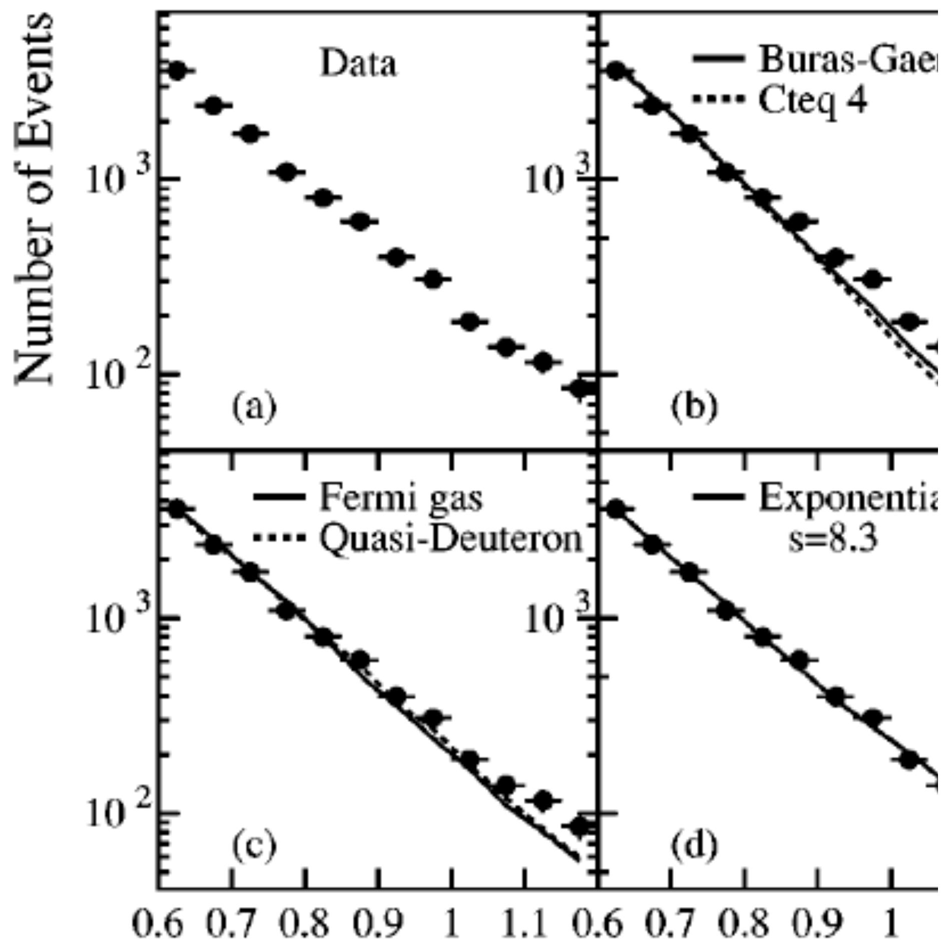
Phys. Rev. D61 2000

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

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

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

$$s = 8.3 \pm 0.7(stat) \pm 0.7(syst)$$



3. E02-019 Experiment 2010 (JLab)

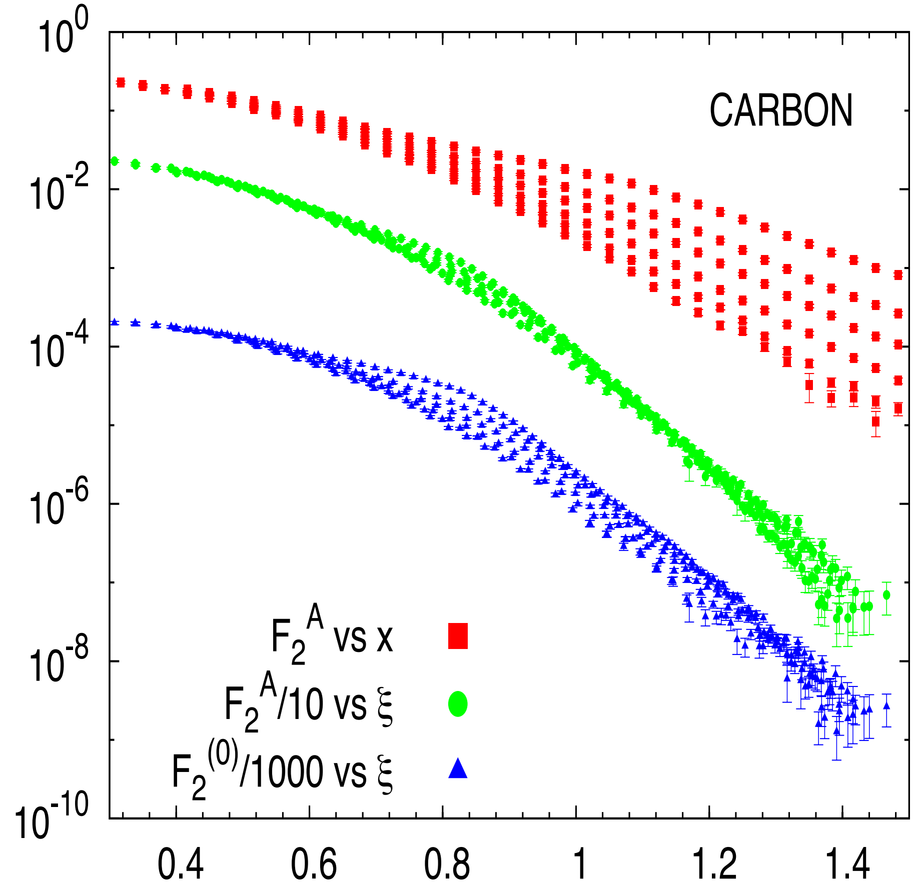
Phys.Rev.Lett 204 2010

(ee') scattering of

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

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

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



QCD Evolution Equation for Nuclear Partonic Distributions

Adam Freese, MS
ArXiv 2015

$$\frac{dq_{i,A}(x,Q^2)}{d\log Q^2} = \frac{\alpha_s}{2\pi}\int_x^A \frac{dy}{y}\left(q_{i,A}(y,Q^2)P_{qq}(\frac{x}{y}) + G_A(y,Q^2)P_{qg}(\frac{x}{y})\right)$$

$$P_{qq}(x) = C_2\left[(1+x^2)\left(\frac{1}{1-x}\right)_+ + \frac{3}{2}\delta(1-x)\right]$$

$$P_{qg}(x) = T\left[(1-x)^2 + x^2\right],$$

with $C_2 = \frac{4}{3}$ and $T = \frac{1}{2}$. Here the + denominator is Altarelli - Parisi function defined as:

$$\int_0^1 dz \frac{f(z)}{(1-z)_+} = \int_0^1 \frac{f(z)-f(0)}{1-z}$$

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

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

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

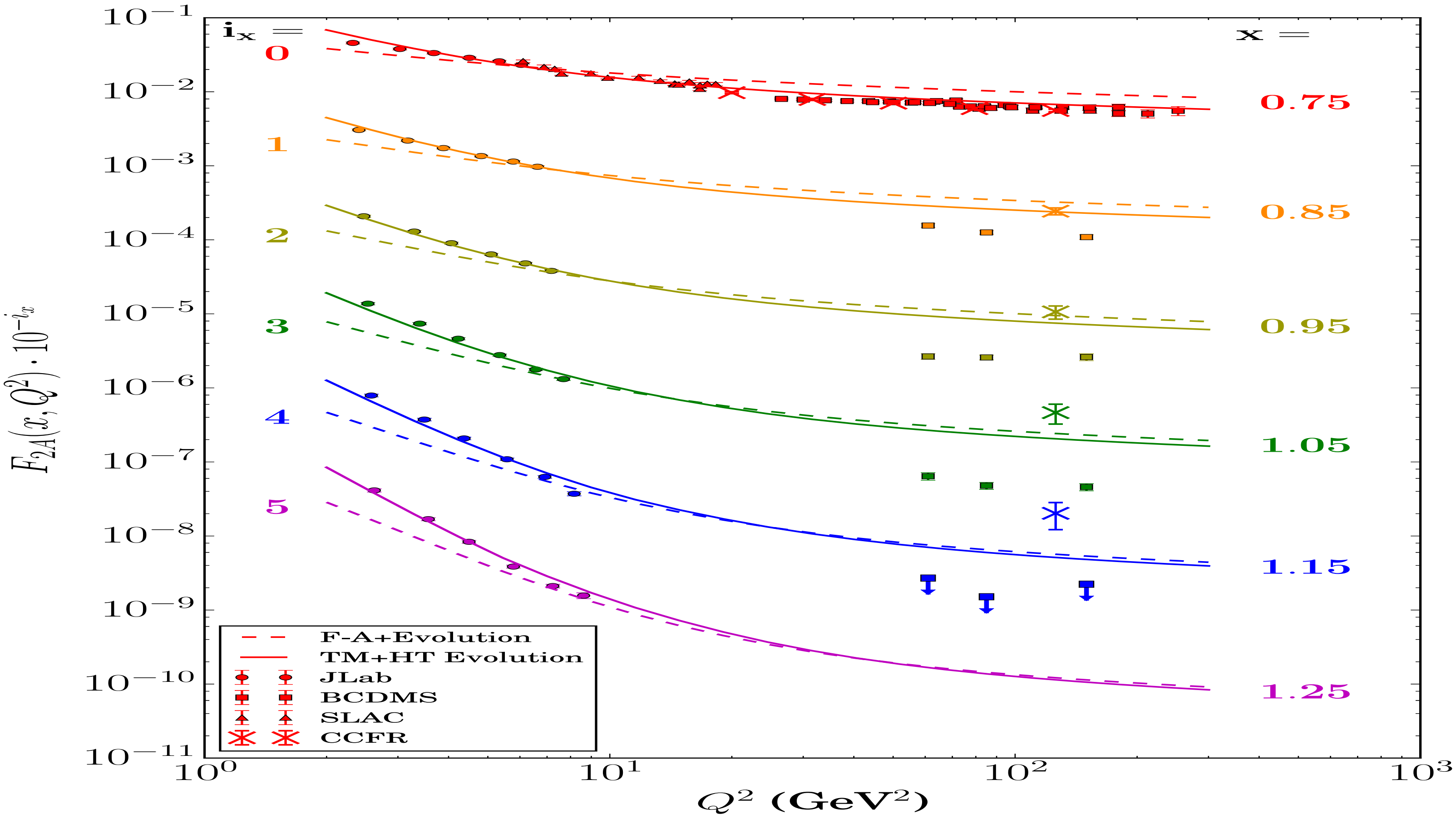
Neglecting $G_A(x, Q^2)$

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

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

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

A.Freese & M.S
ArXiv 2015

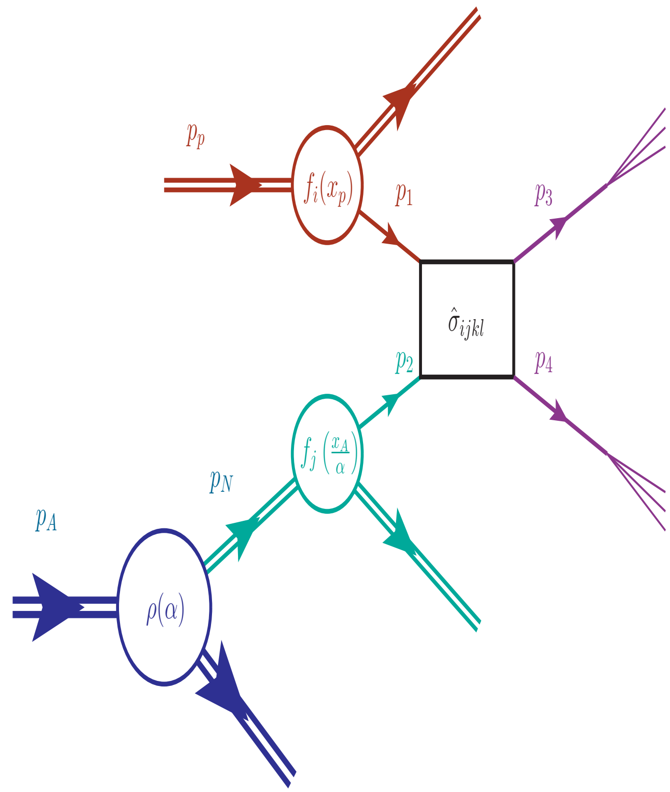


6. Probing superfast quarks in jet production at LHC/EIC

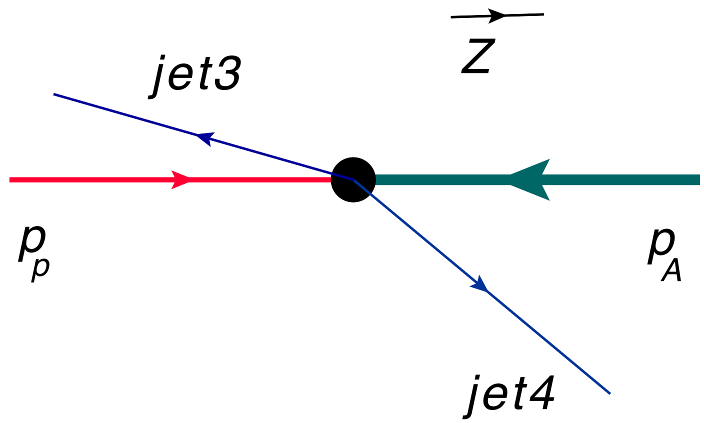
A.Freese, M.S.
M.Strikman, EPJ 2015

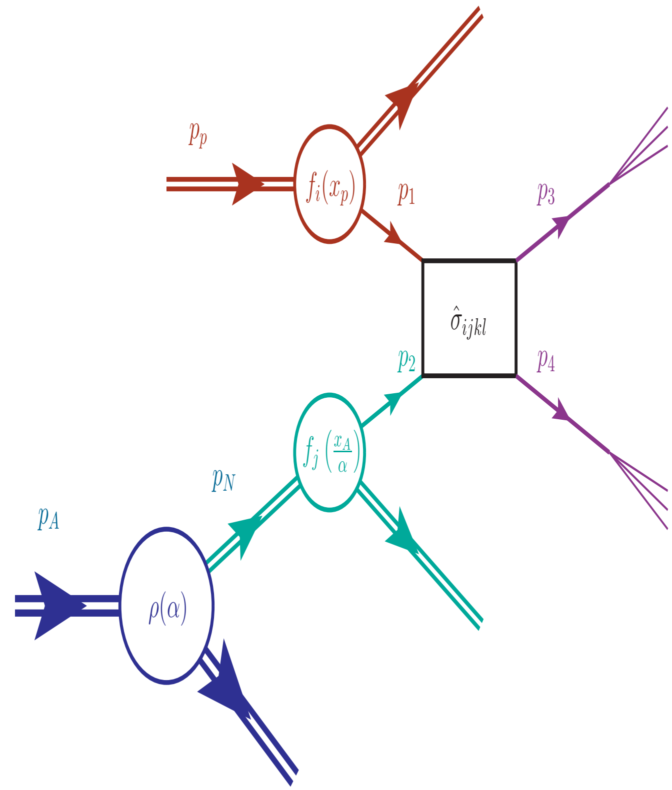
$$p + A \to \text{dijet} + X$$

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



Jet - kinematics

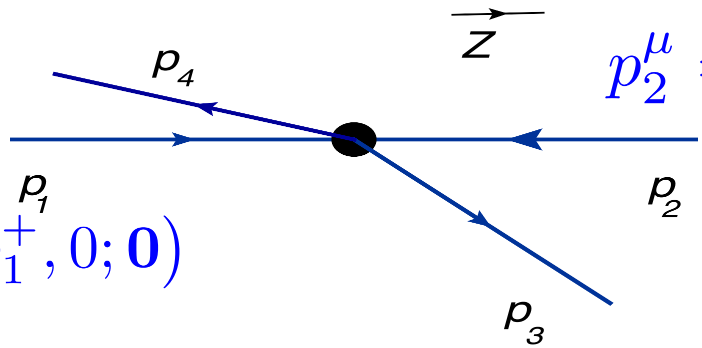




$$p_p^\mu = \left(p_p^+, \frac{m_p^2}{p_p^+}, \mathbf{0}_T\right) = (2E_0, 0, \mathbf{0}_T) = \left(\sqrt{\frac{A s_{NN}^{\text{avg.}}}{Z}}, 0, \mathbf{0}_T\right)$$

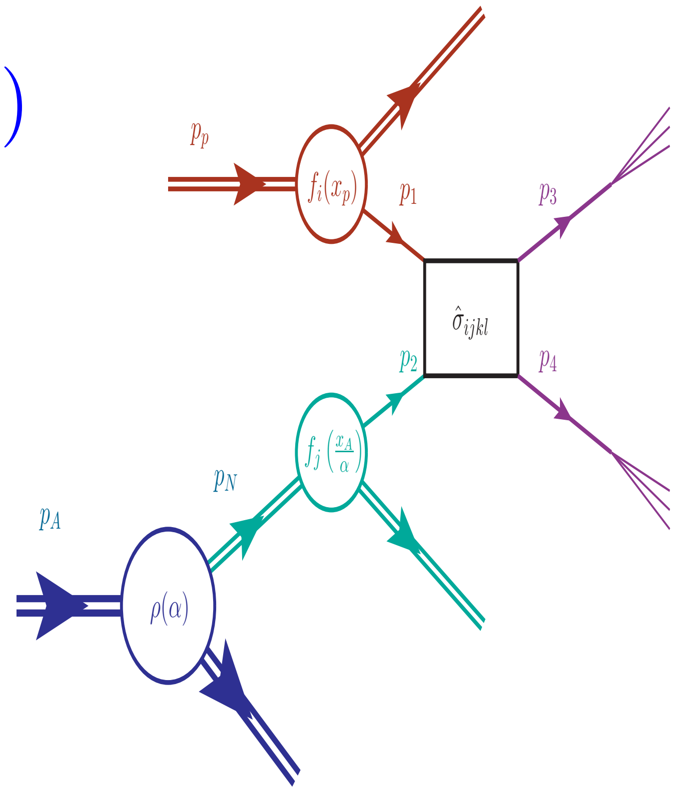
$$p_A^\mu = \left(\frac{M_A^2}{p_A^-}, p_A^-, \mathbf{0}_T\right) = (0, 2ZE_0, \mathbf{0}_T) = \left(0, \sqrt{AZ s_{NN}^{\text{avg.}}}, \mathbf{0}_T\right)$$

Parton - kinematics



$$p_2^\mu = (0, p_2^-; \mathbf{0})$$

$$p_1^\mu = (p_1^+, 0; \mathbf{0})$$



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

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

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

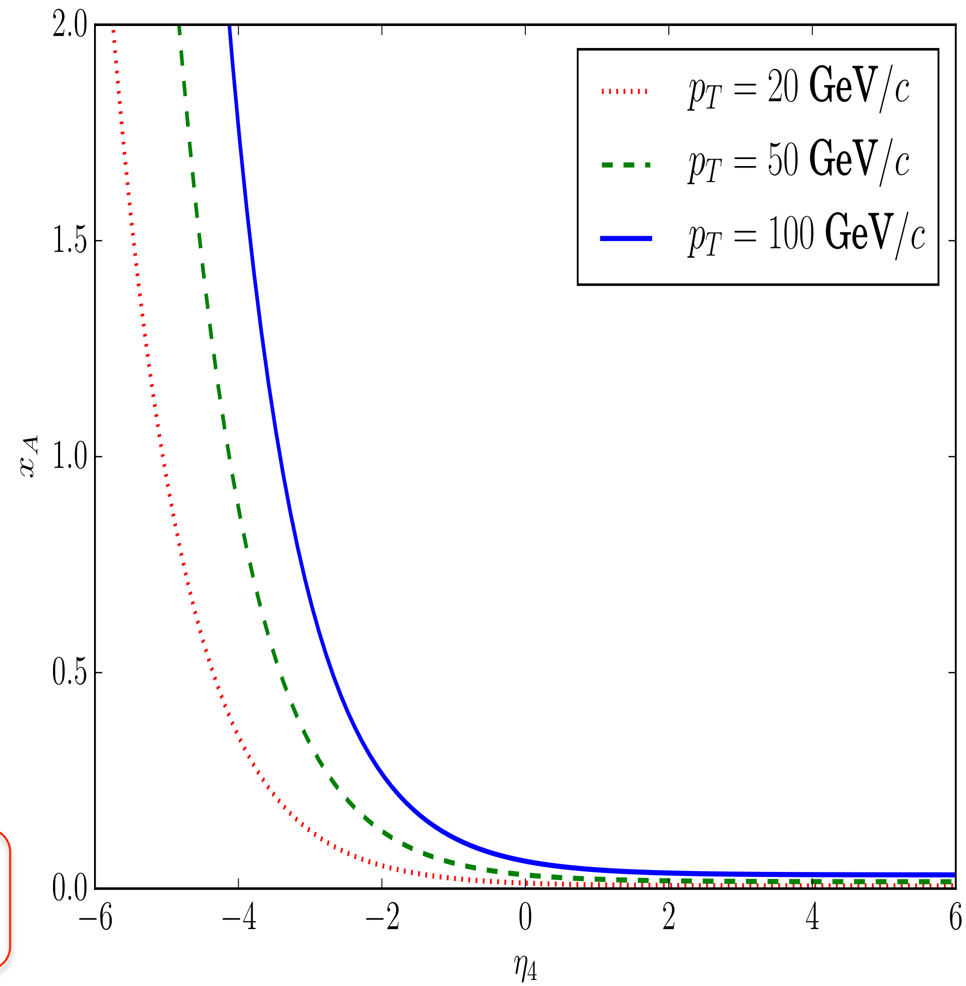
$$p_2^\mu = (0, p_2^-; \mathbf{0}) \qquad x_A = A\frac{p_2^-}{p_A^-}$$

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

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

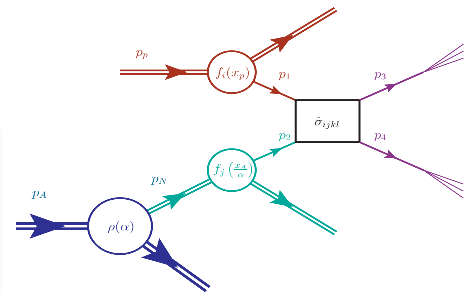
$$x_p = \sqrt{\frac{Z}{A}}\frac{p_T}{\sqrt{s_{NN}^{\text{avg.}}}}\left(e^{\eta_3} + e^{\eta_4}\right)$$

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



Differential Cross Section of the Reaction

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



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

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

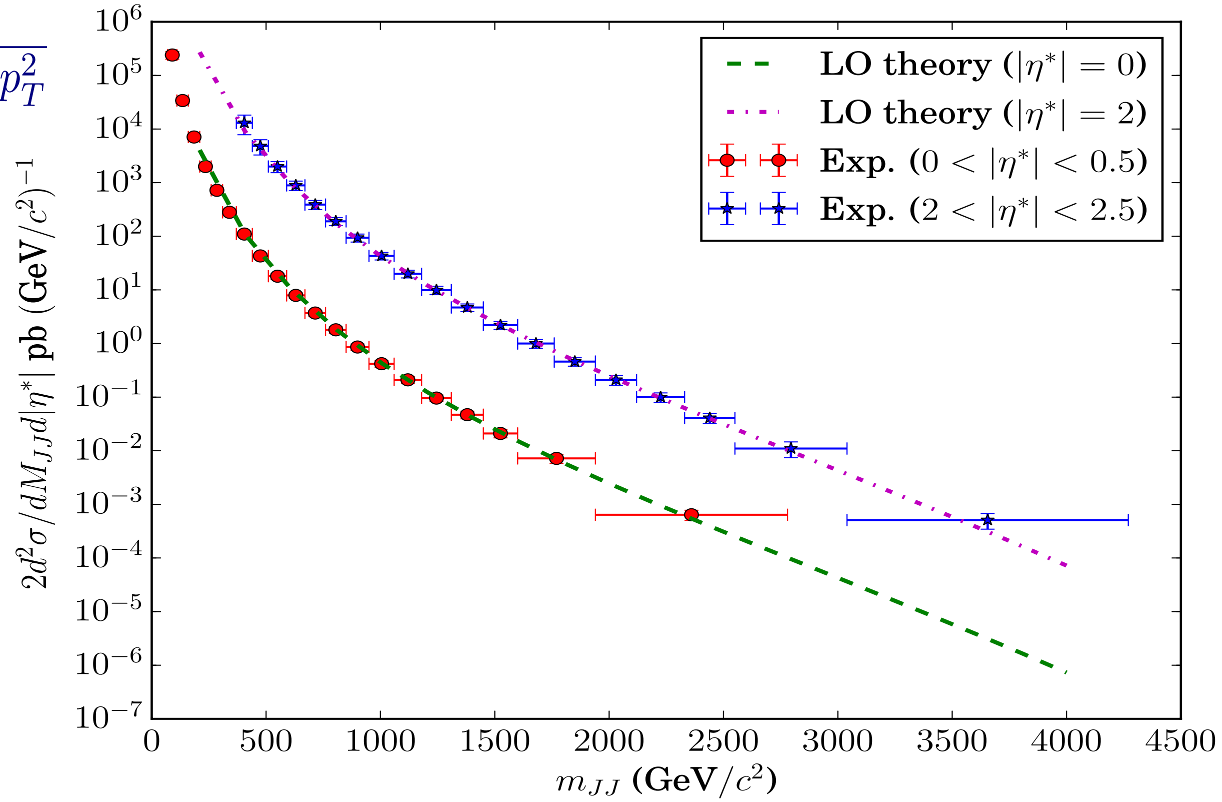
$$f_{i/p}(x_p, Q^2)$$

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

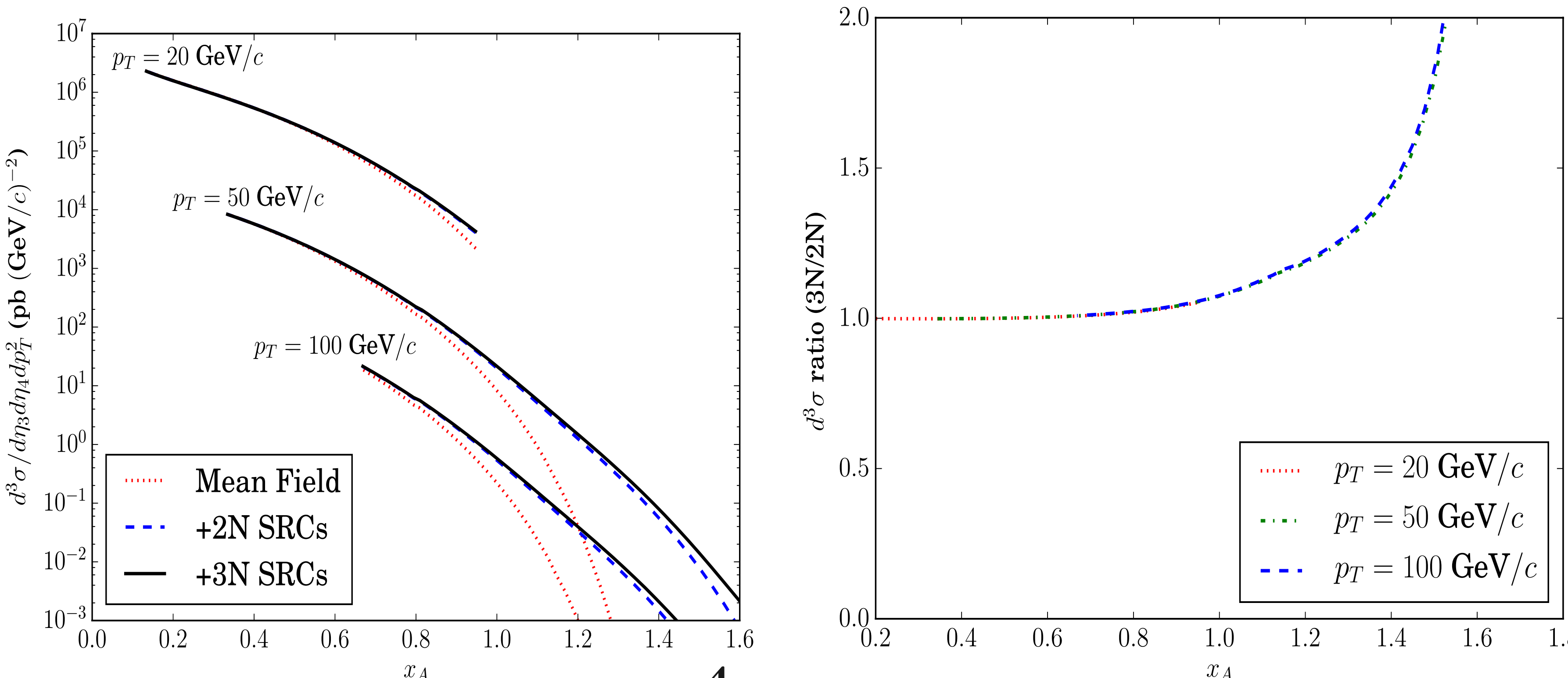
Subprocess	$\frac{\overline{\lvert\mathcal{M}\rvert^2}}{g_s^4}$
$q_j + q_k \to q_j + q_k$	$\frac{4}{9}\frac{s^2+u^2}{t^2}$
$q_j + q_j \to q_j + q_j$	$\frac{4}{9}\left(\frac{s^2+u^2}{t^2} + \frac{s^2+t^2}{u^2}\right) - \frac{8}{27}\frac{s^2}{ut}$
$q_j + \bar{q}_j \to q_k + \bar{q}_k$	$\frac{4}{9}\frac{t^2+u^2}{s^2}$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

Checking Calculation for "Conventional" kinematics

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



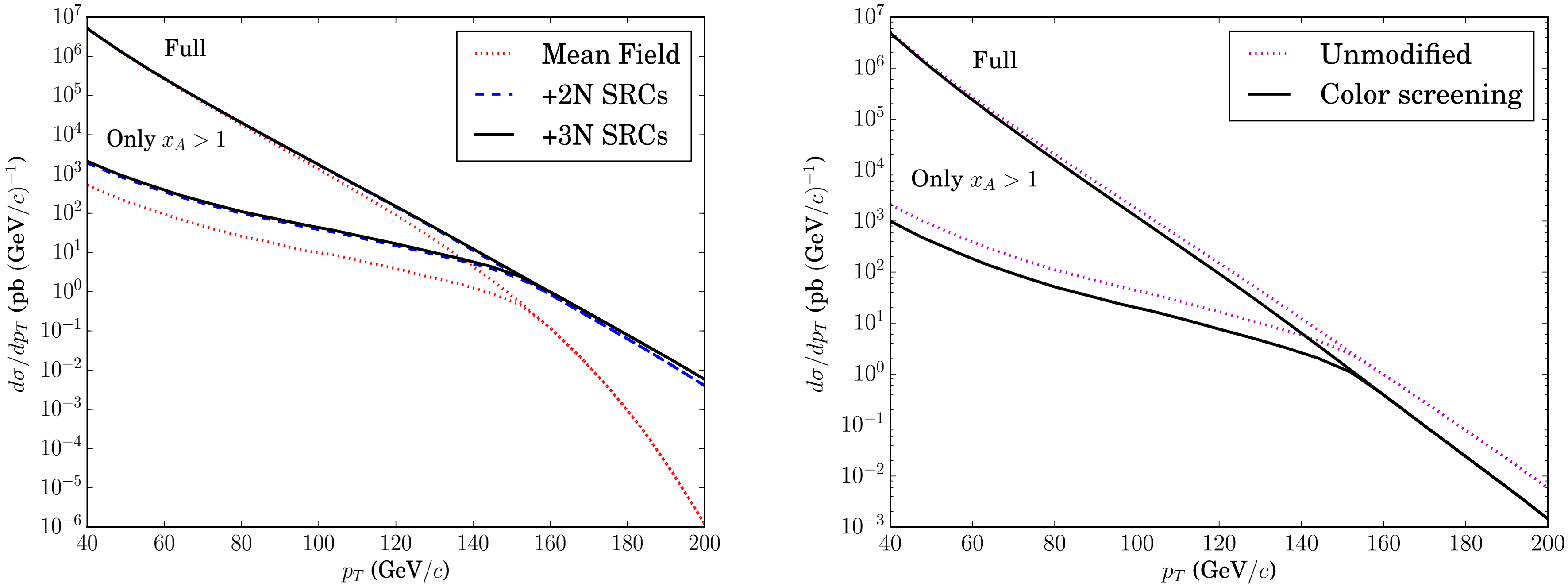
G. Aad et al. (ATLAS Collaboration), Phys. Rev. D 86, 014022(2012).



$p_T = 20$ GeV/c
$p_T = 50$ GeV/c
$p_T = 100$ GeV/c
$d^3\sigma/d\eta_3 d\eta_4 dp_T^2$ (pb (GeV/c)$^{-2}$)
x_A
Mean Field
+2N SRCs
+3N SRCs
$d^3\sigma$ ratio (3N/2N)
x_A
$p_T = 20$ GeV/c
$p_T = 50$ GeV/c
$p_T = 100$ GeV/c

$$\eta_4 = -4$$

$$\frac{d\sigma(x_A > 1)}{dp_T} = \int_{-2.5}^{2.5} d\eta_3 \int_{-5}^{-3} d\eta_4 \frac{2p_T d^3\sigma}{d\eta_3 d\eta_4 dp_T^2} \Theta(x_A - 1)$$



Integrated cross section at 7TeV per proton

$$\frac{d\sigma(x_{max} > x_A > x_{min})}{dp_T} = \int_{50GeV/c} dp_T \int_{-2.5}^{2.5} d\eta_3 \int_{-5}^{-3} d\eta_4 \frac{2p_T d^3\sigma}{d\eta_3 d\eta_4 dp_T^2} \Theta(x_A - x_{min})\Theta(x_{max} - x_A)$$

	Unmodified (SRCs)	Modified (no SRCs)	Modified (SRCs)
All x_A	58 μb	55 μb	55 μb
$0.6 < x_A < 0.7$	1.7 μb	1.2 μb	1.3 μb
$0.7 < x_A < 0.8$	0.60 μb	0.37 μb	0.43 μb
$0.8 < x_A < 0.9$	0.20 μb	0.11 μb	0.13 μb
$0.9 < x_A < 1$	59 nb	20 nb	33 nb
$1 < x_A$	21 nb	3.0 nb	9.3 nb

The expected yield for $x_A > 1$ events at the LHC is 326 events for a month of run time based on previously achieved luminosity of 35.5/nb.

Summary & Outlook

- $x > 1$ Deep Inelastic Scatterings allow to probe nuclei at unprecedented Short-Distances

- They will allow to probe the nuclei at core distances where explicit quark-gluon degrees of freedom become essential

- Price - small cross sections

- Can be studied at Jlab12, LHC and potentially at EIC

II. Inclusive x > 2

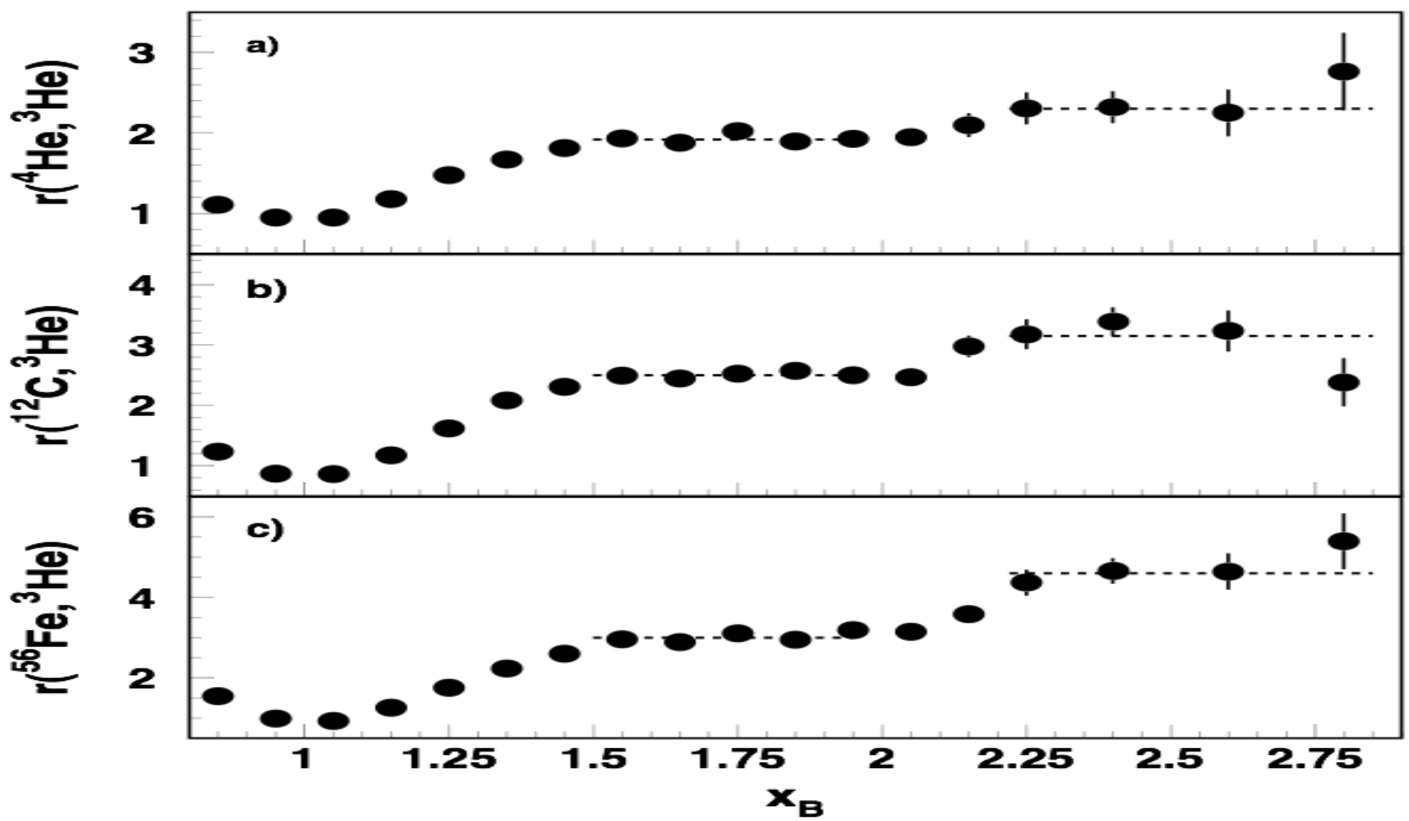
1. Looking for the Plateau in Inclusive Cross Section Ratios

2. Understanding Transition from 2N to 3N SRCs

3. Extraction of Momentum Distribution in 3N SRC Region

4. Center of mass motion effects in 3N SRCs Semi-Inclusive Reactions

1. Looking for the Plateau in Inclusive Cross Section Ratios



Meaning of the scaling values

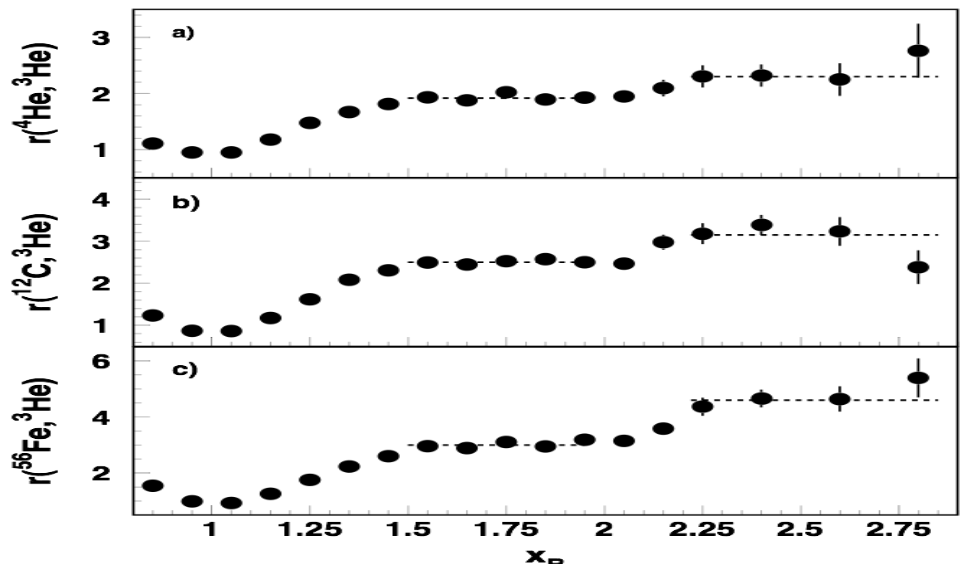
Day, Frankfurt, MS, Strikman, PRC 1993

Frankfurt, MS, Strikman, IJMP A 2008

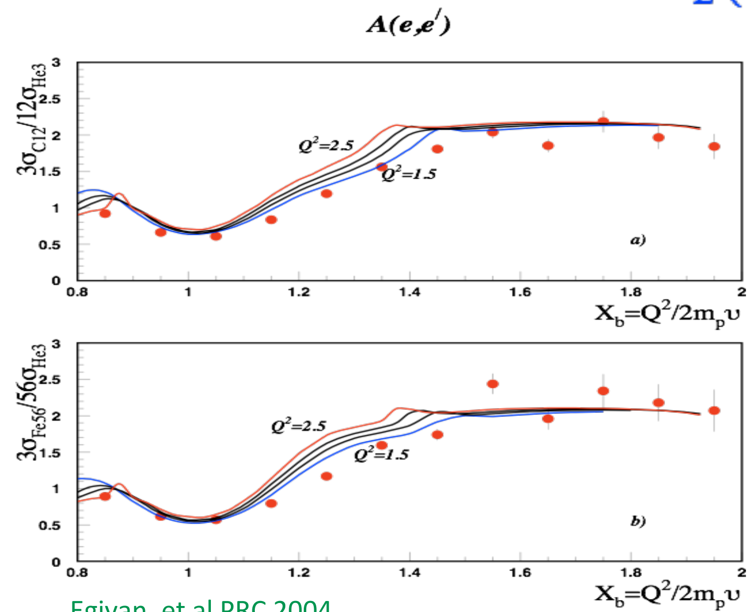
$$R = \frac{A_2 \sigma[A_1(e,e')X]}{A_1 \sigma[A_2(e,e')X]}$$

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

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



Egiyan, et al PRL 2006



Egiyan, et al PRC 2004

What we Learned from A(e,e')X Reactions

	$a_{2N}(A)$
^{3}He	0.080±0.000± 0.004
^{4}He	0.154±0.002± 0.033
^{12}C	0.193±0.002± 0.041
^{56}Fe	0.227±0.002± 0.047

$a_{3N}(A)$
0.0018±0.0000±0.0006
0.0042±0.0002±0.0014
0.0055±0.0003±0.0017
0.0079±0.0003±0.0025

$$a_2(^{12}C) = 0.194\%$$
$$a_3(^{12}C) = 0.0055\%$$

$$a_2(^{56}Fe) = 0.227\%$$
$$a_3(^{56}Fe) = 0.0079\%$$

- Assume: system is dilute

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

- then the k dependence of the wave function for $k^2/2m_N \gg |E_B|$

Amado, 1976

$$\Phi^{(1)}(k_1, \cdots, k_c, \cdots, -k_c, \cdots, k_A) \approx \frac{U_{NN}(k_c)}{k_c^2} F_A(k_1, \cdots' \cdots', \cdots, k_A)$$

- Assume: $U_{NN}(q) \sim \frac{1}{q^n}$ with $n > 1$

$$\Phi^{(2)}(\cdots k_c, \cdots) \sim \frac{1}{k_c^{2+n}} \int \frac{1}{q^n} dq \sim \frac{U_{NN}(k_c)}{k_c^2} \int_{q_{min}} \frac{1}{q^n} dq$$

- For large k_c $\Phi^{(2)}(k_c) \ll \Phi^{(1)}(k_c)$

Frankfurt, Strikman 1981

- 3N SRCs are parametrically smaller than 2N SRC

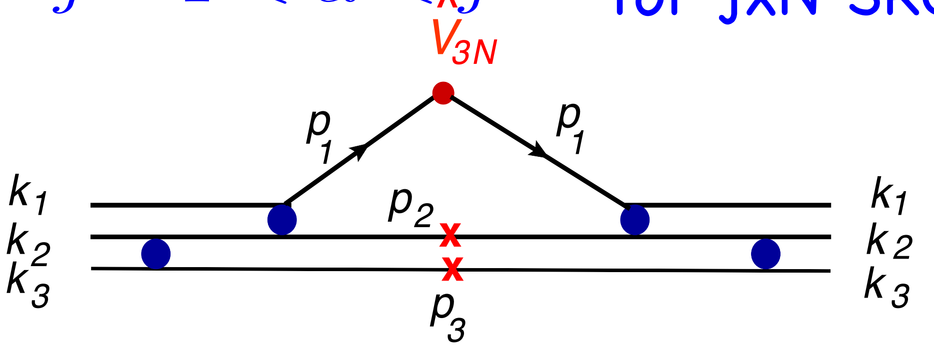
3N SRC:

$$\alpha = \frac{A(E_k + k_z)}{E_A + p_{Az}}$$

Light-Cone Momentum Fraction Distribution

$$j - 1 < \alpha < j$$

for jxN SRC

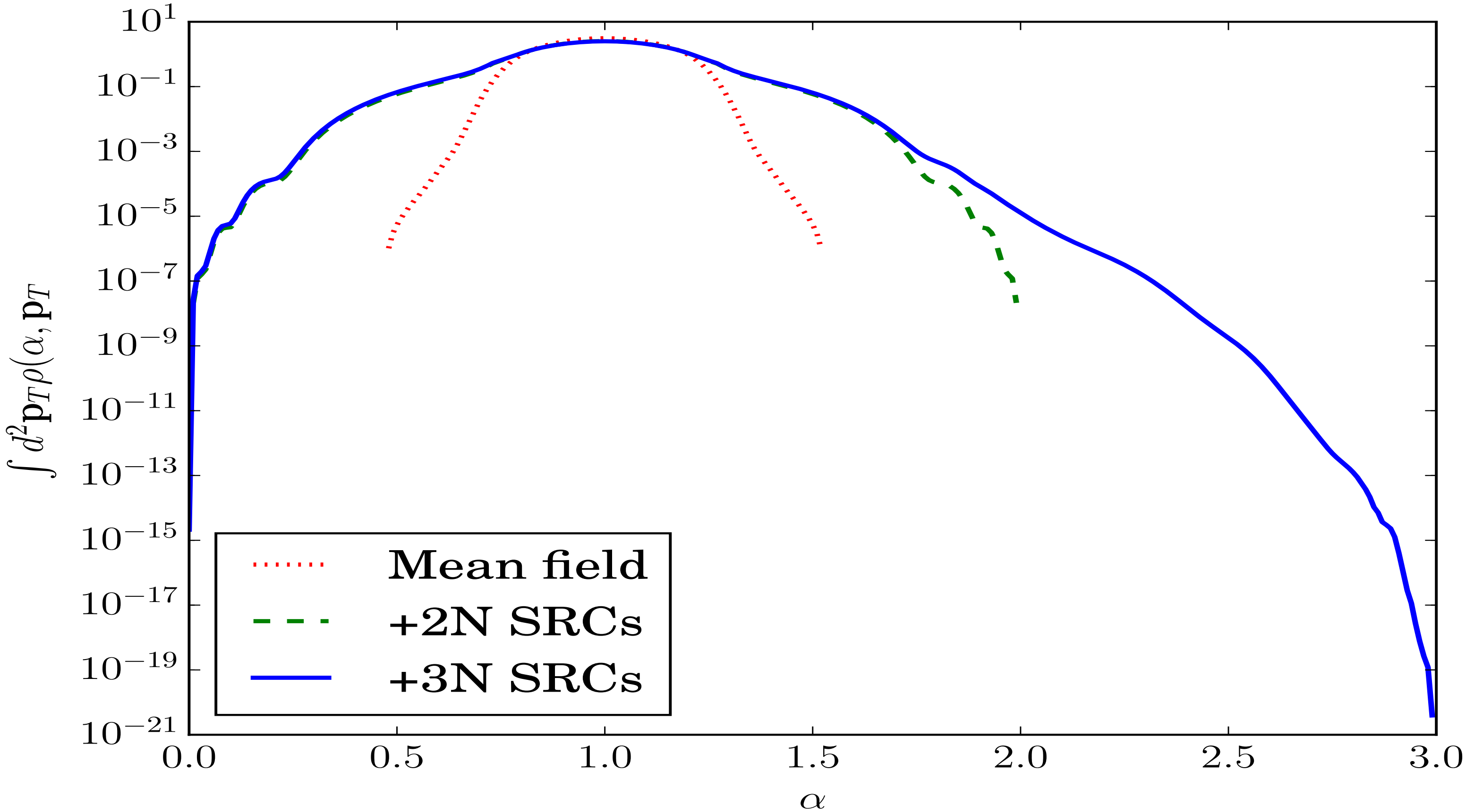


A.Freese, M.S., M.Strikman 2015

O. Artiles M.S. 2016

$$\rho_3(\alpha, \mathbf{p}_T) = \mathcal{N}_{3N} \int d\alpha_3 d^2\mathbf{p}_{3T} \frac{1}{\alpha_3(3-\alpha-\alpha_3)} \left\{ \frac{3-\alpha_3}{2(2-\alpha_3)} \right\}^2 |\psi_d(k_{12})|^2 \, |\psi_d(k_{23})|^2$$

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



$\int d^2\mathbf{p}_T \rho(\alpha, \mathbf{p}_T$
10^{1}
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
10^{-13}
10^{-15}
10^{-17}
10^{-19}
10^{-21}
0.0
0.5
1.0
1.5
2.0
2.5
3.0
α
Mean field
+2N SRCs
+3N SRCs

Probing SRCs in Inclusive Scattering:

$$\frac{2\sigma(eA \to e'X)}{A\sigma(ed \to e'X)} = \frac{\rho_A(\alpha_{2N})}{\rho_d(\alpha_{2N})} = a_2(A) \quad \text{For } 1 < \alpha_{2N} < 2$$

$$q + 2m = p_f + p_s$$

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

$$\frac{3\sigma(eA \to e'X)}{A\sigma(e^3He \to e'X)} = \frac{\rho_A(\alpha_{3N})}{\rho_{^3He}(\alpha_{3N})} = a_3(A) \quad \text{For } 2 < \alpha_{3N} < 3$$

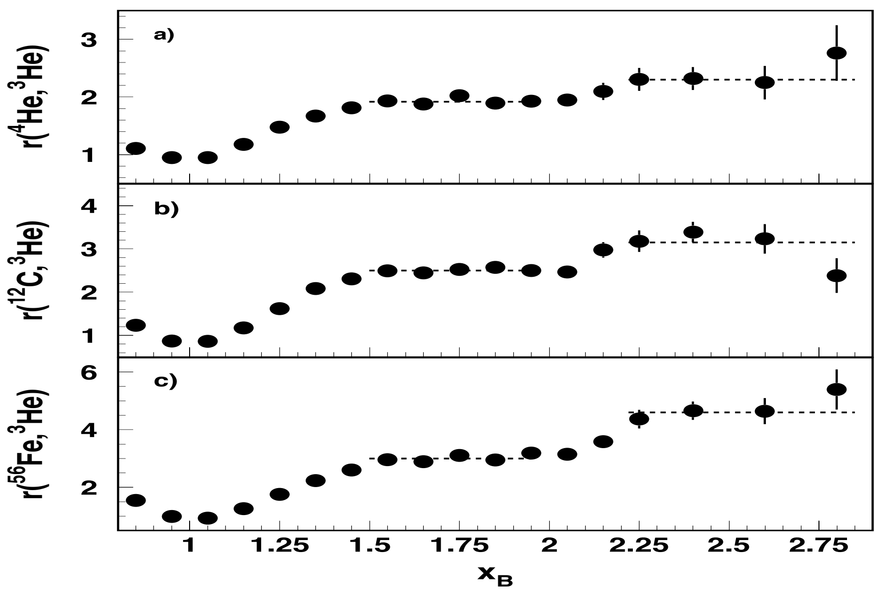
$$q + 3m = p_f + p_s$$

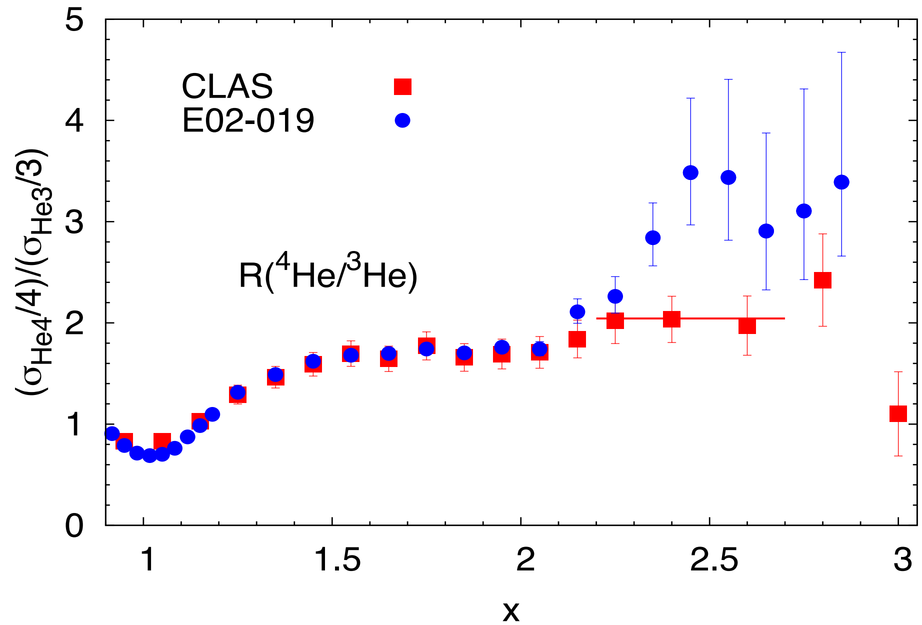
$$\alpha_{3N} = 3 - \frac{q_- + 3m_N}{2m_N}\left[1 + \frac{m_S^2 - m_N^2}{W_{3N}^2} + \sqrt{\left(1 - \frac{(m_S + m_n)^2}{W_{3N}^2}\right)\left(1 - \frac{(m_S - m_n)^2}{W_{3N}^2}\right)}\right]$$

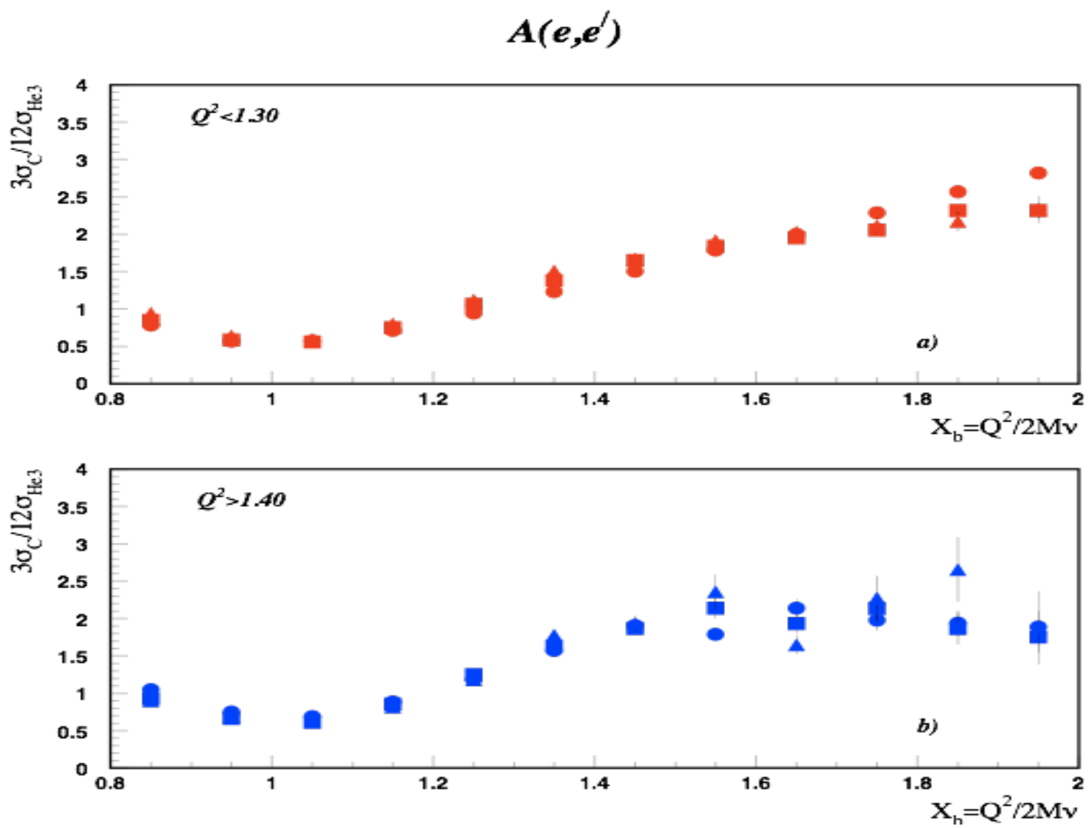
Probing SRCs in Inclusive Scattering:

in $Q^2 \to \infty$ $\alpha_{2N} = \alpha_{3N} = x = \frac{Q^2}{2mq_0}$

$\frac{3\sigma(e+A\to e'X)}{A\sigma(e+^3He\to e'X)}$ scales as a function x at $x > 1$

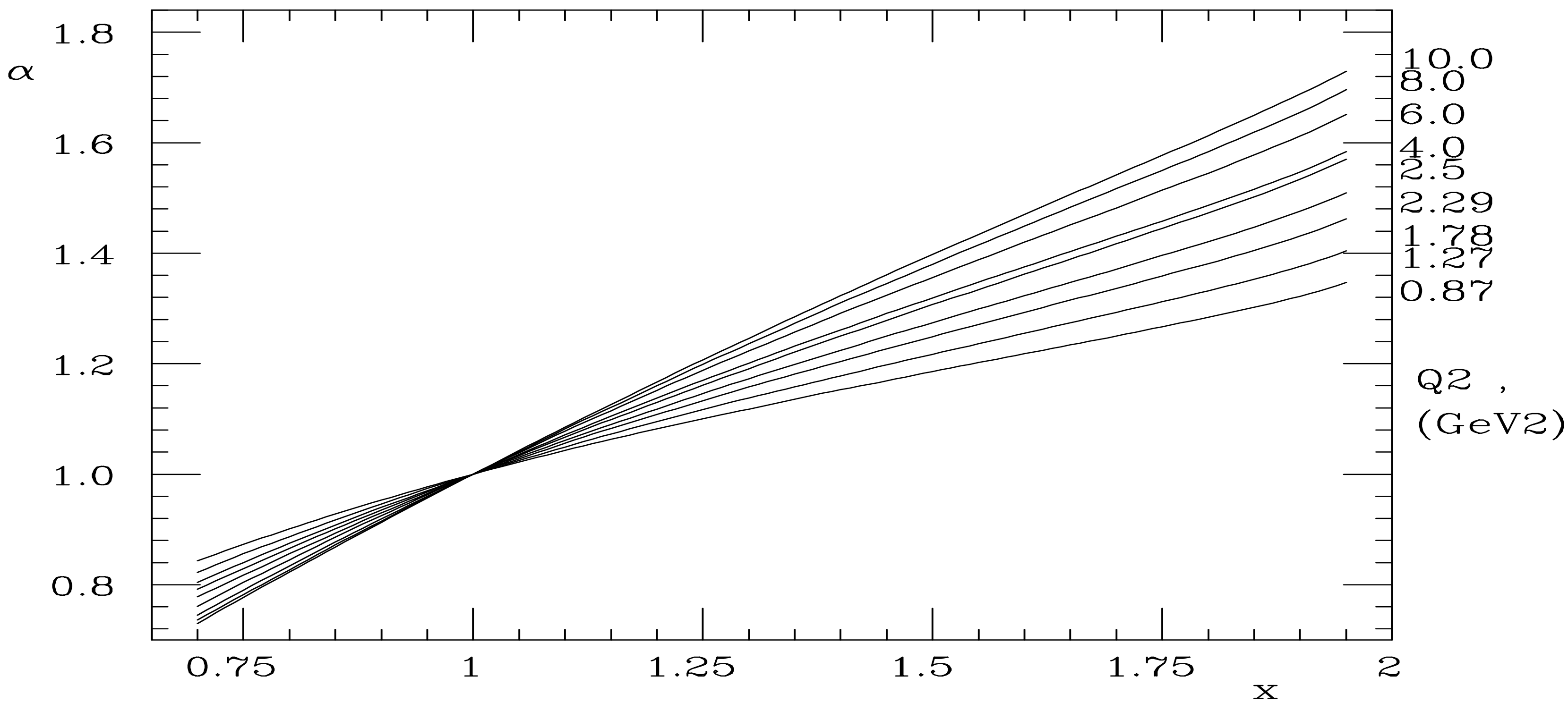




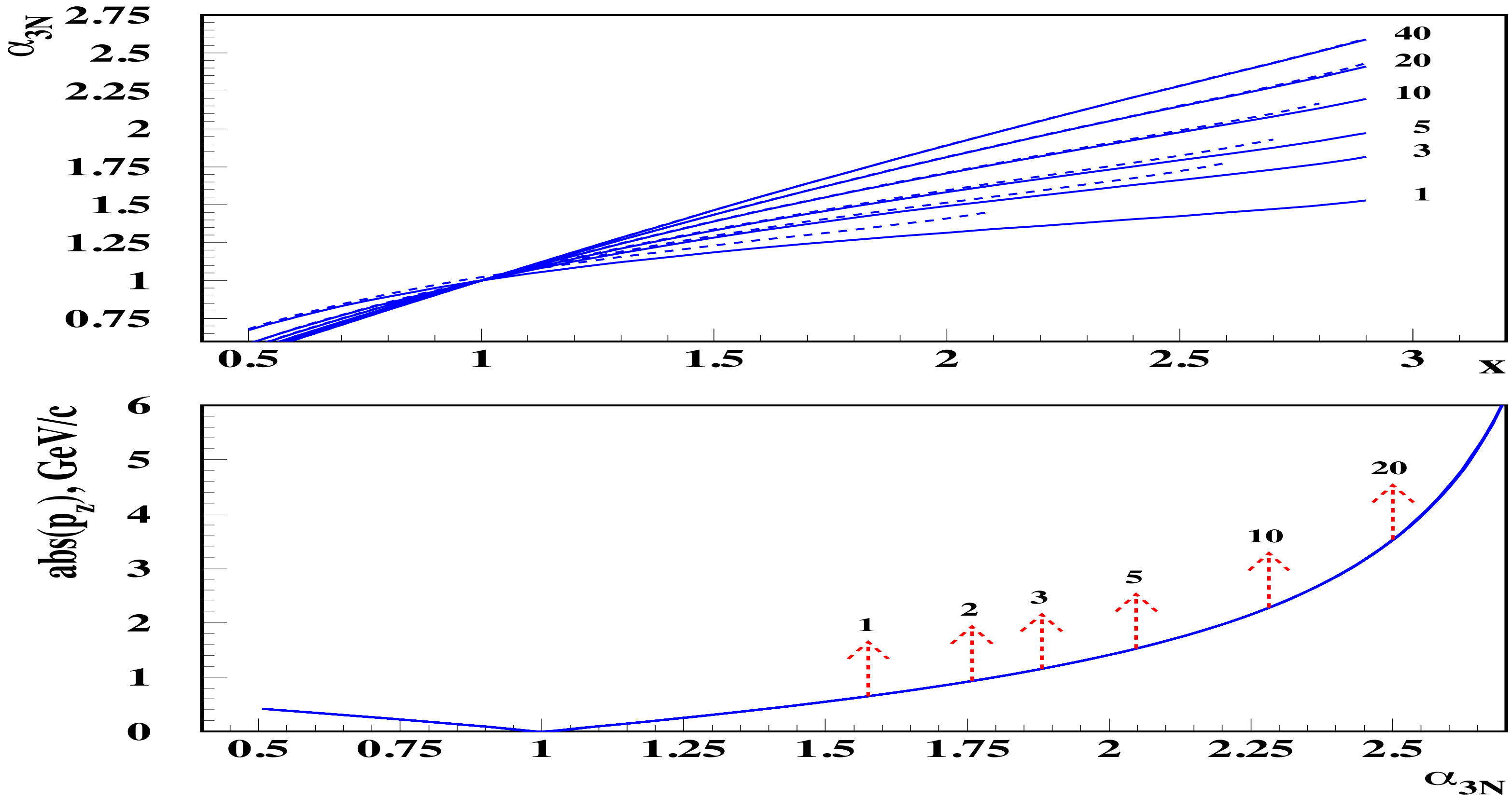


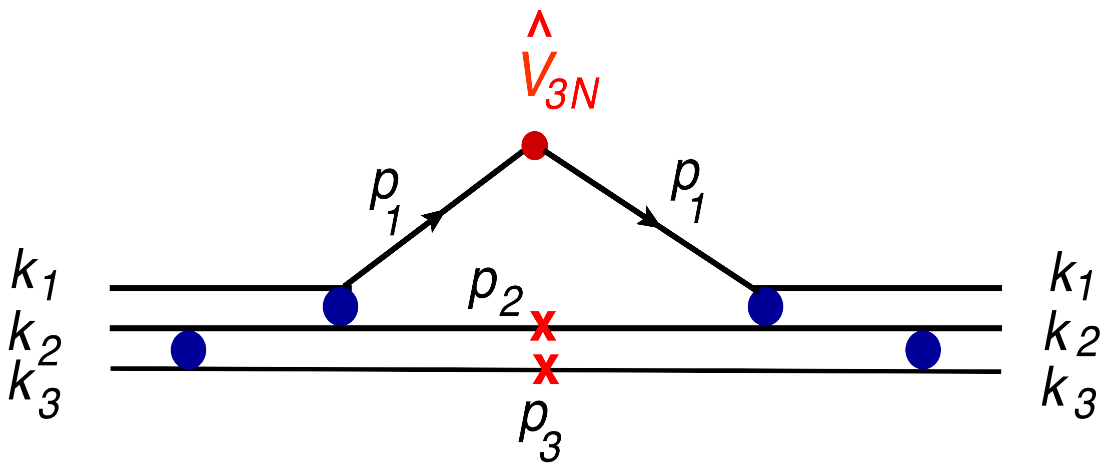
A(e,e/)
Q2<1.30
a)
Q2>1.40
b)
3σC/12σHe3
Xb=Q2/2Mν
0.8
1
1.2
1.4
1.6
1.8
2
0
0.5
1
1.5
2
2.5
3
3.5
4

For finite Q2 - 2N SRCs



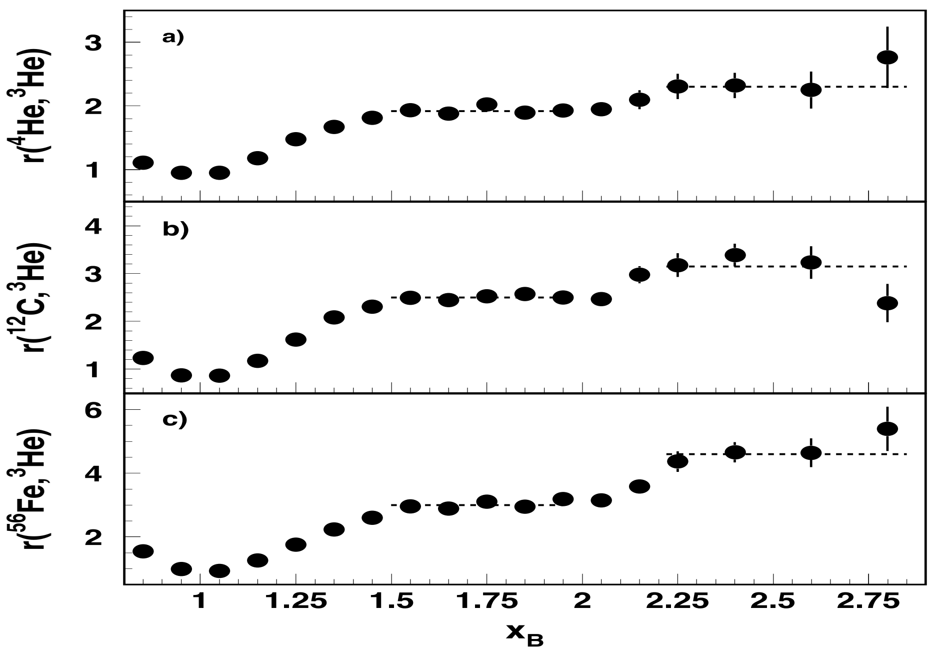
For finite Q2 - for 3N SRCs





$$\sim a_2(A)^2$$

$$R_3 = \frac{3\sigma(e+A\rightarrow e'X)}{A\sigma(e+{}^3He\rightarrow e'X)} = \frac{a_3(A)}{a_3({}^3He)} \sim \frac{a_2(A)^2}{a_2({}^3He)^2}$$



A	R_3^{exp}	R_3^{pred}
4	$2.33 \pm 0.12 \pm 0.04$	2.8
12	$3.18 \pm 0.14 \pm 0.19$	4
56	$4.63 \pm 0.19 \pm 0.27$	5.7

$R_3(A)/R_3({}^4He)$

12	1.3	1.4
56	1.9	2.0

2. Extraction of Light-Front Momentum Distribution of Nuclei

$$F_{2A} = K\alpha f_A(\alpha)$$

$$K \sim \sigma_{eN}^{LF}$$

$$f_A(\alpha) = \int \frac{1}{\alpha}\rho_A(\alpha, p_t) d^2 p_t$$

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

III. Semi-Inclusive Processes

1. Probing Deuteron & Extracting Nuclear TMDs

2. Looking for the Plateaus? in (e,e'N) Reactions

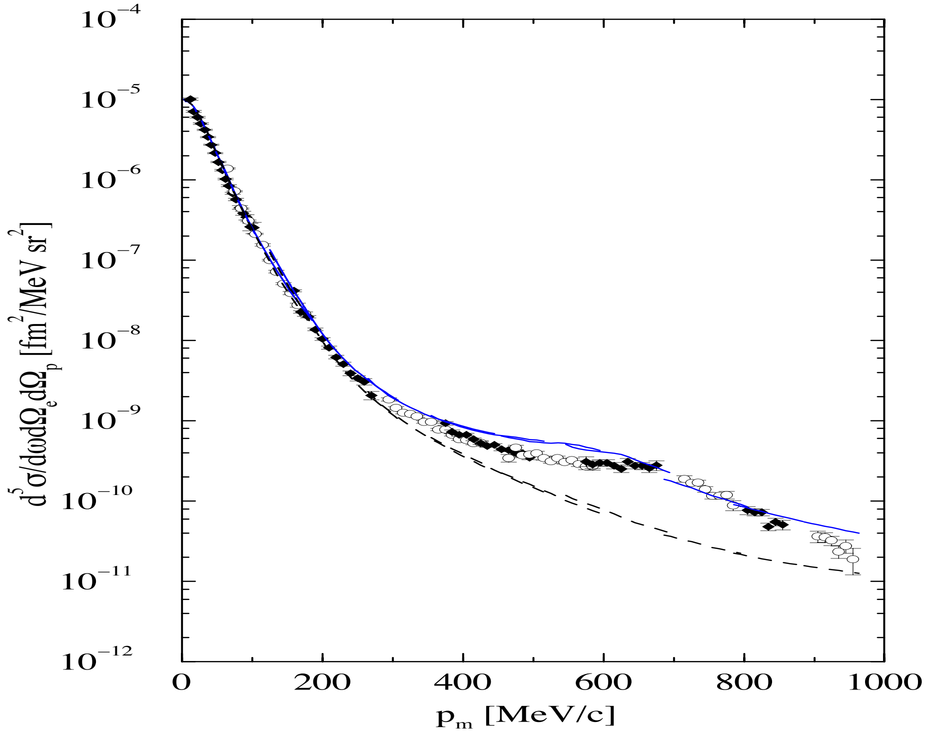
3. Probing $x - \alpha$ correlations in fast backward production off nuclei

4. Probing Non-nucleonic Components in Nuclei in Backward Production of Resonances

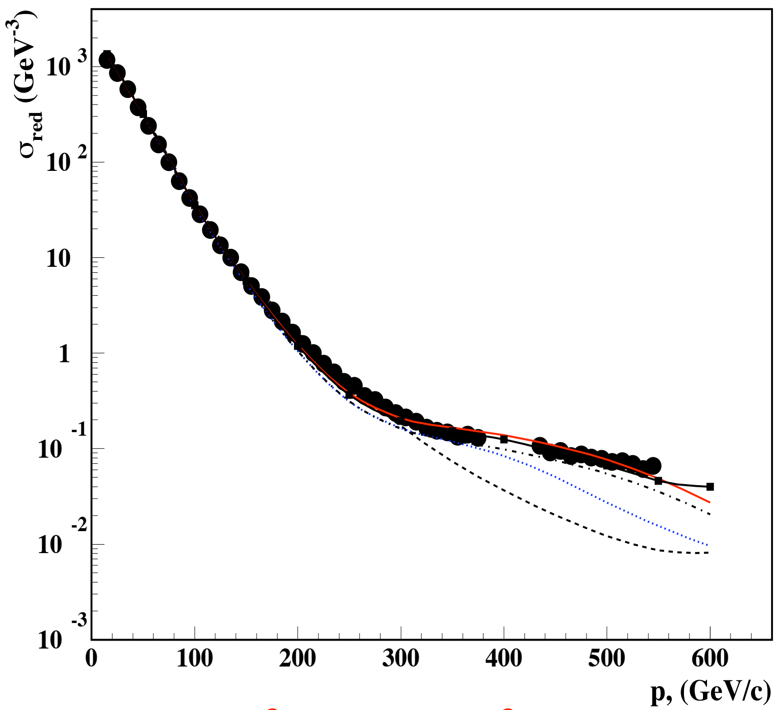
Trident Experiments

1. Probing Deuteron & Extracting Nuclear TMDs $d(e, e'p)n$

Impossibility to Probe Deuteron at Small Distances at low Q^2



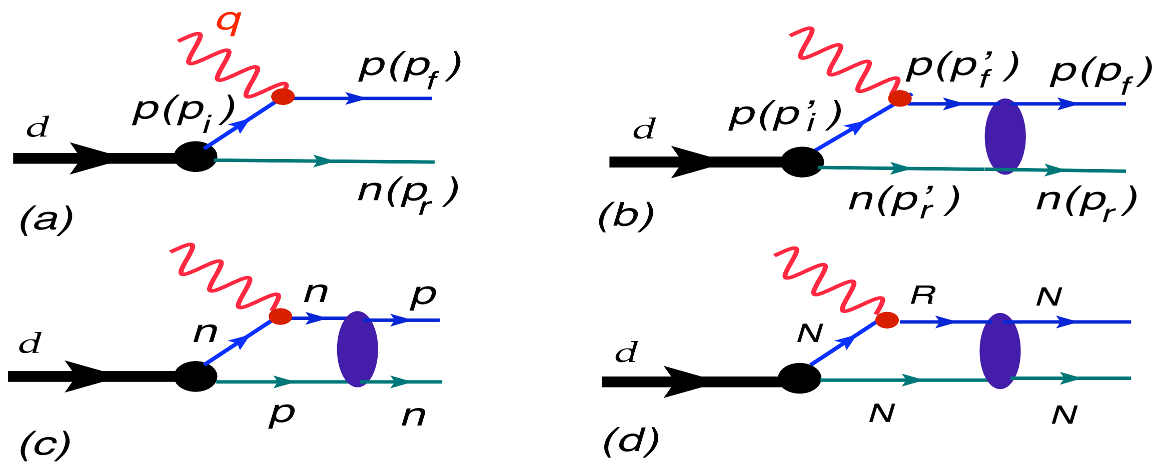
Mainz, $Q^2 = 0.33$ GeV^2



JLab, $Q^2 = 0.66$ GeV^2

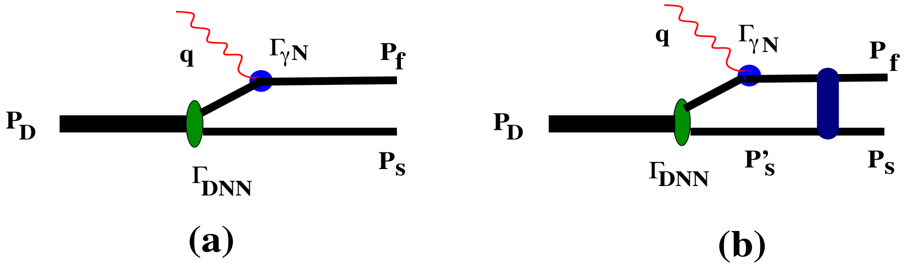
1. Probing Deuteron & Extracting Nuclear TMDs

$$d(e, e'p)n$$



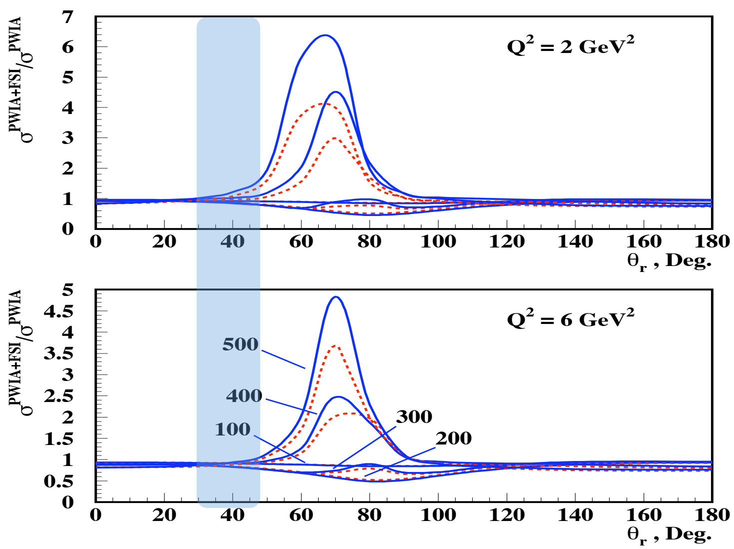
Generalized Eikonal Approximation at large Q2, 1997-2010

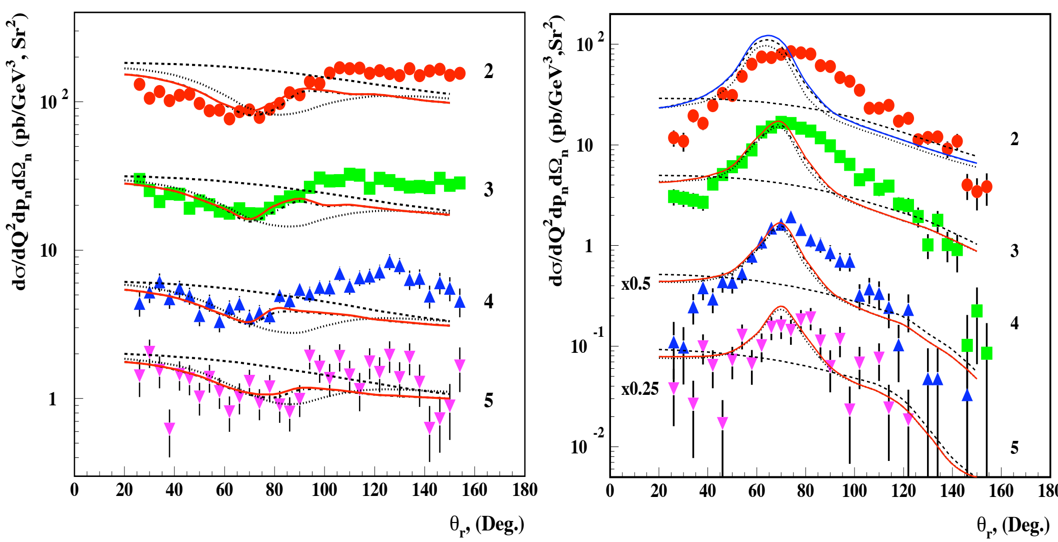
At Large $Q^2 > 1\text{-}2$ GeV^2 Eikonal Regime is Established)



For the case of
e+ d → e' + p_f + p_s

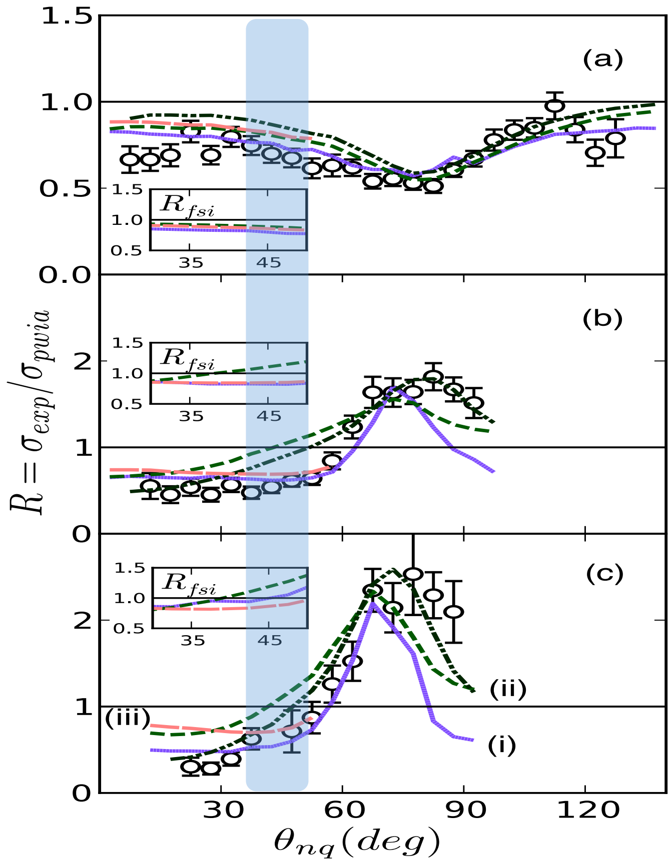
K.Egiyan at al 2008



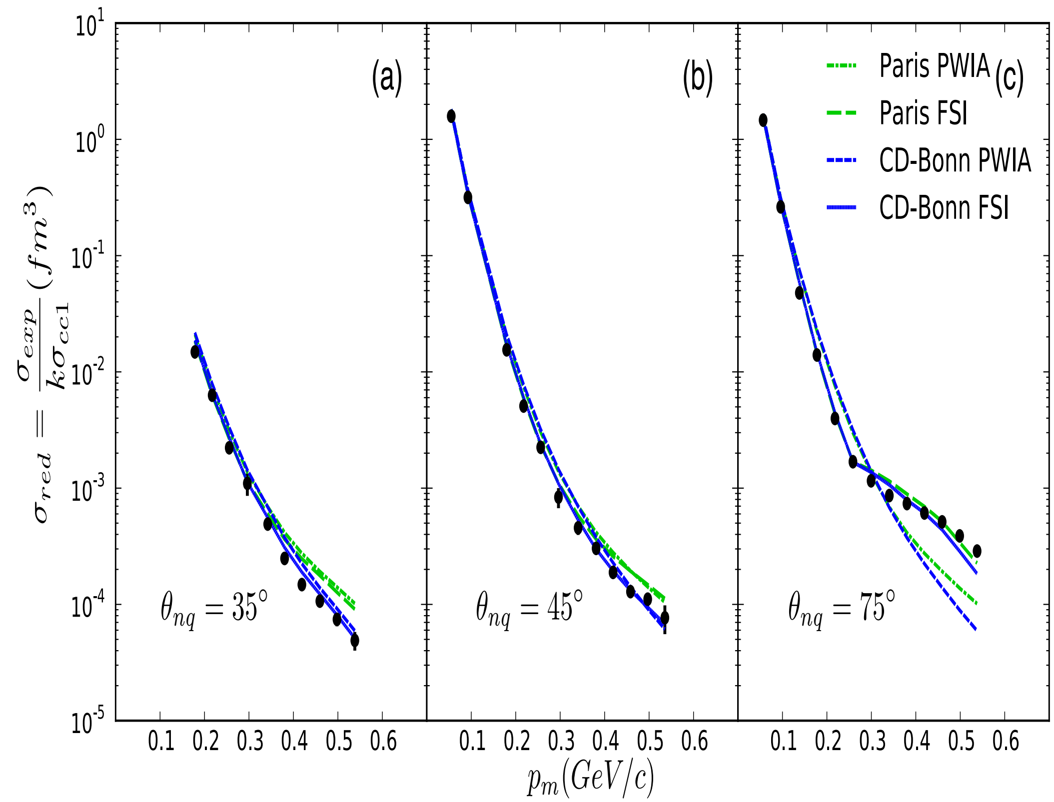


M.Sargsian, PRC 2010

Probing Deuteron at Small Distances at large Q^2

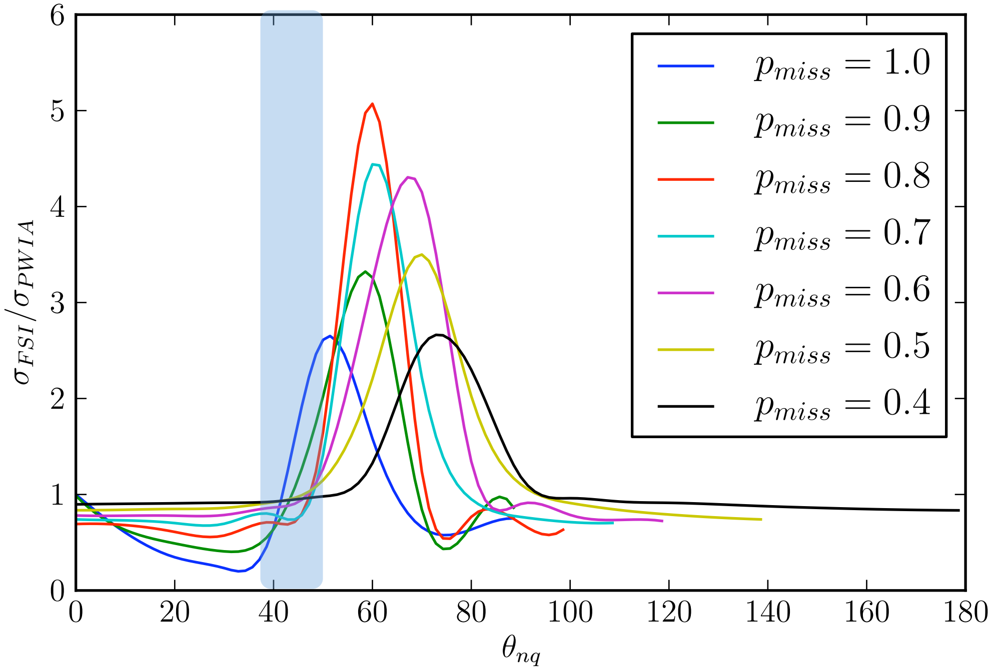


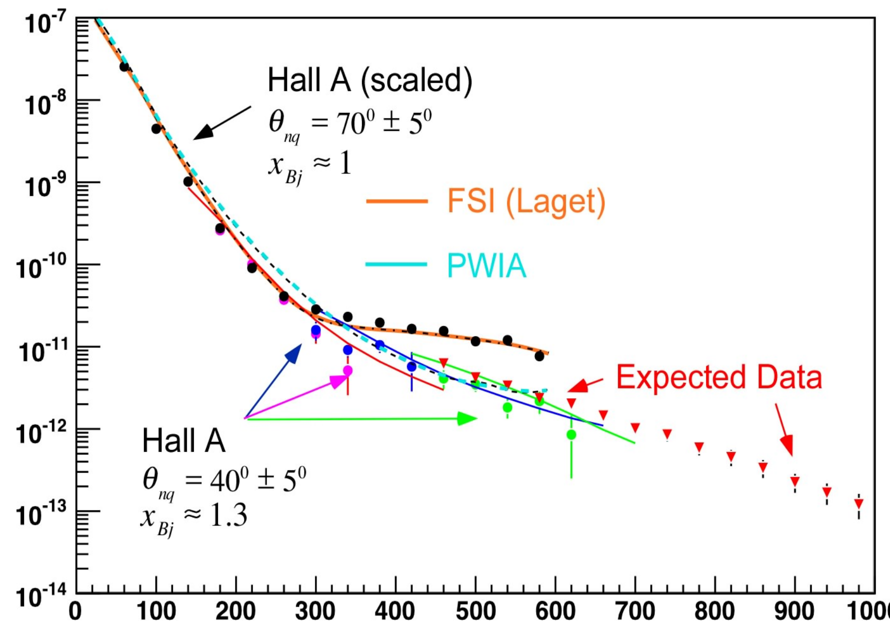
JLab, $Q^2 = 3.5\ GeV^2$



Boeglin et al 2011, deuteron probed at up to 500MeV/c

Probing Deuteron at Core Distances at large Q^2



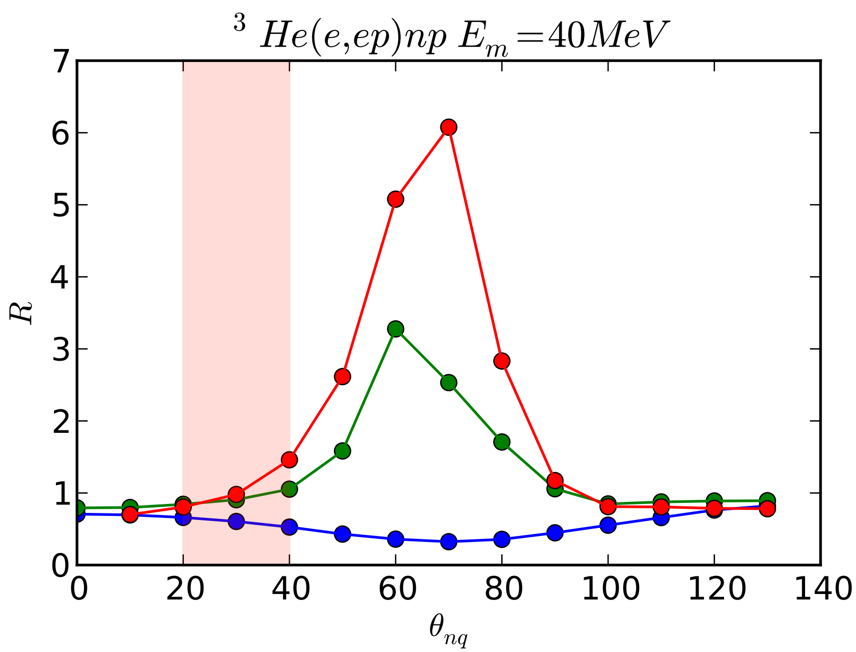


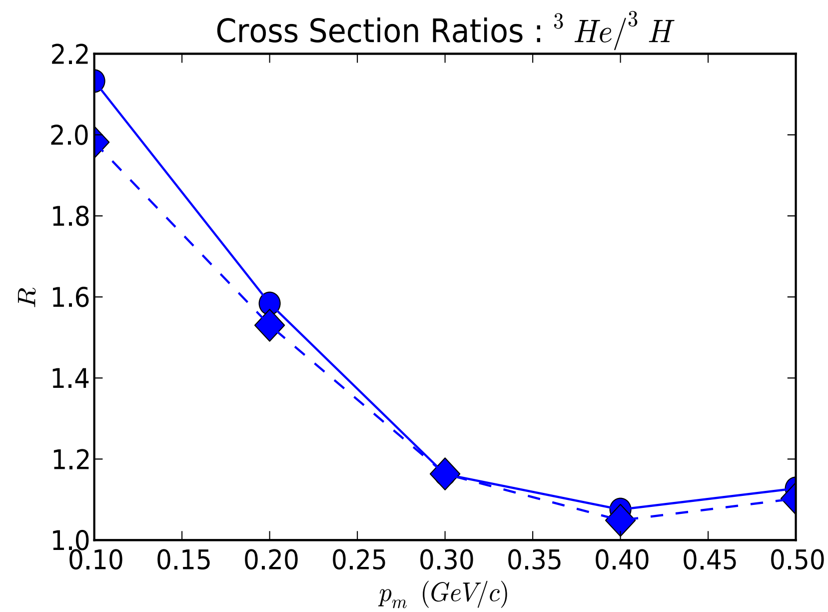
JLab proposal $Q^2 = 4$ GeV^2

Instead of measuring neutron momentum distribution, the above predictions can be checked for proton distributions from ^3He and ^3H in $^3He(e,e'p)X$ and $^3H(e,e'p)X$ reactions

New proposal: L. Weinstein, O. Hen, W.Boeglin, S.Gilad - SPKS

- How to probe 300-600 ? --- Using the "Window"





III. Semi-Inclusive Processes

1. Extracting Nuclear TMDs

2. Looking for the Plateaus? in (e,e'N) Reactions

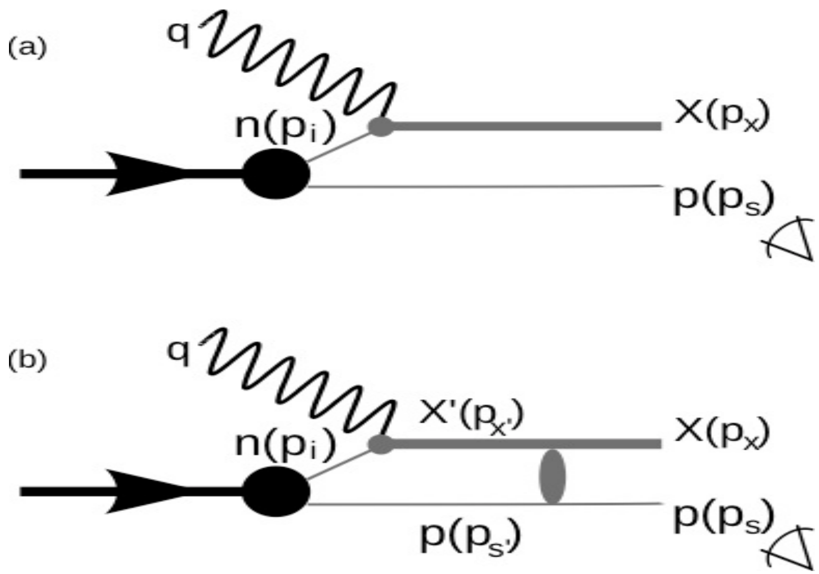
3. Probing $x - \alpha$ correlations in fast backward production off nuclei

4. Probing Non-nucleonic Components in Nuclei in Backward Production of Resonances

Trident Experiments

- Hadronization Studies in Semi-Inclusive $d(e,e,p_s)X$ DIS

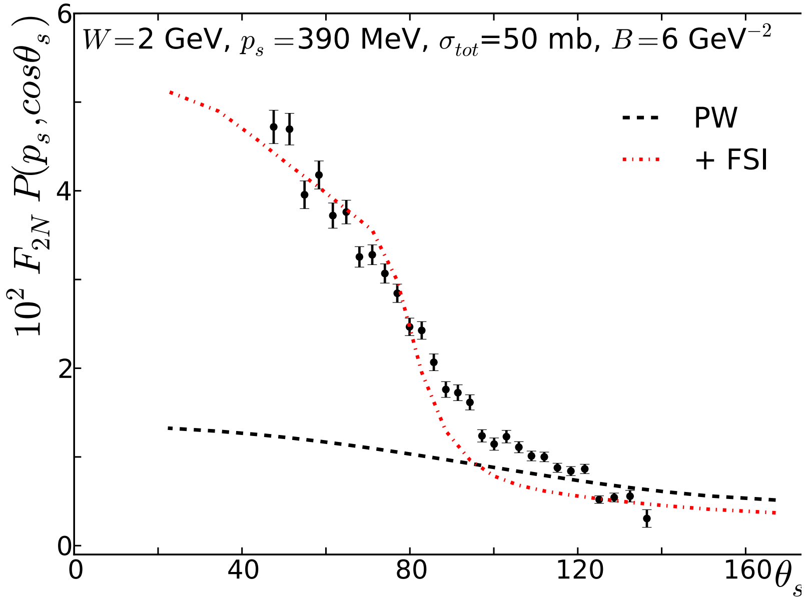
W.Cosyn & M.Sargsian
PRC2011



Extension of GEA for Inelastic and Deep-Inelastic Processes

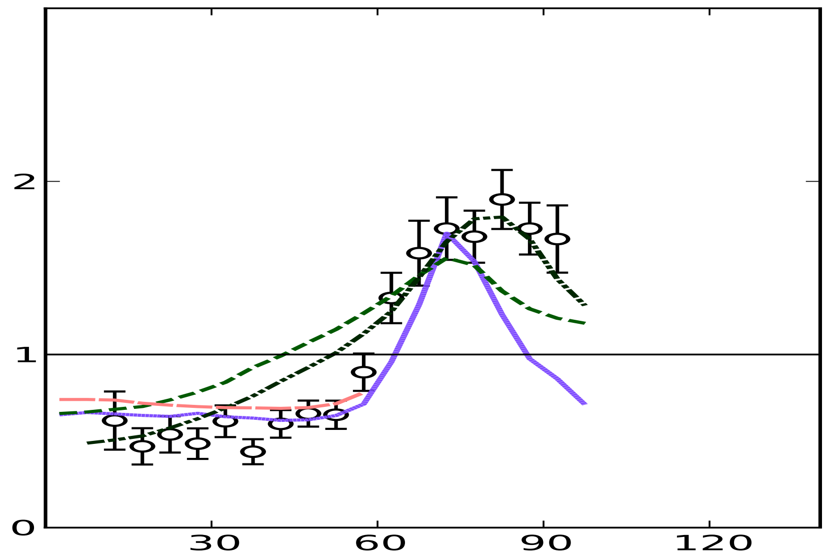
W.Cosyn & M.Sargsian, PRC 2011

For the DIS processes of e+ d → e' + X + p_s



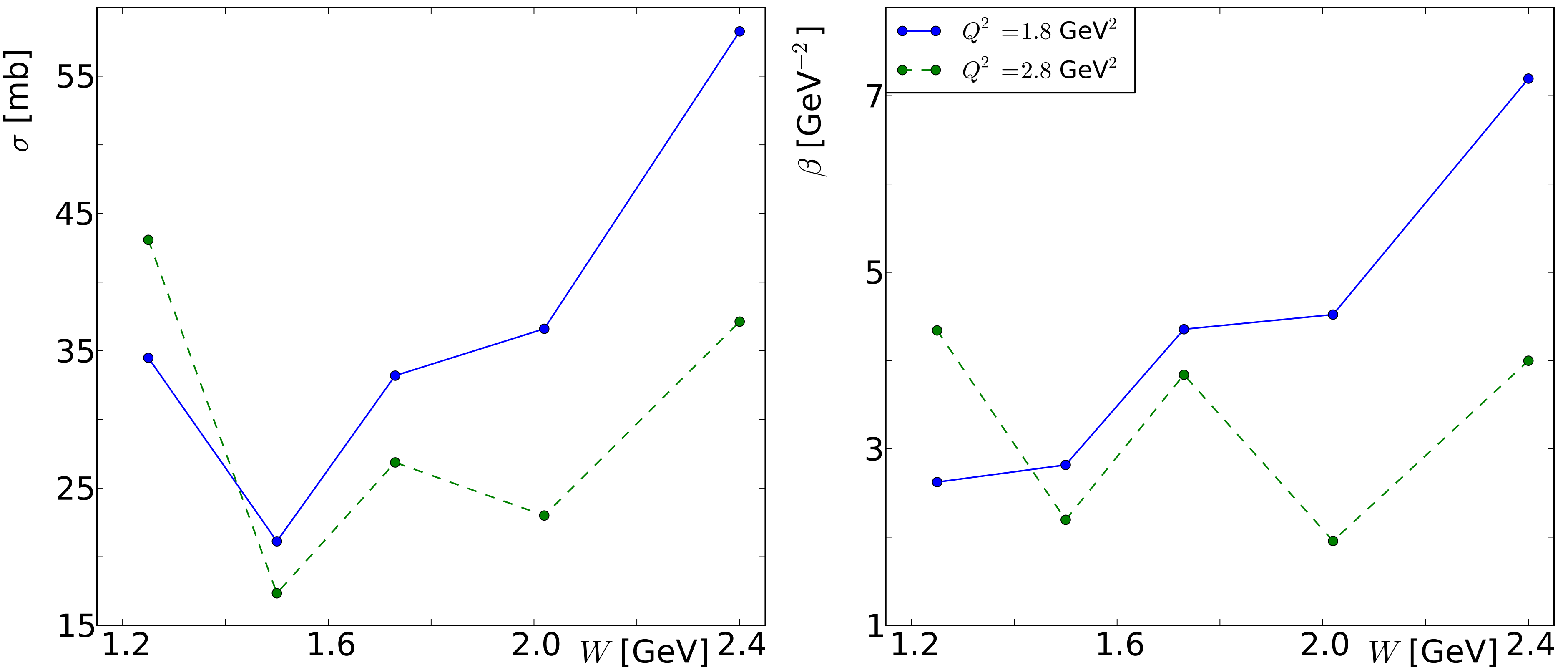
A. Klimenko et al PRC 2006

For quasielastic of e+ d → e' + p_f + p_s

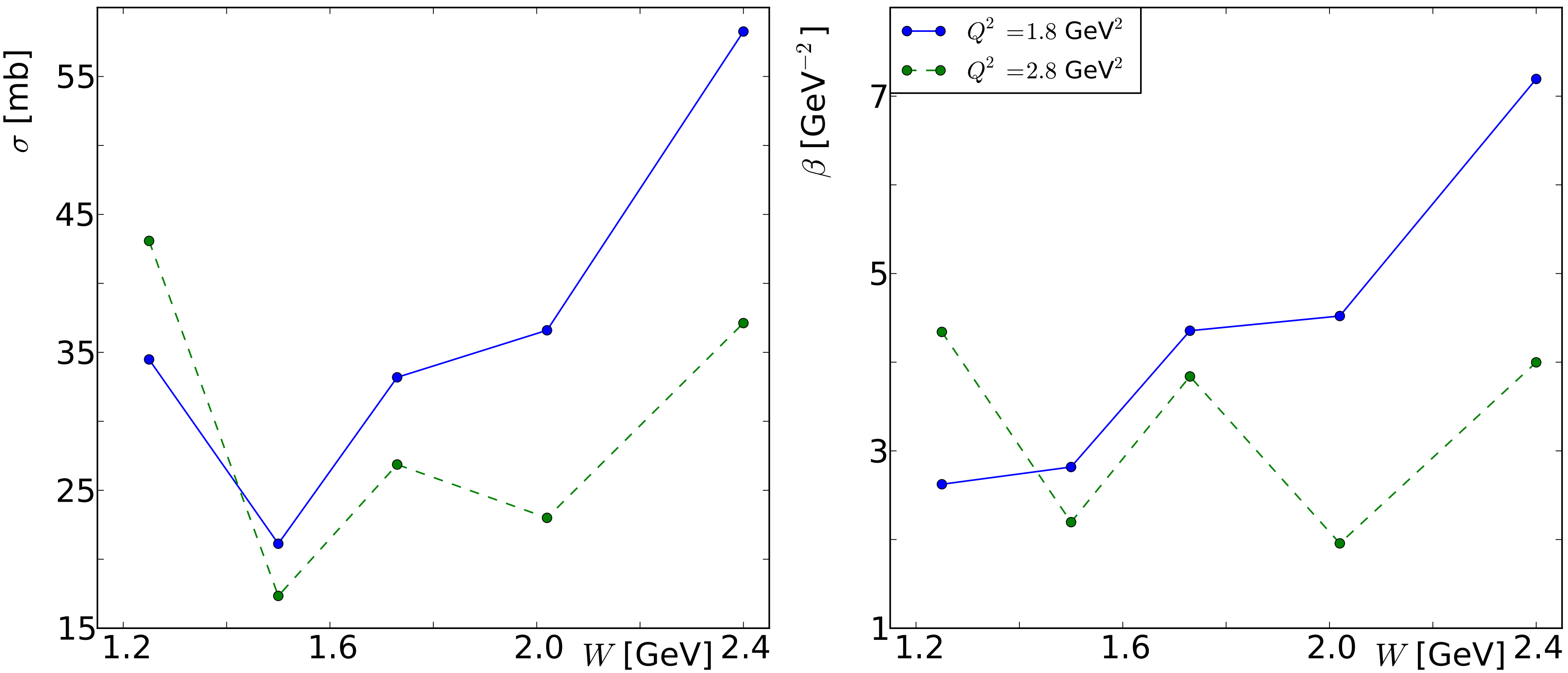


W. Boeglin et al PRL 2011

Extraction of XN cross section



Extraction of XN cross section



for large $k > k_{Fermi}$

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

- Isospin composition ?

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

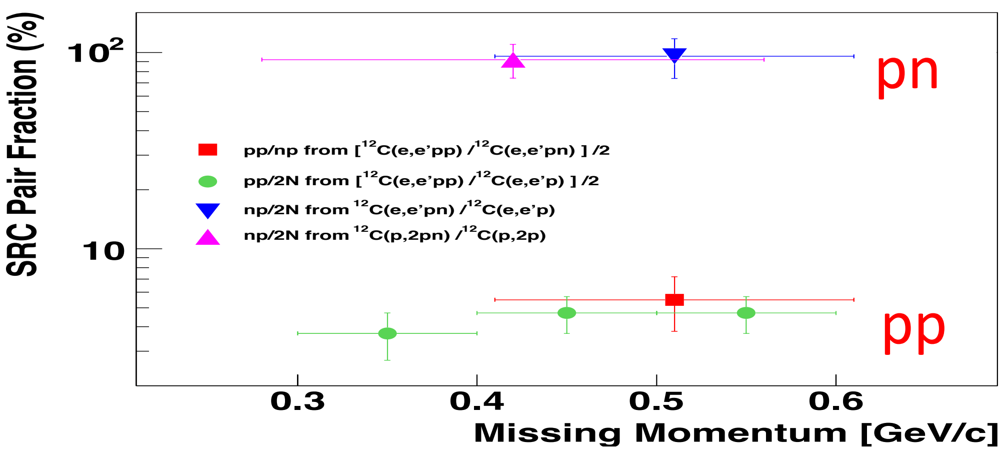
$$\frac{P_{pp}}{P_{pn}} \leq \frac{1}{2}(1 - P_{pn/pX}) = 0.04^{+0.09}_{-0.04}.$$

Theoretical analysis of BNL Data

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

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

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



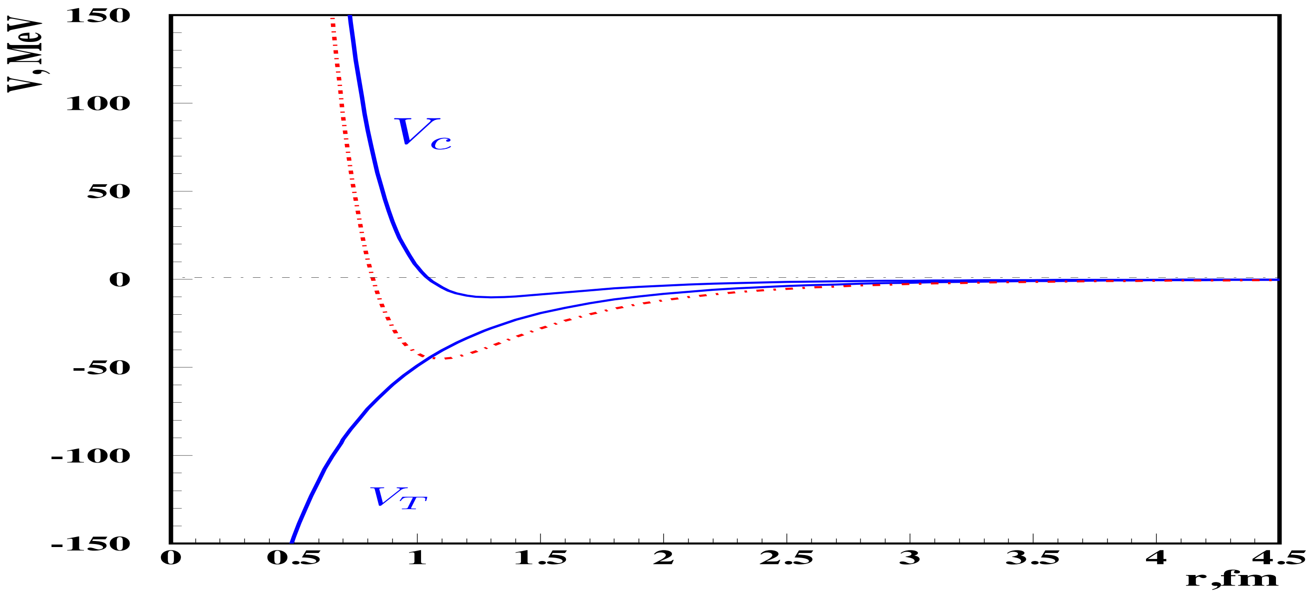
Factor of 20

Expected 4
(Wigner counting)

Theoretical Interpretation

$$\Phi^{(1)}(k_1,\cdots,k_c,\cdots,-k_c,\cdots,k_A) \approx \frac{U_{NN}(k_c)}{k_c^2} F_A(k_1,\cdots'\cdots',\cdots,k_A)$$

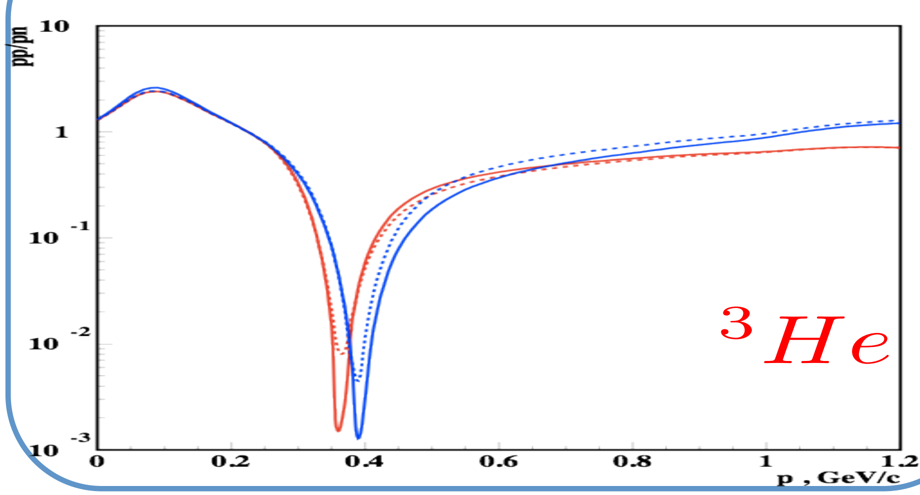
$$n_A(k) \approx a_{NN}(A) n_{NN}(k)$$



$$V_{NN}(r) \approx V_c(r) + V_t(r) \cdot S_{12}(r) + V_{LS} \cdot \vec{L}\vec{S}$$

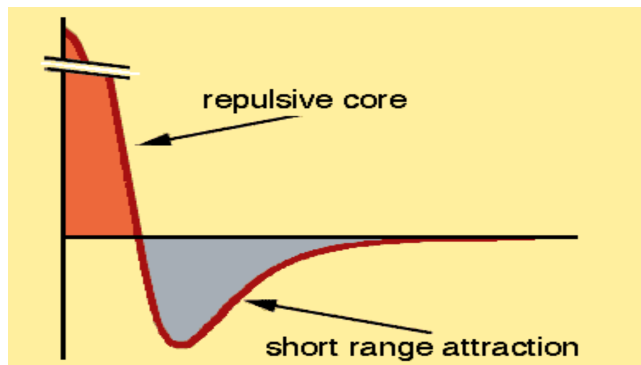
$$S_{12} = 3(\sigma_1 \cdot \hat{r})(\sigma_2 \cdot \hat{r}) - \sigma_1 \sigma_2$$

M.S, Abrahamyan, Frankfurt,Strikman PRC,2005



Isospin 1 states

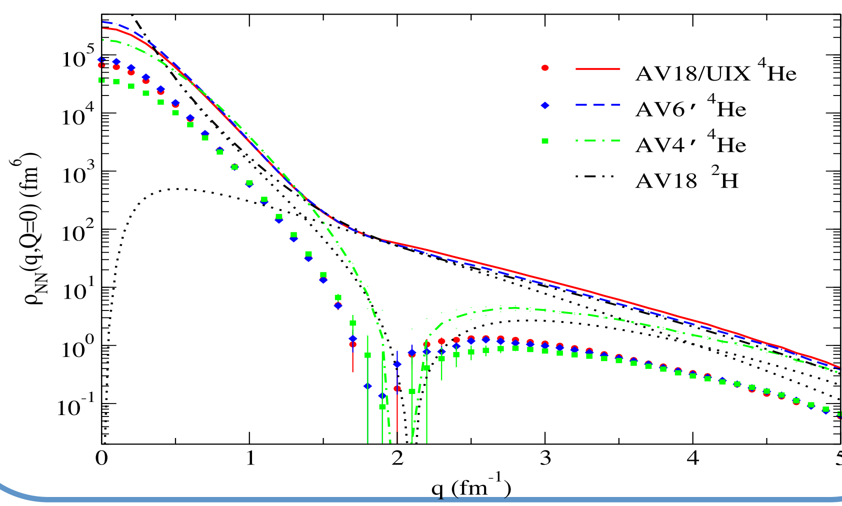
Isospin 0 states



$$V_{NN}(r) \approx V_c(r) + V_t(r) \cdot S_{12}(r) + V_{LS} \cdot \vec{L}\vec{S}$$

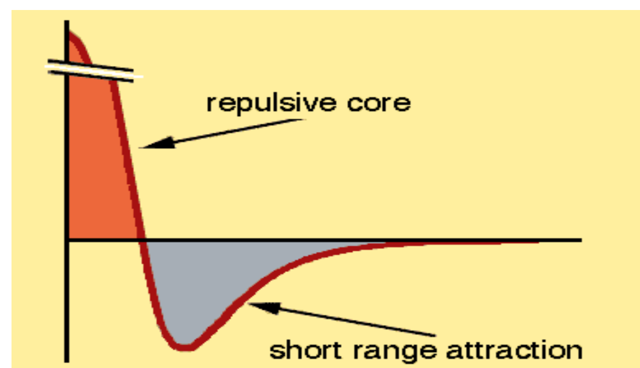
$$S_{12} = 3(\sigma_1 \cdot \hat{r})(\sigma_2 \cdot \hat{r}) - \sigma_1\sigma_2$$

Sciavilla, Wiringa, Pieper, Carlson PRL,2007



Isospin 1 states

Isospin 0 states



- Dominance of pn short range correlations as compared to pp and nn SRCS

2006-2008s

- Dominance of NN Tensor as compared to the NN Central Forces at <= 1fm

- Two New Properties of High Momentum Component

- Energetic Protons in Neutron Rich Nuclei at $p > k_F$

$$n^A(p) \sim a_{NN}(A) \cdot n_{NN}(p) \qquad (1)$$

- Dominance of pn Correlations
(neglecting pp and nn SRCs)

$$n_{NN}(p) \approx n_{pn}(p) \approx n_{(d)}(p) \qquad (2)$$

$$n^A(p) \sim a_{pn}(A) \cdot n_d(p)$$

$$a_2(A) \equiv a_{NN}(A) \approx a_{pn}(A)$$

- Define momentum distribution of proton & neutron

$$n^A(p) = \frac{Z}{A} n_p^A(p) + \frac{A-Z}{A} n_n^A(p) \qquad (3)$$

$$\int n_{p/n}^A(p) d^3p = 1$$

- Define

$$I_p = \frac{Z}{A} \int_{k_F}^{600} n_p^A(p) d^3p \qquad I_n = \frac{A-Z}{A} \int_{k_F}^{600} n_n^A(p) d^3p$$

- and observe that in the limit of no pp and nn SRCs

$$I_p = I_n$$

- Neglecting CM motion of SRCs $\quad \frac{Z}{A} n_p^A(p) \approx \frac{A-Z}{A} n_n^A(p)$

First Property: Approximate Scaling Relation

-if contributions by pp and nn SRCs are neglected and
the pn SRC is assumed at rest

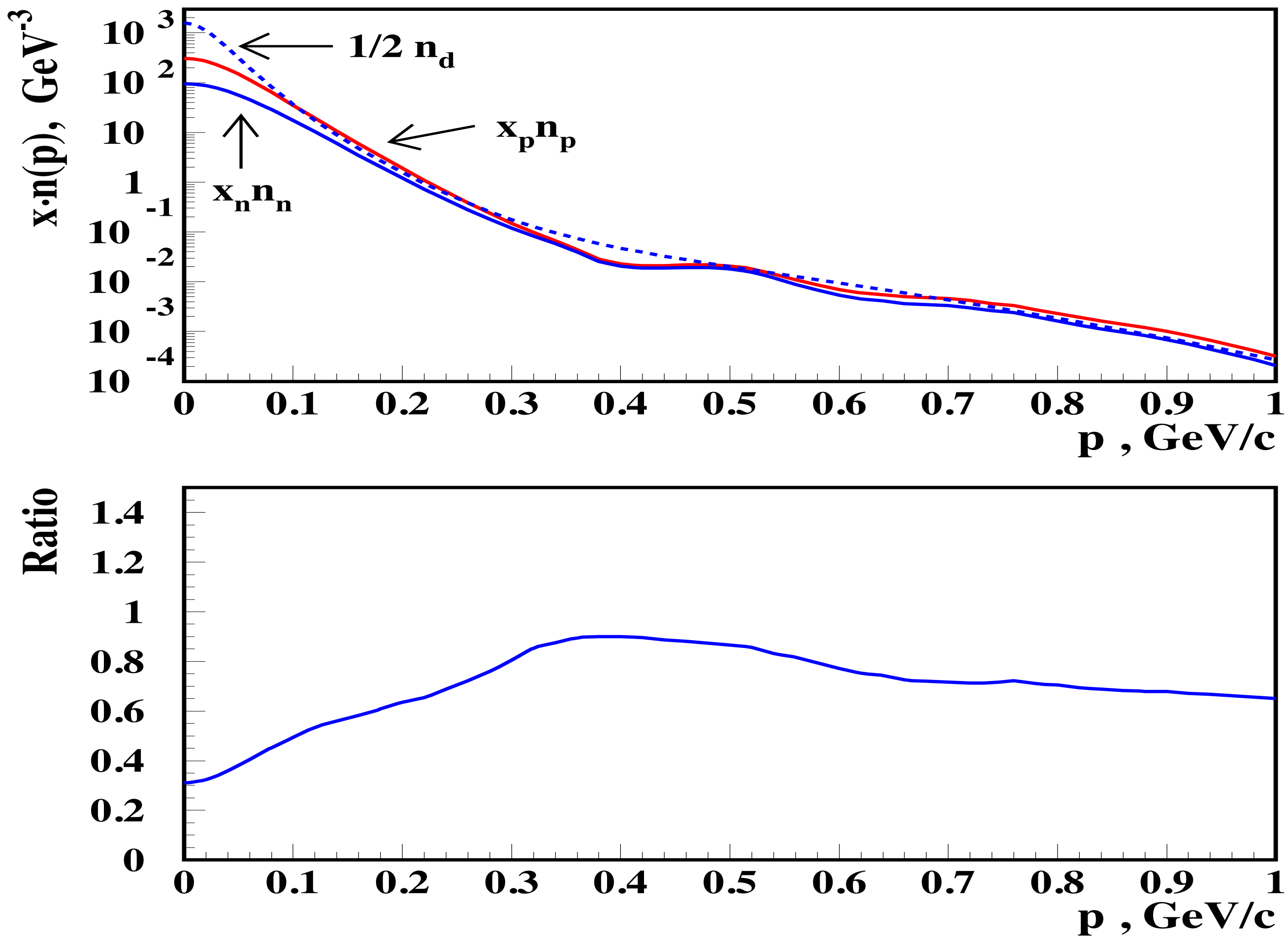
MS,arXiv:1210.3280
Phys. Rev. C 2014

- for $\sim k_F - 600$ MeV/c region:

$$x_p \cdot n_p^A(p) \approx x_n \cdot n_n^A(p)$$

where $x_p = \frac{Z}{A}$ and $x_n = \frac{A-Z}{A}$.

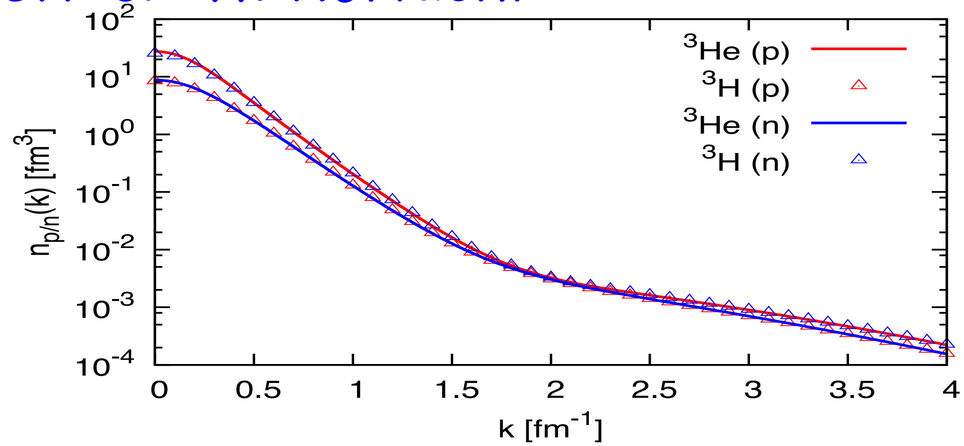
Realistic 3He Wave Function: Faddeev Equation

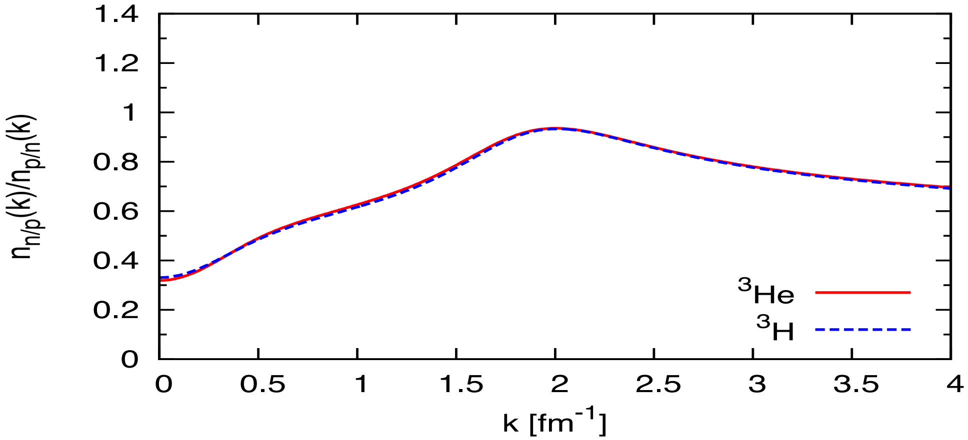


MS,PRC 2014

Realistic 3He Wave Function: Correlated Gaussian Basis

T.Neff & W. Horiuchi

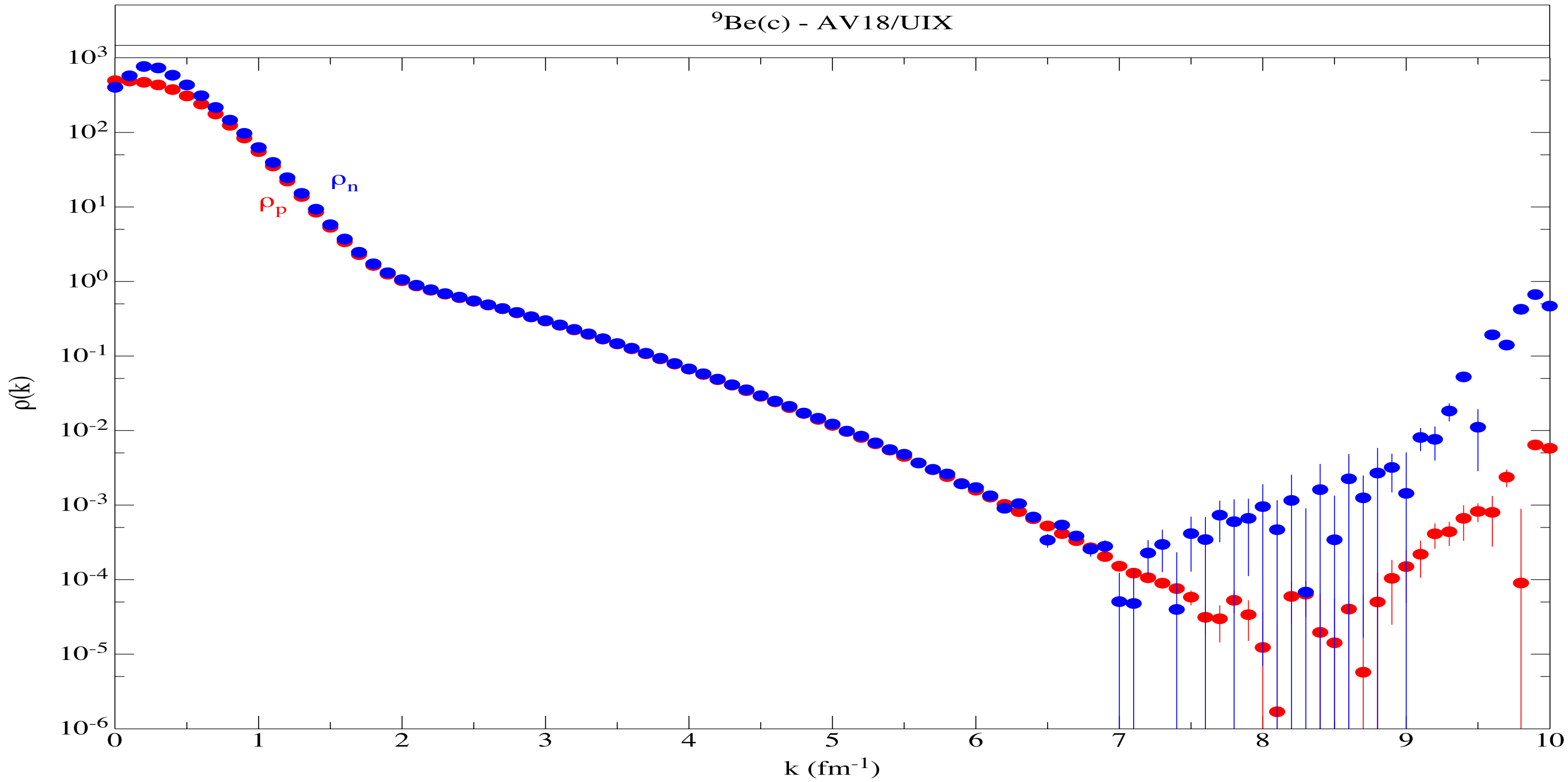




April 2013

Be9 Variational Monte Carlo Calculation:

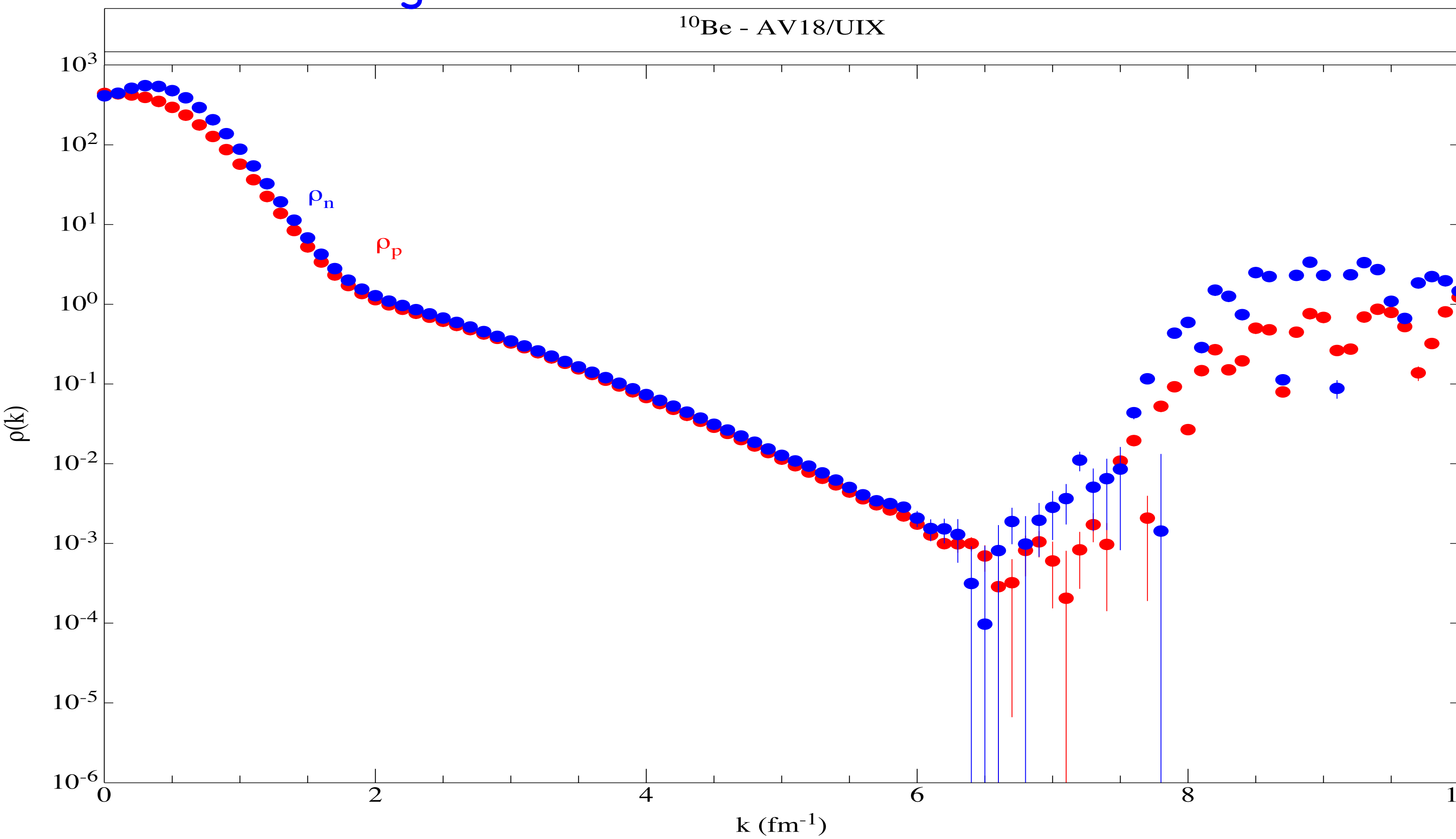
Robert Wiringa 2013 http://www.phy.anl.gov/theory/research/momenta/



Tanks to S. Pastore

B10 Variational Monte Carlo Calculation:

Robert Wiringa



Second Property:

MS,arXiv:1210.3280
Phys. Rev. C 2014

Using Definition: $n^A(p) = \frac{Z}{A} n_p^A(p) + \frac{A-Z}{A} n_n^A(p)$

Approximations:
$$n^A(p) \sim a_{NN}(A) \cdot n_{NN}(p)$$
$$n_{NN}(p) \approx n_{pn}(p) \approx n_{(d)}(p)$$

And: $I_p = I_n$ $\quad I_p + I_n = 2I_N = a_{pn}(A) \int_0^{600} n_d(p) d^3p$

One Obtains:
$$x_p \cdot n_p^A(p) \approx x_n \cdot n_n^A(p) \approx \frac{1}{2} a_{NN}(A, y) n_d(p)$$

where $y = |1 - 2x_p| = |x_n - x_p|$

- $a_{NN}(A, 0)$ corresponds to the probability of pn SRC in symmetric nuclei
- $a_{NN}(A, 1) = 0$ according to our approximation of neglecting pp/nn SRCs

Second Property: Fractional Dependence of High Momentum Component

$$a_{NN}(A,y) \approx a_{NN}(A,0) \cdot f(y)$$ with $f(0) = 1$ and $f(1) = 0$

$$f(|x_p - x_n|) = 1 - \sum_{j=1}^{n} b_i |x_p - x_x|^i \text{ with } \sum_{j=1}^{n} b_i = 0$$

In the limit $\sum_{j=1}^{n} b_i |x_p - x_x|^i \ll 1$ Momentum distributions of p & n are inverse proportional to their fractions

$$n^A_{p/n}(p) \approx \frac{1}{2x_{p/n}} a_2(A,y) \cdot n_d(p)$$

$$x_{p/n} = \frac{Z/N}{A}$$

Observations: High Momentum Fractions

MS,arXiv:1210.3280
Phys. Rev. C 2014

$$P_{p/n}(A,y) = \frac{1}{2x_{p/n}} a_2(A,y) \int_{k_F}^{\infty} n_d(p) d^3p$$

A	Pp(%)	Pn(%)
12	20	20
27	23	22
56	27	23
197	31	20

Requires dominance of pn SRCs
in heavy neutron reach nuclei

O. Hen, M.S. L. Weinstein, et.al.
Science, 2014

Is the total kinetic energy inversion possible?

MS,arXiv:1210.3280
Phys. Rev. C 2014

Checking for He3

Energetic Neutron

$$E^{p}_{kin} = 14 \text{ MeV } (\text{p}= 157 \text{ MeV/c})$$

$$E^{n}_{kin} = 19 \text{ MeV } (\text{p}= 182 \text{ MeV/c})$$

Energetic Neutron
(Neff & Horiuchi)

$$E^{p}_{kin} = 13.97 \text{ MeV}$$

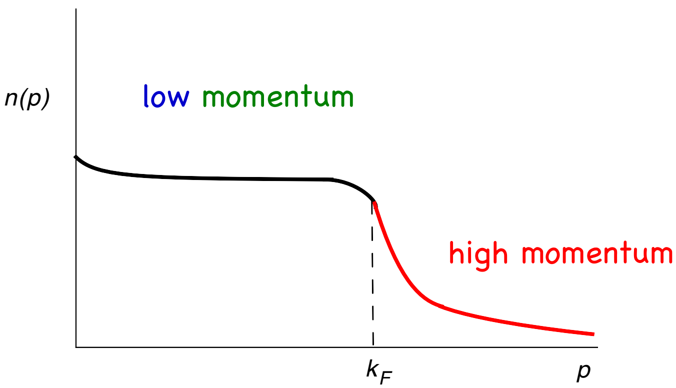
$$E^{n}_{kin} = 18.74 \text{ MeV}$$

VMC Estimates: Robert Wiringa

MS,arXiv:1210.3280
Phys. Rev. C 2014

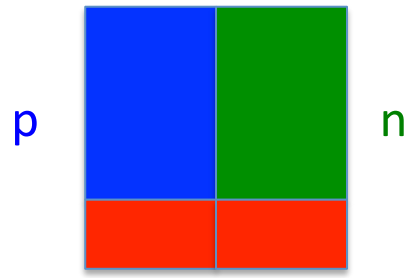
Table 1: Kinetic energies (in MeV) of proton and neutron

A	y	E^p_{kin}	E^n_{kin}	$E^p_{kin} - E^n_{kin}$
^{8}He	0.50	30.13	18.60	11.53
^{6}He	0.33	27.66	19.06	8.60
^{9}Li	0.33	31.39	24.91	6.48
^{3}He	0.33	14.71	19.35	-4.64
^{3}H	0.33	19.61	14.96	4.65
^{8}Li	0.25	28.95	23.98	4.97
^{10}Be	0.2	30.20	25.95	4.25
^{7}Li	0.14	26.88	24.54	2.34
^{9}Be	0.11	29.82	27.09	2.73
^{11}B	0.09	33.40	31.75	1.65



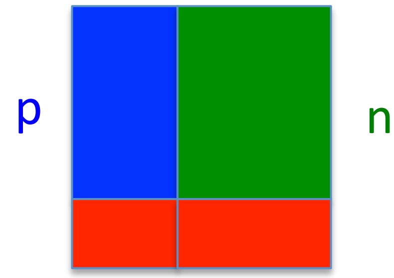
$$k_F = (3\pi^2 \rho_N)^{\frac{1}{3}}$$

Symmetric Nuclei



$$K_p = K_n$$

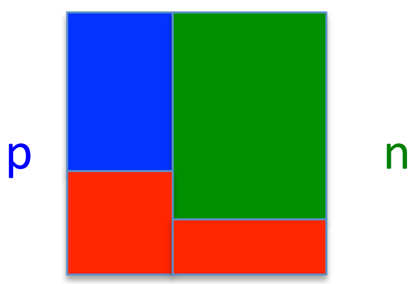
Asymmetric Nuclei



Conventional Theory: $K_n > K_p$

(Shell Model, HO Ab Initio)

Asymmetric Nuclei



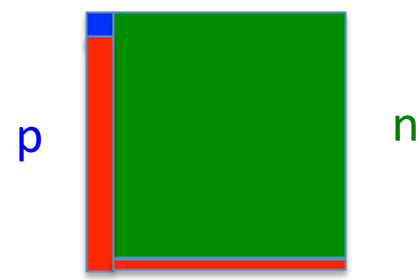
New Predictions

1. Per nucleon, more protons are in high momentum tail

2. Kin Energy Inversion

$K_p > K_n$?

Neutron Stars



Protons my completely populate the high momentum tail

- New Properties of High Momentum Distribution of Nucleons in Asymmetric Nuclei — MS, arXiv:1210.3280 Phys. Rev. C 2014

- Protons are more Energetic in Neutron Rich High Density Nuclear Matter — M. McGauley, MS arXiv:1102.3973

  - First Experimental Indication — O. Hen, M.S. L. Weinstein, et.al. Science, 2014, "accepted"

  - Confirmed by VMC calculations for A<12 — R.B. Wiringa et al, Phys. Rev. C 2014

  - For Nuclear Matter — W. Dickhoff et al Phys. Rev. C 2014

  - For Medium/Heavy Nuclei — M. Vanhalst. W. Cosyn J. Ryckebusch, arXiv 2014

Implications: Energetic Protons in neutron rich Nuclei

Implications: Protons are more modified in neutron rich nuclei
u-quarks are more modified then d-quarks in Large A Nuclei

- Flavor Dependence of EMC effect
- Different explanation of NuTev Anomaly
- Can be checked in neutrino-nuclei or in pvDIS processes

NuTeV Experiment: Zeller et al PRL 2002

- CC and NC scattering of ν_μ and $\bar{\nu}_\mu$ of ^{56}Fe at energies 64 and 53 GeV

- Measured Paschos Wolfenstein Ratio

$$R^{PW} \equiv \frac{R^{\nu} - rR^{\bar{\nu}}}{1-r} = (g_L^2 - g_R^2)$$

$$R^{\nu(\bar{\nu})} \equiv \frac{\sigma(\nu(\bar{\nu})N \to \nu(\bar{\nu})X)}{\sigma(\nu(\bar{\nu})N \to l^-(l^+)X)} \qquad r = \frac{\sigma(\bar{\nu}N \to l^+ X)}{\sigma(\nu N \to l^- X)} \approx \frac{1}{2}$$

$$R^{PW} |_{Z=N} \approx \frac{1}{2} - sin^2\theta_W$$

$$sin^2\theta_W = 0.2277 \pm 0.0013(stat) \pm 0.0009(syst)$$

$$sin^2\theta_W = 0.2227 \pm 0.0004$$

Anomaly's explanation: Bentz,Cloet,Londergan,Thomas, PRL09, 2011

- Presence of static - isovector ρ^0 field in neutron reach matter

- u - quarks feel less vector repulsion that d quarks

- Estimates in Nambu-Jona-Lasino model

$$\Delta R^{\rho^{0}} = -0.0025$$

- with NuTev functionals

$$\Delta R^{\rho^{0}} = -0.0019 \pm 0.0006$$

Anomaly's explanation: Our explanation

$$R^{PW} = \frac{(\frac{1}{6} - \frac{4}{9} sin^2\theta_W)\langle x_A u_A^- \rangle - (\frac{1}{6} - \frac{2}{9} sin^2\theta_W)\langle x_A d_A^- \rangle)}{\langle x_A d_A^- \rangle - \frac{1}{3}\langle x_A u_A^- \rangle}$$

$$\Delta R^{PW} \approx (1 - \frac{7}{3} sin^2\theta_W)\frac{\langle x_A u_A^- \rangle - \langle x_A d_A^- \rangle)}{\langle x_A d_A^- \rangle + \langle x_A u_A^- \rangle}$$

$$\langle x_A u_A^- \rangle = \int_x^A \frac{x}{\alpha}\left[u(\tfrac{x}{\alpha}) - \bar{u}(\tfrac{x}{\alpha})\right] \delta_u(p_k^2 - m^2)\rho_A^u(\alpha, p_t)\frac{d\alpha}{\alpha} d^2p_t$$

$$\langle x_A d_A^- \rangle = \int_x^A \frac{x}{\alpha}\left[d(\tfrac{x}{\alpha}) - \bar{d}(\tfrac{x}{\alpha})\right] \delta_d(p_k^2 - m^2)\rho_A^d(\alpha, p_t)\frac{d\alpha}{\alpha} d^2p_t$$

- EMC Effect in A(e,e')X scattering

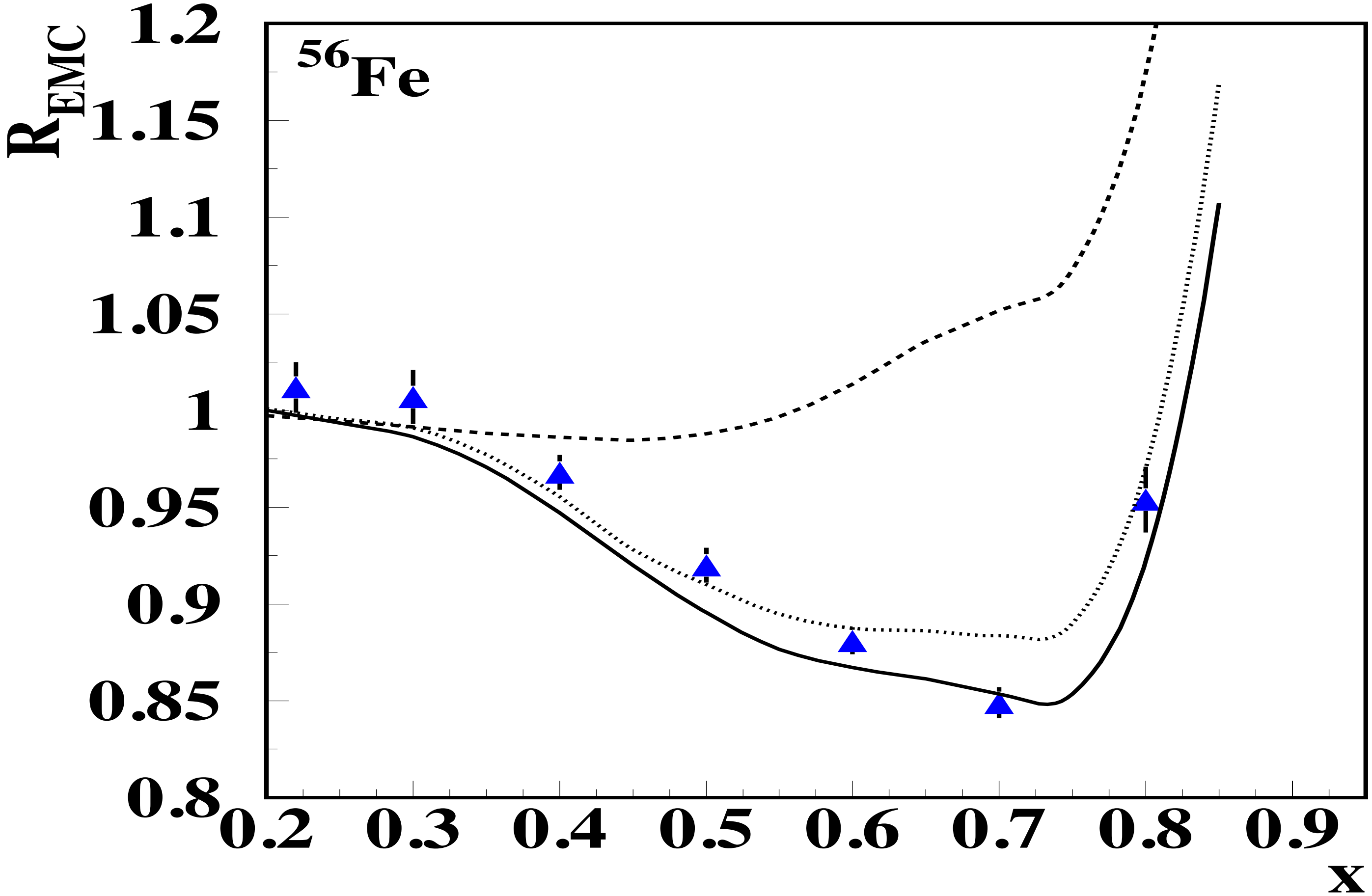
$$F_{2A} = (A - Z) \int_x^A F_{2n}(\tfrac{x}{\alpha}) \rho_n(\alpha, p_t) \tfrac{d\alpha}{\alpha} d^2 p_t$$

$$+ \quad Z \int_x^A F_{2p}(\tfrac{x}{\alpha}) \rho_p(\alpha, p_t) \tfrac{d\alpha}{\alpha} d^2 p_t$$

Color Screening Model: Frankfrut Strikman 1987

$$F^{eff}_{2n/p}(\tfrac{x}{\alpha}) = F_{2p/n}(\tfrac{x}{\alpha}) \delta_{p/n}(p_k^2 - m^2)$$

- EMC Effect



Anomaly's explanation: Our explanation

$$\Delta R^{PW} \approx (1 - \frac{7}{3} sin^2\theta_W) \frac{\langle x_A u_A^- \rangle - \langle x_A d_A^- \rangle)}{\langle x_A d_A^- \rangle + \langle x_A u_A^- \rangle}$$

$$\langle x_A u_A^- \rangle = \int_x^A \frac{x}{\alpha} \left[u(\frac{x}{\alpha}) - \bar{u}(\frac{x}{\alpha}) \right] \delta_u(p_k^2 - m^2) \rho_A^u(\alpha, p_t) \frac{d\alpha}{\alpha} d^2 p_t$$

$$\langle x_A d_A^- \rangle = \int_x^A \frac{x}{\alpha} \left[d(\frac{x}{\alpha}) - \bar{d}(\frac{x}{\alpha}) \right] \delta_d(p_k^2 - m^2) \rho_A^d(\alpha, p_t) \frac{d\alpha}{\alpha} d^2 p_t$$

$$\Delta R^{virt} = -0.0032 \pm 0.00096$$ Preliminary

to be compared

$$\Delta R^{\rho^0} = -0.0025$$

Are the observed effects universal for any two-component asymmetric/imbalanced Fermi Systems?

- In Atomic Physics

- In QCD

Observations: High Momentum Fractions

$$P_{p/n}(A,y) = \frac{1}{2x_{p/n}} a_2(A,y) \int_{k_F}^{\infty} n_d(p) d^3p$$

Checking for He3

Energetic Neutron

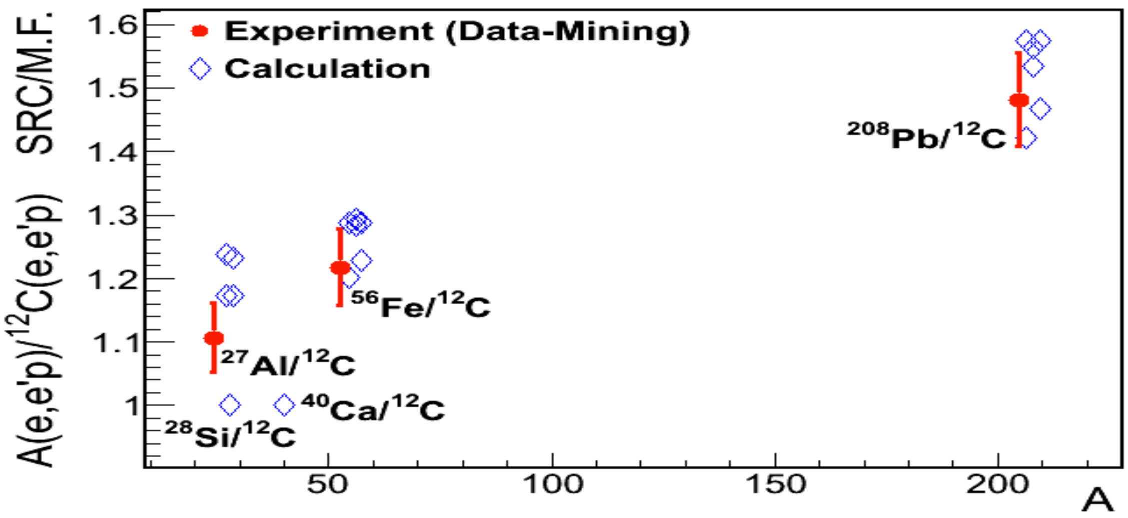
$E^p_{kin} = 14$ MeV (p= 157 MeV/c)

$E^n_{kin} = 19$ MeV (p= 182 MeV/c)

Implications: Protons are more energetic in neutron reach Nuclei

- Can be checked in A(e,e'p) Reactiosn (Or Hen & Eli Piasetzky)

$$R_A = \frac{\int_{k_F}^{\infty} \sigma_A(p_{in}) d^3 p_{in}}{\int_{0}^{k_F} \sigma_A(p_{in}) d^3 p_{in}} \qquad R = \frac{R_A}{R_{C12}}$$



Implications: If proton are more energetic theirs structure may be more modified than neutrons in the nuclear medium

u-quarks are more modified then d quarks in Large A Nuclei

- Different explanation of NuTev Puzzle

- Can be checked in neutrino-nuclei or in pvDIS processes

What these studies can tell us about structure of Neutron Stars ?

Number of nucleons beyond the Fermi Energy

$$P_{p/n}(A,y) = \frac{1}{2x_{p/n}} a_2(A,y) \int_{k_F}^{\infty} n_d(p) d^3p$$

$$a_2(A,y) = a_2(\rho,y)$$

$$a_2(\rho,y) \mid_{\rho\to\infty} = ?$$

Implications: For Nuclear Matter

$$P_{p/n}(A,y) = \frac{1}{2x_{p/n}} a_2(A,y) \int_{k_F}^{\infty} n_d(p) d^3p$$

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

$$a_2(A,y) \equiv a_2(\rho,y)\ ,\ y = |1-2x_p|\ ,\ x_p \equiv \frac{Z}{A}$$

(1)

Parametric Form

(2) For we analyze data for symmetric nuclei

and for other A's use the relation

where

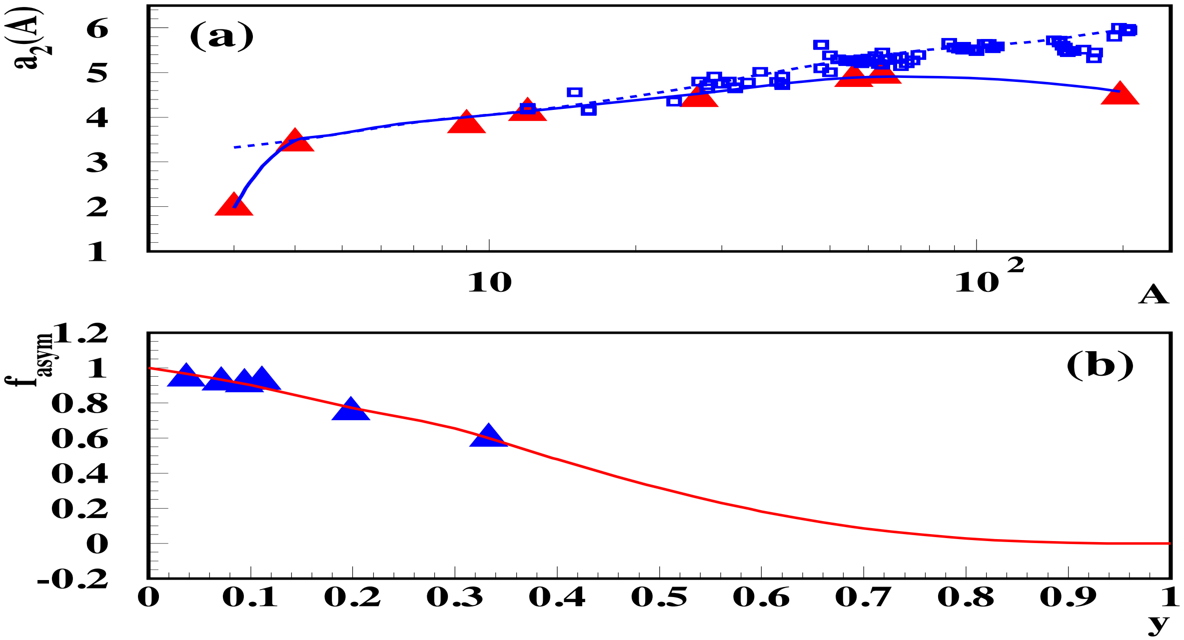
(3) Neglecting contributions due to pp and nn SRCs one obtains boundary conditions

M. McGauley, MS Feb. 2011
arxiv 1102.3973

Implications: For Nuclear Matter

$$a_2(A, y) = a_2(A, 0) f(y)$$

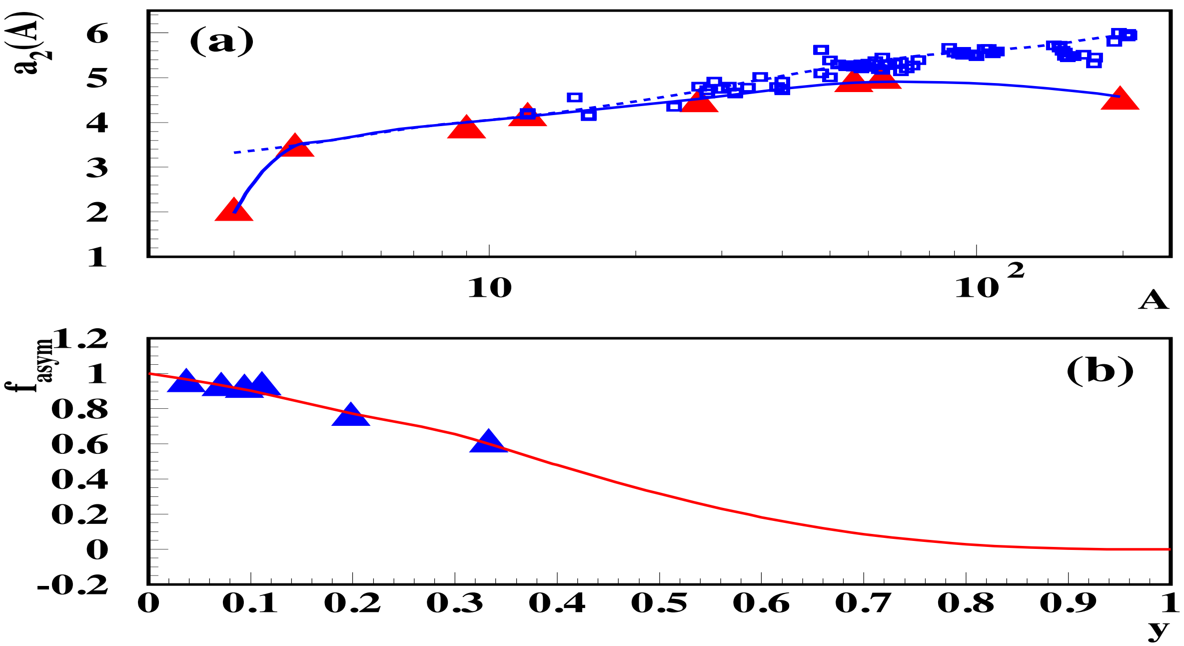
$$a_2(A, 0) = C \int \rho_A^2(r) d^3 r$$



$C = 49.1 \pm 2.6$

Implications: For Nuclear Matter

$$a_2(A,y) = a_2(A,0)f(y)$$



Fitting $f(y)$

- 4 data points
- 2 boundary conditions due to the neglection of pp/nn SRCs

$$f(0) = 1 \text{ and } f(1) = 0$$

- 2 more boundary conditions due to

$y \to 1$ and $y \to 0$ corresponds to $A \to \infty$

$$f'(0) = f'(1) = 0$$

- 1 more positiveness of f(y)

$$f(y) \approx (1 + (b-3)y^2 + 2(1-b)y^3 + by^4) \qquad b \approx 3$$

Extrapolation to infinite and superdense nuclear matter

with

compare

$a_2(\rho_0, 0) \approx 8 \pm 1.24$

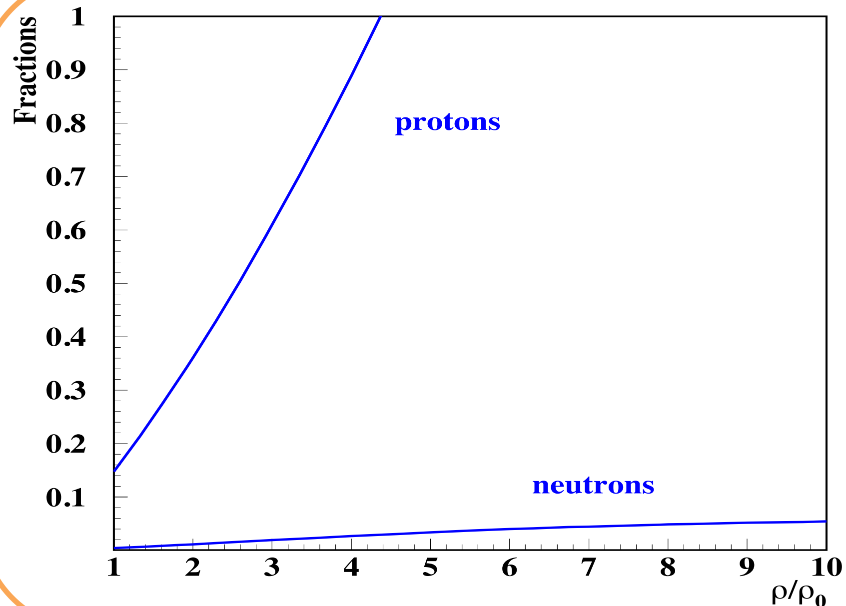
C.Ciofi degli Atti, E. Pace, G.Salme, PRC 1991

Asymmetric and superdense nuclear matter:

Implications: For Nuclear Matter

$$P_{p/n}(A,y) = \frac{1}{2x_{p/n}} a_2(A,y) \int_{k_F}^{\infty} n_d(p) d^3p$$

For $x_p = \frac{1}{9}$ and $y = \frac{7}{9}$
and using $k_{F,N} = (3\pi^2 x_N \rho)^{\frac{1}{3}}$



Fractions
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
protons
neutrons
1
2
3
4
5
6
7
8
9
10
ρ/ρ0

Some Possible Implication of our Results

Cooling of Neutron Star:

Superfluidity of Protons in the Neutron Stars:

Protons in the Neutron Star Cores:

Isospin Locking and Large Masses of Neutron Stars

Is the Observed Effects Universal for Two Component Asymmetric Fermi Systems?

- *Start with Two Component Asymmetric Degenerate Fermi Gas*
- *Asymmetric:*
- *Switch on the short-range interaction between two-component*
  - *While interaction between each components is weak*
  - *Spectrum of the small component gas will strongly deforme*

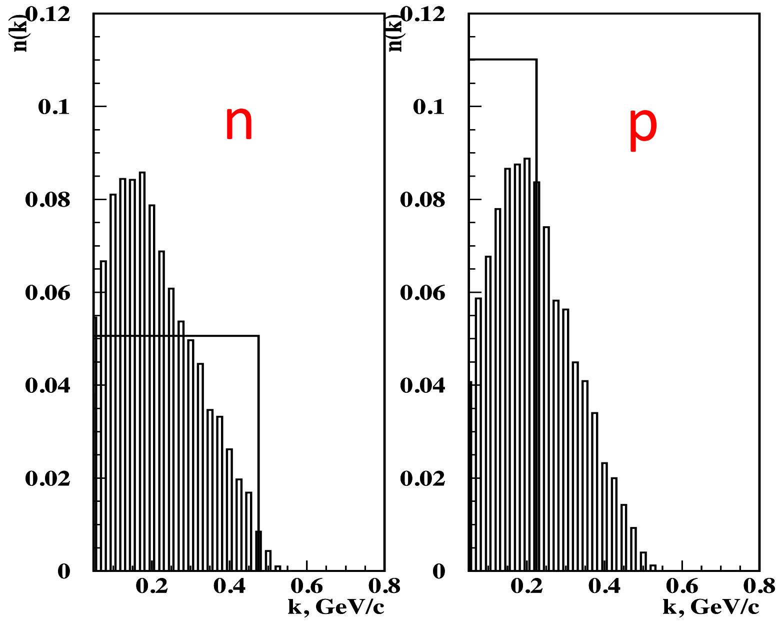
Cold Atoms

A. Bulgac, and M.M. Forbes, Zero Temperature Thermodynamics of Asymmetric Fermi Gases at Unitarity, Phys. Rev. A 75, 031605(R) (2007).

Finite T Nuclear Gas

A. Rios, A. Polls and W. H. Dickhoff, Depletion of Nuclear Fermi Gas Phys. Rev. C 79, 064308 (2009).

Is the Observed Effect Universal to Two Component Asymmetric Fermi Systems?



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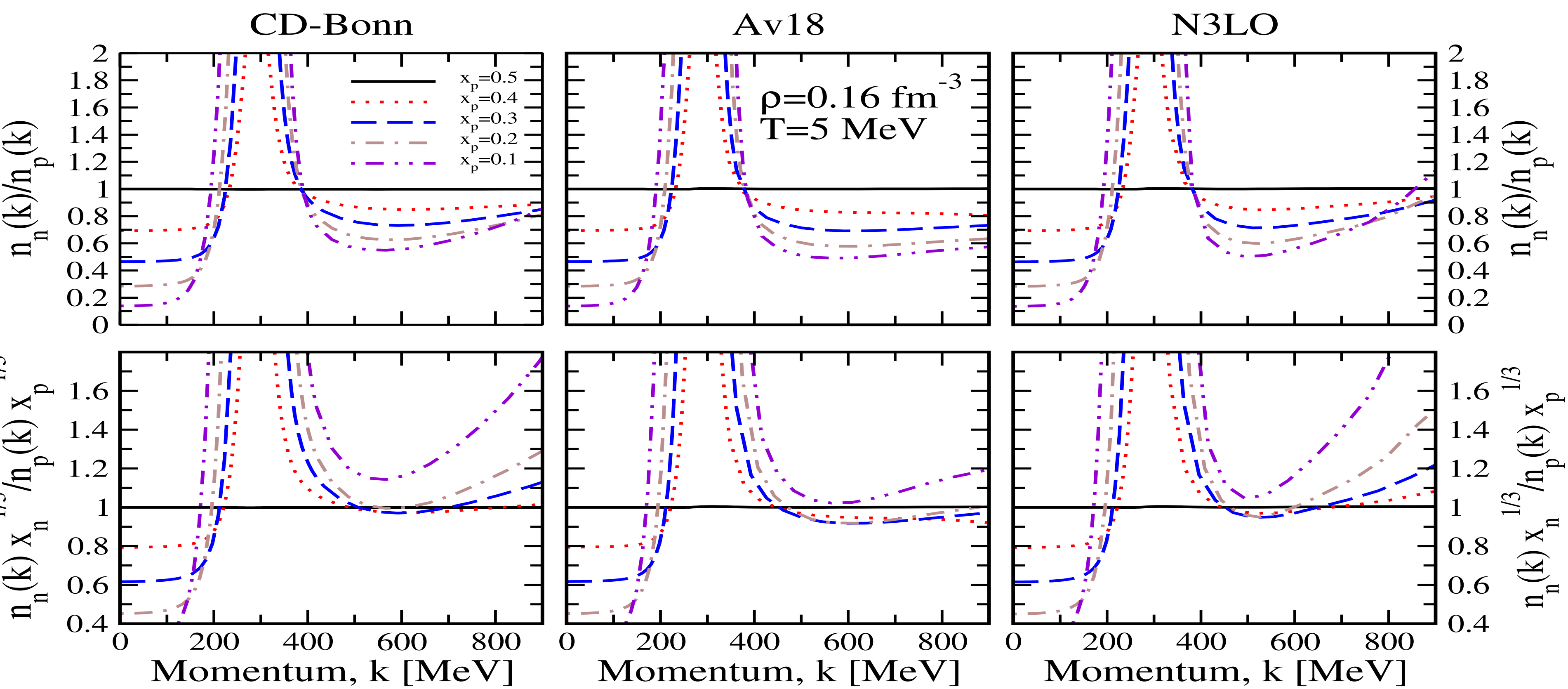
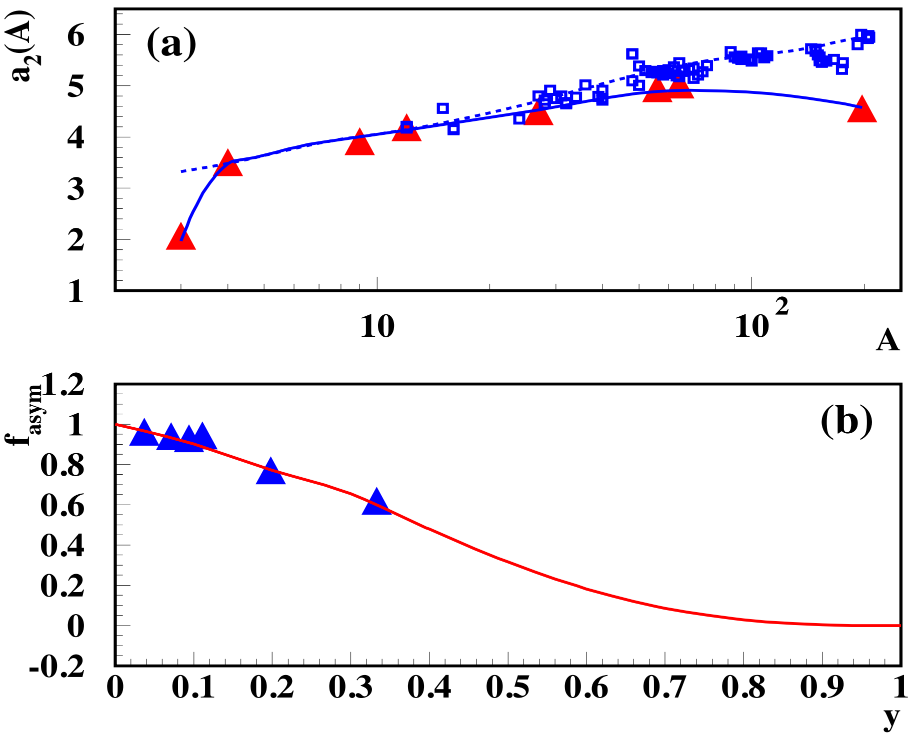


Some Outlook



- *More Symmetric Nuclei*
- *Measurements of pp/nn*
  - *3N SRCS*
- *Nuclei with large asymmetry parameters*
- *Break-down of nucleon framework*