Two Nucleon SRC and Inclusive Electron Scattering off Nuclei

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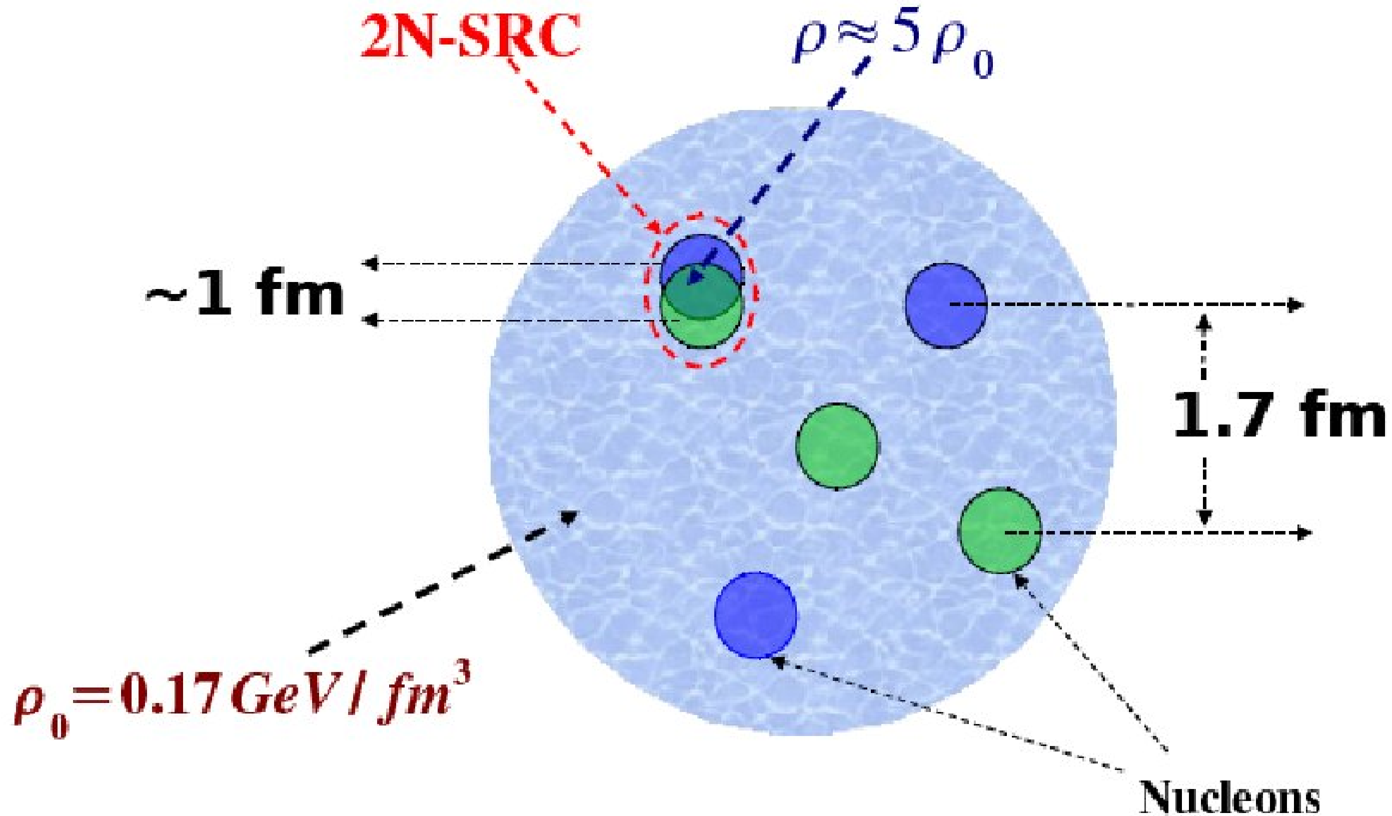
Outline

- Short Range Correlations and A(e,e')X cross section ratios
- A new approach to the treatment of inclusive cross section
- Inclusive cross section ratios
- Conclusions

Short Range Correlations and A(e,e')X cross section ratios

A cartoon of SRC in nuclei



What is the percentage of correlated nucleons in nuclei?

SEMI-ESCLUSIVE SCATTERING OFF ^{12}C(P,P'PN) AND ^{12}C(E,E'PN)

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DOI: 10.1126/science.1156675

REPORTS

Probing Cold Dense Nuclear Matter

R. Subedi,[1] R. Shneor,[2] P. Monaghan,[3] B. D. Anderson,[1]
H. Benaoum,[7,8] F. Benmokhtar,[9] W. Boeglin,[10] J.-P. Che
S. Frullani,[13] F. Garibaldi,[13] S. Gilad,[3] R. Gilman,[11,15] O.
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L. J. Kaufman,[9,21] A. Kelleher,[17] A. Kolarkar,[22] G. Kumba
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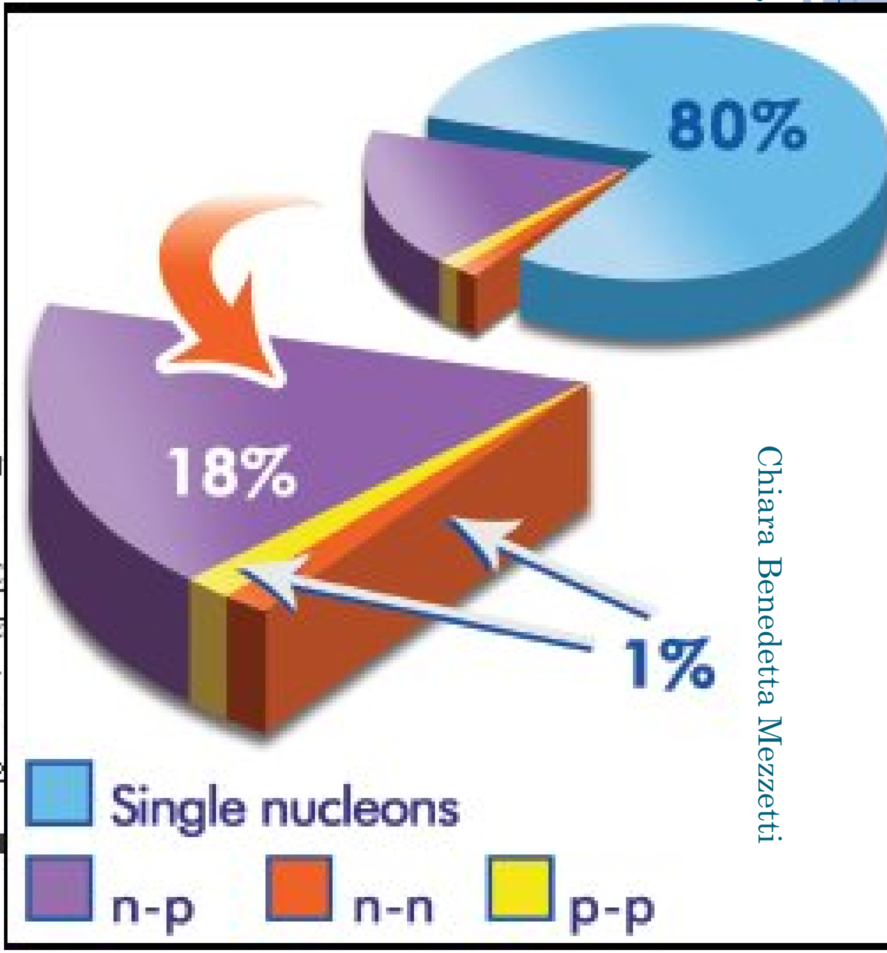


These experiments provide quantitative information on 2NC only. What about 3NC?

Cross section ratios at CLAS

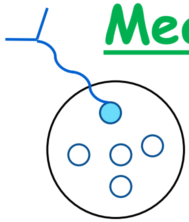
Original idea:

$$\sigma_A\left(Q^2, x_B\right) = \sum_{j=2}^{A} A \frac{a_j(A)}{j} \sigma_j\left(Q^2, x_B\right)$$

Frankfurt & Strikman, Phys. Rep. 5 (1988) 235

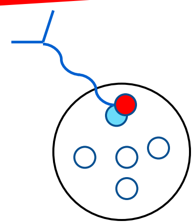
Mean Field

$x_B \le 1.5$



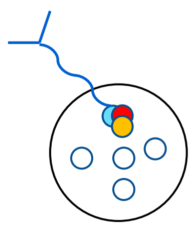
2NC

$1.5 \le x_B \le 2$



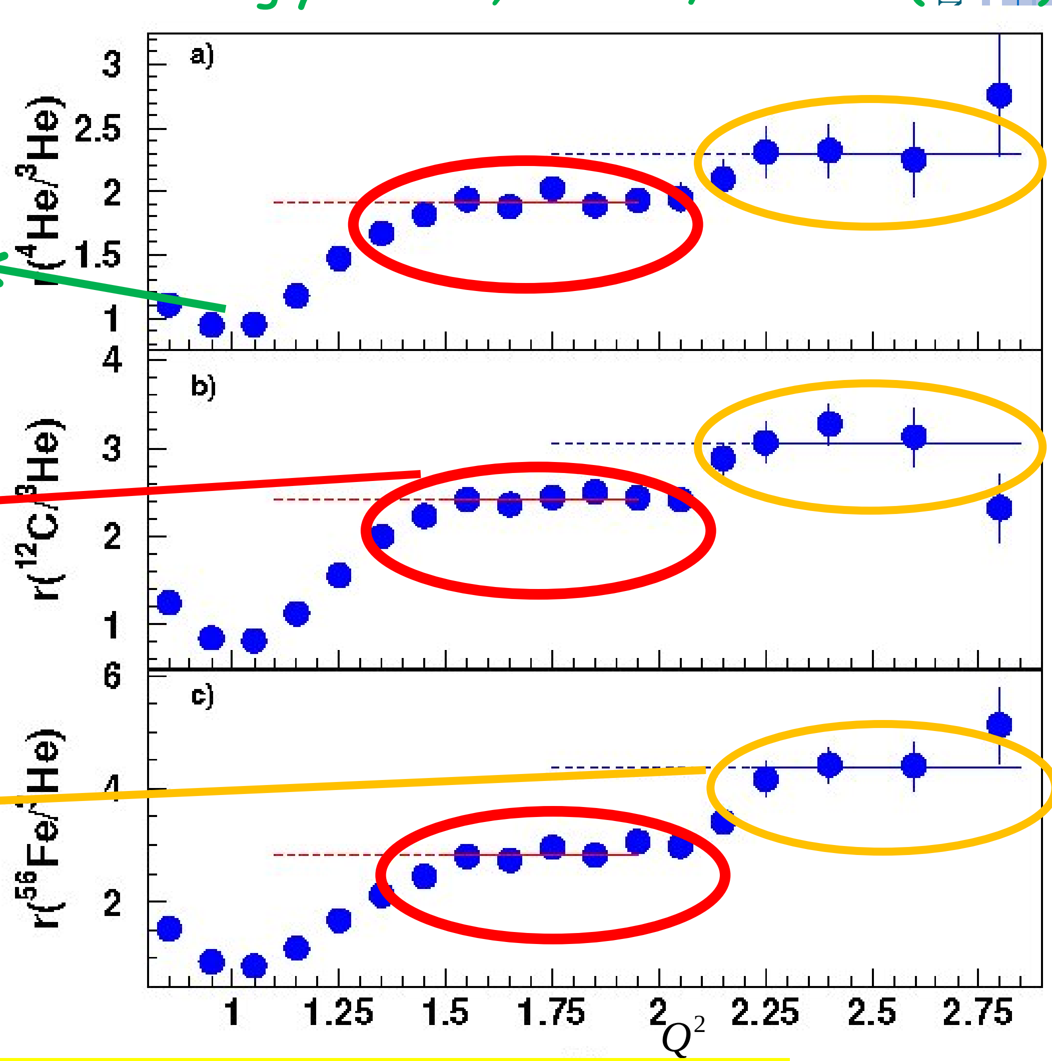
3NC

$2 \le x_B \le 3$



Experimental data:

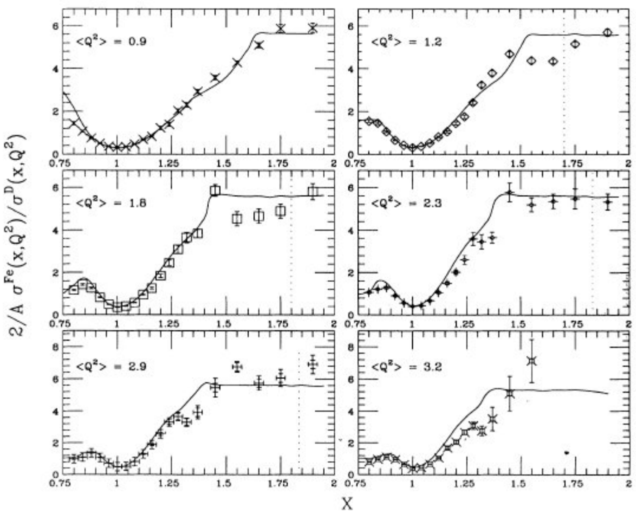
K.S. Egiyan *et al*, PRL 96, 082501 (2006)



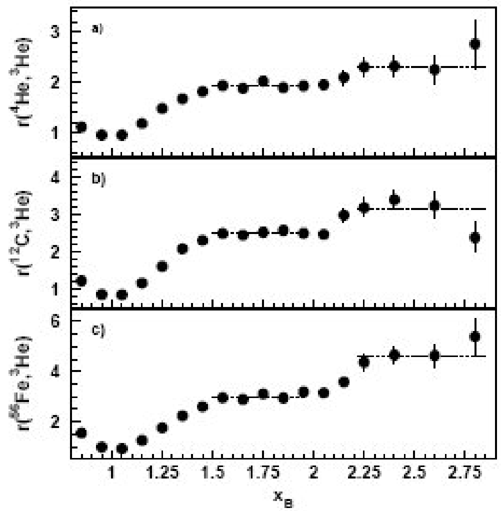
But: no direct microscopic many-body calculation of the ratio $r(A/^3He)$ → This is just our aim

DIFFERENT EXPERIMENTS WITH CONSISTENCE RESULTS

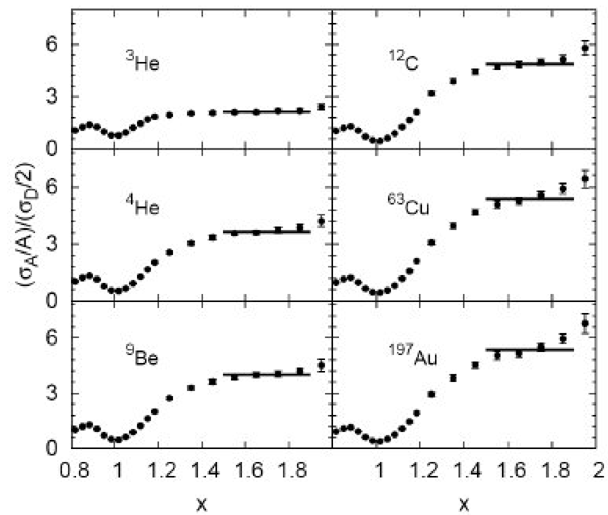
SLAC 1993
Frankfurt et al, PRC48(1993) 2451



CLAS 2006
Egiyan et al, PRL96 (2006) 082501



E02 – 019 (2012)
Fomin et al, PRL 108 (2012) 092502



What is the meaning of

$$R_{2N} = (2\sigma_A)/(A\sigma_D)\ ?$$

Is it the ratio of probabilities of 2NC in A and D?

Is it the ratio of the momentum distributions of A and D?

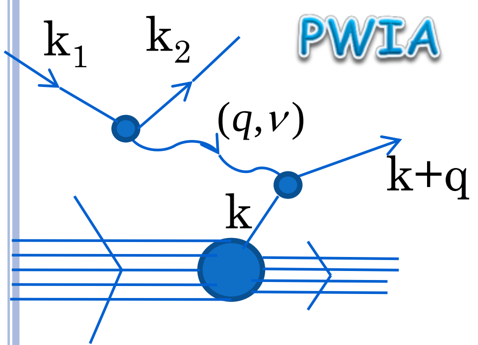
Is it an effect of FSI?

Something else?

A	R_{2N} (E02-019)	SLAC	CLAS	F_{CM}
^{3}He	1.93±0.10	1.8±0.3	–	1.10±0.05
^{4}He	3.02±0.17	2.8±0.4	2.80±0.28	1.19±0.06
Be	3.37±0.17	–	–	1.16±0.05
C	4.00±0.24	4.2±0.5	3.50±0.35	1.19±0.06
Cu(Fe)	4.33±0.28	(4.3±0.8)	(3.90±0.37)	1.20±0.06
Au	4.26±0.29	4.0±0.6	–	1.21±0.06
$\langle Q^2 \rangle$	~2.7 GeV^2	~1.2 GeV^2	~2 GeV^2	
x_{min}	1.5	–	1.5	
α_{min}	1.275	1.25	1.22–1.26	

A new approach to the treatment of inclusive cross sections

Inclusive lepton scattering off nuclei



PWIA

Nuclear Structure Function

$$\frac{d^2\sigma}{d\nu d\Omega'} = F^A(q,\nu) K(q,\nu)\left[Z\sigma_{ep} + N\sigma_{en}\right]$$

$$\nu + M_A = \sqrt{\left(M_{A-1} + E^*_{A-1}\right)^2 + k^2} + \sqrt{m^2 + \left(\vec{k} + \vec{q}\right)^2}$$

$$F^A(q,\nu) = 2\pi \int_{E_{\min}}^{+\infty} dE \int_{k_{\min}(q,\nu,E)}^{+\infty} k dk P^A(k,E)$$

Longitudinal momentum distribution

$$f^A(Y) = 2\pi \int_{|Y|}^{\infty} k dk n^A(k)$$

Let us introduce a generic scaling variable

$$Y = Y(q,\nu)$$

$$F^A(q,\nu) = F^A(q,Y) = f^A(Y) - B^A(q,Y)$$

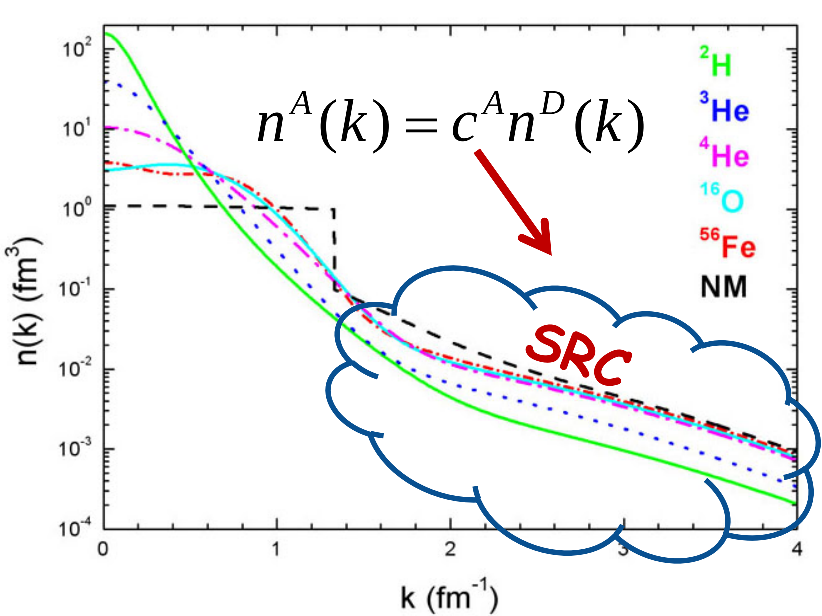
Binding correction

$$B^A(q,Y) = 2\pi \int_{E_{\min}}^{\infty} dE \int_{|Y|}^{k_{\min}(q,Y,E)} k dk P_1^A(k,E)$$

Our aim is to find Y such that

$$B^A(q,Y) \to 0$$

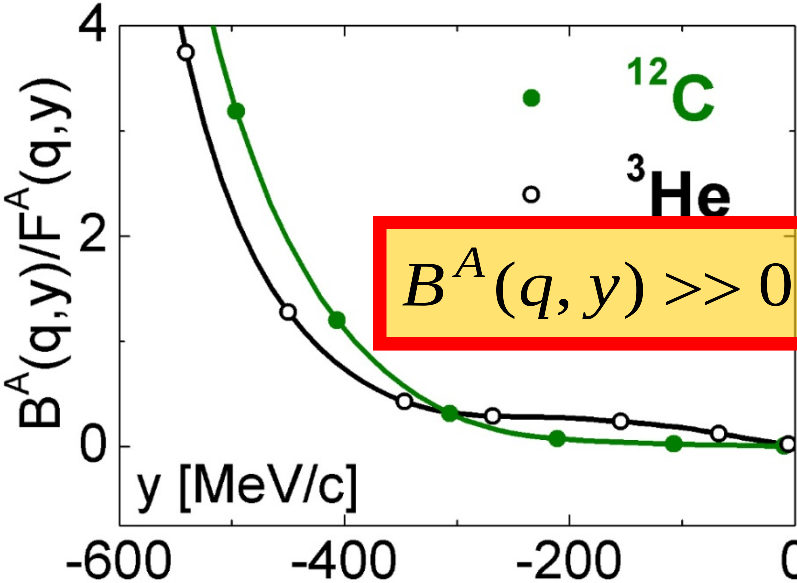
$$n^A(k) = c^A n^D(k)$$



The mean field scaling variable

$$Y = y \longrightarrow \nu + M_A = \sqrt{(M_{A-1} + E^*_{A-1})^2 + y^2} + \sqrt{m^2 + (y+q)^2}$$

INT,



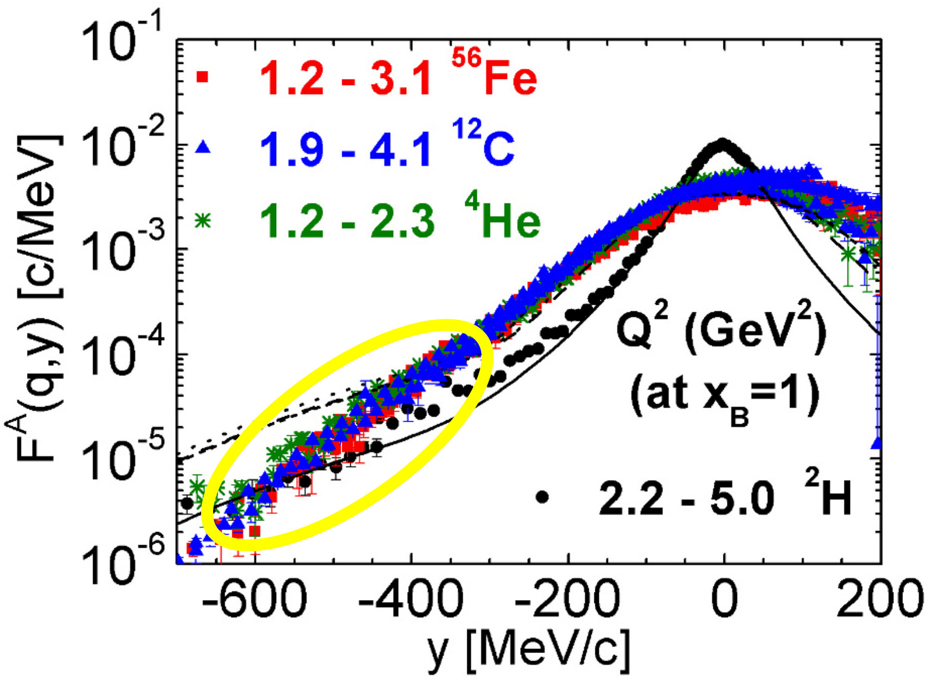
$B^A(q,y) >> 0$

Minimum longitudinal momentum of a nucleon having the minimum value of the removal energy $E = E_{min}$

$$F^A(q,y) \neq f^A(y)$$

$$F^A_{ex}(q,y) = \frac{\sigma^A_{2,ex}}{[Z\sigma_{ep} + N\sigma_{en}]K}$$

$$F^A(q,y) \neq f^D(y)$$

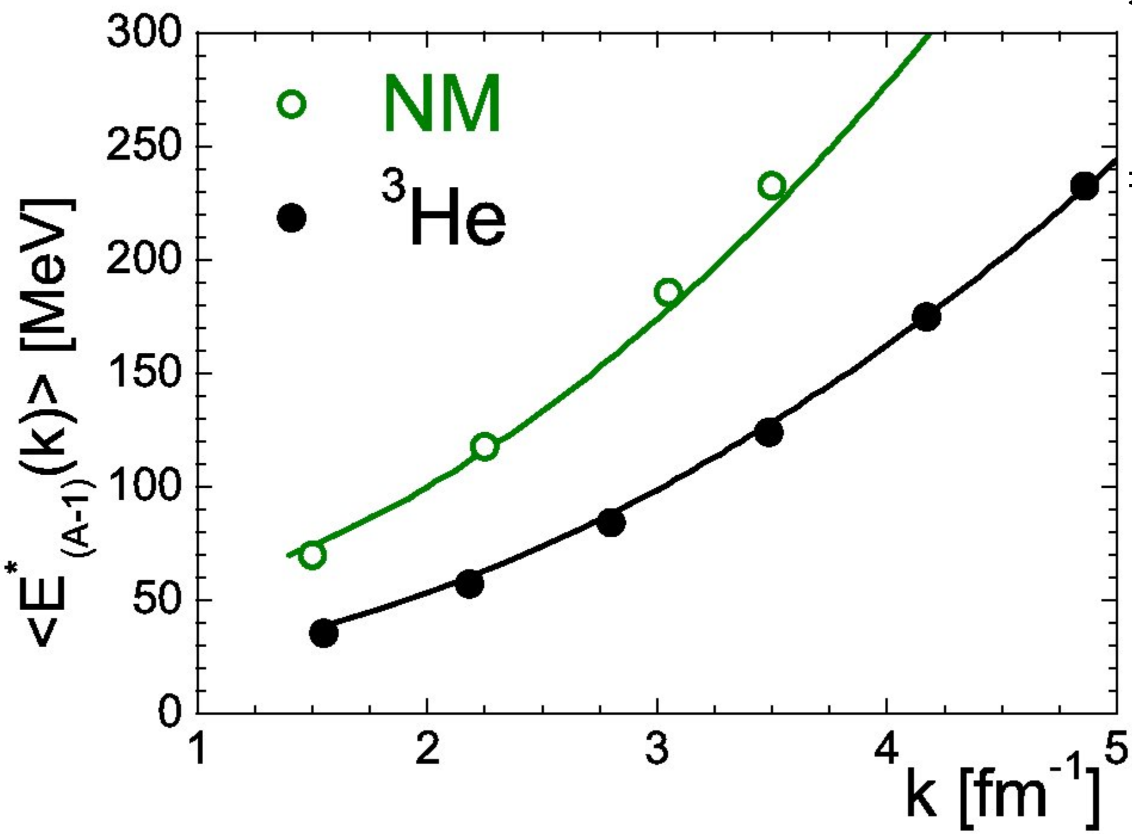


The 2NC scaling variable

$$Y = y_{CW}$$

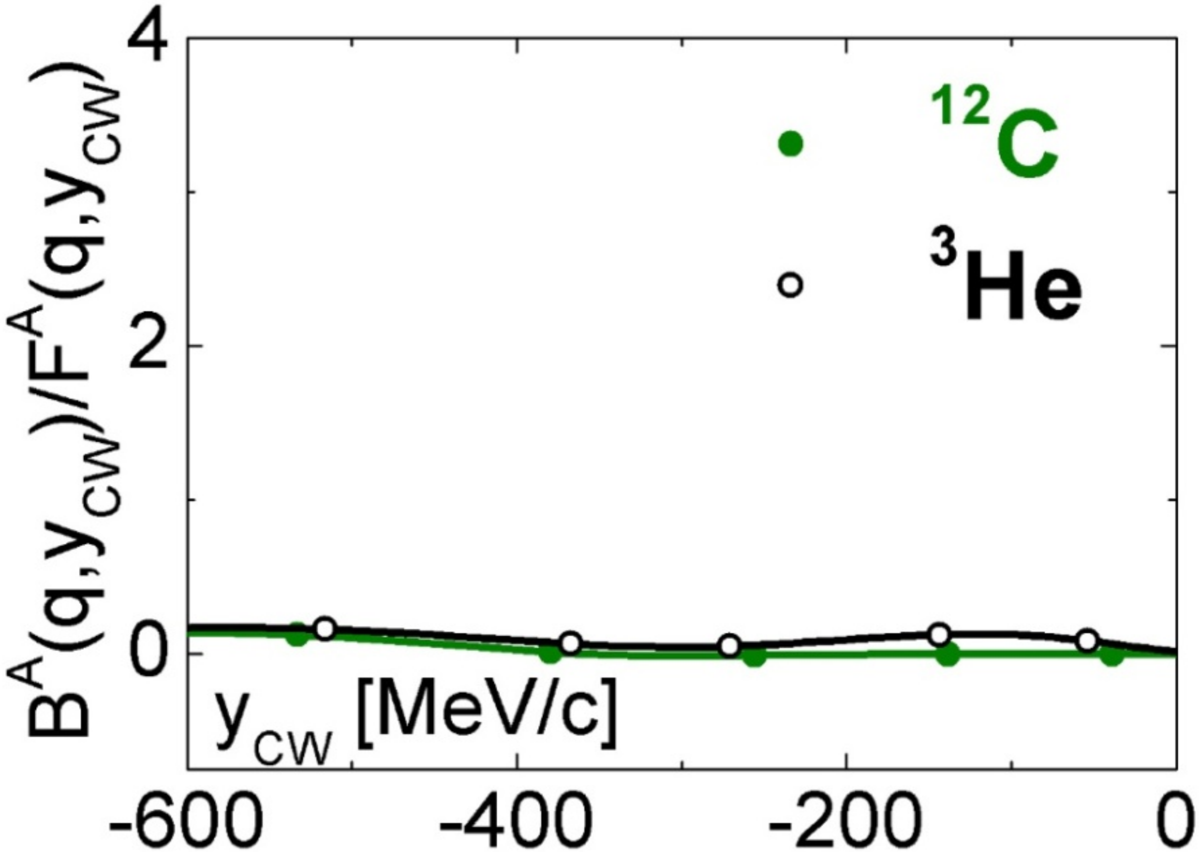
Minimum longitudinal momentum of a nucleon with removal energy $E = E_{min} + \langle E^*_{A-1}(k) \rangle_{2NC}$

$$\nu + M_A = \sqrt{\left(M_{A-1} + \langle E^*_{A-1}(y_{CW}) \rangle_{2NC}\right)^2 + y_{CW}^2} + \sqrt{m^2 + (y_{CW} + q)^2}$$



$$\langle E^*_{A-1}(k) \rangle_{2NC} = \frac{\int P_1^A(k, E^*_{A-1}) E^*_{A-1} dE^*_{A-1}}{n^A(k)}$$

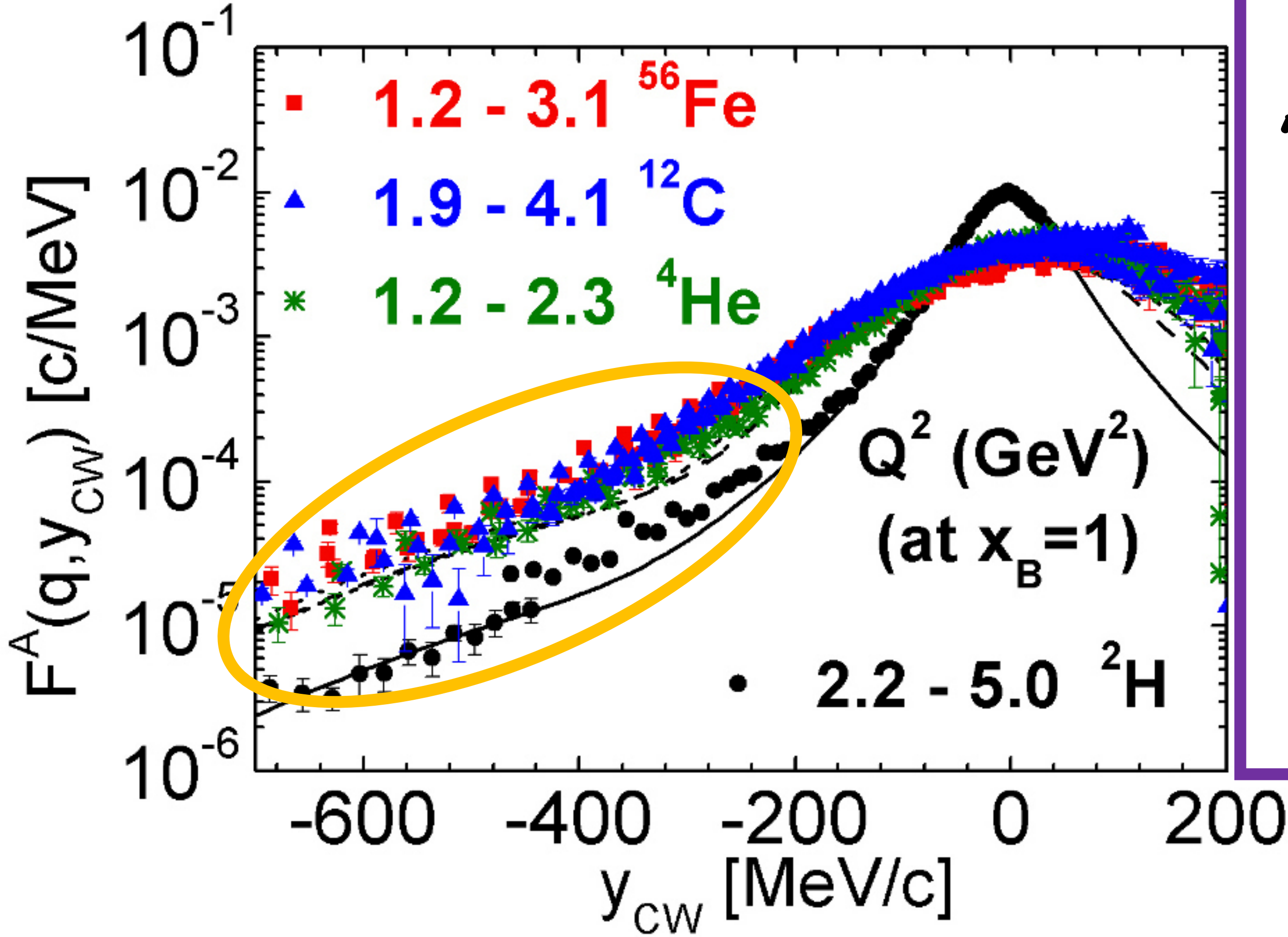
$$\langle E^*_{A-1}(k) \rangle_{2NC} = \frac{A-2}{A-1} T_N + b_A - c_A k$$



C. Ciofi degli Atti, C.B. Mezzetti, Phys. Rev. C79, 051392(R), (2009)

$$B^A(q, y_{CW}) \square 0$$

$$\begin{cases} F^A(q, y_{CW}) \approx f^A(y_{CW}) \\ n^A(k) = -\dfrac{1}{2\pi y_{CW}} \dfrac{dF^A(q, y_{CW})}{dy_{CW}}, k = | y_{CW} | \end{cases}$$



C. Ciofi degli Atti, G.B. West, PLB 458 (1999) 447;

C. Ciofi degli Atti, C.B. Mezzetti, Phys. Rev. C79, 051392(R), (2009)

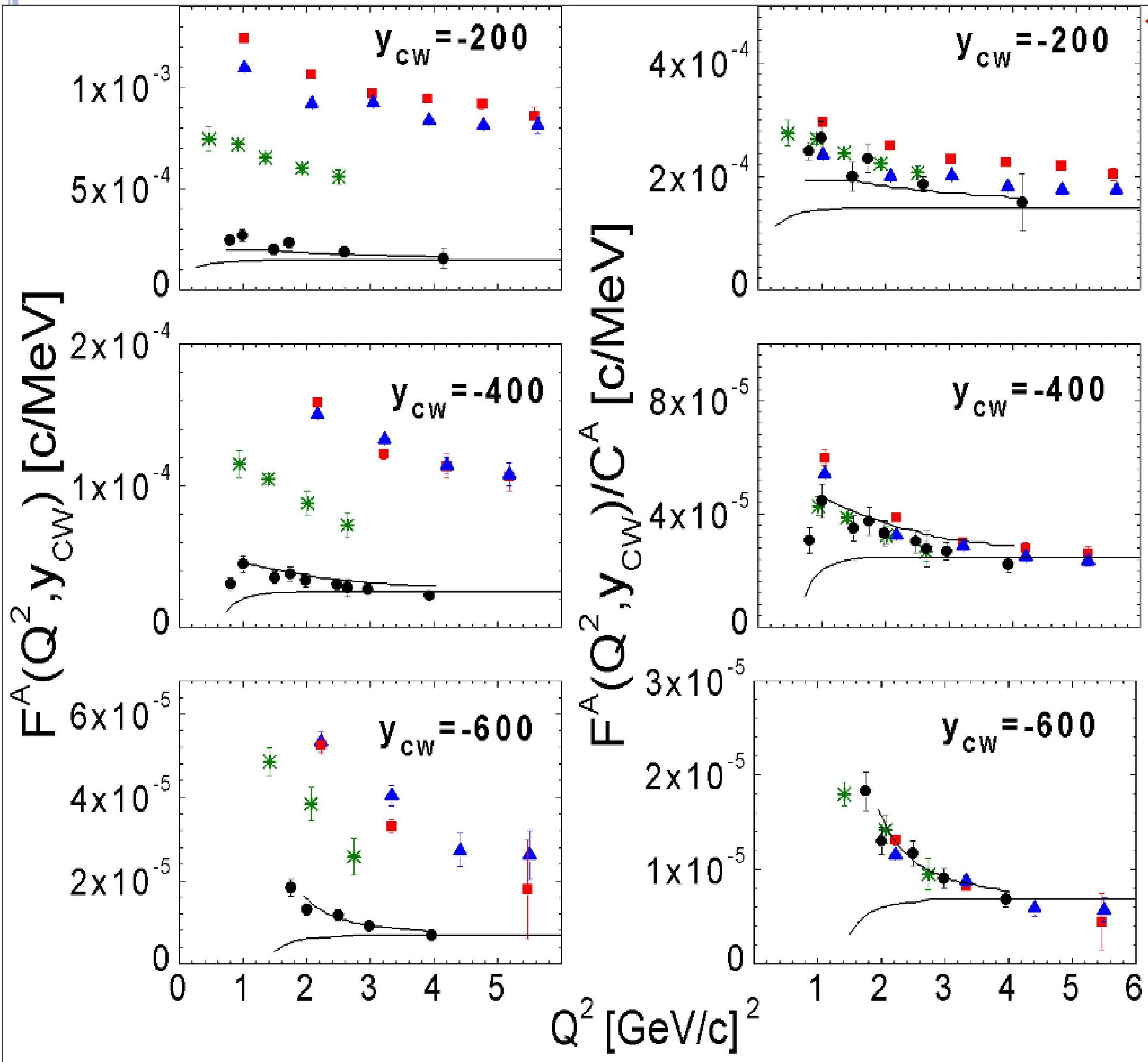
Confirmation of the theoretically prediction of

Deuteron scaling

$$F^{A}(q,y_{CW}) \simeq C^{A} f^{D}(y_{CW})$$

$$n^{A}(k) \simeq C^{A} n^{D}(k)$$

More quantitative analysis



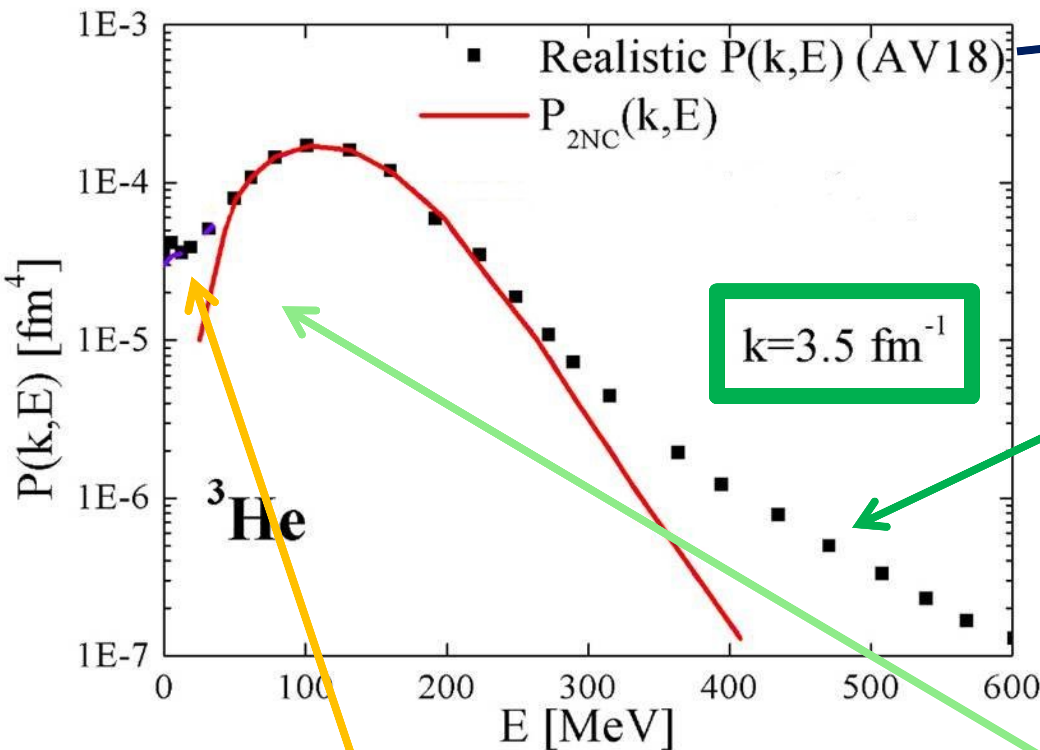
✓ Deuteron scaling again demonstrated

✓ C^A in agreement with Frankfurt, Strikman, Day, Sargsyan, PRC 48 (1993) 2451

✓ FSI important but similar in Deuteron and in A

✓ In the SRC region FSI acts mainly within the correlated pair

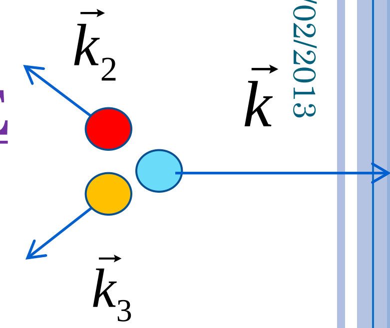
What about 3N SRC?



$$P_{2NC}(k,E) + P_{3NC}(k,E)$$

INT,13/02/2013

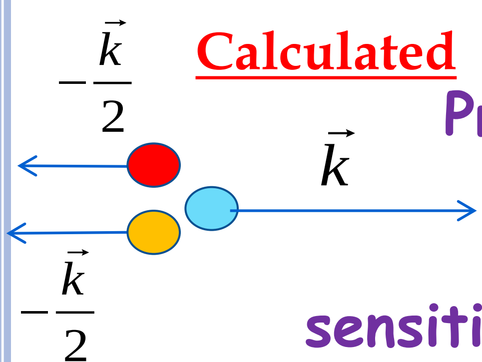
High k, high E



Under investigation

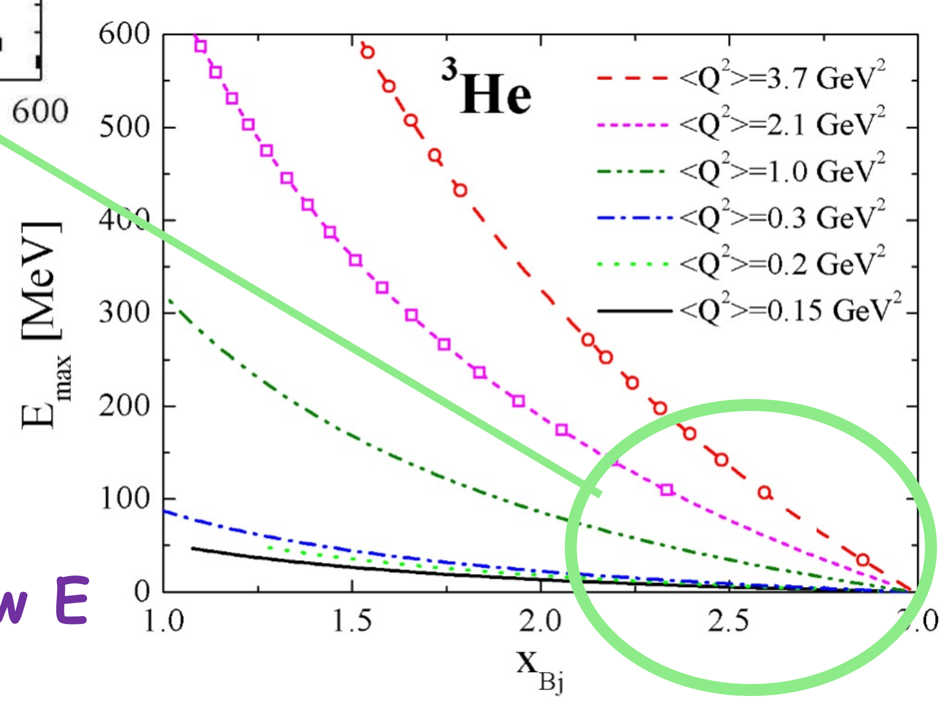
High k, low E

$$E = \frac{(\vec{k}_2 - \vec{k}_3)^2}{m_N}$$



Calculated

Present A(e,e')X kinematics at $2<x_B<3$ sensitive to high k, low E 3NC configuration

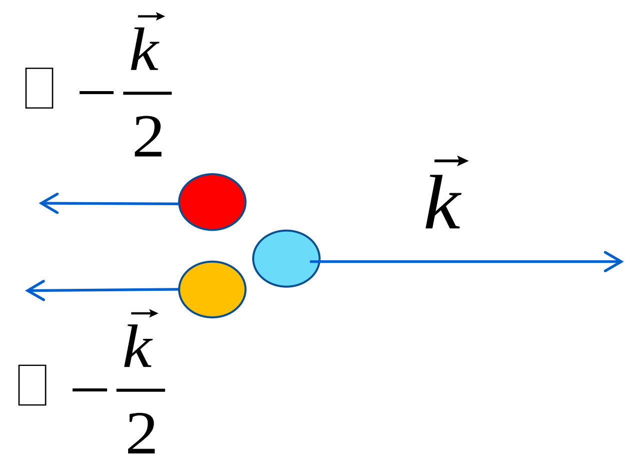


The 3NC scaling variable

$$Y = y_3$$

$$\nu + M_A = \sqrt{\left(M_{A-1} + < E^*_{A-1}(y_3) >_{3NC}\right)^2 + y_3^2} + \sqrt{m^2 + \left(y_3 + q\right)^2}$$

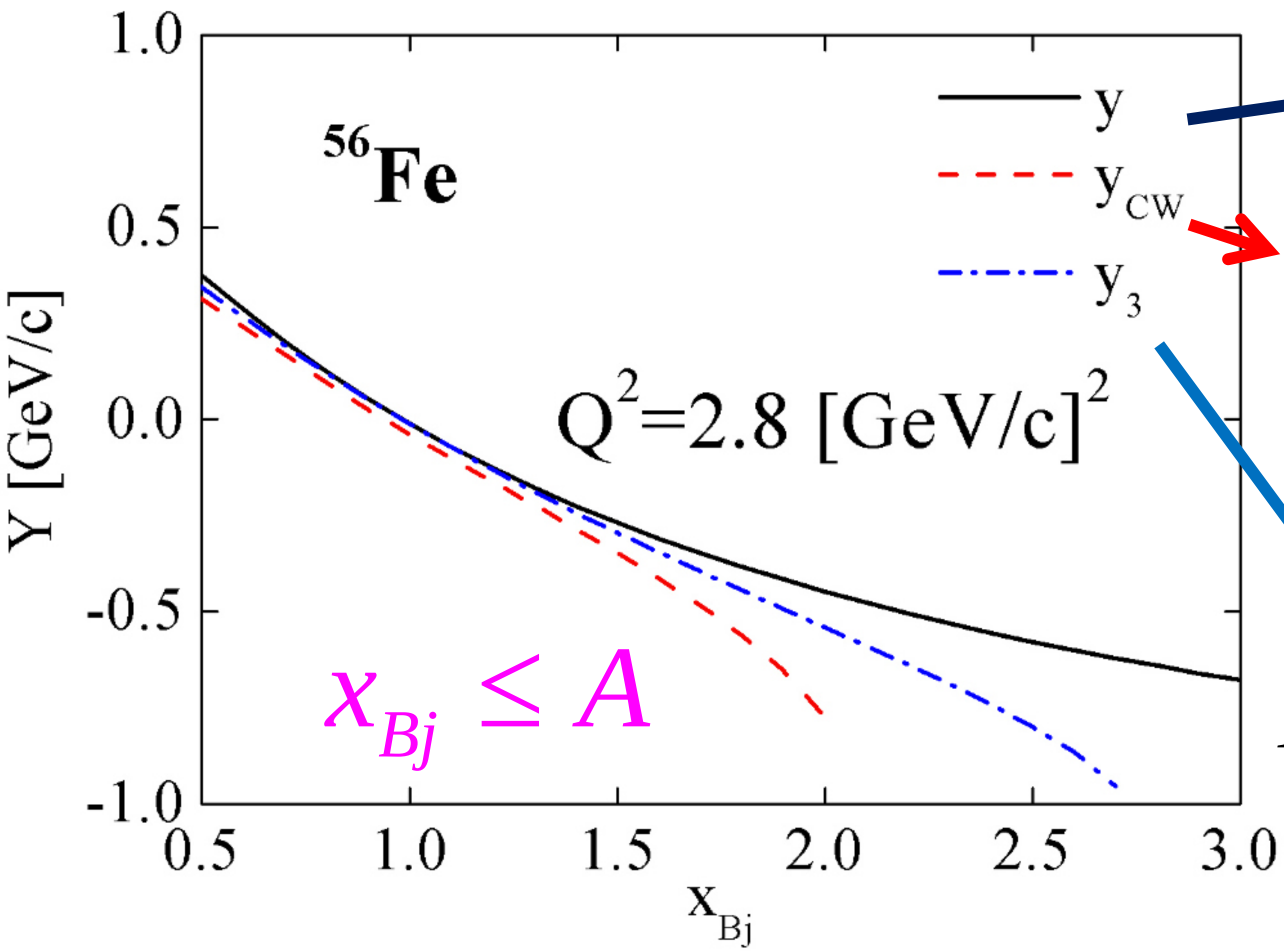
Minimum longitudinal momentum of a nucleon with removal energy
$E = E_{min} + < E^*_{A-1}(k) >_{3NC}$



$$< E^*_{A-1}(k) >_{3NC} = \frac{A-3}{A-1}\frac{k^2}{4m}$$

Scaling variables vs. x_{Bj}

$$\nu + M_A = \sqrt{\left(M_{A-1} + E^*_{A-1}\right)^2 + Y^2} + \sqrt{m^2 + (Y+q)^2}$$



$$E^*_{A-1} = 0$$

$$x_{Bj} \leq A$$

$$E^*_{A-1} = < E^*_{A-1}(k) >_{2NC}$$

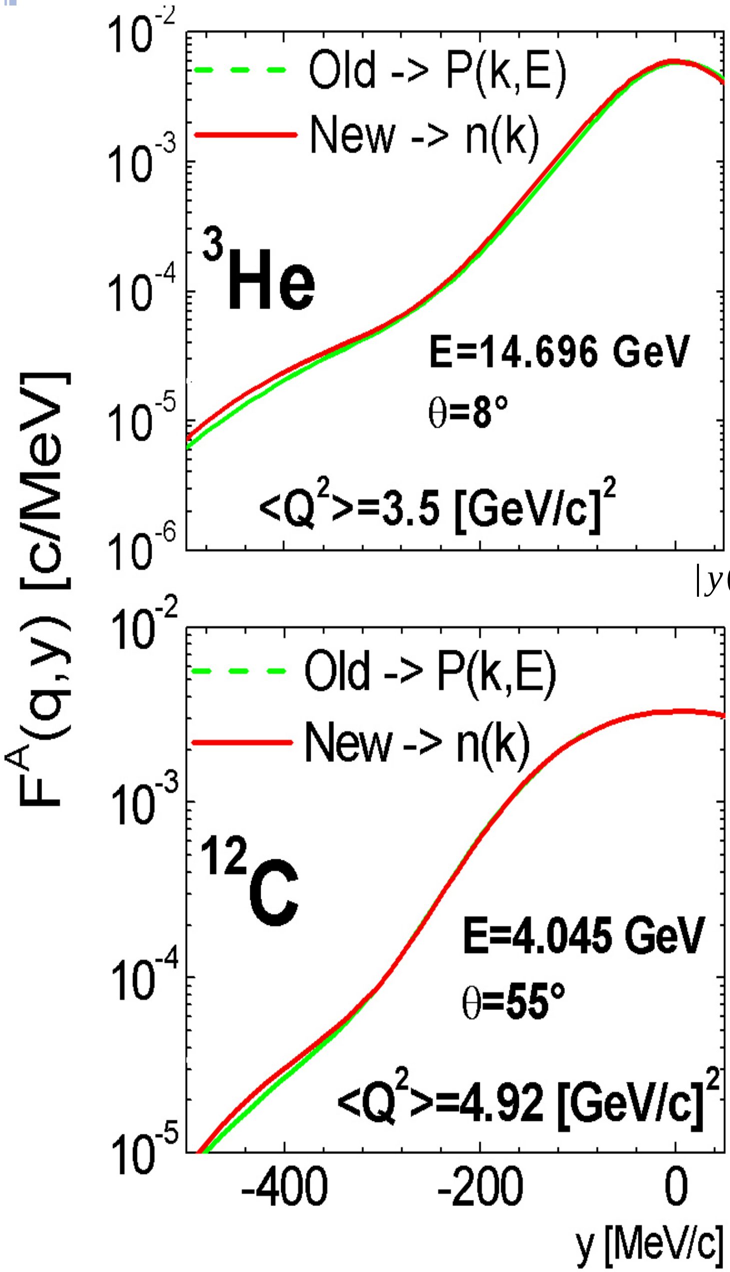
$$x_{Bj} \leq 2$$

$$E^*_{A-1} = < E^*_{A-1}(k) >_{3NC}$$

$$x_{Bj} \leq 3$$

Chiara Benedetta Mezzetti

Our new inclusive cross section



$$\frac{d^2\sigma}{d\Omega d\nu} \propto \int_{E_{\min}}^{E_{\max}} dE \int_{k_{\min}(q,\nu,E)}^{k_{\max}(q,\nu,E)} k dk P^A(k,E) \approx$$

$$\int_{|y(q,\nu)|}^{\infty} n_0^A(k) k dk + \int_{|y_{CW}(q,\nu)|}^{\infty} n_2^A(k) k dk + \int_{|y_3(q,\nu)|}^{\infty} n_3^A(k) k dk$$

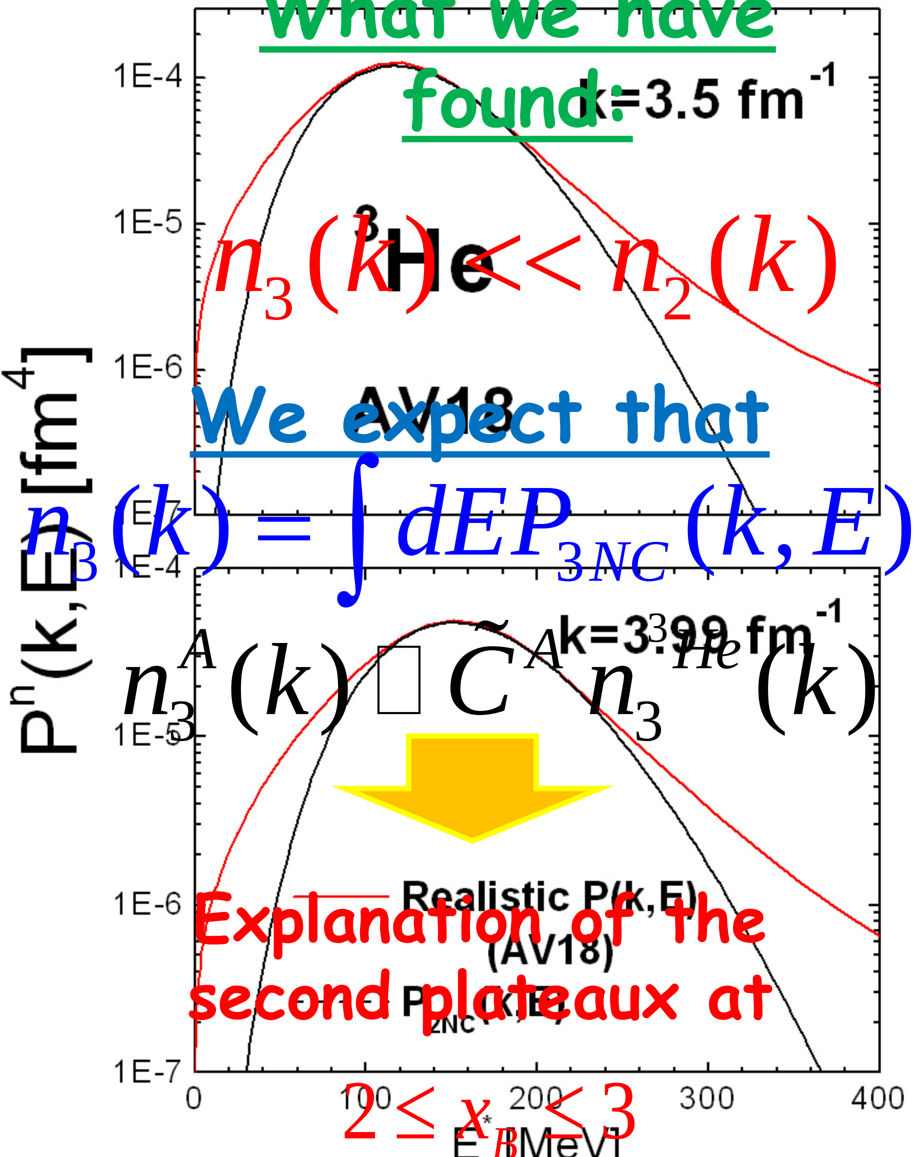
Mean Field **2NC** **3NC**

$$n_2(k) = \int d k_{CM} n_{rel}\left(\vec{k} + \vec{k}_{CM}\right) n_{CM}^{soft}(\vec{k}_{CM})$$

$$n_3(k) = \int d k_{CM} n_{rel}(\vec{k} + \vec{k}_{CM}) n_{CM}^{hard}(\vec{k}_{CM})$$

Inclusive cross section ratios and plateaux

Searching for $n_3(k)$



What we have found:

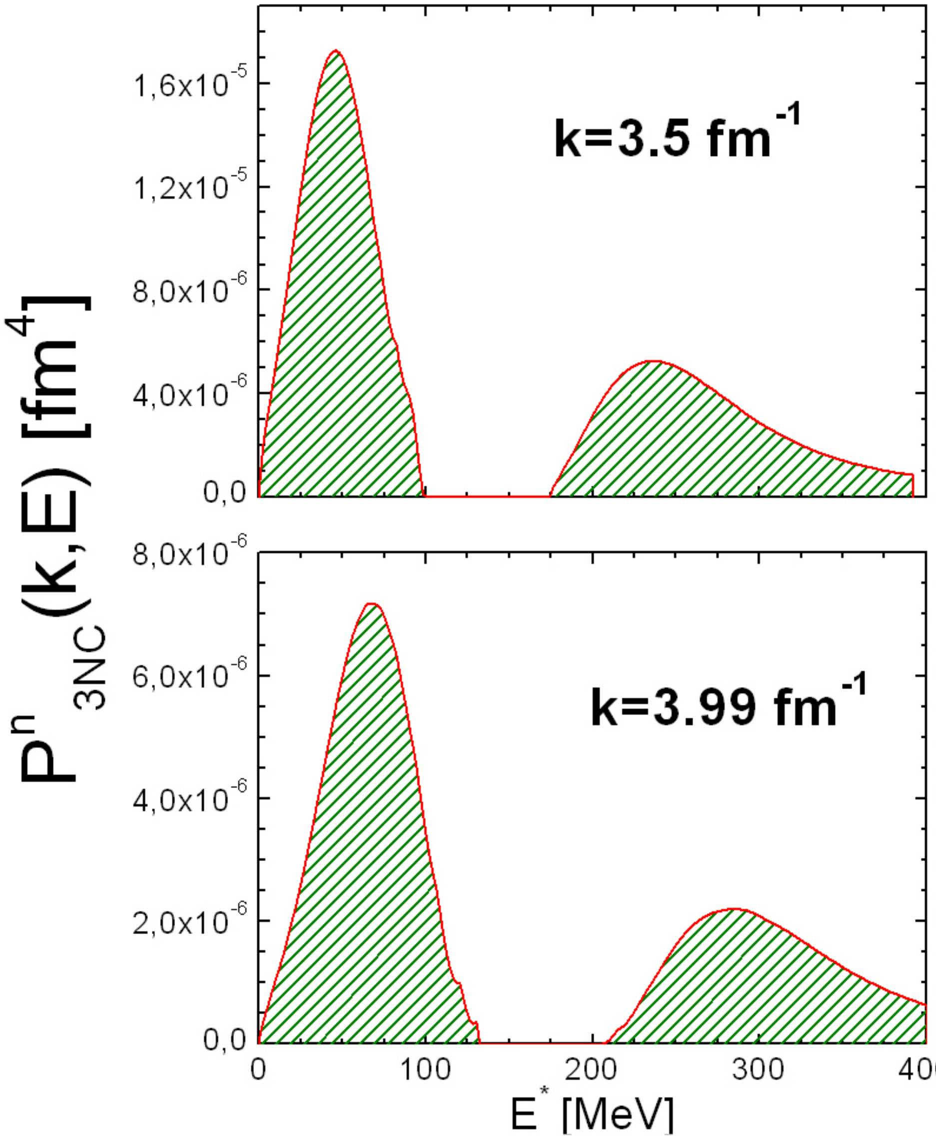
$$n_3(k) << n_2(k)$$

We expect that

$$n_3(k) = \int dE P_{3NC}(k,E)$$

$$n_3^A(k) \square \tilde{C}^A n_3^{^3He}(k)$$

Explanation of the second plateaux at $2 \le x_B \le 3$



SRC vs. x_{Bj}

2NC

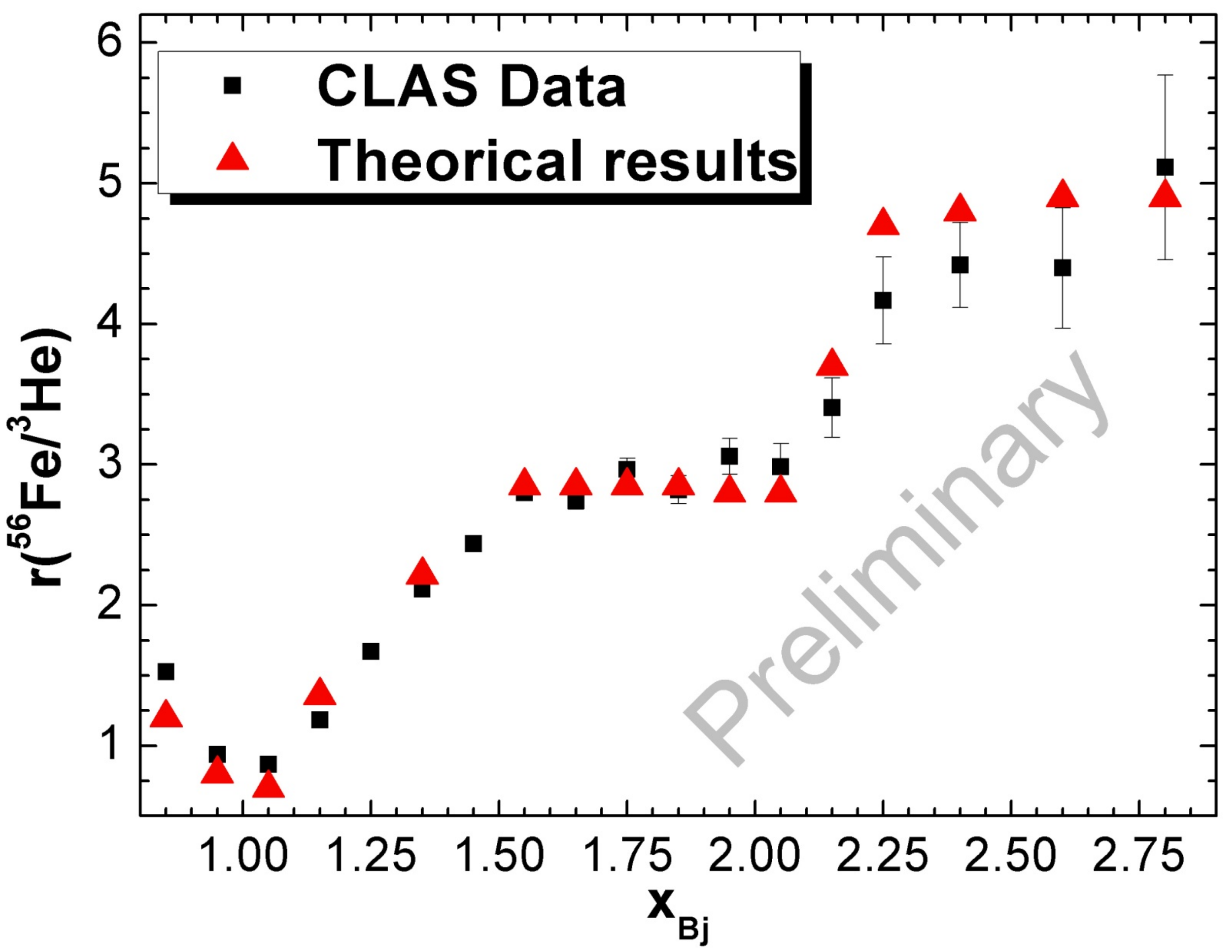
$$1.5 \leq x_B \leq 2$$

3NC

$$2 \leq x_B \leq 3$$

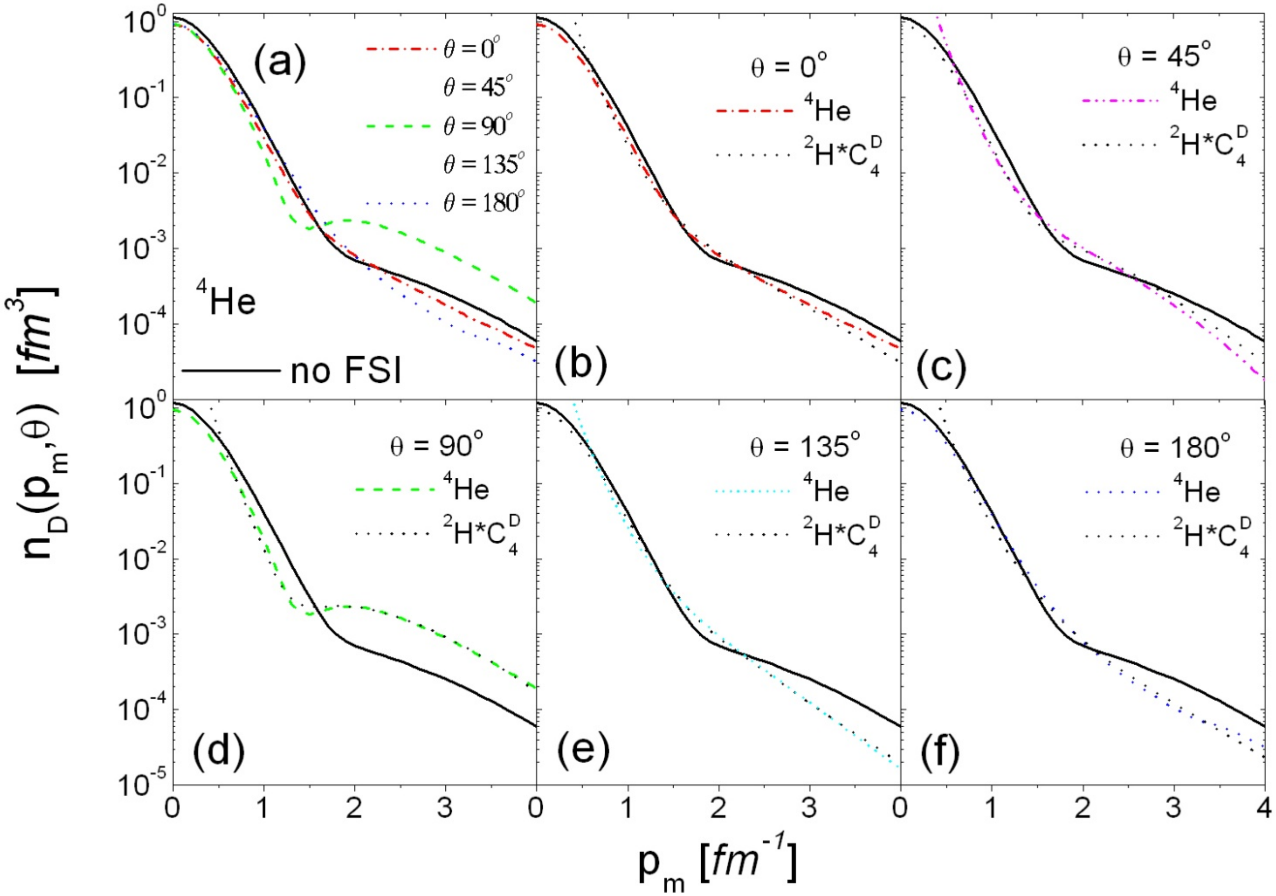
Mean Field

$$x_B \leq 1.5$$



Distorted nucleon momentum distributions

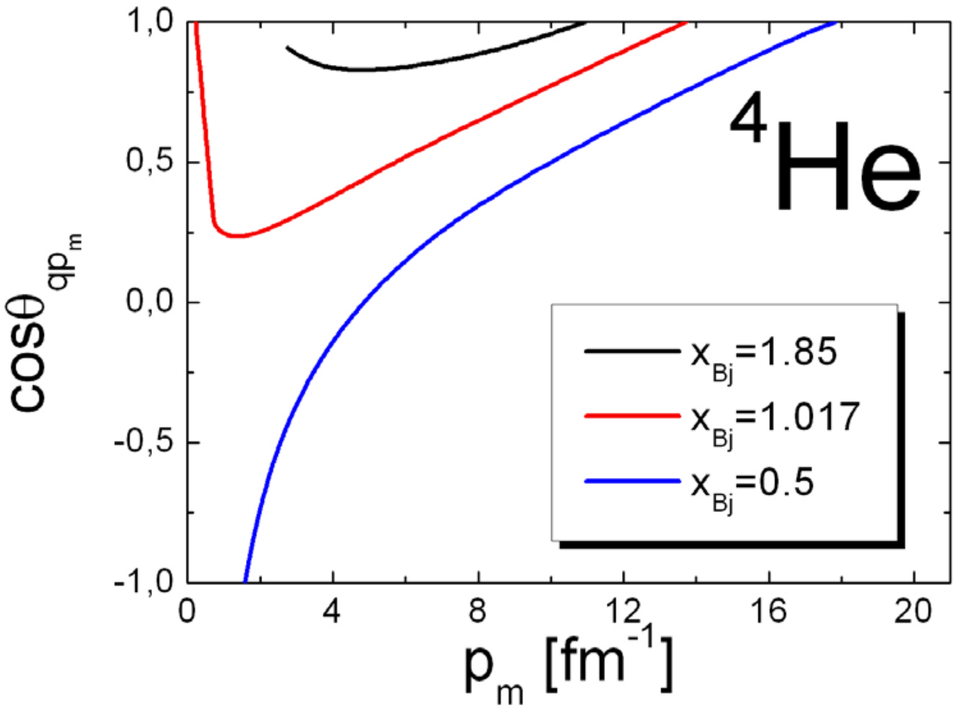
Alvioli, Ciofi, Kaptari, Mezzetti, Morita, Scopetta, PRC85 (2012) 021001



Cosθ vs. p_m

$$\sigma^{(2)} \approx \int_{|p_{\min}|}^{p_{\max}} p_m dp_m n_G^D \left(p_m, \cos\vartheta_{pm} \right)$$

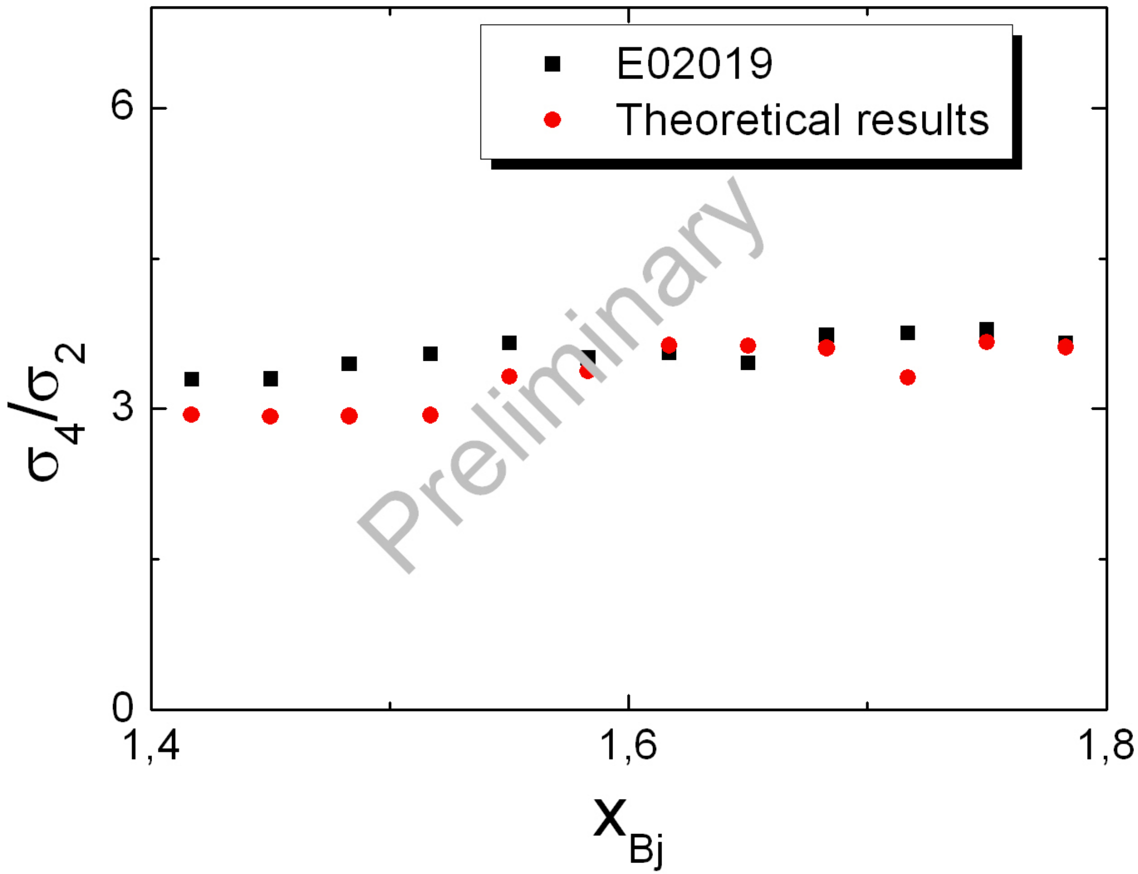
$$\cos\vartheta_{qp_m} = \frac{2(\nu + M_A)\sqrt{\left(M_{A-1}^{*f}\right)^2 + p_m^2} - \left(M_{A-1}^{*f}\right)^2 + m_N^2 - s}{2qp_m}$$



$$s = (\nu + M_A)^2 - q^2$$

2NC preliminary results

$$\cos \vartheta_{qp_m} = 1$$



Conclusions

- **The FSI in a nucleus A in the region of $1.5<x<2$ seems to be confined within the 2N correlated pair.**

- **This is clearly illustrated by the scaling function of the Deuteron which includes exactly the FSI and which shows the same behaviour of the scaling function of complex nuclei**

- **This is furthermore illustrated by the calculation of distorted momentum distributions which appear to be the rescaled deuteron distorted momentum distributions.**

- **If FSI factorizes (not yet demonstrated) the plateuax ratios do not exhibit any FSI.**