Correlations in Nuclei: Which way forward?

Donal Day
University of Virginia

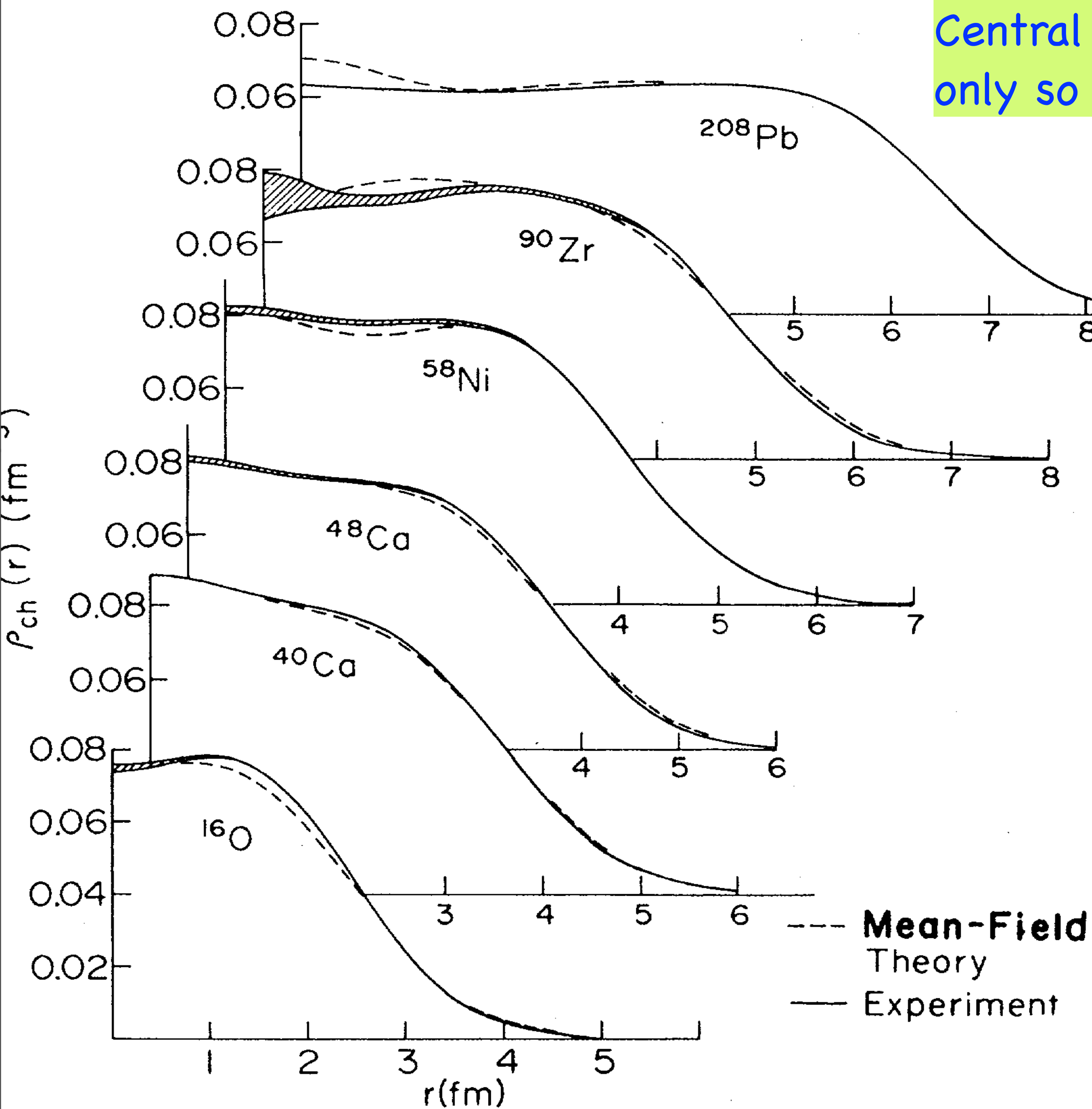
Hadrons in the Nuclear Medium

ECT* Trento, May 14-19, 2012

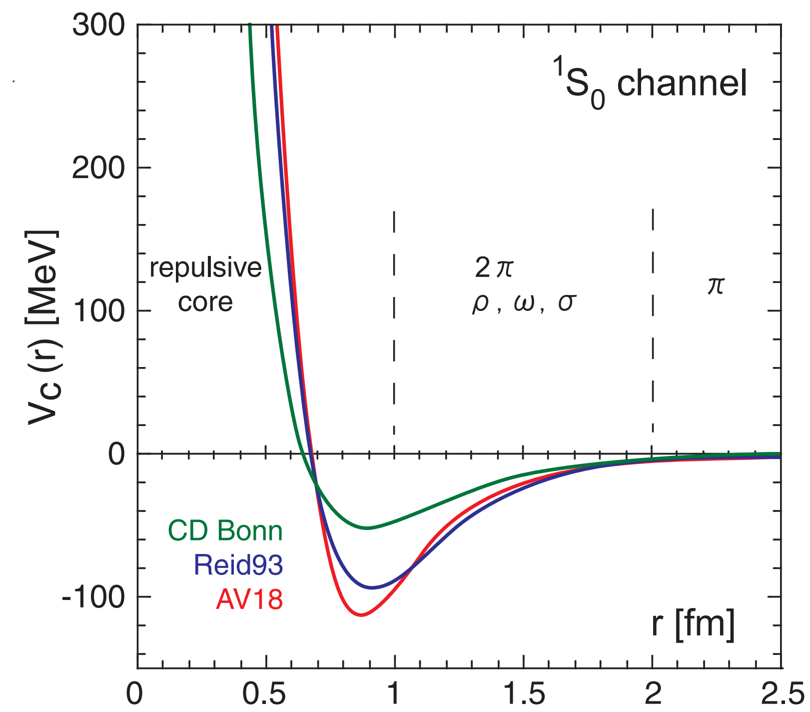
Outline

- Short range Correlations Exist!
  - Can be studied via inclusive quasielastic and deep inelastic electron scattering
- A few points about the Spectral Function and integration limits
- Do FSI obstruct us from gleaning information about SRCs in inclusive electron scattering?
- SRC through ratios
- Connection between SRC and EMC
- SRC Wish list

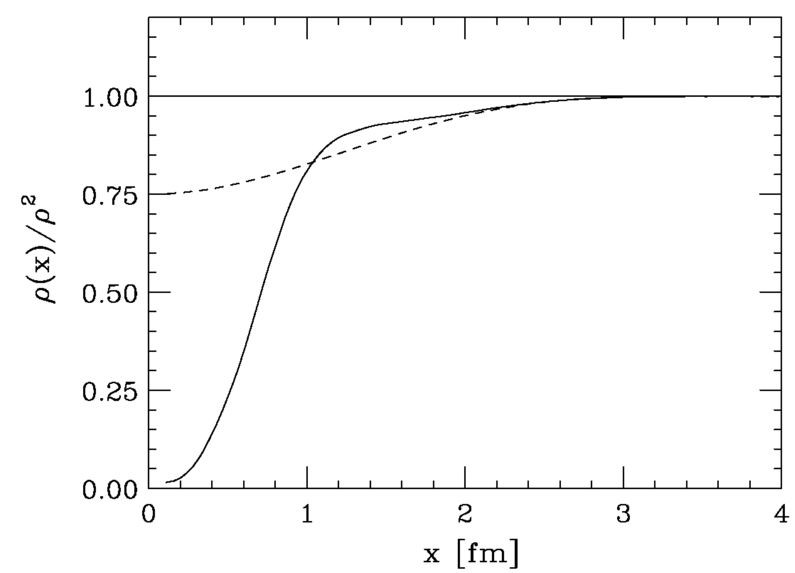
How do we know short range correlations exist?



Central density is saturated - nucleons can be packed only so close together: ρ_{ch} * (A/Z) = constant



$$\rho(x, x') = \rho(x)\rho(x')g(x, x')$$



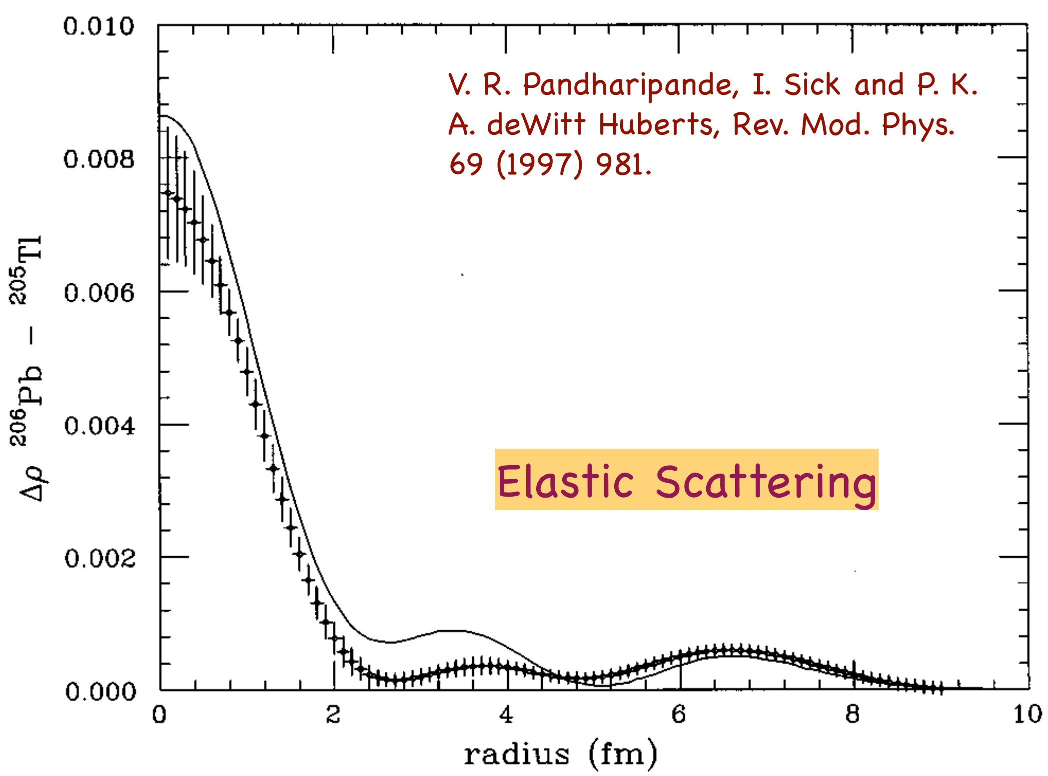
$$|x - x'| \lesssim r_c \Longrightarrow g(x, x') \ll 1$$

Spatial correlations

O. Benhar, AIP Conf.Proc. 1189 (2009) 43-50

J.W. Negele RMP 54 (913) 1982

What else? Occupation Numbers

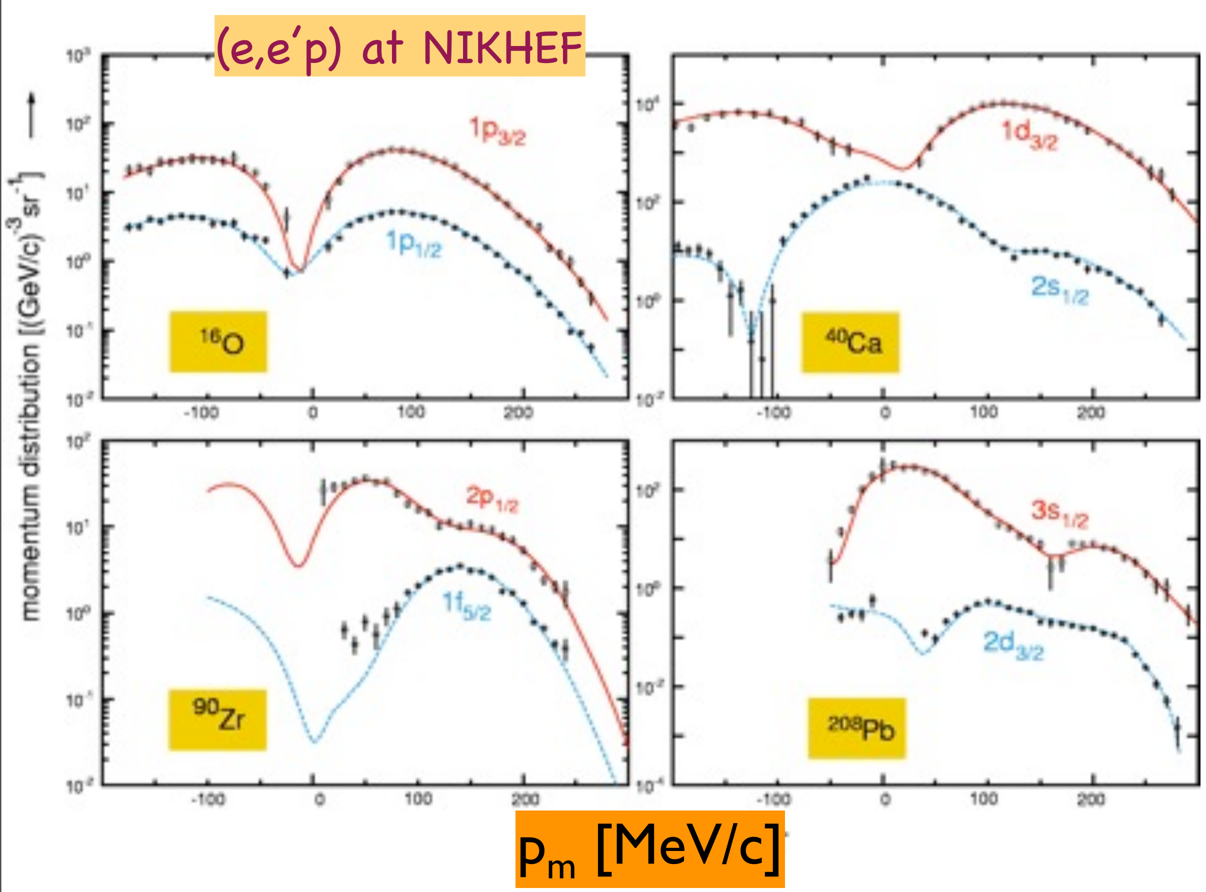


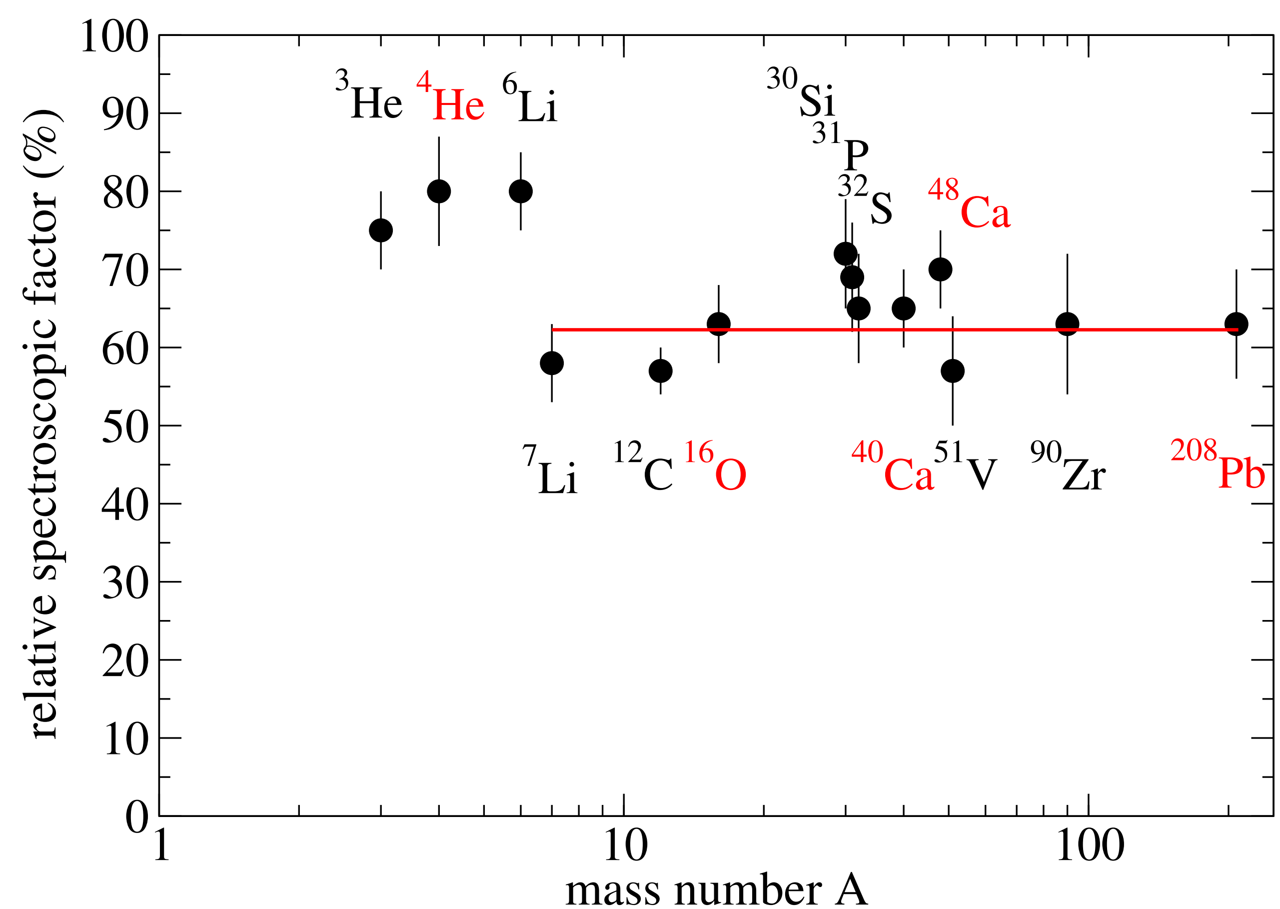
Density difference between ^{206}Pb and ^{205}Tl.

Experiment - Cavedon et al (1982)
Theory: Hartree-Fock orbitals with adjusted occupation numbers is given by the curve.

The shape of the $3s^{1/2}$ orbit is very well given by the mean field calculation.

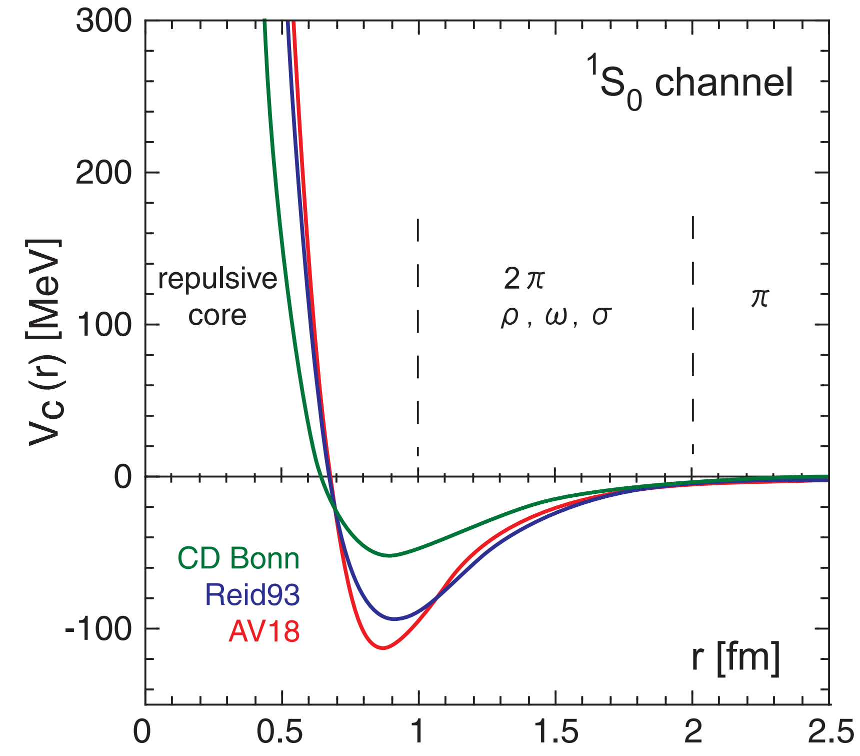
Occupation numbers scaled down by a factor ~0.65.

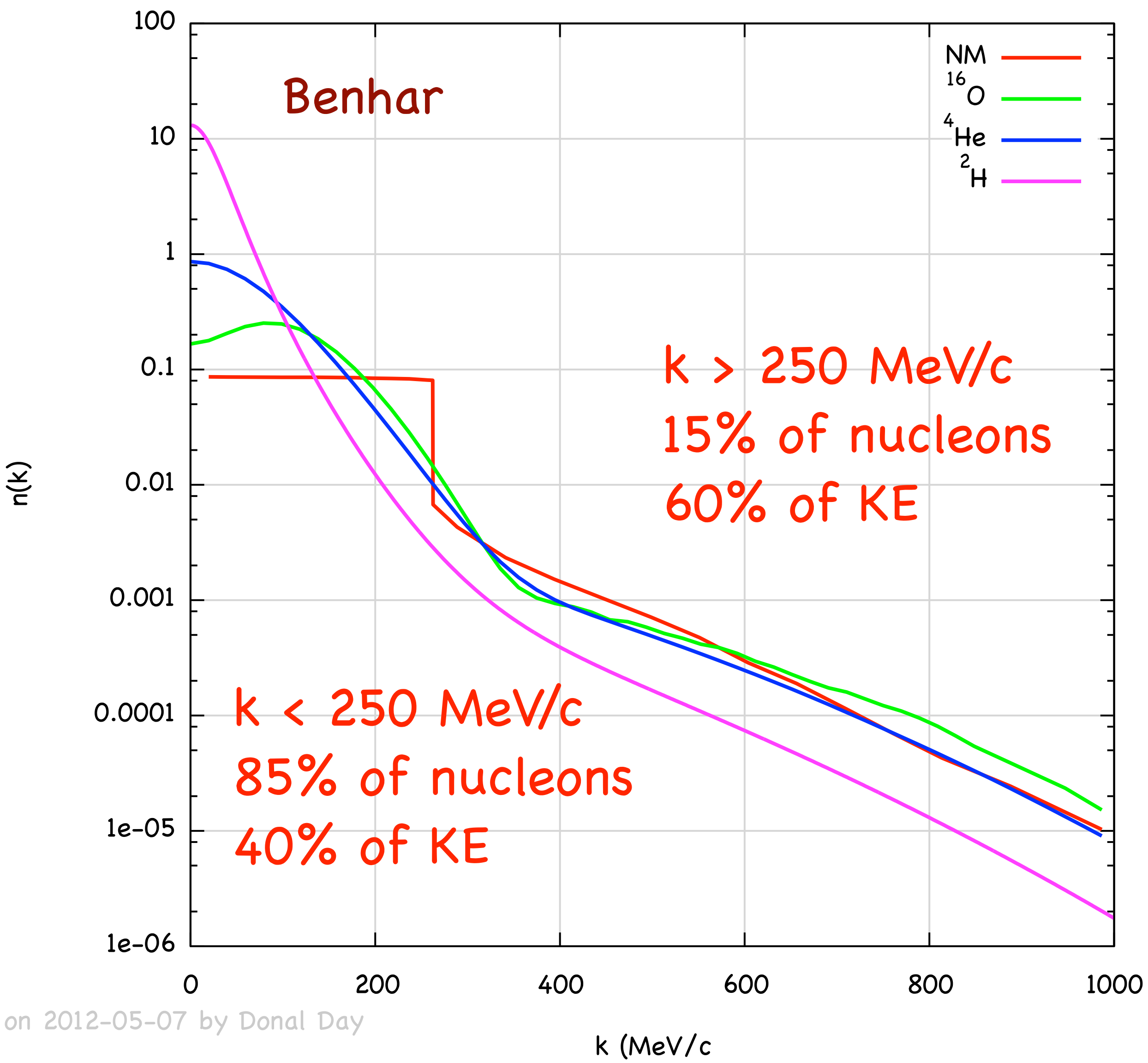


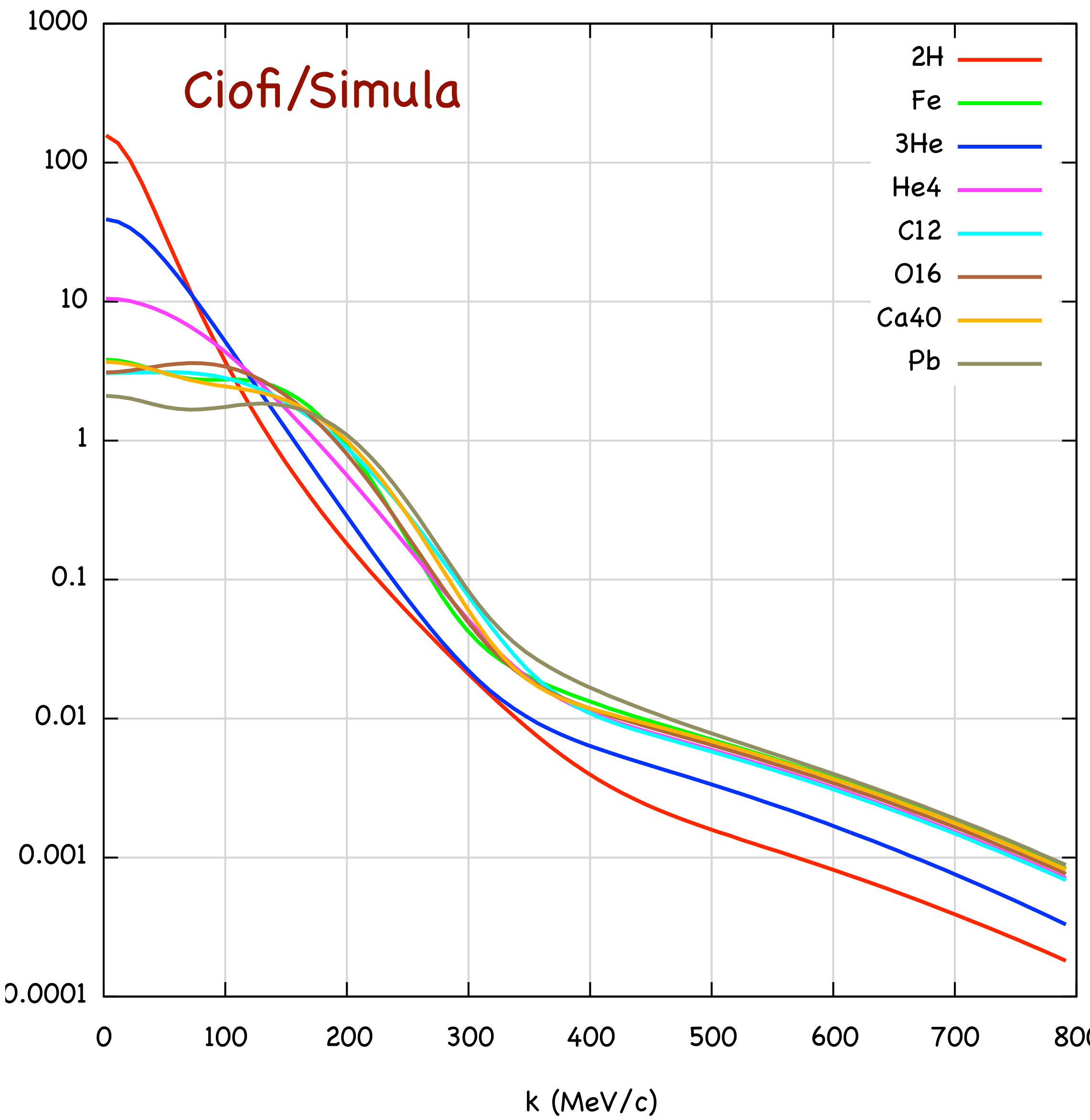


Theory suggests a common feature for all nuclei

What many calculations indicate is that the tail of n(k) for different nuclei has a similar shape – reflecting that the NN interaction, common to all nuclei, is the source of these dynamical correlations.



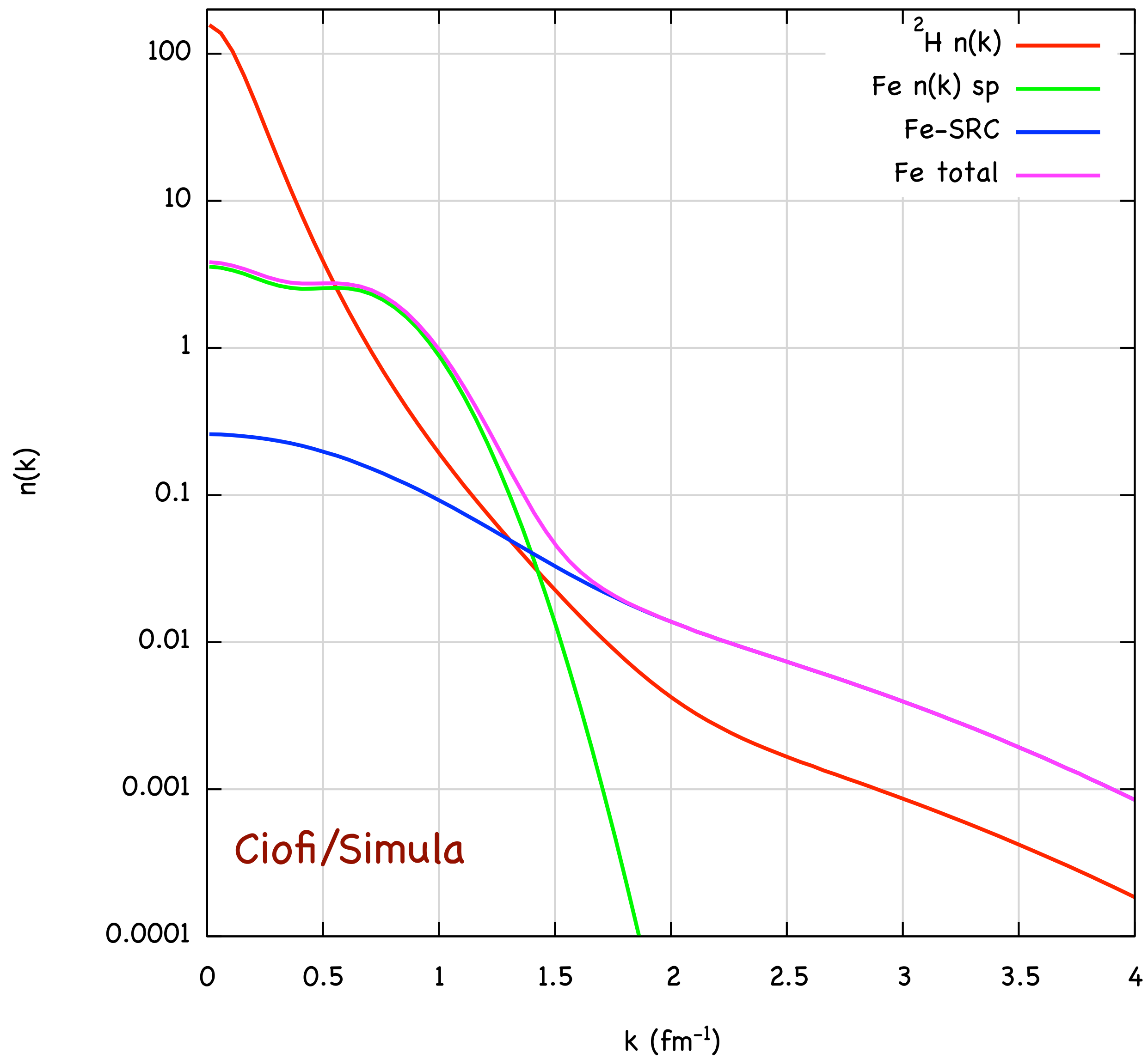


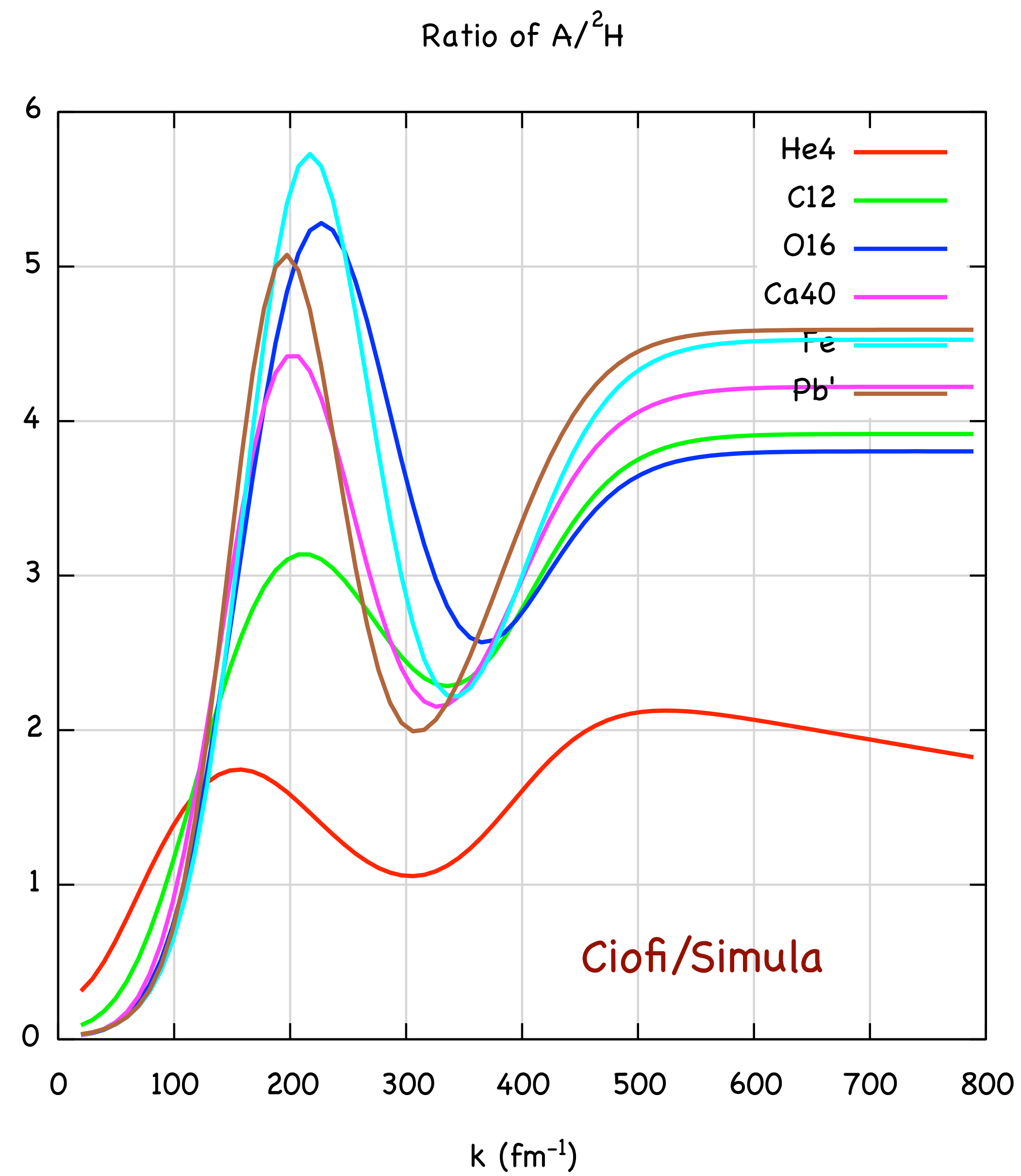


Universality of SRC

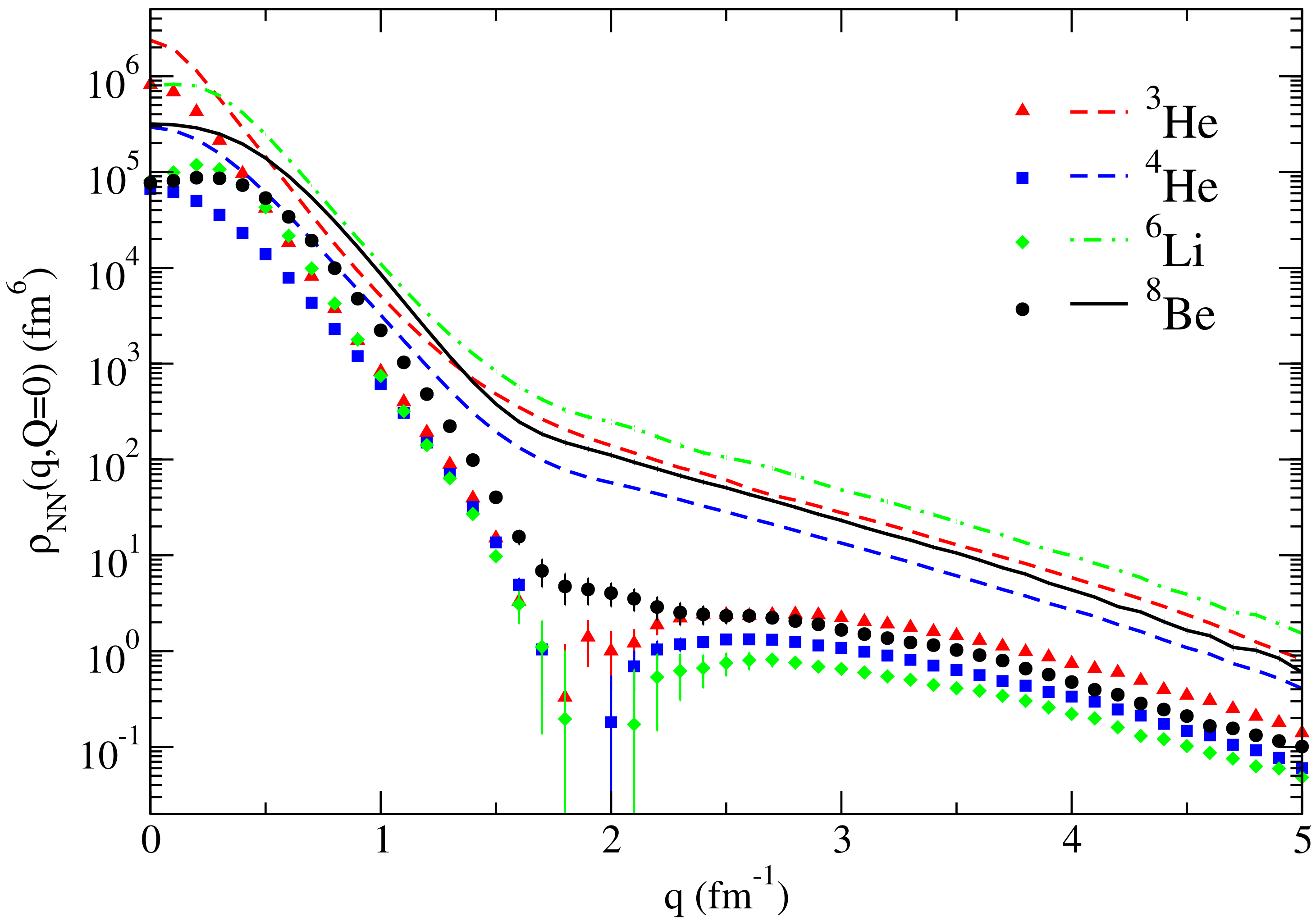
The momentum distribution is made of a mean field piece and piece due to short range correlations.

At large k the ratio between the ^2H and heavy approaches a constant

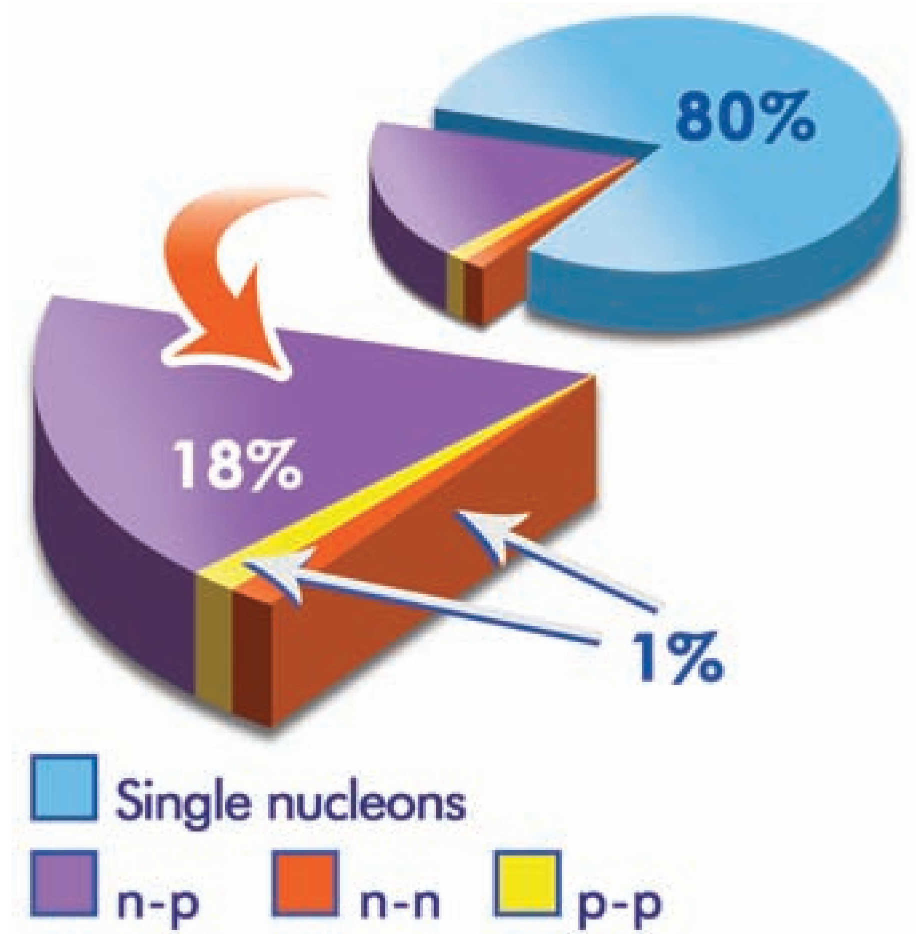




Tensor force responsible for dominant part of SRC and correlations are largely of pn pairs



Schiavilla et al. PRL 98, 132501 (2007), VMC and AV18/UIX

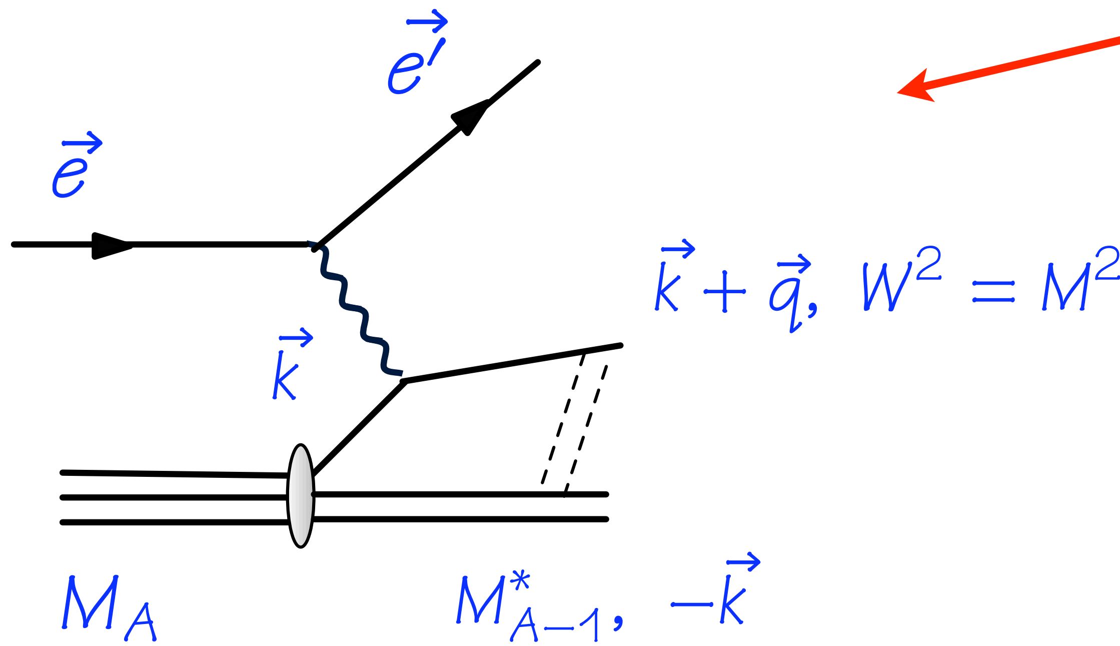


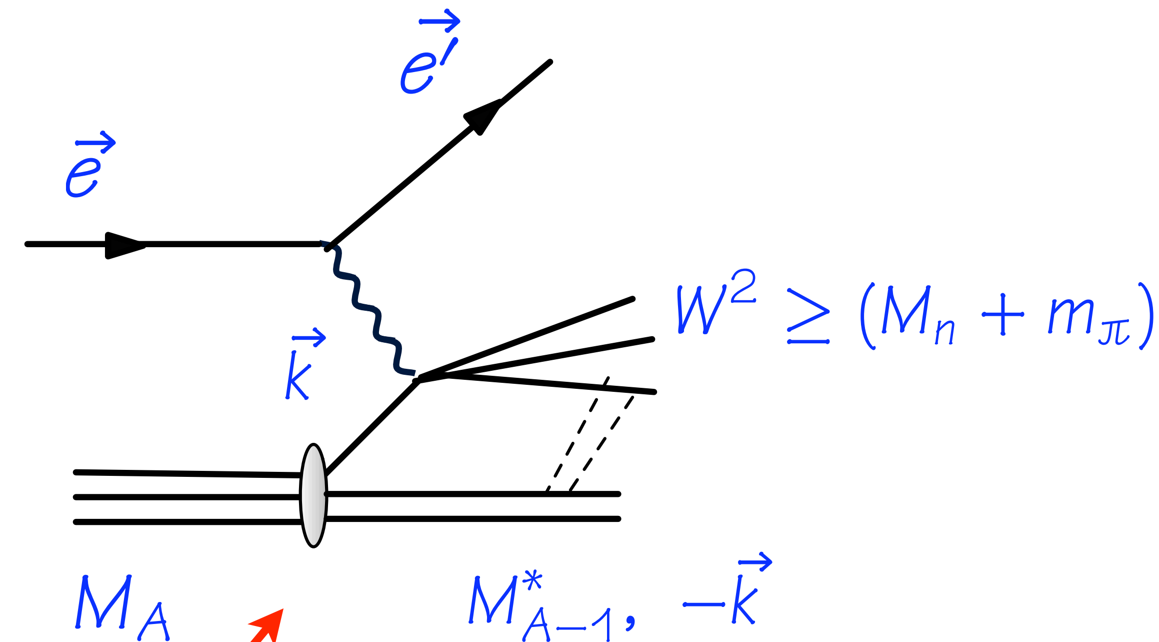
JLAB A(e,e'NN) data from Hall A
R. Subedi et al.
Science 320, 1476 (2008)

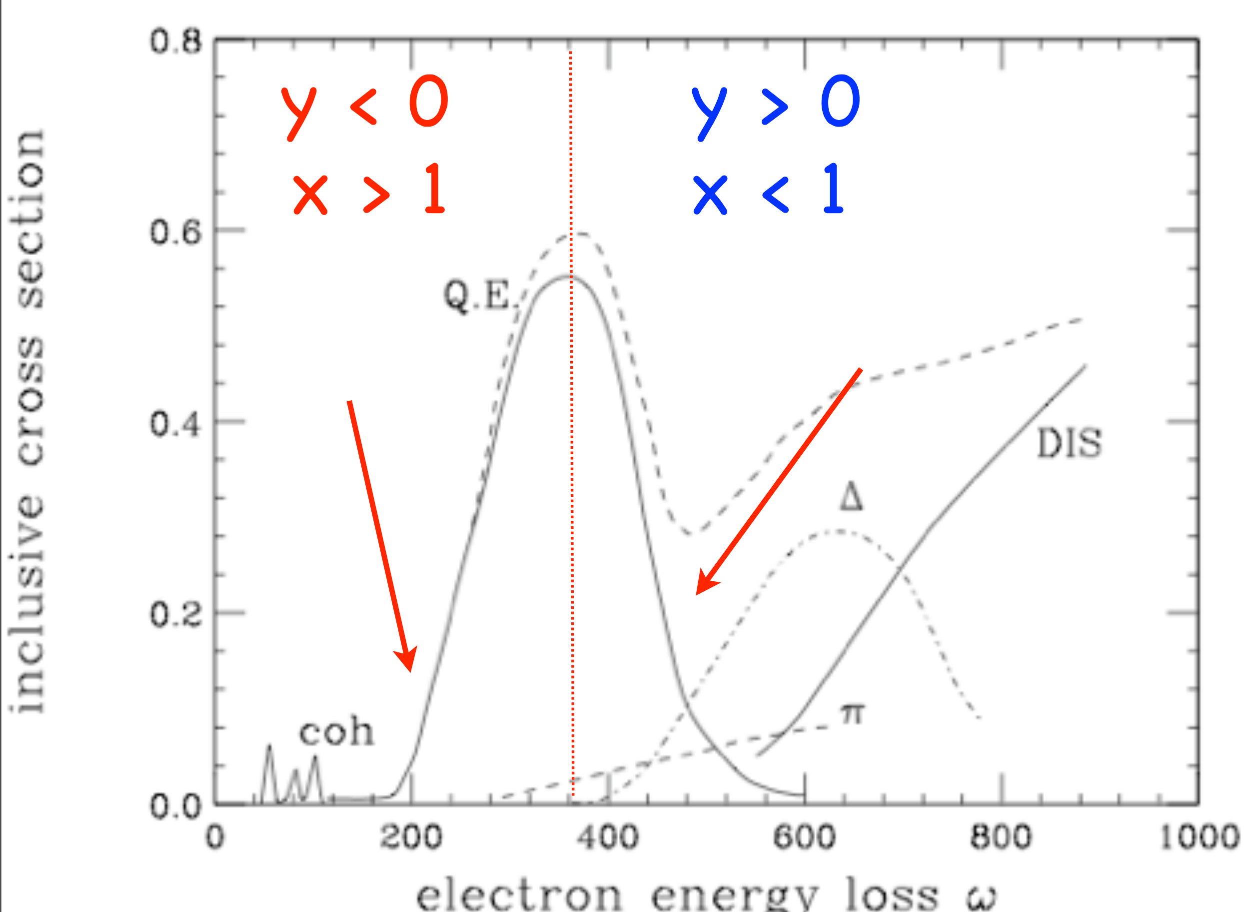
Inclusive Electron Scattering from Nuclei

Two dominant and distinct processes

Quasielastic from the nucleons in the nucleus





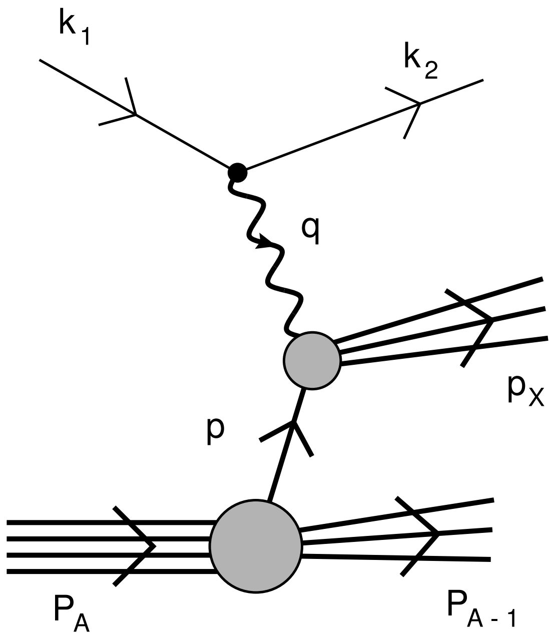


Inelastic (resonances) and DIS from the quark constituents of the nucleon.

Inclusive final state means no separation of two dominant processes

$x = Q^2/(2m\upsilon)$

υ,ω=energy loss



$$\frac{d\sigma^2}{d\Omega_{e'}dE_{e'}} = \frac{\alpha^2}{Q^4}\frac{E'_e}{E_e}L_{\mu\nu}W^{\mu\nu}$$

The two processes share the same initial state

QES in IA

$$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE\sigma_{ei} \underbrace{S_i(k,E)}_{\text{Spectral function}} \delta()$$

The limits on the integrals are determined by the kinematics. Specific (x, Q^2) select specific pieces of the spectral function.

DIS

$$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE\ W_{1,2}^{(p,n)} \underbrace{S_i(k,E)}_{\text{Spectral function}}$$

$$n(k) = \int dE\ S(k,E)$$

However they have very different Q^2 dependencies

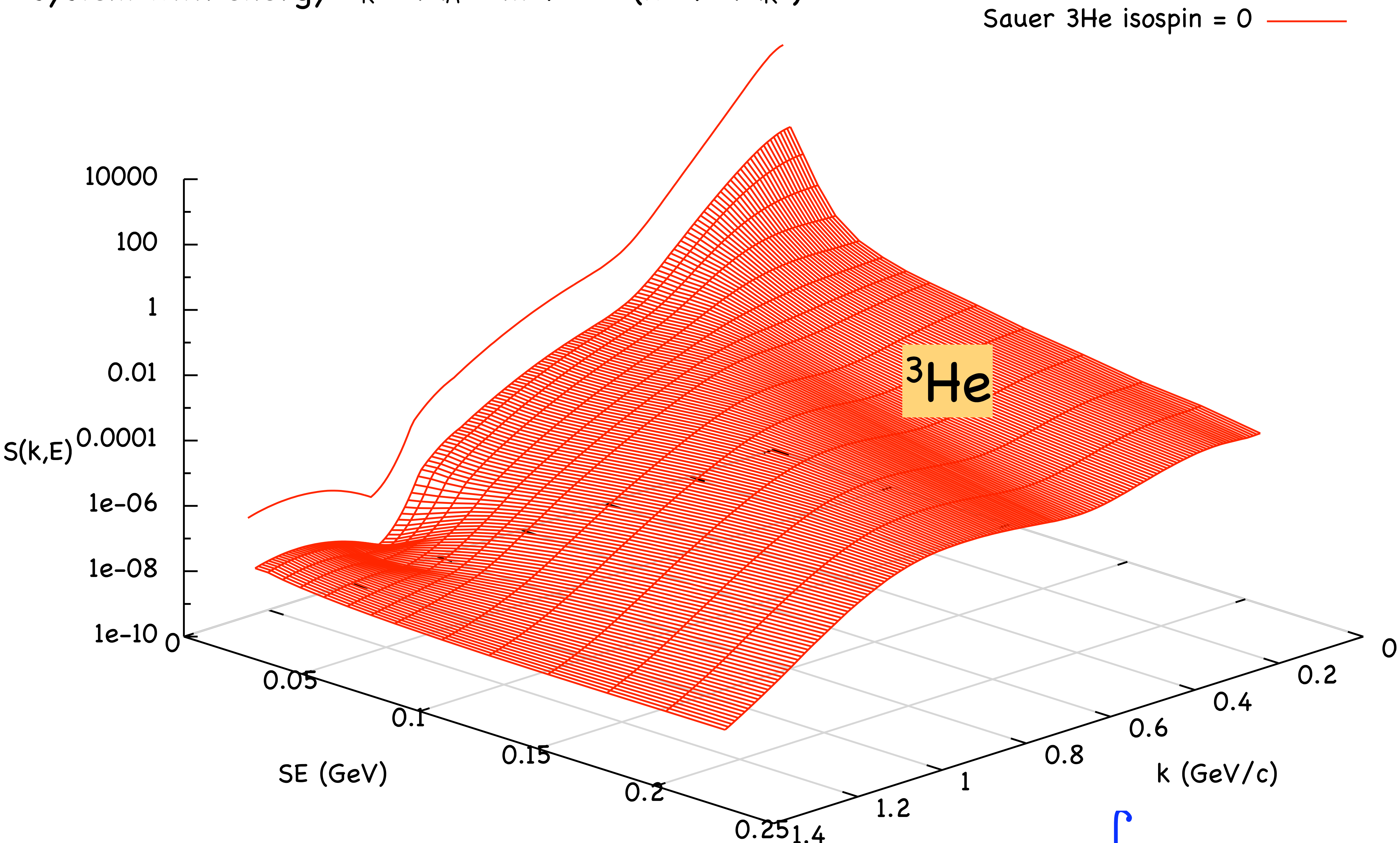
$\sigma_{ei} \propto$ elastic (form factor)$^2 \approx 1/Q^4$

$W_{1,2}$ scale with ln Q^2 dependence

Exploit this dissimilar Q^2 dependence

Spectral Function

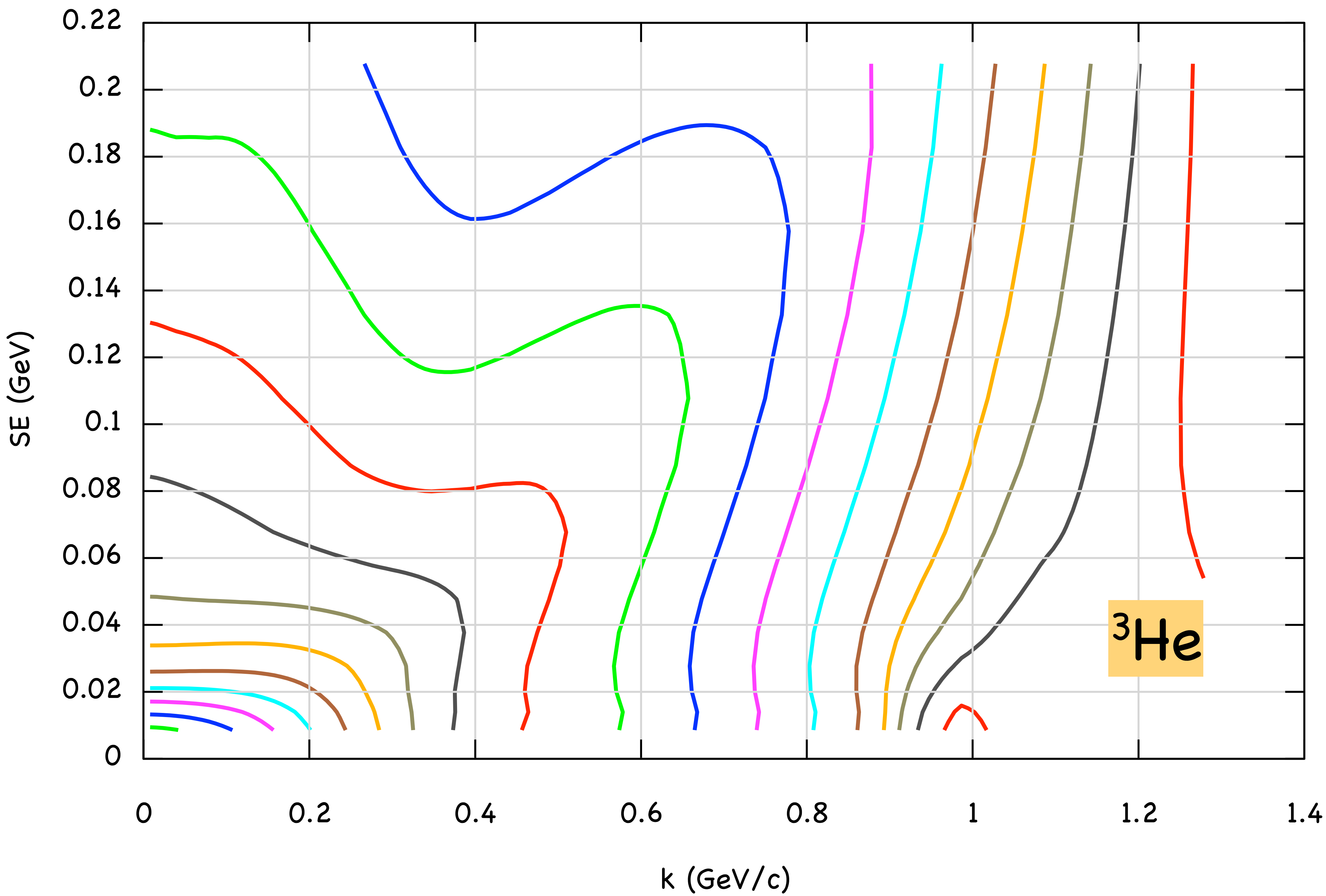
probability to remove a nucleon leaving the residual system with energy $E_R = M_A - m + E = (k^2 + M_R^2)^{1/2}$



$$n(k) = \int S(E_s, k)\, dE_s$$

Access to existing spectral functions!!

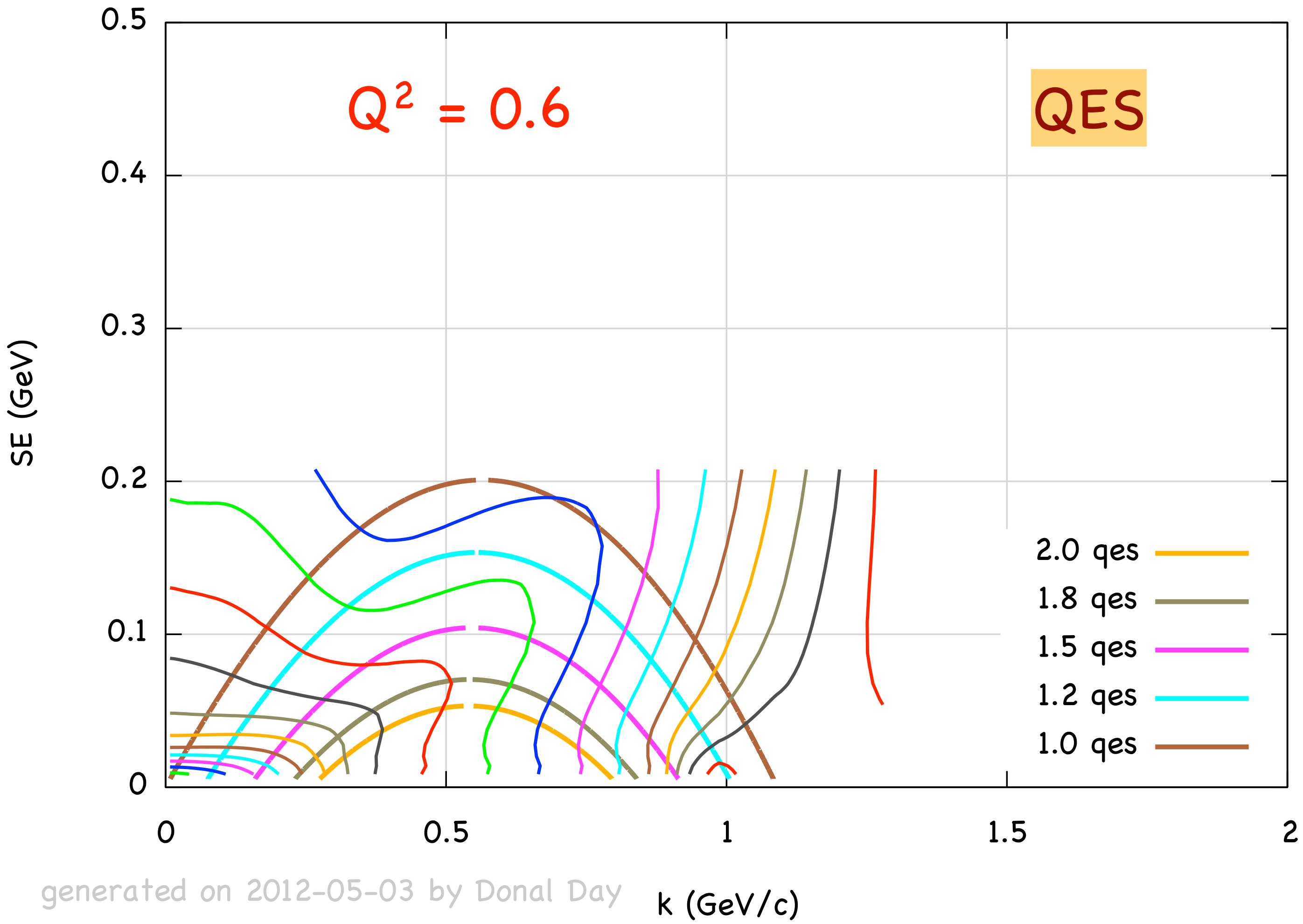
Spectral Function

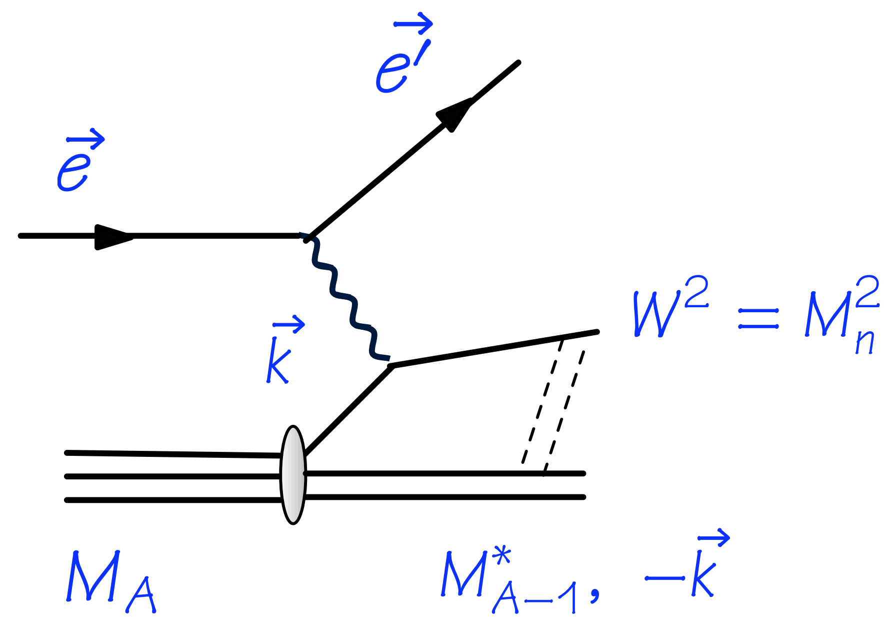


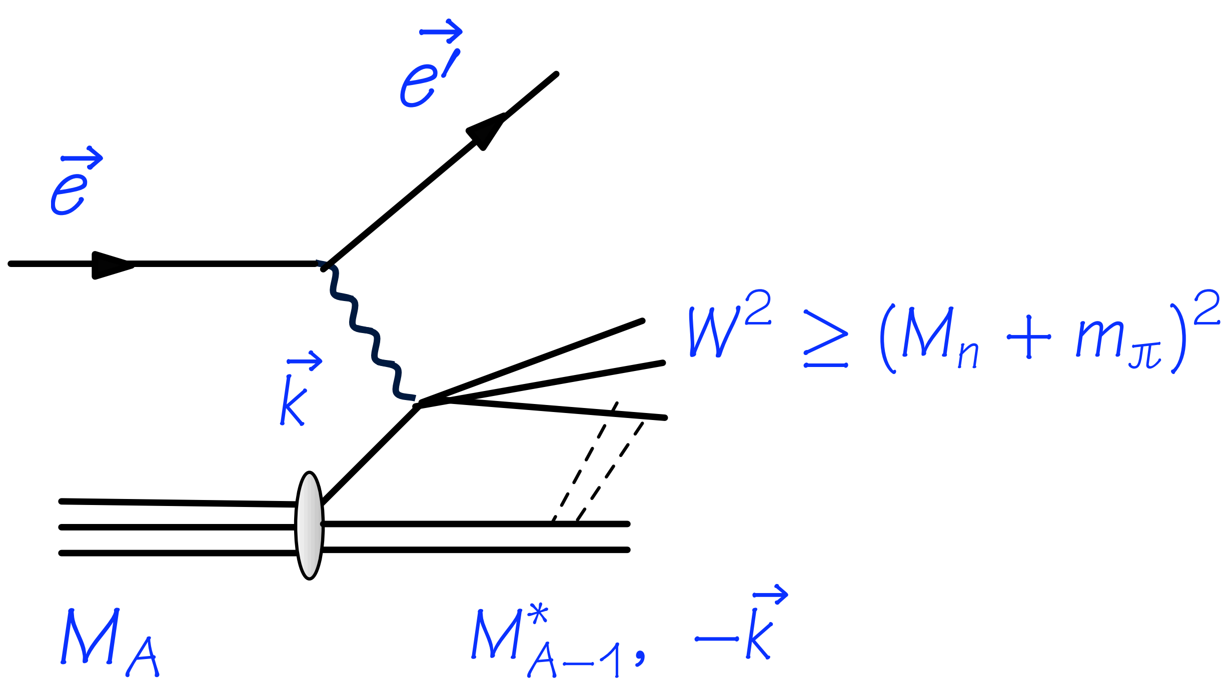
Strength is spread out in E, all of which must be integrated over to get n(k)

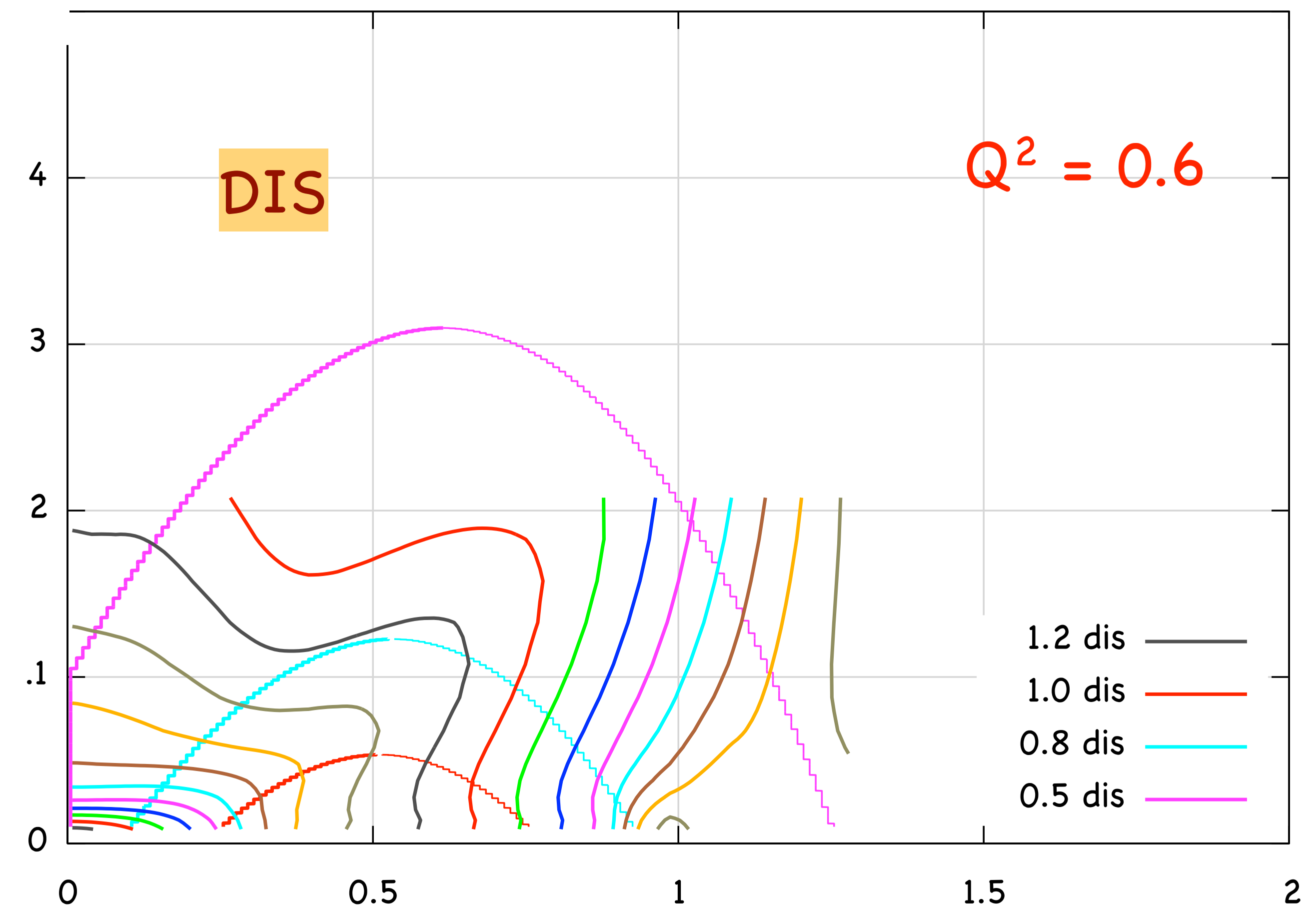
A ridge at approx $E = k^2/2/m$ reflects the correlation in the gs

Integration limits over spectral function



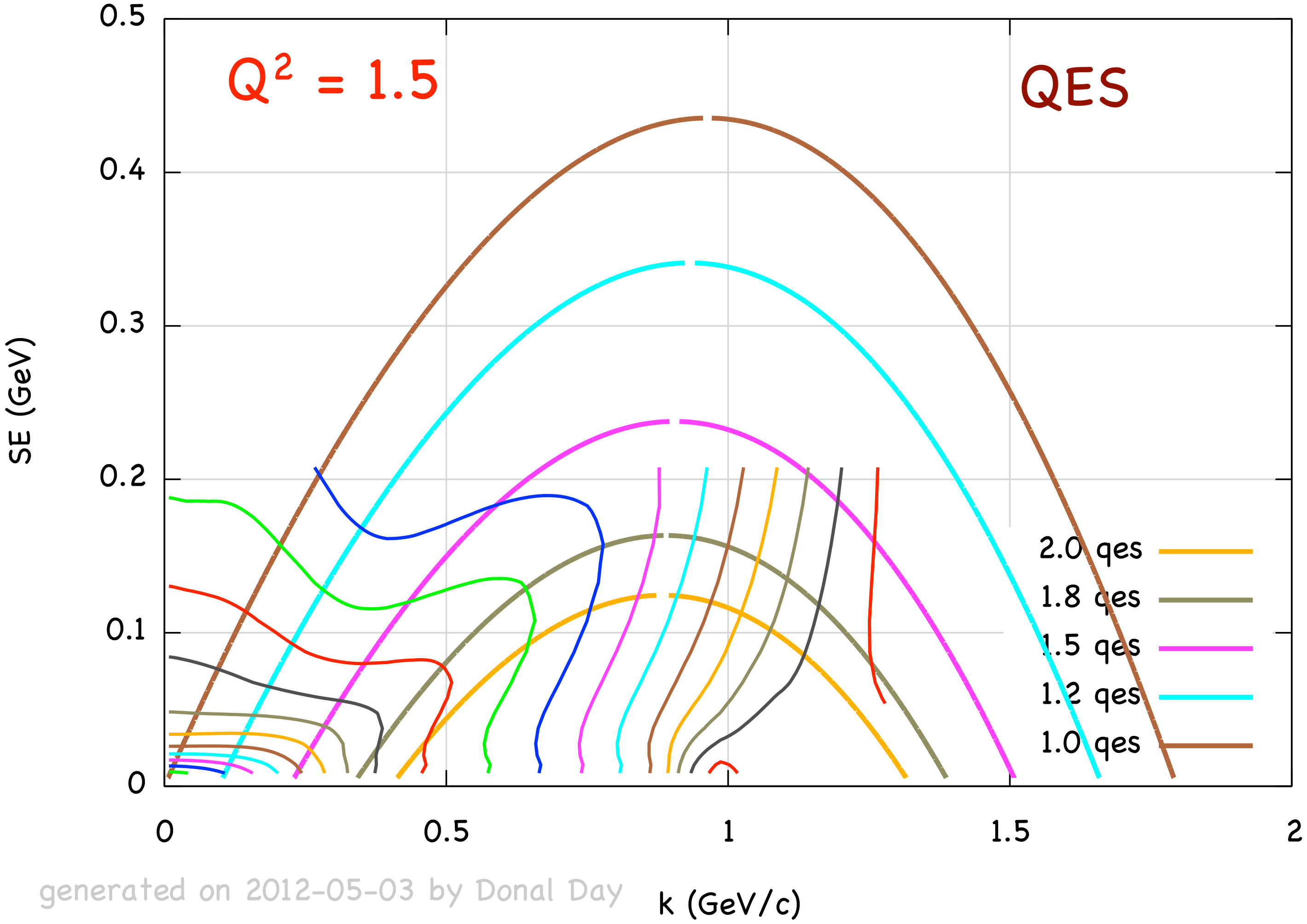


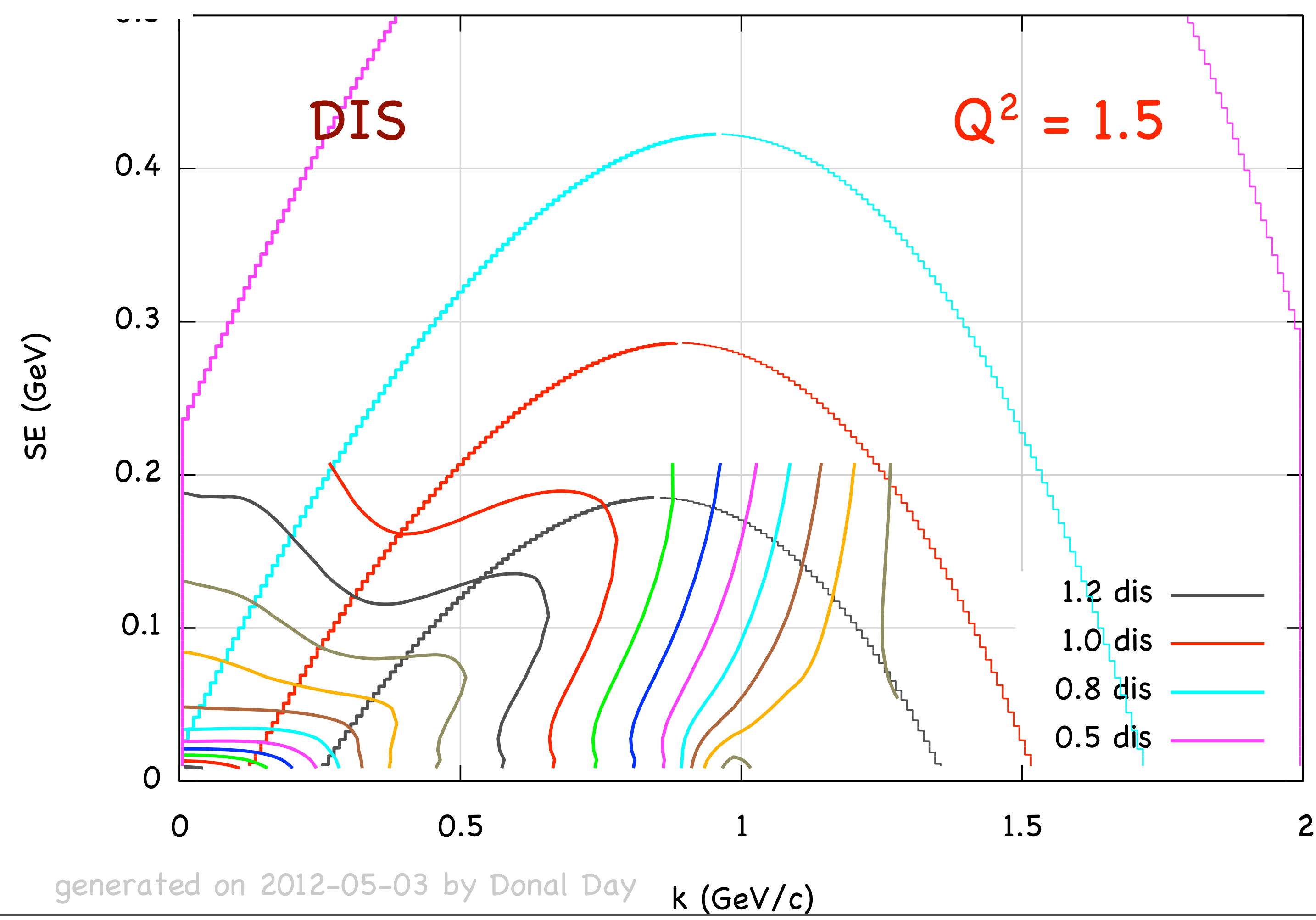




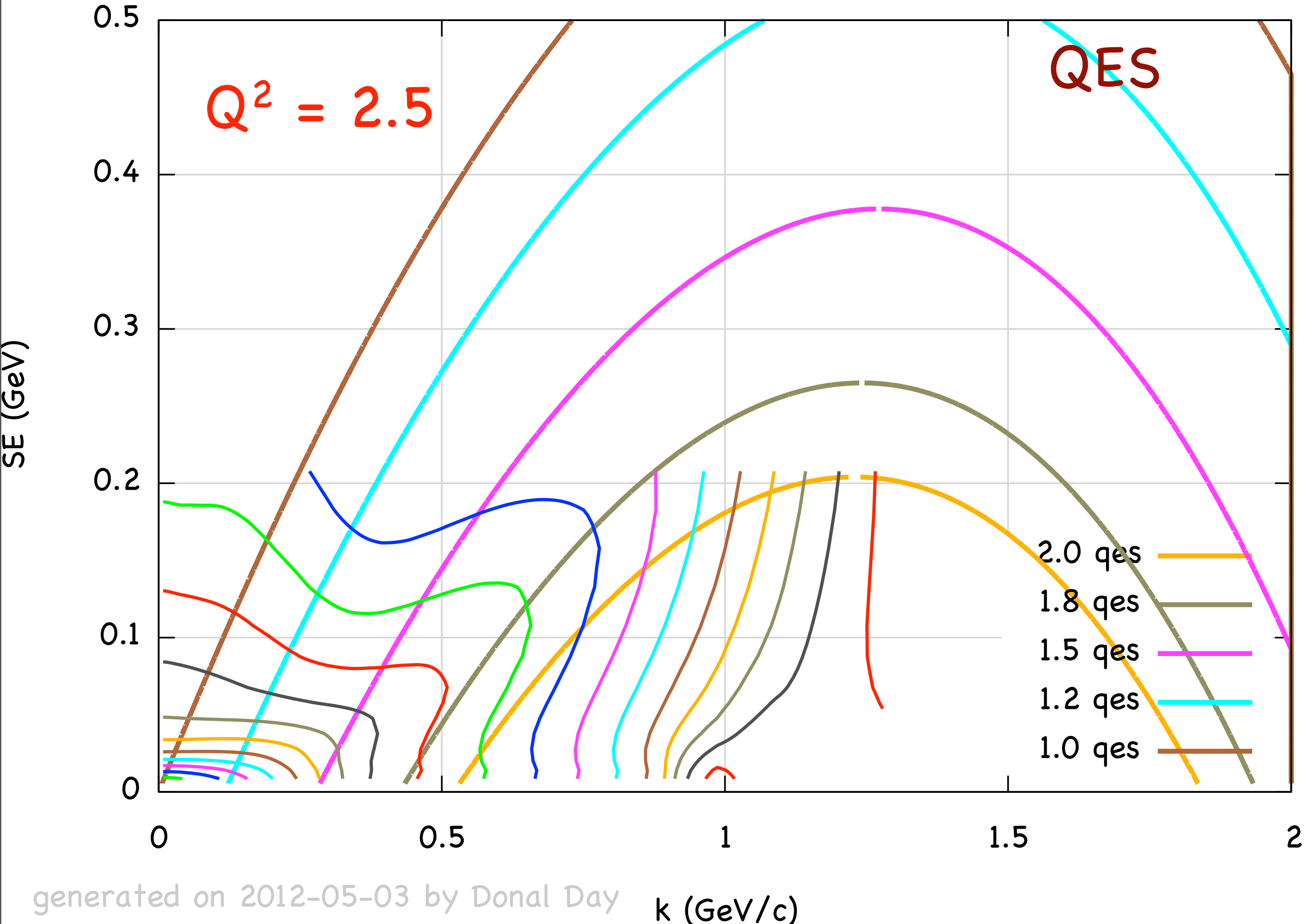
Fix e and θ, shift e′

Integration limits over spectral function

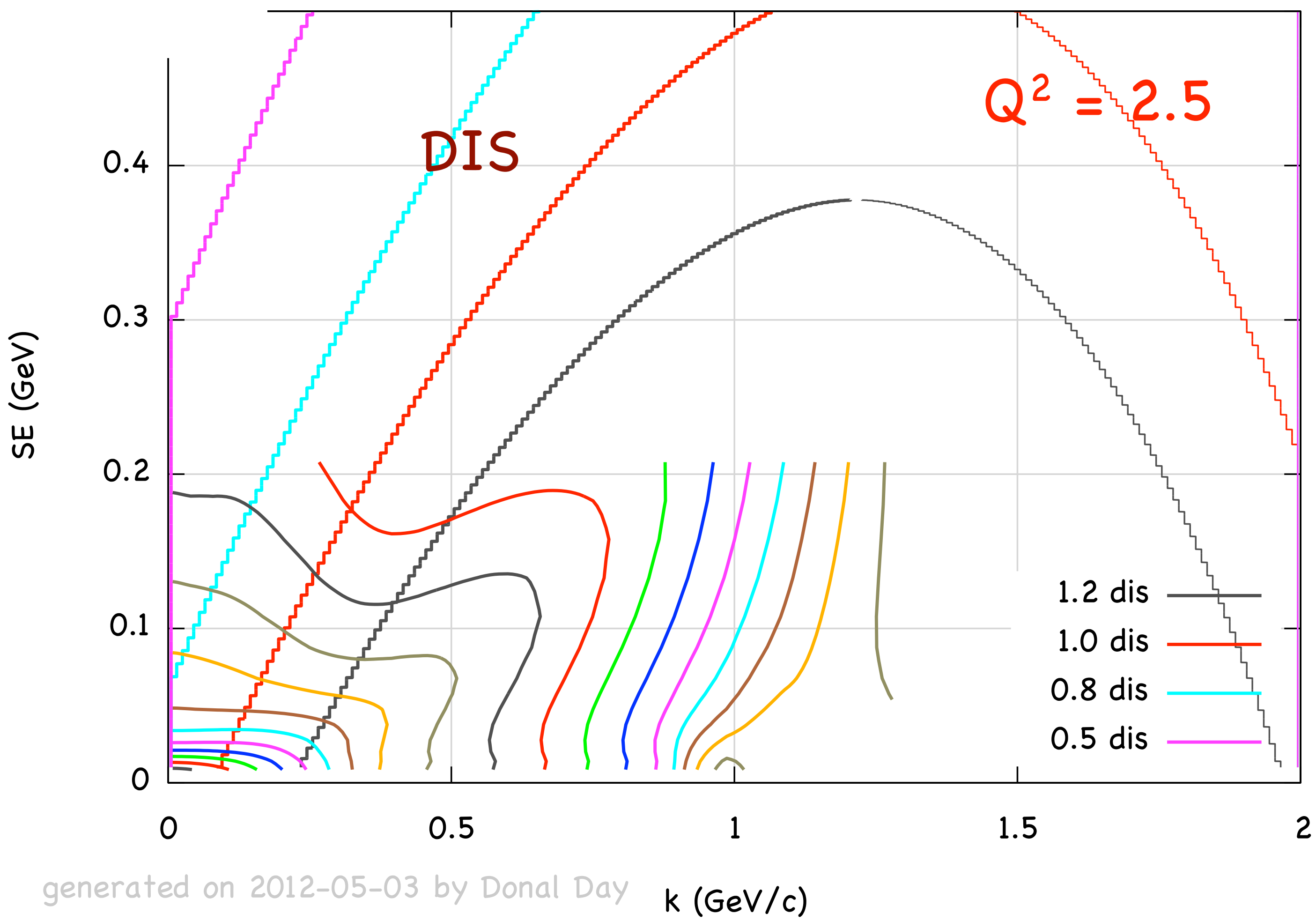




Integration limits over spectral function



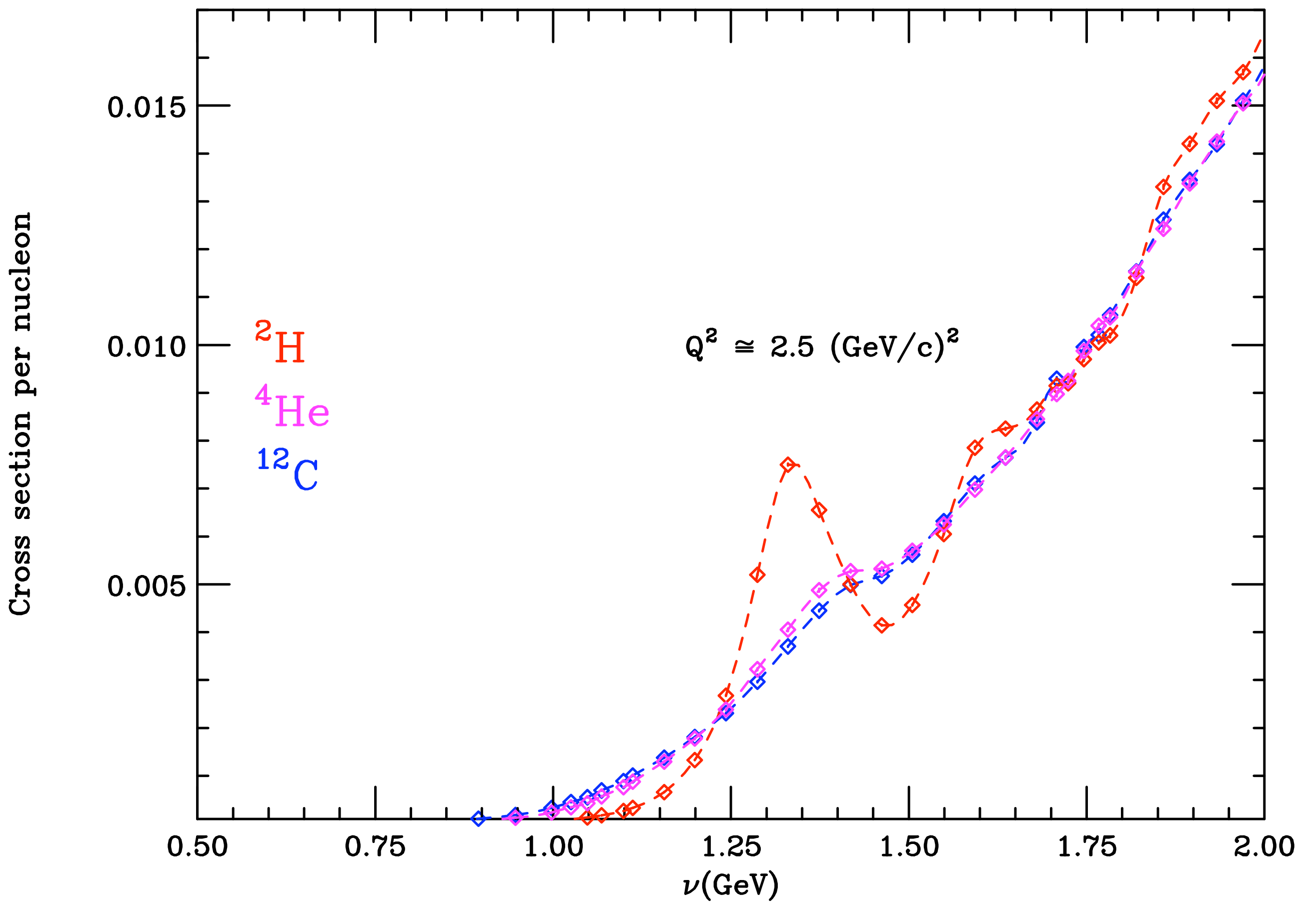
$e = 5.766,\ \theta = 18$

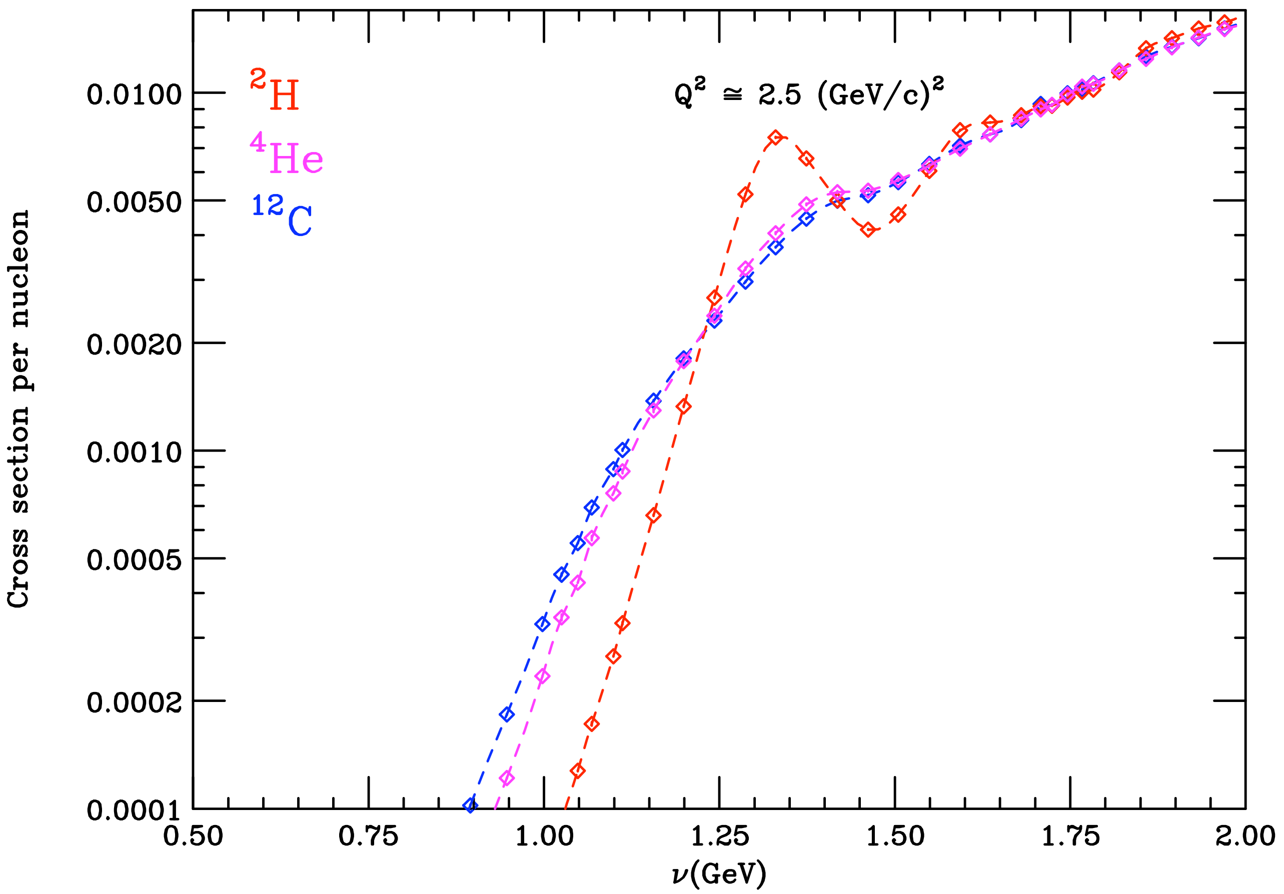


Conclusion: SRC region and EMC region sample different part of the ground state

Conclusion: With increasing Q^2, QES and DIS, at the same x, sample very similar parts of the ground state.

A dependence: higher internal momenta broadens the peak

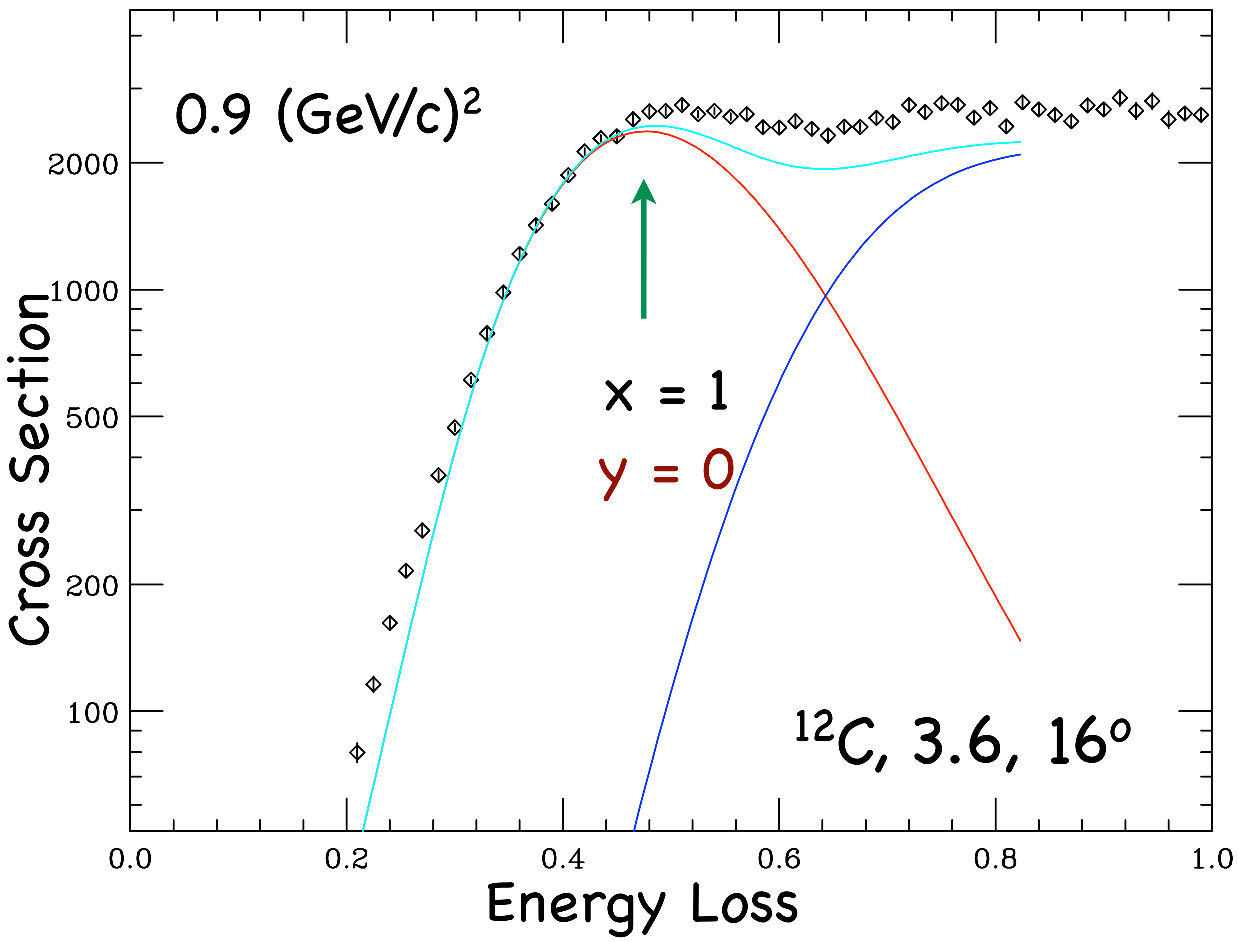


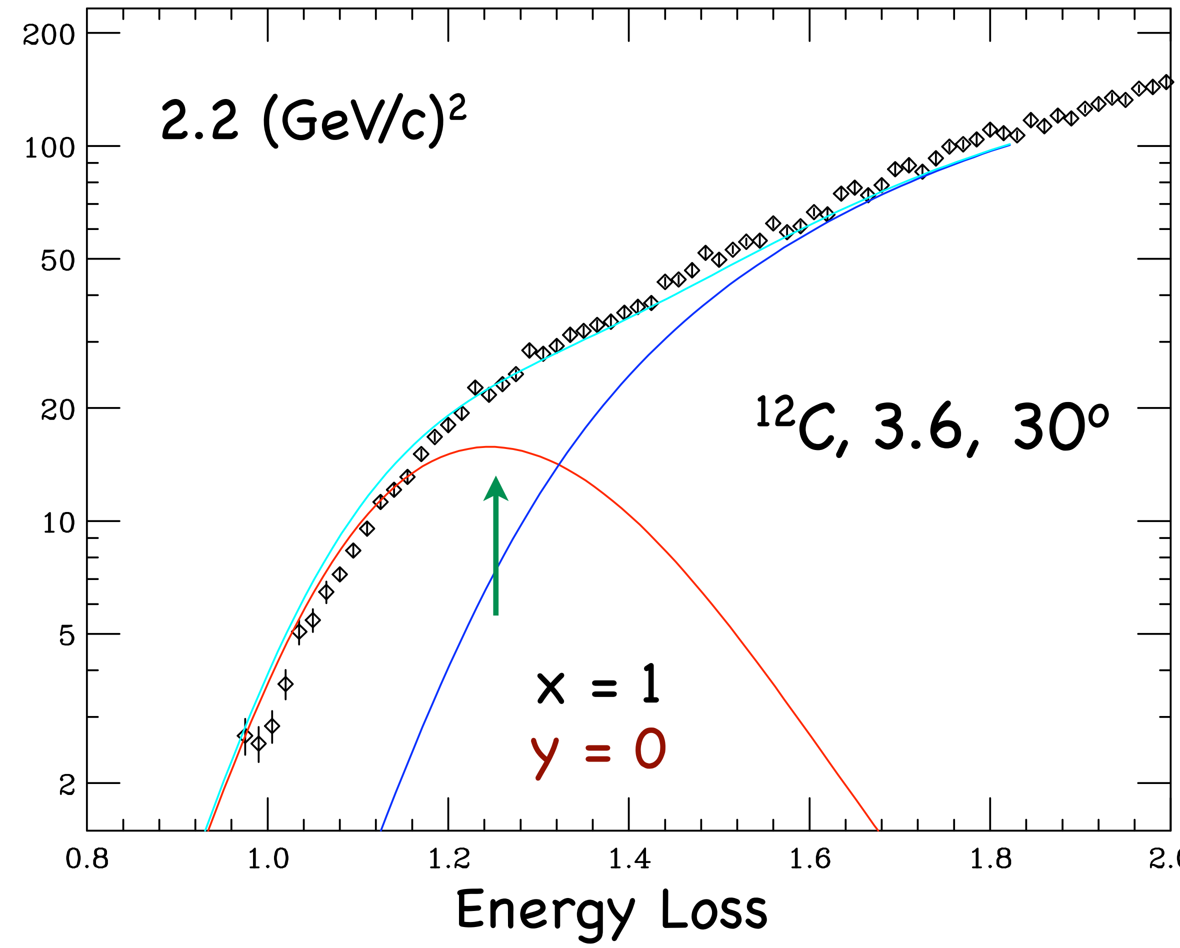


$$\Delta\omega = \sqrt{(\vec{k_f} + \vec{q})^2 + m^2} - \sqrt{(\vec{k_f} + \vec{q})^2 + m^2}$$

But.... plotted against x, the width gets narrower with increasing q -- momenta greater than k_f show up at smaller values of x (x > 1) as q increases

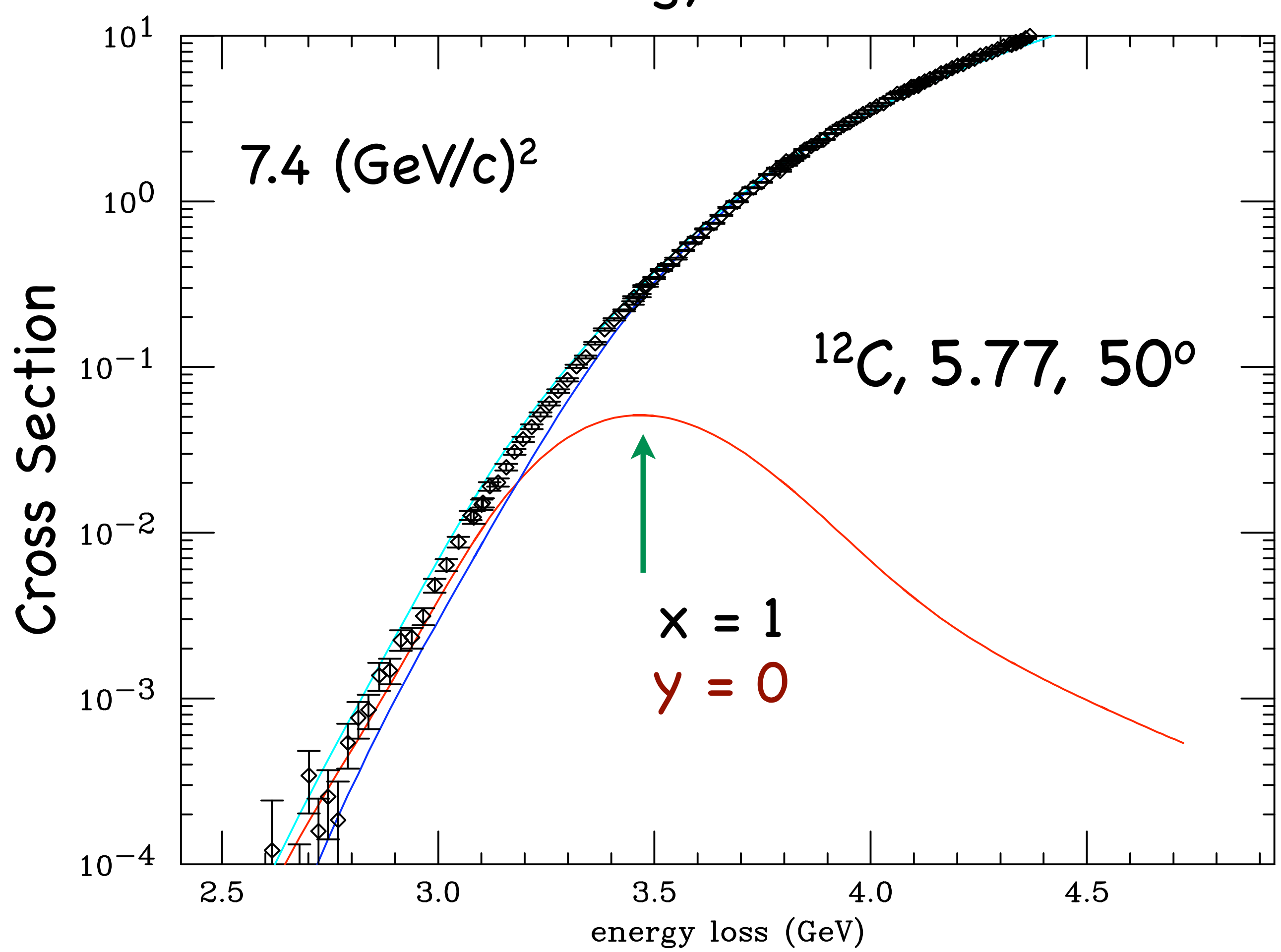
Inelastic contribution increases with Q^2





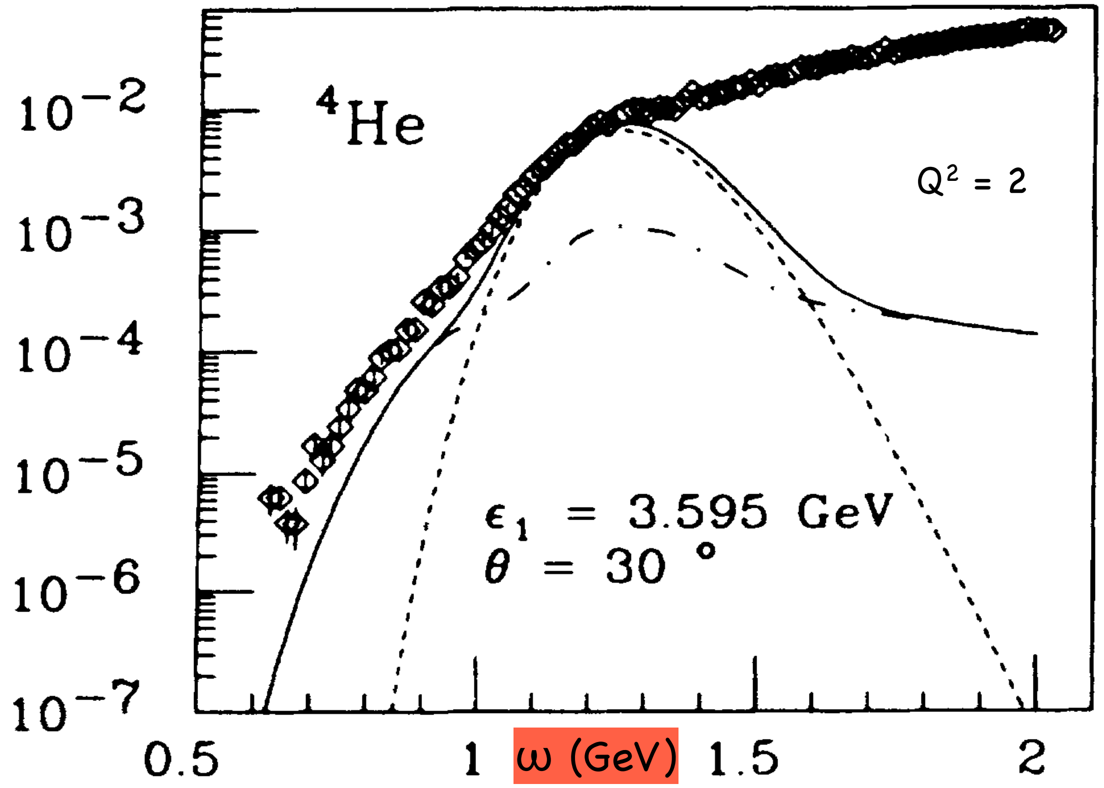
DIS begins to contribute at $x > 1$

Convolution model

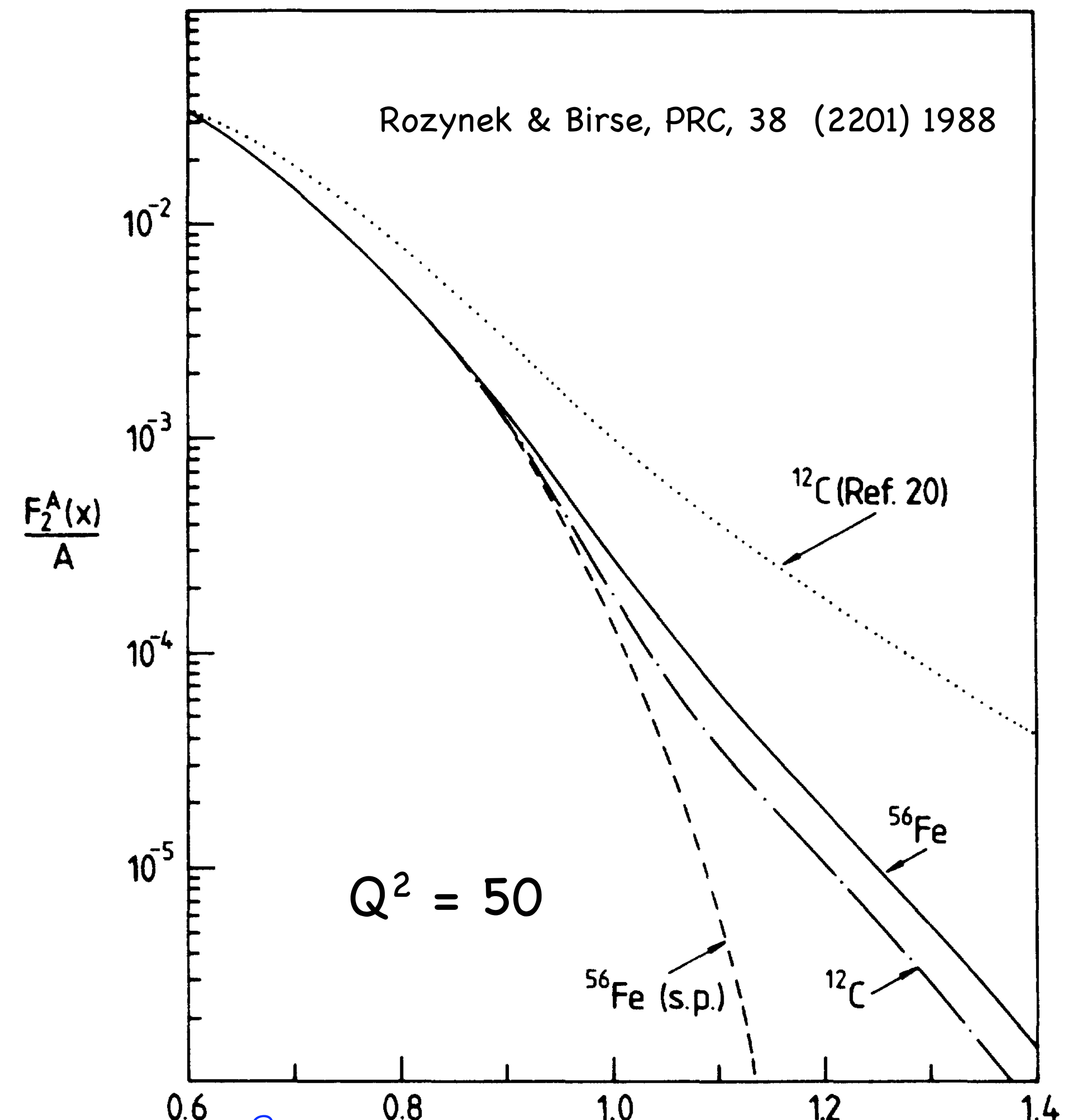


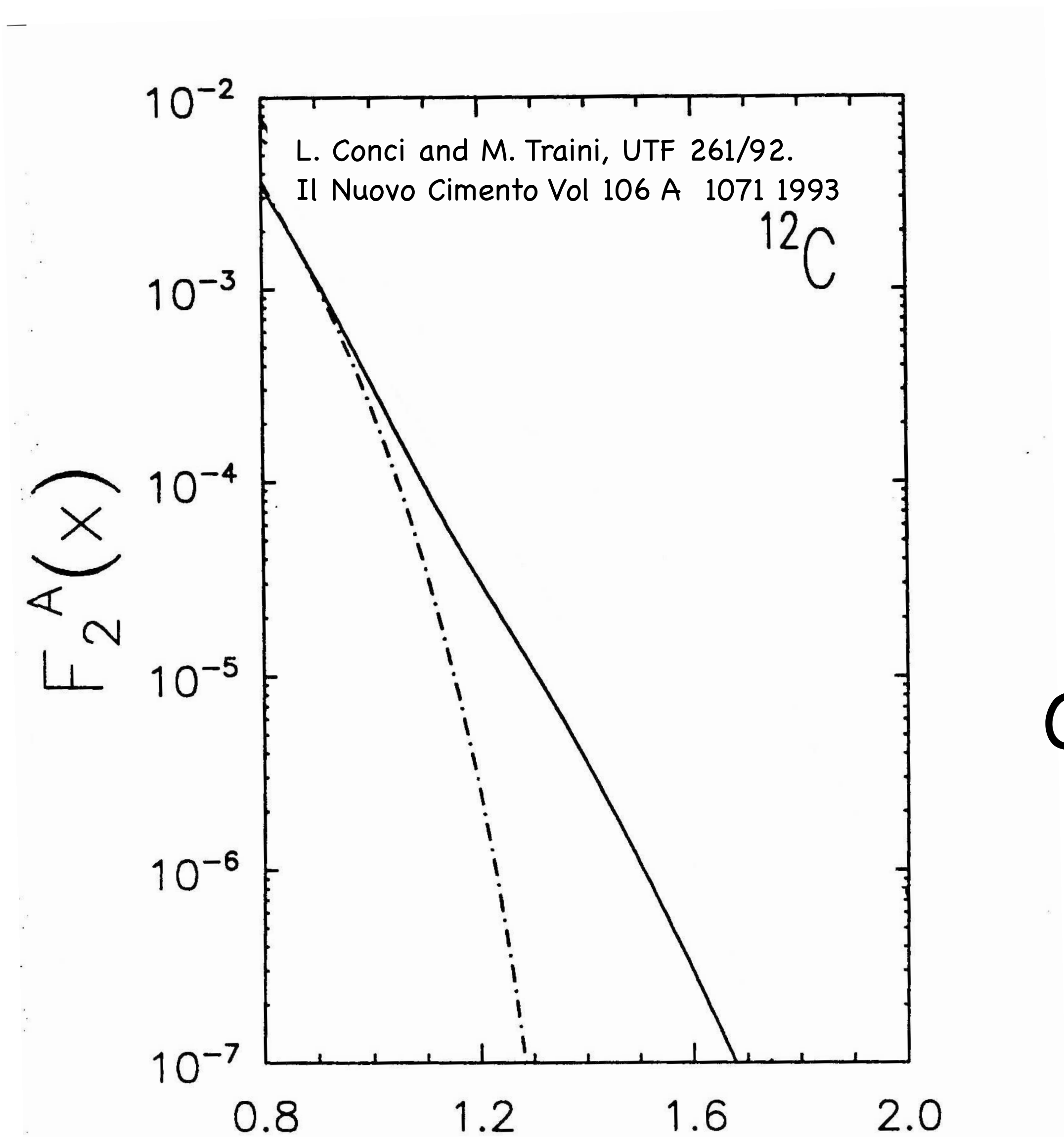
We expect that as Q^2 increases to see evidence for x-scaling - and Q^2 independence.

Correlations are accessible in QES and DIS at large x (small energy loss)



CdA, Day, Liuti, PRC 46 (1045) 1992



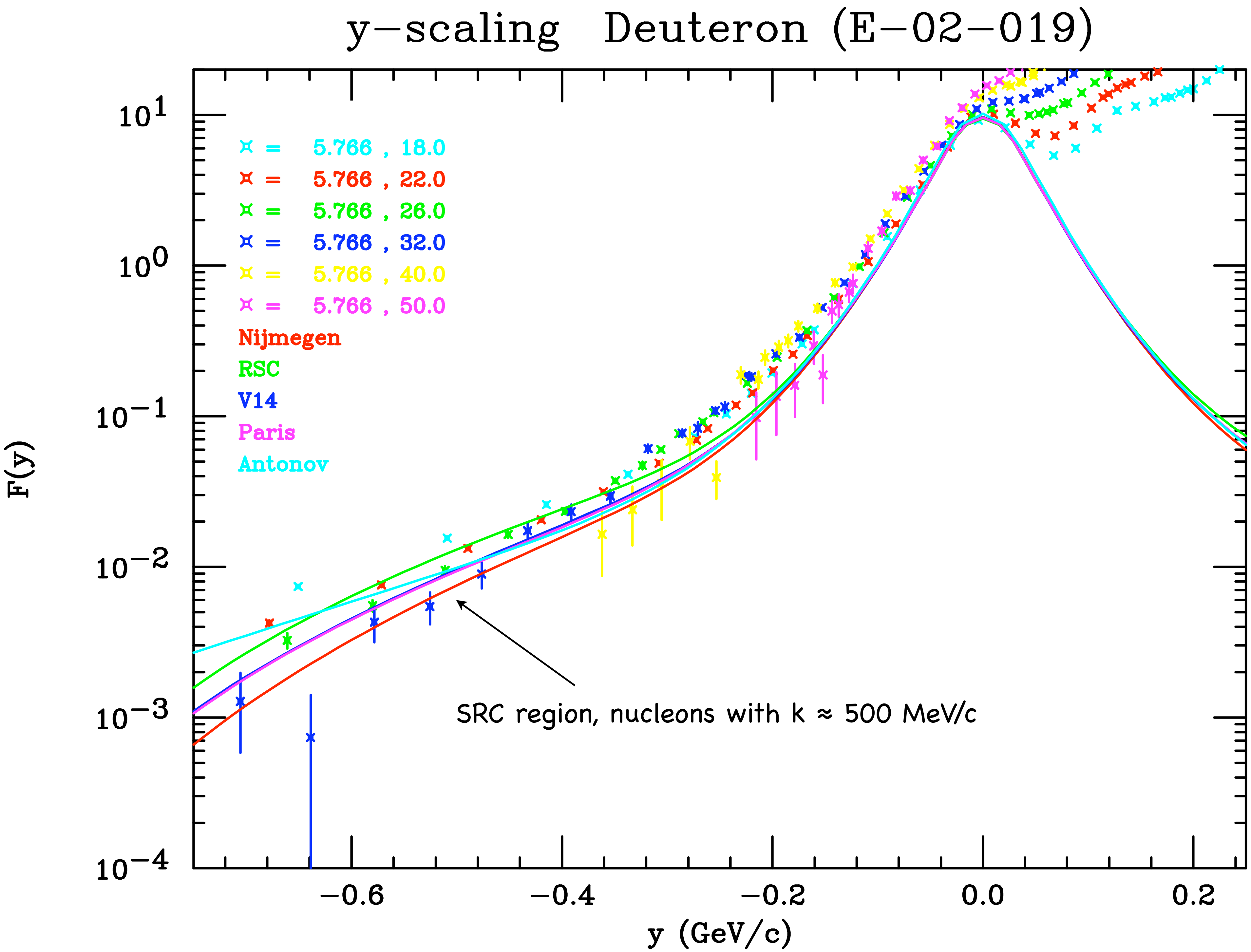


QES in IA

$$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE \sigma_{ei} \underbrace{S_i(k,E)}_{\text{Spectral function}} \delta()$$

DIS

$$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE\, W_{1,2}^{(p,n)} \underbrace{S_i(k,E)}_{\text{Spectral function}}$$



Deuteron F(y) and calculations based on NN potentials

S(k,E=2.2MeV) = n(k)

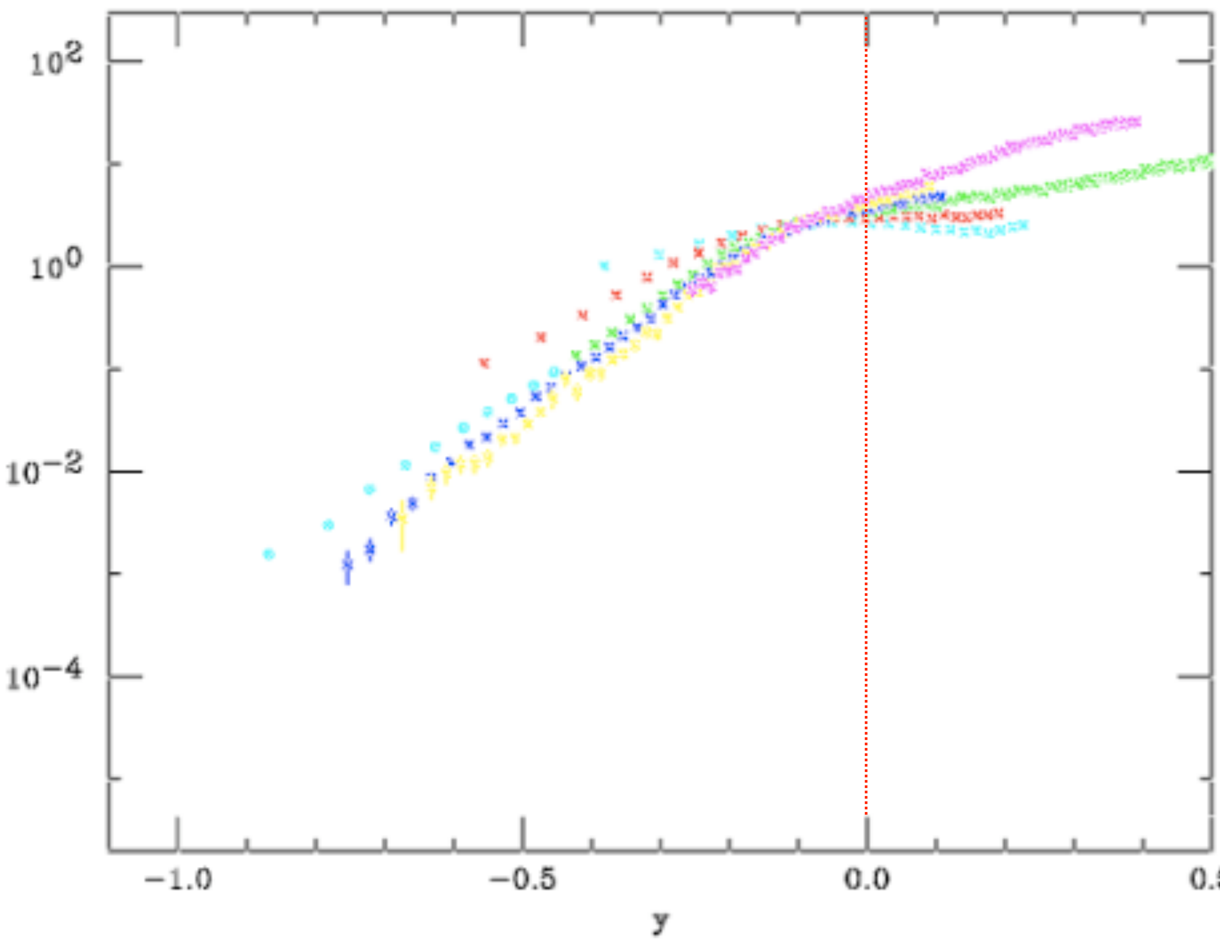
$$F(y) = \frac{\sigma^{exp}}{(Z\sigma_p + N\sigma_n)} \cdot K$$

Assumption: scattering takes place from a quasi-free proton or neutron in the nucleus.

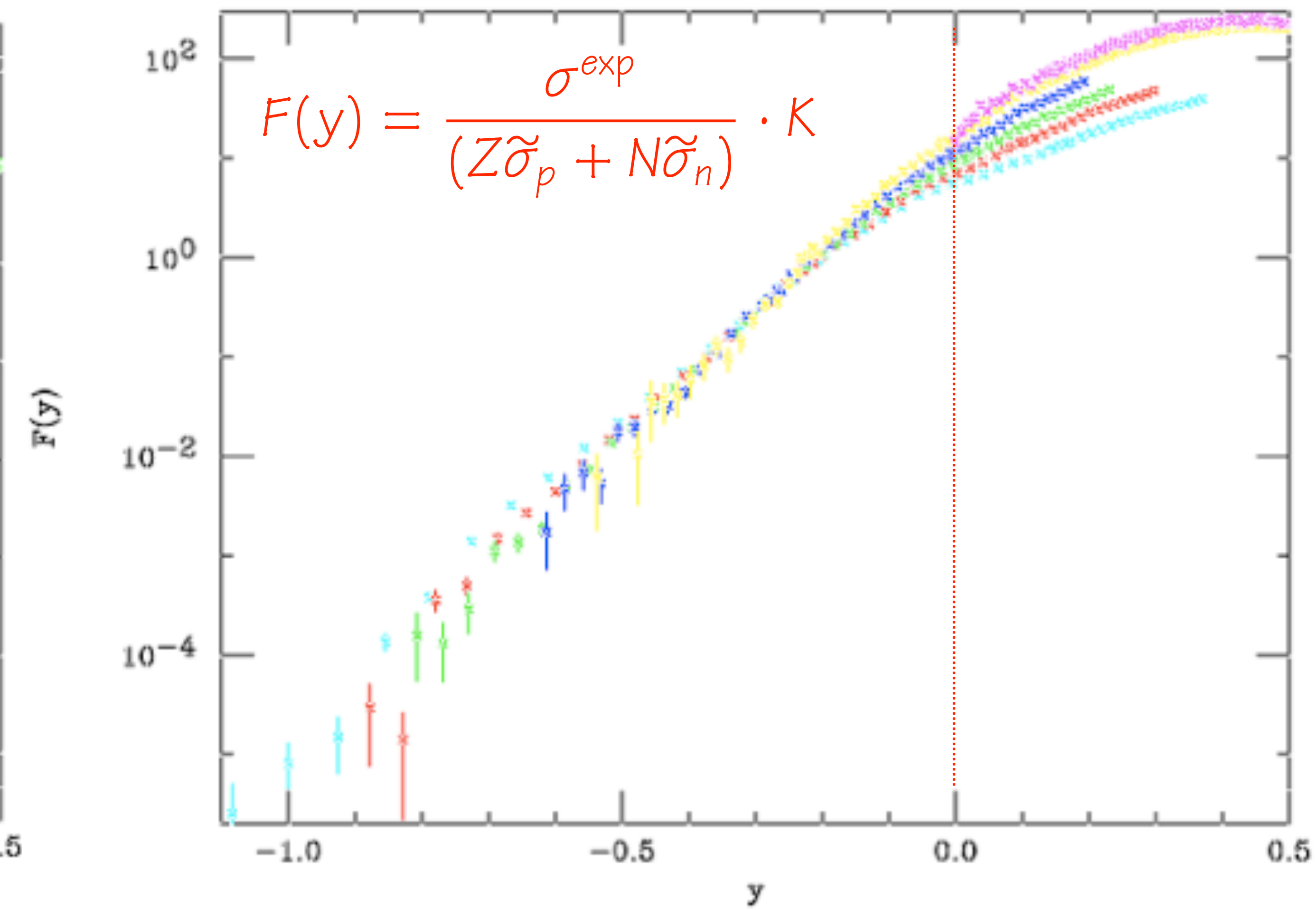
$$n(p) = -\frac{1}{2\pi y}\frac{dF(y)}{dy}$$

y is the momentum of the struck nucleon parallel to the momentum transfer: y ≈ -q/2 + mν/q

Convergence of F(y) at fixed y with Q^2



NE3 Au data from SLAC
Q^2_{max} = 2.2



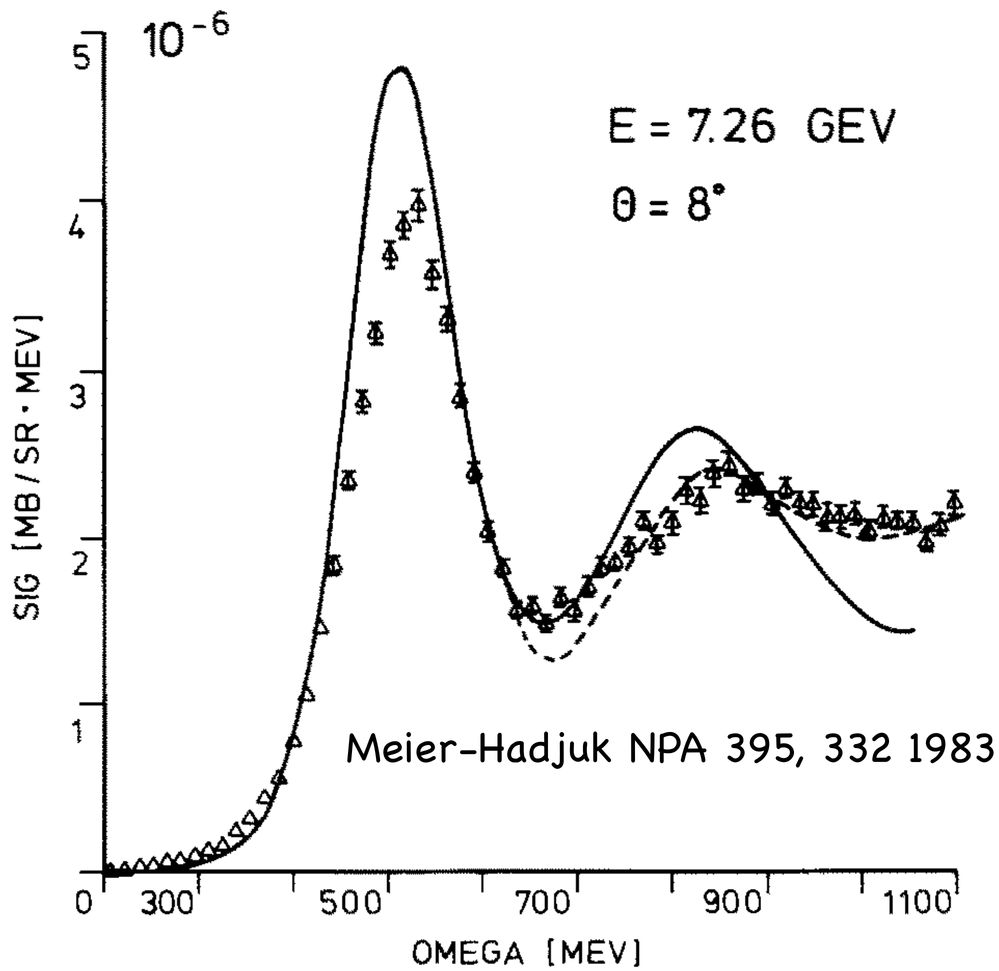
E02-019 Au data from JLAB
Q^2_{max} = 7.4

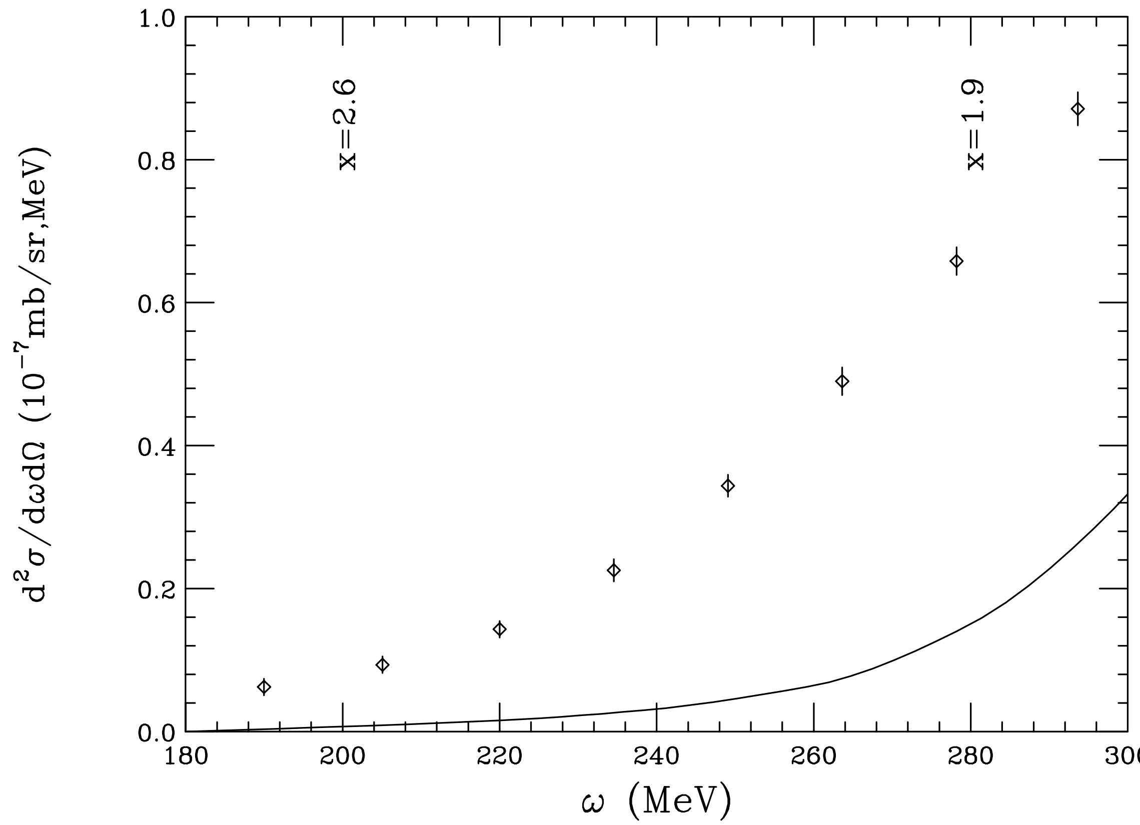
- PWIA would demand convergence from below- growing integration over S(k,E)
- Final State Interactions cause F(y,q) to converge from above with increasing q
- FSI in higher Q^2 data are diminished

What role FSI?

In (e,e′p) flux of outgoing protons strongly suppressed: 20-40% in C, 50-70% in Au

In (e,e′) the failure of IA calculations to explain dσ at small energy loss





Some of this could be resolved by a rearrangement of strength in SE

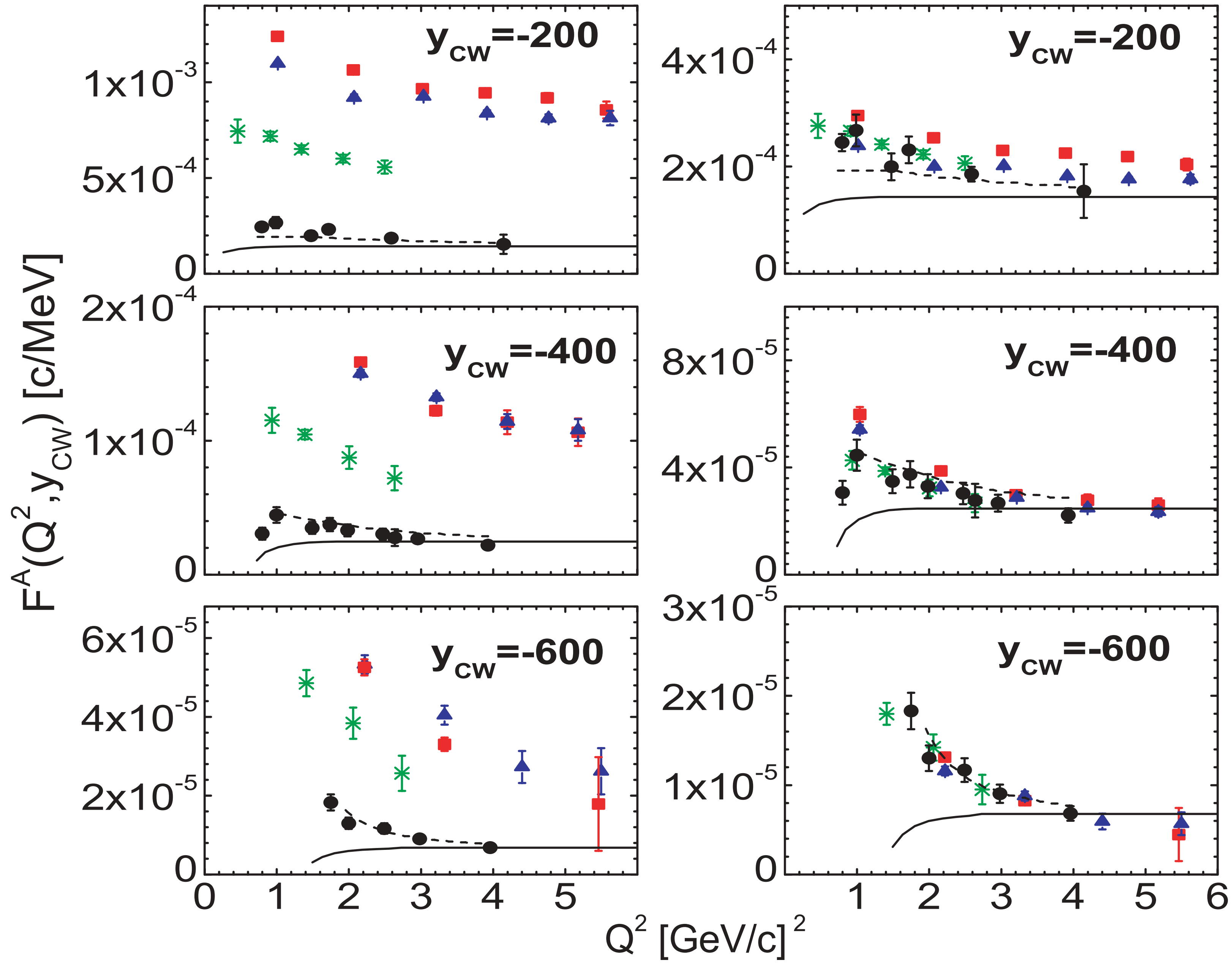
Old problem: real/complex optical potential. Real part generates a shift, imaginary part a folding of cs, reduction of qep.

Role of SRC on Lorentzian tail?? Off-shell effects on NN interaction??

Can they ever be neglected?

What role FSI?

- Large Violation of PWIA at low Q^2
  - scaling from above
- Once Q^2 gets large, we see little Q^2 dependence in the scaling

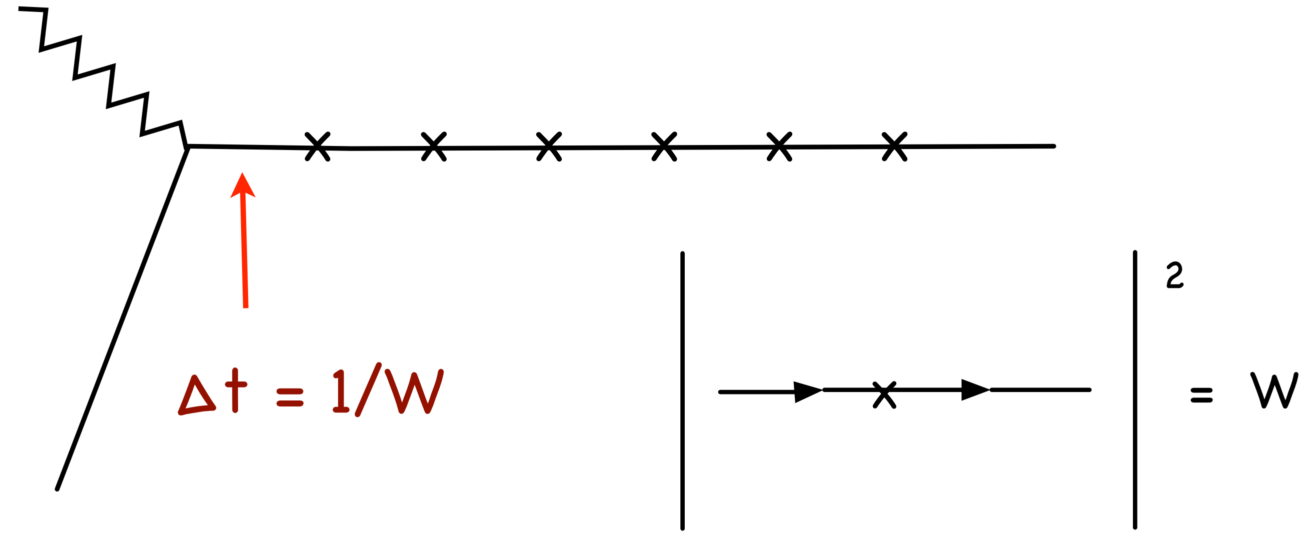


Studies show that FSI are small at large Q^2 and track the FSI in the deuteron

Ciofi-Mezzetti,PhysRevC.79.051302

FSI in Correlated Glauber

a) the struck nucleon moves along a straight line with a constant velocity (eikonal approximation), and



b) the spectator nucleons are seen by the fast struck particle as a collection of fixed scattering centers (frozen approximation)

V is small and the dominant part comes from the "damping" of the motion of the struck nucleon by the imaginary potential W

$$W^A_{\mu\nu}(q,\omega) = \int_0^\infty d\omega' F(\omega-\omega') W^A_{\mu\nu,IA}(q,\omega'-V(q))$$

folding function

$$F(\omega-\omega') = \frac{1}{\pi}\Re\int_0^\infty dt\; e^{i(\omega-\omega')t}\, e^{-W(q,t)t}$$

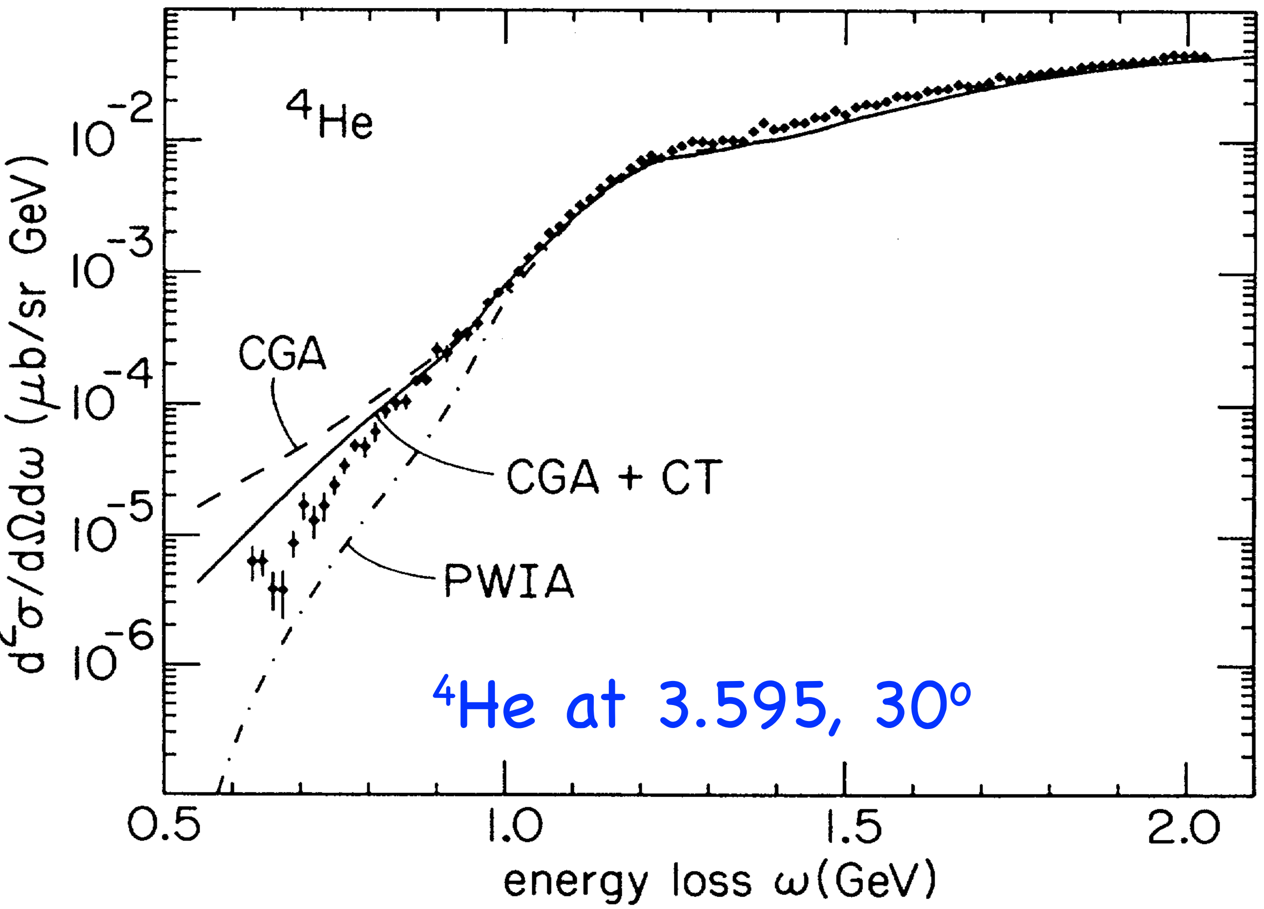
If W = 0 then F(ω - ω') becomes δ function and $W_{\mu\nu}{}^A \Rightarrow W_{\mu\nu,IA}{}^A$

Imaginary part of optical potential

$$W(p') = \frac{\hbar}{2}\rho v(p')\sigma_{NN}(p')$$

density

Benhar et al.



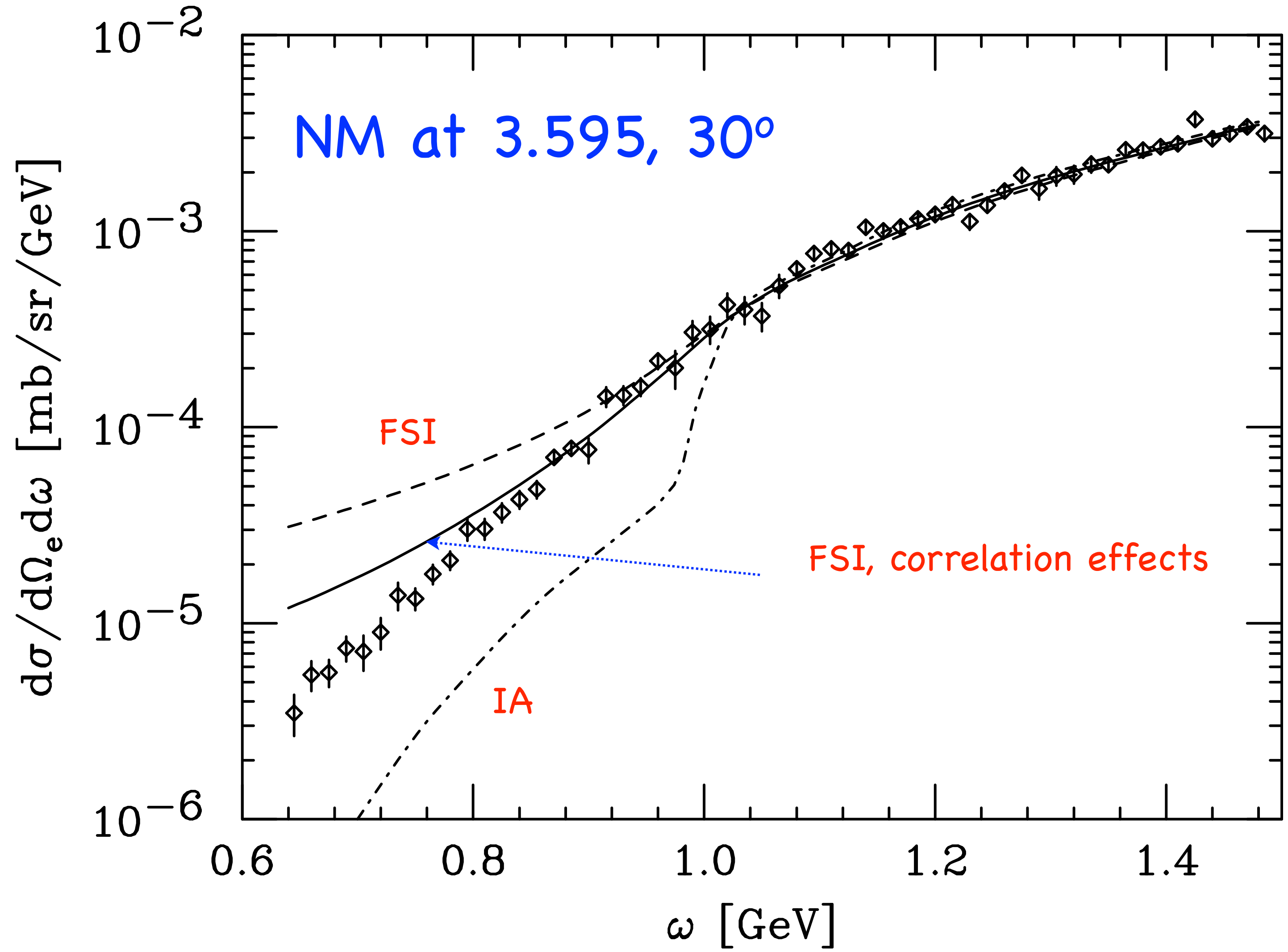
Final State Interactions in CGA

FSI has two effects: energy shift and a redistribution of strength from QEP to the tails, just where correlation effects contribute.

Benhar et al. PRC 44, 2328

Benhar, Pandharipande, PRC 47, 2218

Benhar et al. PLB 3443, 47



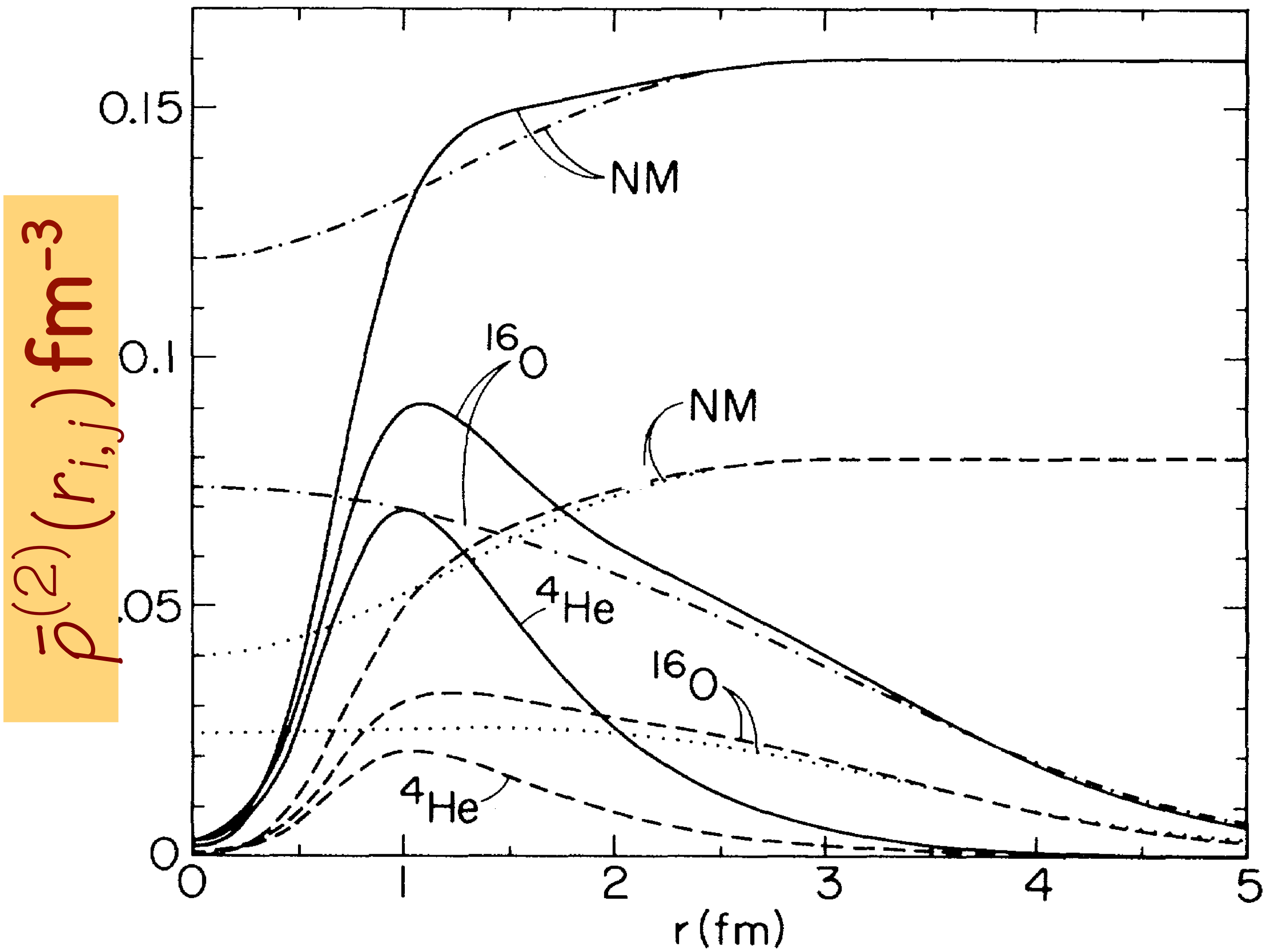
CGA over estimates the FSI

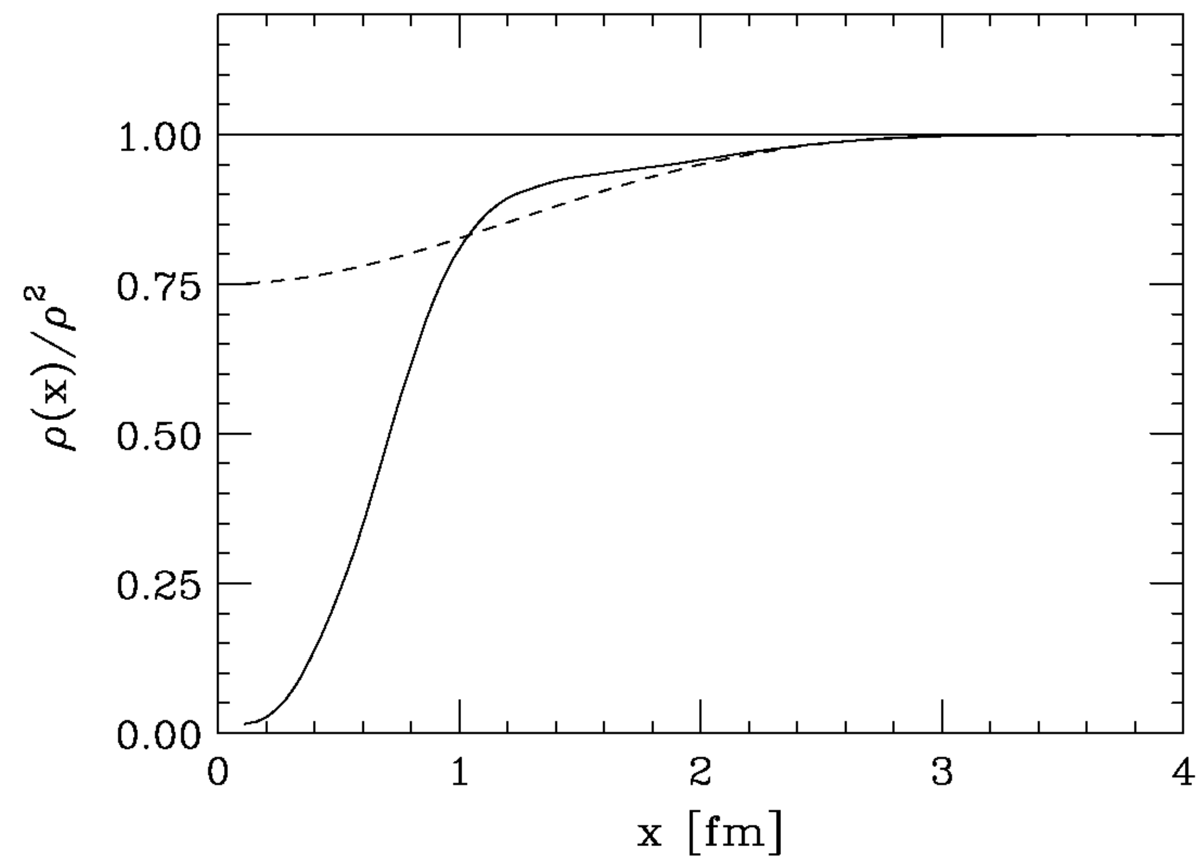
Modifications of the free space NN scattering amplitude in the medium?

Rescattering depends on joint probability of finding the struck particle at position r_i and a spectator at position r_j

Two-body density not uniformly distributed at $r_i = r_j$ - nucleons are surrounded by a hole because of correlations

$$\rho^{(2)}(r_i, r_j) = \rho_A(r_i)\rho_A(r_j)g(r_i, r_j)$$





$$\bar{\rho}^{(2)}(r_{i,j}) = \frac{1}{A}\int d^3R_{ij}\rho^{(2)}(r_i, r_j)$$

SRC suppress FSI

If density is 0, the motion is undamped

Sensitivity to g(r)

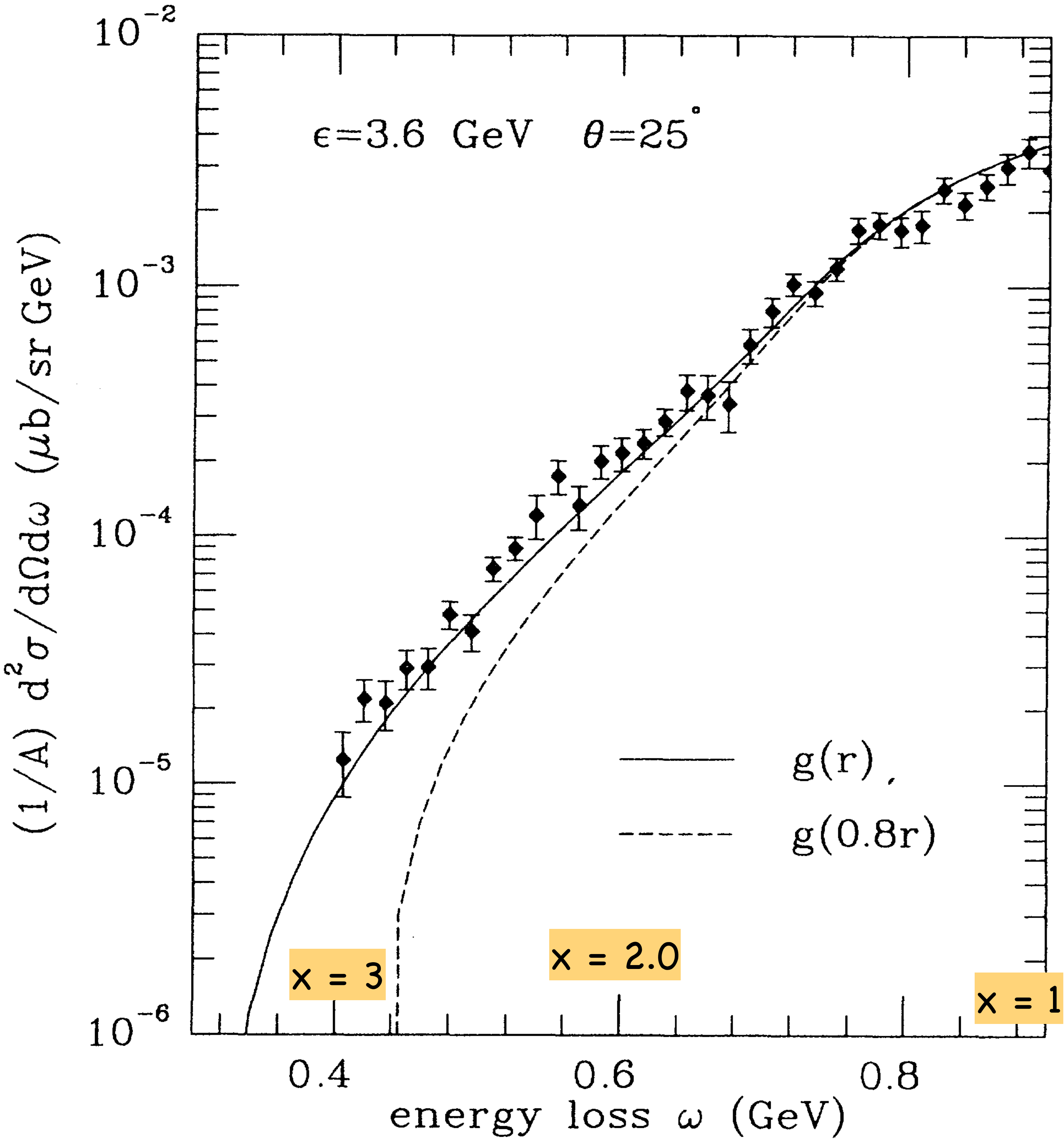


FIG. 13. Sensitivity of the inclusive cross section to the *N*-*N* pair distribution function at $\epsilon=3.6$ GeV and $\theta=25°$.

Q^2 modest by comparison to new data

Ratios, to come, are between x = 1.5 and 2.

Issues about CGA FSI

- Extreme sensitivity to hole size
- On-shell cross sections: nucleon is off-shell by in E by $\hbar/\Delta t = \hbar W$, modification of NN interaction
- total cross section?
- Unitarity?   Folding function is normalized to one.
- Role of momentum dependent folding function (Petraki et al, PRC 67 014605, 2003) has lead to a quenching of the tails.
  - Comparison to data with this new model for a range of A and Q^2 be very useful

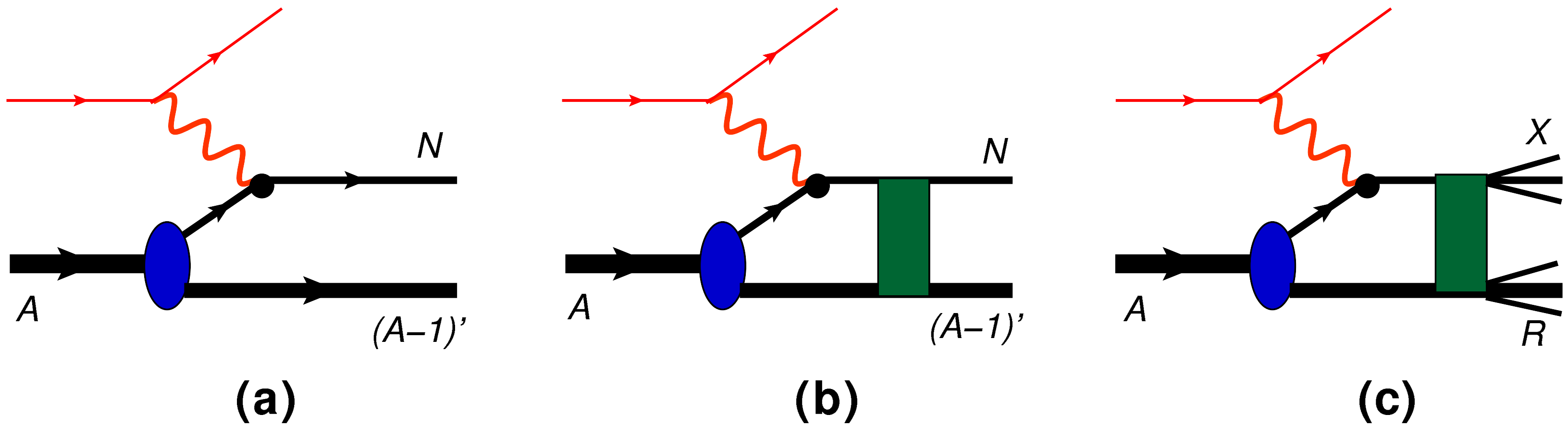
"The discrepancy with the measured cross sections increases as q increases, while the suppression of FSI's due to the momentum dependence of the folding function appears to be larger at lower momentum transfer.

A different mechanism, leading to a quenching of FSI's and exhibiting the opposite momentum-transfer dependence still seems to be needed to reconcile theory and data."

Petraki et al, PRC 67 014605

Why might a 'different mechanism' be necessary. Why are the cross sections too large?

Arrington, Higinbotham, Rosner and Sargsian, arXiv:1104.1196v3[nucl-ex]



Calculation of (c) is nearly impossible - too many channels are involved

When eikonal theorem valid FSI can be expressed as a series of diffractive elastic and inelastic rescatterings

Apply optical theorem

$$Im\,[f^{el}_{NN}(t=0)] = \sigma^{total}$$

AGK Cutting rules, Bertocchi and Treleani

Inclusive hadron-nucleus scattering

Using only elastic rescattering amplitudes (Glauber theory) violates unitarity, restored by including inelastic rescatterings. There are cancelations between the amplitudes

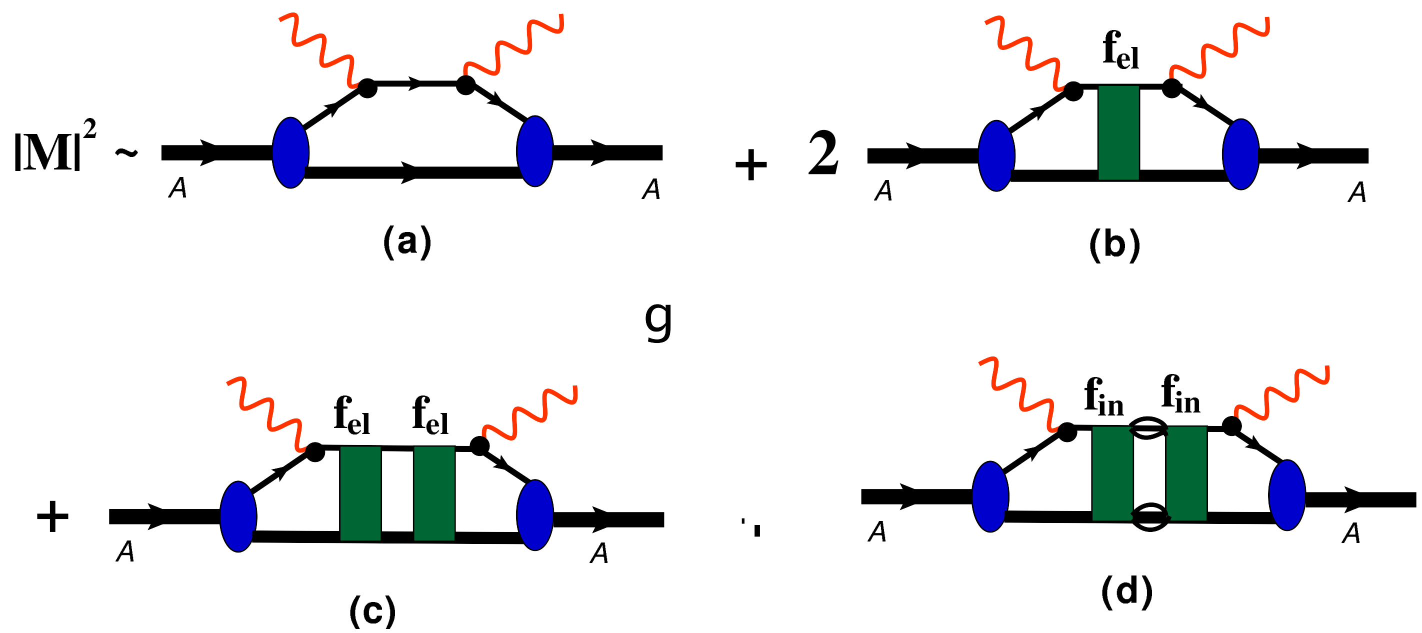
Abramovsky-Kanchelly-Gribov

Why might a ‘different mechanism’ be necessary. Why are the cross sections too large?

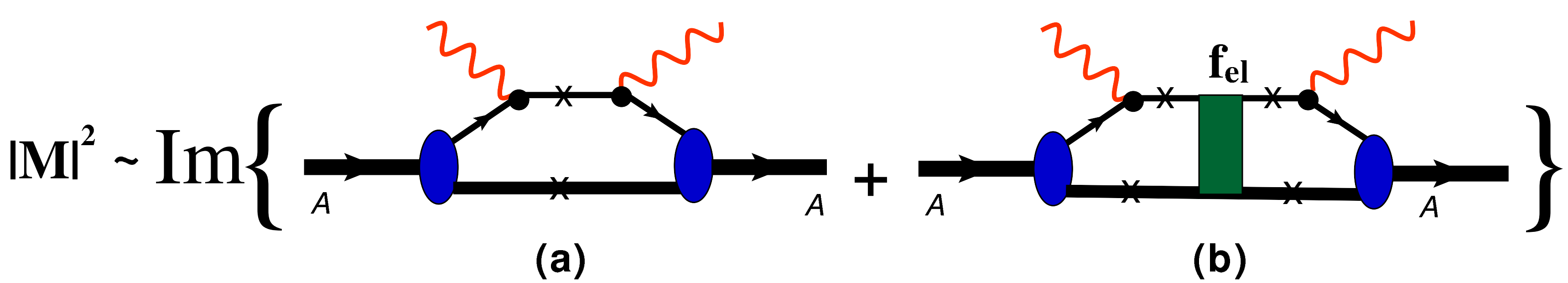
Arrington, Higinbotham, Rosner and Sargsian, arXiv:1104.1196v3[nucl-ex]

AGK Cutting rules, Bertocchi and Treleani

Using only elastic rescattering amplitudes (Glauber theory) violates unitarity, restored by including inelastic rescatterings. There are cancelations between the amplitudes



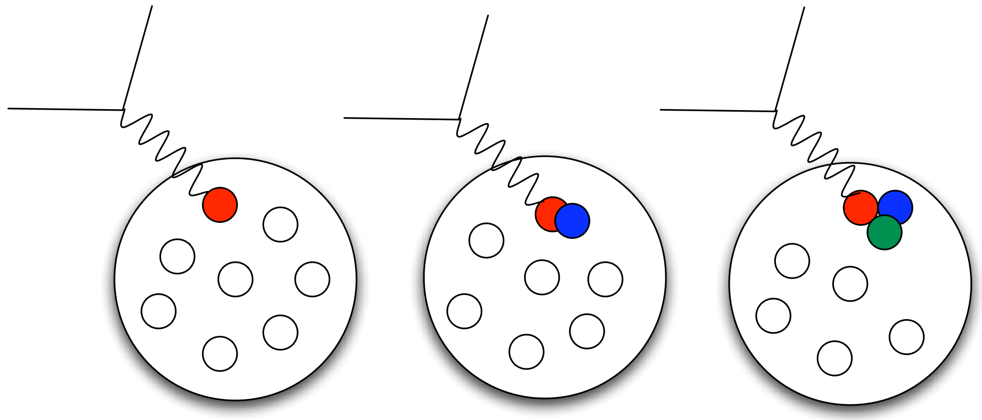
Sum of (c) elastic and (d) inelastic cancels half of interference term (b)



Quantitative results are promised

CS Ratios and SRC

In the region where correlations should dominate, large x,



$$\sigma(x,Q^2) = \sum_{j=1}^{A} A\frac{1}{j}a_j(A)\sigma_j(x,Q^2)$$
$$= \frac{A}{2}a_2(A)\sigma_2(x,Q^2) + \frac{A}{3}a_3(A)\sigma_3(x,Q^2) + \vdots$$

$a_j(A)$ are proportional to finding a nucleon in a j-nucleon correlation. It should fall rapidly with j as nuclei are dilute.

$$\sigma_2(x,Q^2) = \sigma_{eD}(x,Q^2) \text{ and } \sigma_j(x,Q^2) = 0 \text{ for } x > j.$$

$$\Rightarrow \quad \frac{2}{A}\frac{\sigma_A(x,Q^2)}{\sigma_D(x,Q^2)} = a_2(A)\Big|_{1<x\leq 2}$$

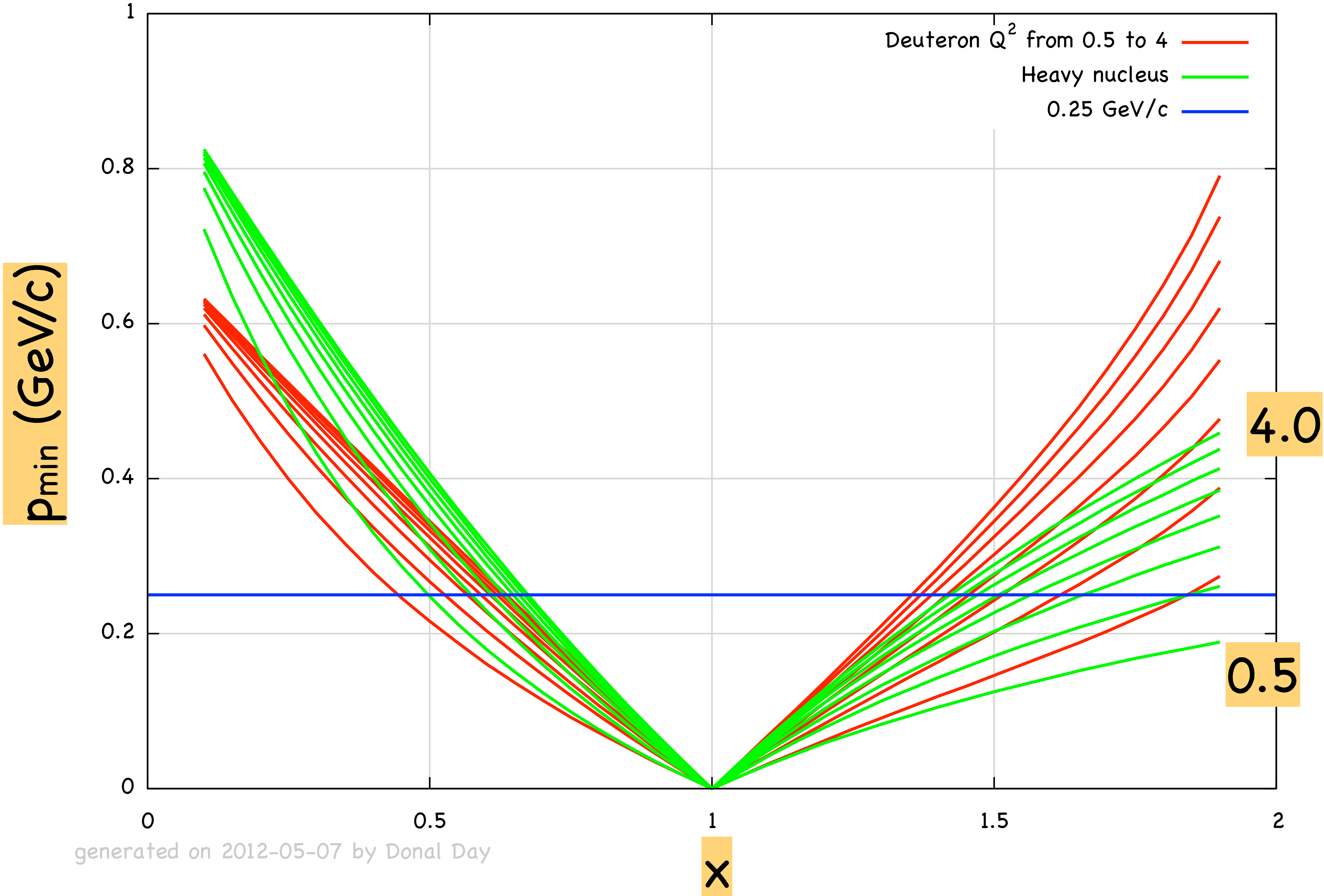
$$\frac{3}{A}\frac{\sigma_A(x,Q^2)}{\sigma_{A=3}(x,Q^2)} = a_3(A)\Big|_{2<x\leq 3}$$

Assumption is that in the ratios, off-shell effects and FSI largely cancel.

$a_j(A)$ is proportional to probability of finding a j-nucleon correlation

F&S

Selection by kinematics



Appearance of plateaus is A dependent.

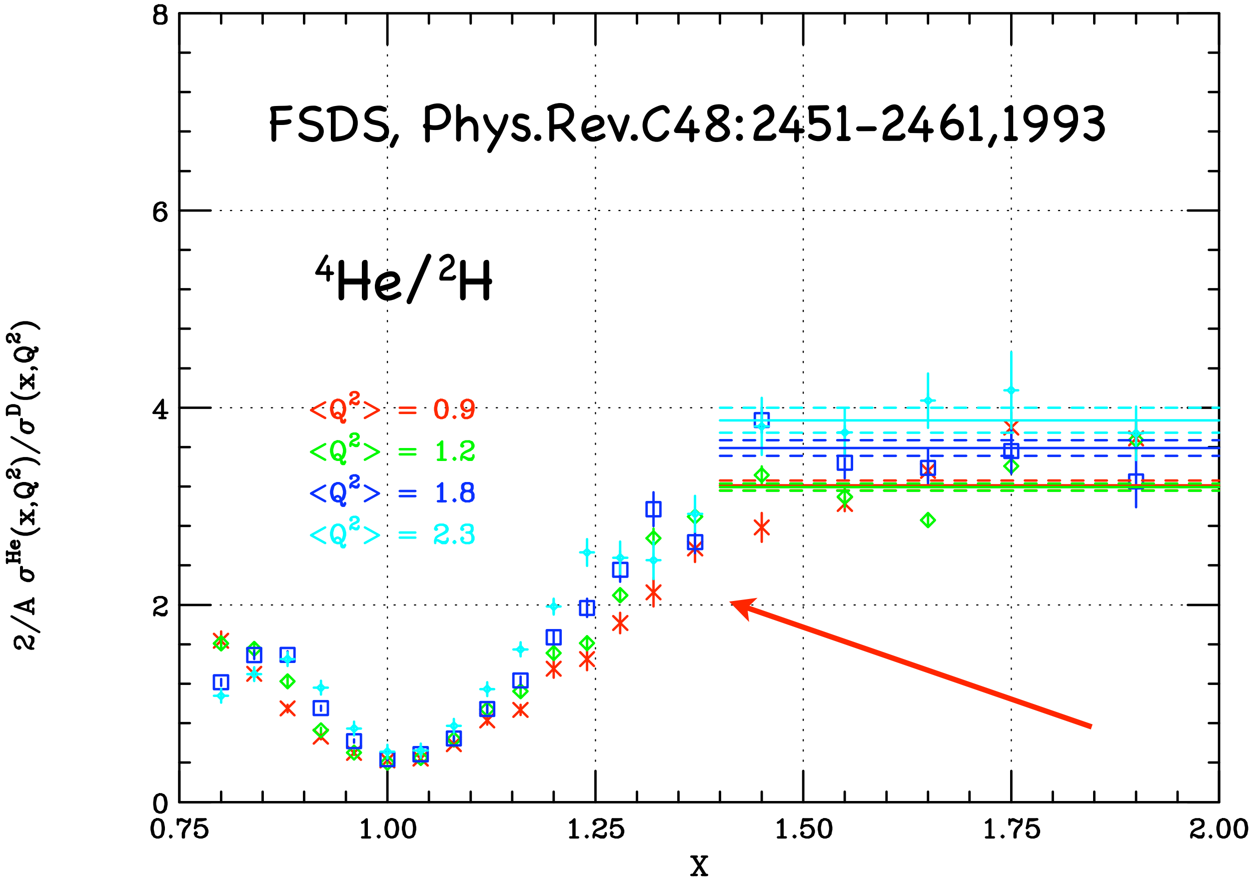
Kinematics: heavier recoil systems do not require as much energy to balance momentum of struck nucleon - hence p_{min} for a given x and Q^2 is smaller.

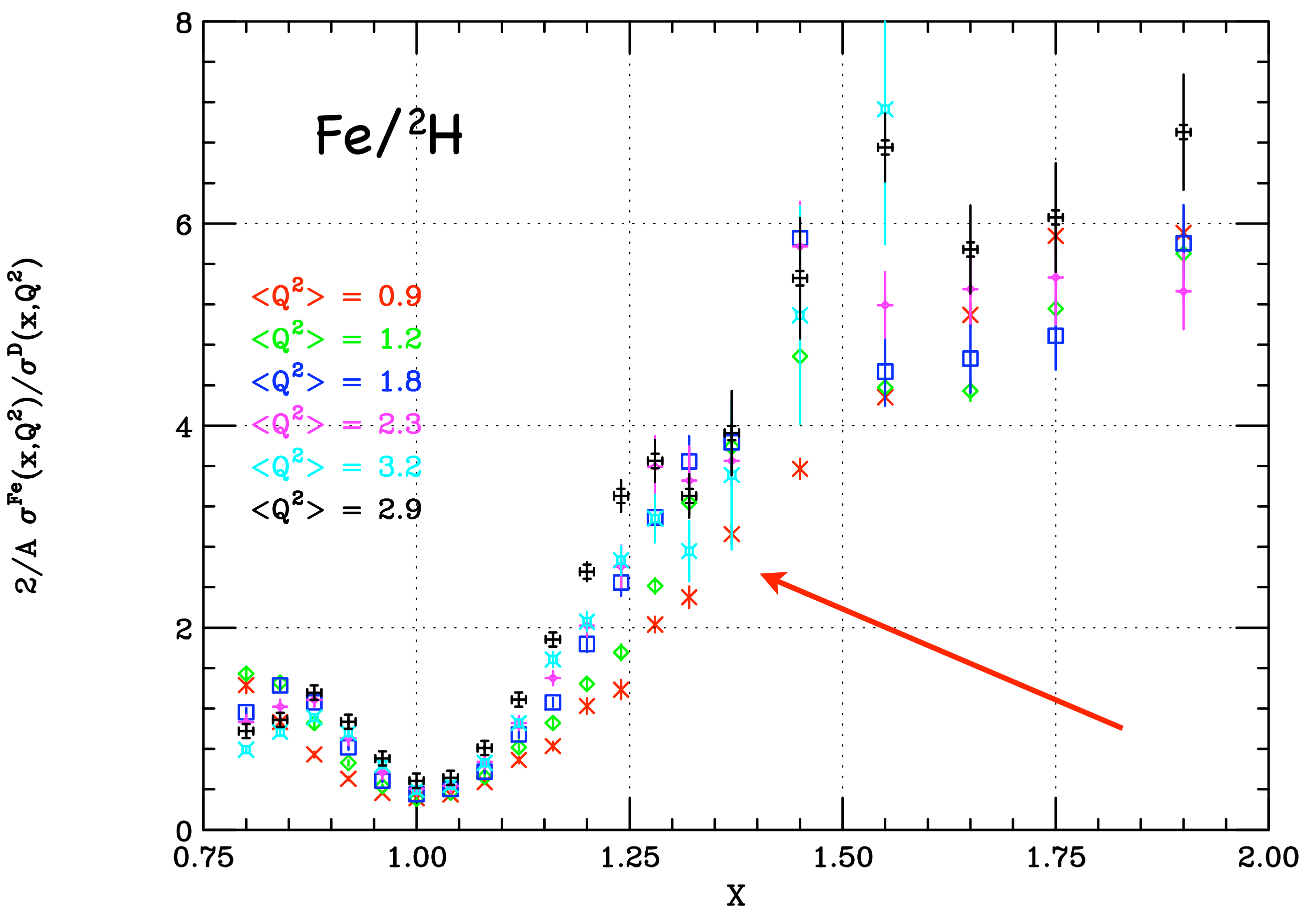
Dynamics: mean field part in heavy nuclei persist in x to larger values

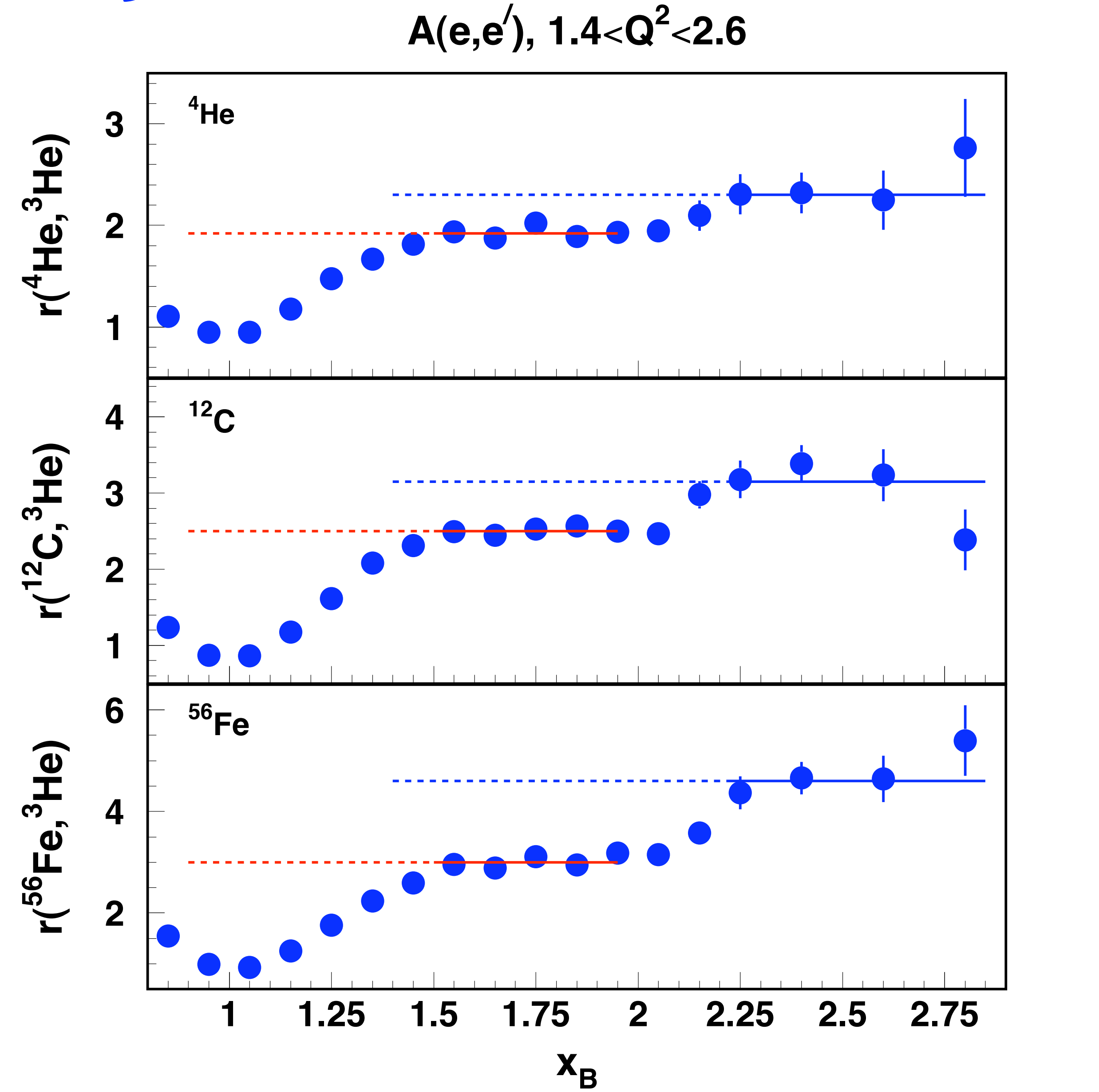
Have to go to higher x or Q^2 to insure scattering is not from mean-field nucleon

Ratios, SRC's and Q^2 scaling

$$\frac{2}{A}\frac{\sigma_A}{\sigma_D} = a_2(A);\ \ (1.4 < x < 2.0)$$







$\alpha_{2N} \approx 20\%$

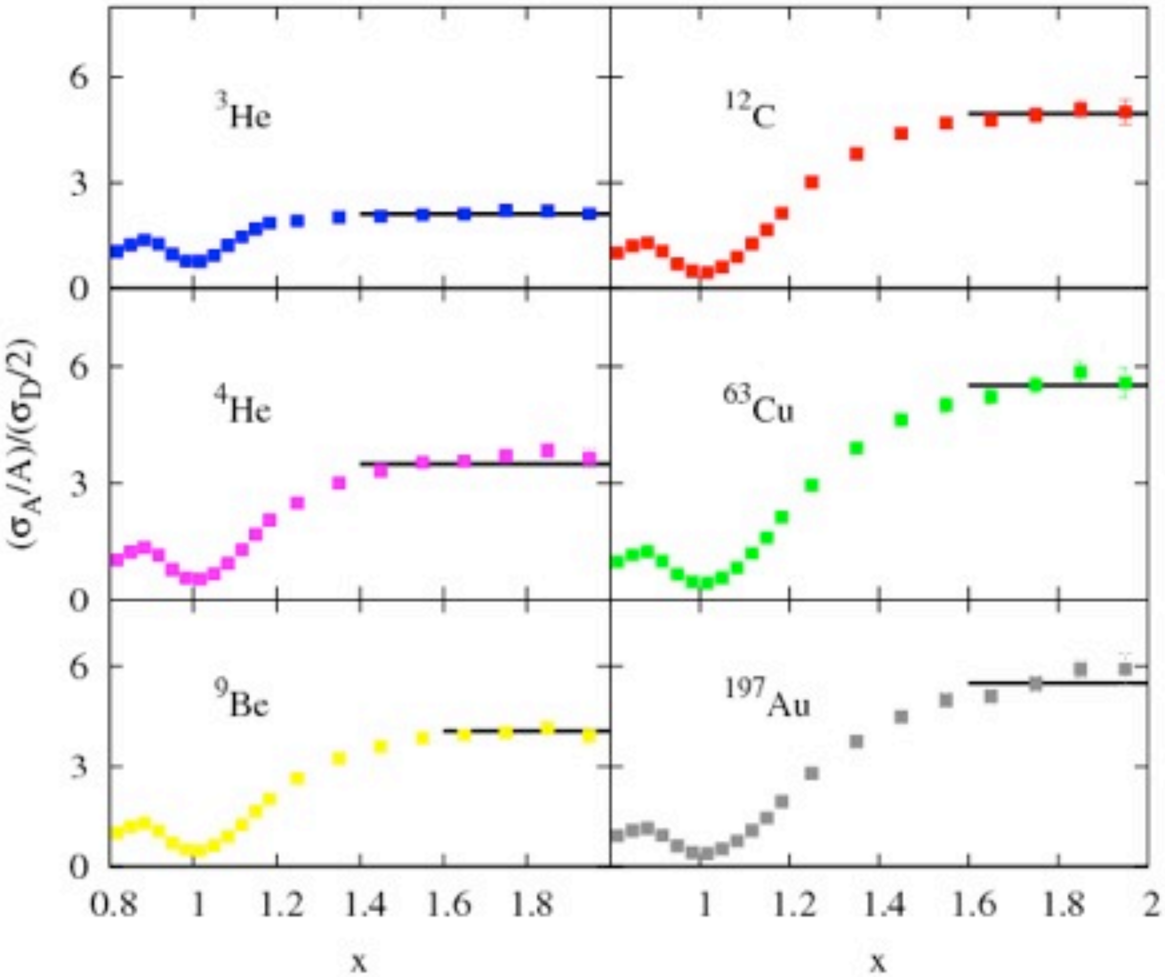
$\alpha_{3N} \approx 1\%$

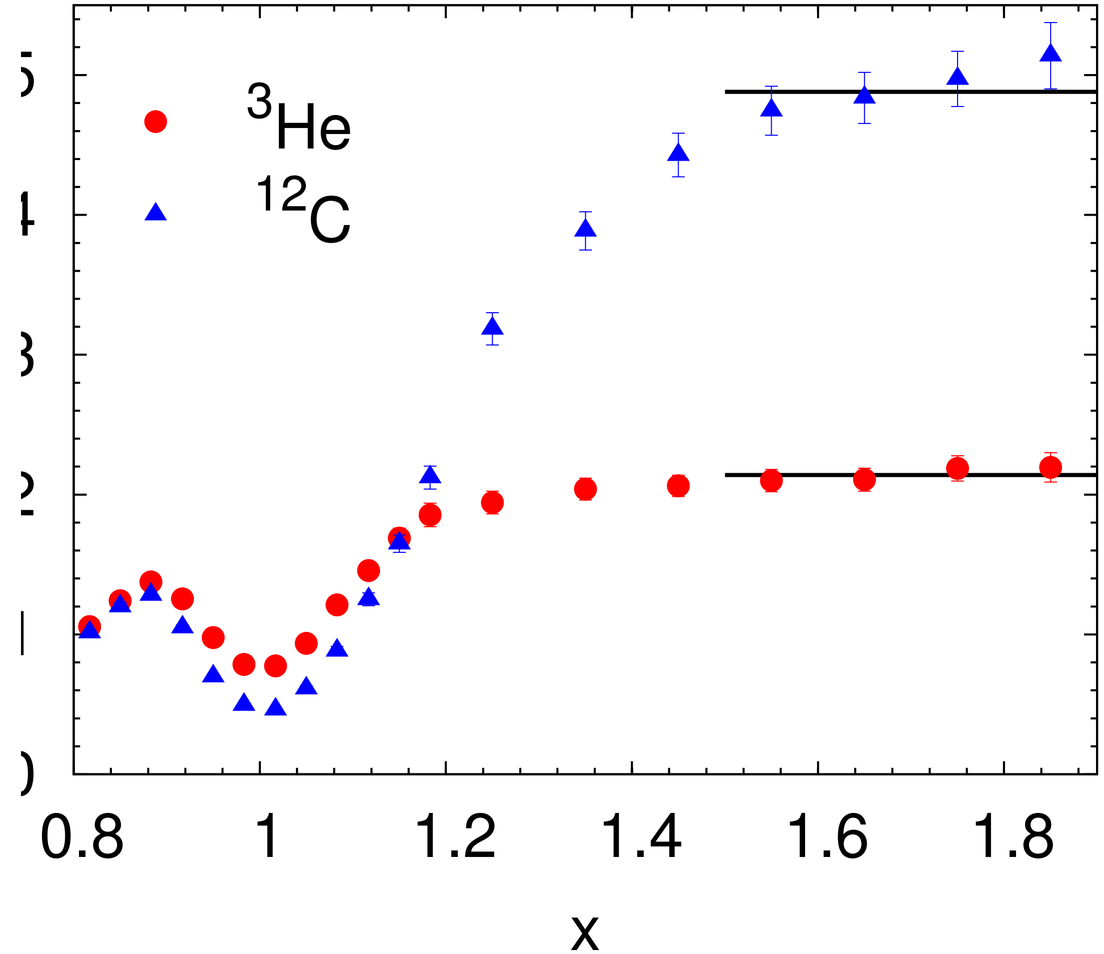
CLAS data

Egiyan et al., PRL 96, 082501, 2006

$a_j(A)$ is probability of finding a j-nucleon correlation

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





A	$\theta_e = 18°$	$\theta_e = 22°$	$\theta_e = 26°$	Inel. sub.
^{3}He	2.14 ± 0.04	2.28 ± 0.06	2.33 ± 0.10	2.13 ± 0.04
^{4}He	3.66 ± 0.07	3.94 ± 0.09	3.89 ± 0.13	3.60 ± 0.10
Be	4.00 ± 0.08	4.21 ± 0.09	4.28 ± 0.14	3.91 ± 0.12
C	4.88 ± 0.10	5.28 ± 0.12	5.14 ± 0.17	4.75 ± 0.16
Cu	5.37 ± 0.11	5.79 ± 0.13	5.71 ± 0.19	5.21 ± 0.20
Au	5.34 ± 0.11	5.70 ± 0.14	5.76 ± 0.20	5.16 ± 0.22
$\langle Q^2 \rangle$	2.7 GeV^2	3.8 GeV^2	4.8 GeV^2	
$x_{\min}$	1.5	1.45	1.4	

Ratio of per nucleon cross sections is NOT ratio of nucleons in a SRC

Convolution of CM motion with ${}^2H$ n(k)

$$n(k) = \int \frac{d^3k'}{(2\pi)^3} n_1(|\vec{k} - \vec{k'}|) n_2(k')$$

if one is a gaussian

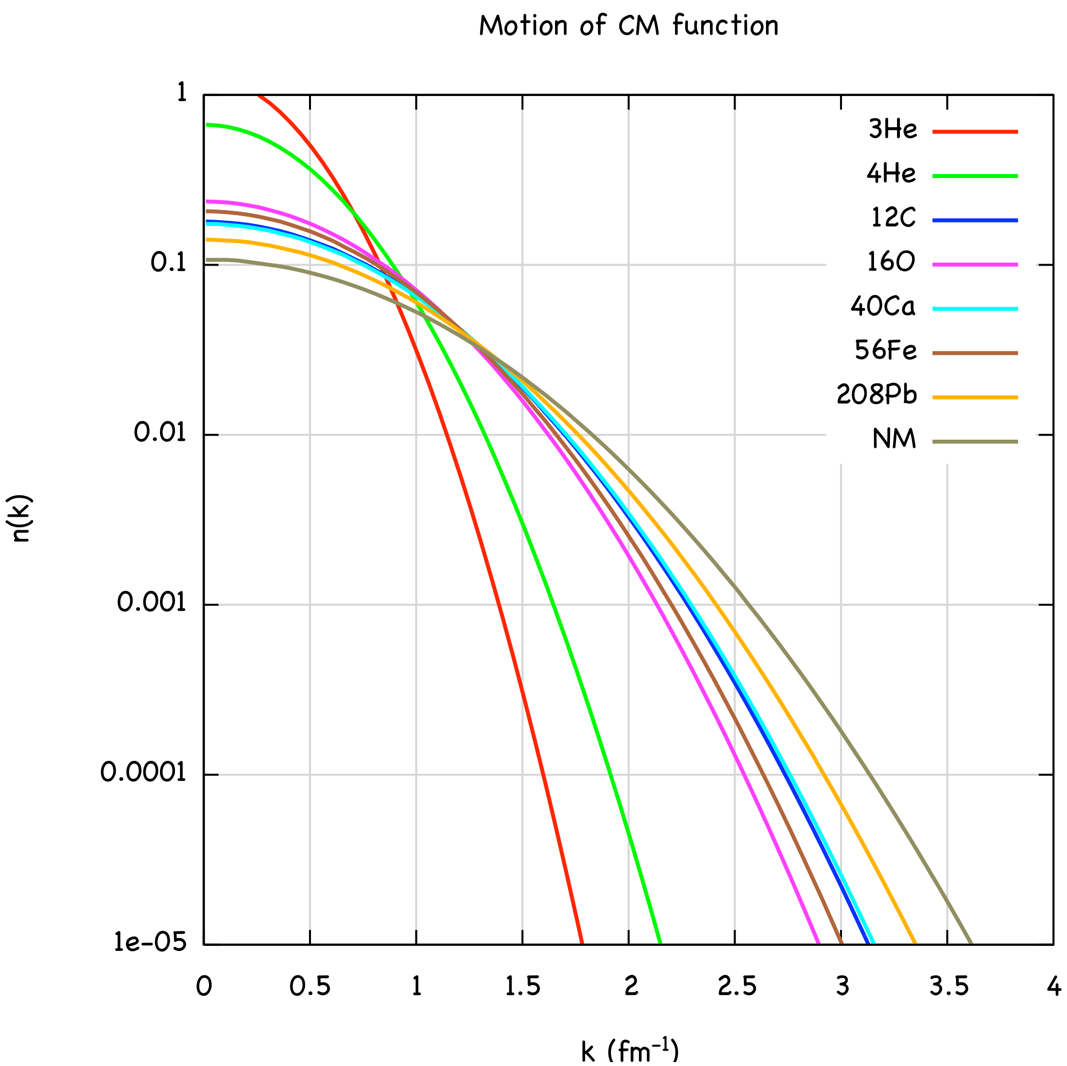
$$n_1(k) = (4\pi a^2)^{3/2} e^{-a^2k^2}$$

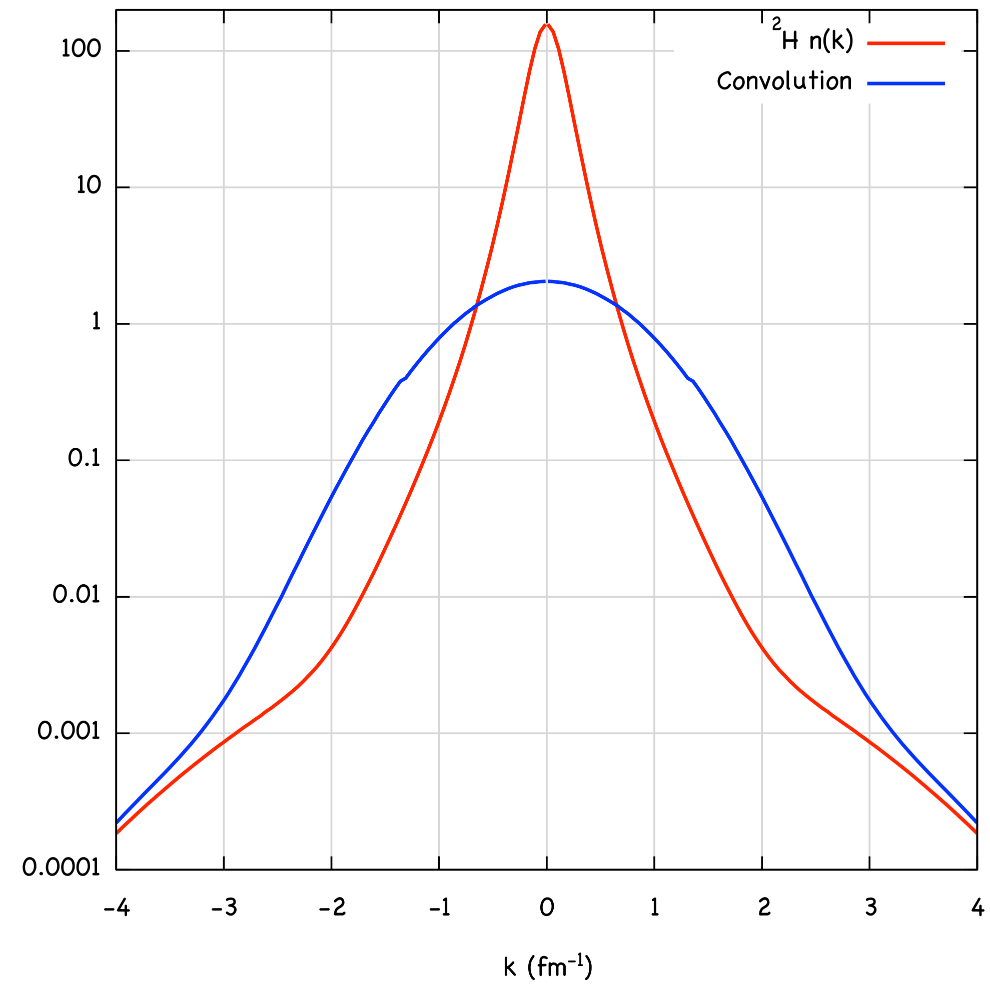
$$n(k) = \frac{2a}{\sqrt{\pi}} \frac{e^{-a^2k^2}}{k} \int_0^\infty dk'k'e^{-a^2k'^2} \sinh(2a^2kk')n_2(k')$$

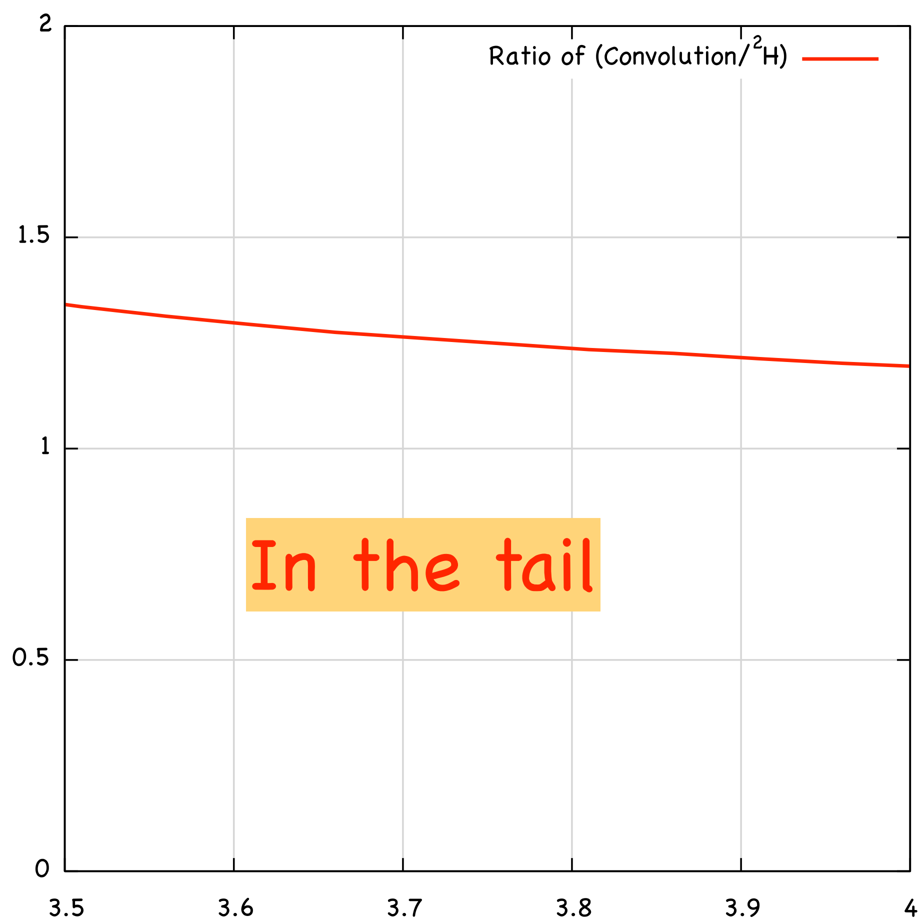
Using forms from Ciofi/Simula PRC 53 (1689)

$$n_{CM}^{eff}(k_{CM}) = \left(\frac{a_{CM}}{\pi}\right)^{3/2} e^{-a_{CM}k_{CM}^2}$$

$$n_0(k) = \sum_{i=1}^{m_0} A_i^0 \frac{e^{-B_i^{(0)}k^2}}{(1 + C_i^{(0)}k^2)^2}$$



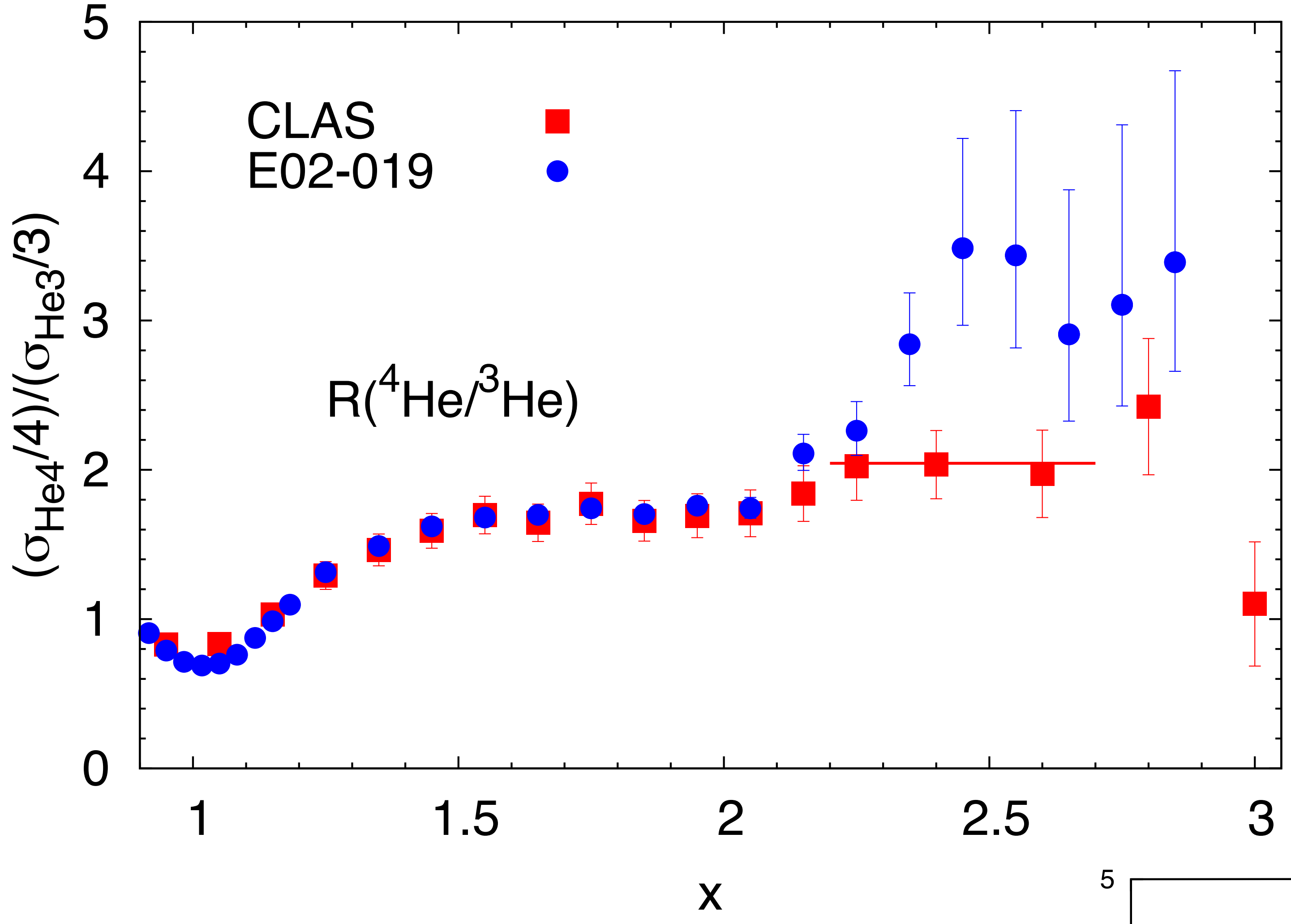




$$\text{Ratio} = \frac{\text{Convolution}}{n^D(k)} \approx 1.2$$

Ratio of nucleon in an (np) pair, COM and no isoscalar correction

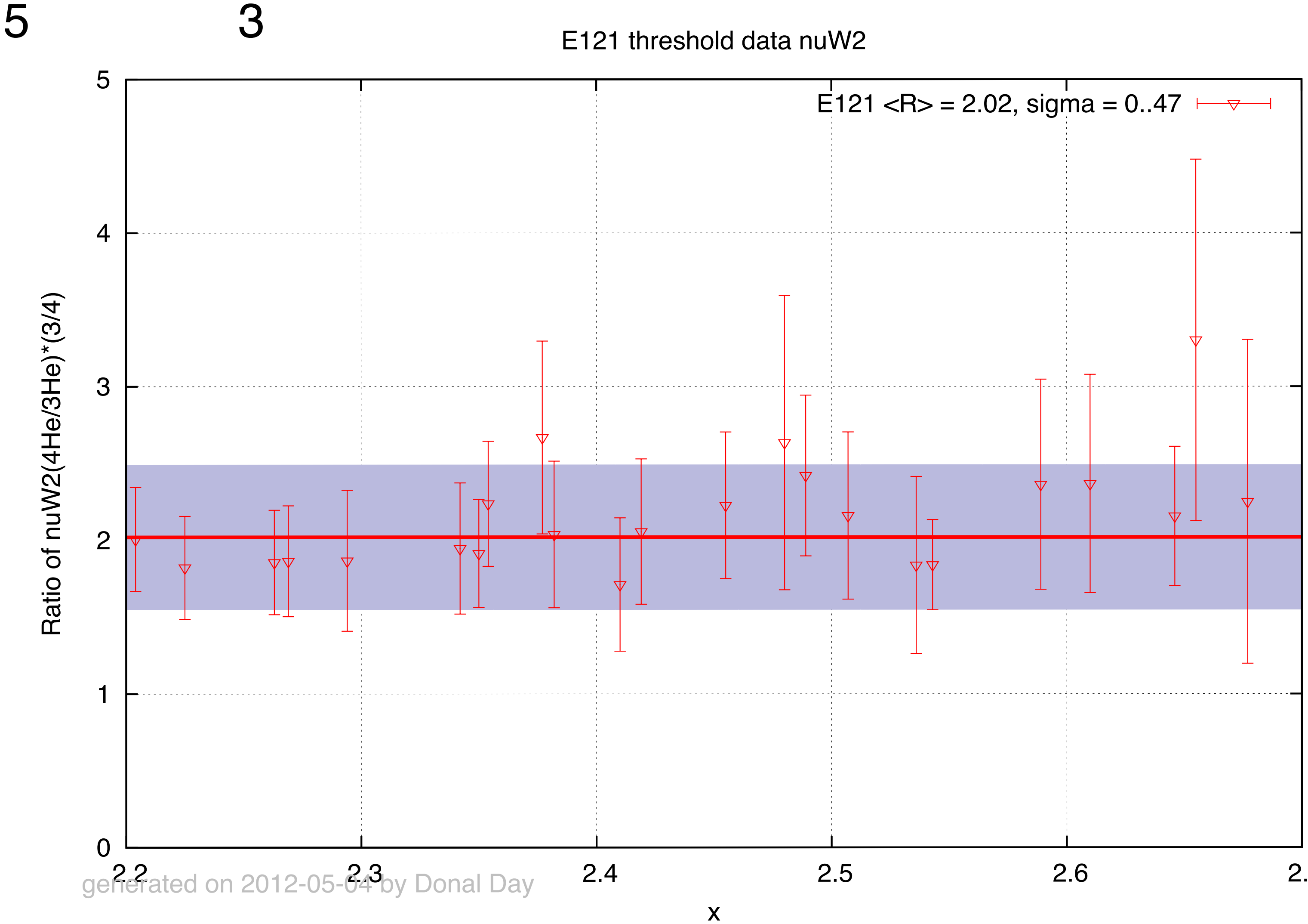
A	R_{2N} (E02-019)	SLAC	CLAS	F_{CM}		Ciofi/Simula
^{3}He	1.93 ± 0.10	1.8 ± 0.3	$\cdots$	1.10 ± 0.05		1.9
^{4}He	3.02 ± 0.17	2.8 ± 0.4	2.80 ± 0.28	1.19 ± 0.06	*	3.8
Be	3.37 ± 0.17	$\cdots$	$\cdots$	1.16 ± 0.05		
C	4.00 ± 0.24	4.2 ± 0.5	3.50 ± 0.35	1.19 ± 0.06		4.0
Cu(Fe)	4.33 ± 0.28	(4.3 ± 0.8)	(3.90 ± 0.37)	1.20 ± 0.06		4.5
Au	4.26 ± 0.29	4.0 ± 0.6	$\cdots$	1.21 ± 0.06		4.8 (^{208}Pb)
$\langle Q^2 \rangle$	$\sim$2.7 GeV^2	$\sim$1.2 GeV^2	$\sim$2 GeV^2			
$x_{\min}$	1.5	$\cdots$	1.5			
$\alpha_{\min}$	1.275	1.25	1.22–1.26			



3N correlations

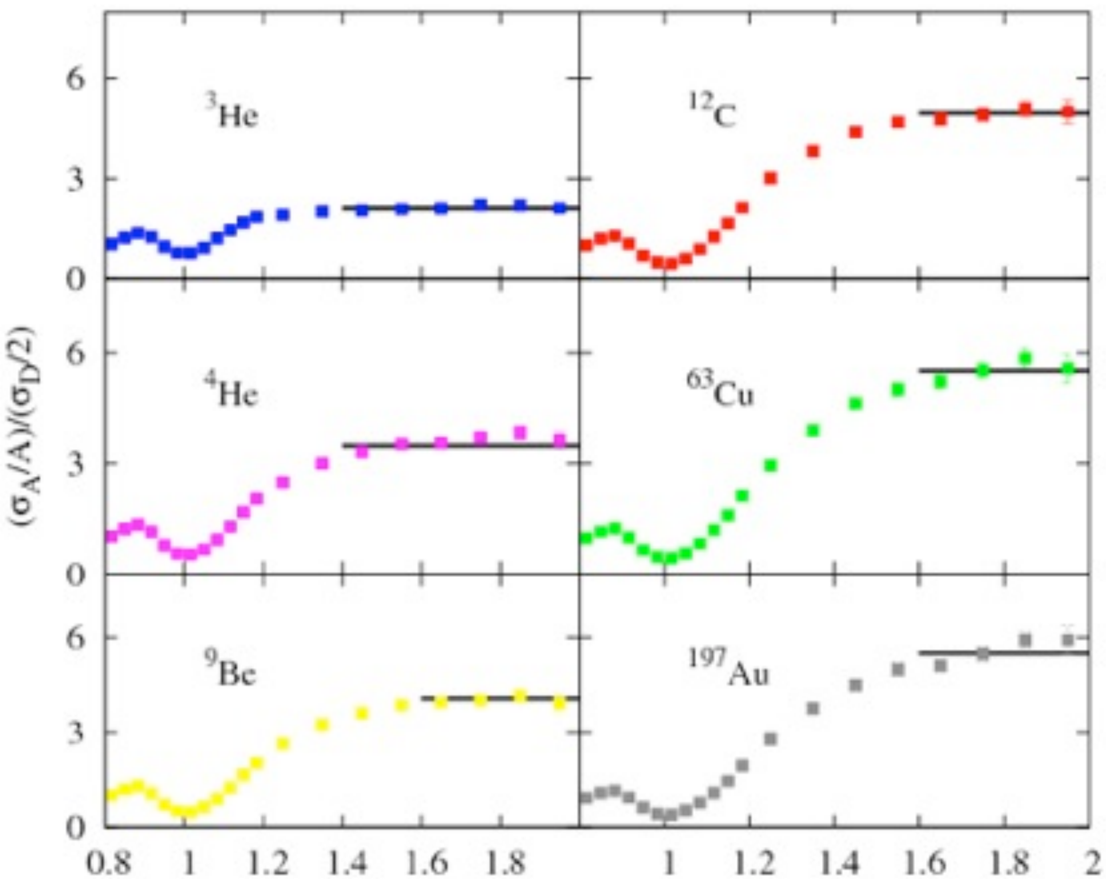
Large error bars prevent making conclusive statements about 3N correlations

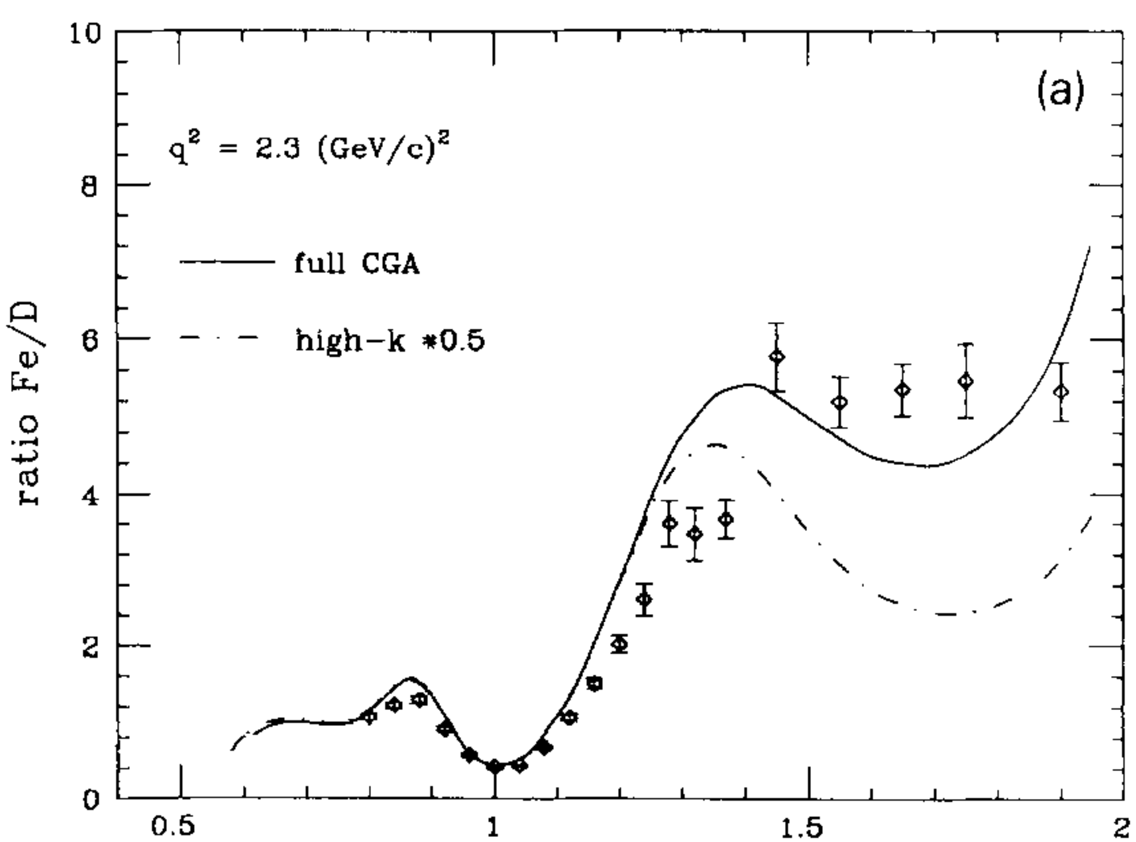
Not clear where the threshold for 3N correlations might be.



But data from SLAC's E121 suggests results closer to CLAS data

FSI and plateaus





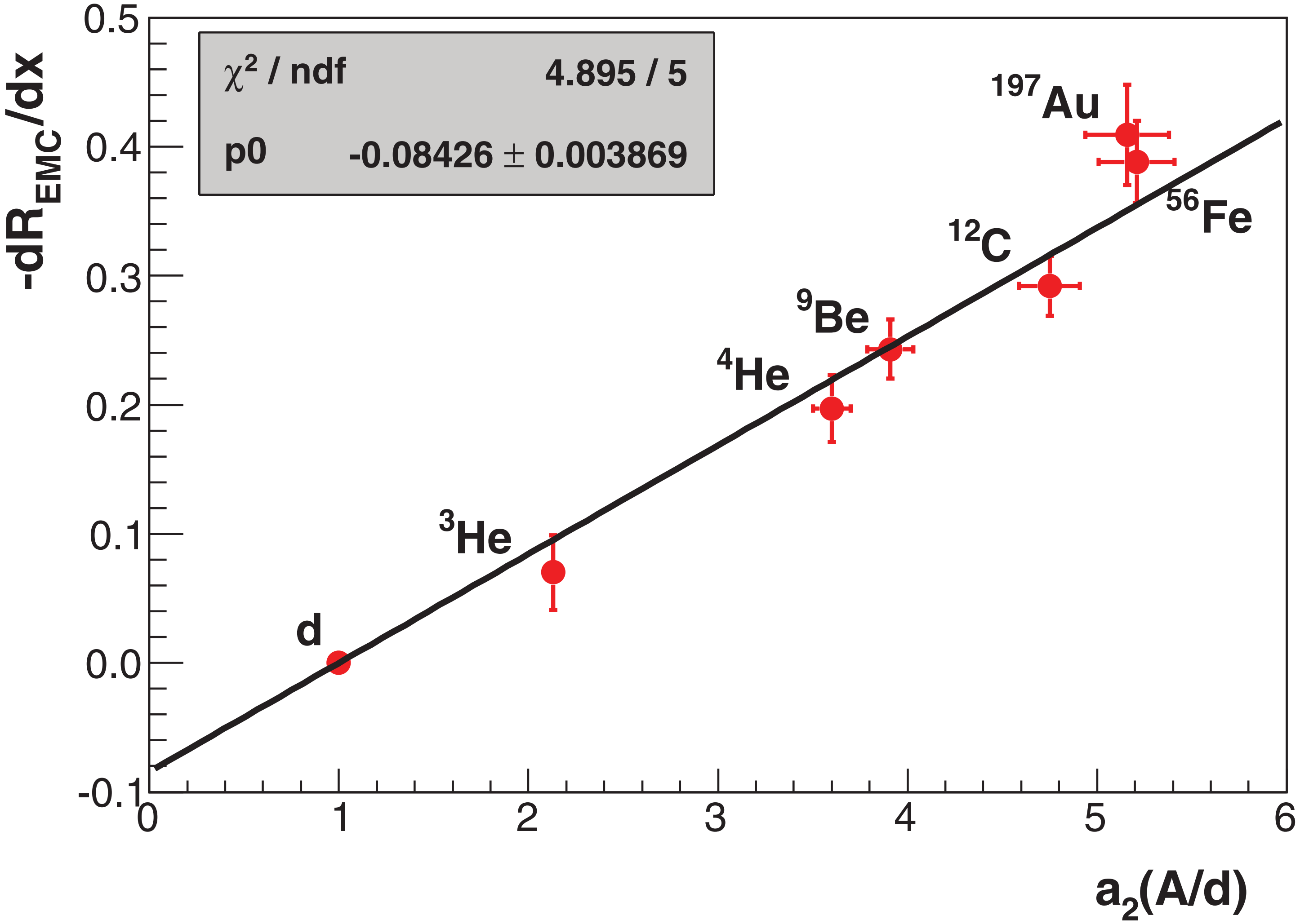
Emphatic arguments have been made that these ratio values are an artifact - can not be interpreted as the ratio of correlated in strength in heavy to light nuclei

The claim is that the plateaus, remarkable as they appear, are a result of FSI (and the role of SRC in FSI)

- If the nuclear medium affects via Initial State Interaction the correlated 2-nucleon system --- it does as the high-k tail is (say) 4 times higher in a nucleus than in the deuteron --- then the nuclear medium also increases the FSI by a comparable factor.
- Glauber-type calculations the FSI effects are explicitly proportional to the nuclear density.

It would be useful to have new calculations over a range of A and Q^2.

Short Range Correlations and the EMC Effect

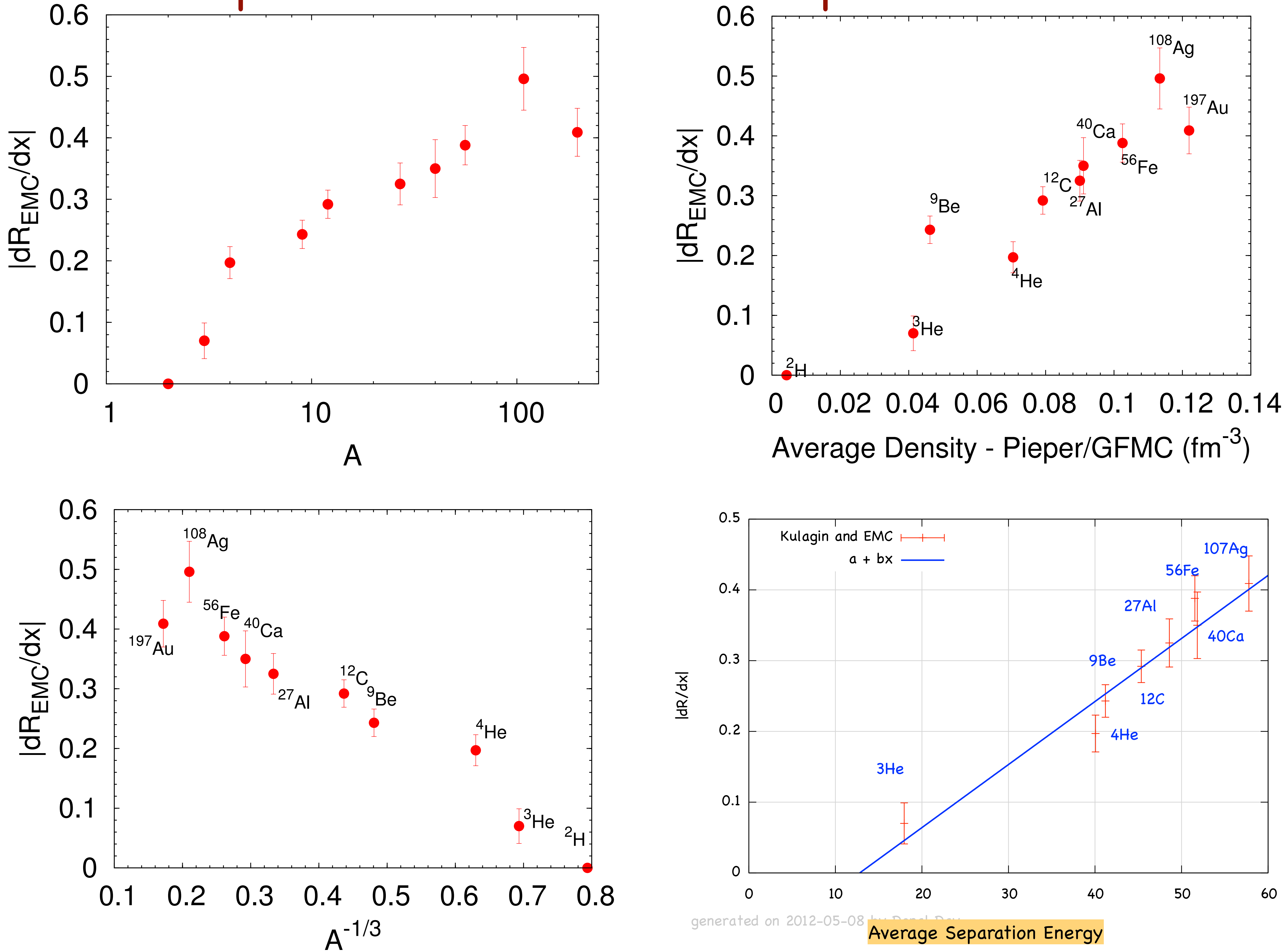


O. Hen, E. Piasetzky, and L. B. Weinstein
Phys. Rev. C 85, 047301 (2012)
L. B. Weinstein, E. Piasetzky, D. W. Higinbotham, J. Gomez, O. Hen, and R. Shneor
Phys. Rev. Lett. 106, 052301 (2011)
Arrington, Daniel, Day, Gaskell and Fomin, in preparation

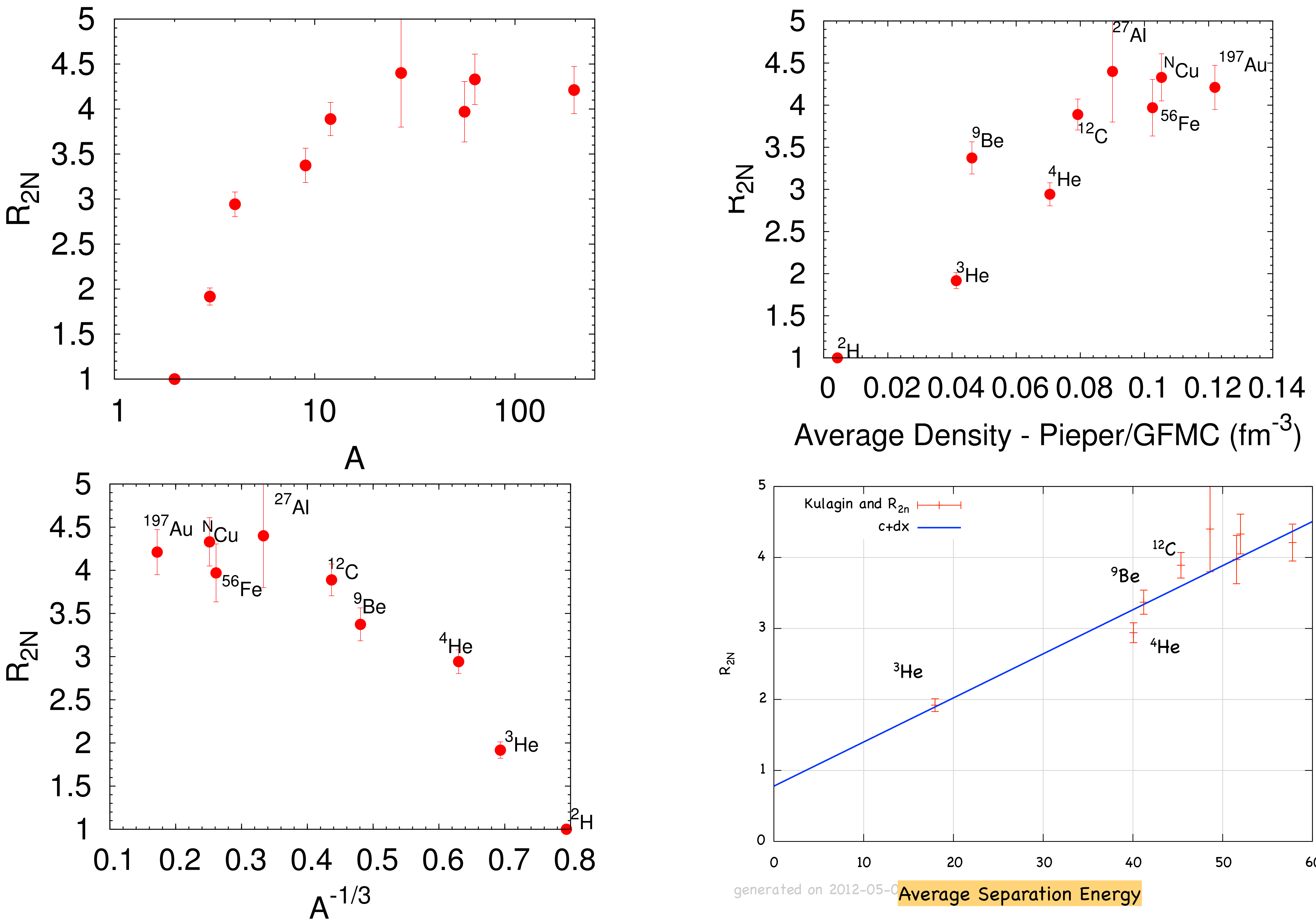
Are plateaus an artifact of complicated FSIs which coincidently relates the EMC to the SRC? Very unlikely.

Given the fact that the inclusive data integrate over very different parts of the spectral function this probably deserves more study.

Slope of EMC versus various parameters



R_{2N} versus various parameters



What is an experimentalist to do?

- Measure ratios to ^2H, ^3He, ^4He out to large x and over wide range of Q^2
  - Study Q^2, A dependence (FSI)
- Absolute Cross section to test exact calculations and FSI
- Extrapolation to NM

- 6 GeV (completed in Spring 2011)
  - E-08-014: Three-nucleon short range correlations studies in inclusive scattering for 0.8 < 2.8 $(GeV/c)^2$ [Hall A]
- 12 GeV
  - E12-06-105: Inclusive Scattering from Nuclei at x > 1 in the quasielastic and deeply inelastic regimes [Hall C], approved.

SRC Wish List 2N-SRC

1. For the 2N-SRC pair, what is the CM , relative momentum and the correlation between them as a function of all relevant parameters

a) What are the most important parameters ? momentum, different nuclei.

b) How to best compare data with theoretical calculations?

2. Can we identify and quantify the amount of 2N-SRC at $X_B \leq 1$?

3. How to characterize the transition between mean field and 2N-SRC dominant regions ?

4. What is the number and isospin structure of 2N-SRC in very asymmetric nuclei ($N \neq Z$) ?

SRC Wish List

2N-SRC

5. Can we identify and quantify the decay of 2N-SRC to non - 2 nucleon final states?

6. Can we identify and quantify signature for exotica (intermediate hidden color state or non-nucleonic DOF) in the 2N-SRC?

7. How to extrapolate the 2N-SRC (and the EMC) to infinite symmetric nuclear matter?

8. How to extrapolate the 2N-SRC (and the EMC) to high density (n star)?

9. Are 2N-SRC relevant to the neutrino nuclear problems?

SRC Wish List

3N-SRC

1.What is the amount of 3N-SRC as a function of relevant parameters (what are the relevant parameters?: momentum, nuclei….

2. Can we identify the structure of 3N-SRC ? Coplanar, star configuration…?

3. Can we study the isospin structure of 3N-SRC and the relation between it and the geometry of the 3N-SRC ?

4. What determines the transition between 2N-SRC and 3N-SRC dominant regions ?

5.What is the number and isospin structure of 3N-SRC in very asymmetric nuclei (N≠Z).

6.What and how can we learn about 3N forces from 3N-SRC ?

EMC-SRC

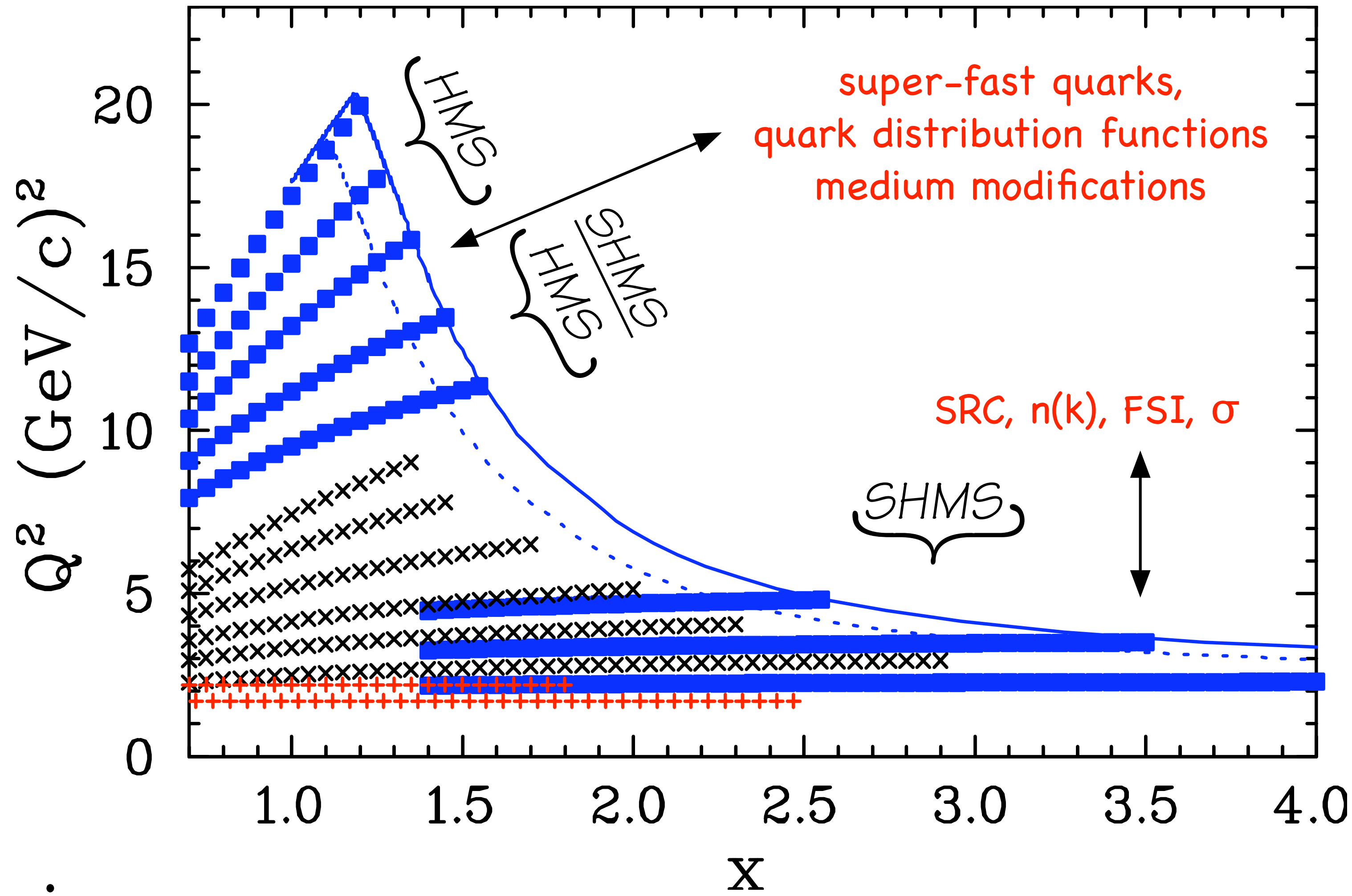
1. What is the dependence of the EMC effect on the virtuality? On local density?
   a) Is it universal?
2. Can we establish better connection between the EMC and SRC other than the linear correlation ?
3. Can we tell if it is a local density or a large virtuality/momentum that connect the two phenomena ?
4. Can we study the isospin dependence of the EMC effect using SRC ?
5. Can we identify/quantify more than 3N SRC ?

Finally, we need

- More precise data over a wider range of A and Q^2,
  - inclusive and exclusive
  - Isospin studies
- Reinvigorated theoretical effort
  - LDA is inadequate, in my view. A finite nucleus is not simply nuclear matter at local densities.
  - Keep pushing the limit for ab-initio calculations
- Create an archive with all available spectral functions
- Study details of <SE> as a possible lever to expose the relationship between SRC and EMC
- Resolve the FSI issues

E12-06-105 Inclusive Scattering from Nuclei at x > 1 in the quasielastic and deeply inelastic regimes

^{2}H, ^{3}He, ^{4}He, $^{6,7}Li$, $^{10,11}Be$, ^{12}C, $^{40,48}Ca$, Cu, Au



Two distinct kinematic regimes

- Moderate Q^2 and large x
  - Two and multi-nucleon correlations
    - A-dependence of strength, density dependence, non-isoscalarity
  - Provide tests of 'exact' calculations [S(k,E)] through σ, expose role of FSI
- Very high Q^2 and $1 < x < 1.5$
  - Extraction of SF and underlying quark distributions at x > 1
  - Provide insight into origin of EMC effect
  - Provide extreme sensitivity to non-hadronic components

Finish

- Inclusive (e,e′) at large Q^2 scattering and x>1 is a powerful tool to explore long sought aspects of the NN interaction
  - Considerable body of data exists
- Provides access to SRC and high momentum components through scaling, ratios of heavy to light nuclei and allows systematic studies of FSI
- Scaling in ξ appears to work well even in regions where the DIS is not the dominate process
  - DIS is does not dominate over QES at 6 GeV but should at 11 GeV and at $Q^2 > 10 - 15$ $(GeV/c)^2$. We can expect that any scaling violations will vanish as we go to higher Q^2
- Once DIS dominates it will allow another avenue of access to SRC and to quark distribution functions
- New experiments have been approved to push these investigations into heretofore unexplored regions

Inclusive (e,e')

- A:: SRC A=3 a_2 (E11-***)
- C:: Light A EMC effect (E10-008)
- C:: SRC a_2 (E06-105)
- C:: Large A EMC and a_2 (Infinite nuclear matter?)

Semi Inclusive (e,e'N)

- C:: EMC-SRC D(e,e'N_{recoil}) with LAD (E11-107)
- C:: Tagged EMC A(e,e'N_{recoil})
- B:: EMC-SRC D(e,e'n_{recoil}) with LAD

Exclusive (e,e'NN)

- B:: SRC deuteron spectator tagging ^{4}He(e,e'pd)
- B:: High statistics, Large Q^2 A(e,e'pN)
- B:: Low recoil neutron with LAD → SRC threshold

• How large are the probabilities of SRCs in nuclei ? • What is the isotopic structure of SRCs? • Are there significant three nucleon SRCs?

• How significant are non-nucleonic degrees of freedom in the SRC?

• What is kinematical range of applicability of the concept of SRC in QCD?

• What is the impact of SRCs on the dynamics of compact stars: neutron stars, hyperon stars etc?

SRC wish list / questions to answer

1. **<u>Understand nucleon modification in nuclei</u>**
    1. Can we identify and quantify signature for exotica (intermediate hidden color state or non nucleonic DOF) in the 2N-SRC ?
    2. What is the dependence of the EMC effect on the virtuality ?
2. Momentum dependence of 2N-SRC
    1. Learn about NN force
3. What is the isospin structure and geometry of 3N-SRC ?
4. How to extrapolate the 2N-SRC (and the EMC) to high density (n star)?
5. Can we study the isospin dependence of the EMC effect using SRC ?
6. Are 2N-SRC relevant to the neutrino nuclear problems ?
7. What and how can we learn about 3N forces from 3N-SRC ?
8. Baseline measurements of d and 3He(e,e'p) at high Q2 and p_miss

Complementarity