Status of the (e,e') data set at $x > 1$

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Short-Range Structure of Nuclei at 12 GeV
October 26 - 27, 2007
Jefferson Lab, Newport News, Va

K. Egiyan Workshop , Cold Dense Nuclear Matter (FIU), Dense and Cold Nuclear Matter and Hard Exclusive Processes, (Ghent)

Outline

- ✳ Correlations in inclusive scattering
- ✳ Basic features
- ✳ SRC and ratios
- ✳ The existing kinematic coverage
- ✳ New JLAB data

Short Range Correlations (SRCs)

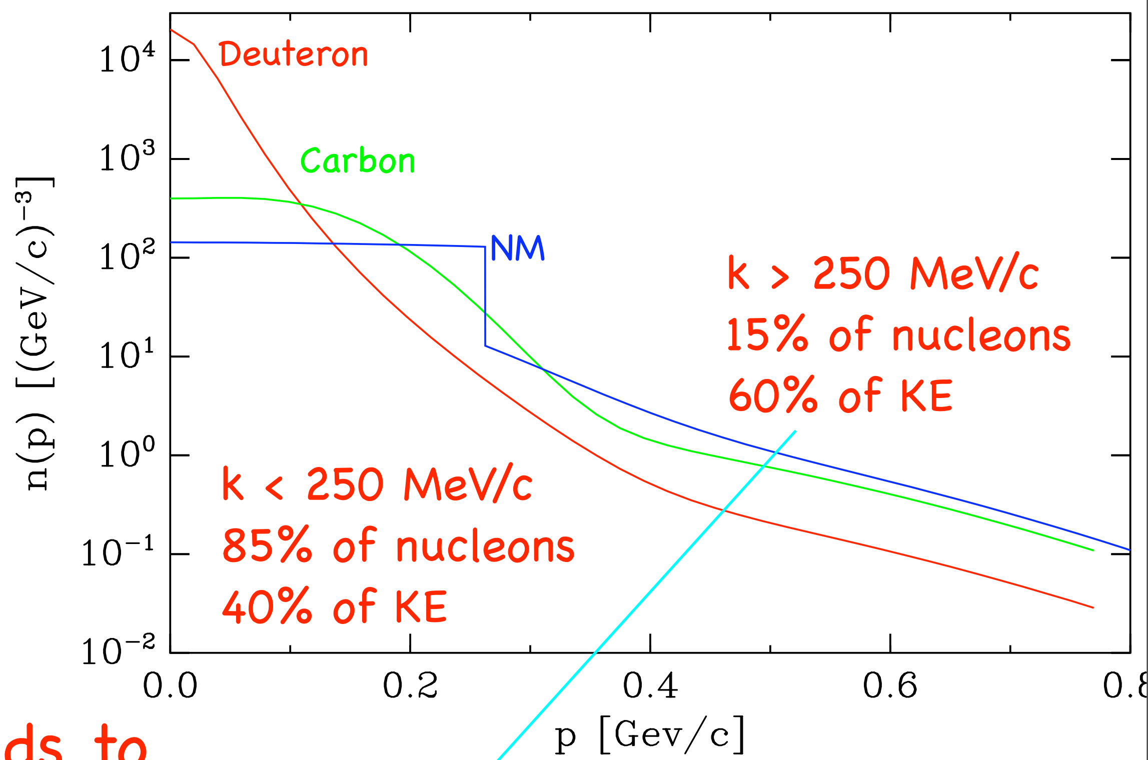
Mean field contributions: $k < k_F$
Well understood, Spectroscopic Factors ≈ 0.65

Similar shapes for $k > k_f$

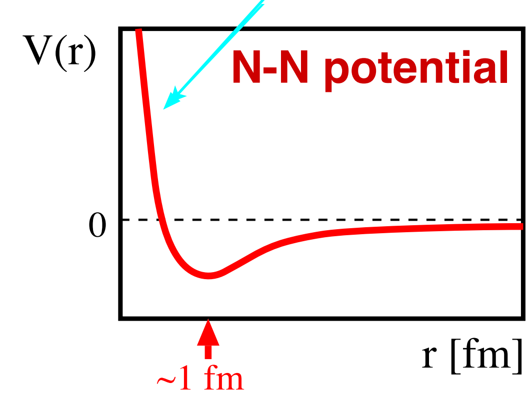
High momentum tails: $k > k_F$
Calculable for few-body nuclei, nuclear matter.
Dominated by two-nucleon short range correlations

Poorly understood part of nuclear structure

Sign. fraction have $k > k_F$



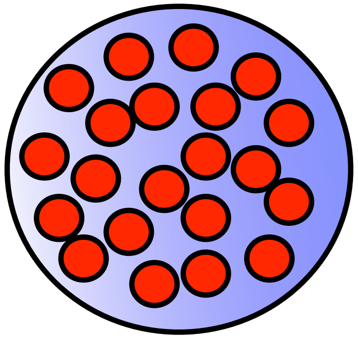
Uncertainty in SR interaction leads to uncertainty at k>>, even for simplest systems



Isolate short range interactions (and SRC's) by probing at high p_m: (e,e'p) and (e,e')

SRC provide unique information on Medium Modifications generated by high density configurations

Gold nucleus

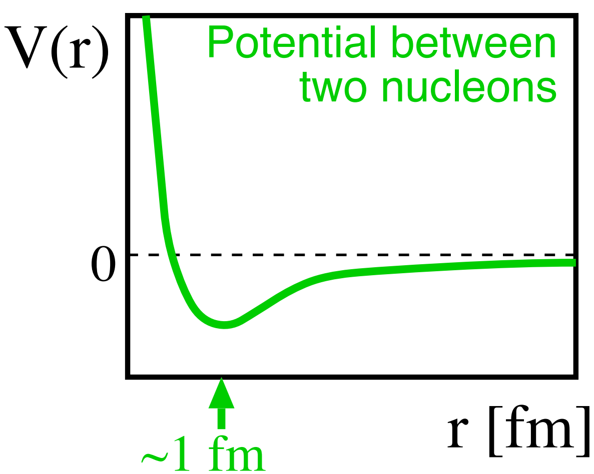


$R = 1.2A^{1/3}$

$Volume = \frac{4}{3}\pi R^3 \simeq 1400 fm^3$

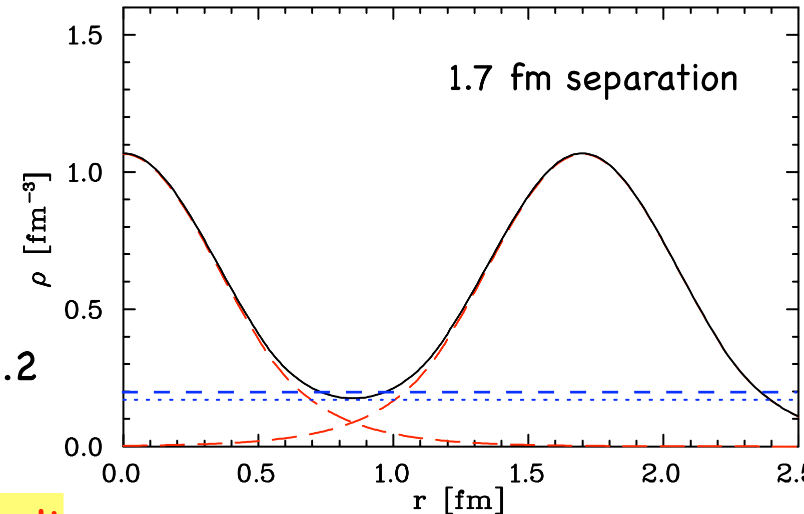
A single nucleon, r = 1 fm, has a volume of 4.2 fm^3:==>197 times 4.2 fm^3 ≈ 830 fm^3

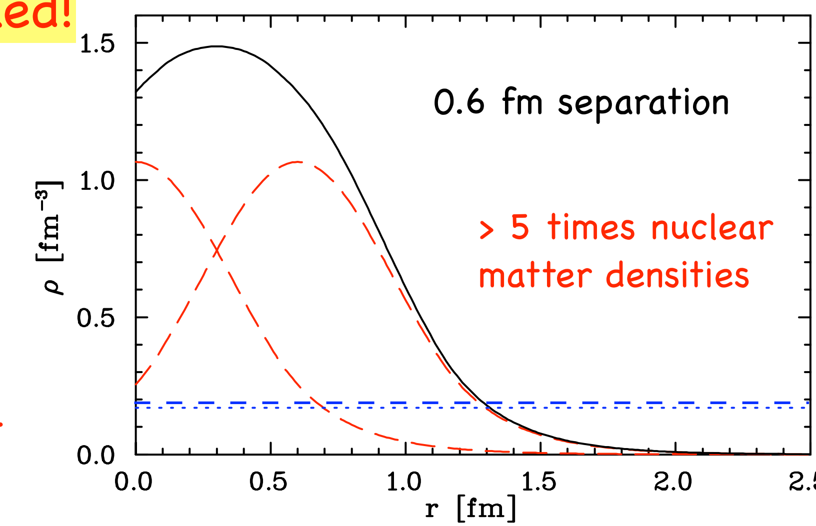
60% of the volume is occupied - very closely packed!



Nucleon separation is limited by the short range repulsive core

Even for a 1 fm separation, the central density is about 4x nuclear matter





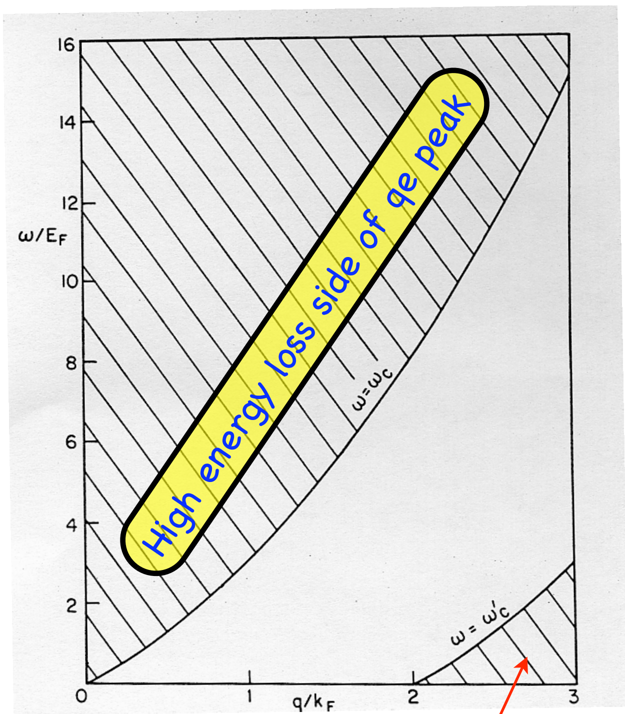
Comparable to neutron star densities!

High enough to modify nucleon structure?

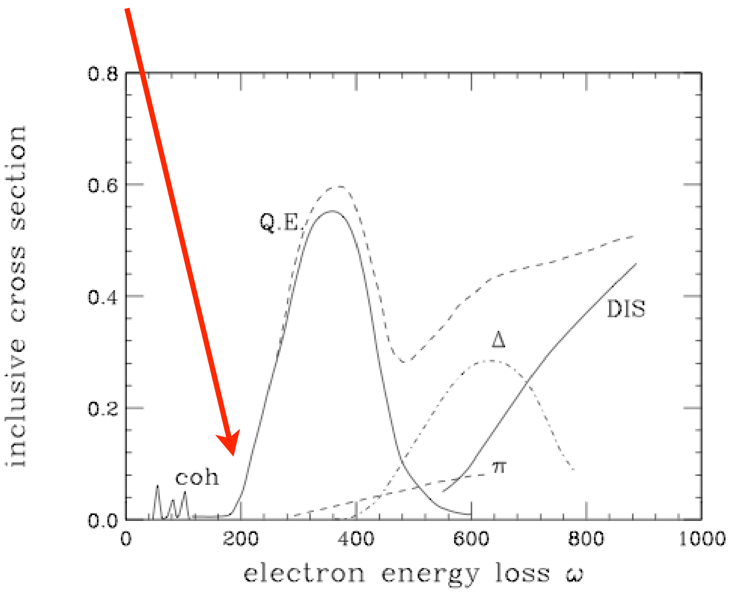
Correlations and Inclusive Electron Scattering

Shaded domain where scattering is restricted solely to correlations. Czyz and Gottfried (1963)

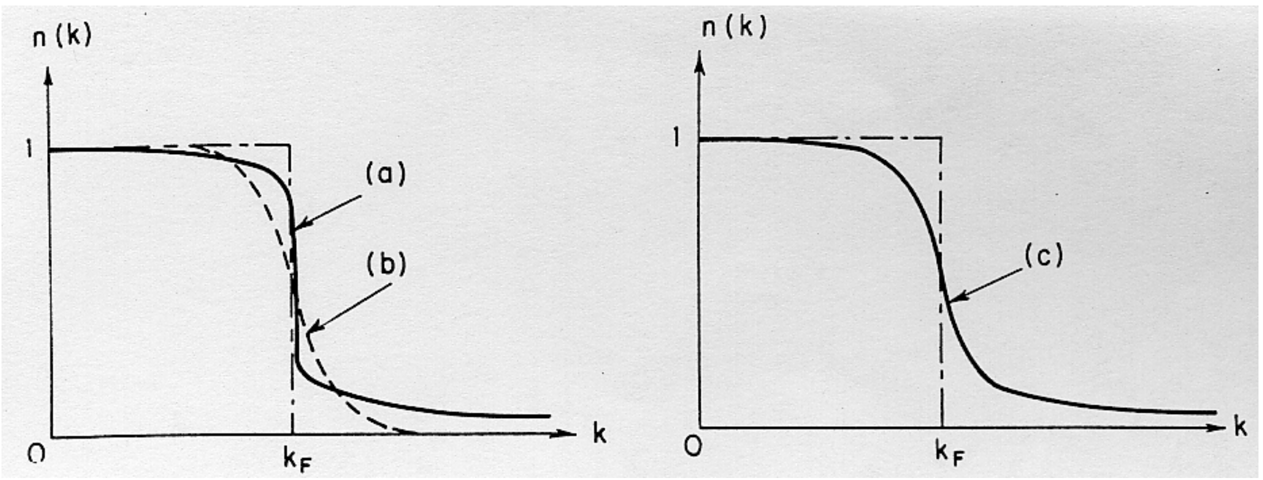
$$\omega_c = \frac{(k+q)^2}{2m} + \frac{q^2}{2m} \qquad \omega_c' = \frac{q^2}{2m} - \frac{qk_f}{2m}$$



Low energy loss side of qe peak

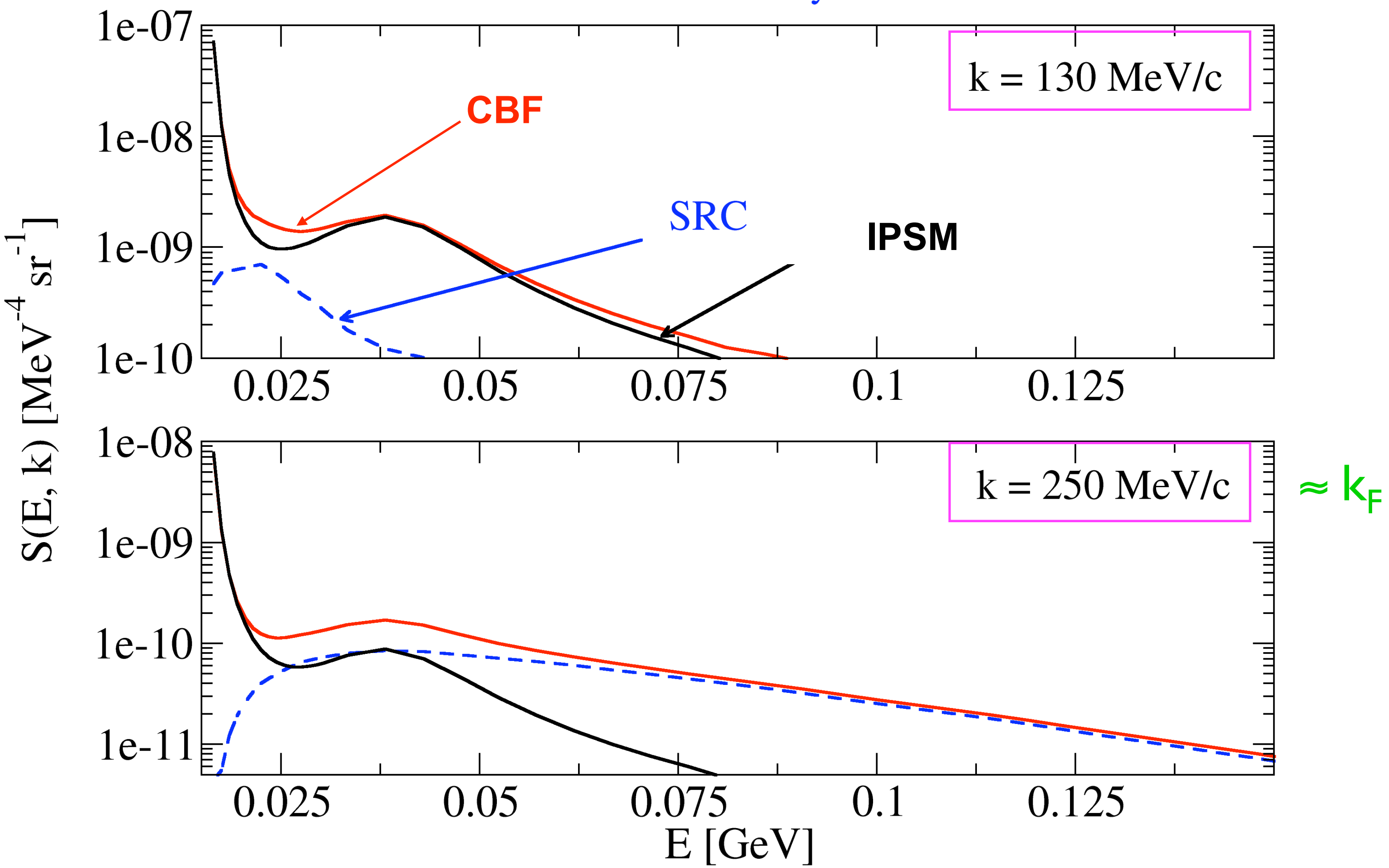


Czyz and Gottfried proposed to replace the Fermi n(k) with that of an actual nucleus. (a) hard core gas; (b) finite system of noninteracting fermions; (c) actual large nucleus.



Spectral function for ^{12}C

CBF theory



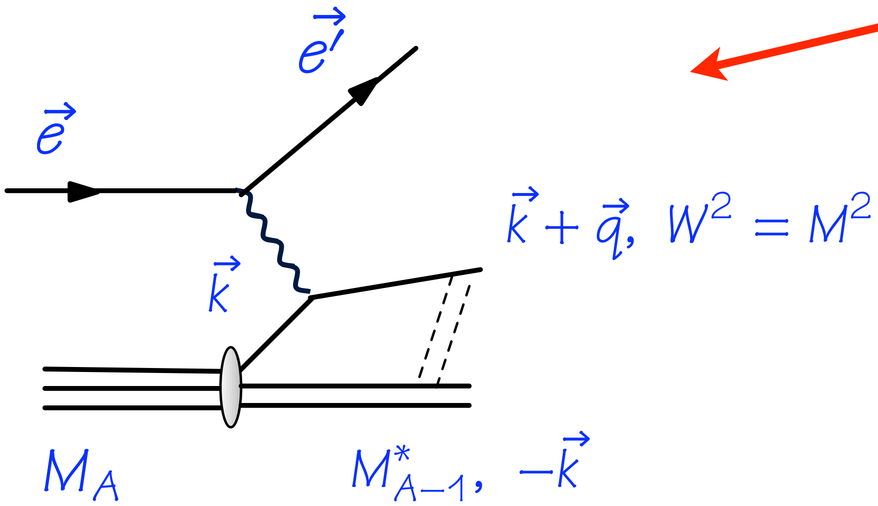
- $k < k_F$: single-particle contribution dominates
- $k \approx k_F$: SRC already dominates for E > 50 MeV
- $k > k_F$: single-particle negligible

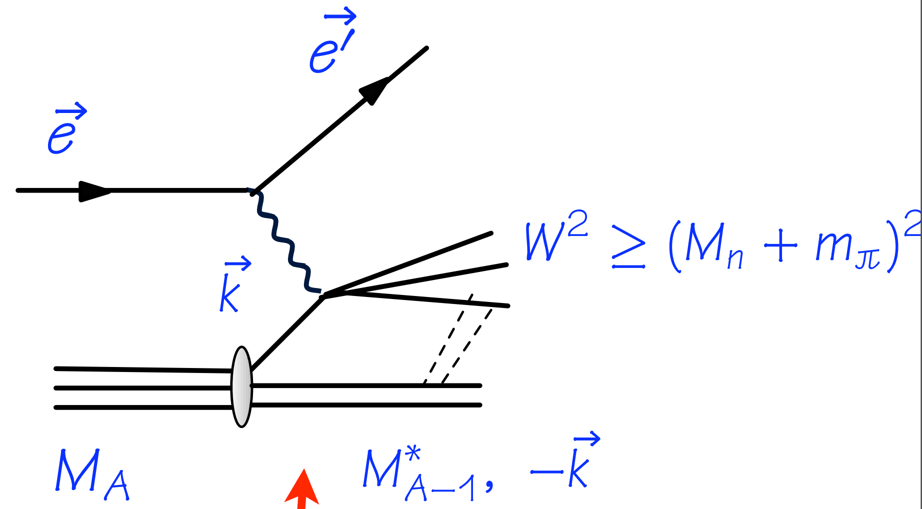
Search for SRC at high k and E in (e,e′p) and (e,e′) experiments

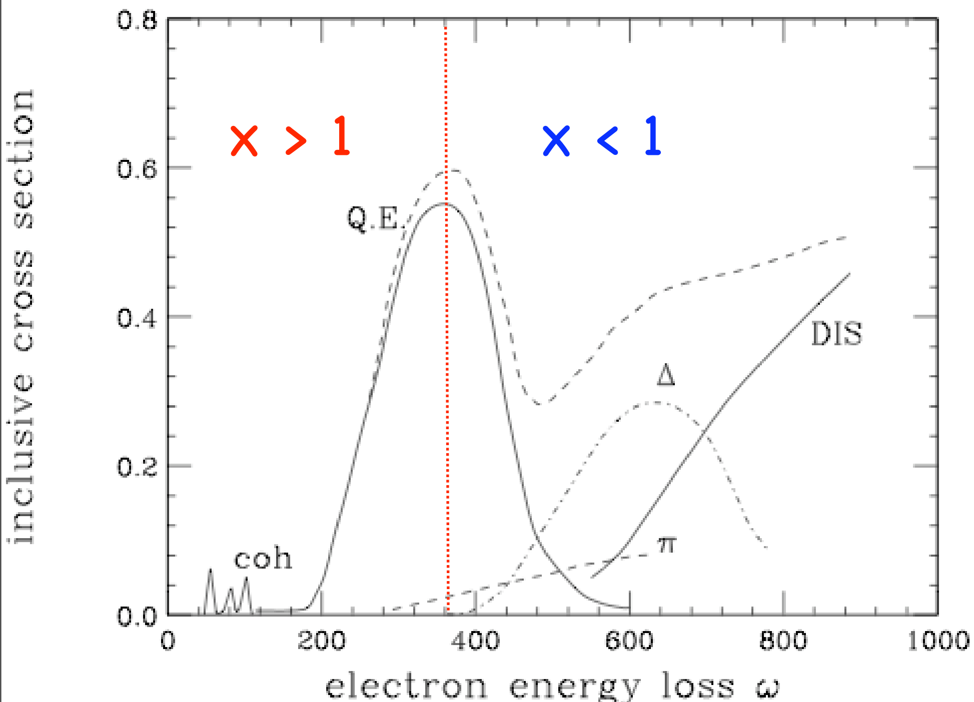
Inclusive Electron Scattering from Nuclei

Two distinct processes

Quasielastic from the nucleons in the nucleus





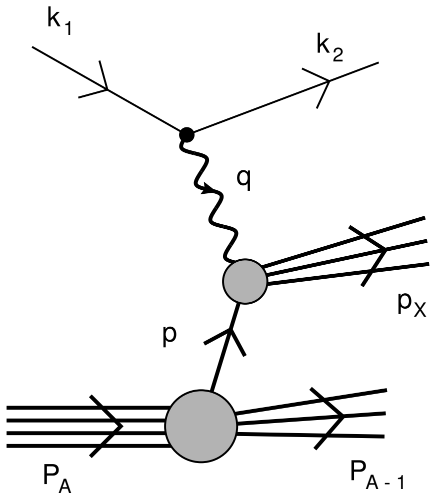


Inelastic and DIS from the quark constituents of the nucleon.

Inclusive final state means no separation of two dominant processes

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

υ,ω=energy loss



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

There is a rich, if complicated, blend of nuclear and fundamental QCD interactions available for study from these types of experiments.

The two processes share the same initial state

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

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

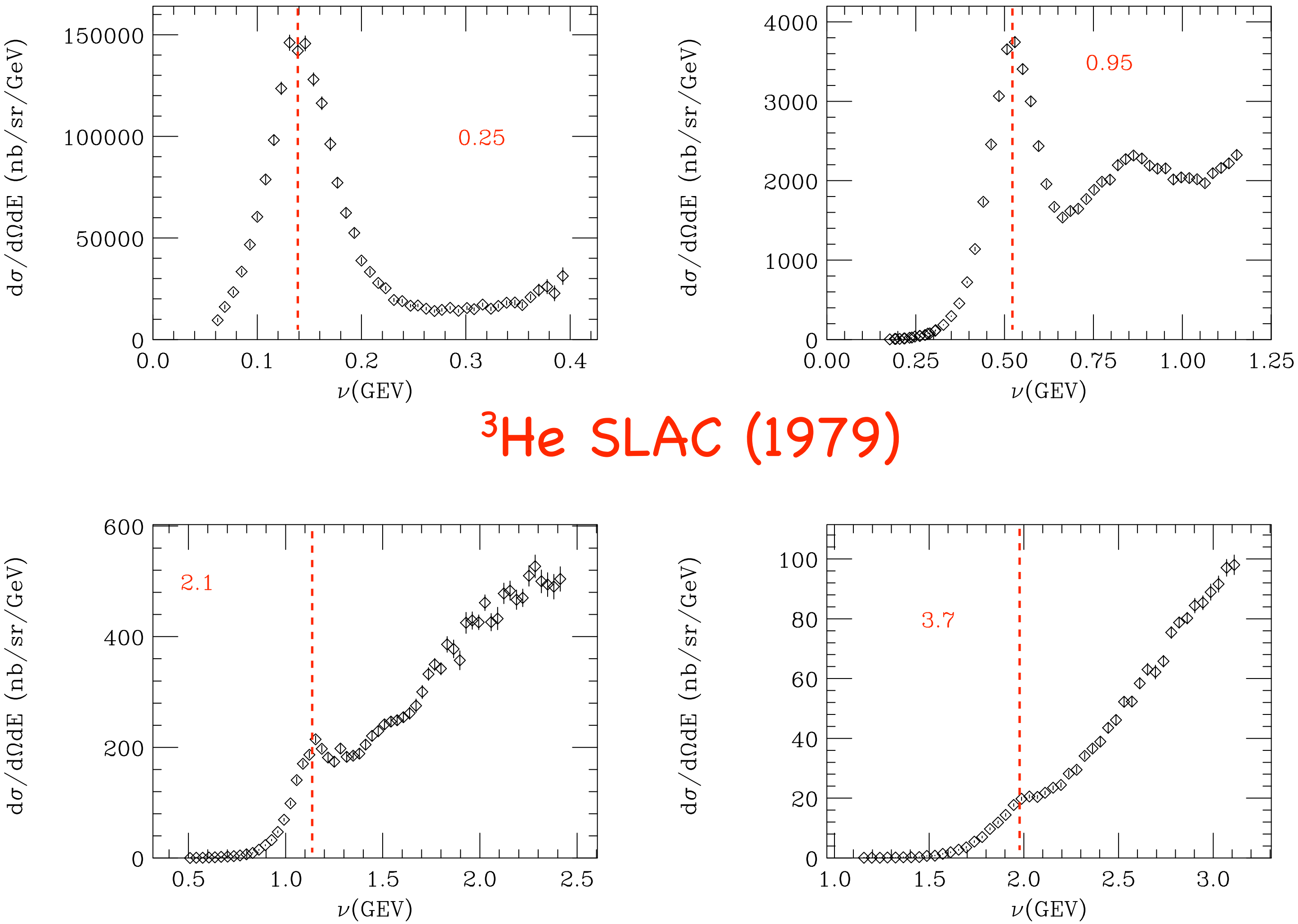
DIS
$$\frac{d^2\sigma}{dQd\nu} \propto \int d\vec{k} \int dE\, W_{1,2}^{(p,n)} \underbrace{S_i(k,E)}_{\text{Spectral function}}$$

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

However they have very different Q^2 dependencies

$\sigma_{ei} \propto$ elastic (form factor)^2 $W_{1,2}$ scale with $\ln Q^2$ dependence

Exploit this dissimilar Q^2 dependence

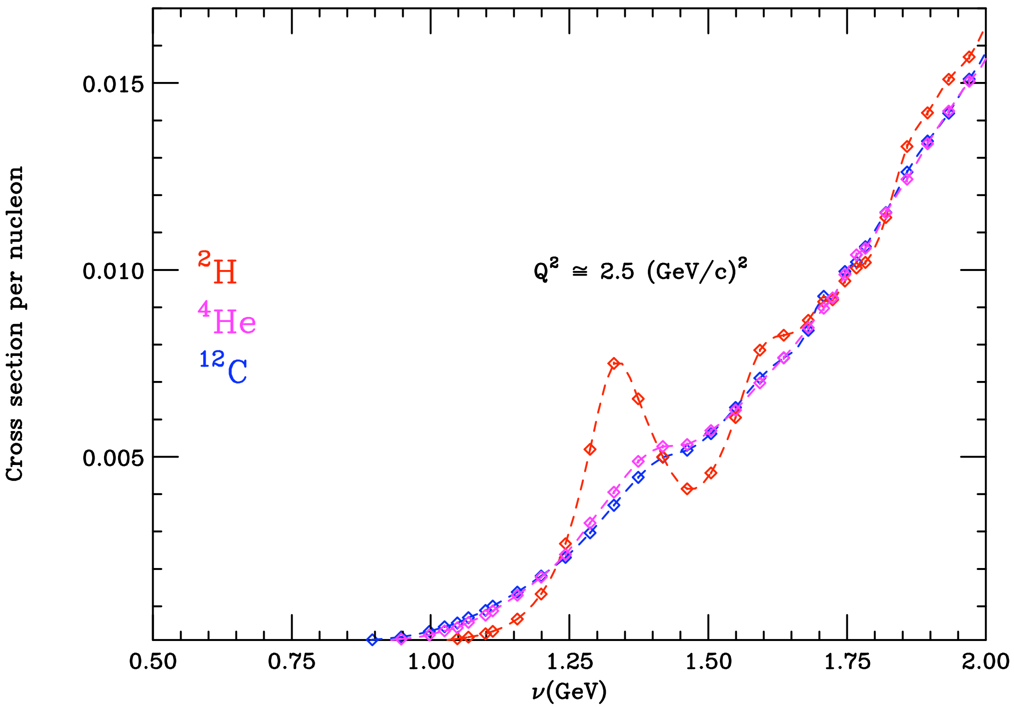


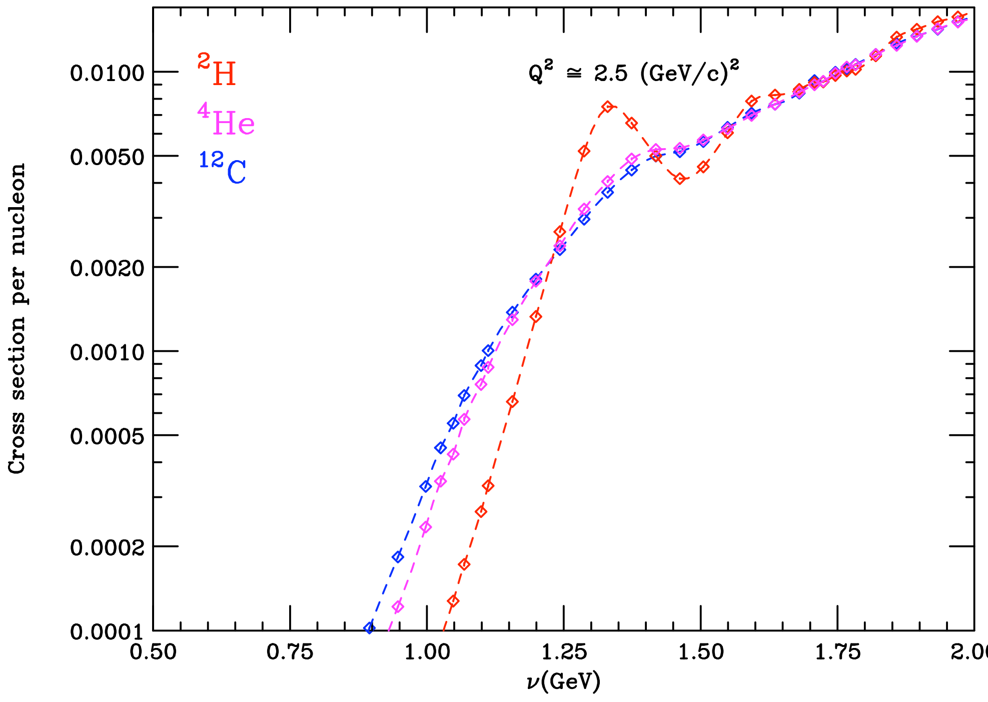
The quasielastic peak (QE) is broadened by the Fermi-motion of the struck nucleon.

The quasielastic contribution dominates the cross section at low energy loss (ν) even at moderate to high Q^2.

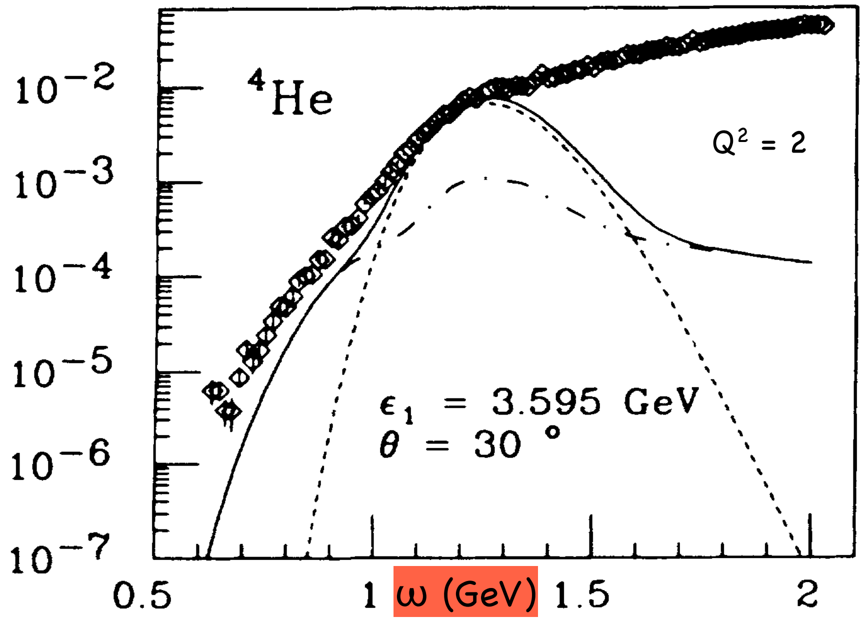
- The shape of the low ν cross section is determined by the momentum distribution of the nucleons.
- As Q^2 >> inelastic scattering from the nucleons begins to dominate
- We can use x and Q^2 as knobs to dial the relative contribution of QES and DIS.

A dependence: higher internal momenta broadens the peak

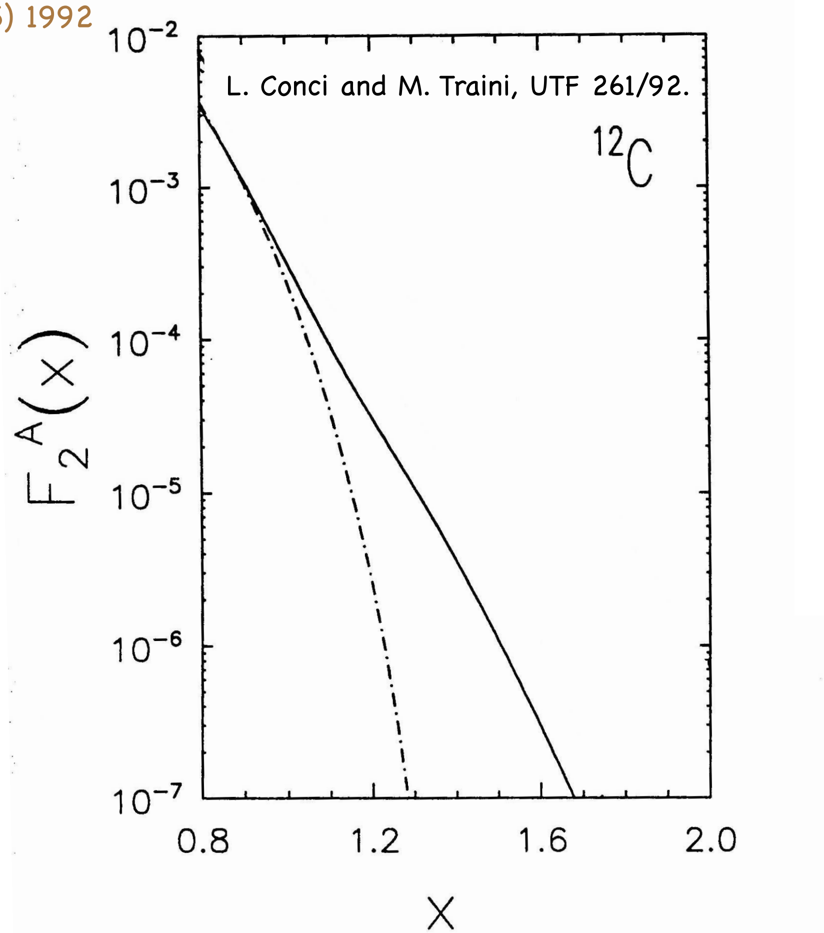


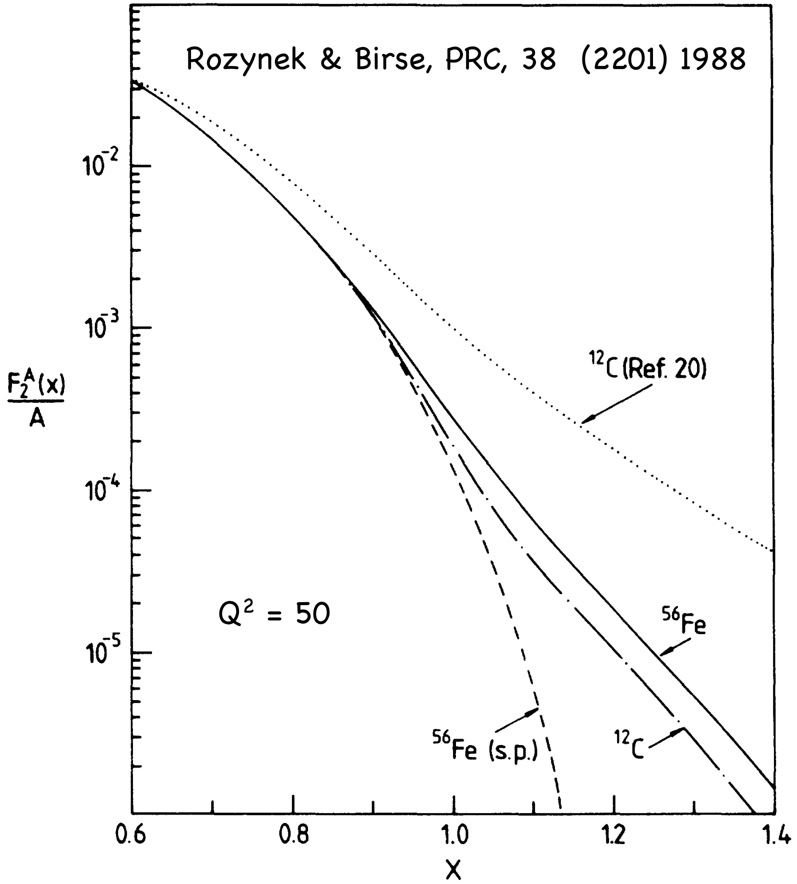


Correlations are accessible in QES and DIS at large x (small energy loss)



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

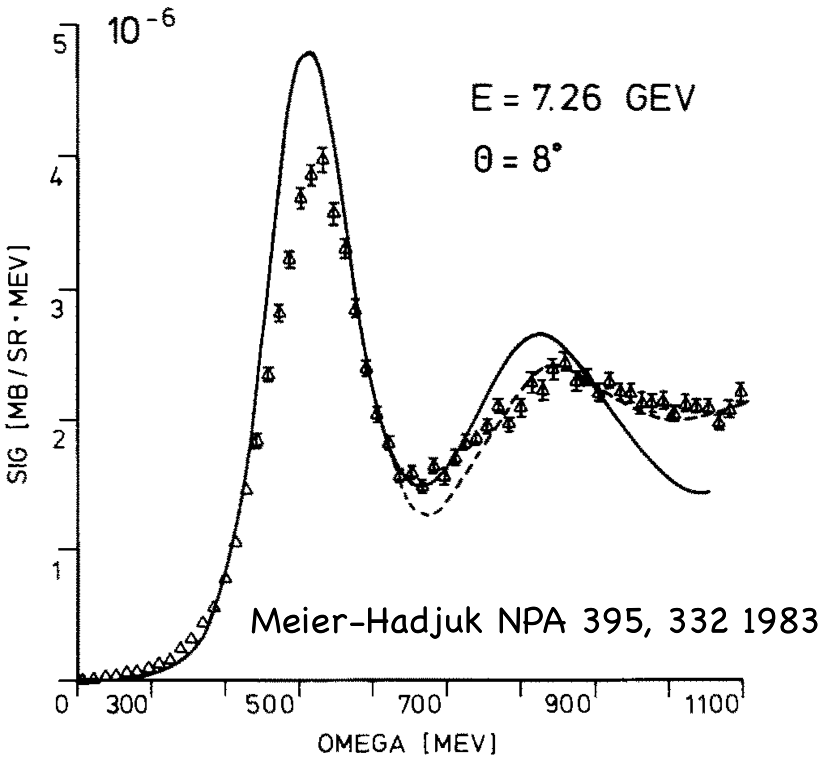


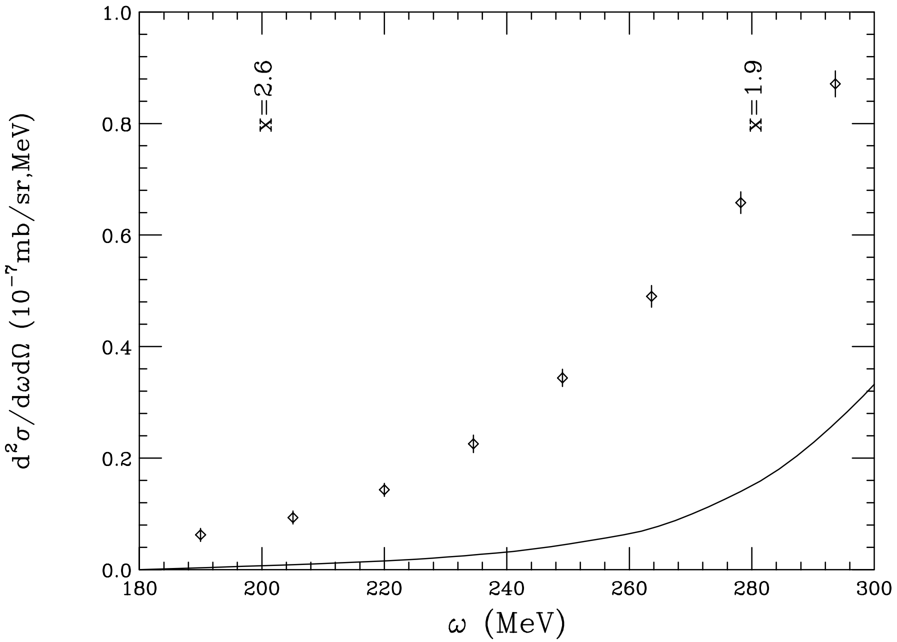


Final State Interactions

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



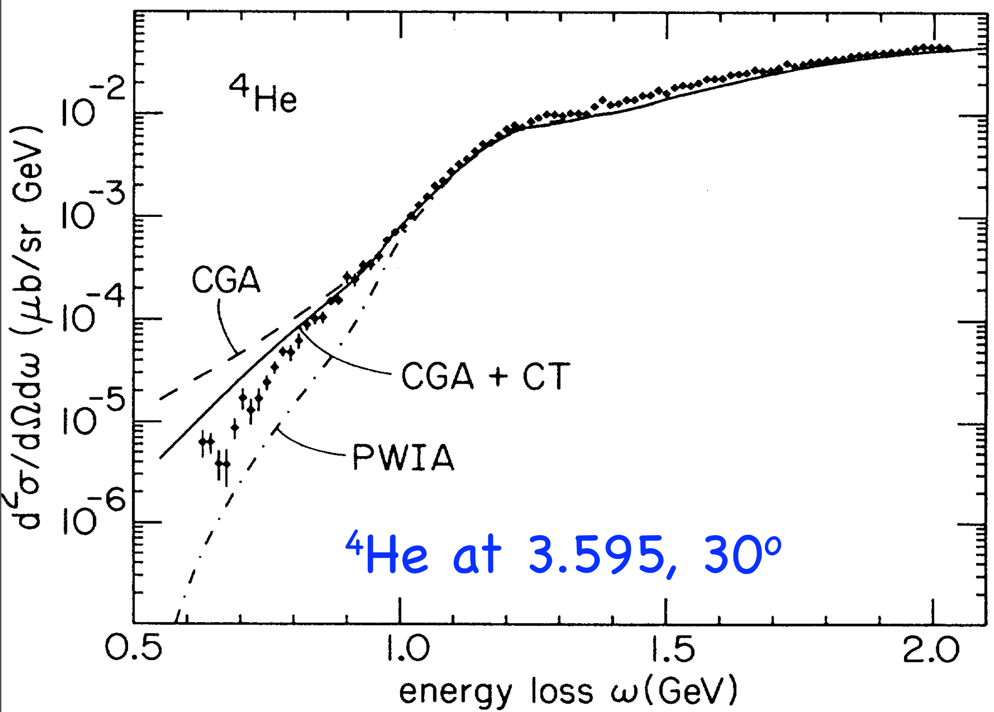


FSI has two effects: energy shift and a redistribution of strength from QEP to the tails, just where correlation effects contribute.

Benhar et al uses approach based on NMBT and Correlated Glauber Approximation

Ciofi degli Atti and Simula use GRS 1/q expansion and model spectral function

Final State Interactions in CGA



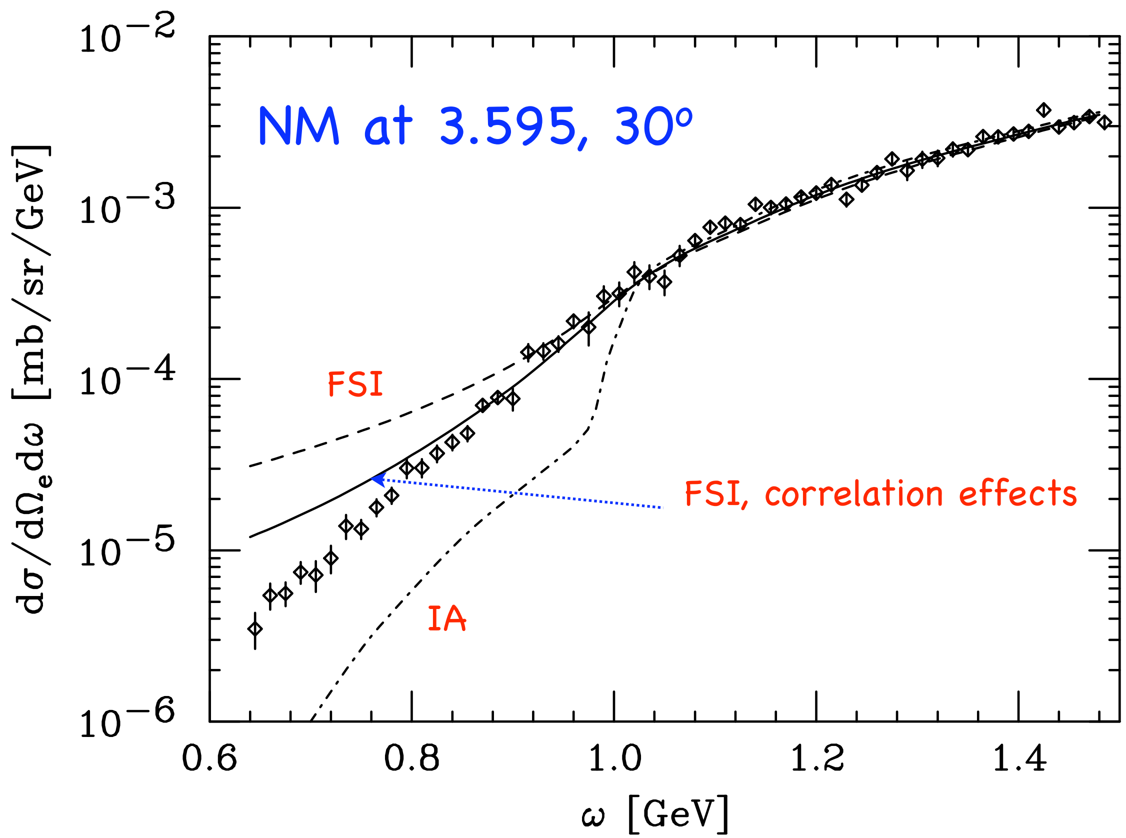
Benhar et al. PRC 44, 2328

Benhar, Pandharipande, PRC 47, 2218

Benhar et al. PLB 3443, 47

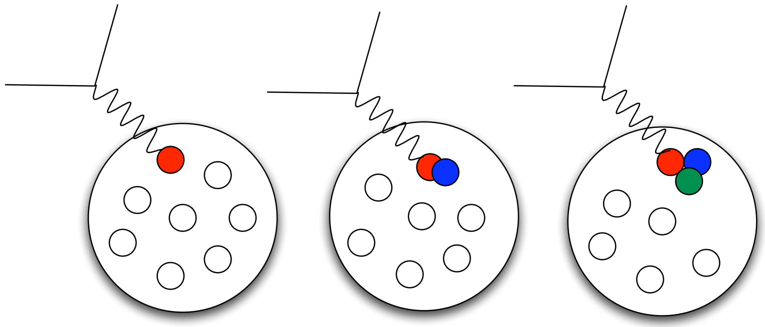
CGA over estimates the FSI

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



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.

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

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

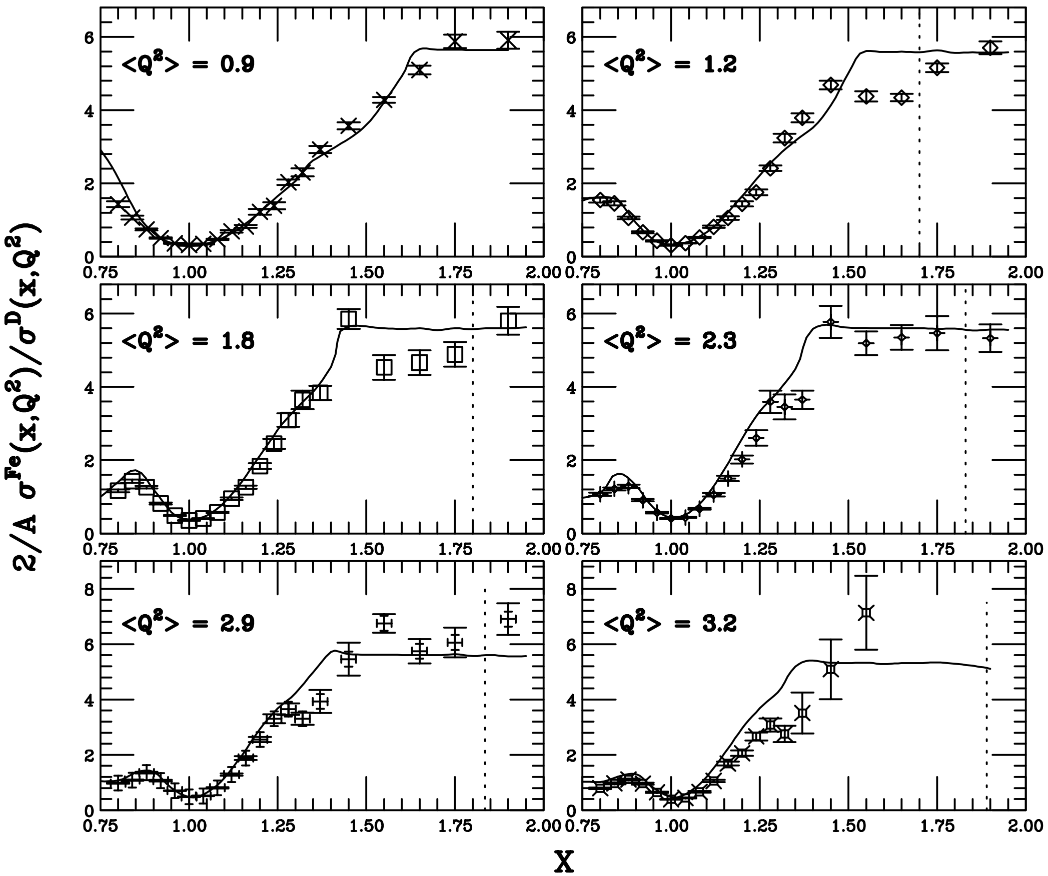
$$\frac{3}{A}\frac{\sigma_A(x,Q^2)}{\sigma_{A=3}(x,Q^2)} = a_3(A)\Big|_{2<x\leq 3}$$

In the ratios, off-shell effects and FSI largely cancel.

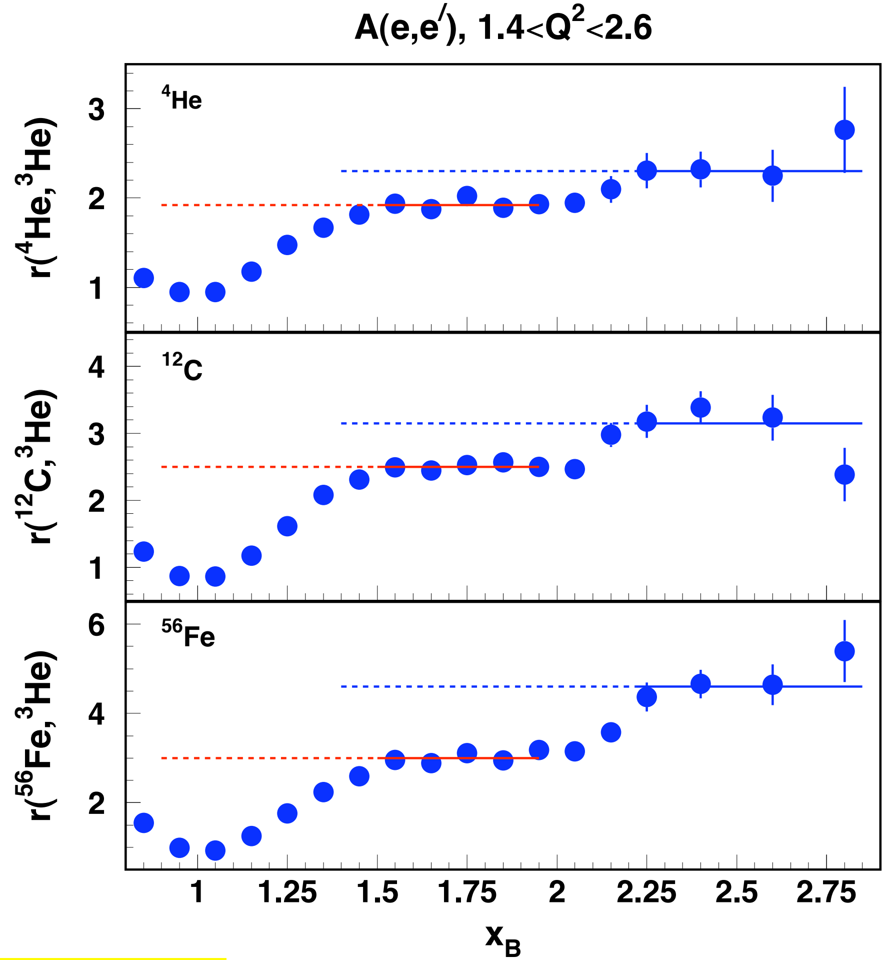
$a_j(A)$ is proportional to probability of finding a j-nucleon correlation

Ratios, SRC's and Q^2 scaling

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



FSDS, Phys.Rev.C48:2451-2461,1993



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

$\alpha_{2N} \approx 20\%$
$\alpha_{3N} \approx 1\%$

CLAS data
Egiyan et al., PRL 96, 082501, 2006

http://faculty.virginia.edu/qes-archive/index.html

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- Utilities
- Bibliography
- Acknowledgements

Quasielastic Electron Nucleus Scattering Archive

Welcome to Quasielastic Electron Nucleus Scattering Archive

New additions to Carbon data set (October 4, 2007)!

In connection with a review article (Quasielastic Electron-Nucleus Scattering, by O. Benhar, D. Day and I. Sick) to be submitted to Reviews of Modern Physics, we have collected here an extensive set of quasielastic electron scattering data in order to preserve and make available these data to the nuclear physics community.

We have chosen to provide the cross section only and not the separated response functions. Unless explicitly indicated the data do not include Coulomb corrections.

Our criteria for inclusion into the data base is the following:

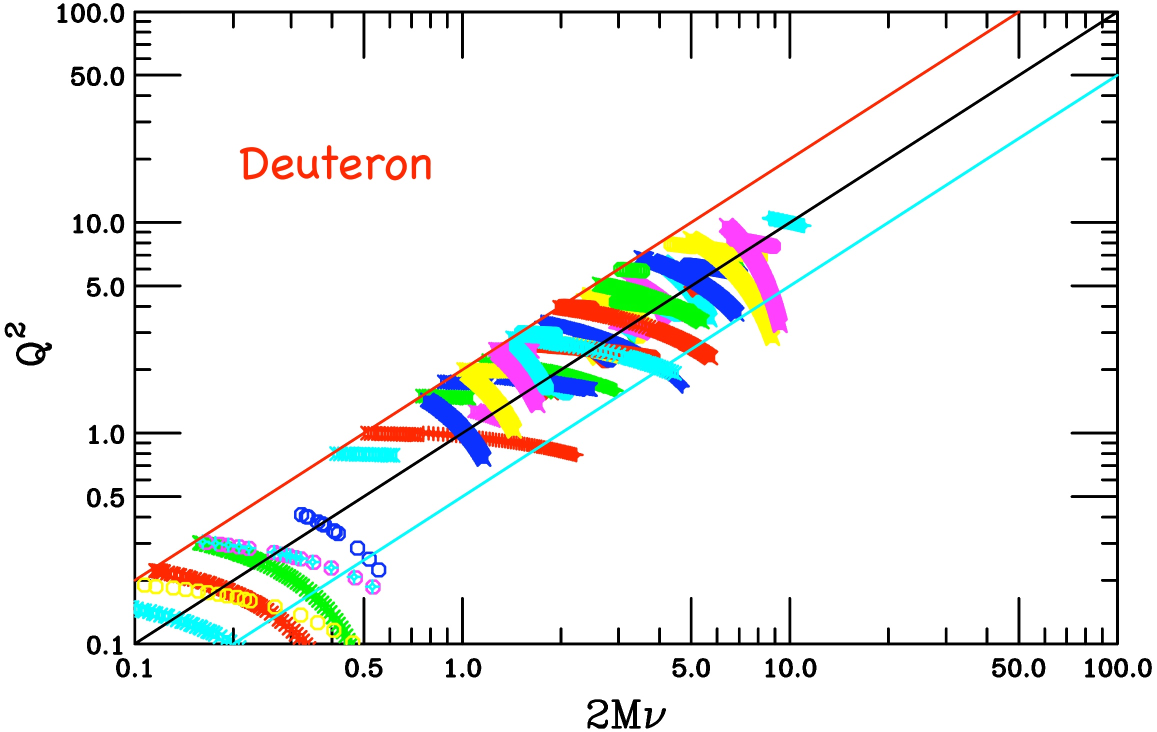
1. Data published in tabular form in journal, thesis or preprint.
2. Radiative corrections applied to data.
3. No known or acknowledged pathologies

At present there are about 600 different combinations of targets, energies and angles consisting of some 19,000 data points.

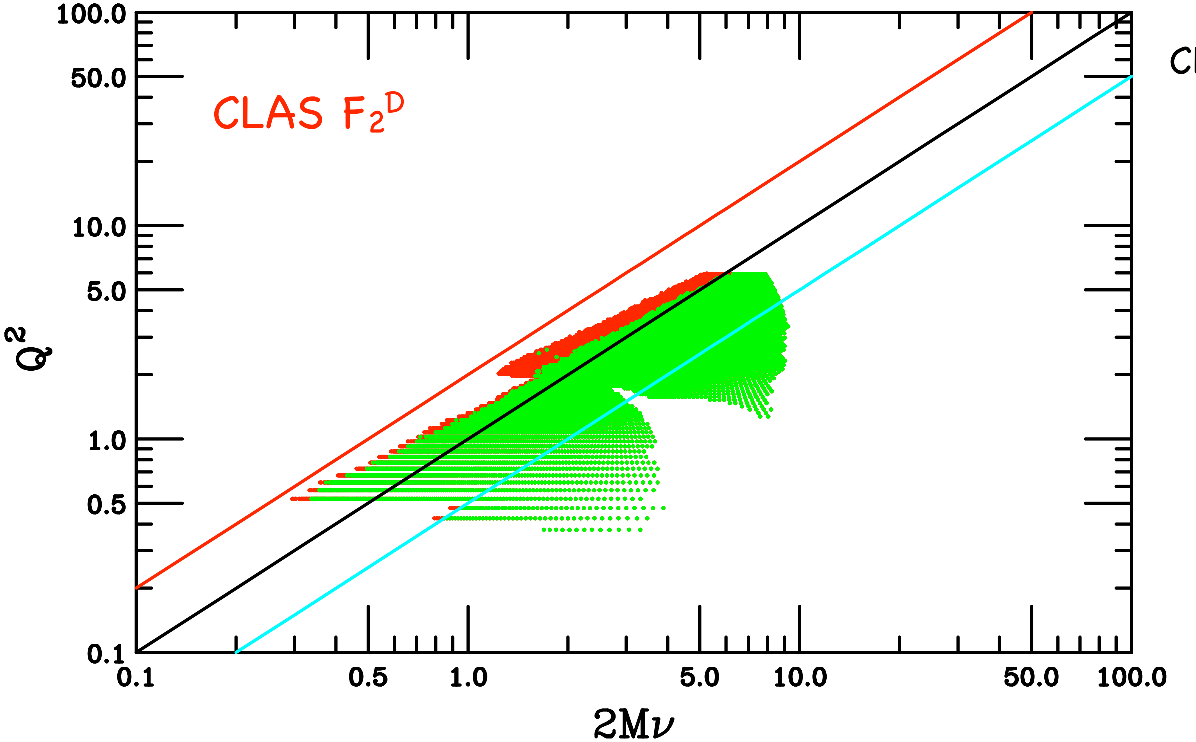
In the infrequent event that corrections were made to the data after the original publications, we included the latest data set, adding an additional reference, usually a private communication.

As additional data become known to us, we will add to the data sets.

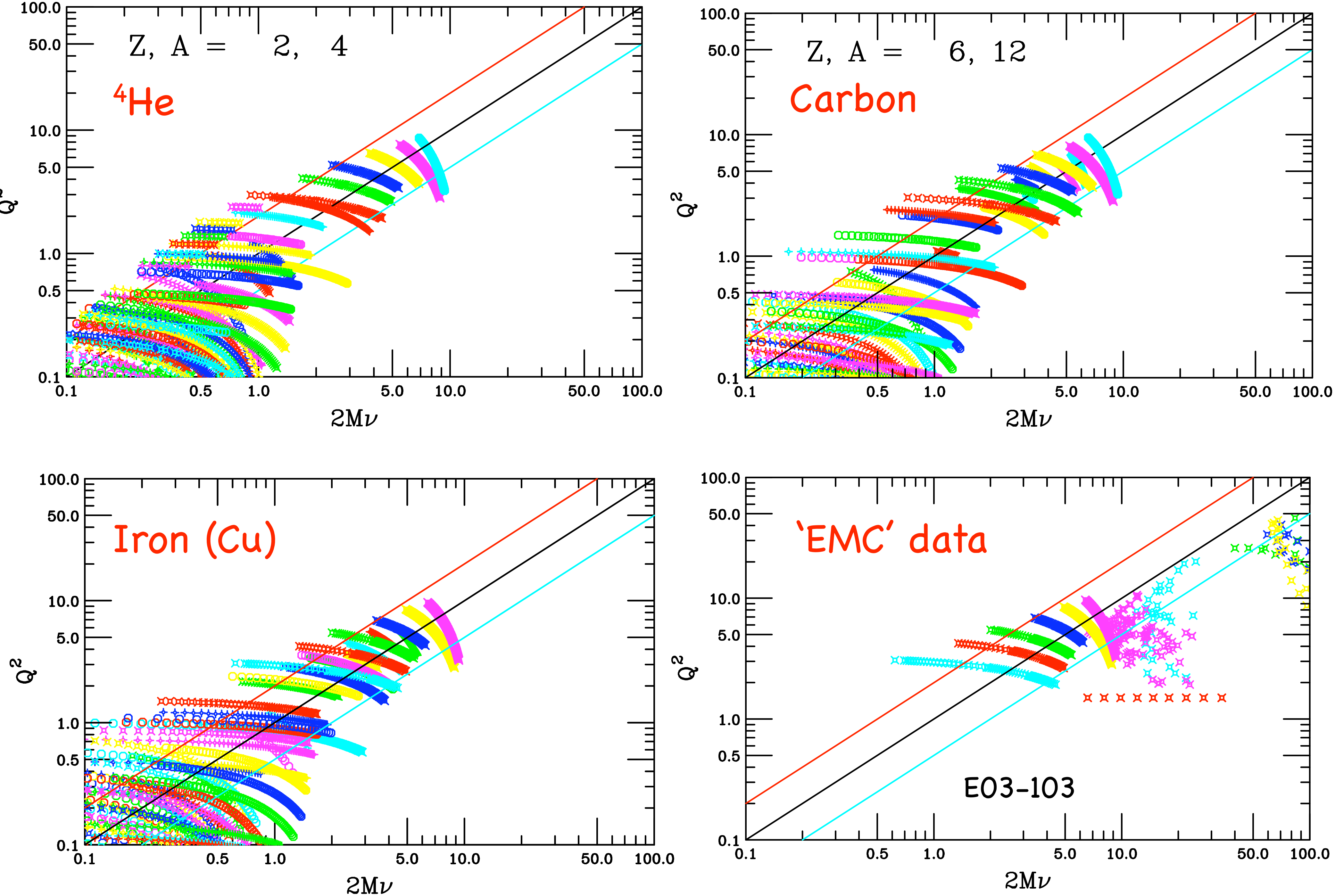
If you wish to be alerted to changes in the archive or to the inclusion of new data, send an email to me (Donal Day) [dbd at virginia.edu]. Send any comments or corrections you might have as well.



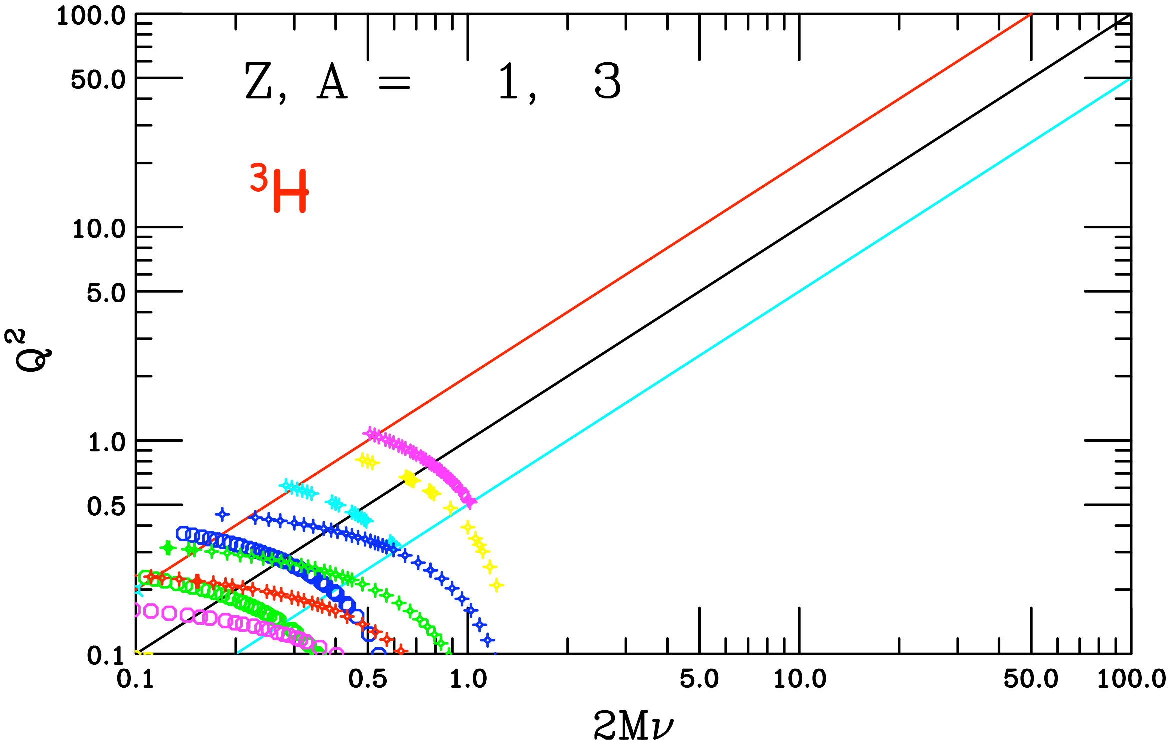
E02-019 not yet in archive



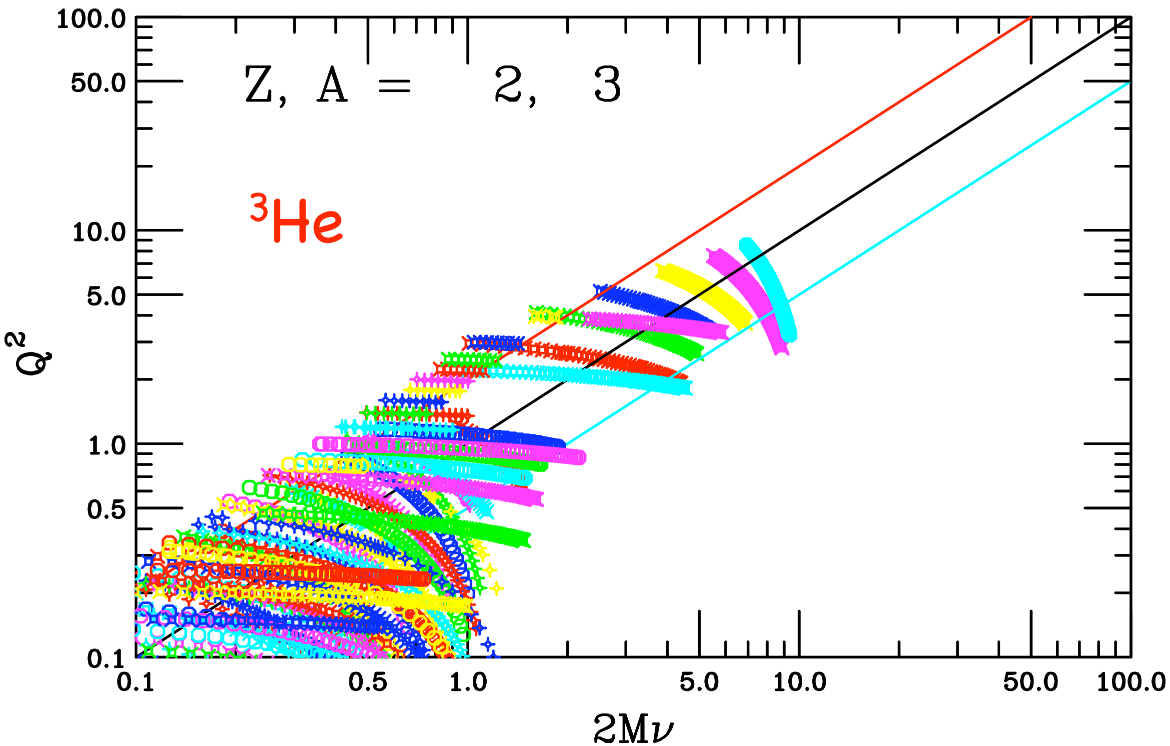
CLAS F_2^D not yet in archive



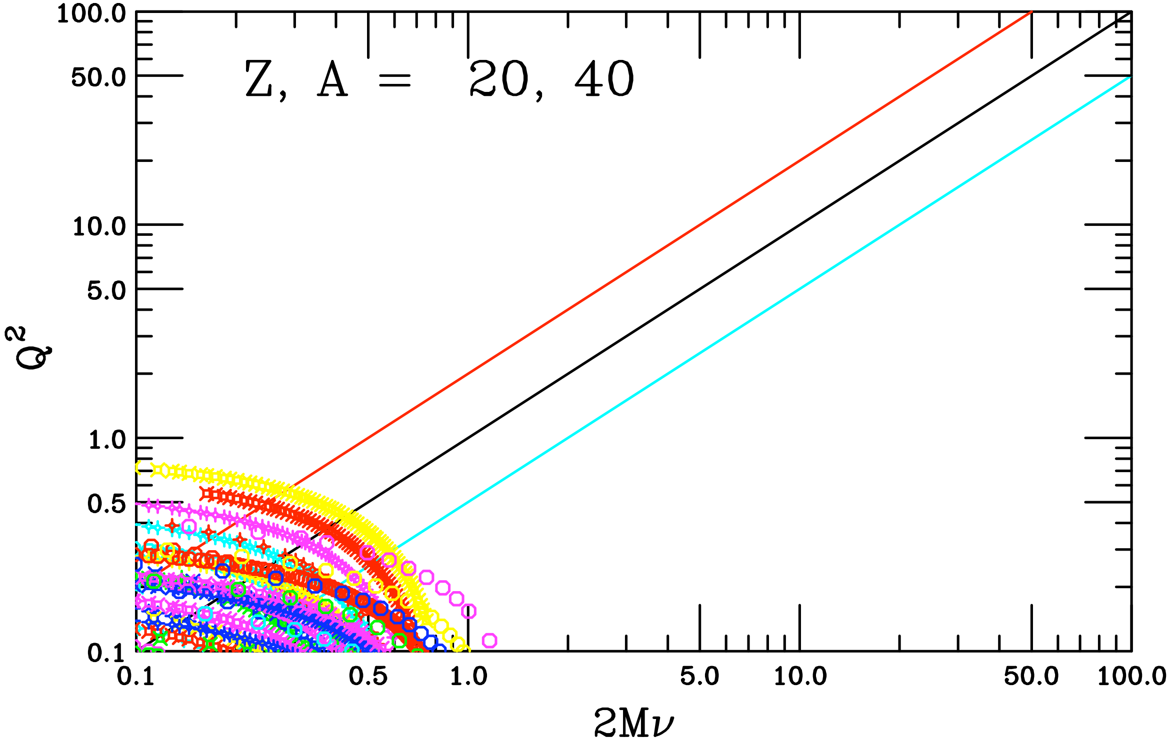
Z, A = 2, 4
⁴He
Carbon
Z, A = 6, 12
Iron (Cu)
'EMC' data
E03-103
Q²
2Mν



Tritium n/p = 2

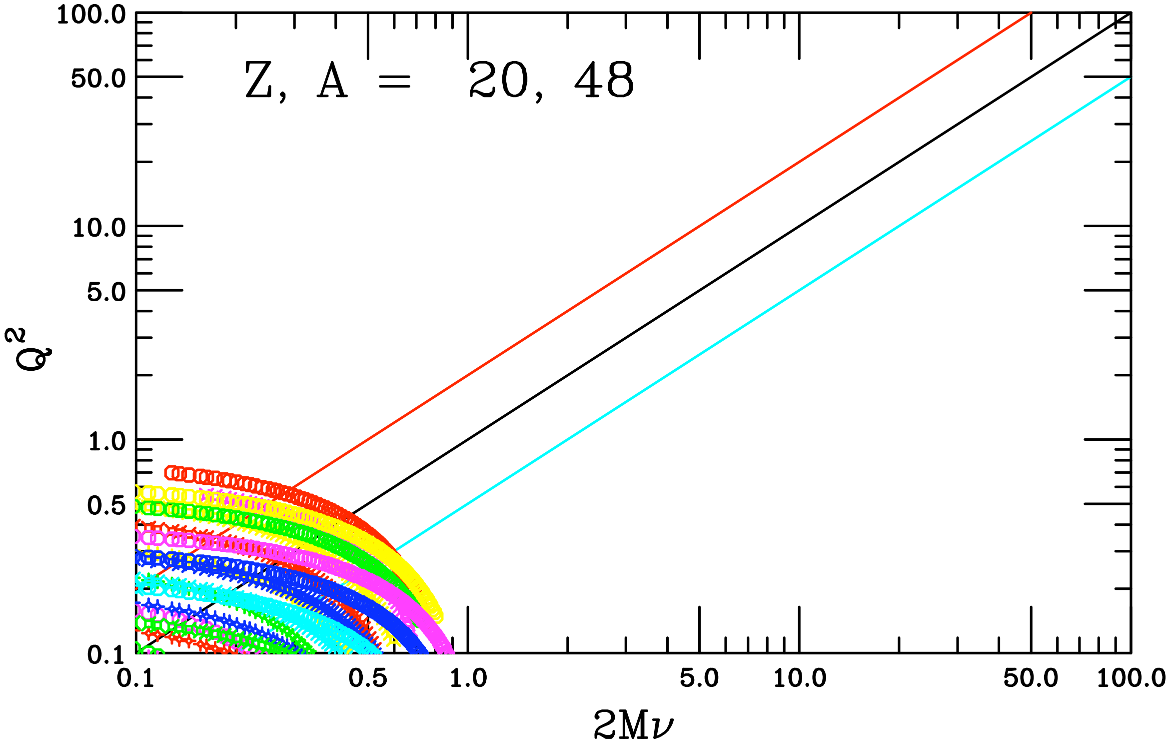


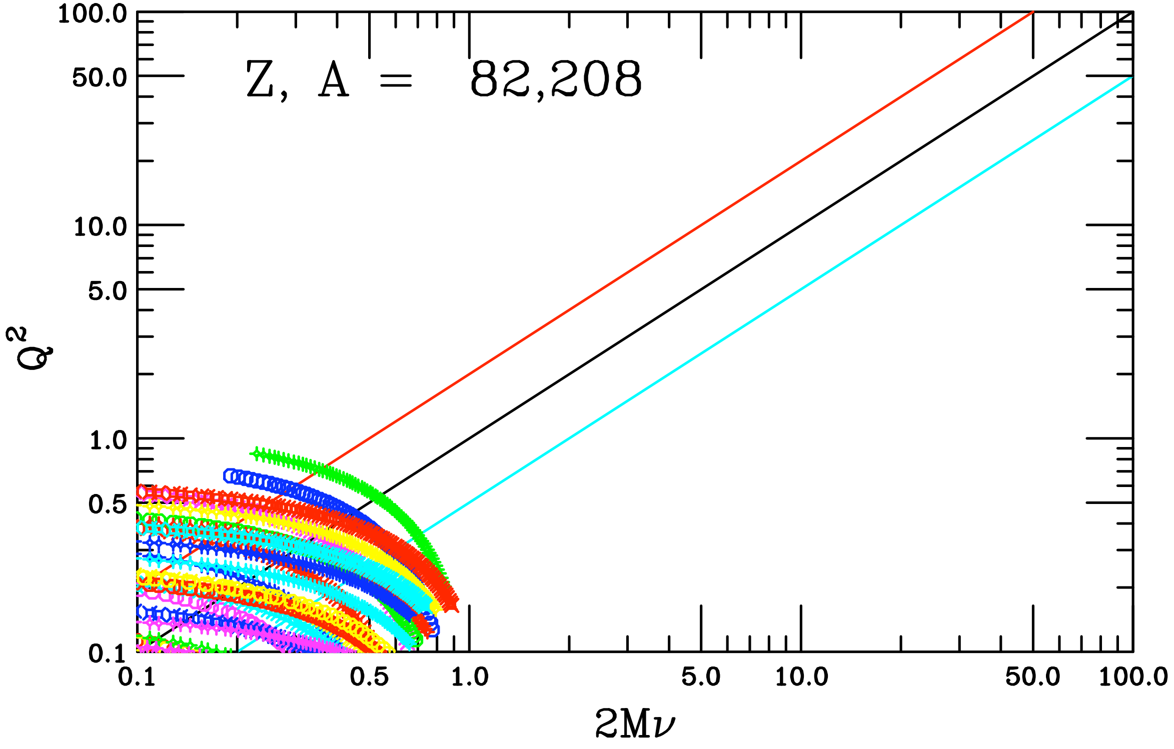
Helium-3 n/p = 0.5



Calcium 40 n/p = 1

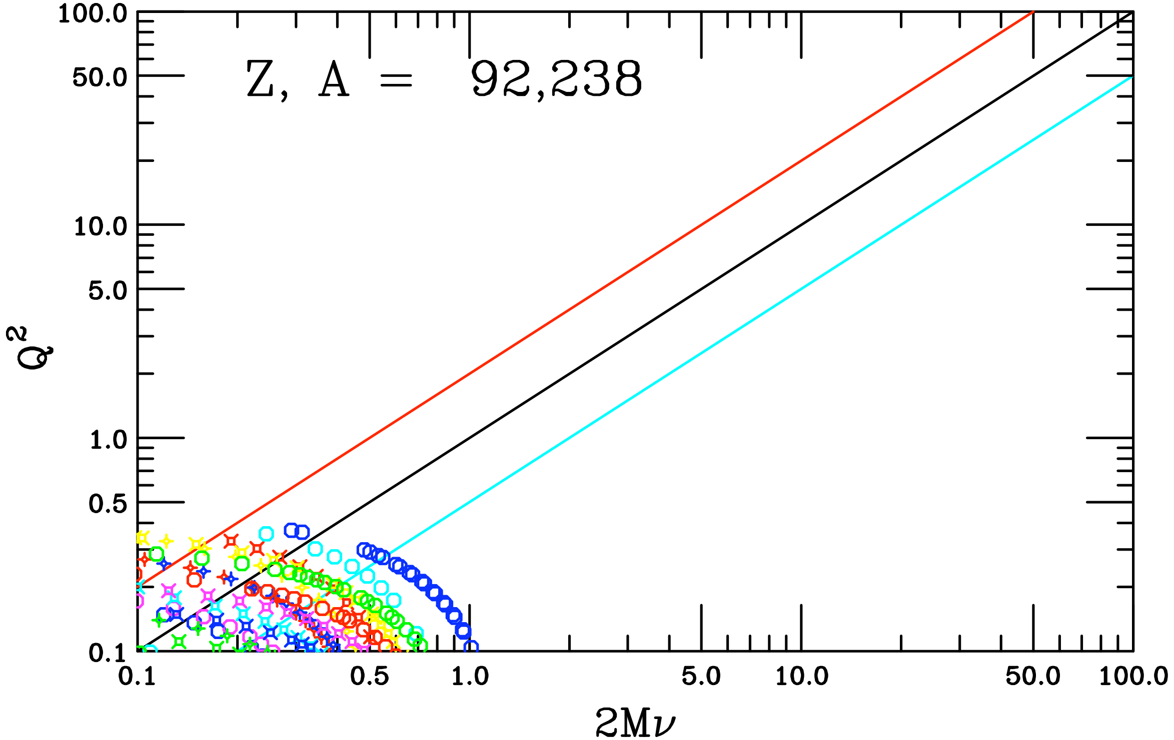
Calcium 48 n/p = 1.4



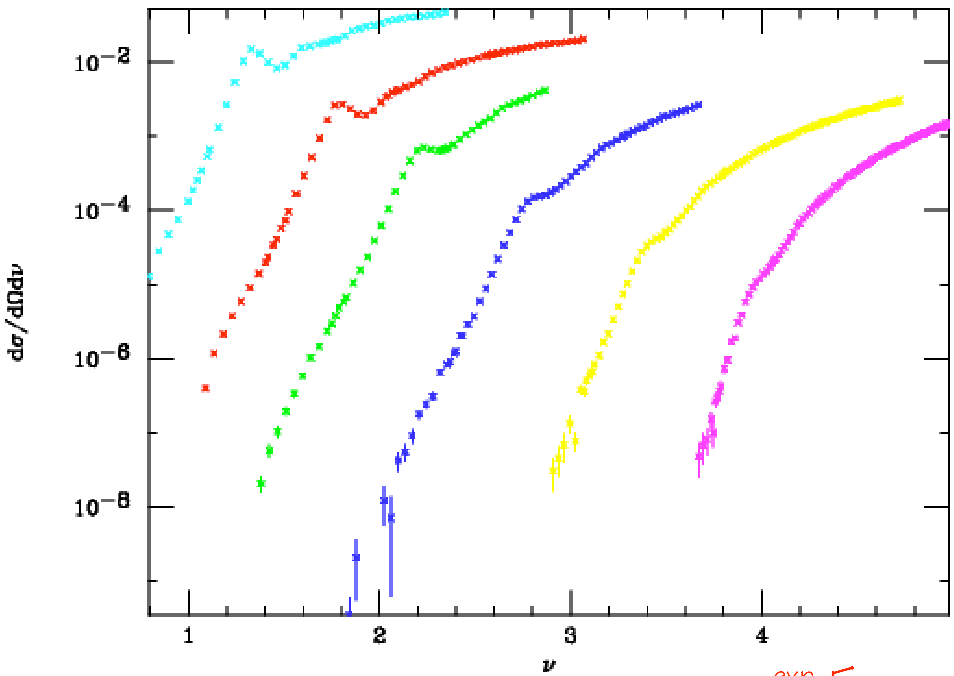


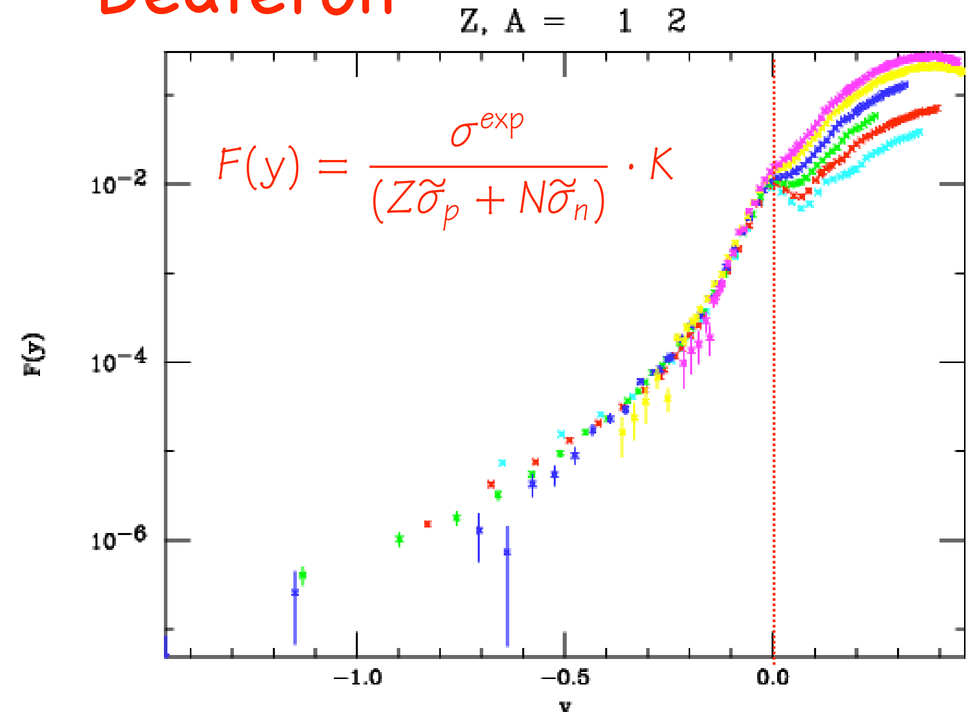
Lead n/p = 1.54

Uranium n/p = 1.6

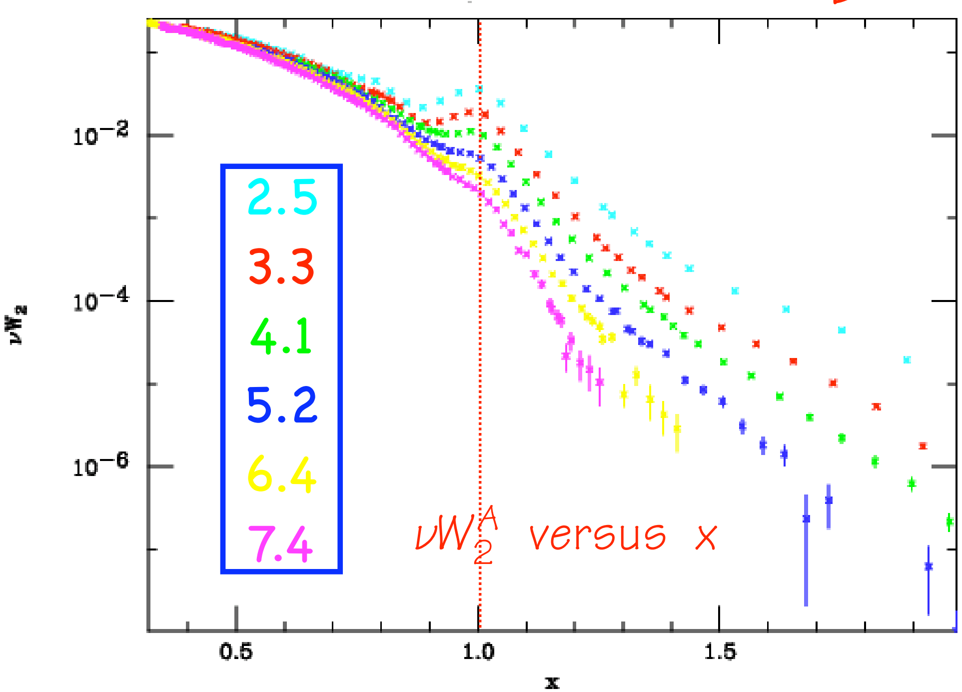


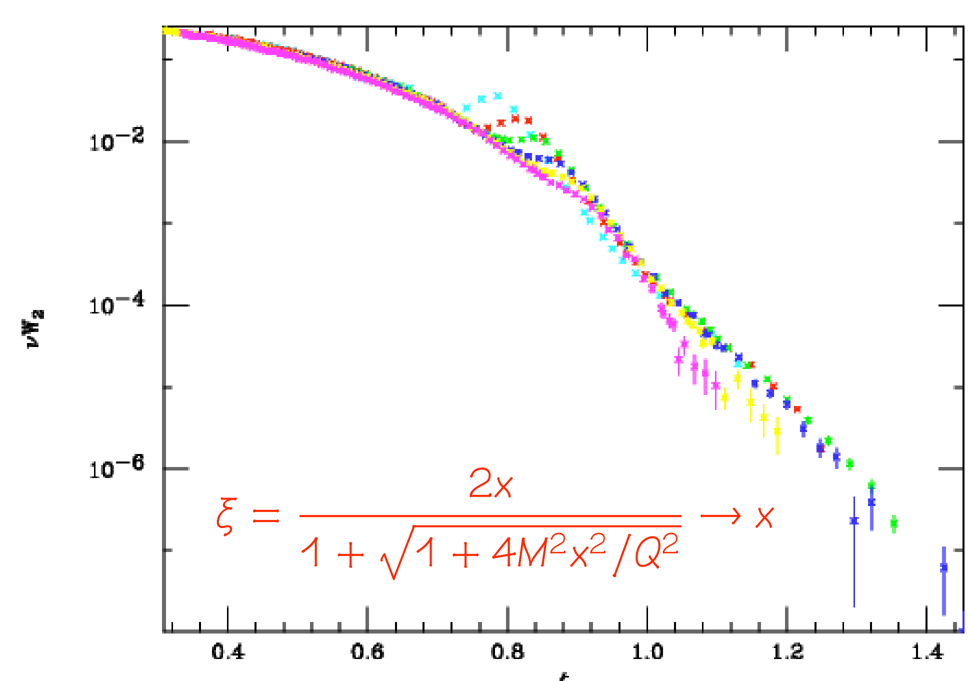
Preliminary Results (E02-019) - Deuteron



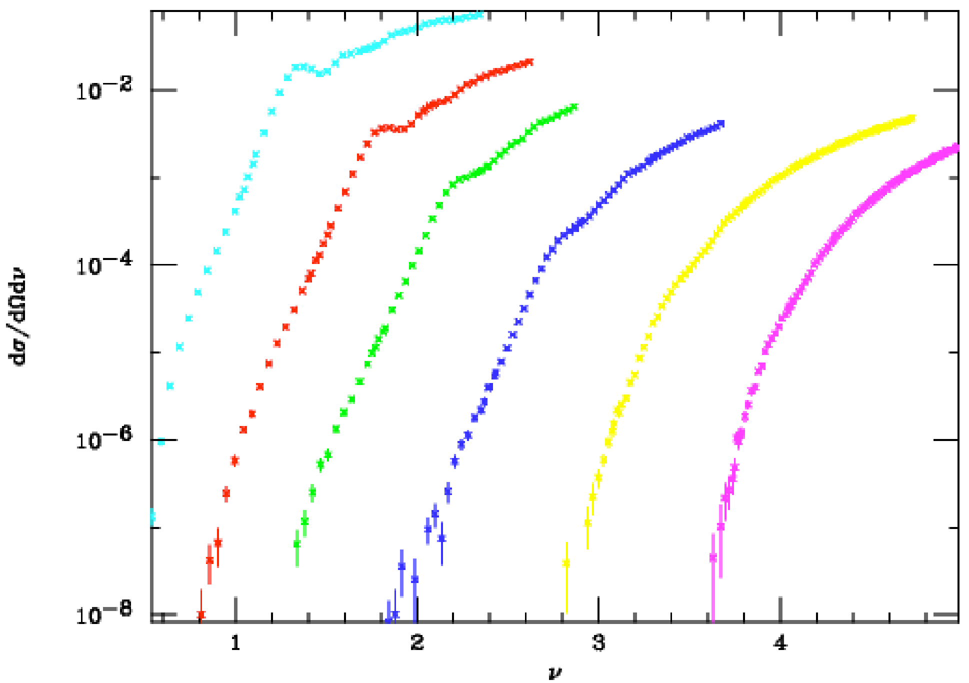


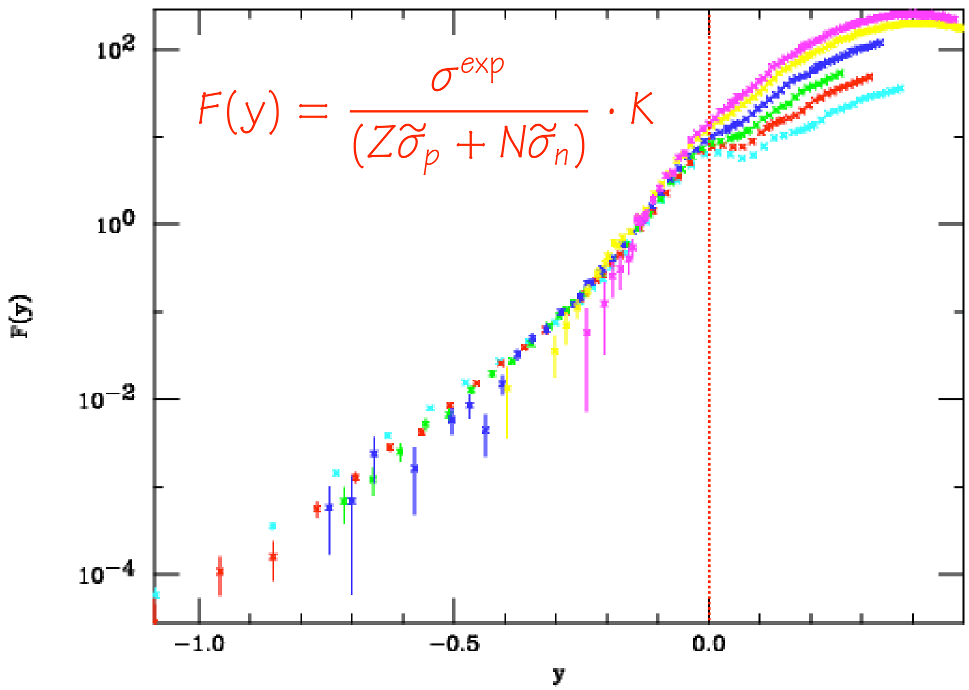
$$\nu W_2^A = \nu \cdot \frac{\sigma^{exp}}{\sigma_M}\left[1 + 2\tan^2(\theta/2)\cdot\left(\frac{1+\nu^2/Q^2}{1+R}\right)\right]^{-1}$$

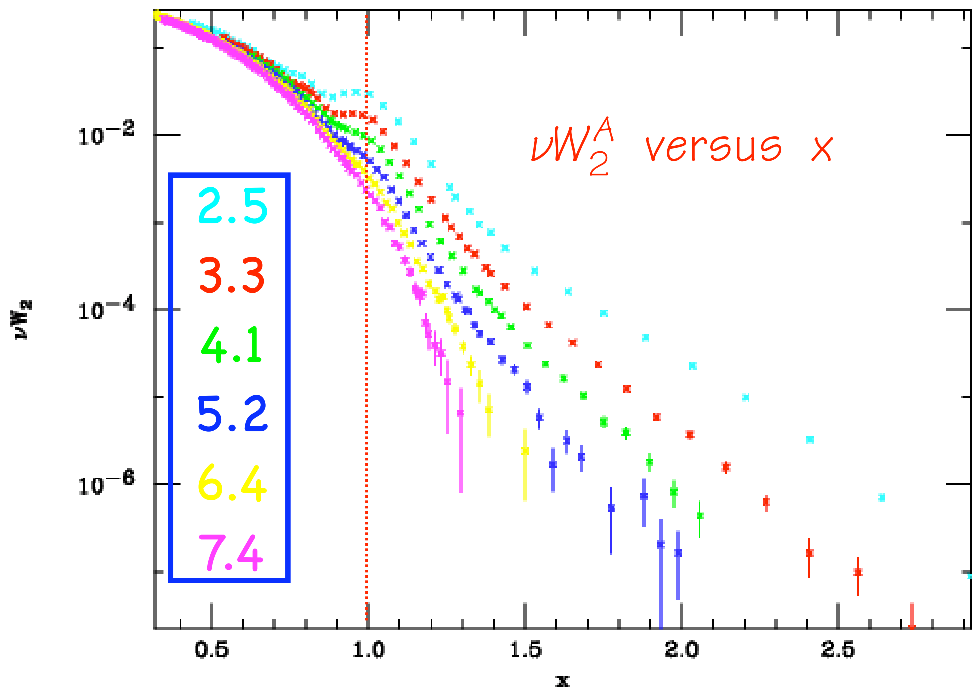


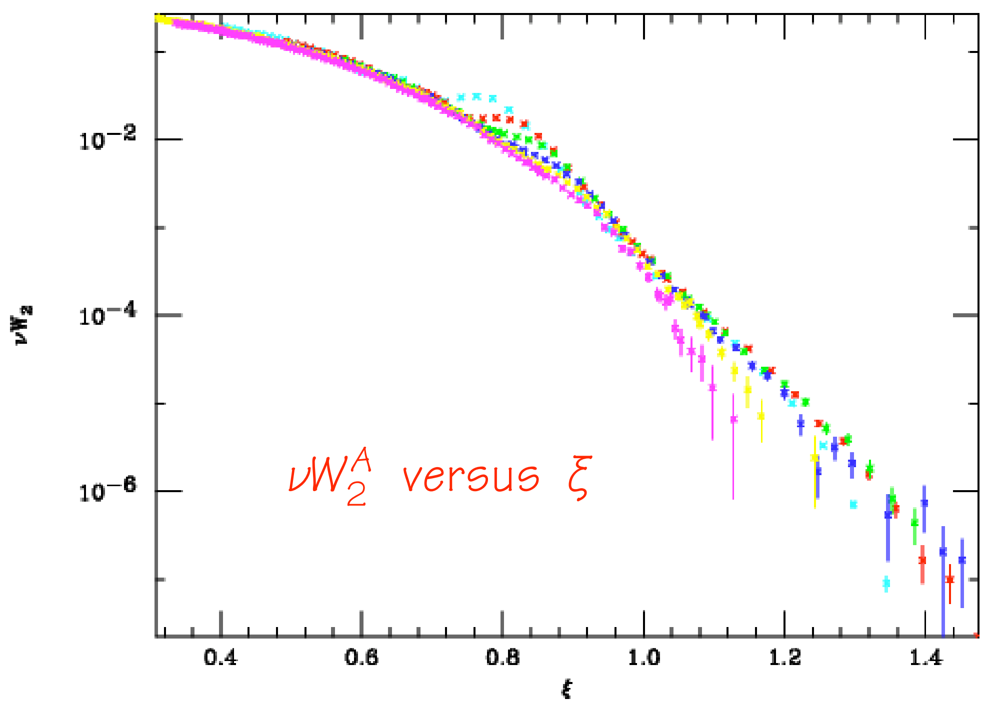


Preliminary Results (E02-019) - ^{3}He

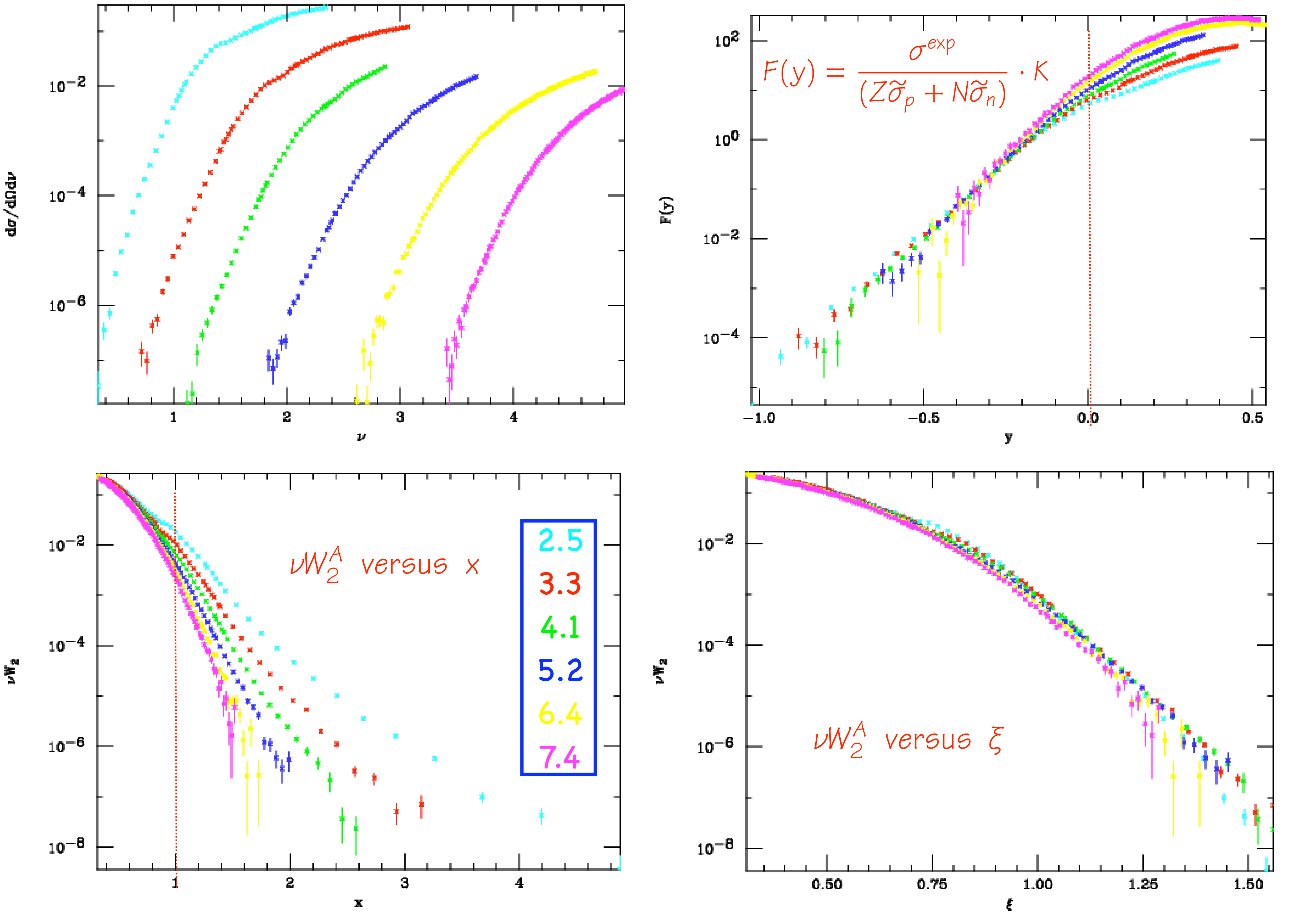


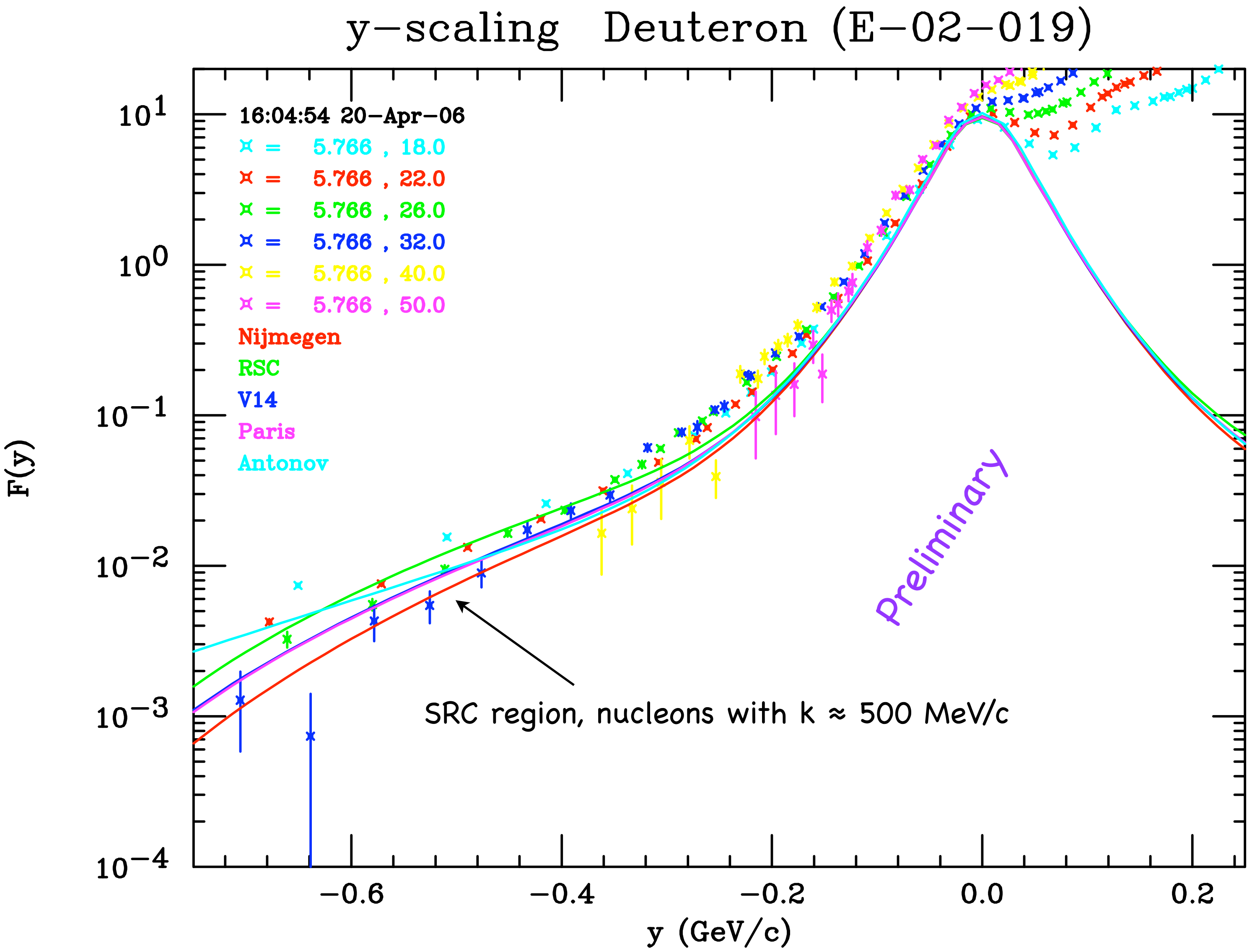






Preliminary Results (E02-019) - ^{12}C





Deuteron F(y) and calculations based on NN potentials

$S(k,E=2.2\text{MeV}) = n(k)$

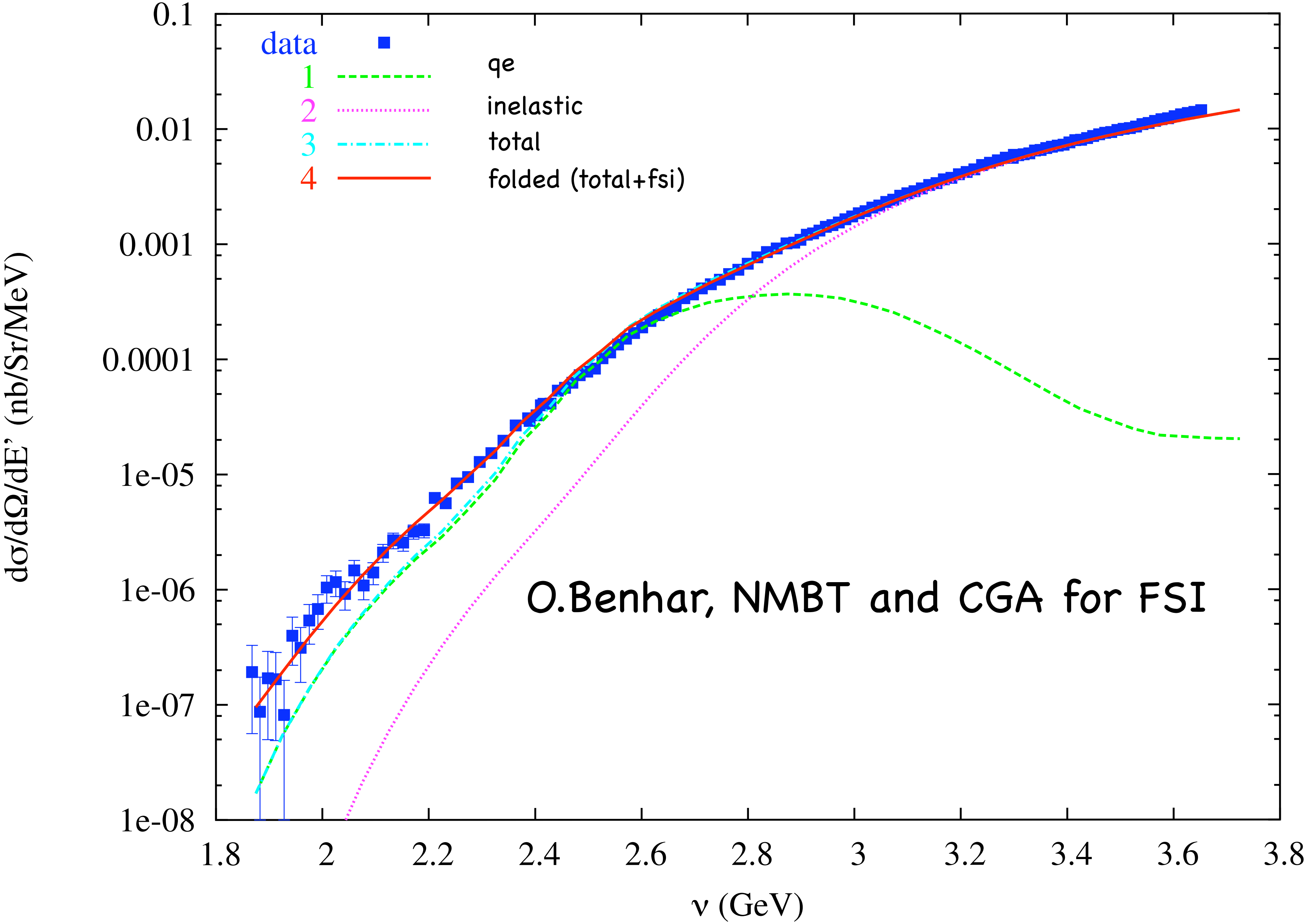
$$F(y) = \frac{\sigma^{exp}}{(Z\sigma_p + N\sigma_n)} \cdot K$$

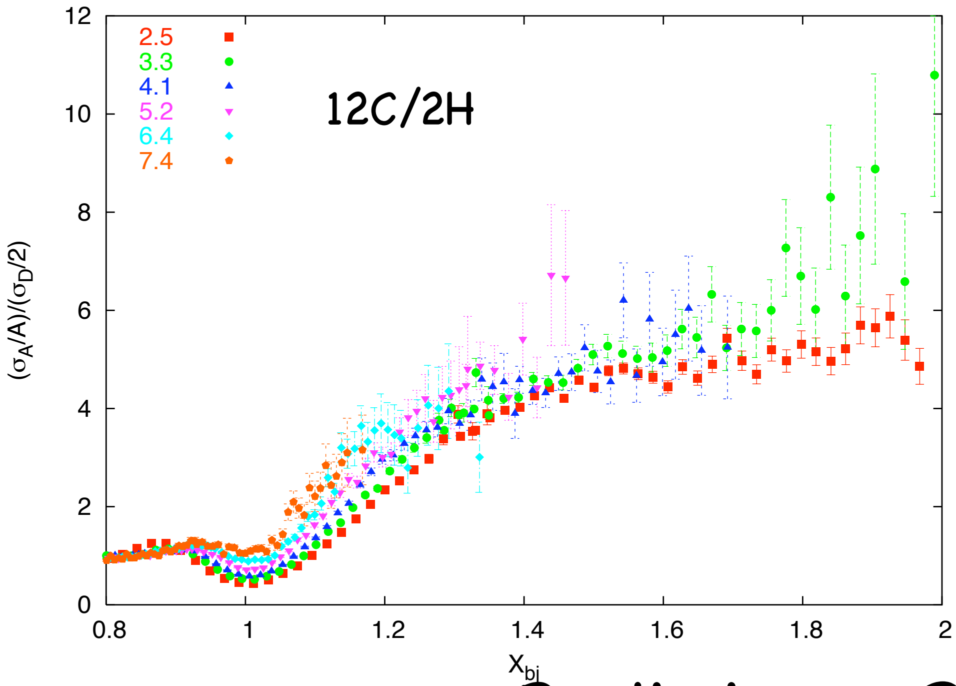
$$n(k) = -\frac{1}{2\pi y}\frac{dF(y)}{dy}$$

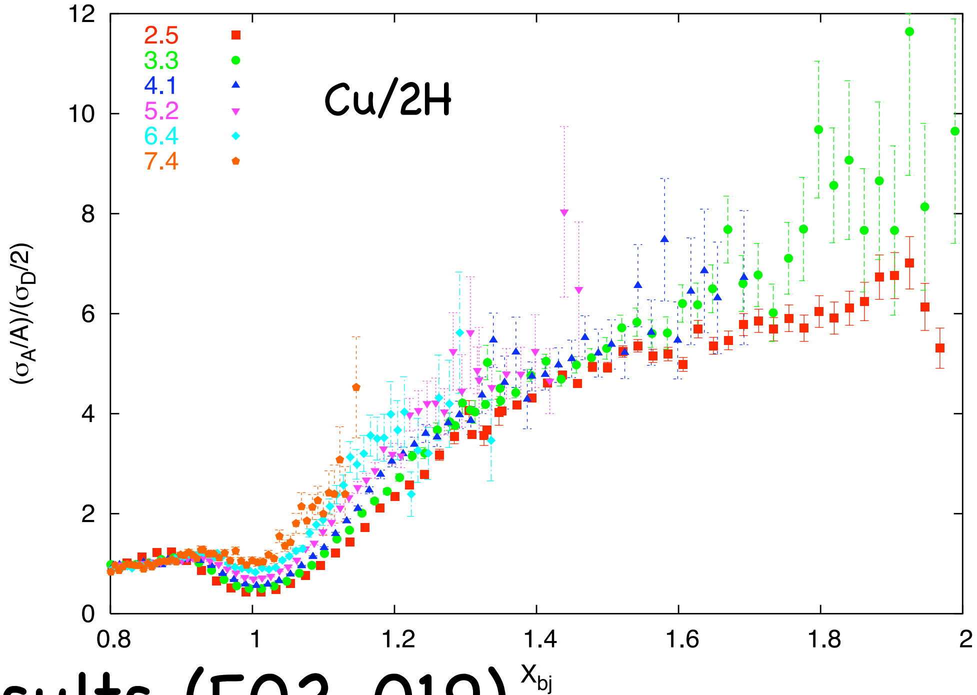
Assumption: scattering takes place from a quasi-free proton or neutron in the nucleus.

y is the momentum of the struck nucleon parallel to the momentum transfer: $y \approx -q/2 + m\nu/q$

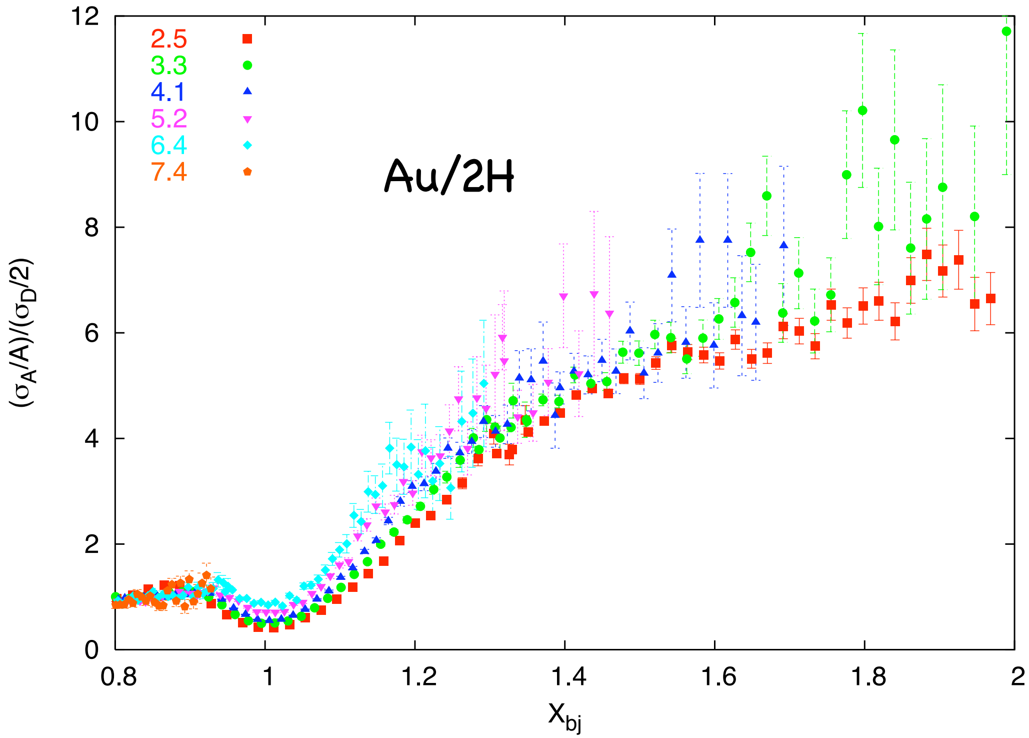
Carbon 5.766, 32 degrees, Q^2 = 5.2 $(GeV/c)^2$

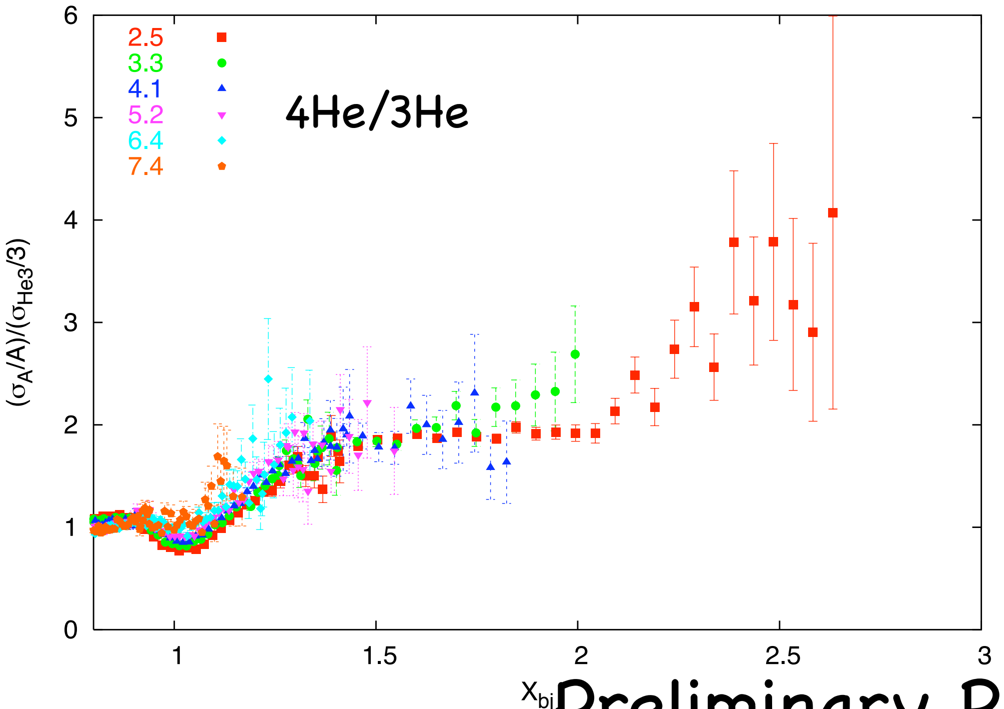


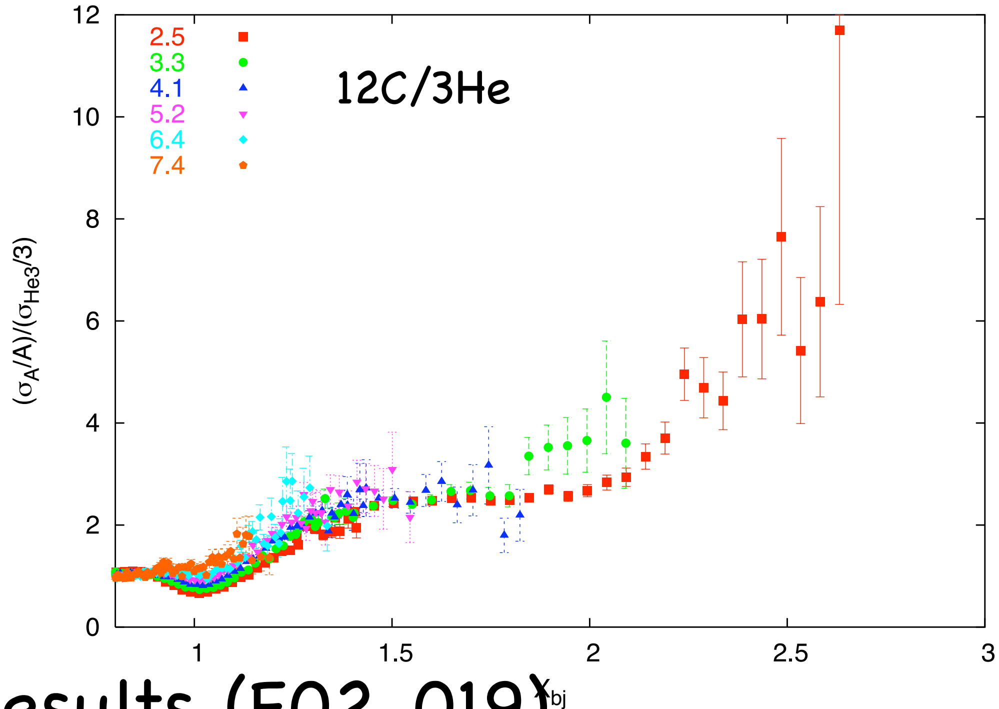




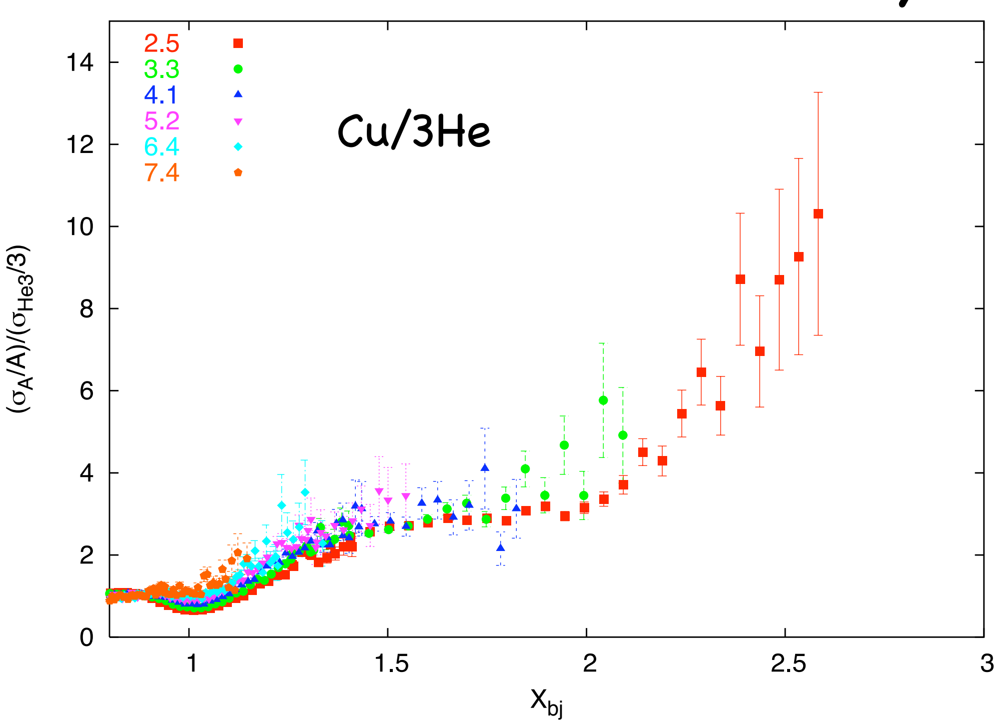
Preliminary Results (E02-019)

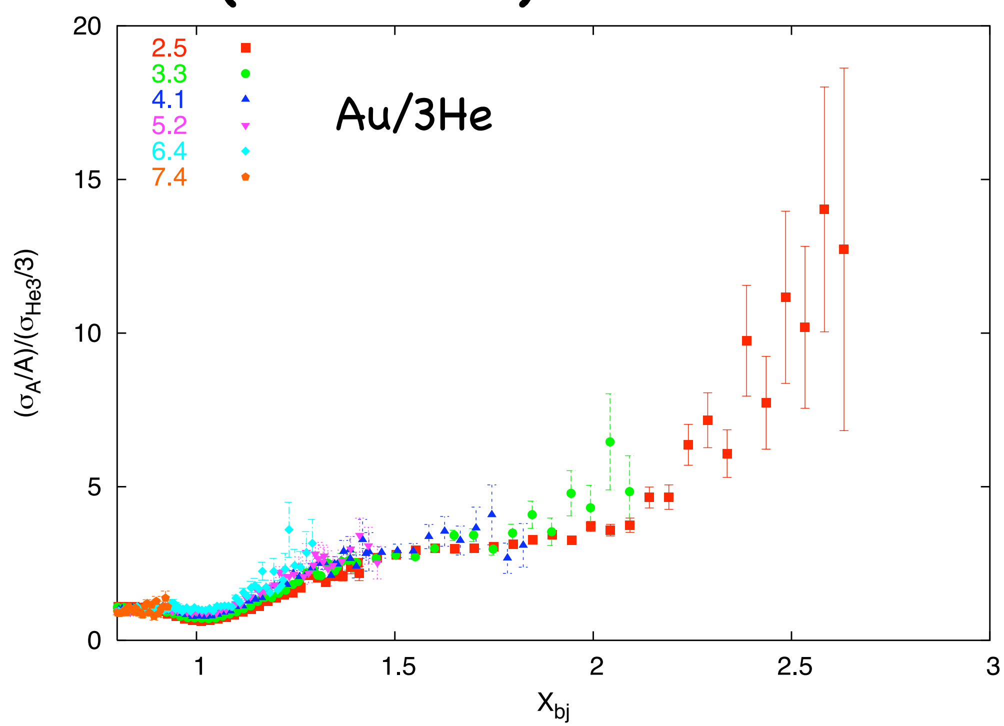






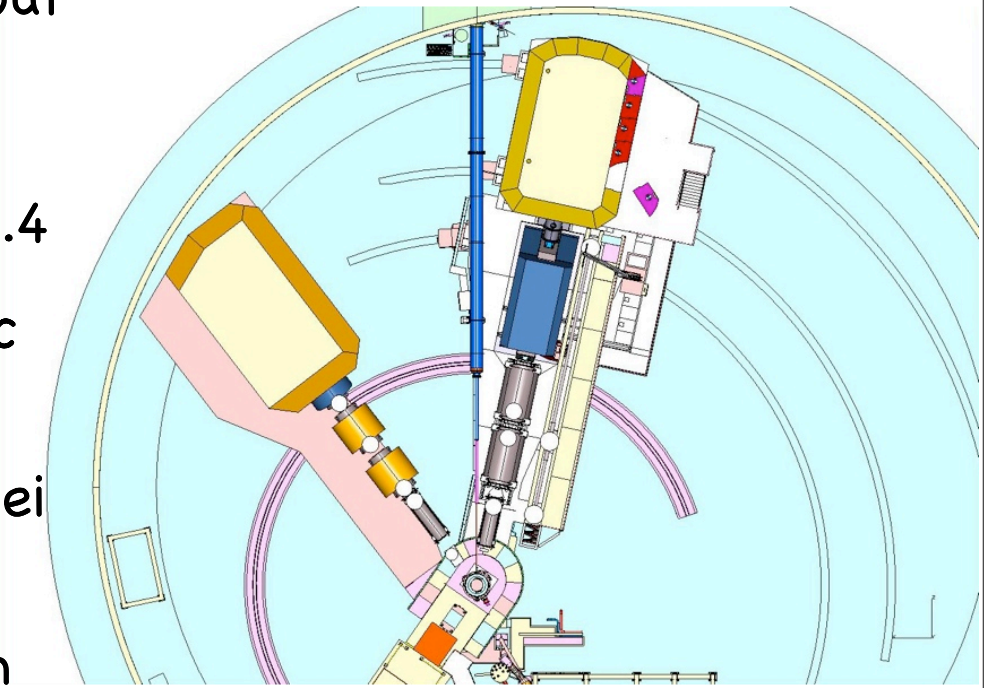
Preliminary Results (E02-019)



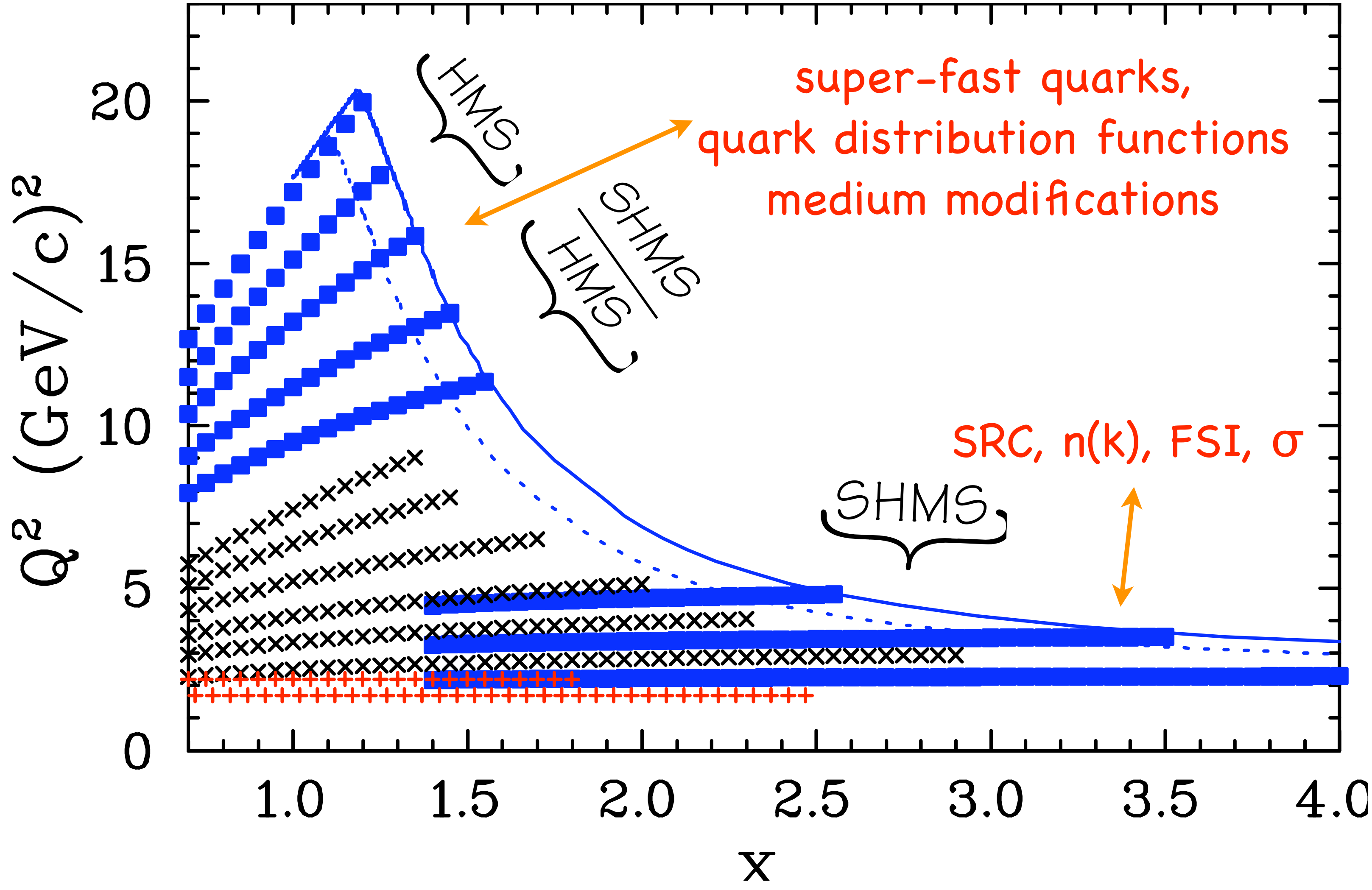


Inclusive DIS at x > 1 at 12 GeV

- New proposal approved at JLAB PAC30
- Target ratios (and absolute cross sections) in quasielastic regime: map out 2N, 3N, 4N correlations
- Measure nuclear structure functions (parton distributions) up to x = 1.3 - 1.4
  - Extremely sensitive to non-hadronic configurations
- Targets include several few-body nuclei allowing precise test of theory.
- Extend measurements to large enough Q^2 to fully suppress the quasielastic contribution
- Extract structure functions at x > 1
- $Q^2 \approx 20$ at x=1, $Q^2 \approx 12$ at x = 1.5



Kinematic range to be explored



Black - 6 GeV, red - CLAS, blue - 11 GeV

Finish

- Inclusive (e,e′) at large Q^2 scattering and x>1 holds great promise
  - Considerable body of data exists
- Provides access to SRC and high momentum components through y-scaling, ratios of heavy to light nuclei, allows systematic studies of FSI
- Testing ground for EMC models of medium modification
- DIS is does not dominate over QES at 6 GeV but should be at 11 GeV and at $Q^2 > 10 - 15$ $(GeV/c)^2$.
- Opportunities at 6 GeV still exist