Probing Short Range Correlations in Inclusive Electron–Nucleus Scattering at High Momentum Transfers

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Nuclear medium effects on the quark and gluon structure of hadrons

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Outline

✳ Correlations in nuclei

✳ Basic features of e-nucleus inclusive scattering

   ✳ Correlations in inclusive scattering

✳ Review of y, y_{cw}, x, ξ, α_{tn}

✳ Scaling functions, ratios

✳ New Data, Theory

✳ Future experiments

✳ Finish

Short Range Correlations (SRCs)

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

High momentum tails: $k > k_F$
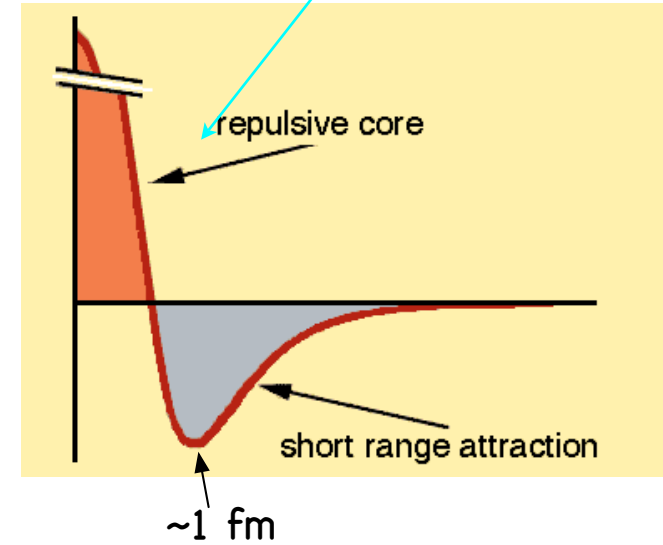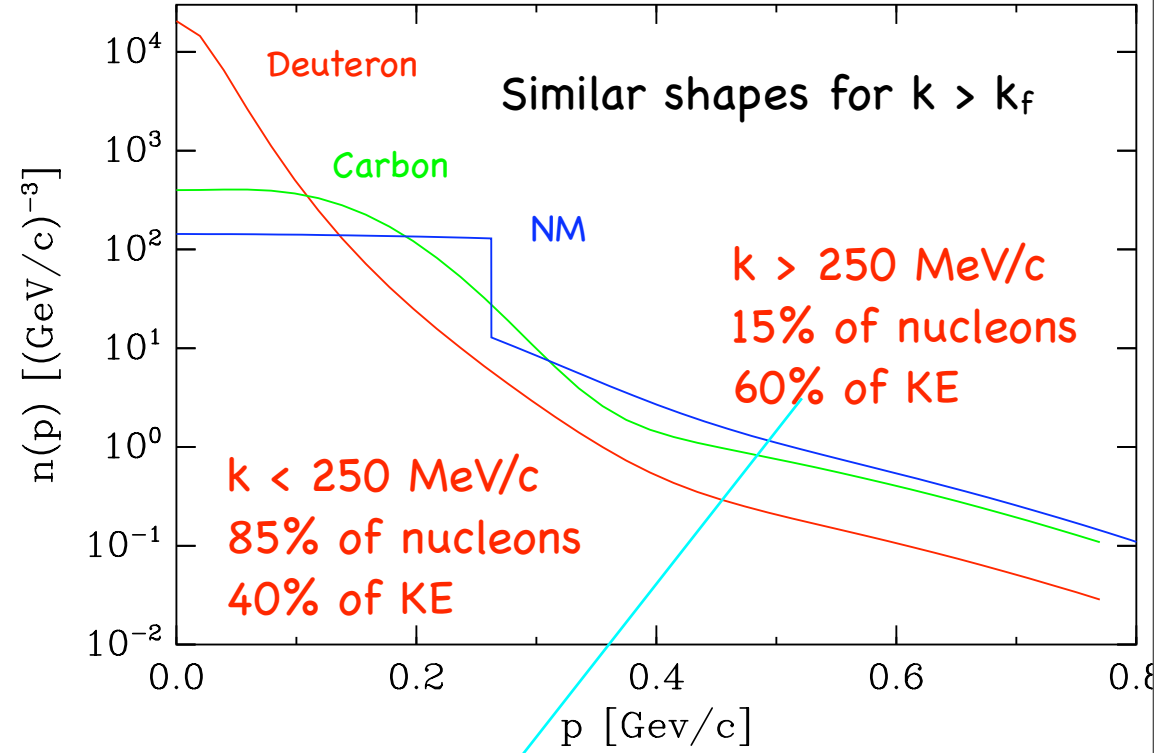Calculable for few-body nuclei, nuclear matter.

Dominated by two-nucleon short range correlations

Poorly understood part of nuclear structure
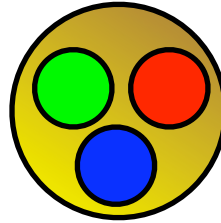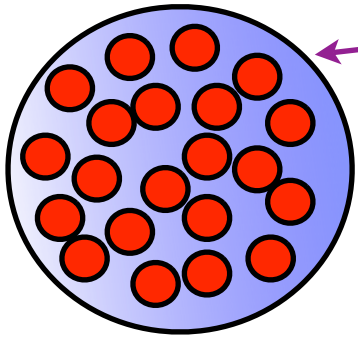
Sign. fraction have $k > k_F$

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')

Deuteron
Carbon
NM
Similar shapes for $k > k_f$

$k > 250$ MeV/c
15% of nucleons
60% of KE

$k < 250$ MeV/c
85% of nucleons
40% of KE

$n(p)$ [(GeV/c)$^{-3}$]

10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}

0.0   0.2   0.4   0.6   0.8
p [Gev/c]

repulsive core
short range attraction
~1 fm

Medium Modifications generated by high density configurations

Gold nucleus
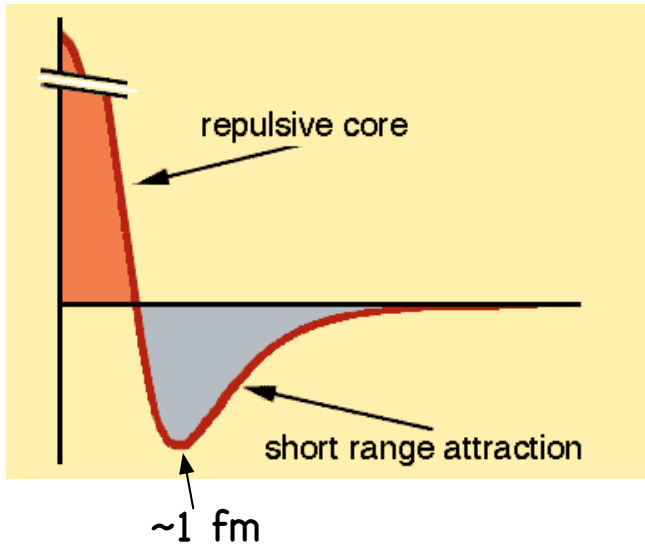
$$R = 1.2A^{1/3}$$
$$Volume = \frac{4}{3}\pi R^3 \simeq 1400 fm^3$$

A single nucleon, r = 1 fm, has a volume of 4.2 fm³
197 times 4.2 fm³ ≈ 830 fm³

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

repulsive core

short range attraction

~1 fm

Nucleon separation is limited by the short range repulsive core

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

1.7 fm separation

ρ [fm⁻³]

r [fm]

0.6 fm separation

> 5 times nuclear matter densities

ρ [fm⁻³]

r [fm]

Comparable to neutron star densities!

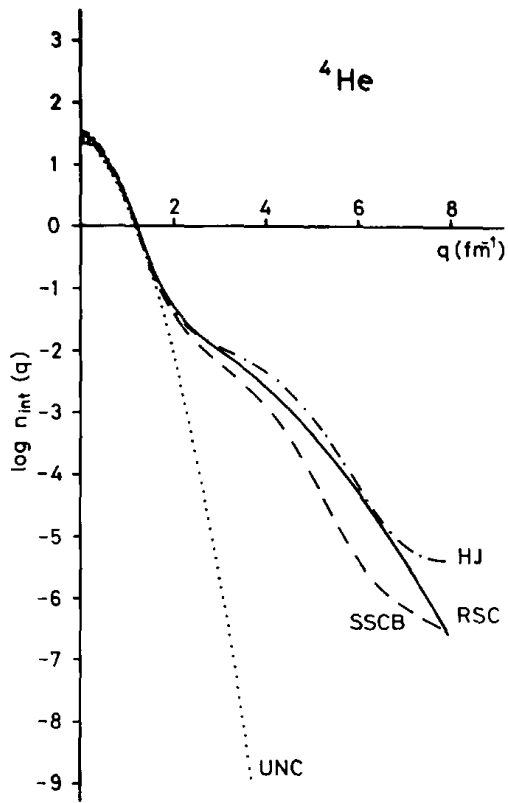## High enough to modify nucleon structure?

To which nucleon does the quark belong?
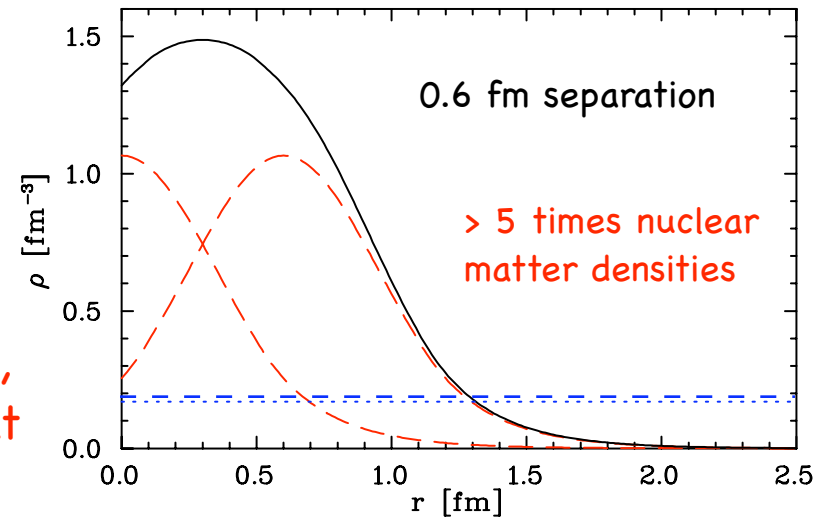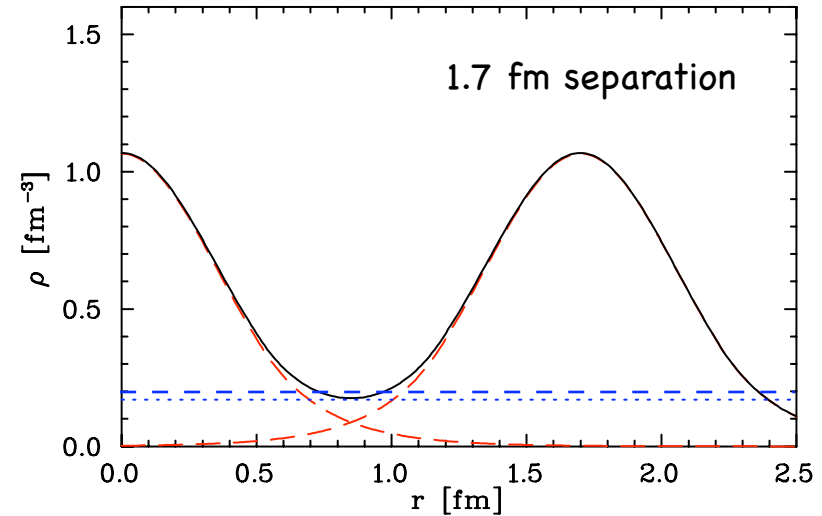
Fig. 2. Momentum distributions for ^{4}He, HJ: Hamada–Johnston potential, RSC: Reid soft core potential, SSCB: de Tourreil–Sprung super soft core potential B, UNC: uncorrelated, for the RSC potential. The other uncorrelated distributions do not differ appreciably for $q > 2$ fm^{-1}.

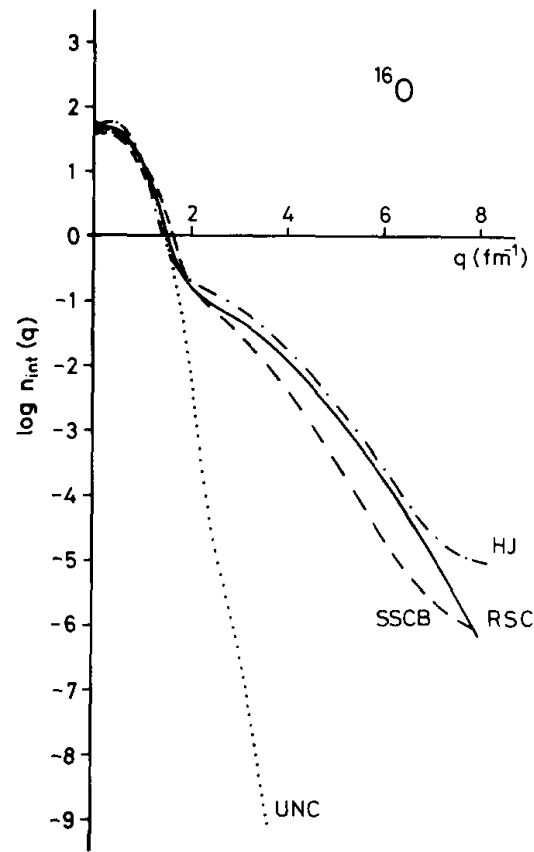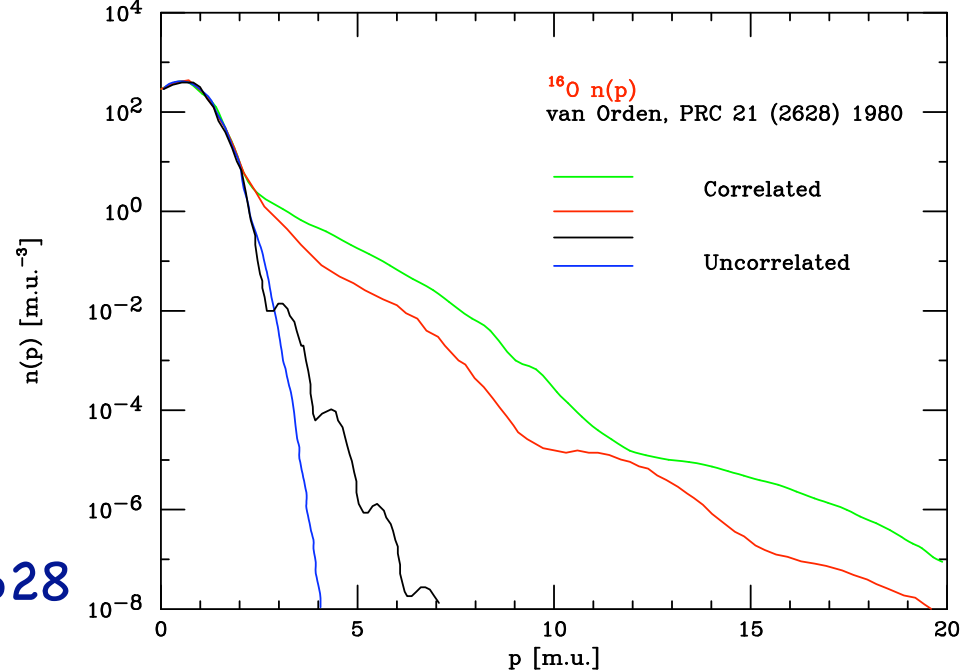Fig. 3. Same as fig. 2, for ^{16}O.

Calculations of SRC

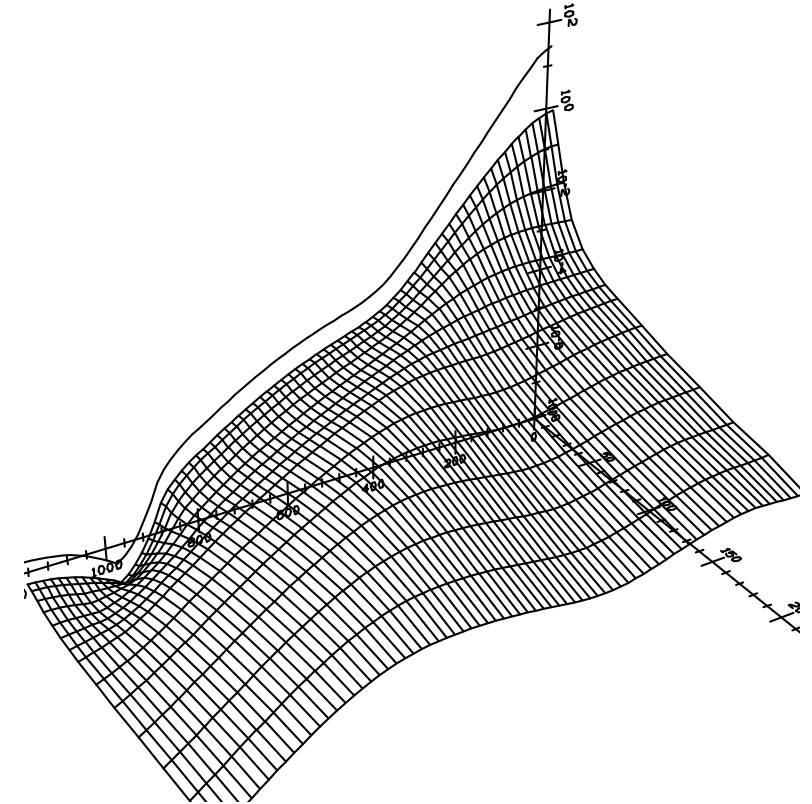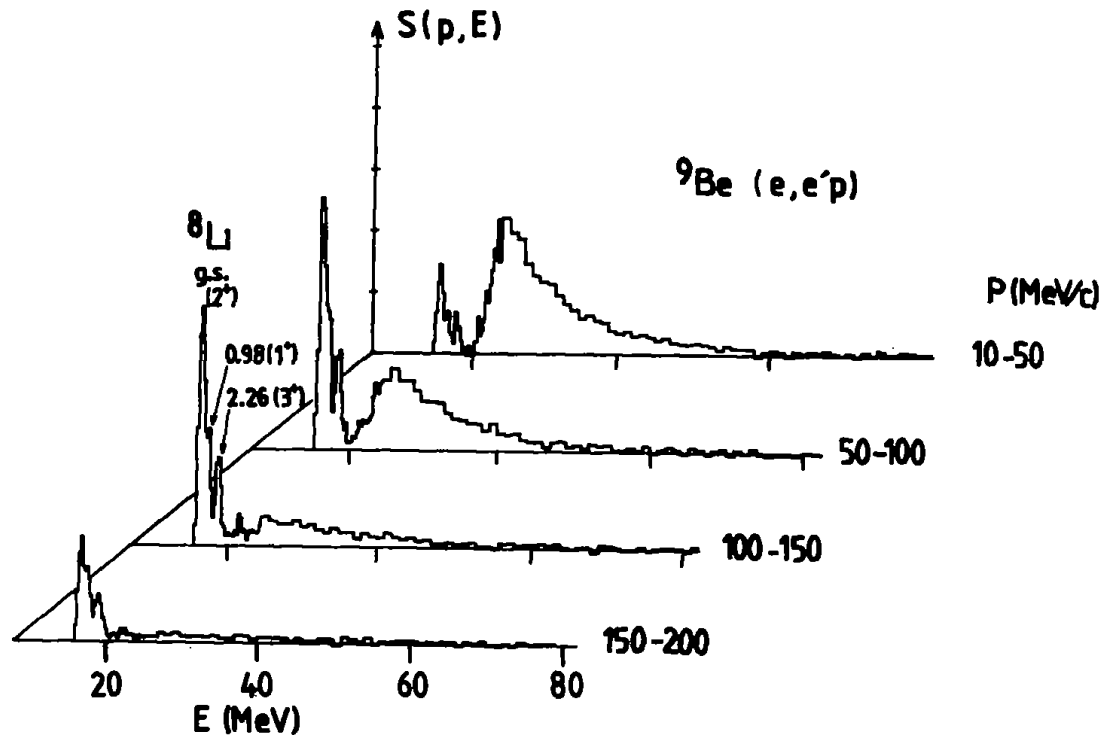Show up at large momentum

Zabolitzky and Ey, PLB 76, 527

Van Orden et al., PRC21, 2628

Spectral function S(E, k), not n(k) describes nuclei:

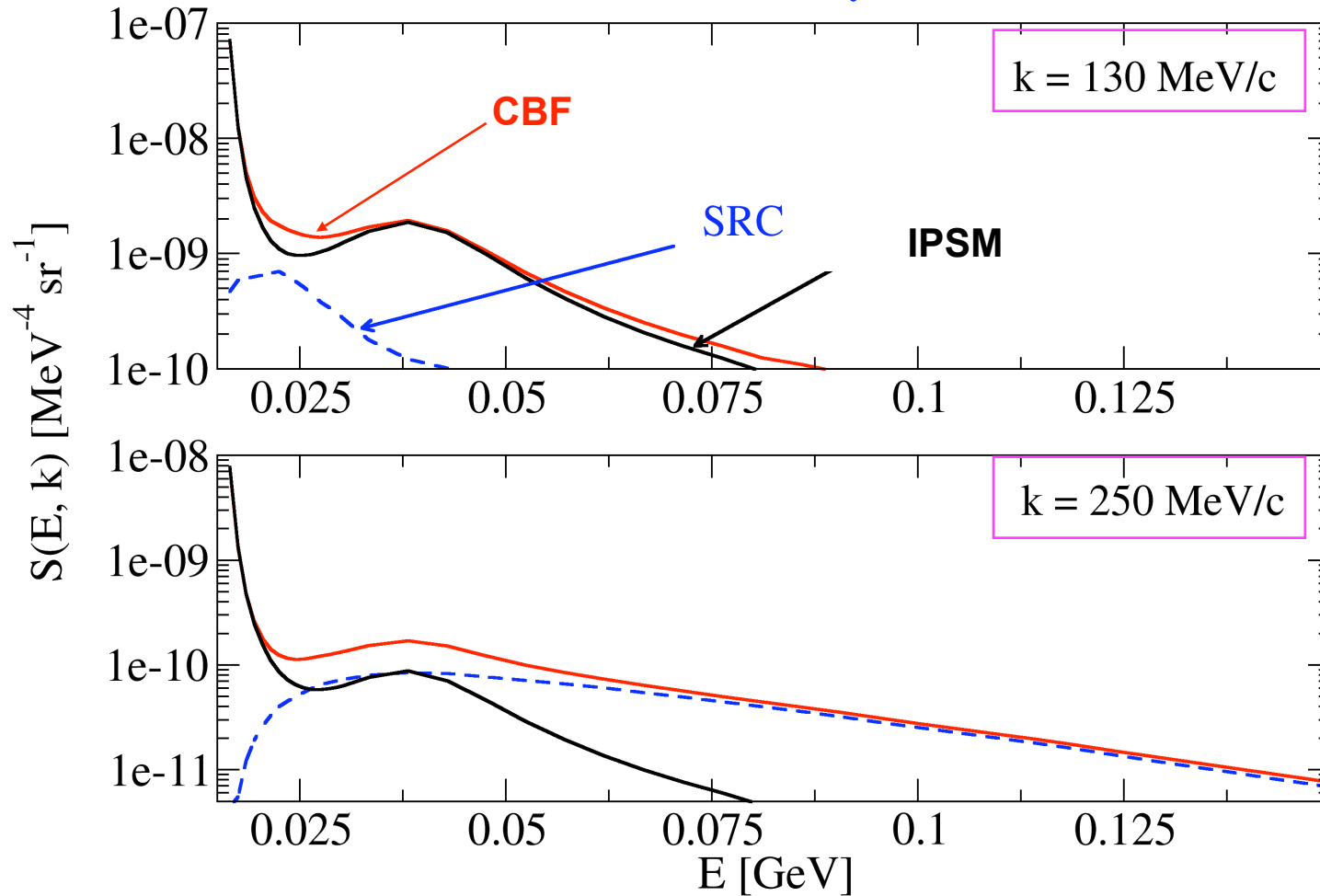probability of finding a proton with initial momentum k and energy E in the nucleus

There is a correlation between momenta and separation energy:
high momenta, k, are associated with large $E \approx k^2/2M$

Spectral function for ^{12}C
## CBF theory

Benhar via Rohe

$\approx k_F$

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
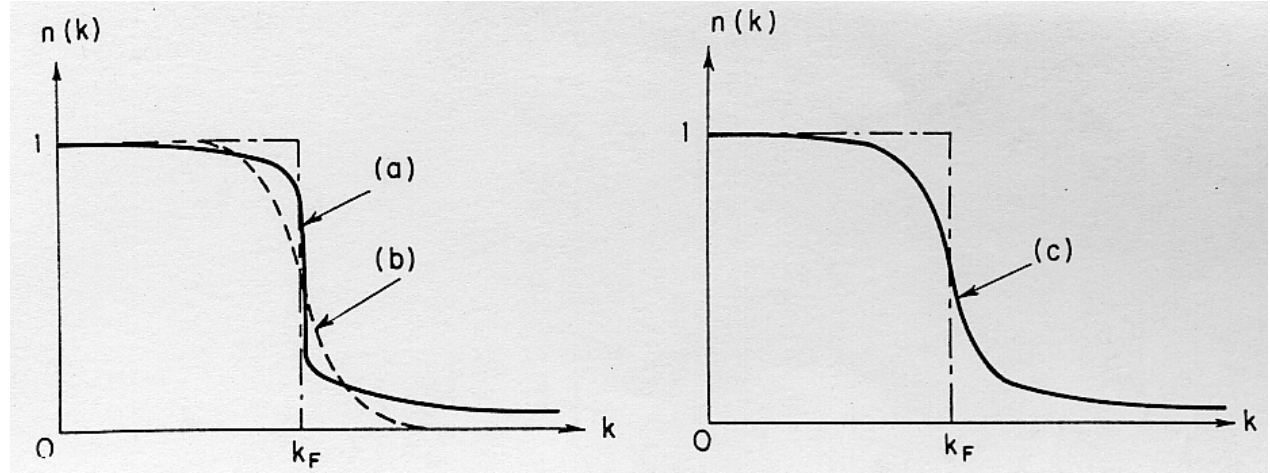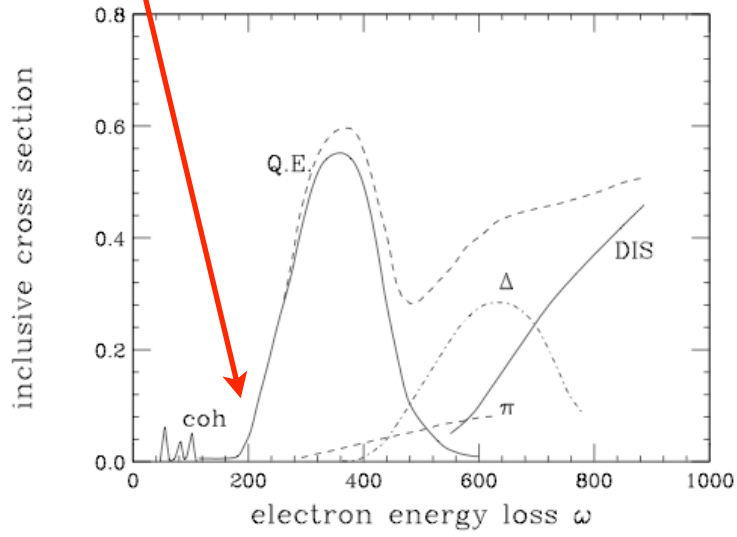
Correlations and Inclusive Electron Scattering

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

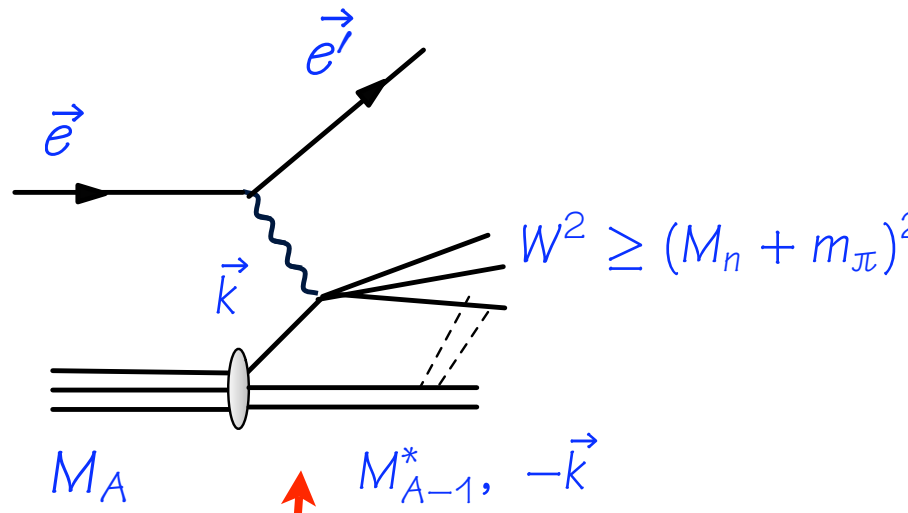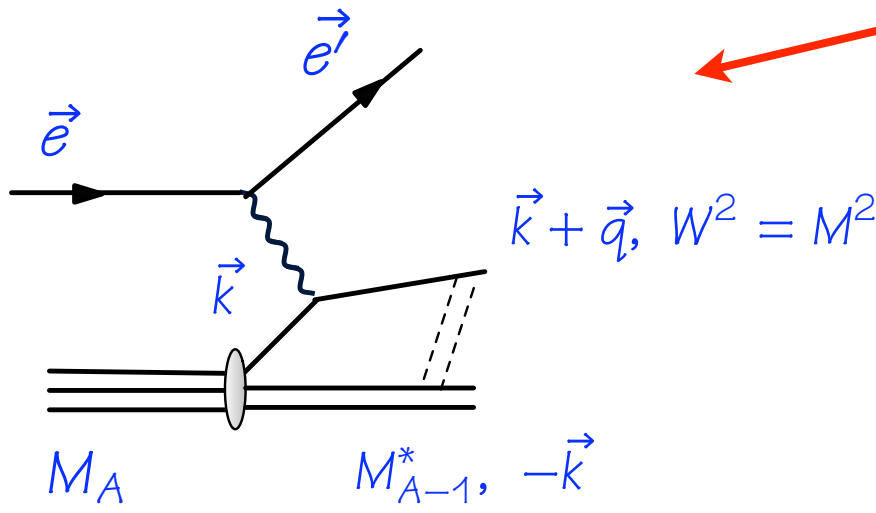$$\omega_c = \frac{(k+q)^2}{2m} + \frac{q^2}{2m} \qquad \omega_c' = \frac{q^2}{2m} - \frac{qk_f}{2m}$$
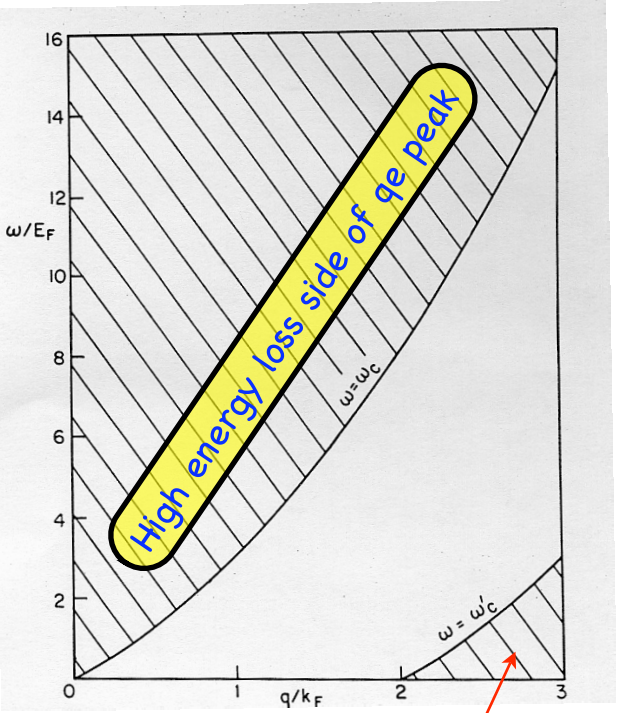
Czyz and Gottfried proposed to replace the Fermi n(k) with that of an actual nucleus. (a) hard core gas; (b) finite system of noninteracting fermions; (c) actual large nucleus.

Inclusive Electron Scattering from Nuclei

Two dominant and distinct processes

Quasielastic from the nucleons in the nucleus

$\vec{e}$ $\vec{e'}$

$\vec{k} + \vec{q}, \ W^2 = M^2$

$\vec{k}$

M_A $M^*_{A-1}, \ -\vec{k}$

$\vec{e}$ $\vec{e'}$

$W^2 \geq (M_n + m_\pi)^2$
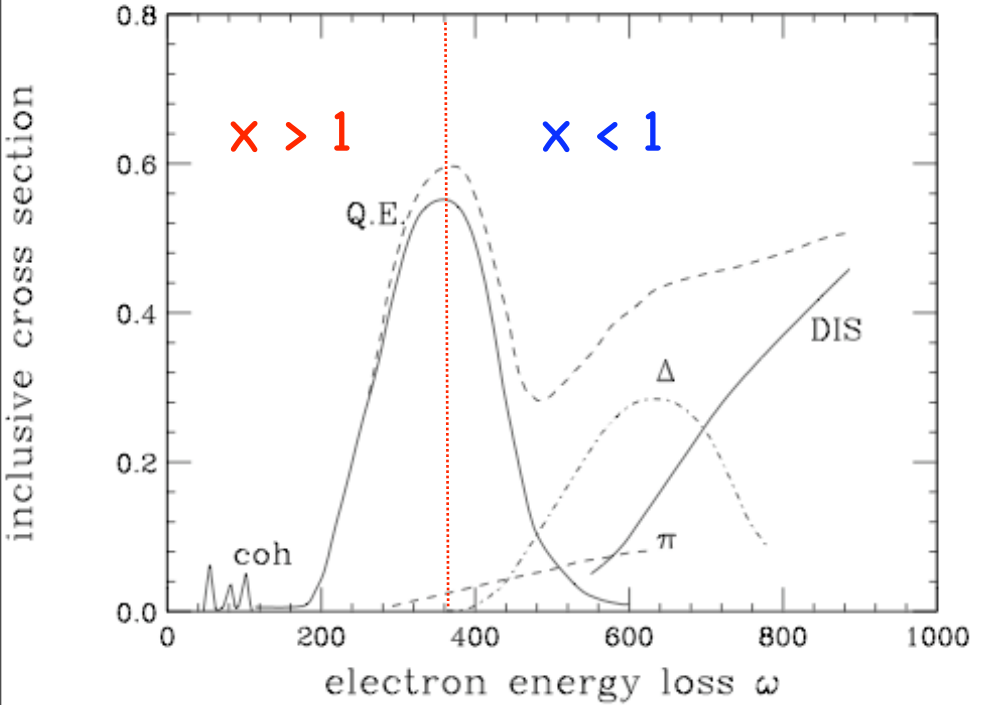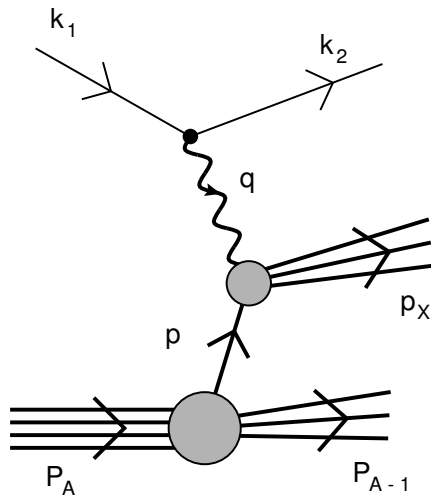
$\vec{k}$

M_A $M^*_{A-1}, \ -\vec{k}$

Inelastic and DIS from the quark constituents of the nucleon.

x > 1   x < 1

Inclusive final state means no separation of two dominant processes

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

υ, ω=energy loss

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

> 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

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

The limits on the integrals are determined by the kinematics. Specific (x, Q²) select specific pieces of the spectral function.
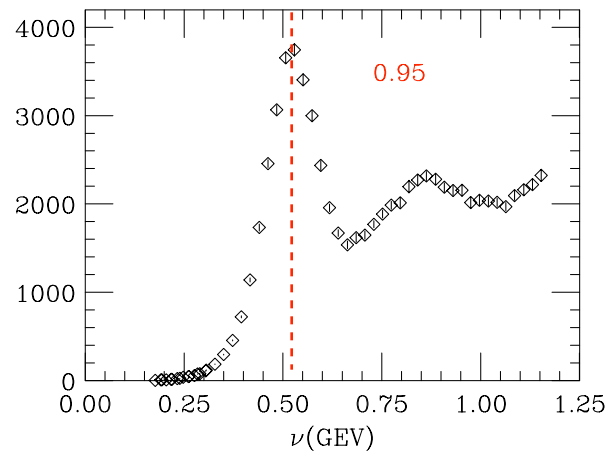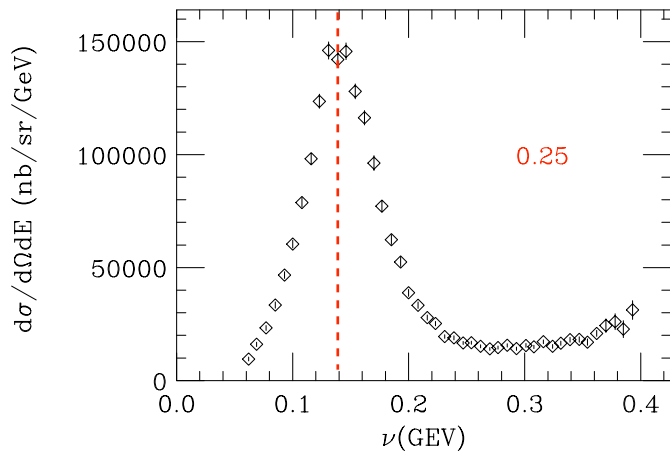
DIS

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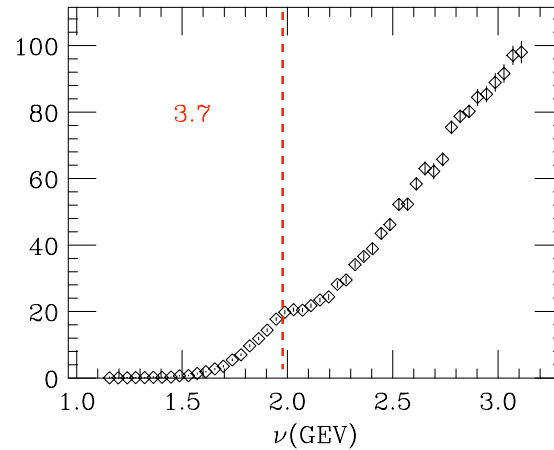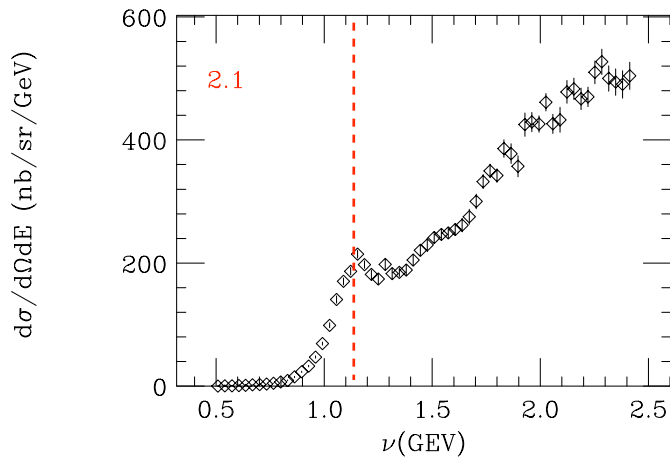
$$n(k) = \int dE \, S(k,E)$$

However they have very different Q² dependencies

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

**Exploit this dissimilar Q² dependence**

³He SLAC (1979)

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 $Q^2 \gg$ 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.
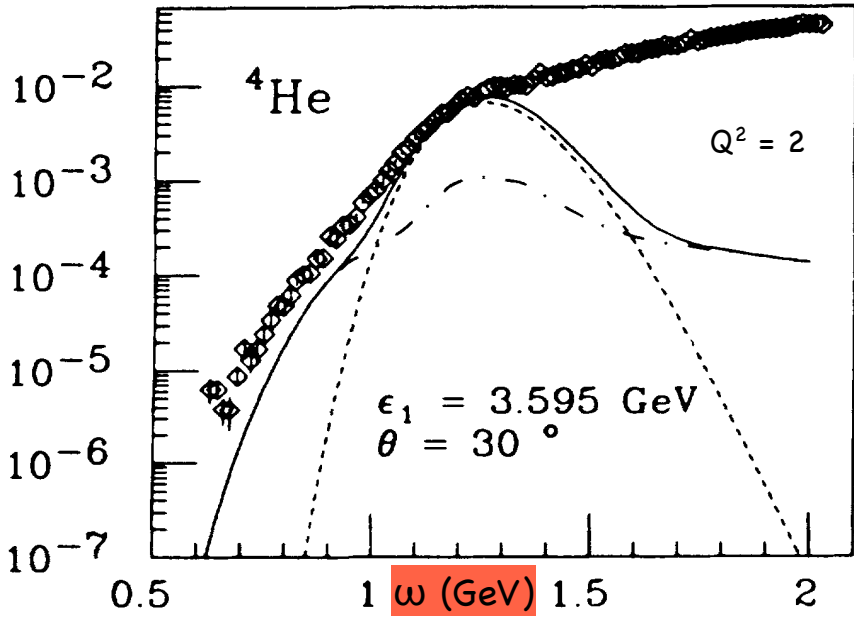
A dependence: higher internal momenta broadens the peak
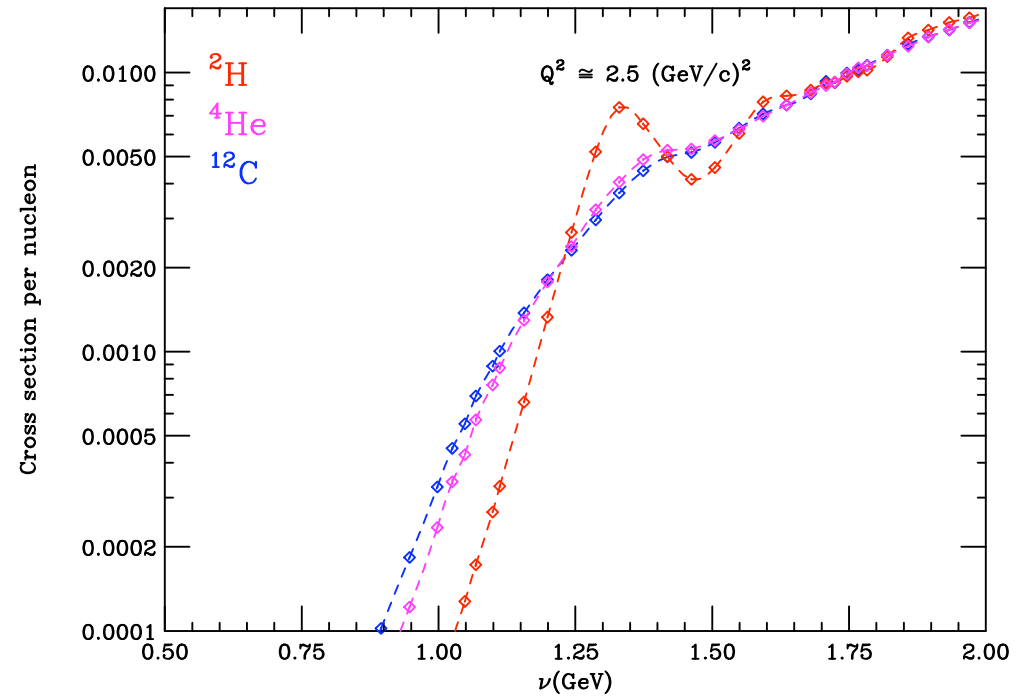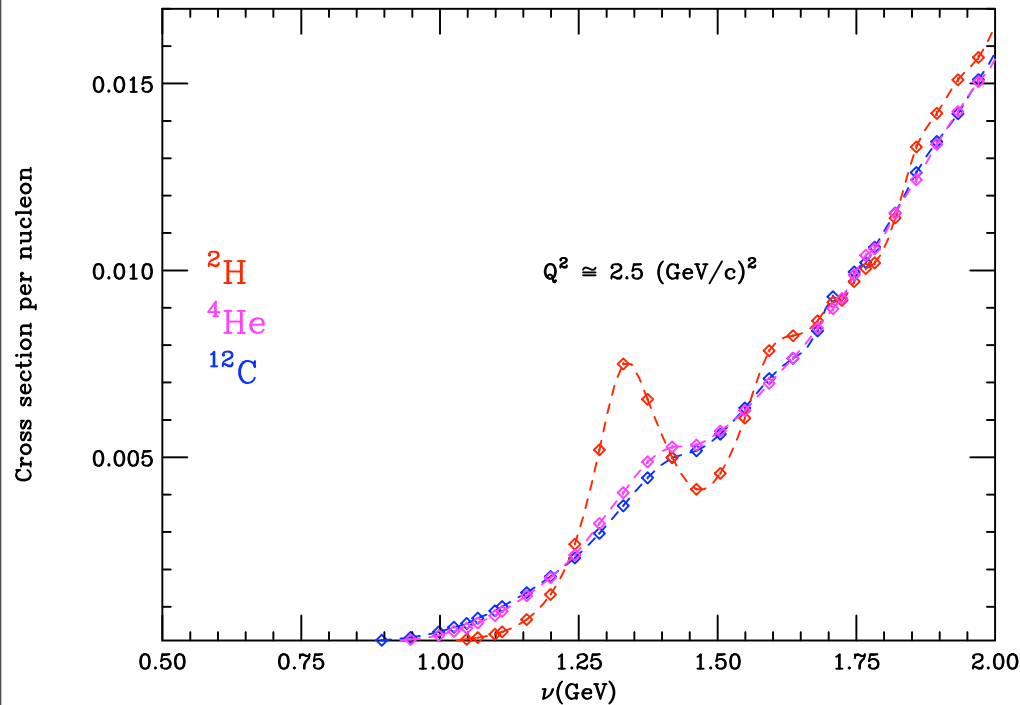
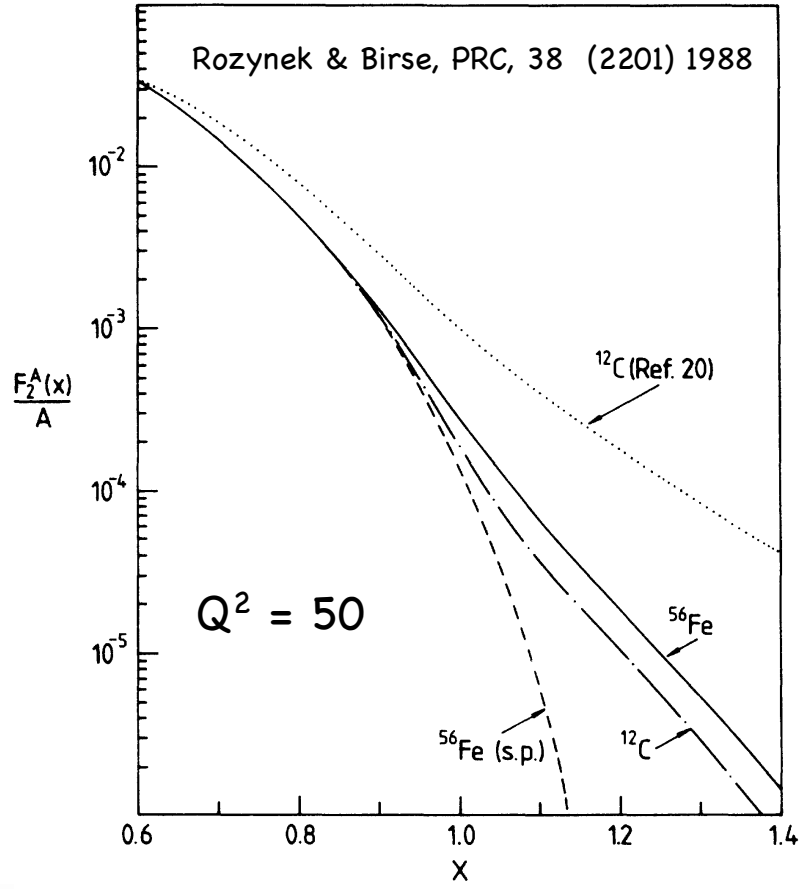$$\Delta\omega = \sqrt{(\vec{k_f} + \vec{q})^2 + m^2} - \sqrt{(\vec{k_f} + \vec{q})^2 + m^2}$$

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

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

^{4}He

$Q^2 = 2$

$\epsilon_1 = 3.595$ GeV
$\theta = 30°$

ω (GeV)

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

L. Conci and M. Traini, UTF 261/92.

^{12}C

$F_2^A(x)$

X

Rozynek & Birse, PRC, 38 (2201) 1988

$\frac{F_2^A(x)}{A}$

^{12}C (Ref. 20)

$Q^2 = 50$

^{56}Fe

^{56}Fe (s.p.)

^{12}C

X
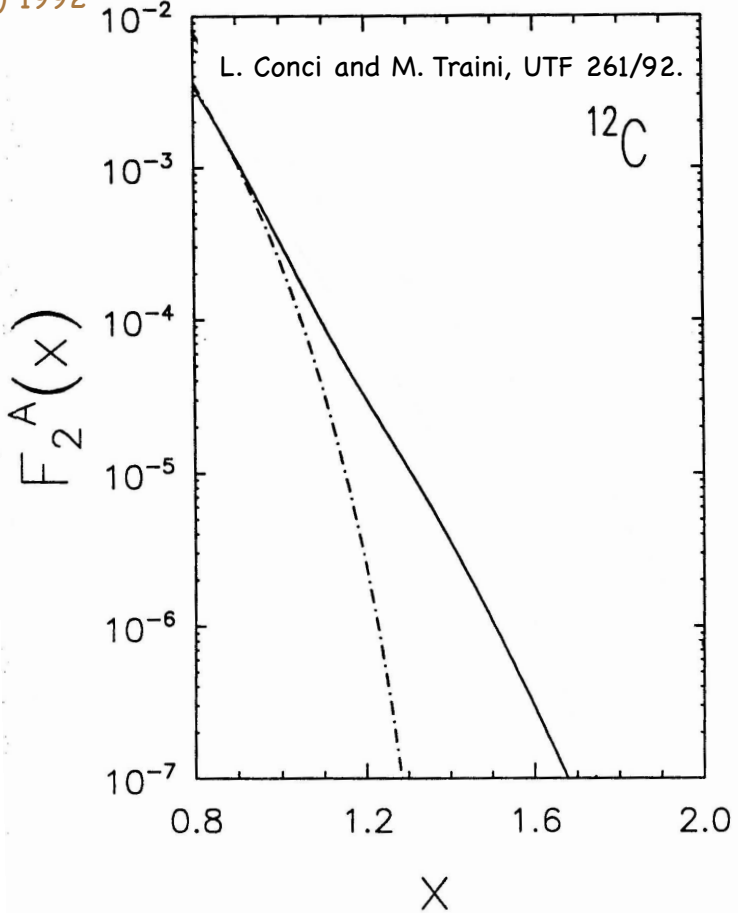
Final State Interactions
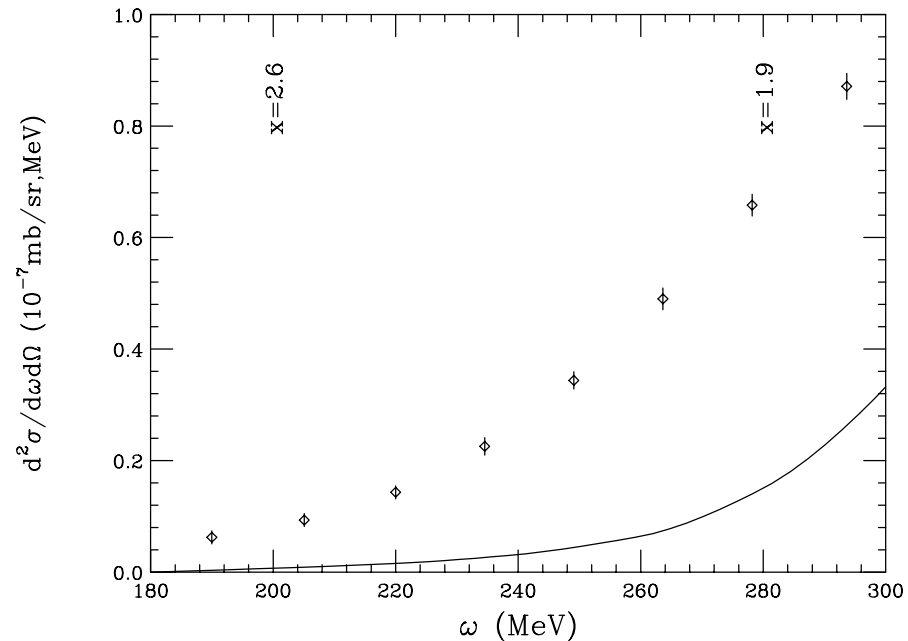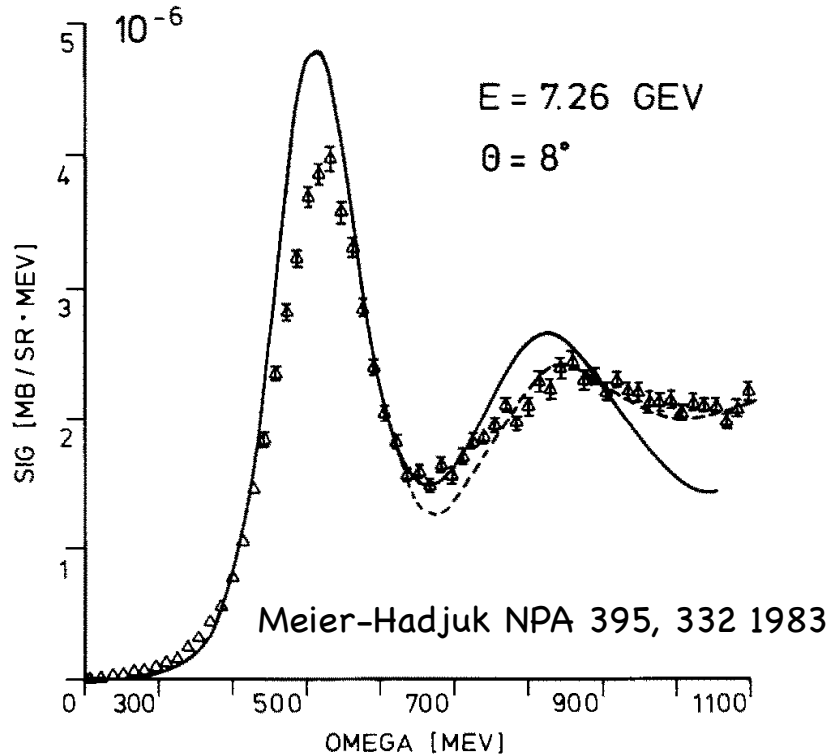
In (e,e'p) flux of outgoing protons strongly suppressed: 20-40% in C, 50-70% in Au

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


Meier-Hadjuk NPA 395, 332 1983

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

⁴He at 3.595, 30°

d²σ/dΩdω (μb/sr GeV) vs energy loss ω(GeV)

CGA

CGA + CT
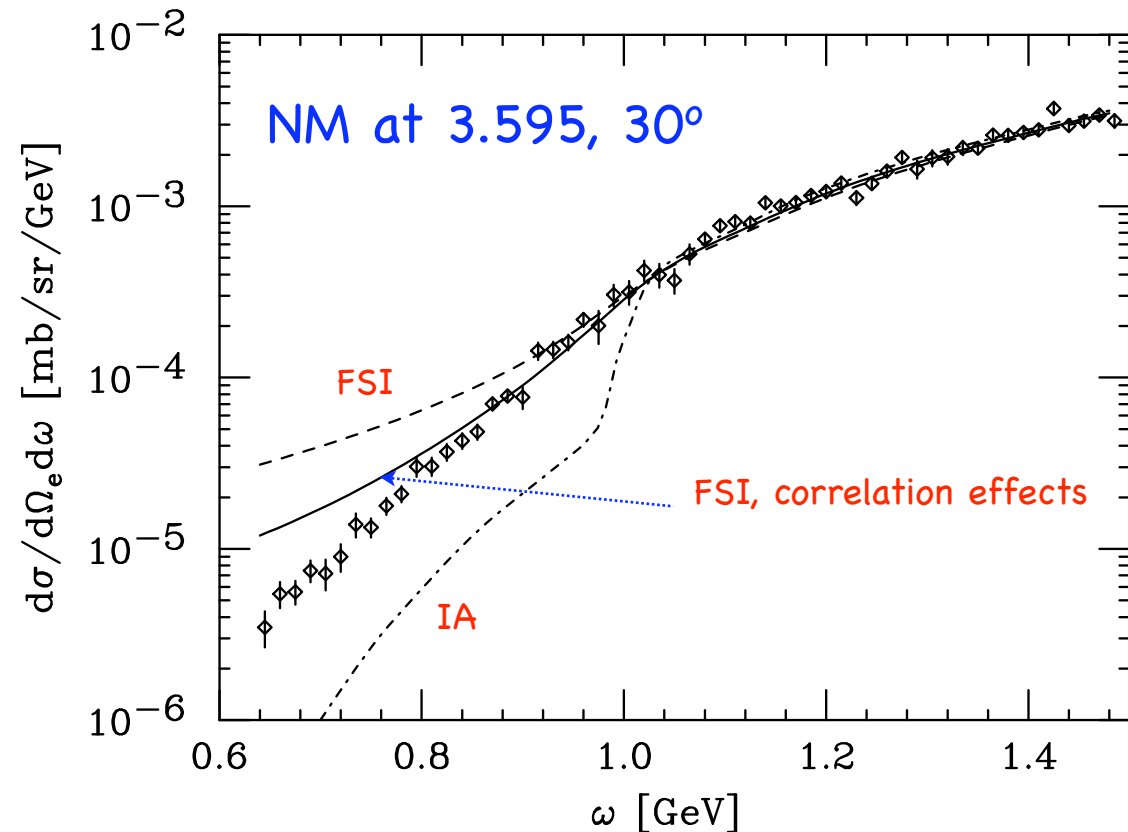
PWIA
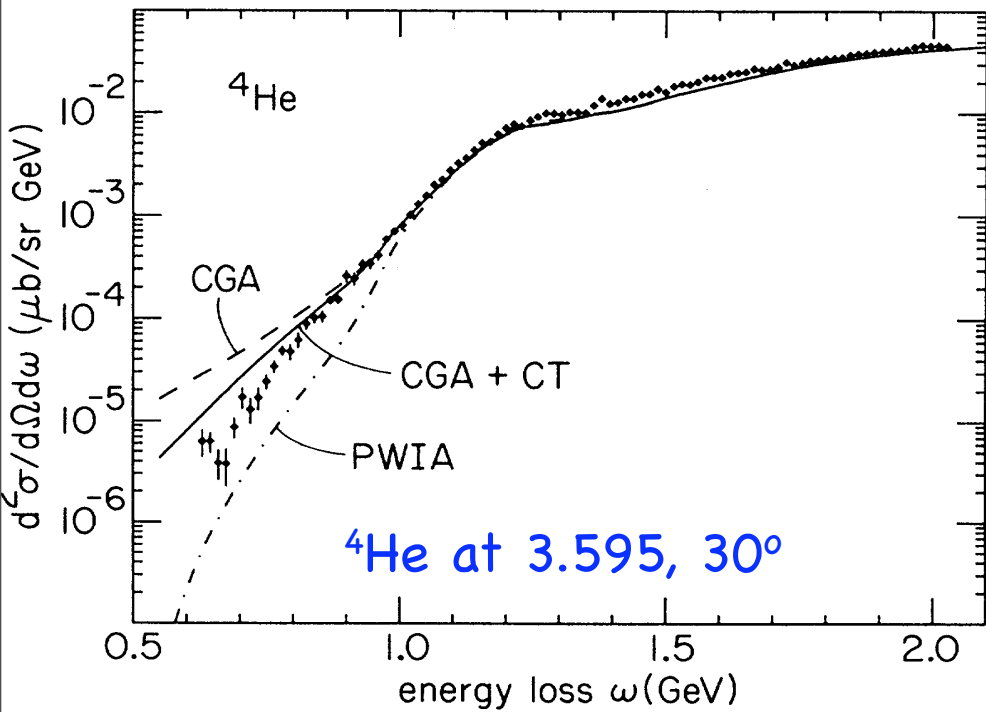
Benhar et al. PRC 44, 2328

Benhar, Pandharipande, PRC 47, 2218
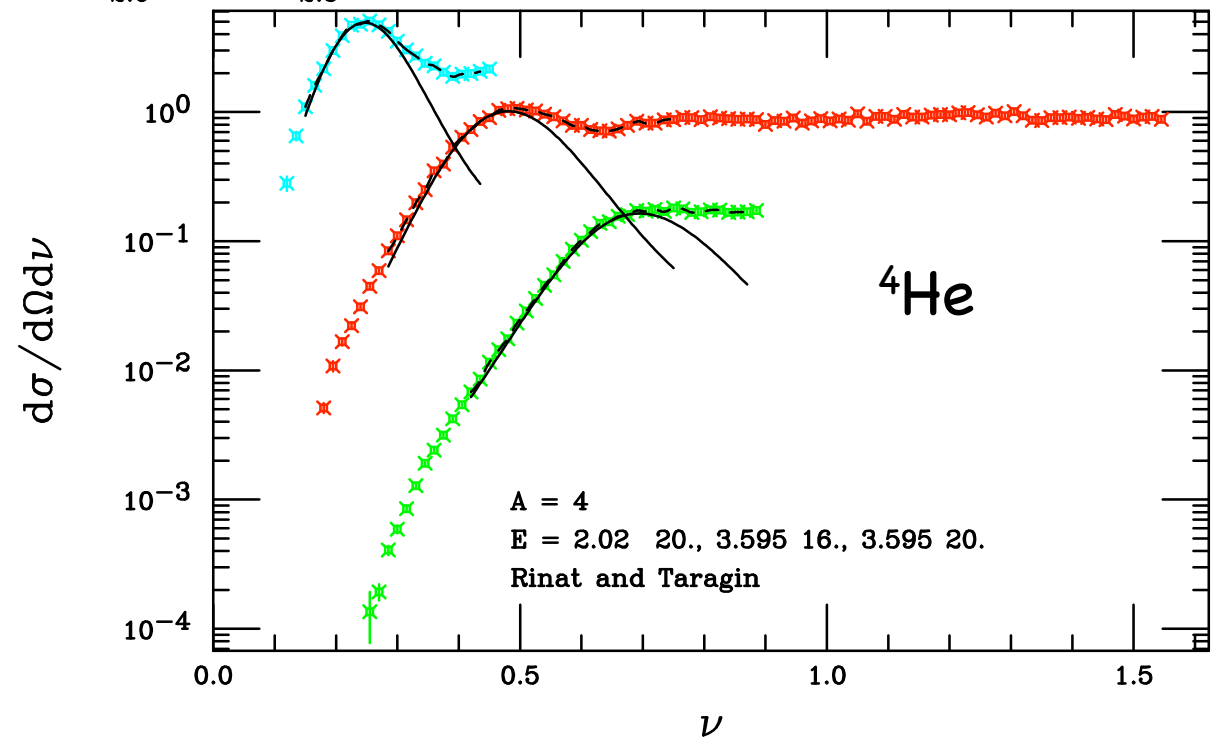
Benhar et al. PLB 3443, 47

CGA over estimates the FSI

SRC suppresses FSI

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

NM at 3.595, 30°

$d\sigma/d\Omega_e d\omega$ [mb/sr/GeV] vs ω [GeV]

FSI

FSI, correlation effects

IA

Rinat & Taragin

$$F_k^d(x, Q^2) = \int_x^2 f^{P,N}(z, Q^2) \left[F_k^P\left(\frac{x}{z}, Q^2\right) + F_k\left(\frac{x}{z}, Q^2\right) \right] / 2$$

^{2}H

A = 2
E = 4.045, theta = 15, 30, 45
Rinat and Taragin

^{4}He

A = 4
E = 2.02 20., 3.595 16., 3.595 20.
Rinat and Taragin
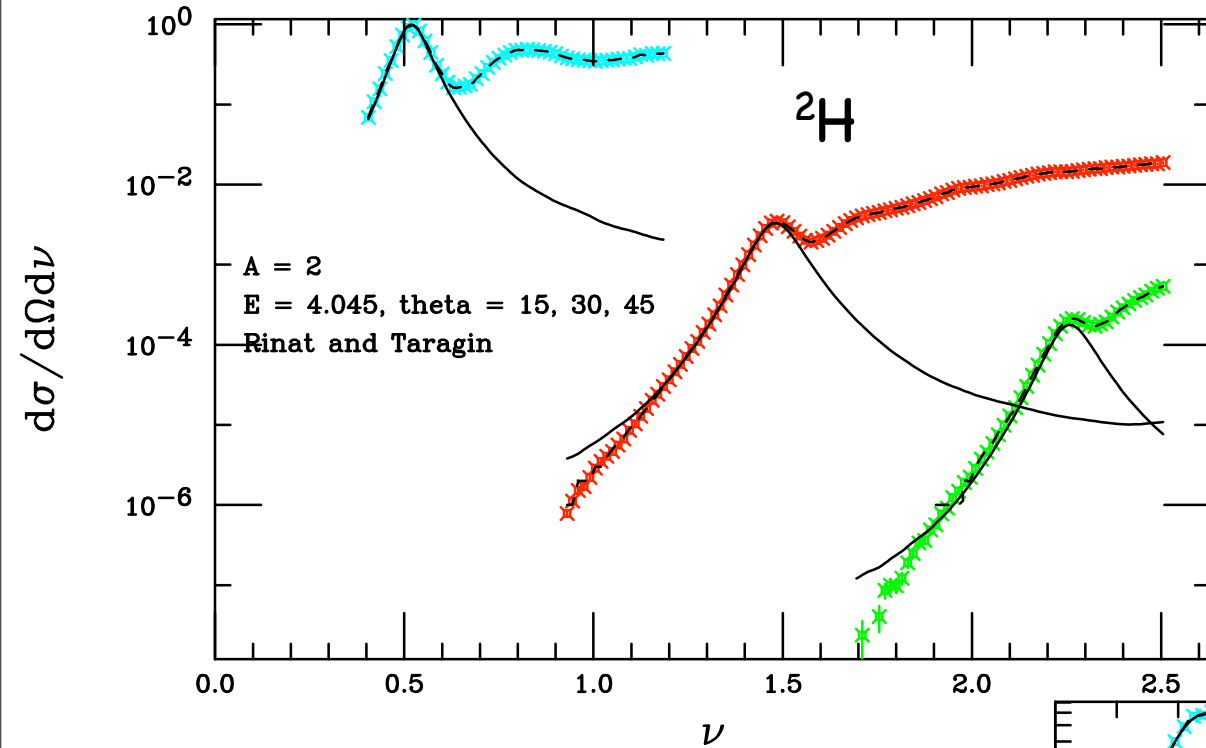
Scaling in DIS

$$F_2(x, Q^2) \to F_2(x)$$
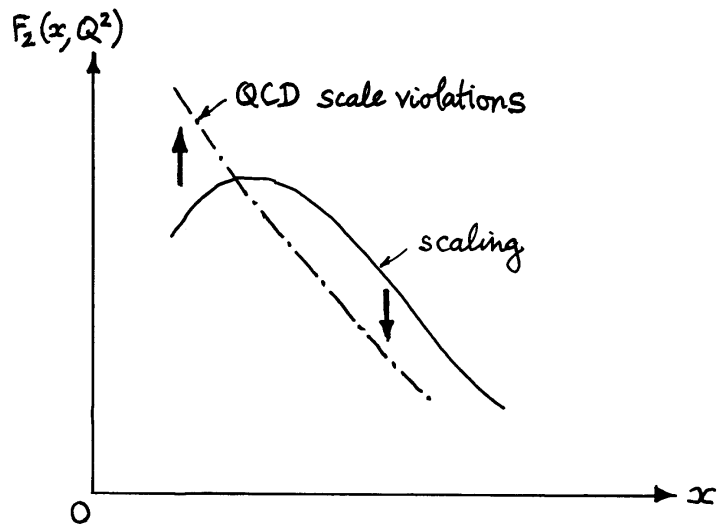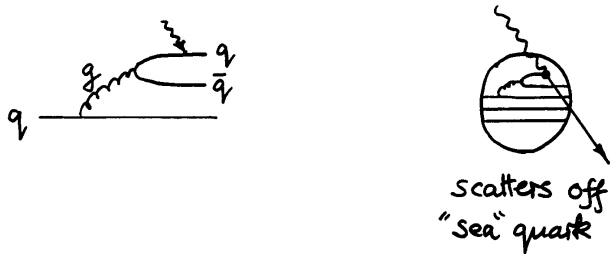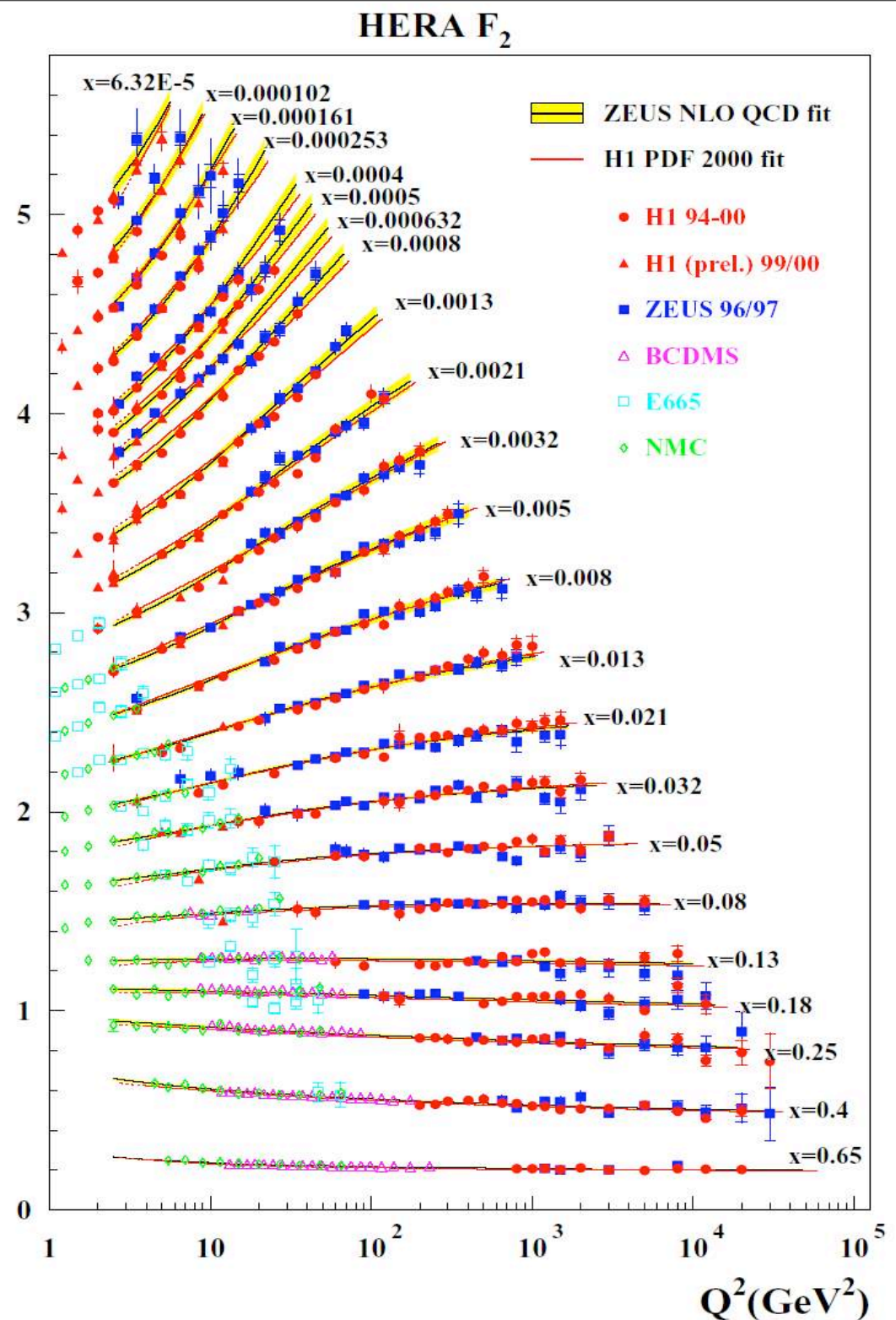
Existence of partons (quarks) revealed by DIS at SLAC in 1960's

scatters off "sea" quark

$F_2(x, Q^2)$

QCD scale violations

scaling

x

O

If the data scales then it validates the assumptions about the underlying physics and scale-breaking provides information about conditions that go beyond the assumptions.

HERA F_2

$F_2^{em} - \log_{10}(x)$

x=6.32E-5
x=0.000102
x=0.000161
x=0.000253
x=0.0004
x=0.0005
x=0.000632
x=0.0008
x=0.0013
x=0.0021
x=0.0032
x=0.005
x=0.008
x=0.013
x=0.021
x=0.032
x=0.05
x=0.08
x=0.13
x=0.18
x=0.25
x=0.4
x=0.65

ZEUS NLO QCD fit
H1 PDF 2000 fit
H1 94-00
H1 (prel.) 99/00
ZEUS 96/97
BCDMS
E665
NMC

$Q^2 (GeV^2)$

y–scaling (ν, q ⇒ y)

Single nucleon knock-out, $E = E_{min}$, A–1 system unexcited

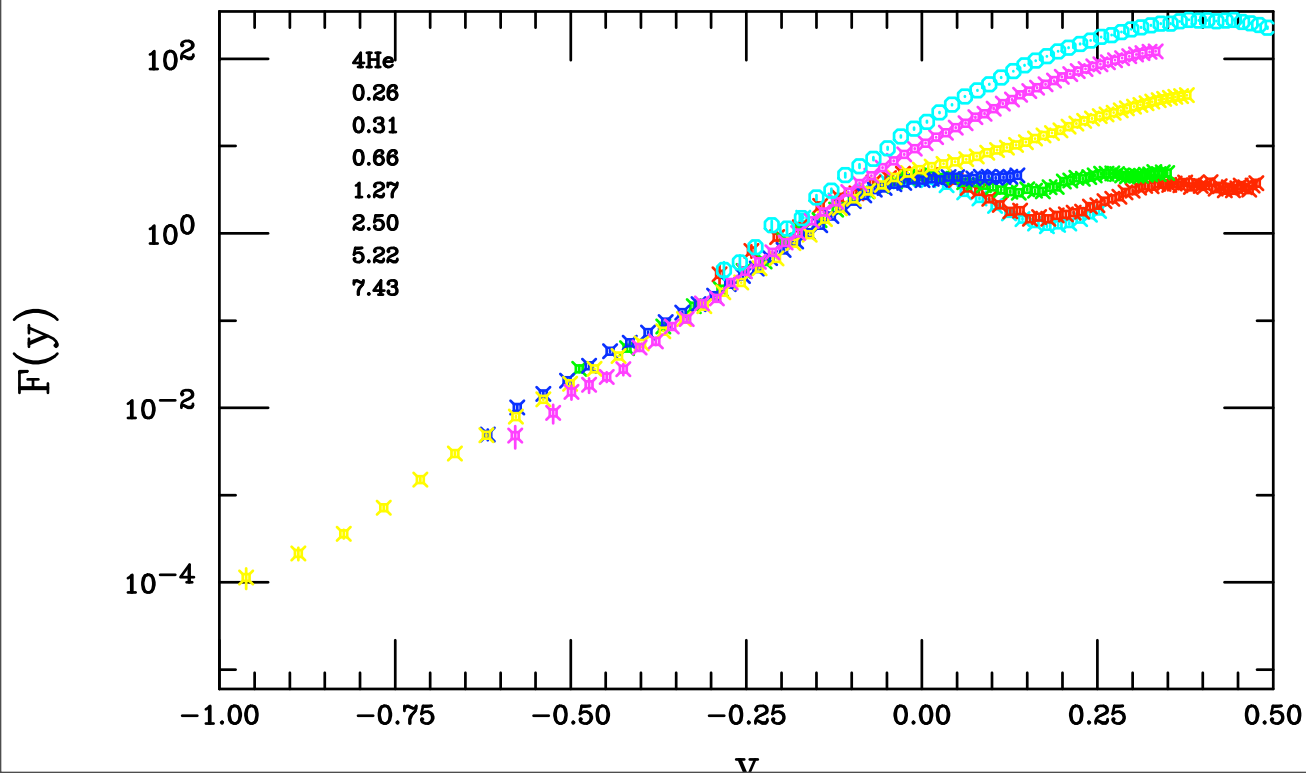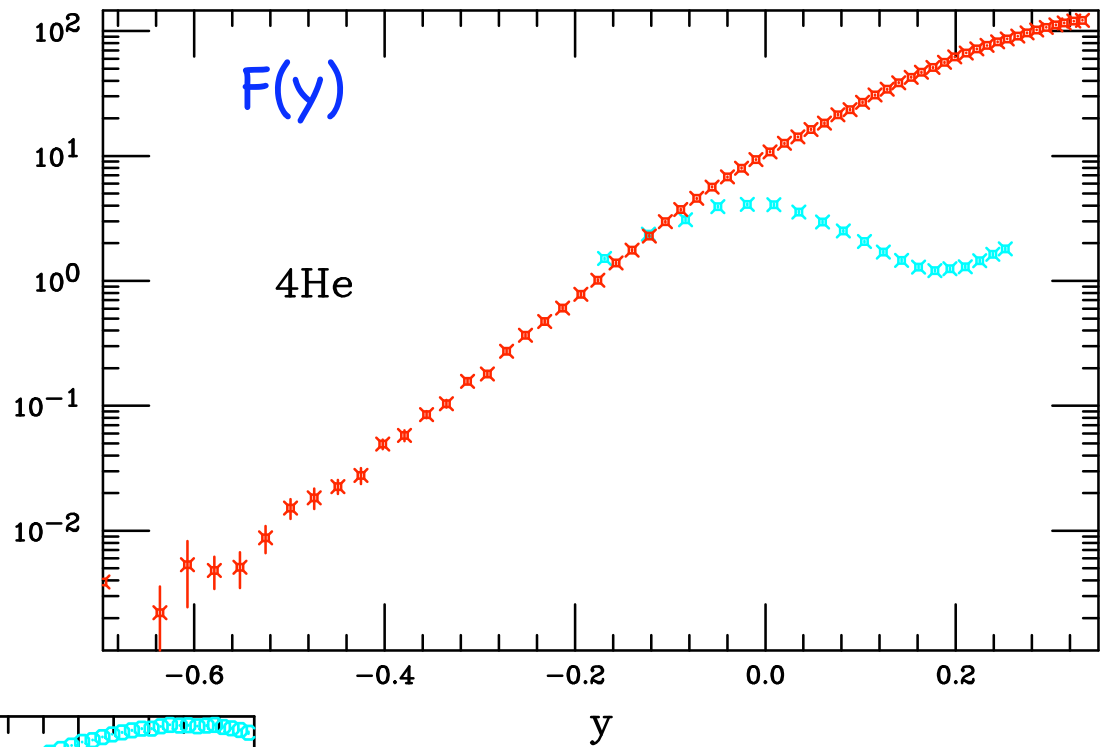$$\nu + M_A = \sqrt{M^2 + (p+q)^2} + \sqrt{M_{A-1}^2 + p^2}$$
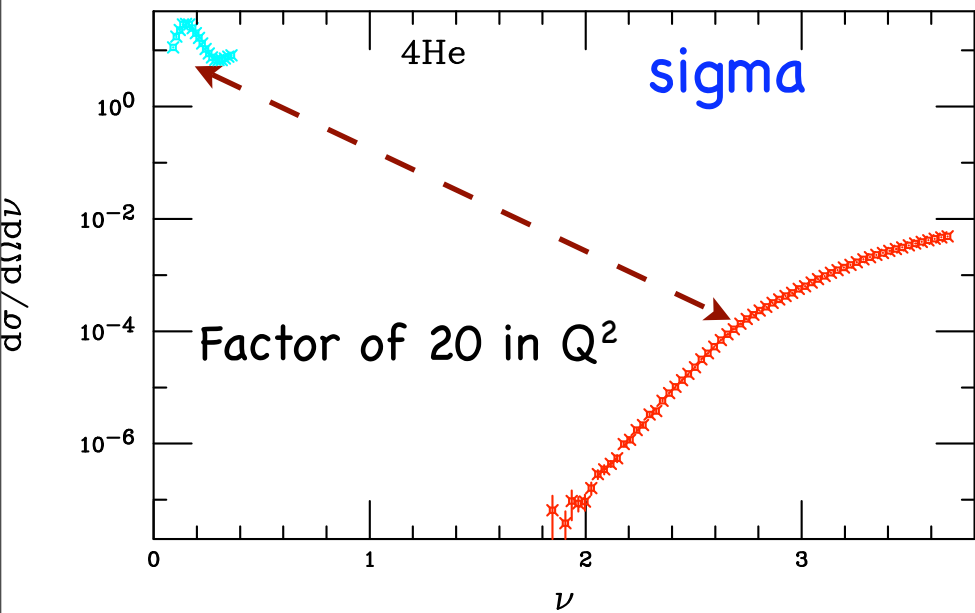
(A-1)
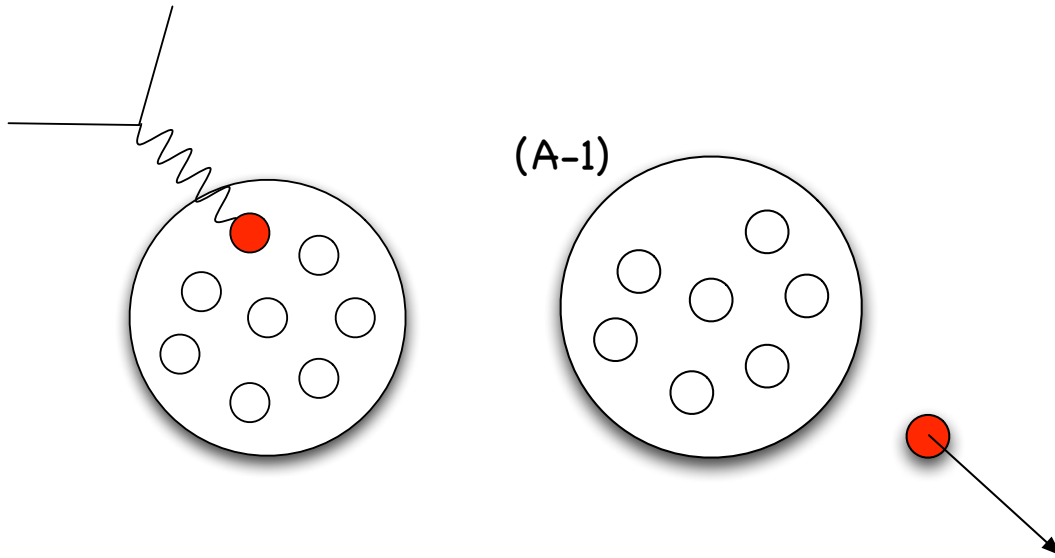
- No FSI
- No internal excitation of (A-1)
- Full strength of Spectral Function can be integrated over at finite q
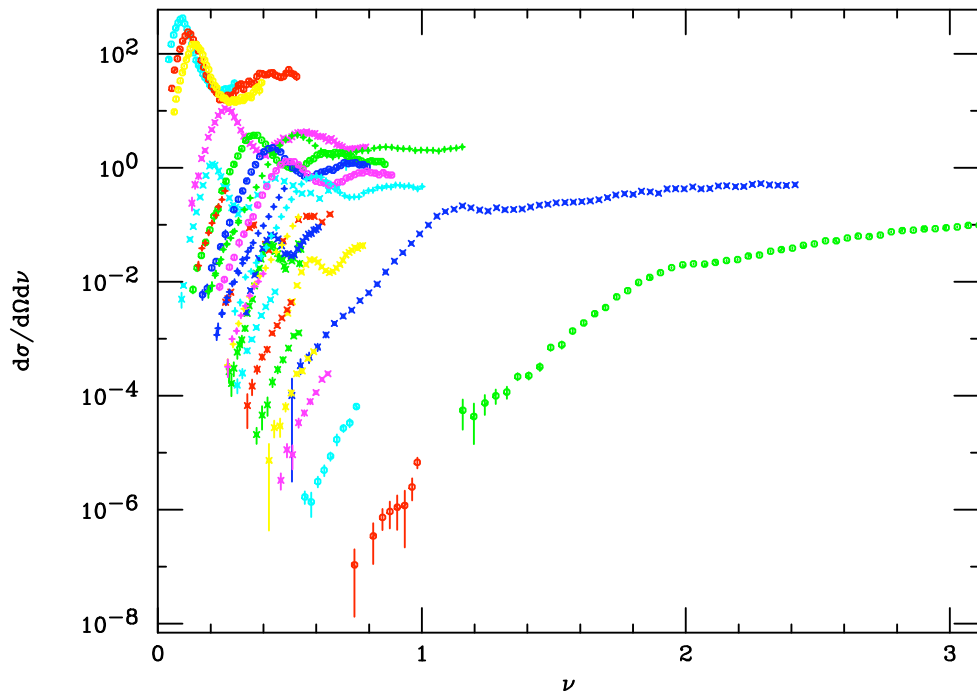- No inelastic processes
- No medium modifications

y: Momentum of knocked-out nucleon parallel to q

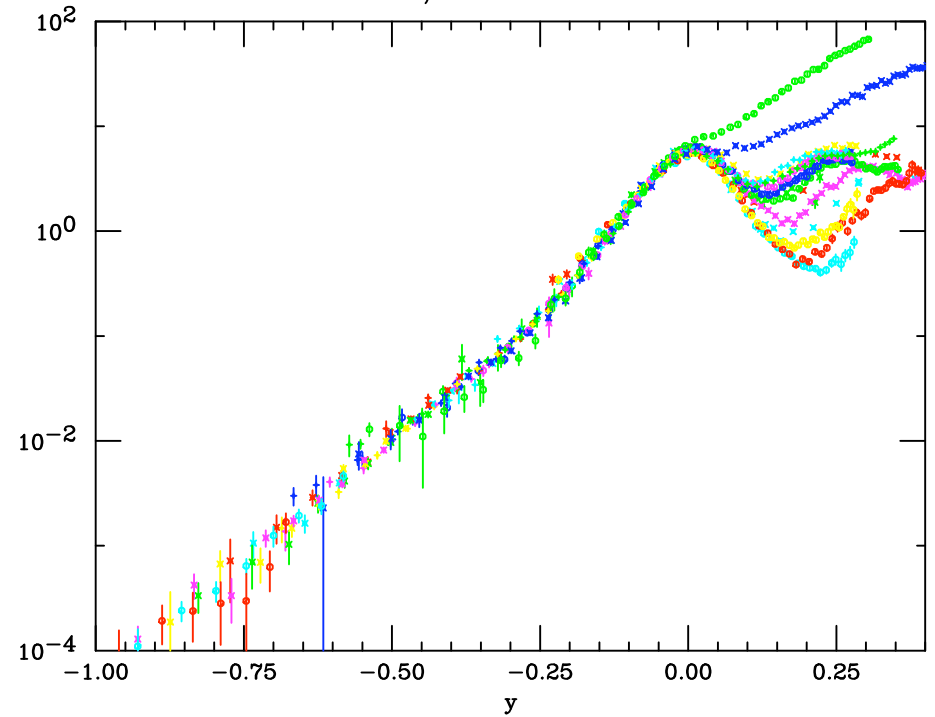$$F(y) = \frac{\sigma^{exp}}{(Z\widetilde{\sigma}_p + N\widetilde{\sigma}_n)} \cdot K \qquad F(y) \equiv 2\pi \int_{|y|}^{\infty} n(p)p\,dp$$

sigma

4He

$\dfrac{d\sigma / d\Omega d\nu}$

Factor of 20 in Q^2

ν

F(y)

4He

y

F(y)

4He
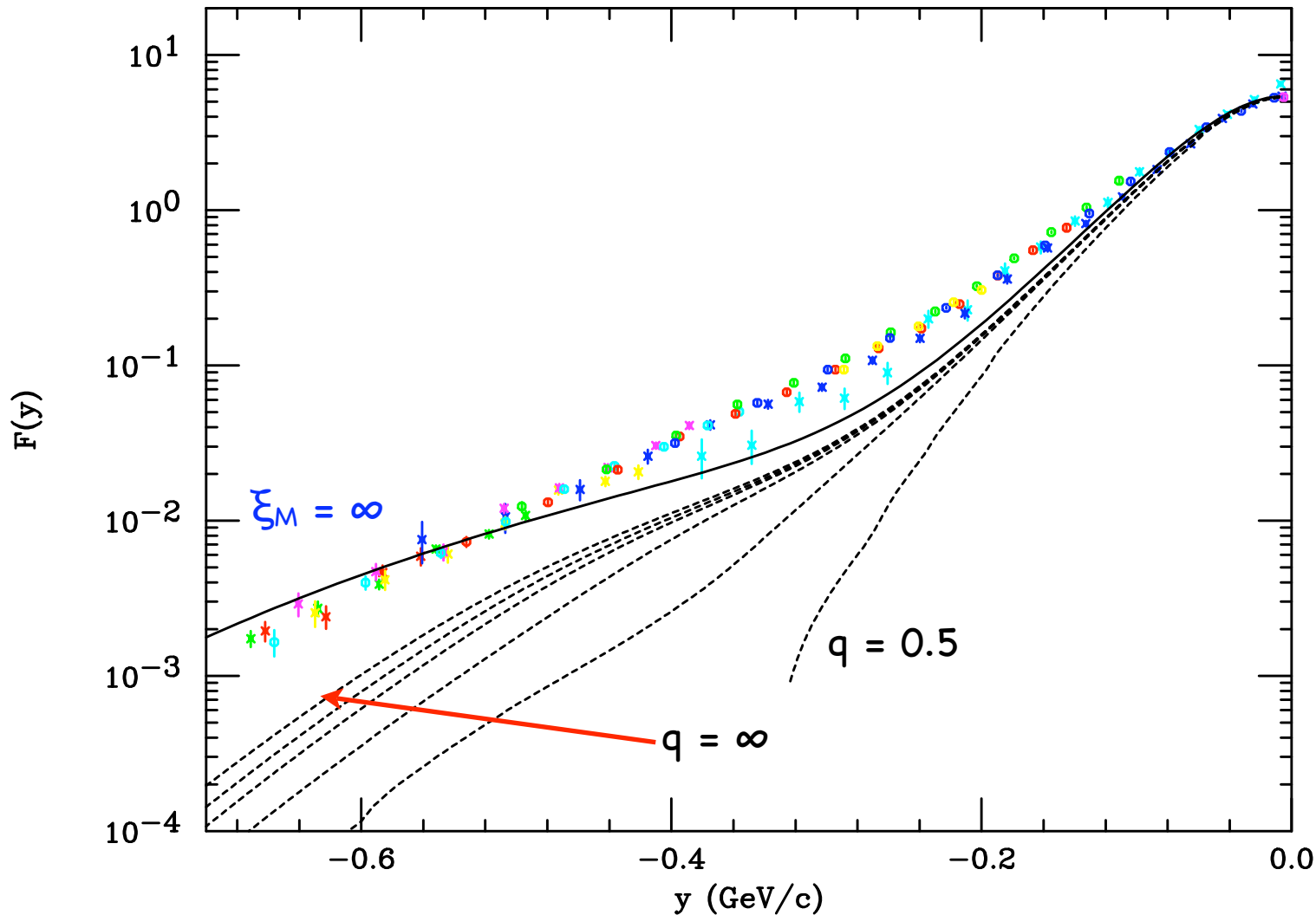0.26
0.31
0.66
1.27
2.50
5.22
7.43

y

Z, A =   2 3

Z, A =   2 3

$$\frac{d\sigma^{QE}}{d\Omega d\omega} \simeq (Z\tilde{\sigma}_p + N\tilde{\sigma}_n) \cdot \frac{E_X}{|\mathbf{q}|} \cdot 2\pi \int_{E_{min}}^{E_{max}} dE_m \int_{p_{min}(E_m)}^{p_{max}(E_m)} p dp S(p, E_M)$$

$$\underbrace{\qquad\qquad\qquad\qquad\qquad\qquad\qquad}_{F(y, |\mathbf{q}|)}$$

$$F(y, |\mathbf{q}|) = 2\pi \int_{E_{min}}^{\infty} dE_m \left[\int_{|y|}^{\infty} - \int_{|y|}^{p_{min}(E_m)} \right] p dp S(p, E_m)$$

$$= 2\pi \int_{|y|}^{\infty} n(p) p dp - B(y, |\mathbf{q}|)$$

Theoretical ^{3}He F(y) integrated at increasing q

Is the energy distribution as calculated (scaling occurs at much lower q)?

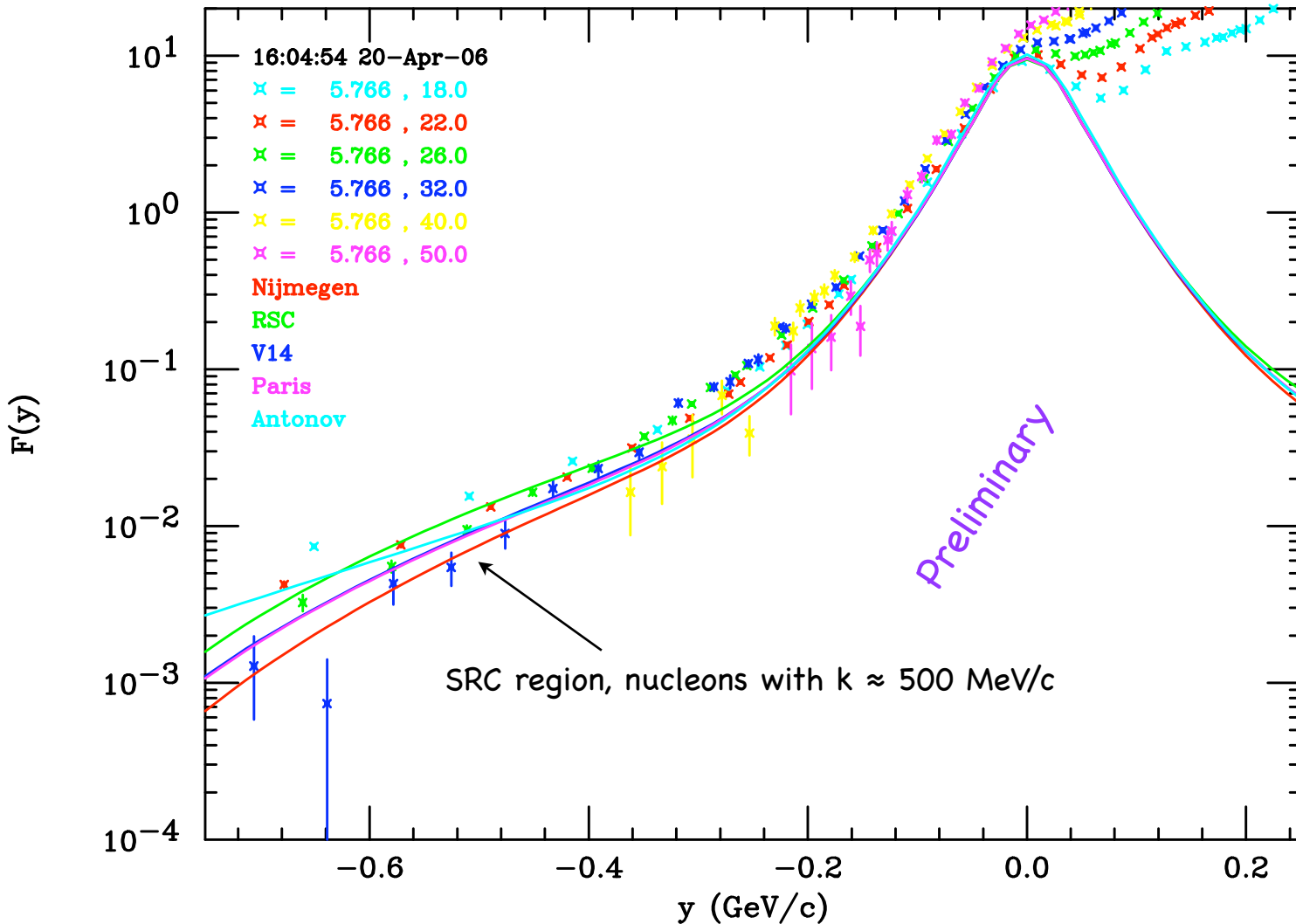Do other processes play a role? FSI?

FSI or/and DIS

distribution of strength?

As q increases, more and more of the spectral function S(k,E) is integrated.

y-scaling Deuteron (E-02-019)

Figure legend and axis labels:

16:04:54 20-Apr-06
x = 5.766 , 18.0
x = 5.766 , 22.0
x = 5.766 , 26.0
x = 5.766 , 32.0
x = 5.766 , 40.0
x = 5.766 , 50.0
Nijmegen
RSC
V14
Paris
Antonov

Preliminary

SRC region, nucleons with k ≈ 500 MeV/c

F(y) axis, y (GeV/c) axis

Deuteron F(y) and calculations based on NN potentials

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

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

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

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: $y \approx -q/2 + m\nu/q$

y-scaling indicates very high-momenta: model incomplete - strength is spread out in E

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

Single nucleon knock-out, $E \neq E_{min}$, A-1 system excited

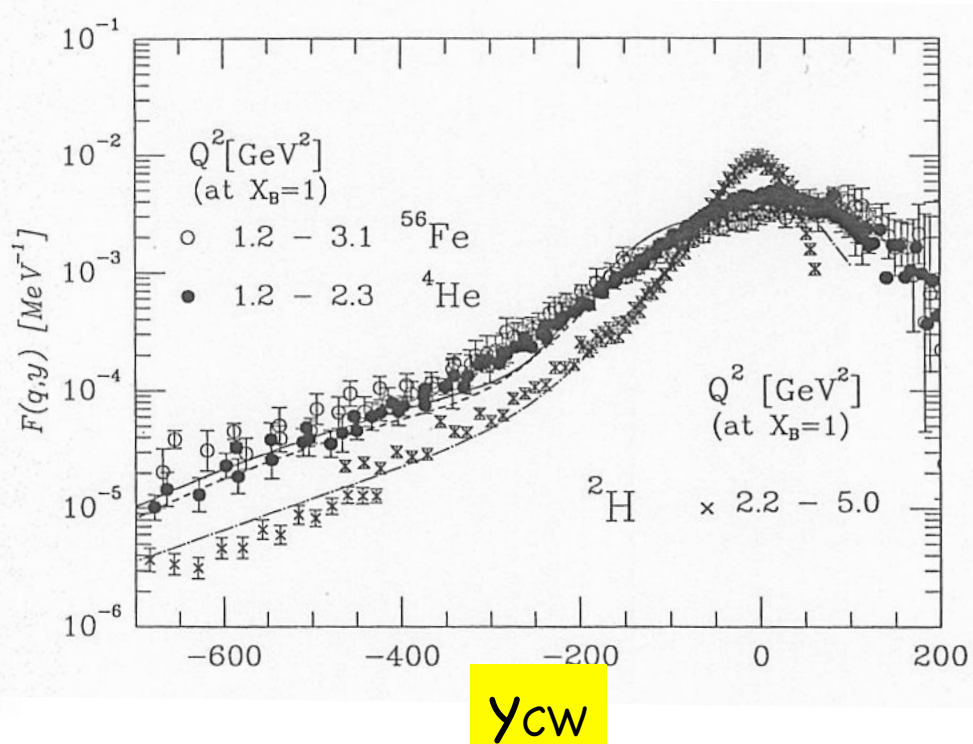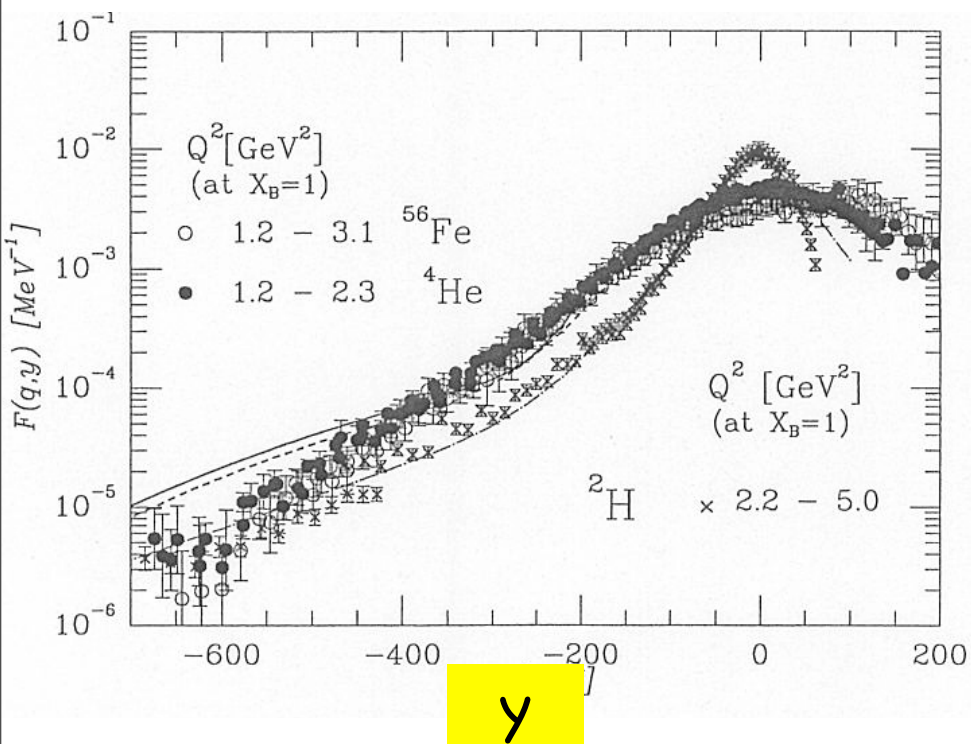$$\nu + M_A = \sqrt{M^2 + (p+q)^2} + M_{A-1} + \frac{p^2}{2M} + \underbrace{b_A - c_A |p|}_{\text{CM motion}} - <E_{gr}>$$

(A-1)*

(A-1)*
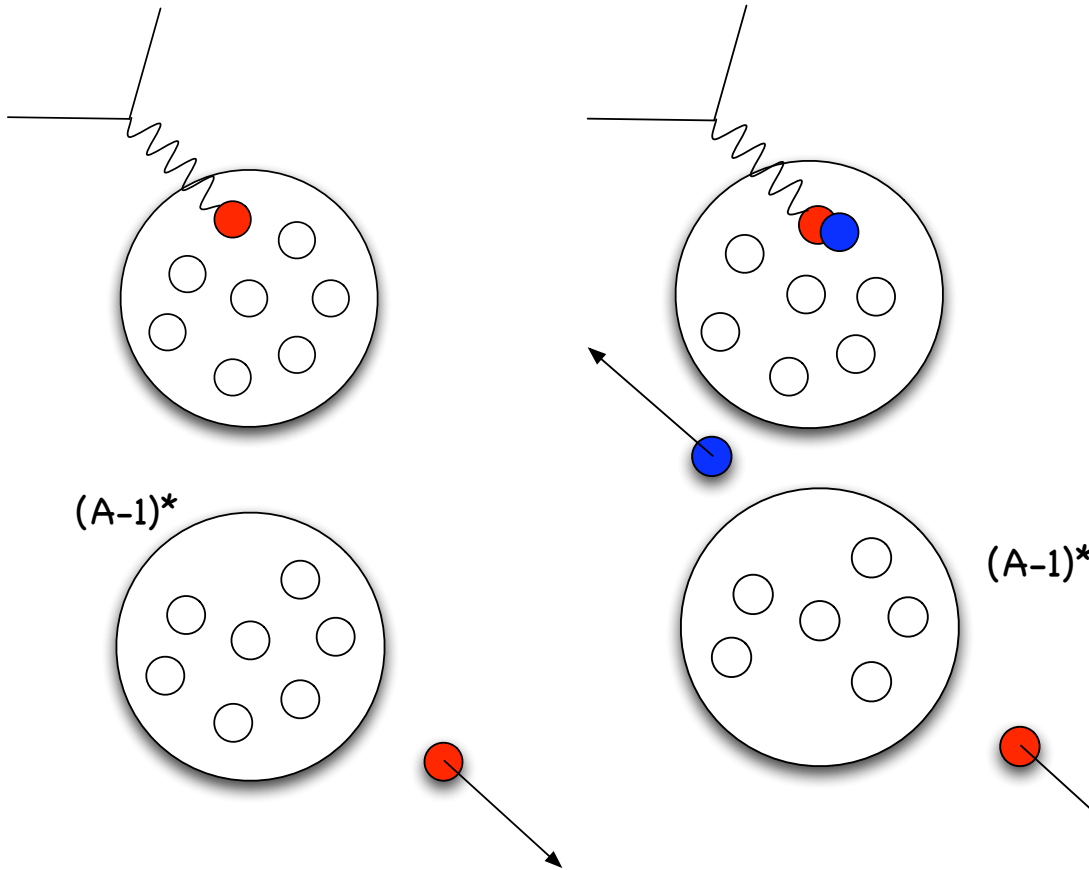
y_{cw}: Like y but accounting for excitation energy of residual system

$$F(y_{cw}) = \frac{\sigma^{exp}}{(Z\tilde{\sigma}_p + N\tilde{\sigma}_n)} \cdot K$$

$$F(y_{CW}) = 2\pi \int_{|y_{CW}|}^{\infty} pdpn(p)$$

Faralli, Ciofi degli Atti & West, Trieste 1999

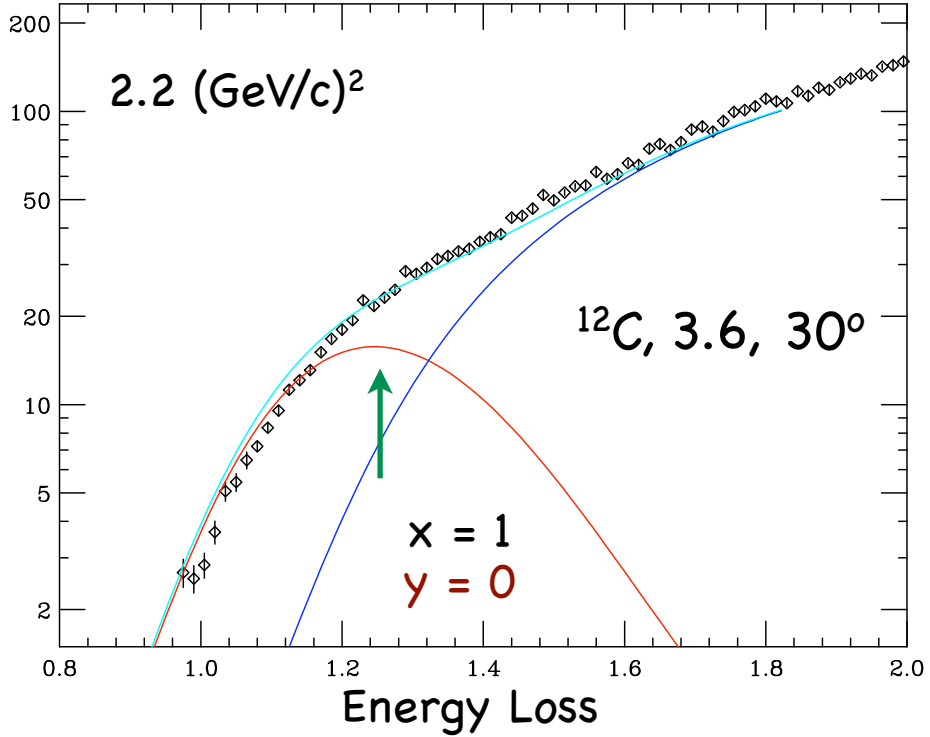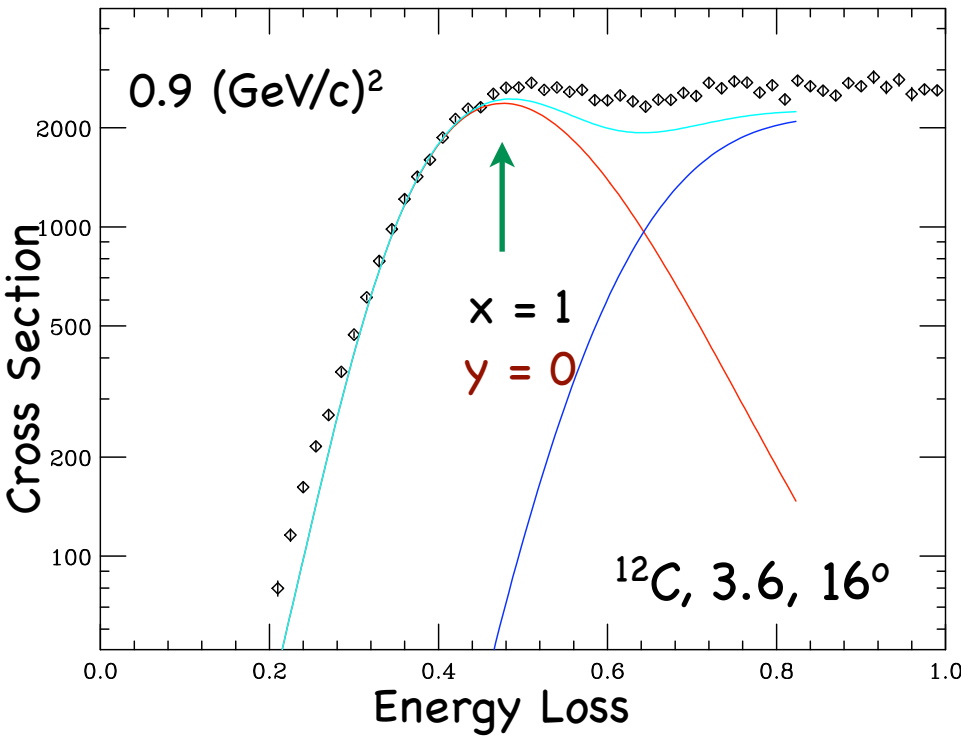Faralli, Ciofi degli Atti & West, Trieste 1999

Many body calculations at high momenta indicate that nuclear momentum distributions are rescaled versions of the deuteron

$$n_A(p) \approx C_A n_D(p)$$

$$F_A(q, y_{CW}) \approx C_A F_D(q, y_{CW})$$

Inelastic contribution increases with Q^2

0.9 (GeV/c)^2

x = 1
y = 0

^{12}C, 3.6, 16°

2.2 (GeV/c)^2

^{12}C, 3.6, 30°

x = 1
y = 0

7.4 (GeV/c)^2

^{12}C, 5.77, 40°

x = 1
y = 0

DIS begins to contribute at x > 1,
y < 0 Convolution model

We expect that as Q^2 increases we
should see for evidence (x-scaling)
that we are scattering from a quark
that has obtained its momenta from
interactions with partons in other
nucleons. These are super-fast
quarks.
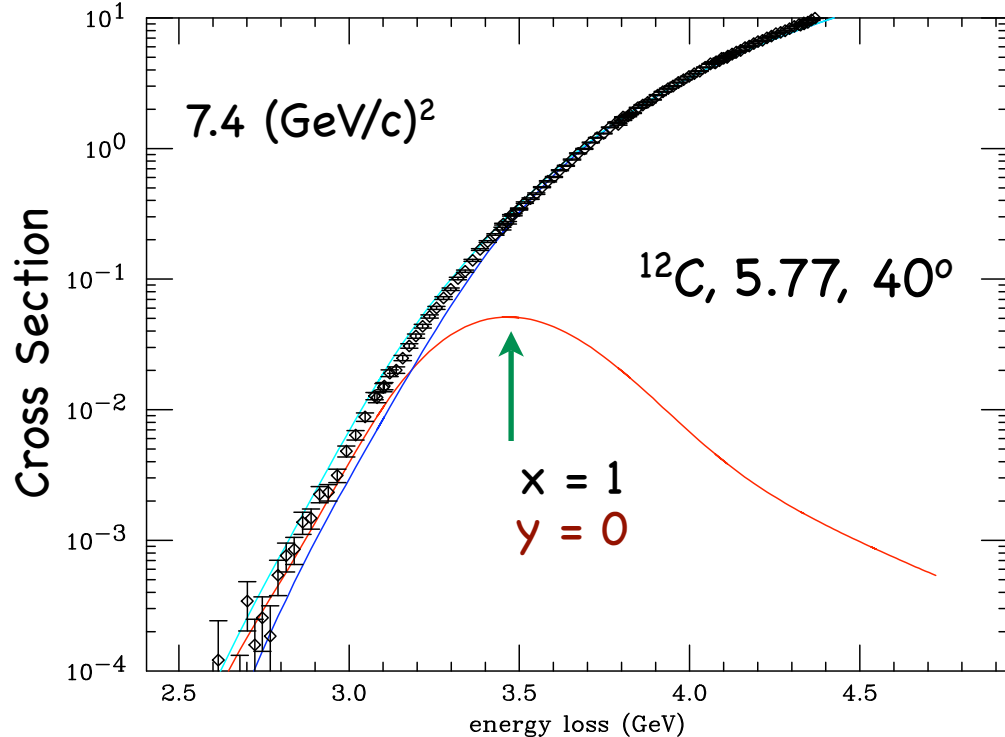
Bjorken Scaling (ν, q $\Rightarrow$ x)

Interaction with a quark in the moving nucleon

x: Momentum fraction of struck parton

$$x = \frac{Q^2}{2m\nu}$$

$$F_2(x) = \nu W_2 = \nu \cdot \frac{\sigma^{exp}}{\sigma_M}\left[1 + 2\tan^2(\theta/2) \cdot \left(\frac{1 + \nu^2/Q^2}{1 + R}\right)\right]^{-1}$$

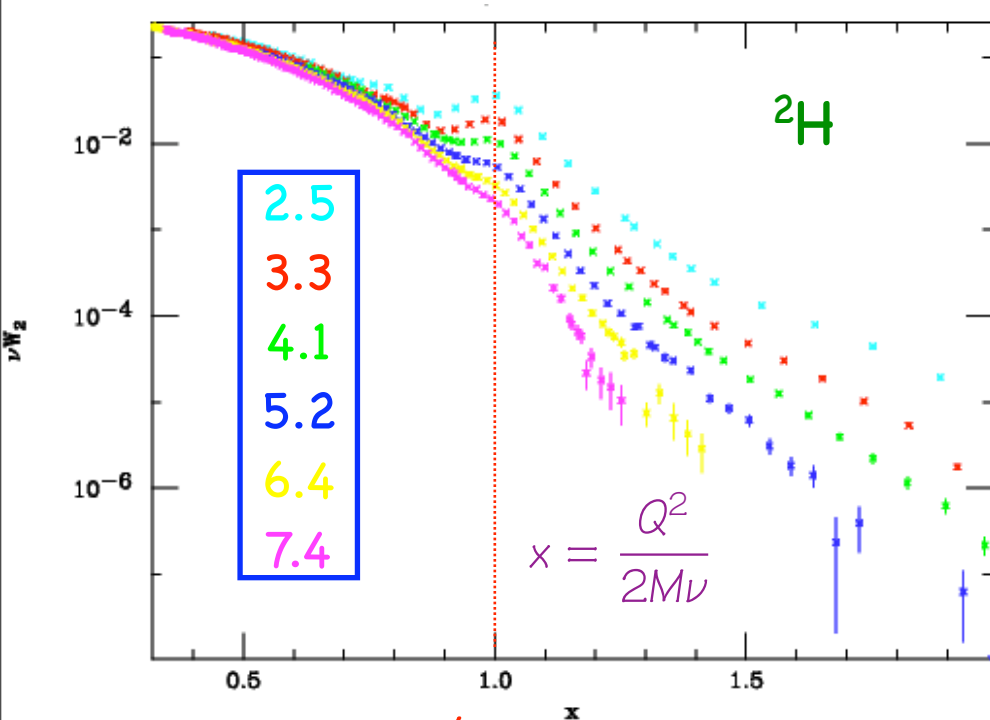ξ : Momentum fraction of struck parton, accounting for target mass effects

$$\xi = 2x / \left(1 + \sqrt{1 + \frac{4m^2x^2}{Q^2}}\right) \rightarrow x \quad (Q^2 >>)$$
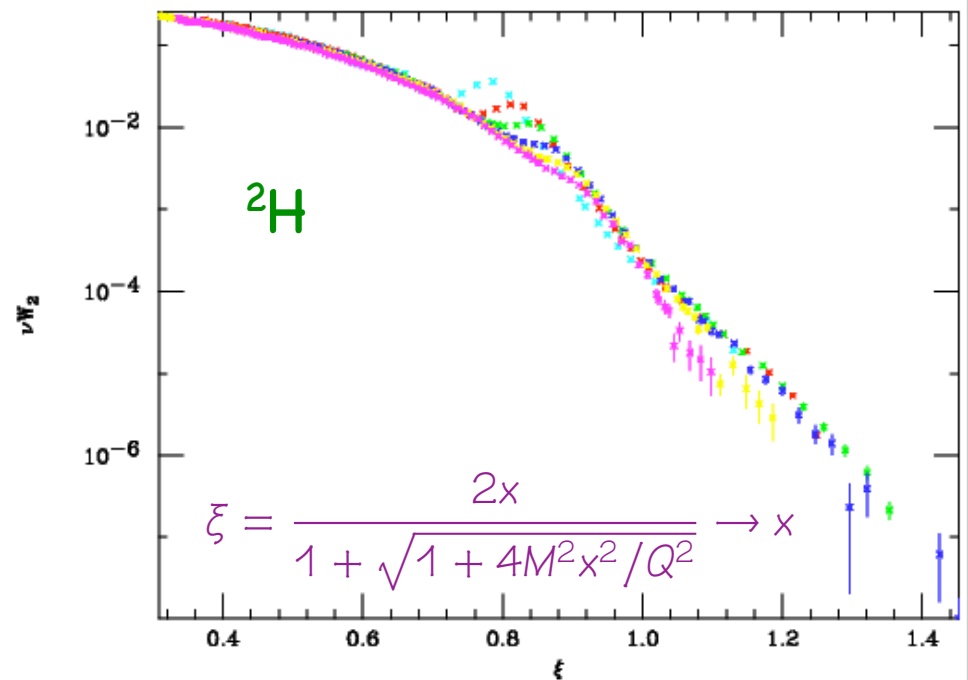
$$F_2(\xi)$$

N.B divide out the Mott cs, not the Rosenbluth – the nucleon FF Q^2 behavior is not included.

x and ξ scaling

An alternative view is suggested when the data (deuteron) is presented in terms of scattering from individual quarks
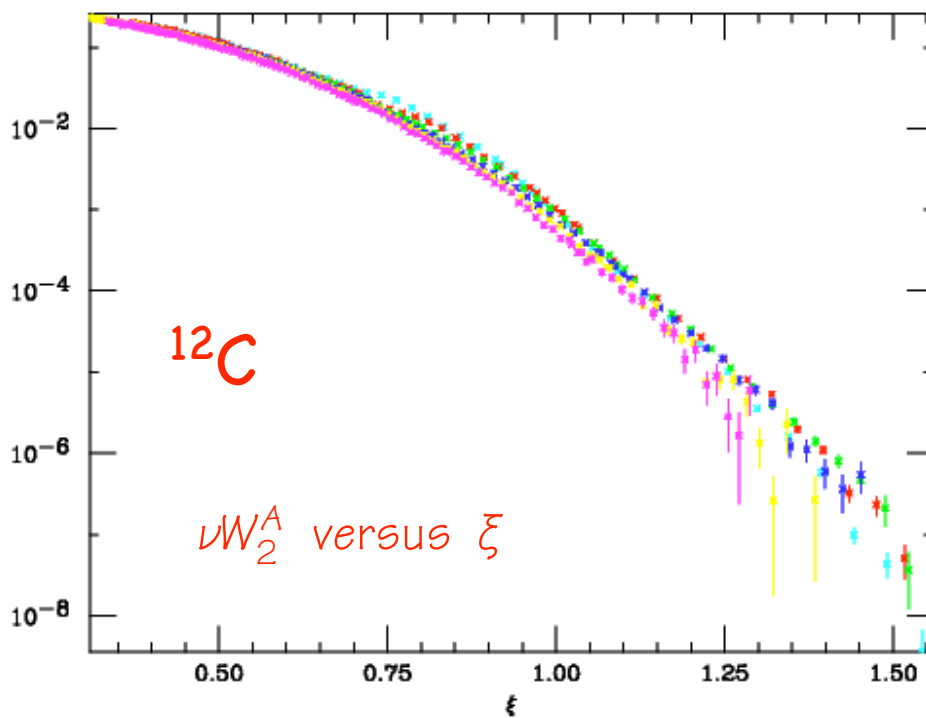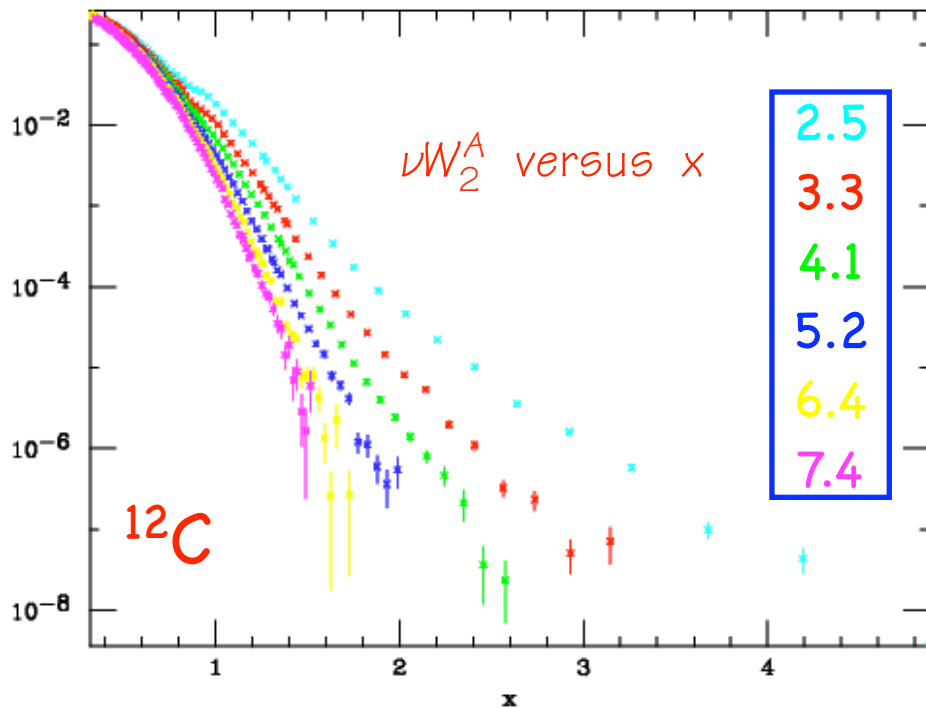

νW_2^A versus x

νW_2^A versus ξ

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

νW_2^A versus x

^{12}C

2.5
3.3
4.1
5.2
6.4
7.4

The Nachtmann variable (fraction ξ of nucleon light cone momentum p⁺) has been shown to be the variable in which logarithmic violations of scaling in DIS should be studied.

Local duality (averaging over finite range in x) should also be valid for elastic peak at x = 1 if analyzed in ξ

$$F_2^A(\xi) = \int_\xi^A dz\, F(z) F_2^n(\xi/z)$$

averaging

^{12}C

νW_2^A versus ξ

Evidently the inelastic and quasielastic contributions conspire to produce ξ scaling. Is this local duality?

$Q^2 = 1$ GeV^2

νW_2
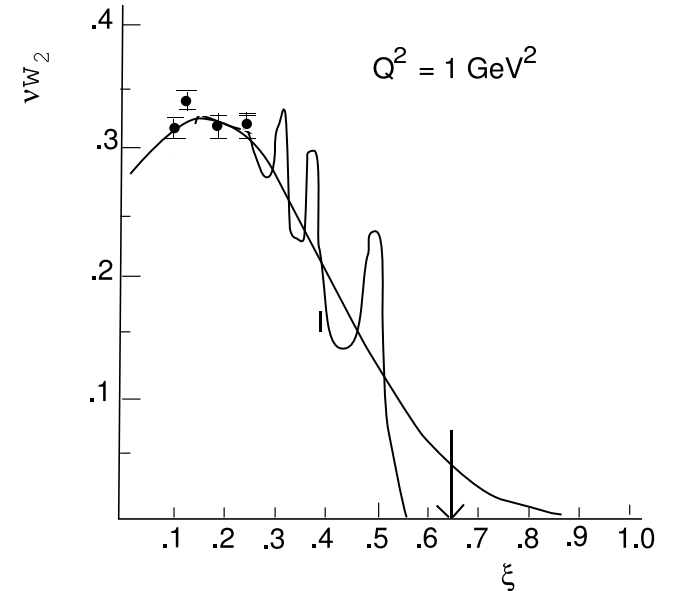
CS Ratios and SRC

$$\sigma(x, Q^2) = \sum_{j=1}^{A} A \frac{1}{j} a_j(A) \sigma_j(x, Q^2)$$

In the region where correlations should dominate, large x,
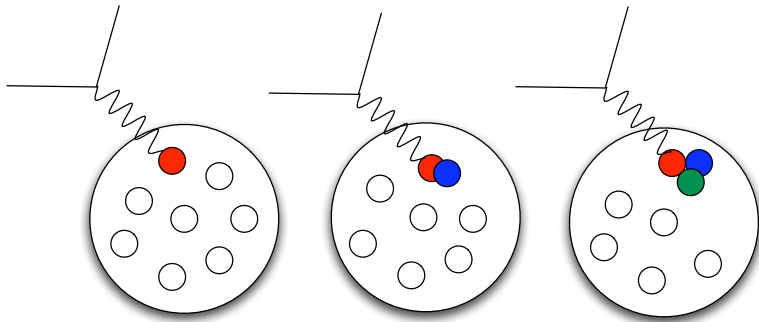
$$= \frac{A}{2} a_2(A) \sigma_2(x, Q^2) +$$

$$\frac{A}{3} a_3(A) \sigma_3(x, Q^2) +$$

$$\vdots$$

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

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

$$\Rightarrow \quad \frac{2}{A} \frac{\sigma_A(x, Q^2)}{\sigma_D(x, Q^2)} = a_2(A) \Big|_{1 < x \leq 2}$$
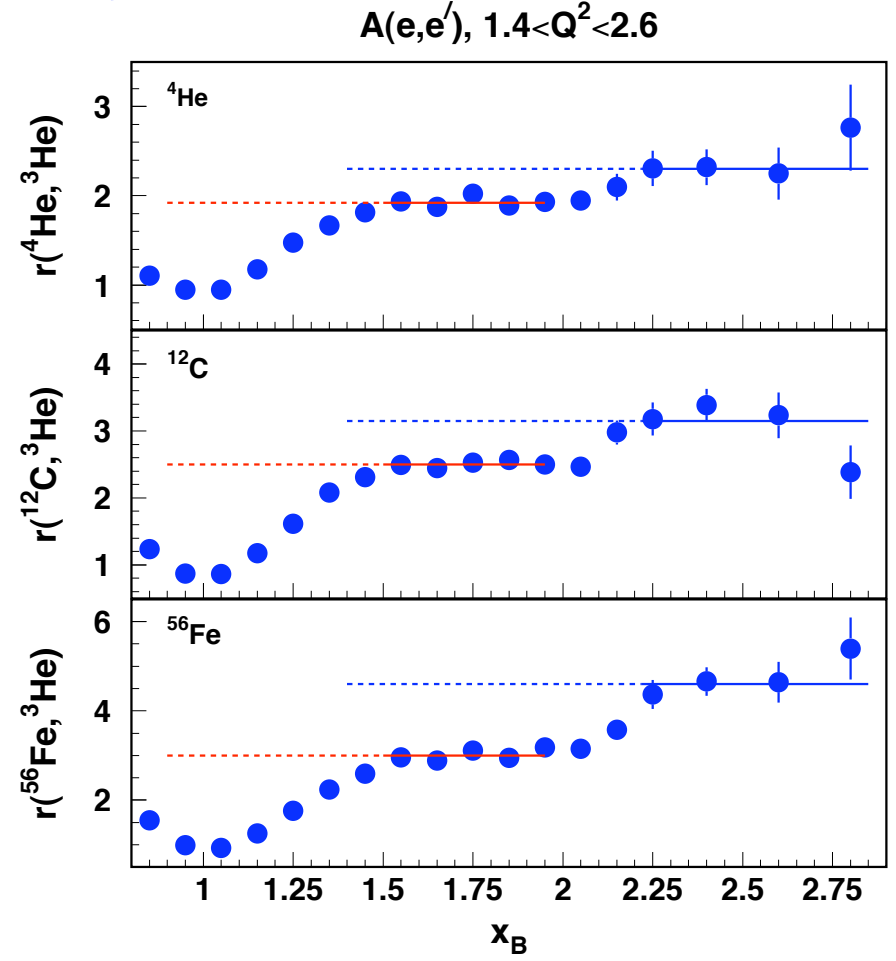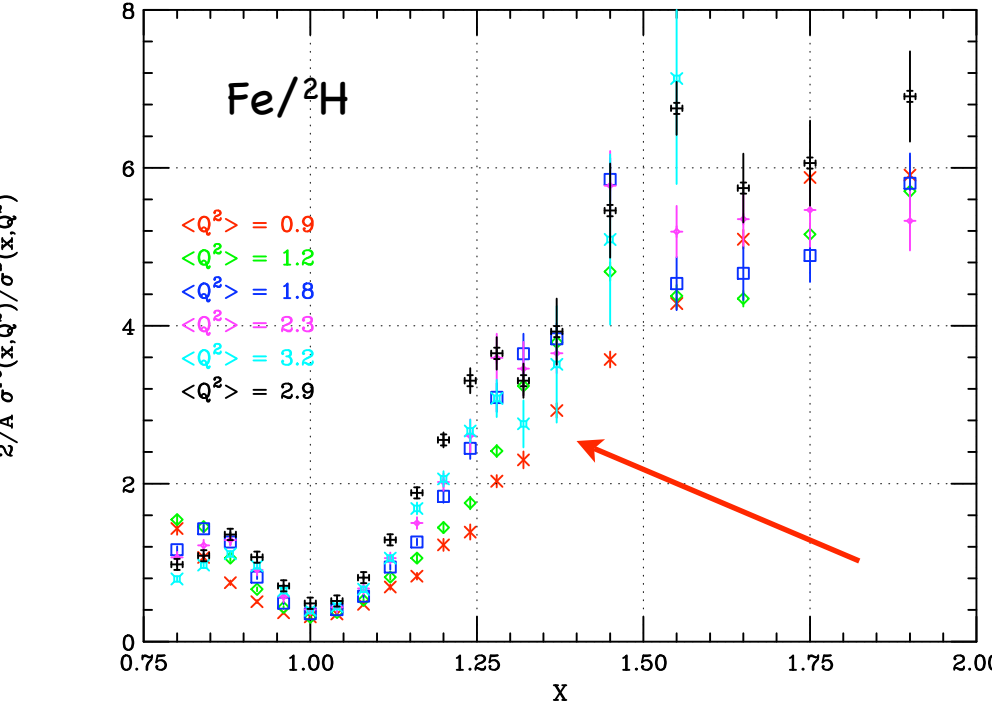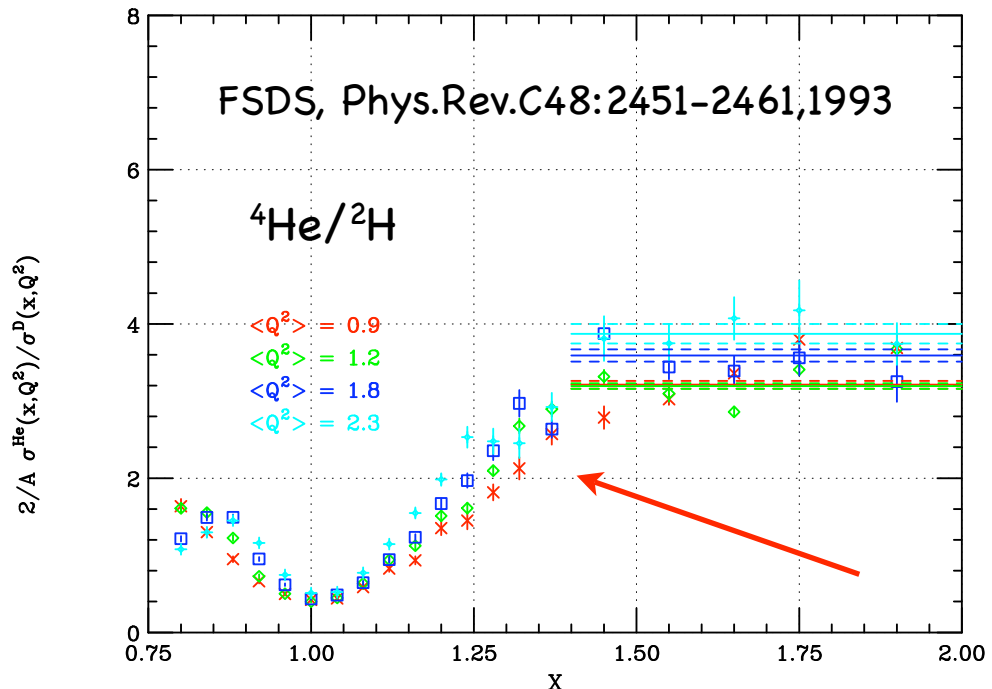
$$\frac{3}{A} \frac{\sigma_A(x, Q^2)}{\sigma_{A=3}(x, Q^2)} = a_3(A) \Big|_{2 < x \leq 3}$$

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

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

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

^{4}He/^{2}H

$\langle Q^2 \rangle = 0.9$
$\langle Q^2 \rangle = 1.2$
$\langle Q^2 \rangle = 1.8$
$\langle Q^2 \rangle = 2.3$

Fe/^{2}H

$\langle Q^2 \rangle = 0.9$
$\langle Q^2 \rangle = 1.2$
$\langle Q^2 \rangle = 1.8$
$\langle Q^2 \rangle = 2.3$
$\langle Q^2 \rangle = 3.2$
$\langle Q^2 \rangle = 2.9$

A(e,e'), 1.4<Q^2<2.6

^{4}He

^{12}C

^{56}Fe
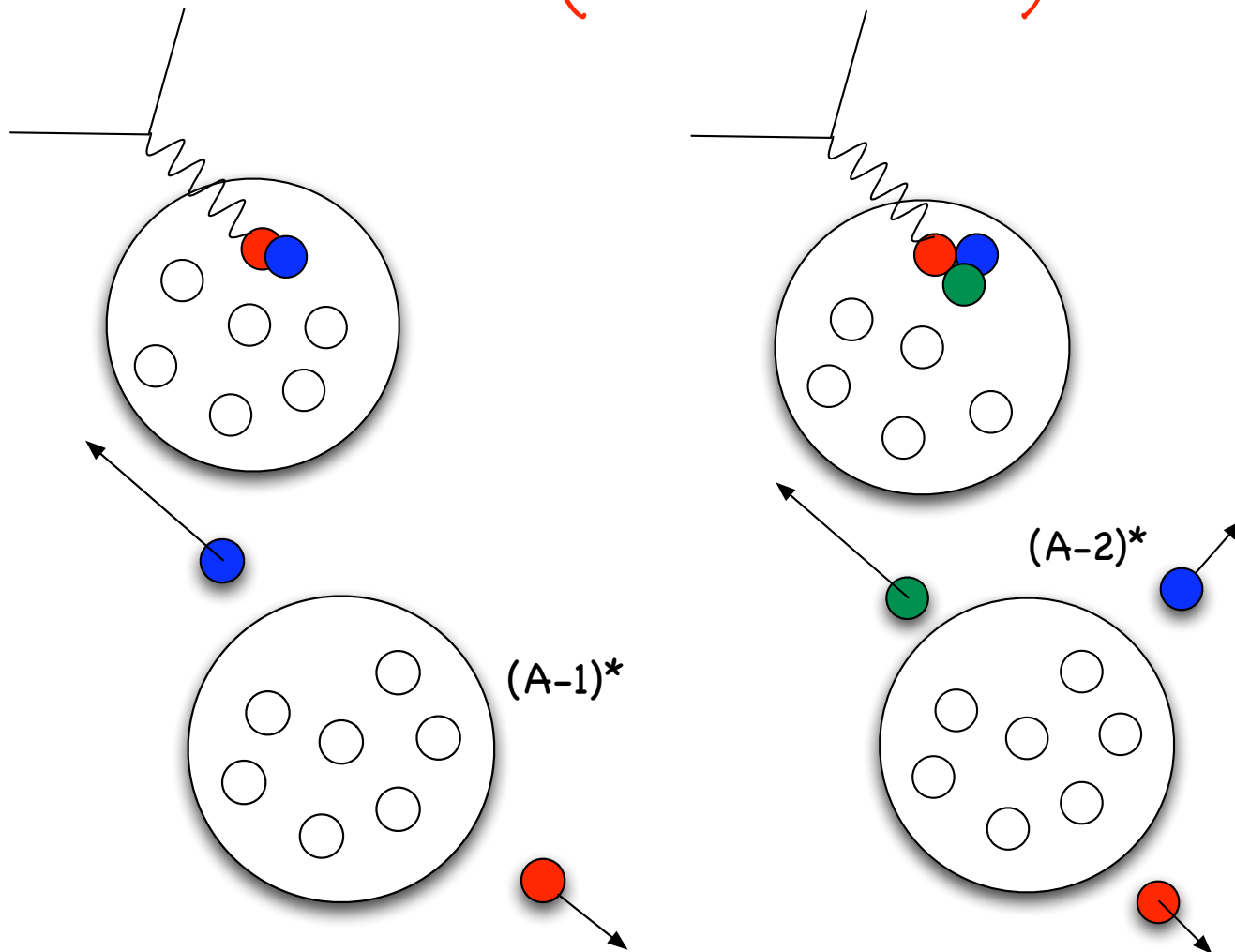
$\alpha_{2N} \approx 20\%$
$\alpha_{3N} \approx 1\%$

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

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

Knocking out a nucleon in a two-nucleon pair

α_{tn}: light cone variable for interacting nucleon belonging to correlated nucleon pair

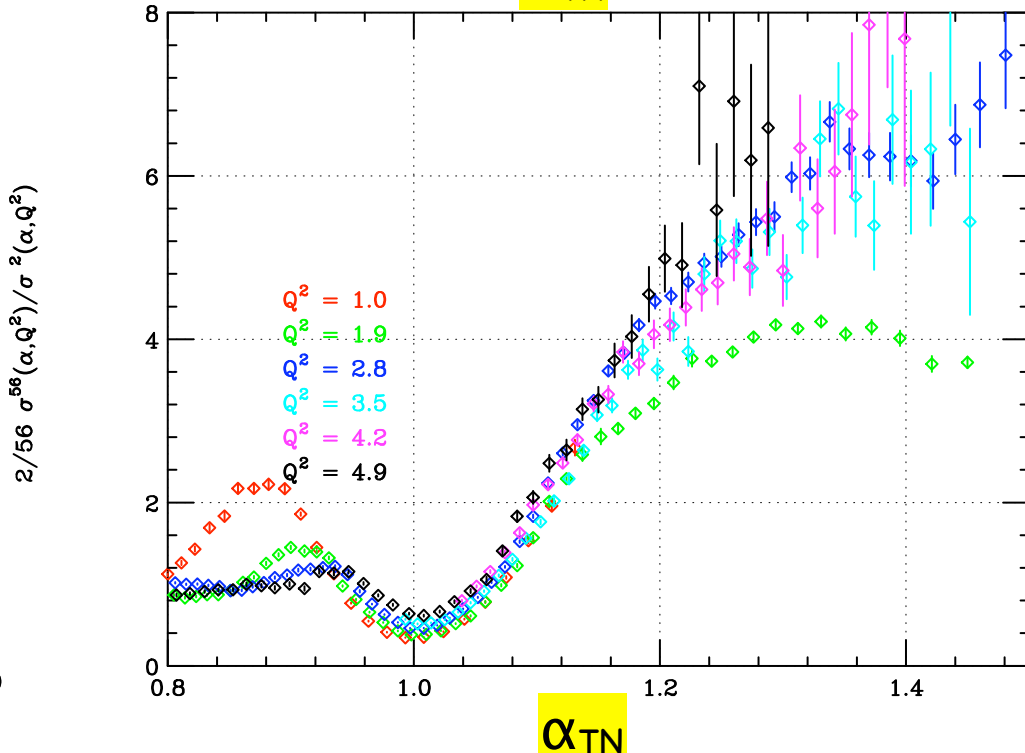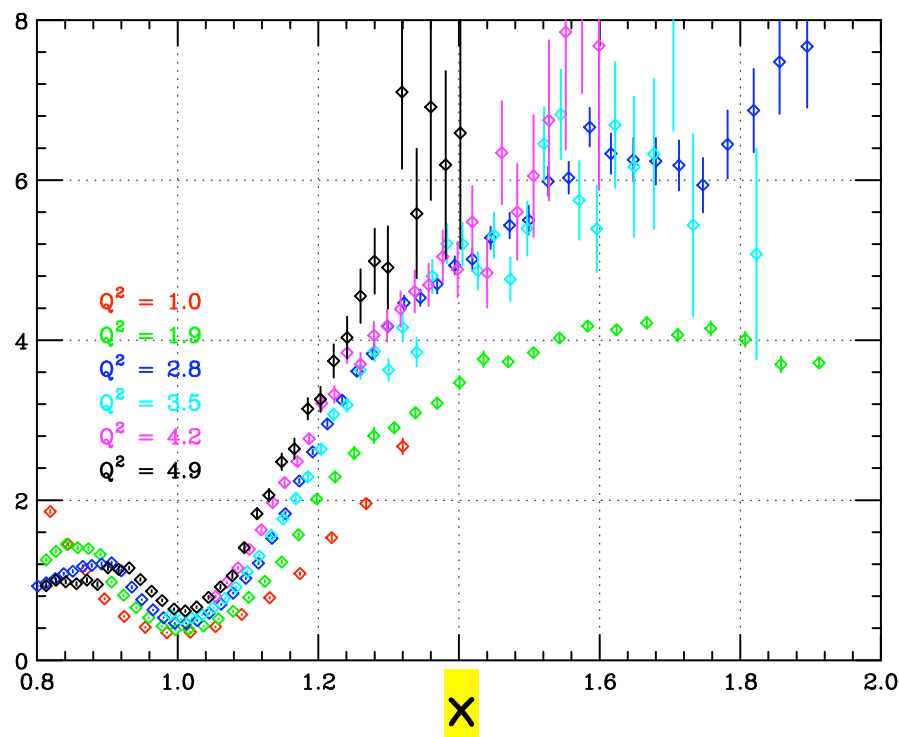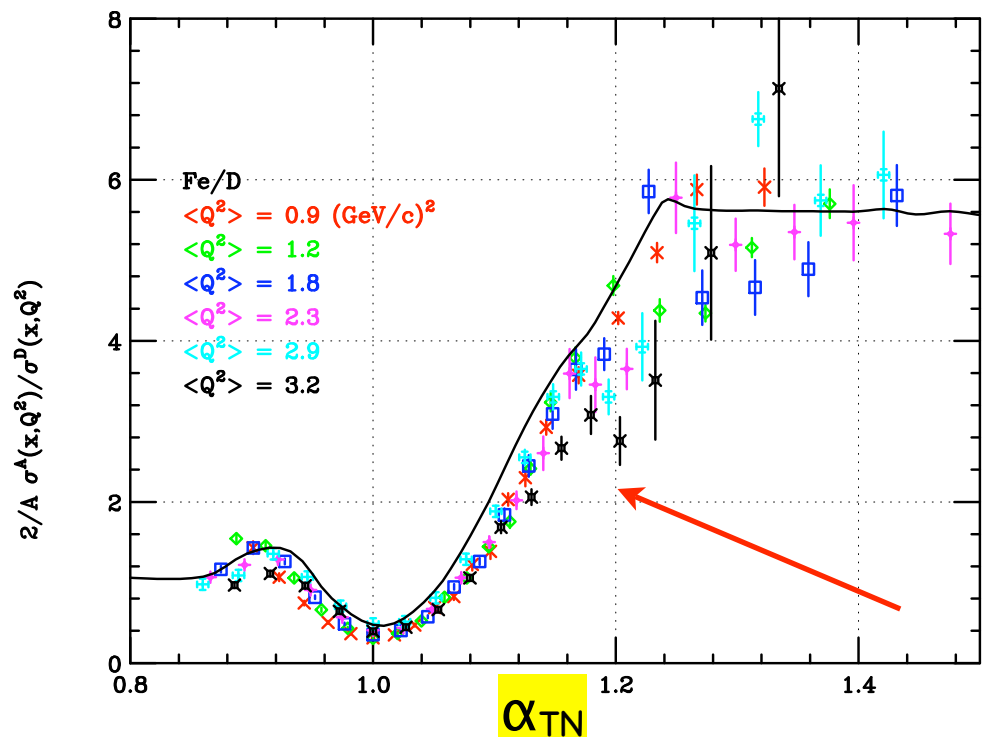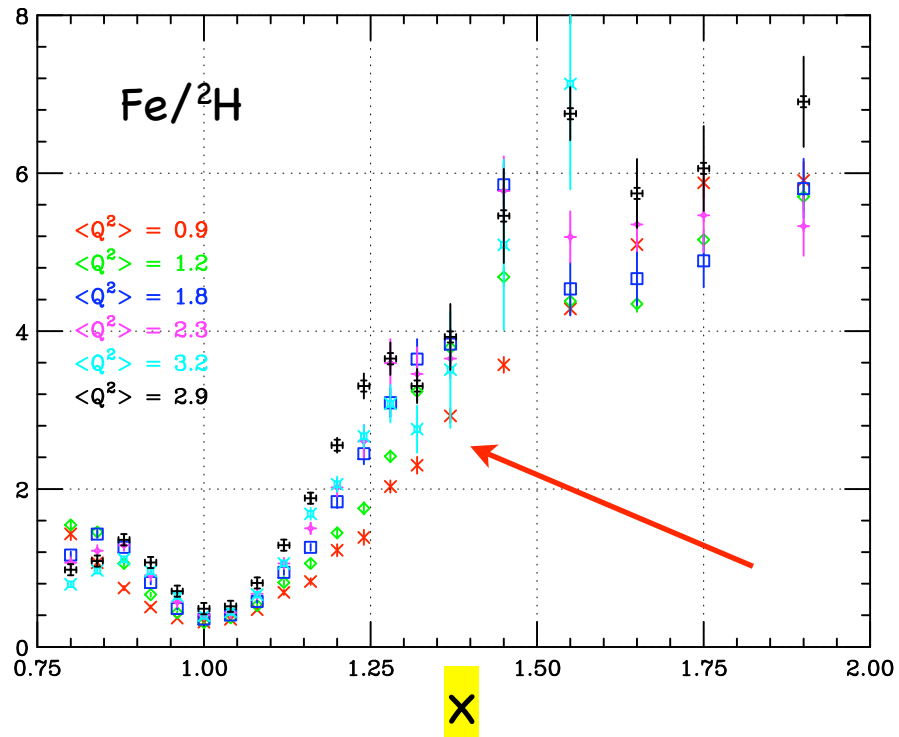$$a_{tn} = 2 - \frac{q_- + 2m}{2m}\left(1 + \frac{\sqrt{W^2 - 4m^2}}{W}\right) \rightarrow x \quad (Q^2 >>)$$

$$F_2(a_{tn})$$

(A-1)*

(A-2)*

Ratios

Accounts for Q^2 dependence

Ratios of Fe/2H

Top left panel (Fe/²H vs X):

Fe/²H

$\langle Q^2 \rangle = 0.9$
$\langle Q^2 \rangle = 1.2$
$\langle Q^2 \rangle = 1.8$
$\langle Q^2 \rangle = 2.3$
$\langle Q^2 \rangle = 3.2$
$\langle Q^2 \rangle = 2.9$

X

Top right panel ($2/A\, \sigma^A(x,Q^2)/\sigma^D(x,Q^2)$ vs α_{TN}):

Fe/D
$\langle Q^2 \rangle = 0.9 \ (GeV/c)^2$
$\langle Q^2 \rangle = 1.2$
$\langle Q^2 \rangle = 1.8$
$\langle Q^2 \rangle = 2.3$
$\langle Q^2 \rangle = 2.9$
$\langle Q^2 \rangle = 3.2$

α_{TN}

Bottom left panel ($2/56\, \sigma^{56}(\alpha,Q^2)/\sigma^2(\alpha,Q^2)$ vs X):

$Q^2 = 1.0$
$Q^2 = 1.9$
$Q^2 = 2.8$
$Q^2 = 3.5$
$Q^2 = 4.2$
$Q^2 = 4.9$

X

Bottom right panel (vs α_{TN}):

$Q^2 = 1.0$
$Q^2 = 1.9$
$Q^2 = 2.8$
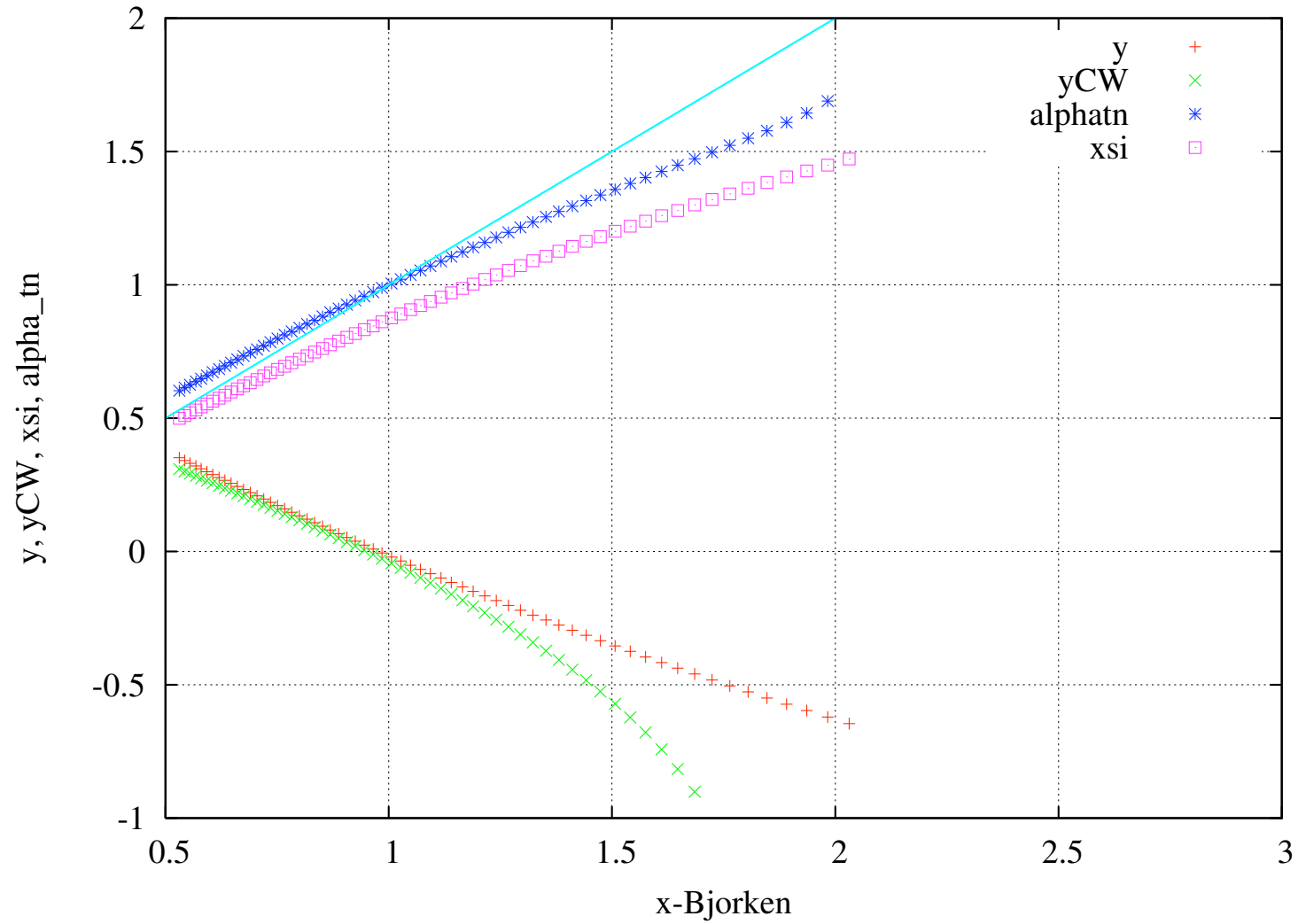$Q^2 = 3.5$
$Q^2 = 4.2$
$Q^2 = 4.9$

α_{TN}

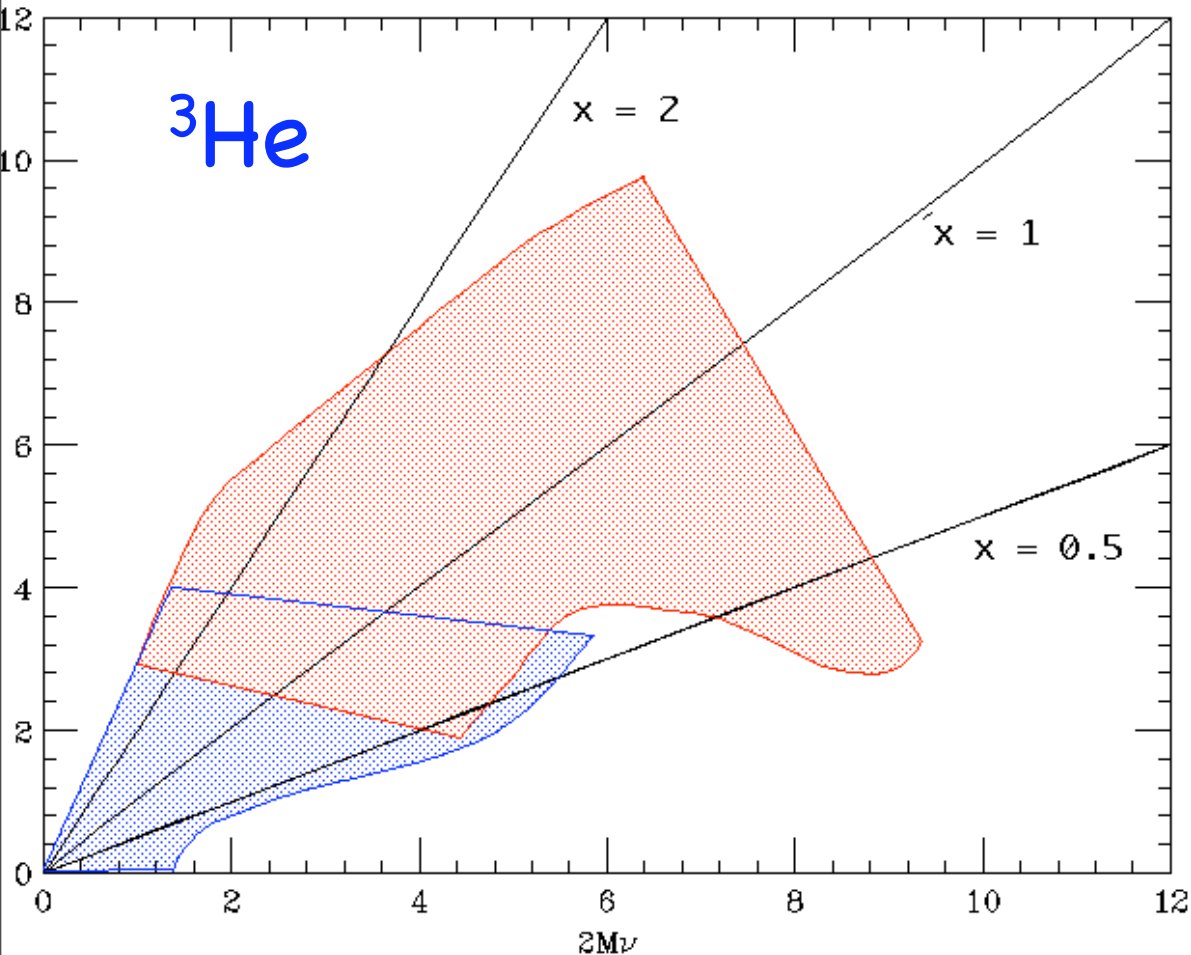# Relationship between variables

$Q^2 = 2.8$ (GeV/c)^2
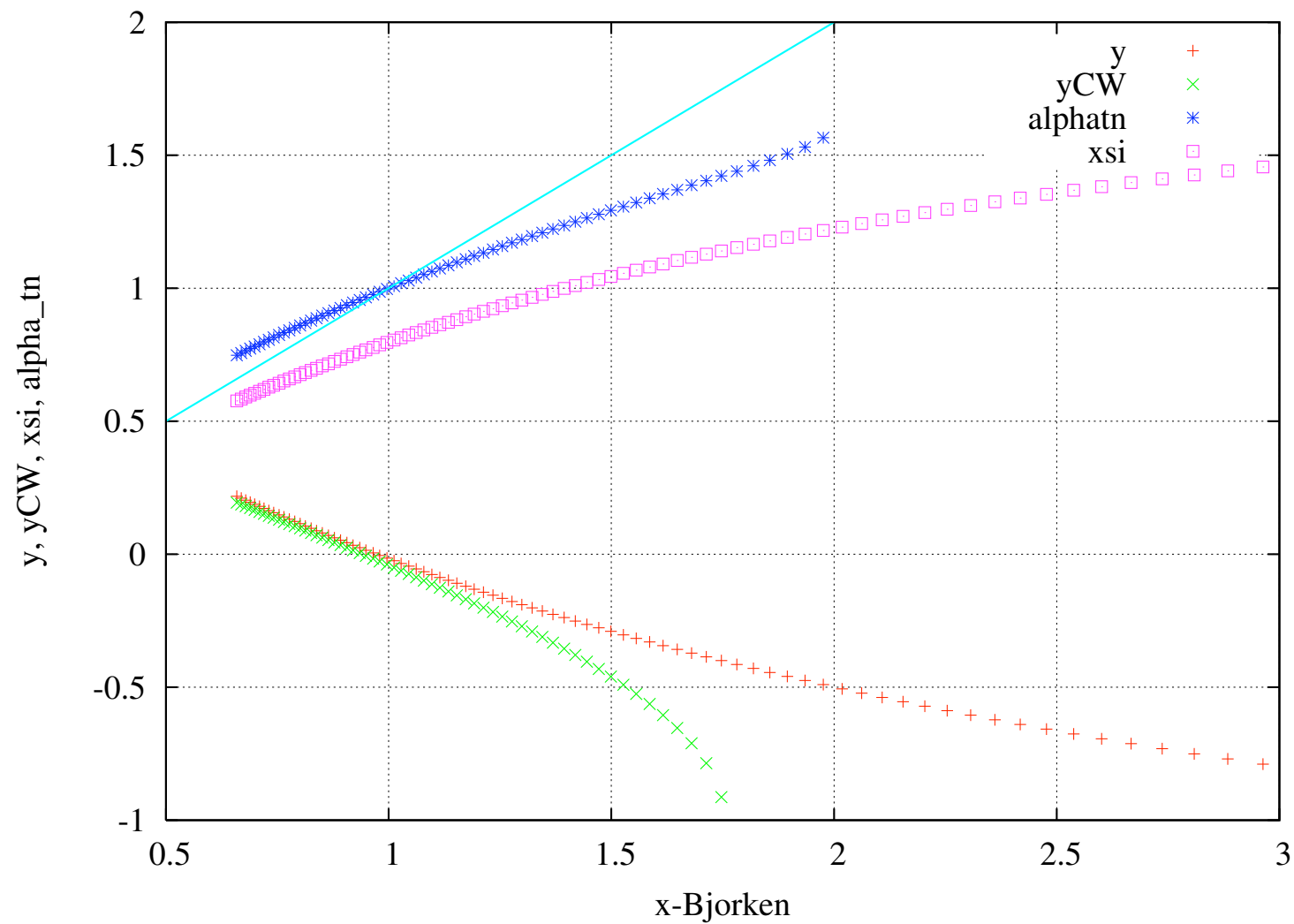
Relationship between variables

$Q^2 = 6.4 \ (GeV/c)^2$
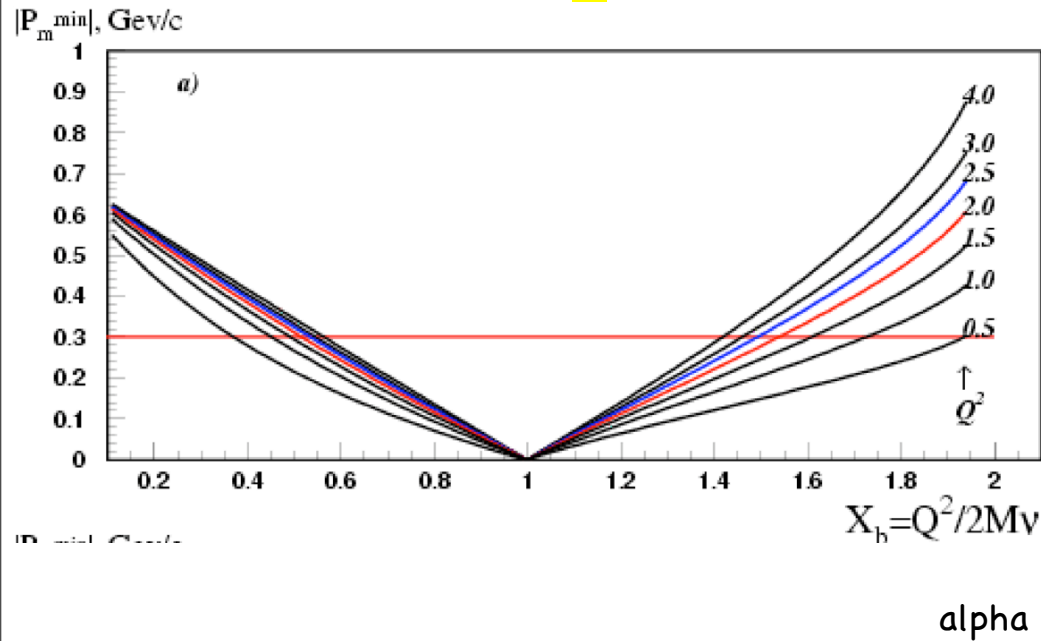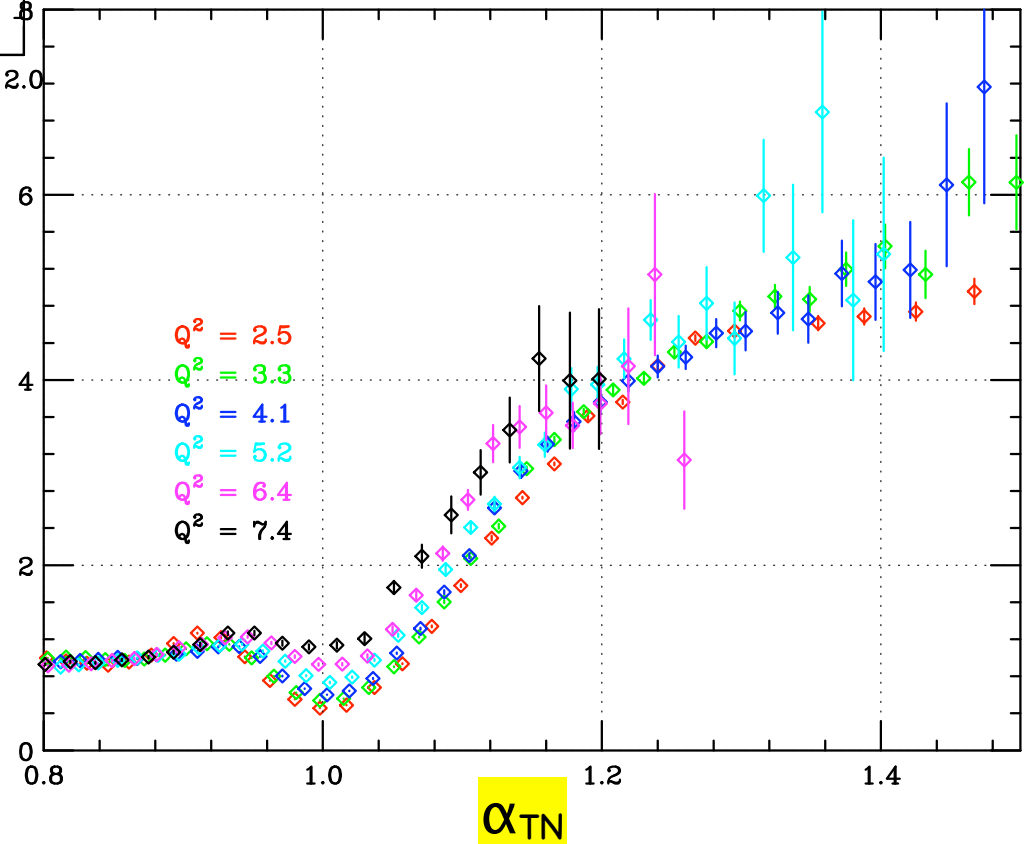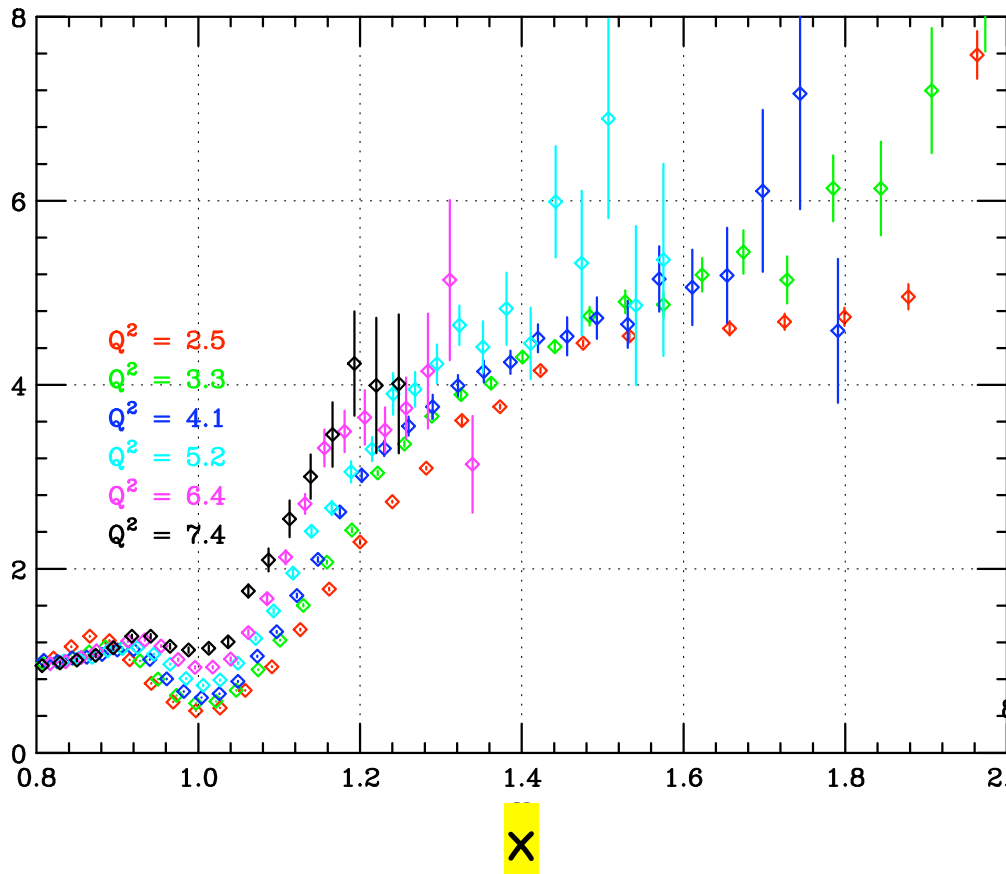
E02-019 explored new kinematic range

^{3}He

NE3, E89-008, E02-109,
E-08-014, E12-06-105

- E02-019 finished in late 2004 in Hall C at Jefferson Lab. Used a beam energy of 5.77 GeV and currents up to 80uA

- Cryogenic Targets: H, ^{2}H, ^{3}He, ^{4}He

- Solid Targets: Be, C, Cu, Au

- Spectrometers: HMS and SOS

- Angles: 18, 22, 26, 32, 40, 50

- Ran concurrently with E03-103

- Nadia Fomin (UVa), Roman Trojer (Basel), Jason Seely (MIT, E03-103), Anji Daniel (Houston, E03-103)

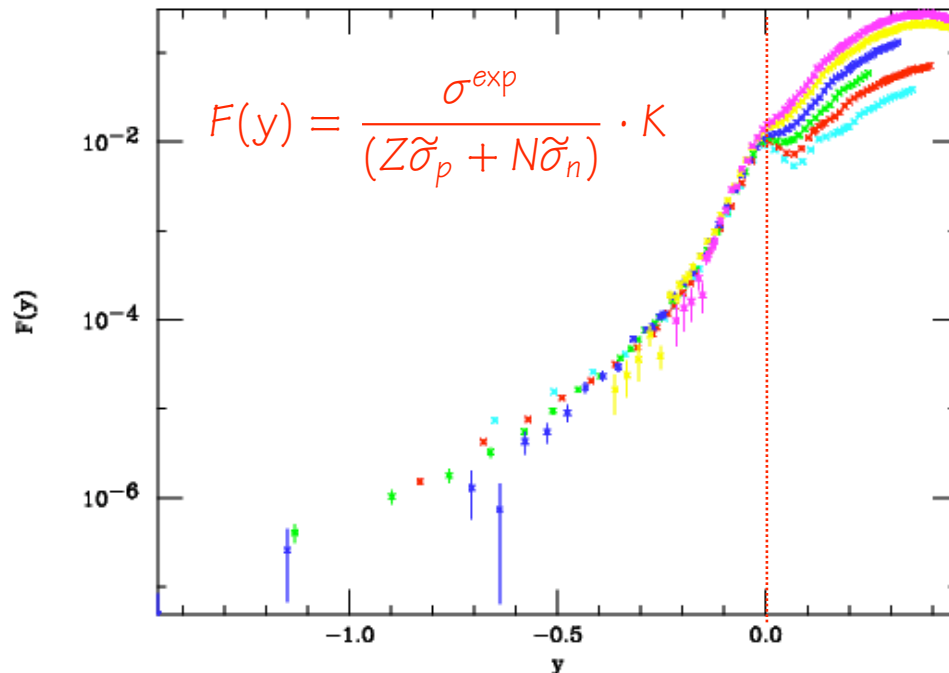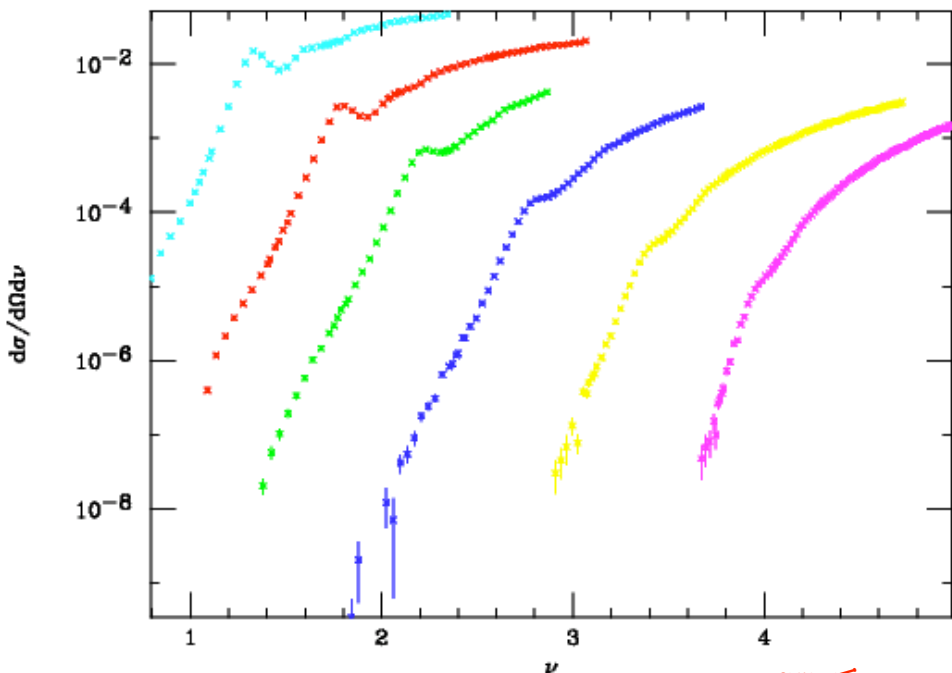- Analysis is basically complete (3 out of 4 Ph.D)

Ratios of $^{12}C/^2H$

E02019 - Preliminary

$Q^2 = 2.5$
$Q^2 = 3.3$
$Q^2 = 4.1$
$Q^2 = 5.2$
$Q^2 = 6.4$
$Q^2 = 7.4$

X

$|P_m^{min}|$, Gev/c

a)

4.0
3.0
2.5
2.0
1.5
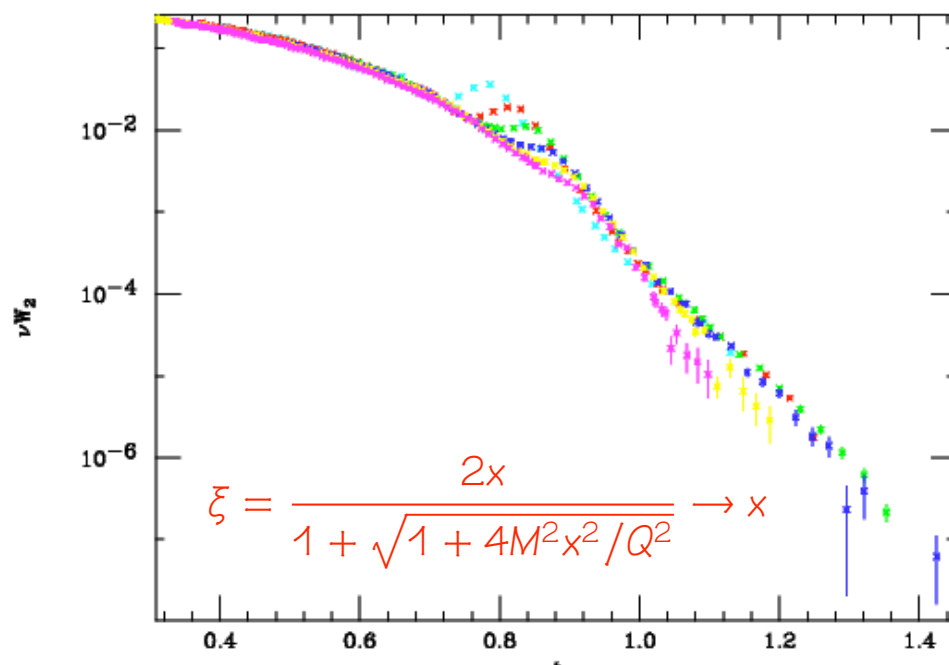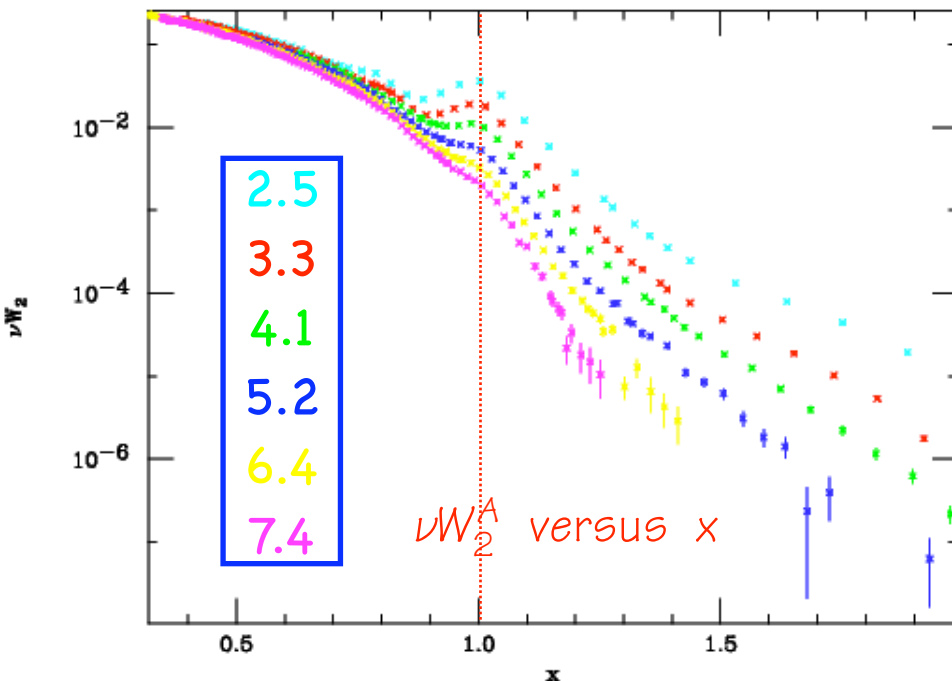1.0
0.5

$\uparrow$
Q^2

$X_h = Q^2/2M\nu$

alpha

$|P_m^{min}|$, Gev/c

α_{TN}

Preliminary Results (E02-019) – Deuteron

Z, A = 1 2

$$F(y) = \frac{\sigma^{exp}}{(Z\tilde{\sigma}_p + N\tilde{\sigma}_n)} \cdot K$$

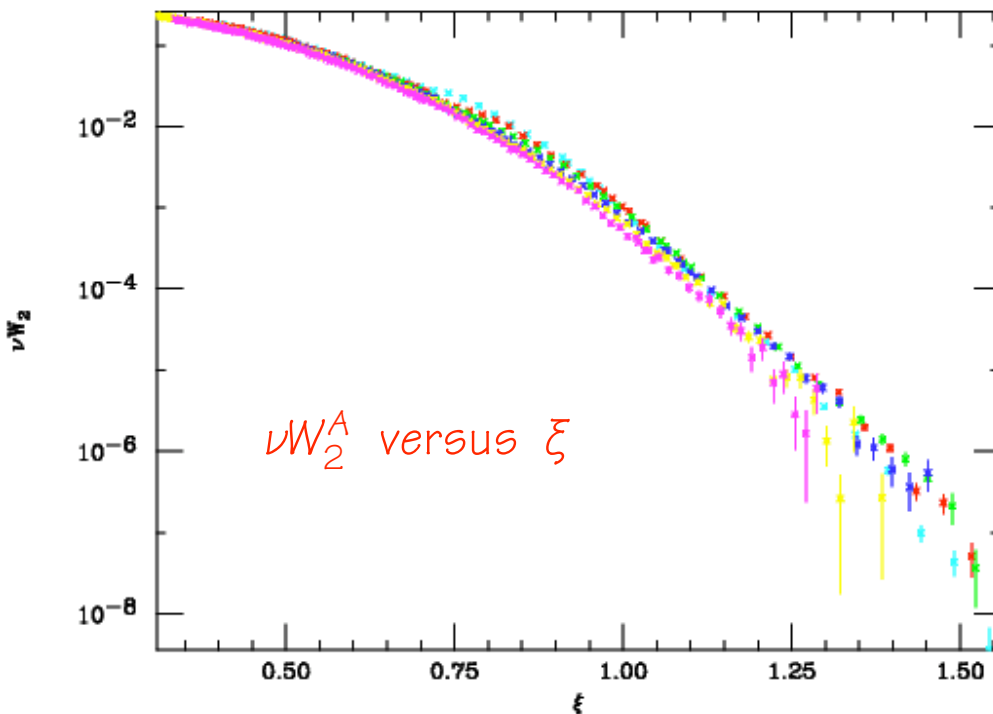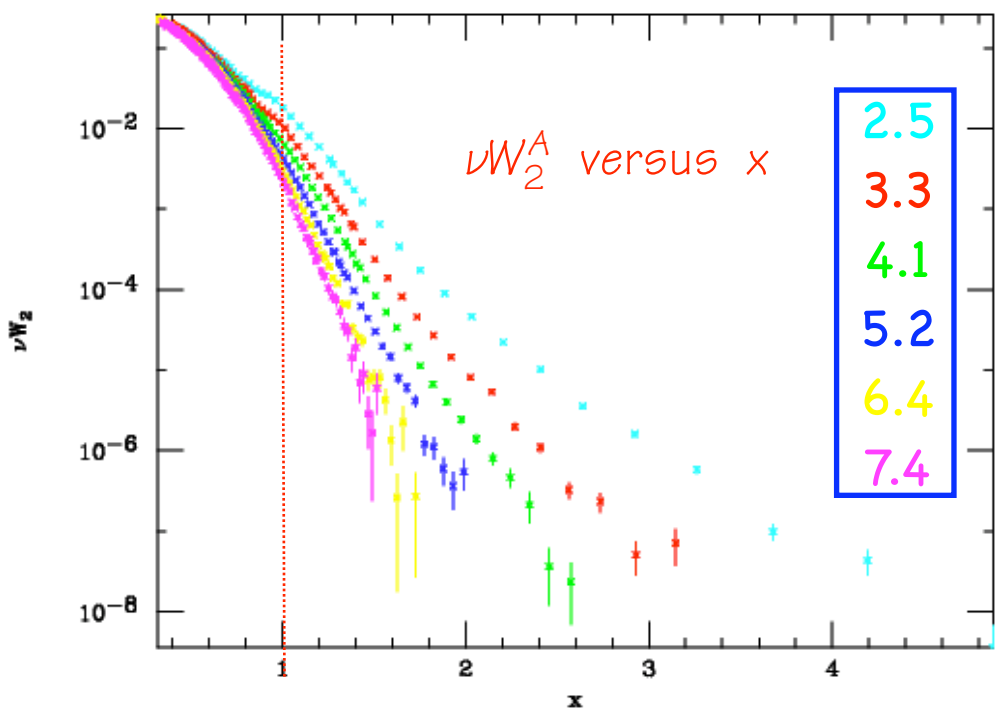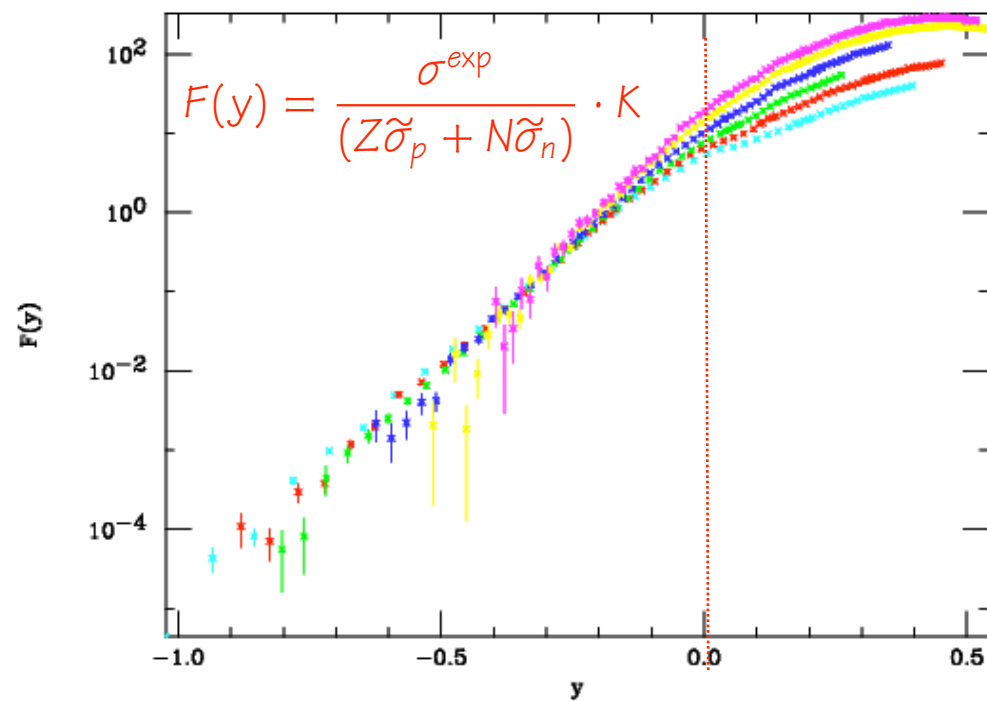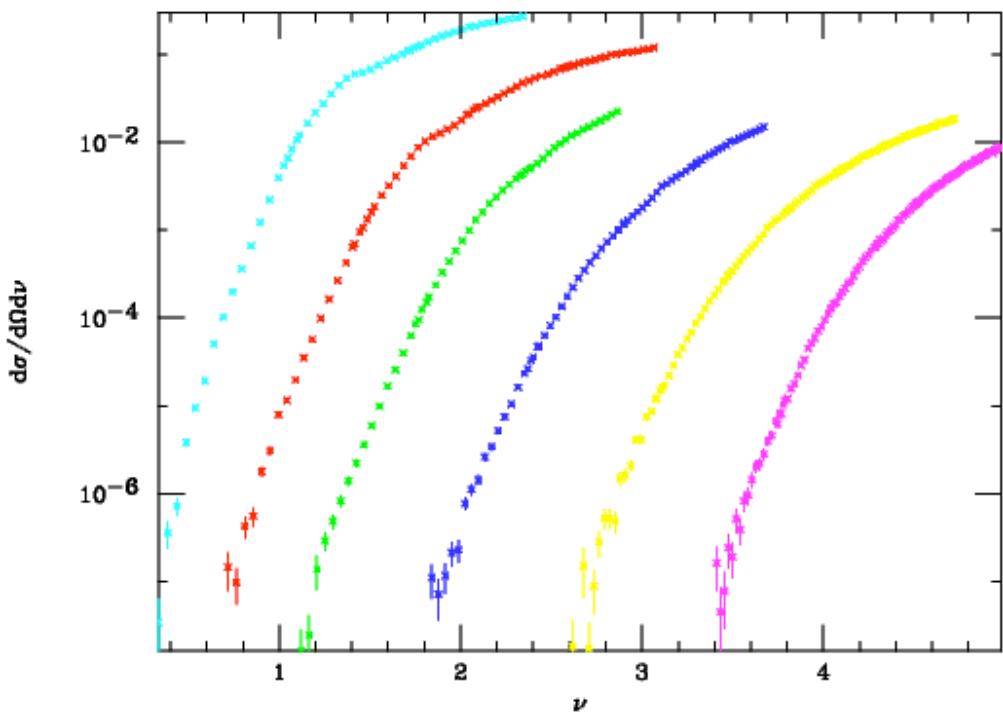$$\nu W_2^A = \nu \cdot \frac{\sigma^{exp}}{\sigma_M}\left[1 + 2\tan^2(\theta/2)\cdot\left(\frac{1+\nu^2/Q^2}{1+R}\right)\right]^{-1}$$

2.5
3.3
4.1
5.2
6.4
7.4

νW_2^A versus x

$$\xi = \frac{2x}{1+\sqrt{1+4M^2x^2/Q^2}} \to x$$

Preliminary Results (E02-019) – ³He

$$F(y) = \frac{\sigma^{exp}}{(Z\tilde{\sigma}_p + N\tilde{\sigma}_n)} \cdot K$$

νW_2^A versus x

νW_2^A versus ξ

2.5
3.3
4.1
5.2
6.4
7.4
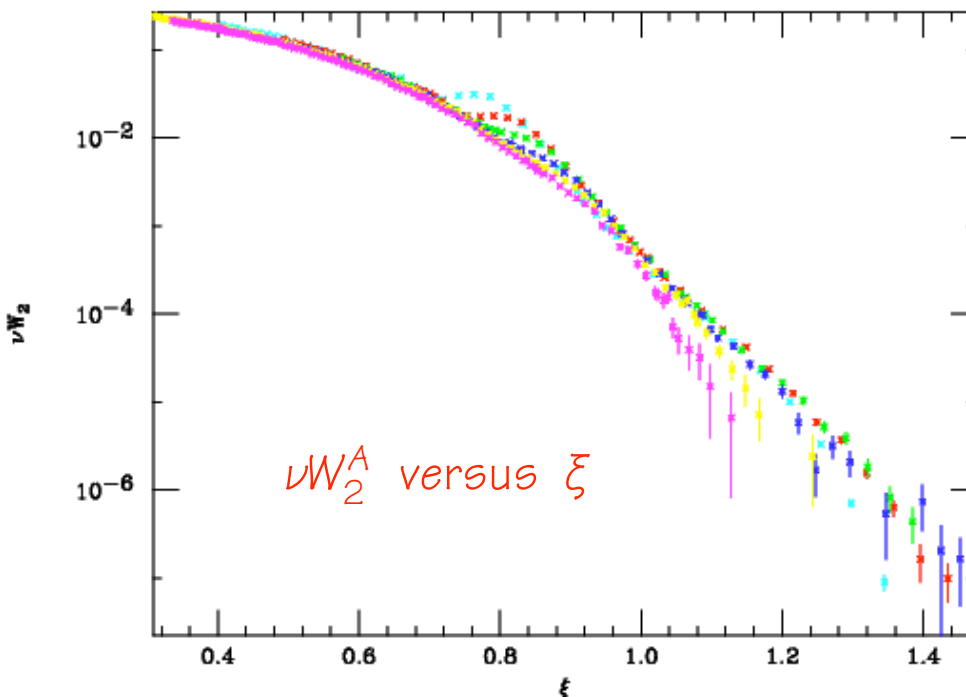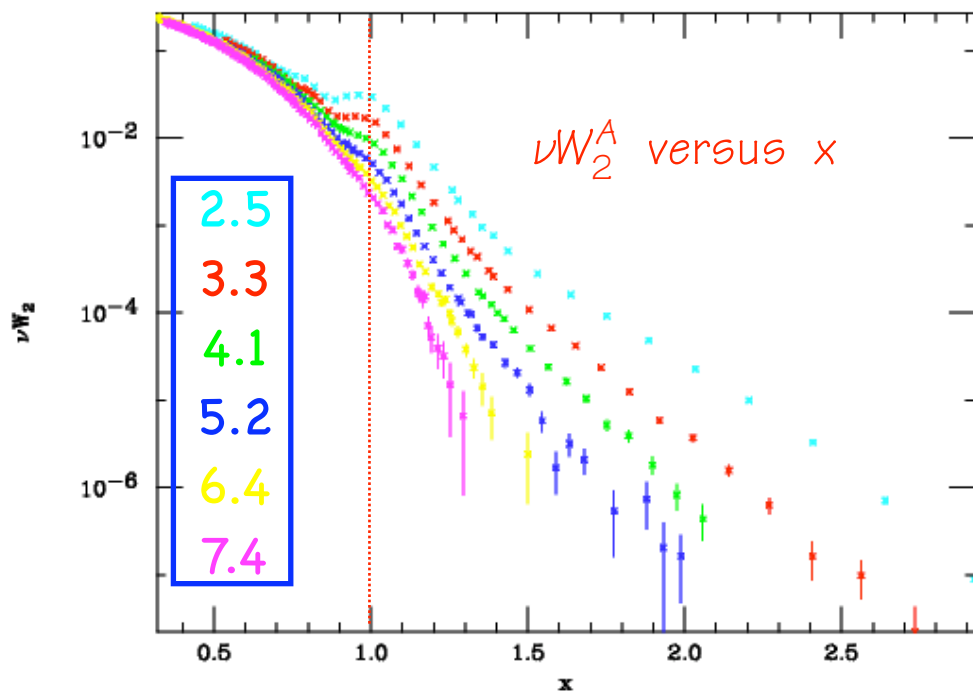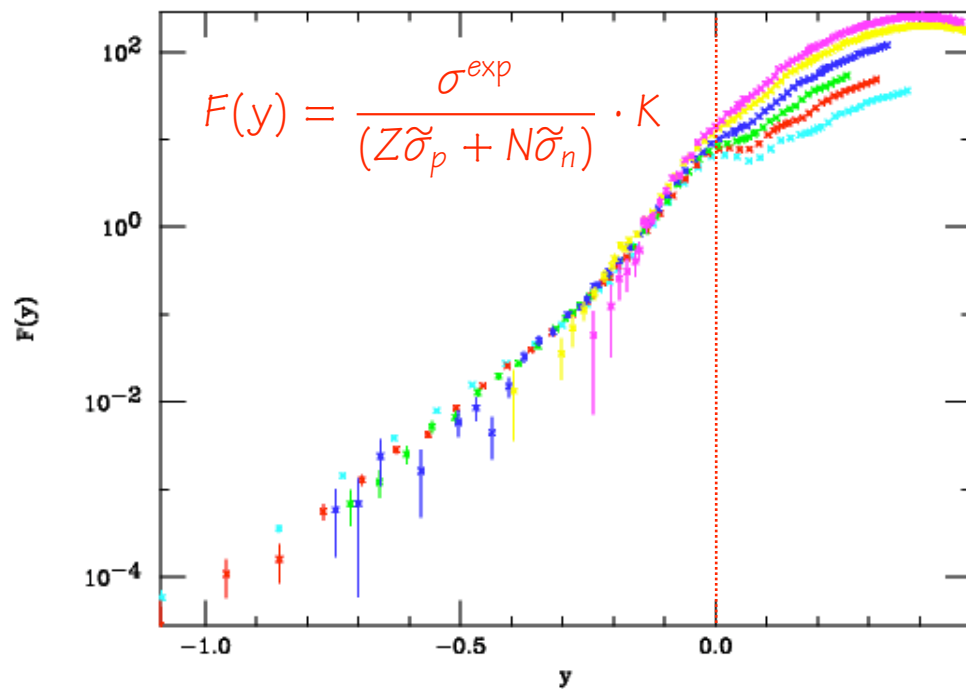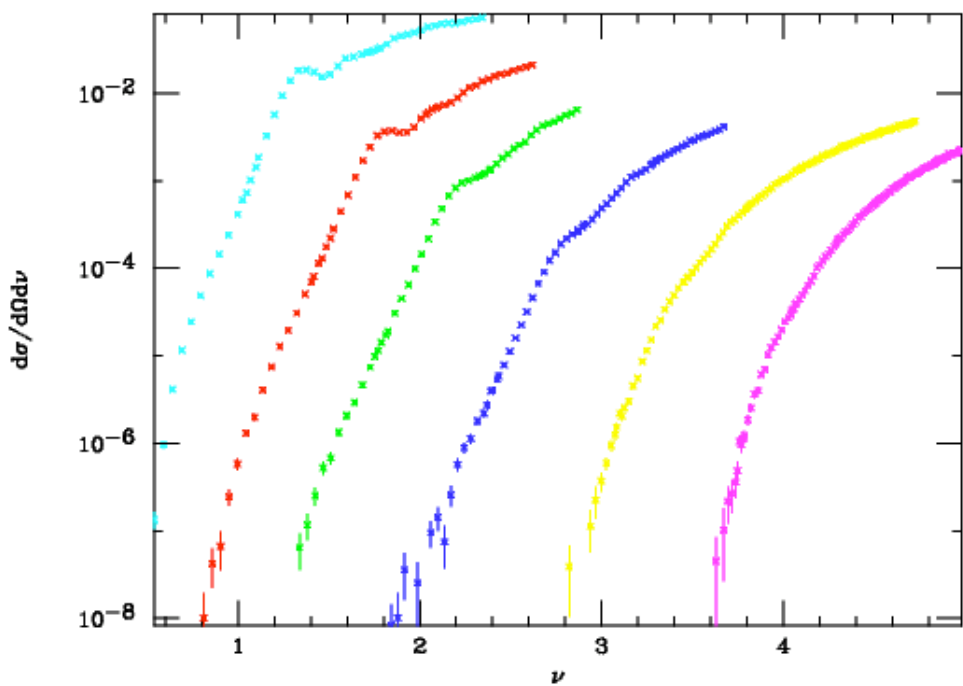
Preliminary Results (E02-019) - ^{12}C

$$F(y) = \frac{\sigma^{exp}}{(Z\tilde{\sigma}_p + N\tilde{\sigma}_n)} \cdot K$$

νW_2^A versus x

| 2.5 |
| 3.3 |
| 4.1 |
| 5.2 |
| 6.4 |
| 7.4 |

νW_2^A versus ξ

O.Benhar, NMBT and CGA for FSI

Carbon 5.766, 18°,
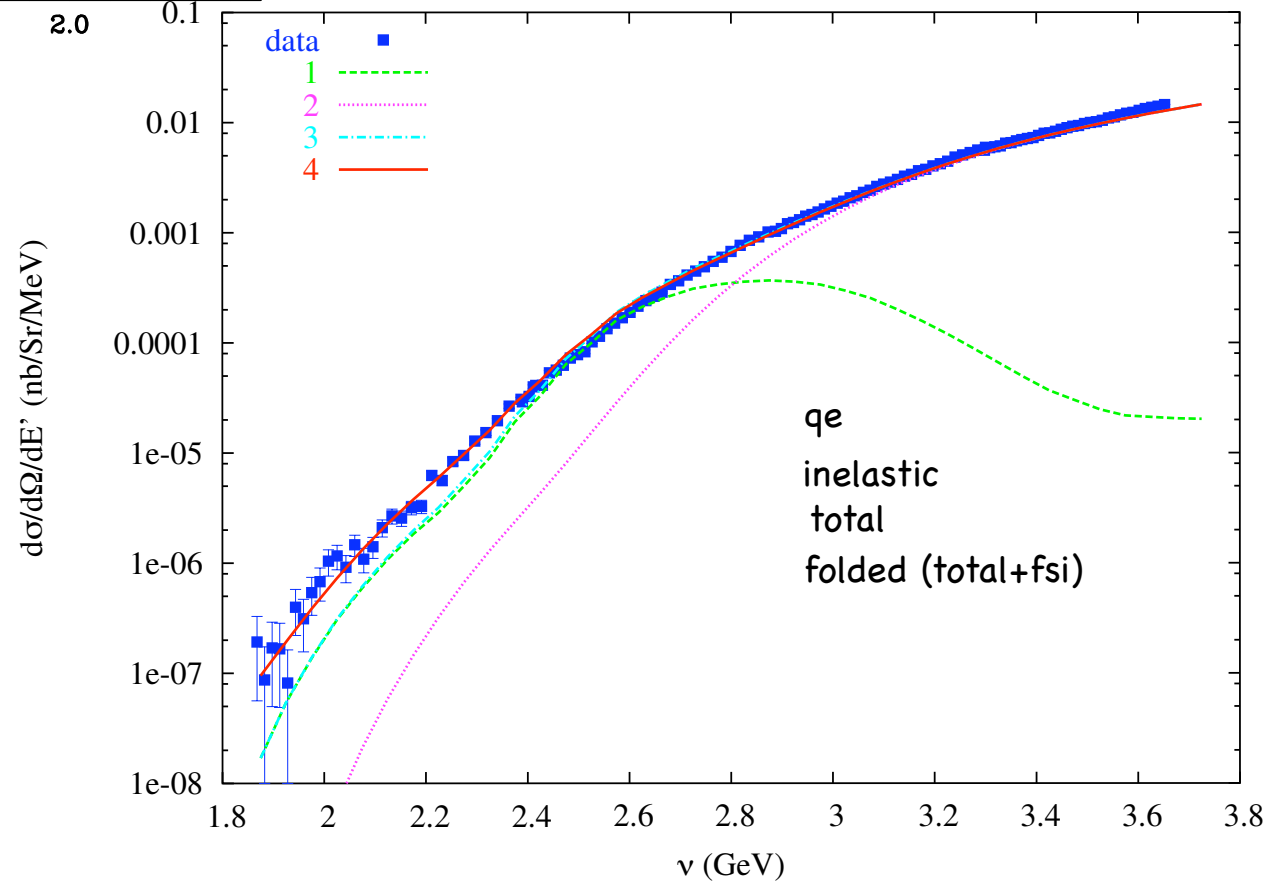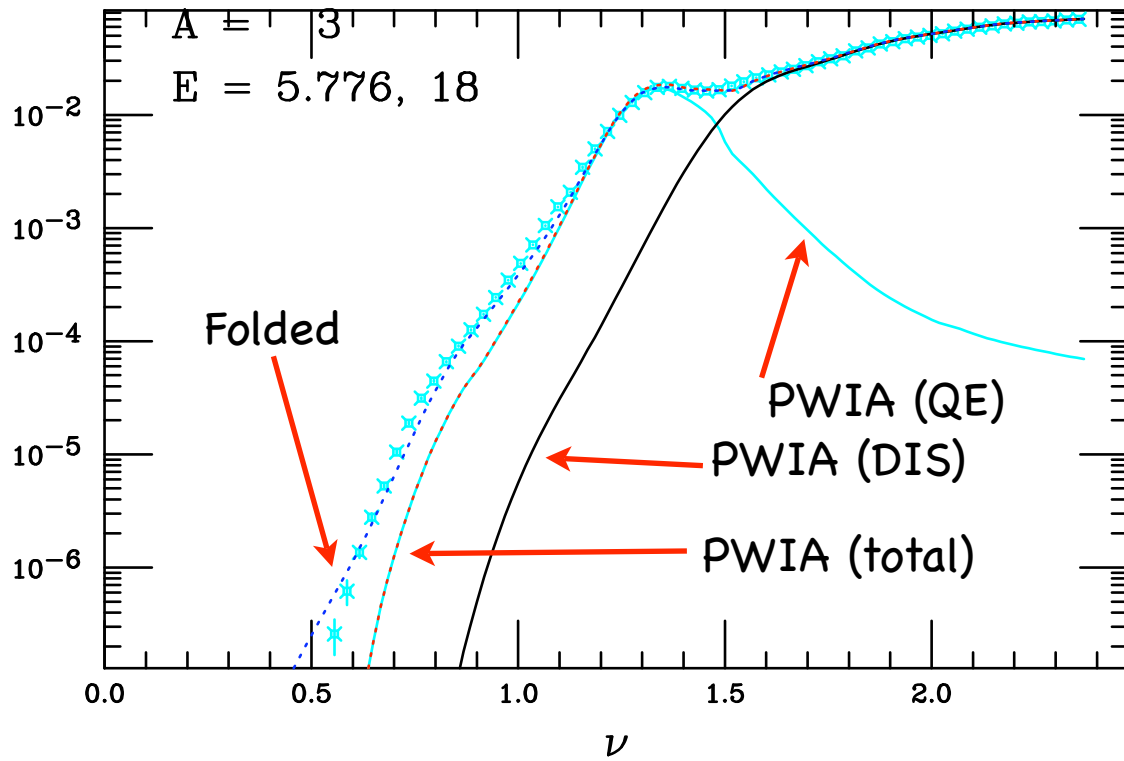Q^2 = 2.5 (GeV/c)^2

A = 12
E=5.776, 18

PWIA

PWIA + folded

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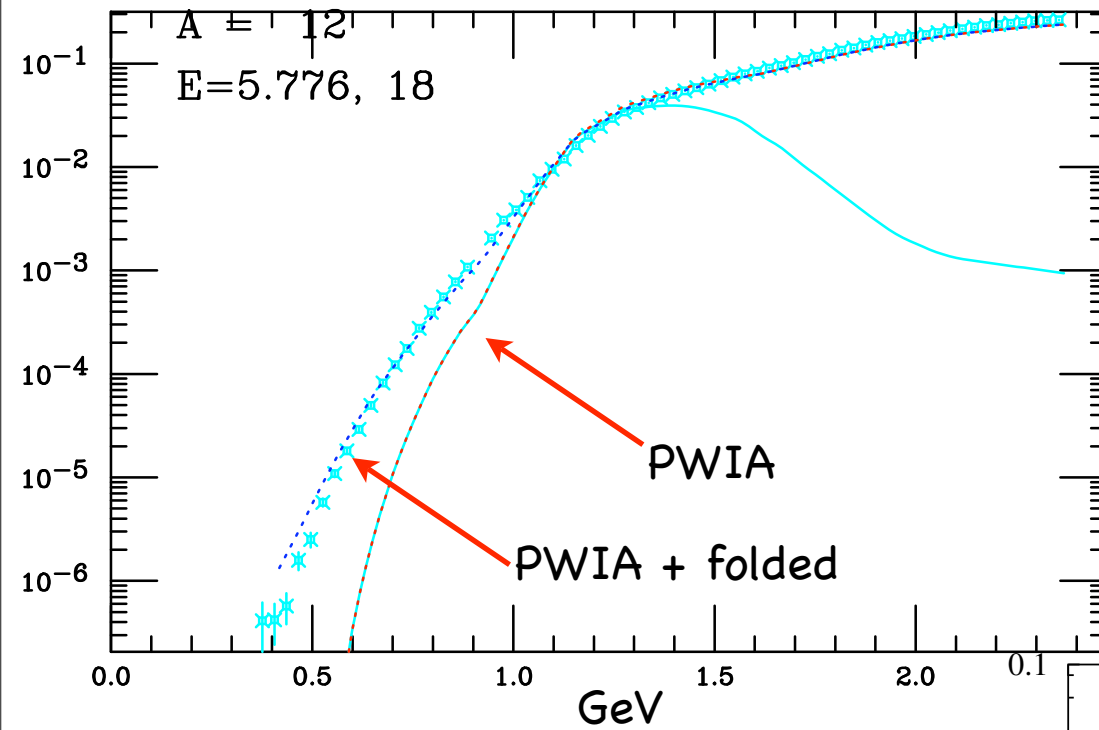
Carbon 5.766, 32°,
Q^2 = 5.2 (GeV/c)^2

Benhar et al. PRC 44, 2328

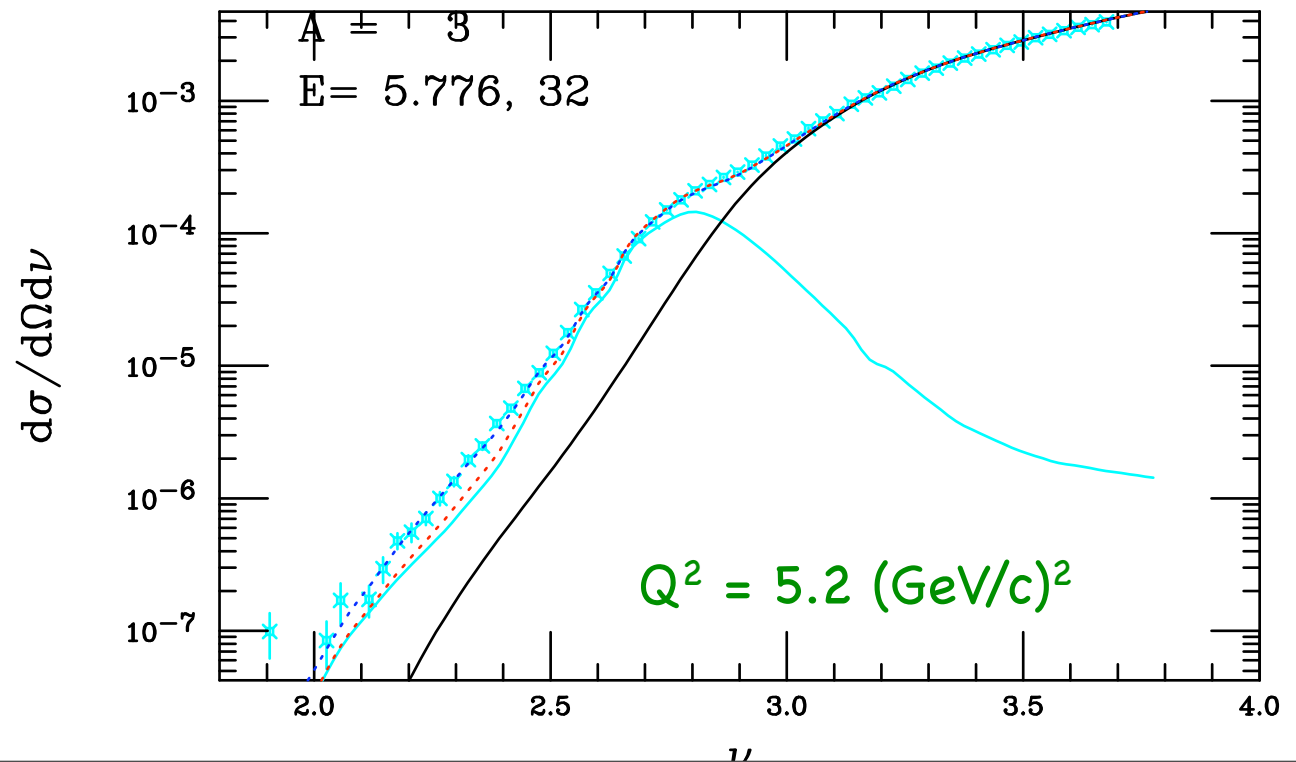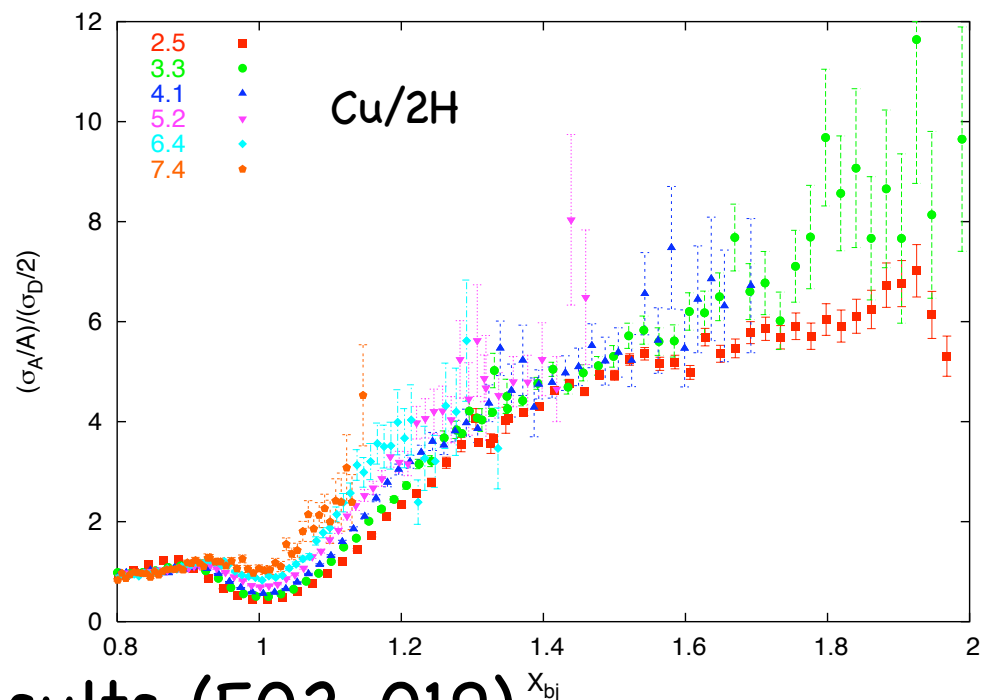Benhar, Pandharipande, PRC 47, 2218

Benhar et al. PLB 3443, 47

data
1
2
3
4

$d\sigma/d\Omega/dE'$ (nb/Sr/MeV)

qe
inelastic
total
folded (total+fsi)

ν (GeV)

A = 3
E = 5.776, 18

³He

$Q^2 = 2.5\ (GeV/c)^2$

Folded

PWIA (QE)
PWIA (DIS)
PWIA (total)
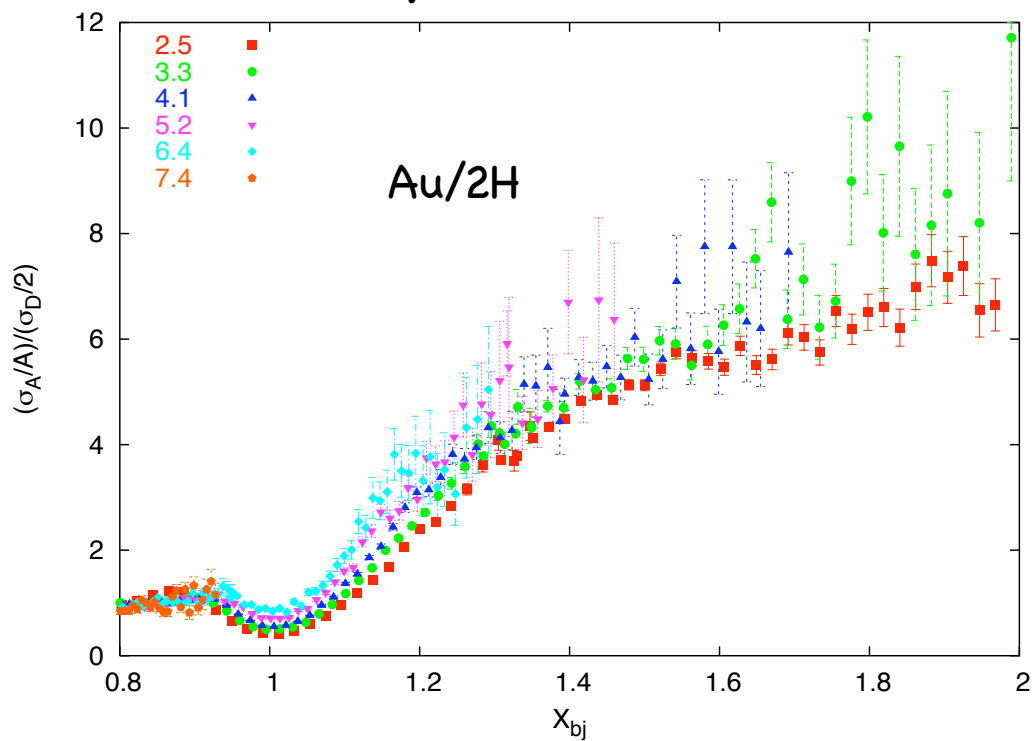
ν

Benhar et al. PRC 44, 2328

Benhar, Pandharipande, PRC 47, 2218

Benhar et al. PLB 3443, 47

A = 3
E= 5.776, 32

$d\sigma/d\Omega d\nu$

$Q^2 = 5.2\ (GeV/c)^2$

ν
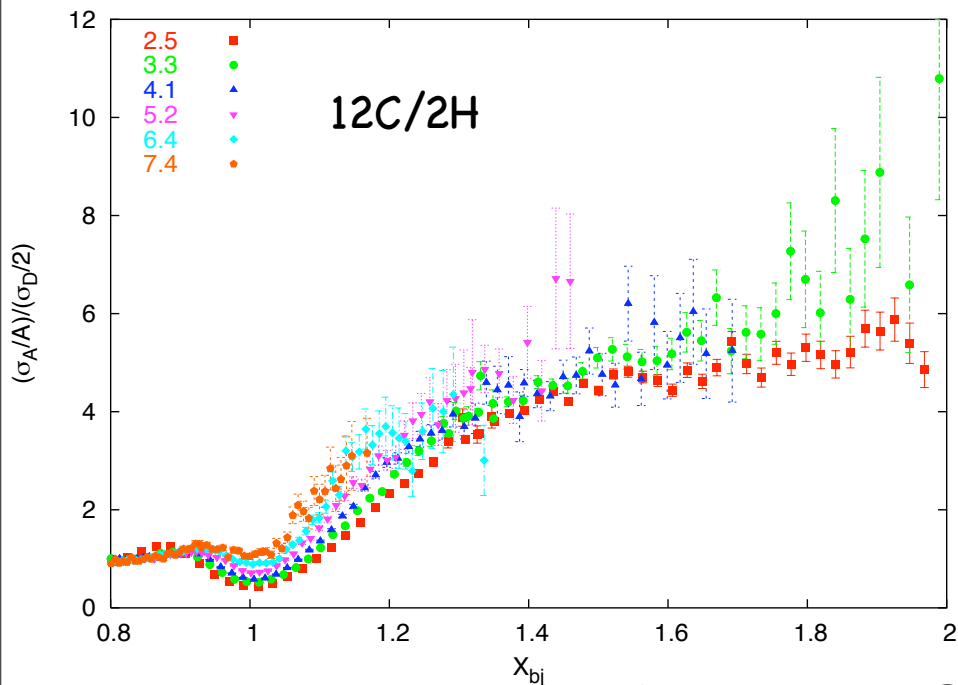
Preliminary Results (E02-019)
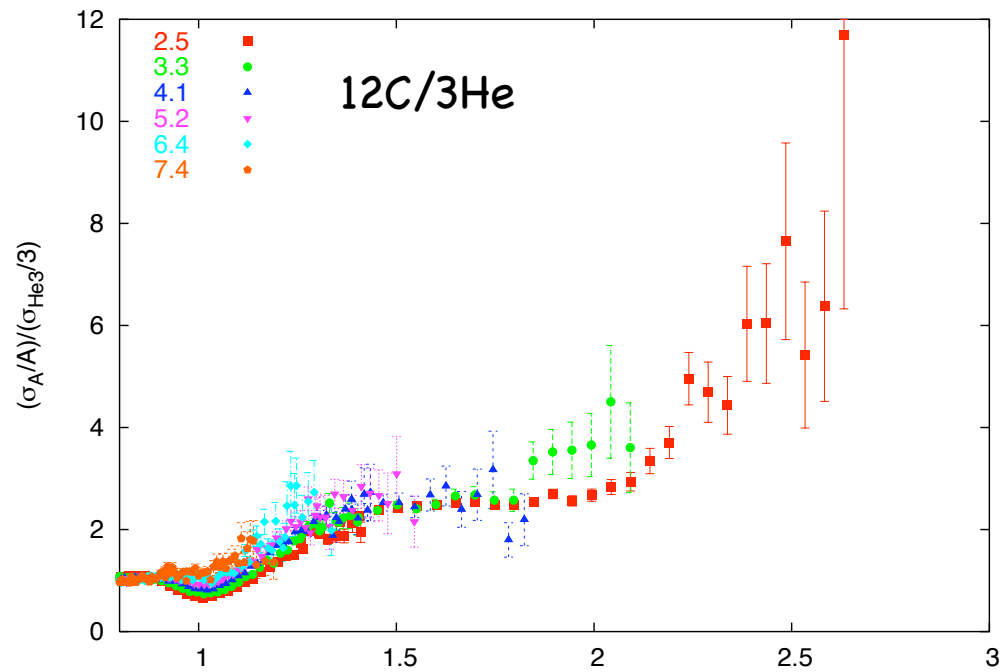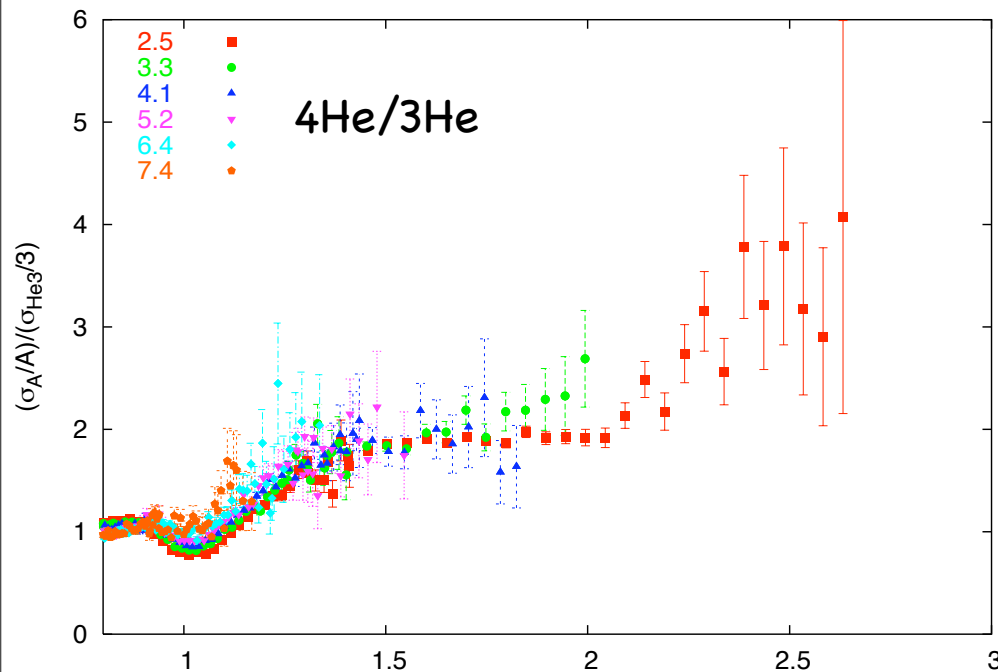
Preliminary Results (E02-019)

Future Experiments

- 6 GeV

  - 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]

Motivation for E08-014

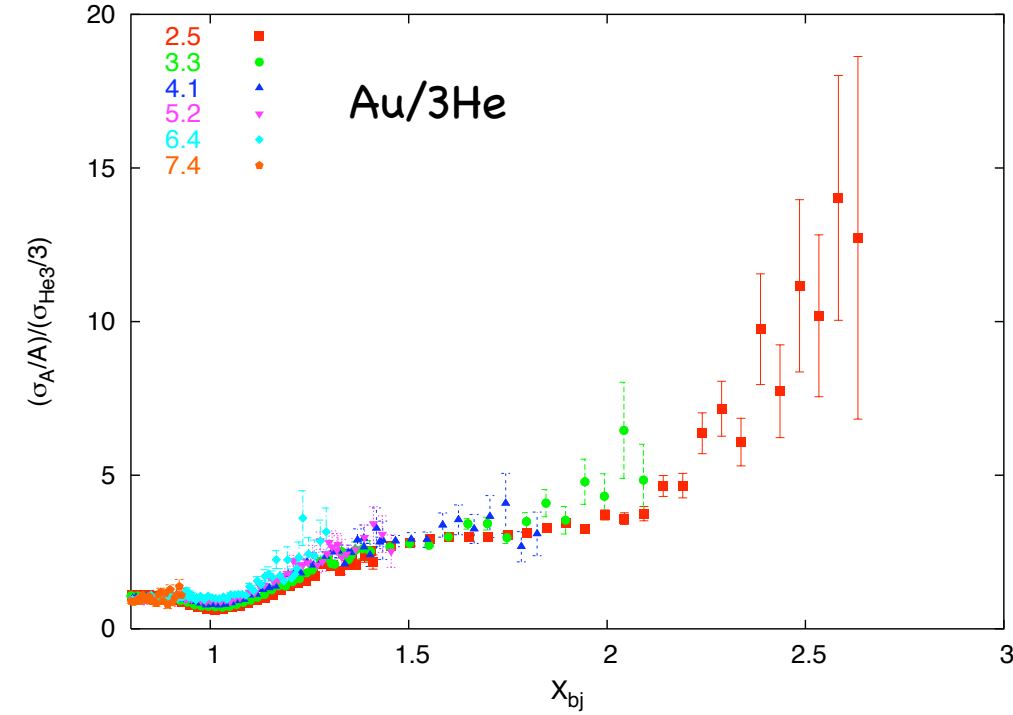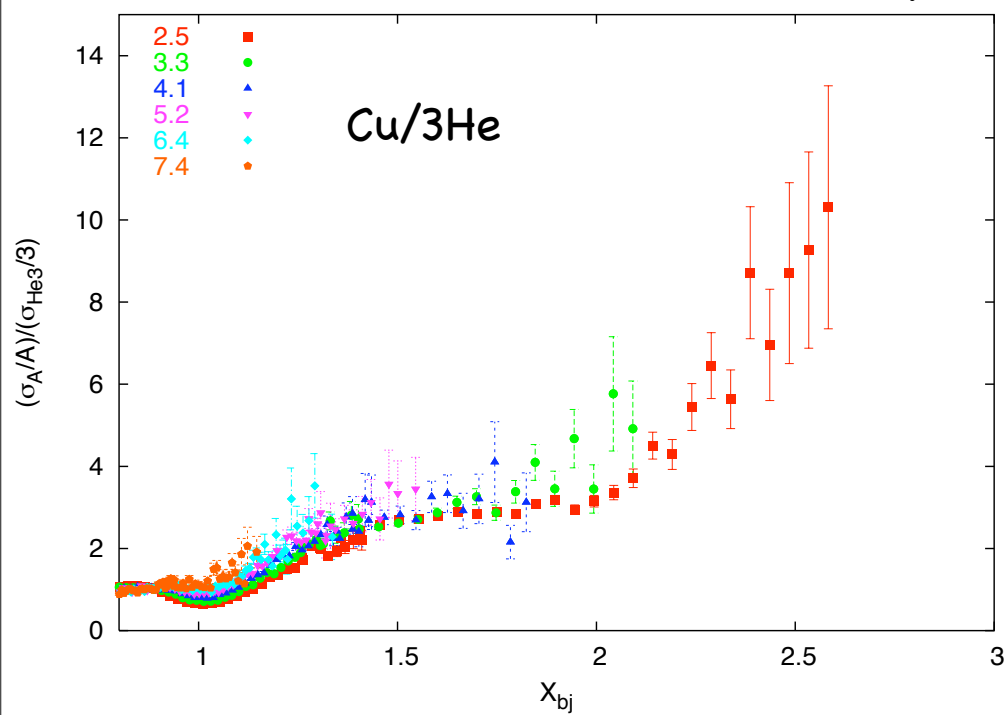- Study onset of scaling, ratios as a function of α_{2n} for 1<x<2
- Verify and define scaling regime for 3N-SRC
- 3N-SRC over a range of density: ^{40}Ca, ^{12}C, ^{4}He ratios
- Test α_{3n} for x> 2
- Absolute cross sections: test FSI, map out IMF distribution $\rho_A()$
  - needed for $q_A(x)$ convolution
  - (EMC, hard processes in A-A collisions, ...)
- Isospin effects on SRCs: ^{48}Ca vs. ^{40}Ca

Kinematic coverage

- Total: 11 kinematics settings

- ^{2}H only for x<2 kinematics
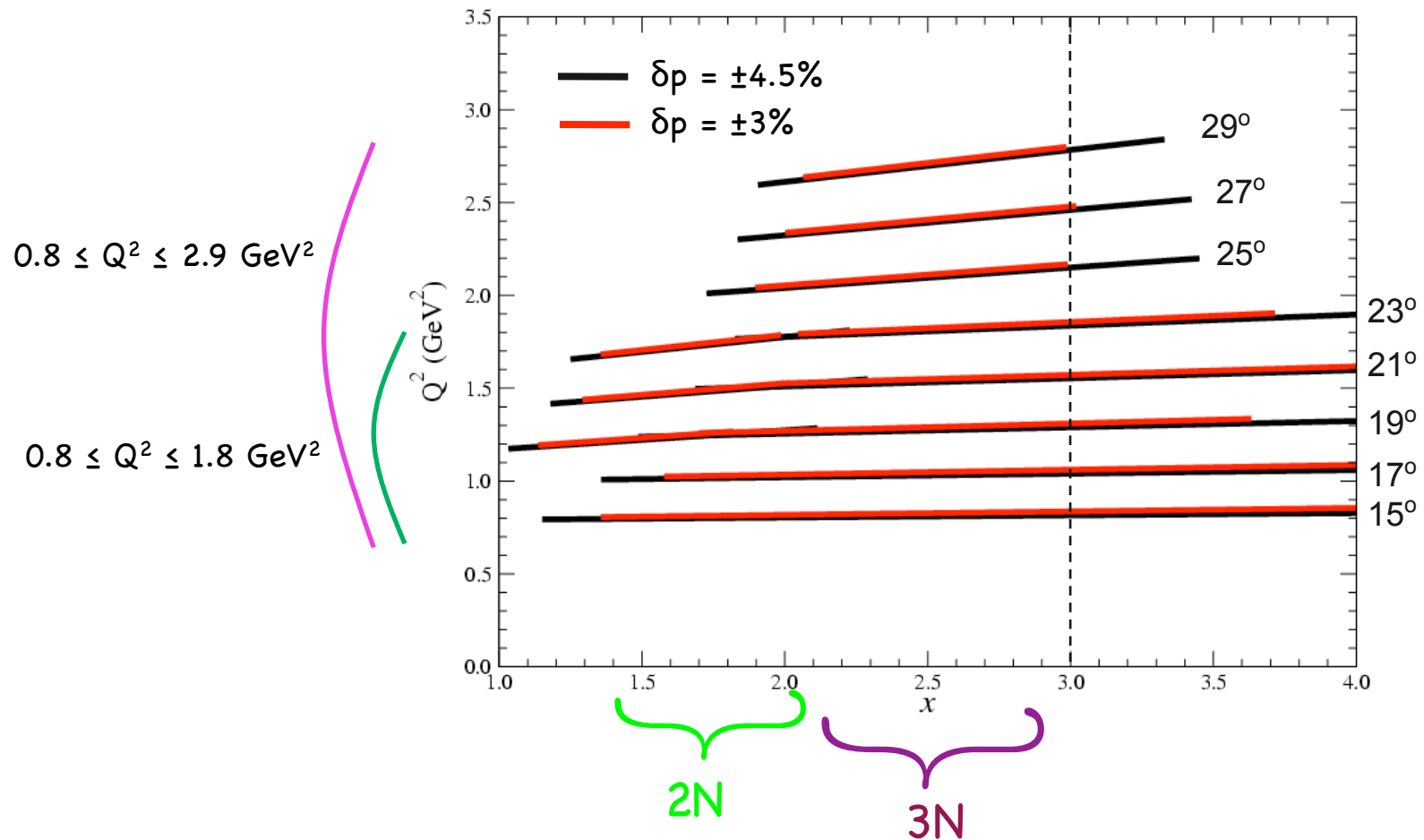
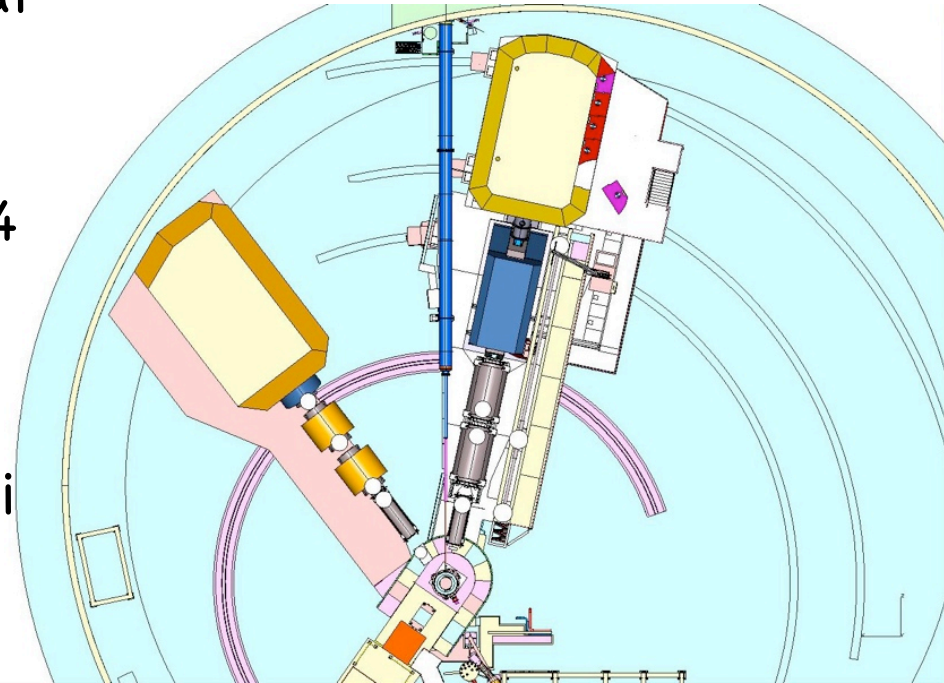# Inclusive DIS at x > 1 at 12 GeV

- 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

super-fast quarks,
quark distribution functions
medium modifications

SRC, n(k), FSI, σ

HMS

SHMS / HMS

SHMS

Q^2 $(GeV/c)^2$

x
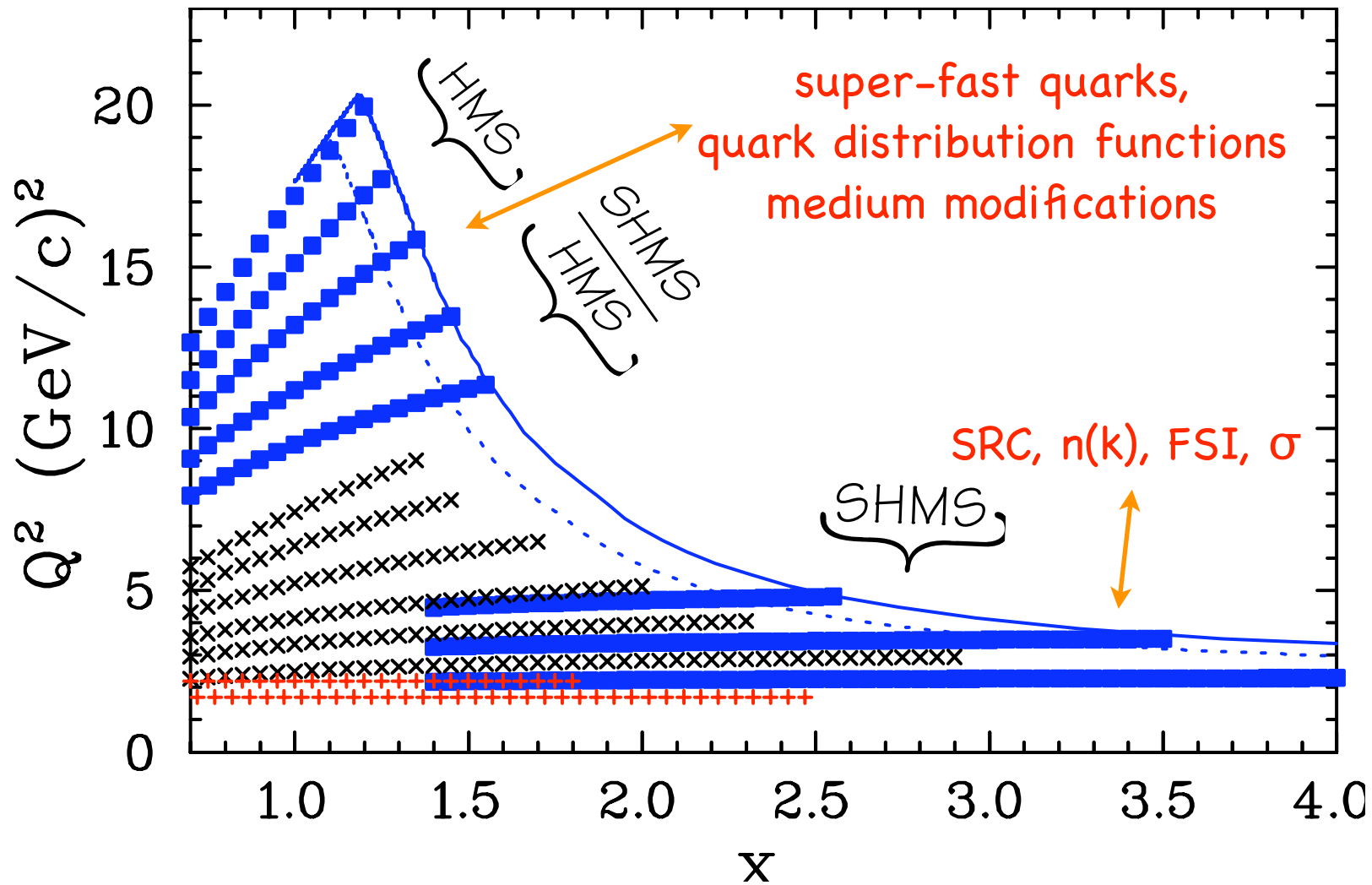
Black – 6 GeV, red – CLAS, blue – 11 GeV

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
- 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.
  - Once DIS dominates it will allow another avenue of access to SRC and to quark distribution functions
- Opportunities at 6 GeV still exist

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

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.
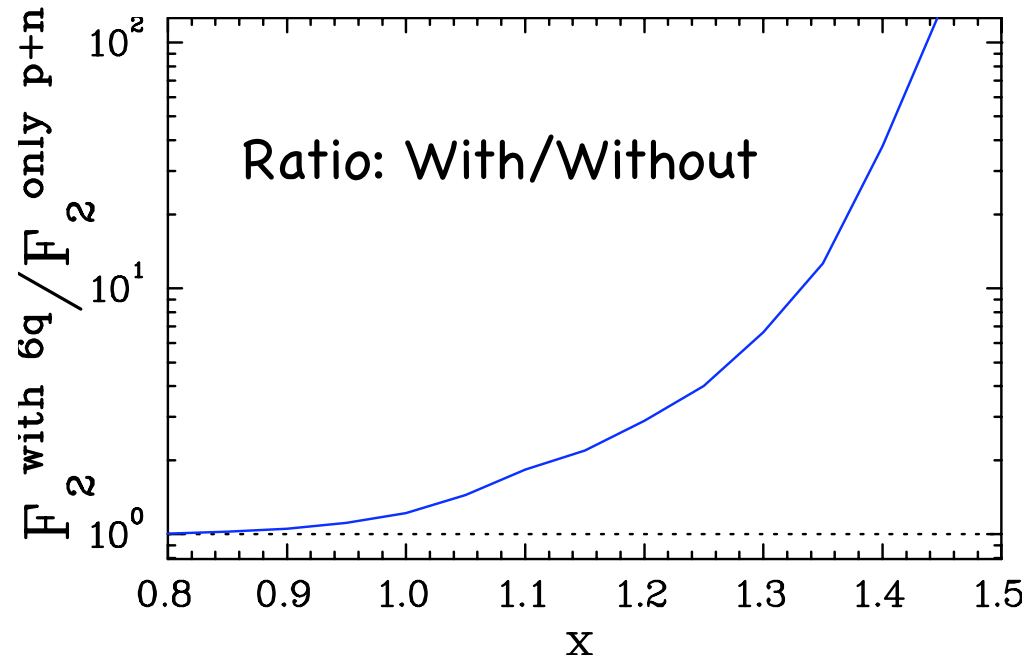2. Radiative corrections applied to data.
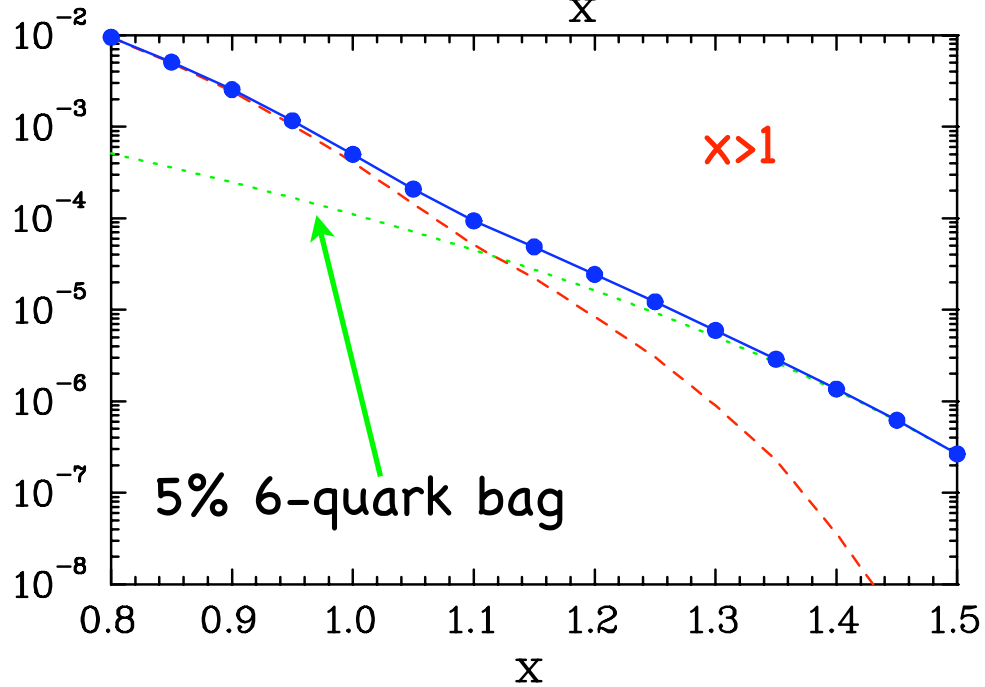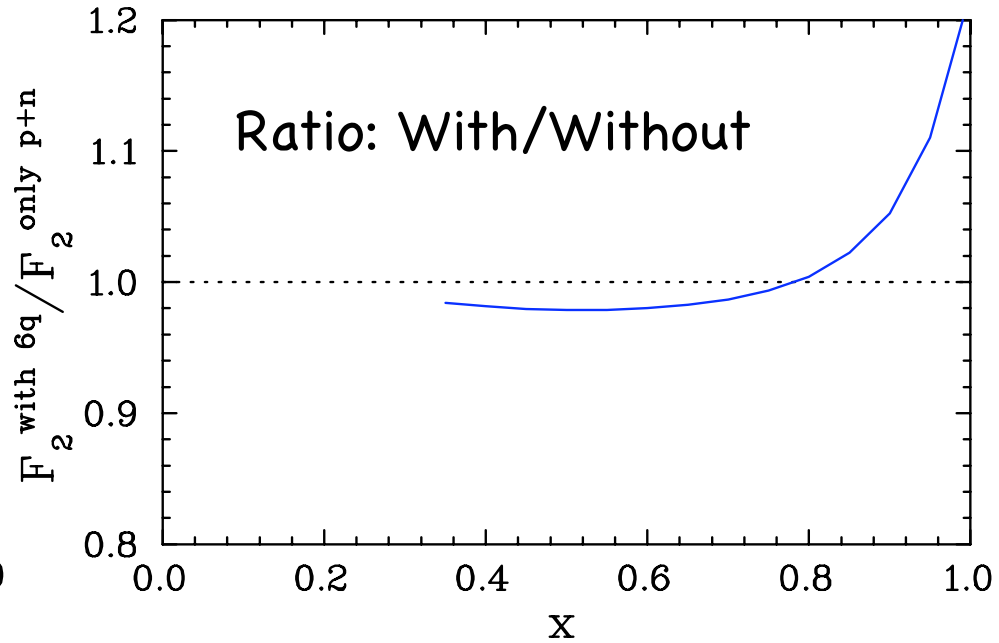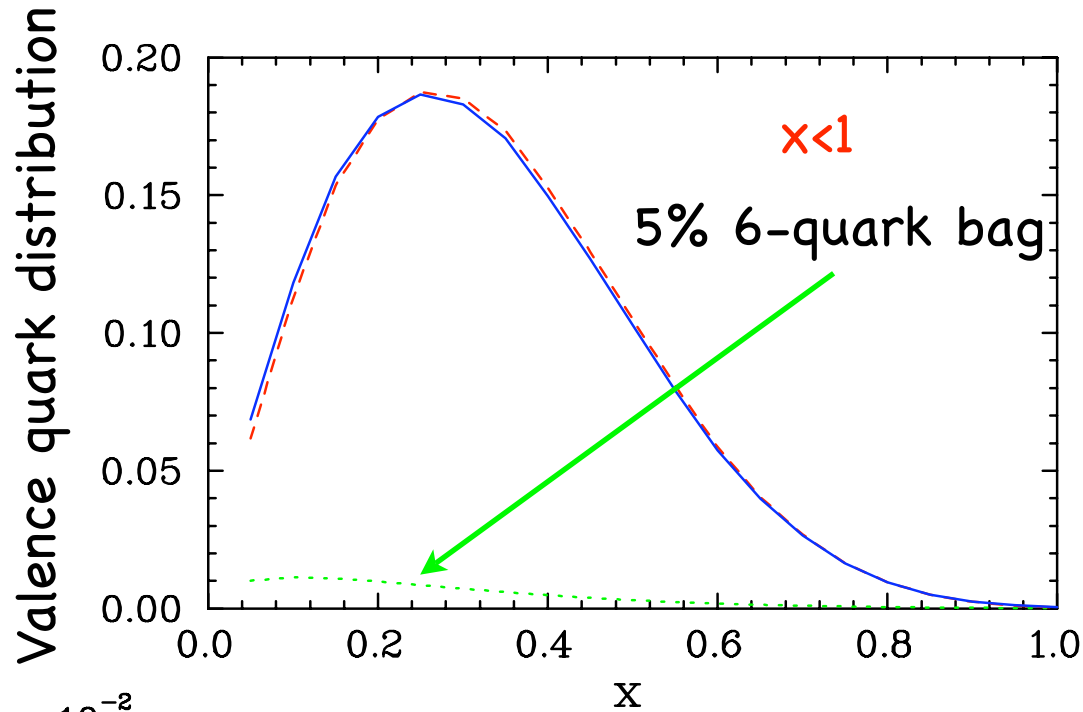3. No known or acknowledged pathologies

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.

Navigation:
- Home page
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Sensitivity to non-hadronic components

Mulders & Thomas

Quark distributions at x > 1
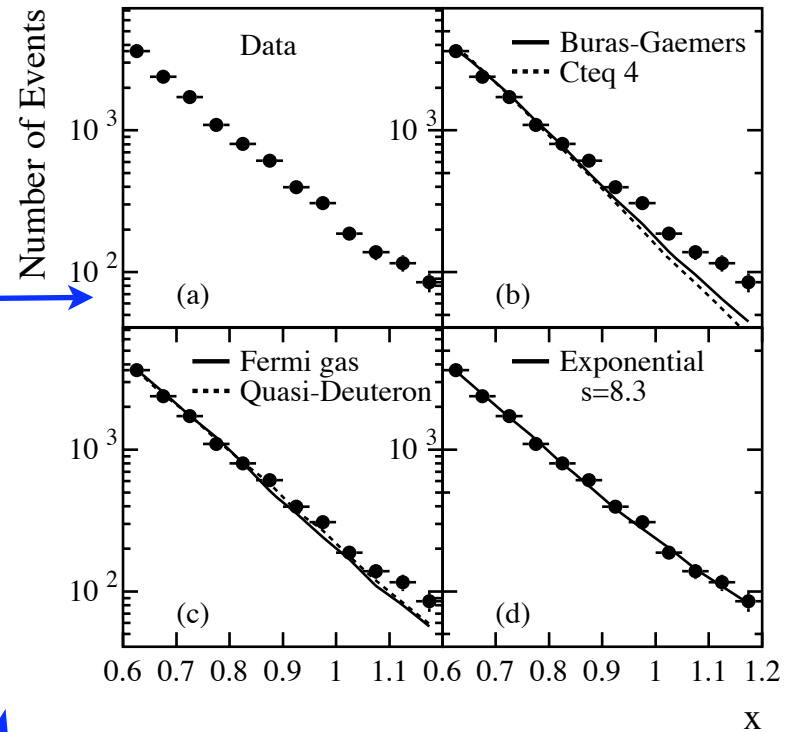
Two measurements (very high Q^2) exist so far:

CCFR (ν–C): $F_2(x) \propto e^{-sx}$ s = 8

BCDMS (μ–Fe): $F_2(x) \propto e^{-sx}$ s = 16
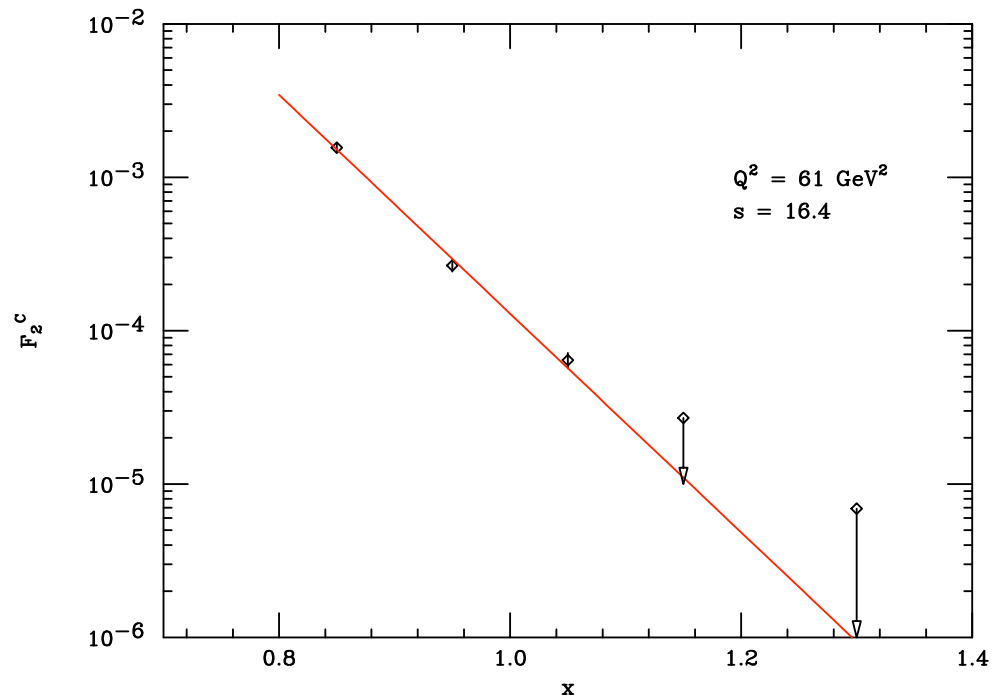
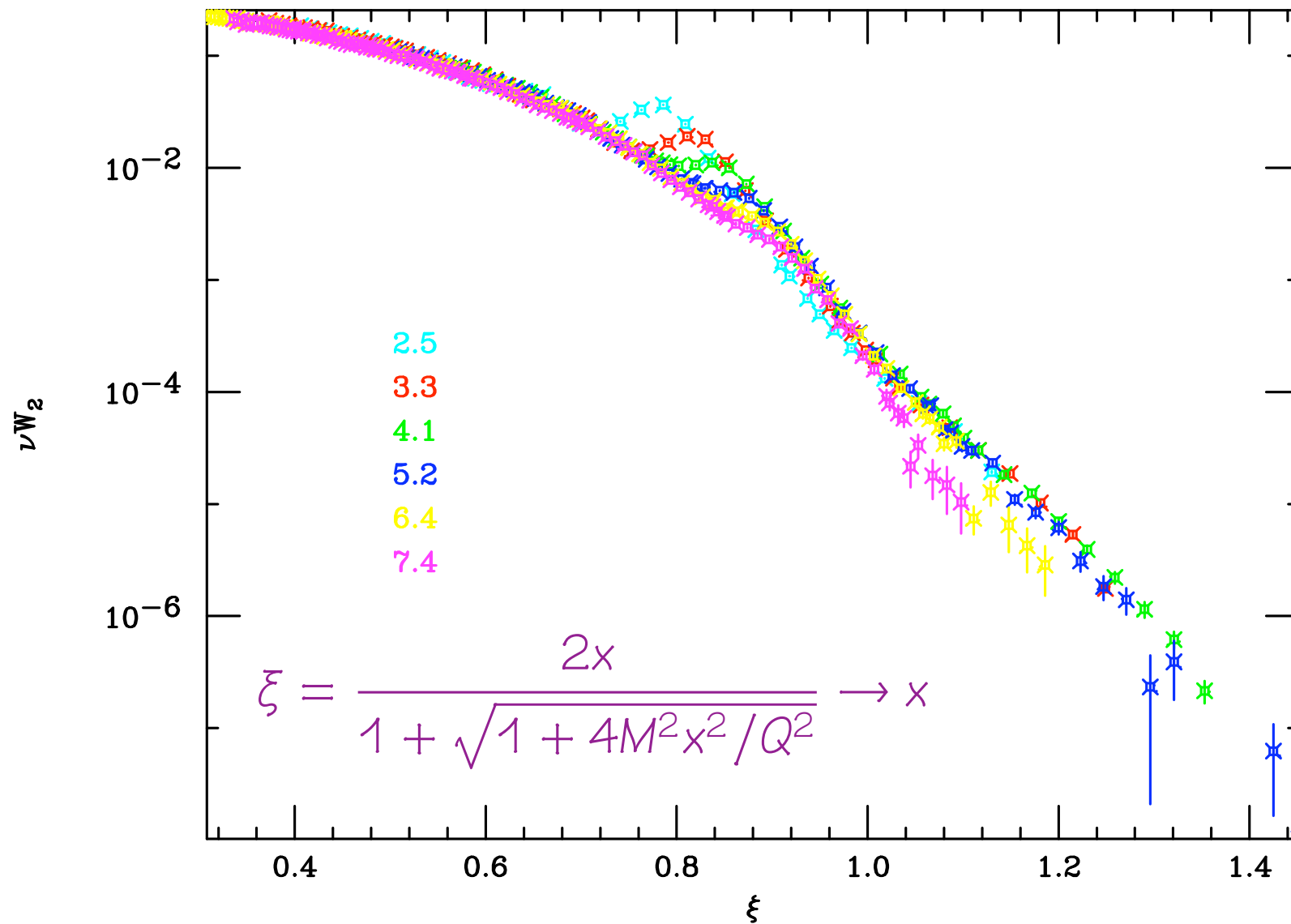Limited x range, poor resolution
Limited x range, low statistics

With 11 GeV beam, we should be in the scaling region up to x≈1.4

Number of Events

Data

Buras-Gaemers
Cteq 4

Fermi gas
Quasi-Deuteron

Exponential
s=8.3

(a) (b) (c) (d)

X

BCDMS 200 GeV muon

$Q^2 = 61$ GeV^2
s = 16.4

F_2^c

x

Quark Distribution Functions

Deuterium

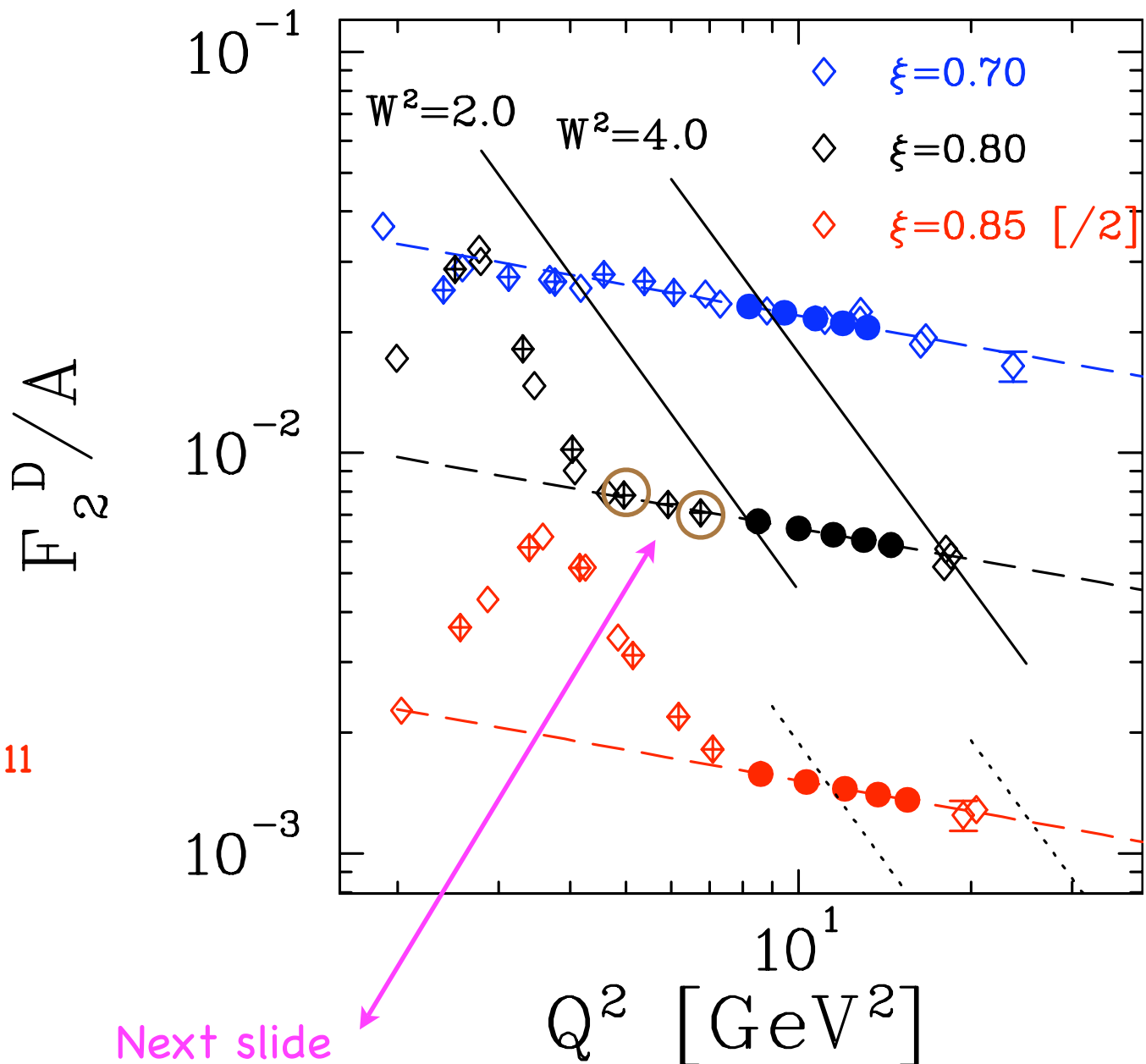$$\xi = \frac{2x}{1 + \sqrt{1 + 4M^2x^2/Q^2}} \longrightarrow x$$
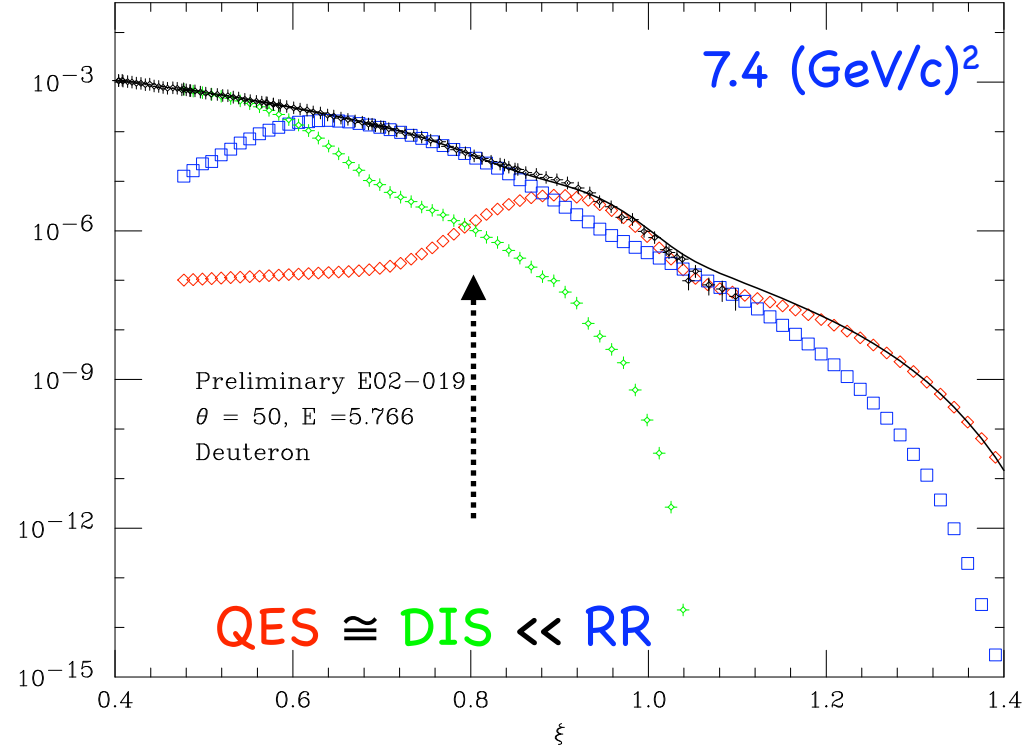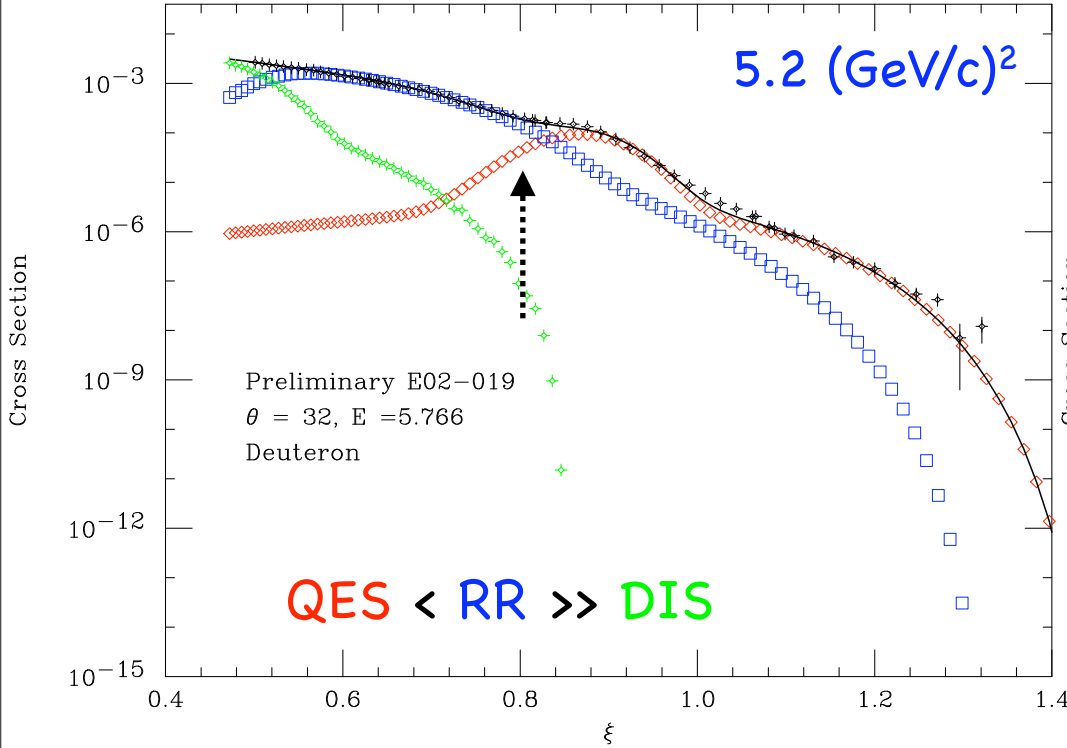
νW_2^A versus ξ

Approach to Scaling - Deuteron

Dashed lines are arbitrary normalization (adjusted to go through the high Q^2 data) with a constant value of $d\ln(F_2)/d\ln(Q^2)$

filled dots - experiment with 11 GeV

Next slide

Approach to Scaling (Deuteron)
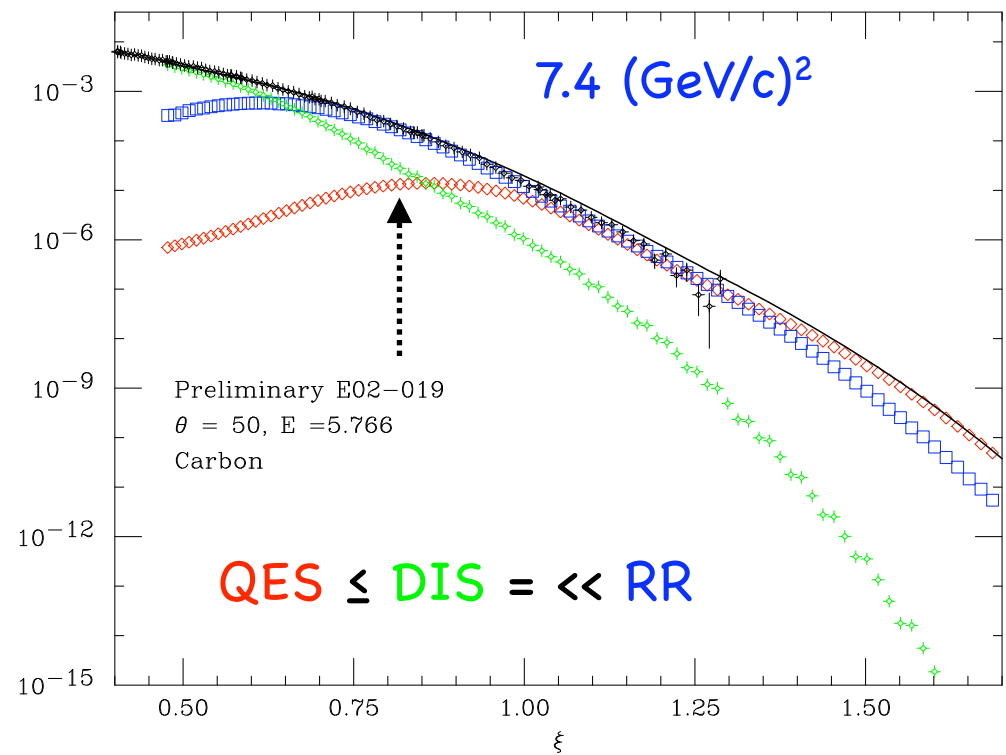

Convolution model
QES
RR (W² < 4)
DIS (W² > 4)

Scaling appears to work well even in regions where the DIS is not the dominate process

We can expect that any scaling violations will melt away as we go to higher Q^2

Approach to Scaling (Carbon)

Left plot: 5.2 (GeV/c)^2, Preliminary E02–019, $\theta = 32$, E = 5.766, Carbon. QES < RR >> DIS

Right plot: 7.4 (GeV/c)^2, Preliminary E02–019, $\theta = 50$, E = 5.766, Carbon. QES $\leq$ DIS = << RR

Convolution model
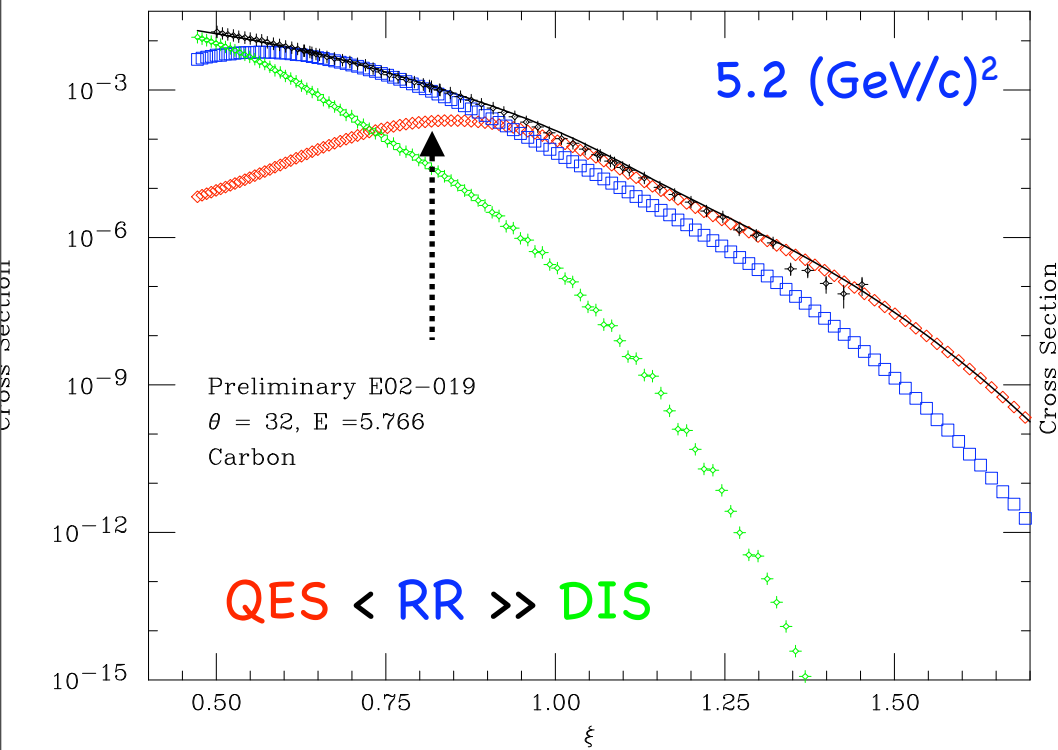QES
RR (W^2 < 4)
DIS (W^2 > 4)

Scaling appears to work well even in regions where the DIS is not the dominate process

We can expect that any scaling violations will melt away as we go to higher Q^2