Inclusive Scattering from Nuclei at $x > 1$ and High Momentum Transfer

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For the E02-019 Collaboration

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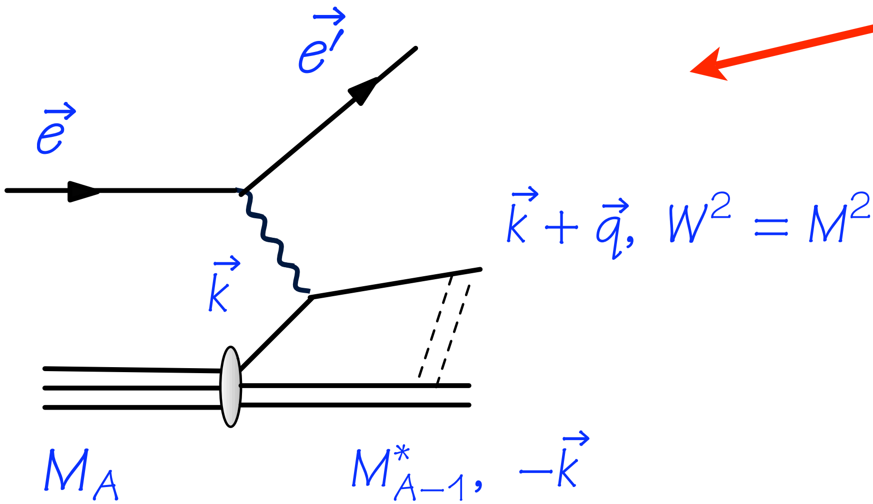
Outline

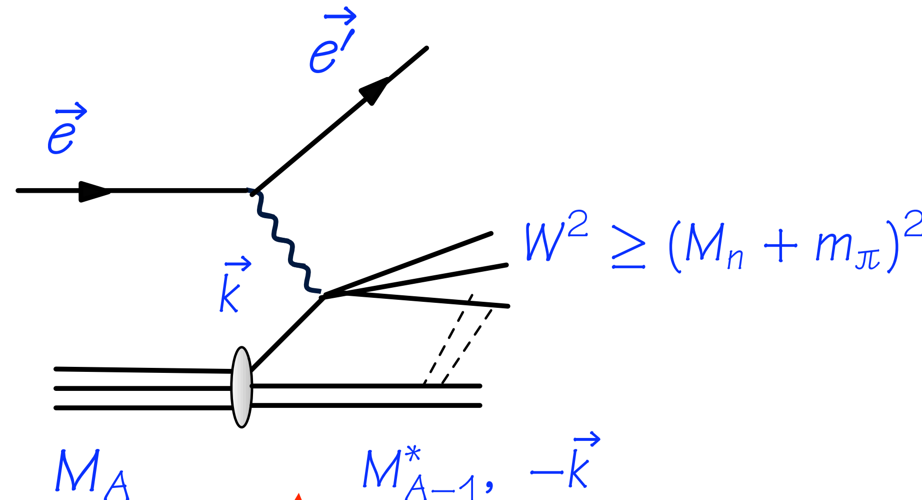
- Introduction
- Physics Background and Motivation
- The Experiment
- Analysis
- Preliminary Results
- Outlook

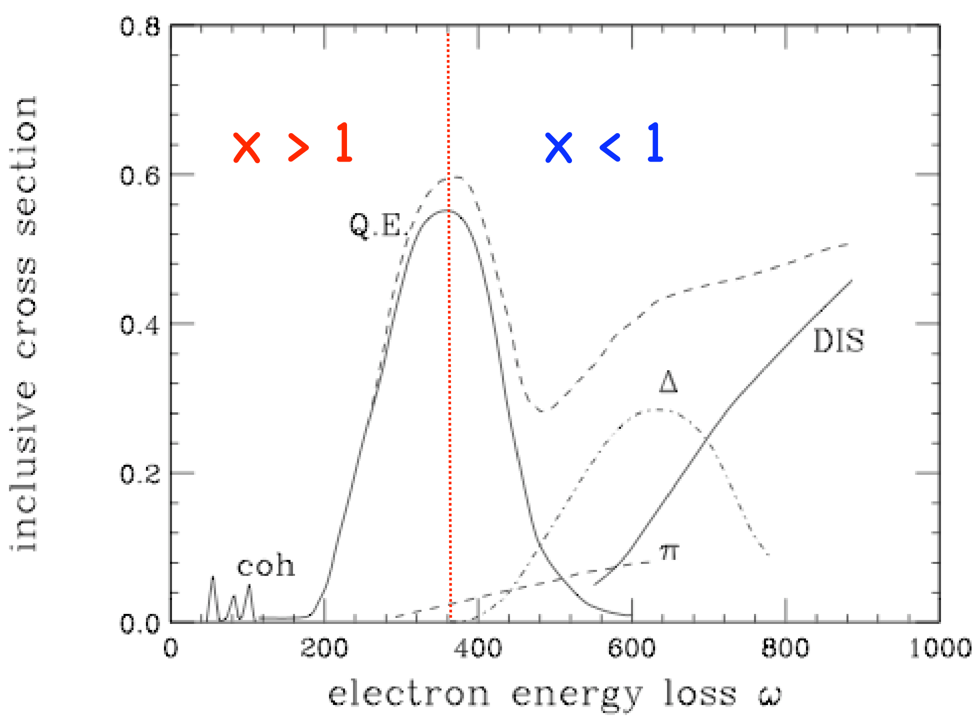
Inclusive Quasielastic and Deep Inelastic Scattering at High Momentum Transfers

Two distinct processes

Quasielastic from the nucleons in the nucleus

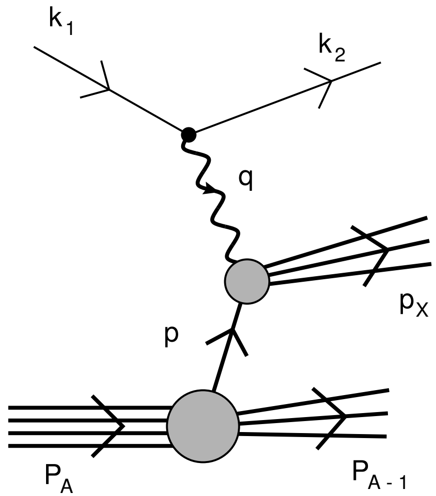






Inelastic, Deep Inelastic from the quark constituents of the nucleon.

Inclusive final state does means no separation of two dominant processes



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

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

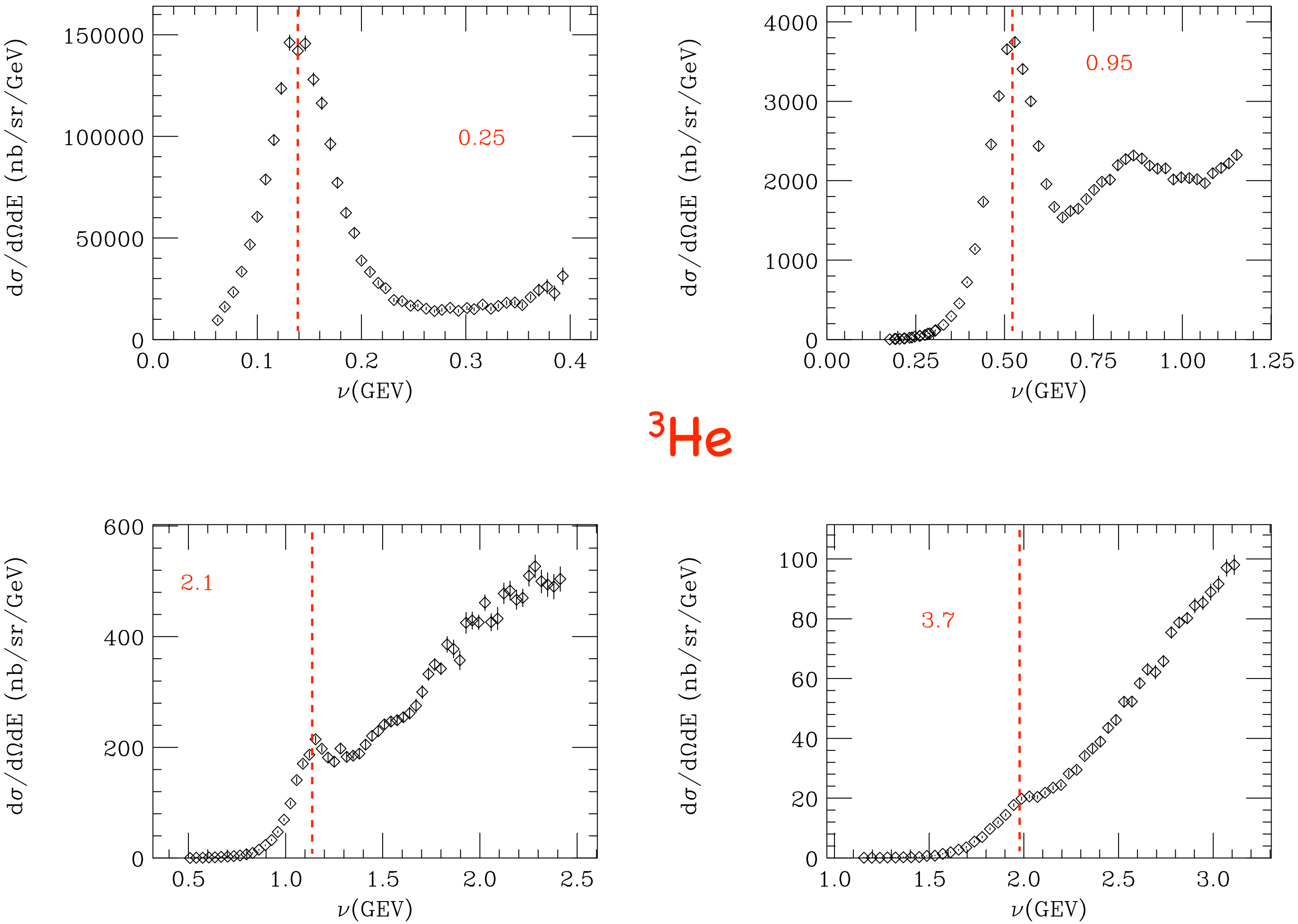
DIS $$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE \; W_{1,2}^{(p,n)} \underbrace{S_i(k,E)}_{\text{Spectral function}}$$

However they have very different Q^2 dependencies

σ_{ei} goes as the elastic (form factor)^2

$W_{1,2}$ scale with <u>ln Q^2</u> dependence

Exploit this 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 the momentum transfer increases inelastic scattering from the nucleons begins to dominate
- We can use Q^2 as a knob to dial the relative contribution of QES and DIS.

Scaling

- Scaling refers to the dependence of a cross section, in certain kinematic regions, on a single variable. If the data scales in the single variable then it validates the assumptions about the underlying physics and scale-breaking provides information about conditions that go beyond the assumptions.

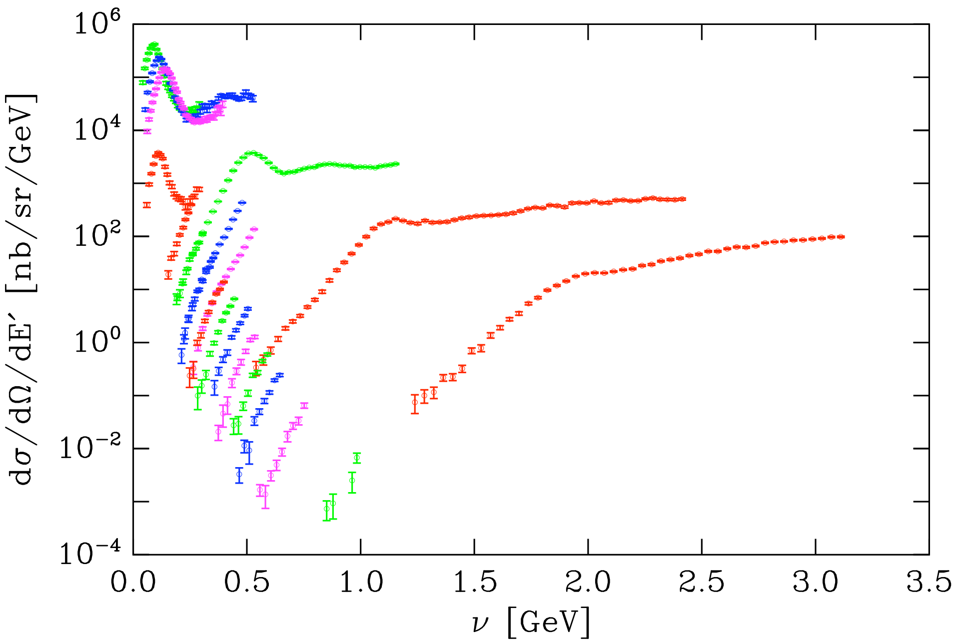
- Scaling of DIS at SLAC in 1960's in terms of the Bjorken x-variable provided evidence for the existence of quarks.

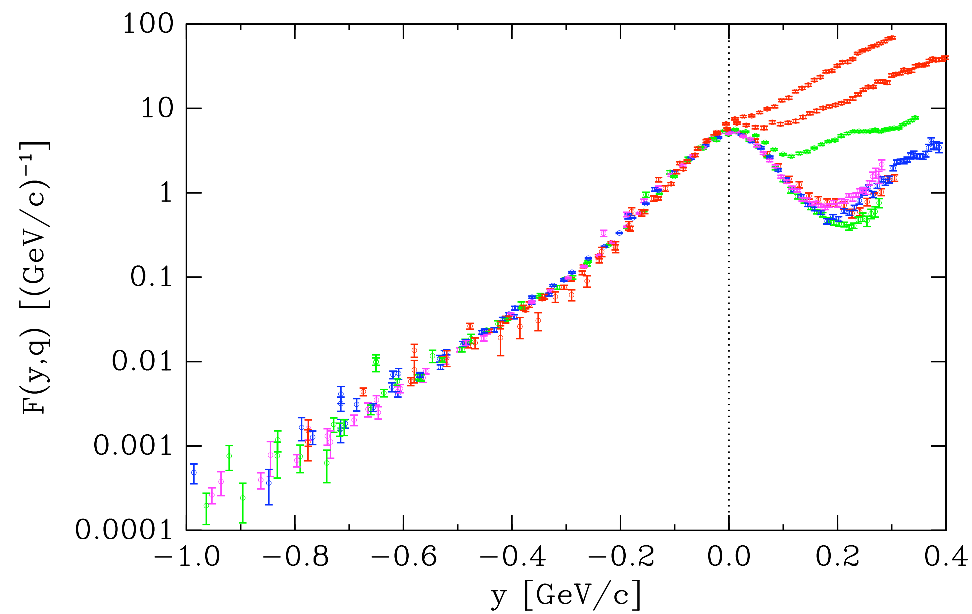
  In a proton (or neutron), $x = Q^2/2m\nu$ is restricted < 1 as single quark can carry, at most, the total momentum of the proton.

- At moderate Q^2 inclusive data from nuclei has been well described in terms y-scaling, one that arises from the assumption that the electron scatters from a quasi-free nucleons.

- 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.

y-scaling in inclusive electron scattering from ^{3}He





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

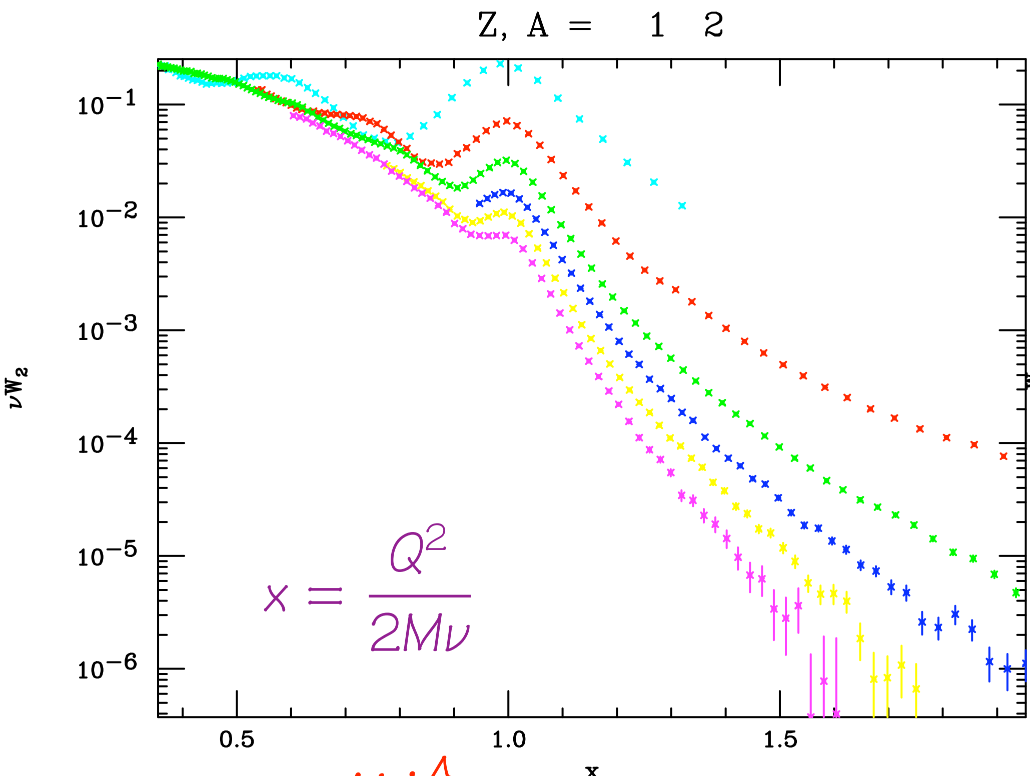
$$\boxed{n(k) = -\frac{1}{2\pi y}\frac{dF(y)}{dy}}$$

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

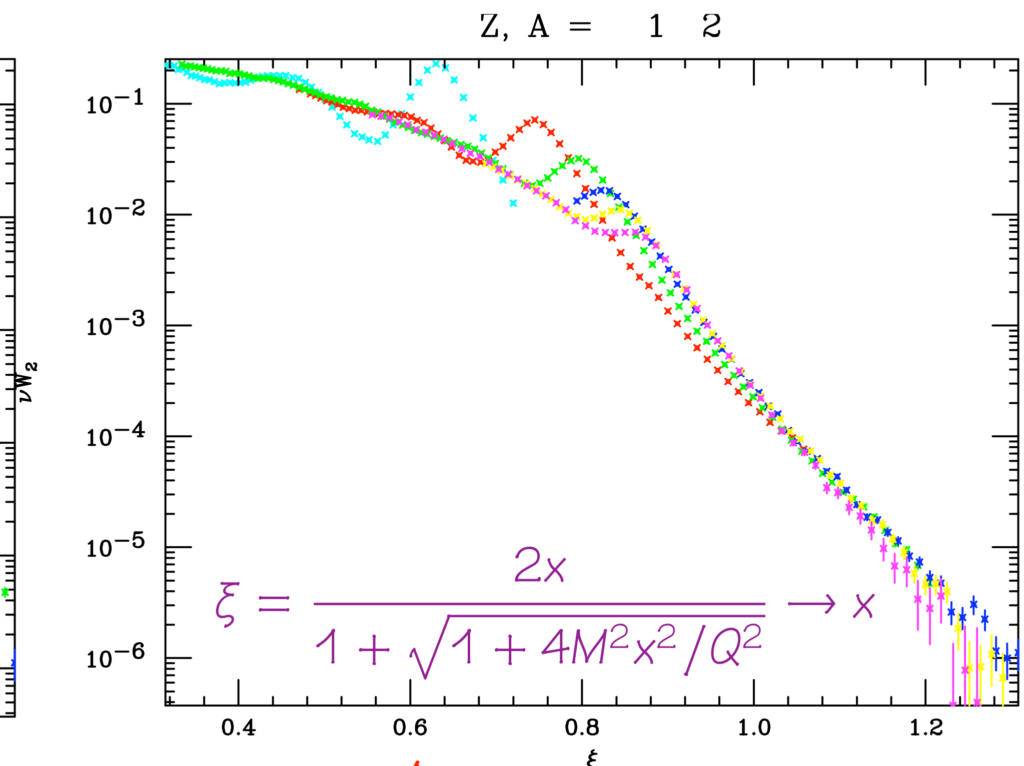
y is the momentum of the struck nucleon parallel to the momentum transfer:
$y \approx -q/2 + m\nu/q$

x and ξ scaling

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

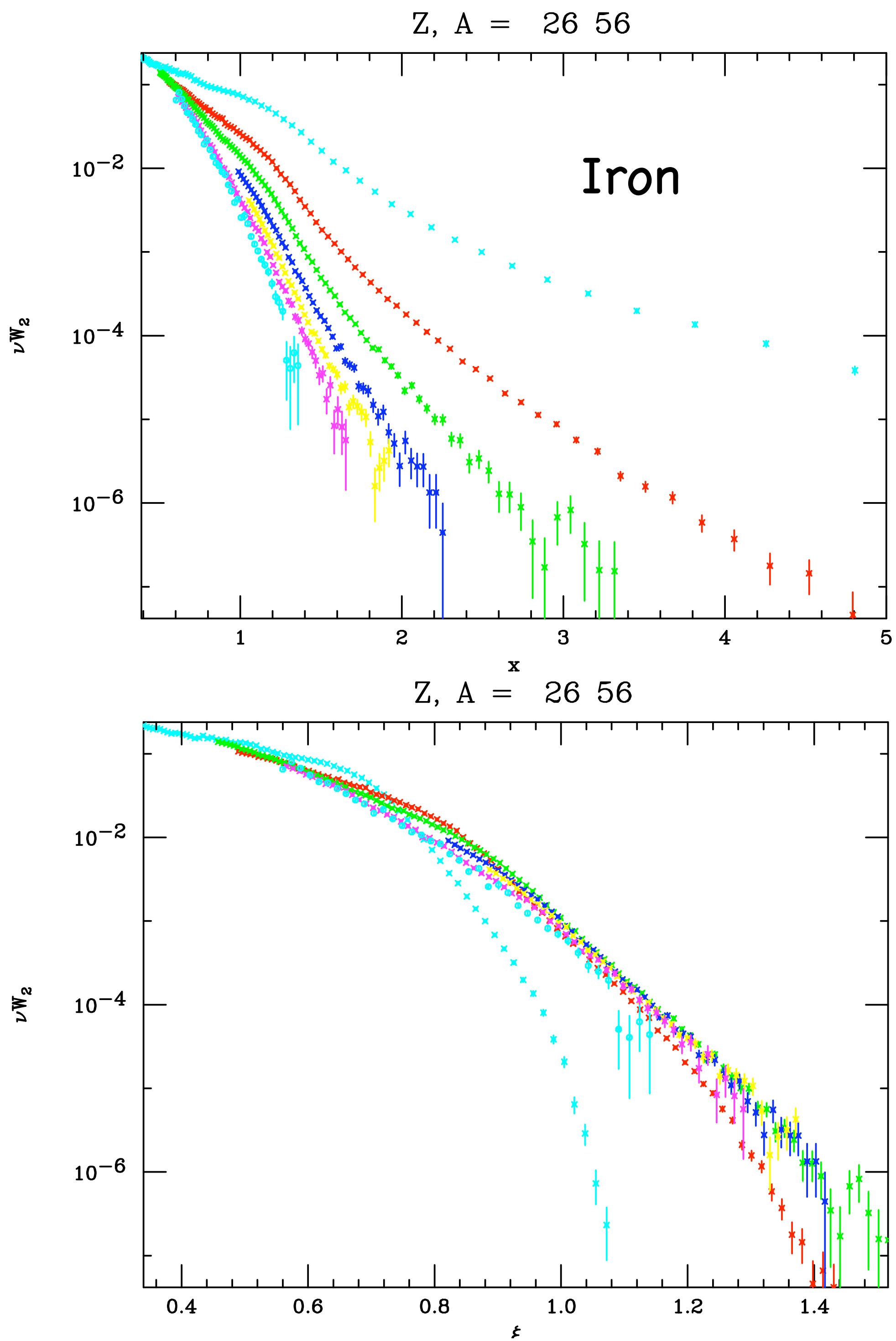


νW_2^A versus x



νW_2^A versus ξ

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



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.

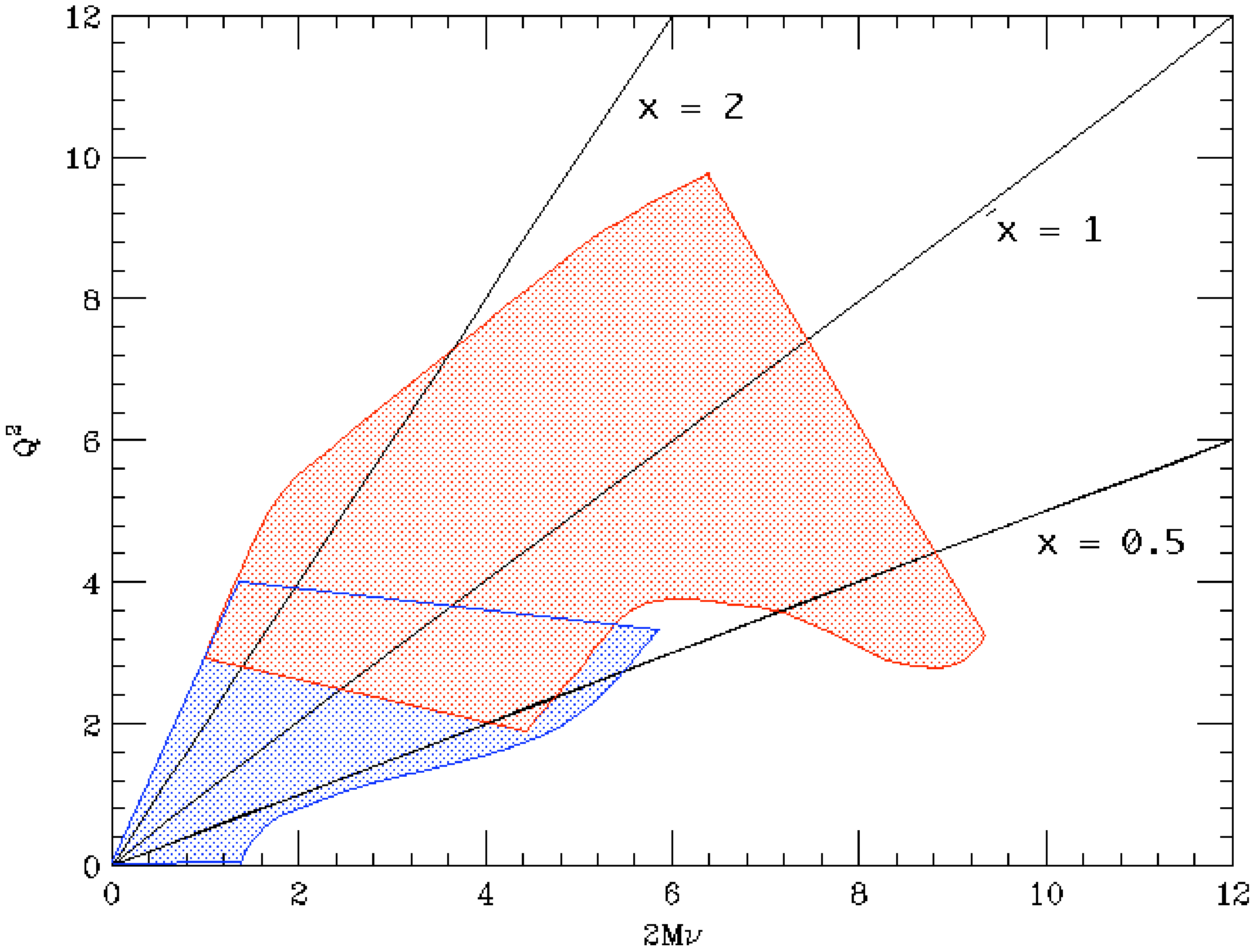
Local duality (averaging over finite range in x) should also be valid for elastic peak at x = 1 if analyzed in ξ

$$F_2^A(\xi) = \underbrace{\int_\xi^A dz F(z) F_2^n(\xi/z)}_{\text{averaging}}$$

Physics Topics

- Momentum distributions and the spectral function S(k,E).
- Scaling of the structure functions or 'reduced' cross sections in (x, y, ξ, ψ')
- Short Range Correlations
- Medium Modifications -- tests of EMC
- Parton Recombination
- Color Transparency
- Bloom--Gilman Duality
- Structure Function Q^2 dependence and Higher Twists

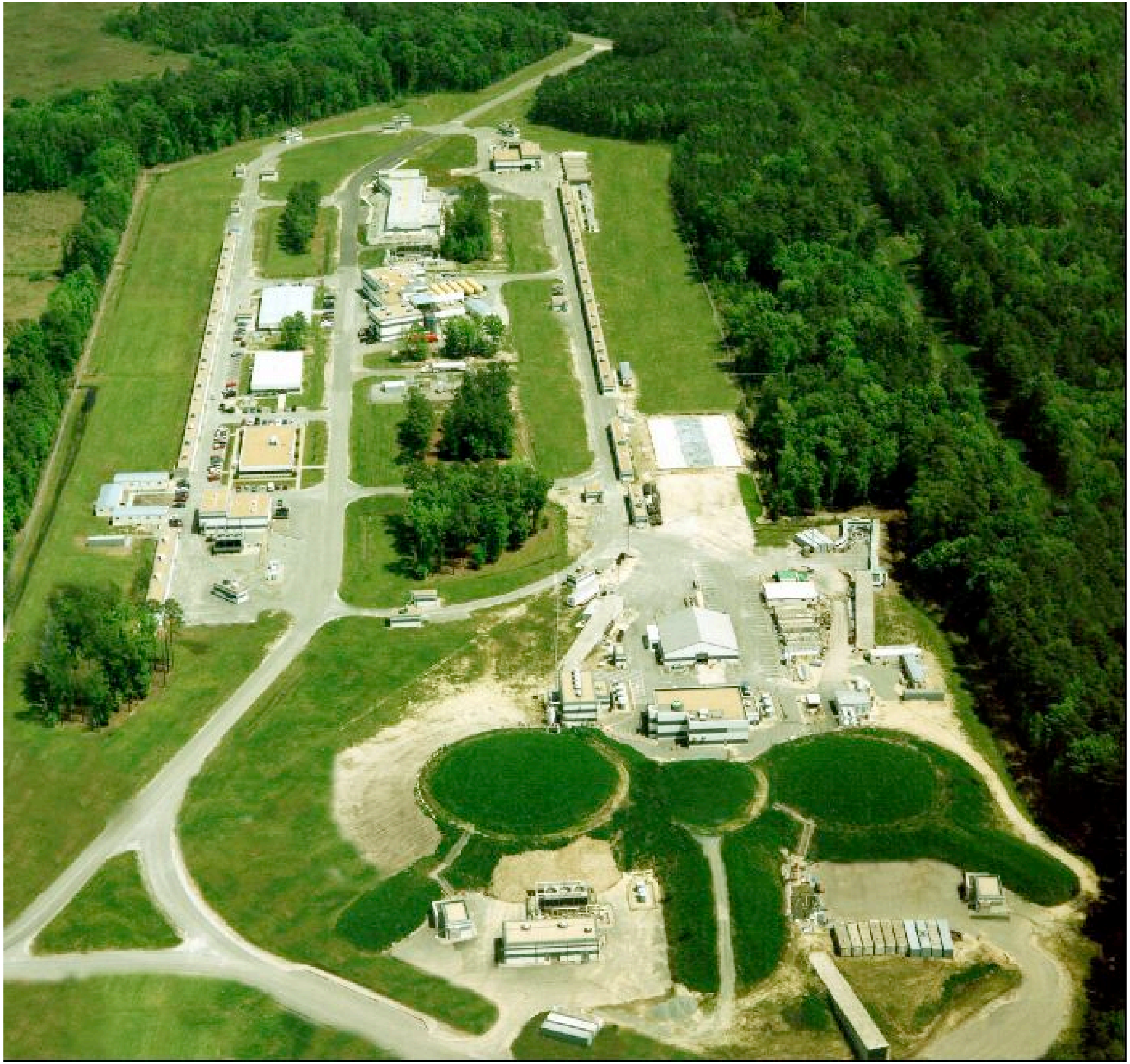
6 GeV at Jefferson Lab allows new kinematic range to be explored



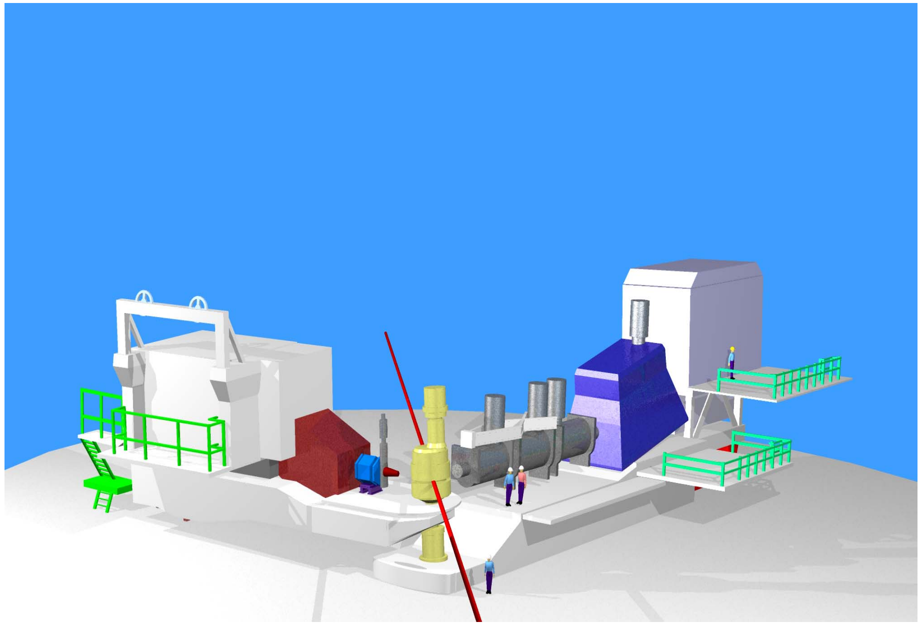
^3He

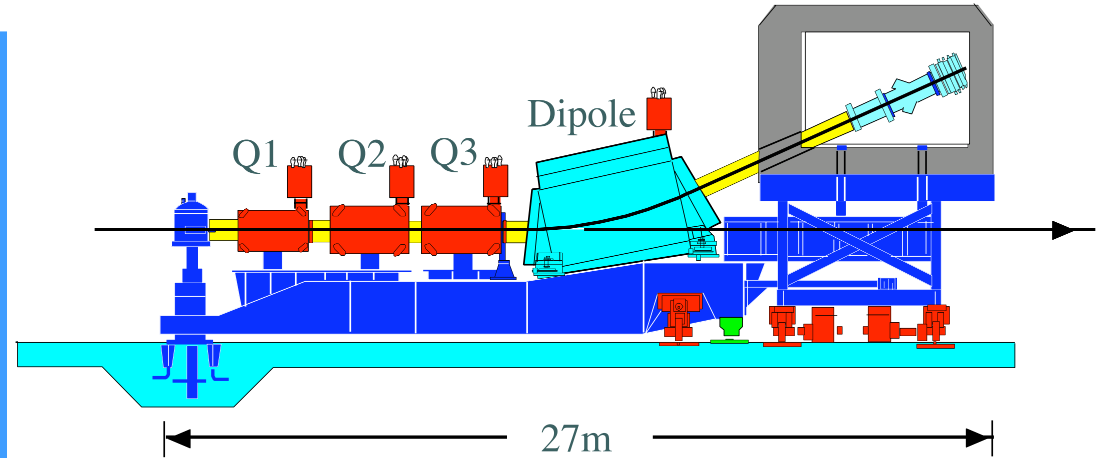
E02-019 Details

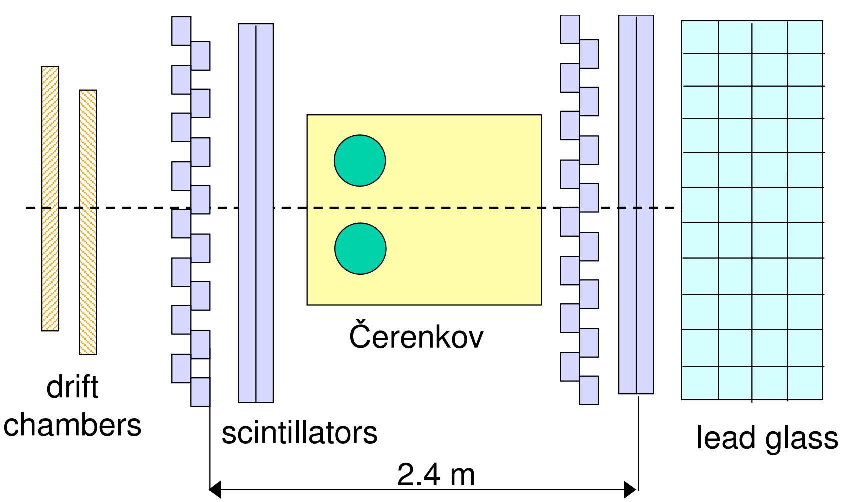
- E02-019 finished in late 2004 in Hall C at Jefferson Lab. Used a beam energy of 5.77 GeV and currents up to 80μA
- Cryogenic Targets: H, ^{2}H, ^{3}He, ^{4}He
- Solid Targets: Be, C, Cu, Au
- Spectrometers: HMS and SOS
- Angles: 18, 22, 26, 32, 40, 50
- Ran concurrently with E03-103

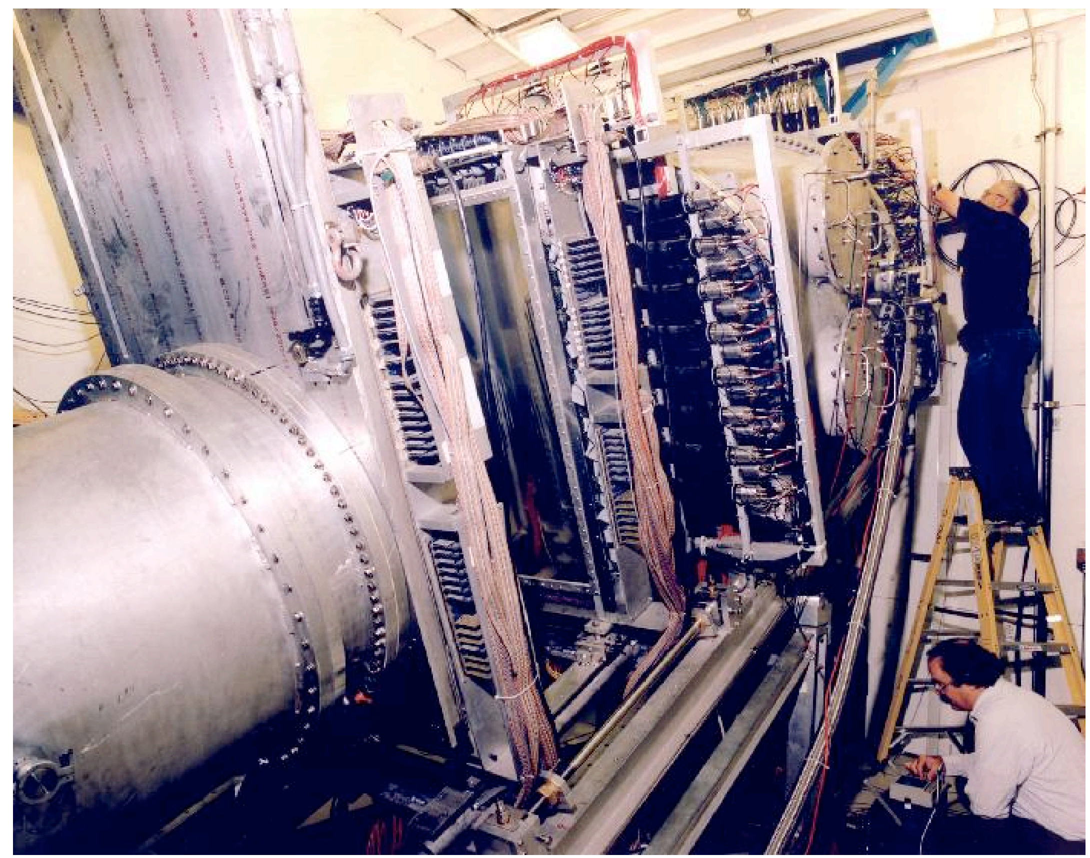


Hall C - HMS




Dipole
Q1
Q2
Q3
27m


drift
chambers
scintillators
Čerenkov
lead glass
2.4 m



Analysis

- Nadia Fomin (UVa)
- Jason Seely (MIT)
- Aji Daniel (Houston)
- Roman Trojer (Basel)

Four graduate students, organized by D. Gaskell (JLAB)

Every student maintained separate analysis code, which gives us 4 cross sections to compare. Two experiments took data together E02-019 & E03-103

Calibrations

- Calorimeter
- Drift Chambers
- TOF

Corrections

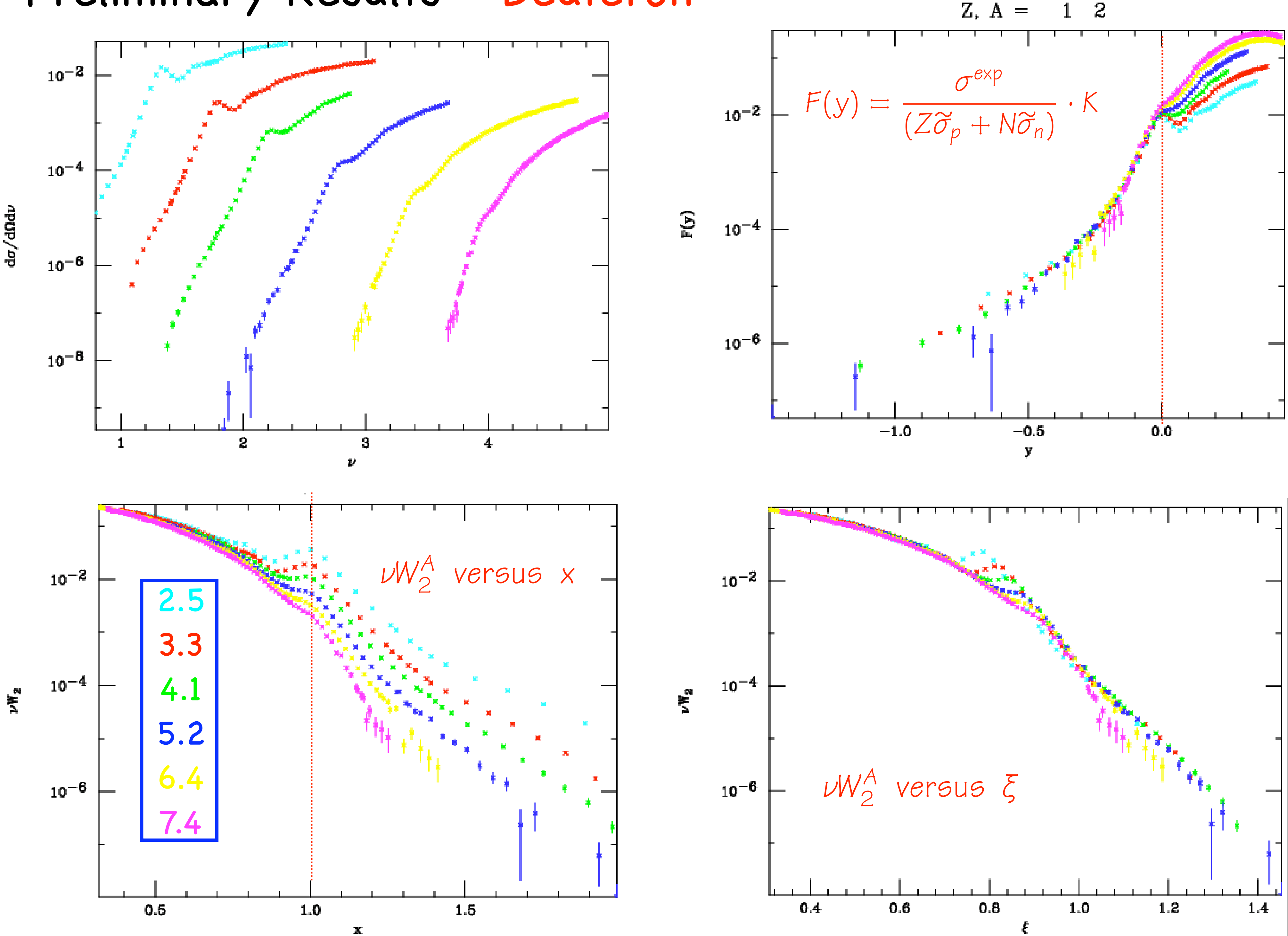
- Bin-centering
- Charge-symmetric background subtraction
- Radiative Corrections
- E-loss Corrections
- Acceptance Corrections
- Target Boiling Corrections

Two methods

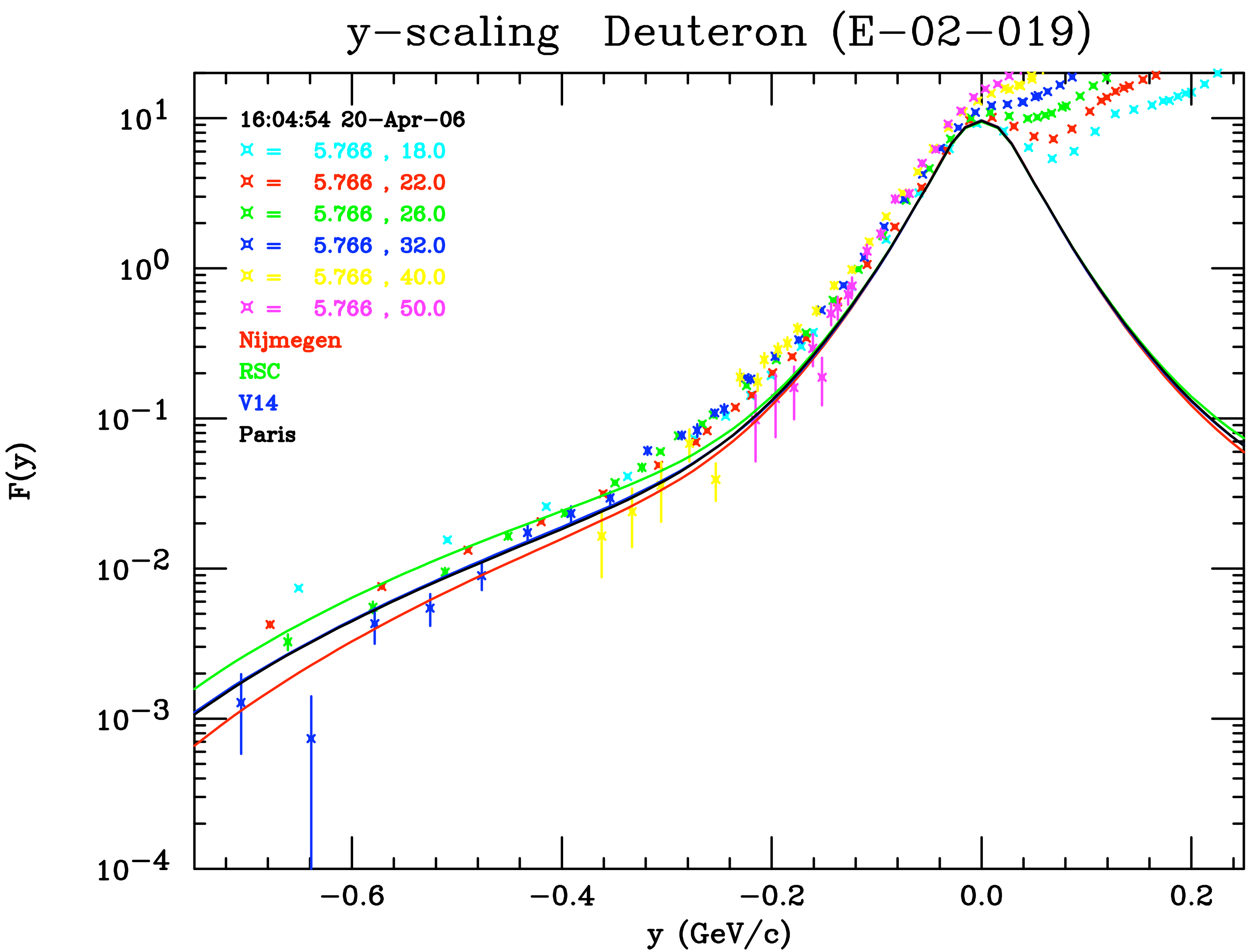
$$\sigma_{Born} = \frac{Y_{Data}}{Y_{MC}} \sigma^{Model}$$

$$\frac{d\sigma}{d\Omega dE'} = \frac{Y \cdot C_{rad} \cdot C_{bin}}{\Delta E' \cdot \Delta\Omega \cdot N_{\#scatt.}}$$

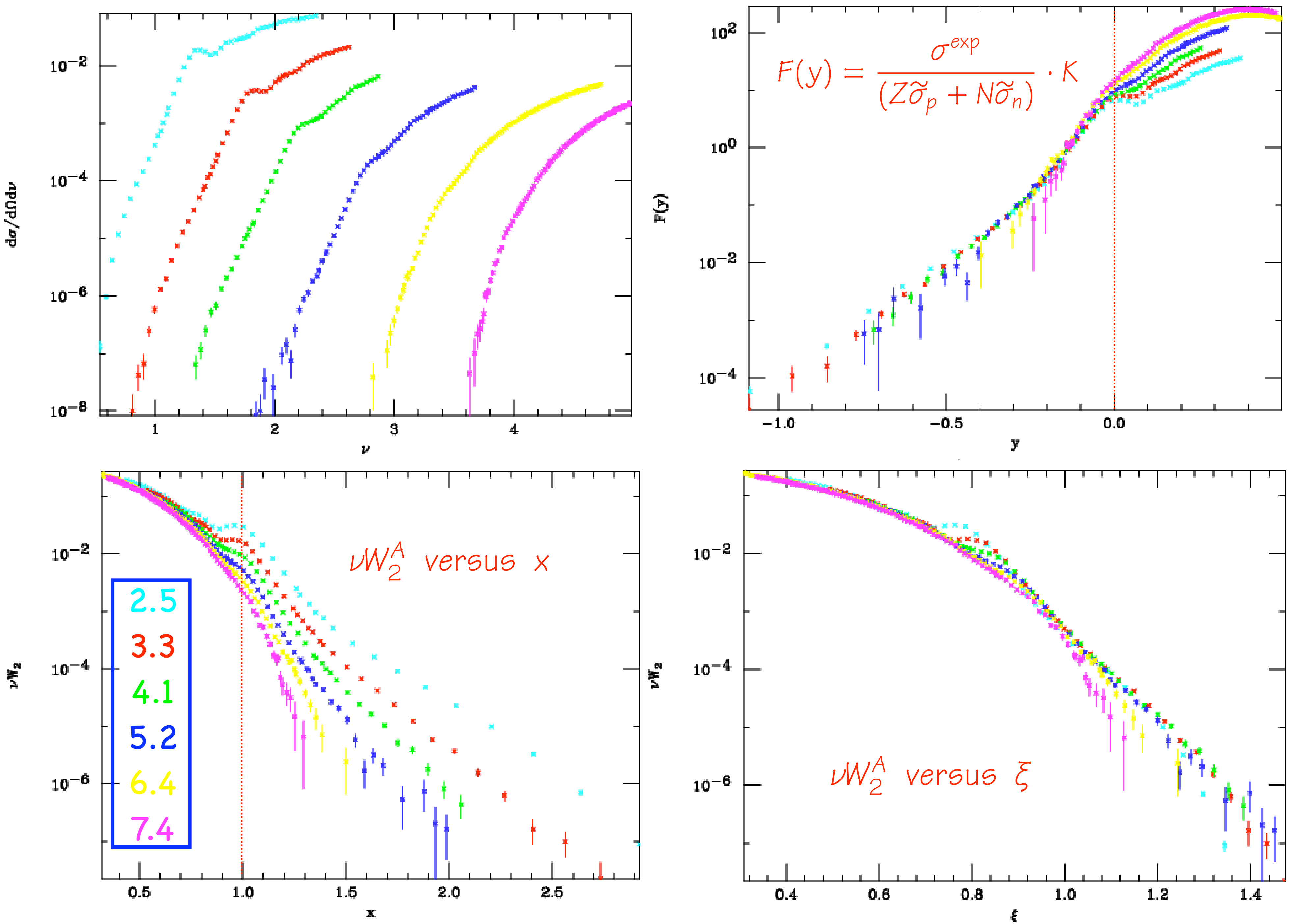
Preliminary Results - Deuteron



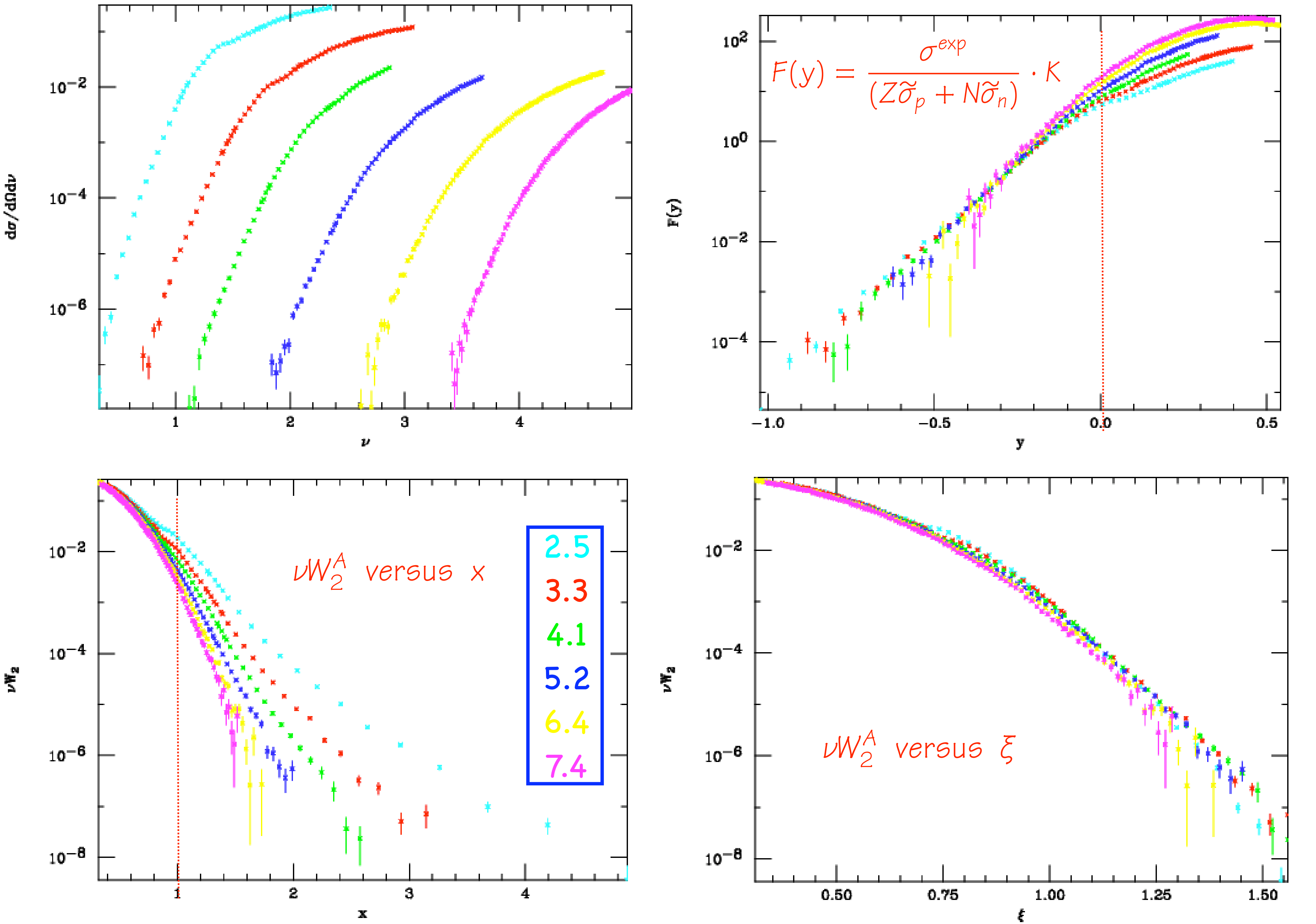
Comparison to Theory



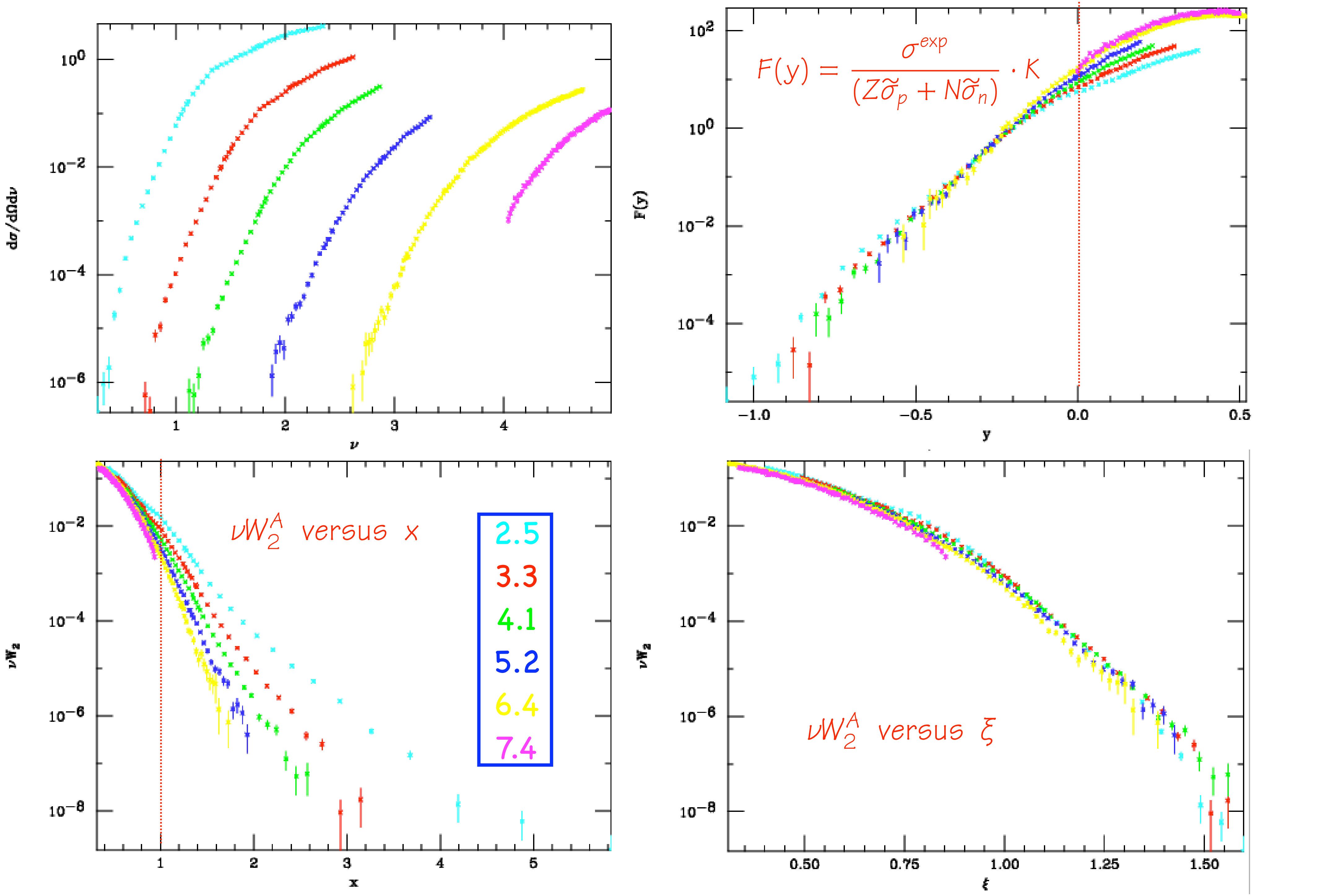
Preliminary Results - ^{3}He



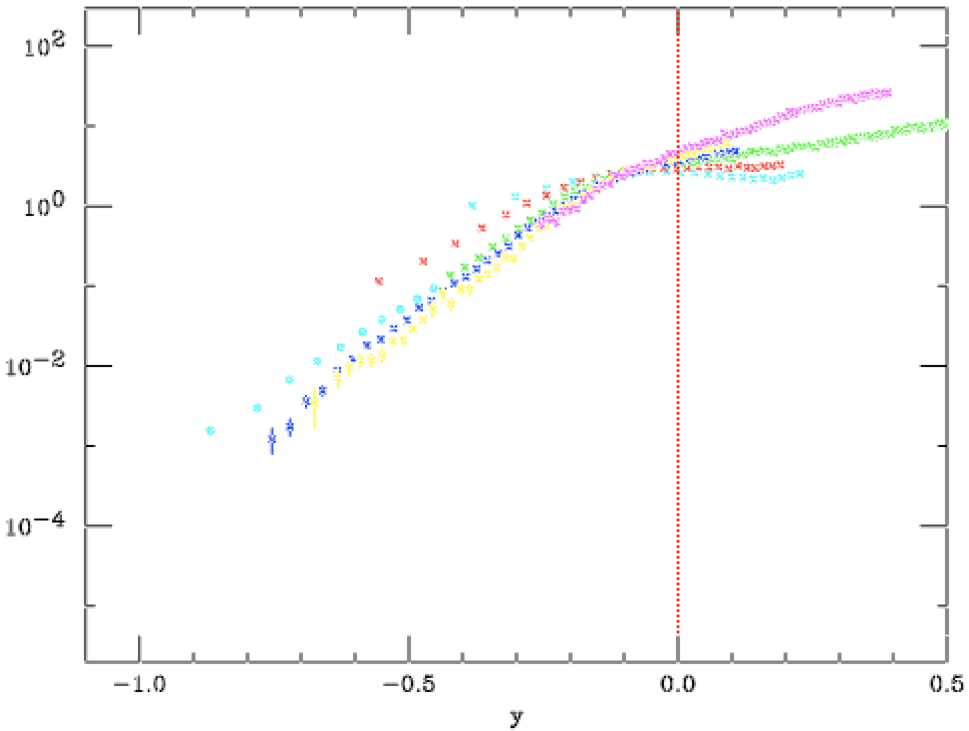
Preliminary Results - ^{12}C



Preliminary Results - ^{197}Au

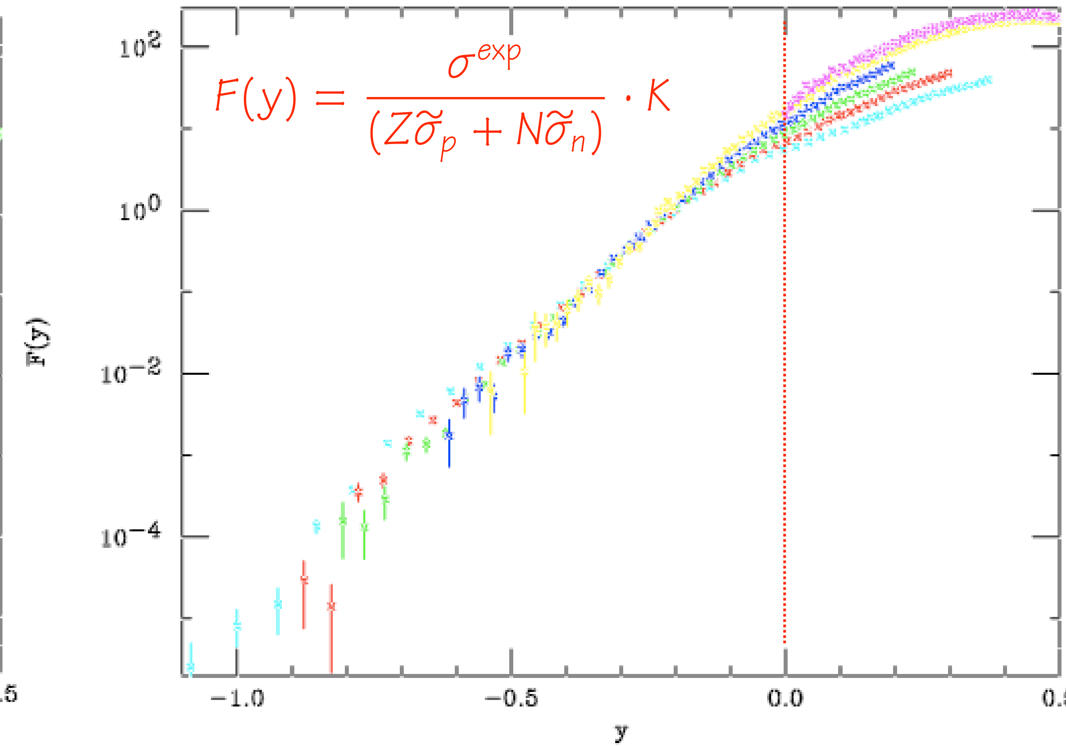


Convergence of F(y) at fixed y with Q^2



NE3 Au data from SLAC

$Q^2_{max} = 2.2$

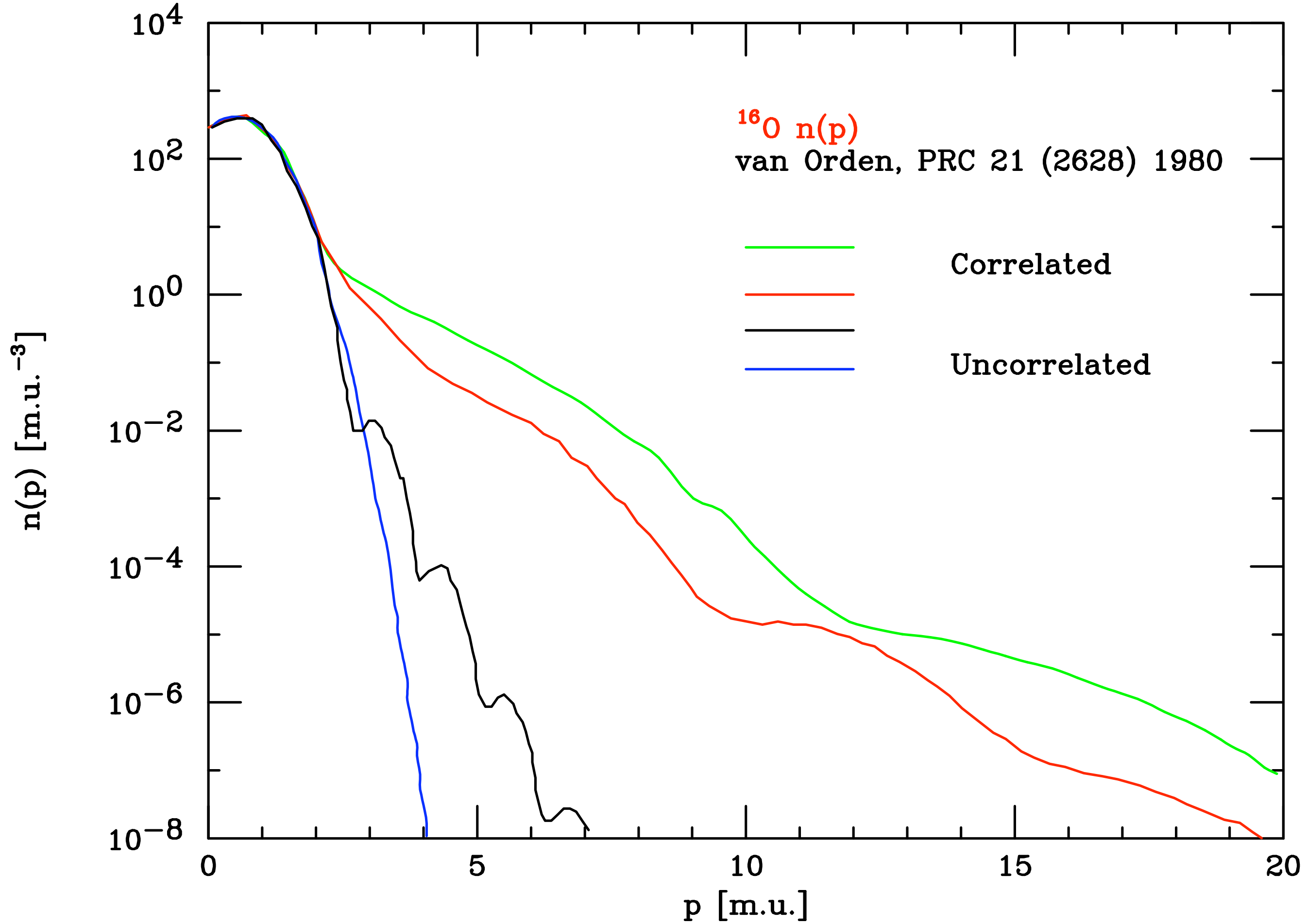


E02-019 Au data from JLAB

$Q^2_{max} = 7.4$

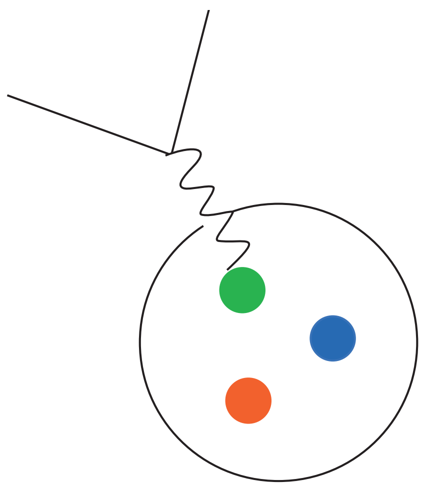
Final State Interactions cause F(y,q) to converge from above with increasing q, not below as should be in PWIA. FSI in higher Q^2 data are diminished

Short Range Correlations



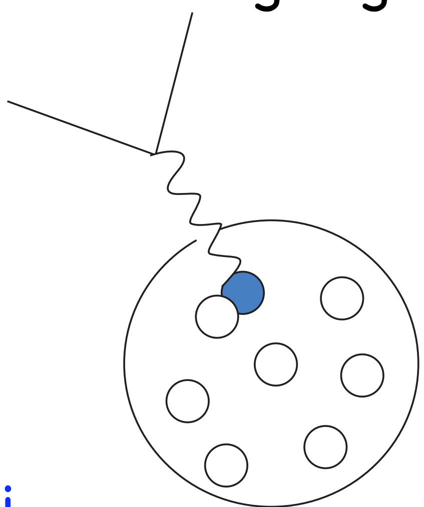
- Short distance behavior
- Inside nuclear volume
- FSI are unavoidable, generated by the interactions responsible for SR behavior
- MEC, isobars have same dynamical source as the SRC

Short Range Correlations



For a nucleon at rest, $x < 1$
as $x = 1$ is the elastic limit

For e-A scattering x is not so restricted; $x > j-1$
where j is the number of nucleons coming together.
Recall for $k = k_F$, $x \leq 1.2$.



$x > 1 \Rightarrow$ 2 nucleons close together

$x > 2 \Rightarrow$ 3 nucleons close together

Further, when j nucleons are close together the A-j nucleons have little influence.

The Spectral Function with a high-k nucleon can be represented as a sum over 2,3 … nucleon correlations; one must account for the CM motion of the correlation.

In the region where correlations should dominate, large x,

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

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

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

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

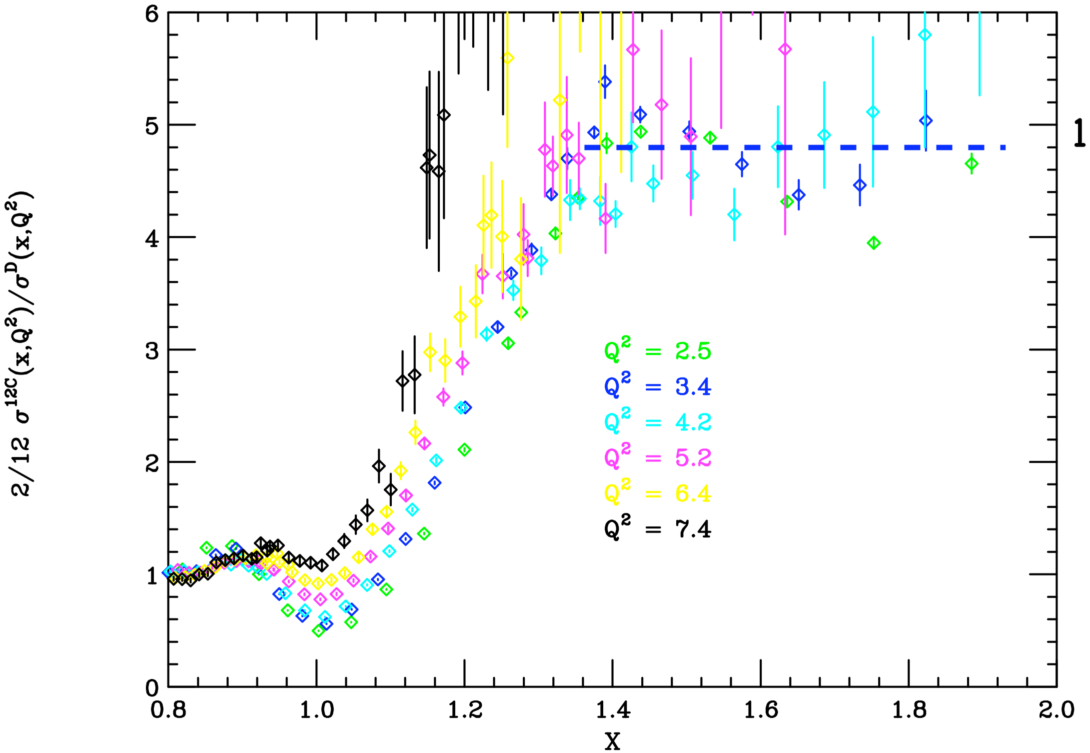
$$\frac{3}{A}\frac{\sigma_A(x,Q^2)}{\sigma_{A=3}(x,Q^2)} = a_3(A)\Big|_{2<x\leq 3}$$

In the ratios, offshell effects and FSI largely cancel.

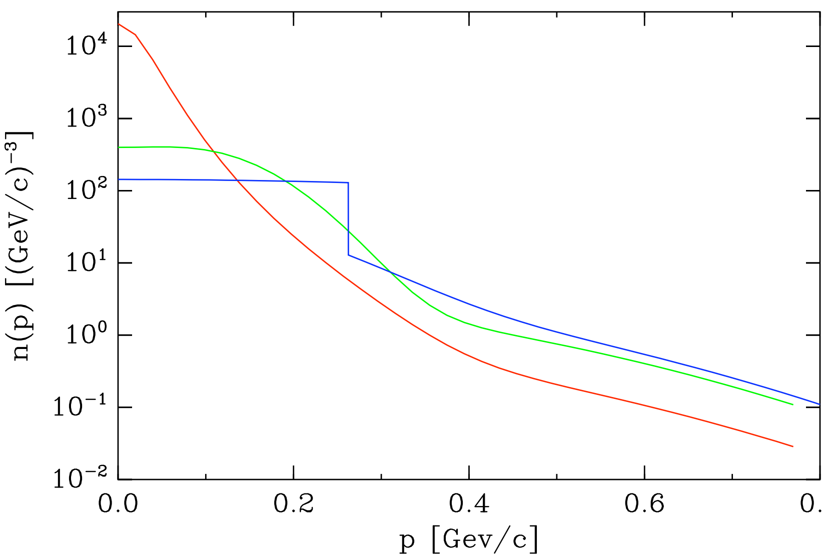
Short Range Correlations

$$\frac{2}{A}\frac{\sigma_A}{\sigma_D} = a_2(A)$$

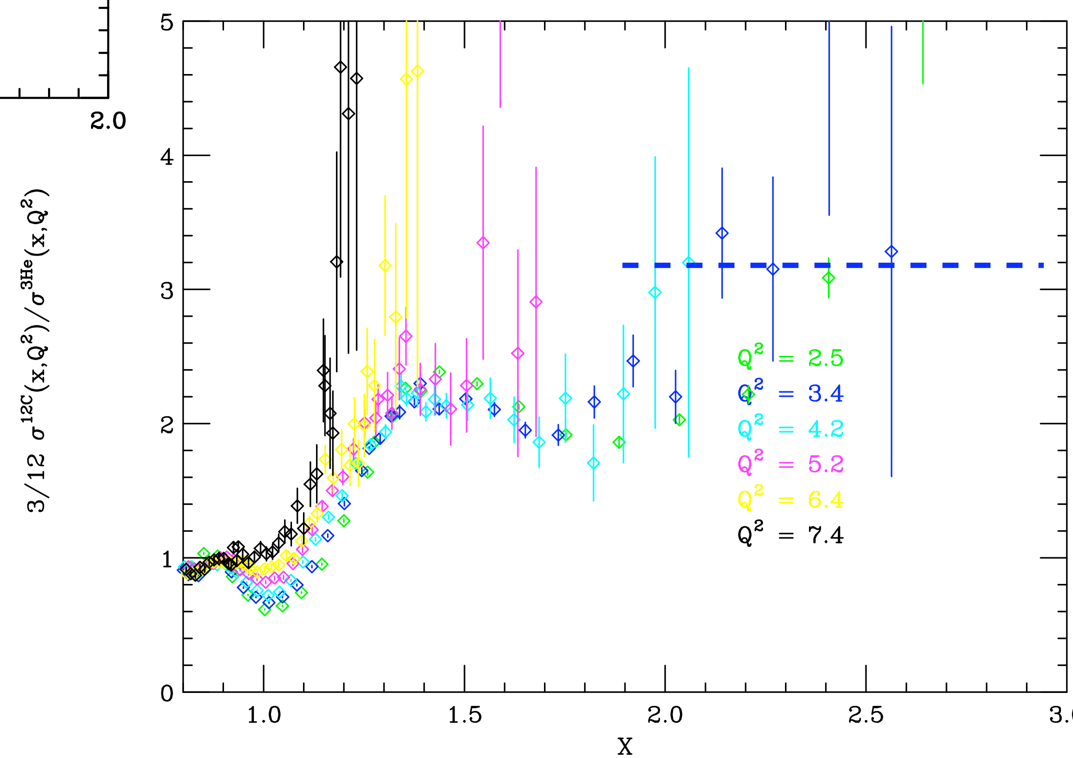
$^{12}C/^{2}H$



$a_2(A)$ is proportional to probability of finding a j-nucleon correlation



$^{12}C/^{3}He$



To Do List

- Coulomb Corrections
- Model Refinements
- Create Ratios of Heavy/Light nuclei
  - Correlations
- Nuclear Matter Extrapolation
- Examine details of scaling behaviors
  - extract information on n(k)
  - Evidence for duality?
- Structure Function Q^2 dependence

Inclusive DIS at $x > 1$ at 12 GeV

- New proposal for next JLAB PAC
- 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 $x = 1.5$

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

Quasielastic Electron Nucleus Scattering Archive

Welcome to Quasielastic Electron Nucleus Scattering Archive

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. Send any comments or corrections you might have as well.

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