New Results from Jefferson Lab (Hall C): Data and Fit

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e-nucleus scattering data facilitates understanding and modeling of nuclear effects such as:

(i) Spectral functions (nuclear wave functions)

(ii) Pauli blocking

(iii) Final state interactions

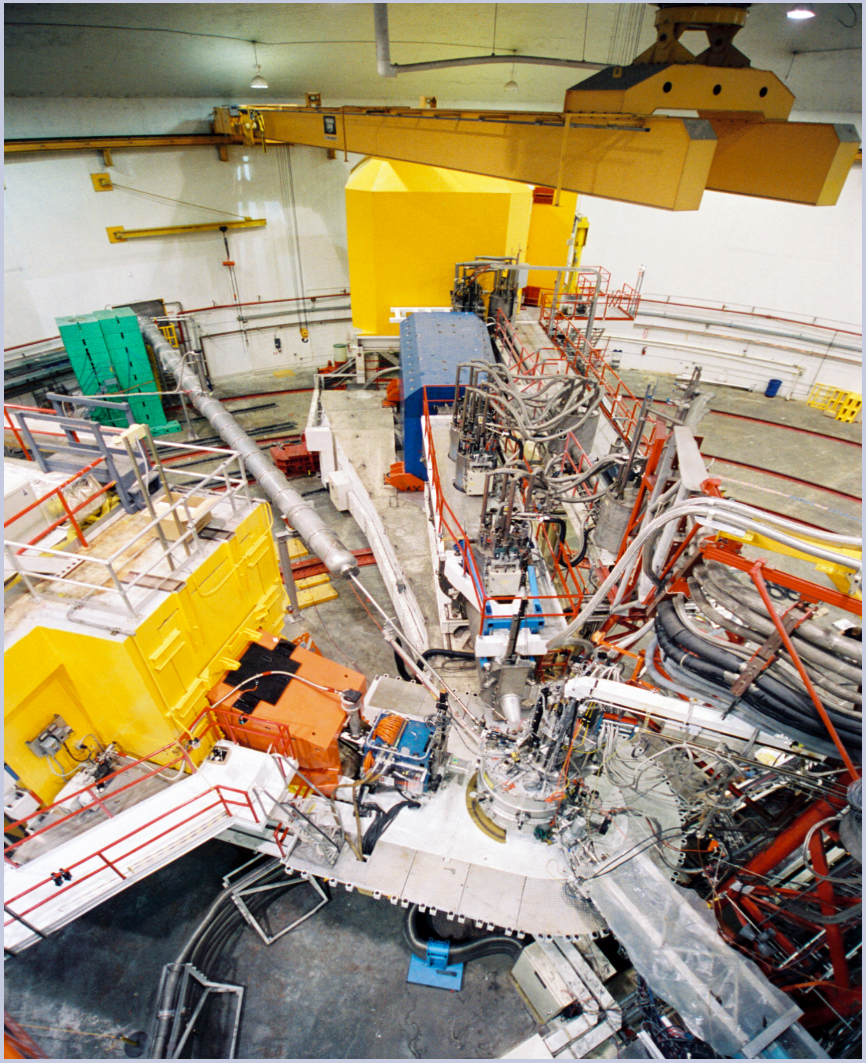
(iv) Meson exchange currents

(v) Modifications to quark structure of nucleons (nuclear PDFs, EMC, shadowing, anti-shadowing, etc)

(vi) Medium effects on form factors

Also…form factors and structure functions (nucleon and nuclear) provide crucial vector input!

A Program of Precision Inclusive Cross Section Measurements in Hall C at Jefferson Lab



- E88-008: x>1
- E94-110: L/T Hydrogen Resonance Region
- E99-118: L/T Low x, Q^2 A-Dependence
- E00-002: L/T Low Q^2 Deep Inelastic H, D
- E00-116: High Q^2 H,D
- E04-001: L/T Nuclear Dependence, Neutrino Modeling
- E02-109: L/T Deuterium Resonance Region
- E02-109: x>1, A-Dependence
- E03-103: EMC Effect

Hall C Inclusive Data to be discussed

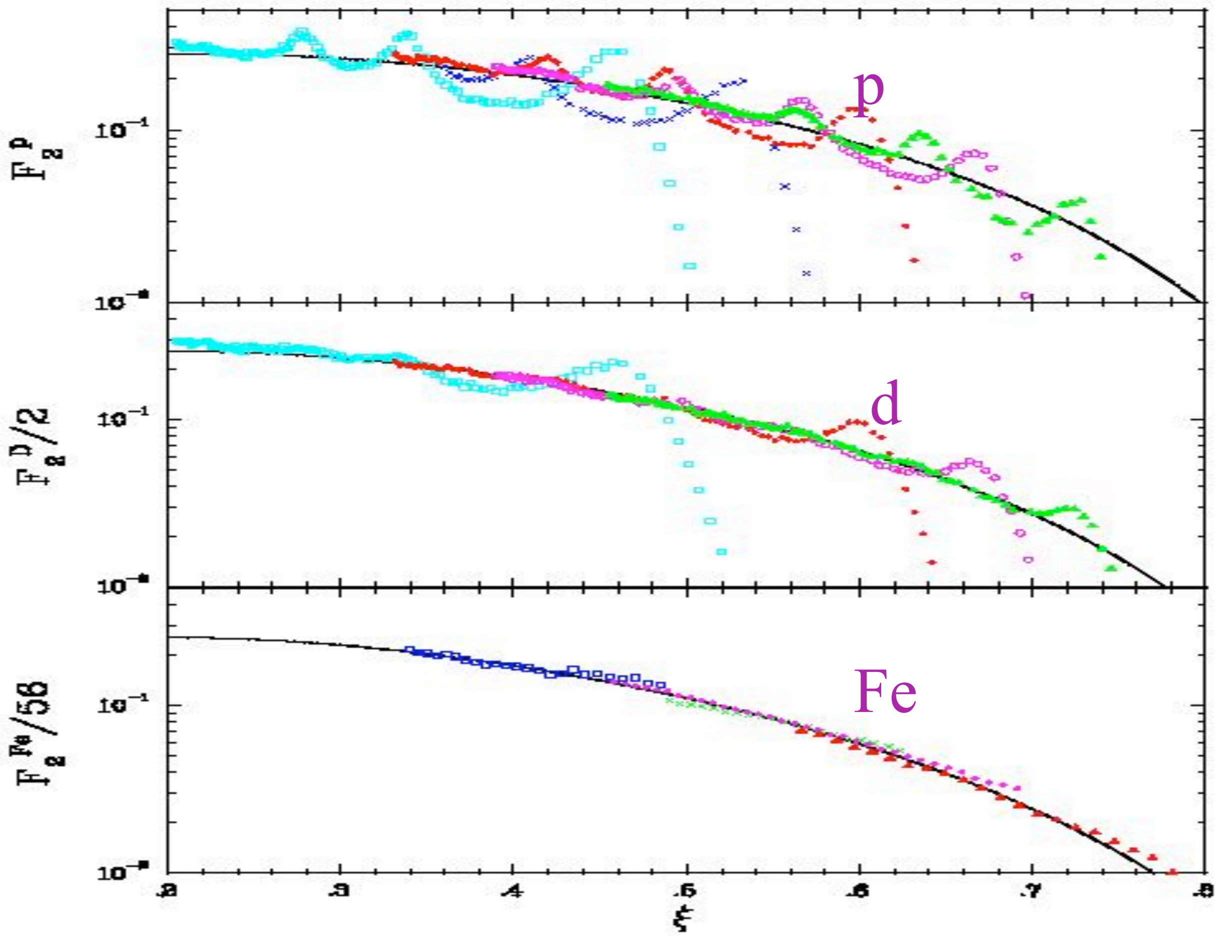
Experiment	target(s)	W range	Q^2 range	L/Ts	Status
E94-110	p	RR	0.3 - 4.5	✔	nucl-ex/0410027
E99-118	p,d	DIS+RR	0.1 - 1.7	✔	PRL98:14301
	C,Al,Cu			✔	Finalizing
E00-002	p,d	DIS+RR	0.03 - 1.5	limited	Finalizing
E00-116	p,d	RR	3.9 - 6.5	✘	Publication in progress
E02-109	d	RR+QE	0.2 - 2.5	✔	Analyzing
E06-009	d	RR+QE	0.7 - 4.0	✔	Running now
E04-001 - I	C,Al,Fe	RR+QE	0.2 - 2.5	✔	Analyzing
E04-001 - II	C,Al,Fe,Cu	RR+QE	0.7 - 4.0	✔	Running now
Low Q^2 run	p,d,Al,C	Delta+QE	0.02 – 0.25	✘	Preliminary results available
E03-103	p,d,^{3}He,^{4}He Be,C,Al,Cu,Au	DIS+RR	2.0 - 6.5	✘	Finalizing

Reminders from the “old” (2000 - 2005) data….

Duality in F_2…let the nucleus do the averaging

$$\xi = 2x\left[1 + (1 + 4M^2x^2/Q^2)^{1/2}\right]$$

- Data in resonance region, spanning Q^2 range 0.7 - 5 GeV^2
- GRV curve
- For larger A, resonance region indistinguishable from DIS
- Quark-hadron duality works well in nuclei! But, to what Q^2?



J. Arrington, R. Ent, CK, J. Mammei, I. Niculescu Phys.Rev.C73:035205 (2006)

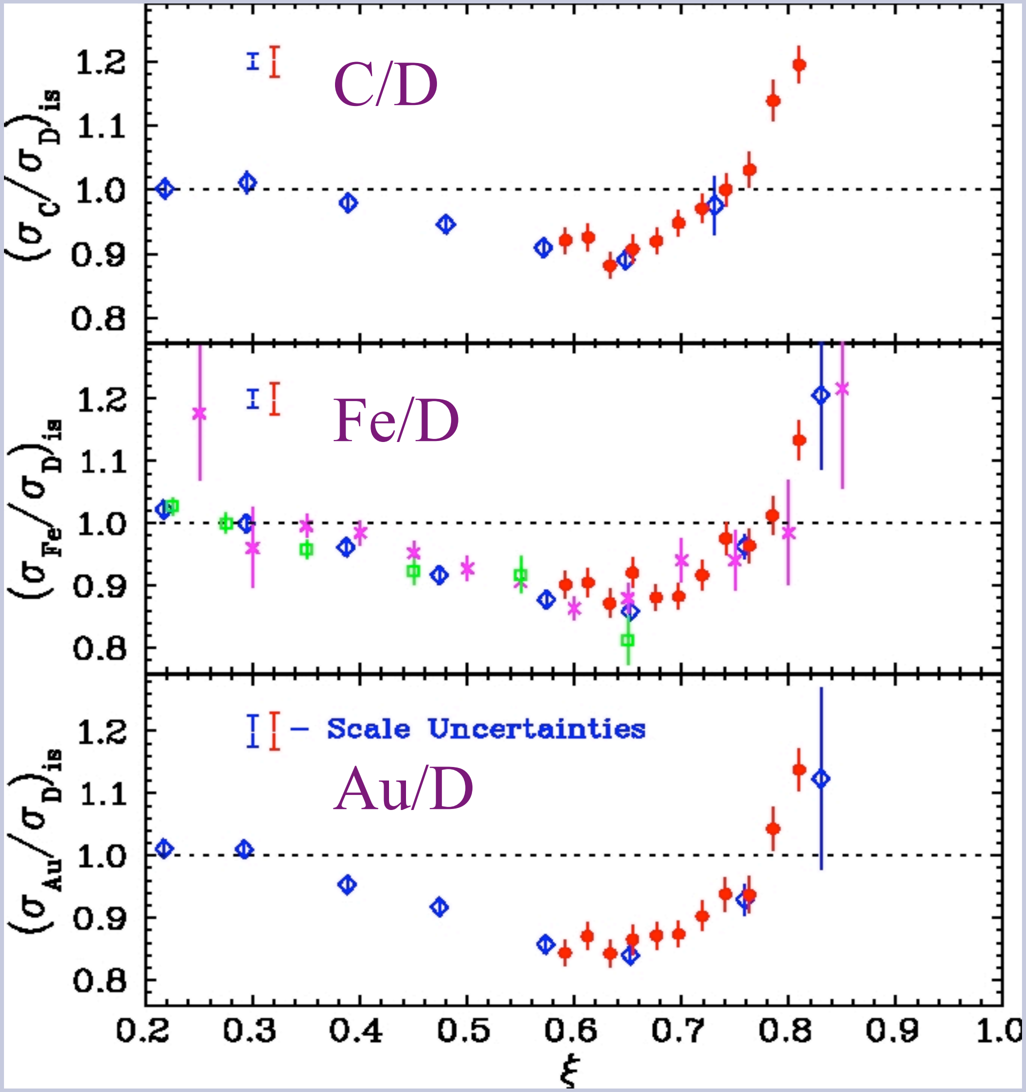
Duality and the EMC Effect

Red = resonance region data

Blue, purple, green = deep inelastic data from SLAC, EMC

Medium modifications to the structure functions ***are the same*** in the resonance region as in the DIS

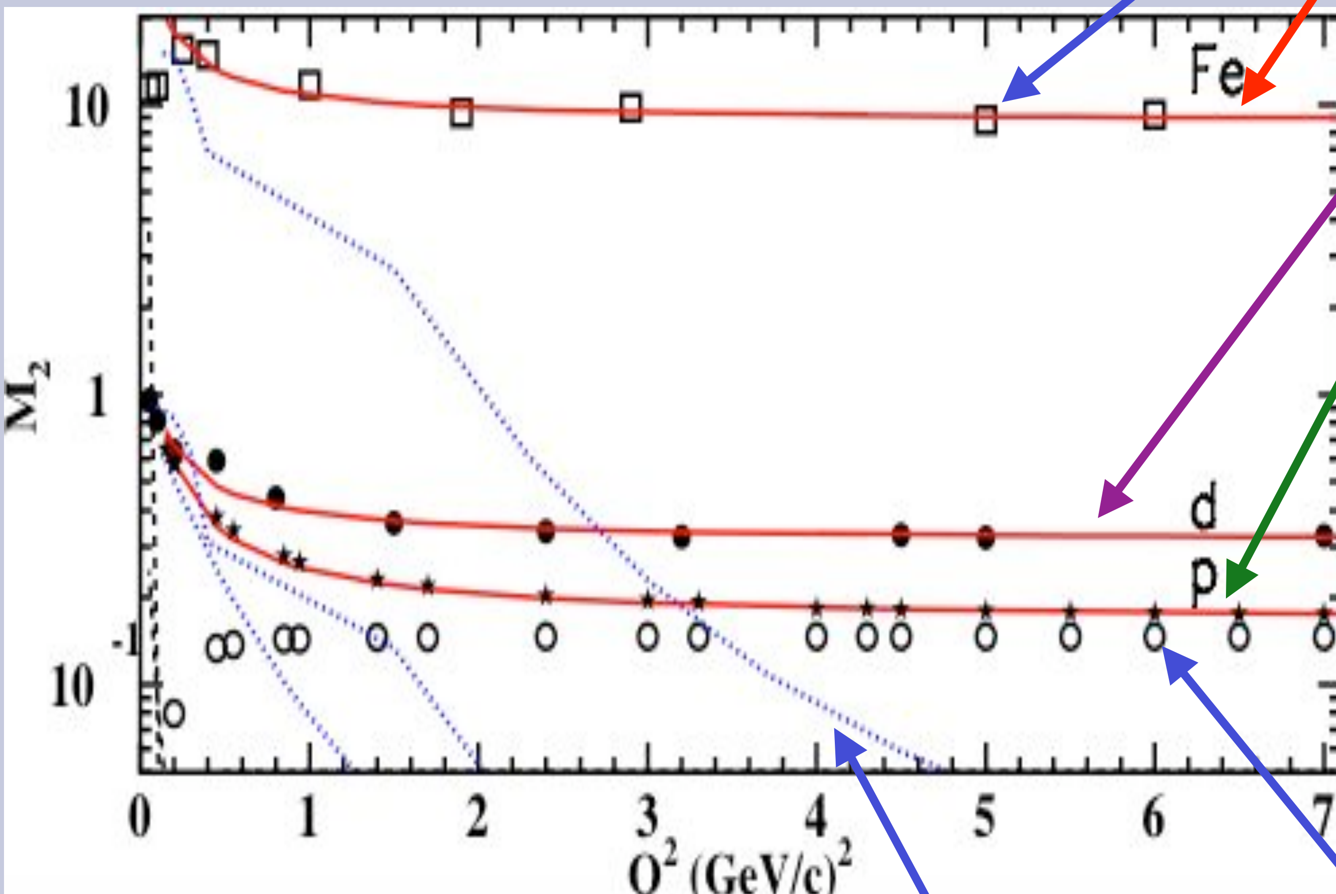
Extended recently - beautiful new data shown here at NuInt by Dave Gaskell



Full x range of data allows for integration to obtain moments!!!…

First Moment: Momentum Sum Rule

$$M_2(Q^2) = \int_0^1 dx\, F_2(x,Q^2)$$



Fe data = data:)

Fe curve = 26p + 30n**

d from e-d data (sum = 0.31)

p from e-p, QPM gives: $(1/3)^2(0.17) + (2/3)^2(0.34) = 0.17$

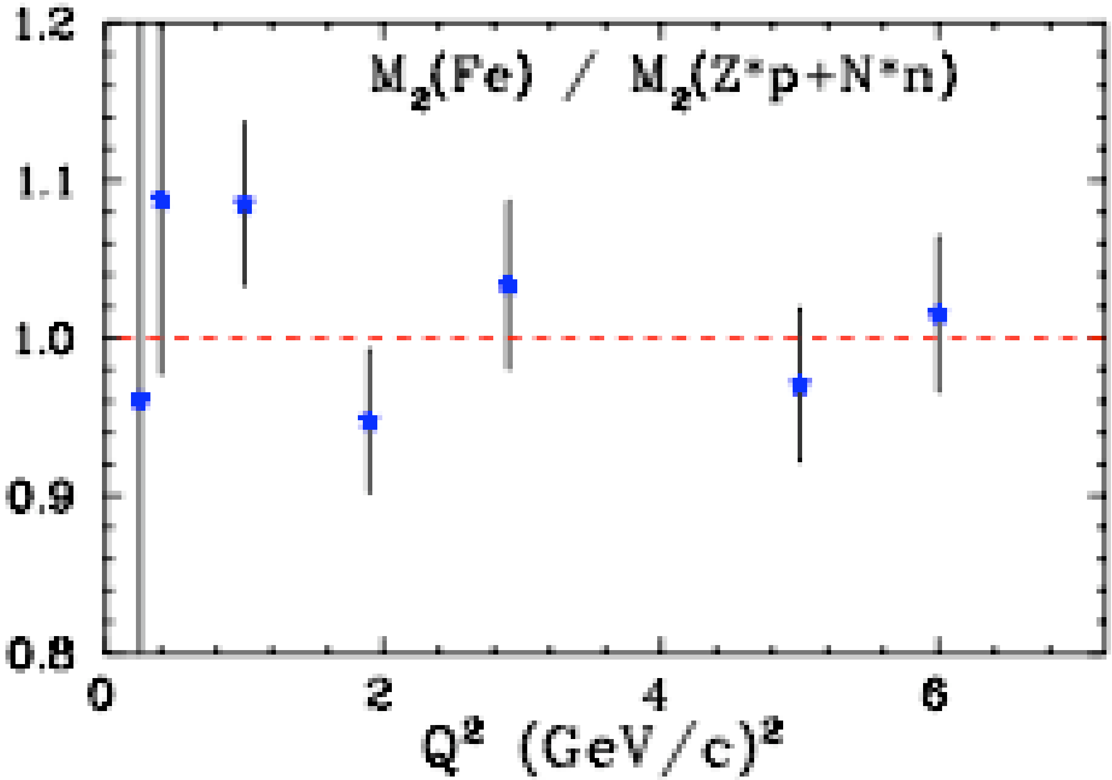
Momentum Sum Rule

elastic contributions

$**$n = d-p (pdf sum rule = 0.14)

I. Niculescu, J. Arrington, R. Ent, CK
Phys.Rev.C73:045206 (2006)

More quantitatively…..



Momentum sum rule from iron agrees with simple sum p,n to within 5%

(not very sensitive to neutron excess)

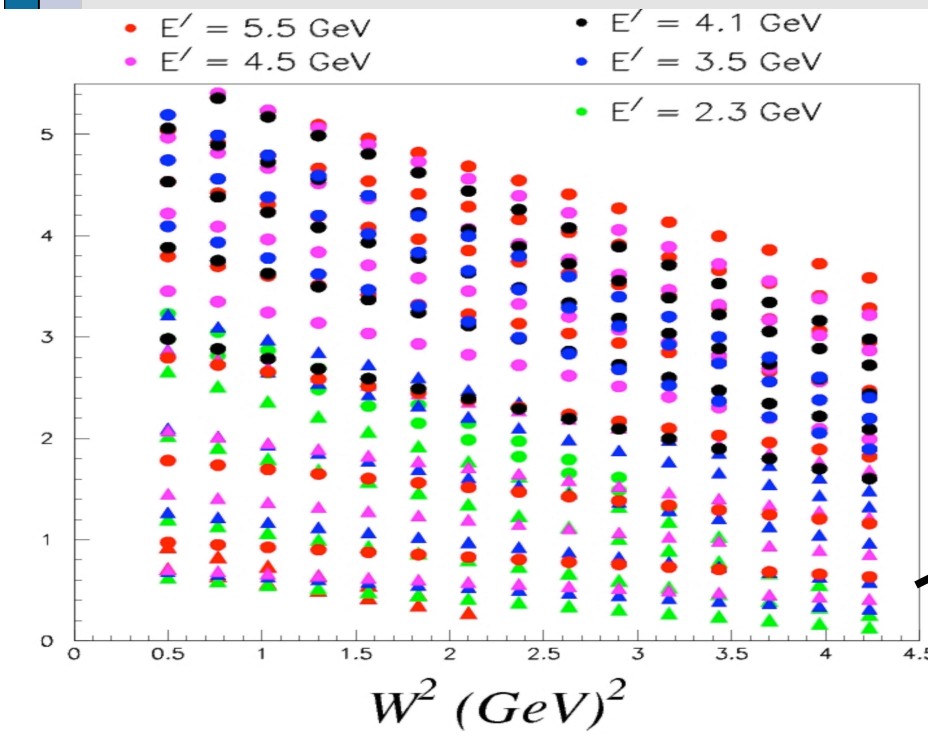
Nuclear modifications represent a redistribution of, momentum of quarks

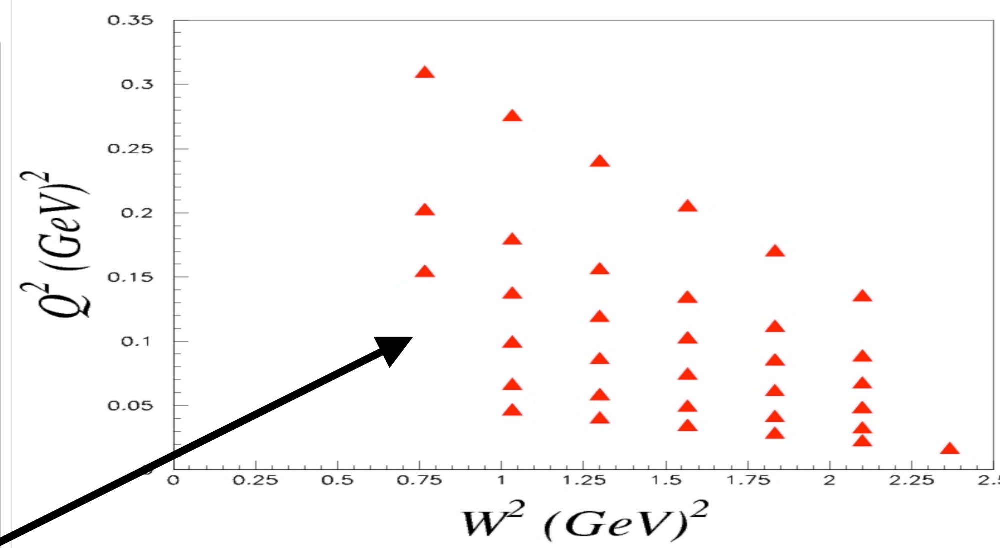
Can use as a constraint for nuclear models!

And some new data….

L/T Separated Structure Functions on Nuclei (JLab E02-109, E04-001 and E06-009)

Targets: (P), D, C, Al, Fe, Cu - Final uncertainties 1.6% pt-pt in ε (2% overall) - obtained for proton data from E94-110.

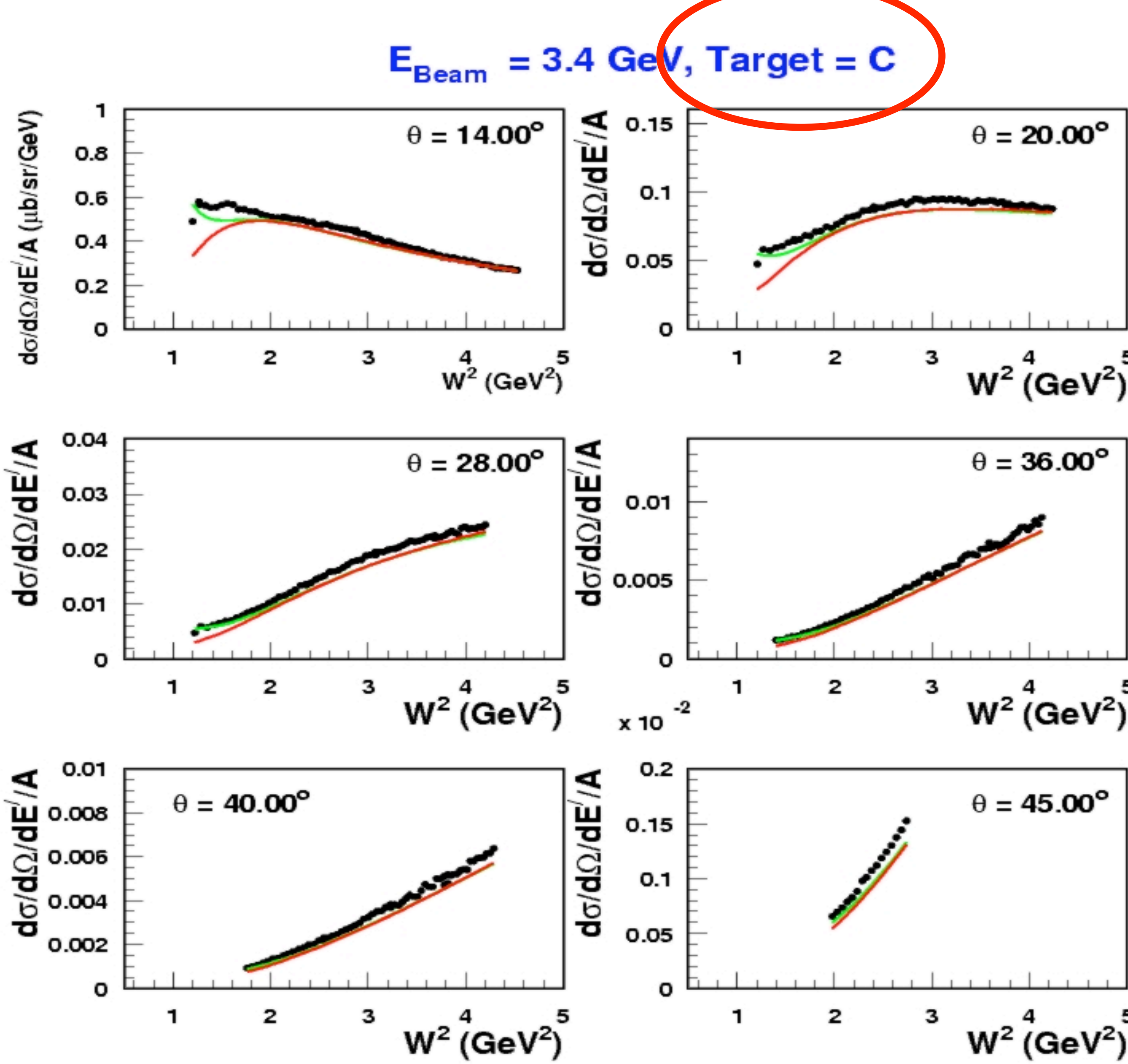




L/T separations where multiple energies (differing ε needed for Rosenbluth technique)

Low Q^2 "JUPITER" modeling data

- Targets: H,D, C, Al
- Uncertainties in preliminary data estimated at ~3 - 8% (Larger RCs and rates)



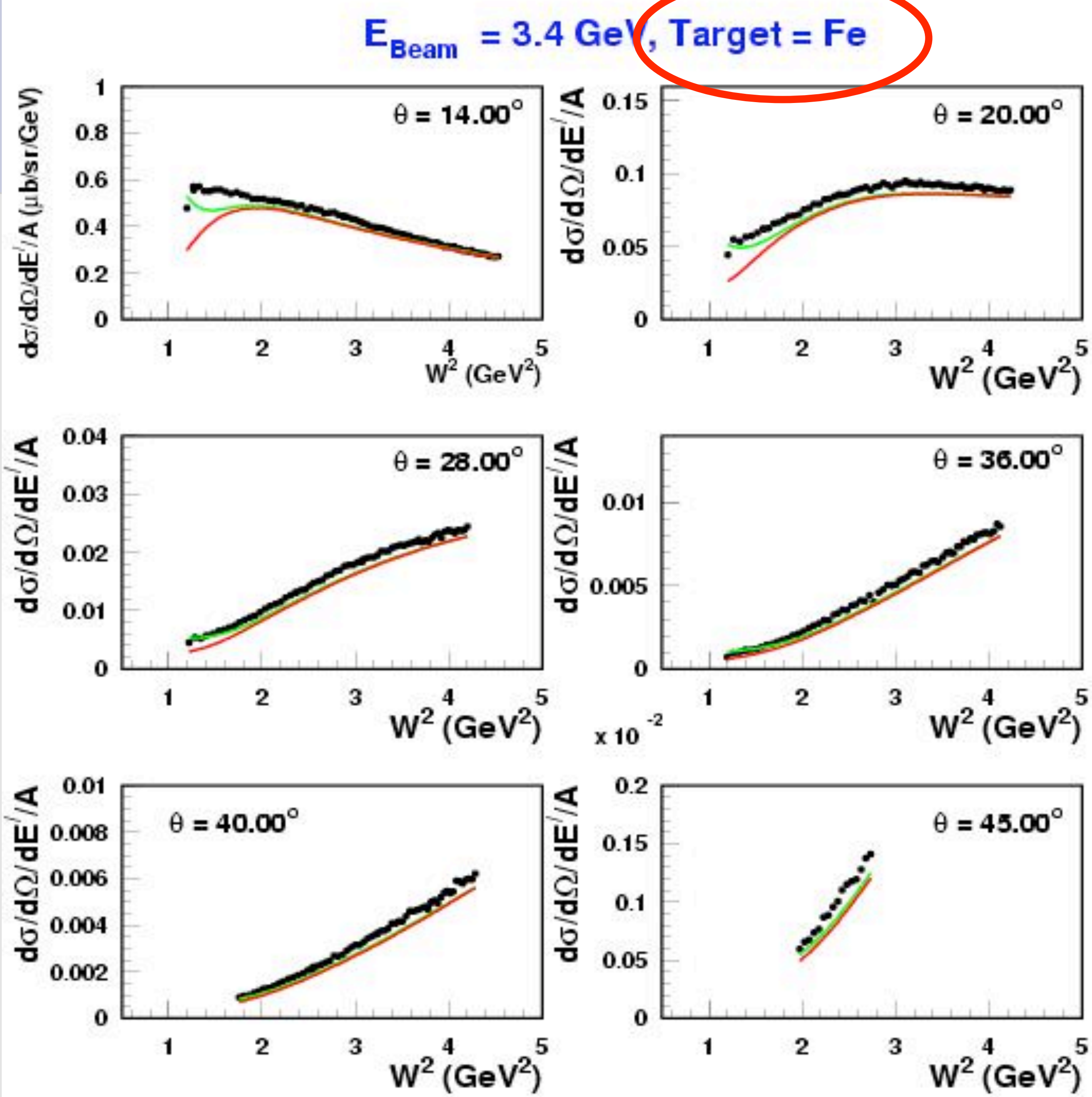
LOTS of new low Q^2 nuclear data en route…

Preliminary data
H,D,C,Al,Cu,Fe,Au resonance region

Models:

D resonance - JLab
n/p - d/u = 1/5
EMC - SLAC
DIS - F2allm (NMC) R - JLab e99118

Red curve is not radiated



Data will be used for:

Neutrino cross section model development

Nuclear duality

Deuterium (neutron) moments

A-dependence of structure functions (and moments) at low Q^2

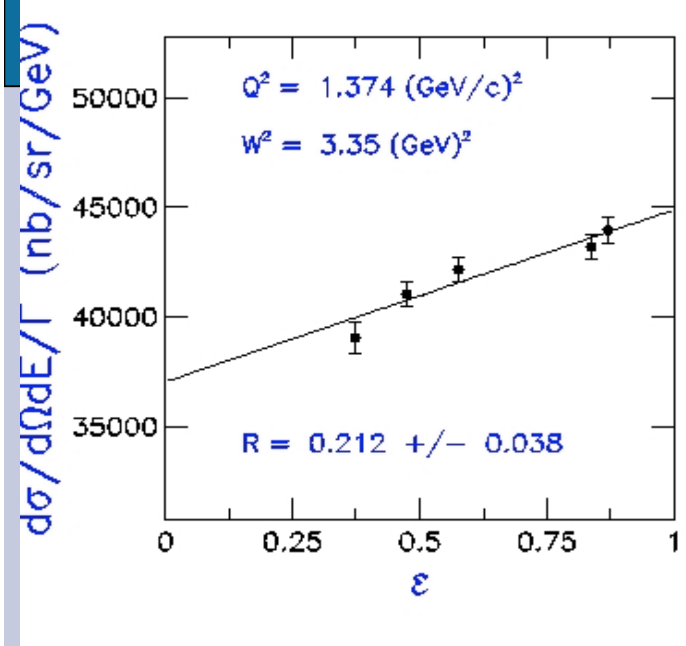
Search for nuclear pions (G. Miller prediction)

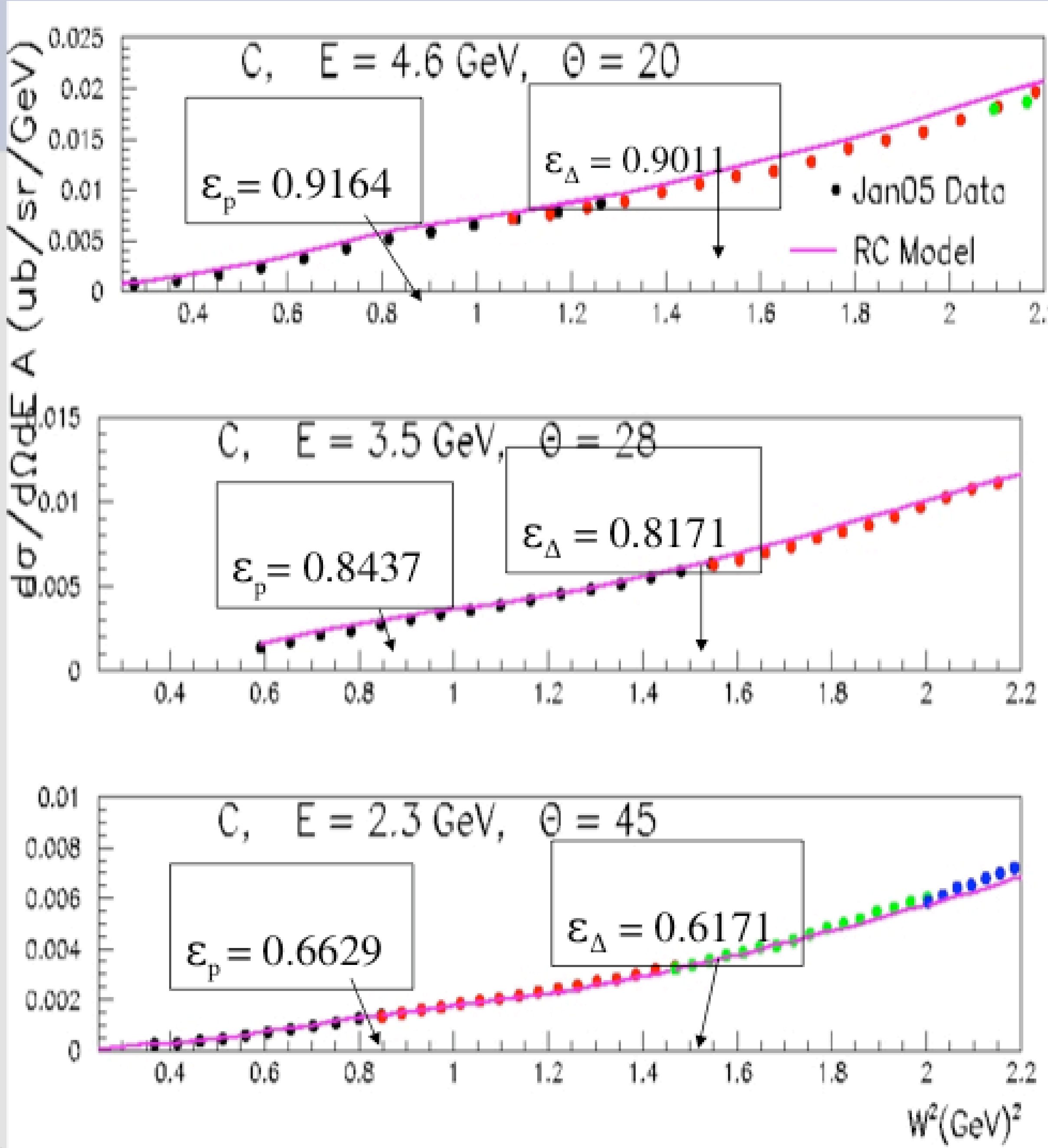
L/T separations on nuclei in resonance region….

Rosenbluth:

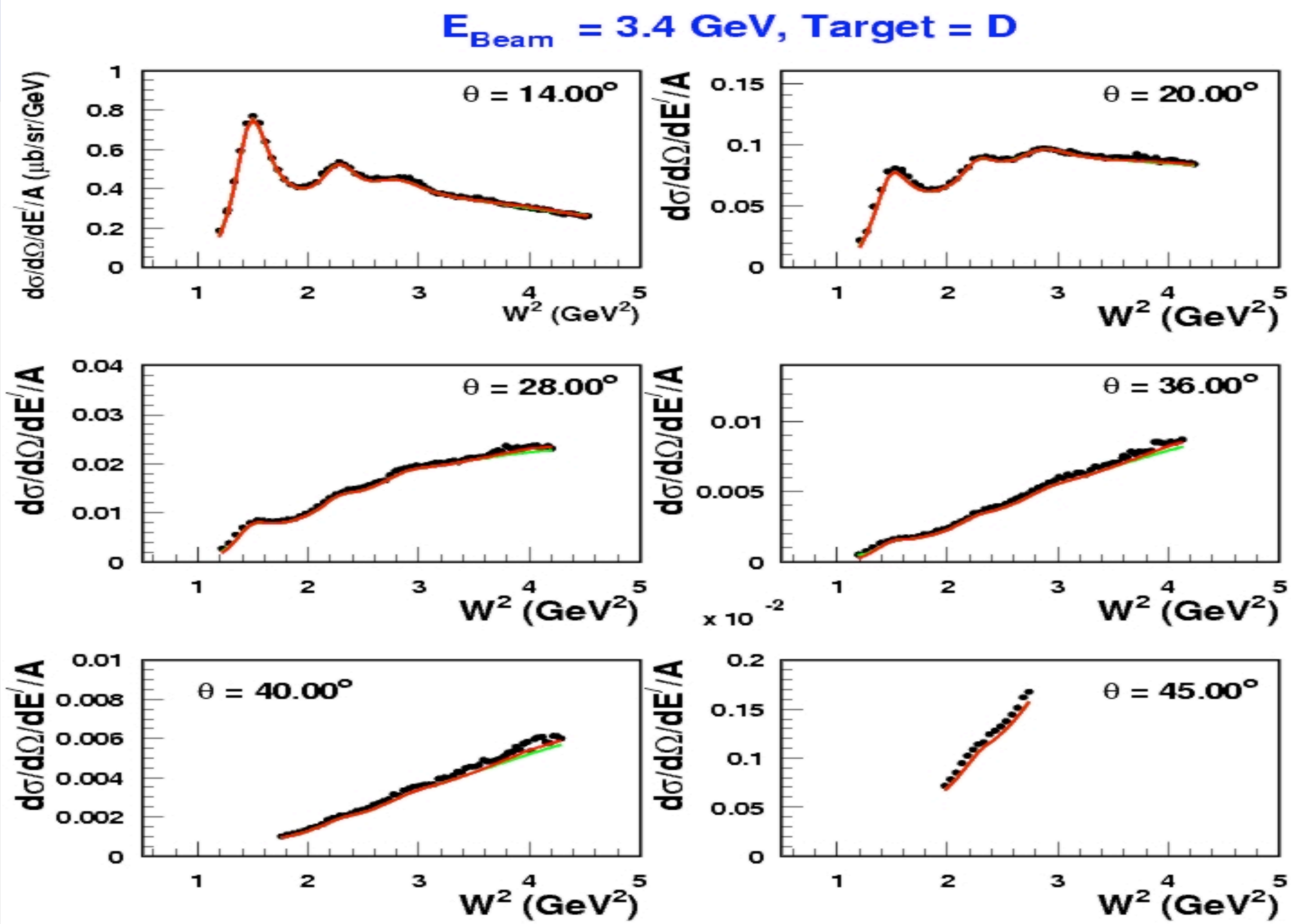
$$\frac{d\sigma}{d\Omega dE'} = \Gamma(\sigma_T + \varepsilon\sigma_L)$$

example



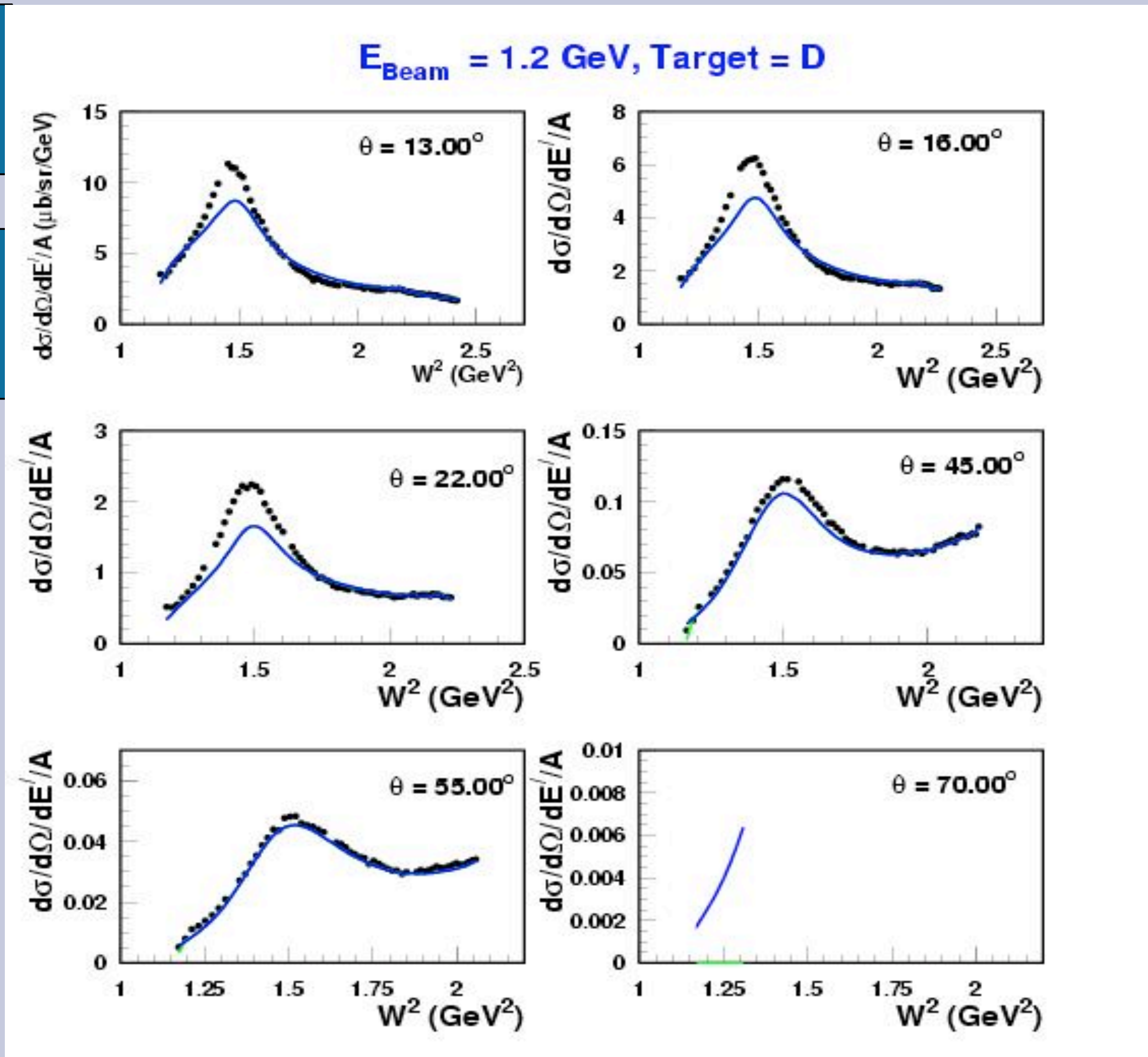


Deuterium Cross Sections, higher Q^2



The curves are from a fit to other Hall C Deuterium data (largely at higher Q^2)

Low Q^2 Cross Sections, D

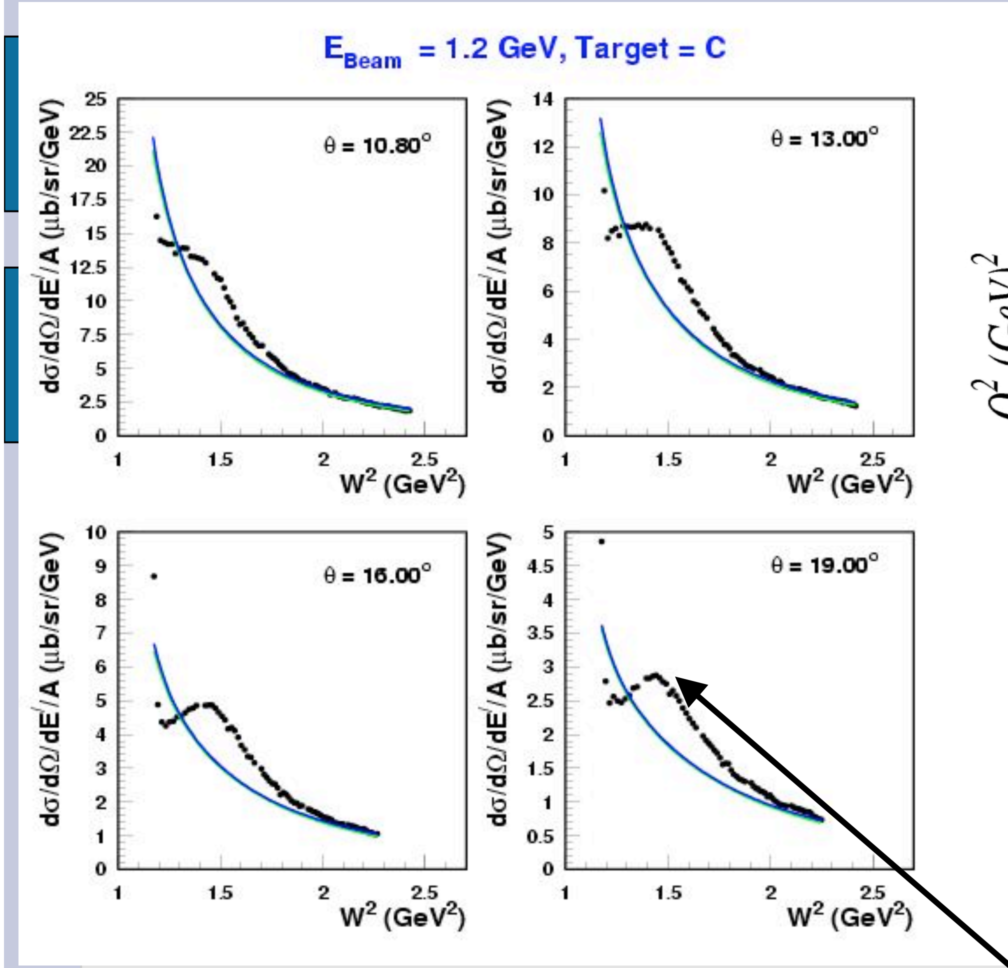


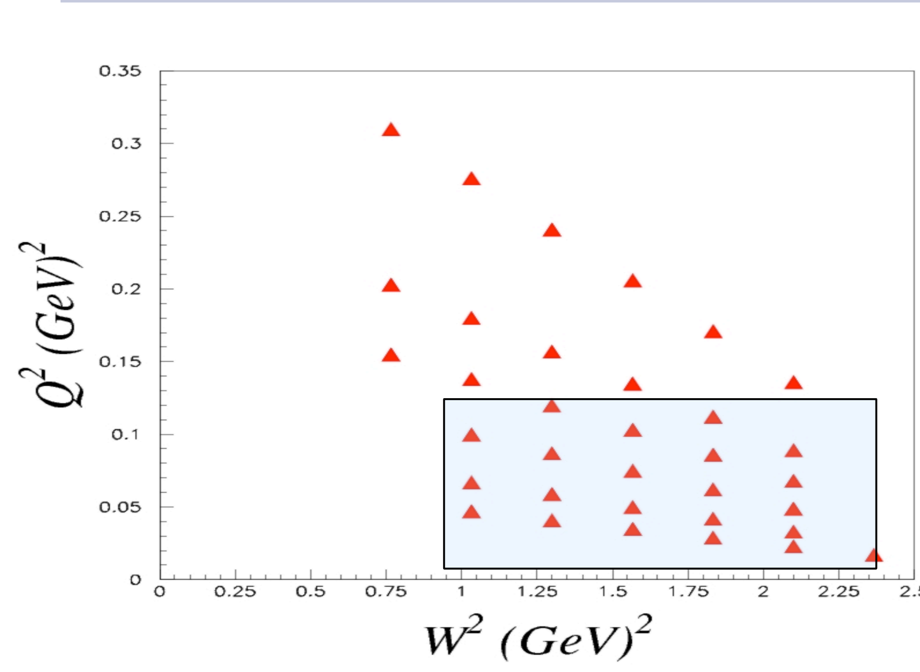
Expect 3% final uncertainty (systematic)

Even for deuterium, we need better models at lowest Q^2 values - can be dominant uncertainty, use for radiative corrections and theta bin centering

Quasi-elastic data still to be analyzed.

Low Q^2 Cross Sections, C





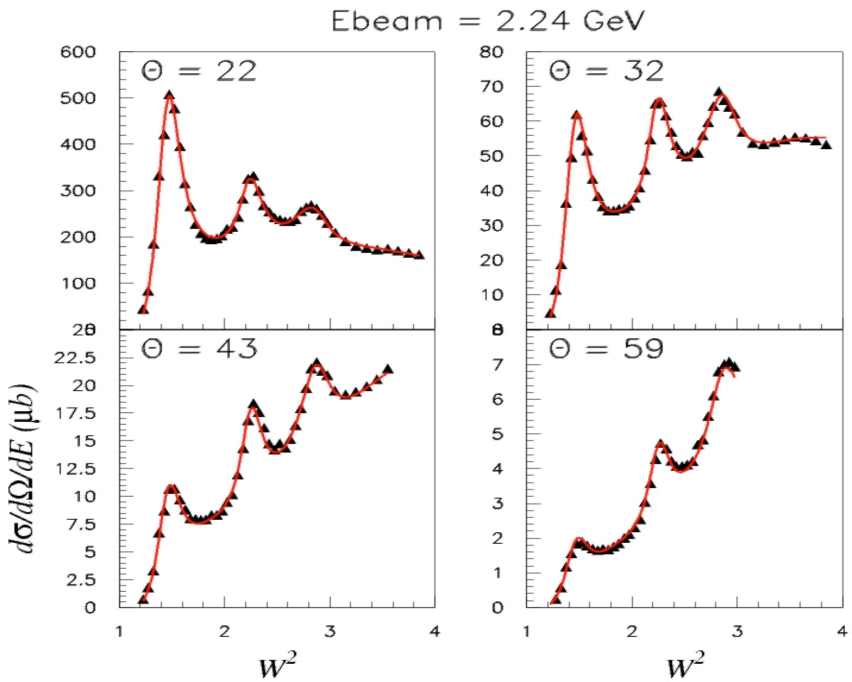
Need to improve fits!!…

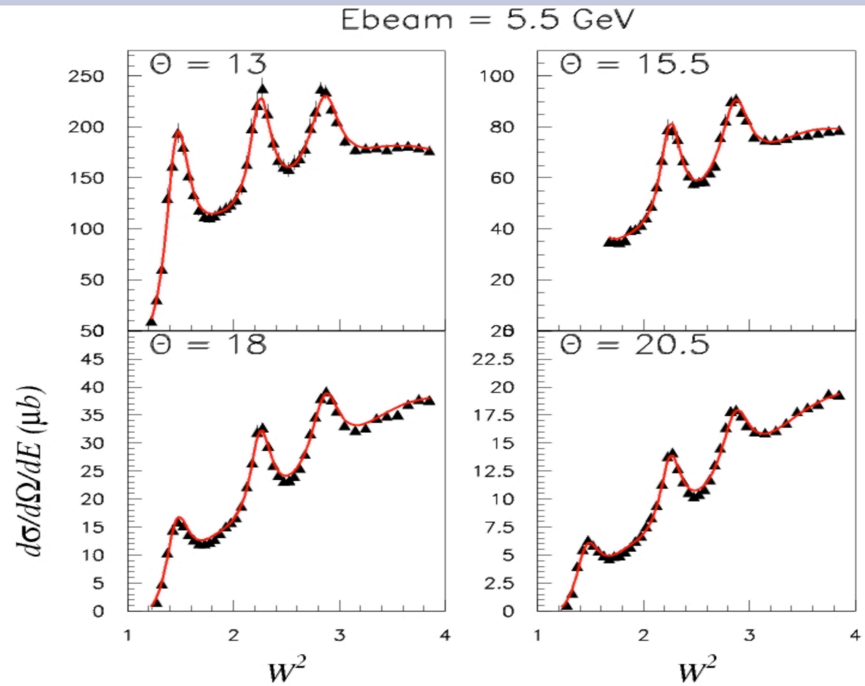
- Low Q^2 A>2 data (< 0.15 GeV^2) will provide ~3-6% uncertainty cross sections
- Δ resonance is quite strong in nuclei at low Q^2.
- Preliminary data set (6%) available

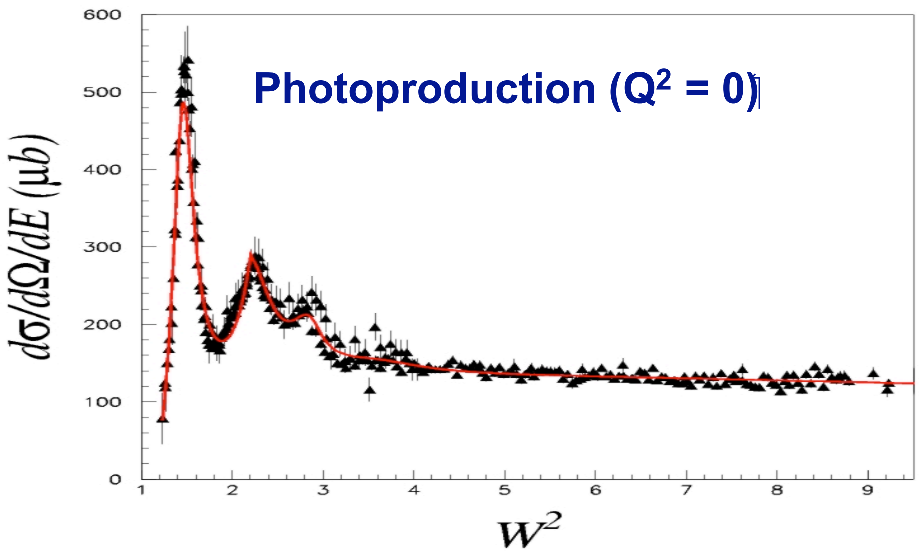
Electron Cross Section Fitting / Modeling Efforts

Proton, Deuteron, and Nuclei

Resonance Proton fit (M.E. Christy)







Kinematic range of fit:

$0 < Q^2 < 8$

and $W_{p\ thresh} < W < 3$

- **reproduces cross section data to ~3%**

Finite mass nucleon => modification of massless limit structure functions.

Commonly-utilized Prescription (Georgi & Politzer '76, etc.)

Modern update for electroweak structure functions

(*S. Kretzer and MH Reno, Phys. Rev. D 66, 113007 (2002)*)

$$F_2(x,Q^2)=\frac{x^2}{\kappa^3}F_2^{bg}(\xi)+6\frac{M^2}{Q^2}\frac{x^3}{\kappa^4}\int_\xi^1 dx'\,F_2^{bg}(x')+12\frac{M^4}{Q^4}\frac{x^4}{\kappa^5}\int_\xi^1 dx'\int_{x'}^1 dx''\,F_2^{bg}(x'')$$

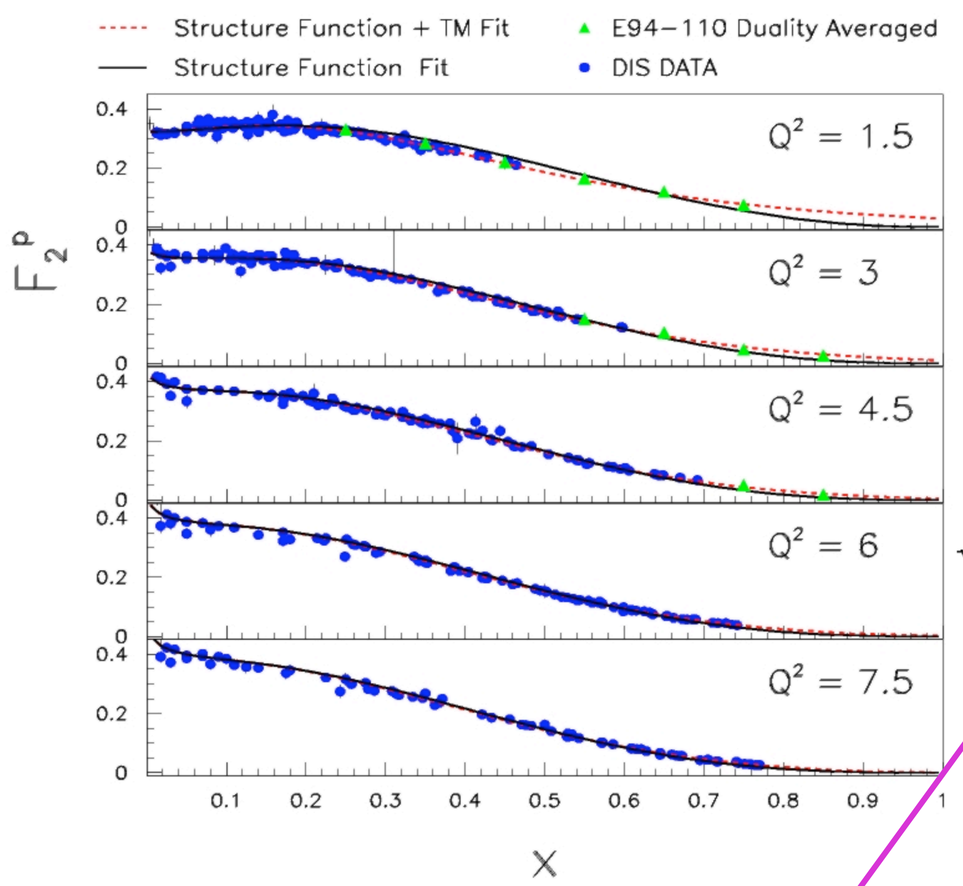
$\xi = 2x / \left[1 + (1 + 4M^2x^2/Q^2)^{1/2}\right]$ is Nachtman variable

From Kretzer & Reno, the M=0 structure function given by $F_2^{M=0} = x^2 F_2^{bg}$

This is true too all orders in pQCD!

New approach: Parameterize $F_2^{M=0}(x,Q^2)$ and fit $F_2(x,Q^2)$ to world data set => determine TMCs directly from data.

procedure similar to radiative unfolding



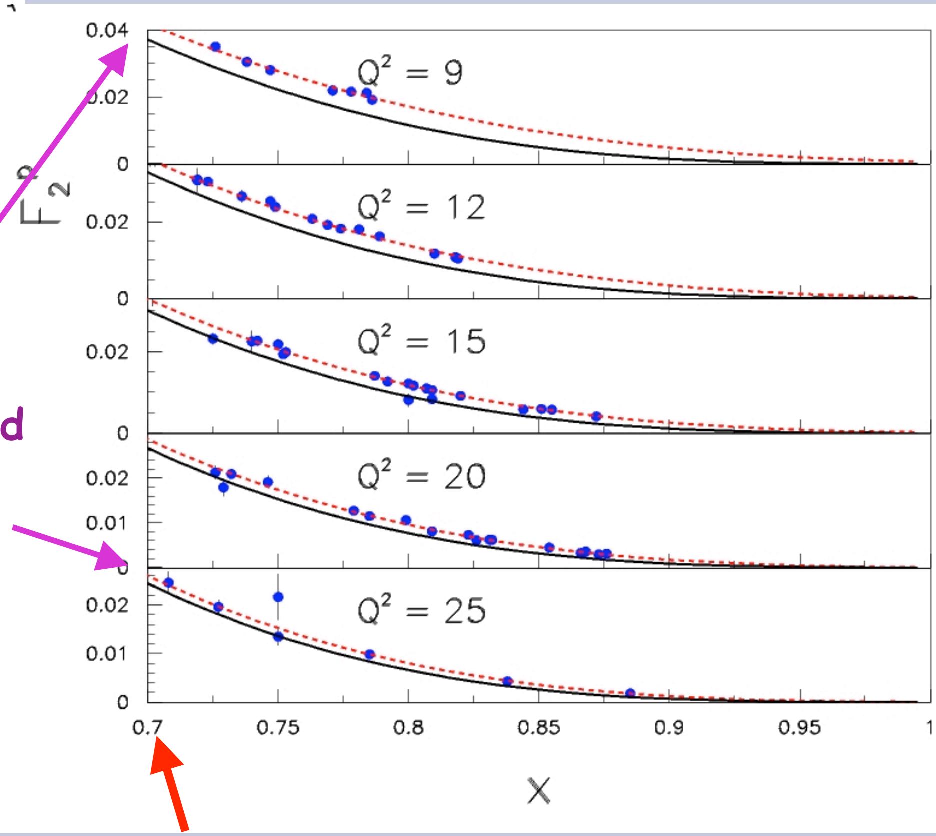
Fit form $x^a(1-x)^b(1 + cx + dx^{1/2})e$

Covers range $0.3 < Q^2 < 250$ GeV^2

http://www.jlab.org/~christy/TM/tm_fits.html

$\chi 2$ / dof = 0.98

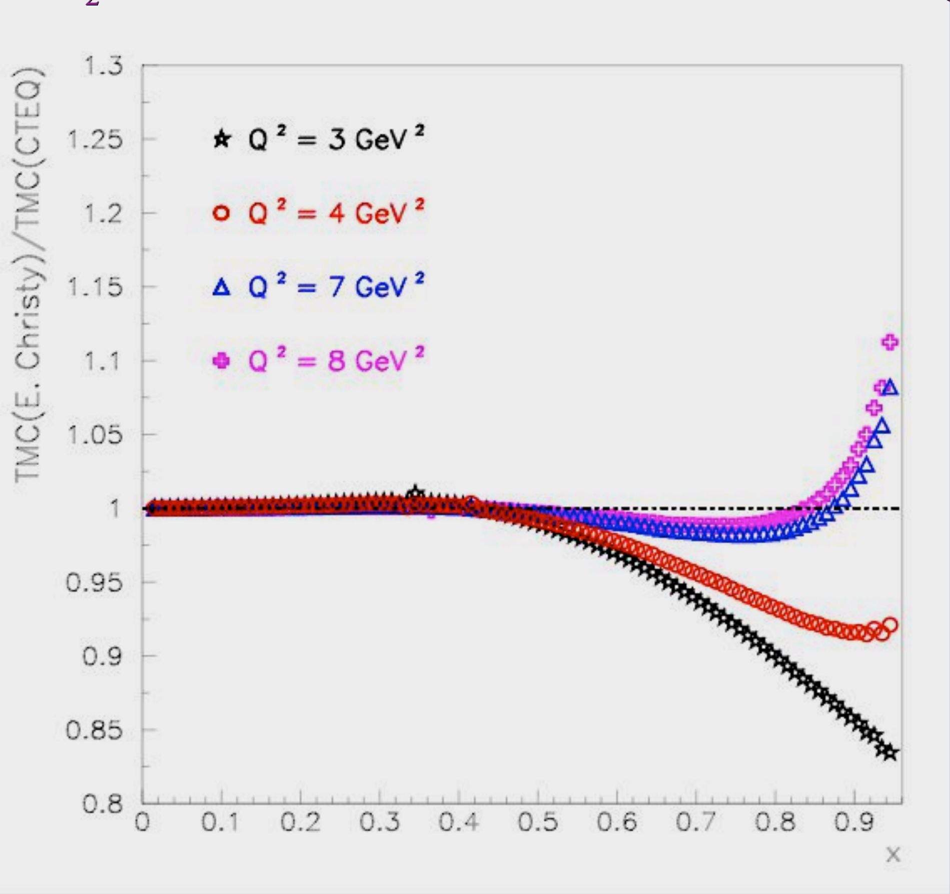
Fit provides both $F_2^{M=0}$ and full F_2



Target Mass is ~15% effect at x = 0.7 and Q^2 = 9 GeV^2, ~8% even at Q^2 = 25 GeV^2!

Compare to Kretzer-Reno using CTEQ pdfs…

F_2 TM fit from data / TM calc. from K-R and CTEQ



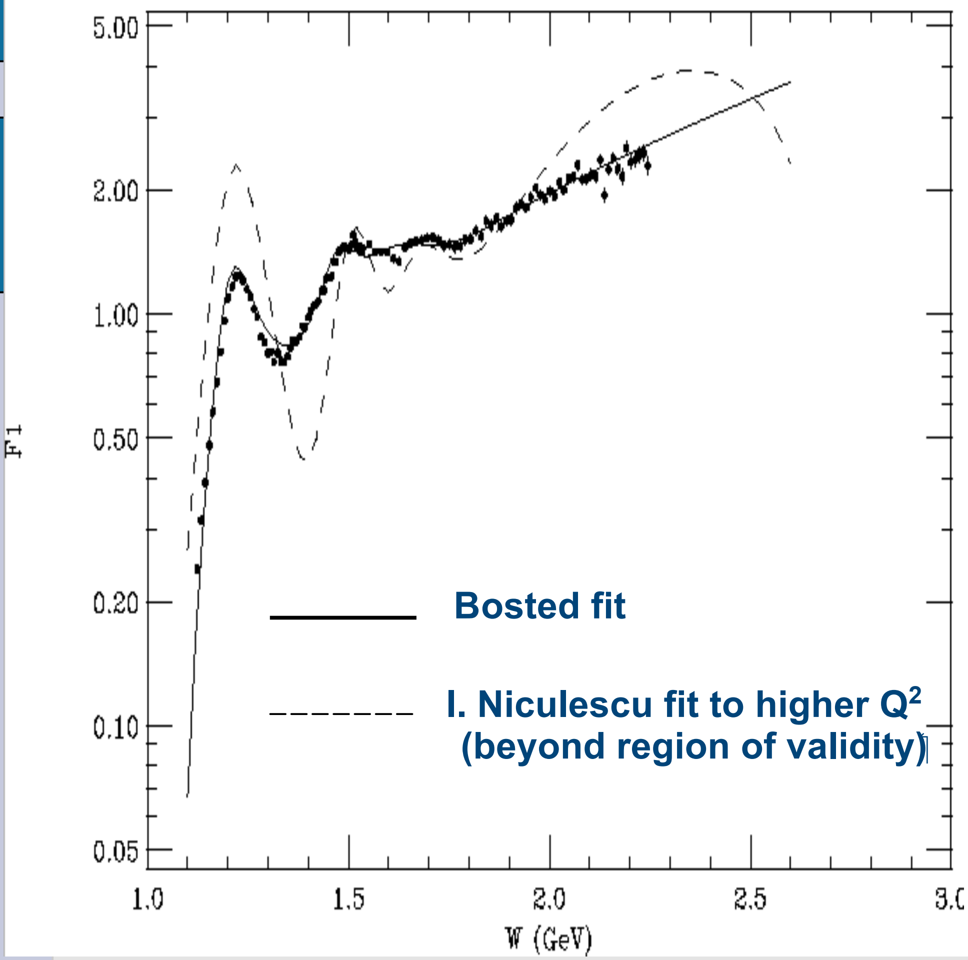
- Two approaches ~same for x < 0.5
- Two approaches differ by 10-15% at large x and lowest Q^2
- Approaches converge by Q^2 ~ 5 GeV^2 other than at very highest x
- At lowest Q^2, "data approach" requires *smaller* correction!

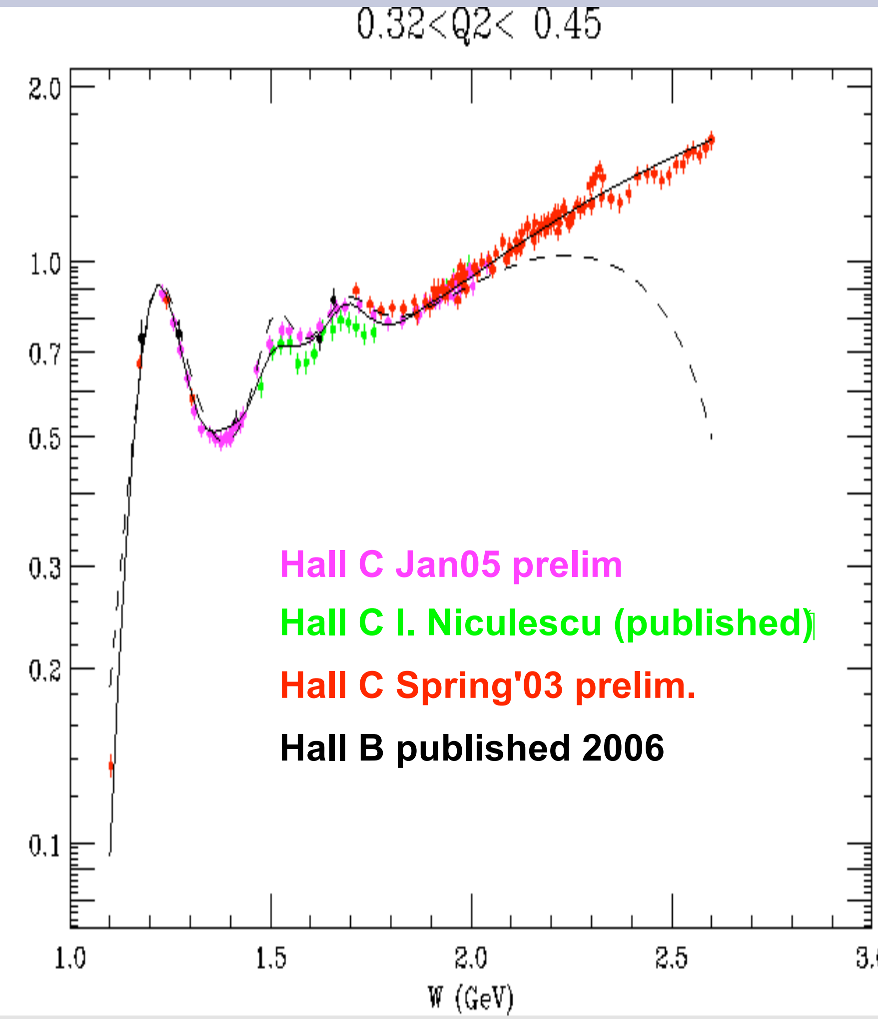
P. Bosted Fit to Deuterium

- New fit to quasi-elastic plus inelastic for A=2.
- Range of validity larger than previous fits $0<Q^2<10$ GeV^2, W<3 GeV.
- Data from E02-109 (JUPITER) and F2LowQ2 (E02-002) crucial to constrain low Q^2 behavior.
- Fit utilizes Fermi smeared Christy proton fit and determines F_1^n/F_1^p including Fermi momentum effects on nucleon resonance widths.
- A work in progress!

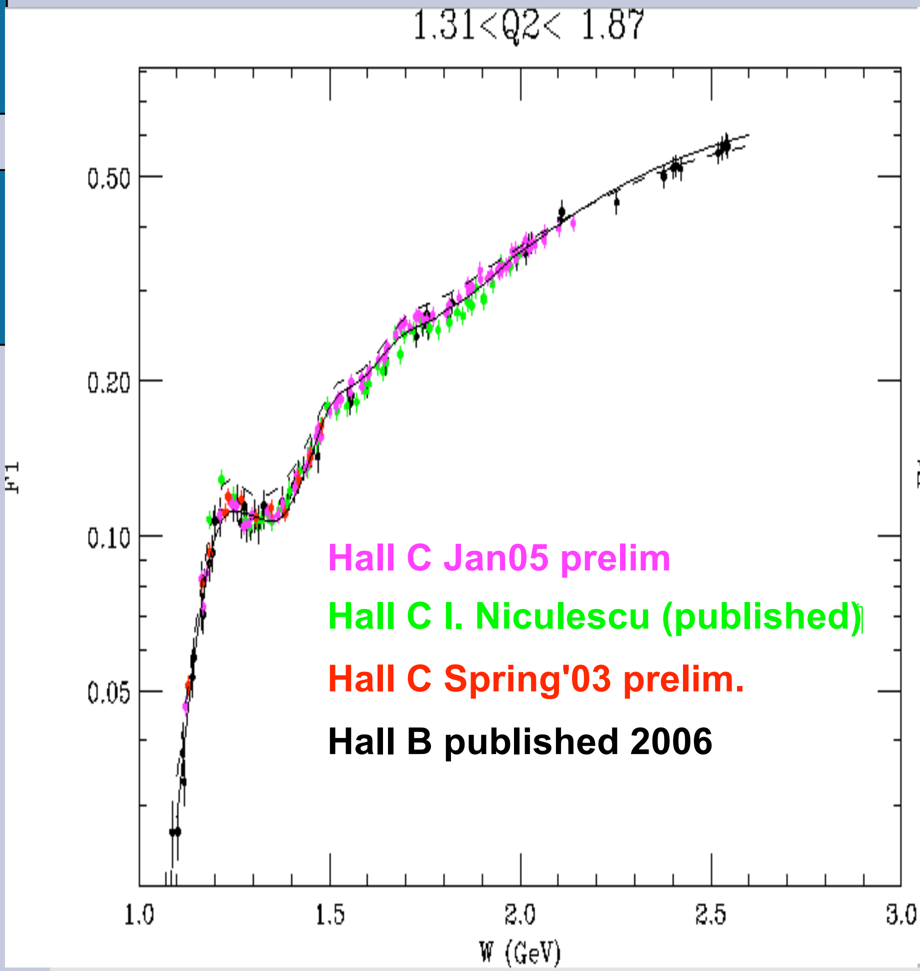
Deuteron Comparisons

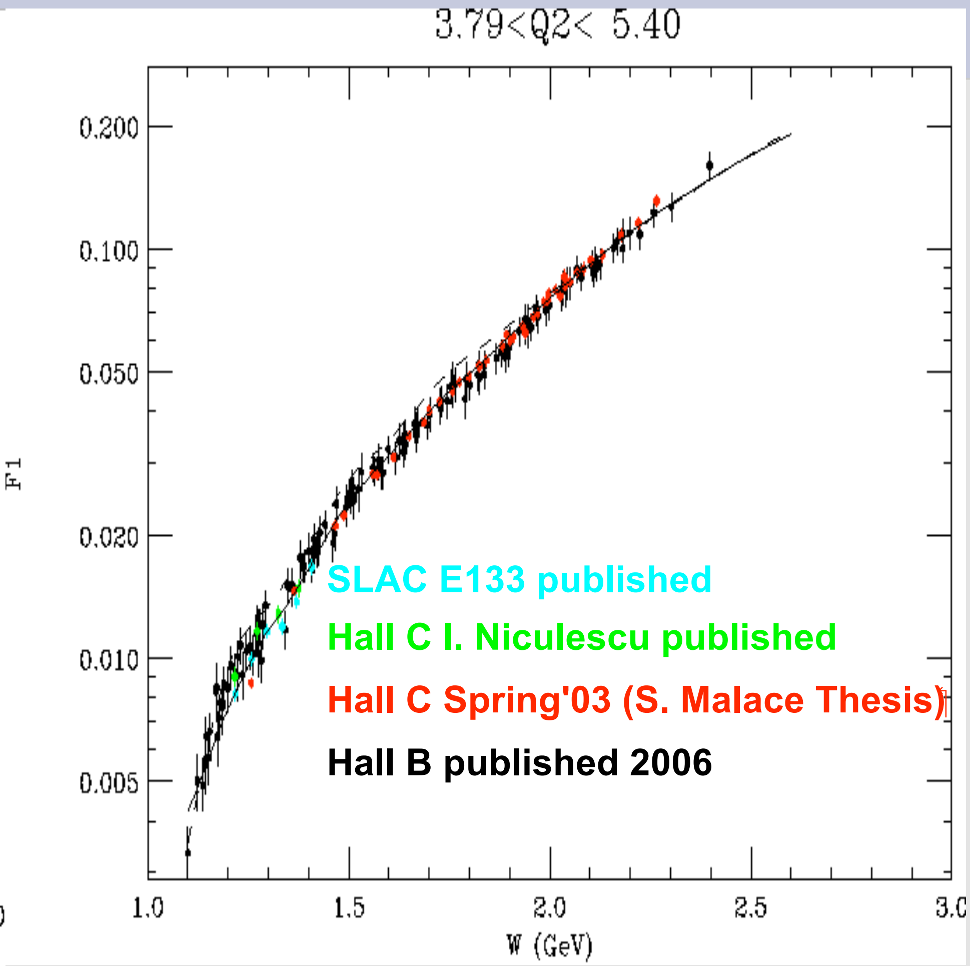
DAPHNE photoproduction





Fit compared to deuteron data





To do for deuteron and free neutron

- Include data at higher W (W>3), or use NMC fit.

- Better consistency of proton and neutron fit forms. Improve underlying physics (for example, Roper is thought to have a diffractive minimum at moderate Q^2).

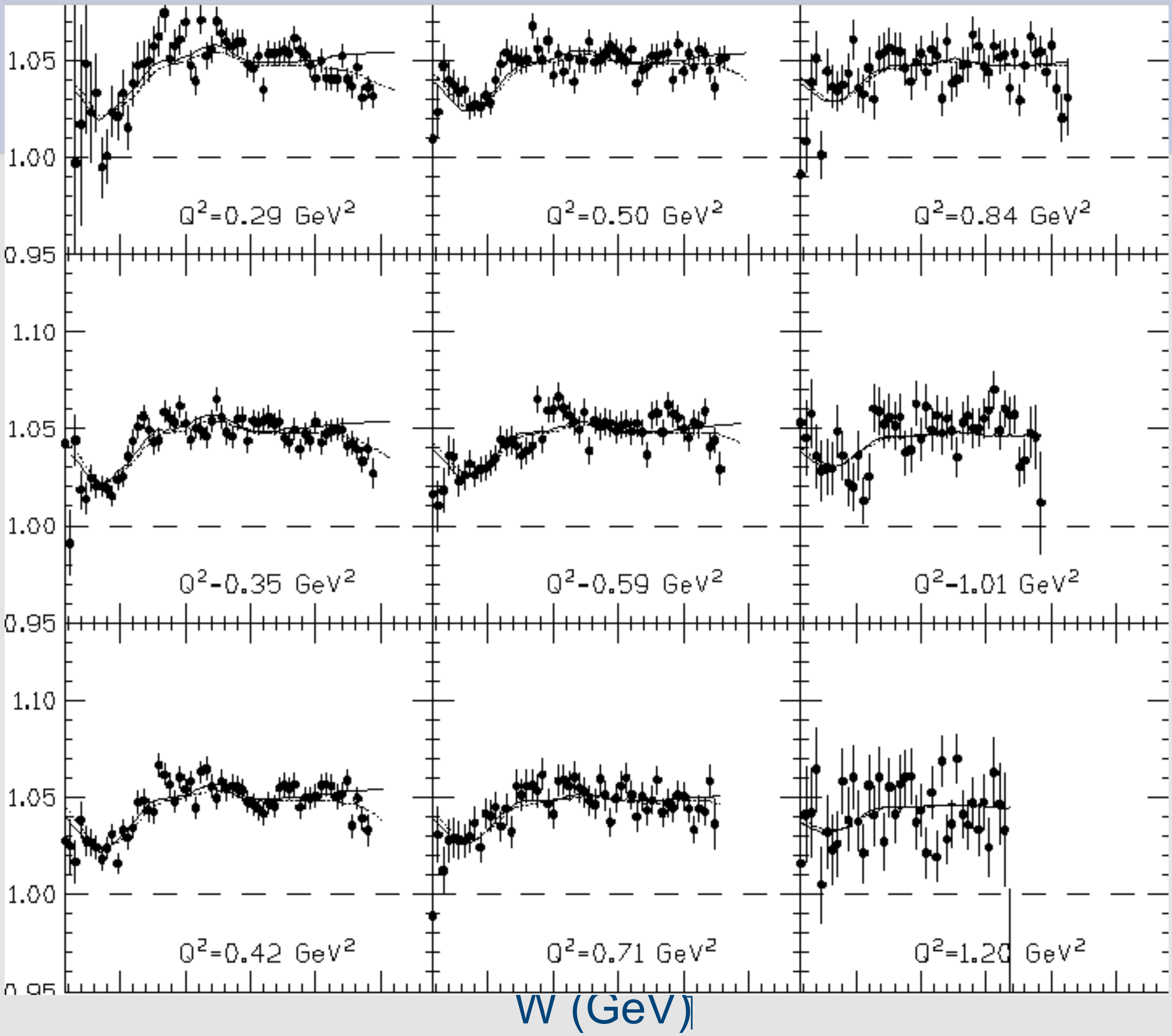
- Find photoproduction data W>2.5 GeV.

- Utilize Final Hall C results available soon.

Inelastic scattering on nuclei

- Presently, apply simple y-scaling-based Fermi smearing model to free neutron and proton fits, plus Steve Rock's (SLAC) fit to "EMC" ratio for x<0.8 to take into account binding and shadowing.
- This prescription predicts ratio of ^{15}N to C essentially independent of W in the resonance region, except at q.e. peak.
- This seems to be born out by preliminary ratios measured in CLAS and E03-103.

Preliminary ratios 15N/C (per gm) from CLAS Eg1b



P. Bosted Conclusions

- New fit to quasi-elastic plus inelastic for A=2 seems pretty good, at least to do radiative corrections. Range of validity larger than previous fits ($0<Q^2<10$ GeV^2, W<3 GeV).

- Data from E02-109 (JUPITER) and F2LowQ2 (E02-002) crucial to constrain low Q2 behavior.

- Need to study behavior A>2, espeically for $Q^2<1$ GeV^2 (higher Q^2 seems o.k. using traditional “EMC” correction).

Conclusions

- ***Lots*** **of high precision inclusive electron scattering data coming from Hall C on nuclear targets and spanning a wide range of W, Q - kinematically matched to new era of neutrino experiments and oscillation physics**

- **Fits being developed, in very good agreement with data**

- **Quark-hadron duality observed, Momentum sum rule works in nuclei, New target mass approach developed, EMC holds in resonance region, ………**