Structure Function Measurements, Fits, and Target Mass Corrections

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Jlab Users Meeting

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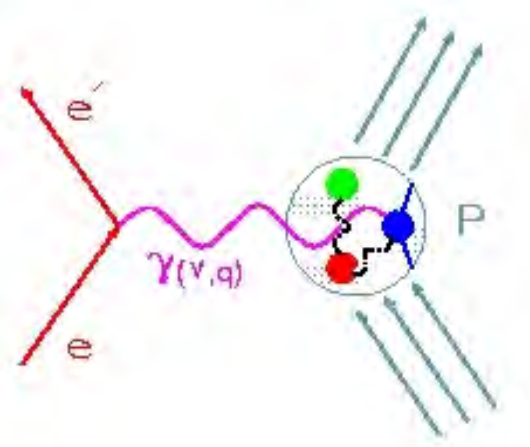
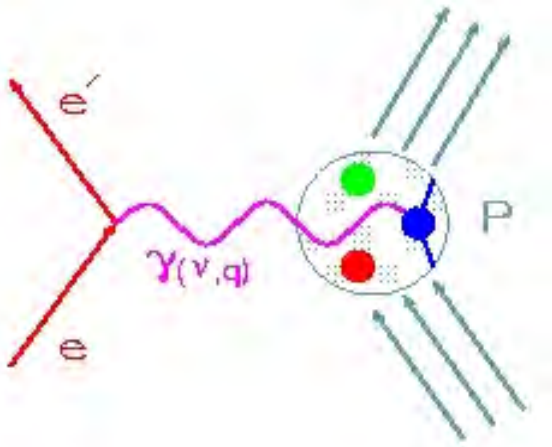




- JLab has a large program of structure function measurements at low Q^2 (much at high x and in the resonance region and above) on **proton**, **deuteron**, and ***nuclear*** *targets*

- This talk will focus on **unpolarized** structure function measurements in Hall C and specifically

Longitudinal *and* ***Transverse*** *(L/T) separated structure functions,*

F_L, F_1, *and the linear combination*

$$F_2 = (2xF_1 + F_L)/(1+4M^2x^2/Q^2),$$

for both **protons** and **deuterons**.

L/T separations - Rosenbluth Method

Reduced cross-section:

$$\frac{1}{\Gamma}\frac{d\sigma}{d\Omega dE'} = \sigma_T(x,Q^2) + \varepsilon\sigma_L(x,Q^2)$$

Γ : flux of transversely polarized virtual photons

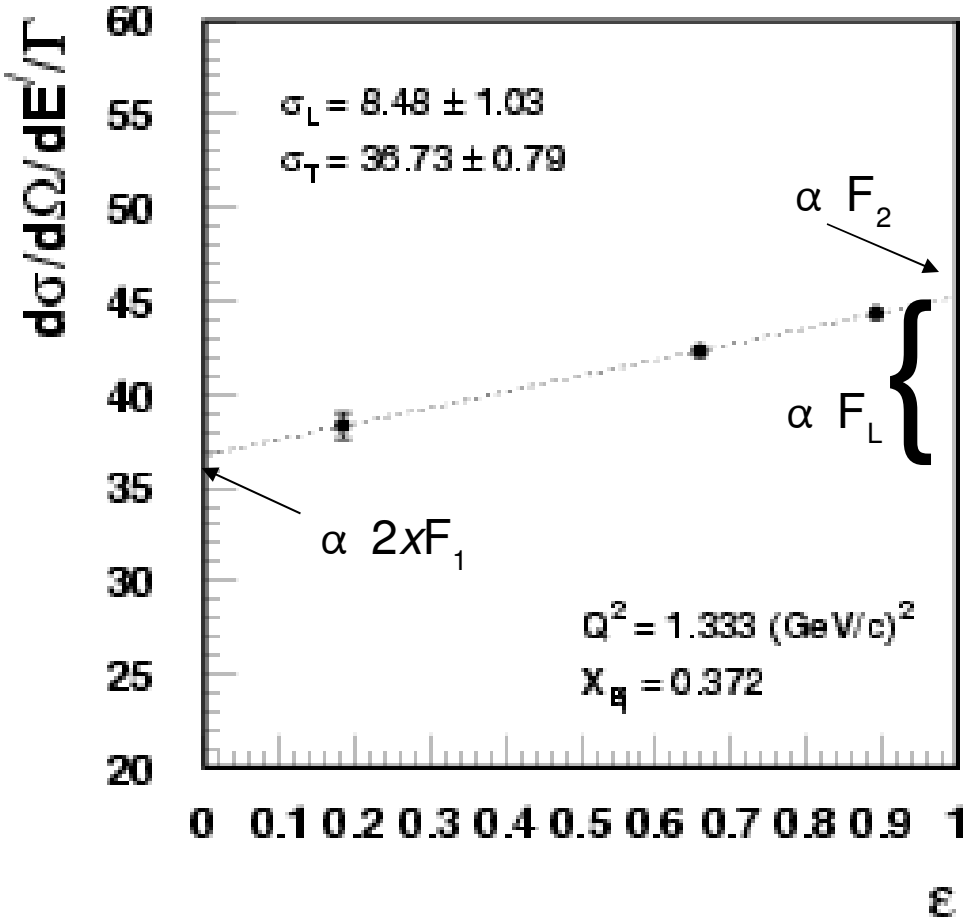
ε : relative longitudinal polarization

- **Fit reduced cross section linearly with ε at fixed W^2 and Q^2 (or x, Q^2) --> *Need multiple beam energies*.**
- **Linear fit yields:**

  σ_L = Slope

  σ_T = Intercept

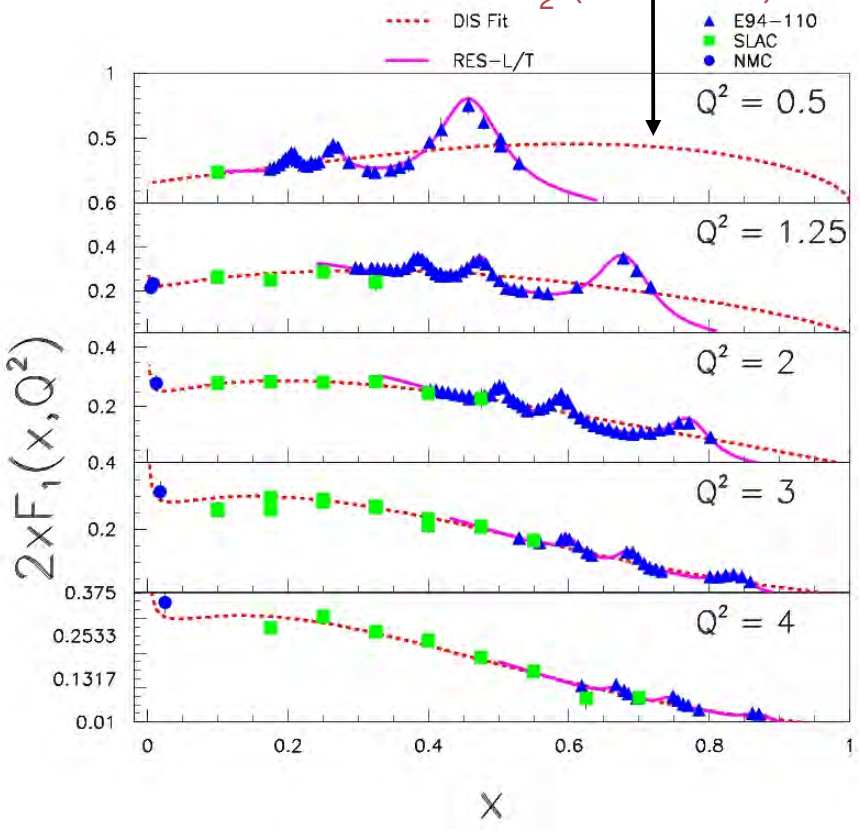
- **Need ε point-point uncertainties < 2 %**

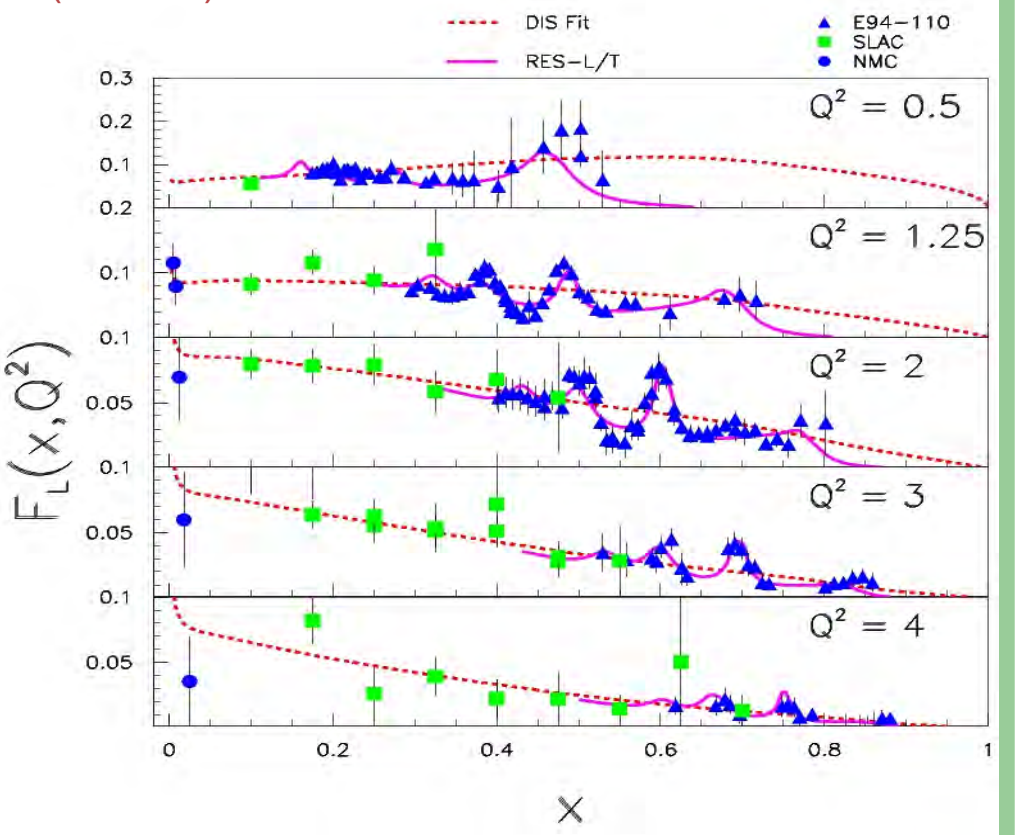


Extraction of F_2 depends on $R = \sigma_L/\sigma_T = F_L/2xF_1$ and ε!

Proton L/T Separated SFs (E94-110)

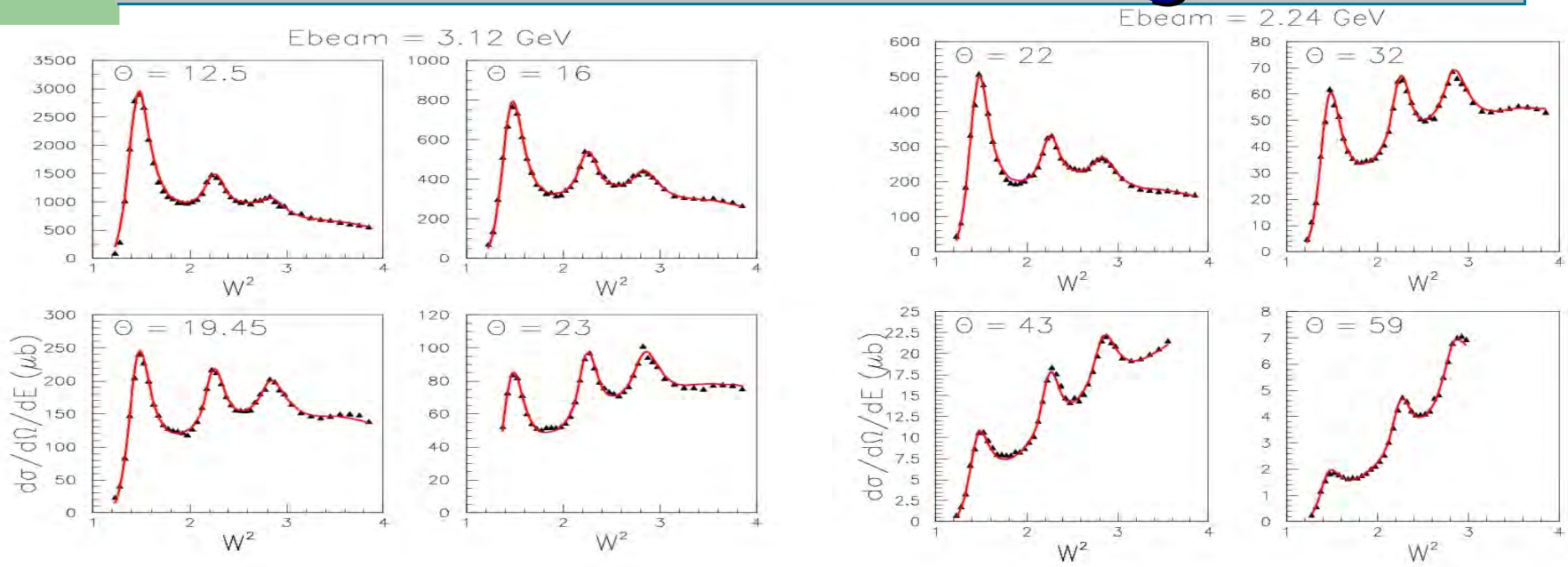
DIS fits to F_2 (ALLM97) and R (R1998).

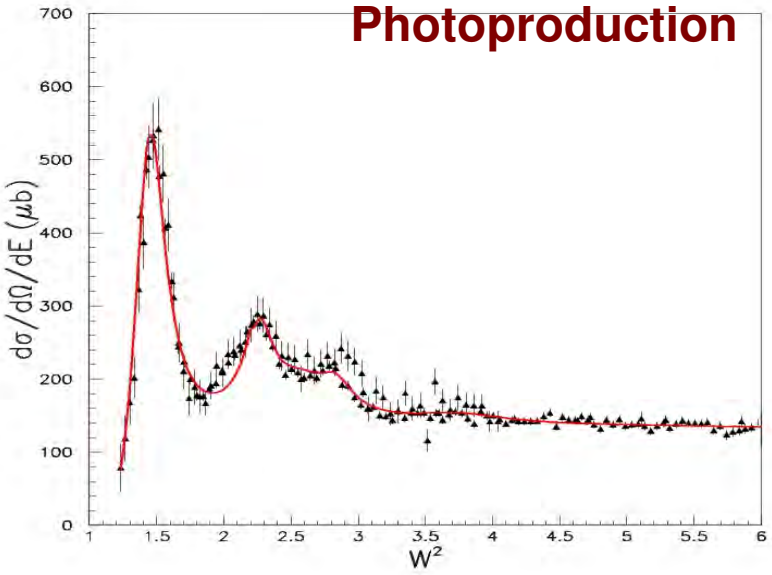




- Large body of high precision resonance data ($0.3 < Q^2 < 4.5$) - links smoothly to DIS data set.
- Quark-Hadron Duality observed in both transverse and longitudinal structure functions
  – average in RR has same *x* and Q^2 dependence as expected from DIS fits.
- Sparse L/T separations for deuterium and heavier targets at JLab kinematics .
- Resonance region fit to σ_T ***AND*** σ_L available ....

Fit to Proton Resonance Region Data

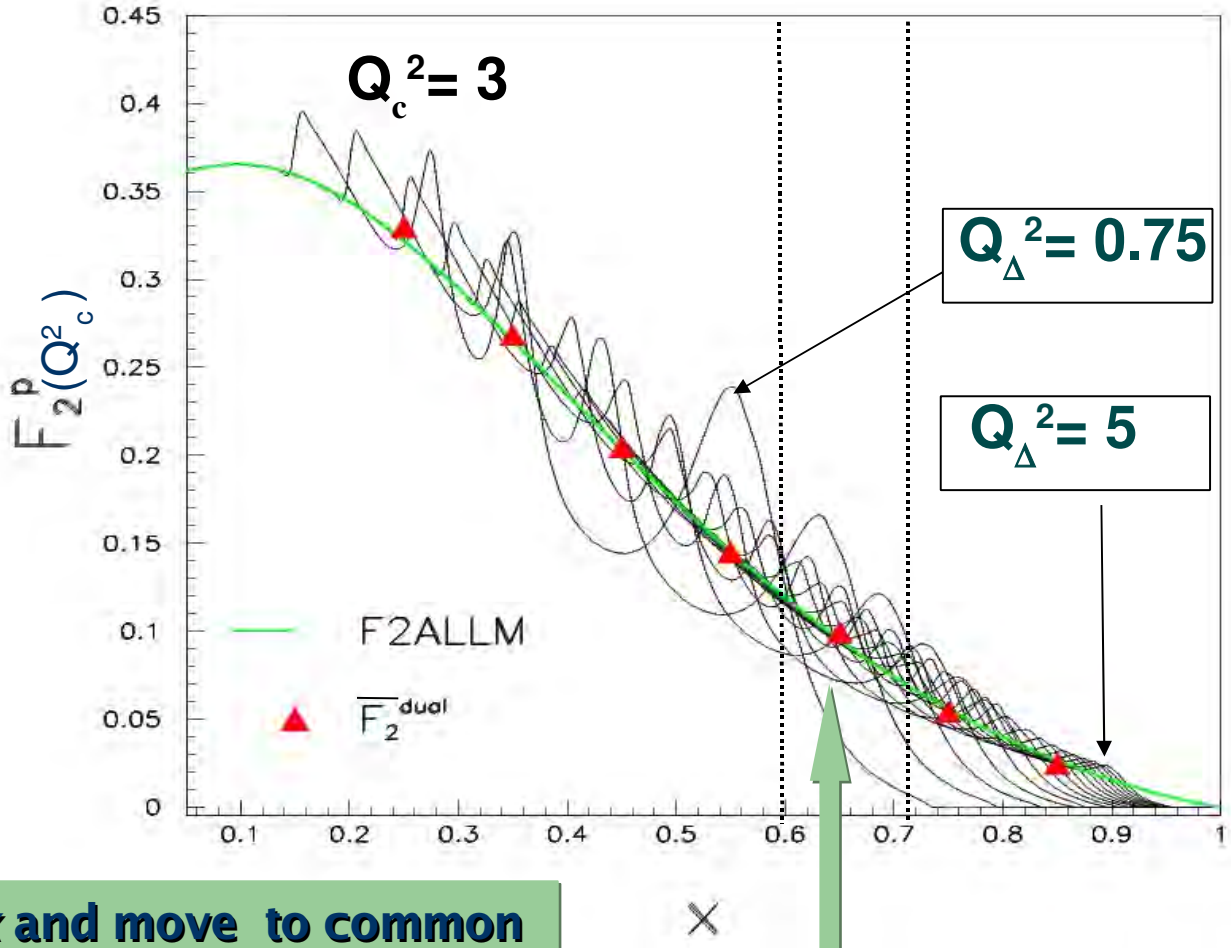




- Energy dependent Breit-Wigners with current best guess of dominant resonances, including decay modes and branching fractions.
- σ_T constrained by photoproduction data.
- Preliminary 2003 Hall C data used for $5.5 < Q^2 < 7.5$
- Fit typically reproduces data to better than 3%.
- Fit available at www.jlab.org/~christy/cs_fits/cs_fits.html

Duality Averaged Proton Data

** Construct DIS like data utilizing the observation of duality.



Fix *x* and move to common Q^2 at using Q^2 dependence of DIS fits.

Average over this x-bin to get F_2^{dual}

=> 'DIS-like' data

Global Fitting of DIS + Ave. Resonance data

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

Prescription due to Geogi & Politzer '76 **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

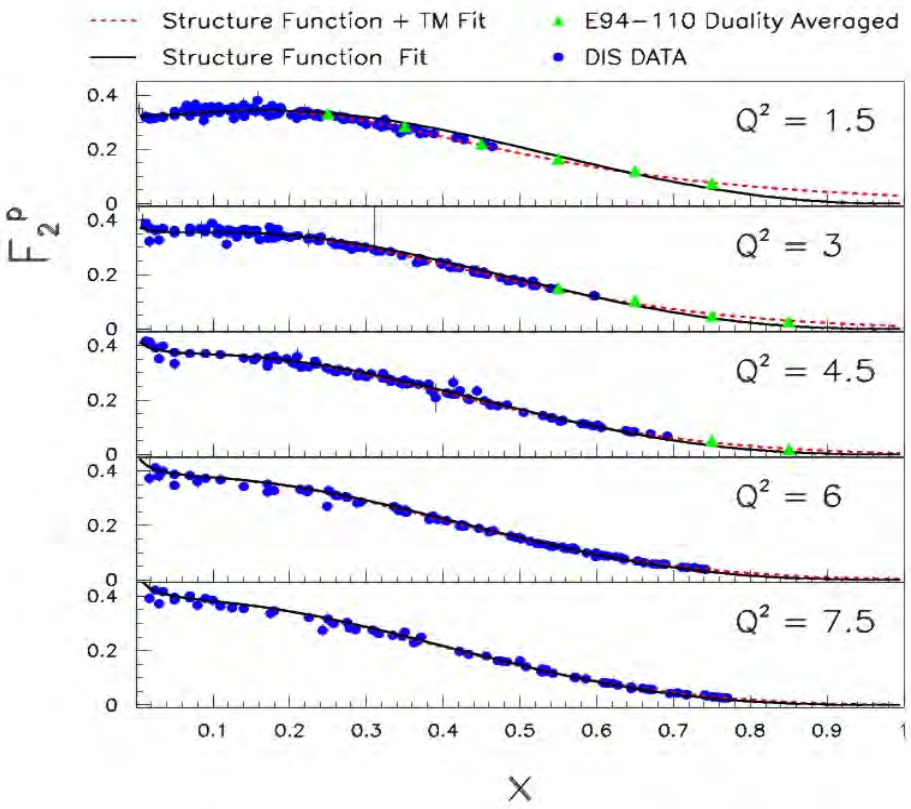
From Kretzer & Reno, the M=0 structure function given by $F_2^{M=0} = x^2 F_2^{bg}$

This is true too all orders in pQCD!

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

** use duality averaged data used to constrain large *x)*

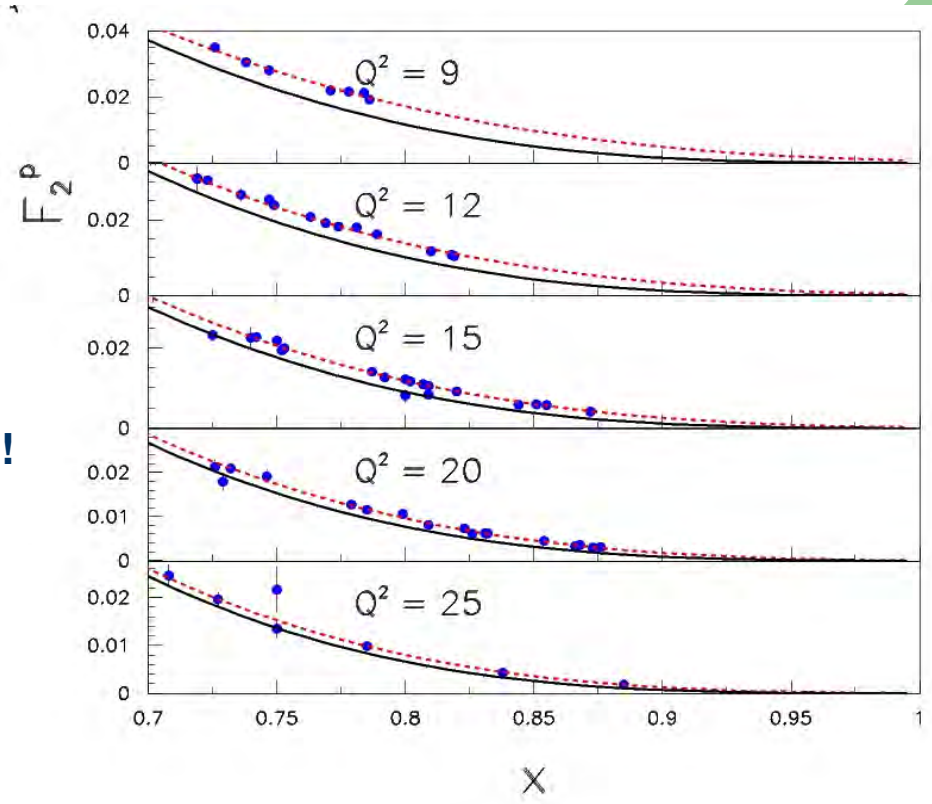
procedure similar to radiative unfolding



- Full data set fit covers

  $0.3 < Q^2 < 250$ GeV

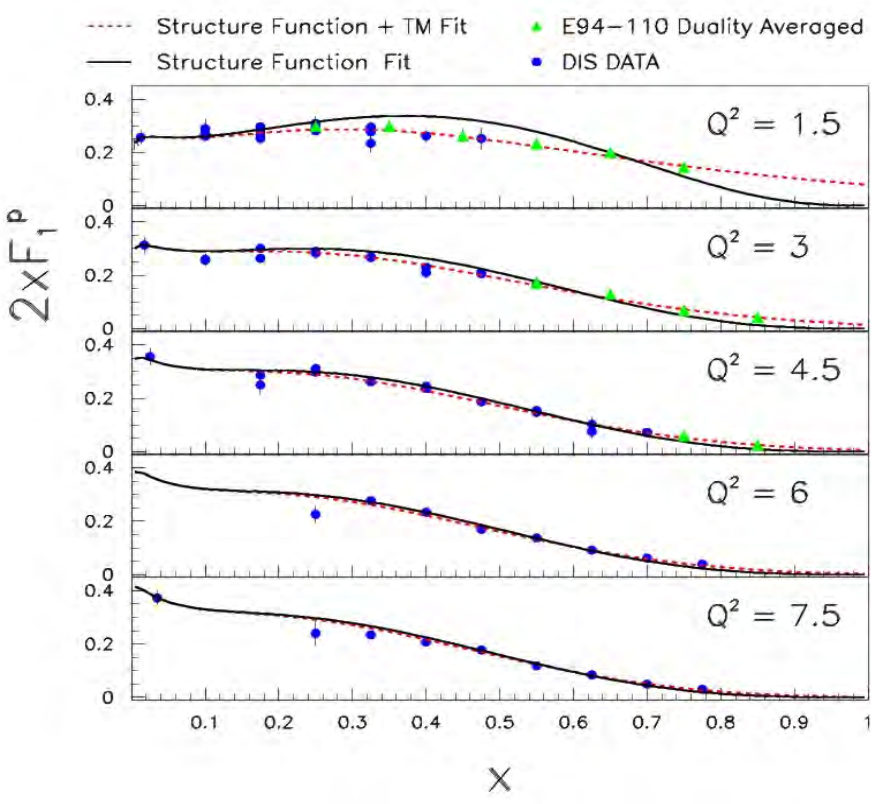
- $x^2/dof = 0.98$

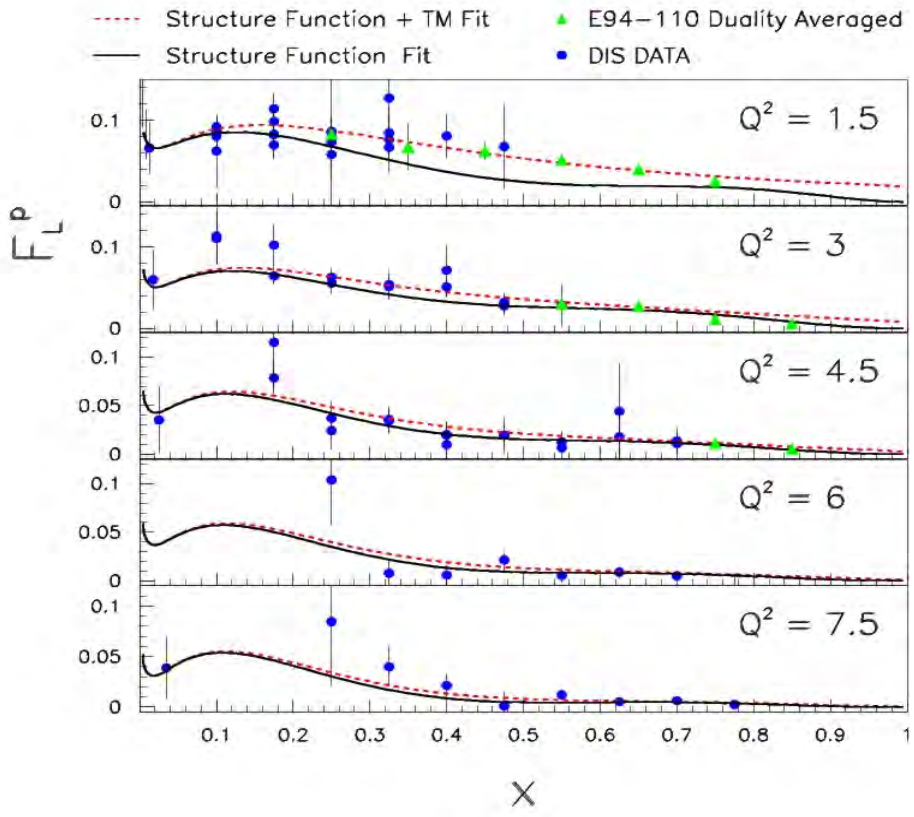


- Even at $Q^2 = 9$ TM is ~7% effect at x = 0.7!
- Fit results provide both $F_2^{M=0}$ and full F_2.

F_1 and F_L …

- For F_1 only L/T separated data are fit in order to limit correlations with the F_2 data set .
- Need L/T separated data for $x < 0.2$ for $Q^2 > 3$! (*Much more limited data set*)
- F_L is determined from F_2 & F_1 fits via $F_L = (1+4M^2x^2/Q^2)*F_2 - 2xF_1$.

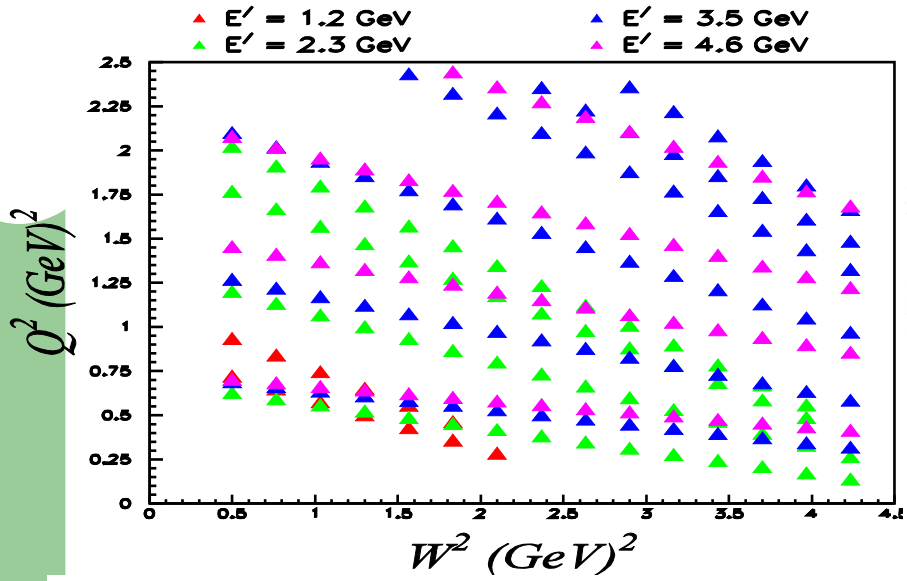




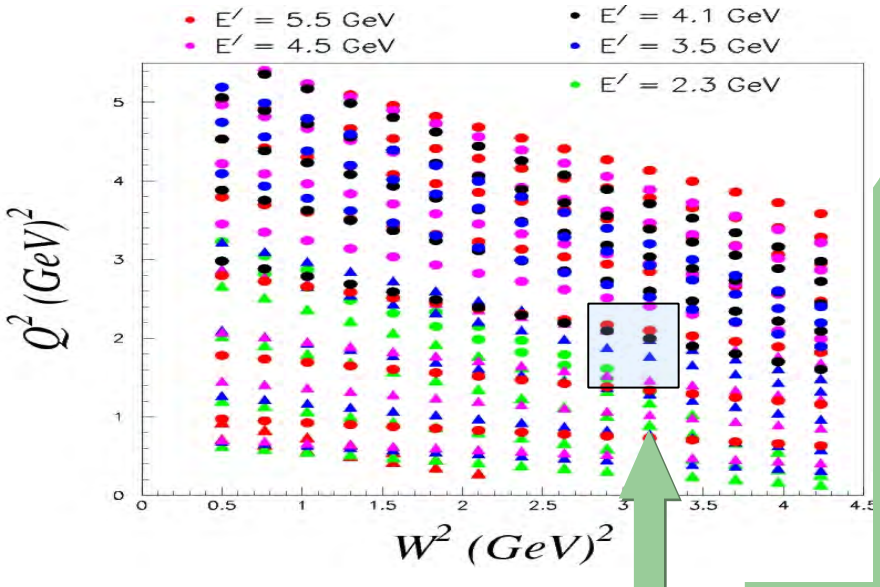
L/T separated structure functions on deuterium and nuclei (JLab E02-109, E04-001 and E06-009)

- **L/T Separation Data:** Targets: D, C, Al, Fe - Final uncertainties 1.6 % pt-pt in ε (2% normalization) - essentially, duplicate proton data set.

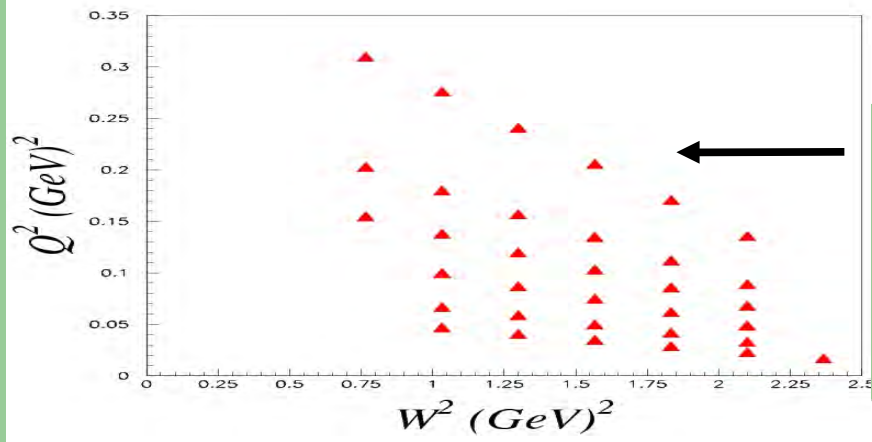
Data from Jan '05



Approved future running



L/T separations where multiple energies.

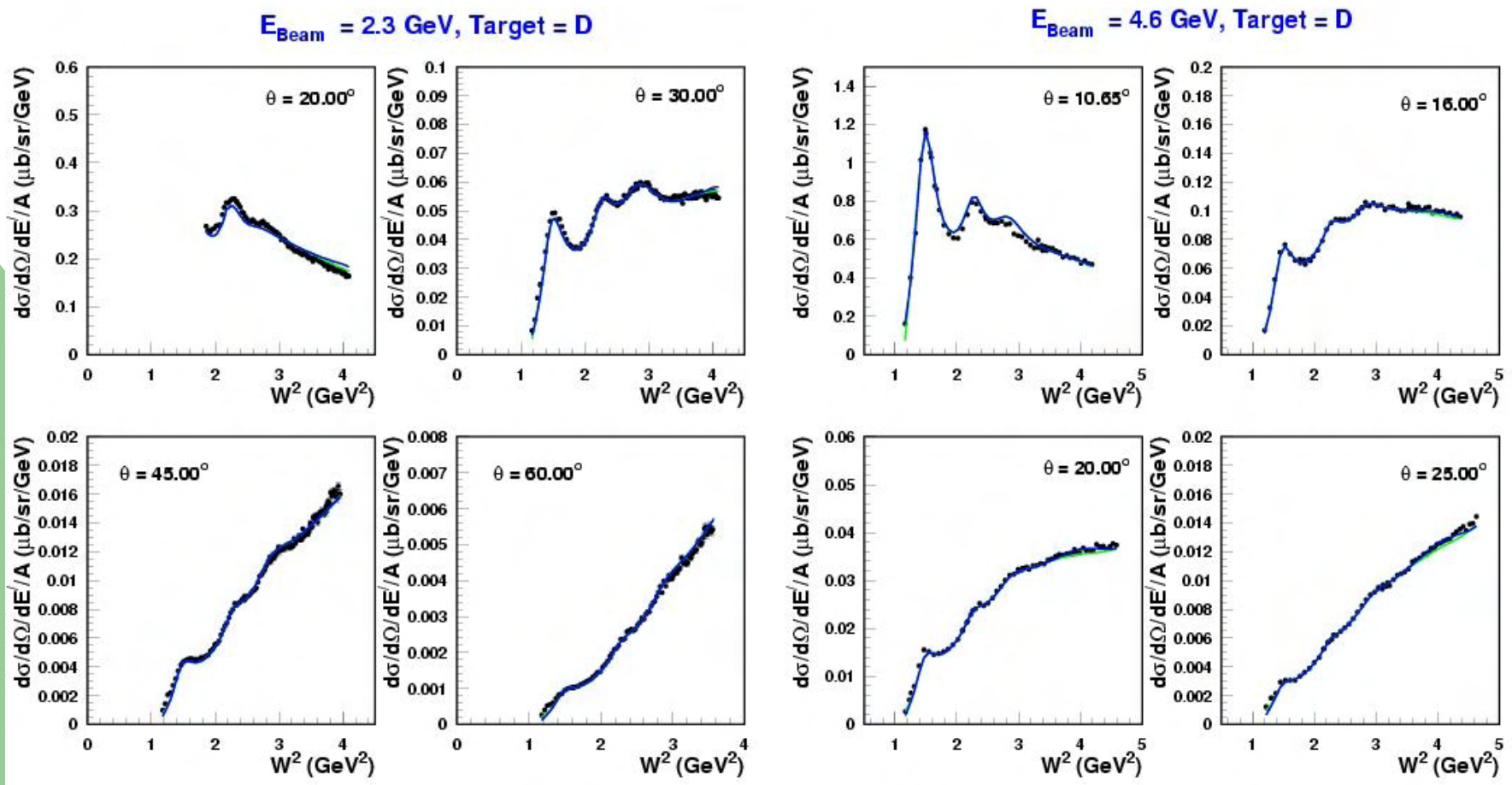


Low Q^2 modeling data (EM SF input for ν cross section modeling)

- Targets: H,D, C, Al

Uncertainties in preliminary data estimated at ~3 - 8% *(Much larger RCs and rates)*

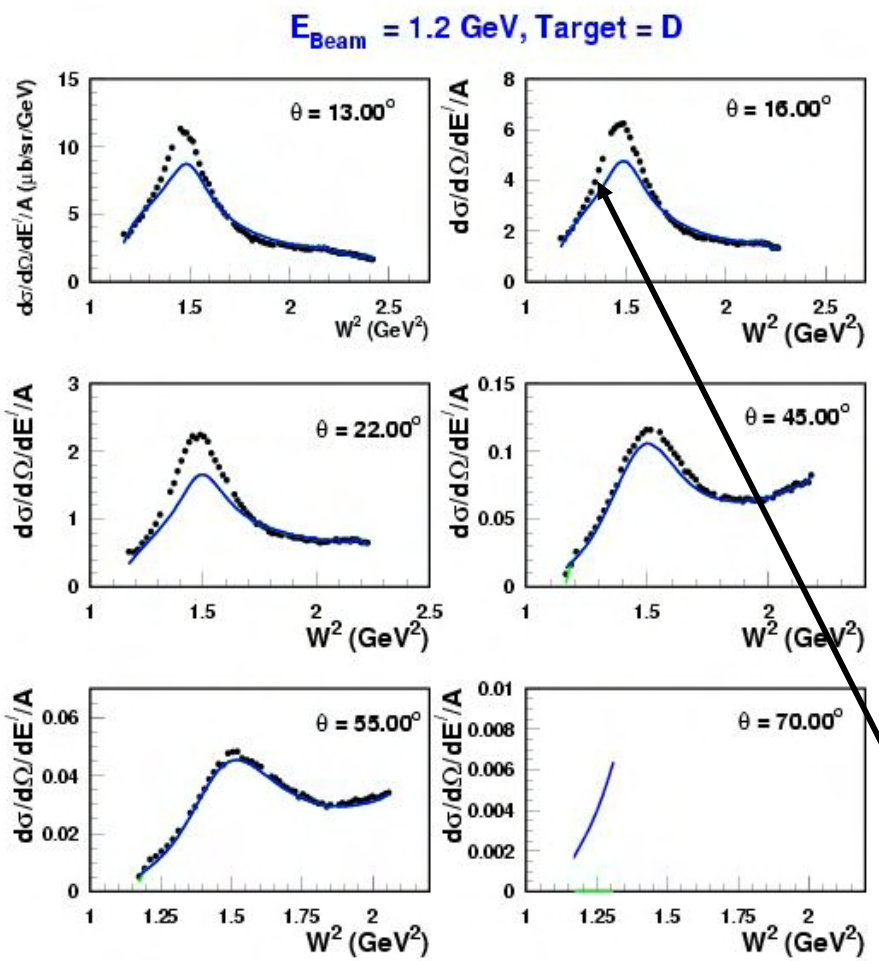
Jan'05 Preliminary Cross Section Results

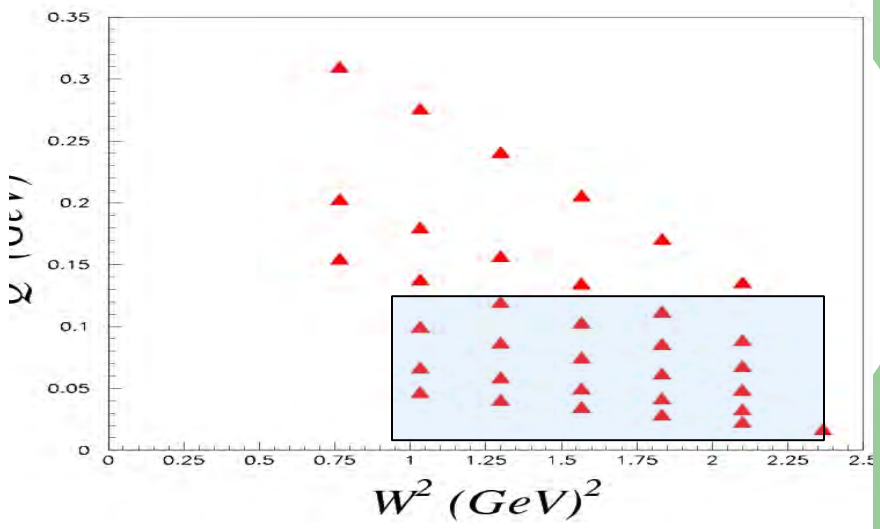


- Error bars are statistical only.
- Only inelastic data shown but Quasielastic & nuclear elastic was taken..

Deuterium: Fits to previous JLab & SLAC resonance region data.

Low Q^2 Cross Sections





- Low Q^2 data (< 0.15 GeV²) will provide ~3-6% cross sections.
- Need better models at low Q^2 --> *produce resonance fit of same quality as proton fit.*
- Quasi-elastic data still to be analyzed.

Moments and Duality in pQCD

- Moments of the Structure Function

$$M^{2,L}_{(n)}(Q^2) = \mathbf{S}_0^1 dx\, x^{n-2} F_{2,L}(x,Q^2) \text{ and } M^{1}_{(n)}(Q^2) = \mathbf{S}_0^1 dx\, x^{n-1} F_1(x,Q^2)$$

If n = 2, this is the Bloom-Gilman duality integral!

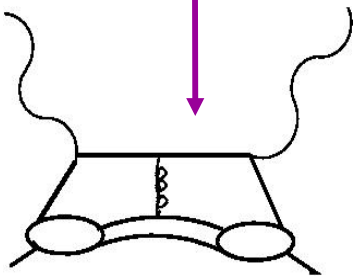
- Operator Product Expansion

$$M_n(Q^2) = \sum_{k=1}^{\infty} (nM_0^2/Q^2)^{k-1} B_{nk}(Q^2)$$

higher twist

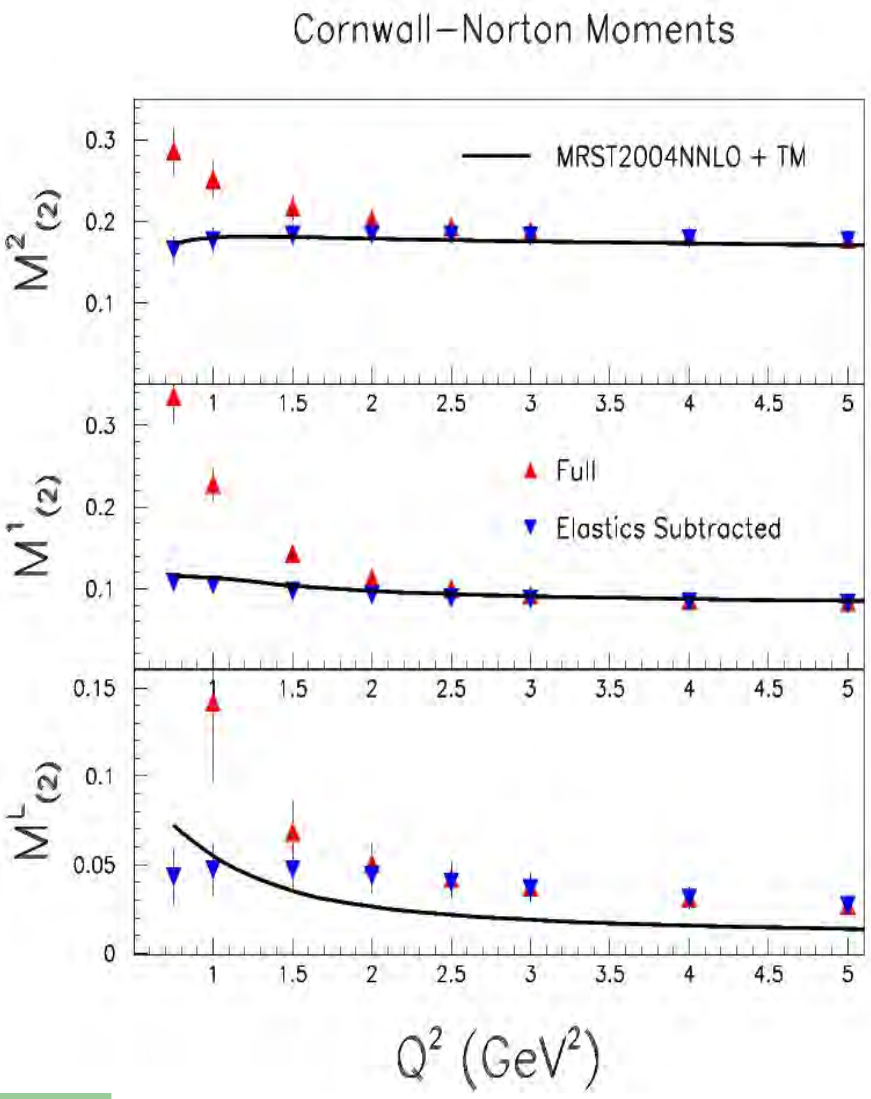
logarithmic dependence

(pQCD)



- Duality is described in the Operator Product Expansion *as higher twist effects being small or cancelling* **DeRujula, Georgi, Politzer (1977)**

Experimental lowest Moments of Proton L/T SFs

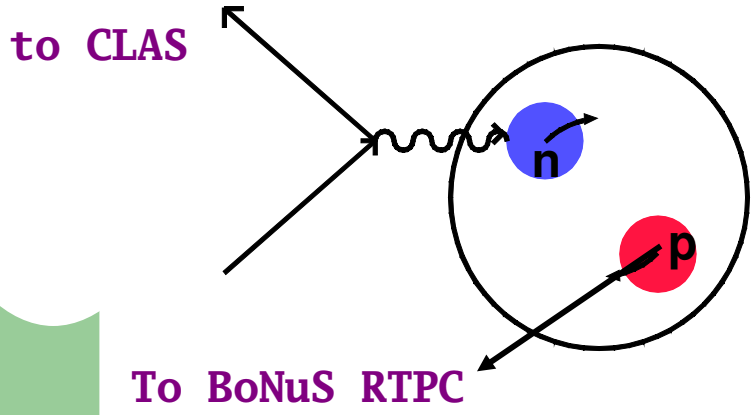


After subtracting known higher-twist component

– the elastic contribution

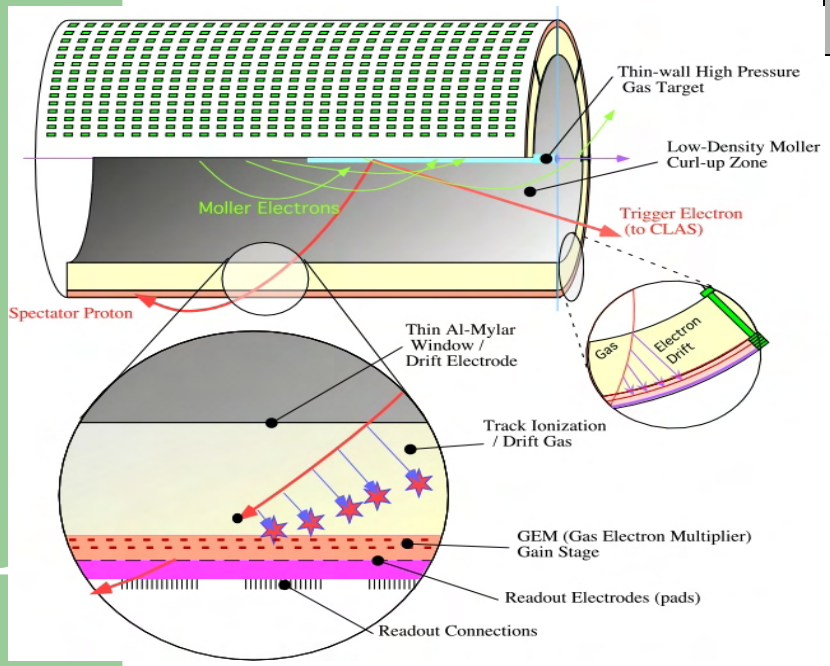
- pQCD using MRST PDFs describes data well down to remarkably low Q^2 for F_2, F_1!
  - => global duality observed to high degree!
- Shape for F_L moment is well reproduced down to Q^2 ~ 1.5 GeV^2, but overall strength predicted is too low!
  - => higher-twist or not enough strength in glue?
- p-n would provide access to non-singlet where lattice calculations are now becoming available!

BoNuS (Barely on-shell Neutron Structure): Neutron structure functions via spectator tagging



- Electron scattering from deuterium gas target
- Electron detected in Hall B CLAS spectrometer
- Recoil proton detected in radial TPC (utilizing GEMs)
- Tagging of slow, backward moving moving

recoil proton minimized sensitivity to **FSIs**



BoNuS combined with inclusive deuterium

=> pin down nuclear corrections

=> correct L/T separated deuterium structure functions to get out neutron L/T SFs!

Summary

- Proton L/T separated SFs measured in RR for $0.3 < Q^2 < 4.5$.
- Resonance region cross section fit to precision proton data constrained to photoproduction data at $Q^2 = 0$.
- SF fit performed to world DIS + RR duality data including *target mass* contributions.
- Preliminary low Q^2 data for L/T separations of SFs on deuterium - larger Q^2 to come.
- BoNuS + deuterium L/Ts => neutron L/T SFs and moments.