Measurements of the Separated Structure Functions F_1 and F_L

Cynthia Keppel

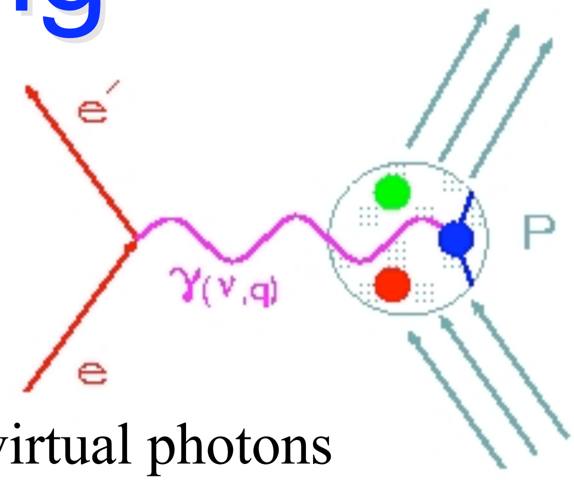
Hampton University / Jefferson Lab

Deep Inelastic Scattering 2005
Madison, WI

Inclusive e + p → e + X Scattering

Rosenbluth:

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



Where: Γ = flux of transversely polarized virtual photons
ε = relative longitudinal polarization

Alternatively:

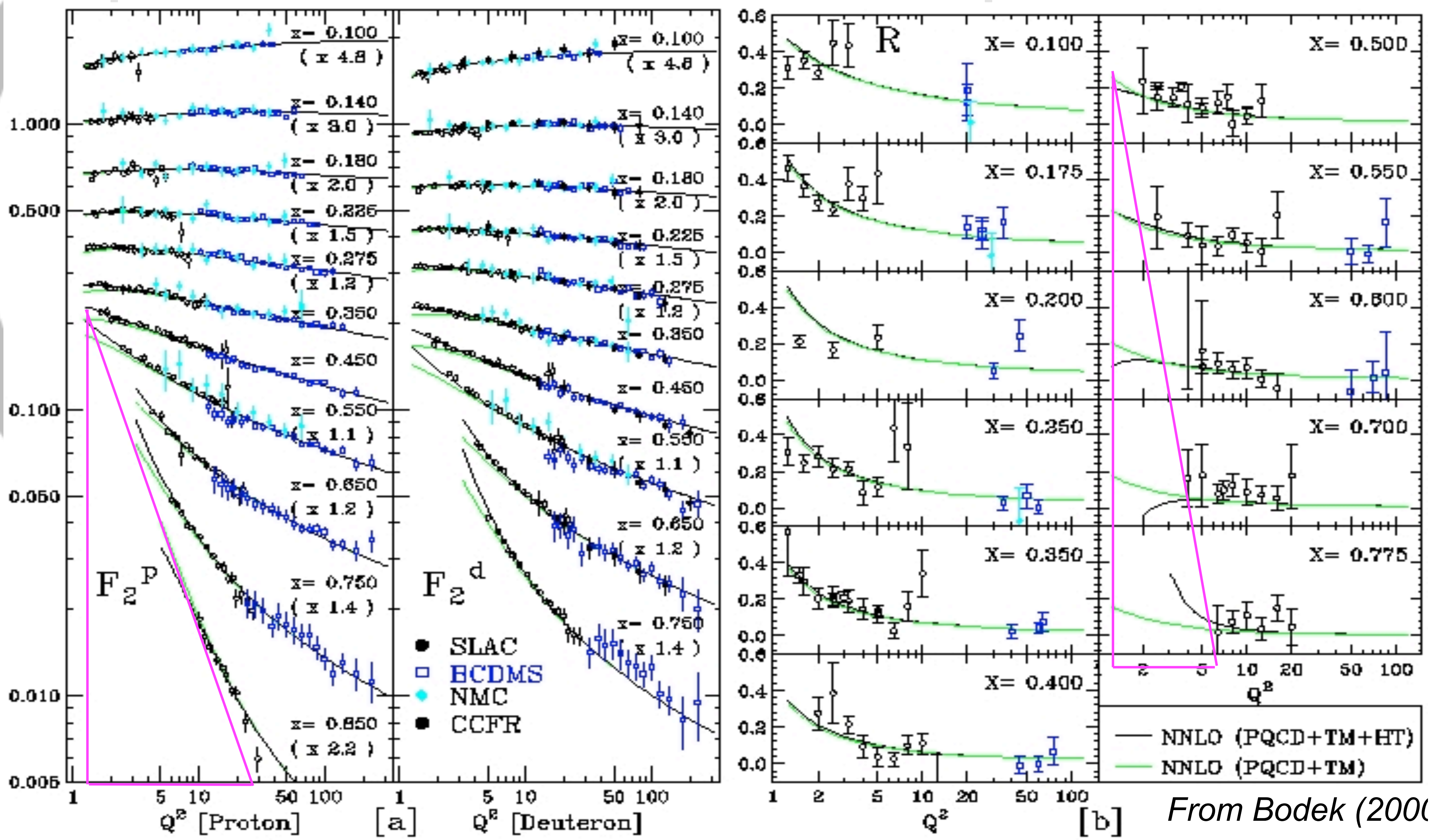
$$\frac{d\sigma}{d\Omega dE'} = \sigma_{mott}(F_2/\nu + 2F_1\tan^2(\theta/2)/M)$$

$$R = \frac{\sigma_L}{\sigma_T} = \frac{F_L}{2xF_1}$$

$$F_L = (1 + \frac{4M^2x^2}{Q^2})F_2 - 2xF_1$$

longitudinal — TRANSVERS — mIxEd

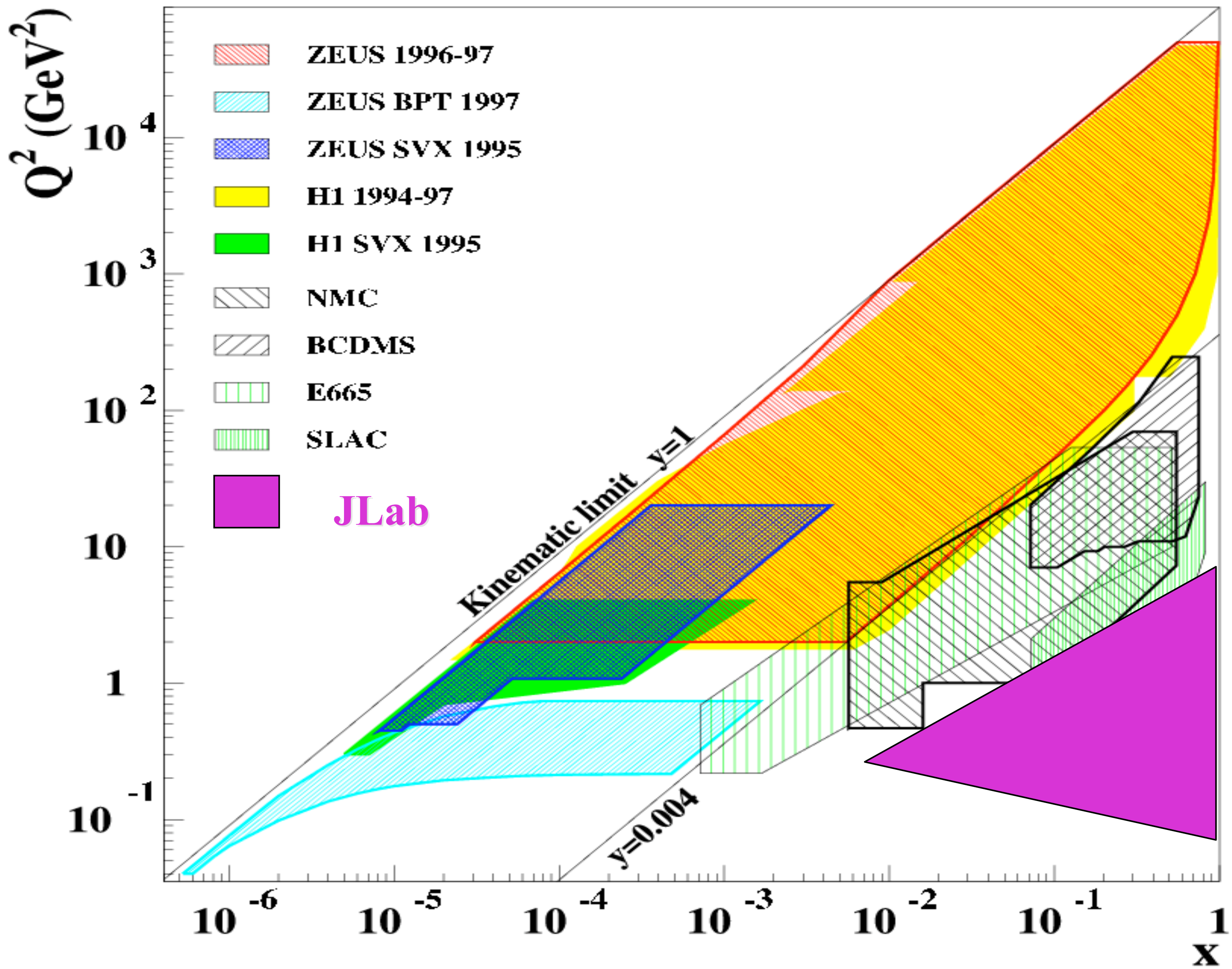
Experimental Status of Unpolarized SF



From Bodek (200

- F_2 well measured - responsible for much understanding of proton struct
- Nonetheless, large *x*, low Q^2 region is sparse
- R (F_L), is not at all so well measured (especially large *x*, low Q^2)
- Situation is worse for nuclei

This is the Jefferson Lab Regime



Here, L/T Separations are Crucial….

1) F_2 is sometimes referred to as the "*transverse*" SF.

   - *In fact* $F_2 \sim \sigma_L + \sigma_T$

2) F_2 can't be obtained precisely independent of R and L/T separations

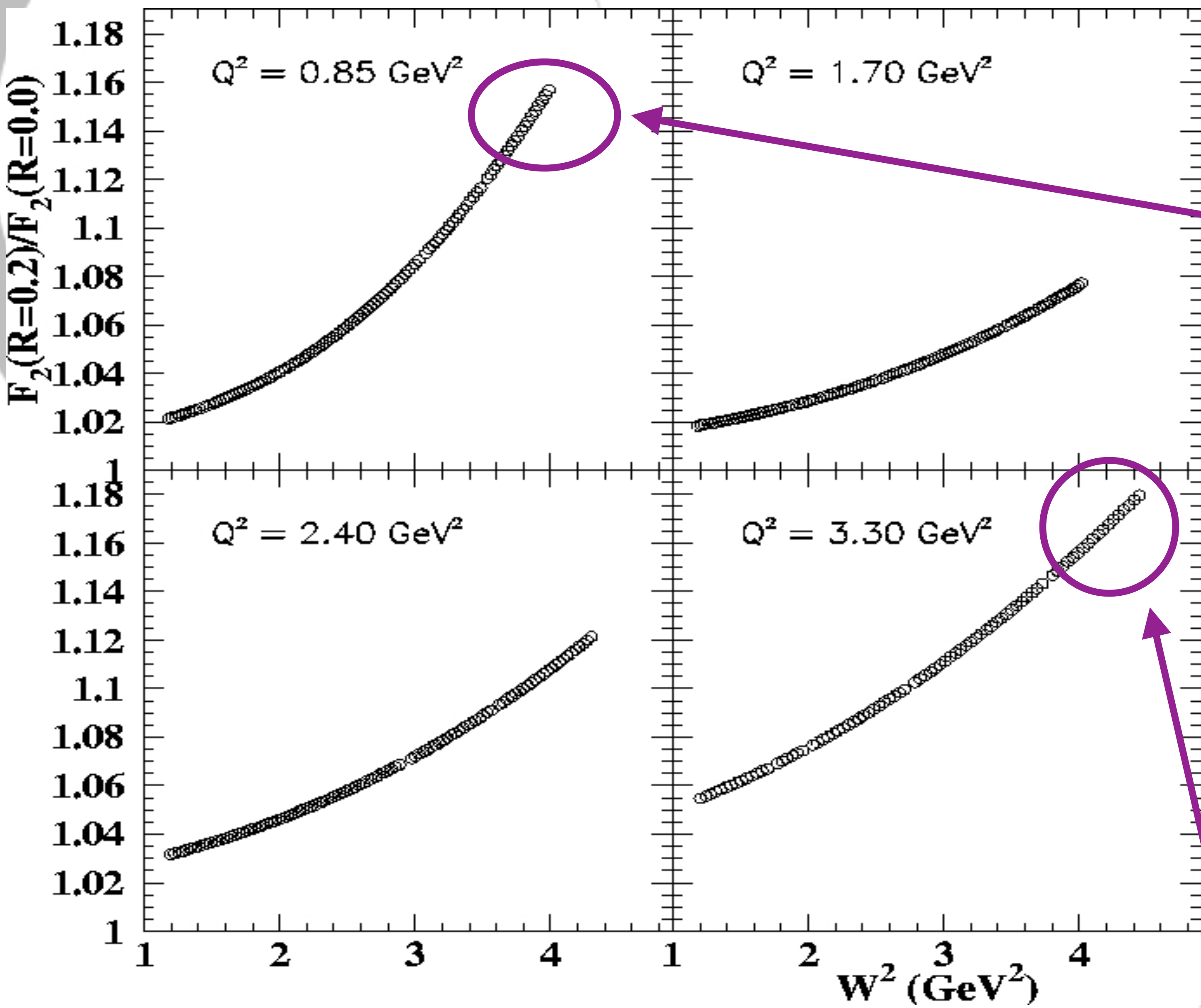
   - *Except at* $\varepsilon = 1$ or Q^2 large, *F_2 extracted from cross sections requires knowledge of R.*

3) Behaviour of F_2 at low Q^2 is not actually well determined ($F_2 \rightarrow 0$ at $Q^2 \rightarrow 0$).

4) R must be small for $Q^2 < 1$ (R = 0 at the photon point, $Q^2 = 0$).

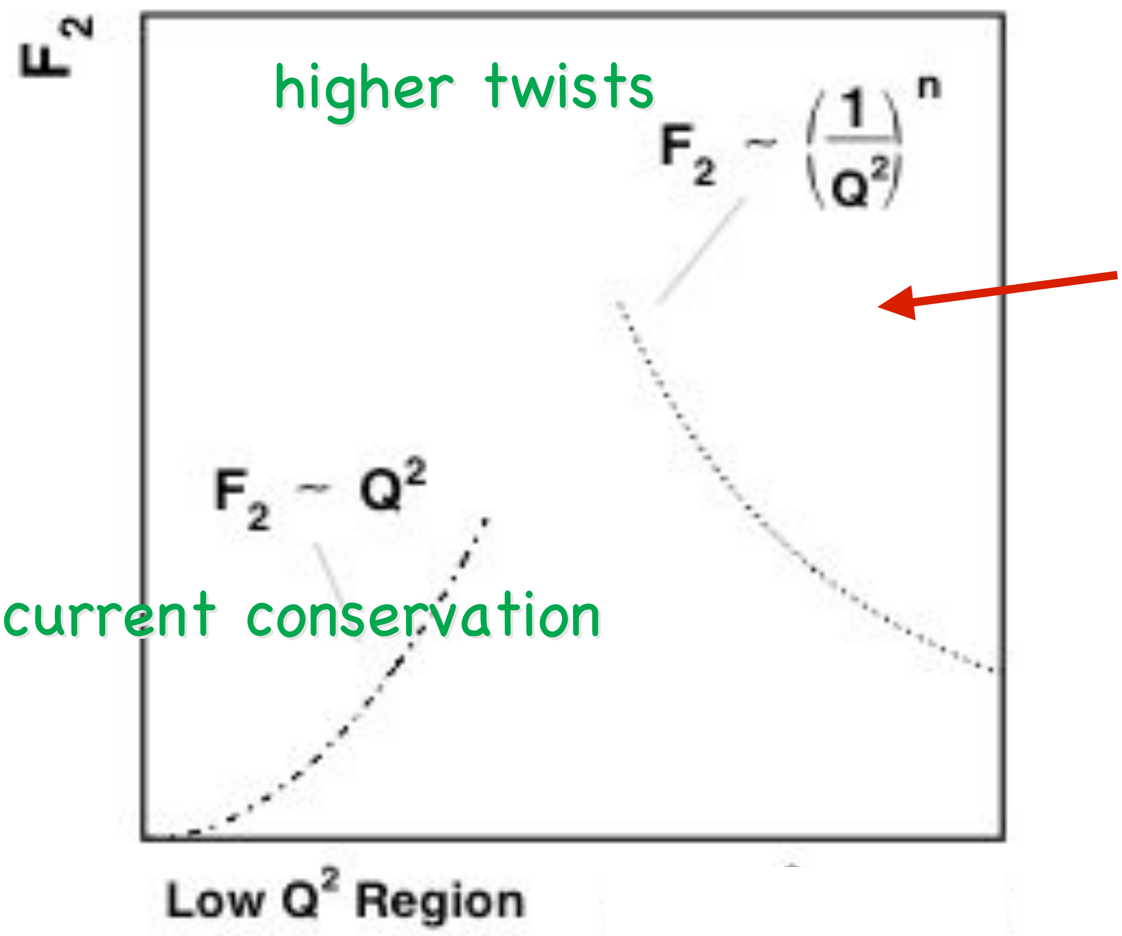
This has not yet been observed in the data - in fact, quite the opposite

Just an example….



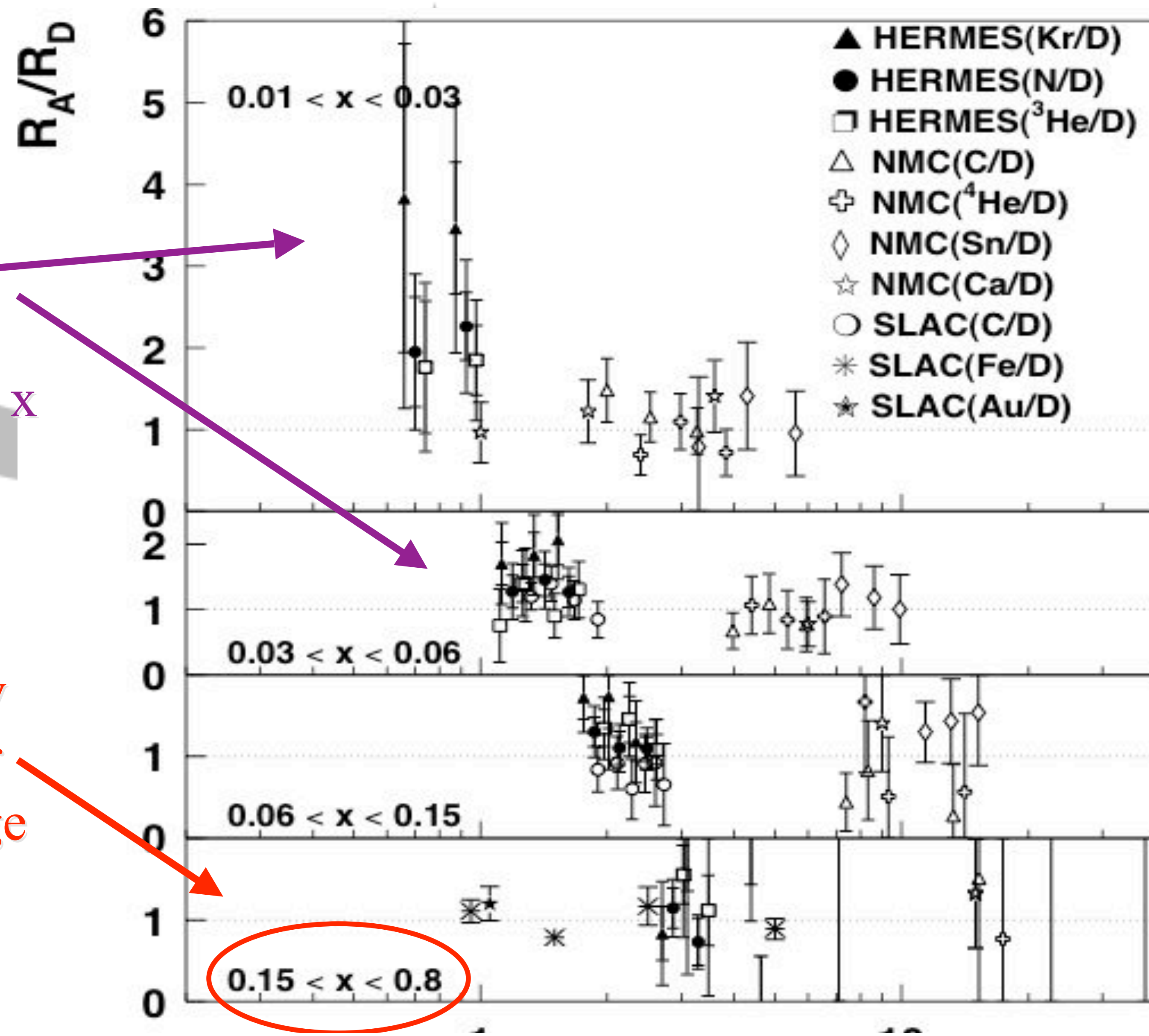
At W^2 = 4 GeV^2 and Q2 < 1 GeV^2, F_2 will vary b 15% depending on the choice of R = 0 or R = 0.2. At higher Q2, this can be as much as

Challenges / Issues / Physics at Low Q^2, Large x



- NEED L/T separations to extract inclusive Structure Functions F_1 F_L, *and* F_2
- Low Q^2 Behavior
- Large x Parton Distribution Function Uncertainties
- Structure Function Moments (Compare to Lattice QCD), Sum Rules
- Enter the Resonance Region
- Parton-Hadron Duality

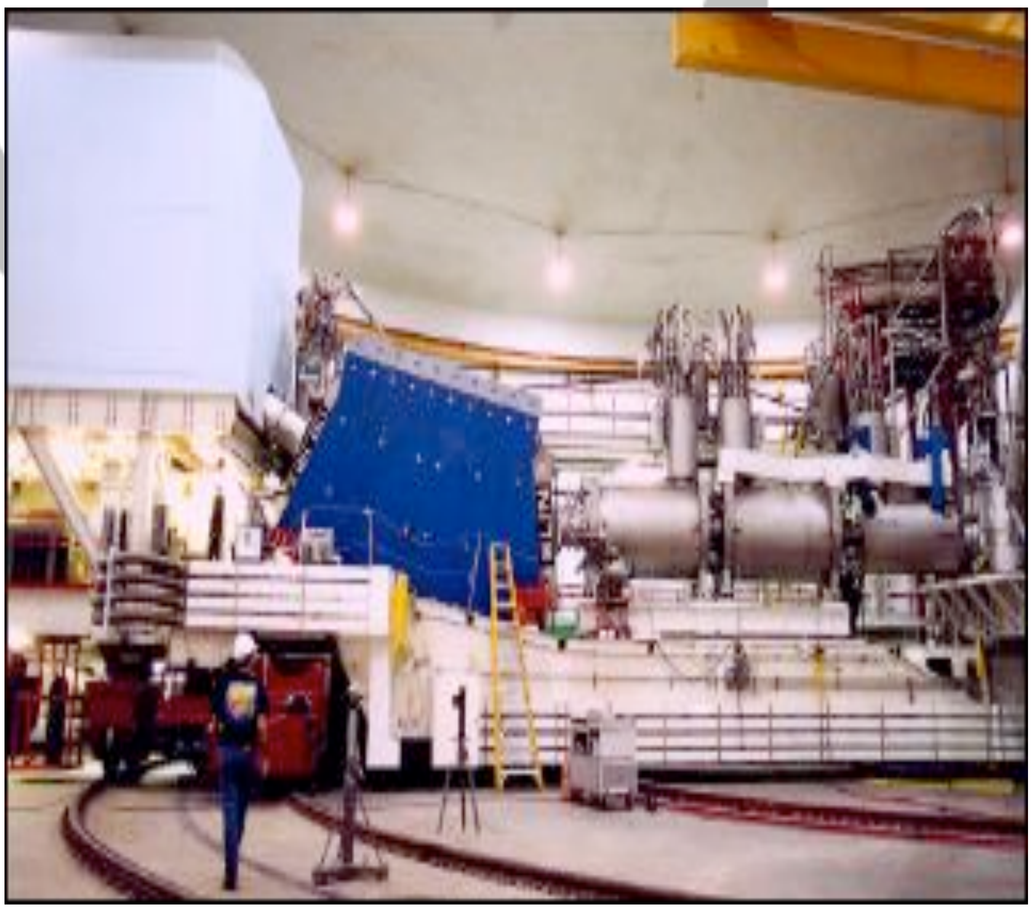
Nuclear Dependence
Is there an EMC effect in R?



maybe some rise at low Q^2, x

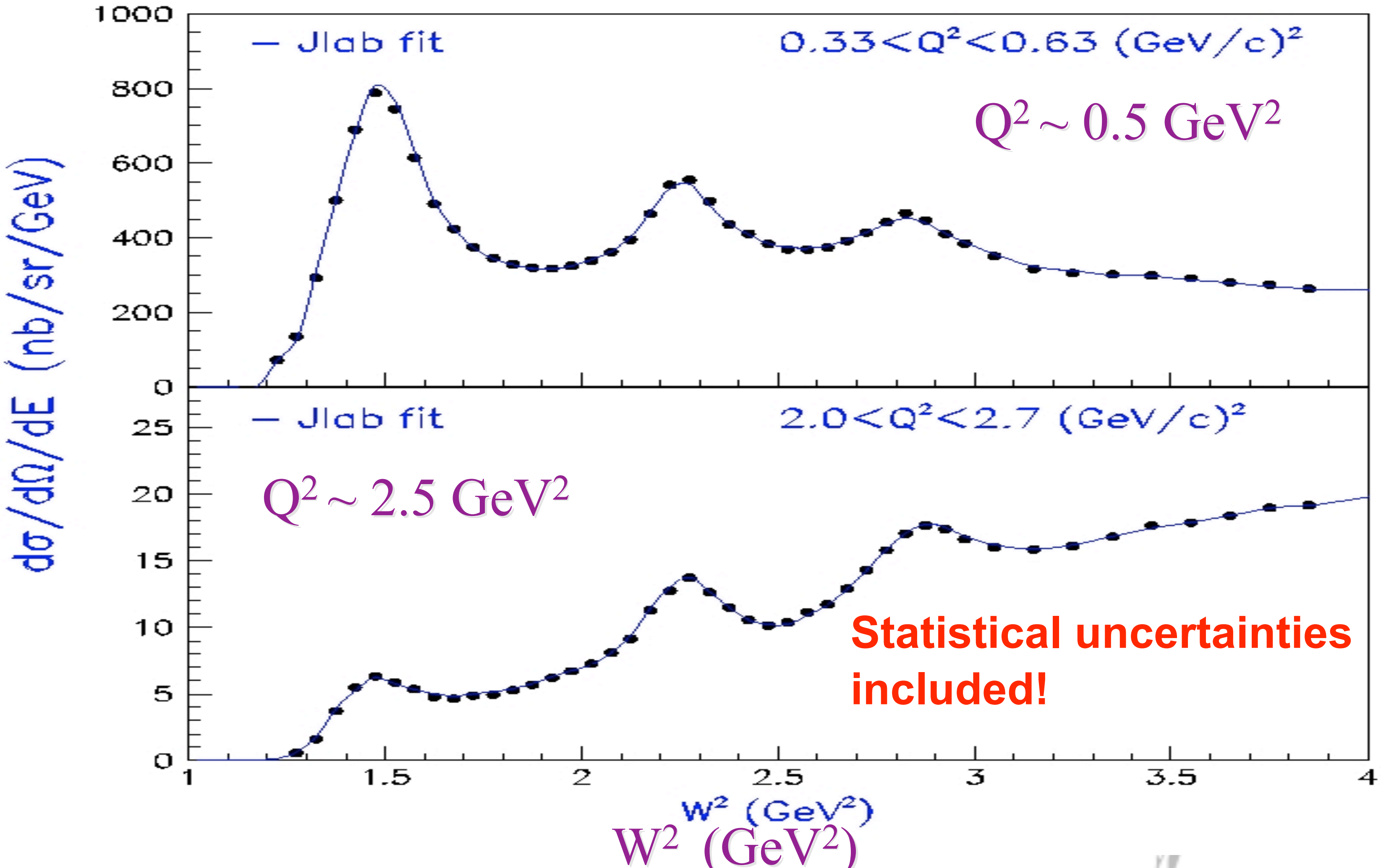
data extremely sparse for *wide* range in x!

A Program of L/T Separated Structure Functio Measurements in Hall C at Jefferson Lab



- E94-110: Hydrogen Resonance Region
- E99-118: Low x, Q^2 Dependence
- E00-002: Low Q^2 Deep Inelastic H, D
- E04-001: Nuclear Dependence, Neutr Modeling
- E02-109: Deuterium Resonance Region, Neutron Structure Function Moments

E94-110: (Example) Cross Sections



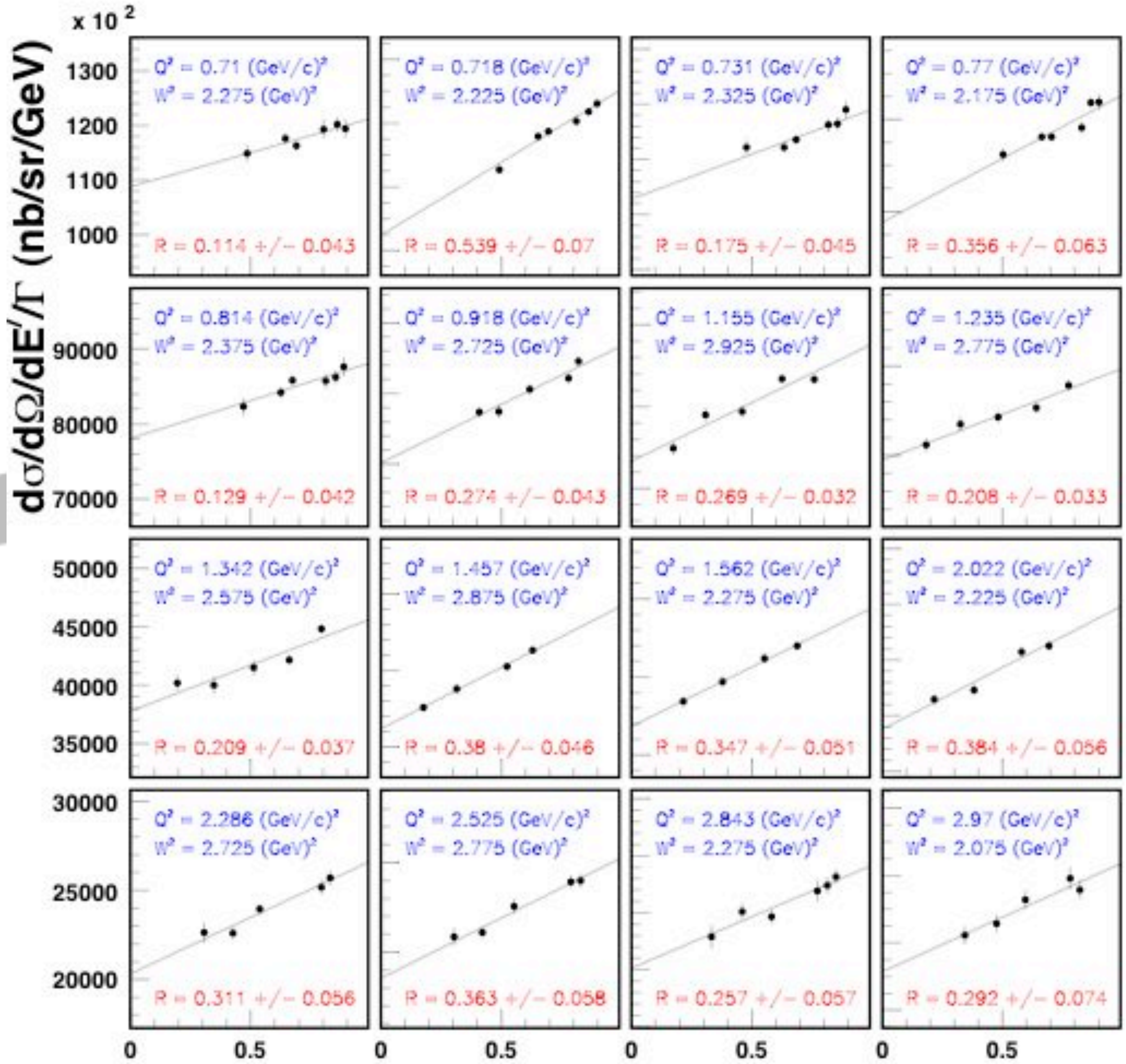
- Hydrogen resonance region cross sections
- Full spectrum obtained in less than 1/2 shift

Rosenbluth Separations (170 +!)

Need:

range in ε

small point-to-point systematic uncertainty!



Point-to-Point Systematic Uncertainties for E94-110

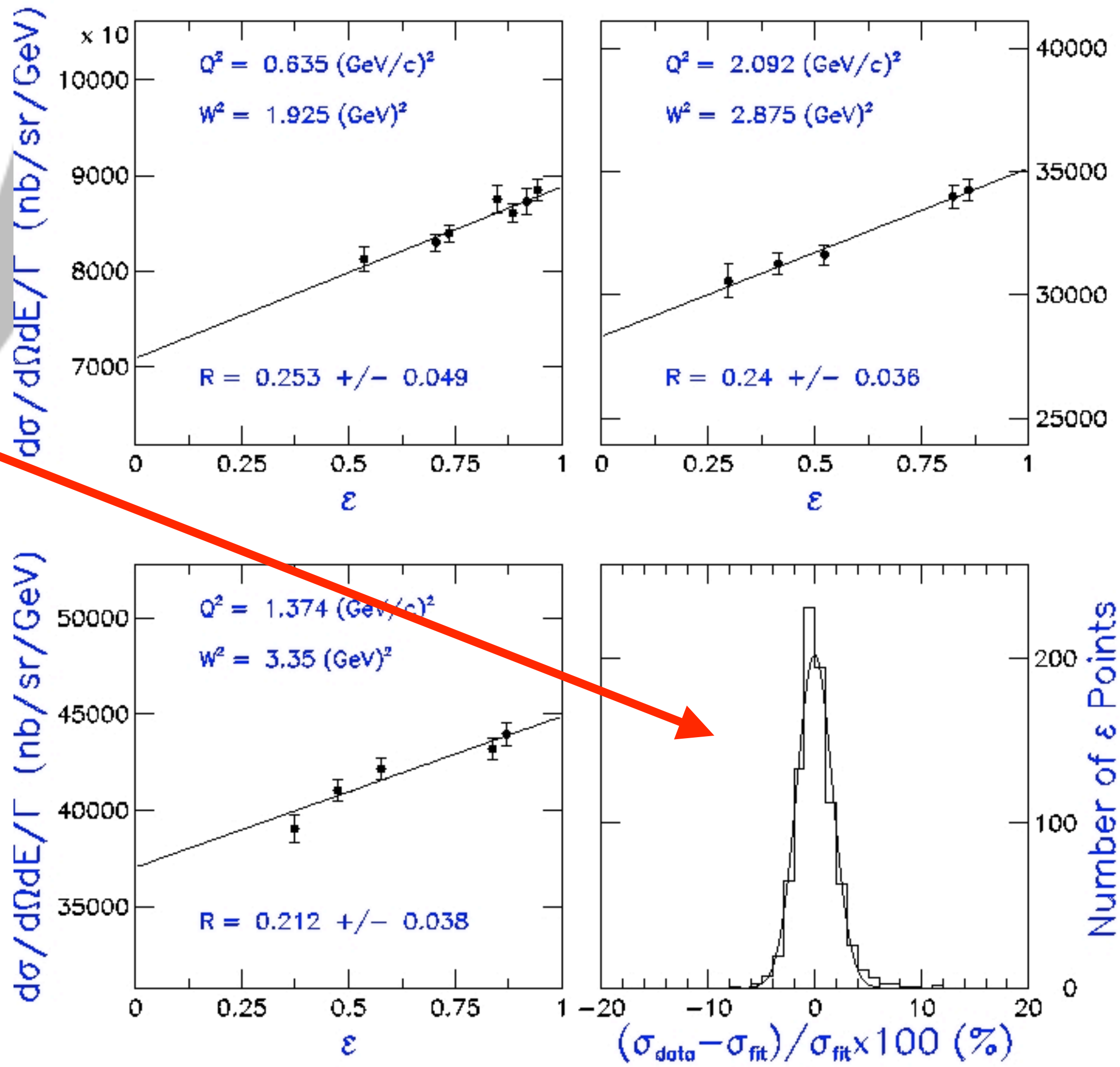
Quantity	Uncertainty	$\delta_\sigma(\%)$
Beam energy	$\sim 5 \times 10^{-4}$	0.30
Scattered e^- energy	$\sim 5 \times 10^{-4}$	0.25
Scattering e^- angle	~ 0.2 mrad	0.26
Target density (relative)	0.05%	0.05
Beam charge (relative)	0.1%	0.1
Dead Time Correction	0.2%	0.2
Detector Efficiency	0.55%	0.55
$e+/e-$ background	0.2%	0.2
Acceptance	0.7%	0.7
Model Dependence	0.6%	0.6
Radiative Correction (ε)	1.05%	1.05
Total point-to-point		1.6

Total estimated point-to-point systematic uncertainty for E94-110 is 1.6%.

Systematic Uncertainties

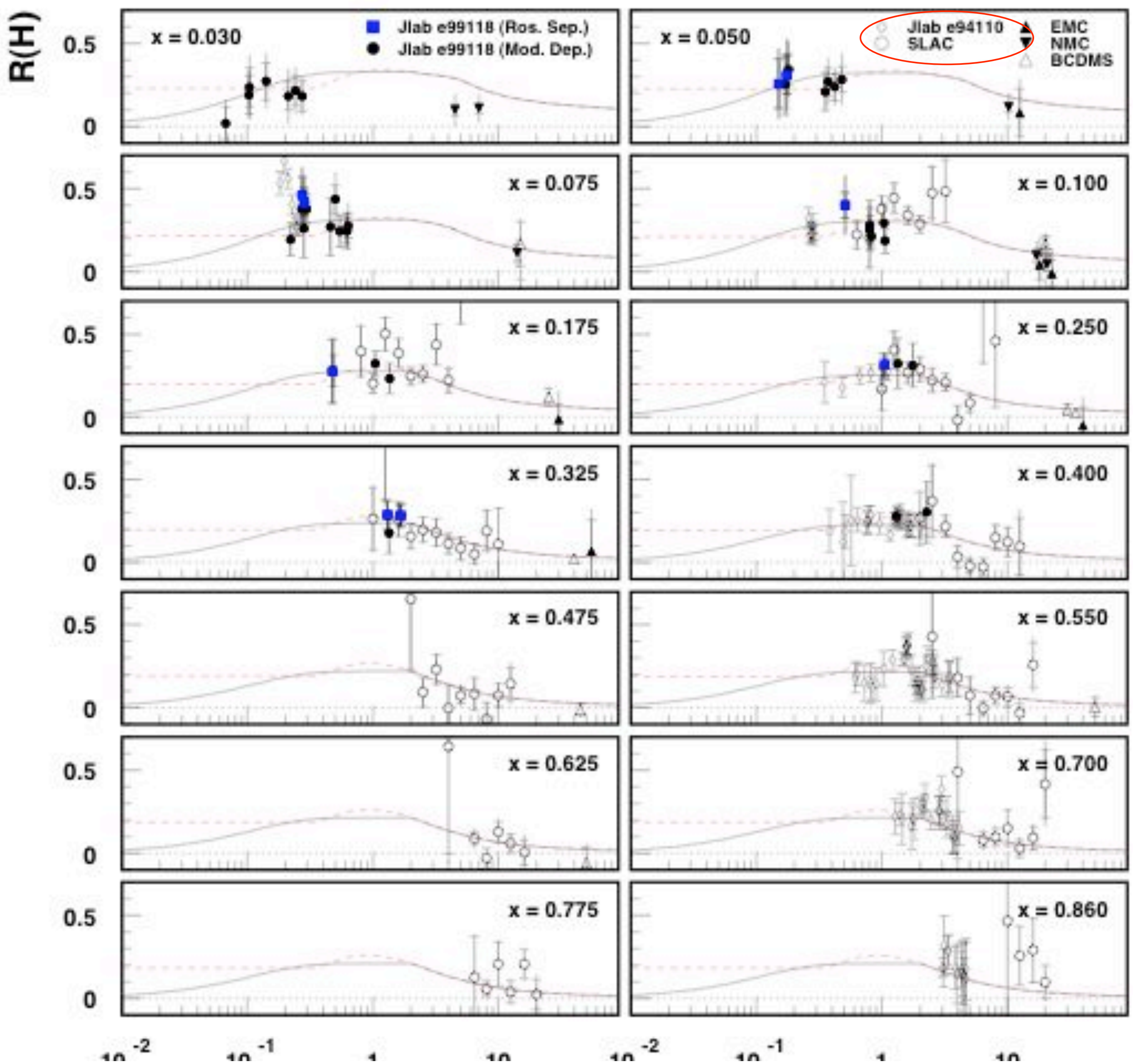
- Spread of points about the linear fits is fairly Gaussian with σ ~ 1.6 %

This is very consistent with the estimated pt-pt uncertainties.



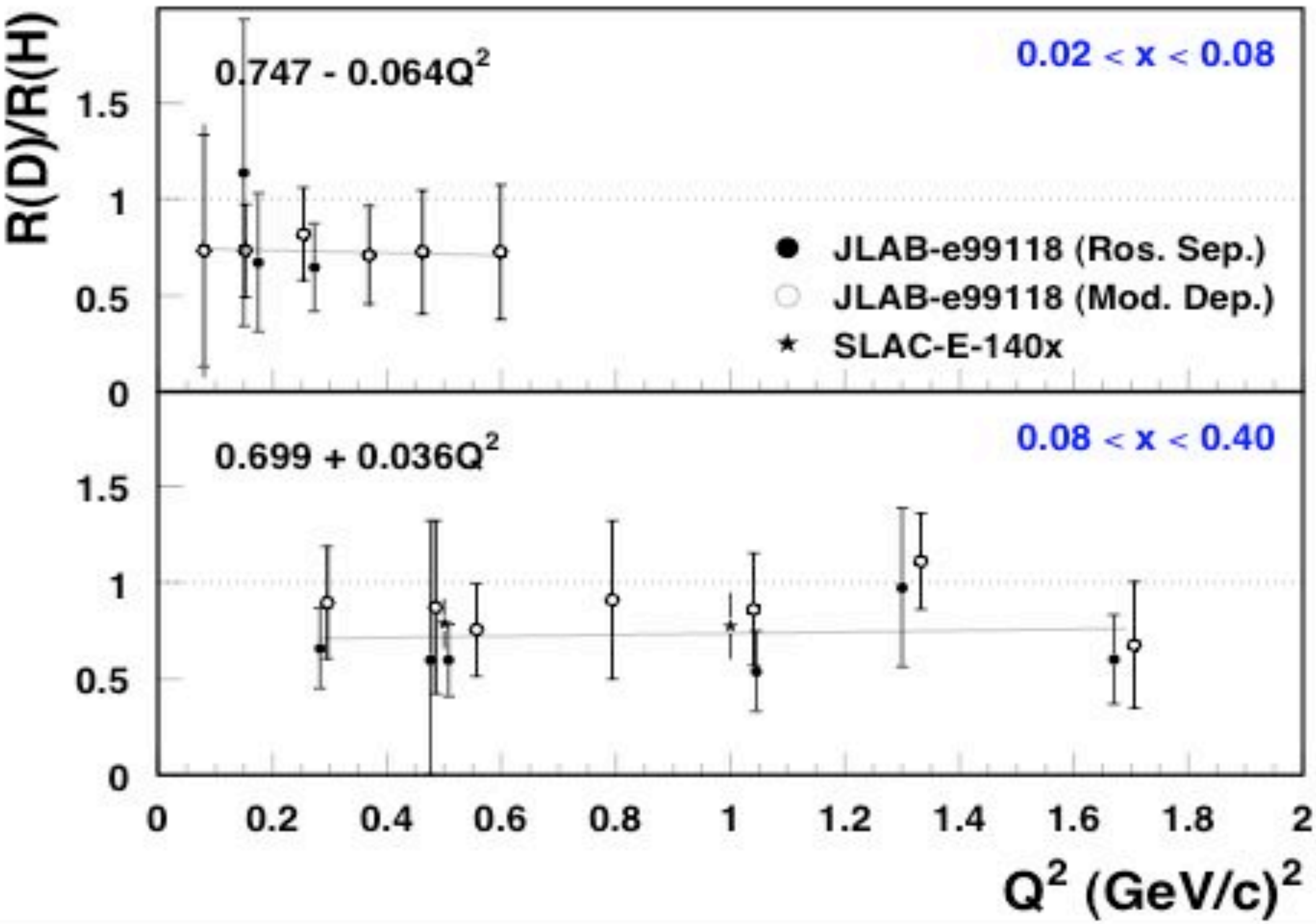
...and indicative of minimal two photon exchange corrections

R on the proton today…getting better



Note: R still not small at low Q2 expected

Ratio R_H / R_D



Very limit
previous
data

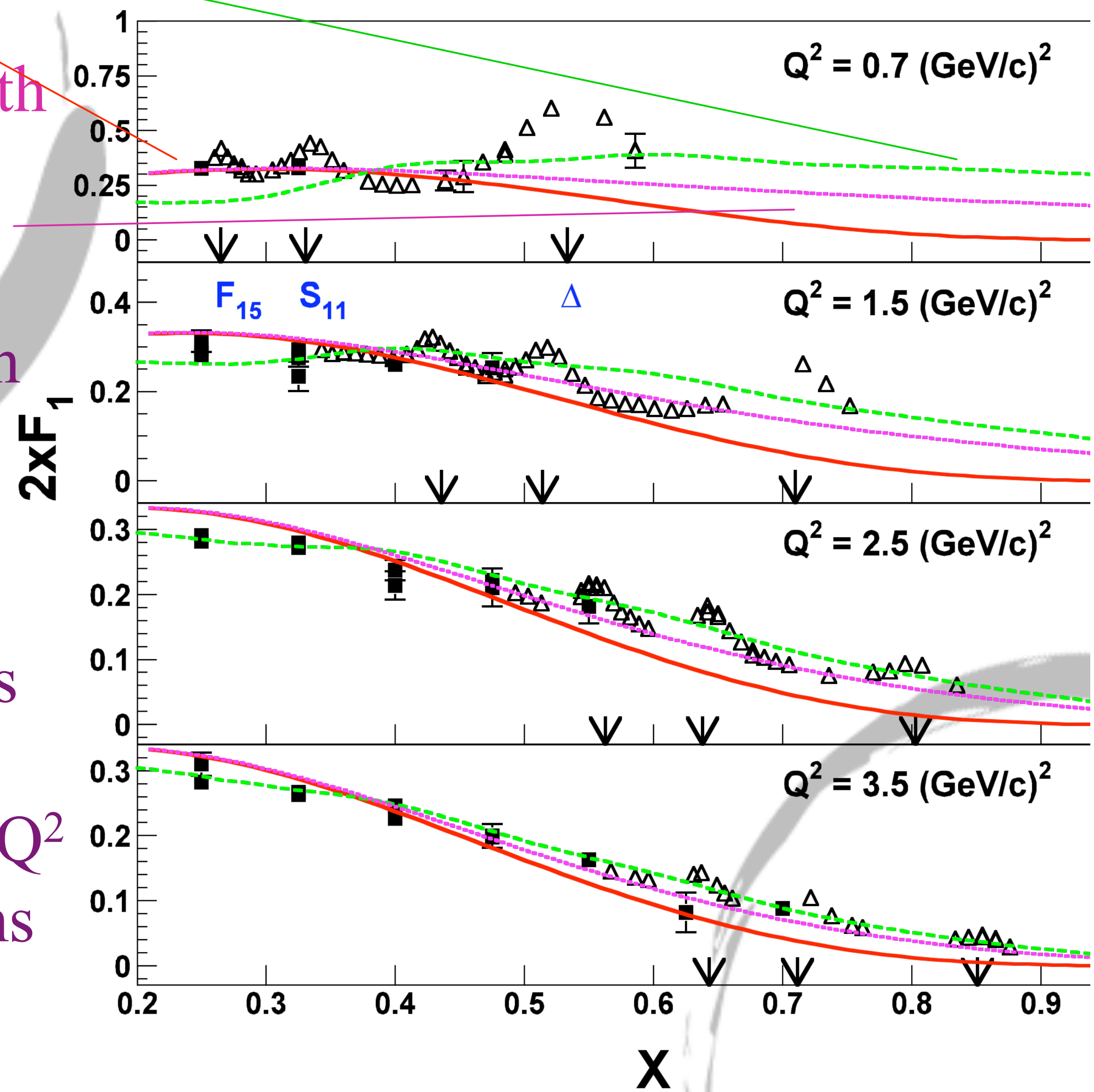
$R_D \sim 0.7$ l
(within
large
uncertaint

Experimental Status of L/T Separated Structure Functions: $2xF_1$

Alekhin NNLO

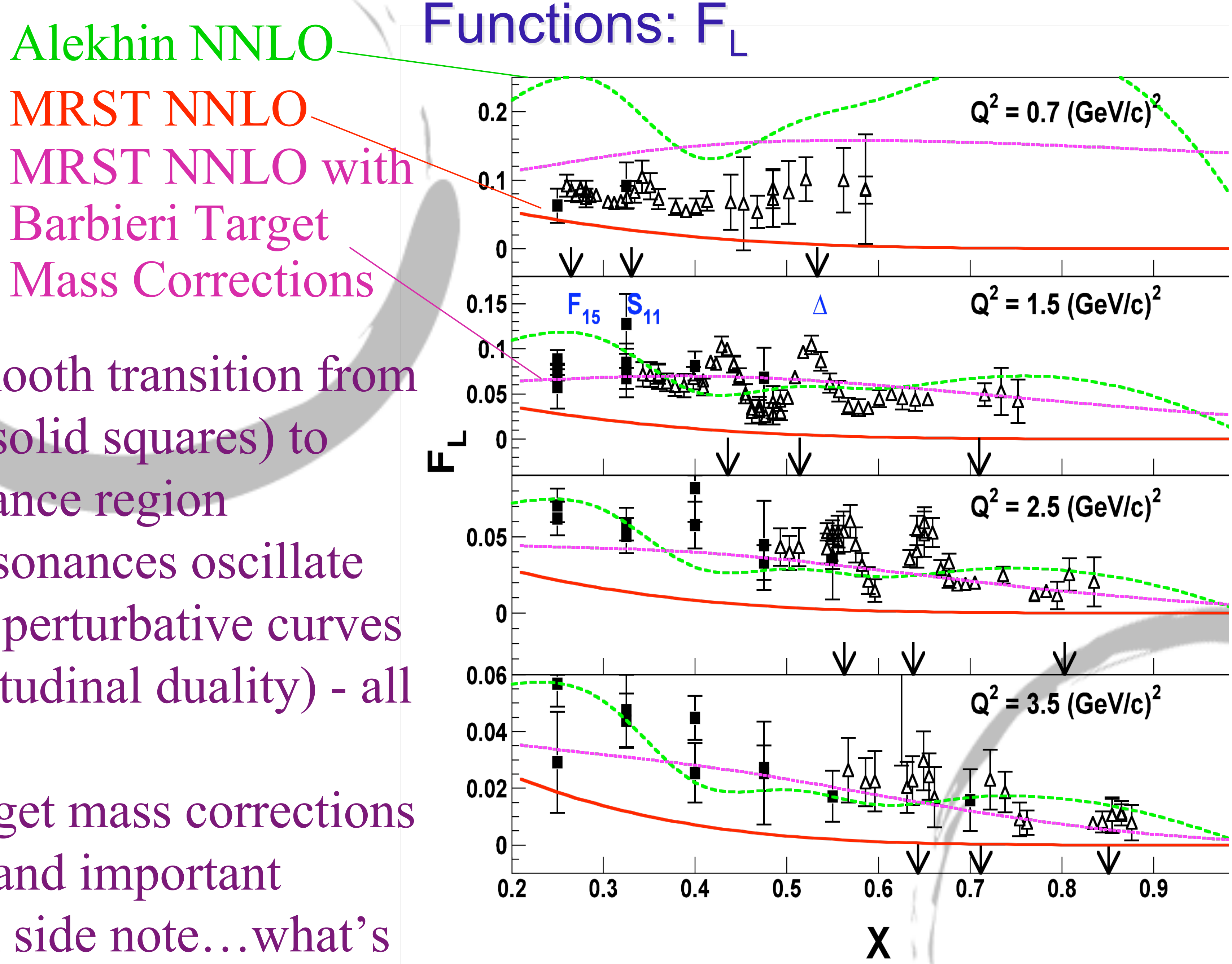
MRST NNLO

MRST NNLO with Barbieri Target Mass Corrections



- Smooth transition from DIS (solid squares) to resonance region
- Resonances oscillate about perturbative curves (quark-hadron duality in transverse channel) - all Q^2
- Target mass corrections large and important

Experimental Status of L/T Separated Structure Functions: F_L



- Smooth transition from DIS (solid squares) to resonance region
- Resonances oscillate about perturbative curves (longitudinal duality) - all Q^2
- Target mass corrections large and important
- Fun side note…what's

The new data buys us, in particular:

- Ability to extract structure function moments
  - Evaluate higher twist
  - Compare to lattice QCD
  - F_L yields G(x)
- Unique access to large x
  - Large pdf uncertainties
  - Duality a big help

- Moments of the Structure Function

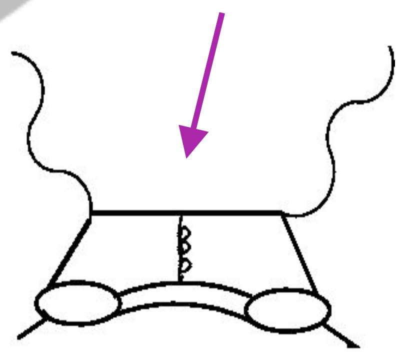
$$M_n(Q^2) = \int_0^1 dx\, x^{n-2} F(x,Q^2)$$

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

- Operator Product Expansion

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

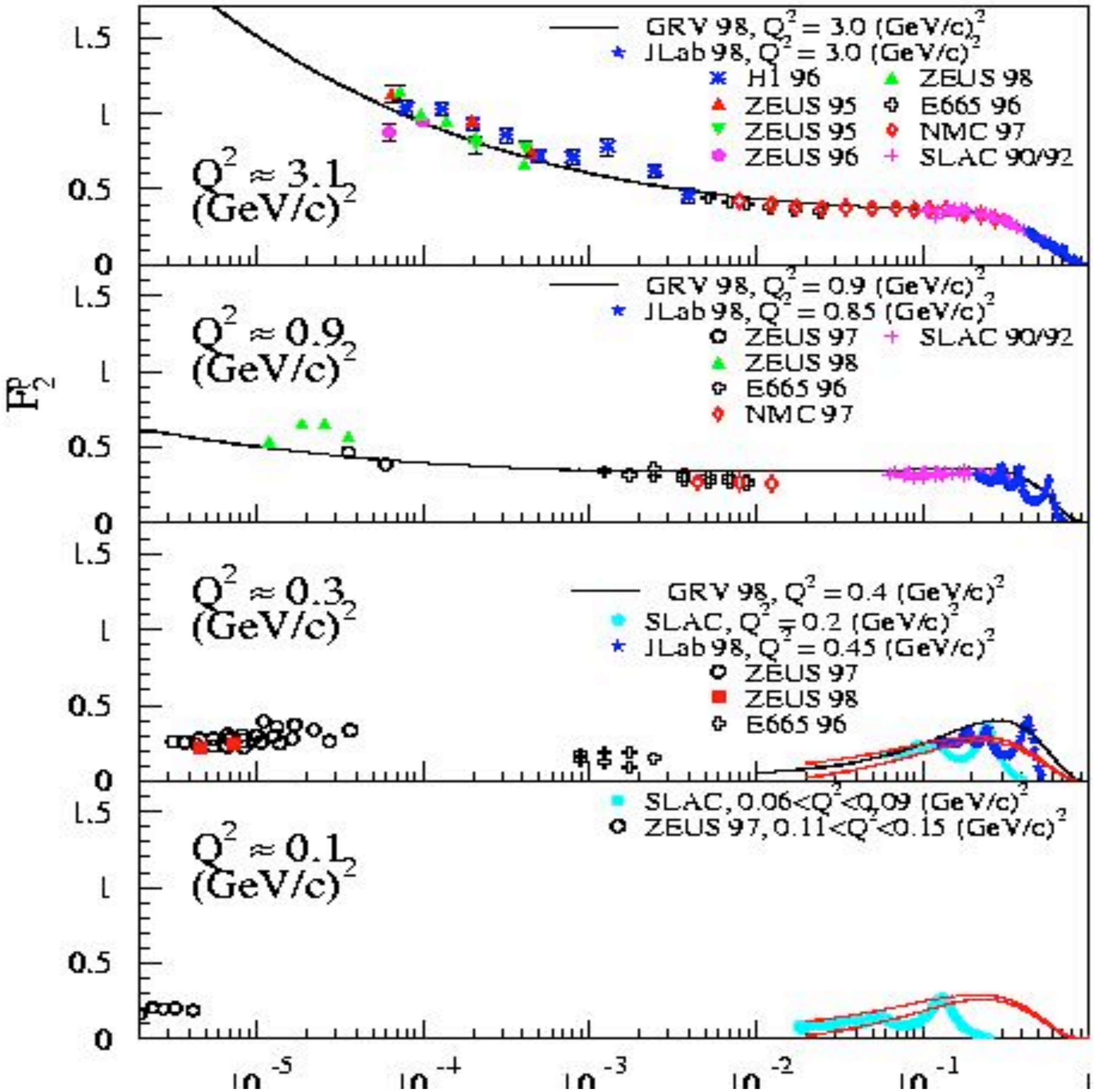
higher twist logarithmic (pQCD)



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

$$M^n(Q^2) = \int_0^1 dx\, x^{n-2} F(x,Q^2)$$

F_2

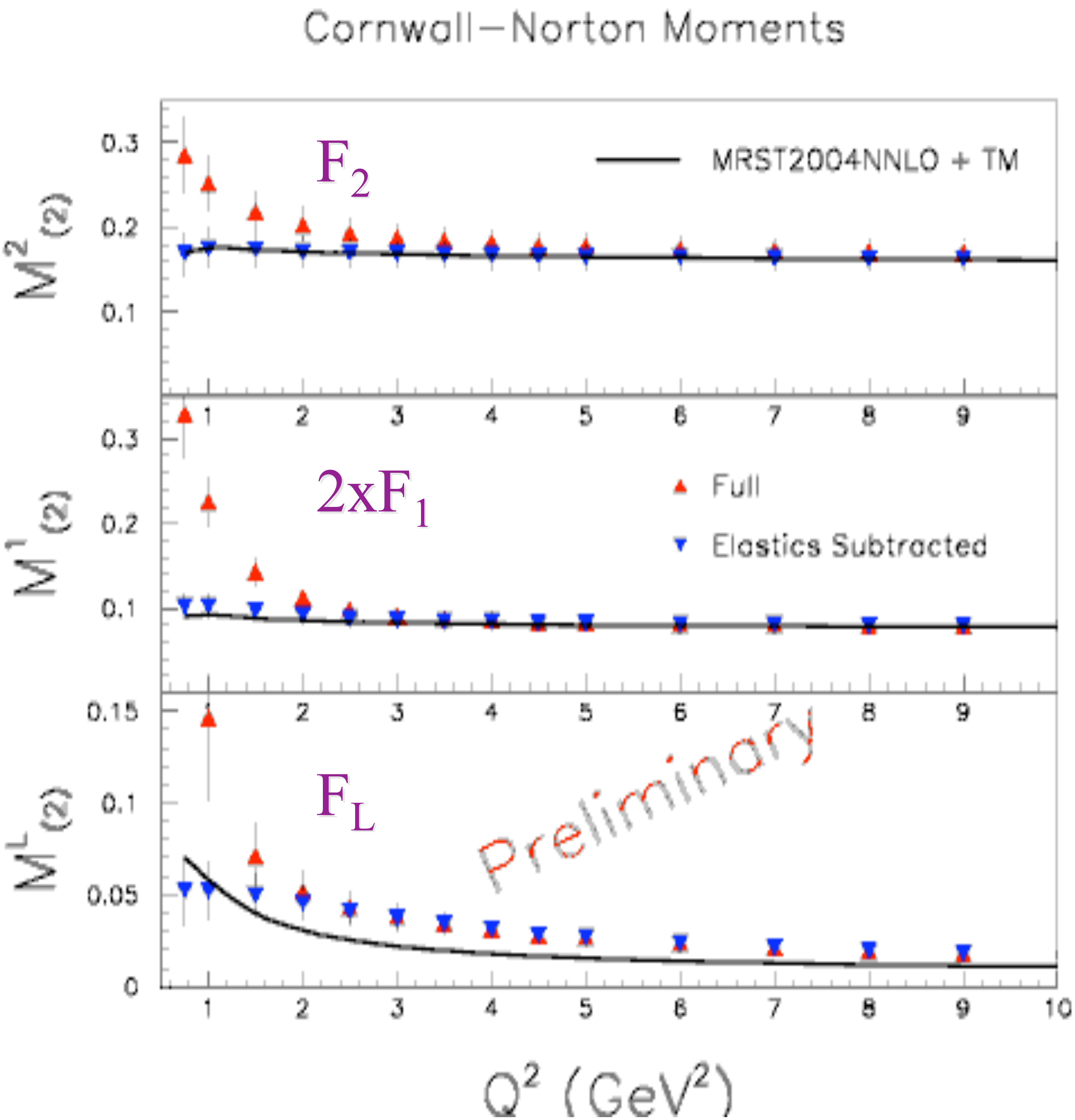


Need data covering *wide range* in x, at fixed Q2

Large x increasingly important at large n

+ elastics……

n = 2 Cornwall-Norton Moments



F_2, F_1 in excellent agreement with NNl + TM above $Q^2 = 2$ GeV^2

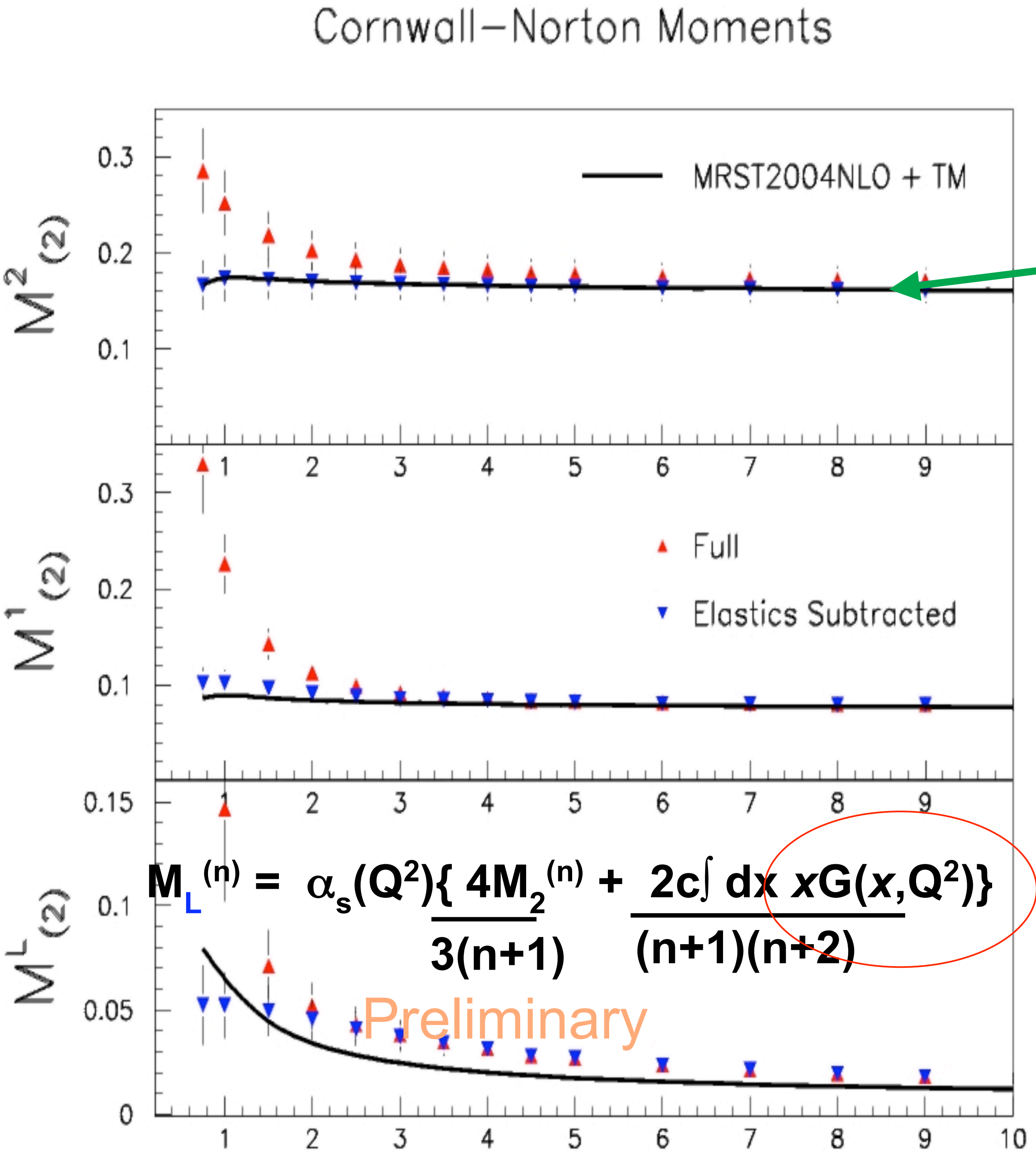
No (or canceling) higher twists

Yet, dominated by la x and resonance reg

Remove known HT bit novel), the elastic and there is no more down to $Q^2 = 0.5$ Ge

The case looks diffe for F_L (data or curve

Momentum Sum Rule



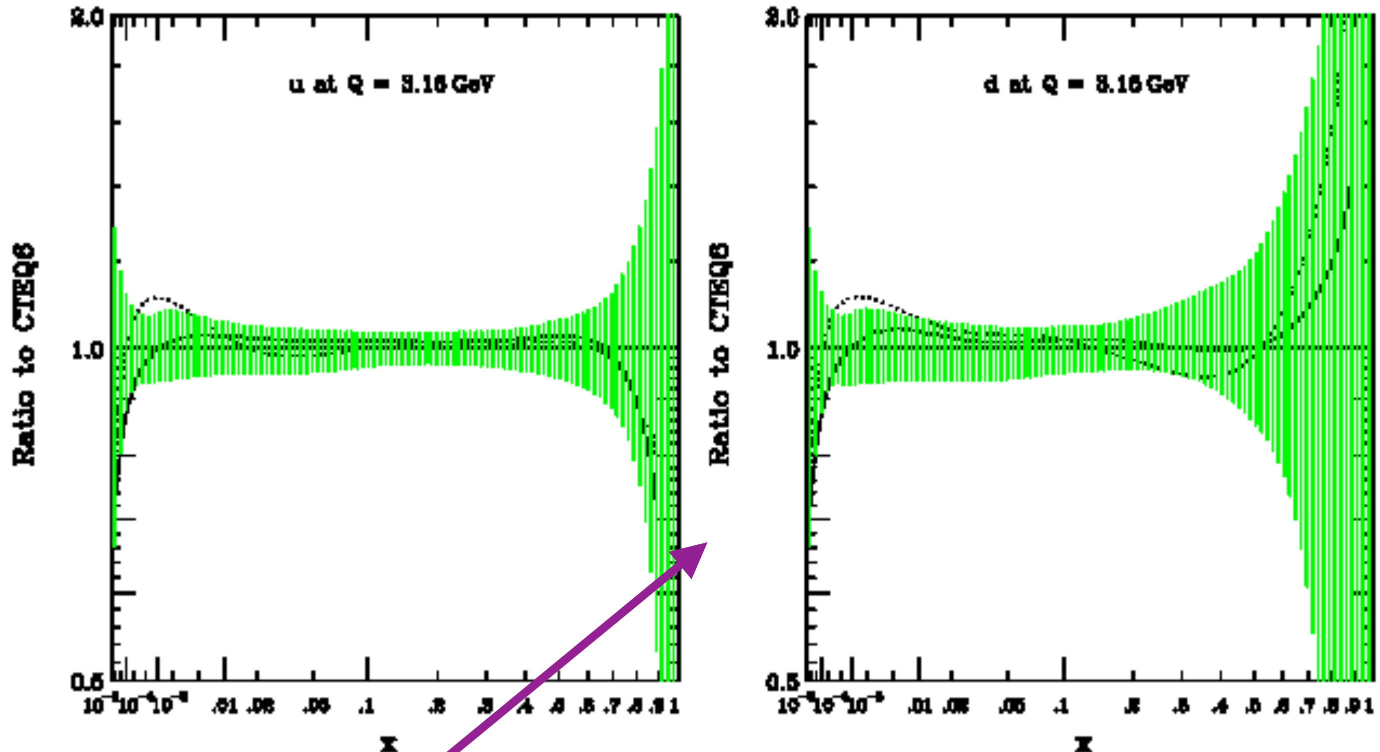
For F_2, QPM gives:
$(1/3)^2(0.17) + (2/3)^2(0.3$
= 0.17

~50% of momentum carried by quarks – the rest, assumably, by the glue

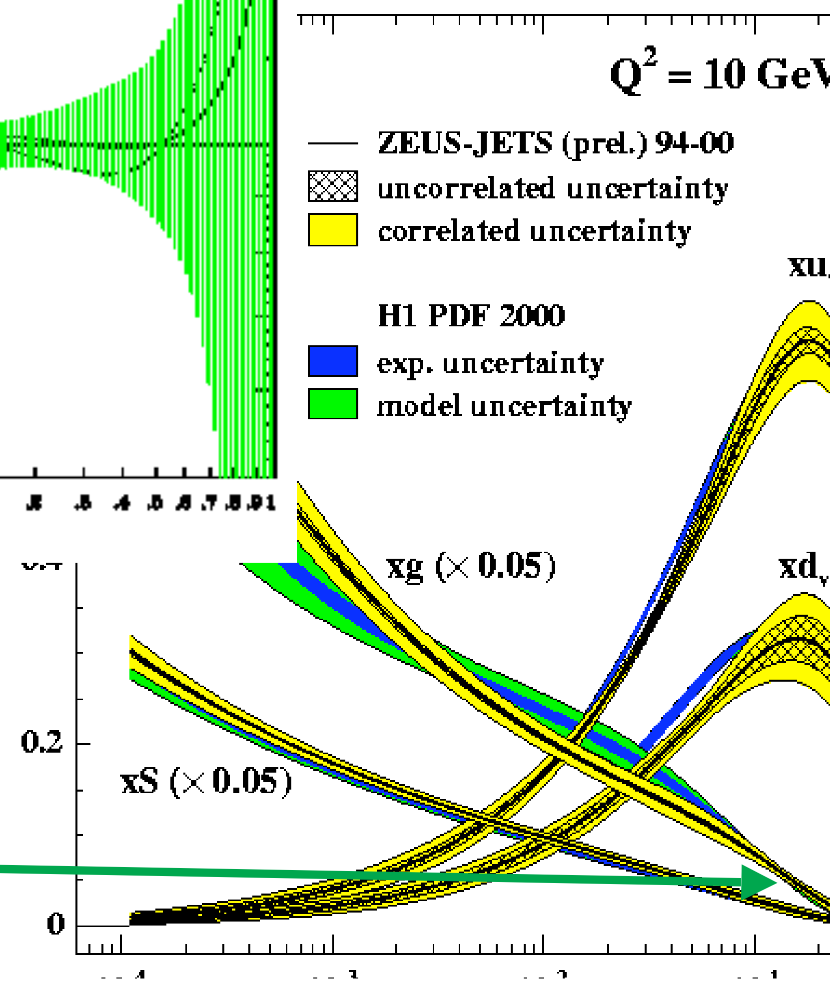
F_L gives a direct measurement of the g

But, we get 0.70 (preliminary) – also different from pdfs

Parton Distribution Functions – not well known at large x

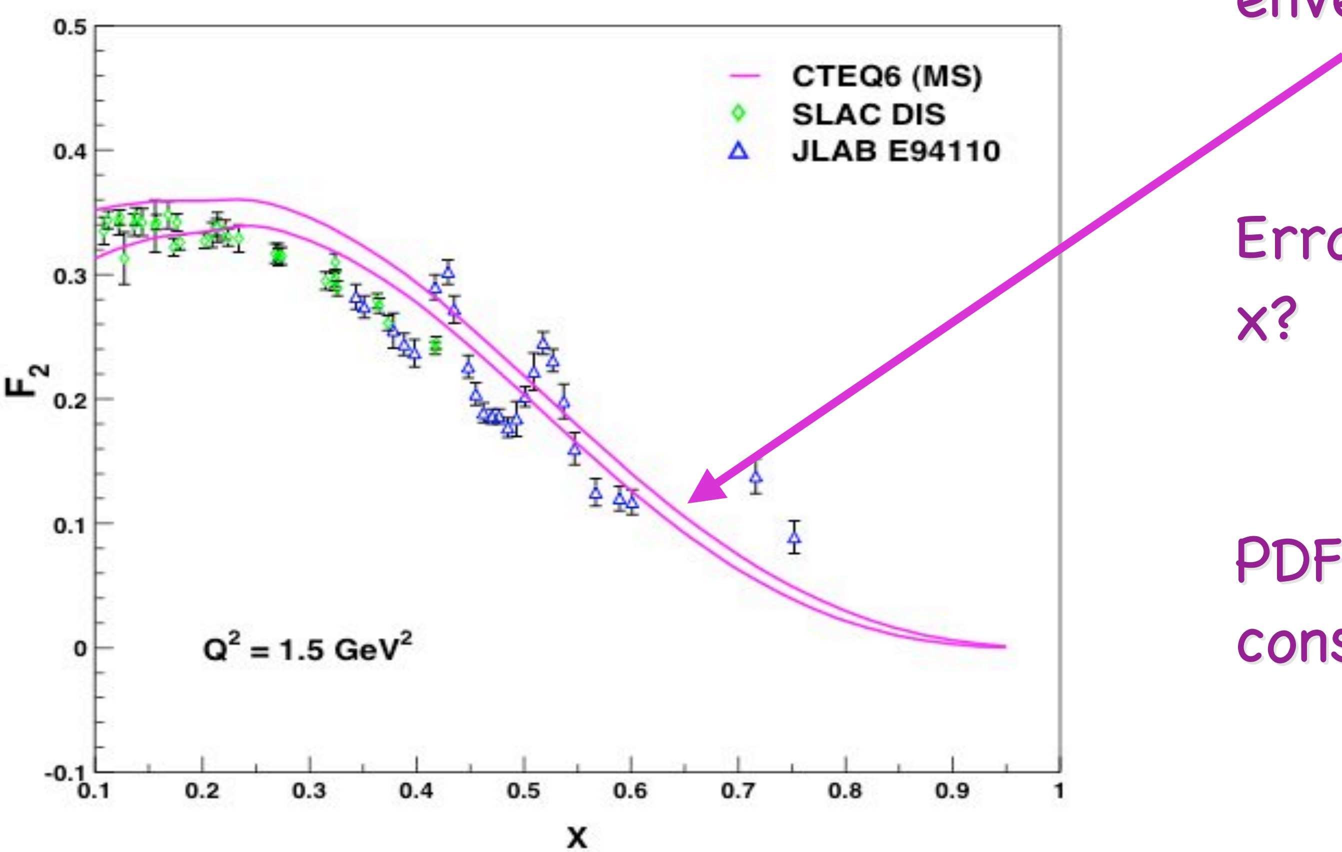


CTEQ u,d(x) uncertainty bands



Similar for HERA, note also glue important still at large x

Can the Jlab data help reduce the uncertainties?



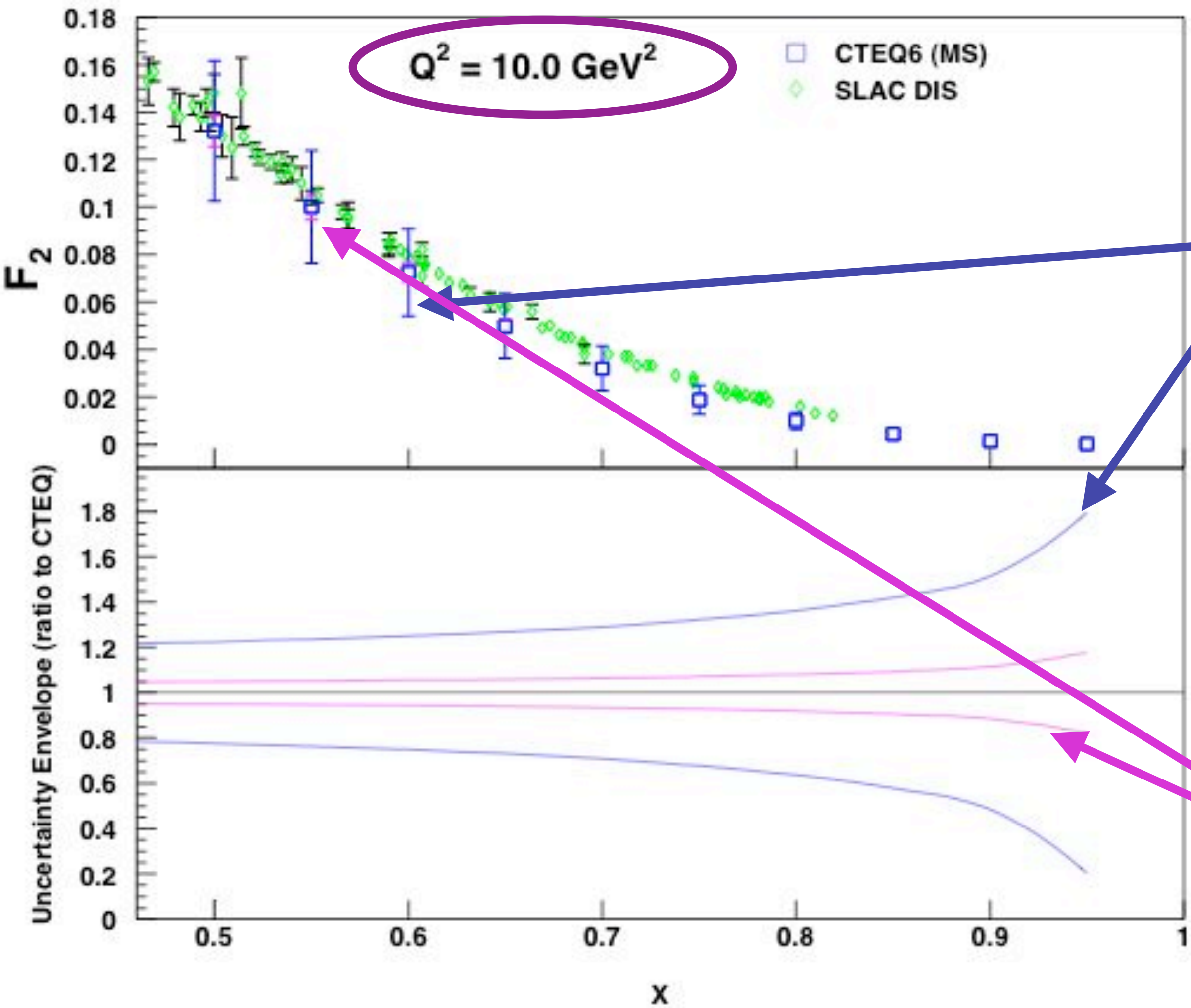
CTEQ6 Hessian error envelope

Errors smaller at low x?

PDF envelope constrained by fit form

...and by choice of d/u (fixed)

Can the Jlab (SLAC) data help reduce th uncertainties? - another approach



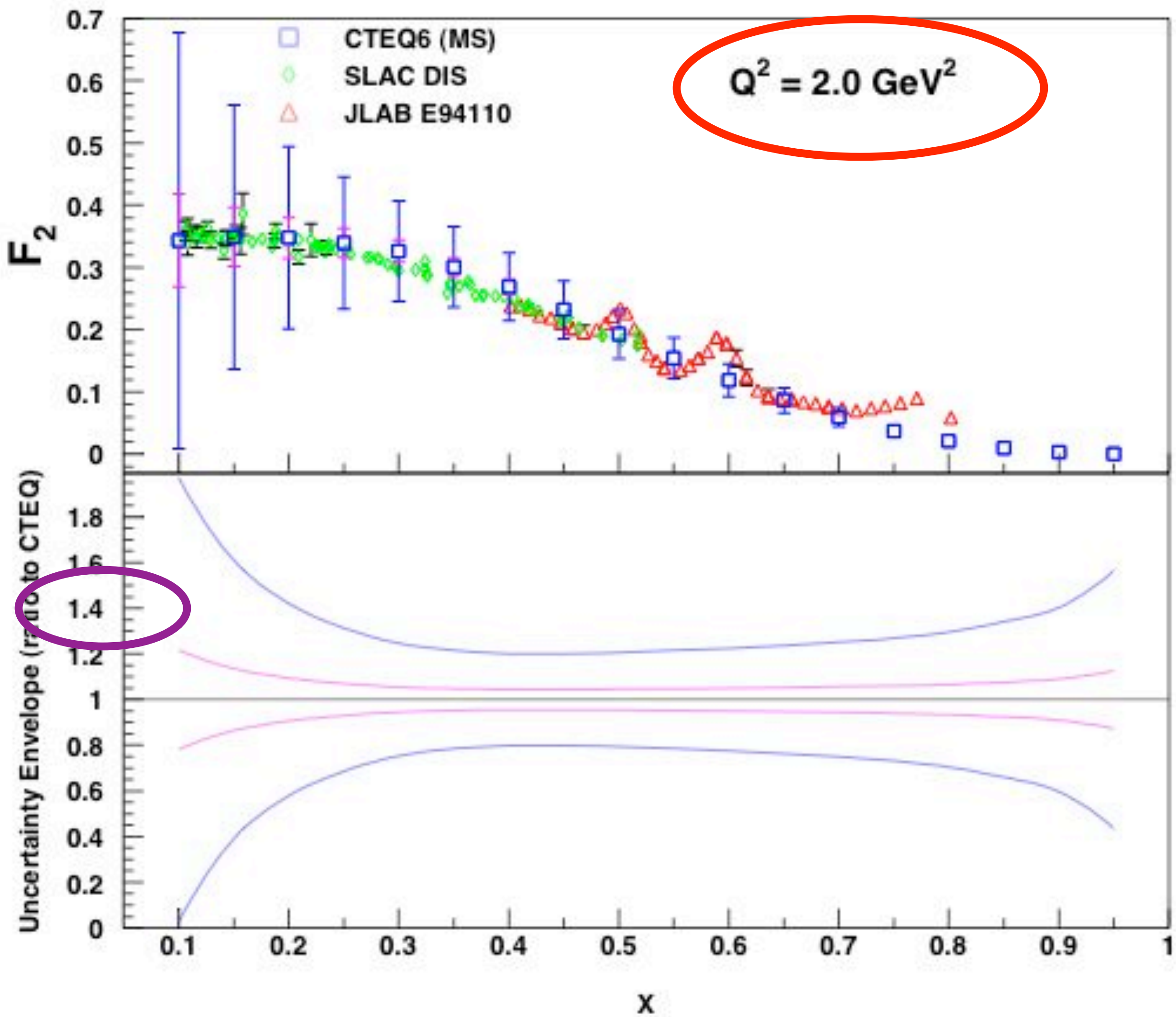
Current cut is W^2 = 10 GeV, Q^2 = 10 GeV^2

Blue is SF error due to pdf errors (likely an overestimate)

Pink is SF error due to pdf errors, but normalized to x = 0.5 data

Bottom plot better

Can the Jlab (SLAC) data help reduce th uncertainties? - another approach



Uncertainties associated with higher twist, large x evolution

But, it looks mayb useful even if the "data uncertainty" were increased 20

May help LHC....

A work in progres

Summary

- Precision measurements of $R = \sigma_L/\sigma_T$, and therefore separated structure functions, now available from Jefferson Lab
- Significant longitudinal strength and structure at large x
- Dictates L/T separations necessary even for F_2
- Quark-hadron duality observed in separated structure functions independently
- R on proton differs from R on deuterium
- New data allows for moment extractions - very minimal higher twist observed
- F_L moments probe the glue
- Perhaps we use this large x data to better constrain large x pdfs
- More to come:
  - Nuclei
  - Lower Q^2