F_2 and R in Deuterium and Nuclei - Phase II

(E06-009/E04-001)

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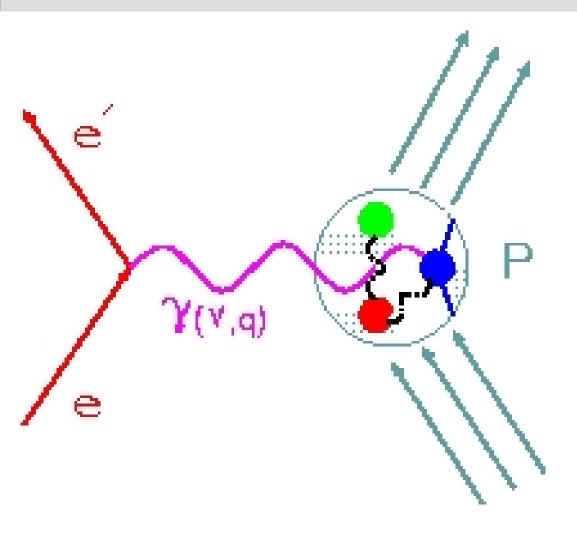
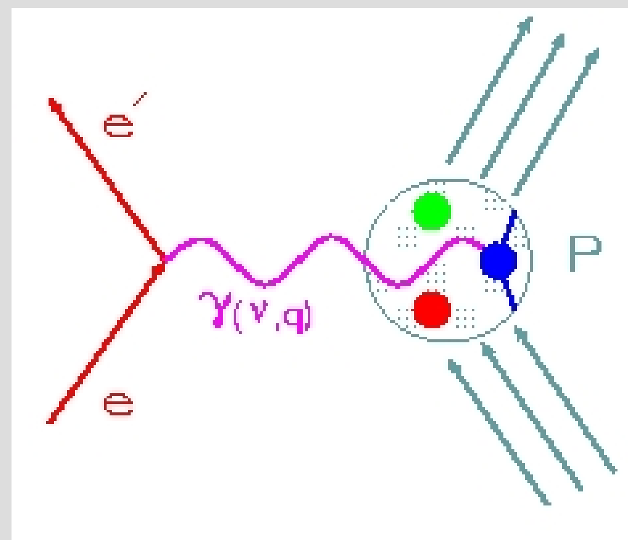


Hall C Users Meeting

Jan 26, 2007



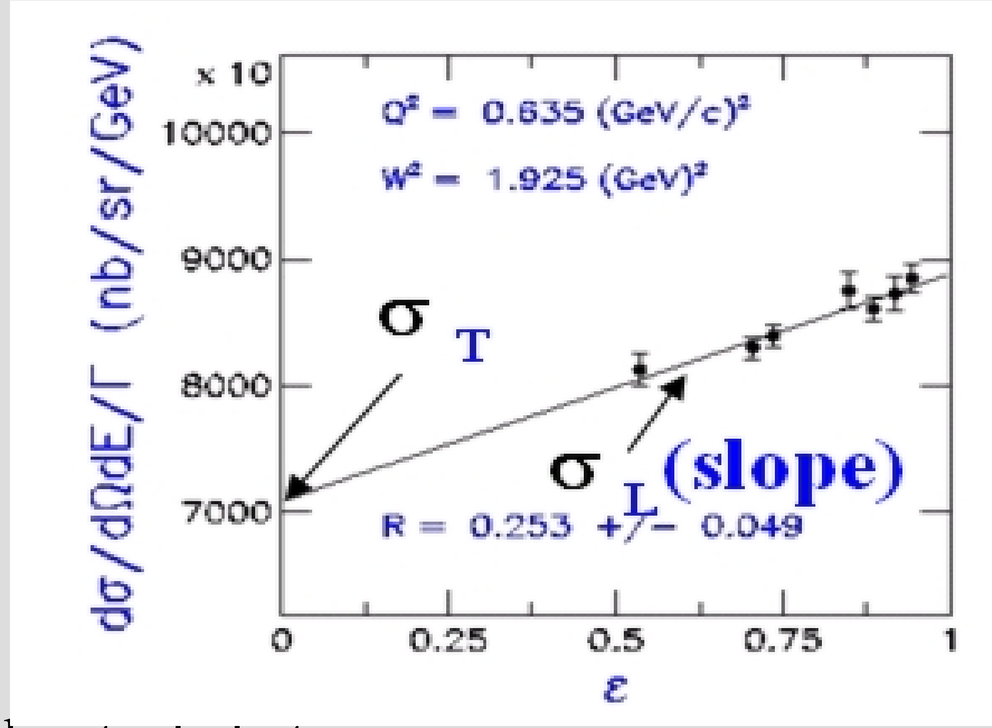
E06-009 & E04-001 Physics

- F_L, F_1, F_2 Fundamental Structure Function Measurements on Deuterium and Nuclei
- Structure Function Moments
  - Lattice QCD comparisons
  - Singlet and non-singlet distribution functions from deuteron and proton
- Support Broad Range of Deuteron Physics
  - Elastic form factors
  - BONUS neutron structure functions
  - Input to extract spin structure functions from asymmetry measurements.
- Important input for neutrino physics
- Quark-hadron duality studies

Inclusive e + A → e + X *Scattering*

Rosenbluth Separation Technique:

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



Where: Γ = flux of transversely polarized virtual photons

ε = relative longitudinal polarization

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

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

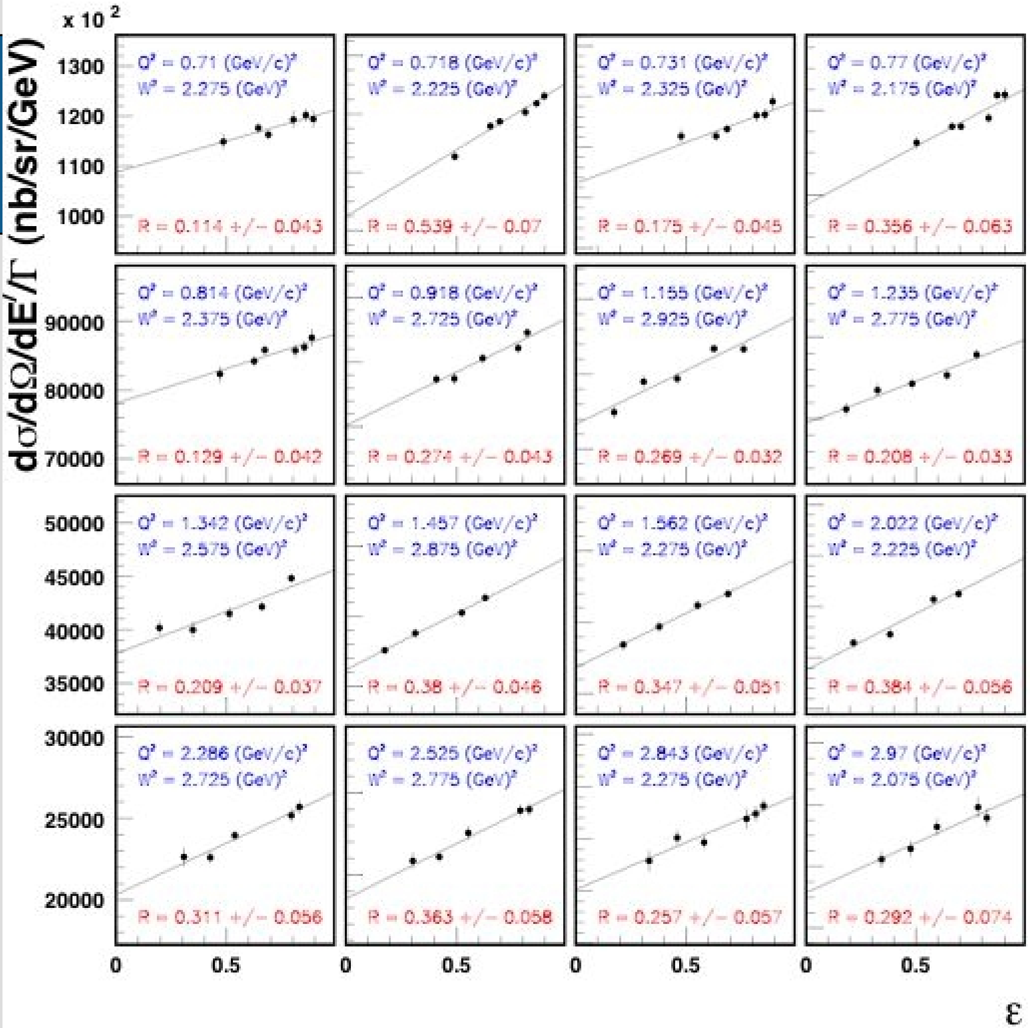
Transverse

longitudinal

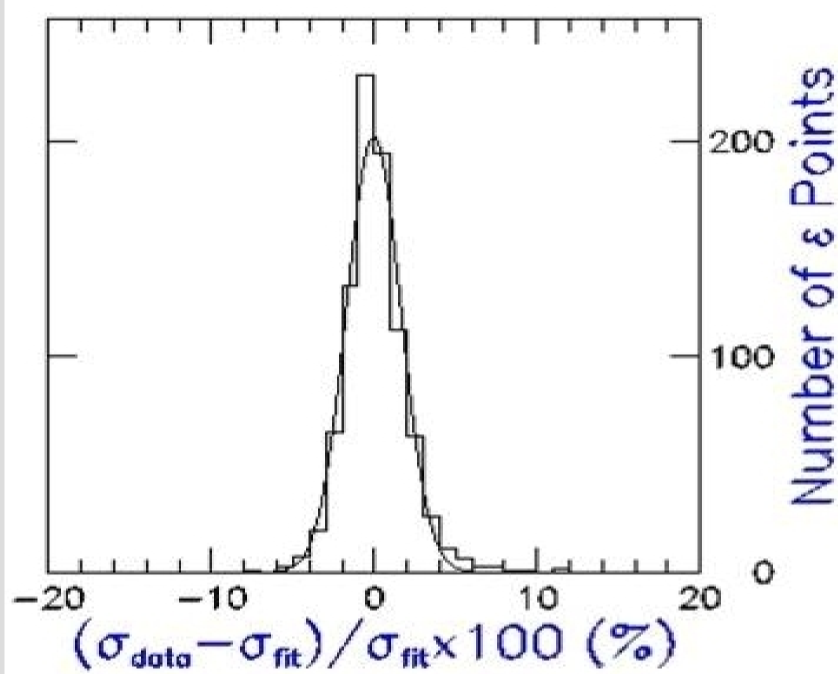
mIxEd

Reproduce successful precision proton L/T separations….

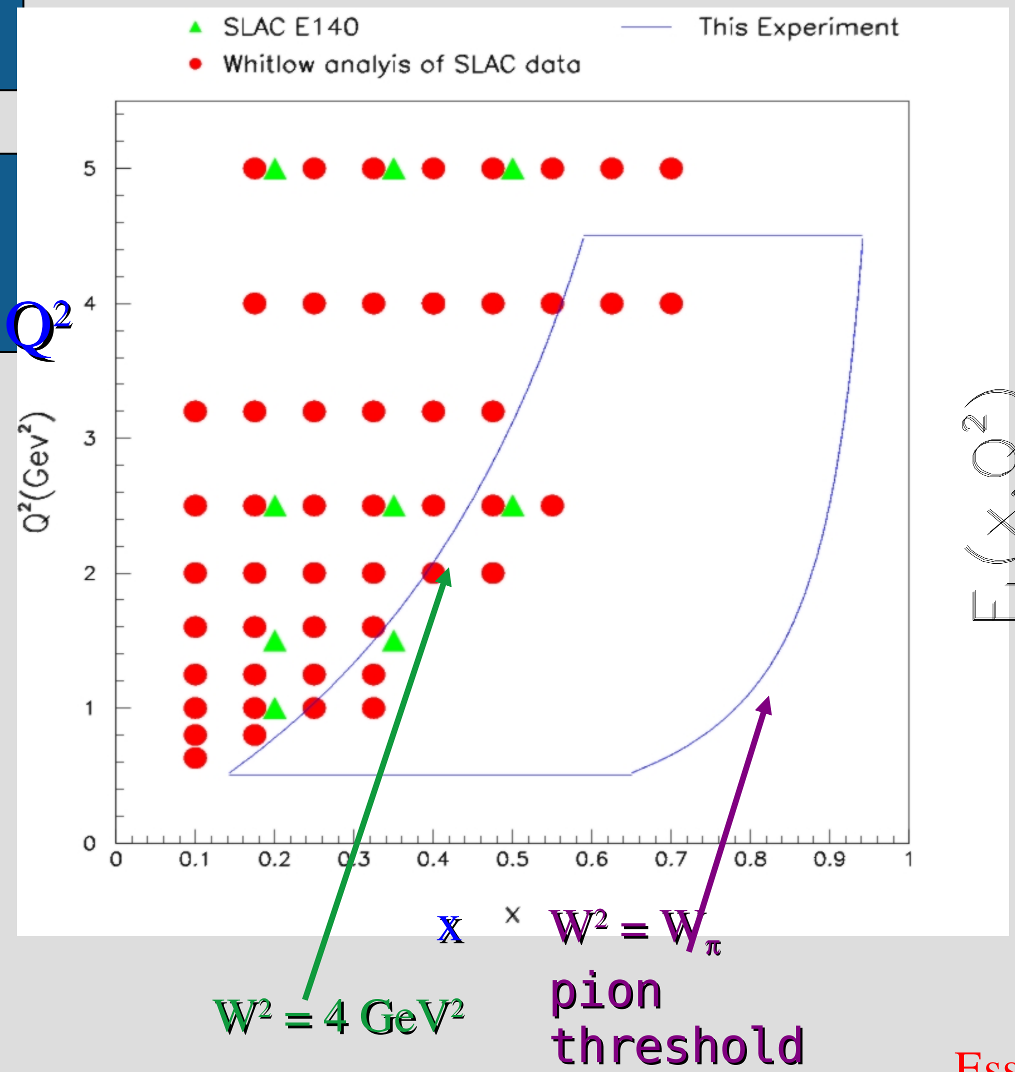
E94-110 performed 195 separations!

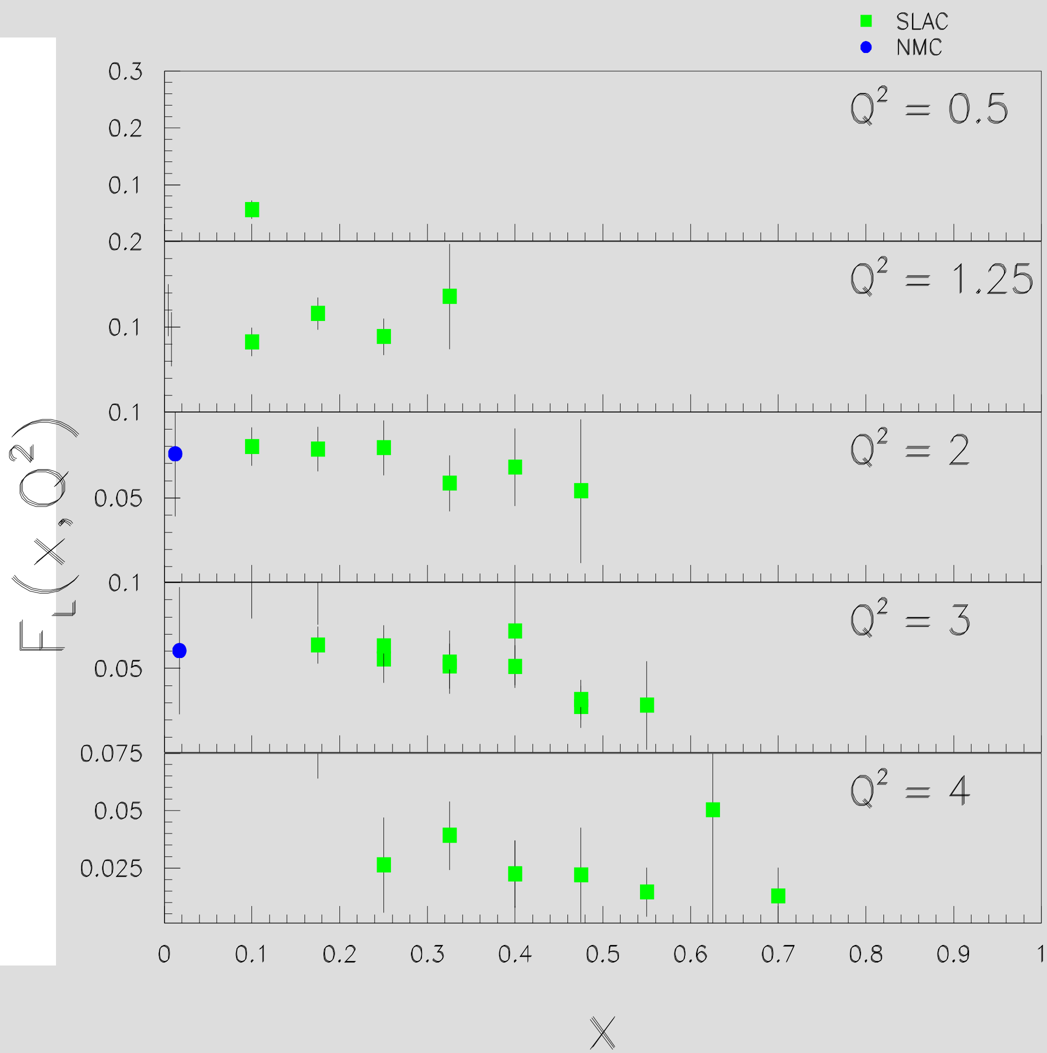


Quantity	Uncertainty	$\delta_\sigma(\%)$
Beam energy	$\sim 5 \times 10^{-4}$	0.30
Scattered e^- energy	$\sim 5 \times 10^{-4}$	0.25
Scattering e^- angle	~ 0.2 mrad	0.26
Target density (relative)	0.05%	0.05
Beam charge (relative)	0.1%	0.1
Dead Time Correction	0.2%	0.2
Detector Efficiency	0.55%	0.55
$e+/e-$ 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



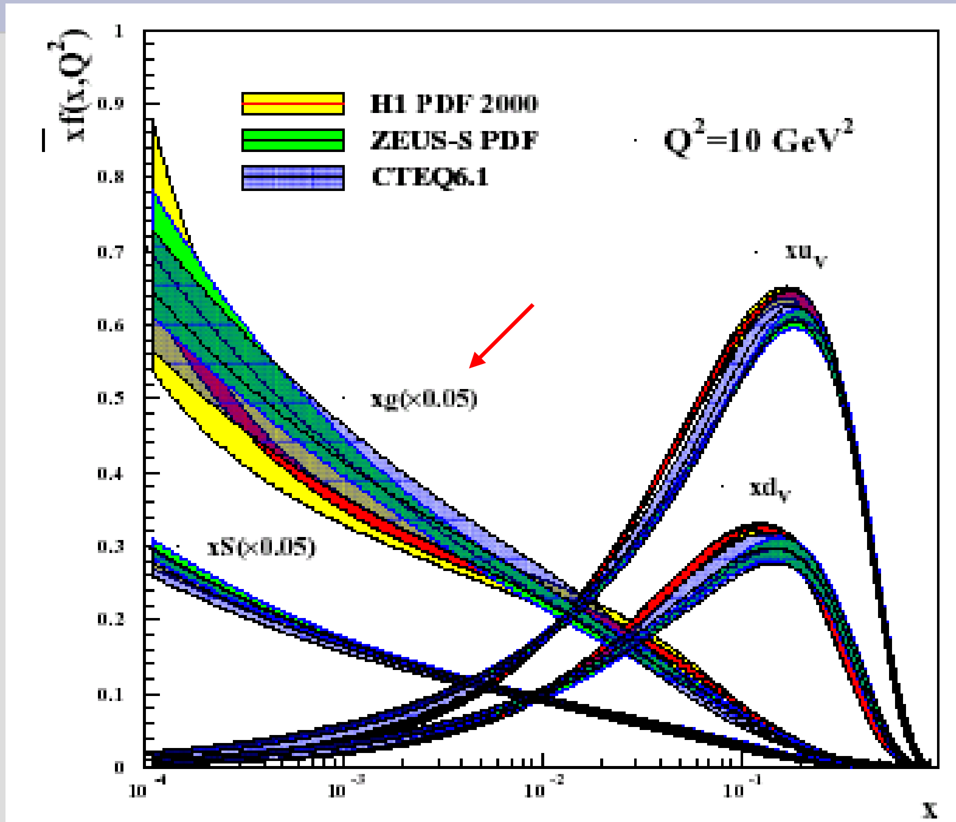
Global Survey of Longitudinal Strength in the Nucleon Resonance Region for Deuterium and Nuclei

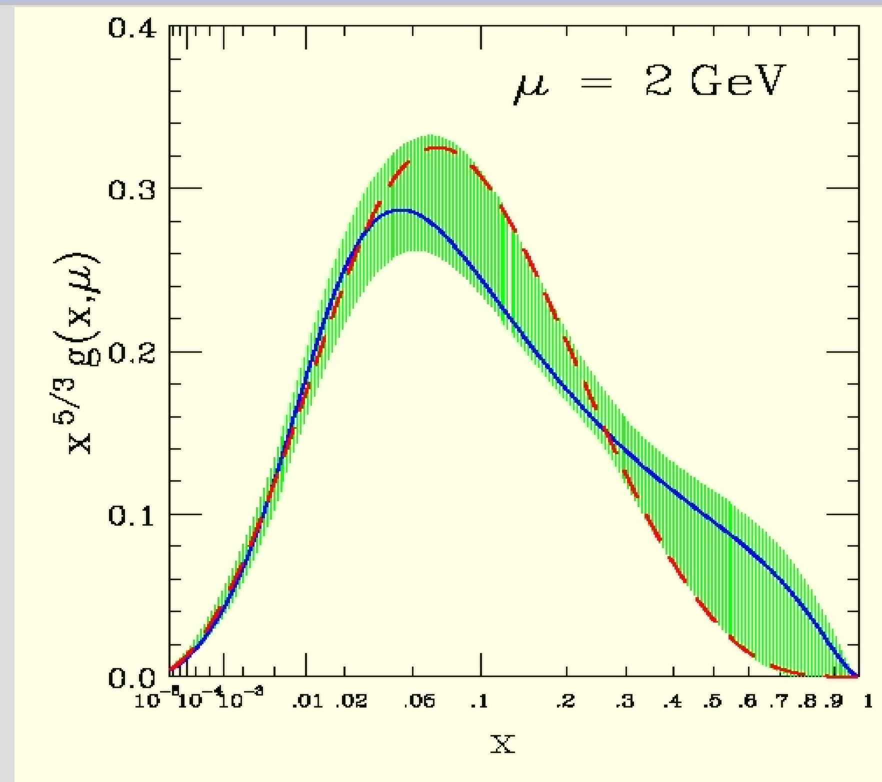




Essentially NO L/T separated data exist in the resonance region currently!

F_L sensitive to gluon distributions.....





- Nucleon structure composed of singlet (gluons, sea) and non-singlet (valence) distributions
- At moderate x (~ 0.3), singlet comparable to non-singlet
- Large uncertainties on singlet distribution in structure function measurements, comes from (small) scaling violations in F_2
- F_L is directly sensitive to glue!

$\int(2F_2^p - F_2^D)dx$ yields non-singlet distribution

- Q^2 evolution is simpler for the non-singlet (reduced number of splitting functions)
- Assuming a charge-symmetric sea, p-n isolates the non-singlet
- Need to pin down non-singlet (p-n) to extract singlet (F_L)

"..highly precise deuteron data - due to the above aspects - are forming a conditio sine qua non for any real precision test of QCD." – Johannes Bluemlein

For similar reasons (non-singlet calculations), p-n moments are now available from lattice QCD at $Q^2 = 4\ GeV^2$!

F_2 moments	Detmold et al. 2002	Dolgov et al. 2002	Gockeler et al. 2004	Niculescu et al. (hep-ph/0509241)
n=2	0.059 +/- 0.008	0.269	0.245	0.049 +/- 0.017
n=4	0.008 +/- 0.003	0.078	0.059	0.015 +/- 0.003

Lattice QCD calculations *experiment*

Calculated on the lattice at $Q^2 = 4$ GeV^2
Well understood in QCD Operator Product Expansion

For proton, n= 2 F_2 moment = 0.182 +/- 0.006
For deuteron, n=2 F_2 moment / nucleon = 0.165 +/- 0.008

In the difference, uncertainties in R matter!

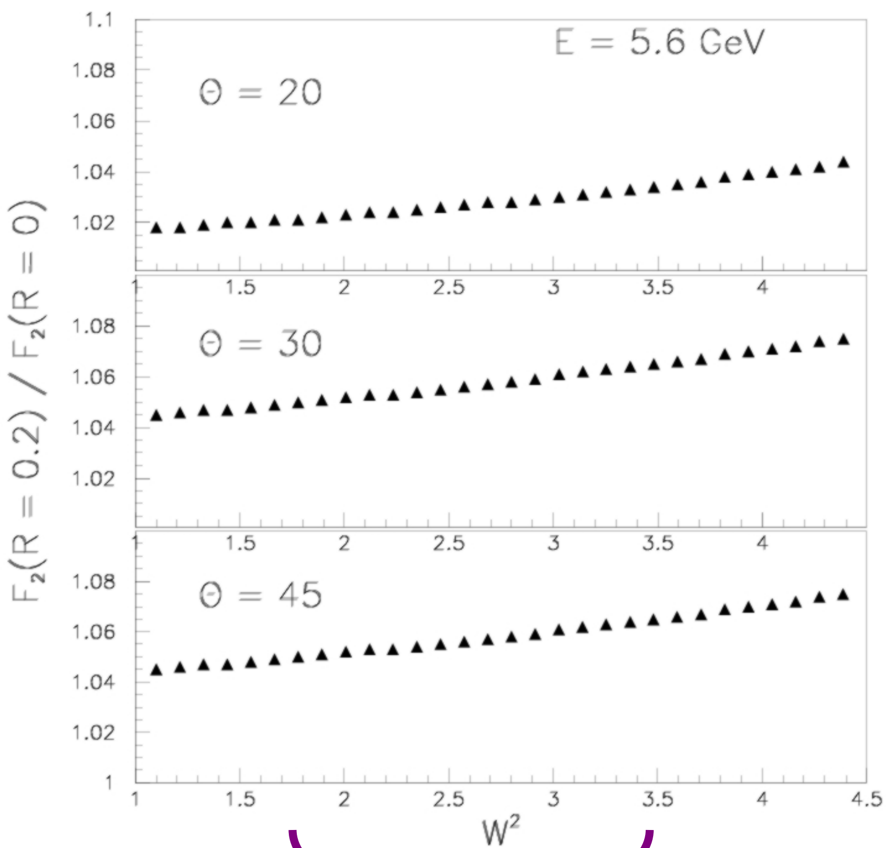
Moreover, can't even obtain F_L moments really – missing resonance region data!

percentage contribution of resonance region to total moment (from proton moment data):

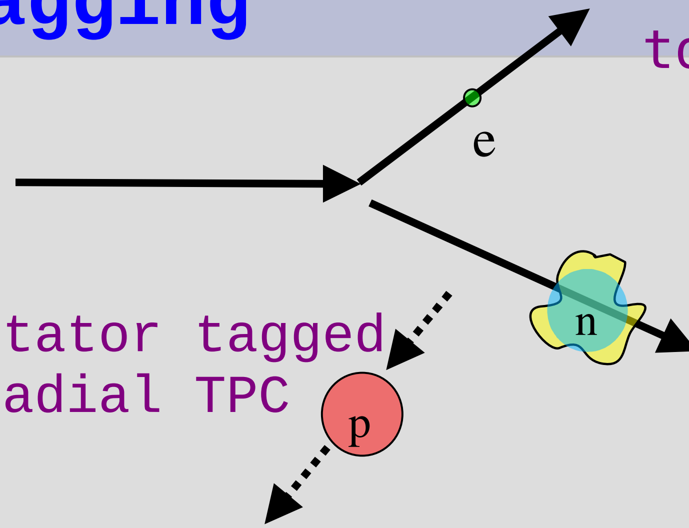
Q^2 (GeV^2)	F_1 (n=2)	F_1 (n=4)	F_L (n=2)	F_L (n=4)
1.5	55%	91%	48%	89%
3.0	24%	64%	21%	64%
4.0	15%	49%	13%	52%

BONUS: NEUTRON cross sections via spectator tagging

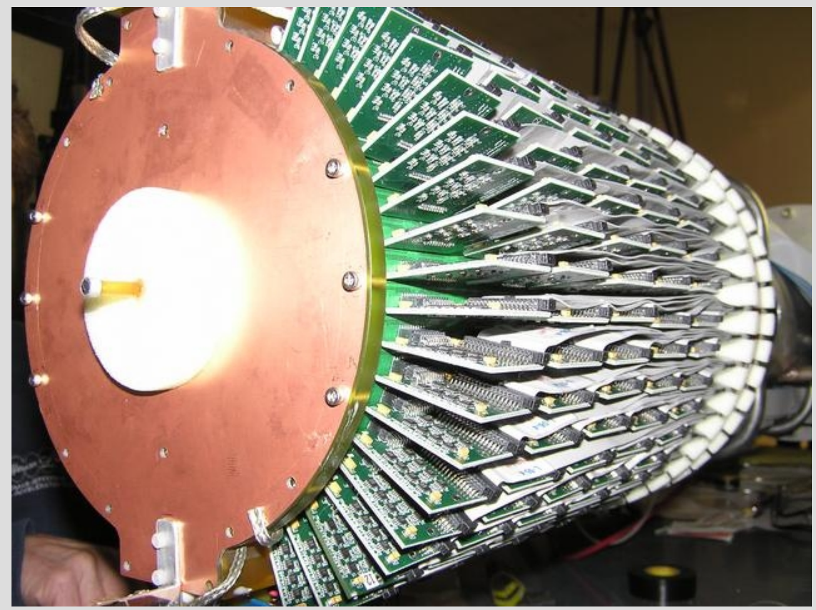
Change in F_2 with R



to CLAS



spectator tagged in radial TPC



Uncertainty in R introduces ~5% uncertainty -
true for all F_2 extractions from cross sections (CLAS deuterium as well as BONUS)

BoNuS combined with inclusive deuterium

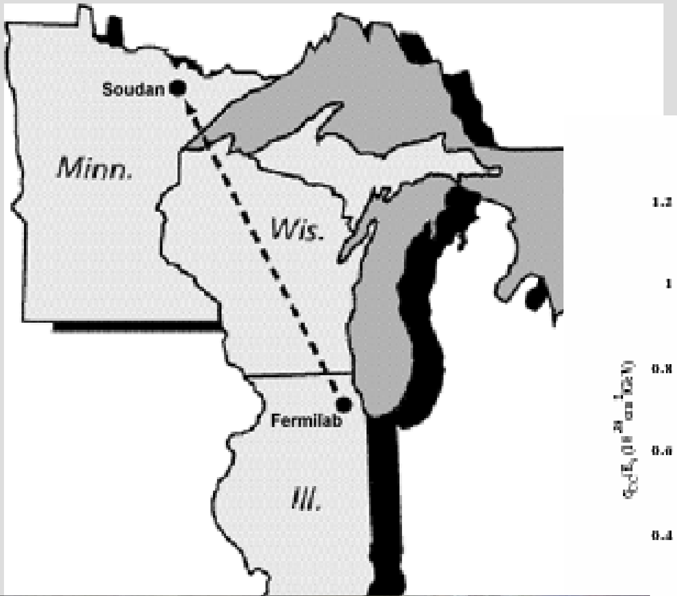
=> help pin down nuclear corrections with BoNuS

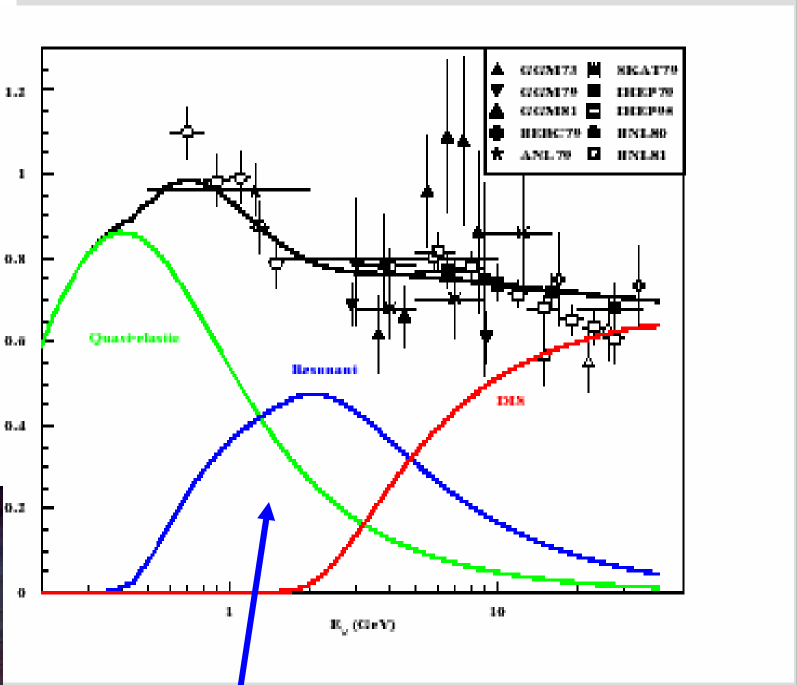
=> correct L/T separated deuterium structure functions to get out neutron L/T SFs!

Neutrino Oscillations $m^2 \sim E / L$, requires E in few GeV range (same as JLab!)

Input for neutrino cross section models, needed for new generation of oscillation experiments around the world

Jlab measurements can provide input on vector couplings





Resonance region is a major contribution!

Form Factors for "Free"

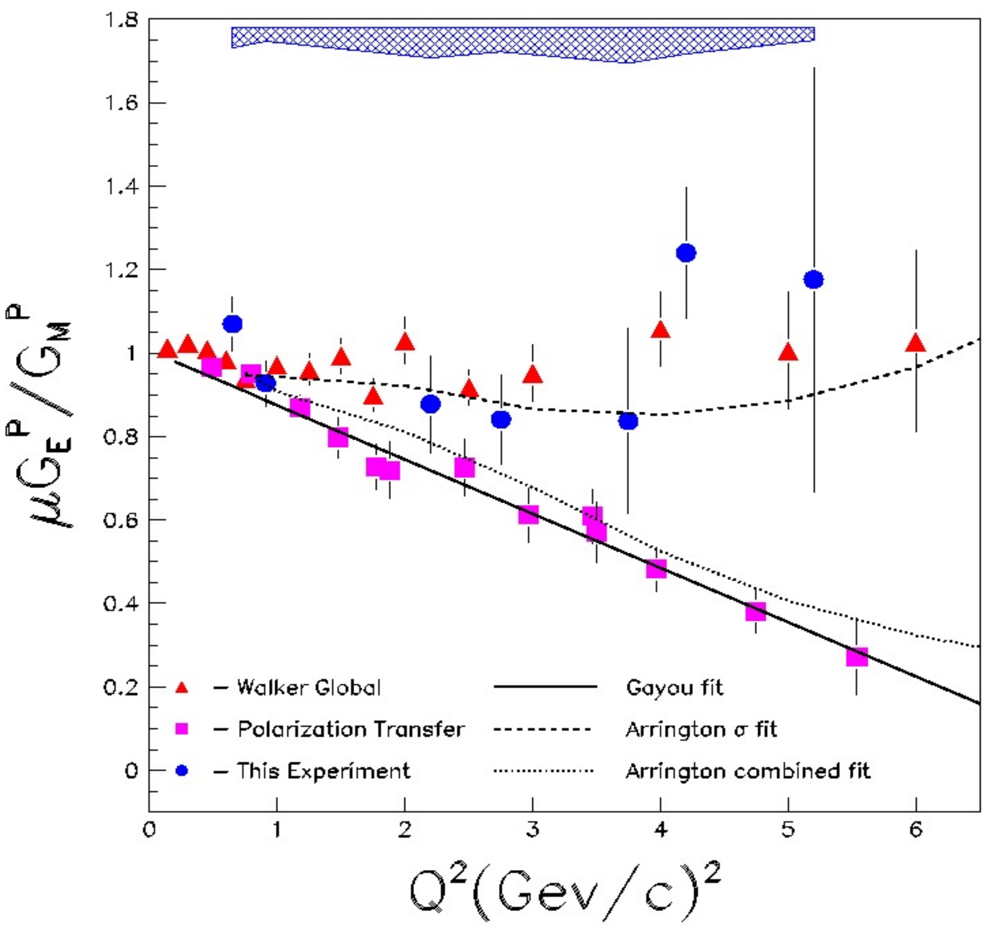
Jlab E94-110 measurements confirm SLAC hydrogen Rosenbluth results for G_{Ep}/G_{Mp}!

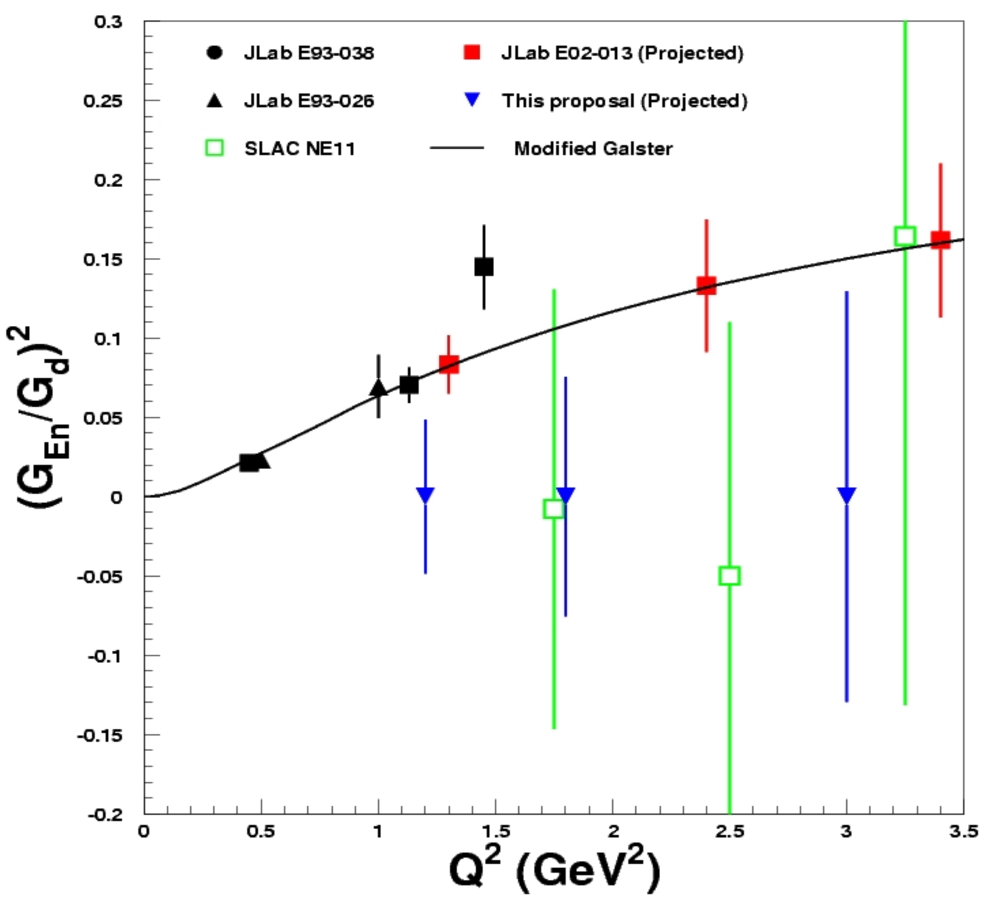
Discrepency from PT results now ascribed to radiative 2-photon effects

2-photon effects on G_{En} should be larger than proton

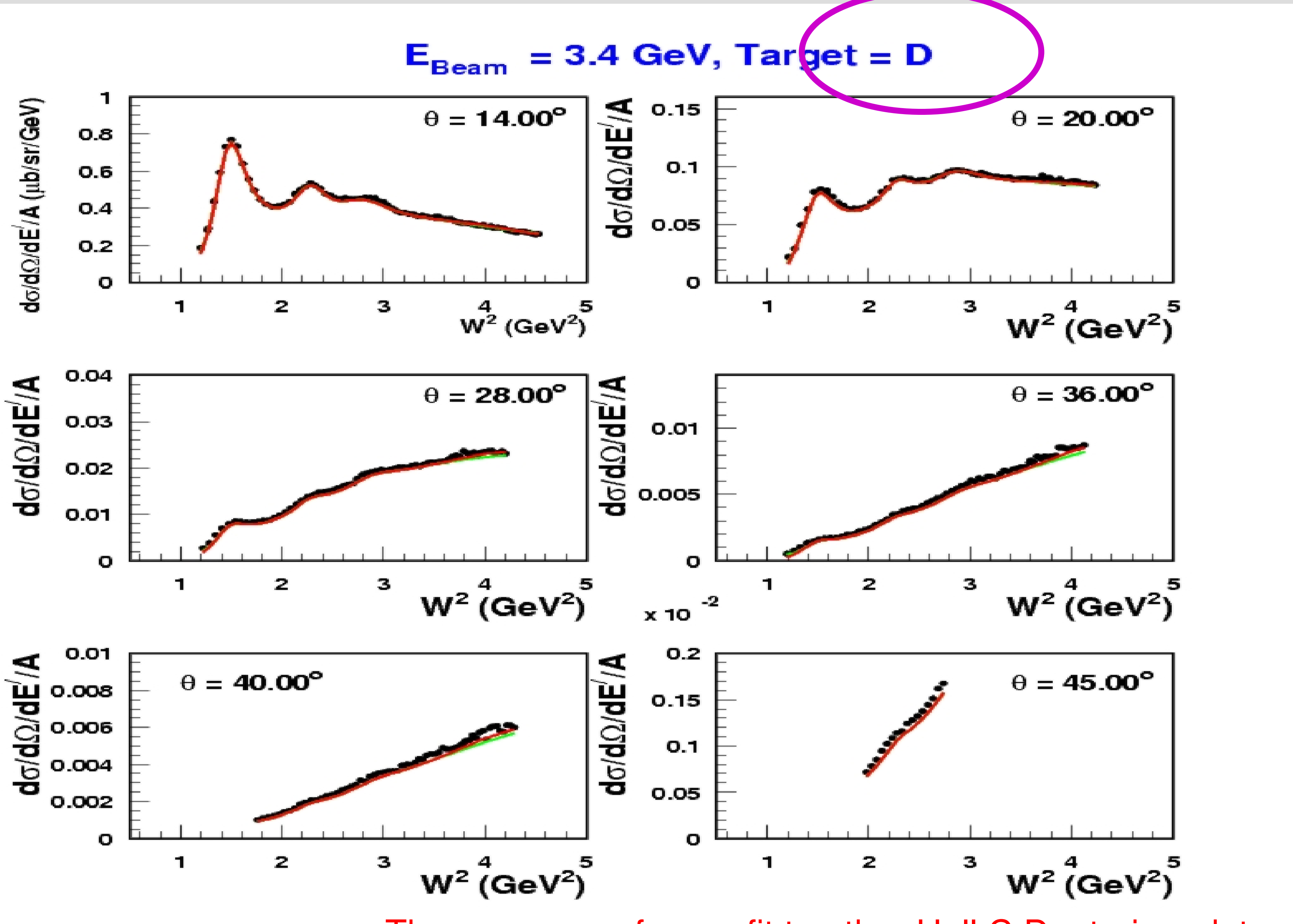
Blunden, Tjon, Melnitchuk, Phys.Rev. C72 (2005)

(Rosenbluth measurements could result in $G_{En}^2 < 0$?)



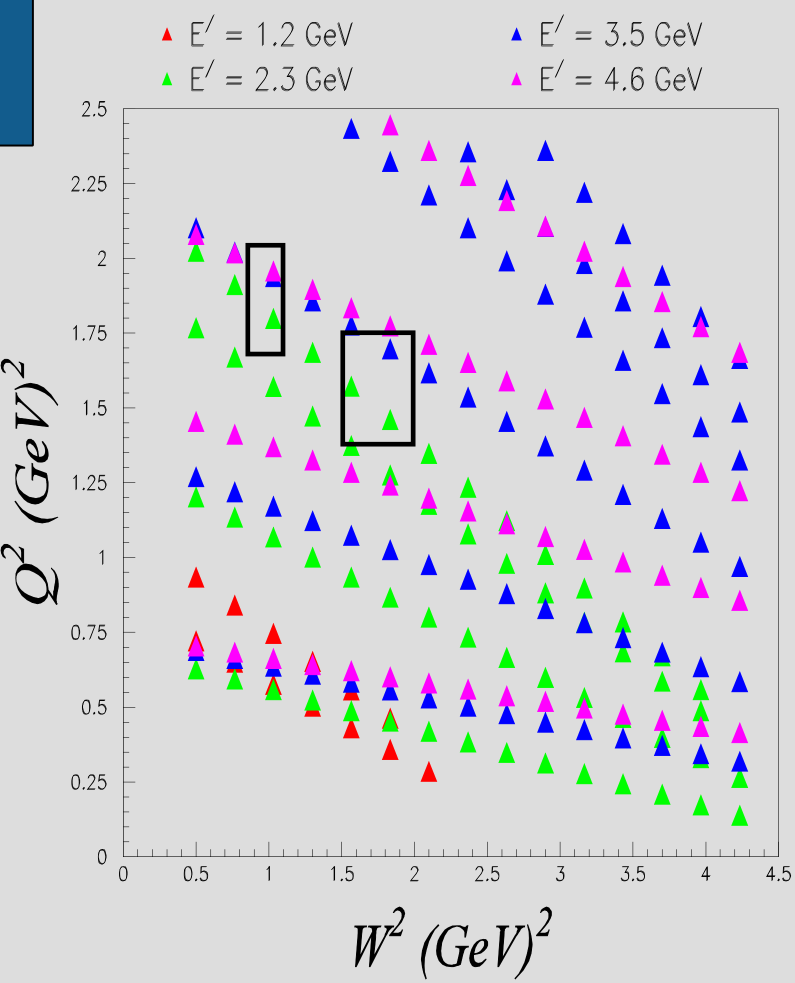


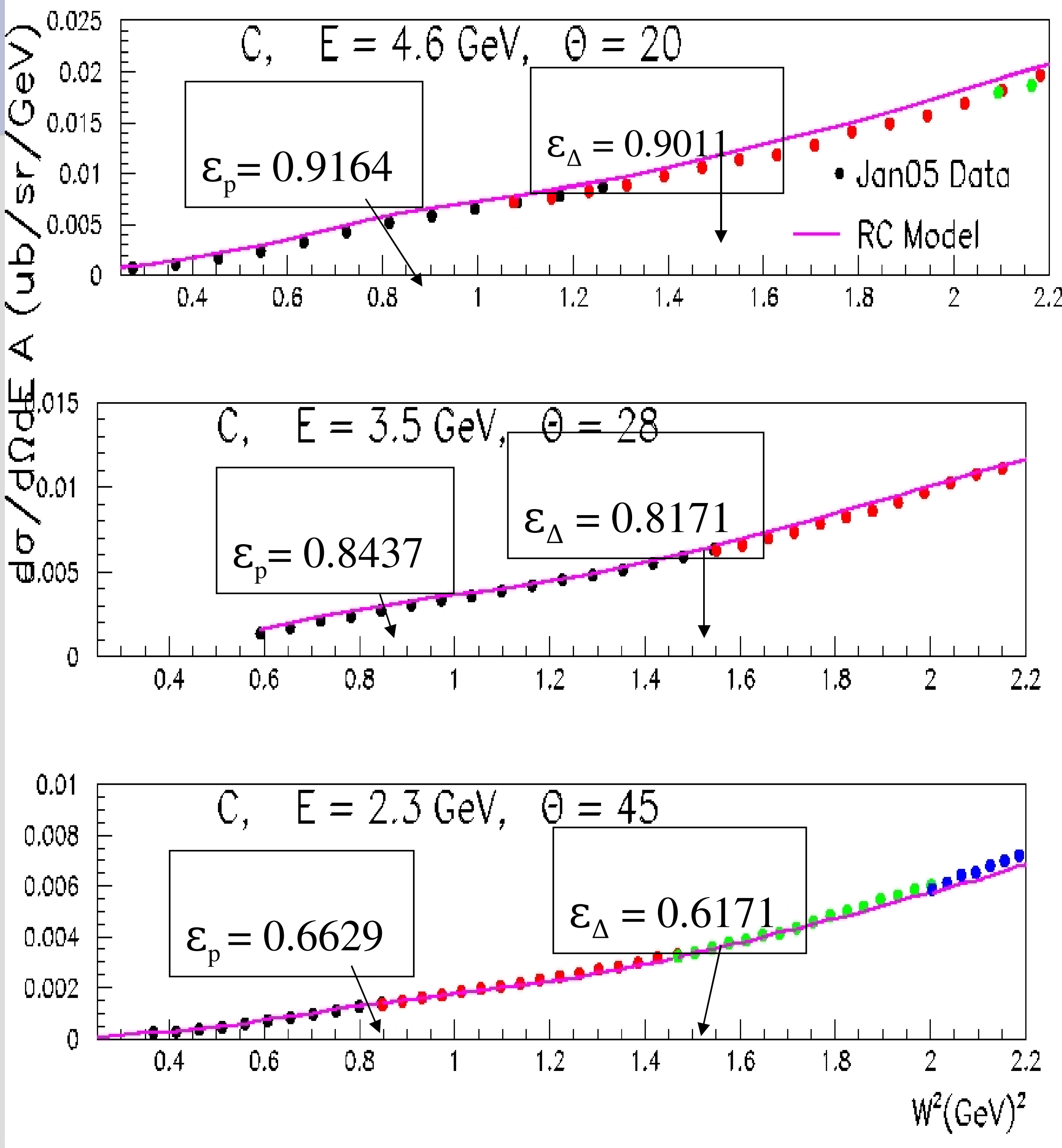
Preliminary Phase-I Cross Sections



The curves are from a fit to other Hall C Deuterium data (largely at higher Q^2, all not L/T separated).

Phase-I Carbon Cross Sections for L/T Separations (Q^2 ~ 2)

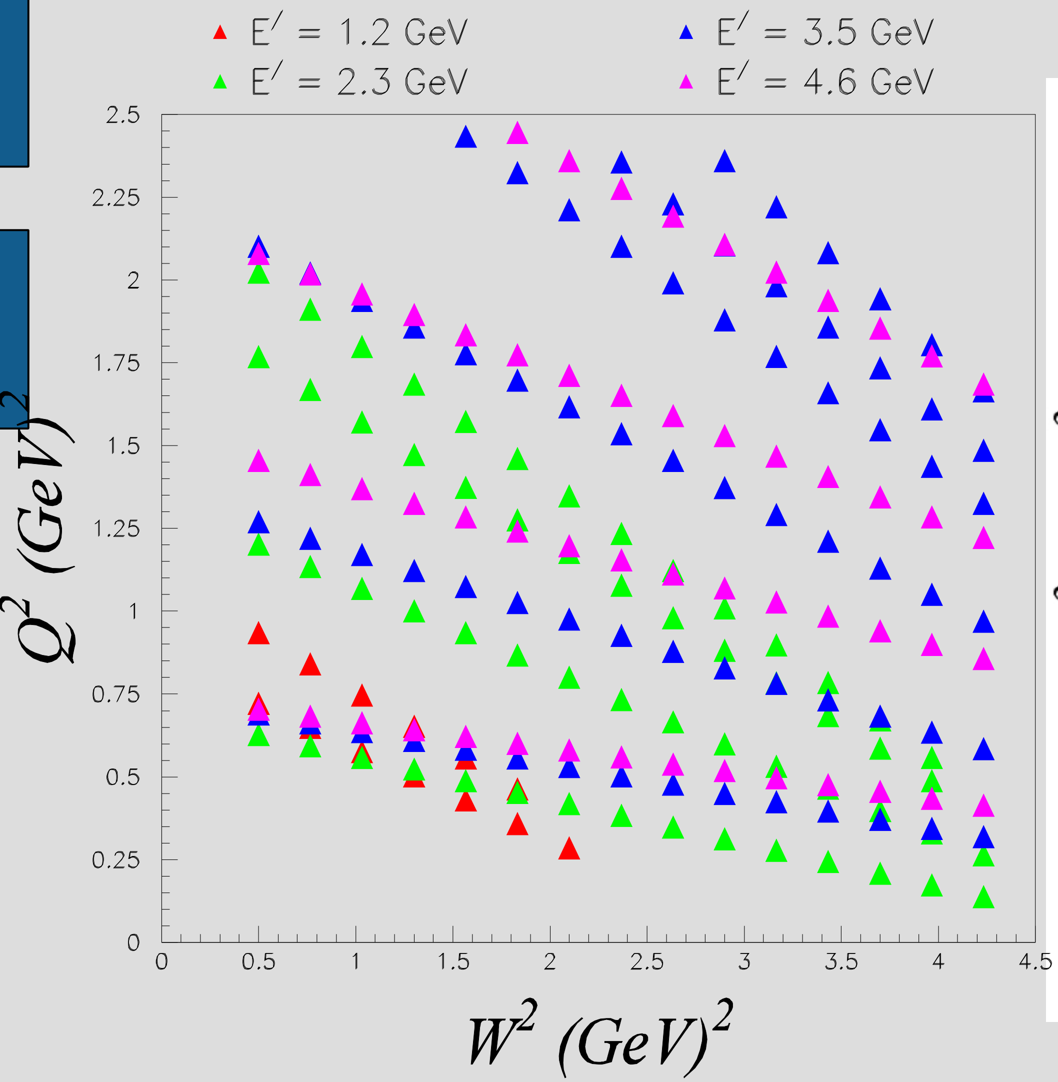




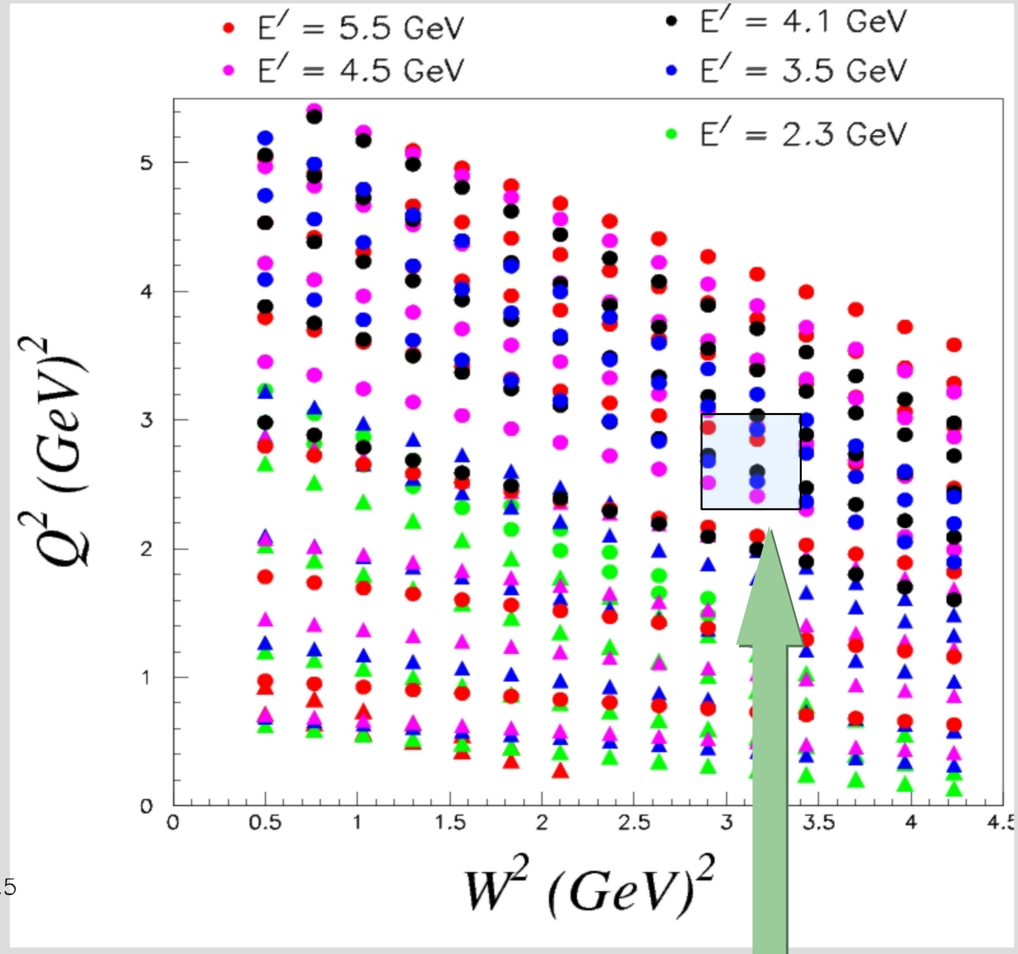
Need Phase-II data to supply additional epsilon points, even for $Q^2 < 2.5$.

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

Phase I kinematics (Jan '05)



Proposed Phase II kinematics

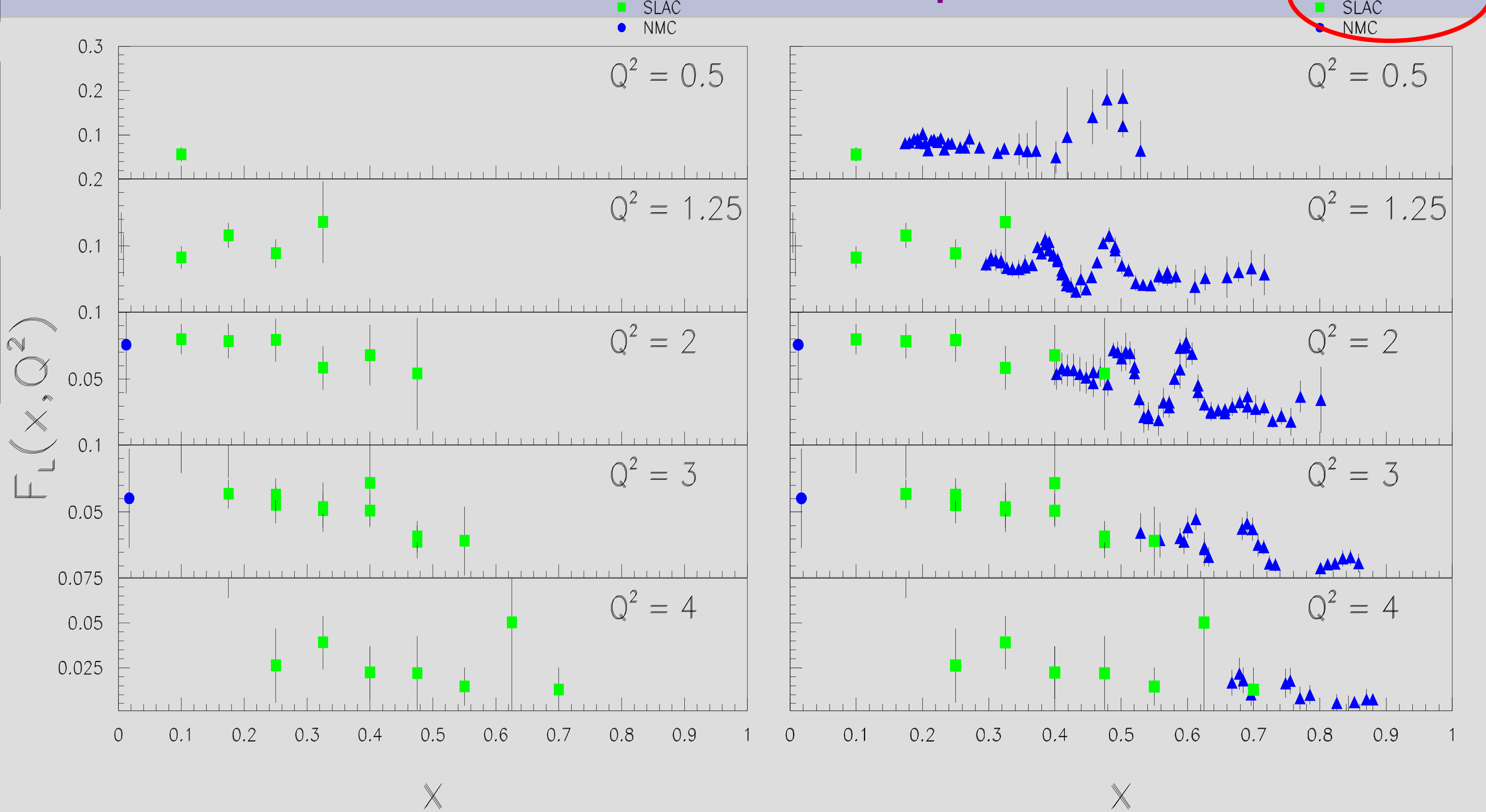


L/T separations where multiple energies.

projected from hydrogen

current deuterium

After phase II data!



- No L/T separated resonance region (large x) data on deuterium currently (little on heavier targets)
- Impossible to extract high precision moments

- Moments available
- Compare to lattice
- F_L to access singlet

Issues during Phase-I

- Low HMS hodoscope efficiencies
  - Hodoscope refurbishment - see talk by Vardan Tadevosyan
- Problems setting and locking hms dipole
  - New HMS controls - see talk by Steve Lassiter
- Thick HMS exit window (20 mil Ti)... large multiple scattering at low E' -> serious reconstruction issues!
  - New Al exit window installed.

Additional Requirements

- Stable Beam - position and energy
- Stable BCMs
- High trigger efficiencies
- Veto pions with Cerenkov
- Stable magnet Fields