New Determinations of the Generalized Baldin Sum Rule

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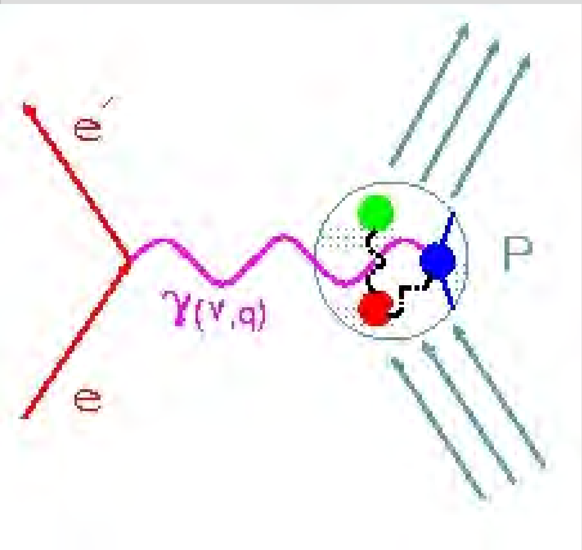
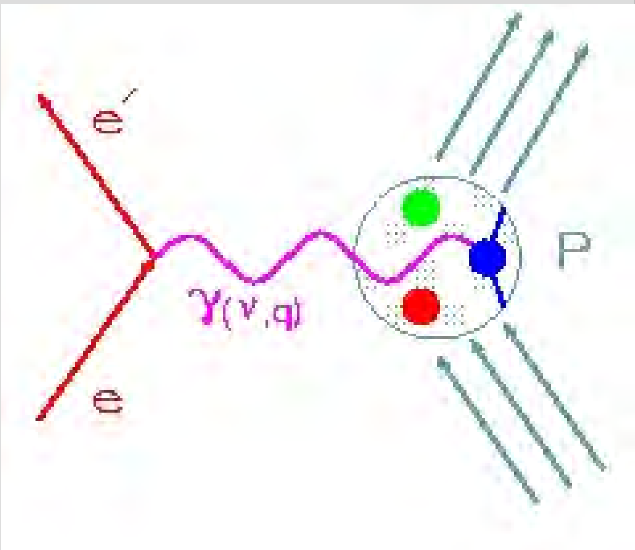


Jlab Users Group Meeting

June 12, 2006



Dispersion Relations, LETs and Sum Rules

Dispersion relations for forward Compton amplitudes

+

Low Energy Theorems => Sum rules which relate integrals of photoabsorption cross sections to constants of nucleon structure, such as ...

$Q^2 = 0$, Photoproduction

GDH Sum Rule

$$-\frac{\kappa^2}{4} = \frac{M^2}{2\pi e^2} \int_{\nu_0}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{\nu} d\nu$$

Baldin Sum Rule

$$(\alpha + \beta)_N = \frac{1}{4\pi^2} \int_{\nu_0}^{\infty} \frac{\sigma_{1/2} + \sigma_{3/2}}{\nu^2} d\nu$$

Where κ : anomalous magnetic moment of the nucleon.

α , β : electric and magnetic polarizabilities of the nucleon respectively.

ν_0 : pion photoproduction threshold

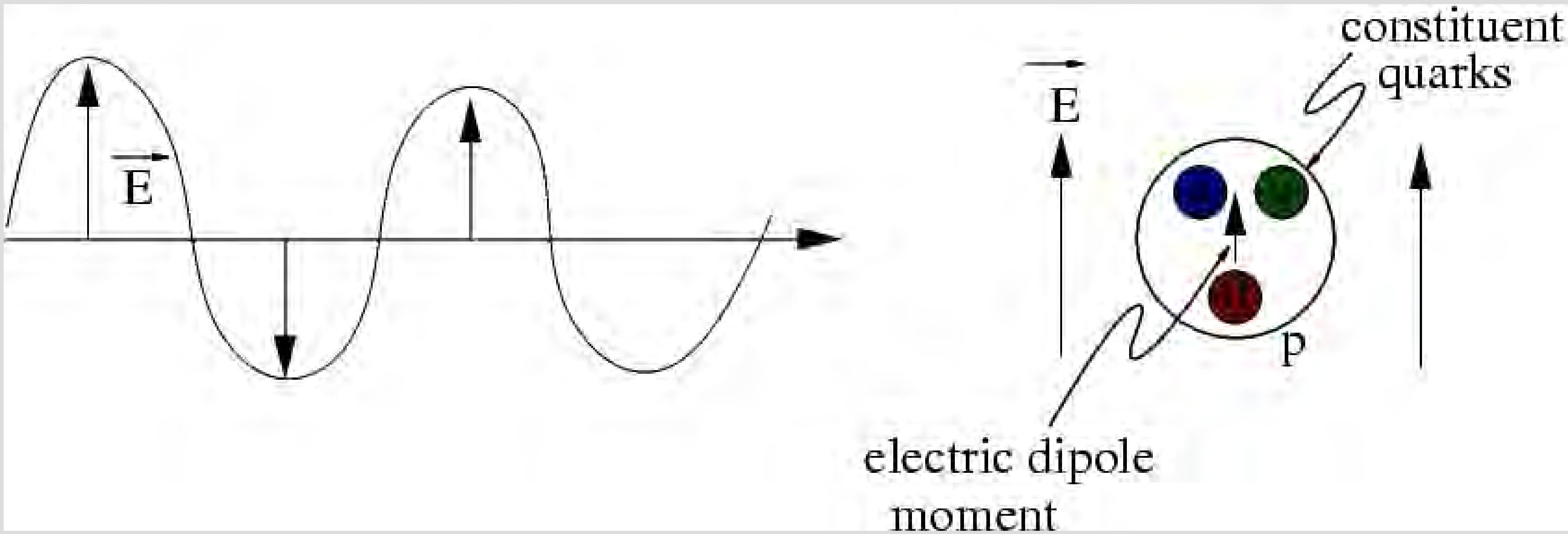
$\sigma_{1/2}$, $\sigma_{3/2}$: photoproduction cross section of 1/2 and 3/2 helicity states

For proton, $(\alpha + \beta)_p = (13.69 \pm 0.14) \cdot 10^{-4}\ \mathrm{fm}^3$

(D. Babusci et al., Phys.Rev. C57, 1998)

Electric and Magnetic Polarizabilities

Simplistic picture of the electric polarizability α



Electric field induces electric dipole moment with

$\alpha = \delta d / \delta E$ (derivative of dipole moment with $\vec{E}$)

The magnetic polarizability β is defined similarly in terms of magnetic dipole moment and $\vec{B}$.

Generalized Sum Rules

In inclusive electron-nucleon scattering, optical theorem =>

photoabsorption cross sections are related to Im(VVCS amplitude)

Doubly virtual Compton scattering

$Q^2 > 0$, electroproduction

Generalized GDH Sum Rule

$$I_{GDH}(Q^2) = \frac{M^2}{\pi e^2} \int_{\nu_0}^{\infty} \frac{K}{\nu} \frac{\sigma_{TT}}{\nu} d\nu = \frac{2M^2}{Q^2} \int_0^{x_0} g_1 dx$$

Generalized Baldin Sum Rule

D. Drechsel, B. Pasquini, M. Vanderhaeghen
hep-ph/0212124

$$\alpha(Q^2) + \beta(Q^2) = \frac{1}{2\pi^2} \int_{\nu_0}^{\infty} \frac{K}{\nu} \frac{\sigma_T}{\nu^2} d\nu = \frac{e^2 M}{\pi Q^4} \int_0^{x_0} 2xF_1 dx$$

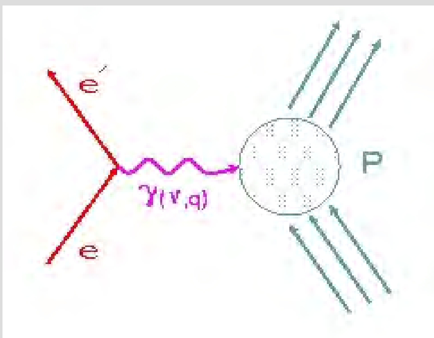
Where $\sigma_{TT} = \sigma_{3/2} - \sigma_{1/2}$ and $\sigma_T = \sigma_{3/2} + \sigma_{1/2}$

- $Q^2 = 0$ these integrals are related to static electromagnetic properties of nucleons,
- Large Q^2 they are proportional to moments of DIS structure functions => pQCD.
- $Q^2 \sim 10^2$ MeV described by χ PT (LQCD?)

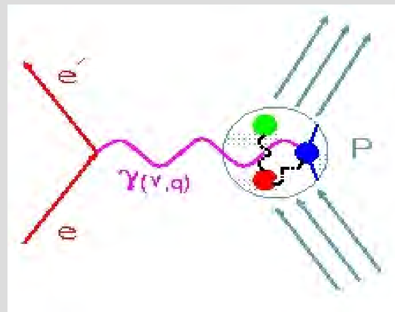
Inclusive e + p → e + X scattering

Single Photon Exchange

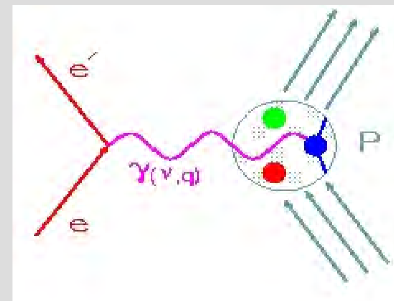
Elastic



Resonance



DIS



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

Γ : flux of transversely polarized virtual photons

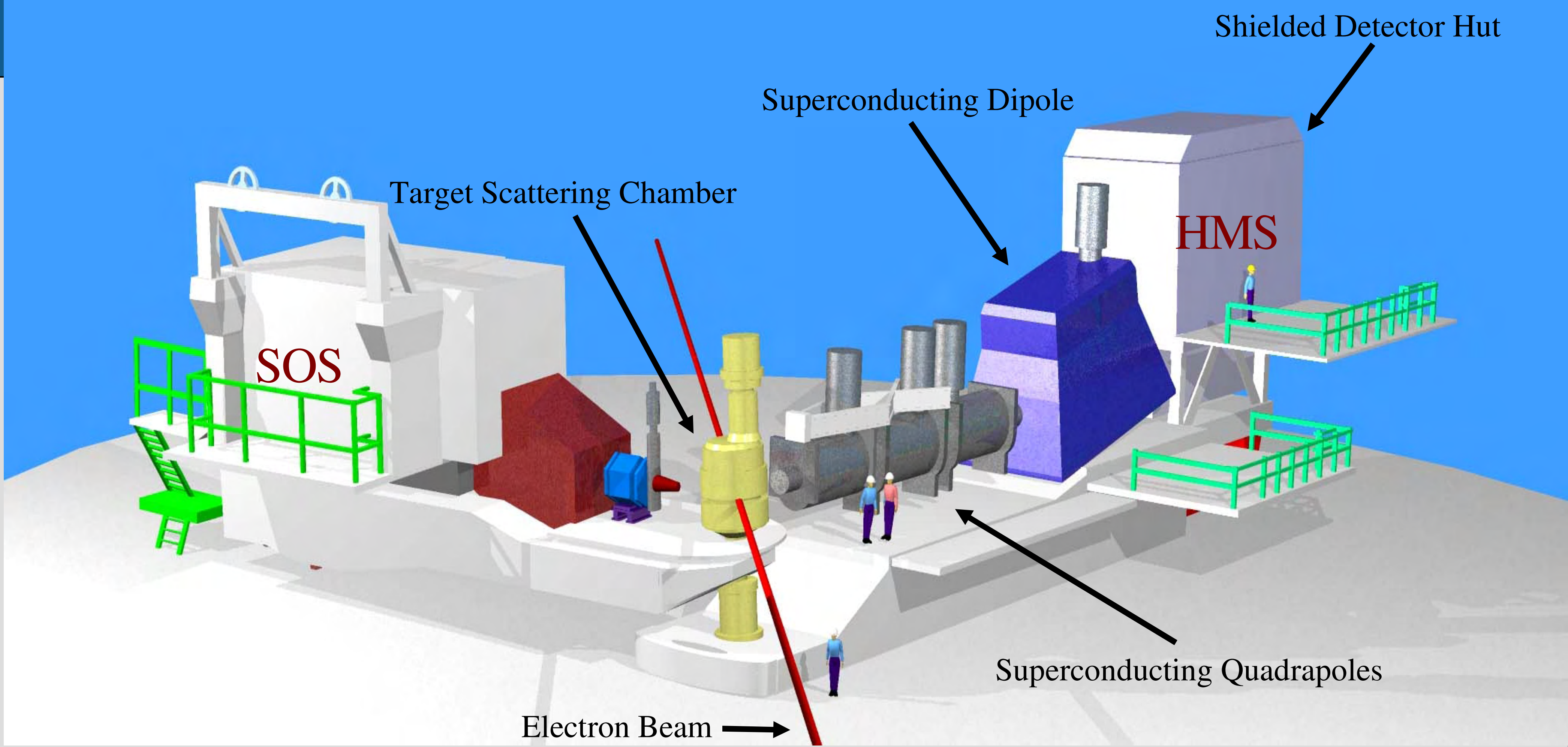
ε: relative longitudinal polarization

Alternatively:

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

$$\sigma_{mott} = \frac{\alpha^2 \cos^2(\theta/2)}{4E^2 \sin^4(\theta/2)} \qquad R = \frac{\sigma_L}{\sigma_T} = \frac{F_L}{2xF_1} \qquad F_L = (1 + \frac{4M^2x^2}{Q^2})F_2 - 2xF_1$$

JLAB HALL C

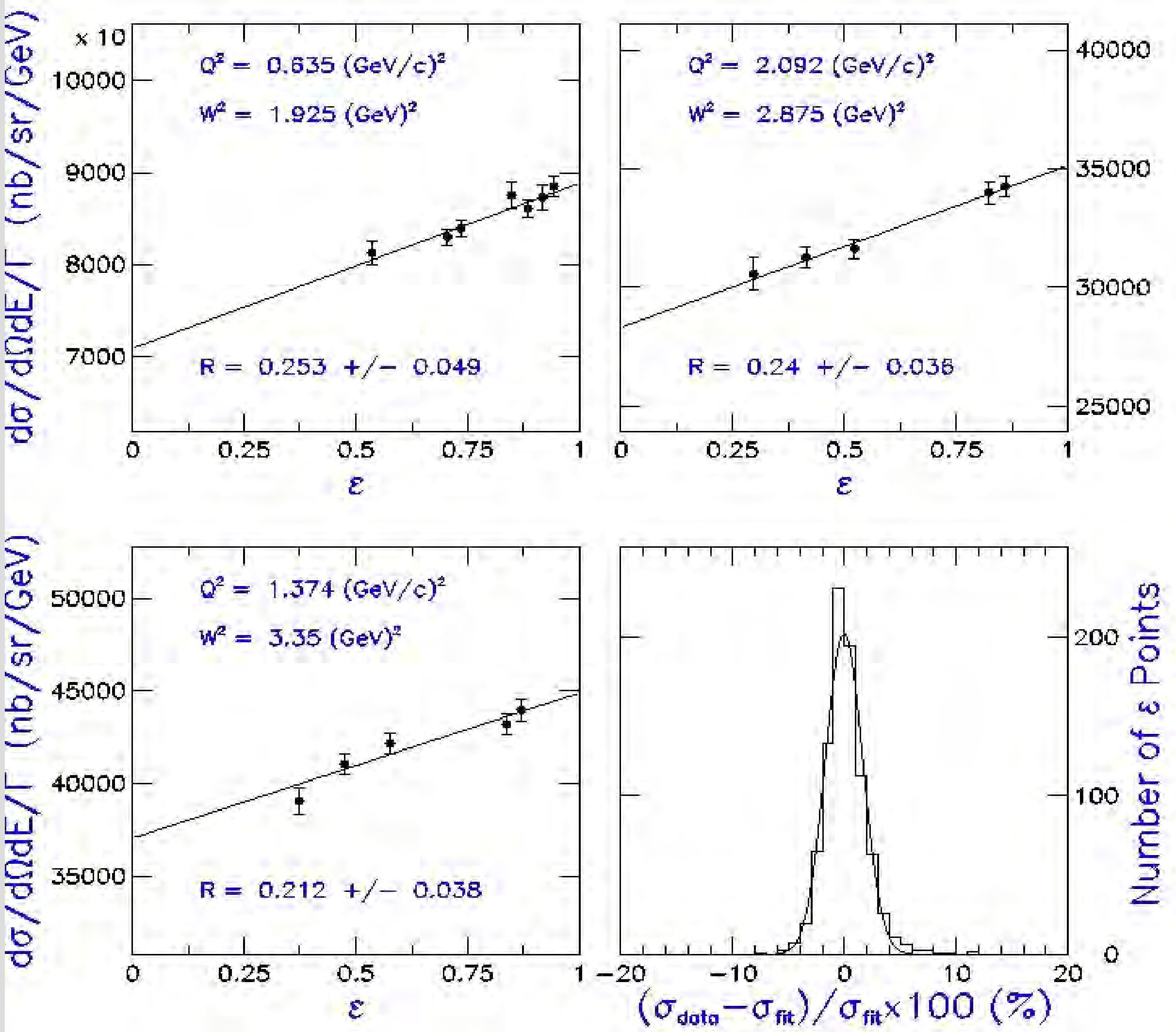


Shielded Detector Hut
Superconducting Dipole
Target Scattering Chamber
HMS
SOS
Superconducting Quadrapoles
Electron Beam

E94-110 L/T Separations

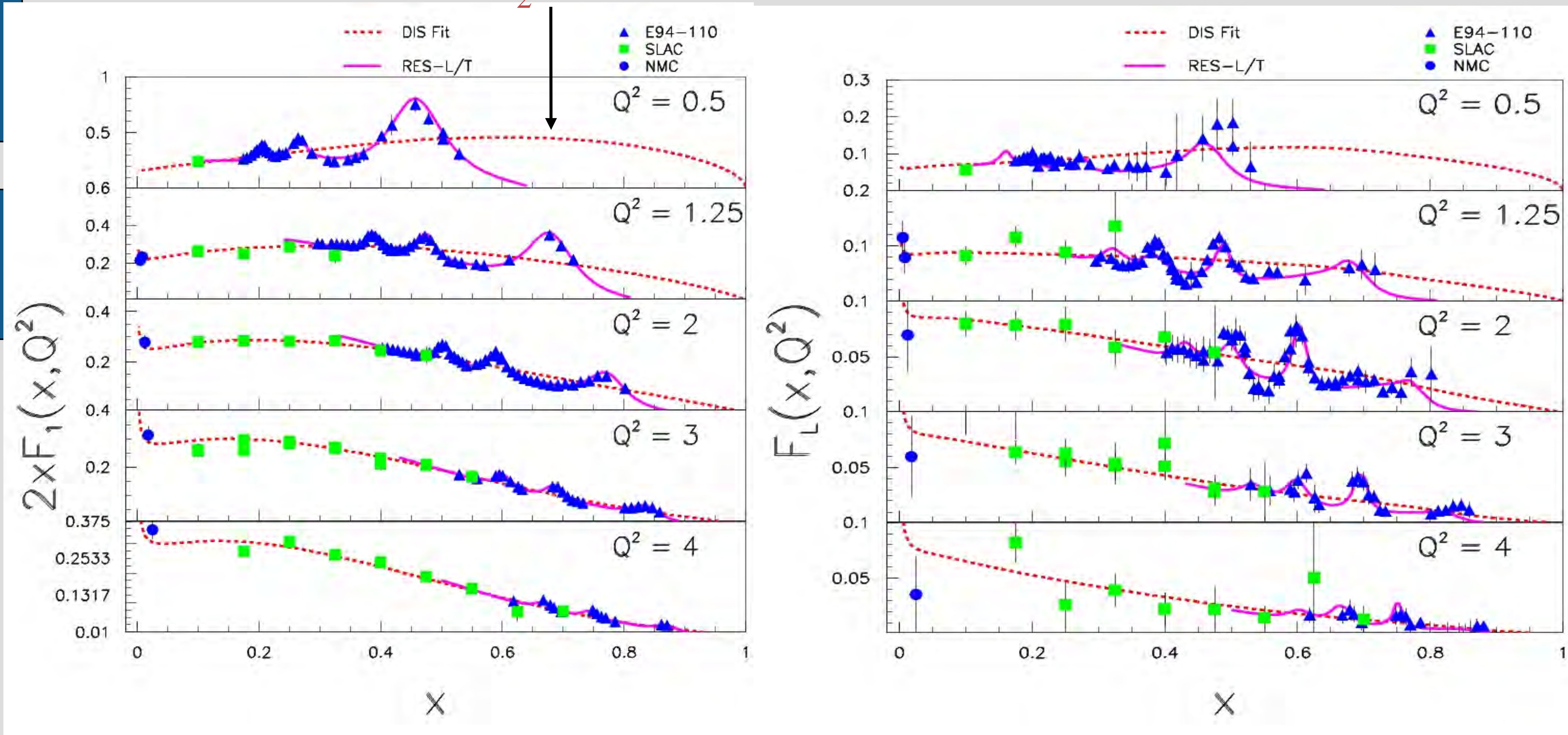
- Over 180 separations total (most with 4-5 ε points)
- Small movement in Q^2 is sometimes needed
- Spread of points about the linear fits is fairly Gaussian with $\sigma \sim 1.6$ %

Consistent with the estimated E94-110 pt-pt uncertainties.



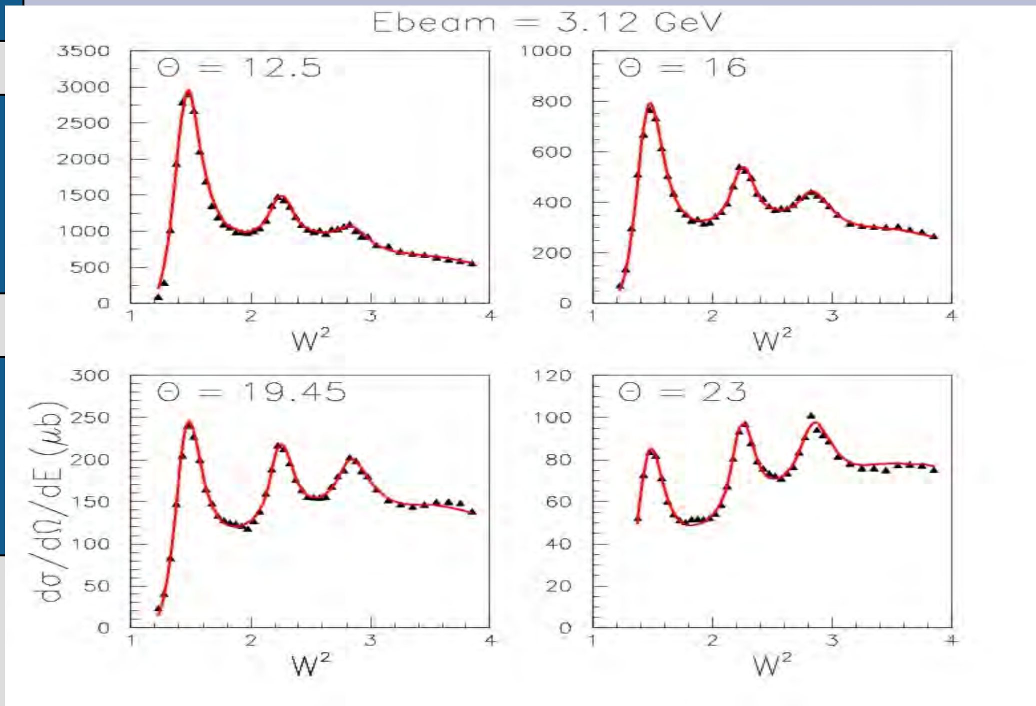
Proton L/T Separated SFs (E94-110)

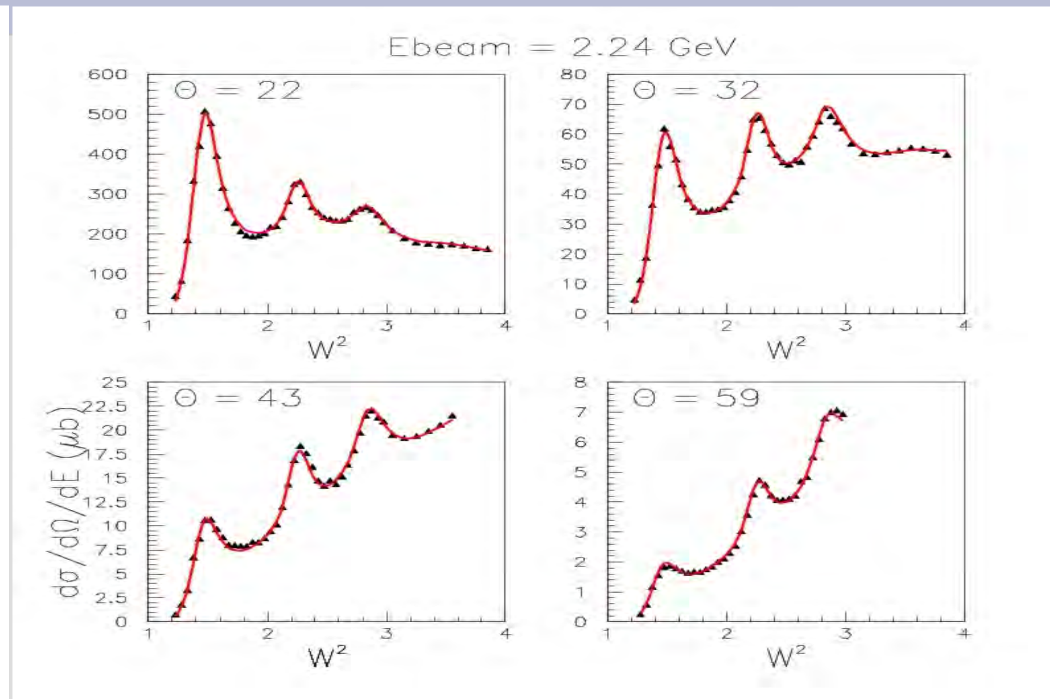
DIS fits to F_2 (ALLM97) and R (R1998).

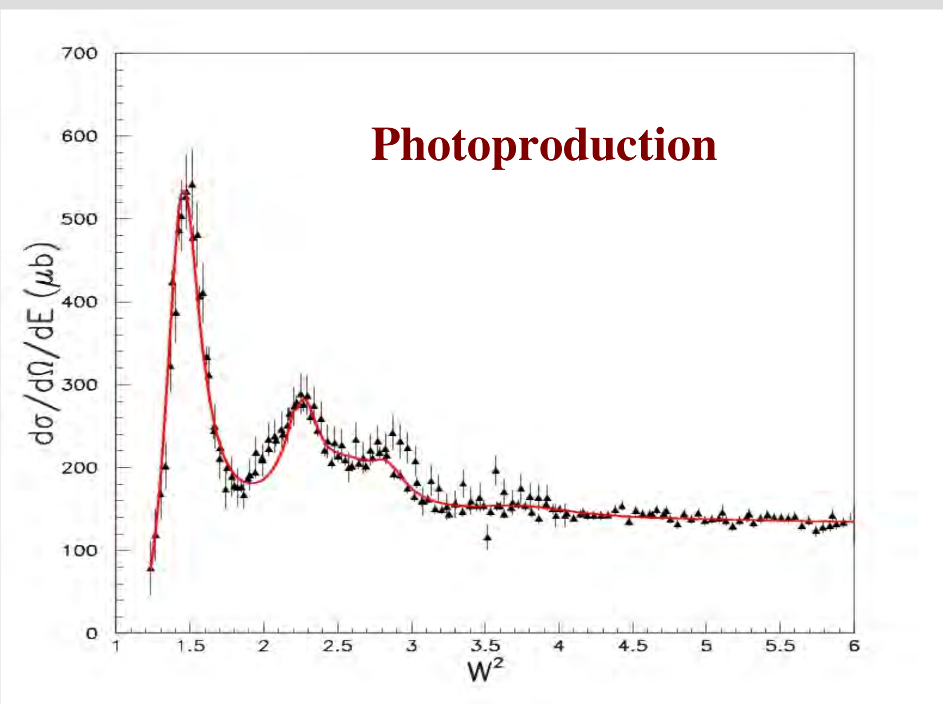


- Large body of high precision resonance data ($0.3 < Q^2 < 4.5$) - links smoothly to DIS data set.
- Quark-Hadron Duality observed in both transverse and longitudinal structure functions –
average in RR has same x and Q^2 dependence as expected from DIS fits.
- Sparse L/T separations for deuterium and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

Fit to Proton Resonance Region Data

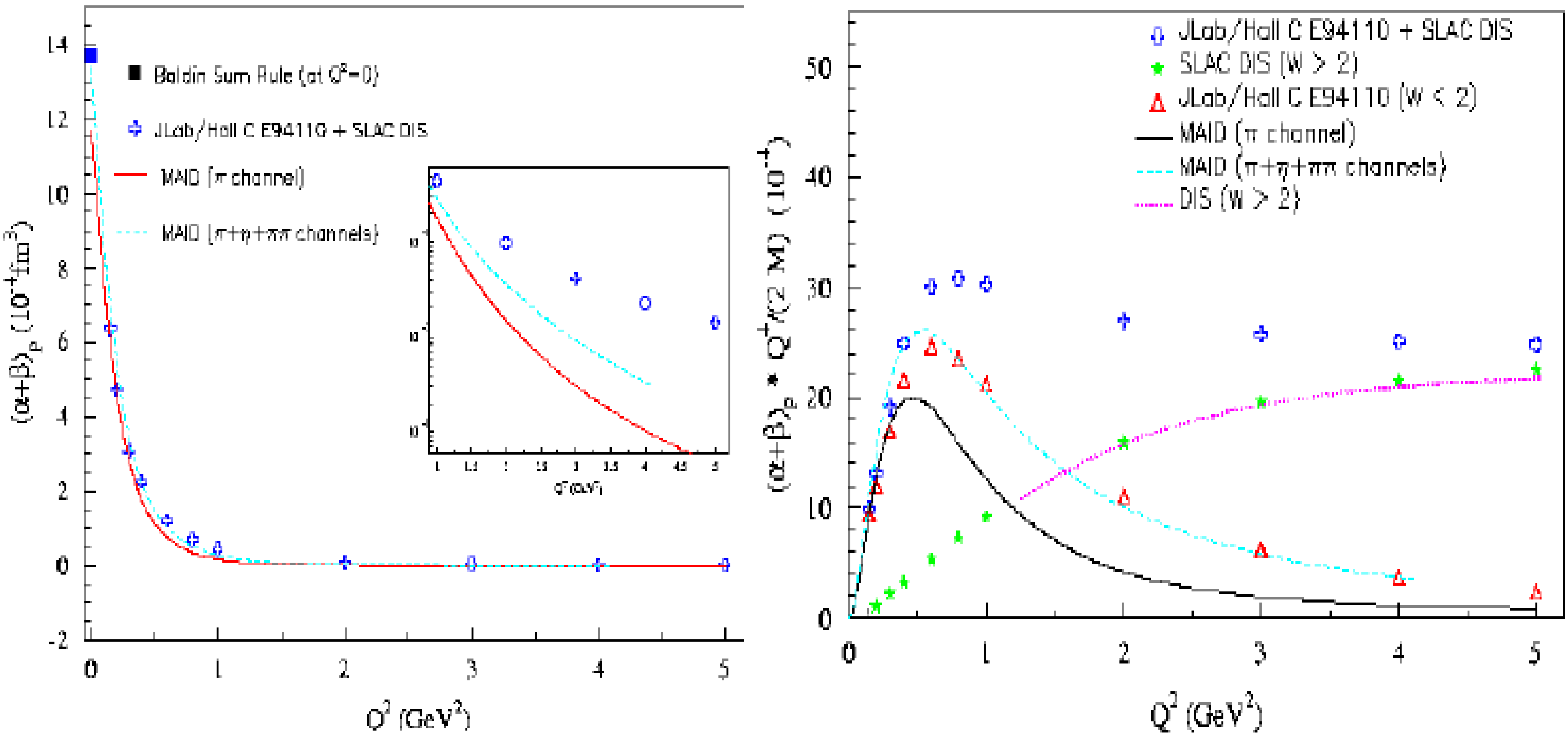






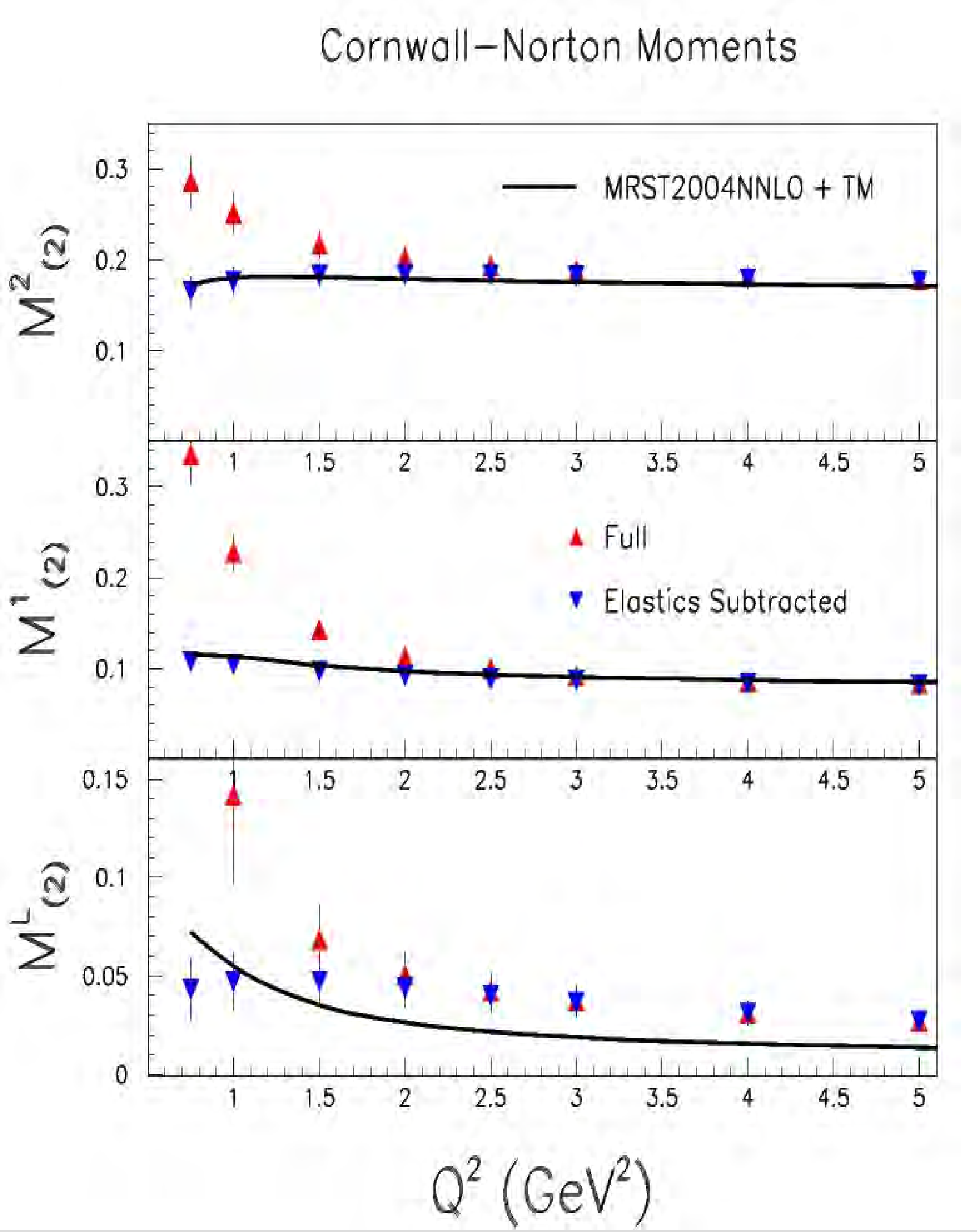
- Energy dependent Breit-Wigners with current best guess of dominant resonances, including decay modes and branching fractions.
- σ_T constrained by photoproduction data.
- Preliminary 2003 Hall C data used for $5.5 < Q^2 < 7.5$
- Fit typically reproduces data to better than 3%.
- Fit available at www.jlab.org/~christy/cs_fits/cs_fits.html

Q^2 Evolution of Generalized Baldin Sum Rule for Proton



- Generalized Baldin Integral goes smoothly from $Q^2 > 0$ to real photon point ($Q^2 = 0$), unlike the generalized GDH sum rule.
- E94-110 data ($W < 2$) is consistent with MAID ($\pi + \eta + \pi\ \pi$) model (resonance estimate) at $0.6 < Q^2 < 5$.
- At $Q^2 < 1$, sum rule value is dominated by resonance contribution (hadronic picture); at $Q^2 > 2$, DIS contribution dominates (quark-gluon picture). Transition occurs at $1 < Q^2 < 2$.

Experimental lowest Moments of Proton L/T SFs



<u>After subtracting known higher-twist component – the elastic contribution</u>

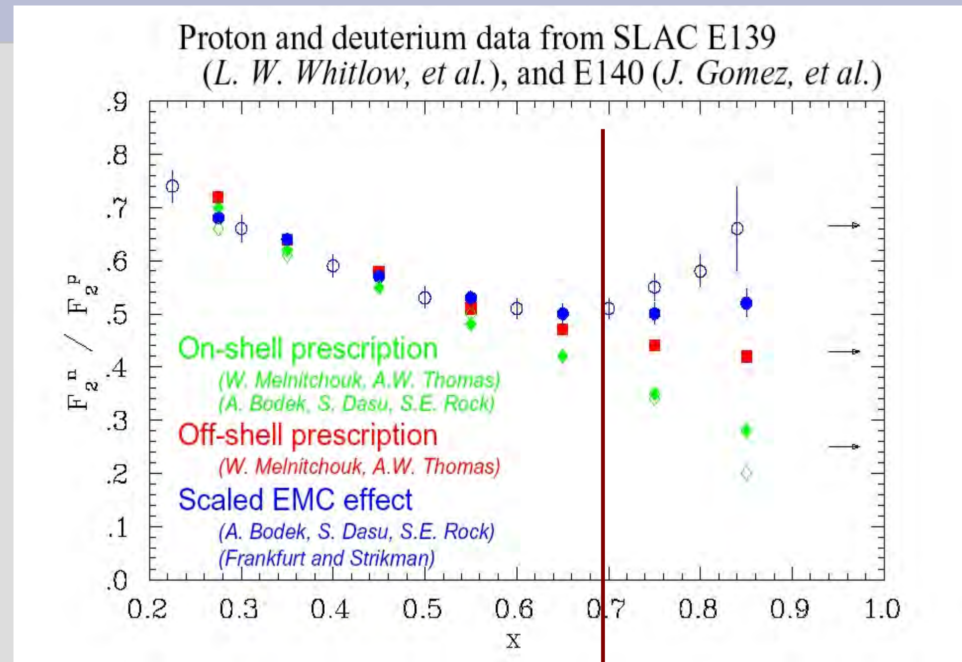
- pQCD using MRST PDFs describes data well down to remarkably low Q^2 for F_2, F_1!

  => global duality observed to high degree!

- For F_1 this is the generalized Baldin integral.

  => parton and hadron degrees of freedom give the same answer!

Extraction of Baldin sum rule for Neutron

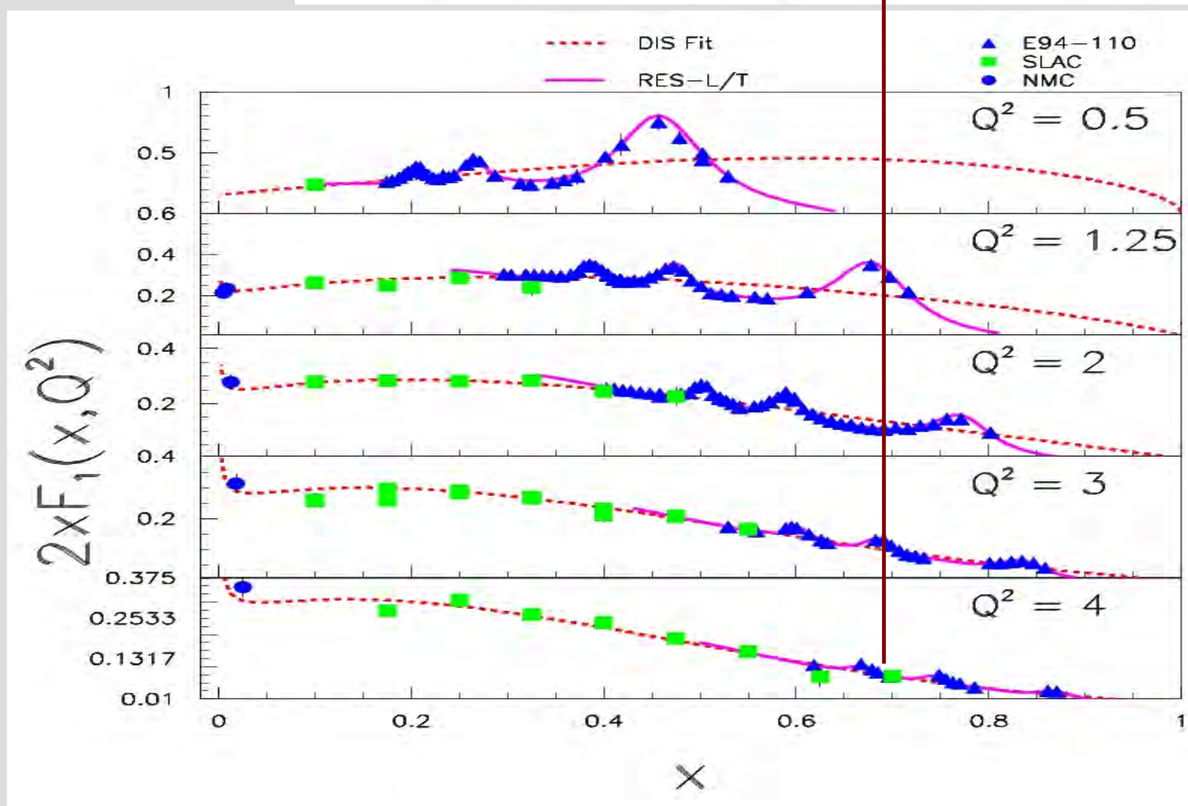


At low Q^2, data largely at x < 0.7

❖ can extract low Q^2 *neutron* moments with minimal uncertainties from nuclear corrections!

Use BoNuS and HallC deuteron data to determine best nuclear correction prescripton.

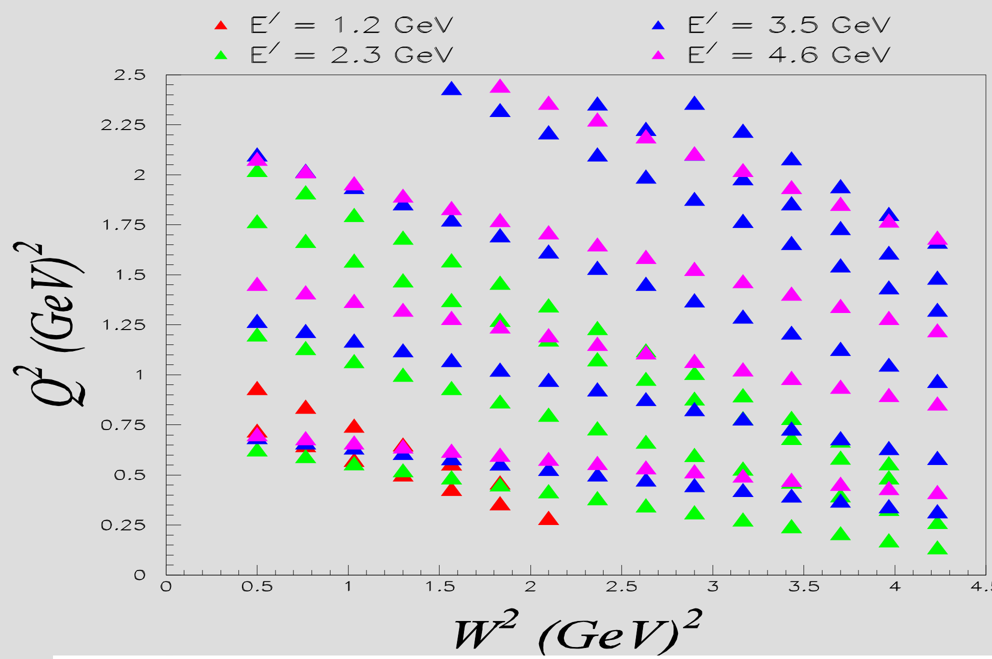
❖ Neutron L/T SFs can be extracted using proton and deuteron L/T SFs.



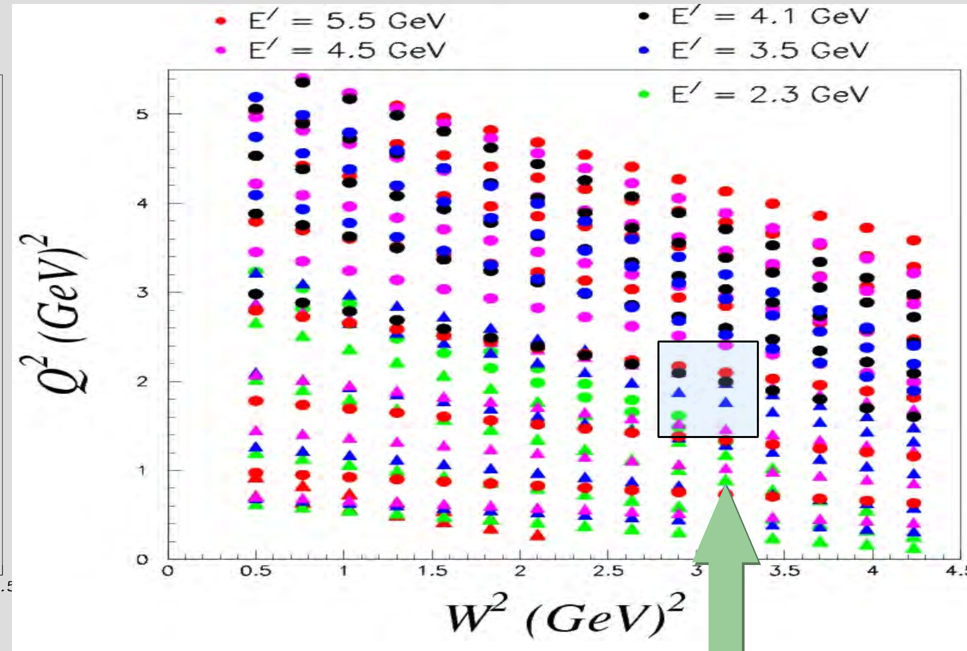
L/T separated structure functions on deuterium and nuclei (JLab E02-109, E04-001 and E06-009)

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

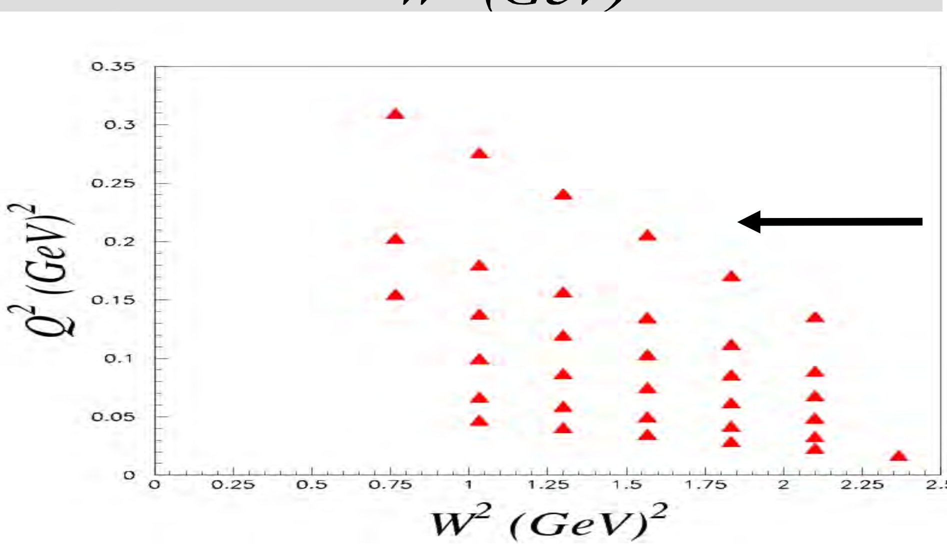
Data from Jan '05



Approved future running



L/T separations where multiple energies.

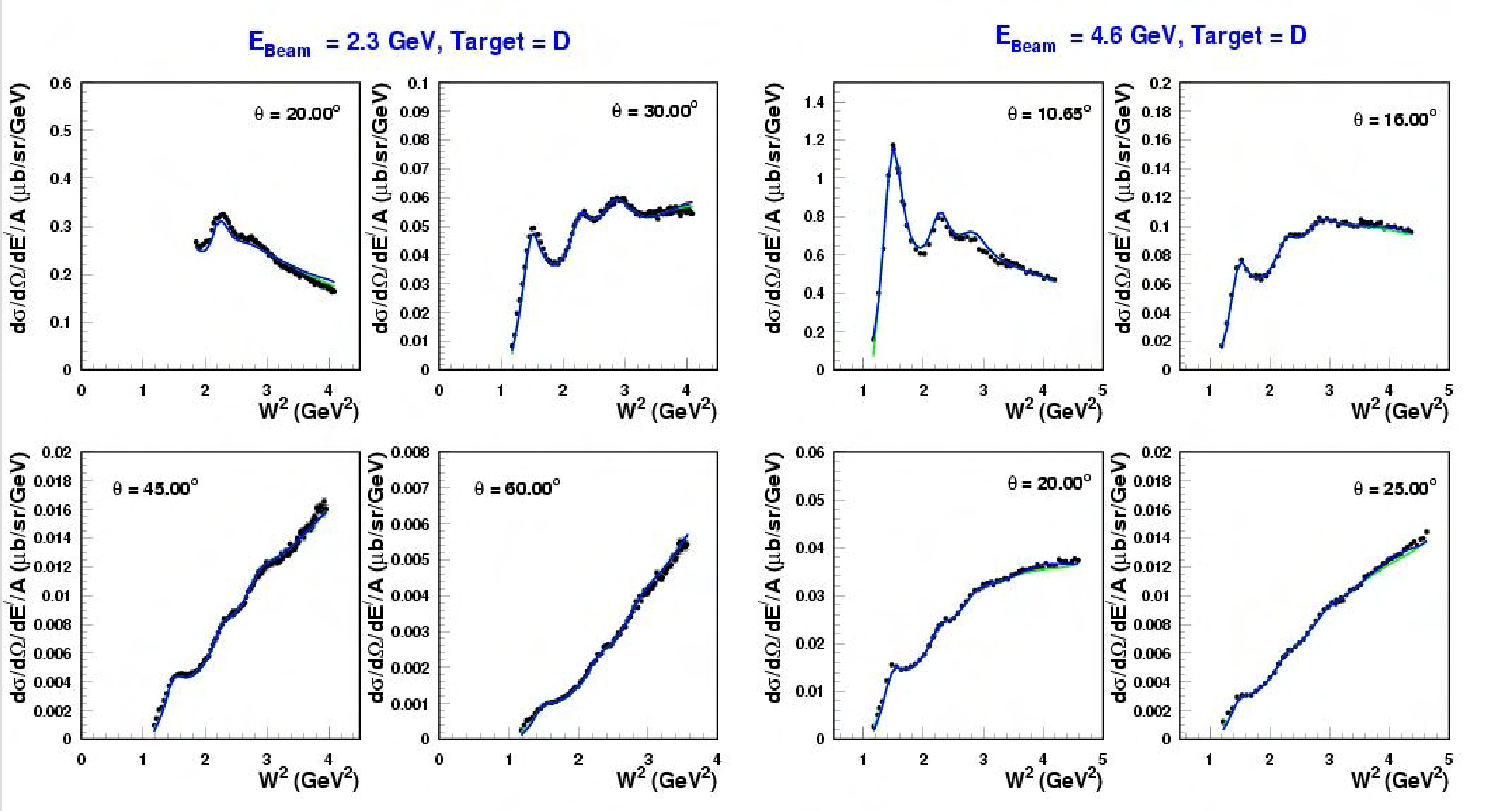


Low Q^2 modeling data (EM SF input for ν cross section modeling)

- Targets: H,D, C, Al

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

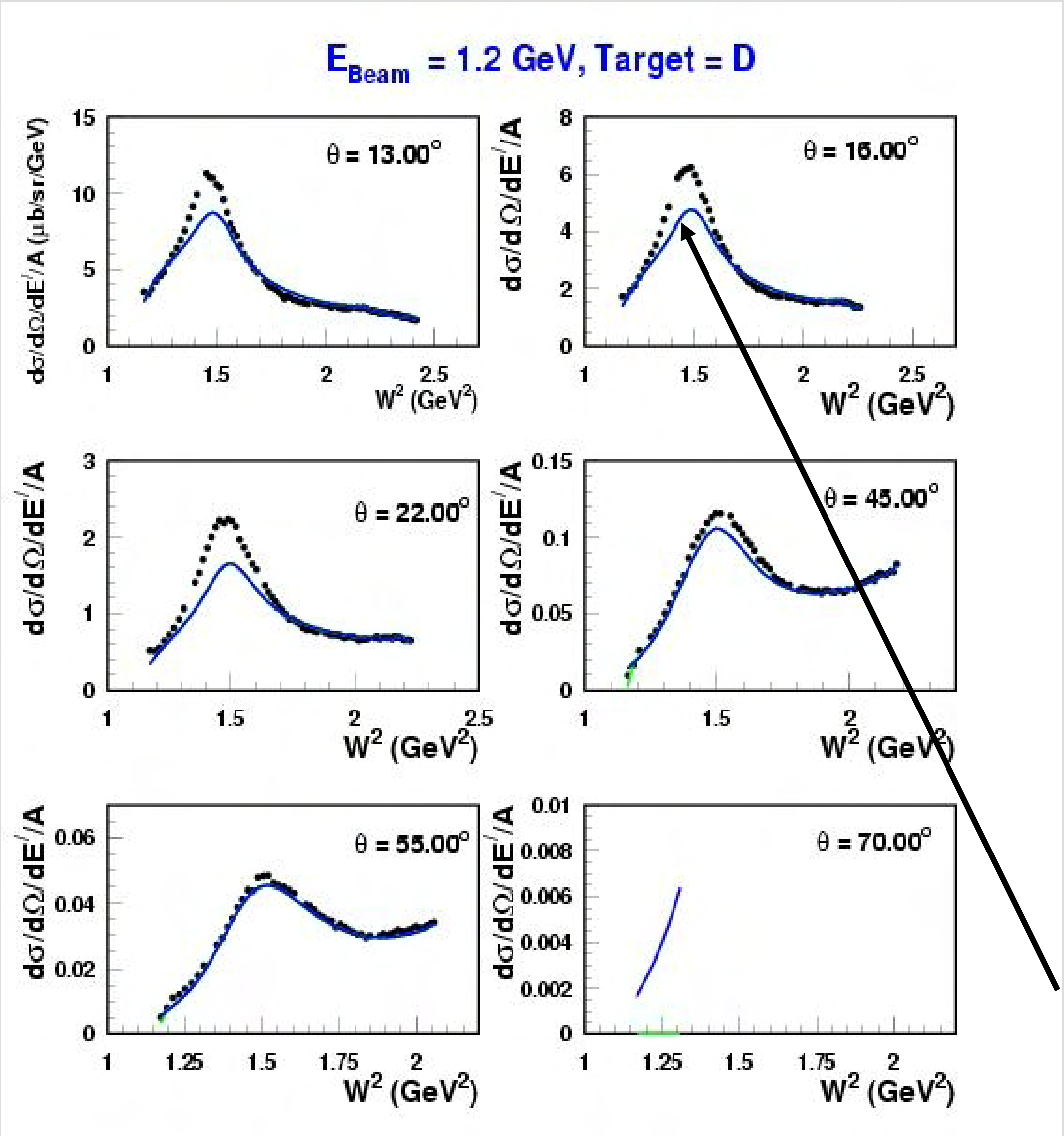
Jan'05 Preliminary Cross Section Results

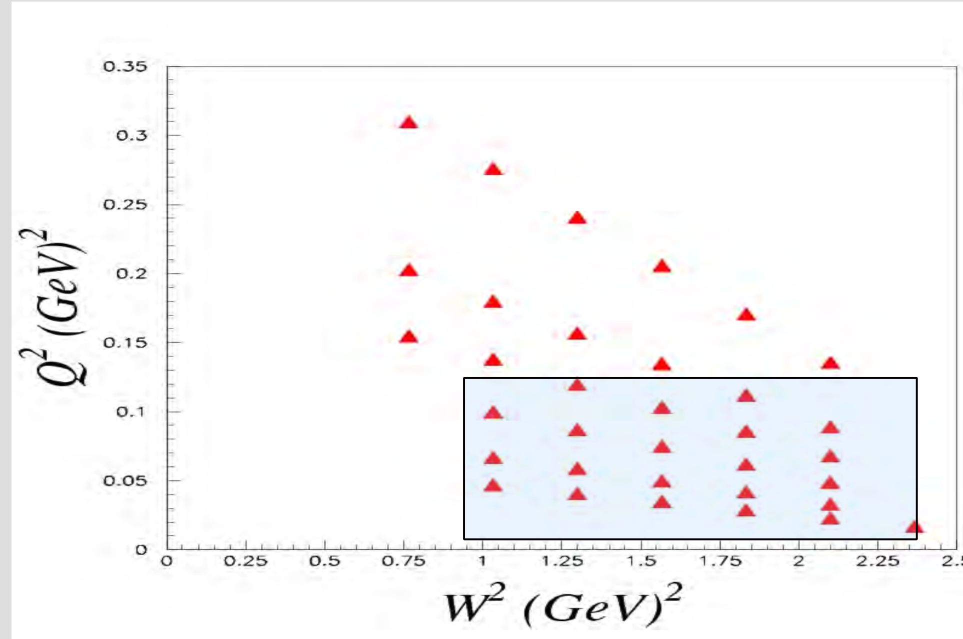


- Error bars are statistical only.
- Only inelastic data shown but Quasielastic & nuclear elastic was taken..

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

Low Q^2 Cross Sections





- **Low Q^2 data (< 0.15 GeV^2) will provide ~3-8% 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.**

Data will provide an important constraint on photoabsorbtion cross sections near $Q^2 = 0$ for both the proton **and** neutron!

The Baldin sum rule only gives **$\alpha + \beta$**

$\alpha - \beta$ can be determined from low energy backward angle RCS.

However, *J. Berabou & R. Tarrach 1975*

$$\alpha = (e^2/4\pi)\kappa^2 + 1/(2\pi^2)\int_{\nu_{th}}^{\infty} d\nu \lim_{Q^2 \to 0} \frac{\sigma_L(\nu, Q^2)}{Q^2}$$

Extract **α** from a measurement of the *slope* of **σ_L** at **$Q^2 = 0$**

Need accurate L/T separations at low Q^2 for entire W^2 range.

*It would be interesting to test this relation for the **proton** and **neutron**.*

Summary

- E94-110 performed a precision inclusive cross section measurements in the nucleon resonance region.

- Measured the Q^2 evolution of generalized Baldin sum rule, which goes smoothly from finite Q^2 to real photon point ($Q^2 = 0$).

- Observed the transition from hardonic description to partonic description of generalized Baldin sum rule at $1 < Q^2 < 2$.

- Low Q^2 *deuterium* L/T measurements are being analyzed as well as *neutron* cross section measurements from the BoNuS experiment.

- Possibility of extracting α from low Q^2 L/T separations.