JUPITER e-A - L/T (Longitudinally and Tranverse) Separated Structure Functions at low Q^2 on Nuclei at Jefferson Lab

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E04-001/E02-109~ 2 weeks of beam time in Hall C during Jan'05 (~1/3 of approved time) to measure the low Q^2 ($0.3 < Q^2 < 2$) part of a continuing ongoing program:

E94-110 : L/T separated structure functions protons -done

E02-109: L/T separated structure functions deuterons - new

E04-001: L/T separated structure functions on nuclei - new

(part of *JUPITER* e-A */MINERvA Program*)

Also taken during Jan 05 run:

Dedicated very Low Q^2 cross section measurements for the neutrino community K2K, MiniBoone, MINOS, MINRvA (part of JUPITER* e-A */MINERvA Program).

JUPITER e-A Physics includes:

- $(0.3 < Q^2 < 5)$ Resonance Region F_1 and F_L for deuterons and nuclei (*Fundamental*) & combine with proton data and extract neutron data - Related by CVC to *νA Vector* F_1 F_L

- QCD moments of deuteron, nuclei -
  & combine with proton-data and extract neutron data.
- Quark-Hadron duality in nuclei.

- Nuclear dependence of F_1 and F_L in Resonance Region for a Range in Q^2.
- E.g. for excess-pions in nuclei

- Quasielastic scattering on nuclear Targets at Low Q2 (in collaboration with the neutrino physics community)
- Coulomb Sum Rule

Neutrino Experiments Need:

- **Neutrino experiments need good models of cross sections and final states to extract cross sections**
  - **Neutrino Monte Carlo models *must* be based on understanding of the physics, and checked by data**
- **A collaborative program between the high and medium energy communities to develop reliable global models linking electron and neutrino scattering measurements**

- **Nuclear data necessary for comparison with neutrino measurements**
- **No L/T separated structure function measurements exist on nuclei in the resonance region**
- **In the resonance region, nuclear effects may be large, different from the DIS region, and Q^2 dependent.**

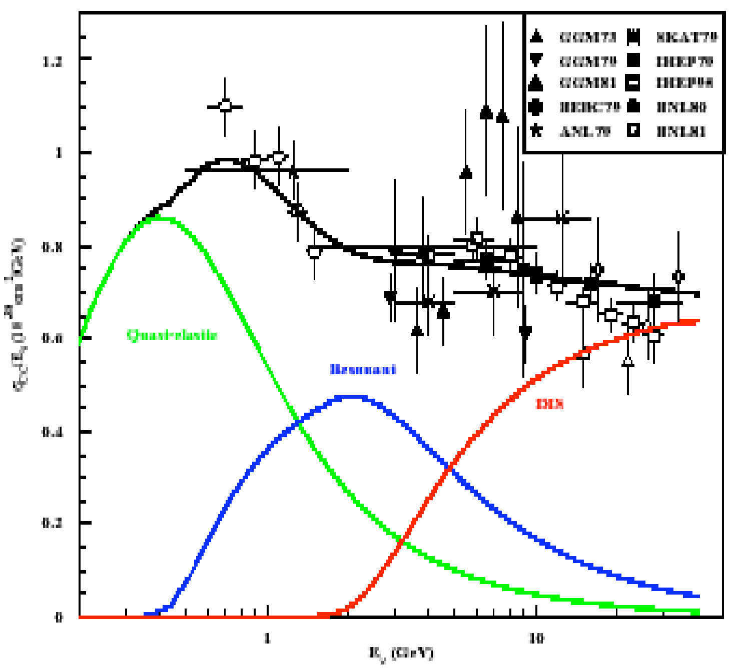
R =L/T directly effects neutrino, anti-neutrino cross section models - aim at ΔR =+-0.02 (factor of 10 better than previous data)

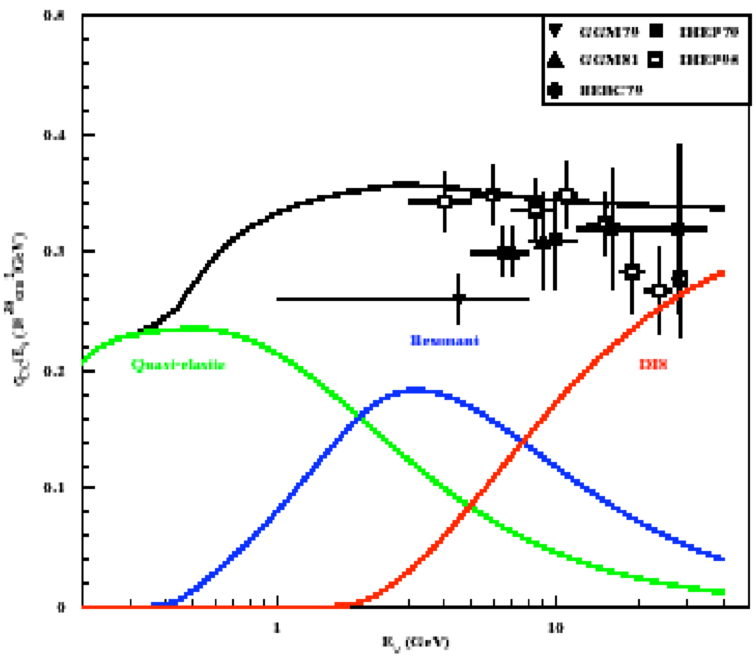
$\sigma^{\nu N}$ fractional error ~ 0.5ΔR

$\sigma^{\nu N}$ fractional error ~ 1.5ΔR

ΔR = +-0.2 implies *10% error on* $\sigma^{\nu N}$, *30% error on* $\sigma^{\nu N}$

(Neutrino, Anti-neutrino cross sections / Energy) versus E





$$R = 2K/(Q+\overline{Q})$$

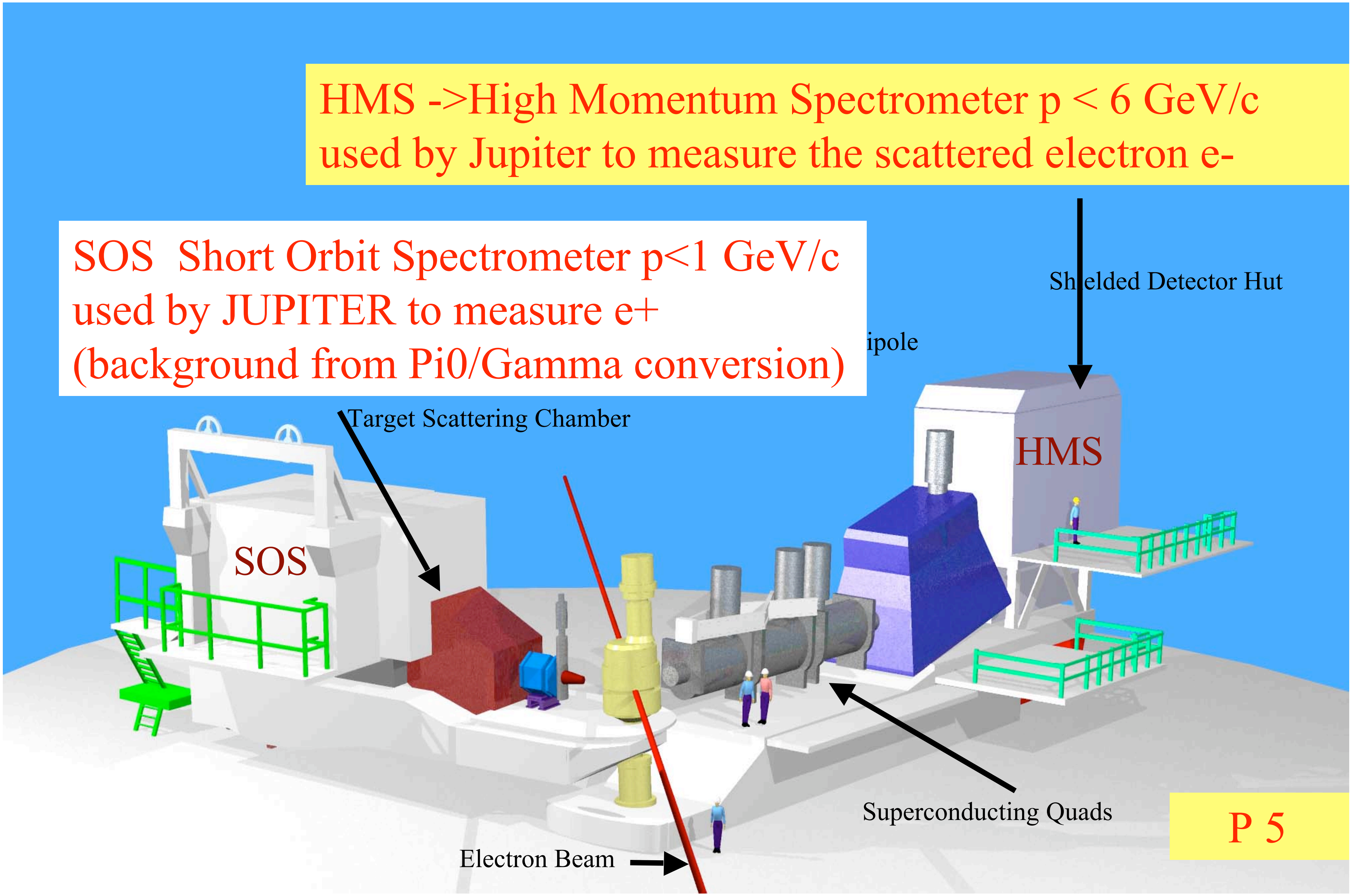
$$\sigma^{\nu N} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\left[Q^{\nu N} + (1/3)\overline{Q}^{\nu N} + K^{\nu N}\right]$$

$$\sigma^{\overline{\nu} N} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\left[\overline{Q}^{\overline{\nu} N} + (1/3)Q^{\overline{\nu} N} + K^{\overline{\nu} N}\right]$$

Jlab Hall C

HMS ->High Momentum Spectrometer p < 6 GeV/c
used by Jupiter to measure the scattered electron e-

SOS Short Orbit Spectrometer p<1 GeV/c
used by JUPITER to measure e+
(background from Pi0/Gamma conversion)

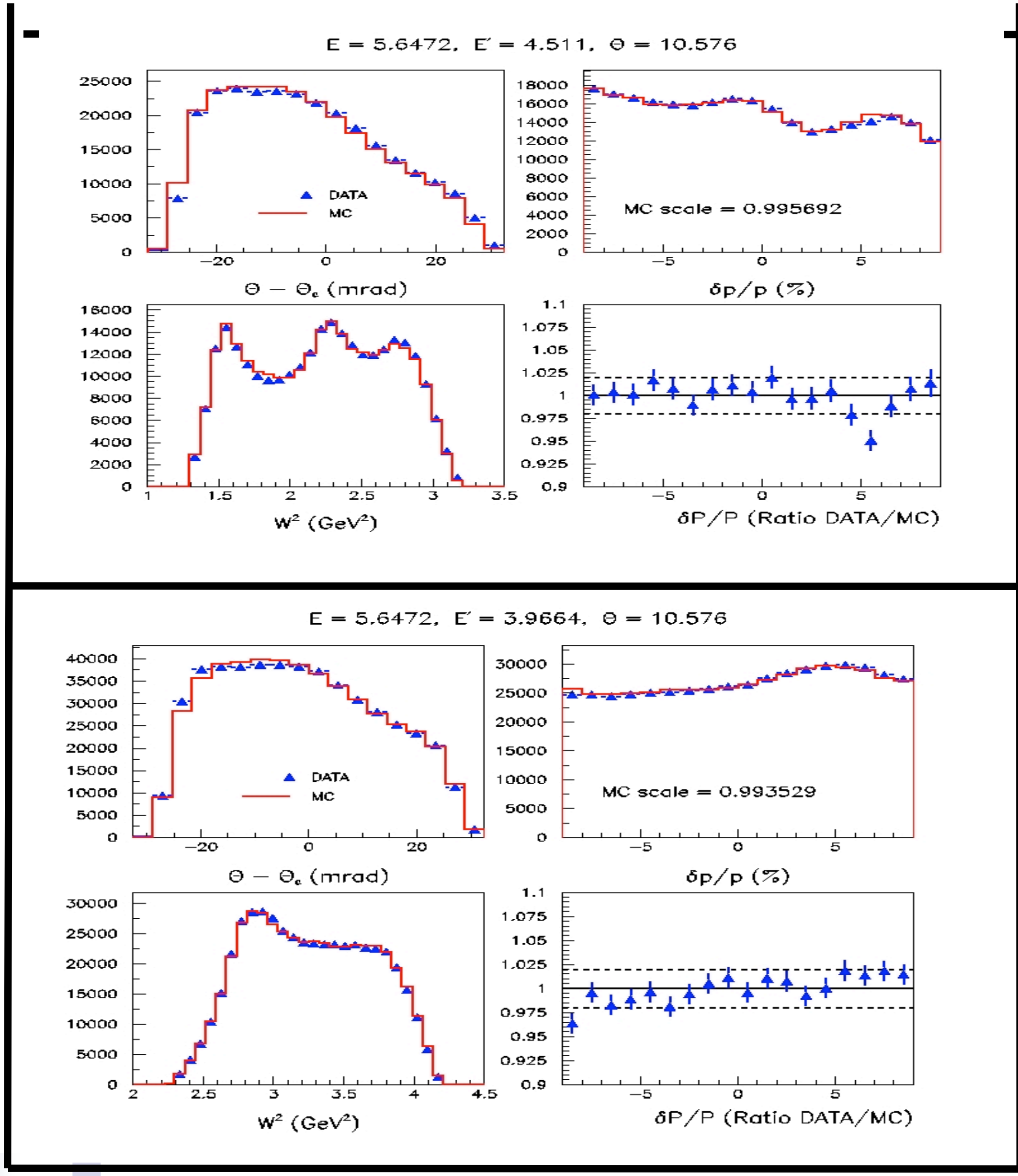


Hall C hosts the **High Momentum Spectrometer (HMS) and the Short Orbit Spectrometer (SOS)**. The acceptance is high (respectively 18% and 40%). The HMS spectrometer has been made to detect high momentum particles (up to 6 GeV/c protons).

The SOS is shorter and limited at 1 GeV/c,

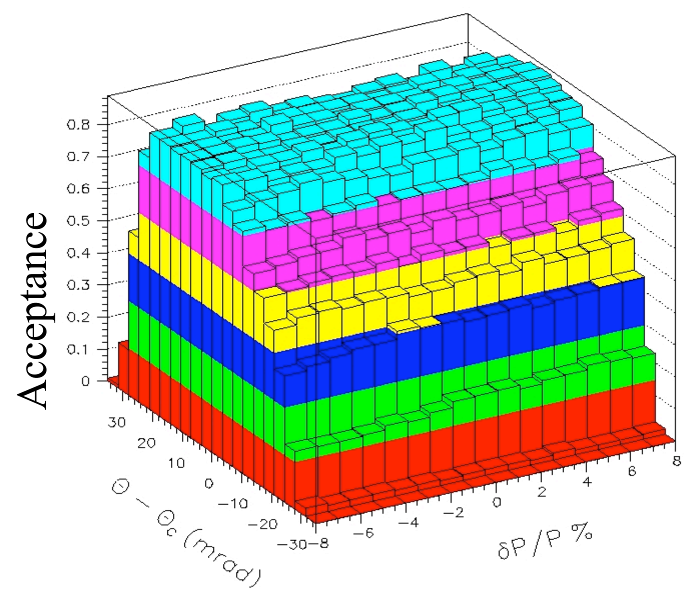
- **Additional technical details for Jlab experts,**
- **Need *stable* beam currents (60uA) and Beam Current Monitors - so keep current at this value**
- **For some small Q^2 C data, rates is very large => so reduce current< 10uA for these runs.**

Acceptance HMS Monte Carlo -Geometry and spectrometer modelling only



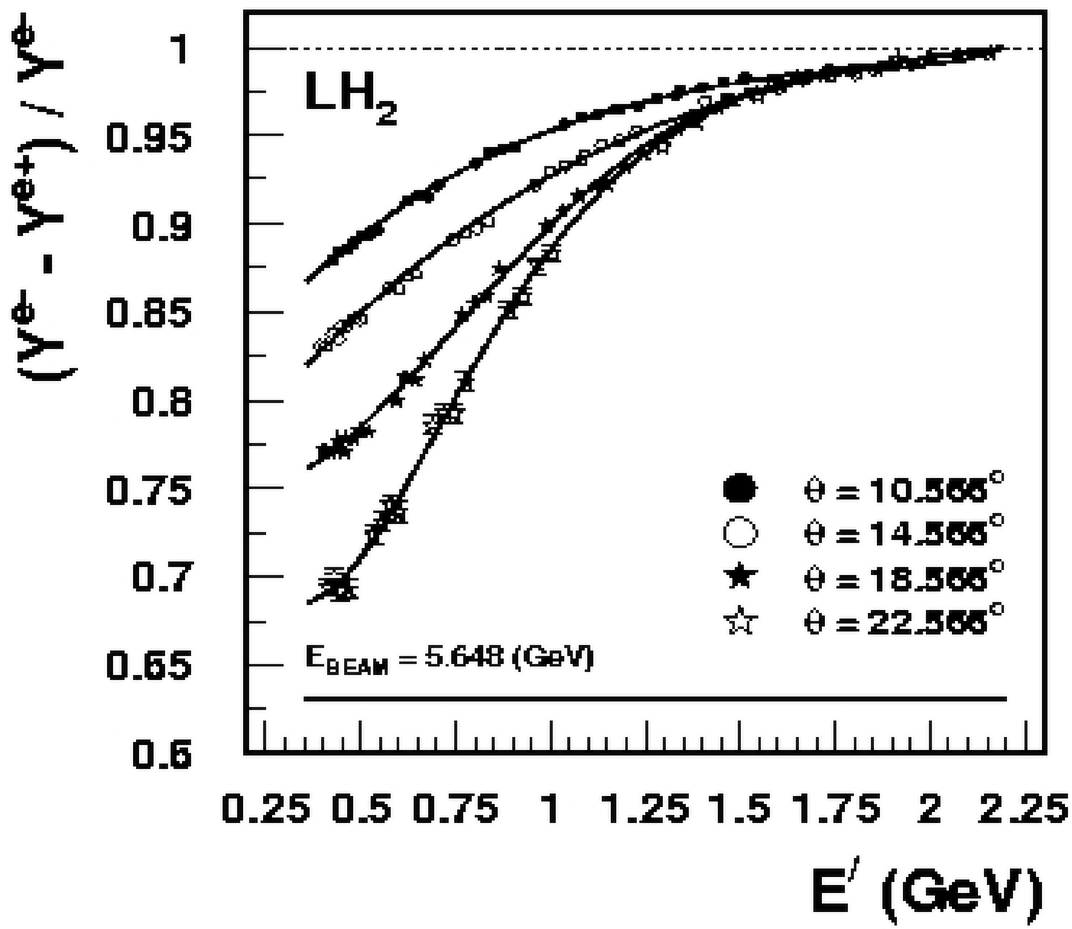
- Comparison of MC to E99-118 data using E94-110 resonance region model.

- Excellent agreement between different experiments!
- Acceptance is determined to < 1% pt-pt in the kinematics.



- MC not used for physics, just ray tracing

Charge Symmetric Background

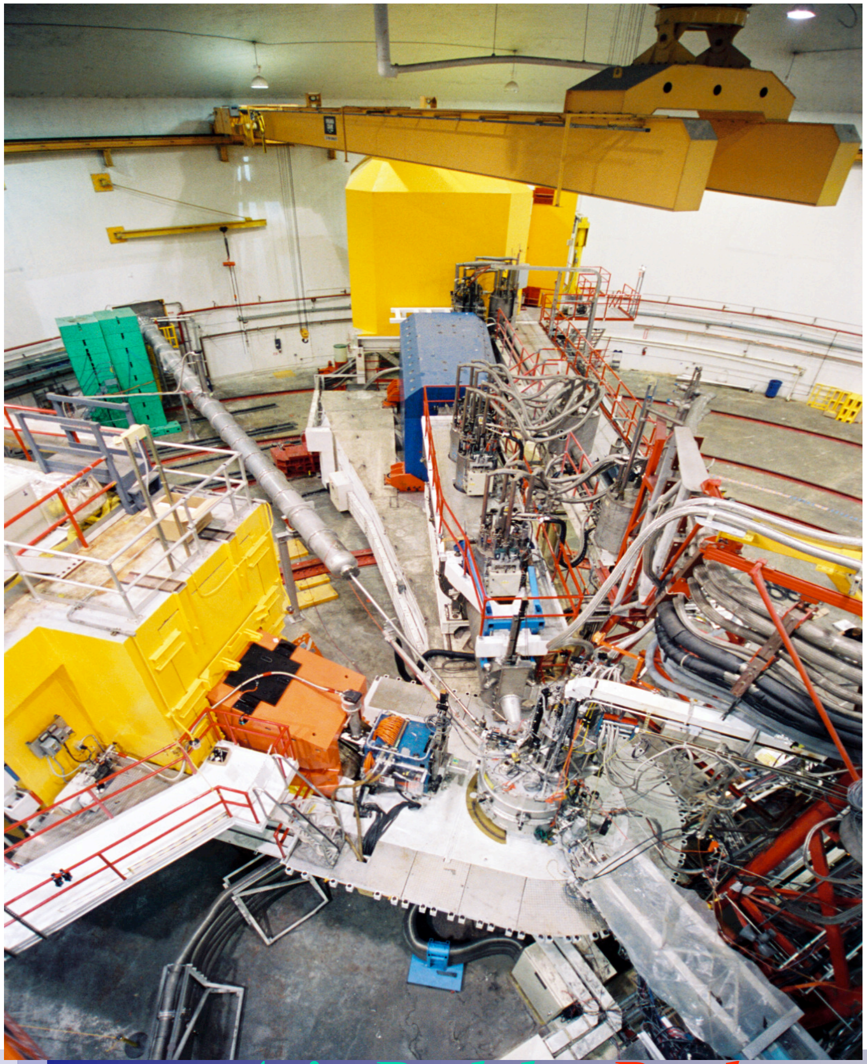


If the CS background is not too large then a multiplicative correction factor can be applied to the electron yield, as

$$CScor = (Y^{e-} - Y^{e+})/Y^{e-}$$

Plot from Vladas Tvaskis' PhD Thesis

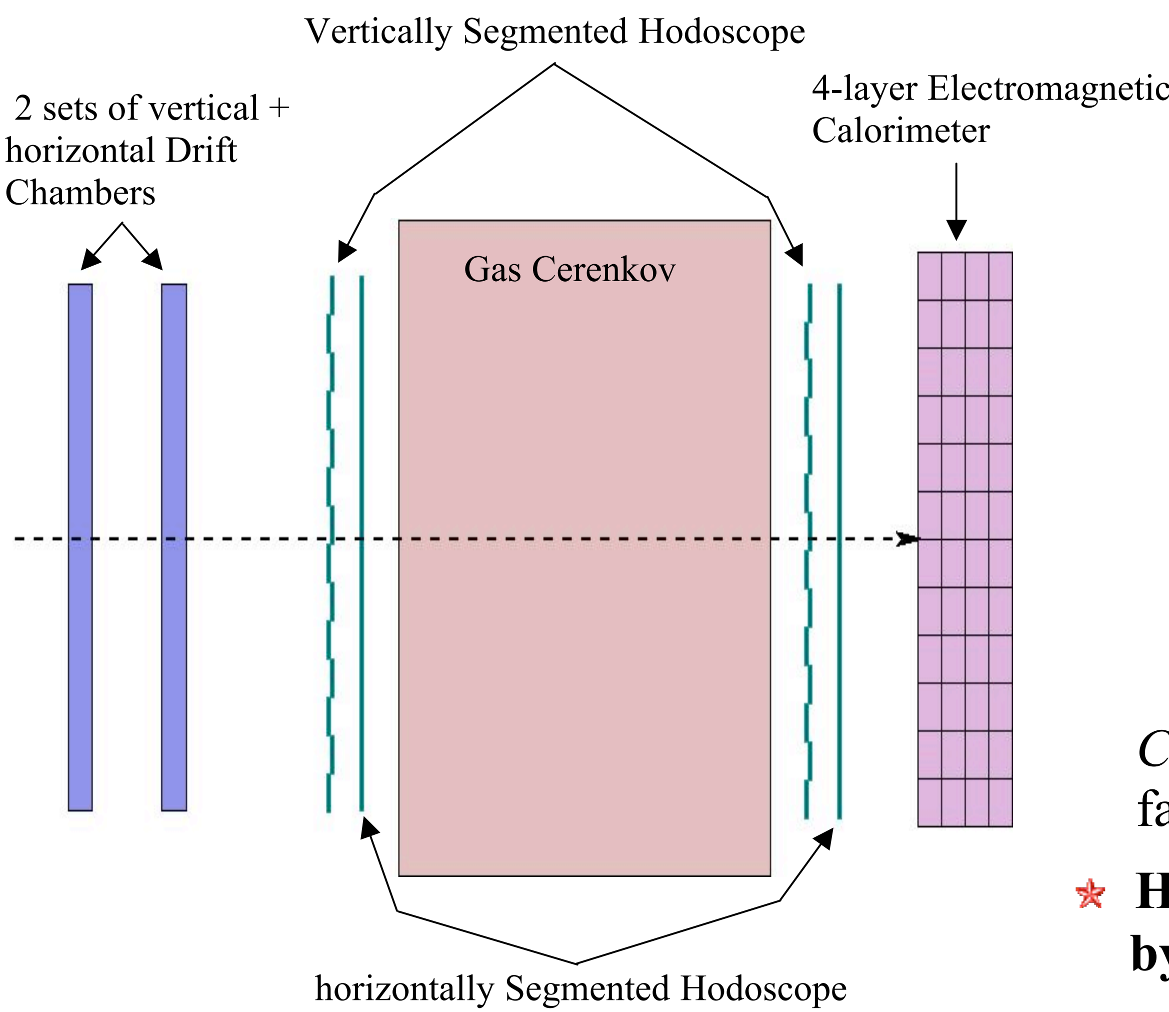
A Program of Inclusive Structure Function Measurements in Hall C at Jefferson Lab



- E94-110: L/T Hydrogen Resonance Region - all done
- 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 - JUPITER e-A
- E02-109: L/T Deuterium Resonance Region
- E02-109: x>1, A-Dependence
- E03-103: EMC effect
- Use all of these data to get a complete picture of the vector structure functions

HMS Spectrometer

Detector Stack
(view from above)



HMS Properties (pt-pt tune)

Kinematic Range:

Momentum:	0.5 – 7.5 GeV/c
Angular:	10.5^{O} - 80^{O}

Acceptance:

ΔΩ:	~6.5 msr
Dp/p:	+/-9%

Resolution:

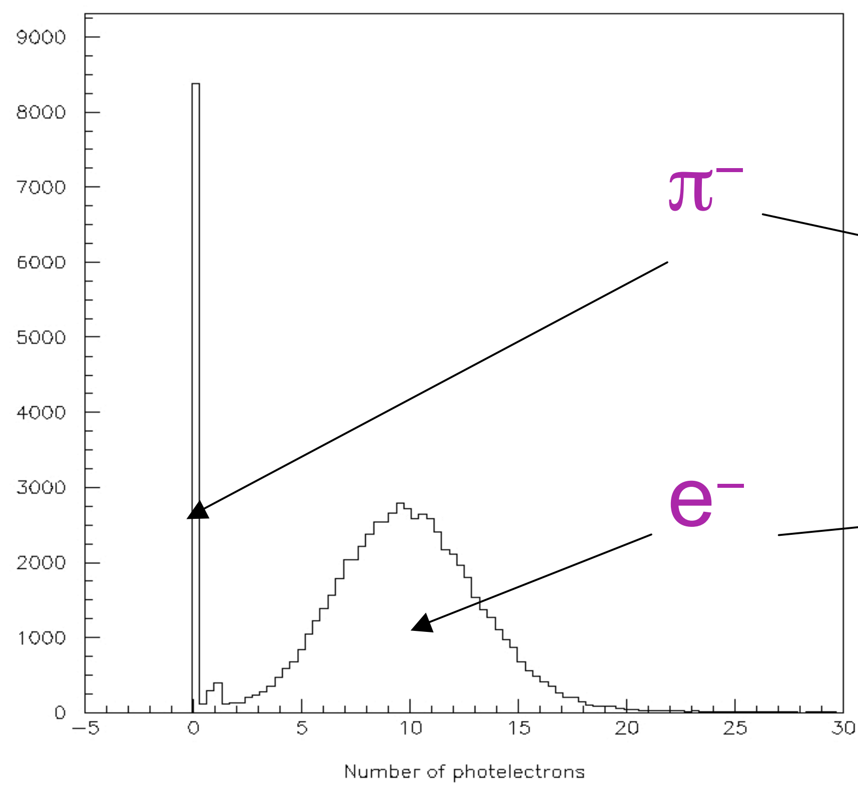
Dp/p:	< 0.1 %
Θ:	~ 1 mrad

Cer + *Cal* provide p rejection factor ~ 10000/1 At 1 GeV

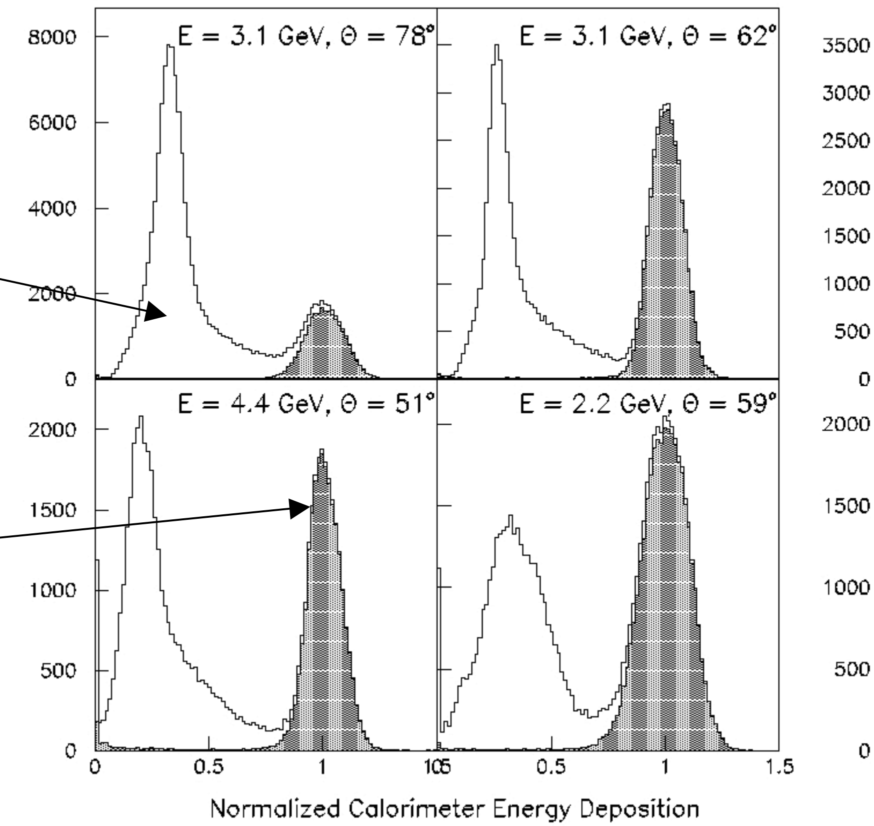
- **HMS Acceptance is dominated by the octagonal collimator!**

PID Detectors and π^- elimination

Cerenkov # photo-electrons



Calorimeter energy deposition



Experimental Considerations for L/Ts

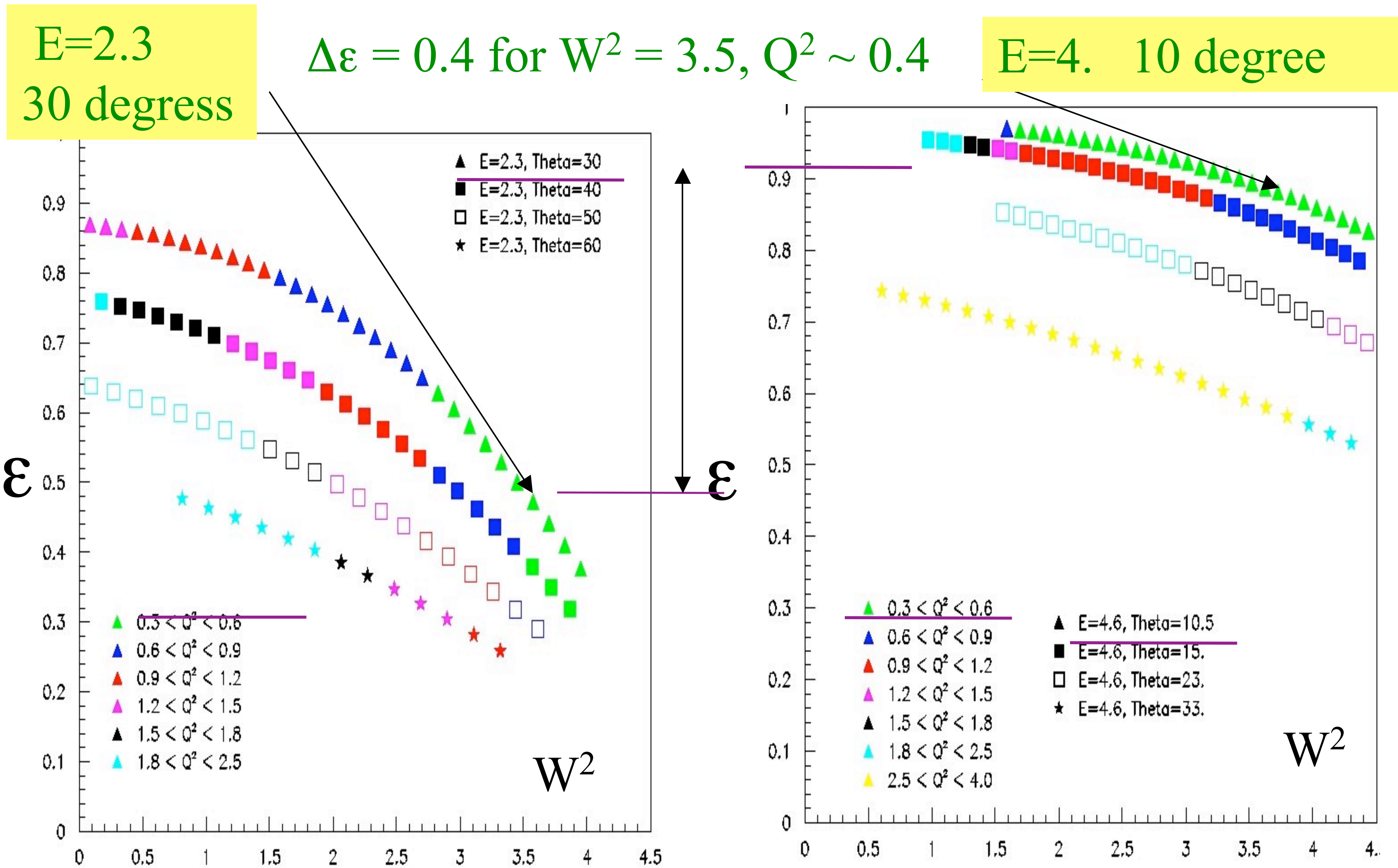
General Considerations:

- Want multiple ε points to reduce uncertainty in linear fit
  => take data at as many beam energies as possible.
- Need adequate ε spread to perform L/T separations.
- For $Q^2 > 1$, the maximum ε is at the larget E_{beam} (4.612 GeV) and forward angles
- Minimum ε is at smallest beam energy (1.201 GeV) and larger angles... However, for HMS $E'_{min} \sim 0.45$, $W^2_{max} = 2.2$ GeV^2. Change energies between 4.612 (highest) to 1.201 (lowest).
  Change spectrometer (momentum , angle) at same time to vary W, ε

Hall C base equipment:

- Measure inclusive e^- cross sections in HMS (high momentum spectrometer p< 6 GeV/c)
- Measure e^+ for charge-symmetric corrections in SOS (p<1 GeV/c) (single orbit spectrometer) where needed - at the same time.

- Need different E_{beam} for different ε at same W^2, Q^2.
- Increasing θ at fixed E_{beam} slides fixed Q^2 range to larger W^2.



Jan 05 e-D and e-A data:

~85 different kinematics

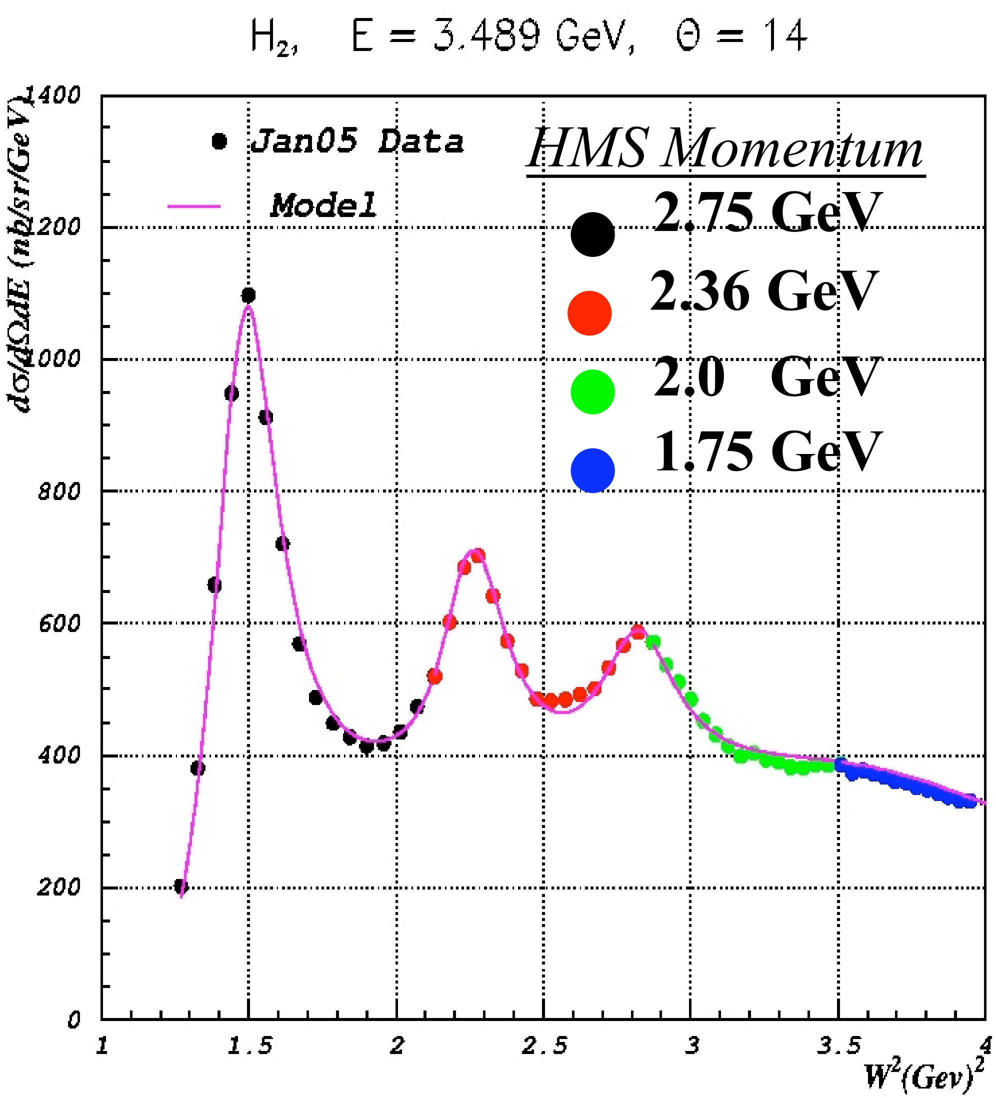
- Targets: D_2, C, Al, Fe for L/Ts
  H_2 for checks against completed H data set.

Also: Carbon data at very low Q^2 in the Quasielastic region for ν cross section modelling (no L'T 's possible for these very low Q2 Quasielastic kinematics)

- Total runs ~375 with ~15 minutes per run
- Overhead for kinematic / target changes ~*doubles* time requirements

  -- Because of frequent High Momentum Spectrometer magnet trips => So scan by angle instead of usual scan by momentum (technical detail)

Analysis Methodology

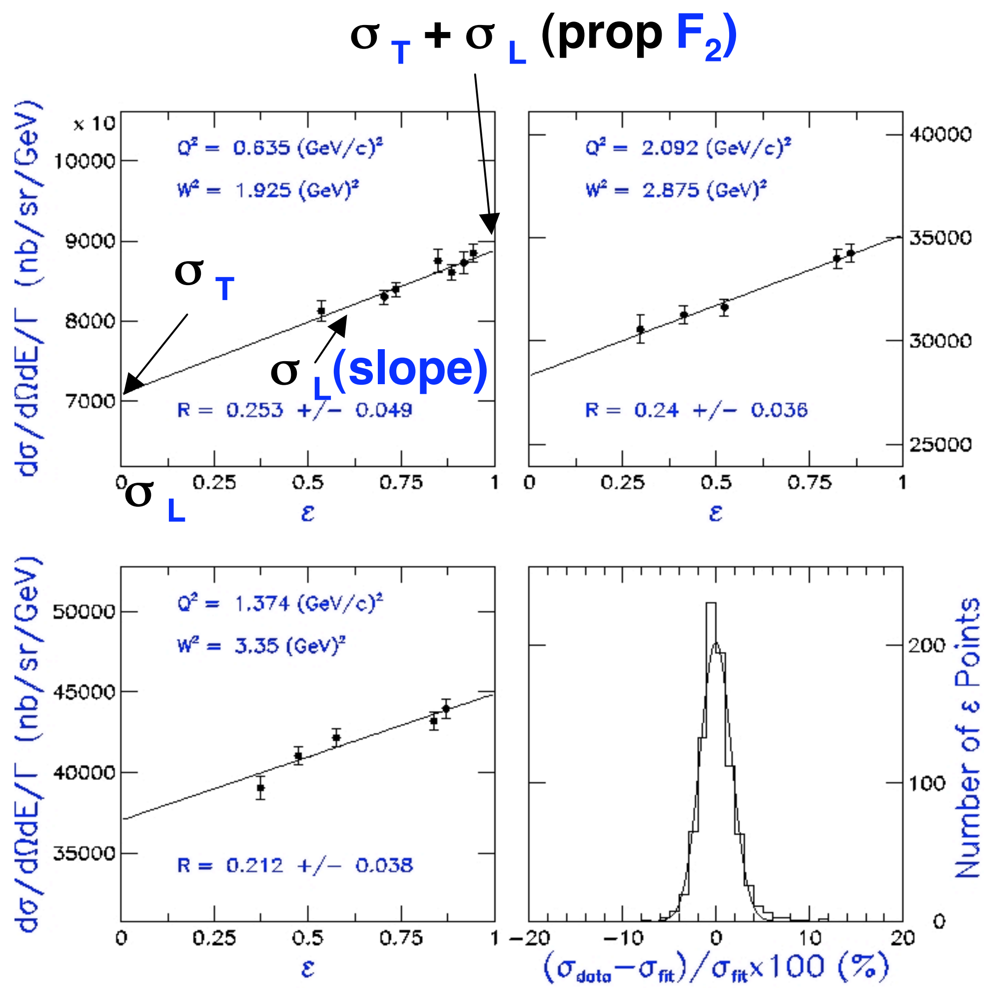


- Bin efficiency corrected e^- yield in $\delta p/p$ - θ. ($\delta p/p$ = +/- 8%, Dq = +/- 35 mrad)
- Subtract scaled dummy yield bin-by-bin to remove e^- Al background.
- Subtract charge symmetric e^- yield bin-by-bin.
- Apply acceptance correction for each δ-θ bin.
- Apply radiative corrections bin-by-bin.
- Apply θ bin-centering correction and average over θ => for each δ bin.

E94-110 e-p Rosenbluth Separations

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

- Extract F_L (L), F_1 (T), and $R = \sigma_L/\sigma_T$
- 180 separations total (most with 4-5 ε points)
- Small movement is Q^2 is sometimes needed
- Spread of points about the linear fits is fairly Gaussian with $\sigma \sim 1.6$ %, (consistent with estimated pt-pt uncertainties)

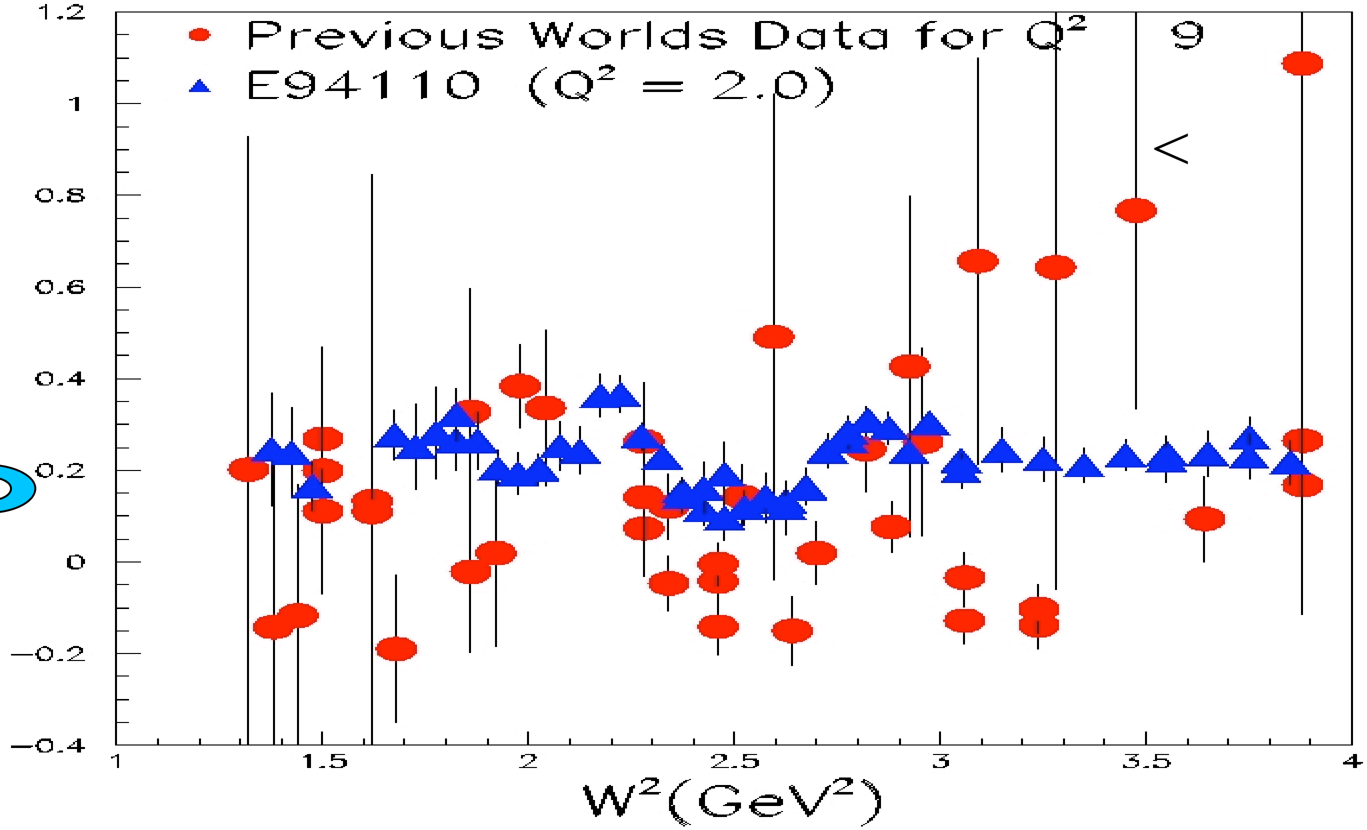


2005: e-p Data submitted for publication and available on-line

New e-p Rosenbluth Extractions of R

R=L/T

ΔR = +-0.2



ΔR = 0.2 implies *10% error* on $\sigma^{\nu N}$,

***30% error* on $\sigma^{\bar{\nu} N}$**

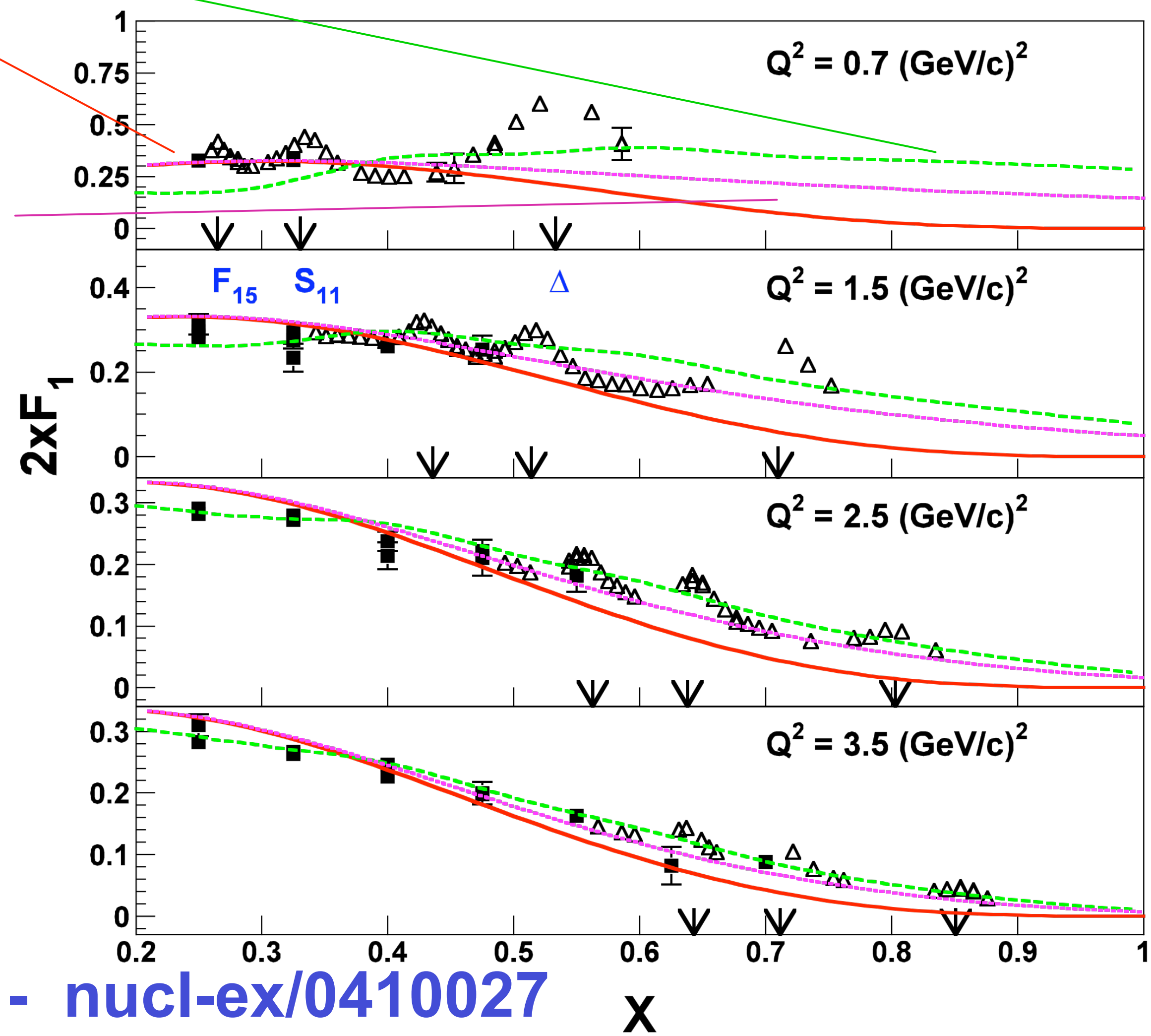
- **Red: All previous world data *at all Q2***
- **Blue new e-p data: *Only one* of many Q^2 range shown**
- ***JUPITER- measure same accuracy for the deuteron (less well measured), and Nuclei no resonance L/T data-existed).***

e-p : submitted for publication: L/T Separated Structure Functions: shown are results for $2xF_1$ (hydrogen)

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
- Target mass corrections large and important

Preprint JLab Hall C - nucl-ex/0410027

e-p : submitted for publication: L/T Separated Structure Functions: shown are results for F_L (Hydrogen)

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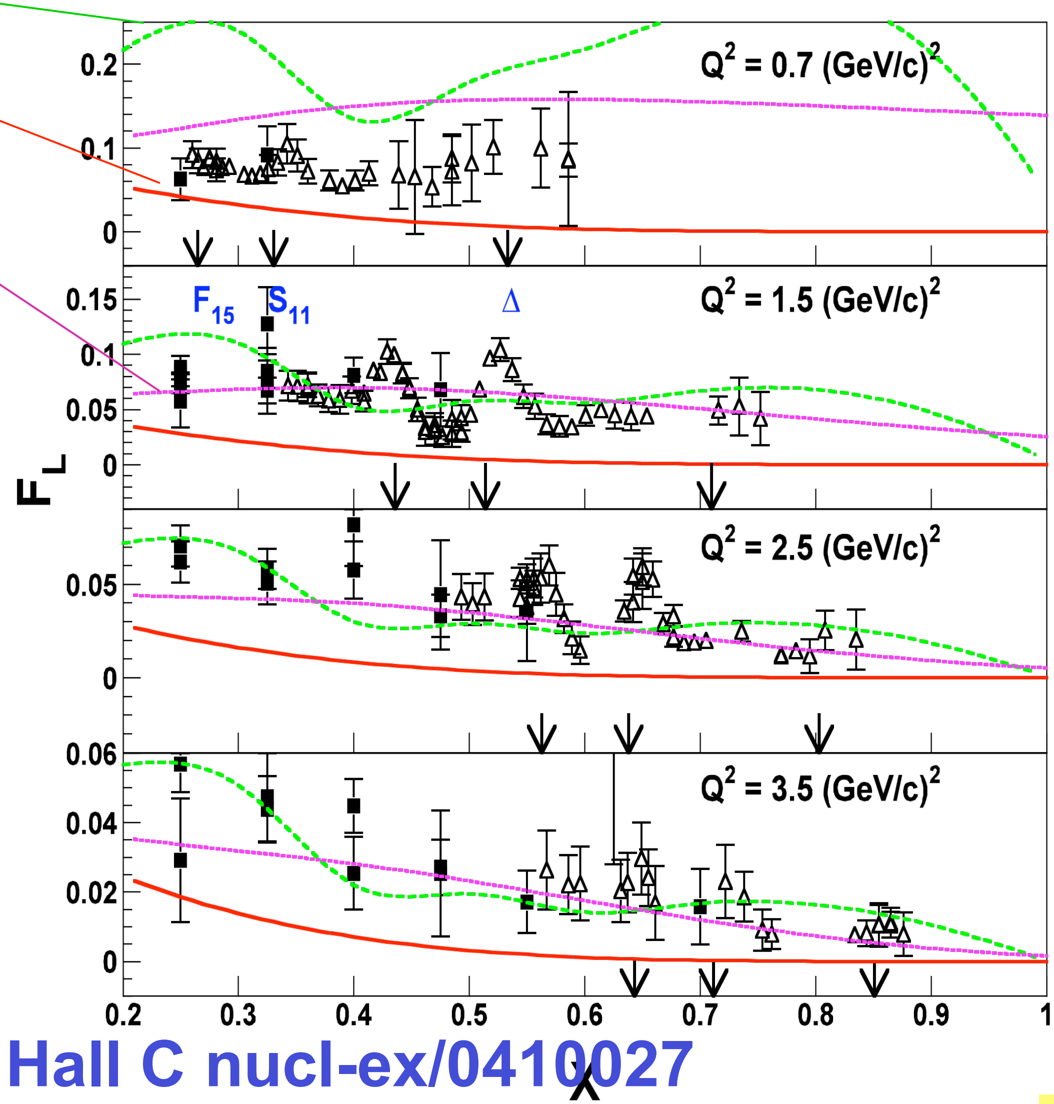


- Smooth transition from DIS (solid squares) to resonance region
- Resonances oscillate about perturbative curves
- Target mass corrections large and important
- Resonances in F1 and FL are different

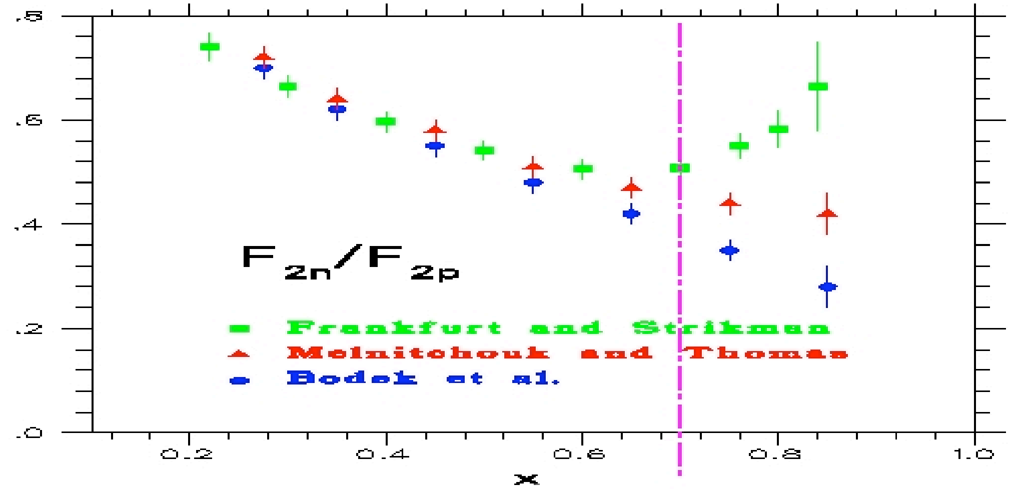
Preprint- JLab Hall C nucl-ex/0410027

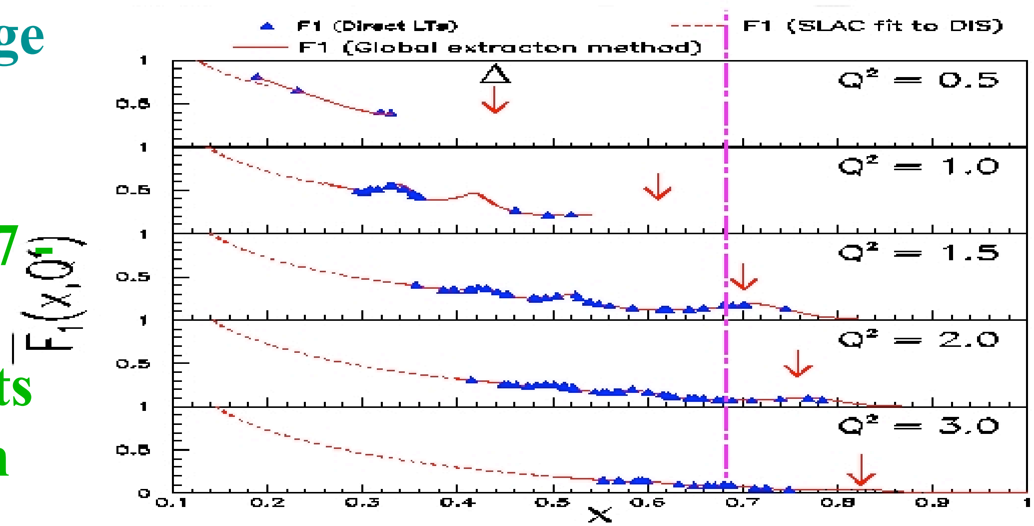
L/T Separations on Deuterium: JLab E02-109

E02-109 (Hall C) runs at the same time as E04-001 and measures separate deuterium structure functions in the Resonance Region for $0.3 < Q^2 < 4.5$

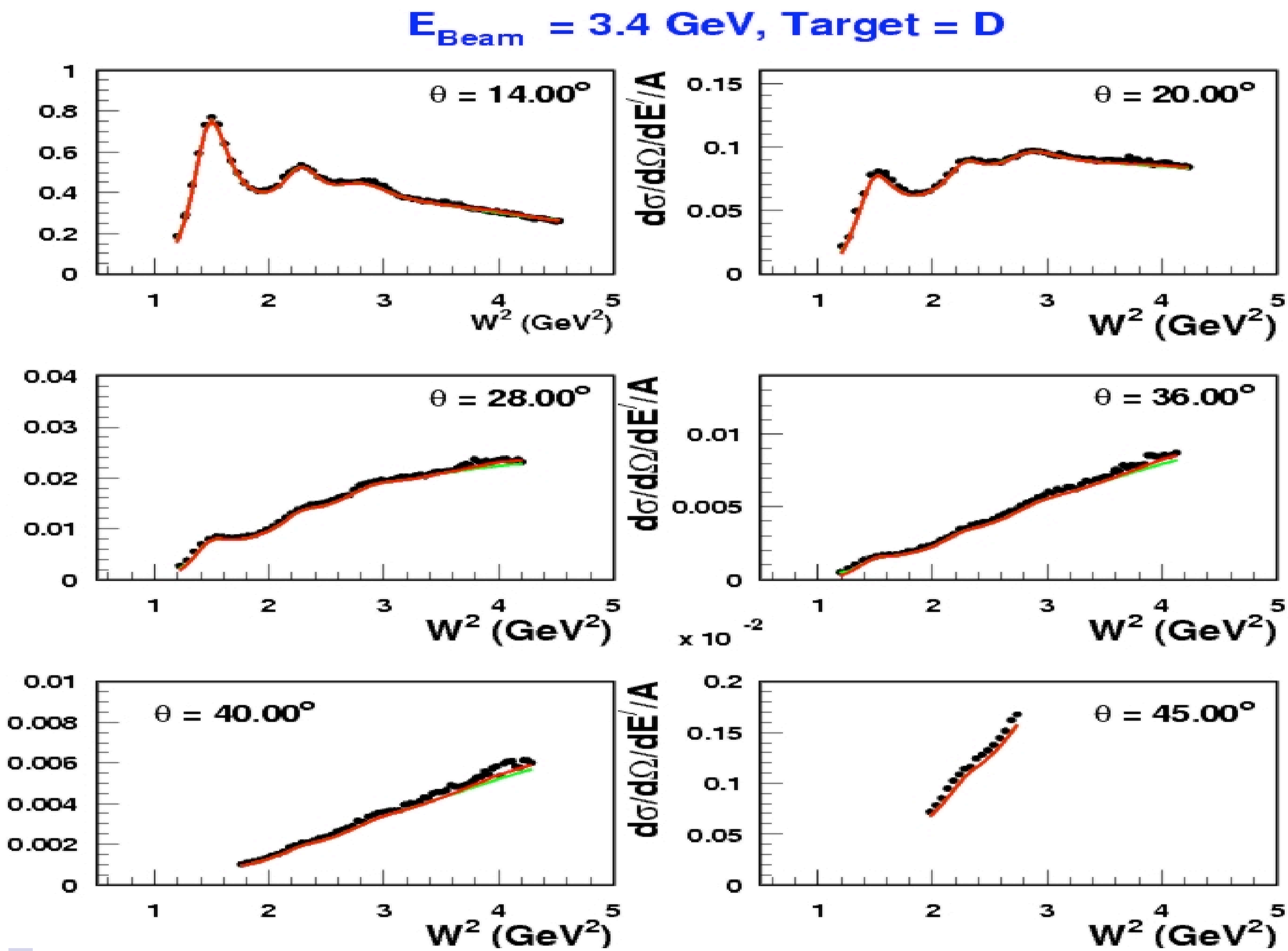
Data quality and kinematic range similar to that shown for the proton

At low Q^2, data largely at $x < 0.7$ - can extract low Q^2 *neutron* structure functions and moments with minimal nuclear extraction uncertainty

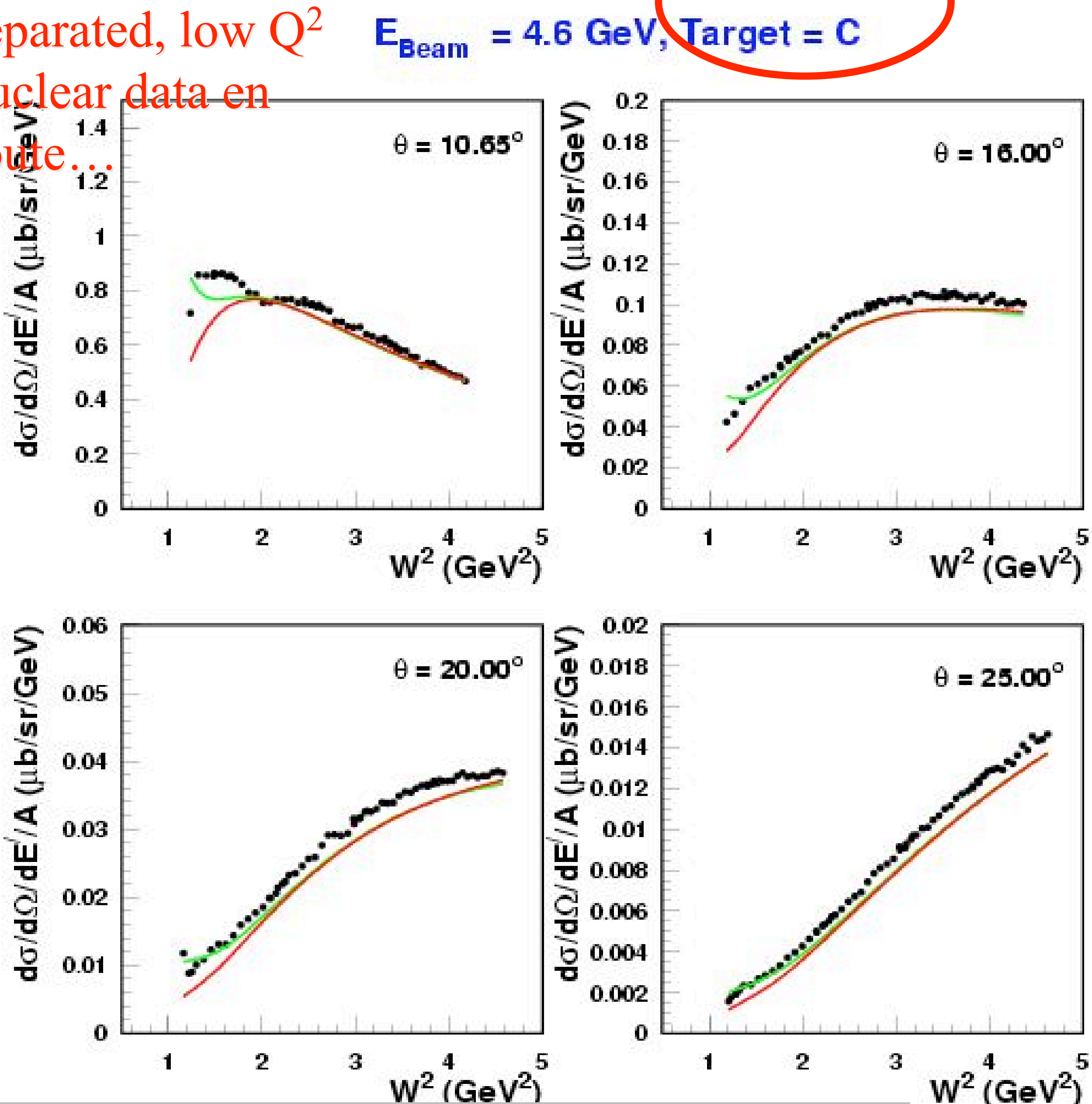




Deuterium Cross Sections Jan 05



LOTS of new, L/T separated, low Q^2 nuclear data en route...



Very preliminary ***raw data no radiative corrections*** (just obtained January 2005)

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

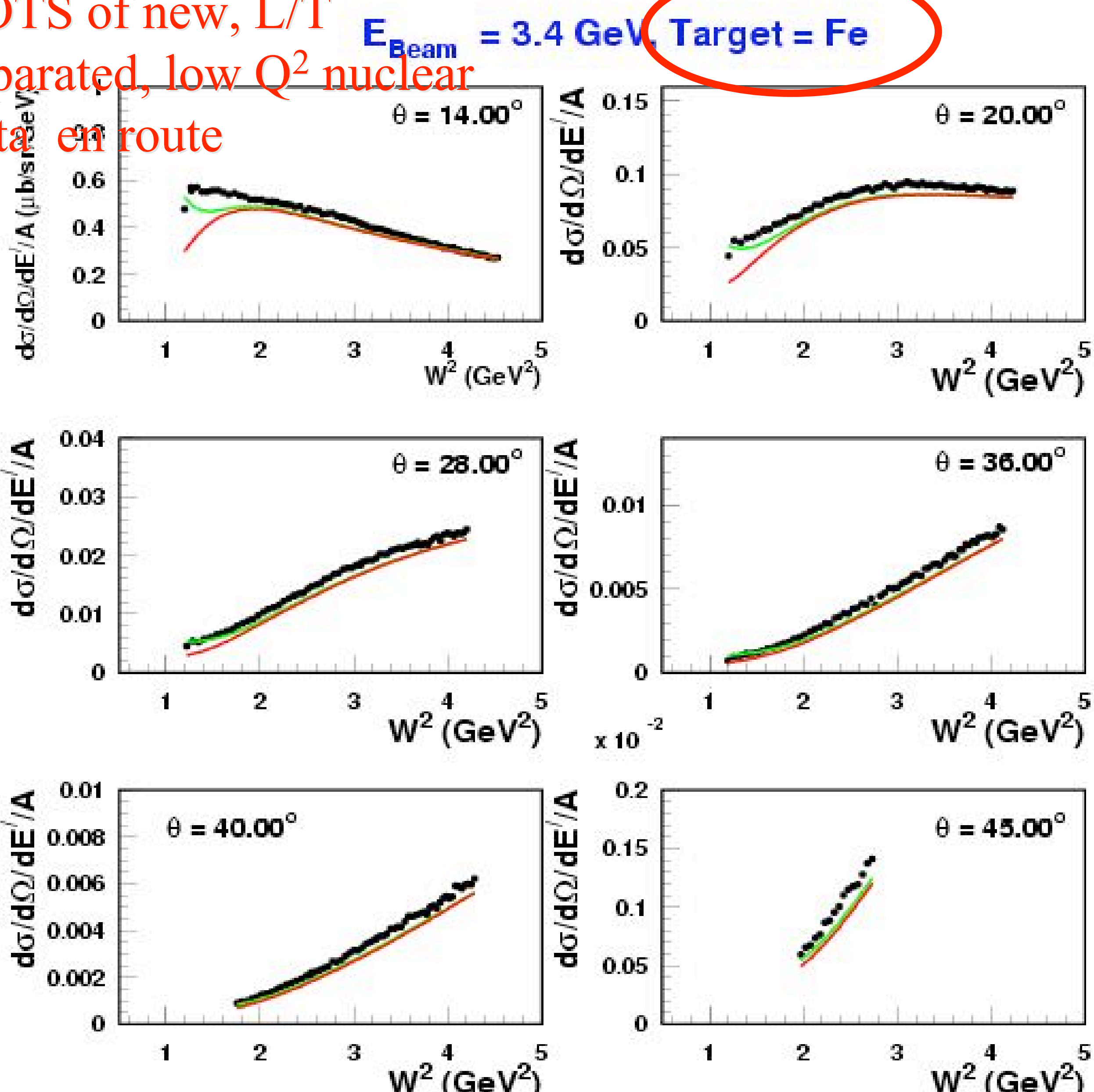
Models:

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

R - JLab e99118

Here **Red curves are un-radiated**

LOTS of new, L/T separated, low Q^2 nuclear data en route



Raw Data (no radiative corrections: will be used for:

Nuclear duality

Neutrino modeling

Deuterium (neutron) moments

R on deuterium in resonance region

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

Search for nuclear pions (G. Miller prediction)

Here **Red curves are un-radiated**

Much more to come …

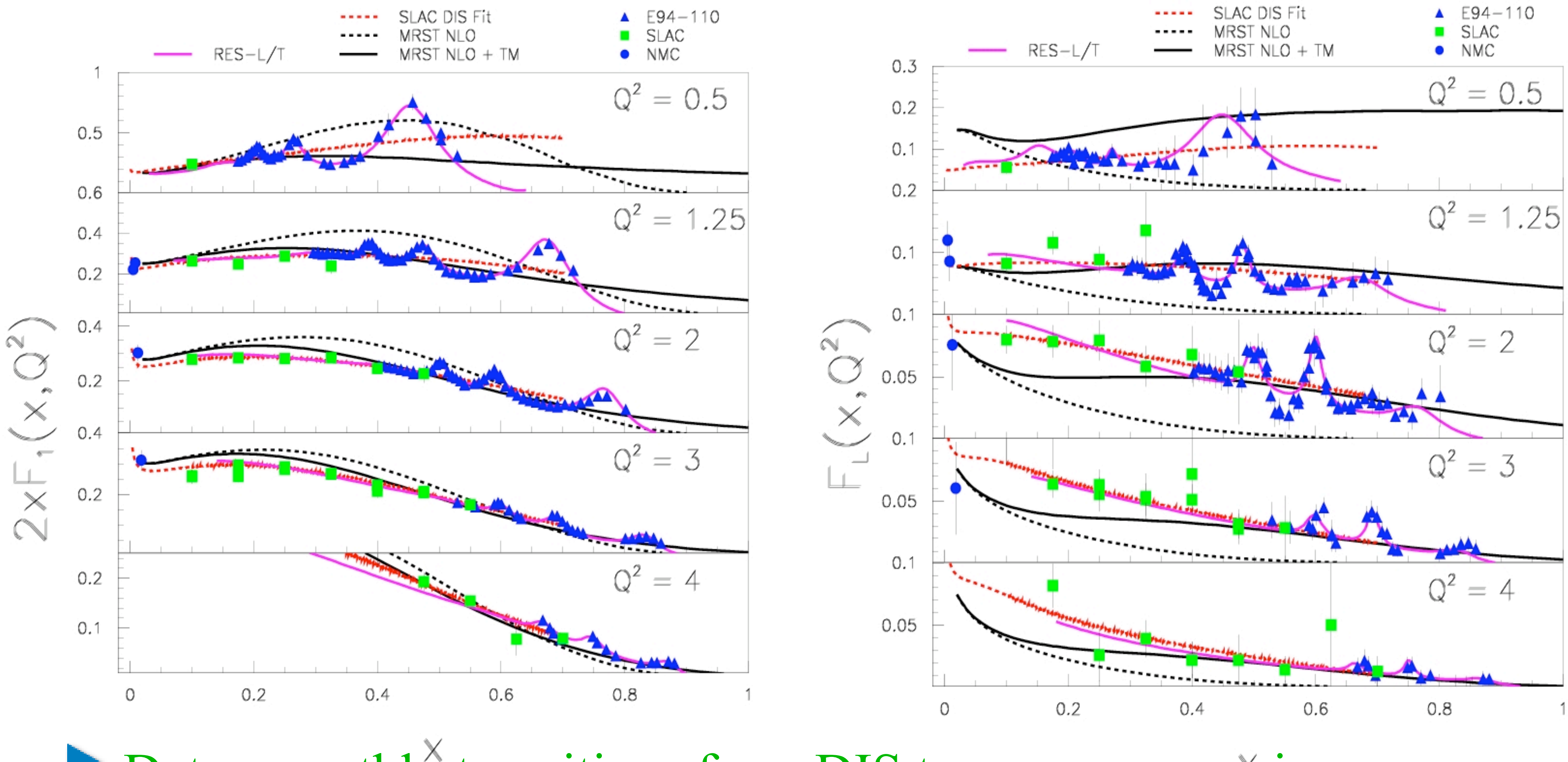
Fast track analysis at the 5% level of quasielastic cross sections on Carbon for low energy neutrino cross section modelling is moving well - Checks nuclear models and nuclera binding effects on nucleon form factors.

Inelastic cross sections on nuclear targets available soon!

L/T separations will take a bit longer to reduce cross section errors to < 2%.

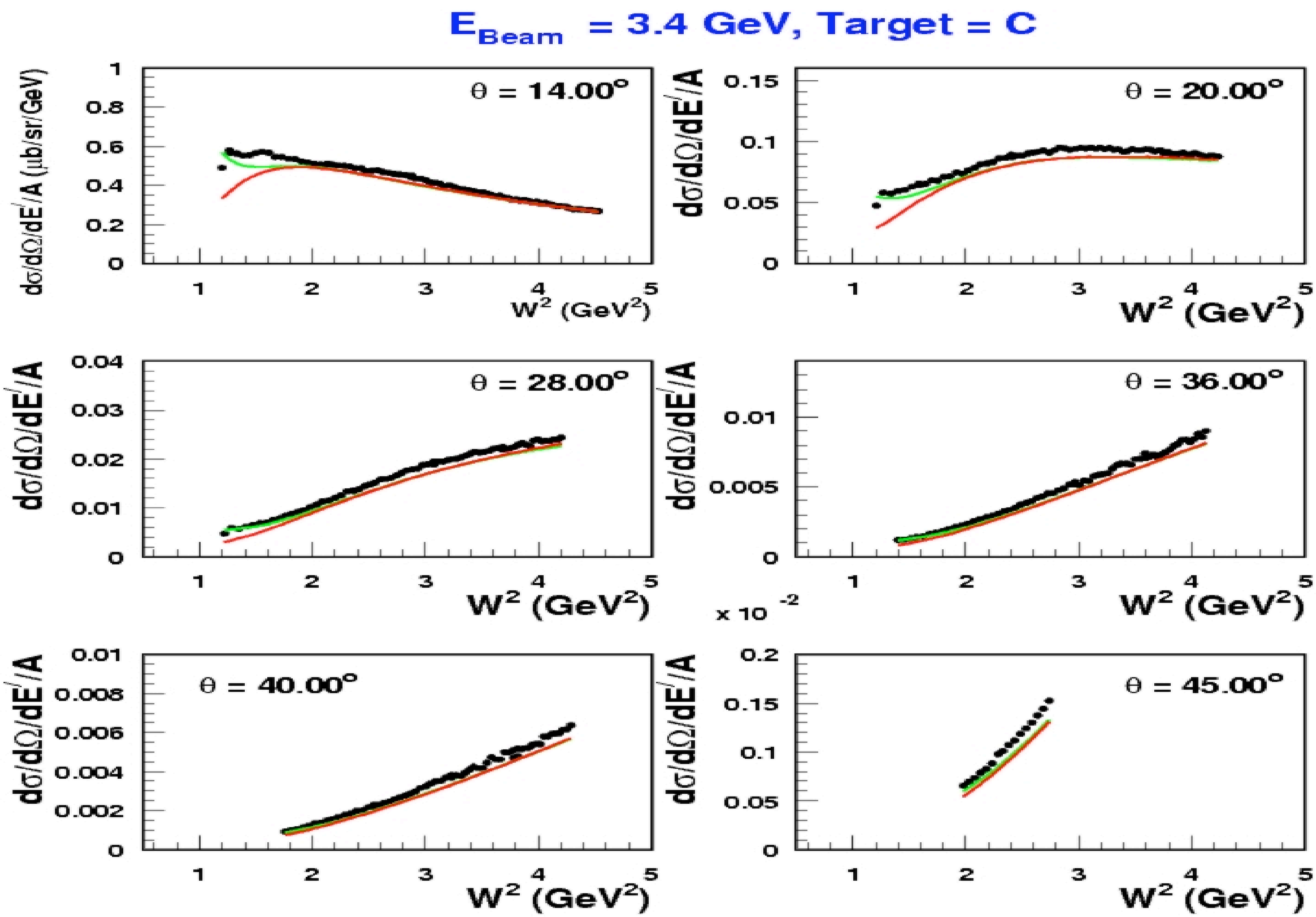
Additional Slides

Proton L/T Separated Structure Functions at low Q^2



- Data smoothly transitions from DIS to resonance region
- Resonances oscillate about DIS Fits ... duality in **BOTH** channels!
- large x-range -> extract moments from data.
- TM corrections can be quite large, especially in F_L!

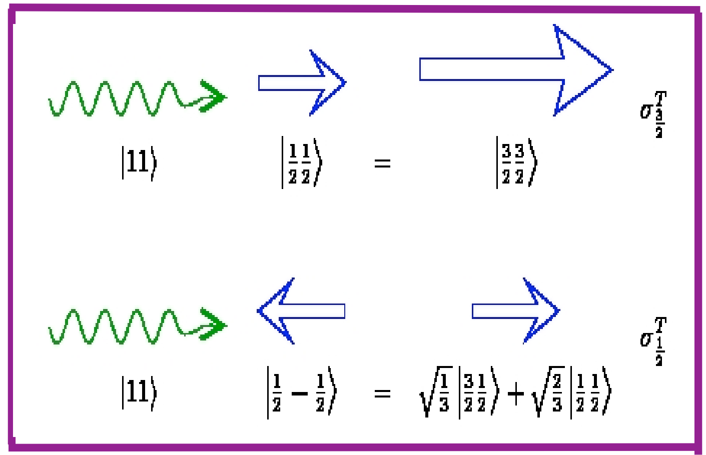
Carbon Cross Sections Jan 05



Resonance Region L-Ts Needed For spin structure - move out

<u>Extracting spin structure functions from spin asymmetries</u>

$$A_1 \propto \frac{\sigma_{/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \propto \frac{s_{1/2} - s_{3/2}}{F1_T}$$



$$(2xF_1 \propto \sigma_{1/2} + \sigma_{3/2})$$

$$\frac{\Delta A_1}{A_1} = \varepsilon \Delta R$$

From measurements of F_1 and A_1 extract $s_{1/2}$ and $s_{3/2}$!

$$g_1 \propto \frac{F_1(A_1 - gA_2)}{1 + g^2}$$

(Get complete set of transverse helicity amplitudes)