Extracting the Proton Longitudinal Structure Function Moments from World Data

Peter Monaghan
Hampton University, Virginia

in collaboration with,

Lingyan Zhu, Eric Christy, Alberto Accardi, Wally Melnitchouk, and Cynthia Keppel

APS April Meeting 2012

This Analysis of Longitudinal Moments

- At Next-to-Leading order, F_L is sensitive to gluon distribution

$$F_L(x) = \frac{\alpha_s}{\pi}\int_x^1 \frac{dy}{y}\left(\frac{x}{y}\right)^2 \left\{\frac{4}{3}F_2(y) + 2c(n_f)\left(1-\frac{x}{y}\right)yG(y)\right\} \qquad y = \frac{\nu}{E}$$

- F_L also sensitive to power corrections in Q^2
- Parton Distribution Functions calculate leading twist (twist-2) structure functions
- Previous study by Ricco, Simula and Battaglieri (Nucl. Phys. **B555**, 306-334, 1999)

⇒ little data at low Q^2 and high x

⇒ "... transverse data with better quality at $x > 0.6$ and $Q^2 < 10$ $(\text{GeV/c})^2$ and more precise, systematic determinations of the L/T cross-section ratios are still required ...."

- New data available from JLab (at high x and low Q^2) and HERA (low x)

⇒ high precision measurements, from dedicated experiments

⇒ **DATA driven analysis**

Nachtmann Moments

- Nachtmann moments defined in terms of ξ, accounts for finite Q^2 corrections

$$\xi = \frac{2x}{1+\sqrt{1+4M^2x^2/Q^2}}$$

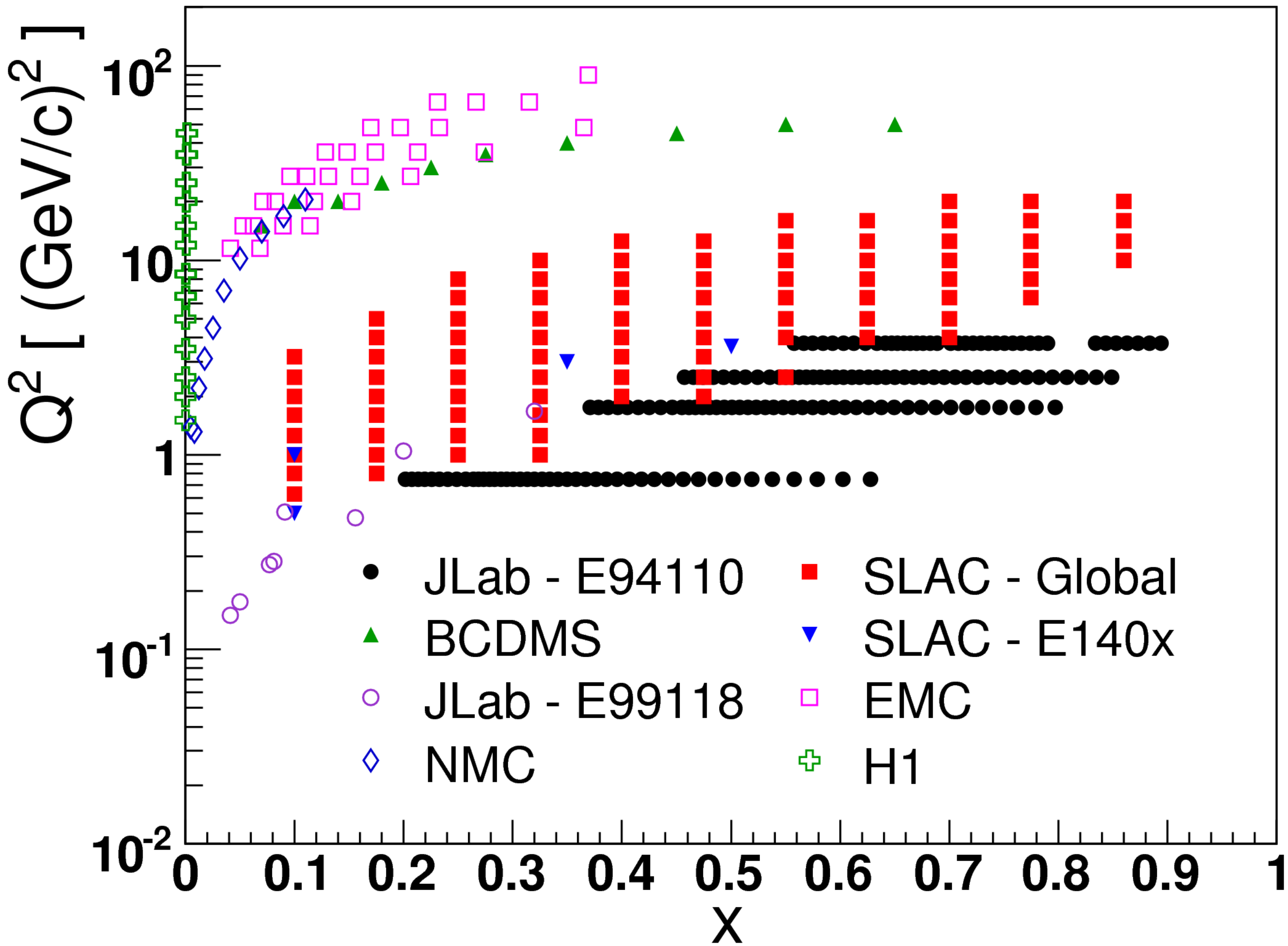
$$M_L^{N(n)}(Q^2) = \int_0^1 dx\, \frac{\xi^{n+1}}{x^3} \left\{ F_L(x,Q^2) + \frac{4M^2x^2}{Q^2} \frac{(n+1)\xi/x - 2(n+2)}{(n+2)(n+3)} F_2(x,Q^2) \right\}$$

- Longitudinal moment depends on both F_L and F_2 structure functions
- Nachtmann moments from experiment are compared to Cornwall-Norton (leading-twist) moments from pQCD calculations

  ⇒ are higher twist components important?

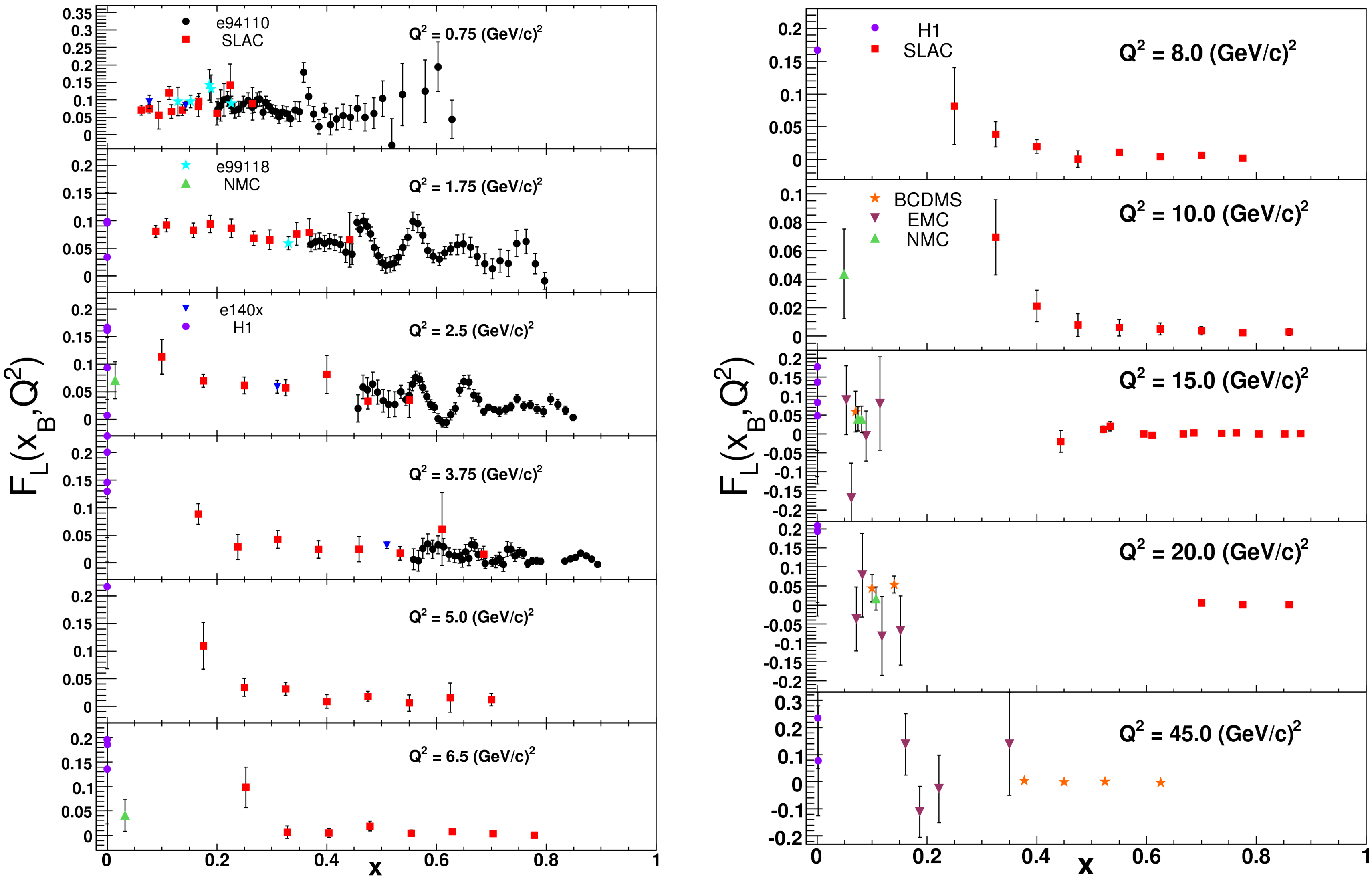
  ⇒ is the gluon contribution in the PDF calculation sufficient?

Data Coverage in Q^2 and x

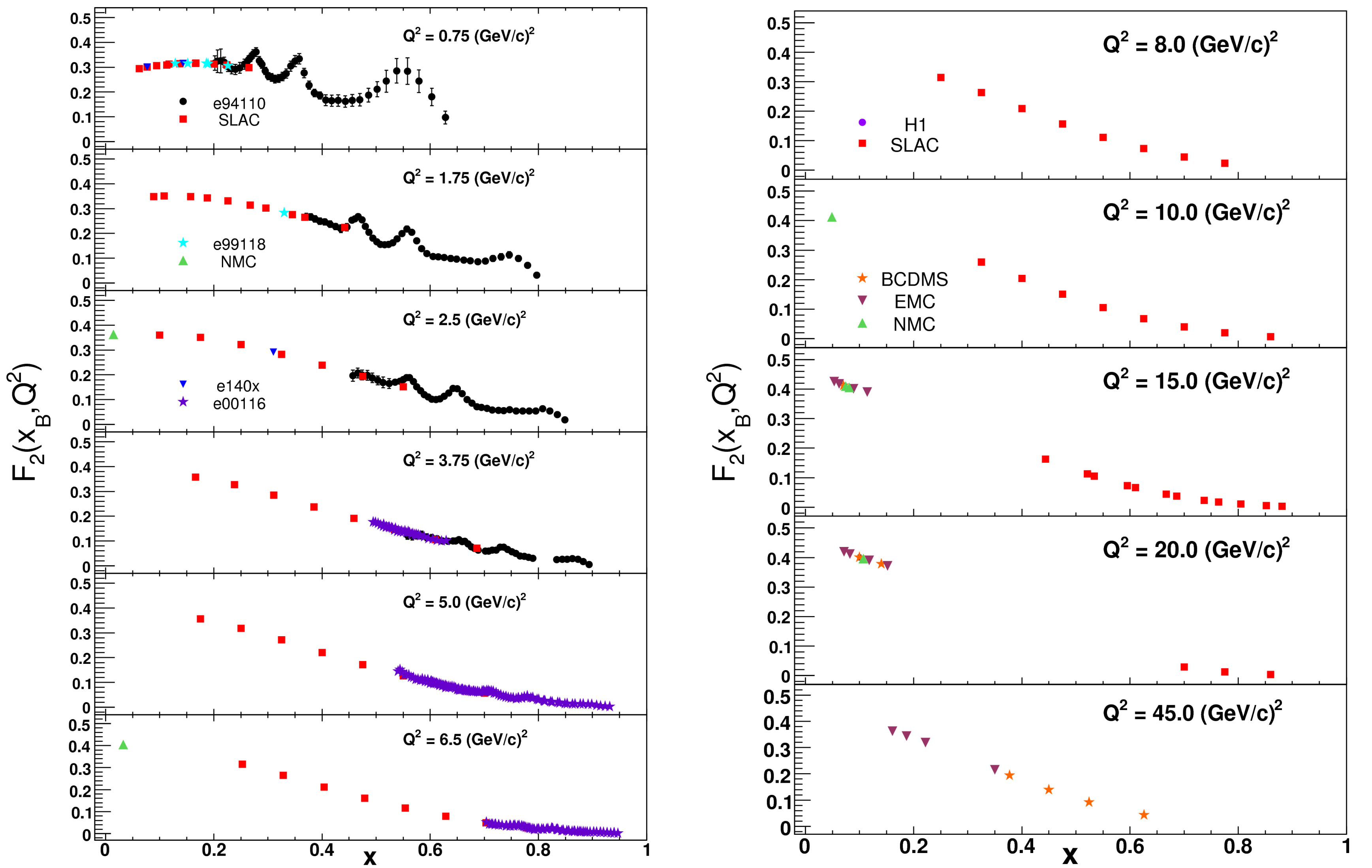


- Only using L/T separated data
- Proton data only
- JLab data covers region with higher x and lower Q^2
- for $Q^2 < 4$, JLab data is covers ~50% of x range

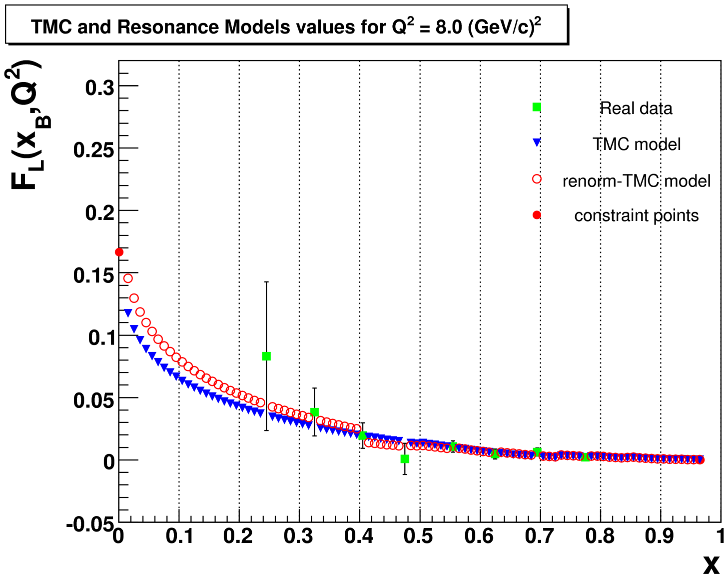
Bin-center F_L Data in Q^2

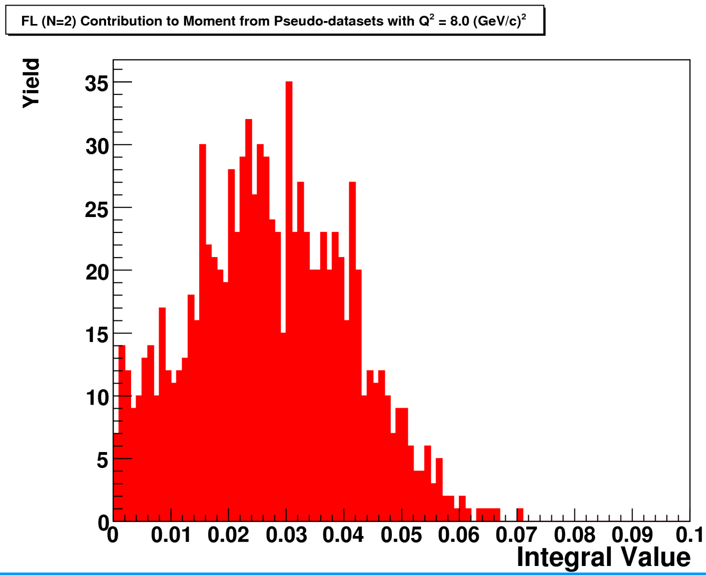


Similarly, bin-center F_2 Data in Q^2



Analysis Method and Error Estimation





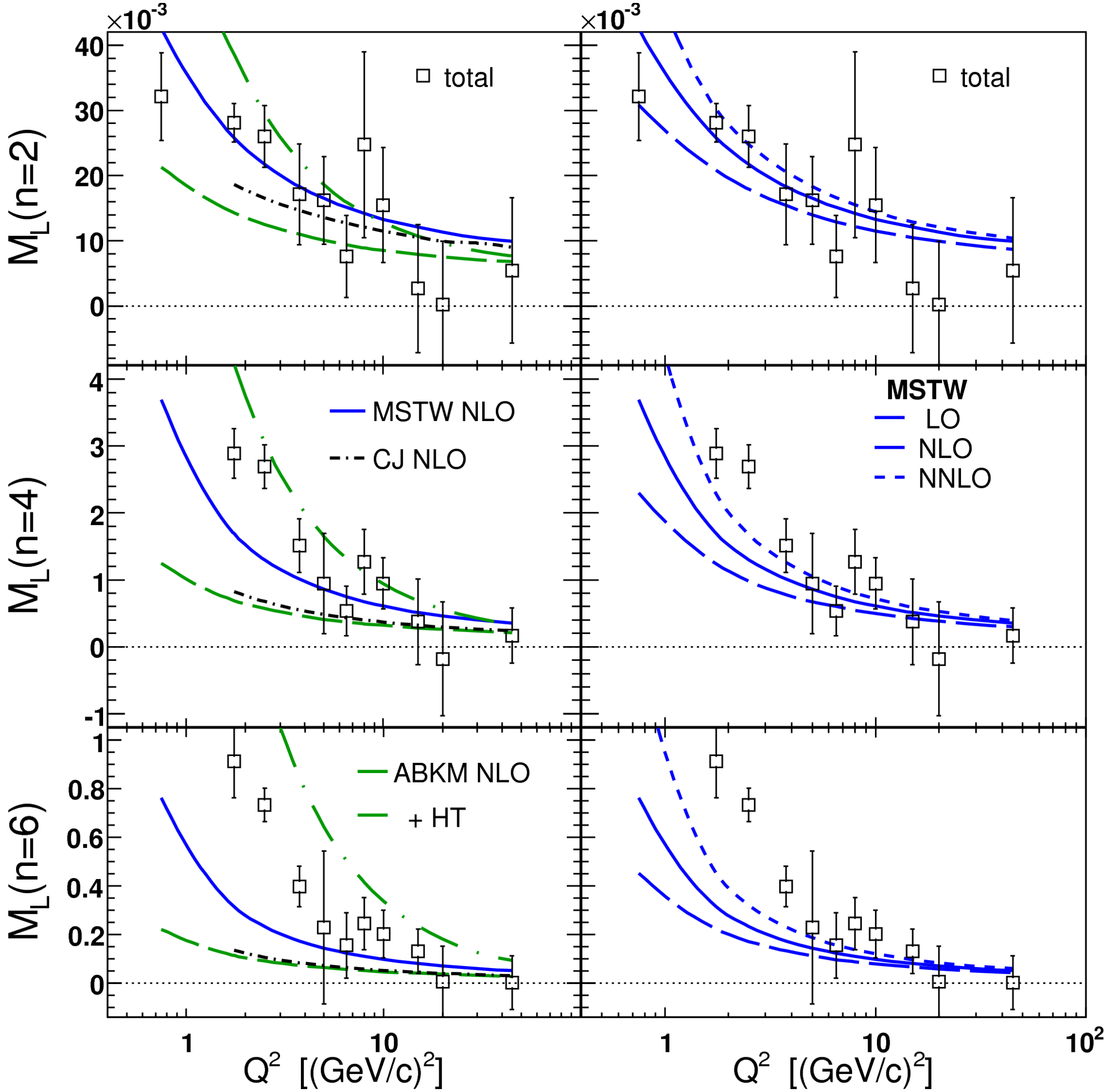
- Use model calculations in empty bins
- Apply rescale factor to model based on error weighted average of adjacent data points
- Integrate to generate moment contribution

- Use Monte Carlo method to estimate uncorrelated errors in data
- Generate pseudo-data via gaussian randomisation of data within error bars

  ⇒ distribution of moment contributions
  ⇒ derive statistical error from standard deviation of moment distributions

- Model dependent error estimated via analysis using different models

Nachtmann Longitudinal M_L Moments



- Comparing data to global PDF fits
- Including elastic contributions
- Observe missing strength in higher moments
  - ⇒ require larger gluon contribution at large x?
  - ⇒ higher twist effects?

- MSTW excludes high x data
- CJ includes high x data, but not F_L data directly
- ABKM includes higher twist terms but fits to a subset of the data

Summary and Outlook

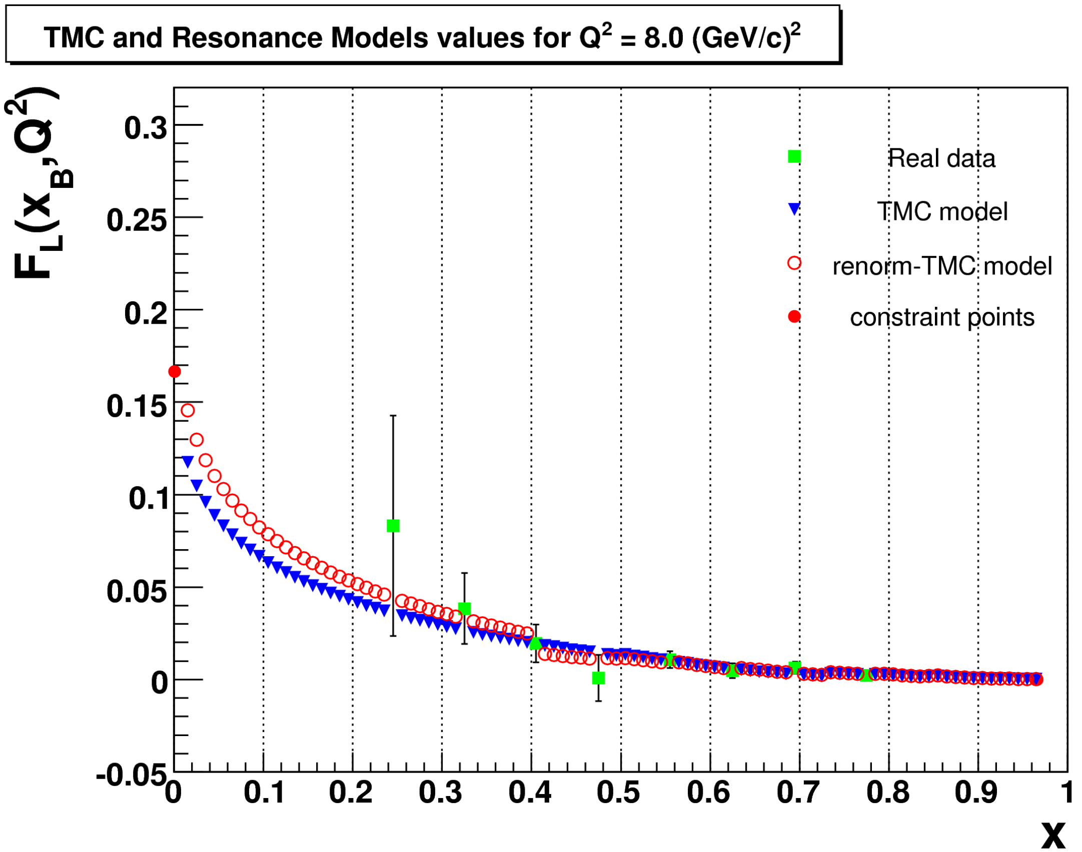
- Extracted longitudinal Nachtmann moments from available structure function data
- Large error bars on the data drive larger errors in the extracted moments

  ⇒ more experimental data will improve the statistics!

  ⇒ JLab @ 12 GeV : higher precision data at moderate to high x
- Comparison with global PDF fits shows an interplay between higher twist terms and a larger gluon contribution
- Intend to include F_L data in the CJ fit to learn more about the gluon and higher contributions

Extra Slides

Filling the Gaps in the Data



- Some bins with no data
- Use model calculations in empty bins

  DIS : $W^2 > 3.9\ GeV^2$

  Resonance : $W^2 < 3.9\ GeV^2$

⇒ apply rescale factor based on the error weighted average of adjacent data points

⇒ for x<0.4, use all data points to determine the rescale factor

DIS model : M. E. Christy, J. Blumlein and H. Bottcher (2012), hep-ph/1201.0576 ⇒ "TMC model"
Resonance model : Y. Liang, Ph. D. thesis, The American University (2003) ⇒ "Liang model"

Error Estimation using Monte Carlo Technique

- Calculate moment by integrating data from x = 0.01 – pion threshold
- For each data point, generate a random number within its error bar

  ⇒ generate a complete pseudo-dataset
- Fill in gaps in the pseudo-dataset with the same models
- Integrate to generate moment for that pseudo-dataset
- Repeat 1000 times

  ⇒ obtain a distribution of moments from the pseudo-datasets
- Repeat process for F_2
- Obtain the mean and standard deviation of each distribution of moments

Define data point : $$M_L^{N(n)}(Q^2) = \overline{i_{F_L}^{(n)}} + \overline{i_{F_2}^{(n)}}$$

Define error bar : $$\delta M_L^{N(n)} = \sqrt{(\delta i_{F_L})^2 + (\delta i_{F_2})^2}$$

Model Dependent Error Estimate

- Other DIS and resonance region models available
  - ⇒ DIS: R1990 and ALLM parameterisation

    see references: H. Abramowicz & A. Levy (1997), hep-ph/9712415
    L. W. Whitlow, Ph. D. Thesis, Stanford University (1990), SLAC-0357
  - ⇒ Resonance model: C-B fit

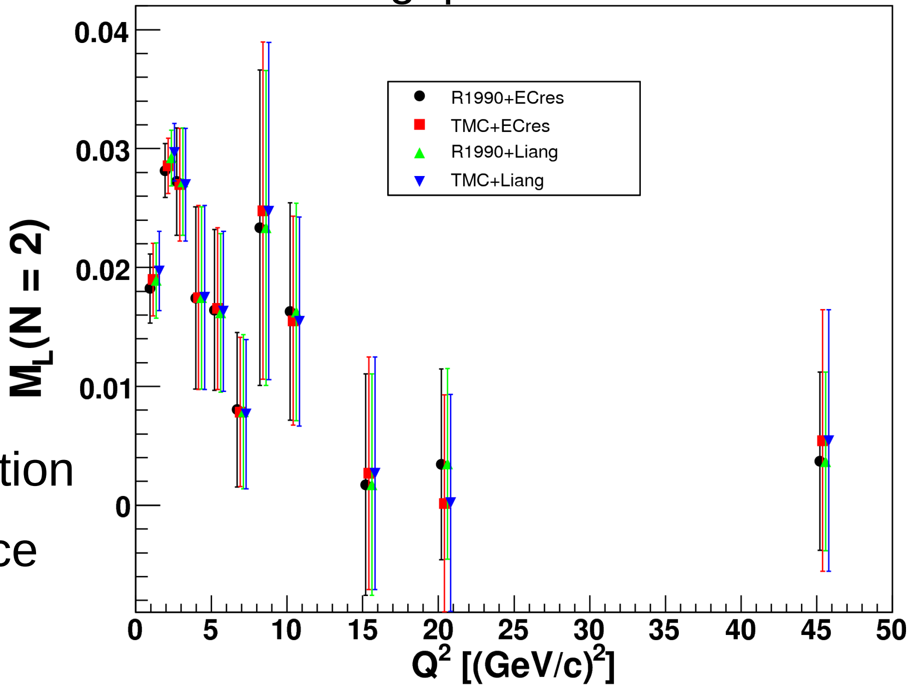
    see reference: M. E. Christy & P. E. Bosted, Phys. Rev. C **81**, 055213 (2010)
- Evaluate four possible combinations of models to fill gaps

  i. TMC + Liang ⇒ ideal case

  ii. TMC + C-B

  iii. R1990 + Liang

  iv. R1990 + C-B



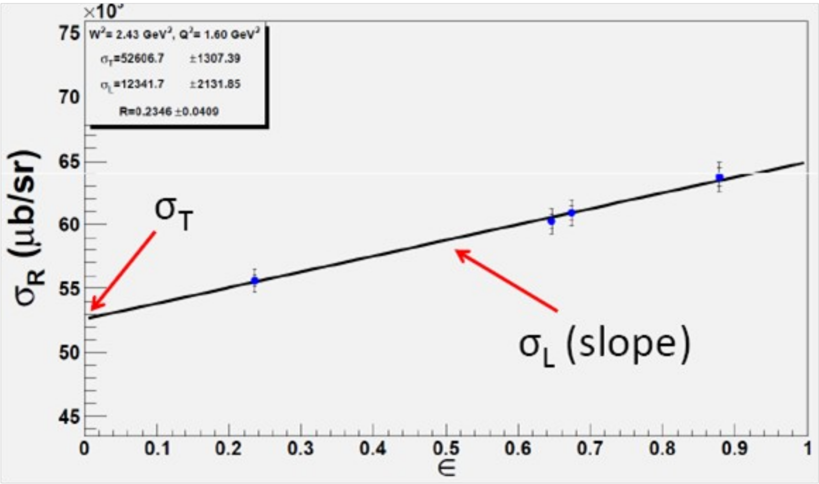
- Repeat analysis for each combination
- Define error as maximum difference from the ideal case

Measuring the Longitudinal Structure Function

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

$$\sigma_T \propto F_1 \qquad\qquad \sigma_L \propto F_L$$

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



- Determine F_L through a Rosenbluth separation of the cross-section
- Require data measured at fixed Q^2 and x, at multiple ε points

⇒ need **multiple** beam energies and spectrometer settings

- F_L ~ 25% of cross-section for JLab kinematics σ_T and σ_L

⇒ require < 2% uncertainty (pt-to-pt) in ε to extract F_L to ~ 15%