Global analysis of polarized parton distribution functions

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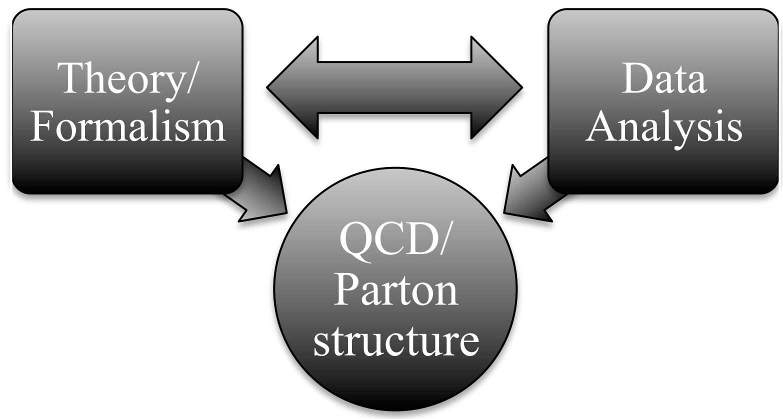
Overview of JAM Analysis

- Extracting reliable spin PDFs through a χ^2 fit to world polarized scattering data

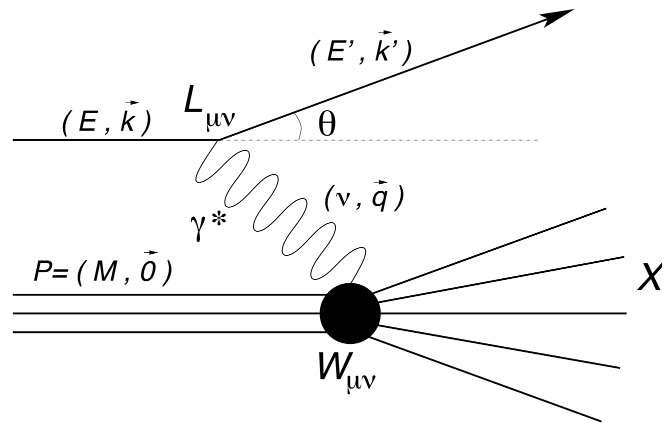
- **Data:**
  - Fitting ~2880 data points
  - Less stringent kinematic cuts
  - Inclusion of new JLab data



- **Theory:**
  - Finite-Q^2 and nuclear corrections implemented

Deep-inelastic Scattering (DIS)

- **Unpolarized** $\sigma \equiv \frac{d^2\sigma}{d\Omega dE'}$



$$\sigma = \sigma_{Mott}\left(\frac{2}{M}tan^2\frac{\theta}{2}F_1(x,Q^2) + \frac{1}{\nu}F_2(x,Q^2)\right)$$

- **Polarized**

$$\sigma^{\uparrow\Uparrow} - \sigma^{\uparrow\Downarrow} = \sigma_{Mott}\frac{1}{M\nu}4tan^2\frac{\theta}{2}\left([E + E'cos\theta]g_1 - 2Mxg_2\right)$$

$$\sigma^{\uparrow\Rightarrow} - \sigma^{\uparrow\Leftarrow} = \sigma_{Mott}\frac{1}{M\nu}4E'tan^2\frac{\theta}{2}sin\theta\left(g_1 - \frac{2E}{\nu}g_2\right)$$

$$Q^2 = -q^2 \approx 4EE'sin^2\frac{\theta}{2}$$

$$x = \frac{Q^2}{2M\nu}$$

$$W^2 = M^2 + \frac{Q^2(1-x)}{x}$$

Polarized DIS Observables

- Experiment measure electron polarization asymmetries

$$A_{\parallel} = \frac{\sigma^{\uparrow\Downarrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\uparrow\Downarrow} + \sigma^{\uparrow\Uparrow}} = D\left(A_1 + \eta A_2\right)$$

$$A_{\perp} = \frac{\sigma^{\uparrow\Rightarrow} - \sigma^{\uparrow\Leftarrow}}{\sigma^{\uparrow\Rightarrow} + \sigma^{\uparrow\Leftarrow}} = d\left(A_2 + \xi A_1\right)$$

where A_1 and A_2 are defined in terms of polarized structure functions g_1 and g_2

$$A_1 = \frac{2x}{(1+\gamma^2)F_2 - F_L}\left(g_1 - \gamma^2 g_2\right)$$

$$A_2 = \frac{2x}{(1+\gamma^2)F_2 - F_L}\gamma\left(g_1 + g_2\right)$$

$$g_i = g_i(x, Q^2)$$

Finite-Q^2 Corrections

- **Higher Twist** – $1/Q^2$ corrections arise from local (higher twist) operators in QCD matrix elements – can decompose g_1 and g_2 as a sum of twist terms

$$g_1(x,Q^2) = {g_1}^{\tau 2+TMC} + {g_1}^{\tau 3+TMC} + g_1^{\tau 4}$$
$$g_2(x,Q^2) = g_2^{\tau 2+TMC} + {g_2}^{\tau 3+TMC}$$

$1/Q^2$ suppressed

- Leading twist ($\tau = 2$) at NLO without target mass corrections (TMC)

$${g_1}^{\tau 2}(x) = \frac{1}{2}\sum_q e_q^2 \left[\Delta C_{qq} \otimes \Delta q(x) + \Delta C_{qg} \otimes \Delta g(x)\right]$$

- Relationship between twist-3 g_1 and g_2 (*Bluemlein, Tkabladze NPB **553**, 427 (1999)*)

$${g_1}^{\tau 3} = \frac{4M^2x^2}{Q^2}\left[{g_2}^{\tau 3} - 2\int_x^1 \frac{dy}{y}{g_2}^{\tau 3}\right]$$

Finite-Q^2 Corrections

- **Target mass corrections** - M^2/Q^2 suppressed contributions to LT structure functions from finite nucleon mass

$$g_1{}^{\tau 2+TMC}(x) = \zeta_1^1 g_1{}^{\tau 2}(\xi) + \zeta_1^2 \int_\xi^1 \frac{dz}{z} g_1{}^{\tau 2}(z) + \zeta_1^3 \int_\xi^1 \frac{dz}{z} g_1{}^{\tau 2}(z) log\left(\frac{z}{\xi}\right)$$

$$\zeta = \zeta\left(x, \frac{M^2}{Q^2}\right) \qquad \xi = \xi\left(x, \frac{M^2}{Q^2}\right)$$

- **Nuclear smearing** - effects from bound nucleons in ^{3}He and deuterium nuclei - convolute nucleon structure functions with momentum distribution functions

$$g_1^A(x, Q^2) = \sum_N \int \frac{dy}{y} f_{ij}^N(y) g_j^N(\frac{x}{y}, Q^2)$$

Parameterization

- Parton plus distributions parameterized as

$$x\Delta q^{+}(x) = N x^{\alpha}(1-x)^{\beta}(1+\gamma x)$$

$$\Delta q^{+} \equiv \Delta q + \Delta \bar{q}$$

- Twist-3 structure function parameterization enters at the parton level

$$D^{\tau 3}(x) = N' x^{\alpha'}(1-x)^{\beta'}(1+\gamma' x)$$

- Twist-4 structure function parameterized by

$$g_1^{\tau 4} = \frac{1}{Q^2} N'' x^{\alpha''}(1-x)^{\beta''}(1+\gamma'' x)$$

- Total # of parameters = 10 shape parameters for spin PDFS + 8 x 2 higher twist parameters = 26

Fitting Procedure

- Standard χ^2 fit is defined

$$\chi^2(\vec{p}) = \sum_{i=1}^{N_{exp}} \left[\sum_{j=1}^{N_{data}^{(i)}} \left(\frac{D_j - T_j(\vec{p})}{\sigma} \right)^2 \right]$$

Uncertainties added in quadrature

- JAM analysis uses modified χ^2 to account for correlated errors (e.g. overall normalization)

- PDF uncertainties computed using Hessian method

$$H_{ij} = \frac{1}{2} \left. \frac{\partial \chi^2(\vec{p})}{\partial p_i \partial p_j} \right|_{\vec{p}=best} \qquad C = H^{-1}$$

Covariance matrix

Uncertainties

- In the eigenbasis $\{\hat{e}_i\}$ of the covariance matrix, the shift of parameters from best value is defined by scale factors $\{t_i\}$

$$\Delta\vec{p} = \sum_i t_i \hat{e}_i$$

- Uncertainties on observables are defined by

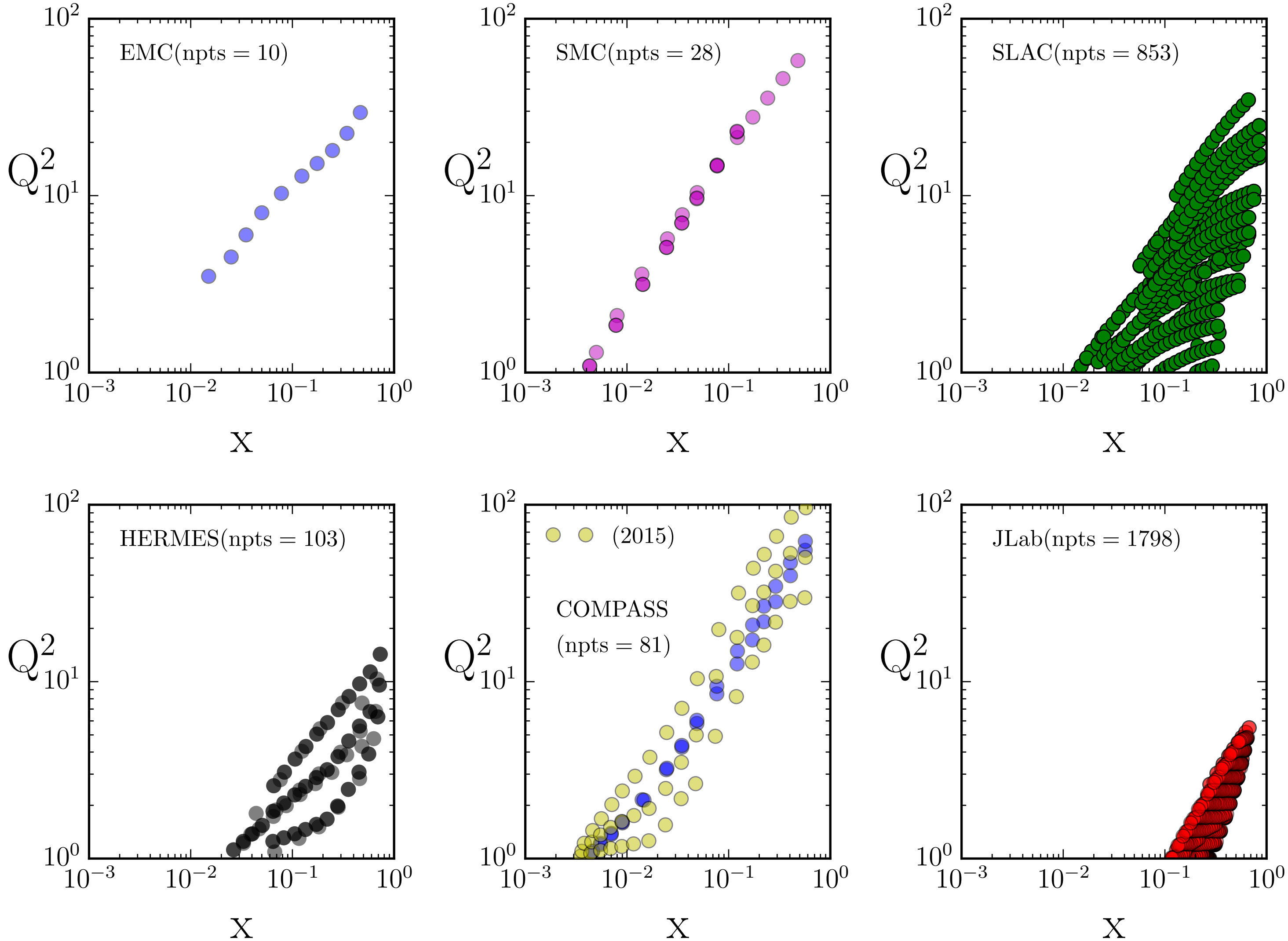
$$\delta\mathcal{O}_+^2 \simeq \sum_i max\left[\mathcal{O}(t_i^+) - \mathcal{O}^{(0)}, \mathcal{O}(t_i^-) - \mathcal{O}^{(0)}, 0\right]^2$$

$$\delta\mathcal{O}_-^2 \simeq \sum_i max\left[\mathcal{O}^{(0)} - \mathcal{O}(t_i^+), \mathcal{O}^{(0)} - \mathcal{O}(t_i^-), 0\right]^2$$

Observable at best parameter values

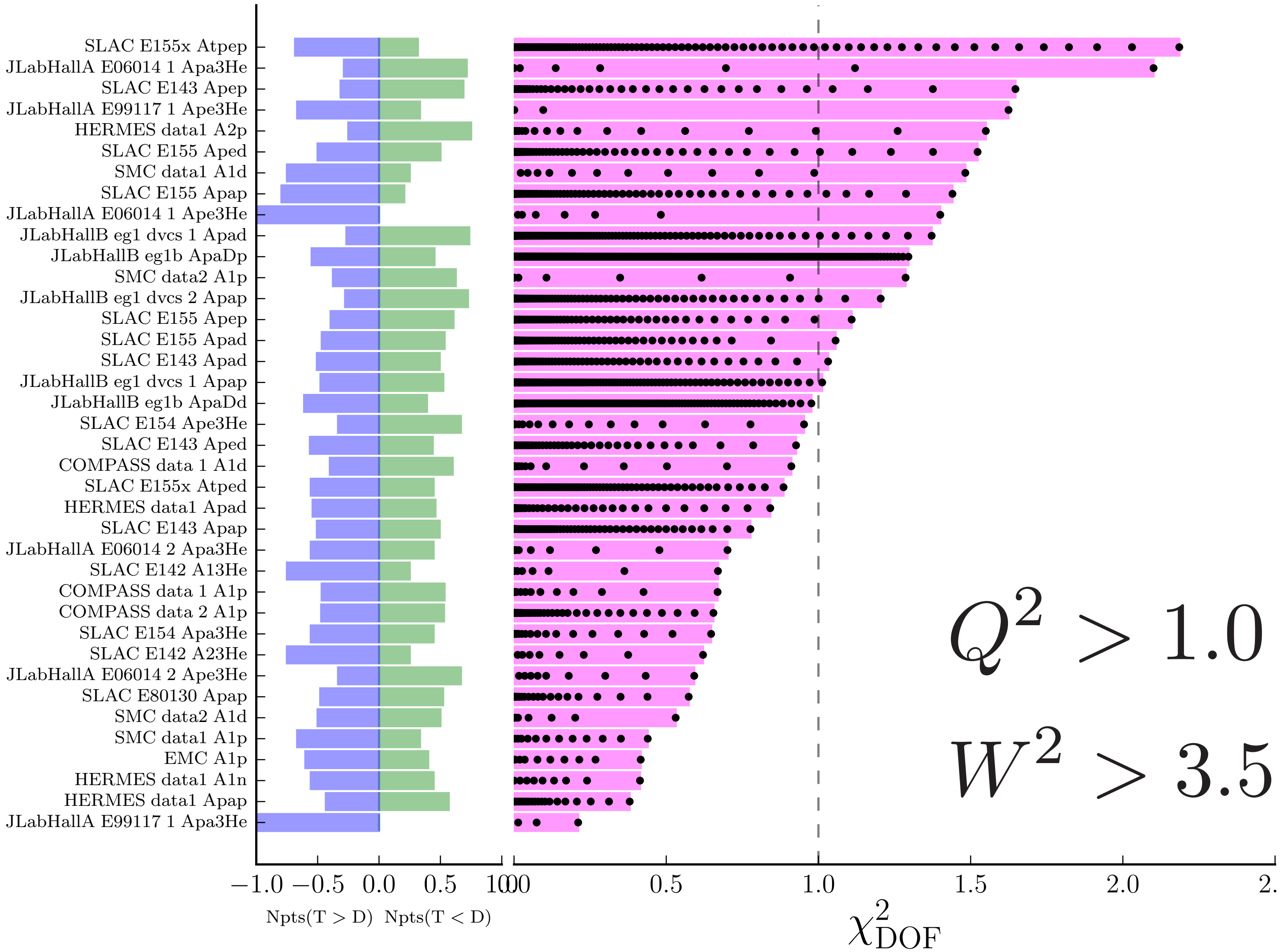
Edges of confidence regions (e.g. 68% or 98%)

Inclusive DIS Data



Preliminary Results

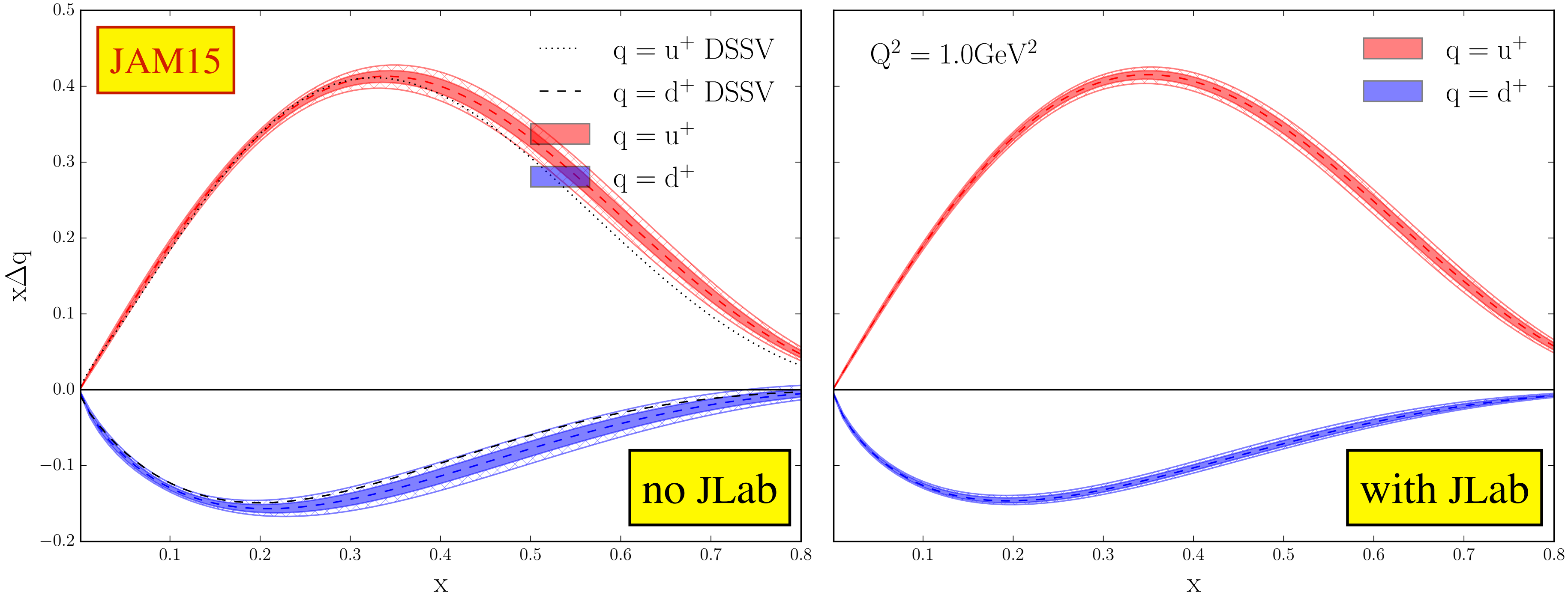
Total of 2887 data points, $\chi^2_{\mathrm{dof}} = 1.18$



$Q^2 > 1.0\ \mathrm{GeV}^2$

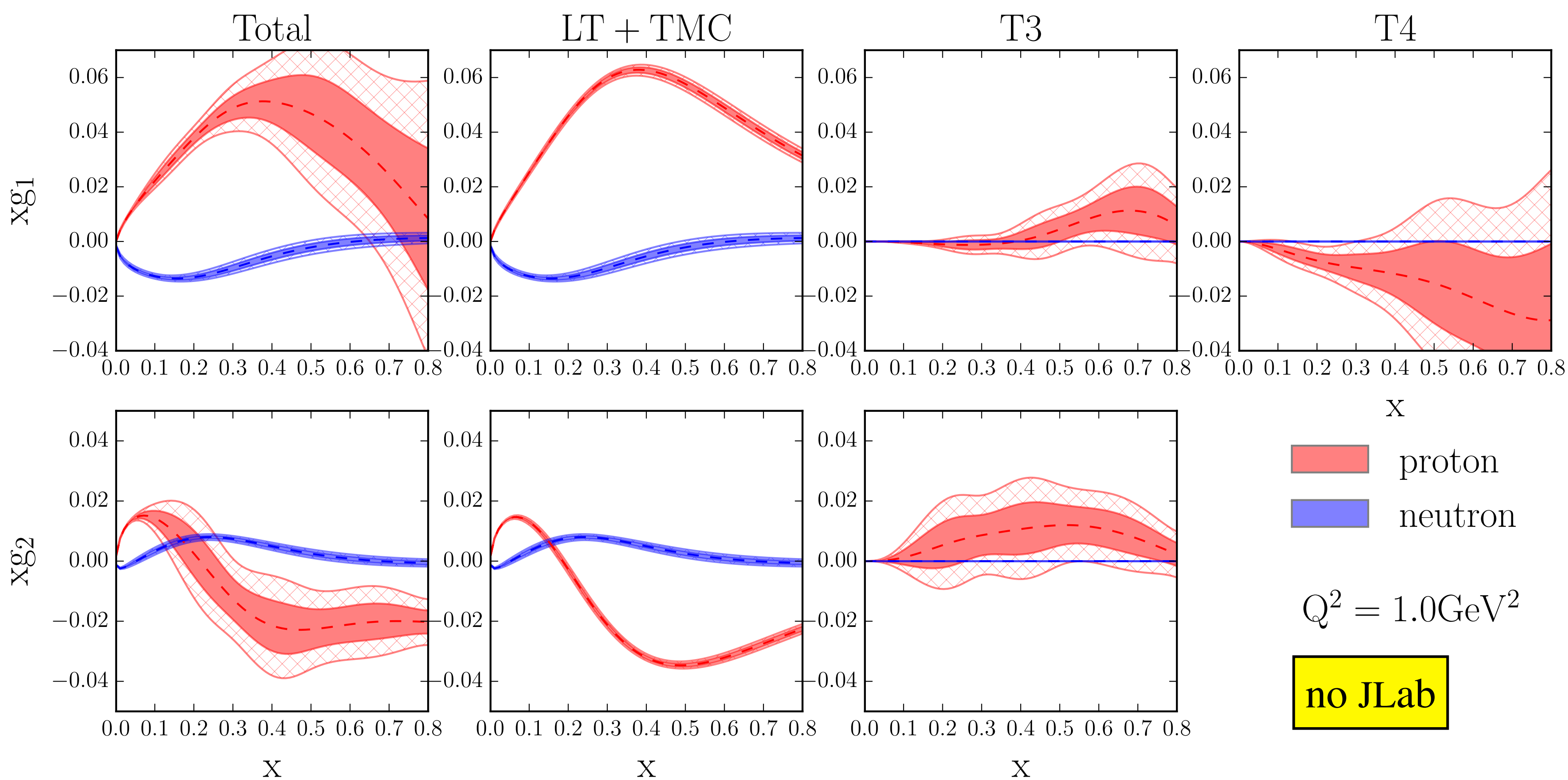
$W^2 > 3.5\ \mathrm{GeV}^2$

Preliminary Results



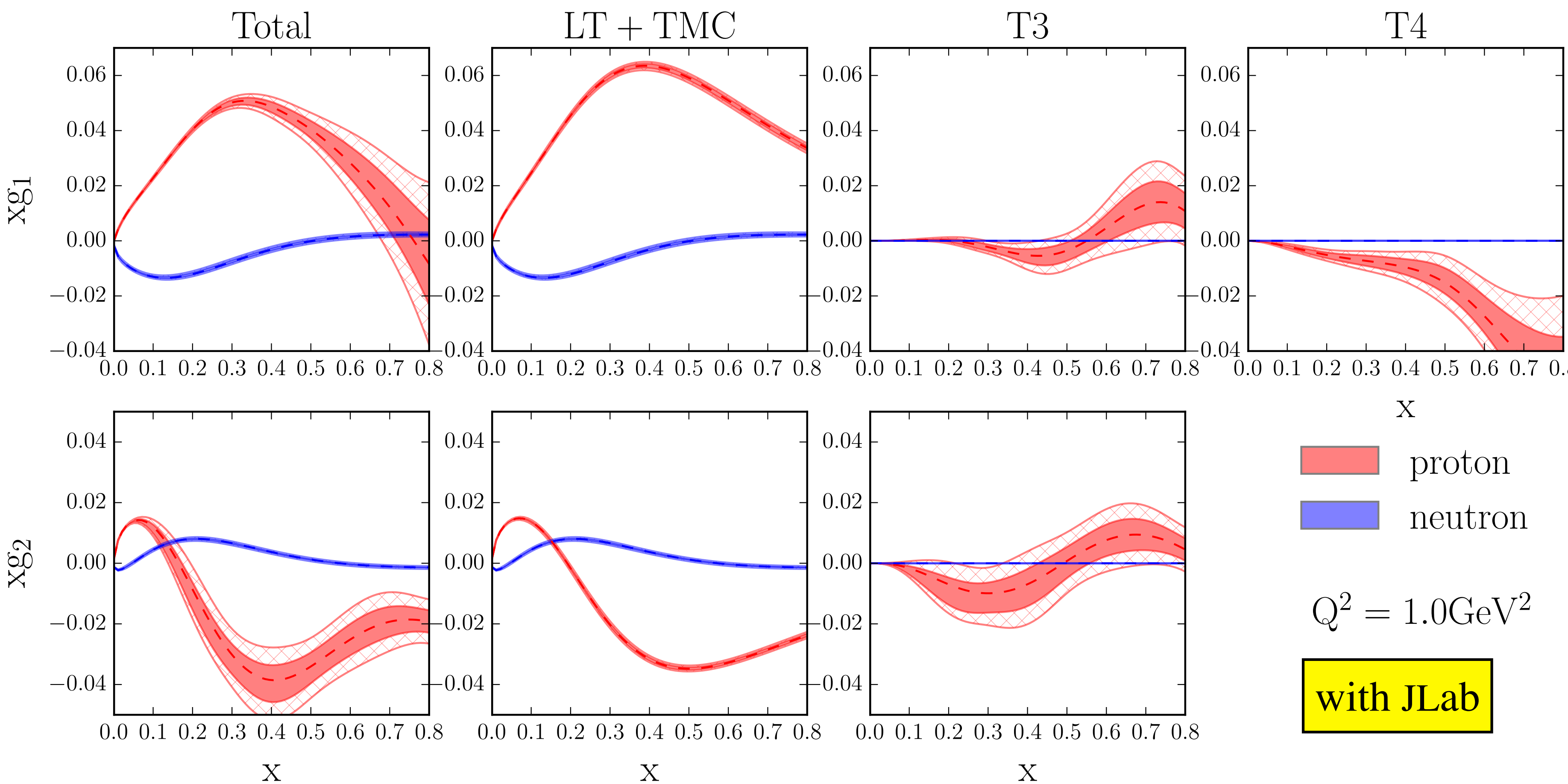
- Consistent with DSSV
- Reduction of uncertainties with JLab data

Preliminary Results



- Neutron higher twist set to zero (not well constrained)

Preliminary Results



- Reduced uncertainties with the inclusion of JLab data

Summary

- Finalized results will reveal impact of JLab 6 GeV data on LT PDFs and higher twist matrix elements

- Future work:
  - Universal fit to extract unpolarized and polarized PDFs from DIS data simultaneously
  - Inclusion of SIDIS and polarized *pp* data
    - Constrains gluon and sea distributions
  - Extension to transverse momentum dependent PDFs

- www.jlab.org/JAM

Thank You!