PV DIS: SUSY and Higher Twist

M.J. Ramsey-Musolf

Caltech
Wisconsin-Madison

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

S. Mantry, K. Lee, G. Sacco   *Caltech*

Outline

I. *PV DIS & new physics*

Model independent analysis

SUSY effects

II. PV DIS & Higher twist

Puzzles from JLab data

The twist expansion

What does QCD predict?

Q^2-dependence, operator matrix elements

III. General remarks

I. PV DIS & New physics

Model Independent Constraints

Low energy effective PV eq interaction

$$L_{PV}^{eq} = \frac{G_\mu}{\sqrt{2}} \sum_q \left[C_{1q} \bar{e} \gamma^\mu \gamma_5 e \bar{q} \gamma_\mu q \; + \; C_{2q} \bar{e} \gamma^\mu e \bar{q} \gamma_\mu \gamma_5 q \right]$$

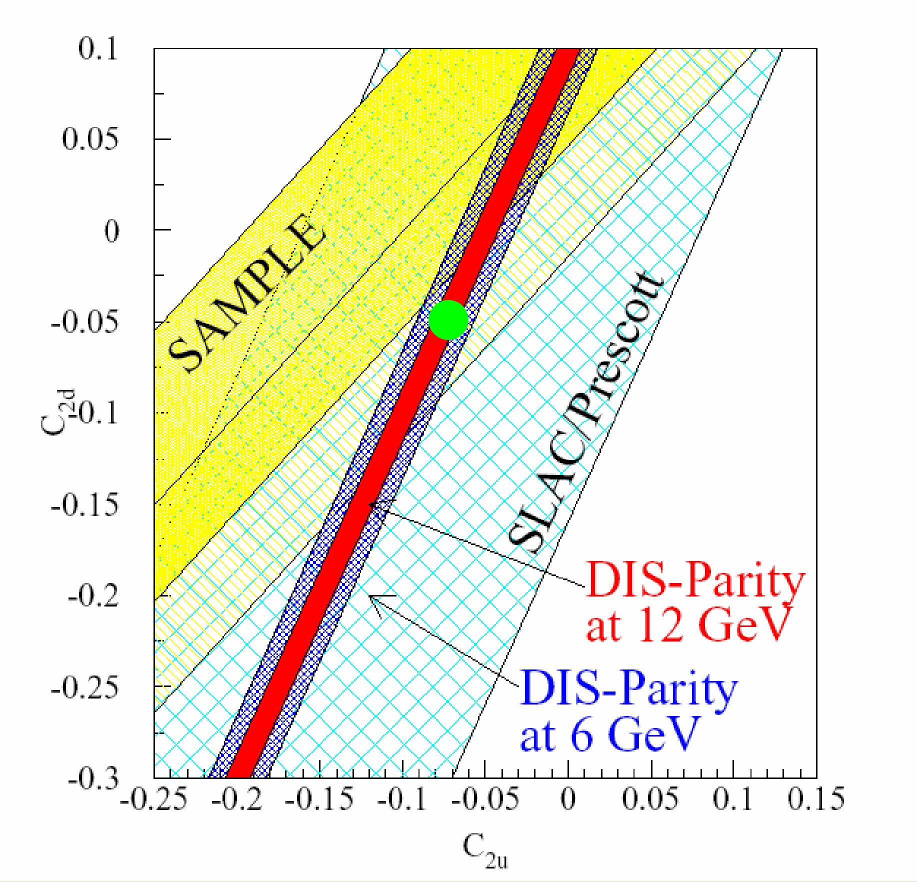
PV DIS eD asymmetry: leading twist

$$A_{PV}^{eD} = \frac{3 G_\mu Q^2}{2\sqrt{2}\pi\alpha} \left[\frac{2C_{1u} - C_{1d} + Y(2C_{2u} - C_{2d})}{5} \right]$$

$$Y = \frac{1 - (1-y)^2}{1 + (1-y)^2 - y^2 R/(1+R)}$$

$$R(x, q^2) = \frac{\sigma_L}{\sigma_R} \approx 0.2$$

Model Independent Constraints



P. Reimer, X. Zheng

Q_W and SUSY Radiative Corrections

Tree Level

Like $Q_W^{p,e} \sim 1 - 4 \sin^2\theta_W$

$$C_{2q} = -\frac{1}{2} g_A^q g_V^e = 2 I_3^q \left(I_3^e - 2 Q_e \hat{s}^2 \right)$$

Flavor-dependent

Radiative Corrections

$$C_{2q} = 2 \hat{\rho}_{NC} I_3^q \left(I_3^e - 2 Q_e \hat{\kappa}\, \hat{s}^2 \right) - \frac{1}{2} \hat{\lambda}_2^q$$

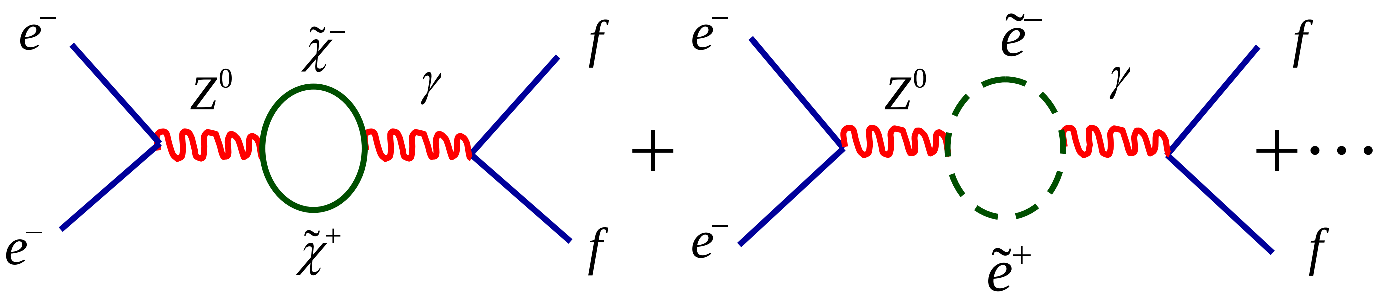
Constrained by Z-pole precision observables

Scale-dependent effective weak mixing

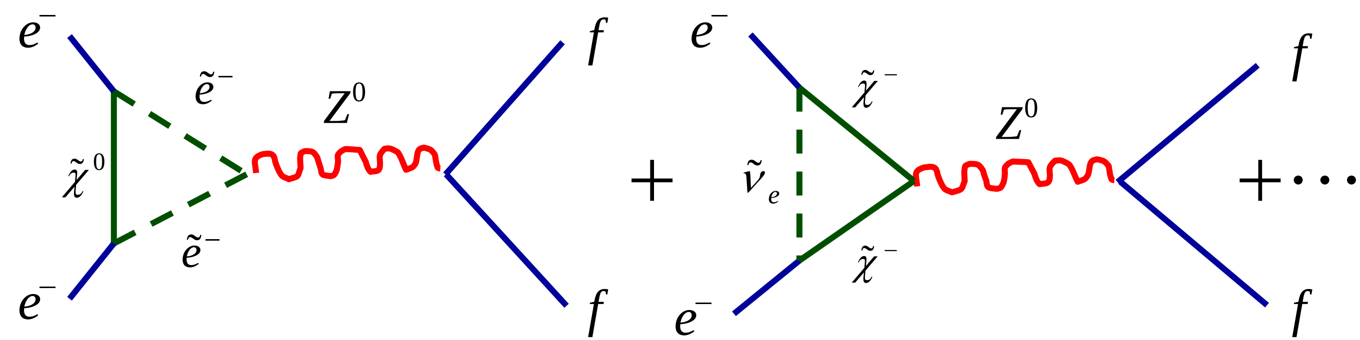
Flavor-independent

SUSY Radiative Corrections

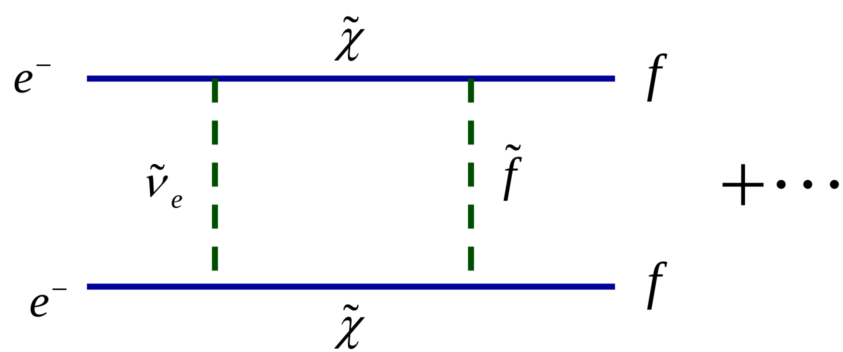
Propagator



Vertex &
External leg



Box



SUSY RPV Effects

$$\Delta C_{1u}^{\rm RPV} = -[C_{1u} - \frac{4}{3}\lambda_x]\Delta_{12k}(\tilde{e}_R^k) - \Delta'_{11k}(\tilde{d}_R^k),$$

$$\Delta C_{1d}^{\rm RPV} = -[C_{1d} + \frac{2}{3}\lambda_x]\Delta_{12k}(\tilde{e}_R^k) + \Delta'_{1k1}(\tilde{q}_L^k),$$

$$\Delta C_{2u}^{\rm RPV} = -[C_{2u} - 2\lambda_x]\Delta_{12k}(\tilde{e}_R^k) - \Delta'_{11k}(\tilde{d}_R^k),$$

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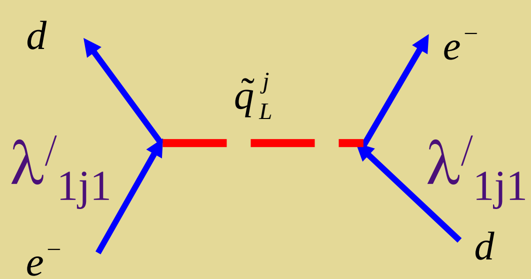
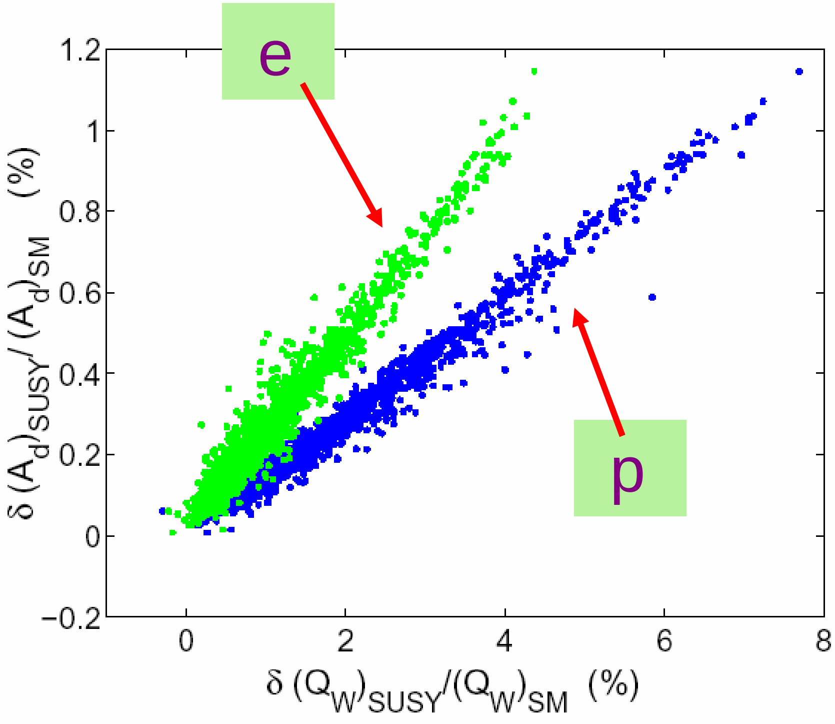
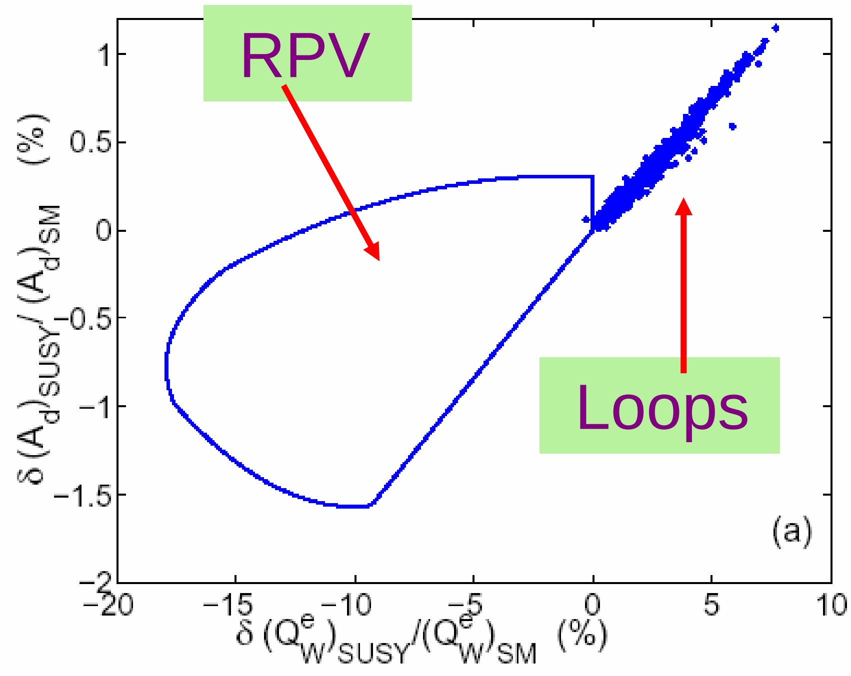


$$\Delta'_{1j1} = \frac{\left|\lambda'_{iji}\right|^2}{4\sqrt{2}G_F M^2_{\tilde{q}_L^j}}$$

$$\lambda_x = \frac{\hat{s}^2(1-\hat{s}^2)}{1-2\hat{s}^2}\frac{1}{1-\Delta\hat{r}^{\rm SM}} \approx 0.35$$

Comparing A_d^{DIS} and $Q_w^{p,e}$





Probing SUSY with PV eN Interactions

$$\frac{\delta Q_W^e}{Q_W^e} \approx -30\,\Delta_{12k}(\tilde{e}_R^k) \approx -45\left(\frac{100\,GeV}{m_{\tilde{e}_R^k}}\right)^2 |\lambda_{12k}|^2$$

λ_{12k} ~ 0.3 for m_{SUSY} ~ 1 TeV & $\delta Q_W^e / Q_W^e$ ~ 5%

$0\nu\beta\beta$ sensitivity

$$\lambda'_{111} \leq 2 \times 10^{-4} \left(\frac{m_{\tilde{q}}}{100\text{ GeV}}\right)^2 \left(\frac{m_{\tilde{g}}}{100\text{ GeV}}\right)^{1/2}$$

λ_{111}' ~ 0.06 for m_{SUSY} ~ 1 TeV

LFV Probes of RPV: μ!eγ

$$|\lambda_{131}\lambda_{231}| \leq 2.3 \times 10^{-4} \left(\frac{m_{\tilde{\ell}}}{100\text{ GeV}}\right)^2$$

$$|\lambda'_{111}\lambda'_{211}| \leq 7.6 \times 10^{-5} \left(\frac{m_{\tilde{q}}}{100\text{ GeV}}\right)^2$$

λ_{k31} ~ 0.15 for m_{SUSY} ~ 1 TeV

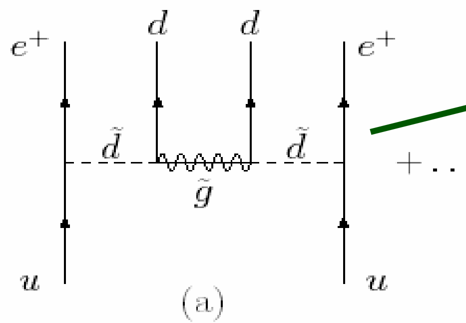
LFV Probes of RPV: μ!e

$$|\lambda_{131}\lambda_{231}| \leq 1.1 \times 10^{-5} \left(\frac{m_{\tilde{\ell}}}{100\text{ GeV}}\right)^2$$

$$|\lambda'_{111}\lambda'_{211}| \leq 6.0 \times 10^{-7} \left(\frac{m_{\tilde{q}}}{100\text{ GeV}}\right)^2$$

λ_{k31} ~ 0.03 for m_{SUSY} ~ 1 TeV

Lepton Flavor & Number Violation

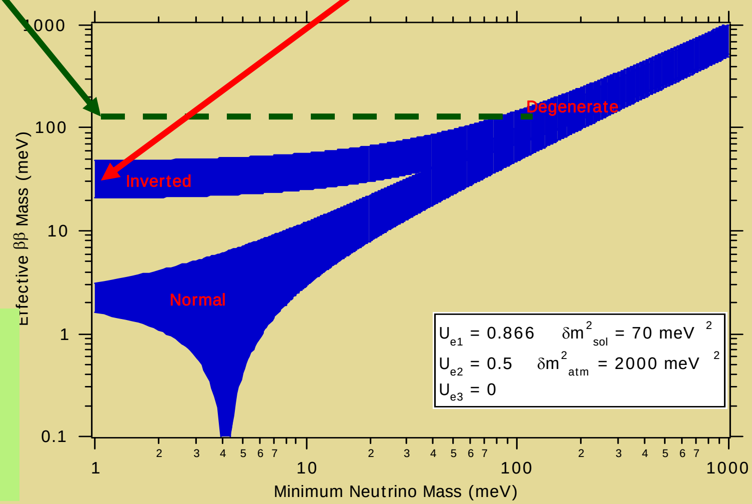


$$\lambda'_{111} \le 2 \times 10^{-4} \left(\frac{m_{\tilde q}}{100\,\mathrm{GeV}}\right)^2 \left(\frac{m_{\tilde g}}{100\,\mathrm{GeV}}\right)^{1/2}$$

$\lambda_{111}' \sim 0.06$ for $m_{SUSY} \sim 1$ TeV

(b)

$0\nu\beta\beta$ signal equivalent to degenerate hierarchy



Loop contribution to m_ν of inverted hierarchy scale

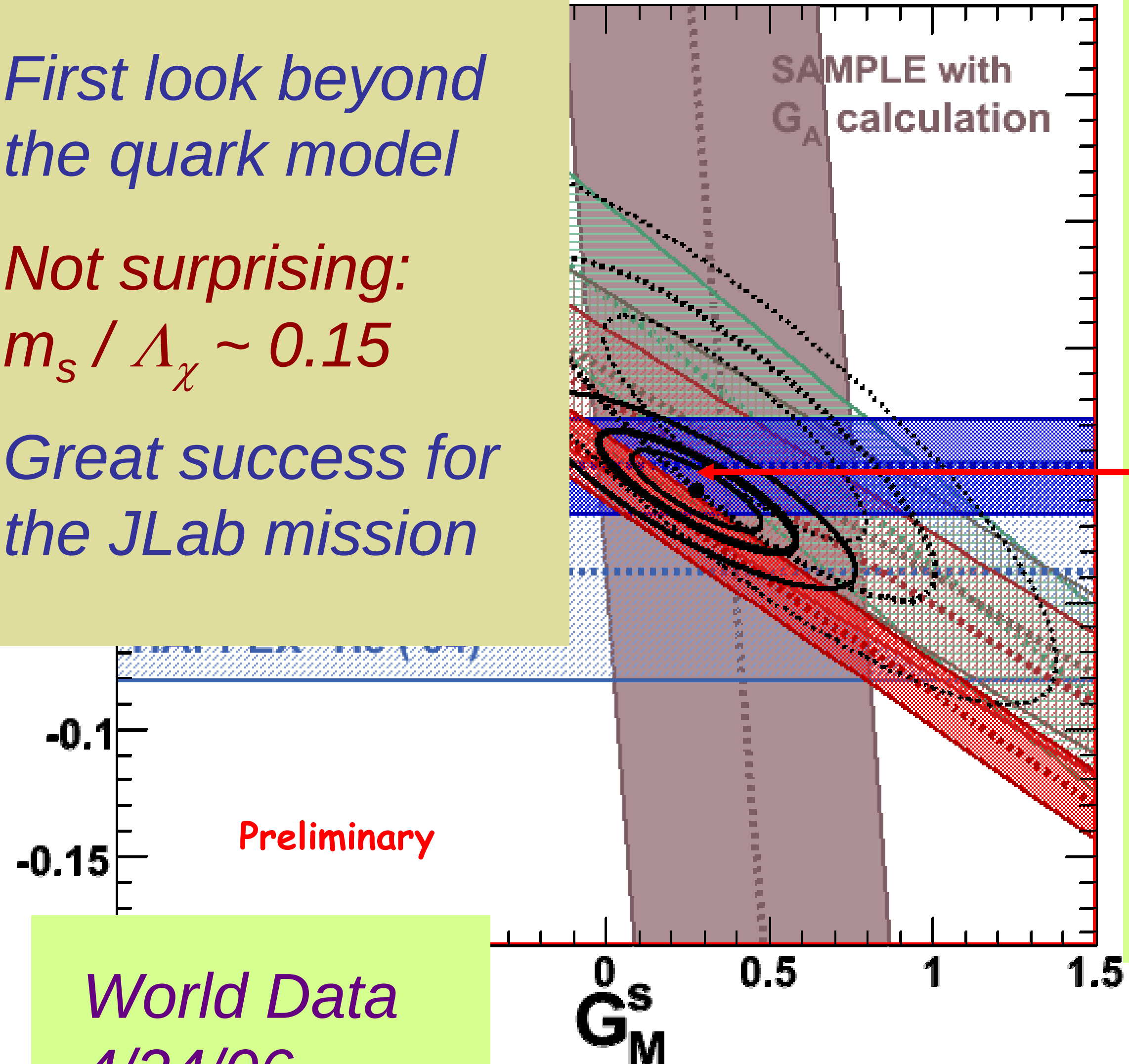
II. PV DIS & Higher Twist

Probing the strange sea with PV

First look beyond the quark model

Not surprising: $m_s / \Lambda_\chi \sim 0.15$

Great success for the JLab mission



World Data 4/24/06

G_M^s = 0.28 +/- 0.20

G_E^s = -0.006 +/- 0.016

~3% +/- 2.3% of proton magnetic moment

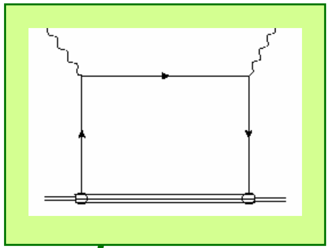
~20% +/- 15% of isoscalar magnetic moment

~0.2 +/- 0.5% of Electric distribution

Consistent with s-quark contributions to m_P & J_P but smaller than early theoretical expectations

Courtesy of Kent Pashke (U Mass)

Probing Higher Twist: Beyond the Parton Model



$2xF_1$ Experimental Status

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- Smooth transition from DIS (solid squares) to resonance region
- Resonances oscillate about perturbative curves (quark-hadron duality in transverse channel) - all Q^2
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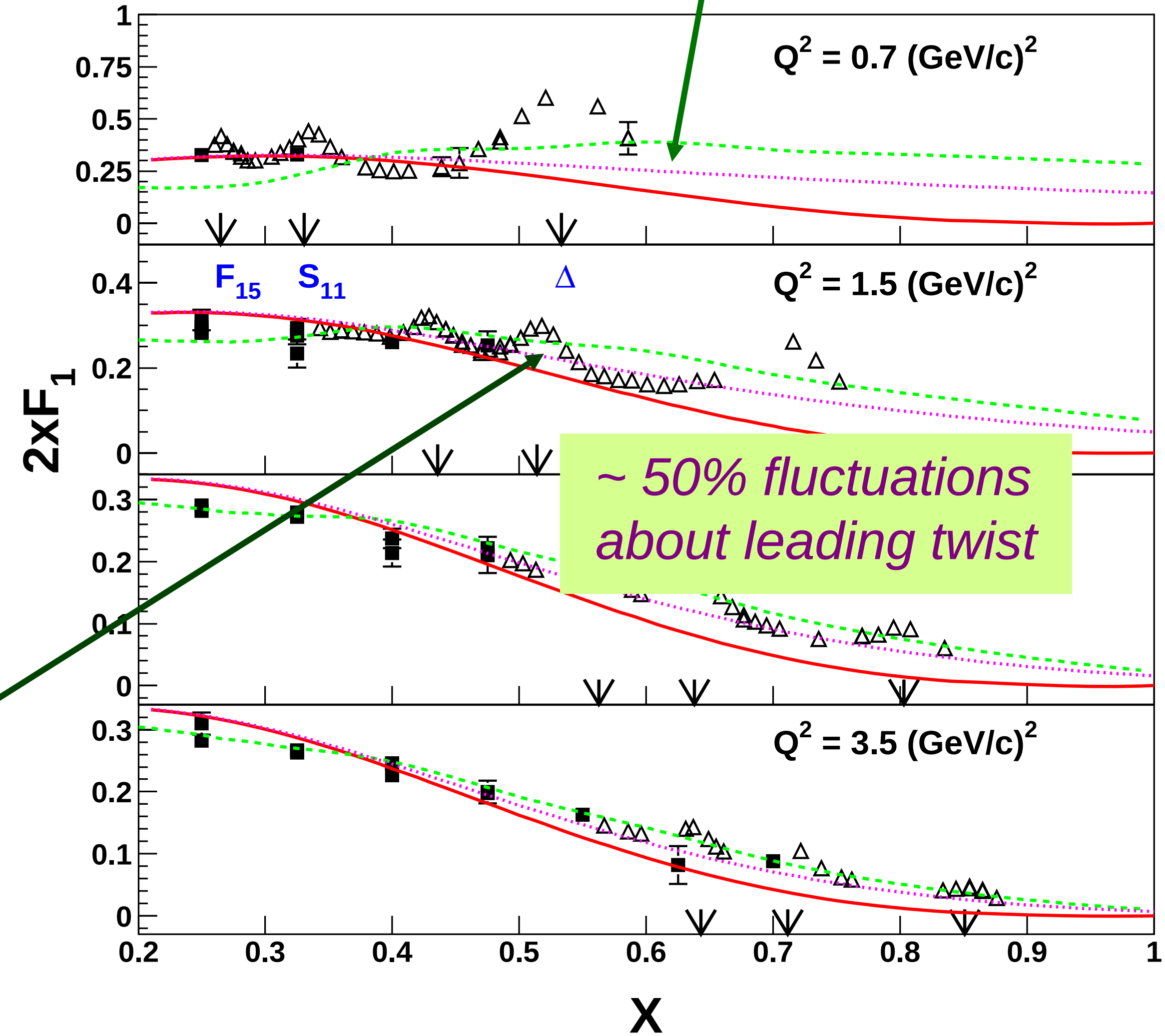
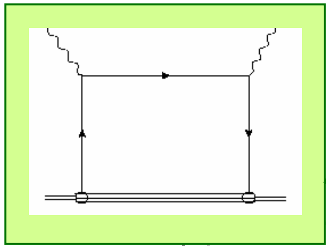
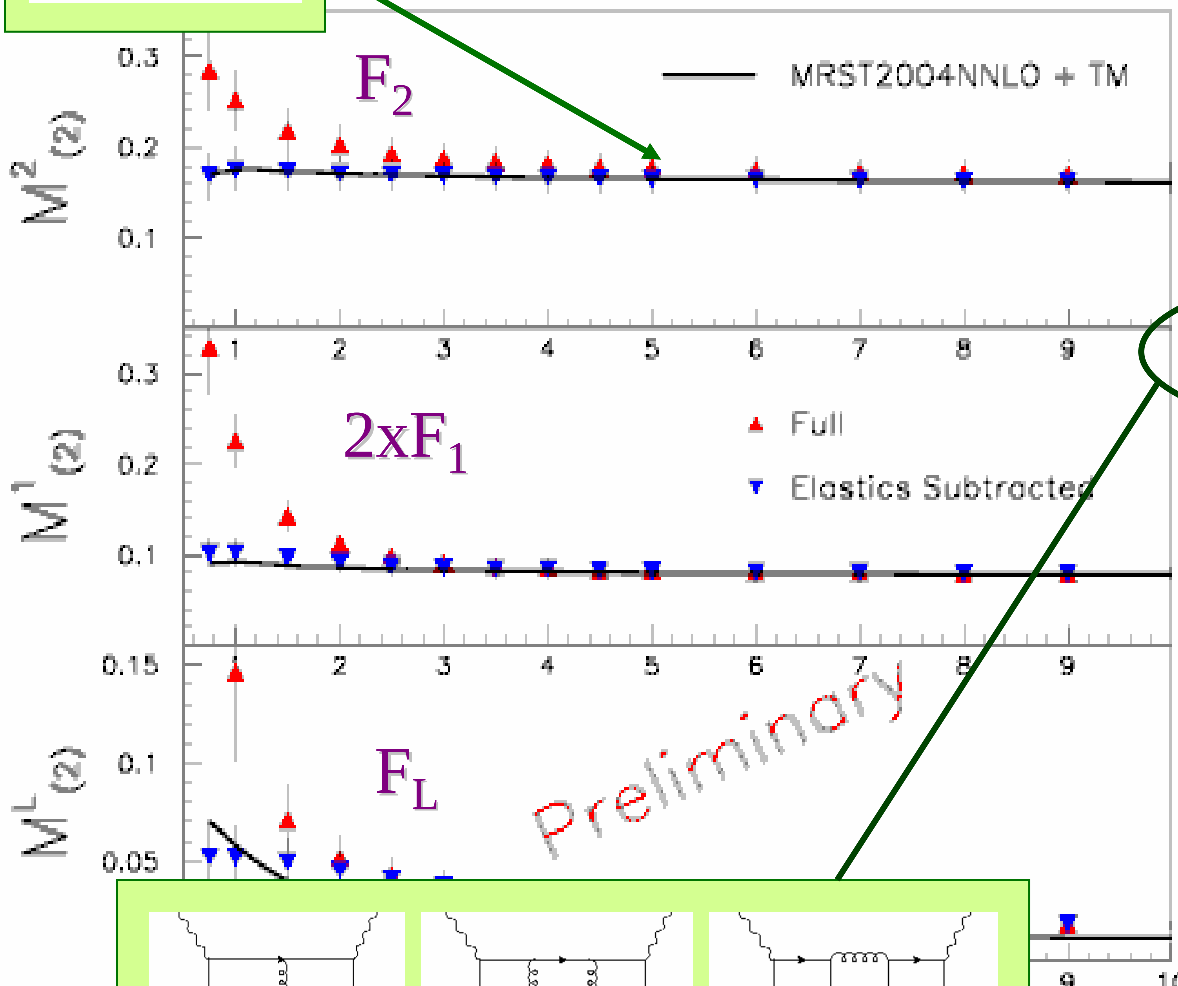
~ 50% fluctuations about leading twist

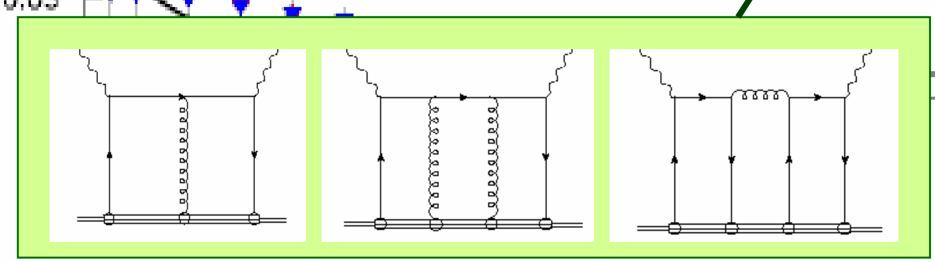


Data from JLab E94-110 (nucl-ex/0410027, submitted to PRL) Courtesy C Keppel

$n = 2$ Cornwall-Norton Moments







F_2, F_1 in excellent agreement with NNLO + TM above $Q^2 = 2$ GeV^2

No (or canceling) higher twists

Yet, dominated by large x and resonance region

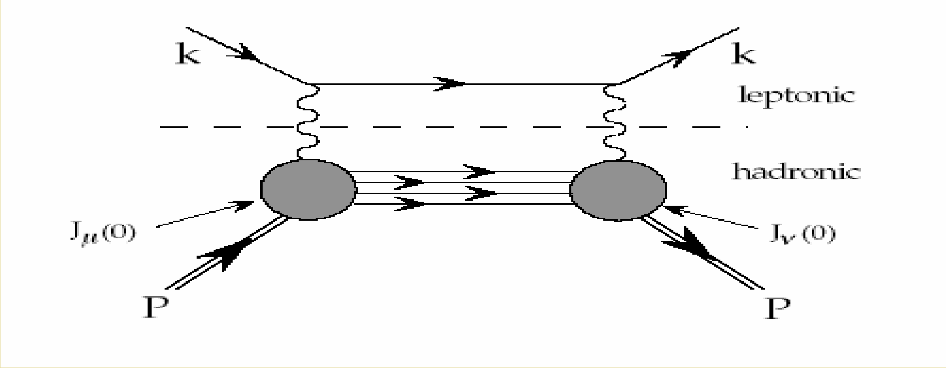
Remove known HT (a bit novel), the elastic, and there is no more down to $Q^2 = 0.5$ GeV2

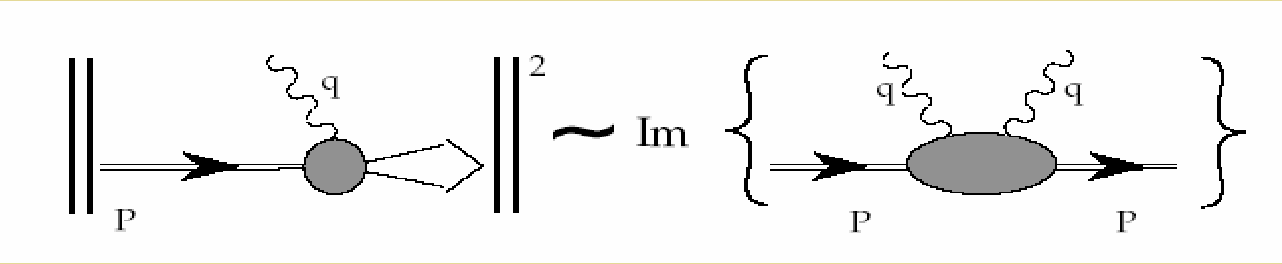
Where are the qq and qqg correlations ?

Twist Expansion

Light cone expansion: $x^2 \sim 0$

$$T\left\{J_\mu^a(x)J_\nu^b(0)\right\}$$





Jaffe '97

Twist Expansion

Light cone expansion: $x^2 \sim 0$

$$T\left\{J_\mu^a(x)J_\nu^b(0)\right\} \sim \Gamma_{\mu\nu}\sum_{n,k} x^{\mu_1}\ldots x^{\mu_n}\, C_k^{(n)}(x^2)\,\hat{O}^{(n)}_{k,\,\mu_1\ldots\mu_n}(0)$$

Momentum sum rules

$$M_j^{(n)}(Q^2) \equiv \int_0^1 dx_B\, x_B^{n-j} F_j(x_B,Q^2) \propto \sum_k \tilde{C}^{(n)}_{1,k}(Q^2/\mu^2,g)\; A_k^{(n)}(\mu)$$

$$\langle P|\hat{O}^{(n)}_{k,\,\mu_1\ldots\mu_n}(0)|P\rangle = A_k^{(n)}\left(P_{\mu_1}\ldots P_{\mu_n}+\cdots\right)$$

Twist = d(n) - j

Power corr:

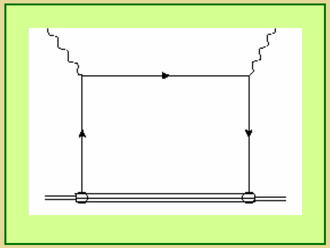
Λ^2_{HAD}/Q^2

$$\tilde{C}^{(n)}_{j,k}(Q^2) \sim \ln\frac{Q^2}{\mu^2}$$ *twist 2*

$$\tilde{C}^{(n)}_{j,k}(Q^2) \sim \frac{1}{Q^2}\ln\frac{Q^2}{\mu^2}$$ *twist 4*

Twist Expansion: Q^2 Evolution

Twist two



Singlet moments:
2 x 2 mixing only

$$\hat{O}_{NS}^{(n)} = \frac{(i)^{n-1}}{n!}\Big\{\bar{q}(x)\,\frac{\lambda^a}{2}\gamma_{\mu_1} \ldots$$

$$\hat{O}_{Sq}^{(n)} = \frac{(i)^{n-1}}{n!}\Big\{\bar{q}(x)\,\gamma_{\mu_1} \ldots$$

$$\hat{O}_{Sg}^{(n)} = \frac{2(i)^{n-2}}{n!}\,Tr\,\Big\{G_{\mu_1}^{\nu} \ldots$$

$$\Delta\cdot Q_n^{1(k,l)} = g\bar{\psi}_R \Delta \overleftarrow{d}^{\,l}\overrightarrow{d}^{\,k}\psi_R\bar{\psi}_R\Delta\overrightarrow{d}^{\,n-2-k-l}\psi_R\,,$$

$$\Delta\cdot Q_n^{2(k,l)} = g\bar{\psi}_R\tau_a \Delta \overleftarrow{d}^{\,l}\overrightarrow{d}^{\,k}\psi_R\bar{\psi}_R\Delta\overrightarrow{d}^{\,n-2-k-l}\tau_a\psi_R\,,$$

$$\Delta\cdot Q_n^{3(k,l)} = g\bar{\psi}_R \Delta \overleftarrow{d}^{\,l}\overrightarrow{d}^{\,k}\psi_R\bar{\psi}_L\Delta\overrightarrow{d}^{\,n-2-k-l}\psi_L\,,$$

$$\Delta\cdot Q_n^{4(k,l)} = g\bar{\psi}_R\tau_a \Delta \overleftarrow{d}^{\,l}\overrightarrow{d}^{\,k}\psi_R\bar{\psi}_L\Delta\overrightarrow{d}^{\,n-2-k-l}\tau_a\psi_L\,,$$

$$\Delta\cdot Q_n^{5(k,l)} = g\bar{\psi}_L \Delta \overleftarrow{d}^{\,l}\overrightarrow{d}^{\,k}\psi_L\bar{\psi}_L\Delta\overrightarrow{d}^{\,n-2-k-l}\psi_L\,,$$

$$\Delta\cdot Q_n^{6(k,l)} = g\bar{\psi}_L\tau_a \Delta \overleftarrow{d}^{\,l}\overrightarrow{d}^{\,k}\psi_L\bar{\psi}_L\Delta\overrightarrow{d}^{\,n-2-k-l}\tau_a\psi_L\,,$$

$$\Delta\cdot Q_n^{7(k)} = \bar{\psi}\overleftarrow{d}^{\,k} * f\gamma_5\overrightarrow{d}^{\,n-1-k}\psi\,,$$

$$\Delta\cdot Q_n^{8(k)} = i\bar{\psi}\overleftarrow{d}^{\,k} f\overrightarrow{d}^{\,n-1-k}\psi\,,$$

$$\Delta\cdot Q_n^{9(k,l)} = g\bar{\psi}\overleftarrow{d}^{\,k} f_a^{\alpha}(\overrightarrow{d}^{\,l} f_{\alpha})_a\overrightarrow{d}^{\,n-3-k-l}\Delta\psi\,,$$

$$\Delta\cdot Q_n^{10(k,l)} = igf_{abc}\bar{\psi}\overleftarrow{d}^{\,k} f_a^{\alpha}(\overrightarrow{d}^{\,l} f_{\alpha})_b\overrightarrow{d}^{\,n-3-k-l}\Delta\tau_c\psi\,,$$

$$\Delta\cdot Q_n^{11(k,l)} = gd_{abc}\bar{\psi}\overleftarrow{d}^{\,k} f_a^{\alpha}(\overrightarrow{d}^{\,l} f_{\alpha})_b\overrightarrow{d}^{\,n-3-k-l}\Delta\tau_c\psi\,,$$

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$$\Delta\cdot Q_n^{14(k,l)} = igd_{abc}\bar{\psi}\overleftarrow{d}^{\,k} * f_a^{\alpha}(\overrightarrow{d}^{\,l} f_{\alpha})_b\overrightarrow{d}^{\,n-3-k-l}\Delta\gamma_5\tau_c\psi\,.$$

Twist Expansion : Q^2 Evolution

Equivalence to parton model: twist two

$$\frac{M^{(n)}(t)}{M^{n)}(t_0)} = \left(\frac{t}{t_0}\right)^{-\gamma_{n,0}/2\beta_0}$$

$$\gamma_{n,0} = \int_0^1 dz\, z^n P_{qq}(z)$$

DGLAP splitting function

$$\left(\mu\frac{\partial}{\partial\mu} + \beta(g)\frac{\partial}{\partial g} - \gamma_n\right)\tilde{C}_j^{(n)}\left(\frac{Q^2}{\mu^2}, g\right) = 0$$

Anomalous dimension

No known analog for twist four

Need RGE & anom dim computation

Twist Expansion : Q^2 Evolution

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Flavor: isosinglet mixing

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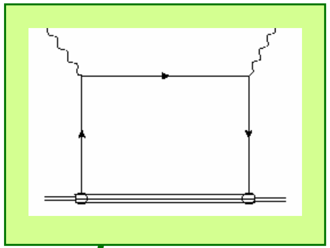
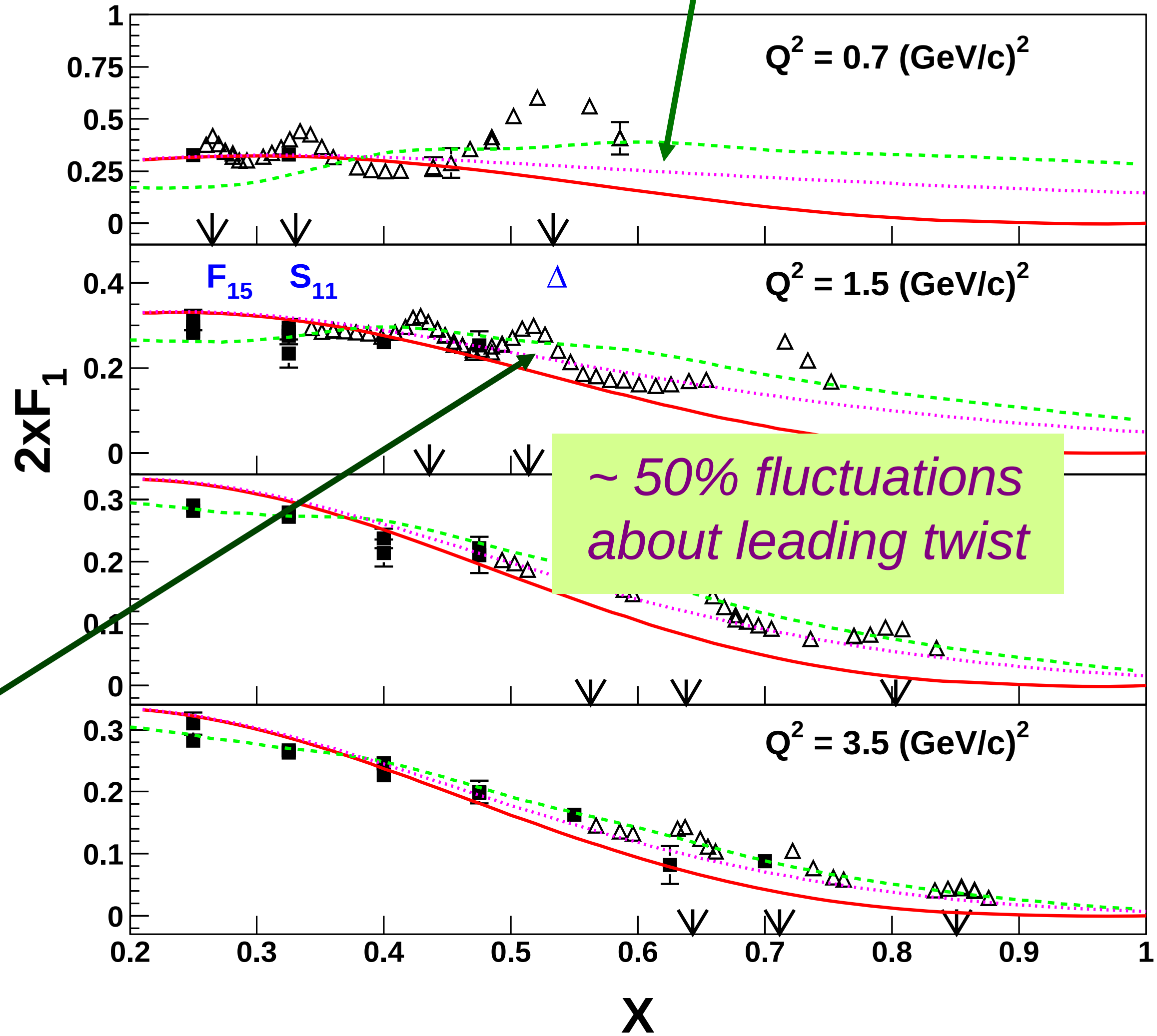
Probing Higher Twist: Beyond the Parton Model



$2xF_1$ Experimental Status

- - - Alekhin NNLO
——— MRST NNLO
········ MRST NNLO with Barbieri Target Mass Corrections



~ 50% fluctuations about leading twist

- Smooth transition from DIS (solid squares) to resonance region
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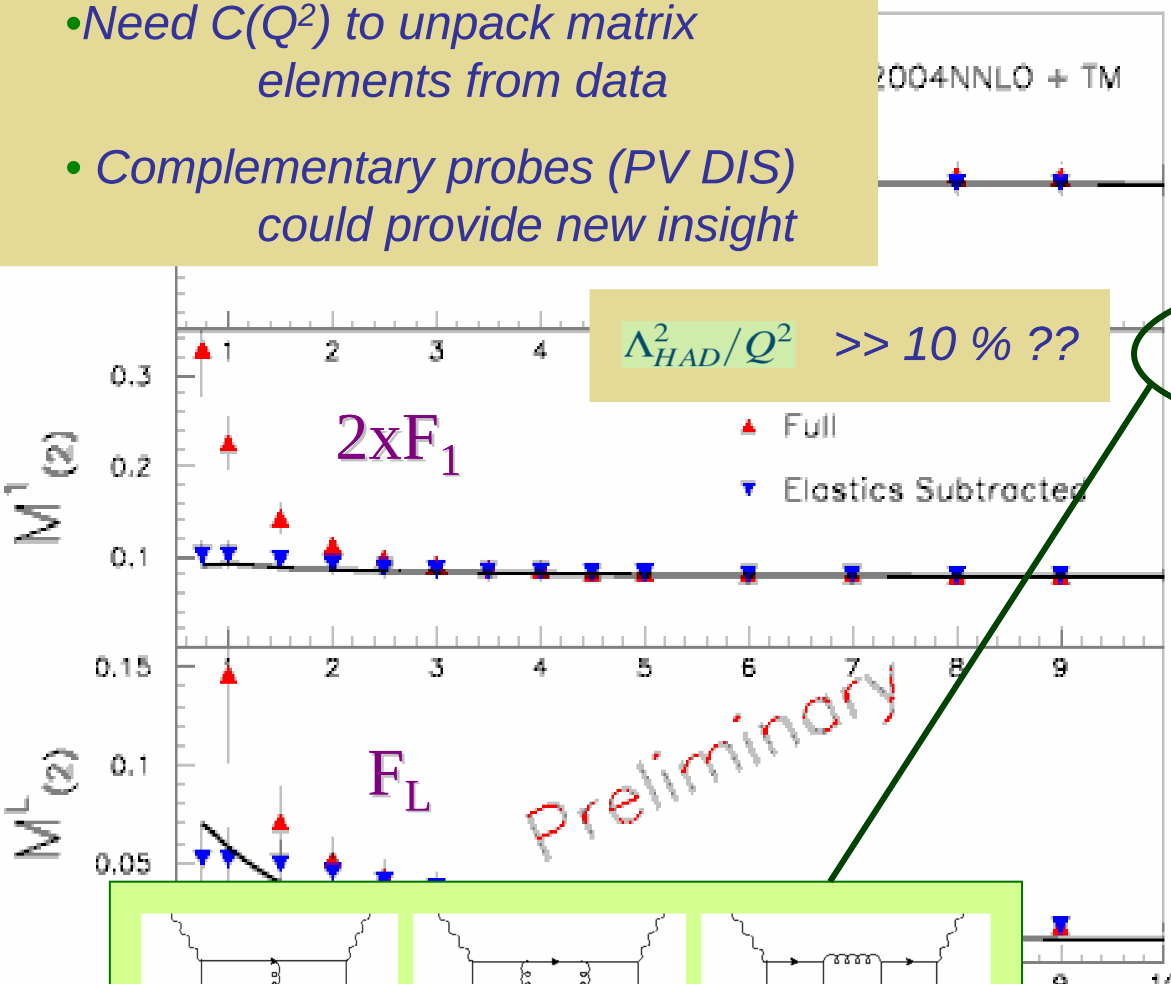
Data from JLab E94-110 (nucl-ex/0410027, submitted to PRL) Courtesy C Keppel

vall-Norton Moments

nts

- *Are twist 4 matrix elements suppressed or canceling?*
- *Need $C(Q^2)$ to unpack matrix elements from data*
- *Complementary probes (PV DIS) could provide new insight*



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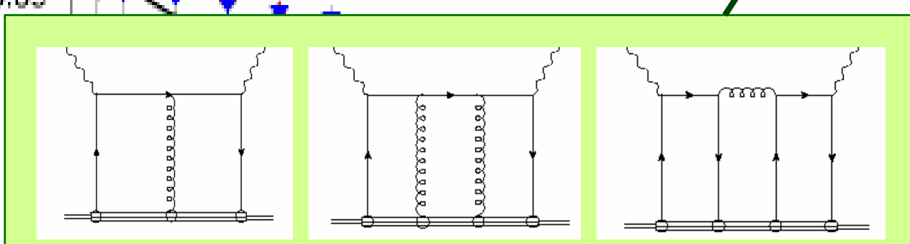
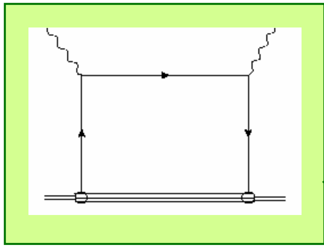
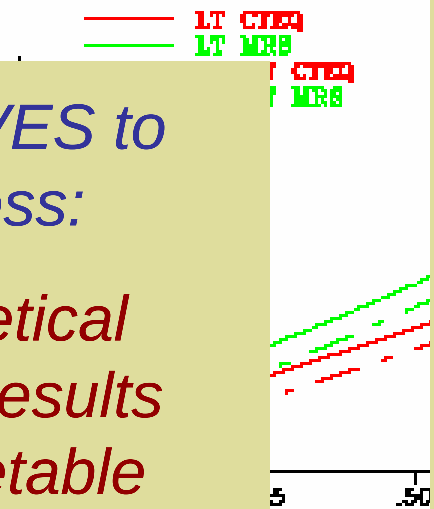


Where are the qq and qqg correlations ?

Probing Higher Twist with PV



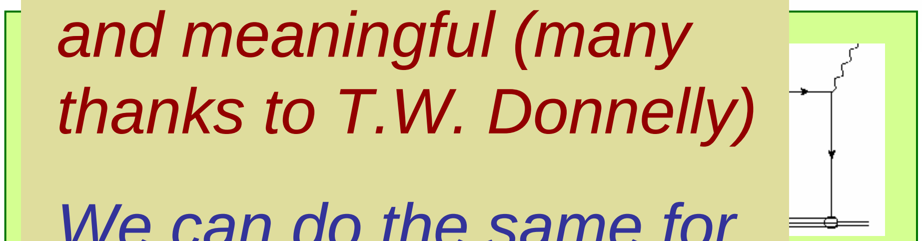
PV Deep Ineslastic eD (J Lab 12 GeV)



Early days of PVES to probe strangeness:

Extensive theoretical work to ensure results would be intepretable and meaningful (many thanks to T.W. Donnelly)

We can do the same for PV DIS



Theoretical Challenges

pQCD evolution of twist four moments

Lattice QCD for τ =4 matrix elements

Organizing the program: what kinematics, complementarity with PC $F_{1,2}$, …

preliminary

III. General remarks

- PV DIS provides a comprehensive probe of QCD beyond the parton model & possible deviations from the SM EW sector
- Looking beyond the parton model is a natural continuation of the JLab strange quark searches
- Rich set of challenges for theory & experiment: higher twist, CSB in pdfs, d/u…
- Important complement to 12 GeV Moller that would be a focused and powerful probe of EW SM & possible new physics