Theoretical Summary

Andrei Belitsky

Arizona State University

PV DIS provides a comprehensive probe of QCD beyond the parton model & possible deviations from the SM EW sector

Michael's slogan

$$A_{\rm iso} = -\left[\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right]\frac{2C_{1u} - C_{1d}\left[1 + R_s\right] + Y\left(2C_{2u} - C_{2d}\right)R_v}{5 + R_s}$$

Paul and Paul's talks

$$R_s(x) = \frac{2S(x)}{U(x) + D(x)}$$

$$R_v(x) = \frac{u_v(x) + d_v(x)}{U(x) + D(x)}$$

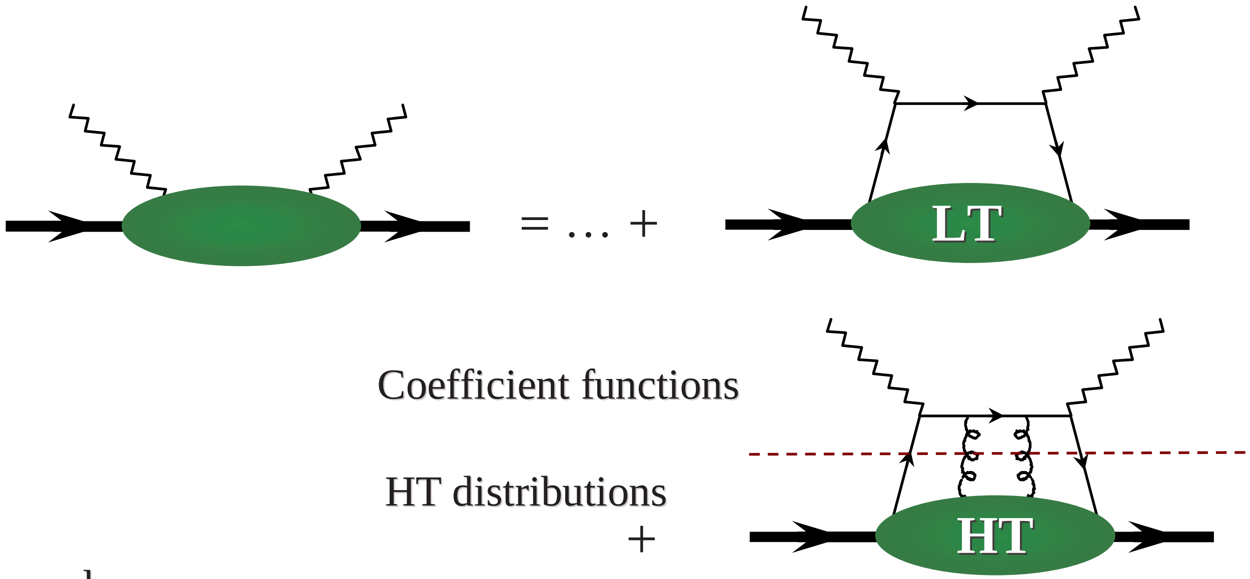
$$Y = \frac{1 - (1-y)^2}{1 + (1-y)^2 - y^2 R/(1+R)}$$

$$R(x, Q^2) = \sigma_L/\sigma_R \approx 0.2$$

For deuteron:

$$A \sim \int d^4 z\, e^{iqx} \left\langle \overline{u}(z)\gamma u(z)\overline{d}(0)\gamma d(0)\right\rangle$$

Factorization



Kinematical HT:
target mass corr.

Dynamical HT

Generals:

- Story of HT is well known for polarized structure functions in DIS

  Talk by Alexandre

- Account for finite mass of the target: induce kinematical HT corrections

  Nachtmann '73
  Georgi, Politzer '74

- Construction of the complete basis of twist-4 operators

  Jaffe, Soldate '80s
  Ellis, Furmanski, Petronzio'80s
  Balitsky, Braun '89

- Choice is driven by good transformation properties w.r.t. conformal group (if one is interested in subsequent evolution)

  See, e.g., Braun et al '09

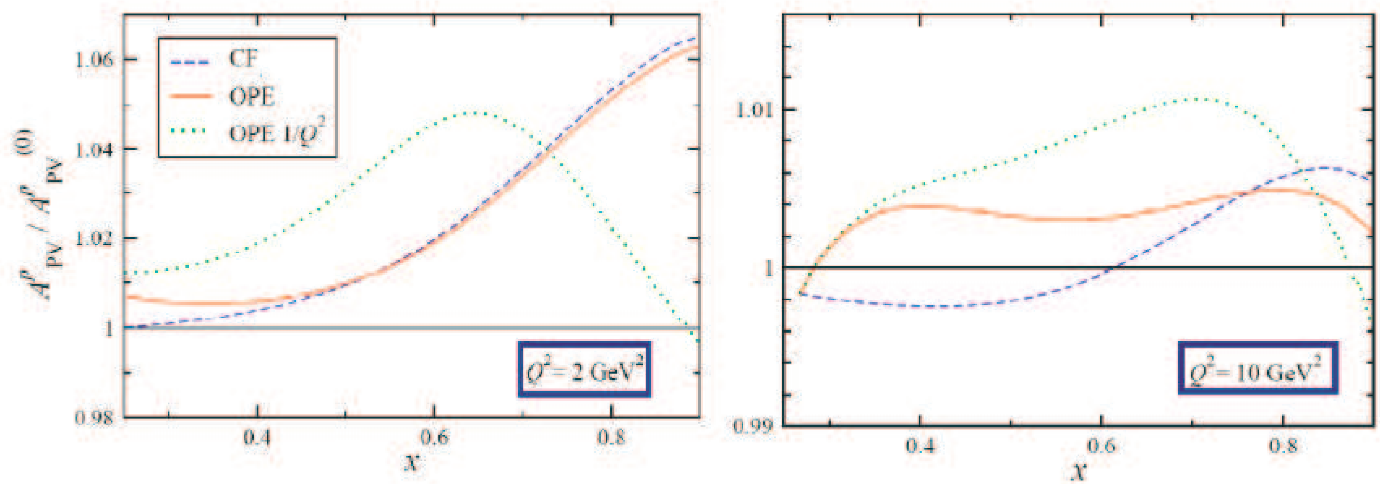
Target mass corrections

Talk by Tim

$$F_1^{\rm OPE}(x,Q^2) \approx F_1^{(0)}(x,Q^2) + \frac{x^3M^2}{Q^2}\left(2\int_x^1 \frac{dz}{z^2}F_1^{(0)}(z,Q^2) - \frac{\partial}{\partial x}F_1^{(0)}(x,Q^2)\right)$$

$$F_2^{\rm OPE}(x,Q^2) \approx \left(1-\frac{4x^2M^2}{Q^2}\right)F_2^{(0)}(x,Q^2) + \frac{x^3M^2}{Q^2}\left(6\int_x^1 \frac{dz}{z^2}F_2^{(0)}(z,Q^2) - \frac{\partial}{\partial x}F_2^{(0)}(x,Q^2)\right),$$

$$F_3^{\rm OPE}(x,Q^2) \approx \left(1-\frac{2x^2M^2}{Q^2}\right)F_3^{(0)}(x,Q^2) + \frac{x^3M^2}{Q^2}\left(2\int_x^1 \frac{dz}{z^2}F_3^{(0)}(z,Q^2) - \frac{\partial}{\partial x}F_3^{(0)}(x,Q^2)\right).$$



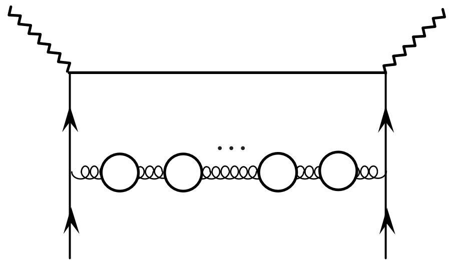
2-3% uncertainty contribution at low Q^2

Coefficient function

- Calculate the coefficient functions of the contributing HT operators to the amplitude using EFP or BB formalisms

Michael and Piet's talks

- Get an estimate on HT contributions to various structure functions via IR renormalon analysis



$$\sim \left(\frac{\Lambda}{Q}\right)^2 \int_0^1 dy\, C(x,y) q^{\mathrm{tw2}}(y)$$

E.g., HT in F_3

Dasgupta, Webber'96

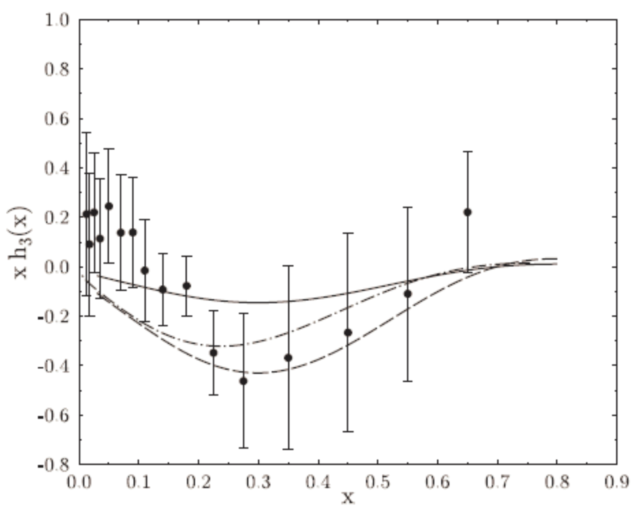


Figure 4: Renormalon prediction for $xh_3(x)$ using the LO GRV [27] parametrization (solid line). The data points taken from Ref. [28] correspond to the NLO analysis, which provides the best fit of the higher-twist corrections. However, to be consitent within the renormalon approach the parton distribution sets used for the renormalon prediction have to be LO. The dashed line shows the prediction with the scale μ^2 adjusted to the description of the coefficients C_p and C_d, as in [7]. The dot-dashed line shows the original prediction of [7], obtained using the MRSA parametrization [29] normalized at $Q^2 = 10$ GeV^2.

Ref.[28] hep-ph/9706534

Matrix elements

- Estimate magnitude of matrix elements of HT operators via UV renormalons (will match into IR renormalon analysis above, but will provide info on what operators to evolve)

See, e.g., Beneke's Phys. Rept.

$$\frac{F_L(x,Q^2)}{2x}_{|\text{twist}-4} = \frac{1}{Q^2}\int d\xi_1 d\xi_2 \left[C^3_{4,L}(x,\xi_1,\xi_2)\,T_3(\xi_1,\xi_2) + C^7_{4,L}(x,\xi_1,\xi_2)\,T_7(\xi_1,\xi_2)\right]$$

$$\langle N(p)|\mathcal{O}_3(v,y)|N(p)\rangle(\mu) = 2\,p\cdot y\int d\xi_1 d\xi_2\, e^{ip\cdot y[\xi_1(1-v)+\xi_2(1+v)]}\,T_3(\xi_1,\xi_2,\mu),$$

$$\langle N(p)|\mathcal{O}_7(v,y)|N(p)\rangle(\mu) = 2\,(p\cdot y)^2\int d\xi_1 d\xi_2\, e^{ip\cdot y[\xi_1(1-v)+\xi_2(1+v)]}\,T_7(\xi_1,\xi_2,\mu).$$

$$\mathcal{O}_3(v,y) = \frac{1}{2}\epsilon_{\alpha\beta\gamma\delta}\,\bar\psi(y)y^\alpha\gamma^\beta\gamma_5 g_s G^{\gamma\delta}(vy)\psi(-y),$$

$$\mathcal{O}_7(v,y) = \bar\psi(y)\,\not{y}\,y^\beta D^\alpha g_s G_{\alpha\beta}(vy)\psi(-y).$$

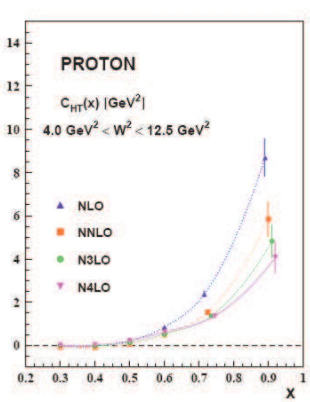
IR renormalons

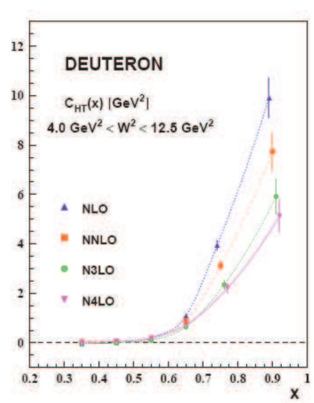
$$T_3(\xi_1,\xi_2)_{|\text{q. div.}} = (-K)\left\{\frac{1}{\xi_1}\left(1+\frac{\xi_2}{\xi_1}\right)F(\xi_1)\,\theta(\xi_1-\xi_2) + (\xi_1\leftrightarrow\xi_2)\right\}\theta(\xi_1)\theta(\xi_2)$$

$$T_7(\xi_1,\xi_2)_{|\text{q. div.}} = 2K\left\{\frac{\xi_2}{\xi_1}F(\xi_1)\,\theta(\xi_1-\xi_2) + (\xi_1\leftrightarrow\xi_2)\right\}\theta(\xi_1)\theta(\xi_2).$$

Reduction of higher twist effects with inclusion of N...NLO corrections to coefficient function

Johannes' talk





Similar higher twist effects in F_L for deuteron and proton

Matrix elements, cont'd

- Model estimates (hierarchy of matrix elements)

Christian's comments

Two NP scales (hadronic and chiralSB scale) provide typical magnitudes for two sets of operator matrix elements

$$\langle \overline{\psi}\, D_\perp^2\, \psi \rangle \sim m_\rho^2 \langle \overline{\psi}\ \psi \rangle$$
$$\langle (\overline{\psi}\ \psi)(\overline{\psi}\ \psi) \rangle \sim 0.1 m_\rho^2 \langle \overline{\psi}\ \psi \rangle$$

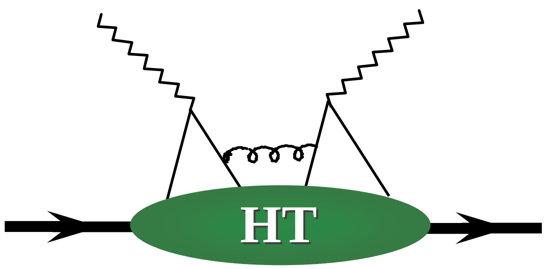
In agreement with phenomenology

$$F_L \sim (\text{large coefficient}) \langle \overline{\psi}\, D_\perp^2\, \psi \rangle$$
$$F_2 \sim (\text{small coefficient}) \langle \overline{\psi}\, D_\perp^2\, \psi \rangle$$

- Lattice (within sight?)

Deuteron

$$A \sim \int d^4 z\, e^{iqx} \langle \bar{u}(z)\gamma u(z)\bar{d}(0)\gamma d(0)\rangle$$



$$\sim \frac{1}{Q^2}\langle \bar{u}(z_-)\gamma_+ u(z_-)\bar{d}(0)\gamma_+ d(0)\rangle$$

- Twist four is leading at zeroth order in perturbation theory
- Corrections suppressed by coupling or/and higher power of Q^2
- Good matrix elements for lattice measurements: disconnected diagrams do not contribute

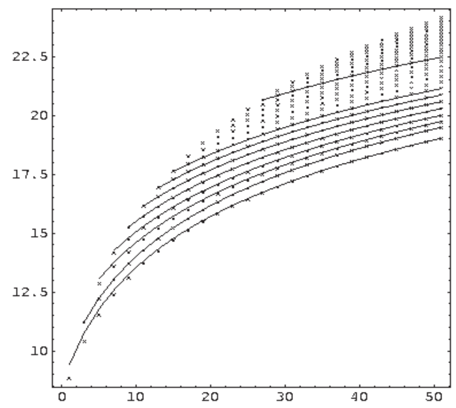
Evolution of matrix elements

$$\frac{d}{d \log Q}\begin{pmatrix} O_{\mathrm{nQP}} \\ O_{\mathrm{QP}} \end{pmatrix} = \begin{pmatrix} * & * \\ 0 & * \end{pmatrix}\begin{pmatrix} O_{\mathrm{nQP}} \\ O_{\mathrm{QP}} \end{pmatrix}$$

Talk by Gil

- Use of light-ray formalism
- Match conformal structures to Feynman diagrams ("easy" bookkeeping)

- Diagonalization:
  - Possible for specific conformal spins
  - Use of integrability to find semianalytical structure of the spectrum (a few lowest trajectories are needed)



Conclusion

Theoretical support of PV DIS program can be with us within near future:

- rigorous perturbative analyses
- semi-quantitative or model estimates of nonperturbative correlation functions