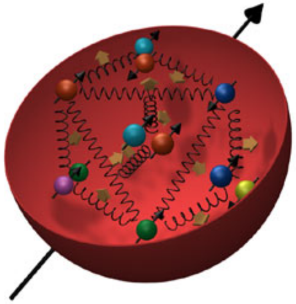

Quark Helicity Distribution at large-x

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Collaborators: H. Avakian, S. Brodsky, A. Deur, **arXiv:0705.1553** [hep-ph]

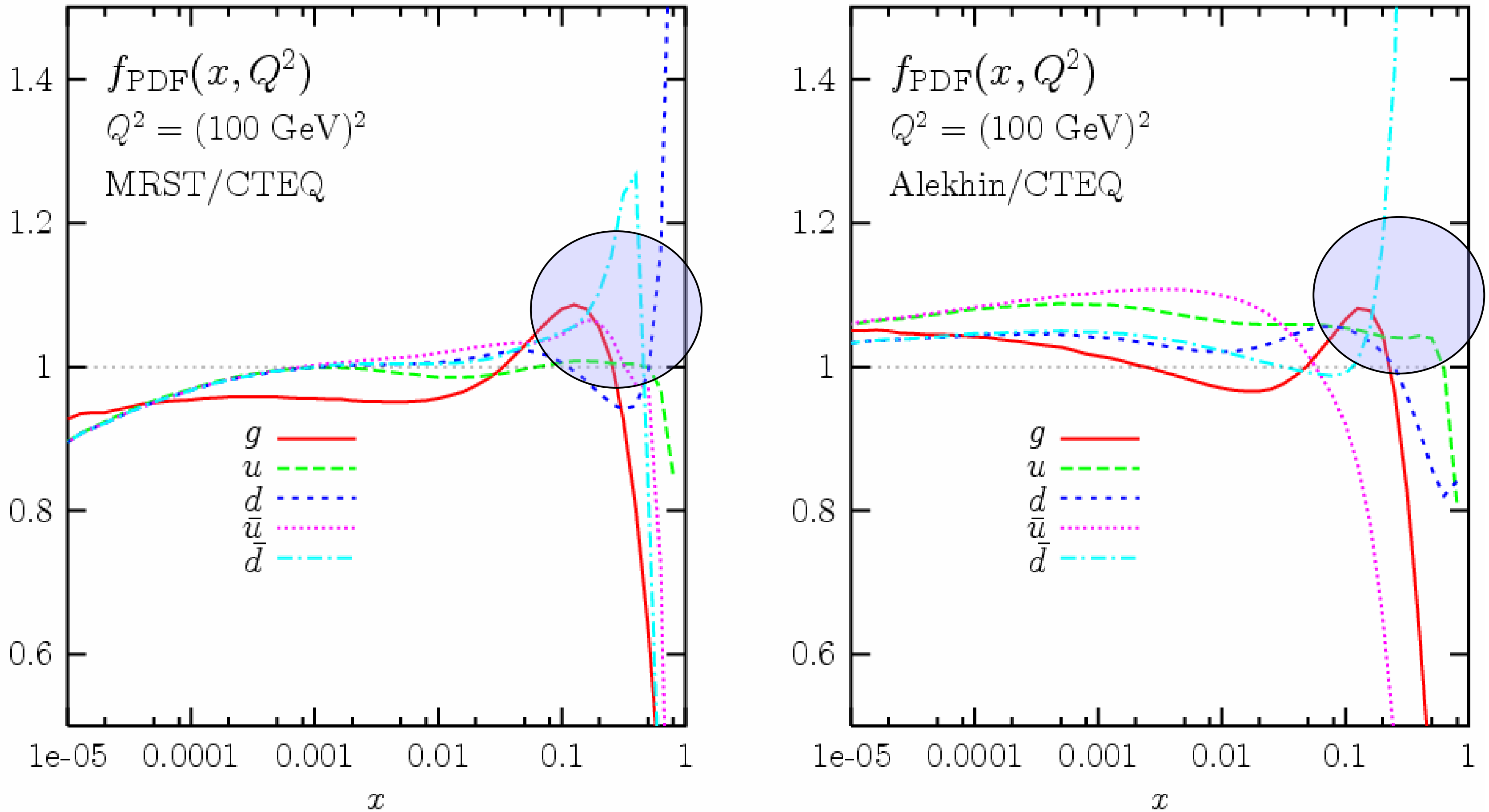
Outline

- Introduction
- Problems at large-x
- Quark orbital angular momentum contribution
- Consequences

Physics Motivation for large-x

- Global fit for the PDFs
- New Physics at Tevatron and LHC
- Precision Test of EW physics at Colliders
- …
- **Itself is very interesting to study QCD effects, such as resummation; and nucleon structure, such as quark orbital angular momentum,…**

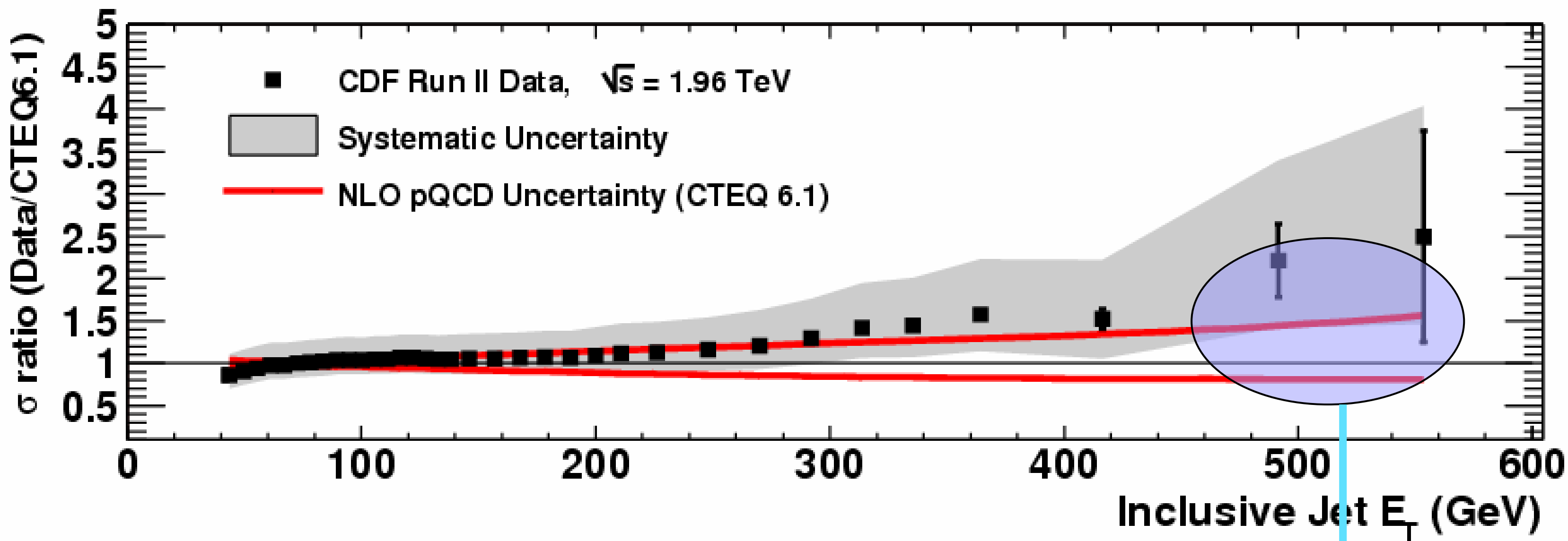
Importance of high x in global fit



Djouadi and Ferrag, hep-ph/0310209

New physics or PDF uncertainty?

Inclusive Jet production at Tevatron, hep-ex/0506038

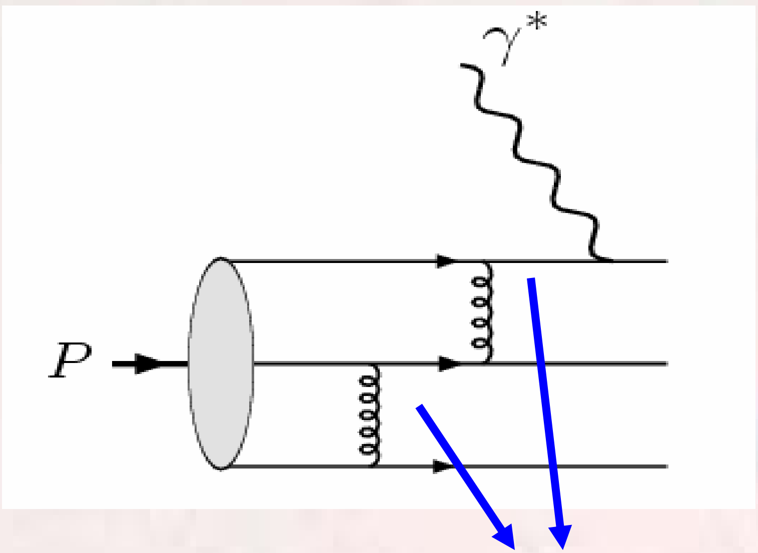


High x Partons relevant

Theoretical Issues at High x

- Resummation
- Power counting, pQCD predictions

Why Perturbative calculable



- **All propagators are far off-shell: $\propto k_\perp^2/(1\text{-}x) \gg \Lambda_{QCD}^2$**
- **Spectator power counting**

Power counting of Large x structure

- Drell-Yan-West (1970)

$$F_1(q^2) \xrightarrow[q^2\to-\infty]{} (-1/q^2)^n \longleftrightarrow \nu W_2(x) \xrightarrow[x\to 1]{} (1-x)^{2n-1}$$

- Farrar-Jackson (1975)

$$\nu W_2^{\pi} \sim (1-x)^2 \quad \text{and} \quad \nu W_2^{p} \sim (1-x)^3$$

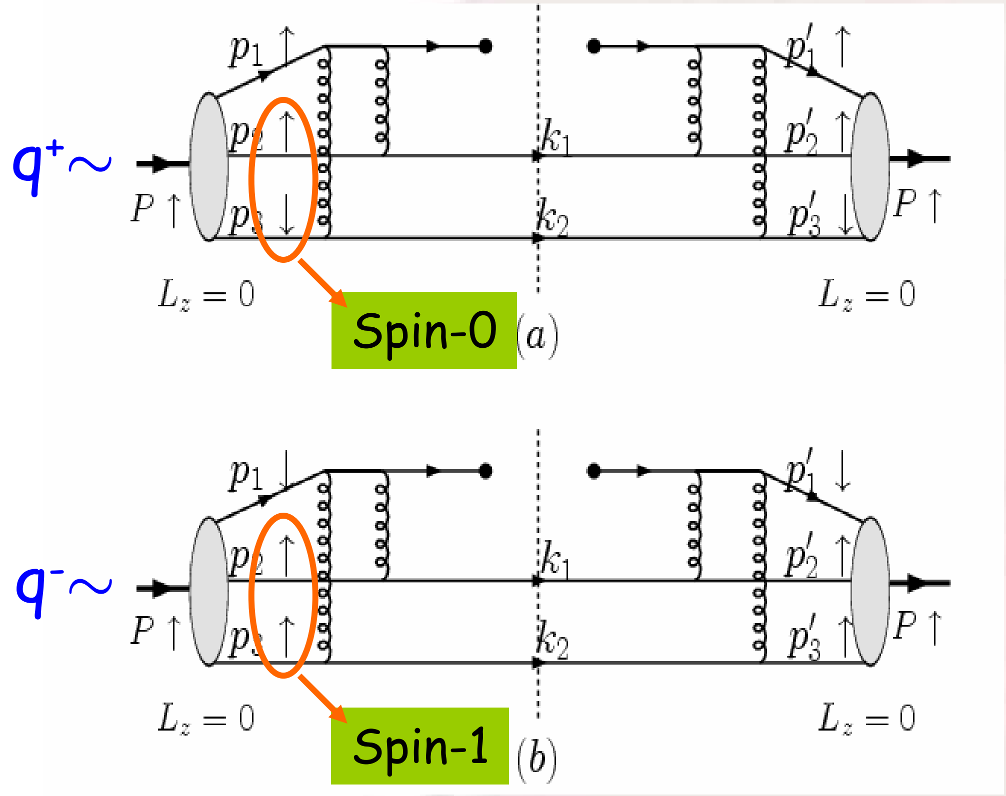
- Brodsky-Lepage (1979)

$$G_{q\uparrow/p\uparrow} \sim (1-x)^3 \quad ; \quad G_{q\downarrow/p\uparrow} \sim (1-x)^5$$

- Brodsky-Burkardt-Shmidt (1995)

  fit the polarized structure functions.

Power counting from L_z=0

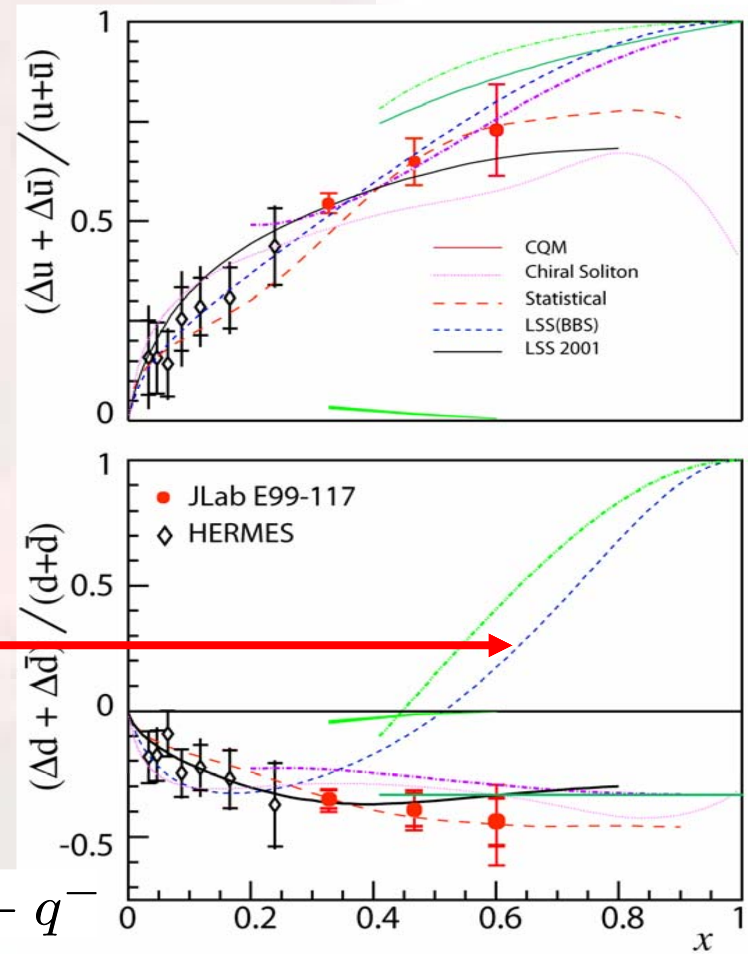


- Eight propagators $(1-x)^8$, $(1-x)^{-4}$ from the scattering, $(1-x)^{-1}$ from the phase space integral
  - $(1-x)^3$
- Spectator two quarks with spin-1 configuration will be suppressed by $(1-x)^2$ relative to spin-0
  - $q^- \sim (1-x)^2 q^+$

Quark polarization at large-x

JLab Hall A, PRL04

- Power counting rule:
  $q^{+} \sim (1-x)^3$, $q^{-} \sim (1-x)^5$
- The ratio of $\Delta q/q$ will approach 1 in the limit of x->1
  - Brodsky-Burkardt-Shmidt (1995)



$$\Delta q = q^{+} - q^{-}$$

RIKEN BNL Research Center

Quark orbital angular momentum of proton

Light-front wave function decomposition:

$$|P\uparrow\rangle = |P\uparrow\rangle_{-\frac{3}{2}} + |P\uparrow\rangle_{-\frac{1}{2}} + |P\uparrow\rangle_{\frac{1}{2}} + |P\uparrow\rangle_{\frac{3}{2}}$$

Total quark spin

$$|P\uparrow\rangle_{\frac{1}{2}} = \int d[1]d[2]d[3]\left(\tilde{\psi}^{(1)}(1,2,3) + i(k_1^x k_2^y - k_1^y k_2^x)\tilde{\psi}^{(2)}(1,2,3)\right) \times \frac{\epsilon^{abc}}{\sqrt{6}} u_{a\uparrow}^{\dagger}(1)\left(u_{b\downarrow}^{\dagger}(2)d_{c\uparrow}^{\dagger}(3) - d_{b\downarrow}^{\dagger}(2)u_{c\uparrow}^{\dagger}(3)\right)|0\rangle$$

L_z=0

$$|P\uparrow\rangle_{-\frac{1}{2}} = \int d[1]d[2]d[3]\left(\underline{(k_1^x + ik_1^y)}\tilde{\psi}^{(3)} + \underline{(k_2^x + ik_2^y)}\tilde{\psi}^{(4)}(1,2,3)\right) \times \frac{\epsilon^{abc}}{\sqrt{6}}\left(u_{a\uparrow}^{\dagger}(1)u_{b\downarrow}^{\dagger}(2)d_{c\downarrow}^{\dagger}(3) - d_{a\uparrow}^{\dagger}(1)u_{b\downarrow}^{\dagger}(2)u_{c\downarrow}^{\dagger}(3)\right)|0\rangle$$

L_z=1 L_z=1

OAM relevance to nucleon structure

- Finite orbital angular momentum is essential for
  - Anomalous magnetic moment of nucleons
  - Helicity-flip Pauli form factor F_2
  - g_2 structure function
  - Asymmetric momentum-dependent parton distribution in a transversely polarized nucleon, Sivers function
  - Large-x quark helicity distribution
  - …

For example, the Sivers functions

- **Quark Orbital Angular Momentum**

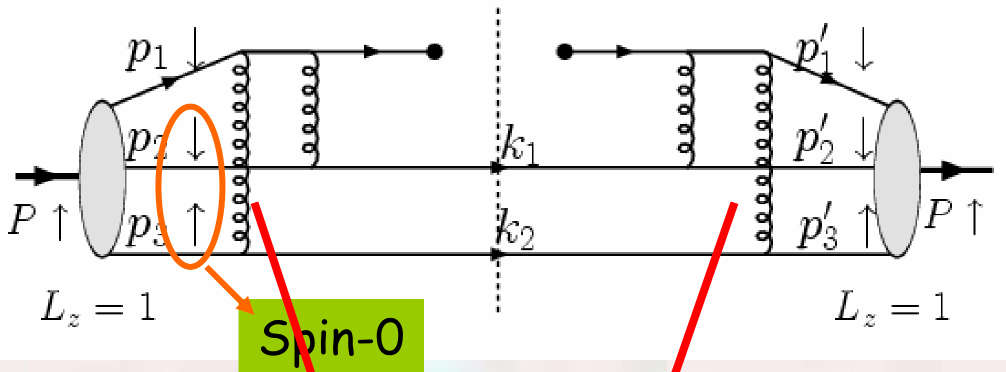
  e.g, Sivers function ~ the wave function amplitude with nonzero orbital angular momentum!

  Vanishes if quarks only in s-state!

Ji-Ma-Yuan, NPB03
Brodsky-Yuan, PRD06

L_z=1 contributions to q^-

$(p_1^x + ip_1^y)\tilde{\psi}$



$(p_1'^x + ip_1'^y)\tilde{\psi}$

- No suppression from the partonic scattering part
- Intrinsic pt expansion will lead to power suppression

$$\approx \frac{\beta(1-x)}{y_3 k_{2\perp}^2}\left(1 - \frac{\beta(1-x)}{y_3 k_{2\perp}^2} 2p_{3\perp} \cdot k_{2\perp}\right)$$

- Total suppression factor will be

$$\frac{(1-x)^2}{y_3 y'_3}$$

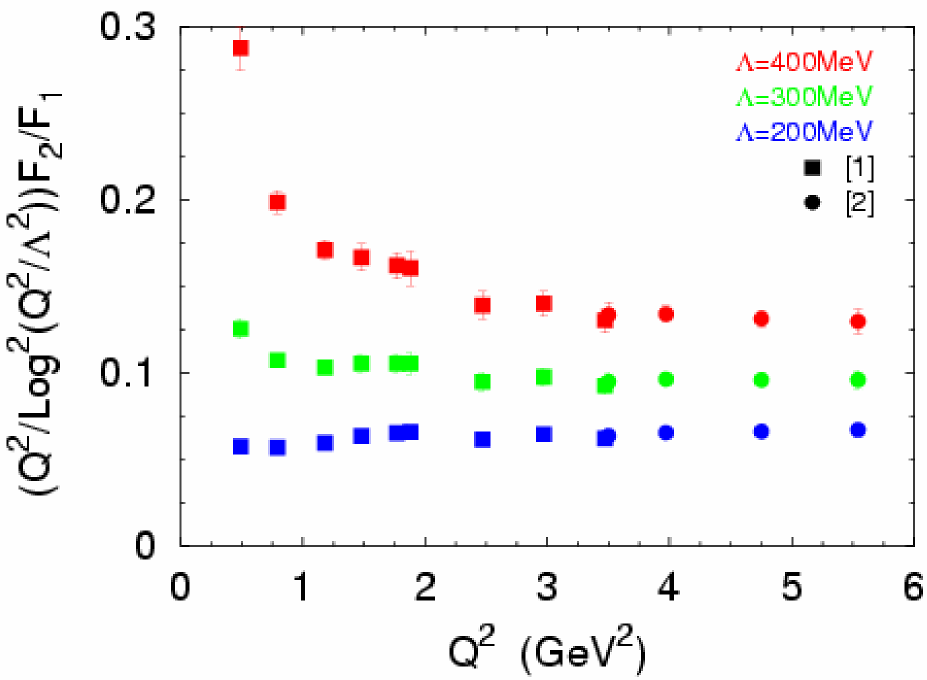
Orbital angular momentum contribution

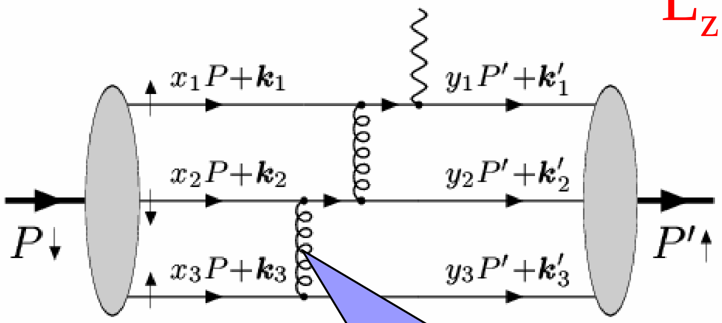
- It does not change the power counting
  - $q^- \sim (1-x)^5$
- It introduces double logarithms to q^-
  - $q^- \sim (1-x)^5 \log^2(1-x)$
  - Coming from additional factor $1/y_3 y_3'$ in the intrinsic pt expansion
  - $q^-/q^+ \sim (1-x)^2 \log^2(1-x)$ at $x \to 1$

OAM contribution to the Pauli form factor F_2

$$F_2(Q^2) = \int [dx_i][dy_i]\left[x_3\Phi_4(x_1,x_2,x_3)T_\Phi(x_i,y_i) + x_1\Psi_4(x_2,x_1,x_3)T_\Psi(x_i,y_i)\right]\Phi_3(y_i)$$

$L_z=1$ $L_z=0$



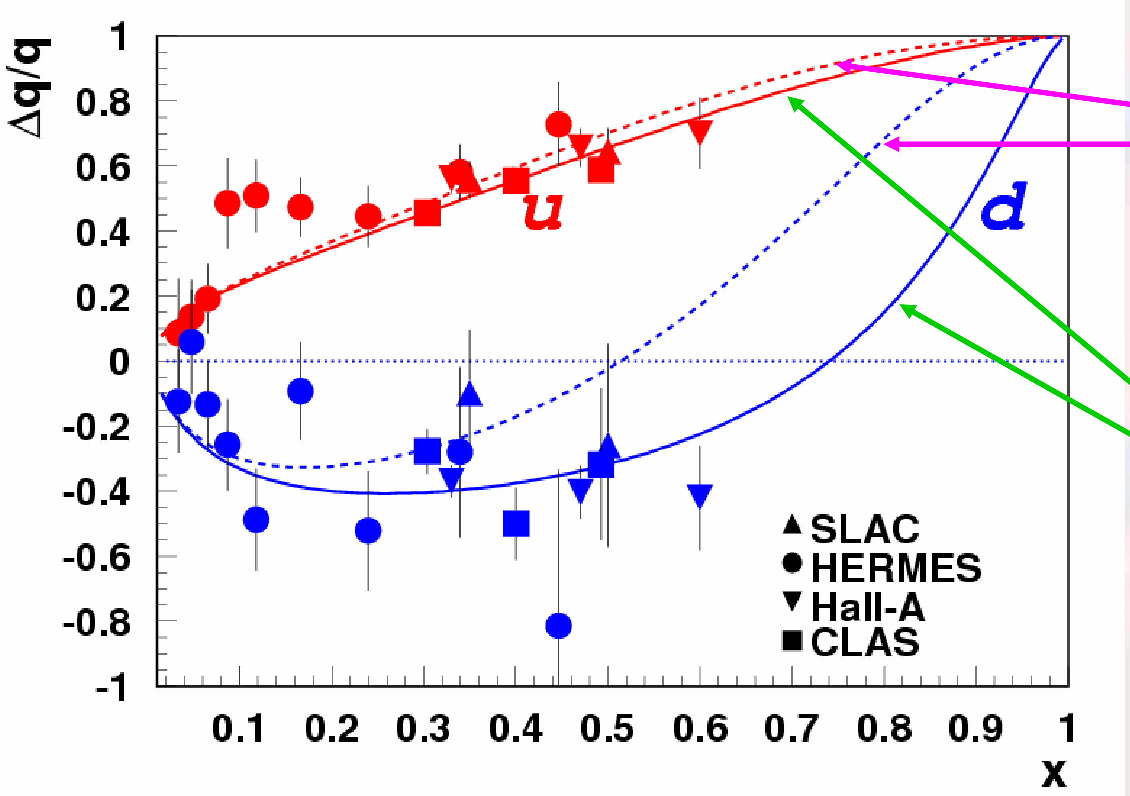


Expansion $\sim 1/x_3y_3$

It predicts that F_2 goes like $(\ln^2Q^2)/Q^6$ and hence $F_2/F_1 \sim (\ln^2Q^2)/Q^2$

Belitsky-Ji-Yuan, PRL, 2003

Quark orbital angular momentum contribution at large-x

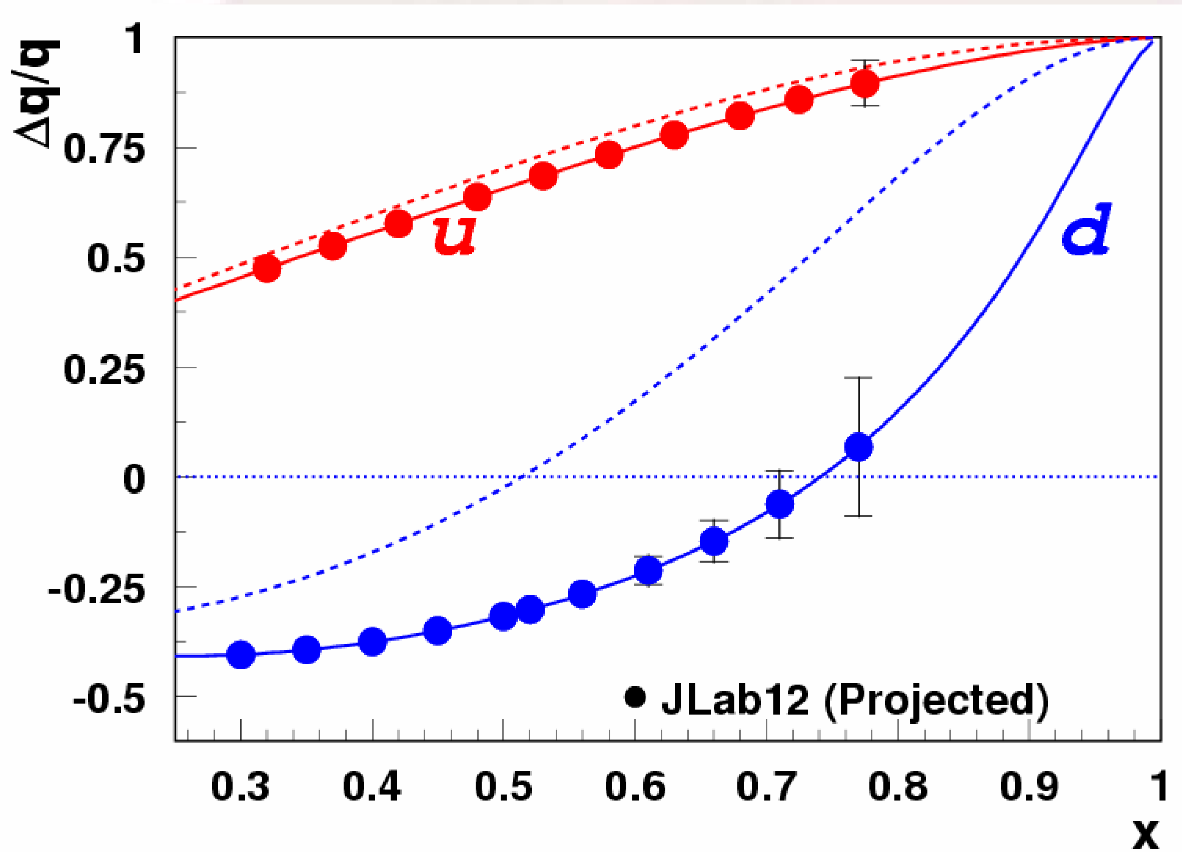


Power counting rule
Brodsky-Burkardt-Schmidt 95
Leader-Sidorov-Stamenov 98
$q^-/q^+ \sim (1-x)^2$

Quark-orbital-angular Momentum contribution
Avakian-Brodsky-Deur-Yuan,07
$q^-/q^+ \sim (1-x)^2 \log^2(1-x)$

It will be interested to see how this compares with the future data from JLab

12GeV JLab Upgrade

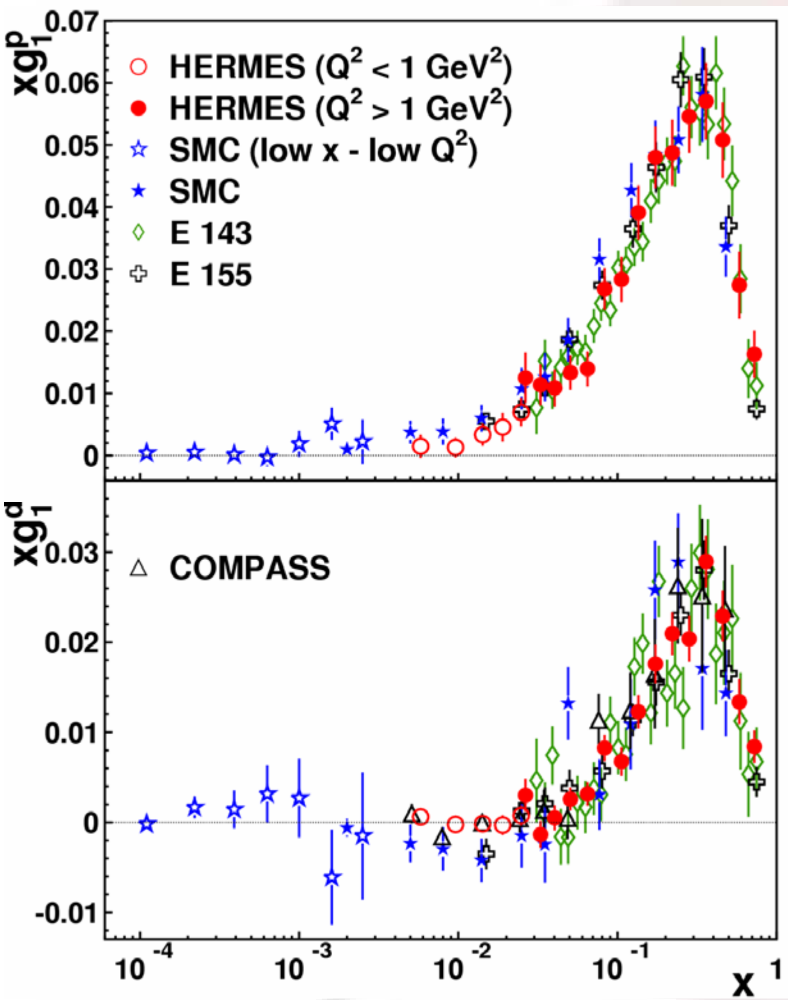


Conclusion

- Quark orbital angular momentum contribution changes significantly power counting results for the quark helicity distribution at large-x
- More precise determination of these contributions requires a NLO global fit with all experimental data

Back-up

Summary of the polarized DIS data



- The follow-up experiments confirm the EMC results
  - SLAC: E142-155
  - HERMES
  - SMC
  - COMPASS
- The combination of the polarized structure functions from proton and neutron leads to the total quark helicity contribution

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$
$$\approx \ 0.25$$

- Quarks only carry $\frac{1}{4}$ of the proton spin

Quark spin:

- Have been well determined from polarized DIS experiments
  - Total quark spin contribution is about ¼
- Questions remains
  - Quark polarization at $x \to 1$?
    - Nontrivial QCD dynamics
  - Sea quark polarizations?
    - a potential contribution to the proton spin (-8% from the current global analysis)

Quark polarization at large-x

- The QCD configuration of the proton wave function becomes far off-shell and can be treated from perturbative QCD
- Power counting rule:

  $q^{+} \sim (1-x)^3$, $q^{-} \sim (1-x)^5$
  - Farrar-Jackson, 75
  - Brodsky-Lepage, 80
  - Brodsky-Burkardt-Schmidt, 95

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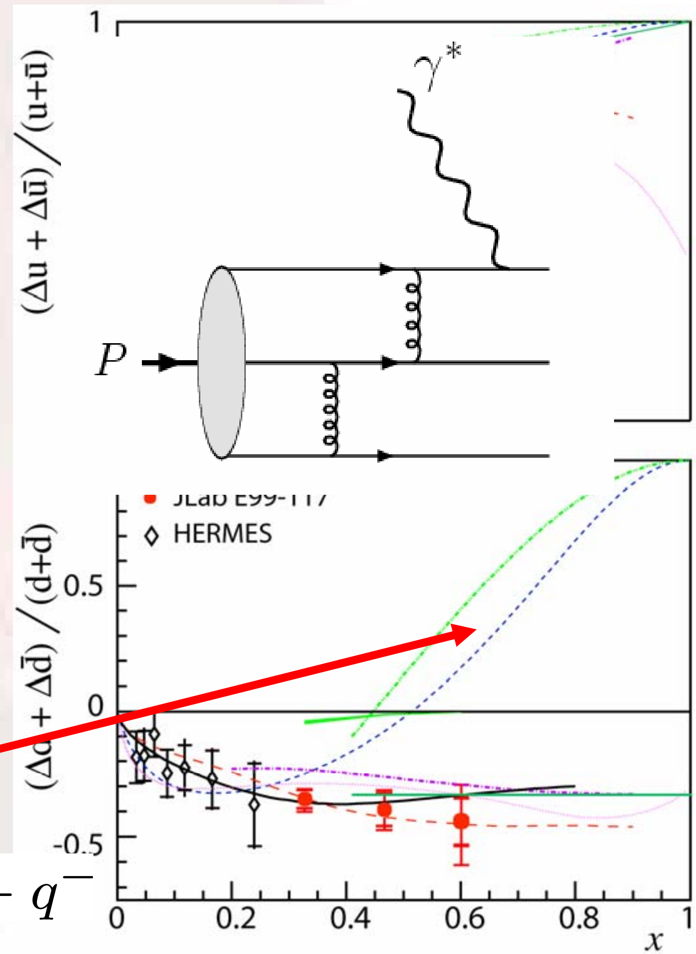
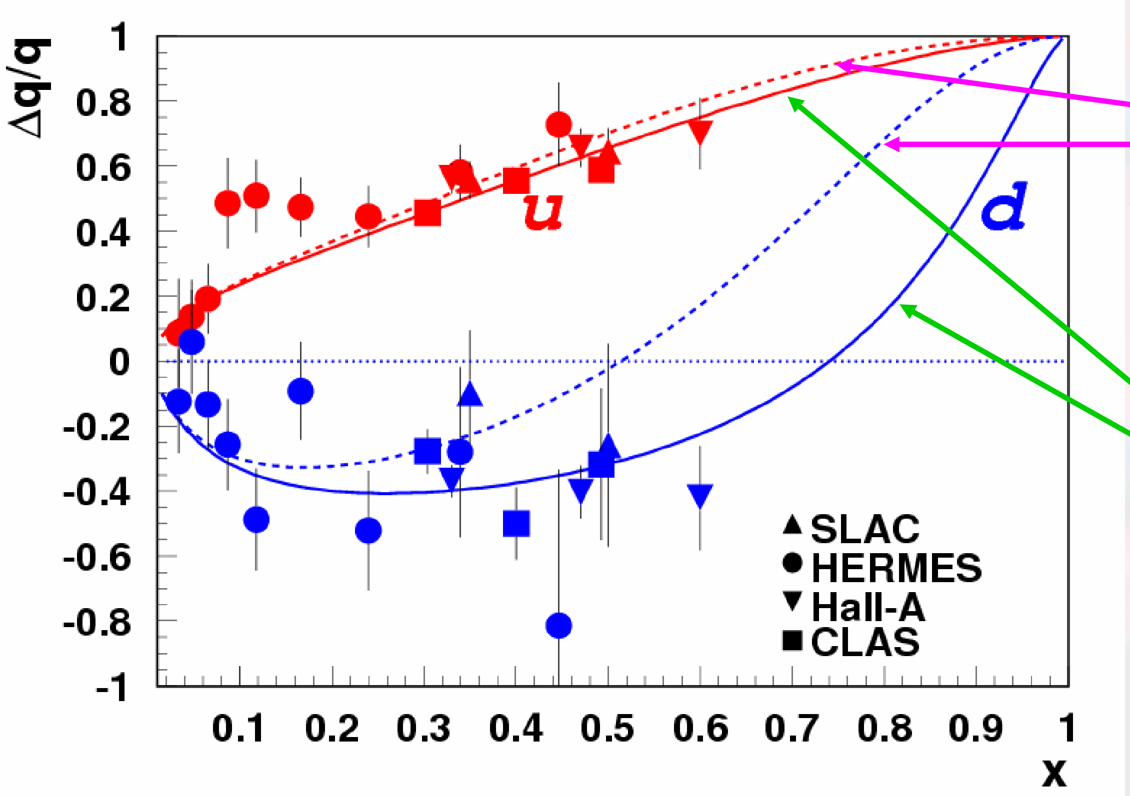


$$\Delta q = q^{+} - q^{-}$$

Quark orbital angular momentum contribution at large-x



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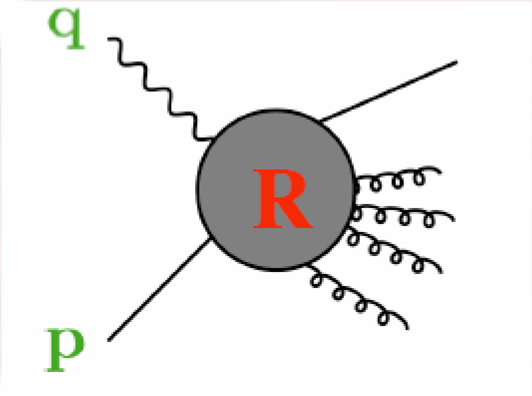
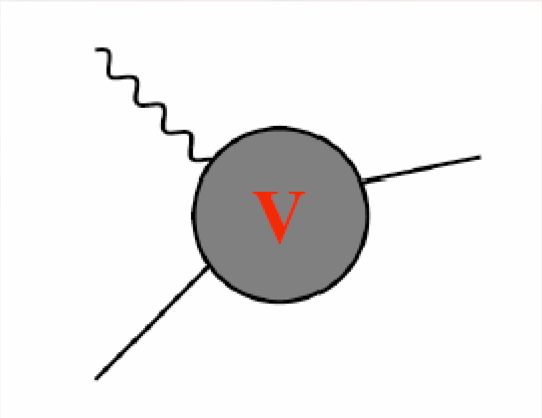
Why Resummation is Relevant

- Additional scale, $Q^2 \gg (1-x)Q^2 \gg \Lambda_{QCD}^2$

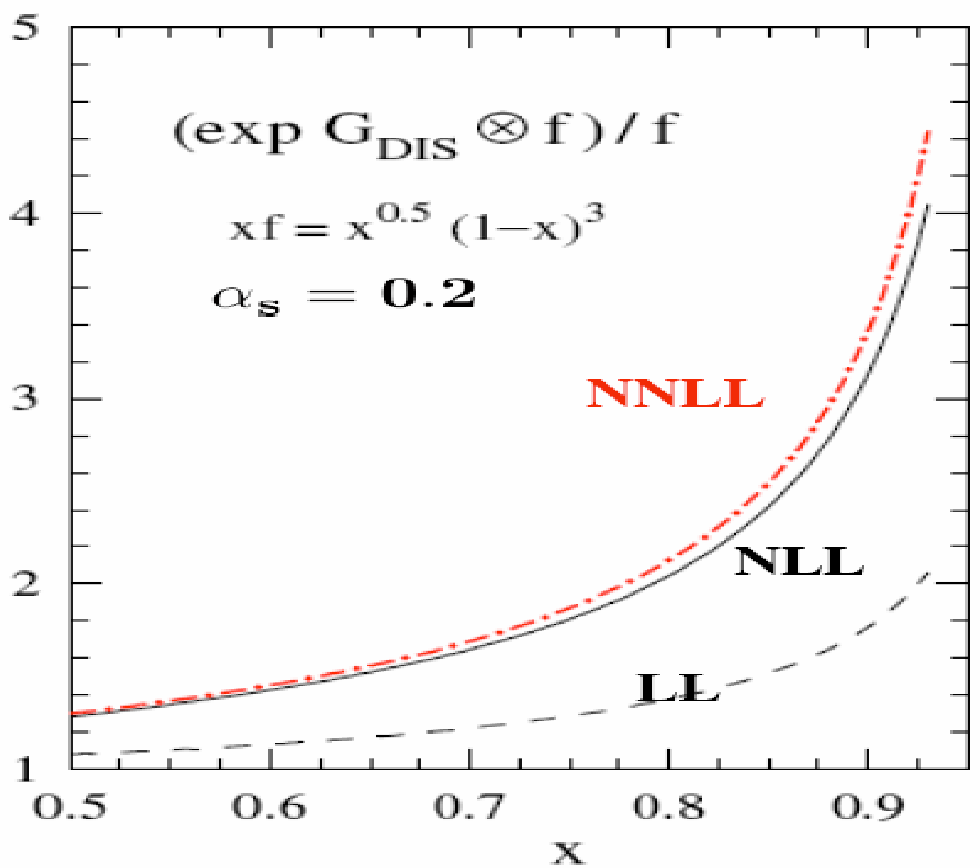




- Real and Virtual contributions are "imbalanced" IR cancellation leaves large logarithms (implicit)

Example I

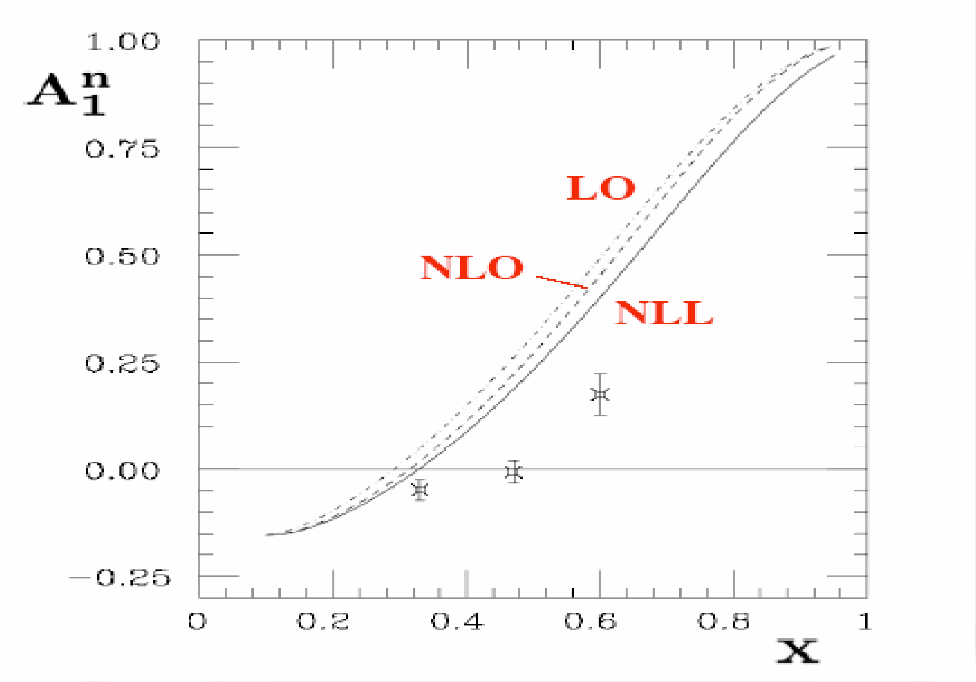
Net Enhancement for the DIS Structure functio



A. Vogt

Example II: Spin Asymmetry

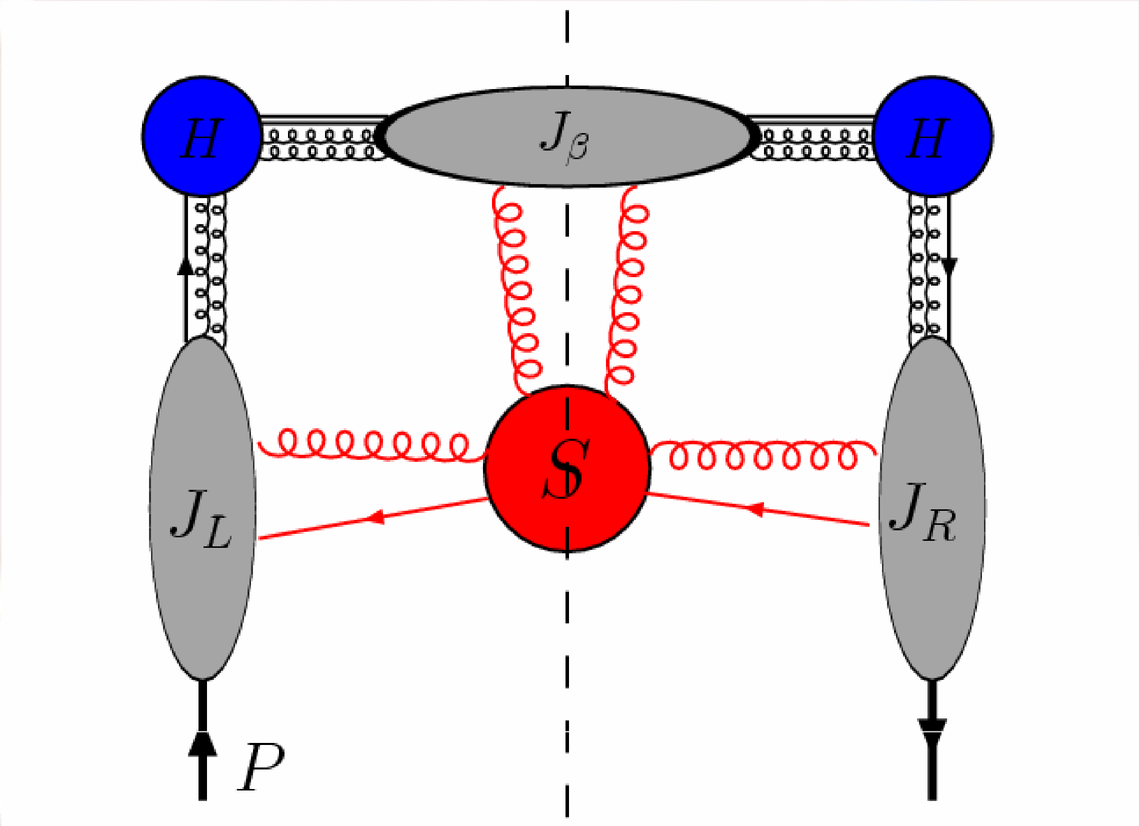
- Resummation effects cancel exactly in moment space, and "almost" in x-space



W. Vogelsang

Factorization (II)

- Leading region



Factorization (III)

- Factorization formula

$$q(x) = H_L(p,\mu)H_R(p,\mu)J_L(p,\mu)J_R(p,\mu)\sigma^{\text{eik}}((1-x)p,\mu)$$

- The power behavior of q(x) is entirely determined by the eikonal cross section

$$\sigma^{\text{eik}}((1-x)p,\mu) = \frac{1}{N_c}\int\frac{dy^-}{2\pi}e^{i(1-x)p^+y^-}\sum_{n,a}\langle 0|\overline{\Psi}_a(y^-)|n\rangle\gamma^+\langle n|\Psi_a(0)|0\rangle$$

Ji,Ma,Yuan,PLB610(2005)

Power Counting for GPDs

- No *t*-dependence at leading order
- Power behavior at large x

$$H_q^\pi(x,\xi,t) = \frac{1}{1-\xi^2} q^\pi(x)$$ ~ $(1-x)^2$

Forward PDF

$$H_q(x,\xi,t) = \frac{1}{(1-\xi^2)^2} q(x)$$ ~ $(1-x)^3$

$$E_q(x,\xi,t) = \frac{(1-x)^5}{(1-\xi^2)^3} f(\xi)$$ ~ $(1-x)^5$

Yuan, PRD69(2004)