STRUCTURE FUNCTIONS ARE NOT PARTON PROBABILITIES

Paul Hoyer
ICHEP-02 Amsterdam
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What do parton distributions
– extracted from DIS –
tell us about target structure?

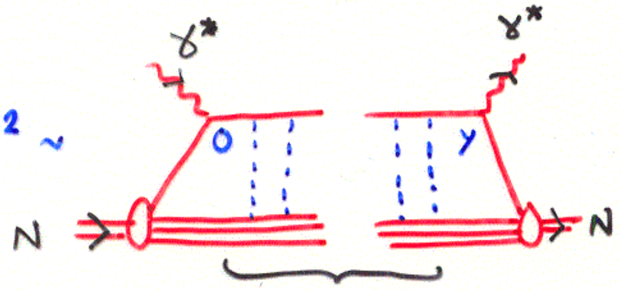
Common belief: $q(x, Q^2)$ is the probability to find a quark carrying momentum fraction x at resolution $1/Q$

Turns out to be wrong! Brodsky, PH, Marchal, Peigné, Sannino
hep-ph/0104291 = PR D65 (2002) 114025

- Misses interference effects ⇒ Shadowing, Diffraction, Polarization
- Corrections may be large at small x

DYNAMICS OF DIS: View from $q^z \simeq -\nu$ frame (!)

$\sigma \sim |T|^2 \sim$



Struck quark Coulomb scatters in target

Effect missed in probability interpretation

Space-time separation of γ^* vertices in T, T^*:

$y = (y^+, y^-, \vec{y}_\perp)$

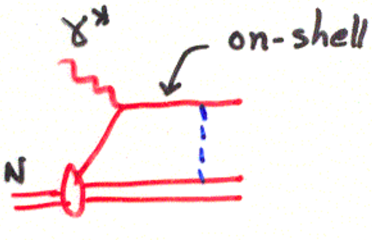
$y^+ = (y^0 + y^3) \sim \frac{1}{q^-} \sim \frac{1}{\nu} \to 0$

$|\vec{y}_\perp| \sim \frac{1}{Q} \to 0$

$y^2 = y^+y^- - y_\perp^2 \to 0$ Light like separation

γ^* coherence length along light-cone: $y^- \sim \frac{1}{q^+} \sim \frac{\nu}{Q^2} \sim \frac{1}{2m_N x}$ Large at small x

- Coulomb rescattering within $\frac{1}{2m_N x}$ affects σ_{DIS}
- On-shell intermediate states give DIS amplitudes complex, dynamic phases



⇒ Interference phenomena

Why did we believe that rescattering is irrelevant?

QCD factorization proofs give, in a general gauge:

$$q(x, Q^2) = \frac{1}{8\pi} \int dy^- \exp\left(-\frac{i}{2} x p^+ y^-\right)$$

$$\times \langle N(p) | \bar{q}(y^-) \gamma^+ \underbrace{\mathbb{P}\exp\left[ig \int_0^{y^-} dw^- A^+(w^-)\right]} q(0) | N(p) \rangle_{\substack{y^+=0 \\ y_\perp \sim 1/Q}}$$

Path-ordered exponential describes Coulomb scattering

- All fields are at $y^+ = 0$: Equal LC time
- Expression is gauge invariant due to $\mathbb{P}\exp[\;]$, and valid at leading order in Bj limit:

  $q^- A^+ \sim 2\nu A^+ \gg \vec{q}_\perp \cdot \vec{A}_\perp, \ldots$ assumed
- In $A^+ = 0$ gauge: $\mathbb{P}\exp[\;] = 1$ and matrix element reduces to a som of probabilities for finding a quark in $|N\rangle$

BUT: $A^+ = 0$ gauge is not allowed!

Resulting expression for $q(x, Q^2)$ is incorrect

Reason: $q^- A^+ = 0$ is not large, derivation fails

i.e: Bj limit ($\nu, Q^2 \to \infty$) and LC gauge limit ($A^+ \to 0$) do not commute

c.f. $e\mu \to e\mu$ at Born level: $\left\{ \begin{array}{c} s \to \infty \\ \text{vs} \\ A^+ \to 0 \end{array} \right.$ Limits do not commute

REMARKS

* Correct expression for $q(x, Q^2)$ in $A^+ = 0$ gauge is not yet known, cf. X. Ji & F. Yuan, hep-ph/020605

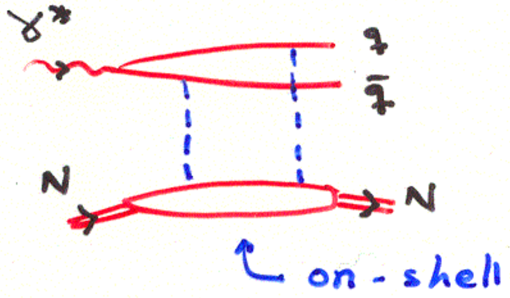
* Phase due to Coulomb scattering causes single spin asymmetry in semi-inclusive DIS: $\gamma^* N_\uparrow \rightarrow \pi(\vec{k}) + X$

  Brodsky, Hwang & Schmidt, hep-ph/0201296
  Collins, hep-ph/0204004

  This 'Sivers Effect' is unrelated to a transverse polarization of the struck quark in $|N\rangle$

* Diffractive DIS is due to Coulomb rescattering

  Imaginary phase of Pomeron ~ two-gluon exchange arises due to on-shell intermediate state, i.e., via rescattering



  ⇒ No "Pomeron" in target wave function!

* Are the rescattering effects the same in all processes
  i.e., is $q(x, Q^2)$ universal?

  Spin asymmetry is reversed in Drell-Yan
  Collins, hep-ph/0204004
  Brodsky, Hwang & Schmidt, hep-ph/0206259

  Is shadowing the same in DY as in DIS?
  Peigné hep-ph/0206138

⇒ Novel questions on 'classic' parton distributions