Effect of Rescattering on the DIS Cross Section

\[ q^a(p) \rightarrow \gamma^a(q) \rightarrow X \rightarrow P_i + \ldots \]

\[ P_i: \text{aligned jet} \]

\[ P_j: \text{spectral jet} \]

\[ P \rightarrow P' \]

\[ Q^2 \frac{d^2 \sigma}{dQ^2 dk^2} = \frac{\alpha}{16\pi^2} \frac{1 - \frac{y}{2}}{y - 2mv} \int \frac{d^2 \vec{p}}{P_i} d^2 \vec{r}_1 d^2 \vec{r}_2 |M|_2 \]

\[ |M| = \left| \sin \left[ \frac{q^2 W(r_1, r_2)/2}{y^2 W(r_1, r_2)/2} \right] M_{\text{Born}}(P_i, r_1, r_2) \right| \]

\[ \frac{e^2}{y} \text{ for all } r_1, r_2 \]

Equal to sum all cuts to forward virt. comp. amp.

\[ P \rightarrow P' \]

Find shadowing only arises from diagrams involving attributes to \( P_i \) in F.G.

cuts give Gluck-Weiss shadowing

Some result in Feynman, e.g. \( \angle (\vec{w}) \)

\[ \uparrow \text{ from } \frac{2p_i^2 - q^2}{kt^2} \text{ term} \]
Model calculation

Scalar quarks, crossed + uncrossed graphs, large + Regge

Eikonal factorization in $r_1, r_2$
Revisited to 3-loops in Feynman, e.g.

$M = M_{\text{Born}} \left[ 1 - e^{-i g^2 W} \right]$

$m_{\text{Born}} = -2 i e M \rho_1 \nu V(m_1, r_L)$

$V(m_1, r_L) = \int d^2 p_1 \frac{e^{i r_L \cdot p_1}}{p_1^2 + m_{11}^2}$

$m_{11}^2 = p_1 \cdot M \times \rho_1 + m^2$

$W(r_1, r_2) = \int d^2 k_1 \frac{1 - e^{i r_1 \cdot k_1}}{k_1^2} e^{i r_2 \cdot k_1} \frac{1}{2\pi} \ln \frac{k_1^2}{m^2}$

$\frac{d^2 \sigma}{d^2 q d k} = \frac{\alpha}{16 \pi^2} \frac{(1 - y)}{2 m v} \int \frac{d p_2}{p_2^2} d^2 n_1 d^2 n_2 / m^2$
In light-cone gauge (kouchniren prescription) must keep

\[ d_{LC}^{\mu\nu} = \frac{i}{k^2 + i\epsilon} \left[ -g^{\mu\nu} + \frac{n_+ k^\nu + n_- k^\mu}{n \cdot k} \right] \]

and \( n \cdot k = k^+ = O(\frac{1}{\nu}) \) for on-shell states!

Result: identical answer as Feynman gauge

* Not included in d.c.g. wavefunctions!

m-L, PV prescriptions differ by resid. s.t.rans
Light-Cone Gauge Prescriptions

\[ d_{LC}^{\mu} (k) = \frac{i}{k^2 + i\epsilon} \left[ -g^{\mu\nu} + \frac{n^\mu k^\nu + k^\mu n^\nu}{n \cdot k} \right] \]

The pole at \( n \cdot k = k^+ = 0 \) requires an analytic presc:

\[ \frac{1}{k^+} = \begin{cases} \frac{k^+}{(k^+ + i\epsilon)(k^+ - i\epsilon)} & \text{Principal Value} \\ \frac{1}{k^+ - i\epsilon} & \text{Kovchegov} \\ \frac{1}{k^+ - i\epsilon n} & \text{Mandelstam-Lubbrad} \end{cases} \]

\[ \varepsilon(x) = \varepsilon(x) - \delta(-x) \]

M-L: \[ \frac{k^-}{k^+ - i\epsilon n} = \frac{k^-}{k^+ + i\epsilon n} \]

Kovchegov: non-causal!

\[ * \text{Find FSI of current jet vanishes in LC pres!} \]

\[ * \text{But corresponds to solving LC w.f. in external field!} \]

Mckeehan et al.
In lab frame, i.e., gauge case, looks like:

\[ \ldots \]

- On-shell rescattering \& line $P_2$
- Shadowing \& structure functions
- Leading twist
- Large color dipole moment $R_1 \sim O(1/A)$

- Leading twist diffractive dissociation
- Not part of i.e., wavefunction

\[ \ldots \]
Diffractive Dissociation $\gamma^* p \rightarrow q\bar{q} P'$

is leading twist contrib to
DIS structure function $F_2(x, Q^2)$

$\gamma^* P \rightarrow q\bar{q} P' \rightarrow q\bar{q} P$

$\gamma^* P \rightarrow q\bar{q} P' \rightarrow q\bar{q} P$

* Not given by $|\Psi_n^A(x, t, \lambda)|^2$!

3) Nucleon shadowing from destructing interference of diffractive dissociation channels

* Not given by $|\Psi_n^A(x, t, \lambda)|^2$!

Structure Function's not Pauli Dist!

Hoyer, Peigne, Marchel, Savina, Sza
Nuclear shadowing due to destructive interference of diffractive amplitude $(2\times s_{12} + 1\times s_{23})$

Phase structure critical

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\gamma^* N_1 \rightarrow q\bar{q} N_1
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Diffractive $\gamma^* N_1 \rightarrow q\bar{q} N_1$

None of this in l.c.w.f. $\Psi(x, 4)$ real! FST!
Diffractive Dissociation (large rapidity gaps) is leading twist in QCD

\[ \frac{d\sigma}{dm^2} \sim \left( \frac{1}{m^2 + Q^2} \right)^2, \]

aligned jet regime

By Kogut

large color dipole

Hoyer, Nomura, 89E

- Coherence for \( L_{\text{max}} = \frac{2V}{Q^2} > R_N \)

- Shadowing in nuclei for \( L_{\text{max}} = \frac{2V}{Q^2} > R_A \)
Color-dipole picture of Diffractive Events

\( \rho^s \) \( \rightarrow \rho^s \)
\( r^L \sim O(1/a) \)
\( \rho^s \rightarrow m, L \)

**Hard BFKL Pomeron**
\( Q_L \sim \frac{1}{Q^2} S_{p^{-1}} \)

**Leading twist**
\( Q_T \sim \frac{1}{Q^2} S_{p^{-1}} \)

**Soft Pomeron**
\( \rho^s \rightarrow m, L \)

**Frankfurt, Gomar, Mueller, Stirling, SFLS**
Hard Diffraction

\[ p^+ p \rightarrow V^0 p \]

Frankfurt, Gurian, Strikhanov, Mullen, SJB

\[ V^0 = p^0, \omega, \phi, \eta, \eta', \gamma \ldots \]

Pyzhan, et al.

Odderon, \( q \) exchange.

\( J_L \) dominates: small \( b \), \( s \) 

Sensitive to \( \phi_H(x, Q) \)

Color transparency

S-dep corresponding to \( g(x, Q^2) \)

\[ M \sim S_{xp}(t) F(t) \]

BFWL Pom.
Comparison of diffractive and DIS cross sections

ZEUS 1994

\[ \sigma_{\text{diff}} / \sigma_{\text{tot}} \]

- $Q^2 = 8 \text{ GeV}^2$
- $Q^2 = 14 \text{ GeV}^2$
- $Q^2 = 27 \text{ GeV}^2$
- $Q^2 = 60 \text{ GeV}^2$

$M_x < 3 \text{ GeV}$

$3 < M_x < 7.5 \text{ GeV}$

$7.5 < M_x < 15 \text{ GeV}$

$W(\text{GeV})$

Diffractive cross section has same energy dependence as inclusive cross section!

\[ p + QCD \rightarrow e^+ + e^- + x \]

\[ \frac{\Delta \sigma_{\text{diff}}}{\Delta \sigma_{\text{tot}}} \sim \frac{(x_q)^2}{(x_g)} \sim (W^2)^{\lambda_1} \]

\[ \frac{\Delta \sigma_{\text{diff}}}{\Delta \sigma_{\text{tot}}} \sim \frac{d\sigma_{\text{diff}}}{dt} \sim (t^{\text{tot}})^{\lambda_2} \sim (W^2)^{\lambda_2} \]

\[ \frac{d\sigma_{\text{diff}}}{dt} \sim (W^2)^{\lambda_3} \]

PQCD Optical theorem Regge
minimal excitation of proton

Ref: Hebecker
hep-ph/9909504
Non-universal Pomeron Coupling

DIS
Diffraction

\( \ell \rightarrow l' \)

\( e_p \rightarrow l' p' x \) (e.g. gap)

\( P \rightarrow l' p' \)

- 2nd gluon occurs after \( g^* \) interaction
- Cut gives imaginary phase!
- Coupling depends on com dimuon moment 1, 15
- Pomeron not part of proton Wf.
- Not universal!
- \( P \gamma / p(x), P q / p(x), P g / p(x), P pom / p(x) \)
**Diffraction at HERA**

Non-universal pomeran coupling

BHMP3

**Double Diffraction at Tevatron**

\[ \bar{p} p \rightarrow \bar{p}' p' + jet + two\ cop.\ jets. \]

**UPC at RHIC**

\[ A_1 A_2 \rightarrow A_1' A_2' + jet + UPC + two\ jets. \]

\[ 0 \sim q_1^2 A_2' \]
Diffraction leads to nuclear shadowing:

- Destructive interference leads to shadowing at low x.
- Shadowing of quark, gluon distributions
- Reggeon exchange leads to outshadowing

Gruber, Gluken
Pomplin, 88 A
Now apply Glauber theory to $T_{QA}$

$$T_{QA}(s, n') = T_{QN}(s, n')$$

$$\sum_{j=1}^{A} \frac{i}{j} \left[ A \right] \left[ \frac{i T_{QN}(s, n')}{4\pi E_\text{cm} s^{1/2} (n'+2)} \right]$$

The diagrams illustrate the interaction processes.

$$\frac{F_{2A}(x)}{A F_{2N}(x)} = \frac{\int ds d^2h_z A T_{QA}}{\int ds d^2h_z A T_{QN}}$$

Produces shadowing for Pomeron $x < 0.1$

Anti-shadowing for Reggeon $x > 0.15$
Nuclear shadowing due to destructive interference of diffractive channels.

Pomeron exchange \( \rightarrow i \)
Cut contribution \( \Rightarrow i \)

But \( \Phi_n/N(k_i, \bar{k_i}, \lambda) \)
\( \Phi_{A'/A}(k_i, \bar{k_i}, \lambda) \)

are real! No phase info from intermediate or shell states for stable targets.

Anti-shadowing from non-singlet Reggeon exchange.

H.J. Le
+ S.D.B.
Nuclear structure functions

coherence length of hadronic configurations

\[ \lambda \approx \frac{1}{Mx} > 2 \text{fm} \leftrightarrow x < 0.1 \]
Given $M_{qqp ightarrow qqp}(s,t)$

predict $T_{q
u}(q^2, p.q, t)$

$\nu^2$ + crossed $q
u^2$

gauge-invariant crossing

+ crossed $q
u^2$

Measure real part from interference with BH.
In $T_{q
u}(q^2, p.q, t=0) = W_{q
u}(q^2, p.q)$

By scaling structure functions

Extra $J=0$ pieces from "fixed pole"

Instantaneous quark exchange
Is the handbag approximation for DVCS accurate?

In DIS, FSI causes shadowing, diffraction,

\[ W = \frac{1}{2\pi} \log \frac{|t'|}{|t|} \]

Correction factor,

\[ \frac{\sin^2 W g^{1/2}}{W^2} < 1 \]

Expect phases, \( \frac{1}{S_p} = \frac{1}{K} \cdot \frac{1}{K'} \) SSA.

Hwang, Vandeheuze (in progress)

Alternate: Regge forms give phase form \( g^{1/2} \).

Close, Gunion, 818
Summary:

* Diffractive Dissociation $\gamma^* \rightarrow q\bar{q}$
  leading twist contribute to $F_2(x, Q^2)$!
  $\gamma^* p \rightarrow \text{Jet Jet } p'$

* Leads to leading twist nuclear shadowing!

* Rescattering effect coherent if
  \[
  \frac{2\gamma}{Q^2} = \frac{1}{M_{X_B}} \rightarrow R_{\text{total}}
  \]

** Not included in $\psi_{LC}$!

\[
\frac{F_2(x, Q^2)}{x} \neq \sum e_i q_i \times q_i(x, Q^2)
\]

\[
q_i(x, Q^2) = \sum \int \psi_i(x, h_t, h_L) \sqrt{d}(h_t-h_L)
\]

* Light-cone gauge can be misleading

* Many consequences for sum rules, low $x$ etc.
  Interpretation of DIS.