The ambiguity in the identification of the scale energy parameter $\tilde{Q}^2$ in the parton distribution functions

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Abstract

We discuss Z-production in Deep Inelastic Scattering (DIS) $e + p \to e + Z + X$ using the Parton Model (PM), in the context of the Standard Model (SM). In contrast to the deep inelastic ep-scattering ($e + p \to e + X$), where $\tilde{Q}^2$ the transferred momentum square is unique, in the case of boson production it depends upon the mechanism involved, that it is related to the electroweak interaction. We present results for the total cross section rates for ep collisions with an electron energy $E_e = 60$ GeV and a proton energy $E_p = 7$ TeV, these energies are expected to be reached at LHeC. We use different assignments for $\tilde{Q}^2$; namely, Q^2, $Q'2$ and s . We perform our calculations at NNLO by making use of the Calc-HEP package.

Kinematics

Process $e(p) + p(P_p) \to e(p') + Z(k) + X(P_X)$

X stands for $anything$. As usual, the following invariants are defined for the process:

$s = (p + P_p)^2$, $Q^2 = -(p - p')^2$, $\nu = P_p(p - p')$,
$s' = (p + P_p - k)^2$, $Q'^2 = -(p - p' - k)^2$,
$\nu' = P_p(p - p' - k)$.

Subprocess

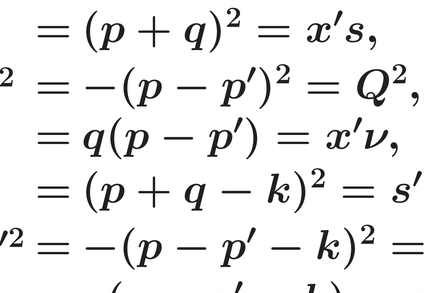
$e(p) + p(q) \to e(p') + Z(k) + e(q')$, with $q^\mu = x' P_p^\mu$.

The following invariants are corresponding for the subprocess:

$$\begin{aligned}
\hat{s} &= (p + q)^2 = x's, \\
\hat{Q}^2 &= -(p - p')^2 = Q^2, \\
\hat{\nu} &= q(p - p') = x'\nu, \\
\hat{s'} &= (p + q - k)^2 = s' - (1 - x')s + 2(1 - x')(\nu - \nu')s, \\
\hat{Q'^2} &= -(p - p' - k)^2 = Q'^2, \\
\hat{\nu'} &= q(p - p' - k) = x'\nu'.
\end{aligned}$$

Problem Statement

Process $\mathrm{e} + \mathrm{P} \to \mathrm{e} + \mathrm{X}$



Conservation of momentum:

$$p + q = p' + q'$$

$$(p' - p)^2 = (q' - q)^2$$

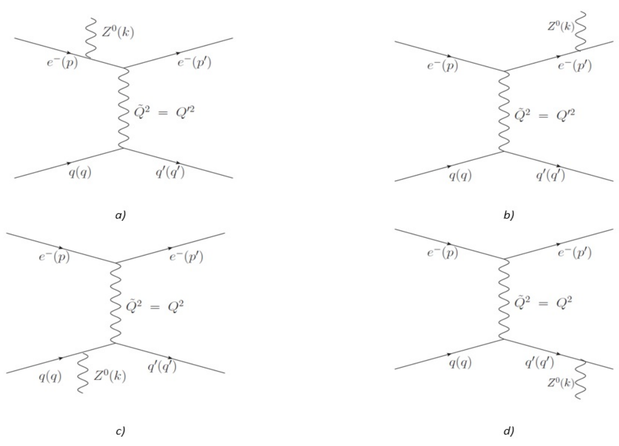
then

$$Q^2 = Q'^2$$

$$Q^2 = Q'^2 \doteq \tilde{Q}^2$$

Unambiguous

Process $\mathrm{e} + \mathrm{P} \to \mathrm{e} + \mathrm{Z}^0 + \mathrm{X}$



Conservation of momentum:

$$p + q = p' + q' + k$$

Production at lepton line (a and b):

momentum transfer$= Q'^2$

Production at quark line (c and d):

momentum transfer$= Q^2$

$\tilde{Q}^2 = Q'^2$? $\quad \tilde{Q}^2 = Q^2$?

There is ambiguity!

Results

↳ *Case* $\tilde{Q}^2 = Q'^2$ *(20 sessions,* $2x10^6$ *calls)*

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Case: S25
Total Cross Section 1.304E+00 [pb] (3.886E-01%)
Total Cross Section 1.309E+00 [pb] (5.244E-01%)
Total Cross Section 1.301E+00 [pb] (4.151E-01%)
Total Cross Section 1.301E+00 [pb] (3.939E-01%)
Total Cross Section 1.301E+00 [pb] (3.606E-01%)
Total Cross Section 1.300E+00 [pb] (4.078E-01%)
Total Cross Section 1.310E+00 [pb] (6.961E-01%)
Total Cross Section 1.298E+00 [pb] (3.591E-01%)
Total Cross Section 1.299E+00 [pb] (3.649E-01%)
Total Cross Section Mean 1.301E+00 [pb] (1.300E-01%) or (1.692E-03 [pb])
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↳ *Case* $\tilde{Q}^2 = Q^2$ *(20 sessions,* $2x10^6$ *calls)*

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Case: S14
Total Cross Section 2.367E+00 [pb] (1.972E+01%)
Total Cross Section 2.337E+00 [pb] (1.222E+01%)
Total Cross Section 2.013E+00 [pb] (8.301E+00%)
Total Cross Section 4.131E+00 [pb] (4.845E+01%)
Total Cross Section 1.913E+00 [pb] (4.023E+00%)
Total Cross Section 2.033E+00 [pb] (4.700E+00%)
Total Cross Section 1.915E+00 [pb] (2.904E+00%)
Total Cross Section 1.900E+00 [pb] (2.416E+00%)
Total Cross Section 2.528E+00 [pb] (1.271E+01%)
Total Cross Section 2.026E+00 [pb] (4.315E+00%)
Total Cross Section Mean 1.944E+00 [pb] (1.443E+00%) or (2.806E-02 [pb])
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↳ *Case* $\tilde{Q}^2 = s$ *(20 sessions,* $2x10^6$ *calls)*

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Case: M12
Total Cross Section 2.465E+00 [pb] (1.398E+01%)
Total Cross Section 1.859E+00 [pb] (1.840E+00%)
Total Cross Section 2.052E+00 [pb] (9.568E+00%)
Total Cross Section 2.257E+00 [pb] (8.150E+00%)
Total Cross Section 5.092E+00 [pb] (5.895E+01%)
Total Cross Section 2.282E+00 [pb] (1.242E+01%)
Total Cross Section 2.113E+00 [pb] (6.337E+00%)
Total Cross Section 2.037E+00 [pb] (4.188E+00%)
Total Cross Section 4.097E+00 [pb] (2.778E+01%)
Total Cross Section 1.759E+00 [pb] (4.731E+00%)
Total Cross Section Mean 1.901E+00 [pb] (1.443E+00%) or (2.806E-02 [pb])
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From our results, we conclude that the best choice is

$$\tilde{Q}^2 = Q'^2$$