Light gluinos and the longitudinal structure function

A.V. Kotikov

Laboratory of Particle Physics, Joint Institute for Nuclear Research
101 000 Dubna, Russia

G. Parente

Department of Physics, University of California
Irvine, CA 92717, USA

O.A. Sampayo

Departamento de Física,
CINVESTAV-IPN, Mexico

Abstract

The leading effect of light gluinos on the deep inelastic longitudinal structure function is calculated. We present the explicit analytic expression for the Wilson coefficient. After convolution with quark, gluon and gluino distributions we found that the size of the contribution is of order a few percent of the total $F_L$. Some phenomenological implications for HERA and LEP/LHC are given.
The modification of the standard QCD predictions due to the existence of supersymmetric particles has been extensively investigated in the last decade. It was suggested that the effect of some of these particles could be detected in the (low) energy range of current experiments. In particular a light gluino, a strongly interacting neutral fermion which is the spin-1/2 partner of the gluon, of mass of a few GeV, has not been ruled out by experiment\textsuperscript{1} and even its effect (if they exist) could explain a certain claimed discrepancy between low and high energy measurements of the strong coupling constant (see for example \cite{3}).

The effect of gluinos on the scaling violation of deep inelastic structure functions has been calculated in perturbative QCD at leading order (LO) \cite{4} and at next-to-leading order (NLO) \cite{5}. As the contribution was found to be smaller than the precision of the data, it can be concluded that such experiments can not exclude the presence of gluinos of mass lower than 10 GeV. Recently the gluino effect on $F_2$ was investigated in the kinematical range of HERA using modern parton distributions at NLO and it was found to be small and of the size comparable to the effect due to the uncertainty in the QCD energy scale, which makes it very hard to detect.

Until now the part of the interaction represented by the Wilson coefficient, where the gluino starts to contribute at order $\alpha_s^2$, was never considered in the calculations. Although for $F_2$ it is expected to be small because the correction follows in importance to those from quarks and gluons proportional to $\alpha_s^0$ and $\alpha_s^1$, for $F_L$ which starts at order $\alpha_s$ the effect could be relevant and an explicit calculation is required.

The aim of this work is to investigate the effect of light gluinos on the longitudinal structure function and to explore the possibility of detection in HERA or larger colliders. Now the calculation can be easily done because one has enough information about the two building blocks in a parton model approach, i.e. the hard part of the interaction and the gluino momentum distribution inside the proton.

We have translated to the gluino case the results from some of the quarks and gluon diagrams contributing to the $O(\alpha_s^2) F_L$ Wilson coefficient. For the soft part of the interaction we use a recent set of parton densities determined

\footnote{Recently it was claimed \cite{1} that the light gluino scenario is disfavoured by current LEP data on chargino and Higgs assuming a radiative symmetry breaking of the gauge group but there is controversy on that point \cite{2}.}
from global fits which includes the influence of a light gluino \[3\]. Throughout this work we will assume the hypothesis used in the extraction of such parton and gluino distributions, i.e. that the gluino is of Majorana type of mass of 5 GeV \[2\]. We do not consider the influence of the scalar partners of quarks because it is assumed they are heavy enough to be decoupled in the low energy region.

The diagrams in fig. 1 are the Compton amplitudes at the lowest order involving gluinos. Their contribution can be extracted from the analogous quark diagrams, those with the gluino line being replaced by a quark line, with an appropriate change of the group factors. The result of diagram (a) can be read from the term proportional to $C_F n_f$ in the non singlet coefficient (see eq. (8) from \[7\]), changing the number of species in the quark loop ($n_f$) to $C_A$, which is the corresponding number in case of a Majorana-type gluino. Also, the contribution of diagrams in fig. (b) can be obtained from the singlet coefficient (eq.(9) of the same reference) with the substitution $C_F \rightarrow C_A$.

The gluino contribution to $F_L$ is connected to the quark and gluino ($\tilde{g}$) densities by the parton model relation (see \[7\] for notation):

\[
F_{\tilde{g}L}^g(x, Q^2) = \left( \frac{\alpha_s}{4\pi} \right)^2 \int_x^1 \frac{dy}{y} J_{L,\tilde{g}}^{(2)}(y) F(x/y, Q^2) + \left( \frac{\alpha_s}{4\pi} \right)^2 \int_x^1 \frac{dy}{y} J_{L,\tilde{g}}^{(2)}(y) \delta_\psi^2 G_{\tilde{g}}(x/y, Q^2),
\]

where

\[
F(x, Q^2) = \sum_{i=1}^{n_f} e_i^2 x \left( q_i(x, Q^2) + \bar{q}_i(x, Q^2) \right),
\]

\[
G_{\tilde{g}}(x, Q^2) = x \tilde{g}(x, Q^2), \quad \delta_\psi^2 = \left( \frac{\sum_{i=1}^{n_f} e_i^2}{n_f} \right)
\]

The coefficients in eq. (I) that were calculated with the help of the changes

\[2\] In our calculation the value of the mass defines the threshold point, $Q^2 = 4m_{\tilde{g}}^2$, above which the gluino evolves as a massless parton, and below it is zero. It also affects the running coupling constant through the coefficients of the $\beta$-function (see ref. \[3\] for details). An alternative mass dependent $\alpha_s$ evolution can be found in ref. \[4\].
mentioned above have the following form in the $\overline{\text{MS}}$ scheme:

$$f_{L,q}^{(2)}(x) = -\frac{8}{3}C_FC_Ax^2 \left[ \ln \left( \frac{x^2}{1-x} \right) - \frac{6 - 25x}{6x} \right]$$

$$f_{L,\tilde{g}}^{(2)}(x) = \frac{16}{9}C_An_f \left[ 3 \left( 1 - 2x - 2x^2 \right) (1 - x) \ln(1 - x) 
+ 9x^2 \left( \text{Li}_2(x) + \ln^2(x) - \zeta(2) \right) + 9x(1 - x - 2x^2) \ln x 
- 9x^2(1 - x) - (1 - x)^3 \right],$$

Subindexes $q$ and $\tilde{g}$ label the type of parton distribution in the convolution integral. $n_f$ is the number of active quarks flavours. $C_F$ and $C_A$ are the Casimir operators in QCD. $\zeta$ is the Riemann zeta-function and $\text{Li}_2$ is the dilogarithm function.

Although in our calculation we use the $\overline{\text{MS}}$ results given above in order to be (scheme) consistent with the parton densities, for completeness we present below the transformations to a renormalization scheme which preserves supersymmetry and gauge invariance and that has been extensively used in the literature, i.e. the so-called dimensional reduction renormalization scheme $\overline{\text{DR}}$ \[8\]. The relation between quark and gluon coefficients in both schemes are:

$$f_{L,q}^{NS(2)}(\overline{\text{DR}}) = f_{L,q}^{NS(2)}(\overline{\text{MS}}) - f_{L,q}^{(1)} \otimes \Delta O_{qq}$$

$$f_{L,q}^{S(2)}(\overline{\text{DR}}) = f_{L,q}^{S(2)}(\overline{\text{MS}}) - f_{L,G}^{(1)} \otimes \Delta O_{Gq}$$

$$f_{L,G}^{(2)}(\overline{\text{DR}}) = f_{L,G}^{(2)}(\overline{\text{MS}}) - f_{L,q}^{(1)} \otimes \Delta O_{qG} - f_{L,G}^{(1)} \otimes \Delta O_{GG}$$

$f_{L,q}^{NS(2)}$, $f_{L,q}^{S(2)}$ and $f_{L,G}^{(2)}$ in $\overline{\text{MS}}$ can be found, for example, in ref. \[4\] (with the corrections given in \[8\] or \[12\] for the gluon coefficient). $f_{L,q(G)}^{(1)}$ are the first order coefficients. $\otimes$ is the convolution symbol. For the pure gluino contributions, Eq. \[8\] and \[12\] it reads:

$$f_{L,q}^{\tilde{g}(2)}(\overline{\text{DR}}) = f_{L,q}^{\tilde{g}(2)}(\overline{\text{MS}})$$

$$f_{L,\tilde{g}}^{(2)}(\overline{\text{DR}}) = f_{L,\tilde{g}}^{(2)}(\overline{\text{MS}}) - f_{L,G}^{(1)} \otimes \Delta O_{Gq}$$

The moments of the functions $\Delta O_{ij}$, $i, j = q, G$ (see \[8\] for notation) are the pieces that must be added to the matrix elements of the Wilson operator.
in the \(\overline{\text{MS}}\) scheme to get the result in \(\overline{\text{DR}}\) \cite{10}. We have calculated the convolutions of eq. (5) obtaining:

\[
\begin{align*}
    f_{L,q}^{(1)} \otimes \Delta O_{qq} &= 8C_f^2x(1 - \frac{3}{2}x + x \ln x) \\
    f_{L,q}^{(1)} \otimes \Delta O_{qG} &= 0 \\
    f_{L,G}^{(1)} \otimes \Delta O_{Gq} &= 16n_fC_fx^2(1 - x + \ln x) \\
    f_{L,G}^{(1)} \otimes \Delta O_{GG} &= -32n_fC_Ax^2\left((1 + x) \ln x + \frac{25}{12}(1 - x)\right)
\end{align*}
\]

The coefficients from diagrams involving gluinos are shown in fig. 2 for the \(\overline{\text{MS}}\) case and \(n_f = 4\). For comparison the well-known contributions from quarks and gluon are plotted. We checked that the use of the \(\overline{\text{DR}}\) scheme does not change significantly its value and shape.

To calculate the longitudinal structure functions Eq. (1) was integrated numerically convoluting the above coefficients with parton densities from set MRS-D'\(0\) and also from the version with gluinos from ref. \[3\]. We have considered the running coupling constant at NLO and the gluino threshold was crossed with the same prescription used for quarks, i.e. matching \(\alpha_s\) above and below threshold changing the QCD energy scale \(\Lambda\) to compensate the change in the renormalization group \(\beta\) function.

The result is presented in fig. 3, where for a better appreciation of the gluino effect we plotted the ratio \(\tilde{F}_L(x, Q^2)/F_L\), \(F_L\) being the standard quark and gluon contribution up to second order in QCD. The difference is a few percent in the relevant kinematic range for HERA and LEP/LHC. Notice that for \(x\) values higher than 0.1 the contribution becomes relatively more important, but there \(F_L\) is very small and will not be measured.

Whether it will be possible or not to detect the effect of gluinos in \(F_L\) is illustrated by the ratio plotted in figs. 4(a) and (b). One can see that both predictions are very similar in almost the whole region accessible to HERA \((Q^2 < 10^5\ \text{GeV}^2, 10^{-5}Q^2 < x < 1)\) and future LEP/LHC \((Q^2 < 1.6 \times 10^6\ \text{GeV}^2, 6.25 \times 10^{-7}Q^2 < x < 1)\).\[3\]

\[\text{As we are considering the gluino as a massless particle above the threshold, the use of Eq. (3) (see diagram 1a) for } x \text{ and } Q^2 \text{ close to the gluino production threshold is not correct. A different approach to cross the discontinuity at the threshold similar to those used for heavy quarks (see ref. [4]) is needed but here we do not treat this problem.}\]
Notice how at low $x$ the ratio of structure functions rises with $Q^2$ with the same shape as the ratio of coupling constants, which is what one naively would expect from $F_L$ being proportional to $\alpha_s$. At higher $x$ this effect is not so pronounced due to the balance from others contributing terms. A similar behavior can be observed in $F_2$ (see fig. 2 in ref. [3]), i.e. at low $x$ the structure function is dominated by sea-quarks and gluons that in turn depend on $\alpha_s$.

Similar results as those obtained above for the size and shape of the gluino contribution hold for the ratio of the longitudinal and transverse cross-sections $R = \sigma_L/\sigma_T = F_L/2xF_1$.

In conclusion, the influence of light gluinons in $F_L$ is of order of a few percent in the $x$ and $Q^2$ range of current and future machines. For example, at $Q^2 = 400$ GeV$^2$ and $x = 10^{-2}$ the gluino would produce a 2 % negative contribution. In LEP/LHC and for the same $Q^2$ one could go down to $x = 10^{-3}$ and see as much as a 3.5 % effect. These values are smaller than the contribution of the second order QCD correction for a non singular gluon but similar in size to the correction from a steep gluon of type $x^{-3/2}$ [11]. Only a very precise measurement of $F_L$, which is not expected at HERA, could separate both second order gluon and gluino effects.

Acknowledgments

We are grateful to J.W. Stirling for providing the parton distributions used in this work. One of the authors, Gonzalo Parente, acknowledges the financial support from the ‘Comision Interministerial de Ciencia y Tecnología’, Spain.

References

[1] Jorge L. Lopez, D.V. Nanopoulos and Xu Wang, Phys. Lett. B313 (1993) 241.
[2] F. de Campos and José W.F. Valle, preprint FTUV/93-9 and IFIC/93-5.
[3] R.G. Roberts and W.J. Stirling, Phys. Lett. B313 (1993) 453.
[4] B.A. Campbell, J. Ellis and S. Rudaz, Nucl. Phys. B198 (1982) 1.
[5] I. Antoniadis, C. Kounnas and R. Lacaze, Nucl. Phys. B211 (1983) 216.
[6] D.V. Shirkov and S.V. Mikhailov, Preprint BI-TP 93/75 and E2-93-336, JINR, Dubna.

[7] J. Sánchez Guillén, J.L. Miramontes, M. Miramontes, G. Parente and O.A. Sampayo, Nucl. Phys. B353 (1991) 337.

[8] W. Siegel, Phys. Lett. 84B (1979) 193.

[9] D.I. Kazakov and A.V. Kotikov, Phys. Lett. B291 (1992) 171.

[10] I. Antoniadis and E.G. Floratos, Nucl. Phys. B191 (1981) 217.

[11] G. Parente and J. Sánchez Guillén, Proceedings of the “XXII International Symposium on Multiparticle Dynamics”, Santiago de Compostela, July 1992, Ed. C. Pajares; S. Keller, M. Miramontes, G. Parente, J. Sánchez Guillén and O.A. Sampayo, Phys. Lett. B270 (1991) 61.
Figure captions

Figure 1: The diagrams involving gluinos (dashed line) contributing to the $F_L O(\alpha_s^2)$ Compton amplitude.

Figure 2: $O(\alpha_s^2)$ part of the $F_L$ quark, gluon and gluino coefficients: (a) $f_{NS}^{(2)}$, (b) $f_{2L,G}^{(2)}\delta_\psi$, (c) $f_{S}^{(2)}$, (d) $f_{L,\tilde{g}}^{(2)}$ and (e) $f_{L,q}^{\tilde{g}(2)}$.

Figure 3: The solid lines are the gluino contribution to $F_L$ relative to the NLO prediction at $Q^2 = 10^3$ and $10^4$ (lowest solid line at low x) GeV$^2$. The dashed (dash-dotted) line is the contribution due to the interaction represented by the diagrams in fig. 1a(1b) at $Q^2 = 10^3$ GeV$^2$.

Figure 4: Ratio of structure functions $F_L$ calculated with and without the influence of gluinos at fixed $Q^2$ (a) and $x$ (b). In (a) the upper (lower) curve was obtained at $Q^2 = 10^4 (10^3)$ GeV$^2$. The dashed line in (b) is the evolution of the ratio of the corresponding strong coupling constants.
This figure "fig1-1.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9402246v1
This figure "fig1-2.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9402246v1
This figure "fig1-3.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9402246v1