

**BOUNDS ON SECOND GENERATION SCALAR LEPTOQUARKS
FROM THE ANOMALOUS MAGNETIC MOMENT OF THE MUON**

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ABSTRACT

We calculate the contribution of second generation scalar leptoquarks to the anomalous magnetic moment of the muon (AMMM). In the near future, E-821 at Brookhaven will reduce the experimental error on this parameter to $\Delta a_\mu^{\text{exp}} < 4 \times 10^{-10}$, an improvement of 20 over its current value. With this new experimental limit we obtain a lower mass limit of $m_{\Phi_L} > 186$ GeV for the second generation scalar leptoquark, when its Yukawa-like coupling λ_{Φ_L} to quarks and leptons is taken to be of the order of the electroweak coupling g_2 .

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Recently there has been a lot of interest in leptoquarks theoretically [1–4] as well as experimentally [5–8] (and references within). Leptoquarks are quite common in extensions of the Standard Model. They are $SU(3)_C$ triplets and can occur as vectors or scalars. Since vector quarks are of more difficult nature in a low-energy theory we restrict ourselves in this Brief Report to scalar leptoquarks, which are $SU(2)$ doublets.

There exist already severe constraints on the characteristics of leptoquarks. Flavour changing neutral current (FCNC) forces the leptoquarks to be flavour diagonal; that is we have to suppose that they couple to only a single generation of leptons and quarks [9]. On the other hand from pseudoscalar mesons (π , K and D) leptonic decays we also have to conclude that leptoquarks couple only chirally; that is they couple either to left-handed or to right handed quarks only, but not to both at the same time [10].

The most stringent lower mass bound for the first generation leptoquarks is given by HERA experiments [8] $m_{\Phi_L} > 145$ GeV, where the Yukawa-like coupling of the leptoquarks to electrons and up quarks was supposed to be of electromagnetic strength $\lambda_{\Phi_L} = e$. In a recent report the CDF collaboration [7 the latter] presented for the second generation a lower mass bound of $m_{\Phi_L} > 135$ GeV if the branching ratio into muon and quark is taken to be 100% and $m_{\Phi_L} > 95$ GeV for a branching ratio of 50%*. In [4] the authors obtain via the leptonic partial widths of the Z boson a lower mass limit of about 680 GeV for a left-type leptoquark and of about 280 GeV for a right-type leptoquarks when the top mass is taken to be 180 GeV.

In this Brief Report we consider the contribution of second generation scalar leptoquarks to the AMMM. The QED contribution has been calculated to eighth order and estimated to tenth order[12]. The Standard Model contributions to the AMMM are also very well know: the W-boson contribution is the most important ($\Delta a_\mu^W \sim 40 \times 10^{-10}$), the Z contribution interferes destructively ($\Delta a_\mu^Z \sim -20 \times 10^{-10}$), and a heavy neutral Higgs contribution is totally negligible[13]. The charged Higgs contribution is also very small for a mass of a few GeV's or more [14], while the supersymmetric contributions can be large in certain mass domains [15]. Recently, two groups have performed 2-loop calculations in the context of the SM: the authors found that those contributions can be as large as 10%-12% of the 1-loop SM contribution [16]. In the near future, E-821 at Brookhaven will reduce the experimental error on the AMMM by a factor of 20 [17] thus leading to an experimental error of $\Delta a_\mu^{\text{exp}} < 4 \times 10^{-10}$. The main goal is to see the weak contributions but it is clear that such a measurement will lead to severe constraints for models beyond the SM.

The diagrams leading to the AMMM are given in Fig.1 and the Lagrangian that describes the coupling of the leptoquarks to photon and to the strange quark and muon is given by [4,18]

$$\mathcal{L} = +ee_{\Phi_L}^q (k_1 + k_2)^\mu \Phi_L^\dagger \Phi_L A^\mu + \lambda_{\Phi_L} \bar{\mu} [g_L^q P_L + g_R^q P_R] q \Phi \quad (1)$$

* In a recent report the D0 obtains $m_{\Phi_L} > 111$ GeV for a branching ratio of 100% and $m_{\Phi_L} > 89$ GeV for a branching ratio of 50%[11]

with $e_{\Phi_L}^q = -2/3, -5/3$ if $q = s, c$ respectively. The chiral coupling of the leptoquarks forces us to consider $g_L^q = 1, g_R^q = 0$ (left-type leptoquark) or $g_L^q = 0, g_R^q = 1$ (right-type leptoquark). The calculation of the first and second diagram shown in Fig.1 and the last two self energy diagrams lead to the following results:

$$\begin{aligned}
iM_1 &= + \frac{ee_q \lambda_{\Phi_L}^2}{(4\pi)^2} g_a^{q2} \int_0^1 d\alpha_1 \int_0^{1-\alpha_1} d\alpha_2 \bar{u}_{p_2} \left\{ \left[\frac{1}{\epsilon} - 1 - \gamma + \log(4\pi\mu^2) - \log G(m_{\Phi_L}^2, m_q^2) \right] P_a \gamma_\mu \right. \\
&\quad \left. + P_a [(\not{p}_2 - \not{\tilde{p}})\gamma_\mu (\not{p}_1 - \not{\tilde{p}}) + m_q^2 \gamma_\mu] \frac{1}{G(m_{\Phi_L}^2, m_q^2)} \right\} u_{p_1} \epsilon^{*\mu} \quad (2) \\
iM_2 &= + \frac{ee_q \lambda_{\Phi_L}^2}{(4\pi)^2} g_a^{q2} \int_0^1 d\alpha_1 \int_0^{1-\alpha_1} d\alpha_2 \bar{u}_{p_2} \left\{ \left[\frac{1}{\epsilon} - \gamma + \log(4\pi\mu^2) - \log G(m_q^2, m_{\Phi_L}^2) \right] P_a \gamma_\mu \right. \\
&\quad \left. + P_a [\not{\tilde{p}}(p_1 + p_2 - 2\tilde{p})^\mu \frac{1}{G(m_q^2, m_{\Phi_L}^2)}] \right\} u_{p_1} \epsilon^{*\mu} \\
iM_{SE} &= + \frac{e \lambda_{\Phi_L}^2}{(4\pi)^2} g_a^{q2} \int_0^1 d\alpha_1 \alpha_1 \bar{u}_{p_2} \left\{ \left[\frac{1}{\epsilon} - \gamma + \log(4\pi\mu^2) - \log H(m_q^2, m_{\Phi_L}^2) \right] P_a \gamma_\mu \right\} u_{p_1} \epsilon^{*\mu}
\end{aligned}$$

$$G(m_i^2, m_j^2) = m_i^2 - (m_i^2 - m_j^2)(\alpha_1 + \alpha_2) - m_\mu^2(\alpha_1 + \alpha_2)(1 - \alpha_1 - \alpha_2) - q^2 \alpha_1 \alpha_2$$

$$H(m_i^2, m_j^2) = m_i^2 - (m_i^2 - m_j^2)\alpha_1 - m_\mu^2 \alpha_1 (1 - \alpha_1)$$

$$\tilde{p} = p_1 \alpha_1 + p_2 \alpha_2$$

with $e_q = -1/3, +2/3$ for $q = s, u$ respectively and $a = L, R$. $q^2 = (p_1 - p_2)^2 = 0$ for a real photon. After the summation of all diagrams the divergencies cancel out. To obtain the AMMM we have to make use of gauge invariance $q^\mu \epsilon^{*\mu} = 0$ that is $p_1^\mu \epsilon^{*\mu} = p_2^\mu \epsilon^{*\mu}$, of the Dirac equation $\bar{u}_{p_2} P_L \not{p}_2 u_{p_1} = m_\mu u_{p_2} P_R u_{p_1}$ ($\bar{u}_{p_2} P_L \not{p}_1 u_{p_1} = m_\mu u_{p_2} P_L u_{p_1}$) and perform a Gordon decomposition $2\bar{u}_{p_2} p_1^\mu u_{p_1} = \bar{u}_{p_2} (i\sigma_{\mu\nu} q^\nu + 2m_\mu \gamma_\mu) u_{p_1}$. As a finite result we obtain a term proportional to the γ_μ term, which has to be renormalised by adding a counter term [4] and a term proportional to $\sigma_{\mu\nu} q^\nu$ from which the AMMM a_μ can be extracted by $V_\mu = \frac{e}{2m_\mu} a_\mu \bar{u}_{p_2} i\sigma_{\mu\nu} q^\nu u_{p_1}$. After some calculation the contribution of the second generation scalar leptoquark to the AMMM is given by

$$\begin{aligned}
\Delta a_\mu^{\Phi_L} &= + \frac{\lambda_{\Phi_L}^2}{(4\pi)^2} g_a^{q2} m_\mu^2 \int_0^1 d\alpha_1 \alpha_1^2 (1 - \alpha_1) \left[\frac{e_{\Phi_L}^q}{H(m_q^2, m_{\Phi_L}^2)} - \frac{e_q}{H(m_{\Phi_L}^2, m_q^2)} \right] \quad (3) \\
&= + \frac{\lambda_{\Phi_L}^2}{(4\pi)^2} g_a^{q2} \frac{1}{6} (e_{\Phi_L}^q - 2e_q) \left(\frac{m_\mu}{m_{\Phi_L}} \right)^2
\end{aligned}$$

Eq.(3) is exact while the last result makes use of $m_{\Phi_L}^2 \gg m_s^2, m_\mu^2$. As a result we have that for $q = s$ the first order in the expansion of $1/m_{\Phi_L}^2$ is identical to 0 ($e_{\Phi_L}^s - 2e_s \equiv 0$), whereas for $q = c$ we have $e_{\Phi_L}^c - 2e_c = -3$. Parametrizing the

Yuakawa-like leptoquark coupling with electroweak strength $\lambda_{\Phi_L}^2 = g_2^2 k$ ($k = 1 - 10$) [4] we have $|\Delta a_\mu^{\Phi_L}| = 1.38 \times 10^{-5} k (\text{GeV}/m_{\Phi_L})^2$ when the charm quark is taken within the loop. Combining this result with the expected experimental error on the AMMM ($\Delta a_\mu^{\text{exp}} = 4 \times 10^{-10}$) we obtain a lower mass limit of a second generation scalar lepton quark (left-type or right-type) of $m_{\Phi_L} > 186$ GeV for $k = 1$ and $m_{\Phi_L} > 588$ GeV for $k = 10$. These bounds compare very well with direct searches at current accelerators.

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FIGURE CAPTIONS

Fig.1 The penguin and self energy diagrams with the second generation scalar lepton-quark and quarks contributing to the AMMM. The q within the loop denotes an up or strange quark, whereas the q at the photon denotes its momenta $q = p_1 - p_2$.