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On the charm-squark interpretation of the HERA events

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The charm squark resonance in the e^+q channel provides one of the plausible interpretations of the reported anomaly at HERA. We show that the relevant R violating coupling λ'_{121} is required to be large, typically around 0.1 in a large class of supergravity based models including the minimal one with the universal boundary condition at the GUT scale. Existing constraints on these couplings are reanalysed in this light a nd it is argued that such large couplings may be feasible but would require fine tuned cancelations.

The anomalous events seen by the ZEUS and the H1 detectors [1] at HERA in the deep inelastic e^+p scattering have generated considerable excitement [2, 3, 4, 5, 6, 7, 8]. These events would constitute evidence for physics beyond standard electroweak model if they are established firmly in the future. The presently available information when taken seriously allows two possible interpretations: (*i*) The presence of some lepton number violating contact interaction [2] or (*ii*) production of a resonance in the e^+q channel [3, 4, 5, 6]. Supersymmetry, with violation of R parity[3, 4, 5] provides a natural theoretical framework to incorporate the second possibility although an alternative in terms of a scalar leptoquark [6] is also open.

The supersymmetric interpretation of the HERA events assumes that the excess events seen at HERA are due to resonant production and subsequent decay of the squark to e^+q. Three possibilities have been considered in this context[3, 4, 5]: $e_R^+ d_R \to \tilde{c}_L, e_R^+ d_R \to \tilde{t}_L, e_R^+ s_R \to \tilde{t}_L$. In analyzing these scenarios [3, 4, 5] it has been implicitly assumed that the squark masses are free parameters of the model. While this would be true in the most general situation, specific model dependence can alter some of the conclusions. Our aim is to show that the very minimal model dependent assumption on the charm squark mass necessarily requires large λ'_{121} to understand HERA events and this large coupling by itself is ruled out from other constraints.

The specific assumption that we make and which leads to the above conclusion is that the charm squark mass squared is positive at the unification scale. This assumption is true in the radiative electro-weak breaking scenario with universal boundary conditions at the GUT scale, but it can also be true in a much more general context. We shall first assume that the gaugino masses are unified at M_{GUT} but demonstrate later that the removal of this assumption does not significantly change the basic conclusion.

The argument leading to the above conclusion is largely insensitive to the details of the radiative $SU(2) \times U(1)$ breaking in the MSSM and runs as follows.

Consider the following R violating couplings:

$$W_R = \lambda'_{ijk}(-\nu_i d_l K_{lj} + e_i u_j) d^c_k \tag{1}$$

The above terms are defined in the quark mass basis and K denotes the Kobayashi-Maskawa matrix. The charm squark interpretation of the HERA anomaly requires λ'_{121} to be non-zero. The HERA data can be explained provided

$$\lambda'_{121} \sim \frac{0.025 - 0.034}{B^{1/2}} \tag{2}$$

The number in the numerator of eq.(2) is indicative of the required range and depends upon the weightage given to the different experiments as well as on the next to leading order QCD corrections [7]. In the following, we shall take [9] the value 0.025 for the numerator in the RHS of eq.(2). B refers to the branching ratio for the squark decay to qe^+. This decay would take place through the coupling in eq.(1) itself. B is also influenced by the R conserving decays of the charm squark to an s (c) and a chargino (neutralino) . The λ'_{121} and the parameters $\mu, M_2, \tan\beta$ determine B in the MSSM. HERA data can be reconciled if for a region in these parameters (*i*) eq.(2) is satisfied, (*ii*) λ'_{121} is consistent with other constraints [10, 11, 12, 13] due to R breaking and (*iii*) charm squark has a mass around 180-220 GeV.

In supergravity based models, the charm squark mass at the weak scale is governed by the gauge couplings and the gaugino masses. Its value at $Q_0 = 200\,\mathrm{GeV}$ is given in the limit of neglecting Kobayashi-Maskawa and $\tilde{c}_L - \tilde{c}_R$ mixing by [14]

$$m^2_{\tilde{c}_L}(Q_0) \approx m^2_{\tilde{c}_L}(M_{GUT}) + 8.83 M_2^2 + 1/2\ M_Z^2\ \cos 2\beta\ (1 - 4/3 \sin^2\theta_W) \tag{3}$$

where we have assumed that the gauge couplings and the gaugino masses are unified at the GUT scale, $M_{GUT} = 3 \times 10^{16}\,\mathrm{GeV}$ and chosen $\alpha_s(M_Z) = 0.12$. The M_2 in eq.(3) is the value of the wino mass at the weak scale identified here with M_Z. The last term in the above equation is a (-ve) contribution from the D-term. It follows that the charm squark mass provides strong upper bound on M_2 as long as $m^2_{\tilde{c}_L}(M_{GUT}) > 0$:

$$M_2 \leq 74.04\,\mathrm{GeV} \left(\frac{m_{\tilde{c_L}}}{220\,\mathrm{GeV}}\right) \left(1 - 0.06 \cos 2\beta \left(\frac{220\,\mathrm{GeV}}{m_{\tilde{c_L}}}\right)^2\right)^{1/2} \tag{4}$$

The branching ratio B is determined in the MSSM by the following widths [15]:

$$\Gamma(\tilde{c}_L \to e^+ c) = \frac{\lambda'^2_{121}}{16\pi} m_{\tilde{c}_L} \tag{5}$$

$$\Gamma(\tilde{c}_L \to \chi_i^0 c) = \frac{\alpha}{2\ m^3_{\tilde{c}_L}} \lambda^{\frac{1}{2}}(m^2_{\tilde{c}_L}, m^2_c, m^2_{\chi_i^0}) \left[\ (\mid F_L \mid^2 + \mid F_R \mid^2)(m^2_{\tilde{c}_L} - m^2_c - m^2_{\chi_i^0}) - 4 m_c m_{\chi_i^0} Re(F_R F_L^\star)\ \right] \tag{6}$$

$$\Gamma(\tilde{c}_L \to \chi_i^+ s) = \frac{\alpha}{4 sin^2\theta_W m^3_{\tilde{c}_L}} \lambda^{\frac{1}{2}}(m^2_{\tilde{c}_L}, m^2_s, m^2_{\chi_i^+}) \left[\ (\mid G_L \mid^2 + \mid G_R \mid^2)(m^2_{\tilde{c}_L} - m^2_s - m^2_{\chi_i^+}) - 4 m_s m_{\chi_i^+} Re(G_R G_L^\star)\ \right] \tag{7}$$

$$where, F_L = \frac{m_c N'^\star_{i4}}{2\ m_W\ sin\theta_W\ sin\beta},$$

$$F_R = e_c N'_{i1} + \frac{\frac{1}{2} - e_c sin^2\theta_W}{cos\theta_W\ sin\theta_W} N'_{i2},$$

$$G_L = -\frac{m_s U^\star_{k2}}{\sqrt{2}\ m_W\ cos\beta},$$

$$G_R = V_{k1}.$$

We have adopted the same notation as in [15]. From the expression for B in terms of the above decay widths, and the HERA constraint, eq.(2), one can solve for the allowed λ'_{121}. The contours in the $\mu - M_2$ plane for different values of λ'_{121} are displayed in fig 1a ($\tan\beta$=1) and fig 1b ($\tan\beta = 40$). The horizontal lines in these figures show the upper bound on M_2, eq.(4). We also display, the curves corresponding to two representative values of the chargino masses namely 45 and 85 GeV. The later is the present experimental bound obtained assuming R conservation. This need not hold in the presence of R violation. It is seen from fig.1b that for chargino mass around 85 GeV, the bound on M_2 by itself rules out charm squark interpretation for large tan β independent of the value of λ'_{121} [16]. But irrespective of the value of $\tan\beta$ and the chargino mass one needs very large $\lambda'_{121} \geq 0.13$ in order to satisfy the bound on M_2 coming from the charm squark mass. This strong bound on λ'_{121} arises because of the following reason. For $M_2 \leq 74\,\mathrm{GeV}$, at least one of the charginos is sufficiently light and contributes dominantly to the $\tilde{c}_L$ decay. This reduces B [17] and results in large value for λ'_{121} due to eq.(2). In contrast, the chargino decay is suppressed kinematically for $\tan\beta \sim 1$ if $M_2 > 200\,\mathrm{GeV}$. This results in smaller allowed value as seen from the figure. But these are in conflict with the charm squark mass.

Let us now see if one could make large λ'_{121} consistent with other constraints. The strong constraints come from atomic parity violation [10], the decay $K^+ \to \pi\nu\bar{\nu}$ [11] and the electron neutrino mass [12]. The recent data from Cs on the relevant weak charge have been argued [4, 18] to imply

$$\lambda'_{121} \leq 0.074 \tag{8}$$

at 2σ level in conflict with the large value required here. In principle, the extra contribution due to charm squark to atomic parity violation can be canceled by a similar contribution from the scalar bottom or strange squark but the existing constraints on the relevant couplings make this cancelation difficult [18]. Thus, one cannot easily avoid the atomic parity violation constraint strictly in the MSSM but this can be done by postulating new physics, e.g. the presence of an extra Z [18].

The other significant constraint comes from the decay $K^+ \to \pi\nu\bar{\nu}$ which implies [11]

$$\lambda'_{121} \leq 0.02 \left(\frac{m_{\tilde{d}_R}}{200\,\mathrm{GeV}}\right). \tag{9}$$

The electron neutrino mass also gives similar constraint in the same parameter range [12]. The question of choice of the basis becomes relevant in the discussion of these constraints. This is particularly so when one assumes only one λ'_{ijk} to be non-zero. For λ'_{121} defined in the mass basis as in eq.(1) the above constraint is unavoidable if rest of the couplings are zero. This basis choice is natural from the point of view of interpreting HERA results but is not unique. One may redefine the couplings as

$$\bar{\lambda}'_{ijk} \equiv K_{jl}\lambda'_{ilk}$$

and rewrite eq.(1) as follows:

$$W_R = \bar{\lambda}'_{ijk}(-\nu_i d_j + e_i K^\dagger_{lj} u_l) d^c_k \tag{10}$$

HERA result would now require $\bar{\lambda}'_{121}$ to be large. If this is the only non-zero $\bar{\lambda}'_{ijk}$ then there will not be any constraint on $\bar{\lambda}'_{121}$ from the neutrino mass or from the $K^+ \to \pi\nu\bar{\nu}$ decay

[11]. But eq.(10) will now generate a contribution to the neutrinoless double beta decay which is also severely constrained. Specifically, one has [13]

$$K_{12}^{\dagger}\bar{\lambda}'_{121} \leq 2.2 \times 10^{-3} \left(\frac{m_{\tilde{u}_L}}{200\,\mathrm{GeV}}\right)^2 \left(\frac{m_{\tilde{g}}}{200\,\mathrm{GeV}}\right)^{1/2} \tag{11}$$

This clearly does not allow $\bar{\lambda}'_{121}$ of O(0.1). Thus, notwithstanding basis dependence one has problem in accommodating large value for the relevant coupling. An alternative is to allow more than one non-zero $\bar{\lambda}'_{ijk}$. It is seen from eq.(10) that $\bar{\lambda}'_{1j1}$ (j=1,2,3) contribute to the neutrinoless $\beta\beta$ decay and simultaneous presence of these may lead to cancelations. Eq.(11) now gets replaced by

$$(\bar{\lambda}'_{111} + K_{12}^{\dagger}\bar{\lambda}'_{121} + K_{13}^{\dagger}\bar{\lambda}'_{131}) \leq 2.2 \times 10^{-3} \left(\frac{m_{\tilde{u}_L}}{200\,\mathrm{GeV}}\right)^2 \left(\frac{m_{\tilde{g}}}{200\,\mathrm{GeV}}\right)^{1/2} \tag{12}$$

With $\bar{\lambda}'_{121} \sim 0.13$, cancelation between the last two terms is unlikely as it requires $\bar{\lambda}'_{131} \sim 2$. The first two terms can cancel but the $\bar{\lambda}'_{111}$ is independently constrained from the neutrino mass [12]. Its presence generates a large contribution to the electron neutrino mass induced through neutrino-gaugino mixing [12]. This is given by

$$m_{\nu} \sim \frac{g^2}{m_{SUSY}} < \tilde{\nu} >^2 \tag{13}$$

The value of the induced sneutrino *vev* is sensitive to the MSSM parameters but can be approximately written as [12]

$$< \tilde{\nu} > \sim \frac{9\ \bar{\lambda}_{111}}{16\ \pi^2}\ m_d\ \ ln\left(\frac{M_{GUT}^2}{M_Z^2}\right) \tag{14}$$

Requiring $m_{\nu} \leq 2eV$ leads for $m_{SUSY} \sim 100\,\mathrm{GeV}$ to

$$\bar{\lambda}_{111} \leq .04$$

It is seen that cancelations between the first two terms in eq.(12) are feasible and can allow $\bar{\lambda}_{121} \sim 0.13$ if this fine tuning is accepted. It must be added that the bound in the previous equation is quite sensitive to the MSSM parameters and for a large range in these parameters, the actual bound can be stronger [12] than the generic bound displayed above.

While wino and zino control the decay of the charm squark, its mass is mainly controlled by the large radiative corrections driven by the gluino mass. The unification of the gaugino mass parameters relates the two and leads to the above difficulty. Thus giving up this unification may open up a possibility of reconciling HERA events . Let us treat the gaugino masses $M_{1,2,3}$ at M_Z as independent parameters. Then integration of the RG equation for the charm-squark from M_{GUT} to $Q_0 = 200\,\mathrm{GeV}$ leads to

$$m^2_{\tilde{c}_L}(Q_0) \approx m^2_{\tilde{c}_L}(M_{GUT}) + 0.77M_3^2 + 0.70M_2^2 + 0.024M_1^2 + 1/2\ M_Z^2\ \cos 2\beta\ (1 - 4/3\sin^2\theta_W) \quad (15)$$

If gaugino masses were to be unified at M_{GUT} then $M_3 \sim 3.25M_2$ and $M_1 \sim 0.5M_2$. Even in the absence of such unification, the physical gluino mass $m_{\tilde{g}} \sim (1 + 4.2\frac{\alpha_s}{\pi})M_3$ must be greater than the charm squark mass if large λ'_{121} is to be avoided. This follows since in the converse case, the charm squark would predominantly decay to a gluino and a quark. This decay being governed by strong coupling, would dominate the other decays and would reduce B. The later is given in case of $m_{\tilde{c}_L} \gg m_{\tilde{g}}$ by

$$B \sim \frac{3\ \lambda'^2_{121}}{32\ \pi\ \alpha_s} \sim 2.5 \times\ 10^{-3} \left(\frac{\lambda'_{121}}{0.1}\right)^2$$

Such a tiny value of B would need unacceptably large λ'_{121}. It therefore follows that one must suppress the squark decay to gluino kinematically by requiring $m_{\tilde{g}} \geq m_{\tilde{c}_L}$. Given this bound on M_3 it follows from eq.(15) that

$$M_2 \leq 170\,\mathrm{GeV} \quad (16)$$

if $m_{\tilde{c}_L} \sim 220\,\mathrm{GeV}$. This bound on M_2 is weaker than the one in the case of the gaugino mass unification, eq.(4). But it nevertheless cannot suppress the decay of squarks to chargino kinematically. It follows [19] from Fig. 1 that one now approximately needs $\lambda'_{121} \geq 0.08$. This value is close to the 2σ limit coming from the atomic parity violation but one would still need some cancelations to satisfy other constraints as discussed above. Thus giving up unification helps only partially.

An alternative possibility is to allow for a -ve (mass)^2 for the charm squark at the unification scale. In view of the large positive contribution induced by the gluino mass such negative (mass)^2 need not lead to colour breaking and may be consistent phenomenologically. In fact a -ve (mass)^2 for top squark has been considered in the literature [20] in a different context. The universality is a simplifying feature of MSSM but it does not follow from any general principle. It does not hold in a large class of string based models which may allow negative (mass)^2 for some sfermions as well [21]. Such masses can also arise when SUSY is broken by an anomalous $U(1)$ [22] with some of the sparticles having -ve charge under this $U(1)$.

The large radiative corrections induced through the running in squark masses from a high $\sim M_{GUT}$ to the weak scale has played an important role in this analysis. In contrast to the supergravity based models, this running is over a much smaller range in models with gauge mediated supersymmetric breaking. But in these models, the initial value of the charm squark (mass)^2 is positive and large with the result that these models are incompatible with the charm squark interpretation of HERA anomaly even without the radiative corrections [23].

The interpretation of HERA events in terms of stop may not suffer from the above mentioned difficulty encountered for the charm interpretation for two reasons. Firstly, the stop mass is reduced compared to the charm squark mass due to the possible large $\tilde{t}_L - \tilde{t}_R$ mixing as well due to the large top coupling. Secondly, this mass also involves one more parameter (the trilinear couplings A) compared to the charm squark mass. Thus while this is a less constrained possibility, imposition of the requirement that $m_{\tilde{t}} \sim 200\,\mathrm{GeV}$ would certainly lead to more constrained parameter space than considered in model independent studies [3].

In summary, we have shown that the charm squark interpretation of HERA events is possible only for large $\lambda'_{121} \sim O(0.1)$ in a large class of supersymmetric standard models characterized by a positive charm squark (mass)^2 at the GUT scale. The simplest and the most popular minimal supergravity model with universal boundary condition falls in

this class. The required large value of R violating parameter is difficult to admit without postulating new physics and /or fine tuned cancelations.

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[1] ZEUS Coll., Z. Phys. **C74**, 207; H1 Coll., Z. Phys. **C74**, 191 (1997); talk presented by B. Straub at the Lepton-Photon Symposium, paper contributed to the Lepton-Photon Symposium, Hamburg, 1997.

[2] V. Barger, K. Cheung, K. Hagiwara, and D. Zeppenfeld, Phys. Lett. **B404**, 147 (1997); A. Nelson, Phys. Rev. Lett. **78**, 4159 (1997); N. Bartolomeo and M. Fabbrichesi, Phys. Lett. **B406**, 237 (1997); W. Buchmüller and D. Wyler, Phys. Lett. **B407**, 147 (1997); M.C. Gonzalez-Garcia and S.F. Novaes, Phys. Lett. **B407**, (1997) 255; K. Akama, K. Katsuuara, and H. Terazawa, Phys. Rev. **D56**,(1997) 2490; S. Godfrey, Mod. Phys. Lett. **A12**, 1859 (1997); N.G. Deshpande, B.Dutta, and Xiao-Gang He, Phys. Lett. **B408** (1997) 288; D.Zeppenfeld hep-ph/9706357; F. Caravaglios, hep-ph/9706288; L. Giusti and A. Strumia, hep-ph/9706298; F. Cornet and J. Rico, hep-ph/9707299; V. Barger, K. Cheung, K. Hagiwara, and D. Zeppenfeld, hep-ph/9707412.; J. A. Grifols, E. Massó, and R. Toldrà, hep-ph/9707531.

[3] D. Choudhury and S. Raychaudhuri, Phys. Lett. **B401**, 54 (1997);S.L. Adler, hep-ph/9702378; J. Kalinowski, R. Rückl, H. Spiesberger, and P.M. Zerwas, Z. Phys. **C74**, 595 (1997); G. Altarelli, J. Ellis, G.F. Guidice, S. Lola, and M.L. Mangano, hep-ph/9703276; E.Perex, Y.Sirios and H.Driener, hep-ph/9703444; H. Dreiner and P. Morawitz, Nucl. Phys. **B503** (1997) 55; J. Kalinowski, R. Rückl, H. Spiesberger, and P.M. Zerwas, Phys. Lett. **B406**, 314 (1997); D. Choudhury and S. Raychaudhuri, Phys. Rev. **D56**, 1778 (1997); G.F. Giudice and R. Rattazzi, Phys. Lett. **B406**, 321 (1997); T. Kon and T. Kobayashi, Phys. Lett. **B409** (1997) 265; G.K. Leontaris and J.D. Vergados, Phys. Lett. **B409** (1997) 283; R. Barbieri, A. Strumia, and Z. Berezhiani,

Phys. Lett. **407** (1997) 250; S.F. King and G.K. Leontaris, hep-ph/9704336; A.S. Belyaev and A.V. Gladyshev, hep-ph/9704343; B. Dutta, R. Mohapatra, and S. Nandi, hep-ph/9704428; G. Altarelli, G. F. Guidice, M. L. Mangano, hep-ph/9705287; J. Ellis, S. Lola, and K. Sridhar, Phys. Lett. **B408** (1997) 252; J.E. Kim and P. Ko, hep-ph/9706387; N. G. Deshpande and B. Dutta, hep-ph/9707274; T. Kon, T. Matsushita, and T. Kobayashi, hep-ph/9707355; M. Carena, D. Choudhury, S. Raychaudhury, and C. Wagner, hep-ph/9707458; J. Kalinowski, et al., hep-ph/9708272; K. Cheung, D. Dicus, and B. Dutta, hep-ph/9708330; J. Hewett and T. Rizzo, hep-ph/9708419.

[4] G. Altarelli, hep-ph/9708437.

[5] M.Guchait and D.P.Roy, hep-ph/9707275;

[6] J. Blümlein, Z. Phys. **C74**, 605 (1997);hep-ph/9706362; K.S. Babu, C. Kolda, J. March-Russell, and F. Wilczek, Phys. Lett. **B402**, 367 (1997); T.K. Kuo and T. Lee, hep-ph/9703255; J. Hewett and T. Rizzo, Phys. Rev. **D56**,(1997) 5709; C.G. Papadopoulos, hep-ph/9703372; D. Friberg, E. Norrbin, and T. Sjöstrand, Phys. Lett. **B403**, 329 I. Montvay, Phys. Lett. **B407**, 22 (1997); M. Krämer et al., Phys. Rev. Lett. **79**, 341 (1997); (1997); J. Elwood and A. Faraggi, hep-ph/9704363; M. Heyssler and W.J. Stirling, Phys. Lett. **B407** (1997) 259; S. Jadach, W. Placzek, and B. Ward, hep-ph/9705395; K. S. Babu, C. Kolda, and J. March-Russell, Phys. Lett. **B 408**(1997) 261; A. Blumhofer and B. Lampe, hep-ph/9706454; E. Keith and E. Ma, hep-ph/9707214;

[7] T. Plehn et al., Z. Phys. **C74**, 611 (1997); Z. Kunszt and W.J. Stirling, Z. Phys. **C75**, 453 (1997);

[8] Z. Cao, X.-G. He, and B. McKellar, hep-ph/9707227; B. A. Arbuzov, hep-ph/9703460;A. R. White, hep-ph/9704248; N.I.Kochelev hep-ph/9710540;R.N.Mohapatra hep-ph/9707518; K.S.Babu et.al Phys. Lett. **B408** 268 (1997); M.V.Chizhov hep-ph/9704409,Phys. Lett. **B409** (1997) 271.

[9] The lower limit is obtained when H1 and ZEUS data from 1997 run are also included while the upper limit corresponds to inclusion of H1 data alone. In both cases, 30% increase in the relevant

cross section due to next to leading order corrections [7] is assumed, S. Raychoudhury (private communication).

[10] C.S.Wood et al., Science **275** (1997) 1759.

[11] K. Agashe and M. Graesser, Phys. Rev. **D54** (1996) 4445.

[12] A.S. Joshipura, V. Ravindran, and S.K. Vempati, hep-ph/9706482; B. de Carlos and P.L. White, Phys. Rev. **D54** (1996) 3427. E. Nardi, Phys. Rev. **D55** (1997) 5772.

[13] M. Hirsch, H.V. Klapdor-Kleingrothaus and S.G. Kovalenko, Phys. Rev. Lett. **75** (1995) 17.

[14] We also neglect the effect of additional trilinear R violating couplings on the running of the charm squark mass. Their inclusion does not significantly alter the charm squark mass even when they are large, see e.g. K. Cheung, D. Dicus and B. Dutta [3].

[15] T. Kon and T. Kobayashi, Phys. Lett. **B270** (1991) 81; T. Kon, T. Kobayashi and S. Kitamura, Phys. Lett. **B333** (1994) 263; Int. J. Mod. Phys.**A11** (1996) 1875.

[16] Specifically, the upper bound on M_2 can be reconciled with the chargino mass of 85 GeV or more only if $\tan\beta \leq 2.5$.

[17] Reduction in the branching ratio for charm squark decay in case of the minimal model was also noticed in [5].

[18] V.Barger,K.Cheung,D.P.Roy and D.Zeppenfeld, hep-ph/9710353;

[19] Note that fig. 1 is based on the assumption of $M_1 = .5M_2$ but does not use any relation between M_3 and M_2.

[20] J.L. Feng, N. Polonsky and S. Thomas, Phys. Lett. **B 370** (1996) 95.

[21] A.Brignole, L.E.Ibanez and C.Munoz, Nucl. Phys. **B422** (1994) 125; hep-ph/9707209.

[22] see for example, G. Dvali and A. Pomarol, *Phys. Rev. Lett.* **77** (1996) 3728; P. Binetruy and E. Dudas, *Phys. Lett.* **B389** (1996) 503.

[23] See, K. Cheung, D. Dicus and B. Dutta [3].

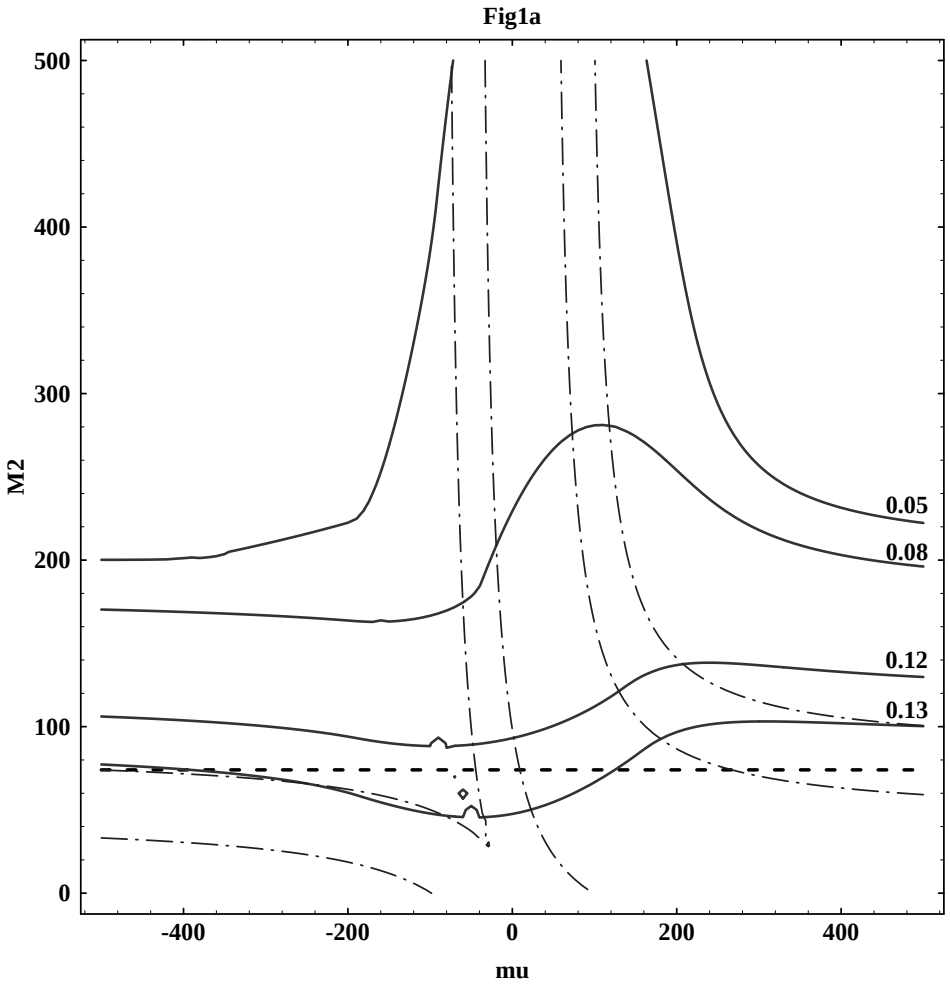

Fig 1 a: *The contours (continuous lines) of constant* λ'_{121} *obtained by imposing HERA constraint, eq.(2). The contours are for values 0.05, 0.08, 0.12, and 0.13. The horizontal dashed line represents the bound on* M_2 *coming from requiring* $m_{\tilde{c}_L} = 220\,\mathrm{GeV}$. *The vertical dash-dot lines represent the bounds on the chargino mass, the upper one for a mass of 85* GeV*and the lower one for a mass of 45* GeV. *All the above are computed for* $\tan\beta = 1$.

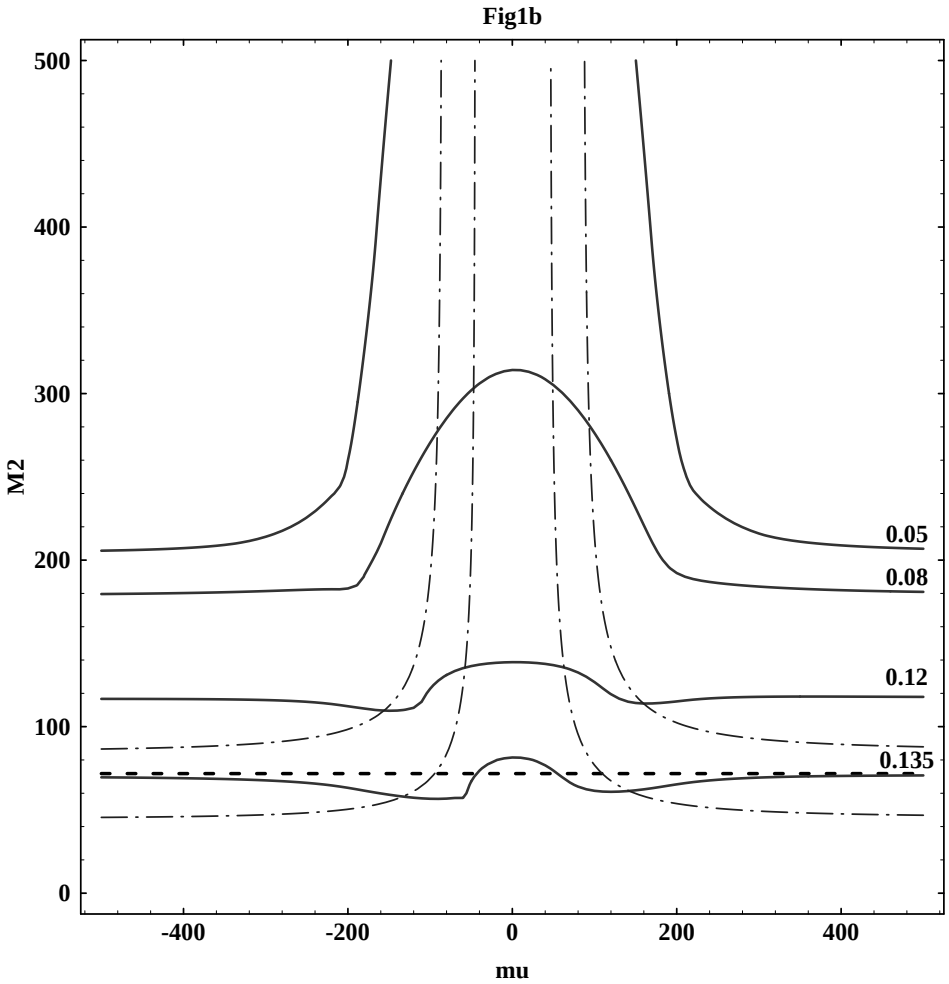

Fig 1 b: *Same as fig 1a but for tanβ = 40 and λ'_{121}=0.05, 0.08, 0.12, and 0.135.*