SUSY in the Light of B Physics and Electroweak Precision Observables

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Abstract. Indirect information about the possible scale of supersymmetry (SUSY) breaking can be obtained from the comparison of precisely measured observables (and also of exclusion limits) with accurate theory predictions incorporating SUSY loop corrections. Recent results are reviewed obtained from a combined analysis of the most sensitive electroweak precision observables (EWPO), M_W, $\sin^2\theta_{\rm eff}$, Γ_Z, $(g-2)_\mu$ and M_h, and B-physics observables (BPO), BR($b \to s\gamma$), BR($B_s \to \mu^+\mu^-$), BR($B_u \to \tau\nu_\tau$) and ΔM_{B_s}. Assuming that the lightest supersymmetric particle (LSP) provides the cold dark matter density preferred by WMAP and other cosmological data, χ^2 fits are performed to the parameters of the constrained minimal supersymmetric extension of the Standard Model (CMSSM), in which the SUSY-breaking parameters are universal at the GUT scale, and the non-universal Higgs model (NUHM), in which this constraint is relaxed for the soft SUSY-breaking contributions to the Higgs masses. Within the CMSSM indirect bounds on the mass of the lightest $\mathcal{CP}$-even Higgs boson are derived.

PACS. 12.60.Jv Supersymmetric models – 12.15.Lk Electroweak radiative corrections

1 Introduction

Phenomenological analyses of supersymmetry (SUSY) often make simplifying assumptions that drastically reduce the dimensionality of the parameter space of the minimal supersymmetric extension of the Standard Model (MSSM). One assumption that is frequently employed is that (at least some of) the soft SUSY-breaking parameters are universal at some high input scale, before renormalisation. One model based on this simplification is the constrained MSSM (CMSSM), in which all the soft SUSY-breaking scalar masses m_0 are assumed to be universal at the GUT scale, as are the soft SUSY-breaking gaugino masses $m_{1/2}$ and trilinear couplings A_0. The assumption that squarks and sleptons with the same gauge quantum numbers have the same masses is motivated by the absence of identified supersymmetric contributions to flavour-changing neutral interactions and rare decays. Universality between squarks and sleptons with different gauge interactions may be motivated by some GUT scenarios [1]. However, the universality of the soft SUSY-breaking contributions to the Higgs scalar masses is less motivated, and is relaxed in the non-universal Higgs model (NUHM) [2,3,4].

In Ref. [5] a combined χ^2 analysis has been performed of electroweak precision observables (EWPO), going beyond previous such analyses [6,7] (see also Ref. [8]), and of B-physics observables (BPO), including some that have not been included before in comprehensive analyses of the SUSY parameter space (see, however, Ref. [9]). The set of EWPO included in the analysis of Ref. [5] are the W boson mass M_W, the effective leptonic weak mixing angle $\sin^2\theta_{\rm eff}$, the total Z boson width Γ_Z (using for these three observables the recent theory predictions obtained in Refs. [10,11]), the anomalous magnetic moment of the muon $(g-2)_\mu$ (based on Refs. [12,13], see Ref. [14] for recent reviews), and the mass of the lightest MSSM Higgs boson M_h (obtained from the program `FeynHiggs` [15,16,17]). In addition, four BPO are included: the branching ratios BR($b \to s\gamma$) (based on the results of Ref. [18], incorporating also the latest SM corrections provided in Ref. [19]), BR($B_s \to \mu^+\mu^-$) (based on results from Ref. [20], which are in good agreement with Ref. [21]) and BR($B_u \to \tau\nu_\tau$) (based on Ref. [22]), and the B_s mass mixing parameter ΔM_{B_s} (based on Ref. [22]).

For the evaluation of the BPO minimal flavor violation (MFV) at the electroweak scale is assumed. Non-minimal flavor violation (NMFV) effects can be induced by RGE running from the high scale, see e.g. Ref. [23], that may amount to $\sim 10\%$ of the SUSY corrections. These additional contributions are neglected in the present analysis.

For each observable, the χ^2 function is constructed including both theoretical and experimental systematic uncertainties, as well as statistical errors [5]. The analysis is carried out in the CMSSM and the NUHM, taking into account the fact that the cold dark matter density is known from astrophysics and cosmology with an uncertainty smaller than 10 % [24], effectively reducing the dimensionality of the parameter space by one. The combined χ^2 function for the EWPO and the BPO is investigated in the CMSSM and the NUHM.

For the CMSSM furthermore indirect constraints on the lightest Higgs-boson mass, M_h, are discussed.

2 CMSSM analysis including EWPO and BPO

In Fig. 1 we show for the CMSSM the combined χ^2 values for the EWPO and BPO, computed as described in Ref. [5], for $\tan\beta = 10$ (upper panel) and $\tan\beta = 50$ (lower panel). We see that the global minimum of $\chi^2 \sim 4.5$ for both values of $\tan\beta$. This is quite a good fit for the number of experimental observables being fitted. There is a slight tension between the EWPO, which show a preference for small $m_{1/2}$, and the BPO, which do not exhibit this behaviour, see Ref. [5] for a more detailed discussion. For both values of $\tan\beta$, the focus-point region is disfavoured by comparison with the coannihilation region, though this effect is less important for $\tan\beta = 50$. For $\tan\beta = 10$, $m_{1/2} \sim 300$ GeV and $A_0 > 0$ are preferred, whereas, for $\tan\beta = 50$, $m_{1/2} \sim 600$ GeV is preferred, and there is a slight preference for $A_0 < 0$. This change-over is largely due to the impact of the LEP M_h constraint for $\tan\beta = 10$ and the $b \to s\gamma$ constraint for $\tan\beta = 50$.

In Fig. 2 we display the total χ^2 functions for M_h, as calculated in the CMSSM for $\tan\beta = 10$ (upper panel) and $\tan\beta = 50$ (lower panel) including the information from all EWPO and BPO, *except* from the direct Higgs search at LEP. This corresponds to the fitted value of M_h in the CMSSM. In the case of the SM, it is well known that tension between the lower limit on M_h from the LEP direct search and the relatively low value of M_h preferred by the EWPO has recently been increasing [25,26]. Fig. 2 shows that this tension is significantly reduced within the CMSSM, particularly for $\tan\beta = 50$. We see that all data (excluding M_h) favour a value of $M_h \sim 110$ GeV if $\tan\beta = 10$ and $M_h \sim 115$ GeV if $\tan\beta = 50$. On the other hand, the currently best-fit value for the SM Higgs boson of $M_H^{\rm SM}$ is 76 GeV [25], i.e. substantially below the SM LEP bound of 114.4 GeV [27]. Our results for the indirect constraints on M_h have meanwhile been confirmed by a more elaborate χ^2 fit where all CMSSM parameters and the constraint from the dark matter relic density are included in the fit [28].

In Ref. [5] we have also determined the total χ^2 functions for M_h based on the information from all EWPO and BPO, *including* the limit from the direct Higgs search at LEP. In this case the favoured M_h value for $\tan\beta = 10$ is increased by ~ 5 GeV, whereas the difference is only ~ 1 GeV if $\tan\beta = 50$.

3 NUHM analysis including EWPO and BPO

The NUHM has two more parameters in addition to those of the CMSSM. They characterise the degree of non-universality of the two Higgs mass parameters. After imposing the electroweak vacuum conditions the two parameters can be traded for M_A and μ. It has been pointed out in Refs. [5,29] that $m_{1/2}$ or μ can be varied such that (essentially) the whole $(M_A, \tan\beta)$ plane is compatible with the WMAP constraint on the dark matter relic density.

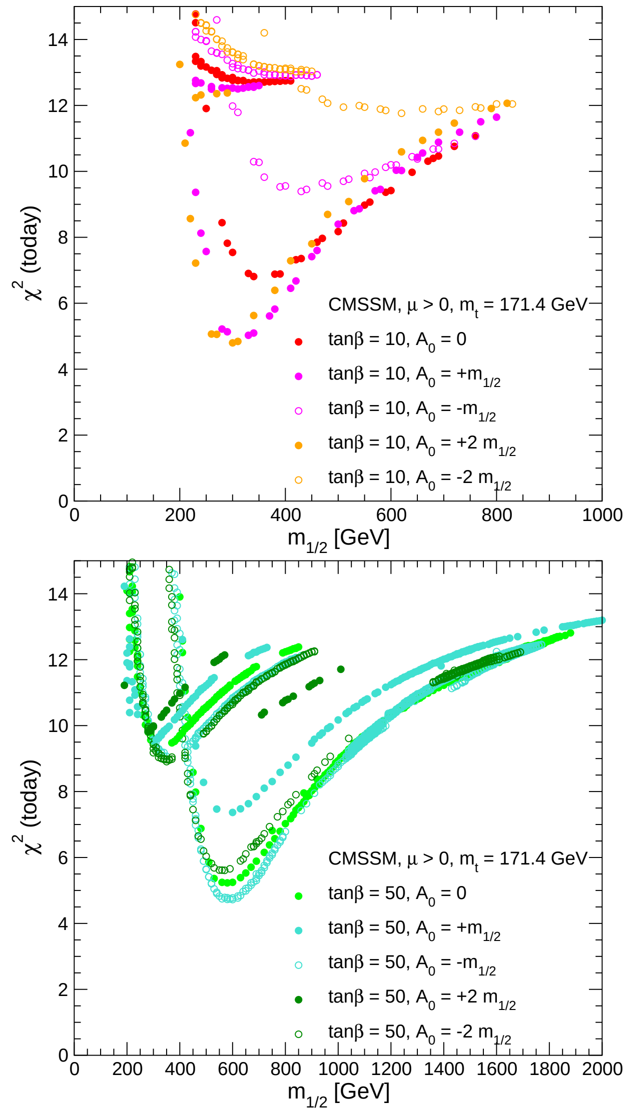

Fig. 1. The combined χ^2 function for the electroweak observables M_W, $\sin^2\theta_{\rm eff}$, Γ_Z, $(g-2)_\mu$, M_h, and the b physics observables BR$(b \to s\gamma)$, BR$(B_s \to \mu^+\mu^-)$, BR$(B_u \to \tau\nu_\tau)$ and ΔM_{B_s}, evaluated in the CMSSM for $\tan\beta = 10$ (upper plot) and $\tan\beta = 50$ (lower plot) for various discrete values of A_0. We use $m_t = 171.4 \pm 2.1$ GeV and $m_b(m_b) = 4.25 \pm 0.11$ GeV, and m_0 is chosen to yield the central value of the cold dark matter density indicated by WMAP and other observations for the central values of m_t and $m_b(m_b)$.

Fig. 3 shows the combined EWPO and BPO χ^2 function for a $(M_A, \tan\beta)$ plane in the NUHM (called plane **P1** in Refs. [5,29]) with $m_0 = 800$ GeV and $\mu = 1000$ GeV, where $m_{1/2}$ is chosen to vary across the plane so as to maintain the WMAP relationship with

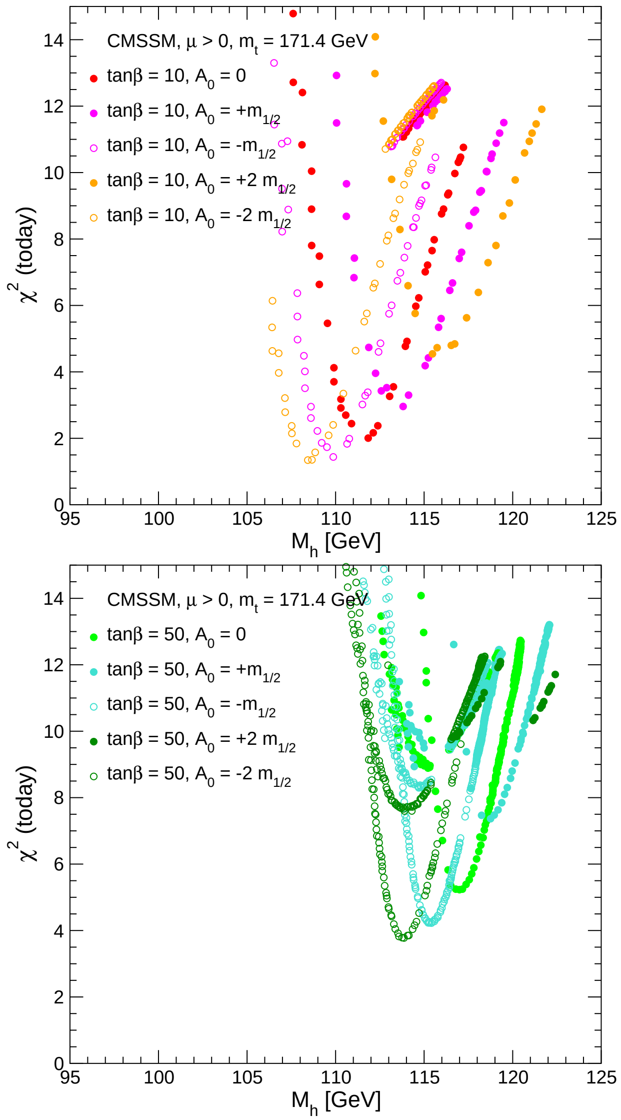

Fig. 2. The combined χ^2 function for M_h, as obtained from a combined analysis of all EWPO and BPO *except* the LEP Higgs search, as evaluated in the CMSSM for $\tan\beta = 10$ (upper plot) and $\tan\beta = 50$ (lower plot) for various discrete values of A_0. We use $m_t = 171.4 \pm 2.1$ GeV and $m_b(m_b) = 4.25 \pm 0.11$ GeV, and m_0 is chosen to yield the central value of the cold dark matter density indicated by WMAP and other observations for the central values of m_t and $m_b(m_b)$.

M_A:

$$\frac{9}{8} M_A - 12.5 \text{ GeV} \leq m_{1/2} \leq \frac{9}{8} M_A + 37.5 \text{ GeV}. \quad (1)$$

The best-fit point in this example has $M_A \sim 440$ GeV and $\tan\beta \sim 50$. It has $\chi^2 = 7.1$, which is slightly worse than the CMSSM fits in Fig. 1. We also display the $\Delta\chi^2 = 2.30$ and 4.61 contours, which would correspond to the 68 % and 95 % C.L. contours in the $(M_A, \tan\beta)$ plane *if* the overall likelihood distribution, $\mathcal{L} \propto e^{-\chi^2/2}$, was Gaussian. This is clearly only roughly the case in this analysis, but these contours nevertheless give interesting indications on the preferred region

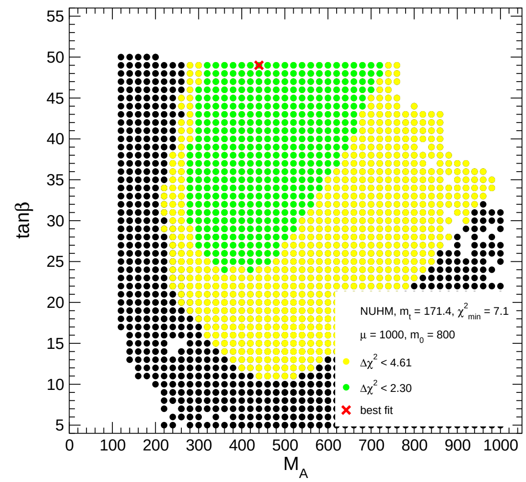

Fig. 3. The combined EWPO and BPO χ^2 function for a WMAP-compatible $(M_A, \tan\beta)$ plane in the NUHM (plane **P1** of Refs. [5, 29]). We use $m_t = 171.4 \pm 2.1$ GeV and $m_b(m_b) = 4.25 \pm 0.11$ GeV, and $m_{1/2}$ is adjusted continuously so as to yield the central value of the cold dark matter density indicated by WMAP and other observations for the central values of m_t and $m_b(m_b)$.

in the $(M_A, \tan\beta)$ plane. No results are shown in the upper right corner of the plane (with high M_A and high $\tan\beta$) because there the relic density is low compared to the preferred WMAP value. The lower left portion of the plane is missing because of the finite resolution of our scan.

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References

1. J. Ellis, S. Kelley and D. Nanopoulos, *Phys. Lett.* **B 260** (1991) 131;
   U. Amaldi, W. de Boer and H. Furstenau, *Phys. Lett.* **B 260** (1991) 447;
   C. Giunti, C. Kim and U. Lee, *Mod. Phys. Lett.* **A 6** (1991) 1745.
2. J. Ellis, K. Olive and Y. Santoso, *Phys. Lett.* **B 539** (2002) 107, hep-ph/0204192.
3. J. Ellis, T. Falk, K. Olive and Y. Santoso, *Nucl. Phys.* **B 652** (2003) 259, hep-ph/0210205.
4. V. Berezinsky, A. Bottino, J. Ellis, N. Fornengo, G. Mignola and S. Scopel, *Astropart. Phys.* **5** (1996) 1, hep-ph/9508249;
   M. Drees, M. Nojiri, D. Roy and Y. Yamada, *Phys. Rev.* **D 56** (1997) 276, [Erratum-ibid. **D 64** (1997) 039901], hep-ph/9701219;

M. Drees, Y. Kim, M. Nojiri, D. Toya, K. Hasuko and T. Kobayashi, *Phys. Rev.* **D 63** (2001) 035008, hep-ph/0007202;
P. Nath and R. Arnowitt, *Phys. Rev.* **D 56** (1997) 2820, hep-ph/9701301;
A. Bottino, F. Donato, N. Fornengo and S. Scopel, *Phys. Rev.* **D 63** (2001) 125003, hep-ph/0010203;
S. Profumo, *Phys. Rev.* **D 68** (2003) 015006, hep-ph/0304071;
D. Cerdeno and C. Munoz, *JHEP* **0410** (2004) 015, hep-ph/0405057;
H. Baer, A. Mustafayev, S. Profumo, A. Belyaev and X. Tata, *JHEP* **0507** (2005) 065, hep-ph/0504001.

5. J. Ellis, S. Heinemeyer, K.A. Olive, A.M. Weber and G. Weiglein, *JHEP* **0708** (2007) 083, arXiv:0706.0652 [hep-ph].
6. J. Ellis, S. Heinemeyer, K. Olive and G. Weiglein, *JHEP* **0502** (2005) 013, hep-ph/0411216.
7. J. Ellis, S. Heinemeyer, K. Olive and G. Weiglein, *JHEP* **0605** (2006) 005, hep-ph/0602220.
8. J. Ellis, K. Olive, Y. Santoso and V. Spanos, *Phys. Rev.* **D 69** (2004) 095004, hep-ph/0310356;
B. Allanach and C. Lester, *Phys. Rev.* **D 73** (2006) 015013, hep-ph/0507283;
B. Allanach, *Phys. Lett.* **B 635** (2006) 123, hep-ph/0601089;
R. de Austri, R. Trotta and L. Roszkowski, *JHEP* **0605** (2006) 002, hep-ph/0602028; *JHEP* **0704** (2007) 084, hep-ph/0611173; arXiv:0705.2012 [hep-ph];
B. Allanach, C. Lester and A. M. Weber, *JHEP* **0612** (2006) 065, hep-ph/0609295; arXiv:0705.0487 [hep-ph].
9. G. Isidori, F. Mescia, P. Paradisi and D. Temes, hep-ph/0703035;
M. Carena, A. Menon and C. Wagner, arXiv:0704.1143 [hep-ph].
10. S. Heinemeyer, W. Hollik, D. Stöckinger, A.M. Weber and G. Weiglein, *JHEP* **08** (2006) 052, hep-ph/0604147.
11. S. Heinemeyer, W. Hollik, A.M. Weber and G. Weiglein, arXiv:0710.2972 [hep-ph].
12. S. Heinemeyer, D. Stöckinger and G. Weiglein, *Nucl. Phys.* **B 690** (2004) 62, hep-ph/0312264.
13. S. Heinemeyer, D. Stöckinger and G. Weiglein, *Nucl. Phys.* **B 699** (2004) 103, hep-ph/0405255.
14. M. Passera, *Nucl. Phys. Proc. Suppl.* **155** (2006) 365, hep-ph/0509372;
D. Stöckinger, *J. Phys.* **G 34** (2007) R45, hep-ph/0609168;
J. Miller, E. de Rafael and B. Roberts, hep-ph/0703049;
F. Jegerlehner, hep-ph/0703125.
15. S. Heinemeyer, W. Hollik and G. Weiglein, *Comp. Phys. Commun.* **124** 2000 76, hep-ph/9812320. The code is accessible via `http://www.feynhiggs.de` .
16. S. Heinemeyer, W. Hollik and G. Weiglein, *Eur. Phys. J.* **C 9** (1999) 343, hep-ph/9812472.
17. M. Frank, T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, *JHEP* **02** (2007) 047, hep-ph/0611326;
S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, *Phys. Lett.* **B 652** (2007) 300, arXiv:0705.0746 [hep-ph].
18. P. Cho, M. Misiak and D. Wyler, *Phys. Rev.* **D 54**, 3329 (1996), hep-ph/9601360;
A. Kagan and M. Neubert, *Eur. Phys. J.* **C 7** (1999) 5, hep-ph/9805303;
A. Ali, E. Lunghi, C. Greub and G. Hiller, *Phys. Rev.* **D 66** (2002) 034002, hep-ph/0112300;
G. Hiller and F. Krüger, *Phys. Rev.* **D 69** (2004) 074020, hep-ph/0310219;
M. Carena, D. Garcia, U. Nierste and C. Wagner, *Phys. Lett.* **B 499** (2001) 141, hep-ph/0010003;
D. Demir and K. Olive, *Phys. Rev.* **D 65** (2002) 034007, hep-ph/0107329;
T. Hurth, hep-ph/0212304;
K. Adel and Y. Yao, *Phys. Rev.* **D 49** (1994) 4945, hep-ph/9308349;
C. Greub, T. Hurth and D. Wyler, *Phys. Lett.* **B 380** (1996) 385, hep-ph/9602281; *Phys. Rev.* **D 54** (1996) 3350, hep-ph/9603404;
K. Chetyrkin, M. Misiak and M. Münz, *Phys. Lett.* **B 400**, (1997) 206 [Erratum-ibid. **B 425** (1998) 414], hep-ph/9612313.
19. M. Misiak et al., *Phys. Rev. Lett.* **98** (2007) 022002, hep-ph/0609232.
20. K. Babu and C. Kolda, *Phys. Rev. Lett.* **84** (2000) 228, hep-ph/9909476;
S. Choudhury and N. Gaur, *Phys. Lett.* **B 451** (1999) 86, hep-ph/9810307;
C. Bobeth, T. Ewerth, F. Krüger and J. Urban, *Phys. Rev.* **D 64** (2001) 074014, hep-ph/0104284;
A. Dedes, H. Dreiner and U. Nierste, *Phys. Rev. Lett.* **87** (2001) 251804, hep-ph/0108037;
G. Isidori and A. Retico, *JHEP* **0111** (2001) 001, hep-ph/0110121;
A. Dedes and A. Pilaftsis, *Phys. Rev.* **D 67** (2003) 015012, hep-ph/0209306;
A. Buras, P. Chankowski, J. Rosiek and L. Slawianowska, *Nucl. Phys.* **B 659** (2003) 3, hep-ph/0210145;
A. Dedes, *Mod. Phys. Lett.* **A 18** (2003) 2627, hep-ph/0309233.
21. J. Ellis, K. Olive and V. Spanos, *Phys. Lett.* **B 624** (2005) 47, hep-ph/0504196.
22. G. Isidori and P. Paradisi, *Phys. Lett.* **B 639** (2006) 499, hep-ph/0605012.
23. G. Degrassi, P. Gambino and P. Slavich, *Phys. Lett.* **B 635** (2006) 335, hep-ph/0601135;
E. Lunghi, W. Porod and O. Vives, *Phys. Rev.* **D 74** (2006) 075003, hep-ph/0605177.
24. C. Bennett et al., *Astrophys. J. Suppl.* **148** (2003) 1, astro-ph/0302207;
D. Spergel et al. [WMAP Collaboration], Astrophys. J. Suppl. **148** (2003) 175, astro-ph/0302209;
D. Spergel et al. [WMAP Collaboration], astro-ph/0603449.
25. LEP Electroweak Working Group, see: `http://lepewwg.web.cern.ch/LEPEWWG/Welcome.html`.
26. Tevatron Electroweak Working Group, see `http://tevewwg.fnal.gov`.
27. LEP Higgs working group, *Phys. Lett.* **B 565** (2003) 61, hep-ex/0306033.
28. O. Buchmueller et al., arXiv:0707.3447 [hep-ph].
29. J. Ellis, T. Hahn, S. Heinemeyer, K.A. Olive and G. Weiglein, *JHEP* **0710** (2007) 092, arXiv:0709.0098 [hep-ph].