PLANKSUSY - new program for SUSY masses calculations: from Planck scale to our reality

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Abstract

We describe briefly new program for SUSY masses calculations. The main distinction of our program is that we start to solve the renormalization group equations for soft SUSY breaking parameters for SU(5) SUSY GUT model from Planck scale \( M_{PL} = 2.4 \cdot 10^{18} \) Gev. Our program works also for large \( \tan(\beta) \). We find that for \( m_0 \leq 0.5 \cdot m_{1/2} \) the effects of the evolution from Planck scale to GUT scale are very essential. In particular, we find that neutralino even for small \( m_0 \) is always LSP. We also introduced in our program some parameter of non-universality of the gaugino masses at GUT scale. Playing with the non-universality of the gaugino masses at GUT scale it is possible to have the situation when leptonic modes are suppressed and the single SUSY signature is hadronic jets with missing energy.

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Supersymmetric electroweak models offer the simplest solution of the gauge hierarchy problem [1]-[4]. In real life supersymmetry has to be broken and the masses of superparticles have to be lighter than \( O(1) \) TeV [4]. Supergravity gives natural explanation of the supersymmetry breaking, namely, an account of the supergravity breaking in hidden sector leads to soft supersymmetry breaking in observable sector [4]. For the supersymmetric extension of the Weinberg-Salam model soft supersymmetry breaking terms usually consist of the gaugino mass terms, squark and slepton mass terms with the same mass at GUT scale and trilinear soft scalar terms proportional to the superpotential [4].

In this paper we briefly describe our program ”PLANCKSUSY” for SUSY masses calculations (the program can be received by e mail: Vsevolod.Popov@cern.ch). As it has been mentioned in the abstract the main peculiarity of the program is that we can start not from GUT scale \( M_{GUT} \approx 2 \cdot 10^{16}\) Gev but also from Planck scale \( M_{PL} = 2.4 \cdot 10^{18} \) Gev. We assume that physics between Planck scale and GUT scale is described by standard supersymmetric SU(5) GUT model [4]. Of course, we don’t know for sure the physics between Planck and GUT scales so we consider SU(5) SUSY model as the simplest possibility to use it as a ”quasi-realistic” model to take into account the effects of the evolution between Planck and GUT scales. The standard assumption [4, 5] is to start from GUT scale and to impose universal mass relations for squark, slepton and Higgs soft masses and for gauginos at GUT scale

\[
m_{sq} = m_{sl} = m_H = m_0, \tag{1}
\]
\[
m_3 = m_2 = m_1 = m_1^2 \tag{2}
\]

However in standard approach soft SUSY breaking terms arise as a result of the supergravity breaking in hidden sector so it is more valid to impose universal boundary conditions not at GUT scale but at Planck scale. It should be noted that in superstring inspired models in general we expect non-universal boundary conditions for SUSY soft breaking terms [3]. To take into account possible effects from non-universal boundary conditions we introduced in our program some parameter of non-universality for gaugino masses at GUT scale. It should be noted that our program takes nonzero Yukawa couplings for
t-quark, b-quark and tau-lepton so we can use it for large values of \( \tan(\beta) \). Besides we can start both from Planck and GUT scales to compare the results of the calculations.

Our program can be divided roughly speaking into three parts. At first stage we solve numerically renormalization group equations for SUSY soft breaking parameters and coupling constants for SU(5) SUSY model between Planck and GUT scales. Here we use one loop RG equations of ref.[7]. At second stage we solve numerically RG equations for \( SU(3) \otimes SU(2) \otimes U(1) \) MSSM between \( M_{GUT} \) and \( M_{SUSY} \). We use two loop RG equations for couplings and gaugino masses and one loop RG equations for other soft SUSY breaking parameters \([8]\). From \( M_{SUSY} \) to \( m_t \) we use RG equations for standard WS model. At third stage we solve the equations for the determination of the electroweak minimum of the one loop effective potential to determine the absolute value of the \( \mu \) parameter and the Higgs boson masses. We also calculate mixing effects for neutralino, chargino and stops. We calculate the pole gaugino mass and other running sparticle masses \( m(m) \). The difference between running and pole masses for squarks and other sparticles is rather small. Here we use the formulae of refs.[9]-[11]. The input parameters of our program are the standard ones \( (m_0, m_\frac{1}{2}, \tan(\beta), sign(\mu), A, m_t) \). Our program can start both from Planck scale and GUT scale. We also introduced explicitly some parameter of the non-universality for gaugino masses at GUT scale. We use the following formula for gaugino mass matrix at GUT scale:

\[
m = m_\frac{1}{2} I + k\Phi,
\]

where \( I \) is the unit matrix and \( \Phi = \Phi_0 Diag(2, 2, 2, -3, -3) \) Parameter \( k \) determines the non-universality of gaugino masses at GUT scale. Our formulae for SU(3), SU(2) and U(1) gaugino masses can be written in the form

\[
m_3 = m_\frac{1}{2} (1 + 2\delta),
\]

\[
m_2 = m_\frac{1}{2} (1 - 3\delta),
\]

\[
m_1 = m_\frac{1}{2} (1 - \delta)
\]

Here \( \delta \) is some parameter of the gaugino mass non-universality.
Let us briefly consider first nontrivial physical consequences of our program. We have found that for $m_0 \geq 0.5 \cdot m_\frac{1}{2}$ both "Planck" and "GUT" spectra coincide up to 20 percent. For $m_0 \leq 0.5 \cdot m_\frac{1}{2}$ we find essential difference in slepton spectrum. The most interesting difference is that for small $m_0$ and $m_\frac{1}{2} \geq O(300)$ Gev the lightest superparticle in "GUT" model is charged right-handed tau slepton that contradicts to the experimental data on abundances of anomalous super-heavy isotopes and usually this region in $(m_0, m_\frac{1}{2})$ plane is considered to be "theoretically excluded". When we start from Planck scale the lightest superparticle in this region of $(m_0, m_\frac{1}{2})$ parameters is always neutralino so we don’t have at all "excluded" region. Moreover, it appears that it is general situation when we start not from GUT scale but from Planck scale (that is more "scientific"). Even if we work within $SU(3) \otimes SU(2) \otimes U(1)$ MSSM and impose boundary conditions at Planck scale we find that in this case also the lightest sparticle is neutralino. For instance, for $m_0 = 0, m_\frac{1}{2} = 500$ Gev, $A = 0, \text{sign}(\mu) = -$ we find that in "PLANCK"("GUT") model the masses are:

$$
\begin{align*}
    m(\tilde{g}) &= 1377(1278) \text{ Gev,} \\
    m(\tilde{d}_L) &= 1244(1120) \text{ Gev,} \\
    m(\tilde{b}_L) &= 1115(1019) \text{ Gev,} \\
    m(\tilde{t}_1) &= 918(841) \text{ Gev,} \\
    m(\tilde{\nu}_L) &= 471(348) \text{ Gev,} \\
    m(\tilde{e}_R) &= 475(353) \text{ Gev,} \\
    m(\tilde{\nu}_R) &= 471(348) \text{ Gev,} \\
    m(\tilde{\tau}_L) &= 364(196) \text{ Gev,} \\
    m(\tilde{\tau}_R) &= 441(401) \text{ Gev,} \\
    m(\chi_1^+) &= 441(401) \text{ Gev,} \\
    m(\chi_2^+) &= 993(890) \text{ Gev,} \\
    m(h) &= 108(106) \text{ Gev,} \\
    m(A) &= 1252(1098) \text{ Gev,} \\
    m(H^+) &= 1254(1101) \text{ Gev.}
\end{align*}
$$

We think that irrespective of validness of our concrete SU(5) model for the description of physics between Planck and GUT scales for small $m_0$ the effects of the evolution from Planck to GUT scales are very important. Note also that for "Planck" model we have
rather big splitting among the sleptons of the first two generations and the third one (in our program sparticle masses of the first and second generations coincide). Second lesson from our program is that for the case of strong violation of gaugino mass universality at GUT scale we can have the situation when the second neutralino and the first chargino being mainly SU(2) gaugino are heavier than the gluino. For instance, for \( m_0 = 800 \text{Gev} \), \( m_{\tilde{\chi}_2} = 200 \text{Gev} \), \( A = 0 \), \( \tan \beta = 2 \), \( \delta = -1 \), \( \text{sign}(\mu) = - \) in ”GUT” model gluino mass is \( m(\tilde{g}) = 599 \text{Gev} \), whereas the neutralino and chargino made basically from gaugino with small mixing of higgsino have the following masses:

\[
m(\chi_1^0) = 168 \text{Gev}, \quad m(\chi_2^0) = 664 \text{Gev}, \quad m(\chi_1^+) = 664 \text{Gev}.
\]

All squarks masses here are heavier than the gluino mass. It means that gluino can decay only to quark-antiquark and LSP so we shall not have multilepton signatures and the single SUSY signature at LHC and TEVATRON will be multijets with missing \( E_T \). Moreover for the case of the model with R-parity violation of the \( uds \) type LSP will decay into two quarks that makes the observation of such particular scenario very difficult at LHC.

**A brief overview of the code**

A code is written on FORTRAN 77; we might not be keeping to all the standards, but at least, it runs OK under UNIX on CERN clusters. Double precision is used throughout all the calculations. Systems of algebraic and differential equations are solved by calls to CERNLIB subroutine DSNLEQ and DDEQMR. For neutralino matrix eigenvalues subroutine RSM is used (taken from [14]). Some checks are performed during the calculations, so for some “bad” initial values, the code skips further calculations at certain moment and returns with non-zero error flag (see below). Still, no checks on any physical meaning is made, so it is up to user to analyse output masses and error flag. Essentially procedure consists of solving the systems of differential equations with some of the variables \((h_t, h_\tau)\) being fixed in fact at the final scale. To find their values at the starting scale (\( M_{GUT} \) or \( M_{Planck} \)) we start with the solving the system of equations, decoupled
indeed for most (but not for all!) reasonable input parameters:

\[ h_t(x) \big|_{\text{electroweak scale}} = "fixed" h_t, \]

\[ h_\tau(y) \big|_{\text{electroweak scale}} = "fixed" h_\tau \]

in respect to \( x, y \) (values of \( h_t, h_\tau \) at starting scale). Their values at electroweak scale are fixed by the values of \( m_t, m_\tau, \alpha_s \). In the process of solution, we find also the scale, taken as \( \sqrt{m(\tilde{t}_1)m(\tilde{t}_2)} \) to change from two- to one-loop RG equations. To get the values of \( m(\tilde{t}_1), m(\tilde{t}_2) \) we solve the equation to find electroweak minimum \( \mu \). The rest of program flow is rather trivial arithmetics except for masses “tuning” (their values are taken not at common scale but each one is calculated at the scale equal to this very mass). It requires again the solution of equation for the value of the mass, now with the final scale taken as variable.

Masses calculation is performed by the call to steering subroutine SUSYM with the calling sequence:

```fortran
    call susym
    $(iway,AM0,AM_HALF,A_t,tanb,AMT,csign_mu,isec,dnu,idebug,
    $amass,ierr)
```

User must declare

```fortran
    integer iway(3)
    real amass(42)
    character*1 csign_mu
```

Input parameters:

- \( iway(1) = 1 \) : to run from Planck to weak scale
- \( iway(1) = 2 \) : from GUT to weak scale
- \( iway(2) = 1 \) : normal run (all calculations of all the masses)
- \( iway(2) = 2 \) : Stop after \( h_t, h_b \) tuning. Useful in looking for possible pairs of \((\tan(\beta), M_t)\)
– iway(3) is not used for now

• AM0 : $M_0$ at initial scale (real)

• AM\_HALF : $M_{1/2}$ at initial scale (real)

• $A_t$ : $A_t$(real)

• tanb : $tan(\beta)$ (real)

• AMT : $M_t$, mass of top-quark (real)

• isec : second loop coefficient (integer); set it normally to 1

• dnu : non-universality coefficient (real)

• idebug : produce some output if $> 0$ (integer)

Output parameters :

• array amass : values/masses at the weak scale

  1. $g_1^2$

  2. $g_2^2$

  3. $g_3^2$

  4. $M_{1/2}(1)$

  5. $M_{1/2}(2)$

  6. $M_{1/2}(3)$

  7. $h_t$

  8. $h_b$

  9. $h_x$

  10. $A_t$

  11. $A_b$
12. $A_{\tau}$
13. $\tilde{U}_l$
14. $\tilde{D}_l$
15. $\tilde{U}_r$
16. $\tilde{D}_r$
17. $\tilde{v}_l$
18. $\tilde{e}_l$
19. $\tilde{e}_r$
20. $\tilde{B}_l$
21. $\tilde{T}_l$
22. $\tilde{B}_r$
23. $\tilde{T}_r$
24. $\tilde{\nu}_{\tau_l}$
25. $\tilde{\tau}_l$
26. $\tilde{\tau}_r$
27. $\mu$
28. $\tilde{T}_1$
29. $\tilde{T}_2$
30. $\tilde{H}_1$
31. $\tilde{H}_2$
32. $\chi^0_1$
33. $\chi^0_2$
34. $\chi^0_3$
35. $\chi^0_4$
36. $\chi_1^+$  
37. $\chi_2^+$  
38. $\tilde{H}_{\text{axial}}$  
39. $\tilde{H}_{\text{charged}}$  
40. $\tilde{H}_{\text{light}}$  
41. $\tilde{H}_{\text{heavy}}$  
42. Gluino

- ierr =  
  - 0 OK  
  - 1 error in input parameters  
  - 10 bad fitting of $h_t, h_b$  
  - 100 negative $m^2$ for some of sparticles  
  - 1000 first approximation for $\mu^2$ is negative  
  - 2000 low and high limits for $\mu^2$ are 0. both  
  - 3000 no good solution for $\mu$ found  
  - 10000 failed to find eigenvalues for neutralinos  
  - 100000 failed to find eigenvalues for charginos

To conclude, we have written "PLANCKSUSY" program for SUSY masses calculations. The main peculiarity of our program for instance in comparison with ISASUSY program is that we can start from both Planck and GUT scales. We also introduced the non-universality parameter for gaugino masses. It appears that for very interesting region in the parameter space when $m_0$ is much smaller than $m_{\tilde{\chi}^0_1}$ if we start from the Planck scale we find that in this region the LSP is always neutralino unlike to the case when we start from GUT scale and LSP is the right-handed tau-slepton. For the case when we have strong deviation from gaugino mass universality it is possible to realize
the situation when the second neutralino and the first chargino are heavier than gluino. For such scenario lepton signatures for SUSY search at LHC and TEVATRON are absent and the single SUSY signature are multijet events with missing $E_T$. Moreover, for the models with R-parity violation of $uds$ type we shall have only jet events in final states that makes SUSY discovery for such scenario rather difficult. The program can be received by e-mail: Vsevolod.Popov@cern.ch

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