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B physics and collider physics: Working group report

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As will be clear from the following report, the three main areas that came under investigation in the working group on *B*-physics and collider physics are (a) searches for supersymmetric particles, (b) phenomena related to *B*-factories, and (c) the interaction and utilization of electroweak gauge bosons in colliders. Several studies were initiated in different sub-areas coming under the above themes. Some of the studies have already yielded results that are worthy of reporting; others are still at various stages of completion.

The following topics were identified for further research (the names of the participating working group members are given in parentheses)

1. Consequences of non-universal scalar masses in SUSY (Amitava Datta, Aseshkrishna Datta, M Drees and D P Roy)
2. Determination of V_{ub} from semi-inclusive hadronic decays (R Aleksan, Amitava Datta, A Kundu and B Mukhopadhyaya)
3. Long-distance contributions to double-radiative *B*-decays (N G Deshpande and A Kundu)
4. Closing the window in gauge mediated supersymmetry breaking with a nuetrolino NLSP (K Agashe and D Ghosh)
5. Isospin analysis in *B*-decays (R Aleksan, N G Deshpande and A Dighe)
6. Gauge boson scattering in hadronic colliders (Gour Bhattacharya and Anindya Datta)
7. Distinguishing gauge-mediated SUSY breaking signals from SUGRA-type fakes at LEP (Anindya Datta and Sreerup Raychaudhuri)
8. Probing *R*-parity violation in $e-\gamma$ colliders (F Boudjema and A Ghosal)

Brief reports on some of these projects have been received. They are reproduced here.

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1. Consequences of nonuniversal scalar masses for SUSY searches

Amitava Datta, Aseshkrishna Datta, Manuel Drees and D P Roy

It has been known for quite some time that if the rank of a GUT group or some intermediate symmetry group is reduced by spontaneous symmetry breaking, one may obtain D-term contributions leading to nonuniversal squark and slepton masses at a high scale [1, 2]. This may change the predictions of the conventional scenario, based on the assumption of universal sfermion masses at the GUT scale, for the low energy sparticle spectrum and, consequently, SUSY search strategies [3, 4].

In particular it was emphasized in [4] that the R-type ($SU(2)$ singlet) down squarks $\tilde{D}_R$ may be considerably lighter than the L-type squark doublets $\tilde{q}_L$ and the R-type up singlets $\tilde{U}_R$ due to the above D terms. Examples of specific models in which this happens are $SO(10)$ SUSY GUTs breaking down to the standard model gauge group directly or via the Pati–Salam group at an intermediate scale [2]. If this is the case, then the branching ratio of direct gluino decays into the Bino-like lightest super symmetric particle (LSP) mediated by R-type squarks is enhanced relative to the cascade decays leading to signatures different from those expected in scenarios where all sfermions degenerate at the GUT scale.

In this work we focuss on a specific scenario $m_{\tilde{q}_L}, m_{\tilde{U}_R} > m_{\tilde{g}} > m_{\tilde{D}_R}$, which was only briefly commented upon in [4]. Our main goal is to compare and contrast the SUSY signals predicted by this scenario with the predictions of the conventional scenario, which usually assumes that there are ten degenerate squarks of L and R-type excluding the stop.

As an example we generate the mass spectrum with the following choices of parameters (all mass parameters are in GeV): $m_0 = 175$, $m_{\tilde{g}} = 225$, $D = 0.4 m_0^2$, $\mu = -300$, $A = 0$ and $\tan\beta = 2$. Here D is the unknown coefficient in the D-term contributions to sfermion masses, which breaks universality (see eqs (4.2)–(4.6) or (4.9)–(4.13) of [2]). For all other parameters we have followed the conventional notation. The resulting squark masses are:

$$m_{\tilde{q}_L} = 275(263.5)(q = u, d, s, c), m_{\tilde{U}_R} = 271.4(260)(U = u, c), m_{\tilde{b}_L} = 235(221),$$
$$\text{and} \quad m_{\tilde{D}_R} = 221.6(260)(D = d, s, b).$$

The numbers in parentheses correspond to the universal case ($D = 0$). Note that the mass of $\tilde{b}_L$ is much suppressed compared to the other L-type squark masses because of the contribution of the top quark Yukawa coupling to the RGE for $m_{\tilde{b}_L}$.

Some distinctive features of the gluino production signal follow immediately. Gluinos will decay directly into $\tilde{D}_R$s with nearly 100% BR since this is the only allowed strong 2-body decay. The $\tilde{D}_R$s in turn will mostly decay directly into the LSP (which is Bino-like). The production of gluinos, U_R and D_R type squarks will lead to signals with very little cascade decay and to a missing energy spectrum harder than that expected in the universal scenario. The production of L-type squarks can of course lead to cascades. However, except for the $\tilde{b}_L$ the other L-type squarks will be produced with smaller cross sections because of their larger masses. Thus the signal is indeed expected to be quite different than the conventional one. The computation of SUSY signals in this scenario is in progress and will be presented elsewhere.

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2. Probing tau sneutrino NLSP scenario in gauge mediated supersymmetry breaking models at LEP-2

Dilip Kumar Ghosh and K Agashe

The mass spectrum of the scalar fermions and gauginos in the gauge mediated supersymmetry breaking model (GMSB) [1, 2] are determined by four input parameters, viz. M, the messenger mass scale, Λ, the ratio of the VEV's of the auxiliary and scalar components of superfield S in the messenger sector, μ (the Higgsino mass parameter) and $\tan\beta$ (the ratio of the VEV's of two neutral components of the Higgs doublet). Recently it has been suggested in ref. [3] that one can construct model with the number of messenger generation $N_m = 3$ or 4 which has a tau sneutrino as a next to lightest supersymmetric particle (NLSP) with following heirarchy in the scalar fermion spectrum:

$$m_{\tilde{\nu}_\tau} < 54\,\text{GeV}; \quad m_{\tilde{e}_R} < 57\,\text{GeV}; \quad m_{\tilde{e}_L} < 95\,\text{GeV}. \tag{1}$$

In table 1, we show for $N_m = 3$, 4, the mass spectrum in this scenario, for some representative values of μ and $\tan\beta$. We varied μ from -700 to 700 GeV and $\tan\beta$ from 2 to 10. This mass hierarchy is valid for a very narrow range of Λ, from 11.5 TeV to 13.5 TeV for $N_m = 3$ and 10 TeV to 11.5 TeV for $N_m = 4$.

The above mentioned mass hierarchy can give rise to interesting signals which can be observed in slepton pair production at e^+e^- collider LEP-2.

In this note we begin our study with the pair production of left and right selectron through the process $e^+e^- \to \tilde{e}_L^\pm + \tilde{e}_R^\mp$ at centre-of-mass energies $\sqrt{s} = 172$ and 183 GeV assuming the left and right selectron masses $m_{\tilde{e}_L}$ and $m_{\tilde{e}_R}$ respectively satisfy equation (1). The production mechanism occurs via t-channel $\tilde{\chi}_i^0$ $(i = 1, 2, 3, 4)$ exchange. The produced scalar electrons decay into an electron and lightest neutralino, which is kinematically favoured, $\tilde{e}_{L,R}^\pm \to e^\pm + \tilde{\chi}_1^0$ inside the detector. The left selectron can also

Table 1. Particle spectrum for $N_m = 3, 4$ in GMSB model. The numbers shown in the parenthesis corresponds to $N_m = 4$.

Λ (TeV)	μ (GeV)	$\tan\beta$	$m_{\tilde{e}_L}$ (GeV)	$m_{\tilde{e}_R}$(GeV)	$m_{\tilde{\nu}_\tau}$ (GeV)	$m\tilde{\chi}_1^0$ (GeV)
11.5(10)	−700(−700)	2(2)	77.21(77.43)	47.22(47.20)	46.15(46.51)	50.96(58.82)
12.5(11)	348(200)	3(3)	85.05(86.05)	53.04(53.31)	46.10(47.91)	47.87(48.35)
13(11.5)	−500(−500)	4(6)	88.64(90.80)	55.47(56.98)	47.13(46.95)	56.96(66.41)

Table 2. The $\tilde{e}_L^{\pm}\tilde{e}_L^{\mp}$ (first row) and $\tilde{e}_L^{\pm}\tilde{e}_R^{\mp}$ (second row) pair production cross-section (pb) with cuts (mentioned in the text) for centre-of-mass energies $\sqrt{s} = 172$ and 183 GeV. The numbers in the parenthesis are for $\sqrt{s} = 183$ GeV. The higgsino mass parameter μ, $\tilde{e}_L$, $\tilde{e}_R$ and $\tilde{\nu}_\tau$ masses are in unit of GeV. $[e^{\pm}]$ denotes the soft electron.

N_m	Λ (TeV)	μ	$\tan\beta$	$m_{\tilde{e}_L}$	$m_{\tilde{e}_R}$	$m_{\tilde{\nu}_\tau}$	Final state	σ
3	11.5 (12.5)	−575 (300)	2 (3)	77 (85)	47 (53)	46 (46)	$e^{\pm}e^{\mp} + \not{E}$	0.18 (0.12)
4	11 (11.5)	−500 (625)	3 (6)	86 (90)	53 (57)	48 (47)	$e^{\pm}[e^{\mp}] + \not{E}$	0.82 (0.76)

decay into a neutrino and chargino, hence, we must take into account the reduction in the branching ratio to electron and neutralino final state, on the other hand the corresponding right handed selectron has 100% branching ratio into this channel. Each of these lightest neutralinos then undergo the following two body decay $\tilde{\chi}_1^0 \to \tilde{\nu}_\tau \nu_\tau$. However, in some region of parameter space, one can have $m_{\tilde{\chi}_1^0} > m_{\tilde{\ell}_R}$, then $\tilde{e}_R$ undergo three-body decay into $e^{\pm}\tilde{\nu}_\tau\nu_\tau$ via virtual $\tilde{\chi}_1^0$. Finally the NLSP $\tilde{\nu}_\tau$ decays into a tau neutrino and a gravitino, which is the LSP in GMSB model. Hence, the final state contains $e^{\pm}e^{\mp}$, and large missing energy $\not{E}$ carried away by neutrino and gravitino. The masses of $\tilde{e}_R$ and $\tilde{\chi}_1^0$ are nearly degenerate, which implies that the energy of the electron which comes from the decay of $\tilde{e}_R$ is below the threshold energy required to identify an electron at the electron calorimeter. The remaining electron passes through the following minimum identification requirements.

$$E_\ell > 2\,\text{GeV}; \quad P_T(\ell) > 2\,\text{GeV}; \quad |\eta_\ell| > 3. \tag{2}$$

We also demand that the missing energy ($\not{E}$) > 15 GeV.

Next we consider the pair production of left selectron through the process $e^+e^- \to \tilde{e}_L^{\pm} + \tilde{e}_L^{\mp}$ which occurs via s-channel γ, Z^0 exchange or t-channel $\tilde{\chi}_i^0$ exchange. The produced selectrons then decay into either lighter chargino and a neutrino or into a neutralino and electron. We do not consider the neutrino and chargino final states in this note. We take into account the reduction in the branching ratio to electron and neutralino final state. We only consider here the decay of left selectron into an electron and lightest neutralino which is kinematically possible. Once the neutralinos are produced, they decay as before, giving rise to two electrons and missing energy. In this case both the electrons are hard enough to be observed at the electron calorimeter. As before we demand that both the electrons should satisfy the minimum identification criteria eq. (2). In table 2, we show the cross-sections for two hard electron plus missing energy arising from $\tilde{e}_L^{\pm}\tilde{e}_L^{\mp}$ pair production and one hard and soft electron plus missing energy from $\tilde{e}_L^{\pm}\tilde{e}_R^{\mp}$ pair production. For illustration we choose some representative points in the GMSB parameter space where the production cross-section is large.

One can see from the last column of table 2 that the cross-sections for these events are large enough to be observed in the data sample collected at $\sqrt{s} = 172\,\text{GeV}$ and $\sqrt{s} = 183\,\text{GeV}$ with 10.2 pb^{-1} and 57.1 pb^{-1} integrated luminosities respectively. Hence, a detailed study at LEP-2 can either establish or rule out this particular mass hierarchy in a GMSB model.

Acknowledgements

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3. γW Luminosity at the large hadron collider

Gour Bhattacharya and Anindya Datta

There has been a revival of interest in photon induced processes at hadron colliders. One of us had previously investigated [1] heavy charged lepton pair production via $\gamma\gamma$ and $Z\gamma$ fusion at the proposed CERN large hadron collider (LHC). We had also presented $\gamma\gamma$ and $Z\gamma$ differential luminosities at the LHC. Here we extend these previous work to present γW differential luminosities for inelastic and semi-elastic pp collisions at the LHC. For inelastic pp scattering, a proton may be regarded essentially as a collection of freely travelling elementary constituent partons. We have used the effective photon or Weizsäcker–Williams approximation (WWA) [2] to calculate the photon spectrum from quarks for inelastic pp collisions. For the inelastic case, the luminosity depends upon the threshold energy of the production process, i.e. the masses of the final state particles. Here we will assume that γW fusion produces a heavy charged lepton L, and its associated heavy neutrino, N. We will present the inelastic luminosity results assuming $m_N = m_L = 200\,\mathrm{GeV}$. Within WWA, the photon spectrum, $f^{\mathrm{inel}}_{\gamma/q}(x)$, from a quark (of charge e_q) is given by

$$f^{\mathrm{inel}}_{\gamma/q}(x) = \frac{e_q^2}{8\pi^2}\,\frac{1+(1-x)^2}{x}\log\frac{t_{\max}}{t_{\min}}, \tag{1}$$

where x is the fraction of quark energy carried off by the photon, and $t_{\max}$ and $t_{\min}$ are the characteristic maximum and minimum photon momentum transfers. Here we have taken $t_{\max} = (\hat{s} - (m_N + m_L)^2)/4$, and $t_{\min} = 1\,\mathrm{GeV}^2$, with $\sqrt{\hat{s}}$ being the center-of-mass energy in the parton frame. The choice of $t_{\min}$ ensures that the photons are obtained from the deep inelastic scattering of protons, when the quark-parton model is valid.

For inelastic pp scattering, the incident protons ceases to exist and the constituents hadronize. For semi-elastic scattering, one of the incident protons remains intact. Using the following parametrizations of the electric and magnetic form factors of the proton,

$$G_E(t) = (1 - t/0.71\,\mathrm{GeV}^2)^{-2}, \quad G_M(t) = 2.79 G_E(t). \tag{2}$$

Kniehl has obtained a closed analytical expression [3] for $f^{\mathrm{el}}_{\gamma/p}$, the photon spectrum from protons for the elastic case, in a modified WWA. We have used this in our calculation.

For multi-TeV hadron interactions, one can also consider the vector bosons as constituents of protons. Effective vector boson approximations have been developed in analogy with WWA, which considerably simplify calculations involving gauge bosons. However unlike photons, a massive gauge boson has two transverse and one longitudinal polarizations, and the effective W and Z approximations give the spectra of longitudinally and transversely polarized W's and Z's from quarks in the proton. In the original formulation of the effective W approximation. Dawson [4] presents the distribution function of W

bosons in quarks, both in the leading logarithmic (LL) approximation, and also gives the non-leading order corrections upto $\mathcal{O}(M_W^2/E_q^2)$, where E_q is the quark energy. In our calculations of the inelastic and semi-elastic γW luminosities we have used the non-leading order W distributions.

The γW differential luminosity for inelastic pp collisions is given by

$$\left.\frac{\mathrm{d}L^{\text{inel}}}{\mathrm{d}\tau}\right|_{\gamma W/pp} = \sum_{i,j} \int_\tau^1 \frac{\mathrm{d}\tau'}{\tau'} \int_{\tau'}^1 \frac{\mathrm{d}x}{x} f_{q_i/p}(x) f_{q_j/p}(\tau'/x) \left.\frac{\mathrm{d}L}{\mathrm{d}\xi}\right|_{\gamma W/q_i q_j}, \tag{3}$$

where $\xi = \tau/\tau'$ and

$$\left.\frac{\mathrm{d}L}{\mathrm{d}\xi}\right|_{\gamma W/q_i q_j} = \int_\xi^1 \frac{\mathrm{d}x}{x} f_{W/q_i}(x) f_{\gamma/q_j}(\xi/x). \tag{4}$$

In the above expression, $f_{q/p}$ represents the quark structure functions of the proton, which we have chosen to be the Martin–Roberts–Stirling (MRS) (set A) structure functions [5], and $f_{W/q}$ represents the Dawson distribution function of W bosons from quarks. The γW differential luminosity for semi-elastic pp collisions is given by

$$\left.\frac{\mathrm{d}L^{\text{semi}}}{\mathrm{d}\tau}\right|_{\gamma W/pp} = 2 \int_{\tau/x_{\max}}^{x_{\max}} \frac{\mathrm{d}x}{x} f^{\text{el}}_{\gamma/p}(x) f^{\text{inel}}_{W/p}(\tau/x), \tag{5}$$

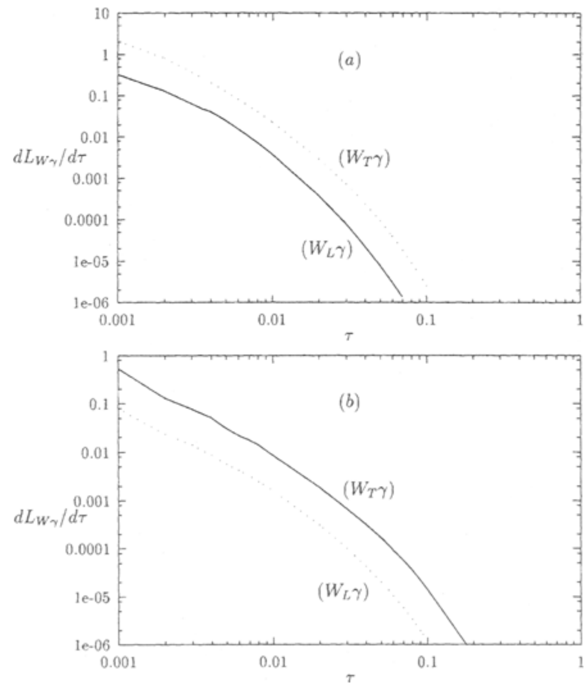

Figure 1. The differential γW luminosity for (**a**) inelastic and (**b**) semi-elastic pp collision at the LHC.

where

$$f_{W/p}^{\,\text{inel}} = \sum_i \int_{x_{\min}}^{1} \frac{dx'}{x'} f_{q_i/p}(x') f_{W/q_i}(x/x'), \tag{6}$$

where $x_{\max} = (1 - 2m_p/\sqrt{s})$ is an upper limit of integration given by kinematical considerations, m_p being the proton mass and $\sqrt{s} = 14\,\text{TeV}$ is the center-of-mass energy of the colliding protons at the LHC. $x_{\min}$ is a lower limit of integration consistent with the quark-parton model.

In figure 1, we show the differential γW luminosity for inelastic (a) and semi-elastic (b) pp collisions at the LHC. The solid lines represent the $W_{L\gamma}$ luminosity, corresponding to the longitudinal polarization of the W, and the dashed lines show the differential luminosity for $W_{T\gamma}$, coresponding to an average over the two transverse polarizations of W. As expected, the γW luminosities are larger than the γZ luminosities. For the inelastic case, the γW differential luminosities are larger than those for γZ by approximately a factor of 1.3 over the entire range of τ for which we present the results. For the semi-elastic case, the γW differential luminosities are larger than γZ by approximately a factor of 2.3 over the range of τ shown. The $W_{T\gamma}$ differential luminosities are larger than those for $W_{L\gamma}$ by approximately an order of magnitude, over the range of τ shown, for both the inelastic and semi-elastic cases. For $\tau \approx 10^{-3}$, the inelastic γW differential luminosities (for both the longitudinal and transverse cases) are approximately a factor of 5 larger than the corresponding semi-elastic luminosities, while for $\tau \geq 3 \times 10^{-2}$, the semi-elastic luminosities are larger than the inelastic luminosities.

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4. Determination of V_{ub} from charmless nonleptonic B-decays

Roy Aleksan, Amitava Datta, Anirban Kundu and Biswarup Mukhopadhyaya

Determination of the Kobayashi–Maskawa (KM) element V_{ub} is important to test the unitarity of the KM matrix as well as the standard paradigm for quark mixing and CP-violation. At present, there are three suggested ways to determine this element, and all of them use the semileptonic decay modes of the B-meson [1]. The first is to see the lepton excess below the charm threshold (coming from the decay $b \to u\ell\nu$) where the hadronic final states are supposed to be dominated by π or ρ. One has to depend on phenomenological models [2] to determine quantities which are not directly measurable (like the momentum distribution of the b quark inside the B hadron). However, this model dependence is not so severe. In fact, the major obstacles in this method are the extremely small branching fraction to the charmless semileptonic modes, *a priori* assumptions about the nature and composition of the final hadronic states and the absence of a reliable way to extrapolate the leptonic yield below the charm threshold into the soft-lepton limit, where leptons coming from $b \to c$ decay also contribute, and are overwhelming [3].

The second method requires the measurement of the invariant mass and moments of the final charmless states [4]. Though the statistics is better in this case, the hadronic state has a broad invariant mass distribution. In particular this spectrum has a tail toward invariant masses above the charm threshold. The calculation of the shape of this spectrum suffers from theoretical uncertainties leading to significant errors in the determination of V_{ub} if the experimental cut on the invariant mass cannot exceed, say, the order of 1.5 GeV.

The third method [5] involves the exclusive semileptonic modes such as $\ell\nu\pi$ or $\ell\nu\rho$. The main problem here comes from the poor knowledge that one has on the heavy-to-light form factors. This leads to a determination of V_{ub} which is model dependent.

We plan to use the nonleptonic two-body modes to determine V_{ub}. One of the most crucial points to test is the local duality [6] in such decays, since one has to work in a region where the operator product expansion (OPE) breaks down due to singular terms in the matrix element, and smearing over a certain duality interval is necessary.

The best way to check local parton–hadron duality is to use the charmed modes to determine V_{cb} and see whether it comes out as expected. We concentrate on the semi-inclusive decay modes $B \to D_s X_c$ and $B \to D_s^* X_c$, where X_c represents all possible hadronic states that contains the charm quark coming from the decay of b.

As we know the hadron mass and not the quark mass, we are forced to introduce two unknown quantities – called Λ and λ_1 [7] – for this trading-in. Λ is essentially a measure of the light degrees of freedom and is of the same order (but not the same) to $\Lambda_{\rm QCD}$. The other parameter λ_1 measures the effect of the b-quark kinetic energy inside the B meson, and is *a priori* unknown. Thus, the total decay width to the charmed modes can be expressed in terms of these two unknown parameters.

To determine them, we propose to take the first and second spectral moments $\langle s - m_D^2\rangle$ and $\langle s - m_D^2\rangle^2$, where

$$s = (p_B - q)^2 \tag{1}$$

with $q^2 = m^2_{D_s^{(*)}}$, and p_B is the four-momentum of the B-meson. The spectral moments are defined by

$$\langle s_0 - m_c^2\rangle^n = \frac{1}{\Gamma_0}\int (s_0 - m_c^2)^n \,\frac{\mathrm{d}\Gamma}{\mathrm{d}s_0}\,\mathrm{d}s_0, \tag{2}$$

where s_0 is the parton level analogue of s (they are related), and Γ_0 is the parton-level decay width of the b $(= G_F^2 m_b^5/192\pi^3)$.

Two such moments can be extracted from the CLEO data, and one can check whether V_{cb} comes in the expected region. If it does, then

(i) the assumption of local duality is not totally absurd;
(ii) the higher order QCD corrections (α_s^2 and beyond) are not that significant.

Our ultimate plan is to find Λ and λ_1 from the moments and use them to the total deacy width for $b \to u$ nonleptonic decays to find V_{ub}. The obvious caveats are:

(i) we are using the same set of parameters Λ and λ_1 for B and D mesons, which may be a reasonable assumption but is not necessarily true;
(ii) the decay constant f_{D_s} is not very accurately determined;
(iii) for massless quarks in the final state the OPE breakdown may be more severe as the two singularities in the s_0 plane merge together.

Still, with a large data sample from the future experiments (BABAR, BELLE, ATLAS, CMS, LHC-b, HERA B) one expects to reduce the experimental uncertainties to a minimum and find useful theoretical constraints on the approach used.

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5. Probing R-parity violating processes in an electron–photon collider

Fawzi Boudjema and Ambar Ghosal

We investigate R-parity violating processes in the context of an electron–photon collider at $\sqrt{s} = 500\,\mathrm{GeV}$–1000 GeV. Utilizing the opportunity of polarized electron and photon beams, it is interesting to study the signal of some R-parity violating processes, particularly, the processes: $e^-\gamma \to \tilde{t}d$, $b\tilde{t}$, arising due to the presence of λ' coupling in the R-parity violating part of the Lagrangian $L = \lambda'_{ijk}(\tilde{d}^k_R)^*(\bar{e}^i_L)^c u^j_L +$ h.c., followed by the decay of $t, \tilde{t}, \tilde{d}$. Various stop ($\tilde{t}$), top (t) and $\tilde{d}$ decay modes have to be studied together with b-tagging. We have also considered right-polarized electron beam in order to remove W induced backgrounds. Furthermore, the cross-sections of these processes also depend crucially on the polarization of the photon beam. The work is under progress.