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Answers to the Parameter Group

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Introductory remarks

This note tries to answer the questions posed to us by the Parameter Group of the ILCSC. It summarises the current status of our understanding. Some of the studies have been performed a few years ago for TESLA parameters, others are more recent but still subject to ongoing discussions. Updates of some of these studies according to the most recent design of the interaction regions are planned, but not yet available.

Although today we don't know anything about a possible realisation of SUSY in nature, we can get estimates for different typical cases. The scenarios discussed in this document are two examples of complementary requirements. While for the $\tilde{\tau}$-coannihilation scenario the effect of beamstrahlung has to be taken seriously, the focus-point scenarios would benefit from more luminosity mostly independent of the background conditions. However we have to keep in mind that also something completely different might be realised in nature. In any case mass measurements alone will not be enough to determine the underlying SUSY model, its parameters and the way SUSY is broken. Therefore we also comment on measurements of cross sections and branching ratios. For both examples discussed here and for many others polarisation of both beams is an essential tool for solving the complete SUSY puzzle.

1 Stau–Coannihilation Scenario

What is the achievable precision for the measurement of sparticle properties (in particular the masses)? Please consider the lightest stau in the coannihilation region assuming a mass difference to the LSP of 5 GeV. How much luminosity is needed to reach a precision comparable to the one expected from the measurements with the Planck satellite?

The precision on the relic density of dark matter $\Omega_{\rm DM}h^2$ expected from the Planck satellite experiment is about 2%. Since collider experiments do not measure the relic density directly, it has to be inferred from the properties of sparticles, depending strongly on the exact SUSY scenario under consideration. For typical coannihilation scenarios with small mass difference between the lightest $\tilde{\tau}$ and the LSP, however, the precision of the relic density determination is dominated by the achievable precision on this mass difference. Currently, we are aware of two studies in such scenarios, which differ in their techniques and results. Further studies to understand these differences are still ongoing, as is the adoption of the forward region efficiency for vetoing two photon background events to a 14mrad crossing angle scenario.

1. Two scenarios with $\Delta m_{\tilde{\tau}\rm LSP} = 5$ GeV have been investigated with mass measurements of the $\tilde{\tau}$ and the LSP via the energy endpoint technique in [1]. The study includes ISR, FSR and beamstrahlung and assumes both electron (80%) and positron (60%) polarisation.

   - In the 'post-WMAP' scenario D', a precision of the relic density of 2% is achievable with an integrated luminosity of 300 fb^{-1} at a center-of-mass energy of 600 GeV.
   - In an SPS1a scenario modified such that it fulfills $\Delta m_{\tilde{\tau}\rm LSP} = 5$ GeV, much more luminosity is needed to match the Planck precision. With 200 fb^{-1} at 400 GeV, the resulting precision on the relic density is only 4%. Thus 800 fb^{-1} would be necessary to reach 2%.

   A possible caveat of this study comes from the treatment of the background from two photon processes. Here only contributions from two virtual photons have been taken into account, while simulations with Guinea Pig show that the contributions from real beamstrahlung photons may increase the two photon background by up to a factor of five [2].

2. The D' scenario has also been investigated in [2], where the mass of the $\tilde{\tau}$ is determined from the size of the absolute cross section close to the production threshold, while the mass of the LSP is measured again by an endpoint technique in $\tilde{\mu}$ pair production. With an integrated luminosity of 500 fb^{-1} at a center of mass energy of 500 GeV for the LSP mass measurement plus 500 fb^{-1} at optimised energy of 442 GeV for the $\tilde{\tau}$ mass measurement, a precision of 7% on the relic density is found. For the $\tilde{\tau}$ measurement, both beams are assumed to be unpolarised, because otherwise the cross section would depend additionally on the $\tilde{\tau}$ mixing angle.

These examples illustrate the fact that the expected precision on $\Omega_{\rm DM}h^2$ is highly model dependent even within typical MSSM scenarios, not even considering extended models.

- **At what amount of integrated luminosity are systematic effects becoming dominant?**

  The statistical precision on the $\tilde{\tau}$ - LSP mass difference achieved in [1] for the D' scenario is about 3% with an integrated luminosity of 300 fb^{-1}. Systematic uncertainties due to the beam energy and polarisation measurements are expected to be much smaller. In the case of small mass differences, the most critical issue is the rejection of events from two photon processes. As long as the background level can be kept in the order of 10% after the final selection, the error quoted above should not increase substantially. Thus the amount of integrated luminosity at which systematic effects become important is larger than 300 fb^{-1} in this study. For the threshold approach, the statistical error is much larger even with 500 fb^{-1}. On the other hand, the method of using the absolute cross section is also more dependent on exact knowledge of experimental efficiencies and on the precision of theoretical predictions.

- **Is there any impact of decreasing (increasing) beamstrahlung by a factor of two relative to the standard parameters, i.e. trading off luminosity vs background?**

  The total background is dominated by 2-photon-processes, which are themselves dominated by beamstrahlung [2]. Thus any increase in luminosity which is paid for by a corresponding increase in beamstrahlung is not desirable in this scenario, especially since a finite crossing angle might already increase the background by a factor of 2. Other physics scenarios (e.g. focus point inspired, see below) would take every bit of luminosity, while beamstrahlung conditions are of less importance.

- **Is there any benefit from electron plus positron polarisation (80 and 60%) or from increased electron polarisation in the absence of positron polarisation?**

  Polarisation of both beams increases the signal cross-section by up to a factor of 2, depending on the stau mixing angle, while suppressing W^+W^- background and leaving the dominant 2-photon-background unchanged. Electron polarisation alone, even if increased to 90%, would only increase the signal by a factor 1.5, corresponding to an increase of the neccessary luminosity by a factor of 1.8, i.e. about 530 fb^{-1} for Planck precision in D' or 1400 fb^{-1} in the modified SPS1a scenario.

- **Are there other accelerator parameters strongly influencing this measurement?**

  As already mentioned above, the most critical issue in these scenarios is a highly efficient veto in the forward detectors against two photon processes. Two machine properties that influence the possible veto efficiency are the crossing angle and the time between bunch crossings. This time must be sufficiently long to avoid pile-up of beamstrahlung activity in the forward detectors, which would severely limit the ability to measure small mass differences. Comparisons between 0 and 20 mrad crossing angle options in an otherwise 'TESLA'-like forward region show an increase of the background by a factor of 2 [1, 2]. Studies with the most recent design of the forward regions are not yet available.

2 Neutralino Production

What is the achievable precision for the measurement of sparticle properties (in particular the masses) assuming the case of neutralino production $\tilde{\chi}_1^0\tilde{\chi}_2^0$? Please use a parameter point with masses and mass differences best suited for you to answer the questions in time.

The achievable precision for masses, cross sections and branching ratios in the neutralino sector has been studied in many reactions, all of them being very important for revealing the actual SUSY scenario beneath the experimental observations. Unless stated otherwise, the results collected below have been obtained for the SPS1a scenario.

In the reaction $e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_1^0$, the mass difference $\tilde{\chi}_2^0 - \tilde{\chi}_1^0$ can be determined to about 2% with an integrated luminosity of 500 fb^{-1} at 500 GeV center of mass energy [3]. This study has been carried out for the TESLA interaction region (zero crossing angle, forward detectors) and considers neither polarisation nor ISR/FSR nor beamstrahlung. The same study arrives at an estimate of 2% for the precision of the cross section, with the same caveats as for the mass measurement.

Studies considering $e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0$ in the SPS4 scenario arrive again at a few percent of mass resolution for $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$, but only with a much higher amount of integrated luminosity of roughly 2000 fb^{-1} (10 years of NLC running time) at a center of mass energy of 750 GeV and with 80% electron polarisation [4].

The branching ratios of $\tilde{\chi}_2^0$ to $\tau\tilde{\chi}_1^0$, $\mu\tilde{\chi}_1^0$ and $e\tilde{\chi}_1^0$ can be determined to 8 - 16% with 1000 fb^{-1} at 500 GeV center of mass energy, but only if all four possible combinations of the polarisations of both beams (i.e. LL, LR, RL, RR) are avaible [5].

Within the same analysis, the partial cross sections $\sigma_{\mathrm{RR/LL}} \times BR(\tilde{e} \rightarrow \tilde{\chi}_2^0)$ and $\sigma_{\mathrm{RR/LL}} \times BR(\tilde{e} \rightarrow \tilde{\chi}_2^0) \times BR(\tilde{\chi}_2^0 \rightarrow \tau\tau\tilde{\chi}_1^0)$, which are an essential part of the determination of the supersymmetric U(1) and U(2) Yukawa couplings [6], can be measured with a precision of about 2%.

A slightly different approach is pursued in [2], where chargino and neutralino masses are determined from threshold scans with accuracies of a few 100 MeV. The μ parameter can then be determined at the 1% level from the cross section measurement and the polarisation asymmetry in the $\tilde{\chi}_1^+\tilde{\chi}_1^-$ channel. With these very precise measurements, the parameter limiting the determination of the dark matter relic density would be $\tan\beta$, leading to a precision on $\Omega_{\mathrm{D}M}h^2$ of about 8%.

Results at generator level are available for various chargino and neutralino masses and cross sections in a focus point (LCC2) and in a baryogenesis (BGEN) scenario [7]. With an integrated luminosity of only 250 fb^{-1} at a center of mass energy of 500 GeV, very small statistical uncertainties in the percent or even subpercent range are obtained, however without applying a detector simulation or machine backgrounds etc. Within a global fit, the precision on $\tan\beta$, which limits the relic density determination in the study quoted above, can be improved substancially, leading to an uncertainty of only 2.5% on $\Omega_{\mathrm{D}M}h^2$. This analysis however relies on the fact that neutralinos and charginos are rather light, so that cross sections are sufficiently high and that even the heavier neutralinos $\tilde{\chi}_3^0$ and $\tilde{\chi}_4^0$ are accessible. For LCC2, this is the case with Isajet 7.69, which was used here, but not for other codes like Softsusy, Spheno or Suspect, where only $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and the lightest chargino are accessible with cross sections below 1 fb^{-1}, leading to large statistical errors [8].

- **At what amount of integrated luminosity are systematic effects becoming dominant?**

  Most measurements discussed above would be statistically limited, especially systematic errors arising from beam energy and polarisation are negligible [5]. The details depend strongly on the masses of the neutralinos and charginos, so that even within focus-point type scenarios the differences can be significant. In the case of the heavier neutralinos, the statistical limitation is even more severe. The cross section for $e^+e^- \to \tilde{\chi}^0_3\tilde{\chi}^0_1$ for example can only be measured with a statistical precision of about 20% with an integrated luminosity of 500 fb^{-1} at a center of mass energy of 500 GeV, even if both beams are polarised [9].

- **Is there any impact of decreasing (increasing) beamstrahlung by a factor of two relative to the standard parameters, i.e. trading off luminosity vs background?**

  For the measurements above, the influence of beamstrahlung has not yet been studied in detail, however it is not expected to be as critical as in the small mass difference scenario above.

- **Is there any benefit from electron plus positron polarisation (80 and 60%) or from increased electron polarisation in the absence of positron polarisation?**

  Positron polarisation is essential for most of the measurements quoted above. Especially the measurement of the $\tilde{\chi}^0_2$ branching ratios and partial cross sections (and thus U(1), SU(2) SUSY couplings) is not possible without positron polarisation, since the different polarisation dependencies are essential to disentangle the contributions from other SUSY processes to the same final state from the signal.

  For $\tilde{\chi}^0_3\tilde{\chi}^0_1$ production, the statistical error would increase from 20% to 30% in the absence of positron polarisation. An increase of the total luminosity by a factor of two would be necessary to recover this loss of precision. This cannot be compensated for by increasing the electron polarisation.

  Furthermore, positron polarisation is essential to distinguish between higgsino-like or gaugino-like $\tilde{\chi}^0_1$ and $\tilde{\chi}^0_2$. For certain selectron mass scenarios, this might be impossible without positron polarisation [10].

- **Are there other accelerator parameters strongly influencing this measurement?**

  The influence of other accelerator parameters have not yet been studied for this scenario.

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