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Answers by the SUSY Group to Questions Posed by the ILC Parameters Group on September, 2006

SUSY Group Members

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Report

Here we attempt to answer the questions posed by the ILC Parameters group recognizing that we have had very little time to investigate this questions so most of our anwers are based on studies that have been carried out during the previous decade. In some cases we have not been able to reach a consensus of what to expect from the machine.

At what amount of integrated luminosity are systematic effects becoming dominant.

*There are many cases, where the production cross sections times branching ratios are small, results are statistically limited. See, for example, the work by H.-U. Martyn**hep-ph/** 0408226. In this study the statistical precision on the $\tilde{\tau}$-LSP mass difference for the D' scenario is about 3% with an integrated luminosity of 300 fb^{-1}. Nevertheless, this error is larger that the dark matter density measurement expected from the Planck satellite (2%). Systematic uncertainties due to beam energy and polarization measurements are expected to be much smaller. In the case of small mass differences, the most critical issue is the rejection of events from the $\gamma - \gamma$ process. As long as this background can be kept to less than 10% after the final selection the error quoted above should not change substantially. Hence we feel that the amount of integrated luminosity at which systematic effects become important is larger than 300 fb^{-1} in this study. Using the threshold approach in the measurement of masses, the statistical error is likely much larger even with 500 fb^{-1}.*

*In the measurement of SUSY masses a systematic effect can come from the distortion of the center of mass energy due to beamstrahlung unless this spectrum is known well and corrected for. The presence of beamstrahlung, if not corrected for, systematically shifts the resultant mass measurements (using the edge of the energy spectrum of the observed final state particles in SUSY particle decays) by a few GeV which is larger than the statistical error obtained in many cases with an integrated luminosity of 500 fb^{-1}. Typical results are seen in the study by Bradford Dobos, Jack Gill, and Andrew Hahn presented in **http://hep-www.colorado.edu/SUSY/grpwk_anal.html**. This work was done using ISAJET for a set of old benchmark parameters with a reasonable beamstrahlung spectrum not too different from what we expect for the 14 mrad crossing angle case. This systematic effect can be overcome, as shown in these papers, by other methods, as long as the center of mass energy distribution is well known, but it makes the statistical error larger at these integrated luminosities. On the other hand, if the beamstrahlung deleterious effects on the beam energy are well understood the energy spectra can be corrected and the effect overcome. See, for example **hep-ph/** 0408226. This requires that we constantly measure the center of mass* *energy by other processes so that we can take into account beam instabilities that would constantly change the beamstrahlung effects. This paper also claims that we do not need the beamstrahlung spectrum and that we can determine the masses by determining the end point of the edge energy spectrum. This problem clearly needs further study to determine how well we need to know the center of mass energy spectrum and the effects of WW background on determining the edge of the energy spectrum. One result is clear, there are ways by which we can get very accurate masses as long as the $\gamma - \gamma$ process background is low enough that it does not cover the low energy edge of the spectrum of the standard particles from SUSY decays.*

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

Reducing the level of beamstrahlung has important beneficial consequences in the measurement of a few SUSY masses. See, for example, the analysis by P. Bambade, M. Berggren, F. Richard, Z. Zhang in ***hep-ph/*** *0406010. Reducing the beamstrahlung would allow us to detect the γ-γ background with greater efficiency and hence remove its contribution from the data sample. Thus, any increase in luminosity with an increase in beamstrahlung is not desirable. In this sense, also a non-zero large crossing angle increases the background from γ-γ background.*

There are other measurements (see below) of SUSY channels where we need all the luminosity we can get and where the γ-γ background is not as important.

In many cases, in the determination of the $\tilde{e}$, $\tilde{\mu}$ masses, the low energy edge of the electron and muon energy spectra are low enough that the γ-γ background interferes with that edge if we can not detect it well enough. This is specially a problem where the energy difference between the SUSY mass and the $\tilde{\chi}_1^0$ mass is small and where we are trying to measure the $\tilde{\nu}$ masses where there is no sharp edge in the observed muon and electron energy spectra. It seems that the results of WMAP indicates that we should make sure that we can explore this region of phase space. The point is that reducing the level of beamstrahlung allows us to observe the high energy electron-positron from the γ-γ process down to lower transverse momenta and, therefore, substantially reduce this source of background on the energy spectrum of these types of SUSY particle decays. Typical of these is the observation of $\tilde{\nu}$ decays. Also it helps in the clean measurement of the low energy edges of the electron in $\tilde{e}$ decays and of the μ in $\tilde{\mu}$ decays when these occur at very low energies, in the few GeV regime. Hence it is beneficial to reduce the beamstrahlung at the expense of less luminosity. In general, the correct point of view is that being able to detect with very high efficiency ($> 90\%$) the γ-γ background is important. This then implies as low a beamstrahlung background as possible.

There are cases where this is not an important issue. In the measurement of the $\tilde{\chi}_1^0\tilde{\chi}_2^0$ process *the γ-γ background is not that relevant and hence the level of beamstrahlung background is not a problem.*

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

Polarization of both beams increases the signal cross-section by as much or more than a factor of 2, depending on the $\tilde{\tau}$ mixing angle (in the process above) while suppressing the W^+W^- background and leaving the γ-γ background unchanged. Electron polarization alone is not as effective as having both beams polarized. Electron polarization alone of 90% only increases the signal by a factor of 1.5 requiring a luminosity of 530 fb^{-1} to achieve the 3% accuracy mentioned above.

In the study of SUSY processes the presence of as large as possible electron and positron polarisation is crucial in unraveling the values of the parameters of the theory. See the excellent POWER group report "The role of polarized positrons and electrons in revealing fundamental interactions at the Linear Collider" ***hep-ph/*** *0507011. See more direct input on the importance of positron polarization in* `http://www.ippp.dur.ac.uk/~gudrid/source/physics/pol-sum-web.pdf` *and also the future presentation by Gudrid at the Valencia meeting, Nov. 2006. Also see, for example, the work of Bradford Dobos in* `http://hep-www.colorado.edu/SUSY/grpwk_anal.html` *where we can observe the effect of polarization in separating the energy spectra from right handed and left handed smuons.*

Positron polarisation is essential to determine whether the $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$ are higgsino or gaugino like. See ***hep-ph/*** *0002253.*

Similarly, in the study of $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$ properties, like cross sections and branching ratios, positron polarization is very important. See ***hep-ph/*** *0002253.*

Are there other accelerator parameters strongly influencing SUSY measurements.

The time between bunch collisions greatly affect our ability to read out the BEAMCAL and LUMCAL detectors which are observing the γ-γ background on top of the beamstrahlung background. Hence this time interval should be large enough to acommodate the data readout a bunch collision at a time or the data storage needs to be large enough to cvollect all the data for readout after the beam train has passed. Also the stability of the crossing angle affect the beamstrahlung spectrum which may affect the resolution with which we know the center of mass energy spectrum which affects the resolution in the SUSY mass determinations. Comparison between 0 and 20 mrad crossing angle options shows an increase in the beamstrahlung background by a factor of 2. The understanding of whether the 14 mrad crossing angle option or other accelerator parameters affect these measurements is still under investigation.

The physics questions concerning the SUSY group are as follows:

What is the achievable precision for the measurement of sparticle properties (in particular the masses)? Please consider the lightest stau in the co-annililation 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?

This question will be answered in two sections. One dealing with the measurements that are relevant to the comparison with the Planck satellite measurements and those that deal with mass measurements in general.

Concerning the measurement of the $\tilde{\nu}$ $\tilde{\chi}_1^0$ *mass difference there has been a rather complete study carried out by P. Bambade et. al. See* ***hep-ph/*** *0406010. The study shows that we can observe a fraction of the signal given a* $\tilde{\chi}_1^0$-$\tilde{\tau}$ *mass difference of 5 GeV and this mass difference can be measured to a* $\approx$ *1 GeV. Nevertheless we must consider the following caveats in this analysis:*

- *The* $\gamma - \gamma$ *background is about* $10^{\ 5}$ *times as large as the stau production signal; the conclusions in the P. Bambade et.al. analysis requires that the BEAMCAL detector operate with an efficiency above 90%, specially in the region where the beamstrahlung is most intense, namely near the exit beampipes. That this is possible needs to be confirmed experimentally.*
- *To the best of our knowledge, the* $\gamma - \gamma$ *Montecarlo programs only include the tree level (1st order) processes. There are nine possible Feynman diagrams describing possible second order contributions. In a process that is extremely Pt dependent this is worrisome since these second order processes could alter the Pt dependence, increasing the* $\gamma - \gamma$ *background near the beampipes. Hence, in our opinion, the Montecarlo simulation programs need to be improved before we can conclusively remark on our ability to observe the* $\tilde{\tau}$ *production process in the limit of a small mass difference between it and the* $\tilde{\chi}_1^0$.
- *Given the sensitivity to the detection efficiency of the* $\gamma - \gamma$ *process, this analysis needs to be repeated for the case of 14 mrad crossing angle since the beamstrahlung background is sensitive to this crossing angle. This re-analysis is being done.*

See also ***hep-ph/*** *0408226 which shows a 2% measurement in the* $\tilde{\tau}$-$\tilde{\chi}_1^0$ *mass difference using scenario D' with an integrated luminosity of 300* fb^{-1} *at a center of mass energy of 600 GeV with both beams polarised and a resolution of 4% in a modified SPS1a leading to a* *small mass difference. This is done at a center of mass energy of 400 GeV and an integrated luminosity of 200 fb^{-1}.*

See also ***hep-ph/*** *0406010 where we get a resolution of 7% in scenario D' from a one point threshold scan.*

An analysis has been carried out for a light stop (See ***Phys-Rev D****72, 115008 (2005)). This scenario is motivated by electroweak baryogenesis and also to explain the dark matter density through co-annihilation with the $\tilde{\chi}_1^0$. The case that was studied was for $m(\tilde{t})$=122.5 GeV, $m(\tilde{\chi}_1^0)$=107.2 GeV, $\cos(\theta_{\tilde{t}})$=0.0105 (where 0 means right handed),M_1=118.8 GeV, M_2=225 GeV, μ=225 GeV, ϕ_μ=0.2 (CP phase of the μ), tna(β)=5. We also require that both beams are polarized. The reached a resolution of 1 GeV on $m(\tilde{t})$ with an integrated luminosity of 500 fb^{-1} at a center of mass energy of 500 GeV. With a new analysis which is being prepared for publication we reached an accuracy of 0.12 GeV.*

To answer the question about mass resolution in general we discuss the following results:

We have analyzed the production of selectrons, smuons, sneutrinos to determine the effect of beamstrahlung on the energy end point method. The conclusion is that the resultant measured mass is shifted systematically by a few GeV from the original value. The correct mass can be determined either by correcting for the center of mass energy spectra shift (see the work of Uli Martyns ***hep-ph/*** *408225) or by comparing the measured spectra with ones generated with nearby values and doing a least squares fit (see the analyses presented in* `http://hep-www.colorado.edu/SUSY/grpwk_anal.html`*). The masses can be measured to a fraction of a GeV for the case of the selectron (see the work of Andrew Hahn) and for the case of the smuon (see the work of Bradford Dobos). In both these cases the background due to the $\gamma-\gamma$ signal is assumed controllable and does not affect these analysis. Similarly, the sneutrino, chargino masses can be determined with resolution of a fraction of a GeV (see the work of Jack Gill).*

To compare the errors in ILC measurements with those expected from the Planck satellite (2% in the dark matter density) is difficult because there are many theoretical scenarios connecting these two set of measurements. There is both uncertainty in knowing which type of SUSY model we are dealing with and in the cosmological model. At present the calculations relating particle physics results with the relic dark matter density are not precise at the 1% level even assuming the standard cosmological model and a given SUSY model since all the calculations are to first order only. Nevertheless, there is no technical impediment in improving these and this should be accomplished before the ILC begins to operate. We should point out that in some theoretical scenarios it is not possible to learn anything from the ILC or LHC about the underlying cosmological model or firmly establishing that we have discovered the dark matter candidate while in other scenarios we should be able to make some conclusions in the *relation between our measurements and the cosmological measurements. This is clearly work in progress.*

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.

This analysis has been carried out for a collision energy of 750 GeV by Jeremiah Goodson (`http://hep-www.colorado.edu/SUSY/goodson.ps`). One can obtain these masses with a resolution of a few GeV, 1.5% of the mass values, for an integrated luminosity of 500 fb^{-1}.

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 discussed below have been obtained in the SPS1a scenario

In the reaction $e^+\ e^- \ \rightarrow\ \tilde{\chi}_2^0\tilde{\chi}_1^0$ the mass difference between the $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ can be determined to about 2% with an integrated luminosity of 500 fb^{-1} at 500 GeV center of mass energy (see the diploma thesis of Markus Ball, University of Hamburg,2003; `http://www-flc.desy.de/thesis/diplo.2002.ball.ps.gz`. This was carried out for zero crossing angle and does not include polarization nor ISR/FSR nor Beamstrahlung. The same study arrives at an estimate of 2% of the precision of the cross-section.

The branching ratio of $\tilde{\chi}_2^+$ to $\tilde{\chi}_1^0\tau^+, \mu^+$,e$^+$ can be determined to 8-16% with 1000 fb^{-1} at 500 GeV center of mass energy and with all four combinations of polarization of the beams (see talk by B. Sobloher, ECFA workshop, Vienna 2005).

Within the same analysis we can measure the rates $\sigma_{RR/LL} \times B.R.(\tilde{e} \rightarrow \chi_2^0) \times B.R.(\chi_2^0 \rightarrow \tau\tau\tilde{\chi}_1^0$. This is an essential part of the determination of the supersymmetric U(1) and U(2) Yukawa couplings (see A. Freytas et. al. arXiv:hep-ph/0310182). These couplings can be measured with a precision of about 2%.

In hep-ph/040-6010 the chargino and neutralino masses are obtained from threshold scans with accuracies of a few 100 MeV.The μ parameter can be determined can be determined with accuracy of about 1% from the cross section measurements and polarization asymmetries in the $\tilde{\chi}_1^+\tilde{\chi}_1^-$ channel. With such a precise measurement the limiting parameter in the determination of the dark matter density would be tan(β) with a precision of about 8%.

Although not all of these answers are precise, the SUSY group hopes that they give enough information for the ILC Parameters group to define a set of adequate parameters that will allow us to achieve the observations we are after.