Completing the Sparticle Spectrum at a Multi-TeV Linear Collider?

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Abstract.
If supersymmetry is realised in nature, the approved LHC and the planned sub-TeV linear collider should unravel some, maybe many, of the features of the sparticle world. We survey in this paper the task of comprehensively identifying, understanding and measuring all the particles predicted by the model. We start to address whether a multi-TeV linear collider such as CLIC whose energy may well exceed all the new particle production thresholds is suited to completing this challenging task.

INTRODUCTION

A substantial accelerator R&D effort is proceeding apace to demonstrate the feasibility of the two-beam acceleration scheme. This is currently the most promising technology for a multi-TeV e^+e^- collider and the CLIC (Compact Linear Collider) concept envisages a collider covering the 1 to 5 TeV centre-of-mass energy range with an instantaneous luminosity of 10^{35} cm^{-2} s^{-1} at 3 TeV [1].

We of course do not know what new physics will be discovered by the LHC and the planned sub-TeV linear colliders (STLC). That is why we want to do those experiments ! Nevertheless we need to consider at an early stage what may be the physics goals of a multi-TeV linear collider (MTLC) and whether the collider as conceived and the detectors envisaged allow those goals to be achieved. Particularly CLIC, operating in the high beamstrahlung regime, with considerable energy spread, hadronic backgrounds and a bunch crossing time of 0.67 ns is fundamentally different. Recently a CLIC physics study group [2] was formed to address these issues and give feed back to the accelerator design studies.

This paper starts to address the role of a MTLC in studying supersymmetry. If supersymmetry is realised in nature, it seems likely that the LHC and a STLC will unravel some, maybe many, of the features of the sparticle world. So the MTLC has the ambitious role of comprehensively identifying, understanding and measuring as many of the 32 new particles (sparticles and Higgses) predicted by the model as possible.

SUSY MODELS

The MSSM has 105 new parameters and several possibilities for the supersymmetry breaking mechanism. But, for definiteness, we shall examine the experimental predictions (masses, widths, branching ratios) expected in the most constrained minimal supergravity model (mSUGRA) for various sets of model parameters. This will serve as a useful way of benchmarking the MTLC physics potential compared with other facilities, but should be viewed at best as indicative since the relative sparticle masses are also highly constrained.

In choosing example models, we ensured that the current LEP2 SM Higgs limit of 113.5 GeV is respected. Additionally, Matchev, Ellis and Olive insisted that the chosen points should be compatible with neutralino cold dark matter. At least they should not over-close the universe! The mass spectra for some of the models can be found in [3] evaluated using ISASUGRA 7.51. One of them (KM1) is illustrated in figure 1 with parameters (in GeV) of $m_0 = 1450$, $m_{1/2} = 300$, $\tan\beta = 10$, $\mu > 0$, $A = 0$ and $m_{\mathrm{top}} = 175$. The widths of $\tilde{e}_R$, $\tilde{e}_L$, $\tilde{\nu}_e$ and $\tilde{q}_L$, in this example are 7.3, 19, 19 and 68 GeV respectively. In all models $\sqrt{s} = 5$ TeV is sufficient to pair-produce all particles (gluino excepted).

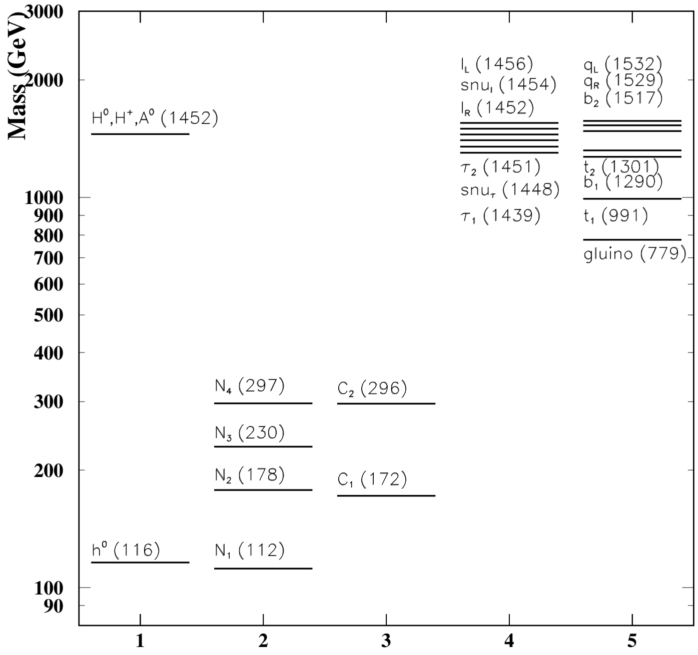

FIGURE 1. Mass spectrum of the KM1 mSUGRA model.

CASE STUDY

We studied in more detail the KM1 model which is inspired by the focus point mSUGRA scenario of [4] in which the scalar sparticles are relatively heavy and the gauginos and Higgsinos much lighter. The sparticle production cross-sections are shown in figure 2. For this model the highest cross-section process at high energies is $e^+e^- \rightarrow \tilde{\nu}_e\ \tilde{\nu}_e$. Additionally the "charginoed current" decays $\tilde{\nu}_e \rightarrow e^-\tilde{\chi}_1^+$ (BR=35%) and $\tilde{\nu}_e \rightarrow e^-\tilde{\chi}_2^+$ (BR=26%) allow identification of the sneutrino flavour and the energetic primary decay electron can be measured well in the electromagnetic calorimeter assumed to have a fractional energy resolution of $10\%/\sqrt{E}\oplus 0.6\%$.

SPYTHIA was used to generate inclusively all SUSY processes including the effects of ISR and CLIC beamstrahlung. As a first step we chose to take an inclusive approach to SUSY exploration at CLIC, by examining the e^+ and e^- spectrum in inclusive di-electron events. In this regime where the missing p_T is large (huge mass differences), the main backgrounds are likely to be SUSY itself. The inclusive approach has two big benefits: it should be largely insensitive to pile-up (whereas eg channels with jet vetoes will not) and it sums over many possible decay chains (more statistics). The resulting energy spectra are shown in figure 3.

It is encouraging to see that with this simple approach the end-points are distinctly visible - although it should be noted that their resolution is compromised also by the detector resolution and the sparticle widths as well as the ISR and

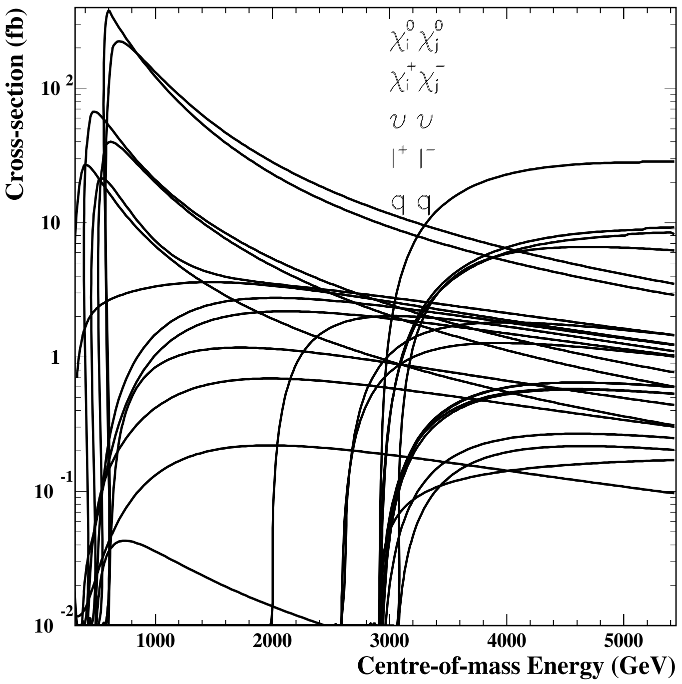

FIGURE 2. Cross-sections for the KM1 model calculated with SUSYGEN 3.0 neglecting ISR and beamstrahlung.

beamstrahlung. Using beam polarisation and more topological information - eg requiring evidence for at least one chargino decay in the sneutrino study would better separate the processes.

The cross-sections for scalar pair production for the squarks, smuons and staus are much less advantageous than for selectrons and electron-sneutrinos - of order fb or less if they are as heavy as 1.5 TeV. The cross-sections near threshold for $e^+e^- \to \tilde{\mu}_R\tilde{\mu}_R$ with $m_{\tilde{\mu}} = 1452$ GeV and width of 7.3 GeV are illustrated in figure 4 for an ideal e^+e^- collider with ISR only, for CLIC with nominal beamstrahlung, beam energy spread and luminosity ($\mathcal{L} = 10^{35}$) and also for a sharper beamstrahlung spectrum with $\mathcal{L} = 4 \times 10^{34}$. Clearly for this particular example even with a narrow width, the factor of 2.5 higher luminosity is preferable especially with cross-sections of order 50 ab. For the example shown the precision on the smuon mass from a threshold scan is about 1% for an exposure of 10^6s. As some of the prerequisites for embarking on such a scan one would need confidence in the knowledge of the smuon branching ratios and ability to control the background at the attobarn level.

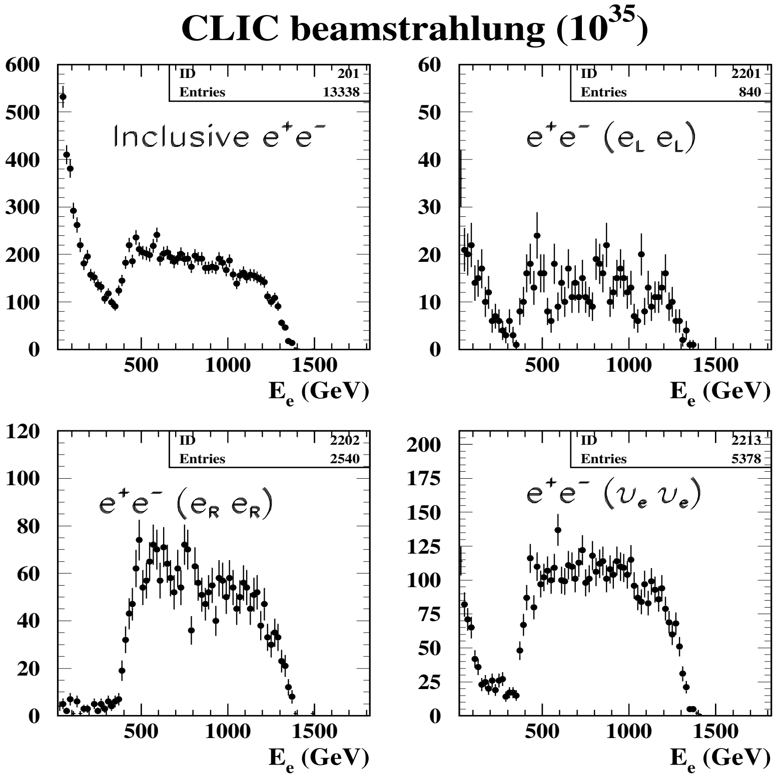

FIGURE 3. Measured electron and positron spectrum for inclusive di-electron events for the KM1 model at $\sqrt{s} = 3.5$ TeV with 650 fb^{-1} using SPYTHIA, CALYPSO and SIMDET. Panels 2,3 and 4 show the di-electron events from $\tilde{e}_L\tilde{e}_L$, $\tilde{e}_R\tilde{e}_R$ and $\tilde{\nu}_e\tilde{\nu}_e$ production assuming ideal process separation.

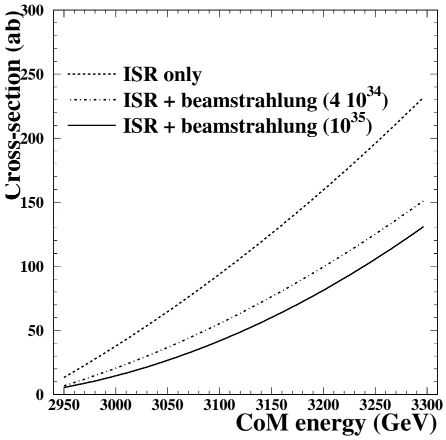

FIGURE 4. Cross-section for $e^+e^- \to \tilde{\mu}_R\tilde{\mu}_R$ near threshold evaluated using SPYTHIA.

Conclusions

These studies have just scraped the surface of what may lie ahead of a MTLC in the study of supersymmetry. From the examples studied so far it is clear that the heavy SUSY particles usually have very rich and complex cascade decays. To progress, we need to understand comprehensively the lighter sparticles by measuring them at lower centre-of-mass energies (STLC).

Exclusive topological channels will receive contributions from many heavy sparticles thus making process separation difficult. The decay widths are usually large (eg 70 GeV for squarks in the KM1 model) and so at least for some applications the beam spectrum is not as critical as high luminosity. The ambitious task of a comprehensive understanding of the sparticle world will require all (and more) of the assets envisaged for e^+e^- colliders: highly polarised beams, high luminosity with energy range (high and low), hermetic detector, $\gamma\gamma$, $e\gamma$ and e^-e^- capability.

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