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New physics searches with the ILD detector at the ILC

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Abstract

Although the LHC experiments have searched for and excluded many proposed new particles up to masses close to 1 TeV, there are many scenarios that are difficult to address at a hadron collider. This talk will review a number of these scenarios and present the expectations for searches at an electron-positron collider such as the International Linear Collider. The cases discussed include the light Higgsino, the stau lepton in the coannihilation region relevant to dark matter, and heavy vector bosons coupling to the s-channel in e^+e^- annihilation. The studies are based on the ILD concept at the ILC.

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1 ILC and BSM

The ILC - the International Linear Collider - is a power-efficient e^+e^- collider with initial $E_{CMS} = 250$ GeV, upgradable up to 1 TeV [1, 2]. As electrons are point-like objects, the initial state is known. Since the production mechanism is electro-weak, the backgrounds will be low meaning that the detectors can be thin and have close to $\sim 4\pi$ coverage, and can be operated without trigger. In addition, at ILC, both beams will be polarised. This combination of polarised beams, low background, known in-state, hermetic detectors and energy upgradability makes the ILC the ideal environment for Beyond the Standard Model (BSM) searches [3].

1.1 BSM at ILC: the SUSY case

SUSY is the most complete theory of BSM. It also serves as a boiler-plate for BSM, since almost any new topology can be obtained in some flavour of SUSY. In addition it is the most studied model with serious simulation: In most cases presented here, used full simulation of the International Large Detector concept at ILC (the ILD [4]), with all SM backgrounds, and all beam-induced backgrounds included.

Although the LHC experiments have searched for and excluded many proposed new particles up to masses in the 1 TeV range, there are many scenarios that are difficult to address at a hadron collider [5, 6]. In SUSY, all is known for given masses, due to SUSY-principle, relating sparticle properties to those of the corresponding SM particles. These relations do not depend on the SUSY breaking mechanism. Obviously, there is one Next-to-lightest SUSY particle (NLSP), and it must have 100 % BR to it's (on- or off-shell) SM-partner and the lightest SUSY particle (the LSP). Therefore, one can perform model independent evaluations of exclusion or discovery reach in $M_{NLSP} - M_{LSP}$ plane - with no loop-holes. One can do this for any possible NLSP, and concentrate on the "worst" cases - the ones with lowest cross-section and most difficult signatures. These are on one hand the bosinos, and on the other the $\tilde{\tau}$. The reaches for these cases are shown in Fig. 1.

Since the discovery and exclusion reaches at the ILC are quite similar, after a possible discovery, one will quickly enter the realm of precision measurements.

In Fig. 2 typical signals of bosino production are shown, for charginos (Fig. 2(a)) and neutralinos (Fig. 2(c)). Both models are higgsino-LSP ones. The one to the left is one of three studied natural SUSY models with moderate mass differences (15-20 GeV) [9], while the one to the right is a cosmology-

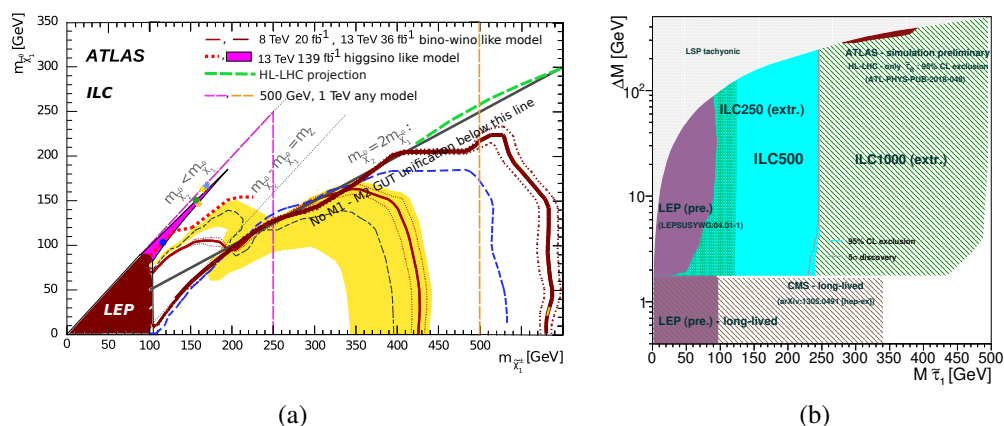


Figure 1: The expected exclusion and *discovery* reaches at ILC for bosinos (a) [7] and $\tilde{\tau}$:s (b)[8], together with obtained or projected *exclusion* limits from LHC/HL-LHC and LEP II (references can be found in [7]). **NB:** At ILC, exclusion and discovery is almost the same, even for difficult channels.

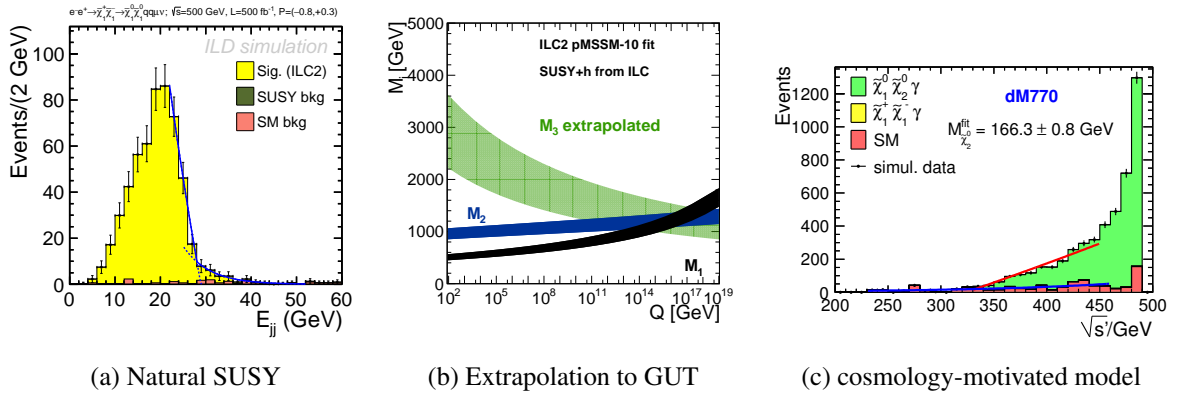


Figure 2: ILC bosino measurements: (a) chargino signal in a natural SUSY model; (b) RGE extrapolation of the gaugino mass-parameters to the GUT scale, with experimental inputs obtained in natural SUSY; (c) neutralino signal in the cosmology-motivated model. The SUSY background was included in the analysis, but was found to completely removed after all cuts were applied.

motivated model, and has a sub-GeV difference [10]. In the natural SUSY analysis, the combination of the measured masses, BR's and Higgs properties, all 10 weak-scale parameters gets constrained, for all three bench-marks. In particular, the bino and wino SUSY breaking masses M_1 and M_2 - the ones most directly related to the higgsino masses - can be determined at percent level. The fitted weak-scale parameters can be evolved with the appropriate RGE's to higher scales. This allows to verify or discard the idea of GUT-scale unification of M_1 and M_2 , see Fig 2(b).

In Fig. 3, typical slepton signals are illustrated. The end-points of the spectra of the slepton decay-products, enables to measure the slepton and LSP masses to percent level accuracy. Fig. 3(a) and (b) are examples of $\tilde{\tau}_1$ and $\tilde{\mu}_R$ signals, in a $\tilde{\tau}$ co-annihilation model [6]. Fig. 3(c) shows the signal that could be obtained from evaluating the decay-kinematics in a model with cascade decays of $\tilde{\mu}'$ s [11].

After the full ILC program, and depending on model, channel, and polarisation, we find experimentally that measured $\delta(\text{masses}) = 0.5\text{-}1\%$, $\delta(\sigma \times \text{BR}) = 1\text{-}6\%$

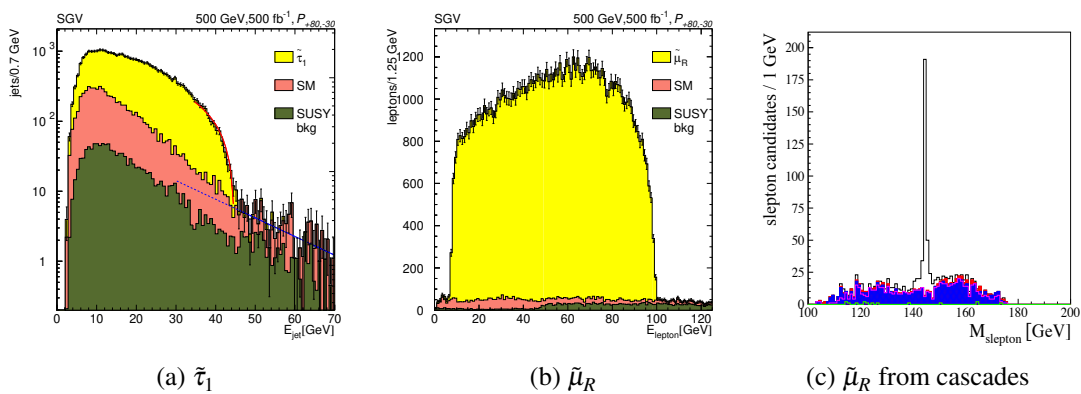


Figure 3: Slepton signals at ILC: (a) τ decay-product spectrum in $\tilde{\tau}_1$ pair-production; (b) μ spectra in $\tilde{\mu}_R$ pair-production; (c) reconstructed $\tilde{\mu}_R$ mass in a model where $\tilde{\chi}_2^0$ decays to $\mu\tilde{\mu}_R$. Open: signal, red: SM background, blue: SUSY background.

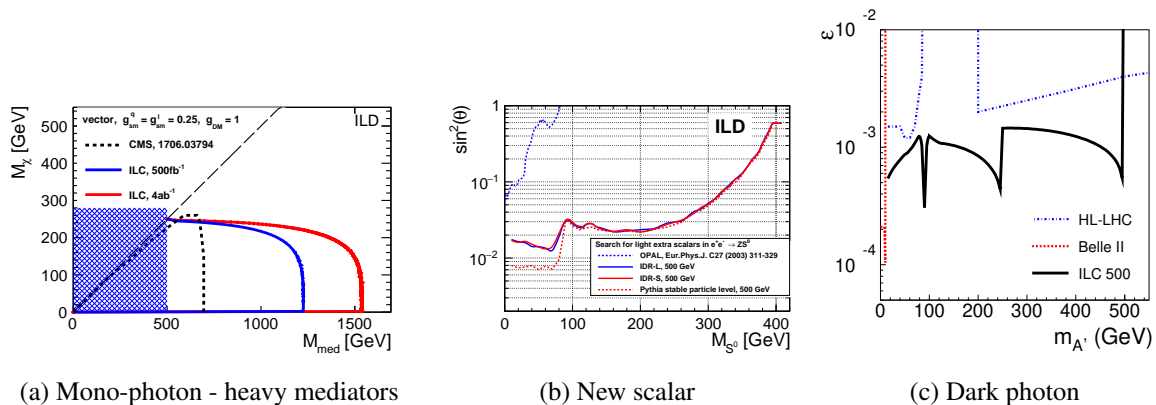


Figure 4: Examples of non-SUSY BSM searches at ILC

1.2 BSM at ILC: not only SUSY.

Dark matter can be searched for at ILC in $e^+e^- \rightarrow (DM)(DM) + \text{ISR}\gamma$, i.e. in Mono-photon searches. Results of such searches are shown in Fig. 4(a) for heavy mediators where a model independent EFT approach is appropriate [12]. Also arbitrary mediators have been studied and also show potential beyond HL-LHC [13]

New Higgs-like scalar (S), produced in $e^+e^- \rightarrow Z^* \rightarrow ZS$ with unknown decays of S, can be searched for it in a decay-mode insensitive way at ILC, using the recoil-mass, i.e. the mass of the system recoiling against the measured Z [14]. Couplings down to a few percent of the SM-Higgs equivalent can be excluded, as shown in Fig. 4(b).

At ILC one can also search for Dark photon/ Z' . Generically, the kinetic mixing term $\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$ in the Lagrangian leads to a tiny, narrow resonance, but still wide enough to make decays prompt. One can search for this as a $\mu\mu$ resonance above background in $e^+e^- \rightarrow Z' + \text{ISR} \rightarrow \mu^+\mu^- + \text{ISR}$. Results (from EPPSU) shown in Fig. 4(c).

Another study that ILC allows for is indirect BSM. Such studies do not only show an important discovery potential, but also can achieve model separation. In [15] the results of an SM effective field theory (SMEFT) study, using ILC results on Higgs properties and TGCs are given There, one selected models that are not discoverable at HL-LHC, and it was shown that, at ILC, not only are the models separable at 5σ from the SM, but also from each other.

2 Conclusion

Sometimes, the capabilities for the direct discovery of new particles at the ILC exceed those of the LHC, since ILC provides a well-defined initial state, a clean environment without QCD backgrounds, extendability in energy and polarised beams. Thanks to the low background levels, detectors - like ILD - can be factors more precise than their LHC counterparts, can be hermetic, and do not need to be triggered.

Many ILC - LHC synergies from energy-reach vs. sensitivity are expected. E.g. if SUSY is reachable at ILC, it means 5σ discovery, and precision measurements. This input might be just what is needed for LHC to transform a 3σ excess to a discovery of states beyond the reach of ILC. Similar synergies can also be expected in many other models for BSM physics.

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