PROCEEDINGS OF SCIENCE

The Potential of the ILC for Discovering New Particles

Mikael Berggren[*][†]
DESY, 22603 Hamburg, Germany
E-mail: `mikael.berggren@dey.de`

Data from the LHC at 7, 8, and 13 TeV, have, so far, yielded no evidence for new particles beyond the Standard Model Higgs boson. However, the complementary nature of physics with e^+e^- collisions still offers many interesting scenarios in which new particles can be discovered at the ILC. These scenarios take advantage of the capability of experiments at e^+e^- colliders to observe particles yielding final states with missing energy and small mass differences, to observe mono-photon events with precisely controlled backgrounds, and to observe the full range of exotic decay modes of the Higgs boson. The searches that an e^+e^- collider makes possible are particularly important for models of dark matter involving a dark sector with particles of 10–100 GeV mass. In this talk, we will review the opportunities that the ILC offers for new particle discovery.

The 39th International Conference on High Energy Physics (ICHEP2018)
4-11 July, 2018
Seoul, Korea

PoS(ICHEP2018)631

---

[*] Speaker.

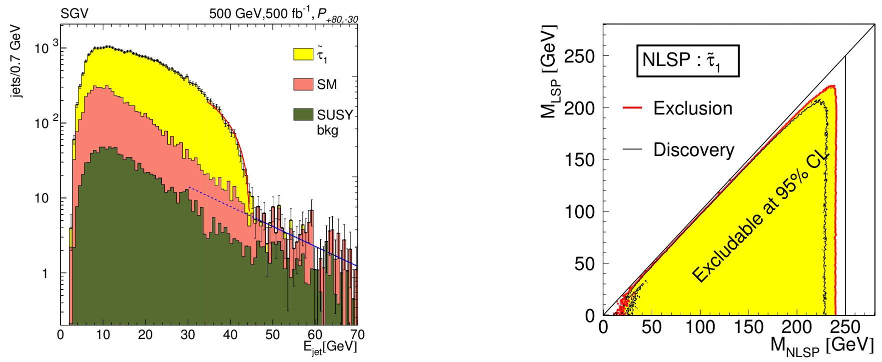
[†] On behalf of the LCC Physics Working group. The talk is mainly based on arXiv:1702.05333

1. Introduction

Several contributions to this conference have shown that ILC has a great potential for *indirect* discovery of BSM. In this contribution, we concentrate on the question whether ILC still can *directly* discover BSM, in view of the current LHC results. In particular, we will discuss SUSY and Dark Matter (DM): SUSY, since it is the most complete theory of BSM and DM since it represents one of the unsolved problems in physics. We will point out the ILC strengths in SUSY searches, namely to perform loop-hole free searches, even if the spectrum is highly compressed. In the case of DM, we point out the strong complementarity between ILC and LHC..

Compressed SUSY with no loopholes

The ILC will be able to detect new particles with electroweak interactions nearly up to the kinematic limit of $\sqrt{s}/2$. In particular, in SUSY - where the couplings cannot become arbitrarily small but are given by those of the corresponding SM partners and their mixings: systematic, loophole-free searches can be performed for production of pairs of NLSPs. In the R-parity conserving case they have to decay into the LSP and their SM partner, and in the clean environment of the ILC, these decays can be detected even for extremely small mass differences $\Delta(M)$. Such small $\Delta(M)$ can occur both in WIMP-motivated models and in naturalness-motivated ones. An example of the first case is $\tilde{\tau}$ coannhilation, which reduces the relic density of the LSP to its observed value and requires a small $\Delta(M)$. The ILC prospects were studied in [1, 2], and the expected $\tilde{\tau}$ signal is shown in Fig. 1(a).. The relevant masses can be measured at the permille-level from kinematic edges. More generally, Fig. 1 (b) shows the discovery and exclusion reach as a scan over *all* accessible $M_{\tilde{\tau}_1}$ and $M_{\tilde{\chi}^0_1}$. Due to the νs in the τ-decays, the $\tilde{\tau}$ NLSP scenario is the worst case. Any other NLSP would be excluded or discovered even closer to the kinematic limit [3].

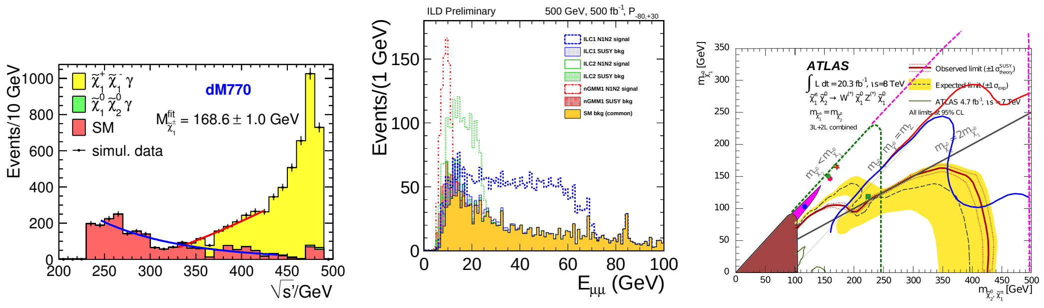


(a) τ-jet energies for selected events [2]

(b) Discovery reach scan [3]

Figure 1: ILC $\tilde{\tau}_1$ NLSP search. The mixing angle is the one yielding lowest possible cross-section.

What regards the second case, a core prediction of natural SUSY is the existence of a triplet of light higgsinos with masses around 100 GeV, and with $\Delta(M) \leq$ 20 GeV. Note that $M_{\tilde{t}}$ and $M_{\tilde{g}}$ may still be multi-TeV. The ILC capabilities have been studied in [4, 5] with $\Delta(M)$ ranging from 770 MeV to 20 GeV. Two examples of the striking signals and the extraction of masses are given in Fig. 2. The resulting precisions on masses and polarised cross sections reach the percent level in all cases and allow to determine other SUSY parameters. More generally, the prospects at LHC



(a) $M_{\tilde{\chi}_1^\pm}$ from recoil against ISR [4] (b) $M_{\tilde{\chi}_2^\pm}$ from energy of decay products [5] (c)

Figure 2: (a) and (b): Higgsino mass determination for $\Delta(M)$ =770 MeV and $\Delta(M)$ = 20 GeV. (c): Discovery or exclusion regions for a $\tilde{\chi}_1^\pm$ or $\tilde{\chi}_2^0$ NLSP, for LEP, LHC, HL LHC and ILC. The symbols indicate the models shown in (a) and (b). The curves are explained in the text

and ILC can be seen in Fig. 2(c), which shows the 8 TeV limits in the $M_{\tilde{\chi}_1^0}$ - $M_{\tilde{\chi}_1^\pm}$ plane from ATLAS [6], together with the projected discovery reach at 14 TeV with $\int \mathscr{L}\,\mathrm{dt}$ = 300 or 3000 fb^{-1} [7], under the assumptions given in the figure, and assuming that $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ are pure Winos. The magenta area is excluded by the recent ATLAS search aimed at compressed spectra [8]. The brown-shaded area indicates the limit from LEP which assumes only $\tilde{\chi}_1^\pm$ pair production, with no assumption on the decay mode. The expected limits for the ILC at $\sqrt{s} = 500$ or 1000 GeV are also shown with the same assumptions as for the LEP exclusion, for $E_{CMS} = 500$ GeV or $1 =$ TeV (green and magenta dashed lines). As can be seen, the low $\Delta(M)$ region is not covered even by the HL LHC, and there is a large discovery potential for the ILC.

Generic WIMP DM

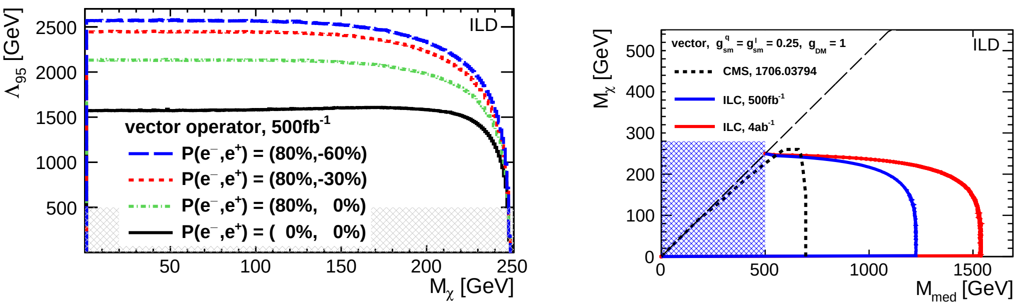
The prospects to detect WIMPs at the ILC at $E_{CMS} = 500$ GeV was studied in [10], and interpreted in the framework of effective operators (parameterised by a mediator mass M_χ, and a coupling Λ)[1]. As seen in Fig. 3, evidence for WIMP production could be obtained over a large region of the parameter-space. These searches - sensitive to couplings to electrons - are complementary to those at LHC and at direct detection experiments, which are sensitive to couplings to quarks. Thus, if LHC does not discover any signal in its "mono-X" searches, it is essential to complement the picture by probing the WIMP-lepton couplings at an e^+e^- collider. Moreover, while LHC can probe larger WIMP *masses* ILC can probe smaller *couplings*, ie. higher energy scales.

2. Conclusion

The capabilities for the direct discovery of new particles at the ILC sometimes exceed those of the LHC, since ILC provides a well-defined initial state, a clean environment without QCD backgrounds, can have hermetic detectors, with *no need for triggering*. In addition, such a machine offers extendability in energy and *polarised beams*.

---

[1] Under ILC conditions the EFT approximation is accurate, while it is questionable in similar analyses at LHC.



(a) Effective operator (b) Simplified model. The CMS curve is from [9]

Figure 3: Exclusion reach (2σ) of the ILC for a WIMP in the vector operator case [10]. Equal couplings to quarks and leptons are assumed and $M_{med} = \sqrt{g_{SM} g_{DM}} \Lambda = \frac{\Lambda}{4}$ is used to relate the descriptions in (b).

There are many ILC - LHC synergies stemming from the energy-reach of LHC vs. the high sensitivity of ILC. For DM, LHC probes higher masses whereas ILC probes lower couplings. For SUSY, LHC offers higher mass-reach, while ILC offers a superior probe to low $\Delta(M)$. If both ILC and LHC observes SUSY, the (sub)percent level measurements from ILC of the lower states will help LHC to disentangle long decay-chains of higher states. Even in the most pessimistic case, with no LHC discoveries, the ILC offers distinct and very powerful strategies for finding BSM.

References

[1] P. Bechtle *et al.*, *Prospects for the study of the $\tilde{\tau}$-system in SPS1a' at the ILC*, *Phys. Rev.* **D82** (2010) 055016, [`arXiv:0908.0876`]

[2] M. Berggren *et al.*, *Non-Simplified SUSY: Stau-Coannihilation at LHC and ILC*, *Eur. Phys. J. C* **76** (2016), no. 4, 183 [`arXiv:1508.04383`]

[3] M. Berggren, *Simplified SUSY at the ILC* `arXiv:1308.1461`.

[4] H. Sert *et al.*, *Tackling light higgsinos at the ILC*, *Eur. Phys. J. C* **73** (2013) no.12, 2660 [`arXiv:1307.3566`]

[5] H. Baer *et al.*, *Naturalness and light higgsinos: A powerful reason to build the ILC*, `arXiv:1611.02846`

[6] **ATLAS Collaboration**, G. Aad *et al.*, *Search for direct production of charginos, neutralinos and sleptons in final states with two leptons and missing transverse momentum in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector* *JHEP* **1405** 071.

[7] **ATLAS Collaboration**, *Physics at a High-Luminosity LHC with ATLAS* `arXiv:1307.7292`

[8] **ATLAS Collaboration**, M. Aaboud *et al.*, *Search for electroweak production of supersymmetric states in scenarios with compressed mass spectra at $\sqrt{s} = 13$ TeV with the ATLAS detector Phys. Rev. D* **97** (2018), no.5,052010 [`arXiv:1712.08119`]

[9] **CMS Collaborationm** A. M. Sirunyan *et al.*, *Search for new physics in the monophoton final state in proton-proton collisions at $\sqrt{s} = 13$ TeV*, *JHEP* **1710** (2017), 073 [`arXiv:1706.03794`].

[10] M. Habermehl, *Thesis, in preparation* (2018).