# Snowmass2021 - Letter of Interest

## Probing Supersymmetry and Dark Matter at the CEPC, $\mathrm{FCC_{ee}}$, and ILC


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### Abstract:

In this Letter of Interest we propose to probe Supersymmertry (SUSY) and Dark Matter (DM) at the Circular Electron Positron Collider (CEPC), which would work well on other future colliders like $\mathrm{FCC_{ee}}$ and ILC too. The generic searches for the charginos, neutralinos, and sleptons will be concentrated, and some relevant dark matter searches will to be considered as well.

Supersymmetry (SUSY) provides a natural solution to the gauge hierarchy problem in the Standard Model (SM). In supersymmetric SMs (SSMs) with $R$-parity, gauge coupling unification can be achieved, the Lightest Supersymmetric Particle (LSP) such as neutralino serves as a viable dark matter (DM) candidate, and electroweak (EW) gauge symmetry can be broken radiatively due to the large top quark Yukawa coupling, etc. Thus, SUSY is the promising new physics beyong the SM. However, the SUSY searches at the LHC have already given the strong constraints on the SSMs[1].

How to probe the natural SUSY at the CEPC, $\mathrm{FCC_{ee}}$, and ILC is an interesting question. To define the SUSY naturalness, we need to define the fine-tuning measures first. There are two kinds of the fine-tuning measures: the high-energy fine-tuning measure, and the low-energy fine-tuning measures. The high-energy fine-tuning measure was defined by Ellis-Enqvist-Nanopoulos-Zwirner (EENZ)[2], and Barbieri-Giudice (BG)[3]. And a simple solution is super-natural supersymmetry[4], whose EENZ-BG fine-tuning measure is automatically at the order one. In the super-natural supersymmetry[4], we obtain that the observed DM relic density is realized via the LSP neutralino-light stau coannihilation, the LSP neutralino is Bino dominant, and the right-handed sleptons are light as well. The naturalness conditions from the low-energy fine-tuning measures[5;6] generically predict the light Higgsinos. Therefore, we shall concentrate on the generic searches for the charginos, neutralinos, and sleptons at the CEPC, $\mathrm{FCC_{ee}}$, and ILC. And we shall consider some relevant dark matter searches as well.

To be concrete, let us explain the projects one by one in the following:

(I) Chargino and Neutralino Searches

We shall mainly consider the light Higgsino searches from the natural SUSY point of view.

(II) Slepton Searches

To explain the anomalous magnetic moment of muon and generate the correct DM relic density via the LSP neutralino-light stau coannihilation, we need light smuon and light stau, respectively. With the universal SUSY breaking soft masses, we shall have light selectron as well. Therefore, we shall study the generic slepton searches.

(III) The Bino-Like LSP Neutralino

We consider that the LSP neutralino is Bino dominant. The correct relic density can be obtained via the LSP neutralino-light stau coannihilation, Higgs resonance, and $Z$ resonance. The LSP neutralino can be probed via the mono-photon searches in general.

For the Higgs resonance, the Bino-like LSP neutralino are pair produced via the t-channel selectron. Because the LSP neutralino mass is around 62.5 GeV, we can search for the selectron via the mono-photon process as well.

Futheremore, we shall study the relevant viable parameter space via the GmSUGRA[7;8].

(IV) The Bino-Like Lightest Neutralino as the Next to the LSP (NLSP)

In general, the Bino-like LSP neutralino might have very large density. One solution is that we introduce axino, which is the SUSY partner of the axion. We assume that axino is lighter than the lightest neutralino and thus is the LSP. And then the Bino-like lightest neutralino is the NLSP, and can decay into axino and photon. In this case, we can search for the Bino-like lightest neutralino via two photons plus missing energy.

Moreover, we shall study the relevant viable parameter space via the GmSUGRA[7;8].

(V) The Light Singlet Higgs Field and Singlino in the Next to the Minimal SSM (NMSSM)

In the NMSSM, the singlet Higgs field can be light, as well as its superpartner singlino. We shall scan the viable parameter space with light singlet Higgs field and light singlino in the NMSSM, and study their searches at the CEPC, $\mathrm{FCC_{ee}}$, and ILC.

(VI) Dark Matter Searches via the Higgs and $Z$ Resonances

We shall study the dark matter scenarios whose observed dark matter relic density is realized via the Higgs and $Z$ resonances in details.

## References


[1] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults; http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS/index.html.

[2] J. R. Ellis, K. Enqvist, D. V. Nanopoulos and F. Zwirner, Mod. Phys. Lett. A **1**, 57 (1986).

[3] R. Barbieri and G. F. Giudice, Nucl. Phys. B **306**, 63 (1988).

[4] T. Leggett, T. Li, J. A. Maxin, D. V. Nanopoulos and J. W. Walker, arXiv:1403.3099 [hep-ph]; Phys. Lett. B **740**, 66 (2015) [arXiv:1408.4459 [hep-ph]]; G. Du, T. Li, D. V. Nanopoulos and S. Raza, Phys. Rev. D **92**, no. 2, 025038 (2015) [arXiv:1502.06893 [hep-ph]]; T. Li, S. Raza and X. C. Wang, Phys. Rev. D **93**, no. 11, 115014 (2016) [arXiv:1510.06851 [hep-ph]].

[5] R. Kitano and Y. Nomura, Phys. Lett. B **631**, 58 (2005) [hep-ph/0509039]; Phys. Rev. D **73**, 095004 (2006) [hep-ph/0602096].

[6] H. Baer, V. Barger, P. Huang, D. Mickelson, A. Mustafayev and X. Tata, Phys. Rev. D **87**, no. 11, 115028 (2013) [arXiv:1212.2655 [hep-ph]].

[7] T. Li and D. V. Nanopoulos, Phys. Lett. B **692**, 121-125 (2010) [arXiv:1002.4183 [hep-ph]].

[8] C. Balazs, T. Li, D. V. Nanopoulos and F. Wang, JHEP **02**, 096 (2011) [arXiv:1101.5423 [hep-ph]].