Probing Relatively Heavier Selectron at the CEPC, FCC_{ee}, and ILC

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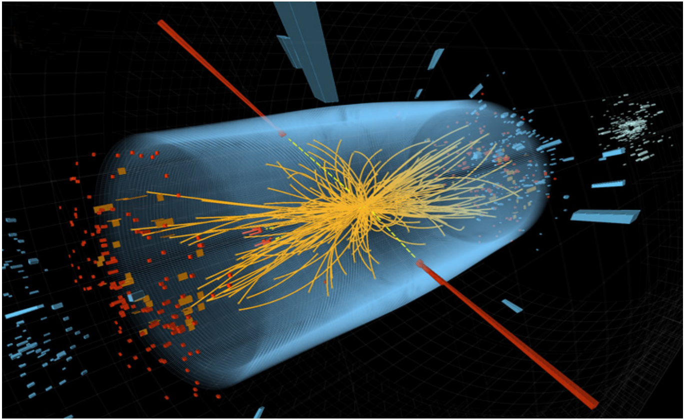
Joint Workshop of the CEPC Physics, Software and
New Detector Concept in 2022.

Outline

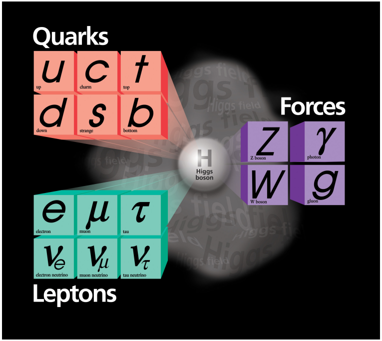
- The Standard Model
- Low Energy Supersymmetry
- SUSY@CEPC
- Scan Results for Light Bino
- Collider Analysis: Probing Relatively Heavy Right-Handed Selectron
- Summary

Discovery of the Higgs Boson



- It is 10th celebration of discovery of the Higgs Boson
- It completes the particle content of the Standard Model (SM)
- Is the party over? No, not yet.

The Standard Model (SM)



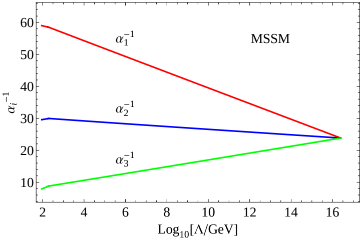
- The SM is a highly successful theory and has been tested rigorously.
- The SM is based on the gauge symmetry groups of strong nuclear force, weak nuclear force and electromagnetic force i.e $SU(3)_c \times SU(2)_L \times U(1)_Y$
- $SU(3)_c \longrightarrow$ QCD part
- $SU(2)_L \times U(1)_Y \longrightarrow$ Electroweak part

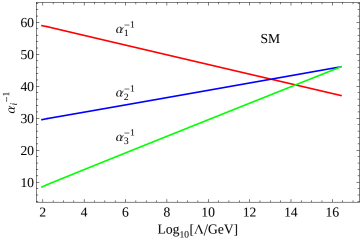
Shortcomings of the SM

- In the SM neutrinos are massless
- No dark matter (non-baryonic) candidate
- Gauge hierarchy problem ($\delta m_h^2 \propto \Lambda^2$)
- Electric charge is not fully quantized
- Non-unification of gauge couplings

Low Scale ($\sim$ TeV) Supersymmetry (SUSY):

- Arguably the most compelling extension of the Standard Model;
- Relates fermions to bosons and vice versa;
- Resolves the gauge hierarchy problem ;
- Provides cold dark matter candidate (LSP);
- Predicts new particles accessible at the LHC, and thereby enables unification of the SM gauge couplings;





The Minimal Supersymmetric Standard Model (MSSM)

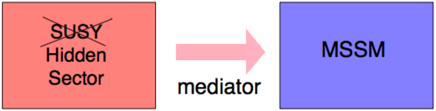
	Chiral Superfields	spin 0	spin $\frac{1}{2}$	$(SU(3), SU(2), U_Y(1))$
squarks and quarks	Q	$(\tilde{u}_L\, \tilde{d}_L)$	$(u_L\, d_L)$	$(3, 2, \frac{1}{6})$
	U^c	$\tilde{u}^c$	u^c	$(\bar{3}, 1, -\frac{2}{3})$
	D^c	$\tilde{d}^c$	d^c	$(\bar{3}, 1, \frac{1}{3})$
sleptons and leptons	L	$(\tilde{\nu}\, \tilde{e}_L)$	$(\nu\, e_L)$	$(1, 2, -\frac{1}{2})$
	E^c	$\tilde{e}^c$	e^c	$(1, 1, 1)$
Higgs and higgsinos	H_u	$(H_u^+\, H_u^0)$	$(\tilde{H}_u^+\, \tilde{H}_u^0)$	$(1, 2, \frac{1}{2})$
	H_d	$(H_d^0\, H_d^-)$	$(\tilde{H}_d^0\, \tilde{H}_d^-)$	$(1, 2, -\frac{1}{2})$

	Vector Superfields	spin $\frac{1}{2}$	spin 1	$(SU(3), SU(2), U_Y(1))$
gluinos and gluons	G	$\tilde{g}$	g	$(8, 1, 0)$
winos and W-bosons	W	$\widetilde{W}^\pm, \widetilde{W}^0$	$W^\pm, W^0$	$(1, 3, 0)$
bino and B-boson	B	$\widetilde{B}$	B	$(1, 1, 0)$

- $h, H, A, H^\pm$
- $R = (-1)^{3(B-L)+2S}$, R=1 (particles), R=-1 (sparticles)
- $\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^0 + N_{13}\tilde{H}_u^0 + N_{14}\tilde{H}_d^0$, Neutralino LSP. This is prime DM candidate.

SUSY Phenomenology

- SUSY is a broken symmetry ($m_e \neq m_{\tilde{e}}$)



- We have to break SUSY by introducing soft supersymmtery breaking terms (SSB)
- MSSM+SSB more than 100 parameters
- We have to relate these parameters, for example, CMSSM,NUHM2 etc.(High scale) and pMSSM(Low scale).

Where is SUSY?

- After Run-1 and Run-2 LHC SUSY searches show no evidence of SUSY particles
- Bounds on SUSY particle masses are getting higher and higher and thus providing strong constraints
- Low mass bounds on gluino (2.3 TeV), first two generation squarks (1.9 TeV), stop (1.25 TeV) and sbottom (1.5 TeV)
- Hint for Electroweak Fine Tuning problem. [1]

[1] for successful solutions see T. Leggett, T. Li, J. A. Maxin, D. V. Nanopoulos and J. W. Walker, PLB 740, 66 (2015), G. Du, T. Li, D. V. Nanopoulos and SR PRD 92, no. 2, 025038 (2015), T. Li, SR and X. C. Wang, PRD 93, no.11, 115014 (2016) and references there in.

Future e^+e^- Colliders

As compared to hadron colliders, in e^+e^- colliders we have:[2]

- well defined energy, momentum and polarization
- high precision measurements
- clean experimental environment
- superior sensitivity for electroweak states
- at lower energies (350GeV), circular e^+e^- colliders can deliver very large luminosities but higher energy e^+e^- requires linear colliders

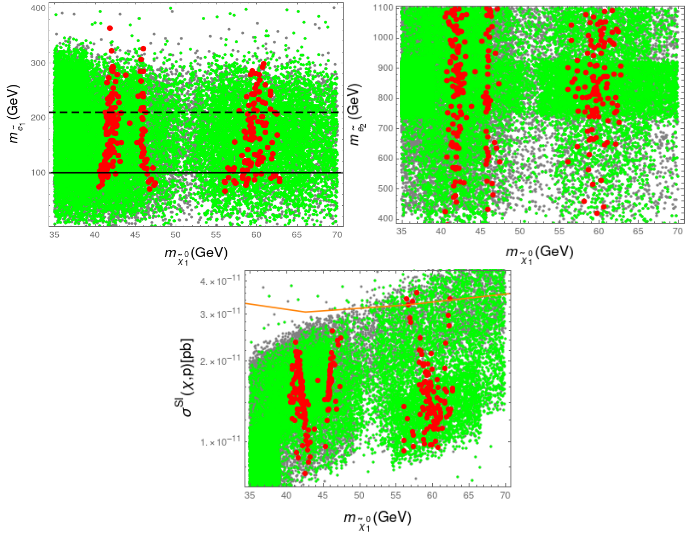
[2] from slides of Mogens Dam, Physics at Lepton Colliders, August 2019

Light Bino and Relatively Heavy Right-Handed Selepton

[W. Ahmed, I. Khan, T. Li, SR and W. Zhang, arXiv:2202.11011]

- We use low energy MSSM to probe right-handed sleptons using Higgs-pole and Z-pole solutions
- Higgs-pole $\rightarrow m_{\tilde{\chi}_1^0} \approx \frac{1}{2} m_h$ and Z-pole $\rightarrow m_{\tilde{\chi}_1^0} \approx \frac{1}{2} m_Z$.
- Our solutions satisfy cold dark matter relic density bounds from Planck2018 within 5σ along with other constraints
- We propose a search for the relatively heavier $\tilde{e}_R$ at the future lepton colliders with $\sqrt{s} = 240$ GeV and integrated luminosity 3000 fb^{-1} via mono-photon channel: $e_R^+ e_R^- \rightarrow \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) + \gamma$.
- The light neutralinos with large relic density may also be probed at the CEPC where the bino can be pair-produced via $t-$ channel selectron and then bino decays into axino and photon $e^+ e^- \rightarrow \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) \rightarrow 2\tilde{a} + 2\gamma$ (in preparation)

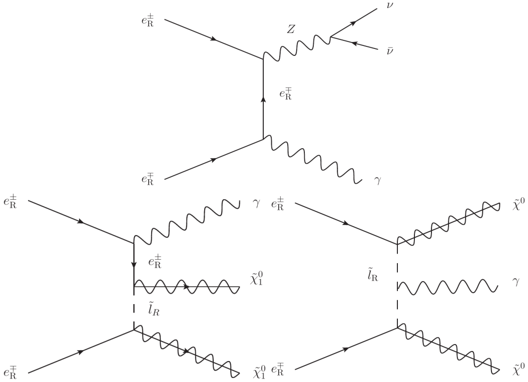
Results of Scans



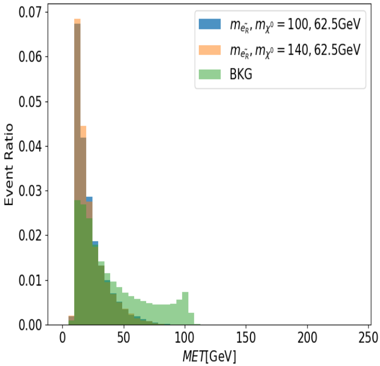
Gray points are consistent with the REWSB and LSP neutralino. Green points satisfy the mass bounds including $m_h = 125 \pm 3\,\mathrm{GeV}$ and the constraints from rare B-meson decays. Red points form a subset of green points and satisfy the 5σ Planck bounds on dark matter relic density. Here orange line represents the current XENON1T with $2\ t \cdot y$ bounds.

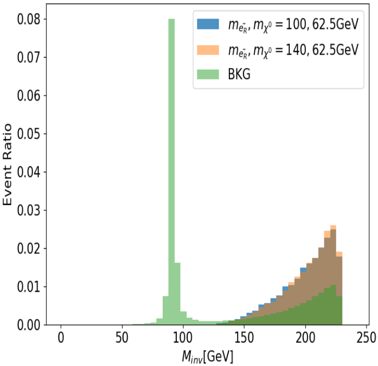
Collider Analysis:Probing Relatively Heavy Right-Handed Selepton

- We consider $e^+e^- \to \nu\bar{\nu}\gamma$ as SM background neglecting events involving $W^\pm$ as mediator.
- We study $e^+e^- \to \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) + \gamma$ @ $\sqrt{s} = 240$ GeV with $3000fb^{-1}$

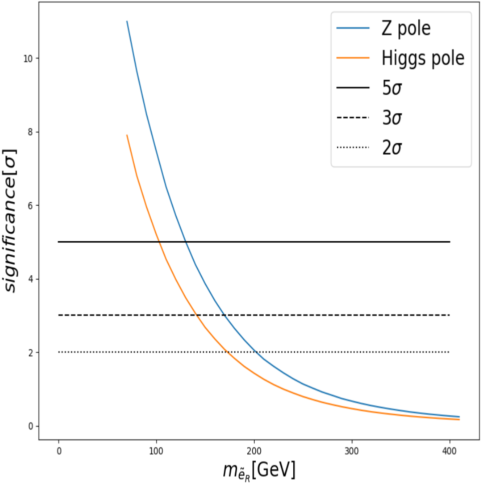


Collider Analysis:Relatively Heavy Right-Handed Selepton





Collider Analysis:Relatively Heavy Right-Handed Selepton



Summary

- The Low scale MSSM parameter space is presented for Z-pole and Higgs-pole
- The light binos with correct relic density may be probed at the CEPC via $e^+e^- \to \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) + \gamma$
- In the Z-pole case the right-handed selectron can be excluded up to 180 GeV and 210 GeV respectively at 3σ and 2σ.
- The right-handed selectron can be excluded up to 140 GeV and 180 GeV respectively at 3σ and 2σ in case of Higgs-pole.
- The light binos with large relic density can decay via $\tilde{\chi}_1^0 \to \tilde{a}\gamma$
- Such binos can be probed at the CEPC via $e^+e^- \to \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) \to 2\tilde{a} + 2\gamma$

Thank you very much!