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

Shabbar Raza

Department Physics,
Federal Urdu University of Arts, Science and Technology, Karachi, Pakistan.

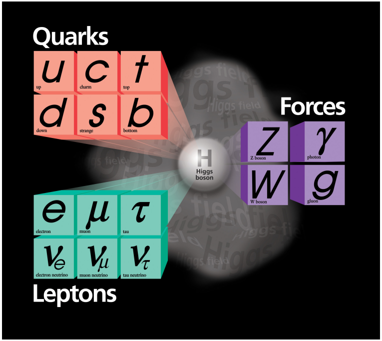
in collaboration with and Waqas Ahmed, Imtiaz Khan,
Tianjun Li and Wenxing Zhang.

The 2021 international workshop on the high energy Circular Electron-Positron Collider (CEPC) Nanjing University, P. R. China.

Outline

- The Standard Model
- Grand Unification
- Low Energy Supersymmetry
- e^+e^- Colliders
- SUSY@CEPC
- General minimal Supergravity Model(GmSUGRA)
- Preliminary Scan Results for Light Bino from GmSUGRA
- Summary

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

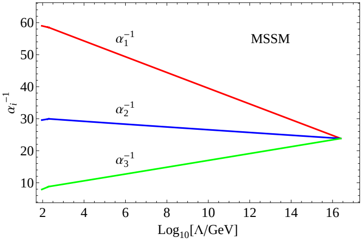
- In the SM neutrinos are massless
- No dark matter (non-baryonic) candidate
- Gauge hierarchy problem ($\delta m_h^2 \propto \Lambda^2$)
- Electric charge is not fully quantized
- Non-unification of gauge couplings

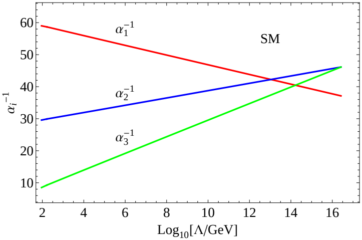
Grand Unification (GUTs)

- Unification of SM gauge couplings ($M_{GUT} \sim 10^{16}\,\mathrm{GeV}$);
- Unification of matter/quark-lepton multiplets;
- Electric charge quantization ;
- Seesaw physics / neutrino oscillations;
- Quark-Lepton mass relations;

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)

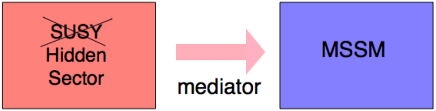
	Chiral Superfields	spin 0	spin $\frac{1}{2}$	$(SU(3), SU(2), U_Y(1))$
squarks and quarks	Q	$(\tilde{u}_L\, \tilde{d}_L)$	$(u_L\, d_L)$	$(3, 2, \frac{1}{6})$
	U^c	$\tilde{u}^c$	u^c	$(\bar{3}, 1, -\frac{2}{3})$
	D^c	$\tilde{d}^c$	d^c	$(\bar{3}, 1, \frac{1}{3})$
sleptons and leptons	L	$(\tilde{\nu}\, \tilde{e}_L)$	$(\nu\, e_L)$	$(1, 2, -\frac{1}{2})$
	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 (CMSSM,NUHM2 ..).

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

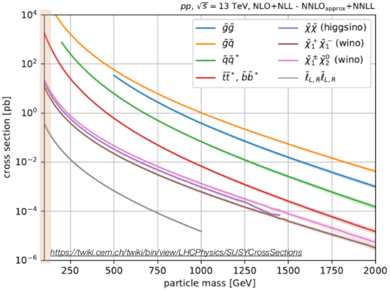
As compared to hadron colliders, in e^+e^- colliders we have:[2]

- 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

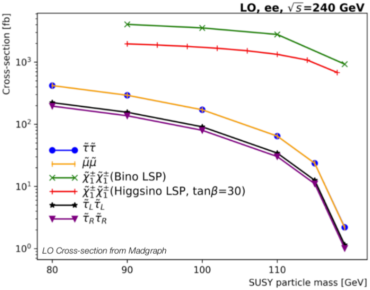
[2] from slides of Mogens Dam, Physics at Lepton Colliders, August 2019

SUSY @ CEPC [3]

Hadron collider



Lepton collider



For slepton prod. of 100 GeV, similar scale in LHC (~10^-1 pb) and CEPC (~10^2 fb).
Lepton collider can be powerful to probe the low mass region.

[3] from slides of Da XU (IHEP, CAS, SUSY2021)

The EWSSUY from General minimal Supergravity (GmSUGRA) Model

$$\frac{1}{\alpha_2} - \frac{1}{\alpha_3} = k \left(\frac{1}{\alpha_1} - \frac{1}{\alpha_3} \right) ,$$

$$\frac{M_2}{\alpha_2} - \frac{M_3}{\alpha_3} = k \left(\frac{M_1}{\alpha_1} - \frac{M_3}{\alpha_3} \right) ,$$

With $k = 5/3$ and assuming gauge coupling unification at the GUT scale ($\alpha_1 = \alpha_2 = \alpha_3$),

$$M_3 = \frac{5}{2} M_1 - \frac{3}{2} M_2 .$$

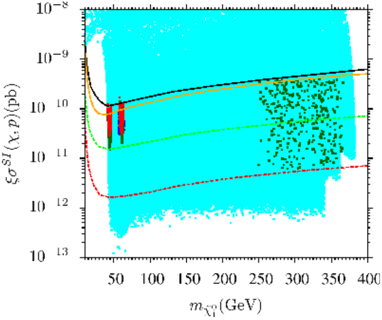
The EWSSUY from General minimal Supergravity (GmSUGRA) Model

$$m^2_{\tilde{Q}_i} = \frac{5}{6}(m_0^U)^2 + \frac{1}{6}m^2_{\tilde{E}_i^c} \ ,$$
$$m^2_{\tilde{U}_i^c} = \frac{5}{3}(m_0^U)^2 - \frac{2}{3}m^2_{\tilde{E}_i^c} \ ,$$
$$m^2_{\tilde{D}_i^c} = \frac{5}{3}(m_0^U)^2 - \frac{2}{3}m^2_{\tilde{L}_i} \ .$$

In addition, the Higgs soft masses m_{H_u} and m_{H_d}, and the trilinear soft terms A_U, A_D and A_E can all be free parameters

Light Neutralino Searches at CEPC

- We have two typed of Light neutralinos solutions that is solutions with correct relic density (Z-resonance and h-resonance)[4] and neutralino with large density [5]
- At CEPC we can probe it via $e^+e^- \to \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) + \gamma$

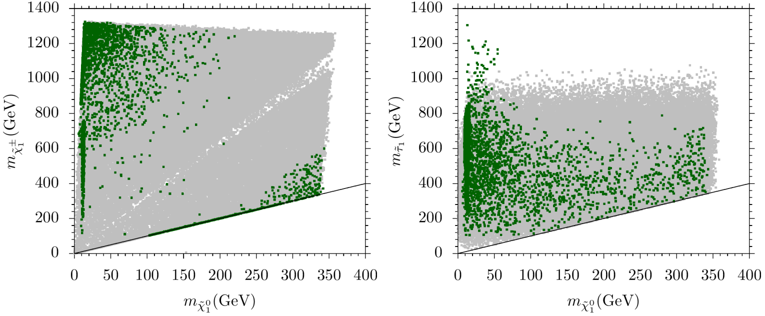


[4] arXiv:1709.06371
[5] arXiv:1409.3930

Light Neutralino Searches at CEPC

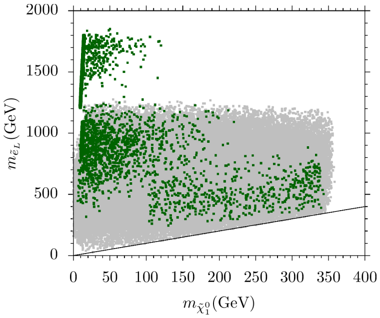
- The light neutralinos with large relic density may also be probed at the CEPC
- At the CEPC, the bino can be pair-produced via $t-$ channel selectron and then bino decays into axino and photon ($\tilde{\chi}_1^0 \to \tilde{a}\gamma$) as follows
- $e^+e^- \to \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) \to 2\tilde{a} + 2\gamma$

Light Neutralino from GmSUGRA (preliminary results)



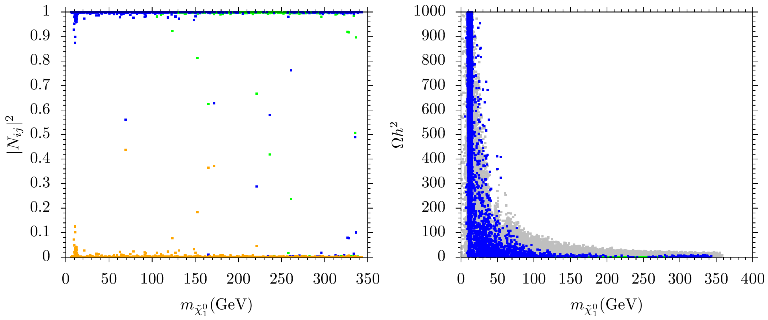
Gray points satisfy REWSB and neutralino as LSP conditions. Dark green points satisfy additional spartcile mass and B-physics bounds including $m_h = 125 \pm 3\,\mathrm{GeV}$ bounds.

Light Neutralino from GmSUGRA (preliminary results)



Gray points satisfy REWSB and neutralino as LSP conditions. Dark green points satisfy additional spartcile mass and B-physics bounds including $m_h = 125 \pm 3\,\mathrm{GeV}$ bounds.

Light Neutralino from GmSUGRA (preliminary results)

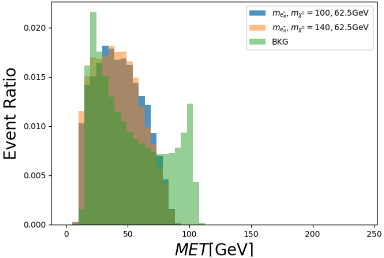


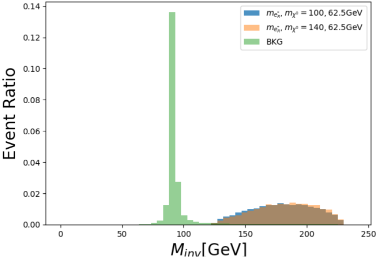
Gray points satisfy REWSB and neutralino as LSP conditions. (Left) Blue, green and orange points satisfy spartcile mass and B-physics bounds including $m_h = 125 \pm 3\,\mathrm{GeV}$ bounds represent bino-component, wino-component and higgsino-component respectively.(Right) Blue points show bino-type neutralino solutions and green points represent wino-dominant solutions.

	Point 1	Point 2	Point 3	Point 4
m_0	1387	1439	1449	1537
$m_{\tilde{Q}}$	1280.8	1316	1358.3	1404.1
$m_{\tilde{U}^c}$	1748.5	1851.1	1765.8	1981.3
$m_{\tilde{D}^c}$	1790.6	1857.7	1715.7	1945.9
$m_{\tilde{L}}$	19.8	140	912.9	475.7
$m_{\tilde{E}^c}$	472.6	192.6	756.2	132.2
M_1	0.1588	1.822	96.81	132.6
M_2	790.9	1015	812.9	1023
M_3	-1186	-1517.9	-977.33	-1203
$A_t = A_b$	3944	3693	3632	4981
A_τ	241	-536.3	-403.1	-238.2
$\tan\beta$	28.3	34.7	17.6	21.3
m_{H_u}	673.5	836.3	2631	3284
m_{H_d}	1193	647.3	2618	3284
m_h	123	122	123	125
$m_{H,A}$	1582,1572	1394, 1385	2515,2499	3060,3040
$m_{H^\pm}$	1585	1397	2516	3061
$m_{\tilde{g}}$	2638	3297	2220	2676
$m_{\tilde{\chi}^0_{1,2}}$	5.84,682	8.8, 878	45.9,326	62,355
$m_{\tilde{\chi}^0_{3,4}}$	2152, 2152	2461,2461	337, 712	363, 882
$m_{\tilde{\chi}^\pm_{1,2}}$	684, 881	2155, 2462	333,704	362,876
$m_{\tilde{u}_{L,R}}$	2625,2832	3165,3342	2374,2542	2752,2975
$m_{\tilde{t}_{1,2}}$	1838, 2056	2394,2607	1173, 1731	1069 ,1811
$m_{\tilde{d}_{L,R}}$	2627, 2880	3166, 3388	2375,2561	2753, 3016
$m_{\tilde{b}_{1,2}}$	1957, 2500	2447,2813	1717 ,2433	1812,2777
$m_{\tilde{\nu}_{(1,2),3}}$	437, 434	549,522	978, 935	670, 532
$m_{\tilde{e}_{L,R}}$	447, 574	550, 546	984 ,909	683, 613
$m_{\tilde{\tau}_{1,2}}$	356,618	265,627	816, 941	264 ,549
σ_{SI}(pb)	3.151×10^{-13}	3.98×10^{-13}	8.05×10^{-11}	7.33×10^{-11}
$\Omega_{CDM}h^2$	574	86	0.11	0.103

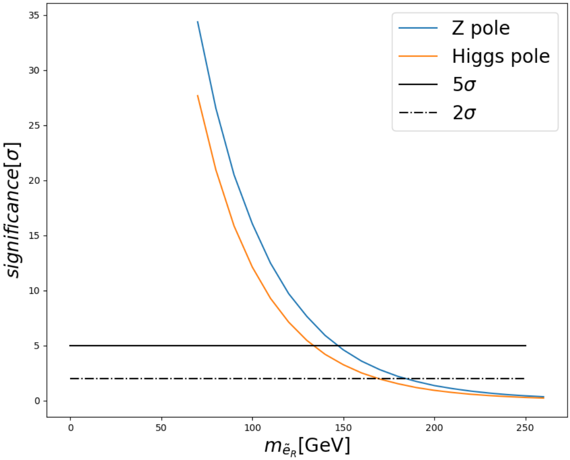
Light Neutralino from GmSUGRA: Collider Analysis (preliminary results)

- 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 $3000 fb^{-1}$





Light Neutralino from GmSUGRA: Collider Analysis (preliminary results)



Summary

- The preliminary scan results for the light bino from GmSUGRA are presented
- The light binos with correct relic density may also be probed at the CEPC via $e^+e^- \to \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) + \gamma$
- 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 $e^+e^- \to \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) \to 2\tilde{a} + 2\gamma$