

zhuangxa@ihep.ac.cn

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中國科學院為能物招為完備 Institute of High Energy Physics Chinese Academy of Sciences

SUSY Introduction



SUSY is one of the most favorite candidate for physics BSM, which can

- > provide a natural solution to the gauge hierarchy problem,
- provide DM candidate with PRC ,
- achieve gauge coupling unification,
- ▶
- CEPC would mainly concentrate on the generic searches for the charginos, neutralinos, and sleptons. And some relevant dark matter searches as well.

Current status: EU Strategy- Wino



ILC 500/CEPC240: discovery in all scenarios up to kinematic limit: $\sqrt{s/2}$

3

Current status: EU Strategy-Higgsino



4

Wino & Higgsino



CEPC240(FCCee/ILC): discovery for gauginos up to kinematic limit: $\sqrt{s/2}$



fine-tuning measures [1-3] generically predict the light Higgsinos

- 1. Phys. Lett. B 631, 58 (2005)
- 2. Phys. Rev. D 73, 095004 (2006)
- 3. arXiv:1212.2655

Stau & smuon



TECHNICAL DETAIL

About CEPC

ECM=240GeV, higgs factory, 100 km circumference, 2 interaction points. ILD-like detector

Software

Signal samples: MadGraph+Pythia8

Simulation: Mokka

Reconstruction: Marlin

- Normalized to 5050 fb^{-1}
- Dominant backgrounds:

> SM processes with two-e or two- μ or two- τ and large missing energy final states.

process	Cross Section [fb]
μμ	4967.58
ττ	4374.94
$WW \to \ell\ell$	392.96
$ZZorWW \rightarrow \mu\mu\nu\nu$	214.81
$ZZorWW \rightarrow \tau \tau \nu \nu$	205.84
$\nu Z, Z \to \mu \mu$	43.33
$ZZ \rightarrow \mu\mu\nu\nu$	18.17
$\nu Z, Z \to \tau \tau$	14.57
$ZZ \rightarrow \tau \tau \nu \nu$	9.2
$\nu\nu H, H \to \tau\tau$	3.07
$e\nu W, W \to \mu \nu$	429.2
$e\nu W, W \to \tau \nu$	429.42
$eeZ, Z \rightarrow \nu\nu$	29.62
$eeZ, Z \rightarrow vv \ or \ evW, W \rightarrow ev$	249.34







Direct stau/smuon



Cross-section based on Madgraph calculation

Chargino (Bino LSP)



Chargino (Higgsino LSP)









(a) E_{μ^-} ($E_{\mu^-} > 0.95$ GeV)

(b) M_{recoil} ($M_{recoil} > 237.5 \text{ GeV}$)

GAUGINO SEARCH

	Bino LSP	Higgsind	DLSP	
Process	Yields	Processes	Yields	
ZZ or $WW \rightarrow \mu\mu\nu\nu$	1638 ± 42	ZZ or $WW \rightarrow \mu\mu\nu\nu$	4.3 ± 2.1	
μμ	609 ± 61	μμ	49 ± 17	
$ZZ ightarrow \mu \mu u u$	27.7 ± 6.2	$ZZ ightarrow \mu\mu u u$	5.5 ± 2.8	
$ u Z, Z ightarrow \mu \mu$	47.9 ± 7.3	$ u Z, Z ightarrow \mu \mu$	36.7 ± 6.4	
$WW ightarrow \ell\ell$	163 ± 13	$WW ightarrow \ell\ell$	1.0 ± 1.0	
au au	88 ± 14	ττ	118 ± 16	>
ZZ or $WW ightarrow au au u u$	0.74 ± 0.74	ZZ or $WW \rightarrow \tau \tau \nu \nu$	3.1 ± 1.8	
ZZ ightarrow au au u u	-	ZZ ightarrow au au u u	$0.52{\pm}~0.52$	
u Z, Z ightarrow au au	-	u Z, Z ightarrow au au	-	
u u H, H ightarrow au au	-	u u H, H ightarrow au au	0.16 ± 0.16	
$e u W, W o \mu u$	-	$evW, W ightarrow \mu v$	-	
e u W, W o au u	-	evW, W o au v	$1.0{\pm}1.0$	
$eeZ, Z \rightarrow vv$	-	$eeZ, Z \rightarrow vv$	-	
$eeZ, Z \rightarrow vv$ or $evW, W \rightarrow ev$	-	$eeZ, Z \rightarrow vv$ or $evW, W \rightarrow ev$	-	
Total background	2568 ± 77	Total background	219 ± 25	
m ($\tilde{\chi}_{1}^{\pm}, \tilde{\chi}_{1}^{0}$) = (110, 1) GeV	5940 ± 130	$(\mu, \tan\beta) = (90 \text{ GeV}, 30)$	546±45	
m ($\tilde{\boldsymbol{\chi}}_{1}^{\pm}, \tilde{\boldsymbol{\chi}}_{1}^{0}$) = (110 , 10) GeV	6470 ± 140	$(\mu, \tan\beta) = (106 \text{ GeV}, 30)$	319±30	_
m ($\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0$) = (110 , 25) GeV	8470 ± 160	$(\mu, \tan\beta) = (118 \text{ GeV}, 30)$	400±23	1



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 ${\tilde \chi}_1^\pm \ W^\pm$

 e^{\pm}

GAUGINO SEARCH



 e^{\pm}

SLEPTON SEARCH













SLEPTON SEARCH



CEPC240(FCCee/ILC): discovery for slepton nearly up to kinematic limit: $\sqrt{32}$

Paper drafts

Prospects for chargino pair production at CEPC

Jia-Rong Yuan (袁家荣)¹², Hua-Jie Cheng (程华杰)²³, Xu-Ai Zhuang (庄胥爱)^{*2}

¹ School of Physics, Nankai University, Weijin Road 94, Nankai District, Tianjin 300071, China

² Institute of High Energy Physics, Chinese Academy of Science, Yuquan Road 19B, Shijingshan District, Beijing 100049, China

³ Department of Physics, National Taiwan University, Roosevelt Road 1 Sec. 4, Taipei 10617, Taiwan

* email:zhuangxa@ihep.ac.cn (corresponding author)

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The proposed Circular Electron Positron Collider (CEPC) with a center-of-mass energy $\sqrt{s} = 240$ GeV will serve as a Higgs factory, while it can offer good opportunity for new physics search at low energy, which is challenging in hadron colliders but motivated by some theory model such as dark matter. This paper presents the sensitivity study of chargino pair production with both Bino $\tilde{\chi}_1^0$ and Higgsino $\tilde{\chi}_1^0$ cases at CEPC using full Monte Carlo (MC) simulation. With the assumption of flat 5% systematic uncertainty, the CEPC has the ability to discover chargino pair production for both Bino $\tilde{\chi}_1^0$ and Higgsino $\tilde{\chi}_1^0$ cases up to kinematic limit $\sqrt{s}/2$. Because of the conserved assumption of systematic uncertainty and limited reliance on the reconstruction and detector geometry in this study, the results can be used as reference for similar searches in other electron positron colliders at a central-of-mass energy close to 240 GeV, such as FCC-ee and ILC.

Keywords: CEPC; chargino; Bino; Higgsino

CONTENTS

1	Introduction	2
2	Detector, Software and Sample	3
3	Search for chargino pair production at CEPC	4
	3.1 Search for chargino pair production with Bino LSP	4
	3.2 Search for chargino pair production with Higgsino LSP	6
4	Conclusion	9
5	Acknowledgements	9

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Prospects for slepton pair production in the future e^-e^+ Higgs factories

^{(D}Jiarong Yuan^{1,2}, ^{(D}Huajie Cheng^{2,3}, ^{(D}Xuai Zhuang^{a,2})

School of Physics, Nankai University, Weijin Road 94, Nankai District, Tianjin 300071, China ²Institute of High Energy Physics, Chinese Academy of Science, Yuquan Road 19B, Shijingshan District, Beijing 100049, China ³Department of Physics, National Taiwan University, Roscevelt Road 1 Sec. 4, Tajaei 10617, Taiwan

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Abstract The Circular Electron Positron Collider (CEPC) with a center-of-mass energy $\sqrt{s} = 240$ GeV is proposed to serve as a Higgs factory, while it can also provide good opportunity for new physics searches at lower energy, which are difficult in hadron collider but well-motivated by some theories, such as dark matter. This paper presents the sensitivity study of direct stau/smuon production searches in CEPC with full Monte Carlo (MC) simulation. With the assumption of a conserved systematic uncertainty at 5%, the CEPC has the potential to discover the production of combined LH and RH stau up to 116 GeV with 5 sigma if existed, or up to 113 GeV for the production of pure LH/RH stau: the discovery potential of direct smuon reaches up to 117 GeV with the same assumption. The results can also provide reference to similar searches in other electron-positron colliders with a close central-of-mass energy, such as the ILC and FCC-ee, due to the conserved systematic uncertainty and small dependence on the detector geometry and reconstruction in the analysis.

Declarations

This study was supported by the National Key Programme (Grant NO.: 2018YFA0404000). The data used in this study won't be deposited, because this study is a simulation study without any experiment data.

1 Introduction

Spuersymmetry (SUSY) [1–7] proposes that there is a superpartner, known as sparticle, for every Standard Model (SM) particle, whose spin is different by a half from the corresponding SM particle. With *R*-parity [8] conserved, SUSY particles are produced in pair, and the lightest supersymmetric particle (LSP) is stable and weakly interacting, which makes LSP can't be detected directly and a dark matter candidate [9, 10].

The linear superpositions of charged and neutral Higgs bosons and electroweak gauge bosons formed two charged mass eigenstates called charginos and four neutral mass eigenstates called neutralinos. The superpartner of a lepton is a slepton whose chirality is the same as the lepton's chirality. The slepton mass eigenstates formed from superpositions of left-handed sleptons and right-handed sleptons.

Models with light sleptons satisfies the dark matter relic density measurements [11]. And lightight sleptons can take part in the coannihilation of neutralinos [12, 13]. Models with light smuons can explain $(g-2)_{\mu}$ excess [14]. In gaugemediated [15–17] and anomaly-mediated [18, 19] SUSY breaking models, the mass of sleptons are expected to be of the order of magnitude of 100 GeV.

LEP set lower mass limit on $\tilde{\mu}_R$ of 94.9 GeV with $m_{\tilde{\mu}_R} - m_{\tau^0}$ above 10 GeV and set a lower mass limit on $\tilde{\tau}$ of 87 - 93

GeV depending on the $\tilde{\chi}_1^0$ mass, for $m_{\tilde{\tau}} - m_{\tilde{\chi}_1^0} > 7$ GeV [20]. ATLAS and CMS have excluded the smuon/stau mass up to 700 / 300 GeV with massless LSP for simplified model, however, for the cases with massive LSP, especially when the mass split of slepton and LSP is very small, the sensitivity from LHC is limited by the trigger requirement [21–24].

Comparing to LHC, CEPC has very clean collision environment, which means less backgrounds. Comparing to LEP, CEPC has higher center-of-mass energy. And there is no trigger requirement for CEPC, so CEPC should have excellent sensitivity in compressed region. Reconstruction and identification efficiencies for tracks and single particles (e.g. muon) are very high in CEPC, which ensures sufficient sensitivities for the scenarios with very soft objects [25].



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ae-mail: zhuangxa@ihep.ac.cn(corresponding author)

Curves contributed to a Snowmass report

summary plot



Summary and Outlook

- Search for sleptons and electroweakinos were performed at CEPC.
 - > The discovery potential for electroweakinos (winolike & higgsino-like) is up to kinematic limit: $\sqrt{s/2}$.
 - The discovery potential for smuon and stau are nearly up to kinematic limit (up to ~116-117 GeV)
- The results can also be used as reference for other lepton colliders like ILC and FCC-ee etc.
- Paper drafts are almost done and to be provided as inputs for snowmass white paper.



STAU SEARCH

process	SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
$ZZ \text{ or } WW \rightarrow \mu\mu\nu\nu$	8.5 ± 3.0	1.1 ± 1.1	$74.8 {\pm} 8.9$
μμ	-	-	408 ± 50
$\nu Z, Z \rightarrow \mu \mu$	$3.3{\pm}1.9$	$2.2{\pm}1.6$	$698{\pm}28$
$ZZ \rightarrow \mu \mu \nu \nu$	$\frac{1.4 \pm 1.4}{2}$	-	$54.0 {\pm} 8.6$
$WW \rightarrow \ell\ell$	91.0 ± 9.6	38.9±6.3	$284{\pm}17$
ZZ or WW ightarrow au au u u u	41.2 ± 6.5	275 ± 17	1247 ± 36
au au	15.9±6.0	$15.9{\pm}6.0$	497±34
u Z, Z ightarrow au au	15.6 ± 3.4	$25.2{\pm}4.3$	$232\pm\!13$
ZZ ightarrow au au u u	17.7 ± 3.1	19.3 ± 3.2	49.3 ± 5.1
u u H, H ightarrow au au	-	-	-
$evW, W ightarrow \mu v$	$39{\pm}20$	-	$9.8{\pm}9.8$
evW, W ightarrow au v	$147{\pm}12$	185 ± 14	$139\pm\!12$
$eeZ, Z \rightarrow vv$	$9.2{\pm}3.1$	-	8.2 ± 2.9
$eeZ, Z \rightarrow vv$ or $evW, W \rightarrow ev$	$98{\pm}10$	$25.7{\pm}5.1$	54.5±7.5
Total background	$488 \pm \! 29$	589 ± 25	3756±81
$\mathbf{m}(\tilde{\tau}_{L,R},\tilde{\boldsymbol{\chi}}_1^0) = (115,20) \mathrm{GeV}$	3400±170	3070±160	2110±140
$m(\tilde{\tau}_{L,R},\tilde{\chi}_1^0) = (100,20) \text{ GeV}$	$200{\pm}15$	377 ± 21	374 ± 21
$m(\tilde{\tau}_{L,R}, \tilde{\chi}_1^0) = (100, 80) \text{ GeV}$	-	1.2 ± 1.2	3143±61

Table 2 The number of events in the signal regions for signal and SM backgrounds with statistical uncertainty for direct stau production



SMUON SEARCH

process	SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
$ZzorWW \rightarrow \mu\mu\nu\nu$	1561±41	18020±140	168±13
<u> </u>	1096 ± 82	$8000{\pm}220$	2180 ± 120
$ u Z, Z ightarrow \mu \mu$	97±10	$423{\pm}22$	$468{\pm}23$
$ZZ ightarrow \mu \mu u u$	69.2 ± 9.8	$160{\pm}15$	52.6 ± 8.5
$WW ightarrow \ell\ell$	$164{\pm}13$	7672 ± 89	$282{\pm}17$
ZZorWW ightarrow au au u u	$3.1{\pm}1.8$	$2128{\pm}47$	$326{\pm}18$
ττ	73 ± 13	3748 ± 92	1782 ± 64
ZZ ightarrow au au u u	$1.07{\pm}0.76$	69.1±6.1	19.8±3.3
u Z, Z ightarrow au au	-	83.7±7.9	51.9±6.2
u u H, H ightarrow au au	-	47.9 ± 2.7	$5.12 {\pm} 0.89$
$e v W, W ightarrow \mu v$	-	-	-
evW, W ightarrow au v	-	-	-
$eeZ, Z \rightarrow vv$	-	-	-
$eeZ, Z \rightarrow vv$ or $evW, W \rightarrow ev$	-	-	-
Total background	3064±94	40350±300	5340±140
$m(\tilde{\mu}, \tilde{\chi}_1^0) = (100, 10) \text{ GeV}$	8820±280	19450±410	190±40
$m(\tilde{\mu}, \tilde{\chi}_1^0) = (100, 50) \text{ GeV}$	$8190{\pm}270$	58680±710	$104{\pm}30$
$m(\tilde{\mu}, \tilde{\chi}_1^0) = (100, 95) \text{ GeV}$	-	$17{\pm}12$	114360±990

Table 4 The number of events in the signal regions for signal and SM backgrounds with statistical uncertainty for direct smuon production



New Physics beyond the SM





ATLAS SUSY Searches* - 95% CL Lower Limits

	Model	S	ignatur	e ∫	<i>L dt</i> [fb ⁻	¹] Mass	limit			Reference	
\$	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q \tilde{\chi}_1^0$	0 e, μ mono-jet	2-6 jets 1-3 jets	E_T^{miss} E_T^{miss}	139 36.1	 <i>q̃</i> [10× Degen.] <i>q̃</i> [1×, 8× Degen.] 	0.43 0.71	1.9	m(𝔅˜¹)<400 GeV m(𝔅)-m(𝔅˜¹)=5 GeV	ATLAS-CONF-2019-040 1711.03301	
arche	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q \tilde{q} \tilde{\chi}_1^0$	0 <i>e</i> , <i>µ</i>	2-6 jets	$E_T^{\rm miss}$	139	ğ ğ	Forbidden	1.15-1.95	$\begin{array}{c} \textbf{.35} \\ m(\tilde{\chi}_1^0){=}0 \text{ GeV} \\ m(\tilde{\chi}_1^0){=}1000 \text{ GeV} \end{array}$	ATLAS-CONF-2019-040 ATLAS-CONF-2019-040	
Se	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}W\tilde{\chi}_1^0$	1 e, µ	2-6 jets		139	ğ			2 m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2020-047	
ive	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	ee,µµ	2 jets	E_T^{miss}	36.1	Ĩ		1.2	$m(\tilde{g})-m(\tilde{\chi}_1^0)=50 \text{ GeV}$	1805.11381	
Iclus	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_1^{\prime\prime}$	0 e, μ SS e, μ	6 jets	$E_T^{\rm mass}$	139 139	ğ ğ	1.	.15	$m(\tilde{\chi}_{1}^{0}) < 600 \text{ GeV}$ $m(\tilde{g}) - m(\tilde{\chi}_{1}^{0}) = 200 \text{ GeV}$	ATLAS-CONF-2020-002 1909.08457	
7	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t \tilde{\chi}_1^0$	0-1 <i>e</i> ,μ SS <i>e</i> ,μ	3 <i>b</i> 6 jets	$E_T^{\rm miss}$	79.8 139	ğ ğ		1.25	25 m($\tilde{\chi}_1^0$)<200 GeV m(\tilde{g})-m($\tilde{\chi}_1^0$)=300 GeV	ATLAS-CONF-2018-041 1909.08457	
	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_1^0 / t \tilde{\chi}_1^{\pm}$		Multiple Multiple		36.1 139	^b ₁ Forbidden ^b ₁ ^c	orbidden 0.74	m($m(\tilde{\chi}_{1}^{0})=300 \text{ GeV}, BR(b\tilde{\chi}_{1}^{0})=1$ $\tilde{\chi}_{1}^{0}=200 \text{ GeV}, m(\tilde{\chi}_{1}^{*})=300 \text{ GeV}, BR(t\tilde{\chi}_{1}^{*})=1$	1708.09266, 1711.03301 1909.08457	
sy	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 \rightarrow b h \tilde{\chi}_1^0$	0 e,μ 2 τ	6 b 2 b	$E_T^{ m miss}$ $E_T^{ m miss}$	139 139	\tilde{b}_1 Forbidden \tilde{b}_1	0 0.13-0.85	3-1.35	$\begin{array}{l} \Delta m(\tilde{\chi}_{2}^{0},\tilde{\chi}_{1}^{0}) {=} 130 \ \text{GeV}, \ m(\tilde{\chi}_{1}^{0}) {=} 100 \ \text{GeV} \\ \Delta m(\tilde{\chi}_{2}^{0},\tilde{\chi}_{1}^{0}) {=} 130 \ \text{GeV}, \ m(\tilde{\chi}_{1}^{0}) {=} 0 \ \text{GeV} \end{array}$	1908.03122 ATLAS-CONF-2020-031	
uar	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$	0-1 e, µ	≥ 1 jet	$E_T^{\rm miss}$	139	ĩ ₁		1.25	$m(\tilde{\chi}_1^0)=1 \text{ GeV}$	ATLAS-CONF-2020-003, 2004.14060	
sd	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow W b \tilde{\chi}_1^0$	1 e, µ	3 jets/1 b	$E_T^{\rm miss}$	139	Ĩ1	0.44-0.59	_	$m(\tilde{\chi}_1^0)=400 \text{ GeV}$	ATLAS-CONF-2019-017	
gen.	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 bv, \tilde{\tau}_1 \rightarrow \tau G$	$1\tau + 1e,\mu,\tau$	2 jets/1 b	ETT ETT	36.1	<i>ī</i> 1	0.95	6	m($\tilde{\tau}_1$)=800 GeV	1803.10178	
3rd dire	$I_1I_1, I_1 \rightarrow cX_1 / cc, c \rightarrow cX_1$	0 e,μ	mono-jet	E_T E_T^{miss}	36.1	\tilde{t}_1 \tilde{t}_1	0.46 0.43		$\begin{array}{c} m(\tilde{x}_1) = 0 \text{ GeV} \\ m(\tilde{t}_1, \tilde{c}) - m(\tilde{\chi}_1^0) = 50 \text{ GeV} \\ m(\tilde{t}_1, \tilde{c}) - m(\tilde{\chi}_1^0) = 5 \text{ GeV} \end{array}$	1805.01649 1805.01649 1711.03301	
	$ \begin{split} \tilde{t}_1 \tilde{t}_1, \tilde{t}_1 {\rightarrow} t \tilde{\chi}_2^0, \tilde{\chi}_2^0 {\rightarrow} Z/h \tilde{\chi}_1^0 \\ \tilde{t}_2 \tilde{t}_2, \tilde{t}_2 {\rightarrow} \tilde{t}_1 + Z \end{split} $	1-2 e,μ 3 e,μ	1-4 b 1 b	$E_T^{ m miss} \ E_T^{ m miss}$	139 139	τ̃ ₁ τ̃ ₂	0.067- Forbidden 0.86	18	$\begin{array}{l} {\sf m}(\tilde{\chi}^0_2){=}500~{\rm GeV} \\ {\sf m}(\tilde{\chi}^0_1){=}360~{\rm GeV},~{\sf m}(\tilde{\iota}_1){\cdot}{\sf m}(\tilde{\chi}^0_1){=}~40~{\rm GeV} \end{array}$	SUSY-2018-09 SUSY-2018-09	
	${ ilde \chi}_1^{\pm} { ilde \chi}_2^0$ via WZ	З е, µ ее, µµ	≥ 1 jet	E_T^{miss} E_T^{miss}	139 139	$ \tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{2}^{0} $ $ \tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{2}^{0} $ 0.205	0.64		$m(\tilde{\chi}_1^0)=0$ $m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)=5 \text{ GeV}$	ATLAS-CONF-2020-015 1911.12606	
	$\tilde{\chi}_{1}^{\pm}\tilde{\chi}_{1}^{\mp}$ via WW	2 e, µ		Emiss	139	$\tilde{\chi}_{\pm}^{1}$	0.42		$m(\tilde{\chi}_1^0)=0$	1908.08215	
_	$\tilde{\chi}_1^{\pm} \tilde{\chi}_2^0$ via Wh	0-1 e, µ	$2 b/2 \gamma$	E_T^{miss}	139	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ Forbidden	0.74		$m(\tilde{\chi}_1^0)=70 \text{ GeV}$	2004.10894, 1909.0022	
V	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp}$ via $\tilde{\ell}_L / \tilde{\nu}$	2 e, µ		E_T^{miss}	139	$\tilde{\chi}_1^{\pm}$	1.0		$m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\ell}_{1}^{\pm})+m(\tilde{\ell}_{1}^{0}))$	1908.09215	
<u> </u>	$\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau \tilde{\chi}_1^0$ $\tilde{\tau} = \tilde{\tau} = \tilde{\tau} + c \tilde{c}^0$	27	0 iots	Emiss Emiss	139	τ [τ _L , τ _{R,L}] 0.16-0.3 0.1	2-0.39		$m(\tilde{\chi}_1^0)=0$	1911.060	
	$\iota_{L,R}\iota_{L,R}, \iota \rightarrow \iota \iota_1$	ee,µµ	≥ 1 jet	E_T^{T}	139	<i>t</i> <i>t</i> 0.256	0.7		$m(\tilde{\ell})-m(\tilde{\chi}_1^0)=10 \text{ GeV}$	1911.12606	
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, μ 4 e, μ	$\geq 3 b$ 0 jets	$\stackrel{E_{T}^{\rm miss}}{E_{T}^{\rm miss}}$	36.1 139	Й 0.13-0.23 Й	0.29-0.88		$\begin{array}{c} BR(\tilde{k}^0_1 \to h\bar{G}){=}1 \\ BR(\tilde{k}^0_1 \to Z\bar{G}){=}1 \end{array}$	1806.04030 ATLAS-CONF-2020-040	
lived	Direct $\tilde{\chi}_1^* \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	$E_T^{\rm miss}$	36.1		0.46		Pure Wino Pure higgsino	1712.02118 ATL-PHYS-PUB-2017-019	
nd-l	Stable g R-hadron		Multiple		36.1	<i>ğ</i>		2.0		1902.01636,1808.04095	
Pa	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow qq \tilde{\chi}_1^0$		Multiple		36.1	$\tilde{g} = [\tau(\tilde{g}) = 10 \text{ ns}, 0.2 \text{ ns}]$		2.0	2.4 $m(\tilde{\chi}_1^0)=100 \text{ GeV}$	1710.04901,1808.04095	
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_1^0 , \tilde{\chi}_1^{\pm} {\rightarrow} Z \ell {\rightarrow} \ell \ell \ell$	3 e, µ			139	$\tilde{\chi}_{1}^{\mp}/\tilde{\chi}_{1}^{0}$ [BR($Z\tau$)=1, BR(Ze)=1]	0.625 1.05		Pure Wino	ATLAS-CONF-2020-009	
	LFV $pp \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow e\mu/e\tau/\mu\tau$	εμ,ετ,μτ	0 into	remiss	3.2	\tilde{Y}_{τ}	0.00	1.9	$\lambda'_{311}=0.11, \lambda_{132/133/233}=0.07$	1607.08079	
	$\chi_1^-\chi_1^-/\chi_2^- \rightarrow WW/Z\ell\ell\ell\ell\nu\nu$	4 e, µ 4	-5 large-R ie	E _T	36.1	$X_1^-/X_2^ [A_{i33} \neq 0, A_{12k} \neq 0]$ $\tilde{x} = [m(\tilde{x}^0) - 200 \text{ GeV} + 1100 \text{ GeV}]$	0.82	1.33	m(X1)=100 GeV	1804.03602	
>	$gg, g \rightarrow qq x_1, x_1 \rightarrow qq q$		Multiple		36.1	$\hat{g} = [\mathcal{X}'_{112} = 20.4, 20.5]$	1.05	2.0	$m(\tilde{\chi}_1^0)=200$ GeV, bino-like	ATLAS-CONF-2018-003	
RF	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow t \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow t b s$		Multiple		36.1	<i>τ̃</i> [λ ₃₂₃ ["] =2e-4, 1e-2]	0.55 1.05		$m(\tilde{\chi}_1^0)$ =200 GeV, bino-like	ATLAS-CONF-2018-003	
	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow b\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{\pm} \rightarrow bbs$		$\geq 4b$		139	ĩ	Forbidden 0.95		m(𝑋1)=500 GeV	ATLAS-CONF-2020-016	
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow bs$	2.4.4	2 jets + 2 b	,	36.7	$t_1 [qq, bs]$	0.42 0.61	0.4.1.45	DD/2 the/hole 000/	1710.07171	
	$t_1t_1, t_1 \rightarrow qt$	2 e, μ 1 μ	2 b DV		136.1	\tilde{t}_1 [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e	e-9] 1.0	0.4-1.45	$BR(t_1 \rightarrow be/b\mu) > 20\%$ BR(t_1 \rightarrow q\mu)=100\%, cos\theta_t=1	2003.11956	
	•										
						L					
*Only	a selection of the available ma	ss limits on i	new state	s or	1	0 ⁻¹	1		Mass scale [TeV]		

phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

ATLAS Preliminary $\sqrt{s} = 13 \text{ TeV}$

EU Strategy- SUSY: ~g

https://arxiv.org/pdf/1910.11775.pdf



Fig. 8.6: Gluino exclusion reach of different hadron colliders: HL- and HE-LHC [443], and FCC-hh [139,448]. Results for low-energy FCC-hh are obtained with a simple extrapolation.



EU Strategy- SUSY: ~q

All Colliders: squark projections



(R-parity conserving SUSY, prompt searches)



Fig. 8.7: Exclusion reach of different hadron and lepton colliders for first- and second-generation squarks.



EU Strategy- SUSY: ~t

All Colliders: Top squark projections

(R-parity conserving SUSY, prompt searches)



	Model ∫⊥	<i>dt</i> [ab ⁻¹]	√ s [TeV]	Mass limit (95% CL exclusion)	Conditions
с	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$	3	14	1.7 TeV	$m(\tilde{X}_1^0) = 0$
нг-гн	$ ilde{t}_1 ilde{t}_1, ilde{t}_1{ ightarrow} t ilde{\chi}_1^0$ /3 body	3	14	0.85 TeV	$\Delta m(ilde{t}_1, ilde{\chi}_1^0) \sim m(ilde{t})$
	$ ilde{t}_1 ilde{t}_1, ilde{t}_1{ ightarrow}c ilde{\chi}_1^0$ /4 body	3	14	0.95 TeV	$\Delta {\sf m}(ilde{t}_1, ilde{\chi}_1^0) {\sim} 5$ GeV, monojet (*)
с	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{\chi}^{\pm}/t\tilde{\chi}^0_1, \tilde{\chi}^0_2$	15	27	3.65 TeV	$m(\tilde{\chi}^0_1) = 0$
Η̈́	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0/3$ -body	15	27	1.8 TeV	$\Delta m(ilde{t}_1, ilde{\chi}_1^0) \sim m(t)$ (*)
I	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 {\rightarrow} c \tilde{\chi}_1^0$ /4-body	15	27	2.0 TeV	$\Delta {\sf m}(ilde{t}_1, ilde{\chi}_1^0)$ ~ 5 GeV, monojet (*)
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$	15	37.5	4.6 TeV	m($ ilde{\mathcal{X}}_1^0$)=0 (**)
-FCC	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0/3$ -body	15	37.5	4.1 TeV	m $(ilde{\mathcal{X}}_1^0)$ up to 3.5 TeV (**)
μ	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 {\rightarrow} c \tilde{\chi}_1^0$ /4-body	15	37.5	2.2 TeV	$\Delta m(ilde{t}_1, ilde{\chi}_1^0)\sim$ 5 GeV, monojet (**)
00	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 {\rightarrow} b \tilde{\chi}^{\pm} / t \tilde{\chi}_1^0$	2.5	1.5	0.75 TeV	$m(\tilde{\chi}_1^0)=0$
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 {\rightarrow} b \tilde{\chi}^{\pm} / t \tilde{\chi}_1^0$	2.5	1.5	0.75 TeV	$\Delta m(ilde{t}_1, ilde{\chi}_1^0) \sim m(t)$
σ	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 {\rightarrow} b \tilde{\chi}^{\pm} / t \tilde{\chi}_1^0$	2.5	1.5	(0.75 - ε) TeV	$\Delta m(ilde{t}_1, ilde{\chi}_1^0)$ ~ 50 GeV
000	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow b \tilde{\chi}^{\pm} / t \tilde{\chi}_1^0$	5	3.0	1.5 TeV	m($ ilde{\mathcal{X}}_1^0$)~350 GeV
:LIC ₃	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 {\rightarrow} b \tilde{\chi}^{\pm} / t \tilde{\chi}_1^0$	5	3.0	1.5 TeV	$\Delta m(ilde{t}_1, ilde{\mathcal{X}}_1^0)$ ~ $m(t)$
0	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 {\rightarrow} b \tilde{\chi}^{\pm} / t \tilde{\chi}_1^0$	5	3.0	(1.5 - <i>e</i>) TeV	$\Delta m(ilde{t}_1, ilde{\chi}_1^0)$ ~ 50 GeV
ę	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	30	100	10.8 TeV	$m(\tilde{\chi}_1^0)=0$
-C-h	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0/3$ -body	30	100	10.0 TeV	m $(ilde{\chi}^0_1)$ up to 4 TeV
ш	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0/4$ -body	30	100	5.0 TeV	$\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) \sim 5$ GeV, monojet (*)
			1	0 ⁻¹ 1 Mass scale [TeV]	

(*) indicates projection of existing experimental searches

(**) extrapolated from FCC-hh prospects

 ϵ indicates a possible non-evaluated loss in sensitivity



MSSM charginos and neutralinos

Mass matrices

$$\begin{array}{c} \text{charginos} \\ \text{in } (\tilde{W}^{-}, \tilde{H}^{-}) \text{ basis} \\ \begin{pmatrix} M_2 & \sqrt{2}m_W c_\beta \\ \sqrt{2}m_W s_\beta & \mu \end{pmatrix} \end{pmatrix} \xrightarrow{\text{neutralinos}} \\ \begin{array}{c} \text{in } (\tilde{B}^0, \tilde{W}^0, \tilde{H}^0_1, \tilde{H}^0_2) \text{ basis} \\ \begin{pmatrix} M_1 & 0 & -m_Z c_\beta s_w & m_Z s_\beta s_w \\ 0 & M_2 & m_Z c_\beta c_w & -m_Z s_\beta c_w \\ -m_Z c_\beta s_w & m_Z c_\beta c_w & 0 & -\mu \\ m_Z s_\beta s_w & -m_Z s_\beta c_w & -\mu & 0 \end{pmatrix} \end{array}$$

 M_2 real, $M_1 = |M_1|e^{i\Phi_1}$, $\mu = |\mu|e^{i\Phi_\mu}$

At tree level:

charginos $M_2, \mu, \tan \beta$ neutralinos $+M_1$ Φ_{μ}, Φ_{1} CP phases

Expected to be among the lightest sparticles



A good starting point towards SUSY parameter determination



EWK-ino production

Mass splitting of the EWKinos depends on M1, M2, μ and tan β

	Bino L	_SP		Hig	igsino LS	SP	Wino LSP			
μ	higgsino		$\widetilde{\chi_3^0}, \widetilde{\chi_4^0}, \widetilde{\chi_2^\pm}$	M ₁)	$\widetilde{\chi_4^0}$	M1	bino		$\widetilde{\chi_4^0}$
M ₂	wino	_	$\widetilde{\chi}_{2}^{0},\widetilde{\chi}_{1}^{\pm}$	M ₂ win		$\widetilde{\chi_{3}^{0}}, \widetilde{\chi_{2}^{\pm}}$	μ	higgsino		$\widetilde{\chi}_{2}^{0}, \widetilde{\chi}_{3}^{0}, \widetilde{\chi}_{2}^{\pm}$
M ₁	bino		$\widetilde{\chi_1^0}$	higgs µ	sino	$\widetilde{\chi_1^0}$, $\widetilde{\chi_2^0}$, $\widetilde{\chi_1^\pm}$	M2	wino	=	$\widetilde{\chi_1^0} \widetilde{\chi_1^\pm}$

Standard wino-bino case: large ∆m between N1 and C1/N2; → MET + hard leptons N1,N2,C1 almost degenerate: experimental challenging; → MET + soft leptons

- Lower xsec than higgsino LSP;
- → WW+MET dominant;



https://indico.cern.ch/event/687651/contributions/3400865/attachme nts/1850992/3038683/Wagner-LHCP2019.pdf

Muon Anomalous Magnetic Moment



Here \tilde{m} represents the weakly interacting supersymmetric particle masses.

For tan $\beta \simeq 10$ (50), values of $\tilde{m} \simeq 230$ (510) GeV would be preferred.

Masses of the order of the weak scale lead to a natural explanation of the observed anomaly !