Snowmass2021 EF08 BSM Model specific session

Probing Supersymmetry and Dark Matter at the CEPC, FCC_ee, and ILC

https://www.snowmass21.org/docs/files/summaries/EF/SNOWMASS21-EF8_EF0_LOI_SNOWMASS21_EF08_SUSY_DM-126.pdf

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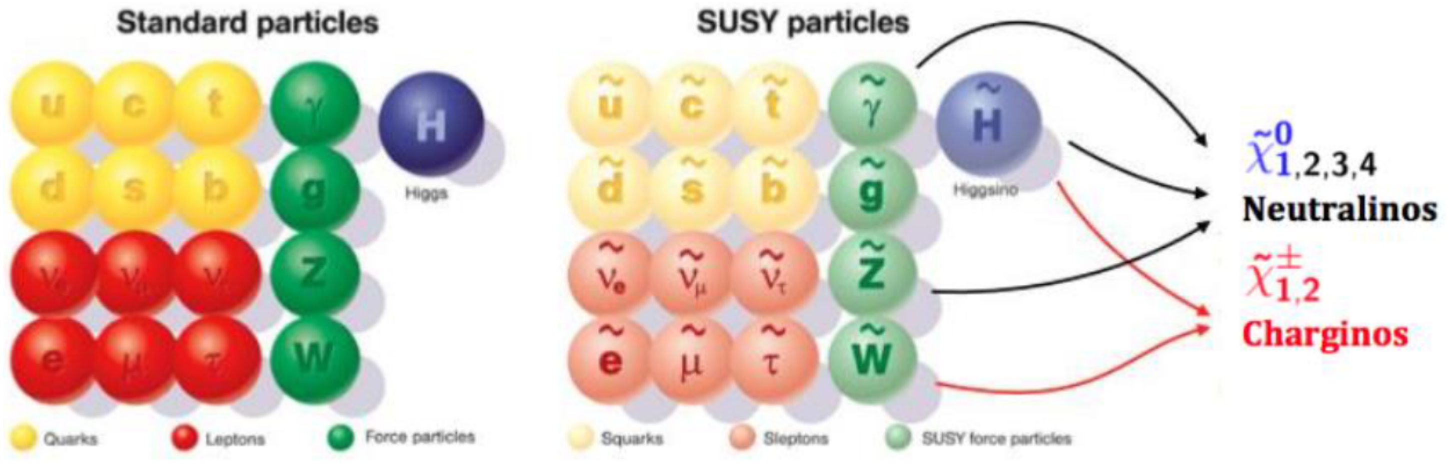
Motivation



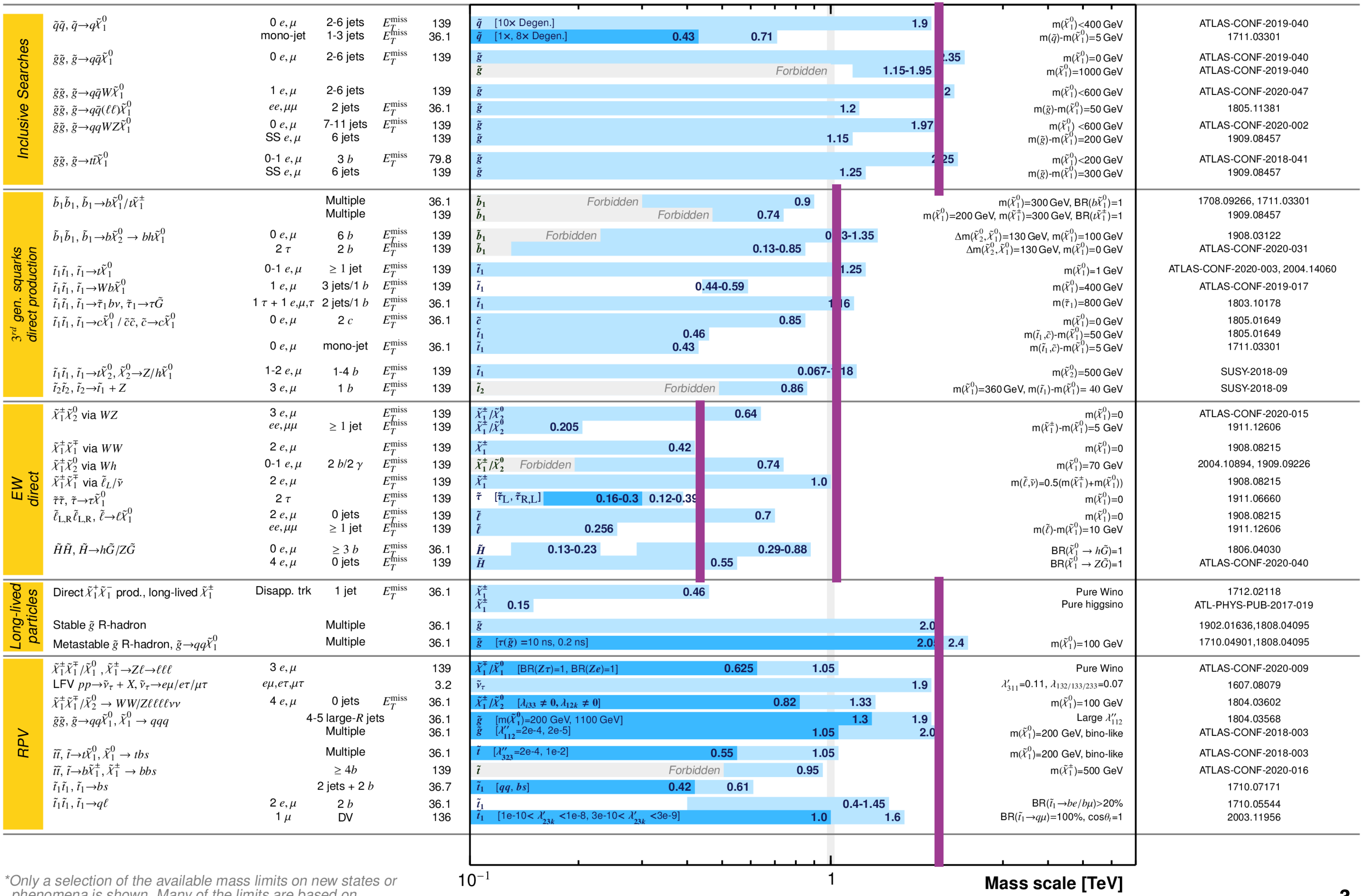
- SUSY is one of the most favorite candidate for physics BSM, which can
  - provide a natural solution to the gauge hierarchy problem,
  - provide DM candidate with PRC ,
  - achieve gauge coupling unification,
  - ……
- However, SUSY searches at LHC have already given very strong constrains on SUSY parameters, see next slide:

ATLAS SUSY Searches* - 95% CL Lower Limits

July 2020

ATLAS Preliminary

$\sqrt{s}$ = 13 TeV



	Model	Signature			$\int\mathcal{L}\,dt$ [fb^{-1}]	Mass limit		Reference
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$	0 e,μ	2-6 jets	$E_T^{\rm miss}$	139	$\tilde{q}$ [10× Degen.] 1.9	m($\tilde{\chi}^0_1$)<400 GeV	ATLAS-CONF-2019-040
		mono-jet	1-3 jets	$E_T^{\rm miss}$	36.1	$\tilde{q}$ [1×, 8× Degen.] 0.43 0.71	m($\tilde{q}$)-m($\tilde{\chi}^0_1$)=5 GeV	1711.03301
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0 e,μ	2-6 jets	$E_T^{\rm miss}$	139	$\tilde{g}$ .35	m($\tilde{\chi}^0_1$)=0 GeV	ATLAS-CONF-2019-040
						$\tilde{g}$ Forbidden 1.15-1.95	m($\tilde{\chi}^0_1$)=1000 GeV	ATLAS-CONF-2019-040
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}W\tilde{\chi}^0_1$	1 e,μ	2-6 jets		139	$\tilde{g}$ 2	m($\tilde{\chi}^0_1$)<600 GeV	ATLAS-CONF-2020-047
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}^0_1$	$ee,\mu\mu$	2 jets	$E_T^{\rm miss}$	36.1	$\tilde{g}$ 1.2	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=50 GeV	1805.11381
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}^0_1$	0 e,μ	7-11 jets	$E_T^{\rm miss}$	139	$\tilde{g}$ 1.97	m($\tilde{\chi}^0_1$) <600 GeV	ATLAS-CONF-2020-002
		SS e,μ	6 jets		139	$\tilde{g}$ 1.15	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=200 GeV	1909.08457
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	$E_T^{\rm miss}$	79.8	$\tilde{g}$ 2 25	m($\tilde{\chi}^0_1$)<200 GeV	ATLAS-CONF-2018-041
		SS e,μ	6 jets		139	$\tilde{g}$ 1.25	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=300 GeV	1909.08457
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_1/t\tilde{\chi}^\pm_1$		Multiple		36.1	$\tilde{b}_1$ Forbidden 0.9	m($\tilde{\chi}^0_1$)=300 GeV, BR($b\tilde{\chi}^0_1$)=1	1708.09266, 1711.03301
			Multiple		139	$\tilde{b}_1$ Forbidden 0.74	m($\tilde{\chi}^0_1$)=200 GeV, m($\tilde{\chi}^\pm_1$)=300 GeV, BR($t\tilde{\chi}^\pm_1$)=1	1909.08457
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_2\to bh\tilde{\chi}^0_1$	0 e,μ	6 b	$E_T^{\rm miss}$	139	$\tilde{b}_1$ Forbidden 0 3-1.35	Δm($\tilde{\chi}^0_2,\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=100 GeV	1908.03122
		2 τ	2 b	$E_T^{\rm miss}$	139	$\tilde{b}_1$ 0.13-0.85	Δm($\tilde{\chi}^0_2,\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=0 GeV	ATLAS-CONF-2020-031
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_1$	0-1 e,μ	$\geq$ 1 jet	$E_T^{\rm miss}$	139	$\tilde{t}_1$ 1.25	m($\tilde{\chi}^0_1$)=1 GeV	ATLAS-CONF-2020-003, 2004.14060
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}^0_1$	1 e,μ	3 jets/1 b	$E_T^{\rm miss}$	139	$\tilde{t}_1$ 0.44-0.59	m($\tilde{\chi}^0_1$)=400 GeV	ATLAS-CONF-2019-017
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to\tilde{\tau}_1b\nu$, $\tilde{\tau}_1\to\tau\tilde{G}$	1 τ + 1 e,μ,τ	2 jets/1 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$ 1 16	m($\tilde{\tau}_1$)=800 GeV	1803.10178
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}$, $\tilde{c}\to c\tilde{\chi}^0_1$	0 e,μ	2 c	$E_T^{\rm miss}$	36.1	$\tilde{c}$ 0.85	m($\tilde{\chi}^0_1$)=0 GeV	1805.01649
						$\tilde{t}_1$ 0.46	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=50 GeV	1805.01649
		0 e,μ	mono-jet	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$ 0.43	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=5 GeV	1711.03301
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_2$, $\tilde{\chi}^0_2\to Z/h\tilde{\chi}^0_1$	1-2 e,μ	1-4 b	$E_T^{\rm miss}$	139	$\tilde{t}_1$ 0.067-1 18	m($\tilde{\chi}^0_2$)=500 GeV	SUSY-2018-09
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ	1 b	$E_T^{\rm miss}$	139	$\tilde{t}_2$ Forbidden 0.86	m($\tilde{\chi}^0_1$)=360 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)= 40 GeV	SUSY-2018-09
EW direct	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via WZ	3 e,μ		$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.64	m($\tilde{\chi}^0_1$)=0	ATLAS-CONF-2020-015
		$ee,\mu\mu$	$\geq$ 1 jet	$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.205	m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=5 GeV	1911.12606
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via WW	2 e,μ		$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1$ 0.42	m($\tilde{\chi}^0_1$)=0	1908.08215
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via Wh	0-1 e,μ	2 b/2 γ	$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ Forbidden 0.74	m($\tilde{\chi}^0_1$)=70 GeV	2004.10894, 1909.09226
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e,μ		$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1$ 1.0	m($\tilde{\ell}$,$\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	1908.08215
	$\tilde{\tau}\tilde{\tau}$, $\tilde{\tau}\to\tau\tilde{\chi}^0_1$	2 τ		$E_T^{\rm miss}$	139	$\tilde{\tau}$ [$\tilde{\tau}_{\rm L}$, $\tilde{\tau}_{\rm R,L}$] 0.16-0.3 0.12-0.39	m($\tilde{\chi}^0_1$)=0	1911.06660
	$\tilde{\ell}_{\rm L,R}\tilde{\ell}_{\rm L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0 jets	$E_T^{\rm miss}$	139	$\tilde{\ell}$ 0.7	m($\tilde{\chi}^0_1$)=0	1908.08215
		$ee,\mu\mu$	$\geq$ 1 jet	$E_T^{\rm miss}$	139	$\tilde{\ell}$ 0.256	m($\tilde{\ell}$)-m($\tilde{\chi}^0_1$)=10 GeV	1911.12606
	$\tilde{H}\tilde{H}$, $\tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ	$\geq$ 3 b	$E_T^{\rm miss}$	36.1	$\tilde{H}$ 0.13-0.23 0.29-0.88	BR($\tilde{\chi}^0_1\to h\tilde{G}$)=1	1806.04030
		4 e,μ	0 jets	$E_T^{\rm miss}$	139	$\tilde{H}$ 0.55	BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1	ATLAS-CONF-2020-040
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1$ 0.46	Pure Wino	1712.02118
						$\tilde{\chi}^\pm_1$ 0.15	Pure higgsino	ATL-PHYS-PUB-2017-019
	Stable $\tilde{g}$ R-hadron		Multiple		36.1	$\tilde{g}$ 2.0		1902.01636,1808.04095
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}^0_1$		Multiple		36.1	$\tilde{g}$ [$\tau(\tilde{g})$ =10 ns, 0.2 ns] 2.0 2.4	m($\tilde{\chi}^0_1$)=100 GeV	1710.04901,1808.04095
RPV	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_1$, $\tilde{\chi}^\pm_1\to Z\ell\to\ell\ell\ell$	3 e,μ			139	$\tilde{\chi}^\mp_1/\tilde{\chi}^0_1$ [BR($Z\tau$)=1, BR(Ze)=1] 0.625 1.05	Pure Wino	ATLAS-CONF-2020-009
	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$			3.2	$\tilde{\nu}_\tau$ 1.9	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ [$\lambda_{i33}\neq 0, \lambda_{12k}\neq 0$] 0.82 1.33	m($\tilde{\chi}^0_1$)=100 GeV	1804.03602
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to qqq$		4-5 large-R jets		36.1	$\tilde{g}$ [m($\tilde{\chi}^0_1$)=200 GeV, 1100 GeV] 1.3 1.9	Large λ''_{112}	1804.03568
			Multiple		36.1	$\tilde{g}$ [λ''_{112}=2e-4, 2e-5] 1.05 2.0	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}$, $\tilde{t}\to t\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to tbs$		Multiple		36.1	$\tilde{t}$ [λ''_{323}=2e-4, 1e-2] 0.55 1.05	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}$, $\tilde{t}\to b\tilde{\chi}^\pm_1$, $\tilde{\chi}^\pm_1\to bbs$		$\geq 4b$		139	$\tilde{t}$ Forbidden 0.95	m($\tilde{\chi}^\pm_1$)=500 GeV	ATLAS-CONF-2020-016
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$ [qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to q\ell$	2 e,μ	2 b		36.1	$\tilde{t}_1$ 0.4-1.45	BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544
		1 μ	DV		136	$\tilde{t}_1$ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0 1.6	BR($\tilde{t}_1\to q\mu$)=100%, cosθ_t=1	2003.11956

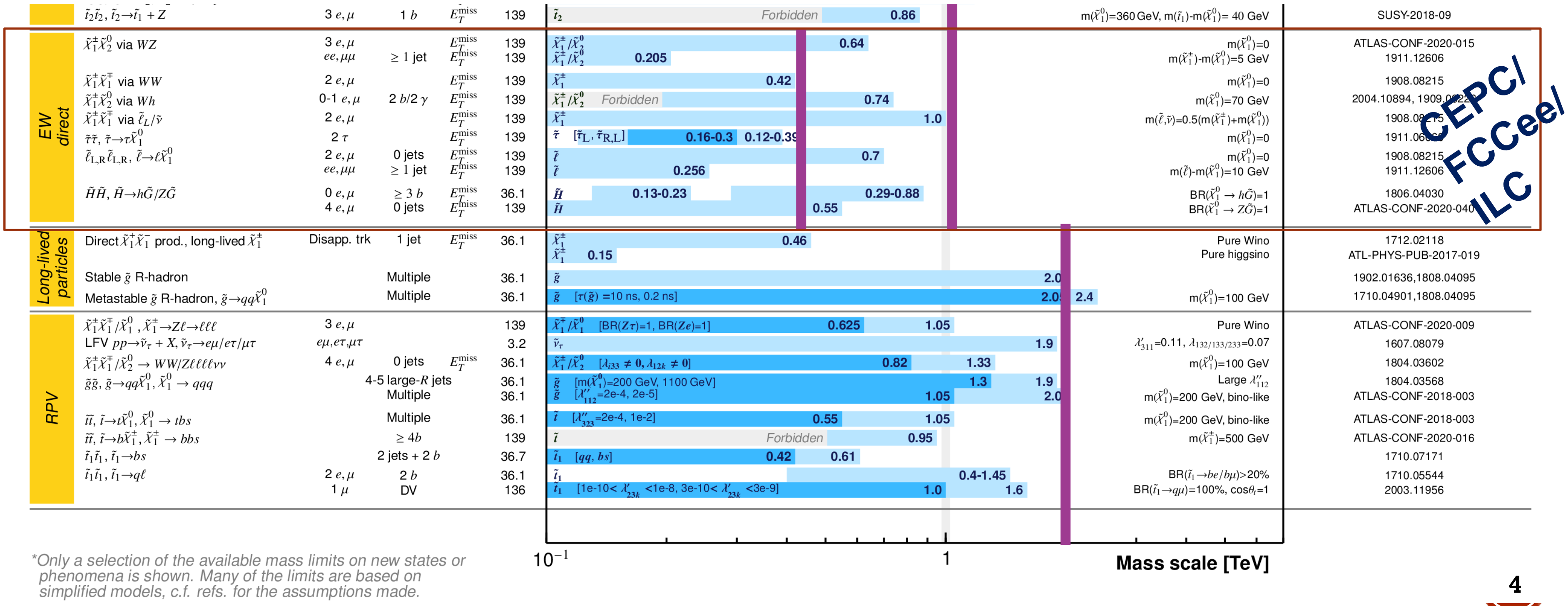
*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

ATLAS SUSY Searches* - 95% CL Lower Limits
July 2020

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

For CEPC, FCCee, and ILC:

- ➢ Difficult for squark/gluino production
- ➢ Mainly concentrate on the generic searches for the charginos, neutralinos, and sleptons. and some relevant dark matter searches as well.



	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ	1 b	$E_T^{\rm miss}$	139	$\tilde{t}_2$ Forbidden 0.86	m($\tilde{\chi}^0_1$)=360 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)= 40 GeV	SUSY-2018-09
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	$\tilde{\tau}\tilde{\tau}$, $\tilde{\tau}\to\tau\tilde{\chi}^0_1$	2 τ		$E_T^{\rm miss}$	139	$\tilde{\tau}$ [$\tilde{\tau}_{\rm L}$, $\tilde{\tau}_{\rm R,L}$] 0.16-0.3 0.12-0.39	m($\tilde{\chi}^0_1$)=0	1911.06[illegible]
	$\tilde{\ell}_{\rm L,R}\tilde{\ell}_{\rm L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0 jets	$E_T^{\rm miss}$	139	$\tilde{\ell}$ 0.7	m($\tilde{\chi}^0_1$)=0	1908.08215
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	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$			3.2	$\tilde{\nu}_\tau$ 1.9	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
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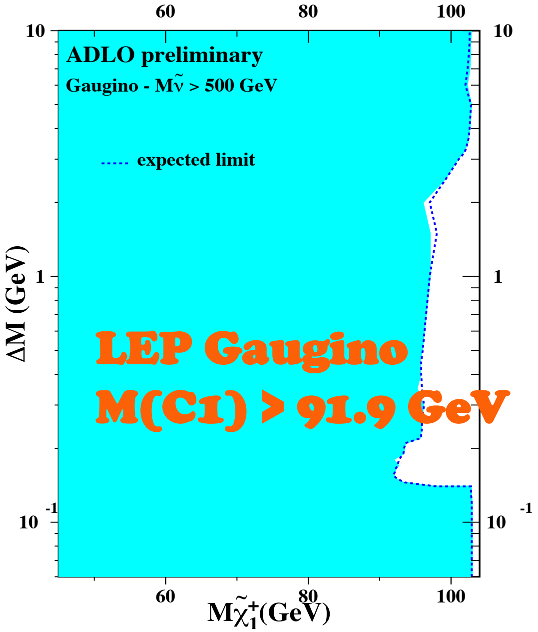
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to qqq$		4-5 large-R jets		36.1	$\tilde{g}$ [m($\tilde{\chi}^0_1$)=200 GeV, 1100 GeV] 1.3 1.9	Large λ''_{112}	1804.03568
			Multiple		36.1	$\tilde{g}$ [λ''_{112}=2e-4, 2e-5] 1.05 2.0	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}$, $\tilde{t}\to t\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to tbs$		Multiple		36.1	$\tilde{t}$ [λ''_{323}=2e-4, 1e-2] 0.55 1.05	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}$, $\tilde{t}\to b\tilde{\chi}^\pm_1$, $\tilde{\chi}^\pm_1\to bbs$		≥ 4b		139	$\tilde{t}$ Forbidden 0.95	m($\tilde{\chi}^\pm_1$)=500 GeV	ATLAS-CONF-2020-016
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$ [qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to q\ell$	2 e,μ	2 b		36.1	$\tilde{t}_1$ 0.4-1.45	BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544
		1 μ	DV		136	$\tilde{t}_1$ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0 1.6	BR($\tilde{t}_1\to q\mu$)=100%, cosθ_t=1	2003.11956

CEPC/ FCCee/ ILC

**Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.*

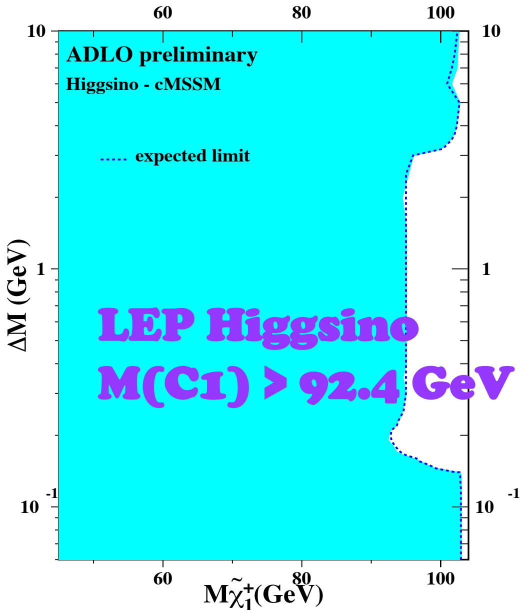
Gaugino & higgsino

- Light gauginos have larger x-sec in lepton colliders with lower energy
- The naturalness conditions from the low-energy fine-tuning measures 【1-3】 generically predict the light Higgsinos



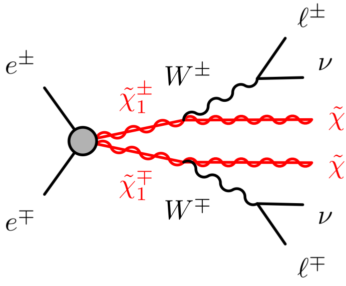
LEP Gaugino

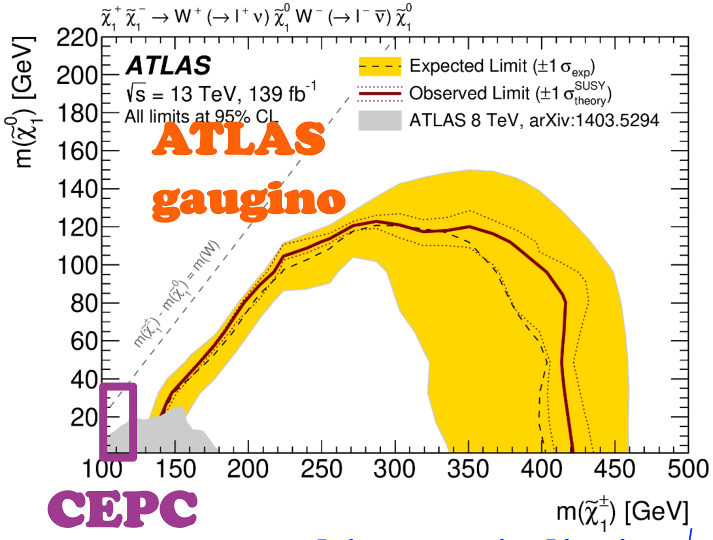
M(C1) > 91.9 GeV



LEP Higgsino

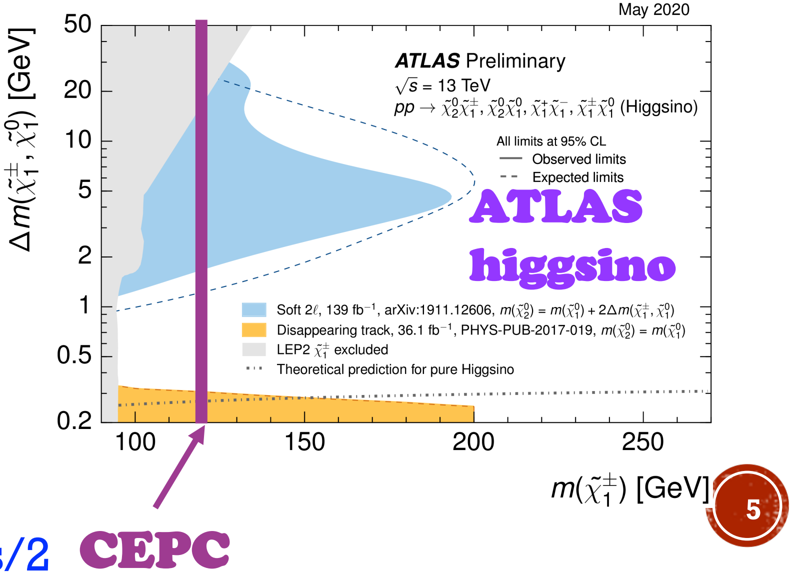
M(C1) > 92.4 GeV





ATLAS gaugino

CEPC



ATLAS higgsino

CEPC

up to kinematic limit: √s/2

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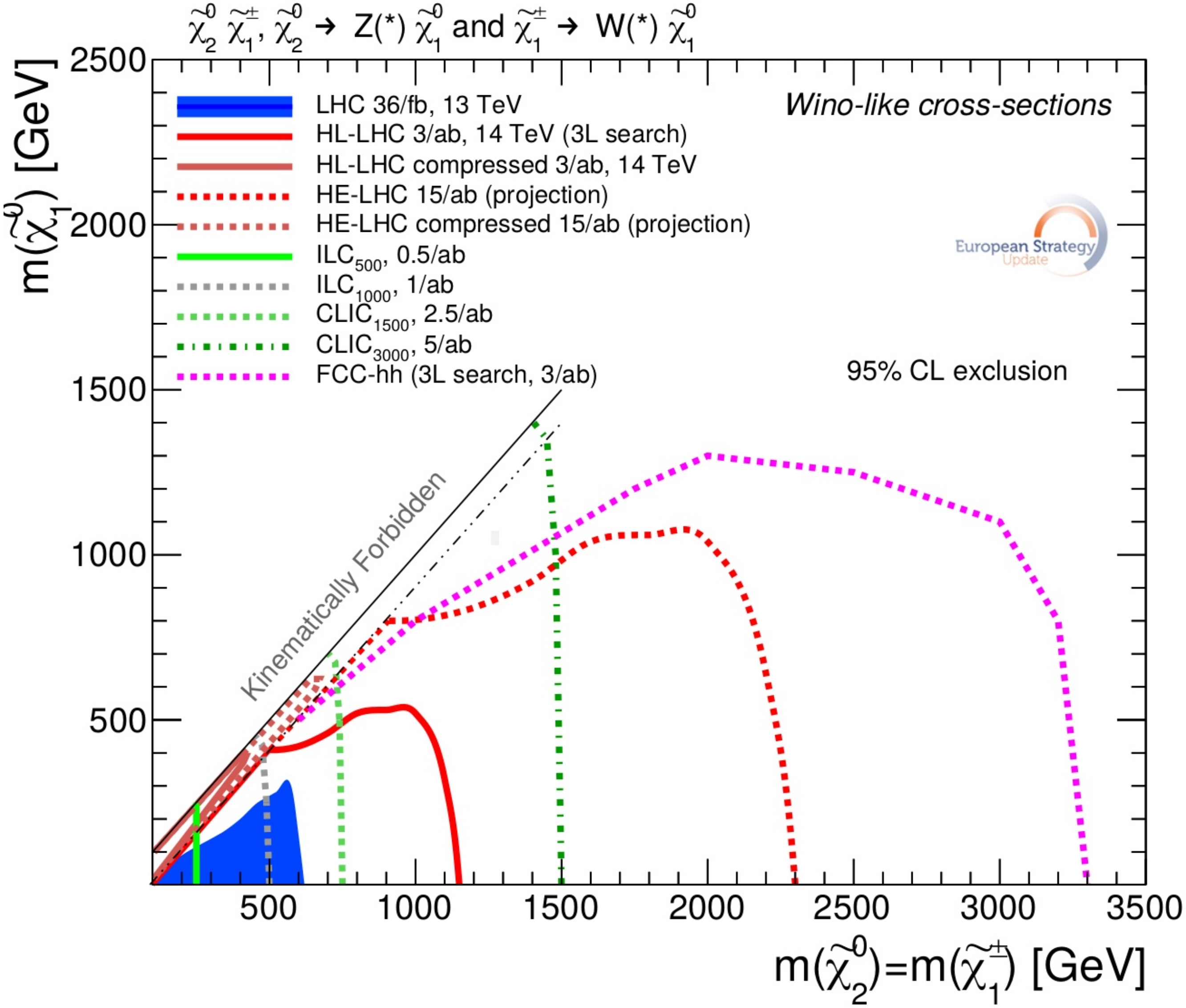
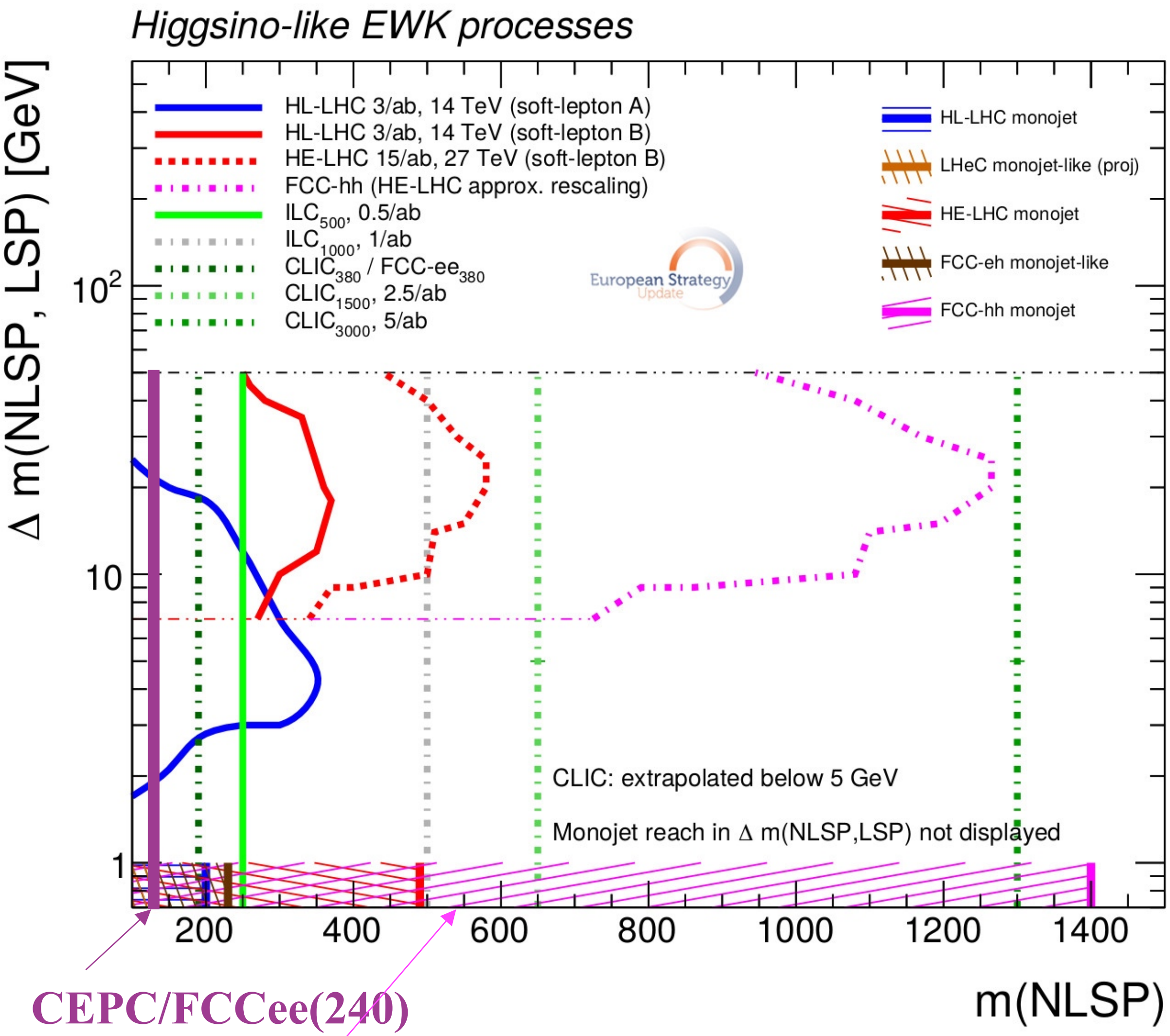
1. Phys. Lett. B 631, 58 (2005)
2. Phys. Rev. D 73, 095004 (2006)
3. arXiv:1212.2655

Current status: EU Strategy- gaugino



ILC 500/CEPC240: discovery in all scenarios up to kinematic limit: √s/2

Current status: EU Strategy- higgsino

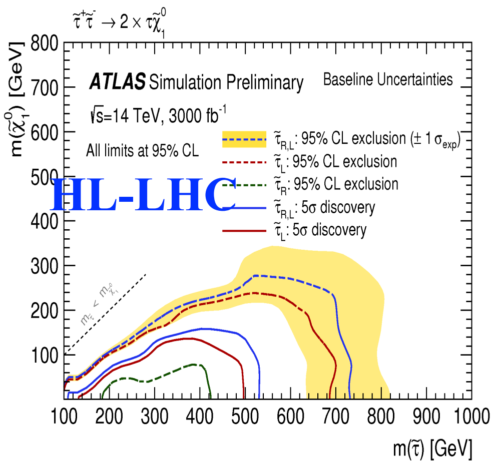


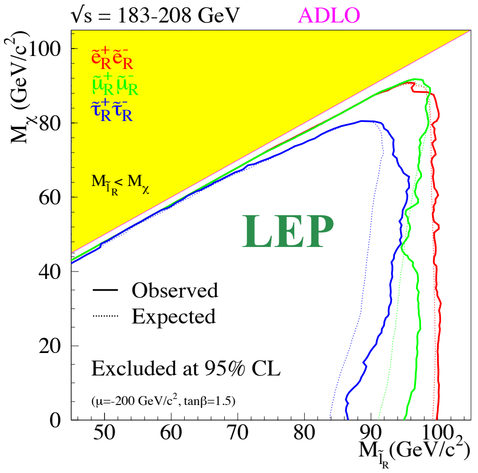
CEPC/FCCee(240)

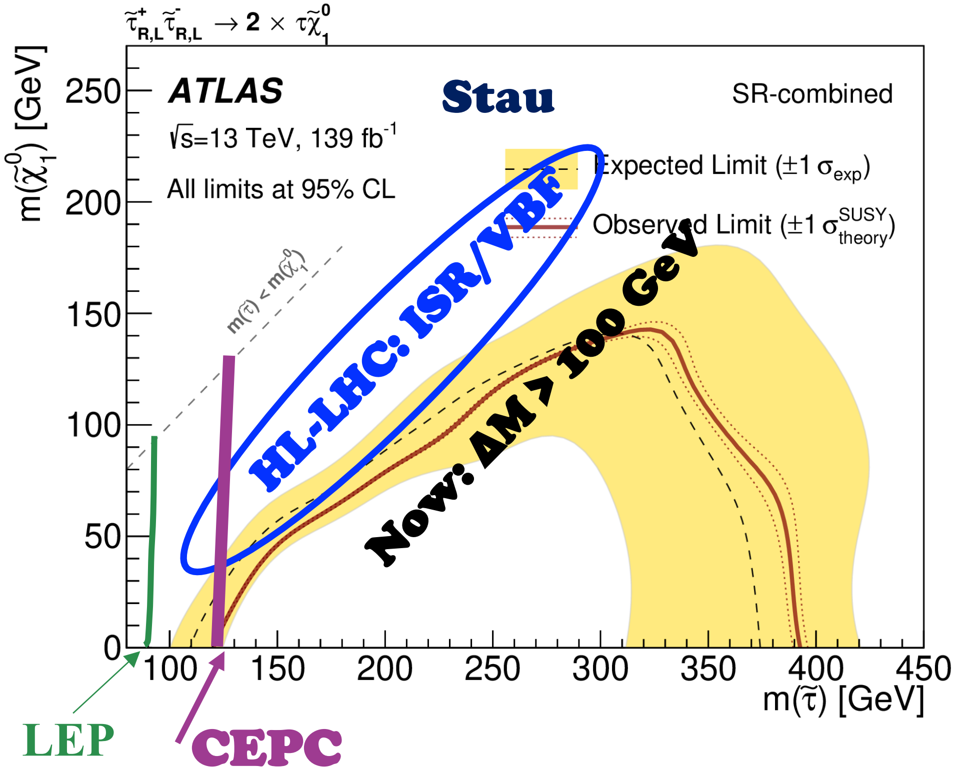
Disappearing tracks exclusion is actually off the scale

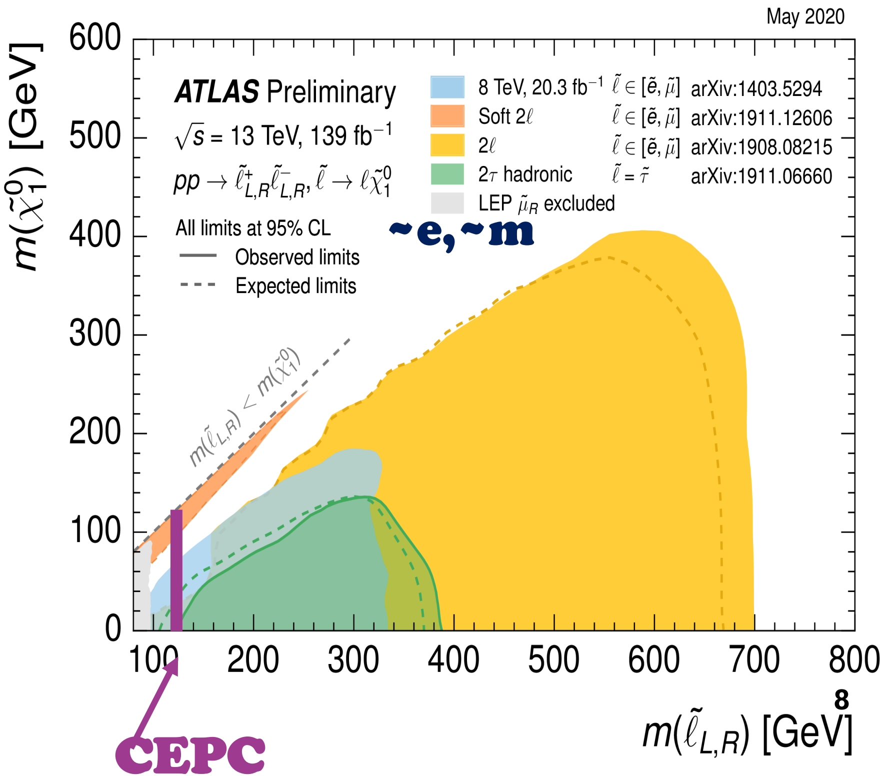
Stau & smuon

- In the super-natural supersymmetry [arXiv:1403.3099 etc.], the observed DM relic density is realized via the LSP neutralino - light stau coannihilation, LSP neutralino is Bino dominant, the right-handed sleptons are light as well
- The muon g-2 excess can be naturally explained by light smuon









From Tianjun Li, Shabbar Raza and Waqas Ahmed

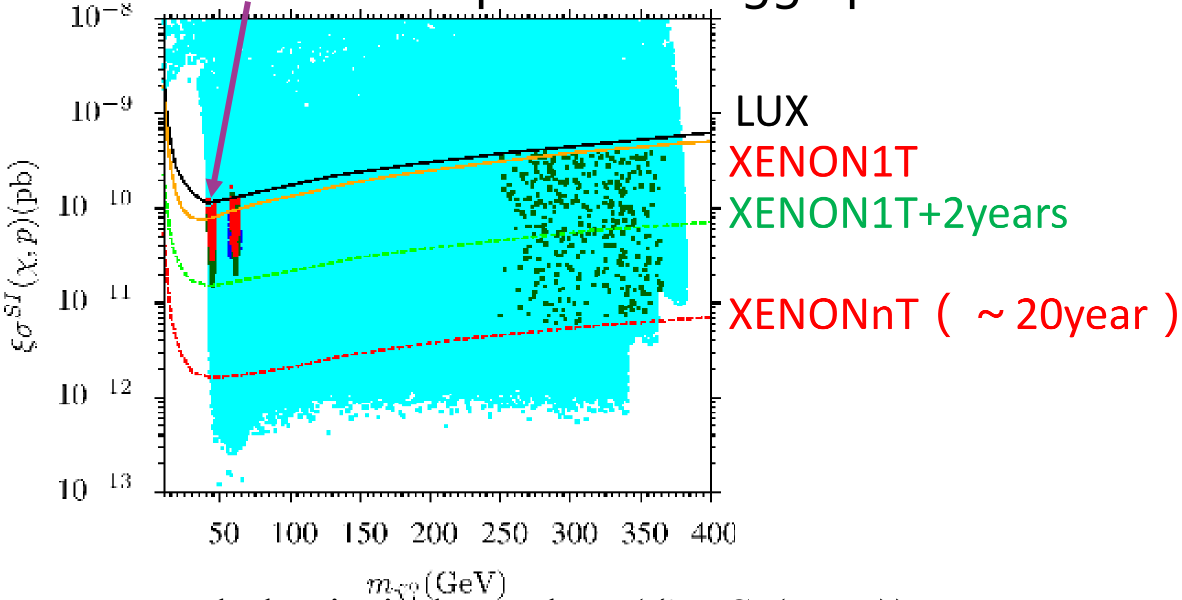
Light Neutralino Searches at CEPC

- We have two typed of Light neutralinos solutions that is solutions with correct relic density (Z-resonamce and h-resonance)[1] and neutralino with large density [2]
- At CEPC we can probe it via $e^+e^- \to e^+e^- + \gamma \to \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) + \gamma$

Aqua points satisfy the REWSB and LSP neutralino conditions.

Red, blue and green solutions represent the sets of points with relic density consistent with, greater than and smaller than 5σ WMAP9 bounds, respectively

The two dips around 45 GeV and 62 GeV indicate the Z-pole and Higgs-pole solutions



Rescaled spin-independent (ξ σ SI(χ , p)) rate vs. LSP neutralino mass m $\tilde{\chi}_1^0$

Generalized Minimal Supergravity (GmSUGRA)

---

[1] arXiv:1709.06371

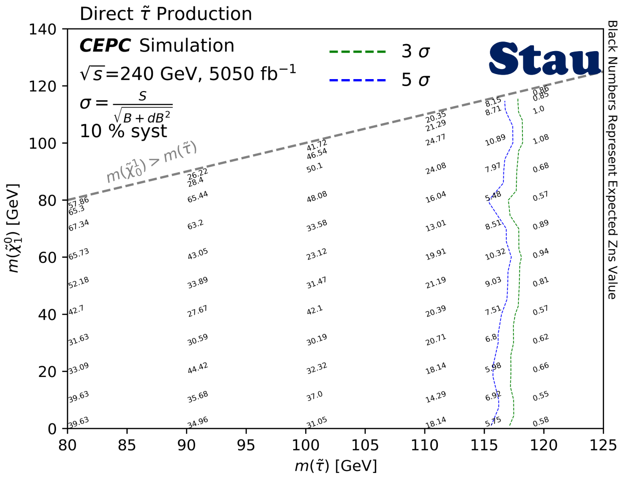
[2] arXiv:1409.3930

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 selecton and then bino decays into axino and photon $(\tilde{\chi}_1^0 \rightarrow \tilde{a}\gamma)$ as follows
- $e^+e^- \rightarrow \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) \rightarrow 2\tilde{a} + 2\gamma$

Inputs for Snowmass report and white paper

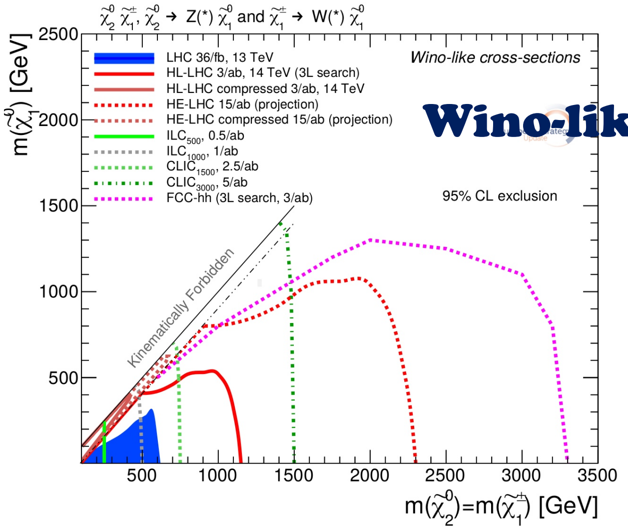
- For light charginos, neutralinos, and sleptons , the prospected 2D 5σ discovery contour as a function of SUSY particle mass will be provided (more at backup)



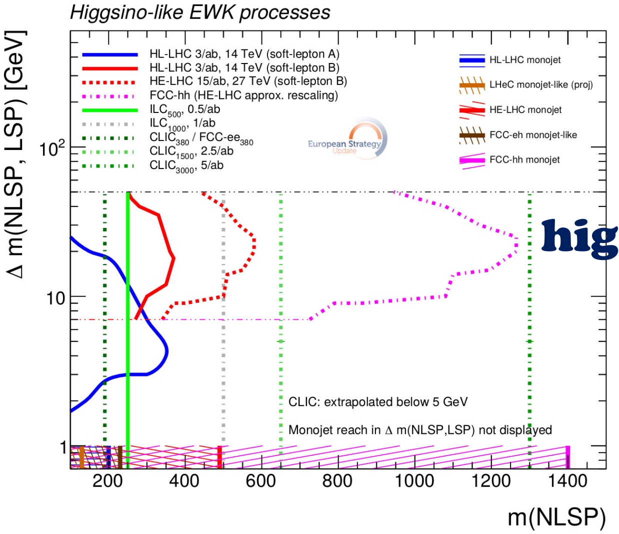
- Status/progress/contributions to snowmass:
  - For bino-like and higgsino-like EWKinos, stau and smuon, results are almost done, paper draft preparing is going-on
  - For light neutralino, GmSUGRA scaning is going on
  - SUSY cross section summary plot is on-going
  - 2-3 paper drafts to be provided as inputs

- Above should be fit the Electroweak pMSSM for EF08

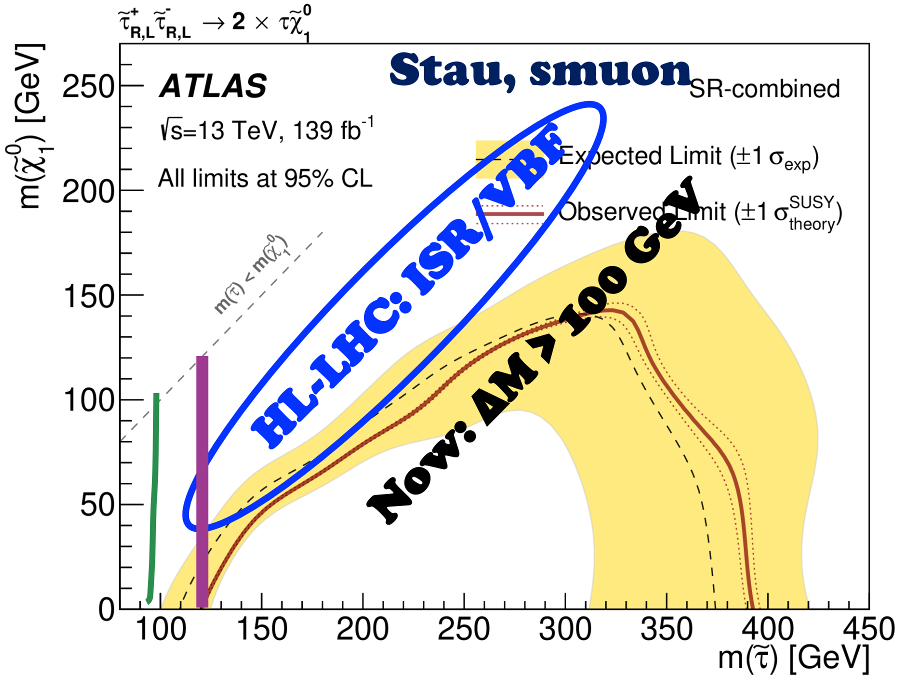
Curves contributed to a Snowmass report summary plot (to be discussed)



Wino-like



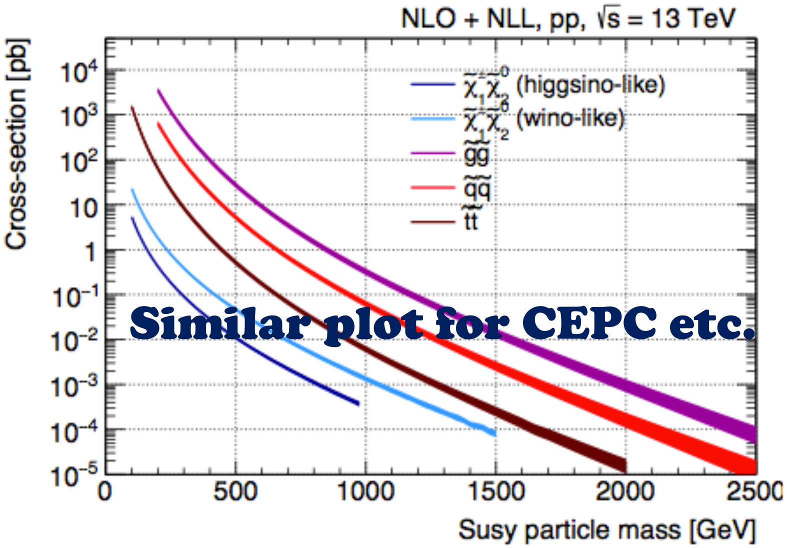
higgsino-like



Stau, smuon

HL-LHC: ISR/VBF

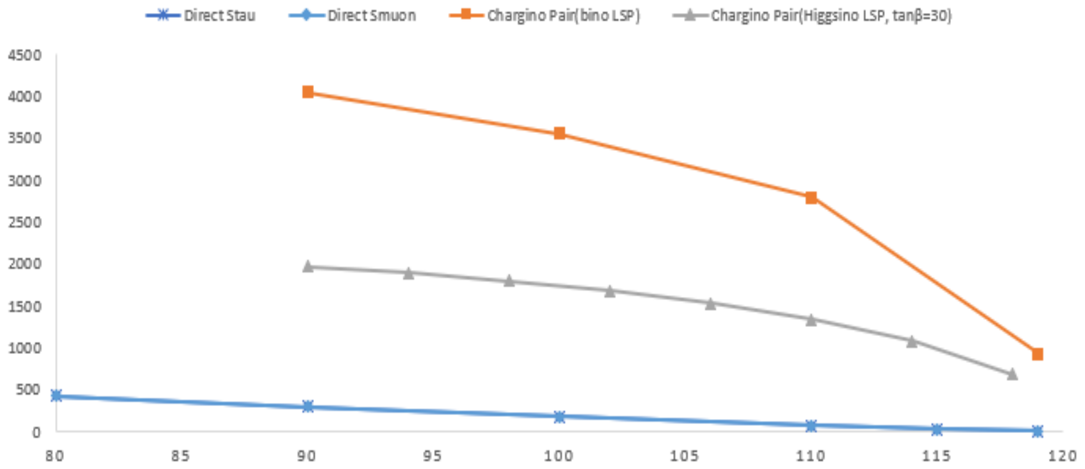
Now: ΔM > 100 GeV



Similar plot for CEPC etc.

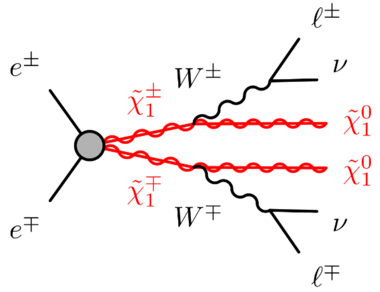
Backup

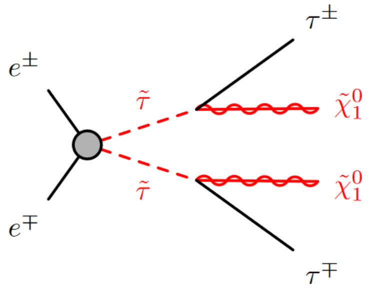
Some Ongoing Analyses

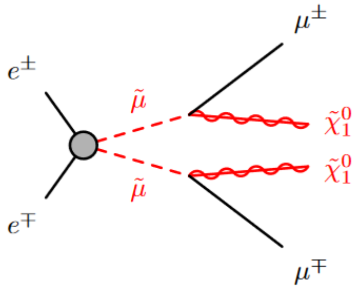


Cross-section based on Madgraph calculation

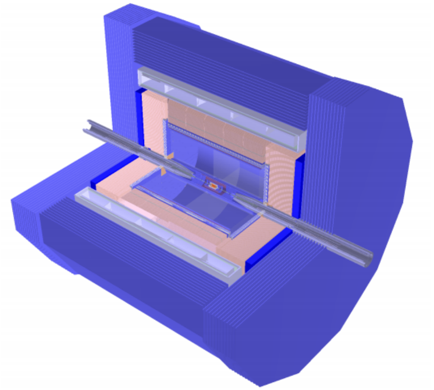
- ➢ Production of chargino pairs decaying via W bosons
- ➢ Production of chargino pairs decaying via W bosons
- ➢ Direct production of stau pairs
- ➢ Direct production of smuon pairs





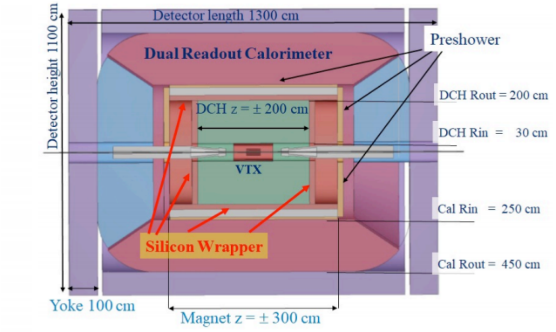


TECHNICAL DETAIL

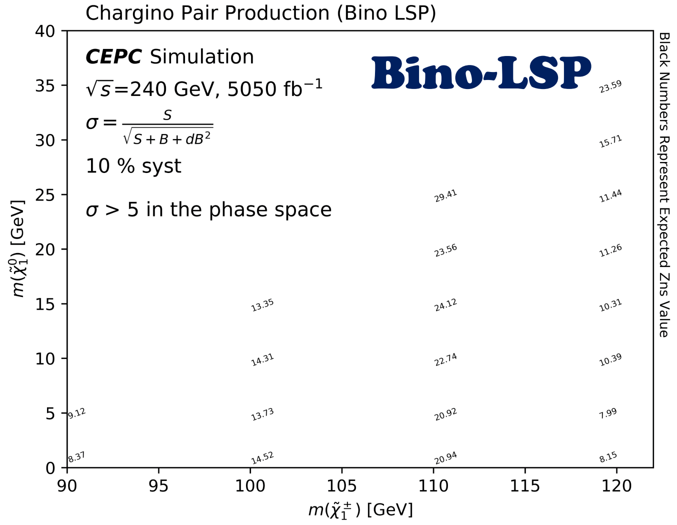


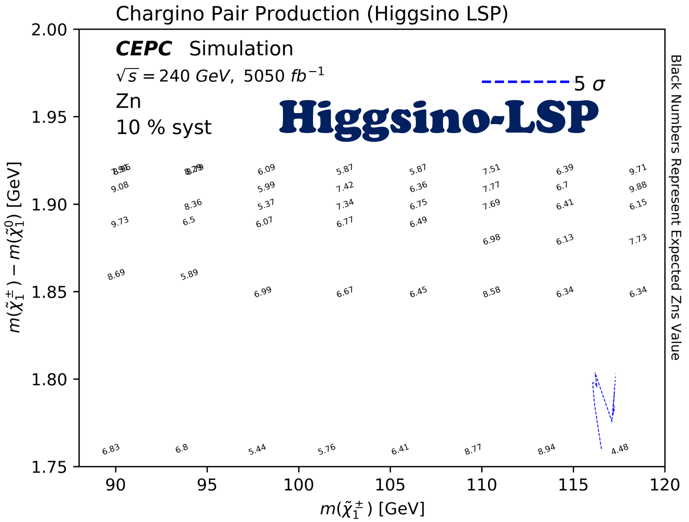
- About CEPC
  - ECM=240GeV, higgs factory, 100 km circumference, 2 interaction points.
  - ILD-like detector
- Software
  - **Signal samples: MadGraph+Pythia8**
  - Simulation: Mokka
  - Reconstruction: Marlin
- Normalized to $5050\ \mathrm{fb}^{-1}$
- **Dominant backgrounds:**
  - **SM processes with two-e or two-μ or two-τ and large missing energy final states.**

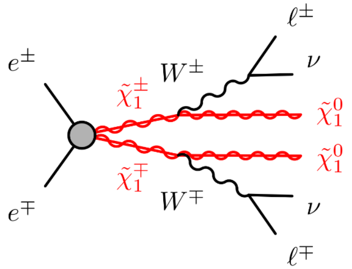
process	Cross Section [fb]
$\mu\mu$	4967.58
$\tau\tau$	4374.94
$WW \to \ell\ell$	392.96
$ZZorWW \to \mu\mu vv$	214.81
$ZZorWW \to \tau\tau vv$	205.84
$vZ, Z \to \mu\mu$	43.33
$ZZ \to \mu\mu vv$	18.17
$vZ, Z \to \tau\tau$	14.57
$ZZ \to \tau\tau vv$	9.2
$vvH, H \to \tau\tau$	3.07
$evW, W \to \mu v$	429.2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

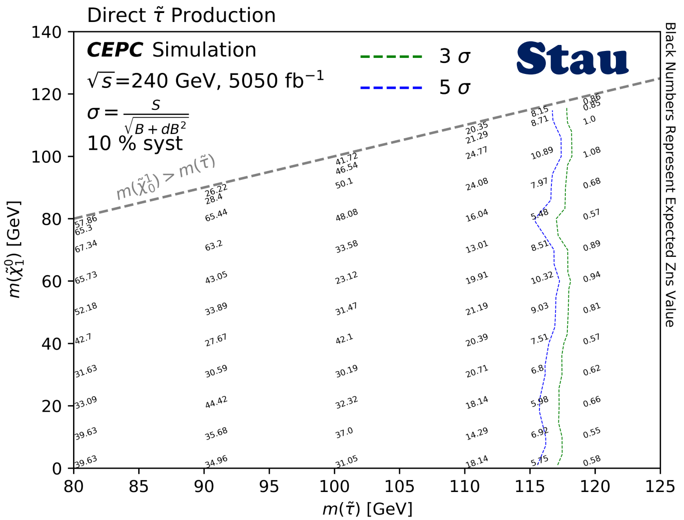


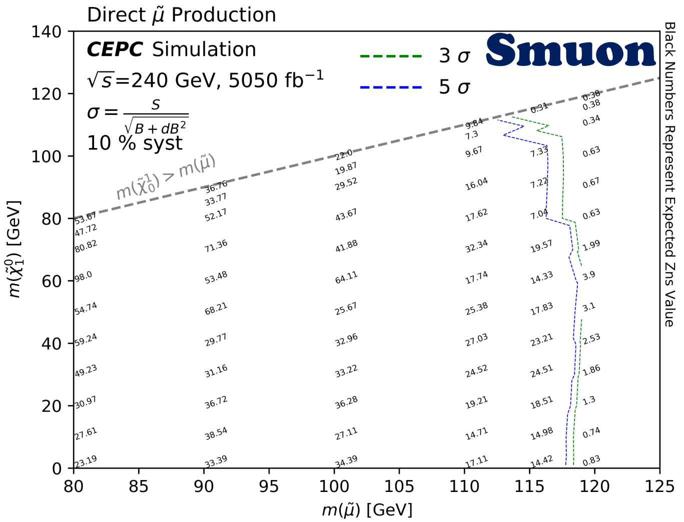
Preliminary Results

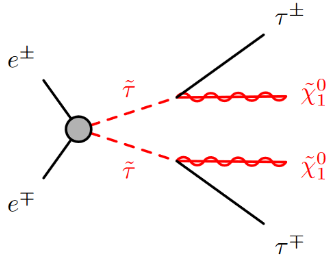


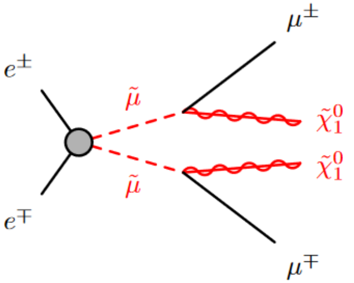










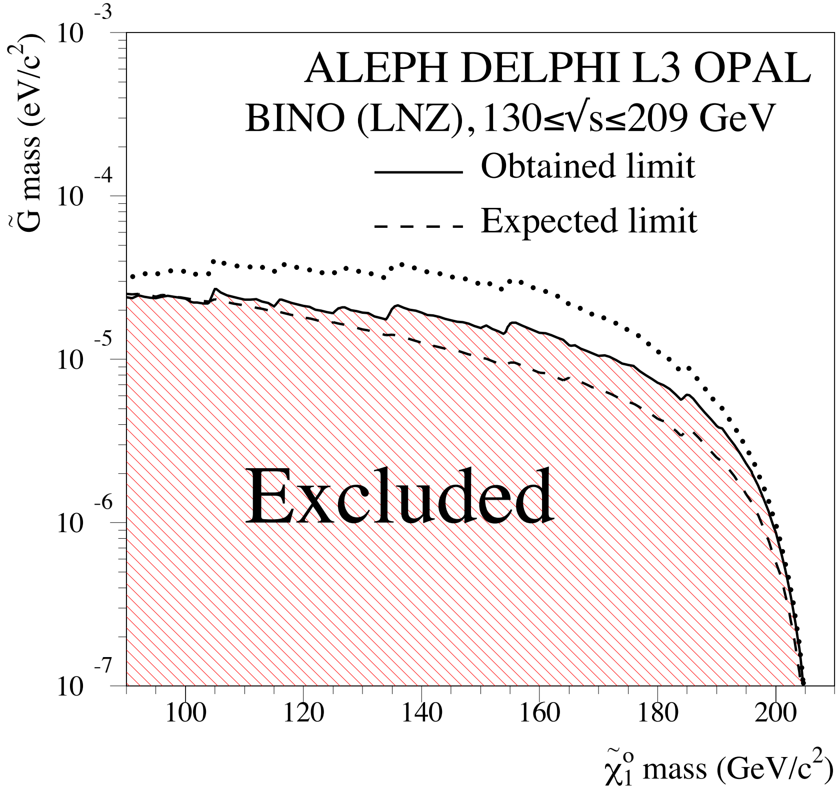


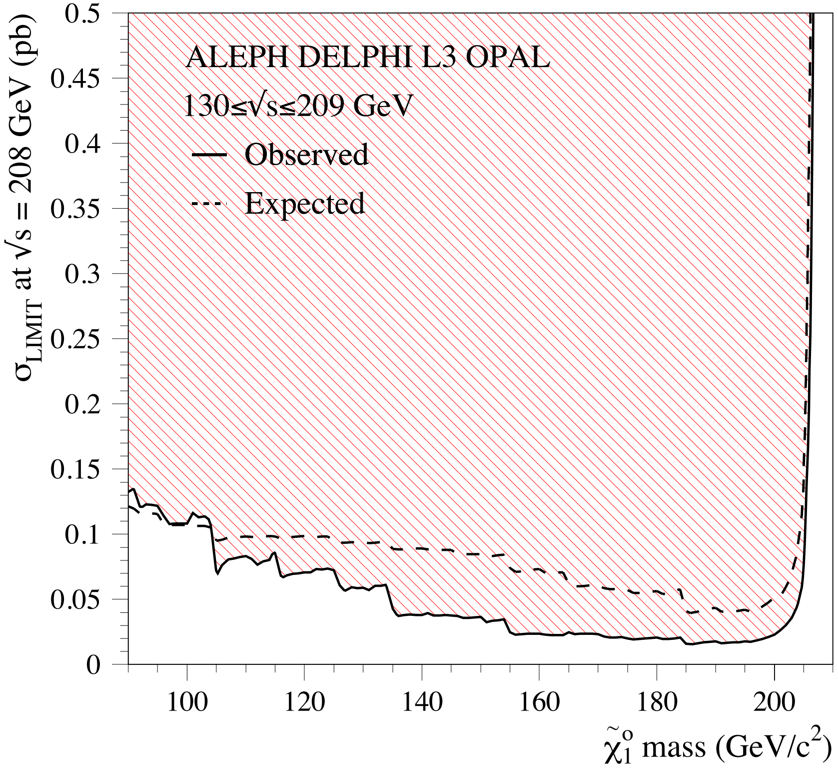
CEPC240(FCCee/ILC): discovery in all scenarios up to kinematic limit: √s/2

The map use $\frac{S}{\sqrt{S+B+dB^2}}$ as the sensitivity (stat + 10% syst)

	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,
$m_{\tilde{\tau}_{1,2}}$	356,618	265,627	816, 941	264 ,549
$\sigma_{SI}(\mathrm{pb})$	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

Mono-photon (SUSY, ED,DM)





e+e- → chi_1 grav → grav grav gamma
grav: gravitino

HL-LHC: DM

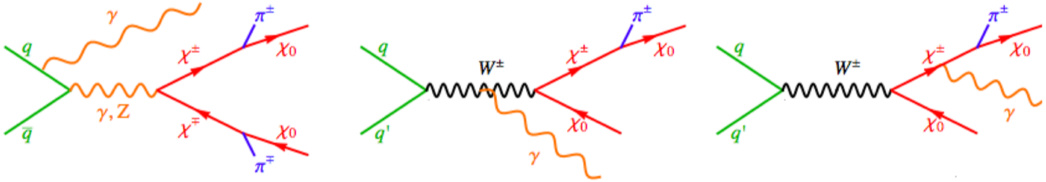
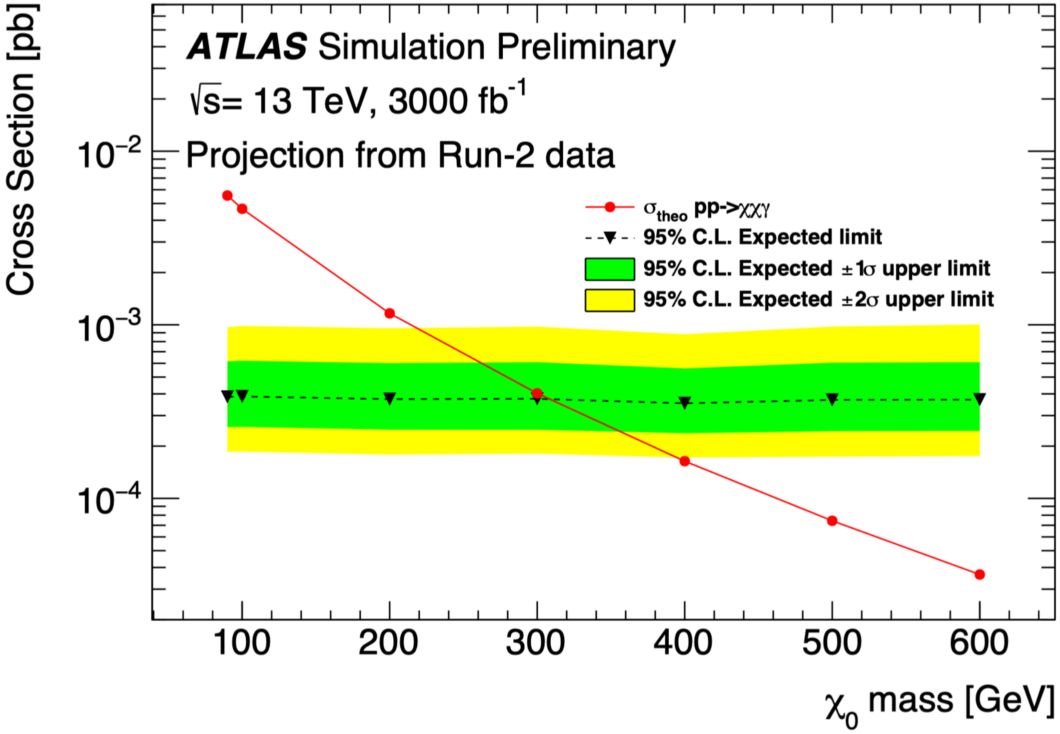
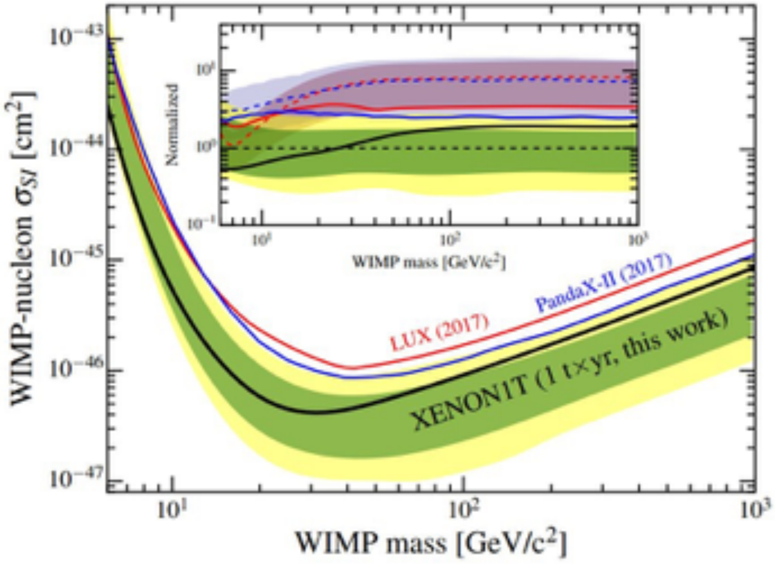


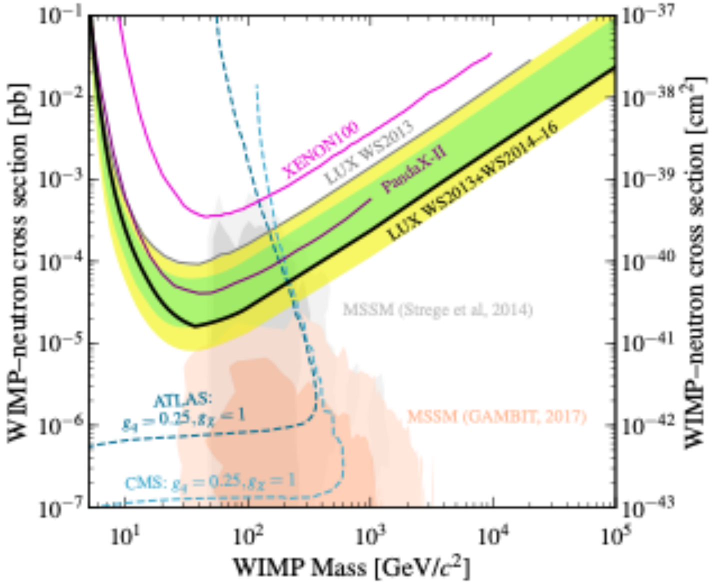
Figure 1: Some representative diagrams for the pure WIMP triplet in $\gamma+E_{\mathrm{T}}^{\mathrm{miss}}$ final states. The $\chi^{\pm}$ particles decay into the stable χ_0 DM candidate and soft pions which are not reconstructed [3].



ATL-PHYS-PUB-2018-038

DM : Direct Detection Bounds





$$\sigma_p^{\rm SI} \propto \frac{m_Z^4}{\mu^4}\left[2(m_{\tilde\chi_1^0} + 2\mu/\tan\beta)\frac{1}{m_h^2} + \mu\tan\beta\frac{1}{m_H^2} + (m_{\tilde\chi_1^0} + \mu\tan\beta/2)\frac{1}{m_{\tilde Q}^2}\right]^2$$

Blind Spot : $$2\left(m_{\tilde\chi_1^0} + 2\frac{\mu}{\tan\beta}\right)\frac{1}{m_h^2} \simeq -\mu\tan\beta\left(\frac{1}{m_H^2} + \frac{1}{2m_{\tilde Q}^2}\right)$$

$\mu \times m_{\tilde\chi^0} < 0$

$m_{\tilde\chi^0} \simeq M_1$

Cheung, Hall, Pinner, Ruderman'12, Huang, C.W.'14, Cheung, Papucci, Shah, Stanford,Zurek'14, Han,Liu,Mukhopadhyay,Wang'18

$$\sigma^{\rm SD} \propto \frac{m_Z^4}{\mu^4}\cos^2(2\beta)$$

EU Strategy- SUSY: ~g

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

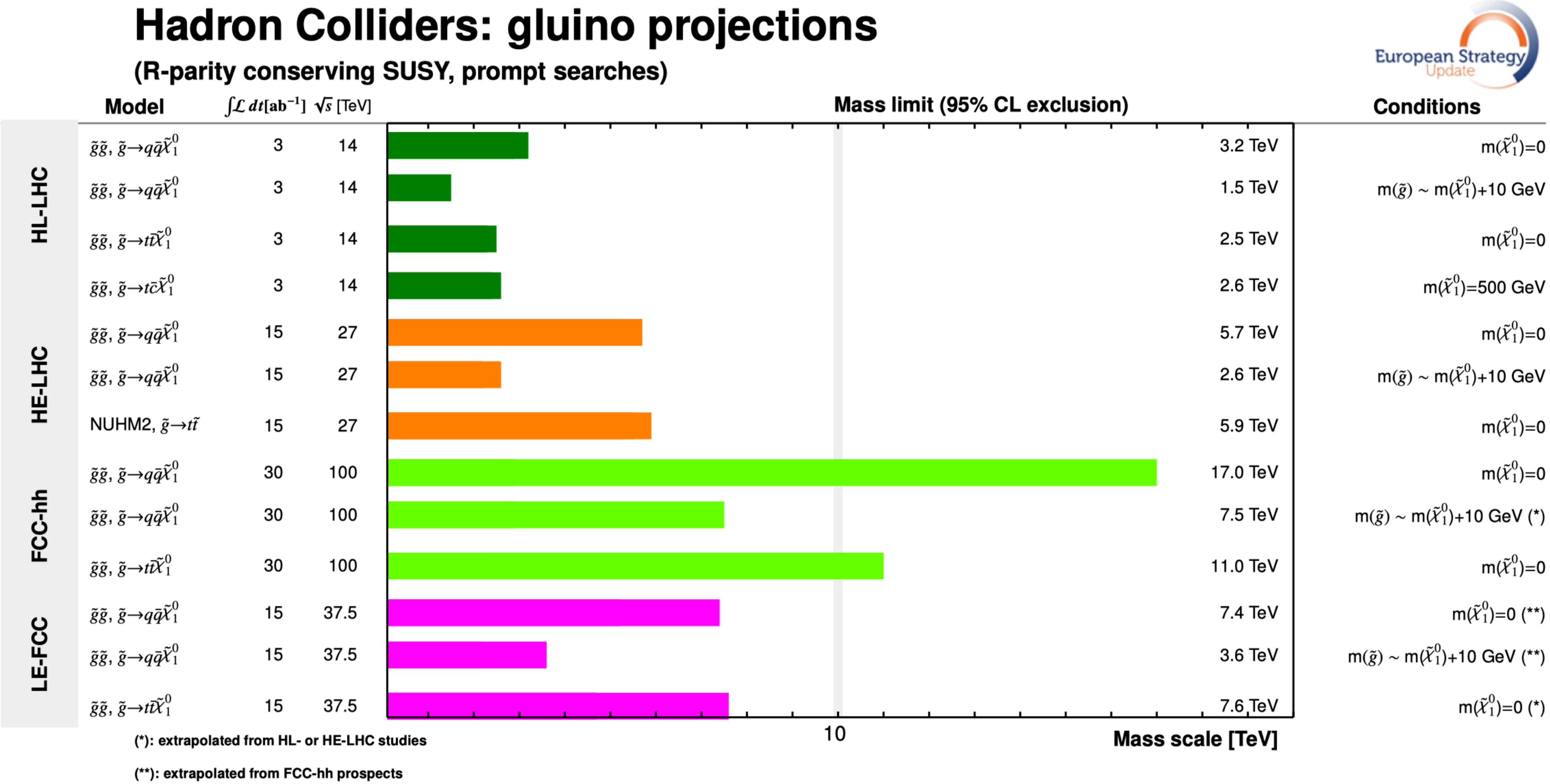


Fig. 8.6: Gluino exclusion reach of different hadron colliders: HL- and HE-LHC [443], and FCC-hh [139, 448]. Results for low-energy FCC-hh are obtained with a simple extrapolation.

EU Strategy- SUSY: ~q

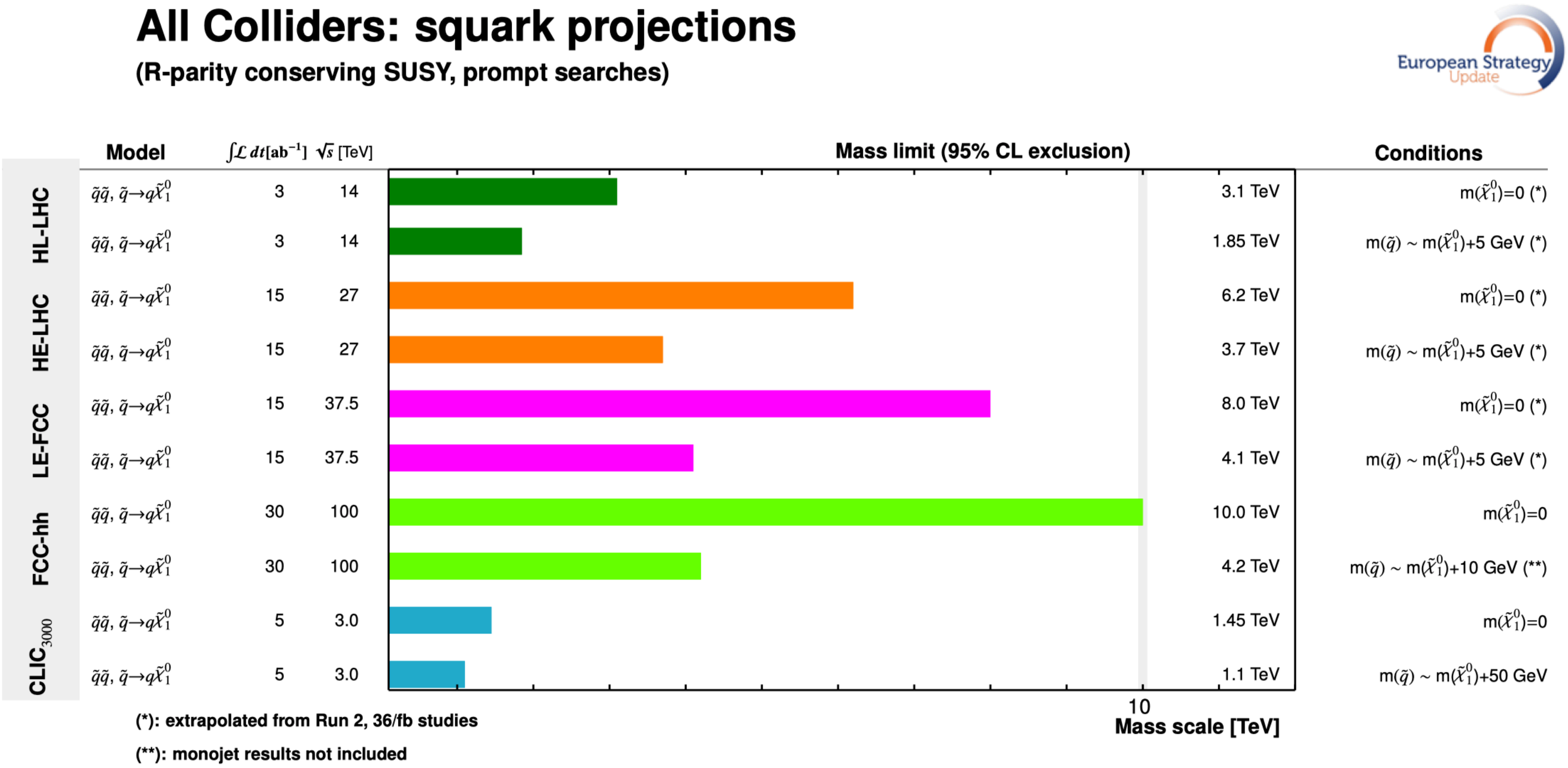
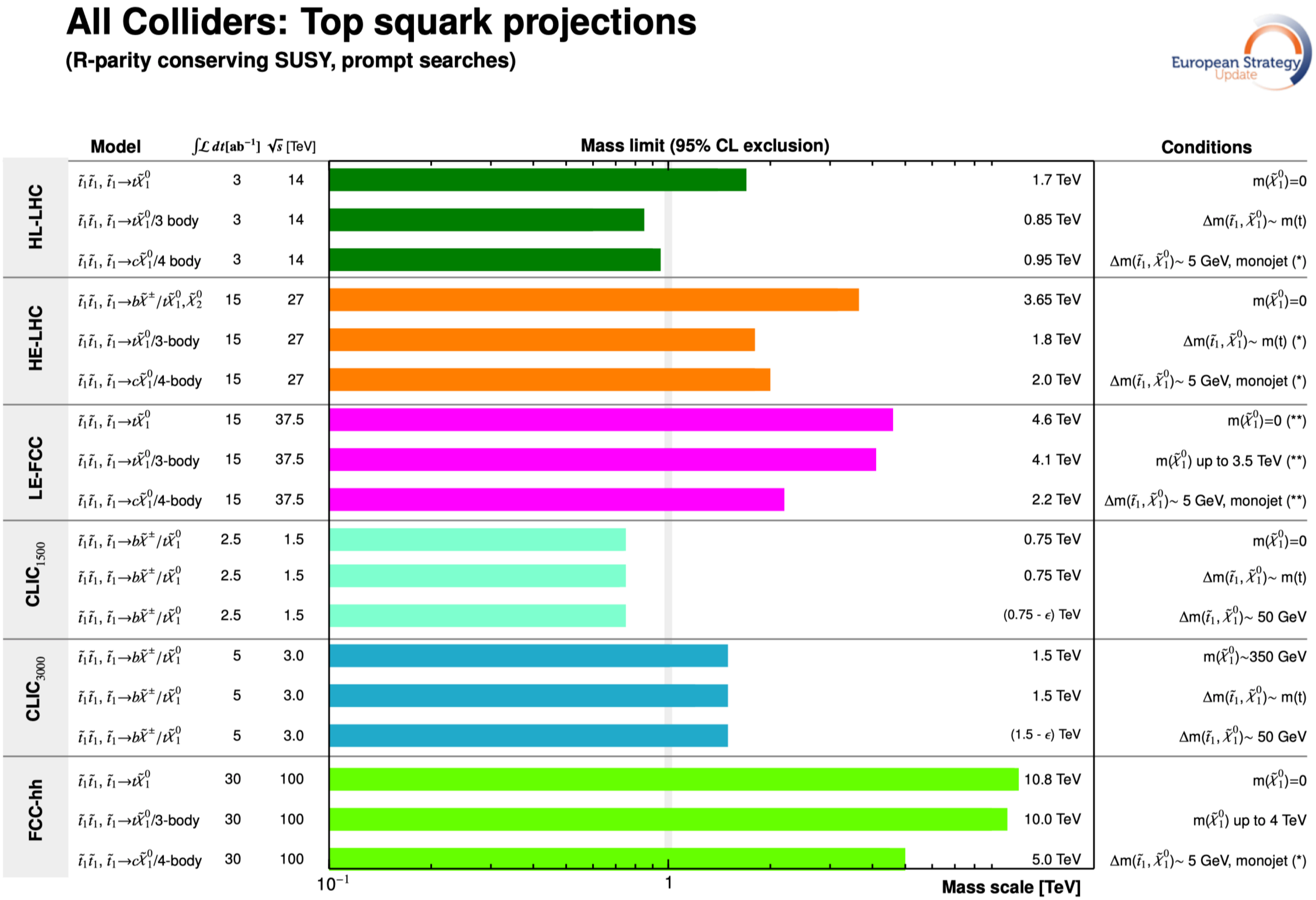


Fig. 8.7: Exclusion reach of different hadron and lepton colliders for first- and second-generation squarks.

EU Strategy- SUSY: ~t



(*) indicates projection of existing experimental searches

(**) extrapolated from FCC-hh prospects

ϵ indicates a possible non-evaluated loss in sensitivity

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

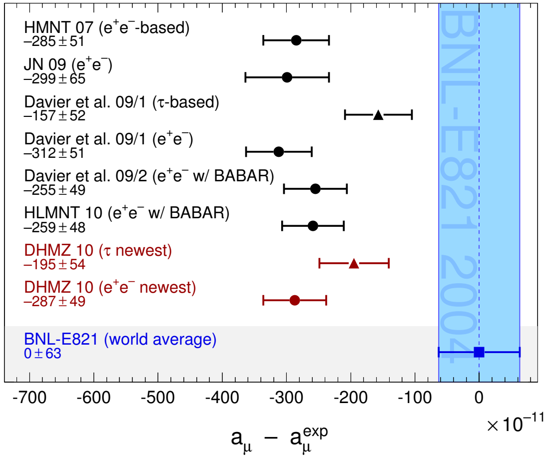
https://indico.cern.ch/event/687651/contributions/3400865/attachments/1850992/3038683/Wagner-LHCP2019.pdf

Muon Anomalous Magnetic Moment

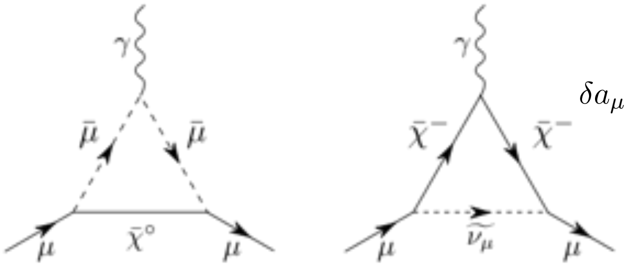
Present status: Discrepancy between Theory and Experiment at more than three Standard Deviation level

$$\delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm theory} = 268(63)(43) \times 10^{-11}$$

3.6σ Discrepancy



New Physics at the Weak scale can fix this discrepancy. Relevant example : Supersymmetry



$$\delta a_\mu \simeq \frac{\alpha}{8\pi s_W^2} \frac{m_\mu^2}{\widetilde{m}^2} {\rm Sgn}(\mu M_2) \tan\beta \simeq 130 \times 10^{-11} \left(\frac{100\ {\rm GeV}}{\widetilde{m}}\right)^2 {\rm Sgn}(\mu M_2) \tan\beta$$

Grifols, Mendez'85, T. Moroi'95,
Giudice, Carena, C.W.'95, Martin and Wells'00 ....

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 !