Progress of BSM analyses at the CEPC Snowmass Studies

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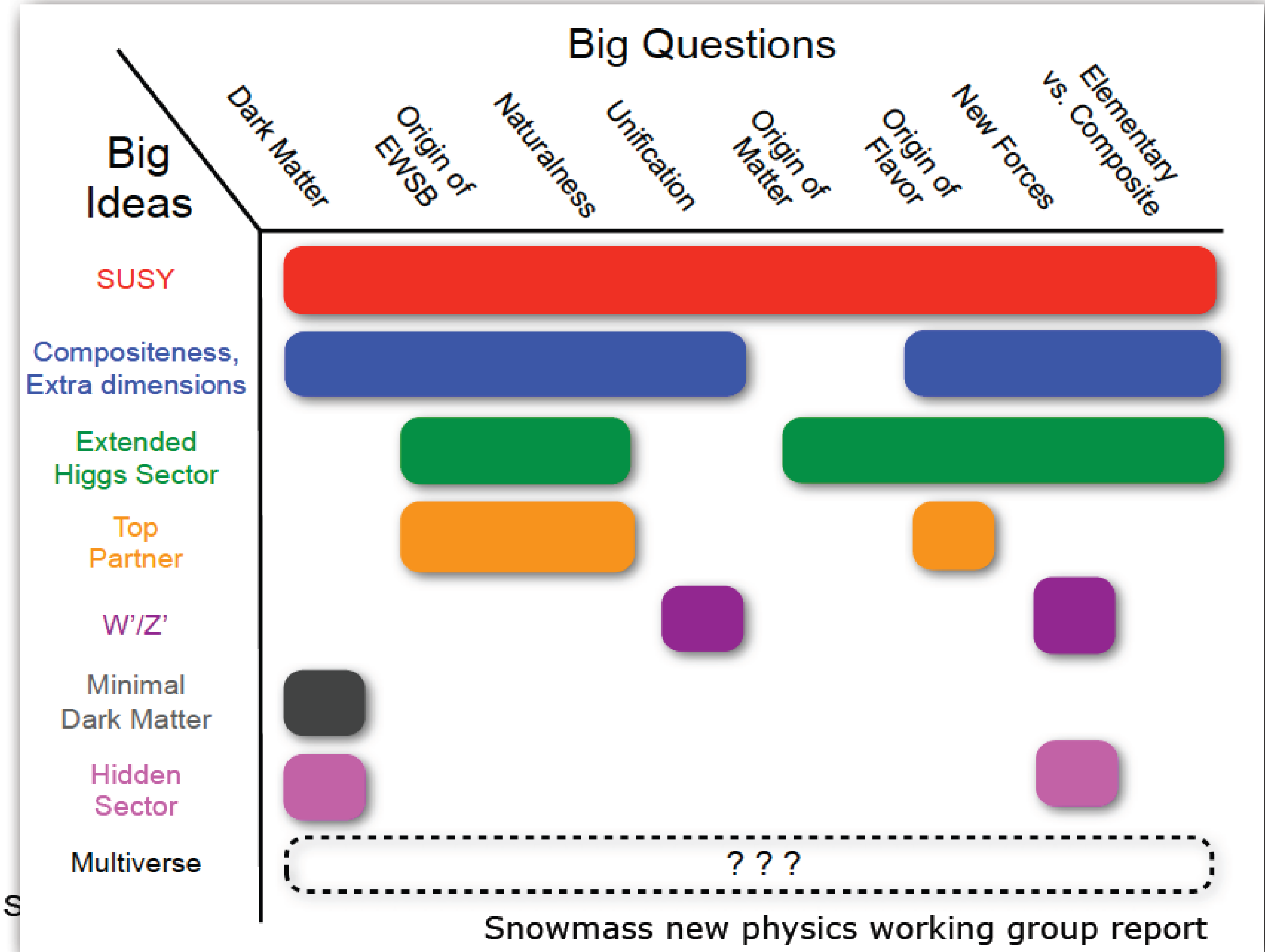
New Physics beyond the SM



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Snowmass & BSM Physics

- **Goal of Snowmass:**
  - Focus on a "set of questions" and the "scientific merits" of the various collider options and proposals
  - Develop a global picture and a future roadmap
- **BSM Physics**
  - EF08: Model specific explorations (simplified models): SUSY, composite models, extra dimensions, …
  - EF09: More general explorations: New bosons, new fermions, MET signatures, long-lived particles, EFT, …
  - EF10: Dark matter at colliders

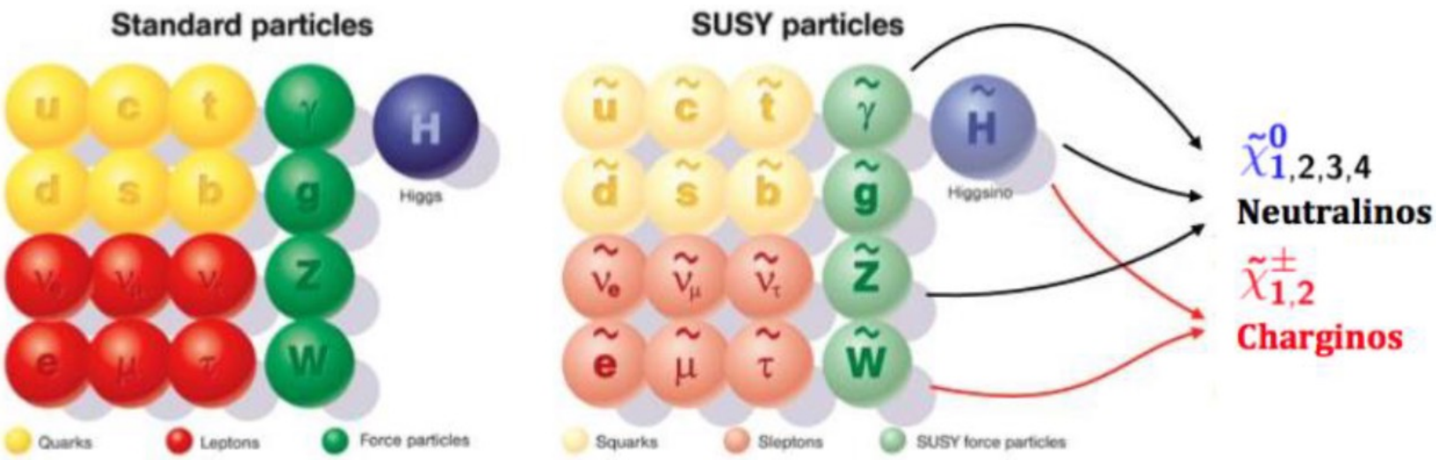
European Strategy Report

- SUSY is the main model considered
- Other models are more like EFT
  - Composite Higgs (EF02)
  - Contact interactions (EF09)
- Dark Matter Simplified Models (EF10)
- **Need to think broadly about which models to consider based on our goals (CEPC/SPPC)**
  - **Want a broad but achievable set of models**

Contributions from China

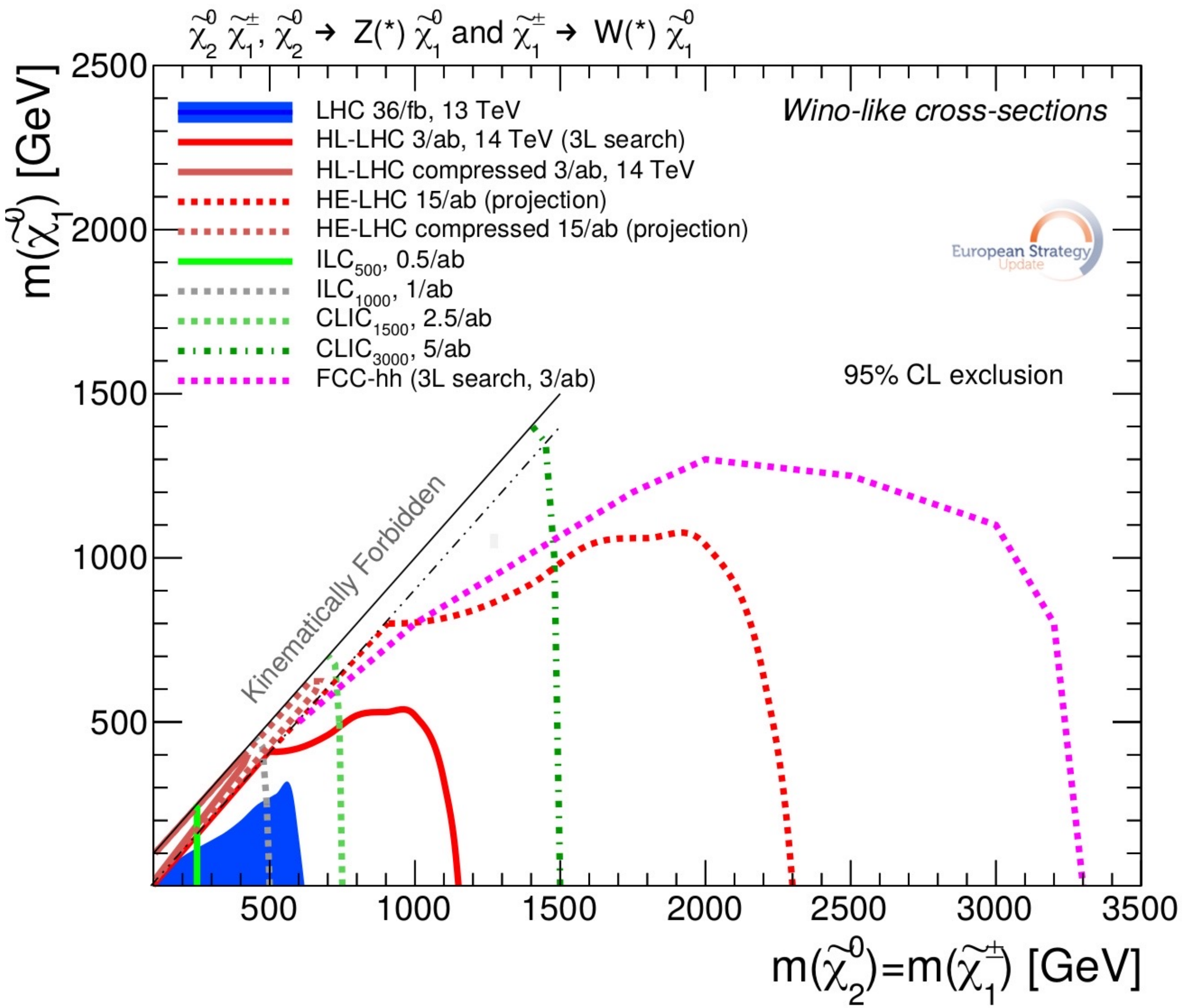
- **EF08-01: SUSY and Dark Matter at the CEPC, FCC_ee, and ILC (Tianjun Li; Lei Wu; Xuai Zhuang; Chengcheng Han etc.)**
- **EF08-02: SUSY global fits with future colliders using GAMBIT (Yang Zhang)**
- **EF10-01: Dark Matter: Top + jet + missing Energy (Peiwen Wu)**
- **EF10-02: Dark Matter: Asymmetric DM by displaced lepton jets (Mengchao Zhang)**
- **EF10-03: Dark Matter: Higgs portal (Xin Shi)**
- **EF10-04: Dark Matter: Lepton portal dark matter, gravitational waves and collider phenomenology (Jia Liu etc.)**
- More BSM:
  - EF02: EW Physics: Higgs Boson as a portal to new physics
  - EF03: EW Physics: Heavy flavor and top quark physics
  - EF02-01: Electroweak Phase Transition with Exotic Higgs Decays (Shu Li)
  - EF02-02: Heavy Neutrino Search in Lepton-rich Higgs boson rare decays (Yu Gao)
  - EF03: Probing top quark FCNC couplings tqγ, tqZ at CEPC (Peiwen Wu)
  - ……

SUSY Introduction



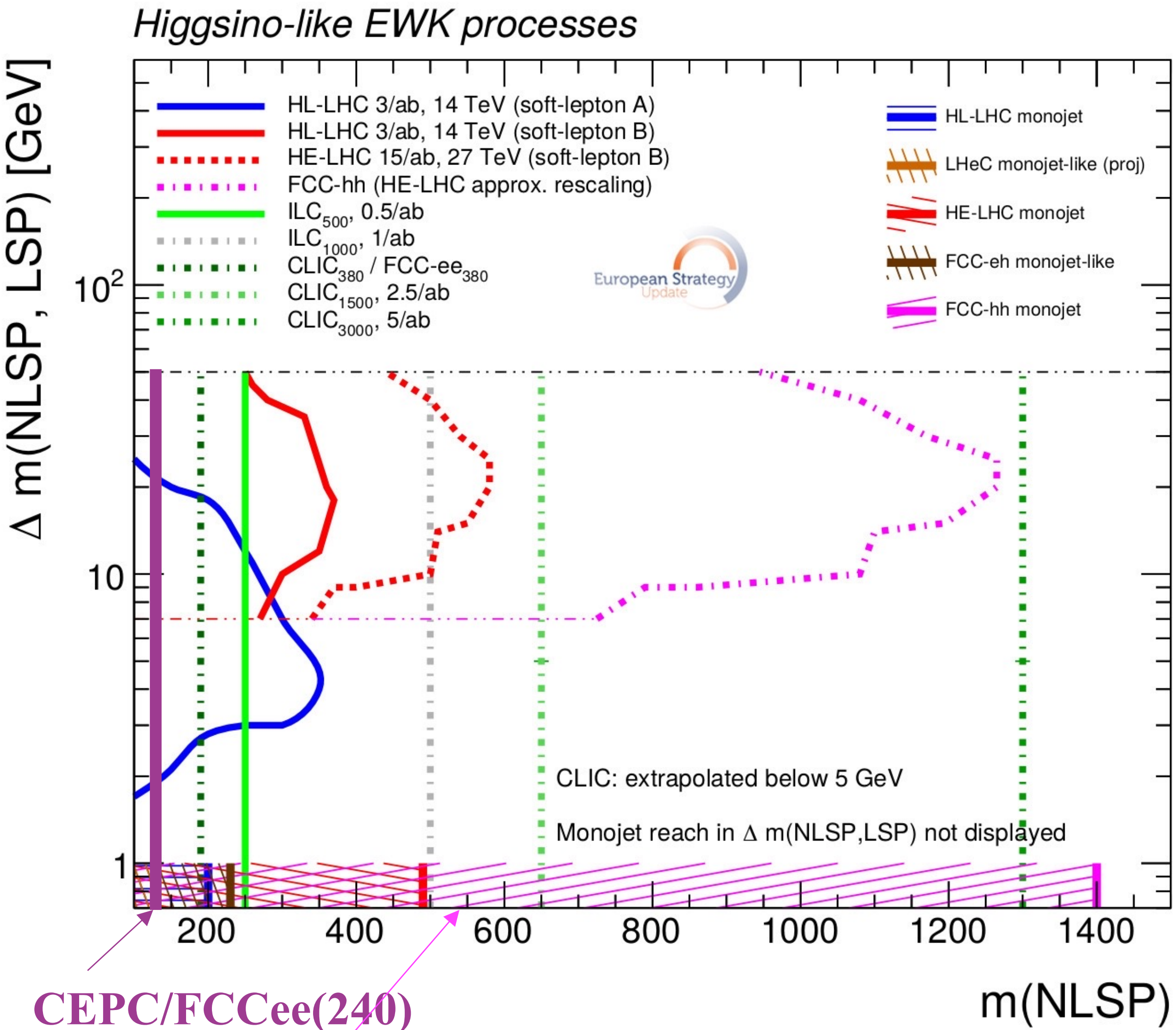
- **SUSY is one of the most favorite candidate for physics BSM, which can**
  - **provide a natural solution to the gauge hierarchy problem,**
  - **provide DM candidate with PRC ,**
  - **achieve gauge coupling unification,**
  - **......**
- **However, SUSY searches at LHC have already given very strong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

Current status: EU Strategy- gaugino



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

Current status: EU Strategy- higgsino

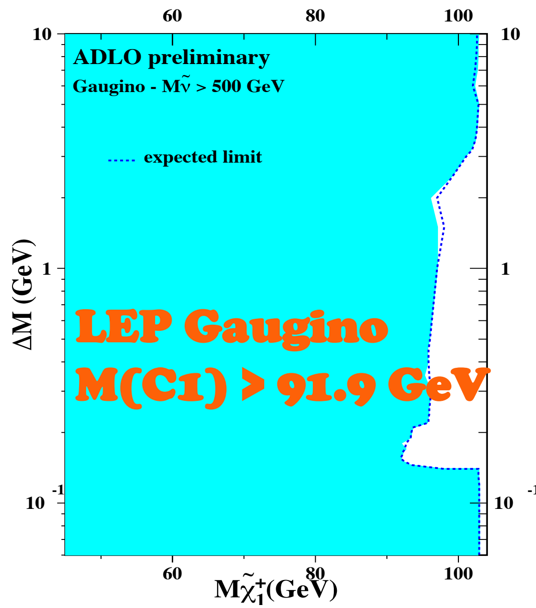


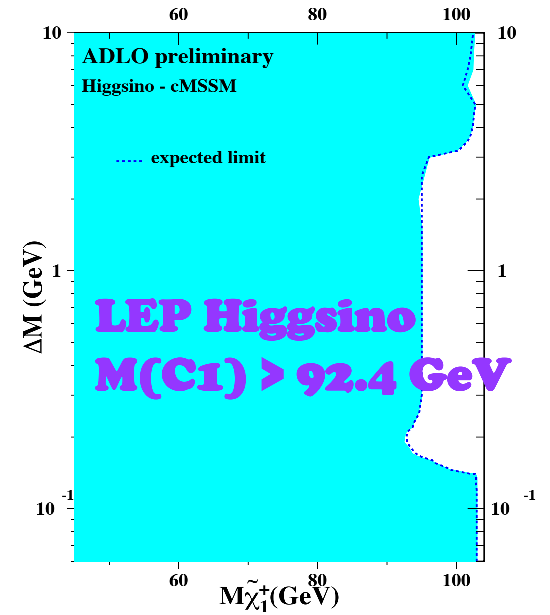
CEPC/FCCee(240)

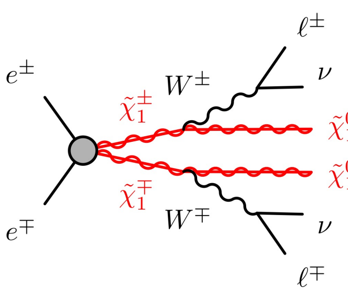
Disappearing tracks exclusion is actually off the scale

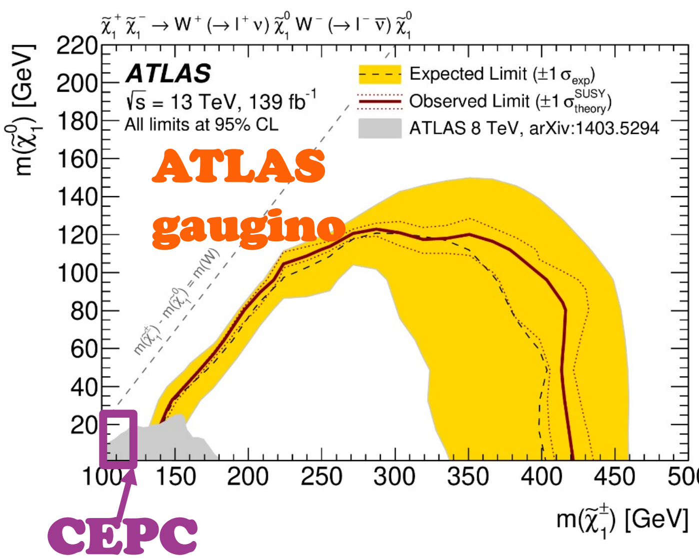
Gaugino & higgsino

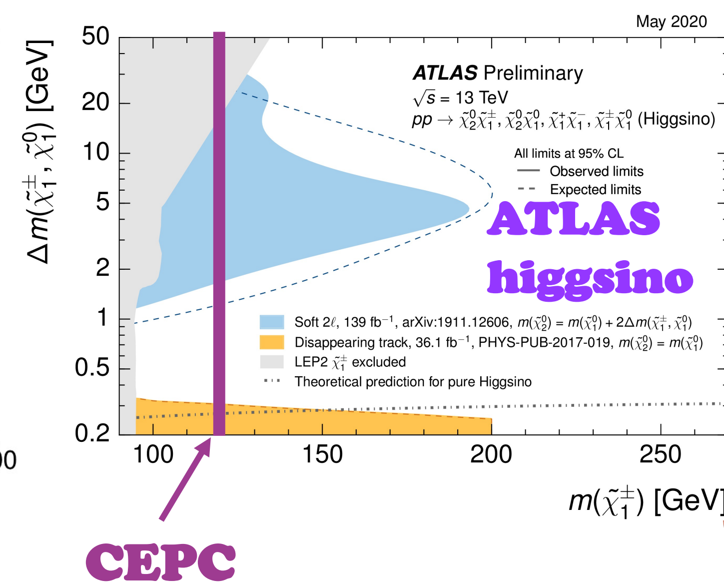
- Light gauginos have larger x-sec in lepton colliders with lower energy
- The naturalness conditions from the low-energy fine-tuning measures 【1-3】 generically predict the light Higgsinos











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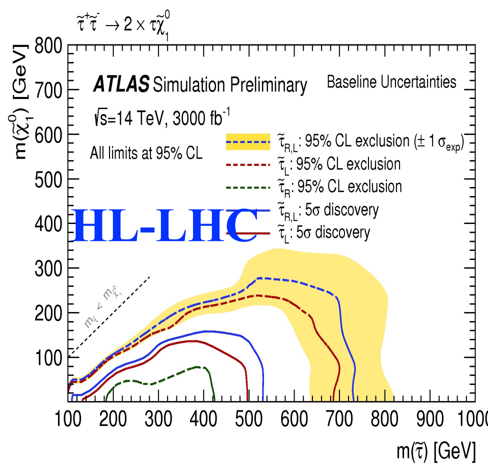
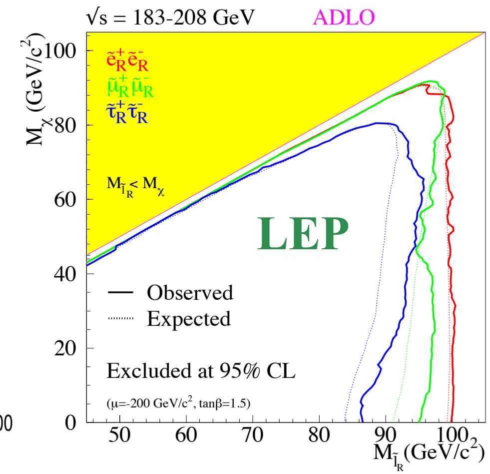
1. Phys. Lett. B 631, 58 (2005)
2. Phys. Rev. D 73, 095004 (2006)
3. arXiv:1212.2655

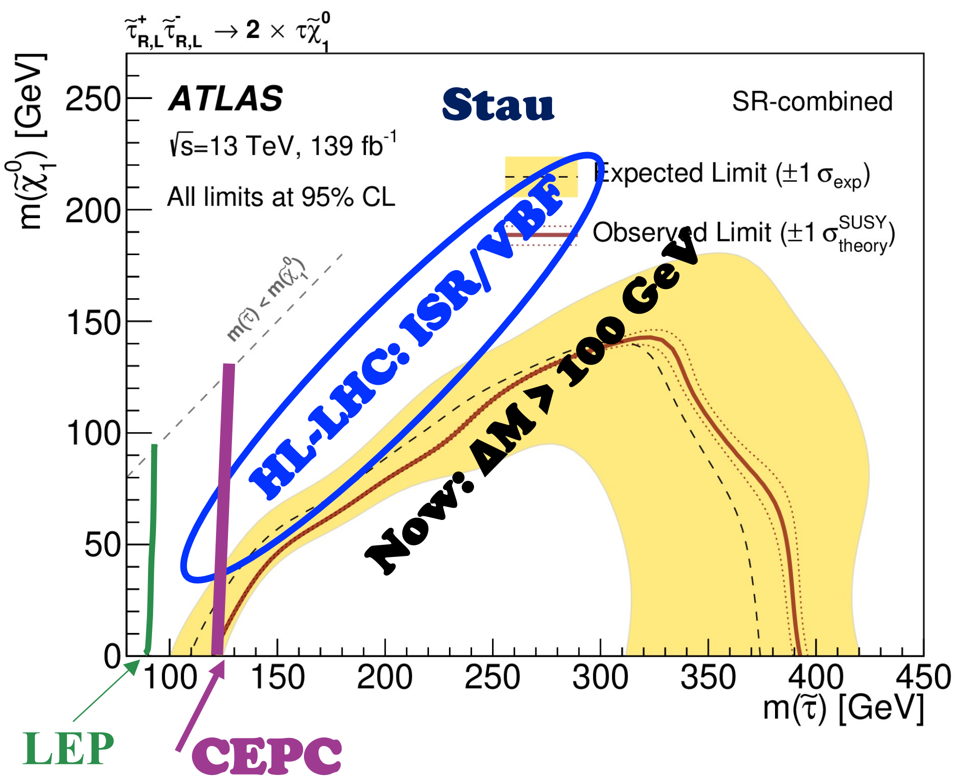
From Xuai Zhuang, Jiarong Yuan, Huajie Cheng

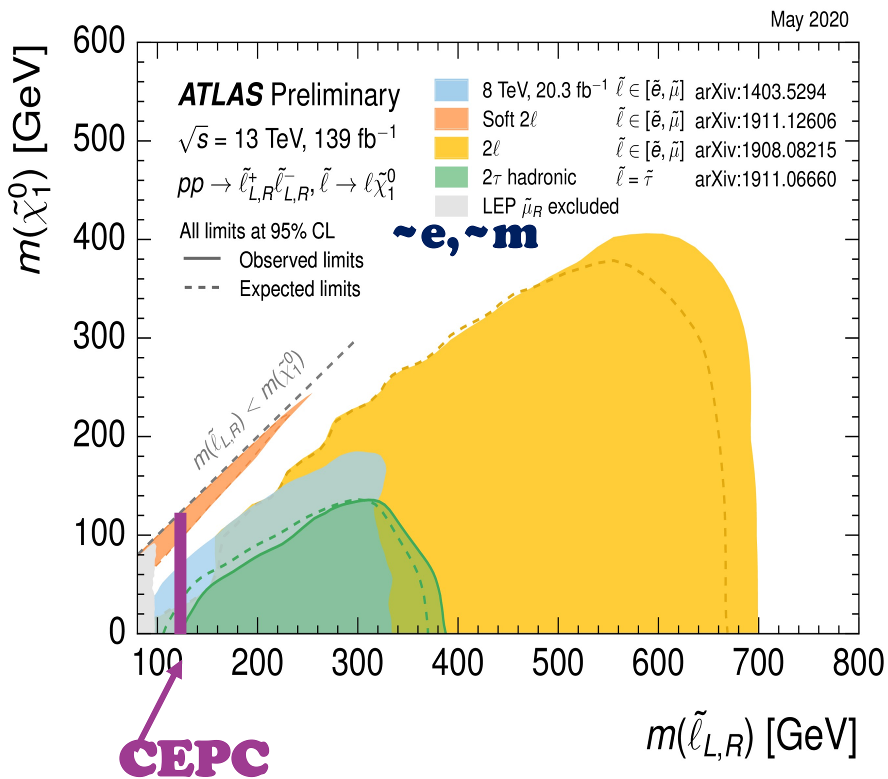
Stau & smuon

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



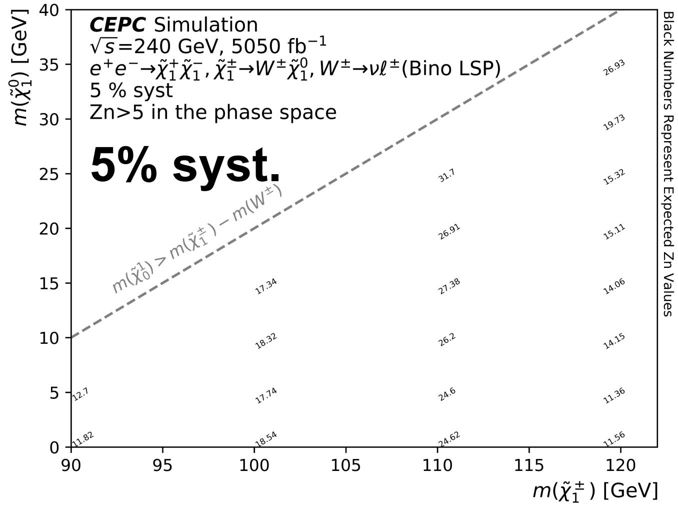


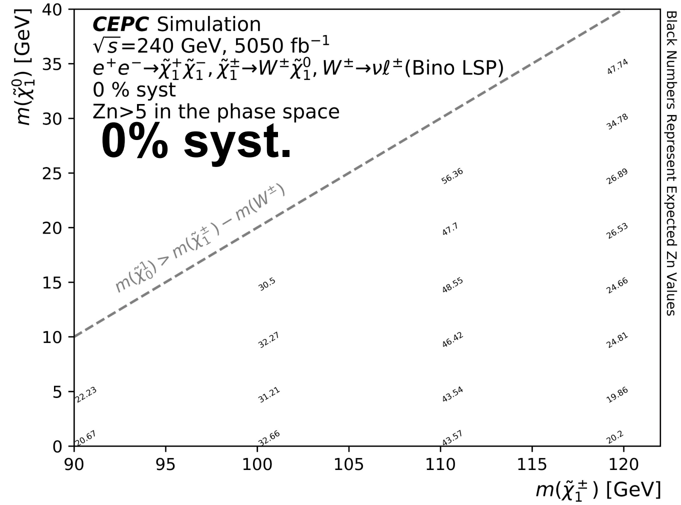




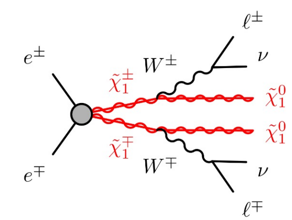
From Xuai Zhuang, Jiarong Yuan, Huajie Cheng

Preliminary Results

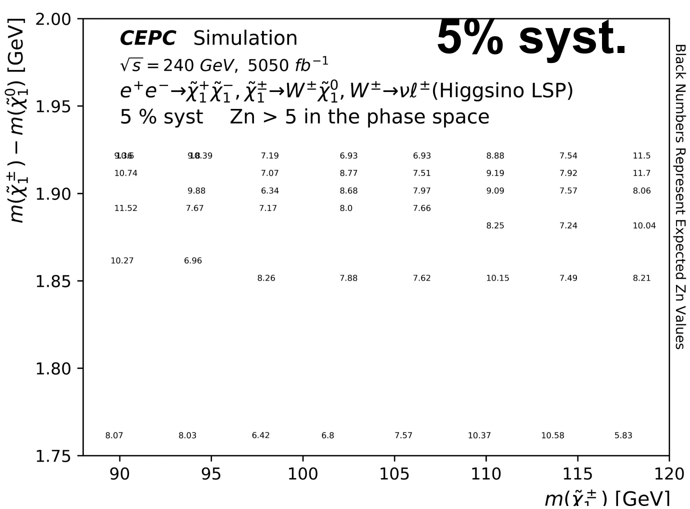


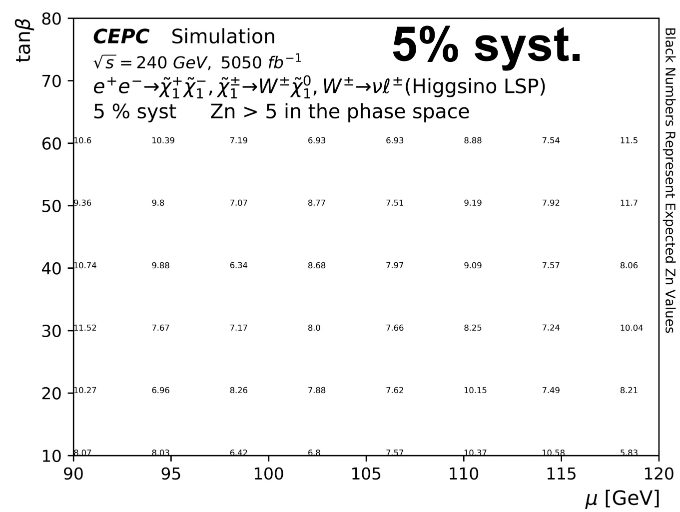


Bino LSP



CEPC240(FCCee/ILC): discovery for gauginos up to kinematic limit: √s/2



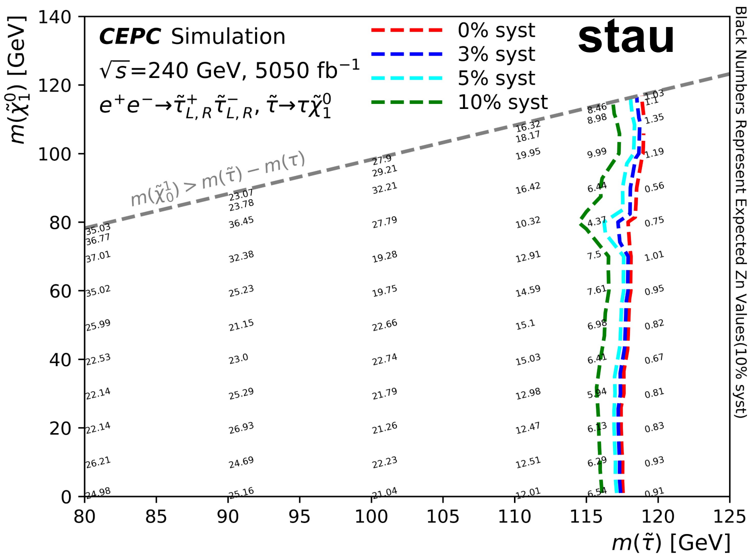


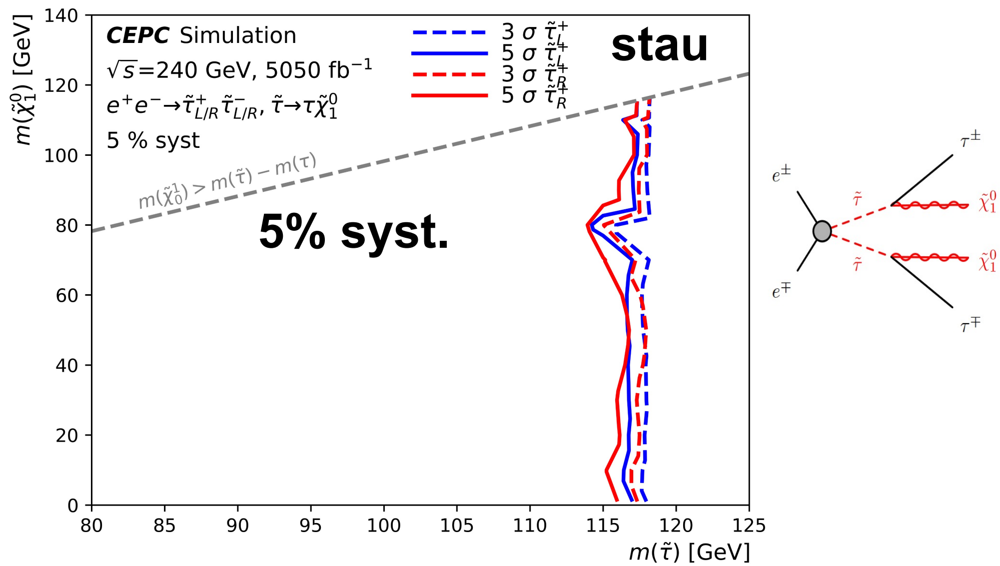
Higgsino LSP

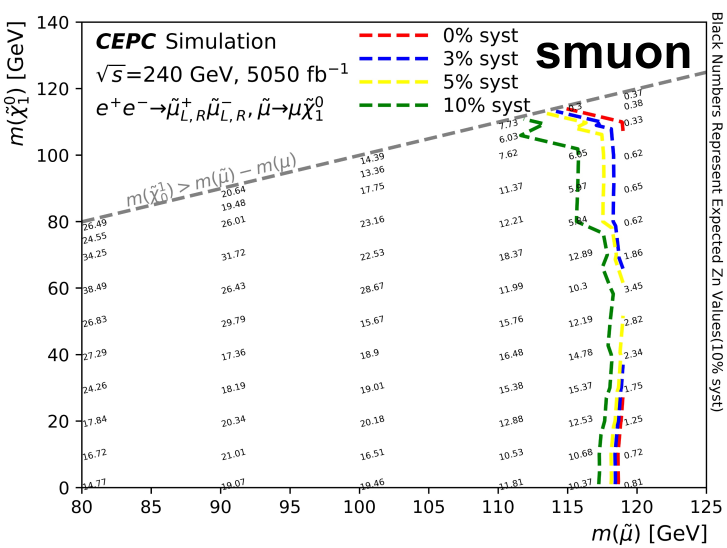
$$Zn = \left[2\left((s+b)\ln\left[\frac{(s+b)(b+\sigma_b^2)}{b^2+(s+b)\sigma_b^2}\right] - \frac{b^2}{\sigma_b^2}\ln\left[1+\frac{\sigma_b^2 s}{b(b+\sigma_b^2)}\right]\right)\right]^{1/2}$$

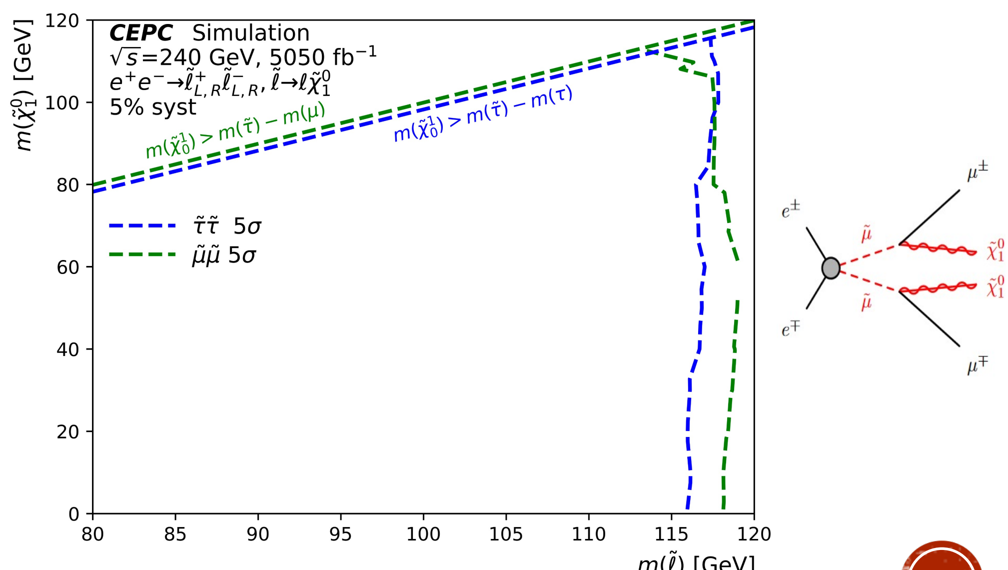
From Xuai Zhuang, Jiarong Yuan, Huajie Cheng

Preliminary Results





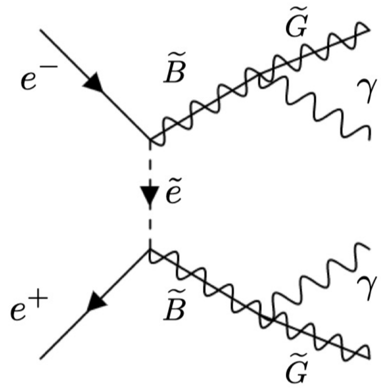




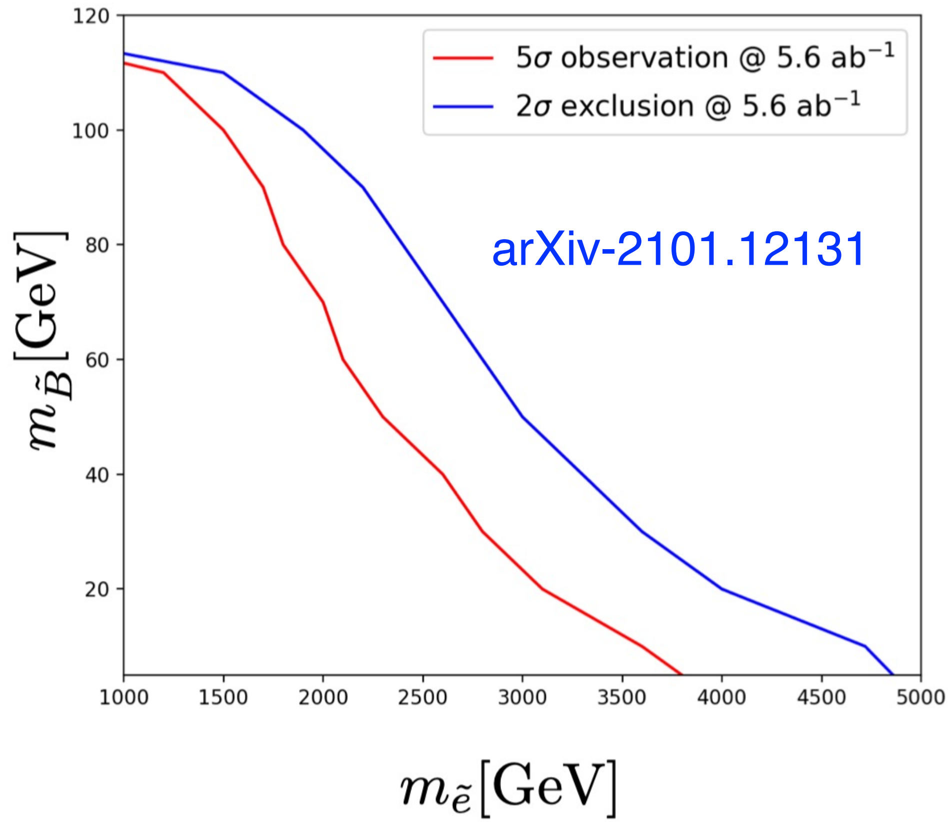
CEPC240(FCCee/ILC): discovery for slepton nearly up to kinematic limit: √s/2

From Junmou Chen, Chengcheng Han, Jinmin Yang, Mengchao Zhang

Bino NLSP at CEPC



$$\tilde{B} \rightarrow \tilde{G}/\tilde{a} + \gamma$$



- **Besides above popular WIMP DM candidates, SUSY also predicted Gravitino/Axino DM from light bino decay**

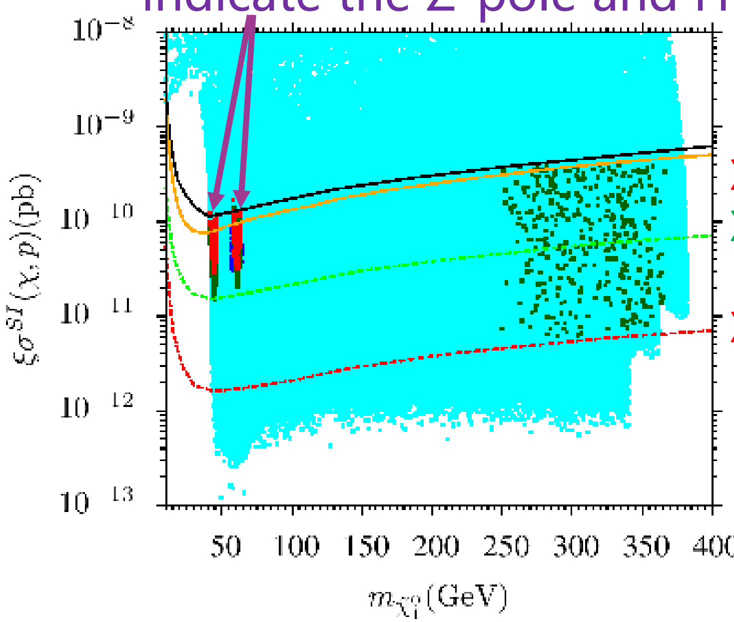
- **Bino mass around 100 GeV can be probed at the 2σ (5σ) level for a slepton below 2 TeV (1.5 TeV) with a luminosity 5.6 ab^{-1} .**
- **For a bino mass around 10 GeV, a slepton mass less than 4.5 TeV (3.5 TeV) can be probed at the 2σ (5σ) level.**
- **It is much beyond the reach of the LHC for direct slepton searches.**

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 $(\tilde{\chi}_1^0 \to \tilde{a}\gamma)$ as follows
- $e^+e^- \to \tilde{\chi}_1^0(bino) + \tilde{\chi}_1^0(bino) \to 2\tilde{a} + 2\gamma$

GmSUGRA scaning is going on

From Yang ZHANG

SUSY global fits with CEPC using GAMBIT

Purpose:

- Study the impact of CEPC on global fits of the SUSY models, such as CMSSM, NUHM1, NUHM2 and pMSSM-7.
- Judge the discovery prospects and reaches of future colliders for SUSY models.
- Provide a further motivation for the construction of future electron-positron colliders.

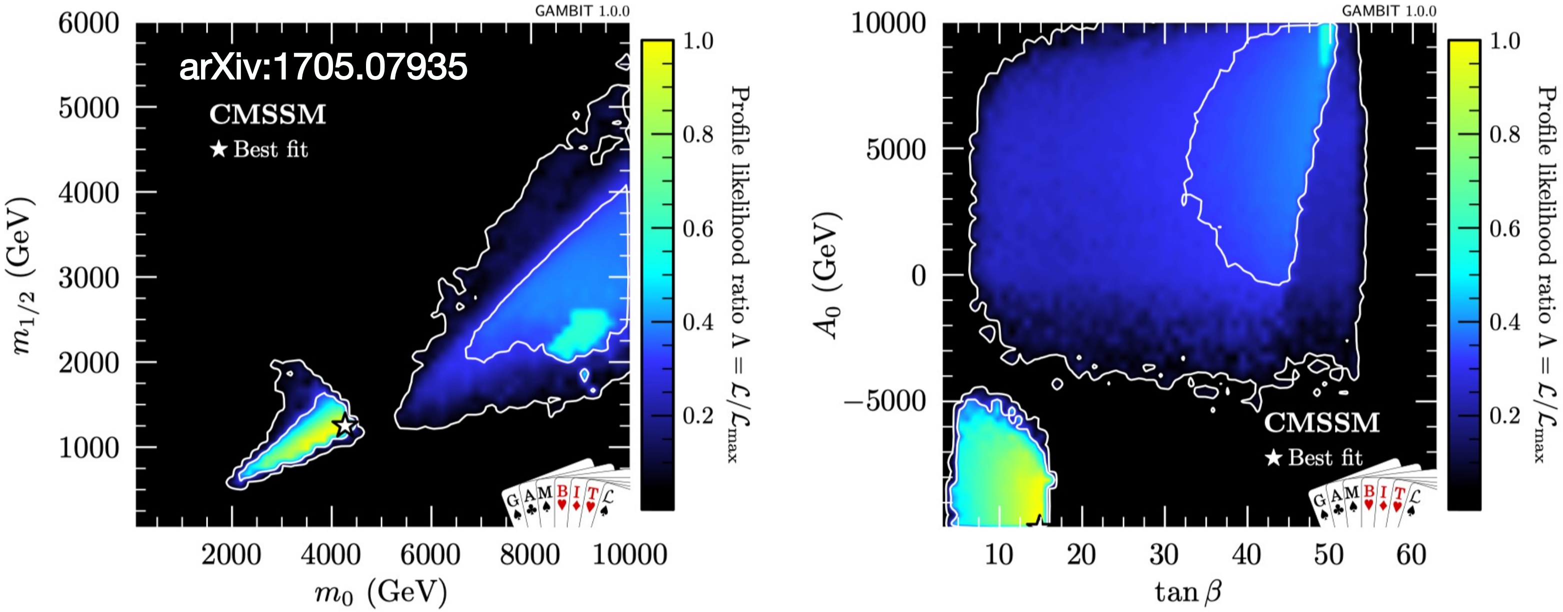
SUSY global fits with CEPC using GAMBIT

Method:

- Using the projected precisions for Higgs properties and assuming the results are SM-like or centering on the present SUSY best-fit point, we can build likelihoods for CEPC.
- Comparing the preferred regions and best fits with and without the likelihoods, we can estimate the prospective reaches and discovery prospects of CEPC.
- As for the preferred regions without the CEPC likelihoods, we can use the publicly available GAMBIT data.

Present preferred regions of CMSSM

From Yang ZHANG

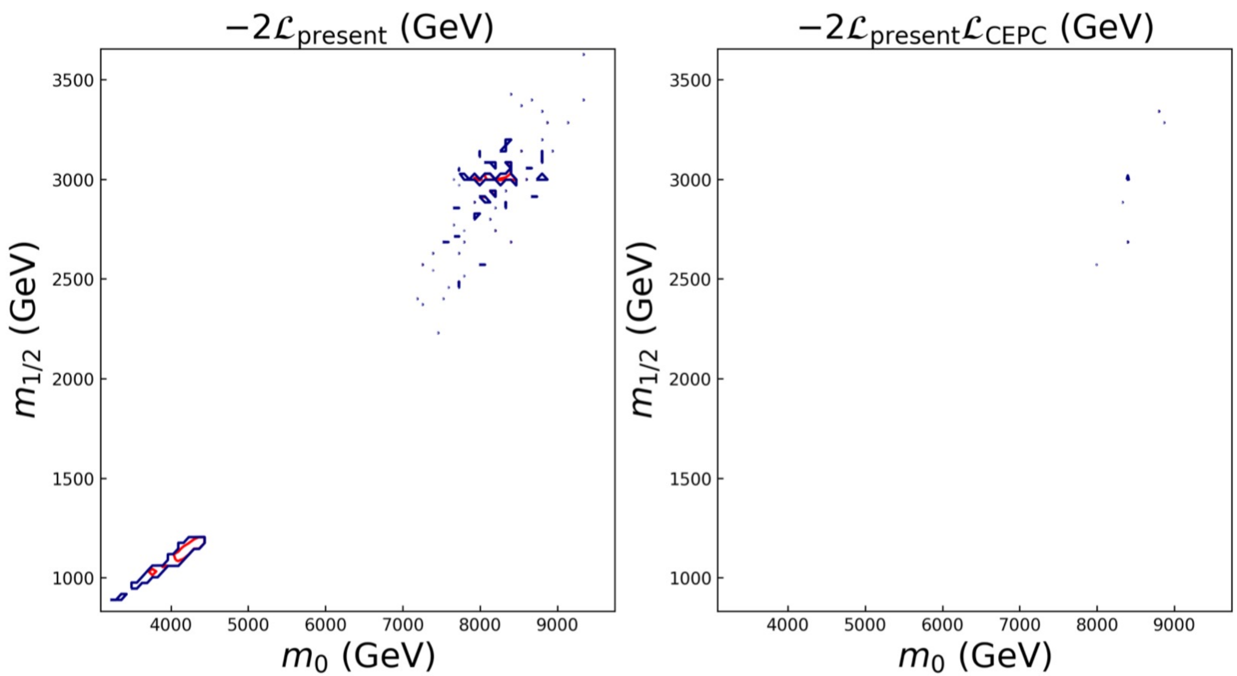


$$\mathcal{L}_{\text{present}} = \mathcal{L}_{\text{collider}}\mathcal{L}_{\text{DM}}\mathcal{L}_{\text{flavor}}\mathcal{L}_{\text{EWPO}}\cdots$$

Including LHC sparticle searches, LHC Higgs, LEP Higgs, ALEPH slepton, L3 slepton, L3 neutralino/chargino, OPAL chargino, $B(s) \to \mu^+\mu^-$, Tree-level B and D decays, $B^0 \to K^{*0}\mu^+\mu^-$, $B \to X_s\gamma$, a_μ, W mass, Relic density, PICO-2L, PICO-60F, SIMPLE 2014, LUX 2015, LUX 2016, PandaX 2016, SuperCDMS 2014, XENON100 2012, IceCube 79-string, γrays (Fermi-LAT dwarfs), $\rho 0$, σ_s and σ_l, $\alpha_s(m_Z)(\overline{\text{MS}})$, Top quark mass.

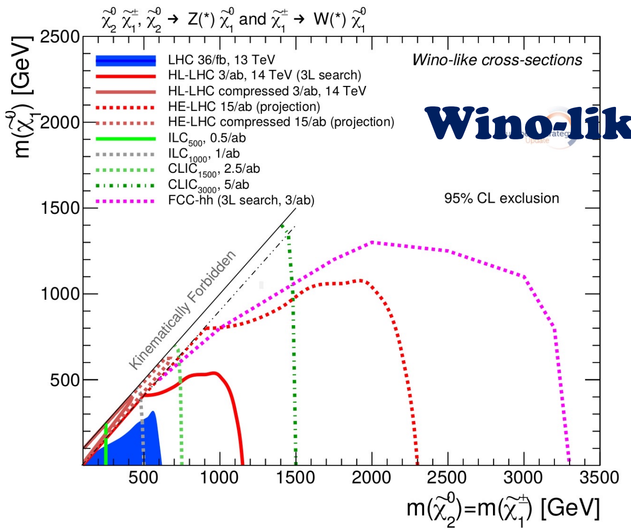
Progress (BF-like)

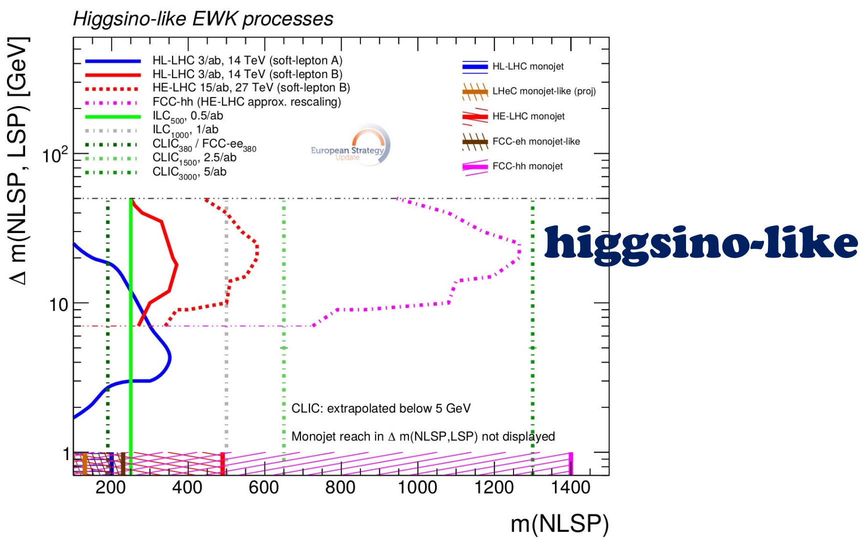
From Yang ZHANG

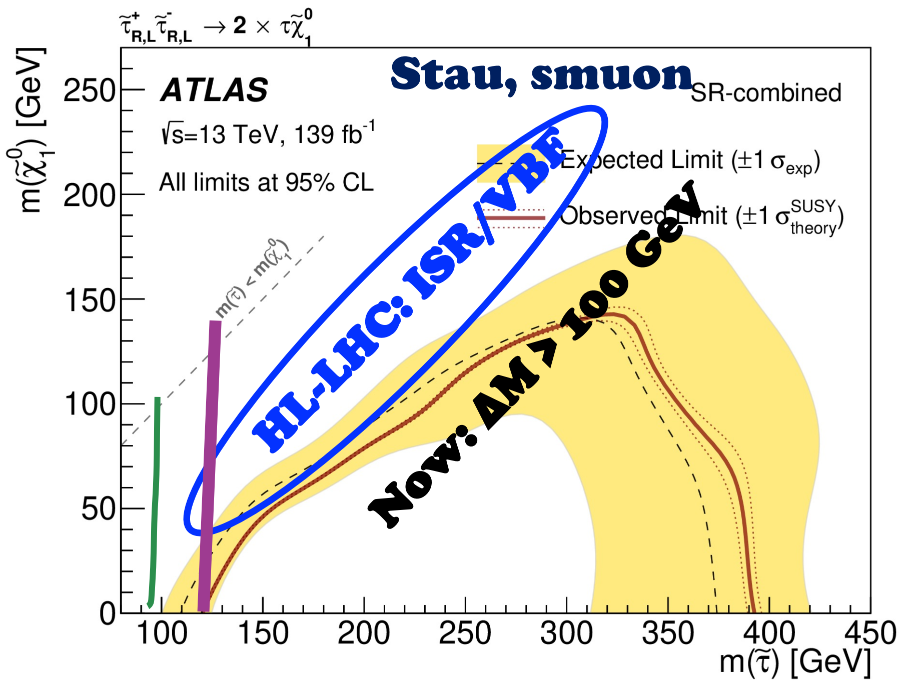


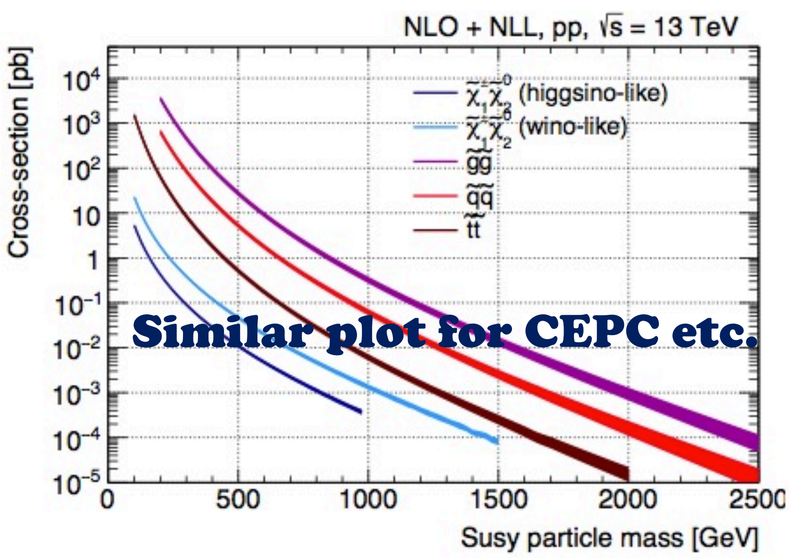
Red: 1σ CL contour lines; Blue: 2σ CL contour lines.
The number of samples that we have post-processed is not enough to form confidence contours. However, it is clear that CPPC will obviously shrink the preferred regions in parameter spaces.

Curves contributed to a Snowmass report summary plot

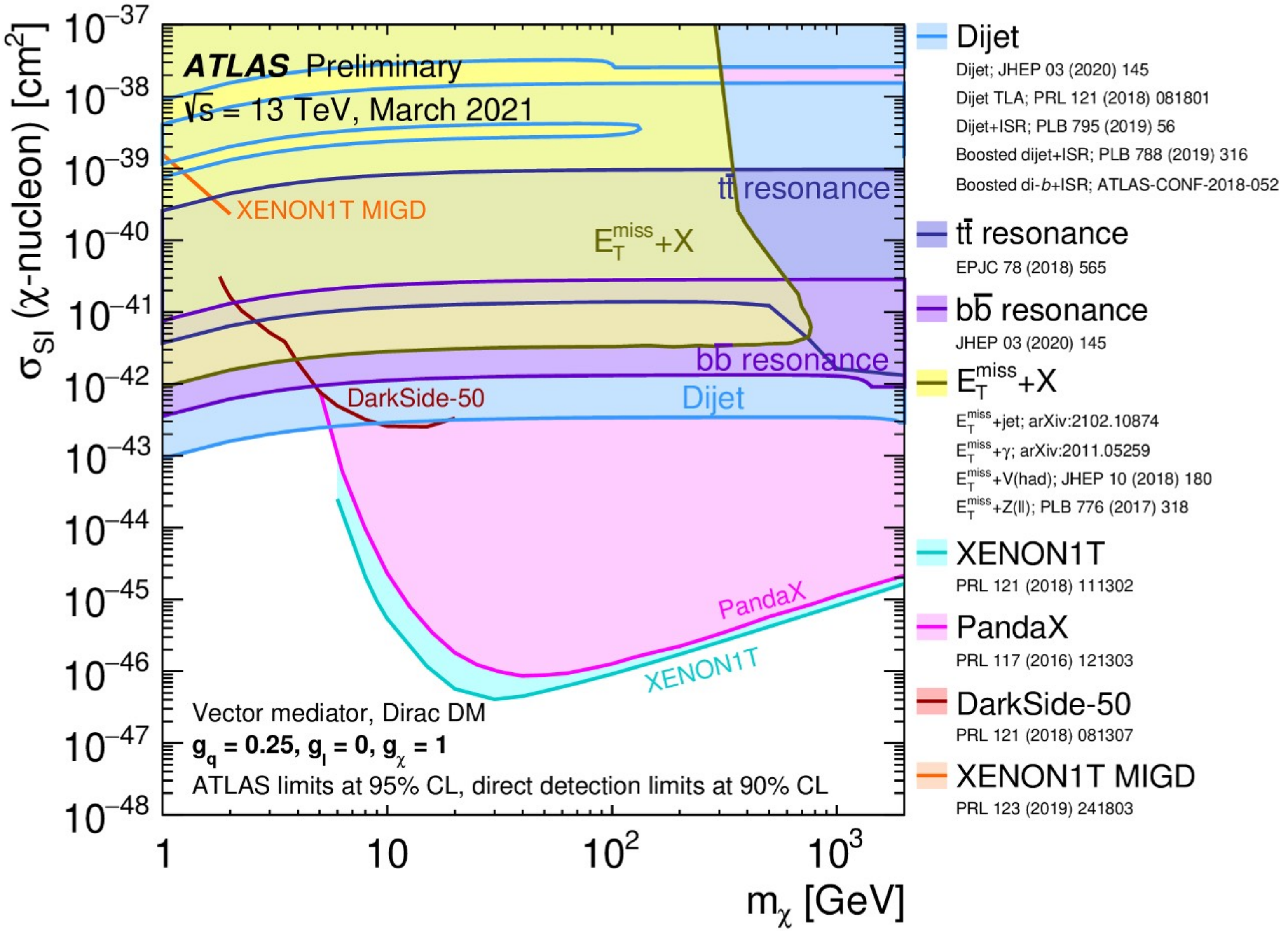








Dark Matter



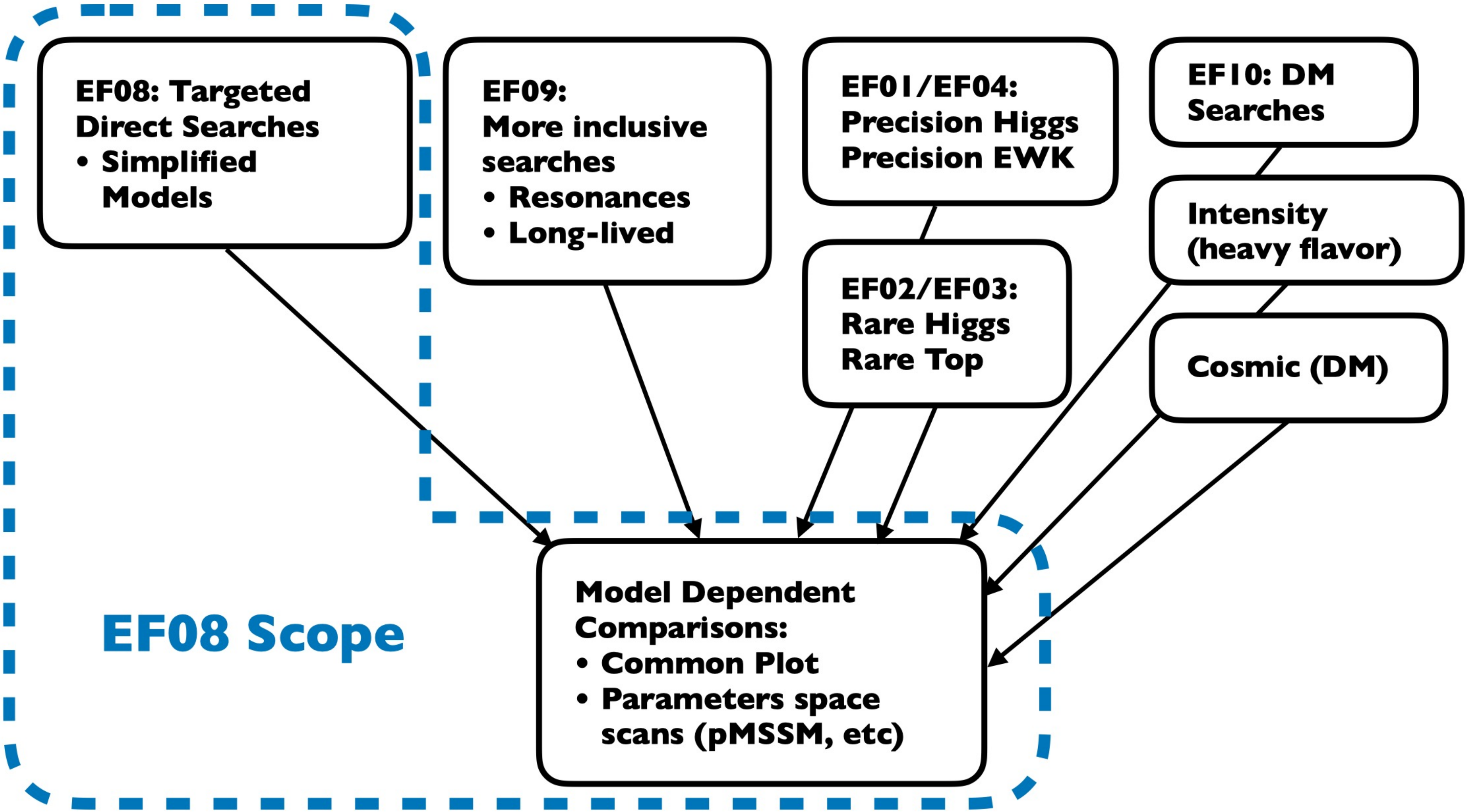
ATLAS Preliminary
√s = 13 TeV, March 2021
XENON1T MIGD
E_T^{miss}+X
tt̄ resonance
bb̄ resonance
Dijet
DarkSide-50
PandaX
XENON1T
Vector mediator, Dirac DM
g_q = 0.25, g_l = 0, g_χ = 1
ATLAS limits at 95% CL, direct detection limits at 90% CL
σ_{SI} (χ-nucleon) [cm²]
m_χ [GeV]
Dijet
Dijet; JHEP 03 (2020) 145
Dijet TLA; PRL 121 (2018) 081801
Dijet+ISR; PLB 795 (2019) 56
Boosted dijet+ISR; PLB 788 (2019) 316
Boosted di-b+ISR; ATLAS-CONF-2018-052
tt̄ resonance
EPJC 78 (2018) 565
bb̄ resonance
JHEP 03 (2020) 145
E_T^{miss}+X
E_T^{miss}+jet; arXiv:2102.10874
E_T^{miss}+γ; arXiv:2011.05259
E_T^{miss}+V(had); JHEP 10 (2018) 180
E_T^{miss}+Z(ll); PLB 776 (2017) 318
XENON1T
PRL 121 (2018) 111302
PandaX
PRL 117 (2016) 121303
DarkSide-50
PRL 121 (2018) 081307
XENON1T MIGD
PRL 123 (2019) 241803

Summary and Outlook

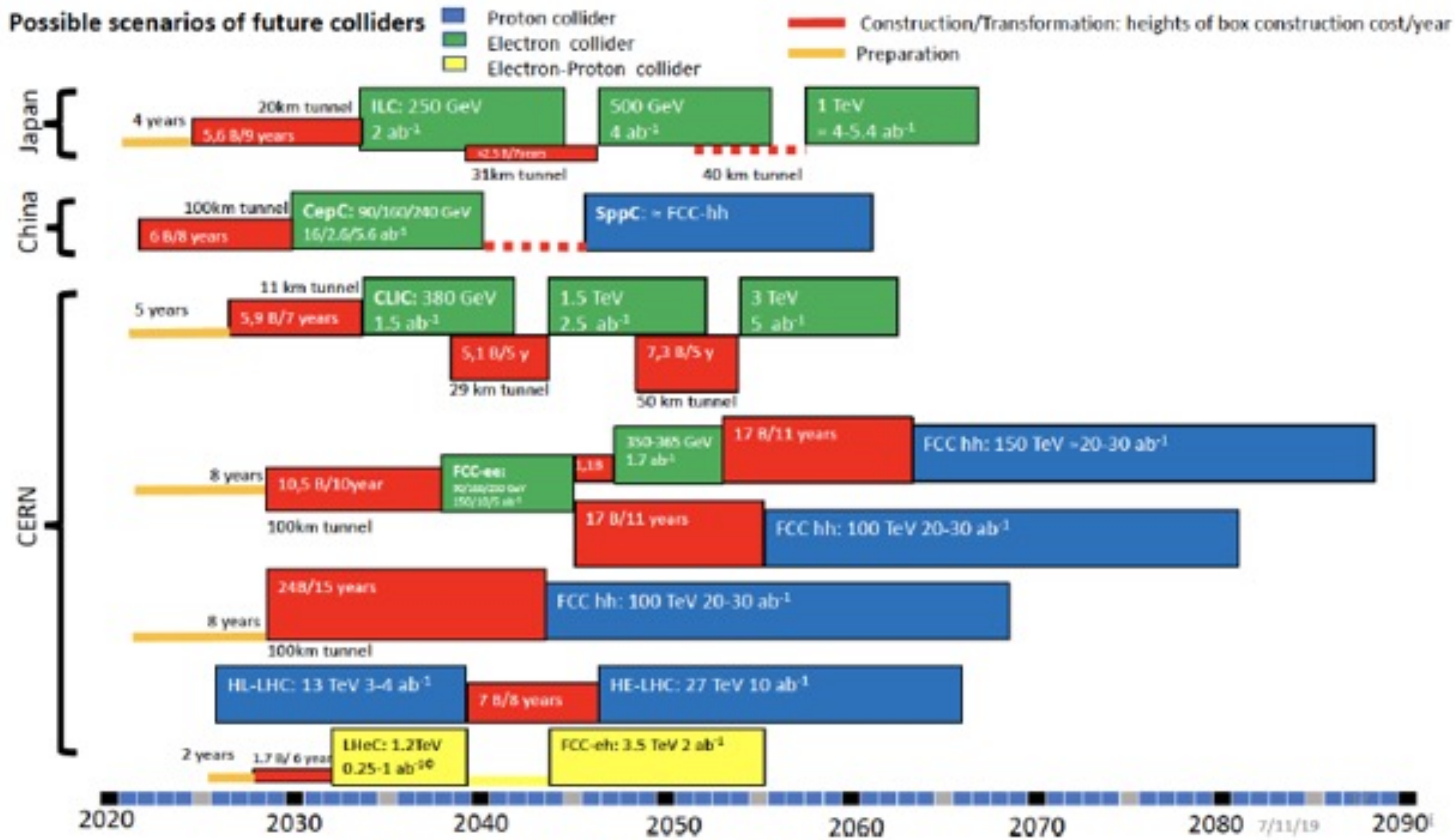
- The BSM analyses to snowmass are going on smoothly, some analyses are in paper draft stage (gaugino, slepton, light bino etc.)
- The detailed results to be presented at Yangzhou conference
- Paper drafts to be provided as inputs for snowmass white paper
- BSM physics white paper for CEPC?

Backup

Focus and interaction with others



Snowmass Process



Ursula Bassler @ Granada meeting

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 139)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt [\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 − 4 j	Yes	36.1	M_D 7.7 TeV	$n = 2$	1711.03301
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09127
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	1707.04147
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	1808.02380
	Bulk RS $G_{KK} \to WW \to qqqq$	0 e, μ	2 J	–	139	G_{KK} mass 1.6 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2019-003
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z' \to bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z' \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	Z' mass 3.0 TeV	$\Gamma/m = 1\%$	1804.10823
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	139	W' mass 6.0 TeV		CERN-EP-2019-100
	SSM $W' \to \tau\nu$	1 τ	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $V' \to WZ \to qqqq$ model B	0 e, μ	2 J	–	139	V' mass 3.6 TeV	$g_V = 3$	ATLAS-CONF-2019-003
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	1712.06518
	LRSM $W_R \to tb$	multi-channel			36.1	W_R mass 3.25 TeV		1807.10473
	LRSM $W_R \to \mu N_R$	2 μ	1 J	–	80	W_R mass 5.0 TeV	$m(N_R) = 0.5$ TeV, $g_L = g_R$	1904.12679
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η^-_{LL}		1703.09127
	CI $\ell\ell qq$	2 e, μ	–	–	36.1	Λ 40.0 TeV η^-_{LL}		1707.02424
	CI $tttt$	≥1 e,μ	≥1 b, ≥1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t}\rvert = 4\pi$	1811.02305
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 − 4 j	Yes	36.1	m_{med} 1.55 TeV	g_q=0.25, g_χ=1.0, $m(\chi) = 1$ GeV	1711.03301
	Colored scalar mediator (Dirac DM)	0 e, μ	1 − 4 j	Yes	36.1	m_{med} 1.67 TeV	g=1.0, $m(\chi) = 1$ GeV	1711.03301
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
	Scalar reson. $\phi \to t\chi$ (Dirac DM)	0-1 e, μ	1 b, 0-1 J	Yes	36.1	m_ϕ 3.4 TeV	$y = 0.4$, $\lambda = 0.2$, $m(\chi) = 10$ GeV	1812.09743
LQ	Scalar LQ 1st gen	1,2 e	≥ 2 j	Yes	36.1	LQ mass 1.4 TeV	$\beta = 1$	1902.00377
	Scalar LQ 2nd gen	1,2 μ	≥ 2 j	Yes	36.1	LQ mass 1.56 TeV	$\beta = 1$	1902.00377
	Scalar LQ 3rd gen	2 τ	2 b	–	36.1	LQ^u_3 mass 1.03 TeV	$\mathcal{B}(LQ^u_3 \to b\tau) = 1$	1902.08103
	Scalar LQ 3rd gen	0-1 e, μ	2 b	Yes	36.1	LQ^d_3 mass 970 GeV	$\mathcal{B}(LQ^d_3 \to t\tau) = 0$	1902.08103
Heavy quarks	VLQ $TT \to Ht/Zt/Wb + X$	multi-channel			36.1	T mass 1.37 TeV	SU(2) doublet	1808.02343
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3} T_{5/3} \vert T_{5/3} \to Wt + X$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt)$= 1, $c(T_{5/3} Wt)$= 1	1807.11883
	VLQ $Y \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B \to Hb + X$	0 e,μ, 2 γ	≥ 1 b, ≥ 1j	Yes	79.8	B mass 1.21 TeV	κ_B= 0.5	ATLAS-CONF-2018-024
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	139	q^* mass 6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2019-007
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	36.1	b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	1 e, μ	≥ 2 j	Yes	79.8	N^0 mass 560 GeV		ATLAS-CONF-2018-020
	LRSM Majorana ν	2 μ	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H^{\pm\pm}_L \to \ell\tau) = 1$	1411.2921
	Multi-charged particles	–	–	–	36.1	multi-charged particle mass 1.22 TeV	DY production, $\lvert q\rvert = 5e$	1812.03673
	Magnetic monopoles	–	–	–	34.4	monopole mass 2.37 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1905.10130

$\sqrt{s} = 8$ TeV | $\sqrt{s} = 13$ TeV partial data | $\sqrt{s} = 13$ TeV full data

10^{-1} 1 10 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

额外维粒子

W', Z'

Contact interactions

暗物质

leptoquark

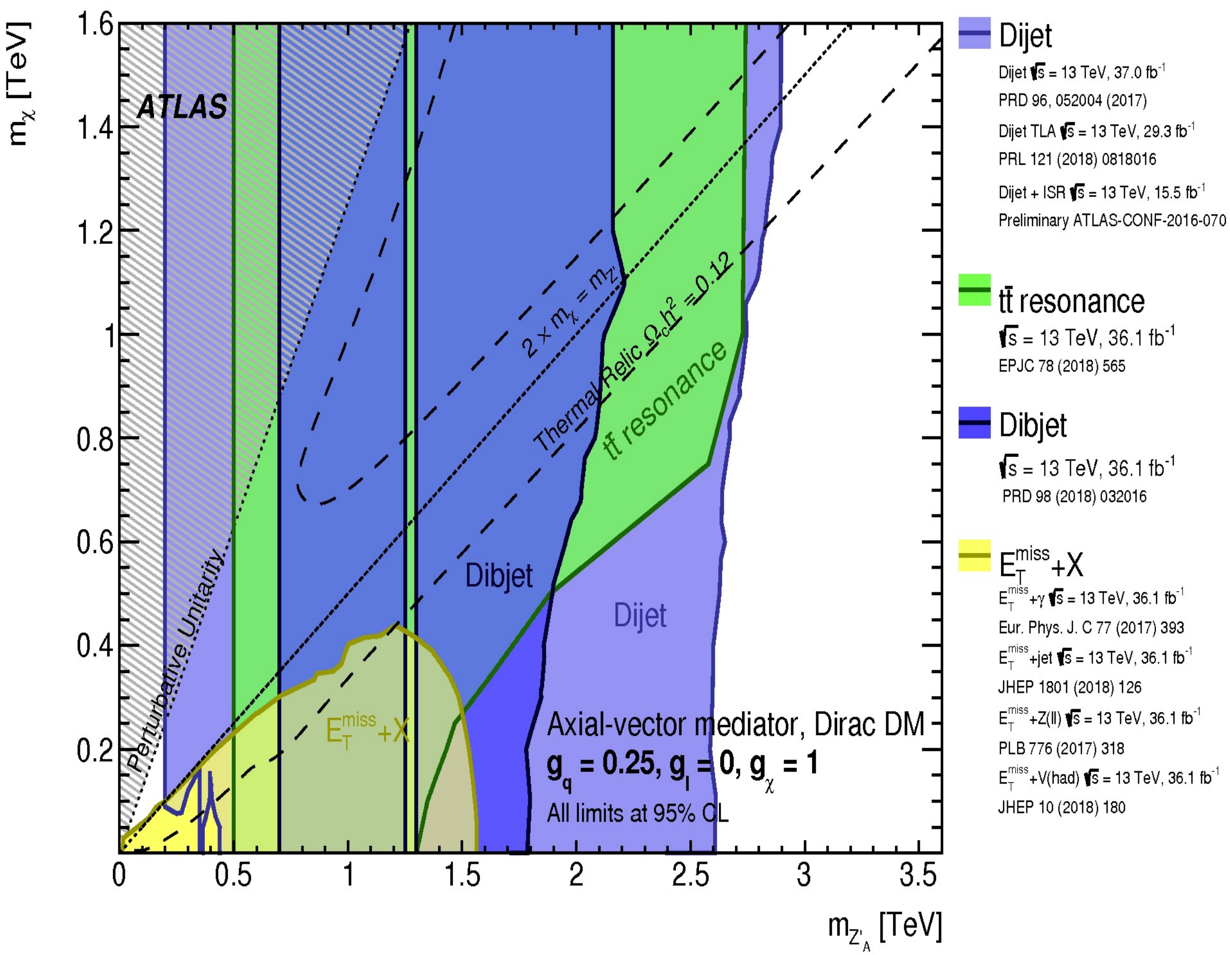
额外夸克

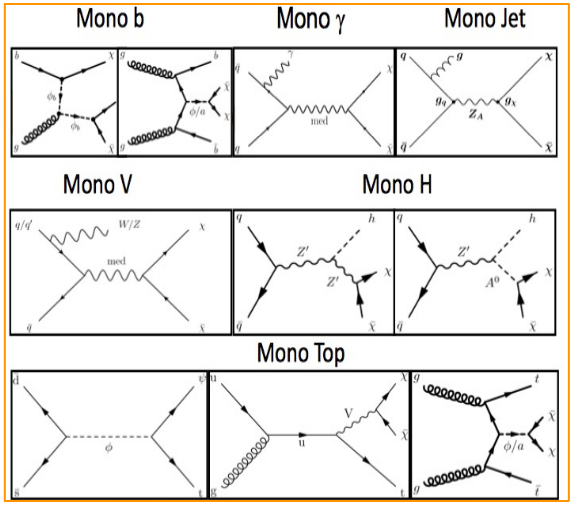
重费米子

其他

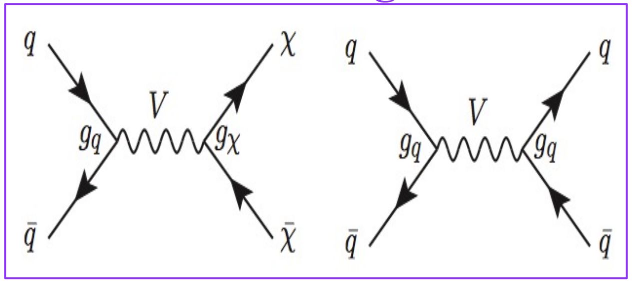
Dark Matter

Searches with MET+X or mediator





- Searches in the Mono-X final states: Many models constrained up to 1.6 TeV
- Searches also in the Di-Jet final states exclude up to 2.6 TeV for almost whole DM range



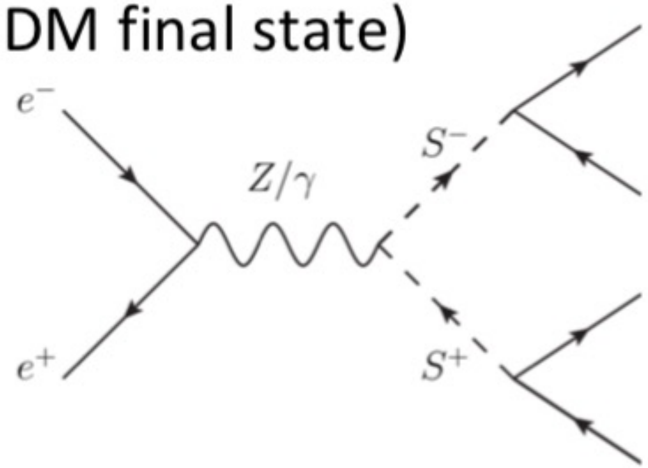
Lepton portal DM

The relevant Lagrangian

Y. Bai and J. Berger, 1402.6696

$$\mathcal{L}_\chi = y_\ell \bar{\chi}_L S^\dagger \ell_R + \text{h.c.},$$
$$\mathcal{L}_S = (D^\mu S)^\dagger D_\mu S - V(S,H),$$
$$V(H,S) = \mu_H^2|H|^2 + \mu_S^2|S|^2 + \lambda_H|H|^4 + \lambda_S|S|^4 + 2\lambda_{HS}|H|^2|S|^2,$$

Pair produced S^+S^- (and 100% to lepton + DM final state)

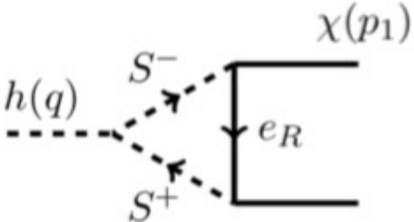


At the 240 GeV CEPC: two kinematics:

- On-shell: $M_S < 120$ GeV;
- Semi-off-shell: $120 < M_S < 240$ GeV;

The semi-off-shell region: also probe the size of y_l (portal coupling)

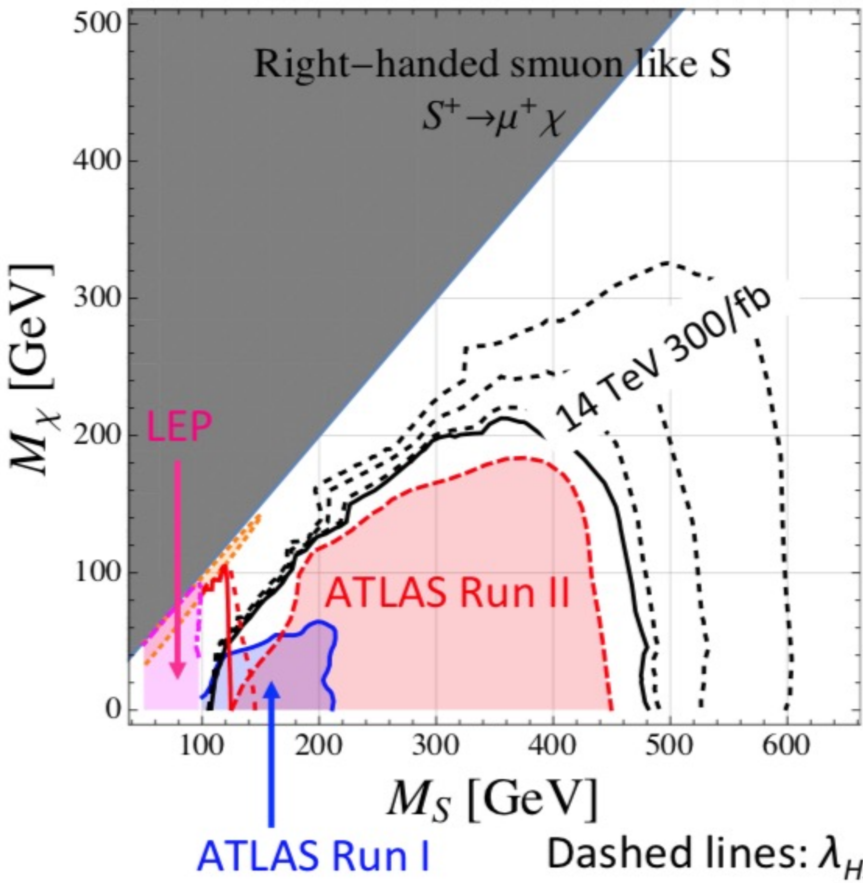
The Higgs/Z exotic decay: another probe for y_l .

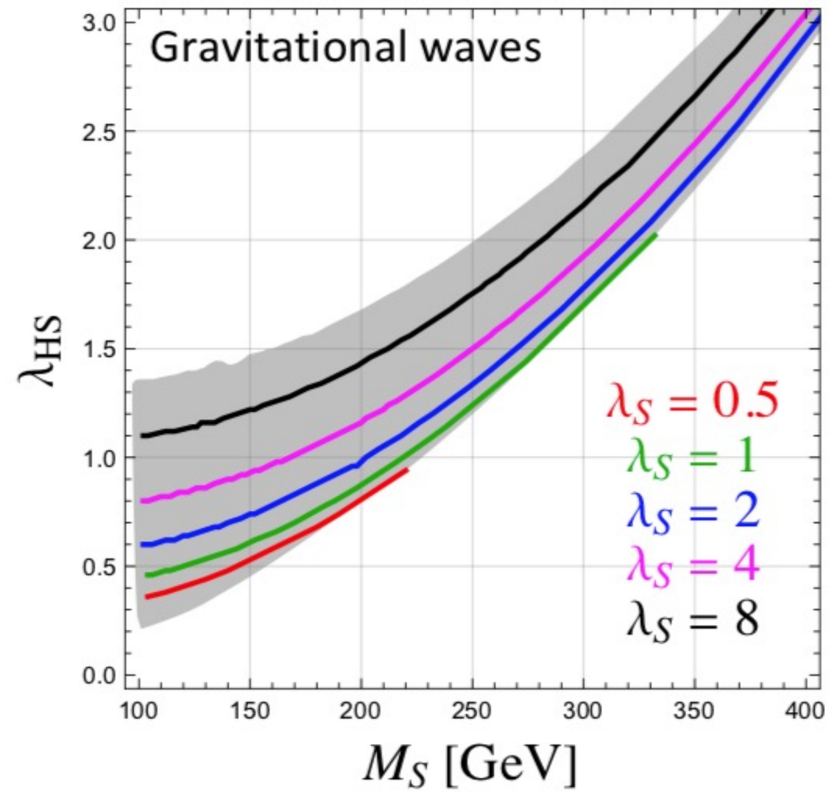


Lepton portal DM

- Preliminary results

The shaded regions: existing bounds; lines: projections

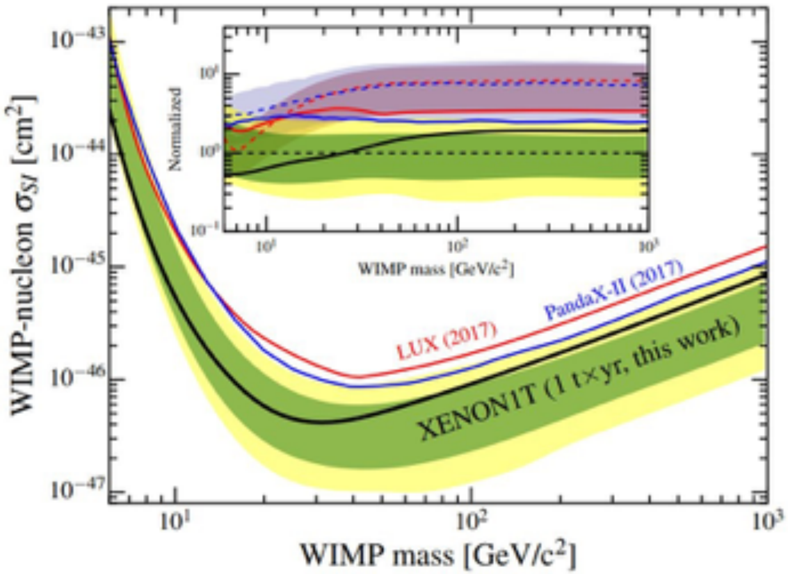


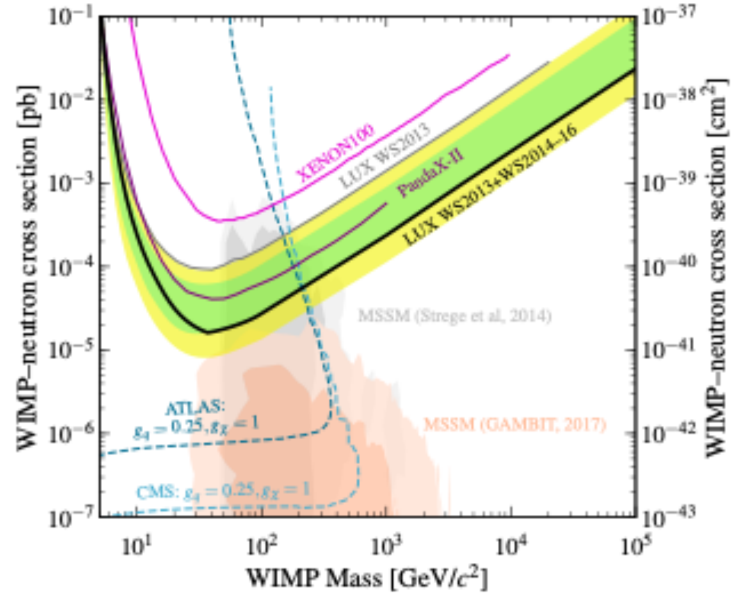


Dashed lines: λ_{HS} = 2, 5, 10

Next step: the exotic decay bounds for y_l.

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

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

HL-LHC: DM

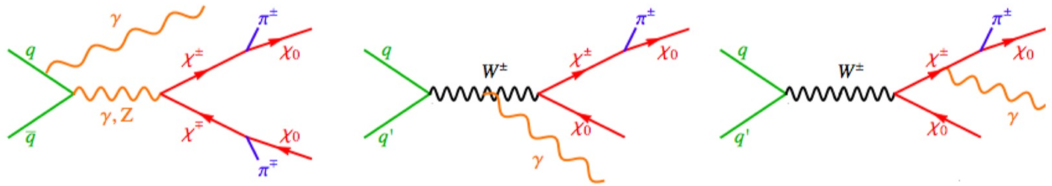
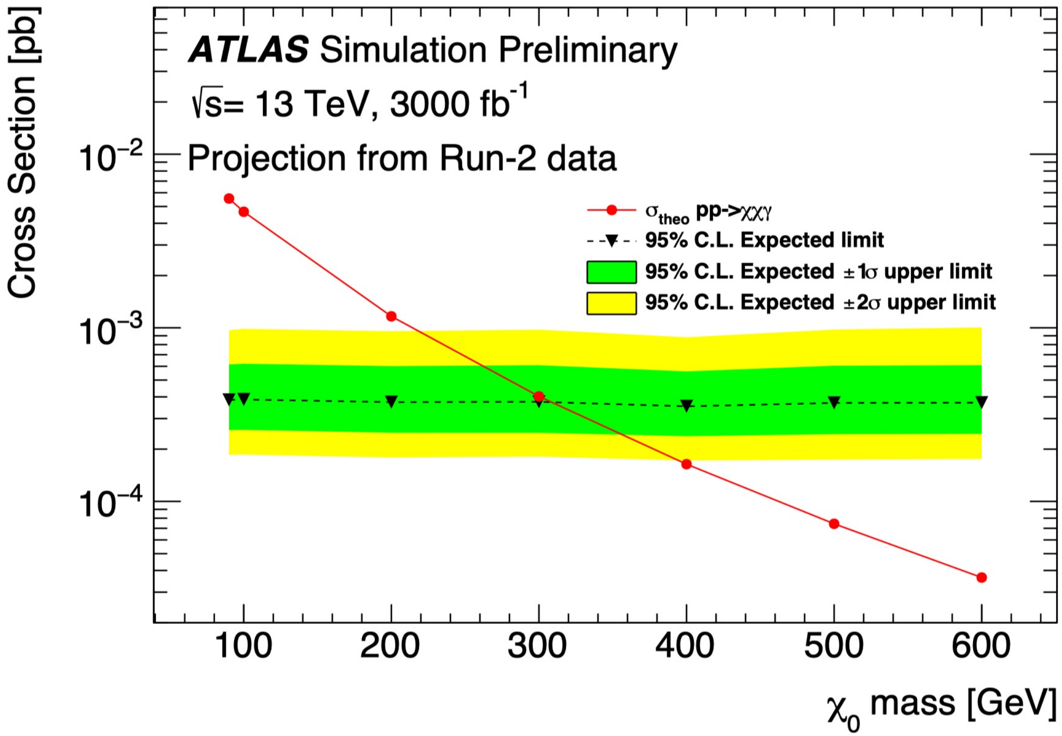
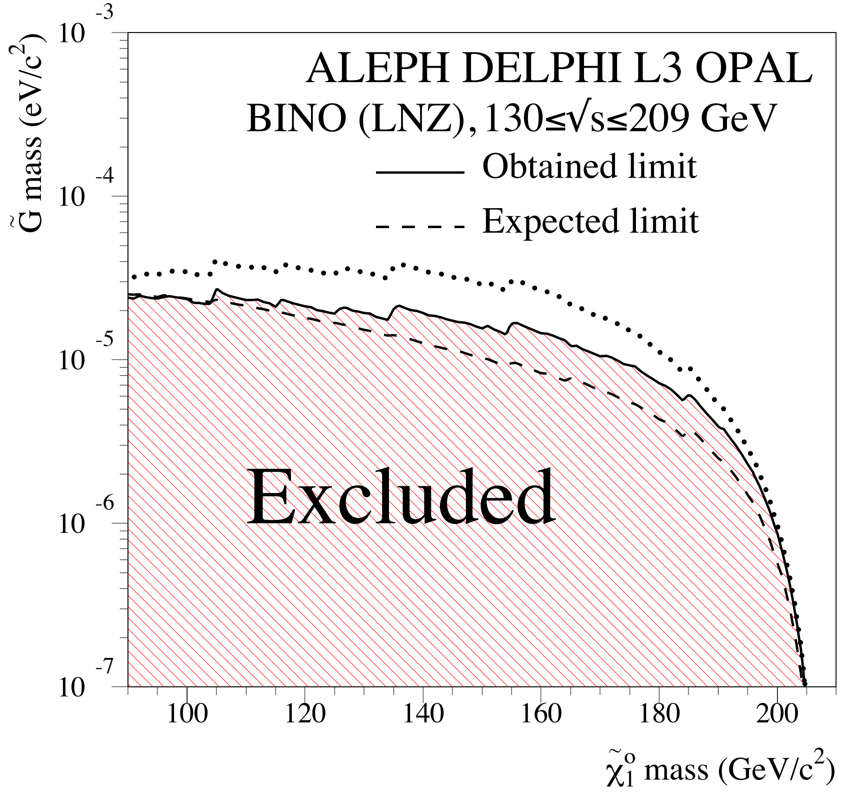


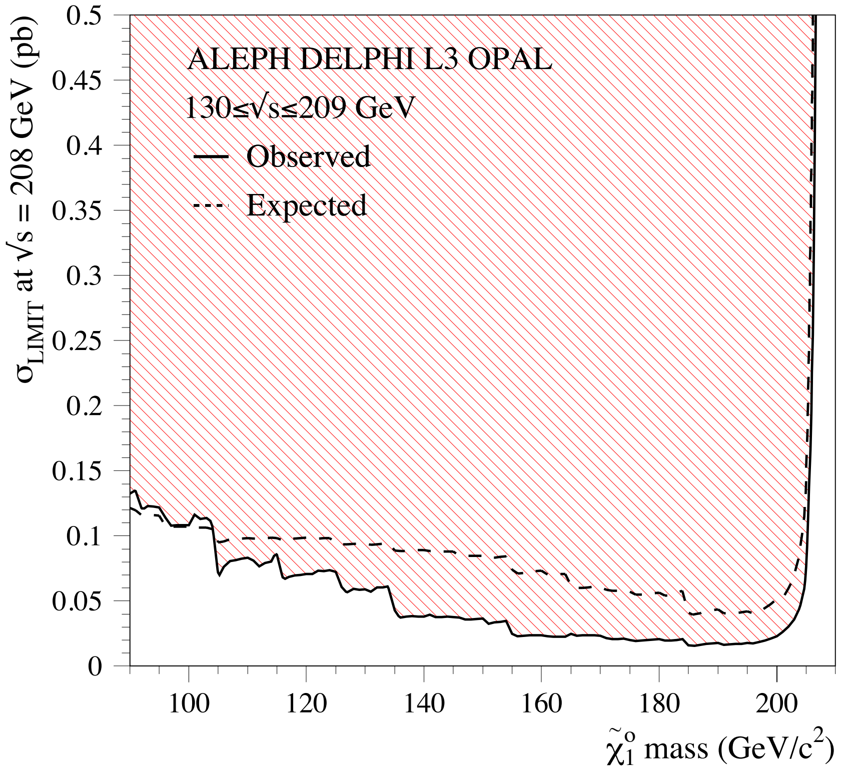
Figure 1: Some representative diagrams for the pure WIMP triplet in $\gamma+E_{\mathrm{T}}^{\mathrm{miss}}$ final states. The $\chi^\pm$ particles decay into the stable χ_0 DM candidate and soft pions which are not reconstructed [3].



ATL-PHYS-PUB-2018-038

Mono-photon (SUSY, ED,DM)





e+e- → chi_1 grav → grav grav gamma

grav: gravitino

EU Strategy- SUSY: ~g

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

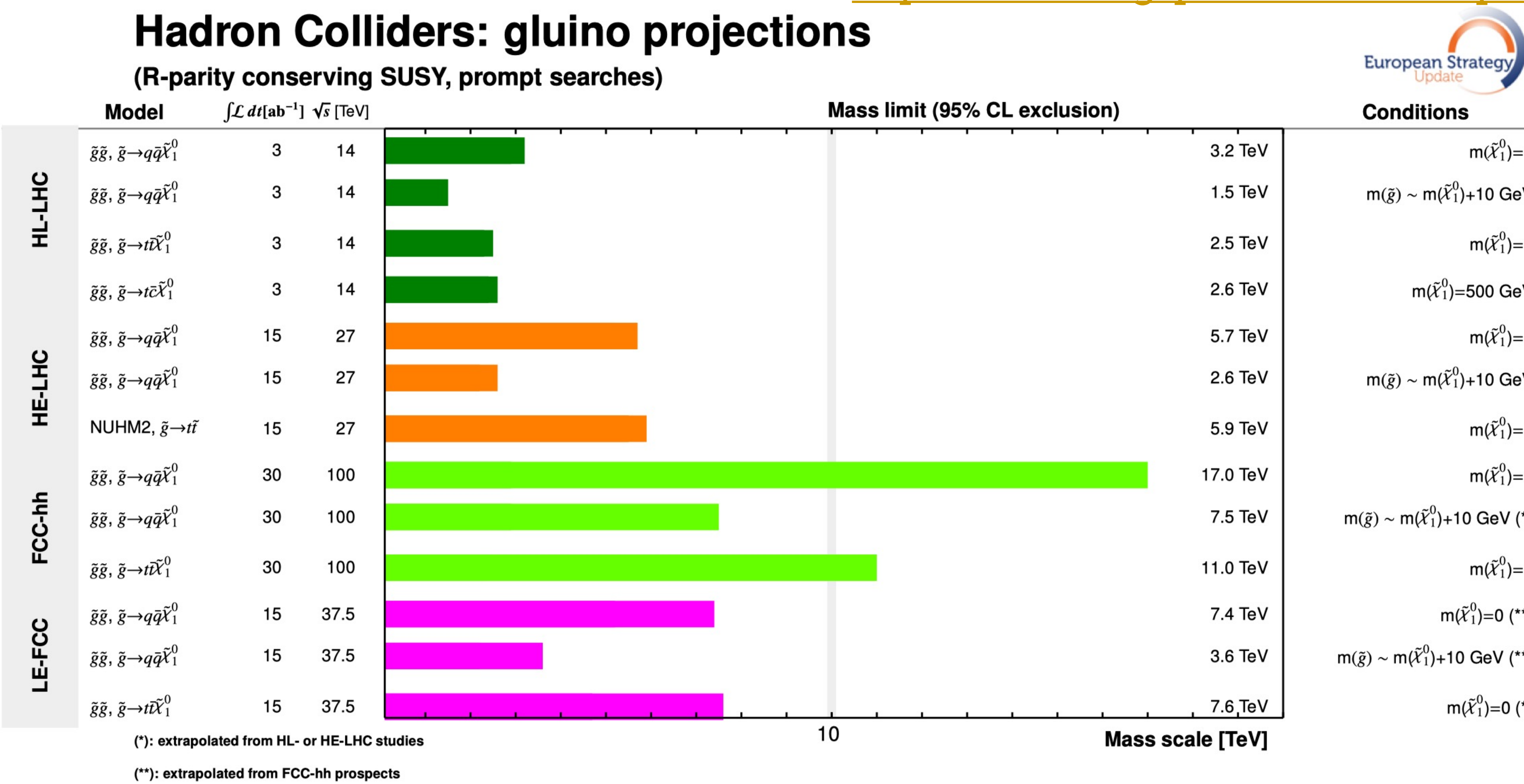


Fig. 8.6: Gluino exclusion reach of different hadron colliders: HL- and HE-LHC [443], and FCC-hh [139, 448]. Results for low-energy FCC-hh are obtained with a simple extrapolation.

EU Strategy- SUSY: ~q

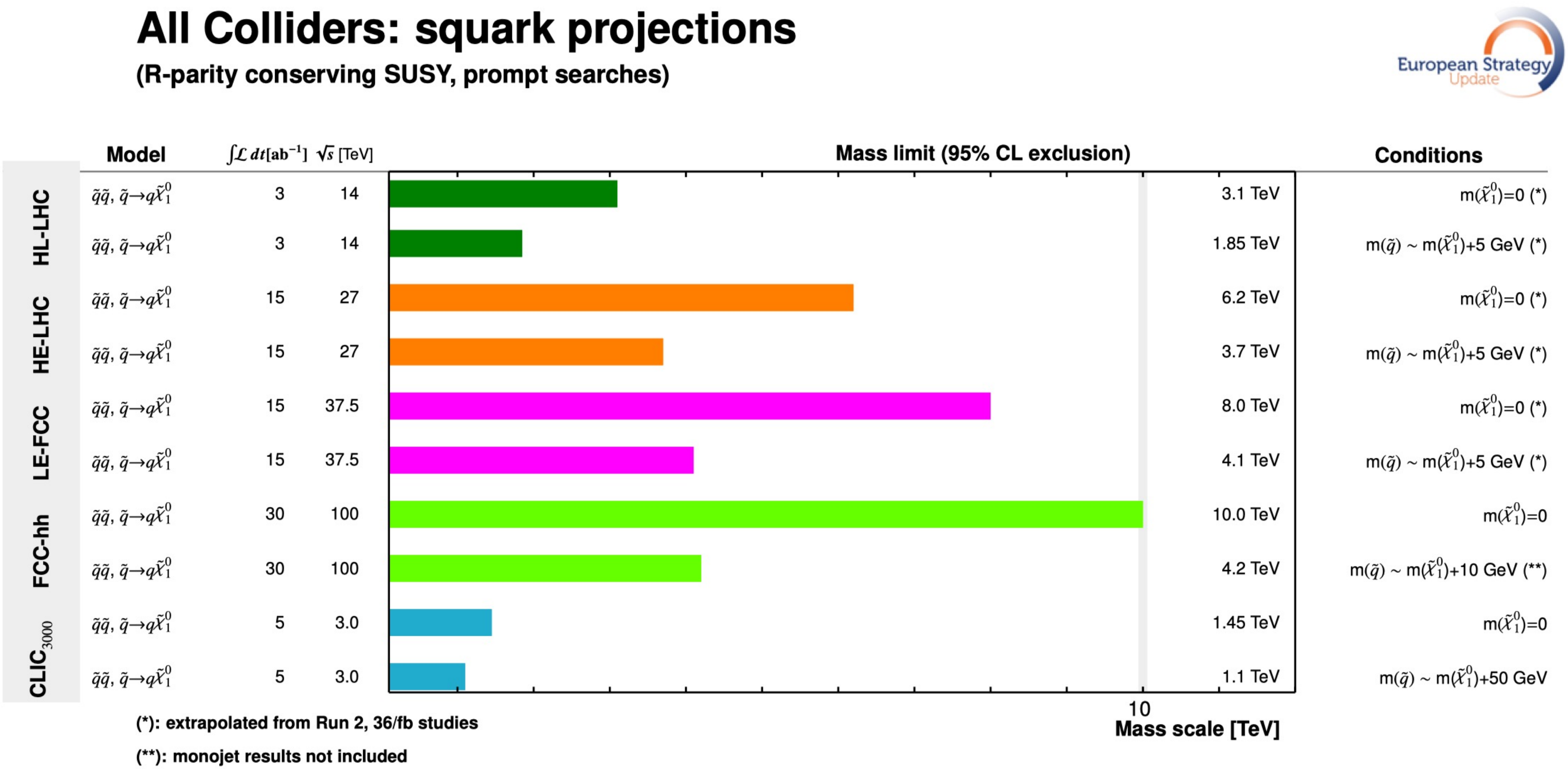
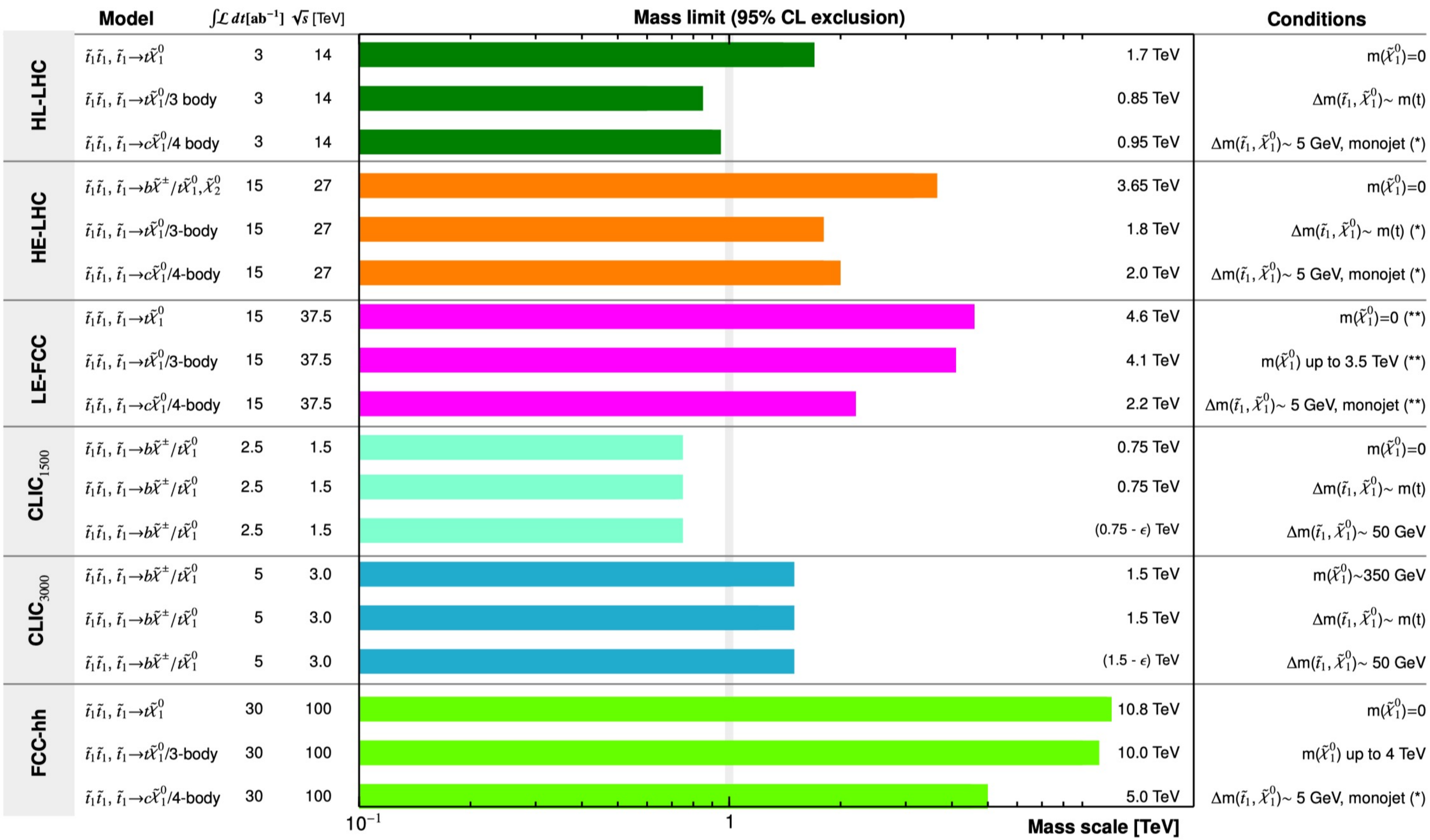


Fig. 8.7: Exclusion reach of different hadron and lepton colliders for first- and second-generation squarks.

EU Strategy- SUSY: ~t

All Colliders: Top squark projections

(R-parity conserving SUSY, prompt searches)



(*) 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 $\sqrt{s}/2$

MSSM charginos and neutralinos

Mass matrices

charginos

in $(\tilde{W}^-, \tilde{H}^-)$ basis

$$\begin{pmatrix} M_2 & \sqrt{2} m_W c_\beta \\ \sqrt{2} m_W s_\beta & \mu \end{pmatrix}$$

neutralinos

in $(\tilde{B}^0, \tilde{W}^0, \tilde{H}_1^0, \tilde{H}_2^0)$ basis

$$\begin{pmatrix} M_1 & 0 & -m_Z c_\beta s_w & m_Z s_\beta s_w \\ 0 & M_2 & m_Z c_\beta c_w & -m_Z s_\beta c_w \\ -m_Z c_\beta s_w & m_Z c_\beta c_w & 0 & -\mu \\ m_Z s_\beta s_w & -m_Z s_\beta c_w & -\mu & 0 \end{pmatrix}$$

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

At tree level:

charginos $\quad M_2, \mu, \tan\beta$

neutralinos $\quad + M_1$

Expected to be among the lightest sparticles

Φ_μ, Φ_1

CP phases

→ A good starting point towards SUSY parameter determination

EWK-ino production

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

Standard wino-bino case: large Δm 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/attachments/1850992/3038683/Wagner-LHCP2019.pdf

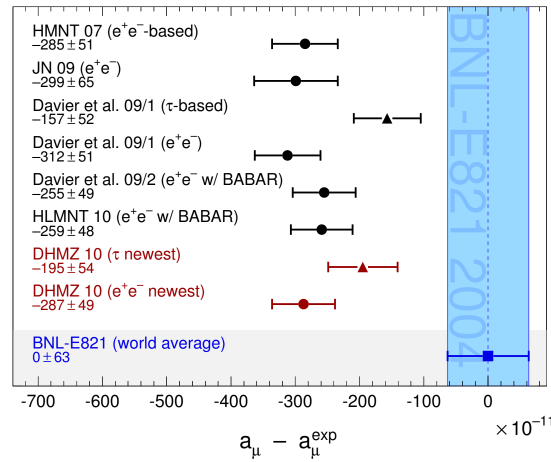
Muon Anomalous Magnetic Moment

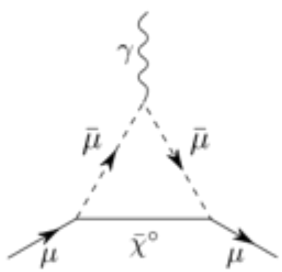
Present status: Discrepancy between Theory and Experiment at more than three Standard Deviation level

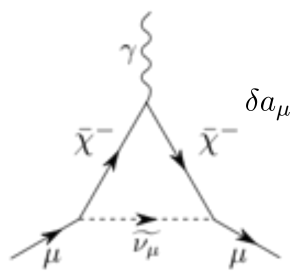
$$\delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm theory} = 268(63)(43) \times 10^{-11}$$

3.6σ Discrepancy

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







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

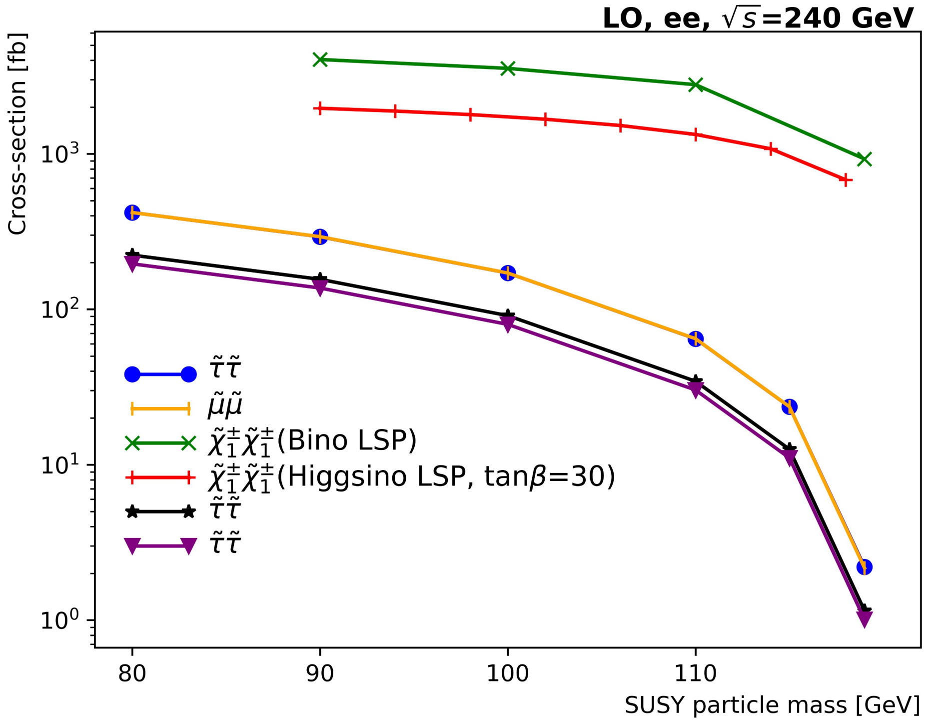
Grifols, Mendez'85, T. Moroi'95,
Giudice, Carena, C.W.'95, Martin and Wells'00 ....

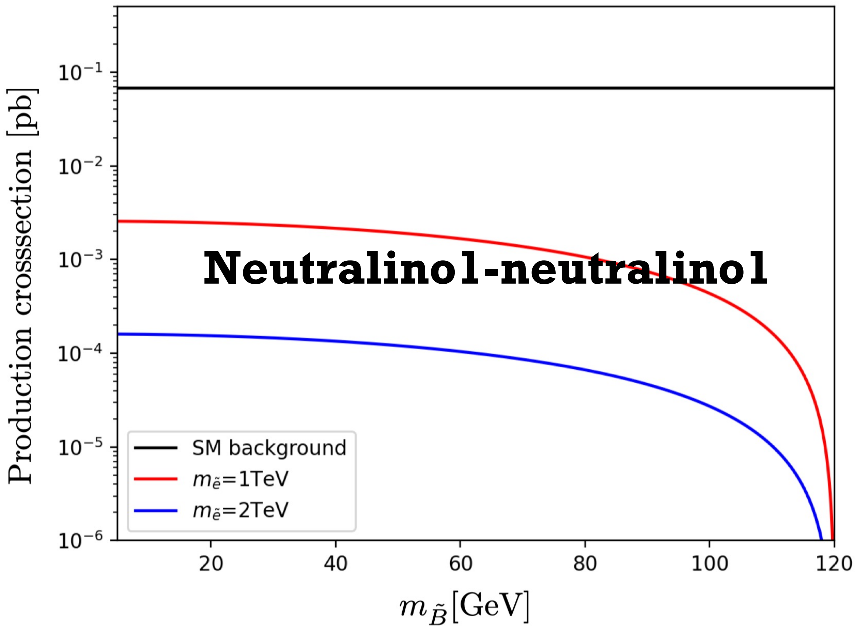
Here $\tilde{m}$ represents the weakly interacting supersymmetric particle masses.

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 !

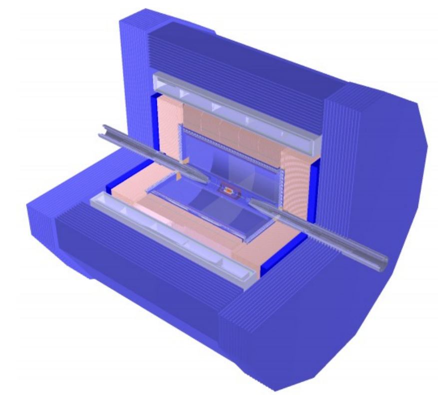
CrossSections





Cross-section based on Madgraph calculation

TECHNICAL DETAIL



- About CEPC

  ECM=240GeV, higgs factory, 100 km circumference, 2 interaction points.

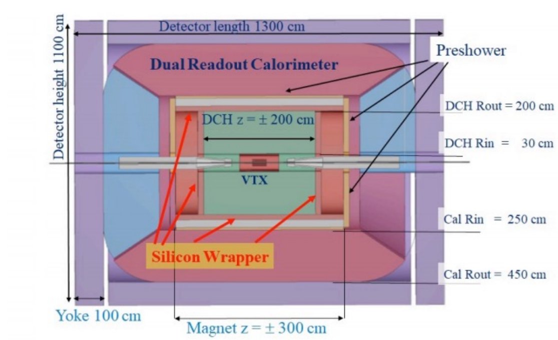
  ILD-like detector
- Software

  Signal samples: MadGraph+Pythia8

  Simulation: Mokka

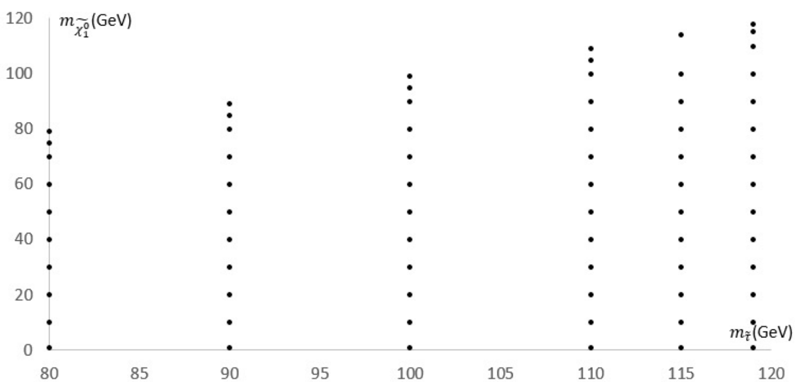
  Reconstruction: Marlin
- Normalized to $5050\ \mathrm{fb}^{-1}$
- **Dominant backgrounds:**
  - **SM processes with two-e or two-μ or two-τ and large missing energy final states.**

process	Cross Section [fb]
$\mu\mu$	4967.58
$\tau\tau$	4374.94
$WW \to \ell\ell$	392.96
$ZZorWW \to \mu\mu\nu\nu$	214.81
$ZZorWW \to \tau\tau\nu\nu$	205.84
$\nu Z, Z \to \mu\mu$	43.33
$ZZ \to \mu\mu\nu\nu$	18.17
$\nu Z, Z \to \tau\tau$	14.57
$ZZ \to \tau\tau\nu\nu$	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
$eeZ, Z \to \nu\nu$	29.62
$eeZ, Z \to \nu\nu\ or\ e\nu W, W \to e\nu$	249.34

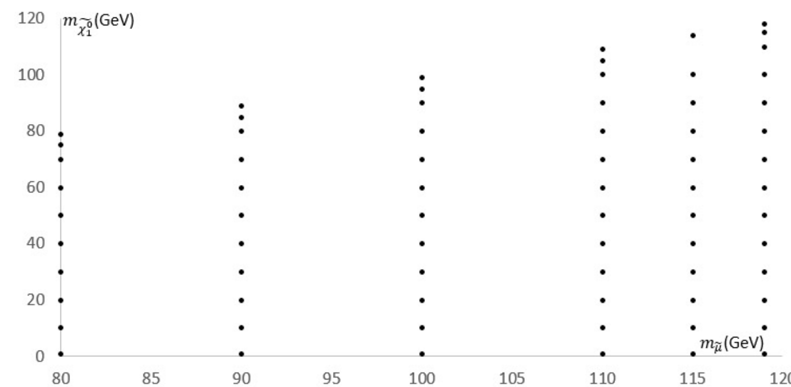


SIGNAL SAMPLES

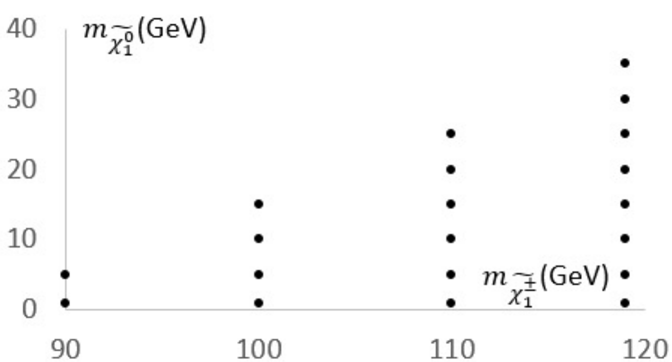
Direct stau



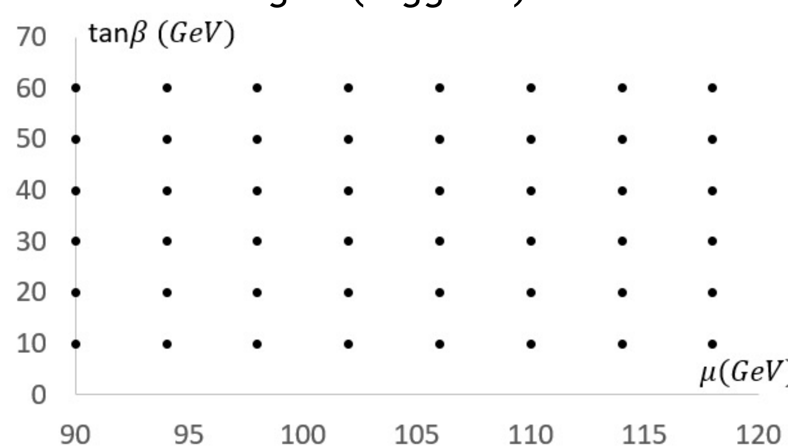
Direct



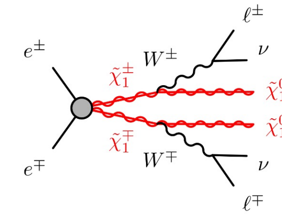
Chargino (Bino)



Chargino (Higgsino)

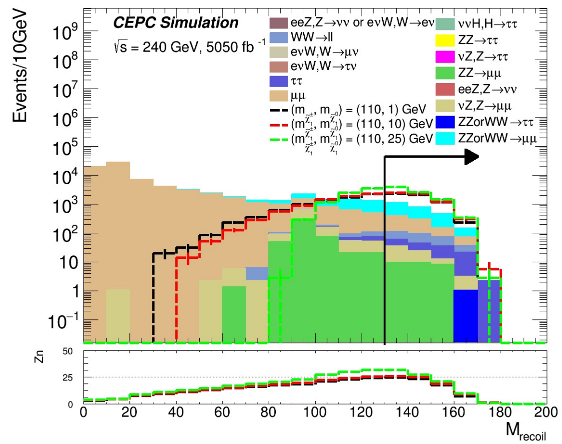


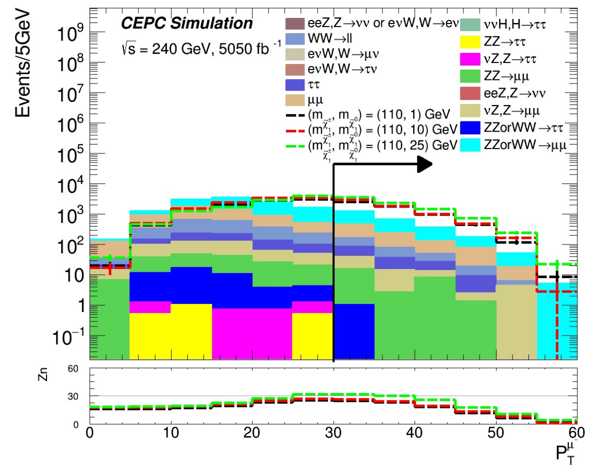
GAUGINO SEARCH



Bino LSP

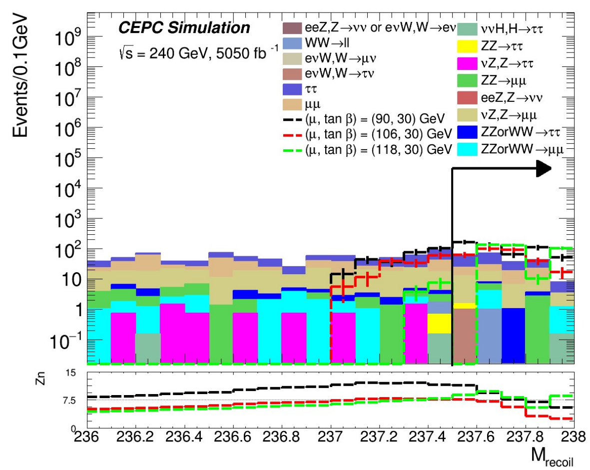
selection
== 2 muons(OS, both energy >10 GeV)
$0.4<\Delta R(\mu^+,\mu^-)<1.6$
M_{recoil} >130 GeV
$P_T^{\mu^\pm}$ >30 GeV/c

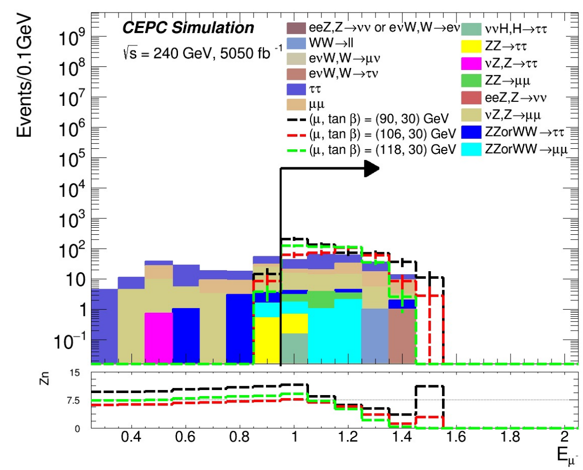




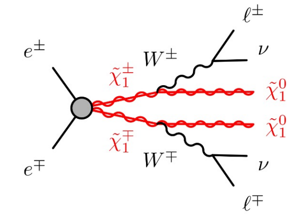
Higgsino LSP

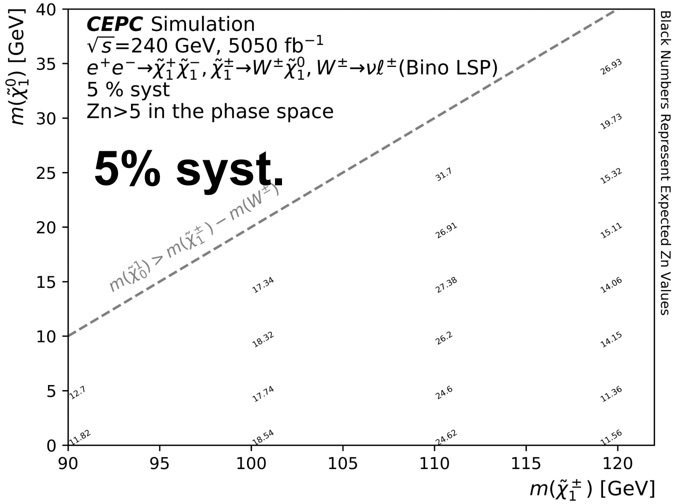
Signal Region
== 2 muons(OS)
$E_{\mu^\pm}$ >0.95 GeV
$3.2 <\Delta R(\mu^\pm, recoil) <4.6$
$\Delta\phi(\mu^\pm, recoil) <2.9$
M_{recoil} >237.5 GeV

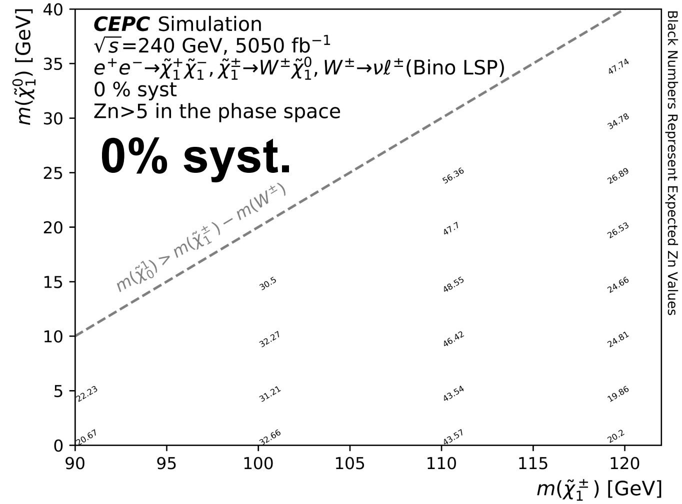




GAUGINO SEARCH

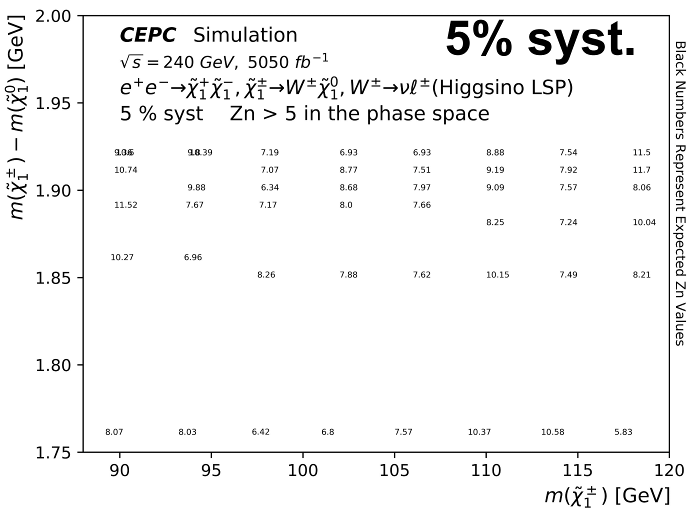


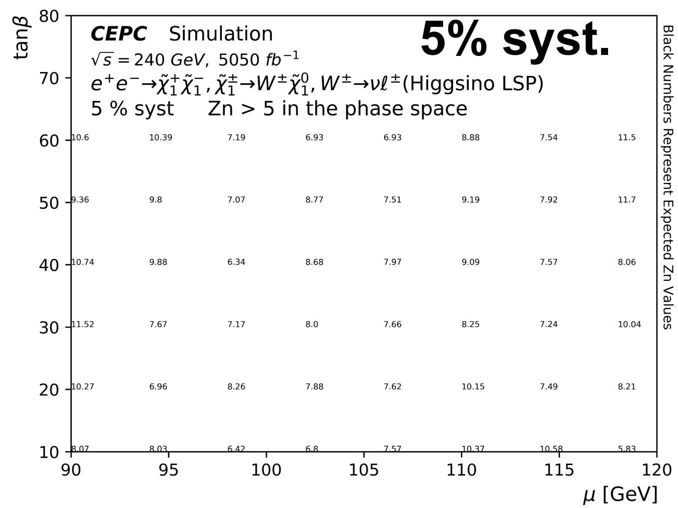




Bino LSP

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



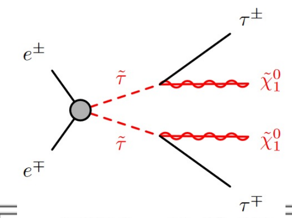


Higgsino LSP

$$Zn = \left[2\left((s+b)\ln\left[\frac{(s+b)(b+\sigma_b^2)}{b^2+(s+b)\sigma_b^2}\right] - \frac{b^2}{\sigma_b^2}\ln\left[1+\frac{\sigma_b^2 s}{b(b+\sigma_b^2)}\right]\right)\right]^{1/2}$$

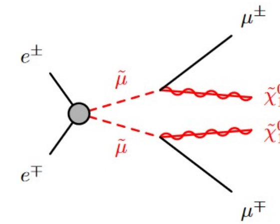
SLEPTON SEARCH

stau

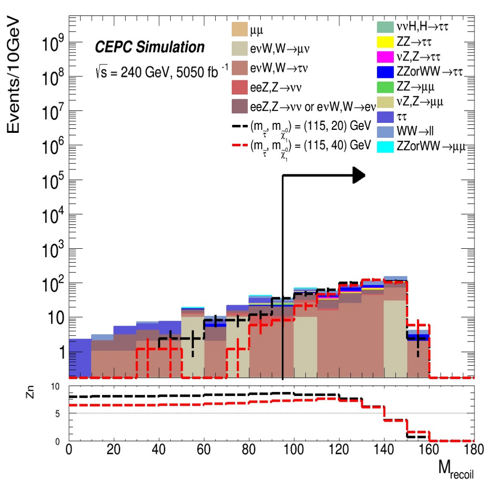


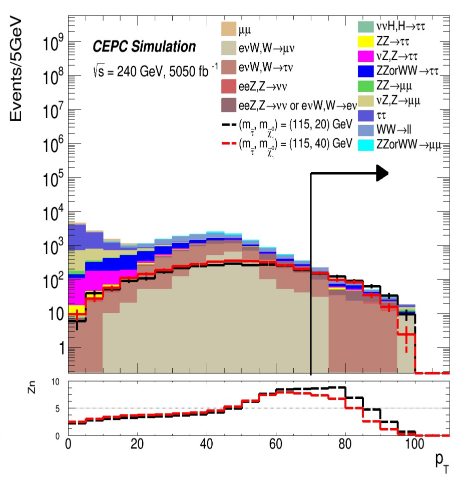
SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
$\Delta R(\tau^{\pm}, recoil) < 3.1$		$\Delta R(\tau^{\pm}, recoil) < 2.9$
$2.4 < \lvert\Delta\phi(\tau^{\pm}, recoil)\rvert < 3$		$\lvert\Delta\phi(\tau^{\pm}, recoil)\rvert > 2.3$
$0.4 < \Delta R(\tau, \tau) < 1$	$0.4 < \Delta R(\tau, \tau) < 1.6$ $0.2 < \lvert\Delta\phi(\tau, \tau)\rvert < 1.2$	$\lvert\Delta\phi(\tau, \tau)\rvert > 0.6$
$E_{\tau^{\pm}} < 34$ GeV	$E_{\tau^{\pm}} < 15$ GeV	
$p_T > 70$ GeV	$p_T > 40$ GeV	
$M_{recoil} > 95$ GeV	$M_{recoil} > 120$ GeV $M_{\tau\tau} < 40$ GeV	$M_{recoil} > 205$ GeV $M_{\tau\tau} < 18$ GeV

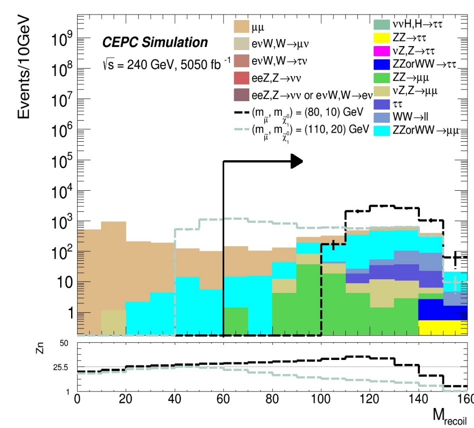
smuon

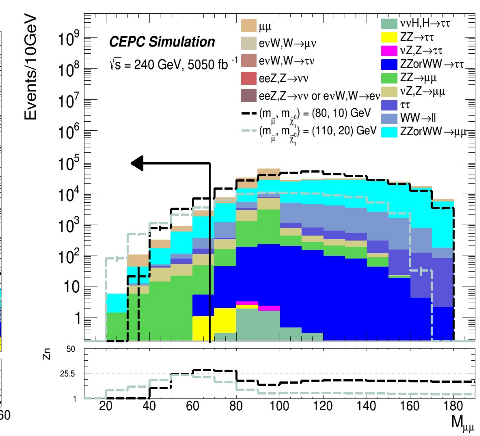


SR-highDeltaM	SR-midDeltaM	SR-lowDeltaM
= 2 muons(OS, both energy > 0.5 GeV)		
$\Delta R(\mu^{\pm}, recoil) < 2.9$	$\Delta R(\mu^{\pm}, recoil) < 2.6$	$\Delta R(\mu^{\pm}, recoil) < 2.7$
$E_{\mu^{\pm}} > 40$ GeV	$E_{\mu^{\pm}} < 50$ GeV	
$M_{\mu\mu} < 68$ GeV	$P_T > 50$ GeV/c	$M_{\mu\mu} < 85$ GeV
$M_{recoil} > 60$ GeV		$M_{recoil} > 135$ GeV

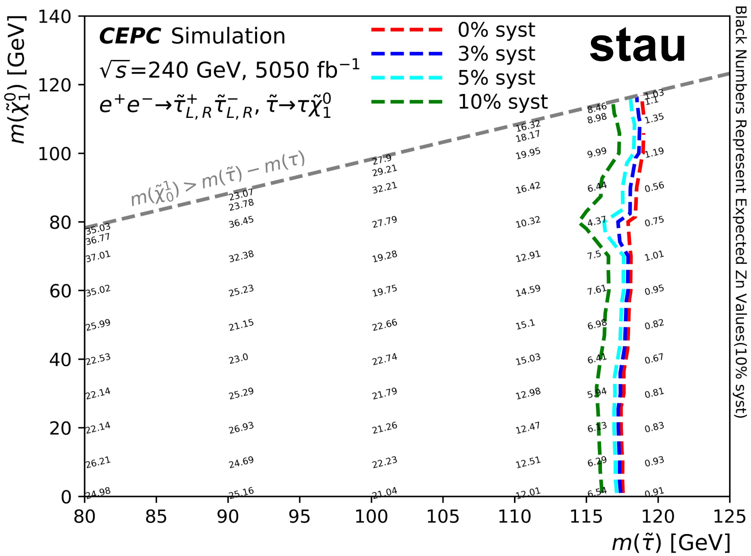


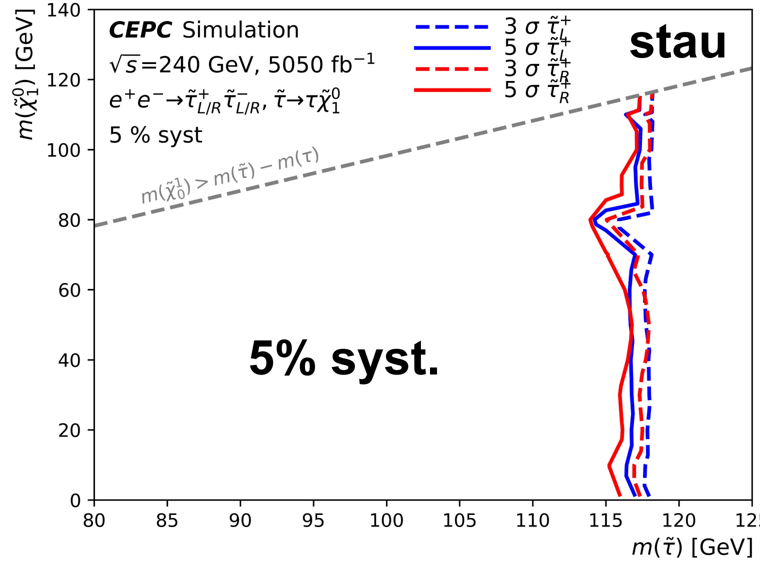


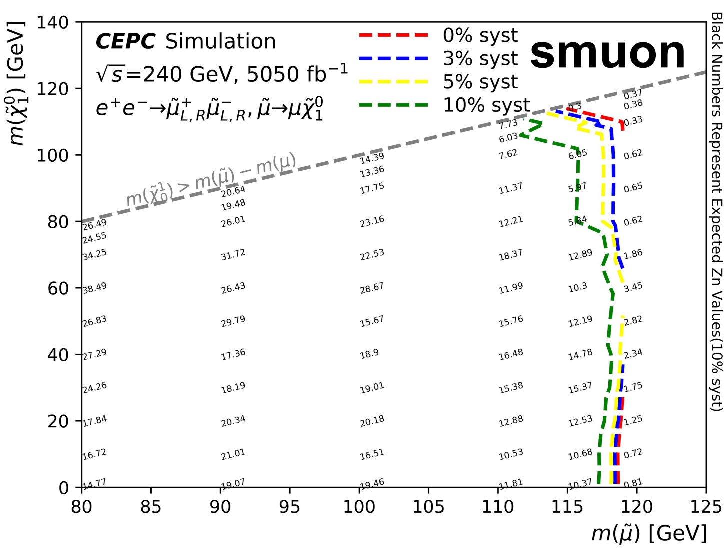


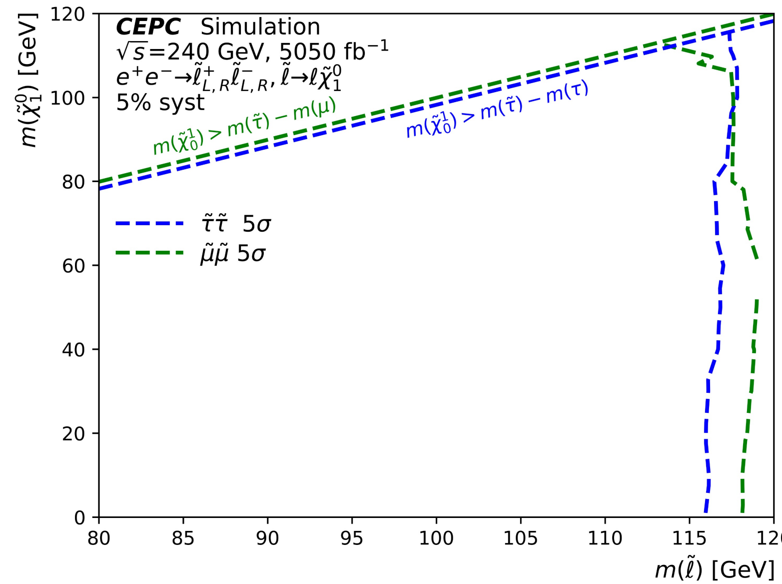


SLEPTON SEARCH





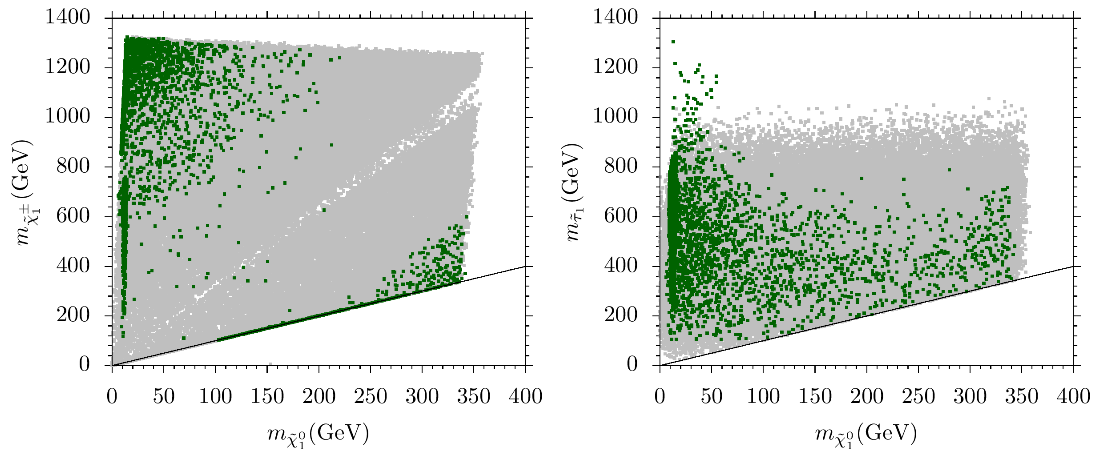




CEPC240(FCCee/ILC): discovery up to kinematic limit: √s/2

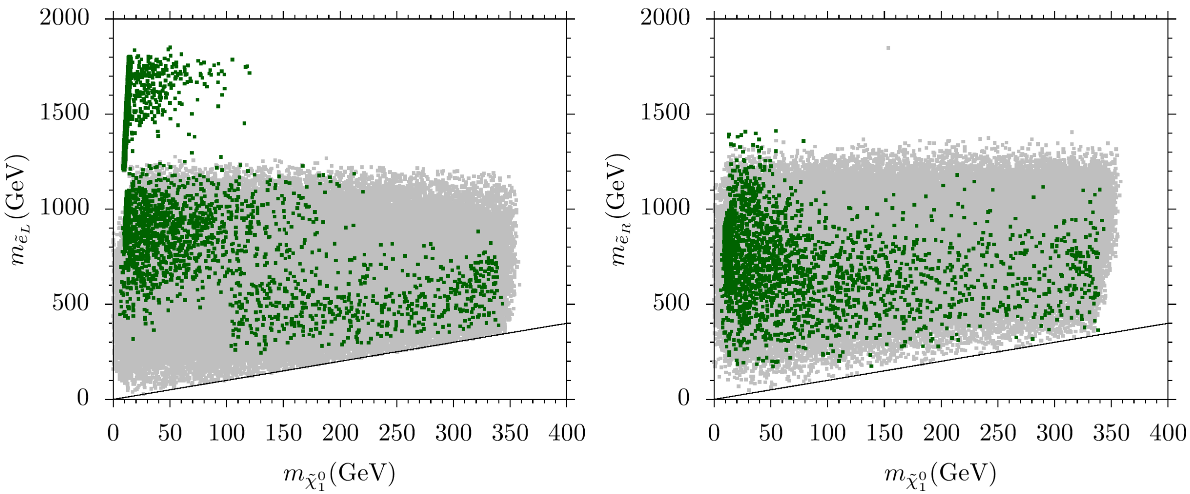
$$Zn = \left[2\left((s+b)\ln\left[\frac{(s+b)(b+\sigma_b^2)}{b^2+(s+b)\sigma_b^2}\right] - \frac{b^2}{\sigma_b^2}\ln\left[1+\frac{\sigma_b^2 s}{b(b+\sigma_b^2)}\right]\right)\right]^{1/2}$$

Light Neutralino from GmSUGRA (preliminary results)



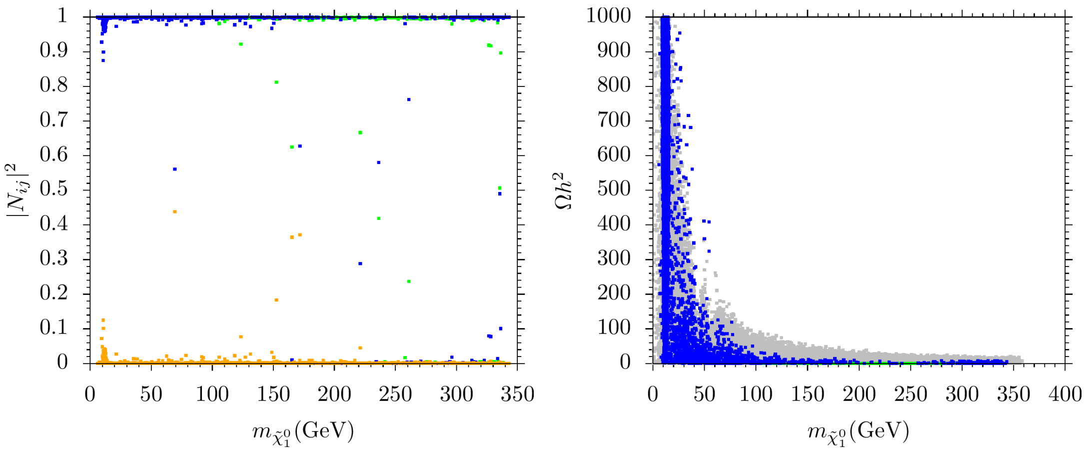
Gray points satisfy REWSB and neutralino as LSP conditions. Dark green points satisfy additional spartcile mass and B-physics bounds including $m_h = 125 \pm 3\,\mathrm{GeV}$ bounds.

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)

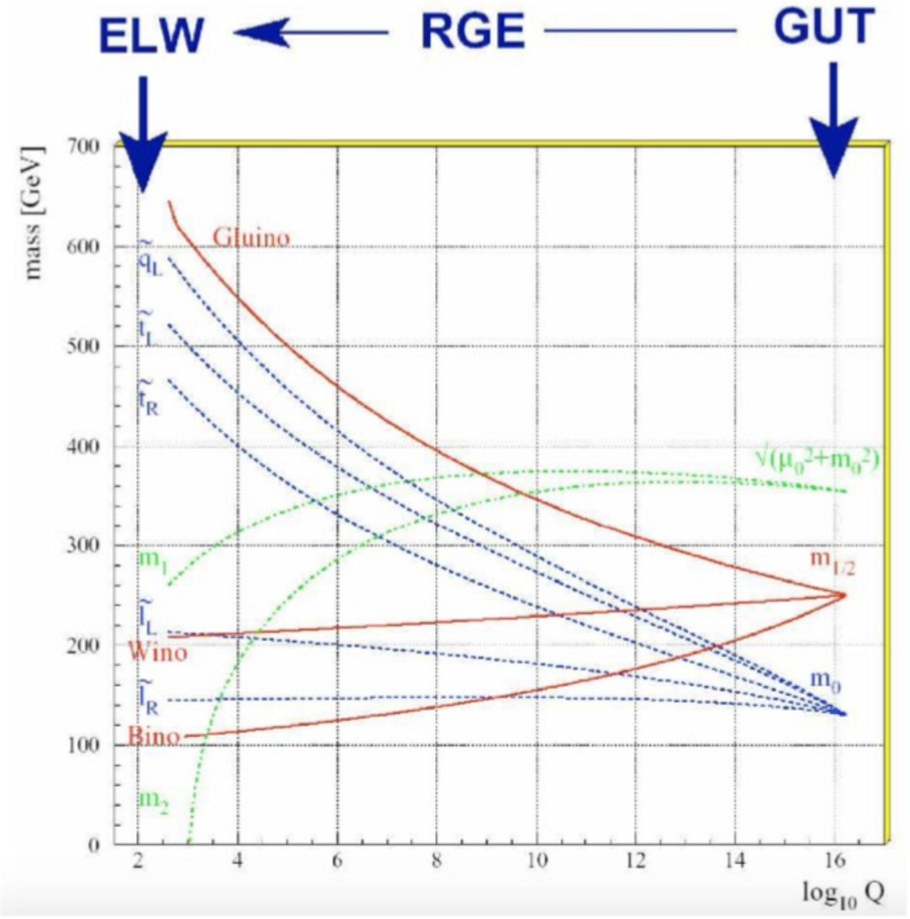


Gray points satisfy REWSB and neutralino as LSP conditions. (Left) Blue, green and orange points satisfy spartcile mass and B-physics bounds including $m_h = 125 \pm 3\,\mathrm{GeV}$ bounds respresent bino-componet, wino-component and higgsino-components respectively.(Right) Blue points show bino-type 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,
$m_{\tilde{\tau}_{1,2}}$	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

CMSSM/mSUGRA

- SUSY is broken by gravity
- Assume universal masses at GUT scale:
  - m_0 – common mass of scalars (squarks, sleptons, Higgs bosons)
  - $m_{1/2}$ – common mass of gauginos and higgsinos
  - A_0 – common trilinear coupling
  - $\tan\beta$ – ratio of Higgs vacuum expectation values
  - $\text{sign}(\mu) = \pm 1$ – sign of μ SUSY conserving Higgsino mass parameter



CEPC likelihood

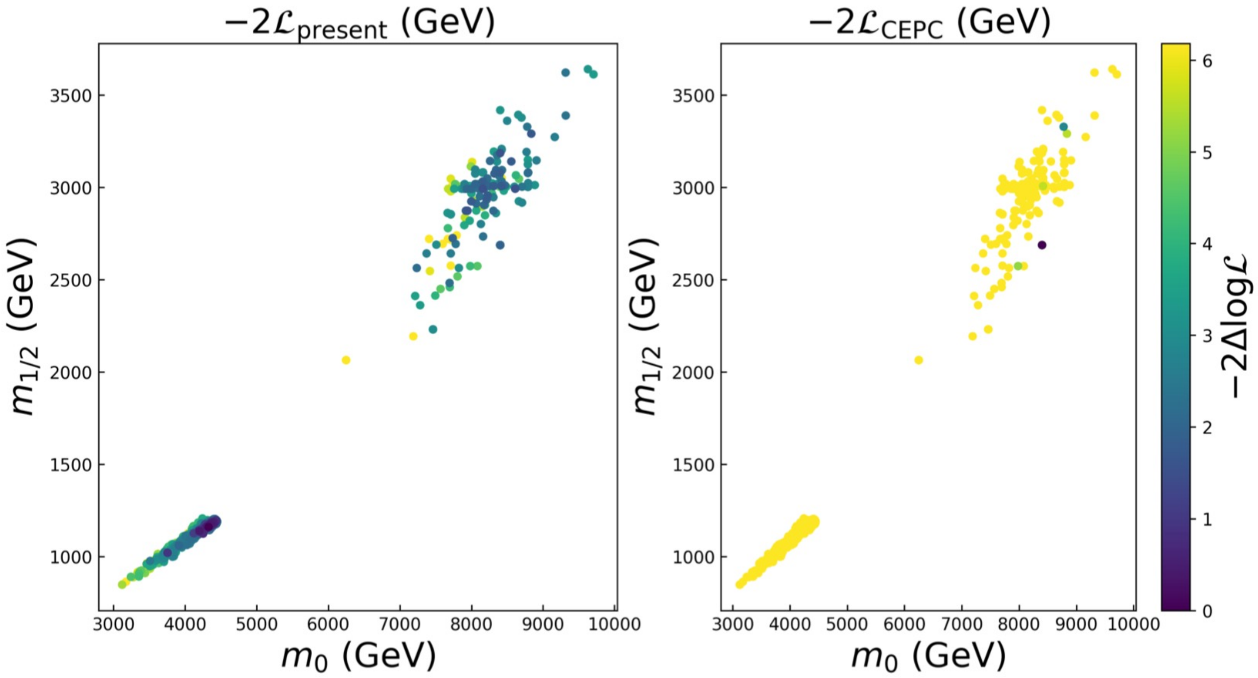
$$-2\mathcal{L}_{\rm CEPC} = \frac{(m_h^{SUSY} - m_h^{obs})^2}{(\Delta_h)^2} + \sum_{i=f,V,...} \frac{(\mu_i^{SUSY} - \mu_i^{obs})^2}{(\Delta_{\mu_i})^2},$$

where $\mu_i^{SUSY} = (\sigma_i \times Br_i)_{SUSY} / (\sigma_i \times Br_i)_{SM}$. Δ_h is dominated by theoretical uncertainties, which we take 2 GeV. Δ_{μ_i} is taken from CEPC CDR.

We have two choices of m_h^{obs} and μ_i^{obs}:

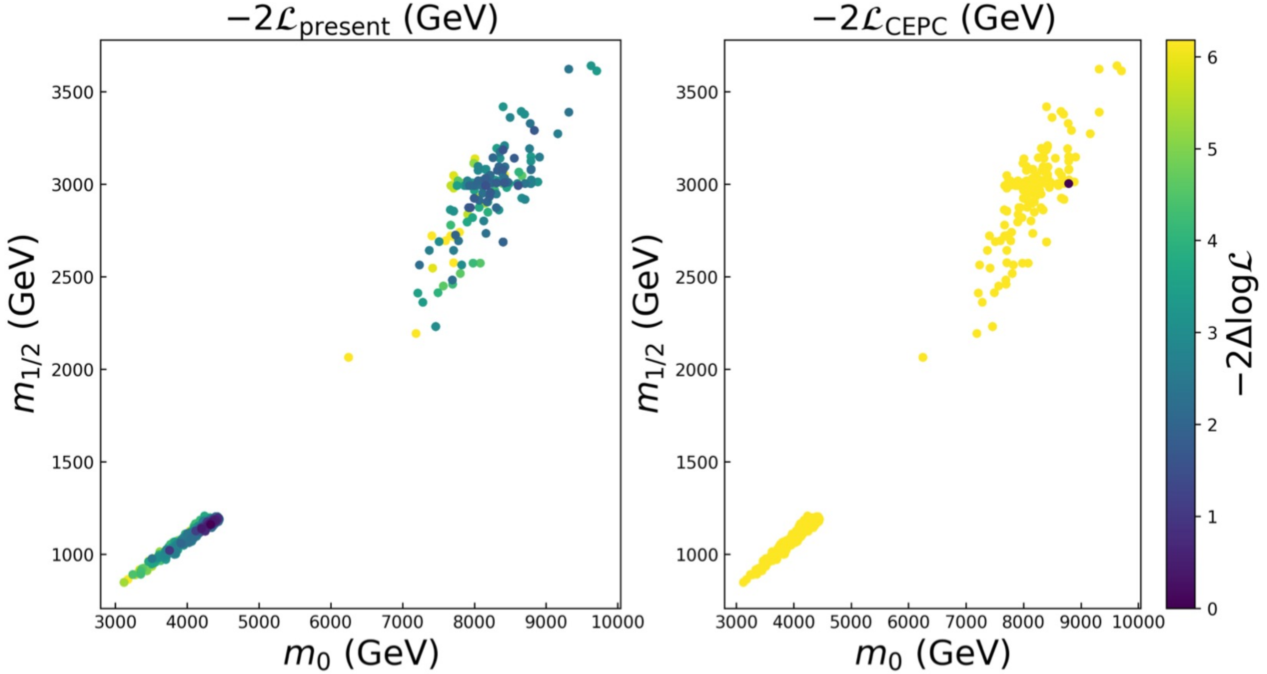
- SM-like. $m_h^{obs} = 125.1$ GeV and $Br_{h\to b\bar{b}} = 57.8\%$, $Br_{h\to W^+W^-} = 21.6\%$, ...
- Centering on the present SUSY best-fit point(BF-like). $m_h^{obs} = 125.0$ GeV and $Br_{h\to b\bar{b}} = 61.9\%$, $Br_{h\to W^+W^-} = 20.8\%$, ...

Progress (BF-like)



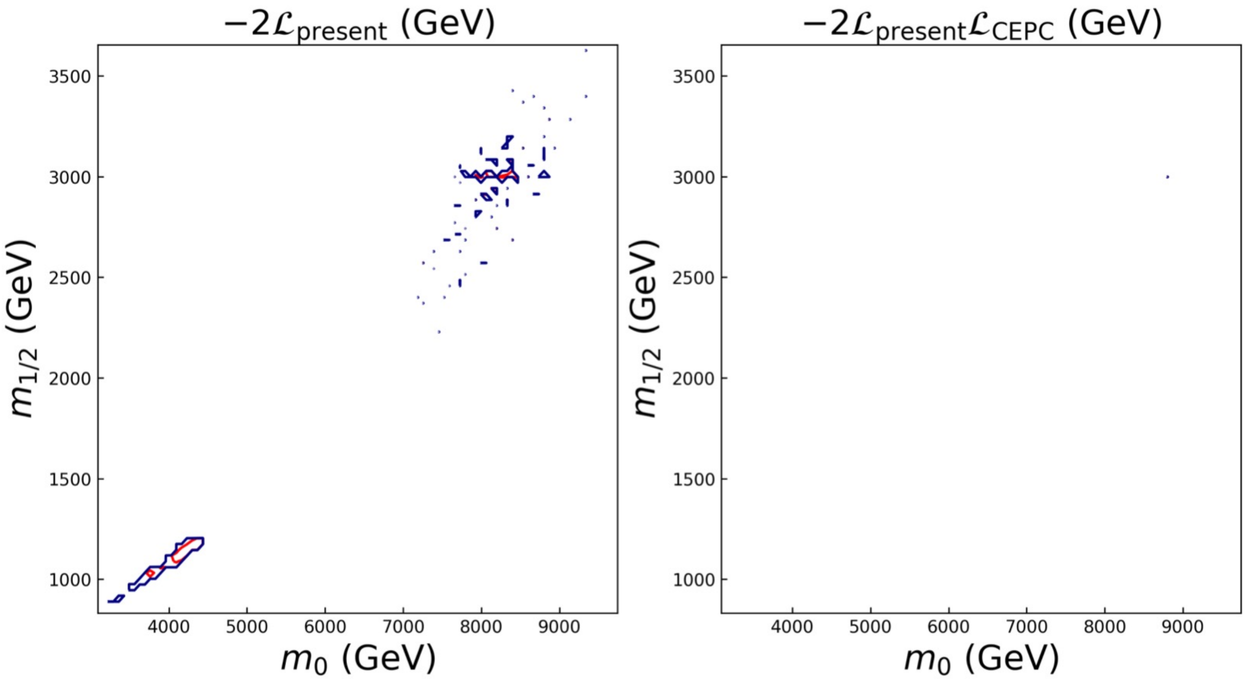
We have post-processed some of the GAMBIT CMSSM data with $\mathcal{L}_{\rm CEPC}$.
With in the present preferred regions, $\mathcal{L}_{\rm CEPC}$ changes dramatically. Only small amounts of samples are with 2σ CL region ($-2\Delta\log\mathcal{L} < 6.18$).
This means that CEPC could exclude most of CMSSM samples preferred by present experimental results.

Progress (SM-like)



Results using SM-like values as central values of CEPC predictions. Conclusion is similar to that of using BF-like central values.

Progress (SM-like)



Red: 1σ CL contour lines; Blue: 2σ CL contour lines.