Implications of the string landscape for LHC SUSY searches

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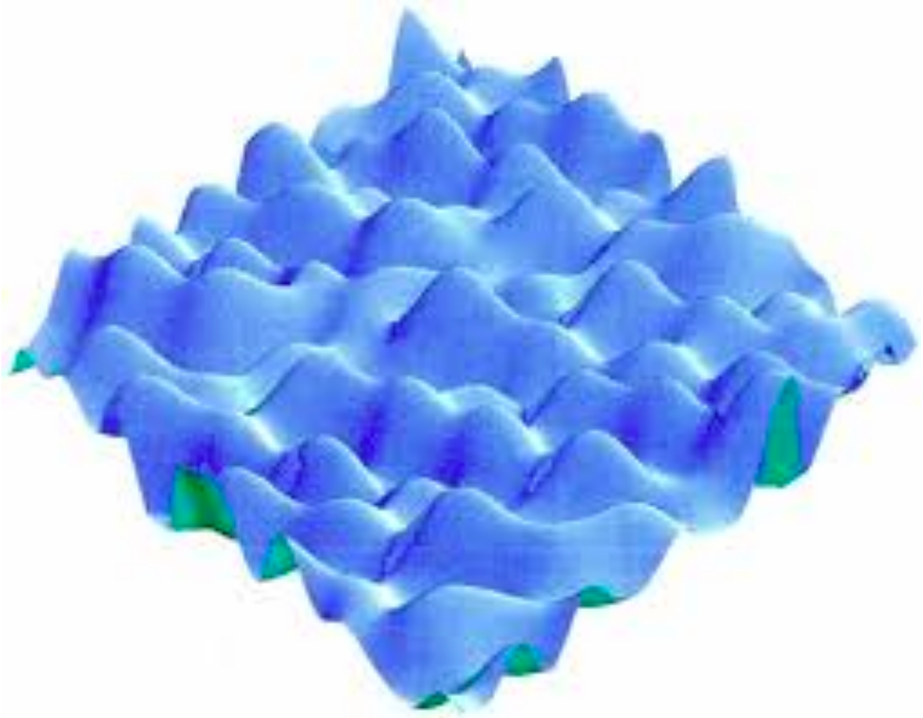

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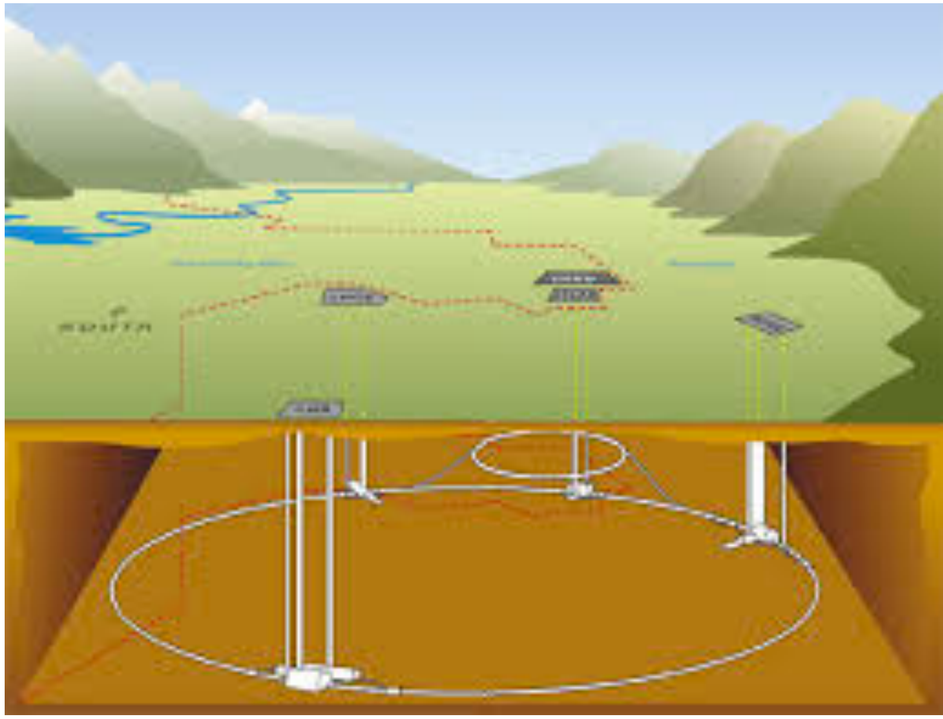
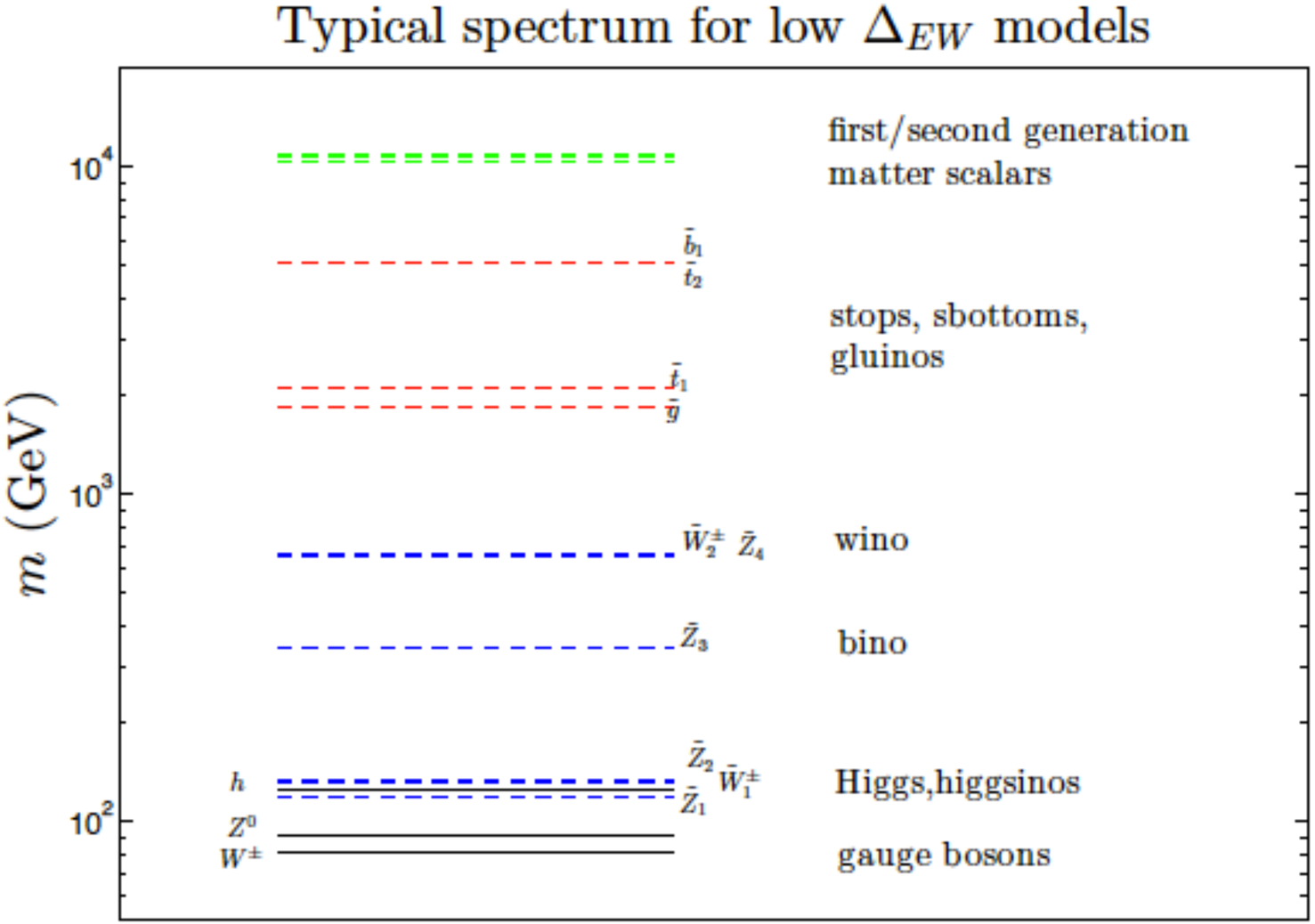


reminder

- >10^500 flux compactifications => different 4-d laws of physics within each pocket universe within eternally inflating multiverse
- provides anthropic solution to cosmological constant problem
- apply also to SUSY breaking scale: no preference for any single SUSY breaking scale in landscape => power-law draw to large soft terms
- must be balanced by weak scale lying within ABDS window: atomic principle
- parsimony: MSSM (+singlets- PQ+moduli) as LE-EFT
- => m(h)~125 GeV with sparticles beyond present LHC reach

for a recent review, see arXiv:2002.03013

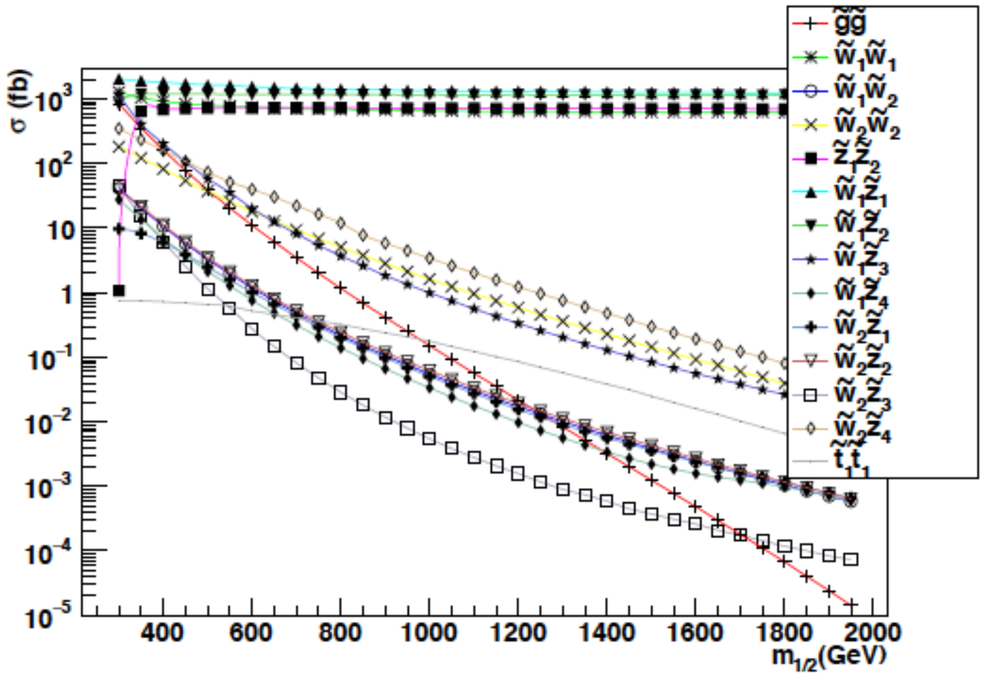


Succeeding analyses within NUHM2-4 models (also possible natSUSY in mirage mediation and anomaly mediation)

There is a Little Hierarchy, but it is no problem

$\mu \ll m_{3/2}$ higgsinos likely the lightest superparticles!

Sparticle prod'n along Radiative Natural SUSY model-line at LHC14:



higgsinos

gauginos

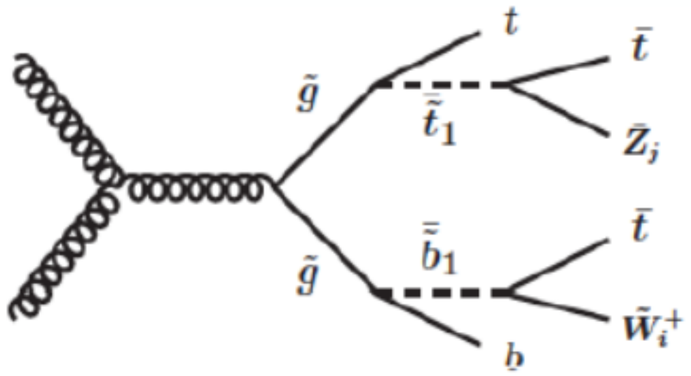
gluinos

higgsino pair production dominant-but only soft visible energy release from higgsino decays

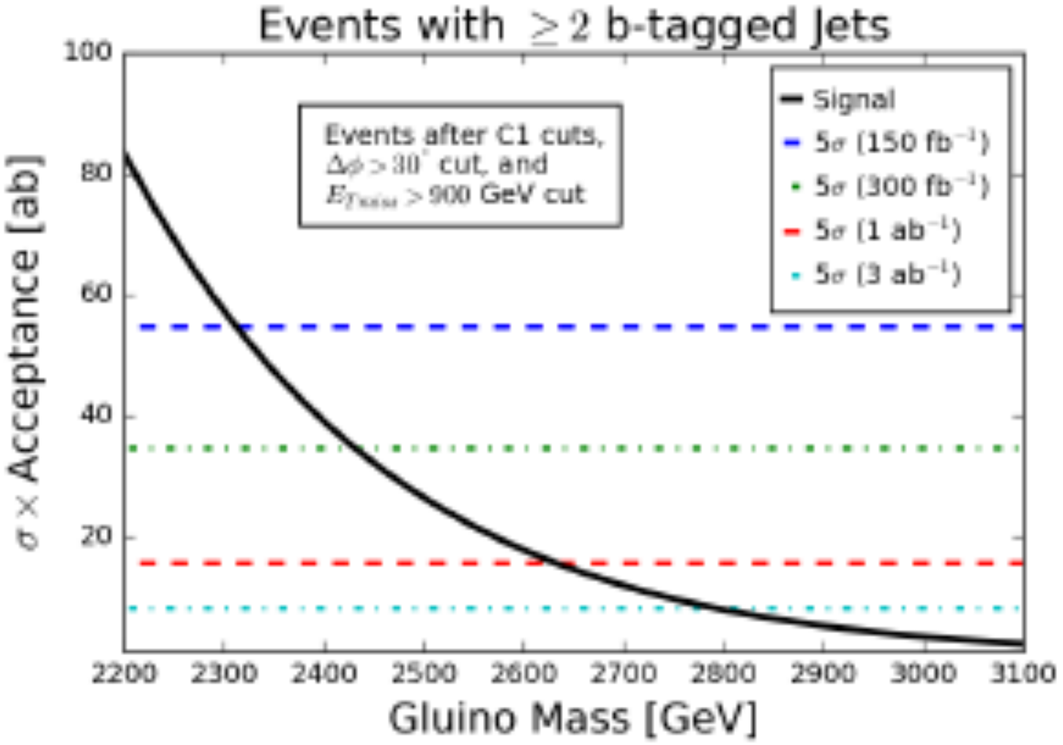
largest visible cross section: wino pairs

gluino pairs sharply dropping

gluino pair cascade decay signatures



LHC14



HB, Barger, Gainer, Huang, Savoy, Sengupta,Tata,arXiv: 1808.04844

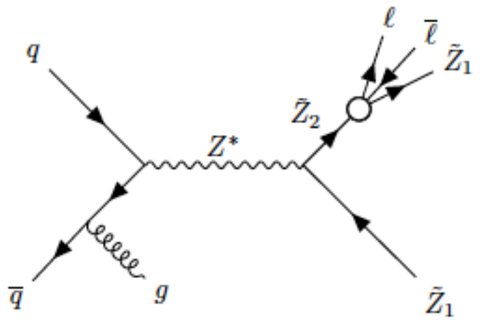
HL-LHC to probe m(gl)~2.8 TeV

FCC-hh(100) to probe m(gl)~10 TeV

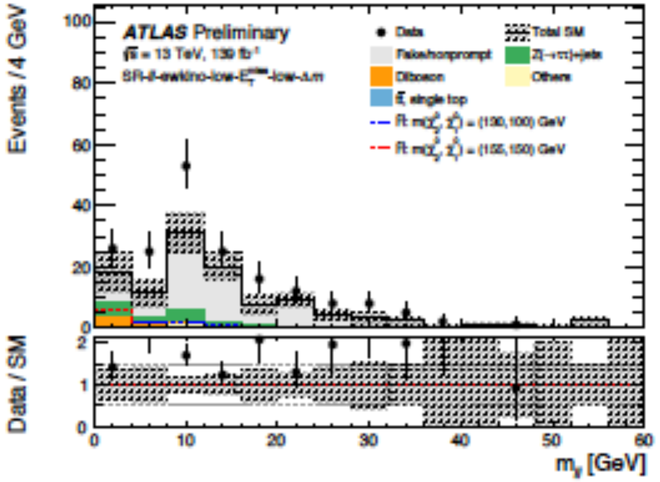
compare: m(glno)~2-6 TeV (landscape)

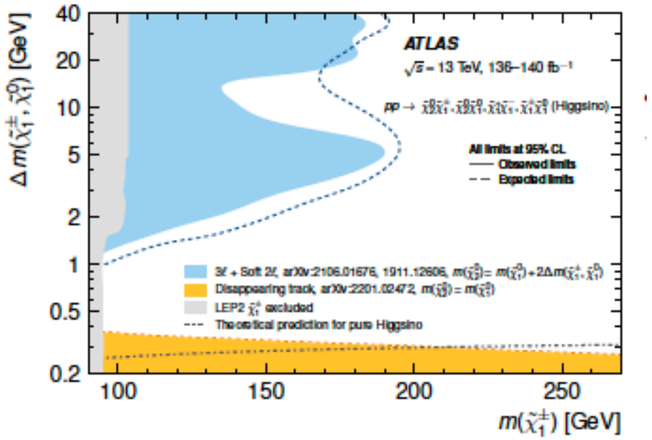
Natural SUSY: only higgsinos need lie close to weak scale

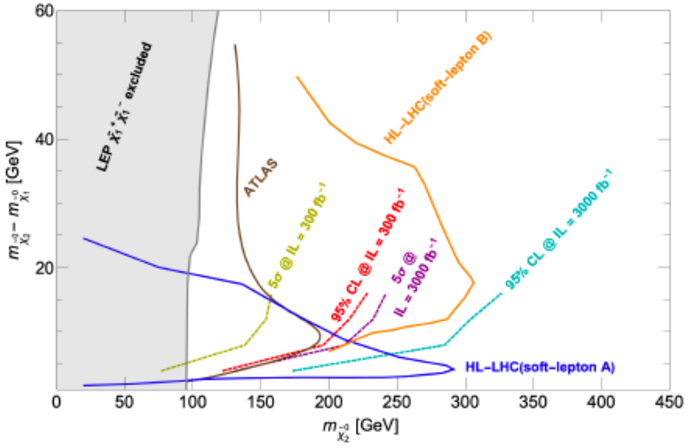
Soft dilepton+jet+MET signature from higgsino pair production



HB, Barger, Huang, 1107.5581;
Z. Han, Kribs, Martin, Menon, 1401.1235;
HB, Mustafayev, Tata; 1409.7058;
C. Han, Kim, Munir, Park, 1502.03734;
HB, Barger, Savoy, Tata, 1604.07438;
HB, Barger, Salam, Sengupta, Tata,2007.09252;
HB, Barger, Sengupta, Tata, 2109.14030



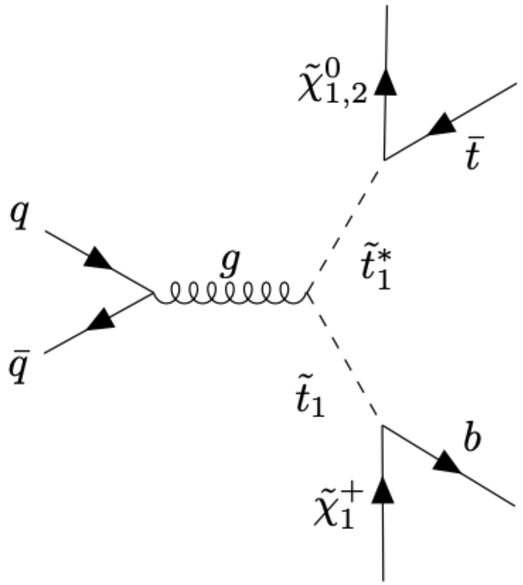




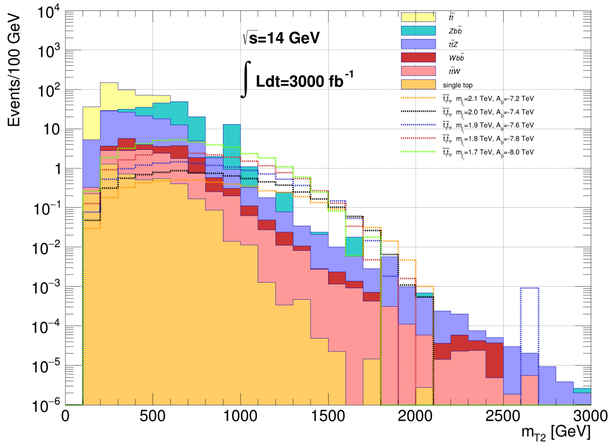
It appears that HL-LHC can see much (but not all) of natural SUSY p-space;
signal in this channel should emerge slowly as more integrated luminosity accrues

ATLAS/CMS: 2-sigma excess from Run 2!

top-squark pair production:



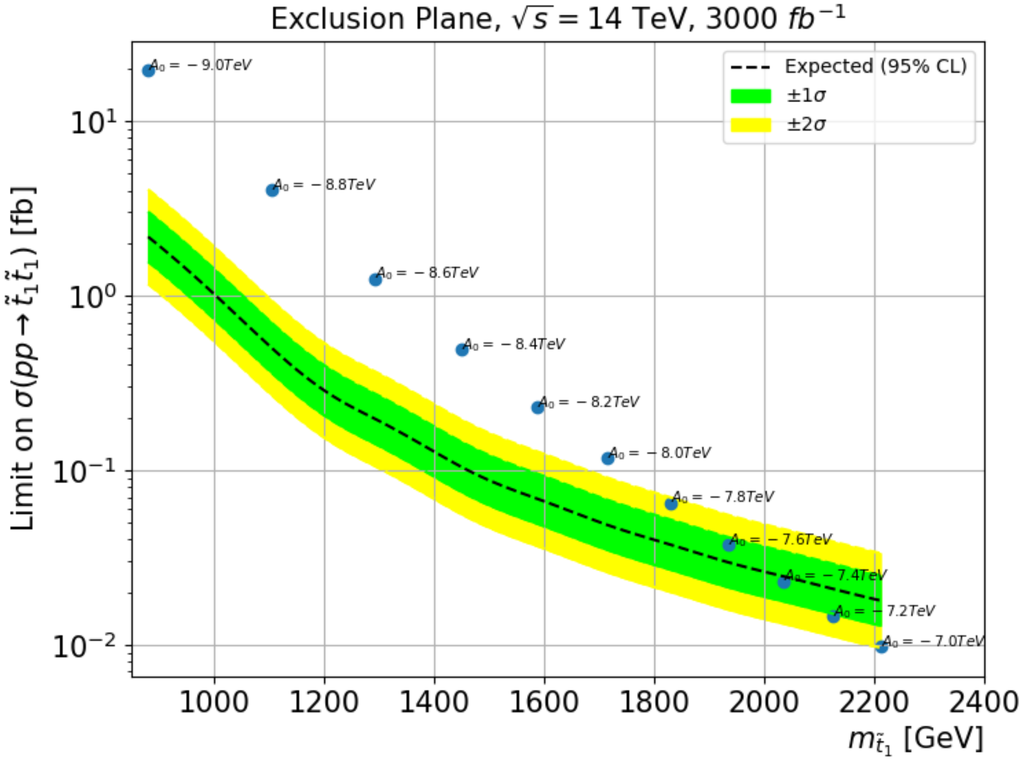
LHC: m(t1)>~1.1 TeV



HL-LHC can see
m(t1)~1.7-2 TeV
@5sigma/ 95% CL

HB, Barger, Dutta, Sengupta, Zhang
arXiv:2307.08067

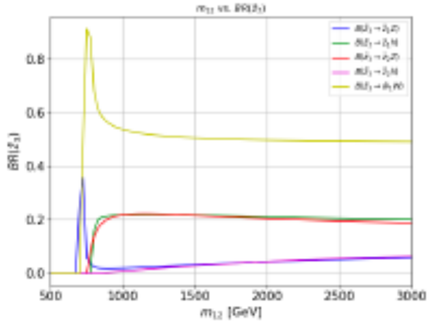
see Friday talk by K. Zhang

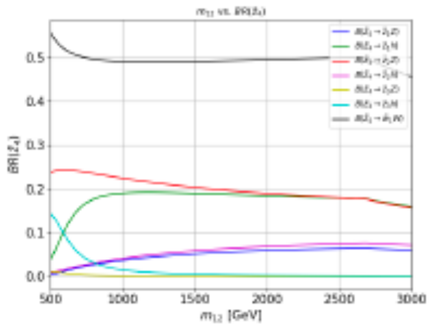


m(t1)~1-2.5 TeV from landscape

EWino (wino) pair prod'n

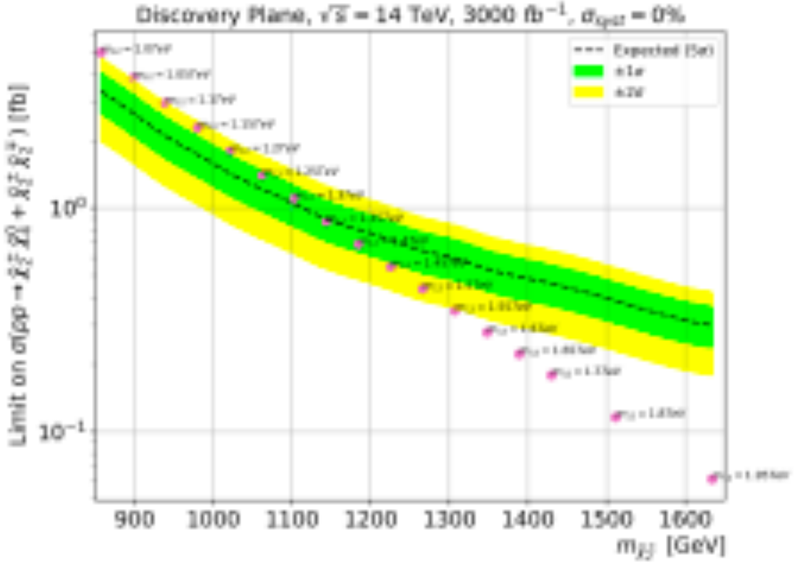
natural SUSY: wino->(V or h)+higgsino where V=W,Z





8 signal channels:

1. $Z(\to \ell^+\ell^-)B+\not{E}_T$,
2. $h/Z(\to b\bar{b})B+\not{E}_T$,
3. $BB+\not{E}_T$,
4. $\ell h+\not{E}_T$,
5. $\ell B_{W/Z}+\not{E}_T$,
6. $Z(\to \ell^+\ell^-)+\not{E}_T$,
7. $h/Z(\to b\bar{b})+\not{E}_T$, and
8. $\ell^\pm\ell^\pm+\not{E}_T$ events from $q\bar{q}' \to \widetilde{W}^\pm(\to W^\pm\tilde{h}^0)\widetilde{W}^0(\to W^\pm\tilde{h}^\mp)$, where the W bosons decay leptonically and the decay products of higgsinos are soft so that these events have hadronic activity only from QCD radiation [59,67].



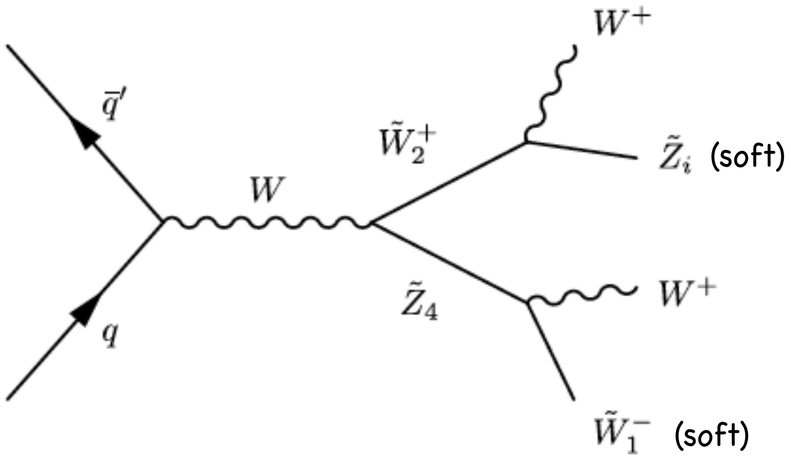
(B=W,Z->jets)

HL-LHC see m(wino) to 1.1 (1.4) TeV at 5-sig (95%CL)

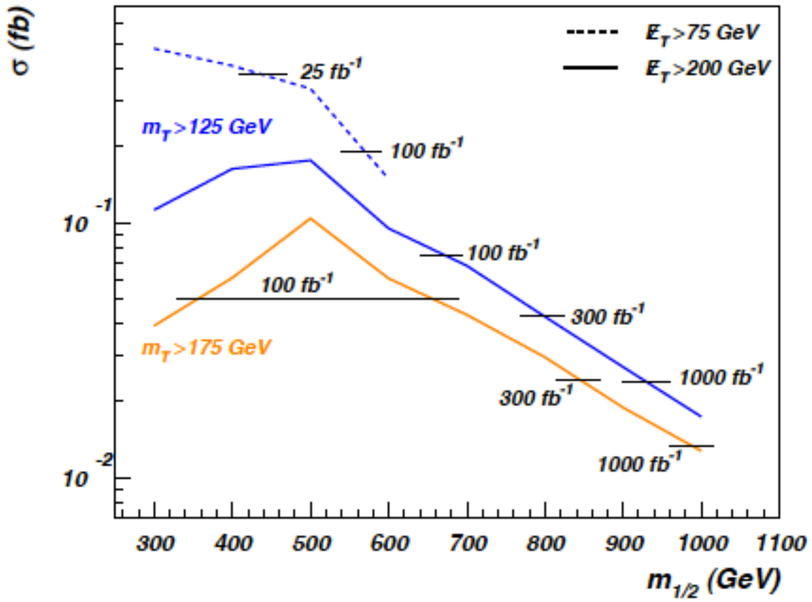
HB, Barger,Tata,Zhang: arXiv:2310.10829

compare: m(wino)~0.7-2.5 TeV from landscape (using gaugino mass unification)

Distinctive new same-sign diboson (SSdB) signature from SUSY models with light higgsinos!



wino pair production



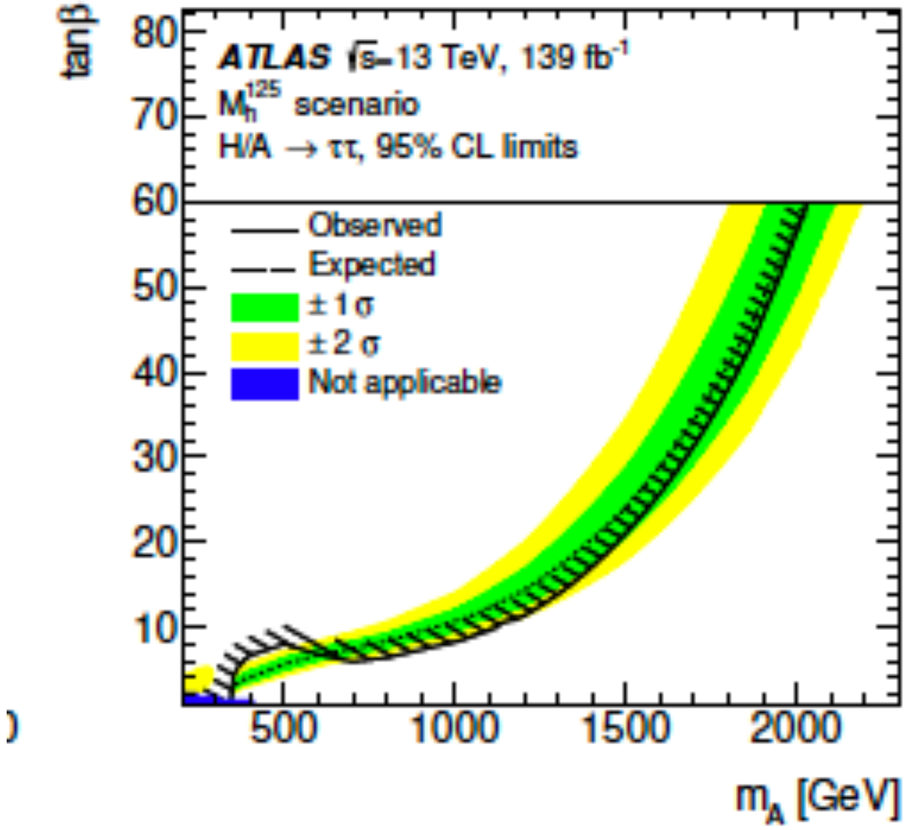
This channel offers added reach of LHC14 for natSUSY; it is also indicative of wino-pair prod'n followed by decay to higgsinos

So far: no distinct ATLAS/CMS analysis

H. Baer, V. Barger, P. Huang, D. Mickelson, A. Mustafayev, W. Sreethawong and X. Tata, *Phys. Rev. Lett.* **110** (2013) 151801.

Heavy Higgs A,H,H+ from natSUSY

best present limit from H,A->tautaubar in mh(125) scenario with decoupled SUSY particles



e.g. for tanb=10, then mA>1 TeV;
tanb=20: mA>1.5 TeV

in natSUSY (plausible) then light higgsinos guarantee H,A->SUSY modes open

Diminished H,A-> ditau BF results in diminished ditau reach projections

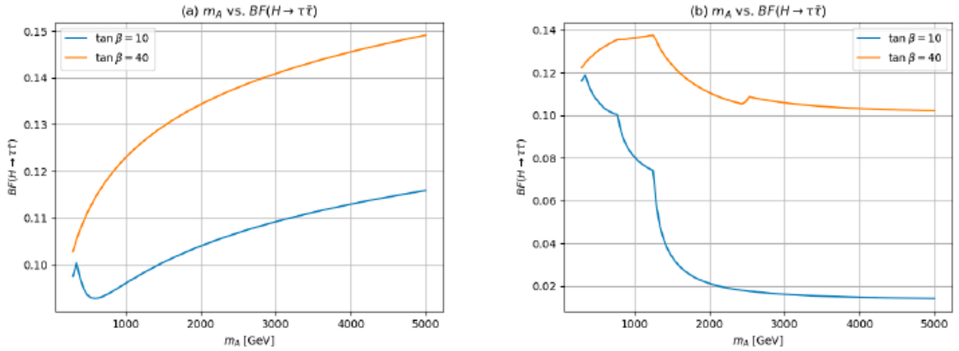


Figure 4: Branching fraction of $H \to \tau\bar{\tau}$ in the *a*) hMSSM and *b*) in the m_h^{125}(nat) benchmark case vs. m_A for $\tan\beta = 10$ and 40.

For given tanb, reach diminishes by ~400 GeV at HL-LHC in going from unnatural to natural SUSY

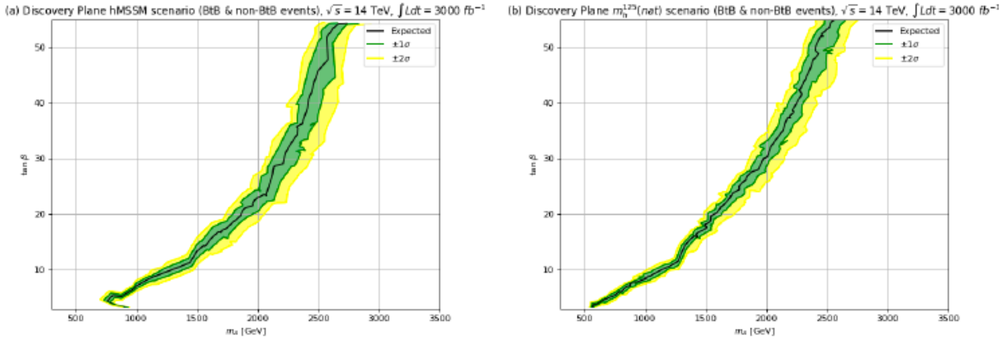


Figure 17: The discovery sensitivity with $\sqrt{s} = 14$ TeV and 3000 fb^{-1} for $H,\ A \to \tau\bar{\tau}$ in *a*) the hMSSM and *b*) the m_h^{125}(nat) scenario.

HB, Barger, Tata, Zhang, arXiv:2209.00063

but new H,A->SUSY search channels arise!

H,A-> gaugino+higgsino dominant if open

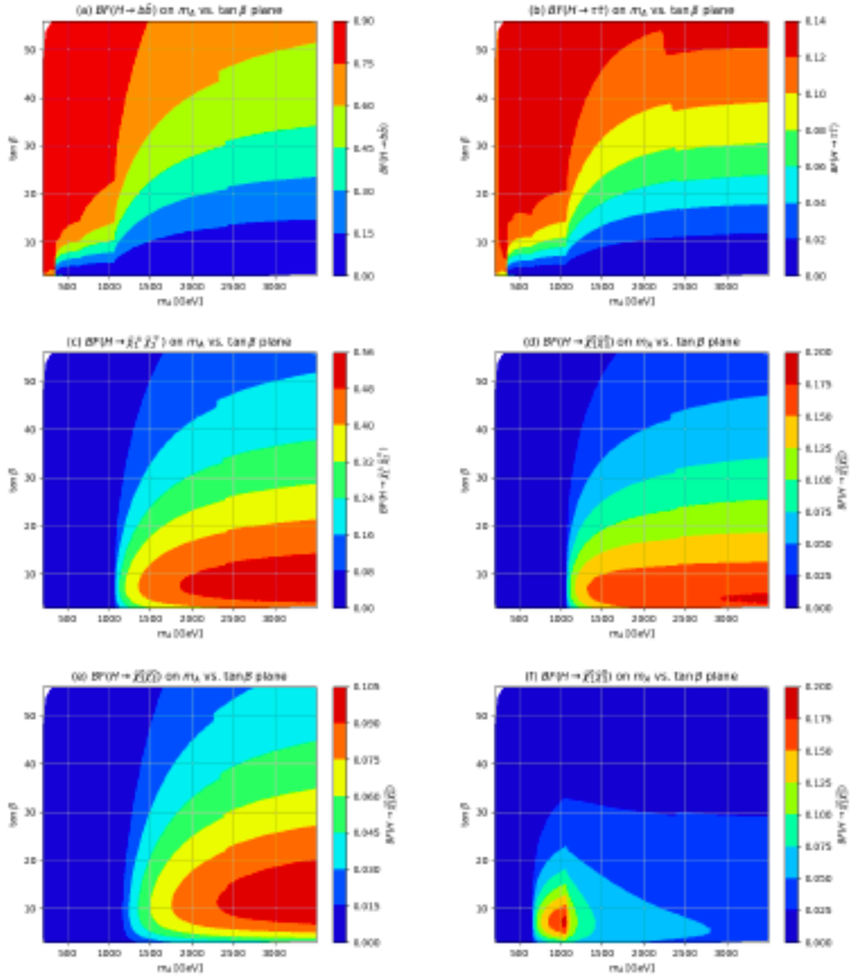


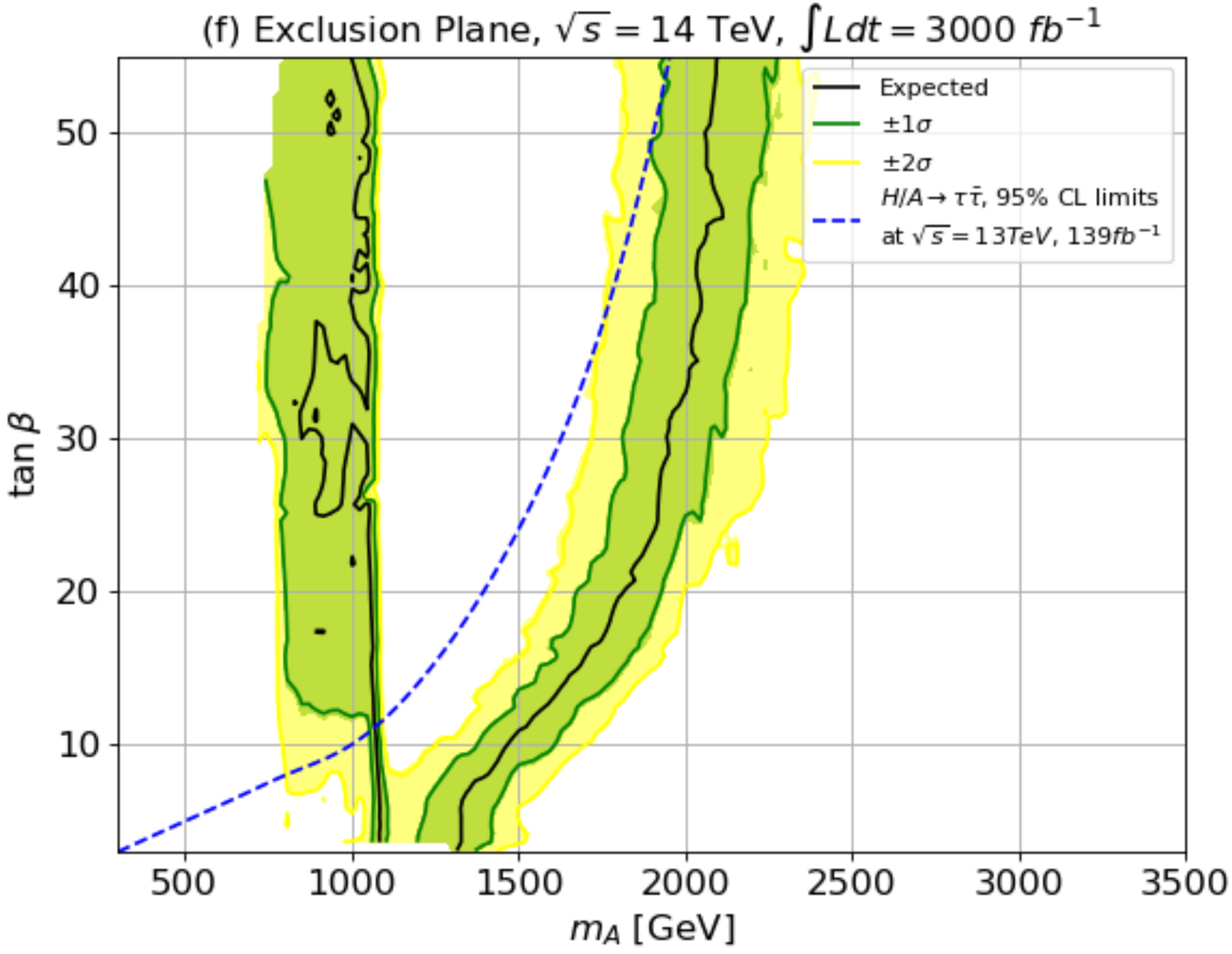
Figure 2: Branching fractions for H to $a)$ $b\bar{b}$, $b)$ $\tau\bar{\tau}$, $c)$ $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{\mp}$, $d)$ $\tilde{\chi}_1^0\tilde{\chi}_4^0$, $e)$ $\tilde{\chi}_2^0\tilde{\chi}_4^0$ and $f)$ $\tilde{\chi}_1^0\tilde{\chi}_3^0$ from Isajet 7.88 [36].

new H,A->natSUSY discovery modes

- $H,\ A \to W + \not{E}_T$,
- $H,\ A \to Z + \not{E}_T$ and
- $H,\ A \to h + \not{E}_T$.

HB, Barger, Tata, Zhang,
arXiv:2212.09198

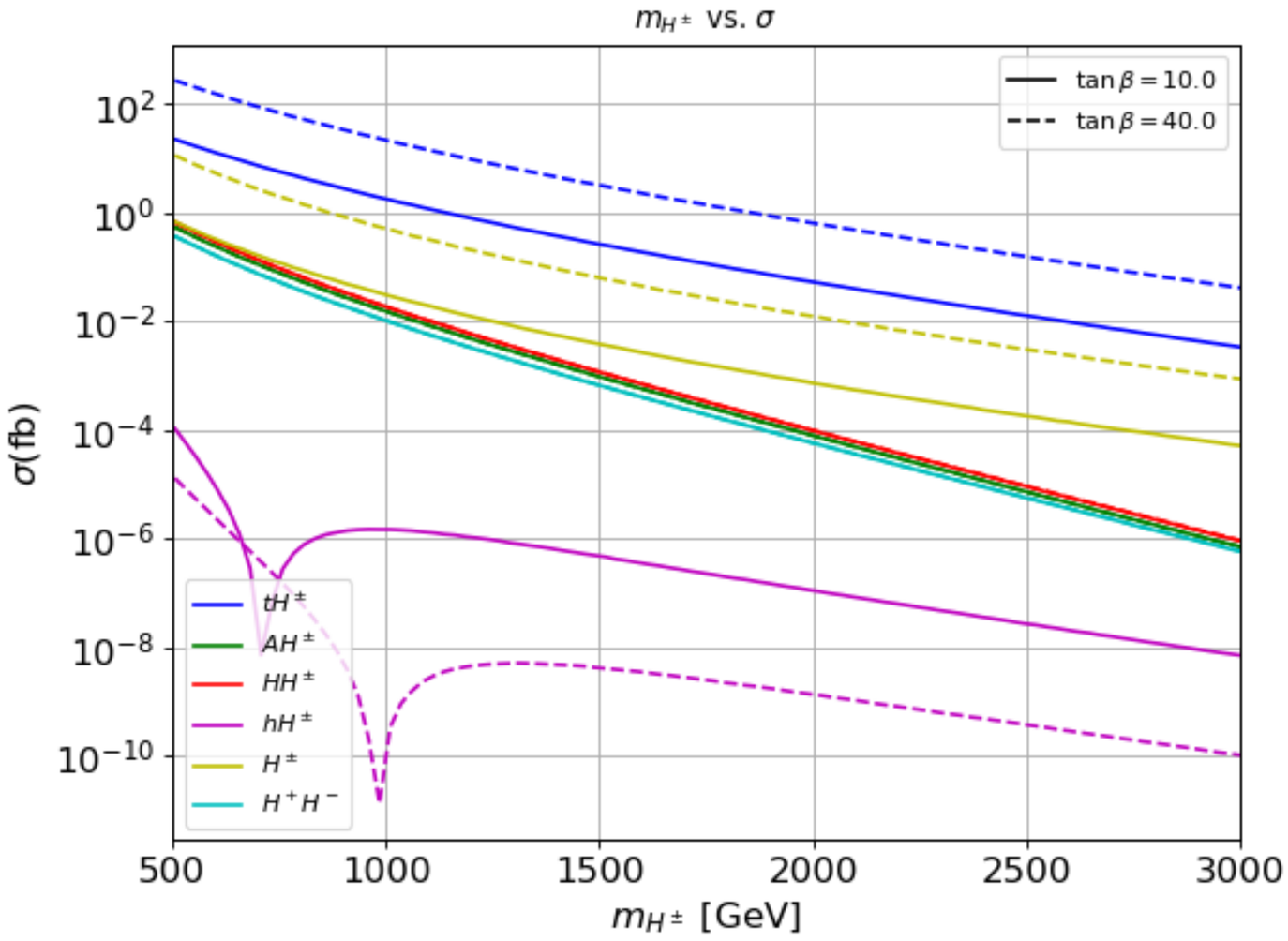
some additional p-space open to HL-LHC discovery/exclusion via H,A-> SUSY beyond present bounds



HB, Barger, Tata, Zhang
arXiv:2212.09198

combined reach via H,A->bbbar+MET, l$^+$l$^-$bar+MET

Charged Higgs is tougher;
pp->tHˆ+ is dominant for LHC in mH+~1 TeV regime



H+ -> gaugino+higgsino dominant if open (usually the case)

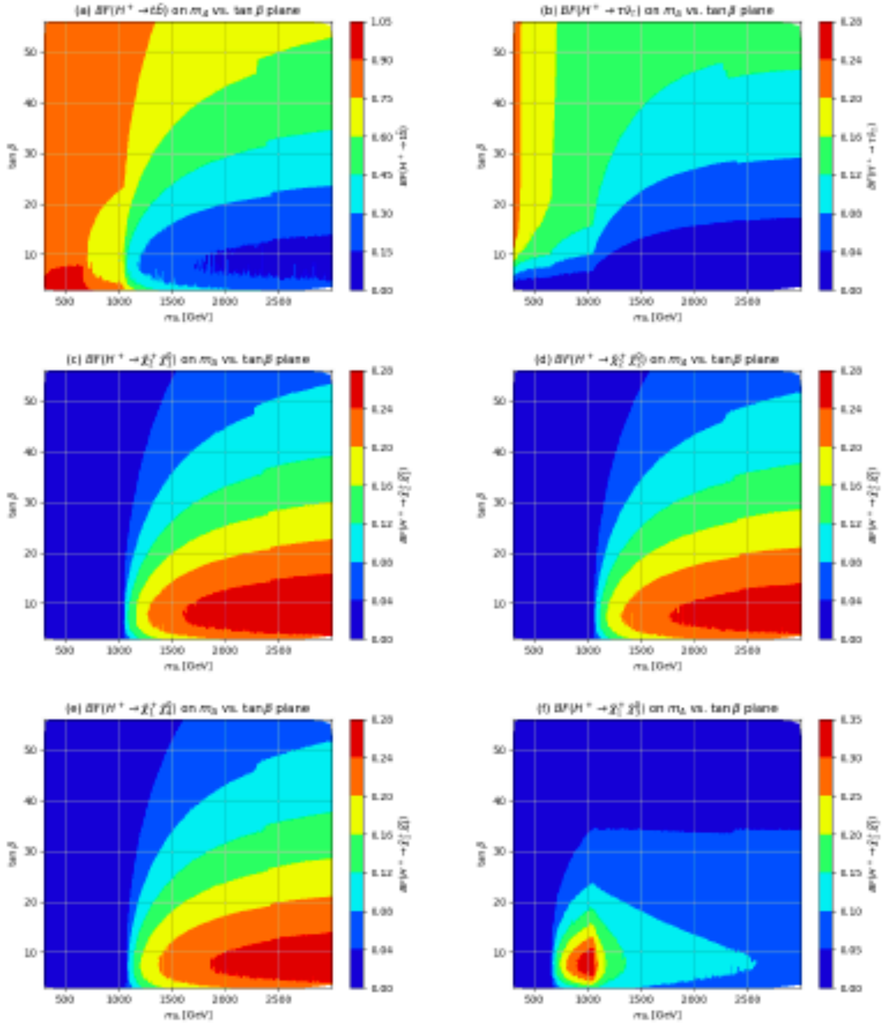


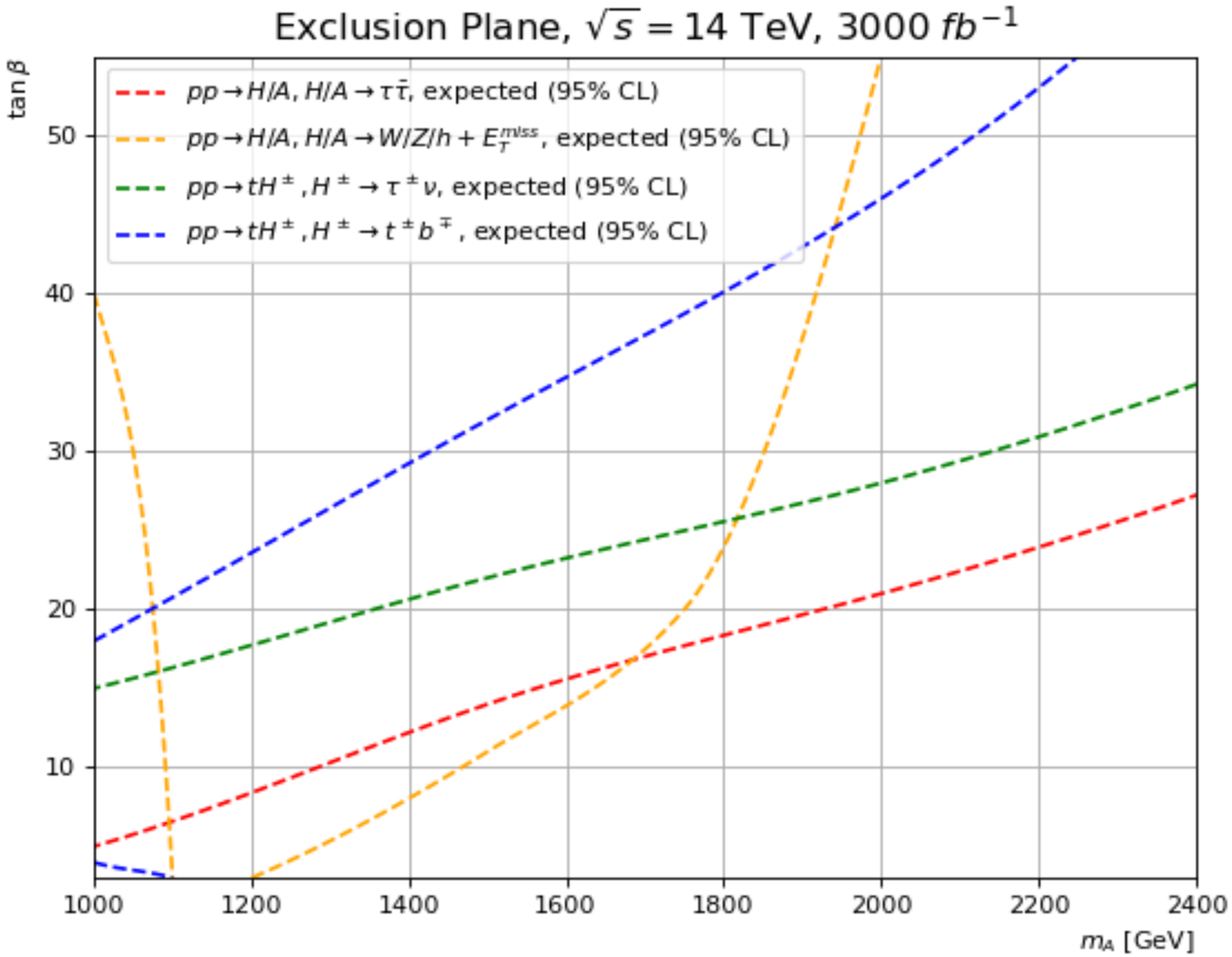
Figure 3: Branching fractions in the m_A vs. $\tan\beta$ plane for H^+ to *a)* $t\bar{b}$, *b)* $\tau^+\nu_\tau$, *c)* $\tilde{\chi}_2^+\tilde{\chi}_1^0$, *d)* $\tilde{\chi}_2^+\tilde{\chi}_2^0$, *e)* $\tilde{\chi}_1^+\tilde{\chi}_4^0$ and *f)* $\tilde{\chi}_1^+\tilde{\chi}_3^0$ from Isajet 7.88 [35] for the model line introduced in the text.

new H+ discovery modes:

- H+ -> tau_h+MET
- H+ -> t+bbar+MET
- tH+ modes

HB, Barger, Tata, Zhang, arXiv:2306.05207

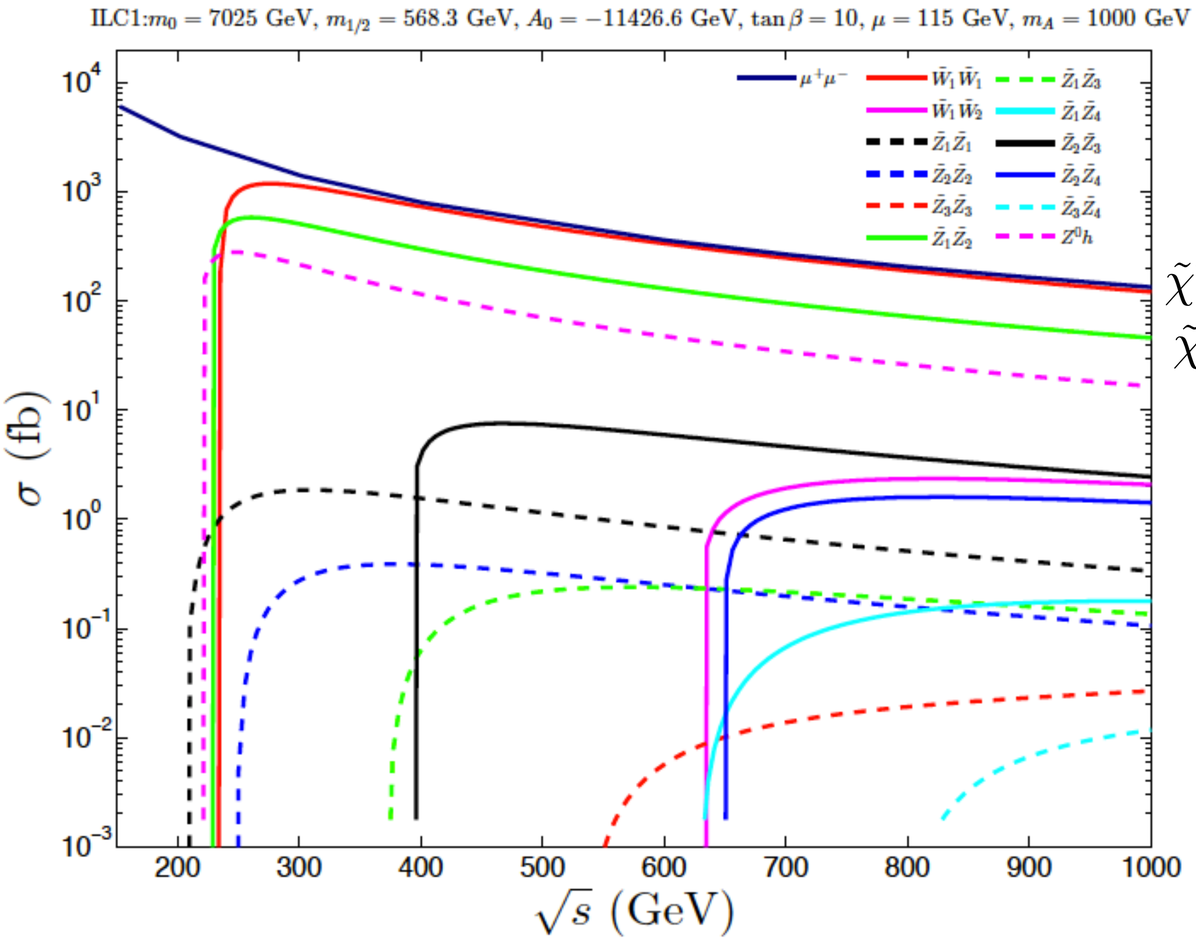
H+- seeable in portion of natSUSY p-space at HL-LHC



HB, Barger, Tata, Zhang, arXiv:2306.05207

Smoking gun signature: light higgsinos at ILC:

ILC is Higgs/higgsino factory!



$\sigma(higgsino) \gg \sigma(Zh)$

$\tilde{\chi}_1^+\tilde{\chi}_1^-$
$\tilde{\chi}_1^0\tilde{\chi}_2^0$

3-15 GeV higgsino mass gaps no problem in clean ILC environment

HB, Barger, Mickelson, Mustafayev, Tata
arXiv:1404:7510

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to (\ell\nu_\ell\tilde{\chi}_1^0) + (q\bar{q}'\tilde{\chi}_1^0)$$

measure $m(jj) < m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$ and $E(jj)$

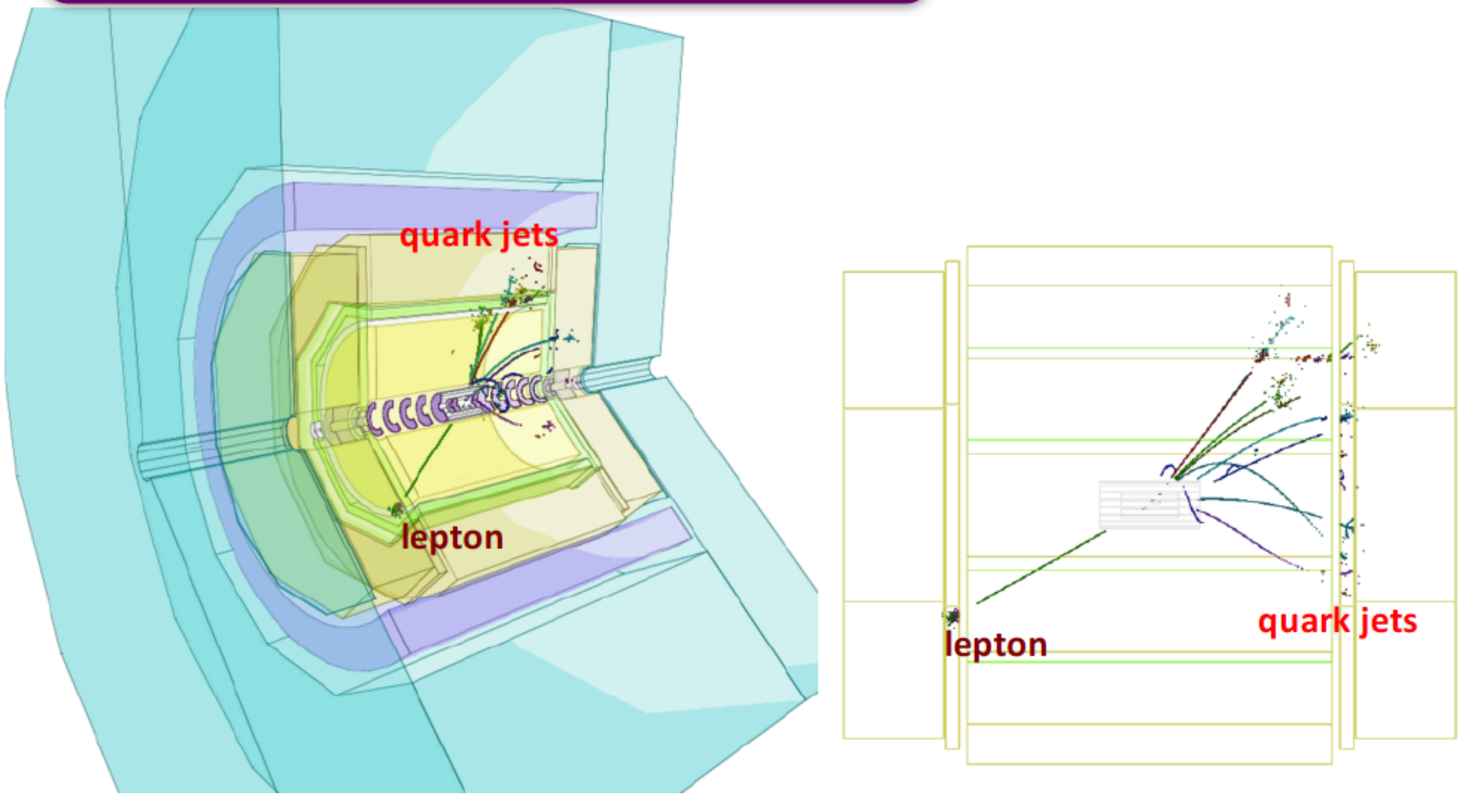
soft visible particles since small higgsino mass gaps

How do these signals look in the detector? (2)

$\sqrt{s}$ =500 GeV

Chargino pair production with semileptonic decay

$$e^+e^- \to \tilde{\chi}_1^+\,\tilde{\chi}_1^- \to \tilde{\chi}_1^0\,\tilde{\chi}_1^0 q q'\ell\nu$$



HB, Berggren, Fujii, List, Lehtinen, Tanabe, Yan, arXiv: 1912.06643

$$e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + (\ell^+\ell^-\tilde{\chi}_1^0)$$

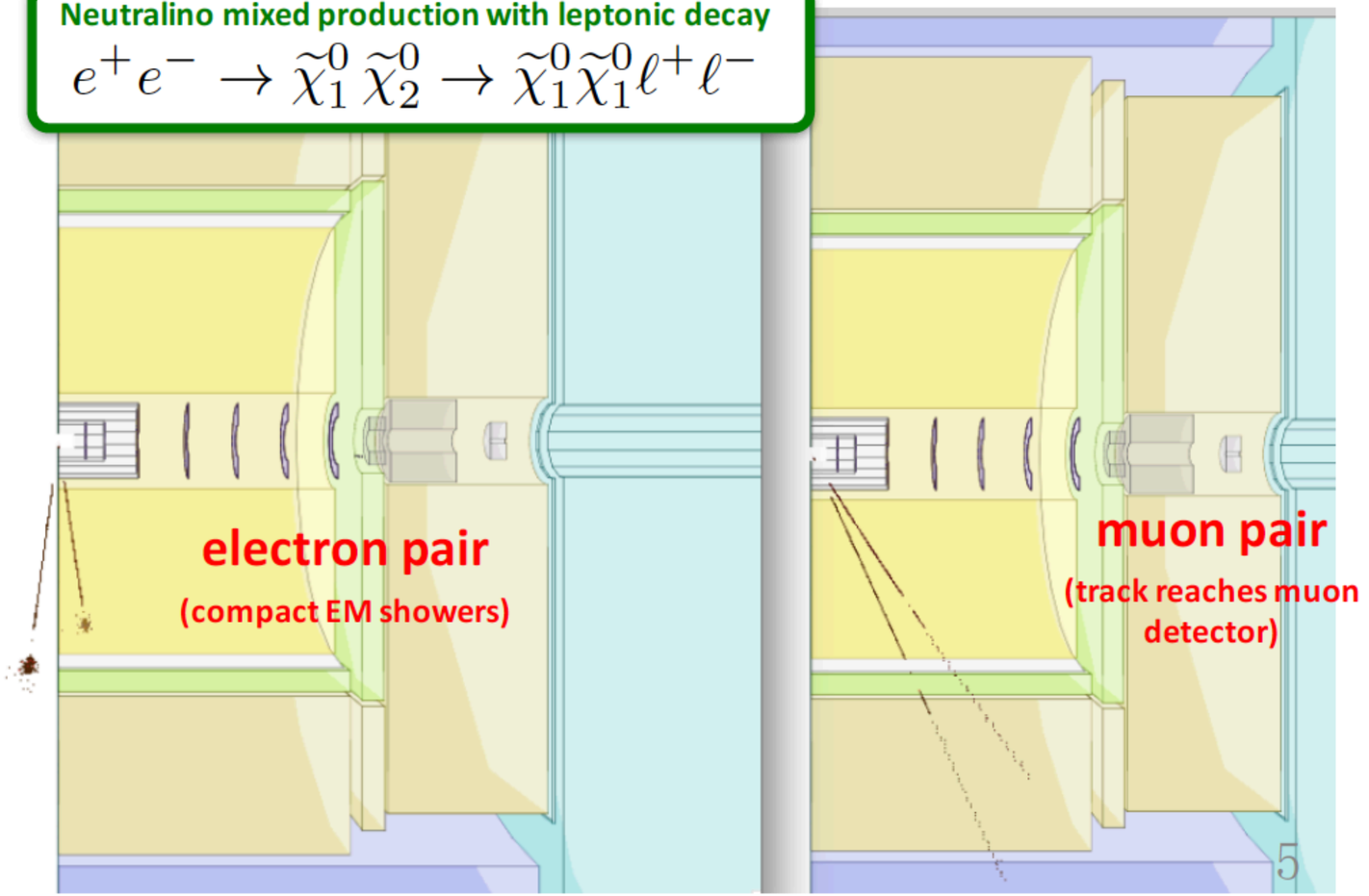
measure $m(\ell^+\ell^-) < m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$ and $E(\ell^+\ell^-)$

How do these signals look in the detector? (1)

Vs =500 GeV

Neutralino mixed production with leptonic decay

$$e^+e^- \to \tilde{\chi}_1^0\,\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$$



HB, Berggren, Fujii, List, Lehtinen, Tanabe, Yan, arXiv: 1912.06643

Conclusions

- natSUSY= plausible SUSY: what the string landscape predicts
- expected LHC signatures change compared to bino LSP/simplified models
- gluino pairs
- stop pairs
- EWino pairs: wino pairs -> SSdB, etc.
- higgsino pairs (compressed spectra; 2-sigma excess for ATLAS/CMS): is this the tip of the iceberg?
- conventional heavy Higgs search diminished; but new search modes: H, A, H+- -> SUSY
- expect SUSY to emerge slowly as LHC accrues more integrated luminosity
- ILC with rs>2m(higgsino): a higgsino factory!