Exploring the Natural Anomaly-Mediated Supersymmetry Breaking Model at the HL-LHC

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Standard Model Hierarchy Problem

Corrections to the Higgs Mass

$$m_{H_{\text{SM}}}^2 = m_{H_0}^2 + \frac{12g^2 m_{H_{\text{SM}}}^2}{32M_W^2}\frac{1}{16\pi^2}\left(\Lambda^2 - m_{H_{\text{SM}}}^2 \ln\frac{\Lambda^2}{m_{H_{\text{SM}}}^2} + \mathcal{O}(\frac{1}{\Lambda^2}\right)$$

- The large corrections at high cutoff scales must be finely tuned.
- Bosonic and fermionic contributions cancel the quadratic term.
- A solution is to pair a fermion to every boson and vice-versa–this is Supersymmetry.

SUSY Breaking

- If SUSY were an exact symmetry, the particles and their superpartners would have the same mass.
- Since we have not observed any bosons with the same mass as an electron, this cannot be the case. So SUSY must be a broken symmetry.
- The exact method of SUSY breaking is not yet known, so there are many models.
- Anomaly mediation: SUSY breaking terms are loop suppressed and require sequestering of the tree level.

Minimal Anomaly Mediated SUSY Breaking (mAMSB)

- If SUSY breaking is sequestered from the visible sector, then anomaly mediation terms may be dominant.
- An example of AMSB contributions to the gaugino mass:

$$M_i = \frac{\beta_{g_i}}{g_i} m_{3/2}$$

- To parametrize ignorance, a phenomenological model called minimal AMSB was developed with the parameter space

$$m_0, m_{3/2}, \tan\beta, \text{sign}(\mu).$$

- m_0 is an ad hoc bulk scalar term added to counter the tachyonic slepton masses resulting from ASMB soft terms.
- Sparticle masses depend explicitly on $m_{3/2}$.
- Wino as the LSP.

Problems with mAMSB

- mAMSB is mostly excluded up to the naturalness limit (e.g. $\Delta_{EW} < 30$).
- No choice of parameters to make the theory natural under Δ_{EW}.
- No choice of parameters to make $m_h = 125$ GeV without heavy top squarks: 10-100 TeV.
- The wino as a dark matter candidate has been excluded by indirect detection constraints (E.G. T. Cohen, M. Lisanti, A. Pierce, T. R. Slatyer, Wino Dark Matter Under Siege, JCAP 10 (2013) 061. arXiv:1307.4082).

Natural Anomaly Mediated SUSY Breaking (nAMSB)

- By adding separate bulk terms for scalar masses as well as trilinear couplings, as originally suggested by Randall and Sundrum, anomaly mediation can fit within current constraints.
- New parameter space:

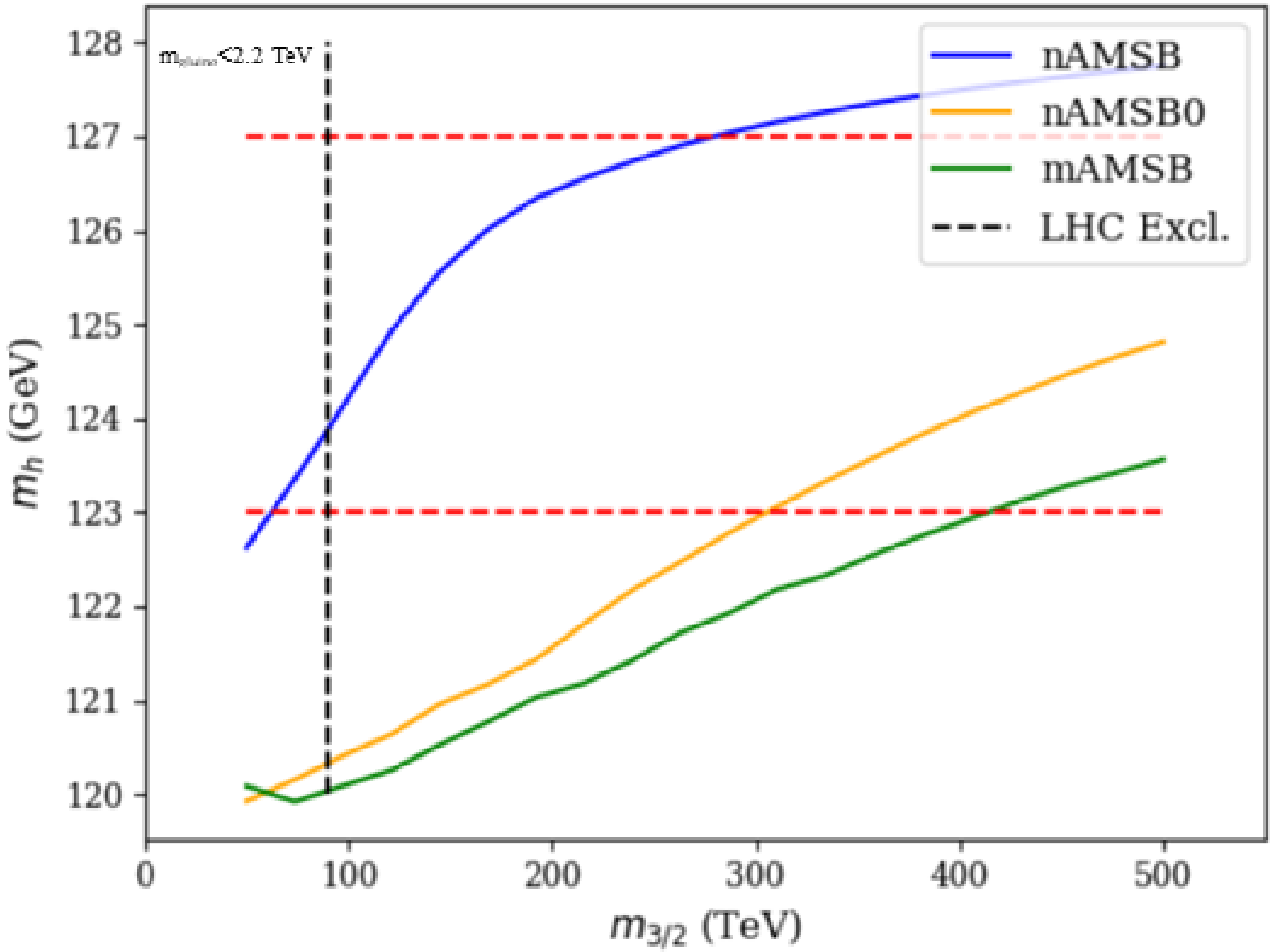
$$m_0(i), m_{3/2}, A_0, m_{H_u}, m_{H_d}, \tan\beta$$

  (See arXiv:2311.1812).
- m_{H_u} and m_{H_d} can be exchanged for μ and m_A.
- nAMSB is completely viable.
- The wino is the lightest gaugino, but the higgsino is now the lightest EWino.

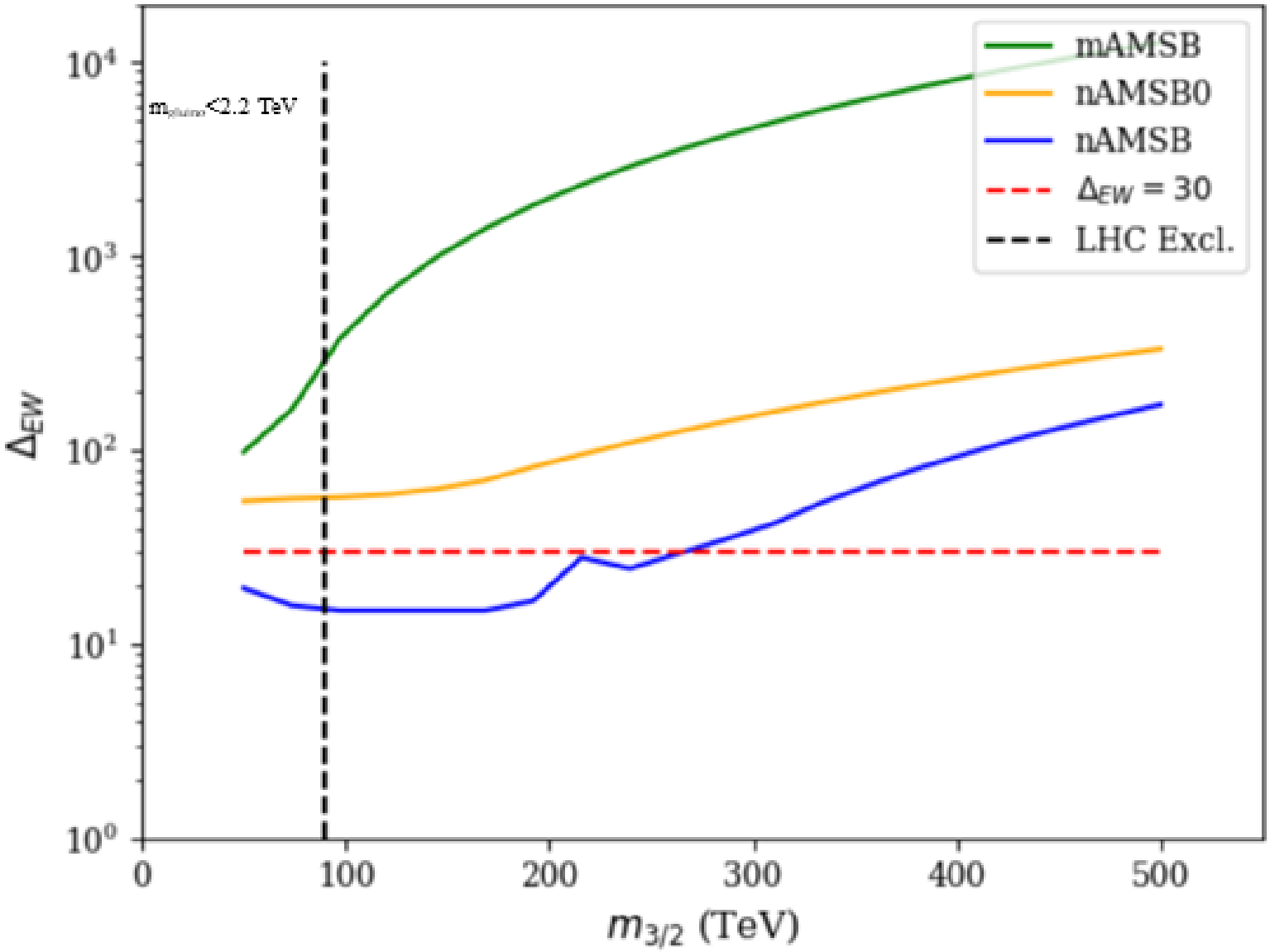
The Model Lines

- mAMSB: $m_0 = 5$ TeV, sign$(\mu) = 1$, $\tan\beta = 10$, $m_{3/2} = 50 - 500$ TeV
- nAMSB0: $m_0(1,2) = 10$ TeV, $m_0(3) = 5$ TeV, $A_0 = 0$ TeV, $\tan\beta = 10$, $\mu = 250$ GeV, $m_A = 2$ TeV, $m_{3/2} = 50 - 500$ TeV
- nAMSB: $m_0(1,2) = 10$ TeV, $m_0(3) = 5$ TeV, $A_0 = 6$ TeV, $\tan\beta = 10$, $\mu = 250$ GeV, $m_A = 2$ TeV, $m_{3/2} = 50 - 500$ TeV

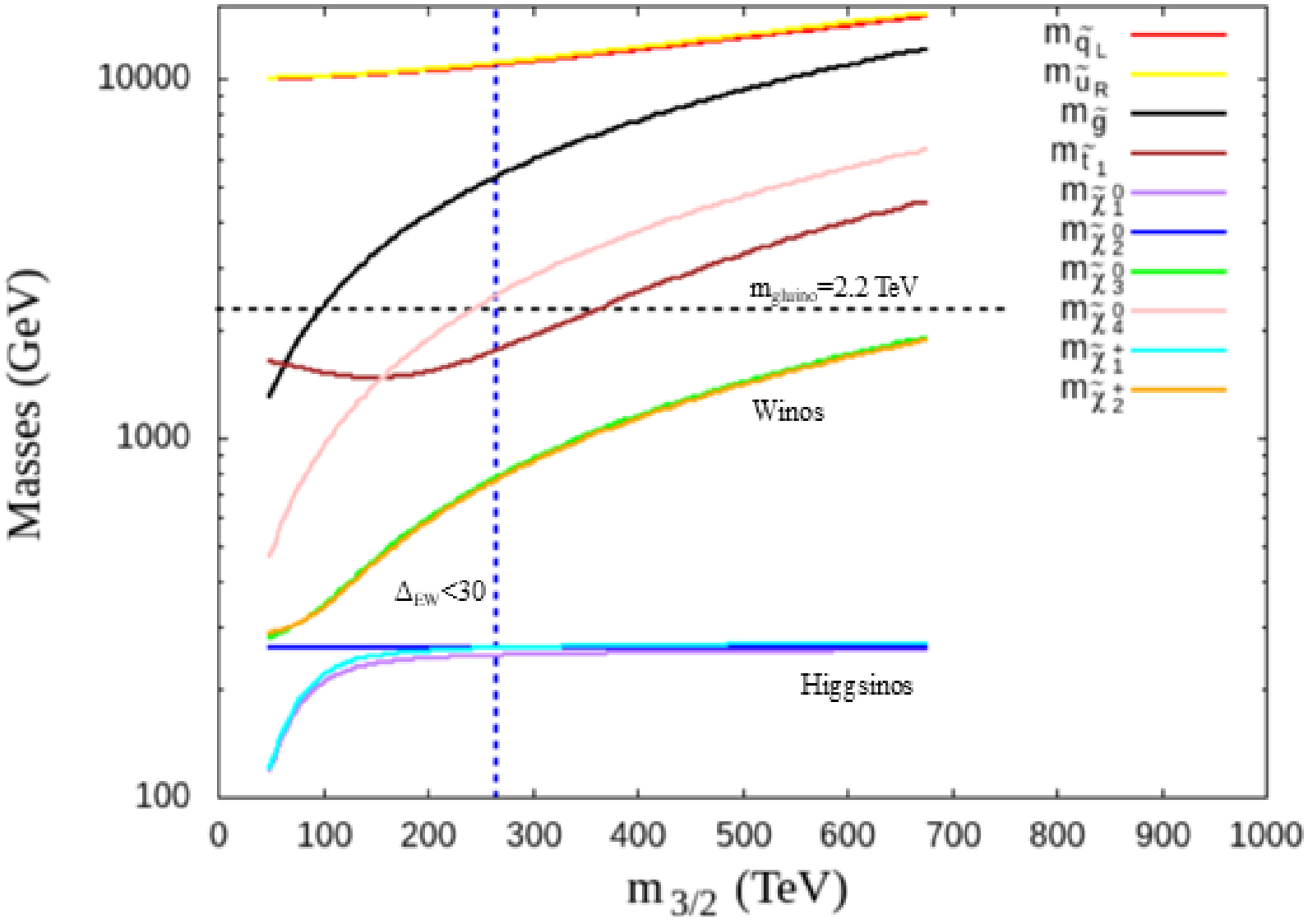
Higgs Mass Bounds



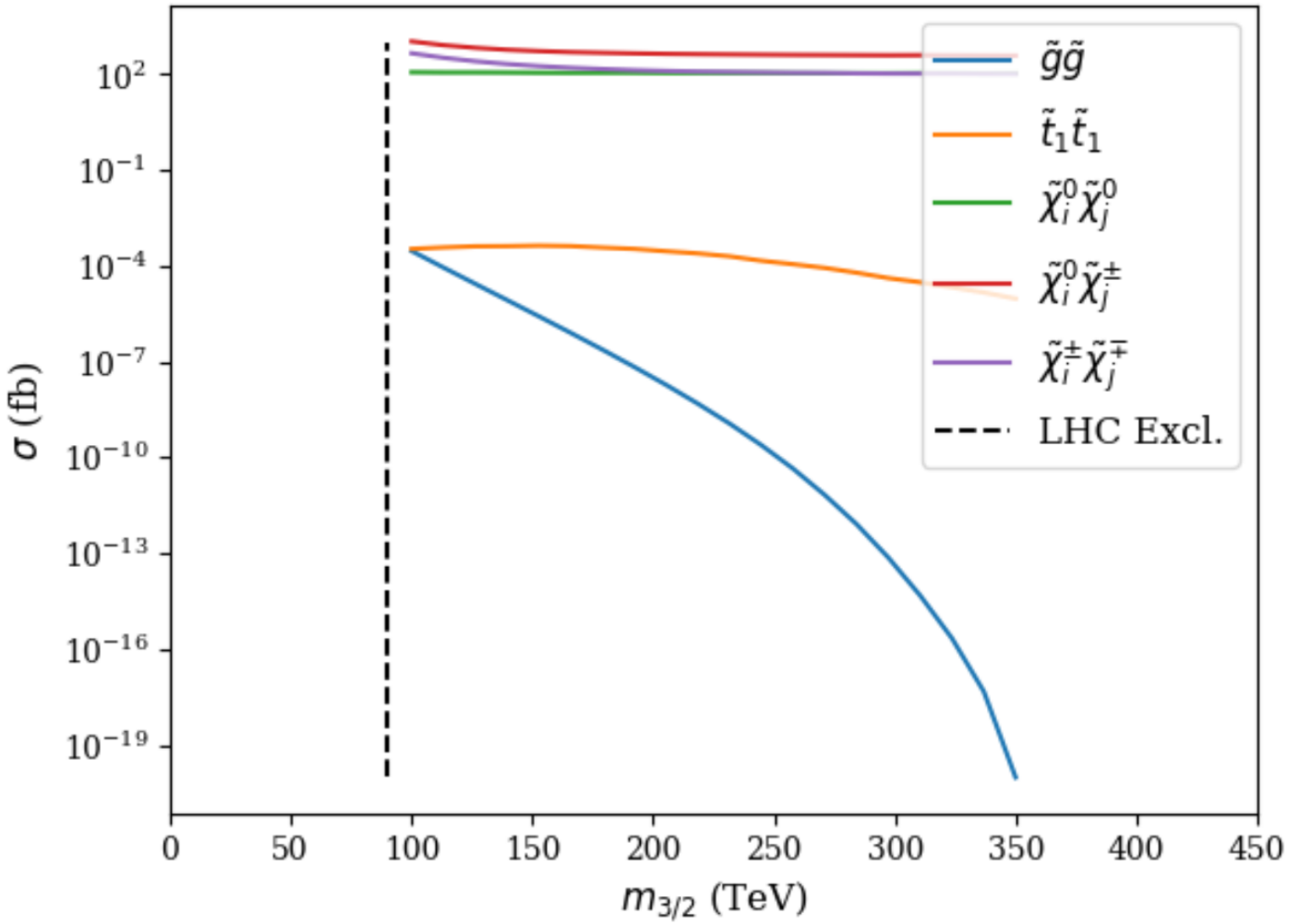
Naturalness Bounds



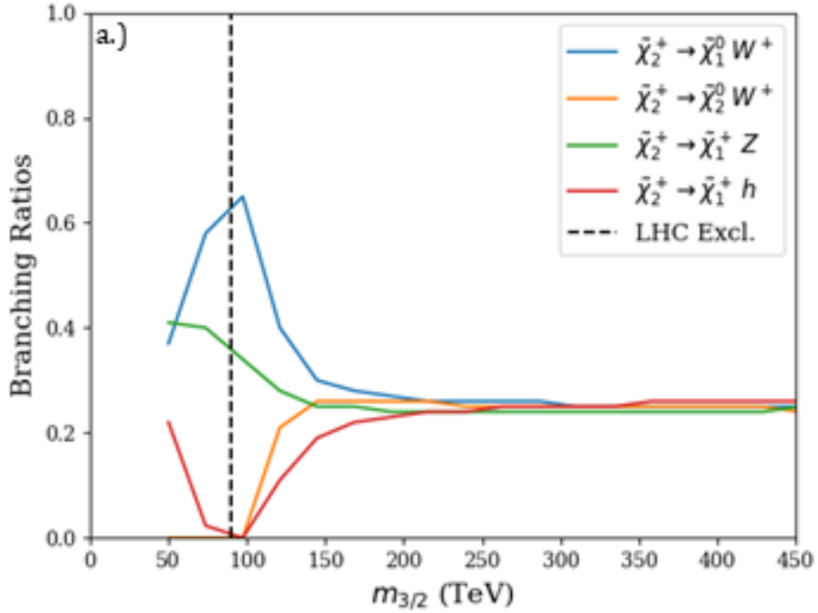
nAMSB Mass Spectra

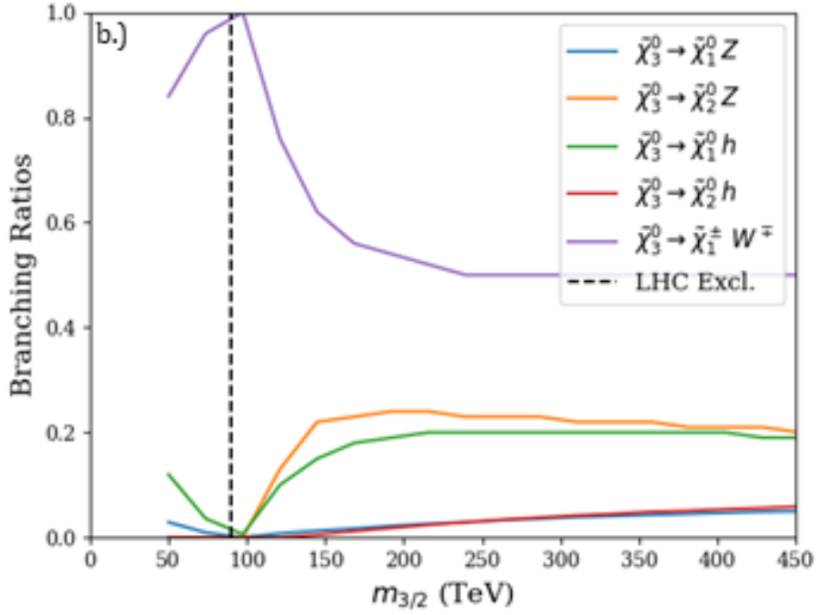


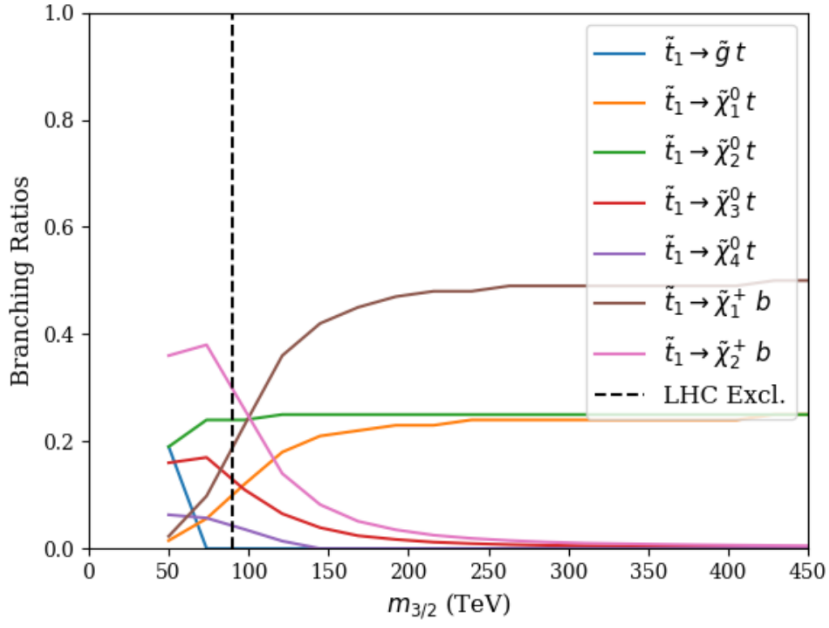
EWino Pair Production Dominant at LHC14



Wino and Stop Branching Fractions

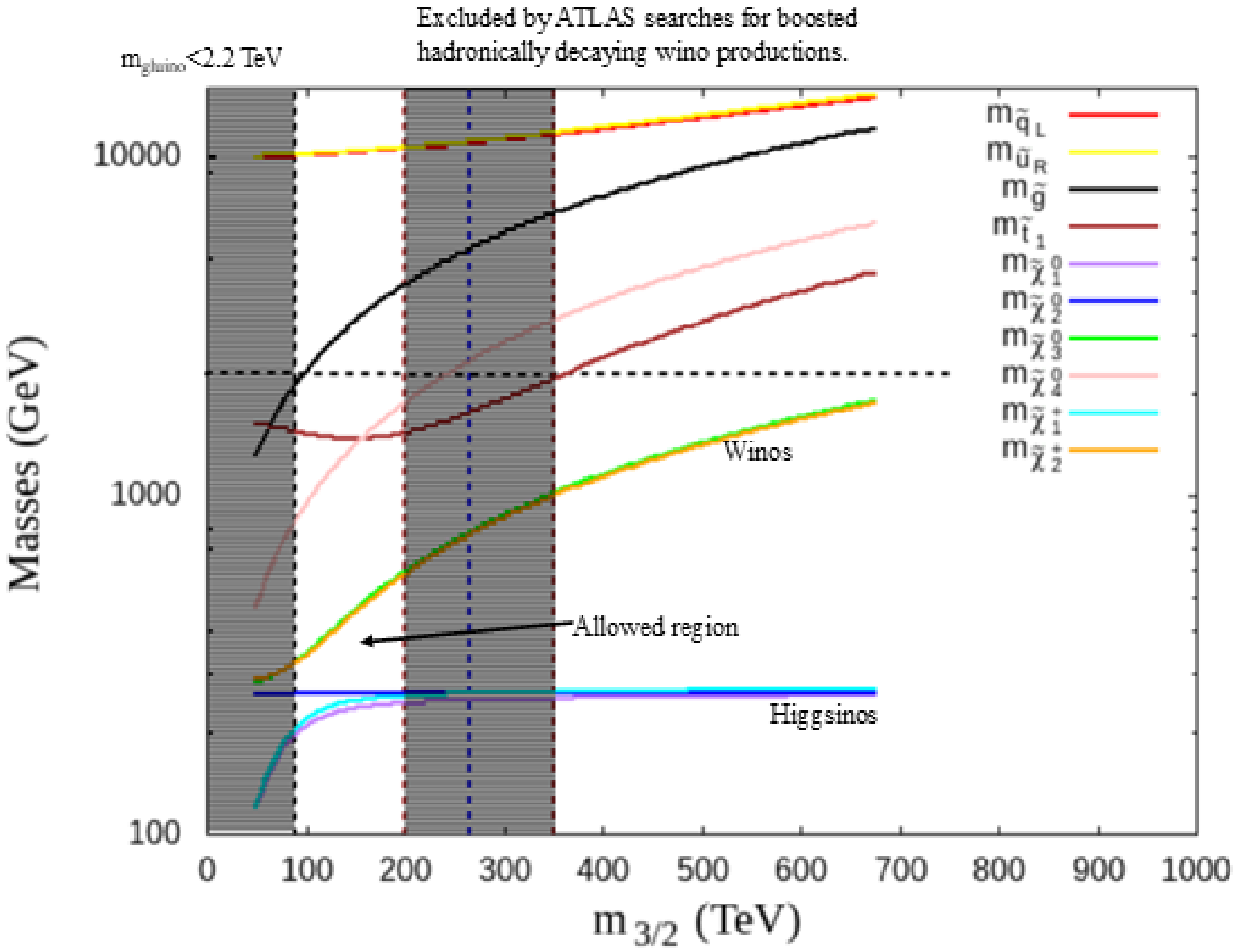






Note: *not* simplified model.

Allowed and Excluded Parameter Space for nAMSB



nAMSB and the Hi-Lumi LHC

- Several possible discovery channels at the HL-LHC to fill the gap in parameter space.
- Soft opposite-sign dilepton plus jets plus missing transverse energy from higgsino pair production.
- Soft trilepton from higgsino pair production.
- Same-sign diboson from wino pair production.
- Hard trilepton plus missing transverse energy from wino pair production.
- Top-squark pair production.

Conclusions

- mAMSB has been ruled out to naturalness limits by LHC and dark matter indirect search constraints.
- nAMSB has generalized bulk terms which allow for naturalness, $m_h = 125$ GeV, and dark matter constraints to be fulfilled.
- Ongoing research: this parameter space should be fully testable at the hi-lumi LHC unlike other SUSY models which can have large sparticle masses within naturalness bounds.