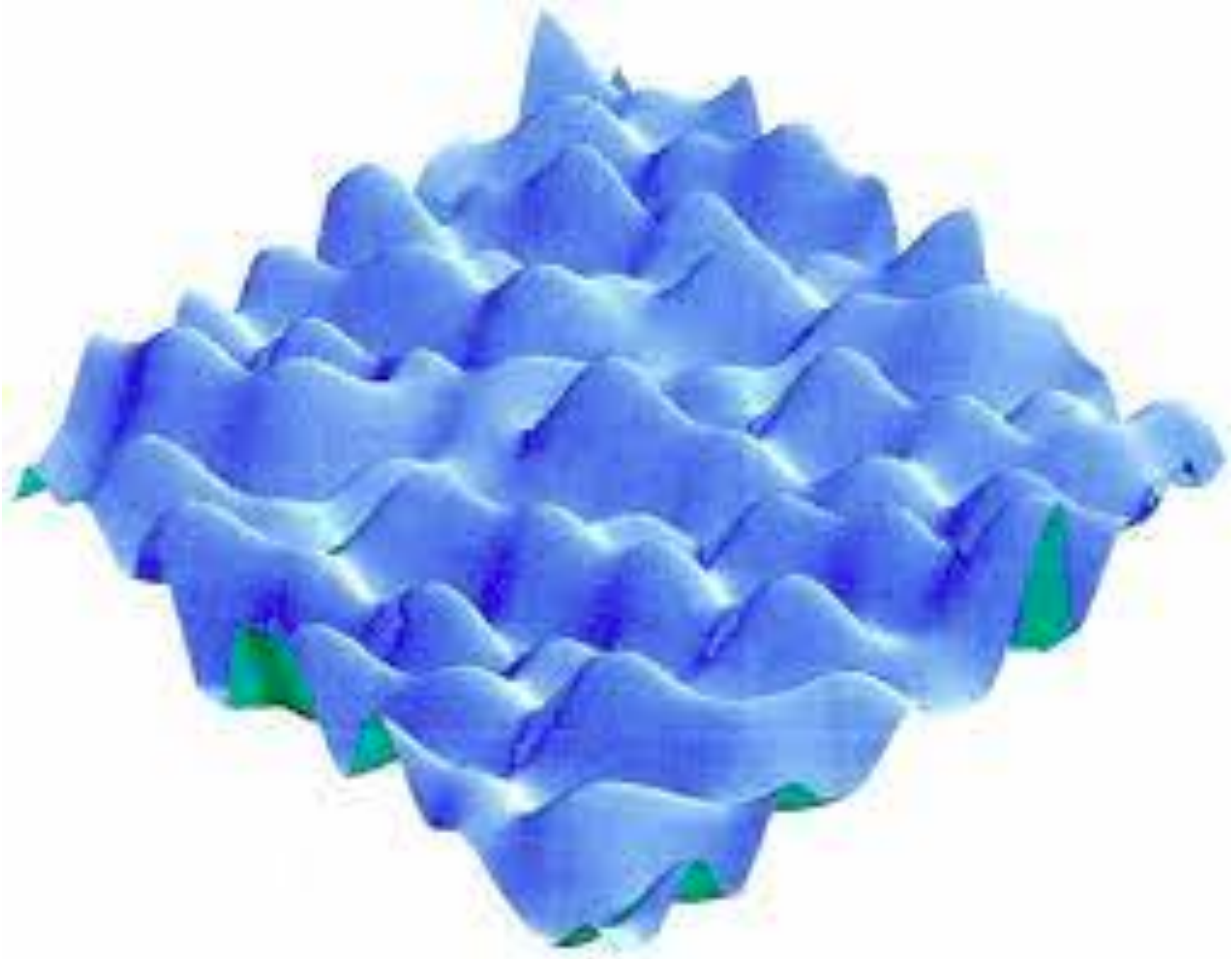
# The string landscape predicts: light higgsinos at ILC

Howard Baer
University of Oklahoma
BSM@ILC meeting, EF03, March 2, 2022



=>

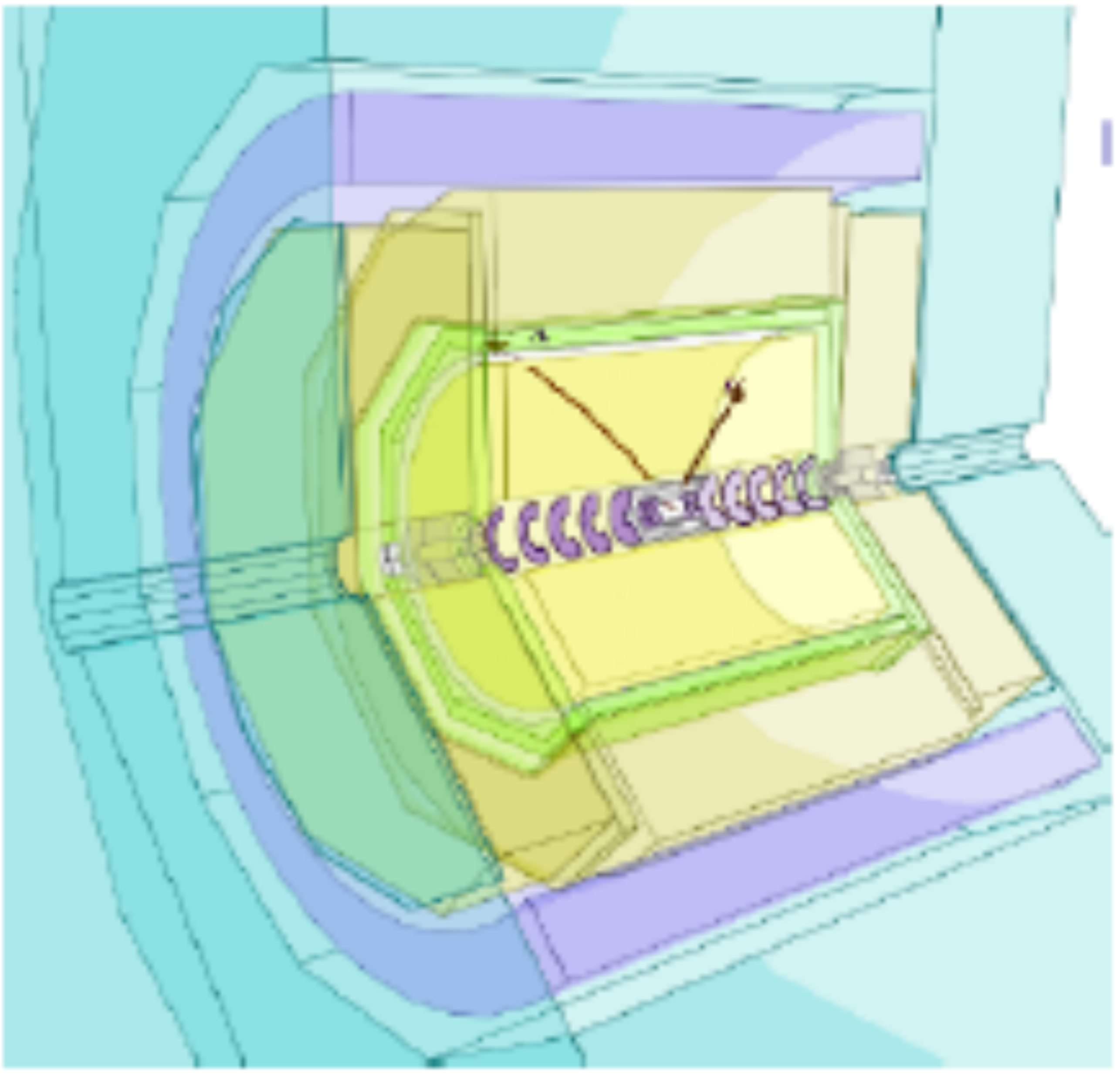


Figure 1: ILD event display of simulated $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2$ with $\tilde{\chi}^0_2 \to \ell^+\ell^-\tilde{\chi}^0_1$.

# Some basics of string landscape

- string theory offers UV complete theory of quantum gravity
- but need 10 (11) spacetime dimensions to cancel anomalies/consistency
- expect extra 6 dimensions compactified on CY manifold (which preserves some remnant supersymmetry)
- various string theories connected by duality relations
- in II-B theory, presence of p-form fluxes; can trap flux lines on cycles; flux quantized ~1-10
- in flux compactifications, expect perhaps 10^500 (or many more) distinct vacuum states, each leading to different 4-d laws of physics

# more basics...

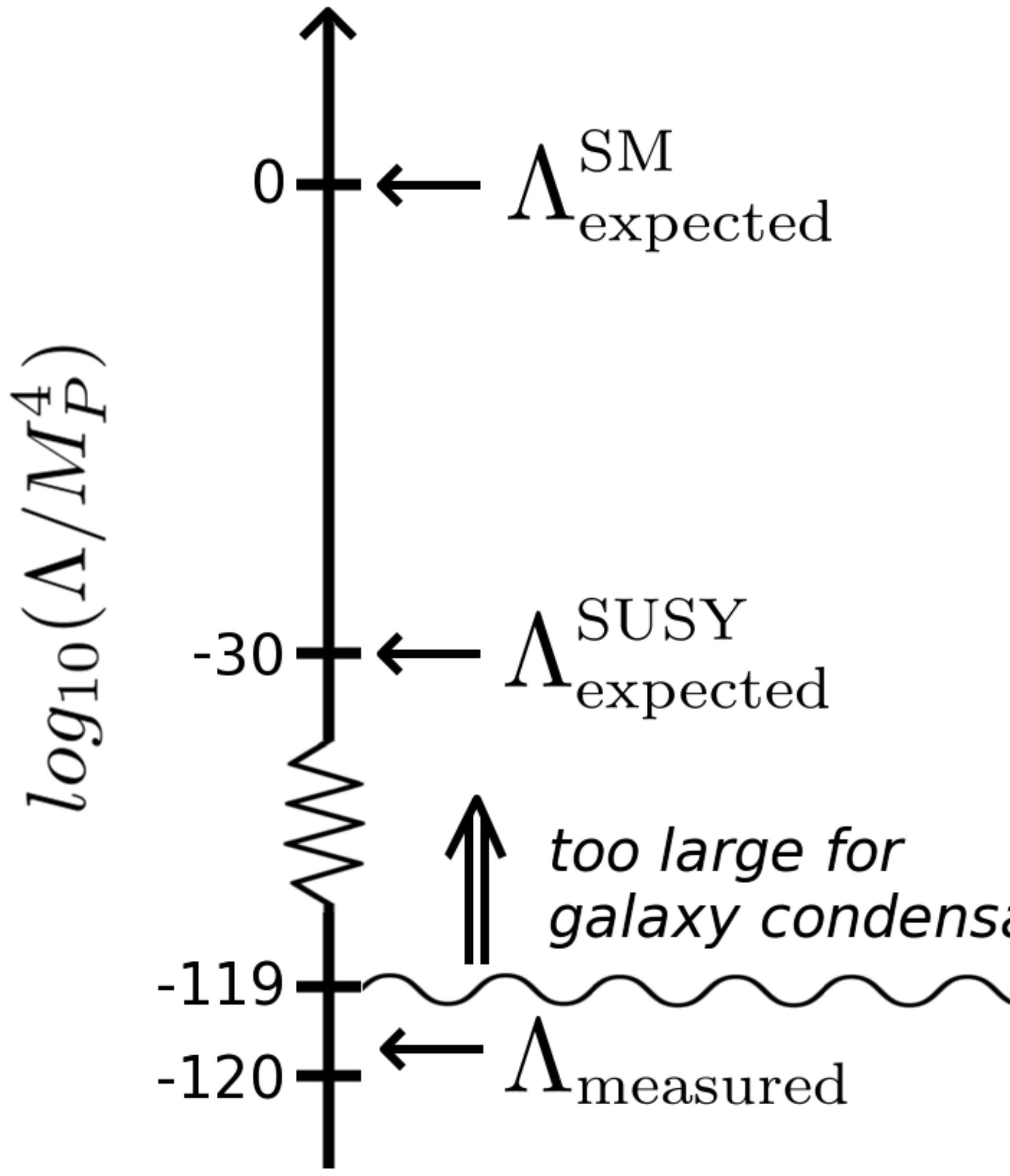
- Third string revolution? Large number of vacuum states provides string setting for Weinberg's anthropic solution to CC problem

- CC should be there, but any value >~10^-122 mP^2 leads to such rapid expansion that galaxies don't form

- then it may not be surprising to find ourselves in universe with tiny CC: if it were much bigger, structure wouldn't form and we wouldn't be here!

- our universe is but one ``pocket universe" within eternally inflating multiverse

- this is what you get if you push QM+GR to their limits: gives initial conditions for origin of universe



# string landscape and SUSY

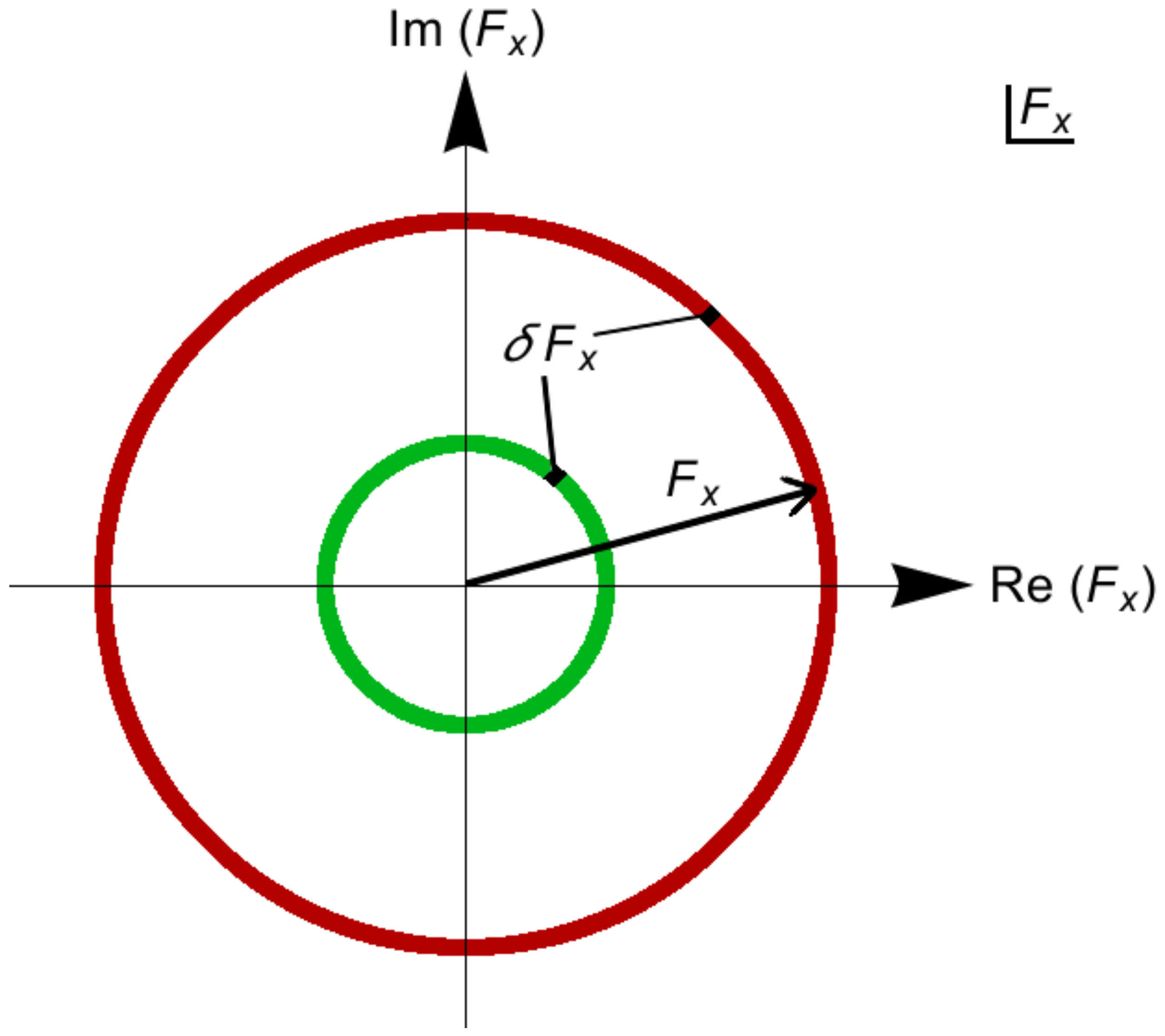
- likely impossible to find exact right compact space out of 10^500 possibilities
- instead, apply statistical techniques (M. Douglas et al.)
- $dN_{vac} \sim f_{SUSY}(m_{soft}) \cdot f_{EWSB} \cdot dm_{soft}$

# f_SUSY

$$f_{SUSY} \sim m_{soft}^{2n_F + n_D - 1}$$

Douglas; Susskind; ADK

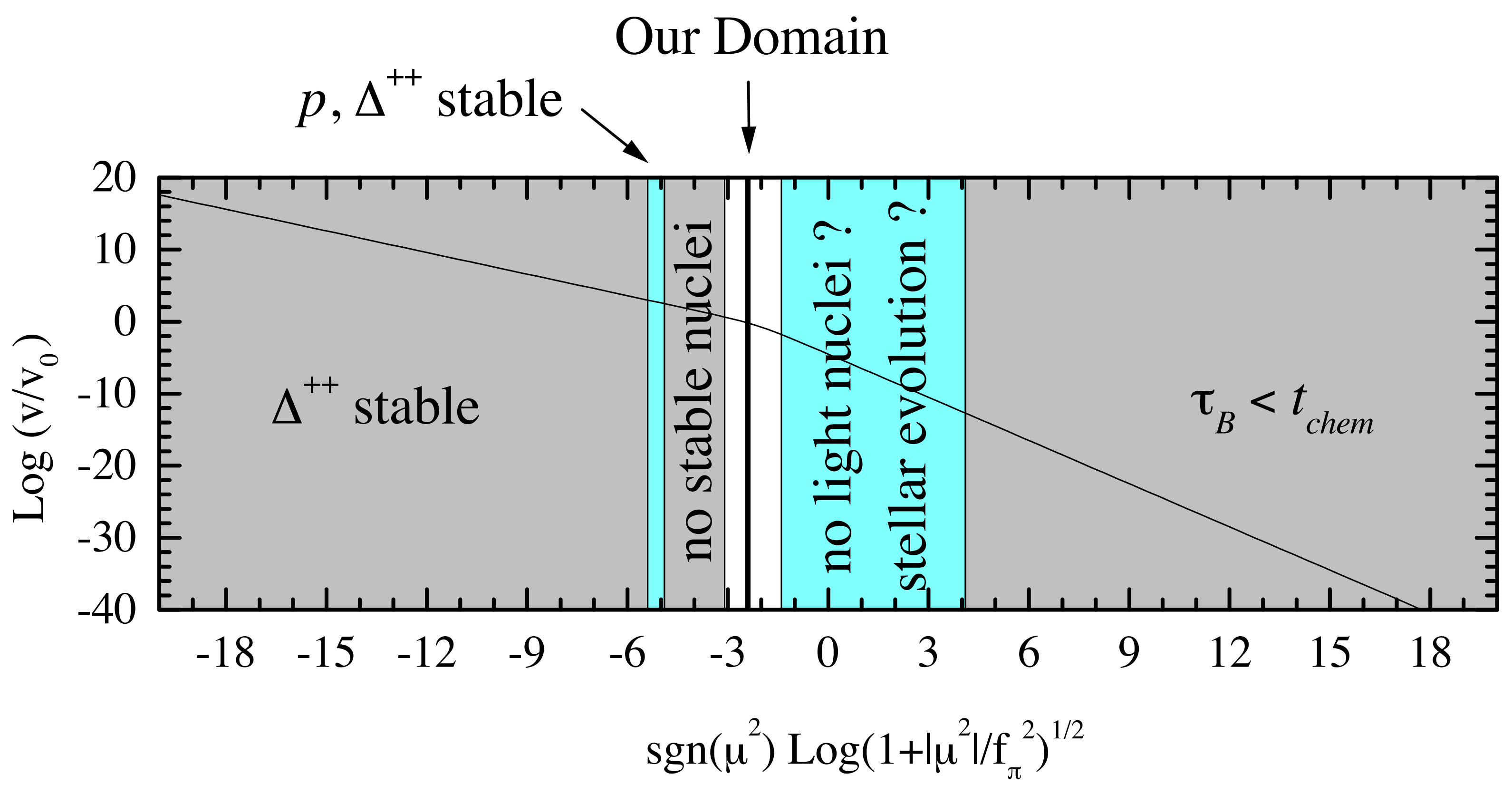
For textbook case of SUSY breaking via single F-term distributed uniformly as complex number, get linear draw to large soft terms




Also, n=1 seems to emerge from KKLT moduli stabilization (Broeckel et al.)

# f(EWSB): (anthropics)

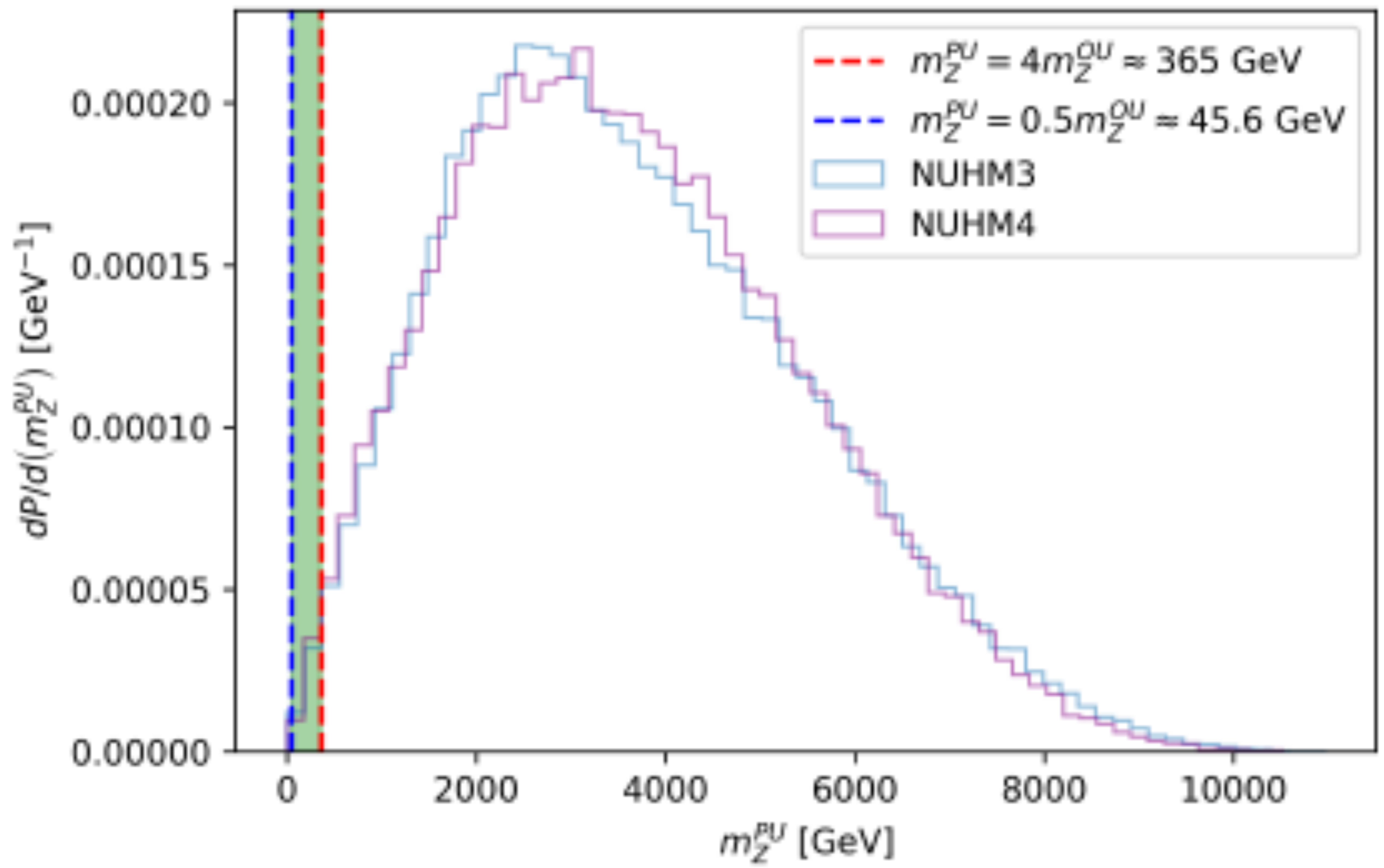
Agrawal, Barr, Donoghue, Seckel (ABDS) anthropic window:
if weak scale too big, no complex nuclei, no atoms (atomic principle)




magnitude of weak scale determined by SUSY-breaking soft terms:

$$m_Z^{PU2}/2 = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

# most important prediction of MSSM that you never heard of:




$$m_Z^{PU} <\sim 4m_Z^{OU} \Rightarrow \Delta_{EW} < 30\ (no\ finetuning)$$

# New DEW4SLHA code for Snowmass 2021

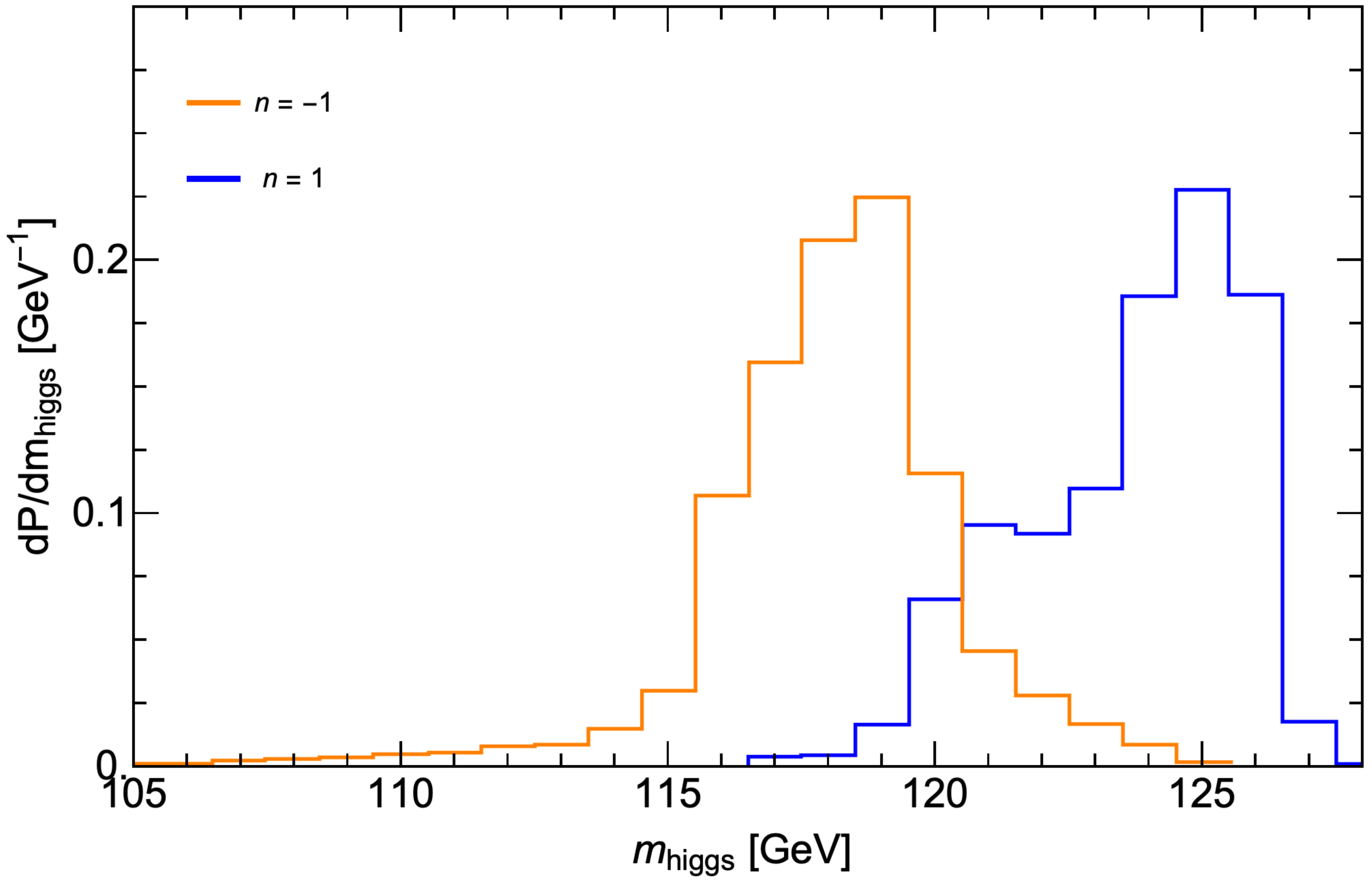
- To facilitate these types of calculations, my student Dakotah Martinez has developed a computer code DEW4SLHA in Python3 that reads any SUSY Les Houches Accord file (from e.g. SoftSUSY, SuSpect, Spheno, Isajet) and computes DEW along with top 40 contributions.

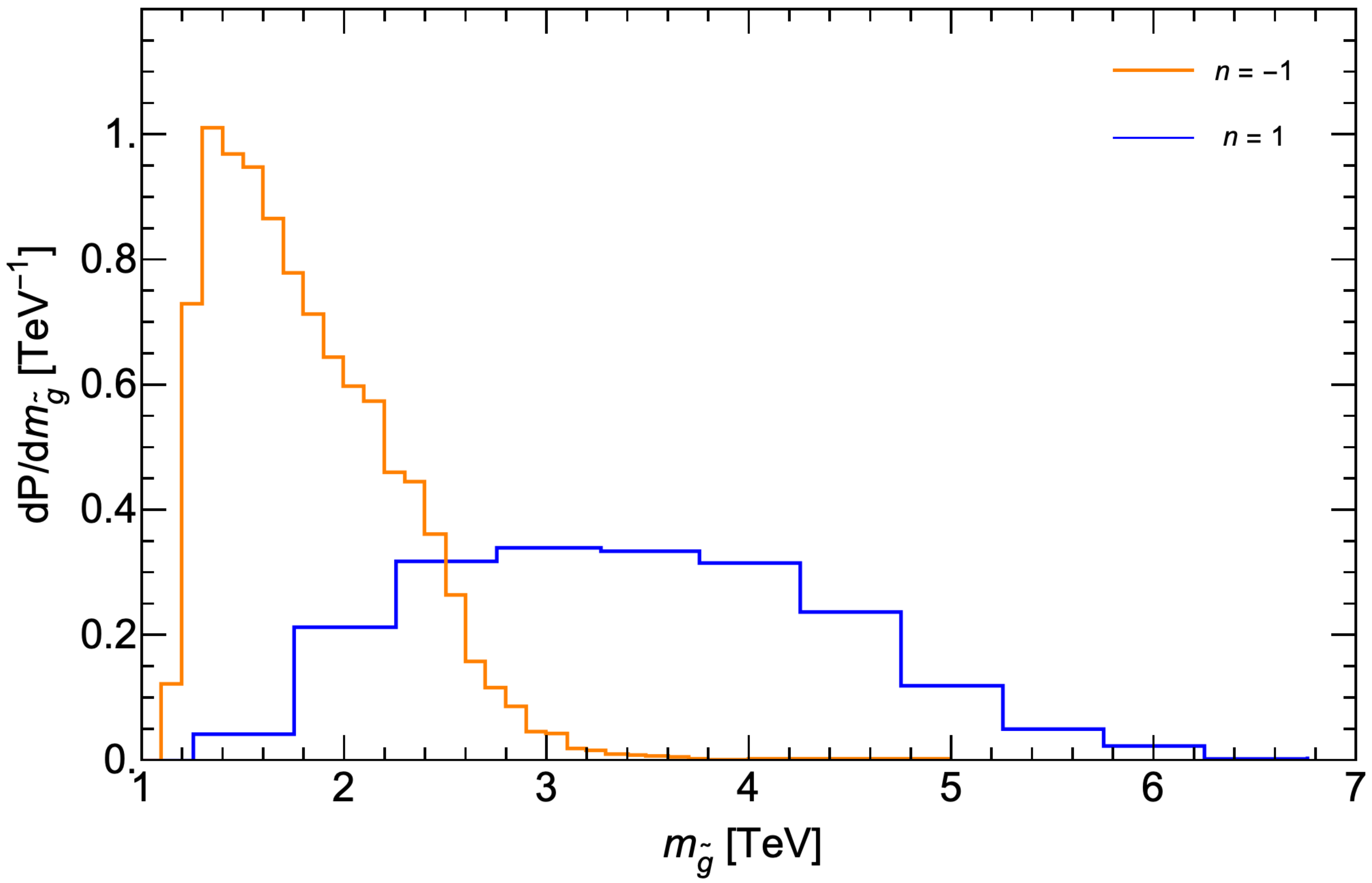
- The loop contributions Sigma_u^u and Sigma_d^d are listed in standard SUSY primer notation in appendix of arXiv:2111.03096

- Code also contains leading 2-loop terms involving mgl, mt1, mt2 from Dedes and Slavich, hep-ph/0212132.

- It is available at dew4slha.com

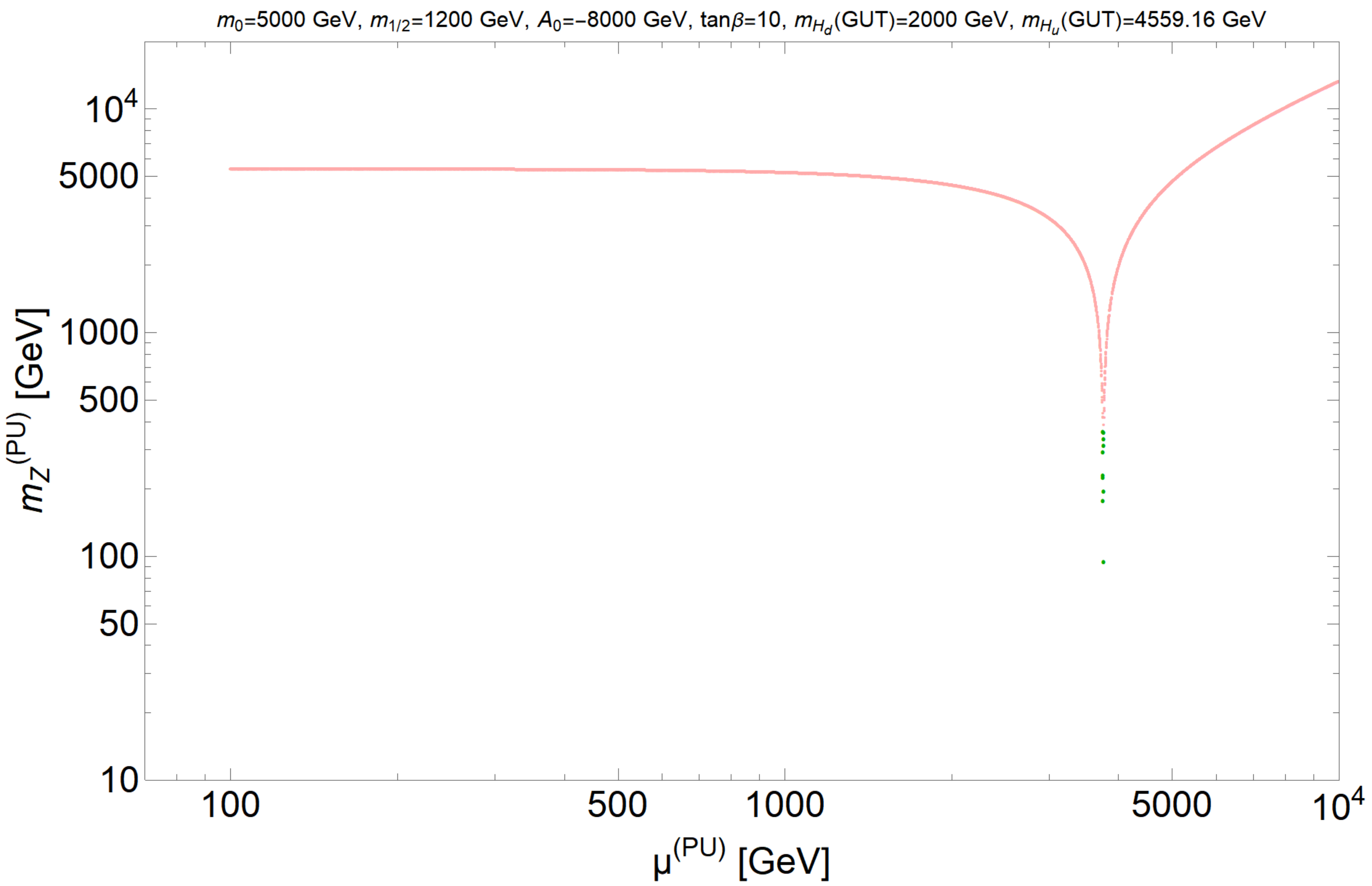
Combining prior+selection effects,
can simulate landscape selection of SUSY spectra
assuming fertile patch of landscape containing
MSSM as 4-d low energy effective theory



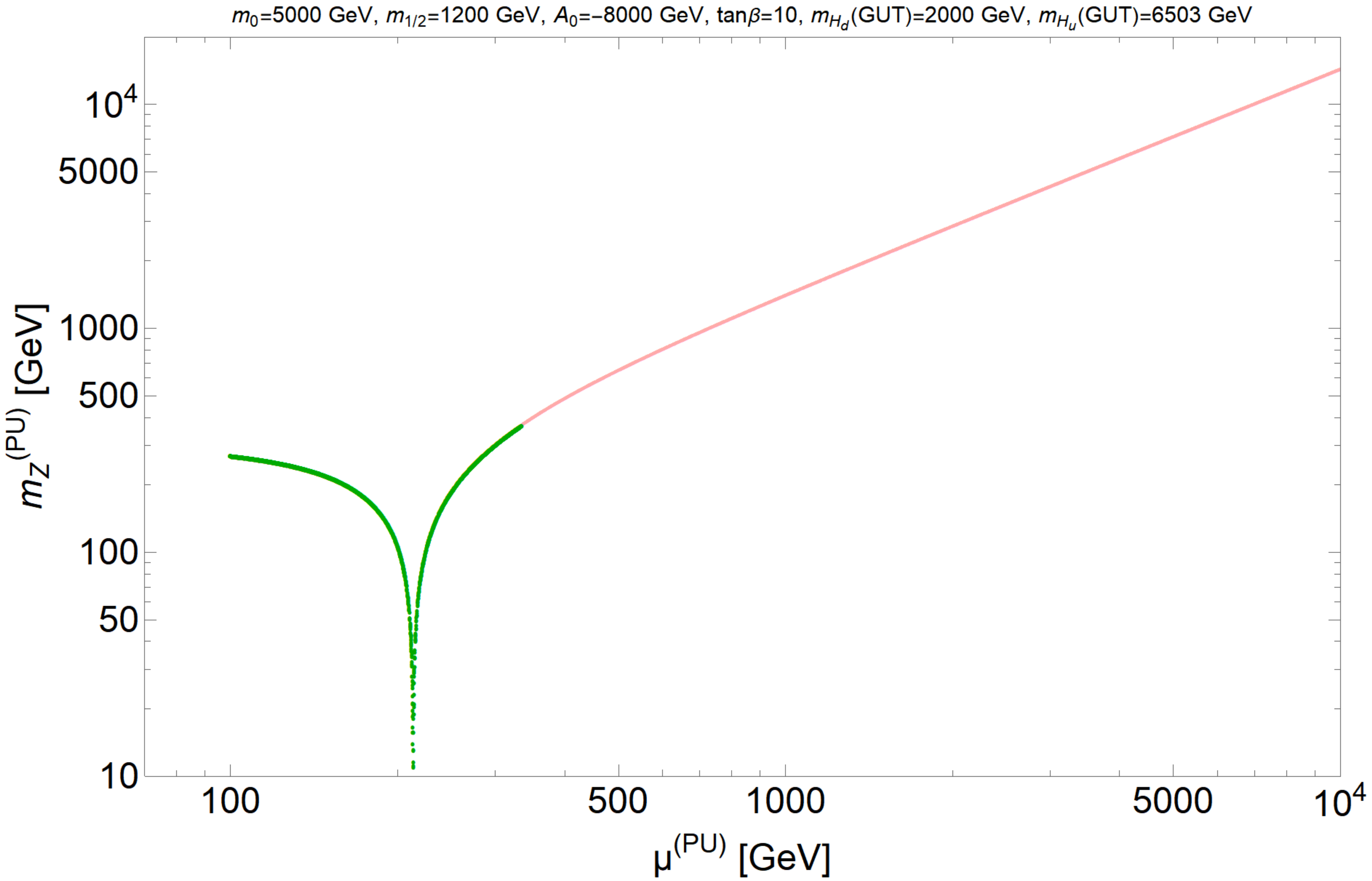




n=1,2 draw to large soft terms predicts m(h)~125 GeV
with sparticles typically beyond LHC reach

# why light higgsinos at LHC/ILC?




unnatural model: teensy hypercube
of p-space which lies in ABDS window




natural model: far bigger hypercube,
greater probability to lie within ABDS window

HB, Barger, Martinez, Salam, arXiv:2202.07046
Radiative natural SUSY emergent from string landscape

# summary

- string landscape => statistical predictions for CC, sparticle and Higgs masses
- for draw to large soft terms+ m(weak)^PU within ABDS window, get m(h)~125 GeV plus sparticle masses beyond LHC limits (stringy naturalness)
- developed code DEW4SLHA so anyone can compute DEW from SLHA file
- landscape => light higgsinos since heavy higgsinos require finetuning which means tiny hypercube of allowed p-space lying within ABDS anthropic window

# for physics at higgsino factory, see:

PHYSICAL REVIEW D 101, 095026 (2020)

**ILC as a natural SUSY discovery machine and precision microscope: From light Higgsinos to tests of unification**

Howard Baer,[1] Mikael Berggren,[2] Keisuke Fujii,[3] Jenny List,[2,*] Suvi-Leena Lehtinen,[4,2] Tomohiko Tanabe,[5] and Jacqueline Yan[3]

# why is mu distributed uniformly on log scale?

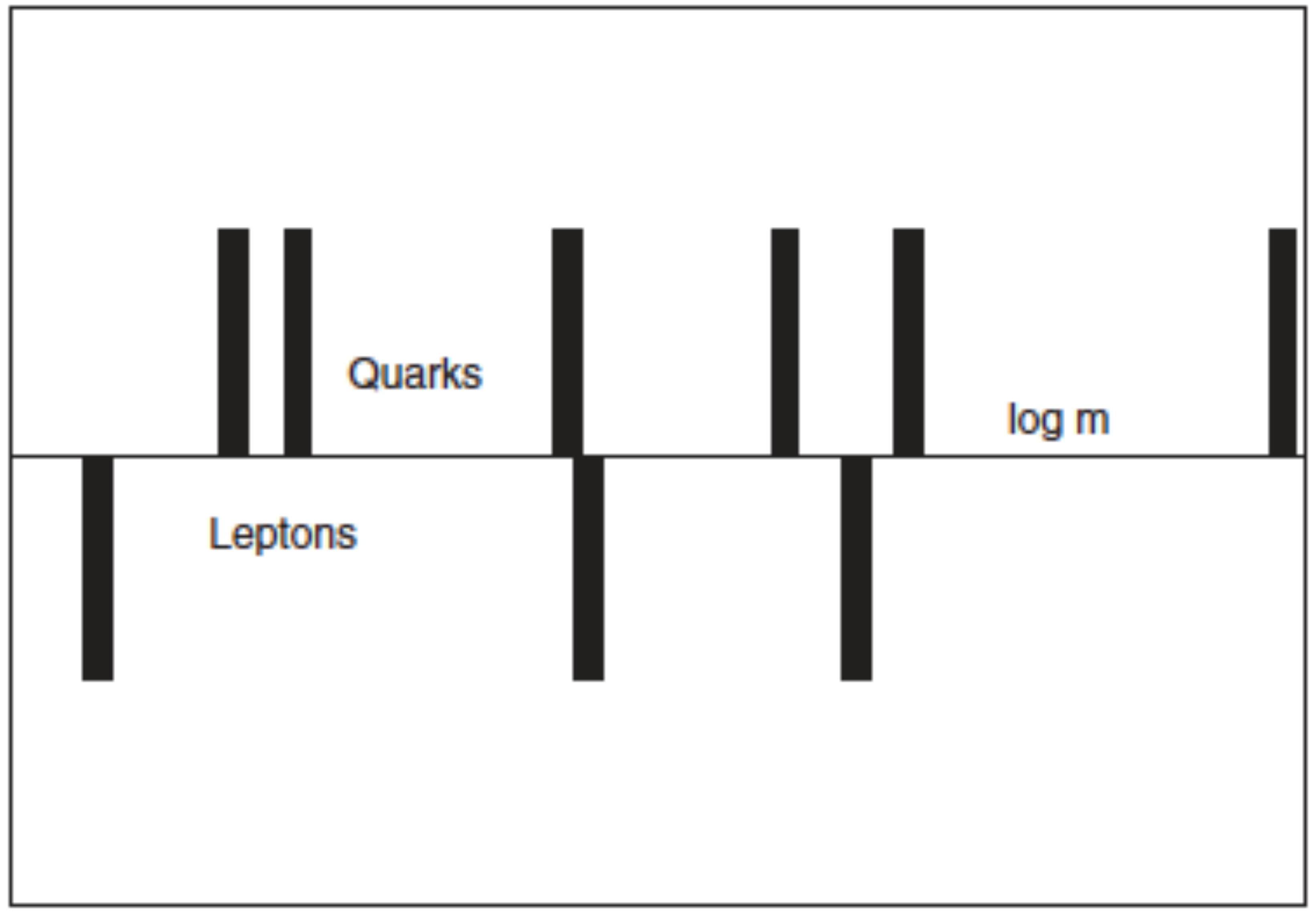



FIG. 1. Quark and lepton masses, defined at the energy $\mu = M_W$, on a logarithmic scale. A scale-invariant weight corresponds to a uniform distribution on this scale.

quark/lepton masses (hence Yukawa couplings)
appear uniformly distributed on log scale:
random accidents from landscape?

Donoghue et al, 2006

the most compelling solutions to
SUSY mu problem occur where
mu arises from superpotential:
Kim-Nilles solution to mu problem
and strong CP problem

here, mu arises from Yukawa term in superpotential;
also expect uniform distribution, hence

$$f_\mu \sim 1/\mu$$