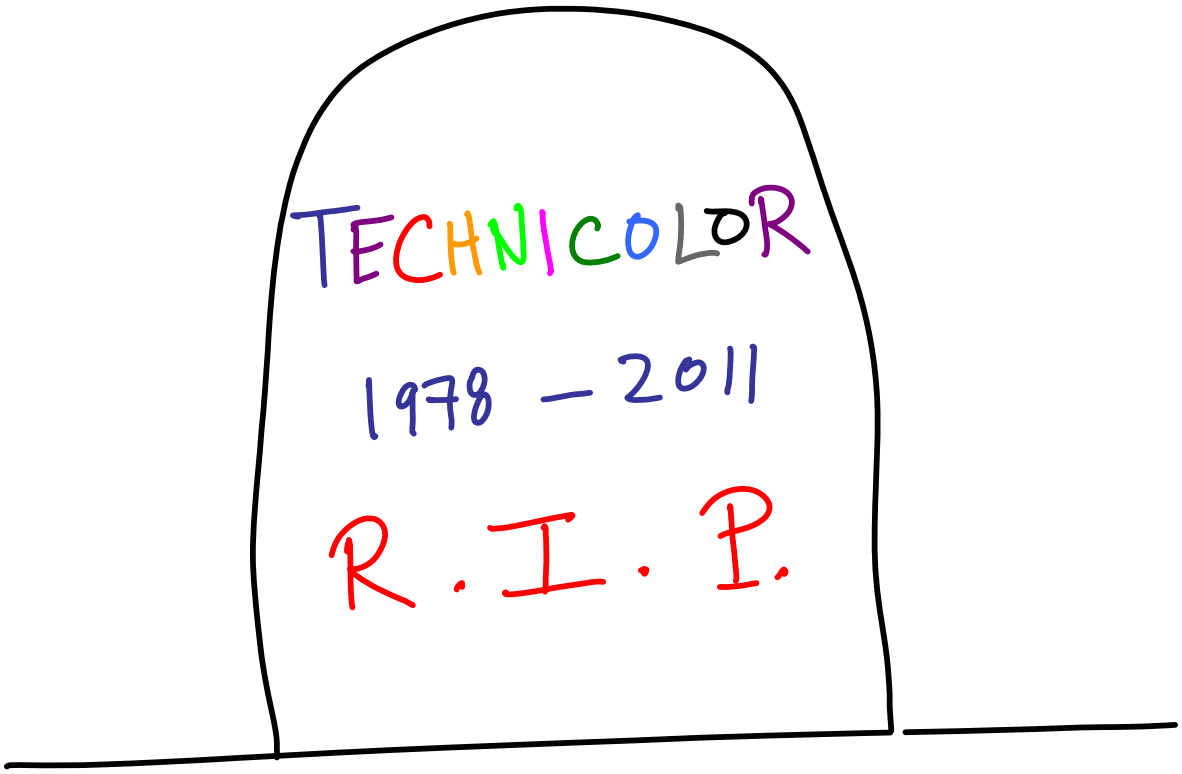
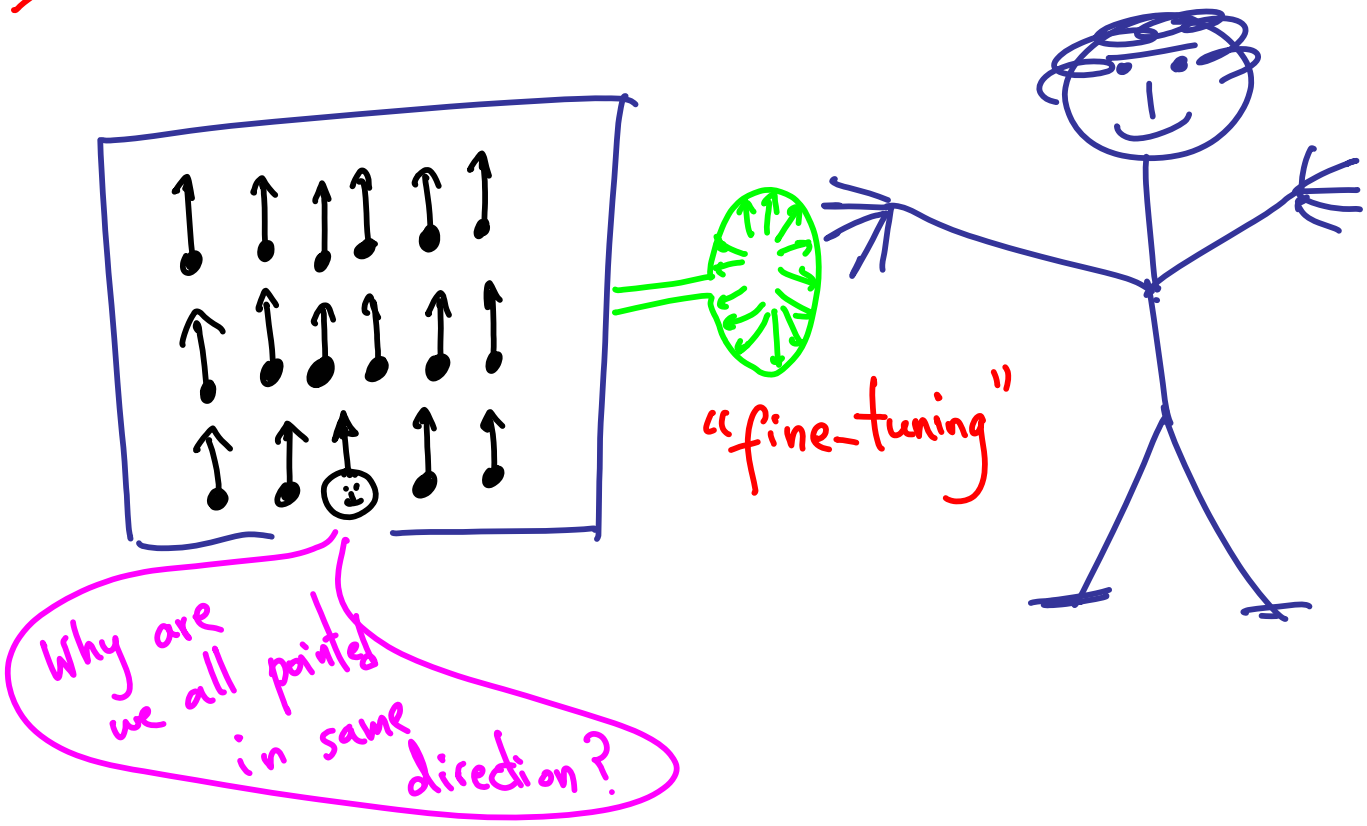
Implications of $m_H \sim 125$ GeV

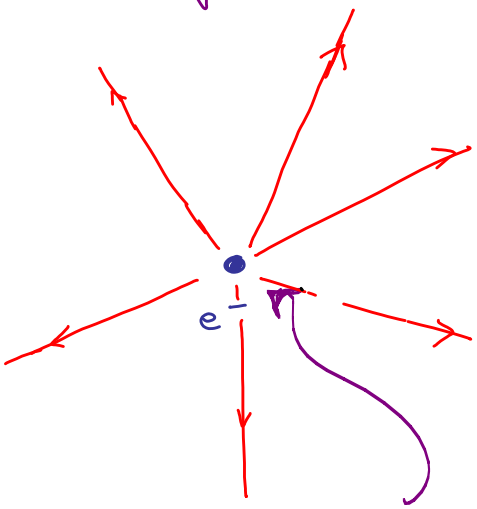
TRIUMPH OF WEAK COUPLING



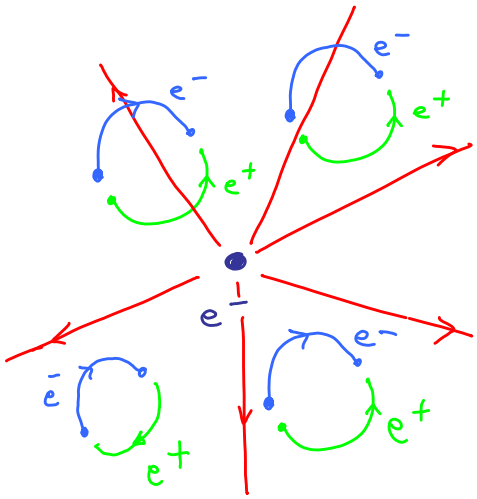
Never seen before in "state of nature"



Infinite Energy In Electric Field



Q.M.
Rel.

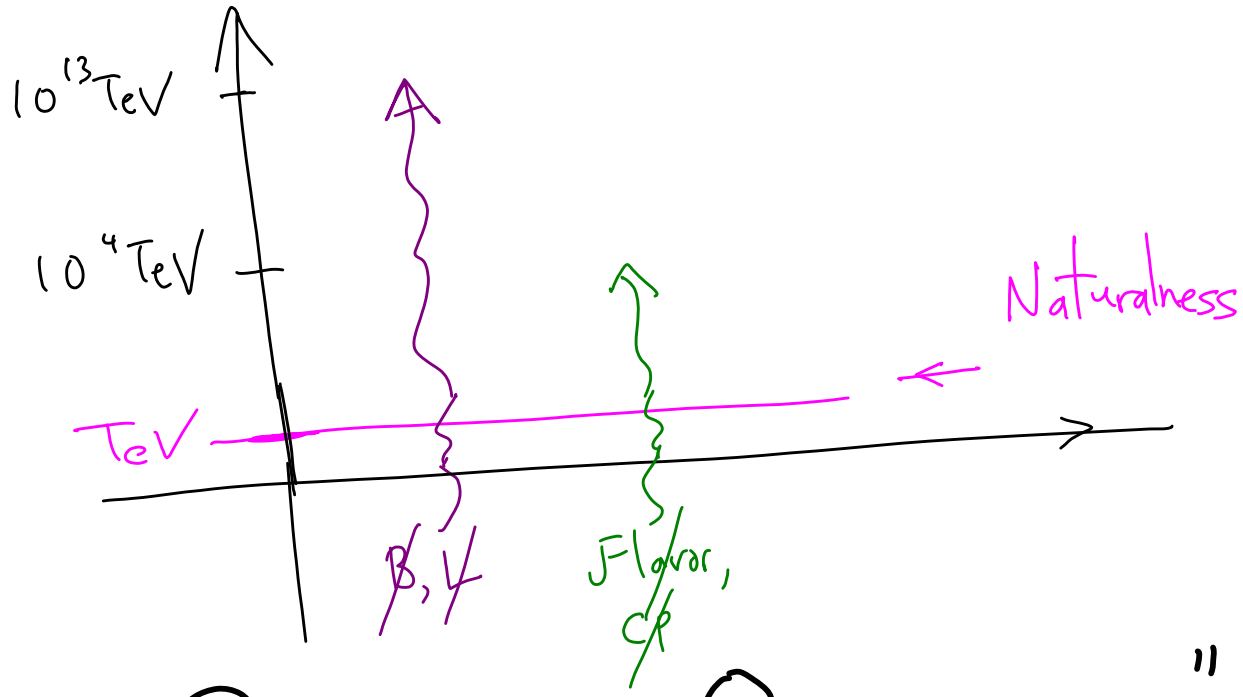


$$\frac{e^2}{4\pi a_{cl}} \sim m_e c^2 \Rightarrow a_{cl} \sim \frac{e^2}{4\pi m_e c^2}$$

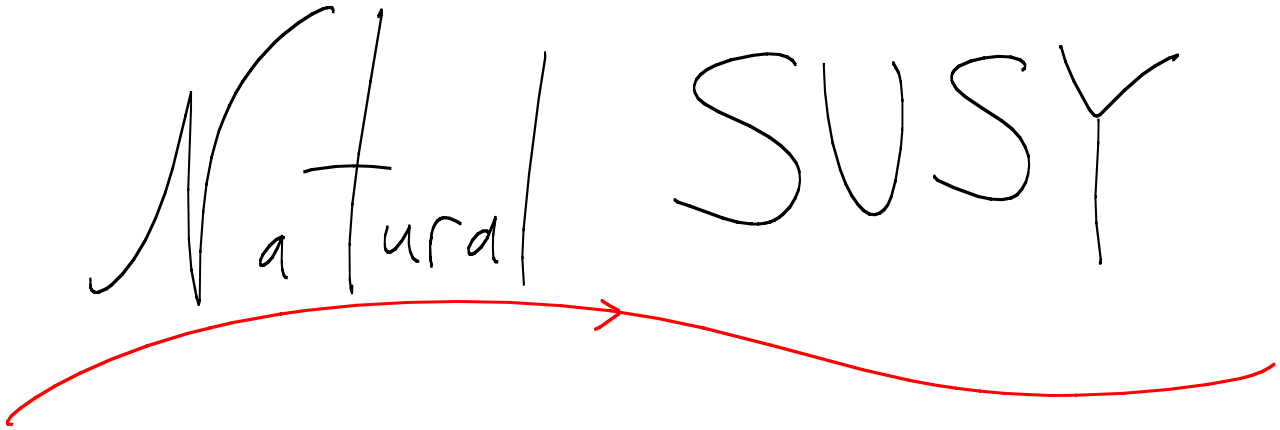
$$a_{compton} \sim \frac{\hbar}{m_e c}$$

$$\sim \left[\frac{e^2}{4\pi\hbar c}\right]^{-1} \times a_{cl} \; !$$

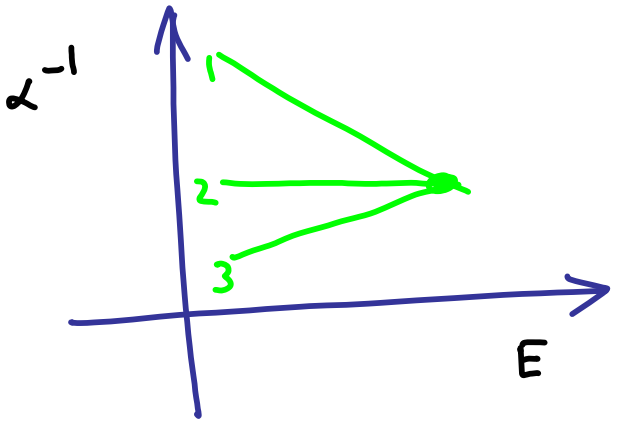
Tension Driving BSM Physics For 30 yrs



"Not Problems – Opportunities"


Natural SUSY

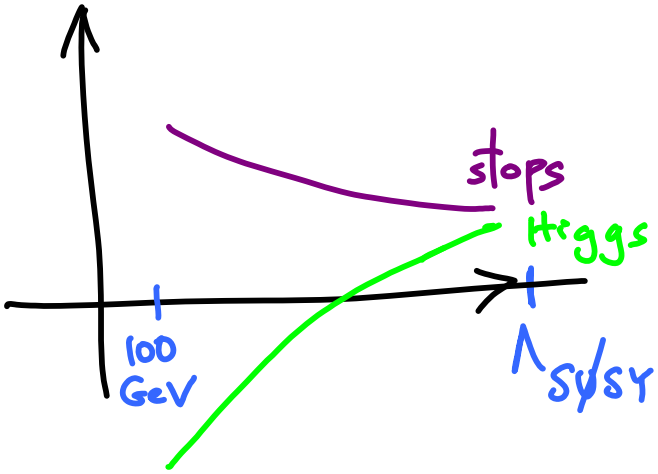
SUSY circa 1990

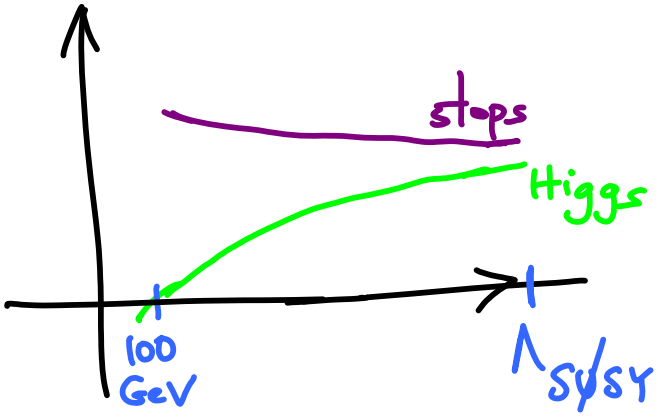


+ D.M.

SPECTACULAR

Why No SUSY @ LEP?





—— $Z, h, \tilde{t}, \tilde{g}$...

—— $\tilde{\ell}$, EWKinos

"Natural" Spectrum

?

↑

—— Z, h

"Nature-al" spectrum

• In the MSSM, a milder cousin of this problem is

$$M_h \lesssim M_Z + M_h^{\text{syst, stops}}$$

threshold + log-enhanced

With $m_h \sim 125$, this alone is a ~ 1% tuning @ best.

Non-dec F terms

$\delta\lambda\,|h|^4$

Non-dec. D terms

$W \supset \lambda S H_u H_d \to |\lambda|^2 |H_u H_d|^2$

$M_h^2 \sim (M_h^2)_{MSSM} + \frac{4|\lambda|^2 v^2}{t_\beta^2}$

$\downarrow$

$(115\ \text{GeV})^2$

$\downarrow$

Boost limited by UV

$\downarrow$

$(125\ \text{GeV})^2$

MSSM + $U(1)_X$

$M_h^2 \sim (M_h^2)_{MSSM} + \left(\frac{g_X^2}{g^2}\right) M_Z^2$

$\downarrow$

$(115\ \text{GeV})^2$

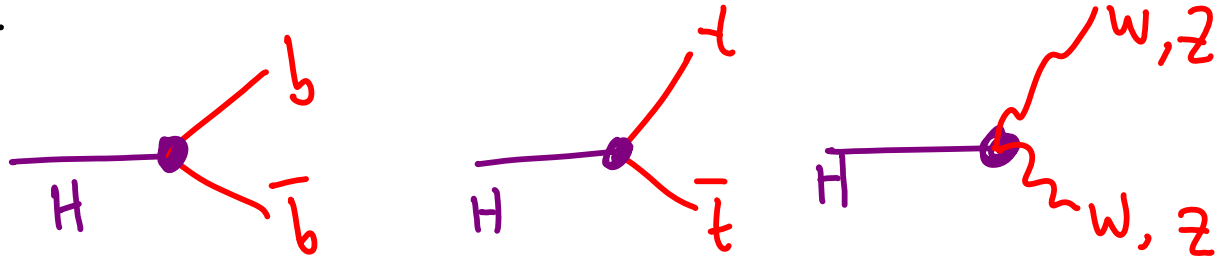
$\downarrow$

Boost limited by UV

$\downarrow$

$(125\ \text{GeV})^2$

{ A ~ 20% deviation in

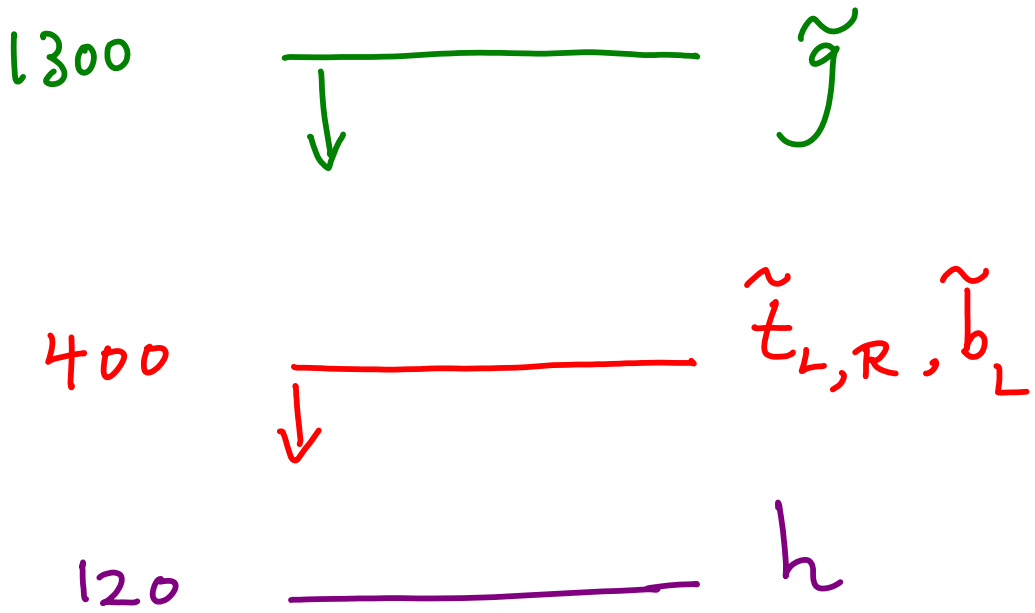


→ must have new, extra light states important for EWSB, aside from Higgs

→ HUGE support for Natural Theories!

Note: $m_H \sim 125$ GeV is pretty close to m_Z! SUSY is only theory where this proximity is reasonable, since $\lambda = g^2$. {For Higgs as PGB, λ_{top} sets potential, $m_H \sim 250$ GeV most reasonable}

Compulsory Natural SUSY



Unavoidable tunings: $\left(\frac{400}{m_{\tilde{t}}}\right)^2, \left(\frac{4 m_{\tilde{t}}}{M_{\tilde{g}}}\right)^2$

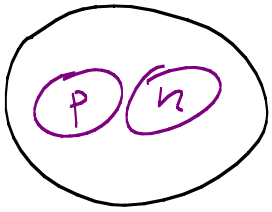
Minimally Split SUSY

or

"Don't Be Too Clever!"

Could the weak scale be tuned?

Next EFT down:

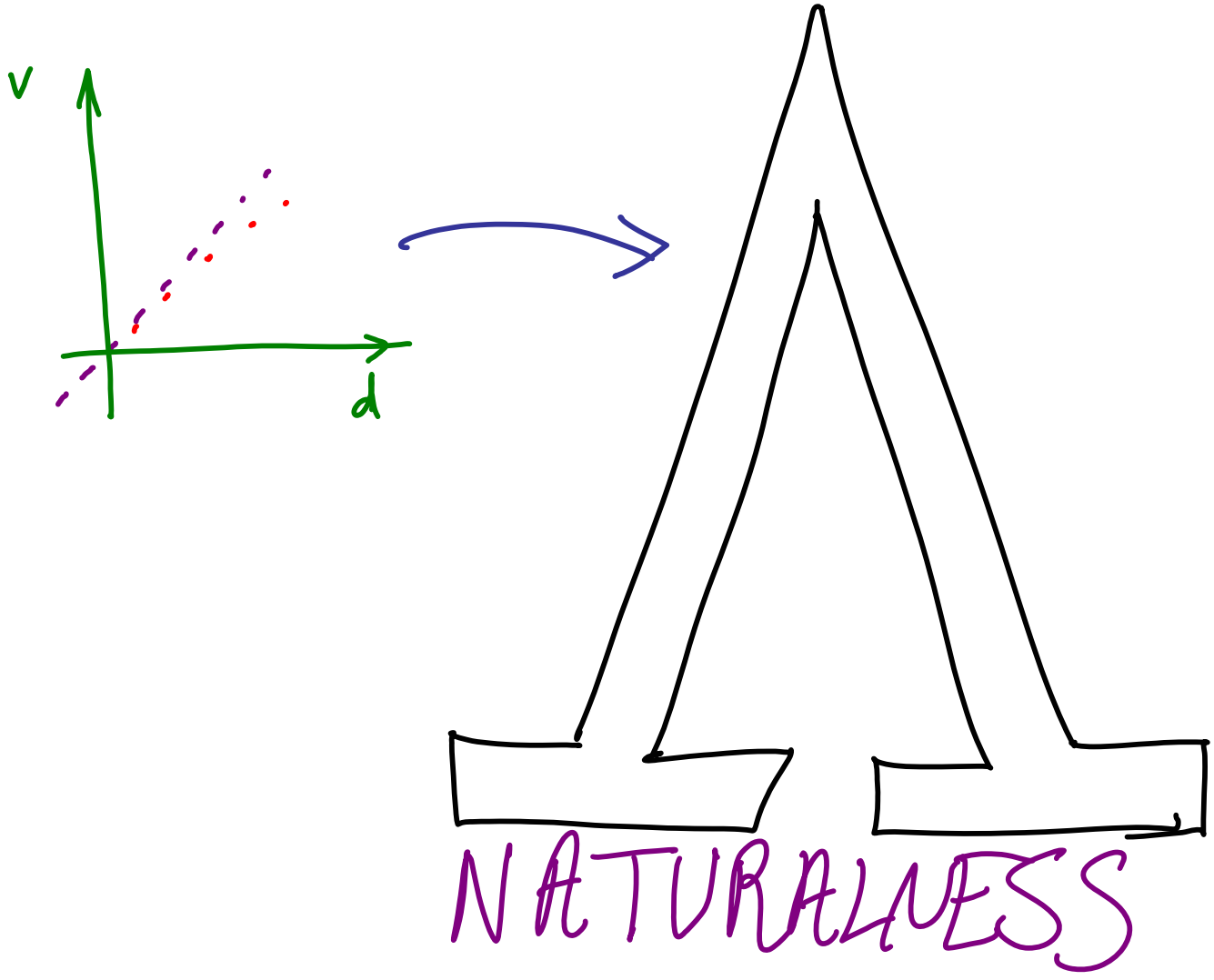


De binding energy
~ 2 MeV
1 in 20 tuning

Not bound by
60 keV (!!)

few in 1000 tuning

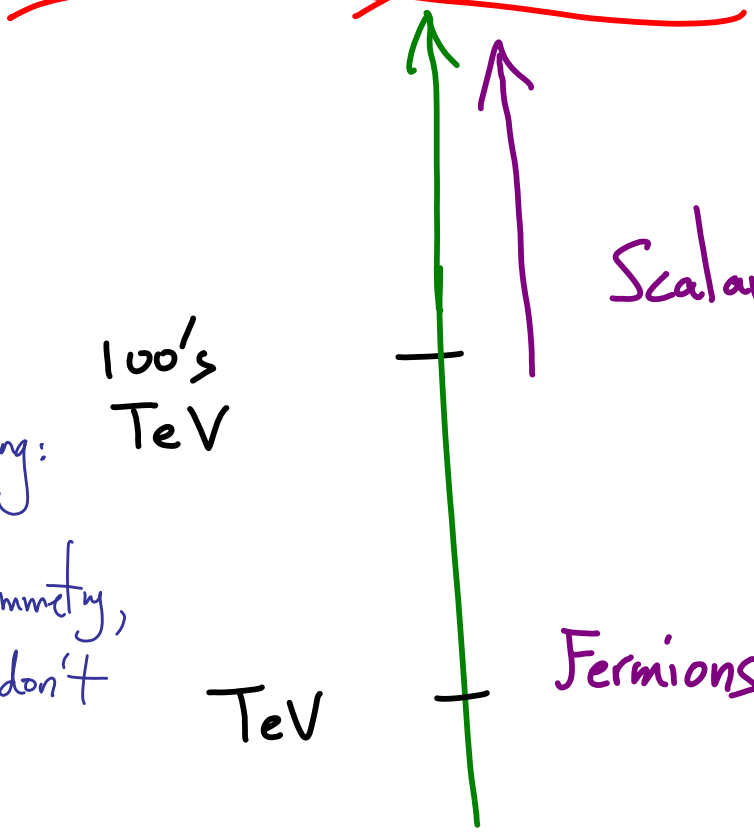
$\sim 10^{-4}$ tuning


v
d
NATURALNESS

Plausible anthropic tuning for weak scale: existence of atoms other than hydrogen

$(m_n - m_p) \gtrsim$ nuclear binding energies

Split Susy



Reason for splitting: fermions carry R symmetry, scalars don't

100's TeV

TeV

Scalars

Fermions

Unification ✓

Dark Matter ✓

NO Flavor, CP, moduli, ... problems

Indeed, a 1-loop splitting between gauginos + scalars was ubiquitous in simplest models of SUSY.

Modern guise: H.S. SUSY: Anomaly med.

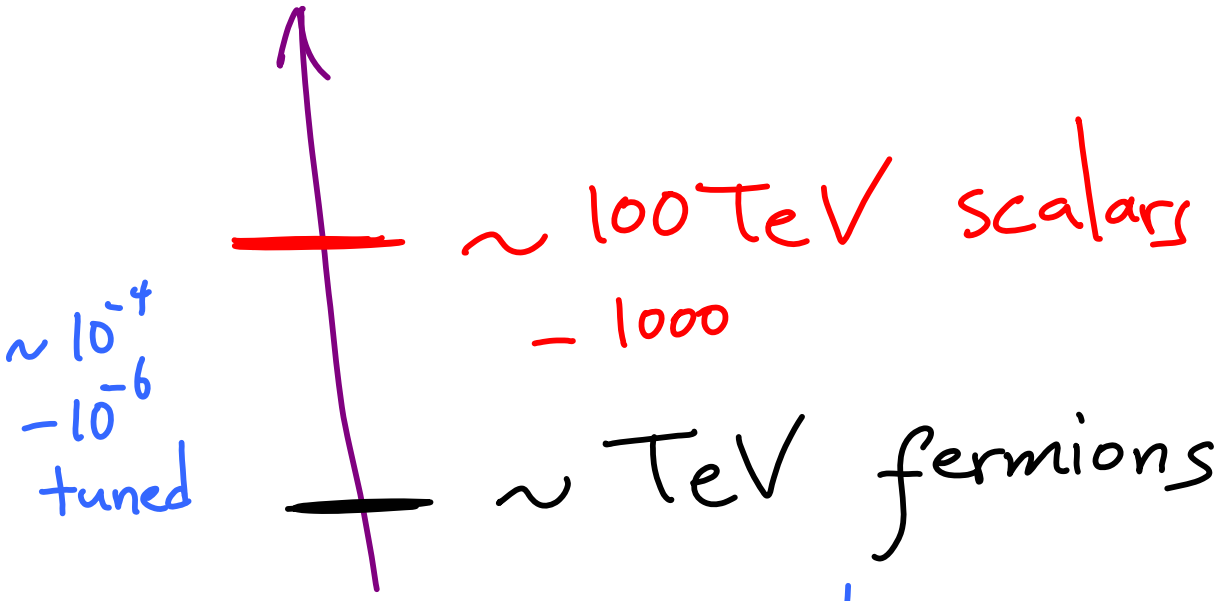
$m_\lambda \sim \frac{\alpha}{4\pi} m_{3/2}$

$m_S \sim m_{3/2}$

Unless you work!

["Not problem-opportunity"]

THIS SPECTRUM

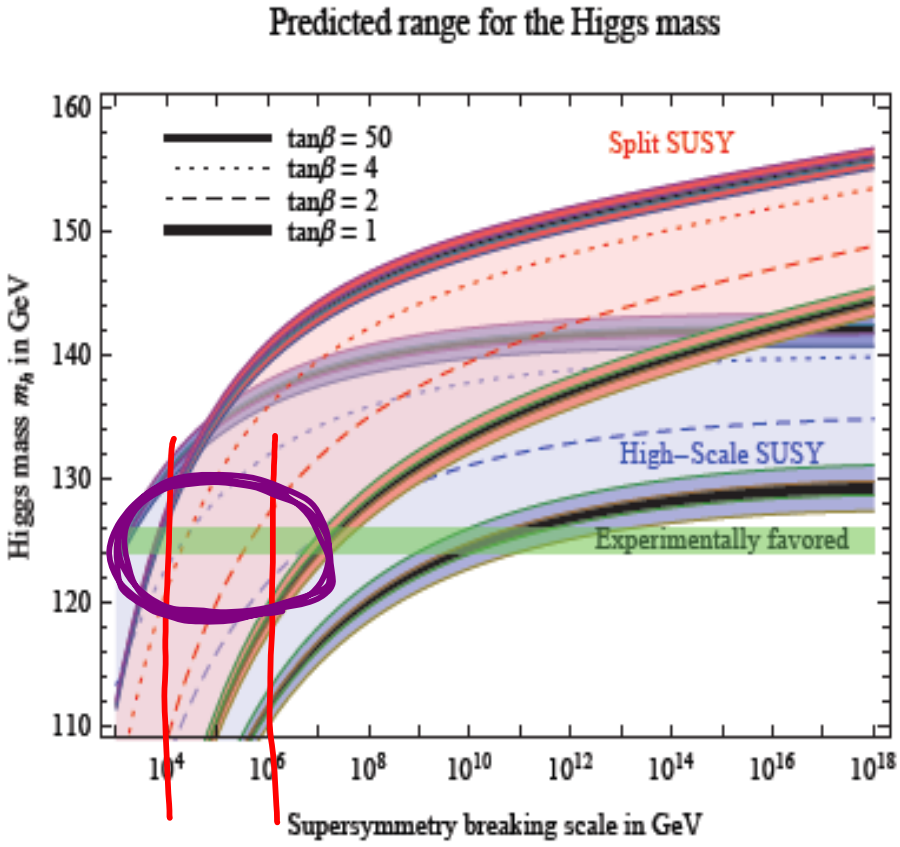


IS WHAT SUSY MODELS "WANT TO DO". LET THEM!

Simplest Split SUSY

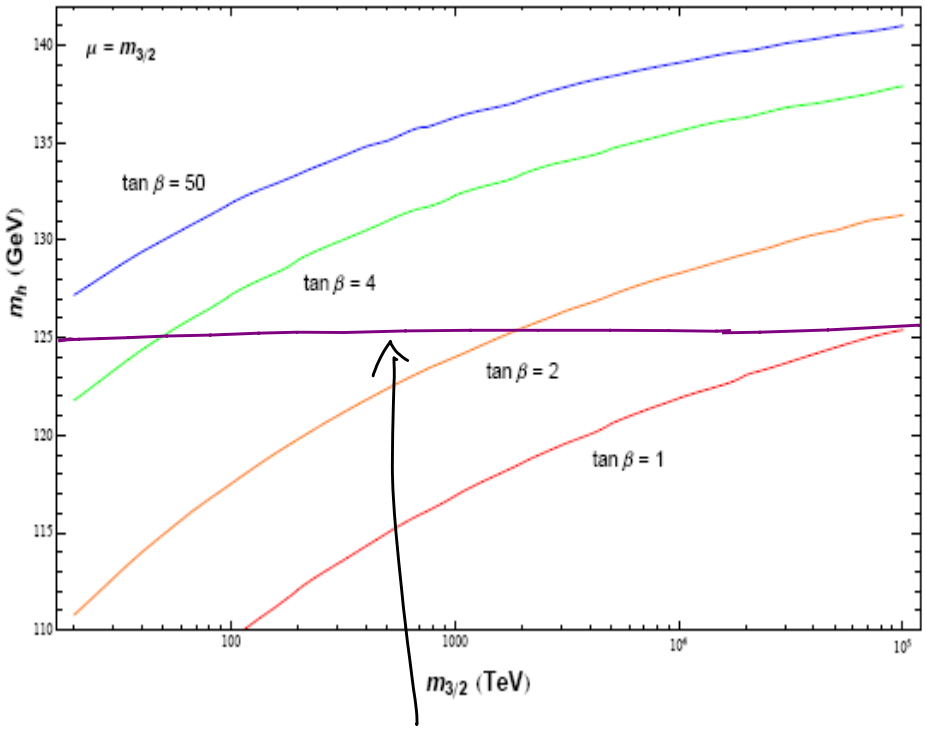
Also $\mu \sim m_S \sim m_{3/2}$ [Giudice-Masiero]

So only gluino, wino, bino light



[Giudice, Strumia]

Simplest Split SUSY



~1000 TeV stops, $\tan\beta \sim 3$ perfectly ok.

[Mindless Solution of Flavor Problem]

$M_h \sim 125$ GeV

Points to the most moderate "split" spectrum – with 10 – 1000 TeV scalars – which is also want SUSY "want to do".

[NOT most radical story with $m_s \gg 10^3$ TeV]

An Idea With a Long History

Early 80's: 1-loop split spectrum common in SUSY models

1999 : Giudice-Luty-Murayama-Rattazzi anom-med.
(not Randall-Sundrum version, no sequestering!)

Split Spectrum thought of as embarrasment

2003 : J. Wells "PeV-scale SUSY"

2004 : NAH + Savas, Giudice + Romanino "Split SUSY"

2006 : NAH, Delgado, Giudice "Simplest Split SUSY"

⋮ Many Others

The Obvious Worry

"WIMP miracle" relic could mean

$m_{\text{Higgsino}} \sim 1\,\text{TeV}$ or $m_{\text{Wino}} \sim 3\,\text{TeV}$.

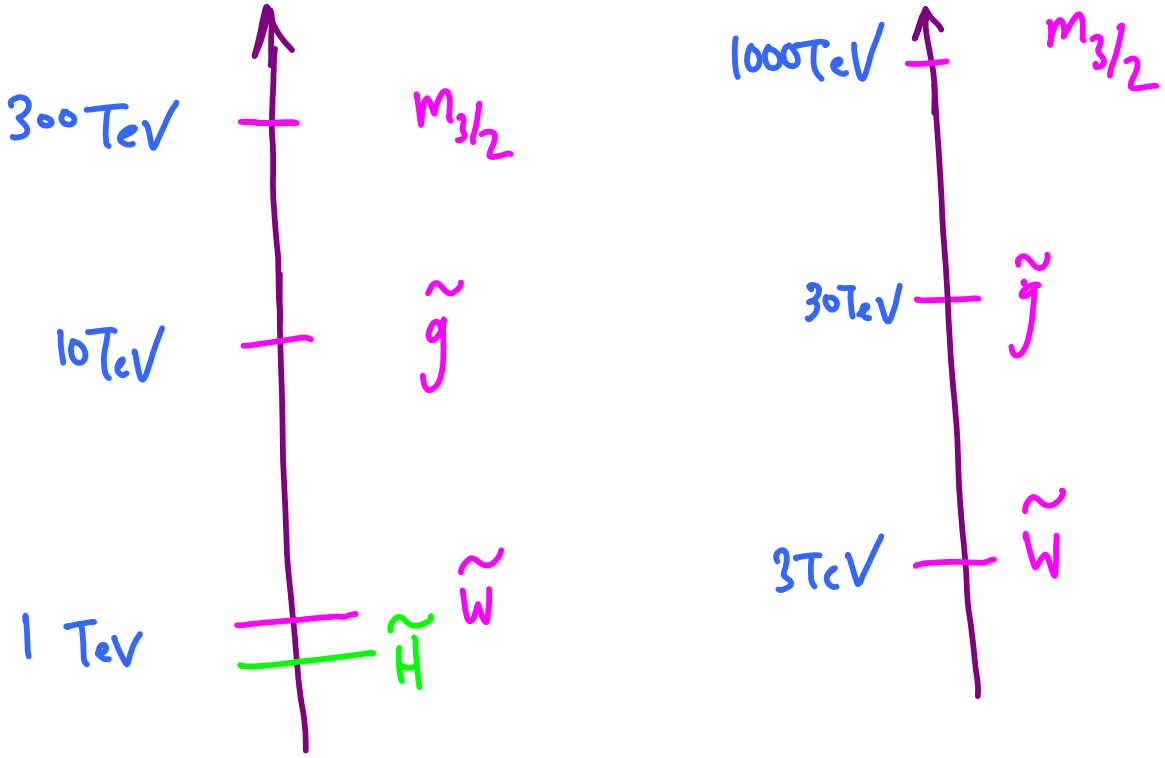
Won't ever see even fermionic superpartners.

(A) Could still be "well-tempered" relic, lighter OK.

(B) Relic could constitute part of DM [rest, say, axions] → lower bottom of spectrum.

(C) Moduli near ~ 100 TeV decay late, dilute initial abundance [+ largely solve axion overclosure problem!], repopulate DM still favors light $\lesssim$ TeV LSP.

"Standard" Anomaly Mediation



SUSY Vector-Like Masses

$$\int d^4\theta\ \phi^\dagger\phi\left(F^\dagger F + F^{c\dagger}F^c\right)$$

$$+\int d^2\theta\ \phi^3\ M F F^c$$

$$\Big\downarrow$$

$$\int d^4\theta\ F^\dagger_{can} F_{can} + \int d^2\theta\ (\phi M) F^c_{can} F_{can}$$

$\left(\frac{B\mu}{M}\right) = +m_{3/2}$, keep on anom-med trajectory

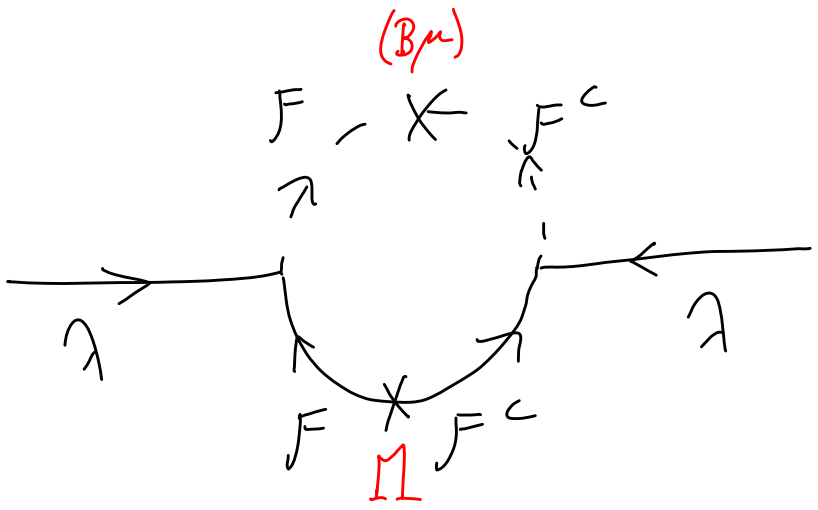
G-M Vector

$$\int d^4\theta\ \phi^\dagger\phi\left[F^\dagger F + F^{c\dagger}F^c + \lambda F F^c + h.c.\right]$$

$$\Big\downarrow$$

$$\int d^4\theta\ F^\dagger F + F^{c\dagger}F^c + \left(\frac{\phi^\dagger}{\phi}\right)\lambda F F^c + h.c.$$

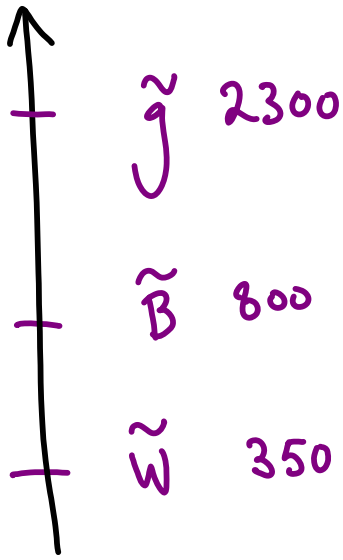
$\left(\frac{B\mu}{M}\right) = -m_{3/2}$, off anom-med trajectory



$\left(\frac{B\mu}{M}\right) = m_{3/2}$ LE m_λ's UV insensitive

$\left(\frac{B\mu}{M}\right) \neq m_{3/2}$ Big Change to Anom-med Spectrum

"Simplest" Split SUSY

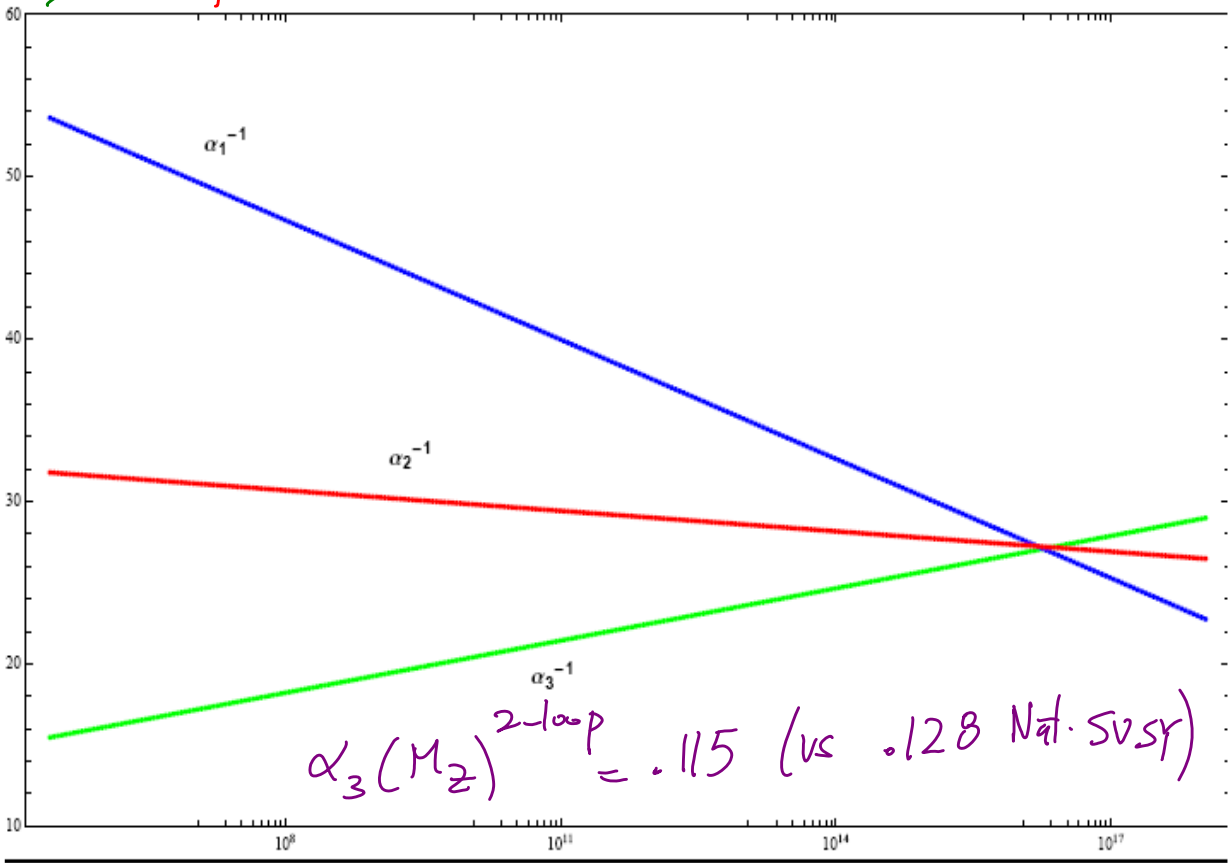


$\mu = m_{3/2} = 100\,\text{TeV}$

$\{\tan\beta \sim 4,$

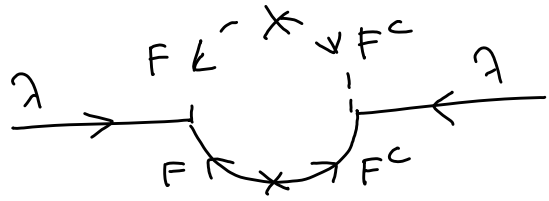
$m_H \sim 125\,\text{GeV}\}$

Unification a Bit Better than Natural SUSY



$\alpha_3(M_Z)^{2\text{-loop}} = .115$ (vs .128 Nat. SUSY)

Additional GM $(5+\bar{5})$'s



N	tan β	m_s (TeV)	$m_{3/2}$ (TeV)	$\mu(TeV)$	M_1 (GeV)	M_2 (GeV)	M_3 (GeV)
0	4.0	80	80	80	802	377	2394
1	2.8	300	75	300	974	773	779
2	3.0	100	80	100	1307	1377	1478
3	2.7	250	50	50	945	1113	1951
4	2.7	250	50	50	1094	1409	2955
5	2.9	150	30	30	742	1025	2457

$\alpha_s(M_Z)$ = .106 −.107

Can Get Quite Compressed Spectra!

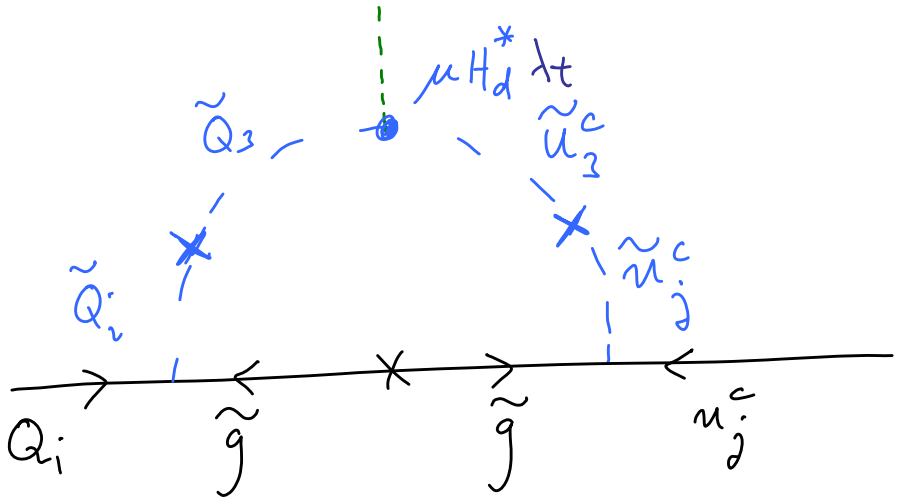
Values of $tan\beta$ and scalar mass m_s chosen to yield higgs mass of 125 GeV; $m_{3/2}$ is gravitino mass, messenger scale $M = \lambda m_{3/2}$, GM term coupling λ chosen such that $M = m_s$.

More Optimistic for LHC Discovery

Some Comments on Flavor

Naturalness' Loss = Flavor Gain

Generic Soft Masses → Need For Split Spectrum



Way too big unless split spectrum!

$$\delta\lambda_{up}^{ij} \sim \lambda_t\left(\frac{\alpha_s}{\pi}\right)\left[\frac{\mu m_{\tilde{g}}}{m_s^2}\right] \sim 10^{-2}\times\left[\frac{\mu m_{\tilde{g}}}{m_s^2}\right]$$

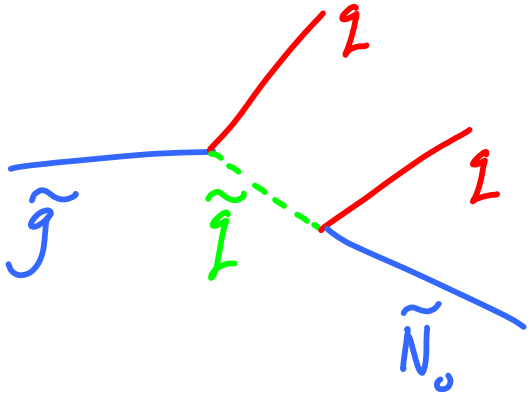
. With $\mu \sim m_S$, $m_{gaugino} \sim \alpha m_S$,

theories of radiative fermion masses are easy to build! SUSY was always crucial for this idea — naturalness made it incredibly hard — minimal split makes it easy!

L·H·C Signals, Smoking Guns

"How can we probe higher scales?"

Possible smoking gun for heavy scalars:



Long lived gluino:

visible displaced vertex

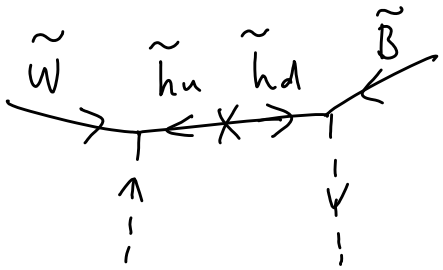
$$m_{\tilde{q}} \gtrsim \left(\frac{\Delta m}{1\,\text{TeV}}\right)^{5/4} \times (400\,\text{TeV})$$

Note that with scalars around ~ 100's TeV, displacements in the 100's μms → cm's are expected. Interesting Challenges to see them.

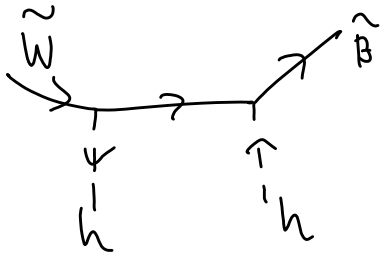
Ewk Production

- With gauginos + higgsinos light, usual multilepton + MET searches
- Extremely constrained + simple story for simplest split:

* Only interactions between $\tilde{W}, \tilde{b}$ from higher-dim ops:

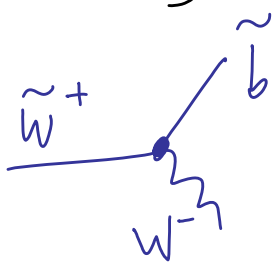


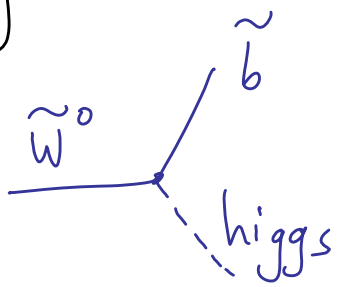
$$\frac{g^2 (h^\dagger \tilde{W} h)\,\tilde{B}}{M} \qquad \text{dim } 5$$

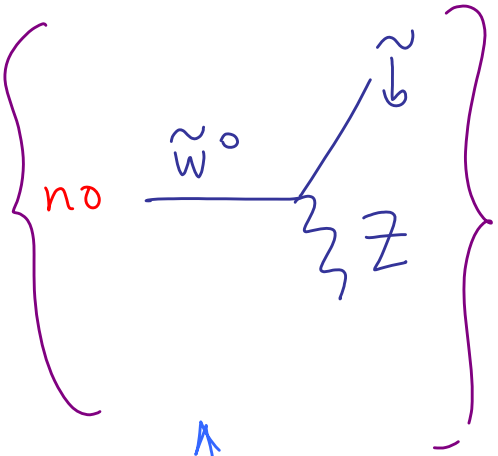


$$\frac{g^2 (h^\dagger \overleftrightarrow{D^\mu} h)\,\bar{\tilde{W}}\,\bar{\sigma}_\mu\,\tilde{B}}{M^2} \qquad \text{dim } 6$$

Leading couplings



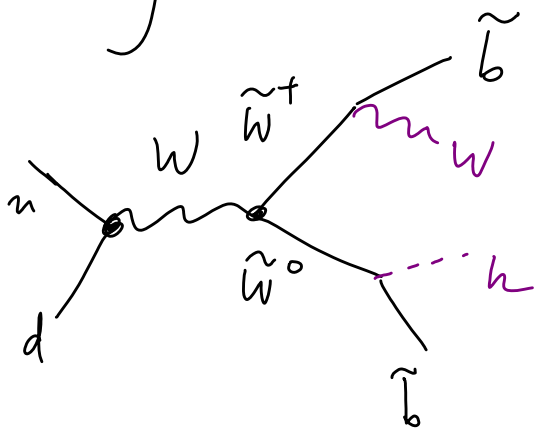




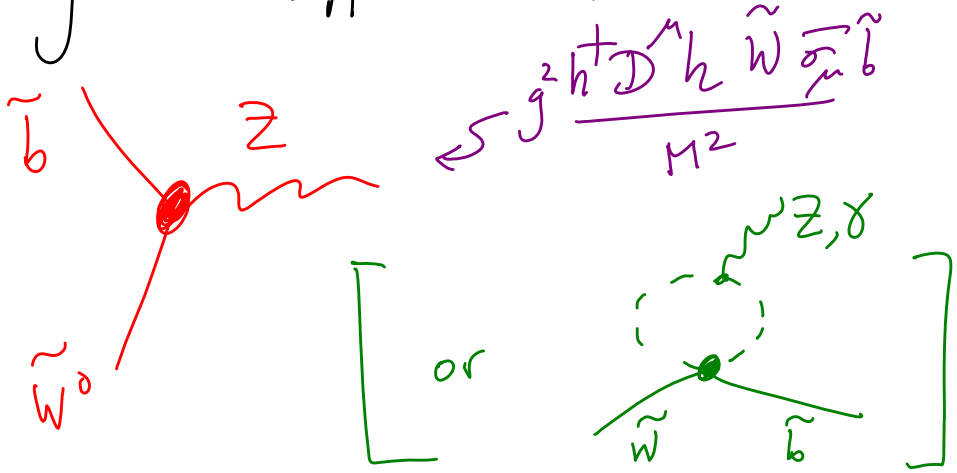
[$\tilde{w}^+ / \tilde{w}^0$ nearly degenerate]

Fingerprint of Heavy Higgsinos!

Only direct EWK production:



Measuring tiny Br for $\tilde{b} \to \tilde{W}^0 Z$ (or $\tilde{W}^0 \to \tilde{b} Z$) is direct probe of dim 6 op, which goes as $1/M^2$ not $1/M^4$!



$$Br\left[\tilde{W}^{0} \rightarrow \tilde{b} Z\right] \sim \left(\frac{m_Z}{M}\right)^2$$

↓

Probes heavy Higgsino, directly tuning

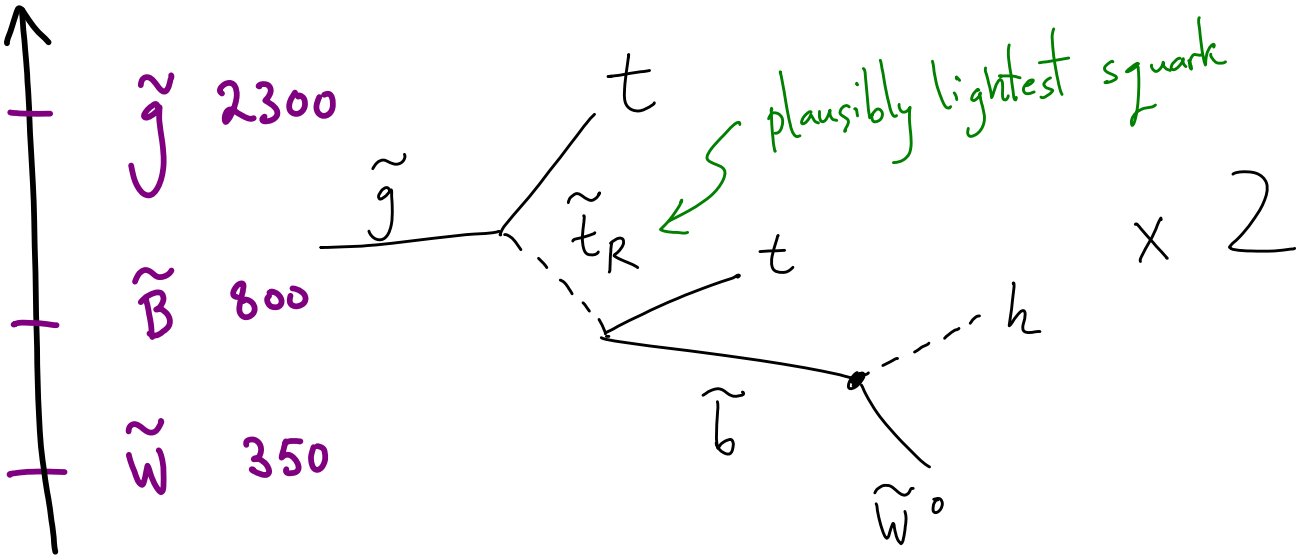
What about

$$g^2 \frac{(h^\dagger \tilde{h}_u)(h h_d)}{M} \rightarrow \text{Splits } \tilde{h}^+, \tilde{h}^0$$

$$\Delta m \sim \left[\alpha M_Z + c \frac{M_Z^2}{M} \right]$$

$$\Gamma \propto \Delta m^5 \,, \quad \Gamma^{-1} \sim 10\,\text{cm}!$$

Deviation $\Rightarrow M_{\tilde{W},\tilde{b}} \lesssim \alpha^{-1} M_{\tilde{h}}$



$\Rightarrow$ 8 b's, 4 W's [+ perhaps displacement]!

in every event!

Finding any deviation in $\sigma \times Br$ for the Higgs, would instantly demolish this picture.

As many people have remarked,

$m_H \sim 125$ seems almost

maliciously designed to prolong the

agony of BSM theorists ....

HIGH DRAMA FOR 2012

- ☆ Higgs $\sigma \times Br$ [+ confirmation !!]
- ☆ Stops
- ☆ Pushing Gluino limits to 1 TeV in SS leptons + b's searches
- ☆ Multileptons

. . . .

The Stakes Are Very High

$M_H \sim 125$ GeV

11th hour naturalness (remember COBE!)

Somewhat elaborate

Un-natural

Simple

(Even minimal split is dramatic tuning!)