The ABC of SUSY:

Models, Parameters and Acronyms

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The ABC of SUSY

- The parameters in the MSSM Lagrangian:

  A, B, C, ... , CMSSM

- Patterns in parameters from experiment?

  FCNC, CP, DM, ...

- Why these patterns? Mediation scenarios:

  PMSB, GMSB, AMSB, ...

- `Advanced topics': what if not standard pattern?

  BMSSM, CS, ...

The ABC of SUSY

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  BMSSM, CS, ...

Concrete questions for scans

- Global fit

a) maybe MSSM fits existing collider data,

e.g. $(g-2)_\mu$ better than SM itself?

(Probably not.)

b) assume MSSM gives WIMP that explains

DM data by itself, fit to e.g. WMAP

not obvious (to me) how to pose prior on neutralino giving 100% of DM, since other combinations possible in MSSM: e.g. 50% axion, 50% neutralino, or gravitino LSP

Concrete questions for scans

- Global fit

c) priors on ranges, e.g. superpartner masses

lower limit: not much of an issue

(all models excluded if set low enough)

upper limit: no real solution to *hierarchy problem* as superpartners get heavier (e.g. beyond 10 TeV) – finetuning problem

But: in scans you allow finetuned values!

e.g. “sneutrino corridor” (LEP chargino bound) , ...

Concrete questions for scans

- Theory vs. experimental constraints

d) "dangerous" couplings that are perfectly allowed in the MSSM, e.g. off-diagonal A-terms, are often set to zero, but really only restricted by experiment to 1/1000 of the diagonal value or so.

Would maybe make more sense to scan over at least some small range, then impose accelerator bounds
– but perhaps this is not too urgent.

Concrete questions for scans

- Modelling (fake) future data

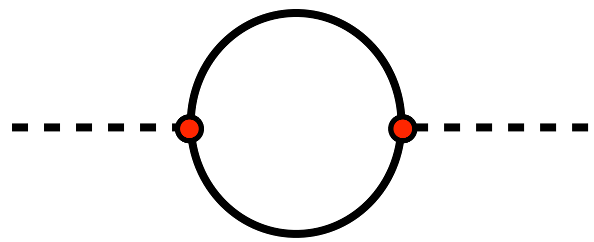
  let's say we see WIMP at XENON 1 ton

  and perhaps some hints at LHC

  - SM won't fit
  - Maybe MSSM will fit
  - Maybe fit will favor more restricted SUSY model (mediation scenario)
  - Maybe we will need more general SUSY model to fit well at all (beyond MSSM models)

Supersymmetric Lagrangians

Quantum (loop) corrections:



scalar mass gets quadratic dependence on cutoff Λ

- very sensitive to physics at very high scales,

  e.g. $\Lambda \sim M_P \sim 10^{18}\,\mathrm{GeV}$

- "technical naturalness" problem

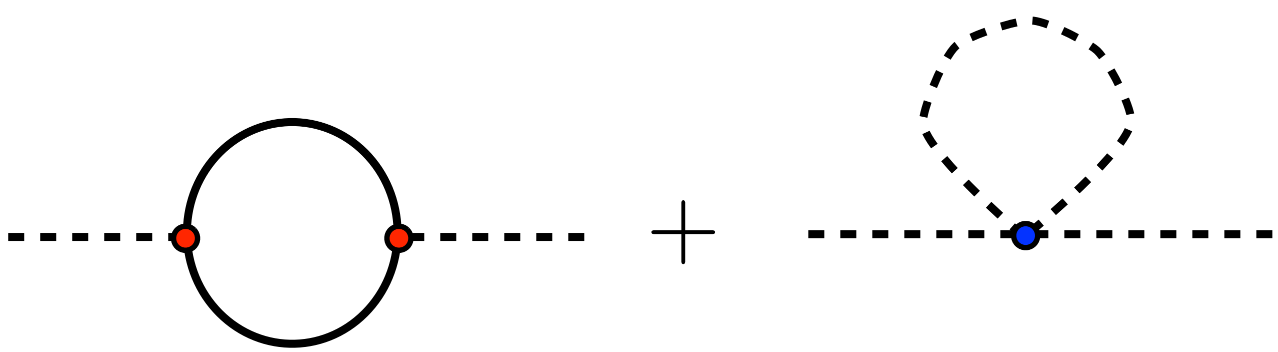
(contrast: "why is $M_{\mathrm{ew}} \ll M_P\,?$")

Supersymmetric Lagrangians

Wess, Zumino ’74

- Simple example: Wess-Zumino model

s $\qquad$ $\widetilde{s}$ $\qquad$ *exactly* same masses



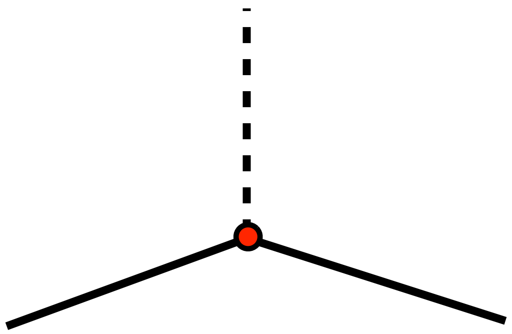
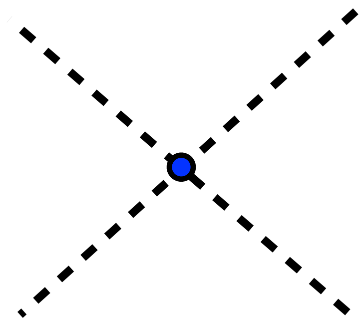
$=$ No power law sensitivity

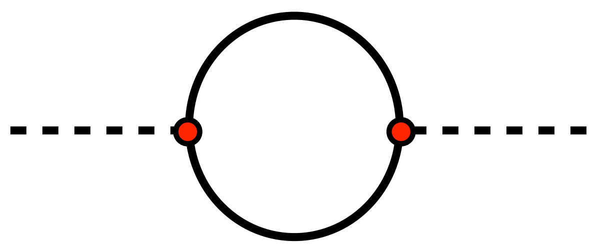
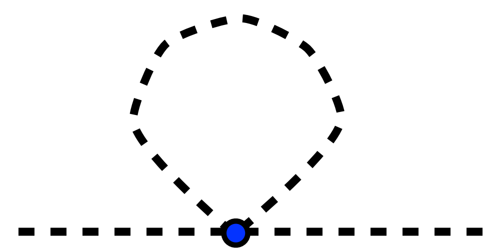
- “String inspired!”
- If there is a mass splitting $s - \widetilde{s}$

  the sensitivity reappears $\sim \Delta m$

Supersymmetric Lagrangians

Wess-Zumino model

 $= y$  $= |y|^2$

 $+$  $=$ No power law divergence

- Interacting! Not enough with just the same masses, also need the above relation.

- relation preserved by loop corrections!

  "line of fixed points"

Hierarchy problem: other solutions

Weinberg '79, Susskind, '79

- No elementary scalar at all ("technicolor")
- Large extra dimensions (ADD) — Arkani-Hamed, Dimopoulos, Dvali '98
- Warped extra dimensions (RS) — Randall, Sundrum '99
- Higgs is Nambu-Goldstone boson

Arkani-Hamed, Cohen, Georgi '01

....

Tend to introduce other hierarchy problems

(like: even if the extra dimensions are relatively large *compared to most models,* why are they still so much smaller than the visible ones?)

The MSSM particles

Simple and minimal: for each existing SM particle, add one hypothetical partner.

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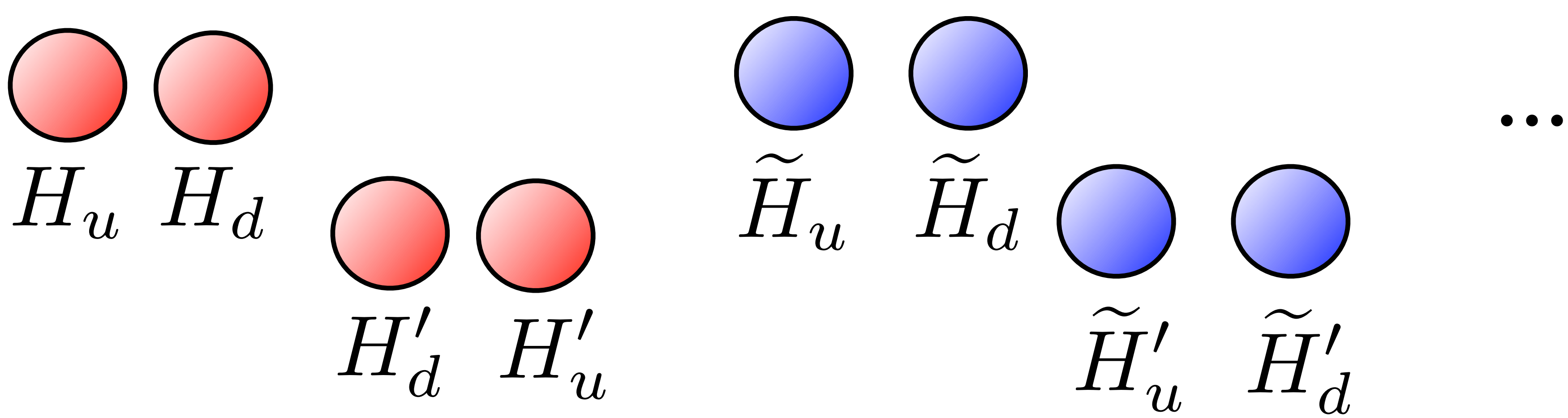
Except that, because couplings are more restricted, we need *two* Higgs fields to give mass to both u and d-type quarks.

The MSSM particles

Simple and minimal: for each existing SM particle, add one hypothetical partner.

If we can have two, why not four? Or six?



The MSSM particles

Anyway, it's important that the superpartner has the same charges and thus similar interactions.

The MSSM particles

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g $\qquad$ $\tilde{g}$

What about *non-minimal*? Add completely new particle (neutral) and its superpartner:

Nilles, Srednicki, Wyler '83

PAMELA excess $\qquad$ S $\qquad$ $\tilde{S}$ $\qquad$ NMSSM (Next-to-Minimal)

Bai, Carena, Lykken '09

The MSSM particles

Or, maybe some of the superpartners are much too heavy to be seen in the reasonable future, so effectively only *some* have superpartners?

Arkani-Hamed, Dimopoulos '04

"Split supersymmetry"

The MSSM particles

Simple and minimal: for each existing SM particle, add one hypothetical partner.

Let’s first stick to the *minimal*, the usual MSSM.

MSSM particle summary

scalar + fermion:

e.g. Martin, hep-ph/9709356

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks	Q	$(\tilde{u}_L \;\; \tilde{d}_L)$	$(u_L \;\; d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
($\times$3 families)	$\bar{u}$	$\tilde{u}_R^*$	$u_R^\dagger$	$(\overline{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	$\bar{d}$	$\tilde{d}_R^*$	$d_R^\dagger$	$(\overline{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons, leptons	L	$(\tilde{\nu} \;\; \tilde{e}_L)$	$(\nu \;\; e_L)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
($\times$3 families)	$\bar{e}$	$\tilde{e}_R^*$	$e_R^\dagger$	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs, higgsinos	H_u	$(H_u^+ \;\; H_u^0)$	$(\tilde{H}_u^+ \;\; \tilde{H}_u^0)$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2})$
	H_d	$(H_d^0 \;\; H_d^-)$	$(\tilde{H}_d^0 \;\; \tilde{H}_d^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$

fermion + vector:

Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	$\tilde{g}$	g	$(\mathbf{8}, \mathbf{1}, 0)$
winos, W bosons	$\widetilde{W}^\pm \;\; \widetilde{W}^0$	$W^\pm \;\; W^0$	$(\mathbf{1}, \mathbf{3}, 0)$
bino, B boson	$\widetilde{B}^0$	B^0	$(\mathbf{1}, \mathbf{1}, 0)$

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MSSM Neutralinos and Charginos

e.g. Martin, hep-ph/9709356

spin:	0	1/2	1
	H_u^0	$\widetilde{H}_u^0$	
	H_d^0	$\widetilde{H}_d^0$	
		$\widetilde{B}^0$	W^0
		$\widetilde{W}^0$	B^0

superpartners: higgsinos

superpartners: bino, wino

organize new uncolored fermions by electric charge, then by mass:

gaugino fraction (of LSP): Z_g

$$\widetilde{H}_u^0, \widetilde{H}_d^0, \widetilde{B}^0, \widetilde{W}^0 \longrightarrow \chi_i^0 \qquad i = 1,2,3,4 \quad \text{neutralinos}$$

$$\widetilde{H}^\pm, \widetilde{W}^\pm \longrightarrow \chi_i^\pm \qquad i = 1,2 \quad \text{charginos}$$

MSSM parameters

Supersymmetry is a symmetry that relates different parameters, so there should be very few free parameters.... right?

MSSM parameters

In fact, in the supersymmetric MSSM, only *one* undetermined parameter!

... the Higgs/Higgsino mass μ .

... but the real world is not exactly supersymmetric.

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... but the real world is not exactly supersymmetric.

All other new parameters come from supersymmetry *breaking*.

MSSM parameters

There are **105** new parameters compared to the Standard Model, which makes **124** total, but I will argue that most of them are very similar to each other, i.e. there are only a few *kinds* of parameters, and the MSSM-124 is actually *fairly restrictive* among SUSY models.

MSSM parameters

There are **105** new parameters compared to the Standard Model, which makes **124** total, but I will argue that most of them are very similar to each other, i.e. there are only a few *kinds* of parameters, and the MSSM-124 is actually *fairly restrictive* among SUSY models.

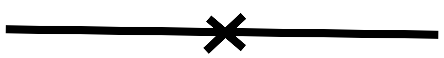
For example, model builders went beyond the MSSM to try to model PAMELA/FERMI excesses. And some parameters must be tiny.

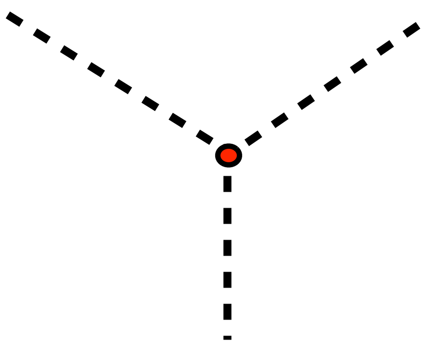
MSSM parameters

"soft" supersymmetry breaking: e.g. Martin, hep-ph/9709356

- causes no power-law sensitivity Girardello, Grisaru '82
- comes from spontaneous SUSY breaking

$$\mathcal{L}_{\rm soft}^{\rm MSSM} = -\frac{1}{2}\left(M_3\widetilde{g}\widetilde{g} + M_2\widetilde{W}\widetilde{W} + M_1\widetilde{B}\widetilde{B} + {\rm c.c.}\right)$$

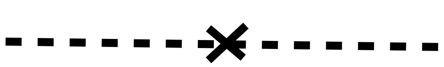




$$-\left(\widetilde{\overline{u}}\,\mathbf{a_u}\,\widetilde{Q}H_u - \widetilde{\overline{d}}\,\mathbf{a_d}\,\widetilde{Q}H_d - \widetilde{\overline{e}}\,\mathbf{a_e}\,\widetilde{L}H_d + {\rm c.c.}\right)$$

$$-\widetilde{Q}^\dagger\,\mathbf{m_Q^2}\,\widetilde{Q} - \widetilde{L}^\dagger\,\mathbf{m_L^2}\,\widetilde{L} - \widetilde{\overline{u}}\,\mathbf{m_{\overline{u}}^2}\,\widetilde{\overline{u}}^\dagger - \widetilde{\overline{d}}\,\mathbf{m_{\overline{d}}^2}\,\widetilde{\overline{d}}^\dagger - \widetilde{\overline{e}}\,\mathbf{m_{\overline{e}}^2}\,\widetilde{\overline{e}}^\dagger$$

$$-m_{H_u}^2 H_u^* H_u - m_{H_d}^2 H_d^* H_d - (bH_uH_d + {\rm c.c.})\,.$$



$+c_i^{jk}\phi^{\dagger\,i}\phi_j\phi_k$ ("C-terms", *absent* in MSSM)

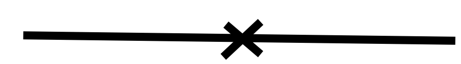
MSSM parameters

"soft" supersymmetry breaking: e.g. Martin, hep-ph/9709356

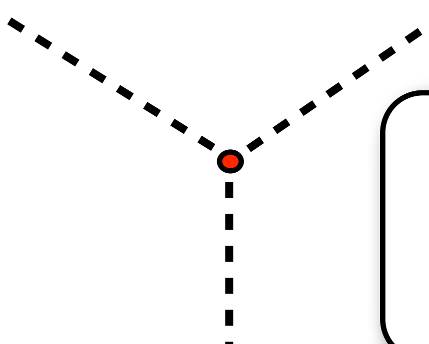
count: 124 total, 105 new and physical

(124 = 18(SM) + 1(Higgs)+105 new) Dimopoulos, Sutter '95

$$\mathcal{L}_{\rm soft}^{\rm MSSM} = -\frac{1}{2}\left(M_3\widetilde{g}\widetilde{g} + M_2\widetilde{W}\widetilde{W} + M_1\widetilde{B}\widetilde{B} + {\rm c.c.}\right)$$



$$-\left(\widetilde{\bar{u}}\,\mathbf{a_u}\,\widetilde{Q}H_u - \widetilde{\bar{d}}\,\mathbf{a_d}\,\widetilde{Q}H_d - \widetilde{\bar{e}}\,\mathbf{a_e}\,\widetilde{L}H_d + {\rm c.c.}\right)$$

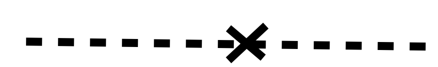


$$3\times 3\times 2 = 18$$
$$\times 3 = 54$$

$$\cdots^\dagger\,\mathbf{m^2_L}\,\widetilde{L} - \widetilde{\bar{u}}\,\mathbf{m^2_{\bar{u}}}\,\widetilde{\bar{u}}^\dagger - \cdots\,\widetilde{\bar{e}}^\dagger$$

$$3\times 3 = 9$$
$$\times 5 = 45$$

$$-m^2_{H_u}H_u^*H_u - m^2_{H_d}H_d^*H_d - (bH_uH_d \cdots$$



(very rough counts)

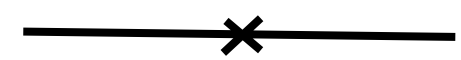
MSSM parameters

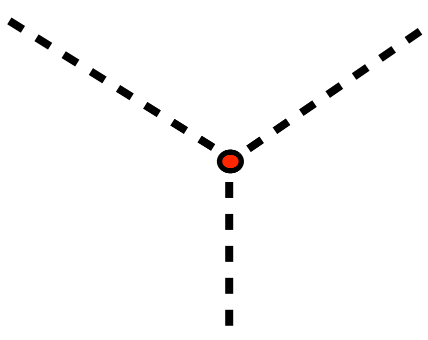
constraint for EWSB: e.g. Martin, hep-ph/9709356

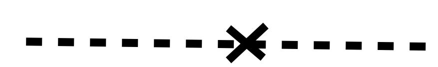
$$v_u^2 + v_d^2 = \frac{2m_W^2}{g^2} \approx (174\,\mathrm{GeV})^2$$

trade: $\{m_{H_u}, m_{H_d}, b, \mu\} \to \{\tan\beta \equiv \frac{v_u}{v_d}, \mu, m_{A^0}\}$

$$\begin{aligned}\mathcal{L}_{\text{soft}}^{\text{MSSM}} \;=\; & -\frac{1}{2}\left(M_3\widetilde{g}\widetilde{g} + M_2\widetilde{W}\widetilde{W} + M_1\widetilde{B}\widetilde{B} + \text{c.c.}\right)\\ & -\left(\widetilde{\overline{u}}\,\mathbf{a_u}\,\widetilde{Q}H_u - \widetilde{\overline{d}}\,\mathbf{a_d}\,\widetilde{Q}H_d - \widetilde{\overline{e}}\,\mathbf{a_e}\,\widetilde{L}H_d + \text{c.c.}\right)\\ & -\widetilde{Q}^\dagger\,\mathbf{m_Q^2}\,\widetilde{Q} - \widetilde{L}^\dagger\,\mathbf{m_L^2}\,\widetilde{L} - \widetilde{\overline{u}}\,\mathbf{m_{\overline{u}}^2}\,\widetilde{\overline{u}}^\dagger - \widetilde{\overline{d}}\,\mathbf{m_{\overline{d}}^2}\,\widetilde{\overline{d}}^\dagger - \widetilde{\overline{e}}\,\mathbf{m_{\overline{e}}^2}\,\widetilde{\overline{e}}^\dagger\\ & -m_{H_u}^2 H_u^* H_u - m_{H_d}^2 H_d^* H_d - (bH_uH_d + \text{c.c.})\,.\end{aligned}$$







MSSM parameters

"soft" supersymmetry breaking:
almost all associated with flavor structure

- trilinear scalar couplings (A-terms)
- Higgs mass mixing term (B-term)
- Higgs masses
- (no C-terms...)
- squark masses
- slepton masses
- gaugino masses

+the supersymmetric Higgs/Higgsino mass μ

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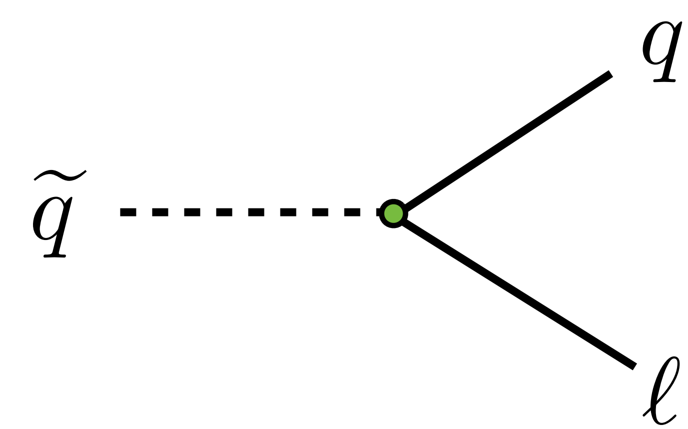
"R-parity violation"

allow baryon or lepton number violating couplings, like



usually *not* considered in the MSSM – drastically different phenomenology, somewhat less clear DM candidate

+the supersymmetric Higgs/Higgsino mass μ

MSSM parameters

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But also, why are there no couplings with more fields, like quartic scalar couplings?
Can sometimes also be soft!

e.g. Martin '99

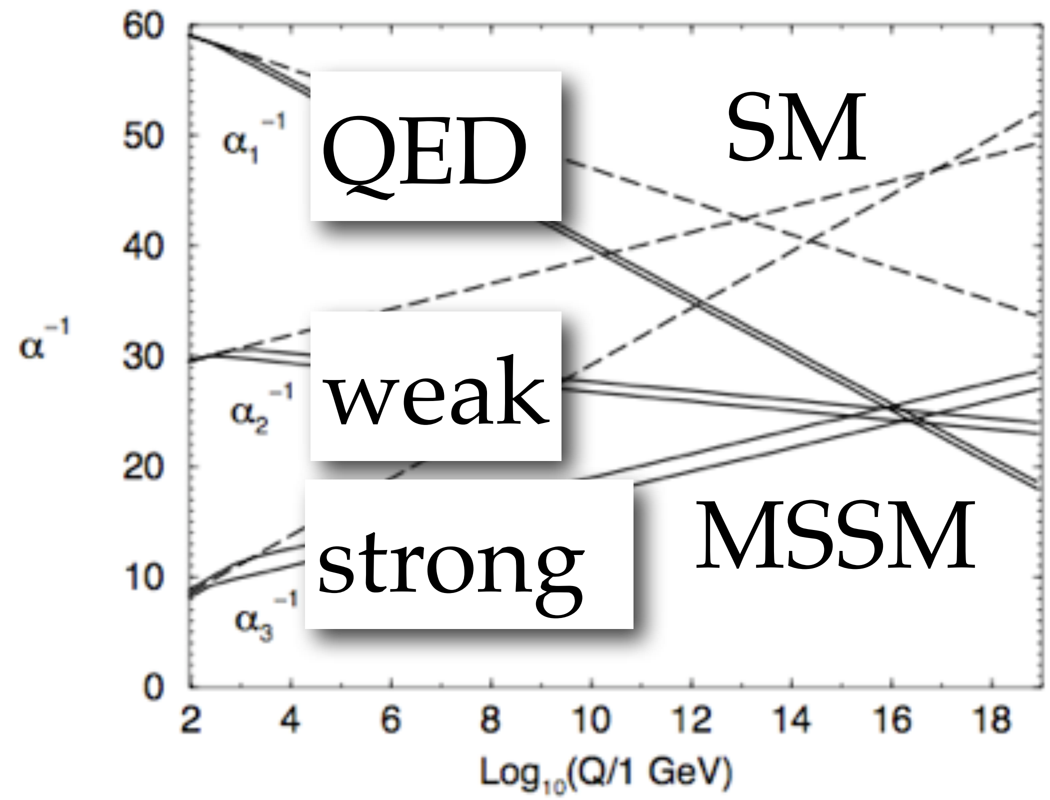
+the supersymmetric Higgs/Higgsino mass μ

At what scale are the parameters given?

"Renormalization group (RG) evolution":
parameters depend on energy scale Q

Georgi, Glashow '74

- Grand unified theory (GUT): maybe couplings meet at some very high energy
- The "low-energy" (TeV) couplings are what appears in experiments.

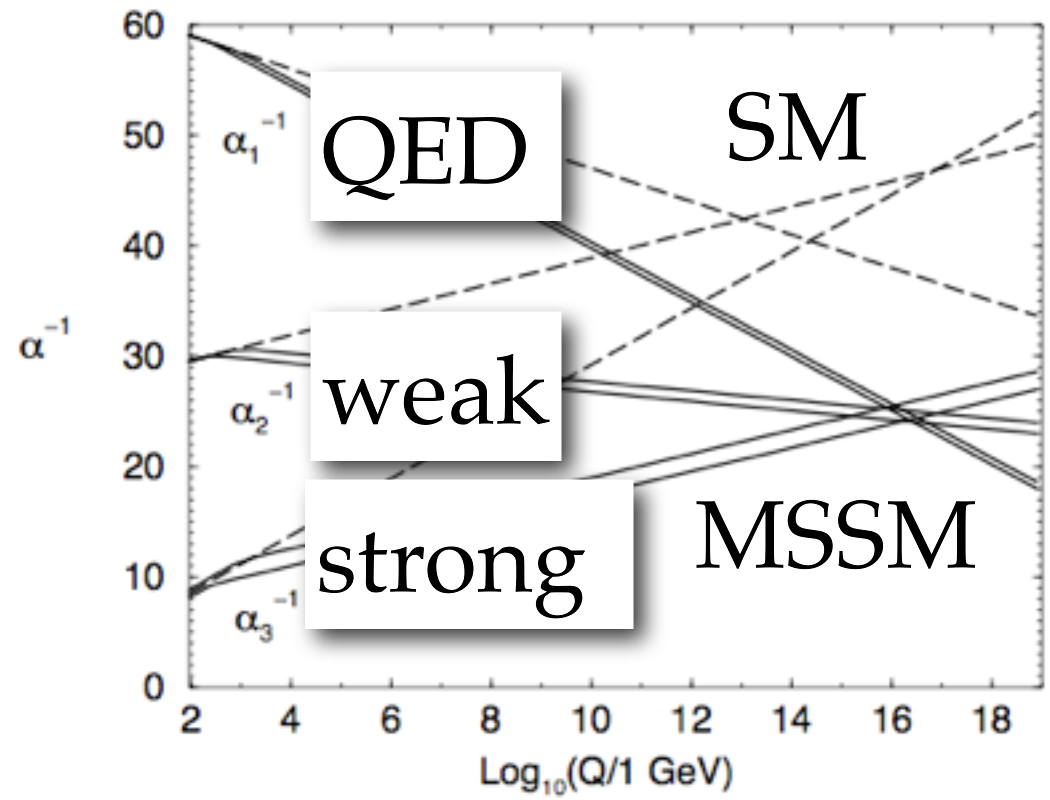


At what scale are the parameters given?

"Renormalization group (RG) evolution":
parameters depend on energy scale Q

Georgi, Glashow '74

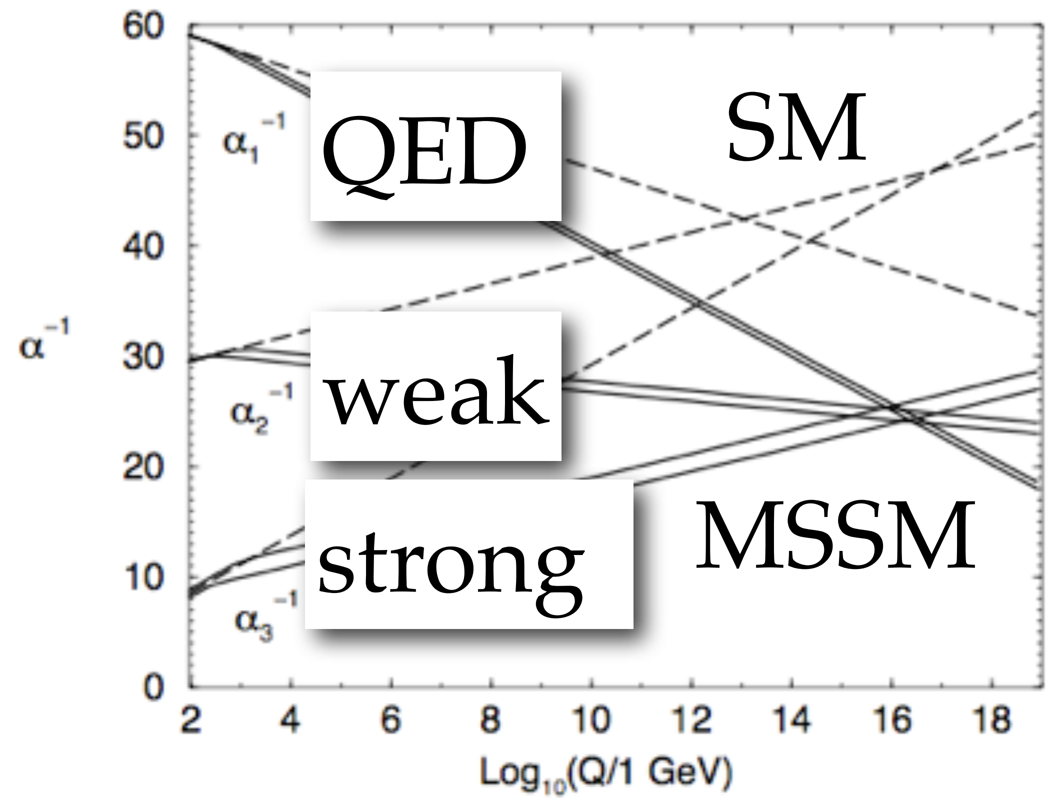
- Grand unified theory (GUT): maybe couplings meet at some very high energy (highly speculative)
- The "low-energy" (TeV) couplings are what appears in experiments.



At what scale are the parameters given?

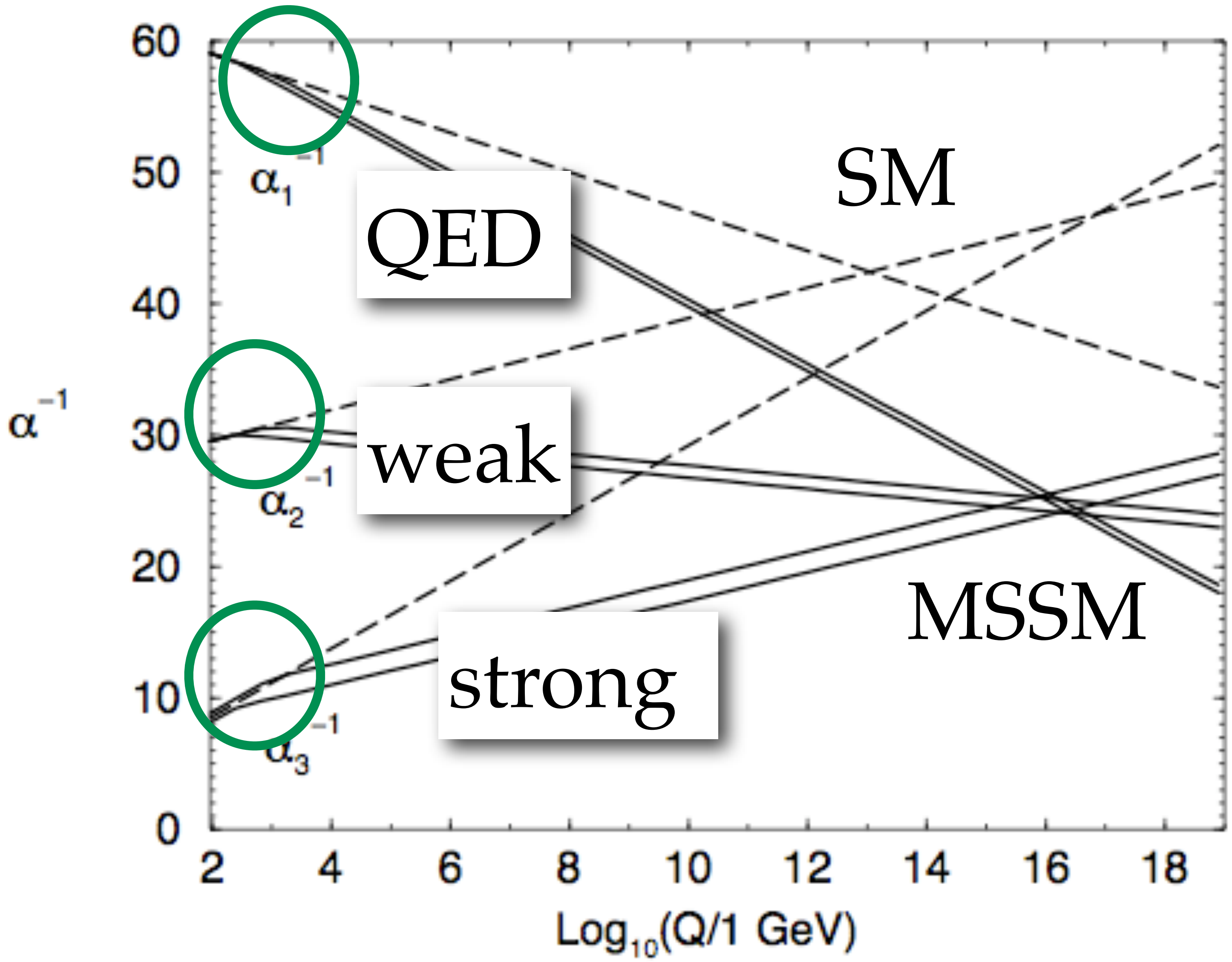
Evolve with software like `SoftSUSY`, ... Allanach

Danger: usually "energy desert" is built in.
For new *intermediate-energy* particle content (e.g. split SUSY) needs to be re-coded



The Energy Desert

(or why standard GUTs are kind of crazy)



Big changes when we discover MSSM ...
then no more changes for next 12-13 orders of magnitude!

The Energy Desert

(or why standard GUTs are kind of crazy)

α^{-1}

This is why there are "only" 105 new parameters in the MSSM: e.g. couplings with mass dimension 5, like $H^2 \widetilde{H}^2$, would be suppressed by some huge scale M_{GUT} .

But even if we accept this, why would this apply to *quartic* terms?

Big changes ... then no more changes for next 12-15 orders of magnitude!

(theoretical) MSSM problems

e.g. Luty, hep-th/0509029

- The mu problem (why μ not large?)
- The SUSY flavor problem

$$\frac{\Delta m^2_{\tilde{s}\tilde{d}}}{m^2_{\tilde{Q}}} \sim 10^{-3}\left(\frac{m_{\tilde{Q}}}{500\,\mathrm{GeV}}\right)$$

- The SUSY CP problem

$$\frac{\mathrm{Im}\,\Delta m^2_{\tilde{Q}}}{m_{\tilde{Q}}} < 0.1\left(\frac{m_{\tilde{Q}}}{500\,\mathrm{GeV}}\right)$$

- The Higgs little hierarchy problem

...

$$m_{h^0}^{\mathrm{tree}} \sim M_Z$$

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...

$$m^{\mathrm{tree}}_{h^0} \sim M_Z$$

- The cosmological constant problem!

C(onstrained)MSSM
or "mSUGRA"

$$M_3 = M_2 = M_1 = m_{1/2},$$
$$\mathbf{m^2_Q} = \mathbf{m^2_{\bar{u}}} = \mathbf{m^2_{\bar{d}}} = \mathbf{m^2_L} = \mathbf{m^2_{\bar{e}}} = m_0^2\,\mathbf{1}, \qquad m^2_{H_u} = m^2_{H_d} = m_0^2,$$
$$\mathbf{a_u} = A_0 \mathbf{y_u}, \qquad \mathbf{a_d} = A_0 \mathbf{y_d}, \qquad \mathbf{a_e} = A_0 \mathbf{y_e},$$
$$b = B_0 \mu,$$

$+\,\mu$: 5 parameters, sometimes restricted even further.

(warning: sometimes slightly different definitions)

C(onstrained)MSSM or "mSUGRA"

$$M_3 = M_2 = M_1 = m_{1/2},$$

$$\mathbf{m^2_Q} = \mathbf{m^2_{\bar{u}}} = \mathbf{m^2_{\bar{d}}} = \mathbf{m^2_L} = \mathbf{m^2_{\bar{e}}} = m_0^2\,\mathbf{1}, \qquad m^2_{H_u} = m^2_{H_d} = m_0^2,$$

"some controversy... whether well-motivated" (Martin)
"if there is no flavor symmetry at the Planck scale, this Ansatz is not natural" (Luty)

[The supposed underlying model is...]
"ad hoc assumption not stable to radiative corrections"
"highly unnatural and the flavor problem prevails"
(Randall, Sundrum '98)

How is supersymmetry broken?

e.g. Martin, hep-ph/9709356

Obvious attempt: try like Higgs mechanism in Standard Model with some "super-Higgs" field Φ

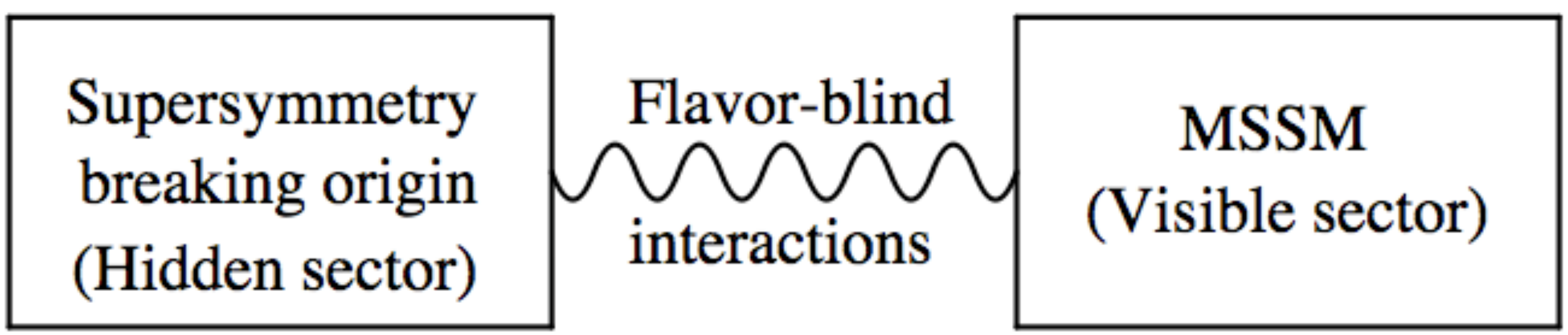
$$\langle \Phi \rangle \neq 0$$

How is supersymmetry broken?

e.g. Martin, hep-ph/9709356

Obvious attempt: try like Higgs mechanism in Standard Model with some "super-Higgs" field Φ ... but doesn't work.   (later: exception)

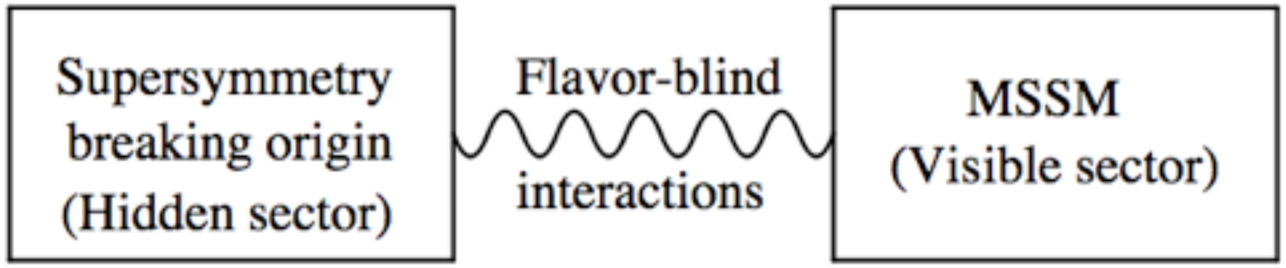
instead: *"hidden sector"* type models



Φ_i $q, \tilde{q}, H_u, \ldots$

$\langle \Phi_i \rangle \neq 0$

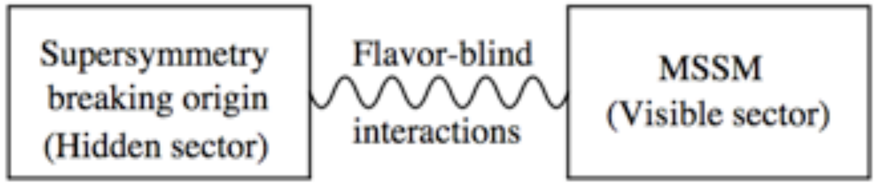
Explain pattern (e.g. flavor structure)?



Mediation scenario: explain MSSM parameters in terms of (hopefully fewer) other parameters

If specific mediation pattern favored by data, the hope is that something is learned about *how* supersymmetry is broken in nature at presently inaccessible energies, which is not evident in the TeV-scale MSSM Lagrangian itself.

PSMB (Planck-scale mediated breaking, gravity mediation)



Chamseddine, Arnowitt, Nath '82, ...

- generic – everything couples to gravity
- big SUSY-breaking energy, weak coupling
- explicit formulas! Kaplunovsky, Louis '93 Brignole, Ibanez, Munoz '93

$$m_{\text{soft}} \sim \frac{F}{M_P} \qquad E_F = \sqrt{F} \sim 10^{10}\,\text{GeV} \quad (M_P \sim 10^{18}\,\text{GeV})$$

- "gravity flavor-blind" not good argument

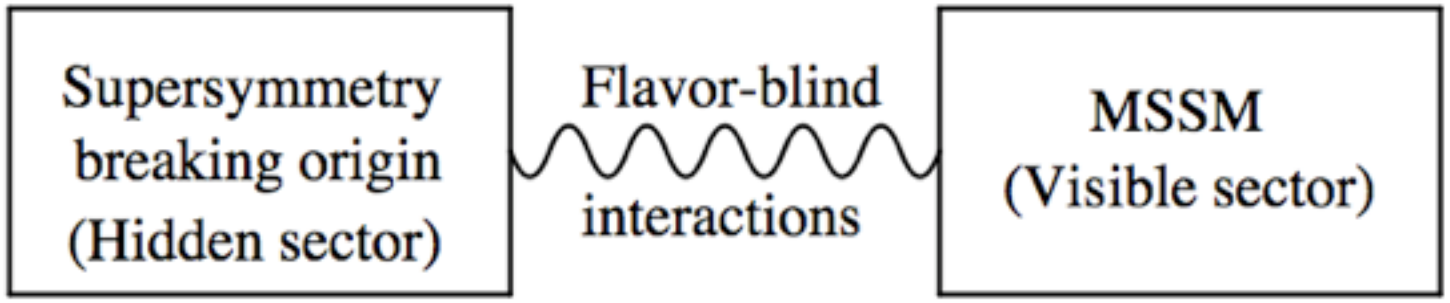
  often SUSY flavor problem remains

GMSB (Gauge mediation)

Dine, Fischler '82

- doesn't probe very high energy physics, doesn't need gravity directly (mixed blessing)
- masses depend only on charges – *flavor blind*
- gravitino (superpartner of the graviton) is LSP – some challenges for cosmology

$$m_{\text{soft}} \sim \alpha \frac{F}{M_{\text{mess}}}\ ,\ E_F = \sqrt{F} \sim 10\,\text{TeV}\ ,\ M_{\text{mess}} \sim 10\,\text{TeV}$$



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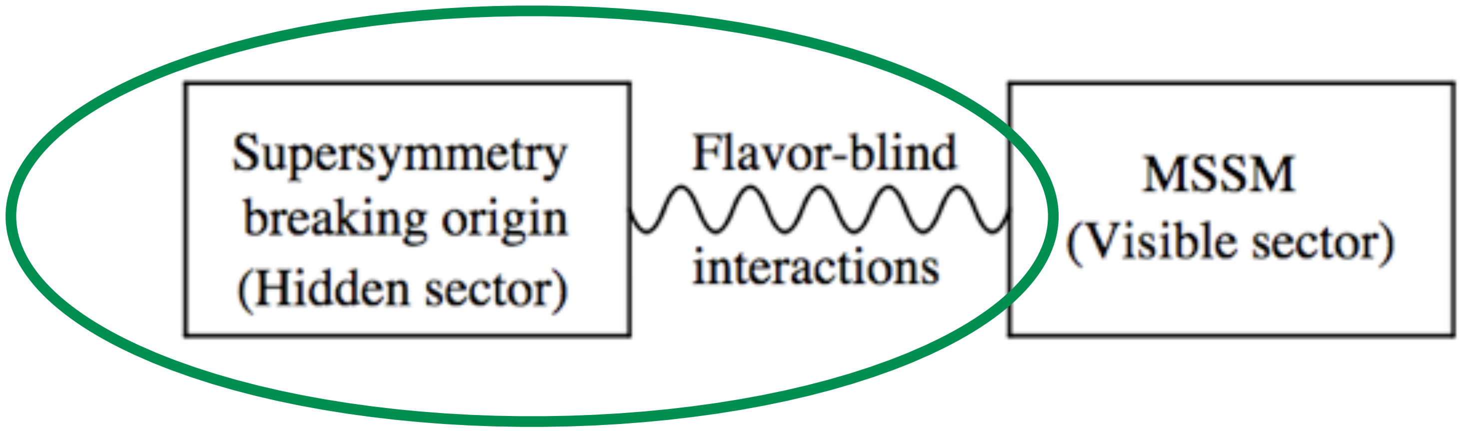
Intriligator, Seiberg, Shih '06
Csaki, Shirman, Terning '06

- "direct" mediation possible (messengers participate in SUSY breaking, i.e. not really "hidden sector" kind of setup)

AMSB
(Anomaly mediation, or Extra-dimensional SUSY breaking)

Randall, Sundrum '98



extra dimensions (e.g. 5th dimension)

- In principle improves on gravity mediation, provides "sequestered" sector = really hidden.

$$m_{\rm soft} \sim \alpha \frac{F}{M_{\rm P}} \;, \; E_F = \sqrt{F} \sim 10^{11}\,{\rm GeV} \quad (M_{\rm P} \sim 10^{18}\,{\rm GeV})$$

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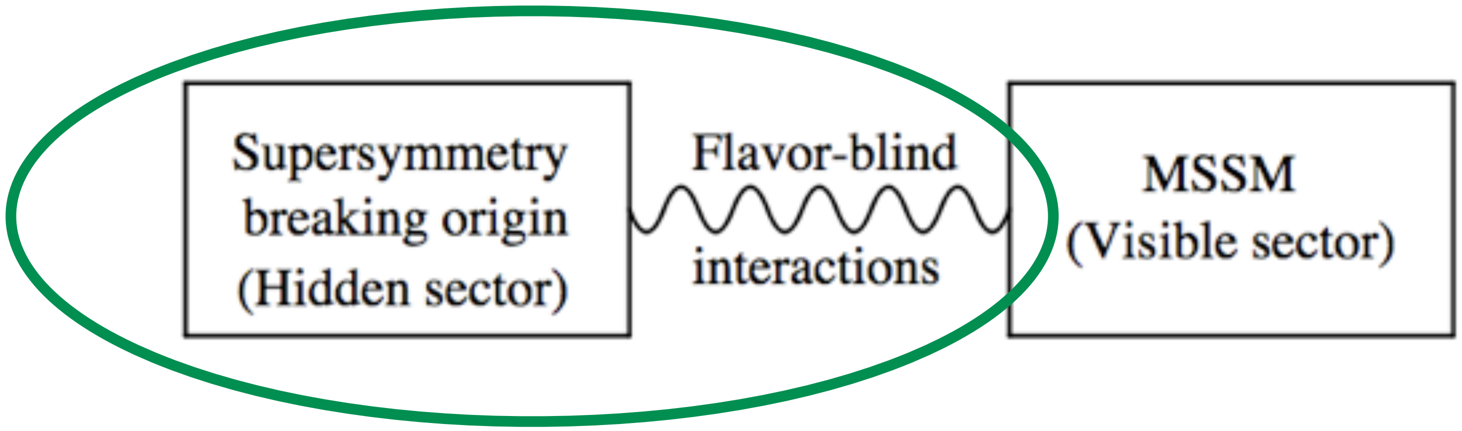

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- In practice also this is problematic,
  – but possible in some models?

Dine, Seiberg '07, ...
de Alwis '10
M.B., Marsh, McAllister, Pajer, '10

More (!) parameters

We have seen that the Minimal Supersymmetric Standard Model (MSSM) is indeed pretty *minimal* (restricted on somewhat shaky theoretical grounds), despite the 124 parameters...

are there interesting and reasonably economical ways to go beyond the MSSM?

Brignole, Casas, Espinosa, Navarro, '03
Casas, Espinosa, Hidalgo '03

Example 1: Beyond the MSSM (BMSSM)

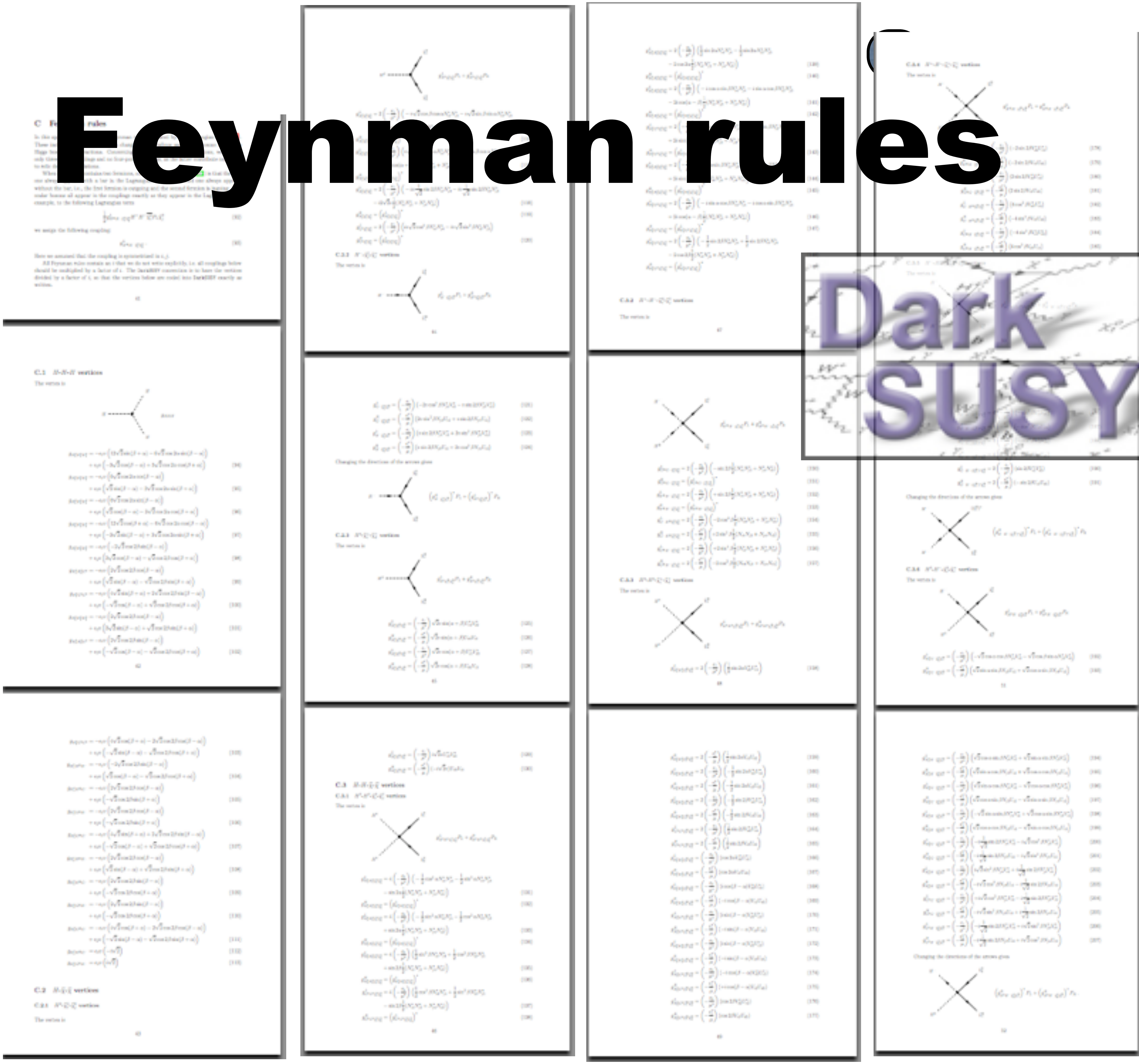
...
Dine, Seiberg, Thomas '07 (Seiberg at STRINGS07)
...

No new particles! Only modifies Lagrangian.
Our BMSSM subset = MSSM +

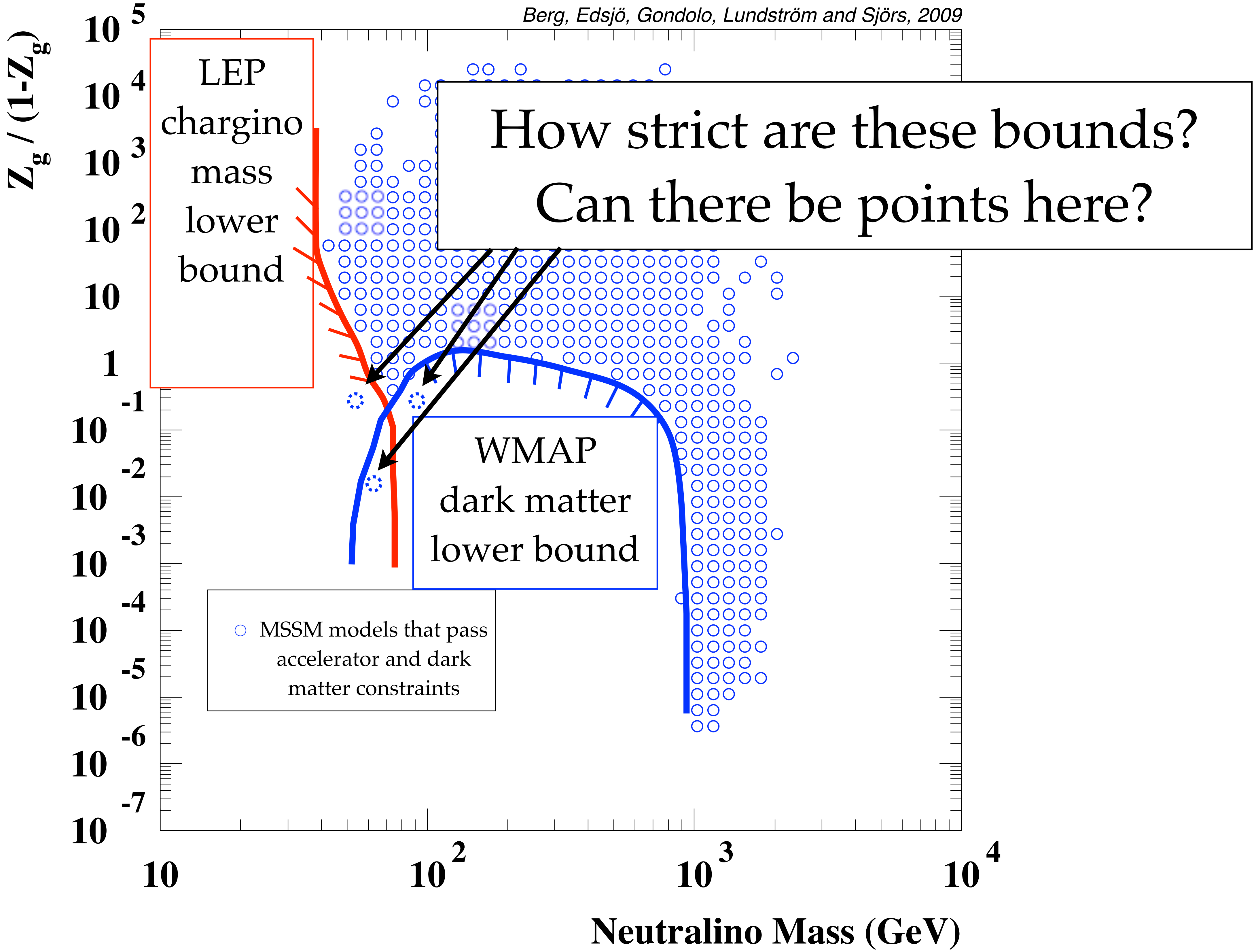
$$\begin{aligned}\delta\mathscr{L} &= -\delta V_1 - \delta V_2 + \delta\mathscr{L}_3 \\ &= -\Big(2\epsilon_1 (H_u H_d)(H_u^\dagger H_u + H_d^\dagger H_d) + \text{ h.c.}\Big) - \big(\epsilon_2 (H_u H_d)^2 + \text{ h.c.}\big) \\ &+ \left[\frac{\epsilon_1}{\mu^*}\Big(2(\widetilde{H}_u \widetilde{H}_d)(H_u H_d) + 2(H_u \widetilde{H}_d)(\widetilde{H}_u H_d) + (\widetilde{H}_u H_d)^2 + (H_u \widetilde{H}_d)^2\Big) + \text{ h.c.}\right]\end{aligned}$$

- modifies Higgs sector, but also charginos and neutralinos (hence modifies dark matter, if Higgsino)
- scaling dimension 4 and 5
- can give 20-30 GeV contribution to Higgs mass, allows light top squark

Feynman rules



Parameter scan



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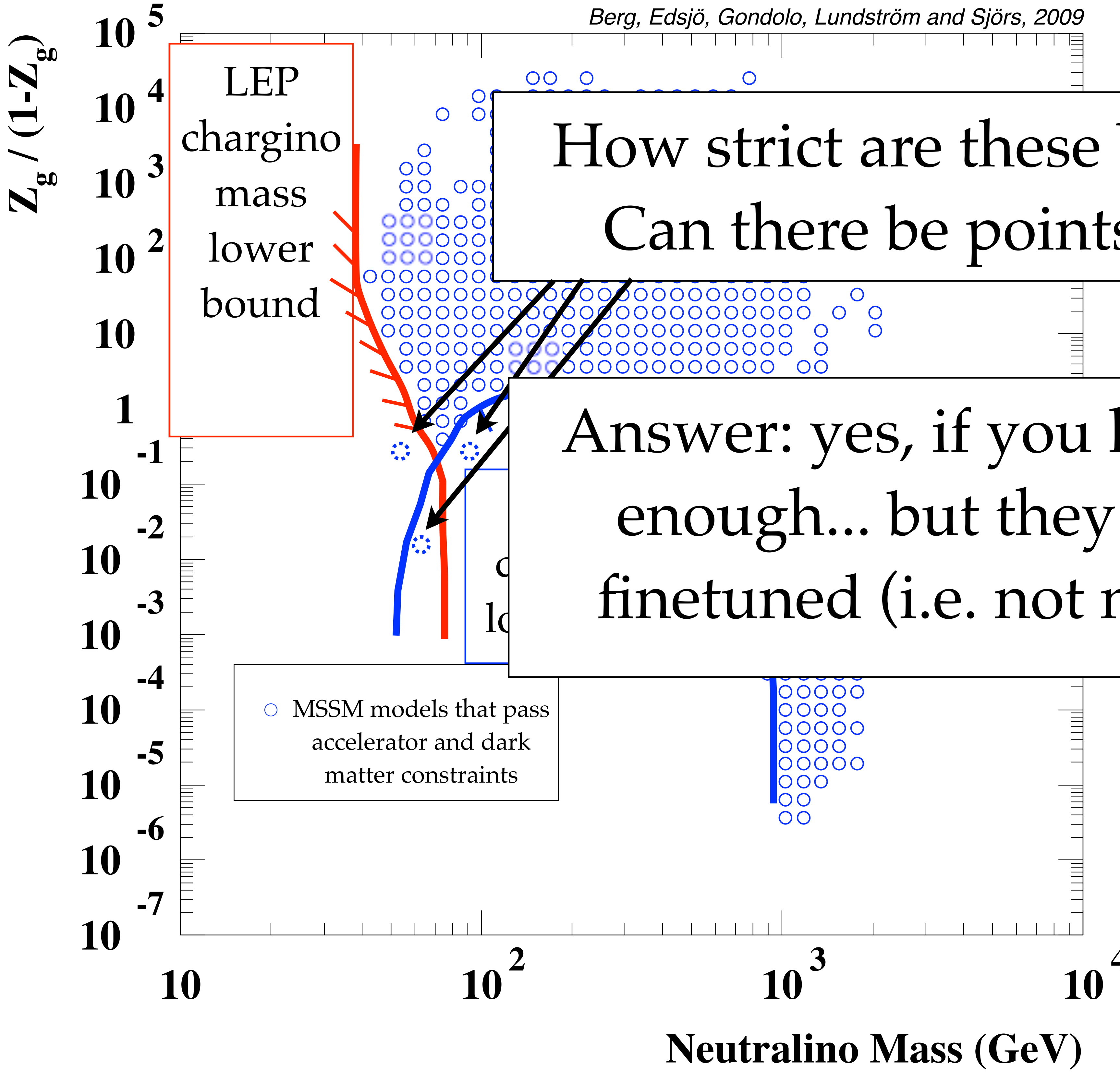


How strict are these bounds? Can there be points here?

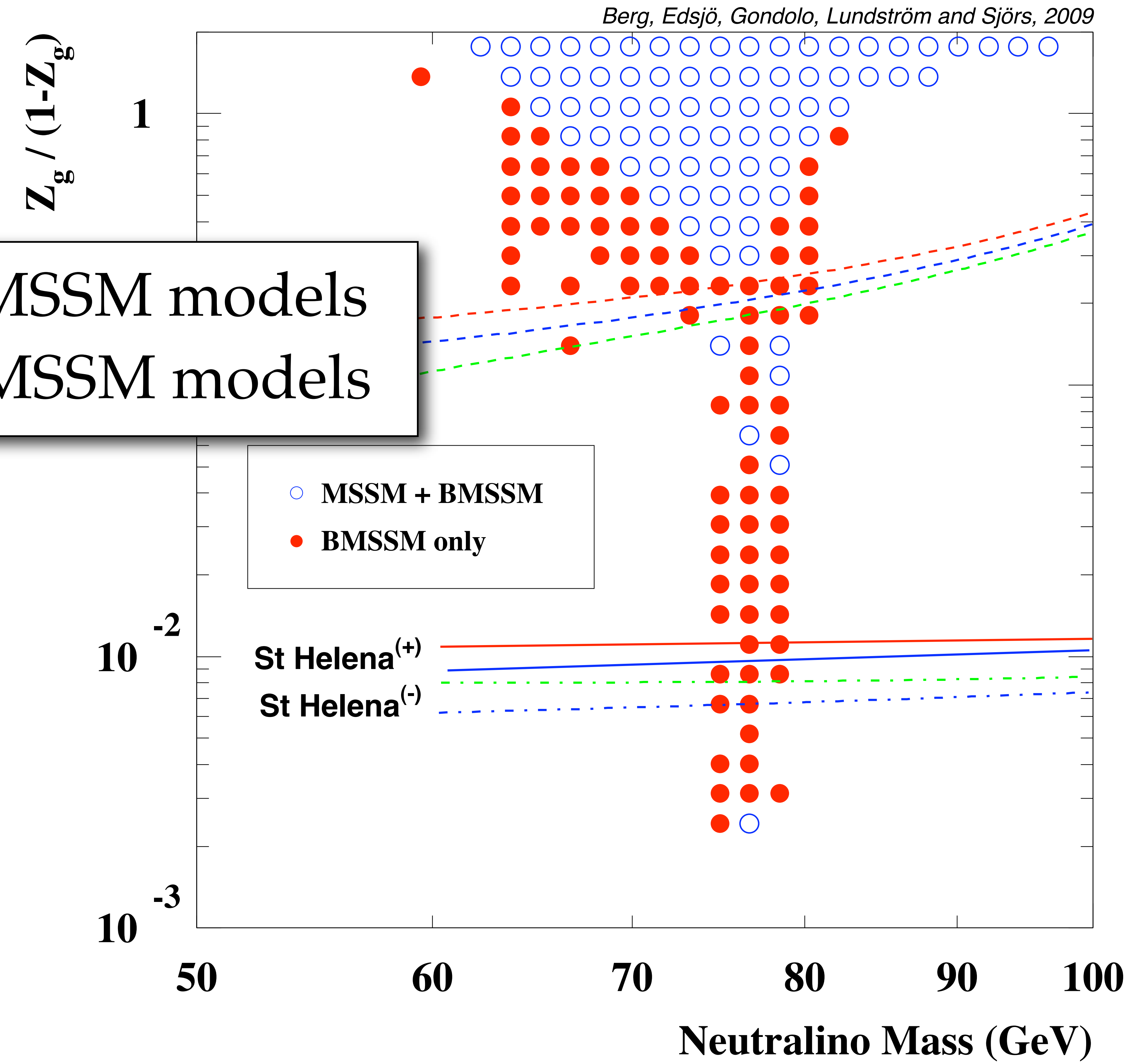
Answer: yes, if you look hard enough... but they will be finetuned (i.e. not natural)!

PDG supersymmetry searches, summary

… from W pair production, was observed. A scan over M_2, μ, and $\tan\beta$ provided a robust chargino mass lower limit of 103 GeV for sneutrino masses larger than 200 GeV [7], except for unnaturally large values of M_2 ($>\sim$ 1 TeV), in the so-called "deep higgsino" region, where the $\tilde{\chi}^{\pm}$–$\tilde{\chi}_1^0$ mass splitting is very small.

This limit is degraded for lower sneutrino masses for two reasons. First, the production cross section is reduced by the negative interference between the s- and t-channel exchanges. Second, two-body decays open up, which may reduce the selection efficiency. This is the case in particular in the so-called "corridor" where $m_{\tilde{\chi}^{\pm}} - m_{\tilde{\nu}}$ is smaller than a few GeV, so that the lepton from the $\tilde{\chi}^{\pm} \to \ell\tilde{\nu}$ decay is hardly visible.

Light Higgsino Dark Matter

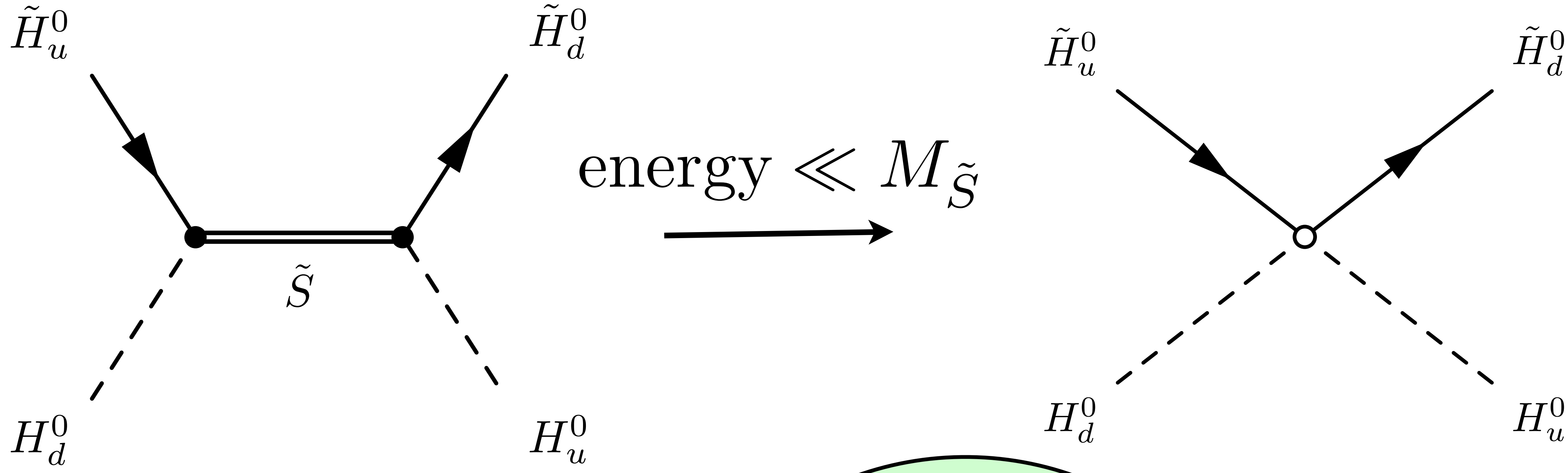


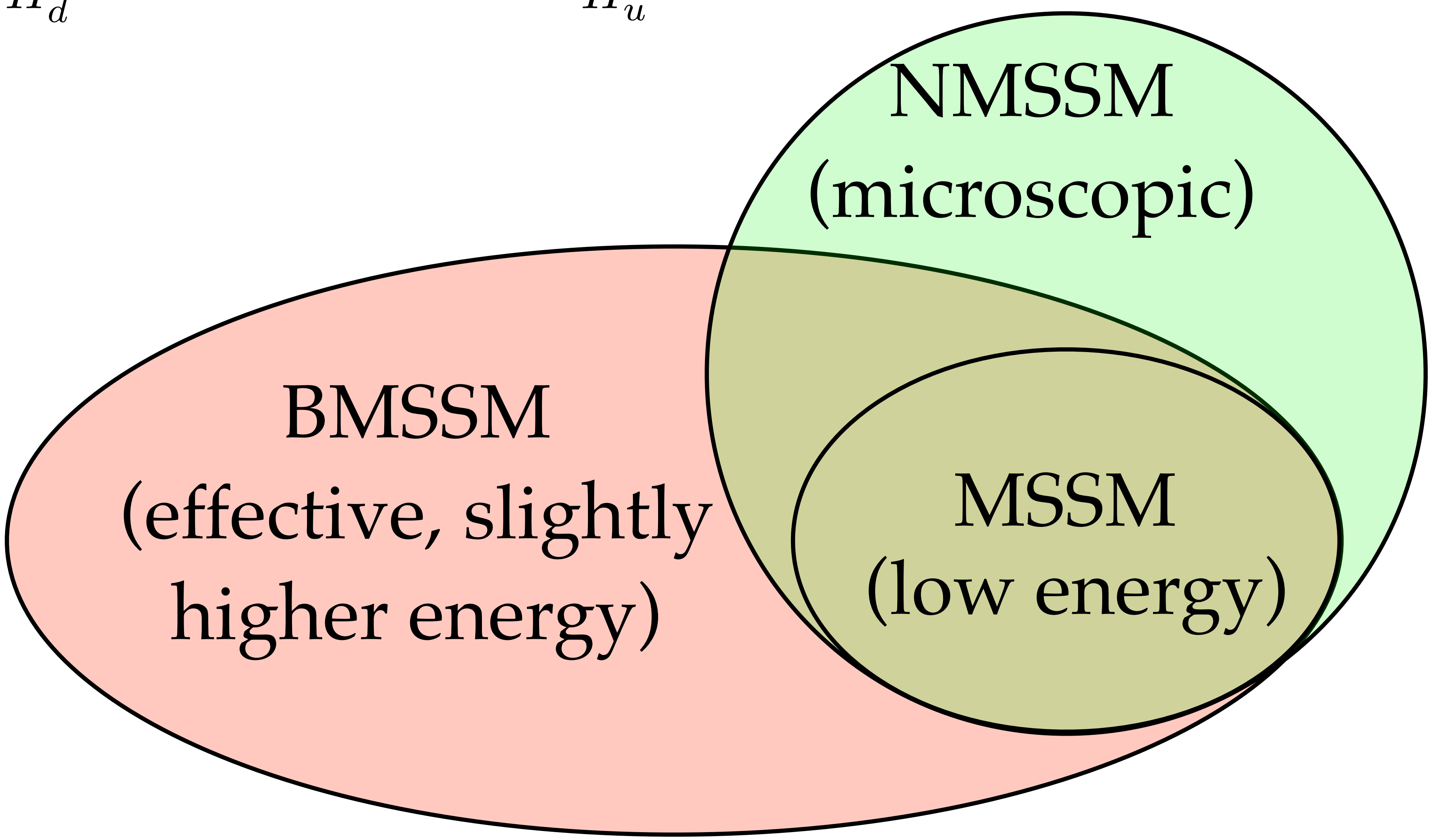
110 000 MSSM models
11 000 BMSSM models

also see e.g.
Bernal, Goudelis '09: "Dark Matter Detection in the BMSSM" (XENON-like, ...)

Microscopic vs. effective

NMSSM = MSSM + gauge singlet chiral superfield S





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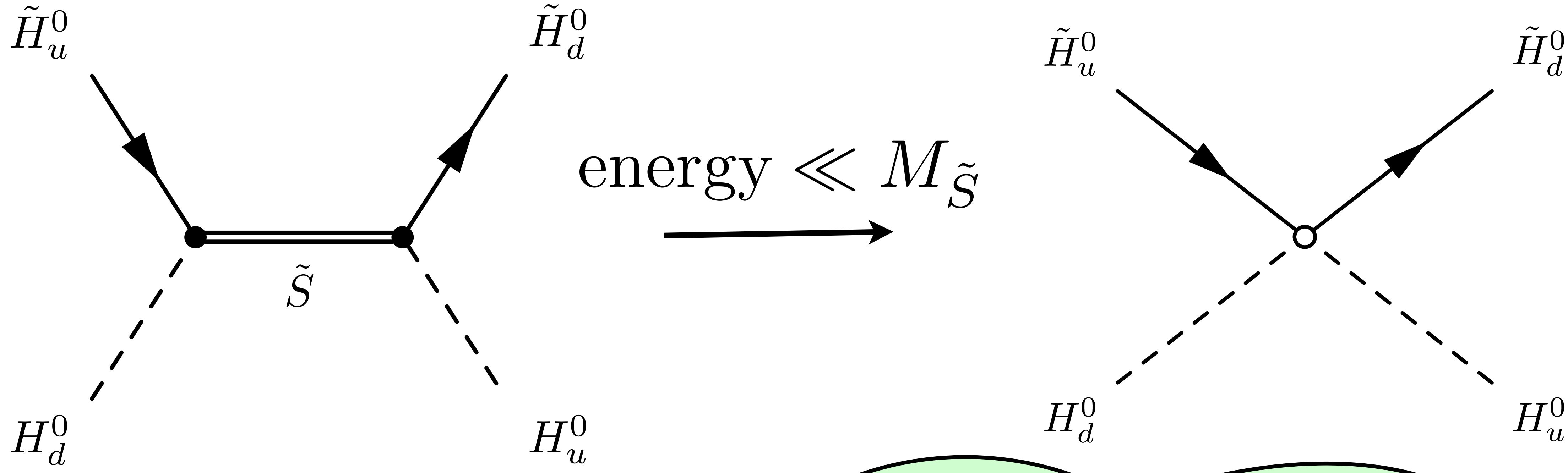
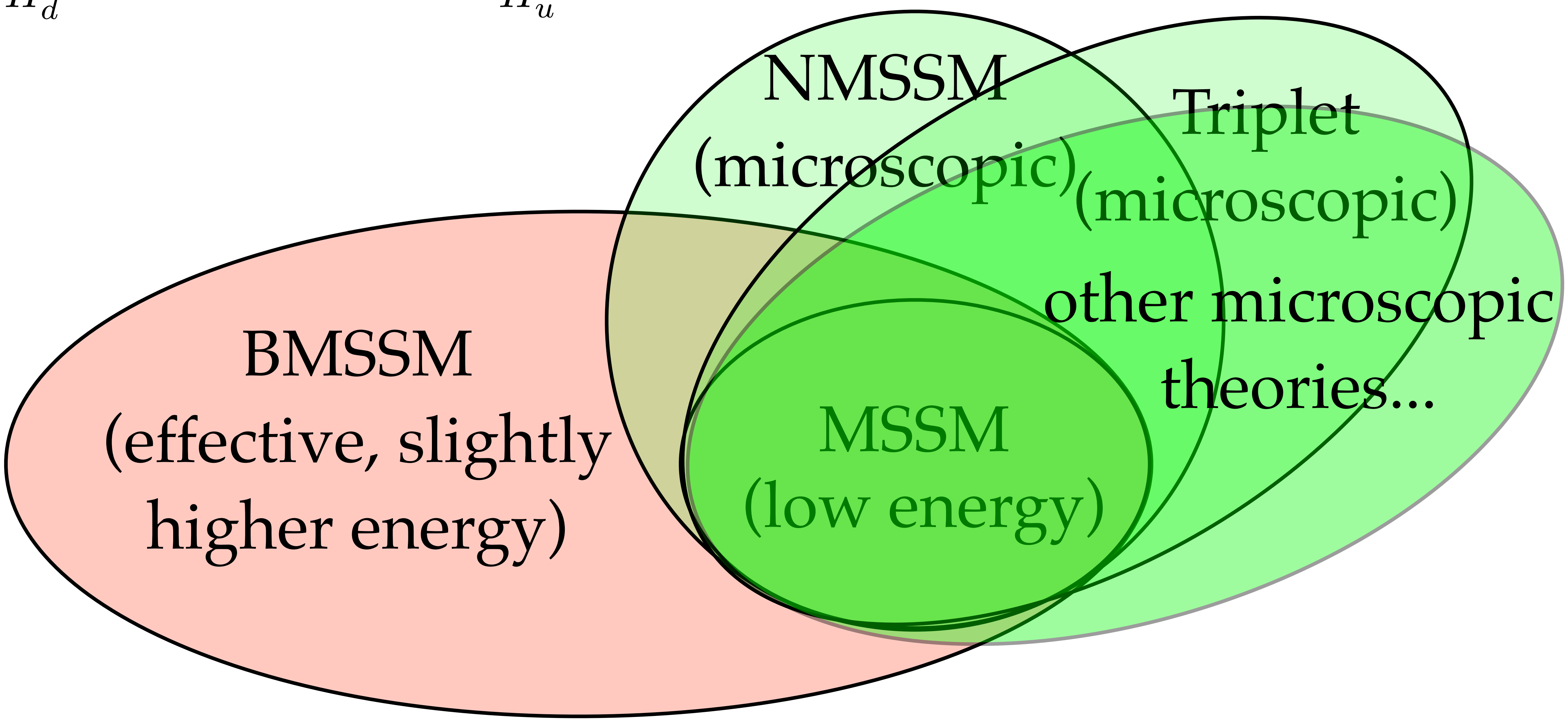
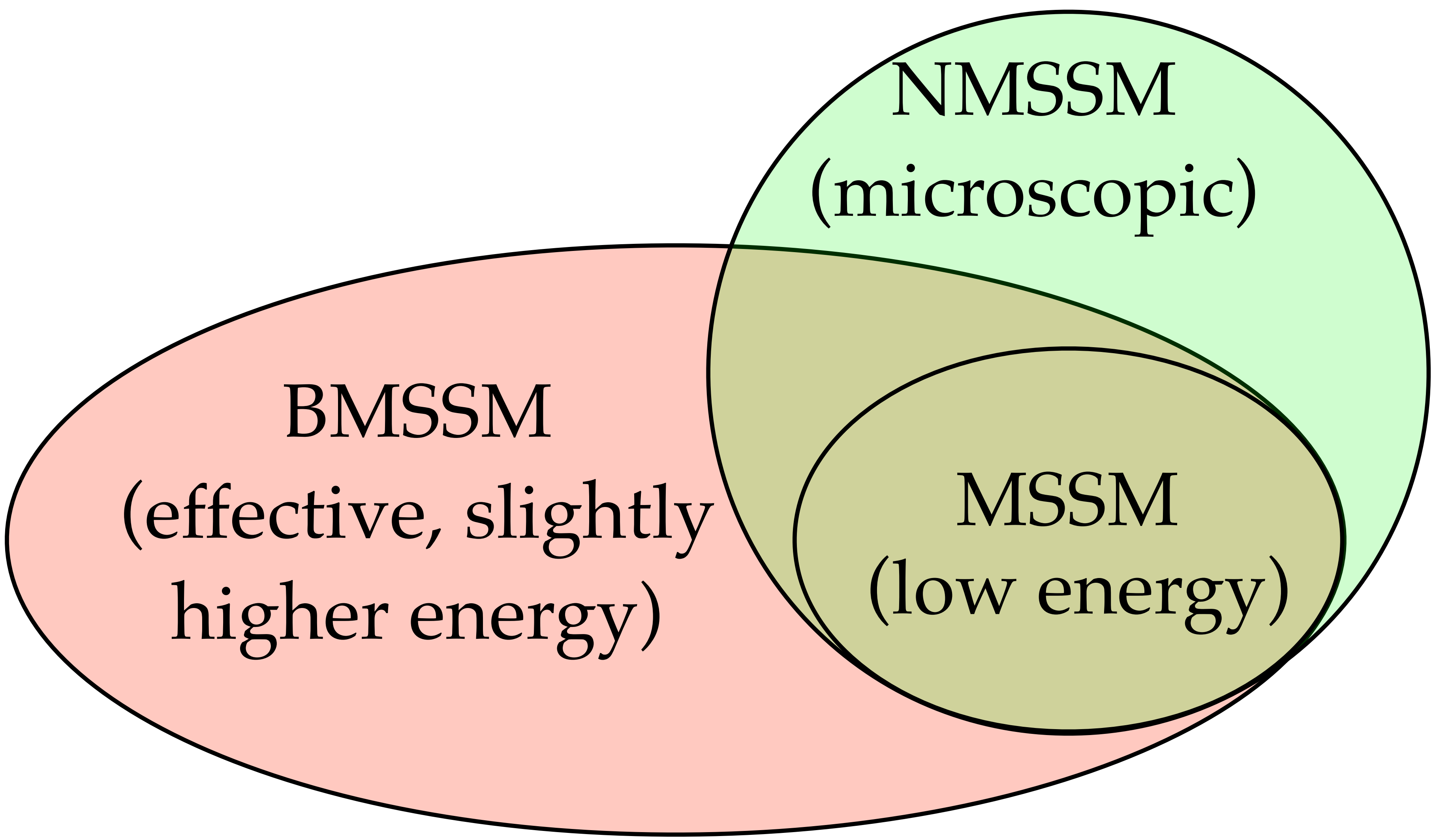




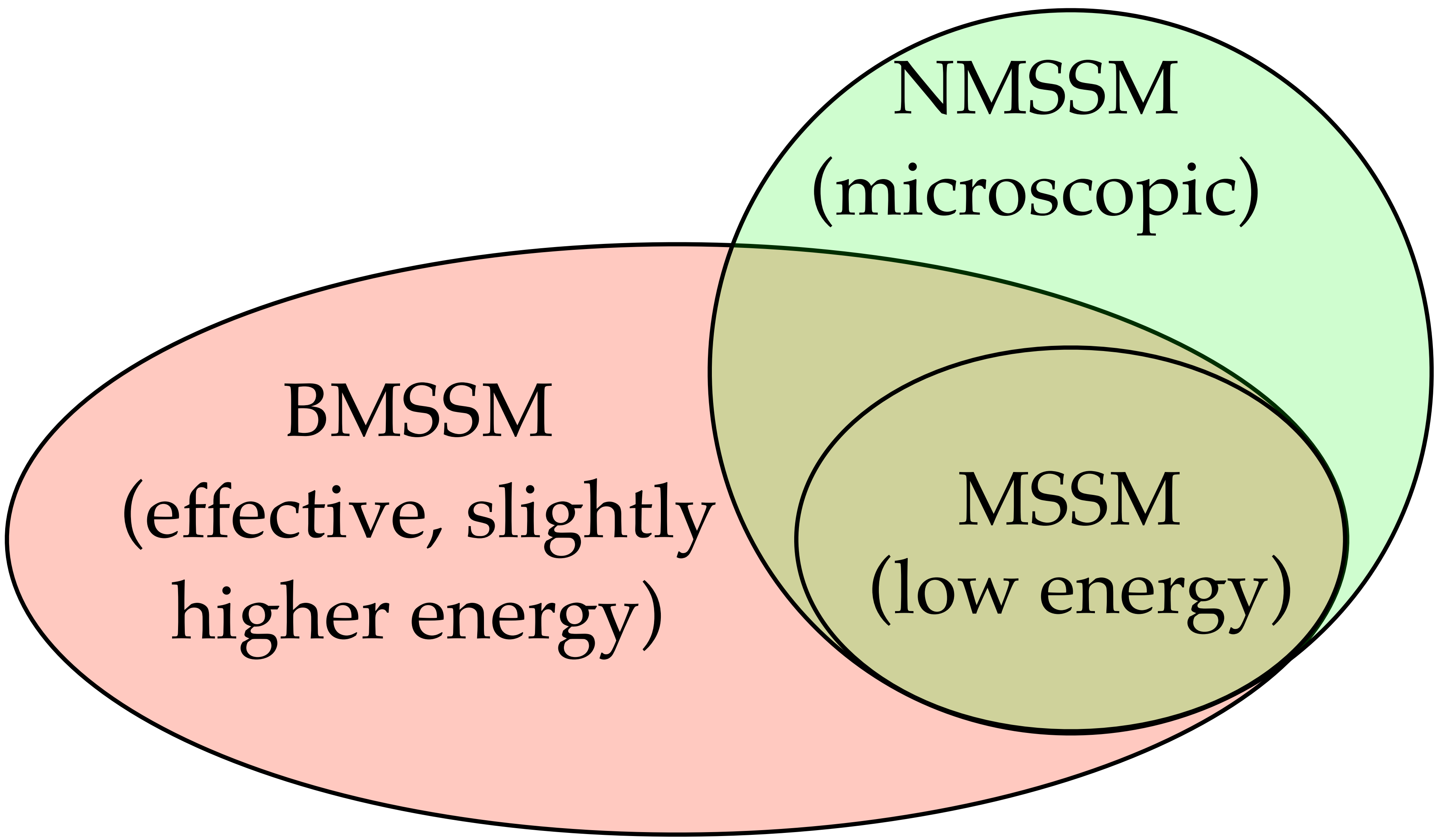
Microscopic vs. effective

Let's be clear:
microscopic is *better* than effective – if you believe in it
(say if it's natural...)



Microscopic vs. effective

Let's be clear:
microscopic is *better* than effective – if you believe in it
(say if it's natural...)
but if you don't know what to believe in,
an effective theory is a good place to start!



Example 2: "Anomalous U(1)" models (not really anomalous)

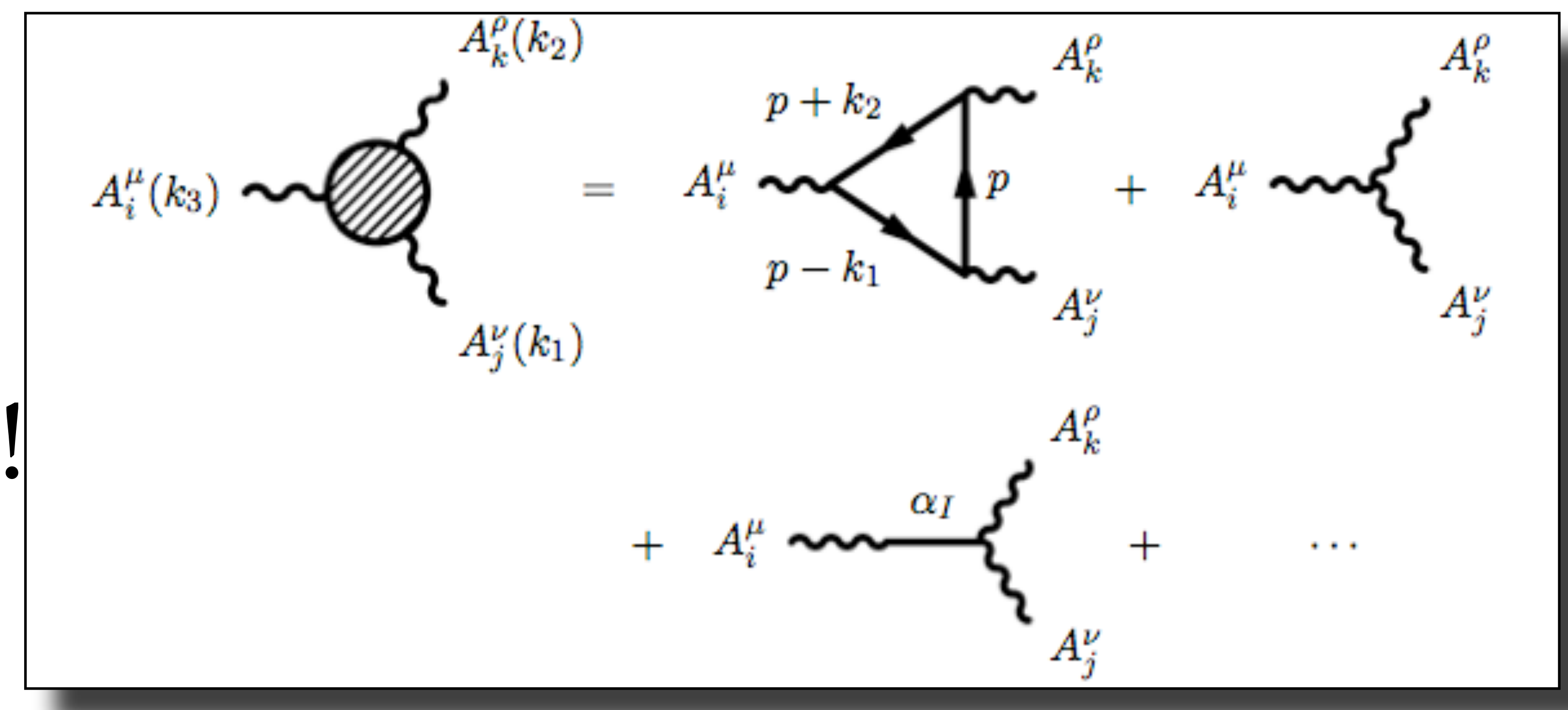
- Z' with generalized "Chern-Simons"(CS) terms

- seem very awkward and contrived at first,

natural and necessary in string theory

- These Z′ particles are hard to produce at LHC

(WW fusion) but easier in DM setting (lineshape)!



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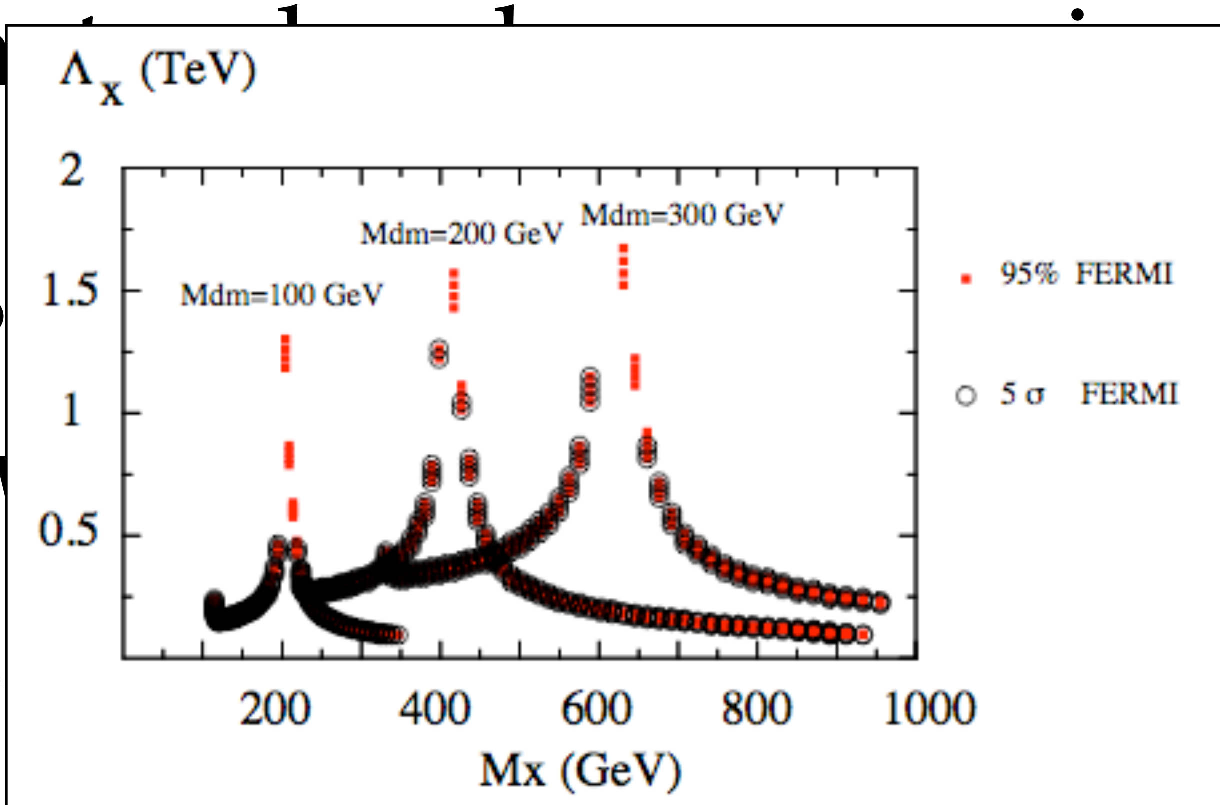
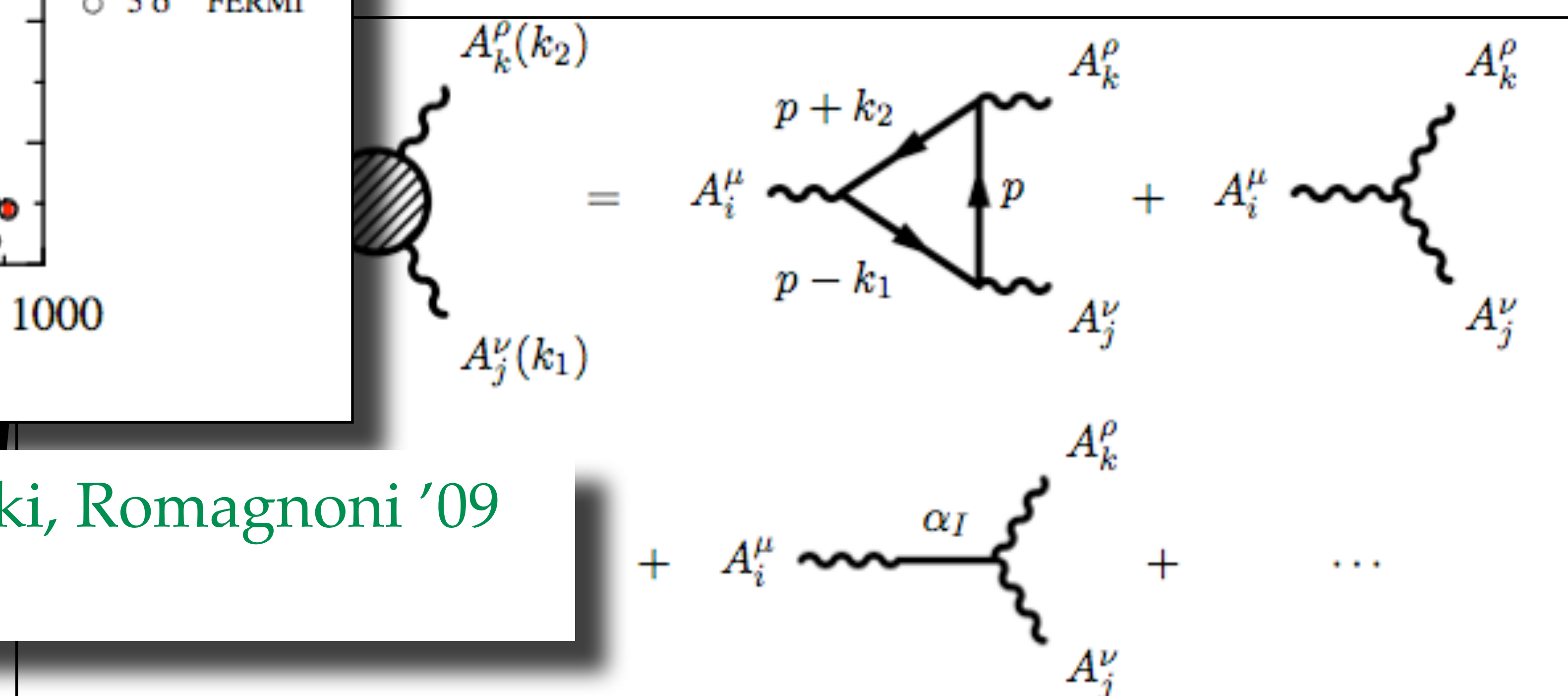




e.g. Dudas, Mambrini, Pokorski, Romagnoni '09
Mambrini '09

Kachru, Kallosh, Linde, Trivedi '03

Balasubramanian, Berglund, Conlon, Quevedo '05

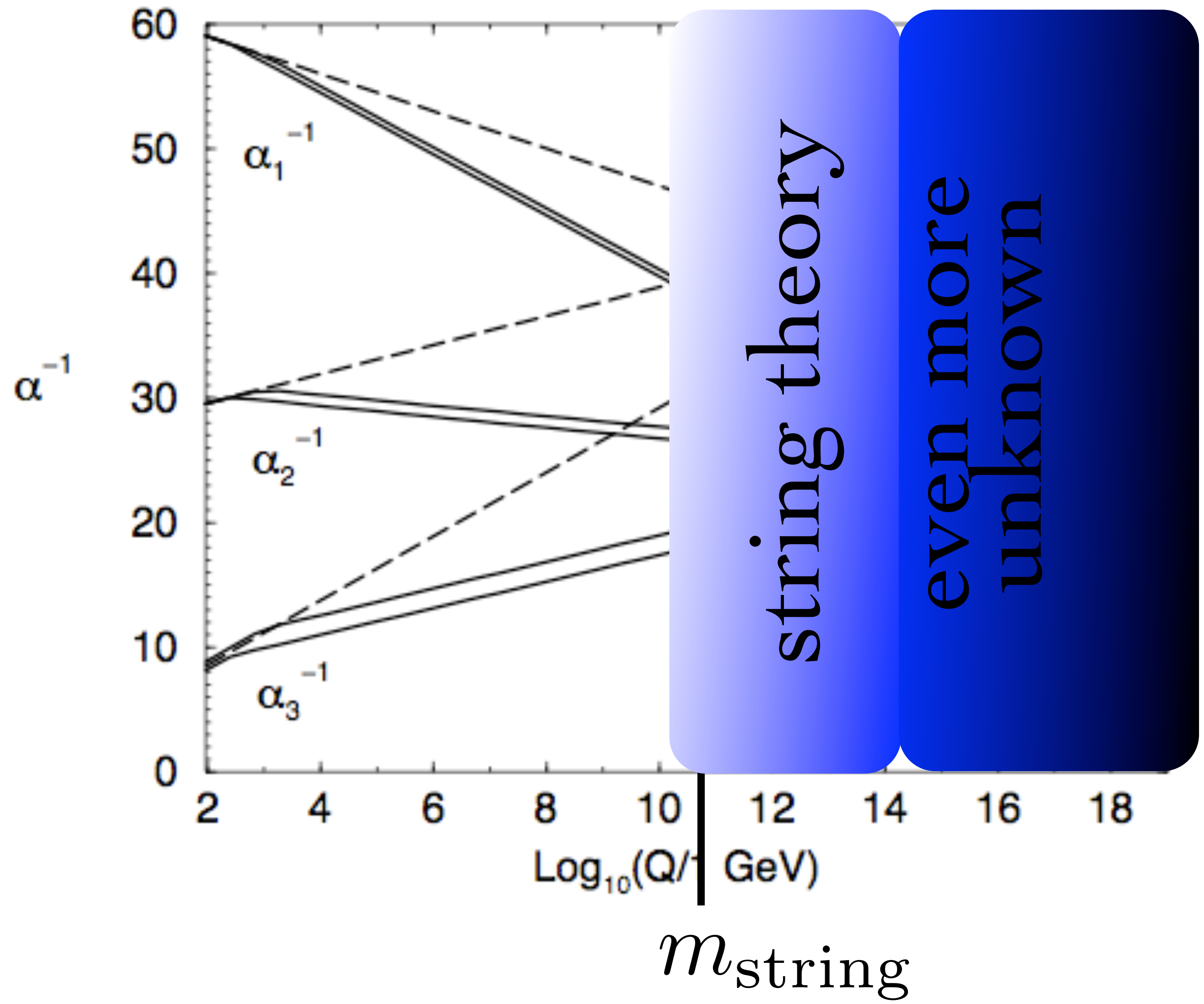
Example 3: Large Volume Scenario

(variant of KKLT string models)

non-minimal Supersymmetric Standard Model: interesting mass scales between the TeV and GUT scale!

e.g. Conlon, Kom, Suruliz, Allanach, Quevedo '07

collider observables

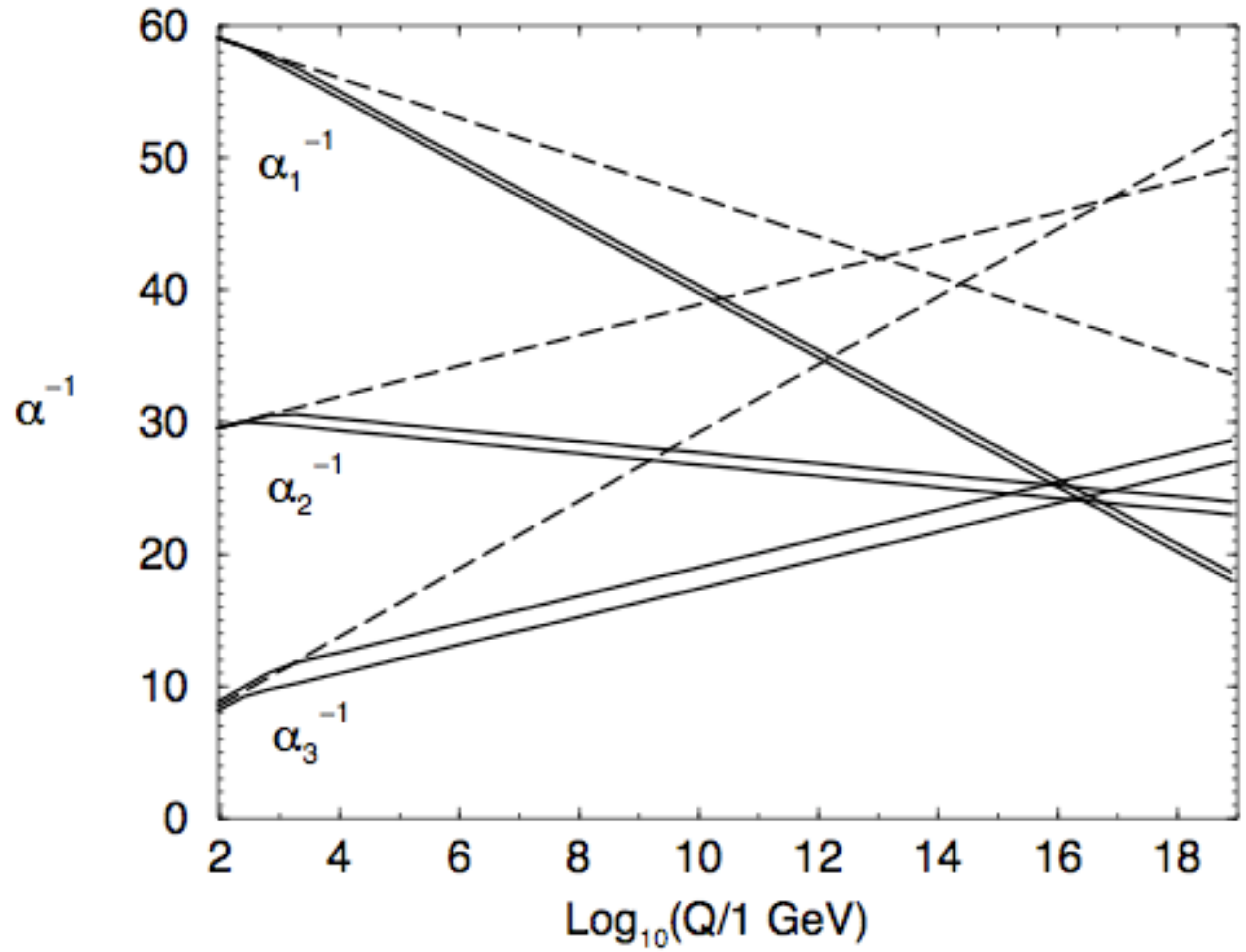


Kachru, Kallosh, Linde, Trivedi '03
Balasubramanian, Berglund, Conlon, Quevedo '05

Example 3: Large Volume Scenario

(variant of KKLT string models)

Contrast the MSSM: no interesting mass scales between the TeV and GUT scale!



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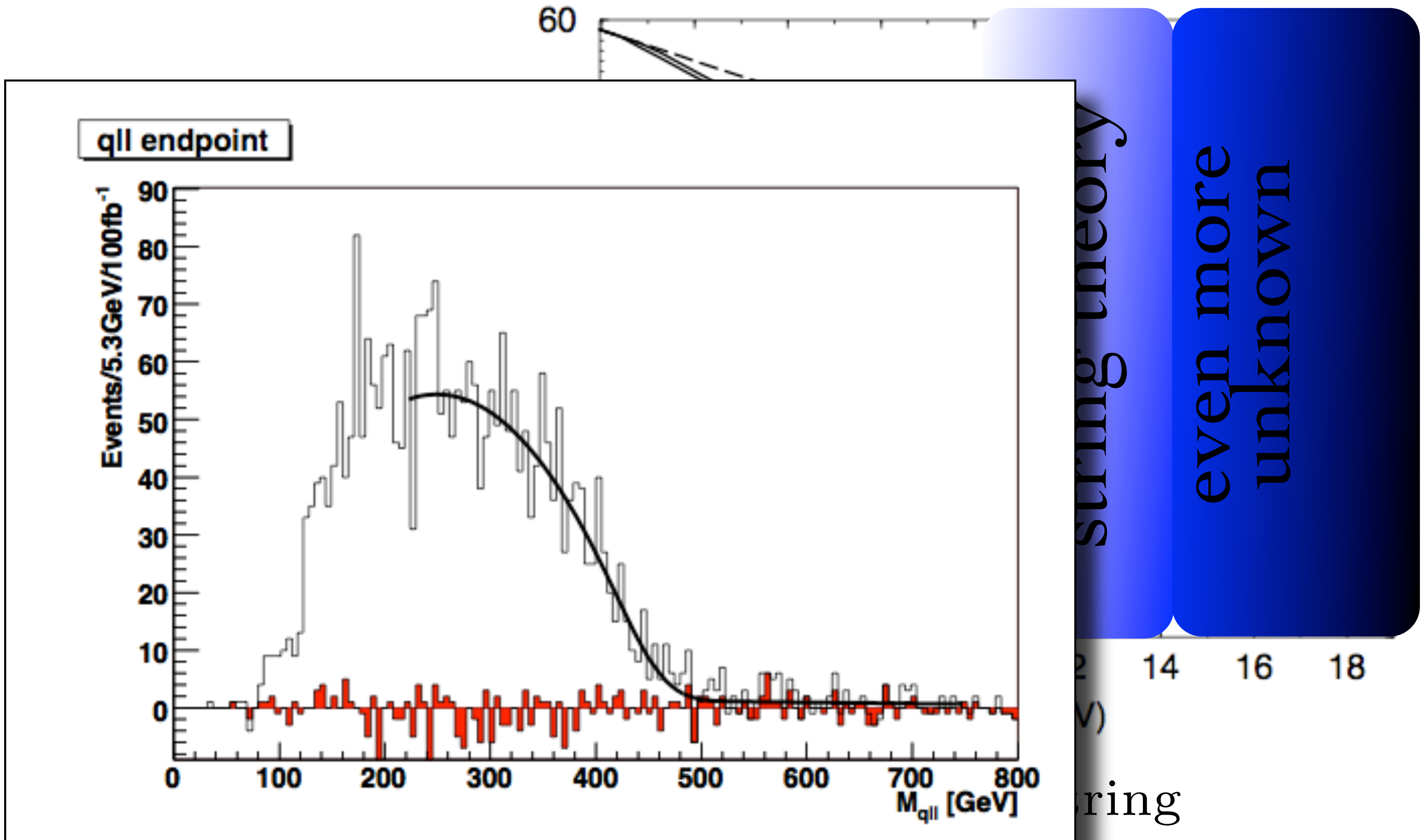

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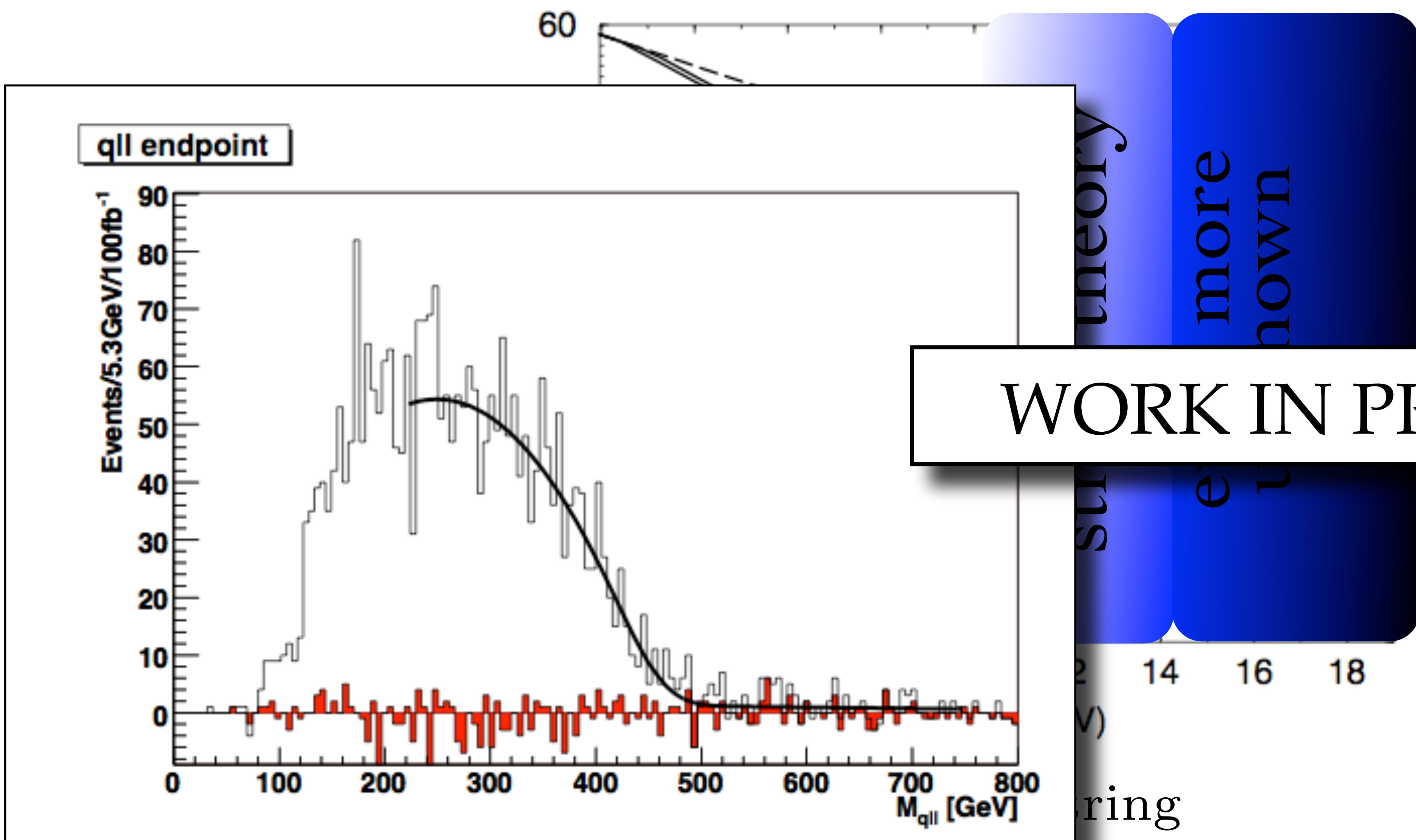

WORK IN PROGRESS

Summary

- Think carefully about priors and finetuning (obviously, check that code allows finetuning!)
- Mediation models (solutions to problems, **fewer** parameters) would be interesting to discuss more in context of scans
- **More** parameters but somewhat orthogonal (?) experimental signatures: *NMSSM* (PAMELA/ FERMI), *BMSSM* (light stops), *Anomalous U(1)* (gamma ray lines), *LVS* (collider,...), etc...

Summary

- A-terms (e.g. squark-squark-Higgs), B-term ($H_u H_d$), Higgs masses, squark, slepton, gaugino masses. (124 = 18(SM)+1(Higgs)+105)

- Restrictions by hand (MSSM):
  - TeV scale SUSY breaking (contrast "split SUSY")
  - one partner for each particle • μ not huge
  - exactly two Higgses • R-parity conservation
  - no SUSY *breaking* terms with dim > 3 • no C-terms
  - tiny flavor violation • tiny CP violation
  - cosmological constant zero

Thank you

- Hope to see you at panel discussion on Friday!