Economically Deflected Anomaly Mediation

Nobuchika Okada

Theory Division, High Energy Accelerator Research Organization (KEK)

In collaboration with

Rabindra Nath Mohapatra (University of Maryland)

Hai-Bo Yu (University of Maryland → UC, Irvine)

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1. Introduction

We need New Physics!

The Standard Model: hierarchy problem

Instability of Electroweak scale

← quadratic divergence of Higgs mass^2

(Cold) Dark Matter: WMAP data

← No candidate in SM

Some New Physics around ``1 TeV'' can solve these problems:

Stabilize the EW scale → New Physics scale O(1 TeV)

Reasonable DM relic density → WIMP hypothesis

$$\left.\begin{array}{l} m_{WIMP} = 100\mathrm{GeV} - 1\mathrm{TeV} \\ \sigma \sim 1/(1\mathrm{TeV})^2 \end{array}\right\} \Omega_{DM} h^2 = 0.1$$

More interestingly….

O(1 TeV) is accessible to future collider experiments

Large Hadron Collider (LHC)	**High discovery potential**
	→ find New Physics
International Linear Collider (ILC)	**precision measurements**
	→ discriminate New Phys. Models

Weak Scale Supersymmetry

SUSY Standard Model with O(1 TeV) soft SUSY breaking terms

The most promising candidate: sparticles around O(1TeV)

neutralino LSP as the DM candidate

And more…

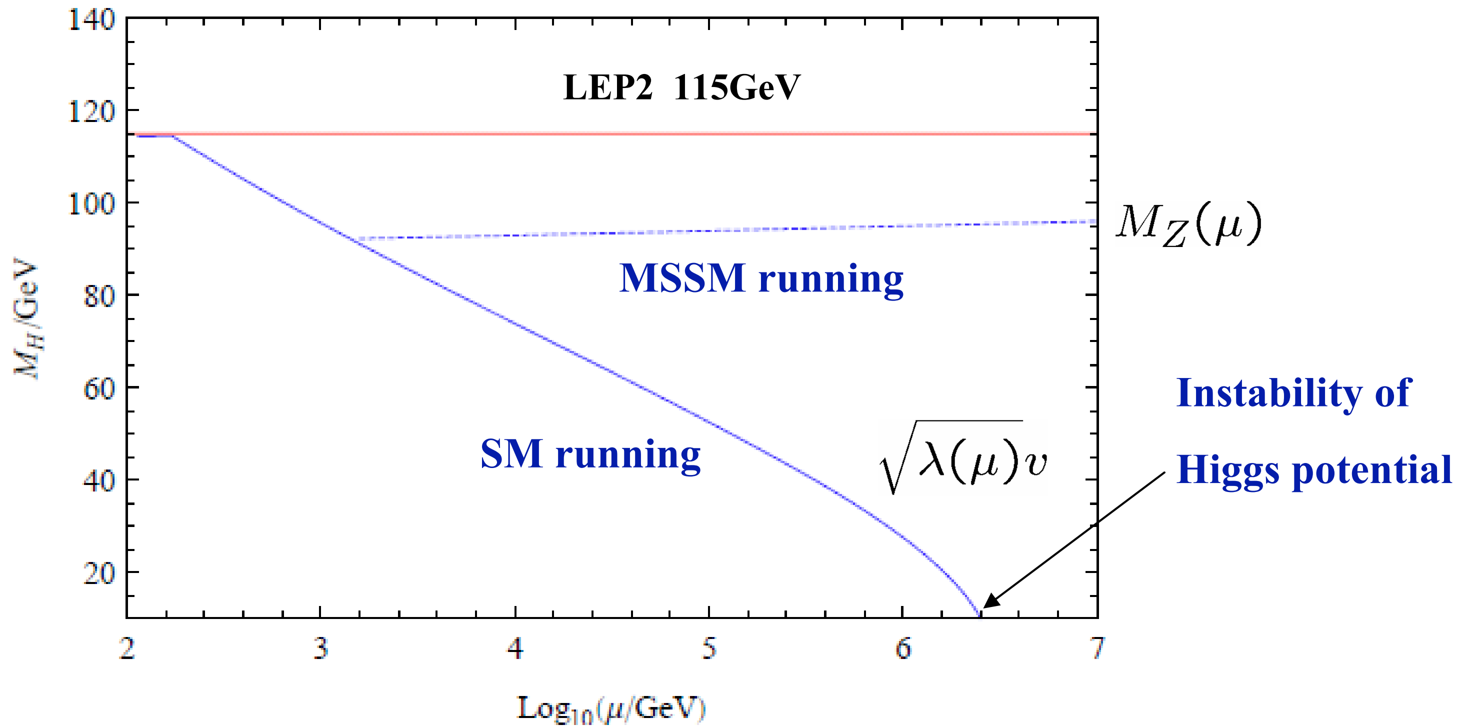
SUSY field theories → easier than non-SUSY field theory

controllable quantum corrections

``stable'' in UV

no quadratic divergence

non-renormalization theorem, …



Important issues in SUSY models

SUSY should be broken at low energies

→ What is the origin of SUSY breaking ?

the mechanism of SUSY breaking mediation ?

Current experiments:

No observation of sparticles

No significant FCNC & CP violation more than SM contributions

→ Clever mediation mechanism is necessary

not to cause SUSY FCNC & CP problems

but provide sparticle masses around 100GeV -1 TeV

Many scenarios have been proposed:

gauge mediation,

anomaly mediation,

gaugino mediation,

radion mediation,

modulus mediation,

mixed modulus-anomaly mediation,

…….

Each scenario provides typical sparticle mass spectrum

What we will do with LHC & ILC

Discovery of SUSY!

Then, sparticle mass spectroscopy

→ understand which is correct

Anomaly Mediation

Randall-Sundrum, '99

Giudice, Luty, Murayama, Rattazzi '99

SUSY breaking mediation through superconformal anomaly

flavor blind sparticle mass spectrum

UV insensitive soft SUSY breaking terms

→ model independent

In supergravity

SUSY breaking in hidden sector	→	Compensating multiplet $\phi = 1 + \theta^2 F_\phi$	→	Pick up F_ϕ through the violation of scale invariance (quantum corrections)

$$M_i = -\frac{\beta(g_i^2)}{2g_i^2} F_\phi = \frac{\alpha_i(\mu)}{4\pi} b_i F_\phi$$

$$m_i^2(\mu) = -\frac{\dot{\gamma}(\mu)}{4} |F_\phi|^2 = 2c_i \left(\frac{\alpha_i(\mu)}{4\pi}\right)^2 b_i |F_\phi|^2$$

Unfortunately, fatal problem: tachyonic slepton problem

For slepton mass^2 → $b_i < 0$ → $m_{\tilde{L}}^2,\ m_{\tilde{e}^c}^2 < 0$

Many efforts to solve this problem

New contributions which make slepton mass^2 positive

tree level: D-term contributions

Jack, Jones; Arkani-Hamed, Kaplan, Murayama, Nomura;

Kitazawa, Maru, N.O.; ….

quantum level: new threshold corrections

Katz, Shadmi, Shirman; Chacko, Luty, Maksymyk, Ponton; Chacko,

Luty, Ponton, Shadmi, Shirman; Allanach Dedes; Kaplan, Kribs;

Chacko, Luty; Chacko, Ponton; Nelson, Weiner; N.O.; Luty, Hsieh; ….

Deflected anomaly mediation **(Pomarol & Rattazzi, '99)**

Introduction of the messenger sector

new threshold contributions by the messengers

→ slepton mass^2 positive at low energy

2. Deflected anomaly mediation

Pomarol & Rattazzi, '99, Generalization → N.O. '02

Introduction of the messenger sector

$$W_{mess} = S\ \overline{\Psi}_i\ \Psi^i$$

Ex) $\overline{\Psi}_{i},\ \Psi^i$: 5+5* representation under SU(5)_SM

$$\langle S \rangle = S + \theta^2 F_S$$

→Gauge mediation contributions

→ soft mass RGEs are deflected from AMSB trajectories

However,

SUSY breaking in the messenger sector originates from AMSB

$$\boxed{\frac{F_S}{S} = d\ F_\phi}$$

d: deflection parameter

$$|d| \lesssim 1$$

$$\begin{cases} d = -1 & \text{Pomarol \& Rattazzi, '99,} \\ d > 0 & \text{N.O. '02} \end{cases}$$

How to get ``d'' of O(1)

In the superconformal framework of SUGRA

$$\mathcal{L} = \int d^4\theta\ \phi^\dagger\phi\ S^\dagger S + \left\{\int d^2\theta\ \phi^3 W(S) + h.c.\right\}$$ **with** $\phi = 1 + \theta^2 F_\phi$

$$V = |F_S|^2 - S^\dagger S|F_\phi|^2 - 3F_\phi W(S) - 3F_\phi^\dagger W(S)^\dagger$$

with $F_S = -\left(\frac{\partial\mathcal{K}}{\partial S^\dagger}F_\phi + \frac{\partial W^\dagger}{\partial S^\dagger}\right)$ **from E.O.M**

$$\frac{\partial V}{\partial S} = 0 \rightarrow \frac{F_S}{S} = -2F_\phi \frac{\frac{\partial W}{\partial S}}{S\frac{\partial^2 W}{\partial S^2}} \longrightarrow \boxed{d = -2\frac{\frac{\partial W}{\partial S}}{S\frac{\partial^2 W}{\partial S^2}}}$$

N.O. '02

To get O(1) ``d'' → SUSY mass of S should be light $\lesssim F_\phi$

$$W \sim S^p \longrightarrow d = \frac{2}{1-p}$$

- **higher dim OP → d < 0**
- **runaway → d > 0**

3. Soft mass spectrum in deflected AMSB

Soft mass can be extracted from

- **renormalized gauge coupling**
- **SUSY wave function renormalization coefficients**

Giudice & Rattazzi '98

Arkani-Hamed, Giudice, Luty & Rattazzi '98

$$\frac{M_i}{\alpha(\mu)} = \frac{F_\phi}{2}\left(\frac{\partial}{\partial \ln\mu} - d\frac{\partial}{\partial \ln|S|}\right)\alpha^{-1}(\mu, S)$$

$$m_i^2(\mu) = -\frac{|F_\phi|^2}{4}\left(\frac{\partial}{\partial \ln\mu} - d\frac{\partial}{\partial \ln|S|}\right)^2 \ln Z_i(\mu, S)$$

For N pairs of (5+5*) messengers

$$\alpha^{-1}(\mu, S) = \alpha^{-1}(\Lambda_{cut}) + \frac{b-N}{4\pi}\ln\left(\frac{S^\dagger S}{\Lambda_{cut}^2}\right) + \frac{b}{4\pi}\ln\left(\frac{\mu^2}{S^\dagger S}\right),$$

$$Z_i(\mu, S) = Z_i(\Lambda_{cut})\left(\frac{\alpha(\Lambda_{cut})}{\alpha(S)}\right)^{\frac{2c_i}{b-N}}\left(\frac{\alpha(S)}{\alpha(\mu)}\right)^{\frac{2c_i}{b}}$$

Sign of ``d'' is important!

For the first 2 generations (neglecting Yukawa coupling)

$$M_i(\mu) = \frac{\alpha_i(\mu)}{4\pi} F_\phi (b_i + dN)$$

$$\tilde{m}_i^2(\mu) = 2c_i \left(\frac{\alpha_i(\mu)}{4\pi}\right)^2 |F_\phi|^2 \, b_i \, G(\mu, S)$$

$$G(\mu, S) = \left(\frac{N}{b_i}\xi_i^2 + \frac{N^2}{b_i^2}(1-\xi_i^2)\right) d^2 + 2\frac{N}{b_i} d + 1$$

$$\xi_i \equiv \frac{\alpha_i(S)}{\alpha_i(\mu)} = \left[1 + \frac{b_i}{4\pi}\alpha_i(\mu) \ln\left(\frac{S^\dagger S}{\mu^2}\right)\right]^{-1}$$

Slepton mass @ messenger scale

pure AMSB: negative

$$\tilde{m}_i^2(S) = 2c_i \left(\frac{\alpha_i(S)}{4\pi}\right)^2 |F_\phi|^2 \left[N d^2 + 2Nd + b_i\right]$$

GMSB: positive

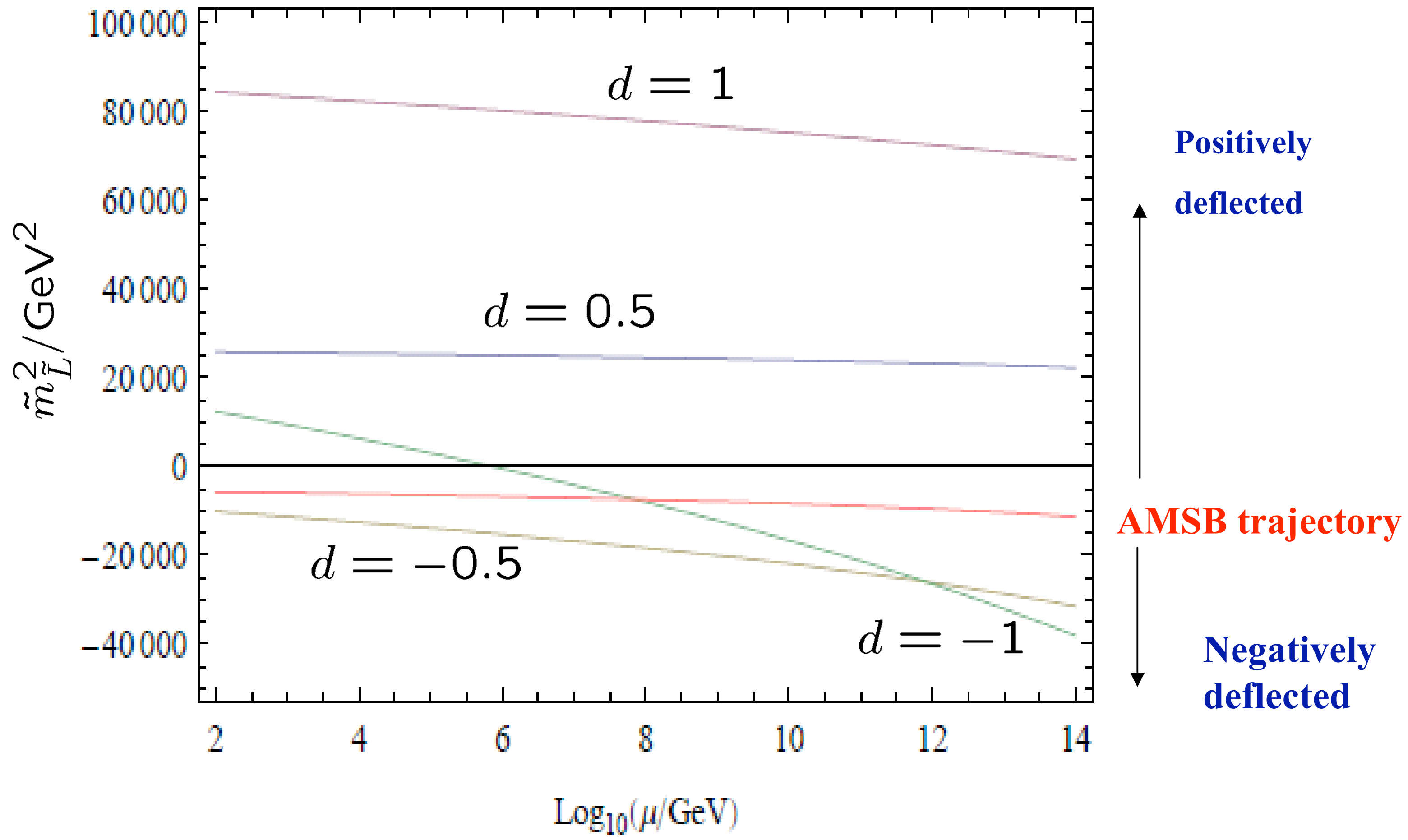
Negative: d < 0

Positive: d >0

Example: $F_\phi = 20$ TeV

$\langle S \rangle = 10^{14}$ GeV

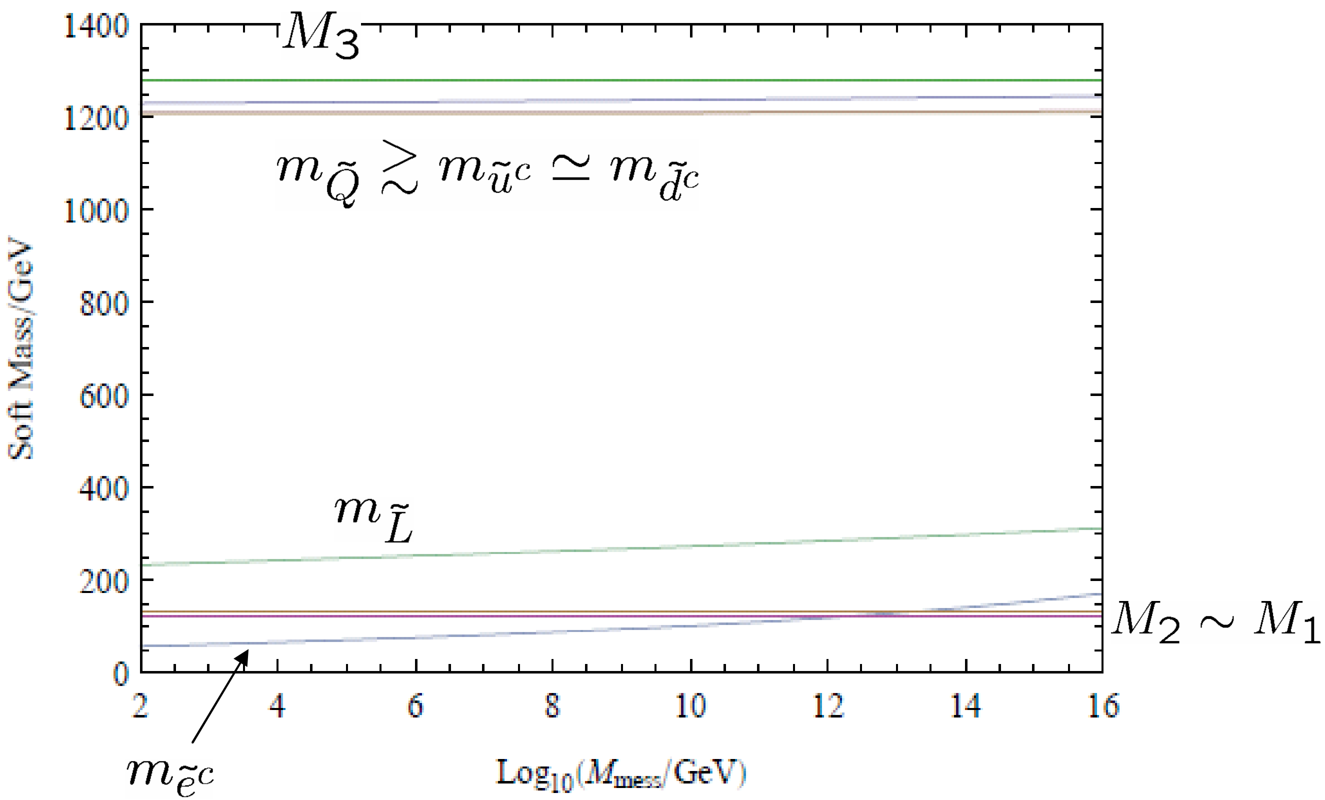
$N = 4$



Example: $F_\phi = 25$ TeV $N = 3$

$d = 1$

Soft mass spectrum @ EW scale as a function of Messenger scale



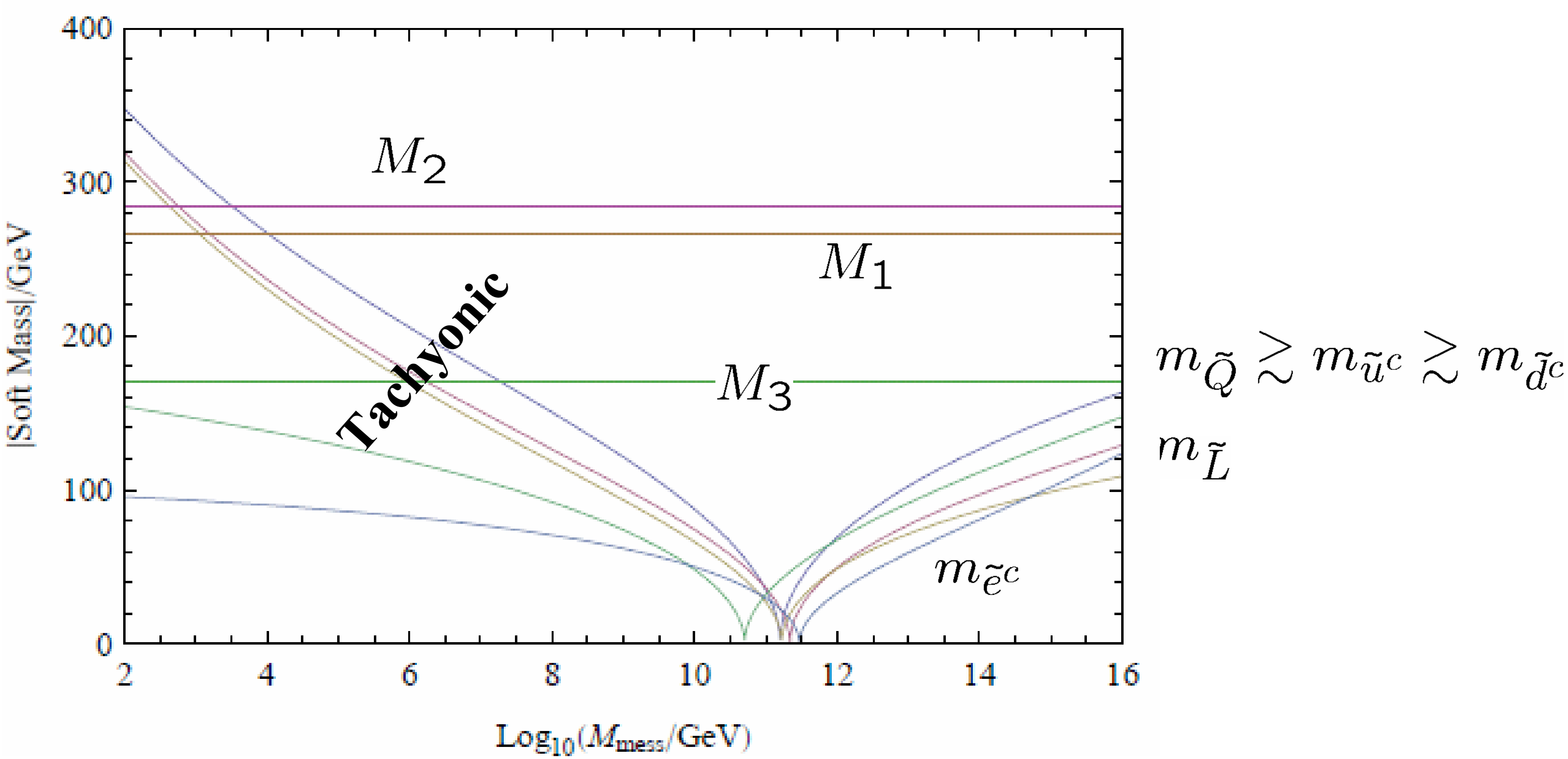
Long running is necessary for B-ino LSP

Messenger scale in the intermediate

Example: $F_\phi = 25$ TeV $N = 4$

$d = -1$

Soft mass spectrum @ EW scale as a function of Messenger scale



Long running is necessary for slepton mass^2 > 0

Slepton LSP → cosmologically disfavored

Very characteristic mass spectrum

4. Economical scenario

Model dependence: **d ?**

messenger scale ?

representation of the messenger ?

General discussion:

$d > 0$ → B-ino LSP is possible (cosmologically favored)

Messenger scale is around intermediate scale or higher

To make slepton mass^2 positive → no need colored messenger

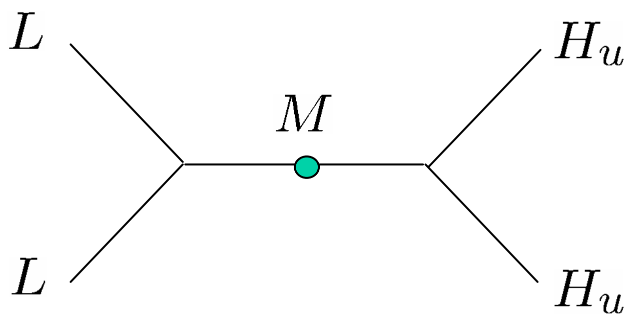
Intermediate scale → the scale of See-Saw mechanism

Can the messenger play an important role in see-saw model?

Yes, in type II see-saw

	SU(2)	U(1)
$\overline{\Delta}$	3	-1
Δ	3	+1

$$W = L\Delta L + H_u\overline{\Delta}H_u + M\overline{\Delta}\Delta$$



$$m_\nu \sim \frac{\langle H_u\rangle\langle H_u\rangle}{M}$$

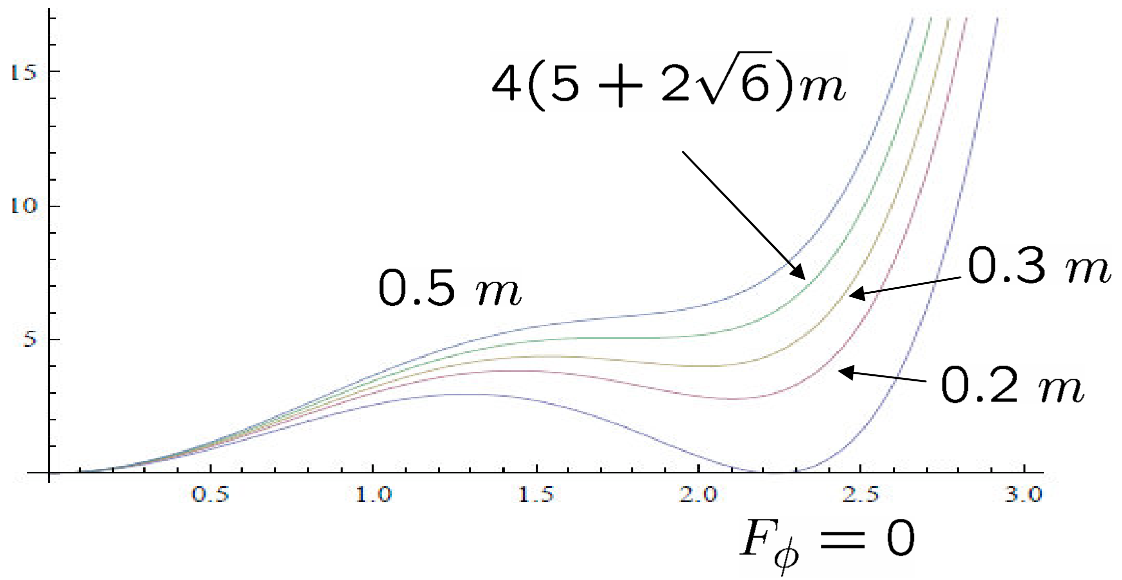
$M = 10^{12-14}$ GeV **gives the right scale for light neutrino mass**

We can use $\overline{\Delta}$, Δ in the messenger in the deflected anomaly mediation scenario!

$$W_{mess} = S\overline{\Delta}\Delta$$

How to naturally generate the intermediate scale? $\langle S \rangle = M$

Simple model: $W(S) = -mS^2 + \lambda \frac{S^4}{M_{Pl}}$



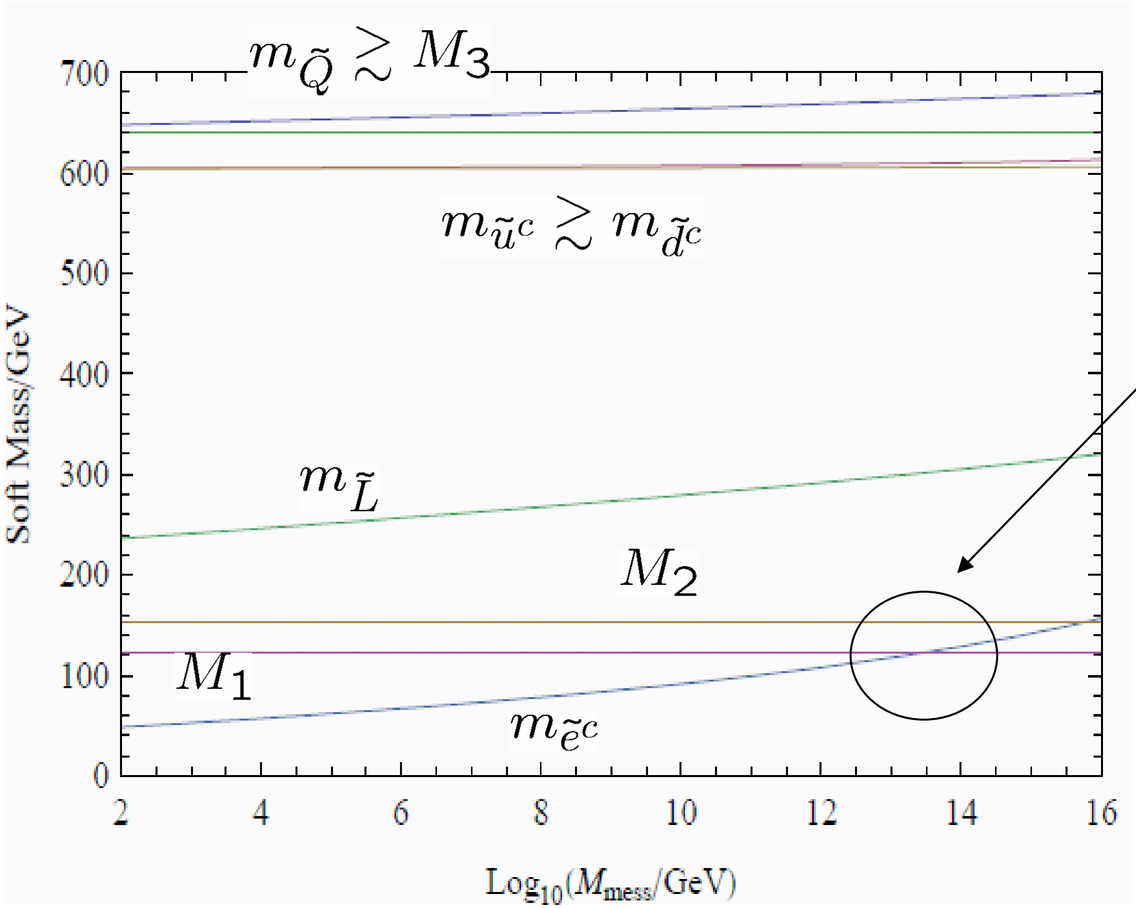
For fixed m, M_Pl

$\langle S \rangle \sim \sqrt{mM_{Pl}} \sim F_\phi M_{Pl}$

$d_{max} \simeq 0.82$

$\begin{cases} d = d_{max} = 0.82 \\ F_\phi = 25 \text{ TeV} \\ \textbf{Messengers: } \overline{\Delta},\ \Delta \end{cases}$

Soft mass spectrum @ EW scale as a function of Messenger scale



B-ino LSP for

$\langle S \rangle = 10^{13-14}$ GeV

degenerating with slepton

→Good for B-ino like LSP

to get correct abundance

5. Conclusion

We have discussed the so-called deflected AMSB, in which ``tachyonic slepton'' problem in pure AMSB scenario can be cured through threshold corrections by the messenger fields.

We propose an economical setup of this scenario with a positive deflection parameter and SU(2) triplet messenger fields.

The messenger fields play another important role in the type II see-saw mechanism.

With the messenger scale being the reasonable see-saw scale, B-ino is the LSP degenerating with sleptons, so that its co-annihilations with sleptons would result in reasonable relic density.