SUGRA without MSUGRA

Tuhin S. Roy

Graham D. Kribs (UO),
Takemichi Okui (FSU)

(work in progress)

Weak scale susy with a R parity is an elegant and cool solution to the hierarchy problem

But it is also a supercomplex beast

*the complexity lies **not** in the number of additional particles introduced*
(superpartners + extra Higgs)

the complexity lies in the peripheral mechanisms that need to be introduced to make susy work

the root cause of all trouble:

SUSY needs to be broken

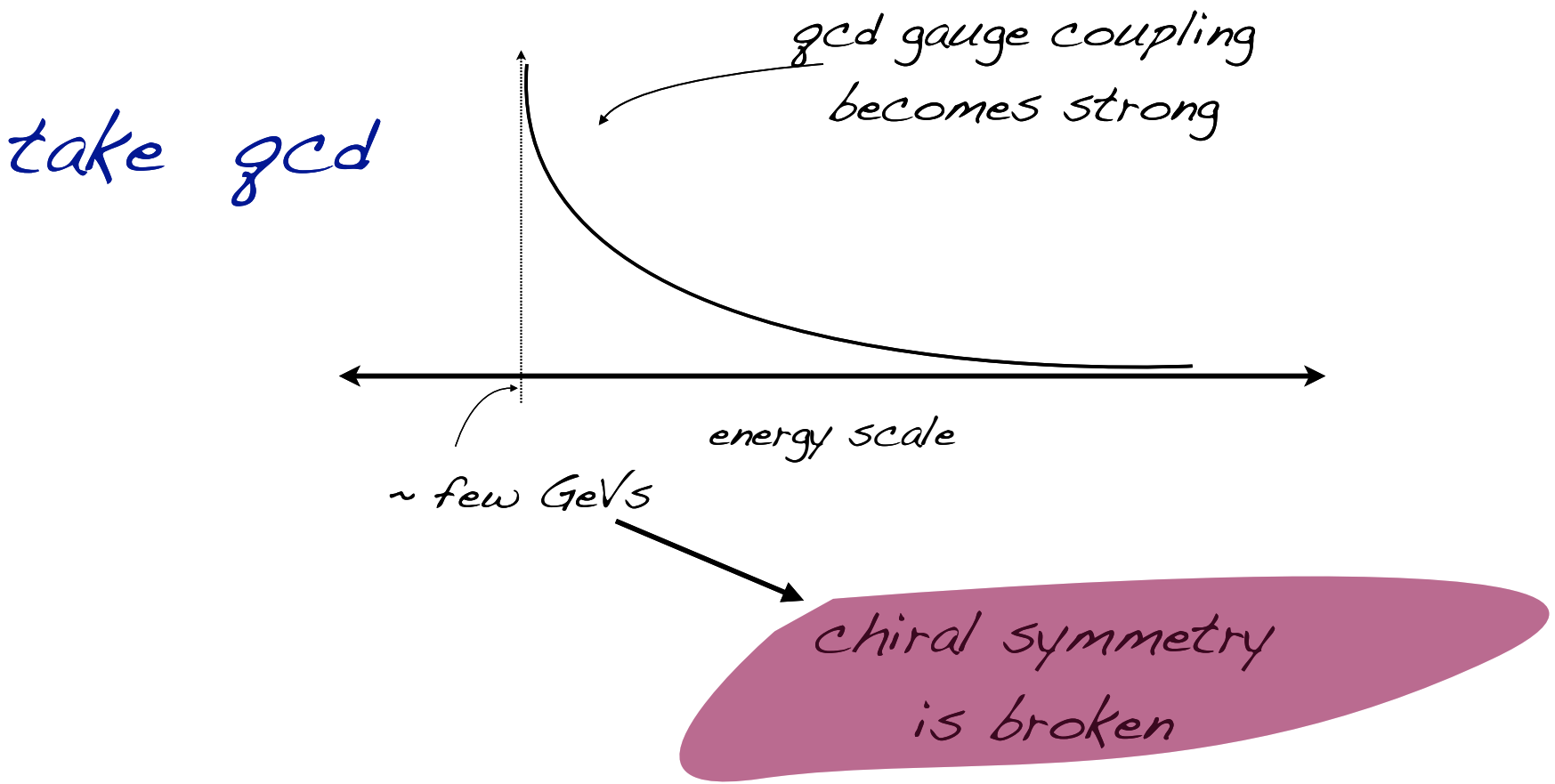
Trouble with breaking SUSY:

susy can't be broken by any of the SM fields or their superpartners because of the sum rule

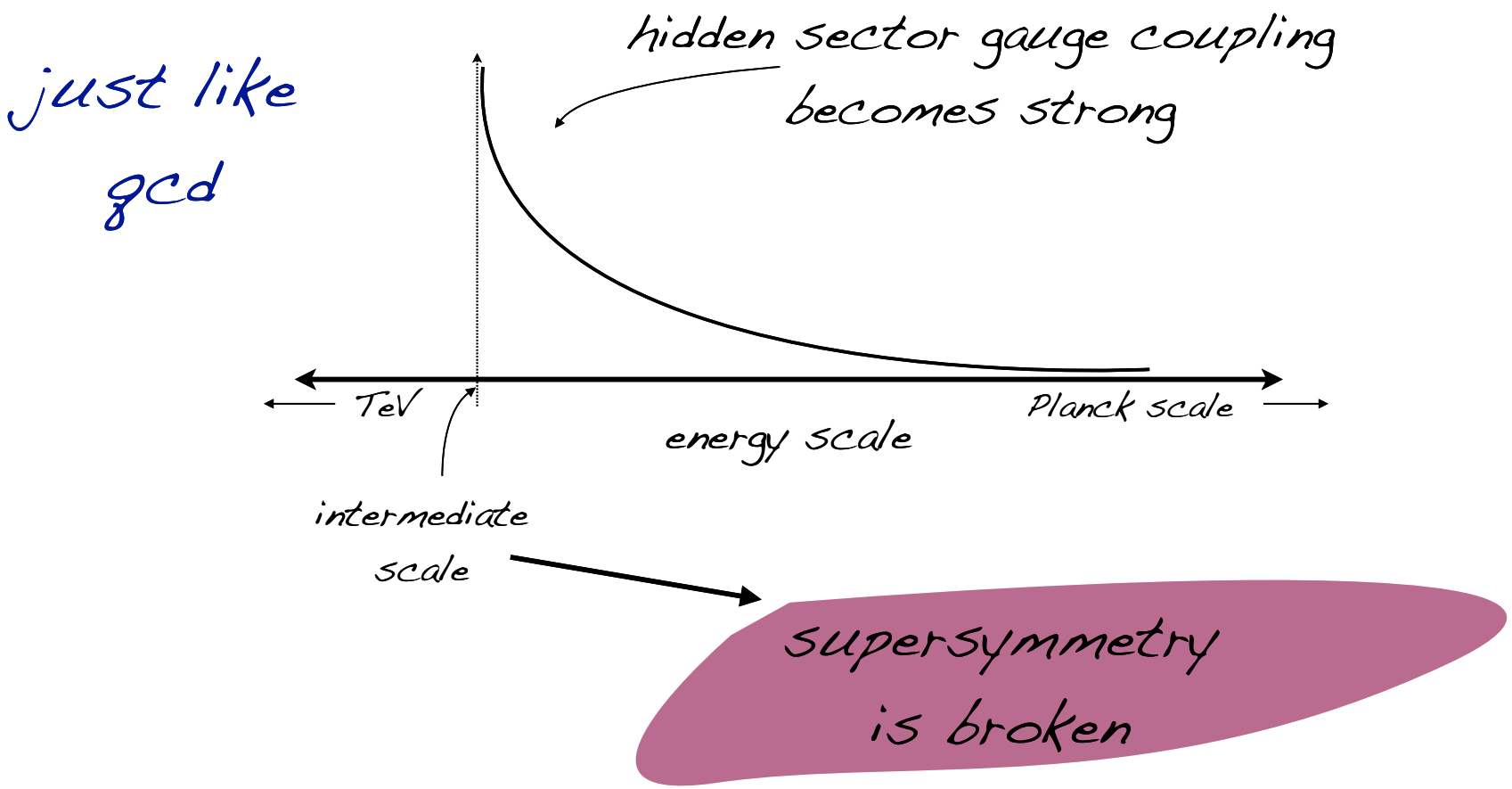
$$\mathrm{Tr}(\mathbf{m_s^2}) \; - \; \mathbf{2}\mathrm{Tr}(\mathbf{m_F^\dagger m_F}) \; + \; \mathbf{3}\mathrm{Tr}(\mathbf{m_V^2}) \; = \; \mathbf{0}$$

need to have a separate sector to break susy

SUSY is broken dynamically in a hidden sector



SUSY is broken dynamically in a hidden sector



Skeleton of a SUSY model

Where is SUSY broken ?

hidden sector

Skeleton of a SUSY model

Where is SUSY broken ?

hidden sector

How is SUSY broken ?

DSB

Skeleton of a SUSY model

Where is SUSY broken ?

hidden sector

How is SUSY broken ?

DSB

How is SUSY breaking communicated ?

messenger mechanism
gauge, gaugino, anomaly etc etc

Skeleton of a SUSY model

Where is SUSY broken ?

hidden sector

How is SUSY broken ?

DSB

How is SUSY breaking communicated ?

messenger mechanism
gauge, gaugino, anomaly etc etc

$\mu - B_\mu$ problem

tachyonic sleptons

Skeleton of a SUSY model

Where is SUSY broken ?

hidden sector

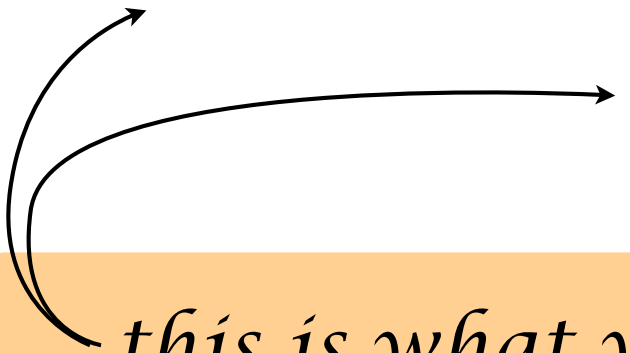
How is SUSY broken ?

DSB

How is SUSY breaking communicated ?

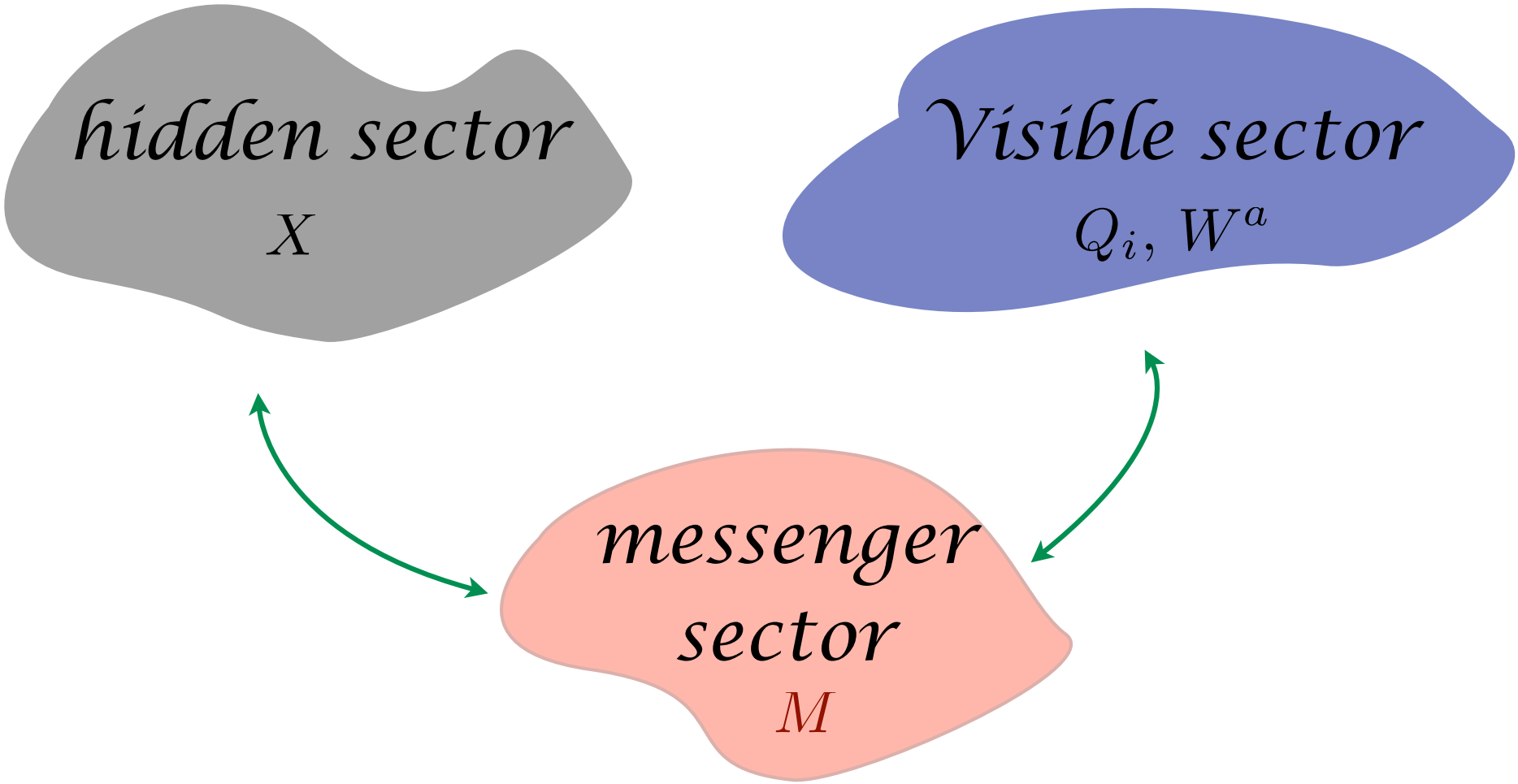
messenger mechanism

gauge, gaugino, anomaly etc etc



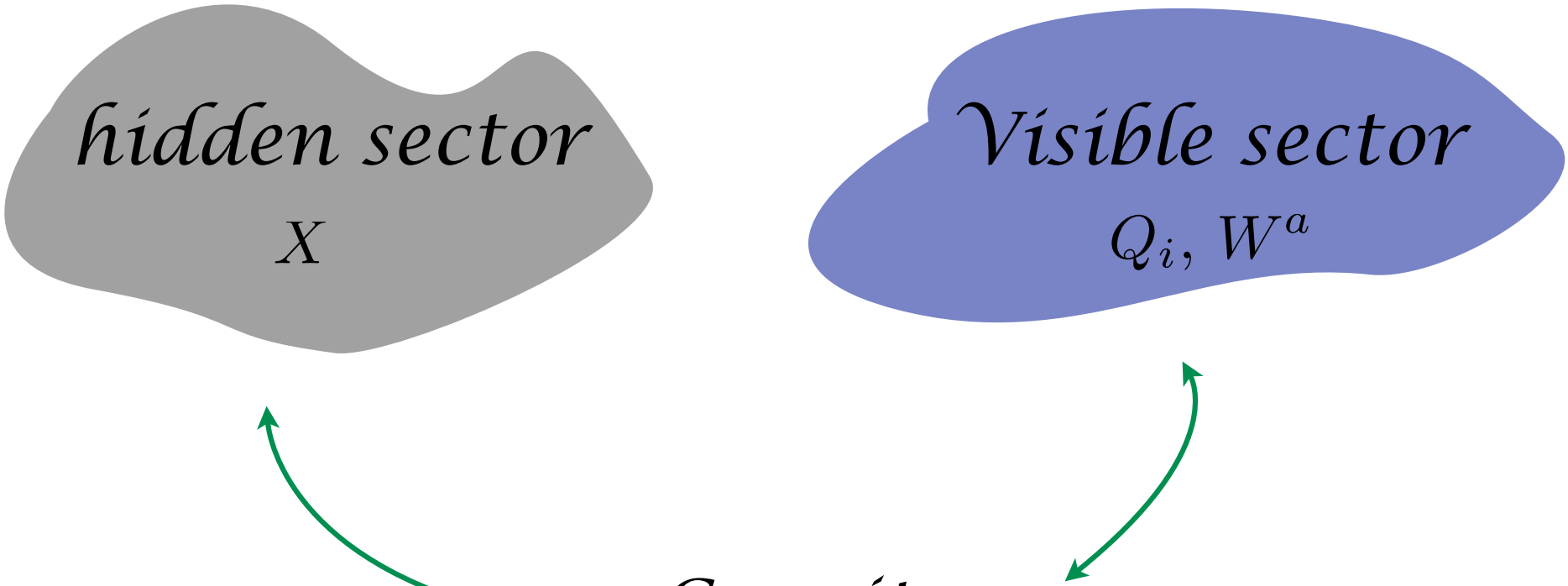
this is what will be simplified in this talk

general structure of a susy model



$$c_{ij}\,\frac{1}{M^2}\;X^\dagger X\;Q_i^\dagger Q_j$$

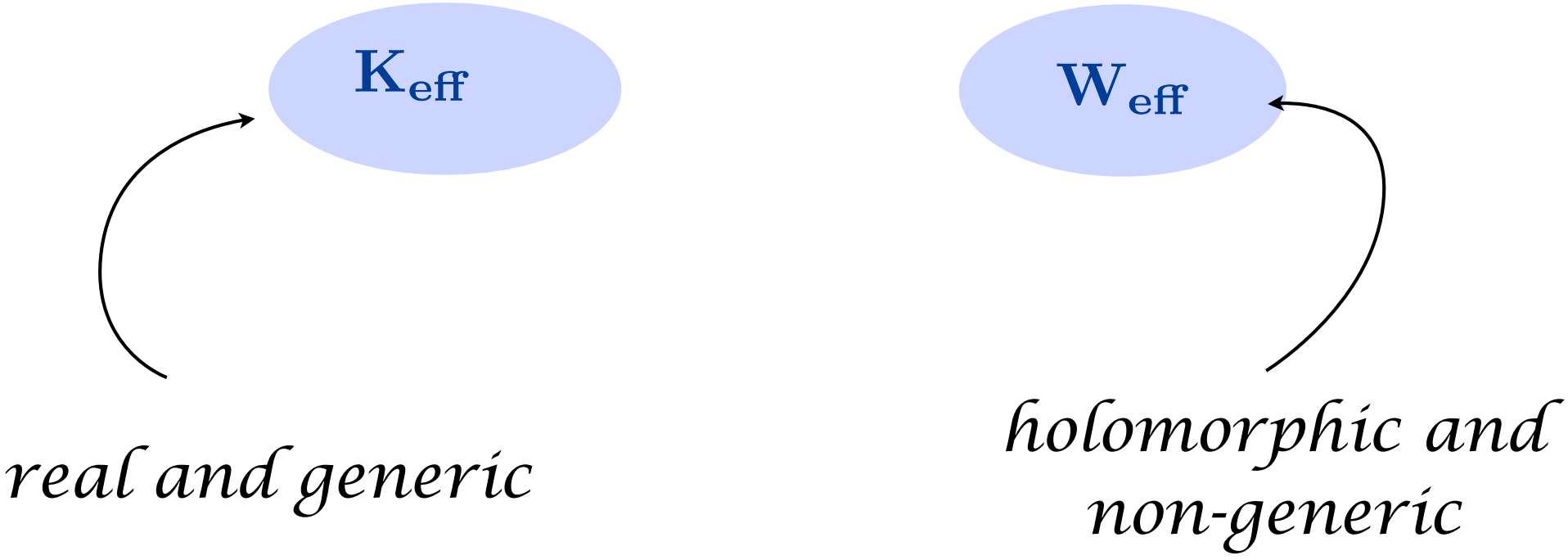
no need for additional messenger mechanism



$$c_{ij}\,\frac{1}{M_{\rm Pl}^2}\;X^\dagger X\;Q_i^\dagger Q_j$$

Gravity mediation

after Planck scale physics is integrated out the effective interactions can be summarized in



Gravity mediation

after Planck scale physics is integrated out the effective interactions can be summarized in

$$\mathbf{K_{eff}} \supset c_{ij} \frac{1}{M_{\rm Pl}^2} X^\dagger X \, Q_i^\dagger Q_j$$

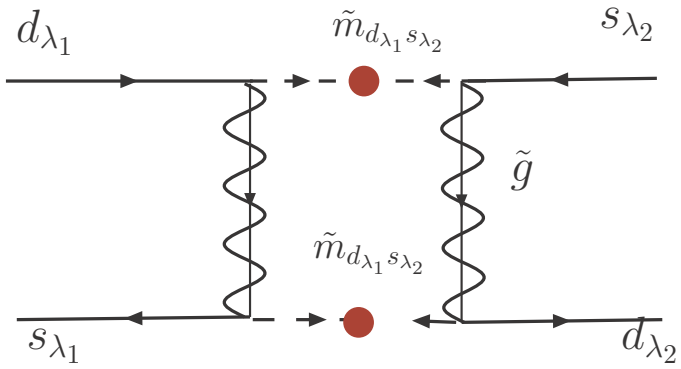
$$m_{ij}^2 \, \tilde{q}_i^* \, \tilde{q}_j$$

can't be flavor diagonal

real and generic

flavor problem

For example, $K_0 - \bar{K}_0$ *mixing*

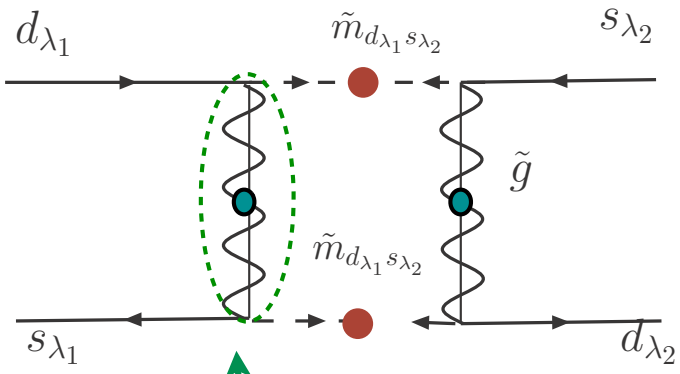


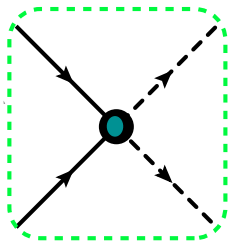
$$\delta_L \equiv \frac{(m^2_{\tilde{Q}})_{12}}{m^2_{\tilde{q}}} \qquad \delta_R \equiv \frac{(m^2_{\tilde{D}})_{12}}{m^2_{\tilde{q}}}$$

$$\delta_L = \delta_R = \delta \lesssim 0.003 \quad \begin{cases} m_{\tilde{q}} = 1 \text{ TeV} \\ m_{\tilde{g}} = 2 \text{ TeV} \end{cases}$$

For example, $K_0 - \bar{K}_0$ *mixing*

$m_{\tilde{g}} \gg m_{\tilde{q}}$





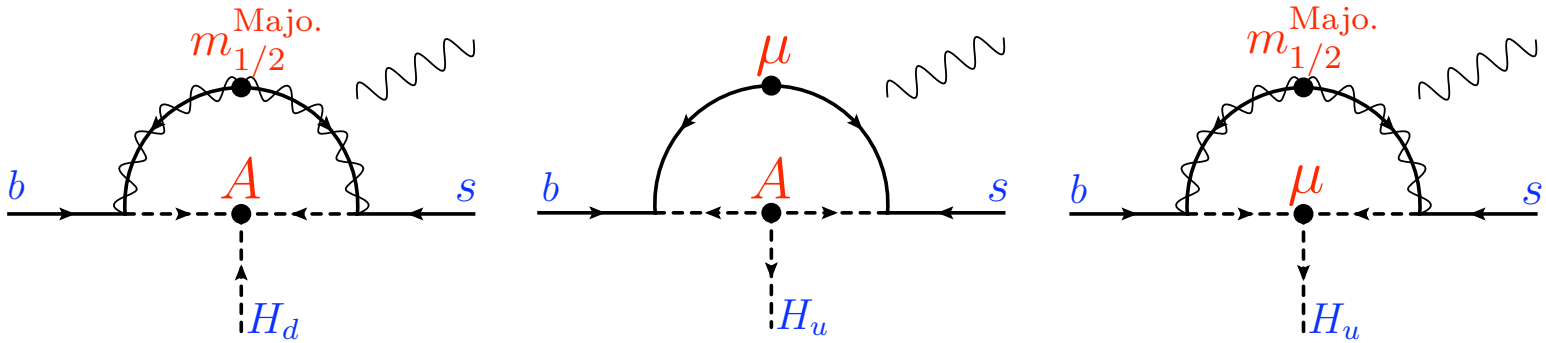
$$\frac{1}{m_{\tilde{g}}}(d_i d_j)\tilde{d}_k^* \tilde{d}_l^*$$

$$\Delta M_{K_0 - \bar{K}_0} \propto \left(\frac{m_{\tilde{q}}}{m_{\tilde{g}}}\right)^2$$

suppressed but not enough

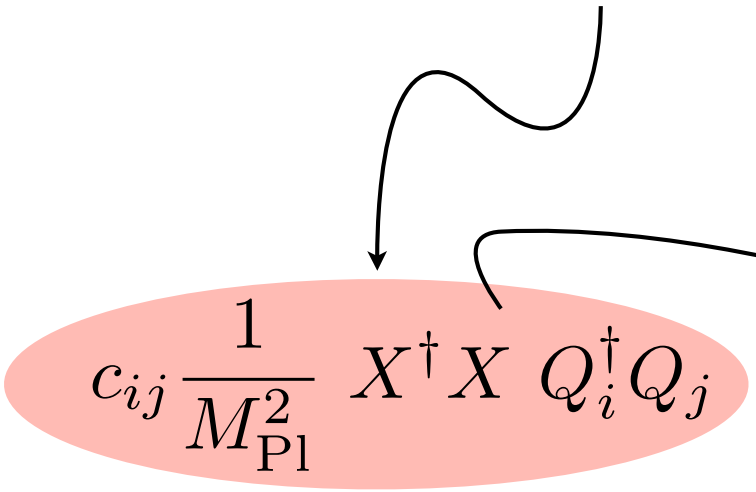
life is worse when we include Higgs sector

--- Excessive $\mu \to e\gamma\,,\ b \to s\gamma$ etc. ---



Flavor problem kills gravity mediation

but gravity mediation is always there



must be suppressed
+
new messenger mediation must be introduced

Here is our solution

old gravity mediation

+

Flow of the talk

current state of affair of susy model building

our solution

step I

step II

a sample point

phenomenology

conclusion

Step 1:

hidden sector

only consider model which has no singlet and has an **U(1)** *that participate in susy breaking*

A concrete example:

(Dine, Nelson, Nir, Shirman, '95)

SU(4) X U(1)

X_1	$\square$	-3
X_2	$\overline{\square}$	-1
X_3	$\begin{array}{|c\|}\hline\square\\\hline\square\\\hline\end{array}$	2
X_4	1	4

$g_4 \gg \lambda \gg g_1$

$W = \lambda X_1 X_2 X_4$

Λ_4

$$W_{np} = \frac{\Lambda_4^5}{X_1 X_2 X_3^2}$$

susy breaking vev at

$$D_1 = 1.4\, F_{X_4} \neq 0$$

that was step I

but even before I proceed to step II
let me briefly mention
how life is significantly better ...

Gravity mediation

let's postpone Higgses for now

$$\mathbf{K}_{\text{eff}} \supset c_{ij} \frac{1}{M_{\text{Pl}}^2} X^\dagger X Q_i^\dagger Q_j$$

$$\mathbf{W}_{\text{eff}} \supset w_a \frac{X}{M_{\text{Pl}}} W_a W_a + \sqrt{2}\, \Omega_a \frac{W'}{M_{\text{Pl}}} W_a \Phi_a$$

majorana mass

Dirac mass

Gravity mediation

let's postpone Higgses for now

$$\mathbf{K}_{\rm eff} \supset c_{ij} \frac{1}{M_{\rm Pl}^2} X^\dagger X Q_i^\dagger Q_j$$

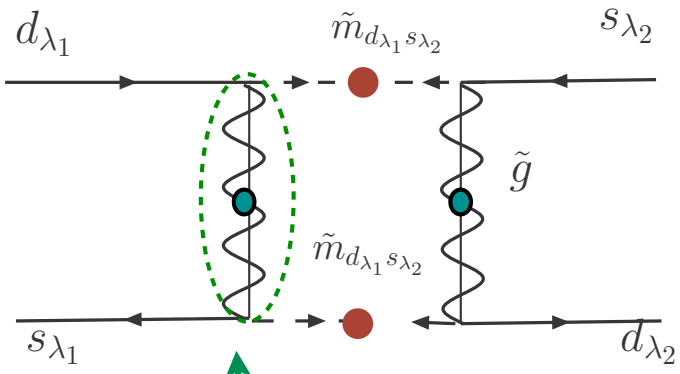
$$\mathbf{W}_{\rm eff} \supset w_a \frac{X}{M_{\rm Pl}} W_a W_a + \sqrt{2}\, \Omega_a \frac{W'}{M_{\rm Pl}} W_a \Phi_a$$

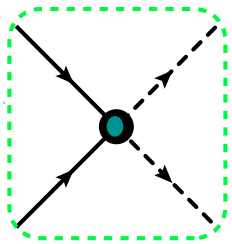
These interactions preserve an $\mathrm{U}(1)_R$

$$R[Q_i] = 1$$
$$R[W_a] = 1$$
$$R[\Phi_a] = 0$$

For example, $K_0 - \bar{K}_0$ mixing

$m_{\tilde{g}} \gg m_{\tilde{q}}$





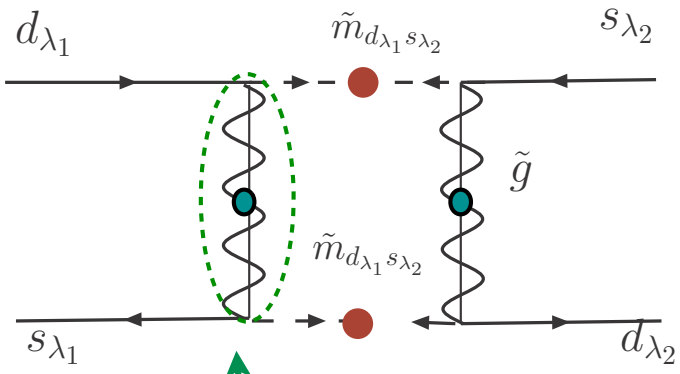
$$\frac{1}{m_{\tilde{g}}}(d_i d_j)\tilde{d}_k^* \tilde{d}_l^*$$

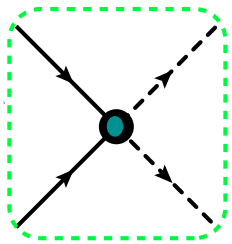
Kribs, Poppitz and Weiner ('08)

No such operator would be generated

breaks R *by* 2 *units*

For example, $K_0 - \bar{K}_0$ *mixing*





$$\frac{1}{m_{\tilde{g}}^2}(\bar{d}_i \bar{\sigma}^\mu d_j)\tilde{d}_k^* \partial_\mu \tilde{d}_l$$

enough suppression if

$$\frac{m_{\tilde{q}}}{m_{\tilde{g}}} \sim 0.1 \qquad \frac{\tilde{m}_{12}^2}{\tilde{m}_q^2} \sim 0.1$$

$$\Delta M_{K_0 - \bar{K}_0} \propto \left(\frac{m_{\tilde{q}}}{m_{\tilde{g}}}\right)^4$$

let's now include the Higgs sector

$$\mathbf{W_{eff}} \supset \frac{1}{M_{\rm Pl}} X \, (QUH_u + QDH_d)$$

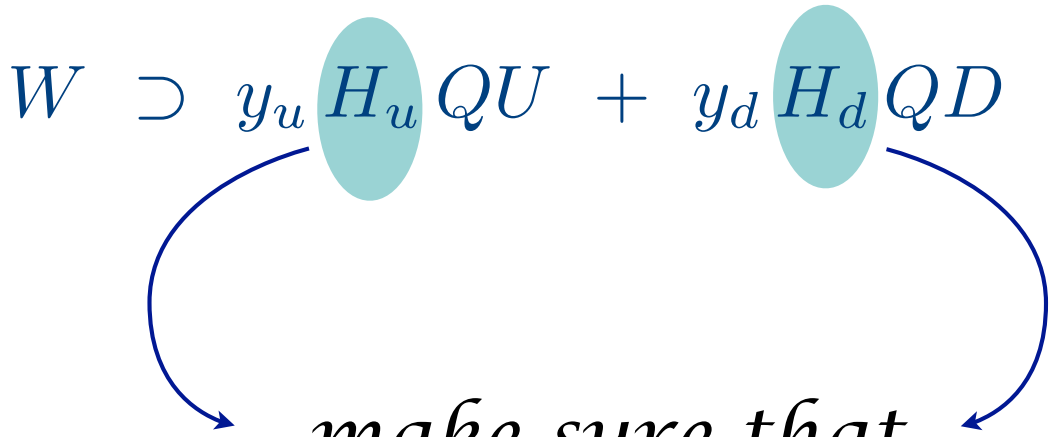
$$\mathbf{K_{eff}} \supset \frac{1}{M_{\rm Pl}} X^\dagger H_u H_d$$

there is no $\mathcal{A}$-term or μ term

all flavor violation due to $\mathcal{A}$ & μ vanish

but Higgsinos are massless!

Prescription for Higgsino mass



make sure that
they don't talk to each other

Also, no singlet means no G-M mass term

step II

as promised I will now
tweak the visible sector

step II

visible sector

$$W \supset S H R + S^2 T$$

	$\mathrm{SU}(2)_W$	$\mathrm{U}(1)_Y$	$\mathrm{U}(1)_X$
$R_{u,d}$	$\square$	$\mp 1/2$	± 1
$S_{u,d}$	1	0	∓ 1
$T_{u,d}$	1	0	± 2

new gauge group

EWSB potential is stable around

$$\langle S \rangle \neq 0, \quad \langle H \rangle \neq 0. \qquad \langle R \rangle = \langle T \rangle = 0$$

no $X^\dagger X \; H^\dagger R$

Gravity mediation

$$\mathbf{K}_{\rm eff} \supset \frac{X^\dagger X}{M_{\rm Pl}^2} c_{ij} Q_i^\dagger Q_j +$$

$$\frac{X^\dagger X}{M_{\rm Pl}^2} (b_h H_u H_d + b_r R_u R_d + b_s S_u S_d + b_t T_u T_d)$$

$$\mathbf{W}_{\rm eff} \supset \sqrt{2}\, \Omega_a \frac{W'}{M_{\rm Pl}} W_a \Phi_a$$

Gravity mediation

$$\mathbf{K}_{\rm eff} \supset \frac{X^\dagger X}{M_{\rm Pl}^2} c_{ij} Q_i^\dagger Q_j + \frac{X^\dagger X}{M_{\rm Pl}^2} (b_h H_u H_d + b_r R_u R_d + b_s S_u S_d + b_t T_u T_d)$$

$$\mathbf{W}_{\rm eff} \supset \sqrt{2}\, \Omega_a \frac{W'}{M_{\rm Pl}} W_a \Phi_a$$

$$R[H_{u,d}] = 0$$
$$R[R_{u,d}] = 2$$
$$R[S_{u,d}] = 0$$
$$R[T_{u,d}] = 2$$

Gravity mediation

$$\mathbf{K}_{\rm eff} \supset \frac{X^\dagger X}{M_{\rm Pl}^2} c_{ij} Q_i^\dagger Q_j + \frac{X^\dagger X}{M_{\rm Pl}^2} (b_h H_u H_d + b_r R_u R_d + b_s S_u S_d + b_t T_u T_d)$$

$$\mathbf{W}_{\rm eff} \supset \sqrt{2}\, \Omega_a \frac{W'}{M_{\rm Pl}} W_a \Phi_a$$

breaks R by 4 unit

$$R[H_{u,d}] = 0$$
$$R[R_{u,d}] = 2$$
$$R[S_{u,d}] = 0$$
$$R[T_{u,d}] = 2$$

wouldn't give rise to dangerous dim-5 flavor violating operators since they break R by 2 unit

Flow of the talk

current state of affair of susy model building

our solution

step I

step II

a sample point

phenomenology

conclusion

A sample point

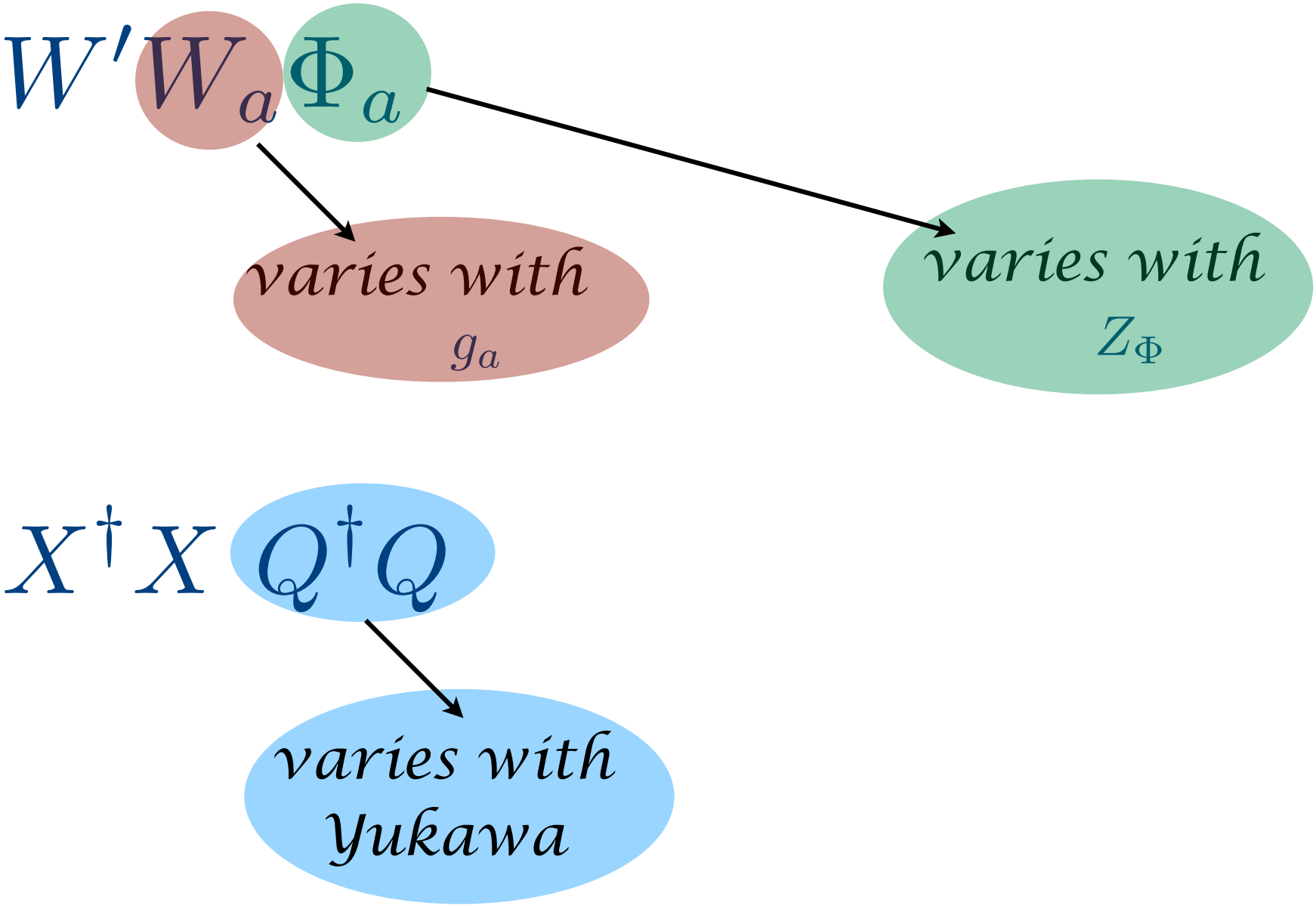
Planck scale inputs

$$\frac{F_X}{M_{\rm Pl}} = \frac{1}{1.4}\frac{D}{M_{\rm Pl}} = 500\ {\rm GeV}$$

$$\left.\begin{array}{l} \Omega_a = 1.4 \\ c_{ij}^{\rm sq} = 0.4 \end{array}\right\} \quad \begin{array}{l} M_a = 1\ {\rm TeV} \\ m_{\tilde{q}}^2 = (300\ {\rm GeV})^2 \end{array}$$

completely anarchic squark soft mass

RGE evolution



A sample point

TeV scale outputs

$$M_a(M_{\rm Pl}) \;=\; 1 \text{ TeV}$$

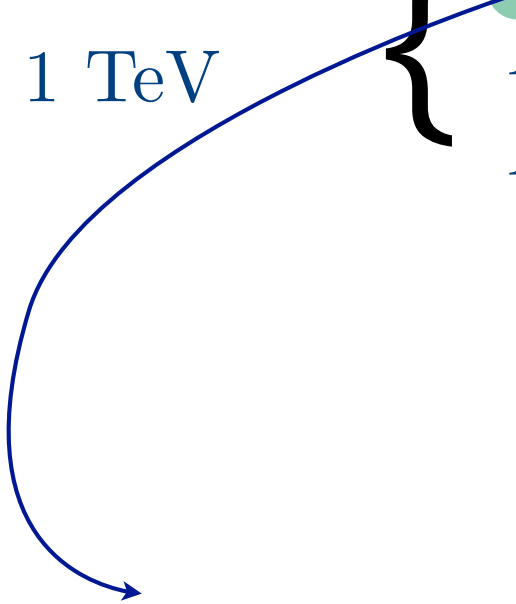
$$\left\{ \begin{array}{lcl} M_3(\text{TeV}) & \sim & 5.4 \text{ TeV} \\ M_2(\text{TeV}) & \sim & 1 \text{ TeV} \\ M_1(\text{TeV}) & \sim & 600 \text{ GeV} \end{array} \right.$$

A sample point

TeV scale outputs

$$M_a(M_{\rm Pl}) \;=\; 1 \text{ TeV}$$

$$\left\{ \begin{array}{lcl} M_3(\text{TeV}) & \sim & 5.4 \text{ TeV} \\ M_2(\text{TeV}) & \sim & 1 \text{ TeV} \\ M_1(\text{TeV}) & \sim & 600 \text{ GeV} \end{array} \right.$$



$$m^2_{\tilde{q}}(\text{TeV}) \;\sim\; (1.3 \text{ TeV})^2 \times \text{ flavor diagonal}$$

A sample point

TeV scale outputs

$$M_a(M_{\rm Pl}) \;=\; 1 \text{ TeV} \qquad \left\{ \begin{array}{lcl} M_3(\text{TeV}) & \sim & 5.4 \text{ TeV} \\ M_2(\text{TeV}) & \sim & 1 \text{ TeV} \\ M_1(\text{TeV}) & \sim & 600 \text{ GeV} \end{array} \right.$$

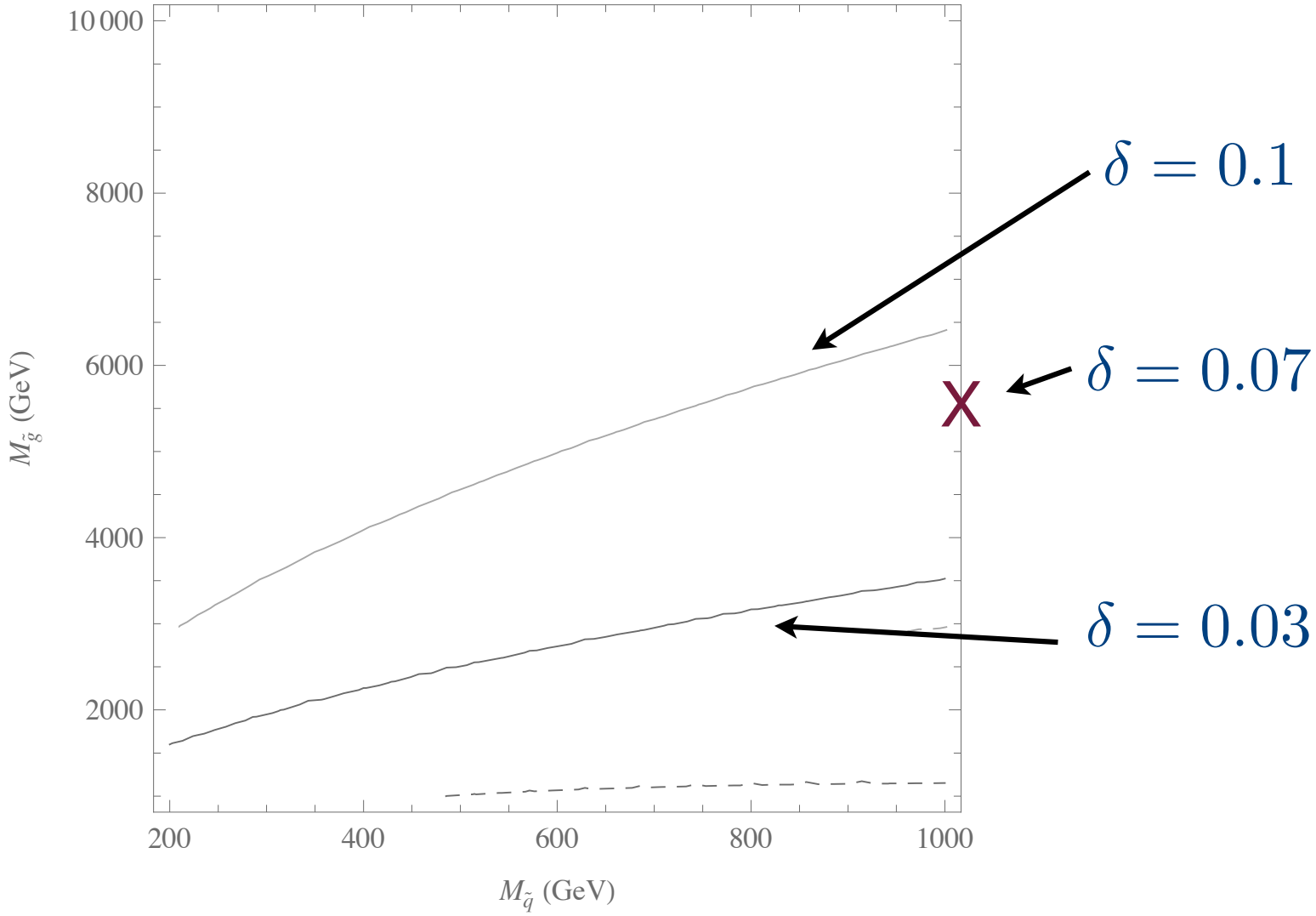
$$m^2_{\tilde{q}}(\text{TeV}) \;\sim\; (300 \text{ GeV})^2 \times \text{ anarchic } + (1.3 \text{ TeV})^2 \times \text{ flavor diagonal}$$

$$\frac{m_{\tilde{q}}}{m_{\tilde{g}}} \sim 0.2 \qquad \frac{\tilde{m}^2_{12}}{\tilde{m}^2_q} \sim 0.05$$

is it safe from $K_0 - \bar{K}_0$

Blechman and Ng ('08)

QCD corrections included



ϵ_K produces stronger bound

$$
\begin{aligned}
M_3(\text{TeV}) &\sim 5.4 \text{ TeV} \\
M_2(\text{TeV}) &\sim 1 \text{ TeV} \\
M_1(\text{TeV}) &\sim 600 \text{ GeV}
\end{aligned}
$$

$$
\begin{aligned}
m^2_{\tilde{q}}(\text{TeV}) \sim\ & (300 \text{ GeV})^2 \times \text{ anarchic } + \\
& (1.3 \text{ TeV})^2 \times \text{ flavor diagonal}
\end{aligned}
$$

$$
\theta \equiv \text{Im}(\delta^*_L \delta_R) \lesssim .01
$$

ϵ_K produces stronger bound

$$M_3(\text{TeV}) \sim 5.4 \text{ TeV}$$
$$M_2(\text{TeV}) \sim 1 \text{ TeV}$$
$$M_1(\text{TeV}) \sim 600 \text{ GeV}$$

$$m^2_{\tilde{q}}(\text{TeV}) \sim (300 \text{ GeV})^2 \times \text{ anarchic } + (1.3 \text{ TeV})^2 \times \text{ flavor diagonal}$$

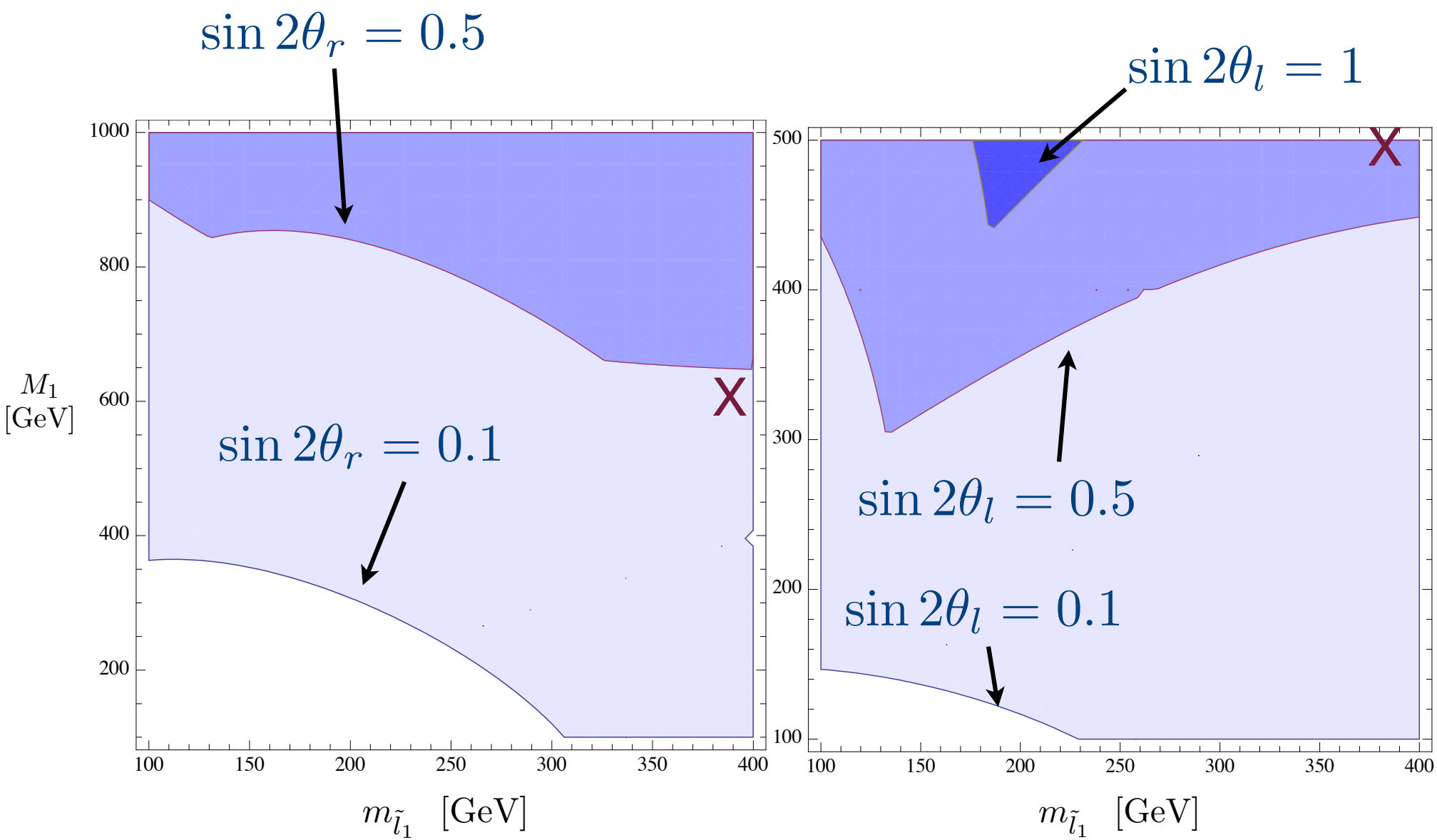
$(150 \text{ GeV})^2$

$$\theta \equiv \text{Im}(\delta^*_L \delta_R) \lesssim .01$$

0.2

lepton flavor constraints

Fok and Kribs ('10)

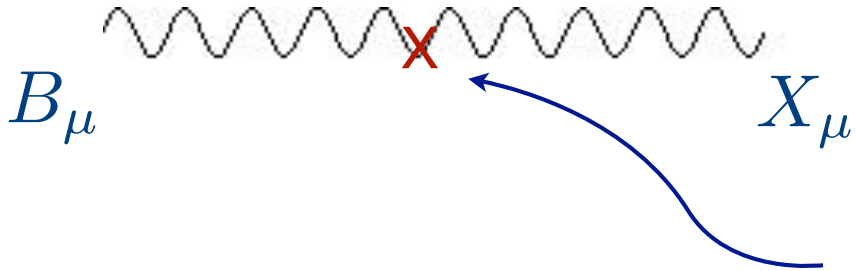


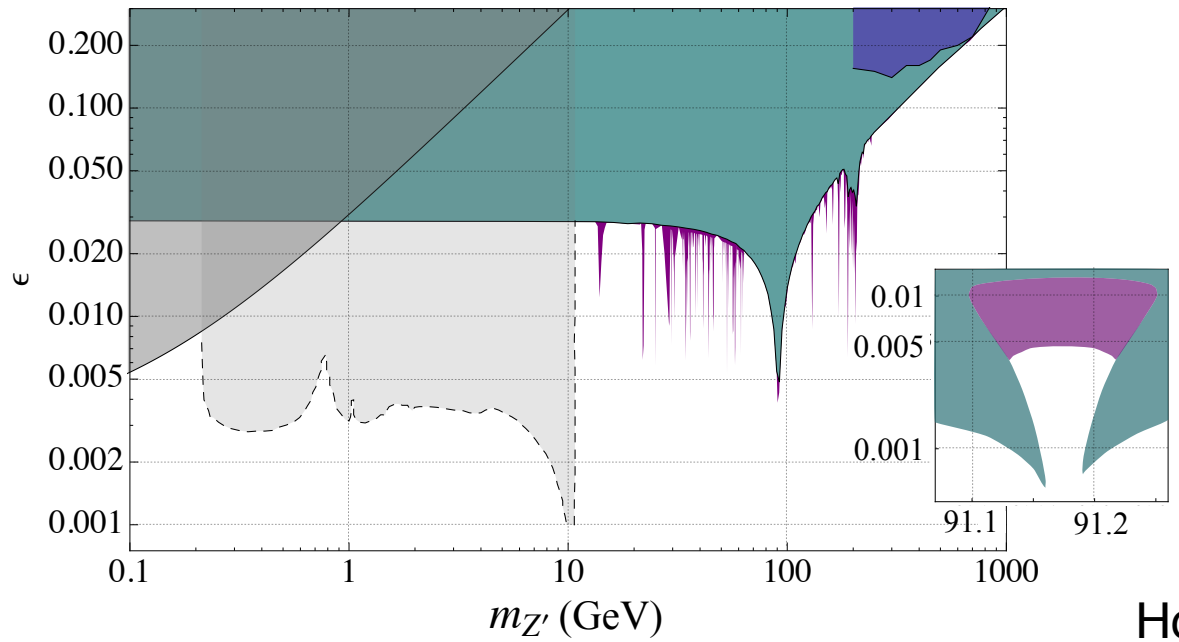
Phenomenology

- gauginos are Dirac
- flavor violation waiting to be discovered at LHC
- prospect of finding Z' at the EWSB scale

Z' at the EWSB scale

$M_{Z'}$ is constrained because of



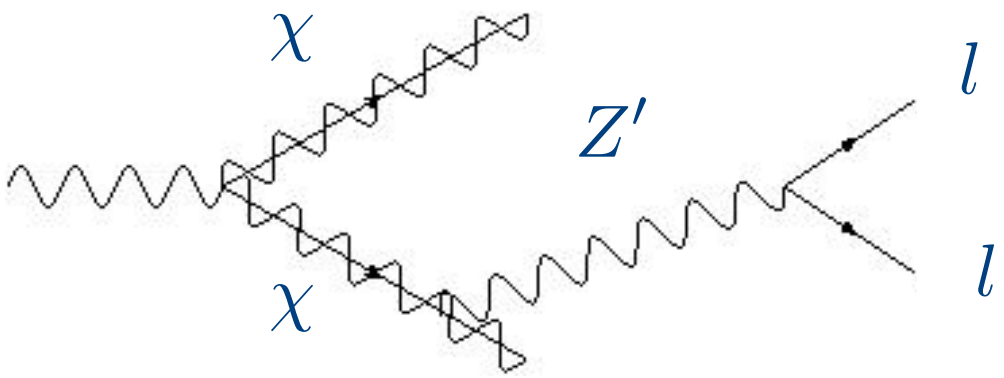


virtually no constraint

Hook, Izaguirre and Wacker ('10)

Z' at the EWSB scale

Z' talks to Higgs sector with g_X strength



Conclusions

- We resurrected gravity mediation
- Our prescription:
  - a singletless hidden sector with an U(1) that participates in susy breaking
  - Higgs sector is extended to include an $\mathrm{U}(1)_X$
- The effective theory contains an accidental (approximate) R-symmetry and RGE assisted hierarchy that solves the flavor problem
- Prospect of finding a Z' at the EWSB scale