SUPERPARTNER MASSES AND HIDDEN SECTOR SUSY BREAKING

(hep-ph/0612100)

with Andy Cohen
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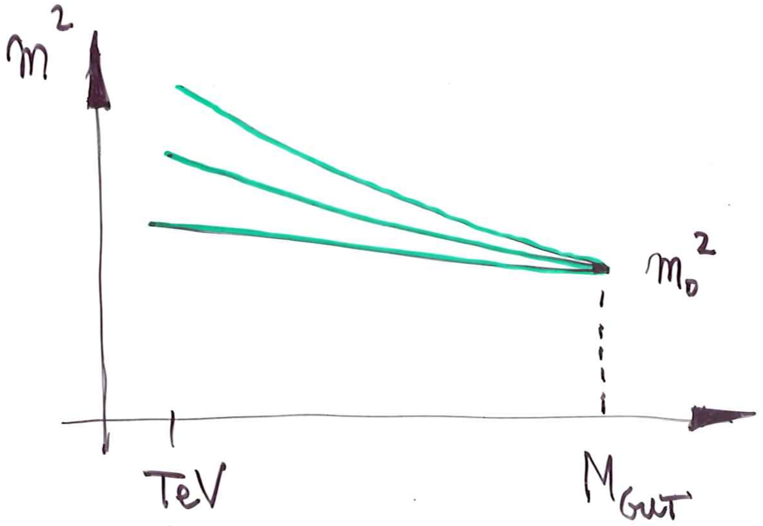
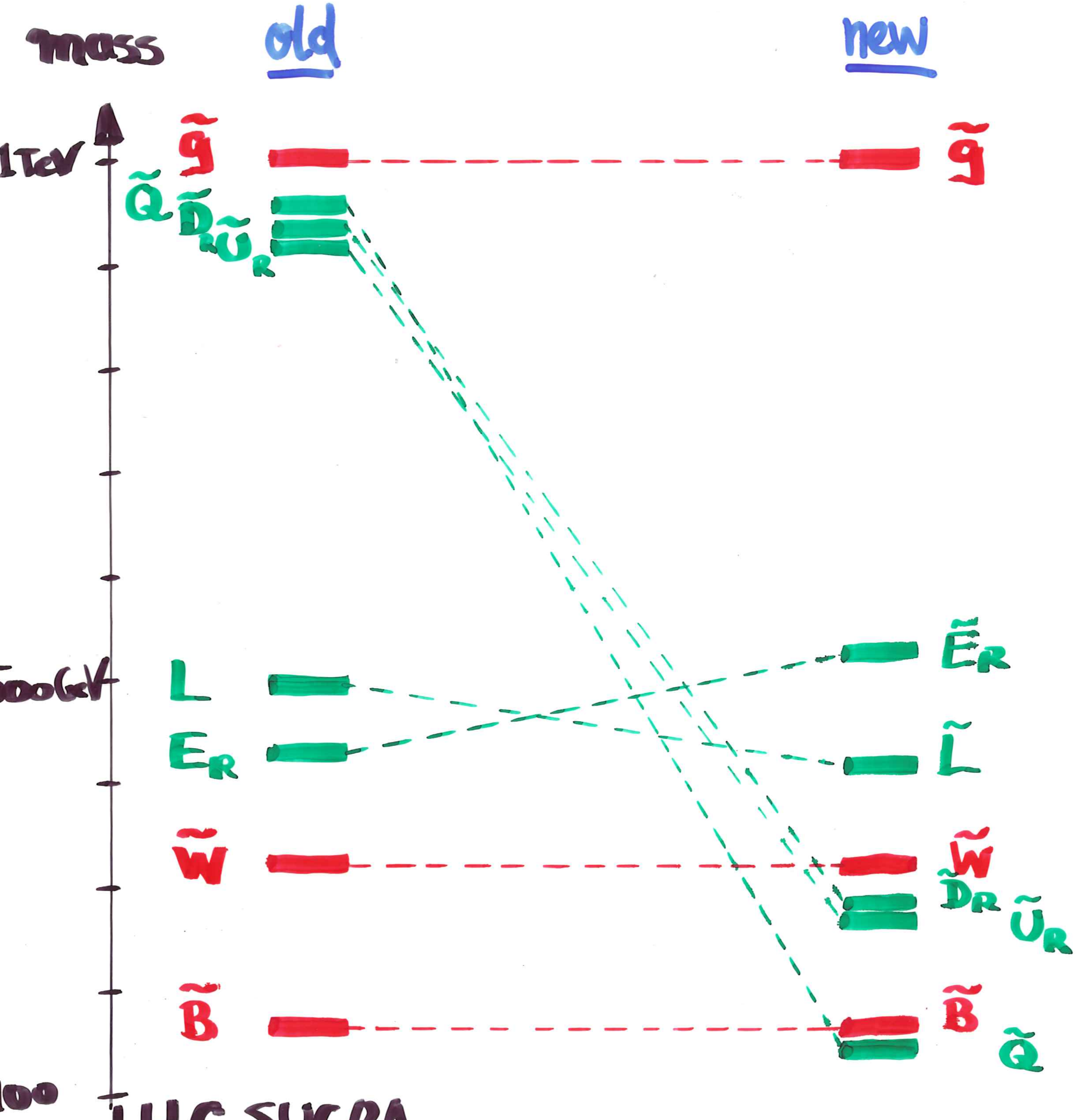
- This talk is about SUSY
- predicting MSSM superpartner masses from renormalization



- **punchline:**

we missed a potentially very large effect and all scalar mass predictions may be totally wrong !

for example ...

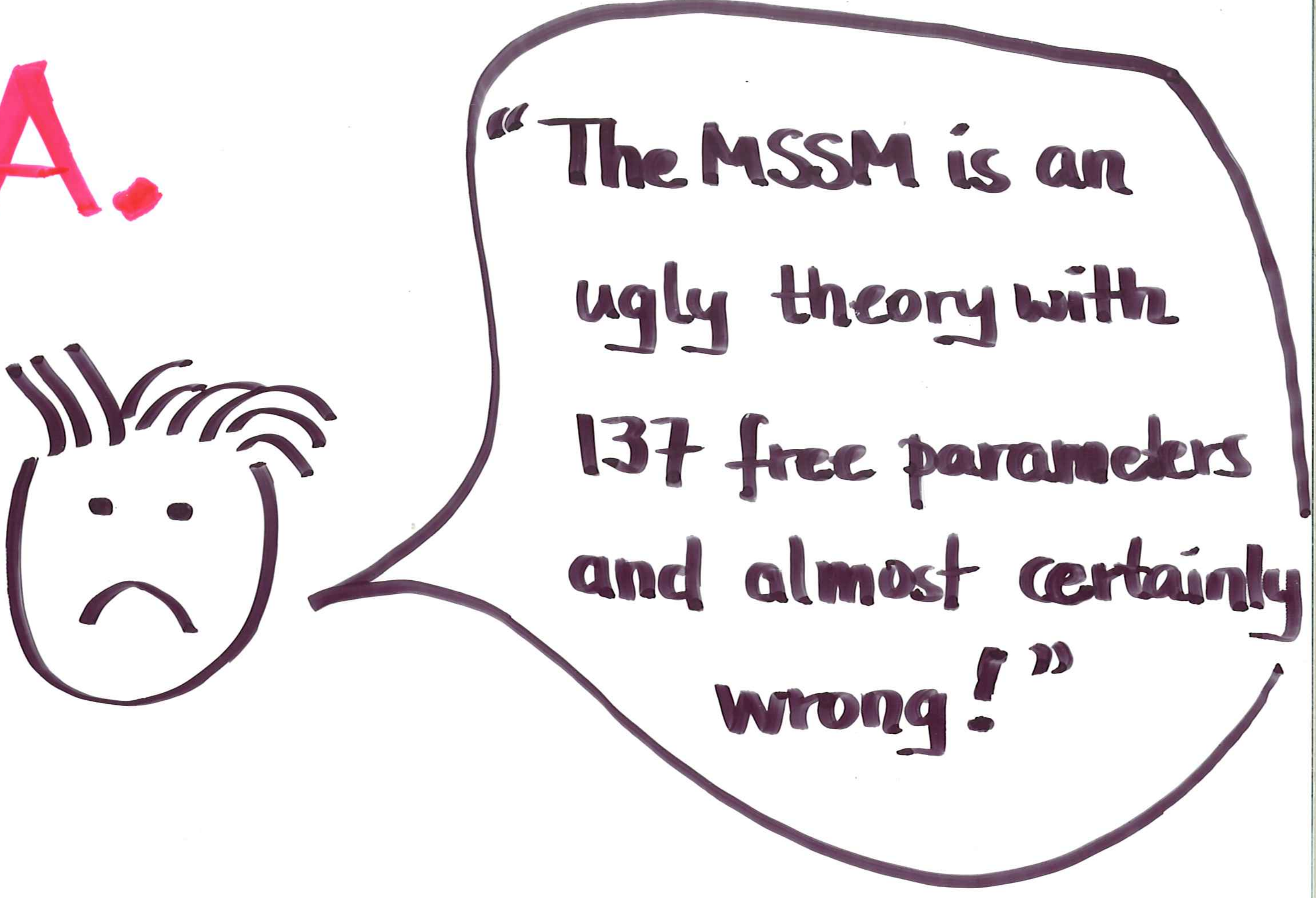


LHC SUGRA
Point 2
ATLAS TDR
(ISAJET)

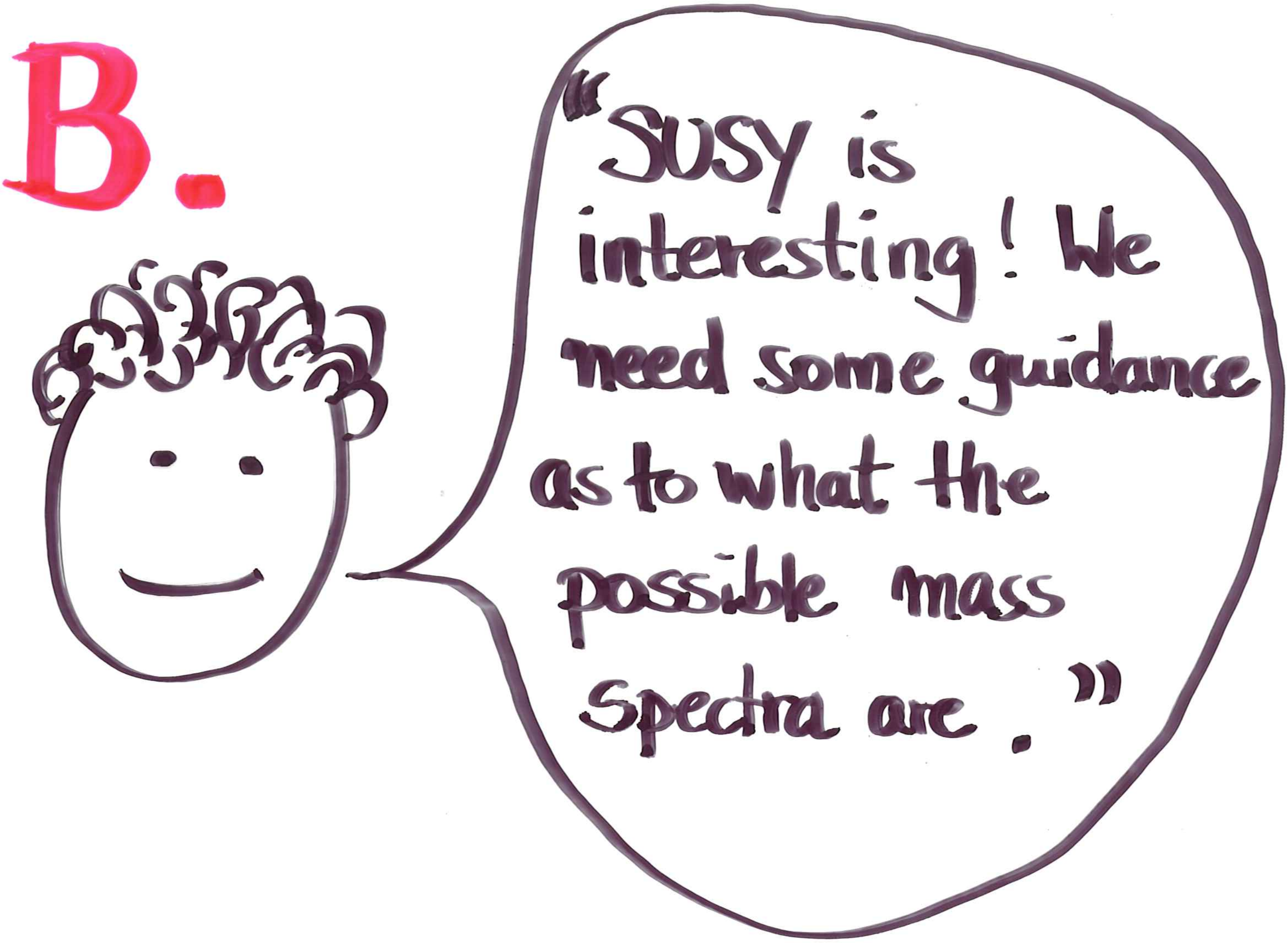
Outline

1. why SUSY?
2. Grand Unification and the LHC
3. running scalar masses
4. Hidden Sectors
5. running with the Hidden Sector
6. Should you care?

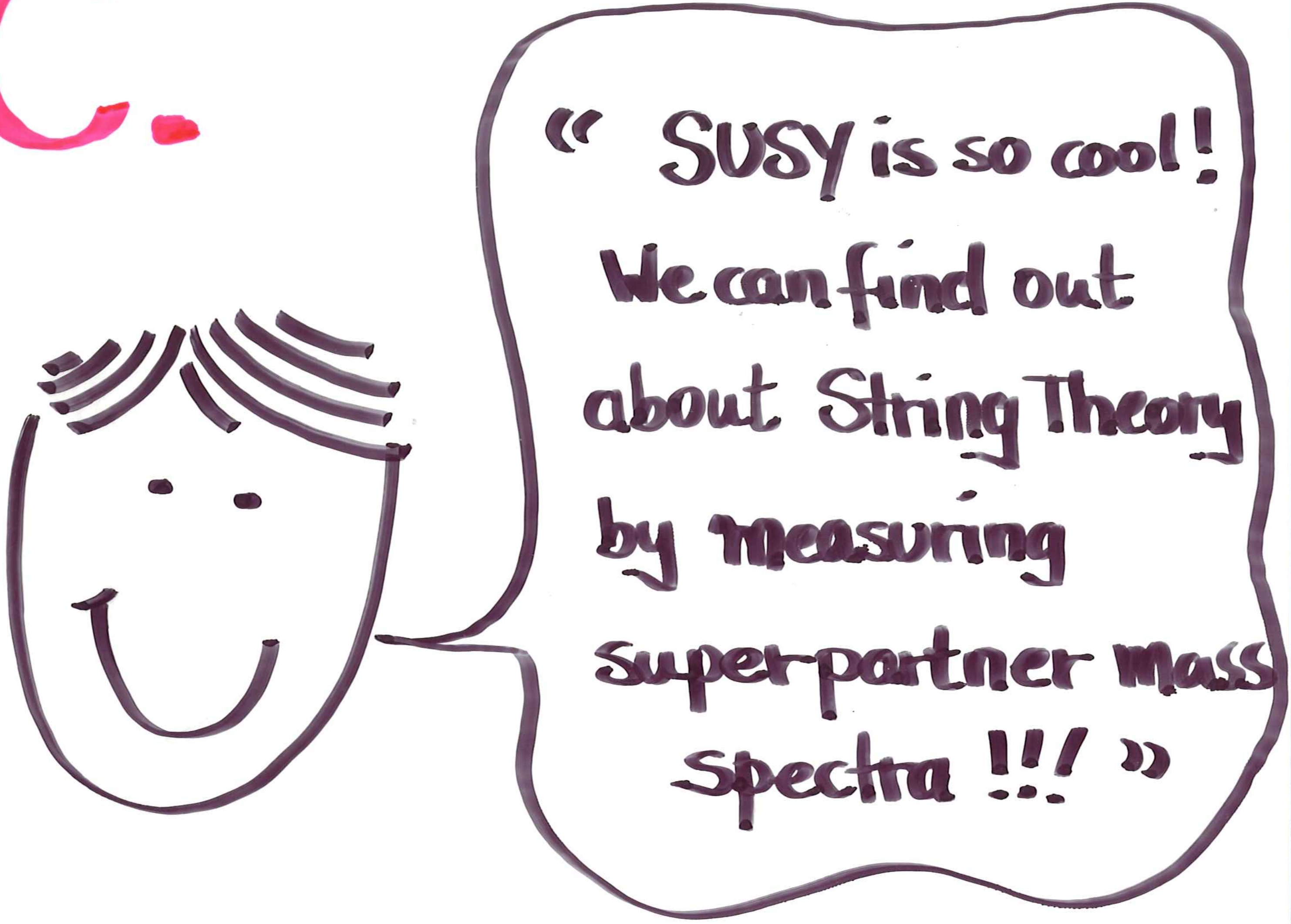
A.


"The MSSM is an ugly theory with 137 free parameters and almost certainly wrong!"

B.


"SUSY is interesting! We need some guidance as to what the possible mass spectra are."

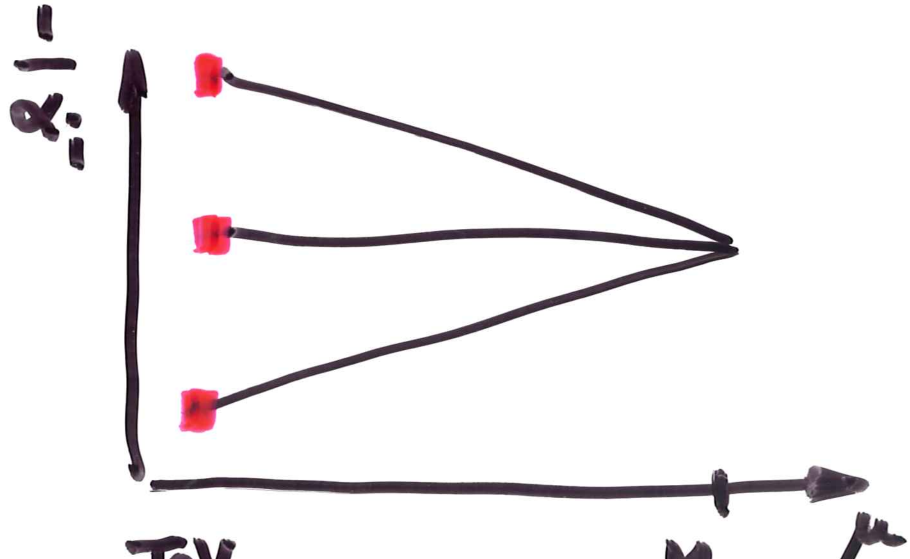
C.


" SUSY is so cool! We can find out about String Theory by measuring superpartner mass spectra !!! "

SUPERSymmetry

attractive because

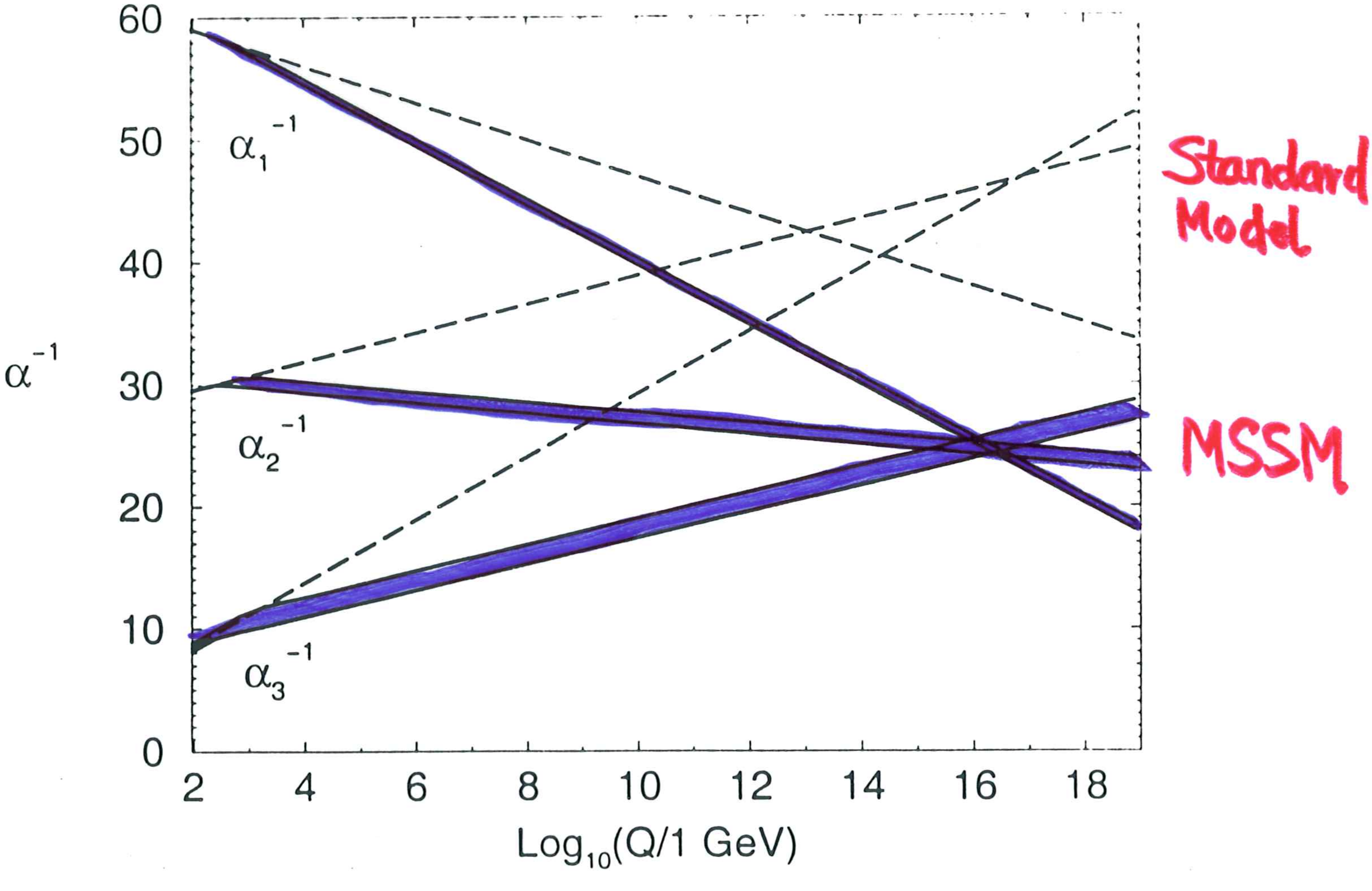
- higgs naturalness
- dark matter
- gauge coupling unification



- **SUPER strings**

but not clear that this "prefers" low-energy SUSY

SUSY prediction :



experimental evidence for

SUSY unification

2

- # Other predictions ?

  - $m_h < 130$ GeV
  - superpartners !
  - superpartner mass unification.

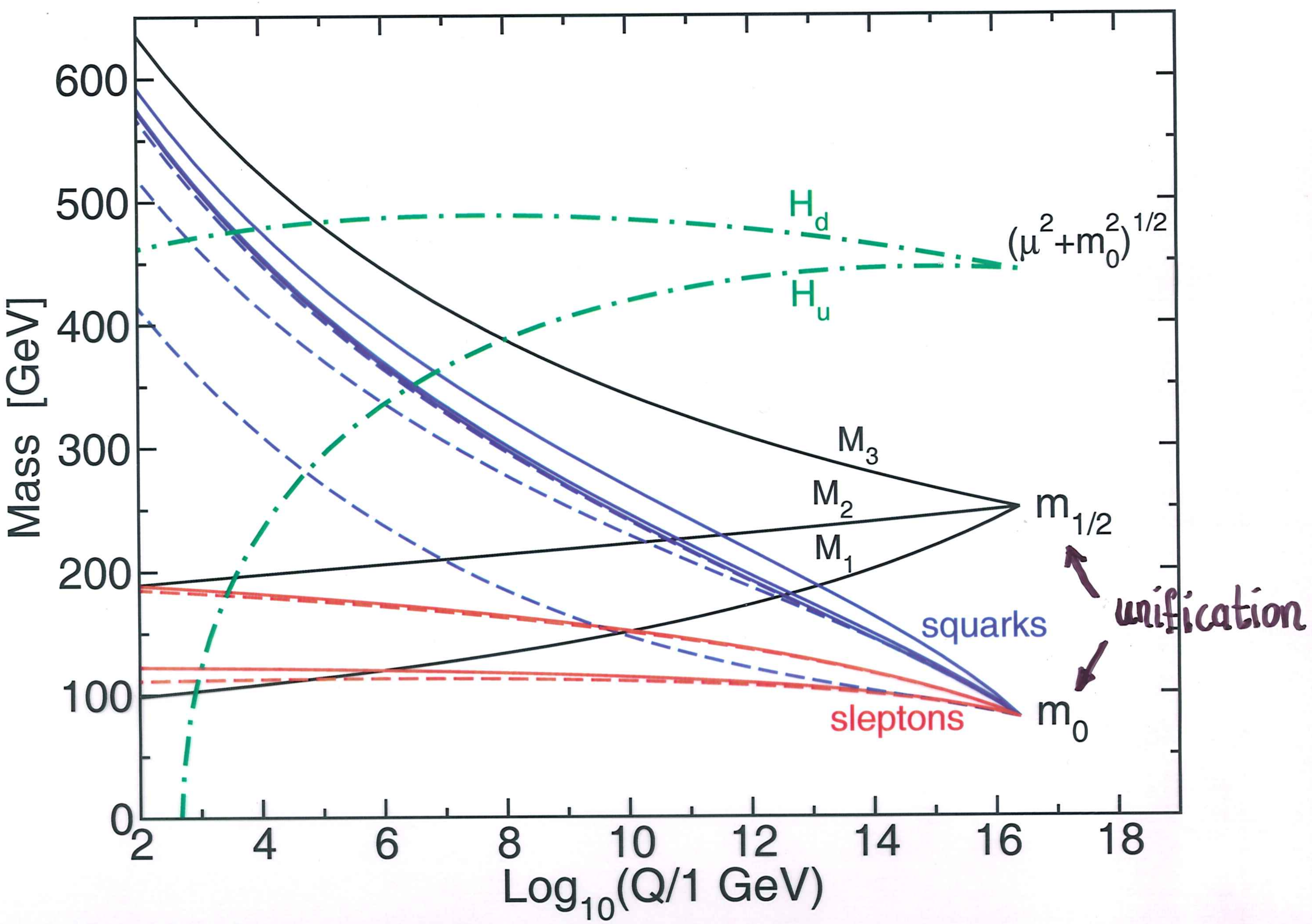
Superpartner mass unification

e.g. SO(10):

QUDLE ⊂ 16

$SU(3)\times SU(2)\times U(1) \subset SO(10)$

unified $\begin{cases} \text{scalar masses} & m_0 \\ \text{gaugino masses} & m_{1/2} \end{cases}$


Mass [GeV]
0
100
200
300
400
500
600
2
4
6
8
10
12
14
16
18
Log$_{10}$(Q/1 GeV)
H_d
H_u
$(\mu^2+m_0^2)^{1/2}$
M_3
M_2
M_1
$m_{1/2}$
squarks
sleptons
m_0
unification

Sparticle masses $(m_0, m_{1/2})$

Table 20-4 Masses in GeV for the five LHCC SUGRA points and the large $\tan\beta$ SUGRA point listed in Table 20-3. The first and second generation squarks and sleptons are degenerate and so are not listed separately. The SUSY masses for the five LHCC points are from ISAJET 7.22 [20-15]; the Higgs masses are from SPYTHIA 2.08 [20-16] and use the approximate two-loop effective potential. The masses for Point 6 are from ISAJET 7.37 [20-15].

Particle	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**
$\tilde{g}$	1004	1009	298	582	767	540
$\tilde{\chi}_1^\pm$	325	321	96	147	232	152
$\tilde{\chi}_2^\pm$	764	537	272	315	518	307
$\tilde{\chi}_1^0$	168	168	45	80	122	81
$\tilde{\chi}_2^0$	326	321	97	148	233	152
$\tilde{\chi}_3^0$	750	519	257	290	497	286
$\tilde{\chi}_4^0$	766	538	273	315	521	304
$\tilde{u}_L$	957	963	317	918	687	511
$\tilde{u}_R$	925	933	313	910	664	498
$\tilde{d}_L$	959	966	323	921	690	517
$\tilde{d}_R$	921	939	314	910	662	498
$\tilde{t}_1$	643	710	264	594	489	365
$\tilde{t}_2$	924	933	329	805	717	517
$\tilde{b}_1$	854	871	278	774	633	390
$\tilde{b}_2$	922	930	314	903	663	480
$\tilde{e}_L$	490	491	216	814	239	250
$\tilde{e}_R$	430	431	207	805	157	219
$\tilde{\nu}_e$	486	485	207	810	230	237
$\tilde{\tau}_1$	430	425	206	797	157	132
$\tilde{\tau}_2$	490	491	216	811	239	259
$\tilde{\nu}_\tau$	486	483	207	806	230	218
h	95	116	69	112	93	112
H	1046	737	379	858	638	157
A	1044	737	371	859	634	157
$H^\pm$	1046	741	378	862	638	182

Majorana fermion, it has equal branching ratios into l^+X and l^-X, giving rise to isolated like-sign dileptons for which the Standard Model background is small. To estimate the reach for each signature, events were generated for many SUGRA points and for Standard Model processes using ISAJET plus a simplified detector simulation. Events were selected to have [20-18]

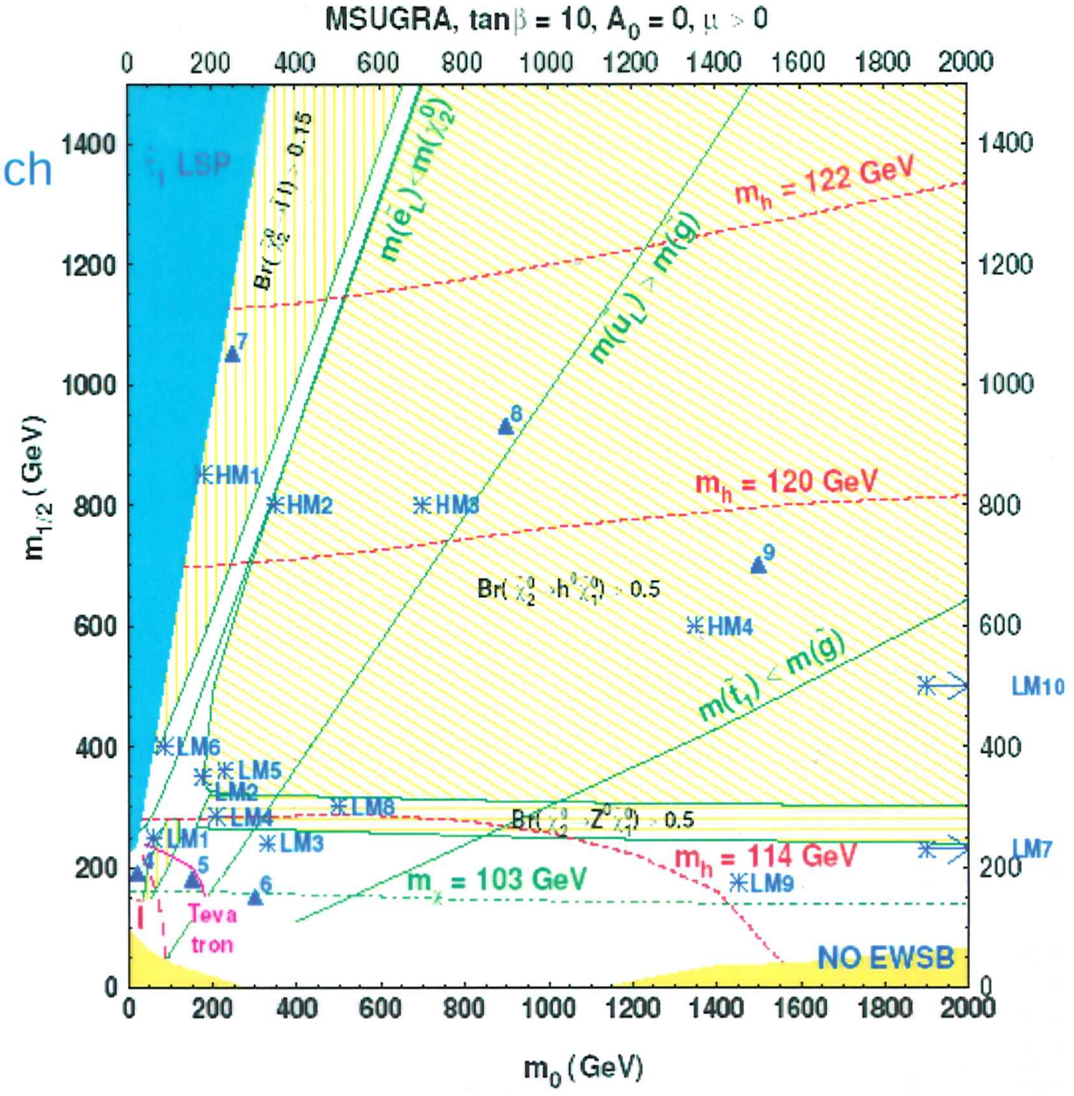
Benchmark Points

CMS TDR

Basis of detailed studies

- Low mass points for early LHC running but above Tevatron reach
- High-mass points for ultimate LHC reach
- Indirect WMAP constraints except LM1, 2, 6, 9 (in favor of signatures)

Point	m_0	$m_{1/2}$	$\tan\beta$	sgn(μ)	A_0
LM1	60	250	10	+	0
LM2	185	350	35	+	0
LM3	330	240	20	+	0
LM4	210	285	10	+	0
LM5	230	360	10	+	0
LM6	85	400	10	+	0
LM7	3000	230	10	+	0
LM8	500	300	10	+	-300
LM9	1450	175	50	+	0
LM10	3000	500	10	+	0
HM1	180	850	10	+	0
HM2	350	800	35	+	0
HM3	700	800	10	+	0
HM4	1350	600	10	+	0



MSSM running
"state of the art"

- ~~2~~ 3 loop running
- 1 loop matching at $\left\{\begin{array}{l}\text{TeV}\\ M_{GUT}\end{array}\right.$
- automated:
  - Isajet
  - Softsusy
  - Spheno
  - Suspect
  - ⋮
- relic abundance, $b \to s\gamma$, ...

Superpartner mass predictions have been done incorrectly!

Origin of SUSY masses:

$$m^2 \, Q^\dagger Q$$

$$X^\dagger X \, Q^\dagger Q$$ ← MSSM matter

SUSY breaking

$$\Rightarrow \quad m^2 \sim \langle X^\dagger X \rangle$$

Compare to Z mass:

$$g^2 h^\dagger h \, Z_\mu Z^\mu \Rightarrow \underbrace{g^2 v^2}_{m_Z^2} Z_\mu Z^\mu$$

EW symmetry breaking

constraints on

$$X^\dagger X \; Q_i^\dagger Q_j \; c_{ij}$$

- c_{ij} must be flavor universal
  (experiments : FCNC $\ll$ FCCC)
- $c_{ij} > 0$ positive scalar masses^2

imply

Hidden Sector Susy breaking

Hidden Sector SUSY breaking.

e.g **SUGRA**

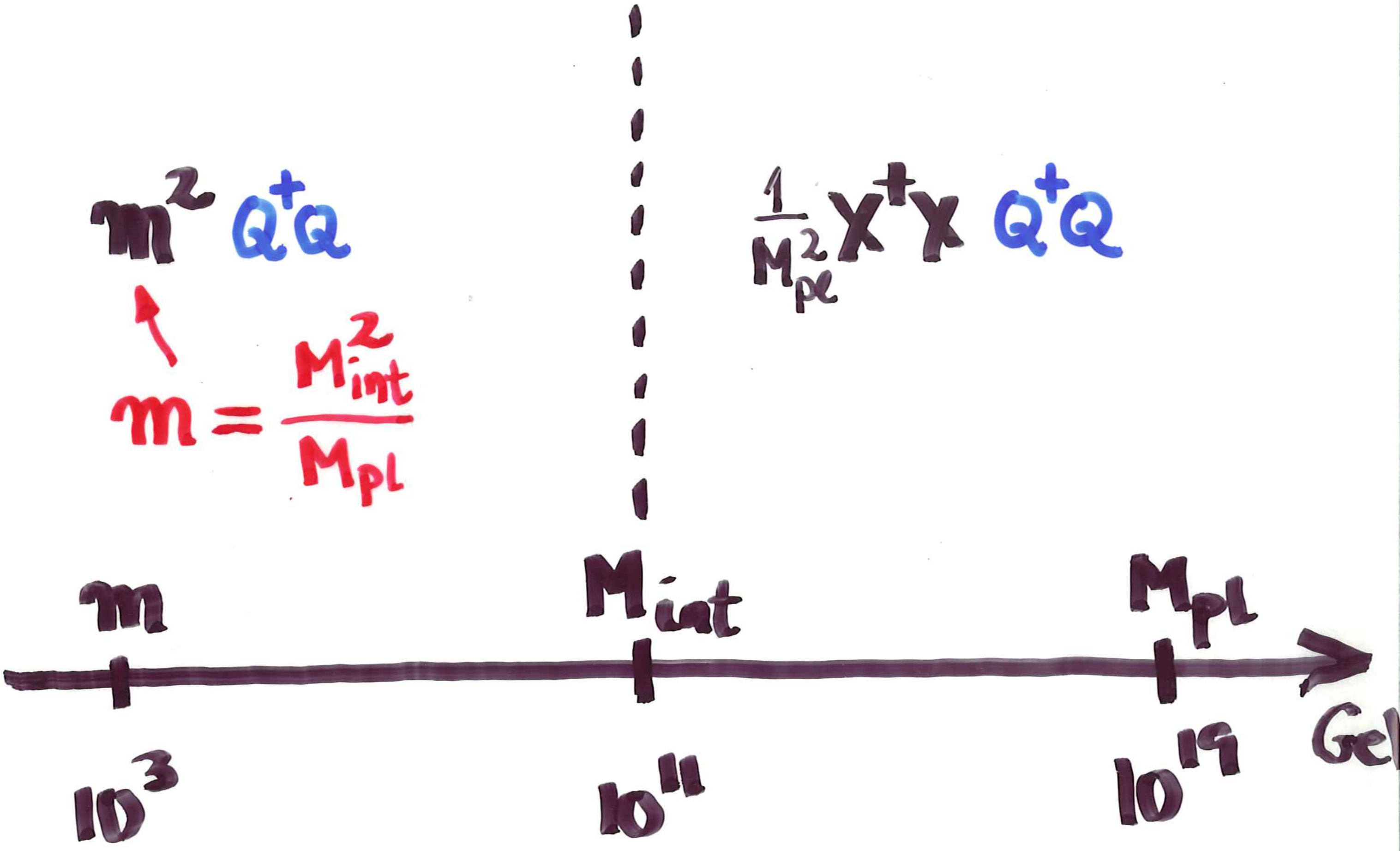
$$\frac{1}{M_{Pl}^2} X^+ X \, Q_i^+ Q_i$$

Scales in SUGRA

$m^2 \, Q^\dagger Q$

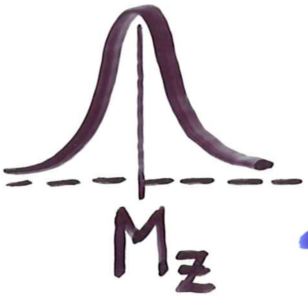
$m = \frac{M_{int}^2}{M_{pl}}$

$\frac{1}{M_{pl}^2} X^\dagger X \, Q^\dagger Q$



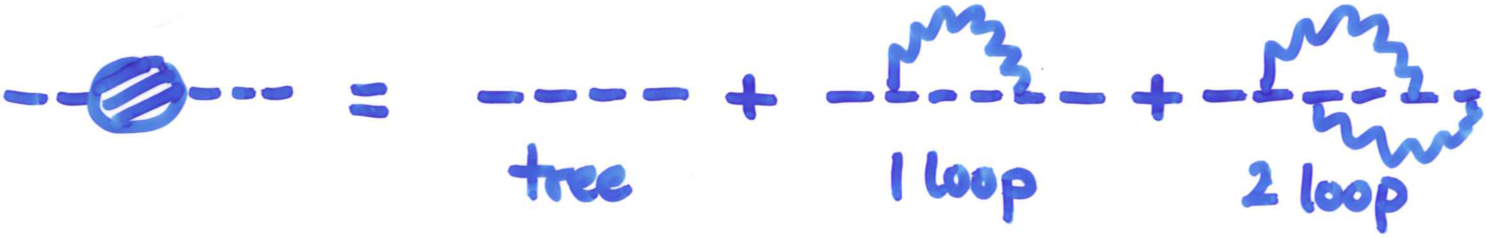
Scale of X vev and X mass

What is a running mass ?



pole mass

$$m_{pole}^2 = m_0^2 \left(1 + \overbrace{\frac{\alpha}{\pi} \log \frac{m_W^2}{m_{GUT}^2}}^{\text{large}, \mathcal{O}(1)} + \mathcal{O}(\alpha^2) \right)$$



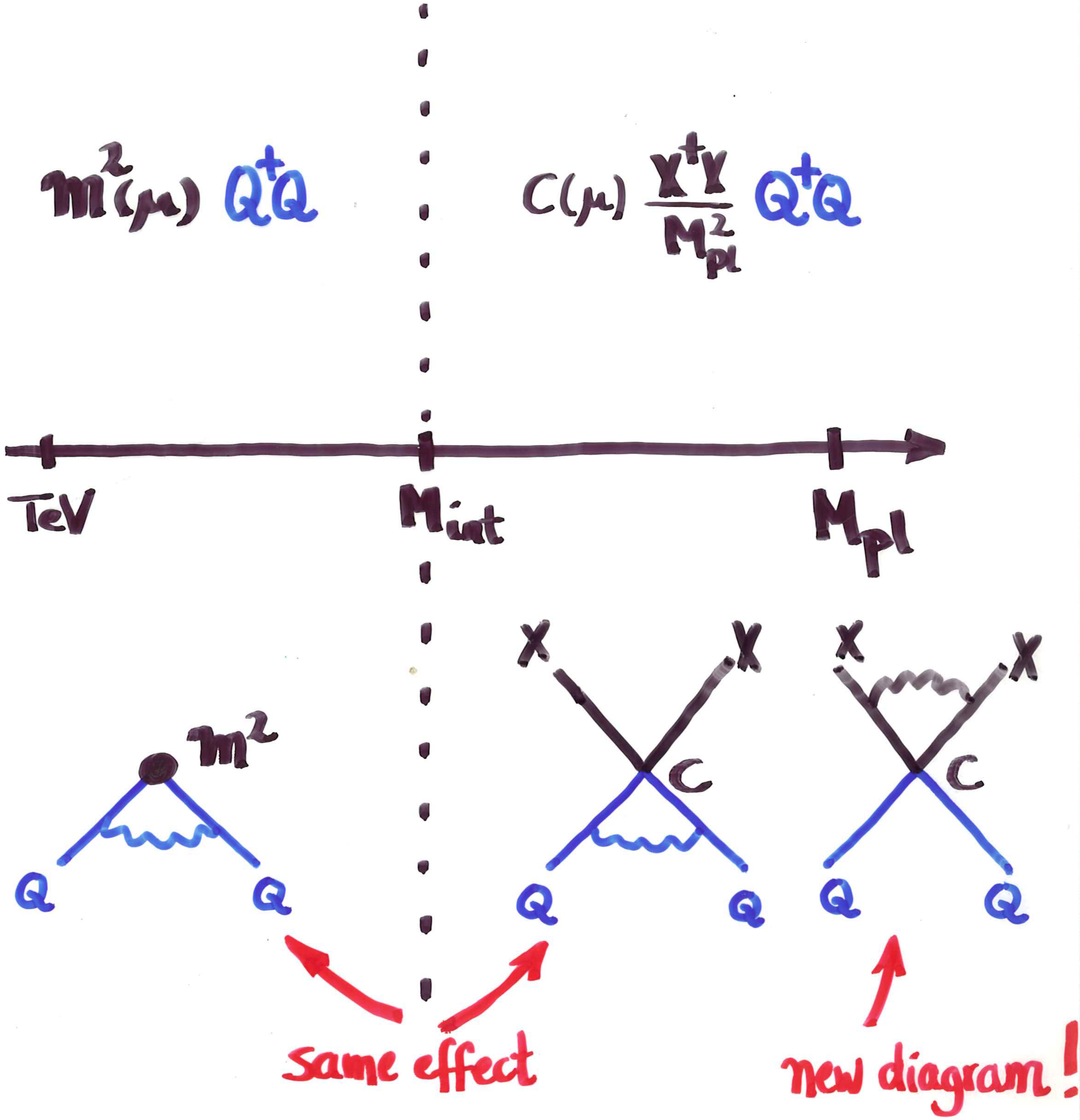
define:

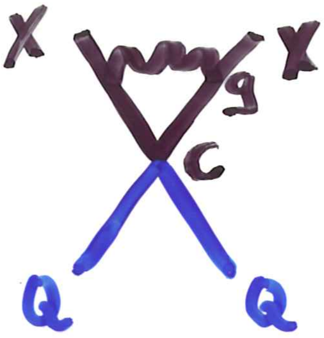
$$m^2(\mu) = m_0^2 \left(1 + \frac{\alpha}{\pi} \log \frac{\mu^2}{m_{GUT}^2} + \dots \right)$$

Solve RGE for $m^2(\mu)$ to re-sum logs

$$m_{pole}^2 \approx m^2(m_W)$$

“mass” renormalization :





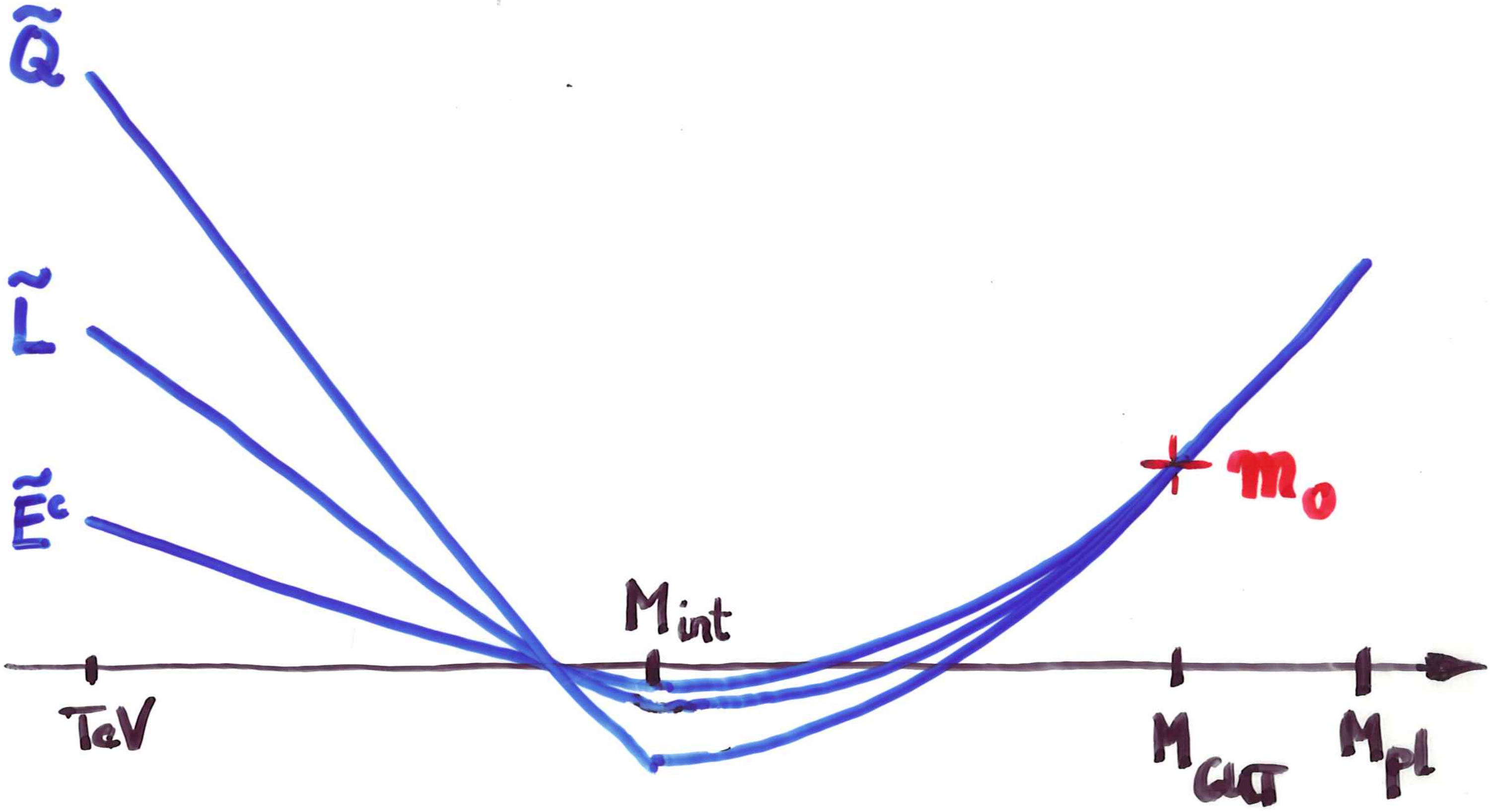
has always been ignored !

how big is the mistake?

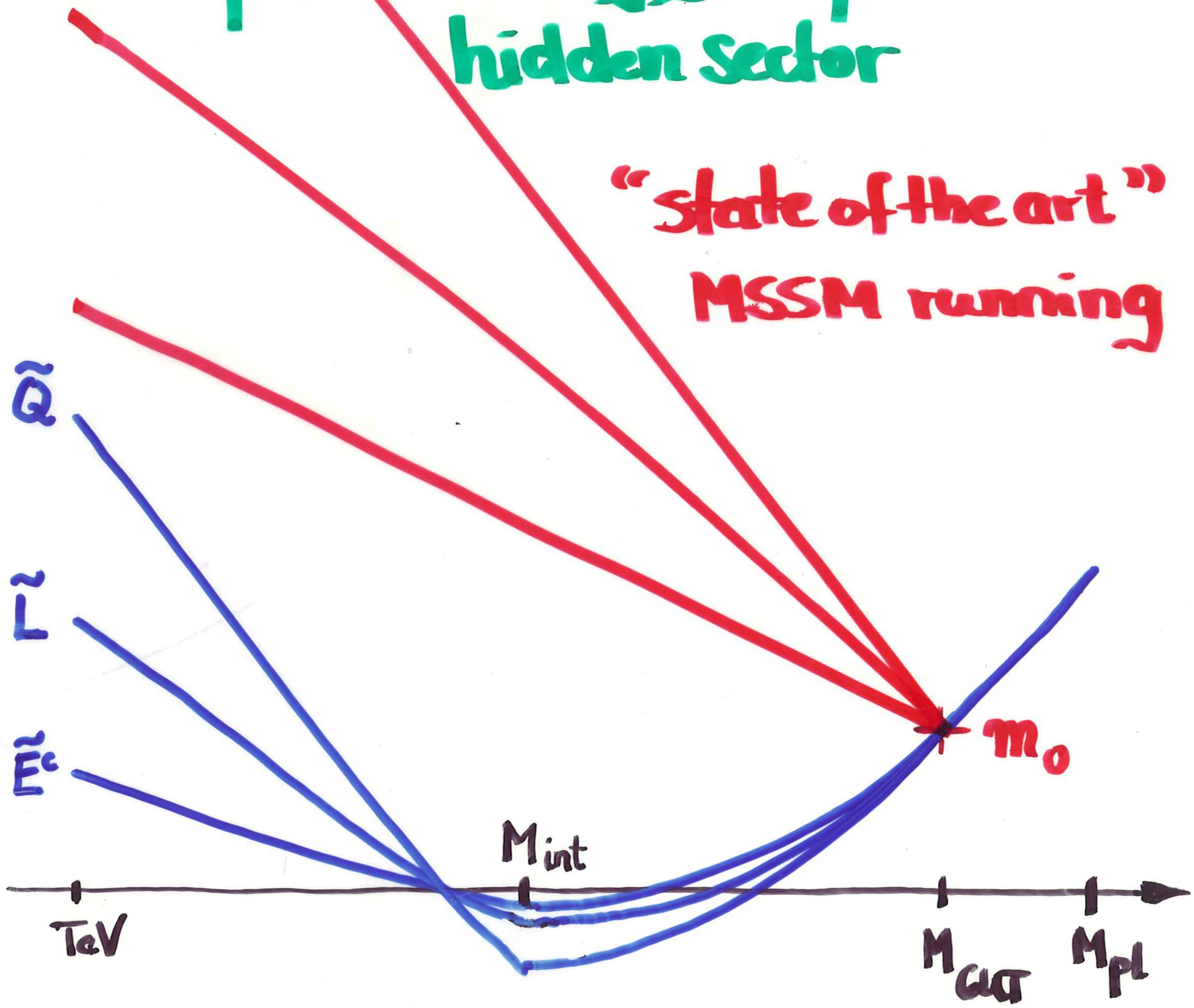
$$\frac{\delta m^2}{m^2} \approx \frac{\delta c}{c} \approx \frac{g^2_{\text{hidden}}}{16\pi^2} \log\left(\frac{M_{\text{int}}}{M_{pl}}\right)$$

- can be large if $g \gtrsim 1$
- uncalculable (we will never know the hidden sector)

Example: Strongly coupled hidden sector

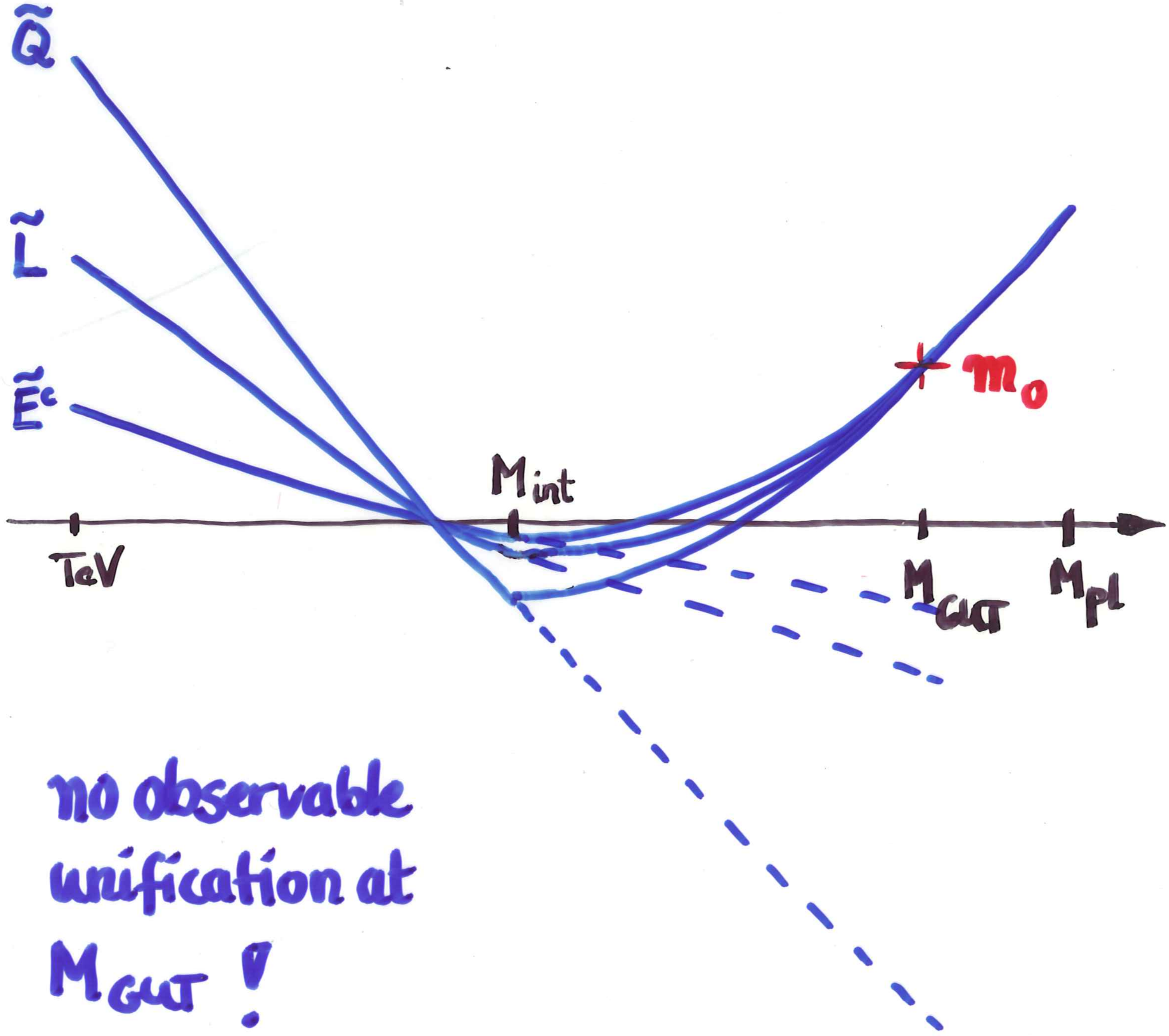


Example: Strongly coupled hidden sector



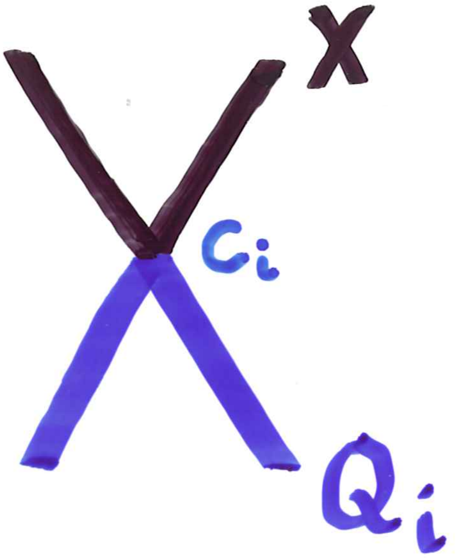
"state of the art" MSSM running

Example: Strongly coupled hidden sector



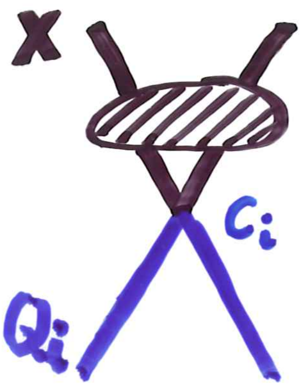
no observable unification at M_{GUT}!

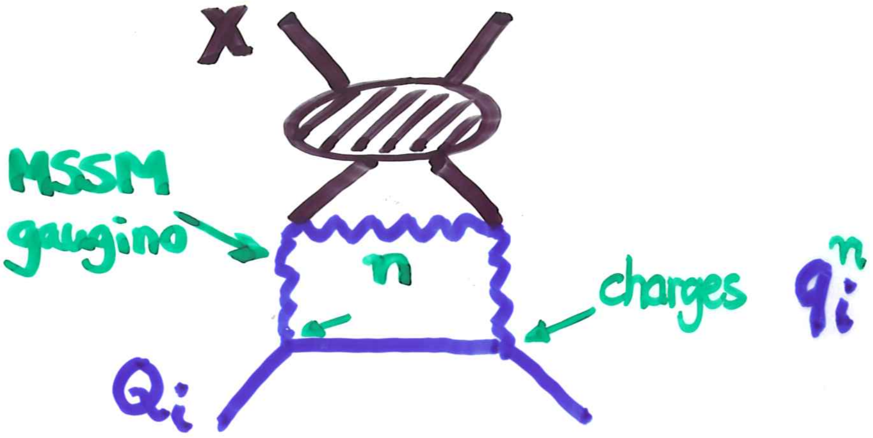
Correct Renormalization from $M_{pl} \to M_{int} \dashrightarrow \text{TeV}$



$i \in \{QUDLE\}$

general RGE's with hidden sector





$$\dot{c}_i = \gamma c_i - \sum_{n=1}^{3} q_i^n g_n^6 G$$

$$c_i = \underbrace{e^{-\int\gamma} c_0}_{\text{1 unknown}} + \sum_n q_i^n \underbrace{\int g_n^6 G e^{-\int\gamma}}_{\text{3 unknowns}_n}$$

$$\boxed{m_i^2 = \tilde{m}_0^2 + \sum_{n=1}^{3} q_i^n \tilde{m}_n^2}$$

5 masses ($\tilde{Q}\tilde{U}\tilde{D}\tilde{L}\tilde{E}$), 4 unknowns

Hidden Sector indep. Prediction

$$\boxed{m^2_{\tilde{Q}} - 2\,m^2_{\tilde{u}} + m^2_{\tilde{D}} - m^2_{\tilde{L}} + m^2_{\tilde{E}} = 0}$$

+ gaugino mass unification

2nd generation ?

identical (flavor universality, FCNC's)

3rd generation ?

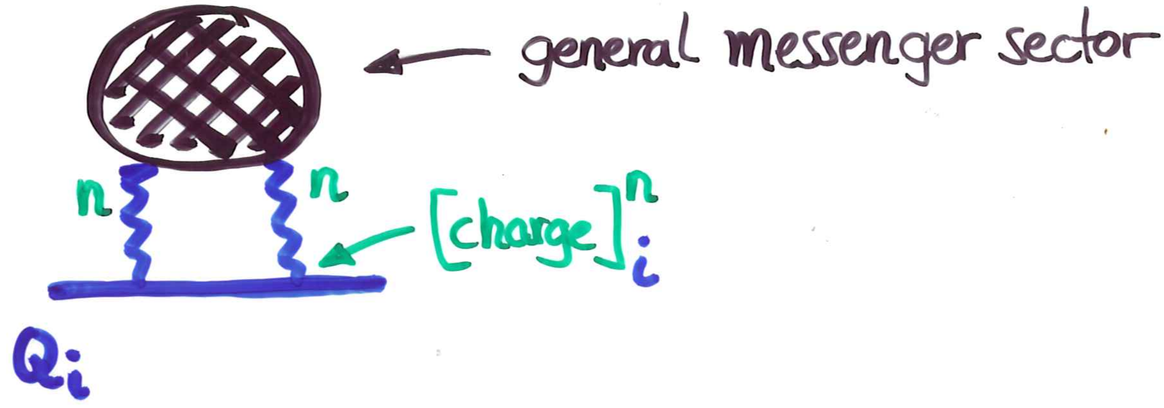
$\lambda_t, \lambda_b, \lambda_\tau, \ldots$

new unkown moments

3^{rd} generation :

Q_3	λ_{top}	must have
U_3	λ_b, λ_τ	large $\tan\beta$
D_3	$H_u + H_d$ mass	$m_H^2 \neq m_0^2$
L_3	$H_u - H_d$ mass	Hypercharge D term
E_3	$X^\dagger H_u H_d$	instead of $\mu H_u H_d$
H_u	λ_ν ?	$\lambda_\nu = \lambda_{top}$ in SO(10)
H_d		
7 predictables	7 "spoilers"	can "measure" the presence of spoilers !!

Gauge Mediation



$$\Rightarrow \quad C_i(M_{Mess}) = \sum_n q_i^n \, G^n_{Mess}$$

$$\swarrow$$

$$\underset{5 \nearrow}{m_i^2} = \underbrace{\sum_n q_i^n \, \tilde{m}_{0n}^2}_{\text{messenger sector}} + \underbrace{\sum_n q_i^n \, \tilde{m}_n^2}_{\text{running}}$$

$$= \sum_n q_i^n \, \hat{m}_n^2 \leftarrow 3$$

$$\boxed{3\left(m^2_{\tilde{u}} - m^2_{\tilde{D}}\right) - m^2_{\hat{E}} = 0}$$

+ previous prediction

robust predictions

$$\boxed{m^2_{\tilde{Q}} - 2m^2_{\tilde{u}} + m^2_{\tilde{D}} - m^2_{\tilde{L}} + m^2_{\tilde{E}} = 0}$$

+ gaugino mass unification

gauge mediation ?

$$\boxed{3\left(m^2_{\tilde{u}} - m^2_{\tilde{D}}\right) - m^2_{\tilde{E}} = 0}$$

Should you care?

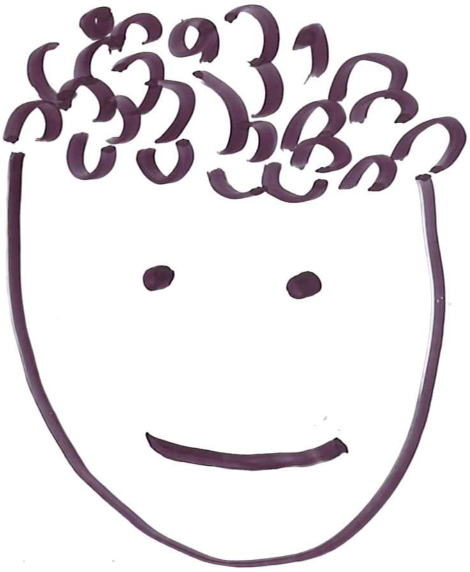
A.
B.
C.

A.

Wake up!

(almost time to go home ...)

B.



make sure to study (search for) general enough spectra!

- $m_i^2 = \tilde{m}_0^2 + \sum_{n=1}^{3} q_i^n \, \tilde{m}_n^2$
- $\left\{ \begin{array}{l} \text{1st + 2nd generation degenerate} \\ \text{3rd generation : stay tuned} \end{array} \right.$
- gauginos as usual

C.

Conclusions

- scalar mass predictions are sensitive to unknown hidden sector physics

- hidden sector independent sum rules:

GUT, gM: $\tilde{Q}^2 - 2\tilde{U}^2 + \tilde{D}^2 - \tilde{L}^2 + \tilde{E}^2 = 0$

gM: $3(\tilde{U}^2 - \tilde{D}^2) - \tilde{E}^2 = 0$

- model dependent "predictions"