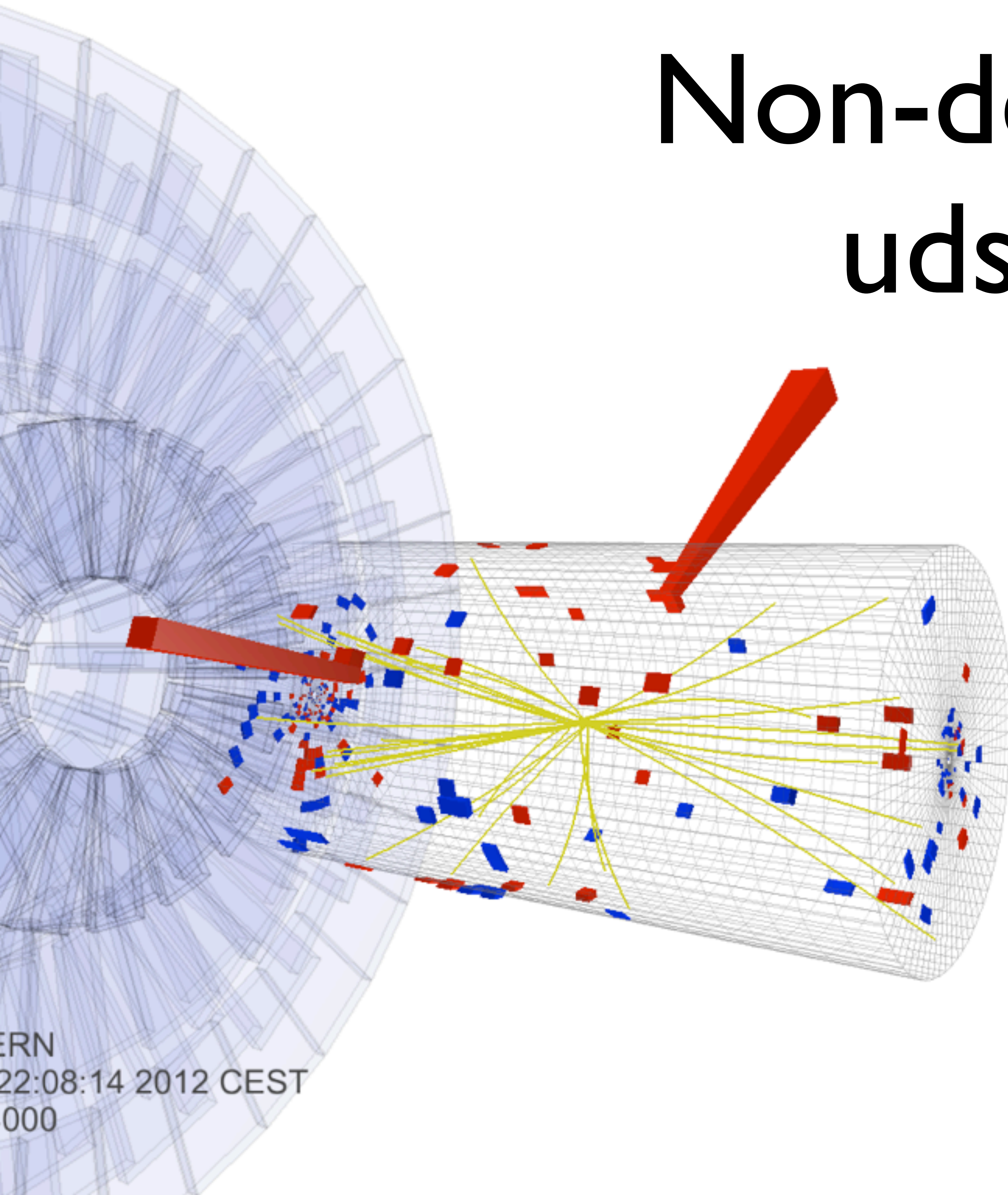
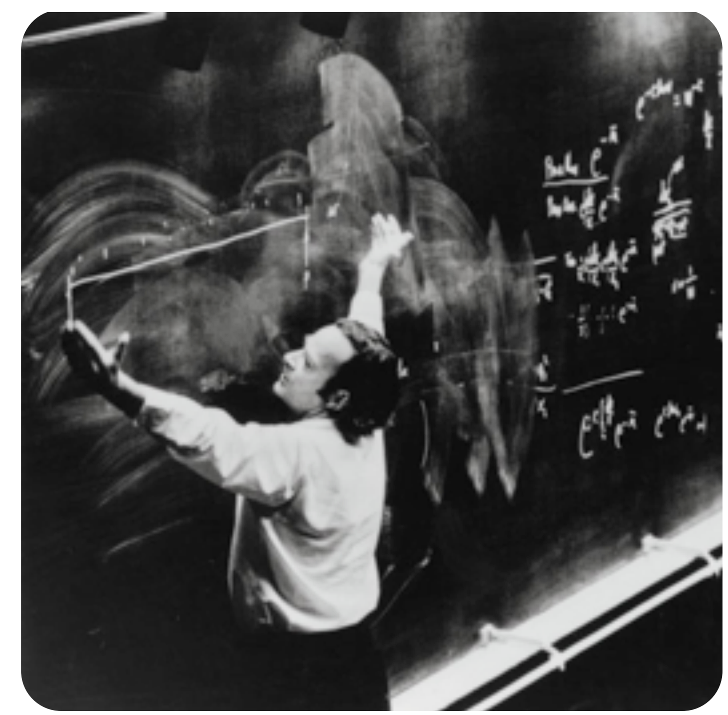
Non-degenerate udsc-squarks



Andreas Weiler
(DESY)

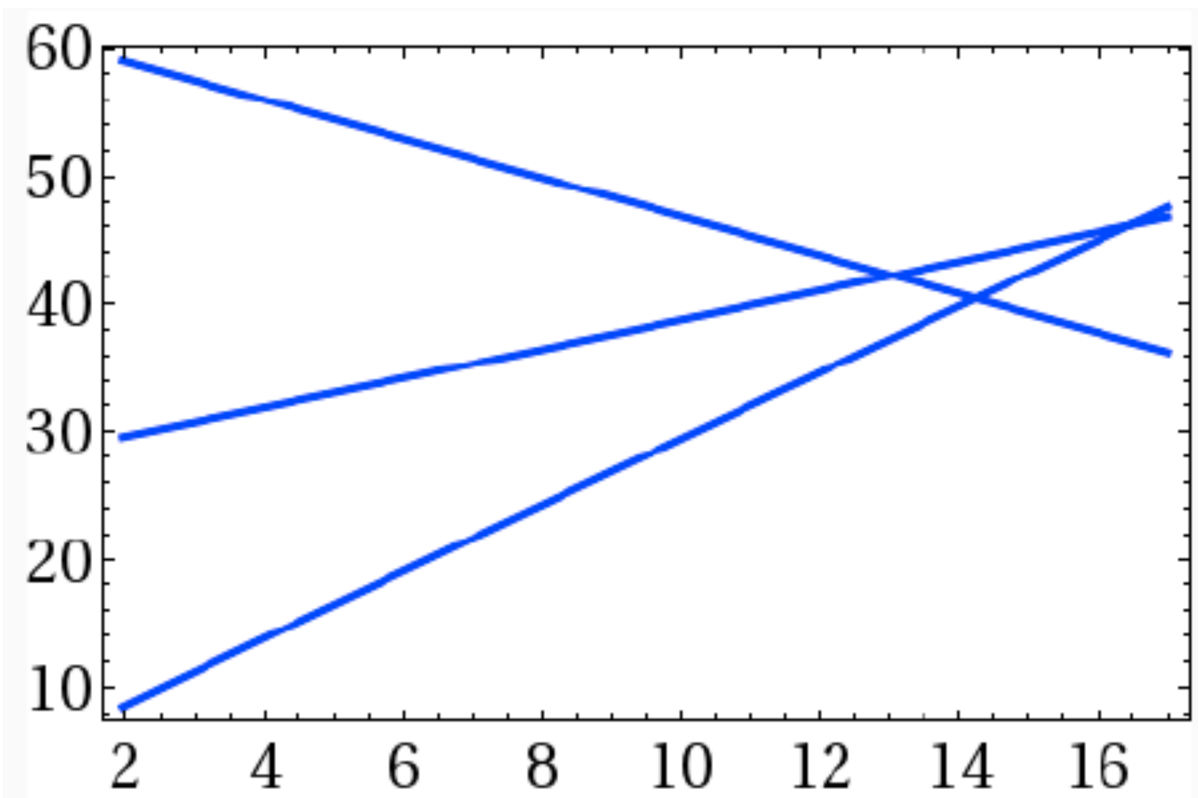


arXiv:1212.3328

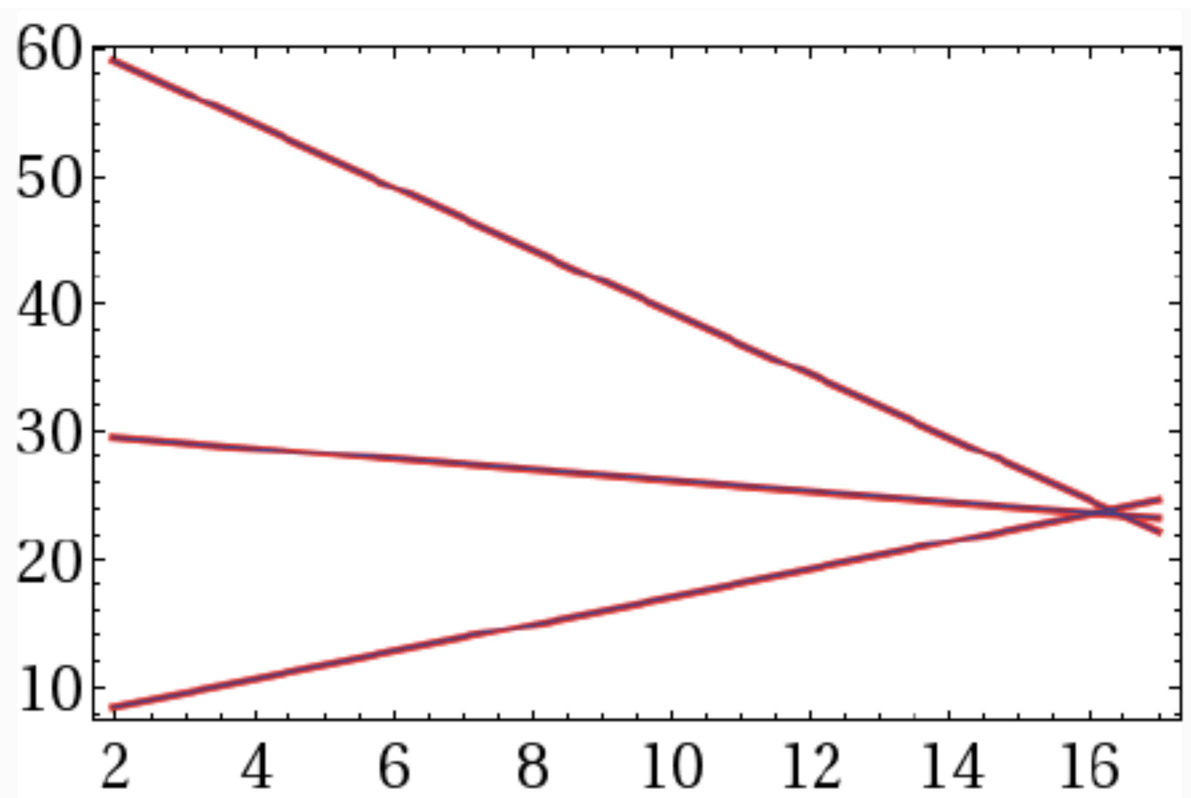
Supersymmetry

A hint?

SM



MSSM

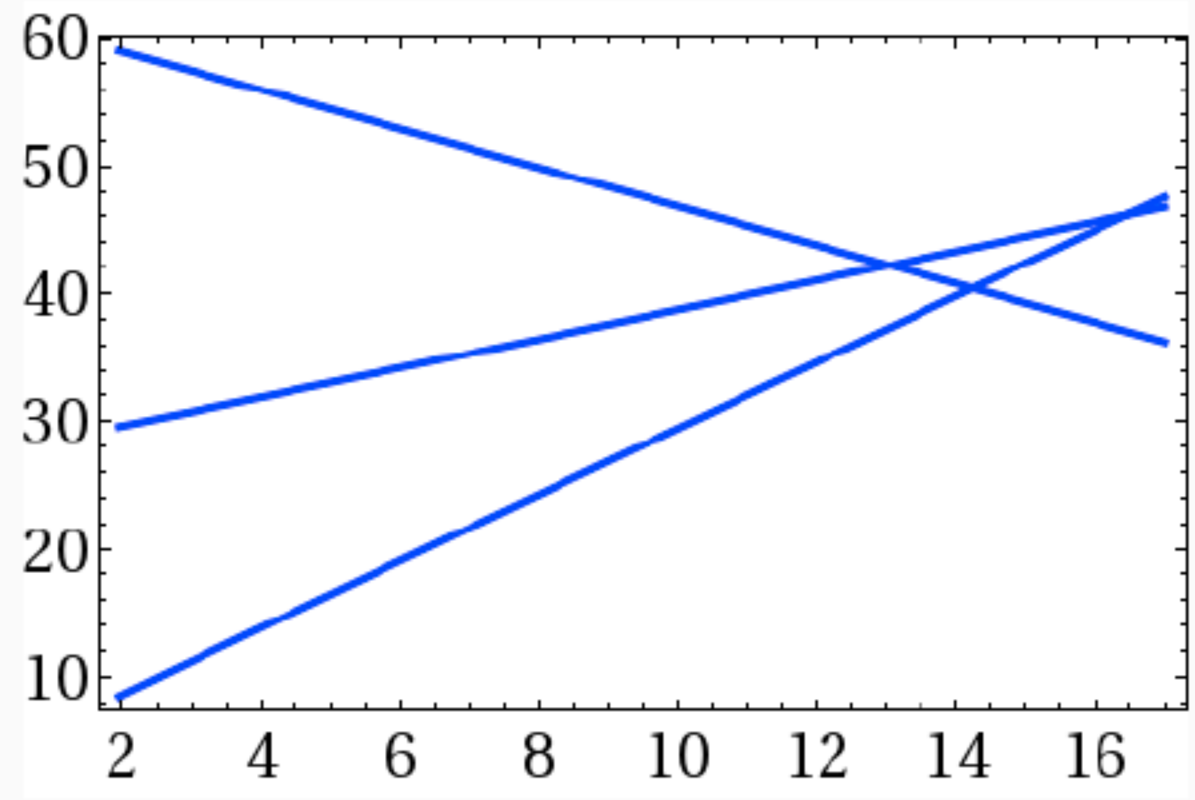


Gauge Coupling running at two loops

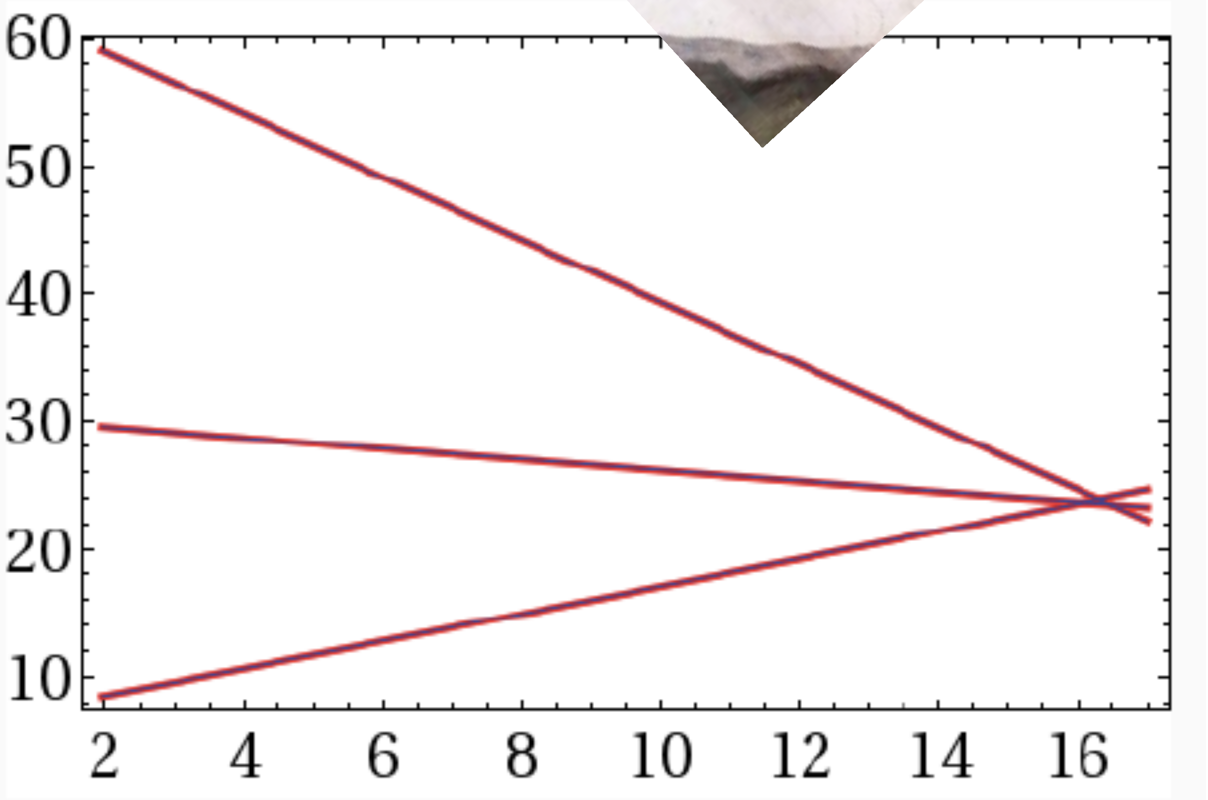
$$S = \int \mathrm{d}^4x \left(\mathrm{d}^2\theta \mathrm{d}^2\bar{\theta}\, \Phi_i^* \exp\left(2 g_A T_A^a V_A^a\right) \Phi_i + \left\{ \mathrm{d}^2\theta \left[\mathcal{W}(\{\Phi_i\}) + \frac{1}{4} W_A^a W_A^a \right] + \mathrm{h.c.} \right\} \right)$$

A hint?

SM



MSSM

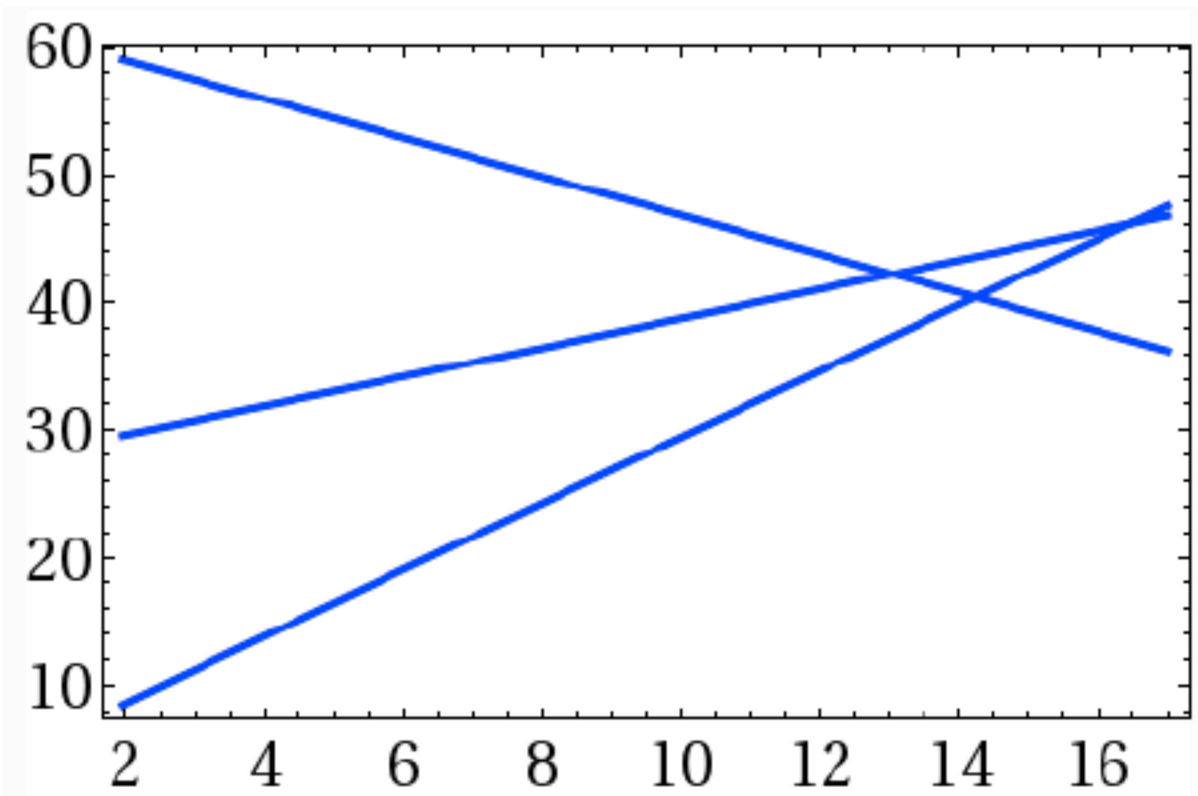


Gauge Coupling running at two loops

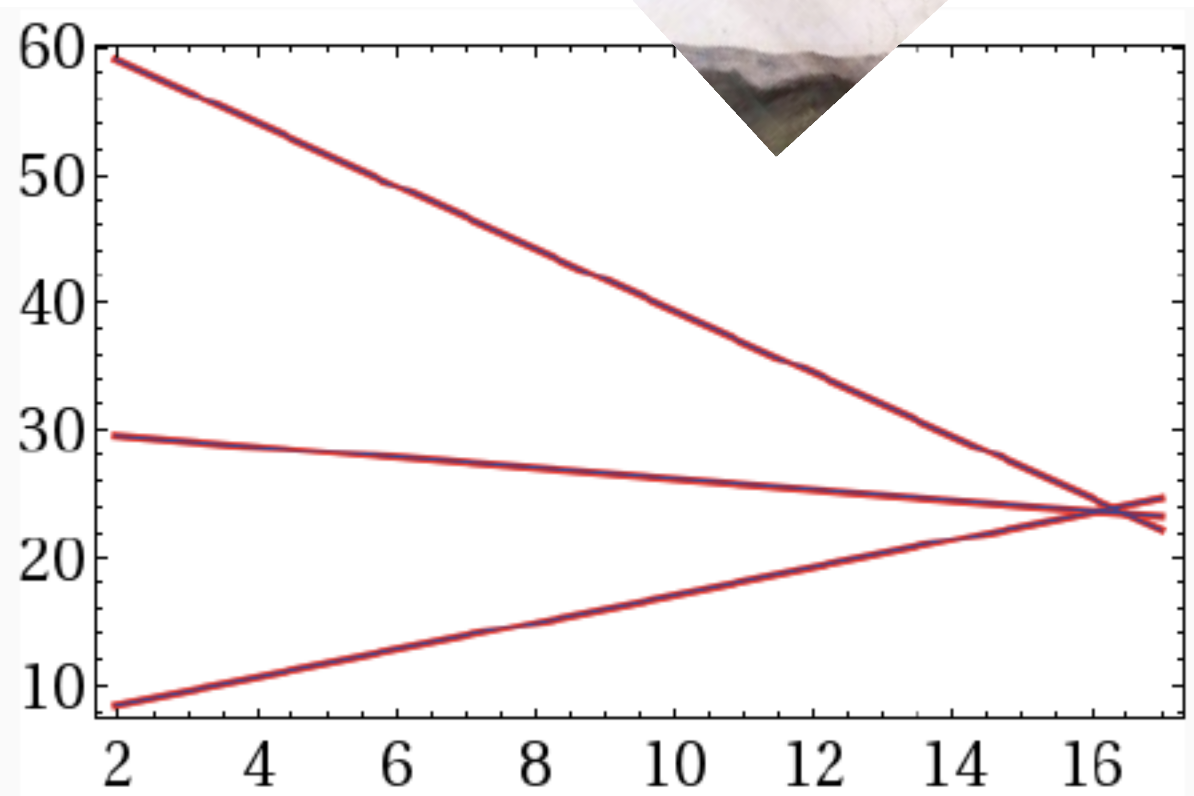
$$S = \int \mathrm{d}^4x \left(\mathrm{d}^2\theta \mathrm{d}^2\bar{\theta}\, \Phi_i^* \exp\left(2g_A T_A^a V_A^a\right) \Phi_i + \left\{ \mathrm{d}^2\theta \left[\mathcal{W}(\{\Phi_i\}) + \frac{1}{4} W_A^a W_A^a \right] + \text{h.c.} \right\} \right)$$

A hint?

SM



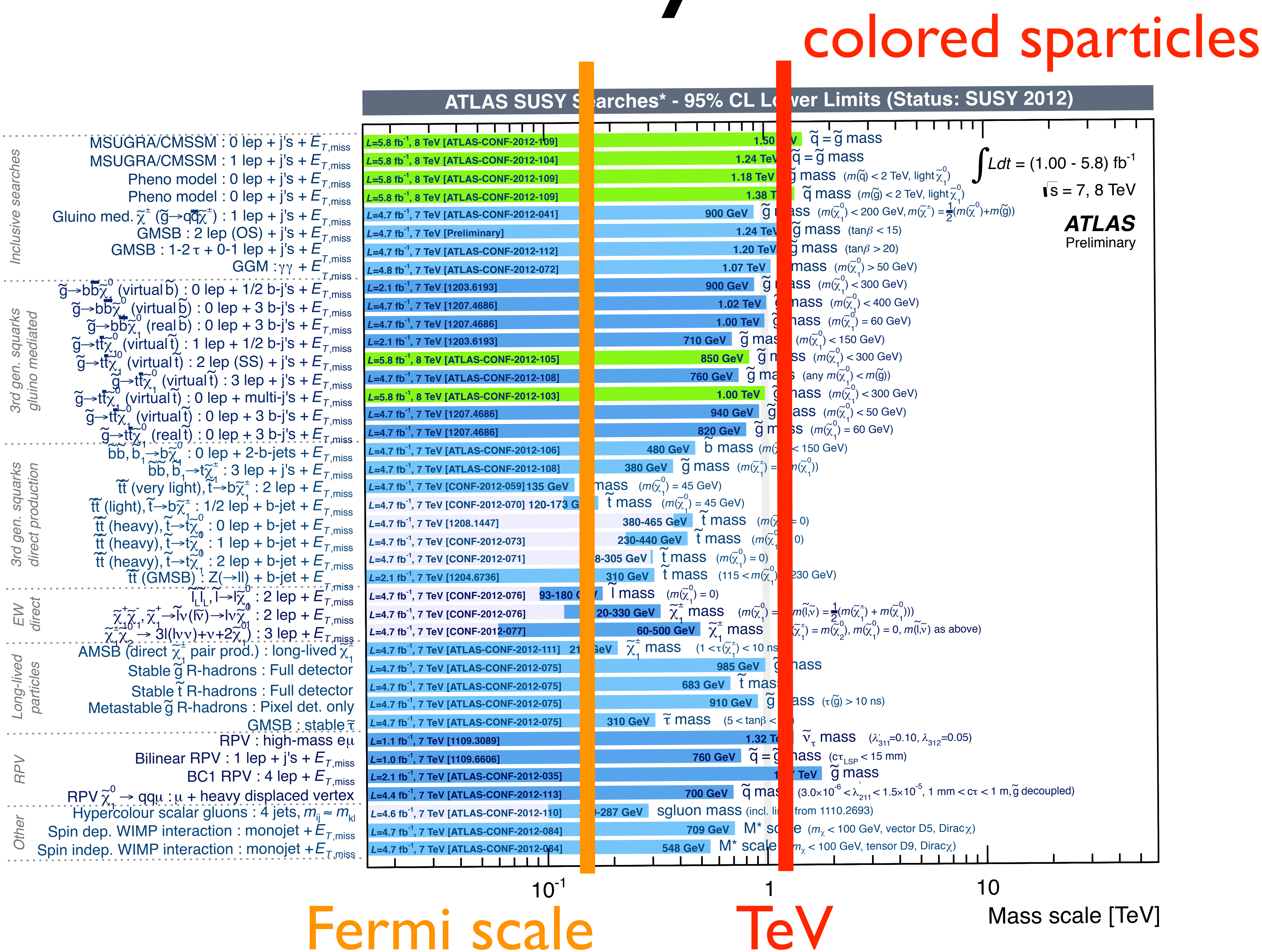
MSSM



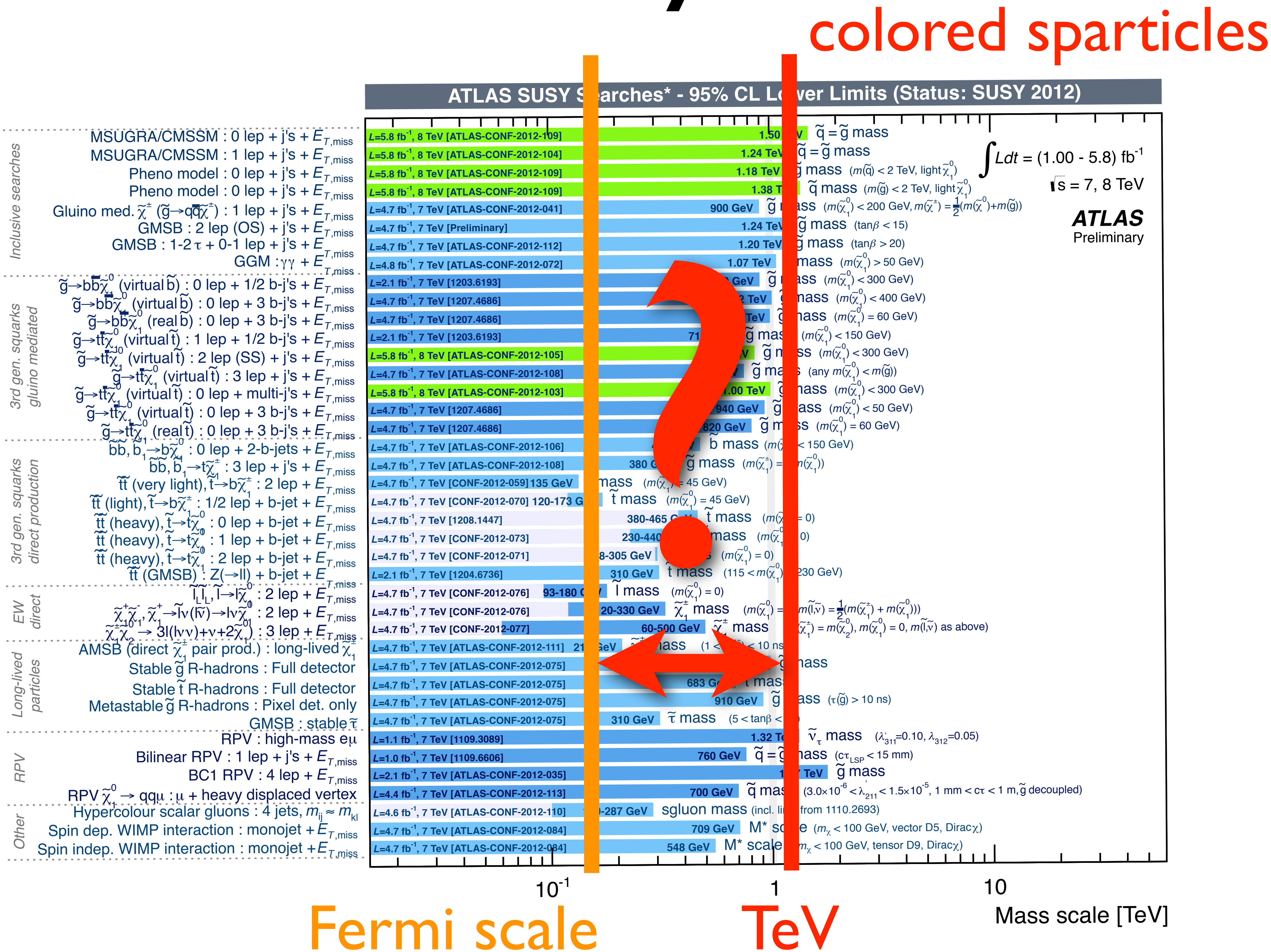
Gauge Coupling running at two loops

$$S = \int \mathrm{d}^4x \left(\mathrm{d}^2\theta \mathrm{d}^2\bar{\theta}\, \Phi_i^* \exp\left(2 g_A T_A^a V_A^a\right) \Phi_i + \left\{ \mathrm{d}^2\theta \left[\mathcal{W}(\{\Phi_i\}) + \frac{1}{4} W_A^a W_A^a \right] + \mathrm{h.c.} \right\} \right)$$

Colored Susy > TeV ?



Colored Susy > TeV ?



~~Natural~~ Ascetic susy

Natural EWSB in times of austerity

MSSM,NMSSM, ...

Fine-tuning of (Higgs mass)^2

$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m^2_H$$

Natural EWSB in times of austerity

MSSM, NMSSM, ...

Fine-tuning of (Higgs mass)^2

$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m^2_H$$

Higgsinos

Natural EWSB in times of austerity

MSSM, NMSSM, ...

Fine-tuning of (Higgs mass)^2

$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m^2_H$$

Higgsinos

1loop $\quad \delta m^2_H|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m^2_{U_3} + m^2_{Q_3} + |A_t|^2 \right) \log\left(\frac{\Lambda}{\text{TeV}} \right)$

stops, sbottom$_L$

2loop $\quad \delta m^2_H|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi} \right) |M_3|^2 \log^2 \left(\frac{\Lambda}{\text{TeV}} \right)$

gluino

Pappucci, Rudermann, AW '11

Inducing splitting via RGE alone does not help

$$\delta m_H^2 \simeq 3\left(m_{Q_3}^2 - m_{Q_{1,2}}^2\right) \simeq \frac{3}{2}\left(m_{U_3}^2 - m_{U_{1,2}}^2\right)$$

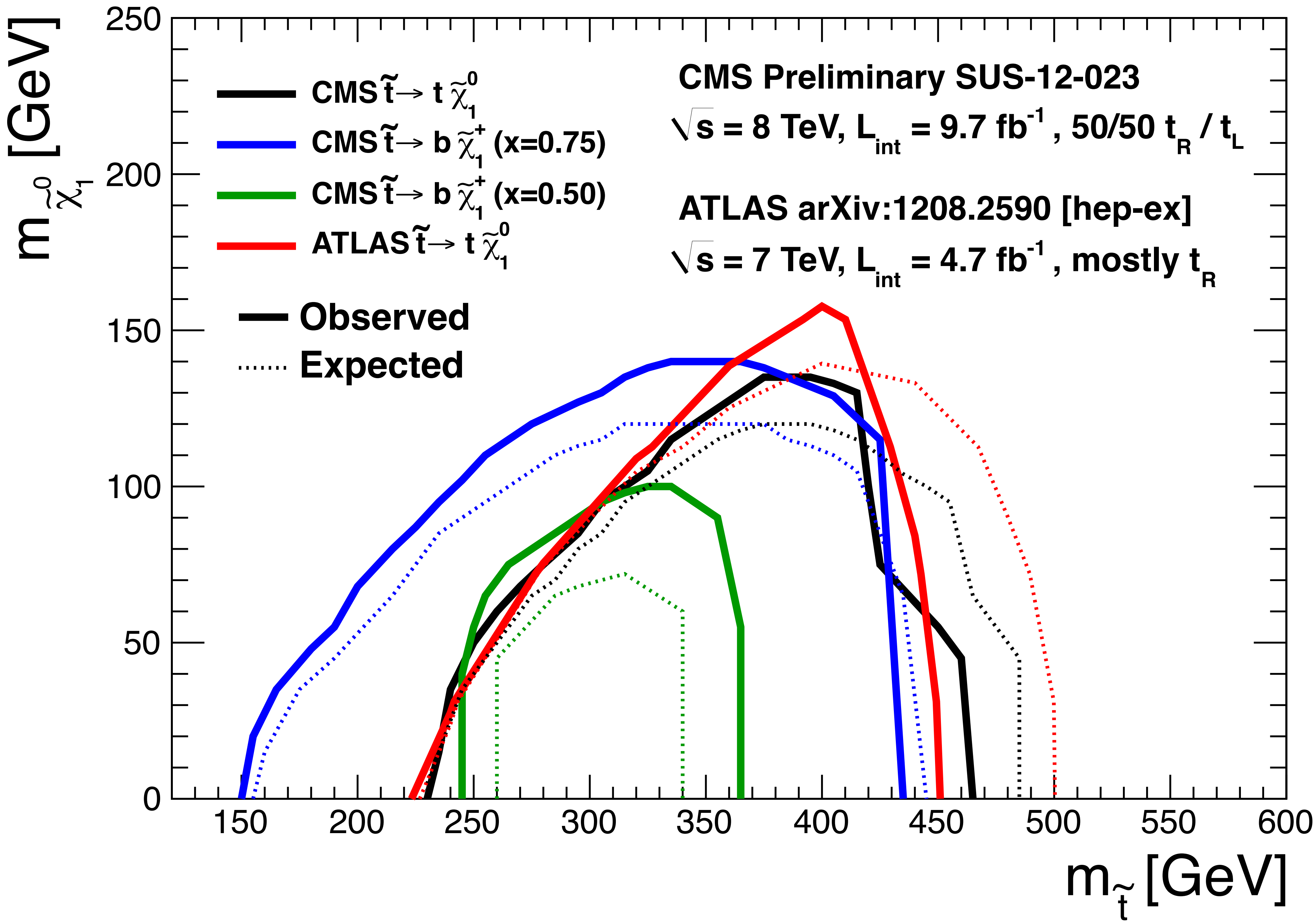
1-loop, LLog,
tanß moderate

fine-tuning

RGE splitting

→ Flavor non-trivial susy breaking!

Direct stop searches



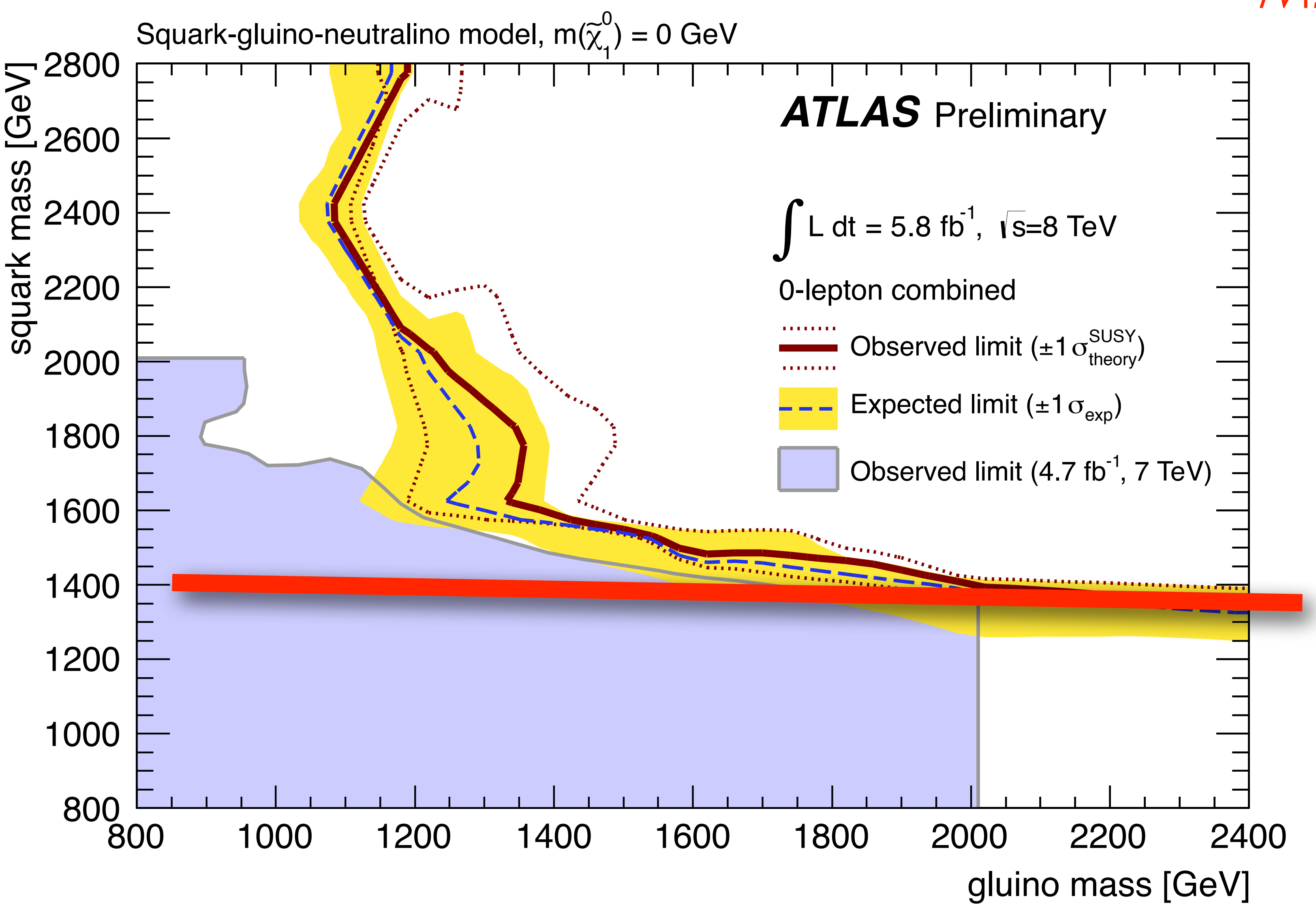
Where's susy hiding?

- Compressed spectra
- R-parity violation
- Natural Susy
- …
- Are we systematic enough?

Light non-degenerate squarks at the LHC

M. Papucci, J. Ruderman (LBL Berkely)
G. Perez, R. Mahbubani (CERN)

squarks

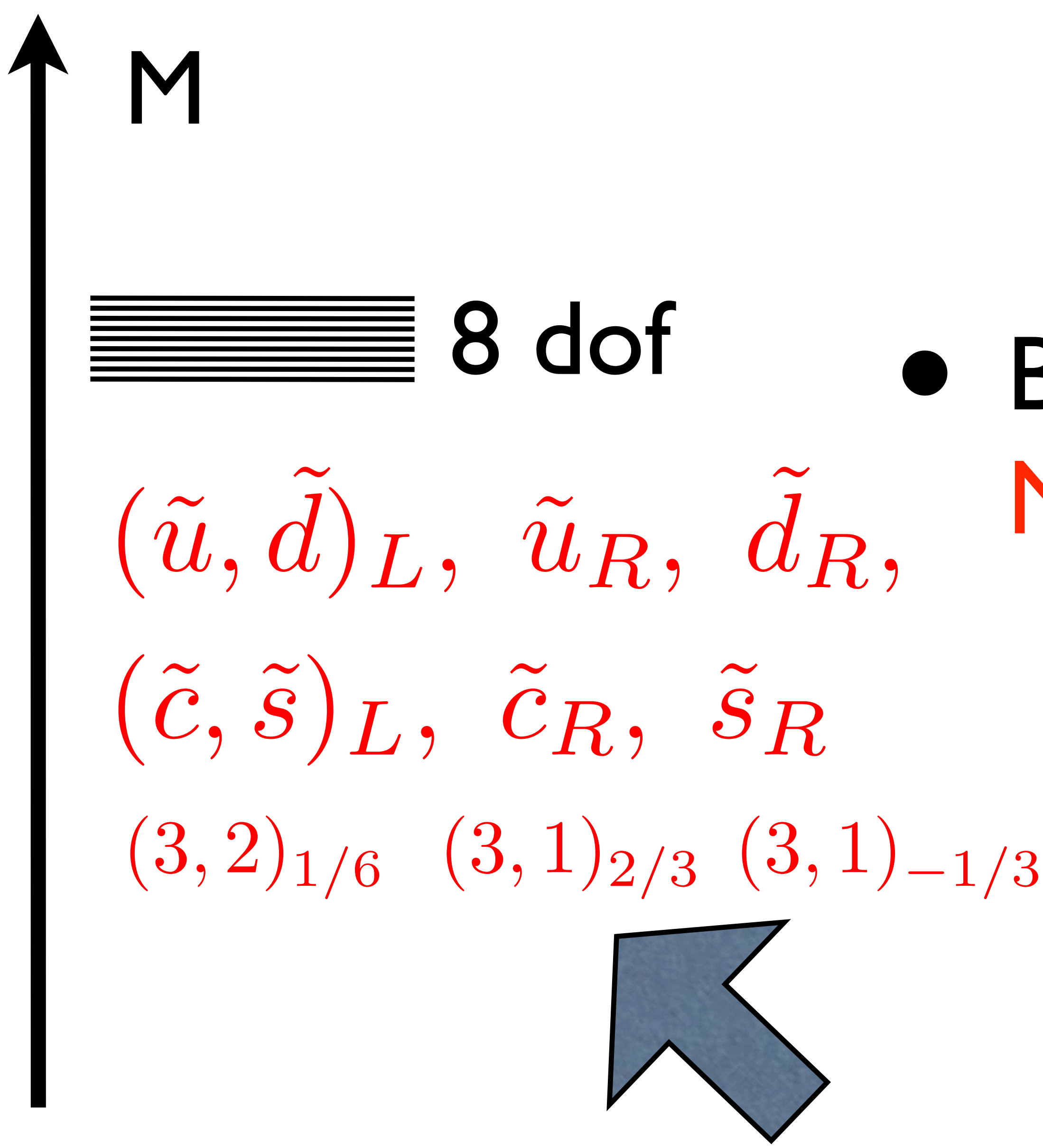


> 1.4 TeV

gluino

arXiv:1212.3328

Do the 1st & 2nd gen' squarks have to be degenerate?



- Because of flavor constraints?
  Not really.

Assumed spectrum in ATLAS/CMS plots

The SM flavor puzzle

$$Y_D \approx \mathrm{diag}\left(2 \cdot 10^{-5} \quad 0.0005 \quad 0.02\right)$$

$$Y_U \approx \begin{pmatrix} 6 \cdot 10^{-6} & -0.001 & 0.008 + 0.004i \\ 1 \cdot 10^{-6} & 0.004 & -0.04 + 0.001 \\ 8 \cdot 10^{-9} + 2 \cdot 10^{-8} i & 0.0002 & 0.98 \end{pmatrix}$$

Other dimensionless parameters of the SM:

$g_s \approx 1$, $g \approx 0.6$, $g' \approx 0.3$, $\lambda_{Higgs} \approx 1$, $|\theta| < 10^{-9}$

Operator	Bounds on Λ in TeV ($c_{ij}=1$)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L\gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	$\Delta m_K;\ \epsilon_K$
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	$\Delta m_K;\ \epsilon_K$
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
$(\bar{b}_L\gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	$\Delta m_{B_d};\ S_{\psi K_S}$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	$\Delta m_{B_d};\ S_{\psi K_S}$
$(\bar{b}_L\gamma^\mu s_L)^2$	1.1×10^2		7.6×10^{-5}		Δm_{B_s}
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	3.7×10^2		1.3×10^{-5}		Δm_{B_s}

UTfit 08, Isidori, Perez, Nir '10

Operator	Bounds on Λ in TeV ($c_{ij}=1$)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_L \gamma^\mu s_L)^2$	1.1×10^2		7.6×10^{-5}		Δm_{B_s}
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	3.7×10^2		1.3×10^{-5}		Δm_{B_s}

Very strong suppression! New flavor violation must either approximately (exactly?) follow SM structure…

UTfit 08, Isidori, Perez, Nir '10

Operator	Bounds on Λ in TeV ($c_{ij}=1$) Re	Im	Bounds on c_{ij} ($\Lambda = 1$ TeV) Re	Im	Observables
$(\bar{s}_L\gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{b}_L\gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_L\gamma^\mu s_L)^2$	1.1×10^2		7.6×10^{-5}		Δm_{B_s}
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	3.7×10^2		1.3×10^{-5}		Δm_{B_s}

Very strong suppression! New flavor violation must either approximately (exactly?) follow SM structure…

… or exist only at very high scales (*10*^{2} - *10*^{5} TeV)

UTfit 08, Isidori, Perez, Nir '10

SUSY & Flavor

Flavor Bounds (K, D, B, Bs mixing, …) controlled by

$$(\delta^q_{ij})_{MM} = \frac{1}{\tilde{m}_q^2} \sum_\alpha (K^q_M)_{i\alpha} (K^q_M)^*_{j\alpha} \Delta \tilde{m}^2_{q_\alpha}$$

SUSY & Flavor

Flavor Bounds (K, D, B, Bs mixing, ...) controlled by

$$(\delta^q_{ij})_{MM} = \frac{1}{\tilde{m}_q^2} \sum_\alpha (K^q_M)_{i\alpha} (K^q_M)^*_{j\alpha} \Delta \tilde{m}^2_{q_\alpha}$$

mixing matrices

SUSY & Flavor

Flavor Bounds (K, D, B, Bs mixing, ...) controlled by

$$(\delta^q_{ij})_{MM} = \frac{1}{\tilde{m}^2_q} \sum_\alpha (K^q_M)_{i\alpha} (K^q_M)^*_{j\alpha} \Delta \tilde{m}^2_{q_\alpha}$$

mixing matrices mass splitting

SUSY & Flavor

Flavor Bounds (K, D, B, Bs mixing, ...) controlled by

$$(\delta^q_{ij})_{MM} = \frac{1}{\tilde{m}^2_q} \sum_\alpha (K^q_M)_{i\alpha}(K^q_M)^*_{j\alpha} \Delta\tilde{m}^2_{q_\alpha}$$

mixing matrices mass splitting

(m=1TeV)

q	ij	$(\delta^q_{ij})_{MM}$	$\langle\delta^q_{ij}\rangle$
d	12	0.03	0.002
d	13	0.2	0.07
d	23	0.6	0.2
u	12	0.1	0.008

SUSY & Flavor

Flavor Bounds (K, D, B, Bs mixing, ...) controlled by

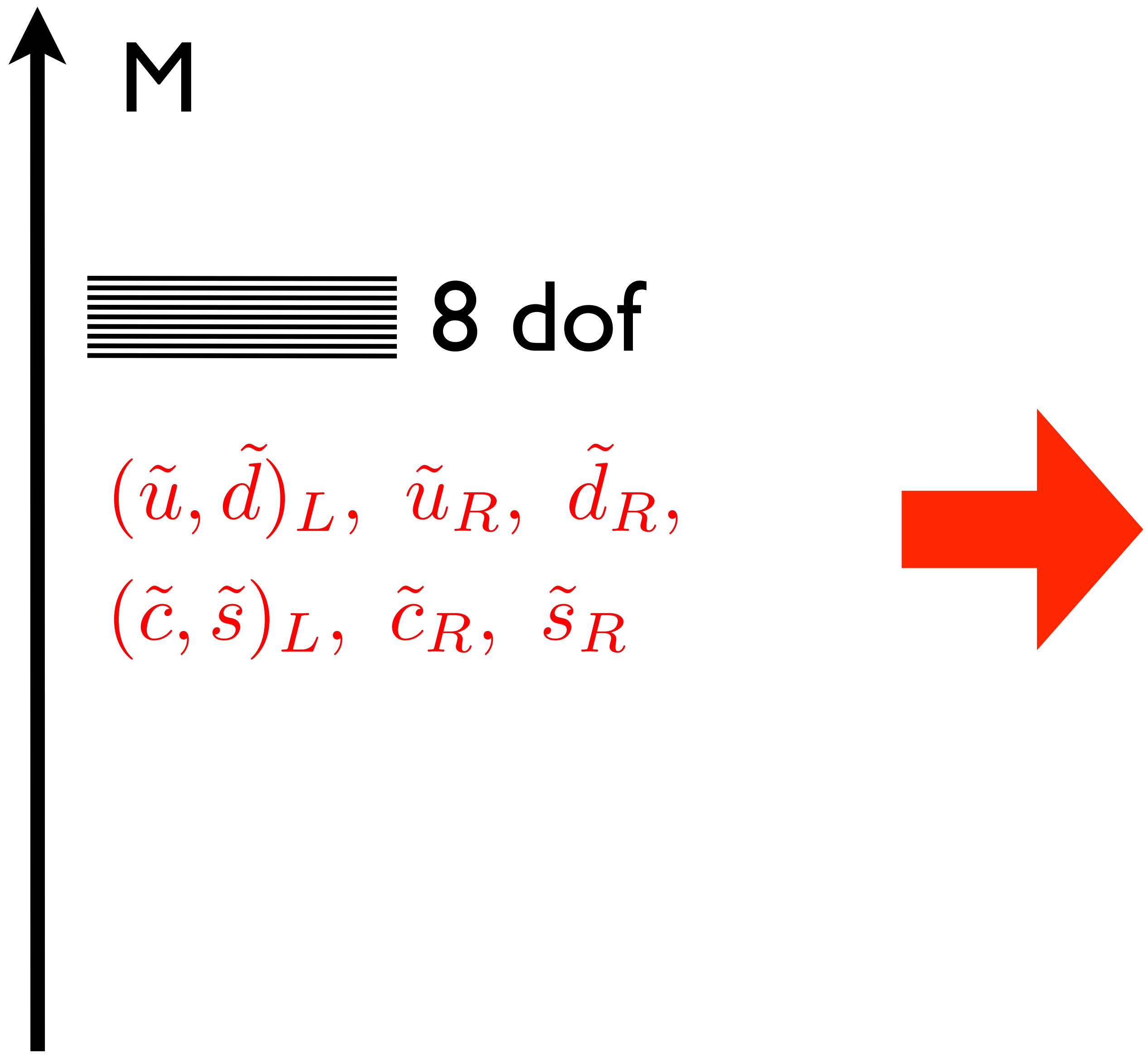
$$(\delta^q_{ij})_{MM} = \frac{1}{\tilde{m}_q^2} \sum_\alpha (K^q_M)_{i\alpha}(K^q_M)^*_{j\alpha} \Delta\tilde{m}^2_{q_\alpha}$$

mixing matrices mass splitting

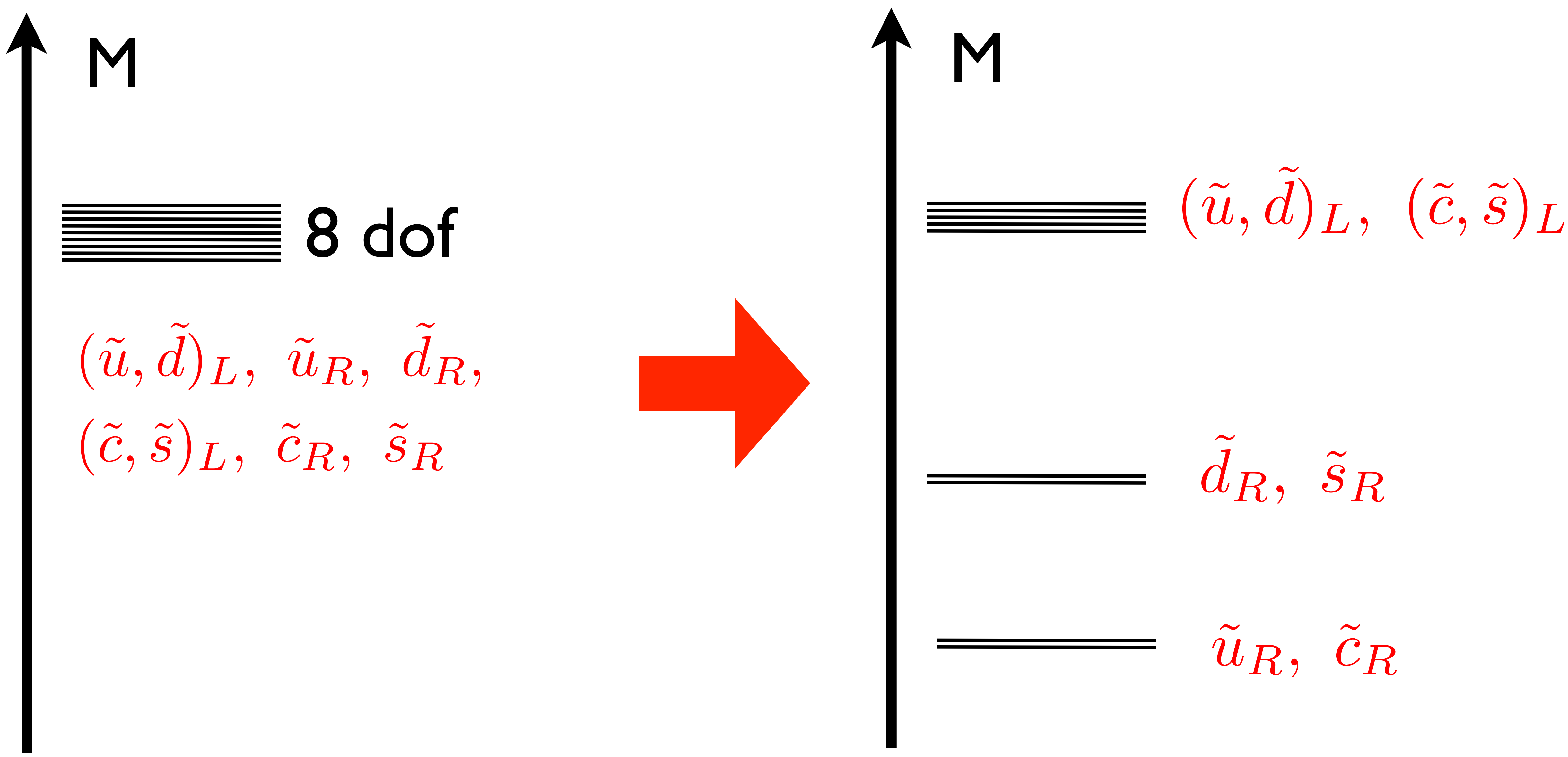
(m=1TeV)

q	ij	$(\delta^q_{ij})_{MM}$	$\langle\delta^q_{ij}\rangle$
d	12	0.03	0.002
d	13	0.2	0.07
d	23	0.6	0.2
u	12	0.1	0.008

large mixing means splitting must be << 1



Fully degenerate

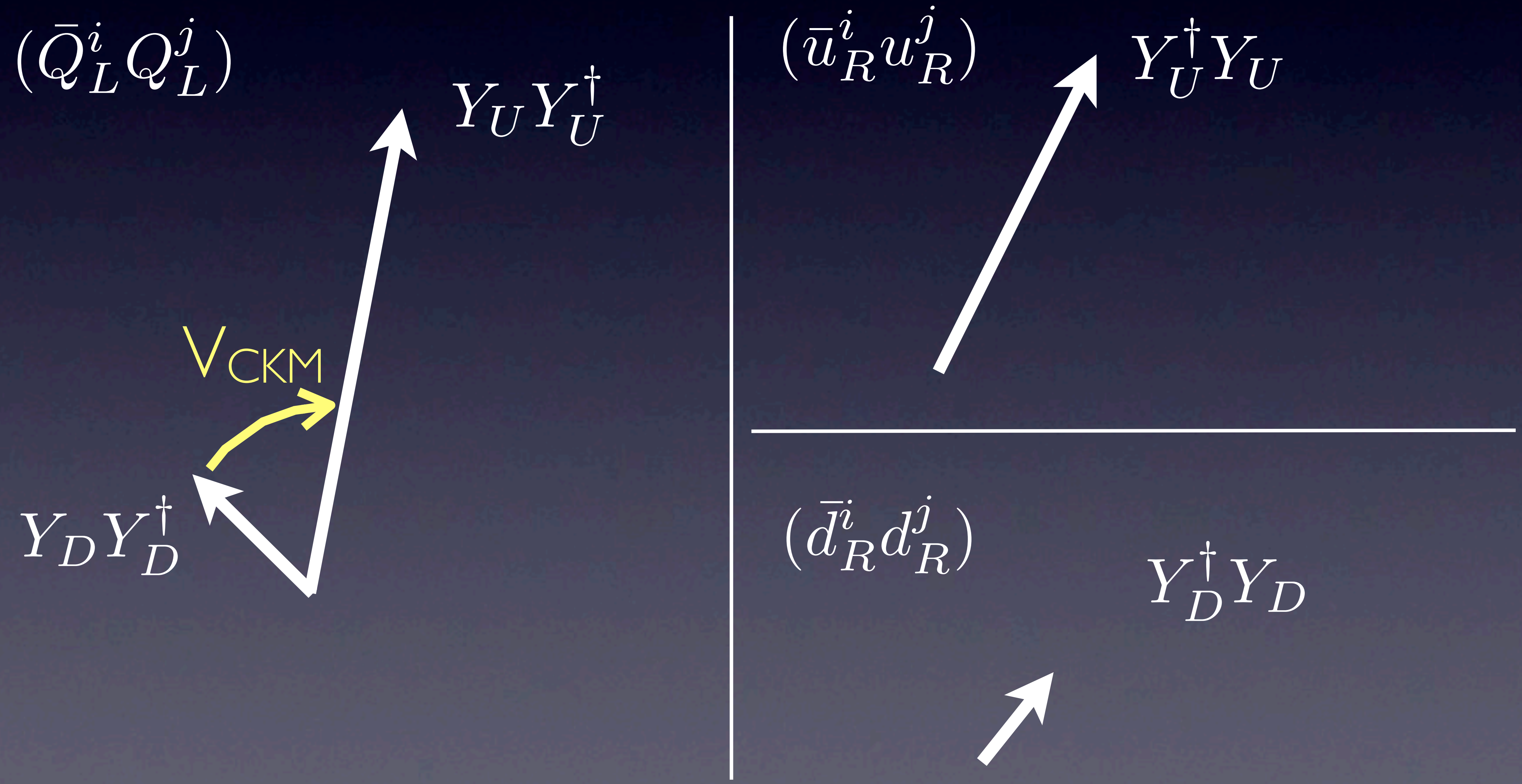


Fully degenerate

Vertical splitting,
MFV & no flavor issues

Flavor dynamics: alignment

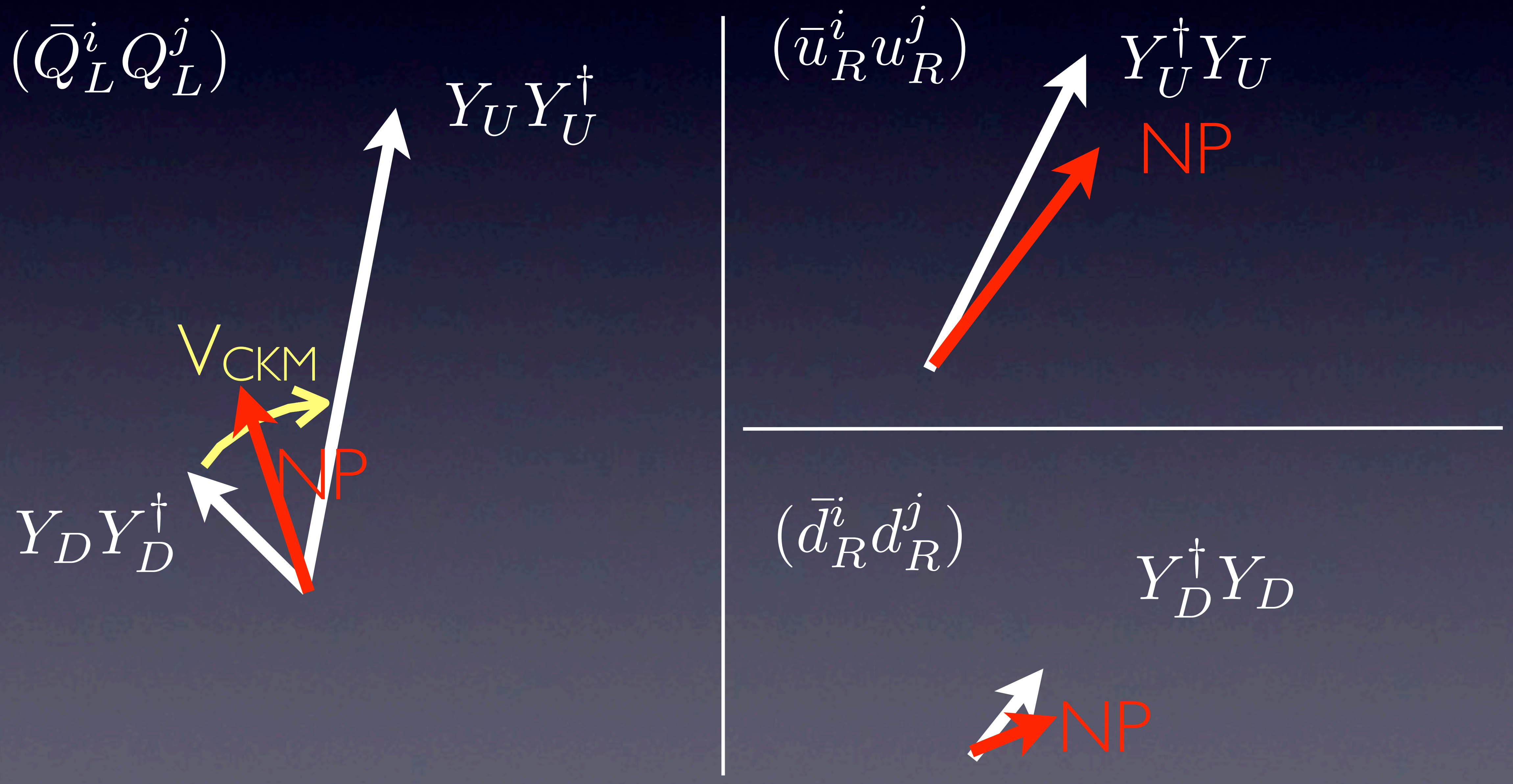
Dynamics (e.g. $U(1)_{horiz.}$) generates hierarchies in masses & mixings. Consequence: partial alignment with SM



+ LR, RL

Flavor dynamics: alignment

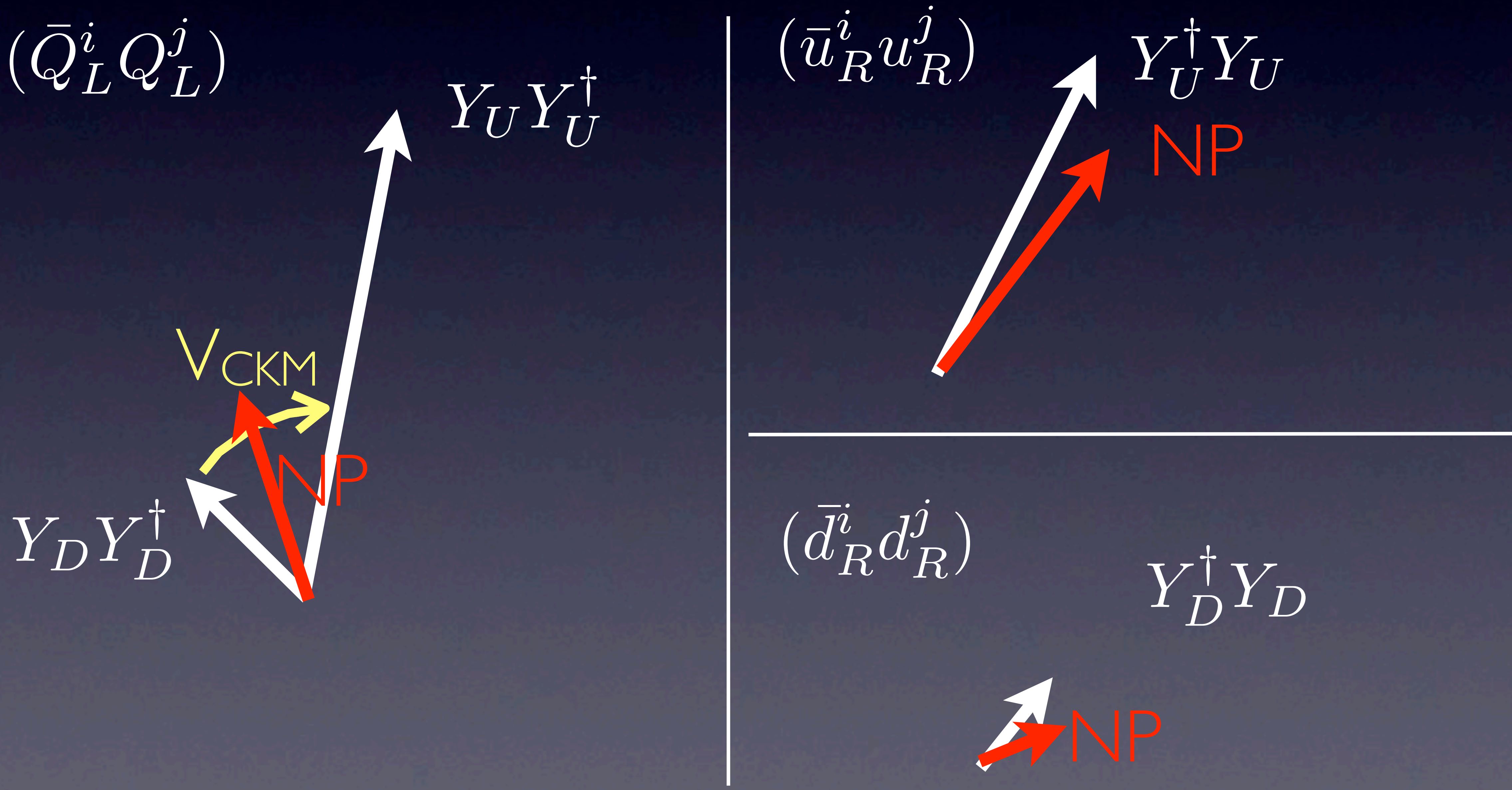
Dynamics (e.g. $U(1)_{horiz.}$) generates hierarchies in masses & mixings. Consequence: partial alignment with SM



+ LR, RL

Left-handed (Q_L^i): aligned with either up or down

Right-handed (u_R, d_R, c_R, d_R): can be fully aligned



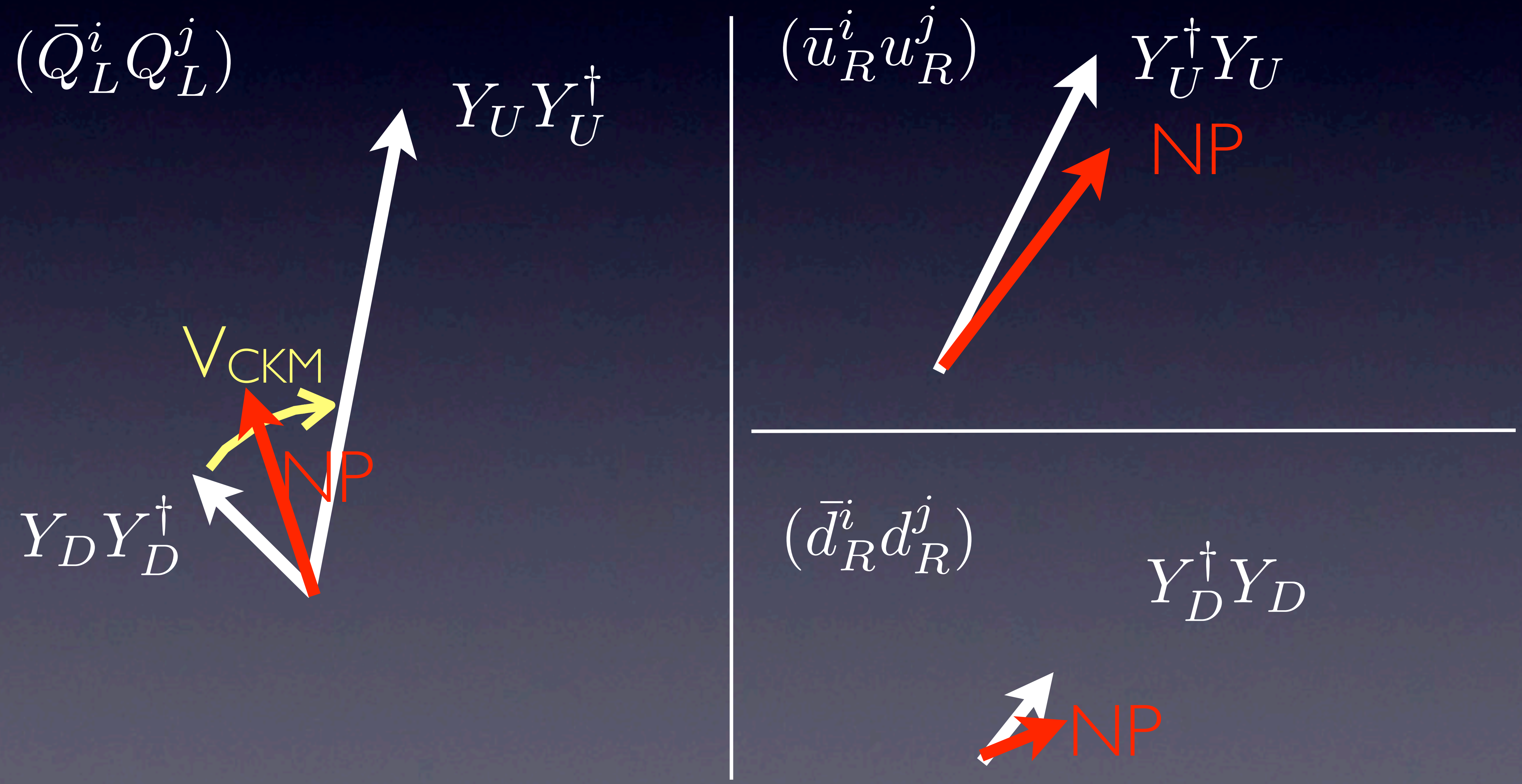
+ LR, RL

Left-handed (Q_L^i): aligned with either up or down

→ **limited splitting**

Right-handed (u_R, d_R, c_R, d_R): can be fully aligned

→ **any splitting**



+ LR, RL

Back of the envelope estimate

Cross-sections roughly scale like ~1/m^6.

Example: 8 light squarks → 2 light squarks

Shift limit only by $\sim 4^{1/6} - 1 \approx 25\%$

→ too naive!

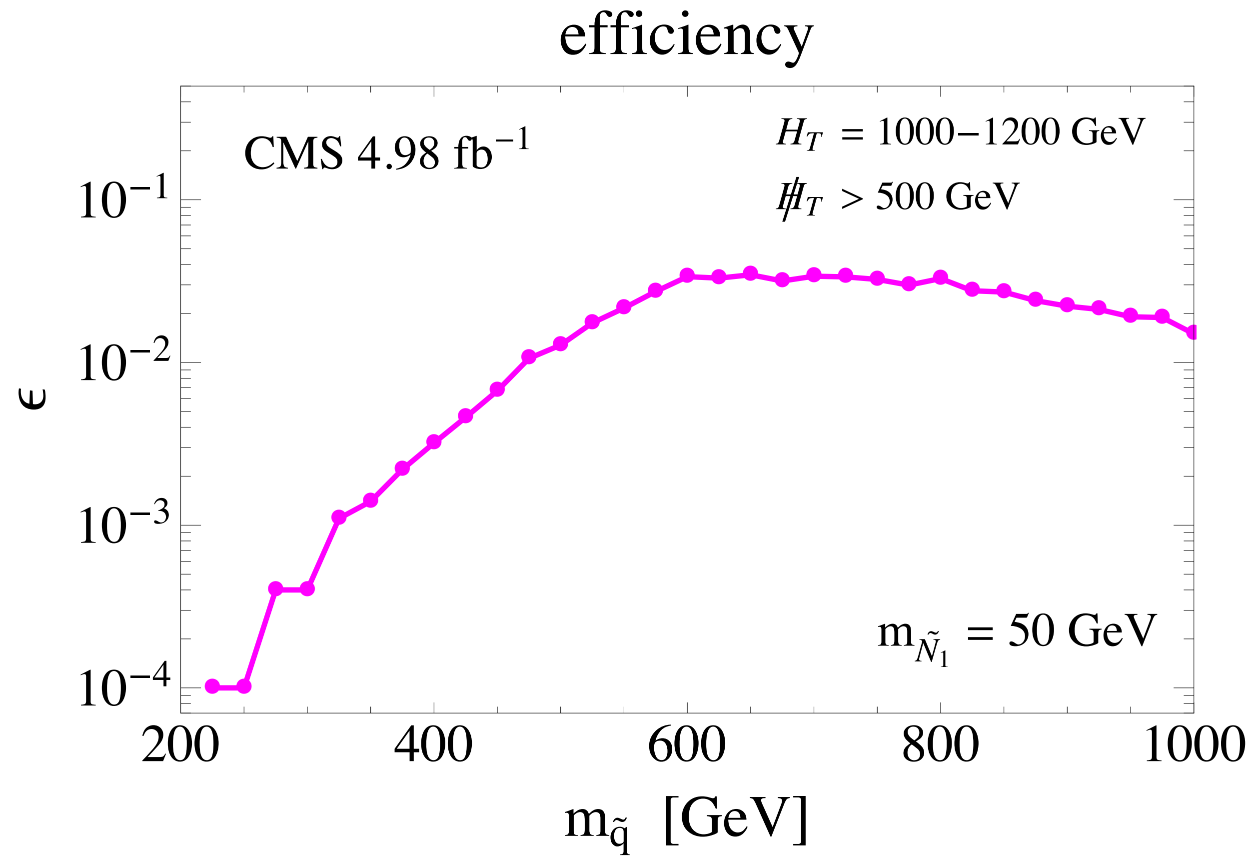
Dedicated study needed

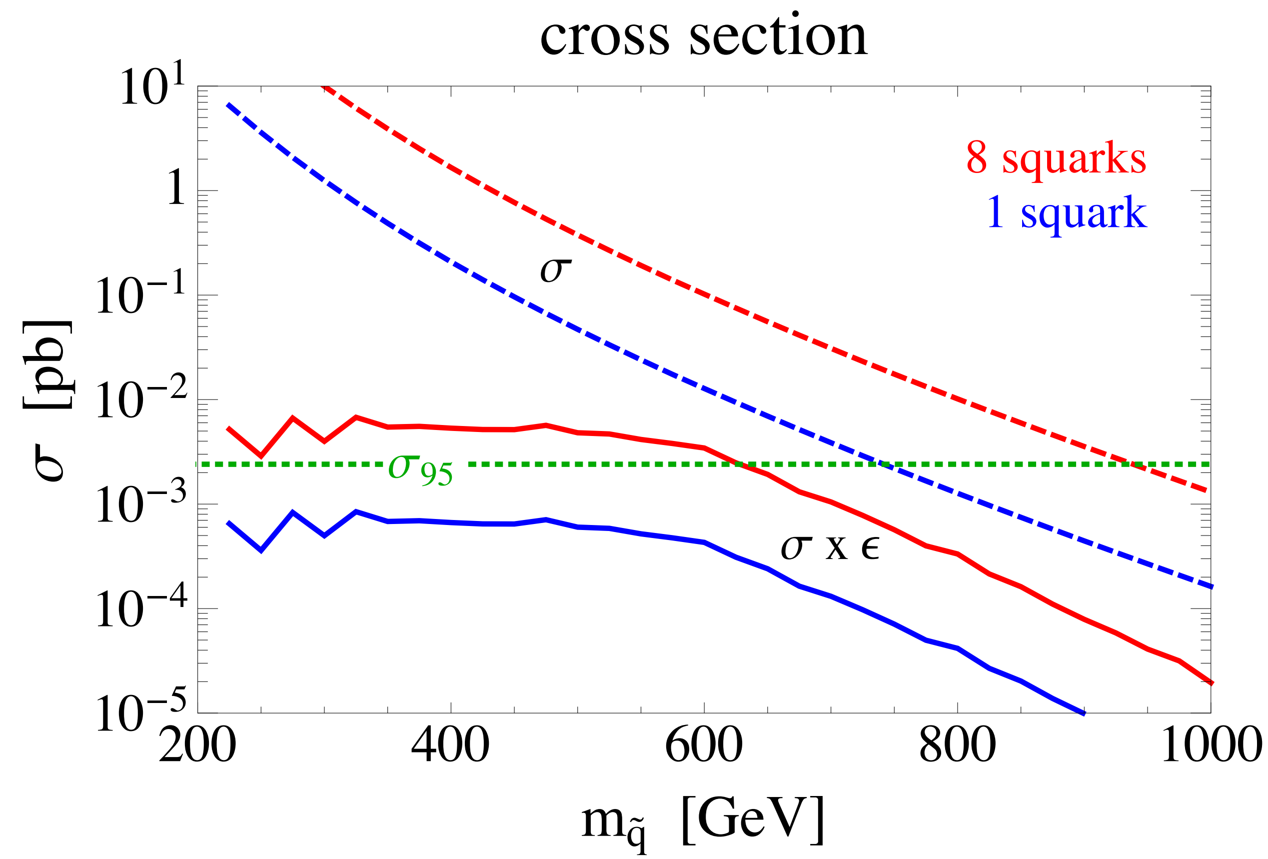
- Production cross-section can be flavor dependent if gluino is not fully decoupled through p.d.f's (u vs. d, sea vs. valence)
- Experimental efficiencies for light squarks efficiencies have thresholds and current limits are on the thresholds

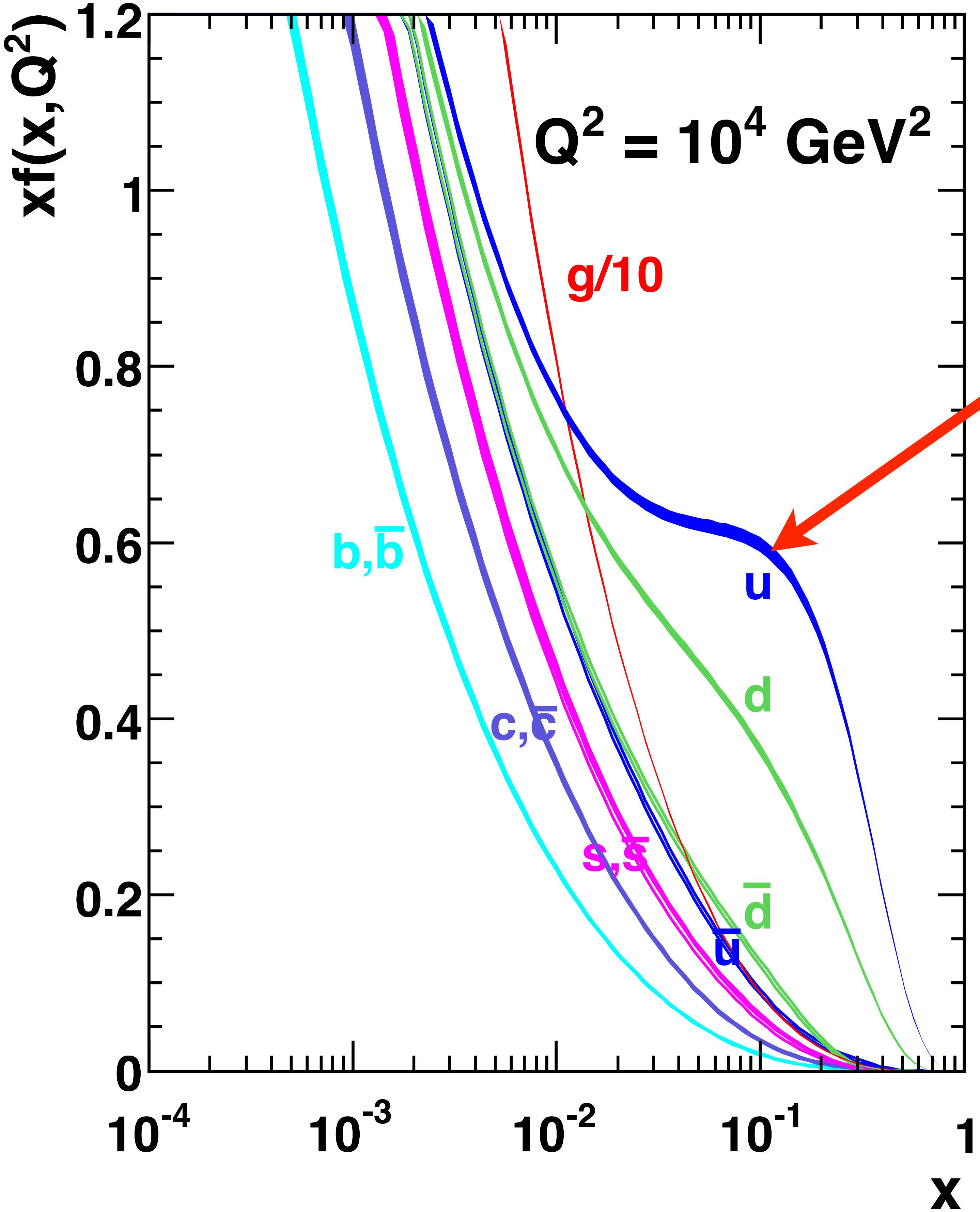
Squark searches

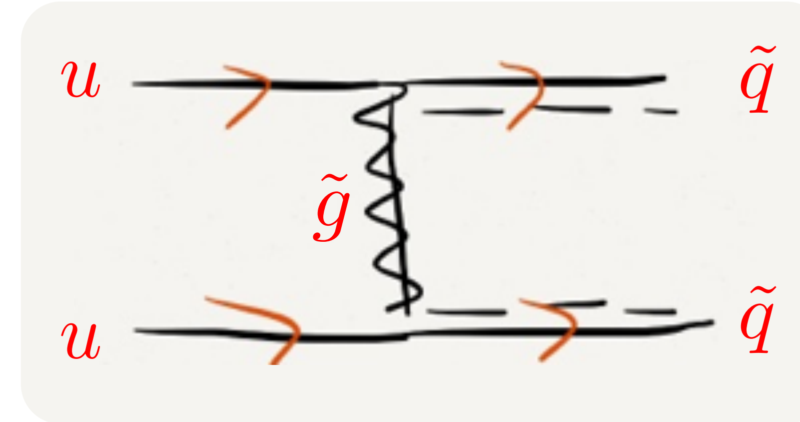
M. Papucci, J. Ruderman
G. Perez, R. Mahbubani, AW

Effect of the efficiency threshold:







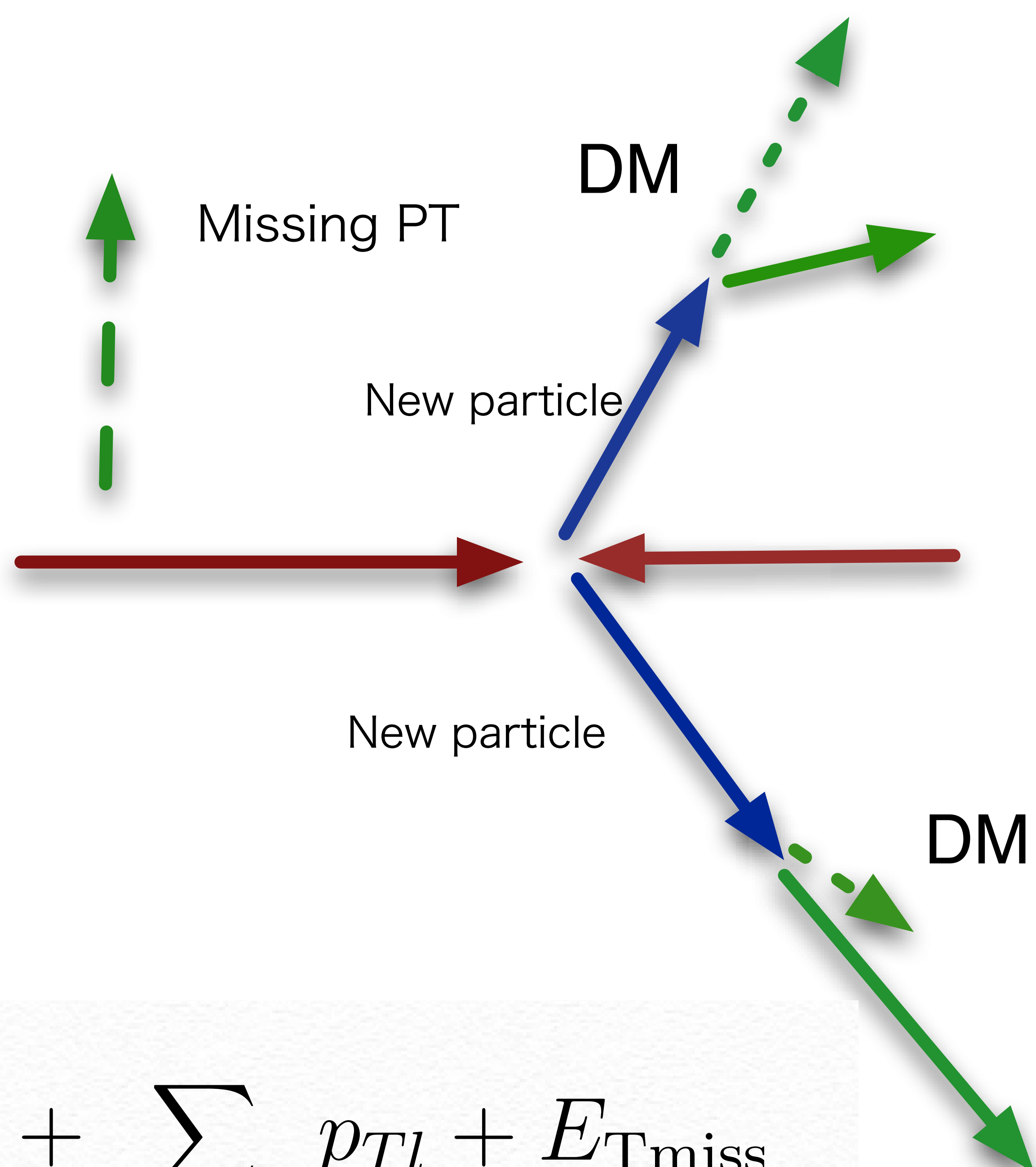


access to large up quark pdf

$$E \approx x \cdot 7\,\mathrm{TeV}$$

What has the LHC done to your favorite Model?

Basic idea



$E_{T\mathrm{miss}}$

$$M_{\mathrm{eff}} \equiv \sum_{i=1,\ldots 4} p_{Ti} + \sum_{\mathrm{leptons}} p_{Tl} + E_{T\mathrm{miss}}$$

DYI limits

CERN-PH-EP-2011-145

Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in $\sqrt{s} = 7$ TeV proton-proton collisions

The ATLAS Collaboration

Example:
jets+ MET, 1ifb

DYI limits

CERN-PH-EP-2011-145

Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in $\sqrt{s}$ = 7 TeV proton-proton collisions

The ATLAS Collaboration

Example:
jets+ MET, 1ifb

signal bins

Signal Region	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	> 500/1000	> 1100

Bgd’s are left to the experimentalists… stay out of control regions!

Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\rm eff}$ > 500 GeV	$\geq$ 4-jet, $m_{\rm eff}$ > 1000 GeV	High mass
Z/γ+jets	$32.3 \pm 2.6 \pm 6.9$	$25.5 \pm 2.6 \pm 4.9$	$209 \pm 9 \pm 38$	$16.2 \pm 2.2 \pm 3.7$	$3.3 \pm 1.0 \pm 1.3$
W+jets	$26.4 \pm 4.0 \pm 6.7$	$22.6 \pm 3.5 \pm 5.6$	$349 \pm 30 \pm 122$	$13.0 \pm 2.2 \pm 4.7$	$2.1 \pm 0.8 \pm 1.1$
$t\bar{t}$+ single top	$3.4 \pm 1.6 \pm 1.6$	$5.9 \pm 2.0 \pm 2.2$	$425 \pm 39 \pm 84$	$4.0 \pm 1.3 \pm 2.0$	$5.7 \pm 1.8 \pm 1.9$
QCD multi-jet	$0.22 \pm 0.06 \pm 0.24$	$0.92 \pm 0.12 \pm 0.46$	$34 \pm 2 \pm 29$	$0.73 \pm 0.14 \pm 0.50$	$2.10 \pm 0.37 \pm 0.82$
Total	$62.4 \pm 4.4 \pm 9.3$	$54.9 \pm 3.9 \pm 7.1$	$1015 \pm 41 \pm 144$	$33.9 \pm 2.9 \pm 6.2$	$13.1 \pm 1.9 \pm 2.5$
Data	58	59	1118	40	18

Table 2: Fitted background components in each SR, compared with the number of events observed in data. The Z/γ+jets background is constrained with co regions CR1a and CR1b, the QCD multi-jet, W and top quark backgrounds by control regions CR2, CR3 and CR4, respectively. In each case the first (sec quoted uncertainty is statistical (systematic). Background components are partially correlated and hence the uncertainties (statistical and systematic) on the background estimates do not equal the quadrature sums of the uncertainties on the components.

Bgd's are left to the experimentalists…

stay out of control regions!

Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\rm eff}$ > 500 GeV	$\geq$ 4-jet, $m_{\rm eff}$ > 1000 GeV	High mass
Z/γ+jets	32.3 ± 2.6 ± 6.9	25.5 ± 2.6 ± 4.9	209 ± 9 ± 38	16.2 ± 2.2 ± 3.7	3.3 ± 1.0 ± 1.3
W+jets	26.4 ± 4.0 ± 6.7	22.6 ± 3.5 ± 5.6	349 ± 30 ± 122	13.0 ± 2.2 ± 4.7	2.1 ± 0.8 ± 1.1
$t\bar{t}$+ single top	3.4 ± 1.6 ± 1.6	5.9 ± 2.0 ± 2.2	425 ± 39 ± 84	4.0 ± 1.3 ± 2.0	5.7 ± 1.8 ± 1.9
QCD multi-jet	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.73 ± 0.14 ± 0.50	2.10 ± 0.37 ± 0.82
Total	62.4 ± 4.4 ± 9.3	54.9 ± 3.9 ± 7.1	1015 ± 41 ± 144	33.9 ± 2.9 ± 6.2	13.1 ± 1.9 ± 2.5
Data	58	59	1118	40	18

Table 2: Fitted background components in each SR, compared with the number of events observed in data. The Z/γ+jets background is constrained with co regions CR1a and CR1b, the QCD multi-jet, W and top quark backgrounds by control regions CR2, CR3 and CR4, respectively. In each case the first (sec quoted uncertainty is statistical (systematic). Background components are partially correlated and hence the uncertainties (statistical and systematic) on the background estimates do not equal the quadrature sums of the uncertainties on the components.

[5] has improved the ATLAS reach at large m_0. The five signal regions are used to set limits on $\sigma_{new} = \sigma A \epsilon$, for non-SM cross-sections (σ) for which ATLAS has an acceptance A and a detection efficiency of ϵ [44]. The excluded values of σ_{new} are 22 fb, 25 fb, 429 fb, 27 fb and 17 fb, respectively, at the 95% confidence level.

upper bound on signal xsec

Bgd's are left to the experimentalists…

stay out of control regions!

Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\rm eff} > 500$ GeV	$\geq$ 4-jet, $m_{\rm eff} > 1000$ GeV	High mass
Z/γ+jets	$32.3 \pm 2.6 \pm 6.9$	$25.5 \pm 2.6 \pm 4.9$	$209 \pm 9 \pm 38$	$16.2 \pm 2.2 \pm 3.7$	$3.3 \pm 1.0 \pm 1.3$
W+jets	$26.4 \pm 4.0 \pm 6.7$	$22.6 \pm 3.5 \pm 5.6$	$349 \pm 30 \pm 122$	$13.0 \pm 2.2 \pm 4.7$	$2.1 \pm 0.8 \pm 1.1$
$t\bar{t}$+ single top	$3.4 \pm 1.6 \pm 1.6$	$5.9 \pm 2.0 \pm 2.2$	$425 \pm 39 \pm 84$	$4.0 \pm 1.3 \pm 2.0$	$5.7 \pm 1.8 \pm 1.9$
QCD multi-jet	$0.22 \pm 0.06 \pm 0.24$	$0.92 \pm 0.12 \pm 0.46$	$34 \pm 2 \pm 29$	$0.73 \pm 0.14 \pm 0.50$	$2.10 \pm 0.37 \pm 0.82$
Total	$62.4 \pm 4.4 \pm 9.3$	$54.9 \pm 3.9 \pm 7.1$	$1015 \pm 41 \pm 144$	$33.9 \pm 2.9 \pm 6.2$	$13.1 \pm 1.9 \pm 2.5$
Data	58	59	1118	40	18

Table 2: Fitted background components in each SR, compared with the number of events observed in data. The Z/γ+jets background is constrained with co regions CR1a and CR1b, the QCD multi-jet, W and top quark backgrounds by control regions CR2, CR3 and CR4, respectively. In each case the first (sec quoted uncertainty is statistical (systematic). Background components are partially correlated and hence the uncertainties (statistical and systematic) on the background estimates do not equal the quadrature sums of the uncertainties on the components.

[5] has improved the ATLAS reach at large m_0. The five signal regions are used to set limits on $\sigma_{new} = \sigma A \epsilon$, for non-SM cross-sections (σ) for which ATLAS has an acceptance A and a detection efficiency of ϵ [44]. The excluded values of σ_{new} are 22 fb, 25 fb, 429 fb, 27 fb and 17 fb, respectively, at the 95% confidence level.

upper bound on signal xsec

"Only" need efficiency x Acceptance of the signal bins for your model…

Bgd's are left to the experimentalists…

stay out of control regions!

Process	Signal Region				
	≥ 2-jet	≥ 3-jet	≥ 4-jet, $m_{\rm eff}$ > 500 GeV	≥ 4-jet, $m_{\rm eff}$ > 1000 GeV	High mass
Z/γ+jets	32.3 ± 2.6 ± 6.9	25.5 ± 2.6 ± 4.9	209 ± 9 ± 38	16.2 ± 2.2 ± 3.7	3.3 ± 1.0 ± 1.3
W+jets	26.4 ± 4.0 ± 6.7	22.6 ± 3.5 ± 5.6	349 ± 30 ± 122	13.0 ± 2.2 ± 4.7	2.1 ± 0.8 ± 1.1
$t\bar{t}$+ single top	3.4 ± 1.6 ± 1.6	5.9 ± 2.0 ± 2.2	425 ± 39 ± 84	4.0 ± 1.3 ± 2.0	5.7 ± 1.8 ± 1.9
QCD multi-jet	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.73 ± 0.14 ± 0.50	2.10 ± 0.37 ± 0.82
Total	62.4 ± 4.4 ± 9.3	54.9 ± 3.9 ± 7.1	1015 ± 41 ± 144	33.9 ± 2.9 ± 6.2	13.1 ± 1.9 ± 2.5
Data	58	59	1118	40	18

Table 2: Fitted background components in each SR, compared with the number of events observed in data. The Z/γ+jets background is constrained with co regions CR1a and CR1b, the QCD multi-jet, W and top quark backgrounds by control regions CR2, CR3 and CR4, respectively. In each case the first (sec quoted uncertainty is statistical (systematic). Background components are partially correlated and hence the uncertainties (statistical and systematic) on the background estimates do not equal the quadrature sums of the uncertainties on the components.

[5] has improved the ATLAS reach at large m_0. The five signal regions are used to set limits on $\sigma_{new} = \sigma A \epsilon$, for non-SM cross-sections (σ) for which ATLAS has an acceptance A and a detection efficiency of ϵ [44]. The excluded values of σ_{new} are 22 fb, 25 fb, 429 fb, 27 fb and 17 fb, respectively, at the 95% confidence level.

upper bound on signal xsec

"Only" need efficiency x Acceptance of the signal bins for your model…

LIMIT!

Bgd's are left to the experimentalists...
stay out of control regions!

Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\mathrm{eff}} > 500$ GeV	$\geq$ 4-jet, $m_{\mathrm{eff}} > 1000$ GeV	High mass
Z/γ+jets	$32.3 \pm 2.6 \pm 6.9$	$25.5 \pm 2.6 \pm 4.9$	$209 \pm 9 \pm 38$	$16.2 \pm 2.2 \pm 3.7$	$3.3 \pm 1.0 \pm 1.3$
W+jets	$26.4 \pm 4.0 \pm 6.7$	$22.6 \pm 3.5 \pm 5.6$	$349 \pm 30 \pm 122$	$13.0 \pm 2.2 \pm 4.7$	$2.1 \pm 0.8 \pm 1.1$
tt+ single top	$3.4 \pm 1.6 \pm 1.6$	$5.9 \pm 2.0 \pm 2.2$	$425 \pm 39 \pm 84$	$4.0 \pm 1.3 \pm 2.0$	$5.7 \pm 1.8 \pm 1.9$
QCD multi-jet	$0.22 \pm 0.06 \pm 0.24$	$0.92 \pm 0.12 \pm 0.46$	$34 \pm 2 \pm 29$	$0.73 \pm 0.14 \pm 0.50$	$2.10 \pm 0.37 \pm 0.82$
Total	$62.4 \pm 4.4 \pm 9.3$	$54.9 \pm 3.9 \pm 7.1$	$1015 \pm 41 \pm 144$	$33.9 \pm 2.9 \pm 6.2$	$13.1 \pm 1.9 \pm 2.5$
Data	58	59	1118	40	18

Table 2: Fitted background components in each SR, compared with the number of events observed in data. The Z/γ+jets background is constrained with co regions CR1a and CR1b, the QCD multi-jet, W and top quark backgrounds by control regions CR2, CR3 and CR4, respectively. In each case the first (sec quoted uncertainty is statistical (systematic). Background components are partially correlated and hence the uncertainties (statistical and systematic) on the background estimates do not equal the quadrature sums of the uncertainties on the components.

[5] has improved the ATLAS reach at large m_0. The five signal regions are used to set limits on $\sigma_{new} = \sigma A \epsilon$, for non-SM cross-sections (σ) for which ATLAS has an acceptance A and a detection efficiency of ϵ [44]. The excluded values of σ_{new} are 22 fb, 25 fb, 429 fb, 27 fb and 17 fb, respectively, at the 95% confidence level.

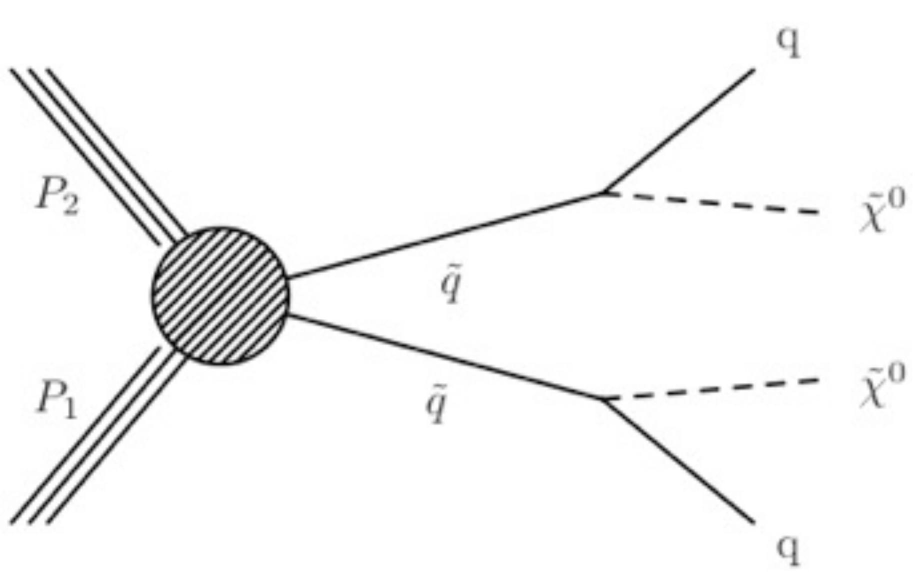
upper bound on signal xsec

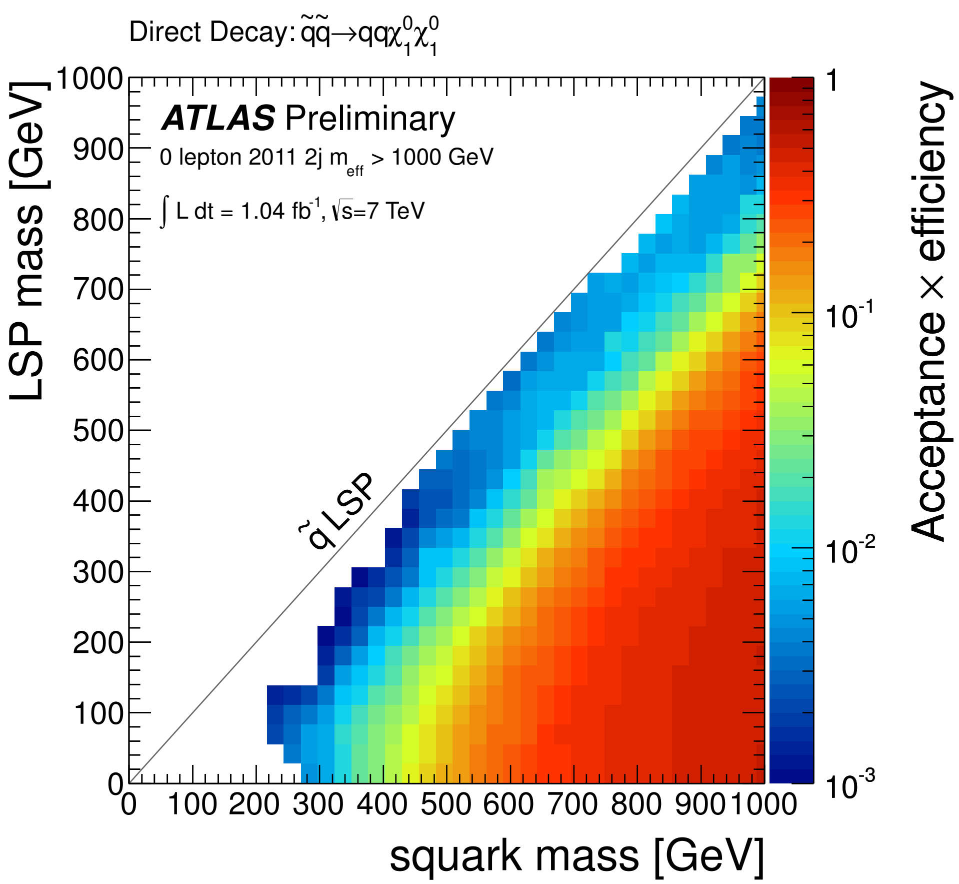
"Only" need efficiency x Acceptance of the signal bins for your model...

LIMIT!

Simplified Models

- ATLAS and CMS provide efficiencies for a small set of simplified models

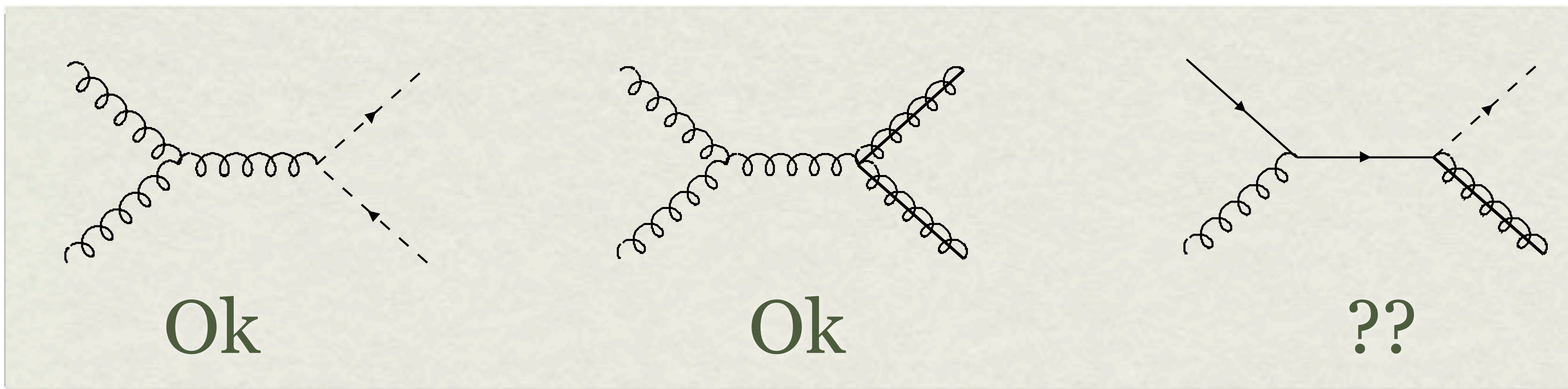




simplified topology

Unfortunately, simplified models are usually not sufficient.

Susy example: jets + MET



Simplified models do not cover associate production, pair produced non-degenerate squarks, …

Unreasonable to produce simplified models for every conceivable case* (especially for only setting limits)

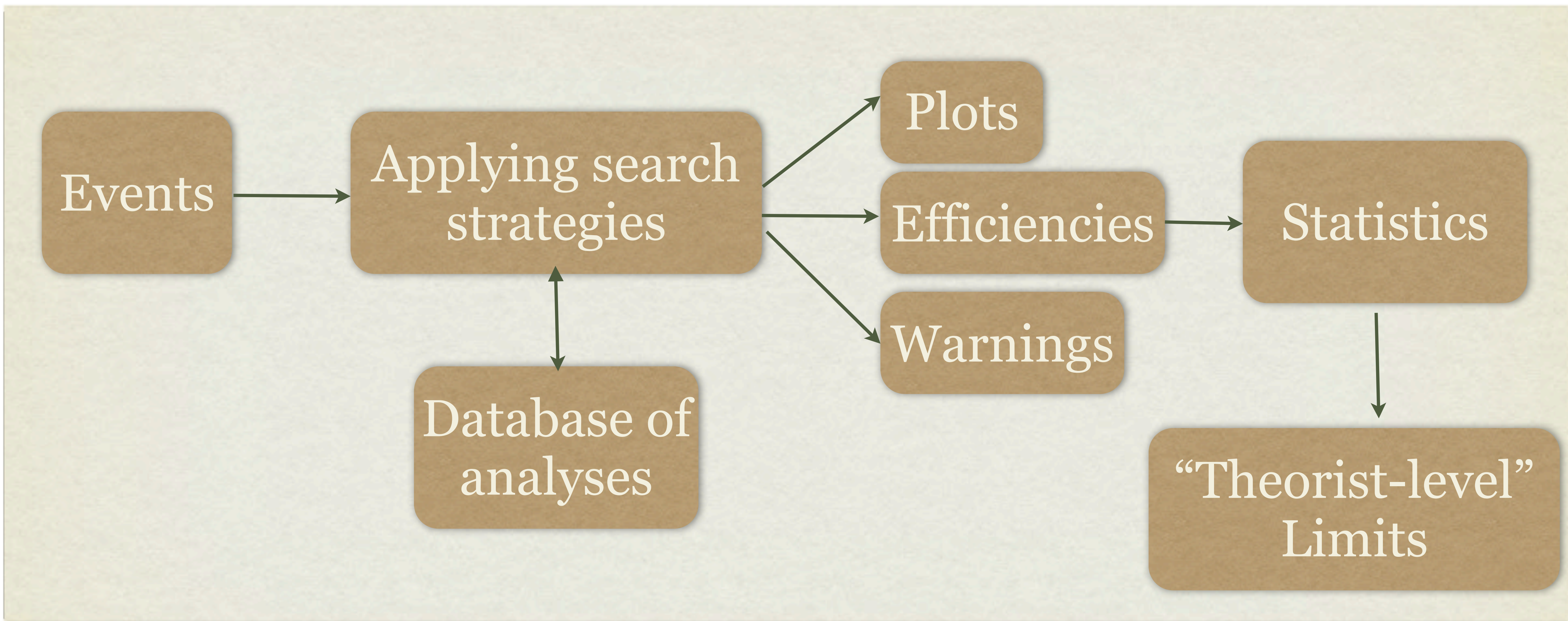
One needs to do something else...

Have to extract ε*A ourselves
(and compare with information provided)

* see e.g. http://www.lhcnewphysics.org for an attempt at an exhaustive list

ATOM: automatic test of models

A fast, local way to (approximately) "re-interpret" LHC analyses



w/ M. Papucci (LBL), D. Neuenfeld

Analyses (12k lines), Atom Core (~25k lines)

```
% atom --list-analyses
```

```
ATLAS_2010_CONF_2010_049    Cross-section of and fragmentation function in anti-kt track jets
ATLAS_2010_S8591806         Charged particles at 900 GeV in ATLAS
ATLAS_2010_S8755477         $Dijet mass distriubtion$
ATLAS_2010_S8814007         Dijet Angular distributions at 7 TeV with $3.1pb^{-1}$.
ATLAS_2010_S8817804         Inclusive jet cross section and di-jet mass and chi spectra at 7 TeV in ATLAS
ATLAS_2010_S8894728         Track-based underlying event at 900 GeV and 7 TeV in ATLAS
ATLAS_2010_S8914249         Diphoton+MET search
ATLAS_2010_S8914702         Inclusive isolated prompt photon analysis
ATLAS_2010_S8918562         Track-based minimum bias at 900 GeV and 2.36 and 7 TeV in ATLAS
ATLAS_2010_S8919674         W+jets jet multiplicities and pT
ATLAS_2011_CONF_2011_036    Anomalous MET in ttbar Events at the LHC 7TeV with $35pb^{-1}$.
ATLAS_2011_CONF_2011_039    Trileptons search at 7 TeV with $35pb^{-1}$.
ATLAS_2011_CONF_2011_086    Jets+MET at 7 TeV with $165pb^{-1}$.
ATLAS_2011_CONF_2011_090    1lepton+jets+MET at 7 TeV with $165pb^{-1}$.
ATLAS_2011_CONF_2011_096    <Insert short ATLAS_2011_CONF_2011_096 description>
ATLAS_2011_CONF_2011_098    bjets+MET+0L at 7 TeV with $830pb^{-1}$.
ATLAS_2011_CONF_2011_123    <Insert short ATLAS_2011_CONF_2011_123 description>
ATLAS_2011_CONF_2011_126    Search for Anomalous Production of Prompt Like-sign Muon Pairs with 1.6 $fb^{-1}$.
ATLAS_2011_CONF_2011_130    bjets+1lept+jets+MET SUSY search at 7TeV with $1fb^{-1}$
ATLAS_2011_CONF_2011_144    <Insert short ATLAS_2011_CONF_2011_144 description>
ATLAS_2011_I919017          Measurement of ATLAS track jet properties at 7 TeV
ATLAS_2011_I925932          Measurement of the W pT with electrons and muons at 7 TeV
ATLAS_2011_I926145          Measurement of electron and muon differential cross-section from heavy-flavour decays
ATLAS_2011_I944826          KS0 and Lambda production at 0.9 and 7 TeV with ATLAS
ATLAS_2011_I945498          Z+jets in pp at 7TeV
ATLAS_2011_S8924791         Jet shapes at 7 TeV in ATLAS
ATLAS_2011_S8970084         1lepton+jets+MET at 7 TeV with $35pb^{-1}$.
ATLAS_2011_S8971293         Dijet azimuthal decorrelations
ATLAS_2011_S8983313         Jets+MET at 7 TeV with $35pb^{-1}$.
ATLAS_2011_S8994773         Calo-based underlying event at 900 GeV and 7 TeV in ATLAS
ATLAS_2011_S8996709         <Insert short ATLAS_2011_S8996709 description>
ATLAS_2011_S9002537         Muon charge asymmetry in W events at 7 TeV in ATLAS
ATLAS_2011_S9011218         bjets+MET at 7 TeV with $35pb^{-1}$.
ATLAS_2011_S9019553         SF lepton pairs SUSY search  at 7 TeV with $35pb^{-1}$.
ATLAS_2011_S9019561         2leptons+MET at 7TeV with $35pb^{-1}$.
ATLAS_2011_S9108483         <Insert short ATLAS_2011_S9108483 description>
ATLAS_2011_S9120726         Diphoton+MET at 7TeV with $36 pb^{-1}$
ATLAS_2011_S9120807         Inclusive isolated diphoton analysis
ATLAS_2011_S9126244         Measurement of dijet production with a veto on additional central jet activity
ATLAS_2011_S9128077         Measurement of multi-jet cross sections
ATLAS_2011_S9131140         Measurement of the Z pT with electrons and muons at 7 TeV
ATLAS_2011_S9203559         <Insert short ATLAS_2011_S9203559 description>
ATLAS_2011_S9225137         multijet SUSY search at 7TeV
ATLAS_2012_CONF_2012_033    2-6 jets + MET SUSY search at 7TeV
ATLAS_2012_I1082009         $D^{*\pm}$ production in jets
ATLAS_2012_I1082936         Inclusive jet and dijet cross sections at 7 TeV
ATLAS_2012_I1083318         W+jets production at 7 TeV
ATLAS_2012_I1084540         Rapidity gap cross sections measured with the ATLAS detector in pp collisions at sqrt(
ATLAS_2012_I1091481         Azimuthal ordering of charged hadrons
```

```
% atom --list-analyses
```

```
ATLAS_2010_CONF_2010_049     Cross-section of and fragmentati
ATLAS_2010_S8591806          Charged particles at 900 GeV in A
ATLAS_2010_S8755477          $Dijet mass distriubtion$
ATLAS_2010_S8814007          Dijet Angular distributions at 7
ATLAS_2010_S8817804          Inclusive jet cross section and d
ATLAS_2010_S8894728          Track-based underlying event at 9
ATLAS_2010_S8914249          Diphoton+MET search
ATLAS_2010_S8914702          Inclusive isolated prompt photon
ATLAS_2010_S8918562          Track-based minimum bias at 900 G
ATLAS_2010_S8919674          W+jets jet multiplicities and pT
ATLAS_2011_CONF_2011_036     Anomalous MET in ttbar Events at
ATLAS_2011_CONF_2011_039     Trileptons search at 7 TeV with $
ATLAS_2011_CONF_2011_086     Jets+MET at 7 TeV with $165pb^{-1
ATLAS_2011_CONF_2011_090     1lepton+jets+MET at 7 TeV with $1
ATLAS_2011_CONF_2011_096     <Insert short ATLAS_2011_CONF_201
ATLAS_2011_CONF_2011_098     bjets+MET+0L at 7 TeV with $830pb
ATLAS_2011_CONF_2011_123     <Insert short ATLAS_2011_CONF_201
ATLAS_2011_CONF_2011_126     Search for Anomalous Production o
ATLAS_2011_CONF_2011_130     bjets+1lept+jets+MET SUSY search
ATLAS_2011_CONF_2011_144     <Insert short ATLAS_2011_CONF_201
ATLAS_2011_I919017           Measurement of ATLAS track jet pr
ATLAS_2011_I925932           Measurement of the W pT with elec
ATLAS_2011_I926145           Measurement of electron and muon
ATLAS_2011_I944826           KS0 and Lambda production at 0.9
ATLAS_2011_I945498           Z+jets in pp at 7TeV
ATLAS_2011_S8924791          Jet shapes at 7 TeV in ATLAS
ATLAS_2011_S8970084          1lepton+jets+MET at 7 TeV with $3
ATLAS_2011_S8971293          Dijet azimuthal decorrelations
ATLAS_2011_S8983313          Jets+MET at 7 TeV with $35pb^{-1}
ATLAS_2011_S8994773          Calo-based underlying event at 90
ATLAS_2011_S8996709          <Insert short ATLAS_2011_S8996709
ATLAS_2011_S9002537          Muon charge asymmetry in W events
ATLAS_2011_S9011218          bjets+MET at 7 TeV with $35pb^{-1
ATLAS_2011_S9019553          SF lepton pairs SUSY search  at 7
ATLAS_2011_S9019561          2leptons+MET at 7TeV with $35pb^{
ATLAS_2011_S9108483          <Insert short ATLAS_2011_S9108483 description>
ATLAS_2011_S9120726          Diphoton+MET at 7TeV with $36 pb^{-1}$
ATLAS_2011_S9120807          Inclusive isolated diphoton analysis
ATLAS_2011_S9126244          Measurement of dijet production with a veto on additional central jet activity
ATLAS_2011_S9128077          Measurement of multi-jet cross sections
ATLAS_2011_S9131140          Measurement of the Z pT with electrons and muons at 7 TeV
ATLAS_2011_S9203559          <Insert short ATLAS_2011_S9203559 description>
ATLAS_2011_S9225137          multijet SUSY search at 7TeV
ATLAS_2012_CONF_2012_033     2-6 jets + MET SUSY search at 7TeV
ATLAS_2012_I1082009          $D^{*\pm}$ production in jets
ATLAS_2012_I1082936          Inclusive jet and dijet cross sections at 7 TeV
ATLAS_2012_I1083318          W+jets production at 7 TeV
ATLAS_2012_I1084540          Rapidity gap cross sections measured with the ATLAS detector in pp collisions at sqrt(
ATLAS_2012_I1091481          Azimuthal ordering of charged hadrons
```

```
CMS_2011_S8950903          Dijet azimuthal decorrelations in $pp$ collisions at $\sqrt{s} = 7$ TeV
CMS_2011_S8957746          Event shapes
CMS_2011_S8968497          Measurement of dijet angular distributions and search for quark compositeness in $pp$ collisions at $\
CMS_2011_S8973270          B/anti-B angular correlations based on secondary vertex reconstruction in pp collisions
CMS_2011_S8978280          Kshort, Lambda, and Cascade- transverse momentum and rapidity spectra from proton-proton collisions at
CMS_2011_S8990433          Diphoton+MET at 7 TeV with $35pb^{-1}$.
CMS_2011_S8991847          OS dileptons at 7TeV with $35pb^{-1}$
CMS_2011_S9036504          Same Sign dileptons at 7TeV in $35pb^{-1}$
CMS_2011_S9086218          Measurement of the inclusive jet cross-section in $pp$ collisions at $\sqrt{s} = 7$ TeV
CMS_2011_S9088458          Measurement of ratio of the 3-jet over 2-jet cross section in pp collisions at sqrt(s) = 7 TeV
CMS_2011_S9120041          Traditional leading jet UE measurement at $\sqrt(s)=0.9$ and 7 TeV
CMS_2011_S9215166          Forward energy flow in MB and dijet events at 0.9 and 7 TeV
CMS_PAS_EXO_11_017         Search for quark compositeness in dijet angular distributions from $pp$ collisions at $\sqrt{s} = 7$ T
CMS_PAS_EXO_11_036         <Insert short CMS_PAS_EXO_11_036 description>
CMS_PAS_EXO_11_050         <Insert short CMS_PAS_EXO_11_050 description>
CMS_PAS_EXO_11_051         Search for pair production of a fourth-generation t' quark in the lepton-plus-jets channel with the CM
CMS_PAS_SUS_10_005         HT,MHT susy search in jets+MET at 7 TeV with $35pb^{-1}$.
CMS_PAS_SUS_10_009         razor analysis on jets+MET and 1lepton+jets+MET at  7 TeV with $35pb^{-1}$.
CMS_PAS_SUS_10_011         $\alpha_T$ analysis on b jets+MET at 7 TeV with $35pb^{-1}$.
CMS_PAS_SUS_11_003         Jets+MET with $\alpha_T$ variable with $1.1 fb^{-1}$
CMS_PAS_SUS_11_004         <Insert short CMS_PAS_SUS_11_004 description>
CMS_PAS_SUS_11_005         <Insert short CMS_PAS_SUS_11_005 description>
CMS_PAS_SUS_11_006         <Insert short CMS_PAS_SUS_11_006 description>
CMS_PAS_SUS_11_010         <Insert short CMS_PAS_SUS_11_010 description>
CMS_PAS_SUS_11_011         <Insert short CMS_PAS_SUS_11_011 description>
CMS_PAS_SUS_11_015         <Insert short CMS_PAS_SUS_11_015 description>
CMS_PAS_SUS_11_017         Search for New Physics in Events with a Z Boson and Missing Transverse Energy
CMS_PAS_SUS_11_028         <Insert short CMS_PAS_SUS_11_028 description>
CMS_PAS_SUS_12_011         <Insert short CMS_PAS_SUS_12_011 description>
CMS_QCD_10_024             Pseudorapidity distributions of charged particles at sqrt(s)=0.9 and 7 TeV
D0_2000_S4480767           Transverse momentum of the W boson
D0_2001_S4674421           Tevatron Run I differential W/Z boson cross-section analysis
D0_2004_S5992206           Run II jet azimuthal decorrelation analysis
D0_2006_S6438750           Inclusive isolated photon cross-section, differential in pT(gamma)
D0_2007_S7075677           $Z/\gamma^* + X$ cross-section shape, differential in $y(Z)$
D0_2008_S6879055           Measurement of the ratio sigma($Z/\gamma^*$ + $n$ jets)/sigma($Z/\gamma^*$)
D0_2008_S7554427           $Z/\gamma^* + X$ cross-section shape, differential in $pT(Z)$
D0_2008_S7662670           Measurement of D0 Run II differential jet cross sections
D0_2008_S7719523           Isolated $\gamma$ + jet cross-sections, differential in pT($\gamma$) for various $y$ bins
D0_2008_S7837160           Measurement of W charge asymmetry from D0 Run II
D0_2008_S7863608           Measurement of differential $Z/\gamma^*$ + jet + $X$ cross sections
D0_2009_S8202443           $Z/\gamma^*$ + jet + $X$ cross sections differential in pT(jet 1,2,3)
D0_2009_S8320160           Dijet angular distributions
D0_2009_S8349509           Z+jets angular distributions
D0_2010_S8566488           Dijet invariant mass
D0_2010_S8570965           Direct photon pair production
D0_2010_S8671338           Measurement of differential $Z/\gamma^*$ pT
D0_2010_S8821313           Precise study of Z pT using novel technique
D0_2011_I895662            3-jet invariant mass
DELPHI_1995_S3137023       Strange baryon production in $Z$ hadronic decays at Delphi
DELPHI_1996_S3430090       Delphi MC tuning on event shapes and identified particles.
```

- Cut flow efficiencies, and final efficiencies per subprocess

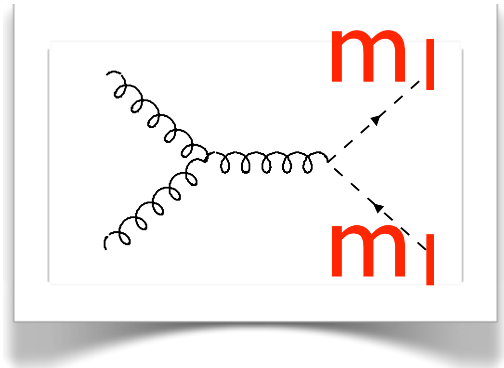
Cuts (click to collapse)

Cut Flow	Description	Efficiency	Derivative
Ht	description of Ht cut	20.00%	-0.767
....MHt		11.72%	-1.089
........dphiJ1	description of dphiJ1 cut	11.53%	0.000
............dphiJ2		10.54%	-0.164
................dphiJ3		9.78%	0.000
....................lowHt		1.15%	0.382
........................lowHt1		0.61%	0.714
............................lowHt2		0.54%	0.000
................................lowHt3		0.00%	0.000
....................................lowHt4		0.00%	0.000
........................medHt		1.73%	0.000
............................high1Ht		1.71%	0.000
................................high1Ht1		0.65%	0.000
....................................high1Ht2		0.79%	1.894
....high1Ht3		0.28%	-5.356
................................high2Ht		1.83%	0.240
....................................high2Ht1		0.80%	0.000
....high2Ht2		1.03%	-1.862
....................................high3Ht		3.36%	-4.281
....high3Ht3		3.36%	-1.299
............................medHt1		0.20%	2.246
................................medHt2		1.15%	0.383
....................................medHt3		0.19%	0.000
....medHt4		0.19%	0.000

Pythia 6.4.24

+Prospino/NLLfast
+checks with MadEvent, MLM matched sample

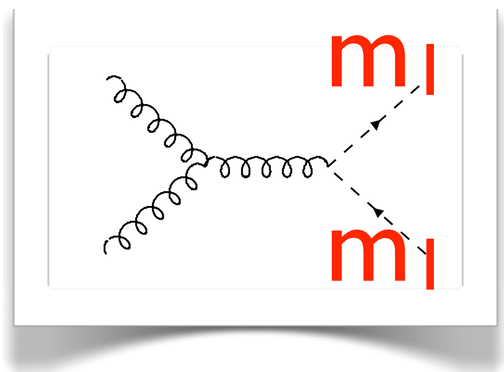
simplified Model
available → CMS



Pythia 6.4.24

+Prospino/NLLfast
+checks with MadEvent, MLM matched sample

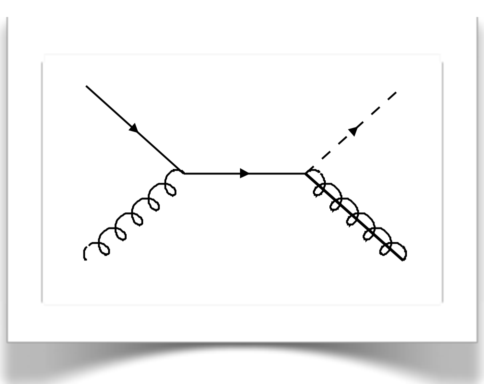
simplified Model available → CMS

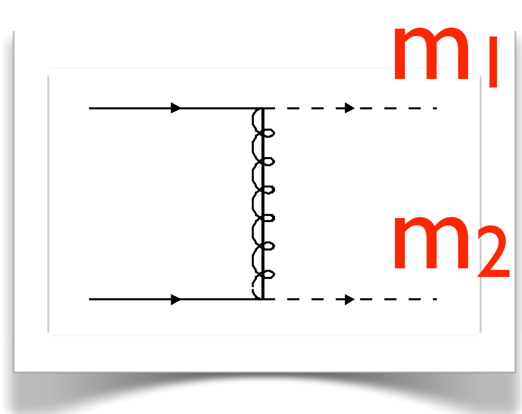


Pythia 6.4.24

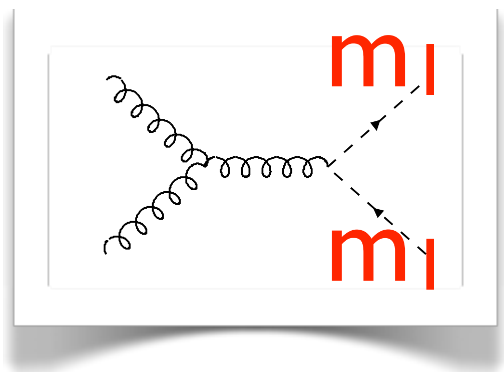
+Prospino/NLLfast
+checks with MadEvent, MLM matched sample

Atom recast





simplified Model available → CMS



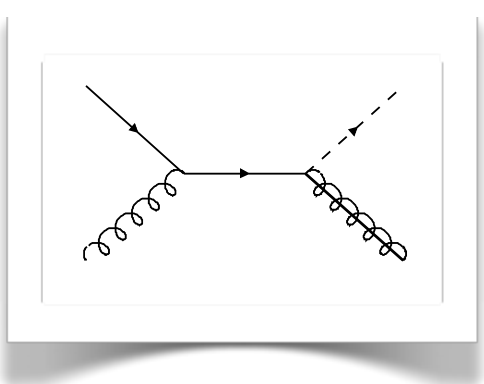
Signal regions

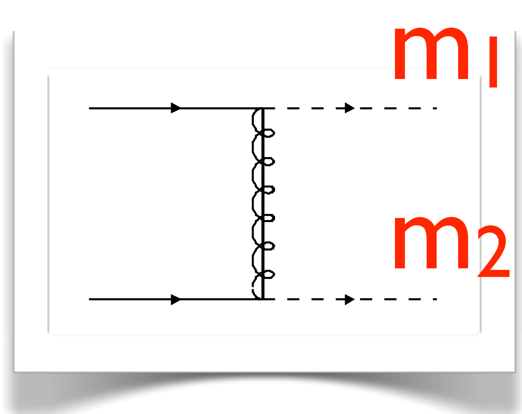
$H_T, \not{H}_T$
$H_T, \not{H}_T$
...
$H_T, \not{H}_T$
$H_T, \not{H}_T$
$H_T, \not{H}_T$

Pythia 6.4.24

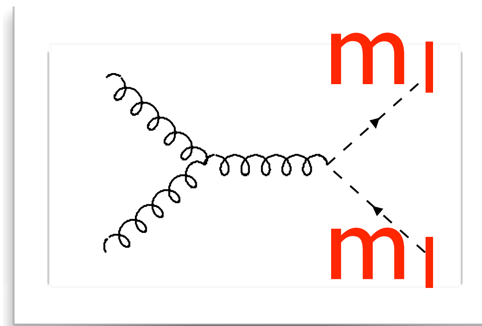
+Prospino/NLLfast
+checks with MadEvent, MLM matched sample

Atom recast





simplified Model available → CMS



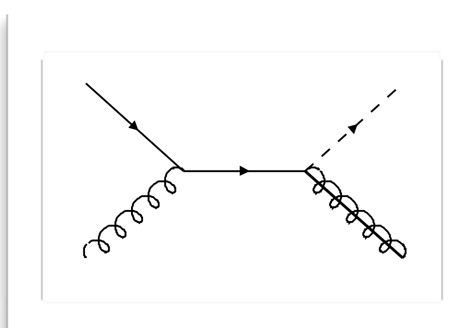
Signal regions

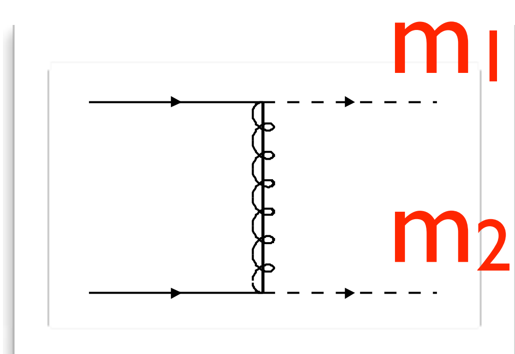
$H_T, \not{H}_T$
$H_T, \not{H}_T$
...
$H_T, \not{H}_T$
$H_T, \not{H}_T$
$H_T, \not{H}_T$

Pythia 6.4.24

+Prospino/NLLfast
+checks with MadEvent, MLM matched sample

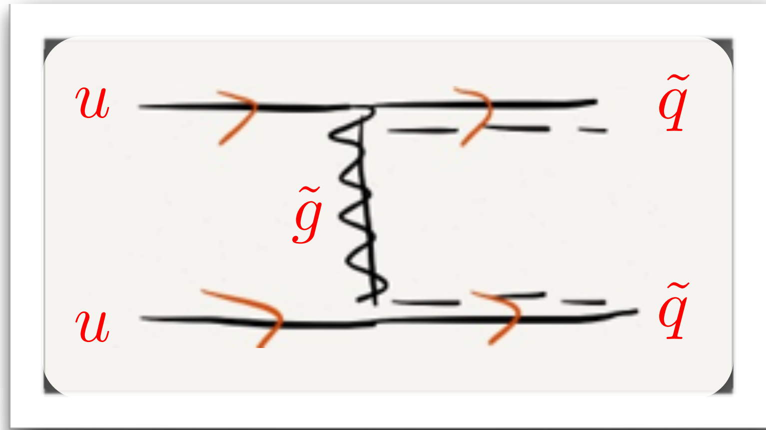
Atom recast





$$\Pi_i \mathrm{poiss}(s_i + b_i \delta b_i)\, \mathrm{gauss}(\delta b_i) \to CL_s$$

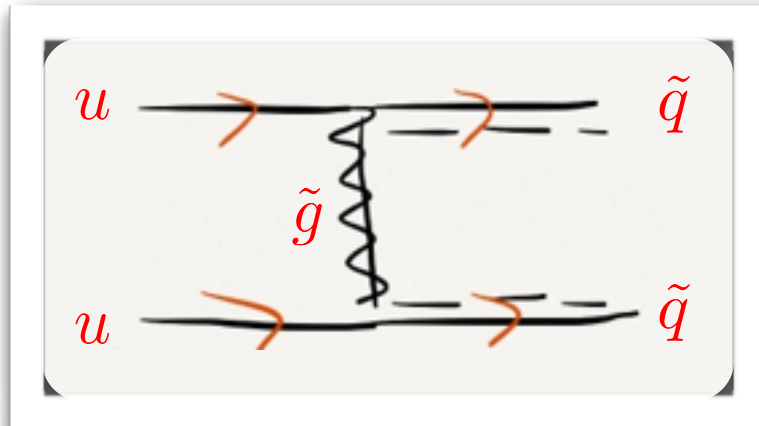
Remark on prospino



$$\frac{1}{m_{\tilde{g}}}\tilde{q}\tilde{q}\,u_R u_R$$ dim5 operator

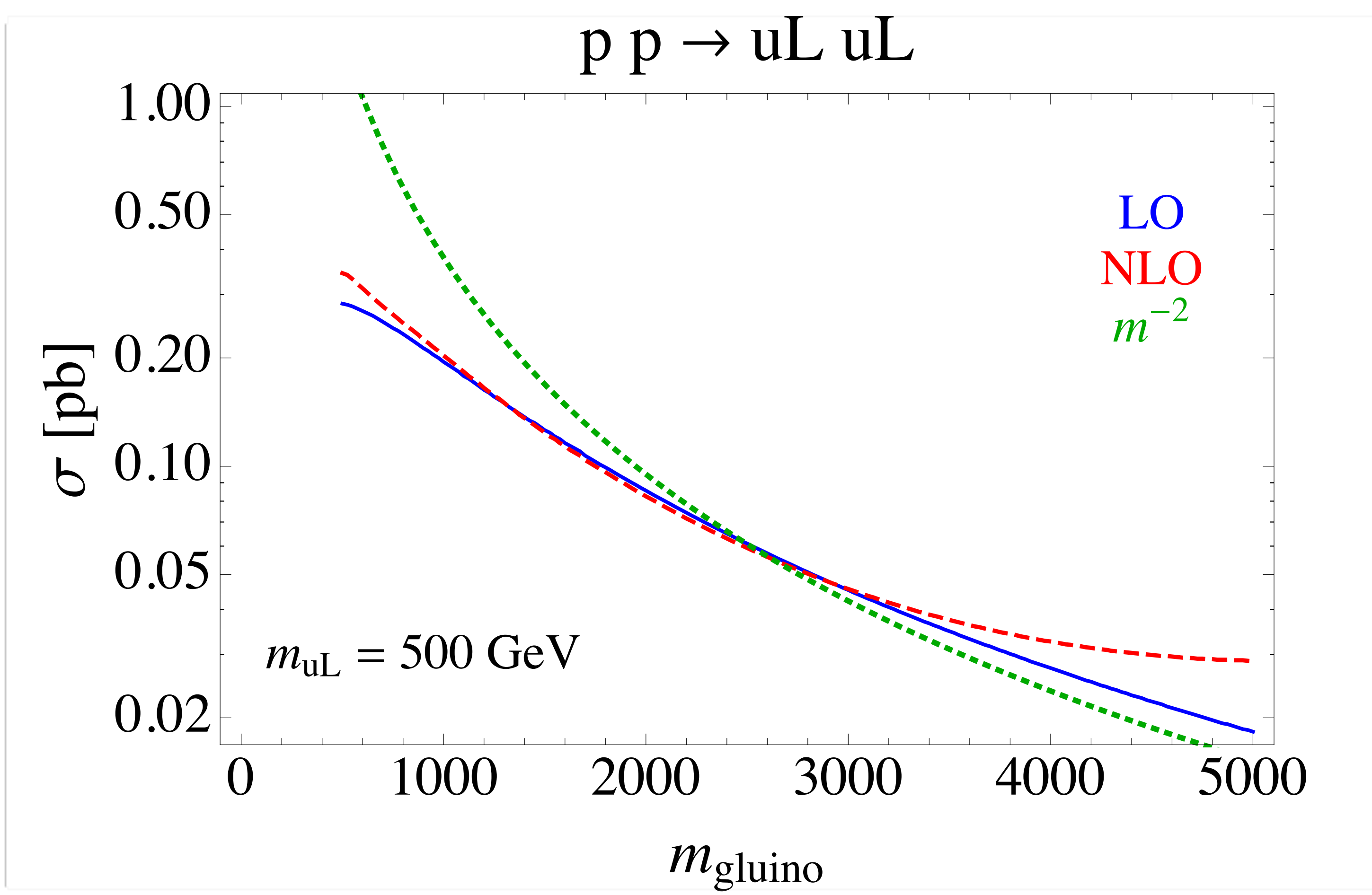
$$\rightarrow \quad \sigma \sim 1/m_{\tilde{g}}^2$$

Remark on prospino

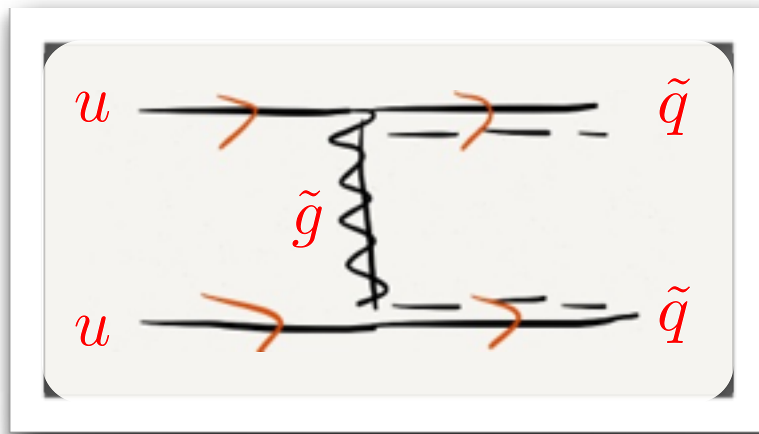


$$\frac{1}{m_{\tilde{g}}}\tilde{q}\tilde{q}\,u_R u_R$$ dim5 operator

$$\rightarrow \quad \sigma \sim 1/m_{\tilde{g}}^2$$

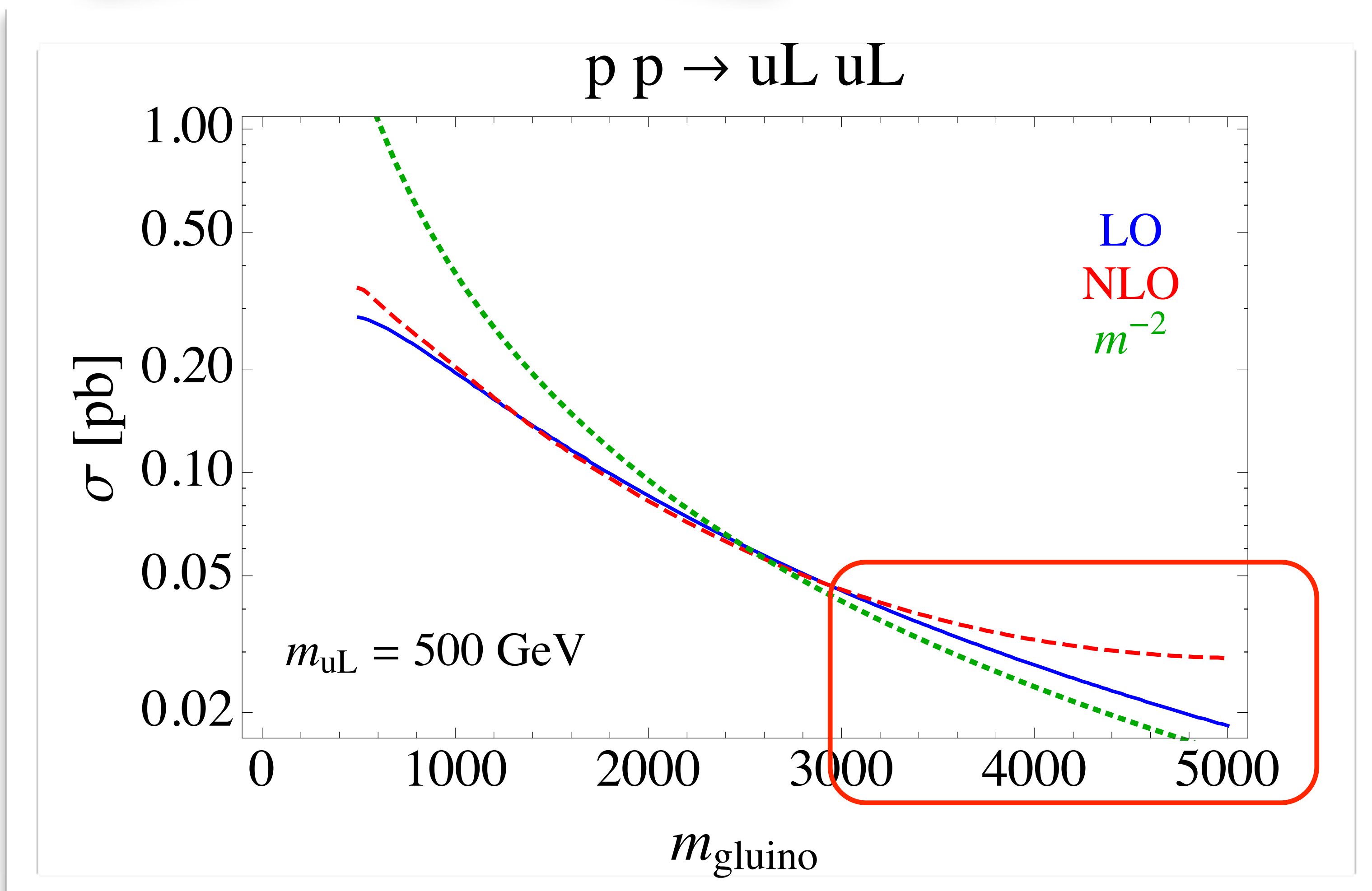


Remark on prospino



$$\frac{1}{m_{\tilde{g}}}\tilde{q}\tilde{q}\,u_R u_R$$ dim5 operator

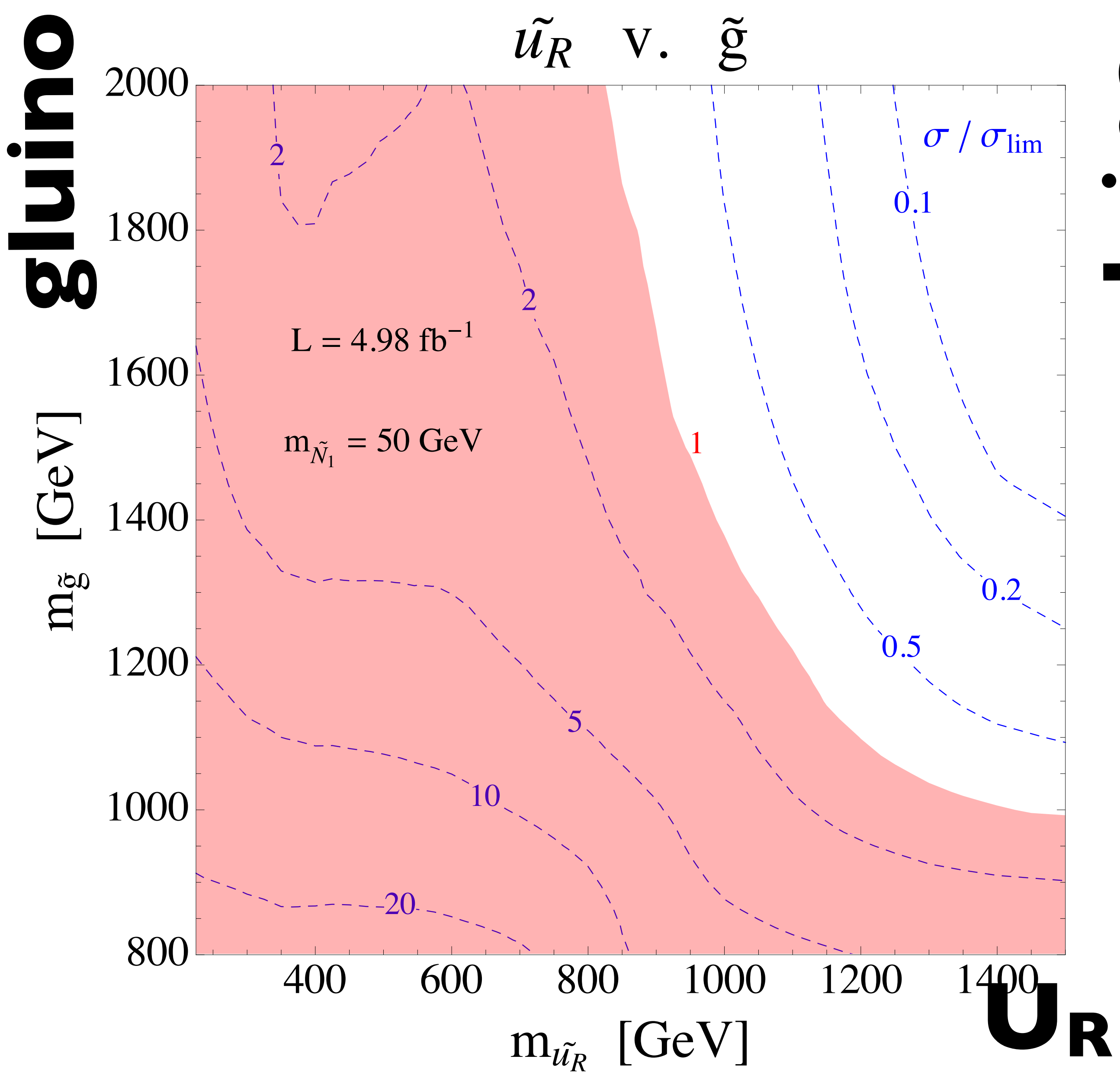
$$\rightarrow \quad \sigma \sim 1/m_{\tilde{g}}^2$$



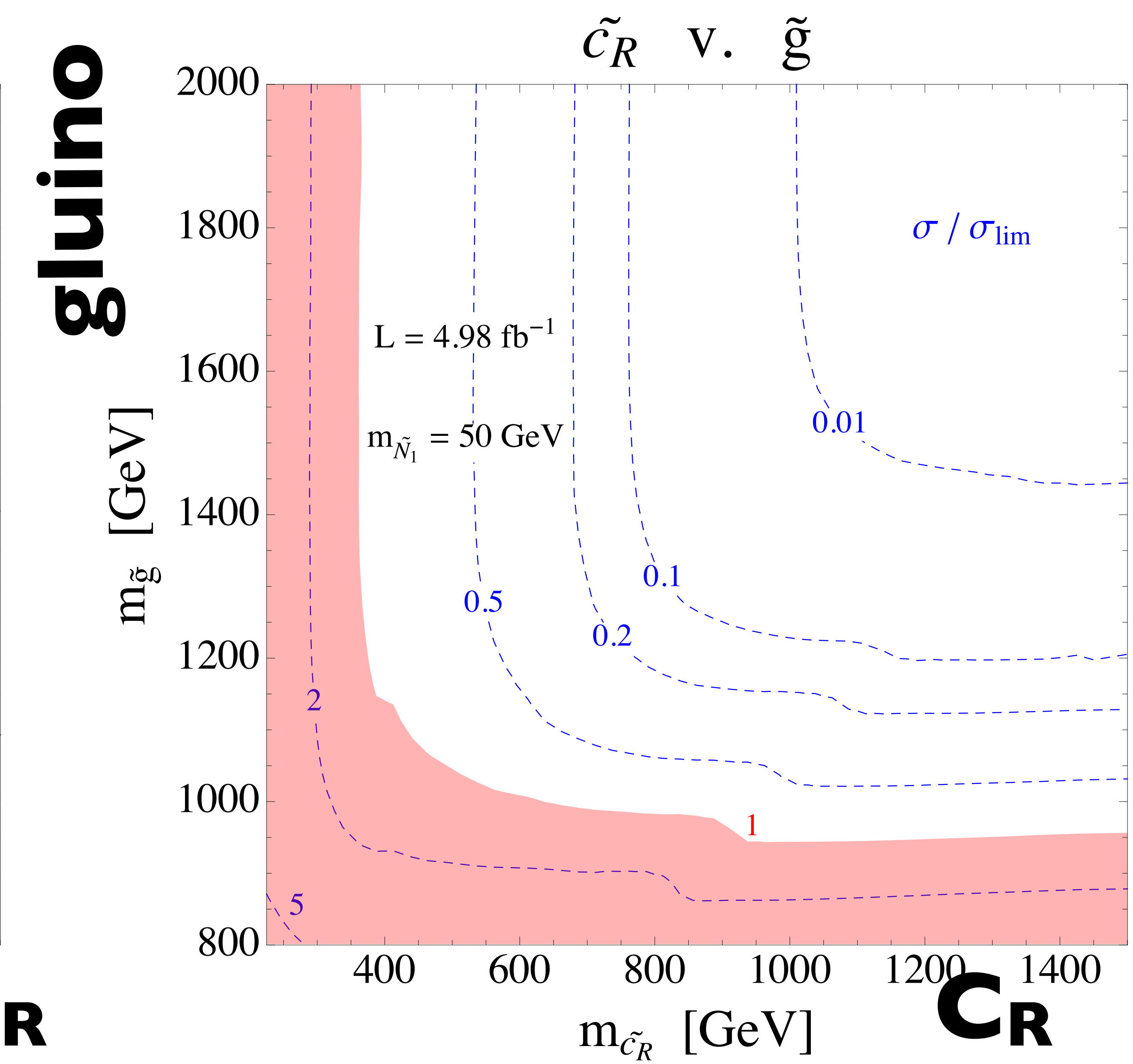
With heavy gluinos prospino fails at reproducing the decoupling behavior

One light squark vs. gluino mass

sea vs. valence squark

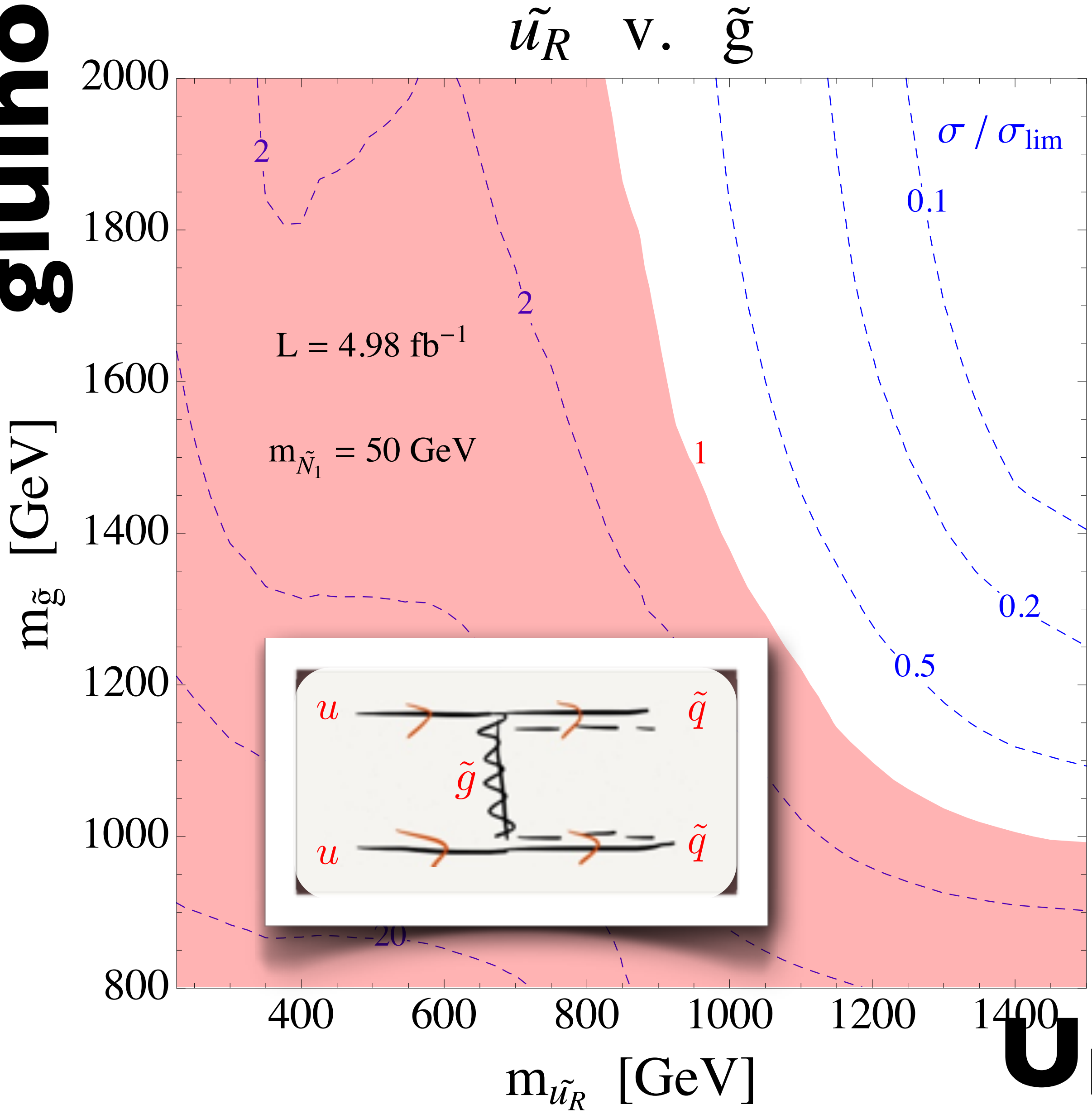


gluino
ũ_R v. g̃
σ / σ_lim
L = 4.98 fb^-1
m_Ñ1 = 50 GeV
m_g̃ [GeV]
m_ũR [GeV]
U_R



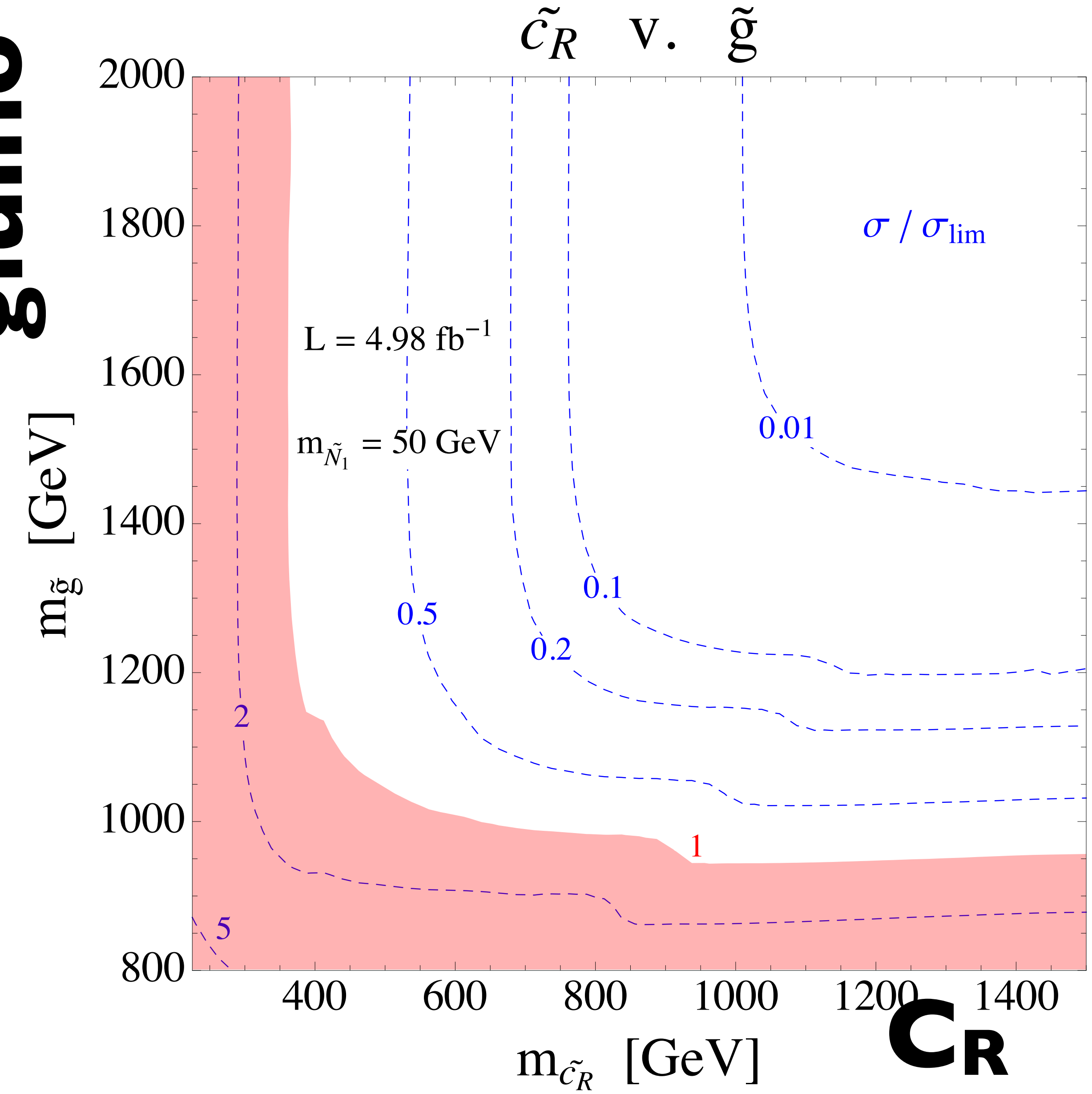
gluino
c̃_R v. g̃
σ / σ_lim
L = 4.98 fb^-1
m_Ñ1 = 50 GeV
m_g̃ [GeV]
m_c̃R [GeV]
C_R

gluino



U_R

gluino

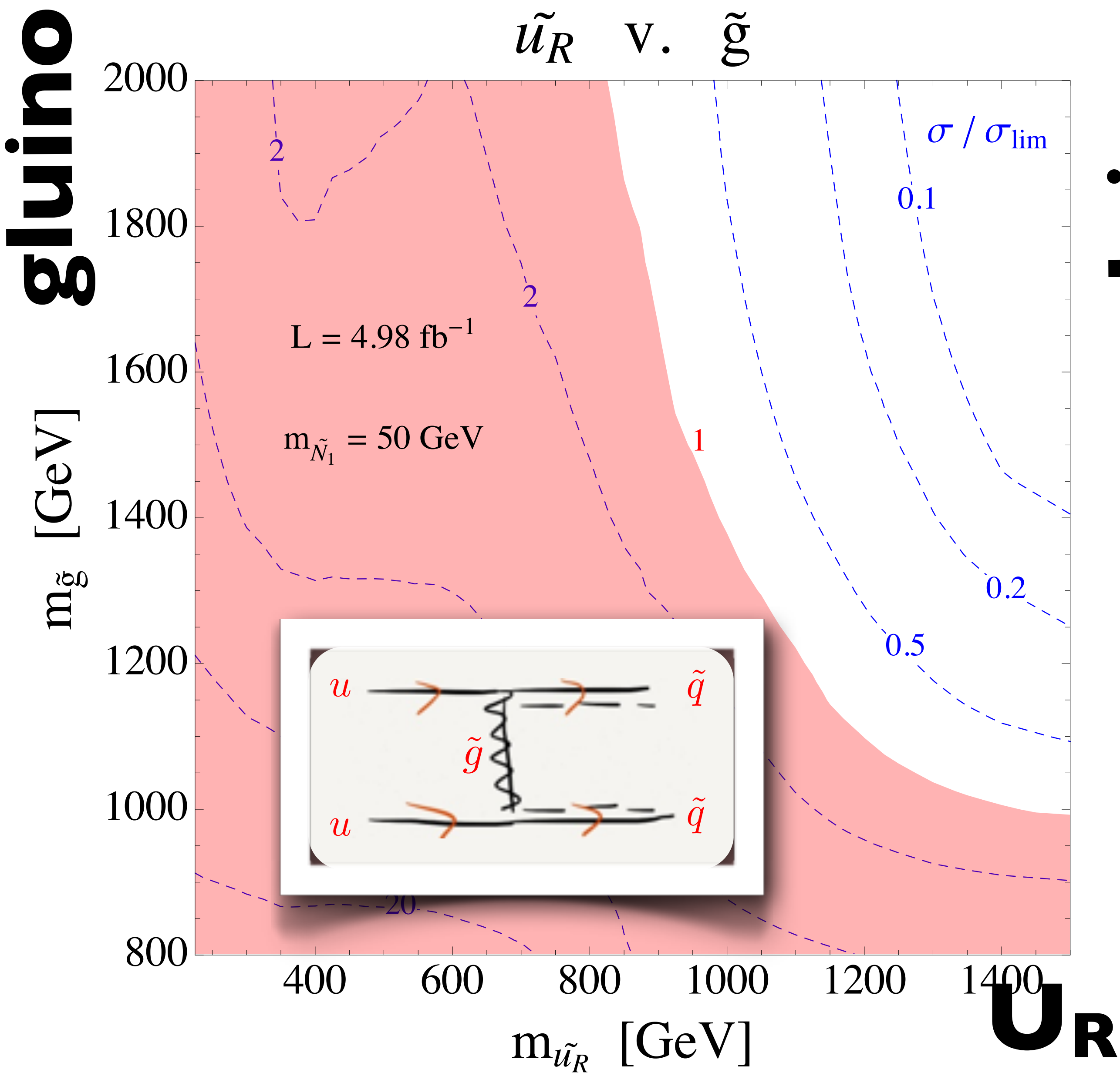


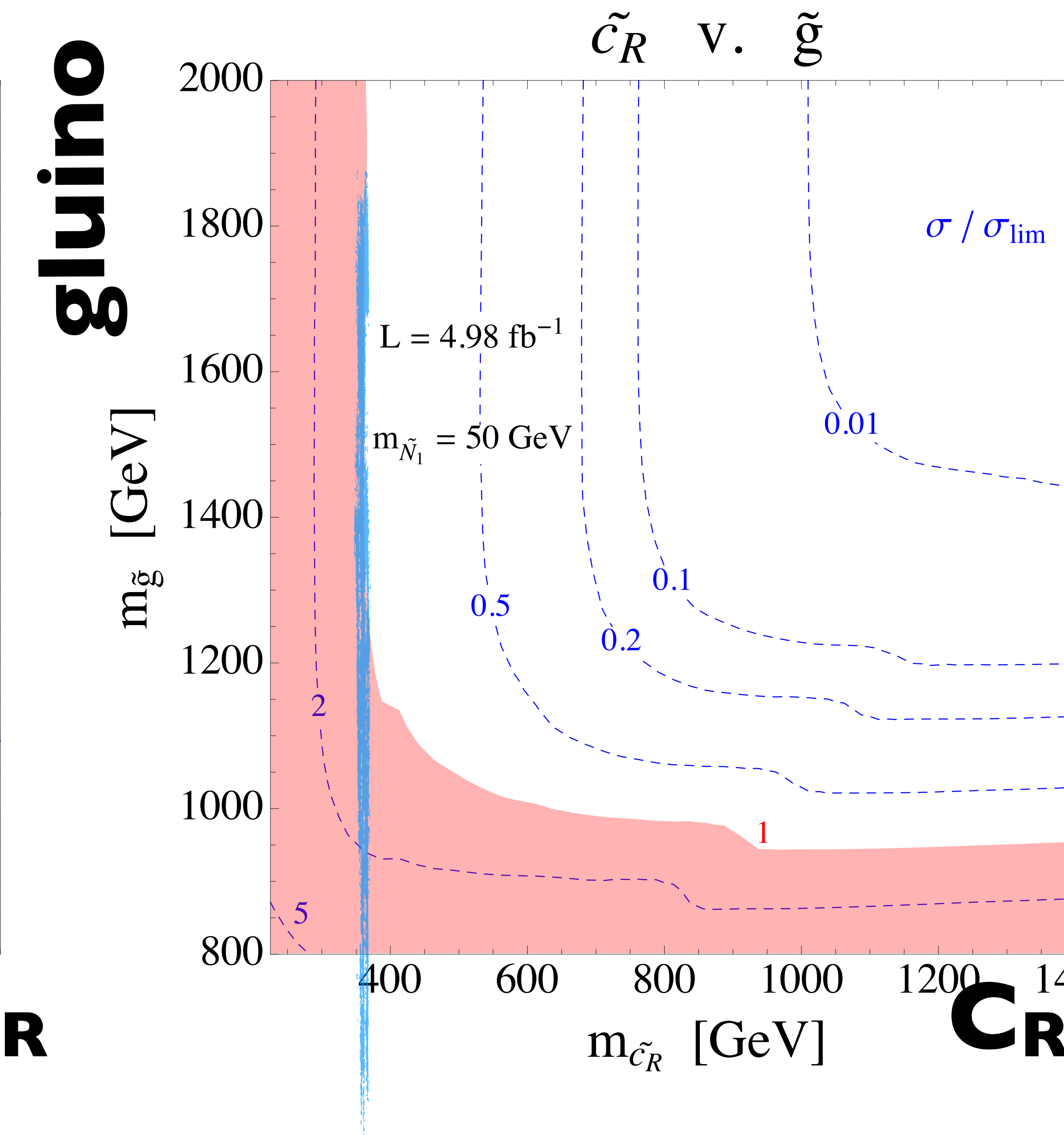
C_R

$$\frac{1}{m_{\tilde{g}}} \tilde{q}\tilde{q}\, u_R u_R$$ dim5 operator

$$\rightarrow \quad \sigma \sim 1/m_{\tilde{g}}^2$$

slow decoupling





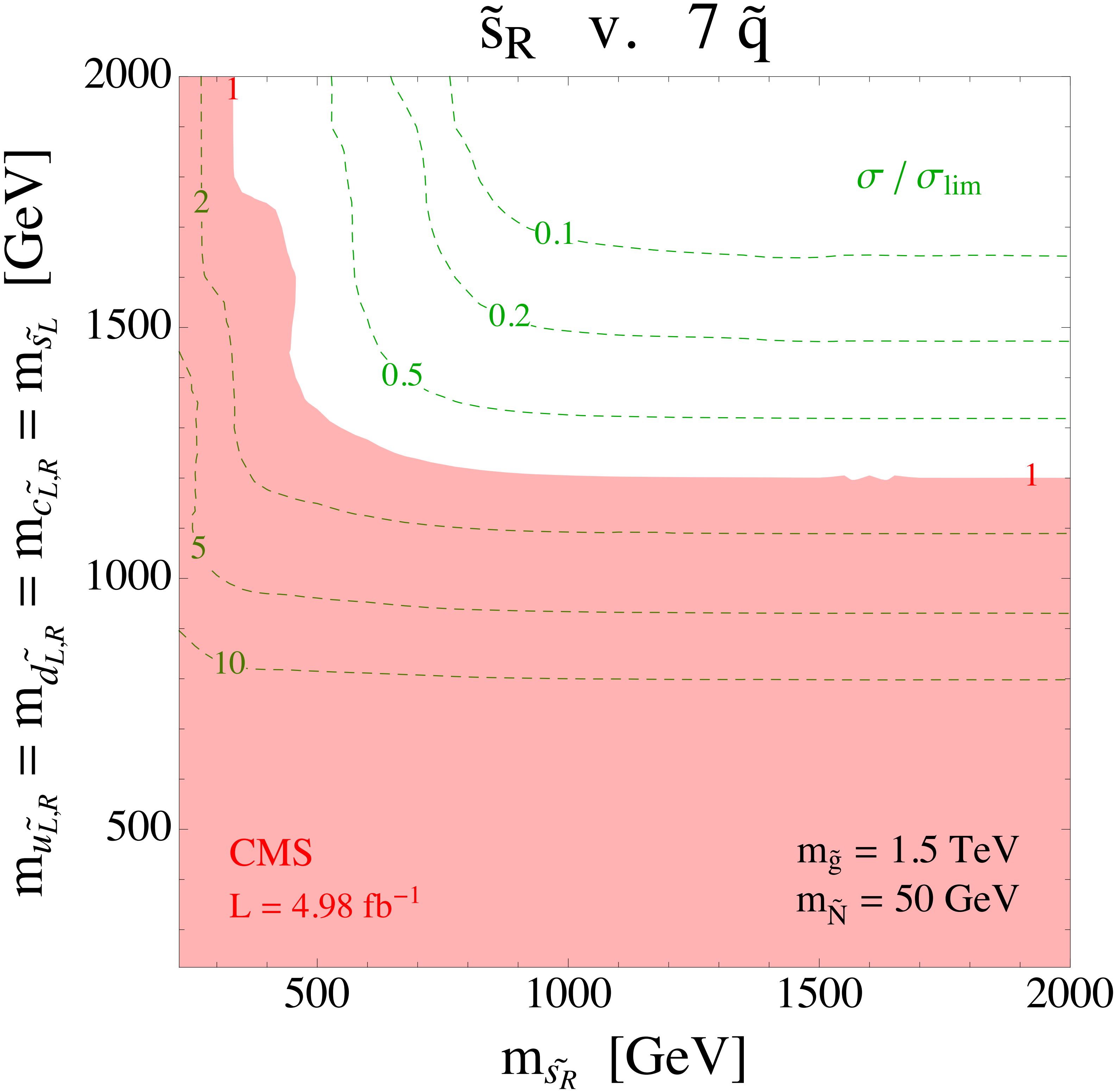
$$\frac{1}{m_{\tilde{g}}}\tilde{q}\tilde{q}\,u_R u_R$$ dim5 operator

$$\rightarrow \quad \sigma \sim 1/m_{\tilde{g}}^2$$

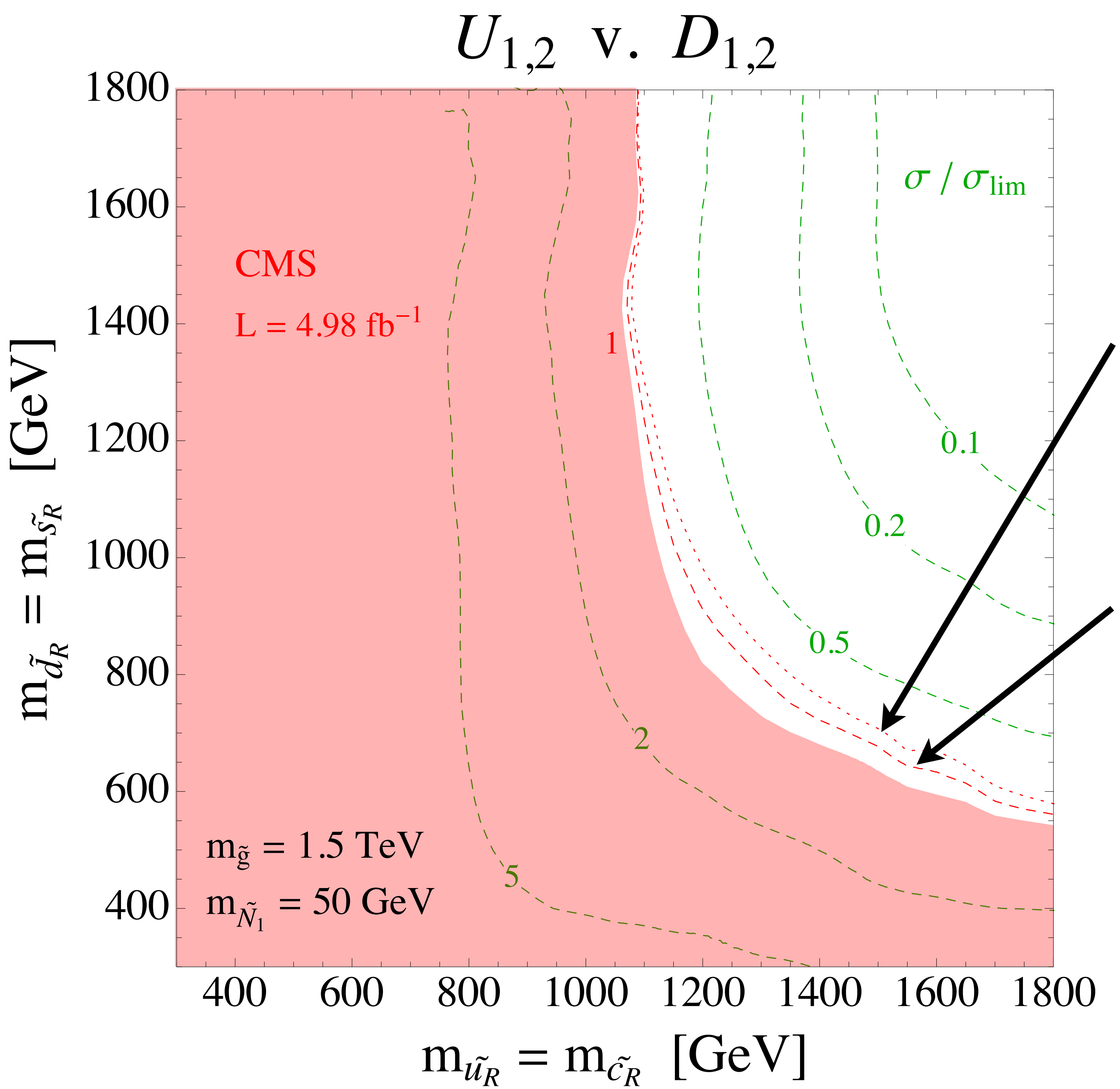
slow decoupling

Sea squarks
can still be < 350 GeV

One light squark & 7 heavy: how fast is the decoupling?



MFV splitting - flavor trivial light squarks

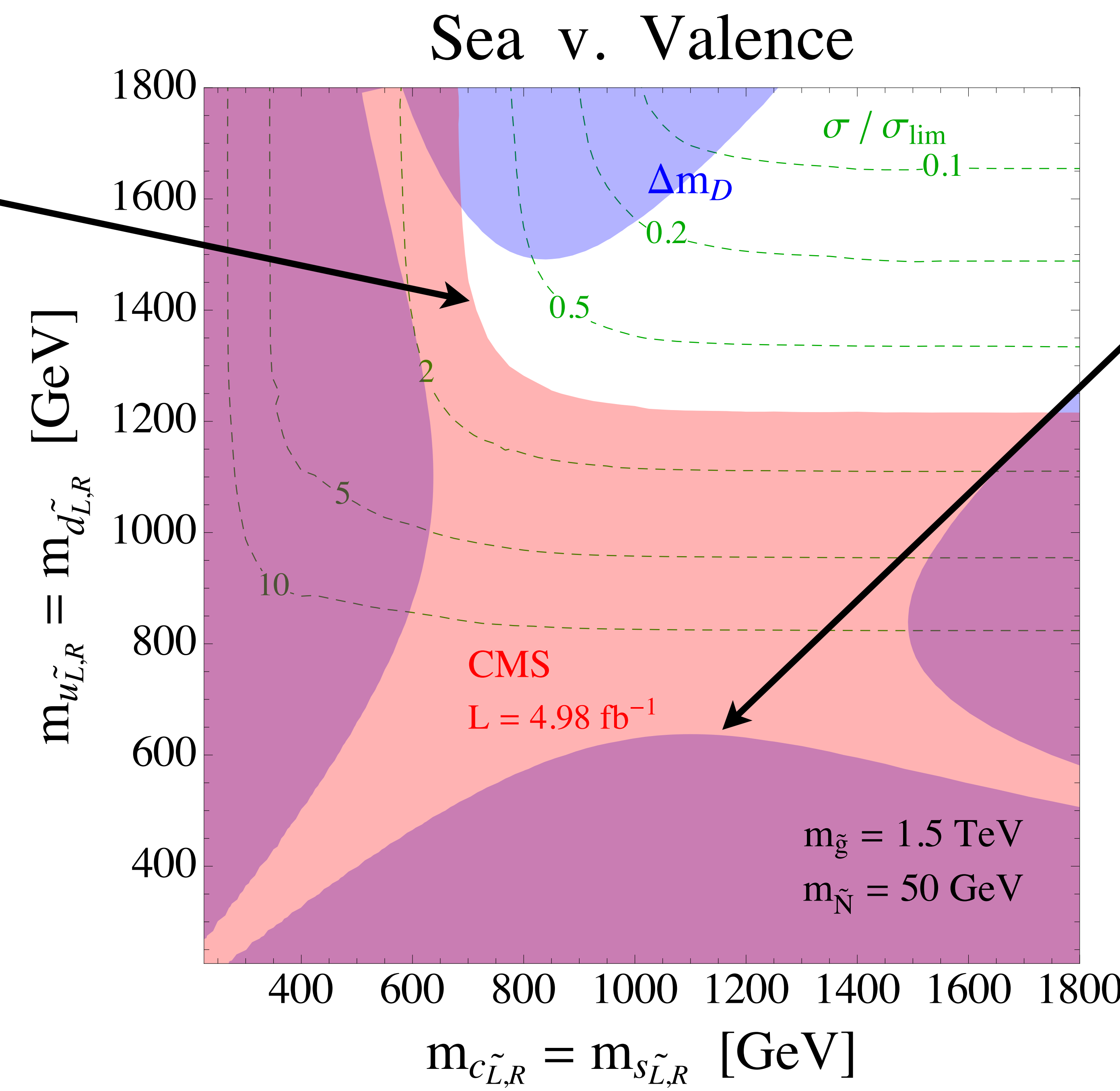


effect of unknown NLO (K=1.5,2)

compared to MadGolem, usually corrections are smaller

Collider vs. Flavor for sea & valence squarks

Collider constraint (CMS recast)



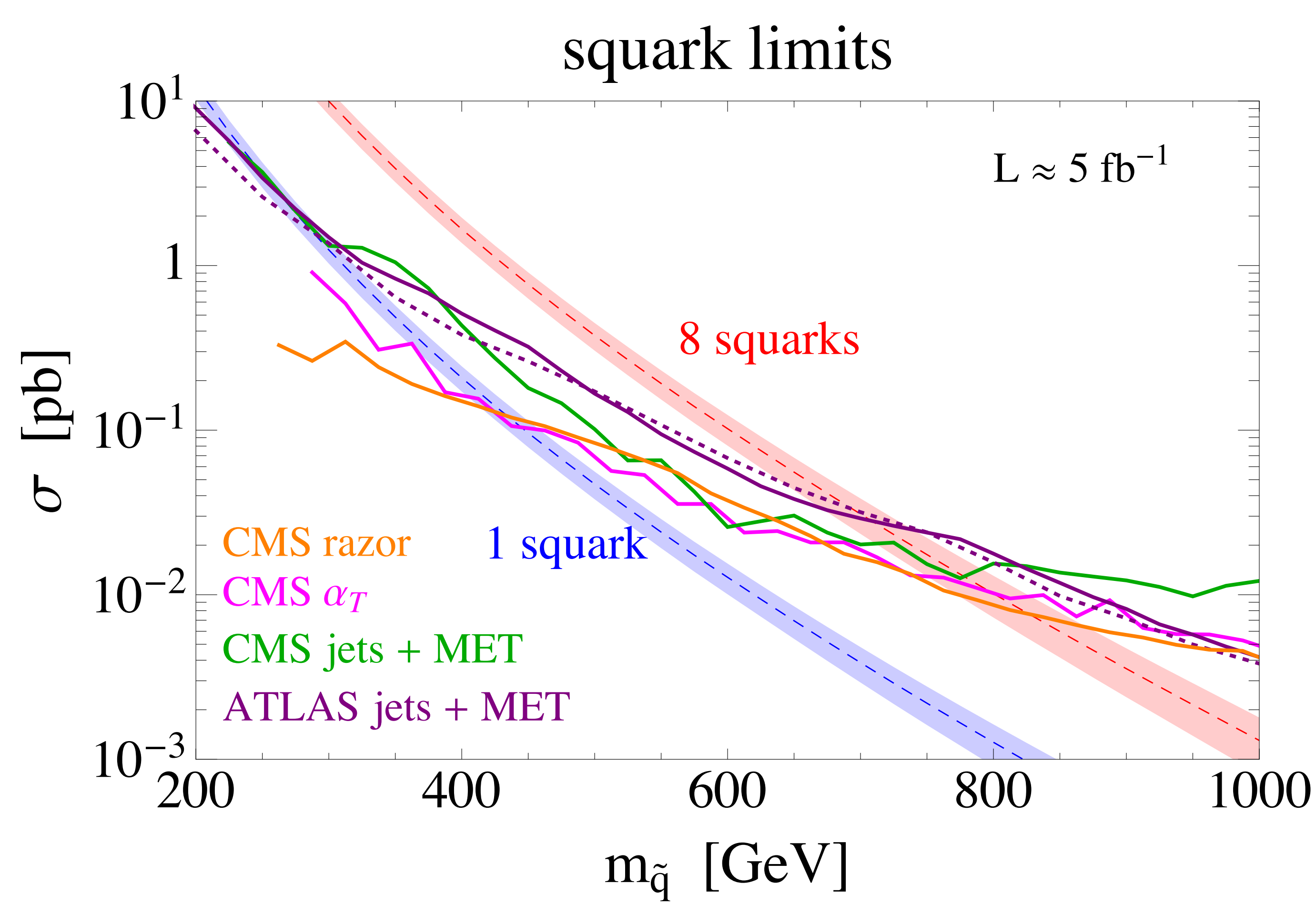
ΔM_D Flavor limit

$$H_{\rm eff} = C_1\ (\overline{u}^i \gamma_\mu P_L\, c^i)\,(\overline{u}^j \gamma^\mu P_L\, c^j)\ , \qquad x_D \simeq 2.6 \times 10^{10}\ {\rm Re}\ C_1$$

Assuming full down alignment, calculated w/o MIA

Conclusions

- Squarks spectra can be vertically and horizontally split and have very different LHC limits.
- Limits for 1st gen' squarks very dependent on gluino mass, for heavy gluino 400 GeV limit
- Are there light squarks hiding in the data?



Need dedicated light squark searches!

SCIENTIFIC AMERICAN™

Supersymmetry Fails Test, Forcing Physics to Seek New Ideas

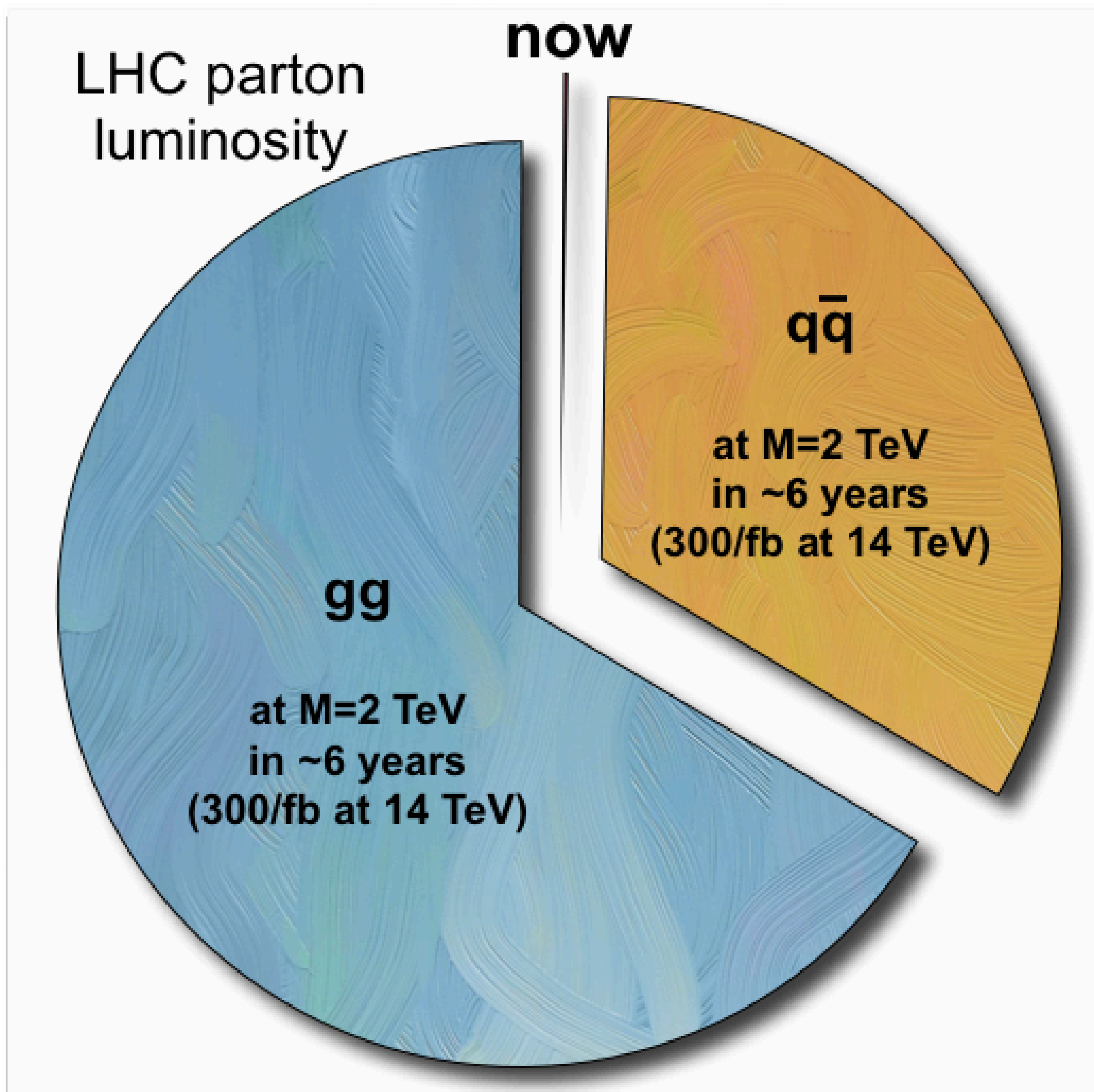
With the Large Hadron Collider unable to find the particles that the theory says must exist, the field of particle physics is back to the "nightmare scenario" -- holes that riddled their picture of the universe three decades ago

By Natalie Wolchover and Simons Science News

From Simons Science News

As a young theorist in Moscow in 1982, Mikhail Shifman became enthralled with an elegant new theory called supersymmetry that attempted to incorporate the known elementary particles into a more complete inventory of the universe.

Outlook



G. Rolandi, private comm.