Non-degenerate 1st & 2nd generation squarks

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DESY

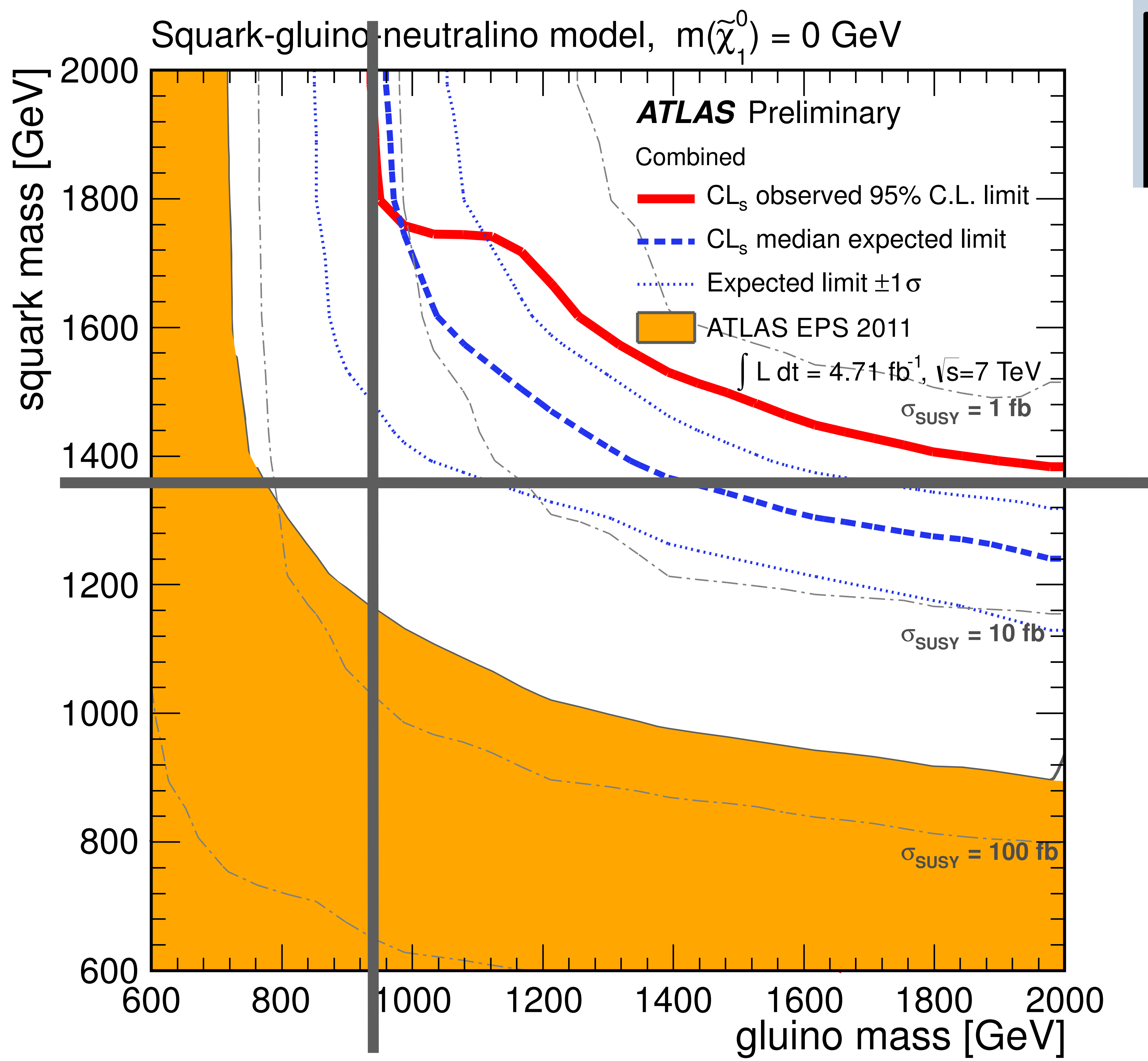
w/ M. Papucci, J. Ruderman (LBL Berkely)
G. Perez, R. Mahbubani (CERN)

1207.xxxx

What have we learned about the susy spectrum after 5 1/fb ?

- 1st & 2nd generation squarks need to be heavy > 1.2-1.5 TeV from jets+MET searches with 5/fb
- Gluino above ~ 900 GeV
- Impressive first limits on 3rd generation

4.7 fb^{-1} Susy, post-Moriond



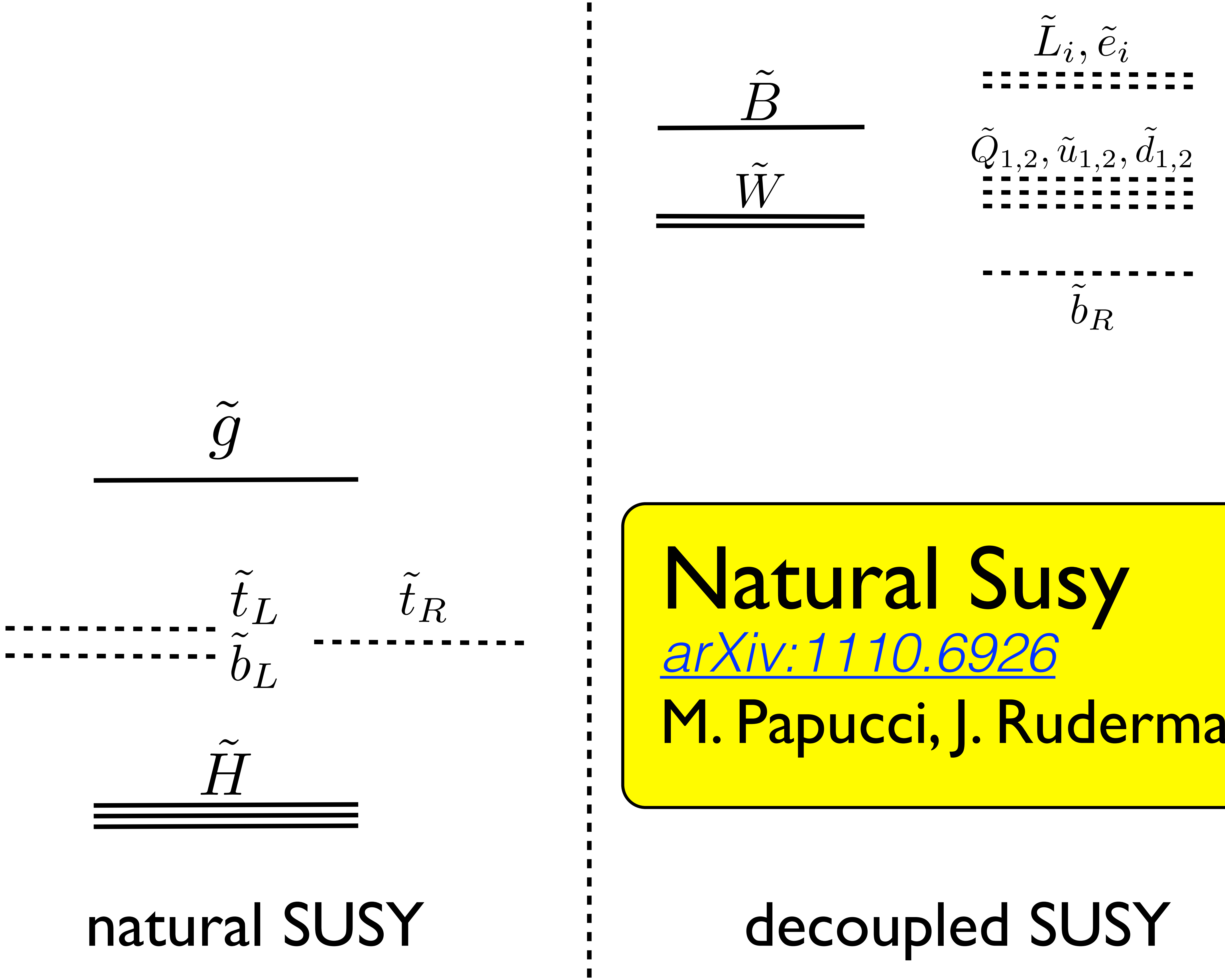
~1400 GeV

~930 GeV

m_{SUSY}* > TeV ?

* colored objects

- Bottom-up natural spectrum!
- Stealth susy?
- Compressed susy? (ISR?)
- R-parity violation?



Natural Susy

arXiv:1110.6926

M. Papucci, J. Ruderman, AW

Any caveats beyond that?

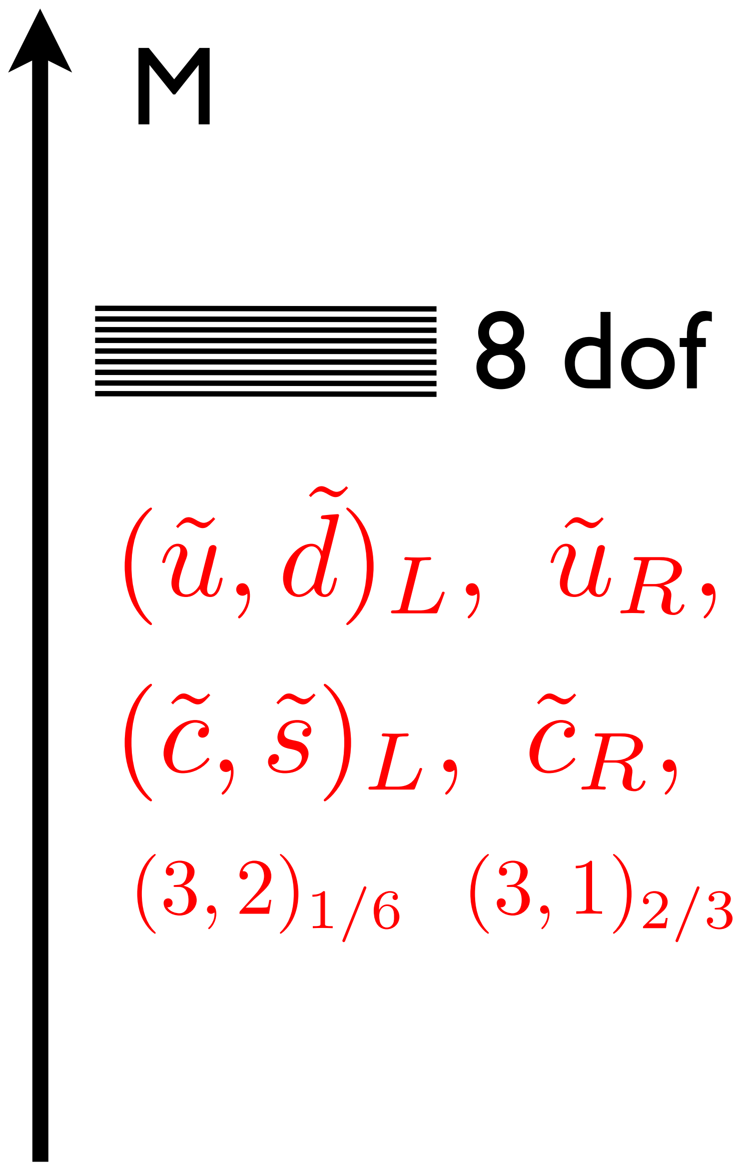
We have already seen that a 1-2 vs. 3 splitting (natural susy) leads to weaker constraints:

- What if there is a splitting in 1-2 sector?
- Not covered even in most exhaustive scans: pMSSM assumes 1-2 degeneracy, all of the constrained MSSMs (CMSSM, …) obviously assume 1-2 degeneracy

Degenerate squarks?

work in progress with
Michele Papucci, Josh Ruderman (LBL Berkely)
Gilad Perez, Rakhi Mahbubani (CERN)

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



$(\tilde{u}, \tilde{d})_L, \ \tilde{u}_R, \ \tilde{d}_R,$

$(\tilde{c}, \tilde{s})_L, \ \tilde{c}_R, \ \tilde{s}_R$

$(3,2)_{1/6} \ (3,1)_{2/3} \ (3,1)_{-1/3}$

- Because of flavor constraints? Not really.

Assumed spectrum in ATLAS/CMS plots

SUSY & Flavor

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

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

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mixing matrices

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mixing matrices   mass splitting

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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

Isidori et. al '10

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d	12	0.03	0.002
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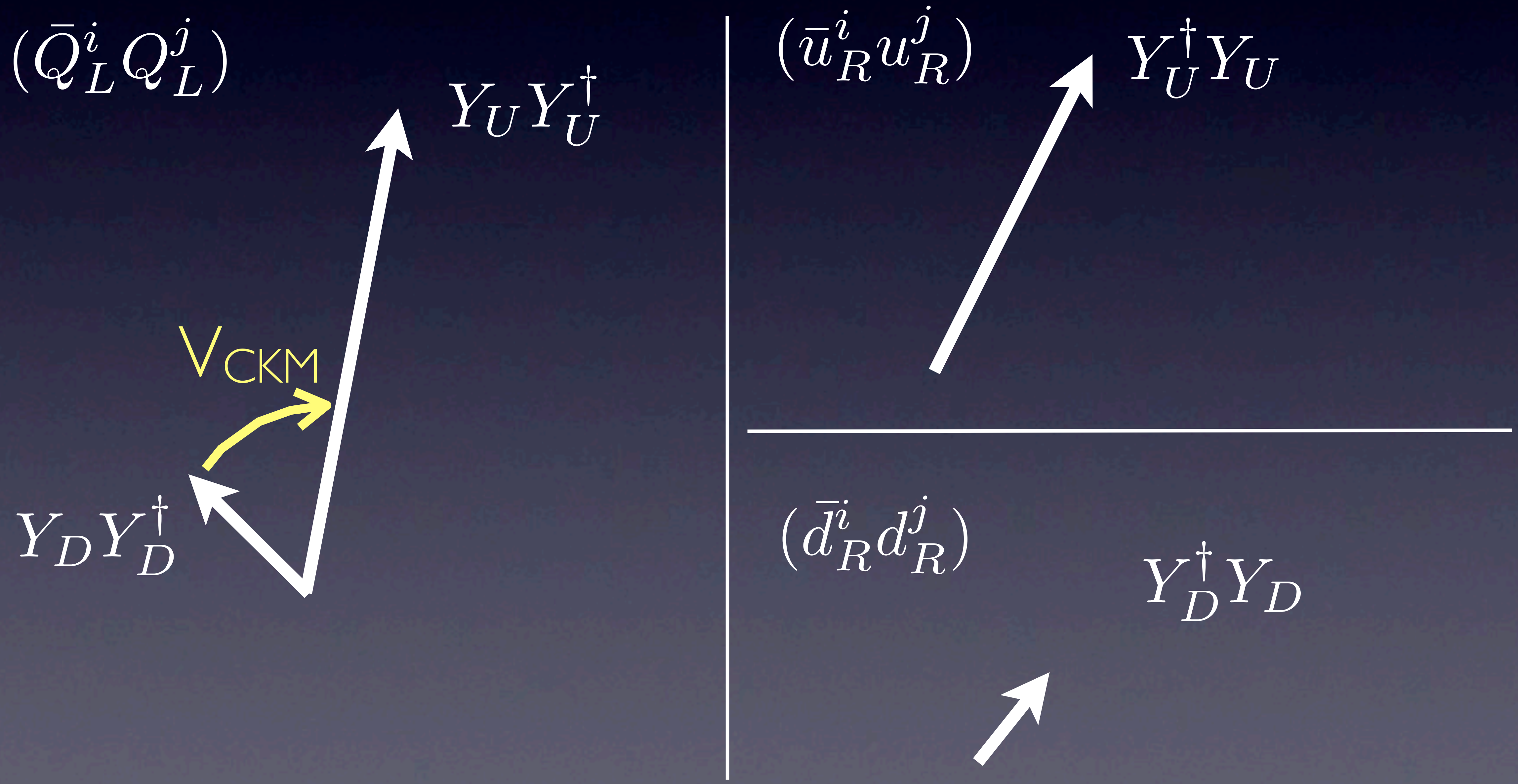
u	12	0.1	0.008

large mixing means splitting must be << 1

Isidori et. al '10

A picture of flavor

Yukawa matrices Y_U & Y_D encode flavor violation



+ LR, RL

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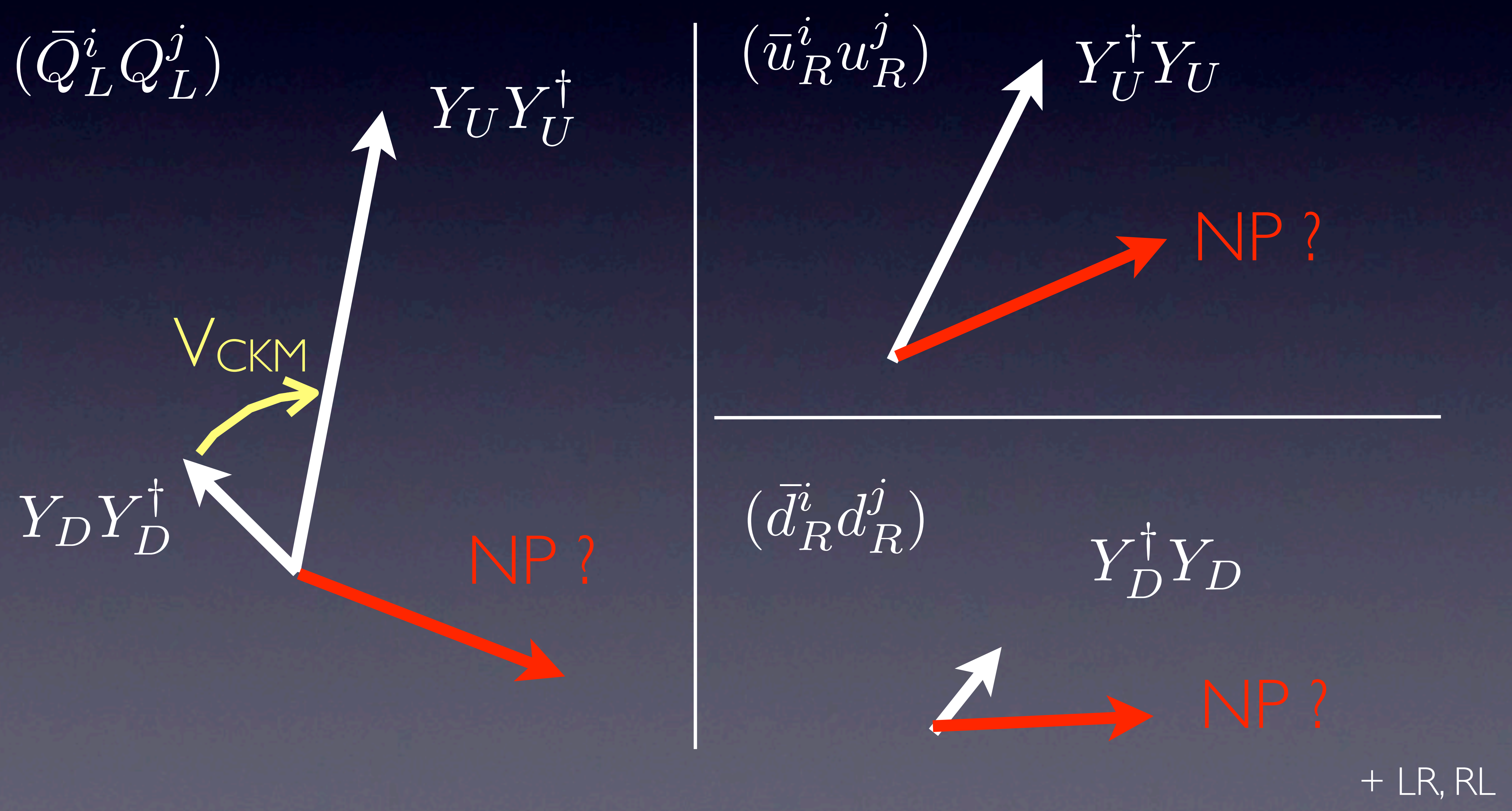
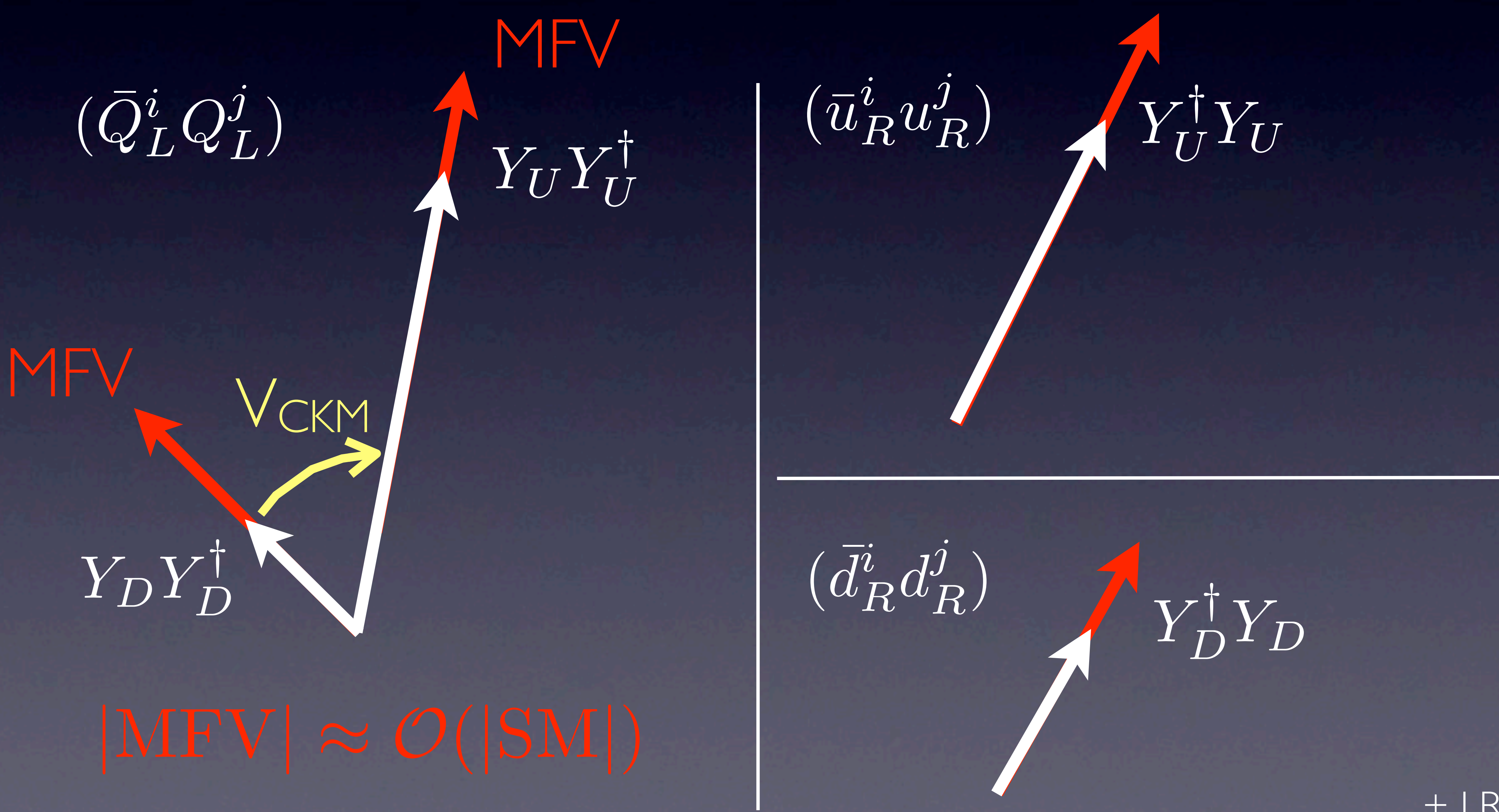


Minimal flavor violation

Chivukula Georgi; Buras et. al; D'Ambrosio et. al

New particles/interactions, but flavor structure $\sim V_{CKM}$



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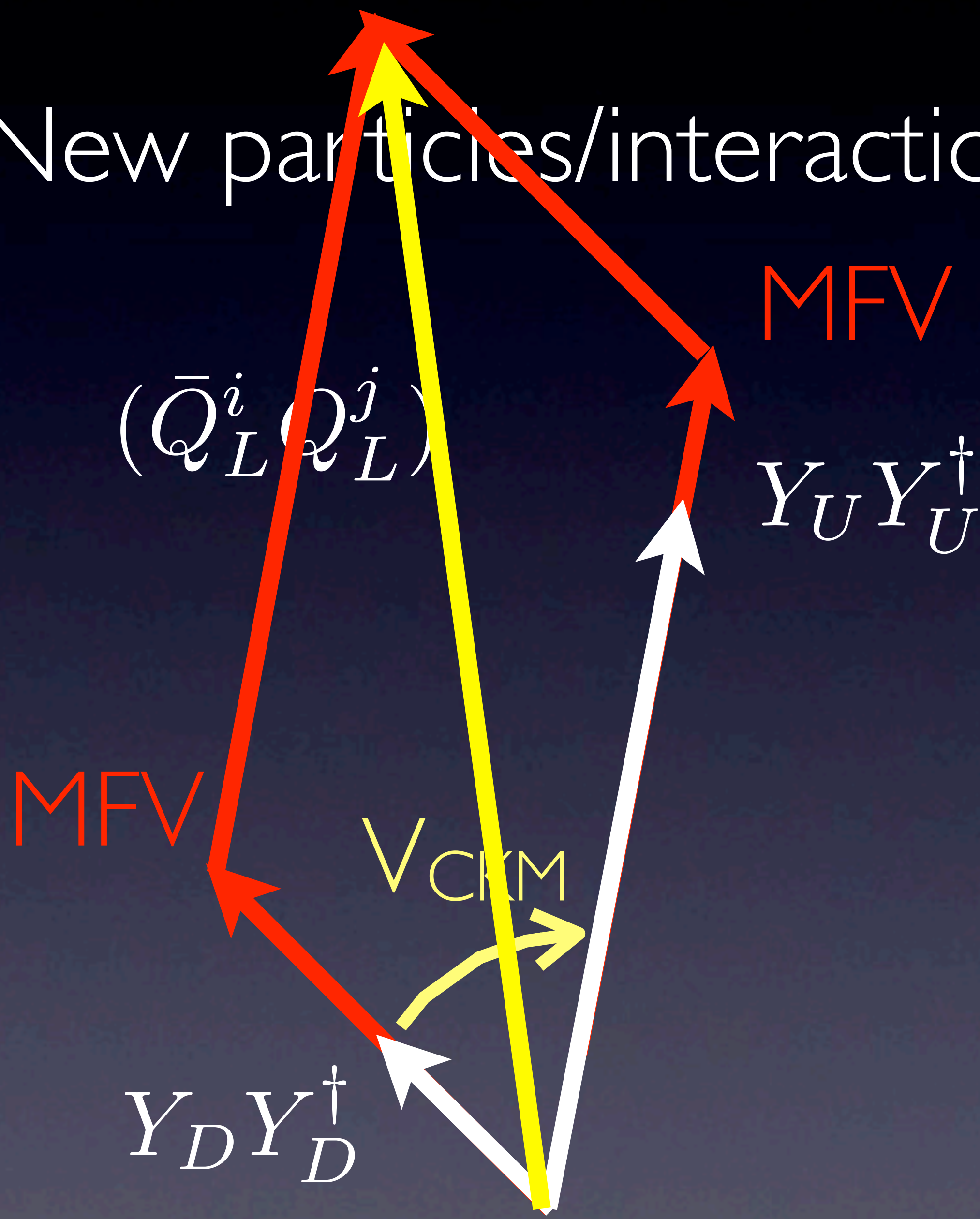
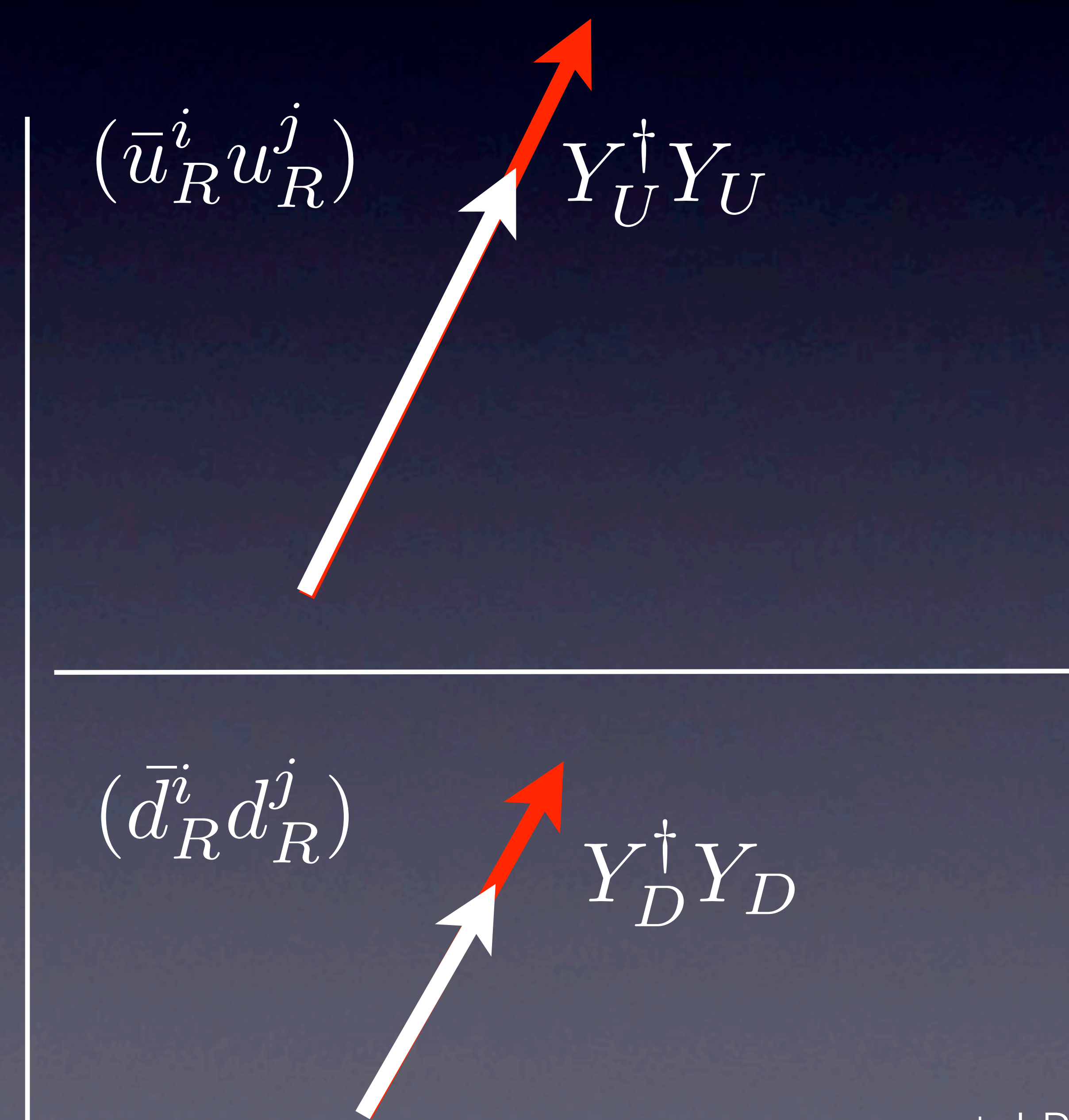


$$|\mathrm{MFV}| \approx \mathcal{O}(|\mathrm{SM}|)$$



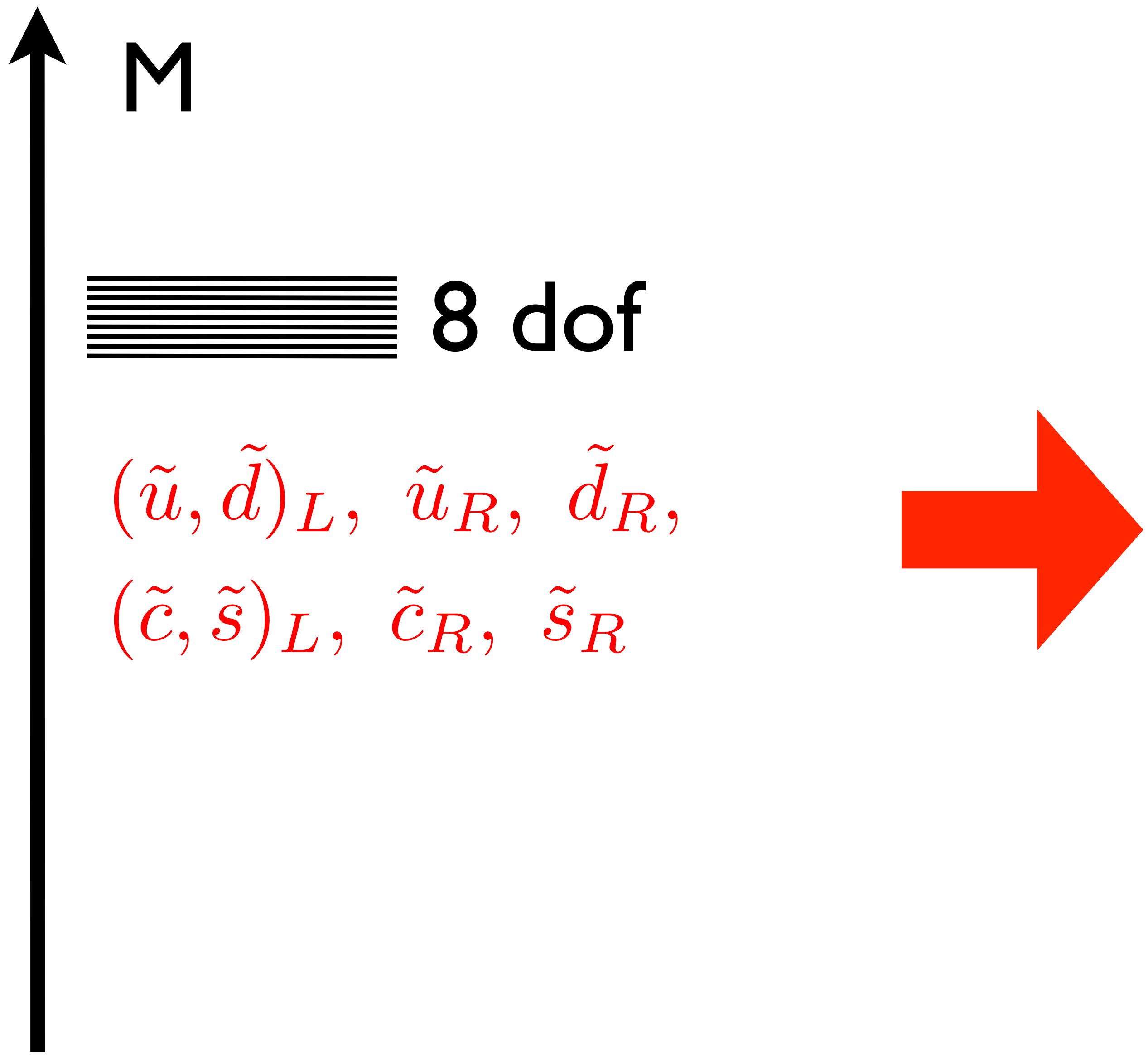
+ LR, RL

Minimal Flavor Violation

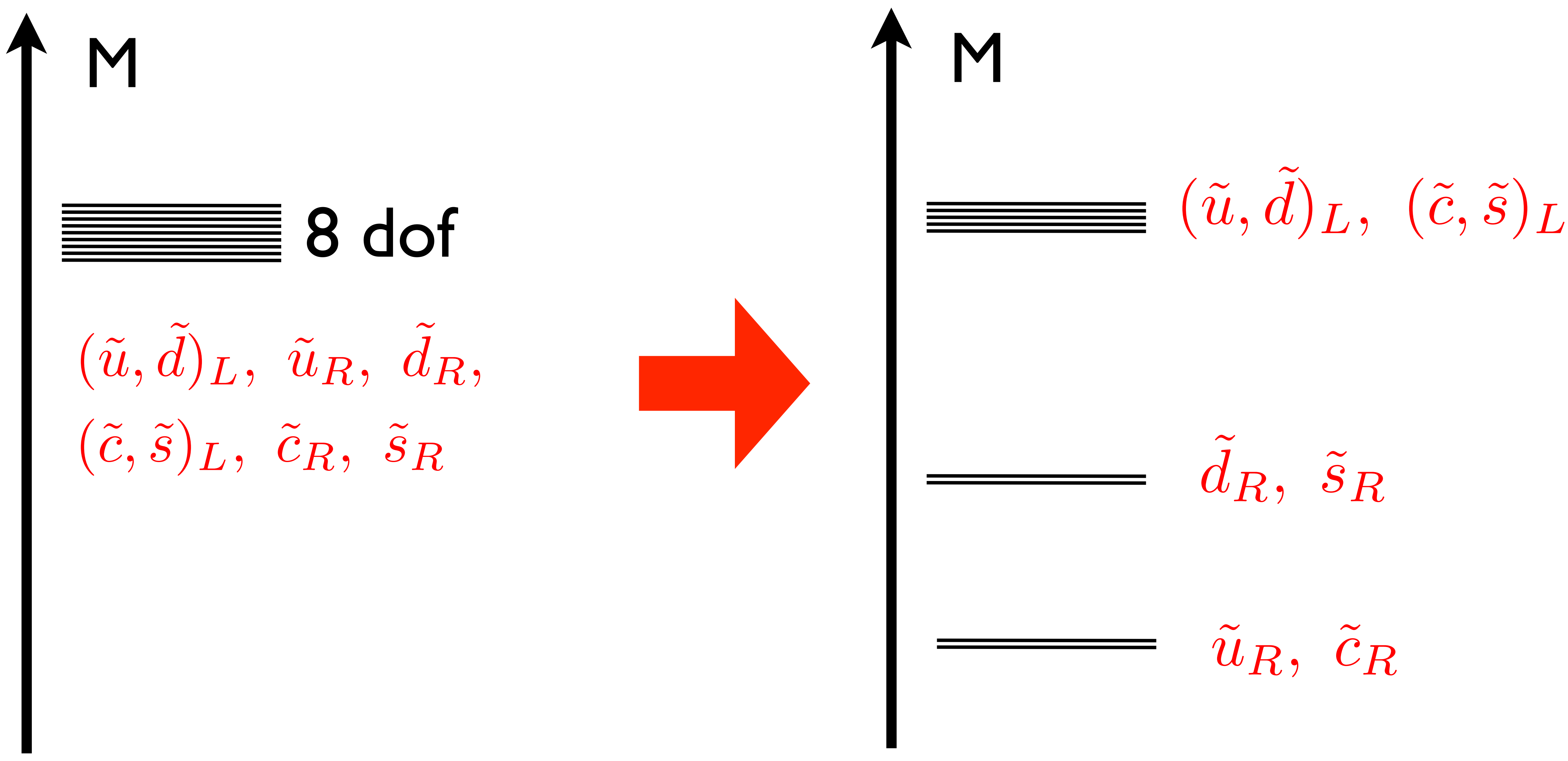
- Vertical: Squark masses same for all three generations but split between $\tilde{Q}_L,\ \tilde{u}_R,\ \tilde{d}_R$
- Can introduce a split between 1-2 and 3,

$$\Delta M^2 \propto Y Y^\dagger \sim (0,0,1)$$

& still have MFV



Fully degenerate

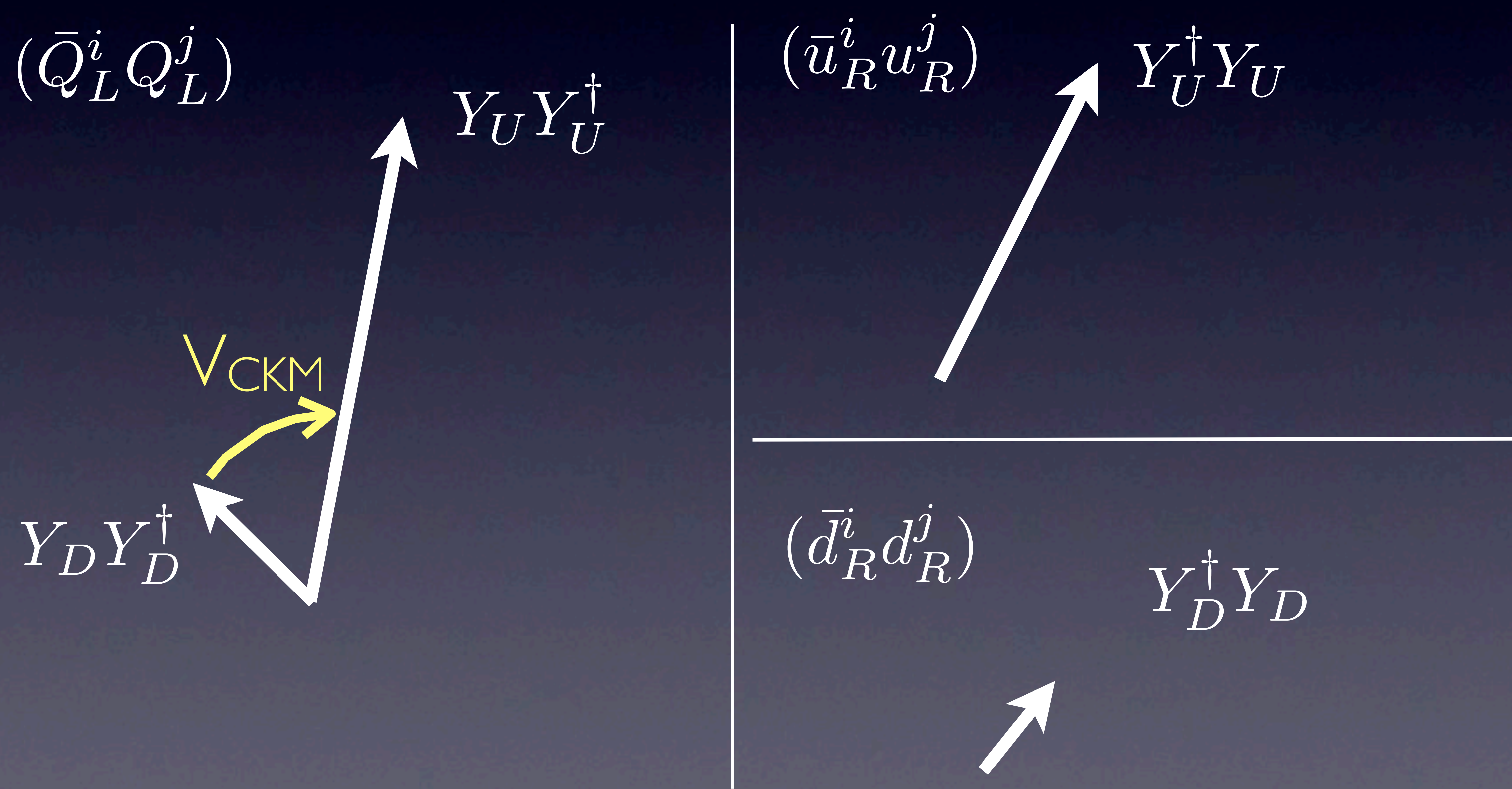


Fully degenerate

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



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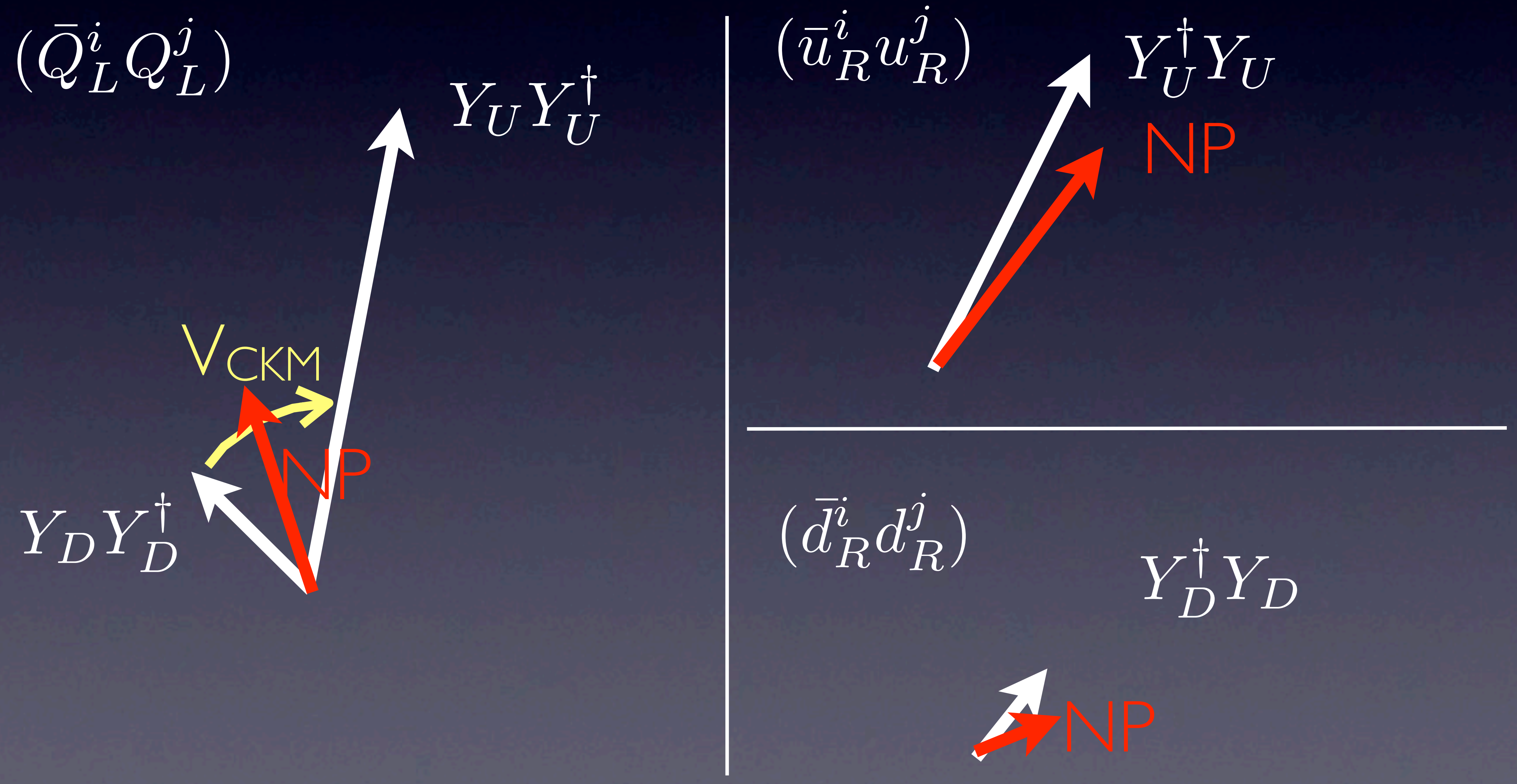
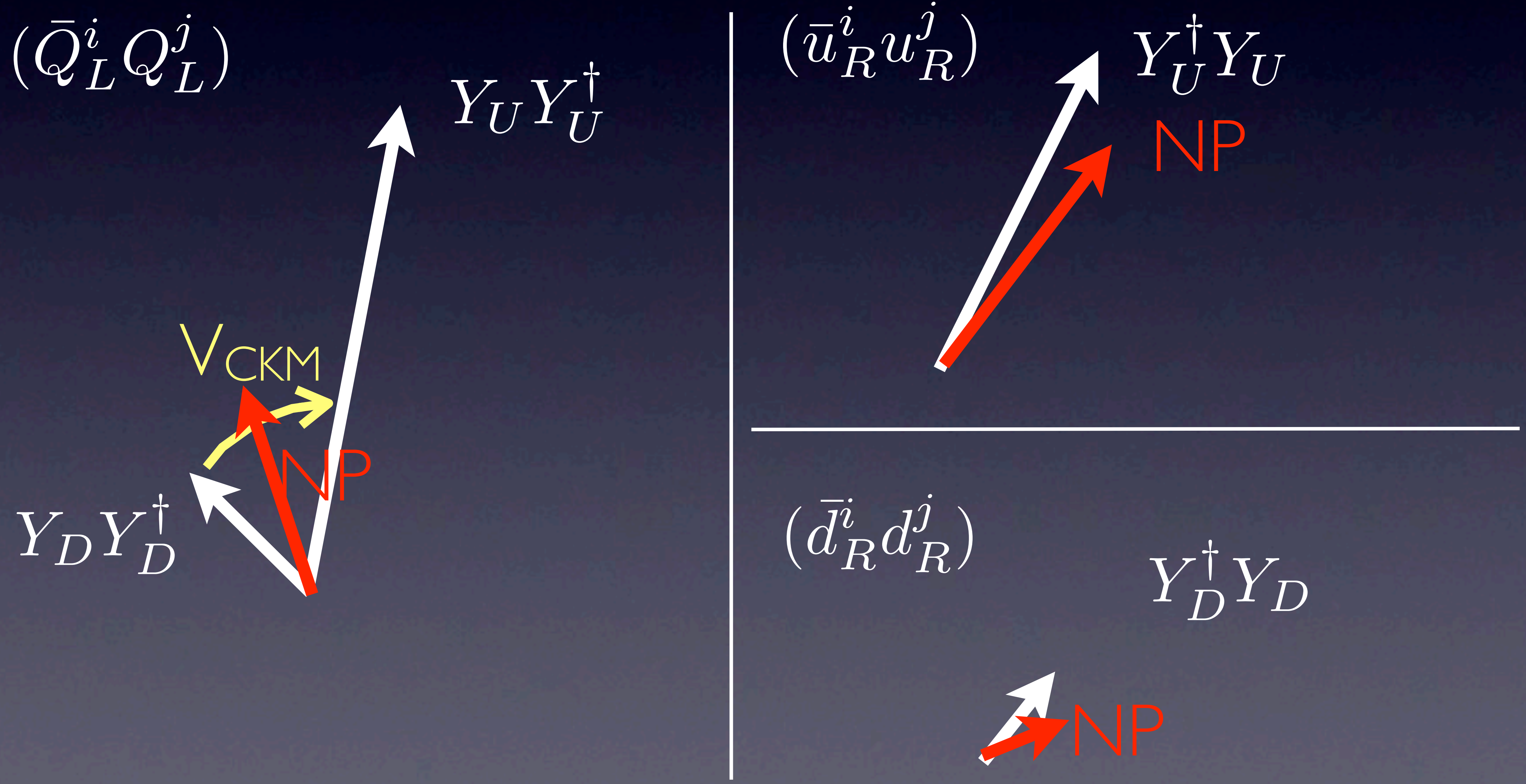


+ LR, RL

Left-handed (Q_L): either aligned with up or downs

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



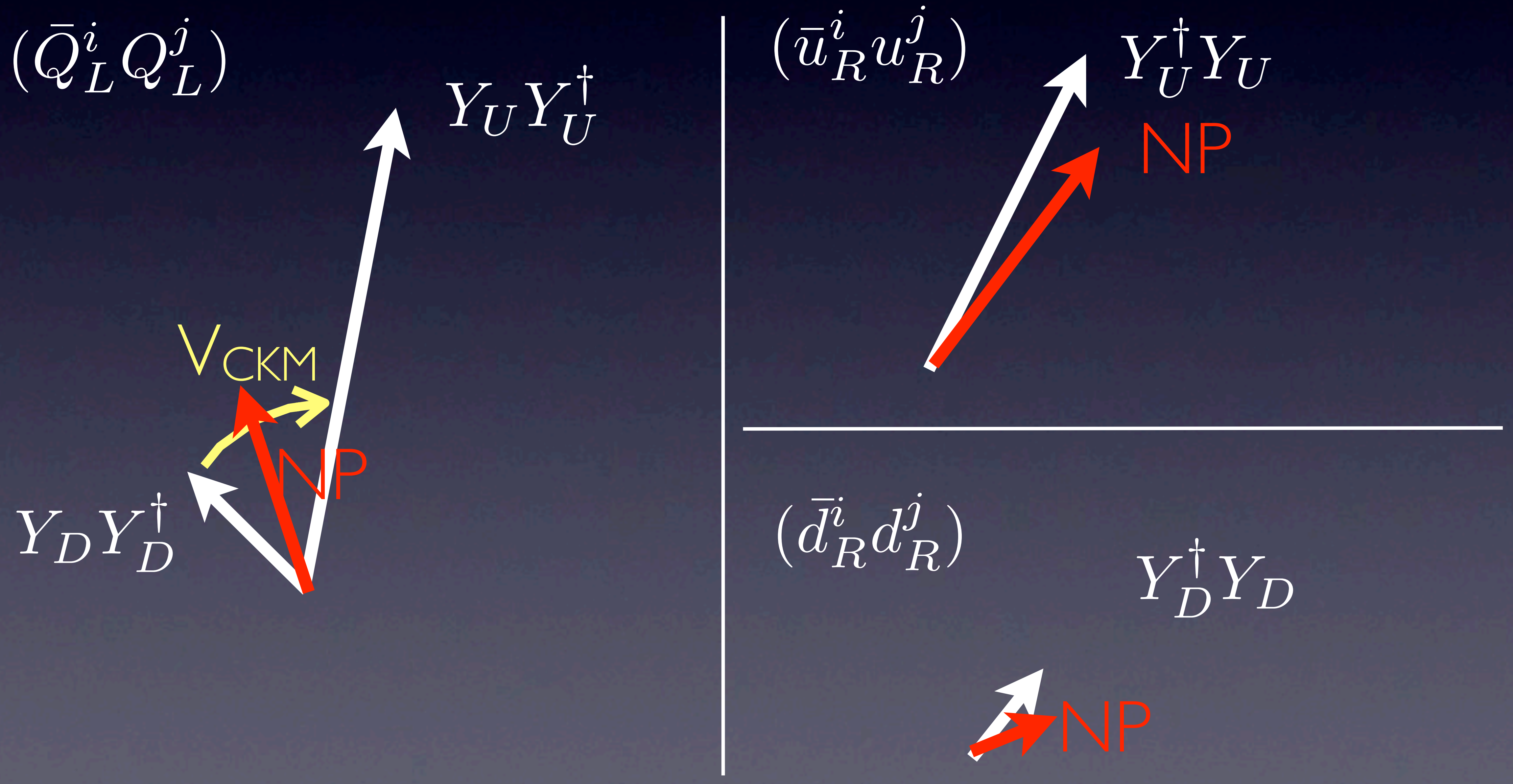
+ LR, RL

Left-handed (Q_L): either aligned with up or downs

→ **limited splitting**

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

→ **any splitting**



+ LR, RL

Alignment

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

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mixing / misalignment between
SM Yukawas and squark mass matrices

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Seiberg & Nir

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If by symmetry: K_{ij} ~ diagonal, O(1) mass splittings ok.

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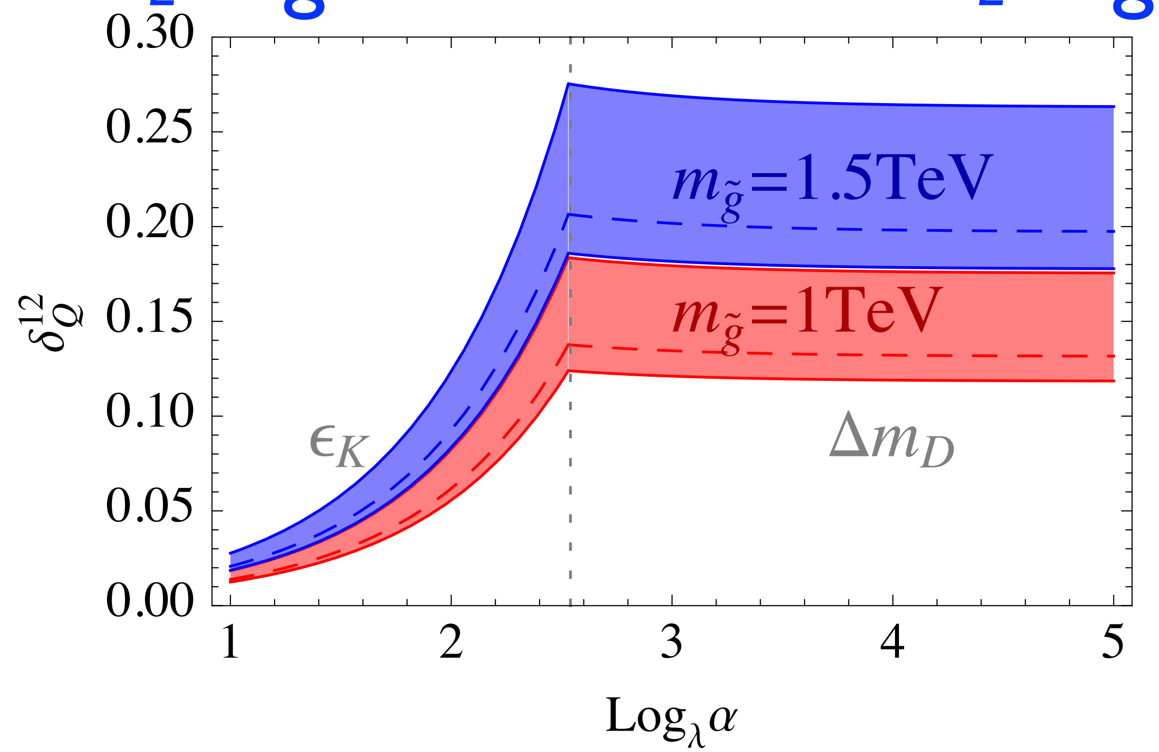
Gedalia et. al

u_L aligned ⟷ d_L aligned

squark splitting



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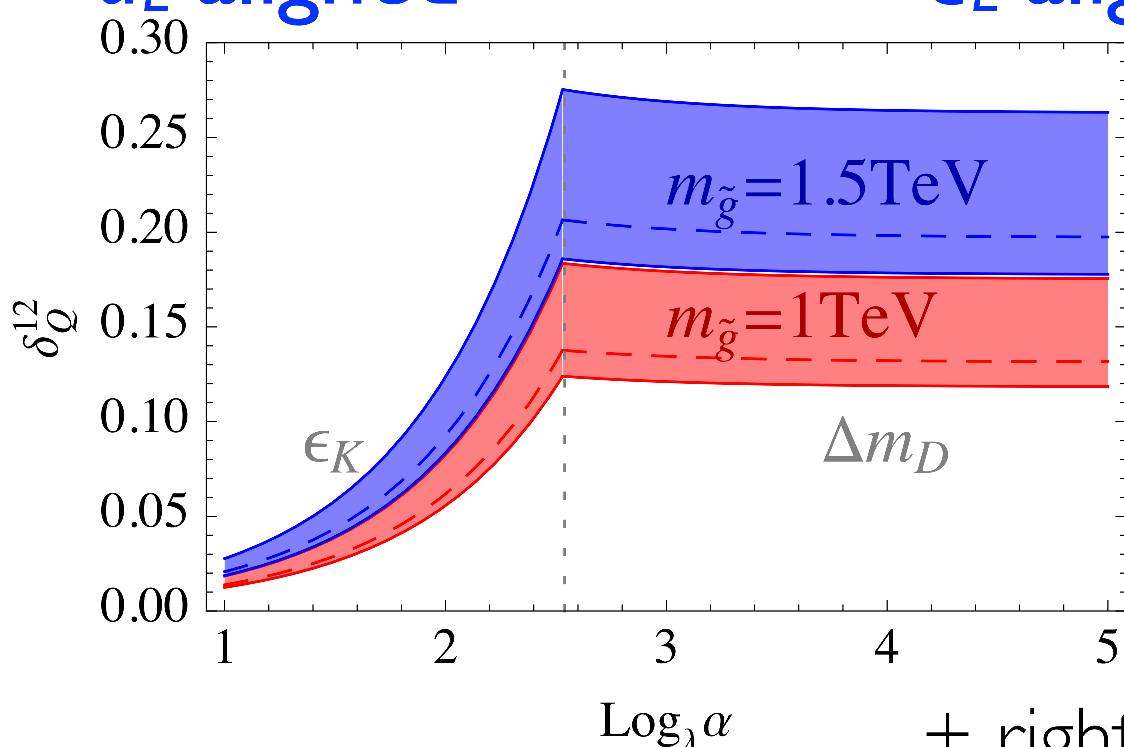


Example:

m_{gluino} = 1.3 TeV

m_{Q1} = 550 GeV

m_{Q2} = 950 GeV

+ right handed squarks split by arbitrary amount

Flavor vs. squark masses: summary

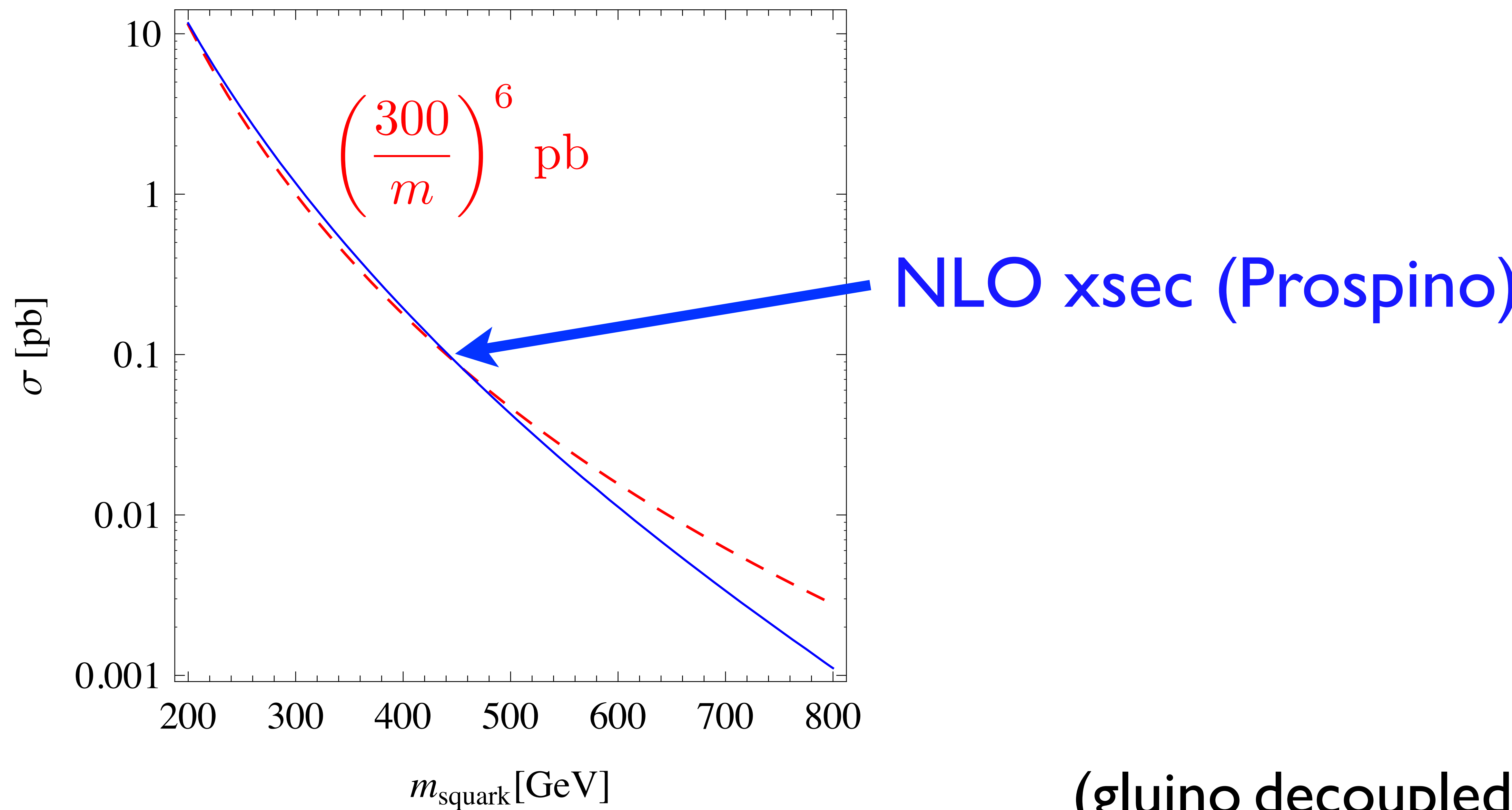
- Generic 1-2 splitting has to be small, but:
- Can split vertically: split Q_L^i vs u_R^i vs d_L^i
- Can split horizontally, if squark mixing aligned

Does it matter if we relax the degeneracy assumption?

Naive answer: not so much.

Cross-sections vs. mass

$$\sigma(pp \to \tilde{u}_R \tilde{u}_R^*) \propto \frac{1}{m^6}$$ (roughly)



(gluino decoupled)

Back of the envelope estimate

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

Example: 8 light squarks → 2 light squarks

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

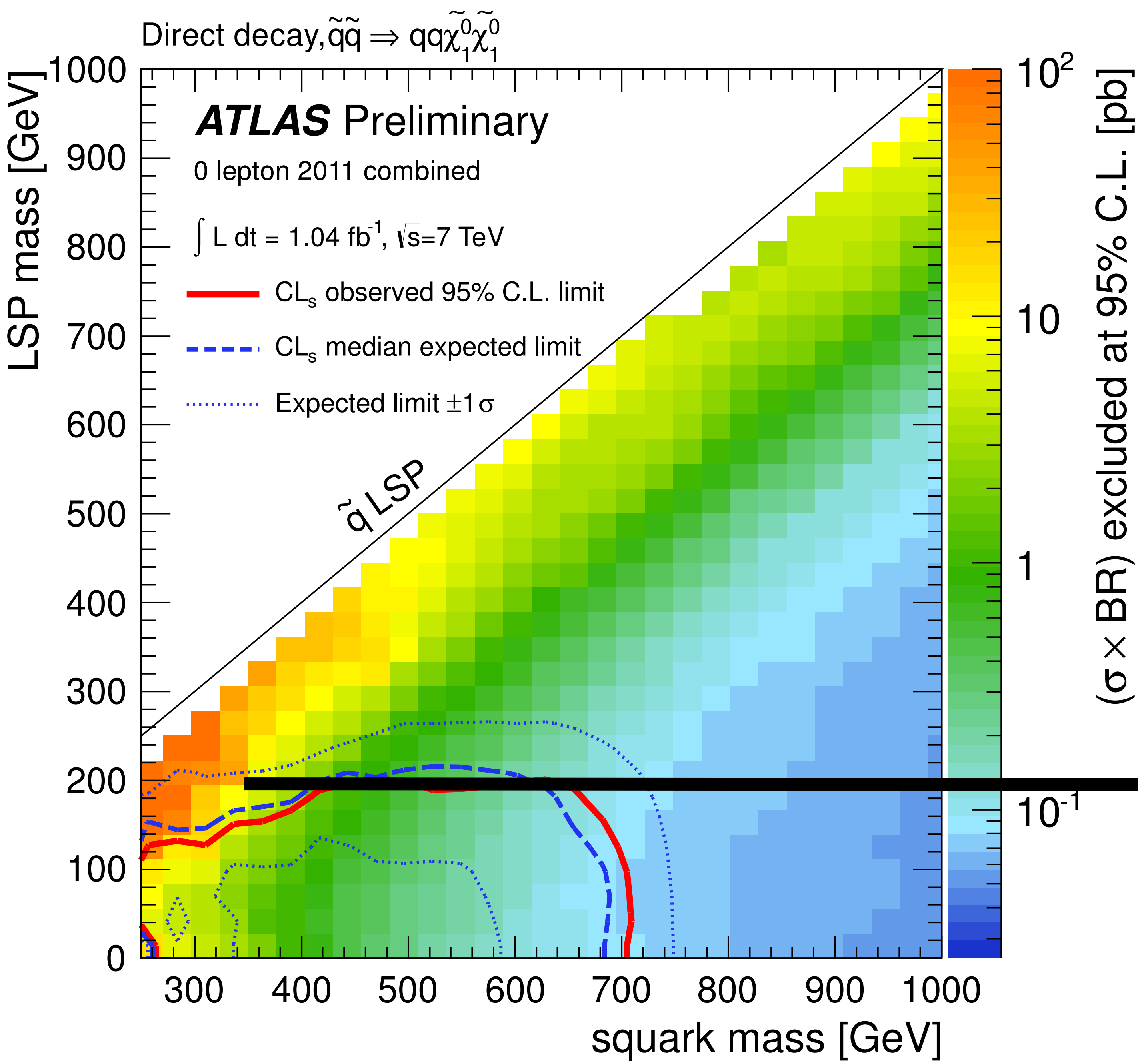
→ too naive!

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

Efficiencies

Searches might become inefficient for light squarks

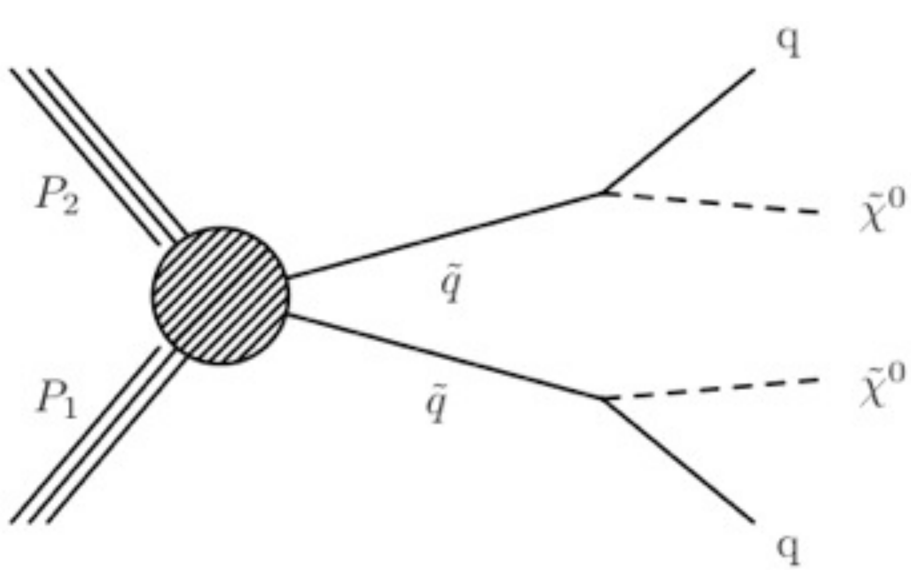


$$\sigma \times A \times \epsilon \approx const.$$

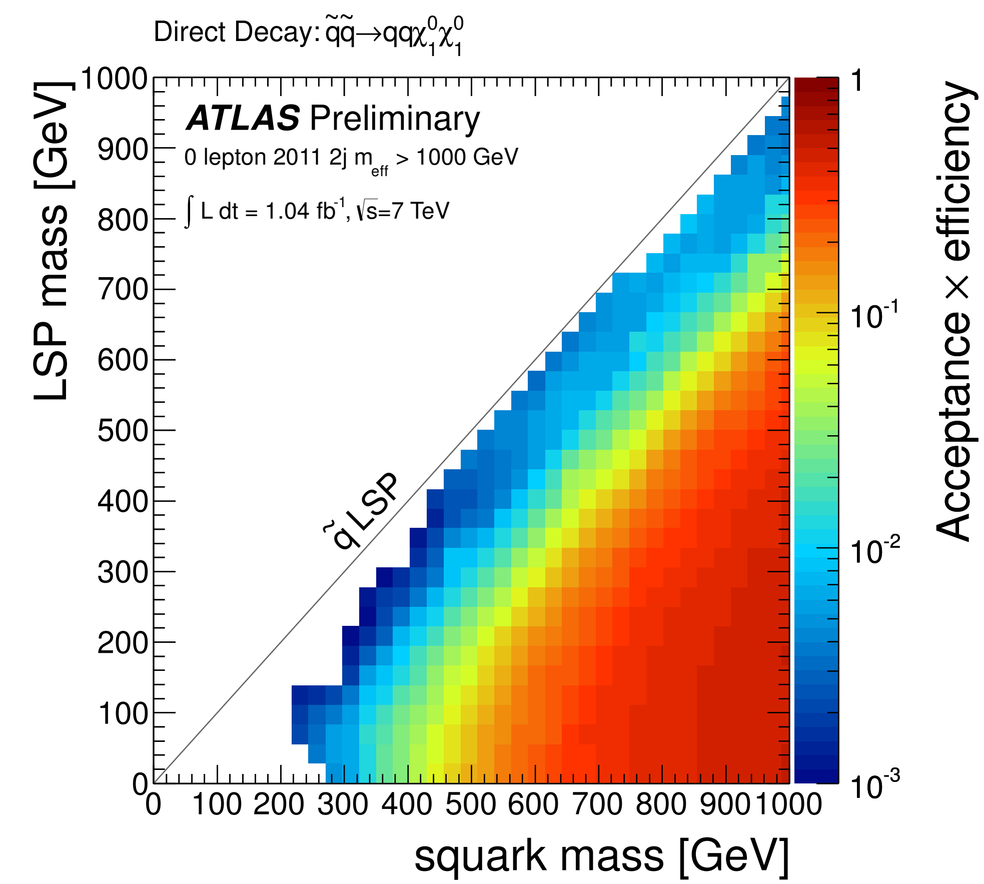
How can we extract limits on non-degenerate 1st and 2nd gen' squarks from experimental searches?

Simplified Models to the rescue!

- ATLAS and CMS provide efficiencies for simplified models (few for 5 fb^{-1})



simplified topology



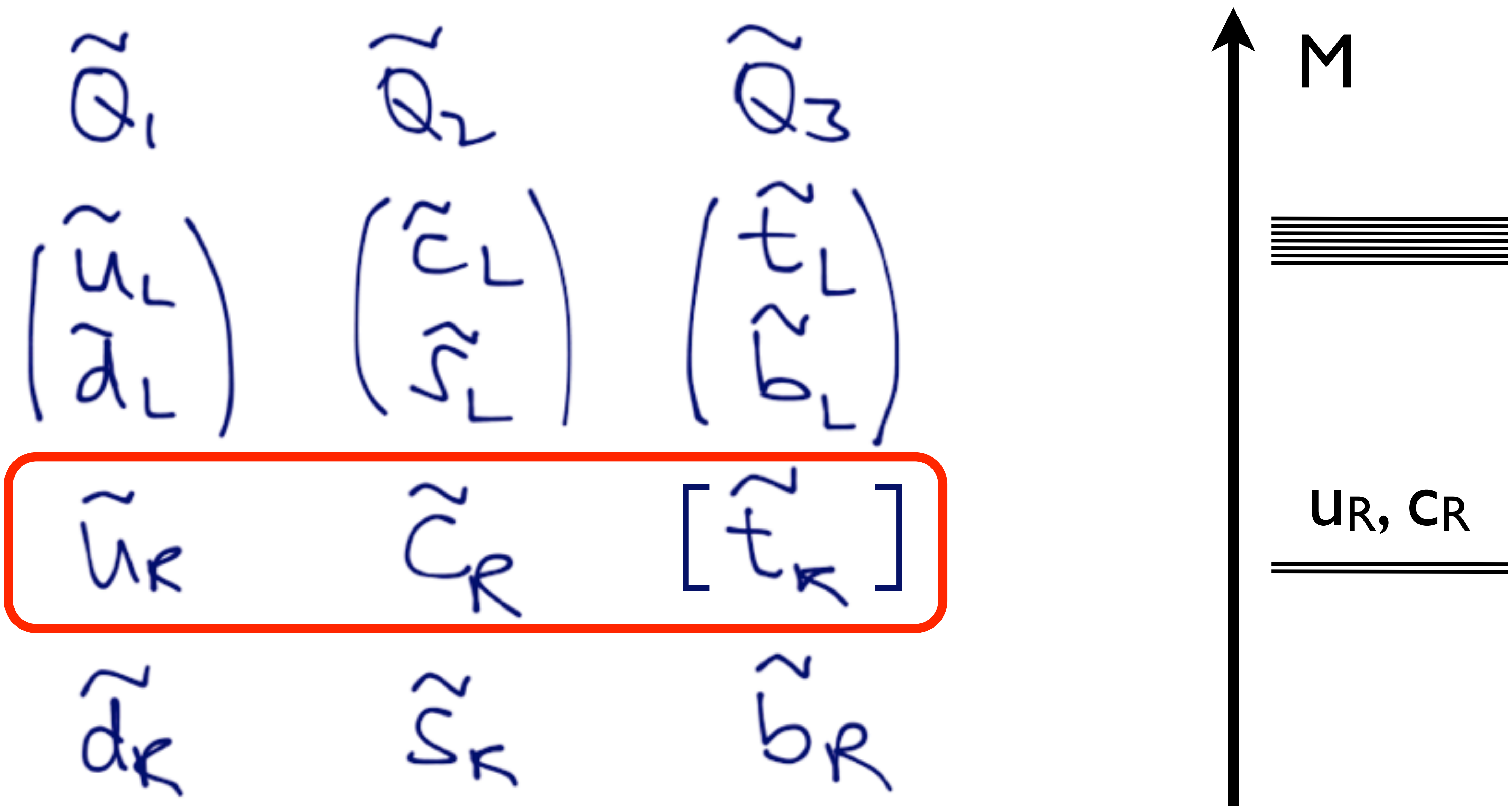
e.g. CMSPublic/PhysicsResultsSUS11004 or ATLAS-CONF-2011-155/
Thanks for providing root files, HEPDATA,...

Comments on simplified models

- Works well for squark pair production T2 only (also compared to our MC mockup)
- Need also squark - gluino associate for complete picture (only provided by ATLAS)
- Doesn't cover more complicated kinematics: e.g. $pp \to \tilde{d}\tilde{s}$ with $m_{\tilde{d}} \neq m_{\tilde{s}}$

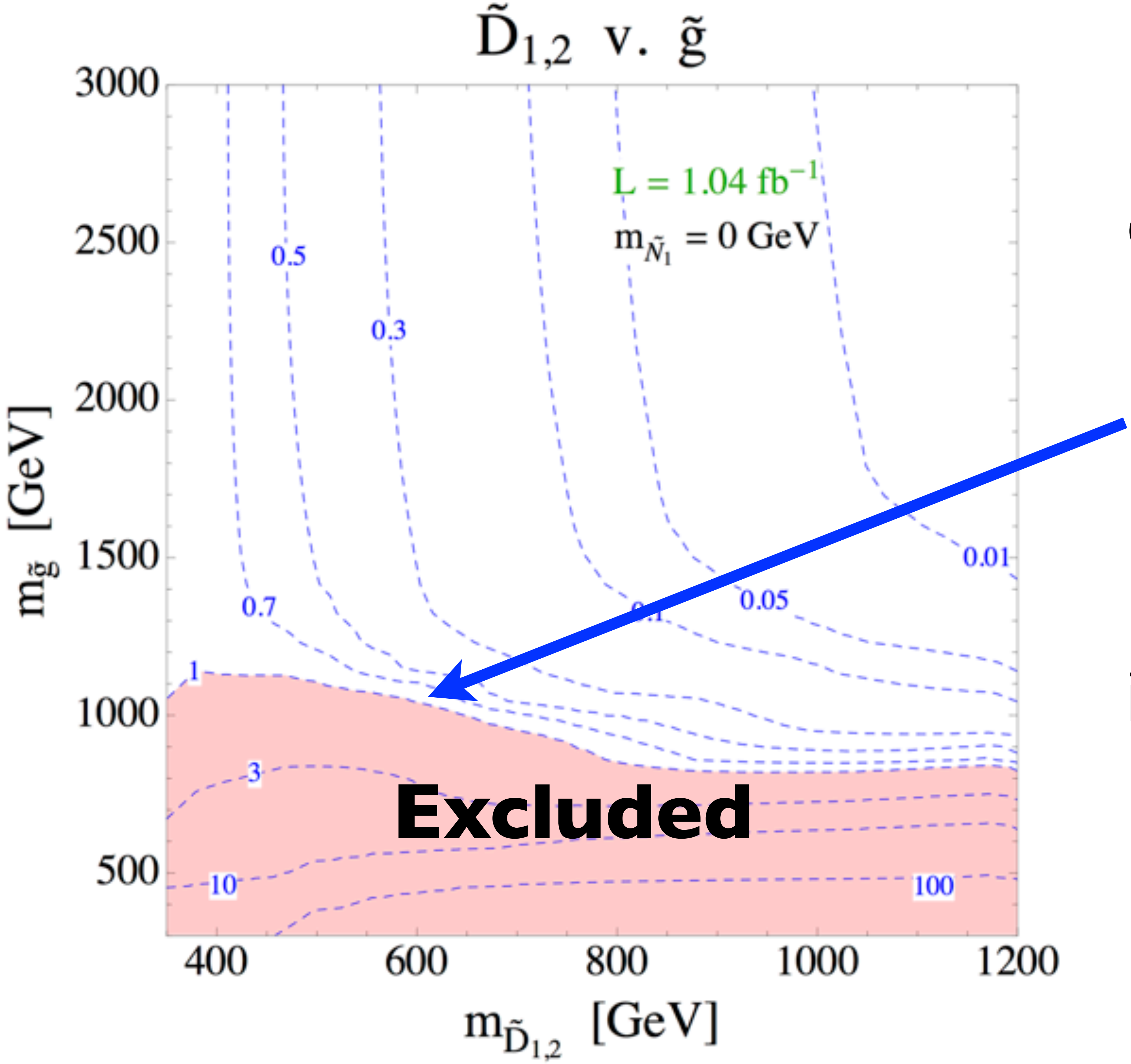
Need MC mockups → used ATOM & PGS

MFV example



Vertical non-degeneracy

Pre-ICHEP



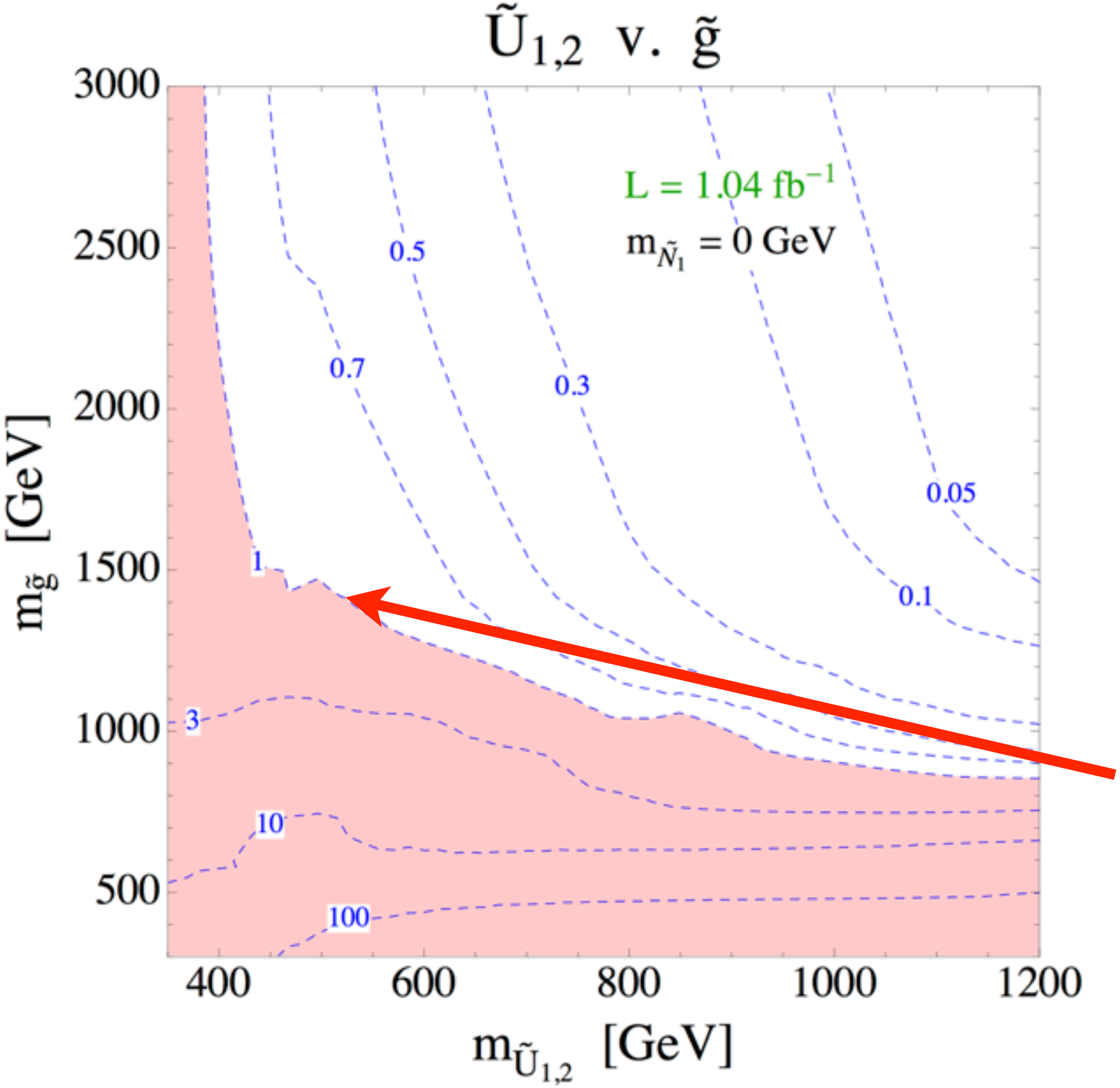
Contours of

$\sigma/\sigma_{\rm limit}$

Exclusion (at 95CL) if this is = 1

For $m_{\rm gluino}$ > 1.2 TeV, limit can even disapear ($m_{\rm LSP}$ =0 GeV)

Pre-ICHEP

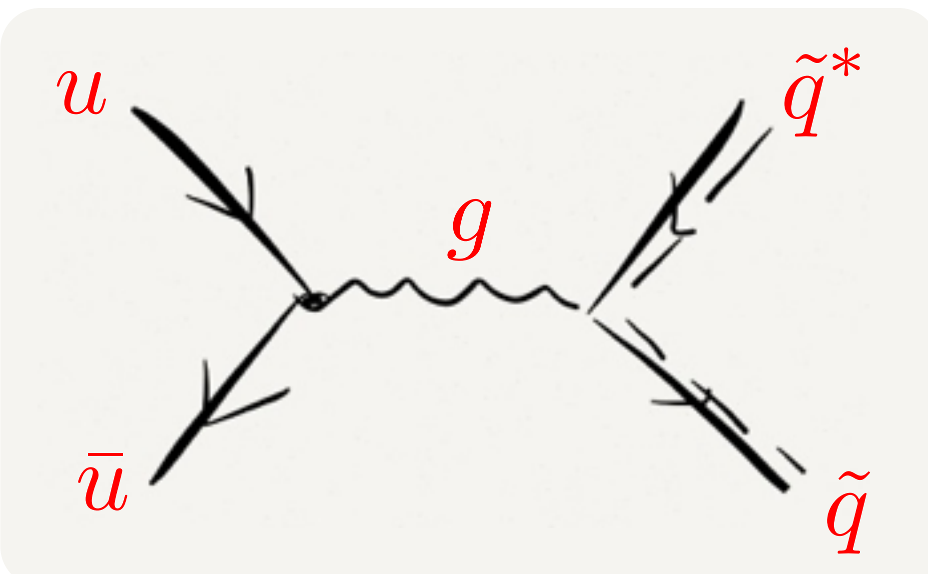


slow decoupling of gluino

Why so sensitive to gluino mass? →

What is driving the strong ATLAS/CMS limit?

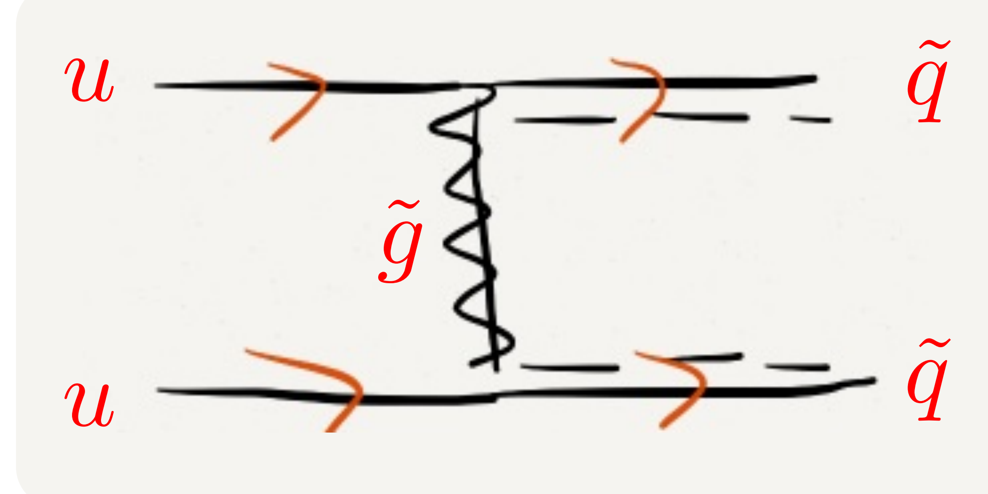
Squark - Squark production:



Independent of squark flavor (and gluino mass)

Simple d.o.f rescaling

Majorana nature of gluino allows **u u** initial state!



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

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

slow decoupling

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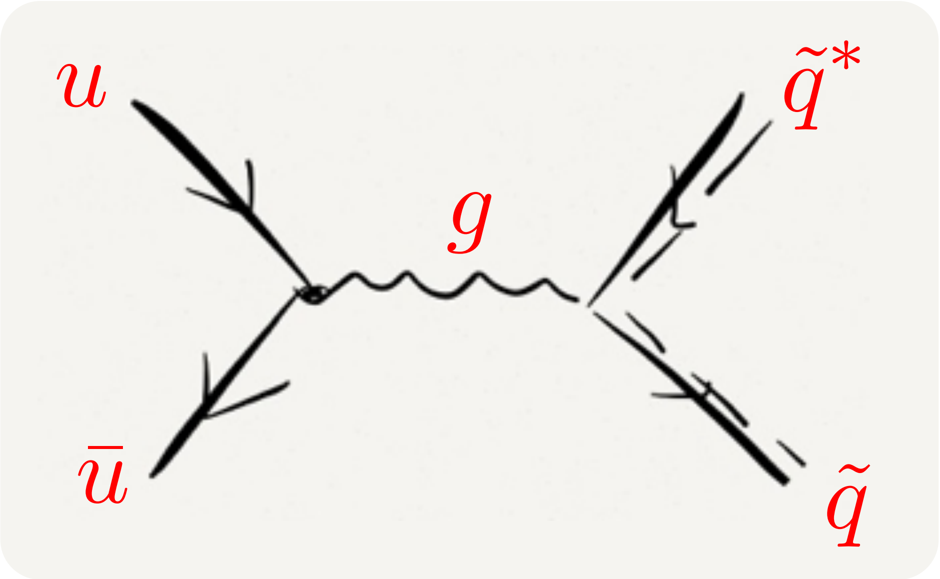

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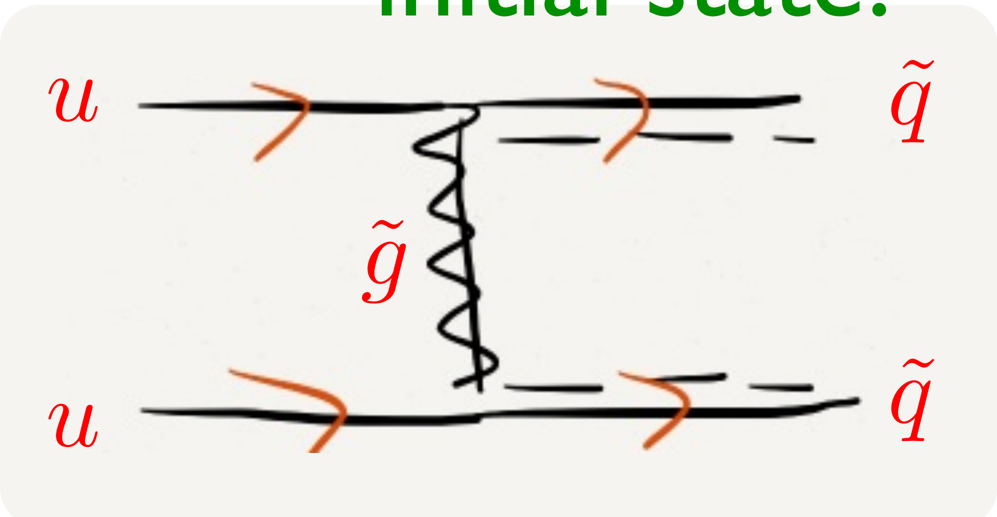

$$\frac{1}{m_{\tilde{g}}}\tilde{q}\tilde{q}\,u_R u_R$$ dim5 op.

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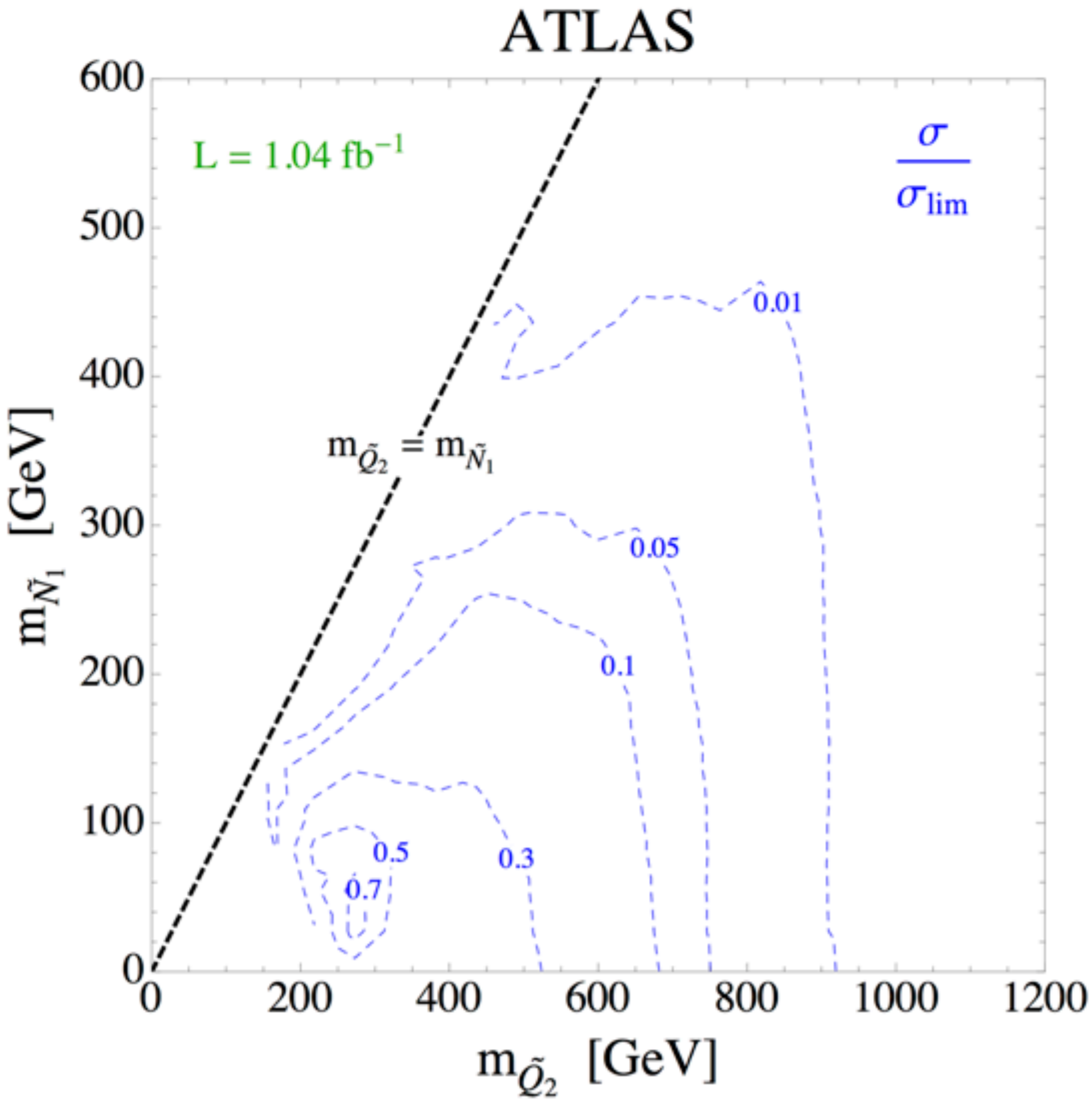
slow decoupling

Aligned LH squarks

	$\tilde{Q}_1$	$\tilde{Q}_2$	$\tilde{Q}_3$
Squarks	$\begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix}$	$\boxed{\begin{pmatrix} \tilde{c}_L \\ \tilde{s}_L \end{pmatrix}}$	$\begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix}$
	$\tilde{u}_R$	$\tilde{c}_R$	$\tilde{t}_R$
2 d.o.f	$\tilde{d}_R$	$\tilde{s}_R$	$\tilde{b}_R$

No limit on LH 2nd gen' squark*

* Pre-ICHEP

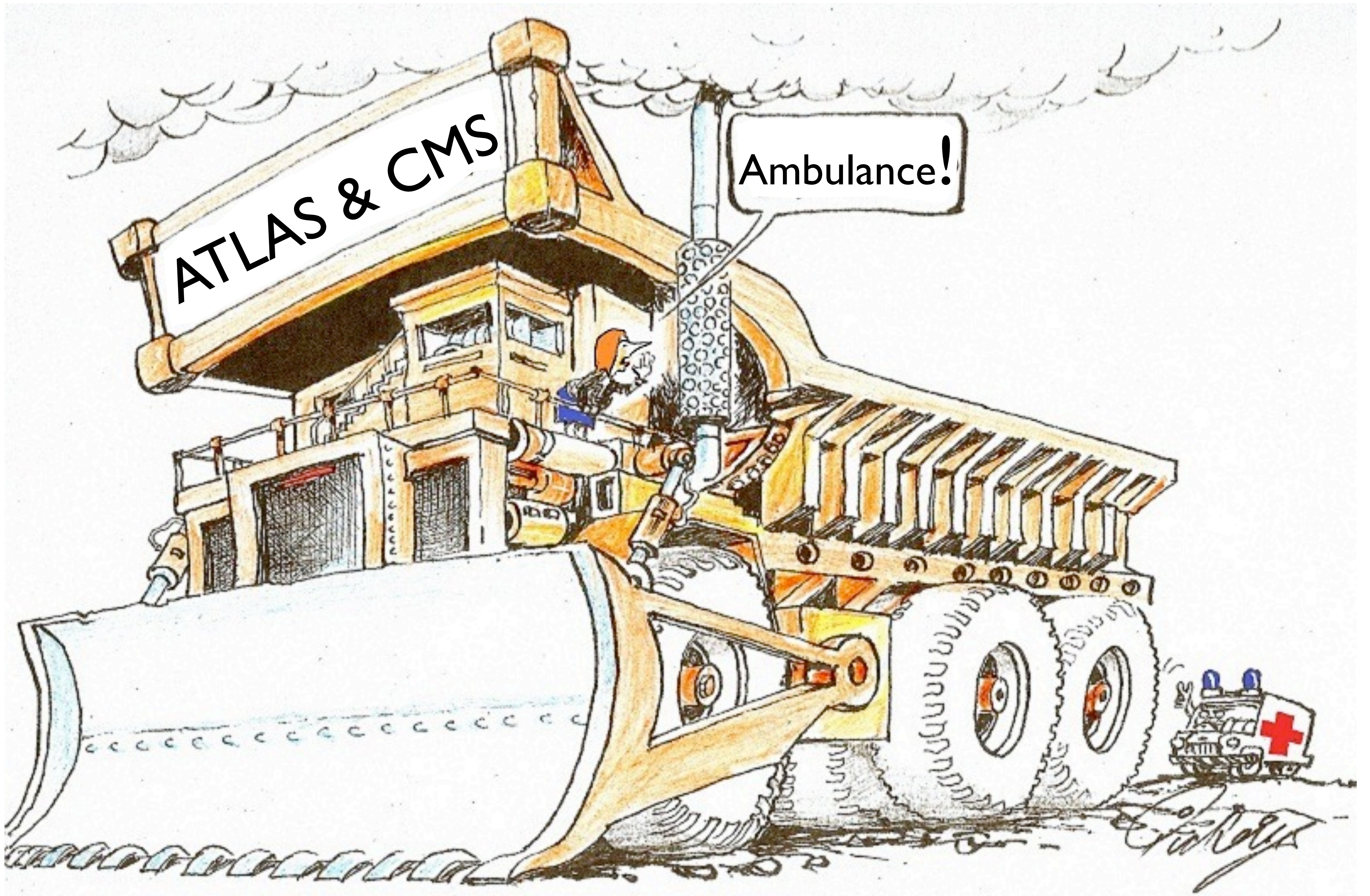


No bounds for Q_2 in 1/fb of data
(decoupled gluinos at 3TeV)

Post-ICHEP

‘I have this great scenario’

Post-ICHEP

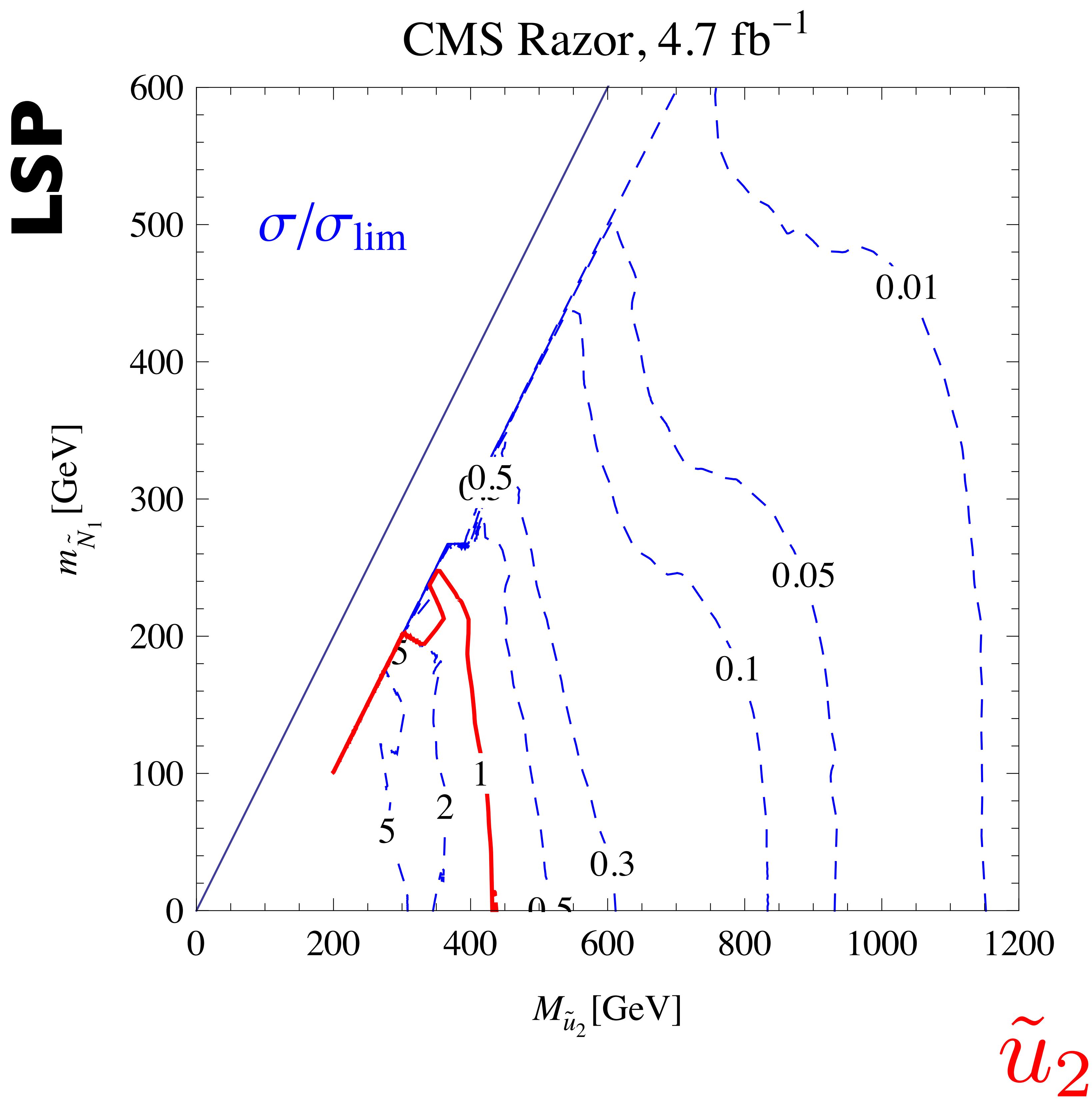


‘I have this great scenario’

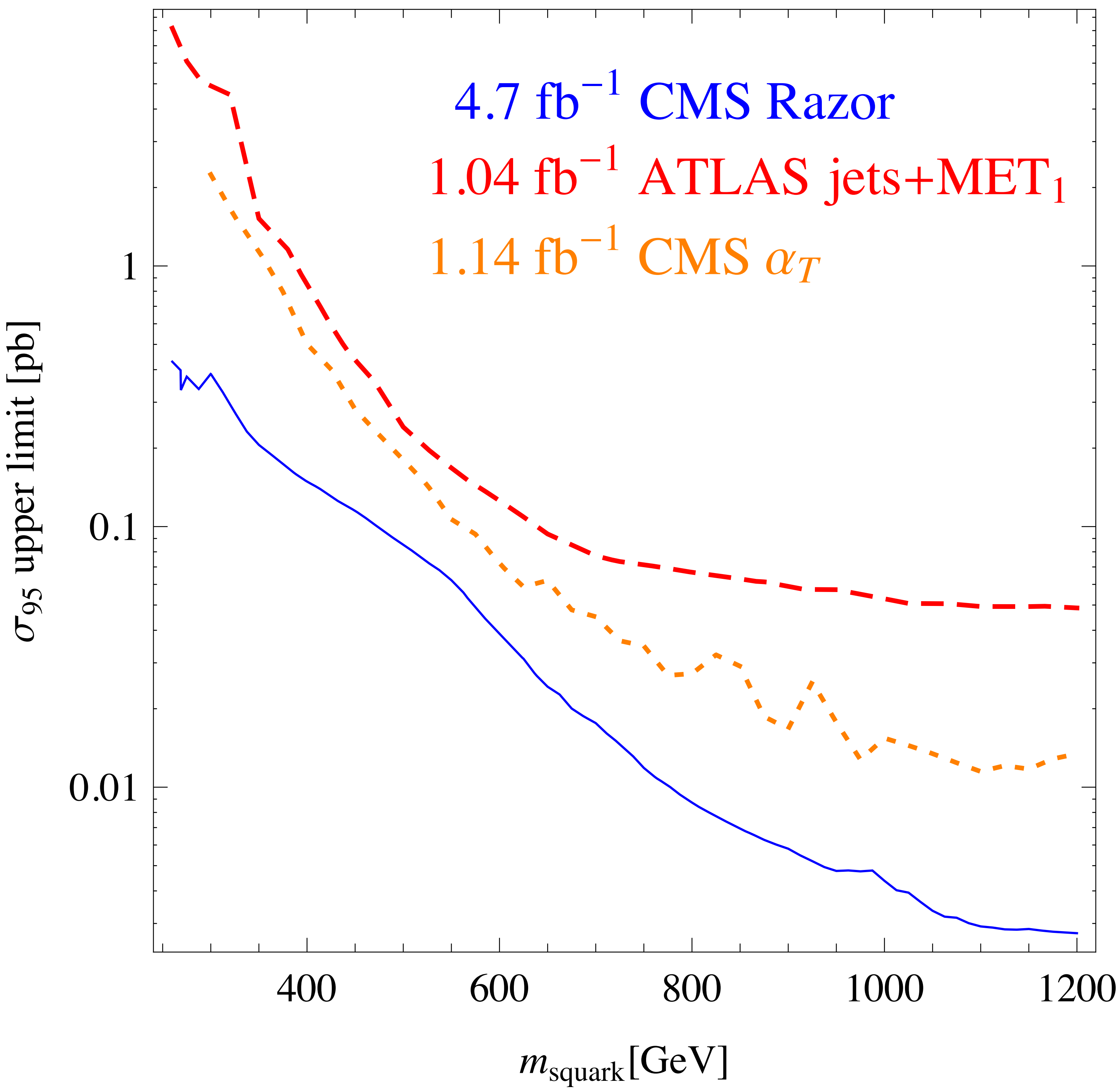
Disclaimer

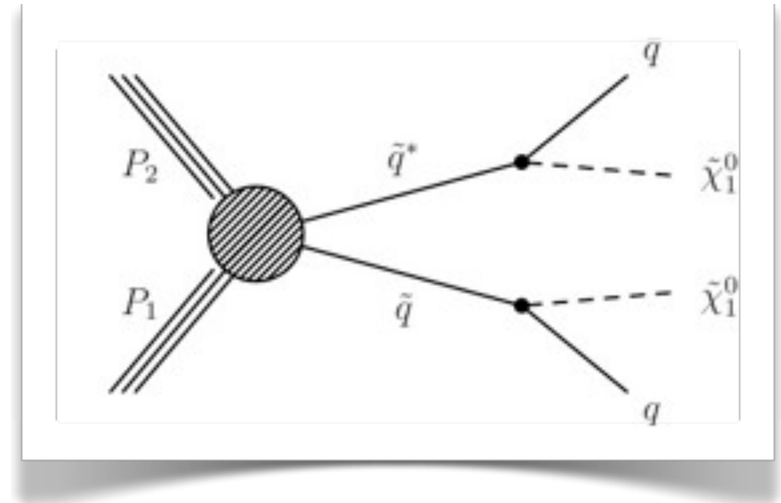
- Only used digitally accessible simplified results (e.g. ROOT or HEPDATA)
- More sensitive 5 fb^{-1} analyses might be available (and will be included later)

Post-ICHEP limit on valence squark

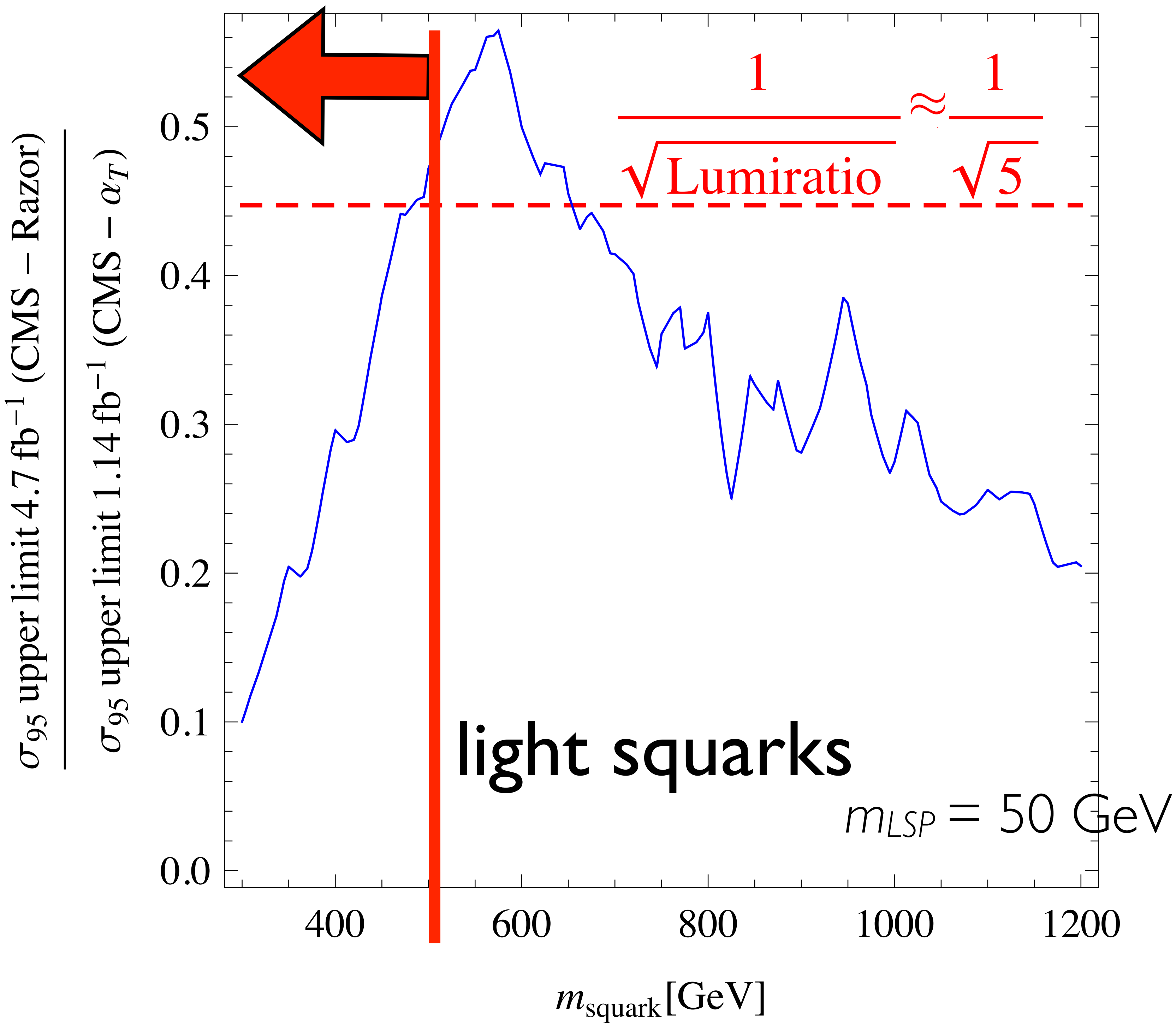


Experimental limit improved

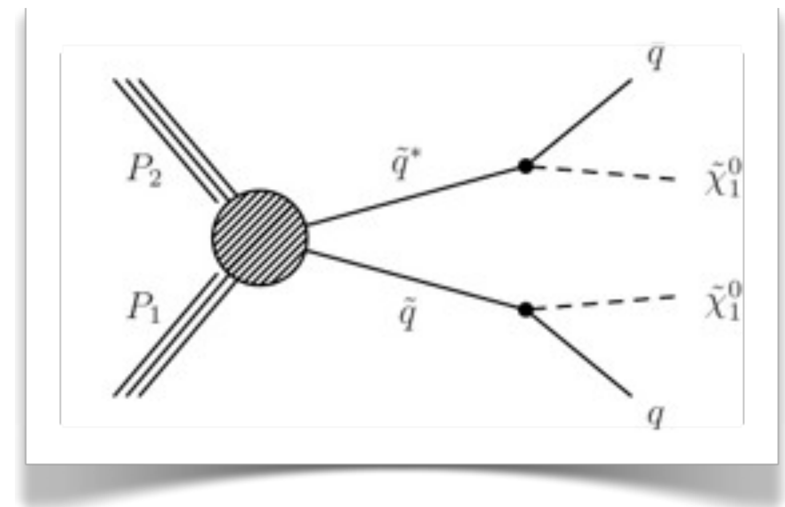




Let's compare to naive luminosity rescaling →

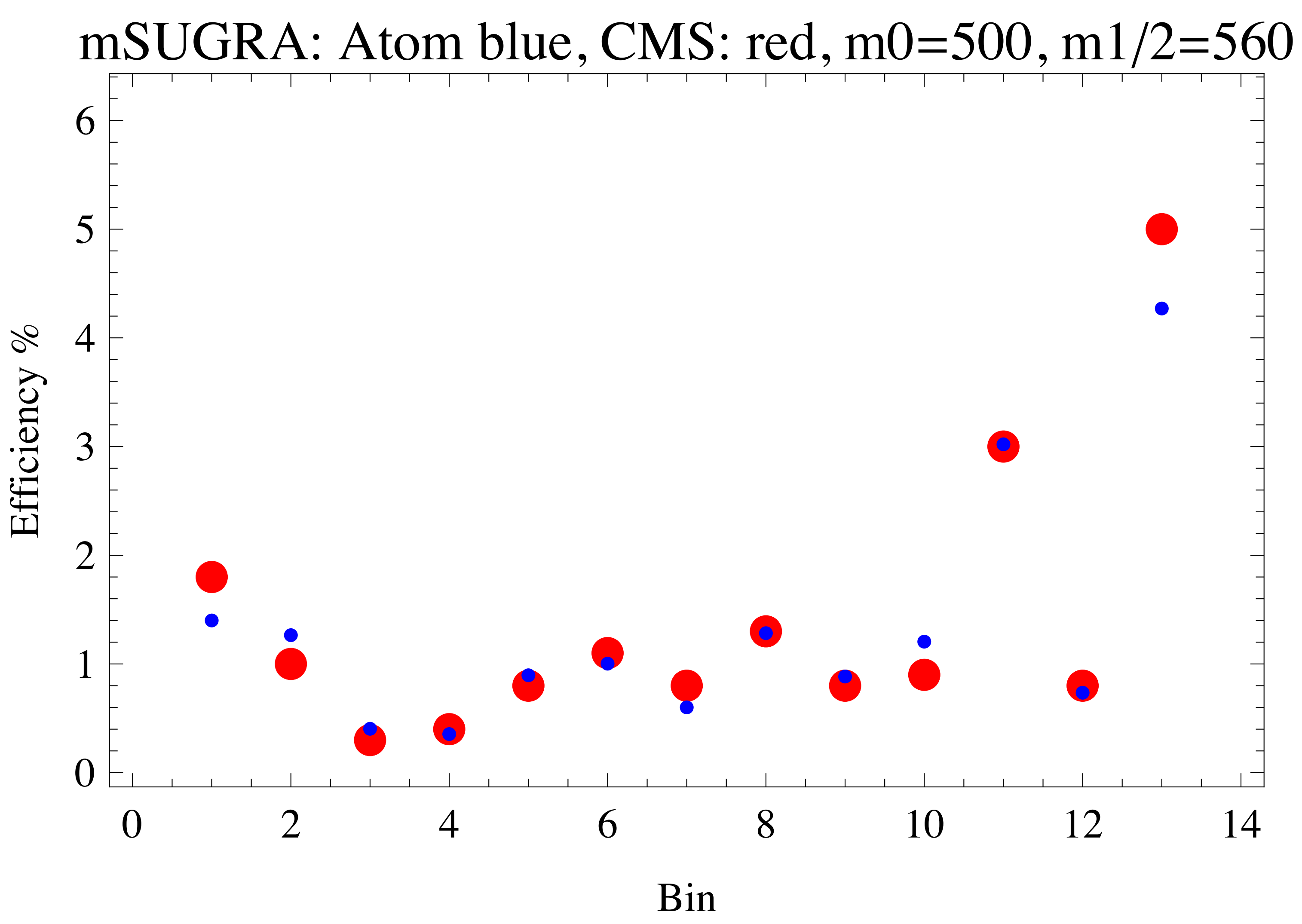


σ95 upper limit 4.7 fb−1 (CMS − Razor) / σ95 upper limit 1.14 fb−1 (CMS − αT)
1/√Lumiratio ≈ 1/√5
light squarks
mLSP = 50 GeV
0.0
0.1
0.2
0.3
0.4
0.5
400
600
800
1000
1200
msquark[GeV]



P2
P1
q̃*
q̃
q
q
χ̃10
χ̃10

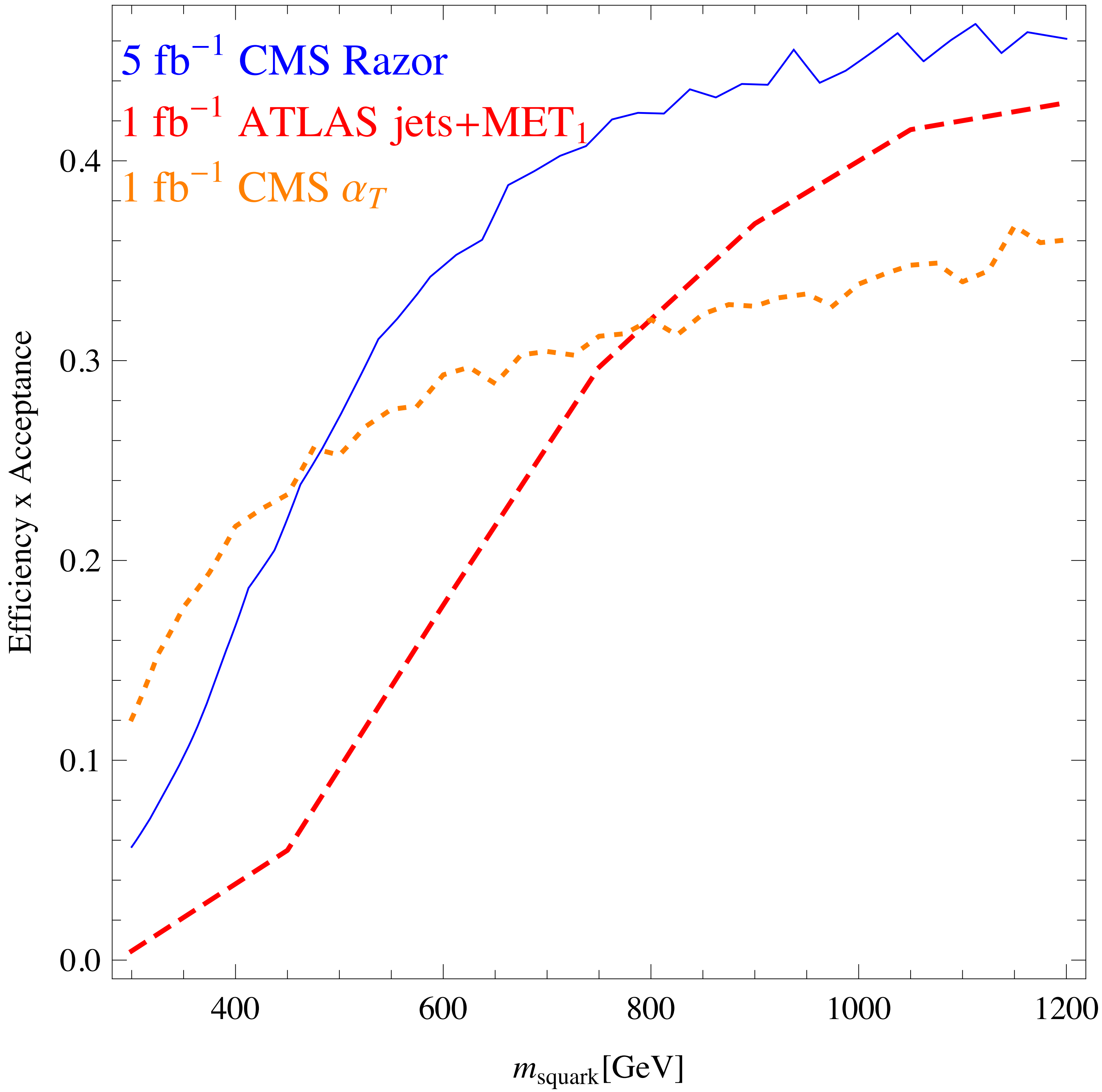
- Limited efficiency maps available for 5 fb^{-1} searches. Currently simulate and validate using Monte-Carlo mockups to check limits (ATOM & pgs)
- Associated prod' of squarks of different mass important in various cases (b/c of efficiency behavior) → need to simulate also for 1/fb, cannot use Prospino NLO out-of-the-box for xsecs



Validation - comparison of efficiencies (13 signal bins)

Summary

- Squarks spectra can be vertically and horizontally split.
- Limits for 1st gen' squarks (sea squarks) strongly dependent on gluino mass.
- Valence squarks can still be ~ 400 GeV.
- Message to experimentalists: keep an eye on lighter squarks with smaller x-secs, keep softer signal bins around.



5 fb^{-1} CMS Razor
1 fb^{-1} ATLAS jets+MET$_1$
1 fb^{-1} CMS α_T
Efficiency x Acceptance
0.0
0.1
0.2
0.3
0.4
400
600
800
1000
1200
m_{squark}[GeV]