Post-LHC RPV SUSY

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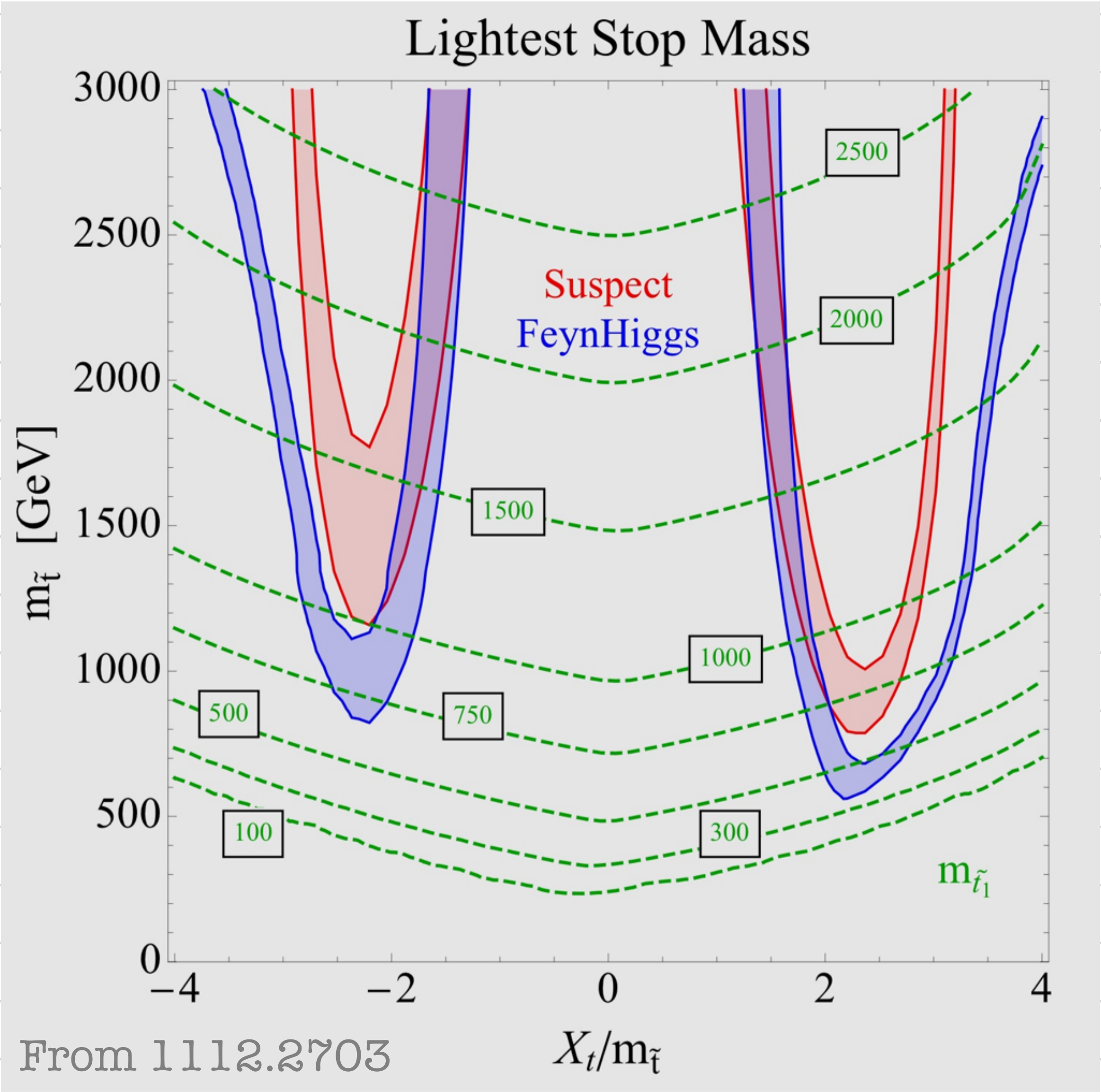
- ArXiv:1301.3637 with R. Mohapatra
- ArXiv:1212.3622 with R. Torre

125 GeV BOSON DISCOVERY AND SUSY

$m_h = 125$ GeV $\gg m_Z$

POSSIBLE IN THE MSSM
BUT REQUIRES LARGISH SOFT MASSES

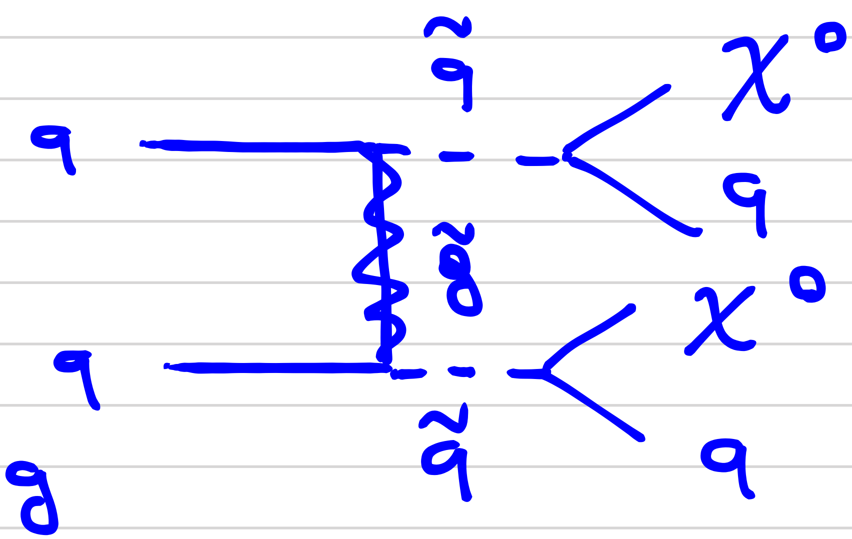


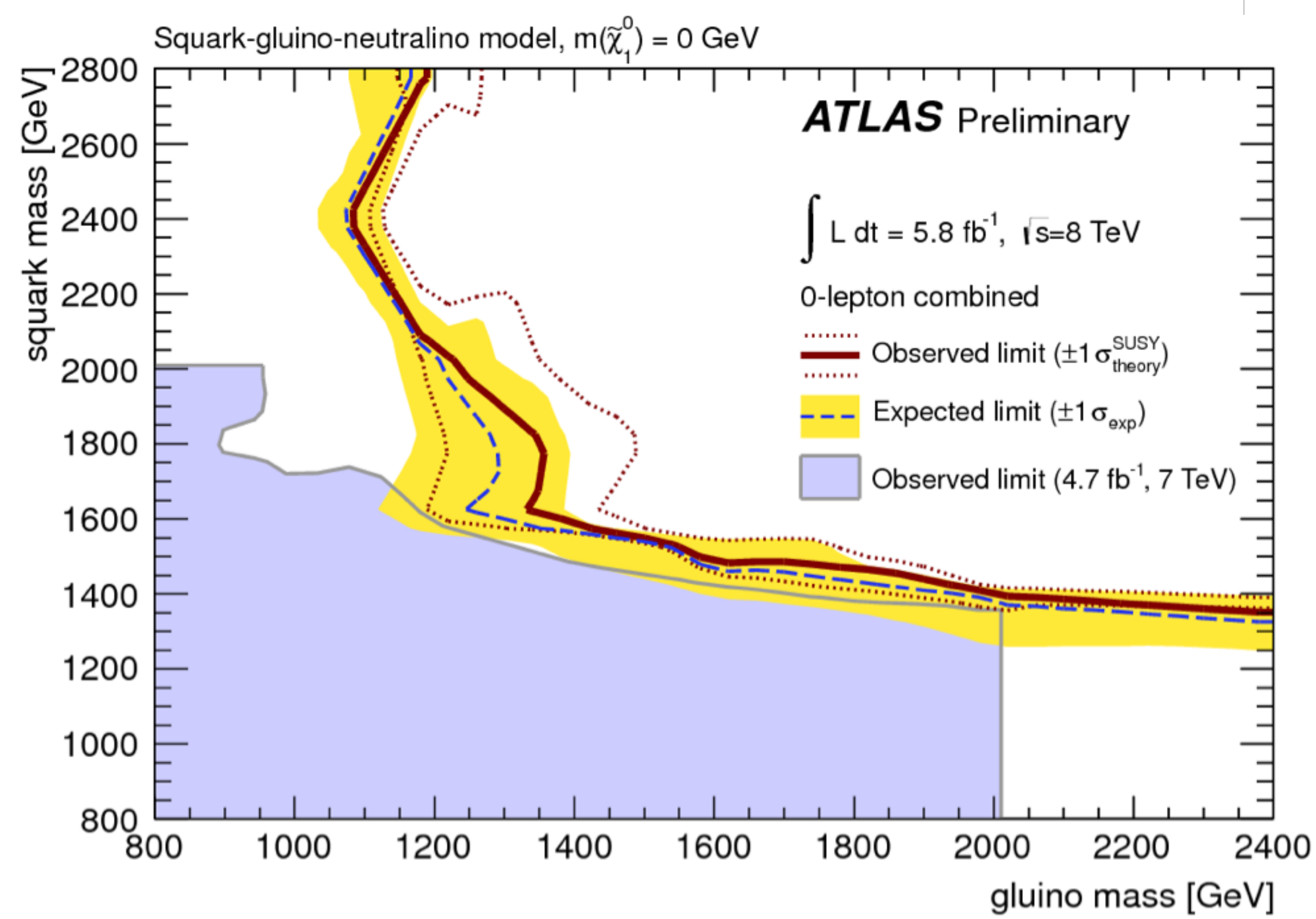
→ NON-MINIMAL MODELS

NO SIGNAL FROM SUPERPARTNERS

SEARCHES IN FINAL STATES jets + leptons + photons + $\boxed{mET}$

MISSING TRANSVERE ENERGY IS ASSUMED FROM THE PRODUCTION OF $\boxed{\text{INVISIBLE } \chi^0}$





$\boxed{\chi^0 \text{ IS THE DM CANDIDATE}}$

$M_{SUSY} > TeV$

SUSY ALTERNATIVES : DIRAC GLUINO

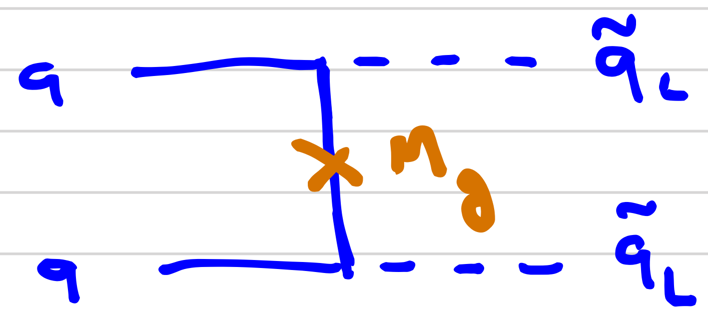
GIVE MASS TO THE GAUGINOS INTRODUCING A_i DIRAC PARTNER

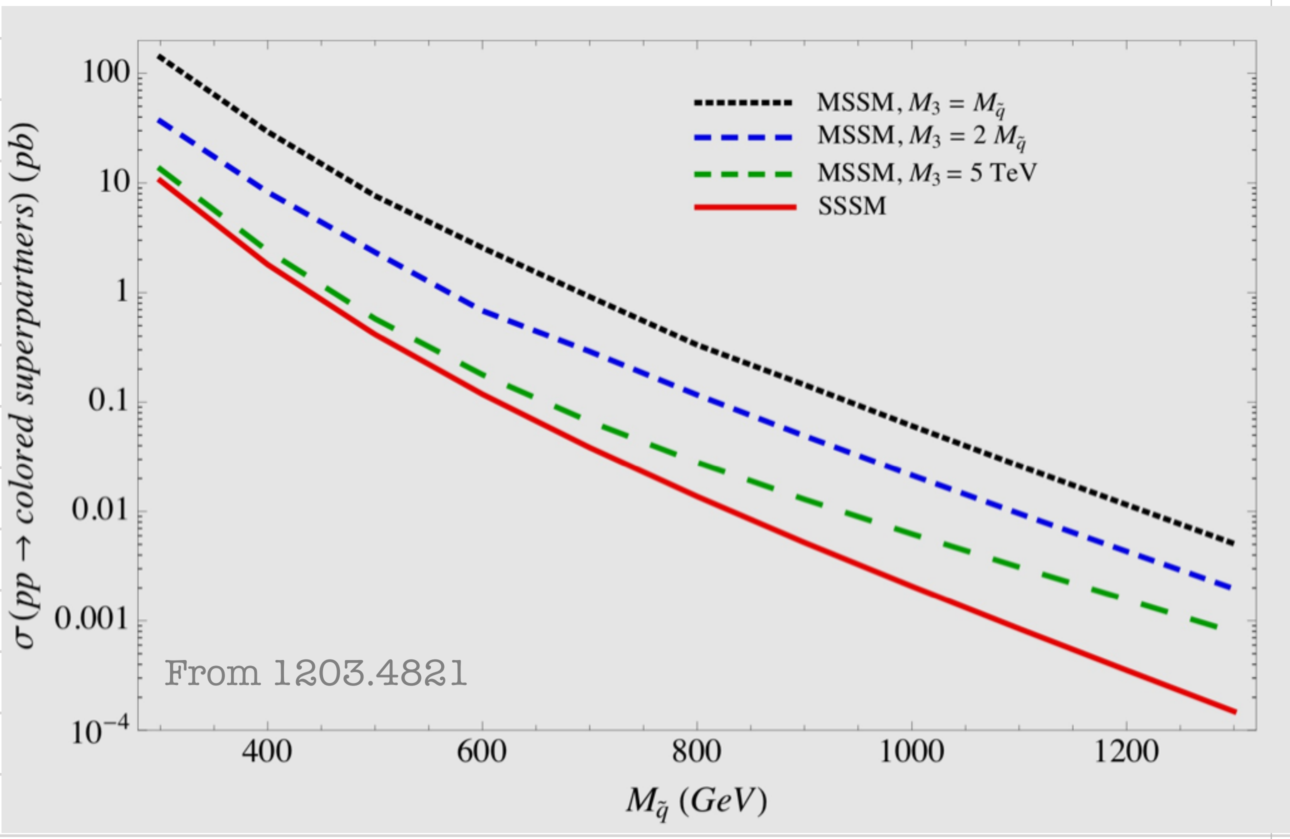
$$\int d^2\theta \, \frac{1}{M} A_i W'_{i,\alpha} W^\alpha \longrightarrow m_D A_i \tilde{\lambda}_i \qquad m_D \sim \frac{D}{M}$$

- DIRAC GLUINO

$$pp \rightarrow \tilde{q}_L \tilde{q}_L \,,\, \tilde{q}_R \tilde{q}_R \,,\, \tilde{q}_L \tilde{q}_R$$

AT HIGH $m_{\tilde{q}}$ $\quad qq \rightarrow \tilde{q}\tilde{q}$





GAUGINO PARTNERS PHENOMENOLOGY $\qquad A_3 \longrightarrow jj$

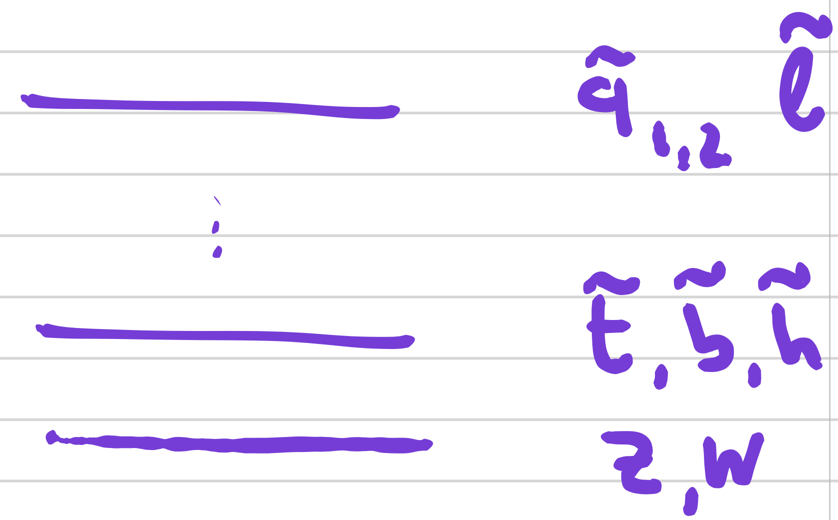
SUSY ALTERNATIVES: EFFECTIVE SUSY

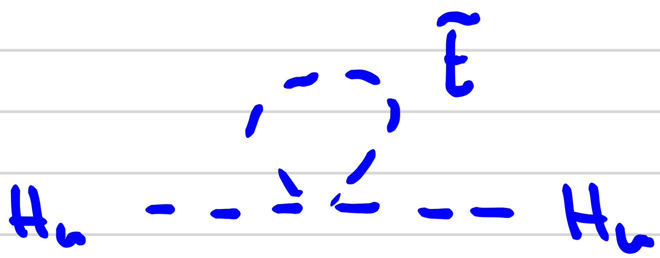
- "NATURAL" SUSY

  ONLY FEW SUPER PARTNERS

  $\tilde{t}, \tilde{b}, \tilde{g}, \tilde{h}$ ARE CRUCIAL

  TO STABILIZE THE WEAK SCALE





$$\delta m^2_{H_u} \propto \frac{1}{16\pi^2} y_t^2 \, m^2_{\tilde{t}}$$

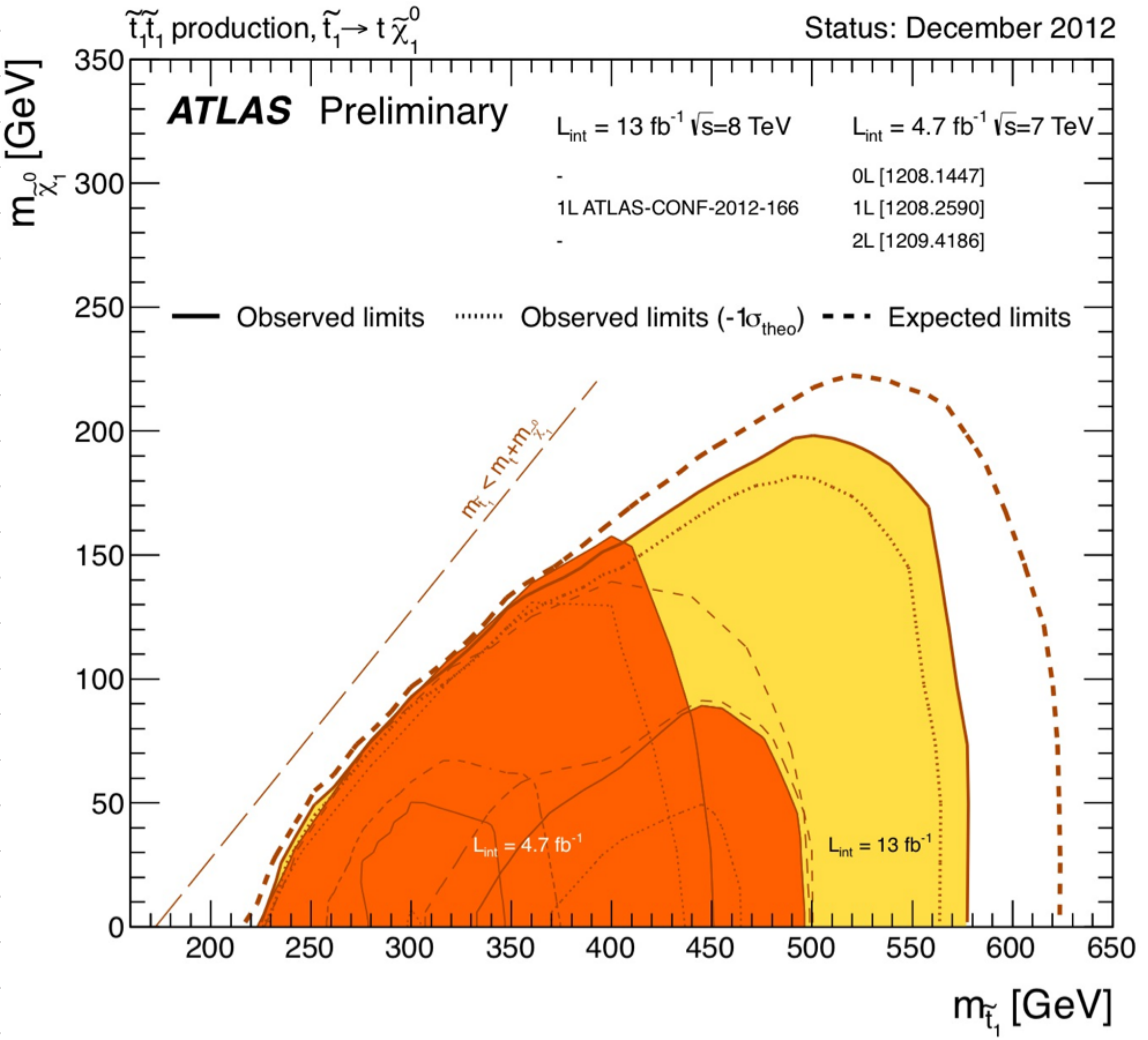
EXPERIMENTAL CHALLENGE

SEARCHES ARE MORE DIFFICULT

HEAVY FLAVOR FINAL STATES

LARGER MULTIPLICITIES, SOFTER OBJECTS

CHALLENGE ACCEPTED!



SUSY ALTERNATIVES: COMPRESSED/STEALTH

REDUCE THE AMOUNT OF MET

- LARGER MULTIPLICITY

1212.1456,1302.1870

- MORE DEGENERATE INVISIBLE PARTICLES $m_{\tilde{\psi}} = m_{\psi} + m_{\chi}$

OR $m_{\tilde{\psi}} = m_{\psi}$ if $m_{\chi} = 0$

ZERO MOMENTUM IN THE χ^0

SUSY ALTERNATIVES: R-PARITY VIOLATION

GAUGE INVARIANCE ALLOWS NEW YUKAWA INTERACTIONS

$$W_{RPV} = \lambda'' u^c d^c d^c + \lambda' Q L d^c + \lambda L L e^c + \mu' L H_u$$

- ALL THE MASSIVE SUSY PARTICLES DECAY INTO SM STATES

- NO BSM SOURCE OF mET

MUCH WEAKER LIMITS.

1211.4025; 1202.6616; 1302.2146;1209.0764,1212.1446,1307.1355

PAIR PROD.

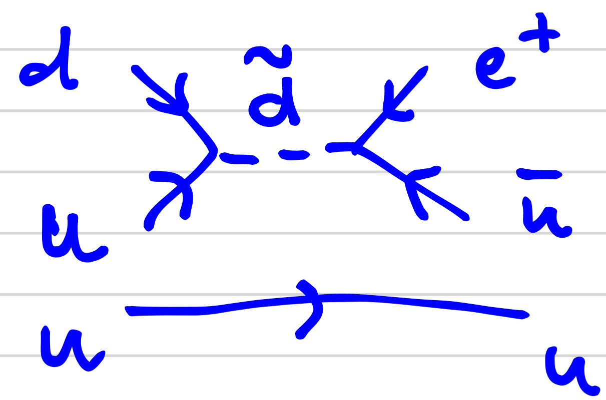
$$\begin{cases} \tilde{g} \to jjj \\ \tilde{g} \to Q\tilde{Q} \to \ell^+\ell^+ + X,\ \ell^-\ell^+ + X,\ \ell + \text{jets},\ \ell + b + \text{jets} \\ \tilde{q} \to jj \end{cases}$$

AT THIS STAGE ALL THESE OPTIONS
ARE WORTH BEING CONSIDERED

WHY NOT RPV

$$W_{RPV} = \lambda'' u^c d^c d^c + \lambda' Q L d^c + \lambda L L e^c + \mu' L H_u$$

- LEPTONIC & BARYONIC NUMBER VIOLATION
- PROTON DECAY $\lambda'' \lambda' < 10^{-24}$



- WIMP DARK MATTER IS NO LONGER STABLE
- UNIFICATION IS HARDER TO ACHIEVE $W_{RPV} = 10\,\bar{5}\,\bar{5}$

hep-ph/9704339
1305.7034

- VERY SMALL COUPLINGS

R-PARITY IS NOT BARYON NUMBER

- PROTON DECAYS VIA HIGHER DIM OPERATORS

$W^{(5)} = \frac{1}{M} u^c u^c d^c e^c$ MEDIATES PROTON DECAY TOO FAST EVEN FOR $M \sim M_{GUT}$

IN LOW-SCALE MODELS R-PARITY IS NOT ENOUGH

"EFFECTIVE" SUSY

TYPICALLY INVOLVES LOW-SCALES OF SUSY MEDIATION

$\Downarrow$

PROTON DECAY BECOMES A UV ISSUE

WHY RPV?

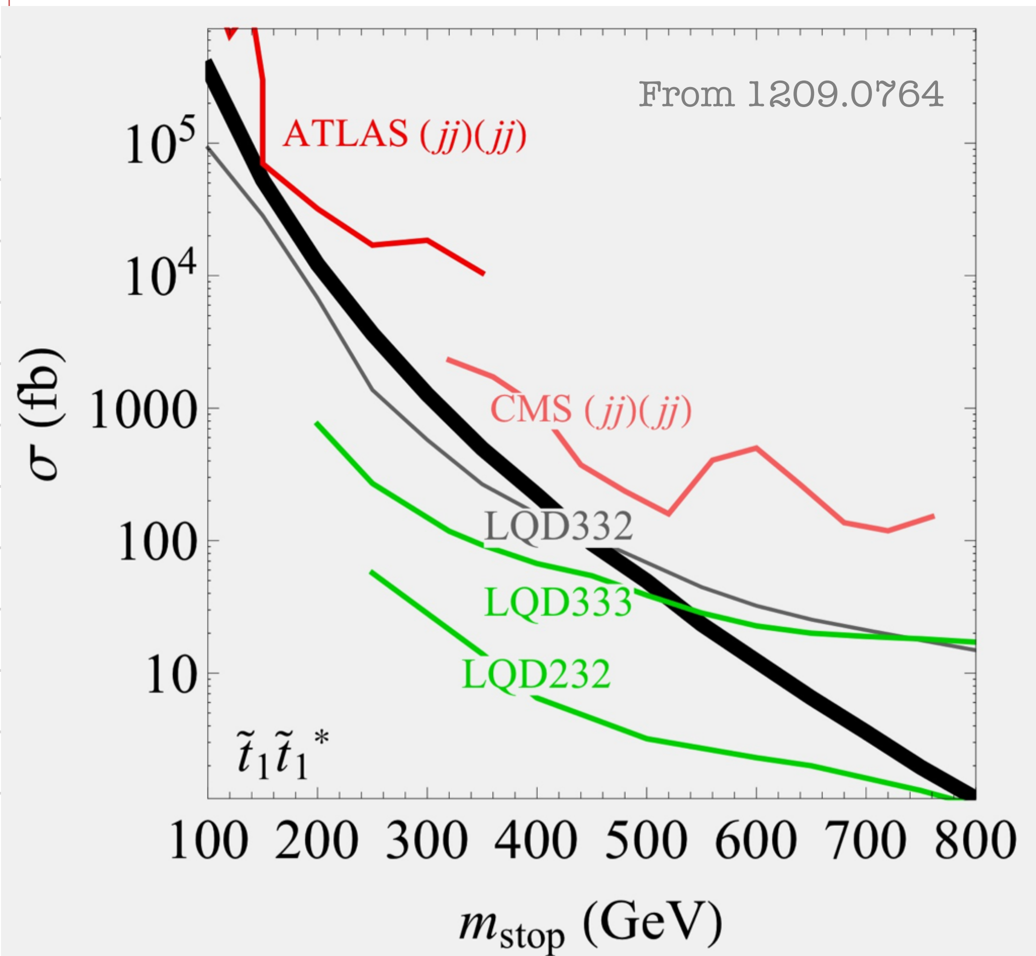
PHENOMENOLOGY IS DISTINCT: REDUCED MISSING ENERGY

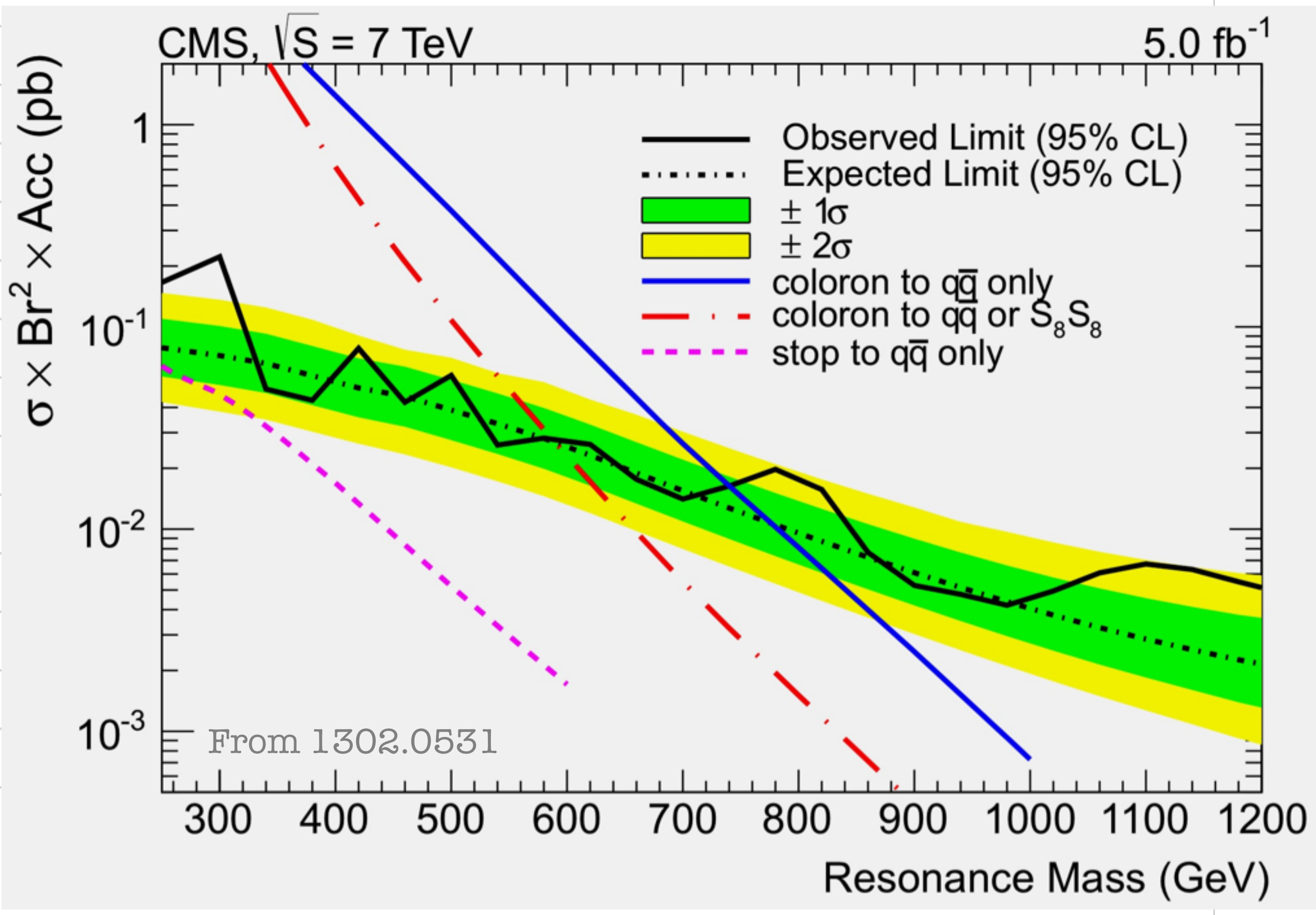
RESONANCES $\tilde{g} \to jjj$, $\tilde{q} \to jj$

META-STABLE, MESINO-OSCILLATION

NATURAL SUSY: RPV LESS CONSTRAINED THAN RPC

DI-JET PAIR PRODUCTION: LIMITS





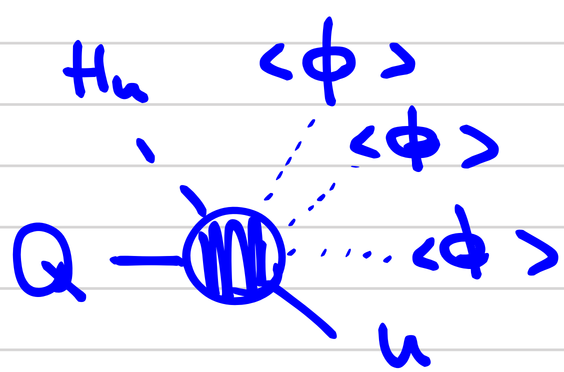
STILL THE FLAVOR STRUCTURE
AND THE SIZE OF THE COUPLINGS
LOOKS AD-HOC

GAUGED FLAVOR SYMMETRIES

- THE YUKAWA COUPLINGS OF THE SM BREAK A LARGE SYMMETRY

  $SU(3)_{Q,L,u,d,e,\nu}$

- THE PATTERN OF YUKAWAS/MASSES/MIXING IS EXPLAINED BY A GAUGED FLAVOR SYMMETRY



$$y_{SM} \sim \frac{\langle\phi\rangle^n}{M^n}$$

- FLAVOR GAUGE BOSONS HAVE MASS $m_\rho \sim \langle\phi\rangle \sim y_{SM}$

$$\frac{1}{m_\rho^2}\bar{\psi}_a\psi_b\bar{\psi}_c\psi_d \qquad \text{FCNC} \sim \frac{1}{m_\rho^2} \sim \frac{1}{m_{light}}$$

$$m_\rho > 10^5\ \text{TeV}$$

SUSY of Grinstein, Redi, Villadoro

Berezhiani '83, '85
1009.2049

FLAVOR DYNAMICS CAN BE AT A MUCH LOWER SCALE IF

$$m_{light} \sim \frac{1}{M_{heavy}} \sim \frac{1}{m_\rho}$$

"seesaw-like"

MSSM FIELDS: $Q, L, u^c, d^c, e^c, \nu^c$

FLAVOR GROUP: $SU(3)_{Q, L, u^c, d^c, e^c, \nu^c}$

EXOTIC FIELDS: U, U^c, D, D^c (TO CANCEL FLAVOR ANOMALIES)

- EACH MSSM FIELD IS A FUNDAMENTAL OF HIS OWN SU(3)
- $U^c, D^c \sim 3^*\ SU(3)_Q$ $\qquad$ $U, D \sim 3\ SU(3)_{u^c, d^c}$

$\boxed{W^{MSSM}_{RPV}}$ is FORBIDDEN BY THE FLAVOR SYMMETRY

$$W^{EXO}_{RPV} = \tilde{\lambda}'' U^c D^c D^c$$

1212.4860

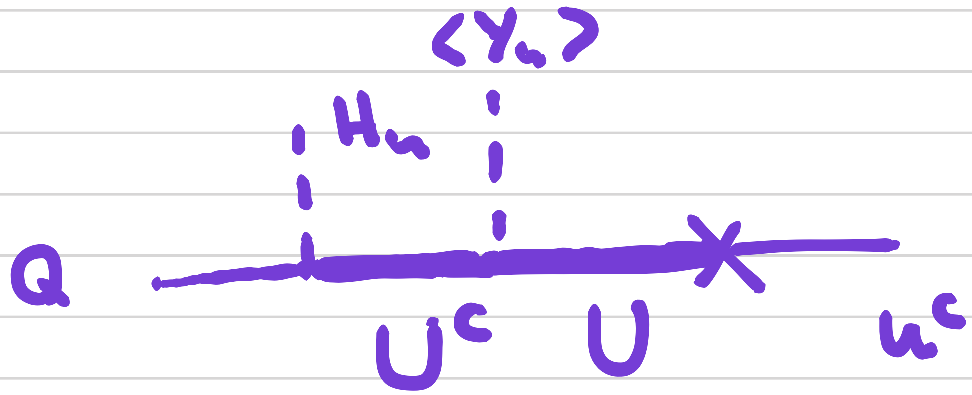
$W = \lambda'_u U U^c Y_u + \mu_u U u^c + \lambda_u Q H_u U^c$

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$SU(3)_Q$	$SU(3)_{u^c}$	$SU(3)_{d^c}$	$SU(3)_L$	$SU(3)_{e^c}$	$SU(3)_{\nu^c}$
Q	3	2	$\frac{1}{3}$	3					
u^c	3^*		$-\frac{4}{3}$		3^*				
d^c	3^*		$\frac{2}{3}$			3^*			
U	3		$\frac{4}{3}$		3				
U^c	3^*		$-\frac{4}{3}$	3^*					
D	3		$-\frac{2}{3}$			3			
D^c	3^*		$\frac{2}{3}$	3^*					
L		2	-1				3		
e^c			2					3^*	
ν^c			0						3^*
E			-2					3	
E^c			2				3^*		
N			0						3
N^c			0				3^*		
H_u		2	1						
H_d		2	-1						
Y_u				3	3^*				
$\bar{Y}_u$				3^*	3				
Y_d				3		3^*			
$\bar{Y}_d$				3^*		3			
Y_ℓ							3	3^*	
$\bar{Y}_\ell$							3^*	3	
Y_ν							3		3^*
$\bar{Y}_\nu$							3^*		3

ANOMALY FREE

$$W = \lambda'_u U U^c Y_u + \mu_u U u^c + \lambda_u Q H_u U^c$$

KRNJAIC, STOLARSKI
1212.4860



$$\mathcal{M}_u = \begin{pmatrix} 0 & \mu_u \\ \lambda_u v & \lambda'_u \langle Y_u \rangle \end{pmatrix}$$

$$\theta_R = \frac{\mu_u}{\lambda'_u \langle Y_u \rangle} \sim \frac{1}{\lambda_u} \frac{m_{SM}}{v}$$

FLAVOR BLIND $\underline{\mu_u}, \lambda_u, \lambda'_u$

$$W^{EFF}_{RPV} = \tilde{\lambda}'' U^c D^c D^c \rightarrow \lambda'' u^c d^c d^c$$

$$Y_{SM} \sim \frac{\lambda_u \mu_u}{\lambda'_u \langle Y_u \rangle}$$

$$\lambda''_{ijk} \sim V^{ckm}_{il} \frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \epsilon_{ljk}$$

HIERARCHY OF SM YUKAWAS FROM INVERSE HIERARCHY OF MASSES OF FLAVOR BOSONS

HIERARCHY OF RPV COUPLINGS FROM HIERARCHY OF SM FERMIONS MASSES

$$\lambda''_{ijk} \sim V^{*}_{il} \frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \epsilon_{ljk}$$

	bs	bd	ds
t	1.46×10^{-7}	3.97×10^{-8}	2.05×10^{-8}
c	1.76×10^{-8}	4.8×10^{-9}	5.81×10^{-12}
u	2.4×10^{-10}	3.17×10^{-12}	3.83×10^{-15}

KRNJAIC, STOLARSKI 1212.4860

Csáki et al 1111.1235

- RPV COUPLINGS ARE PREDICTED

  UP TO AN OVERALL FACTOR

  (RATIO OF COUPLINGS AND $SU(2)_W$ VEVs)

  VERY SMALL COUPLINGS FROM THE SMALL MIXINGS BETWEEN MSSM AND THE RPV SECTOR

- FLAVOR DYNAMICS CAN BE LOW-SCALE

  FLAVOR PARTNERS OF THE TOP ARE THE LIGHTEST

- λ' QLD RPV CANNOT BE GENERATED

  Q AND L ARE CHARGED UNDER DIFFERENT GROUPS

PARTIAL COMPOSITENESS + SUSY

1205.5803
KEREN-ZUR et al

$$\lambda_i \psi_i^{sm} O_i \qquad \psi_{sm} \text{———} O_i$$

O_i OF DIMENSION $\Delta_i = \frac{5}{2} + \delta_i$

$$\lambda_i = g_\rho \underline{\epsilon_i} = \lambda_i(\Lambda_{UV}) \left(\frac{m_\rho}{\Lambda_{UV}}\right)^{\delta_i}$$

$$\boxed{Y_{ij} \sim \epsilon_{Q_i} \epsilon_{u_j}}$$

- NEARLY MARGINAL INTERACTIONS GENERATE THE LARGE MASSES (m_{top})
- TO REPRODUCE CKM $\frac{\epsilon_{Q_1}}{\epsilon_{Q_2}} \sim \lambda \qquad \frac{\epsilon_{Q_2}}{\epsilon_{Q_3}} \sim \lambda^2$

$$O_{u^c} O_{u^c} O_{d^c} \xrightarrow{\text{mixing}} \lambda'' u^c d^c d^c$$

$$\boxed{\lambda''_{ijk} \sim \epsilon_{u_i} \epsilon_{d_j} \epsilon_{d_k} \sim \frac{\epsilon_{q_3}}{\epsilon_{q_i}} \frac{\epsilon_{q_3}}{\epsilon_{q_j}} \frac{\epsilon_{q_3}}{\epsilon_{q_k}} (\epsilon_{u_3})^3 \frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3}}$$

RF, MOHAPATRA 2013

SO FAR

$$\lambda_{BNV}\, u_i^c d_j^c d_k^c \sim \frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3}$$

ALTHOUGH DIFFERENT CKM STRUCTURES

IS THIS ALL THAT ONE CAN DO ?

THE TWO MODELS HAVE VERY SIMILAR LSP PHENO

$$\boxed{BR(\tilde{t} \to bX) \simeq 99\%}$$

SUSY LEFT-RIGHT GAUGED FLAVOR

- EMBED $SU(2)\times U(1)$ IN A $SU(2)_L\times SU(2)_R\times U(1)_{B-L}$ BROKEN BY $\langle\chi\rangle$
- RIGHT-HANDED SM FIELDS IN DOUBLETS
- GAUGE THE FLAVOR GROUP

$$SU(3)_{Q_L}\times SU(3)_{Q_R}\times SU(3)_{\ell_L}\times SU(3)_{\ell_R}$$

	$SU(3)_c$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$	$SU(3)_{Q_L}$	$SU(3)_{Q_R}$	$SU(3)_{\ell_L}$	$SU(3)_{\ell_R}$
Q	3	2		$\frac{1}{3}$	3			
Q^c	3^*		2	$-\frac{1}{3}$		3^*		
U	3			$\frac{4}{3}$		3		
U^c	3^*			$-\frac{4}{3}$	3^*			
D	3			$-\frac{2}{3}$		3		
D^c	3^*			$\frac{2}{3}$	3^*			
L		2		-1			3	
L^c			2	1				3^*
E				-2				3
E^c				2			3^*	
N				0				3
N^c				0			3^*	
$\chi, \bar{\chi}$		2		±1				
$\chi^c, \bar{\chi}^c$			2	±1				
Y_u					3	3^*		
$\bar{Y}_u$					3^*	3		
Y_d					3	3^*		
$\bar{Y}_d$					3^*	3		
Y_ℓ							3	3^*
$\bar{Y}_\ell$							3^*	3
Y_ν							3	3^*
$\bar{Y}_\nu$							3^*	3

ANOMALY FREE

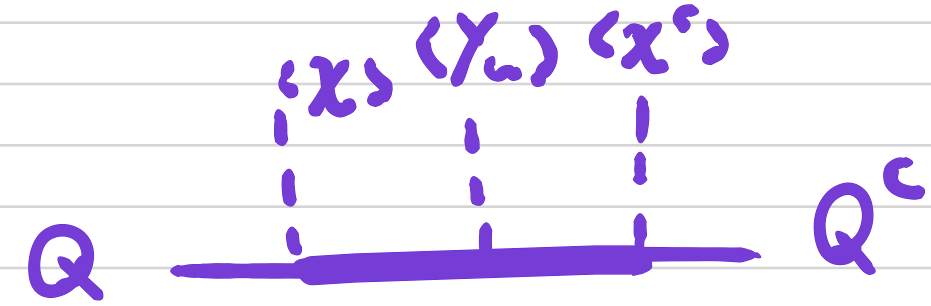
$SU(3)_{Q_L} \times SU(3)_{Q_R} \times SU(3)_{\ell_L} \times SU(3)_{\ell_R}$ L-R

$$W = \lambda_u (Q \chi U^c + Q^c \chi^c U)$$

$$+ \lambda_d (Q \bar{\chi} D^c + Q^c \bar{\chi}^c D)$$

$$+ \lambda'_u Y_u U U^c + \lambda'_d Y_d D D^c$$

NO "μ-TERMS"



$$M_d = \frac{\lambda_d^2}{\lambda'_d} \frac{v_L v_R}{\langle \hat{Y}_d \rangle} \qquad M_u = \frac{\lambda_u^2}{\lambda'_u} \frac{v_L v_R}{V_{CKM}^{\dagger} \hat{Y}_u V_{CKM}}$$

$$\theta^{u,d}_{L,R} = \frac{\lambda v_{L,R}}{\lambda' Y_{u,d}} \qquad v_L \ll v_R \ll \langle \hat{Y}_{u,d} \rangle$$

$$\theta^{u_i} \sim \frac{m_{u_i}}{m_t}$$

$$W^{EXO}_{RPV} = \tilde{\lambda}'' (UDD + U^c D^c D^c)$$

$\downarrow$ MIXING

$$W^{MSSM}_{RPV} = \lambda'' u^c d^c d^c$$

$$\lambda''_{ijk} \sim V^{CKM}_{il} \frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \epsilon_{ljk}$$

$SU(3)_{V,q} \times SU(3)_{V,\ell}$

	$SU(3)_c$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$	$SU(3)_{V,q}$	$SU(3)_{V,\ell}$
Q	3	2		$\frac{1}{3}$	3	
Q^c	3^*		2	$-\frac{1}{3}$	3^*	
U	3			$\frac{4}{3}$	3^*	
U^c	3^*			$-\frac{4}{3}$	3	
D	3			$-\frac{2}{3}$	3^*	
D^c	3^*			$\frac{2}{3}$	3	
L		2		-1		3
L^c			2	1		3^*
E				-2		3^*
E^c				2		3
N				0		3^*
N^c				0		3
$\chi, \bar{\chi}$		2		± 1		
$\chi^c, \bar{\chi}^c$			2	∓ 1		
Δ_u					6	
$\bar{\Delta}_u$					6^*	
Δ_d					6	
$\bar{\Delta}_d$					6^*	
Δ_ℓ						6
$\bar{\Delta}_\ell$						6^*
Δ_ν						6
$\bar{\Delta}_\nu$						6^*

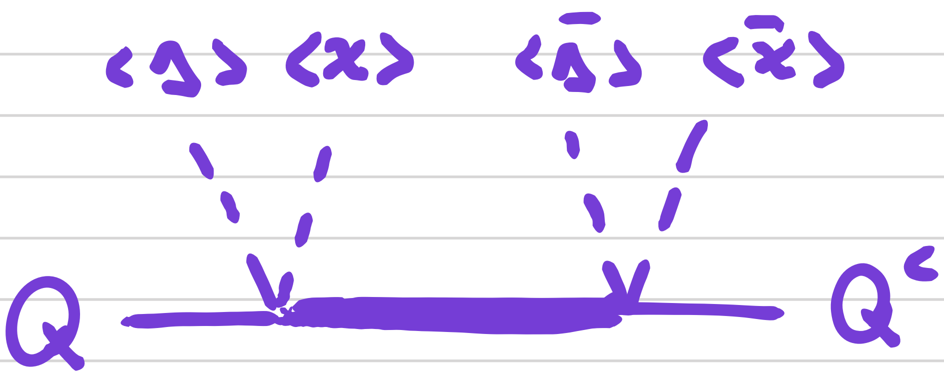
- ANOMALY FREE
- $\Delta \sim 6$ OF FLAVOR GROUP

$SU(3)_{V,q} \times SU(3)_{V,\ell}$

$$W \supset \frac{\lambda_d}{\Lambda}\left(Q \chi D^c \Delta_d + Q^c \chi^c D \bar{\Delta}_d\right) + M_D D D^c$$

MASS TERM

(WITHOUT FLAVON VEV)



$$W_{RPV}^{Exo} = \tilde{\lambda}'' \left(UDD + U^c D^c D^c\right) + \tilde{\lambda}\left(LLE^c + L^c L^c E^c\right)$$

$$m_{d,sm} \sim \frac{\lambda_d^2}{\Lambda^2} \frac{v_L v_R \langle \Delta_d \rangle^2}{M_D}$$

$$\theta_{L,R} \sim \frac{\lambda_d}{\Lambda} \frac{v_{L,R} \langle \Delta_d \rangle}{M_D} \sim \sqrt{\frac{m_{d,sm}}{v_{R,L}} \frac{v_{L,R}}{M_D}}$$

$$W_{RPV}^{MSSM} = \lambda'' u^c d^c d^c + \lambda L L e^c$$

- SEPARATE BNV, LNV

$$W_{RPV}^{MSSM} = \lambda'' u^c d^c d^c + \lambda L L e^c$$

- SEPARATE BNV, LNV
- DIFFERENT DEPENDENCE ON THE SM MASSES

$$\lambda''_{ijk} \sim V^{CKM}_{il} \left(\frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \right)^{1/2} \epsilon_{ljk}$$

$$\theta_{L,R} \sim \sqrt{\frac{m_{d,SM}}{v_{R,L}} \frac{v_{L,R}}{M_D}}$$

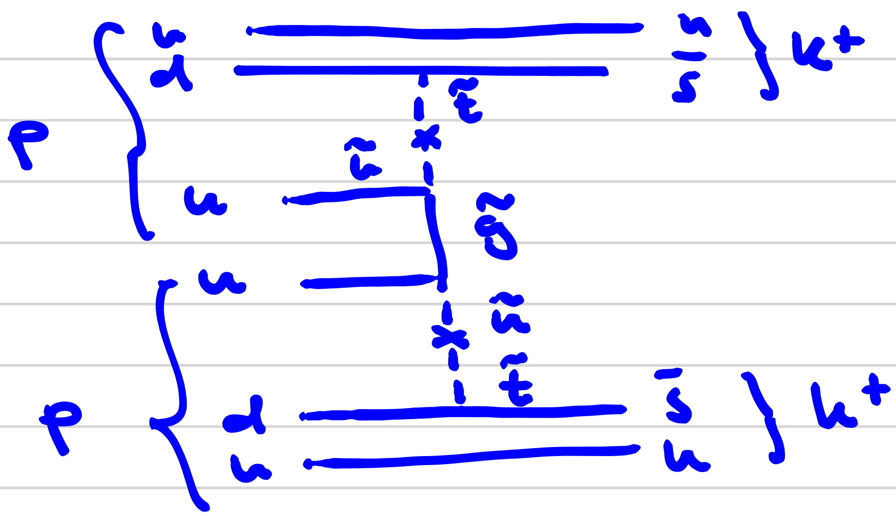
	bs	bd	ds
t	3.94×10^{-5}	4.38×10^{-5}	1.43×10^{-4}
c	6.22×10^{-5}	6.93×10^{-5}	5.3×10^{-7}
u	1.55×10^{-5}	8.35×10^{-7}	6.39×10^{-9}

MORE PROMPT DECAYS

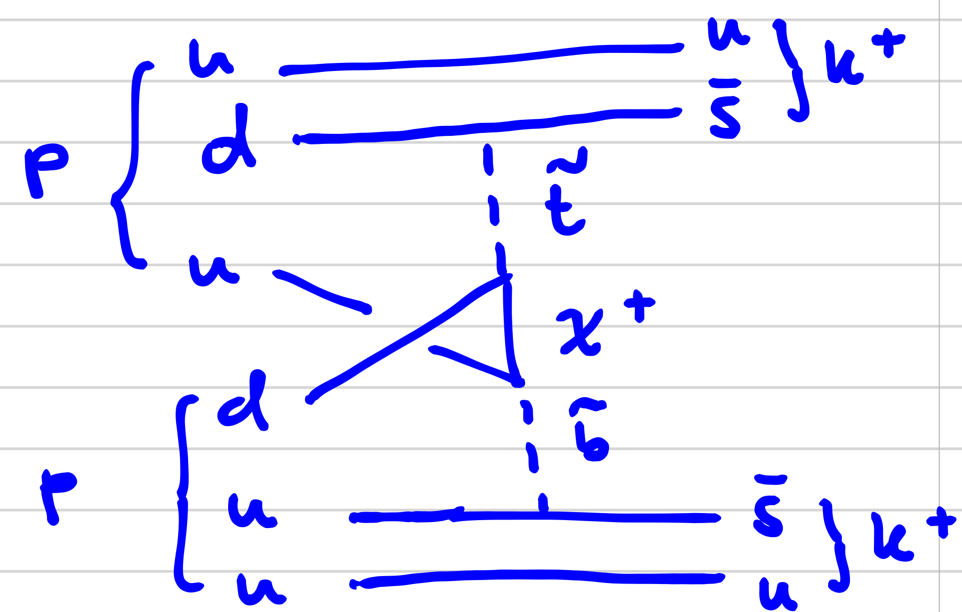
- SIMILARLY LNV $\lambda \sim \left(\frac{m_\ell}{m_t} \right)^{1/2}$
- $m_f^{SM} \sim \langle \text{FLAVON} \rangle$

"NORMAL" HIERARCHY OF FLAVOR GAUGE BOSONS

LIMITS: $pp \to K^+K^+$ $\quad \tau > 1.7 \times 10^{32}$ years



$+$ $\quad \tilde{t} \to \tilde{u}$ $\quad +$



SQUARK FV $\qquad$ FLAVOR CONSERVING

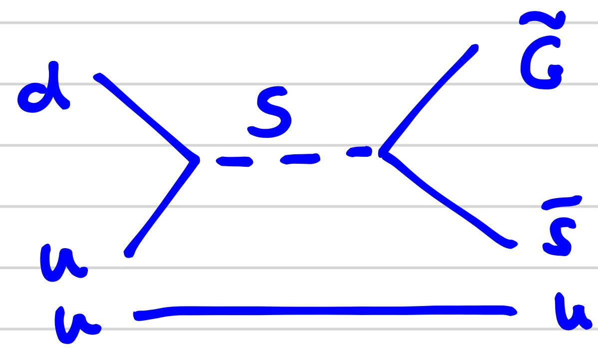
$$A_{FC} \sim \frac{1}{m_{\tilde{g}}}\left(\frac{1}{m_{\tilde{q}}}\right)^4 \left(\frac{m_u m_d m_s}{m_s}\right)^{\mu} V_{td}^2 \qquad \boxed{\mu = 1 \text{ or } 2}$$

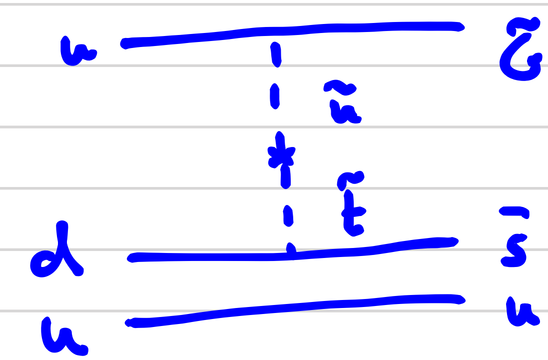
$$\tau_{pp\to KK}(\mu=1) \sim 10^{34}\,y$$

$n-\bar{n}$

proton decay $\quad p \to K^+ \nu \quad \tau > 10^{33}\,y$

$p \to K^+ \tilde{G}$





$$A_{FV} \sim \frac{1}{m_{\tilde{q}}^2} \frac{1}{m_{3/2} M_{pl}} V_{td} \left(\frac{m_d m_s}{m_t} \right)^{\mu} \delta_{13}$$

$$\tau \sim 10^{33} y \left(\frac{m_{3/2}}{\mathrm{keV}} \frac{0.01}{\delta_{13}} \right)^2 \qquad \mu = 2$$

$$\tau \sim 10^{33} y \left(\frac{m_{3/2}}{\mathrm{MeV}} \frac{0.01}{\delta_{13}} \right)^2 \qquad \mu = 1$$

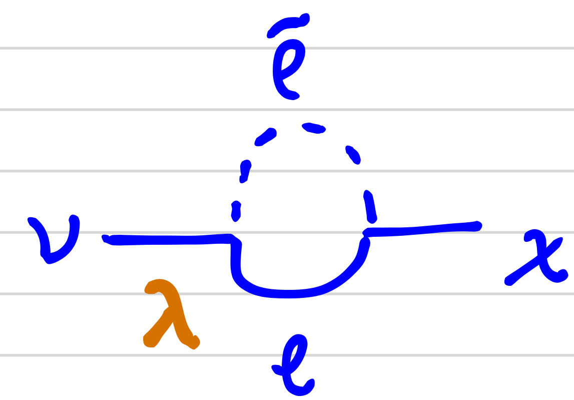
proton decay $\quad p \to K^+ \nu \quad \tau > 10^{33}$ y

$p \to K^+ \nu$

$$W^{MSSM}_{RPV} \supset \lambda_{ijk} L_i L_j e^c_k$$

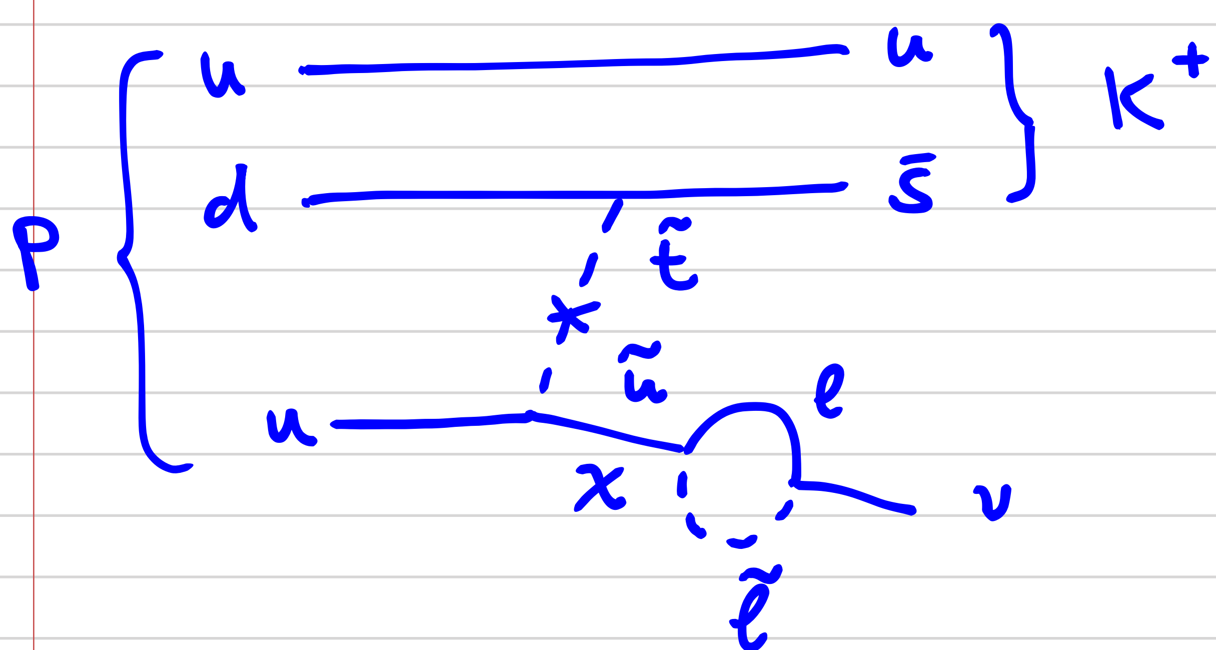
$$\lambda \sim \frac{m_{e_k}}{m_t}$$

IN THE MODEL $SU(3)_{V,q} \times SU(3)_{V,\ell}$



LNV GIVES $\nu - \chi^0$ MIXING

1302.0004



$$A \sim \frac{\lambda}{16\pi^2}\delta_{13} V_{tb}\left(\frac{m_d m_s}{m_t^2}\right)^{1/2}\frac{1}{m_{\tilde{q}}^2 m_\chi}$$

- THE RPV FLAVOR STRUCTURE IS PREDICTED IN TERMS OF SM MASS RATIOS AND CKM

$$\lambda''_{ijk} \sim V^{ckm}_{il} \left(\frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \right)^{\mu} \epsilon_{ljk}$$

- AN OVERALL FACTOR IS TYPICALLY NOT FIXED

$\mu = 1$ $\quad Br(\tilde{t} \to bd + bs) \simeq \underline{99\%}$ $\quad SU(3)_{Q,L,d,u,e,\nu}$

$SU(3)_{Q,Q^c,L,L^c}$

PARTIAL COMPOSITENESS

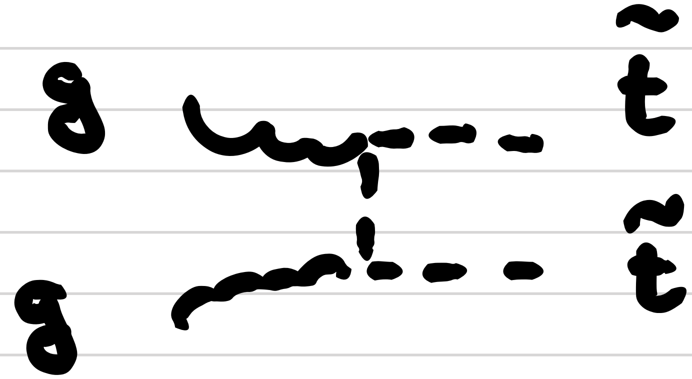
$\mu = 1/2$ $\quad Br(\tilde{t} \to bd + bs) \simeq \underline{14\%}$ $\quad SU(3)_{V,q,e}$

DECAY RATES IN HEAVY FLAVOR OF THE STOP/SBOTTOM LSP

$pp \to \tilde{t}\tilde{t} \to$ jets

RF, TORRE 2012

TeVatron + LEP $m_{\tilde{t}} > 100$ GeV



$\tilde{t} \to jj$

CHALLENGING ESPECIALLY FOR LIGHT $\tilde{t}$

- IN GENERAL FULLY HADRONIC SIGNALS HAVE LARGE BACKGROUNDS FROM

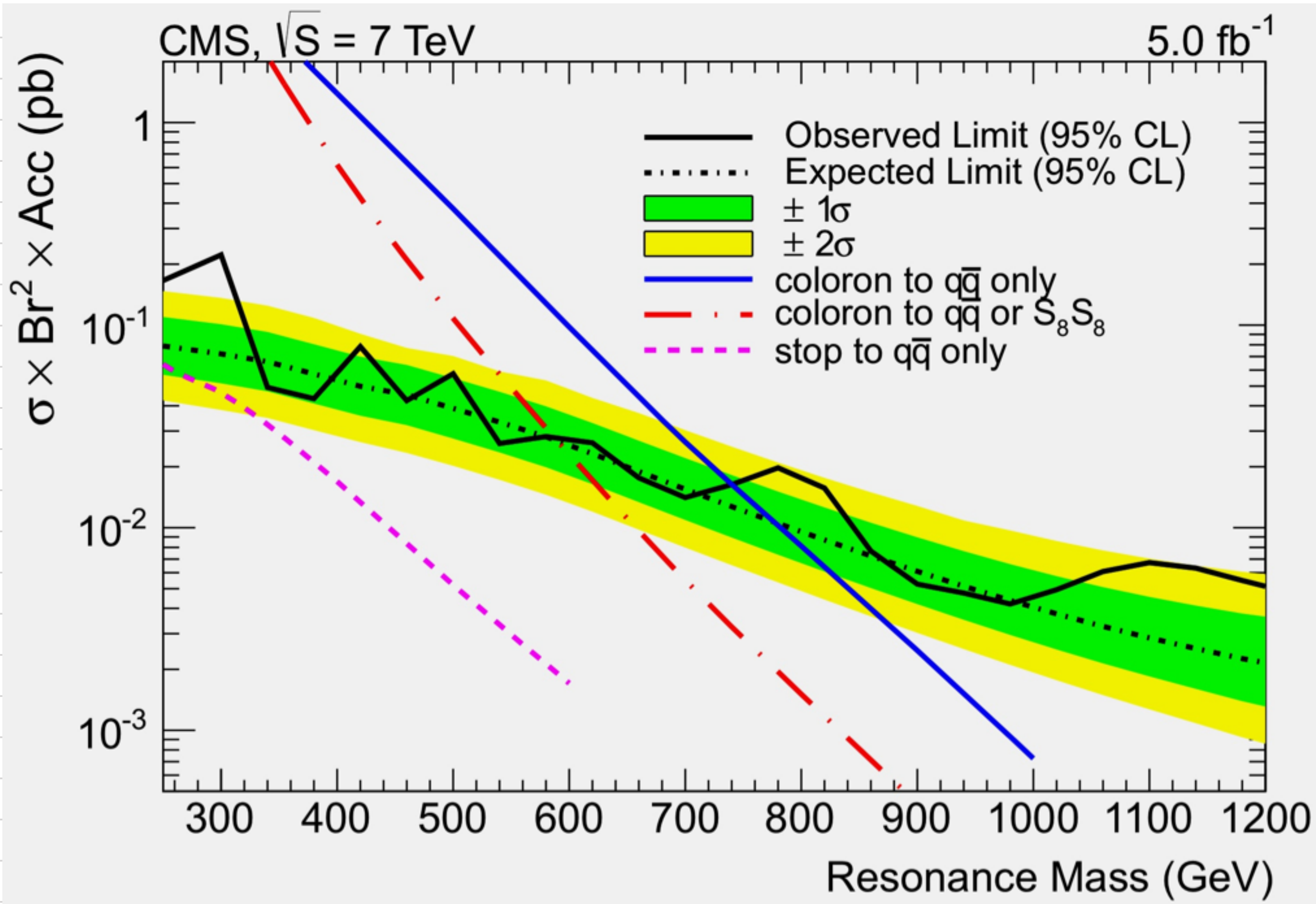
QCD MULTI-JET BACKGROUND

- EVEN TRIGGERING IS AN ISSUE

4 jet $p_T > 85$ GeV @ LHC 8
4 jet $p_T > 45$ GeV "parked"
b-Trigger

- $t \to bq$ $q = d, s$

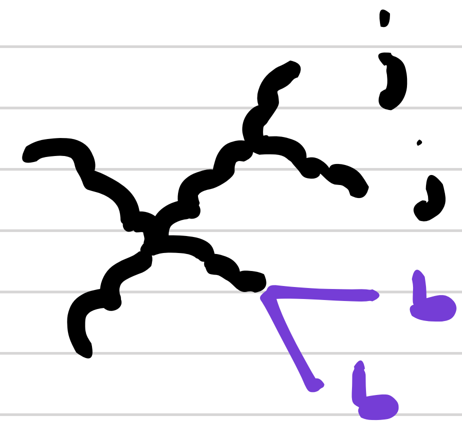
PROVIDES EXTRA HANDLES B-TAG (TRIGGER & ANALYSIS)



CMS, $\sqrt{S}$ = 7 TeV
5.0 fb^{-1}
Observed Limit (95% CL)
Expected Limit (95% CL)
± 1σ
± 2σ
coloron to $q\bar{q}$ only
coloron to $q\bar{q}$ or S_8S_8
stop to $q\bar{q}$ only
$\sigma \times Br^2 \times Acc$ (pb)
Resonance Mass (GeV)
1
10^{-1}
10^{-2}
10^{-3}
300
400
500
600
700
800
900
1000
1100
1200

- $pp \to \tilde{t}\tilde{t} \to bbqq$

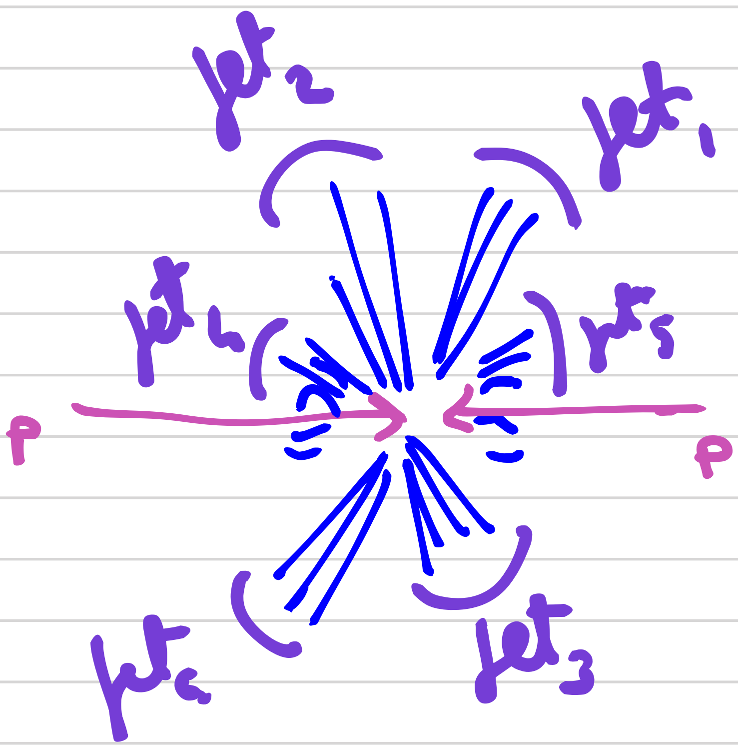
  b-tag $\epsilon \sim 66\%$ $\phi < 10^{-2}$



- $pp \to$ jets QCD $\epsilon \ll 1$ BECAUSE ONE FLAVOR

- $pp \to t\bar{t} \to bbqqqq$

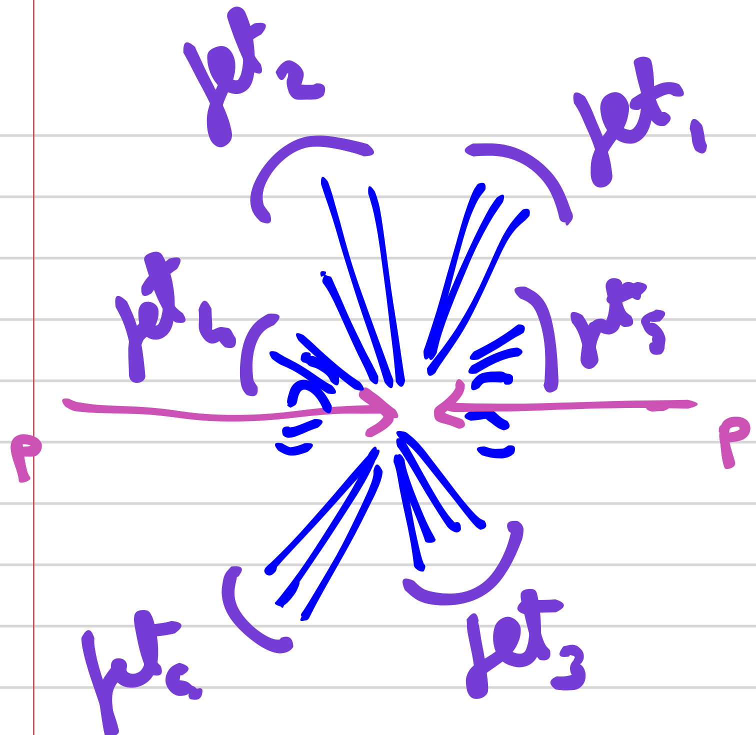
- DOUBLE RESONANCE STRUCTURE



$\tilde{t} = \text{jet}_k \, \text{jet}_i$

$\tilde{t} = \text{jet}_p \, \text{jet}_q$

- IDENTIFICATION OF THE CANDIDATE RESONANCE $\tilde{t}$

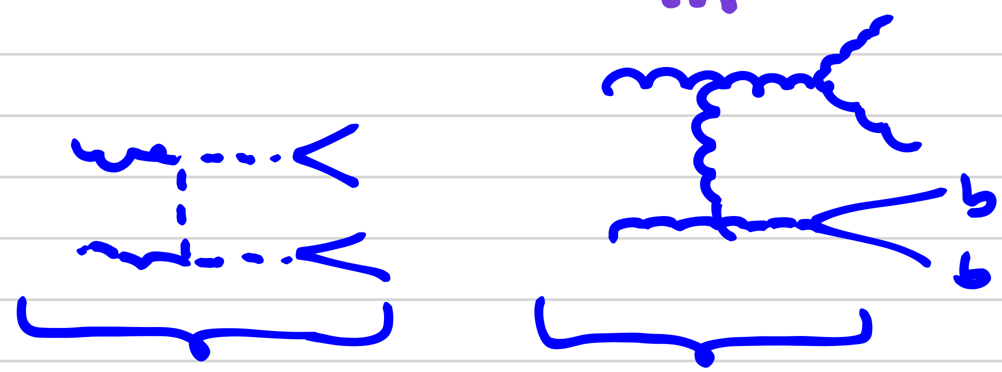


$$m_{\tilde t}^2 \simeq P_{T_{j_1}} P_{T_{j_2}} \Delta R_{jj}^2$$

$$\Delta R \sim \frac{m}{P_T}$$

$$P_T \sim m_{\tilde t}$$
$$\Delta R \simeq 1$$

- PAIRING BY MINIMIZING $|1 - \Delta R_{ij}| + |1 + \Delta R_{kl}|$
- RESONANCE CANDIDATES WITH SIMILAR MASS δ_m
- HARD VS FORWARD PROCESS



$\cos\theta^*$

large angle small angle

- MASS OF THE SIGNAL HAS LITTLE SENSITIVITY TO ΔR

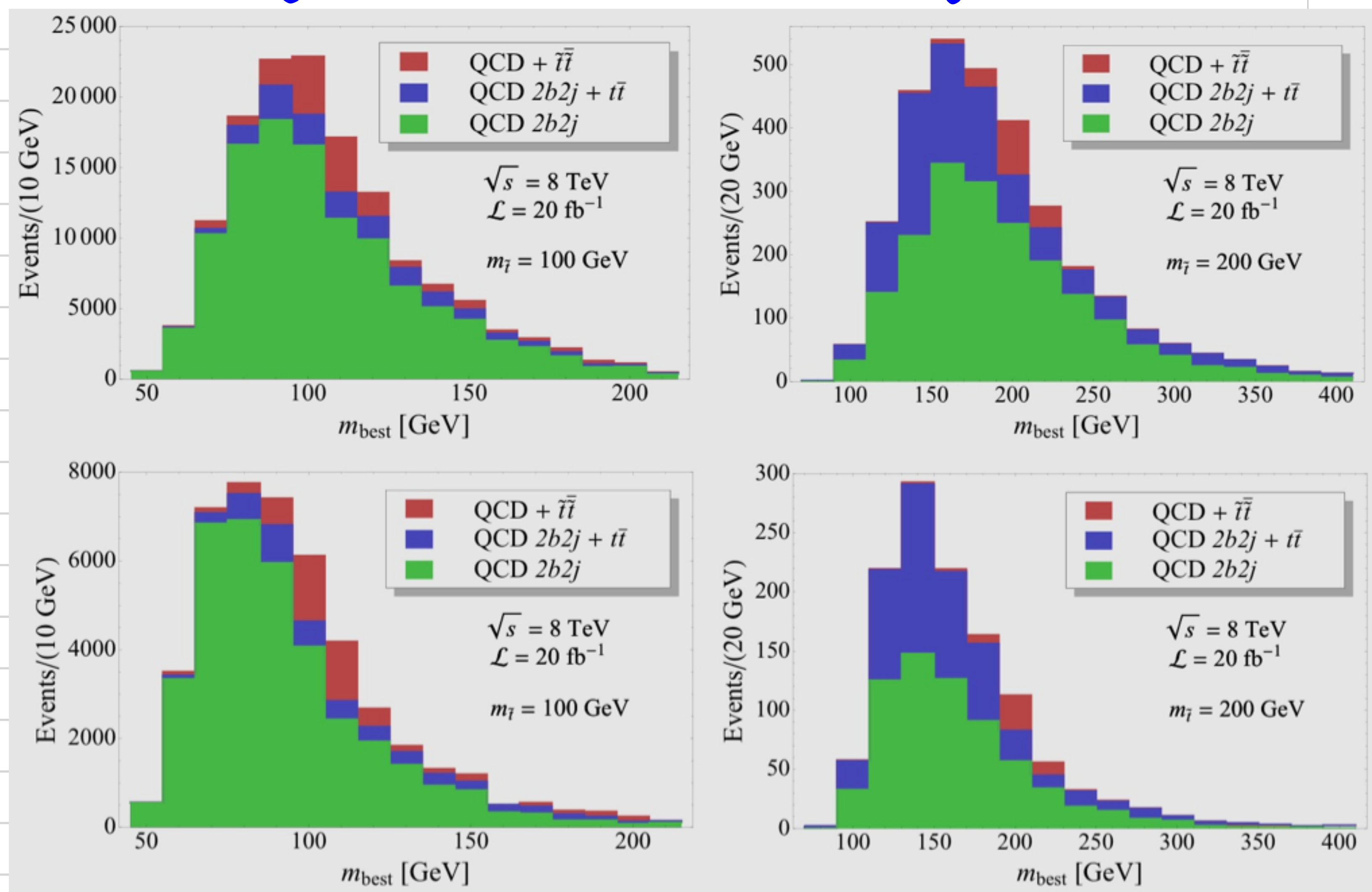
LOOK INSIDE THE CANDIDATE RESONANCES $(\Delta R_{12} + \Delta R_{34})/2$

$$
p_{T,j} > \frac{m_{\tilde{t}}}{2}\,, \qquad |\eta_j| < 2.8\,, \qquad \Delta R_{jj} > 0.7\,,
$$
$$
\delta_m < 0.075\,, \qquad |\cos\theta^*| < 0.4\,, \quad \Delta R_{\rm best} < 1.5\,,
$$
$$
\Delta\eta_{\rm best} < 0.8\,.
$$

$m_{\tilde{t}} = 100$ GeV $\qquad$ $m_{\tilde{t}} = 200$ GeV

ENFORCING LOOSELY COLLINEAR JETS IN THE RESONANCE CANDIDATE

ENFORCING MORE COLLINEAR JETS IN THE RESONANCE CANDIDATE



$\mathcal{L} = 20/\text{fb}$ $\quad \sqrt{s} = 8$ TeV $\longrightarrow$ $m_{\tilde{t}}$ UP TO 200 GeV

CONCLUSIONS AND OUTLOOK

- RPV STILL CAN HAVE SUB-TeV SUPER PARTNERS

- PROTON DECAY IS NOT AUTOMATICALLY SAVED BY R-PARITY IN LOW SCALE MODELS

- BREAKING OF GAUGED FLAVOR SYMMETRIES CONNECTED TO THE SIZE OF RPV COUPLINGS

$$W_{RPV} = \lambda''_{ijk} u_i^c d_j^c d_k^c$$

$$\lambda''_{ijk} \sim V^{ckm}_{il} \left(\frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \right)^{\mu} \epsilon_{ljk}$$

$\mu = 1, \frac{1}{2}$

·) CHALLENGING LIGHT SQUARK SCENARIO

$\tilde{g}, \tilde{h}, \tilde{q}_3$

$\tilde{t}_R$

PAIR STOP PRODUCTION $\tilde{t} \to qq$

- $Br(\tilde{t} \to bd + bs) \simeq \underline{99\%}$

$SU(3)_{Q,L,d,u,e,\nu}$

$SU(3)_{Q,Q^c,L,L^c}$ $\Big\}\ \mu = 1$

PARTIAL COMPOSITENESS

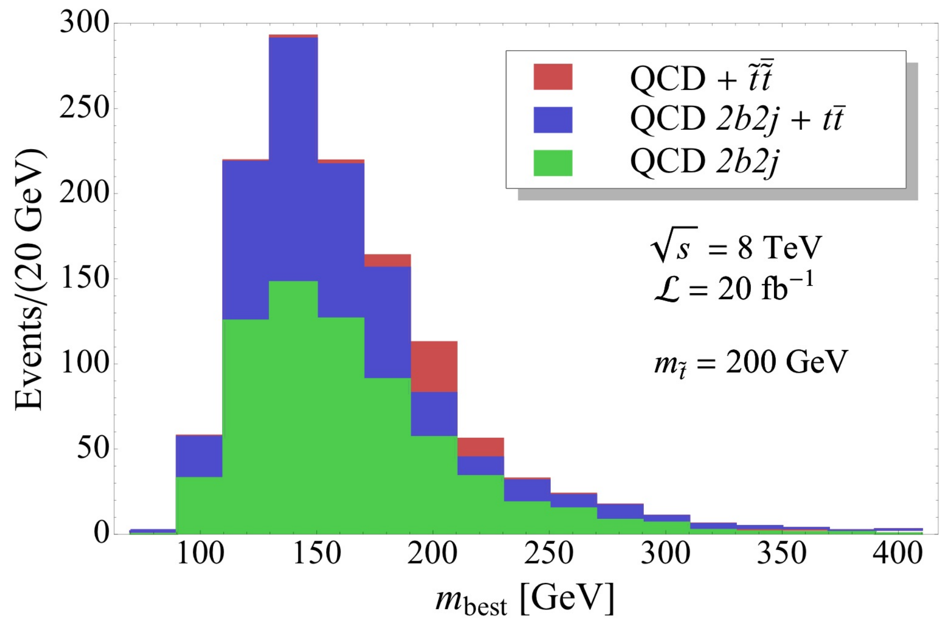
...

- $Br(\tilde{t} \to bd + bs) \simeq \underline{14\%}$

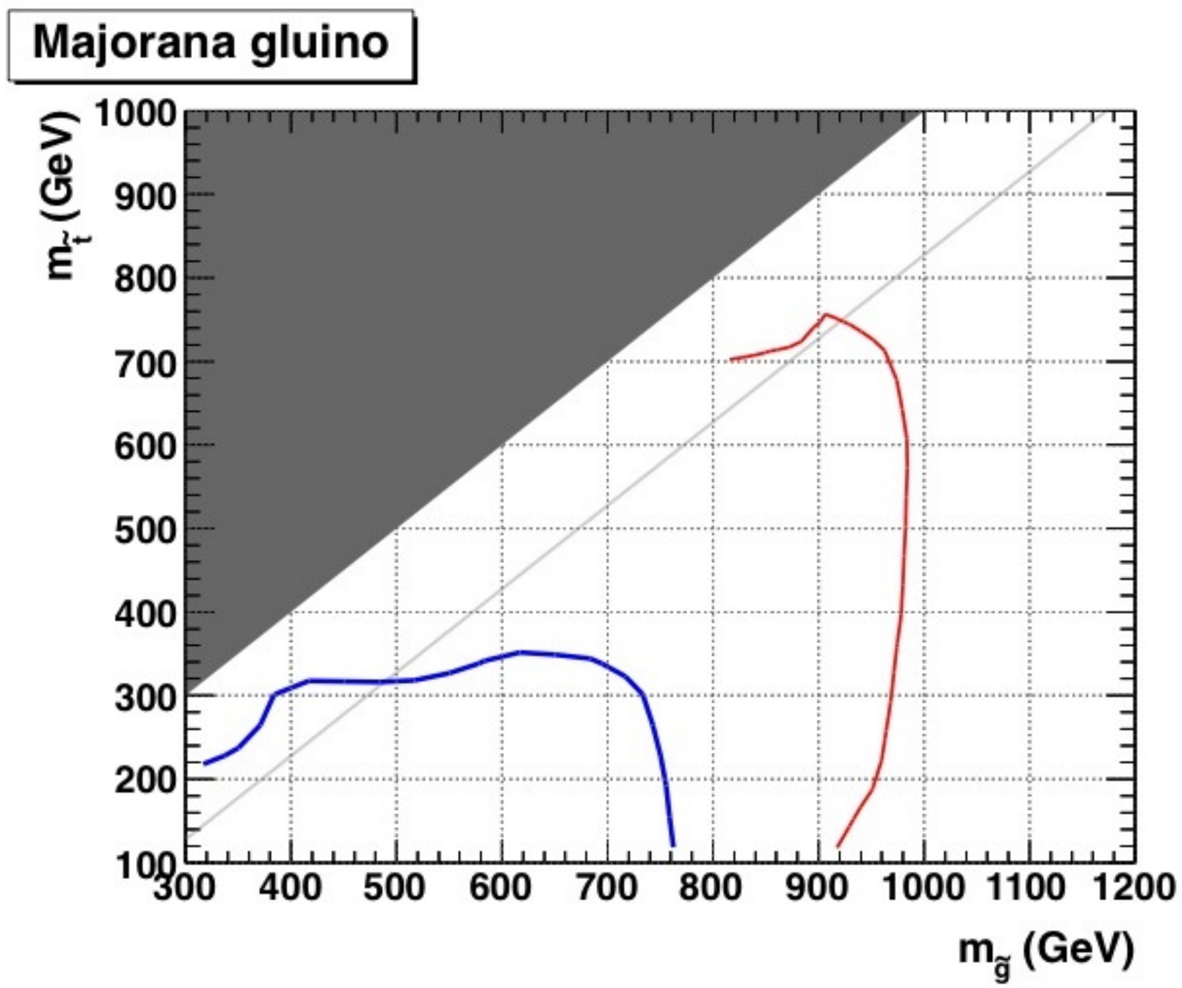
$SU(3)_{V,q,e}$ $\mu = \frac{1}{2}$

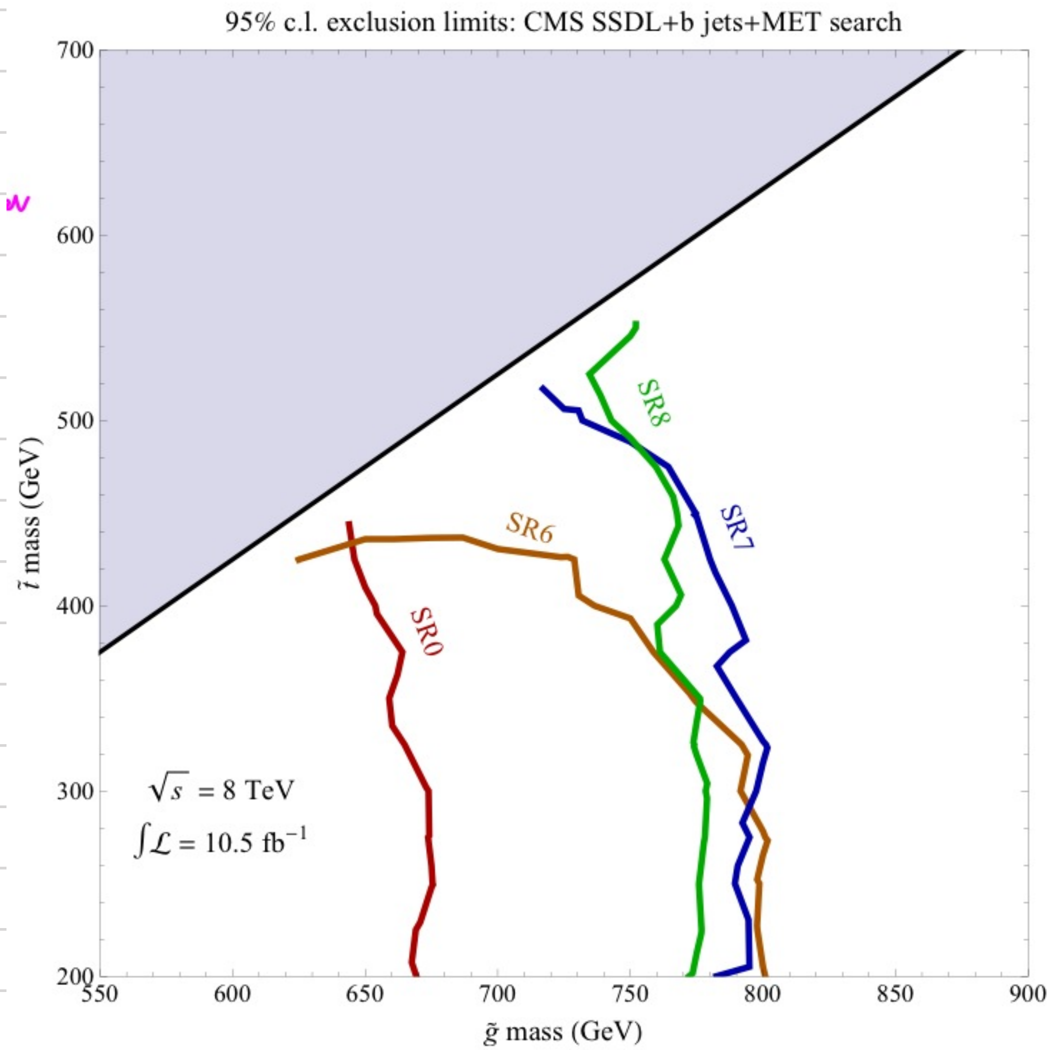
- <u>LHC CAN TELL</u>

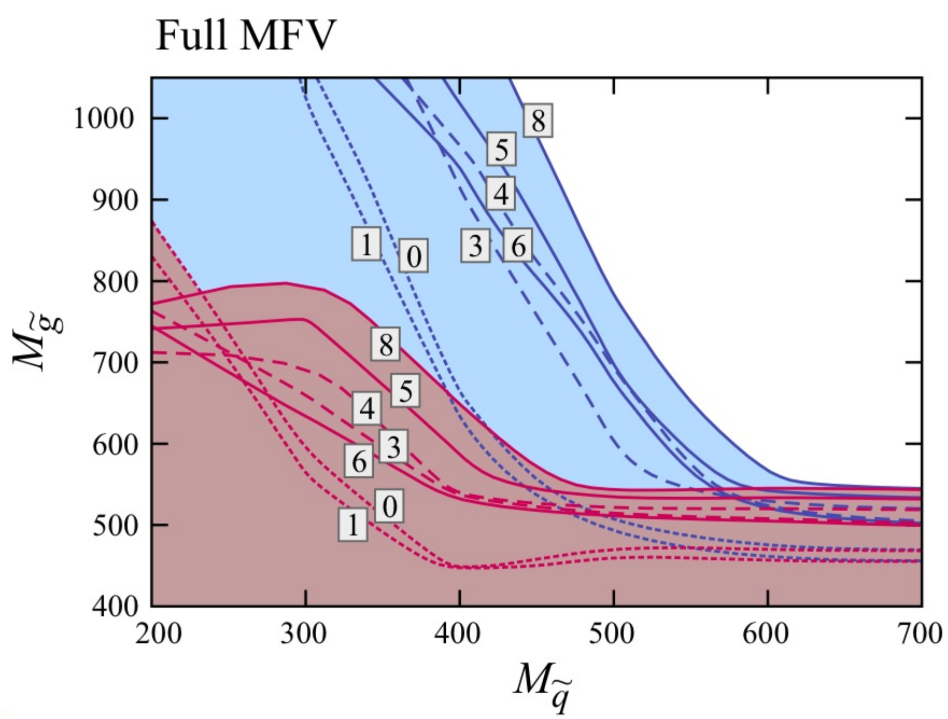
$pp \to \tilde{t}\tilde{\bar{t}} \to b\bar{b}q\bar{q}$

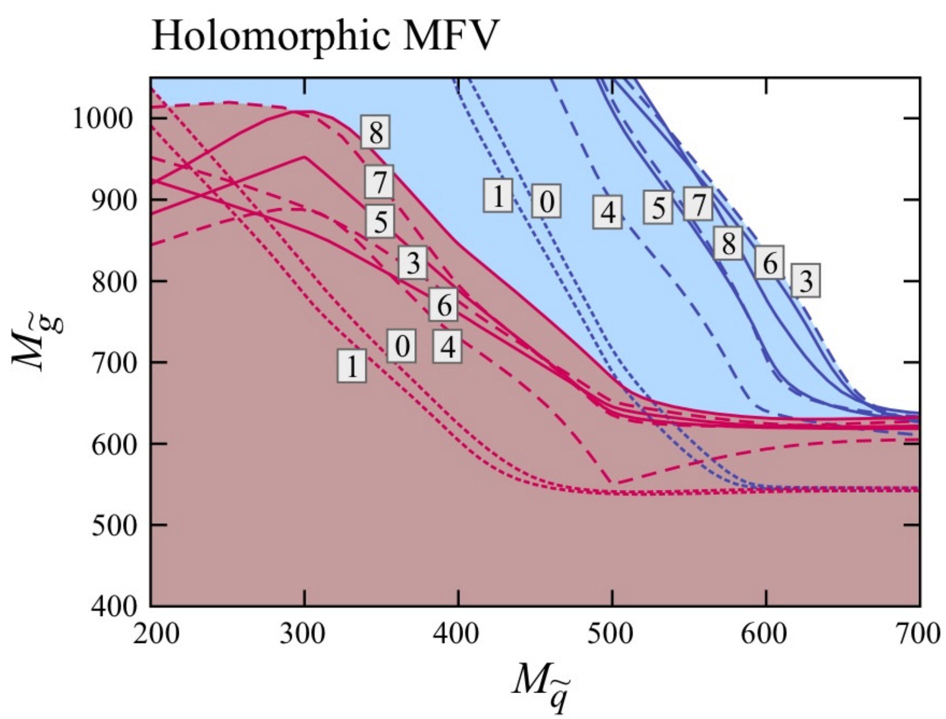


SAME SIGN DILEPTONS (+b)

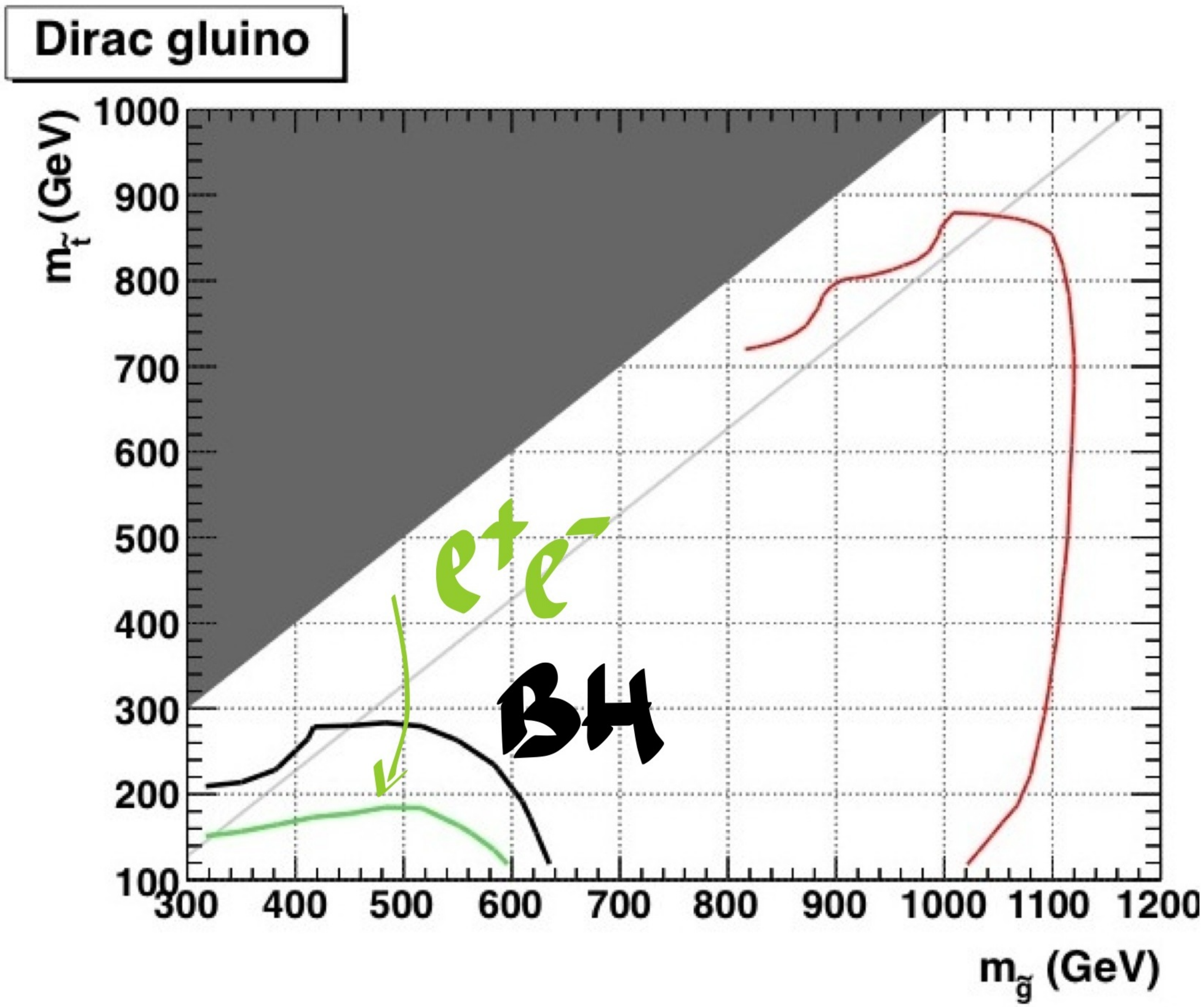




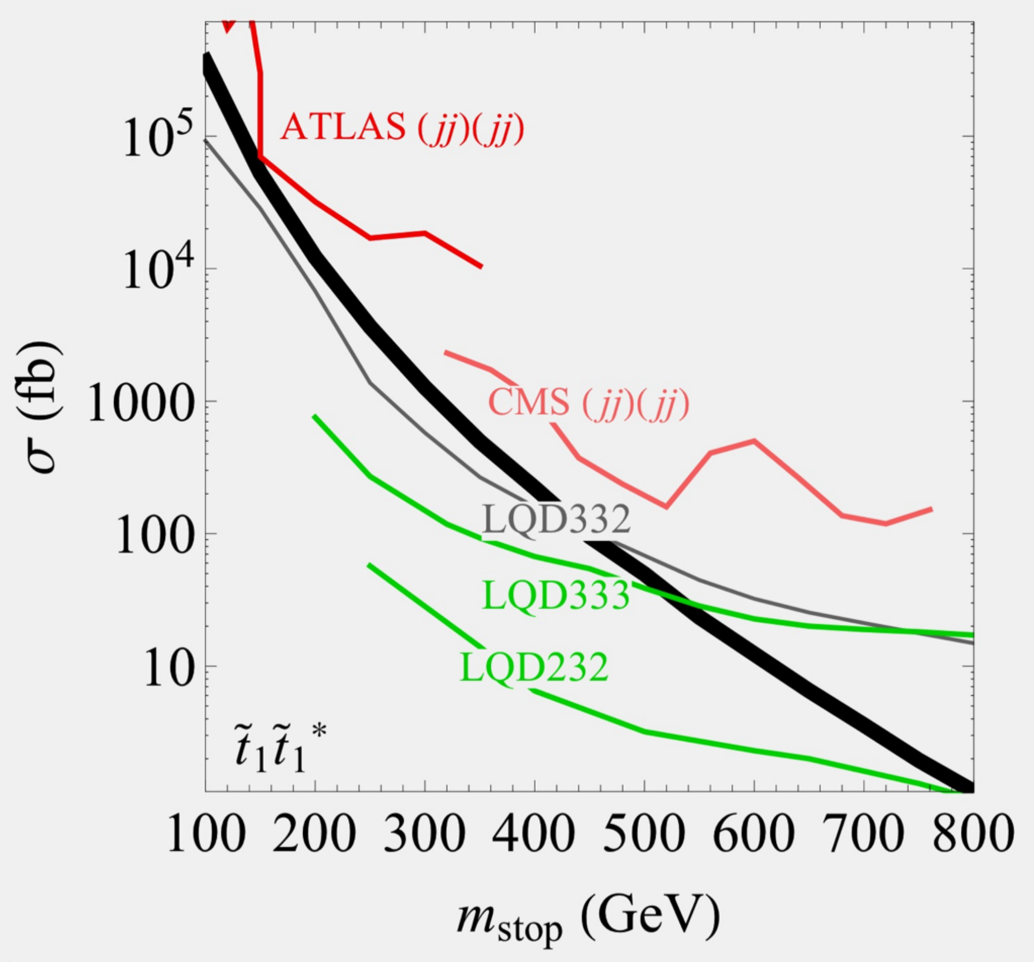


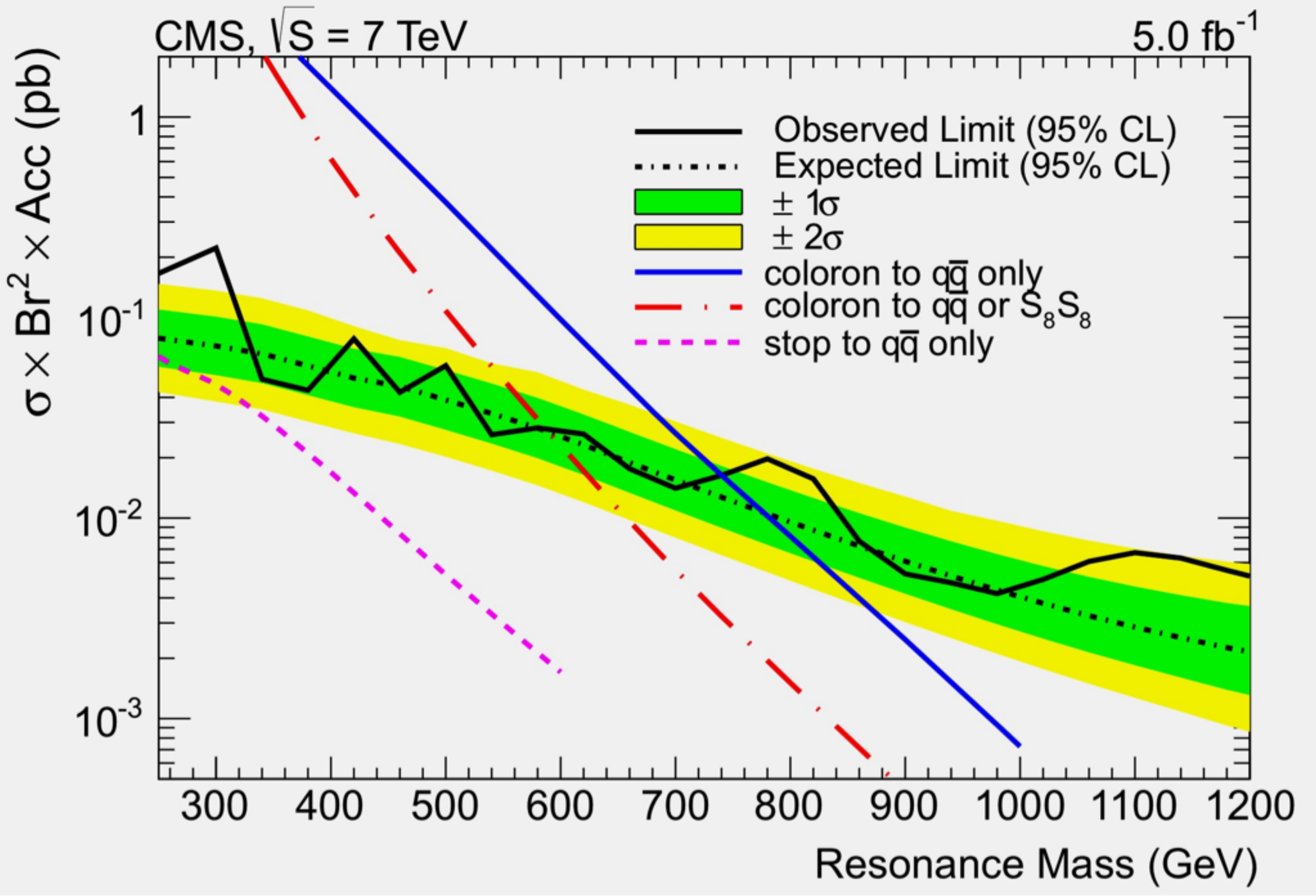


DIRAC GLUINO



PAIRED DIJET $\tilde{q} \to jj$





PAIRED $\tilde{g} \to jjj$

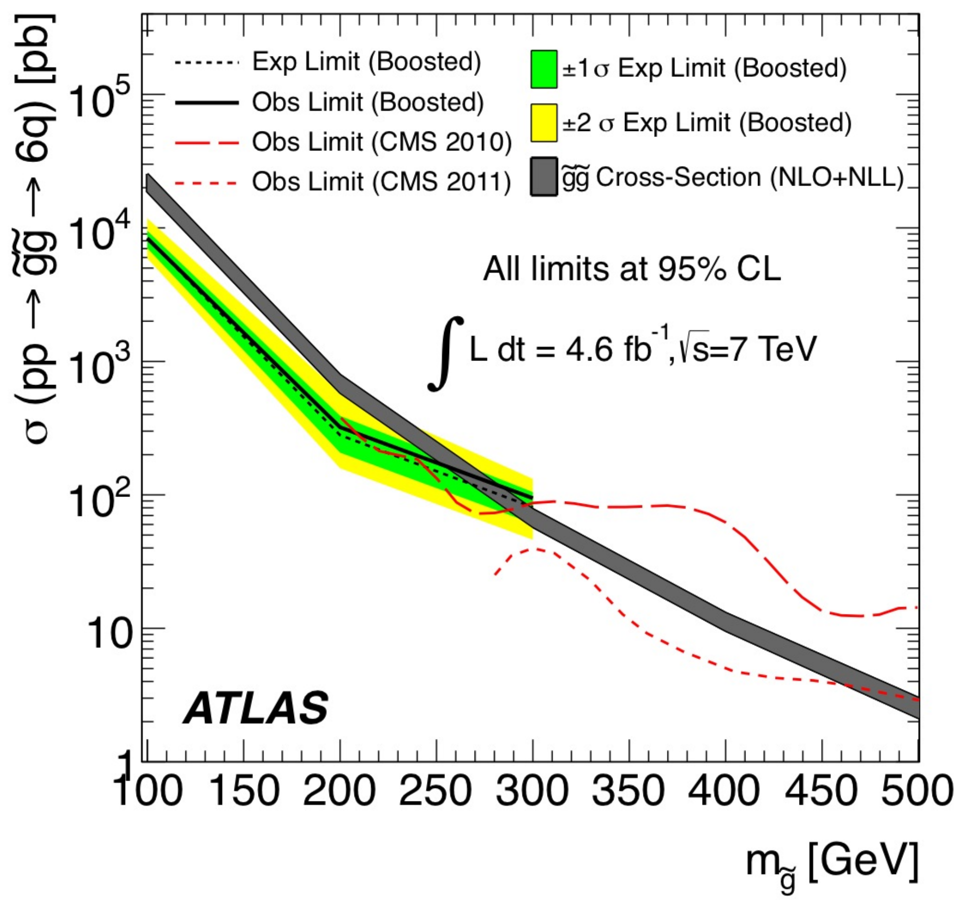


Figure 6. The expected and observed 95% confidence limits are shown for the boosted analyses channel. The published CMS results using 35 pb^{-1} of 2010 data and using 5 fb^{-1} of 2011 data are shown for comparison.

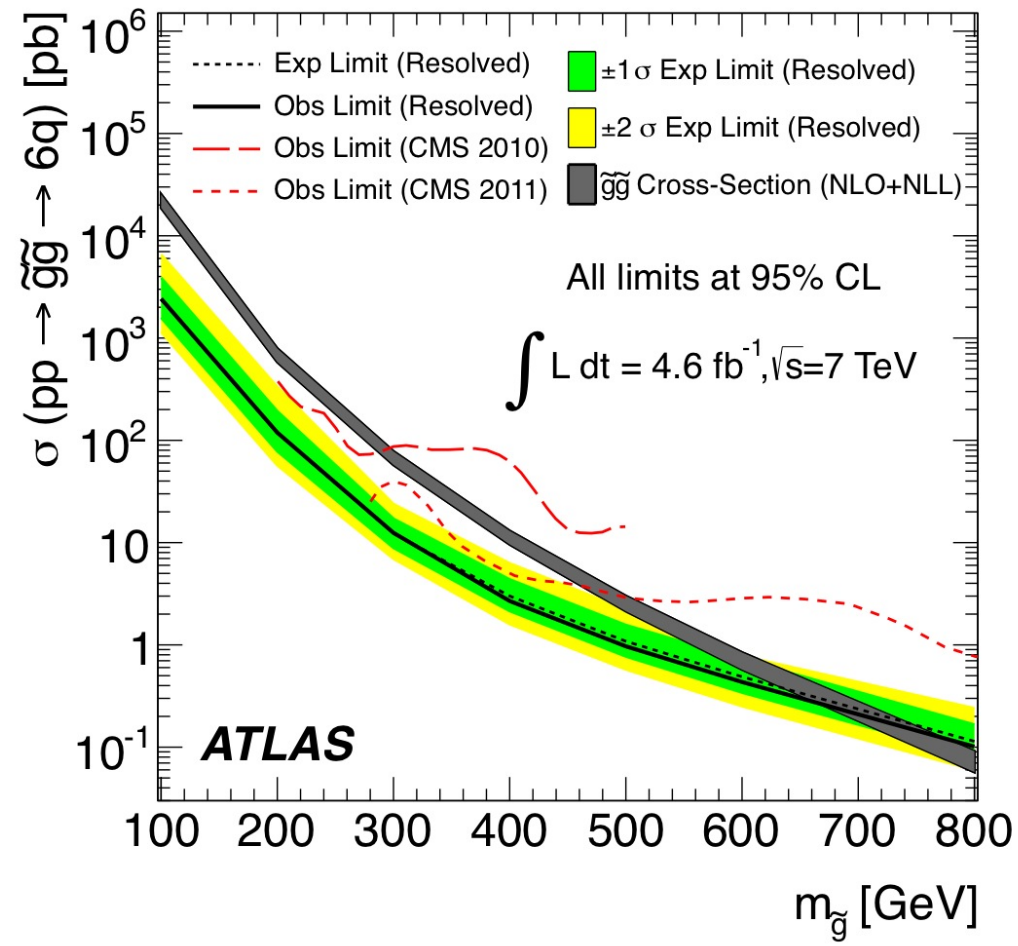


Figure 5. The expected and observed 95% confidence limits are shown for the resolved analyses channel. The published CMS results using 35 pb^{-1} of 2010 data and using 5 fb^{-1} of 2011 data are shown for comparison.

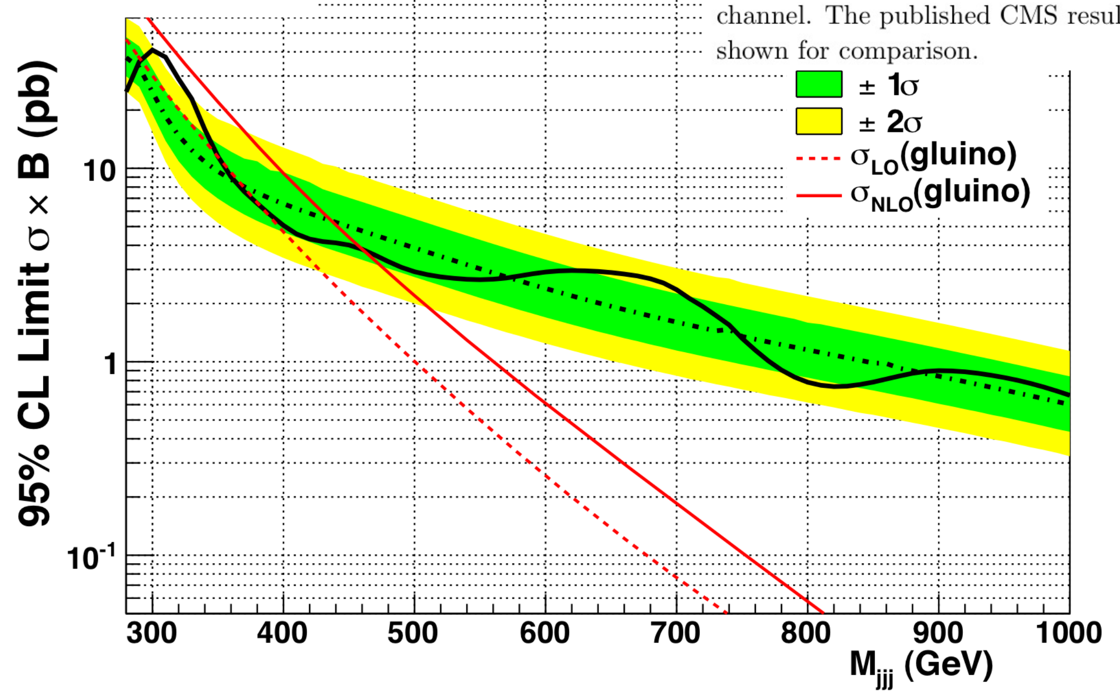


Figure 4: Observed and expected 95% CL upper limits on the cross section times branching fraction for gluino pair production followed by RPV decay of each gluino to three light-flavored quark jets. Also shown are the $\pm 1\sigma$ and $\pm 2\sigma$ bands on the expected limit, as well as the theoretical LO and NLO cross sections for gluino production, assuming a branching fraction of a

HIGH MULTIPLICITY FINAL STATES

$\tilde{g} \rightarrow$ many jets 1207.5787

- SUBSTRUCTURE BY ACCIDENT, JET MASS OBSERVABLES 1212.1456, 1302.1870

$$W_{RPV} = \lambda''_{ijk}\, u^c_i d^c_j d^c_k$$

$$\lambda''_{ijk} \sim V^{CKM}_{il} \left(\frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \right)^{\mu} \epsilon_{ljk} \qquad \mu = 1, \tfrac{1}{2}$$

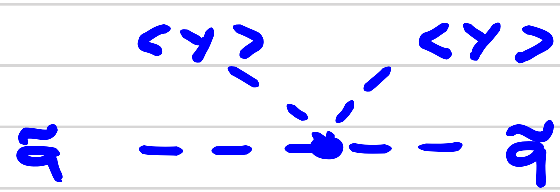
- $m_\rho \sim m_{f,SM}^{\pm 1}$
- $pp \to K^+K^+$ $\quad p \to K^+\nu$ $\quad n-\bar{n}$ $\quad$ OK FOR THE EXPECTED λ''_{ijk}

$\perp$

- $Br(\tilde{t} \to bd + bs) \simeq \underline{99\%}$

$$\left.\begin{array}{l} SU(3)_{Q,L,d,u,e,\nu} \\ SU(3)_{Q,Q^c,L,L^c} \\ \text{PARTIAL COMPOSITENESS} \end{array}\right\} \mu = 1$$

- $Br(\tilde{t} \to bd + bs) \simeq \underline{14\%}$ $\qquad SU(3)_{V,q,e}$ $\qquad \mu = \frac{1}{2}$
- <u>LHC CAN TELL</u> $\quad pp \to \tilde{t}\tilde{t}^* \to b\bar{b}q\bar{q}$
- <u>SUSY BREAKING</u> FOR A COMPLETE ANALYSIS OF FV
- SPARTICLE SPECTRUM



$\sim \delta_{flavor}$

- FLAVOR-AWARE SUSY BREAKING MEDIATION