

Post-LHC RPV SUSY

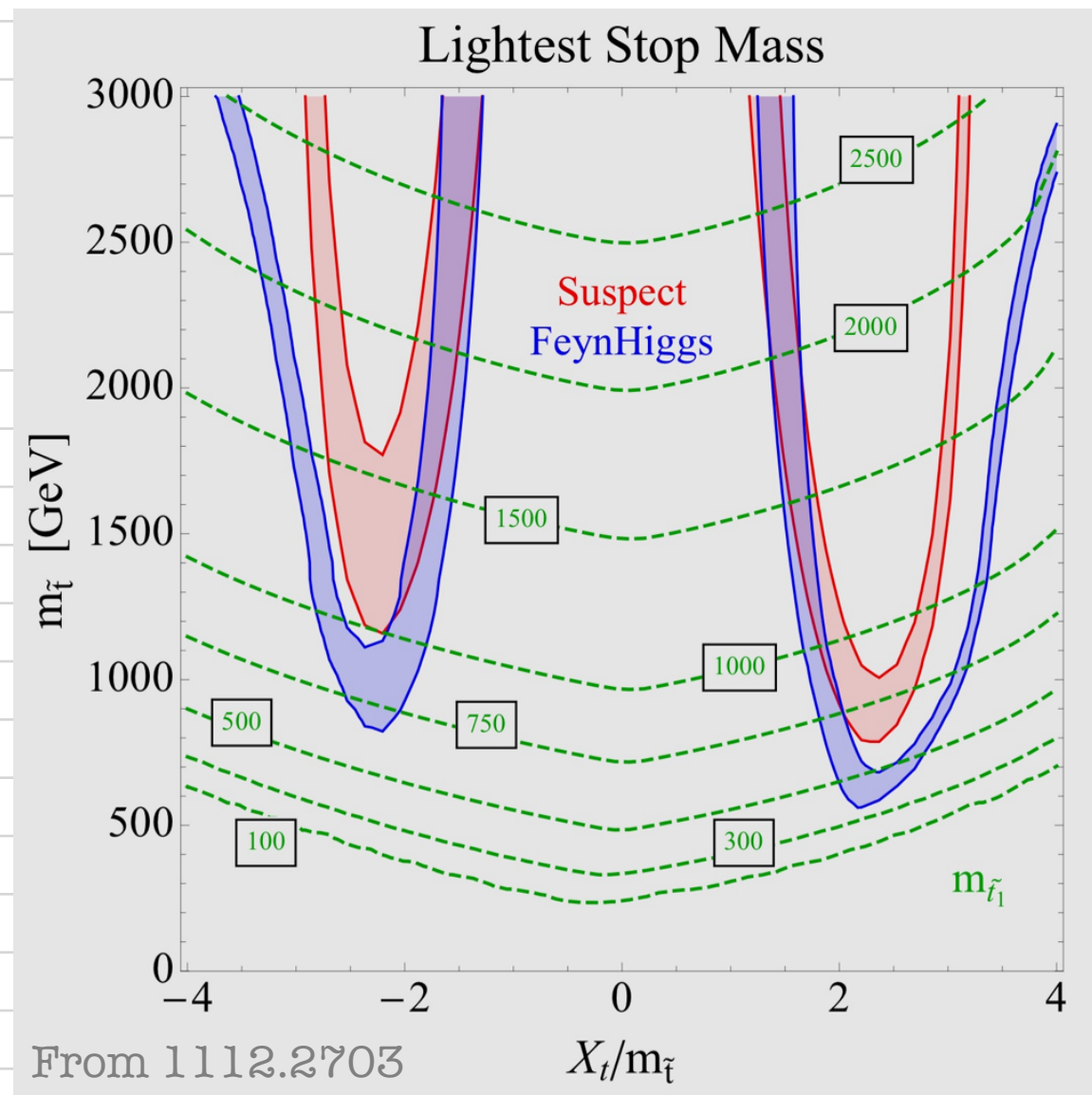
Roberto Franceschini
(University of Maryland)

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

125 GeV BOSON DISCOVERY AND SUSY

$$m_h = 125 \text{ GeV} \gg m_Z$$

POSSIBLE IN THE MSSM
BUT REQUIRES LARGISH SOFT MASSES



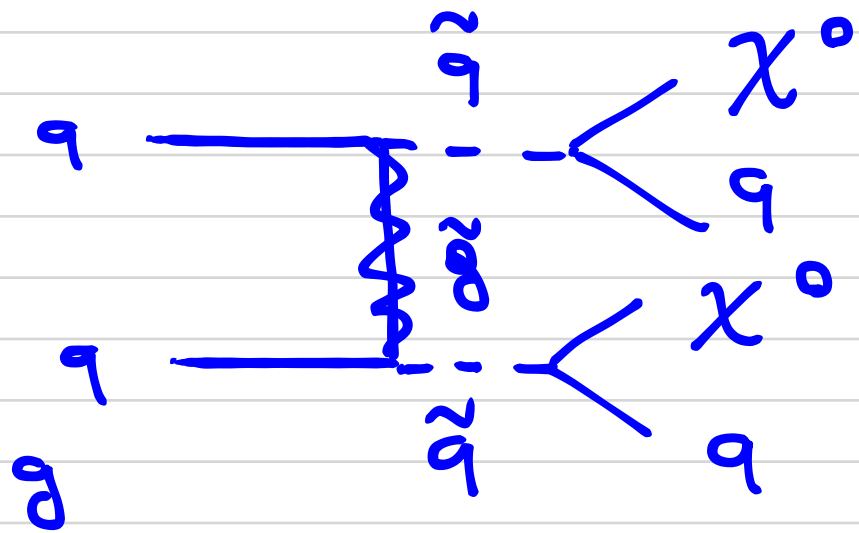
NON-MINIMAL
→ MODELS

NO SIGNAL FROM SUPERPARTNERS

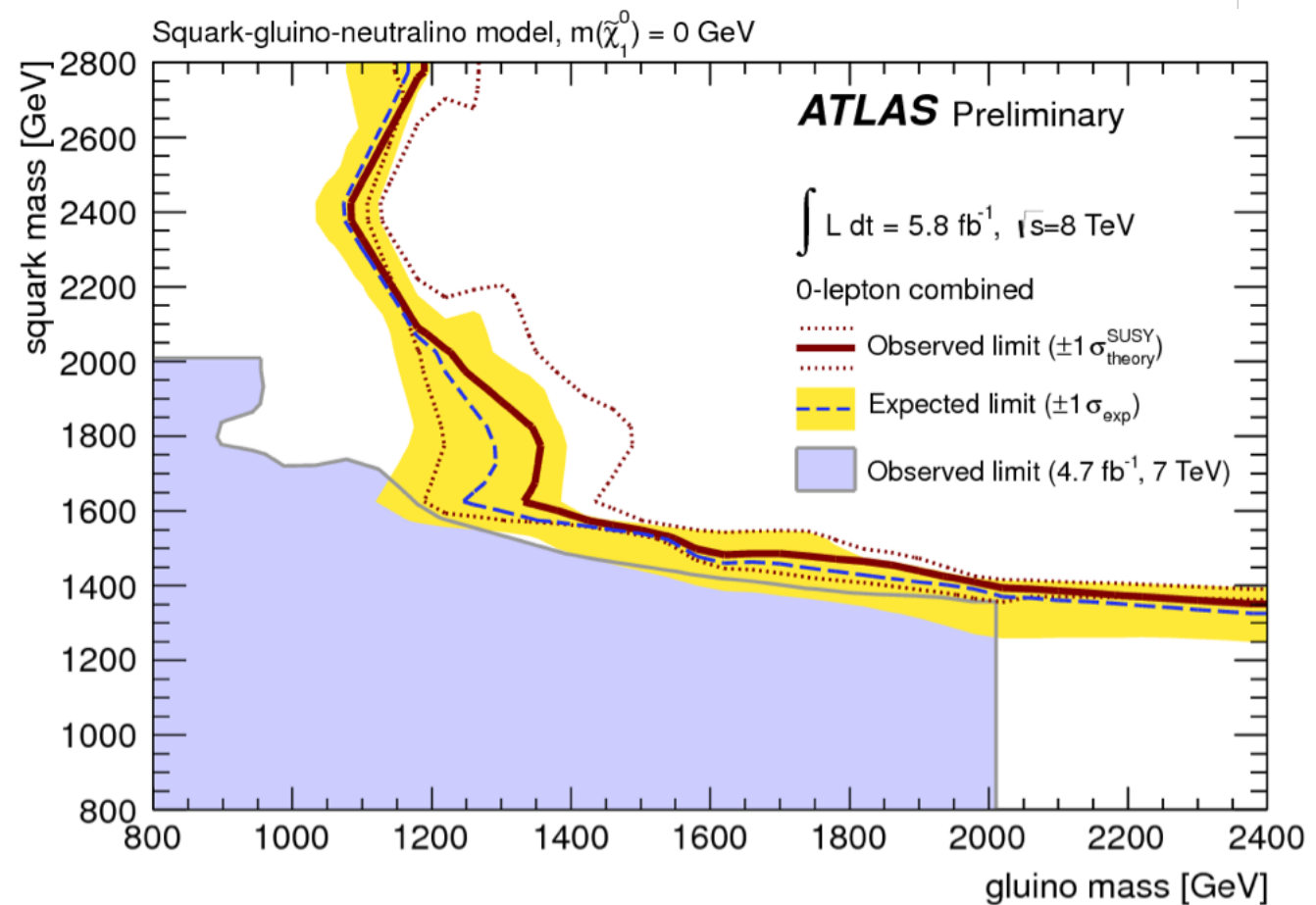
SEARCHES IN FINAL STATES jets + leptons + photons + **mET**

MISSING TRANSVERSE ENERGY
IS ASSUMED FROM THE

PRODUCTION OF **INVISIBLE χ^0**



χ^0 IS THE DM CANDIDATE



$M_{\text{SUSY}} > \text{TeV}$

SUSY ALTERNATIVES : DIRAC GLUINO

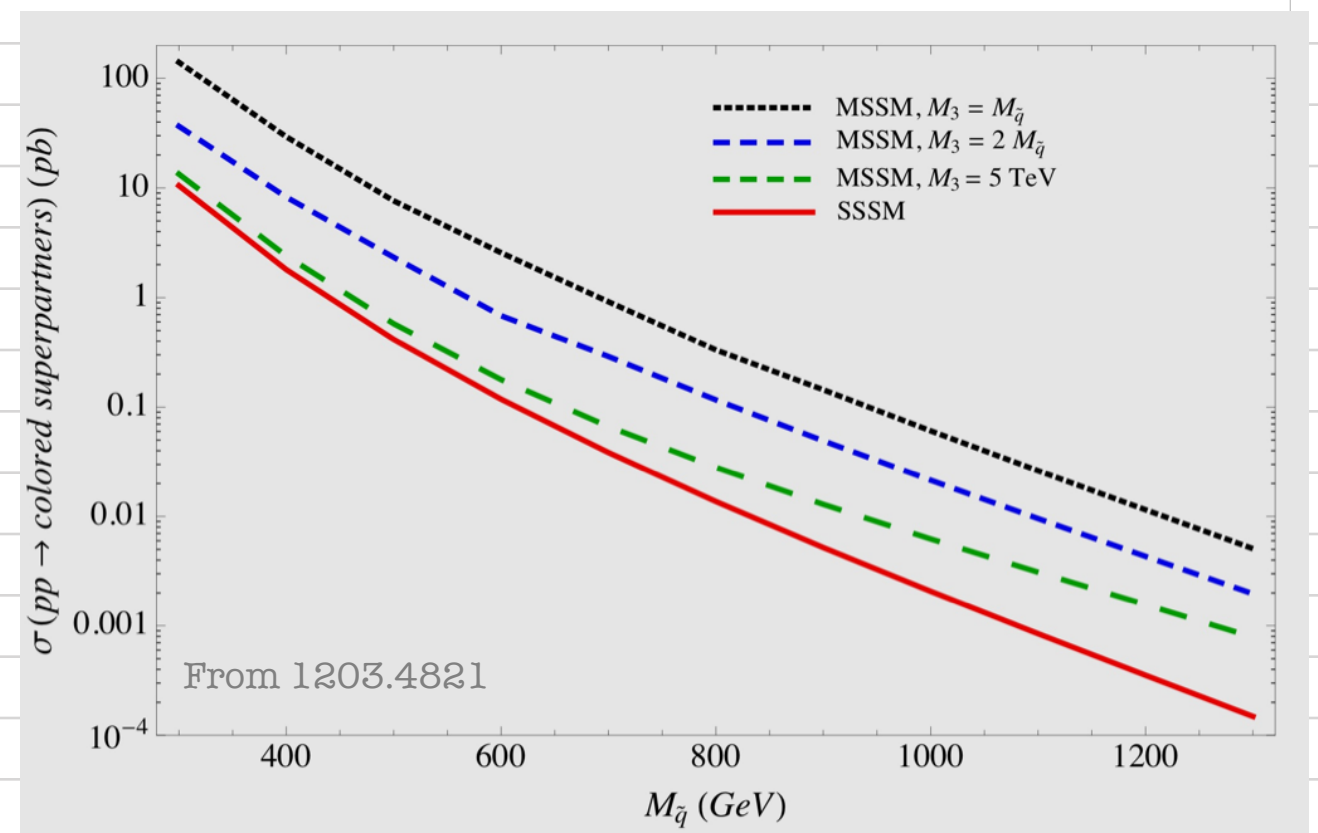
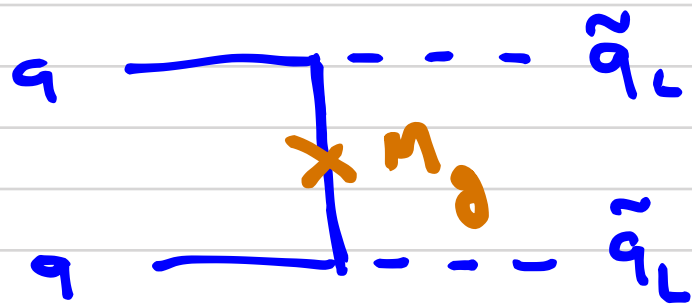
GIVE MASS TO THE GAUGINOS INTRODUCING A_i DIRAC PARTNER

$$\int d^4\theta \frac{1}{M} A_i W_{i,\alpha} W^\alpha \longrightarrow m_D A_i \tilde{\lambda}_i \quad m_D \sim \frac{D}{M}$$

• DIRAC GLUINO

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

AT HIGH $m_{\tilde{q}}$ $q\bar{q} \rightarrow \tilde{q}\tilde{q}$



GAUGINO PARTNERS PHENOMENOLOGY

$$A_3 \rightarrow jj$$

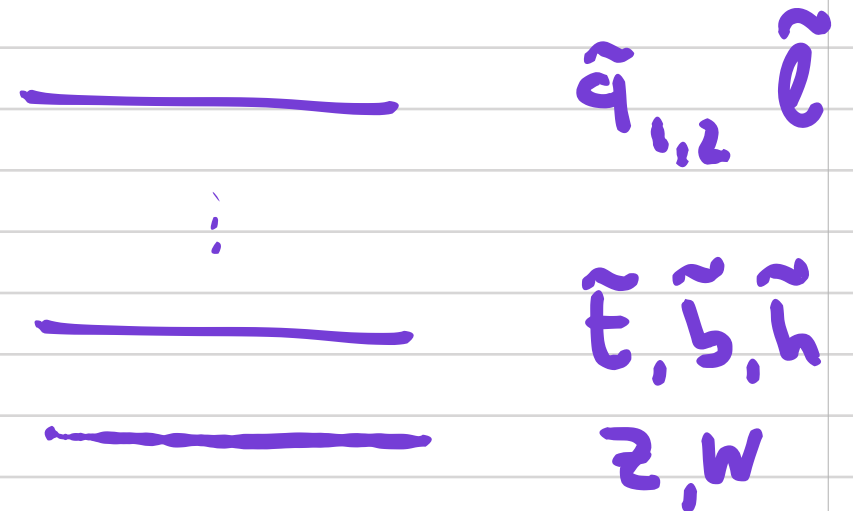
SUSY ALTERNATIVES : EFFECTIVE SUSY

- "NATURAL" SUSY

ONLY FEW SUPER PARTNERS

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

TO STABILIZE THE WEAK SCALE



A Feynman diagram showing a loop of top quarks and top squarks. It consists of two horizontal lines representing the Higgs boson (H_u). The top line is a dashed line, and the bottom is a solid line. A loop is formed by a dashed line (top quark) and a solid line (top squark) connecting the two Higgs lines. To the right of the diagram, the equation is written: $\delta m_{H_u}^2 \propto \frac{1}{16\pi^2} \gamma_t^2 m_{\tilde{t}}^2$.

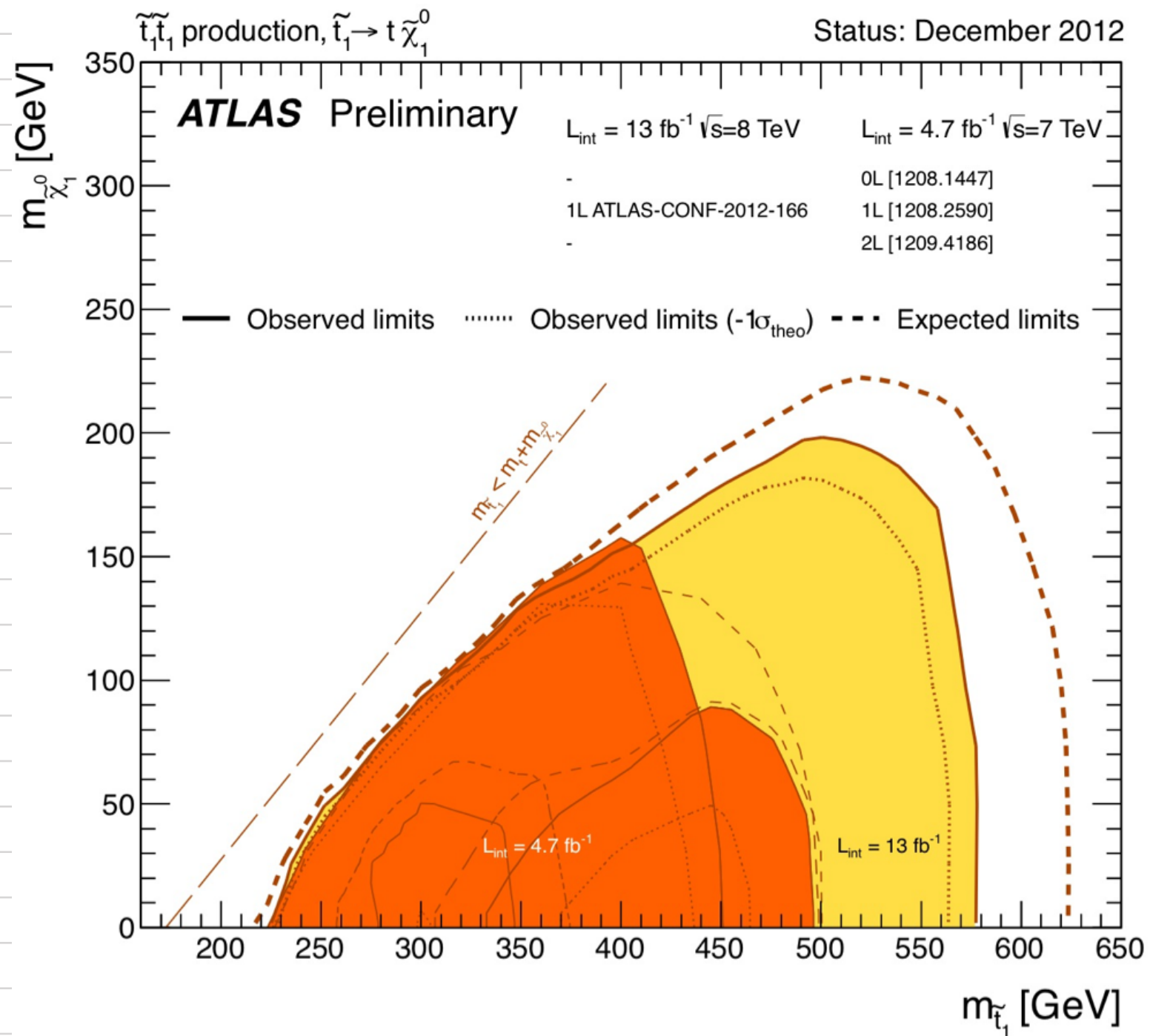
EXPERIMENTAL CHALLENGE

SEARCHES ARE MORE DIFFICULT

HEAVY FLAVOR FINAL STATES

LARGER MULTIPLICITIES, SOFTER OBJECTS

CHALLENGE ACCEPTED!



SUSY ALTERNATIVES : COMPRESSED/STEALTH

REDUCE THE AMOUNT OF m_{ET}

- 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

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

- 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.

$$\left\{ \begin{array}{l} \tilde{g} \rightarrow jjj \\ \tilde{g} \rightarrow Q\bar{Q} \rightarrow l^+ l^+ + x, l^- l^+ + x, l + \text{jets}, l + b + \text{jets} \\ \tilde{q} \rightarrow jj \end{array} \right.$$

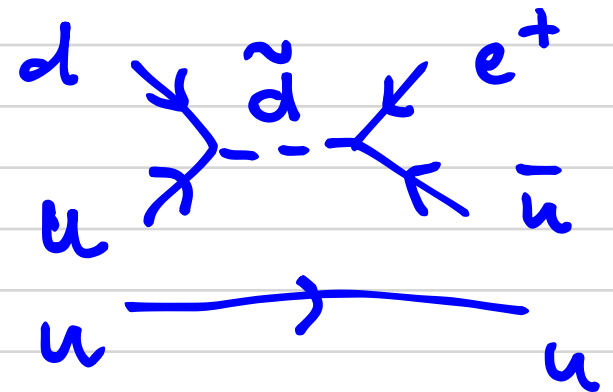
AT THIS STAGE ALL THESE OPTIONS
ARE WORTH BEING CONSIDERED

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 $W_{RPV} = 10^{55}$
- VERY SMALL COUPLINGS

R-PARITY IS NOT BARYON NUMBER

- PROTON DECAYS VIA HIGHER DIM OPERATORS

$$W^{(5)} = \frac{1}{M} u^c u^c d^c e^c$$

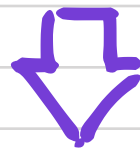
MEDIATES PROTON DECAY

TOO FAST EVEN FOR $M \sim M_{\text{GUT}}$

IN LOW-SCALE MODELS R-PARITY IS NOT ENOUGH

"EFFECTIVE" SUSY

TYPICALLY INVOLVES LOW-SCALES OF SUSY MEDIATION



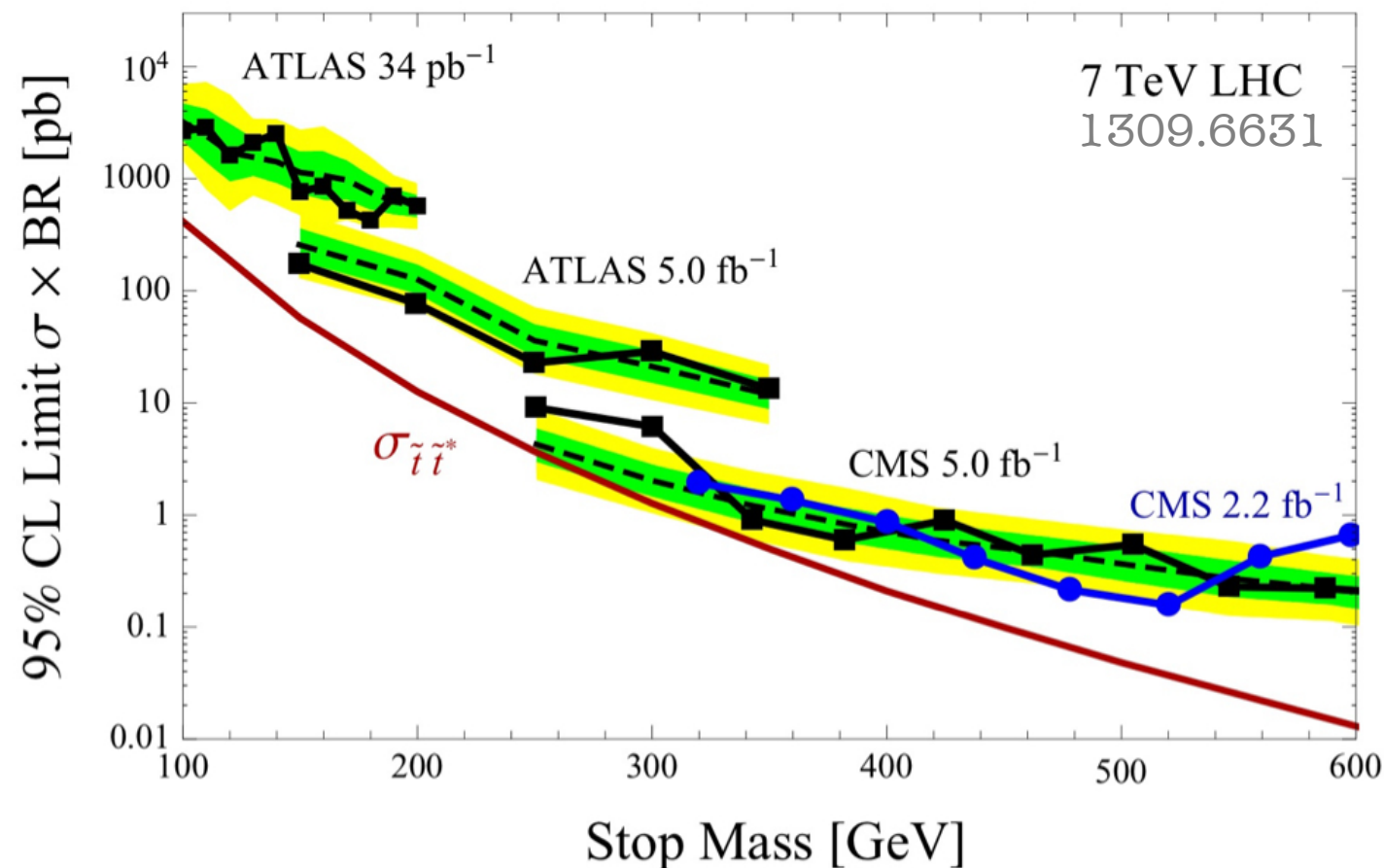
PROTON DECAY BECOMES A UV ISSUE

WHY RPV?

PHENOMENOLOGY IS DISTINCT : REDUCED MISSING ENERGY
RESONANCES $g \rightarrow jj$, $\tilde{g} \rightarrow jj$
META STABLE, MESINO-OSCILLATION

NATURAL SUSY : RPV LESS CONSTRAINED THAN RPC

DI-JET PAIR PRODUCTION : LIMITS



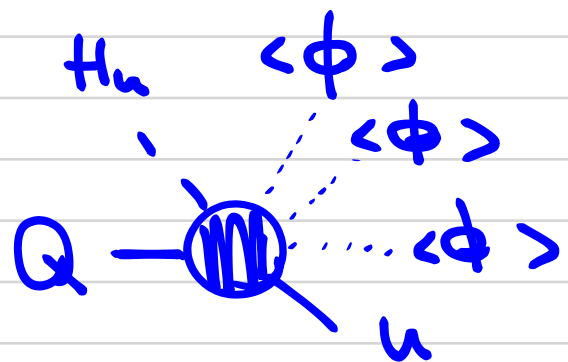
STILL THE FLAVOR STRUCTURE
AND THE SIZE OF THE COUPLINGS
LOOKS AD-HOC

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 $m_p \sim \langle \phi \rangle \sim Y_{SM}$

$$\frac{1}{m_p^2} \bar{\psi}_a \psi_b \bar{\psi}_c \psi_d$$

$$FCNC \sim \frac{1}{m_p^2} \sim \frac{1}{m_{light}}$$

$$m_p > 10^5 \text{ TeV}$$

SUSY of GRINSTEIN, REDI, VILLADOLO

BEREZKHANI '83, '85
1009.2049

FLAVOR DYNAMICS CAN BE AT A MUCH LOWER SCALE IF

$$m_{\text{light}} \sim \frac{1}{M_{\text{heavy}}} \sim \frac{1}{m_f} \quad \text{"seesaw-like"}$$

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 $SU(3)$
- $U^c, D^c \sim 3^* SU(3)_Q$ $U, D \sim 3 SU(3)_{u^c,d^c}$

W_{RPV}^{MSSM} is FORBIDDEN BY THE FLAVOR SYMMETRY

$$W_{RPV}^{\text{EXO}} = \tilde{\lambda}'' U^c D^c D^c$$

1212.4860

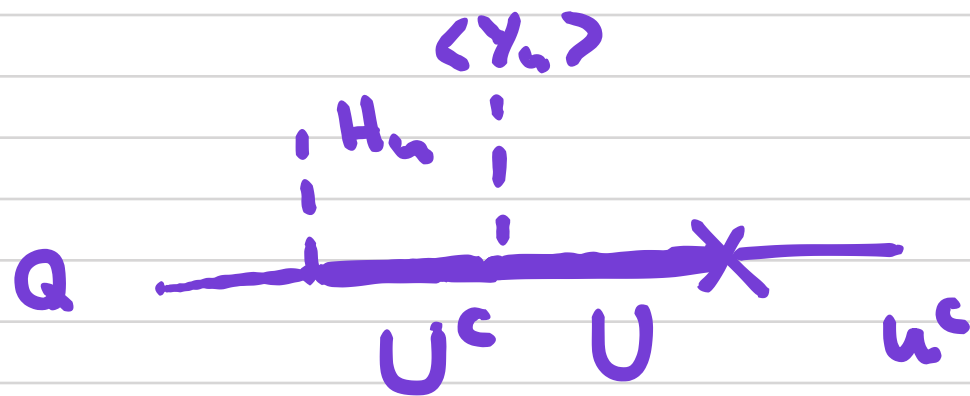
$$W = \bar{\lambda}_\nu U U^c \gamma_\nu + \mu_\nu U u^c + \lambda_\nu Q H_\nu u^c$$

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$SU(3)_Q$	$SU(3)_{u^c}$	$SU(3)_{d^c}$	$SU(3)_L$	$SU(3)_{e^c}$	$SU(3)_{\nu^c}$
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

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

KRNJAC, STOLARSKI
1212.4860



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

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

FLAVOR BLIND μ_u , λ_u , λ'_u

$$W_{RPV}^{EXP} = \tilde{\lambda}'' U^c D^c D^c \rightarrow \lambda' u^c d^c d^c$$

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

$$\lambda''_{ijk} \sim V_{il}^{CKM} \frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \in \mathcal{O}_{ijk}$$

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

**HIERARCHY OF RPV COUPLINGS
FROM HIERARCHY OF SM FERMION
MASSES**

$$\lambda''_{ijk} \sim \sqrt{\frac{a_{ik} m_{u_i} m_{d_j} m_{d_k}}{m_t^3}} \in R_{jk}$$

	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}

KRNJAIĆ, STOLARSKI Csáki et al
1212.4860 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

• χ' QLD RPV CANNOT BE GENERATED

Q AND L ARE CHARGED UNDER DIFFERENT GROUPS

PARTIAL COMPOSITENESS + SUSY

1205 5803
KEREN-ZUR et al

$$\lambda_i \psi_i^{sn} O_i$$

$$\psi_{sn} \text{---} O_i$$

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

$$\lambda_i = g_f \underline{\epsilon}_i = \lambda_i (\Lambda_{uv}) \left(\frac{m_p}{\Lambda_{uv}} \right)^{\delta_i}$$

$$\gamma_{ij} \sim \epsilon_{q_i} \epsilon_{u_j}$$

- NEARLY MARGINAL INTERACTIONS
GENERATE THE LARGE MASSES (m_{top})
- TO REPRODUCE CKM $\frac{\epsilon_{q_1}}{\epsilon_{q_2}} \sim \lambda$ $\frac{\epsilon_{q_2}}{\epsilon_{q_3}} \sim \lambda^2$

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

$$\lambda''_{ijk} \sim \epsilon_{u_i} \epsilon_{d_j} \epsilon_{d_k} \sim \frac{\epsilon_{q_3}}{\epsilon_{q_1}} \frac{\epsilon_{q_3}}{\epsilon_{q_2}} \frac{\epsilon_{q_3}}{\epsilon_{q_3}} (\epsilon_{u_3})^3 \frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3}$$

SO FAR

$$\lambda_{\text{BNV}} u_i^c d_j^c d_k^c \sim \frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^2}$$

ALTHOUGH DIFFERENT CKM STRUCTURES

IS THIS ALL THAT ONE CAN DO ?

THE TWO MODELS HAVE VERY SIMILAR LSP PHENO

$$\text{BR}(\tilde{t} \rightarrow b\chi) \simeq 99\%$$

SUSY LEFT-RIGHT GAUGED FLAVOR

- EMBED $SU(2) \times U(1)$ IN A $SU(3)_L \times SU(3)_R \times U(1)_{B-L}$ BROKEN BY $\langle \chi \rangle$
- RIGHT-HANDED SM FIELDS IN DOUBLET
- 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

$$SU(3)_{Q_L} \times SU(3)_{Q_R} \times SU(3)_{L_L} \times SU(3)_{L_R} \quad L-R$$

$$W = \lambda_u (Q \chi U^c + Q^c \chi^c U) \\ + \lambda_d (Q \bar{\chi} D^c + Q^c \bar{\chi}^c D) \\ + \lambda'_u Y_u U U^c + \lambda'_d Y_d D D^c$$

NO " μ -TERMS"

$$W_{RPV}^{Exo} = \tilde{\lambda}'' (U D D + U^c D^c D^c)$$

↓ MIXING

$$W_{RPV}^{NSM} = \lambda'' u^c d^c d^c$$

$$Q \begin{array}{ccc} \langle \chi \rangle & \langle Y_u \rangle & \langle \chi^c \rangle \\ \vdots & \vdots & \vdots \\ \hline & & \end{array} Q^c$$

$$M_d = \frac{\lambda_d^2}{\lambda'_d} \frac{v_L v_R}{\langle \hat{Y}_d \rangle} \quad M_u = \frac{\lambda_u^2}{\lambda'_u} \frac{v_L v_R}{V_{cm}^+ \hat{Y}_u V_{cm}}$$

$$g_{L,R}^{u,d} = \frac{\lambda U_{L,R}}{\lambda' Y_{u,d}} \quad v_L \ll v_R \ll \langle \hat{Y}_{u,d} \rangle$$

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

$$\lambda''_{ijk} \sim V_{il}^{cm} \frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \in l_{jk}$$

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

	$SU(3)_c$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$	$SU(3)_{V,q}$	$SU(3)_{V,\ell}$
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^*

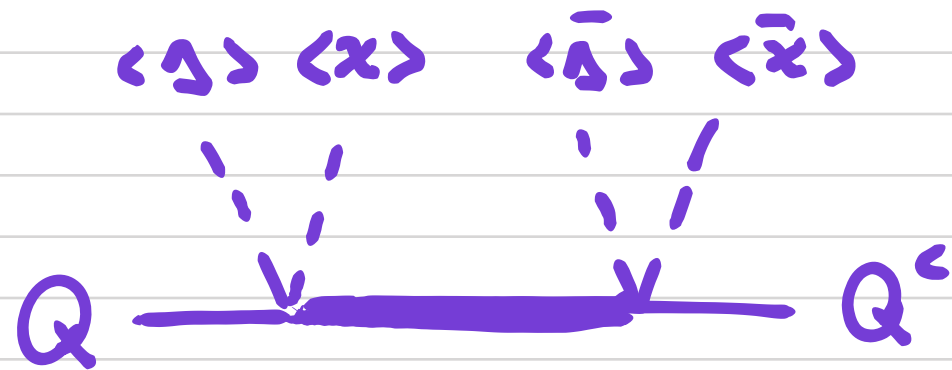
- ANOMALY FREE
- $\Delta \sim 6$ OF FLAVOR GROUP

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

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

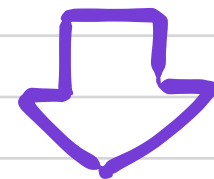
MASS TERM

(WITHOUT FLAVOR VEV)



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

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



$$g_{L,R} \sim \frac{\lambda_d v_{L,R} \langle \Delta_d \rangle}{\Lambda M_D}$$

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

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

• 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

$$g_{L,R} \sim \sqrt{\frac{m_{d,SM}}{v_{R,L}}} \frac{v_{L,R}}{M_0}$$

MORE PROMPT DECAYS

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

	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}

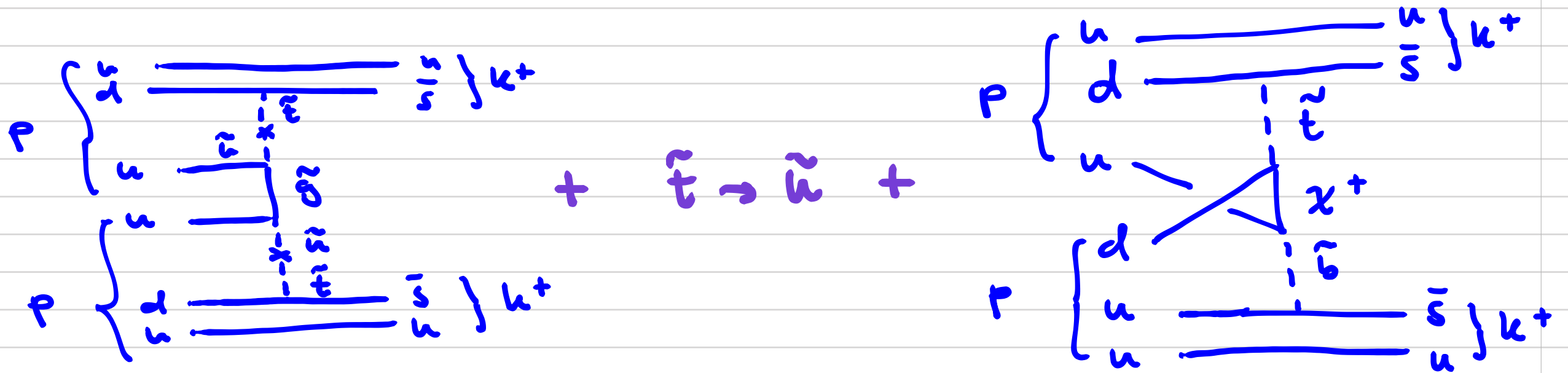
- SIMILARLY LNV $\lambda \sim \left(\frac{m_e}{m_t} \right)^{1/2}$

- $m_f^{SM} \sim \langle \text{FLAVON} \rangle$

"NORMAL" HIERARCHY OF FLAVOR GAUGE BOSONS

LIMITS: $pp \rightarrow K^+ K^+$

$\tau > 1.7 \times 10^{32}$ years



SQUARE FV

FLAVOR
CONSERVING

$$A_{FC} \sim \frac{1}{m_g} \left(\frac{1}{m_{\tilde{q}}} \right)^4 \left(\frac{m_u m_d m_s}{m_s} \right)^\mu V_{td}^2$$

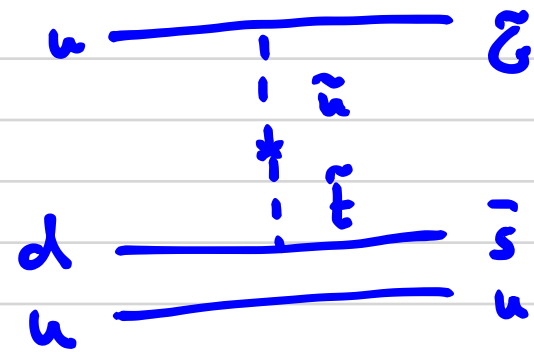
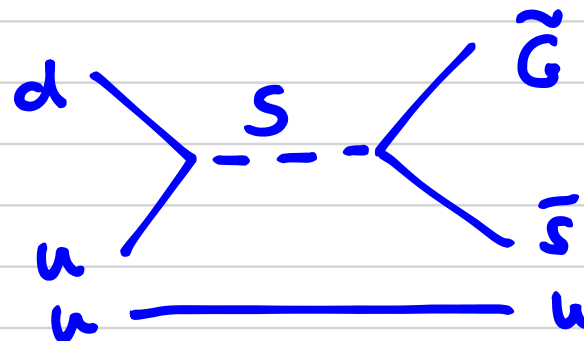
$$\mu = 1 \text{ or } 2$$

$$\tau_{pp \rightarrow K^+ K^+} (\mu=1) \sim 10^{34} \text{ y}$$

$n - \bar{n}$

proton decay $p \rightarrow k^+ \nu$ $\tau > 10^{33} \text{ y}$

$p \rightarrow k^+ \tilde{G}$



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

$$\tau \sim 10^{33} \text{ y} \left(\frac{m_{\nu_2}}{\text{keV}} \frac{0.01}{\delta_{13}} \right)^2$$

$$\mu = 2$$

$$\tau \sim 10^{33} \text{ y} \left(\frac{m_{\nu_2}}{\text{MeV}} \frac{0.01}{\delta_{13}} \right)^2$$

$$\mu = 1$$

proton decay

$$p \rightarrow k^+ \nu$$

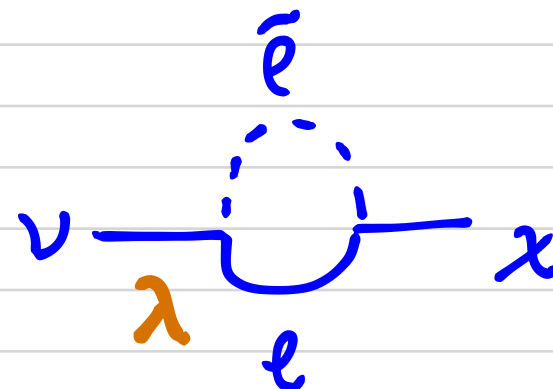
$$\tau > 10^{33} \text{ y}$$

$$p \rightarrow k^+ \nu$$

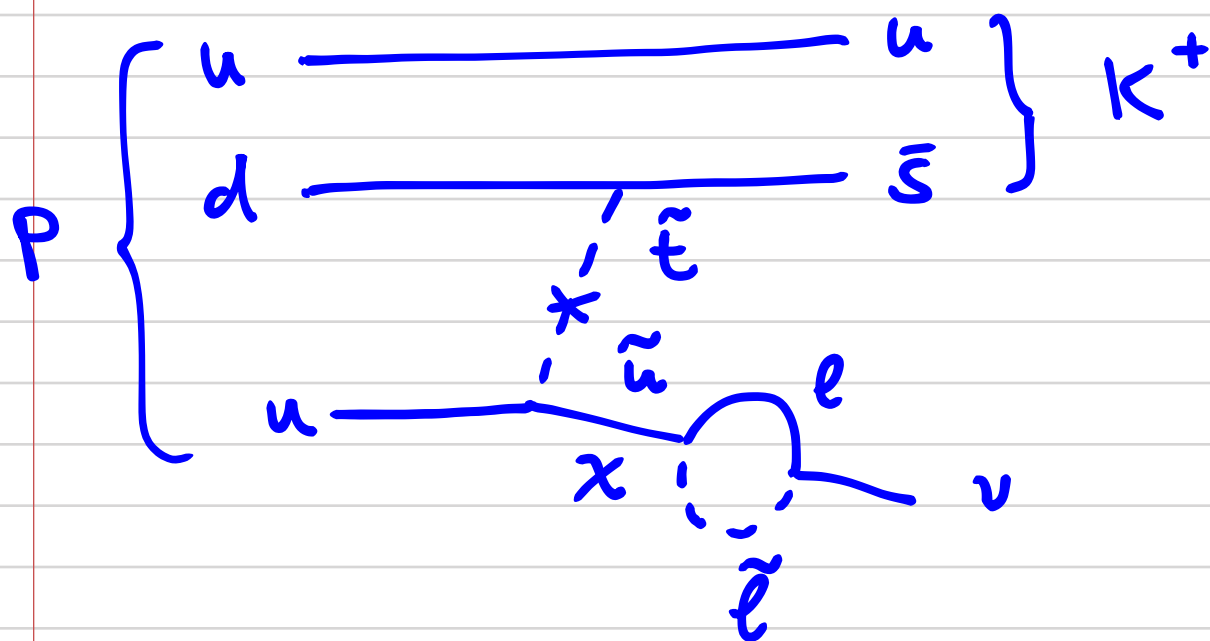
$$W_{RPV}^{\text{mass}} = \lambda_{ijk} L_i L_j e_k^c$$

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

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



LVN GIVES $\nu - x^0$ MIXING



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

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

$$\lambda''_{ijk} \sim V_{il}^{CKM} \left(\frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \right)^\mu \in \mathbb{R}_{ijk}$$

- AN OVERALL FACTOR IS TYPICALLY NOT FIXED

$$\mu = 1 \quad \text{Br}(\tilde{t} \rightarrow bd + bs) \simeq \underline{99\%}$$

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

$$\mu = 1/2 \quad \text{Br}(\tilde{t} \rightarrow bd + bs) \simeq \underline{14\%}$$

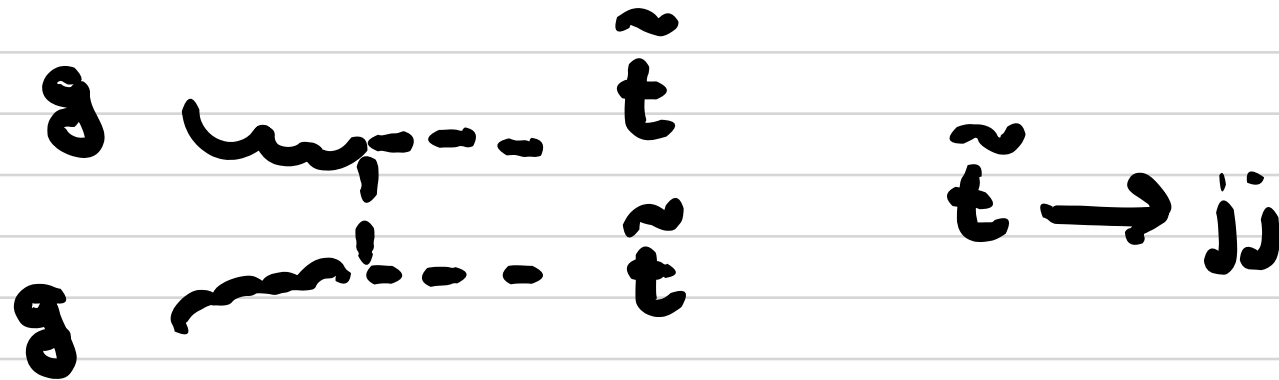
$SU(3)_{\nu, q, e}$

DECAY RATES IN HEAVY FAVOR OF THE STOP/SBOTTOM LSP

$$pp \rightarrow \tilde{t}\tilde{t} \rightarrow \text{jets}$$

RF, TORRE 2012

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

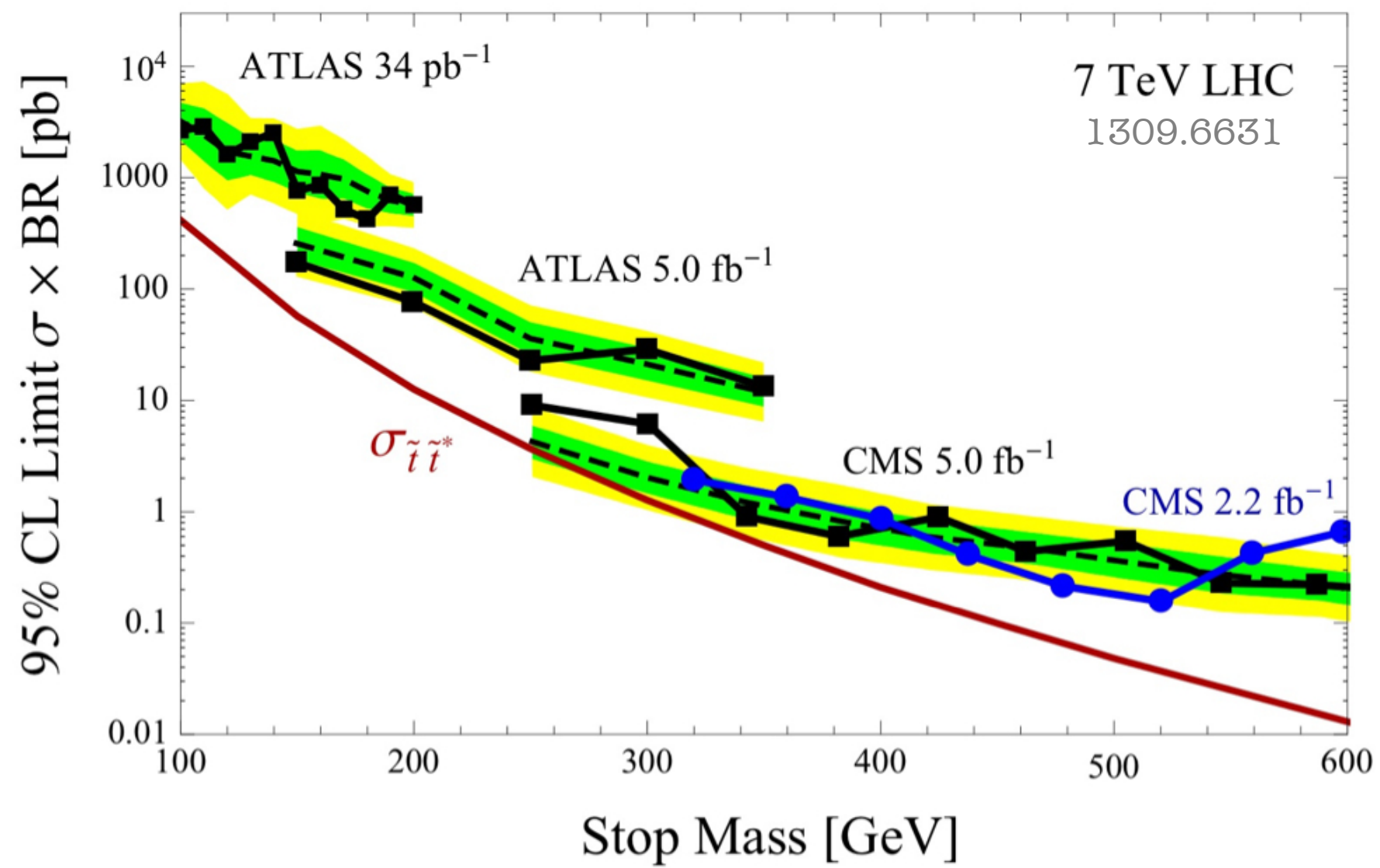


CHALLENGING ESPECIALLY FOR LIGHT $\tilde{t}$

- IN GENERAL FULLY HADRONIC SIGNALS HAVE LARGE BACKGROUNDS FROM

QCD MULTI-JET BACKGROUND

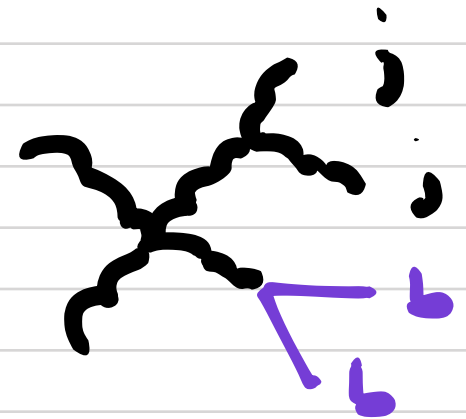
- EVEN TRIGGERING IS AN ISSUE
 - 4 jet $P_T > 85 \text{ GeV}$ @ LHC 8
 - 4 jet $P_T > 45 \text{ GeV}$ "poked"
 - b-trigger
- $\tilde{t} \rightarrow bq$ $q = d, s$
 PROVIDES EXTRA HANDLES B-TAG (TRIGGER & ANALYSIS)



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

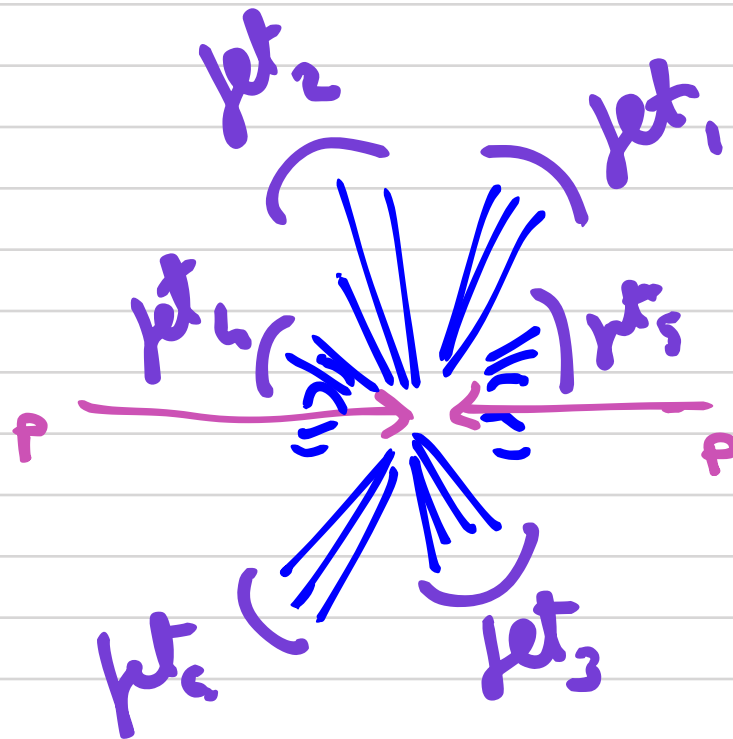
$b\text{-tag} \quad \epsilon \sim 66\% \quad \phi < 10^{-2}$

- $pp \rightarrow \text{jets} \quad \text{QCD} \quad \epsilon \ll 1 \quad \text{BECAUSE ONE FLAVOR}$



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

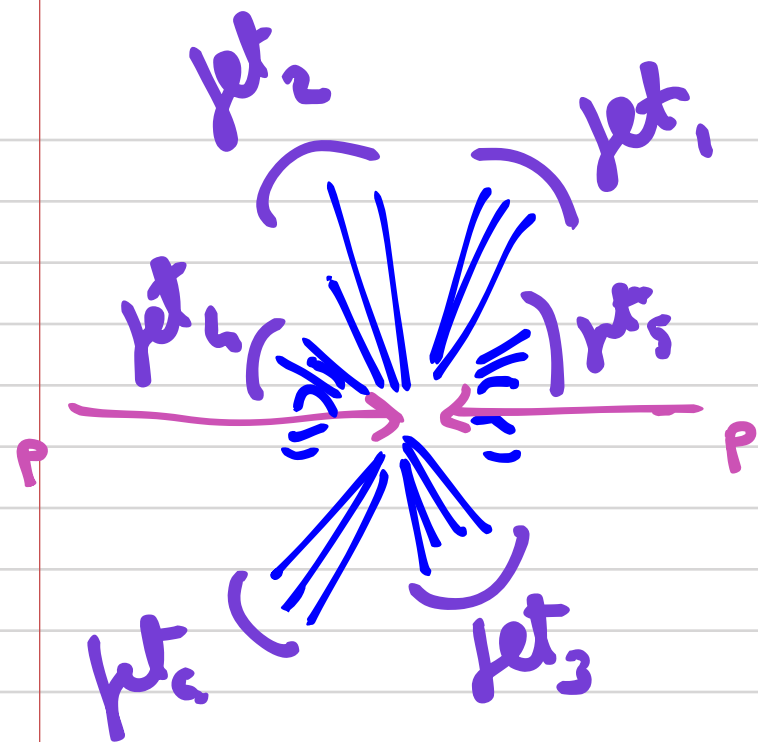
- DOUBLE RESONANCE STRUCTURE



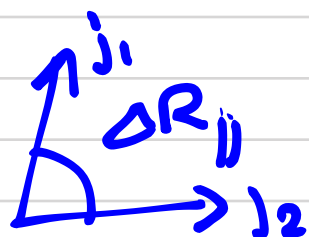
$$\tilde{t} = \text{jet}_k \text{jet}_i$$

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

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



$$m_T^2 \approx P_{T,1} P_{T,2} \Delta R_{12}^2$$



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

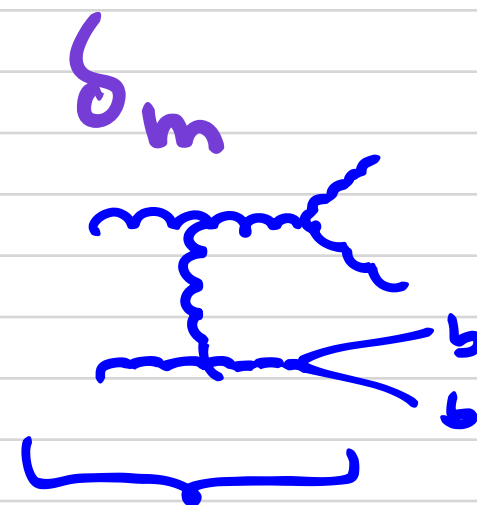
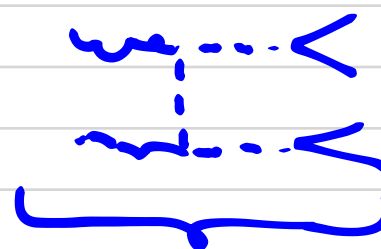
$$P_T \sim m_T$$

$$\Delta R \approx 1$$

• PAIRING BY MINIMIZING $|1 - \Delta R_{12}| + |1 + \Delta R_{34}|$

• RESONANCE CANDIDATES WITH SIMILAR MASS

• HARD vs FORWARD PROCESS



$$\cos \vartheta^*$$

large angle

small angle

• MASS OF THE SIGNAL HAS LITTLE SENSITIVITY TO ΔR

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

$$p_{T,j} > \frac{m_{\tilde{t}}}{2}, \quad |\eta_j| < 2.8, \quad \Delta R_{jj} > 0.7,$$

$$\delta_m < 0.075, \quad |\cos \theta^*| < 0.4, \quad \Delta R_{\text{best}} < 1.5,$$

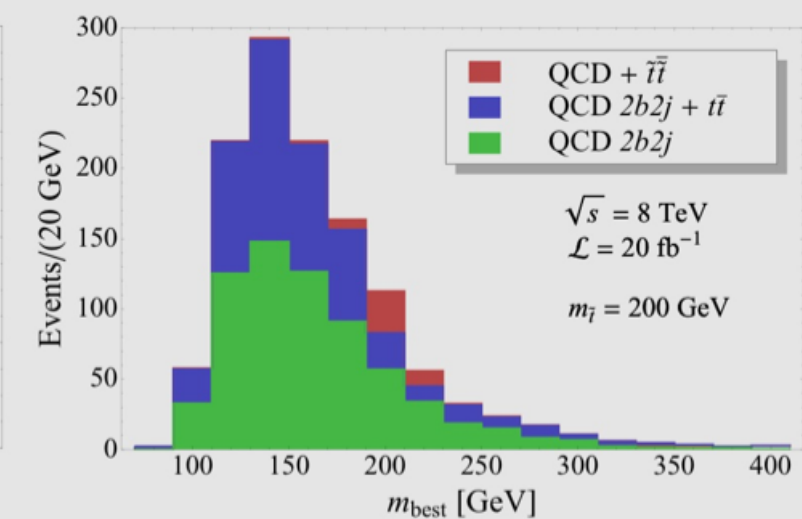
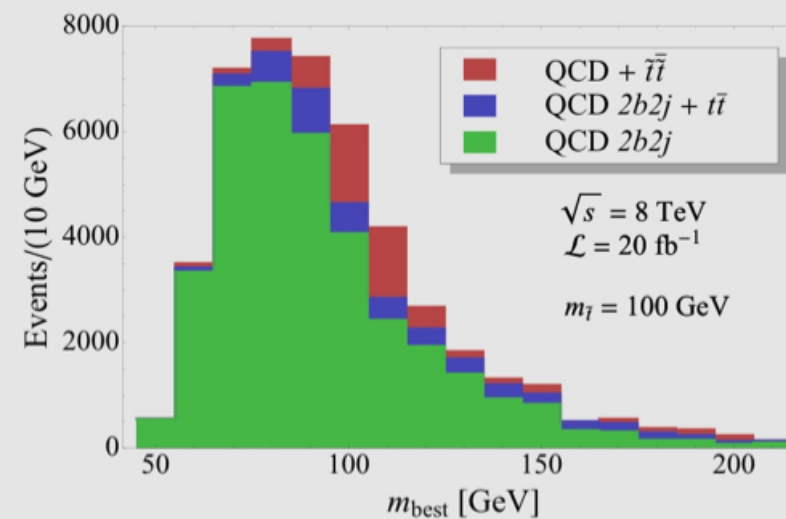
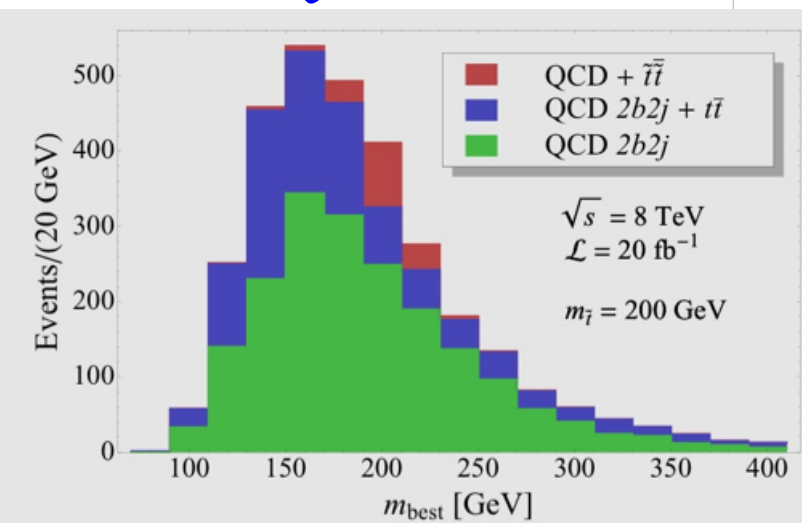
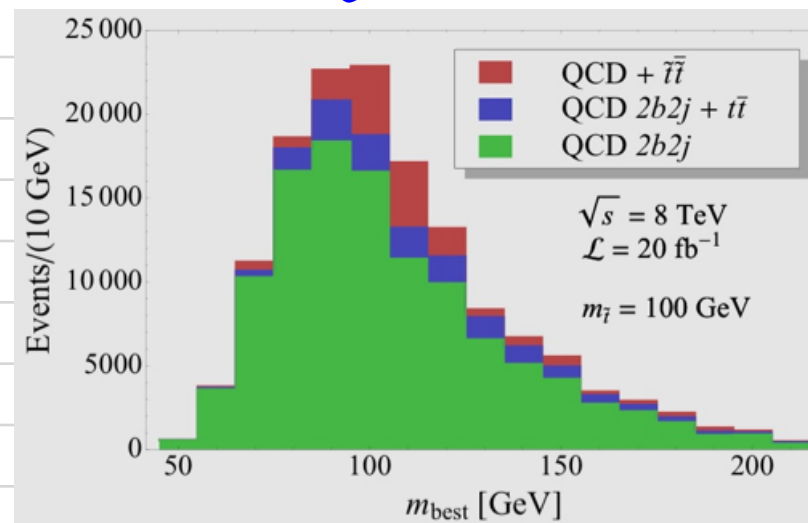
$$\Delta \eta_{\text{best}} < 0.8.$$

ENFORCING LOOSELY COUNTER JETS
IN THE RESONANCE CANDIDATE

ENFORCING MORE COUNTER JETS
IN THE RESONANCE CANDIDATE

$$m_{\tilde{t}} = 100 \text{ GeV}$$

$$m_{\tilde{t}} = 200 \text{ GeV}$$



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

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

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

$$\lambda''_{ijk} \sim V_{il}^{cen} \left(\frac{m_{u_i} m_{d_j} m_{d_k}}{m_t^3} \right)^\mu \in \mathbb{R}_{jk}$$

$$\mu = 1, 1/2$$

•) CHALLENGING LIGHT SQUARK SCENARIO

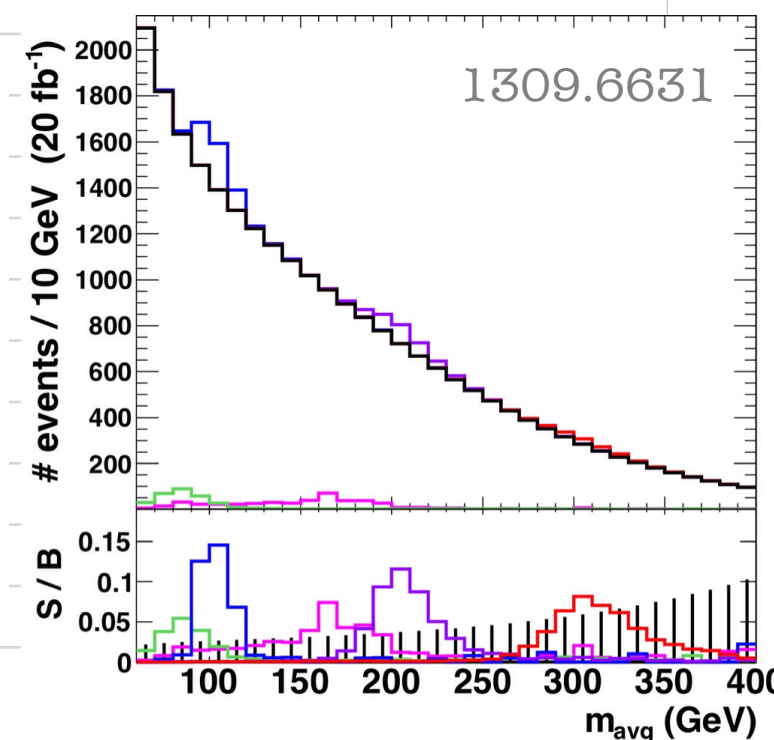
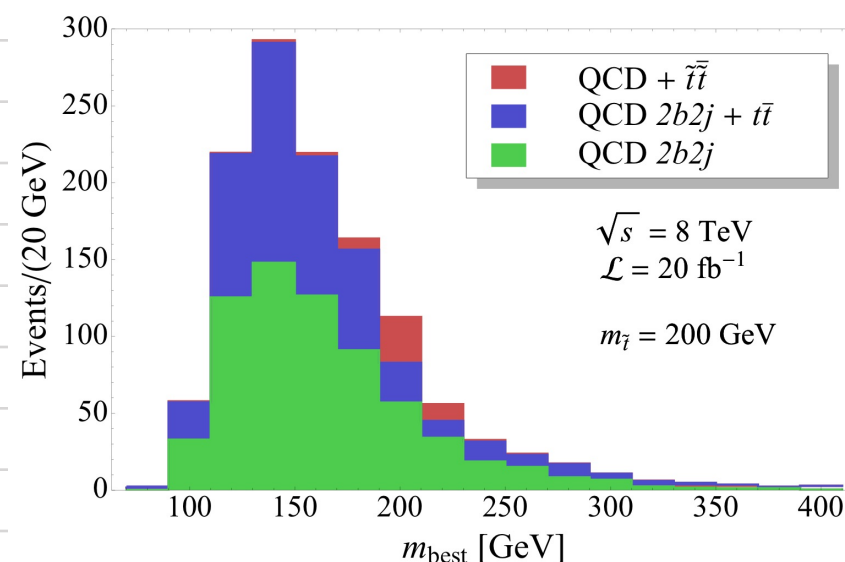
$\begin{array}{c} \text{---} \hat{g}, \hat{t}, \hat{q}_3 \\ \vdots \\ \text{---} \tilde{t}_R \end{array}$
 PAIR STOP PRODUCTION $\tilde{t} \rightarrow q\bar{q}$

$B_r(\tilde{t} \rightarrow b\bar{d} + b\bar{s}) \approx \underline{99\%}$
 $\left\{ \begin{array}{l} SU(3)_{Q,U,D,s,u,c,v} \\ SU(3)_{Q,Q^c,L,L^c} \\ \text{PARTIAL COMPOSITENESS} \end{array} \right\} \mu=1$

$B_r(\tilde{t} \rightarrow b\bar{d} + b\bar{s}) \approx \underline{14\%}$
 $\leftarrow SU(3)_{V,q,e} \mu=\frac{1}{2}$

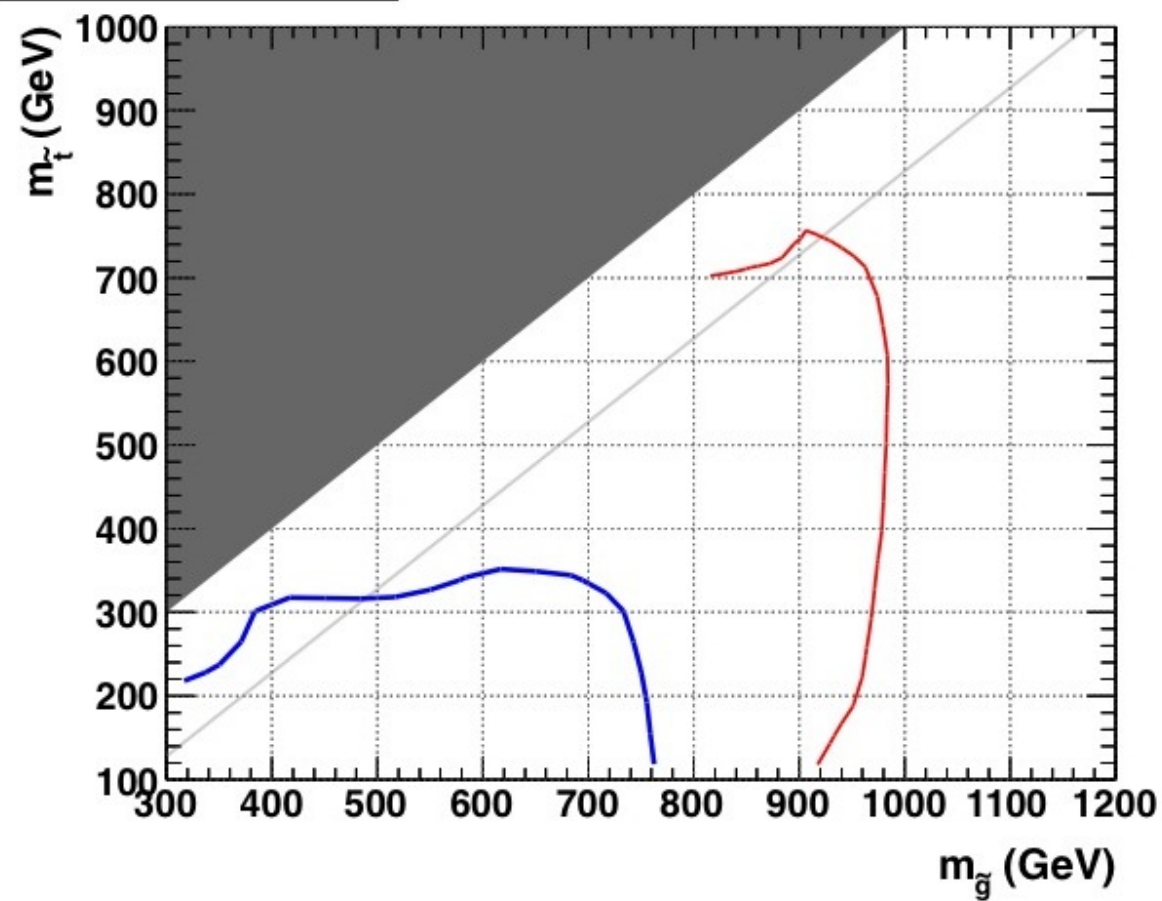
LHC CAN TELL

$pp \rightarrow \tilde{t}\tilde{t} \rightarrow b\bar{b}q\bar{q}$
 $pp \rightarrow \tilde{t}\tilde{t} \rightarrow 4j$

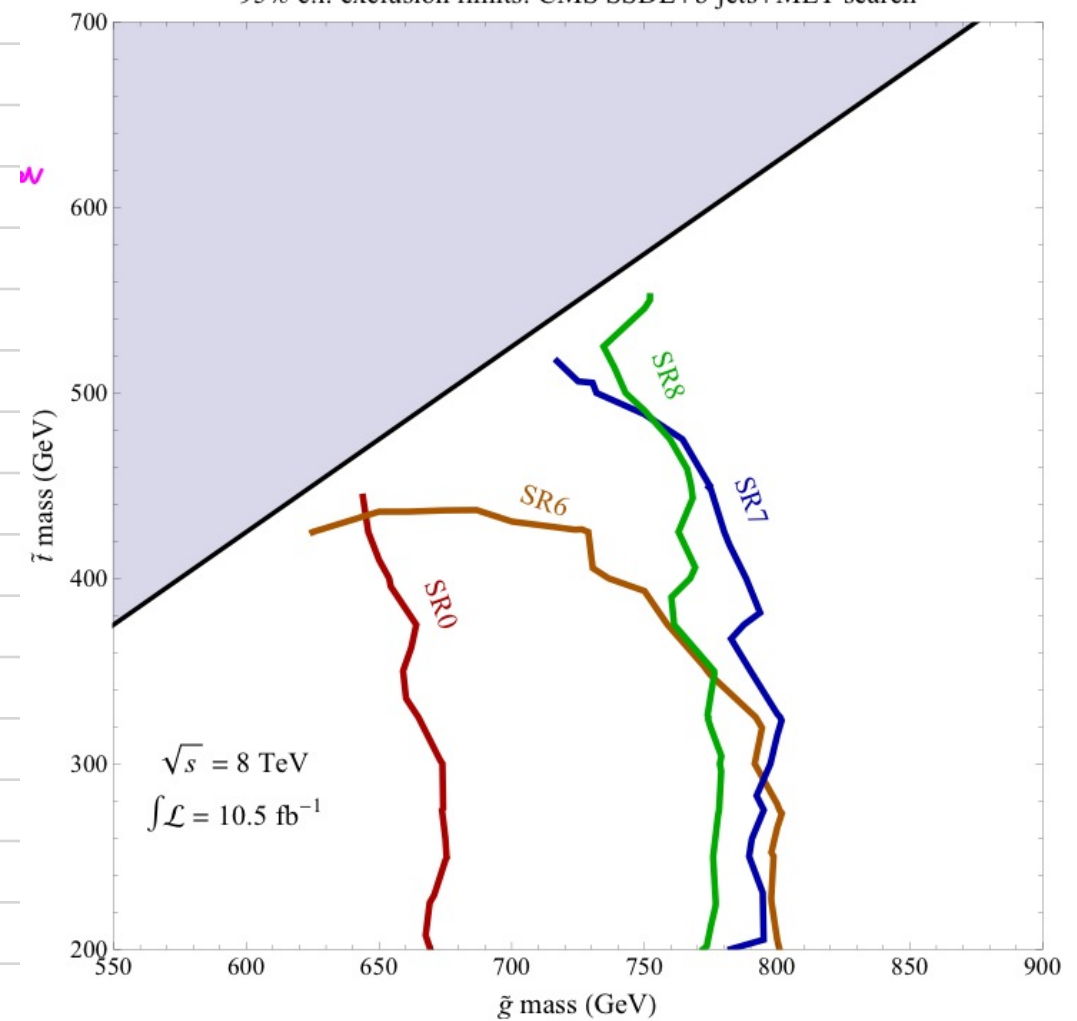


SAME SIGN DILEPTIONS (+b)

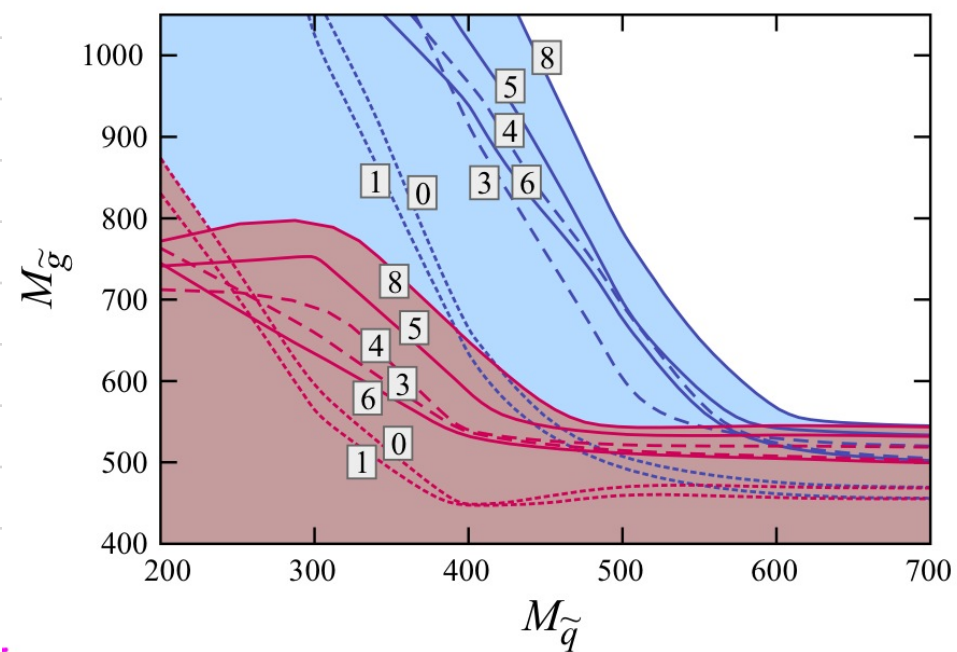
Majorana gluino



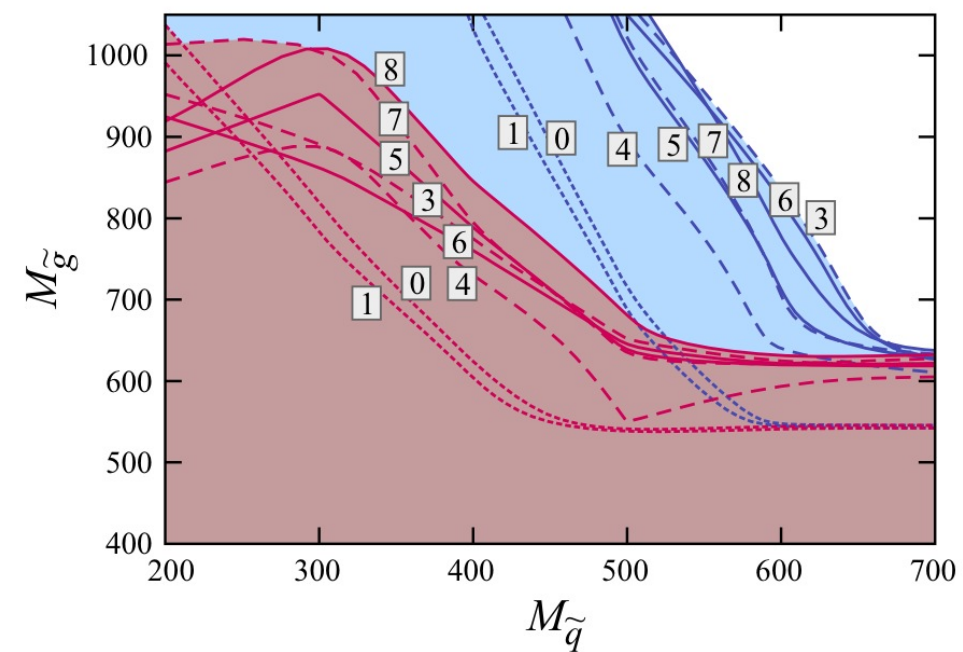
95% c.l. exclusion limits: CMS SSDL+b jets+MET search



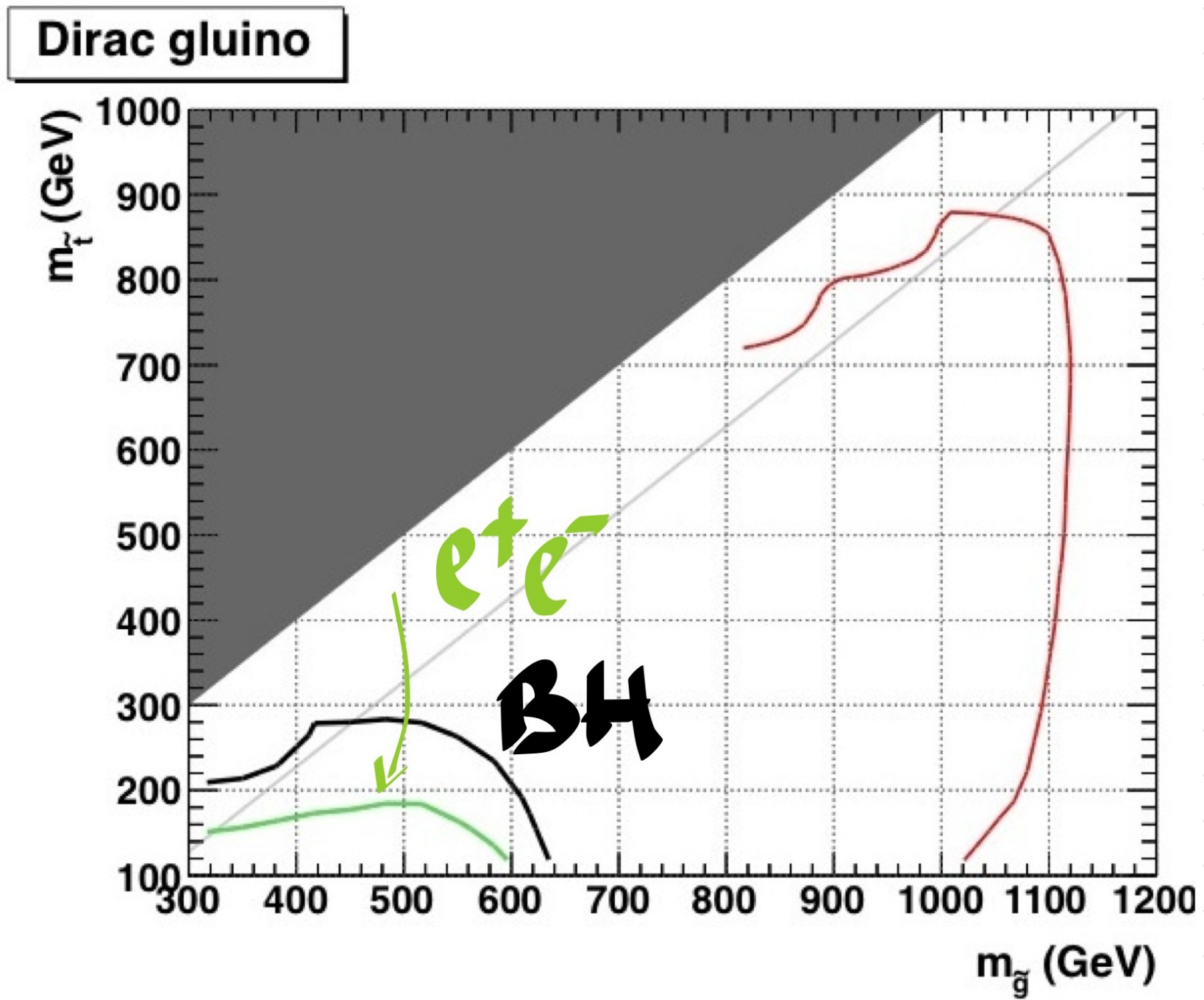
Full MFV



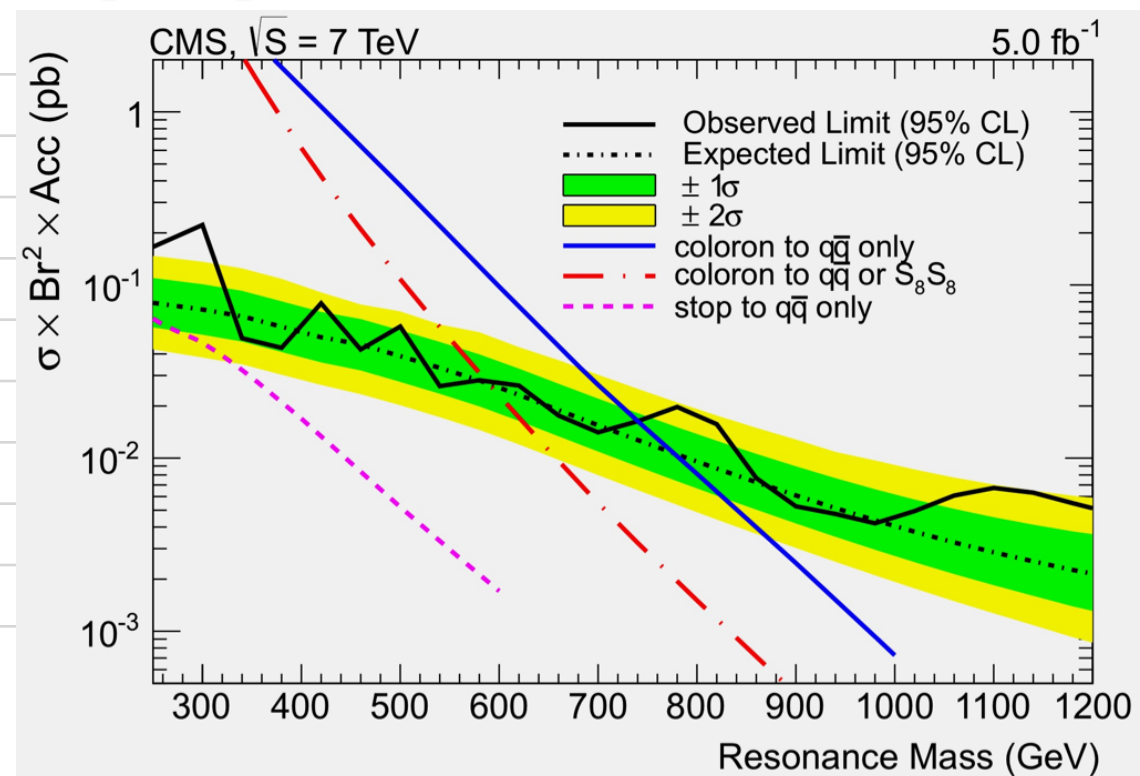
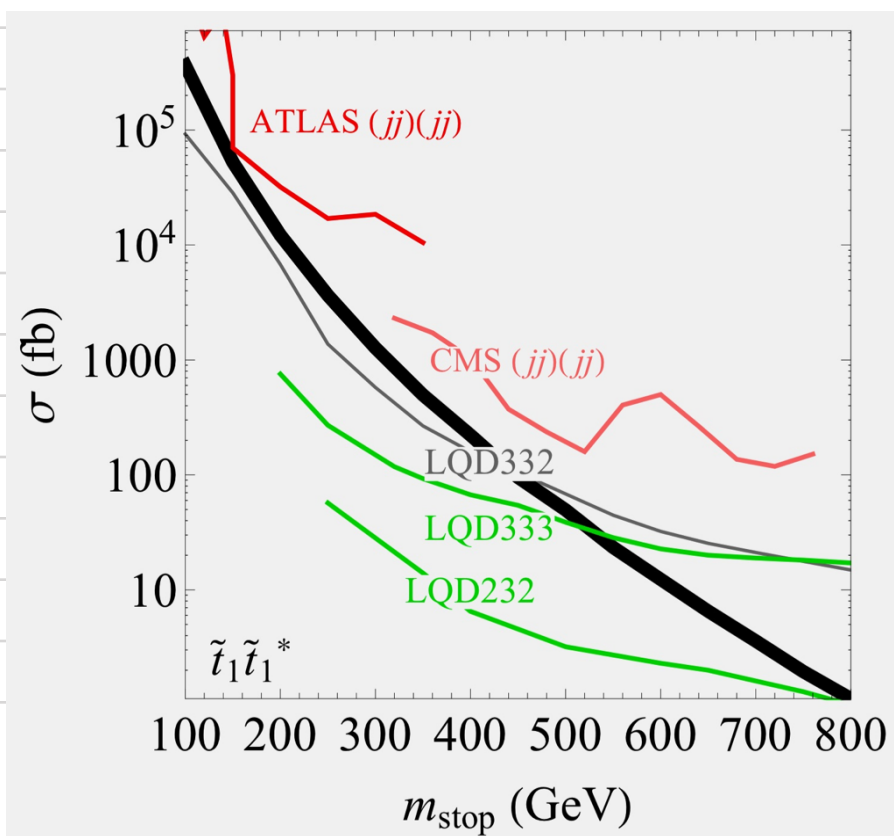
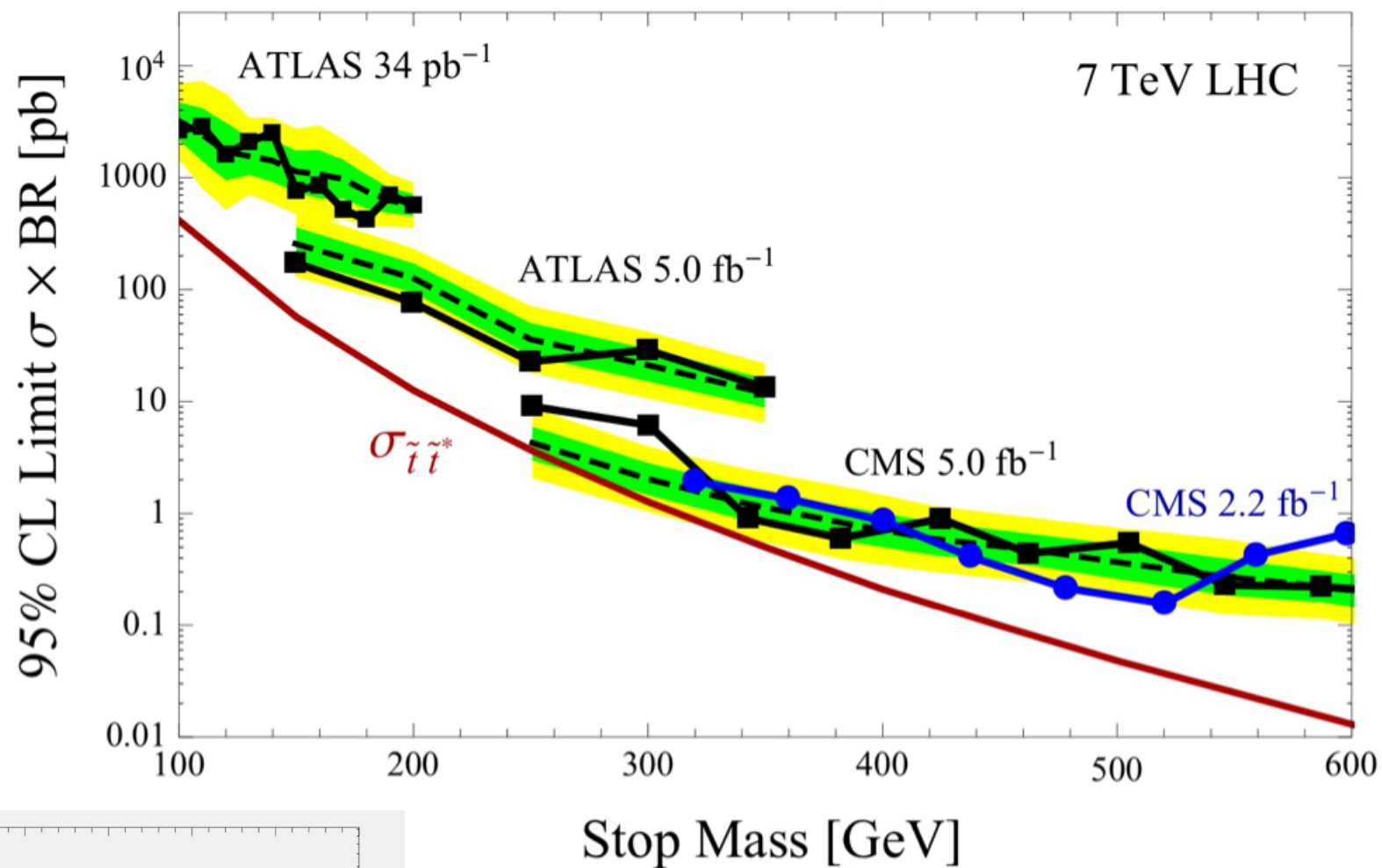
Holomorphic MFV



DIRAC GLUINO



PAIRED DIJET $\tilde{q} \rightarrow j\bar{j}$



PAIRED $\tilde{g} \rightarrow j\bar{j}$

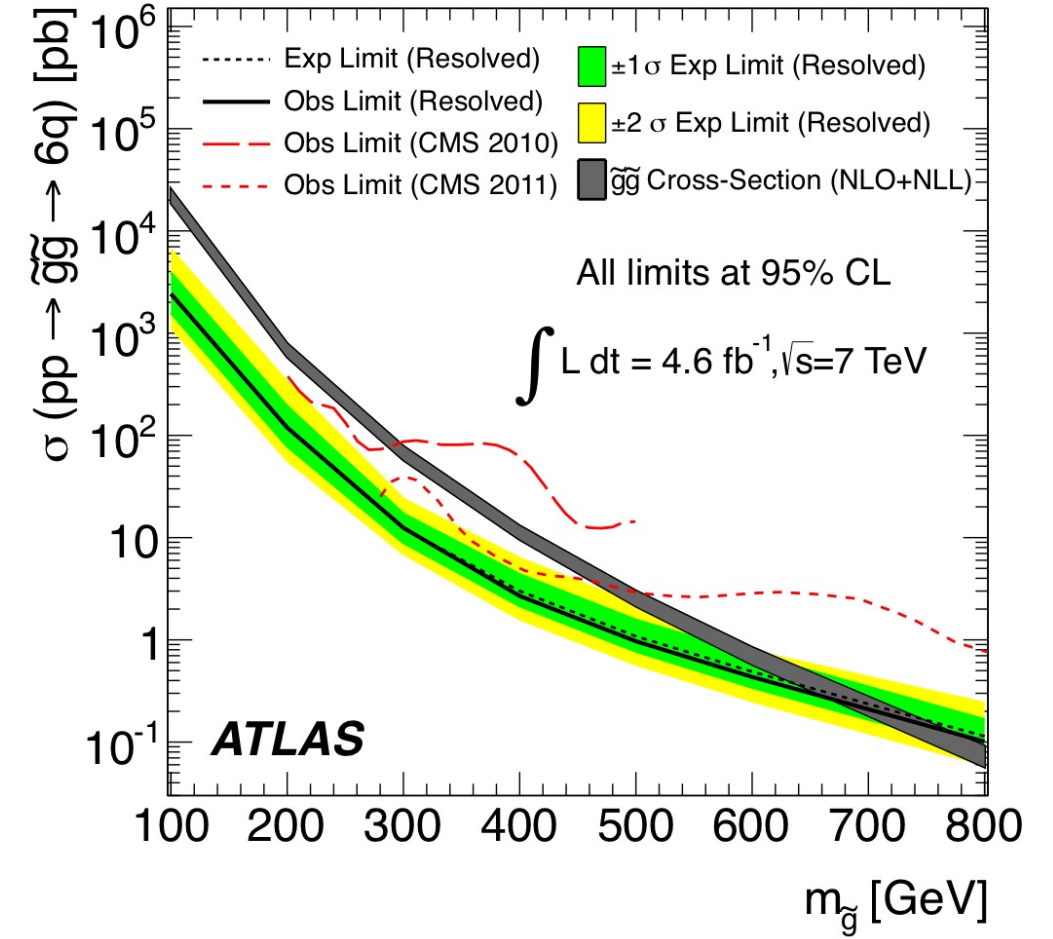
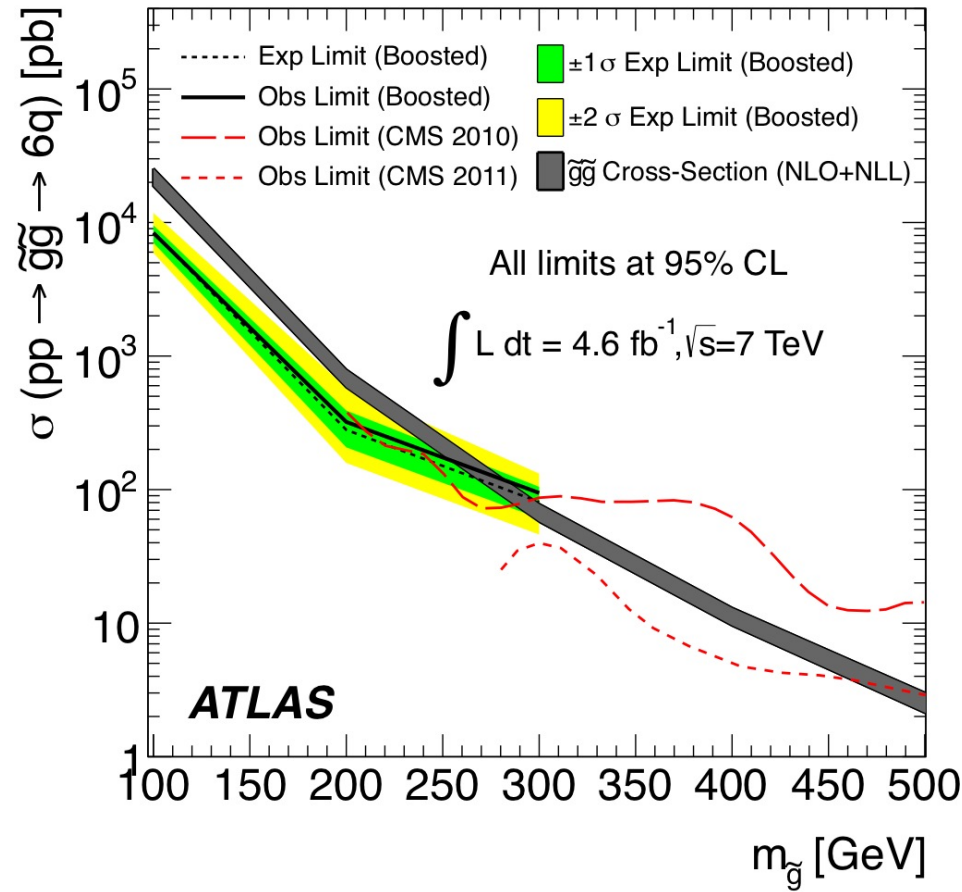


Figure 6. The expected and observed 95% confidence limits are shown for the boosted analyses channel. The published CMS results using 35 pb^{-1} of 2010 data and using 5 fb^{-1} of 2011 data are shown for comparison.

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.

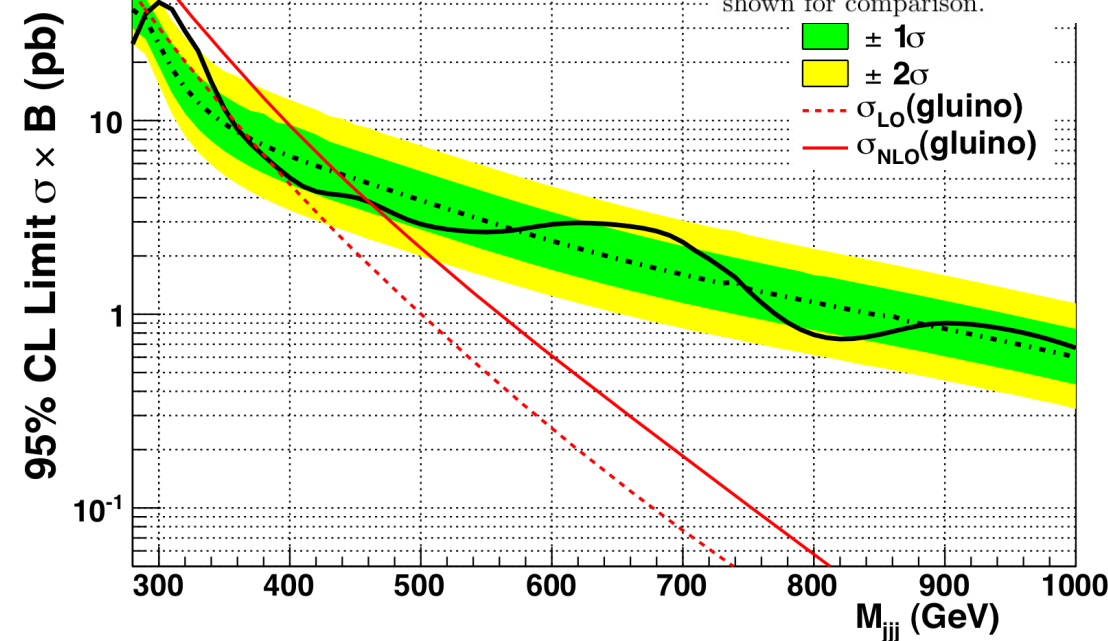


Figure 4: Observed and expected 95% CL upper limits on the cross section times branching fraction for gluino pair production followed by RPV decay of each gluino to three light-flavored quark jets. Also shown are the $\pm 1\sigma$ and $\pm 2\sigma$ bands on the expected limit, as well as the theoretical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

HIGH MULTIPLICITY FINAL STATES

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

1207.5787

● SUBSTRUCTURE BY ACCIDENT, JET MAX OBSERVABLES

1212.1456, 1302.1870