Searches for R-parity-violating SUSY at CMS

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Outline

Will present 8 TeV analyses sensitive to different terms in RPV superpotential*:

$$W_{\mathrm{RPV}} = \frac{1}{2}\lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \frac{1}{2}\lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k + \mu'_i H_u L_i$$

i,j,k=generation indices

- Multilepton search with strong production
- Multilepton search with electroweak production
- Dilepton, single lepton and fully hadronic searches

Conclude with commissioning results at 13 TeV relevant for 2015 RPV analyses

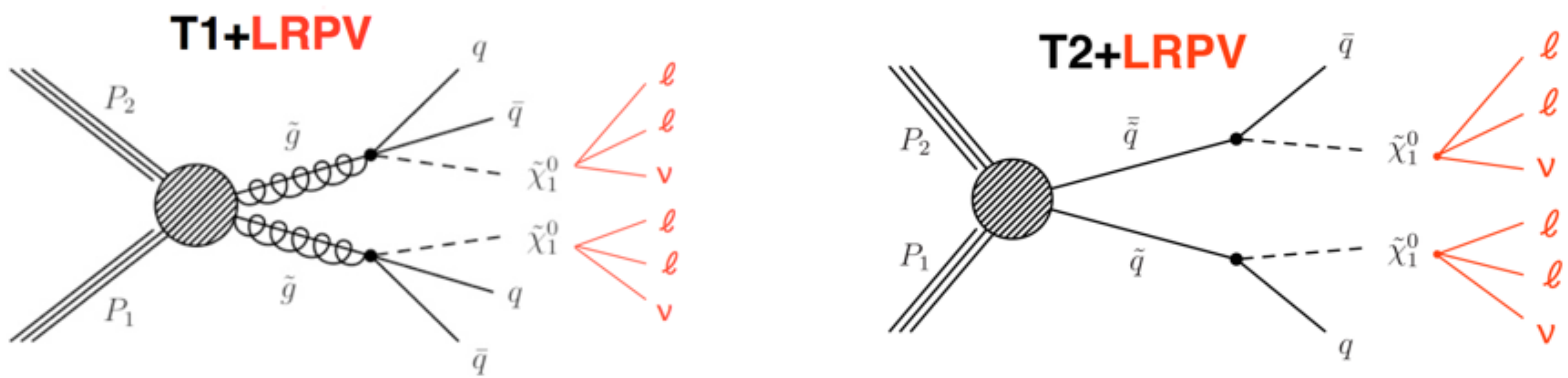
* For a review, see i.e. Phys. Rept. 420 (2005) 1

Leptonic RPV

$$\frac{1}{2}\lambda_{ijk}L_iL_j\overline{E}_k$$

Multilepton analyses with strong production sensitive to fully leptonic RPV

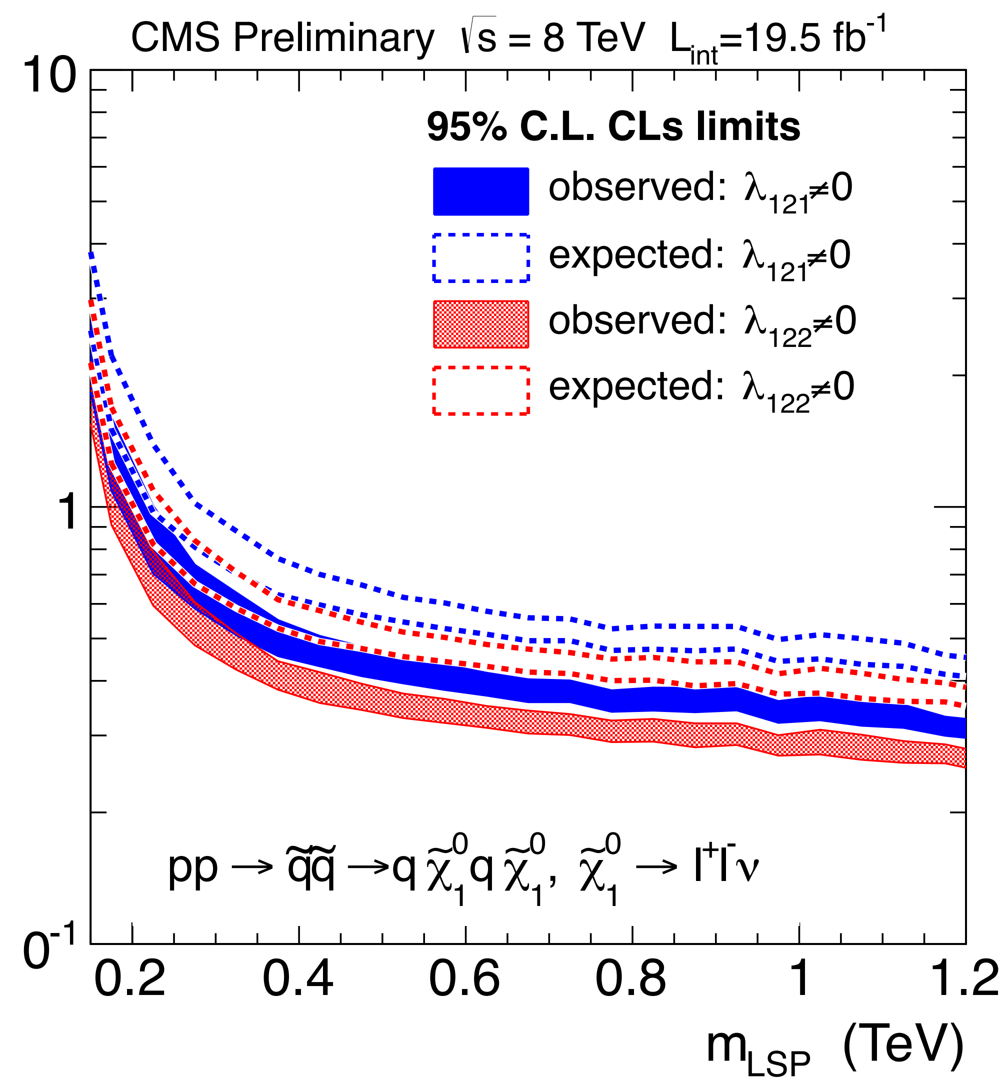
Multilepton search for squarks and gluinos



- Requirement of four isolated leptons is the only selection
- Search in M_1:M_2 plane where
  - M_1=invariant mass of lepton pair that is closest to Z mass
  - M_2=invariant mass of other lepton pair

Multilepton analysis with strong production

		$M_1 < 75$ GeV	$75 < M_1 < 105$ GeV	$M_1 > 105$ GeV
$M_2 > 105$ GeV	ZZ	0.76±0.18	15±4	0.30±0.07
	rare	0.28±0.13	2.7±1.0	0.12±0.05
	non-prompt	0.4±0.4	0.7±0.7	0.05±0.05
	all backgrounds	1.4±0.5	18±4	0.47±0.10
	observed	0	20	0
$75 < M_2 < 105$ GeV	ZZ	0.10±0.03	150*	0.05±0.01
	rare	0.12±0.05	2.5±1.2	0.06±0.03
	non-prompt	0.3±0.3	0.6±0.6	0.05±0.05
	all backgrounds	0.52±0.34	153*	0.16±0.06
	observed	0	160	0
$M_2 < 75$ GeV	ZZ	9.8±2.0	32±8	0.98±0.20
	rare	0.31±0.14	2.5±1.2	0.011±0.005
	non-prompt	0.3±0.3	0.8±0.8	0.06±0.06
	all backgrounds	10.4±2.0	35±8	1.0±0.2
	observed	14	30	1



- ZZ→4ℓ contribution normalized to CMS σ(ZZ) measurement
- Rare backgrounds (WWtt̄, WWZ, WZZ, ZZZ, tt̄Z) taken from MC
- Jet-as-lepton fake rate evaluated in a control sample with three identified leptons

Cross section limits calculated for $\lambda_{121}\neq0$ and $\lambda_{122}\neq0$ models

CMS-PAS-SUS-13-010

Semileptonic RPV

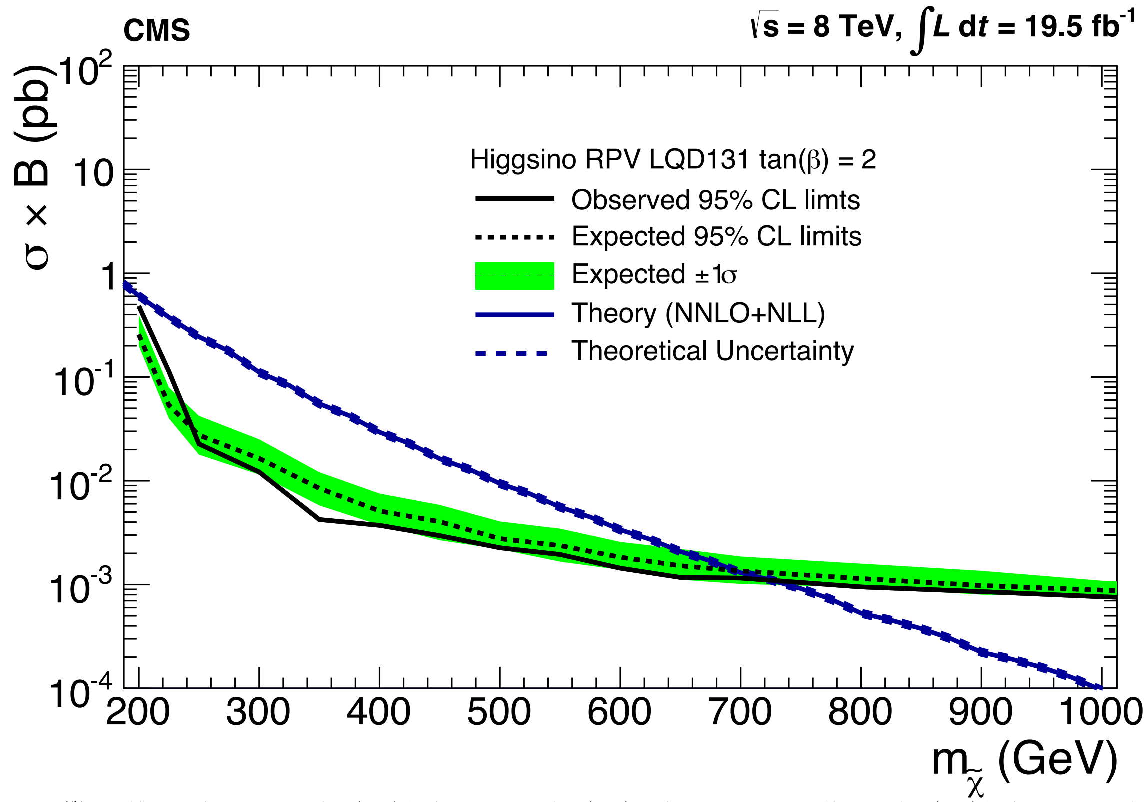
$$\lambda'_{ijk} L_i Q_j \overline{D}_k$$

Multilepton analyses with electroweak production sensitive to semileptonic RPV

Multilepton search for Higgsinos and winos

- Select:
  - ≥3 leptons (incl. taus), veto low m_{ll}
- Background
  - WZ and ZZ from MC, validated in data control samples
  - Mis-identified leptons evaluated from data
- 32 exclusive signal bins in m_{ll}, N_b, N_τ, and S_T=scalar sum of jet and lepton p_T
- Large number of constraints on both LLE and LQD interactions depending on:
  - Type of lepton in the final state
  - State (Higgsino or wino) that is pair-produced

LQD131, tanβ=2



Limits tanβ-dependent due to Higgsino
Full set of limits on LQD and LLE interactions in backup

PRL 111 (2013) 221801

Hadronic RPV

$$\frac{1}{2}\lambda''_{ijk}\overline{U}_i\overline{D}_j\overline{D}_k$$

Dilepton, single lepton and fully hadronic analyses sensitive to hadronic RPV

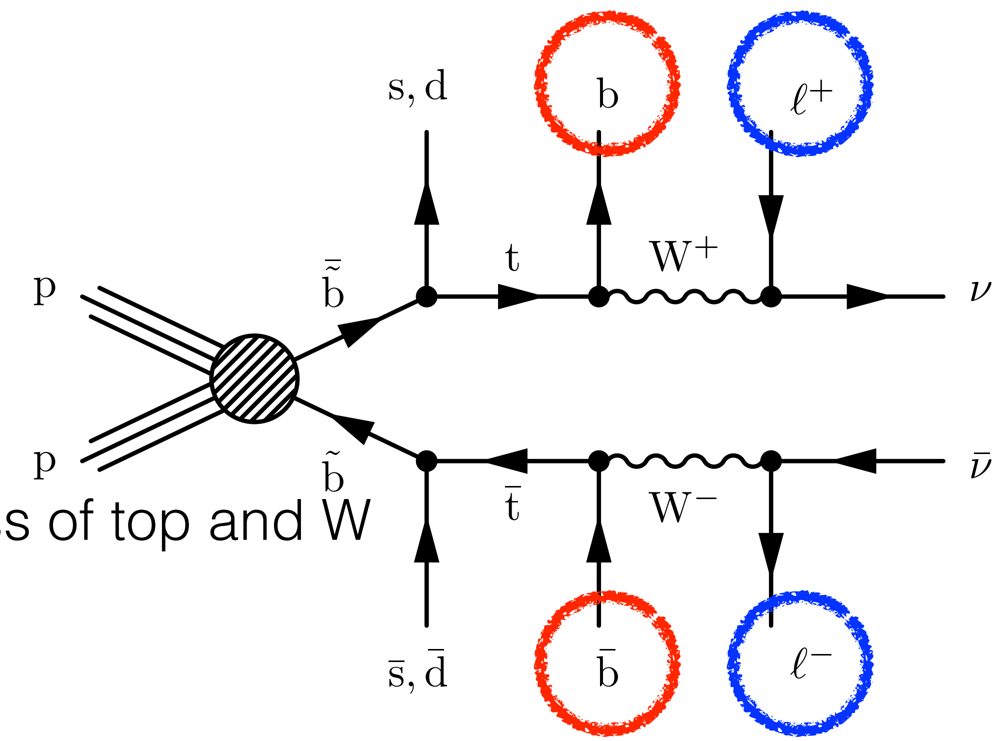
Motivation for hadronic RPV

- Hadronic RPV less constrained by proton decay and neutrino measurements
- Minimal flavor violation* results in a hierarchy of RPV couplings from Yukawa couplings
- λ''_{323} is the largest RPV coupling in some of these models

* E. Nikolidakis and C. Smith, PRD 77 (2008) 15021
C. Csaki, Y. Grossman, and B. Heidenreich, PRD 85 (2012) 095009

Sbottom mass reconstruction in dilepton final state

- Require
  - ≥2 isolated leptons
  - ≥2 loose b-tags (with at least 1 medium)
- Use MET to solve for neutrino 4-momenta, assuming mass of top and W
- Combine with light jet to find sbottom mass



Both light jets arising from sbottom→ts pair production have high p_T, depending on sbottom mass⇒fit as function of mass and p_T of two lead jets:

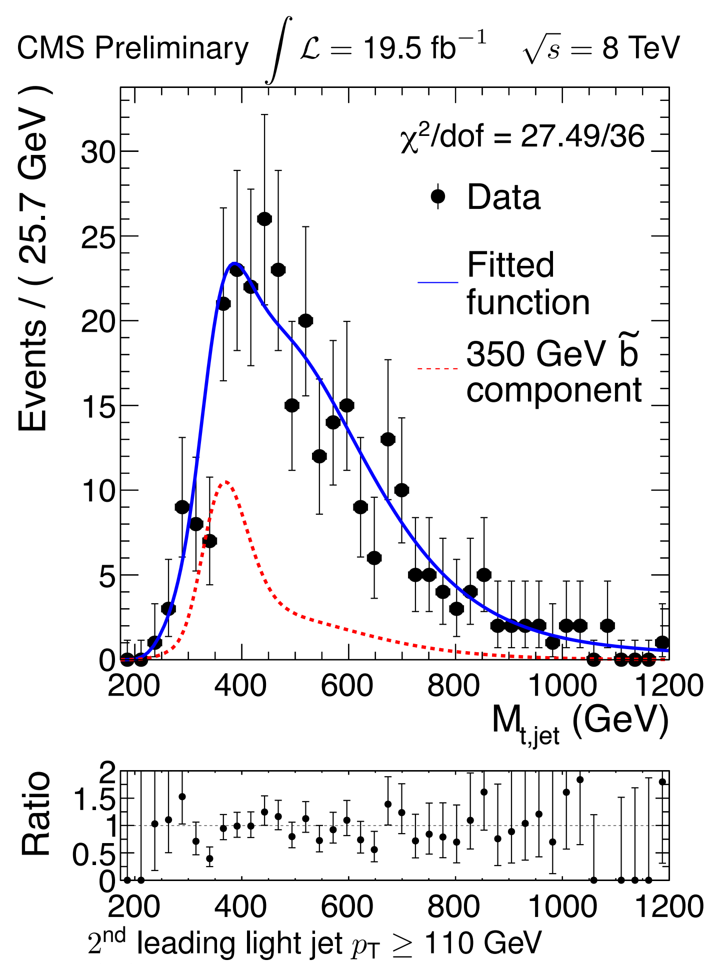
$$\rho^{SM}_{3D}(m, p_T^{(1)}, p_T^{(2)}) = \rho^{SM}_{mass}(m|p_T^{(2)})\rho^{SM}_{2D}(p_T^{(1)}, p_T^{(2)})$$

$$\rho^{signal}_{3D}(m, p_T^{(1)}, p_T^{(2)}) = \rho^{signal}_{mass}(m|p_T^{(2)})\rho^{signal}_{2D}(p_T^{(1)}, p_T^{(2)})$$

CMS-PAS-B2G-12-008

Dilepton final state: results

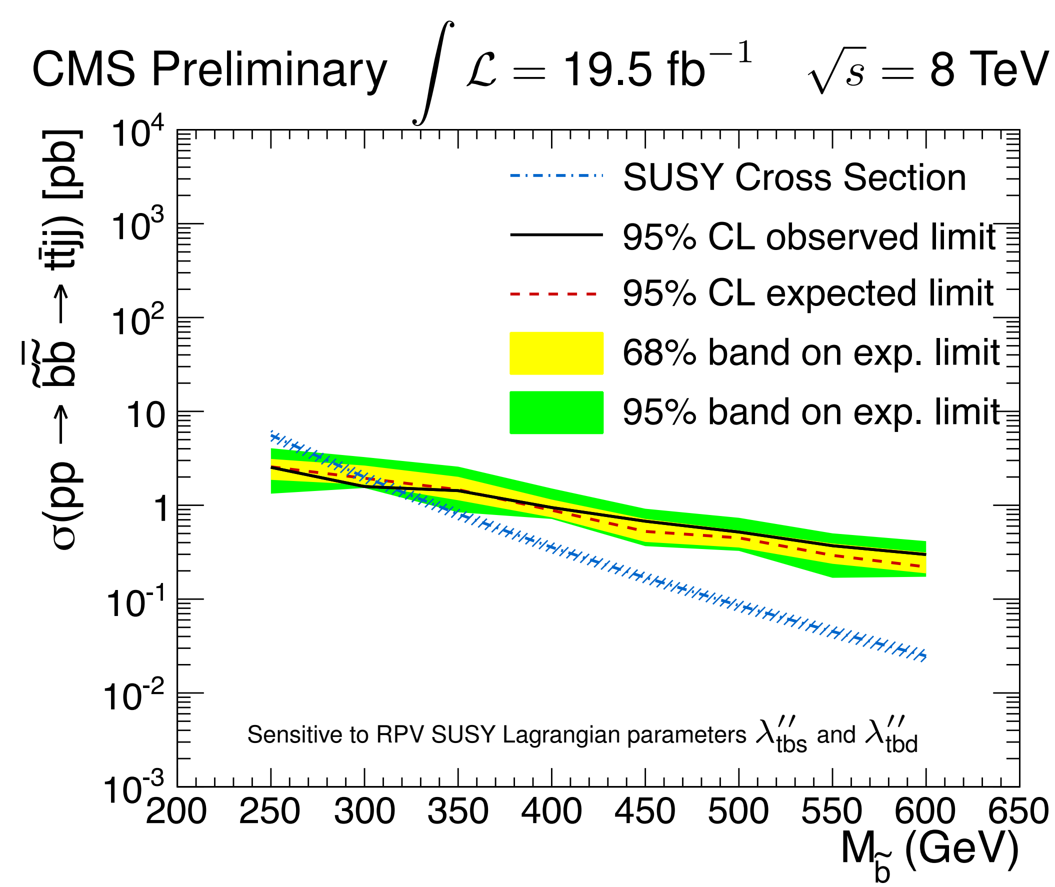
Projection of a typical fit onto sbottom mass axis



Sensitivity to increasing sbottom mass

Signal regions

Second-leading light jet p_T	Region
30 to 50 GeV	control region (CR)
50 to 80 GeV	signal region 1 (SR1)
80 to 110 GeV	signal region 2 (SR2)
$>$ 110 GeV	signal region 3 (SR3)



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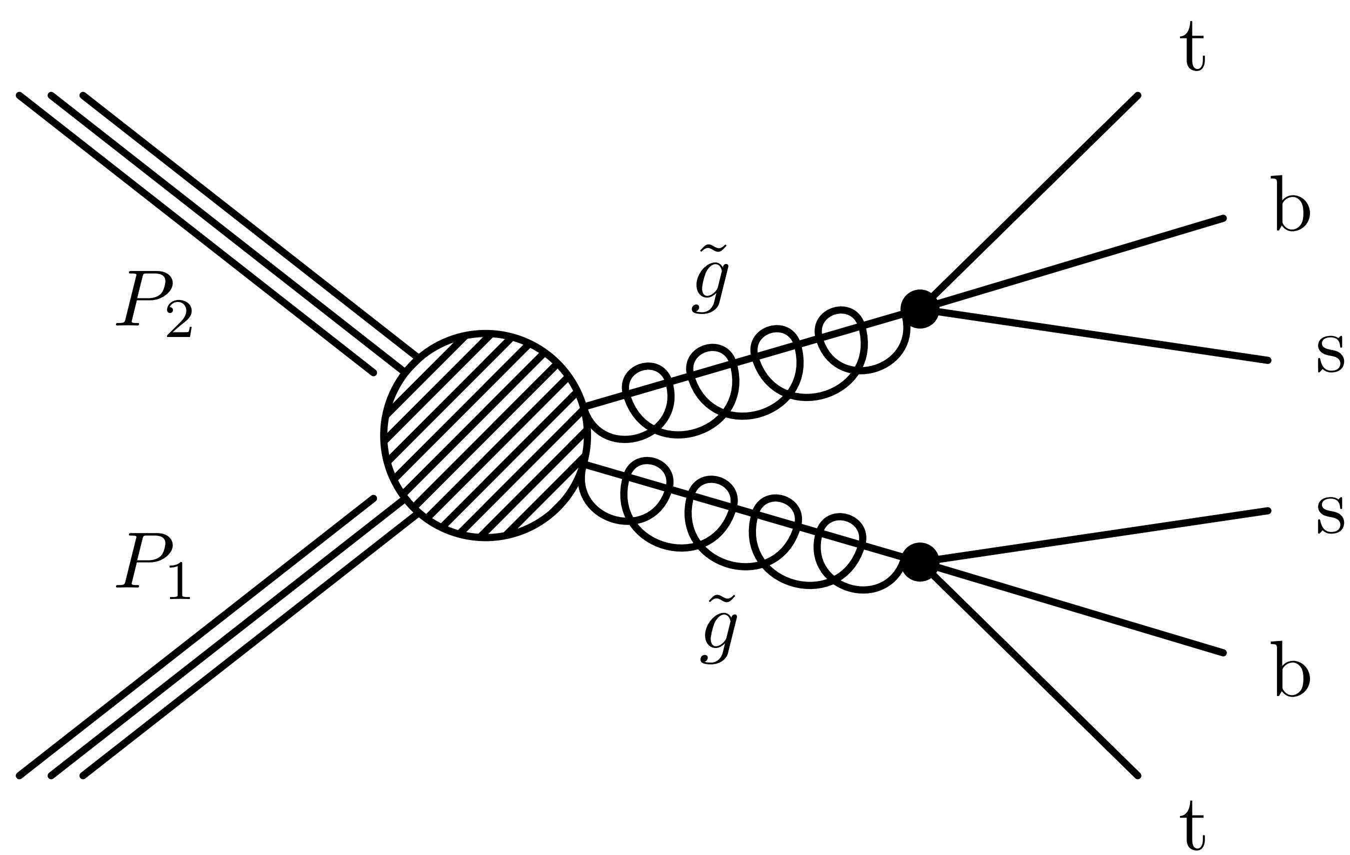
gluino→tbs



4 b's,
up to 10 jets

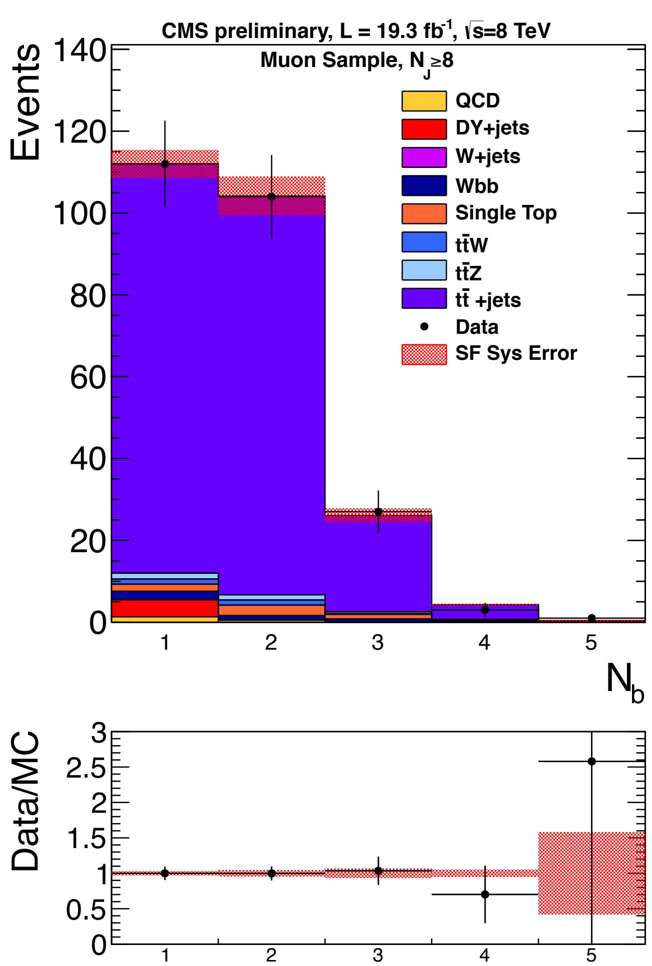
- The single lepton and hadronic analyses are interpreted with the gluino→tbs final state
- Sensitive to λ''_{tbs}

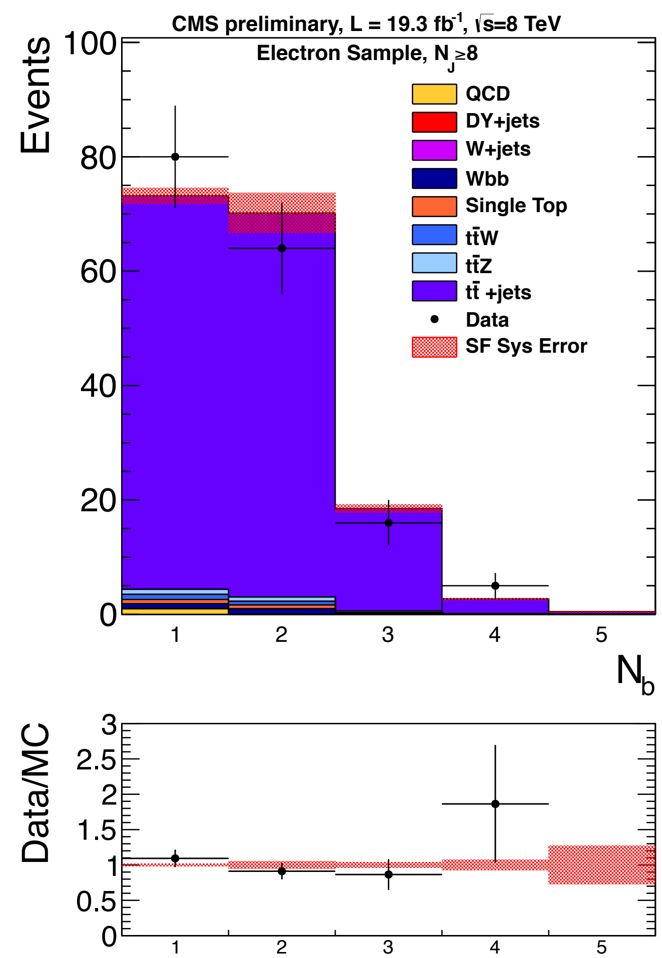
One-lepton final state

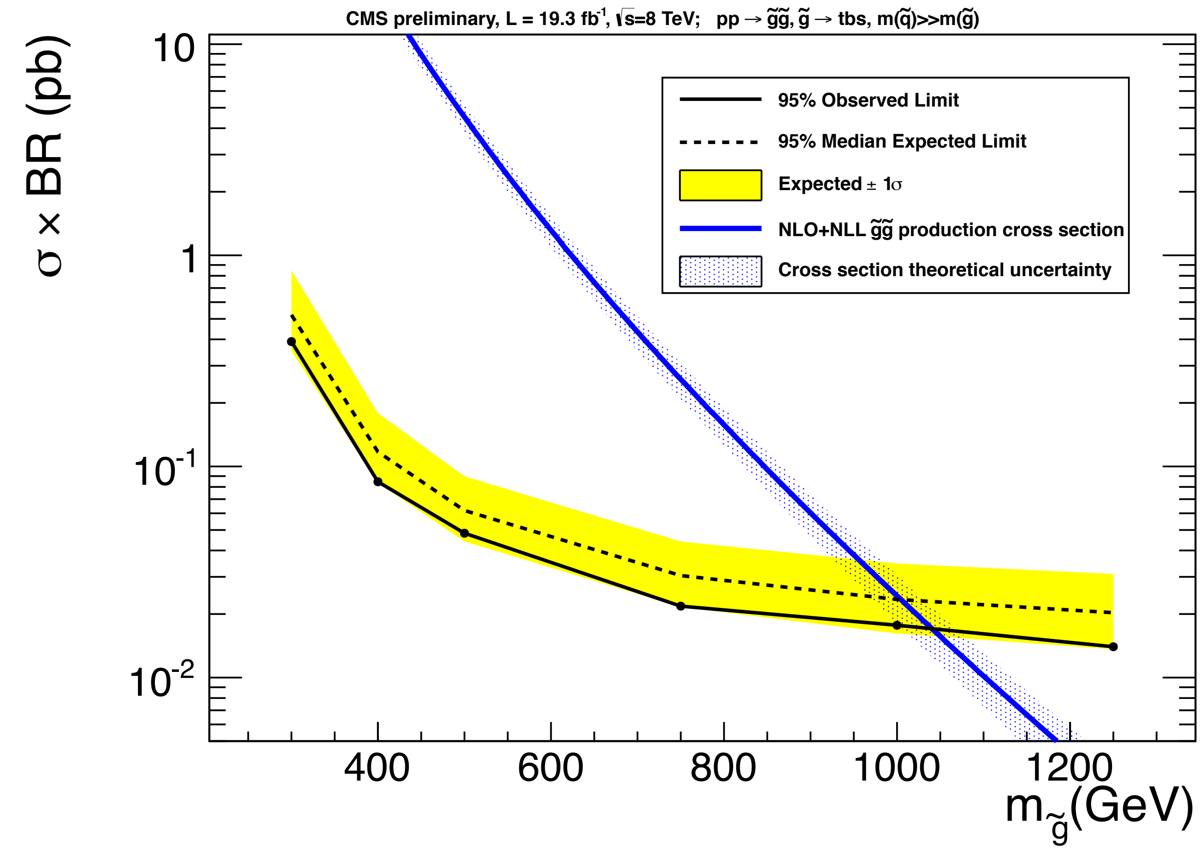
Muon, N_{jet}≥8

Electron, N_{jet}≥8

Exclude m_{gluino}<1.04 TeV







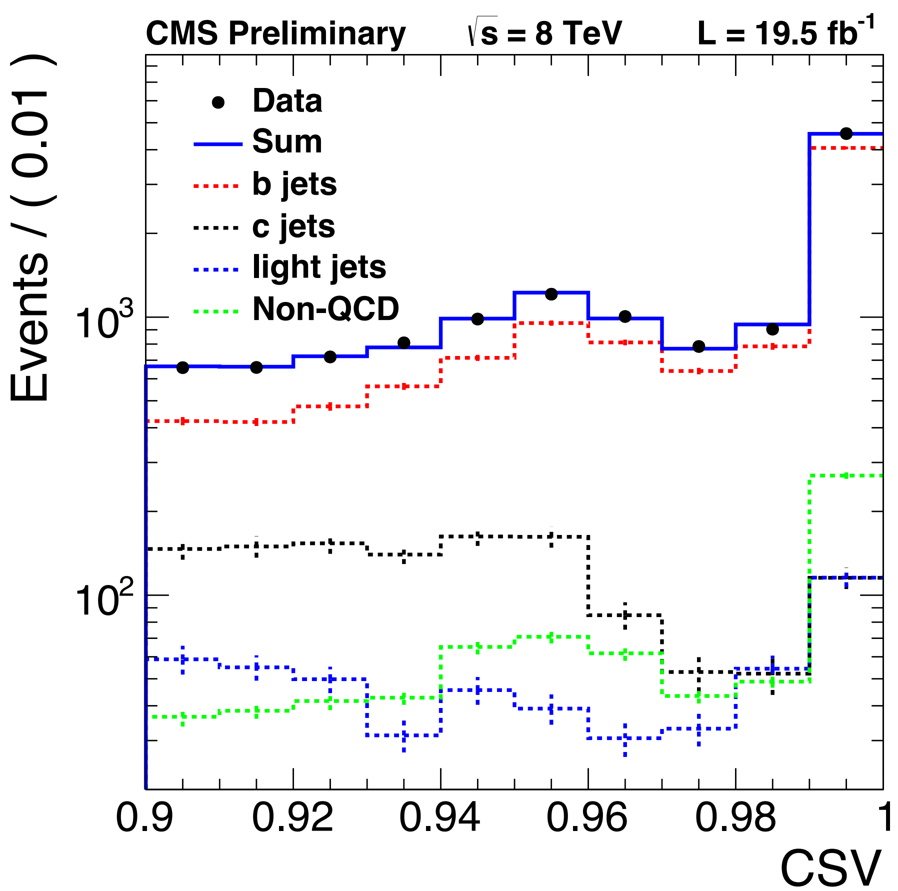
- Template fit of N_b distribution in three bins of N_{jet} (6, 7, ≥8)
- Gluon splitting contribution corrected with e+μ control sample at low N_{jet}

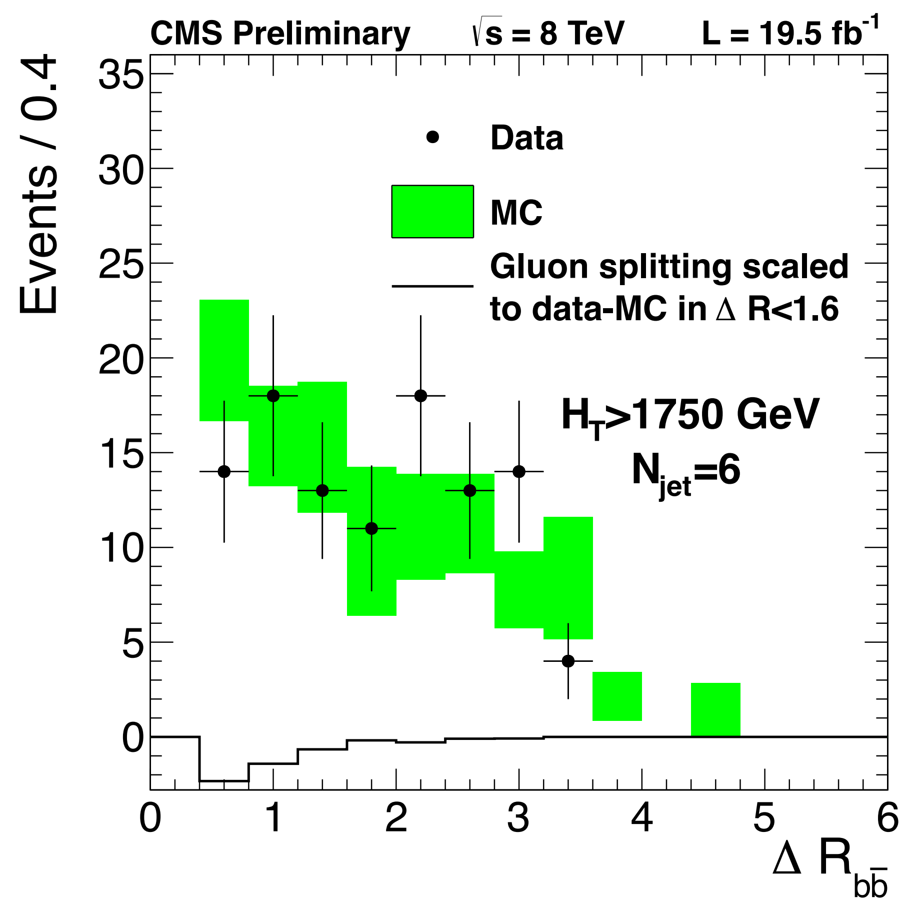
CMS-PAS-SUS-12-015

New

Fully hadronic final state

Data used to correct N_b distributions from MC





Modeling of QCD flavor composition corrected based on fit to b-tag discriminant

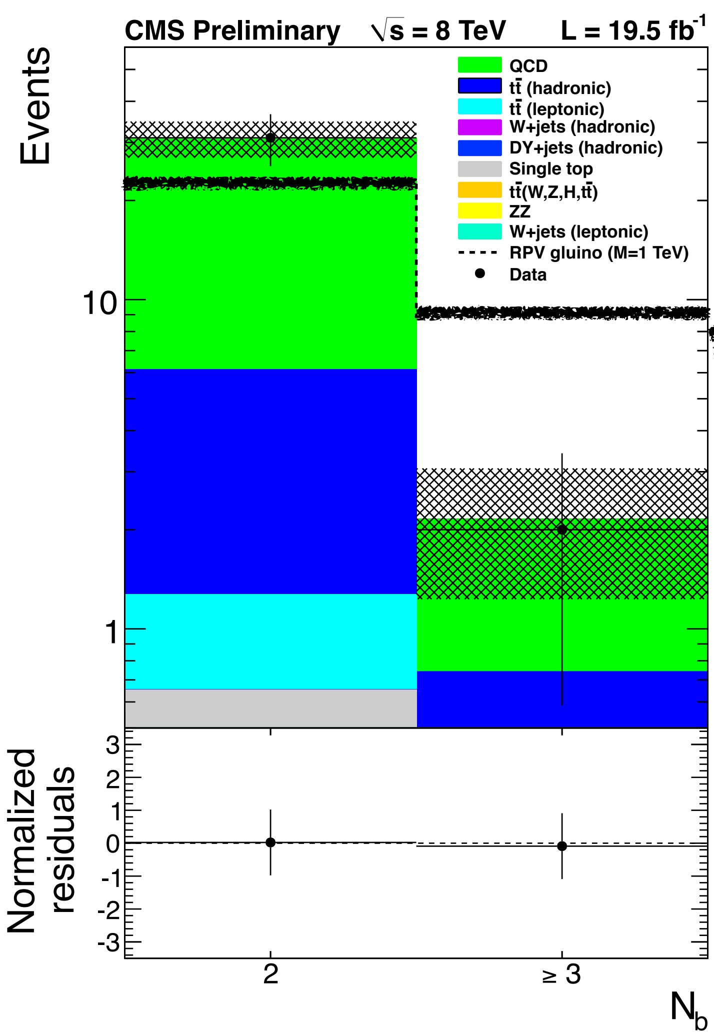
ΔR distribution between b-jets used to correct gluon splitting

CMS-PAS-SUS-14-003

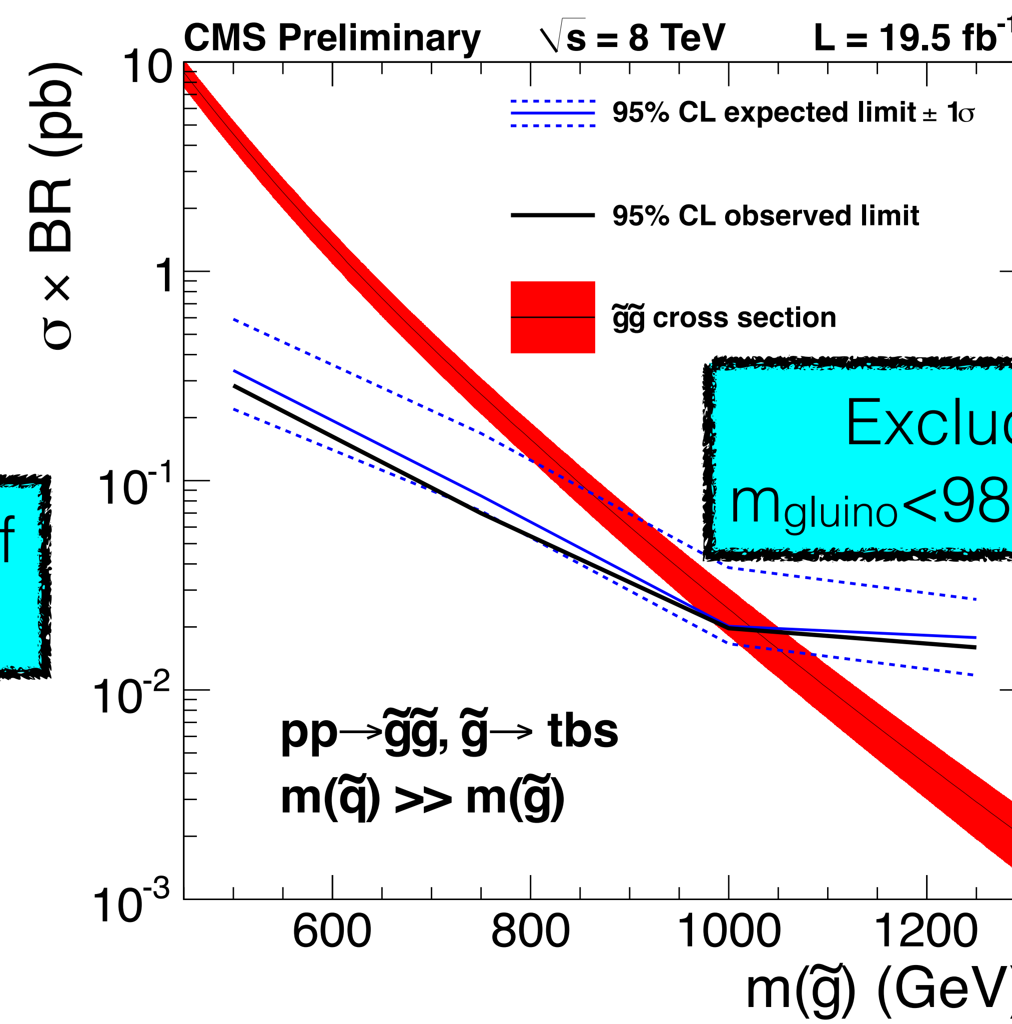
New

Fully hadronic final state

Fit of N_b distribution in (N_{jet}, H_T) bins with floating QCD yield



Contribution of 1 TeV gluino



Exclude m_{gluino}<980 GeV

H_T>1.75 TeV, N_{jet}≥8 bin

CMS-PAS-SUS-14-003

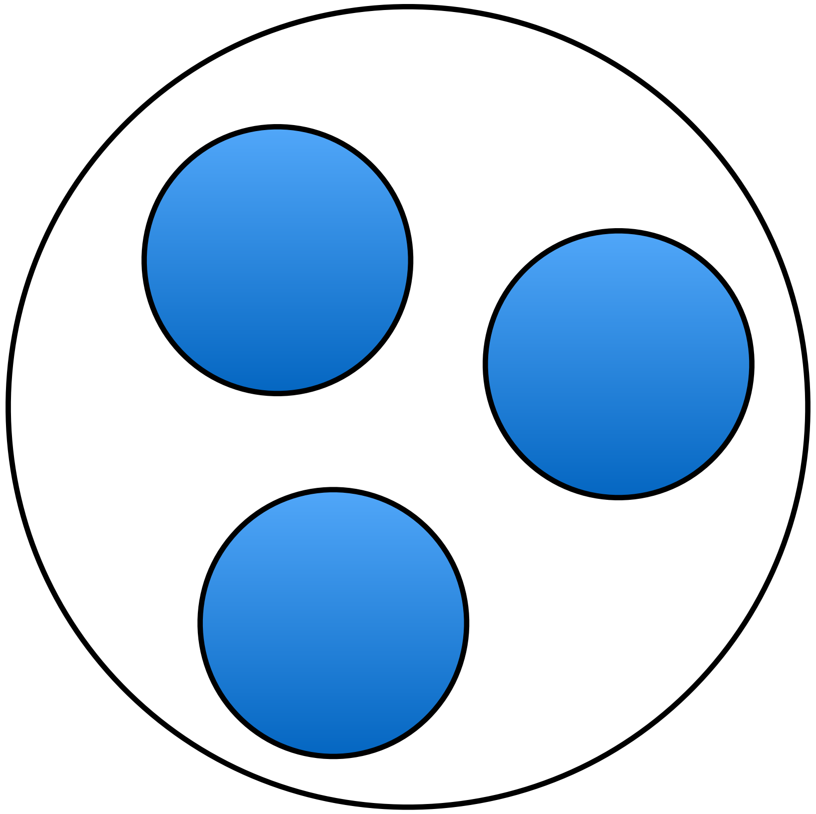
13 TeV commissioning

- The sum of the masses of large radius jets is a useful background discriminator in high multiplicity events[1,2]
- Used by ATLAS in 8 TeV analyses[3]; increased usage planned in CMS analyses at 13 TeV
- Will show commissioning results of R=0.4 anti-k_T jets clustered into R=1.2 anti-k_T jets

$$m(J_i) = \sqrt{p(J_i)^2} = \sqrt{\left(\sum_{\text{objects } n \text{ in } J_i} p_n\right)^2}$$

$$M_J = \sum_{J_i=\text{large}-R \text{ jets}} m(J_i)$$

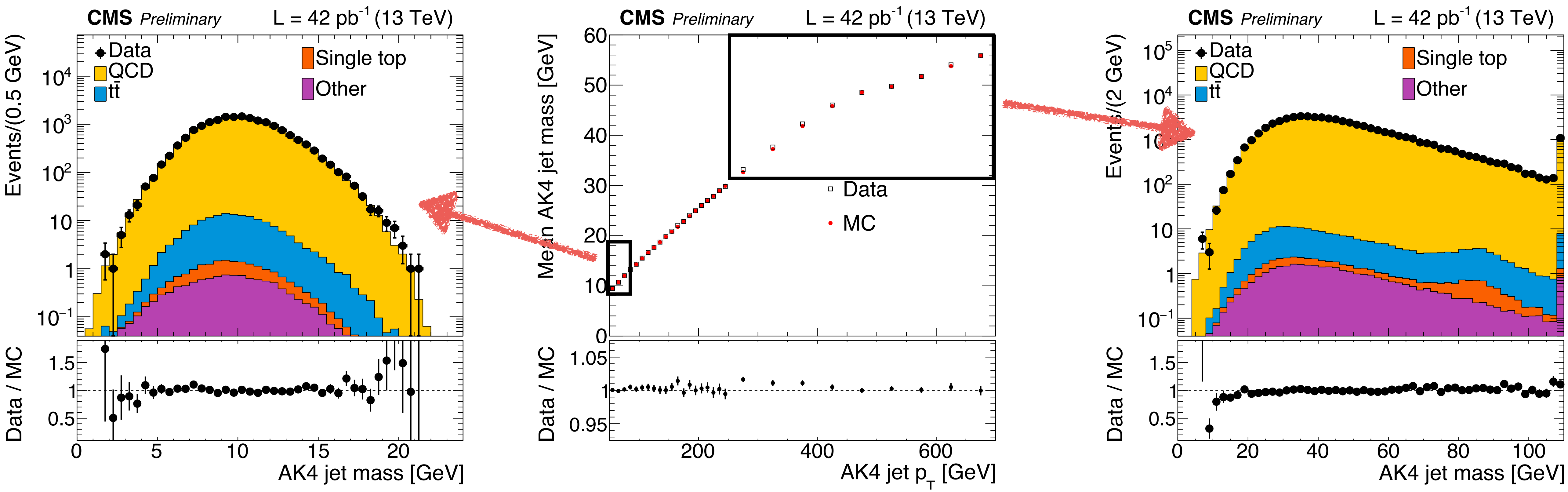
Reclustered R=0.4 jets



[1]PRD 85, 055029 (2012)
[2]JHEP08 (2013) 136
[3]PRD 91, 112016 (2015)

New

Studies of R=0.4 jet masses in 13 TeV data



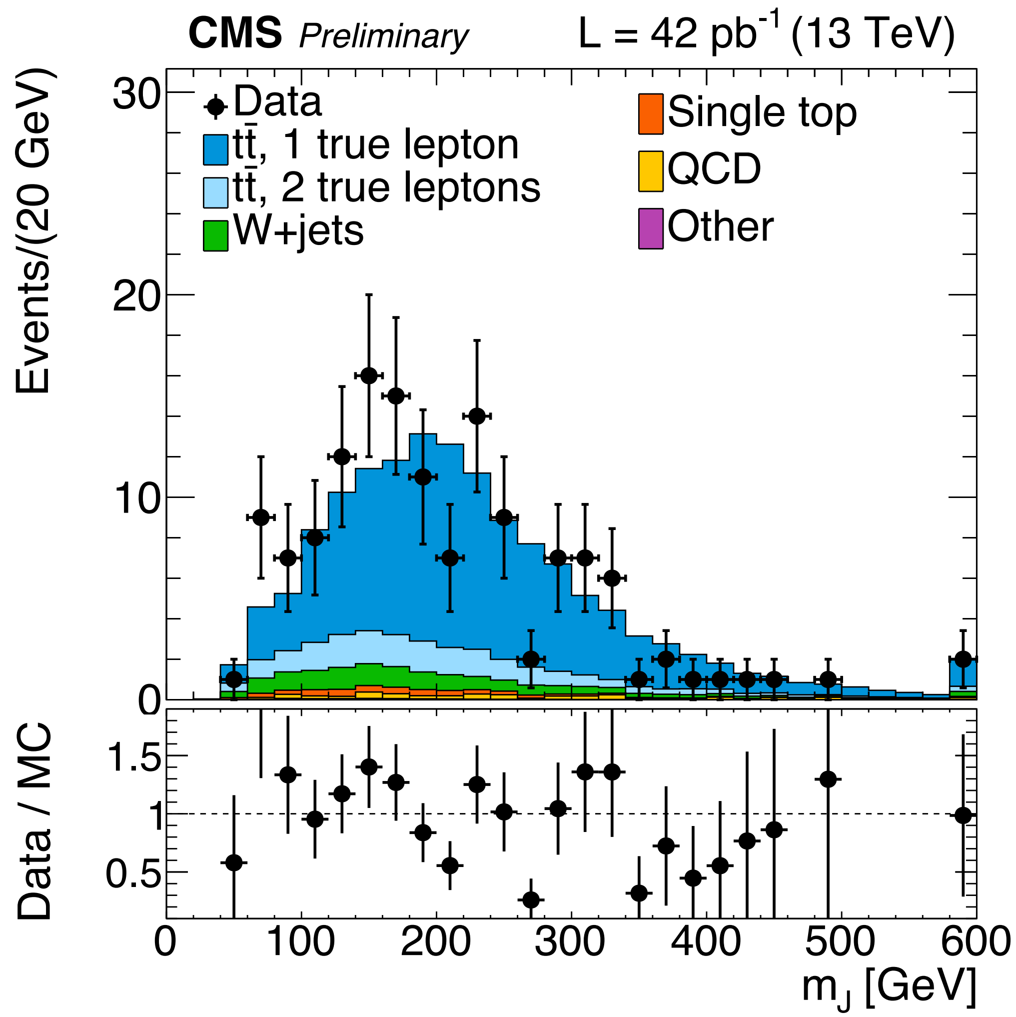
$H_T > 1000$ GeV, MET<50 GeV, $N_{lep}=0$

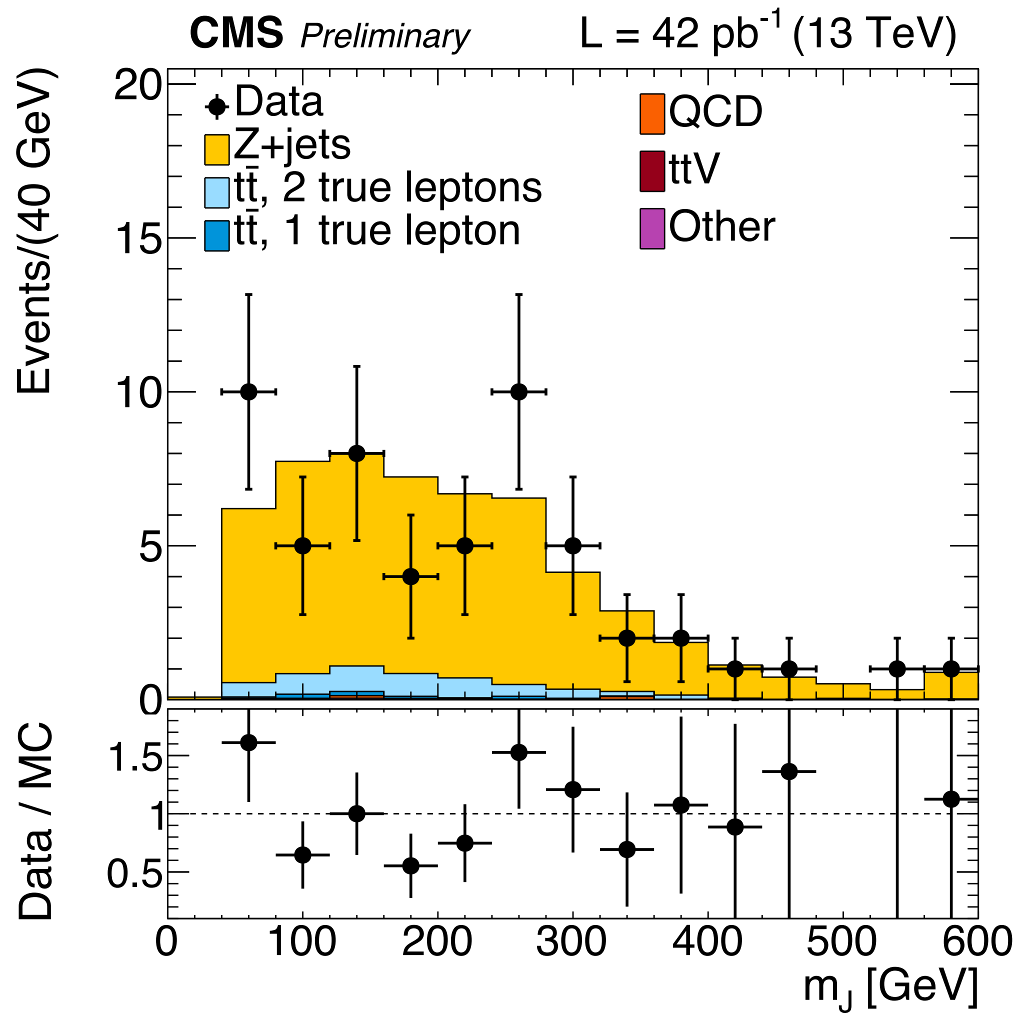
- Small radius jet masses constitute most of the mass of large radius jets at low M_J and up to 30% at high M_J
- Mean jet masses data/MC agreement to within 1%→very little effect on M_J

CMS-PAS-SUS-15-001

New

Sum of R=1.2 jet masses





Tail in M_J distribution in ttbar events arises from ISR jets overlapping with the rest of the event

⇒

Investigate ISR modeling in Z(→μμ)+jets events

→good agreement

CMS-PAS-SUS-15-001

Conclusions

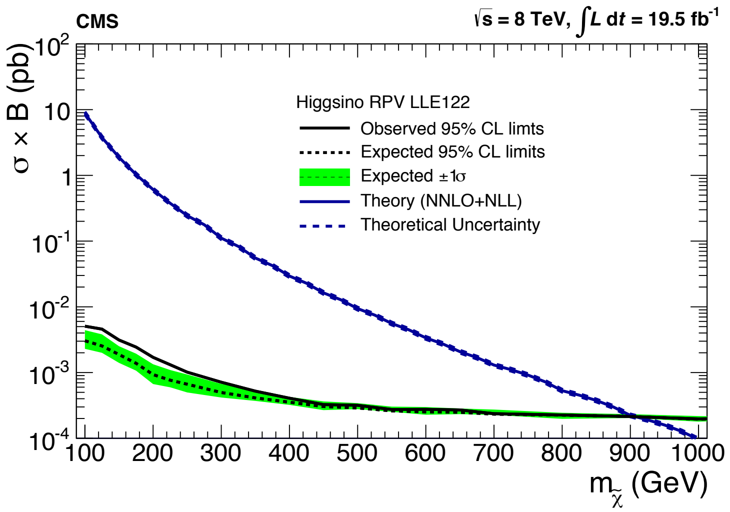
- Broad coverage of RPV-induced final states. Within the specified models, we exclude:
    - m_{gluino}<1.04 TeV
    - $m_{bottom\ squark}$<326 GeV
    - Higgsino and wino masses ranging from 300 to 900 GeV, depending on the coupling
- Still producing interesting results from 8 TeV data!
- Early 13 TeV data used to commission new analysis techniques useful for RPV analyses

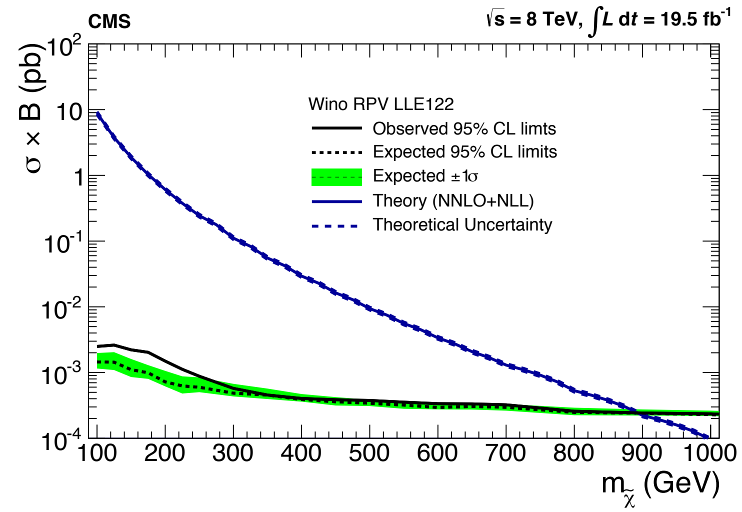
Yields in multilepton analysis with strong production

N_L	N_τ	N_b	N_{OSSF}	$m_{\ell\ell}$	$0 < S_T < 300$		$300 < S_T < 600$		$600 < S_T < 1000$		$1000 < S_T < 1500$		$S_T > 1500$	
					obs	exp	obs	exp	obs	exp	obs	exp	obs	exp
4	0	0	0	–	0	0.06 ± 0.06	0	0.09 ± 0.07	0	0.00 ± 0.03	0	0.00 ± 0.03	0	0.00 ± 0.03
4	0	1	0	–	0	0.00 ± 0.03	0	0.00 ± 0.03	0	0.06 ± 0.05	0	0.00 ± 0.03	0	0.00 ± 0.03
4	0	0	1	on-Z	2	3.1 ± 0.90	5	1.9 ± 0.48	0	0.44 ± 0.16	1	0.06 ± 0.06	0	0.00 ± 0.03
4	0	1	1	on-Z	2	0.07 ± 0.05	2	1.1 ± 0.53	0	0.57 ± 0.30	0	0.12 ± 0.09	0	0.02 ± 0.03
4	0	0	1	off-Z	2	0.48 ± 0.18	0	0.27 ± 0.11	0	0.07 ± 0.05	0	0.00 ± 0.02	0	0.00 ± 0.03
4	0	1	1	off-Z	0	0.04 ± 0.04	0	0.34 ± 0.17	0	0.06 ± 0.08	0	0.04 ± 0.04	0	0.00 ± 0.03
4	0	0	2	on-Z	135	120 ± 29	26	43 ± 10	4	6.0 ± 2.0	1	0.63 ± 0.26	0	0.06 ± 0.04
4	0	1	2	on-Z	1	1.0 ± 0.27	4	3.2 ± 1.1	1	1.1 ± 0.39	0	0.11 ± 0.06	0	0.04 ± 0.04
4	0	0	2	off-Z	7	8.3 ± 2.3	3	1.1 ± 0.30	0	0.11 ± 0.05	0	0.01 ± 0.02	0	0.00 ± 0.02
4	0	1	2	off-Z	0	0.18 ± 0.07	1	0.22 ± 0.11	0	0.15 ± 0.08	0	0.00 ± 0.03	0	0.00 ± 0.03
4	1	0	0	–	2	1.1 ± 0.46	1	0.54 ± 0.20	0	0.12 ± 0.12	0	0.00 ± 0.03	0	0.00 ± 0.03
4	1	1	0	–	0	0.26 ± 0.16	0	0.29 ± 0.13	0	0.13 ± 0.11	0	0.01 ± 0.02	0	0.00 ± 0.03
4	1	0	1	on-Z	43	42 ± 11	10	12 ± 3.1	0	1.8 ± 0.63	0	0.11 ± 0.07	0	0.02 ± 0.03
4	1	1	1	on-Z	2	1.0 ± 0.40	2	1.7 ± 0.5	0	0.78 ± 0.33	0	0.04 ± 0.04	0	0.01 ± 0.03
4	1	0	1	off-Z	18	8.4 ± 2.2	4	2.1 ± 0.52	2	0.48 ± 0.18	0	0.13 ± 0.08	0	0.01 ± 0.03
4	1	1	1	off-Z	1	0.64 ± 0.31	0	1.2 ± 0.44	0	0.30 ± 0.13	0	0.02 ± 0.03	0	0.00 ± 0.03
3	0	0	0	–	72	80 ± 23	32	27 ± 11	3	3.1 ± 1.00	0	0.22 ± 0.18	0	0.07 ± 0.06
3	0	1	0	–	37	33 ± 16	42	39 ± 19	2	5.0 ± 2.0	0	0.36 ± 0.14	0	0.06 ± 0.07
3	0	0	1	on-Z	4255	4400 ± 690	669	740 ± 170	106	110 ± 41	11	15 ± 6.9	3	1.3 ± 0.76
3	0	1	1	on-Z	140	150 ± 25	122	110 ± 25	16	25 ± 7.0	2	3.3 ± 1.2	1	0.32 ± 0.22
3	0	0	1	$m_{\ell\ell} < 75$ (GeV)	617	640 ± 100	84	86 ± 21	14	11 ± 3.6	0	1.2 ± 0.39	1	0.12 ± 0.09
3	0	1	1	$m_{\ell\ell} < 75$ (GeV)	62	74 ± 28	52	57 ± 23	4	8.3 ± 2.7	1	0.69 ± 0.28	0	0.08 ± 0.06
3	0	0	1	$m_{\ell\ell} > 105$ (GeV)	180	200 ± 34	63	66 ± 12	13	10 ± 2.5	2	1.1 ± 0.40	0	0.16 ± 0.09
3	0	1	1	$m_{\ell\ell} > 105$ (GeV)	17	17 ± 6.5	36	35 ± 14	7	7.4 ± 2.5	0	0.54 ± 0.23	0	0.08 ± 0.05
3	1	0	0	–	1194	1300 ± 330	289	290 ± 130	26	28 ± 12	2	2.6 ± 1.3	0	0.23 ± 0.20
3	1	1	0	–	316	330 ± 160	410	480 ± 240	46	58 ± 28	2	3.9 ± 2.0	0	0.46 ± 0.32
3	1	0	1	on-Z	49916	49000 ± 15000	2099	2700 ± 770	108	70 ± 17	9	6.0 ± 1.6	0	0.33 ± 0.18
3	1	1	1	on-Z	795	830 ± 230	325	280 ± 74	17	17 ± 4.8	1	1.8 ± 0.64	0	0.30 ± 0.14
3	1	0	1	$m_{\ell\ell} < 75$ (GeV)	10173	9200 ± 2700	290	280 ± 72	21	11 ± 3.5	1	0.97 ± 0.44	0	0.04 ± 0.06
3	1	1	1	$m_{\ell\ell} < 75$ (GeV)	297	290 ± 97	167	170 ± 87	14	12 ± 6.0	0	1.1 ± 0.74	0	0.06 ± 0.08
3	1	0	1	$m_{\ell\ell} > 105$ (GeV)	1620	1700 ± 480	285	370 ± 96	21	23 ± 7.2	1	1.4 ± 0.61	0	0.22 ± 0.23
3	1	1	1	$m_{\ell\ell} > 105$ (GeV)	97	79 ± 36	169	190 ± 94	23	28 ± 14	1	2.2 ± 1.3	0	0.20 ± 0.18

Limits on LLE and LQD interactions from multilepton analysis with EW production

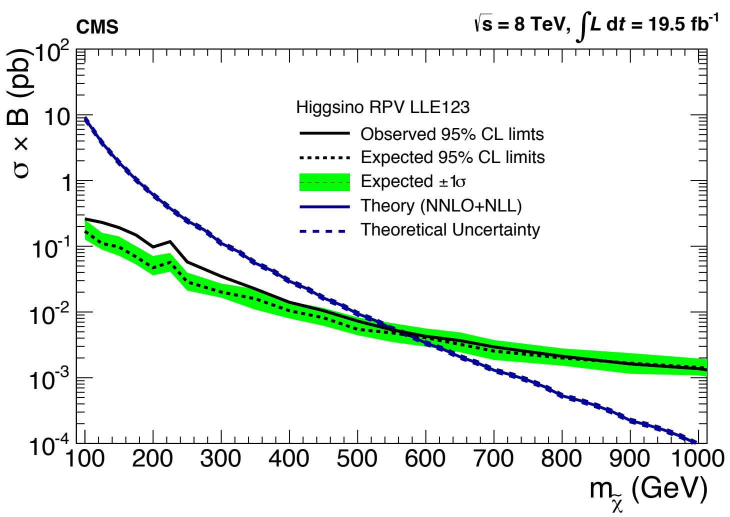
Higgsino, LLE122

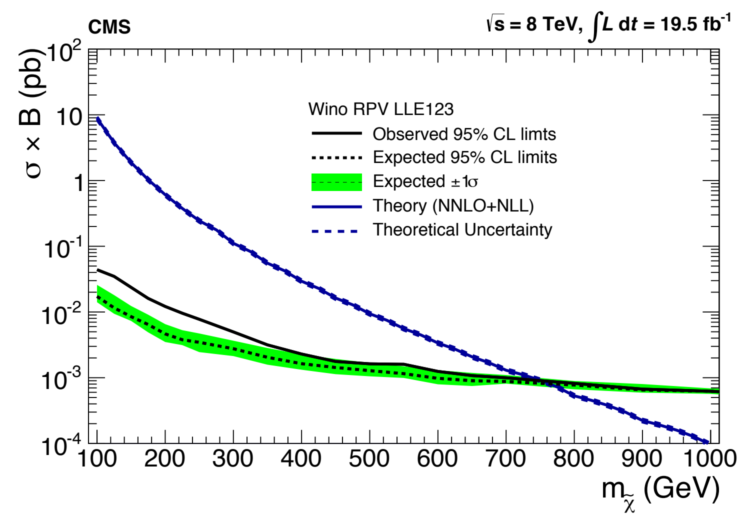




Wino, LLE122

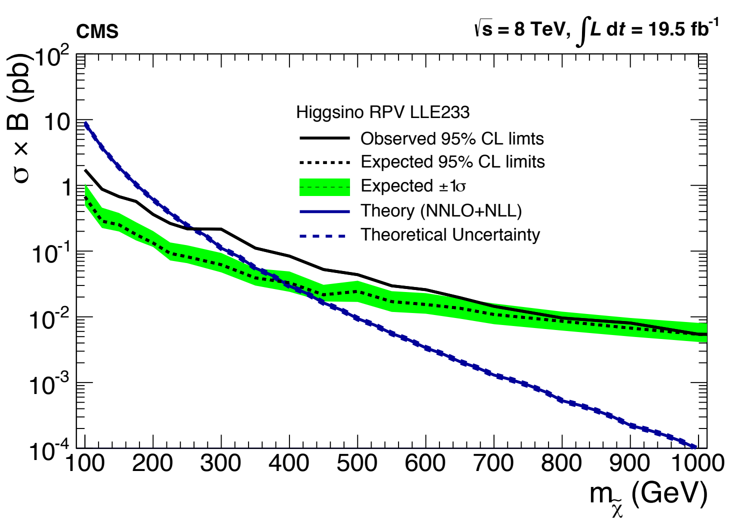
Higgsino, LLE123

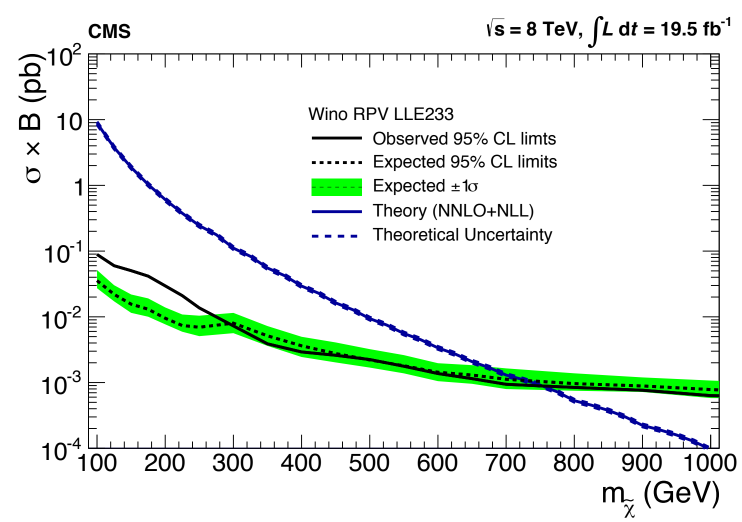




Higgsino, LLE123

Higgsino, LLE233

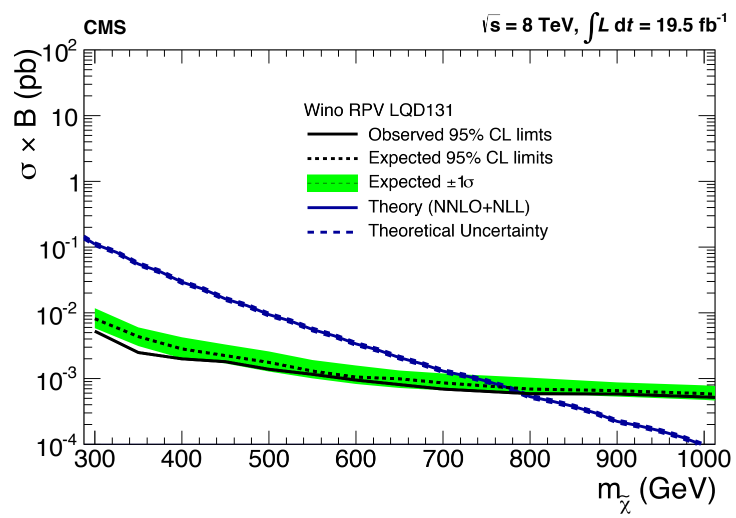


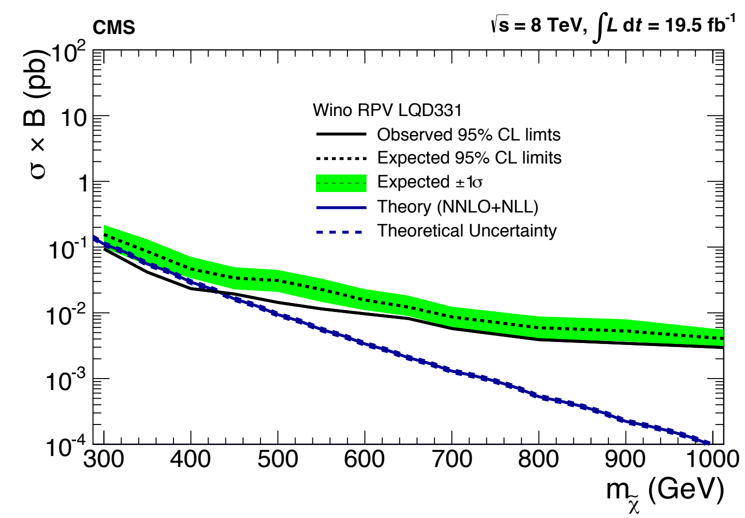


Higgsino, LLE233

Limits on LLE and LQD interactions from multilepton analysis with EW production

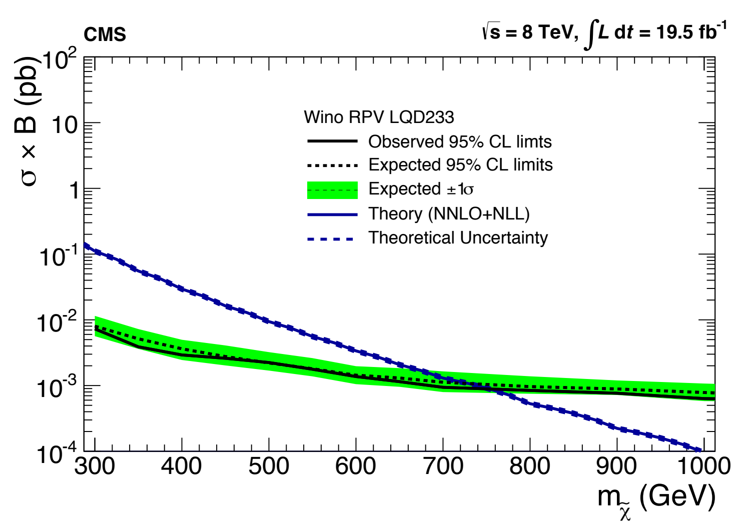
Wino,
LQD131

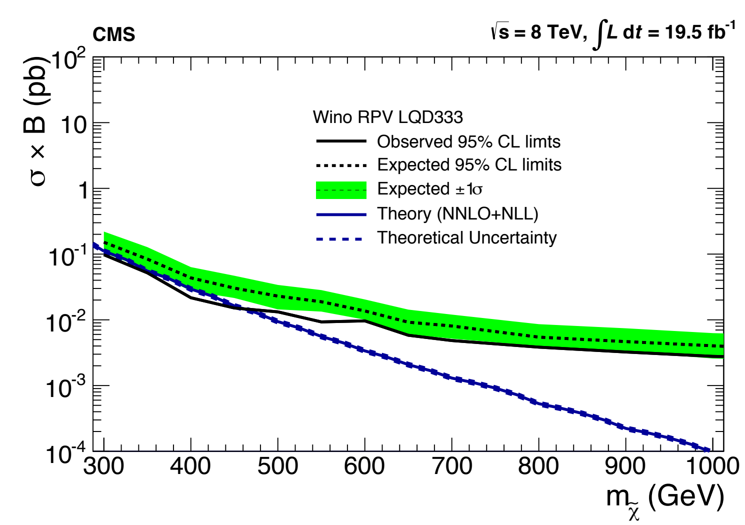




Wino,
LQD331

Wino,
LQD233

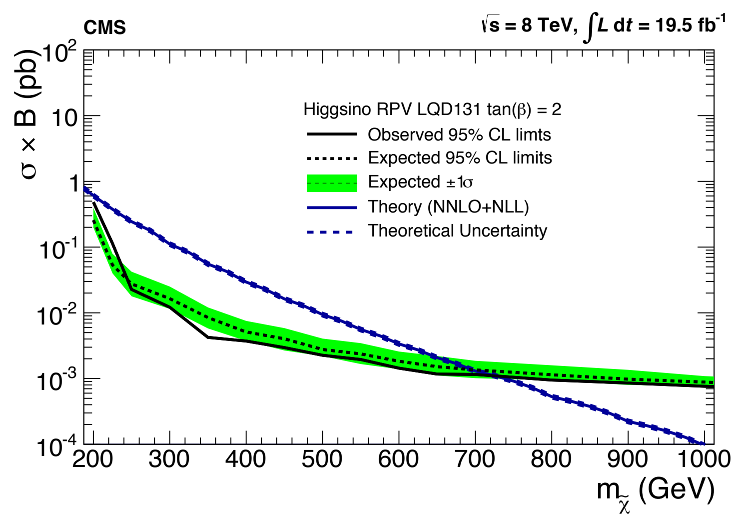


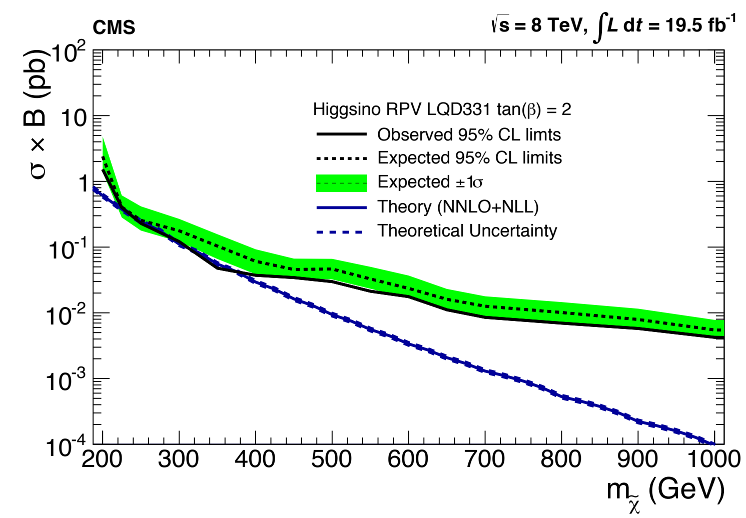


Wino,
LQD333

Limits on LLE and LQD interactions from multilepton analysis with EW production

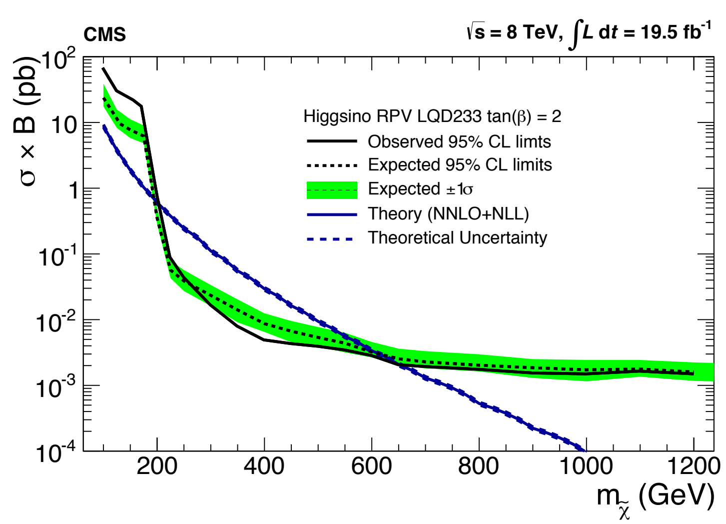
Higgsino,
LQD131
tanβ=2

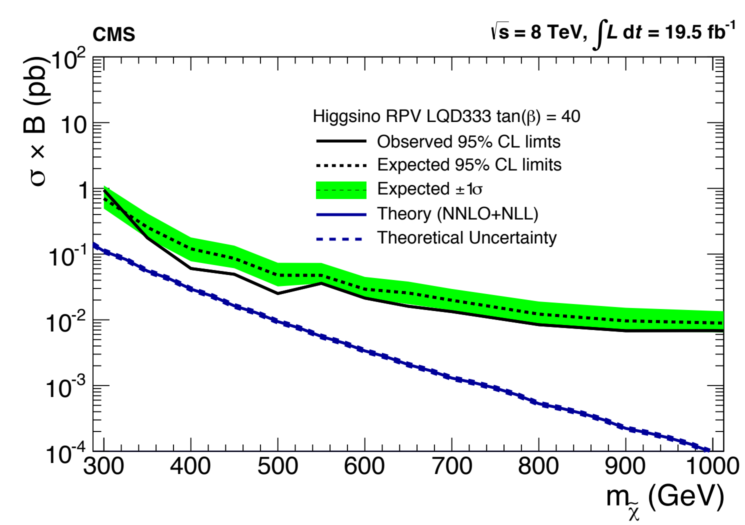




Higgsino,
LQD331
tanβ=2

Higgsino,
LQD233
tanβ=2

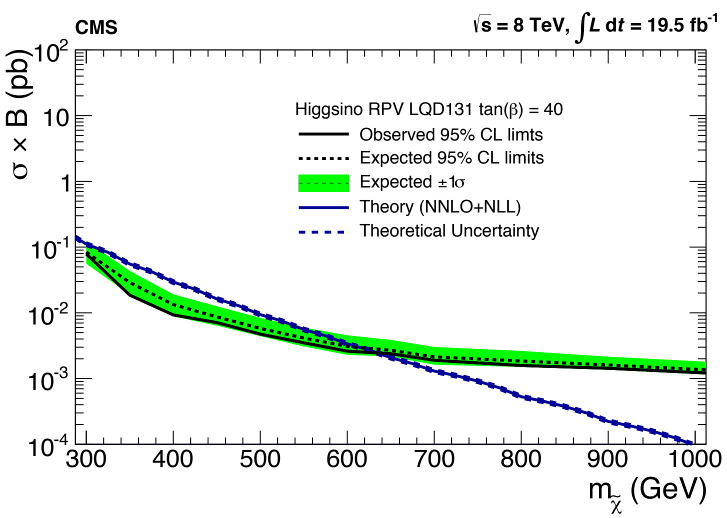


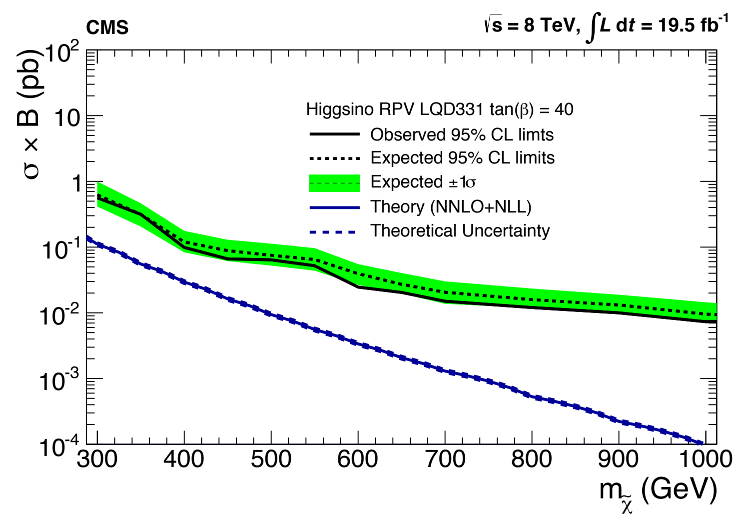


Higgsino,
LQD333
tanβ=2

Limits on LLE and LQD interactions from multilepton analysis with EW production

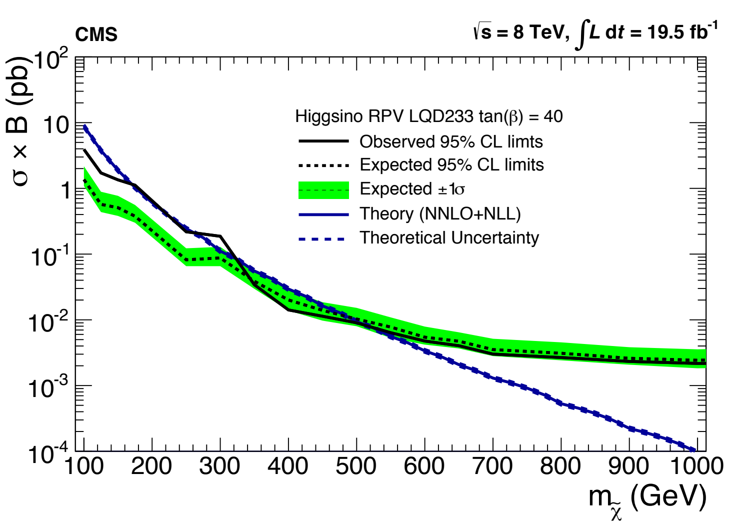
Higgsino,
LQD131
tanβ=40

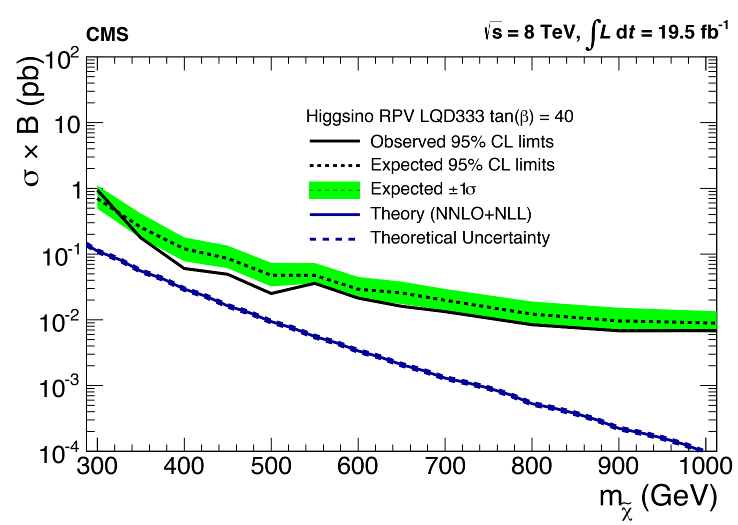




Higgsino,
LQD331
tanβ=40

Higgsino,
LQD233
tanβ=40

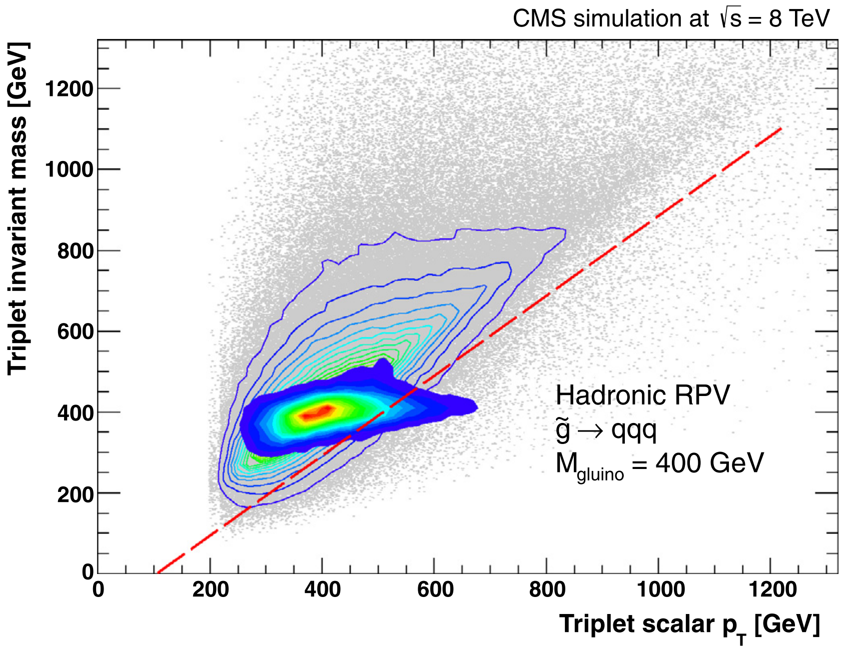


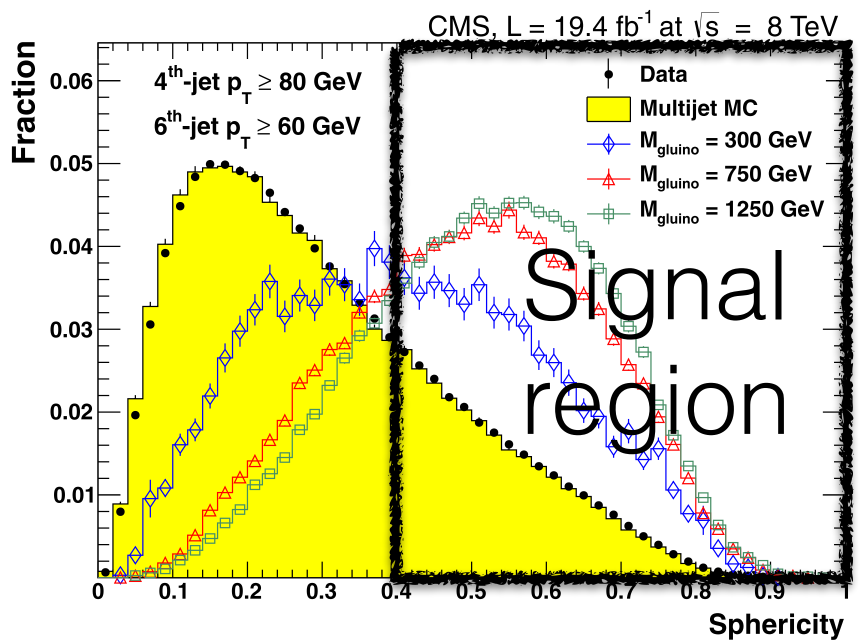


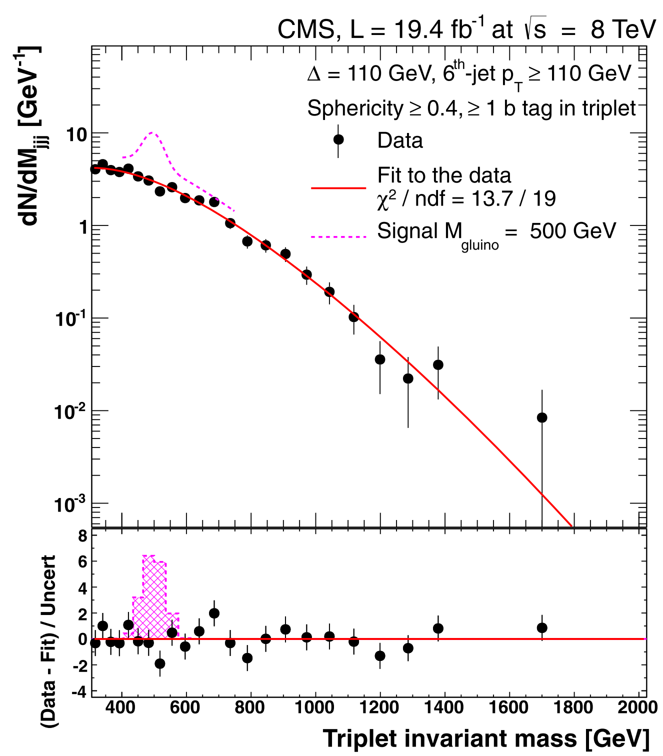
Higgsino,
LQD333
tanβ=40

Multijet resonances

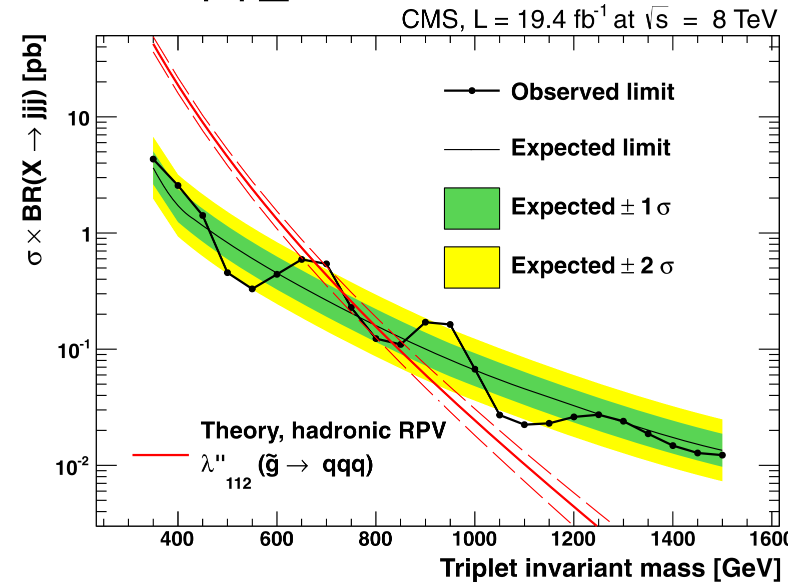
- Select ≥6 jets with p_T>110 GeV
- Cut on triplet invariant mass and scalar p_T
- Require sphericity>0.4
- Fit triplet invariant mass distribution (with or without b)



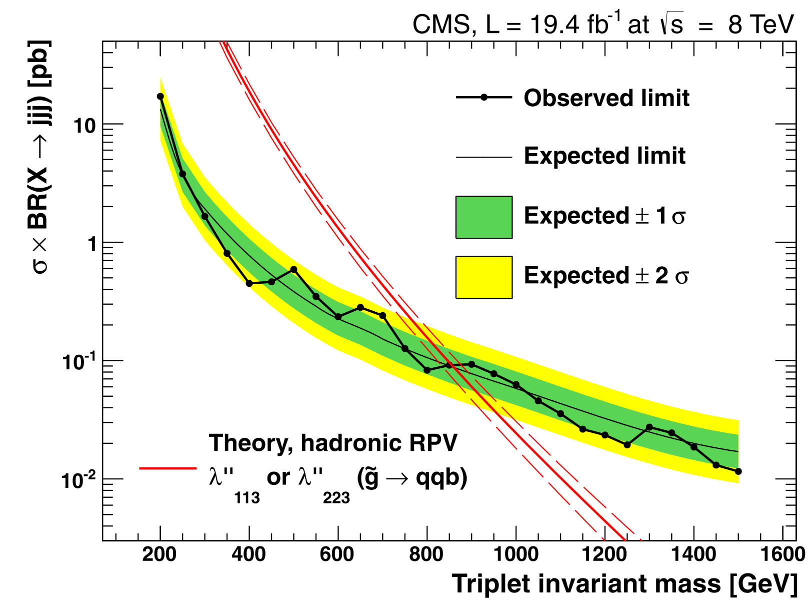




λ"$_{112}$



λ"$_{113}$ or 223



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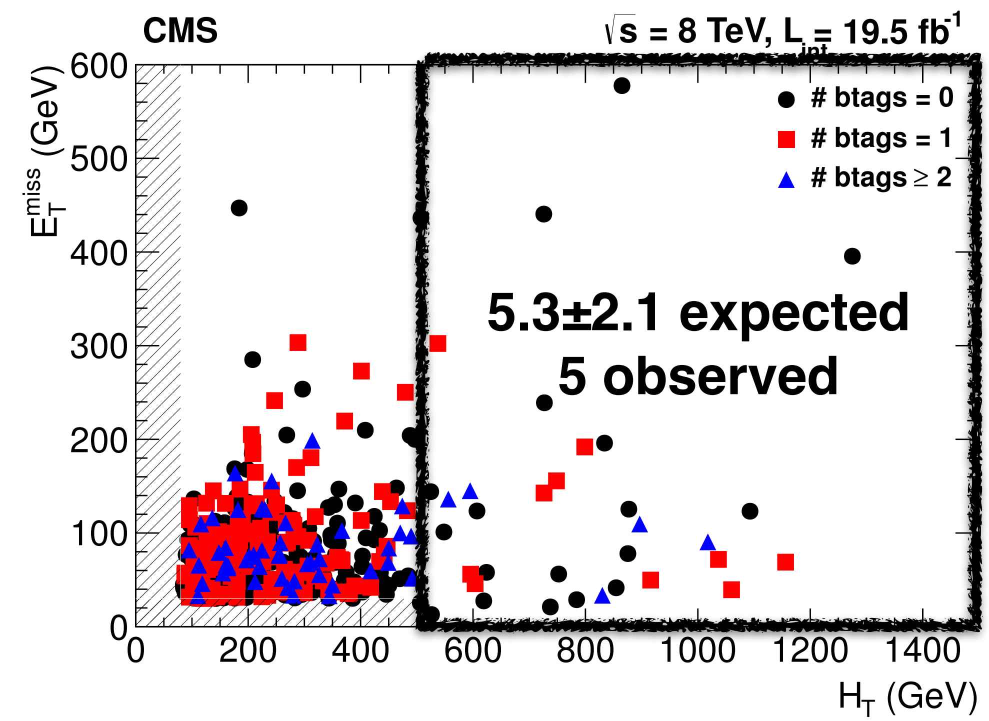
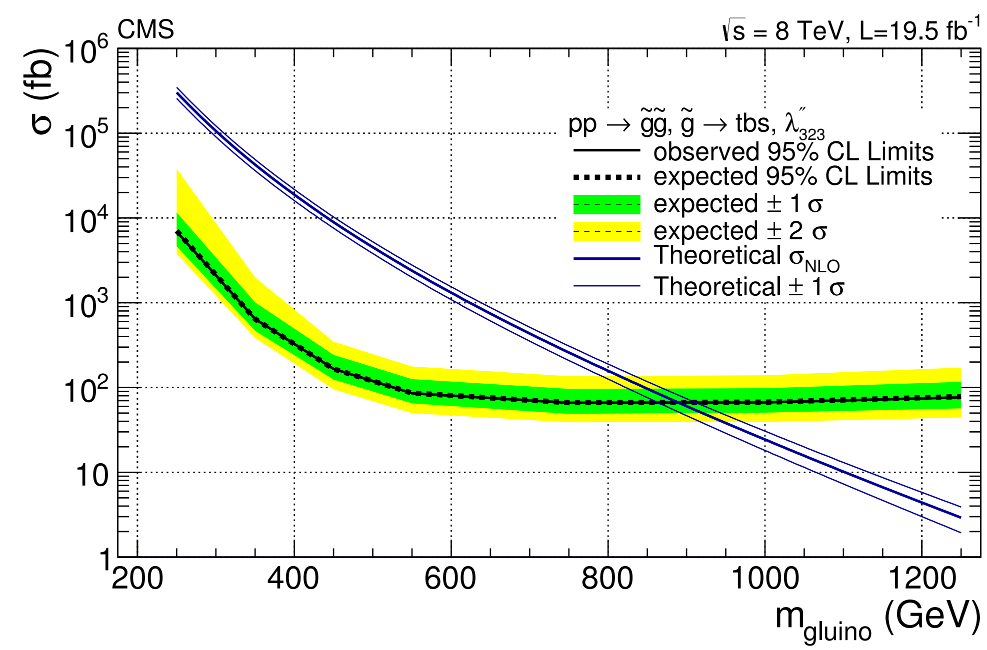
Same-sign dileptons

Search for R-parity-conserving SUSY reinterpreted in an RPV scenario



Object	p_T (GeV)	$\lvert\eta\rvert$
Electrons	>10 (20)	< 2.4 and ∉[1.4442, 1.566]
Muons	>10 (20)	<2.4
Jets	>40	<2.4
b-tagged jets	>40	<2.4



N_{jets}	$N_{\text{b-jets}}$	E_T^{miss} (GeV)	H_T (GeV)	Lepton charge	SR name
≥2	≥0	>0	>500	++/−−	RPV0
≥2	≥2	>0	>500	++/−−	RPV2
≥2	=1	>30	>80	++/−−	SStop1
≥2	=1	>30	>80	++ only	SStop1++
≥2	≥2	>30	>80	++/−−	SStop2
≥2	≥2	>30	>80	++ only	SStop2++

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