Strong SUSY production in leptonic channels at CMS

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for the CMS collaboration

SUSY2019
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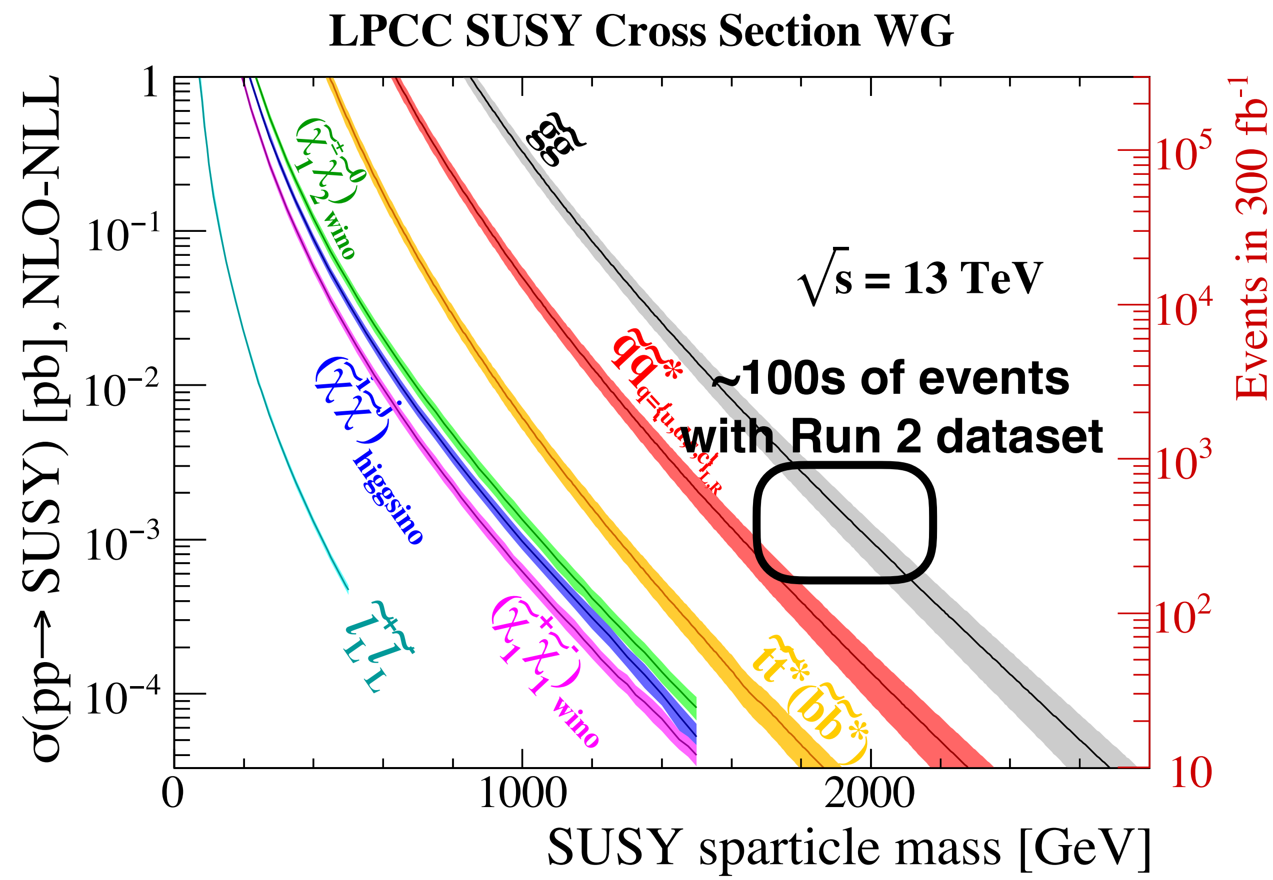
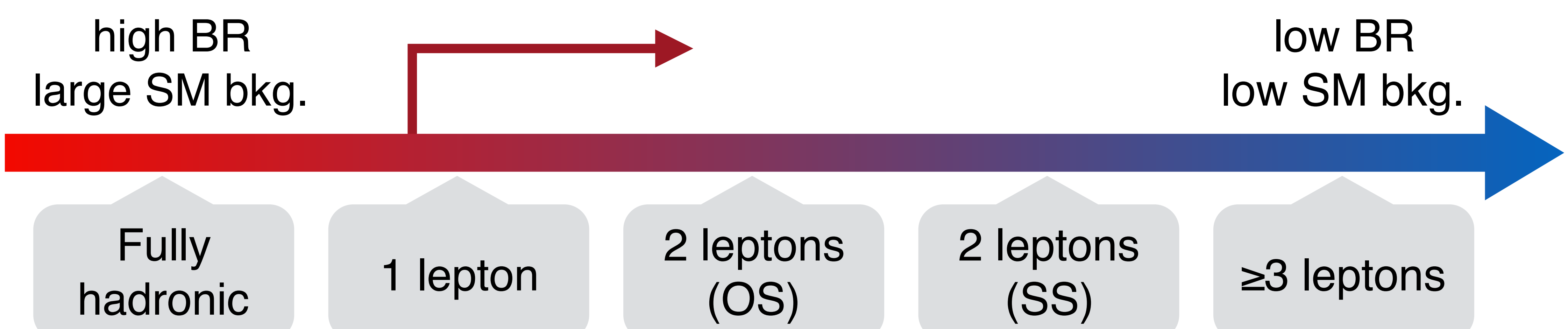
Why?

✓ **Strong** production modes have the largest cross-sections
- often with high boson multiplicity from cascading decays
- hadronic activity/many jets

✓ **Leptonic** final states among the cleanest
- clear detector signal
- lower branching ratio compared to hadronic analyses, but lower SM background (almost no QCD multijet)



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1407.5066



CMS analyses

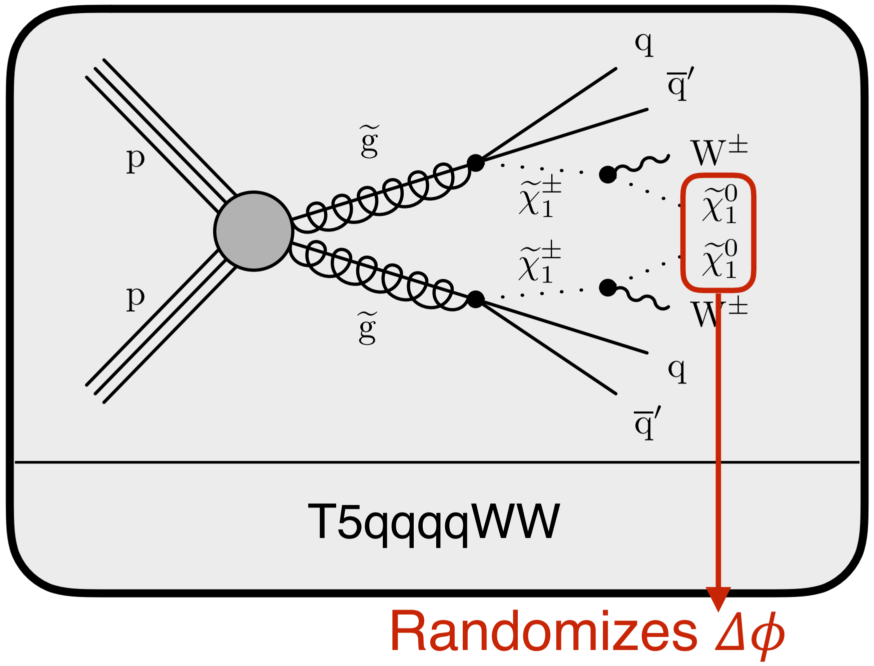
- Variety of CMS results for strong SUSY with final states containing ≥1 lepton + jets + (maybe) missing energy
- Overview of just a subset of results with gluino production
- Full list of public CMS results here

leptons

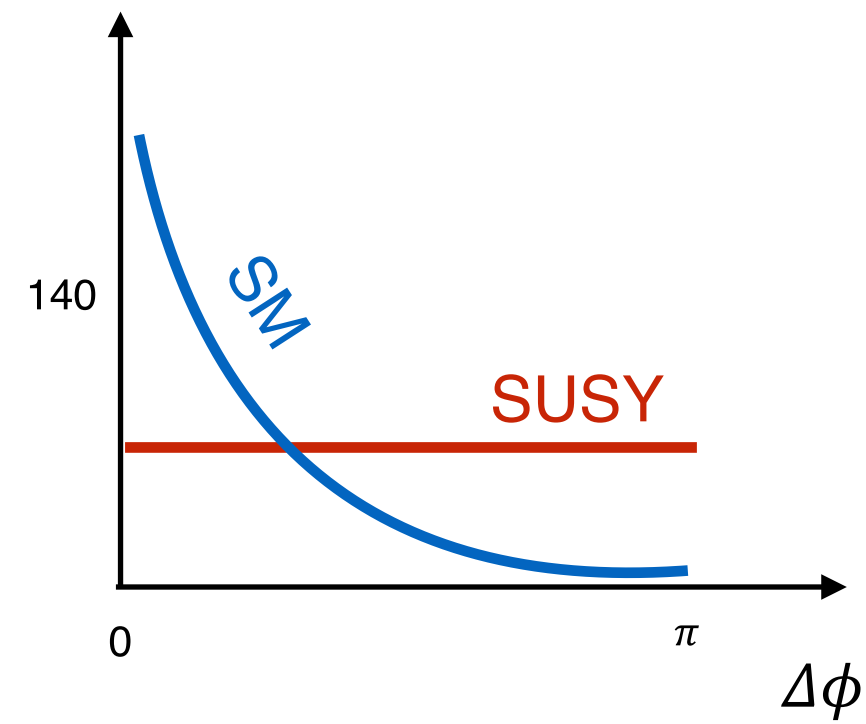
SUS-17-012	**1 lep.** + photon	JHEP 01 (2019) 154
SUS-16-051	top squark, **1 lep.**	JHEP 10 (2017) 019
SUS-16-042	**1 lep.**, $\Delta\phi$(lep,MET)	Phys. Lett. B 780 (2018) 384
SUS-16-037	**1 lep.**, large-R M_J	Phys. Rev. Lett. 119 (2017) 151802
SUS-16-040	RPV with 1 **lep.**, large-R M_J	Phys. Lett. B 783 (2018) 114
SUS-18-003	top squark, **2 OS lep.** ($e^{\pm}\mu^{\mp}$)	JHEP 03 (2019) 101
SUS-16-034	**2 OS same-flavor lep.**,	JHEP 03 (2018) 076
SUS-19-008	**2 same-sign lep.** or **≥3 lep.**	PAS

1L $\Delta\phi$

- Target simplified SUSY models with at least 5 jets, large missing energy (MET) and **one lepton**
  - events binned in N_b, N_{jets}, H_T, L_T = MET + p_T(lep)
  - main backgrounds are $t\bar{t}$ and W+jets
- **Angle between lepton and MET vector** $\Delta\phi$ used as the main handle to suppress **semileptonic** $t\bar{t}$
- **Dileptonic** $t\bar{t}$ background suppressed using the M_{T2} variable with the lepton and a track



$$M_{T2}(\vec{p}_T^{\,\ell}, \vec{p}_T^{\,t}, \vec{p}_T^{\,miss}) = \min_{\vec{p}_T^{\,(1)}+\vec{p}_T^{\,(2)}=\vec{p}_T^{\,miss}} \left\{ \max\left[M_T(\vec{p}_T^{\,\ell}, \vec{p}_T^{\,(1)}), M_T(\vec{p}_T^{\,t}, \vec{p}_T^{\,(2)}) \right] \right\}$$



1L $\Delta\phi$

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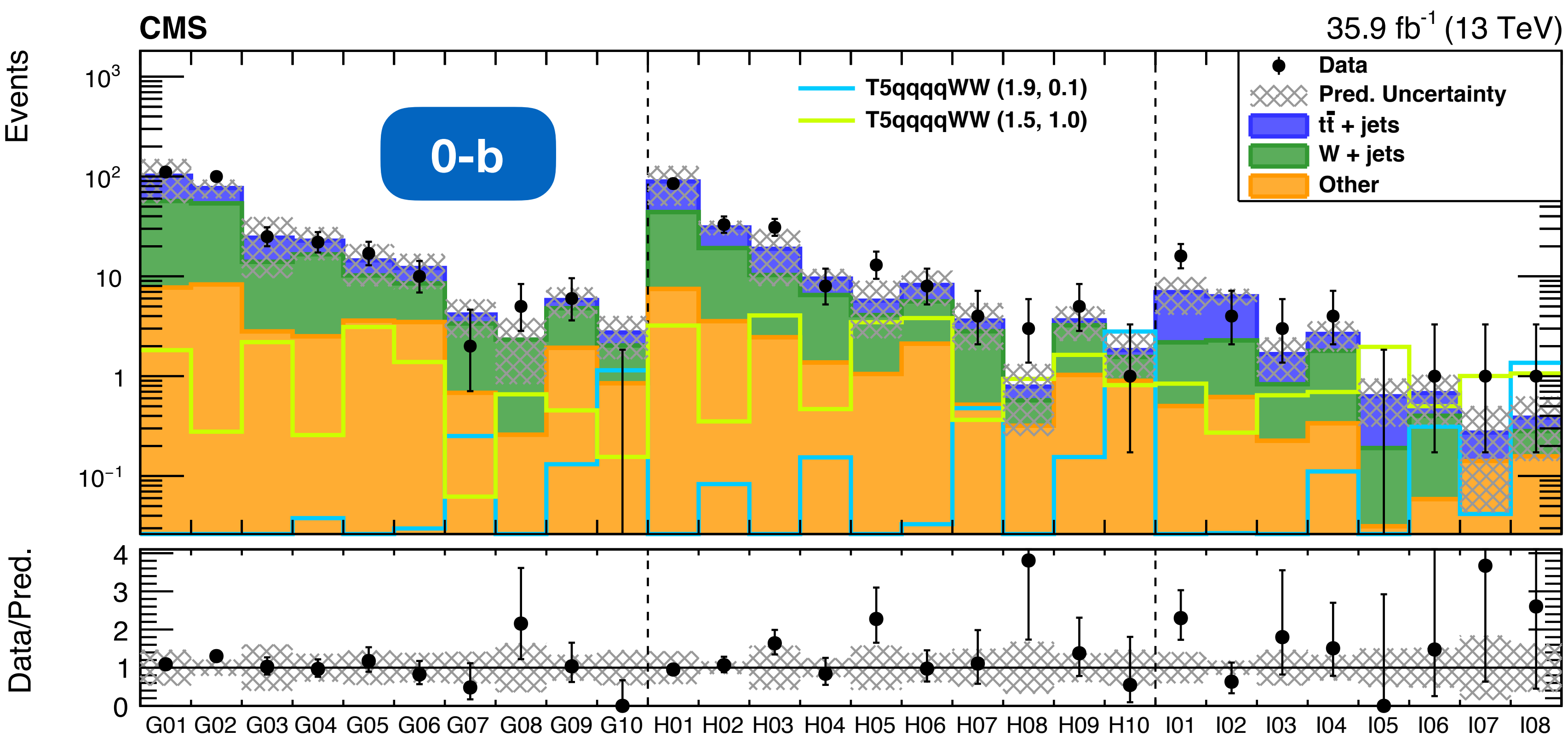
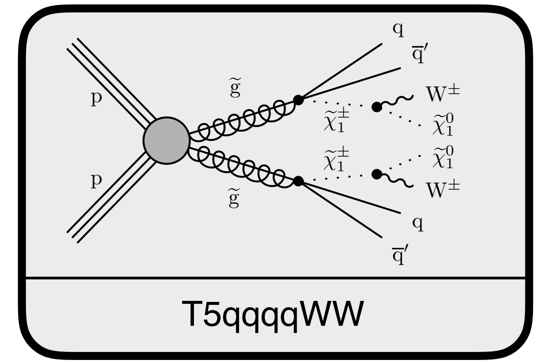
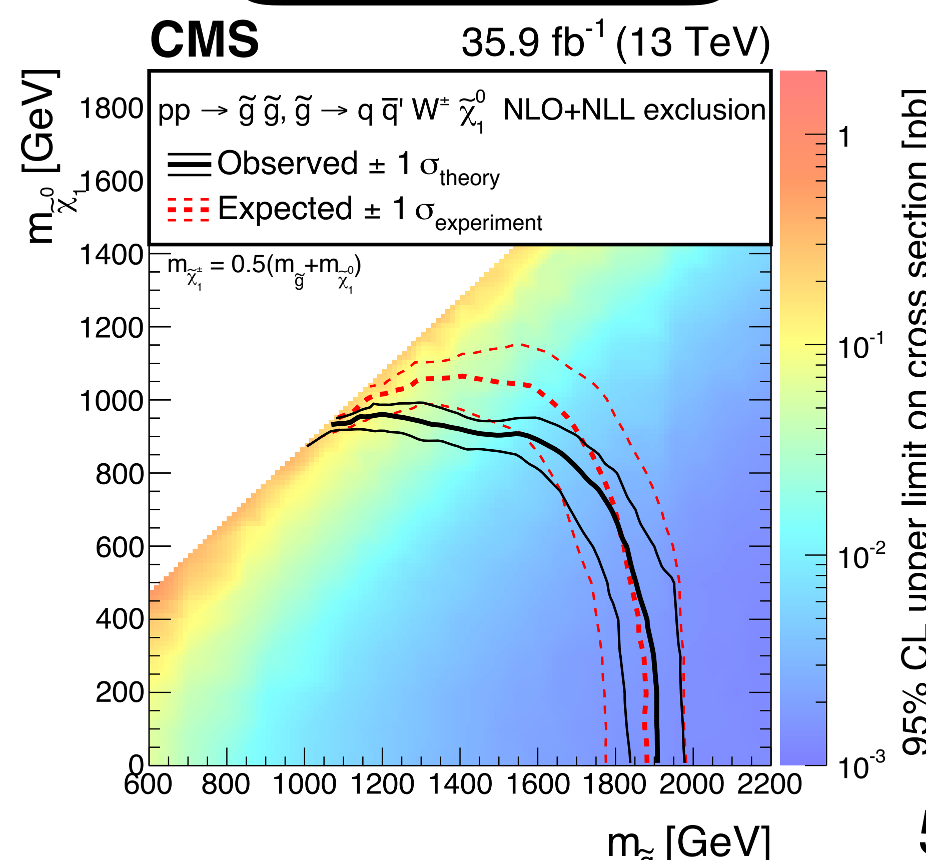
Phys. Lett. B 780 (2018) 384

- Use low $\Delta\phi$ (<0.5-1.0) with a transfer factor to estimate background in high $\Delta\phi$ signal regions
- No significant excesses
  - set upper limits on T5qqqqWW production in gluino-LSP mass plane
  - exclude gluino masses up to 1.9TeV for light LSP







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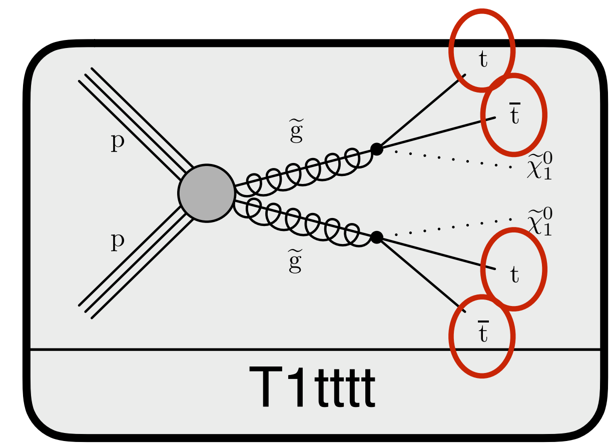
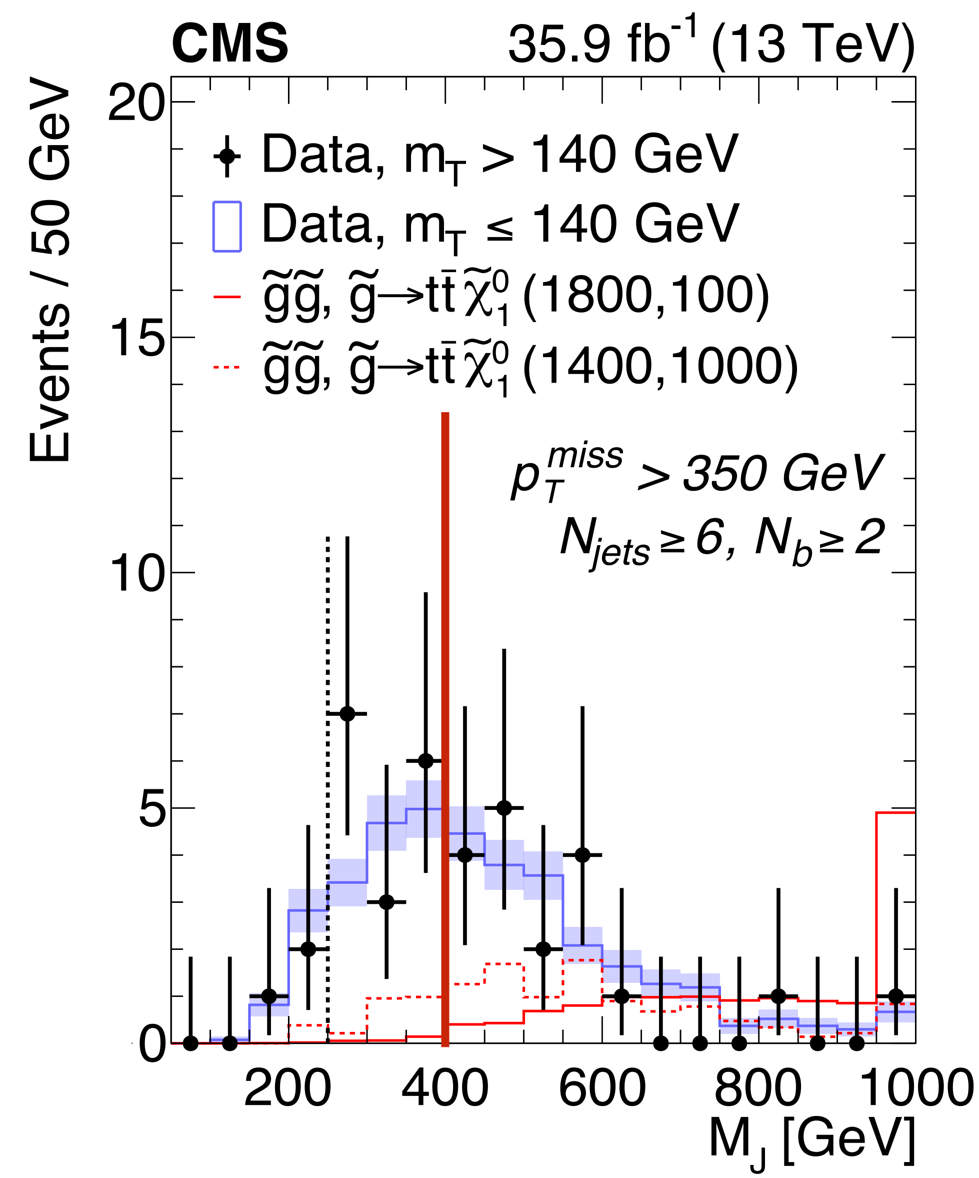
Phys. Rev. Lett. 119 (2017) 151802

1L M_J

- Target models with large top quark multiplicity by selecting events with at least 6 jets (≥1 b tagged), large MET and large $S_T = H_T + p_T(\text{lep})$
  - events split into bins of N_b, then further binned in N_{jets}, H_T, S_T
  - dominant background from $t\bar{t}$
- Variable M_J used to separate signal from $t\bar{t}$
  - recluster anti-k_T R=0.4 jets/leptons into R=1.4 to form "large-R jets"
  - **M_J = sum of large-R jet masses**
  - peaks **higher for signal** vs $t\bar{t}$



four top quarks



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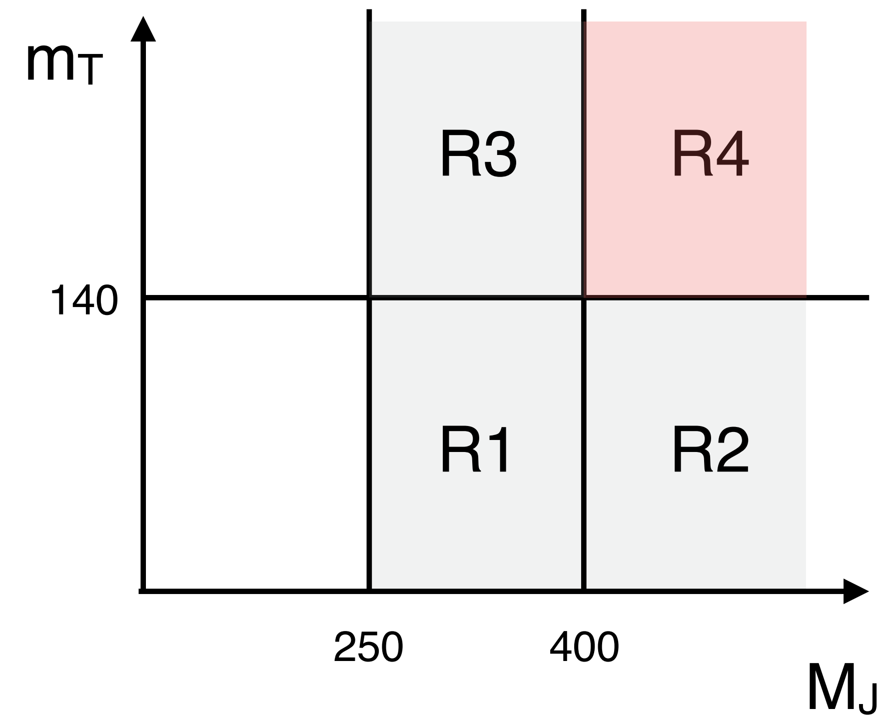
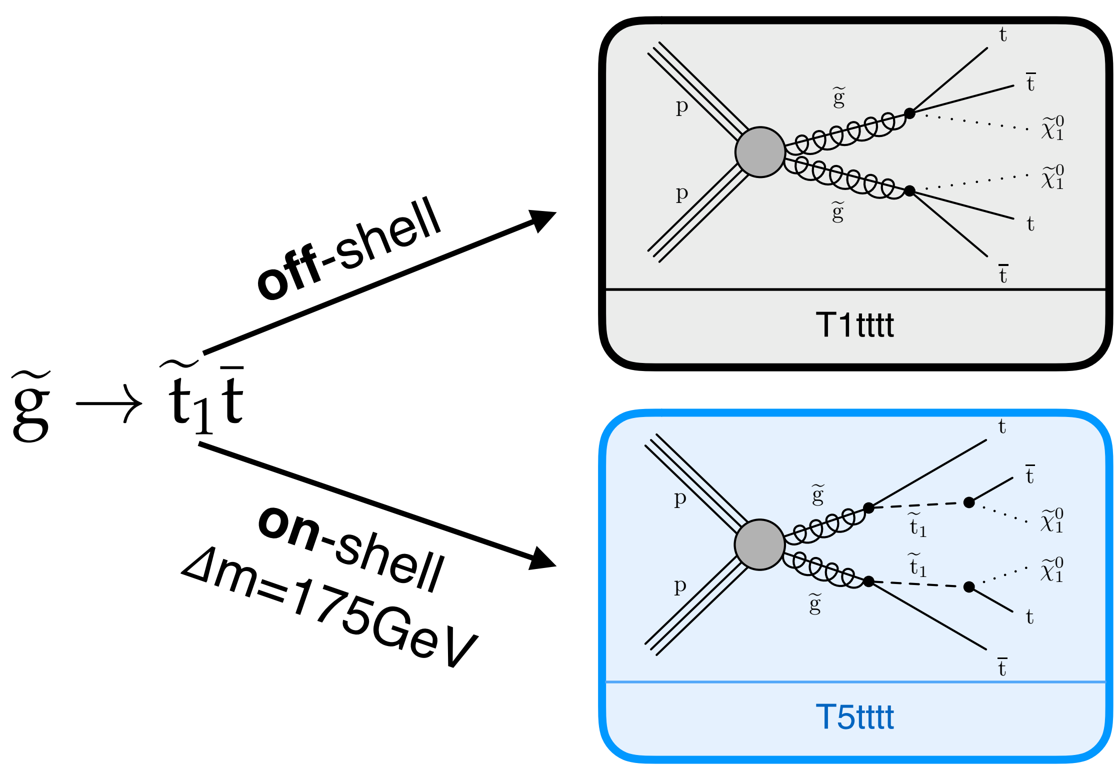
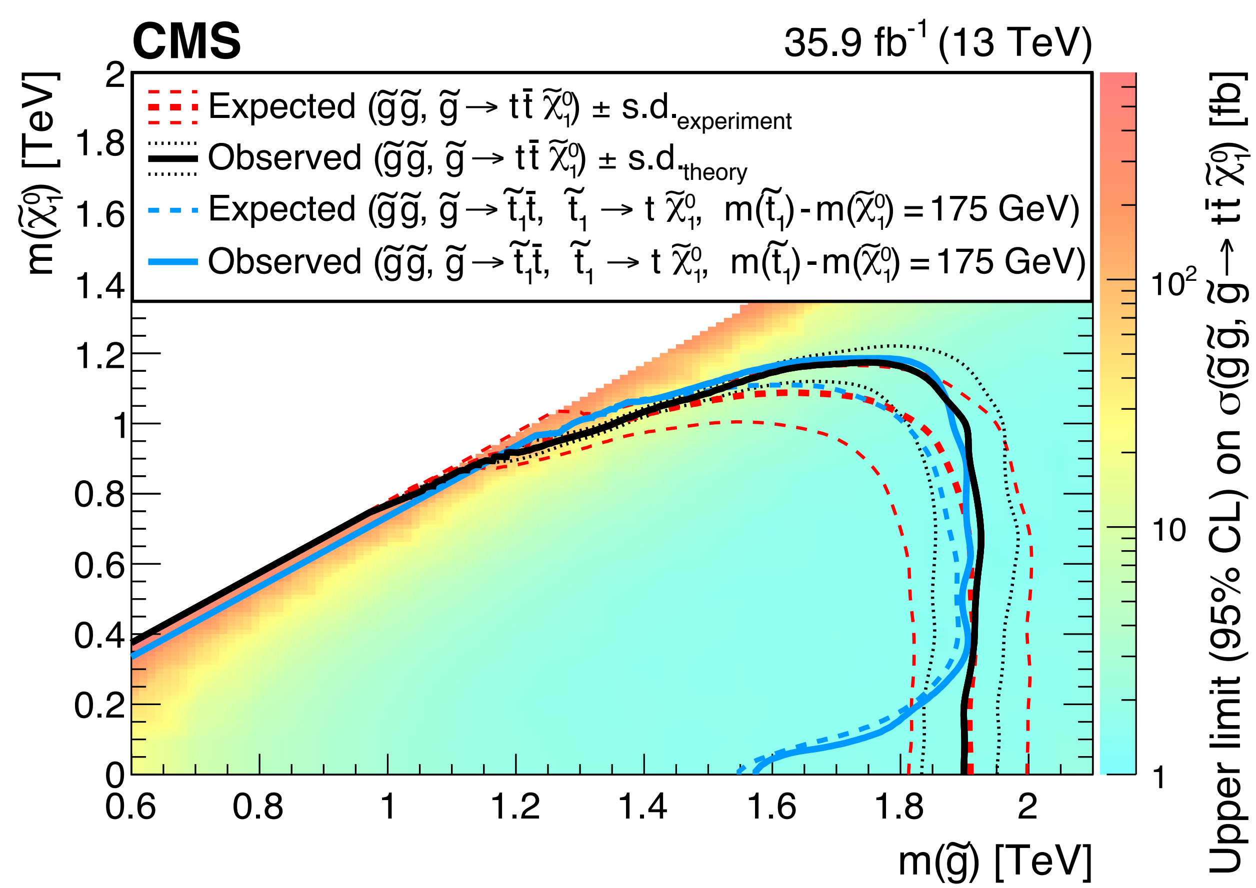
1L M_J

Phys. Rev. Lett. 119 (2017) 151802

- Define signal region as M_J>400 GeV and transverse mass m_T>140 GeV, consisting of 18 kinematic bins
- These variables are nearly uncorrelated, so use an "ABCD" extrapolation method to obtain prediction in signal region R4 from background-enriched R1,R2,R3 via ratios of the form $N_4=N_3(N_2/N_1)$
- Exclusions for off- and on-shell squark mediator models T1tttt, T5tttt reach 1.9TeV





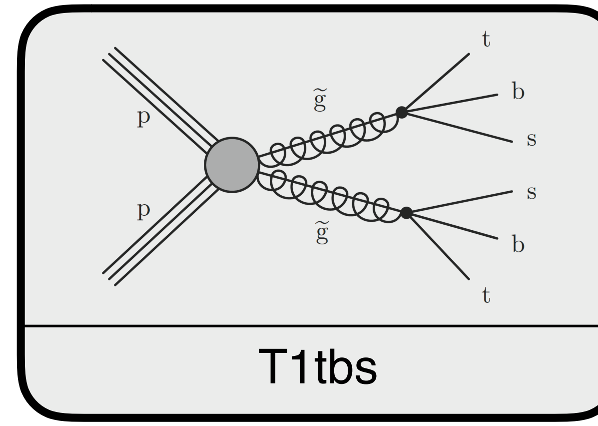


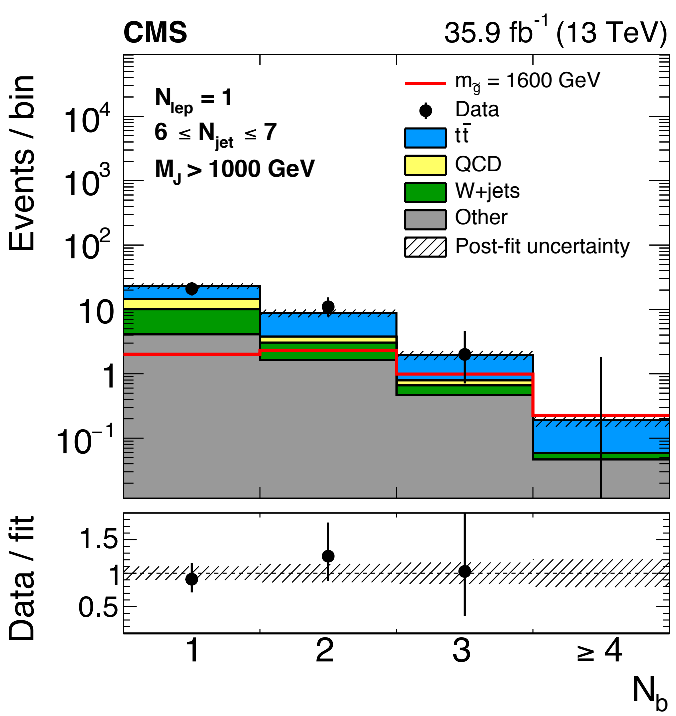
[Phys. Lett. B 783 (2018) 114]

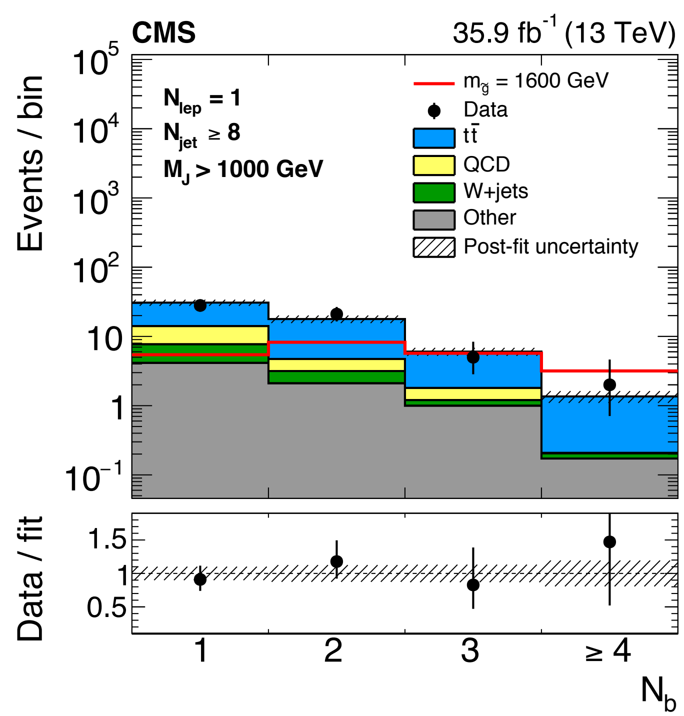
1L M_J (*RPV*)

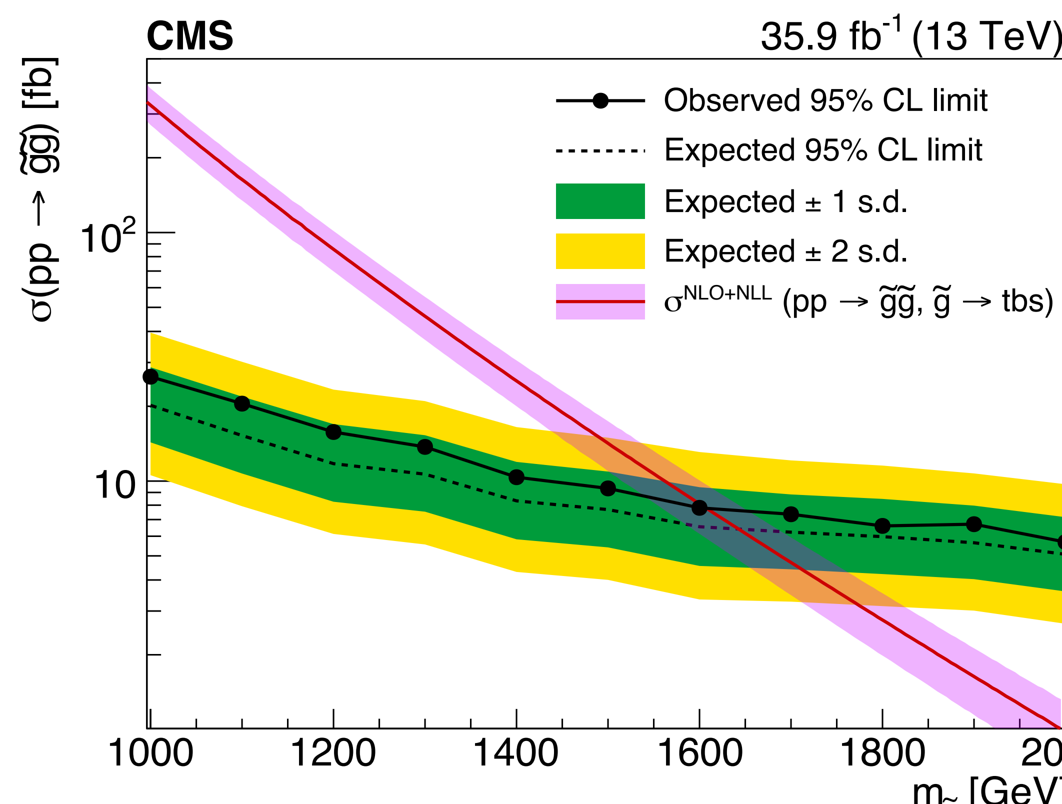
- Discriminant M_J used to probe R-parity **violating** models as well with a separate analysis
  - large third generation RPV couplings → tbs final states
- Fit N_b distribution in bins of N_{jets} and M_J using low N_{jets}, low M_J as control regions to constrain systematics
  - N_b=3,4 bins dominated by gluon splitting ($g \to b\bar{b}$) systematic uncertainty
- Gluinos up to 1.6TeV are excluded

$$\tilde{g} \to t\bar{\tilde{t}} \to tbs$$



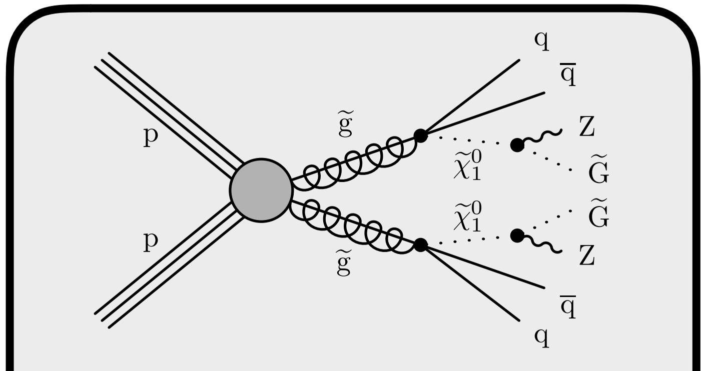




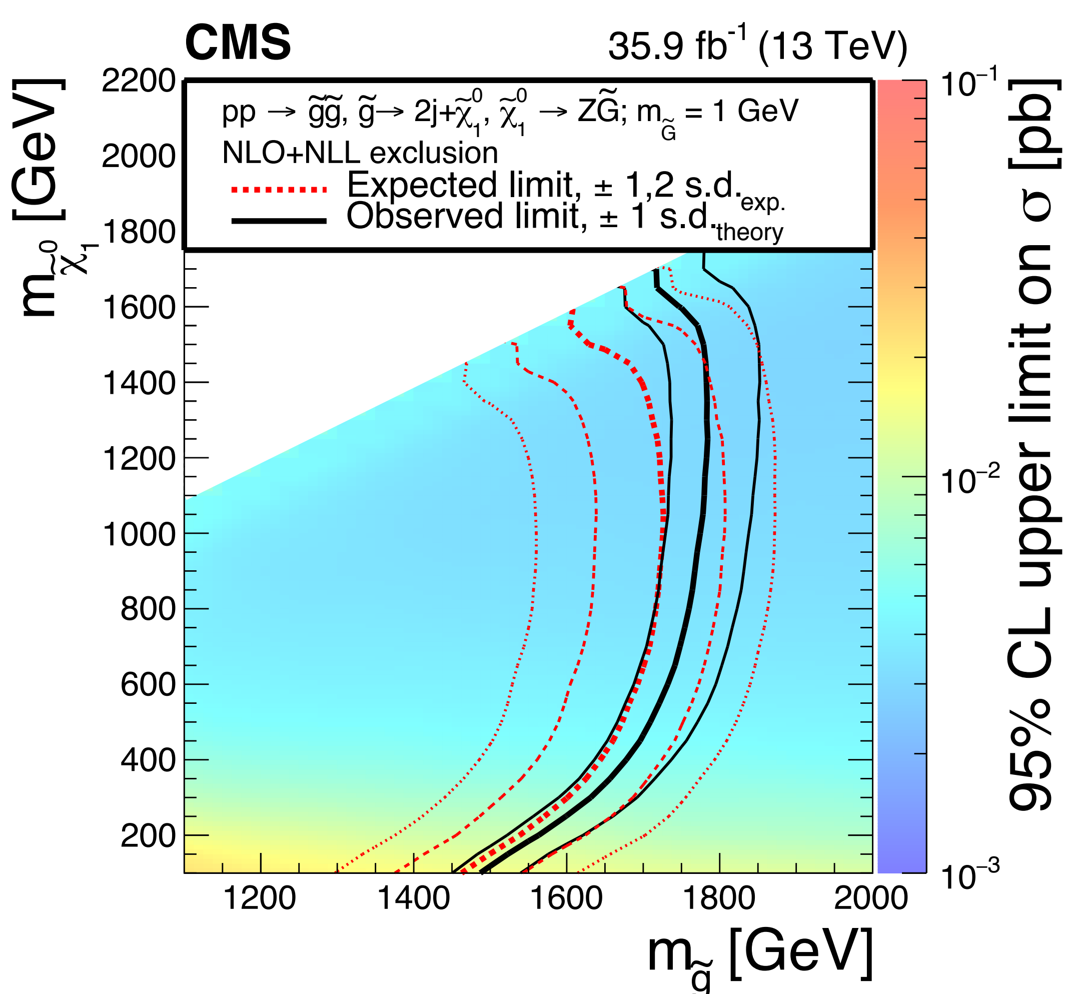


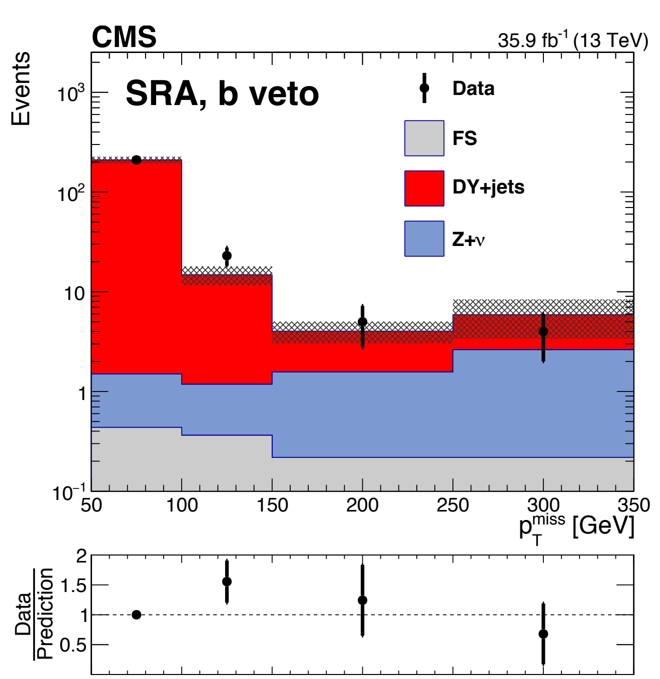
2L OS

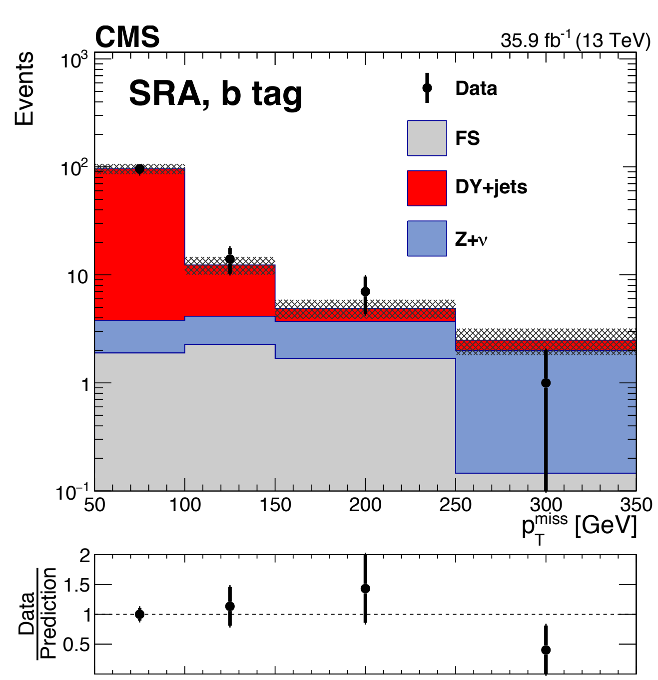
- Analysis probes a wide variety of models in several categories
  - **on-Z strong production** and on-Z electroweak production
  - "edge search" for sleptons in invariant mass distribution
- GMSB model with LSP decaying into **gravitino and Z**
- Select opposite-sign same-flavor (OSSF) events ($e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$) with at least 2 jets and MET > 100 GeV, resulting in 3 main backgrounds
  - **Flavor symmetric** — processes producing same-flavor as often as opposite-flavor events ($t\bar{t}$, W^+W^-) — estimate with $e^{\pm}\mu^{\mp}$ data
  - **DY+jets** — mismeasured MET — estimate with data photons)
  - **Z+ν** — prompt neutrinos (WZ, ZZ, ttV, …) — MC + CR
- Final signal regions based on N_{jets}, N_b, H_T, M_{T2}, and MET
- Gluinos up to 1.8TeV excluded



GMSB model



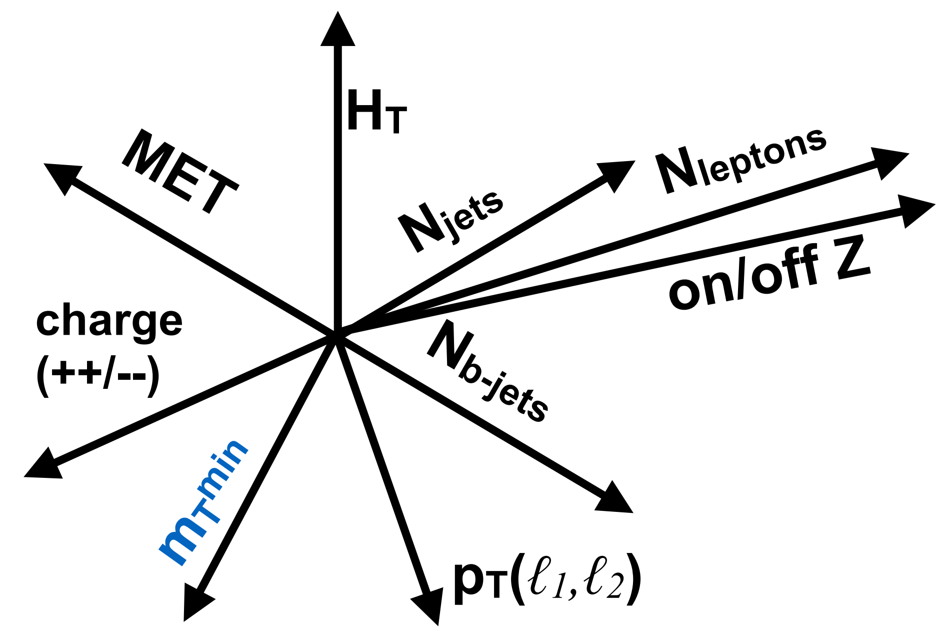


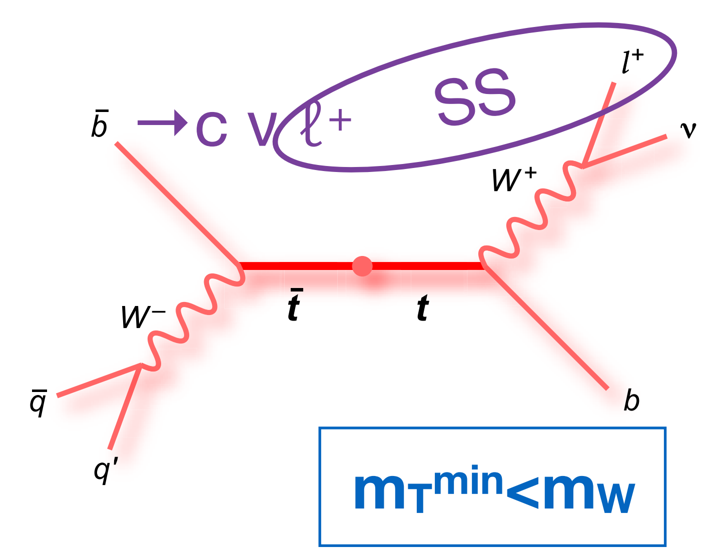


2L SS + ≥3L

- Preliminary full Run2 analysis based on strategies from two published 2016 analyses
  - SUS-16-035/EPJC 77 (2017) 578
  - SUS-16-041/JHEP 02 (2018) 067

- Baseline selection of 2 SS leptons (or 3+) and at least 2 jets
- SS signature **virtually eliminates** QCD, W, Z, $t\bar{t}$ processes
- Main backgrounds then come from
  - **Fake/non-prompt** leptons from $t\bar{t}$, W+jets (data-driven "tight-to-loose" method)
    - Also suppress with m_T^{min} variable
  - **Charge misid**. (data-driven)
  - Rare SM processes: **WZ**, **ttV**, **X+γ**, …
- Then perform a multidimensional binning in $N_{(b)jets}$, MET, H_T, m_T^{min}, …





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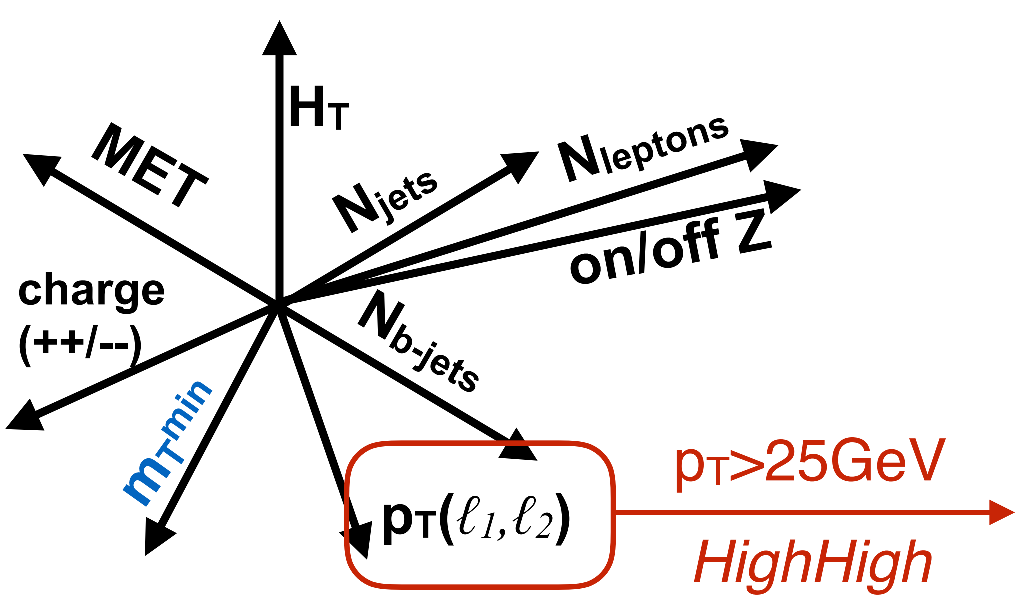
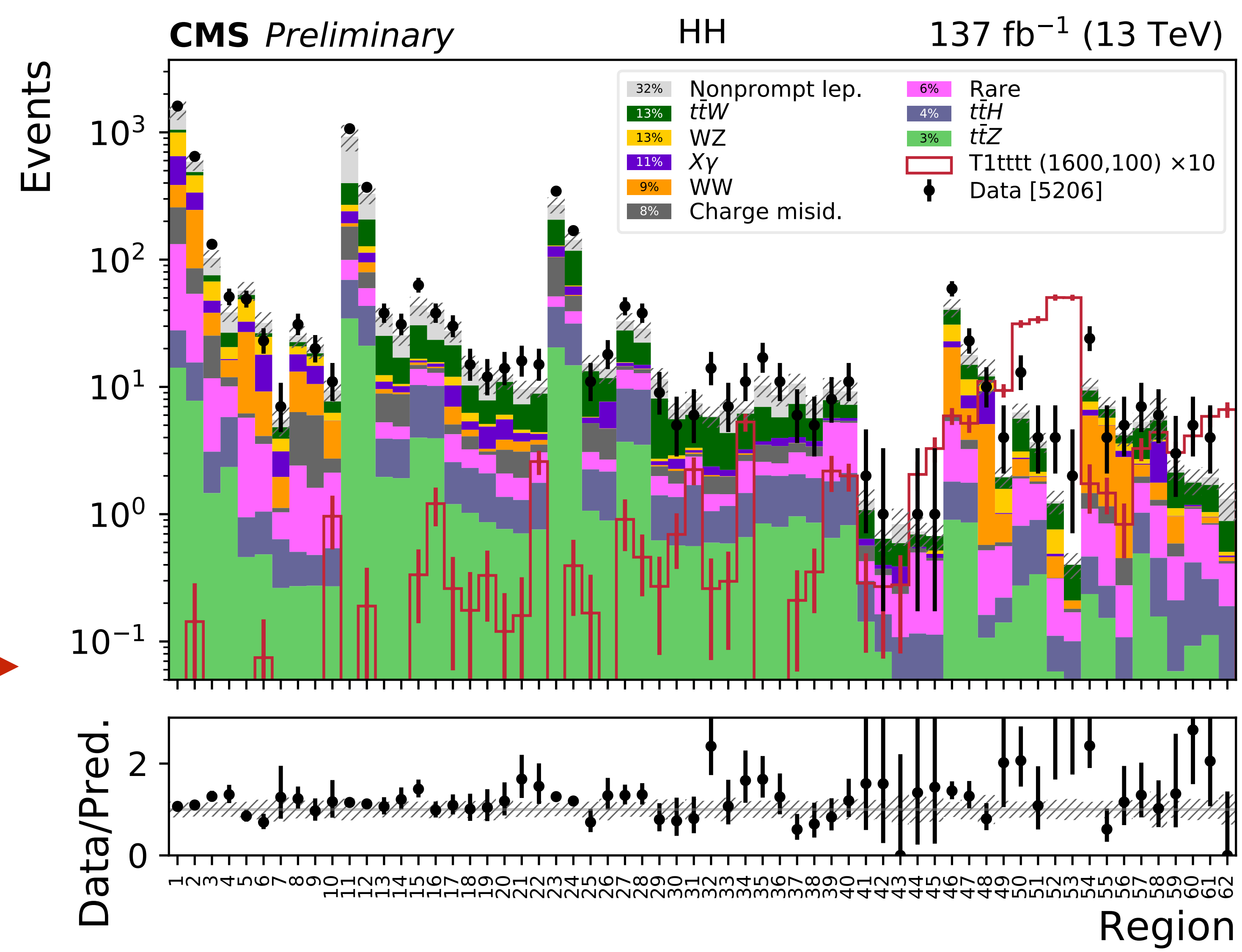
PAS

2L SS + ≥3L

- Group 168 total signal regions into 5 categories (*HighHigh*, *HighLow*, *LowLow*, *MultiLepton*, *LowMET*) → sensitive to particular topologies
- Observe data/MC agreement in combined fit over all signal regions, so set upper limits on simplified models





2L SS + ≥3L

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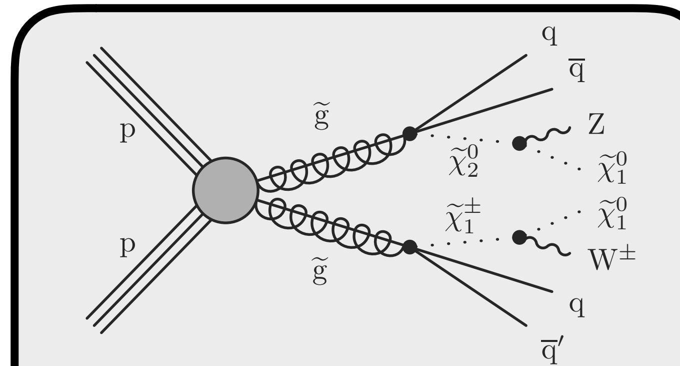
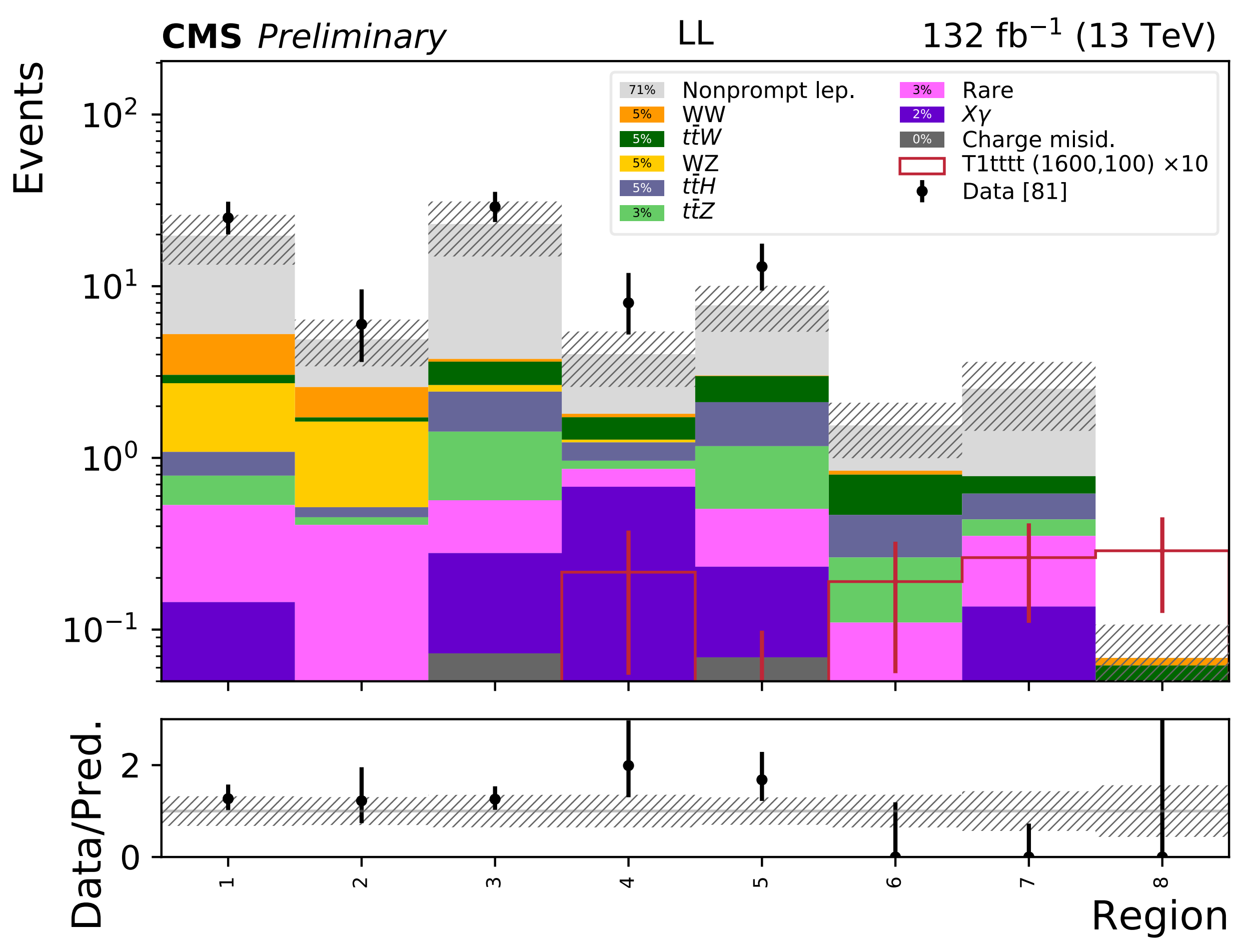
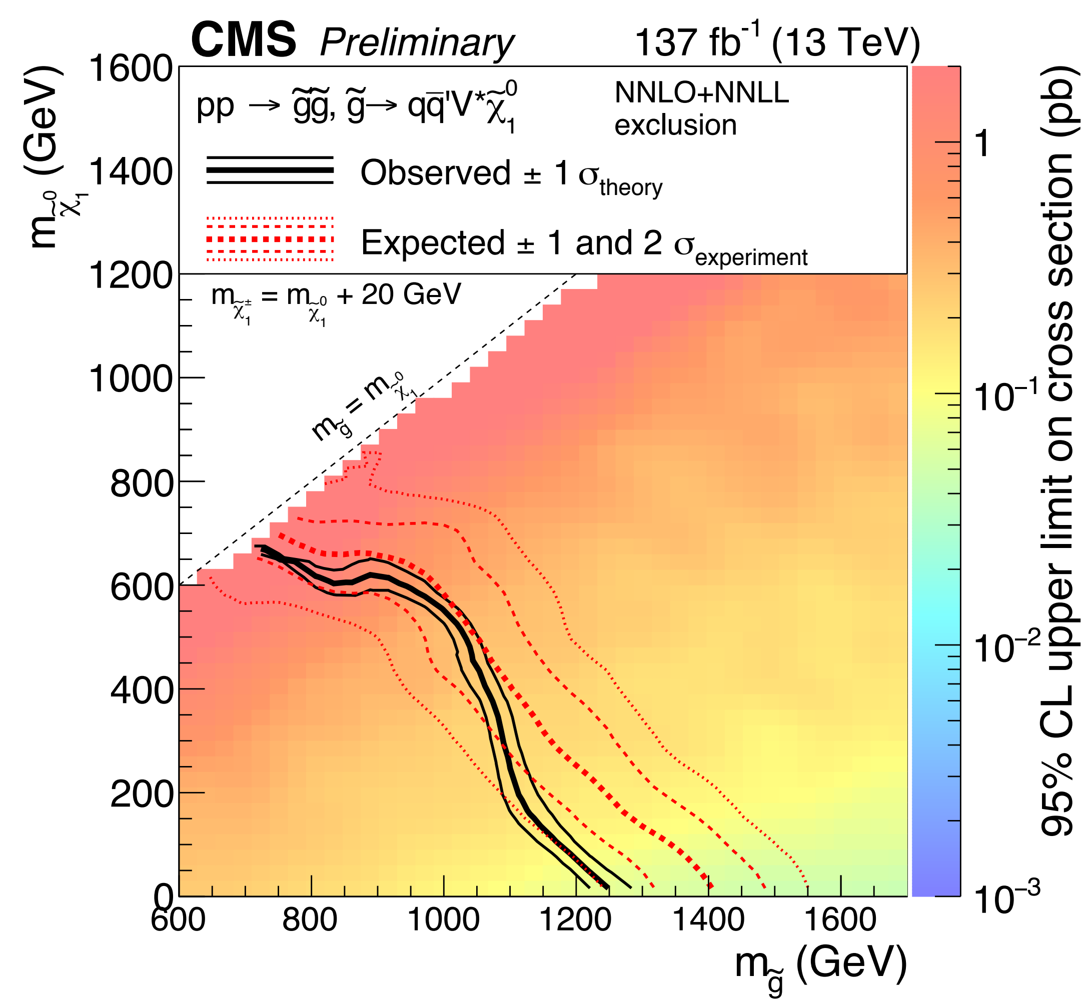
PAS

- LowLow category for leptons with 10/15<p_T<25 GeV provides sensitivity to soft leptons from small mass splittings
- Exclude gluinos up to 1.25TeV in the T5qqqqVV model



T5qqqqVV





2L SS + ≥3L

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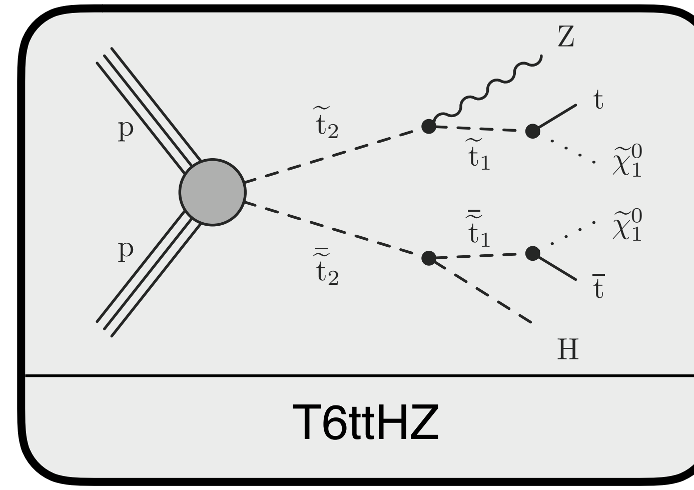
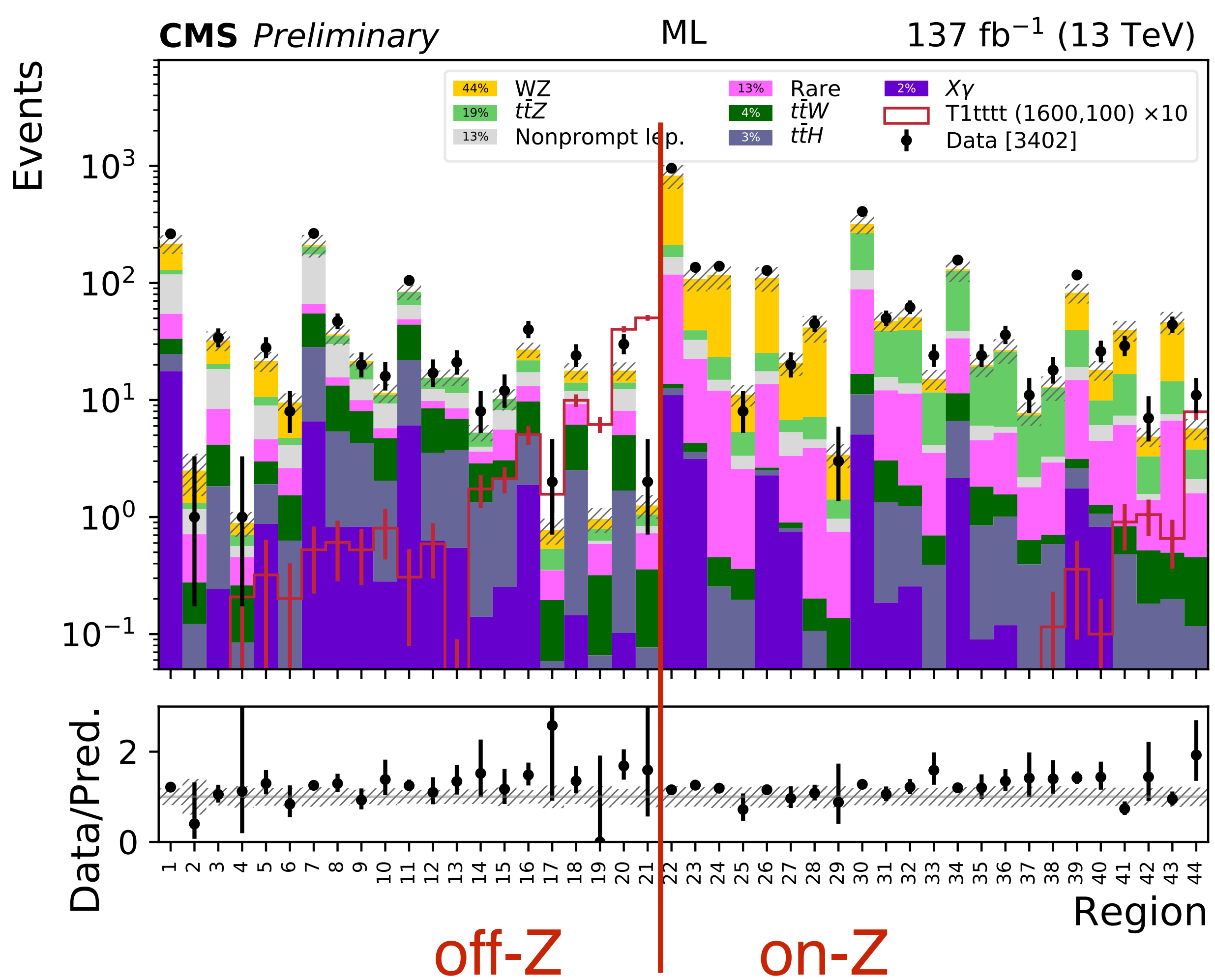
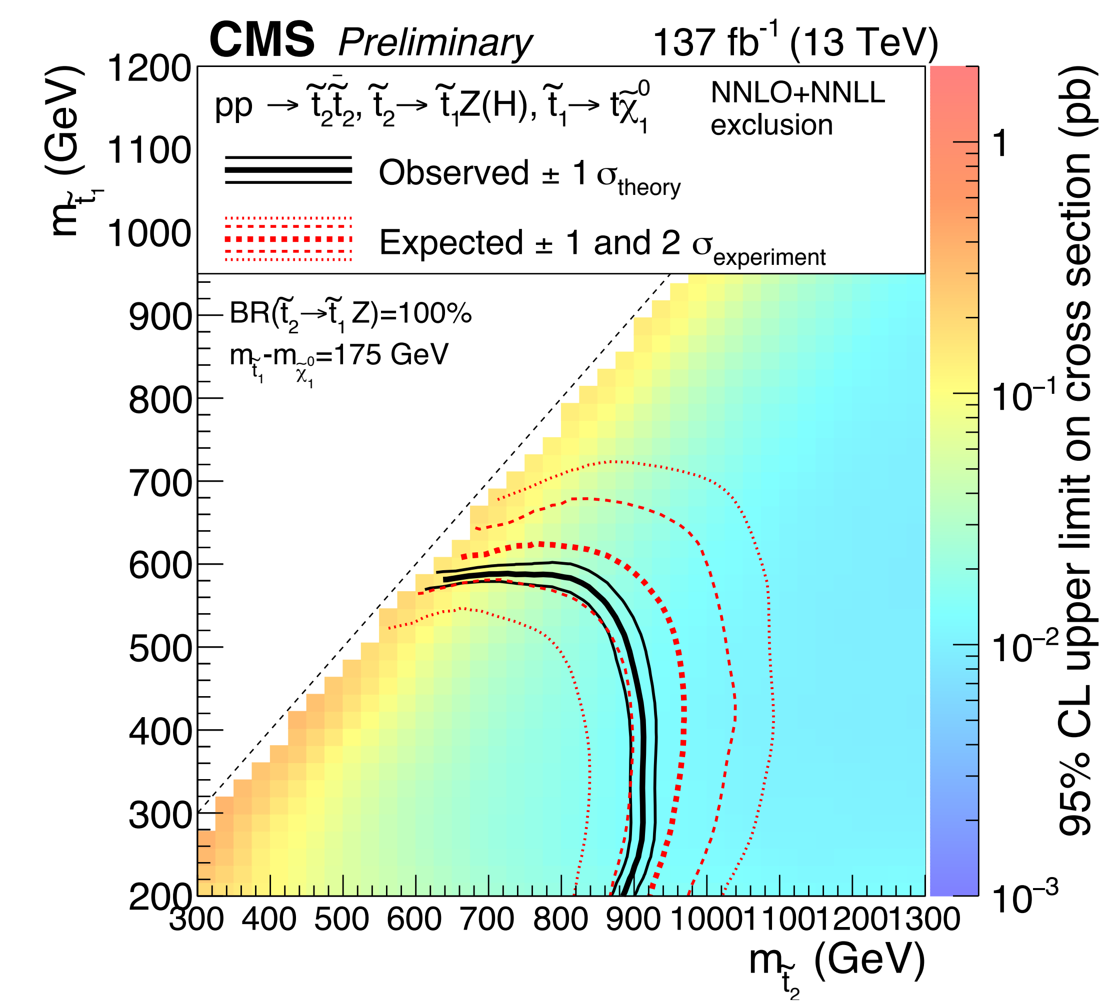
PAS

- MultiLepton category contains both on-Z and off-Z requirements
- Exclusions reaching 900GeV for decays of second generation stop squarks providing H or Z bosons







2L SS + ≥3L

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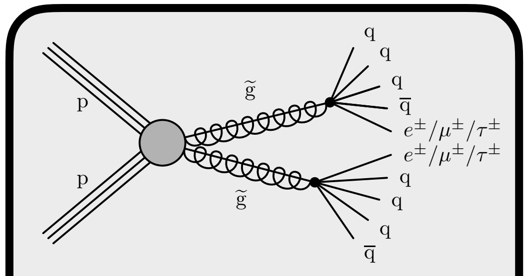
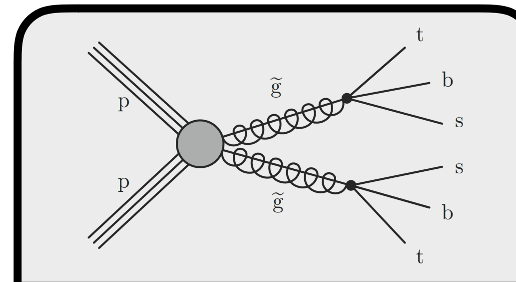
PAS

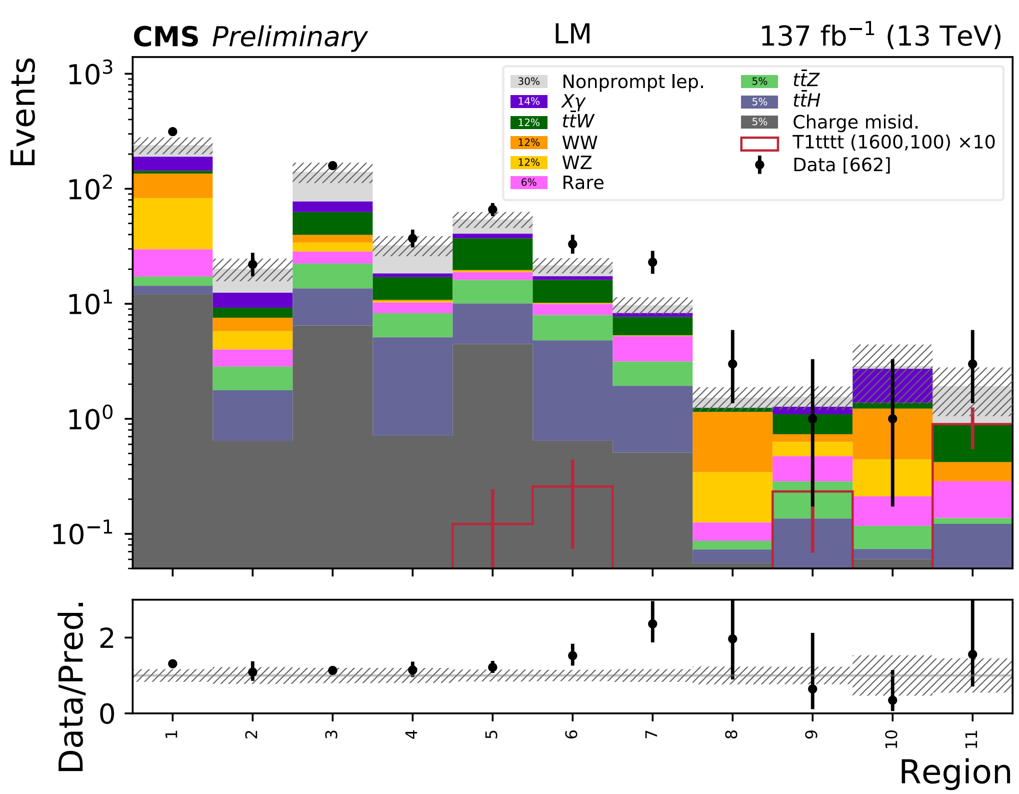
- LowMET category — relaxed MET requirements thanks to the SS signature
- Exclusions on RPV models
  - T1tbs — 1.7TeV
  - T1qqqqL — 2.1TeV **new**

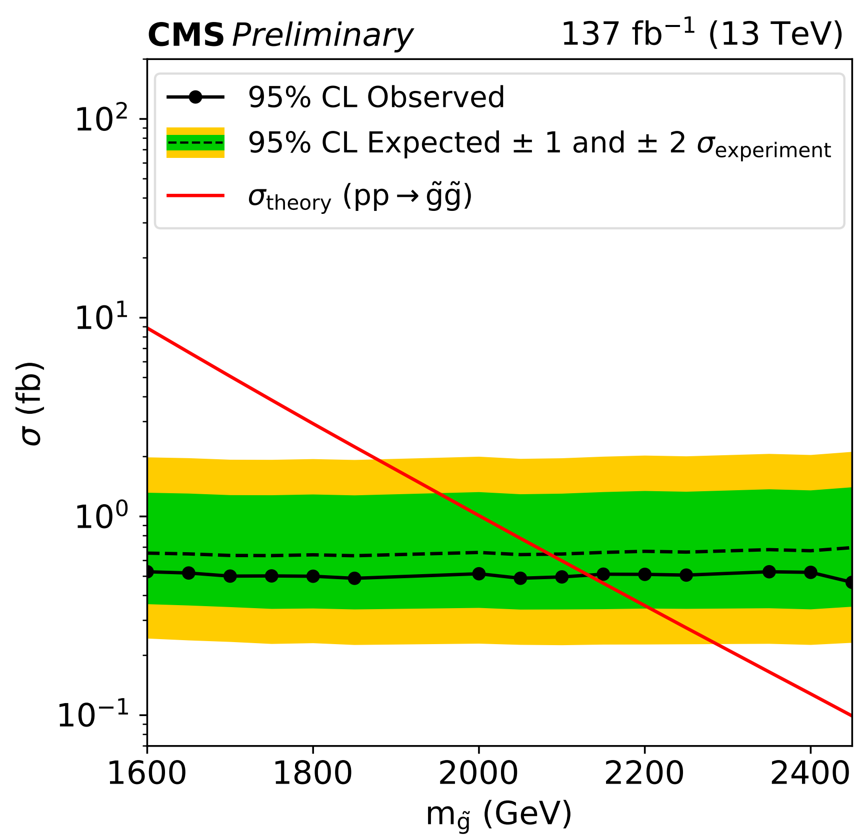


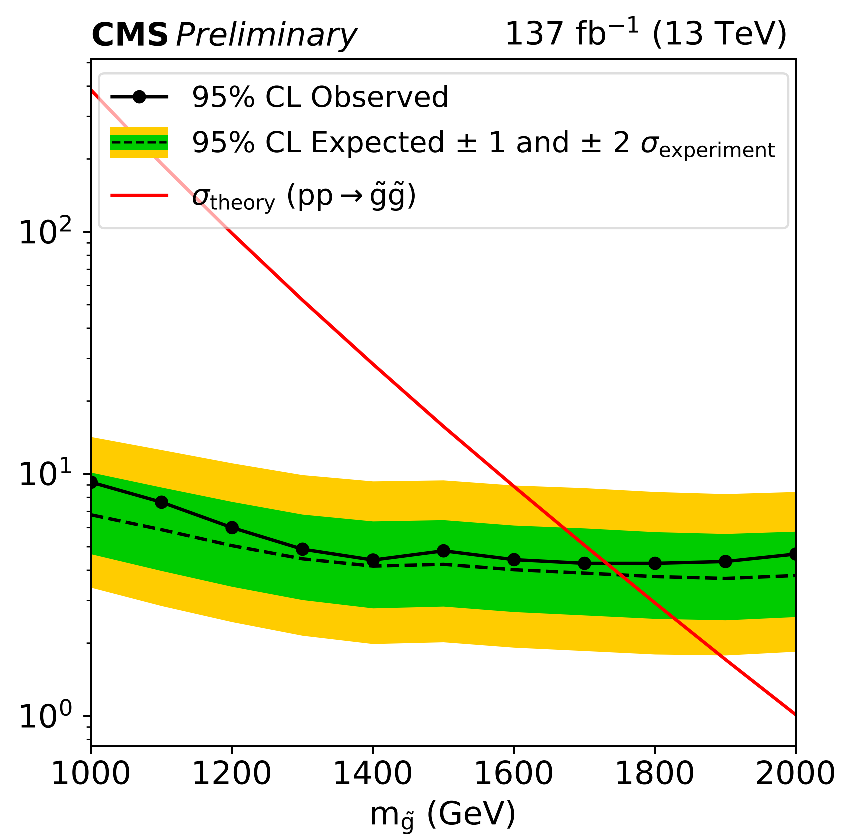
T1qqqqL



T1tbs







Summary

- Strong SUSY probed by many leptonic analyses in CMS
    - so far, no significant excesses, and exclusions pushed toward higher masses close to 2TeV
- There is still lots of **unexplored territory**
    - analyses in progress exploiting full Run2 dataset — almost **4x luminosity** (wrt 2016 dataset) — with sophisticated techniques
    - Run3/HLLHC/HELHC and beyond

Thank you!

Backup

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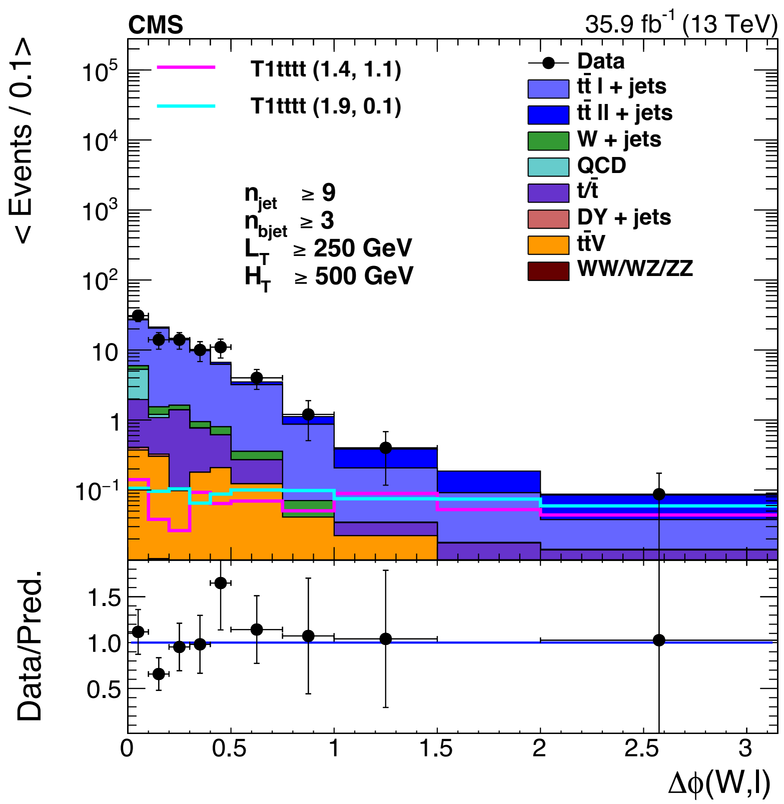
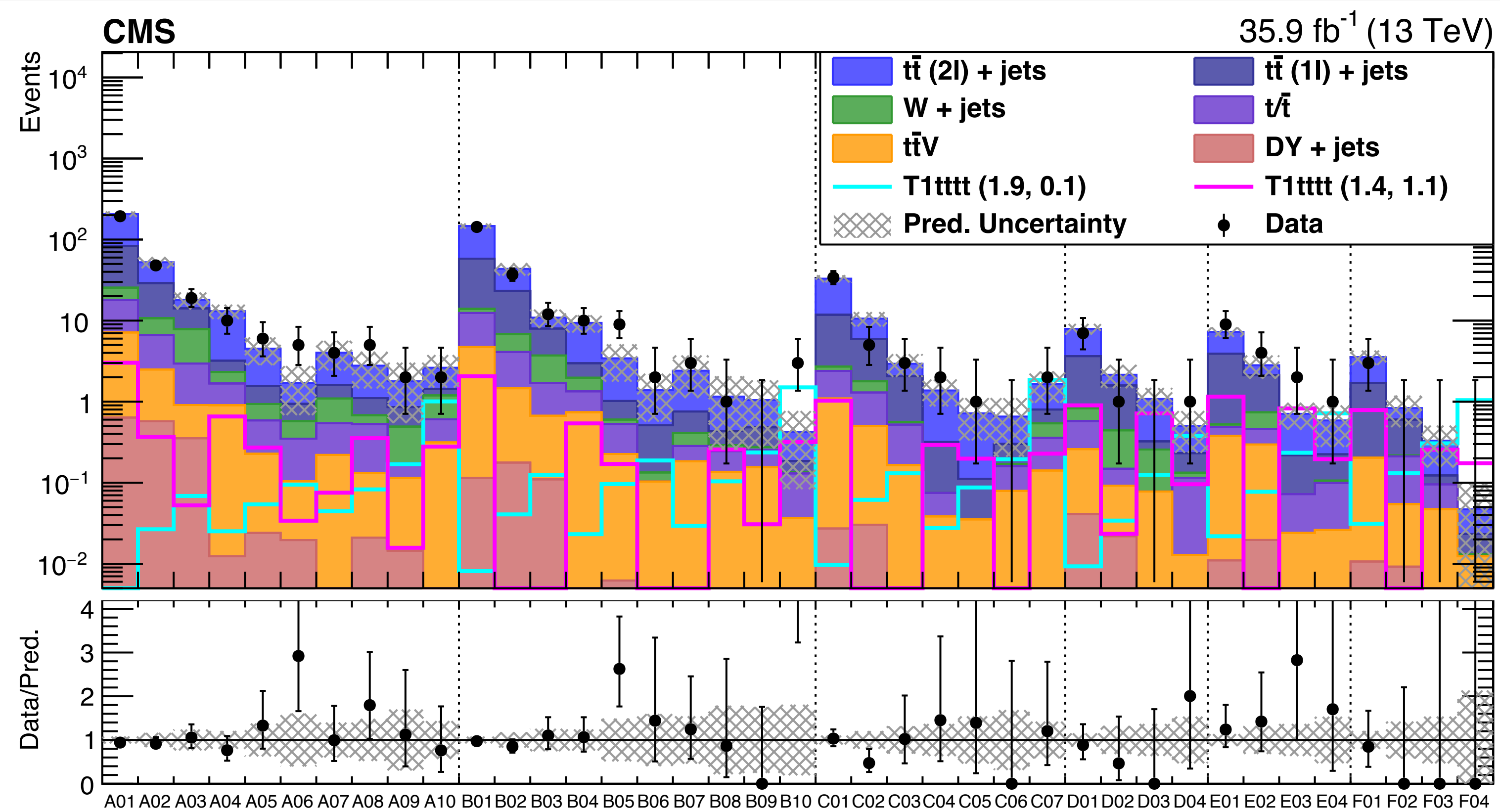
Phys. Lett. B 780 (2018) 384

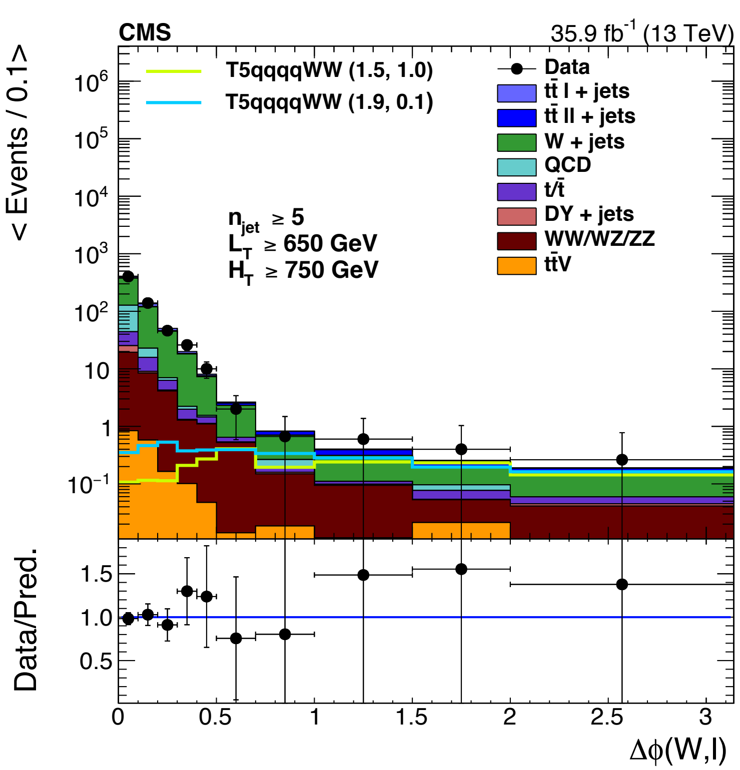
1L $\Delta\phi$

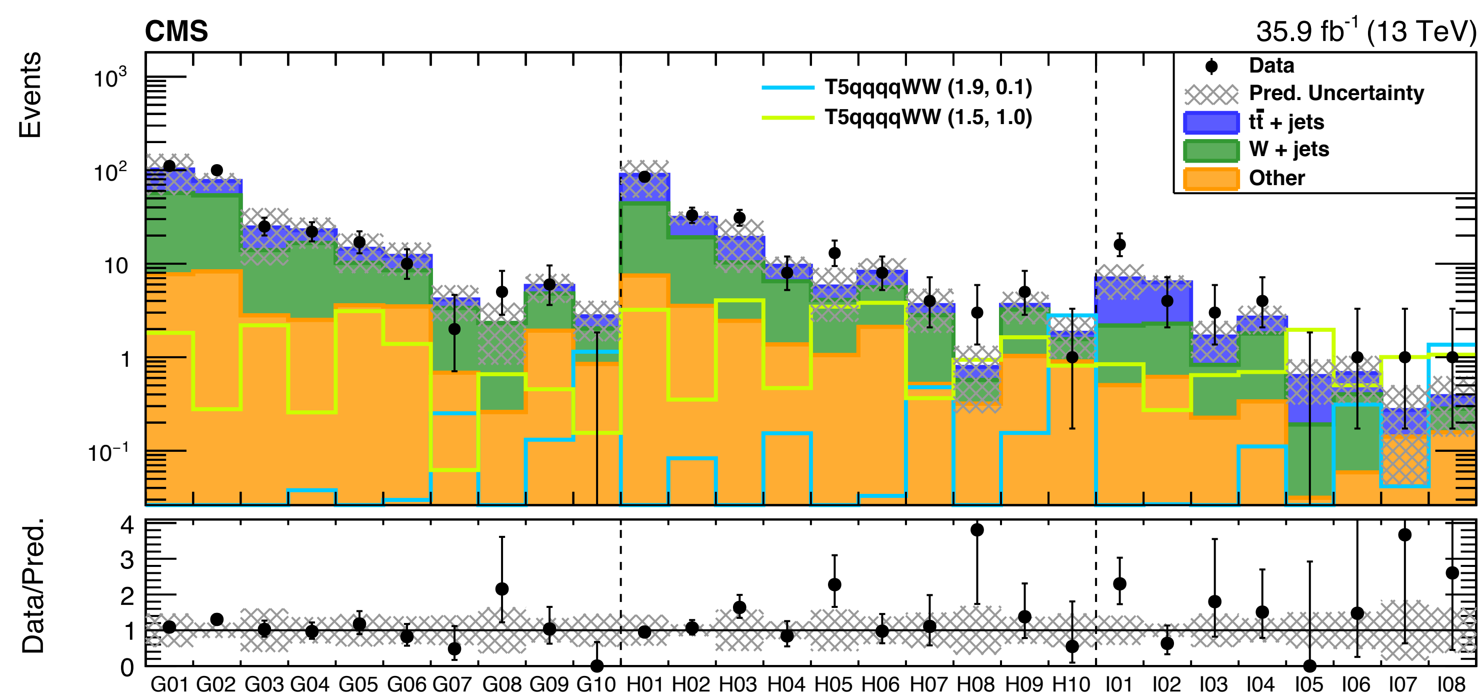
multi-b





0-b





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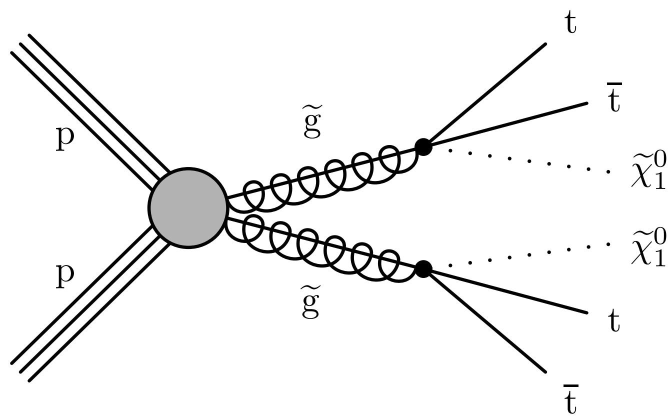
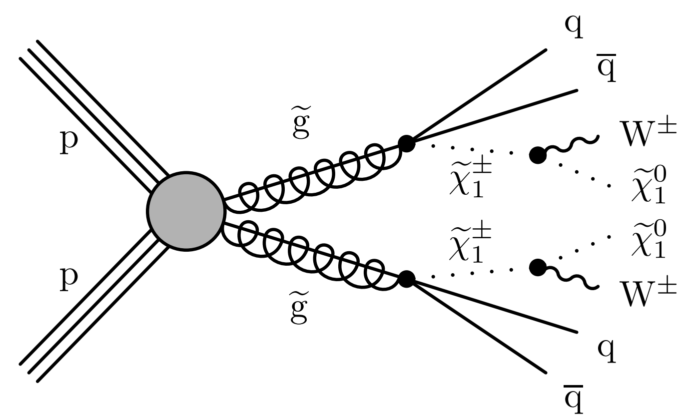
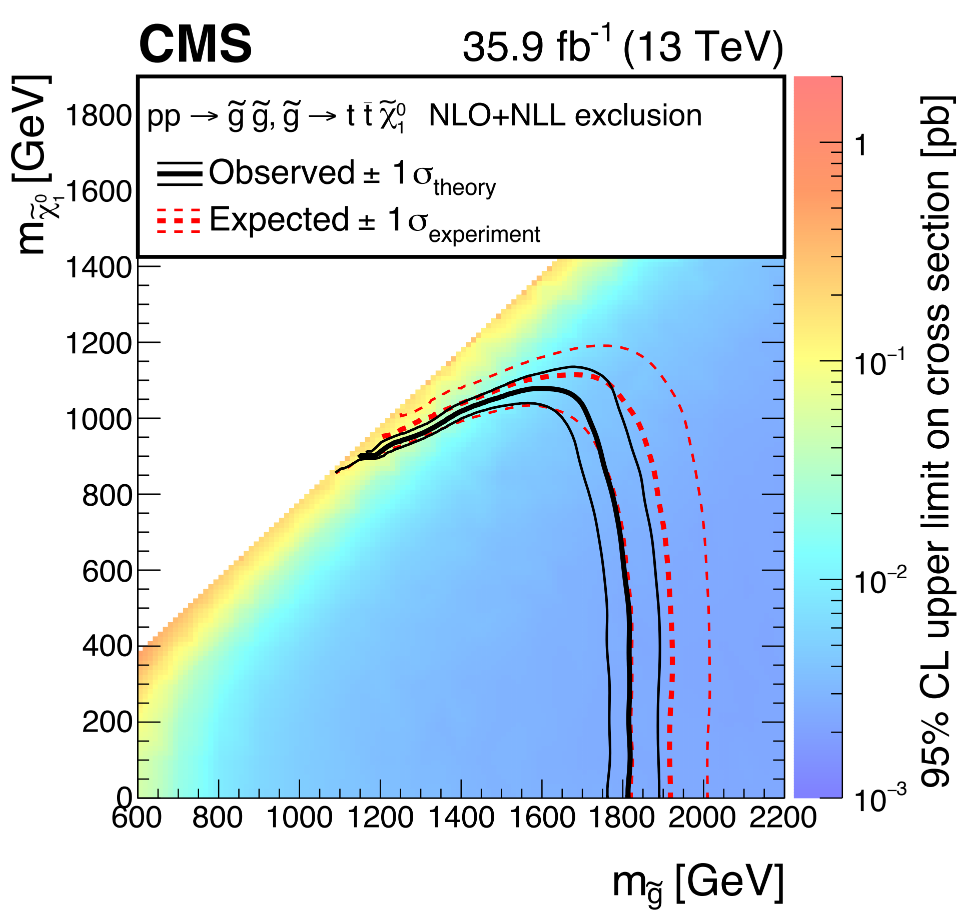
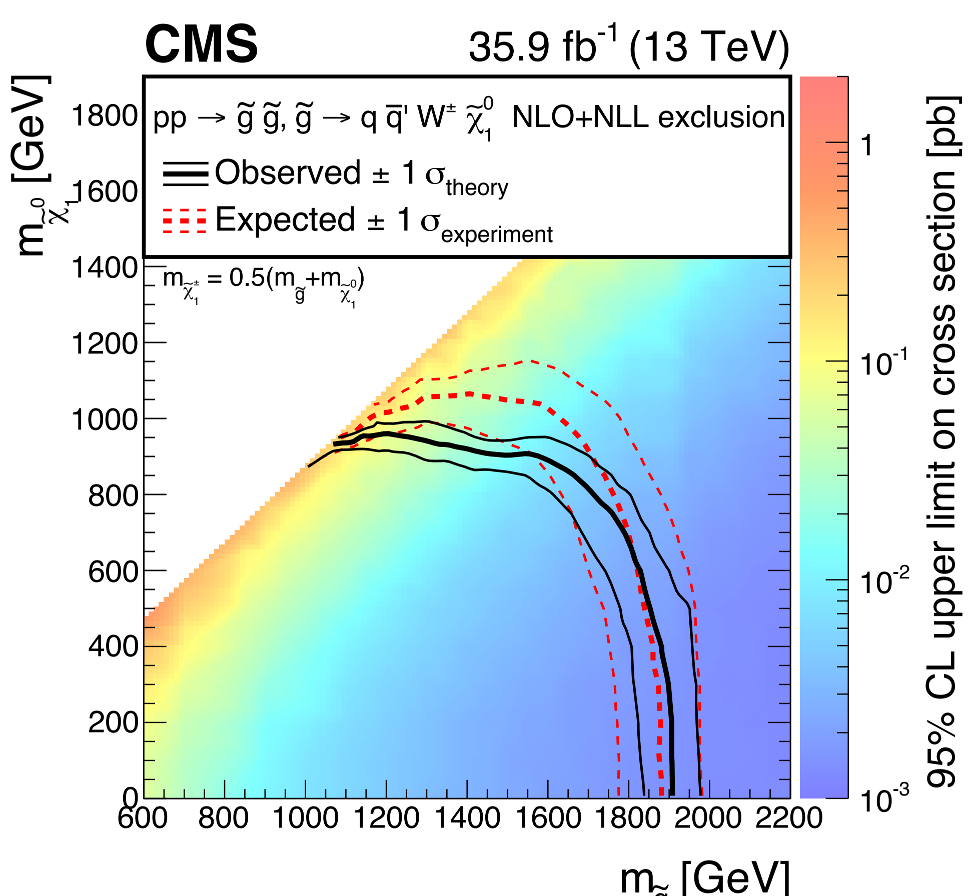
1L $\Delta\phi$









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Phys. Lett. B 780 (2018) 384

1L $\Delta\phi$

<table>
<tr><th>Analysis</th><th colspan="2">Multi-b analysis</th><th colspan="2">0-b analysis</th></tr>
<tr><td></td><td>$n_b = 0$</td><td>$n_b \geq 1$</td><td>$n_b = 0$</td><td>$n_b \geq 1$</td></tr>
<tr><td>$n_{jet} = 3$</td><td rowspan="2">QCD bkg. fit (e sample)</td><td></td><td rowspan="2">$R_{CS}(W^{\pm})$ det. (μ sample), QCD bkg. fit (e sample)</td><td></td></tr>
<tr><td>$n_{jet} = 4$</td><td>R_{CS} det.</td><td>$R_{CS}(t\bar{t}+jets)$ det.</td></tr>
<tr><td>$n_{jet} = 5$</td><td></td><td>R_{CS} det.</td><td>search bins</td><td>$R_{CS}(t\bar{t}+jets)$ det.</td></tr>
<tr><td>$n_{jet} \geq 6$</td><td></td><td>search bins</td><td>search bins</td><td></td></tr>
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Source	Uncertainty for multi-b [%]	Uncertainty for 0-b [%]
Dilepton control sample	0.9–7.0	0.3–18
JES	0.3–18	0.7–26
Tagging of b jets	0.1–0.9	0.1–2.5
Mistagging of light flavor jets	0.1–2.2	0.3–0.8
σ(W+jets)	0.3–9.3	0.3–10
$\sigma(t\bar{t})$	0.1–7.5	0.7–13
$\sigma(t\bar{t}V)$	0.2–20	0.1–3.8
W polarization	0.1–3.3	0.7–14
ISR reweighting ($t\bar{t}$)	0.5–7.0	0.2–11
Pileup	0.4–7.1	0.1–20
Statistical uncertainty in MC events	5–30	5–36

Source	Uncertainty [%]
Trigger	2
Pileup	10
Lepton efficiency	2
Isolated track veto	4
Luminosity	2.5
ISR	2–25
Tagging of b jets	1–6
Mistagging of light flavor jets	1–4
JES	3–40
Factorization/renormalization scale	1–3
p_T^{miss}	2–20

CMS

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1L $\Delta\phi$

UCSB

multi-b

n_{jet}	n_b	L_T [GeV]	$\Delta\phi$ [rad]	H_T [GeV]	Bin name	Signal T1tttt ($m_{\tilde{g}}, m_{\tilde{\chi}^0}$) [TeV] (1.9, 0.1)	(1.4, 1.1)	Predicted background	Observed data
[6, 8]	=1	[250, 450]	1.0	[500, 1000]	A01	<0.01	3.02 ± 0.24	206 ± 15	194
				[1000, 1500]	A02	0.03 ± 0.01	0.37 ± 0.08	52.5 ± 8.2	48
				≥1500	A03	0.07 ± 0.01	0.05 ± 0.03	18.0 ± 4.2	19
		[450, 600]	0.75	[500, 1000]	A04	0.03 ± 0.01	0.66 ± 0.11	13.1 ± 2.7	10
				[1000, 1500]	A05	0.05 ± 0.01	0.27 ± 0.07	4.5 ± 1.7	6
				≥1500	A06	0.09 ± 0.01	0.03 ± 0.02	1.7 ± 1.0	5
		[600, 750]	0.5	[500, 1000]	A07	0.04 ± 0.01	0.08 ± 0.04	4.0 ± 1.6	4
				[1000, 1500]	A08	0.08 ± 0.01	0.35 ± 0.08	2.8 ± 1.3	5
				≥1500	A09	0.17 ± 0.02	0.02 ± 0.02	1.8 ± 1.2	2
		≥750	0.5	≥500	A10	1.01 ± 0.04	0.28 ± 0.07	2.6 ± 1.1	2
	=2	[250, 450]	1.0	[500, 1000]	B01	0.01 ± 0.01	2.06 ± 0.20	147 ± 11	143
				[1000, 1500]	B02	0.04 ± 0.01	<0.01	43.5 ± 7.5	37
				≥1500	B03	0.13 ± 0.01	<0.01	10.9 ± 2.8	12
		[450, 600]	0.75	[500, 1000]	B04	0.02 ± 0.01	0.54 ± 0.10	9.4 ± 2.2	10
				[1000, 1500]	B05	0.10 ± 0.01	0.17 ± 0.06	3.4 ± 1.7	9
				≥1500	B06	0.19 ± 0.02	<0.01	1.39 ± 0.82	2
		[600, 750]	0.5	[500, 1000]	B07	0.03 ± 0.01	<0.01	2.4 ± 1.3	3
				[1000, 1500]	B08	0.10 ± 0.01	0.26 ± 0.07	1.16 ± 0.90	1
				≥1500	B09	0.24 ± 0.02	0.03 ± 0.02	1.05 ± 0.78	0
		≥750	0.5	≥500	B10	1.50 ± 0.05	0.32 ± 0.08	0.42 ± 0.34	3
	≥3	[250, 450]	1.0	[500, 1000]	C01	0.01 ± 0.01	1.03 ± 0.14	32.9 ± 3.3	34
				[1000, 1500]	C02	0.06 ± 0.01	<0.01	10.6 ± 2.1	5
				≥1500	C03	0.13 ± 0.01	<0.01	2.93 ± 0.91	3
		[450, 600]	0.75	[500, 1000]	C04	0.03 ± 0.01	0.29 ± 0.07	1.38 ± 0.50	2
				[1000, 1500]	C05	0.09 ± 0.01	0.20 ± 0.06	0.72 ± 0.39	1
				≥1500	C06	0.20 ± 0.02	<0.01	0.66 ± 0.45	0
		≥600	0.5	≥500	C07	1.85 ± 0.05	0.23 ± 0.06	1.66 ± 0.69	2
≥9	=1	[250, 450]	1.0	[500, 1500]	D01	0.01 ± 0.01	0.90 ± 0.12	7.9 ± 1.1	7
				≥1500	D02	0.03 ± 0.01	0.02 ± 0.02	2.15 ± 0.67	1
		≥450	0.75	[500, 1500]	D03	0.13 ± 0.01	0.72 ± 0.11	1.08 ± 0.39	0
				≥1500	D04	0.38 ± 0.02	0.10 ± 0.04	0.50 ± 0.27	1
	=2	[250, 450]	1.0	[500, 1500]	E01	0.02 ± 0.01	1.15 ± 0.14	7.26 ± 0.97	9
				≥1500	E02	0.08 ± 0.01	<0.01	2.81 ± 0.89	4
		≥450	0.75	[500, 1500]	E03	0.23 ± 0.02	0.83 ± 0.12	0.71 ± 0.26	2
				≥1500	E04	0.72 ± 0.03	0.20 ± 0.05	0.59 ± 0.31	1
	≥3	[250, 450]	1.0	[500, 1500]	F01	0.03 ± 0.01	0.79 ± 0.11	3.55 ± 0.72	3
				≥1500	F02	0.13 ± 0.01	<0.01	0.83 ± 0.35	0
		≥450	0.75	[500, 1500]	F03	0.31 ± 0.02	0.26 ± 0.06	0.33 ± 0.17	0
				≥1500	F04	1.04 ± 0.04	0.17 ± 0.05	0.05 ± 0.05	0

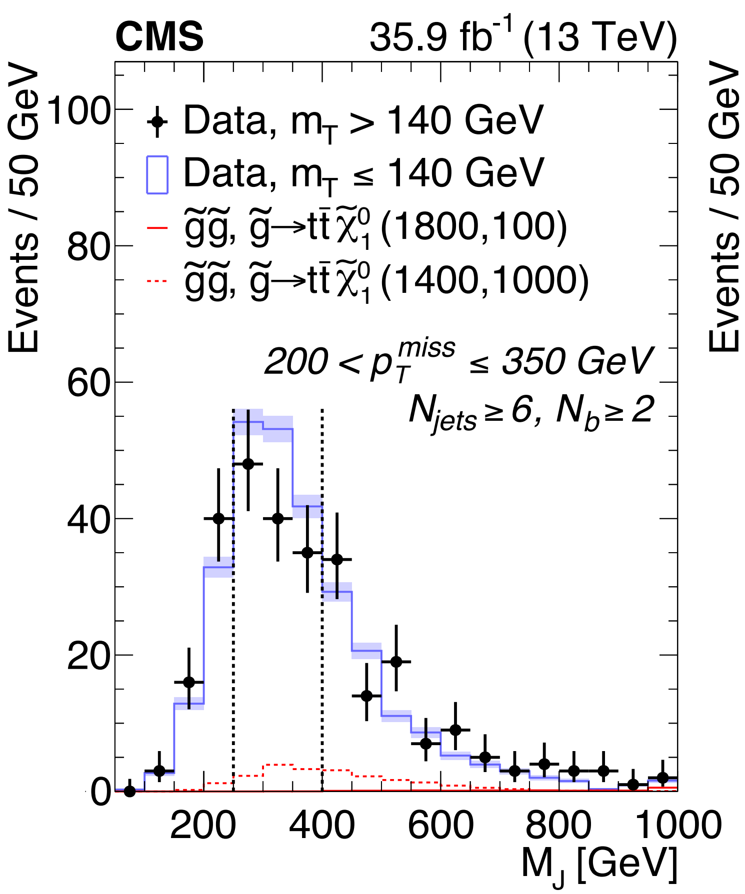
0-b

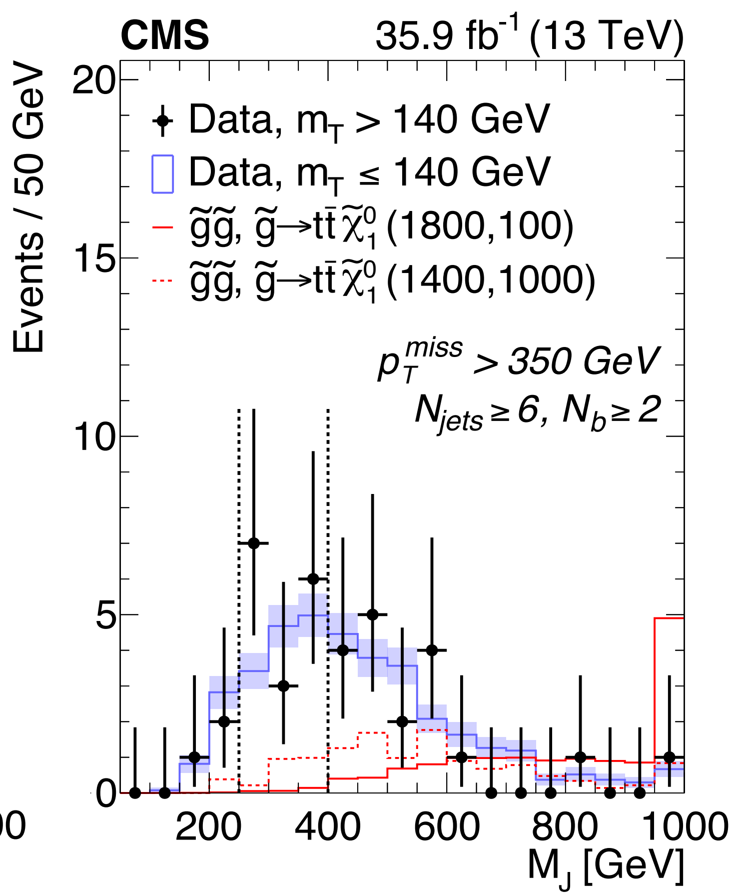
n_{jet}	L_T [GeV]	$\Delta\phi$ [rad]	H_T [GeV]	Bin name	Signal T5qqqqWW ($m_{\tilde{g}}, m_{\tilde{\chi}^0}$) [TeV] (1.5, 1.0)	(1.9, 0.1)	Predicted background	Observed data
5	[250, 350]	1.0	[500, 750]	G01	1.82 ± 0.29	<0.01	102 ± 48	111
			≥750	G02	0.21 ± 0.09	0.01 ± 0.01	77 ± 16	100
	[350, 450]	1.0	[500, 750]	G03	2.25 ± 0.32	<0.01	24 ± 15	25
			≥750	G04	0.29 ± 0.11	0.04 ± 0.01	22.8 ± 8.3	22
	[450, 650]	0.75	[500, 750]	G05	3.02 ± 0.37	<0.01	14.5 ± 6.5	17
			[750, 1250]	G06	1.40 ± 0.25	0.04 ± 0.02	12.1 ± 4.7	10
			≥1250	G07	0.08 ± 0.06	0.25 ± 0.04	4.2 ± 1.7	2
	≥650	0.5	[500, 750]	G08	0.74 ± 0.18	0.01 ± 0.01	2.3 ± 1.5	5
			[750, 1250]	G09	0.49 ± 0.15	0.12 ± 0.03	5.8 ± 2.0	6
			≥1250	G10	0.14 ± 0.07	1.15 ± 0.08	2.7 ± 1.3	0
[6, 7]	[250, 350]	1.0	[500, 1000]	H01	3.02 ± 0.36	<0.01	89 ± 38	85
			≥1000	H02	0.31 ± 0.10	0.09 ± 0.02	30.9 ± 5.1	33
	[350, 450]	1.0	[500, 1000]	H03	4.13 ± 0.41	0.01 ± 0.01	19 ± 11	31
			≥1000	H04	0.52 ± 0.14	0.14 ± 0.03	9.5 ± 2.3	8
	[450, 650]	0.75	[500, 750]	H05	3.63 ± 0.39	<0.01	5.7 ± 3.3	13
			[750, 1250]	H06	3.79 ± 0.39	0.03 ± 0.01	8.2 ± 3.2	8
			≥1250	H07	0.36 ± 0.12	0.47 ± 0.05	3.6 ± 1.8	4
	≥650	0.5	[500, 750]	H08	0.89 ± 0.19	<0.01	0.79 ± 0.53	3
			[750, 1250]	H09	1.77 ± 0.26	0.15 ± 0.03	3.6 ± 1.4	5
			≥1250	H10	0.83 ± 0.18	2.83 ± 0.12	1.83 ± 0.86	1
≥8	[250, 350]	1.0	[500, 1000]	I01	0.88 ± 0.18	<0.01	7.0 ± 2.8	16
			≥1000	I02	0.26 ± 0.09	0.03 ± 0.01	6.3 ± 1.2	4
	[350, 450]	1.0	[500, 1000]	I03	0.55 ± 0.14	<0.01	1.67 ± 0.77	3
			≥1000	I04	0.72 ± 0.15	0.11 ± 0.02	2.65 ± 0.89	4
	[450, 650]	0.75	[500, 1250]	I05	2.07 ± 0.26	0.01 ± 0.01	0.63 ± 0.32	0
			≥1250	I06	0.45 ± 0.12	0.3 ± 0.04	0.68 ± 0.35	1
	≥650	0.5	[500, 1250]	I07	0.97 ± 0.18	0.04 ± 0.01	0.27 ± 0.23	1
			≥1250	I08	1.12 ± 0.18	1.37 ± 0.08	0.38 ± 0.24	1

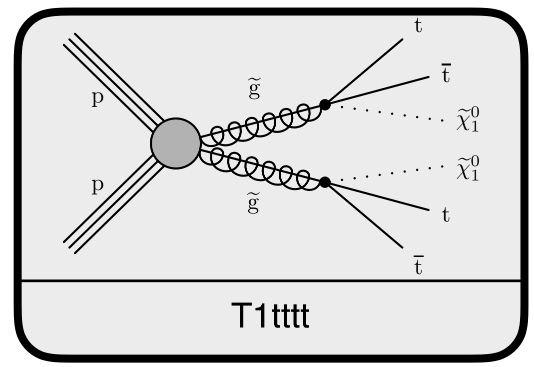
1L MJ

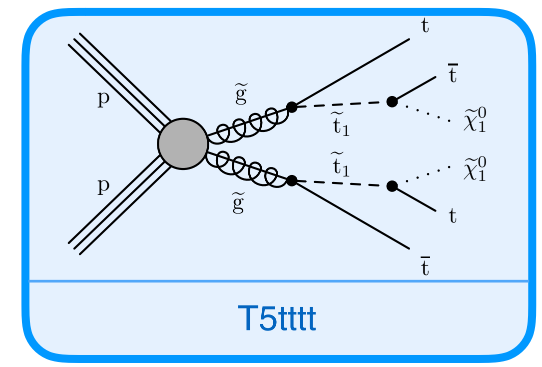
Phys. Rev. Lett. 119 (2017) 151802

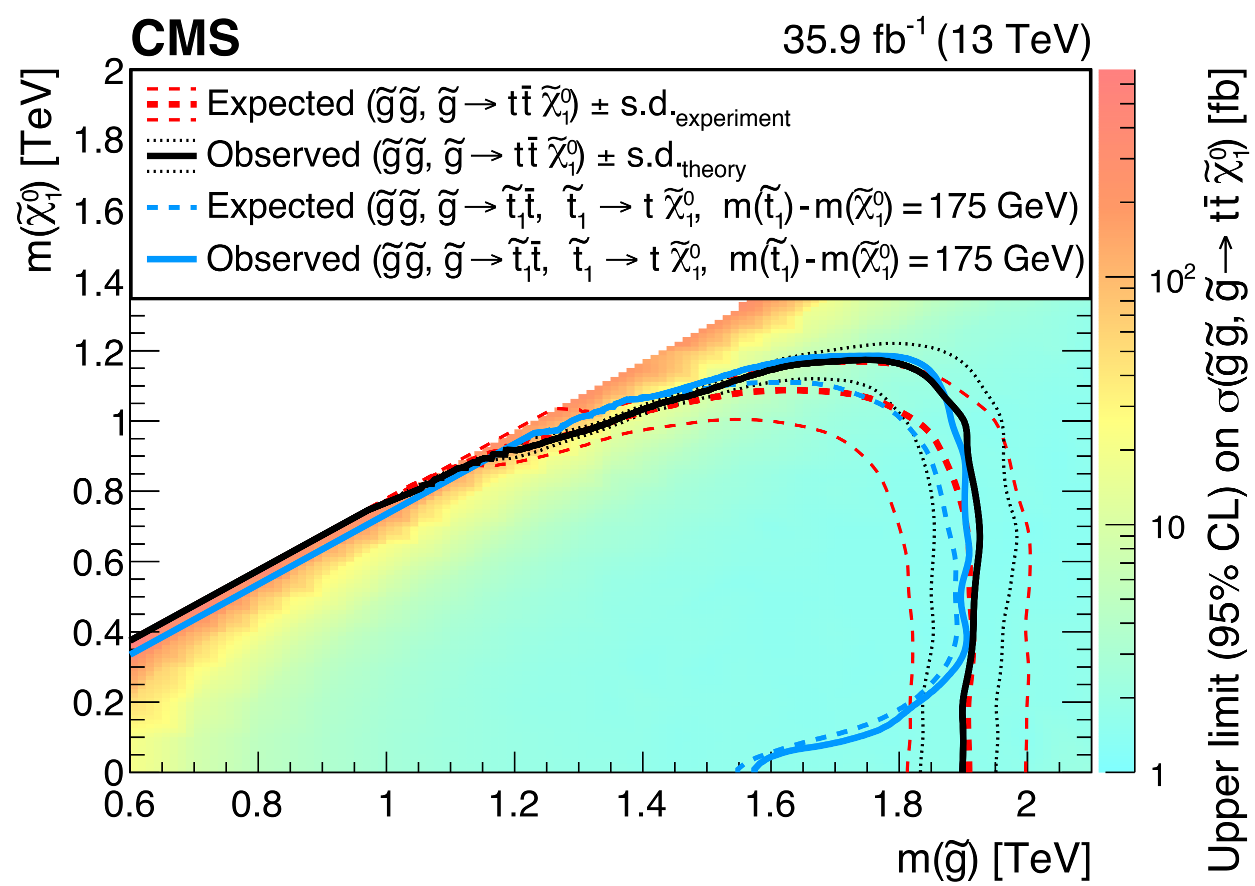
$$\kappa = \frac{\mu_{\mathrm{R4}}^{\mathrm{MC\ bkg}} / \mu_{\mathrm{R2}}^{\mathrm{MC\ bkg}}}{\mu_{\mathrm{R3}}^{\mathrm{MC\ bkg}} / \mu_{\mathrm{R1}}^{\mathrm{MC\ bkg}}}.$$











1L MJ

Phys. Rev. Lett. 119 (2017) 151802

Cutflow

$\mathcal{L} = 35.9$ fb^{-1}	T1tttt (1800,100)	T5tttt (1800,100)	T1tttt (1400,1000)	T5tttt (1400,1000)
1ℓ, $S_T > 500$ GeV, $p_T^{miss} > 200$ GeV	30.9	27.7	92.4	97.7
Track veto	28.4	23.7	80.0	86.5
$N_{jets} \geq 6$	25.0	21.0	74.4	80.9
$N_b \geq 1$	23.6	19.8	70.6	77.4
$M_J > 250$ GeV	23.6	19.8	65.9	73.6
$m_T > 140$ GeV	19.2	11.6	39.3	43.1
$M_J > 400$ GeV	18.9	11.5	25.0	28.1
$N_b \geq 2$	14.2	8.9	18.7	21.9
$p_T^{miss} > 350$ GeV	12.5	5.8	9.1	11.1
$p_T^{miss} > 500$ GeV	9.9	3.1	3.8	5.1
$N_{jets} \geq 9$	3.8	1.2	2.6	3.4

Four aggregate search bins

p_T^{miss} [GeV]	N_{jets}	N_b	NC	C	κ	Pred.	Obs.
>200	≥9	≥3	3.4	6.9	1.4 ± 0.3	3.1 ± 0.8	2
>350	≥9	≥2	5.3	6.2	1.0 ± 0.4	2.7 ± 1.2	2
>500	≥6	≥3	5.4	2.1	1.7 ± 0.6	0.5 ± 0.4	1
>500	≥9	≥1	5.1	3.6	1.2 ± 0.4	0.4 ± 0.4	2

18 bins of signal region R4

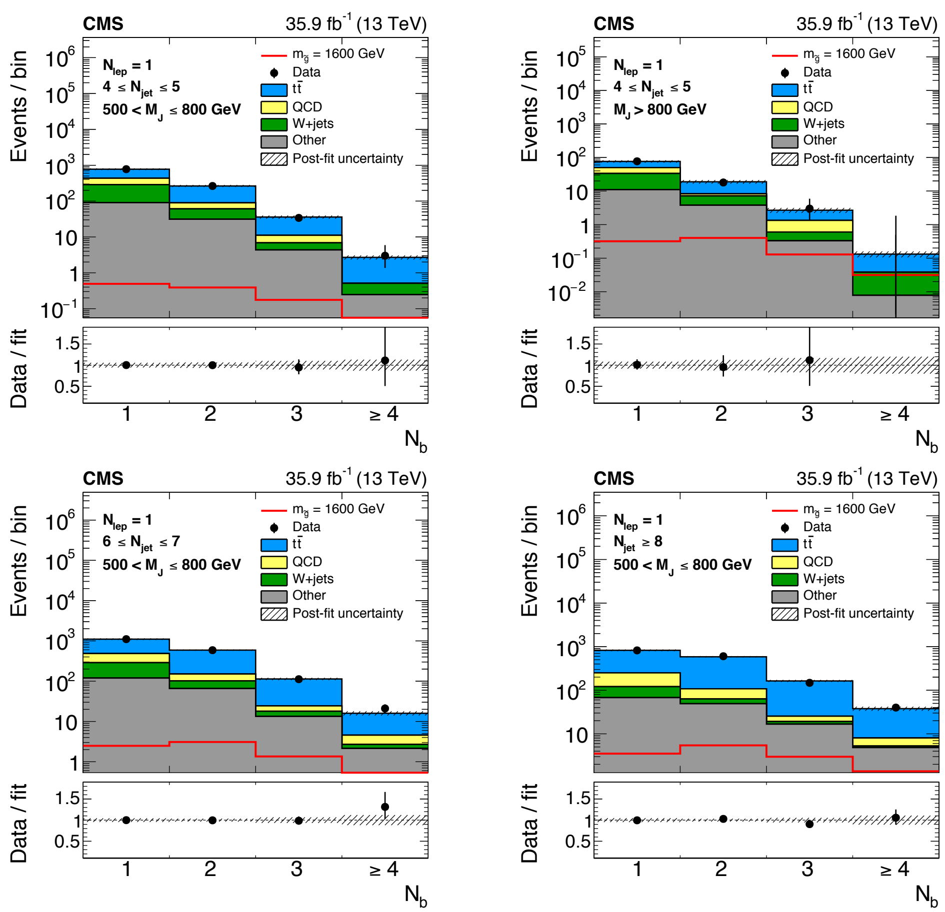
N_{jets}	N_b	NC	C	κ	Pred.	Obs.
$200 < p_T^{miss} \leq 350$ GeV						
6-8	1	0.4	1.9	1.2 ± 0.2	85 ± 14	106
6-8	2	0.6	3.0	1.2 ± 0.2	55.1 ± 9.3	75
6-8	≥3	0.6	2.2	1.5 ± 0.2	16.4 ± 3.0	16
≥9	1	0.2	1.6	1.0 ± 0.2	6.5 ± 1.5	11
≥9	2	0.3	2.1	1.2 ± 0.3	7.6 ± 1.9	11
≥9	≥3	0.4	3.1	1.4 ± 0.3	2.3 ± 0.7	2
$350 < p_T^{miss} \leq 500$ GeV						
6-8	1	0.7	1.1	1.0 ± 0.3	17.4 ± 6.6	25
6-8	2	0.9	1.3	1.1 ± 0.4	13.7 ± 5.3	10
6-8	≥3	0.8	0.9	1.3 ± 0.4	3.8 ± 1.6	1
≥9	1	0.3	1.0	1.1 ± 0.4	1.3 ± 0.6	2
≥9	2	0.5	1.1	0.8 ± 0.3	1.6 ± 0.8	2
≥9	≥3	0.7	2.1	1.2 ± 0.5	0.6 ± 0.4	0
$p_T^{miss} > 500$ GeV						
6-8	1	2.5	0.6	1.0 ± 0.3	1.9 ± 1.5	8
6-8	2	3.6	1.0	1.0 ± 0.4	0.9 ± 0.7	4
6-8	≥3	3.2	0.4	1.5 ± 0.6	0.4 ± 0.4	1
≥9	1	1.0	0.7	1.0 ± 0.4	0.2 ± 0.2	2
≥9	2	1.8	1.2	1.0 ± 0.4	0.1 ± 0.1	0
≥9	≥3	2.3	1.7	3.1 ± 1.5	0.1 ± 0.1	0

1L M_J (*RPV*)

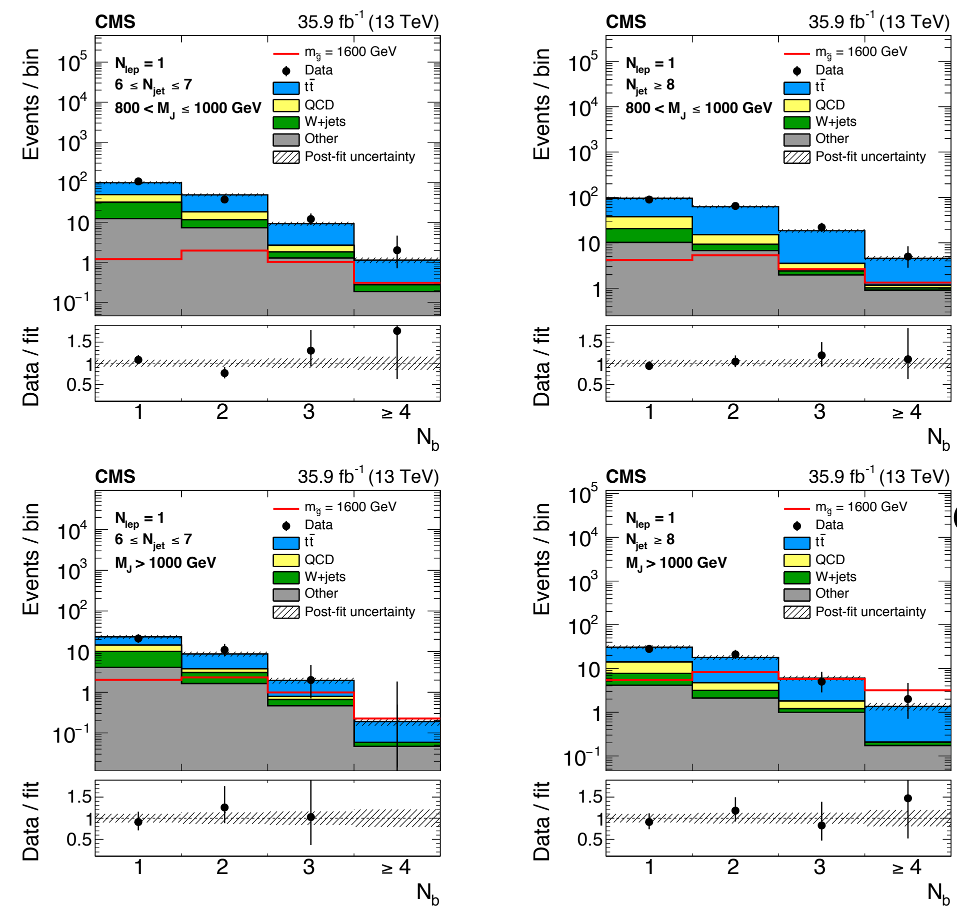
36fb^{-1}

[Phys. Lett. B 783 (2018) 114]

b-only postfit background dominated

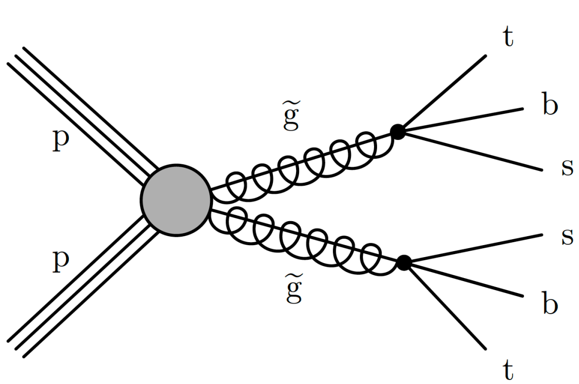


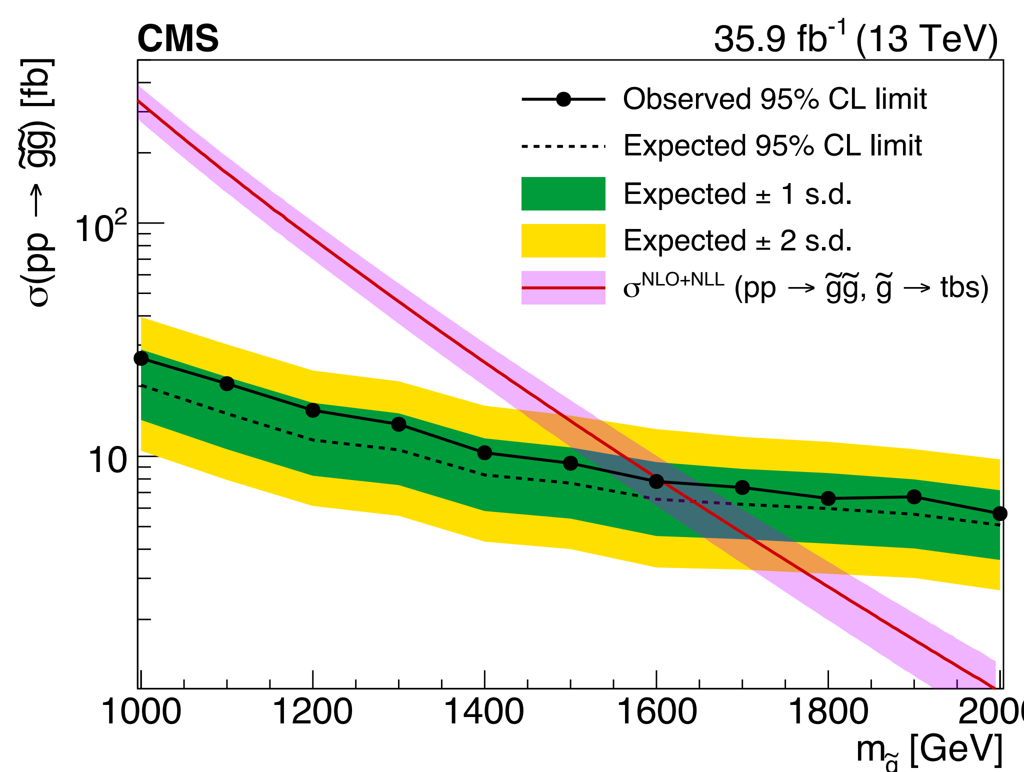
b-only postfit signal dominated



$$W = \frac{1}{2}\lambda^{ijk}L_iL_j\bar{e}_k + \lambda'^{ijk}L_iQ_j\bar{d}_k + \frac{1}{2}\lambda''^{ijk}\bar{u}_i\bar{d}_j\bar{d}_k + \mu'^{i}L_iH_u.$$

$$\tilde{g} \to t(\bar{\tilde{t}} \to bs)$$





1L M_J (*RPV*)

36fb-1

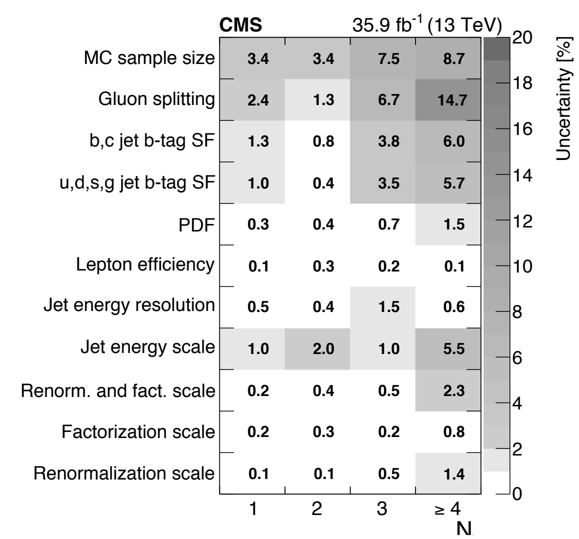
Phys. Lett. B 783 (2018) 114

N_b	QCD	$t\bar{t}$	W+jets	Other	All bkg.	Data	Expected $m_{\tilde{g}} = 1600$ GeV
$4 \leq N_{jet} \leq 5,\ 500 < M_J \leq 800$ GeV							
1	148	340	196	91	775 ± 43	777	0.50 ± 0.13
2	29	175	30	31	264 ± 17	264	0.39 ± 0.11
3	4.3	24.8	2.5	4.4	36 ± 4	34	0.18 ± 0.08
≥4	0.0	2.2	0.3	0.2	2.7 ± 0.4	3	0.04 ± 0.04
$4 \leq N_{jet} \leq 5,\ M_J > 800$ GeV							
1	16.5	26.3	22.5	11.0	76 ± 6	77	0.32 ± 0.11
2	1.1	10.6	3.4	3.8	19 ± 2	18	0.40 ± 0.12
3	0.7	1.3	0.3	0.3	2.7 ± 0.5	3	0.13 ± 0.06
≥4	0.00	0.09	0.03	0.01	0.13 ± 0.03	0	0.03 ± 0.03
$6 \leq N_{jet} \leq 7,\ 500 < M_J \leq 800$ GeV							
1	197	620	169	120	1106 ± 48	1105	2.5 ± 0.3
2	49	440	36	66	591 ± 21	588	3.1 ± 0.3
3	6.4	89.2	4.6	13.4	114 ± 8	112	1.4 ± 0.2
≥4	1.9	11.4	0.6	2.1	16 ± 2	21	0.25 ± 0.09
$N_{jet} \geq 8,\ 500 < M_J \leq 800$ GeV							
1	130	574	53	68	825 ± 38	821	3.5 ± 0.3
2	45	478	14	49	586 ± 20	603	5.4 ± 0.4
3	6.3	138.1	2.5	16.7	164 ± 9	148	3.0 ± 0.3
≥4	2.8	29.8	0.4	4.8	38 ± 4	40	1.4 ± 0.2
$6 \leq N_{jet} \leq 7,\ 800 < M_J \leq 1000$ GeV							
1	17.3	48.4	19.2	12.3	97 ± 8	105	1.2 ± 0.2
2	6.6	30.1	4.3	7.3	48 ± 4	37	2.0 ± 0.3
3	0.8	6.6	0.5	1.3	9.3 ± 1.0	12	1.0 ± 0.2
≥4	0.0	0.9	0.1	0.2	1.1 ± 0.2	2	0.31 ± 0.09
$N_{jet} \geq 8,\ 800 < M_J \leq 1000$ GeV							
1	17.0	58.7	10.3	10.2	96 ± 8	90	4.2 ± 0.4
2	5.8	47.5	2.5	6.8	63 ± 5	65	5.3 ± 0.4
3	1.1	15.0	0.4	2.0	19 ± 2	22	2.6 ± 0.3
≥4	0.2	3.4	0.1	0.9	4.6 ± 0.6	5	1.3 ± 0.2
$6 \leq N_{jet} \leq 7,\ M_J > 1000$ GeV							
1	4.4	8.7	6.0	4.1	23 ± 2	21	2.0 ± 0.3
2	0.7	5.0	1.4	1.6	8.8 ± 1.2	11	2.3 ± 0.3
3	0.1	1.2	0.2	0.5	1.9 ± 0.3	2	1.0 ± 0.2
≥4	0.00	0.13	0.01	0.05	0.19 ± 0.04	0	0.23 ± 0.08
$N_{jet} \geq 8,\ M_J > 1000$ GeV							
1	6.4	16.7	3.5	4.1	31 ± 3	28	5.4 ± 0.4
2	1.6	13.1	1.1	2.1	18 ± 2	21	8.2 ± 0.5
3	0.6	4.2	0.2	1.0	6.0 ± 0.8	5	5.7 ± 0.4
≥4	0.0	1.2	0.0	0.2	1.4 ± 0.3	2	3.2 ± 0.3

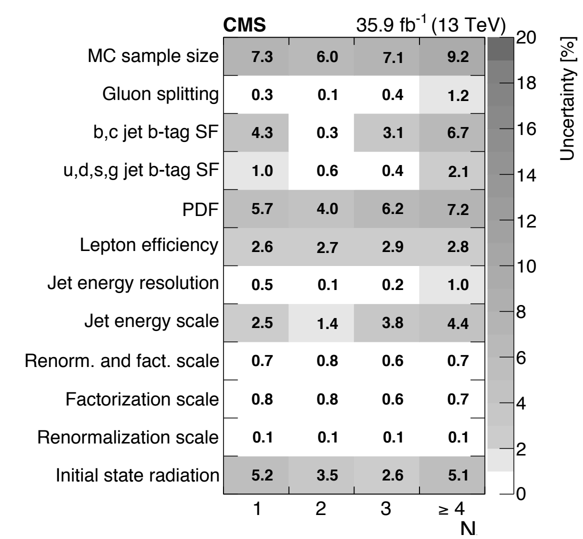
cutflow

$\mathcal{L} = 35.9\ \text{fb}^{-1}$	QCD	$t\bar{t}$	W+jets	Other	All bkg.	$m_{\tilde{g}} = 1600$ GeV
$H_T > 1200$ GeV	1.615×10^7	9.76×10^4	2.718×10^5	2.965×10^4	$(1.655 \pm 0.007) \times 10^7$	2.8×10^2
$N_{lep} = 1$	1.11×10^4	1.292×10^4	2.502×10^4	4.48×10^3	$(5.35 \pm 0.01) \times 10^4$	7.9×10^1
$N_b \geq 1$	3240	10340	4990	2150	20725±80	74
$N_{jet} \geq 4$	2770	9920	3740	1870	18304±70	74
$M_J > 500$ GeV	810	3658	1120	574	6162±40	67
$M_J > 800$ GeV	99	360	150	75	685±9	47
$N_{jet} \geq 8$	38	200	42	29	309±7	36
$M_J > 1000$ GeV	11	43.0	11.3	7.9	73±2	22.6
$N_b \geq 3$	0.7	6.2	0.5	1.1	8.5±0.6	8.9
	QCD	$t\bar{t}$	W+jets	Other	All bkg.	$m_{\tilde{g}} = 1600$ GeV

systematics



background



signal

CMS

$36fb^{-1}$

JHEP 03 (2018) 076

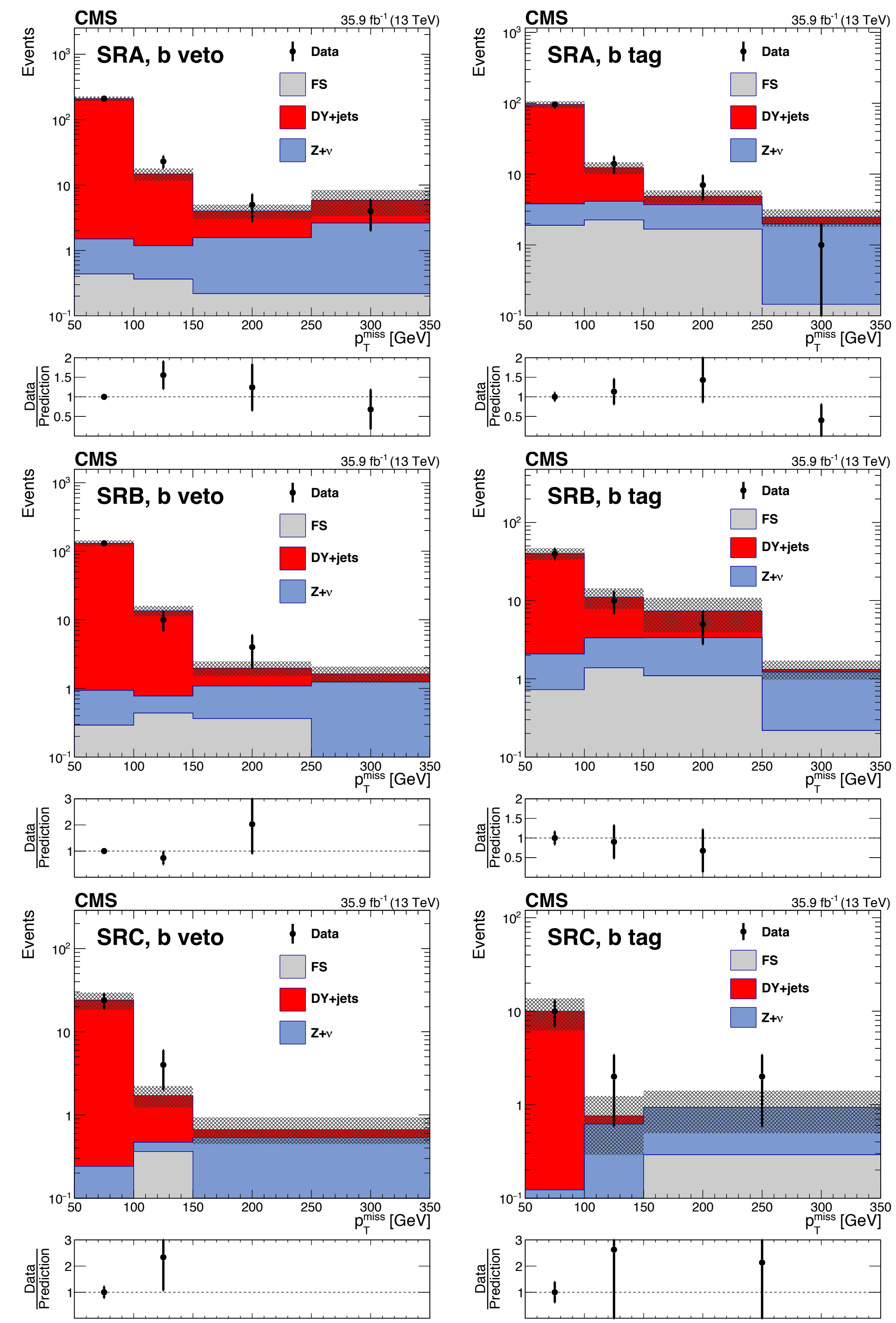
2L OS

UCSB

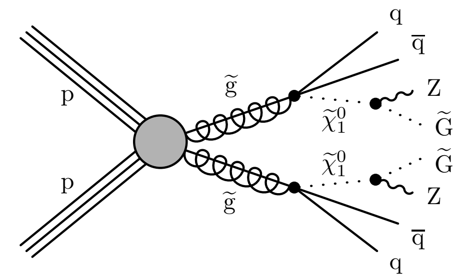
Strong-production on-Z ($86 < m_{\ell\ell} < 96$ GeV) signal regions					
Region	N_{jets}	$N_{b\text{-jets}}$	H_T [GeV]	$M_{T2}(\ell\ell)$ [GeV]	p_T^{miss} binning [GeV]
SRA b veto	2–3	=0	>500	>80	100–150, 150–250, >250
SRB b veto	4–5	=0	>500	>80	100–150, 150–250, >250
SRC b veto	≥6	=0	—	>80	100–150, >150
SRA b tag	2–3	≥1	>200	>100	100–150, 150–250, >250
SRB b tag	4–5	≥1	>200	>100	100–150, 150–250, >250
SRC b tag	≥6	≥1	—	>100	100–150, >150
Electroweak-production on-Z ($86 < m_{\ell\ell} < 96$ GeV) signal regions					
Region	N_{jets}	$N_{b\text{-jets}}$	Dijet mass [GeV]	M_{T2} [GeV]	p_T^{miss} binning [GeV]
VZ	≥2	=0	$m_{jj} < 110$	$M_{T2}(\ell\ell) > 80$	100–150, 150–250, 250–350, >350
HZ	≥2	=2	$m_{bb} < 150$	$M_{T2}(b\ell b) > 200$	100–150, 150–250, >250
Edge signal regions					
Region	N_{jets}	p_T^{miss} [GeV]	$M_{T2}(\ell\ell)$ [GeV]	$t\bar{t}$ likelihood	$m_{\ell\ell}$ binning [GeV]
Edge fit	≥2	>150	>80	—	>20
$t\bar{t}$-like	≥2	>150	>80	<21	20–60, 60–86, 96–150, 150–200, 200–300, 300–400, >400
not-$t\bar{t}$-like	≥2	>150	>80	>21	same as $t\bar{t}$-like

on-Z strong production regions

SRA, b veto	p_T^{miss} [GeV]	100–150	150–250	>250
	DY+jets	13.6±3.1	2.5±0.9	3.3±2.4
	FS	$0.4^{+0.3}_{-0.2}$	$0.2^{+0.2}_{-0.1}$	$0.2^{+0.2}_{-0.1}$
	Z+ν	0.8±0.3	1.4±0.4	2.4±0.8
	Total background	14.8±3.2	4.0±1.0	5.9±2.5
	Data	23	5	4
SRA, b tag	p_T^{miss} [GeV]	100–150	150–250	>250
	DY+jets	8.2±2.1	1.2±0.5	0.5±0.3
	FS	2.3±0.8	$1.7^{+0.7}_{-0.6}$	$0.1^{+0.2}_{-0.1}$
	Z+ν	1.9±0.4	2.0±0.5	1.8±0.6
	Total background	12.4±2.3	4.9±1.0	2.5±0.7
	Data	14	7	1
SRB, b veto	p_T^{miss} [GeV]	100–150	150–250	>250
	DY+jets	12.8±2.3	0.9±0.3	0.4±0.2
	FS	$0.4^{+0.3}_{-0.2}$	$0.4^{+0.3}_{-0.2}$	$0.1^{+0.2}_{-0.1}$
	Z+ν	0.3±0.1	0.7±0.2	1.2±0.4
	Total background	13.6±2.4	2.0±0.5	1.6±0.4
	Data	10	4	0
SRB, b tag	p_T^{miss} [GeV]	100–150	150–250	>250
	DY+jets	7.7±3.2	4.0±3.4	0.1±0.1
	FS	$1.4^{+0.6}_{-0.5}$	$1.1^{+0.5}_{-0.4}$	$0.2^{+0.2}_{-0.1}$
	Z+ν	2.0±0.5	2.3±0.6	1.0±0.3
	Total background	11.1±3.3	$7.4^{+3.5}_{-3.4}$	$1.3^{+0.4}_{-0.3}$
	Data	10	5	0
SRC, b veto	p_T^{miss} [GeV]	100–150	>150	
	DY+jets	1.2±0.4	0.1±0.1	
	FS	$0.4^{+0.3}_{-0.2}$	$0.1^{+0.2}_{-0.1}$	
	Z+ν	0.1±0.1	0.5±0.2	
	Total background	1.7±0.5	$0.7^{+0.3}_{-0.2}$	
	Data	4	0	
SRC, b tag	p_T^{miss} [GeV]	100–150	>150	
	DY+jets	0.1±0.4	0.0±0.3	
	FS	$0.0^{+0.1}_{-0.0}$	0.3±0.2	
	Z+ν	0.6±0.2	0.6±0.2	
	Total background	0.8±0.5	$0.9^{+0.5}_{-0.4}$	
	Data	2	2	

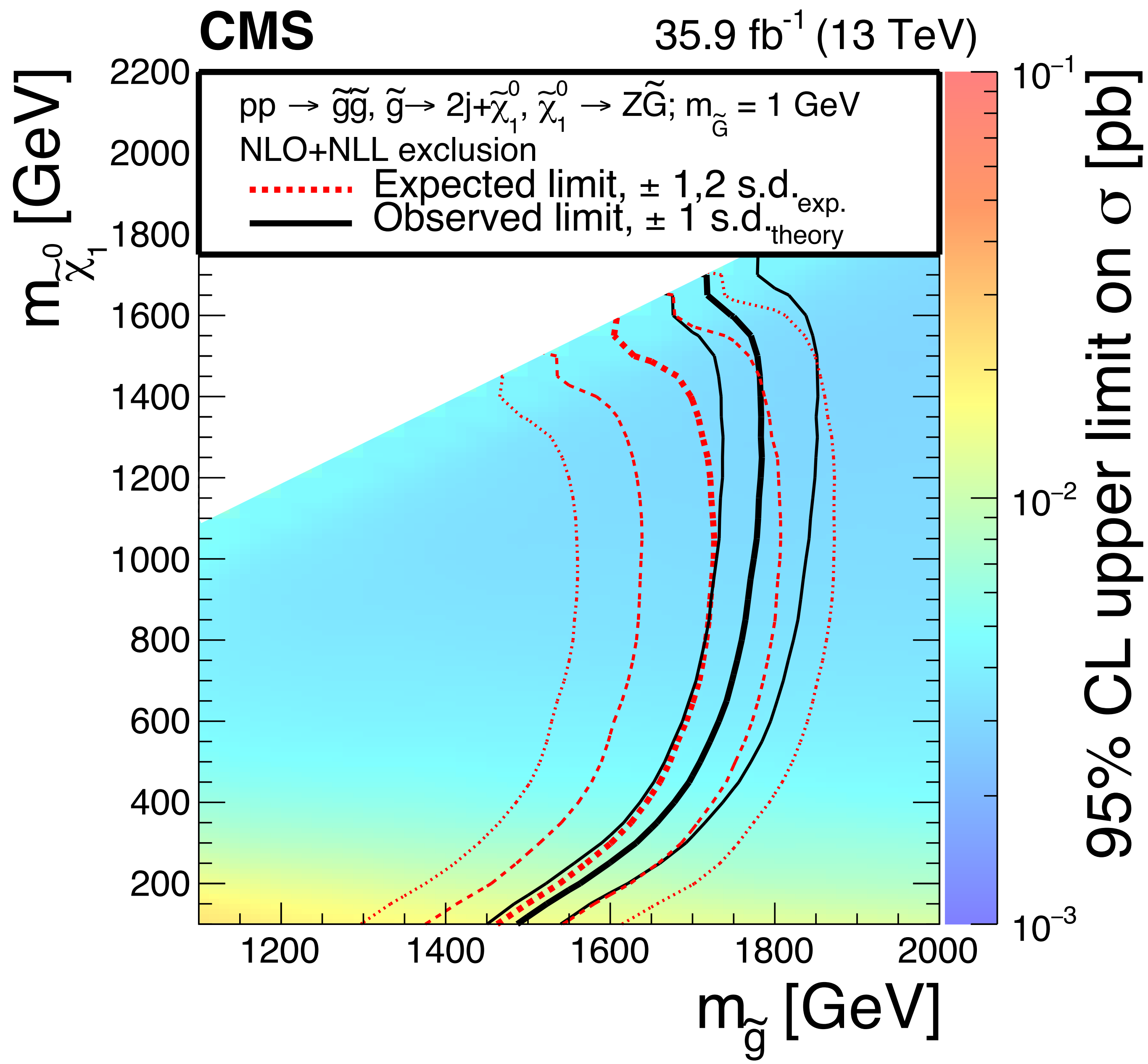


2L OS



typical signal uncertainties

Source of uncertainty	Uncertainty (%)
Integrated luminosity	2.5
Lepton reconstruction and isolation	5
Fast simulation lepton efficiency	4
b tag modeling	0–5
Trigger modeling	3
Jet energy scale	0–5
ISR modeling	0–2.5
Pileup	1–2
Fast simulation p_T^{miss} modeling	0–4
Renorm./fact. scales	1–3
Statistical uncertainty	1–15
Total uncertainty	9–18



2L OS

UCSB

on-Z strong production cutflow

SRA		
Gluino GMSB model, gluino mass: 1400 GeV, $\tilde{\chi}_1^0$ mass: 700 GeV	Events in 35.9 fb^{-1}	
Expected events	174.14	
$\geq$ 2 Leptons ($e^\pm e^\mp$ or $\mu^\pm\mu^\mp$) with (sub)leading $p_T > 25(20)$ GeV	65.24	
Extra lepton vetos	57.81	
Dilepton mass $\in$ Z mass window (86,96) GeV	44.86	
2-3 Jets	1.88	
$\Delta\Phi$ between MET and two highest p_T jets > 0.4 rad	1.54	
Btag requirement	**B Veto**	**$\geq$ 1 Btag**
	1.14	0.40
$M_{T2}(\ell\ell) >$	**80 GeV**	**100 GeV**
	0.36	0.34
$H_T >$	**500 GeV**	**200 GeV**
	0.36	0.34
$E_T^{miss} > 100$ GeV	0.36	0.34
$E_T^{miss} > 150$ GeV	0.36	0.34
$E_T^{miss} > 250$ GeV	0.29	0.29

SRB		
Gluino GMSB model, gluino mass: 1400 GeV, $\tilde{\chi}_1^0$ mass: 700 GeV	Events in 35.9 fb^{-1}	
Expected events	174.14	
$\geq$ 2 Leptons ($e^\pm e^\mp$ or $\mu^\pm\mu^\mp$) with (sub)leading $p_T > 25(20)$ GeV	65.24	
Extra lepton vetos	57.81	
Dilepton mass $\in$ Z mass window (86,96) GeV	44.86	
4-5 Jets	15.32	
$\Delta\Phi$ between MET and two highest p_T jets > 0.4 rad	13.02	
Btag requirement	**B Veto**	**$\geq$ 1 Btag**
	6.46	6.56
$M_{T2}(\ell\ell) >$	**80 GeV**	**100 GeV**
	5.86	5.66
$H_T >$	**500 GeV**	**200 GeV**
	5.83	5.66
$E_T^{miss} > 100$ GeV	5.69	5.54
$E_T^{miss} > 150$ GeV	5.54	5.41
$E_T^{miss} > 250$ GeV	5.00	4.89

SRC		
Gluino GMSB model, gluino mass: 1400 GeV, $\tilde{\chi}_1^0$ mass: 700 GeV	Events in 35.9 fb^{-1}	
Expected events	174.14	
$\geq$ 2 Leptons ($e^\pm e^\mp$ or $\mu^\pm\mu^\mp$) with (sub)leading $p_T > 25(20)$ GeV	65.24	
Extra lepton vetos	57.81	
Dilepton mass $\in$ Z mass window (86,96) GeV	44.86	
$\geq$ 6 Jets	27.67	
$\Delta\Phi$ between MET and two highest p_T jets > 0.4 rad	23.24	
Btag requirement	**B Veto**	**$\geq$ 1 Btag**
	10.31	12.93
$M_{T2}(\ell\ell) >$	**80 GeV**	**100 GeV**
	11.12	10.60
$E_T^{miss} > 100$ GeV	10.87	10.51
$E_T^{miss} > 150$ GeV	10.44	10.09

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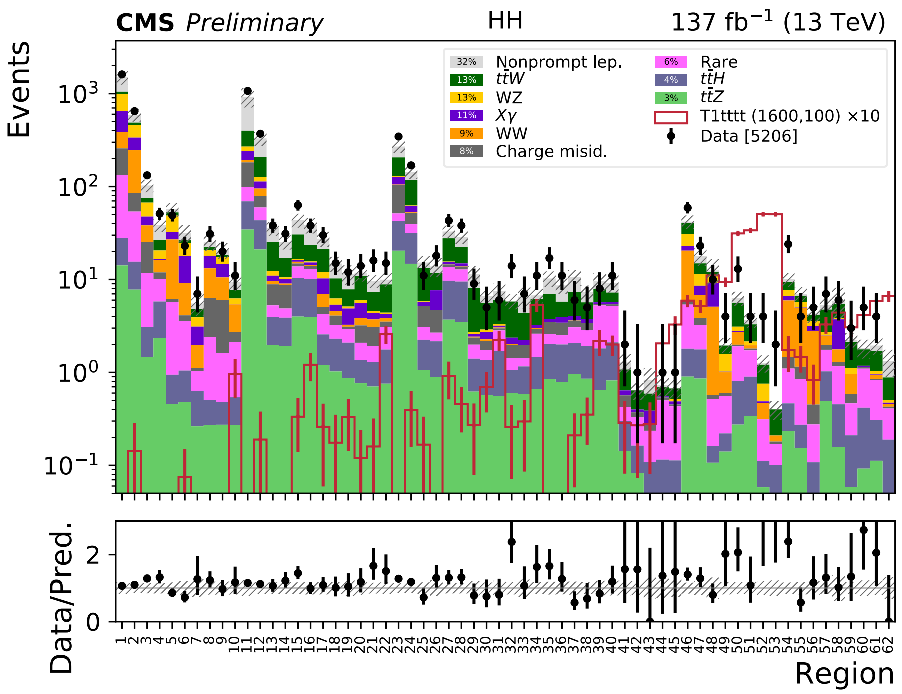
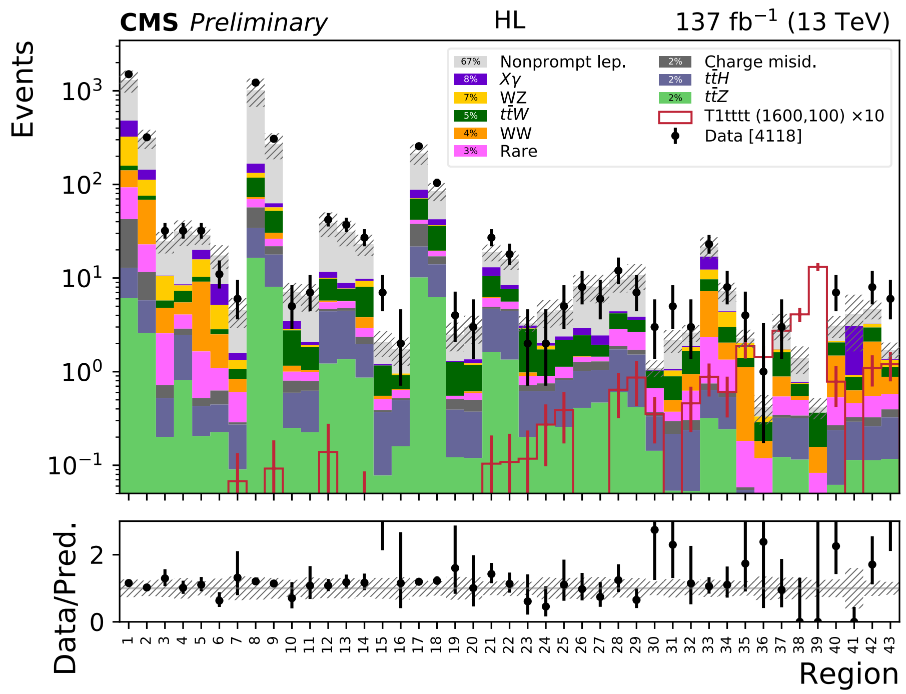
PAS

2L SS + ≥3L

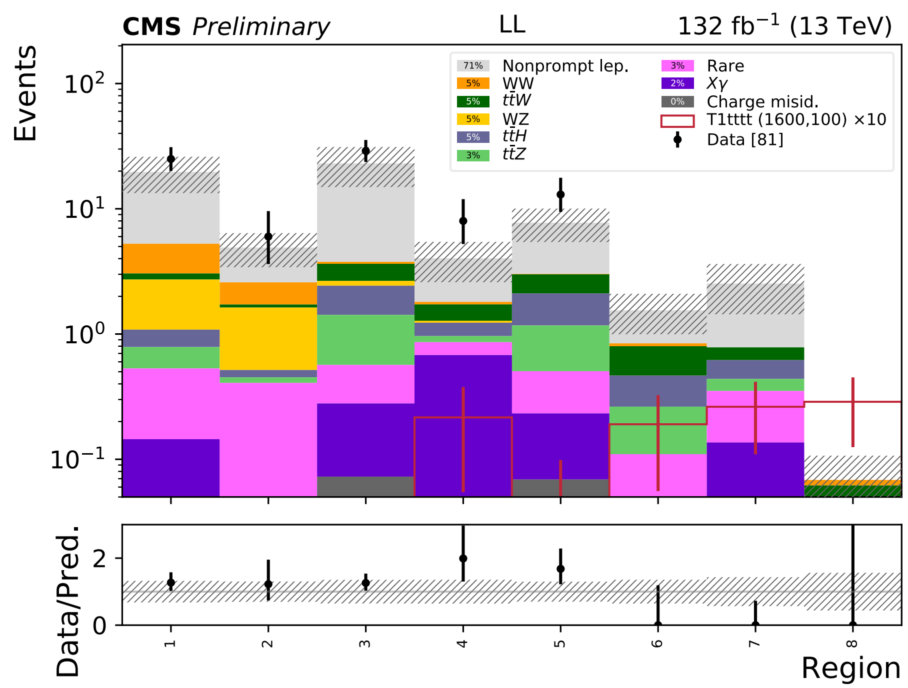
SS HighHigh, p_T>25,25



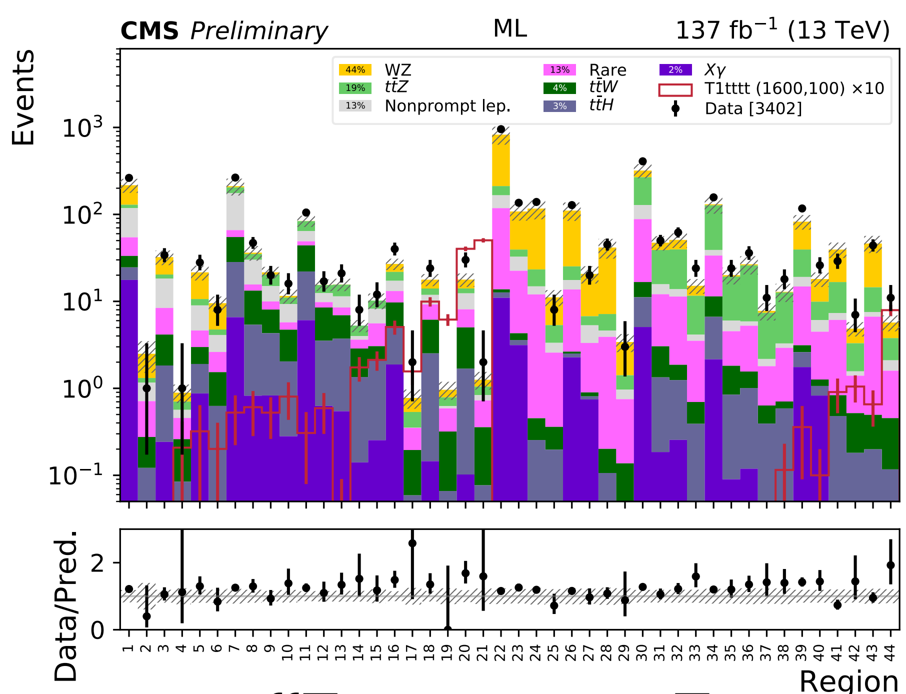
SS HighLow, p_T>25,15/10



SS LowLow, p_T>15/10,15/10

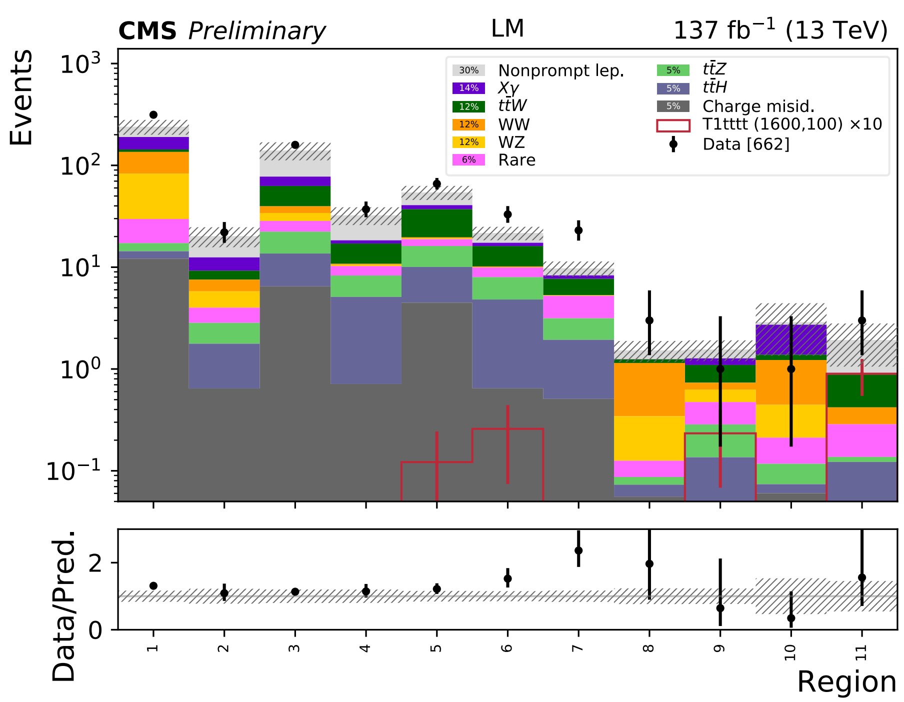


MultiLepton



offZ onZ

LowMET (MET<50)



$137 fb^{-1}$

PAS

2L SS + ≥3L

SRHH/HighHigh, 62 bins

$N_{b\,jets}$	M_T^{min} (GeV)	E_T^{miss} (GeV)	N_{jets}	$H_T < 300$ GeV	$H_T \in [300, 1125]$ GeV	$H_T \in [1125, 1300]$ GeV	$H_T \in [1300, 1600]$ GeV	$H_T > 1600$ GeV
0	< 120	50 – 200	2-4	SR1	SR2	SR54 $N_{jets} < 5$	SR55 $N_{jets} < 5$	SR56 $N_{jets} < 5$
			5+	SR3	SR4			
		200 – 300	2-4		SR5 (++) / SR6 (--)			
			5+		SR7			
	> 120	50 – 200	2-4		SR8 (++) / SR9 (--)			
			5+		SR10			
		200 – 300	2-4					
			5+					
1	< 120	50 – 200	2-4	SR11	SR12	SR57 $N_{jets} = 5$ or 6	SR58 $N_{jets} = 5$ or 6	SR59 $N_{jets} = 5$ or 6
			5+	SR13 (++) / SR14 (--)	SR15 (++) / SR16 (--)			
		200 – 300	2-4		SR17 (++) / SR18 (--)			
			5+		SR19			
	> 120	50 – 200	2-4		SR20 (++) / SR21 (--)			
			5+		SR22			
		200 – 300	2-4					
			5+					
2	< 120	50 – 200	2-4	SR23	SR24	SR60 $N_{jets} > 6$	SR61 $N_{jets} > 6$	SR62 $N_{jets} > 6$
			5+	SR25 (++) / SR26 (--)	SR27 (++) / SR28 (--)			
		200 – 300	2-4		SR29 (++) / SR30 (--)			
			5+		SR31			
	> 120	50 – 200	2-4		SR32 (++) / SR33 (--)			
			5+		SR34			
		200 – 300	2-4					
			5+					
3+	< 120	50 – 200	2-4	SR35 (++) / SR36 (--)	SR37 (++) / SR38 (--)			
			5+		SR39 (++) / SR40 (--)			
		200 – 300	2-4		SR37 (++) / SR38 (--)			
			5+		SR39 (++) / SR40 (--)			
	> 120	> 50	2-4	SR41	SR42 (++) / SR43 (--)			
			5+		SR44 (++) / SR45 (--)			
inclusive	inclusive	300 – 500	2-4		SR46 (++) / SR47 (--)			
		> 500			SR48 (++) / SR49 (--)			
		300 – 500	5+		SR50 (++) / SR51 (--)			
		> 500			SR52 (++) / SR53 (--)			

SRHL/HighLow, 43 bins

$N_{b\,jets}$	M_T^{min} (GeV)	E_T^{miss} (GeV)	N_{jets}	$H_T < 300$ GeV	$H_T \in [300, 1125]$ GeV	$H_T \in [1125, 1300]$ GeV	$H_T > 1300$ GeV
0	< 120	50 – 200	2-4	SR1	SR2	SR40 (++) / SR41 (--)	SR42 (++) / SR43 (--)
			5+	SR3	SR4		
		200 – 300	2-4		SR5 (++) / SR6 (--)		
			5+		SR7		
1	< 120	50 – 200	2-4	SR8	SR9		
			5+	SR10 (++) / SR11 (--)	SR12 (++) / SR13 (--)		
		200 – 300	2-4		SR14		
			5+		SR15 (++) / SR16 (--)		
2	< 120	50 – 200	2-4	SR17	SR18		
			5+	SR19 (++) / SR20 (--)	SR21 (++) / SR22 (--)		
		200 – 300	2-4		SR23 (++) / SR24 (--)		
			5+		SR25		
3+	< 120	50 – 200	2+	SR26 (++) / SR27 (--)	SR28 (++) / SR29 (--)		
		200 – 300			SR30		
inclusive	> 120	50 – 300	2+	SR31	SR32		
inclusive	inclusive	300 – 500	2-4		SR33 (++) / SR34 (--)		
		> 500			SR35 (++) / SR36 (--)		
		300 – 500	5+		SR37 (++) / SR38 (--)		
		> 500			SR39		

SRLL/LowLow, 8 bins

$N_{b\,jets}$	M_T^{min} (GeV)	H_T (GeV)	$E_T^{miss} \in [50, 200]$ GeV	$E_T^{miss} > 200$ GeV
0	< 120	> 400	SR1	SR2
1			SR3	SR4
2			SR5	SR6
≥ 3			SR7	
Inclusive	> 120		SR8	

SRLM/LowMET, 11 bins

$N_{b\,jets}$	N_{jets}	$H_T \in [300, 1125]$ GeV	$H_T \in [1125, 1300]$ GeV	$H_T > 1300$ GeV
0	2-4	SR1	SR8 ($N_{jets} < 5$)	SR10 ($N_{jets} < 5$)
	5+	SR2		
1	2-4	SR3		
	5+	SR4		
2	2-4	SR5	SR9 ($N_{jets} \geq 5$)	SR11 ($N_{jets} \geq 5$)
	5+	SR6		
≥ 3	2+	SR7		

SRML/MultiLepton, 44 bins

$N_{b\,jets}$	H_T (GeV)	off-Z $E_T^{miss} \in [50, 150]$ GeV	off-Z $E_T^{miss} \in [150, 300]$ GeV	off-Z $E_T^{miss} \geq 300$ GeV	on-Z $E_T^{miss} \in [50, 150]$ GeV	on-Z $E_T^{miss} \in [150, 300]$ GeV	on-Z $E_T^{miss} \geq 300$ GeV
0	<400	SR1/SR2†	SR3/SR4†	SR20/SR21†	SR22/SR23†	SR24/SR25†	SR43/SR44†
	400-600	SR5	SR6		SR26/SR27†	SR28/SR29†	
1	<400	SR7	SR8		SR30	SR31	
	400-600	SR9	SR10		SR32	SR33	
2	<400	SR11	SR12		SR34	SR35	
	400-600	SR13	SR14		SR36	SR37	
≥ 3	<600	SR15			SR38		
Inclusive	≥ 600	SR16/SR17†	SR18/SR19†		SR39/SR40†	SR41/SR42†	

2L SS + ≥3L

	HH regions		HL regions		LL regions		ML regions		LM regions	
	Expected SM	Observed	Expected SM	Observed	Expected SM	Observed	Expected SM	Observed	Expected SM	Observed
SR1	1510±310	1609	1300±310	1504	20±6	25	220±40	263	240±50	314
SR2	590±90	647	310±70	319	4.9±1.5	6	2.5±2.5	1	20±5	22
SR3	103±22	132	25±6	32	23±6	29	32±6	34	140±31	159
SR4	38±7	51	32±8	32	4±4	8	0.9±0.5	1	32±7	37
SR5	57±10	49	29±6	32	7.7±2.1	13	22±4	28	54±8	66
SR6	32±9	23	17±6	11	1.5±0.8	0	9.5±1.8	8	22±4	33
SR7	5.5±1.7	7	4.5±2.5	6	2.5±1.2	0	210±40	265	9.7±2.1	23
SR8	25±6	31	1010±250	1223	0.07±0.07	0	36±6	47	1.5±0.5	3
SR9	21±5	20	270±60	307			21.6±3.2	20	1.6±0.4	1
SR10	9.4±1.9	11	7.1±1.7	5			11.6±1.9	16	2.9±2.9	1
SR11	930±230	1068	6.5±1.6	7			84±11	105	1.9±1.4	3
SR12	330±70	370	39±9	42			15.5±2.1	17		
SR13	36±7	38	31±8	37			15.7±2.2	21		
SR14	25±5	31	23±5	27			5.3±0.8	8		
SR15	44±7	63	2.1±1.1	7			10.2±2.1	12		
SR16	39±8	38	1.7±0.9	2			27±4	40		
SR17	27±5	30	210±40	256			0.8±0.5	2		
SR18	14.8±3.2	15	85±14	104			17.8±2.4	24		
SR19	11.5±3.0	12	2.5±1.2	4			1.0±0.4	0		
SR20	11.8±2.6	14	3.0±1.5	3			17.8±3.0	30		
SR21	9.6±2.1	16	18.9±3.5	27			1.26±0.33	2		
SR22	10.0±1.6	15	15.9±2.8	18			830±180	955		
SR23	270±40	345	3.3±0.6	2			108±22	136		
SR24	143±20	169	4.4±1.6	2			117±26	139		
SR25	15.2±2.4	11	4.5±1.7	5			11.1±2.3	8		
SR26	13.8±3.4	18	8.2±2.2	8			111±24	128		
SR27	33±5	43	8.1±2.2	6			21±5	20		
SR28	29±4	38	9.7±2.1	12			42±10	45		
SR29	11.5±2.5	9	10.8±2.8	7			3.4±0.9	3		
SR30	6.7±1.2	5	1.1±0.4	3			320±50	408		
SR31	7.5±1.8	6	2.2±0.5	5			47±8	50		
SR32	5.9±1.0	14	2.6±0.5	3			51±9	62		
SR33	6.5±1.9	7	22±6	23			15.1±2.6	24		
SR34	6.7±1.2	11	7.2±1.4	8			131±24	157		
SR35	10.3±1.9	17	2.3±0.5	4			20±4	24		
SR36	8.6±1.7	11	0.42±0.33	1			27±5	36		
SR37	10.6±2.0	6	3.2±1.5	3			7.8±1.5	11		
SR38	7.3±1.3	5	1.4±0.6	0			12.9±2.6	18		
SR39	9.6±2.2	8	0.41±0.25	0			82±14	117		
SR40	9.2±1.9	11	3.1±0.7	7			18±4	26		
SR41	1.3±0.6	2	4±4	0			39±8	29		
SR42	0.6±0.4	1	4.7±0.9	8			4.9±0.9	7		
SR43	0.8±0.4	0	1.71±0.35	6			46±10	44		
SR44	0.7±0.4	1					5.7±1.2	11		
SR45	0.7±0.5	1								
SR46	42±7	59								
SR47	18±4	23								
SR48	13±9	10								
SR49	2.0±0.5	4								
SR50	6.3±1.0	13								
SR51	3.7±0.7	4								
SR52	1.26±0.33	4								
SR53	0.4±0.4	2								
SR54	10.1±1.5	24								
SR55	7.0±1.1	4								
SR56	4.3±0.9	5								
SR57	5.3±0.8	7								
SR58	6±6	6								
SR59	2.2±0.4	3								
SR60	1.8±0.5	5								
SR61	1.9±0.4	4								
SR62	1.3±0.9	0								

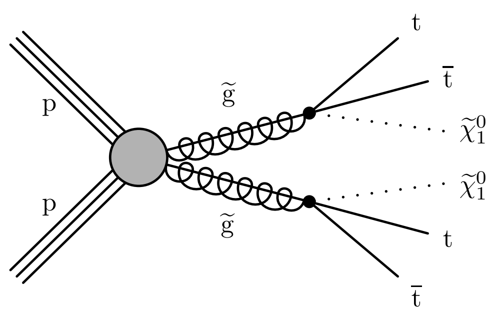
Object	p_T (GeV)	$\|\eta\|$
Electrons	> 15	< 2.5
Muons	> 10	< 2.4
Jets	> 40	< 2.4
b-tagged jets	> 25	< 2.4

Source	Typical uncertainty (%)	Correlation across years
Integrated luminosity	2.3-2.5	Uncorrelated
Lepton selection	2 – 10	Uncorrelated
Trigger efficiency	2 – 7	Uncorrelated
Pileup	0 – 6	Uncorrelated
Jet energy scale	1 – 15	Uncorrelated
b tagging	1 – 10	Uncorrelated
Simulated sample size	1 – 20	Uncorrelated
Scale and PDF variations	10 – 20	Correlated
Theoretical background cross sections	30 – 50	Correlated
Nonprompt leptons	30	Correlated
Charge misidentification	20	Uncorrelated

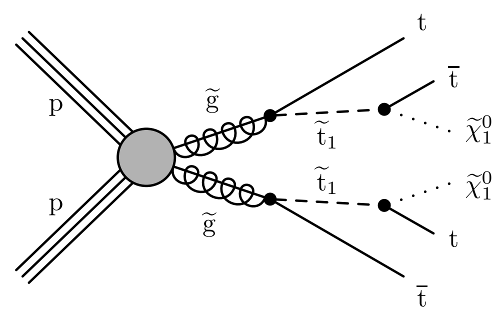
137fb^{-1}

PAS

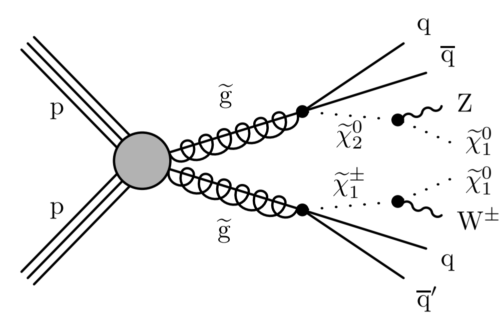
2L SS + ≥3L



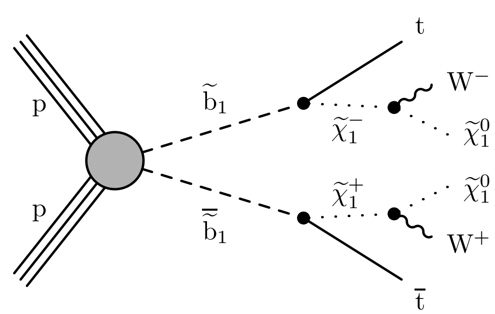
(a) T1tttt



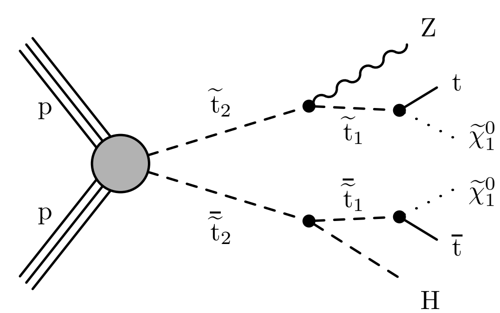
(b) T5tttt



(c) T5qqqqWZ



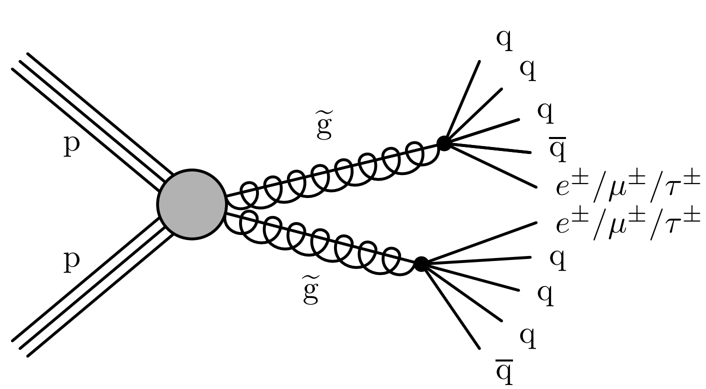
(d) T6ttWW



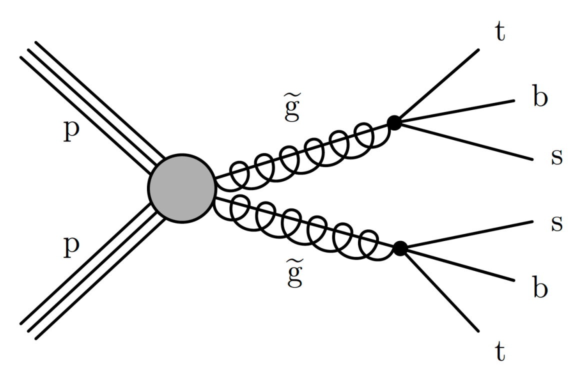
(e) T6ttHZ

RPC

RPV



T1qqqqL



T1tbs

2L SS + ≥3L

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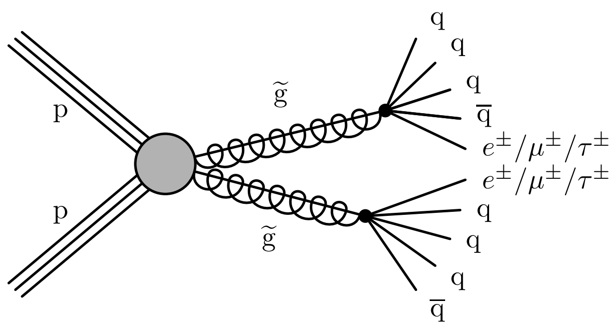
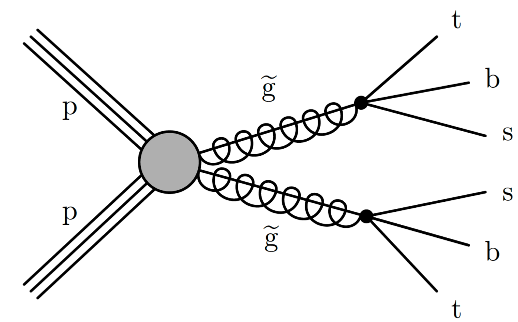
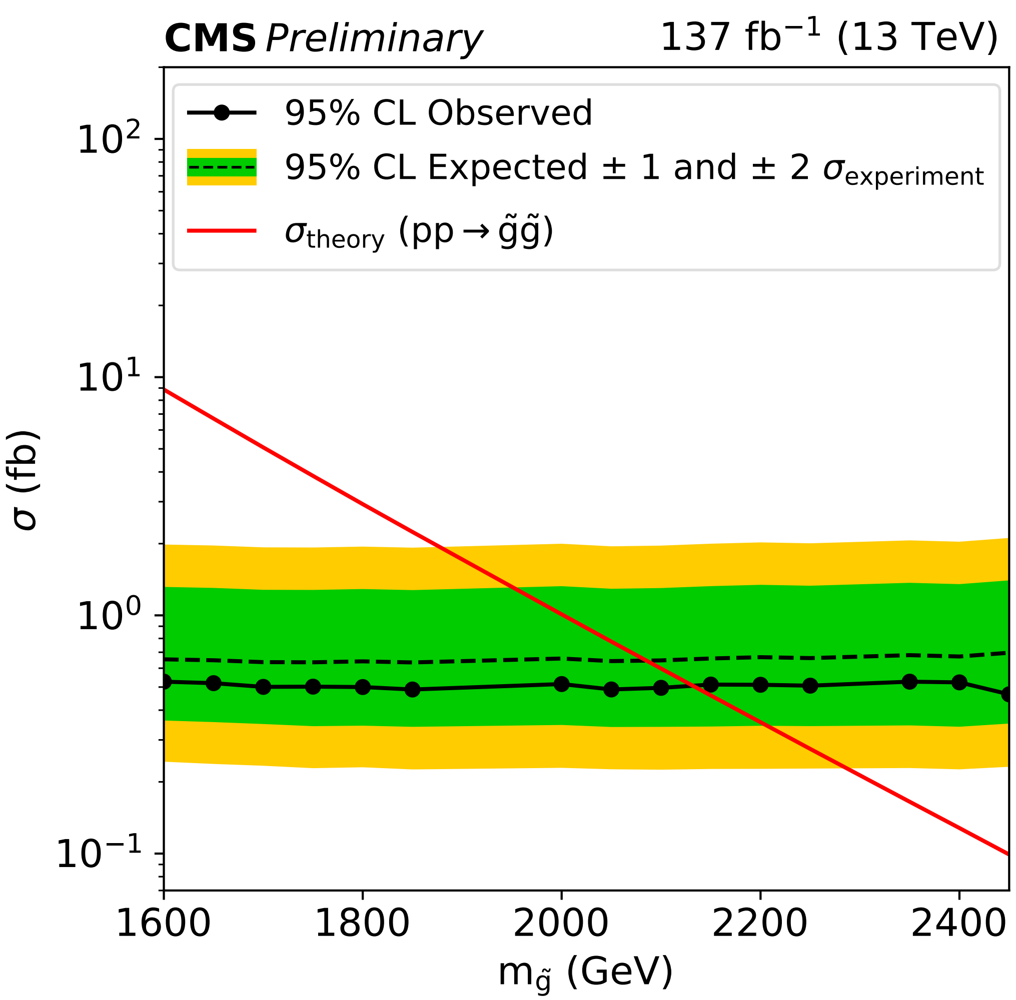
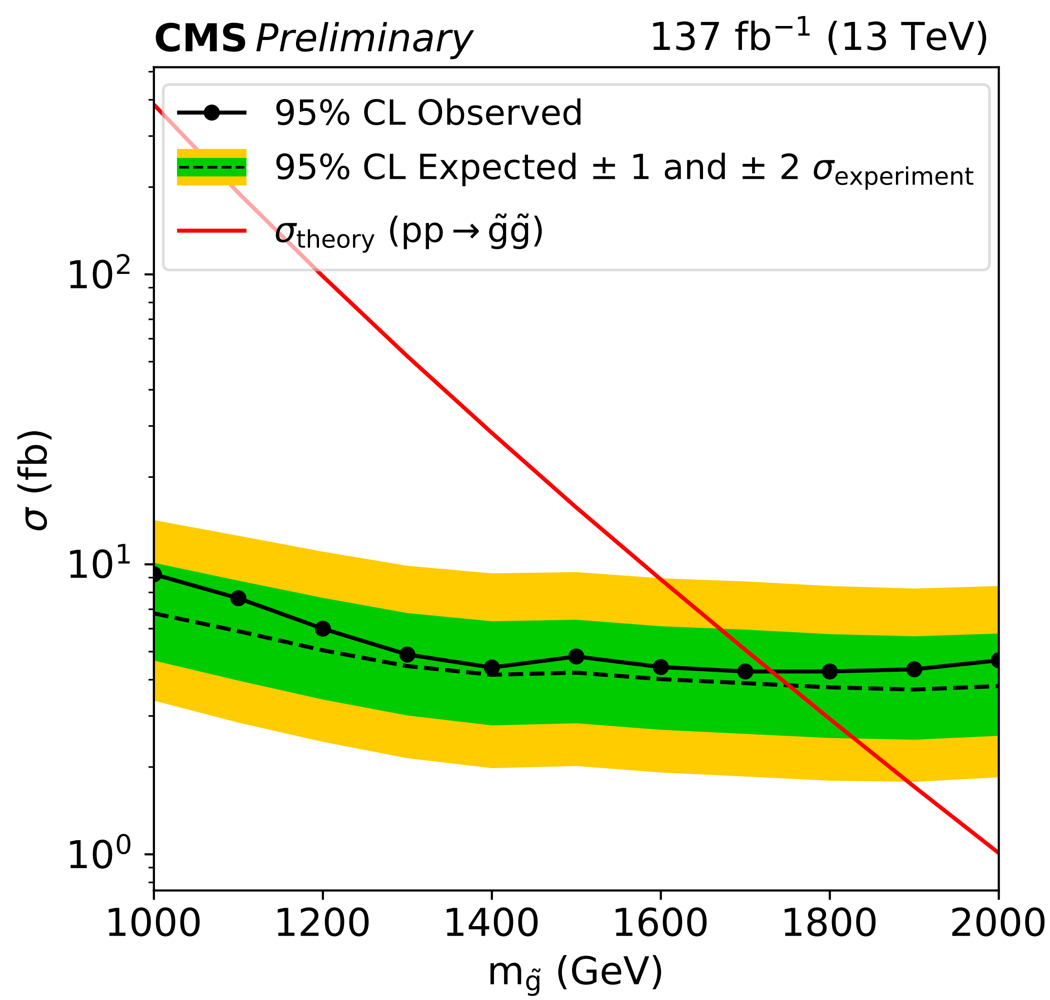
PAS

$$\tilde{g} \to q\tilde{q},\ \tilde{q} \to q\tilde{\chi}_1^0,\ \tilde{\chi}_1^0 \to qql$$









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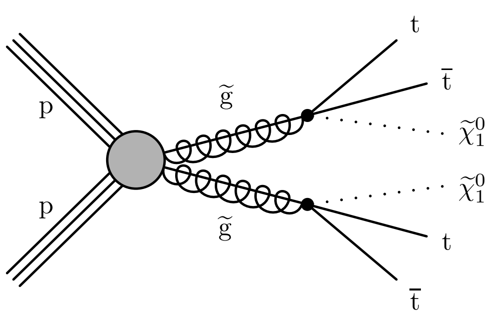
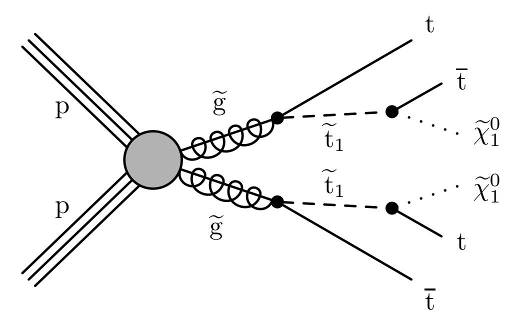
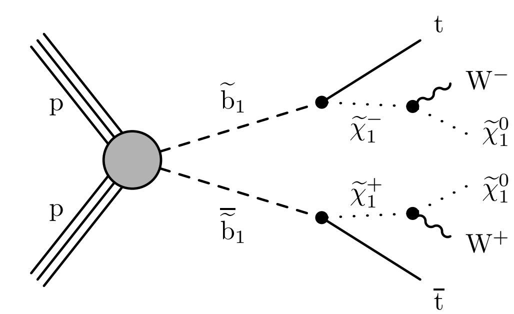
PAS

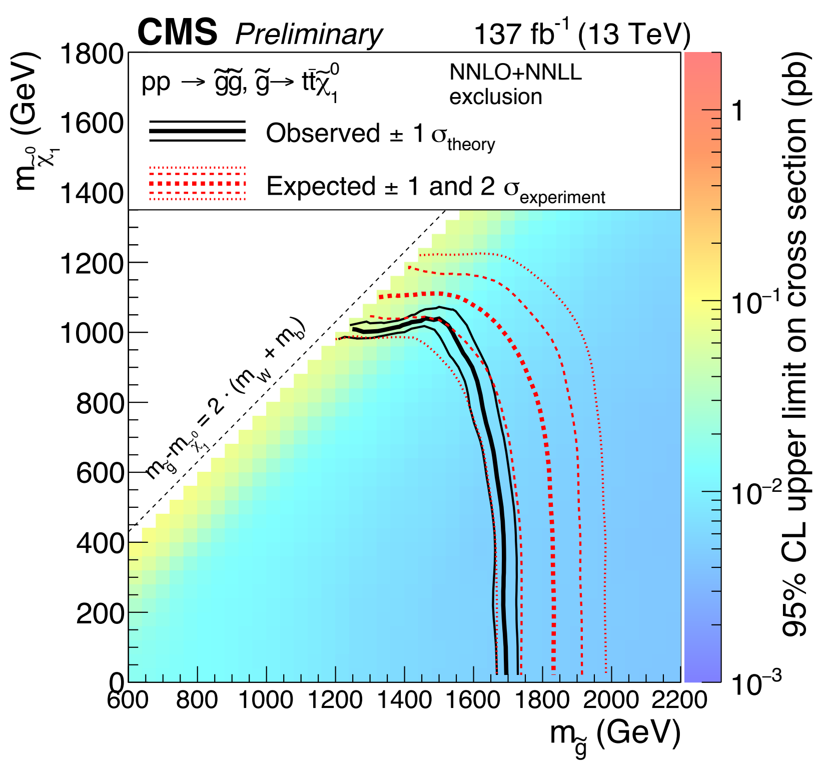
2L SS + ≥3L

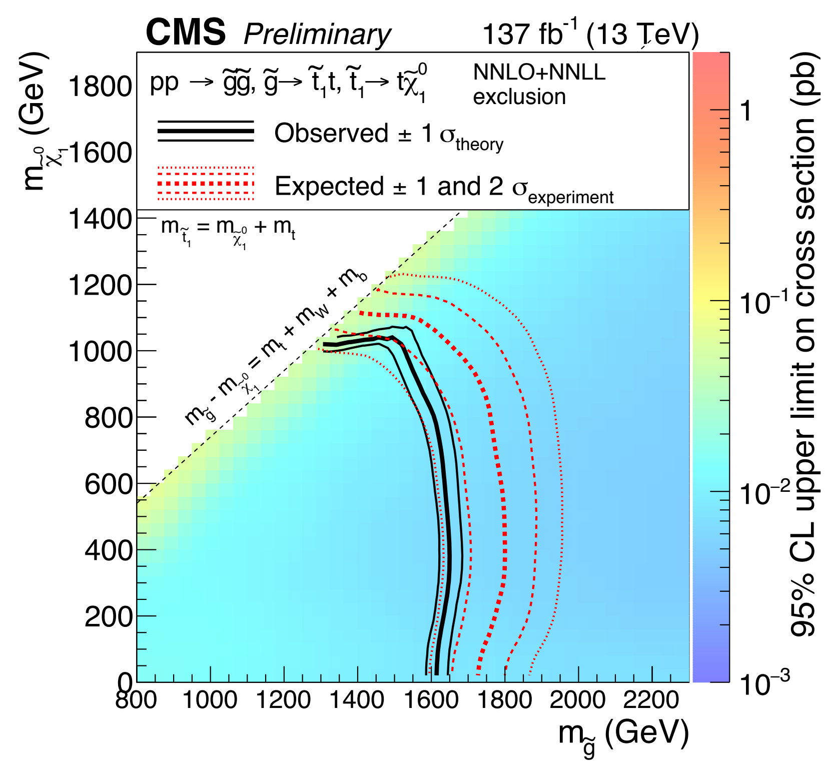
- Gluino pair production models with four top quark final states, T1tttt (left) and T5tttt (center)
- Sbottom squark production model T6ttWW (right)

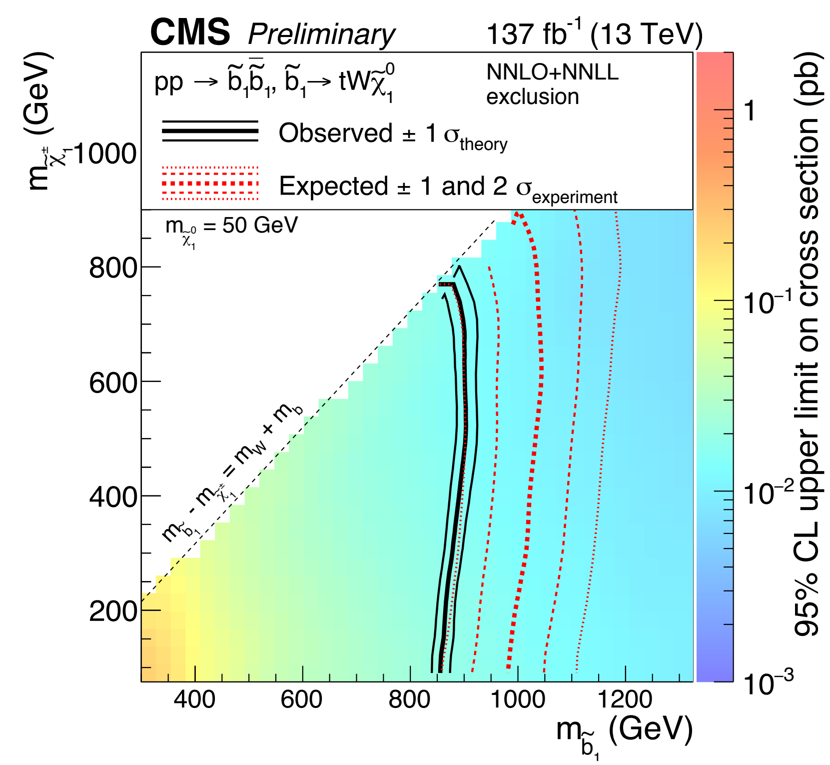










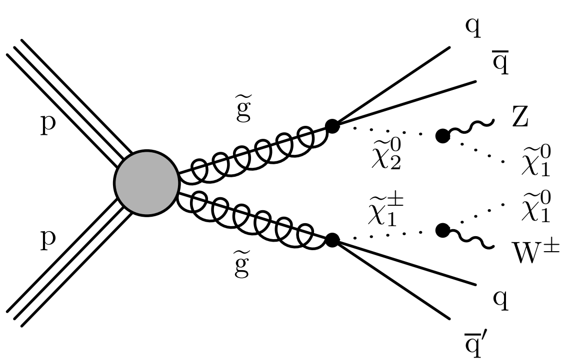


137fb-1

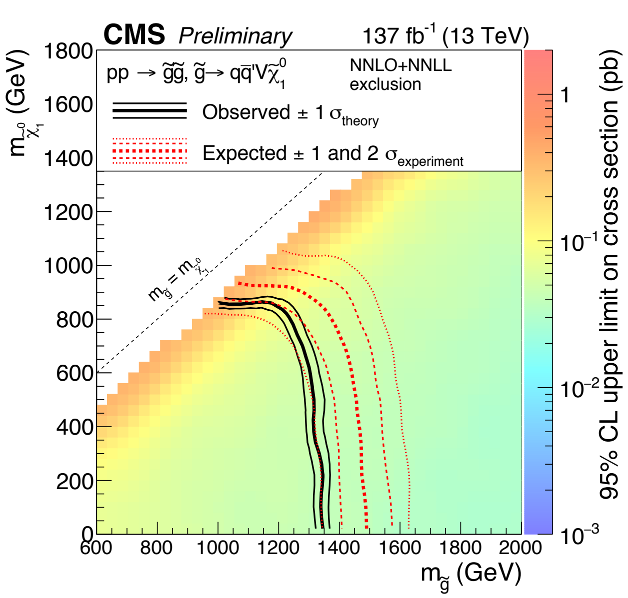
PAS

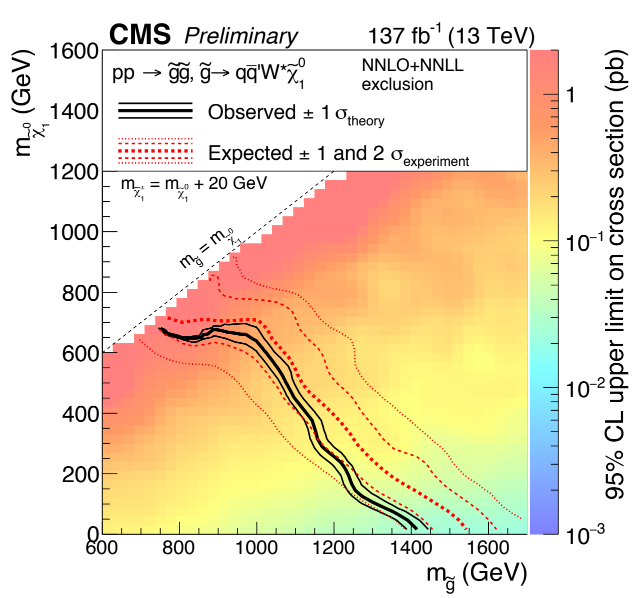
2L SS + ≥3L

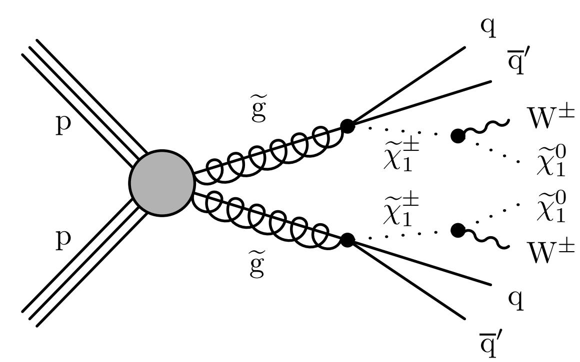
- Gluino pair production models T5qqqqVV (left) and T5qqqqWW (right) decaying into four light flavor quarks and two bosons
  - Two assumptions on chargino mass: halfway in between gluino and LSP mass (sub-left), or 20GeV higher than LSP mass (sub-right)



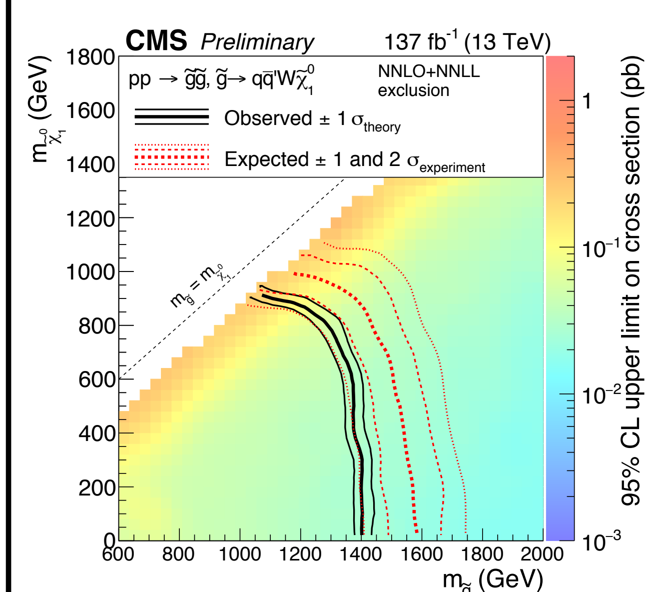
Δm=20GeV

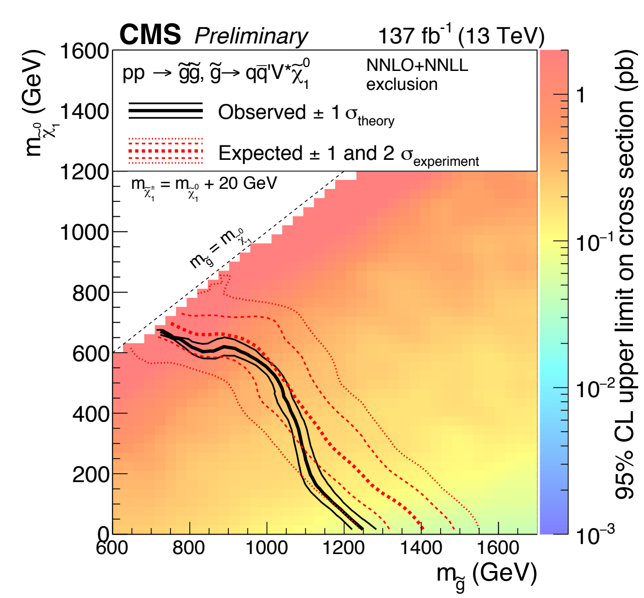






Δm=20GeV



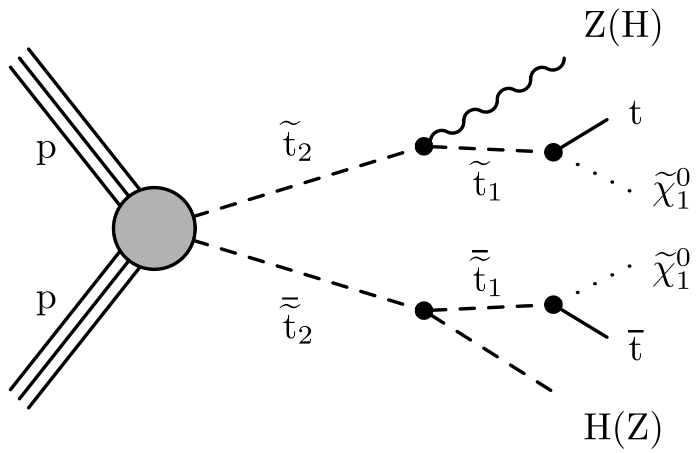


2L SS + ≥3L

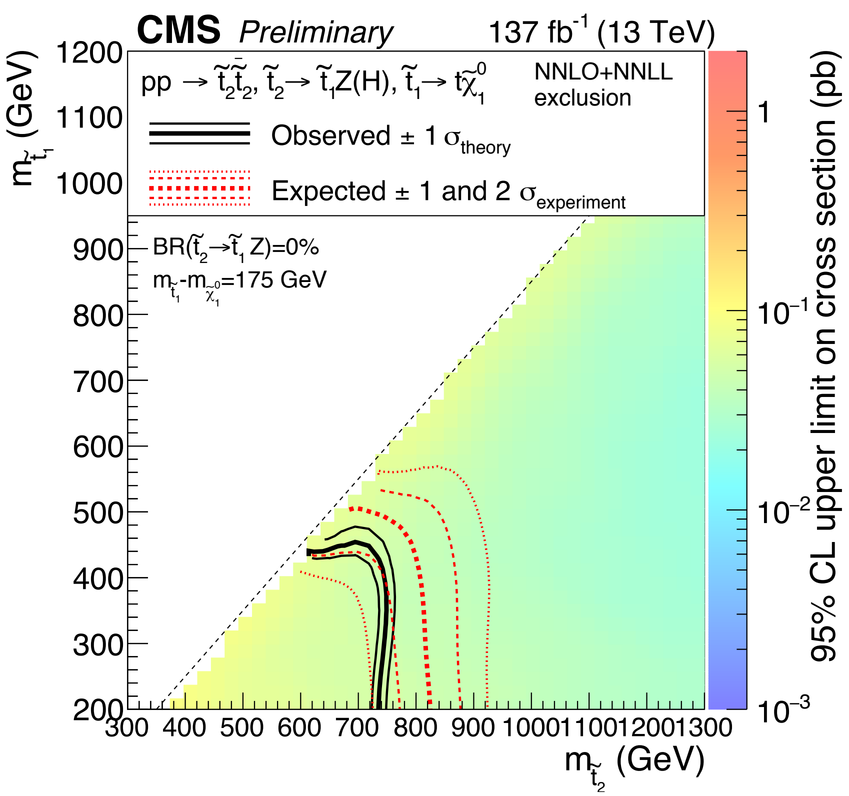
137fb-1

PAS

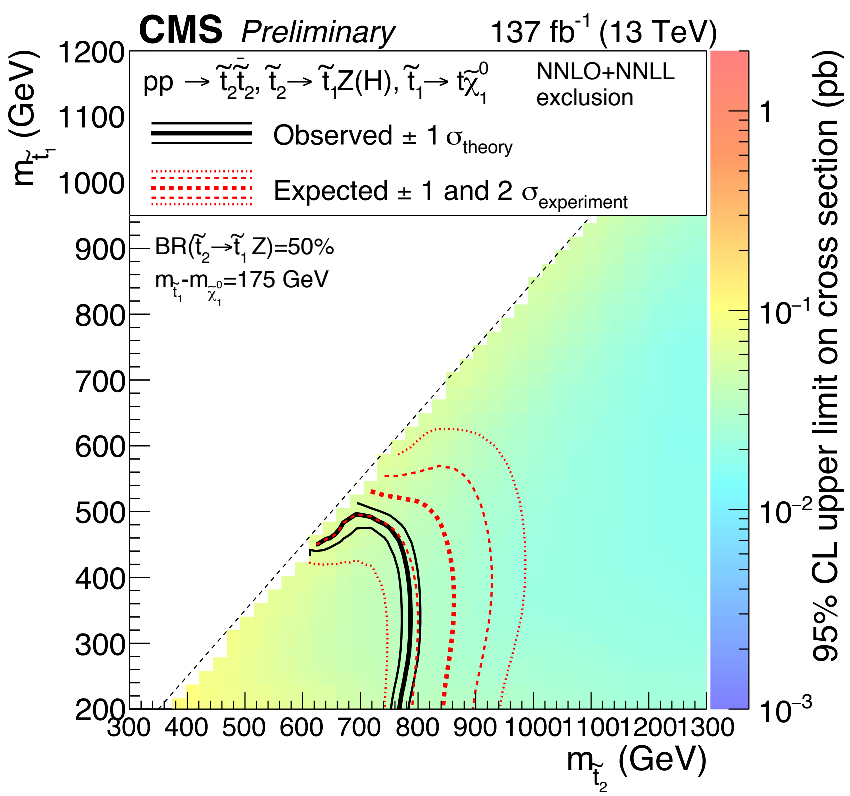
- Stop squark pair production model T6ttHZ with three assumptions on gen-2 squark decay to gen-1 squark + Z/H
  - Z (0%), H (100%)
  - Z (50%), H (50%)
  - Z (100%), H (0%)



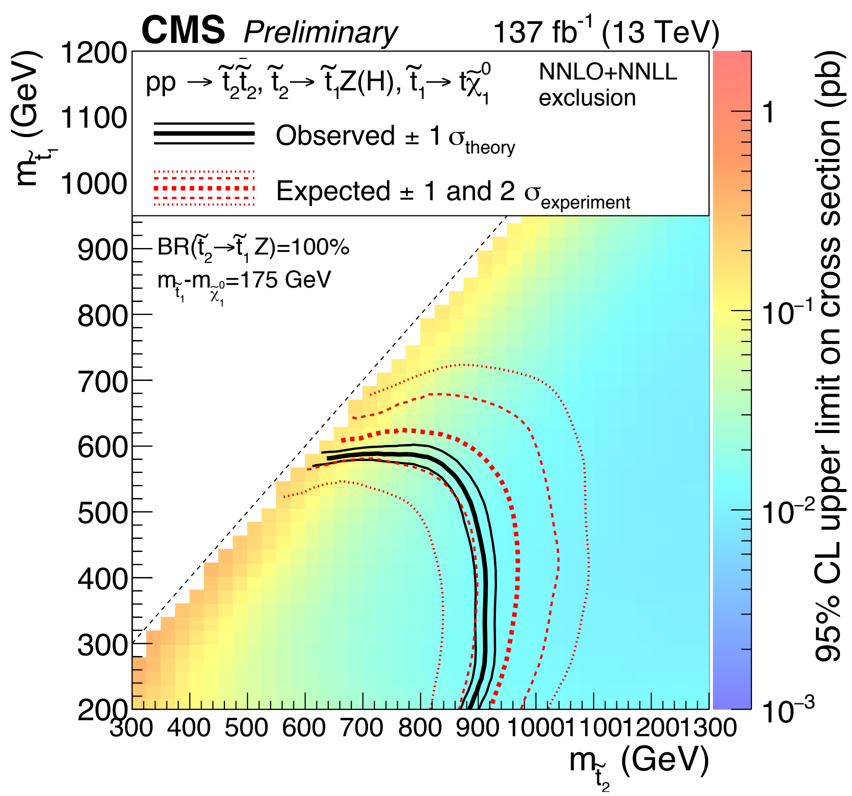
Z (0%)



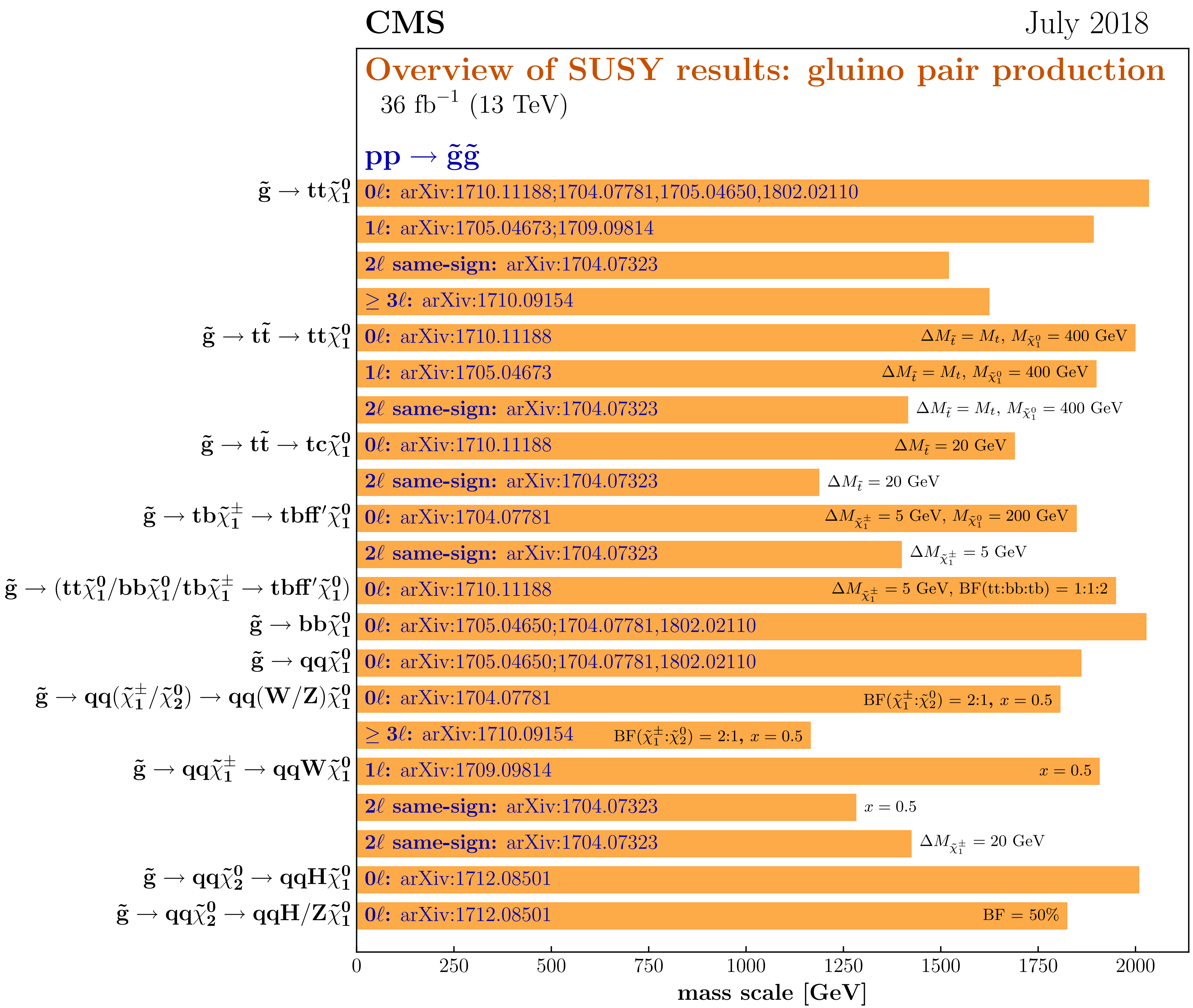
Z (50%)



Z (100%)



Limit summaries



Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

Limit summaries