Searches for gluino pair production in the single lepton final state with CMS

SUSY Conference, Melbourne

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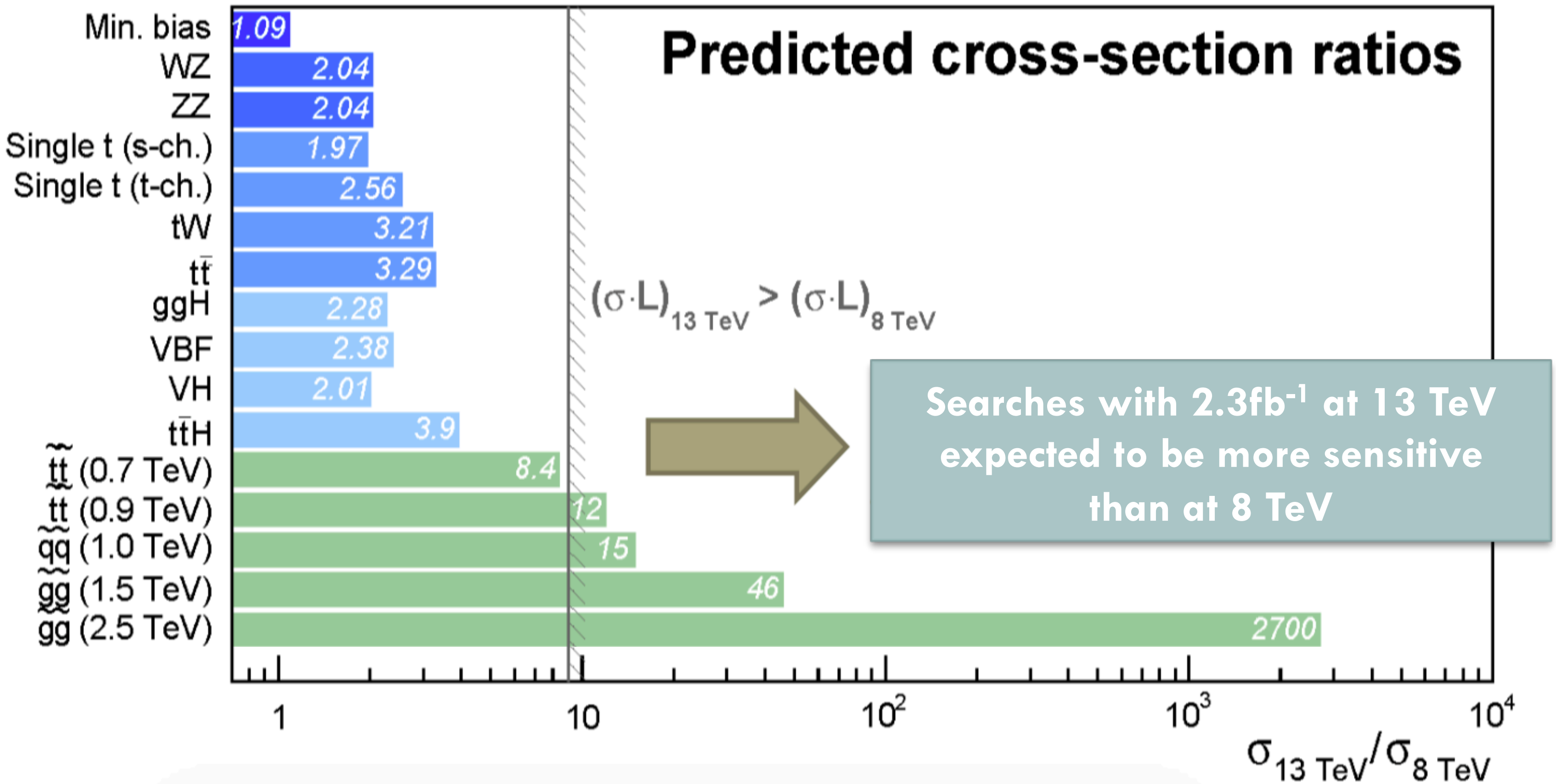
For the CMS Collaboration

Setting the stage for SUSY in Run 2

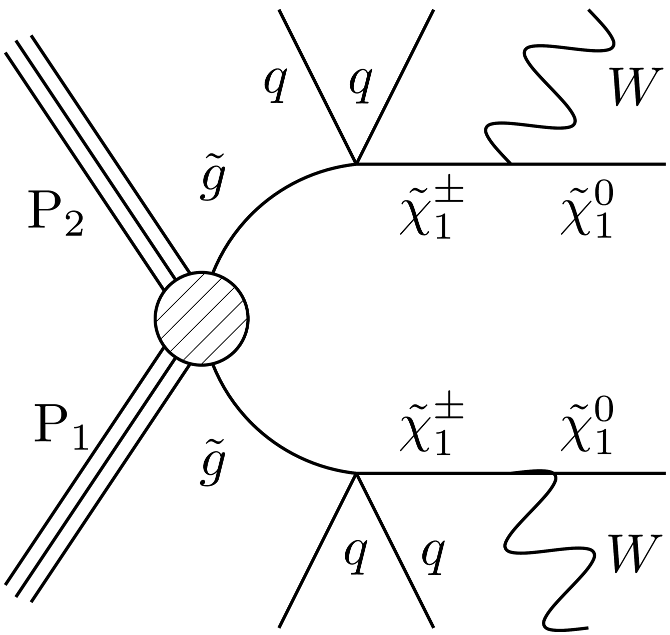


Early SUSY searches mostly aiming at gluino production:
Expect gain in sensitivity due to large increase in cross section when compared to 8 TeV

Gluino induced simplified signal models

SUS-15-006

$\Delta\phi$, = 0b



T5qqqqWW
0 b-jets

Decoupled mass spectrum

R-Parity conservation

Two parameters
m_{LSP} vs. $m_{sparticle}$

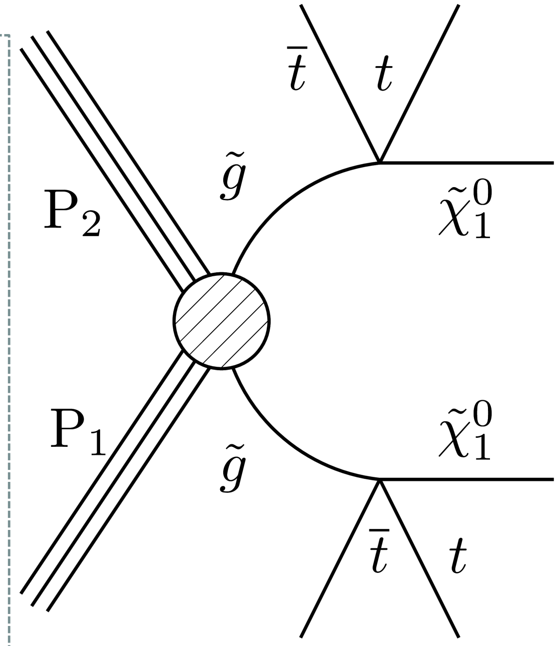
Mostly 100% BR

SUS-15-006

$\Delta\phi$, ≥ 1b

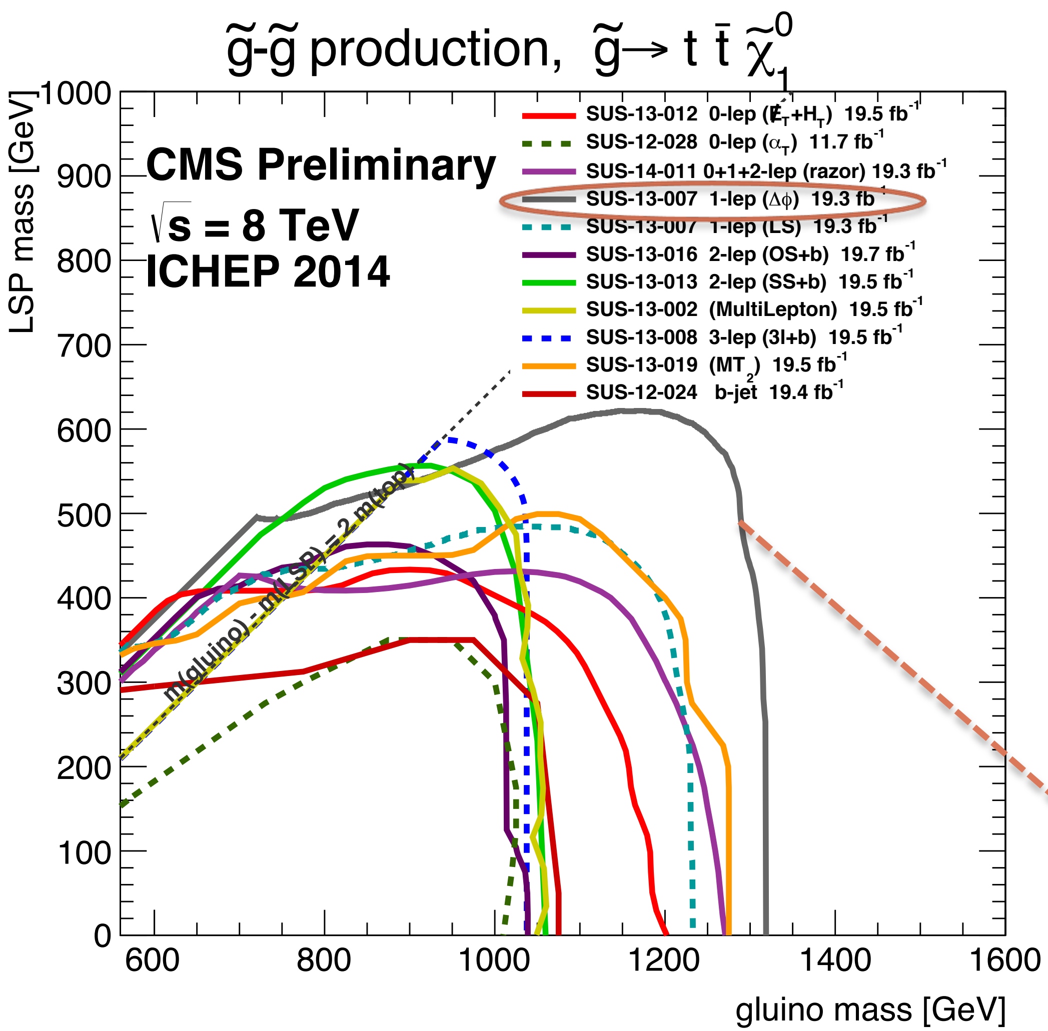
SUS-15-007

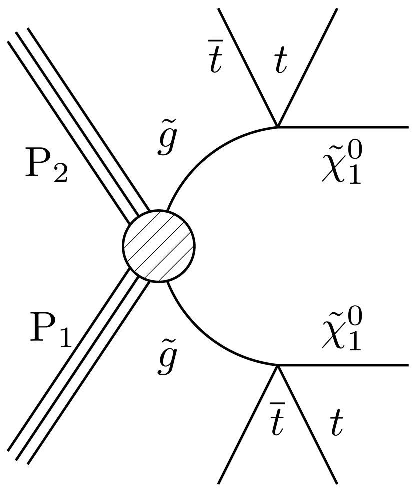
MJ, ≥ 1b



T1tttt
multiple b-jets

Recap of CMS Run 1: T1tttt

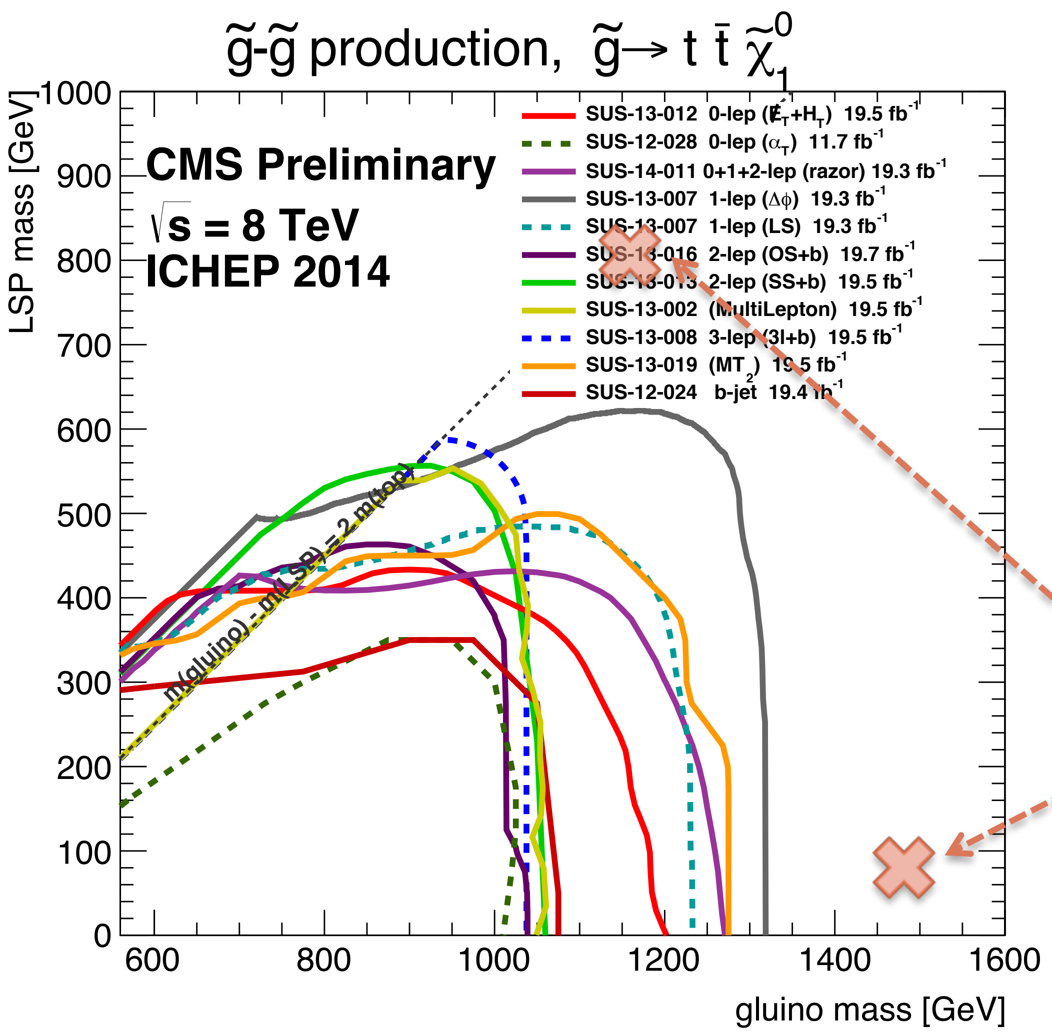


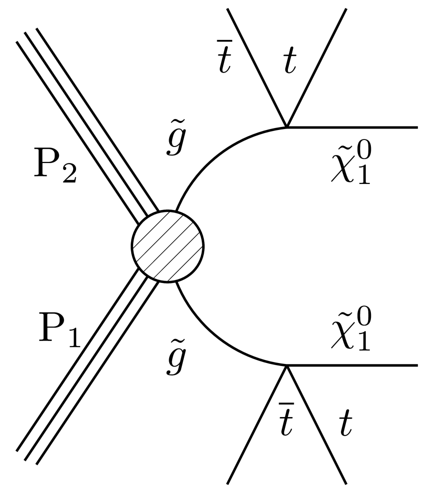


One lepton final state has a high probability when **four top quarks decay ~40%**

Search in this final state gave most stringent limits on this model

Recap of CMS Run 1: T1tttt





Two benchmark scenarios were used to prepare the first searches at 13 TeV

T1tttt 1.2/0.8

T1tttt 1.5/0.1

Baseline selection and analysis strategy

SUS-15-006 Δϕ	
= 0b	≥ 1b

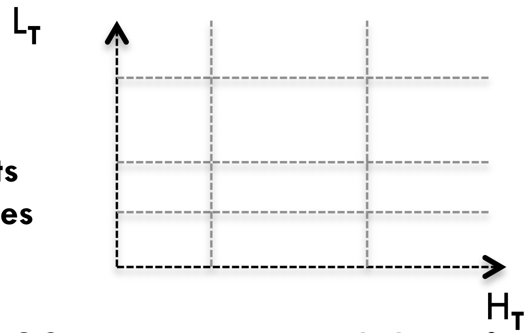
SUS-15-007 MJ
≥ 1b

- One e/μ with p_T > **25 GeV**
- H_T > 500 GeV
- **nJets ≥ 5 or ≥ 6,** lower nJet regions used for bkg estimate
- **L_T = lep p_T + MET > 250 GeV**

- One e/μ with p_T > **20 GeV**
- H_T > 500 GeV
- **nJets ≥ 6**
- **MET > 200 GeV**

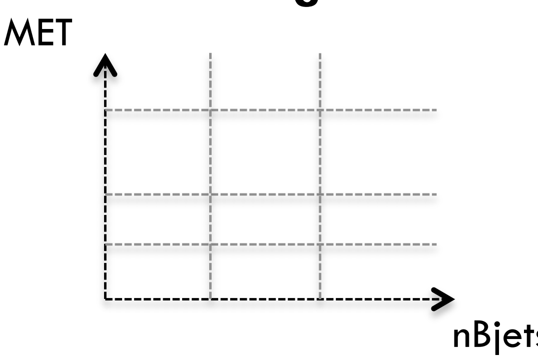
Both analyses use multiple exclusive search categories

+ nBjets categories



30 exclusive search bins for multi-b
13 exclusive search bins for 0-b

Bins in: nJets

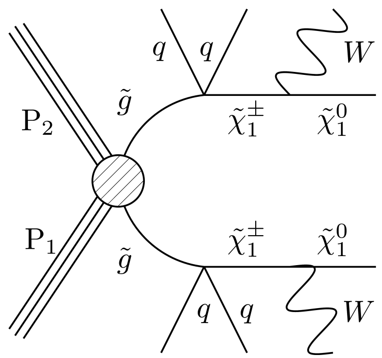


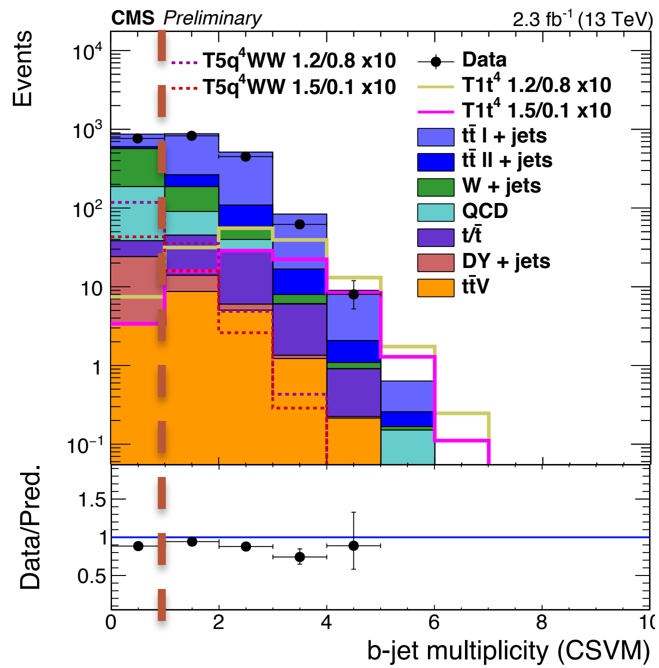
10 exclusive search bins

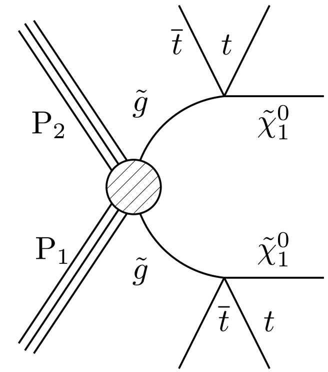
Two different signal scenarios

SUS-15-006 Δϕ

= 0b | ≥ 1b

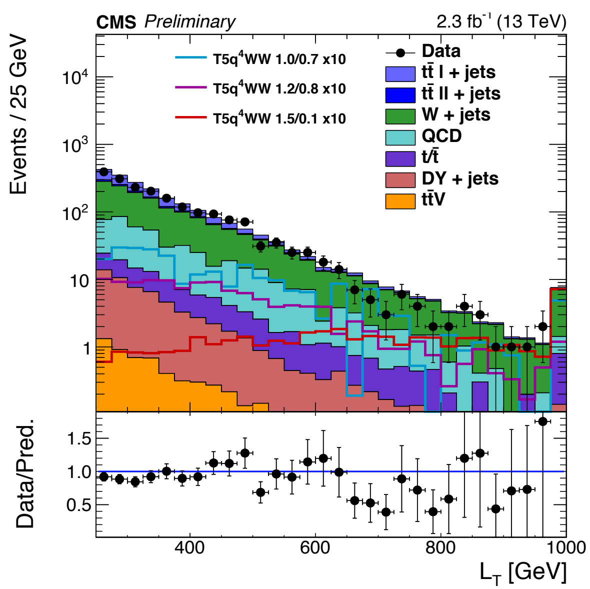






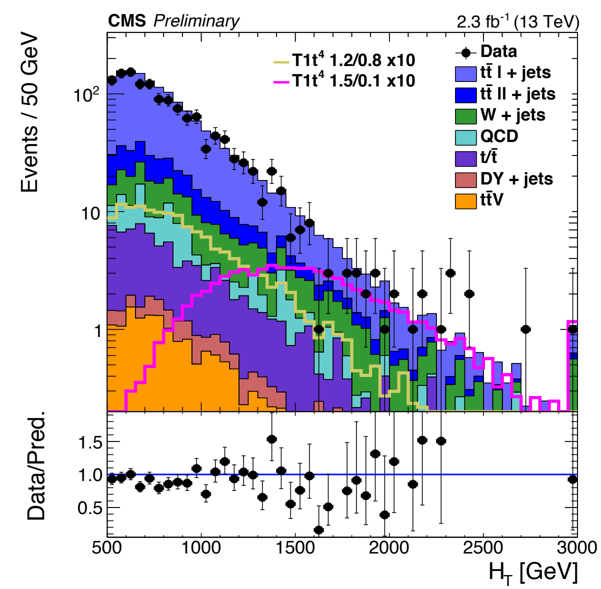
= 0b dominated by W+jets

≥ 1b dominated by tt+jets



H_T = sum p_T of all jets

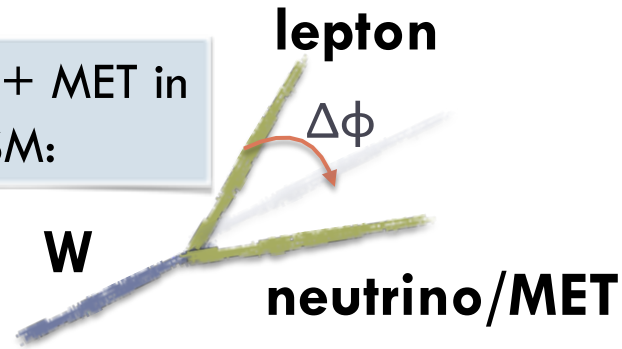
L_T = lepton p_T + MET



Why Δϕ as discriminating variable?

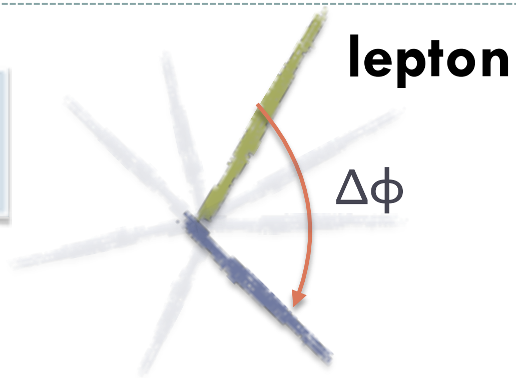
SUS-15-006 Δϕ
= 0b | ≥ 1b

Lepton + MET in SM:

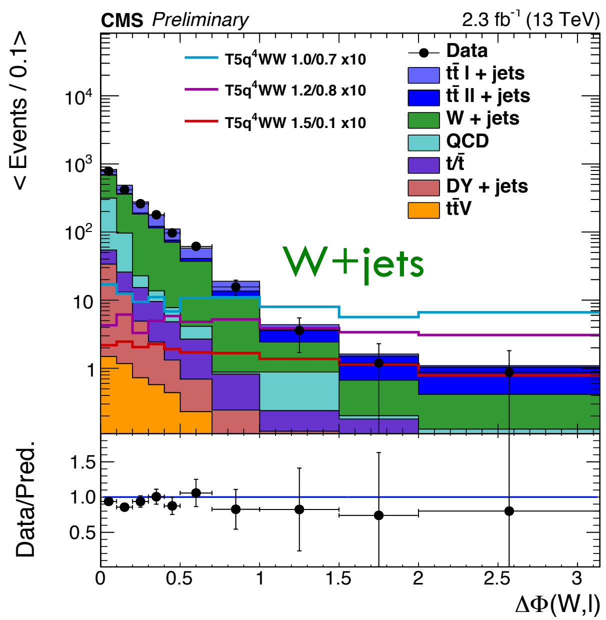


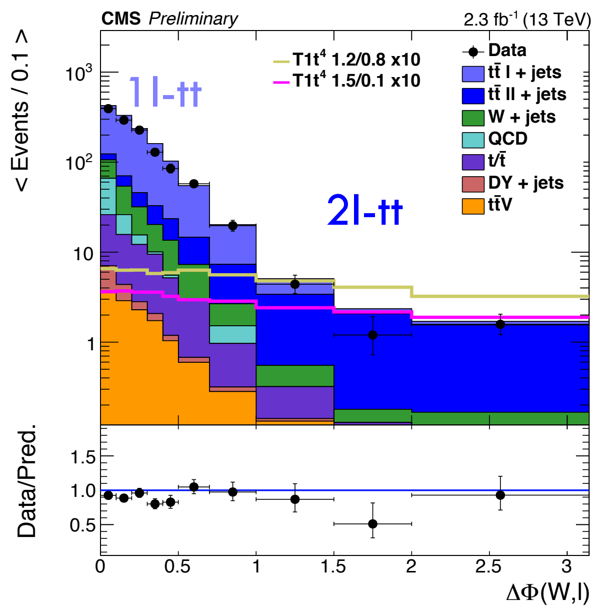
Δϕ: Angle between lepton and reconstructed W

Lepton + MET with SUSY:



MET (mostly) due to LSP → "randomized" reconstructed W → "randomized" Δϕ





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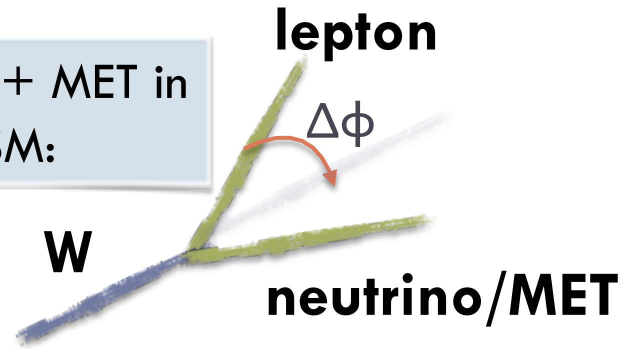

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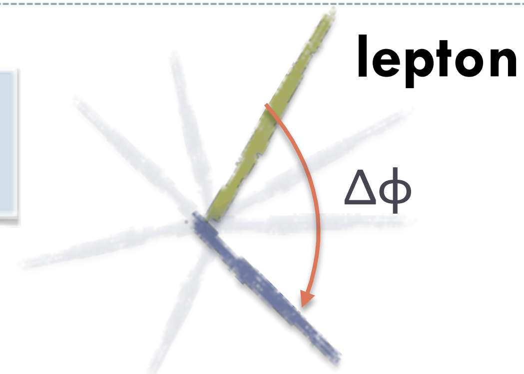

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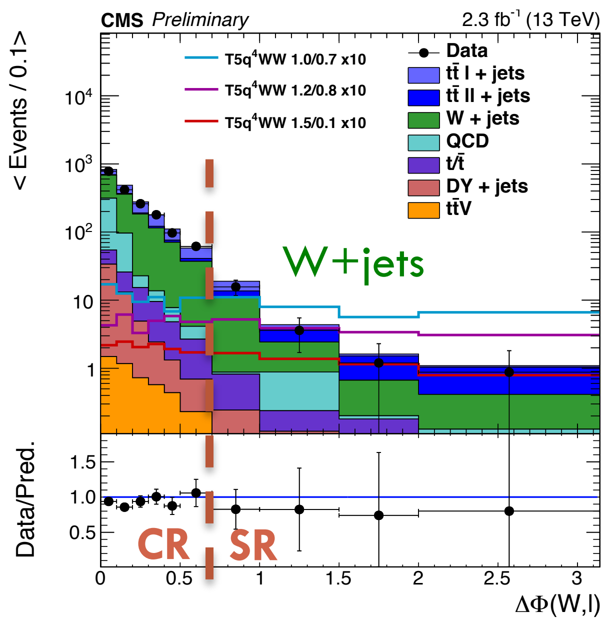
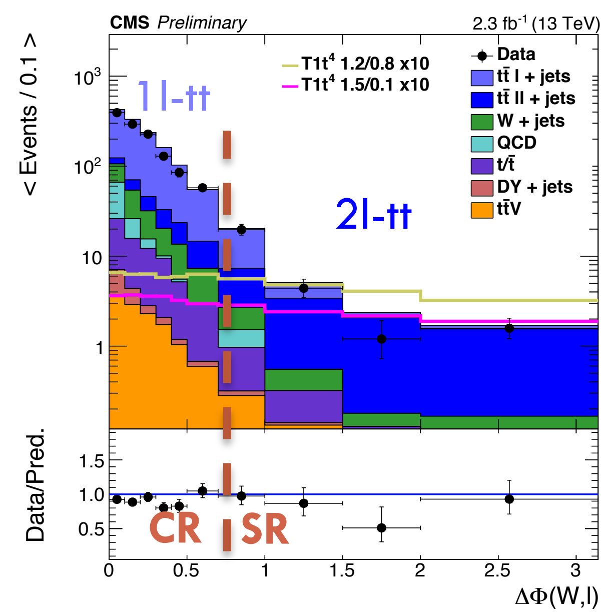


Dynamic Δϕ cut as function of L_T that defines signal and control regions

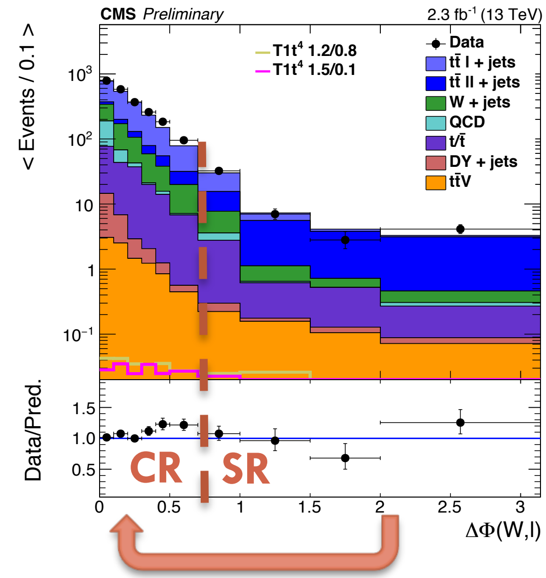


Background estimation: R_{CS} method

SUS-15-006 Δϕ

= 0b	≥ 1b

- Determine transfer factors R_{CS} between $\Delta\phi > x$ and $\Delta\phi < x$ from lower jet multiplicities side band bins
  - Residual differences between SB and MB are corrected by simulation
- Method is similar to an ABCD approach in nJets vs Δϕ



$R_{CS} = N_{SR}(SB)/N_{CR}(SB)$

	$\Delta\phi < X$ CR	$\Delta\phi > X$ SR
Low nJet (3-4j, 4-5j)	$R_{CS}(SB) = N_{SR}(SB)/N_{CR}(SB)$	
High nJet (≥ 5j, ≥ 6j)	$N_{CR}(MB)$	$N_{CR}(MB) \times k^{MC} \times R_{CS}$ (SB)

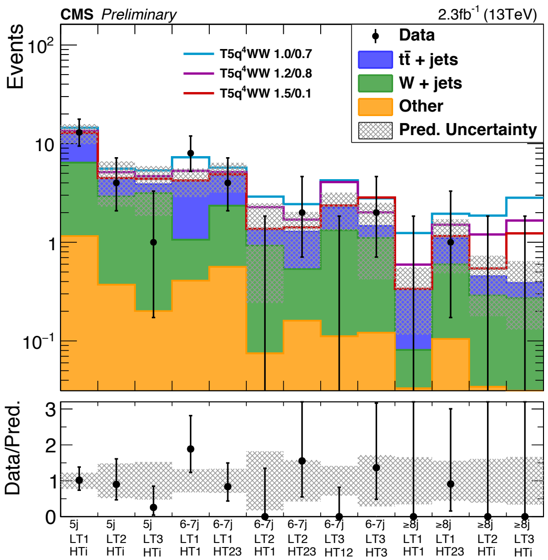
Region of interest

Results

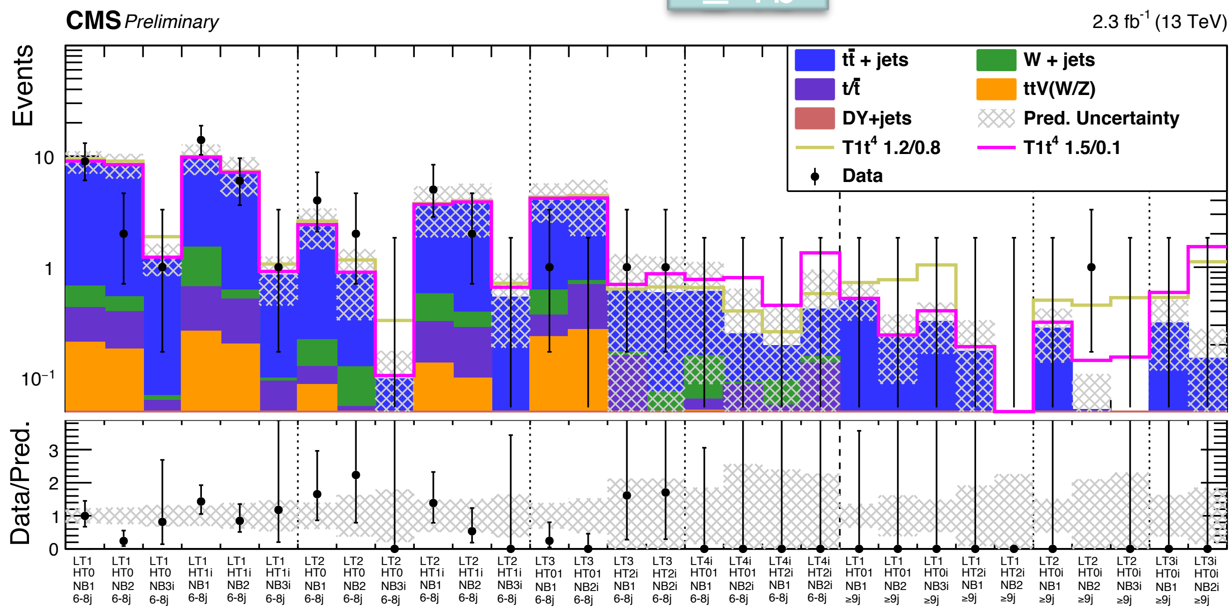
SUS-15-006 Δϕ

= 0b | ≥ 1b

= 0b



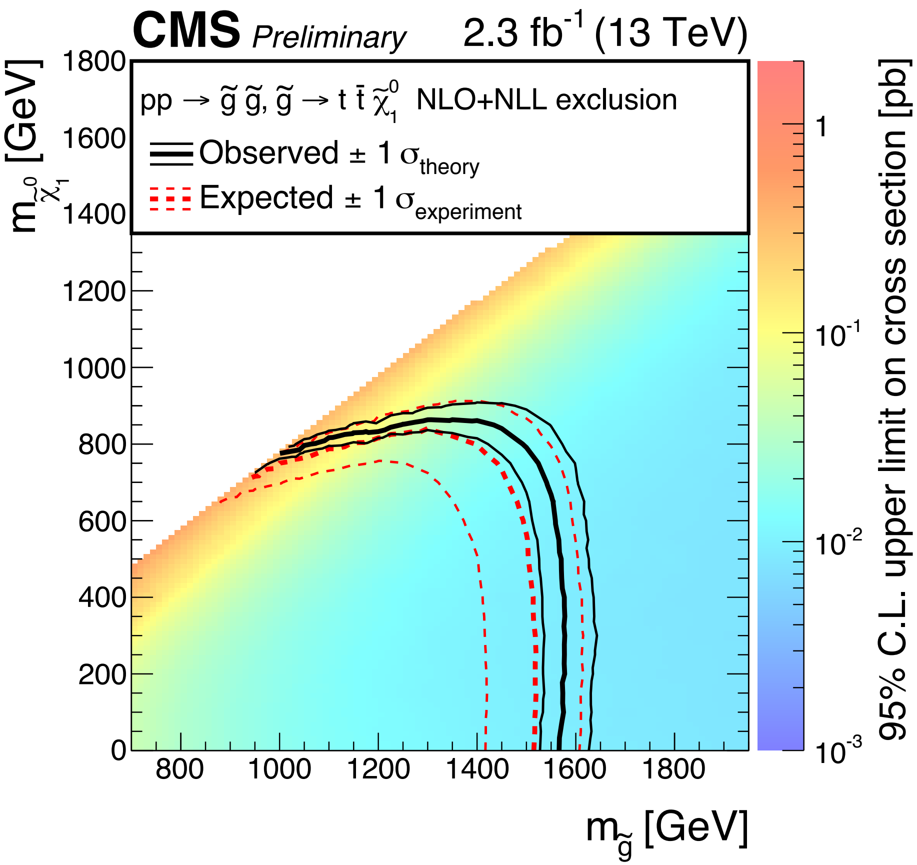
≥ 1b



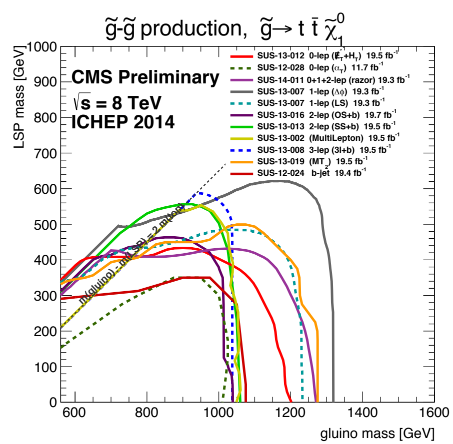
- Good agreement between prediction and observation
- Setting limits on T5qqqqWW and T1tttt model

Limits on T1tttt

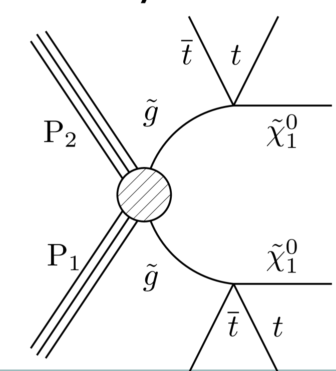
SUS-15-006 Δϕ
≥ 1b



- Profile likelihood method used to set limits at the 95% C.L.
- Gluino mass excluded up to 1575 GeV for LSP masses below 800 GeV in this simplified model

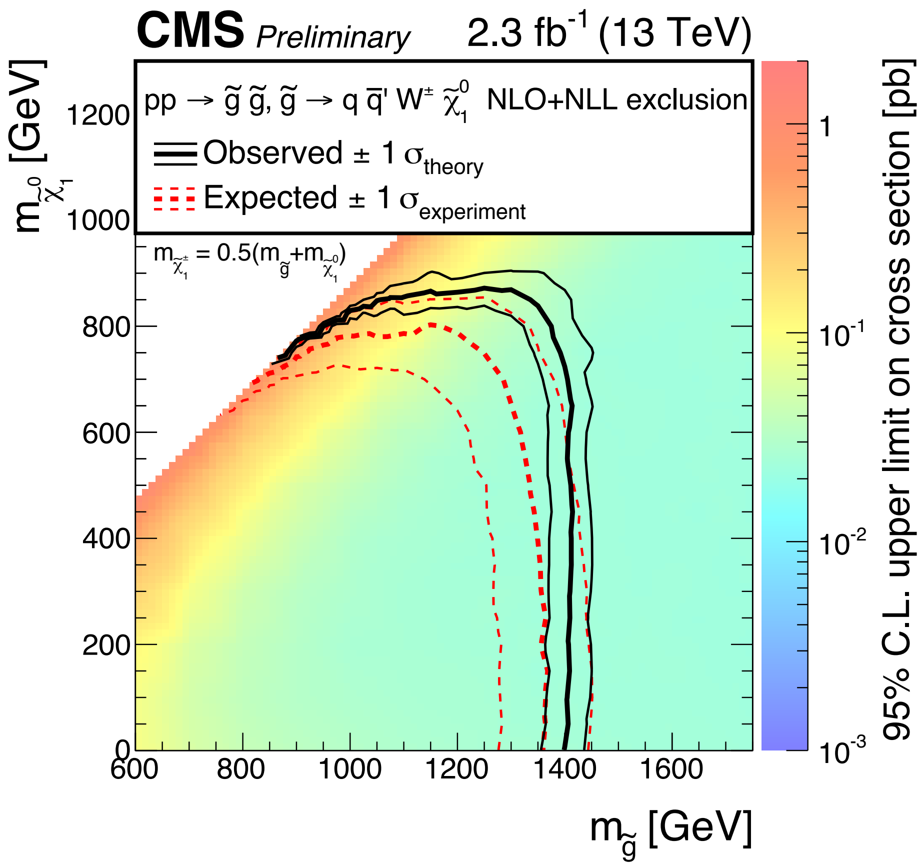


Extending 8 TeV results by 250 GeV

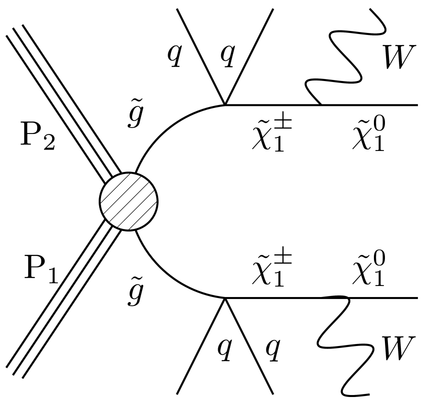


Limits on T5qqqqWW

SUS-15-006 Δϕ = 0b



- Profile likelihood method used to set limits at the 95% C.L.
- Gluinos below 1400 GeV are excluded for neutralino masses below 725 GeV

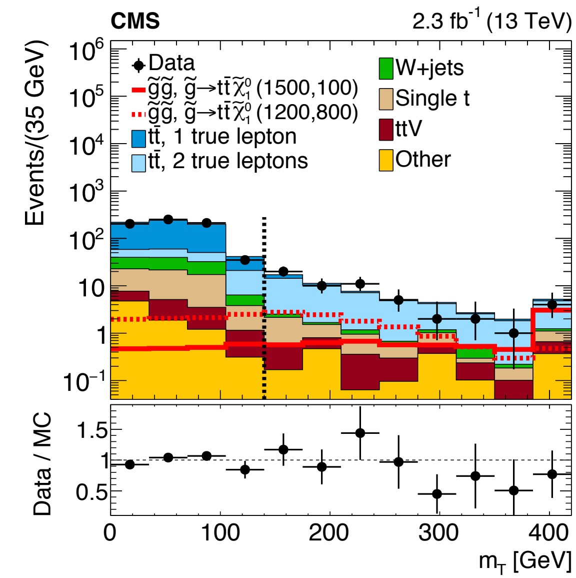


m_T and MJ as discriminating variables

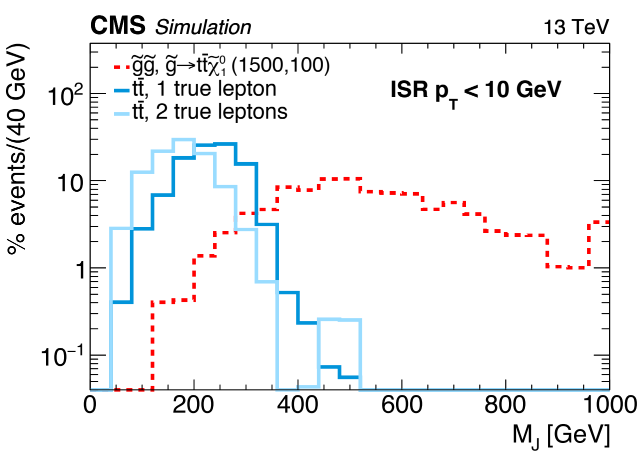
SUS-15-007 MJ

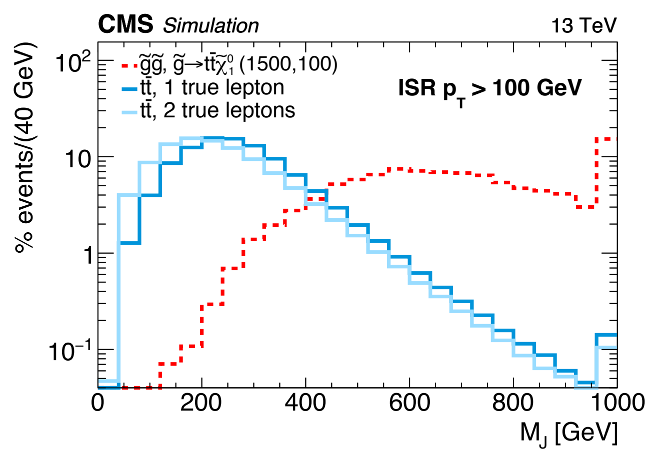
≥ 1b

- Transverse mass m_T: between lepton and MET has endpoint around W mass for 1l-tt and longer tail for 2l-tt events



- Sum of masses of large R jets MJ
  - Small radius (anit-kT 0.4) jets + lepton are clustered into large radius (anit-kT 1.2) jets
  - MJ = sum of large jet masses





Without ISR MJ of the tt system has endpoint at twice the top mass while the signal shape is unaffected

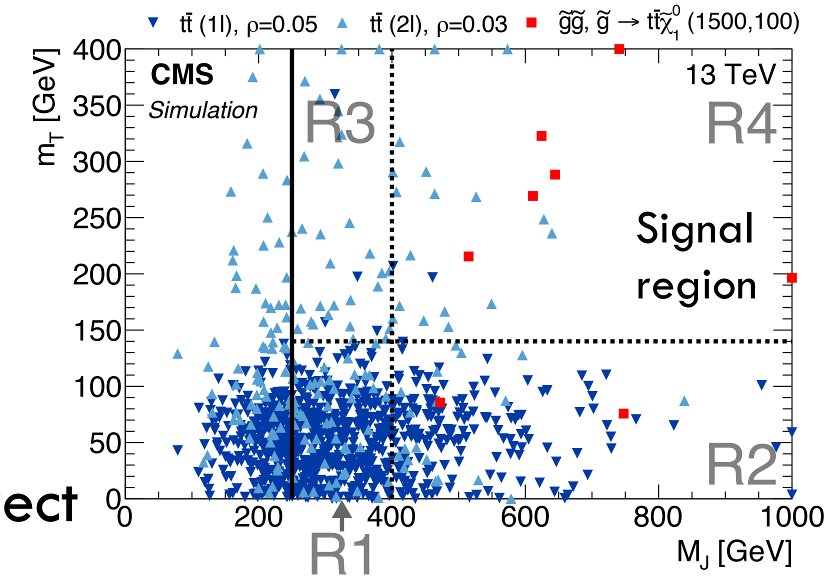
Background prediction

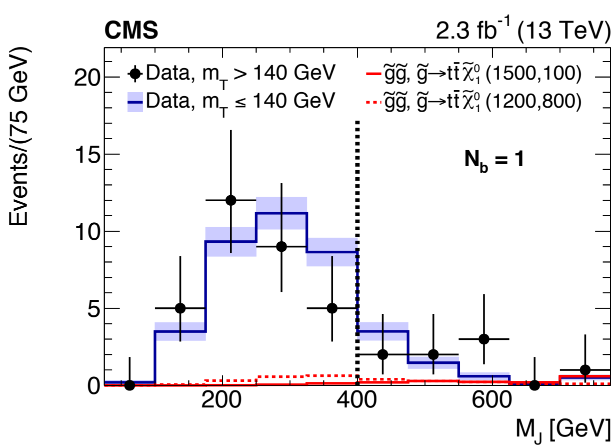
SUS-15-007 MJ
$\geq$ 1b

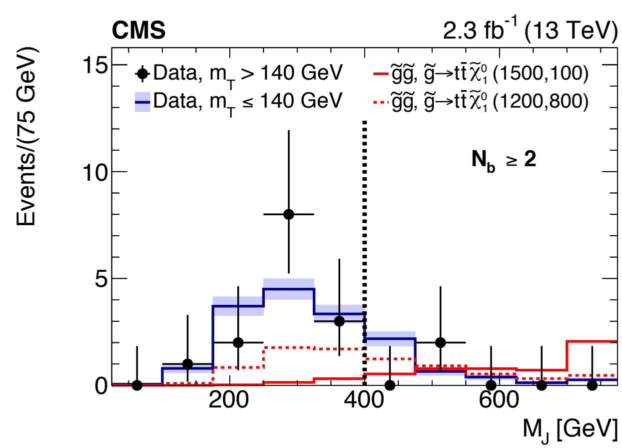
- Background estimation based on m_T and MJ being uncorrelated
- Background in R4 is predicted with ABCD method

$$N_{R4} = k^{MC} \times [N_{R2} \times N_{R3} / N_{R1}]^{Data}$$

- Correction factor k^{MC} used to correct small residual differences





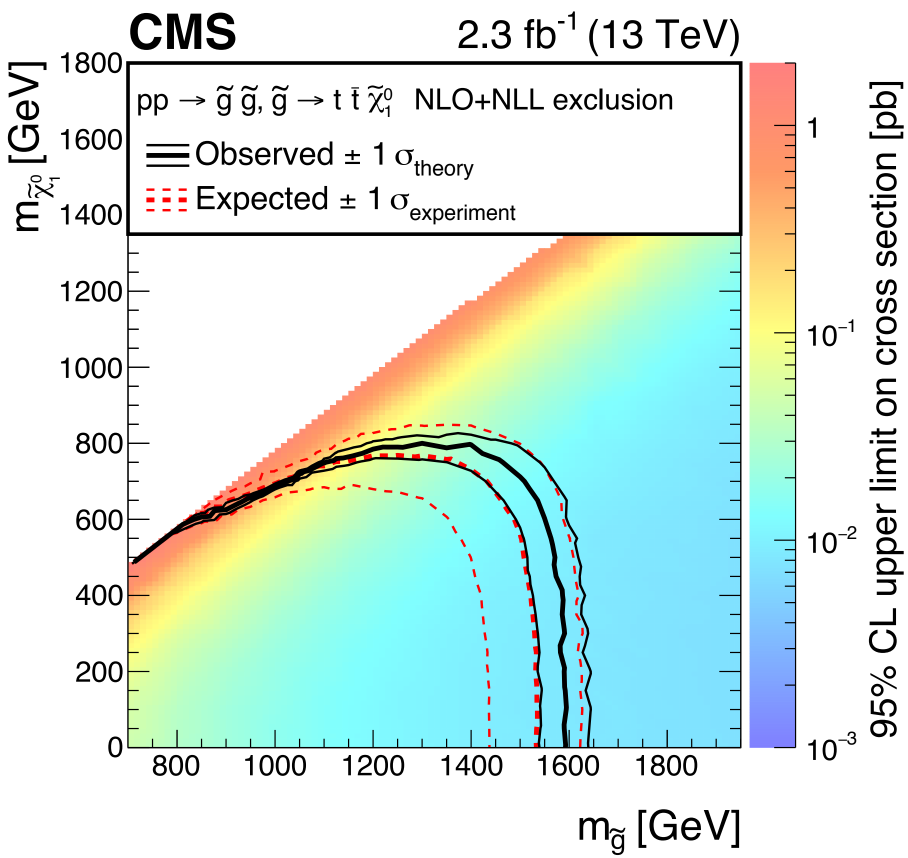


Check the validity of the bkg estimation method by comparing MJ distributions for **low** and **high** m_T regions

Limits on T1tttt

SUS-15-007 MJ

$\geq 1b$



- Profile likelihood method used to set limits at the 95% C.L.
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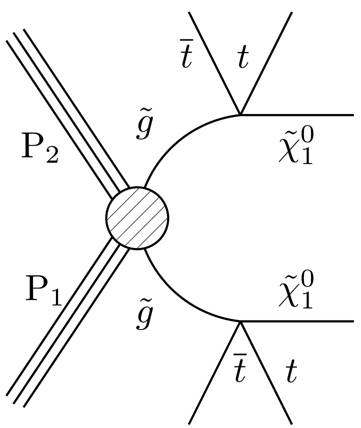
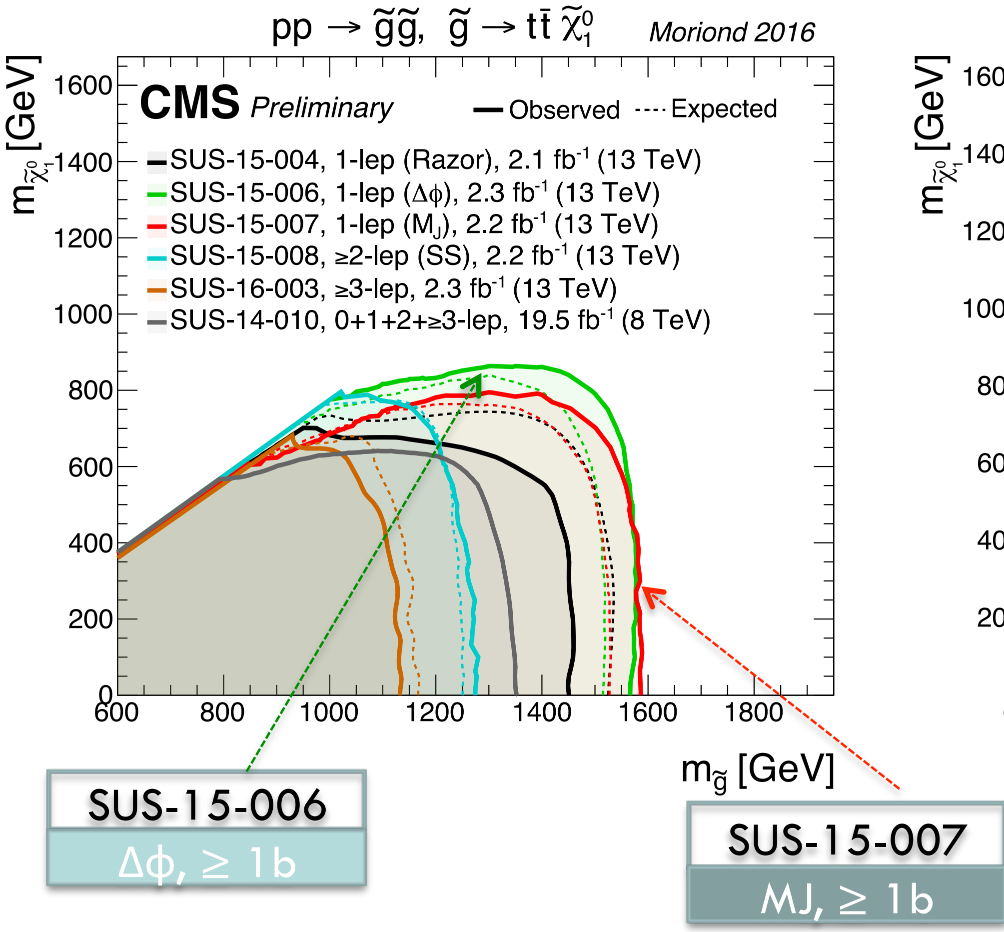
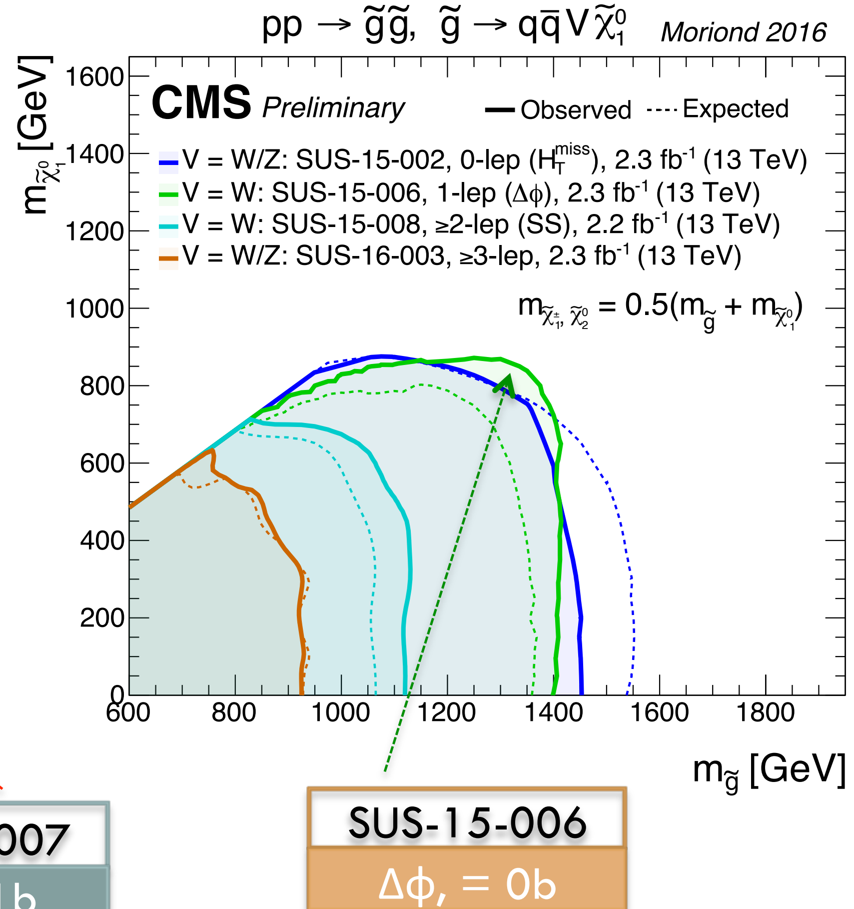


Limit summaries

- Single lepton searches cover a large area of phase space





Summary

- Run2 of the LHC is in full swing

- Many SUSY searches are being performed
  - Unfortunately no sign yet
  - Even with low luminosity limits on simplified models already extent previous searches at 8 TeV by multiple 100 GeV

- Three single lepton results shown for two different models
  - Two different search approaches within the single lepton final state yield similar results
  - In case of an excess can double check each other

- Stay tuned for results this year

Backup

Background estimation: R_{CS} method

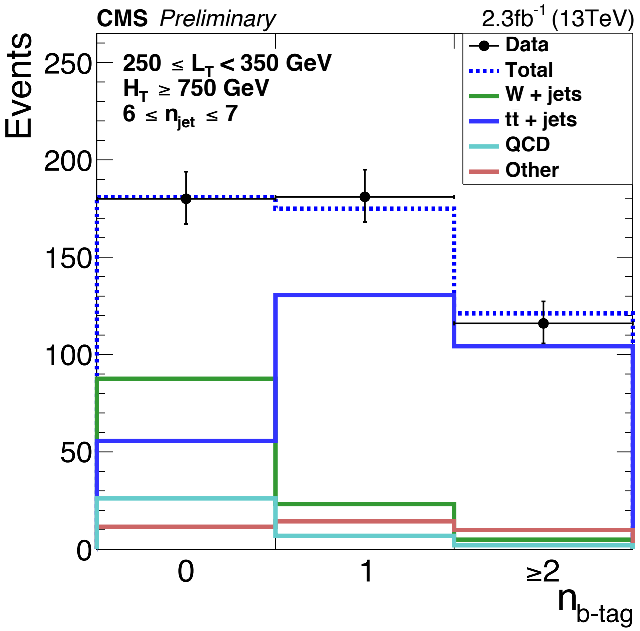
SUS-15-006 $\Delta\phi$

= 0b | ≥ 1b

- Different jet multiplicity side bands are used for W+jets, tt+jets and QCD
- Multi-b is dominated by tt+jets
- 0-b has equal parts W and tt
  - Two independent side bands for both components
  - Mixture is determined from fit to b-tag multiplicity in the $\Delta\phi$ < X of the high nJets search regions

Analysis	Multi-b analysis	
$n_{\text{b-tag}}$	$n_{\text{b-tag}} = 0$	$n_{\text{b-tag}} \geq 1$
$n_{\text{jet}} = 3$	QCD Fit (el. sample)	
$n_{\text{jet}} = 4$		R_{CS} det.
$n_{\text{jet}} = 5$		
$n_{\text{jet}} \geq 6$		MB

Analysis	Zero-b analysis	
$n_{\text{b-tag}}$	$n_{\text{b-tag}} = 0$	$n_{\text{b-tag}} = 1$
$n_{\text{jet}} = 3$	$R_{CS}(W^{\pm})$ det. (μ sample), QCD Fit (el. sample)	
$n_{\text{jet}} = 4$		$R_{CS}(t\bar{t})$ det.
$n_{\text{jet}} = 5$	MB	
$n_{\text{jet}} \geq 6$		

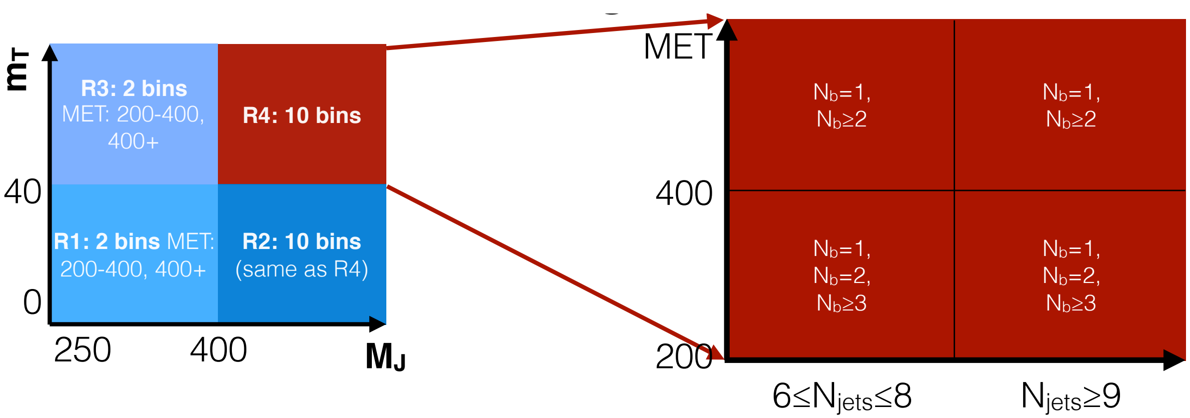


Signal regions

n_{jet}	$n_{\text{b-tag}}$	L_T [GeV]	H_T [GeV]	$\Delta\Phi$
[6,8]	$=1, =2, \geq 3$	$[250, 350]$	$[500, 750]$, ≥ 750	1.0
		$[350, 450]$	$[500, 750]$, ≥ 750	0.75
	$=1, \geq 2$	$[450, 600]$	$[500, 1250]$, ≥ 1250	
		≥ 600	$[500, 1250]$, ≥ 1250	0.5
≥ 9	$=1, =2$	$[250, 350]$	$[500, 1250]$, ≥ 1250	1.0
	≥ 3		≥ 500	
	$=1, =2, \geq 3$	$[350, 450]$	≥ 500	0.75
	$=1, \geq 2$	≥ 450	≥ 500	
5	0	$[250, 350]$, $[350, 450]$, ≥ 450	≥ 500	1.0
[6,7]		$[250, 350]$, $[350, 450]$	$[500, 750]$, ≥ 750	
		≥ 450	$[500, 1000]$, ≥ 1000	0.75
≥ 8		$[250, 350]$	$[500, 750]$, ≥ 750	1.0
		$[350, 450]$, ≥ 450	≥ 500	0.75

SUS-15-006

= 0b | ≥ 1b



SUS-15-007

MJ, ≥ 1b

Systematic uncertainties

Source	Uncertainty [%] for multi-b	Uncertainty [%] for zero-b
dilepton control sample	8-20	8-40
JEC	0.2-11	0.6-8.2
b-tagging	0.1-17	1.4-4.5
$\sigma(\mathrm{W+jets})$	0.3-6.4	<2.5
W polarization variation	0.1-2	0.2-3.4
$\sigma(\mathrm{t\bar{t}}V)$	0.1-5	0.2-2.9
top p_T reweighting	0.1-10	0.1-7.1
pileup	0.3-23	0.1-10
R_{CS} fit	–	3.3-35
Total	8.0-28	10-54
MC statistics	3-30	8-48

SUS-15-006

= 0b | ≥ 1b

Source	Fractional uncertainty [%]
Lepton efficiency	1–5
Trigger efficiency	1
b tagging efficiency	1–15
Jet energy corrections	1–30
Renormalization and factorization scales	1–5
Initial state radiation	1–35
Pileup	5
Integrated luminosity	3

SUS-15-007

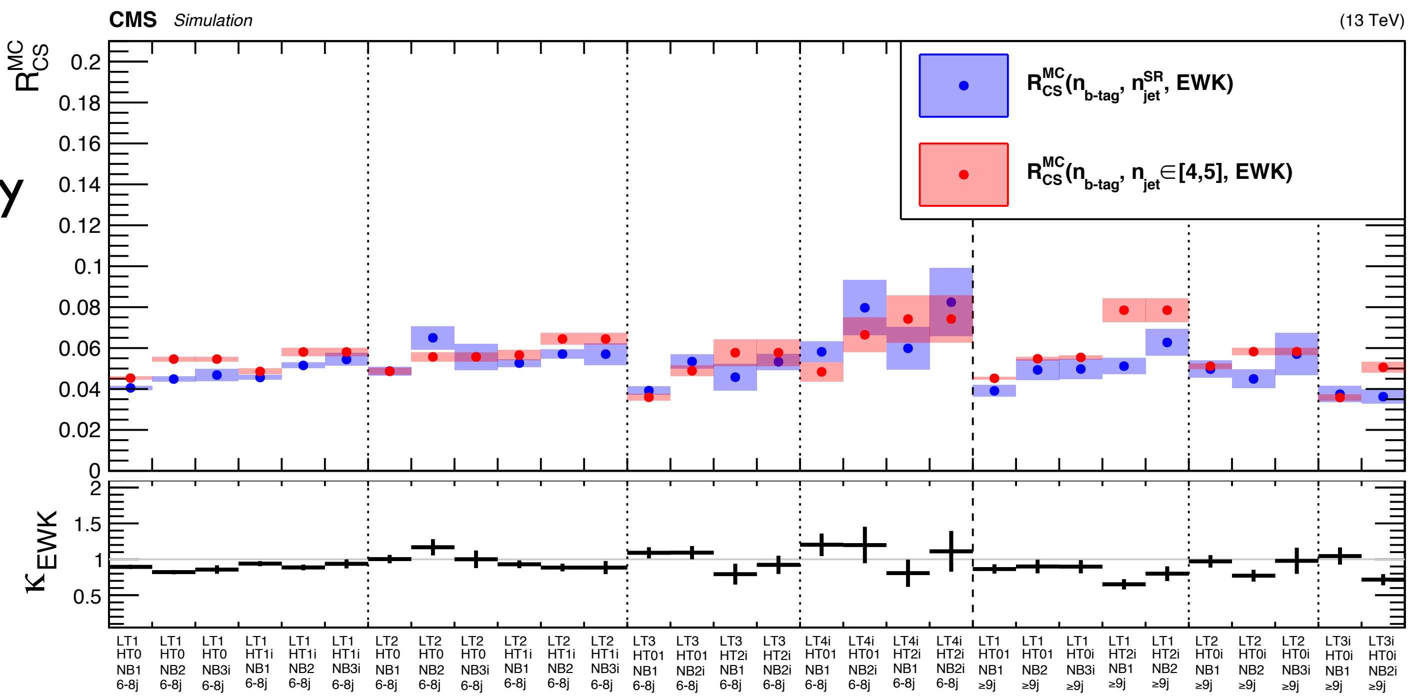
MJ, ≥ 1b

Correction factors from simulation

- Any residual difference on R_{cs} between the SB and MB is corrected by a k^{MC} factor from simulation
- Need to choose kinematically similar SB bins (same H_T, L_T)

R_{cs} in the SB follows closely R_{cs} in the MB

k^{MC} consistent with 1 for most bins



Results MJ

Region: bin	κ	T1tttt(NC)	T1tttt(C)	Fitted μ^{bkg} (PF)	Fitted μ^{bkg} (GF)	Obs.
$200 < E_T^{miss} \leq 400$ GeV						
R1: all N_{jets}, N_b	—	0.1	3.2	336.0 ± 18.3	335.3 ± 18.2	336
R2: $6 \leq N_{jets} \leq 8$, $N_b = 1$	—	0.1	0.2	47.1 ± 6.9	49.5 ± 6.9	47
R2: $N_{jets} \geq 9$, $N_b = 1$	—	0.1	0.3	7.0 ± 2.6	7.5 ± 2.7	7
R2: $6 \leq N_{jets} \leq 8$, $N_b = 2$	—	0.1	0.3	42.0 ± 6.5	41.1 ± 6.2	42
R2: $N_{jets} \geq 9$, $N_b = 2$	—	0.1	0.5	7.0 ± 2.6	6.6 ± 2.5	7
R2: $6 \leq N_{jets} \leq 8$, $N_b \geq 3$	—	0.1	0.2	12.0 ± 3.5	11.1 ± 3.2	12
R2: $N_{jets} \geq 9$, $N_b \geq 3$	—	0.2	0.6	1.0 ± 1.0	0.9 ± 0.9	1
R3: all N_{jets}, N_b	—	0.2	3.8	21.0 ± 4.6	21.6 ± 4.2	21
R4: $6 \leq N_{jets} \leq 8$, $N_b = 1$	$1.12 \pm 0.09 \pm 0.43$	0.2	0.2	3.3 ± 1.4	3.6 ± 1.0	6
R4: $N_{jets} \geq 9$, $N_b = 1$	$0.91 \pm 0.06 \pm 0.81$	0.2	0.4	0.4 ± 0.3	0.4 ± 0.2	1
R4: $6 \leq N_{jets} \leq 8$, $N_b = 2$	$1.11 \pm 0.06 \pm 0.42$	0.3	0.4	2.9 ± 1.2	2.9 ± 0.8	2
R4: $N_{jets} \geq 9$, $N_b = 2$	$1.05 \pm 0.11 \pm 0.94$	0.3	0.6	0.5 ± 0.3	0.4 ± 0.2	0
R4: $6 \leq N_{jets} \leq 8$, $N_b \geq 3$	$1.25 \pm 0.11 \pm 0.47$	0.3	0.3	0.9 ± 0.4	0.9 ± 0.3	0
R4: $N_{jets} \geq 9$, $N_b \geq 3$	$1.05 \pm 0.10 \pm 0.93$	0.3	0.7	0.1 ± 0.1	0.1 ± 0.1	0
$E_T^{miss} > 400$ GeV						
R1: all N_{jets}, N_b	—	0.1	0.5	16.0 ± 4.0	17.1 ± 4.0	16
R2: $6 \leq N_{jets} \leq 8$, $N_b = 1$	—	0.2	0.1	8.0 ± 2.8	6.8 ± 2.5	8
R2: $N_{jets} \geq 9$, $N_b = 1$	—	0.1	0.2	1.0 ± 1.0	1.7 ± 1.2	1
R2: $6 \leq N_{jets} \leq 8$, $N_b \geq 2$	—	0.5	0.3	3.0 ± 1.7	2.5 ± 1.4	3
R2: $N_{jets} \geq 9$, $N_b \geq 2$	—	0.4	0.6	1.0 ± 1.0	0.9 ± 0.9	1
R3: all N_{jets}, N_b	—	0.4	0.9	4.0 ± 2.0	2.9 ± 1.4	4
R4: $6 \leq N_{jets} \leq 8$, $N_b = 1$	$1.09 \pm 0.16 \pm 0.42$	0.7	0.2	2.2 ± 1.7	1.2 ± 0.7	0
R4: $N_{jets} \geq 9$, $N_b = 1$	$0.98 \pm 0.16 \pm 0.87$	0.4	0.3	0.2 ± 0.3	0.3 ± 0.2	1
R4: $6 \leq N_{jets} \leq 8$, $N_b \geq 2$	$1.29 \pm 0.22 \pm 0.50$	1.9	0.5	1.0 ± 0.8	0.5 ± 0.4	0
R4: $N_{jets} \geq 9$, $N_b \geq 2$	$0.90 \pm 0.14 \pm 0.80$	1.6	1.0	0.2 ± 0.3	0.1 ± 0.1	0