Search for New Physics with same-sign leptons

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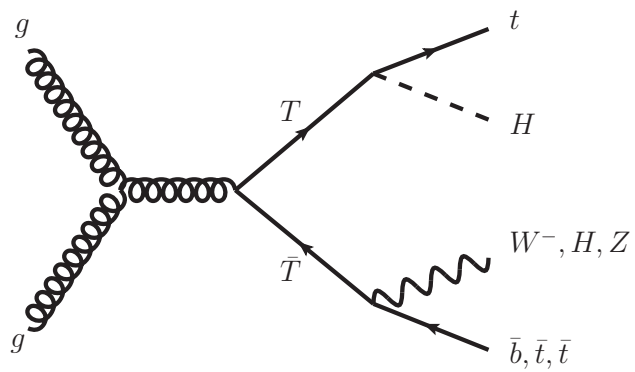
Introduction

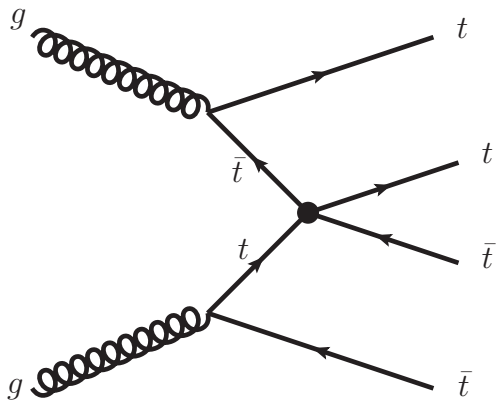
- Same-sign leptons signature has strong theory motivation:
  - Many BSM models: VLQ, 4 tops (extra dimensions, BSM Higgs, etc.)
  - Very low SM background
- In this talk, four 13 TeV analyses will be covered:
  - Search for heavy vector-like quarks decaying to same-sign dileptons
    - ★ CMS-PAS-B2G-16-019 (CMS T5/3), 35.9 fb^{-1}
  - Search for BSM physics in events with two leptons of the same sign, missing transverse momentum, and jets
    - ★ CMS-PAS-SUS-16-035 (CMS SUSY), 35.9 fb^{-1}
  - Search for supersymmetry with two same-sign leptons or three leptons
    - ★ ATLAS-CONF-2016-037 (ATLAS SUSY), 13.2 fb^{-1}
  - Search for new physics using events with b-jets and a pair of same charge leptons
    - ★ ATLAS-CONF-2016-032 (ATLAS VLQ/4tops), 3.2 fb^{-1}

Signatures

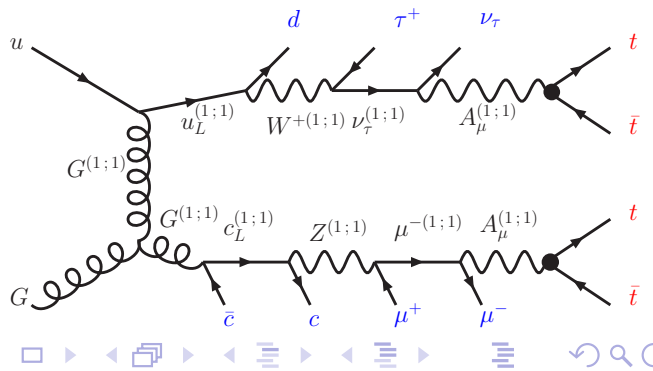
- Vector-like quark production (VLQ)
  - Double production: $T\bar{T}$, $B\bar{B}$, $T_{5/3}\bar{T}_{5/3}$
    - ★ $B \to Wt,\ Zb$ or Hb
    - ★ $T \to Wb,\ Zt$ or Ht
    - ★ $T_{5/3} \to W^+t$



- Four tops: $t\bar{t}t\bar{t}$
  - Effective contact interaction (CI):
    - ★ $\mathcal{L}_{4t} = \frac{C_{4t}}{\Lambda^2}\left(\bar{t_R}\gamma^\mu t_R\right)\left(\bar{t_R}\gamma_\mu t_R\right)$

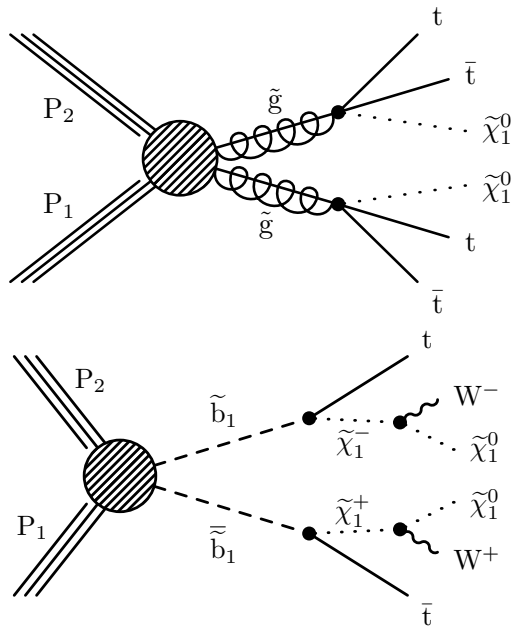


  - Extra dimensions under real projective plane geometry (2UED/RPP):
    - ★ Pair production of Kaluza-Klein (KK) excitations of photon $A^{(1,1)\mu} \to t\bar{t}$

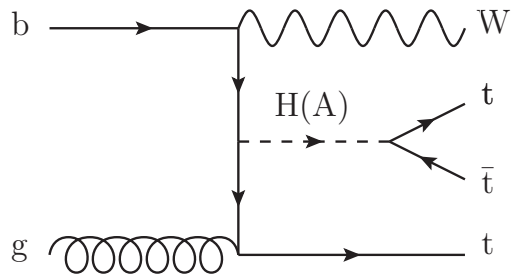


Signatures (continued)

- Supersymmetry
  - Light gluinos and 3rd generation squarks
    - ★ Large production of $\tilde{g}\tilde{g}$, $\tilde{b}\tilde{b}$, $\tilde{t}\tilde{t}$
    - ★ Large E_{T}^{miss} from neutralinos



- Same-sign tops
  - 2HDM type-II
    - ★ Associated production of a heavy (pseudo)scalar
    - ★ Smaller E_{T}^{miss}

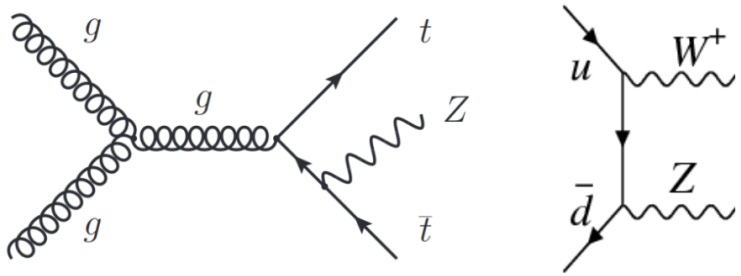


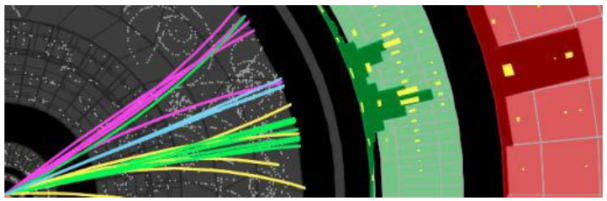
Selection

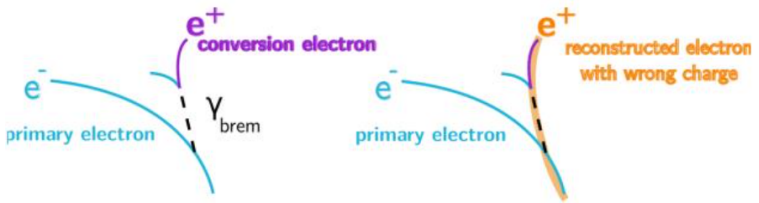
- All analyses require same-sign leptons (or 3 leptons)
- General features:
  - CMS T5/3 and ATLAS VLQ/4tops optimised for energetic tops:
    - ★ High lepton pt cut (∼30 GeV) and high jet activities
  - SUSY searches optimised for massive neutralinos (RPC searches):
    - ★ High E_{T}^{miss} cut (∼150 GeV) and lower lepton pt cut (∼10 GeV)
  - Additional different cuts on N(jets), N(b-jets), H_{T}, etc...
- Signal regions:
  - CMS T5/3 employs incusive signal region
  - Other analyses use several SRs split in kinematic requirements
- More info in backup

Backgrounds

- True same-sign/three leptons:
  - From Standard Model
  - Dominant: $t\bar{t} + V$ and VV
  - Simulated using Monte Carlo
- Fake/non-prompt lepton:
  - Light jets reco-ed as leptons
  - Leptons coming from heavy-flavor jets
  - Data-driven
- Charge mis-identification:
  - Detector effects:
    - ★ Tracker charge reco efficiency
    - ★ Photon conversions
  - Negligible for muons
  - Data-driven

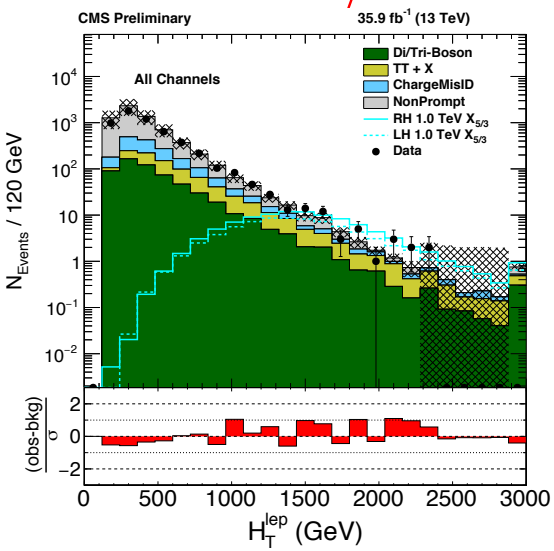




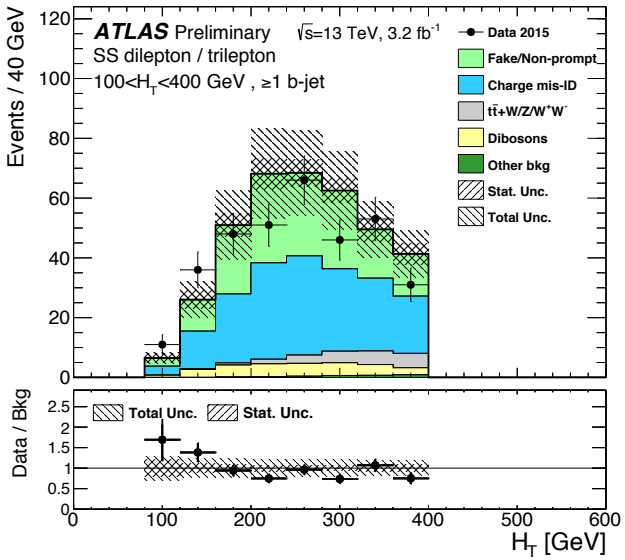


Control plots (preselection level)

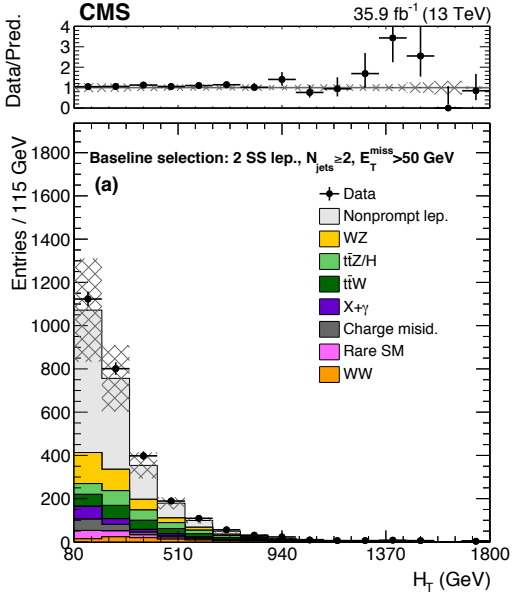
CMS T5/3



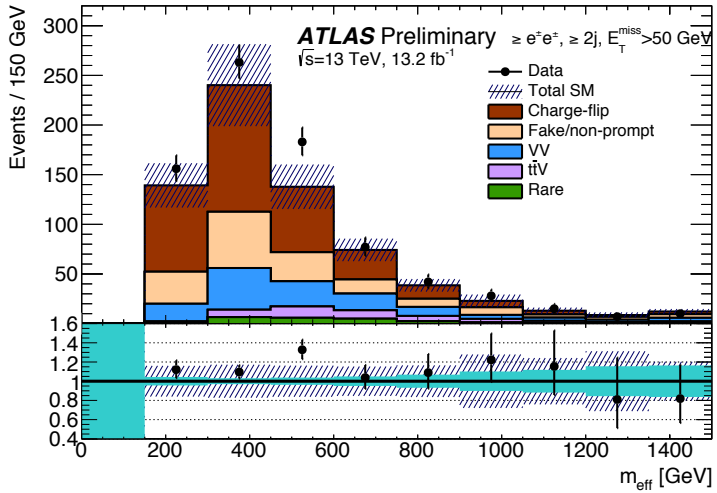
ATLAS VLQ/4tops



CMS SUSY

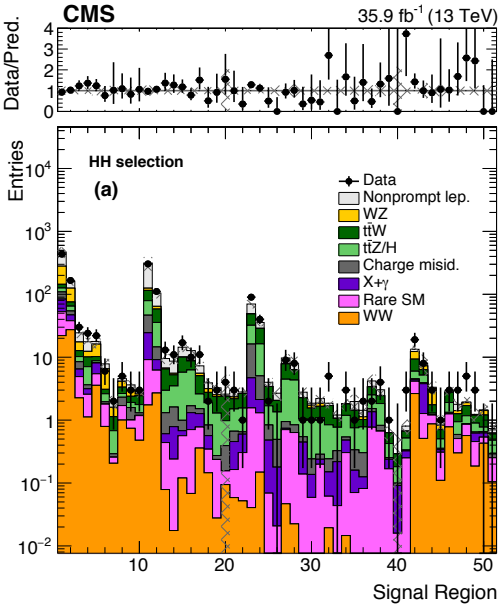


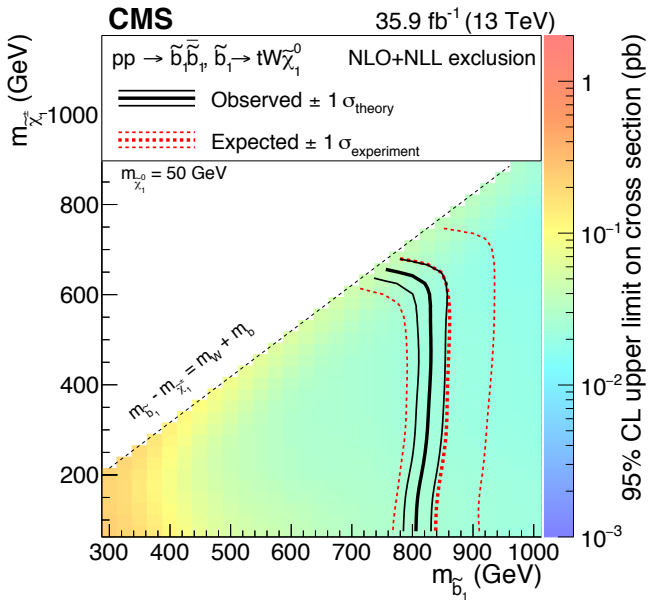
ATLAS SUSY

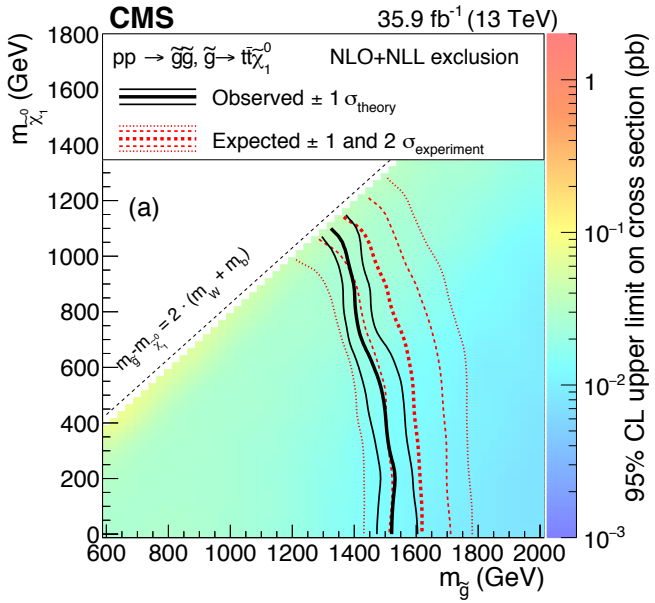


Results – SUSY

CMS SUSY

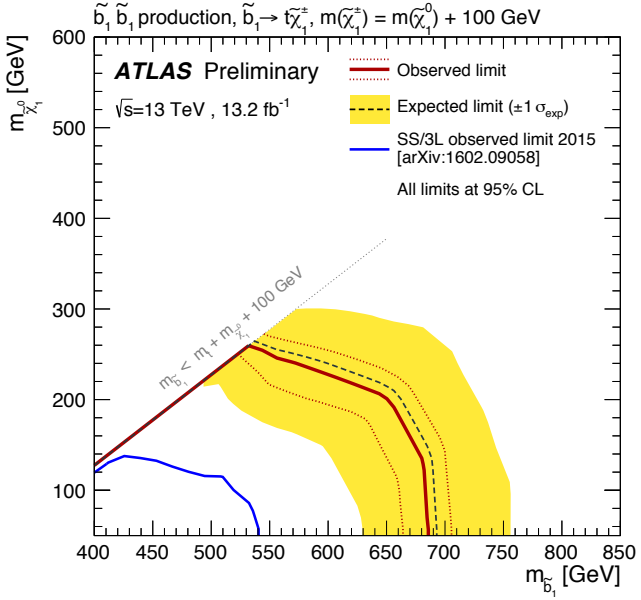


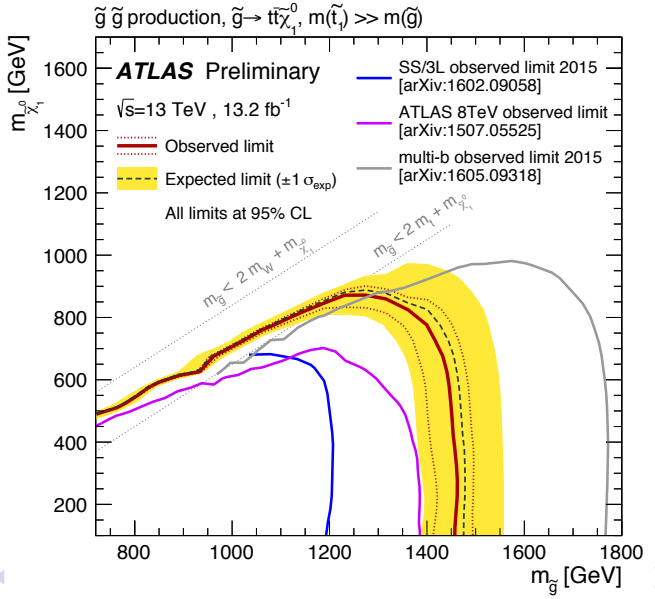




ATLAS SUSY

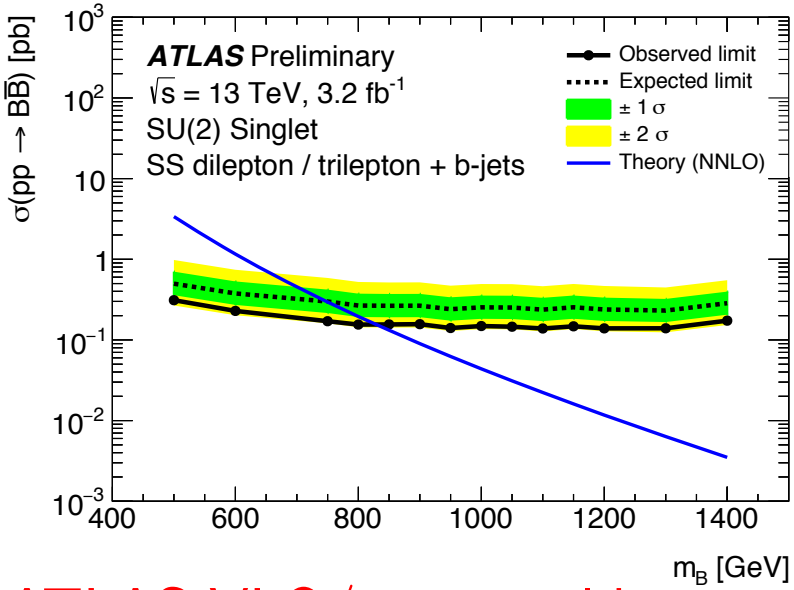
	SR3b
Observed	2
Total SM background	1.6 ± 0.6
$t\bar{t}Z$	0.19 ± 0.07
$t\bar{t}W$	0.17 ± 0.06
Diboson	< 0.1
Rare	0.89 ± 0.31
Fake/non-prompt leptons	0.2 ± 0.5
Charge-flip	0.14 ± 0.03

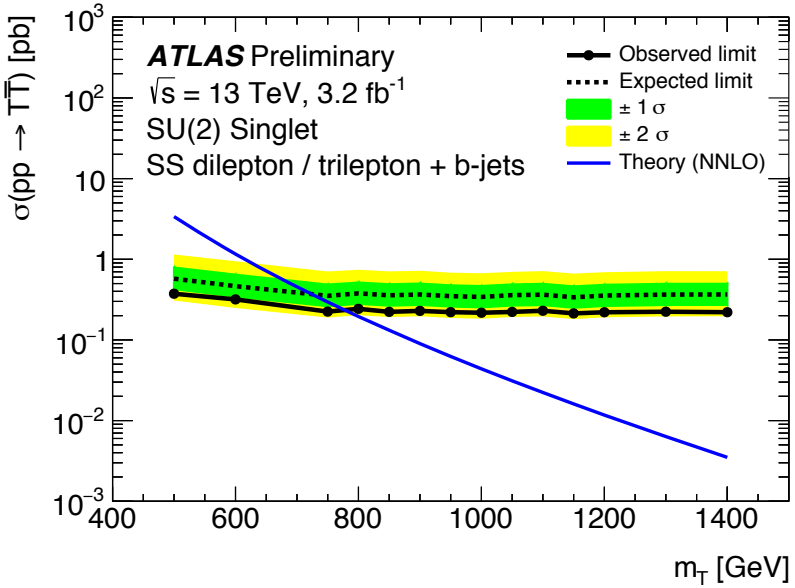




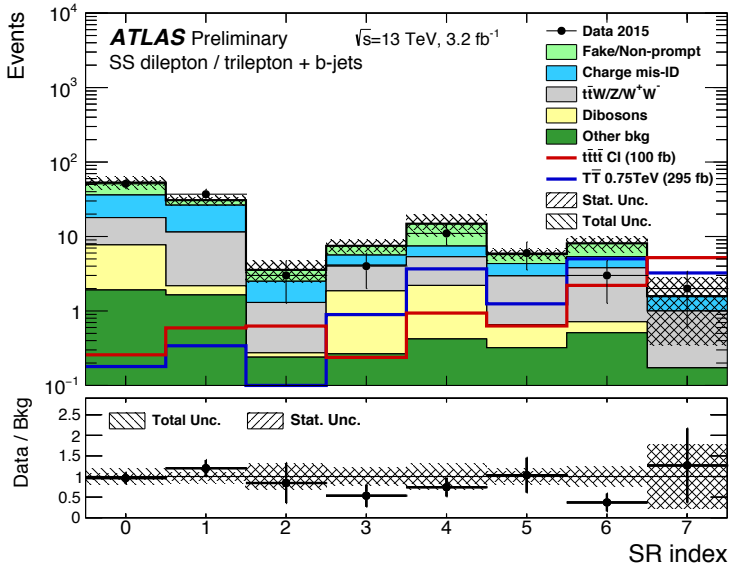
Results – $T\bar{T}/B\bar{B}$

ATLAS limits (mid-2016)





ATLAS VLQ/4tops yields



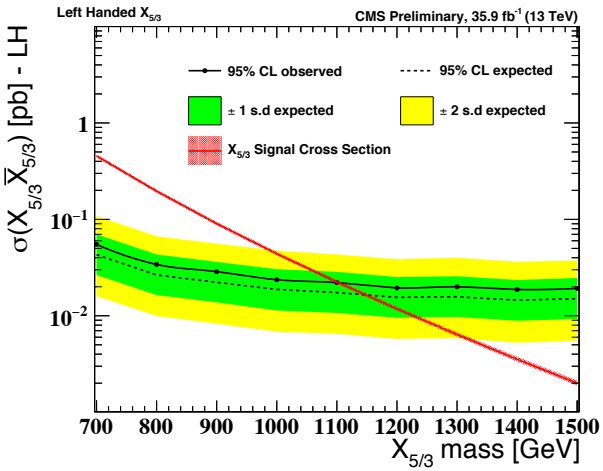
- Newest ATLAS 13 TeV results still converging
- No new CMS $T\bar{T}/B\bar{B}$ spotted

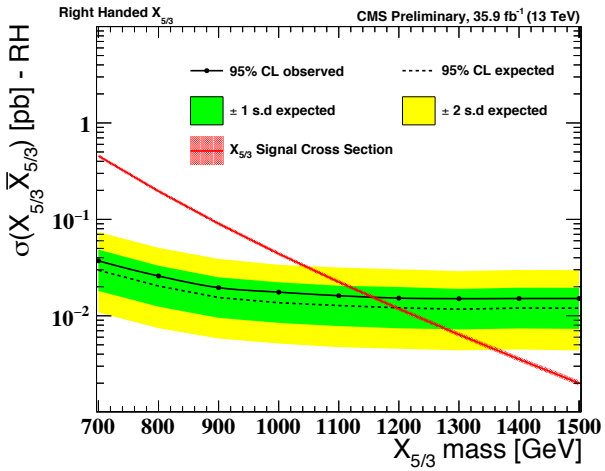
Results – $T_{5/3}\bar{T}_{5/3}$

CMS T5/3 yields

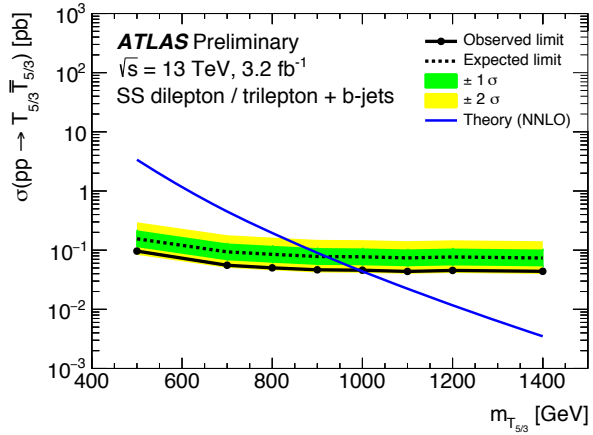
Channel	PSS MC	NonPrompt	ChargeMisID	Total Background	1000 GeV $X_{5/3}$	Observed
Di-electron	4.1 ± 0.6	3.5 ± 2.1	2.4 ± 0.8	10.0 ± 2.3	11.6	10
Electron-Muon	10.7 ± 1.4	8.5 ± 4.6	1.7 ± 0.5	20.9 ± 4.8	26.9	26
Di-muon	5.9 ± 0.8	3.8 ± 2.2	-	9.7 ± 2.4	16.1	12
All	20.7 ± 2.6	15.8 ± 8.2	4.1 ± 1.3	40.6 ± 8.7	54.6	48

CMS T5/3 new limits





ATLAS T5/3 (mid-2016)

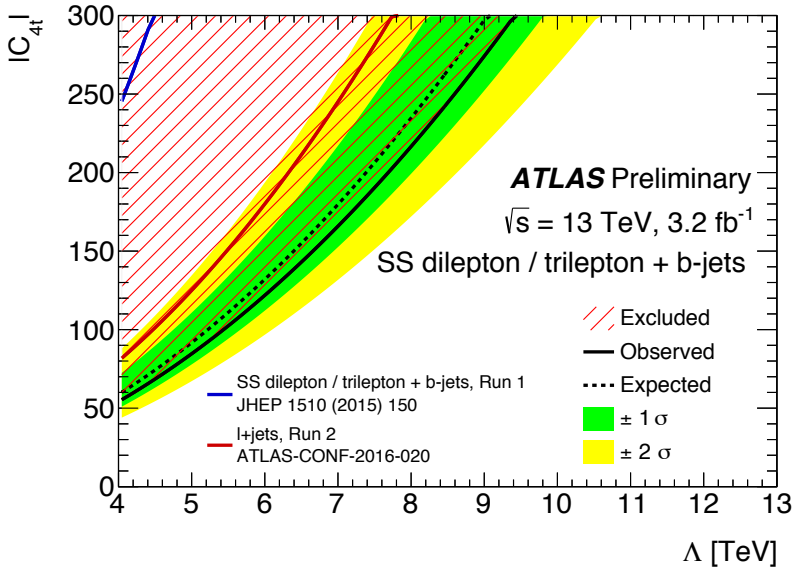


- CMS improved the previous 13 TeV result by impressive ~200 GeV

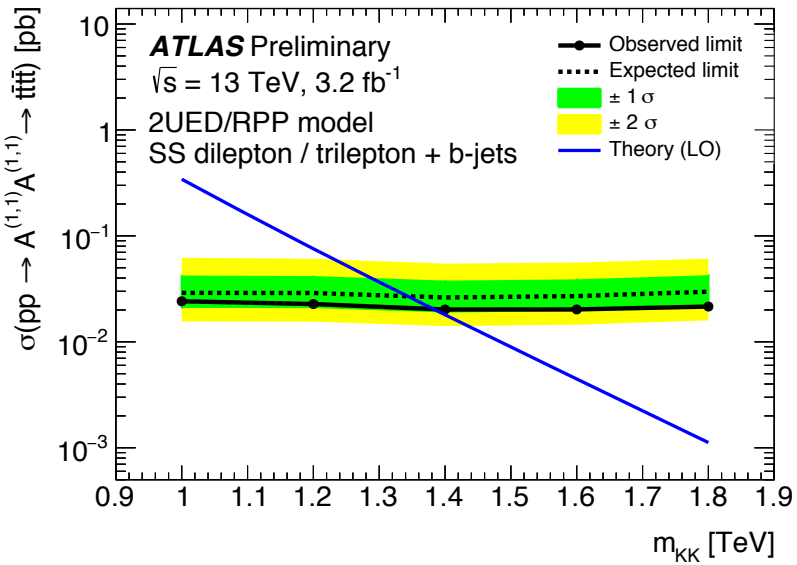
Results – 4 tops

ATLAS limits (mid-2016):

CI model



2UED/RPP model

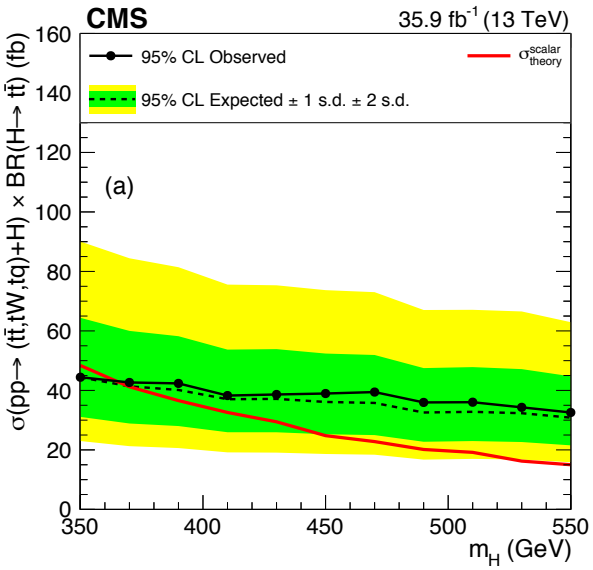


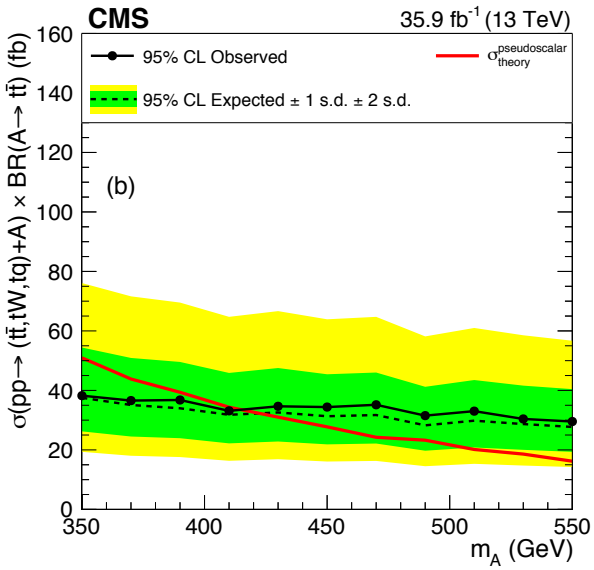
Assuming SM kinematics:

- Mid-2016 ATLAS limit on the 4-tops production: 95 fb (107 fb exp.)
- New CMS limit with 35.9 fb^{-1}: 42 fb (27 fb exp.)
- SM expectation: 9.1 fb

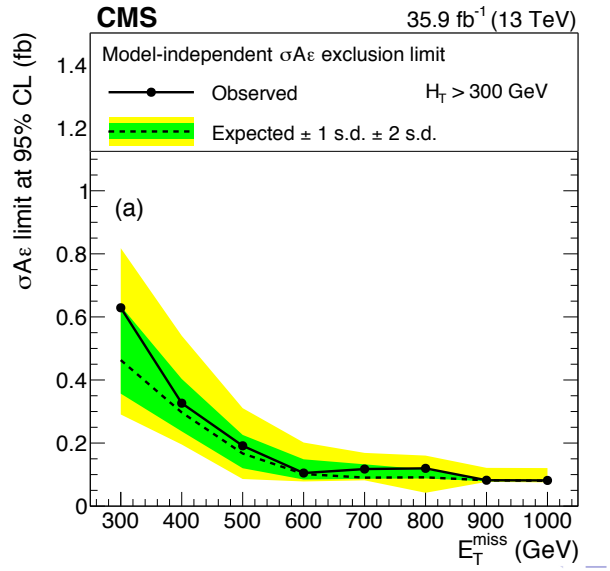
Results – additional CMS limits

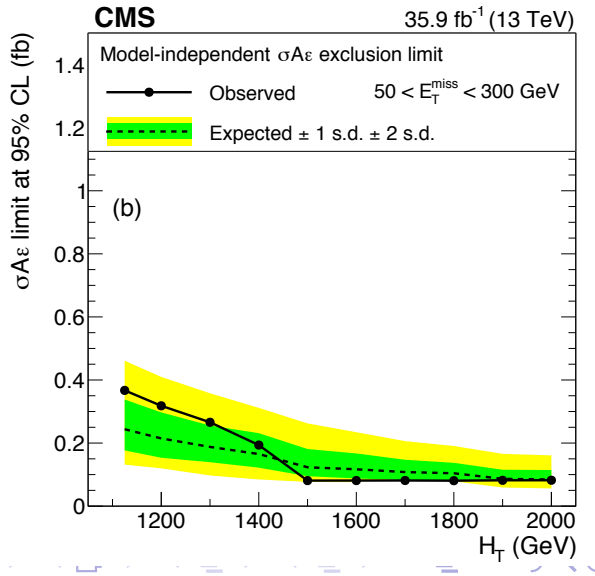
- New 2HDM Type-II:
  - 360 GeV (scalar) and 410 GeV (pseudoscalar)





- Model-independent:
  - 0.1 fb where no events are observed
  - Compared to 1.3 fb (previous result)





Summary

- Same-sign leptons is a promising signature involving many searches for new physics
- Each analysis is unique in defining selection strategy depending on the models covered
- Impressive limits set recently by CMS on $T_{5/3}\bar{T}_{5/3}$ and 4 tops production, as well as associated heavy (pseudo)scalar production (2HDM type-II) and model-independent limits
- Newest ATLAS results still converging... Stay tuned!

Backup

Selection – ATLAS VLQ/4tops

Preselection:

	Electrons	Muons	Jets
Trigger	1 electron, $p_T > 24$ GeV	1 isolated muon, $p_T > 20$ GeV or 1 muon, $p_T > 50$ GeV	
p_T	> 25 GeV	> 25 GeV	> 25 GeV
$\|\eta\|$	< 1.37 or $1.52 < \|\eta\| < 2.47$	< 2.5	< 2.5
Object ID	tight	medium	–
Vertex match	$\|d_0\|/\sigma(d_0) < 5$ $\|\Delta z_0 \sin\theta\| < 0.5$ mm	$\|d_0\|/\sigma(d_0) < 3$ $\|\Delta z_0 \sin\theta\| < 0.5$ mm	JVT requirement (if $\|\eta\| < 2.4$ and $p_T < 50$ GeV)
Isolation	track and calorimeter	track	–
Multiplicity	2 same-charge leptons or ≥ 3 leptons		–

Signal regions:

Definition			Name
$e^\pm e^\pm + e^\pm \mu^\pm + \mu^\pm \mu^\pm + eee + ee\mu + e\mu\mu + \mu\mu\mu$, $N_{\text{jets}} \geq 2$			
$400 < H_T < 700$ GeV	$N_b = 1$	$E_T^{\text{miss}} > 40$ GeV	SR0
	$N_b = 2$		SR1
	$N_b \geq 3$		SR2
$H_T \geq 700$ GeV	$N_b = 1$	$40 < E_T^{\text{miss}} < 100$ GeV	SR3
		$E_T^{\text{miss}} \geq 100$ GeV	SR4
	$N_b = 2$	$40 < E_T^{\text{miss}} < 100$ GeV	SR5
		$E_T^{\text{miss}} \geq 100$ GeV	SR6
	$N_b \geq 3$	$E_T^{\text{miss}} > 40$ GeV	SR7

Selection – ATLAS SUSY

Validation regions:

	$N_{\text{lept}}^{\text{signal}}$ ($N_{\text{lept}}^{\text{cand}}$)	$N_{b-\text{jets}}^{20}$	N_{jets}^{25}	$E_{\text{T}}^{\text{miss}}$ [GeV]	m_{eff} [GeV]	Other
VR-$W^{\pm}W^{\pm}jj$	= 2 (= 2) = 1 SS pair	= 0	≥ 2	> 50	> 500	$m(j_1 j_2) > 500$ GeV $p_{\text{T}}(j_2) > 40$ GeV $p_{\text{T}}(\ell_2) > 25$ GeV $m_T > 40$ GeV veto $80 < m_{ee} < 100$ GeV
VR-WZ4j	= 3 (= 3)	= 0	≥ 4	> 20	> 300	$m_{\ell\ell\ell} > 100$ GeV
VR-$t\bar{t}W$	= 2 (-) = 1 SS pair	≥ 1	≥ 4 ($e^{\pm}\mu^{\pm}$) ≥ 3 ($\mu^{\pm}\mu^{\pm}$)	> 50	> 550	$p_{\text{T}}(\ell_2) > 30$ GeV veto $e^{\pm}e^{\pm}$ pairs
VR-$t\bar{t}Z$	≥ 3 (-) ≥ 1 SFOS pair	≥ 1	≥ 3	> 20	-	$p_{\text{T}}(\ell_2) > 25$ GeV $80 < m_{\text{SFOS}} < 100$ GeV
All VRs	Veto events belonging to any SR, or if ℓ_1 or ℓ_2 is an electron with $\lvert\eta\rvert > 1.37$ (except in VR-WZ4j and VR-$t\bar{t}Z$)					

Signal regions:

Signal region	$N_{\text{lept}}^{\text{signal}}$	$N_{b-\text{jets}}^{20}$	N_{jets}	$p_{\text{T,jets}}$ [GeV]	$E_{\text{T}}^{\text{miss}}$ [GeV]	m_{eff} [GeV]	Other
SR3L1	≥ 3	= 0	≥ 4	40	> 150	-	-
SR3L2	≥ 3	= 0	≥ 4	40	> 200	> 1500	-
SR0b1	≥ 2	= 0	≥ 6	25	> 150	> 500	-
SR0b2	≥ 2	= 0	≥ 6	40	> 150	> 900	-
SR1b	≥ 2	≥ 1	≥ 6	25	> 200	> 650	-
SR3b	≥ 2	≥ 3	≥ 6	25	> 150	> 600	-
SR1b-DD	≥ 2	≥ 1	≥ 4	50	-	> 1200	≥ 2 negatively-charged leptons
SR3b-DD	≥ 2	≥ 3	≥ 4	50	-	> 1000	≥ 2 negatively-charged leptons
SR1b-GG	≥ 2	≥ 1	≥ 6	50	-	> 1800	-

Selection – CMS SUSY

Table 2: Signal region definitions for the HH selection. Regions split by charge are indicated with (++) and (--).

N_b	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	SR46 (++) / SR47 (--)	SR48 (++) / SR49 (--)	SR50 (++) / SR51 (--)
			≥ 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			
			≥ 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			
			≥ 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	SR35 (++) / SR36 (--)	SR37 (++) / SR38 (--)			
		$200 - 300$			SR39			
	> 120	$50 - 300$	≥ 2	SR40	SR41			
inclusive	inclusive	$300 - 500$	≥ 2	-	SR42 (++) / SR43 (--)			
		> 500		-	SR44 (++) / SR45 (--)			

Table 3: Signal region definitions for the HL selection. Regions split by charge are indicated with (++) and (--).

N_b	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	SR38 (++) / SR39 (--)	SR40 (++) / SR41 (--)
			≥ 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 (++) / SR15 (--)		
			≥ 5		SR16 (++) / SR17 (--)		
2	< 120	$50 - 200$	2-4	SR18	SR19		
			≥ 5	SR20 (++) / SR21 (--)	SR22 (++) / SR23 (--)		
		$200 - 300$	2-4		SR24 (++) / SR25 (--)		
			≥ 5		SR26		
≥ 3	< 120	$50 - 200$	≥ 2	SR27 (++) / SR28 (--)	SR29 (++) / SR30 (--)		
		$200 - 300$			SR31		
inclusive	> 120	$50 - 300$	≥ 2	SR32	SR33		
inclusive	inclusive	$300 - 500$	≥ 2	-	SR34 (++) / SR35 (--)		
		> 500		-	SR36 (++) / SR37 (--)		

Table 4: Signal region definitions for the LL selection. All SRs in this category require $N_{jets} \geq 2$.

N_b	m_T^{min} (GeV)	H_T (GeV)	$E_T^{miss} \in [50, 200]$ GeV	$E_T^{miss} > 200$ GeV
0	< 120	> 300	SR1	SR2
1			SR3	SR4
2			SR5	SR6
≥ 3			SR7	
Inclusive	> 120		SR8	

Selection – CMS $T_{5/3}$

- Quarkonia veto: require invariant dilepton mass ($M_{\ell\ell}$) > 20 GeV
- Associated Z boson veto: ignore any event where $M_{\ell\ell'}$ is within 15 GeV of the mass of the Z boson, where ℓ is either lepton in the same-sign pair, and ℓ' is any lepton not in the same-sign pair, but with the same flavor as ℓ.
- Primary Z boson veto: require $M_{\ell\ell} > 106.1$ GeV or $M_{\ell\ell} < 76.1$ GeV for the dielectron channel only. If the muon charge is mismeasured, its momentum will also be mismeasured so a selected muon pair from a Z boson is unlikely to fall within this invariant mass range.
- Number of constituents ≥ 5.
- $H_{\mathrm{T}}^{\mathrm{lep}} > 1200\,\mathrm{GeV}$

The "number of constituents" is defined as the number of AK4 jets in the event passing our jet selection together with the number of other leptons (i.e. not in the same-sign pair) passing our tight selection. The $H_{\mathrm{T}}^{\mathrm{lep}}$ used in this analysis is the scalar sum of the p_{T} of all selected jets and tight leptons in the event.