



Top quarks in SUSY searches, status



TOP2016, Olomouc, CR, September 19-23

**Anna Lipniacka, University of Bergen
on behalf of
ATLAS & CMS**

Top quark in SUSY searches with ATLAS and CMS

SUSY, do we need you ?

Top and SUSY, special relation?

The Data and Search Techniques.

Top as a signal:
third Sfamily direct
and in gluino decays

Top as a background

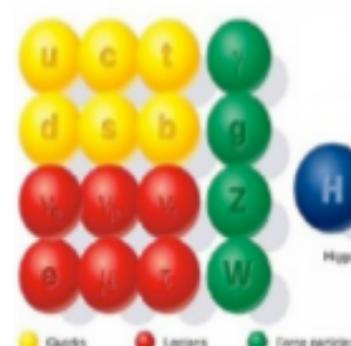
Results and prospects

*There are therefore Agents in Nature
able to make the Particles of Bodies
stick together by very strong
Attractions. And it is the business of
experimental Philosophy to find them
out.*

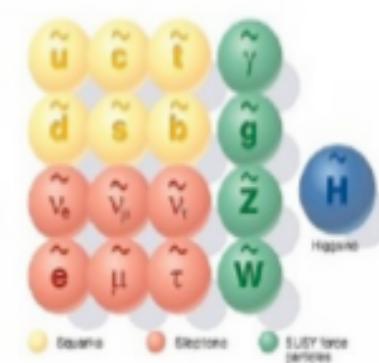
Newton, Principia

Symmetry between
“Agents in Nature” and
“Particles of Bodies”

SUPERSYMMETRY



Standard particles



SUSY particles



The MSSM

Particles in Minimal SUSY

One fermionic/bosonic partner to the SM fermions/bosons
with SM coupling

particle	spin	I	sparticle	spin	name
$l = e, \mu, \tau, \nu$	1/2		\tilde{l}_R, \tilde{l}_L	0	slepton
$q = u, d, s, c, b, t$	1/2		\tilde{q}_R, \tilde{q}_L	0	squark
g	1		\tilde{g}	1/2	gluino
γ	1		$\tilde{\gamma}$	1/2	photino
W^\pm	1		\tilde{W}^\pm	1/2	wino
Z	1		\tilde{Z}	1/2	zino
H_1^0, H_2^0	0		$\tilde{H}_1^0, \tilde{H}_2^0$	1/2	higgsino
H^\pm	0		\tilde{H}^\pm	1/2	higgsino

$$R \text{ parity}, R = -1^{2J+3B+L}, R = -1 \text{ for Sparticles}, R = 1 \text{ for particles}$$

Gauge Eigenstates

$$\tilde{W}^\pm, \tilde{H}^\pm, \tilde{B}, \tilde{W}^0, \tilde{H}_1^0, \tilde{H}_2^0$$

Mass Eigenstates

$$\begin{aligned} &\leftrightarrow \tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm && \text{(Charginos)} \\ &\leftrightarrow \tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0 && \text{(Neutralinos)} \end{aligned}$$

Fermion Eigenstates

$$\tilde{t}_R, \tilde{t}_L, \tilde{b}_R, \tilde{b}_L, \tilde{\tau}_R, \tilde{\tau}_L$$

Mass Eigenstates

$$\begin{aligned} &\leftrightarrow \tilde{t}_1, \tilde{t}_2 && \text{(stop)} \\ &\leftrightarrow \tilde{b}_1, \tilde{b}_2 && \text{(sbottom)} \\ &\leftrightarrow \tilde{\tau}_1, \tilde{\tau}_2 && \text{(stau)} \end{aligned}$$

$$\tan \beta = v_2/v_1$$

Slide 3 If R-parity conserved, LSP is a Dark Matter candidate. RPC results in this talk



Is SUSY still relevant?

Pre-LHC-8 motivations for supersymmetry

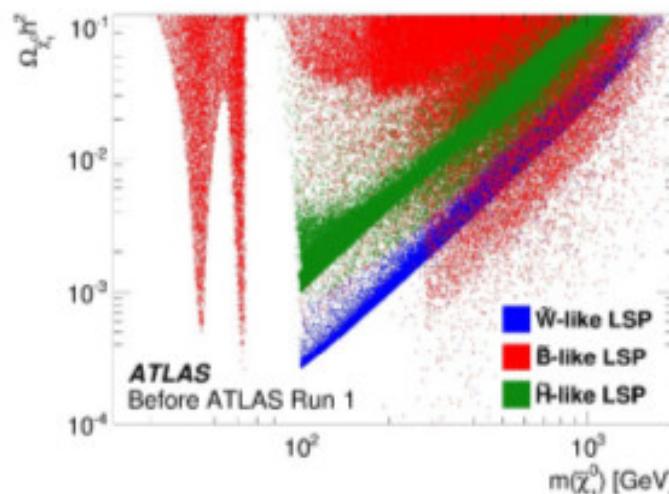
- Solves hierarchy problem
- Provides dark matter candidate
- Helps with gauge coupling unification
- Is an essential ingredient of superstring theory

Post-LHC-8 hangover

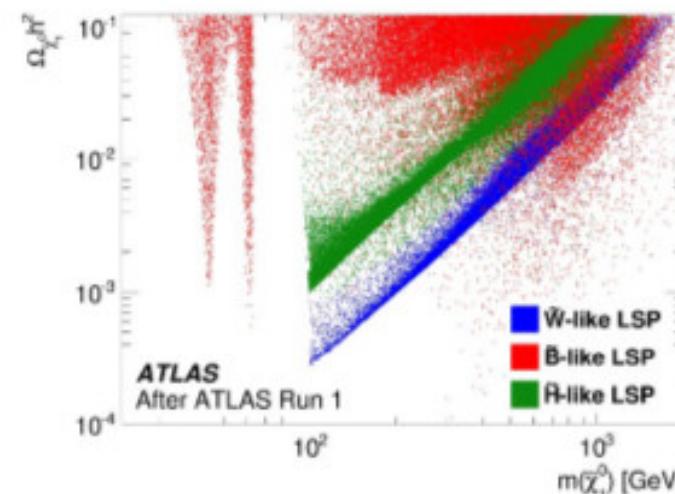
<https://arxiv.org/pdf/1512.07761v2.pdf>

- 
- Solves hierarchy problem ✗
 - Provides dark matter candidate ✗
 - Helps with gauge coupling unification ✗
 - Is an essential ingredient of superstring theory ✓

JHEP10(2015) 134, “Summary of ATLAS experiment sensitivity to supersymmetry..”



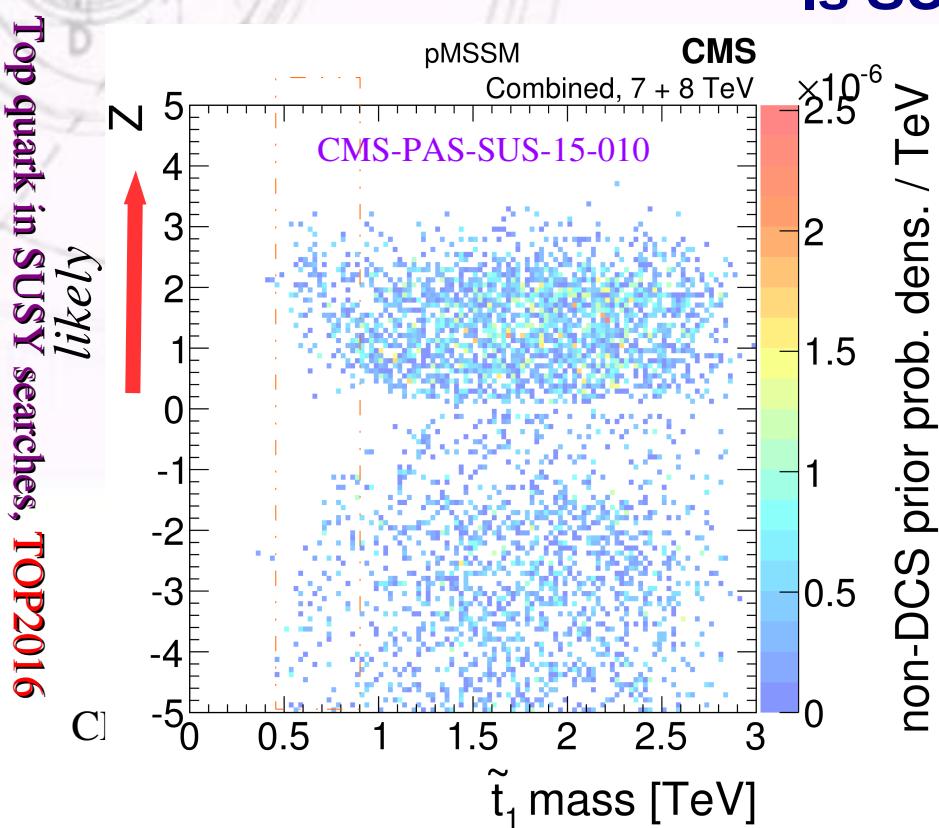
(a) Before ATLAS Run 1.



(b) After ATLAS Run 1.

Fooled by simplified model results? LHC Run 1 hardly makes a dent in interesting pMSSM Dark Matter space.

Is SUSY still relevant?



*Fooled by simplified
model results? 500 GeV
Stop and 1 TeV gluino
still well and alive in
pMSSM after Run 1.
Higgs mass prefers 3
TeV gluino.*

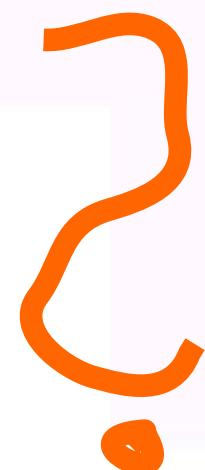
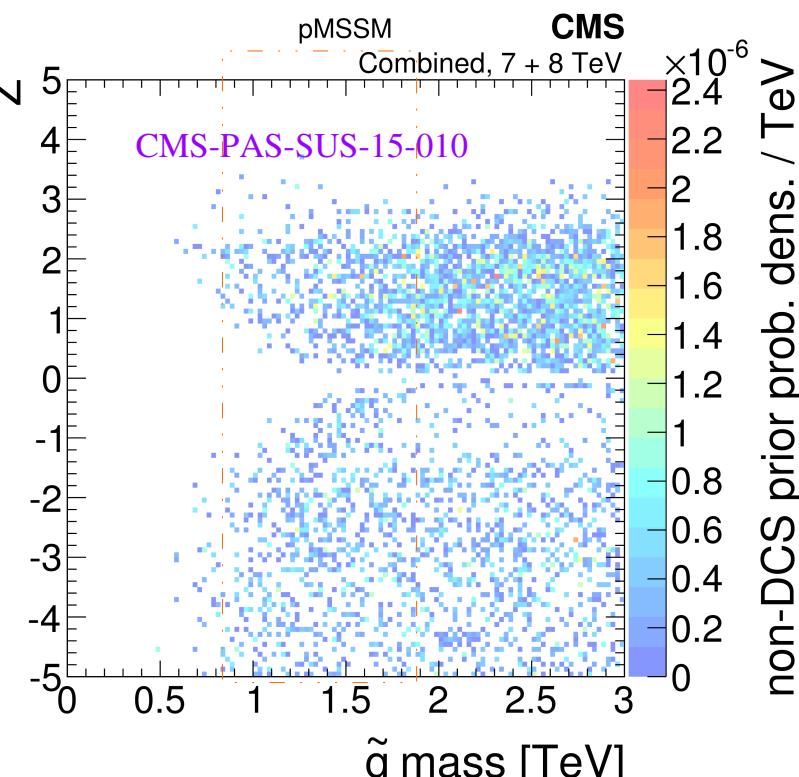
Slide 5

likely

Post-LHC-8 hangover

<https://arxiv.org/pdf/1512.07761v2.pdf>

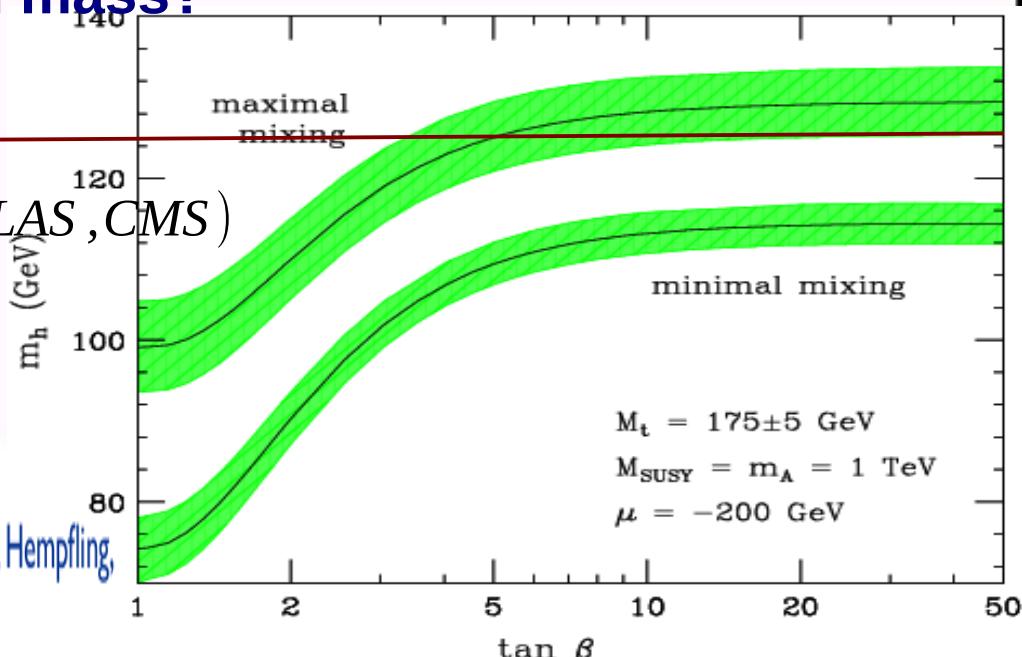
- Solves hierarchy problem ✗
- Provides dark matter candidate ✗
- Helps with gauge coupling unification ✗
- Is an essential ingredient of superstring theory ✓



SUSY and top relation? What is the reason for the Higgs boson mass?

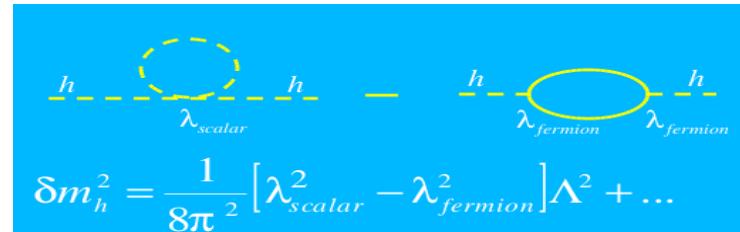
$M_h = 125.09 \pm 0.21 (\text{stat}) \pm 0.11 (\text{syst}) \text{ GeV (ATLAS, CMS)}$
Phys. Rev. Lett. 114, 191803 (2015)

Long list of two-loop computations: Carena, Degrassi, Ellis, Espinosa, Haber, Harlander, Heinemeyer, Hempfling, Hoang, Hollik, Hahn, Martin, Pilaftsis, Quiros, Ridolfi, Rzehak, Slavich, C.W., Weiglein, Zhang, Zwirner



There are 5 Higgs bosons in the Minimal Supersymmetric SM, the lightest one is lighter than ~130 GeV Its mass related mostly to stop squark mass (M_l , M_r) and mixing X_t

$$\Delta m_h^2 \approx \frac{3m_t^4}{2\pi^2 v^2} \ln \frac{M_s^2}{m_t^2} + \frac{3m_t^4}{2\pi^2 v} \left[\frac{X_t^2}{M_s^2} - \frac{X_t^4}{12M_s^4} \right]$$



Golfand, Likhtman, JETP Lett. 1971
 Volkov, Akulov, Phys Lett. B, 1973
 Wess, Zumino, Nucl. Phys. B, Phys. Lett. B, 1974

In SUSY, the mass correction proportional to SUSY breaking.



Is there a stop around the corner? Large Xt could make the stop the lightest squark.

Top



The Higgs boson mass is mass related mostly to stop squark mass and mixing Xt

$$\Delta m_h^2 \approx \frac{3m_t^4}{2\pi^2 v^2} \ln \frac{M_S^2}{m_t^2} + \frac{3m_t^4}{2\pi^2 v} \left[\frac{X_t^2}{M_S^2} - \frac{X_t^4}{12M_S^4} \right]$$

$$M_t^2 = \begin{pmatrix} m_Q^2 + m_t^2 + D_L & m_t X_t \\ m_t X_t & m_U^2 + m_t^2 + D_R \end{pmatrix} \quad \left. \right\}$$

$$X_t = A_t - \mu \cot \beta$$

$$\sim t_L, \sim t_R \rightarrow \sim t_1, \sim t_2$$

Large Xt favors a light stop state (stop 1). This “promotes” gluino decays via stop, and “top”- rich final states, mediated by $\text{stop} \rightarrow \text{LSP} + \text{top}$

SUSY with TOP-quark final states and search techniques

A gallery of topologies with high-medium transverse momentum “objects” and missing LSP.

SEARCH STRATEGY ORIENTED TOWARDS FINAL STATE TOPOLOGIES

- CHARACTERIZED by “object multiplicity” :
- “tagged top”, “tagged W”,
- leptons, b-jets, jets
- missing transverse energy.

** Each topology is interpreted in search for SEVERAL SUSY final states.**

Smart and sophisticated kinematic variables aiming at :

- a) finding the top quark: “topness “, “fat jet mass” , “top tag”
- b) distinguishing between the tails of the SM distributions and candidates for SUSY events

missing transverse energy (MET), effective mass (MEFF), scalar sum of jets pTs (HT), transverse mass (MT) , various variants of “stransverse mass” (MT2), aiming at rejecting ttbar, single top, Z+jets, W+jets. “Razor variables” to indentify “heavy pairs”, $\alpha_T = E_T^{j_2}/M_T$,

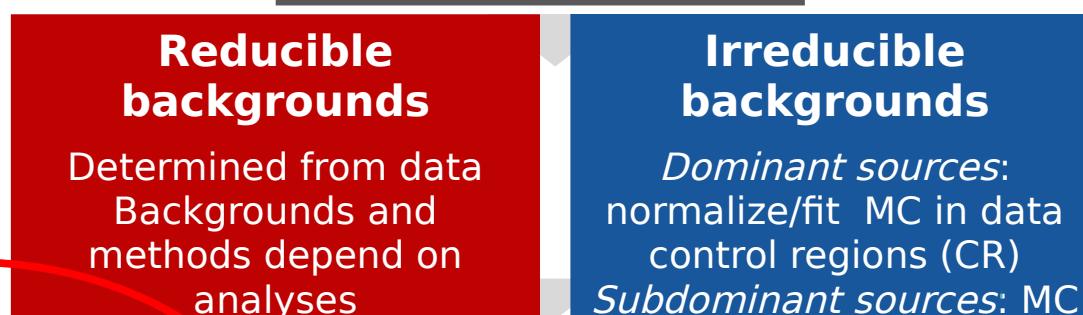
Different techniques targeting different “mass degeneracy” -> “sparticle-LSP” mass difference, for example use of ISR jets.



SUSY search techniques, background control

Good control of backgrounds, typically measured in kinematic “Control Regions” (CR), verified in “Validation Regions” (VR) and “propagated” to the Signal Regions (SR) with simulations.

Likelihood fits to SR/CR takes into account possible signal contamination in CR.



Examples

Z → neutrinos rescaled from photon+jet CR

Charge flip rate measured in Z events

Use “ABCD method” (not always applicable)

Validation

Validation regions used to cross check SM predictions with data

blinded

Example

$$N_{CR1}^{DATA} = SF_{TOP} \times N1_{TOP}^{MC} + SF_{Wjets} \times N1_{Wjets}^{MC} + SF_{Zjets} \times N1_{Zjets}^{MC}$$

$$N_{CR2}^{DATA} = SF_{TOP} \times N2_{TOP}^{MC} + SF_{Wjets} \times N2_{Wjets}^{MC} + SF_{Zjets} \times N2_{Zjets}^{MC}$$

$$N_{CR3}^{DATA} = SF_{TOP} \times N3_{TOP}^{MC} + SF_{Wjets} \times N3_{Wjets}^{MC} + SF_{Zjets} \times N3_{Zjets}^{MC}$$

blinded

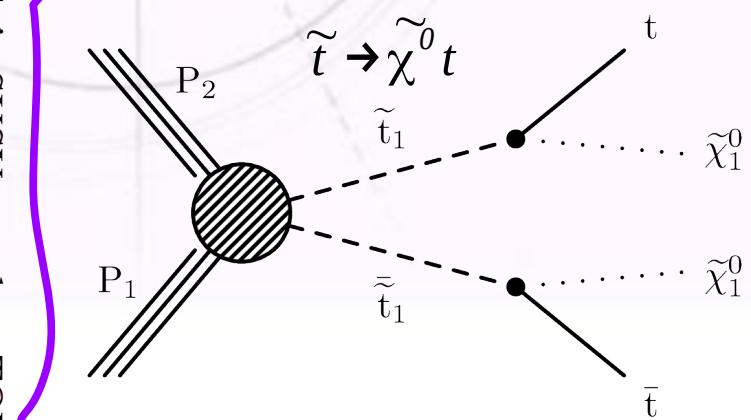
Signal regions (SR)

$$N_{pred}^{signal} = \left(\frac{N_{MC}^{signal}}{N_{MC}^{control}} \right) \times N_{obs}^{control}$$

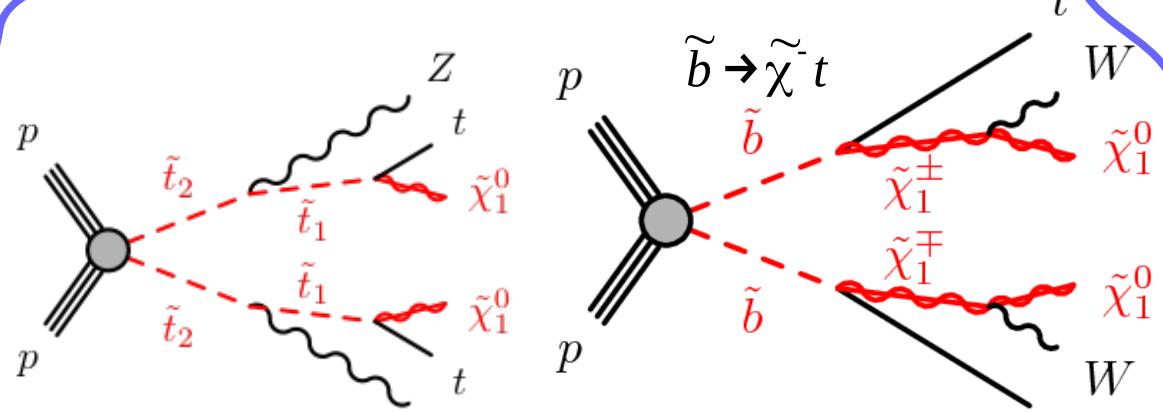
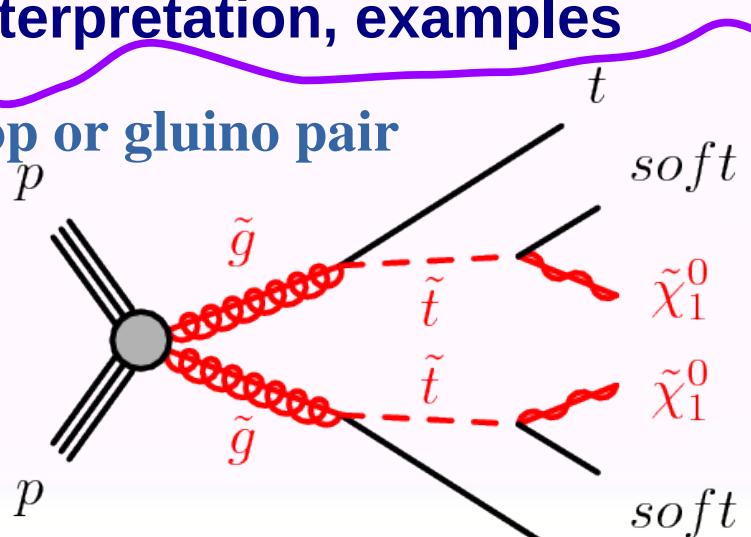
*Solve for DATA/MC Scaling Factors (SF)
Or simultaneous fit to all CR*



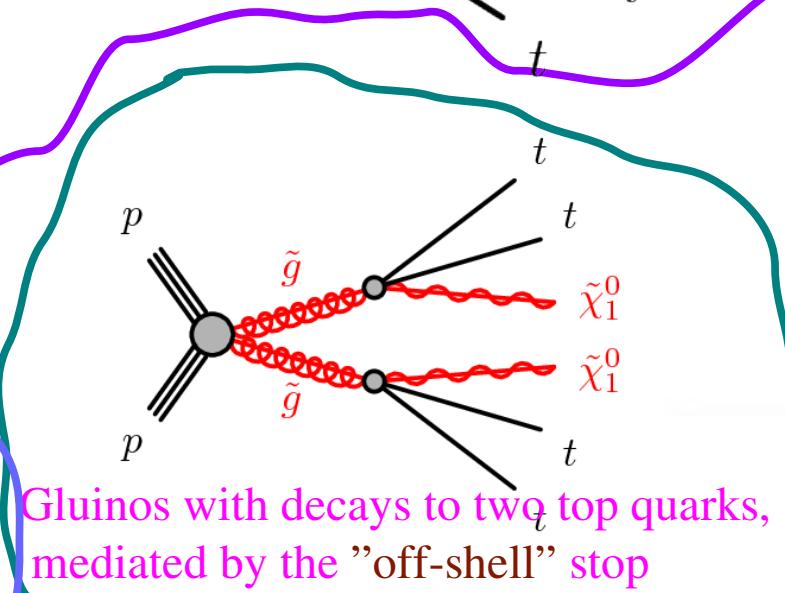
SUSY final states for results interpretation, examples



Topologies with ttbar from stop or gluino pair



Ttbar with extra Z -boson. Production of heavy stops- or sbottom quarks..



Gluinos with decays to two top quarks, mediated by the "off-shell" stop

Tagging the top. “Topness” and “boosted top mass”

“Modified topness” used in 1-lepton topo, CMS-SUS-16-028

$$t_{\text{mod}} = \ln(\min S) \text{ with } S(\vec{p}_W, p_{v,z}) = \frac{(m_W^2 - (p_v + p_\ell)^2)^2}{a_W^4} + \frac{(m_t^2 - (p_b + p_W)^2)^2}{a_t^4}.$$

Example Resolution parameters, 5 GeV, 15 GeV

CMS top tagging (CTT) Top tagging in “all-hadronic topologies”:

HPTT (High Purity Top Tagging) : Boosted top candidates, $R=0.8$ ($\text{pt}>400 \text{ GeV}$) reclustered to at least 3 sub-jets, high invariant mass

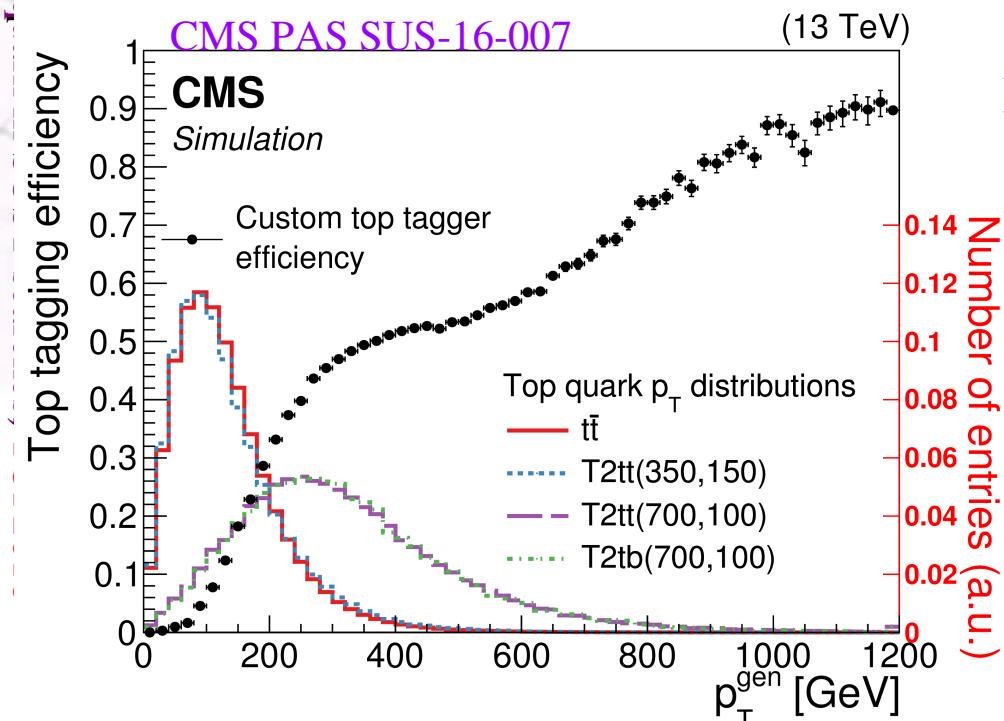


HETT (High Efficiency TT) : Testing various combinations of $R=0.4$ jets for high mass CMS PAS SUS-16-007:

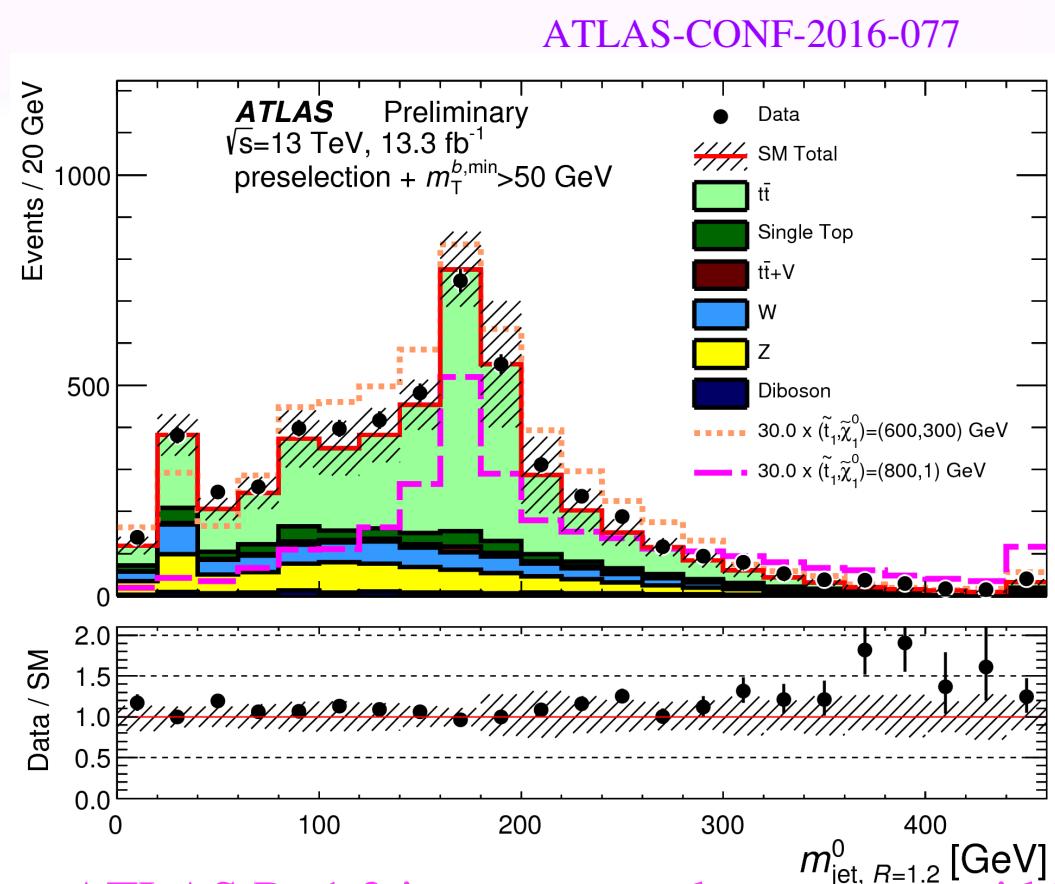
ATLAS “all hadronic” top tagging, mass of the reclustered $R=1.2$ jet



Tagging the top



CMS custom top tagger optimized for high pt top

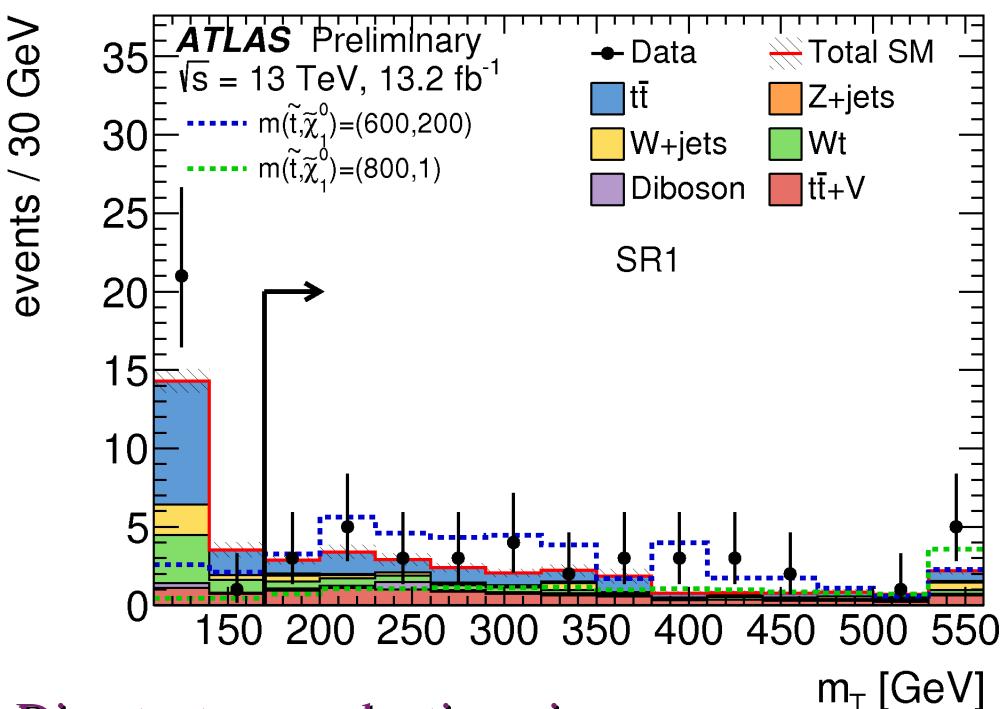


ATLAS R=1.2 jet mass, good agreement within relatively large systematics



SUSY search, rejecting ttbar, kinematic variables, examples

Transverse mass of the lepton and the missing transverse momentum has an “end-point” for leptons and neutrinos from V-bosons decays.



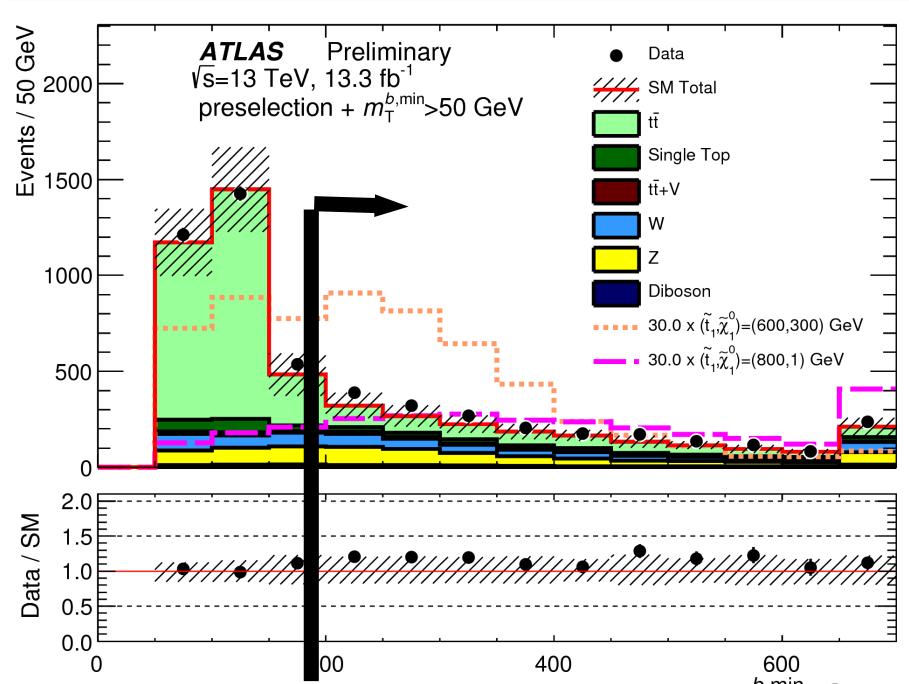
Direct stop production, in one lepton topology

$$m_T = \sqrt{2 \left(|\vec{p}_T^{\text{miss}}| |\vec{p}_T^l| - \vec{p}_T^{\text{miss}} \cdot \vec{p}_T^l \right)},$$

ATLAS-CONF-2016-050

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Transverse mass of the b-jet and the missing transverse momentum has an “end-point” at the top mass for ttbar.



Direct stop production, all had final state

$$m_T^{b,\text{min}} = \sqrt{2 p_T^b E_T^{\text{miss}} \left[1 - \cos \Delta\phi (\mathbf{p}_T^b, \mathbf{p}_T^{\text{miss}}) \right]}$$

ATLAS-CONF-2016-077



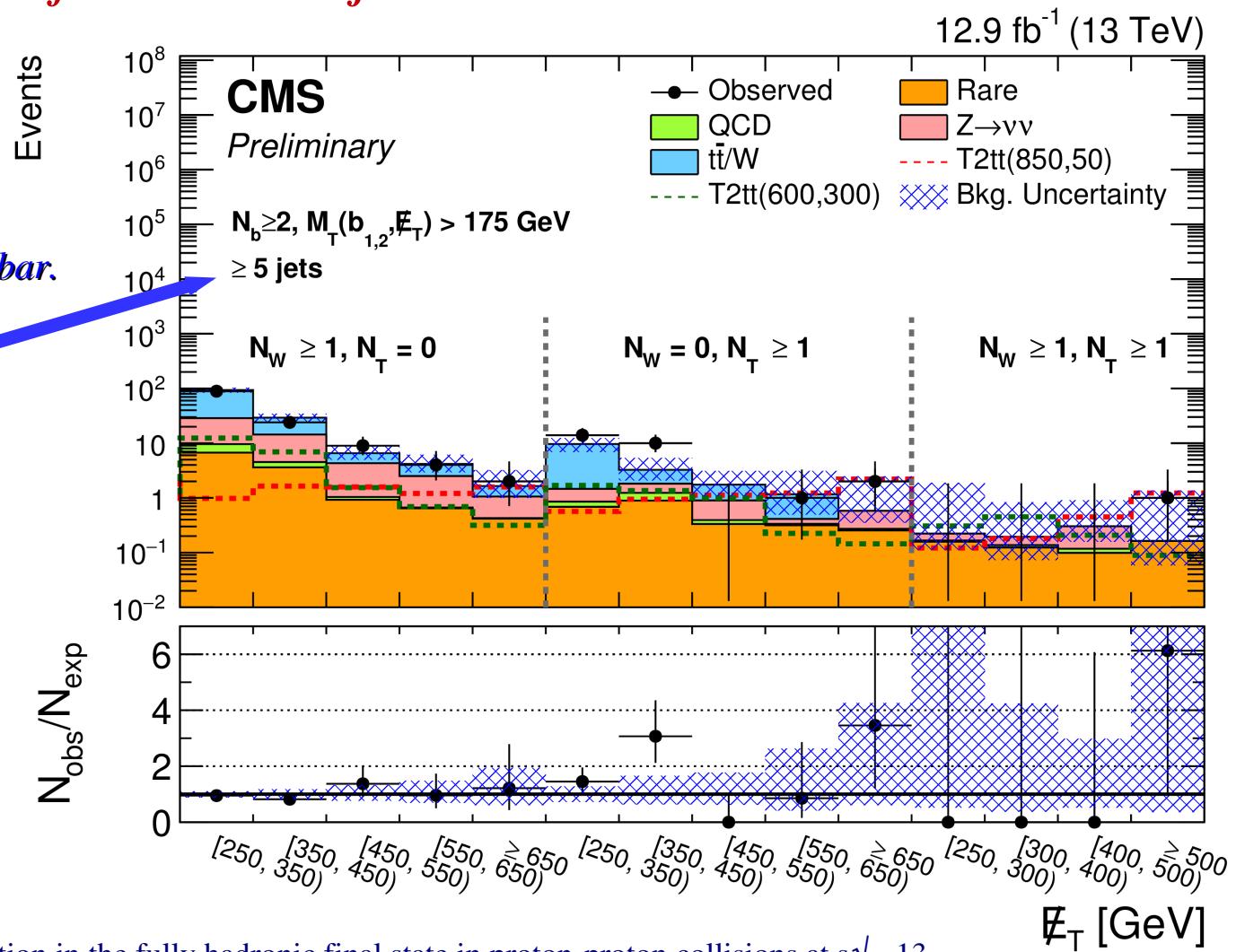
Searching for ttbar+ neutralinos, MET and transverse mass

Missing transverse energy(MET): vector sum of transverse momenta of all visible “objects”. Main tool for the ttbar rejection.

Events with one “tagged top and/or tagged W”. Large transverse mass between any b-jet and MET rejects ttbar.

$$M_T(p_t, E_T^{\text{miss}}) = \sqrt{2 p_T E_T^{\text{miss}} (1 - \cos \Delta\Phi)}$$

Signal from 600 (850)GeV stop pair decaying to top and 300 (50) GeV neutralino



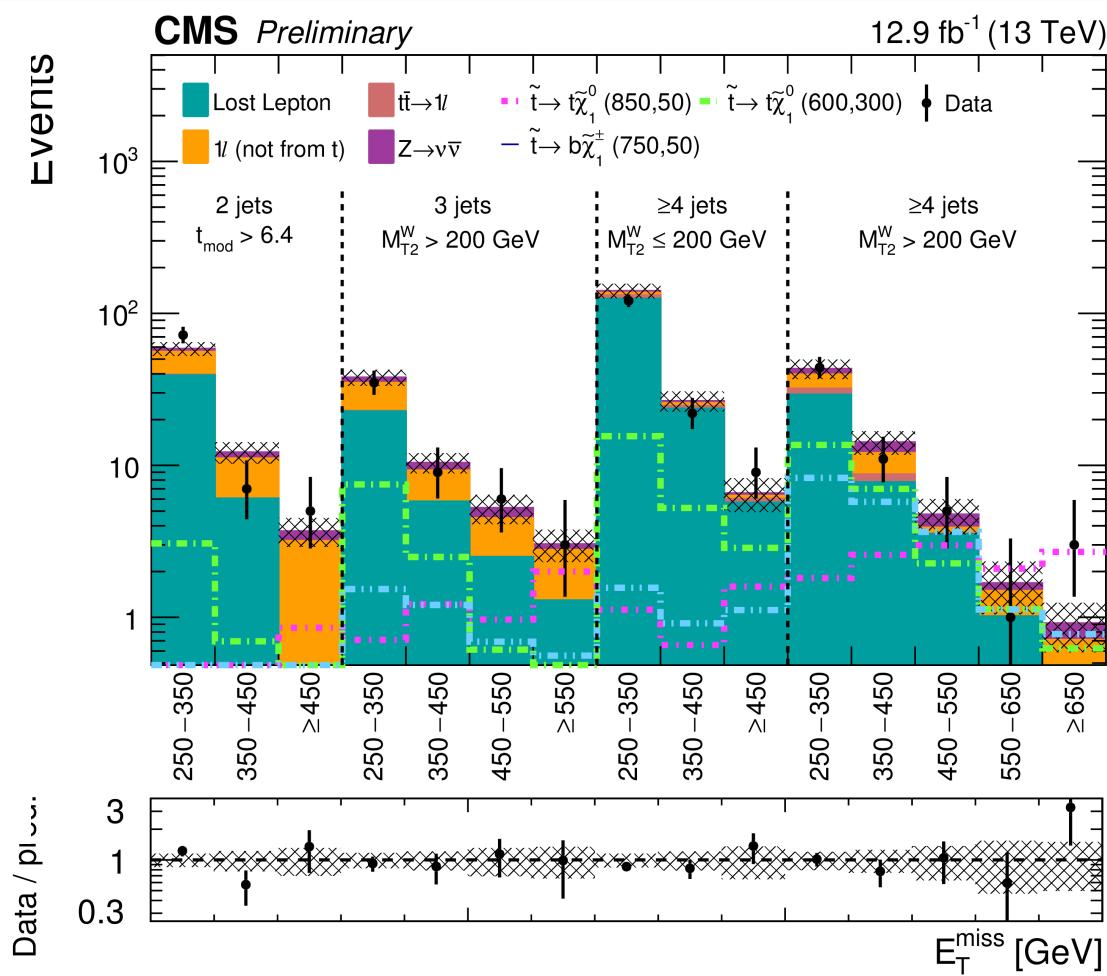
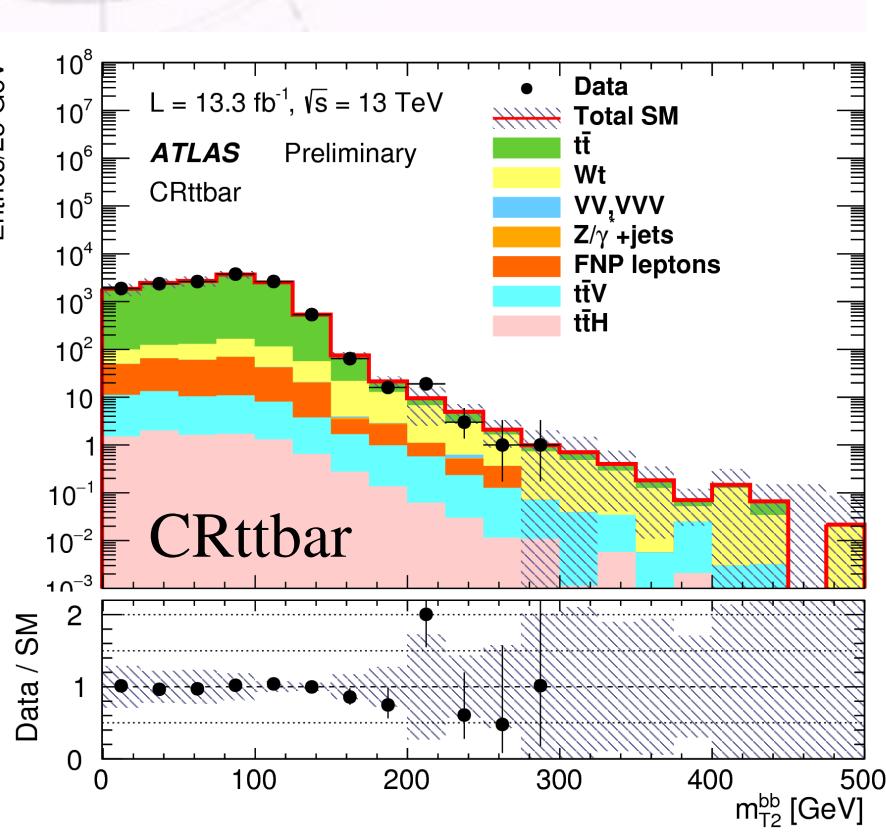
Search for direct top squark pair production in the fully hadronic final state in proton-proton collisions at $s\sqrt{s} = 13$ TeV corresponding to an integrated luminosity of 12.9 fb^{-1} , CMS-PAS-SUS-16-029



Rejecting ttbar, variants of “transverse mass” mt2

“Stranverse mass”: $m_{T2}(\mathbf{p}_{T,1}, \mathbf{p}_{T,2}, \mathbf{q}_T) = \min_{\mathbf{q}_{T,1} + \mathbf{q}_{T,2} = \mathbf{q}_T} \{\max[m_T(\mathbf{p}_{T,1}, \mathbf{q}_{T,1}), m_T(\mathbf{p}_{T,2}, \mathbf{q}_{T,2})]\}$

Decomposing the missing transverse momentum qT between the 2 objects of interest ($pT1, pT2$) and checking the larger transverse mass. Finding the minimum as a function of this decomposition.



Direct stop in 2 leptons final state, Mt2 with b-jets

ATLAS-CONF-2016-076

Direct stop production, single lepton, Mt2 with b-jets CMS-PAS-SUS-16-028



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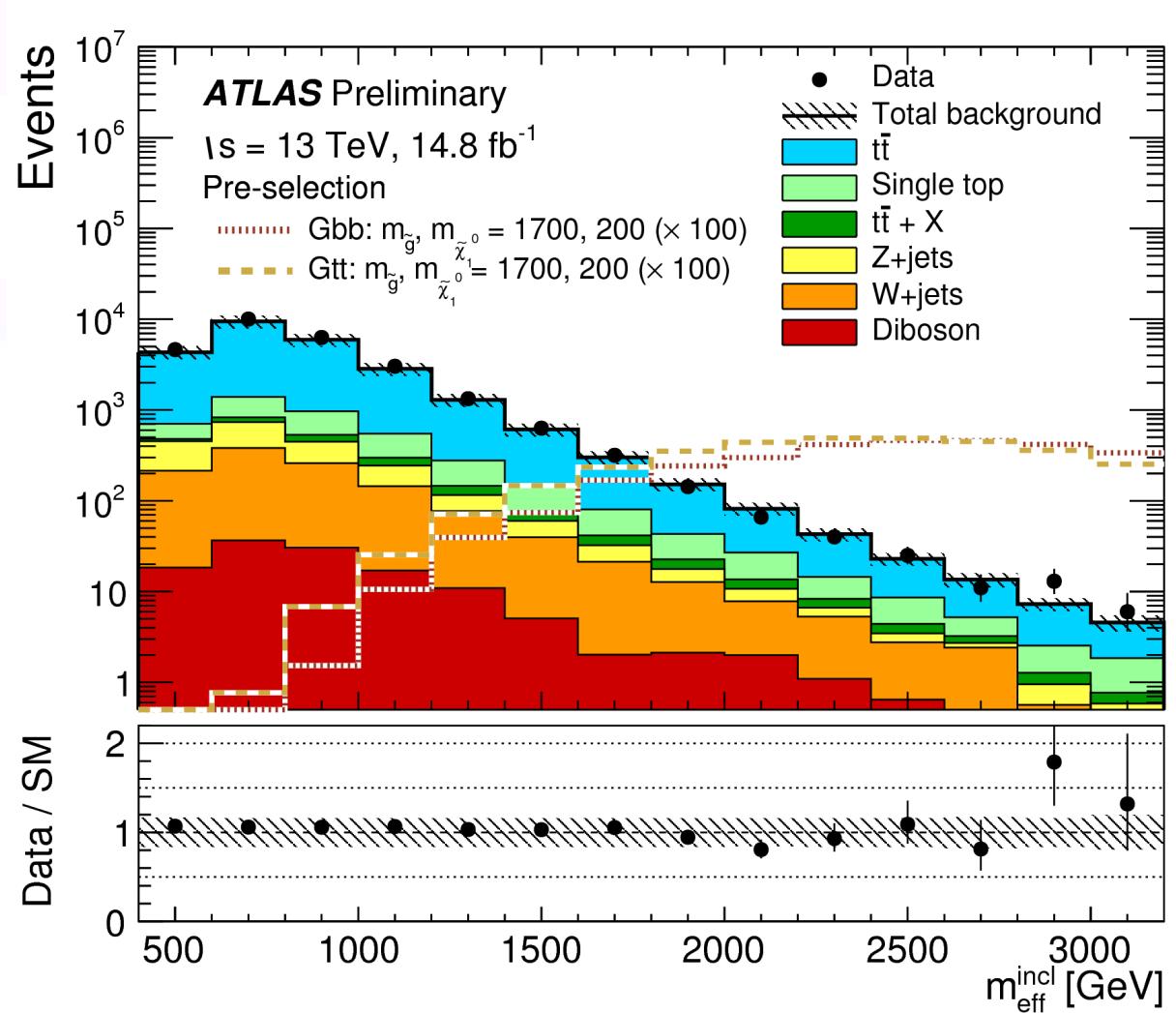
Effective mass (M_{eff}):

$$m_{\text{eff}} = \sum_i (p_T^{\text{jet}})_i + E_T^{\text{miss}} + \sum_j (p_T^{\text{lep}})_j$$

Shown after preselection .
 Typical signal region
 selection: 1500-2000 GeV
 Up to 4 top quark
 topologies, searches for
 more than 3 b jets, 0-1
 lepton.

Rejecting ttbar, effective mass

ATLAS-CONF-2016-052



Search for pair production of gluinos decaying via top or bottom squarks in events with b-jets and large missing transverse momentum in pp collisions at $\sqrt{s}=13$ TeV with the ATLAS detector .

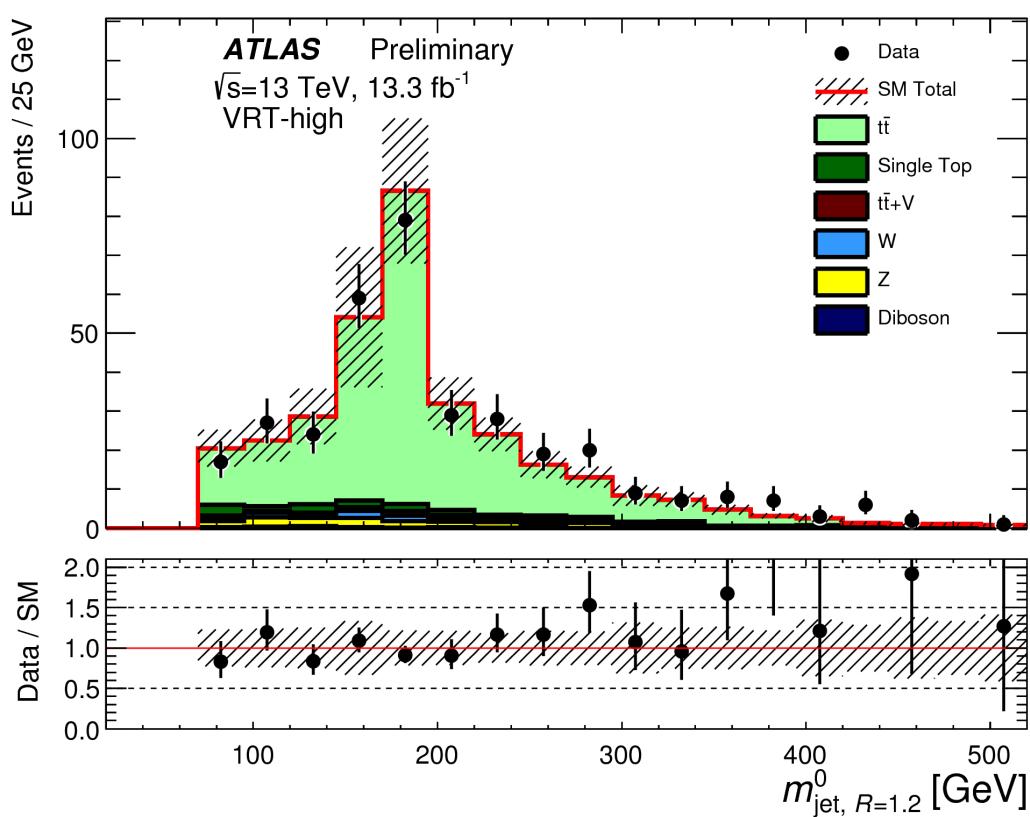
ATLAS-CONF-2016-052



CR+VR: What have we learned about ttbar ?

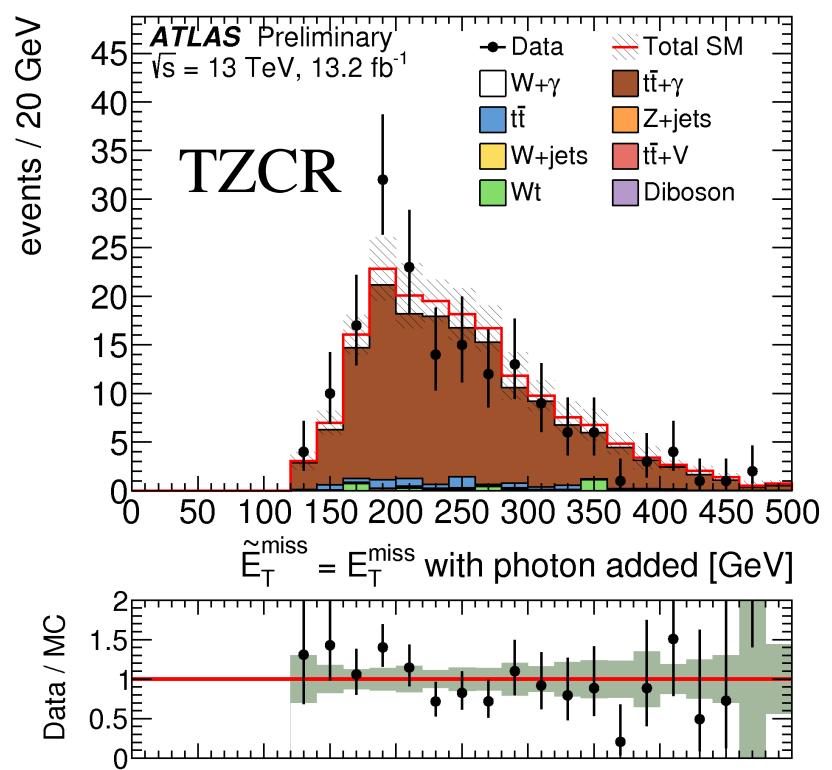
Top VR, MC fitted in CR

ATLAS-CONF-2016-077



Top+Z(gamma) CR

ATLAS-CONF-2016-050

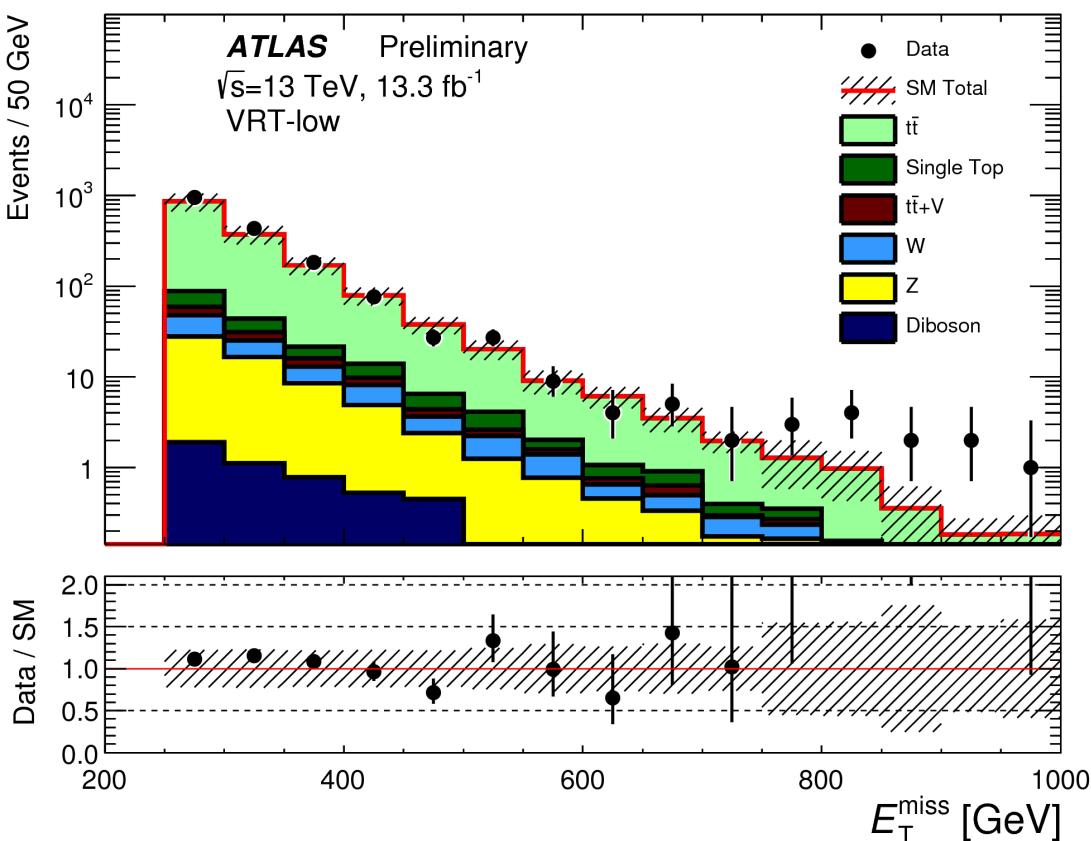


*Agreement in the “bulk” within relatively large systematics.
Uncertain in the tails.*

VR: What have we learned about ttbar and single top?

Top quark in SUSY searches, TOP2016

ATLAS-CONF-2016-077



Agreement in the “bulk” within relatively large systematics.
Uncertain in the tails. (This is NOT the signal region)

Top VR, MC fitted in CR

VRT-low		
Observed	1735	
Total SM	1564	± 350
$t\bar{t}$	1379	± 330
$W + \text{jets}$	40	± 10
$Z + \text{jets}$	58	± 17
$t\bar{t}+W/Z$	22.9 ± 3.0	
Single top	57	± 24
Dibosons	5.1 ± 1.1	
Multijets	$1.0^{+2.1}_{-1.0}$	



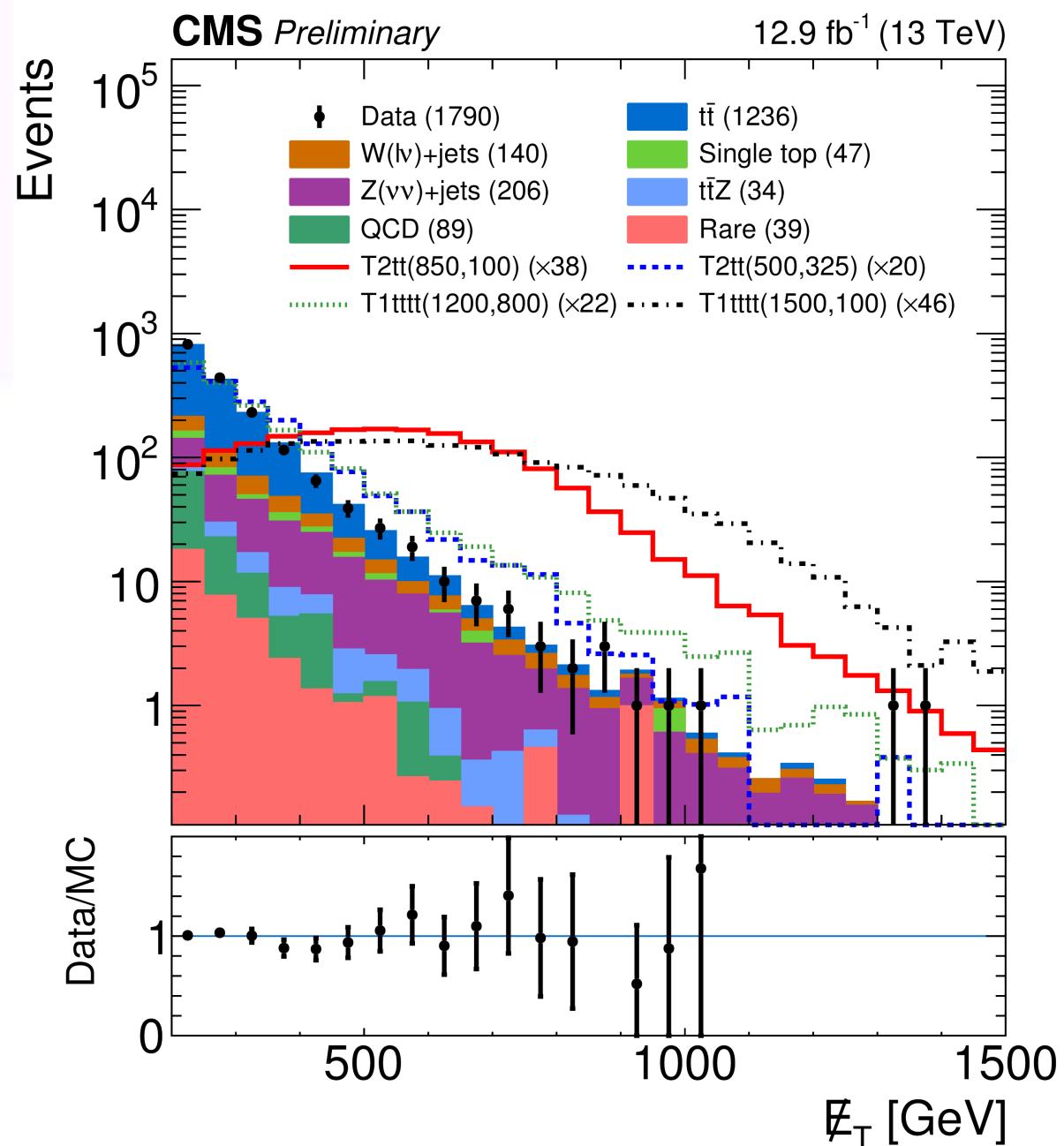
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What have we learned about ttbar and single top?

CMS PAS SUS-16-030

*Signal preselection
in all-hadronic final
state with top
tagging.* Ttbar
background
dominated by
semileptonic ttbar
with a lost lepton. At
high missing Et
substantial Z → nu nu
contribution.



Results, model exclusions

Excluded regions of SUSY parameter space presented in:

- 1) *Gluino vs LSP mass planes. Gluino decays mediated by off-shell or on-shell stop.
Different final state topologies
(simplified models with BR fixed)*

- 2) *Stop vs LSP mass plane, different final states.
(simplified models with BR fixed)*

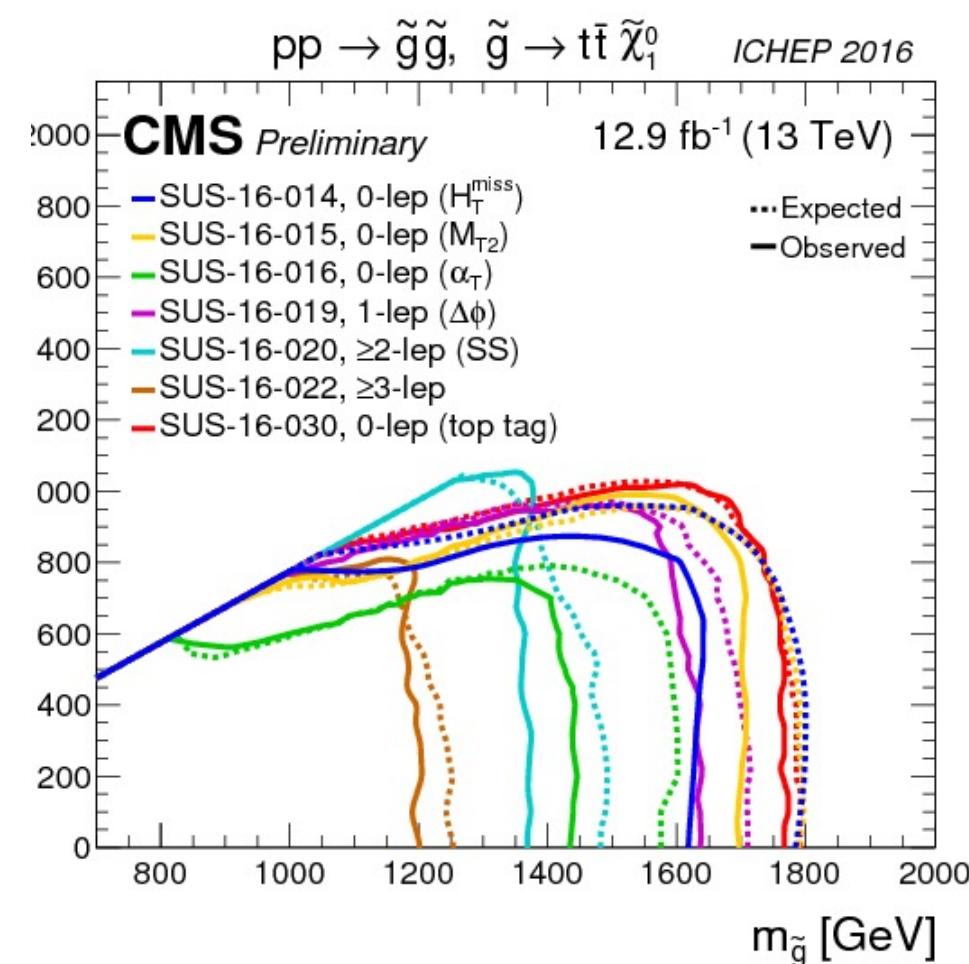
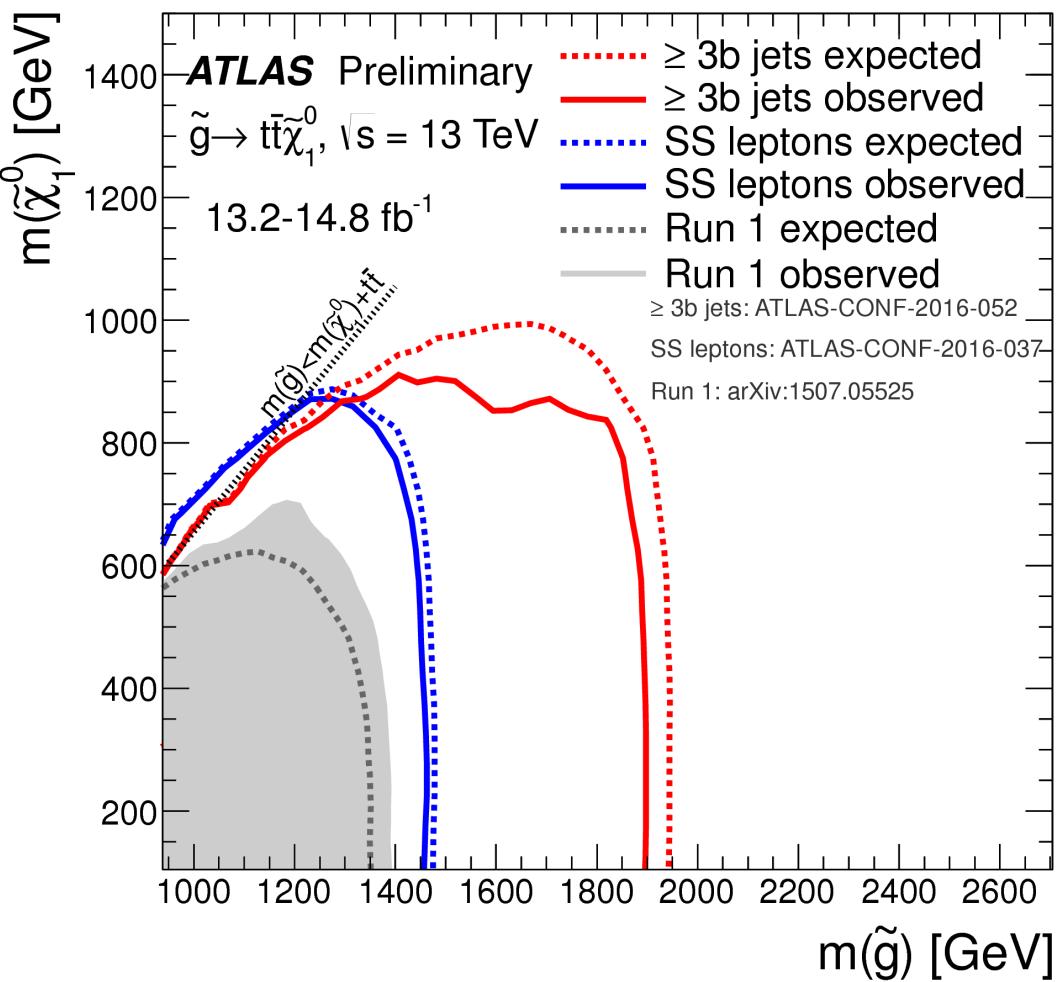
In the following a series of excluded regions...



Results, gluino decays with tops in the final states

Gluinos decaying via off-shell stops heavier than 1.8-2 TeV for the LSP lighter than ~0.4 TeV

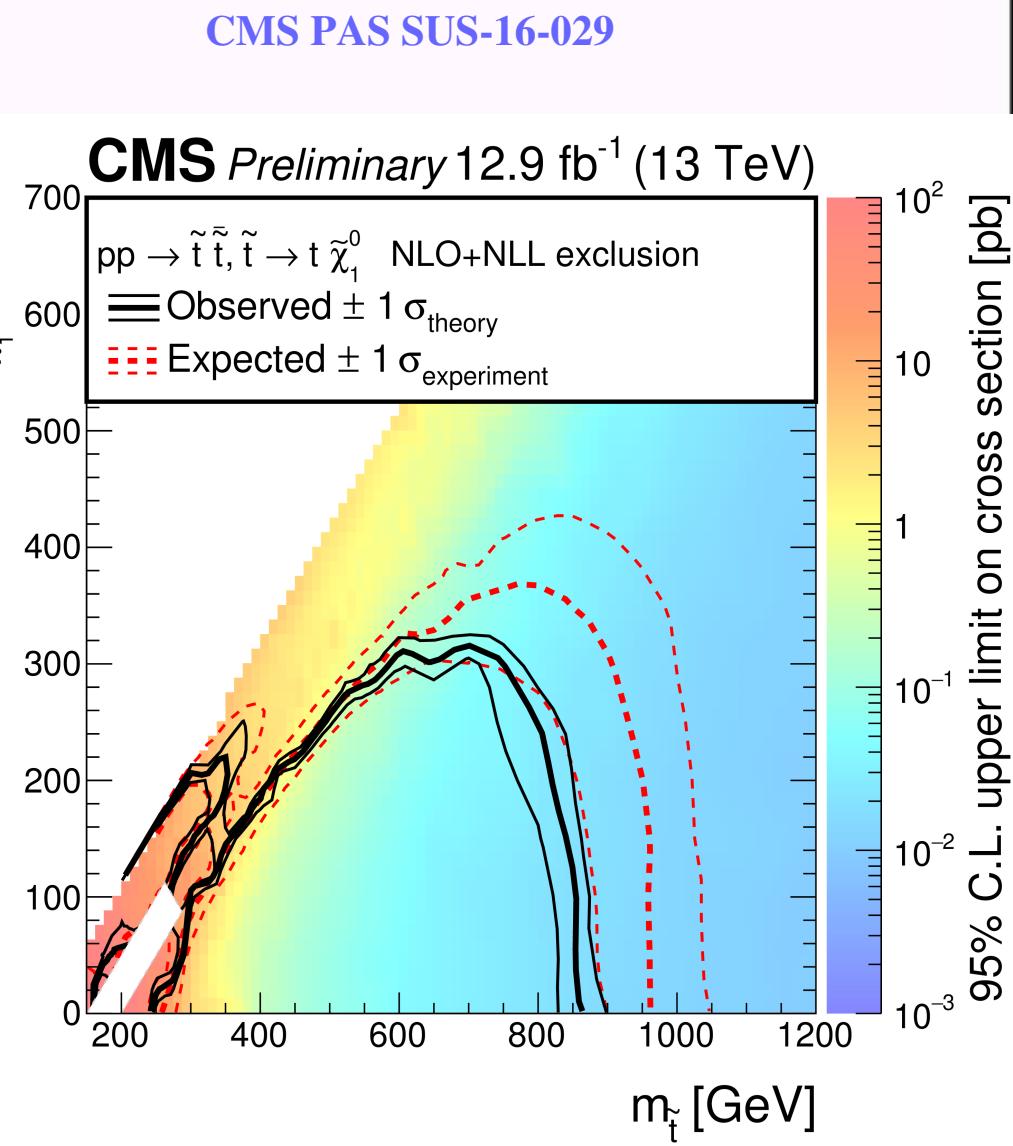
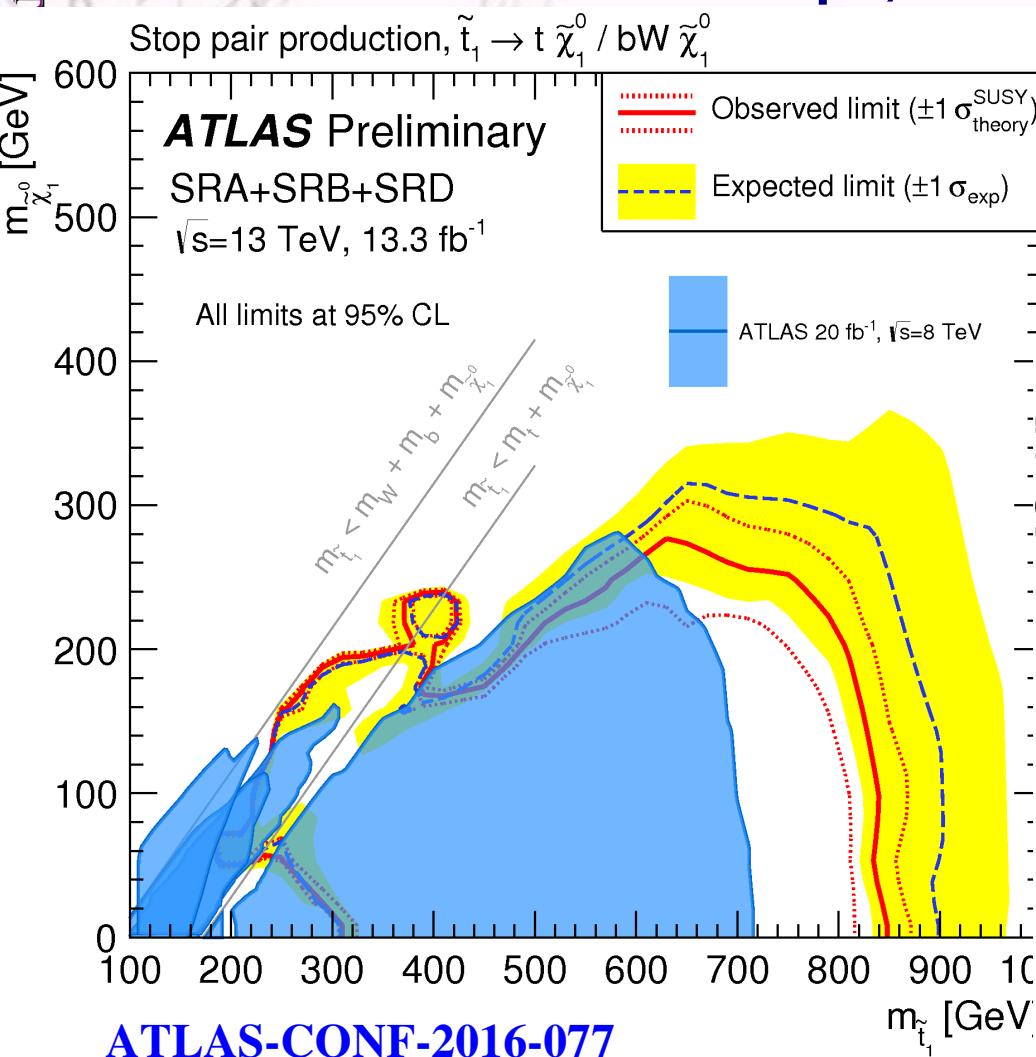
Top quark in SUSY searches, TOP2016



ATLAS-CONF-052,-037, CMS ICHEP2016 summary



Direct stops, no leptons in the final state



Direct stops, no leptons in the final state

Observed limits somewhat below expected limits.

	SRB-TT	SRB-TW	SRB-T0
Observed	17	18	84
Total SM	10.6 ± 2.3	16.7 ± 3.6	60 ± 14
$t\bar{t}$	2.5 ± 1.5	4.4 ± 2.6	14.7 ± 4.4
$W + \text{jets}$	1.33 ± 0.35	1.44 ± 0.46	6.2 ± 1.5
$Z + \text{iets}$	2.40 ± 0.70	5.1 ± 1.6	26.0 ± 8.8
$t\bar{t}+W/Z$	2.51 ± 0.64	3.15 ± 0.79	6.0 ± 1.4
Single top	1.1 ± 1.2	1.7 ± 1.9	6.1 ± 6.7
Dibosons	0.70 ± 0.44	0.87 ± 0.96	1.33 ± 0.75
Multijets	0.06 ± 0.13	0.04 ± 0.08	0.14 ± 0.29

ATLAS-CONF-2016-077

*Small “excess” in 1-top signature,
BCG dominated by Z+jets.*

CMS PAS SUS-16-029

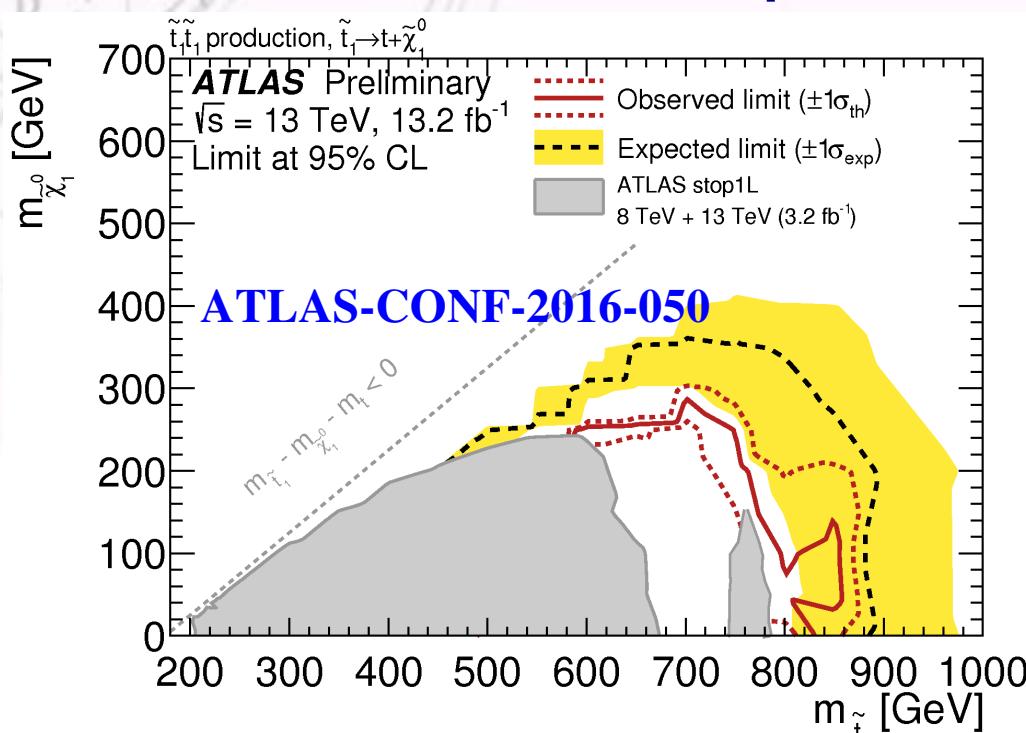
100 disjointed search region
Small excess in high MET,
dominated by
“lost lepton” bkg.

Table 4: Predicted yields for each background with uncertainties in the $M_T(b_{1,2}, E_T^{\text{miss}}) < 175$ GeV regions of the high Δm search. The number of events observed in data is given in the last column.

Search region	E_T^{miss} [GeV]	Lost lepton	$Z \rightarrow \nu\nu$	Rare SM	QCD	Total SM	Observed
$N_b \geq 2, M_T(b_{1,2}, E_T^{\text{miss}}) < 175$ GeV, $N_j \geq 7$							
12	250–300	321 ± 23	17 ± 4	6.5 ± 2.1	7.9 ± 1.9	353 ± 24	342
13	300–400	184 ± 15	12 ± 2	5.6 ± 1.8	3.8 ± 1.1	206 ± 16	177
14	400–500	30 ± 5	2.1 ± 0.7	0.9 ± 0.42	0.44 ± 0.2	33 ± 5	34
15	> 500	$4.8^{+3.0}_{-2.0}$	2.2 ± 0.7	0.55 ± 0.24	0.25 ± 0.19	$7.8^{+3.2}_{-2.2}$	16

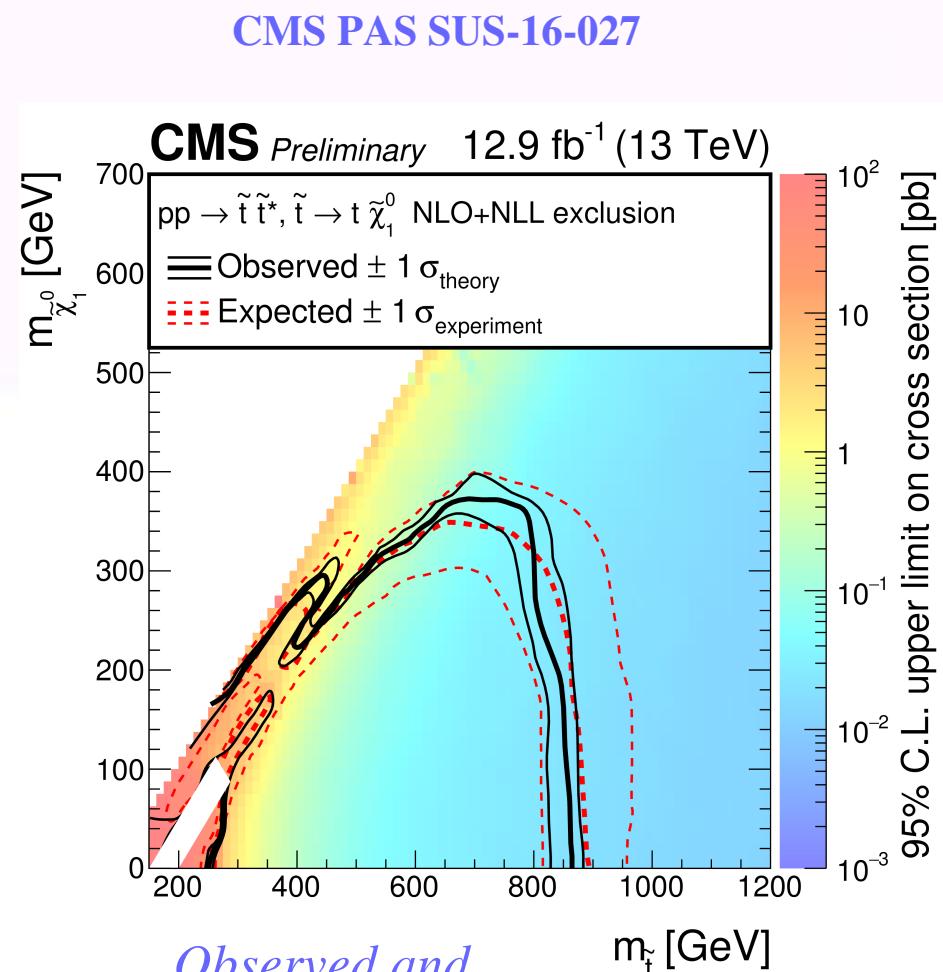


Direct stops, one lepton in the final state



Observed limit “worse” than expected, 2σ “excess”. Dominating $b\bar{c}g$, $t\bar{t}$ and $t\bar{t}+V$

Signal region	SR1
Observed	37
Total background	24 ± 3
$t\bar{t}$	8.4 ± 1.9
$W+jets$	2.5 ± 1.1
Single top	3.1 ± 1.5
$t\bar{t} + V$	7.9 ± 1.6
Diboson	1.2 ± 0.4
$Z+jets$	0.59 ± 0.54
$t\bar{t}$ NF	1.03 ± 0.07
$W+jets$ NF	0.76 ± 0.08
Single top NF	1.07 ± 0.30
$t\bar{t} + W/Z$ NF	1.43 ± 0.21
$p_0 (\sigma)$	
$N_{\text{non-SM exp.}}^{\text{limit}} (95\% \text{ CL})$	$12.9^{+5.5}_{-3.8}$
$N_{\text{non-SM obs.}}^{\text{limit}} (95\% \text{ CL})$	26.0

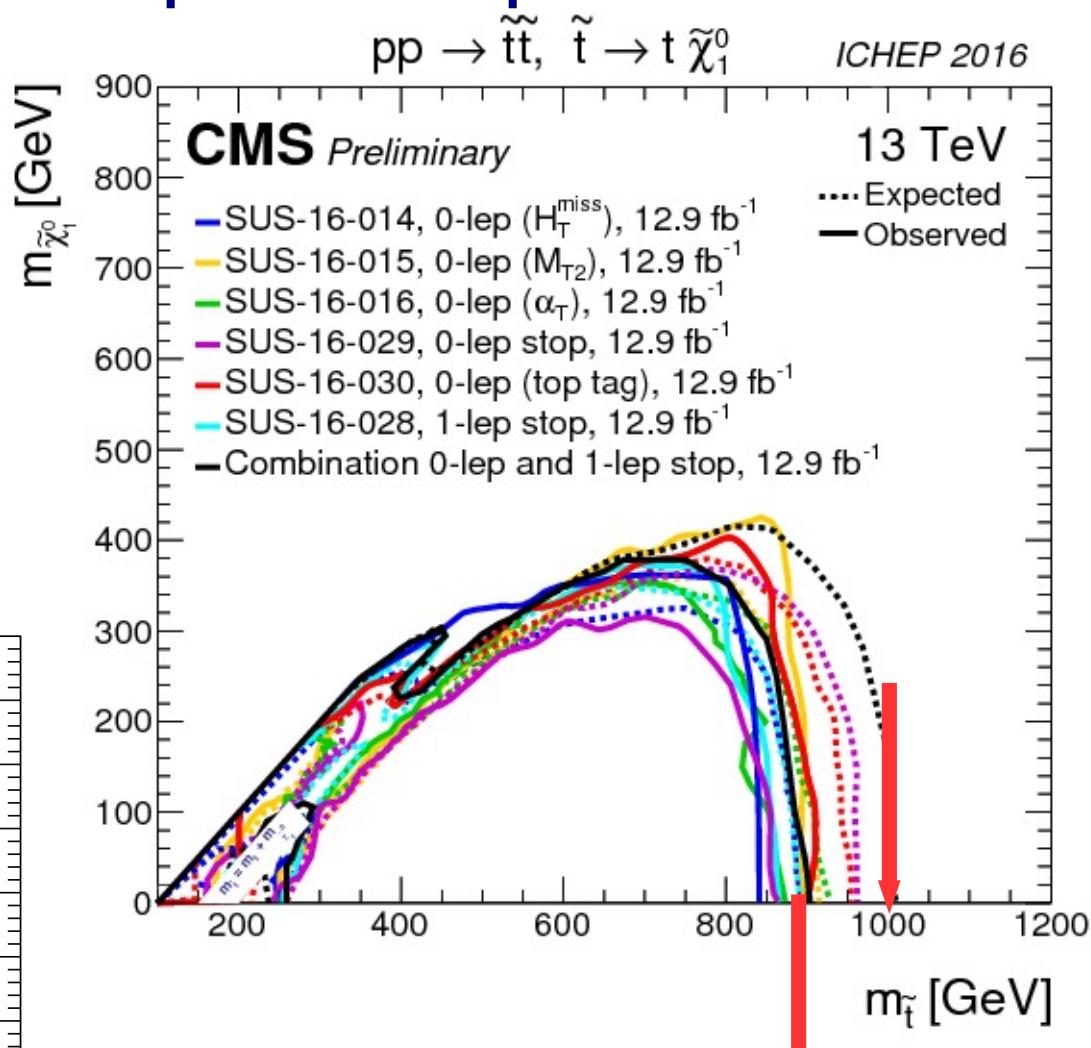
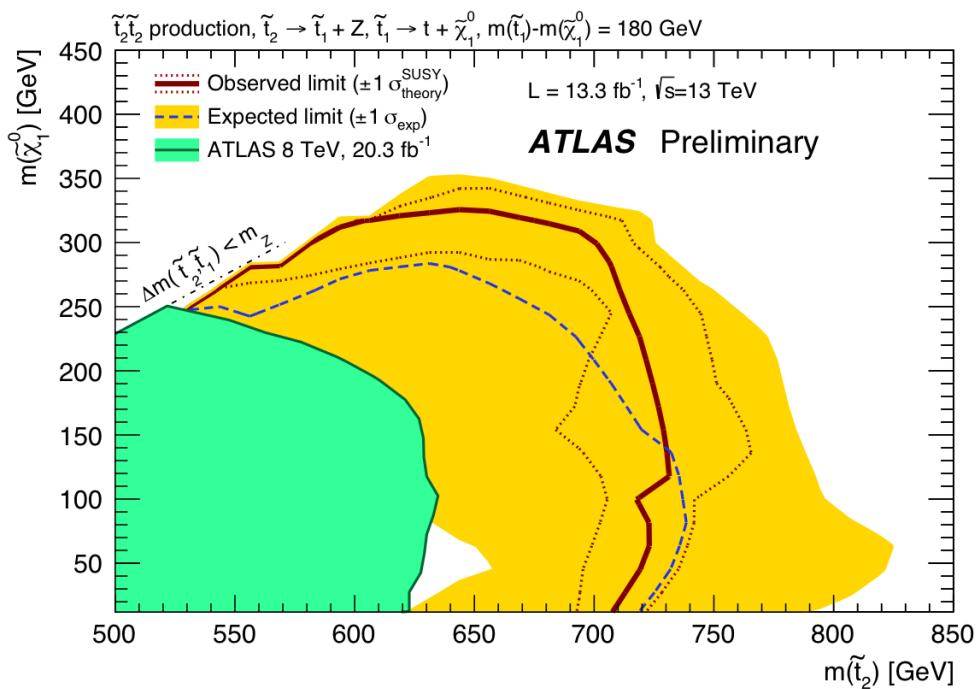


Observed and expected limits spot-on in CMS



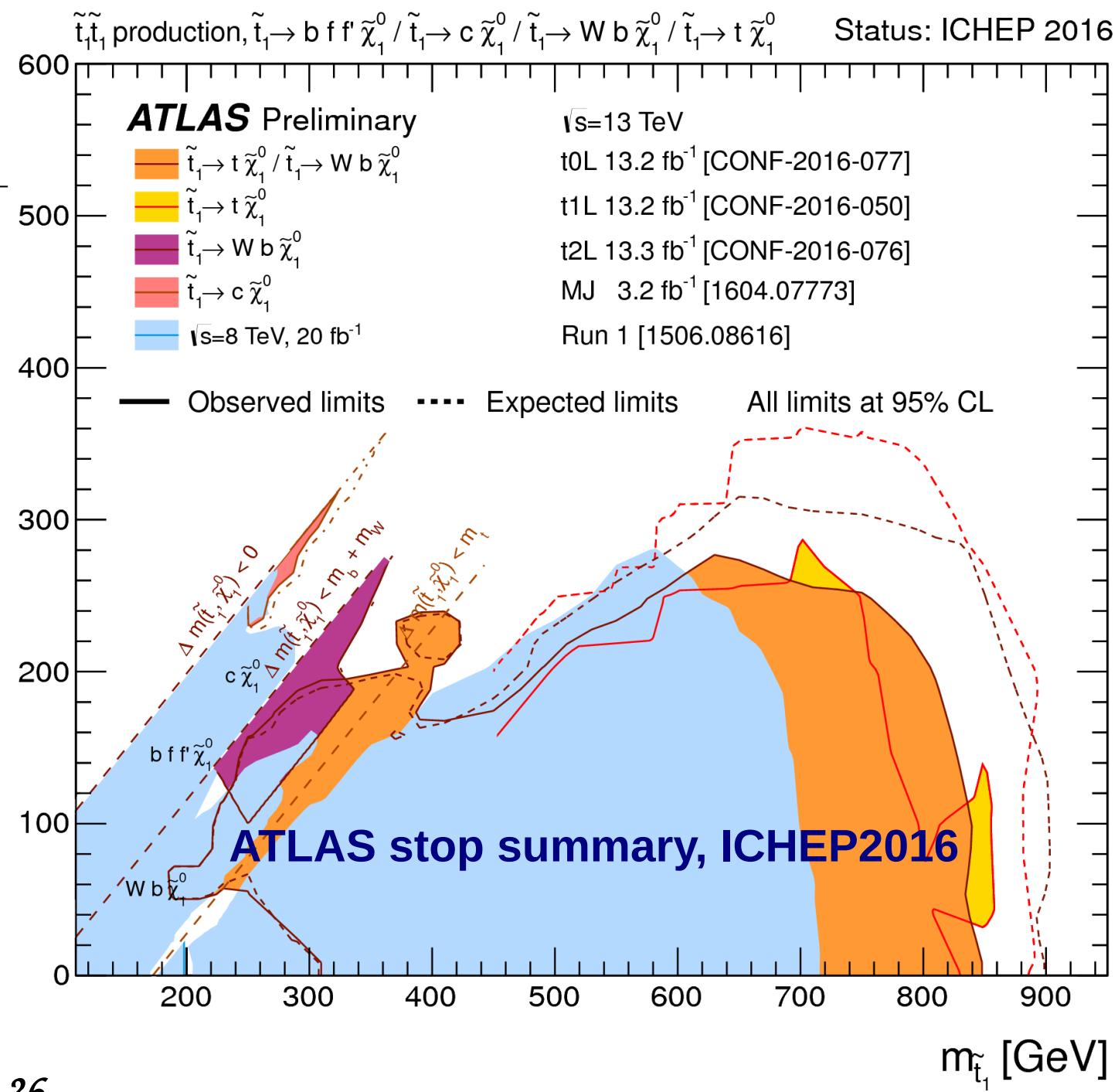
Results, direct stops1 and stop2

“heavy stop” with top +Z tagging
ATLAS-CONF-2016-038



“Observed limit 0.9 TeV for the LSP lighter than 0.1 TeV
Expected limit ~ 1 TeV





Summary and prospects

Observed limits in stop \rightarrow top+LSP somewhat lower than expected. Alas, no significant excess observed.

Stop heavier than 0.8-0.9 TeV for the LSP lighter than ~0.2 TeV. Gluinos decaying via off-shell stop heavier than 2.0-1.8 TeV for the LSP lighter than 0.4 TeV. Remember, these are simplified models results!

Systematics connected with Z+jets and “lost lepton” as important as this of ttbar.

Increased statistics, also in the MC, will give more systematics precision and more sensitivity.

SUSY searches with tops in the final state will remain extremely interesting for the years to come.



Inspirehep.net
6 records <1975
974 records <1985
9809 records today

Far away from 1mln



“Desperately seeking Susan” turned 30 last year. Desperately seeking SUSY?

Yu. A. Golfand and E. P. Likhtman,

Extension of the Algebra of Poincare Group Generators and Violation of p Invariance,

JETP Lett. 13 (1971) 323, [Pisma Zh. Eksp. Teor. Fiz. 13, 452 (1971)] (~45 y..)

backup

ATLAS-CONF-2016-050

Common event selection			
Signal region	SR1	tN_high	bC2x_d
Observed	37	5	37
Total background	24 ± 3	3.8 ± 0.8	22 ± 3
$t\bar{t}$	8.4 ± 1.9	0.60 ± 0.27	6.5 ± 1
$W+jets$	2.5 ± 1.1	0.15 ± 0.38	1.2 ± 0
Single top	3.1 ± 1.5	0.57 ± 0.44	5.3 ± 1
$t\bar{t} + V$	7.9 ± 1.6	1.6 ± 0.4	8.3 ± 1
Diboson	1.2 ± 0.4	0.61 ± 0.26	0.45 ± 0
$Z+jets$	0.59 ± 0.54	0.03 ± 0.03	0.32 ± 0
$t\bar{t}$ NF	1.03 ± 0.07	1.06 ± 0.15	0.89 ± 0
$W+jets$ NF	0.76 ± 0.08	0.78 ± 0.08	0.87 ± 0
Single top NF	1.07 ± 0.30	1.30 ± 0.45	1.26 ± 0
$t\bar{t} + W/Z$ NF	1.43 ± 0.21	1.39 ± 0.22	1.40 ± 0
$p_0 (\sigma)$	$0.012 (2.2)$	$0.26 (0.6)$	$0.004 (2$
$N_{\text{non-SM}}^{\text{limit}}$ exp. (95% CL)	$12.9^{+5.5}_{-3.8}$	$5.5^{+2.8}_{-1.1}$	12.4^{+5}_{-3}
$N_{\text{non-SM}}^{\text{limit}}$ obs. (95% CL)	26.0	7.2	27.5

Variable	SR1	tN_high
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet $p_T > [\text{GeV}]$	(80 50 40 40)	(120 80 50 25)
$E_T^{\text{miss}} [\text{GeV}]$	> 260	> 450
$E_{T,\perp}^{\text{miss}} [\text{GeV}]$	—	> 180
$H_{T,\text{sig}}^{\text{miss}}$	> 14	> 22
$m_T [\text{GeV}]$	> 170	> 210
$am_{T2} [\text{GeV}]$	> 175	> 175
$topness$	> 6.5	—
$m_{\text{top}}^\chi [\text{GeV}]$	< 270	—
$\Delta R(b, \ell)$	< 3.0	< 2.4
Leading large-R jet p_T [GeV]	—	> 290
Leading large-R jet mass [GeV]	—	> 70
$\Delta\phi(\vec{p}_T^{\text{miss}}, \text{2}^{\text{nd}} \text{large-R jet})$	—	> 0.6

Variable	bC2x_diag	bC2x_med	bCbv
Number of (jets, b-tags)	$(\geq 4, \geq 2)$	$(\geq 4, \geq 2)$	$(\geq 2, = 0)$
Jet $p_T > [\text{GeV}]$	(70 60 55 25)	(170 110 25 25)	(120 80)
b-tagged jet $p_T > [\text{GeV}]$	(25 25)	(105 100)	—
$E_T^{\text{miss}} [\text{GeV}]$	> 230	> 210	> 360
$H_{T,\text{sig}}^{\text{miss}}$	> 14	> 7	> 16
$m_T [\text{GeV}]$	> 170	> 140	> 200
$am_{T2} [\text{GeV}]$	> 170	> 210	—
$ \Delta\phi(\text{jet}_i, \vec{p}_T^{\text{miss}}) (i=1)$	> 1.2	> 1.0	> 2.0
$ \Delta\phi(\text{jet}_i, \vec{p}_T^{\text{miss}}) (i=2)$	> 0.8	> 0.8	> 0.8
Leading large-R jet mass [GeV]	—	—	[70, 100]
$\Delta\phi(\vec{p}_T^{\text{miss}}, \ell)$	—	—	> 1.2

Variable	DM_low	DM_high
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet $p_T > [\text{GeV}]$	(60 60 40 25)	(50 50 50 25)
$E_T^{\text{miss}} [\text{GeV}]$	> 300	> 330
$H_{T,\text{sig}}^{\text{miss}}$	> 14	> 9.5
$m_T [\text{GeV}]$	> 120	> 220
$am_{T2} [\text{GeV}]$	> 140	> 170
$\min(\Delta\phi(\vec{p}_T^{\text{miss}}, \text{jet}_i)) (i \in \{1 - 4\})$	> 1.4	> 0.8
$\Delta\phi(\vec{p}_T^{\text{miss}}, \ell)$	> 0.8	—



ATLAS-CONF-2016-077

Signal Region		TT	TW	T0
SRA	$m_{\text{jet}, R=1.2}^0$	> 120 GeV	> 120 GeV	> 120 GeV
	$m_{\text{jet}, R=1.2}^1$	> 120 GeV	60 – 120 GeV	< 60 GeV
	$m_{\text{jet}, R=0.8}^0$		> 60 GeV	
	<i>b</i> -tagged jets		≥ 2	
	$m_T^{b,\min}$		> 200 GeV	
	τ -veto		yes	
SRB	E_T^{miss}	> 400 GeV	> 450 GeV	> 500 GeV
	<i>b</i> -tagged jets		≥ 2	
	$m_T^{b,\min}$		> 200 GeV	
	$m_T^{b,\max}$		> 200 GeV	
	τ -veto		yes	
	$\Delta R(b, b)$		> 1.2	
ATLAS-CONF-2016-077	E_T^{miss}		> 250 GeV	



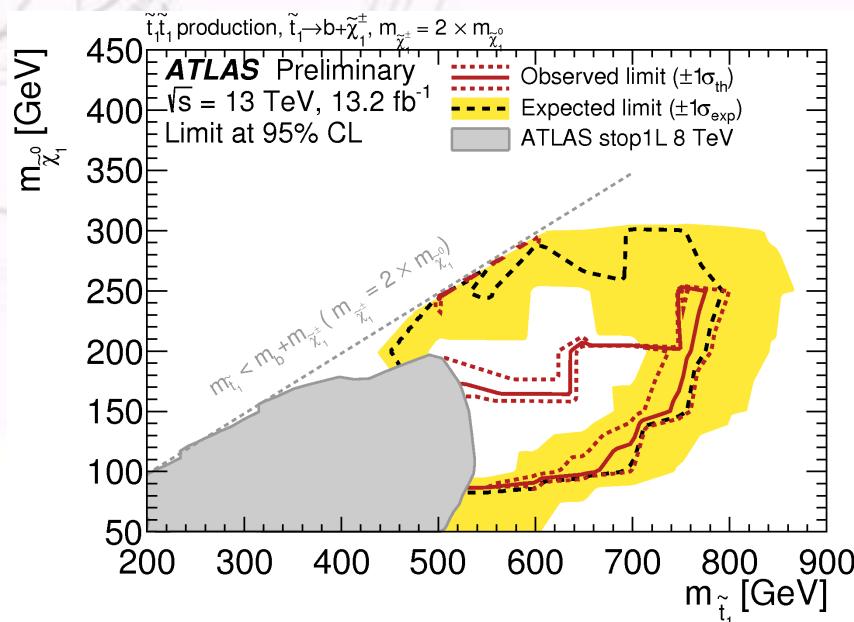
Verification region for Top, all hadronic

ATLAS-CONF-2016-077

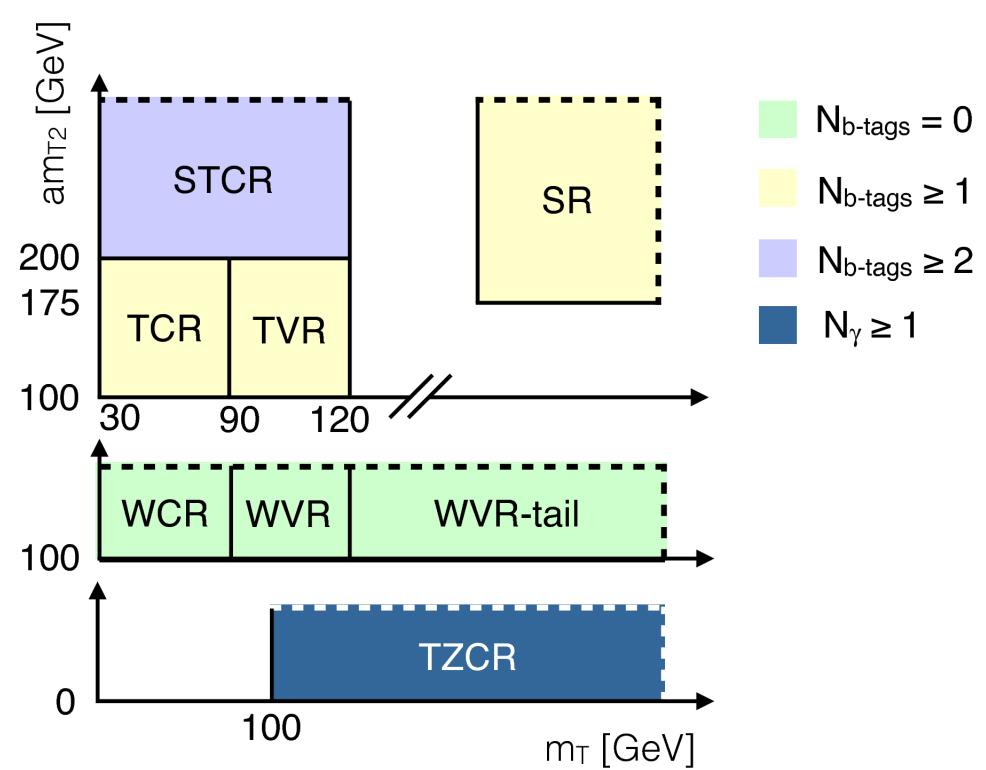
The $t\bar{t}$ background estimate is validated by defining several kinematic regions. In addition to the common all-hadronic preselection requirements, VRT-low (VRT-high) is required to have $E_T \text{ miss} > 250 \text{ GeV}$ ($E_T \text{ miss} > 350 \text{ GeV}$) and is kinematically similar to SRB, SRC, and SRE (SRA and SRF). The events in VRT-low and VRT-high must have at least 2 b-tagged jets and an orthogonal $m_{Tb,\min}$ requirement: $50 < m_{Tb,\min} < 150 \text{ GeV}$



Stop with single lepton. ATLAS



SR, VR, CR



ATLAS-CONF-2016-050



Mass relations in MSSM+

$$M_{\tilde{g}} \simeq 3 M_2$$

$$M_{\tilde{\chi}_1^\pm} \simeq M_2 \text{ (gaugino region)}$$

$$M_{\tilde{\chi}_1^0} \simeq 0.5 M_2 \text{ (gaugino region)}$$

$$M_{\tilde{\nu}}^2 = m_0^2 + 0.77M_2^2 + 0.5M_Z^2 \cos(2\beta)$$

$$M_{\tilde{e}_L}^2 = m_0^2 + 0.77M_2^2 - 0.27M_Z^2 \cos(2\beta)$$

$$M_{\tilde{e}_R}^2 = m_0^2 + 0.22M_2^2 - 0.23M_Z^2 \cos(2\beta)$$

$$M_{\tilde{q}}^2 \sim m_0^2 + 10M_2^2 + O(M_Z^2 \cos(2\beta))$$

\pm (splitting term)

Mixing -> mass splitting for
stop and , sbottom
 $A_t - \mu/\tan\beta$, $A_b - \mu \tan\beta$

and stau
 $A_\tau - \mu \tan\beta$

Gauge unification

and

Sfermion unification

Gauginos and squarks are related
Can use charginos to set
a limit on squarks and sleptons,
and sleptons to set limits on charginos



Rejecting ttbar (example variables):

“Standard susy variables” : Etmiss (MET), effective mass , HT, Etmiss/HT
 Transverse mass, several variants of “stransverse mass”

ATLAS “topness” used in 1-lepton topo, rejecting di-leptonic top with
 one lost leptons , likelihood of compatibility with dileptonic hypothesis:
 arXiv:1212.4495

$$\begin{aligned}
 S(p_{Wx}, p_{Wy}, p_{Wz}, p_{\nu z}) = & \frac{(m_W^2 - p_W^2)^2}{a_W^4} \\
 & + \frac{(m_t^2 - (p_{b_1} + p_\ell + p_\nu)^2)^2}{a_t^4} + \frac{(m_t^2 - (p_{b_2} + p_W)^2)^2}{a_t^4} \\
 & + \frac{(4m_t^2 - (\sum_i p_i)^2)^2}{a_{CM}^4},
 \end{aligned}$$

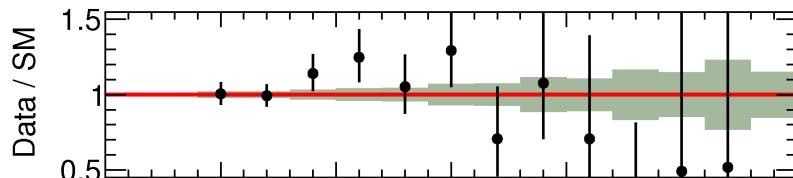
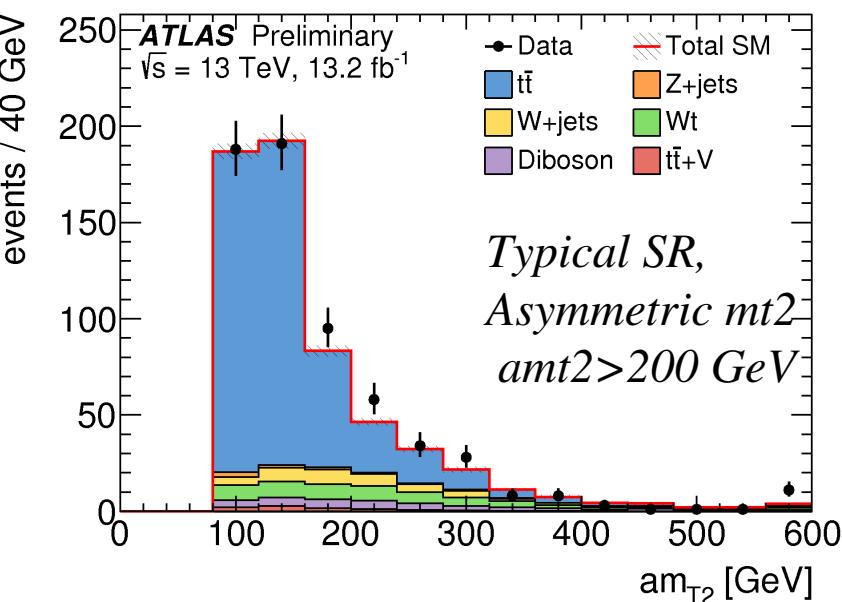


Rejecting ttbar, variants of “stransverse mass” mt2

“Stranverse mass”: $m_{T2}(\mathbf{p}_{T,1}, \mathbf{p}_{T,2}, \mathbf{q}_T) = \min_{\mathbf{q}_{T,1} + \mathbf{q}_{T,2} = \mathbf{q}_T} \{\max[m_T(\mathbf{p}_{T,1}, \mathbf{q}_{T,1}), m_T(\mathbf{p}_{T,2}, \mathbf{q}_{T,2})]\}$

Decomposing the missing transverse momentum qT between the 2 objects of interest ($pT1, pT2$) and checking the larger transverse mass. Finding the minimum as a function of this decomposition.

Top quark in SUSY searches, TOP2016

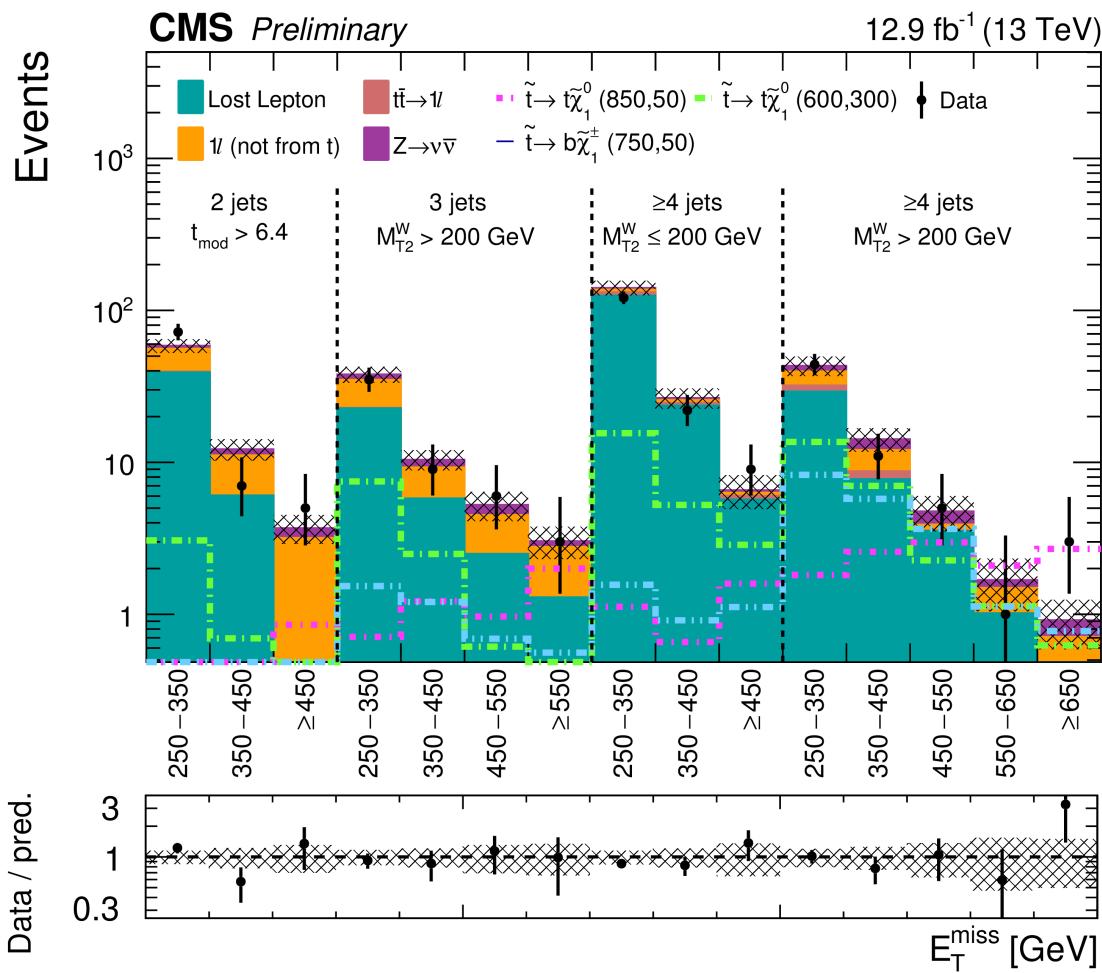


Direct stop with single lepton final state,
amt2



Slide 15

ATLAS-CONF-2016-050



Direct stop production, single lepton,
Mt2 with b-jets CMS-PAS-SUS-16-028



Top quark candidates are identified by the “CMS top tagging” (CTT) algorithm [37, 38], which makes use of jet substructure and jet mass observables in order to identify top quark decays. First, jets are reconstructed with the anti- k_T algorithm using a distance parameter of 0.8 in order to cluster the decay products of a boosted top quark into a single jet. The top candidates are then required to have large p_T (> 400 GeV) and to have their jet axis within the tracker volume ($| \eta | < 2.4$). The next step of the top reconstruction is an attempt to decompose the candidate jets into at least three subjets, where the invariant mass of these subjets is also required to be consistent with the top quark mass (140 – 250 GeV). The final requirement of the top identification is that the minimum invariant mass of any pair of the three highest p_T subjets found by the algorithm must exceed 50 GeV, in order to be consistent with the hadronic decay of a W boson.

The HETT analysis uses a custom top tagging algorithm designed for high efficiency, which is based on the one developed in the context of the earlier top squark search [39]. The algorithm starts with jets reconstructed using the anti- k_T algorithm with distance parameter $R = 0.4$, and tests various combinations of three jets within a large cone of radius 1.5 in η - φ space in order to reconstruct hadronically-decaying top quarks from resolved jets as described in Refs. [40–42]. This approach ensures high top – tagging efficiency at p_T below the range targeted by the boosted top quark algorithms [38]. In the HETT analysis, the efficiency of this top tagging algorithm is further improved at high p_T by using the jet mass to identify boosted scenarios in which decay products from the W boson or top quark are merged into a single jet. Details of this algorithm are presented in Section 4.1.



For the $t\bar{t}$ background, uncertainties are evaluated due to the hard scattering generation (comparing MadGraph5aMC@NLO with Powheg-Box), the choice of the parton showering model (PYTHIA vs. HERWIG++) and the emission of additional partons in the initial and final states [46]. The largest impact of the $t\bar{t}$ systematics on the total background yields arises for SRD and is about 22%, with lower contributions to SRC of 10%. For $t\bar{t} + W/Z$ background, the theoretical uncertainty is dominated by the 13% uncertainty on the production cross section. Additional variations considered include the choice of renormalization and factorization scales (each varied up and down by a factor of two). Uncertainty due to the choice of the generator is also considered comparing SHERPA at NLO with MadGraph5aMC@NLO. The single top background is dominated by the Wt subprocess. Uncertainties are evaluated for the choice of the parton showering model (PYTHIA vs. HERWIG++) and for the emission of additional partons in the initial and final state radiation. These uncertainties are about 10% in SRA and SRB, 17-25% in SRC, 10% in SRE and 16% in SRF. A 100% uncertainty is applied to account for the effect of interference between single-top quark and $t\bar{t}$ production.

