Searches for Beyond Standard Model Physics at the LHC: Run1 Summary and Run2 Prospects.

On behalf of the CMS and ATLAS Collaborations

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Flavor Physics and CP Violation Conference 2015, Nagoya, Japan

Introduction

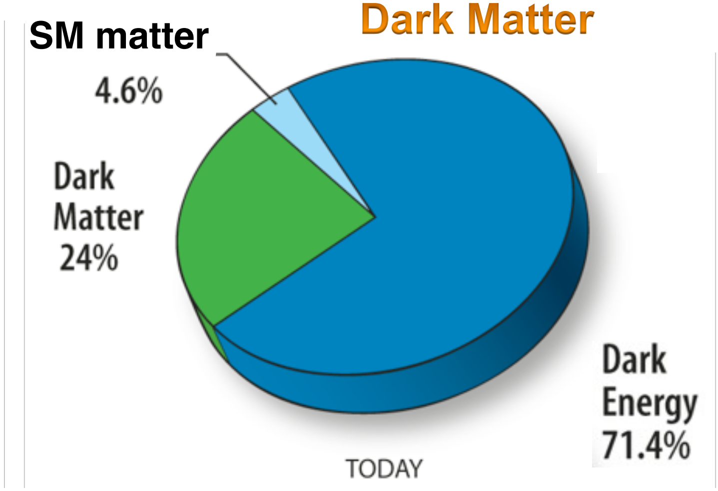
- Despite all its successes, the SM is likely to be an effective theory, i.e. the limit (energies and effective couplings) of a more fundamental theory, with new degrees of freedom

- The discovery of new physics beyond the Standard Model is one of the highest priorities for the current and future Large Hadron Collider (LHC) program

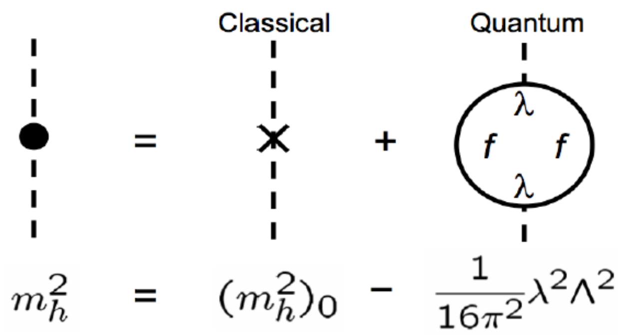
- This talk: Discuss recent results for Beyond the Standard Model searches at the CMS and ATLAS collaborations

Overview of Beyond the Standard Model Searches

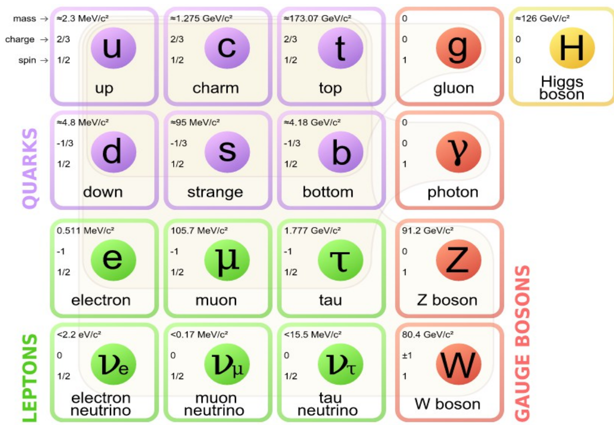
Dark Matter



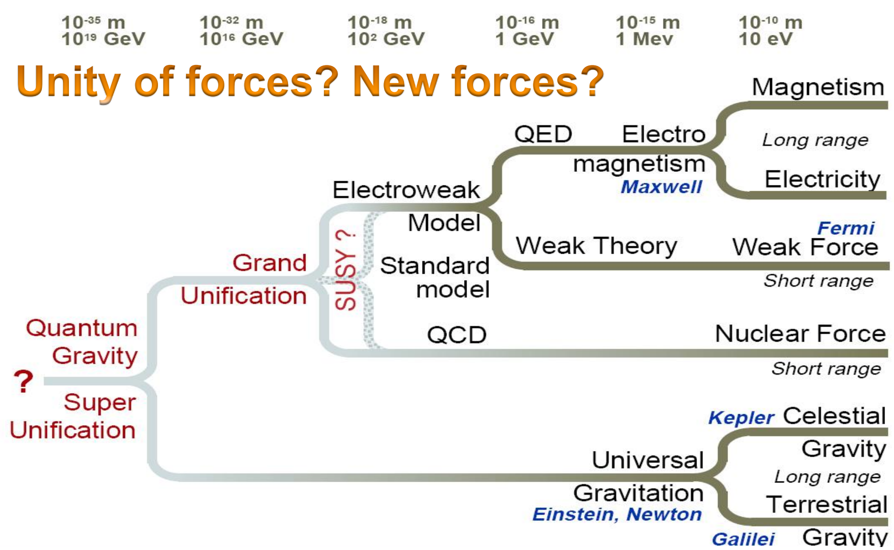
Naturalness and fine tuning



Origin of SM matter and flavor? Are particles elementary or composite?



Unity of forces? New forces?

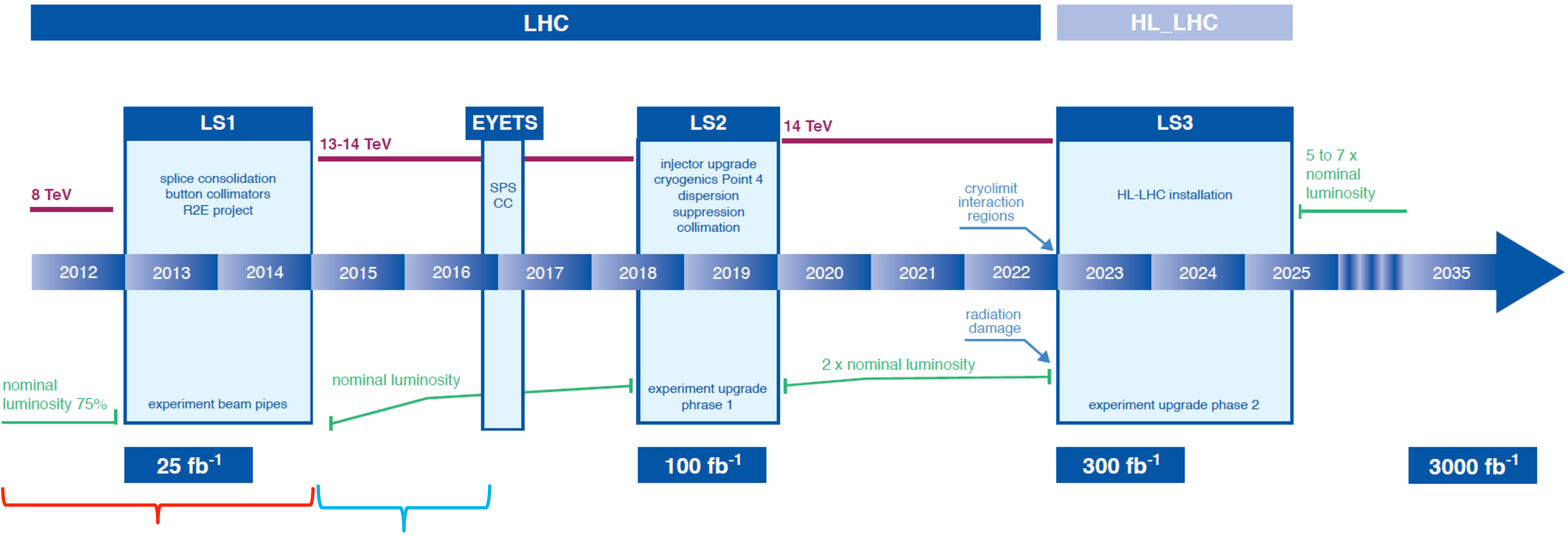


Most interesting theories offer solutions to open problems of the SM?

Large Hadron Collider Schedule

Proton-Proton collisions in 2010-2012 at 50ns bunch spacing

- ❑ 7 TeV in 2010, 2011: **~5.1/fb**
- ❑ 8 TeV in 2012 : **~ 21/fb → Excellent data quality for both experiments!**



Run 1 – Today talk
Summary for BSM
Searches

Run 2

New physics can be just around corner!

Searches for Beyond the Standard Model at the LHC

Searches for Supersymmetry (SUSY) New

- ❑ Third generation squarks in fully hadronic final states at √s = 8 TeV
  - → **CMS Collaboration arXiv: 1503.08037**
- ❑ Same-flavor opposite-sign dilepton pair, jets, and large missing transverse momentum (MET) at √s = 8 TeV
  - → **ATLAS Collaboration arXiv: 1503.03290**

All public results, including some new ones I will not cover in this talk:

- ➢ https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
- ➢ https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
- ➢ https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
- ➢ https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
- ➢ https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

Searches for Exotics (EXO) New

- ❑ Third generation scalar leptoquarks in the top-tau channel
  - → **CMS Collaboration arXiv: 1503.09049**
- ❑ b-jets and a pair of leptons of the same charge in pp collisions at √s = 8 TeV
  - → **ATLAS Collaboration arXiv: 1504.04605**
- ❑ High mass resonances decaying to Z and Higgs bosons
  - → **CMS Collaboration arXiv: 1502.04994**
- ❑ High-mass diphoton resonances in pp collisions at √s = 8 TeV
  - → **ATLAS Collaboration arXiv: 1504.05511**
- ❑ DM in association with top-quark pairs in the single lepton channel
  - → **CMS Collaboration arXiv: 1504.03198**

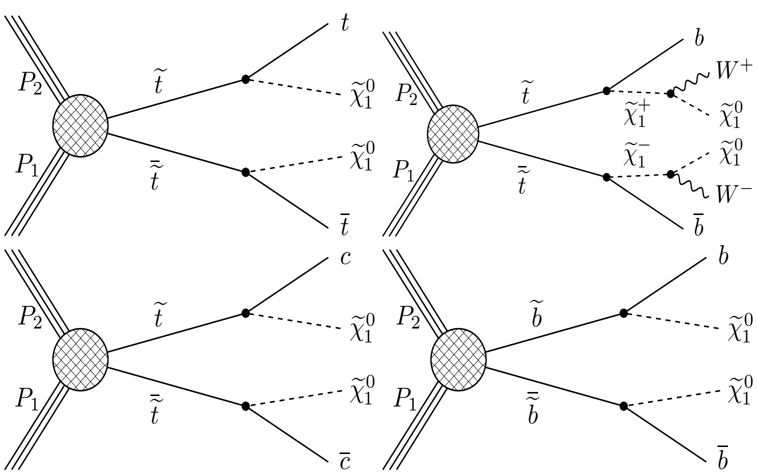
SUSY: 3rd generation squarks in fully hadronic final states

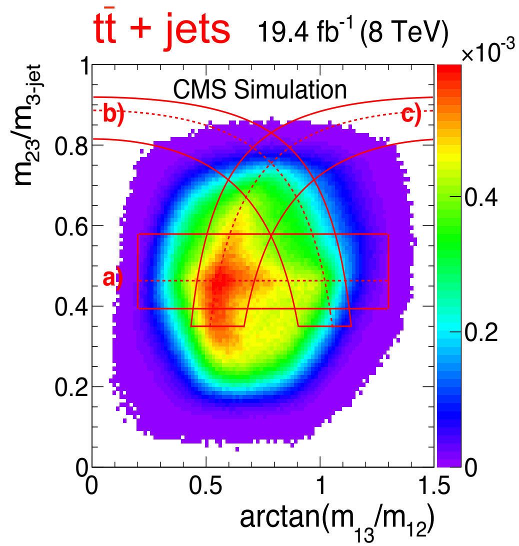
Motivation→ Three mutually exclusive searches are discussed

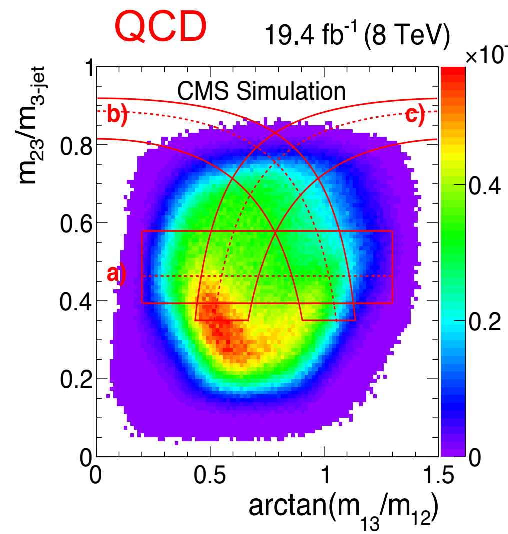
① multijet search requiring **one fully reconstructed top quark**
② dijet search requiring **one or two jets originating from b quarks**
③ **monojet** search

Signal Topologies and Top recons.

- The collection of five or more jets is divided into all possible sets of three jets and a remnant, where the remnant must contain at least one b-tagged jet.







$$\text{(a)}\quad 0.2 < \arctan\left(\frac{m_{13}}{m_{12}}\right) < 1.3 \quad\text{and}\quad R_{\min} < \frac{m_{23}}{m_{3\text{-jet}}} < R_{\max},$$

$$\text{(b)}\quad R_{\min}^2\left[1+\left(\frac{m_{13}}{m_{12}}\right)^2\right] < 1-\left(\frac{m_{23}}{m_{3\text{-jet}}}\right)^2 < R_{\max}^2\left[1+\left(\frac{m_{13}}{m_{12}}\right)^2\right] \quad\text{and}\quad \frac{m_{23}}{m_{3\text{-jet}}} > 0.35,$$

$$\text{(c)}\quad R_{\min}^2\left[1+\left(\frac{m_{12}}{m_{13}}\right)^2\right] < 1-\left(\frac{m_{23}}{m_{3\text{-jet}}}\right)^2 < R_{\max}^2\left[1+\left(\frac{m_{12}}{m_{13}}\right)^2\right] \quad\text{and}\quad \frac{m_{23}}{m_{3\text{-jet}}} > 0.35.$$

$$R_{\min} = 0.85(m_W/m_t),\ R_{\max} = 1.25(m_W/m_t),\ m_W = 80.4\,\text{GeV}\quad m_t = 173.4\,\text{GeV}$$

arXiv: 1503.08037
CMS Collaboration

SUSY: 3rd generation squarks in fully hadronic final states

Results for Multijet Top tagging, dijet b-tagged and monojet

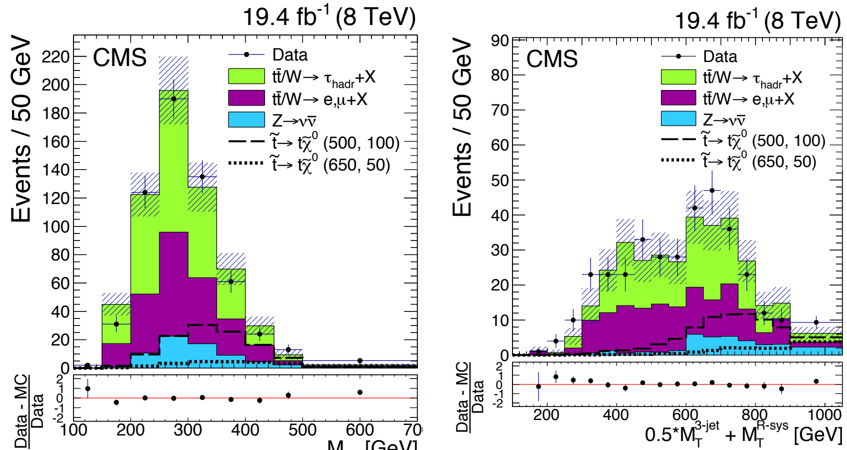
$$M_{T2}(m_X) = \min_{\vec{p}_T^{X(1)}+\vec{p}_T^{X(2)}=\vec{p}_T^{miss}} \left[\max\left(M_T^{(1)}, M_T^{(2)}\right)\right]$$

$$(M_T^{3\text{-jet}})^2 = (m^{3\text{-jet}})^2 + 2(E_T^{3\text{-jet}} p_T^{miss} - p_T^{3\text{-jet}} p_T^{miss} \cos\Delta\phi)$$

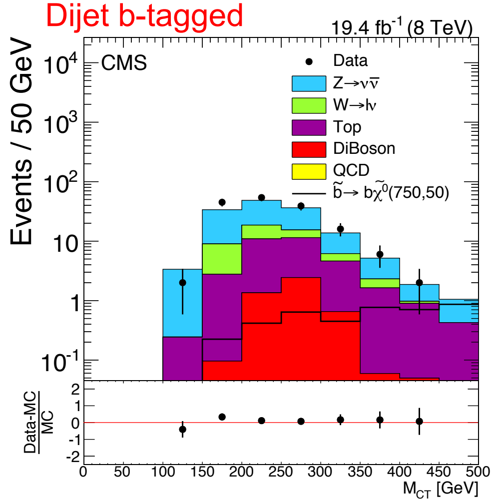
Search regions	$N_{b\ jets}$ ≥ 0		1		2	
Multijet t-tagged search			SM Pred.	Obs.	SM Pred.	Obs.
$p_T^{miss} \in [200, 350]$ GeV			148^{+29}_{-24}	141	81^{+13}_{-12}	68
$p_T^{miss} > 350$ GeV			$33.4^{+7.0}_{-7.8}$	30	$8.6^{+2.6}_{-2.4}$	15
Dijet b-tagged search			SM Pred.	Obs.	SM Pred.	Obs.
$M_{CT} < 250$ GeV			1540±100	1560	93±10	101
$M_{CT} \in [250, 350]$ GeV			754±68	807	50.0±6.4	55
$M_{CT} \in (350, 450]$ GeV			85±10	101	6.5±1.7	8
$M_{CT} > 450$ GeV			16.0±4.1	23	1.0±0.9	1
ISR			356 ± 41	359	26.0 ± 4.1	28
Monojet search	SM Pred.	Obs.				
$p_T^{j_1} > 250$ GeV	35900±1500	36600				
$p_T^{j_1} > 300$ GeV	17400±800	17600				
$p_T^{j_1} > 350$ GeV	8060±440	8120				
$p_T^{j_1} > 400$ GeV	3910±250	3900				
$p_T^{j_1} > 450$ GeV	2100±160	1900				
$p_T^{j_1} > 500$ GeV	1100±110	1000				
$p_T^{j_1} > 550$ GeV	563±71	565				

$$(M_{CT})^2 = [E_T^{j_1} + E_T^{j_2}]^2 - [\vec{p}_T^{j_1} - \vec{p}_T^{j_2}]^2 = 2p_T^{j_1} p_T^{j_2}[1 + \cos\phi(j_1, j_2)]$$

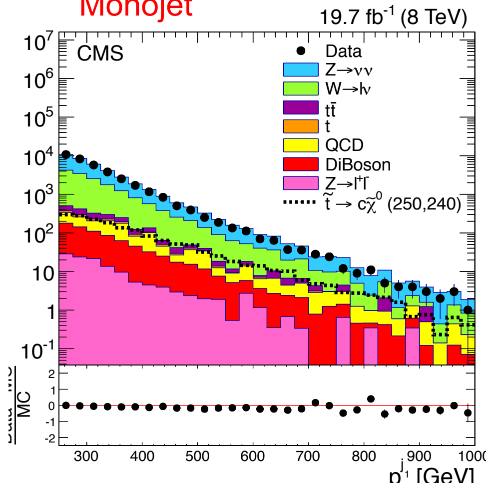
Multijet top-tagging



Dijet b-tagged



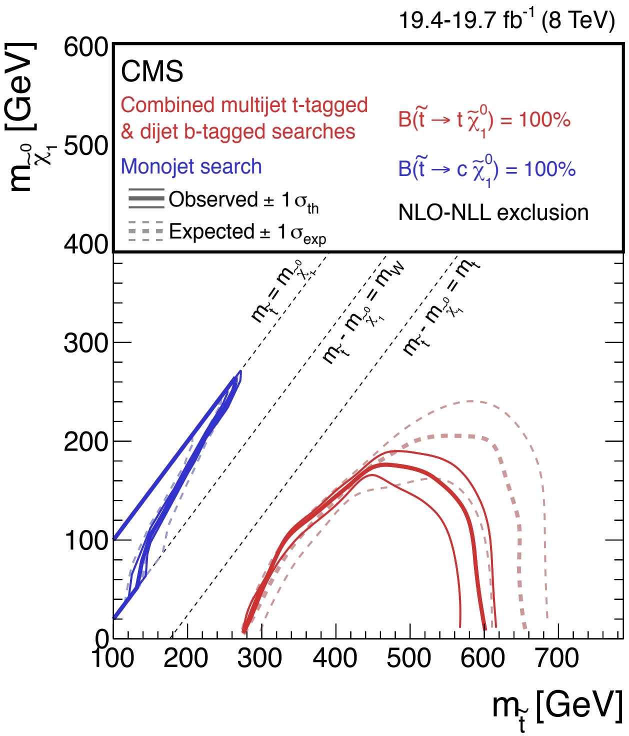
Monojet



arXiv: 1503.08037
CMS Collaboration

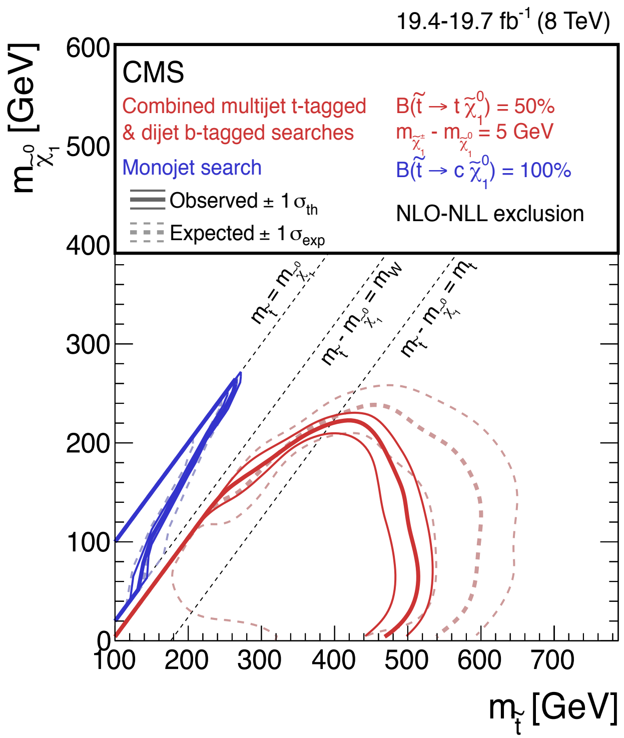
SUSY: 3rd generation squarks in fully hadronic final states

Interpretations of the results



$B(\tilde{t} \rightarrow t\,\tilde{\chi}_1^0) = 100\%$

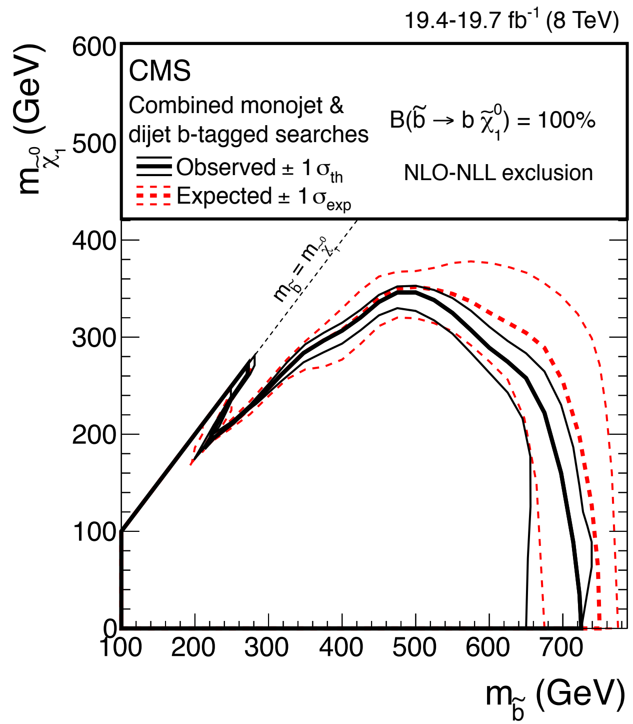
$B(\tilde{t} \rightarrow c\,\tilde{\chi}_1^0) = 100\%$



$B(\tilde{t} \rightarrow t\,\tilde{\chi}_1^0) = 50\%$

$m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0} = 5$ GeV

$B(\tilde{t} \rightarrow c\,\tilde{\chi}_1^0) = 100\%$



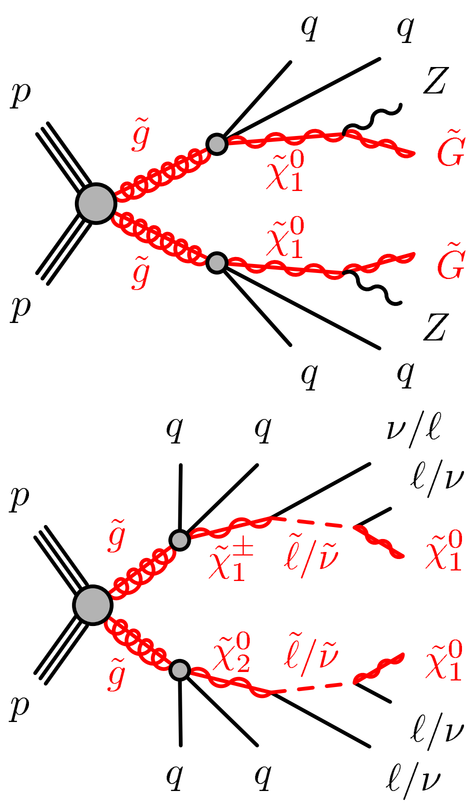
$B(\tilde{b} \rightarrow b\,\tilde{\chi}_1^0) = 100\%$

arXiv: 1503.08037
CMS Collaboration

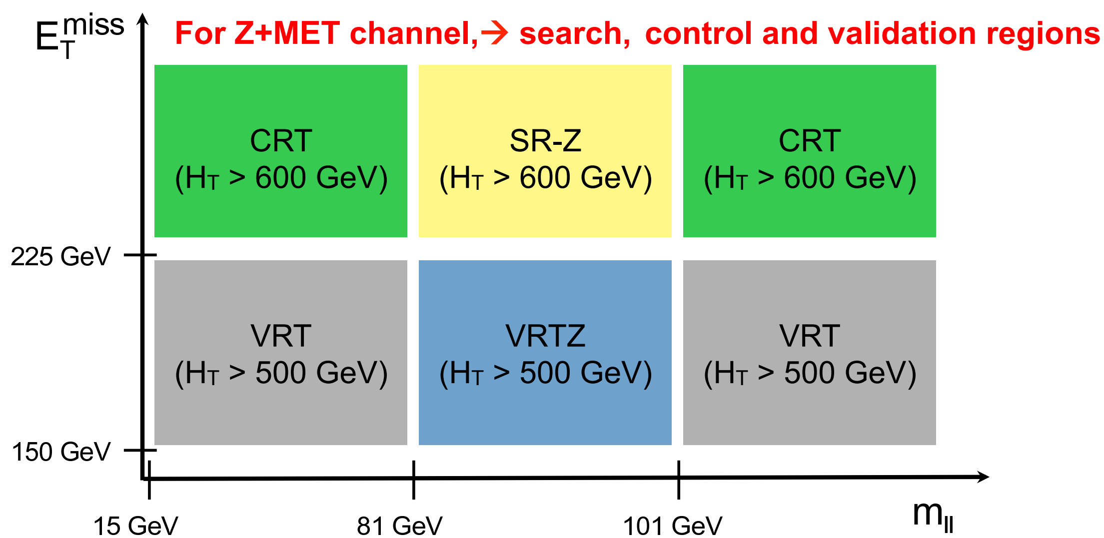
SUSY: Same-flavour opp.-sign dilepton pair, jets, and MET

Motivation→ Two leptonic production mechanism considered

① decays of squarks and gluinos with Z bosons in the final state
② decays of neutralinos resulting in a kinematic endpoint in the dilepton invariant mass distribution



- Various decay chains can give 2l+jets+MET
- $t\bar{t}$ (main background) estimated from data using eμ events with the same cuts as the signal region (SR), cross checked **using Z side-bands**



H_T = scalar sum of all jet p_T

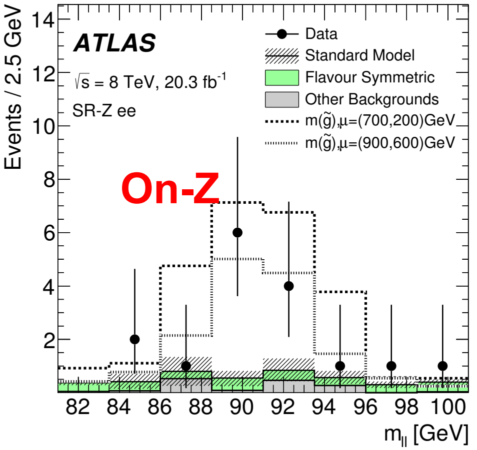
arXiv: 1503.03290
ATLAS Collaboration

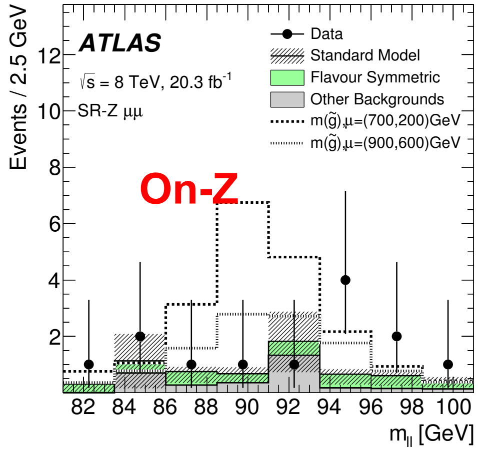
Similar analysis from CMS Collaboration → arXiv: 1502.06031

SUSY: Same-flavour opp.-sign dilepton pair, jets, and MET

Electron
Data: 16
Bkgd: 4.2±1.6
p-value: 3.0σ

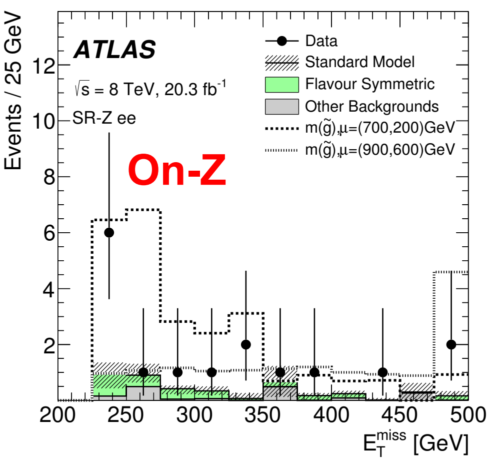
Muon
Data: 13
Bkgd: 6.4±2.2
p-value: 1.7σ

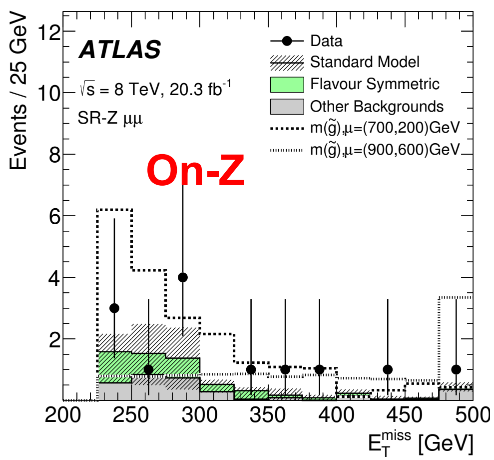


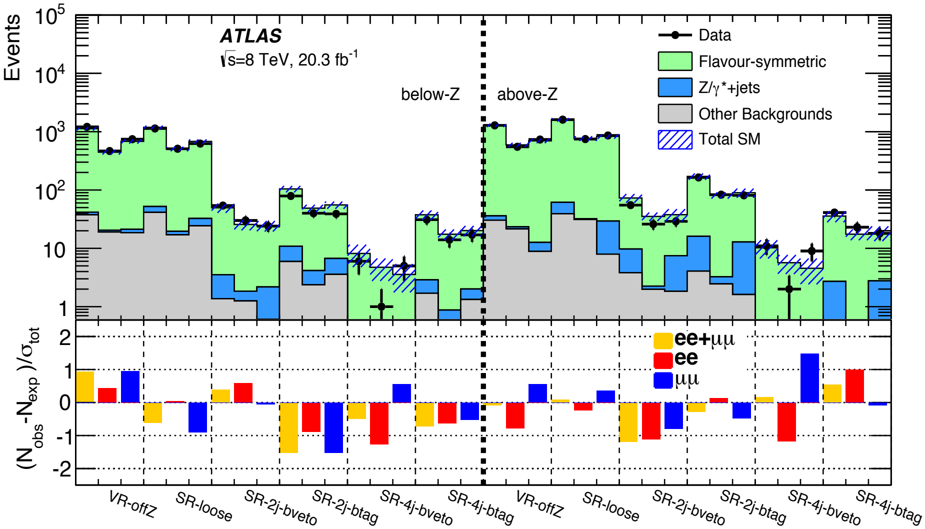


For the on-Z analysis, the data exceeds the background expectations in the *ee* (μμ) channel with a significance of 3 (1.7) σ deviations.

Channel	SR-Z *ee*	SR-Z *μμ*	SR-Z same-flavour combined
Observed events	16	13	29
Expected background events	4.2 ± 1.6	6.4 ± 2.2	10.6 ± 3.2
Flavour-symmetric backgrounds	2.8 ± 1.4	3.3 ± 1.6	6.0 ± 2.6
Z/γ^* + jets (jet-smearing)	0.05 ± 0.04	$0.02^{+0.03}_{-0.02}$	0.07 ± 0.05
Rare top	0.18 ± 0.06	0.17 ± 0.06	0.35 ± 0.12
WZ/ZZ diboson	1.2 ± 0.5	1.7 ± 0.6	2.9 ± 1.0
Fake leptons	$0.1^{+0.7}_{-0.1}$	$1.2^{+1.3}_{-1.2}$	$1.3^{+1.7}_{-1.3}$





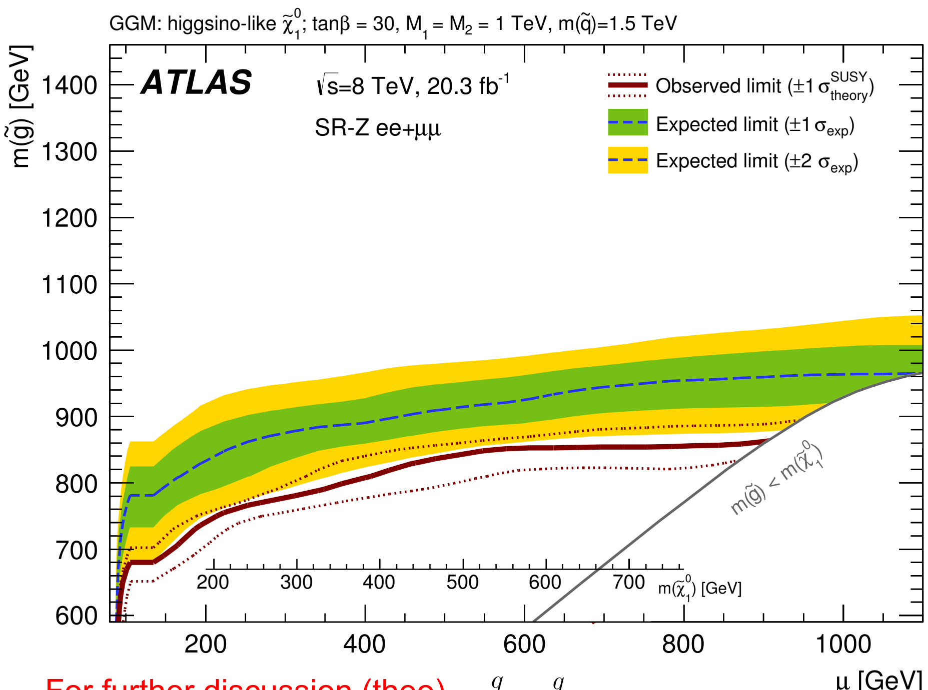


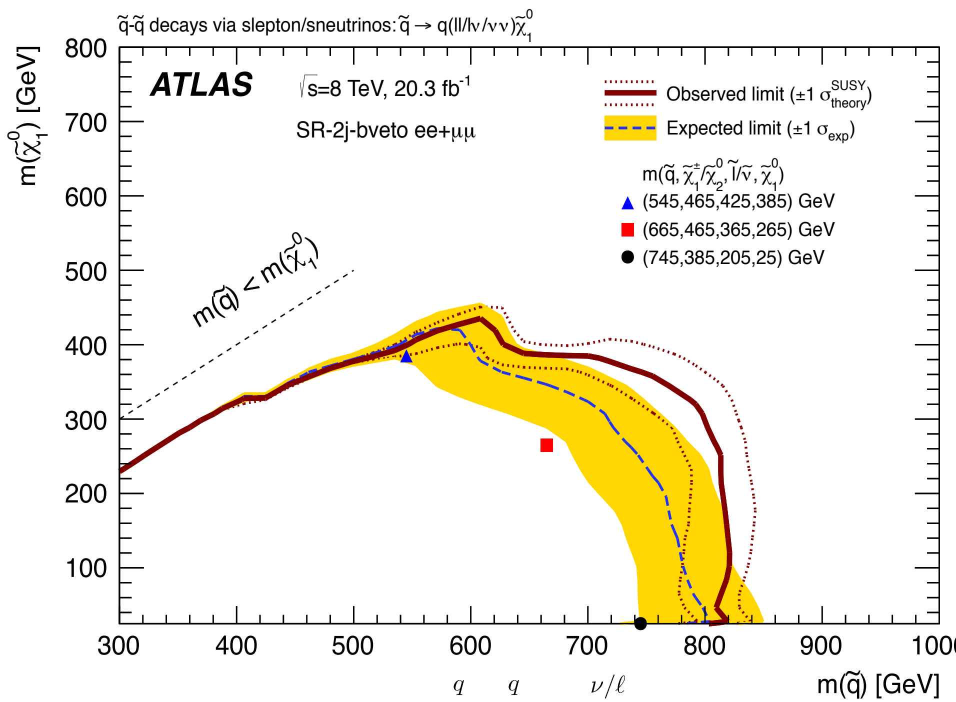
Search bins for Off-Z

arXiv: 1503.03290
ATLAS Collaboration
Similar analysis from CMS Collaboration → arXiv: 1503.08089

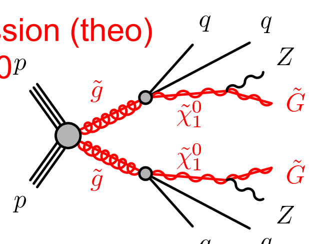
SUSY: Same-flavour opp.-sign dilepton pair, jets, and MET

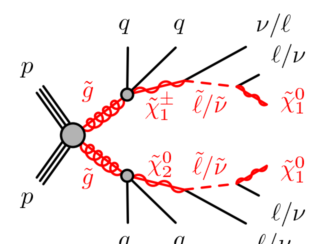
The results are interpreted in **a supersymmetric model of general gauge mediation** and the expected background contribution to the SR the number of events in data is higher than anticipated (left). The second search targets events with **a lepton pair with invariant mass** inconsistent with *Z* boson decay (right)





For further discussion (theo)
arXiv:1504.04390





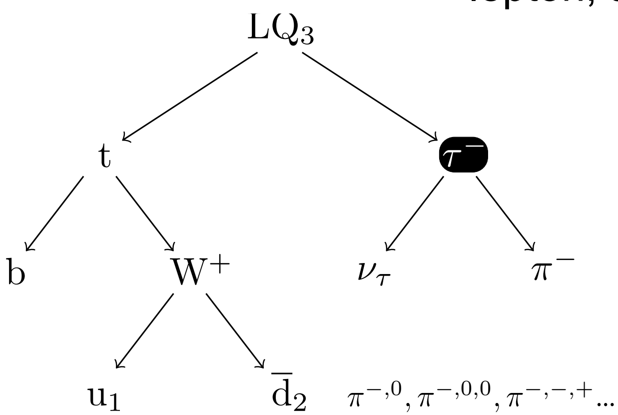
arXiv: 1503.03290
ATLAS Collaboration

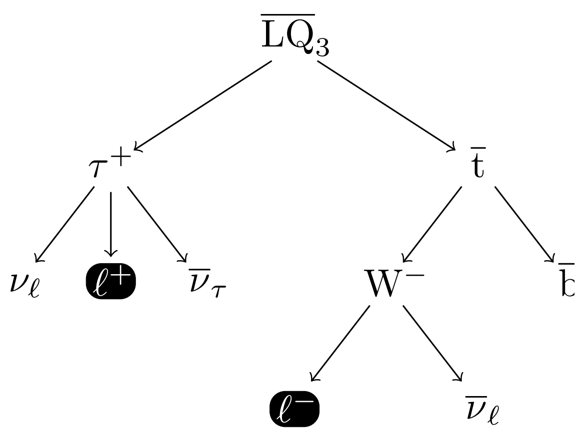
Similar analysis from CMS Collaboration → arXiv: 1503.08089

EXO: Third-generation scalar leptoquarks in the tτ channel

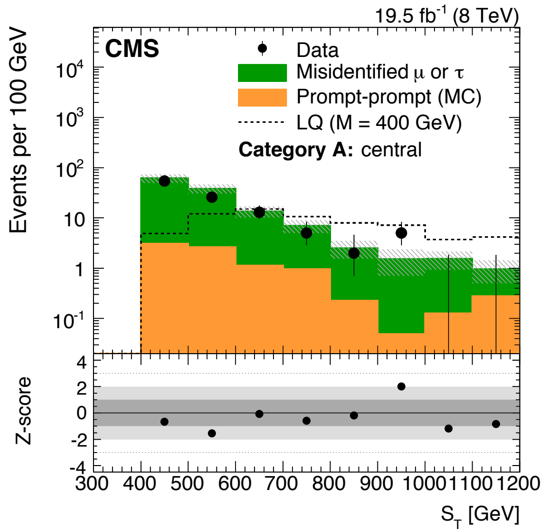
Motivation→ pair production of third-generation scalar **leptoquarks** decaying to top quark and tau lepton pairs

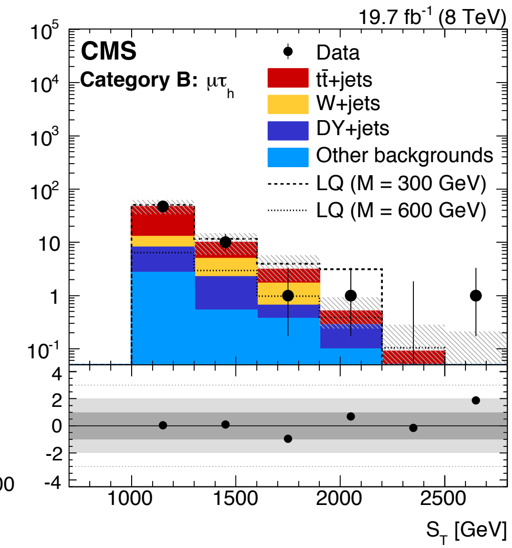
- **Signal topology**: an electron or a muon, a hadronically decaying tau lepton, and two or more jets.





	Category A	Category B
Lepton selection	Same-sign $\mu\tau_h$ pair	$\mu\tau_h$ or $e\tau_h$ pair (category A events are removed)
Jet selection	At least two jets	At least three jets
E_T^{miss} requirement	No E_T^{miss} requirement	$E_T^{miss} > 50$ GeV
S_T and τ lepton p_T requirements	Optimized for each LQ mass hypothesis	$S_T > 1000$ GeV, $p_T^\tau > 20$ GeV
Background estimation	Main component containing misidentified muons & τ leptons estimated using data events	Estimated via simulation, corrections applied for τ lepton misidentification rate and top quark and W p_T distributions
Search regions	2 search regions binned in $\lvert\widetilde{\eta}\rvert$	8 search regions in 4 τ lepton p_T regions for $\mu\tau_h$ and $e\tau_h$ channels

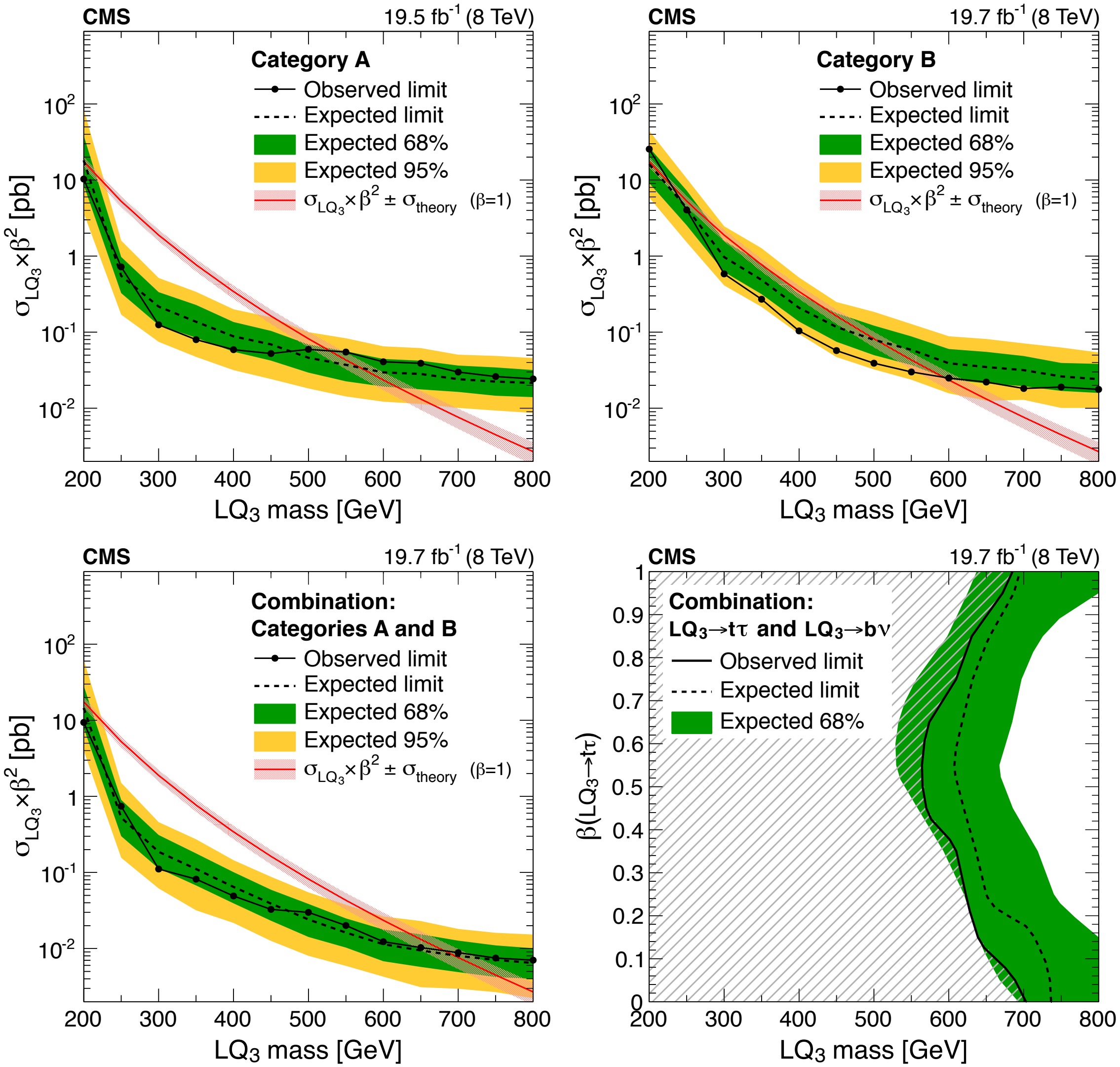




S_T = MET+ $\Sigma_{all}P_T$

arXiv: 1503.09049
CMS Collaboration

EXO: Third-generation scalar leptoquarks in the tτ channel



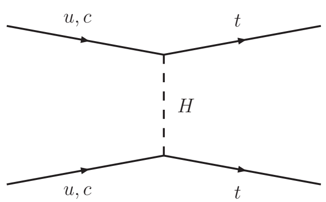
- The exclusion limits at 95% CL on the LQ_3 pair production cross section times β^2 in category and the combination (upper row).
- The expected and observed limits on the LQ branching fraction β as a function of the LQ mass (lower right).
- the mass limit can be directly applicable to pair produced bottom squarks decaying via the RPV coupling λ'_{333}

β → BR parameter for quark and charged lepton with the same generation in LQ: assumed to be 1 for 100% BR to the top quark and tau decays

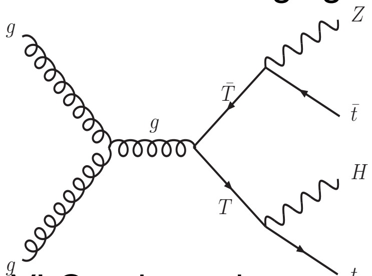
arXiv: 1503.09049
CMS Collaboration

EXO: Events with b-jets and a pair of leptons of the same charge in proton-proton collisions

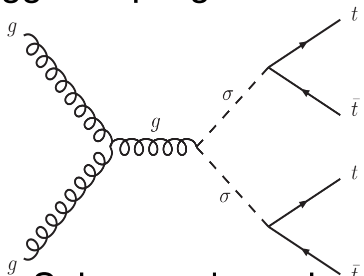
Motivation → the existence of vector-like quarks, an enhancement of the four-top quarks production cross section, the existence of a fourth generation of chiral quarks, or production of two positively charged top quarks.



BSM Flavor changing Higgs coupling



VLQ pair prod.

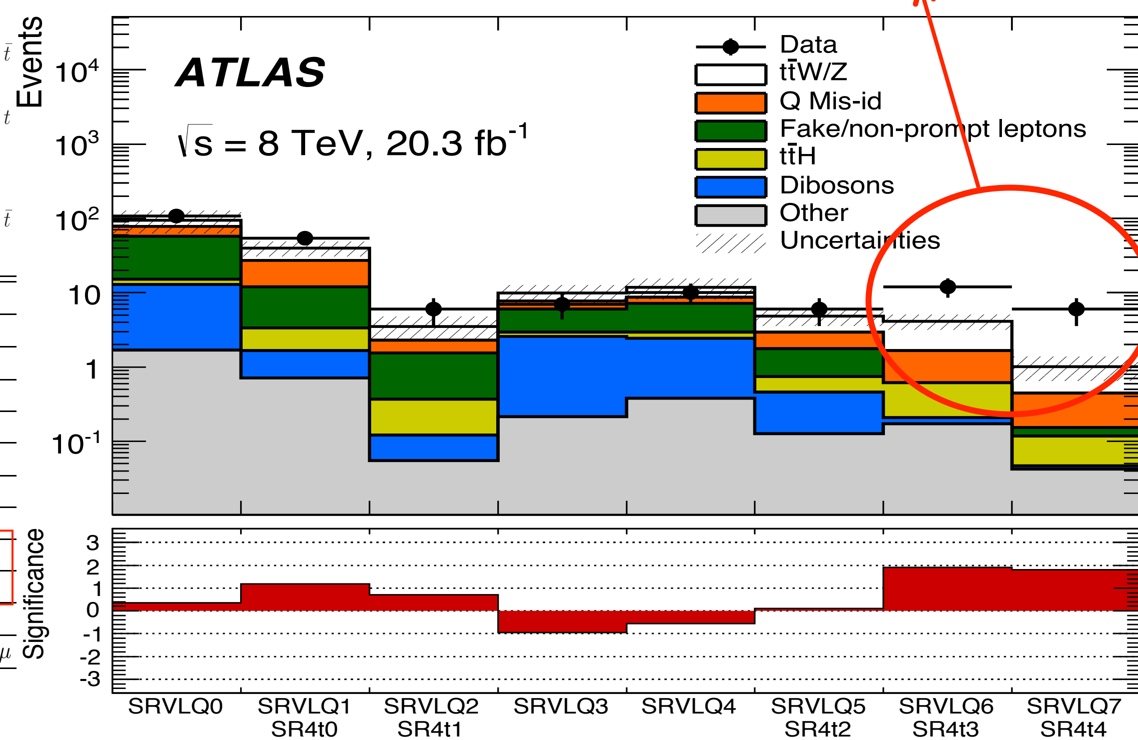


Sgluon pair prod.

Definition			Name	
$e^\pm e^\pm + e^\pm\mu^\pm + \mu^\pm\mu^\pm + eee + ee\mu + e\mu\mu + \mu\mu\mu$, $N_j \geq 2$				
$400 < H_T < 700$ GeV	$N_b = 1$	$E_T^{miss} > 40$ GeV	SRVLQ0	
	$N_b = 2$		SRVLQ1	SR4t0
	$N_b \geq 3$		SRVLQ2	SR4t1
$H_T \geq 700$ GeV	$N_b = 1$	$40 < E_T^{miss} < 100$ GeV	SRVLQ3	
		$E_T^{miss} \geq 100$ GeV	SRVLQ4	
	$N_b = 2$	$40 < E_T^{miss} < 100$ GeV	SRVLQ5	SR4t2
		$E_T^{miss} \geq 100$ GeV	SRVLQ6	SR4t3
	$N_b \geq 3$	$E_T^{miss} > 40$ GeV	SRVLQ7	SR4t4
e^+e^+, $e^+\mu^+$, $\mu^+\mu^+$, $N_j \in [2,4]$, $\Delta\phi_{\ell\ell} > 2.5$				
$H_T > 450$ GeV	$N_b \geq 1$	$E_T^{miss} > 40$ GeV	SRttee, SRtteμ, SRtt$\mu\mu$	

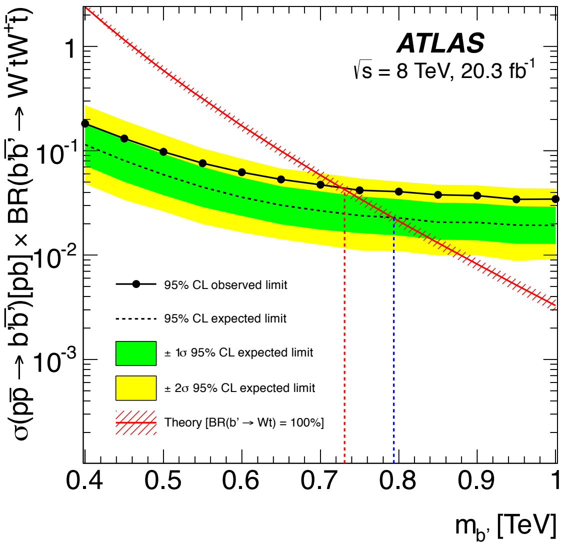
→ vector-like quarks (VLQ)

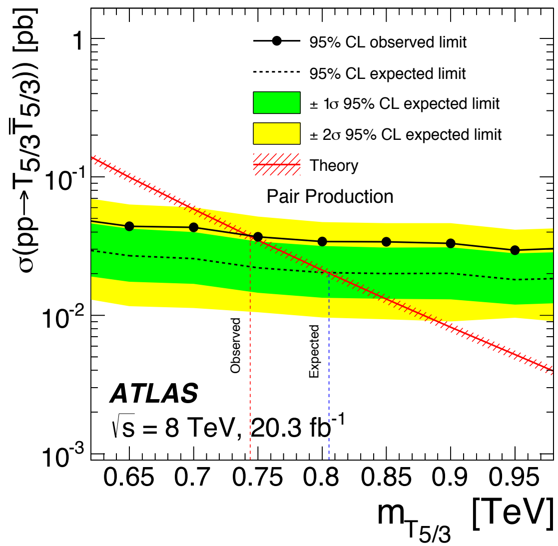
p-value 2.5 σ

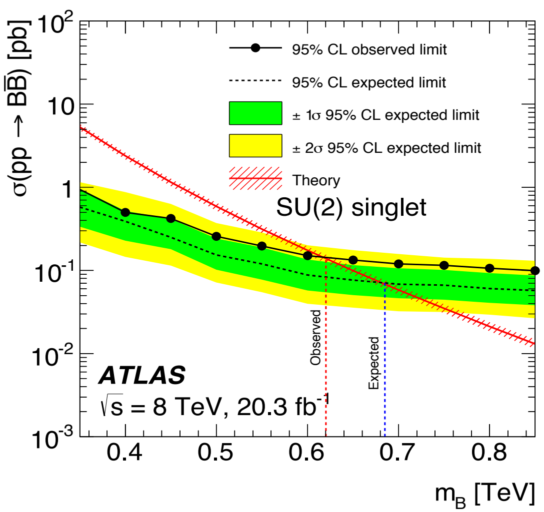


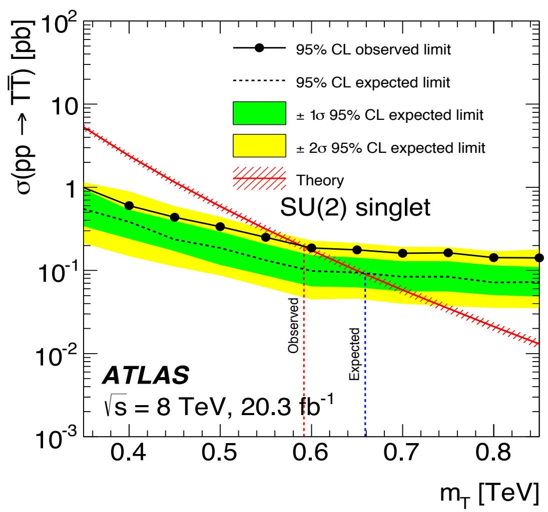
arXiv: 1504.04605
ATLAS Collaboration

EXO: Events with b-jets and a pair of leptons of the same charge in proton-proton collisions





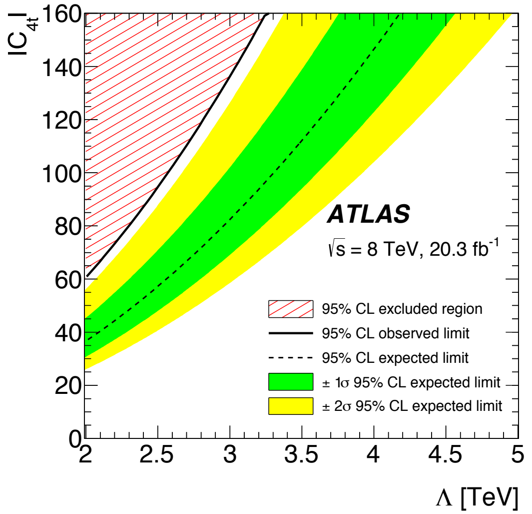


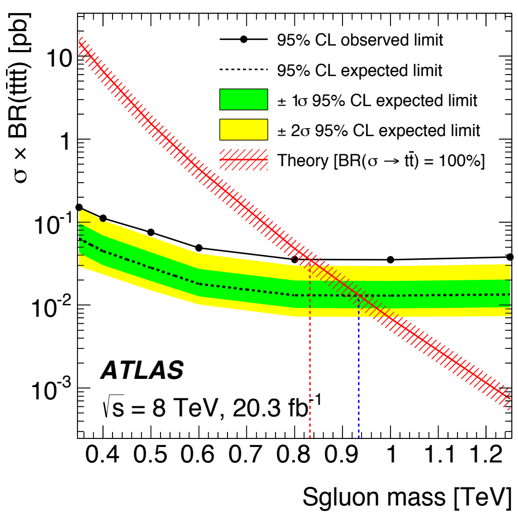


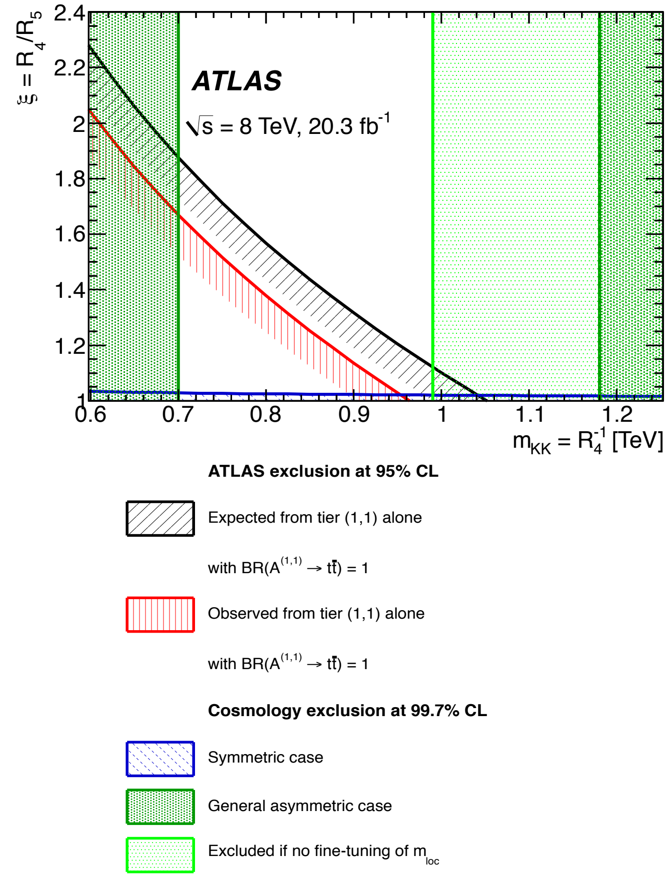
- Observed and expected limits on the pair production cross section as a function of
  - mass for b`-quark pair
  - T5/3 pair production
  - vector-like B
  - vector-like T quarks
- The vertical dashed lines indicate the expected and observed limits on the masses, and the shaded band around the theory cross section indicates the total uncertainty on the calculation

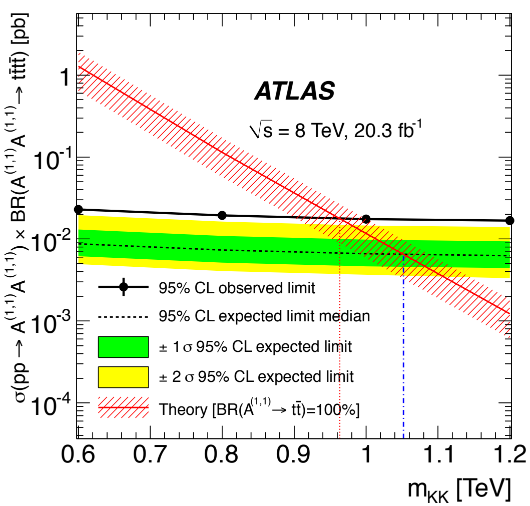
arXiv: 1504.04605
ATLAS Collaboration

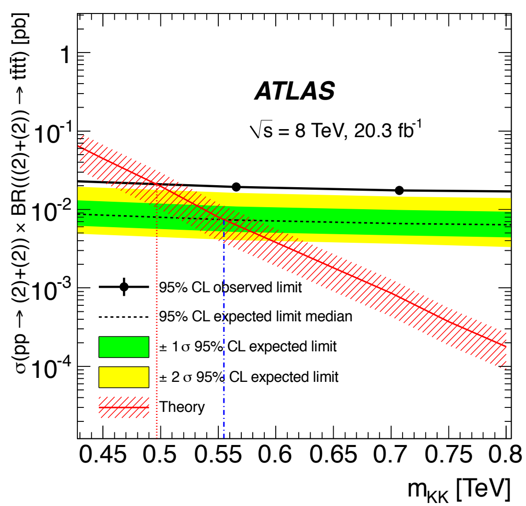
EXO: Events with b-jets and a pair of leptons of the same charge in proton-proton collisions











Four fermion contact interaction

$$\mathcal{L}_{4t} = \frac{C_{4t}}{\Lambda^2} \left(\bar{t}_{\mathrm{R}} \gamma^{\mu} t_{\mathrm{R}}\right) \left(\bar{t}_{\mathrm{R}} \gamma_{\mu} t_{\mathrm{R}}\right)$$

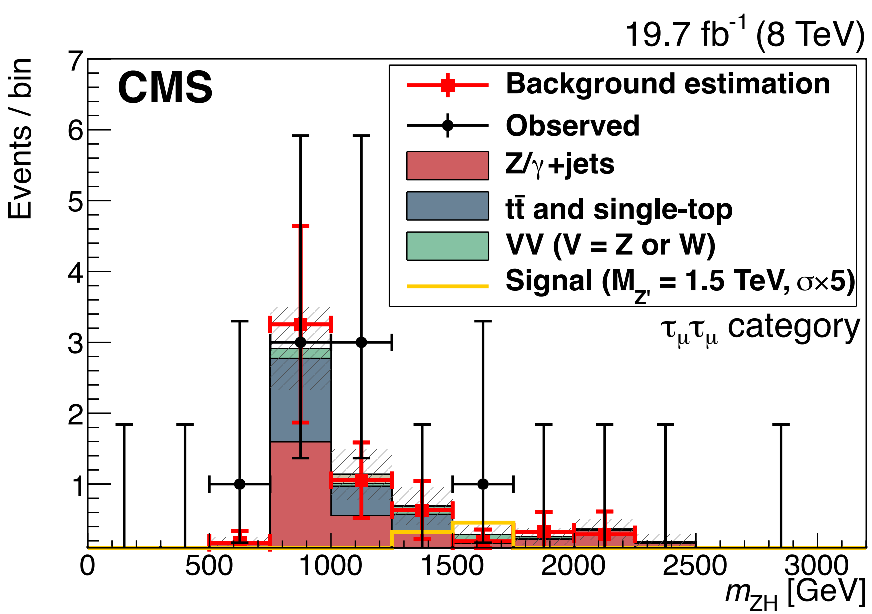
arXiv: 1504.04605
ATLAS Collaboration

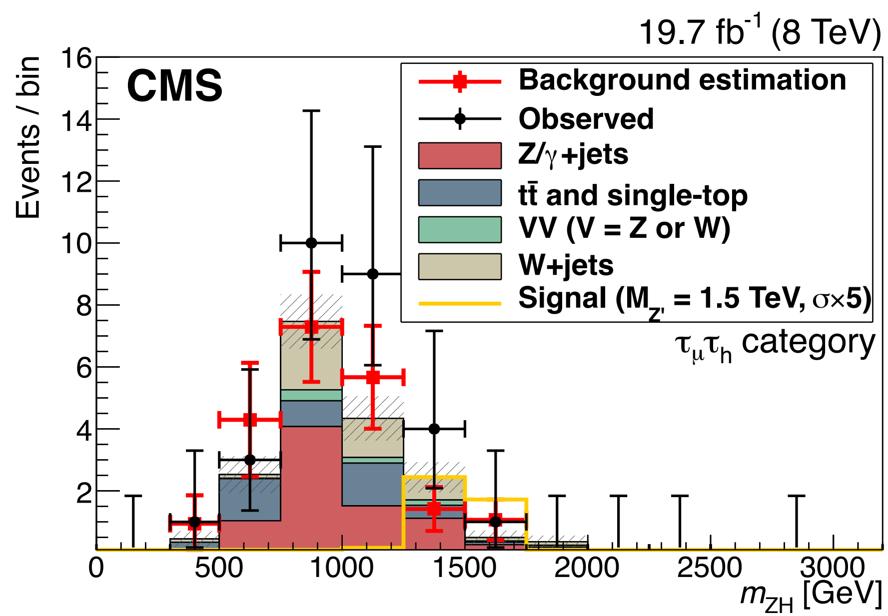
EXO: Search for narrow high-mass resonances decaying to Z and Higgs bosons

Motivation→ The final state consists of a merged jet pair and a τ pair resulting from the decays of Z and H bosons

Selection	$\tau_e\tau_e$, $\tau_e\tau_\mu$, $\tau_\mu\tau_\mu$	$\tau_e\tau_h$, $\tau_\mu\tau_h$	$\tau_h\tau_h$
$\lvert\vec{p}_T^{miss}\rvert$	>100 GeV	>50 GeV	>80 GeV
$p_{T,\ell}^{leading}$	—	>35 GeV	>50 GeV
$N_{b\text{-tagged jet}}$	=0	=0	—
$\Delta R_{\ell\ell}$	<1.0	<1.0	<1.0
$m_{\tau\tau}$	—	—	105–180 GeV

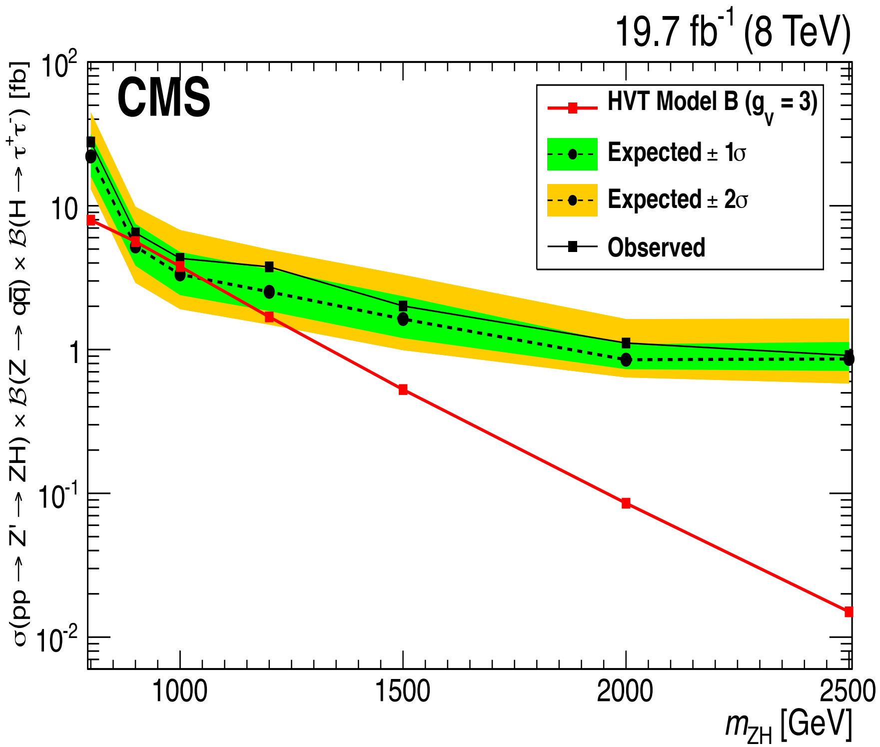
➢ the final products of the two quarks or the two leptons must be detected within a small angular interval

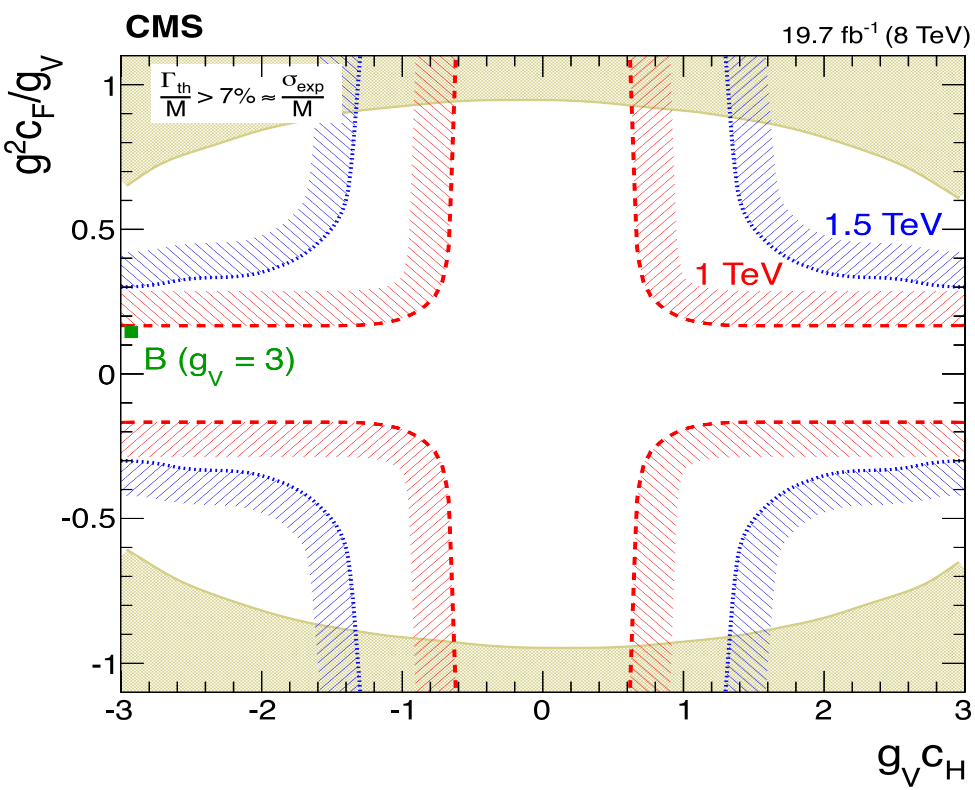




arXiv: 1502.04994
CMS Collaboration
Similar analysis from ATLAS Collaboration → arXiv: 1503.08089

EXO: Search for narrow high-mass resonances decaying to Z and Higgs bosons





Expected and observed upper limit on the

$$\sigma(Z')\,\mathcal{B}(Z' \to ZH)$$

for the six analysis channels combined

$\tau_e\tau_e, \tau_e\tau_\mu, \tau_\mu\tau_\mu \quad \tau_e\tau_h, \tau_\mu\tau_h \quad \tau_h\tau_h$

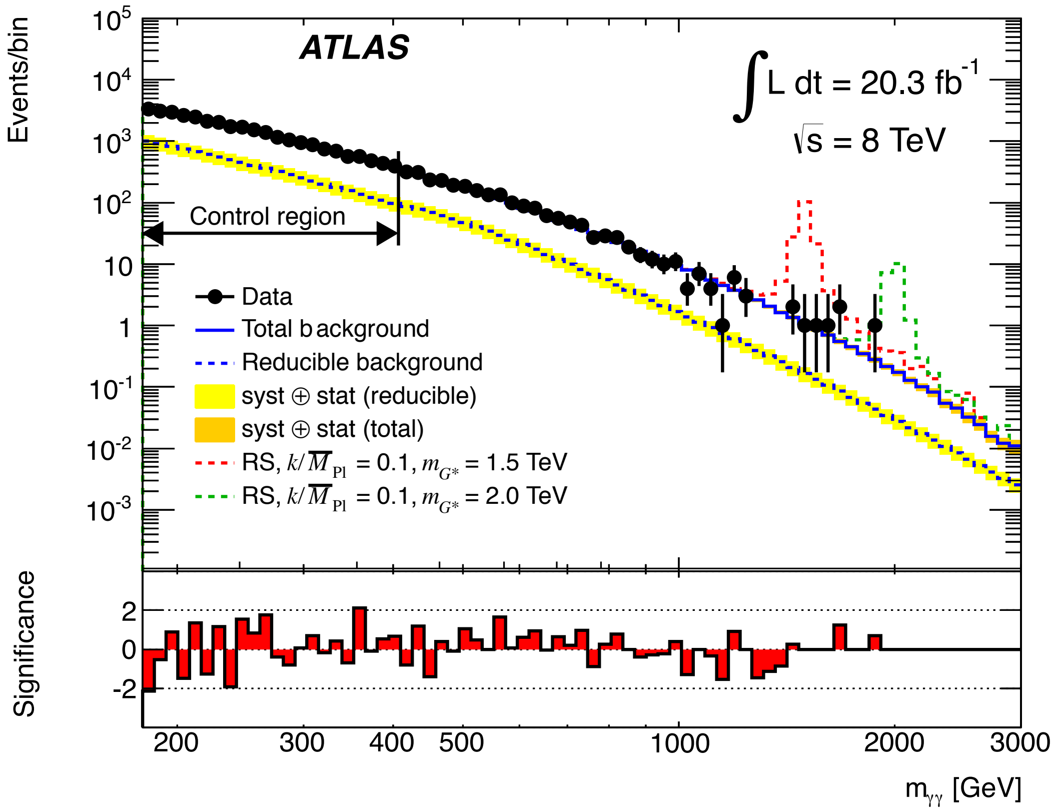
Exclusion regions in the plane of the HVT-model coupling constants for two resonance masses, 1.0 and 1.5 TeV

arXiv: 1502.04994
CMS Collaboration
Similar analysis from ATLAS Collaboration → arXiv: 1503.08089

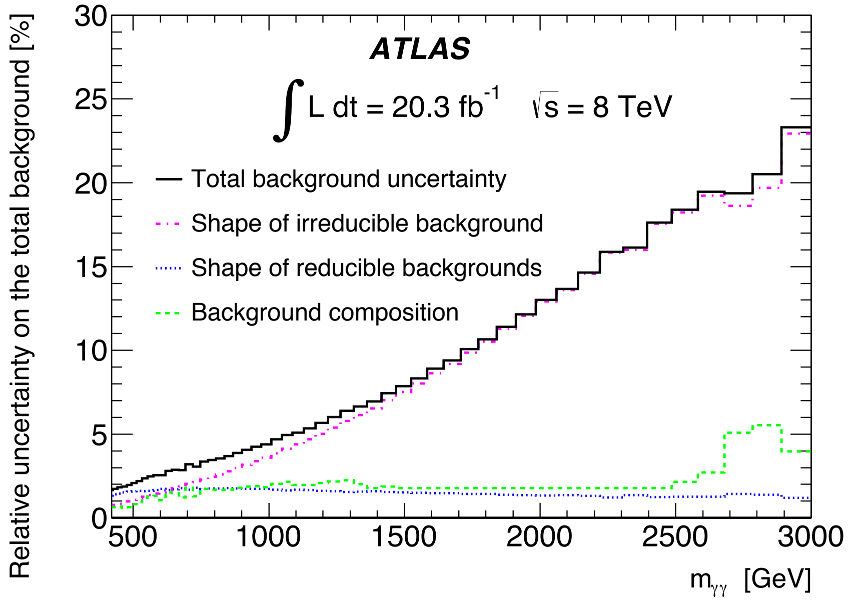
EXO: Search for high-mass diphoton resonances

Motivation→ Search for high mass resonances decaying to pair of photons

- a clean experimental signature: excellent mass resolution and modest backgrounds



Total background uncertainty

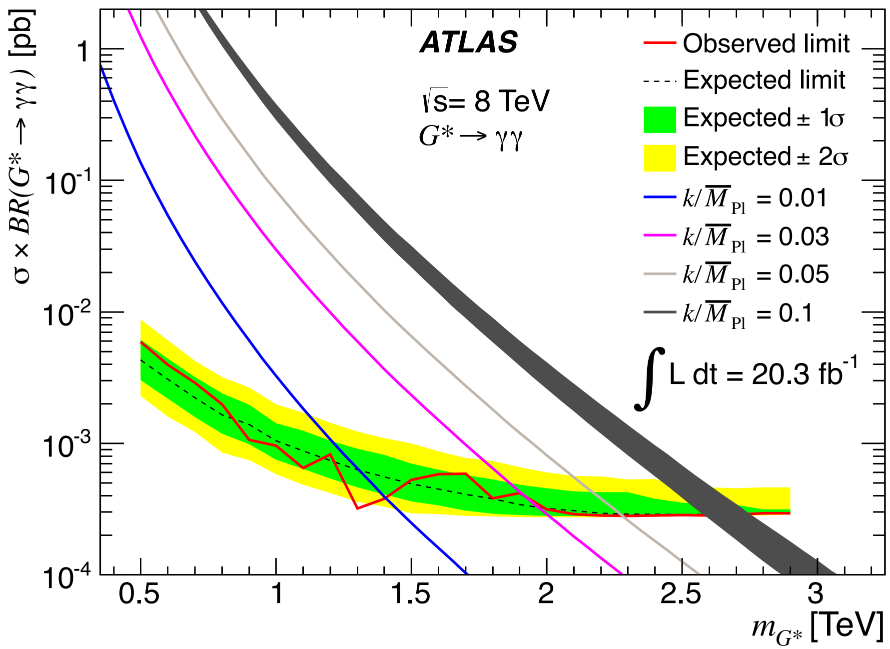


RS → Randall-Sundum Model

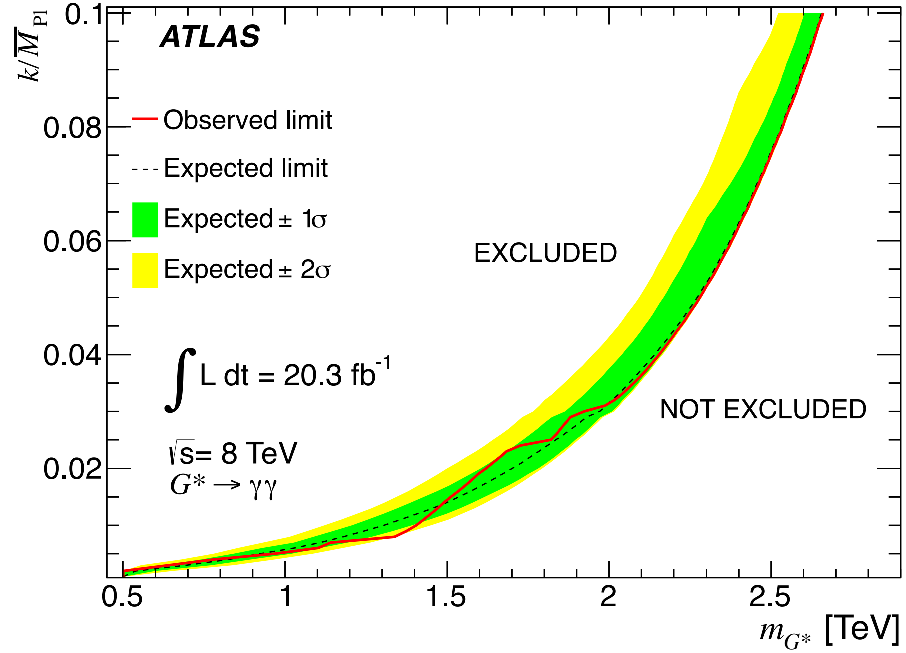
arXiv: 1505.05511
ATLAS Collaboration
Similar analysis from CMS Collaboration → arXiv: 1503.08089

EXO: Search for high-mass diphoton resonances

- As no evidence for a signal is found, upper limits at 95% confidence level are set on the production cross section times branching ratio, σ × *BR*(*G*∗ → γγ), for the lightest RS graviton



Expected and observed upper limits on σ × BR(G∗ → γγ) expressed at 95% CL, as a function of the assumed value of the graviton mass.

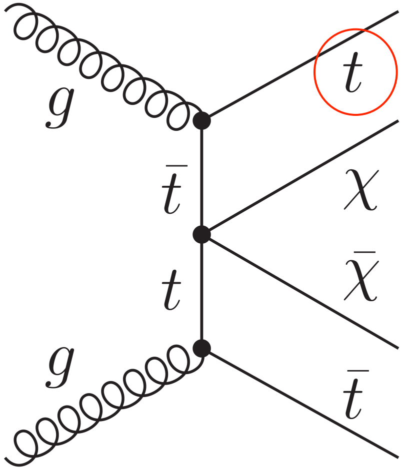


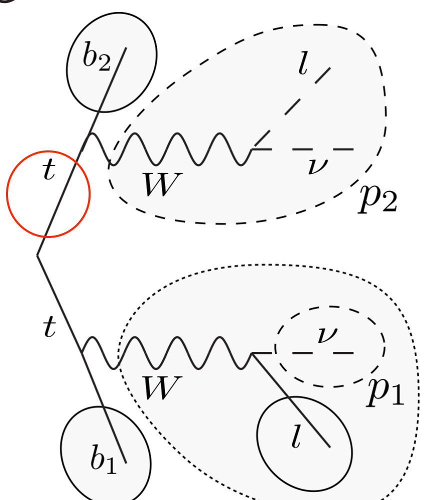
Expected and observed upper limits on *k*/*M*Pl expressed at 95% CL, as a function of the assumed value of the graviton mass.

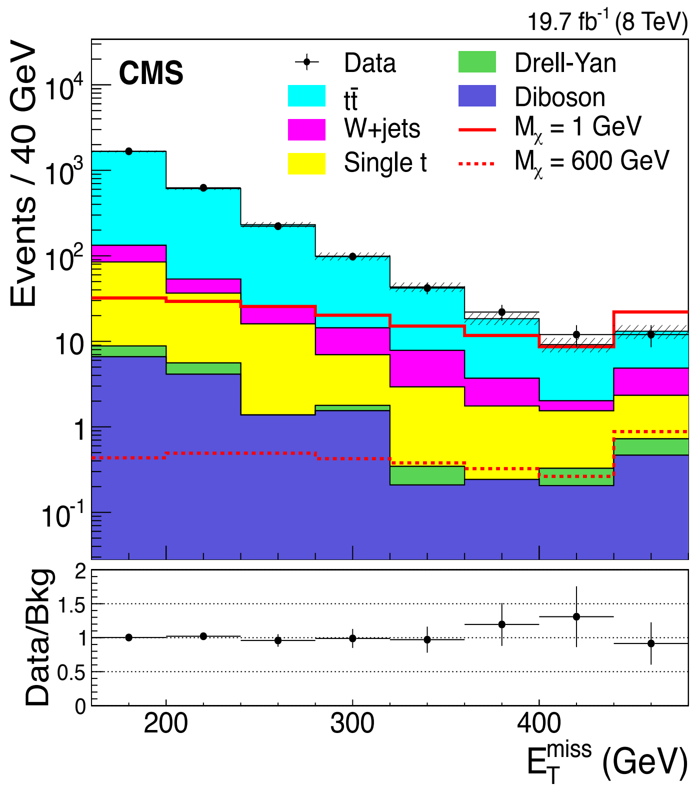
arXiv: 1505.05511
ATLAS Collaboration

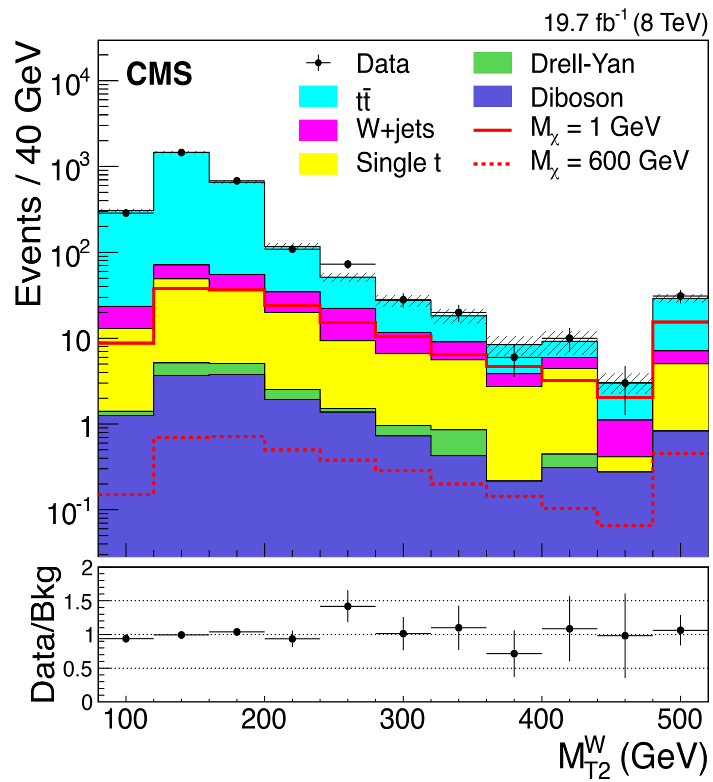
B2G: Dark Matter in association with top-quark pairs in the single lepton final state

Motivation→ Search for the production of DM particles in association with a pair of top quarks, and consider only **the scalar contact interaction between fermionic dark matter and top quarks**









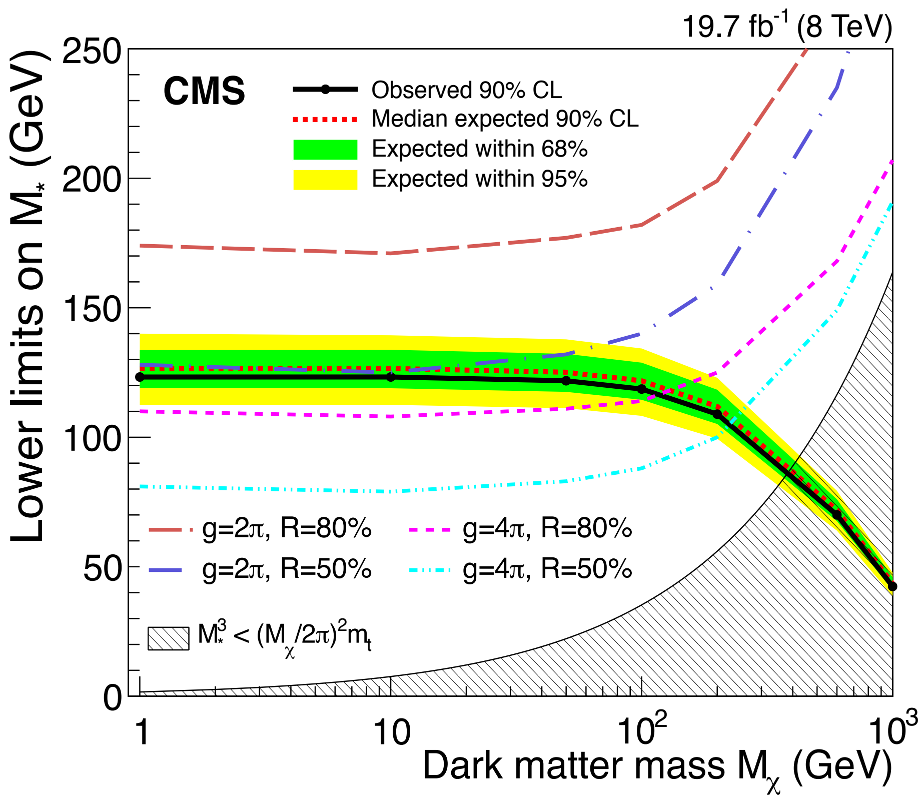
The search requires one lepton, multiple-jets and large MET

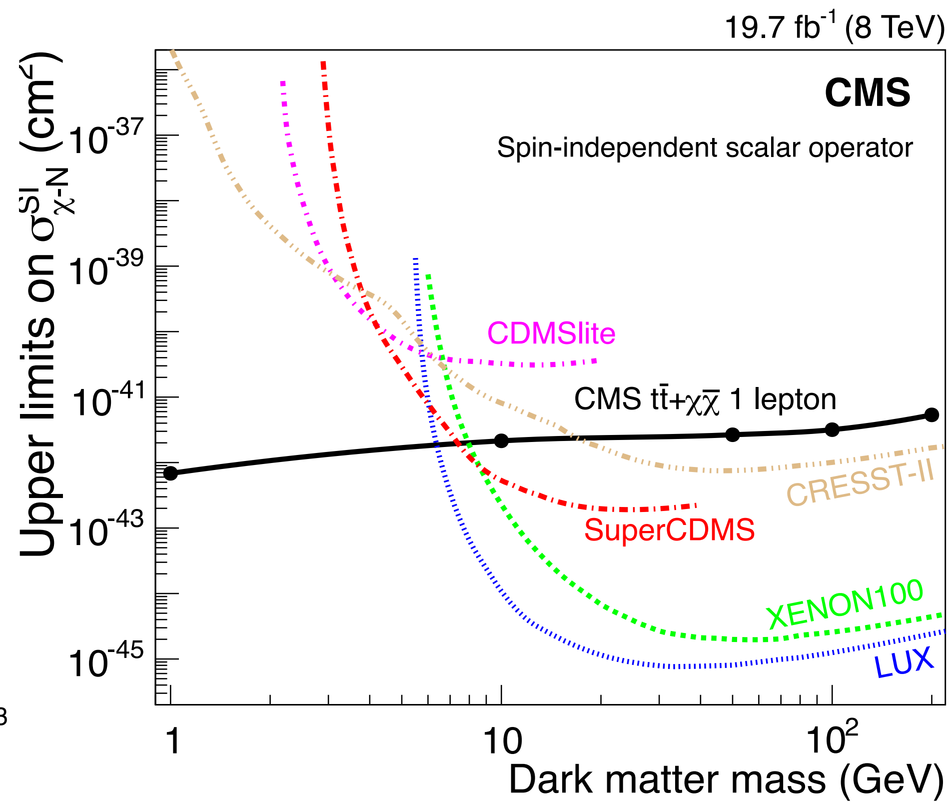
$$M_{T2}^W = \min\left(m_y \text{ consistent with: } \begin{Bmatrix} \vec{p}_1^{\,T} + \vec{p}_2^{\,T} = \vec{p}_T^{\,miss}, p_1^2 = 0, (p_1 + p_\ell)^2 = p_2^2 = M_W^2, \\ (p_1 + p_\ell + p_{b1})^2 = (p_2 + p_{b2})^2 = m_y^2 \end{Bmatrix} \right)$$

→ arXiv: 1203.4813

arXiv: 1504.03198
CMS Collaboration
Similar analysis from ATLAS → arXiv: 1410.4031

B2G: Dark Matter in association with top-quark pairs in the single lepton final state





$$L_{\text{int}} = \sum_q \sum_i C_{q\,i} \left(\bar{q}\Gamma_i^q \mathrm{q}\right)\left(\bar{\chi}\Gamma_i^\chi \chi\right)$$

$$L_{\text{int}} = \frac{m_{\mathrm{q}}}{M_*^3}\bar{q}q\bar{\chi}\chi$$

The 90% CL upper limits on the DM-nucleon spin-independent scattering cross section as a function of the DM particle mass for the scalar operator

arXiv: 1504.03198
CMS Collaboration
Similar analysis from ATLAS → arXiv: 1410.4031

Summary

- **Search for physics beyond the Standard Model is one of the main motivations for the LHC experiments**

- **The CMS and ATLAS Collaborations have very rich new physics programs**

- **So far, no significant deviation from the Standard Model observed**

  → Stringent limits on almost all SUSY scenarios and Exotic particles
  → Great progress in addressing "missing holes" as well as new models
  → There are some indications that Run 2 may show new physics just around the corner!

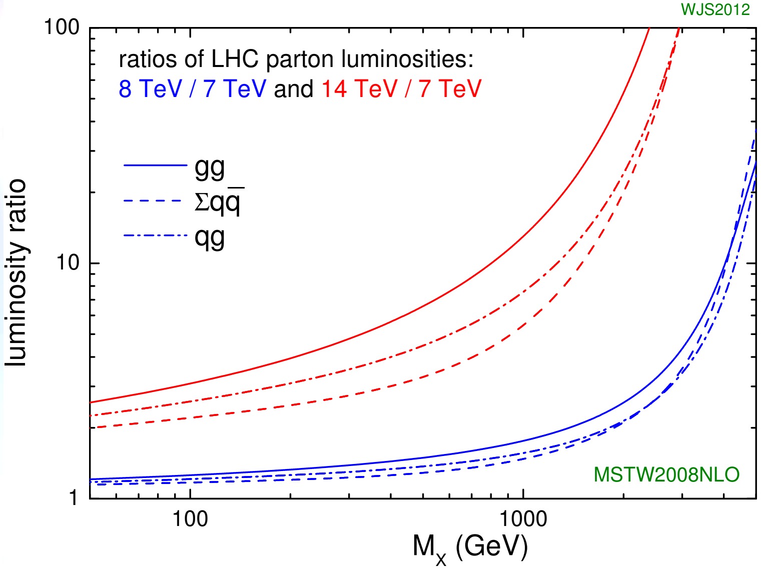
- **In June 2015, the LHC will restart at a centre-of-mass energy of 13 TeV - almost double that used for Run 1. This will affect the cross-sections of all physics processes, both Standard Model and Beyond Standard Model.**

  → The ratio of cross sections 2-2.5 times larger for Higgs processes, 4-5 times larger for ttbar
  → Stop pair production expects to see a boost of around a factor 10, and gluino production even higher ~20-30 times the cross section in Run 1.
  → BSM signatures Z`, excited quarks etc. are predicted a factor between 10-100

- **New era will greatly improve the discovery potential of many BSM searches, giving a very optimistic outlook for the LHC Run 2!**

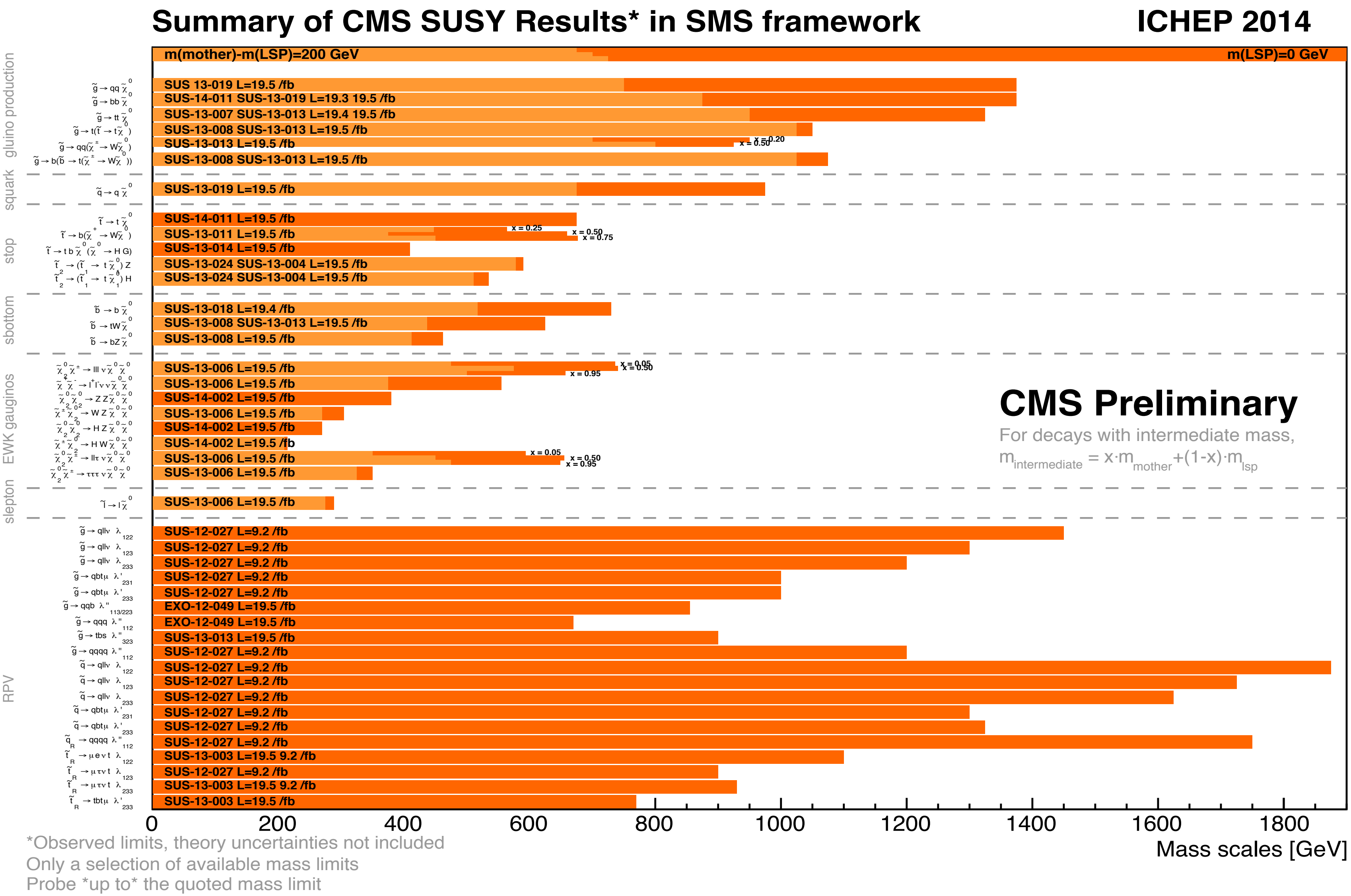
Outlook and Prospects for Run II

- **High expectations from dramatic energy and luminosity increase**
- **Challenges for the new era (TeV leptons boosted objects, higher pile-up etc.)**
- **Will need to start with the foundations (detector conditions, physics objects)**
→ continue the SM precision measurements effort, focus on Higgs and the Top quark
- **Look fast for new physics hints in the obvious directions once enough data collected**



ありがとうございます

SUSY Summary: The CMS Collaboration



SUSY Summary: The ATLAS Collaboration

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Feb 2015

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

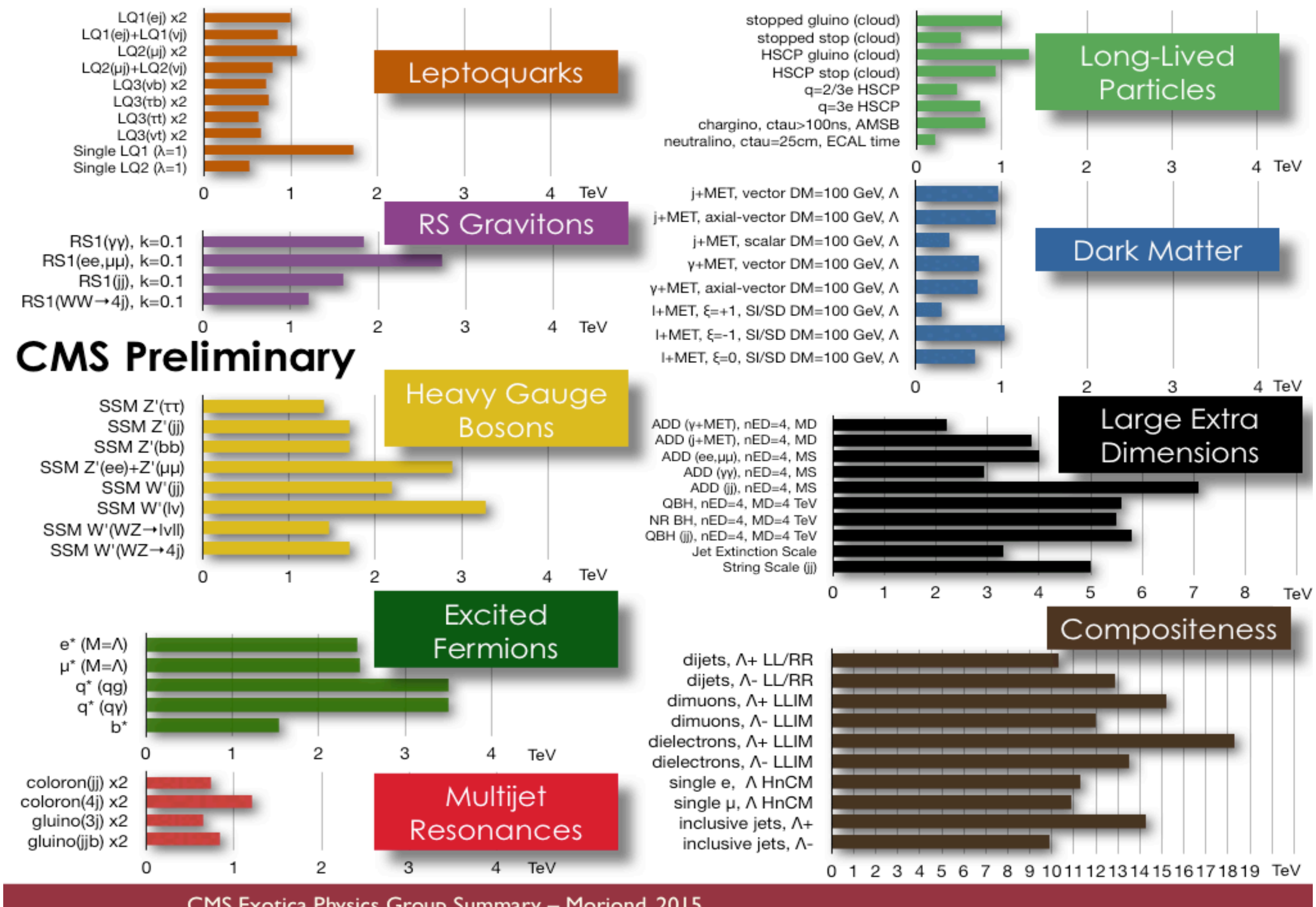
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	1405.7875
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{q}\tilde{q}\gamma, \tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	1 γ	0-1 jet	Yes	20.3	$\tilde{q}$ 250 GeV	$m(\tilde{q})-m(\tilde{\chi}_1^0)$ = m(c)	1411.1559
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	1 e,μ	3-6 jets	Yes	20	$\tilde{g}$ 1.2 TeV	$m(\tilde{\chi}_1^0)$<300 GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	1501.03555
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20	$\tilde{g}$ 1.32 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	$\tan\beta$ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e,\mu+\gamma$	-	Yes	4.8	$\tilde{g}$ 619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	$m(\tilde{\chi}_1^\pm)$=2 $m(\tilde{\chi}_1^0)$	1404.2500
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 110-167 GeV; 230-460 GeV	$m(\tilde{\chi}_1^\pm)$ = 2$m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)$=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 90-191 GeV; 215-530 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1403.4853, 1412.4742
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}_1^0$	0-1 e,μ	1-2 b	Yes	20	$\tilde{t}_1$ 210-640 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1407.0583,1406.1122
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}_1^0)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 140-465 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 100-350 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1407.0350
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 700 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 420 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0, h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 250 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 620 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$ 270 GeV	$m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	1310.3675
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$ 1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	10<$\tan\beta$<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 435 GeV	2<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model	1409.5542
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e+\mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e(\mu)+\tau$	1 $e,\mu+\tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.35 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 750 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^\pm)$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^\pm)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1t, \tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 490 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1501.01325

$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

10^{-1} 1 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

EXOTICA Summary: The CMS Collaboration



EXOTICA Summary: The ATLAS Collaboration

ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2015

ATLAS Preliminary

$\int \mathcal{L}\, dt = (1.0 - 20.3)\ \text{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\text{fb}^{-1}]$	Mass limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	20.3	M_D 5.25 TeV	$n = 2$	1502.01518
	ADD non-resonant $\ell\ell$	2e, μ	–	–	20.3	M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH → ℓq	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	20.3	M_{th} 5.82 TeV	$n = 6$	1407.1376
	ADD BH high N_{trk}	2 μ (SS)	–	–	20.3	M_{th} 4.7 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	20.3	M_{th} 5.8 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	1405.4254
	ADD BH high multijet	–	≥ 2 j	–	20.3	M_{th} 5.8 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	Preliminary
	RS1 $G_{KK} \to \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	20.3	G_{KK} mass 2.66 TeV	$k/\overline{M}_{Pl} = 0.1$	Preliminary
	Bulk RS $G_{KK} \to ZZ \to qq\ell\ell$	2 e, μ	2 j / 1 J	–	20.3	G_{KK} mass 740 GeV	$k/\overline{M}_{Pl} = 1.0$	1409.6190
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	2 j / 1 J	Yes	20.3	W′ mass 700 GeV	$k/\overline{M}_{Pl} = 1.0$	1503.04677
	Bulk RS $G_{KK} \to HH \to b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK} \to t\bar{t}$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.2 TeV	BR = 0.925	ATLAS-CONF-2015-009
	2UED / RPP	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	KK mass 960 GeV		Preliminary
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	20.3	Z′ mass 2.9 TeV		1405.4123
	SSM $Z' \to \tau\tau$	2 τ	–	–	19.5	Z′ mass 2.02 TeV		1502.07177
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	20.3	W′ mass 3.24 TeV		1407.7494
	EGM $W' \to WZ \to \ell\nu\, \ell'\ell'$	3 e, μ	–	Yes	20.3	W′ mass 1.52 TeV		1406.4456
	EGM $W' \to WZ \to qq\ell\ell$	2 e, μ	2 j / 1 J	–	20.3	W′ mass 1.59 TeV		1409.6190
	HVT $W' \to WH \to \ell\nu bb$	1 e, μ	2 b	Yes	20.3	W′ mass 1.47 TeV	$g_V = 1$	Preliminary
	LRSM $W'_R \to t\bar{b}$	1 e, μ	2 b, 0-1 j	Yes	20.3	W′ mass 1.92 TeV		1410.4103
	LRSM $W'_R \to t\bar{b}$	0 e, μ	≥ 1 b, 1 J	–	20.3	W′ mass 1.76 TeV		1408.0886
CI	CI qqqq	–	2 j	–	17.3	Λ 12.0 TeV	$\eta_{LL} = -1$	Preliminary
	CI $qq\ell\ell$	2 e, μ	–	–	20.3	Λ 21.6 TeV	$\eta_{LL} = -1$	1407.2410
	CI uutt	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	Λ 4.35 TeV	$\lvert C_{LL}\rvert = 1$	Preliminary
DM	EFT D5 operator (Dirac)	0 e, μ	≥ 1 j	Yes	20.3	M_* 974 GeV	at 90% CL for $m(\chi) < 100$ GeV	1502.01518
	EFT D9 operator (Dirac)	0 e, μ	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	1 e, μ, 1 τ	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	VLQ $TT \to Ht + X, Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	T mass 785 GeV	isospin singlet	ATLAS-CONF-2015-012
	VLQ $TT \to Zt + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	T mass 735 GeV	T in (T,B) doublet	1409.5500
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $BB \to Wt + X$	1 e, μ	≥ 1 b, ≥ 5 j	Yes	20.3	B mass 640 GeV	isospin singlet	Preliminary
	$T_{5/3} \to Wt$	1 e, μ	≥ 1 b, ≥ 5 j	Yes	20.3	$T_{5/3}$ mass 840 GeV		Preliminary
Excited fermions	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	20.3	q* mass 3.5 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1309.3230
	Excited quark $q^* \to qg$	–	2 j	–	20.3	q* mass 4.09 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1407.1376
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2 j or 1 j	Yes	4.7	b* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \to \ell\gamma$	2 e, μ, 1 γ	–	–	13.0	ℓ* mass 2.2 TeV	Λ = 2.2 TeV	1308.1364
	Excited lepton $\nu^* \to \ell W, \nu Z$	3 e, μ, τ	–	–	20.3	ν* mass 1.6 TeV	Λ = 1.6 TeV	1411.2921
Other	LSTC $a_T \to W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2 e, μ (SS)	–	–	20.3	$H^{\pm\pm}$ mass 551 GeV	DY production, BR($H_L^{\pm\pm} \to \ell\ell$)=1	1412.0237
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \to \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	Preliminary
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g\rvert = 1g_D$	1207.6411

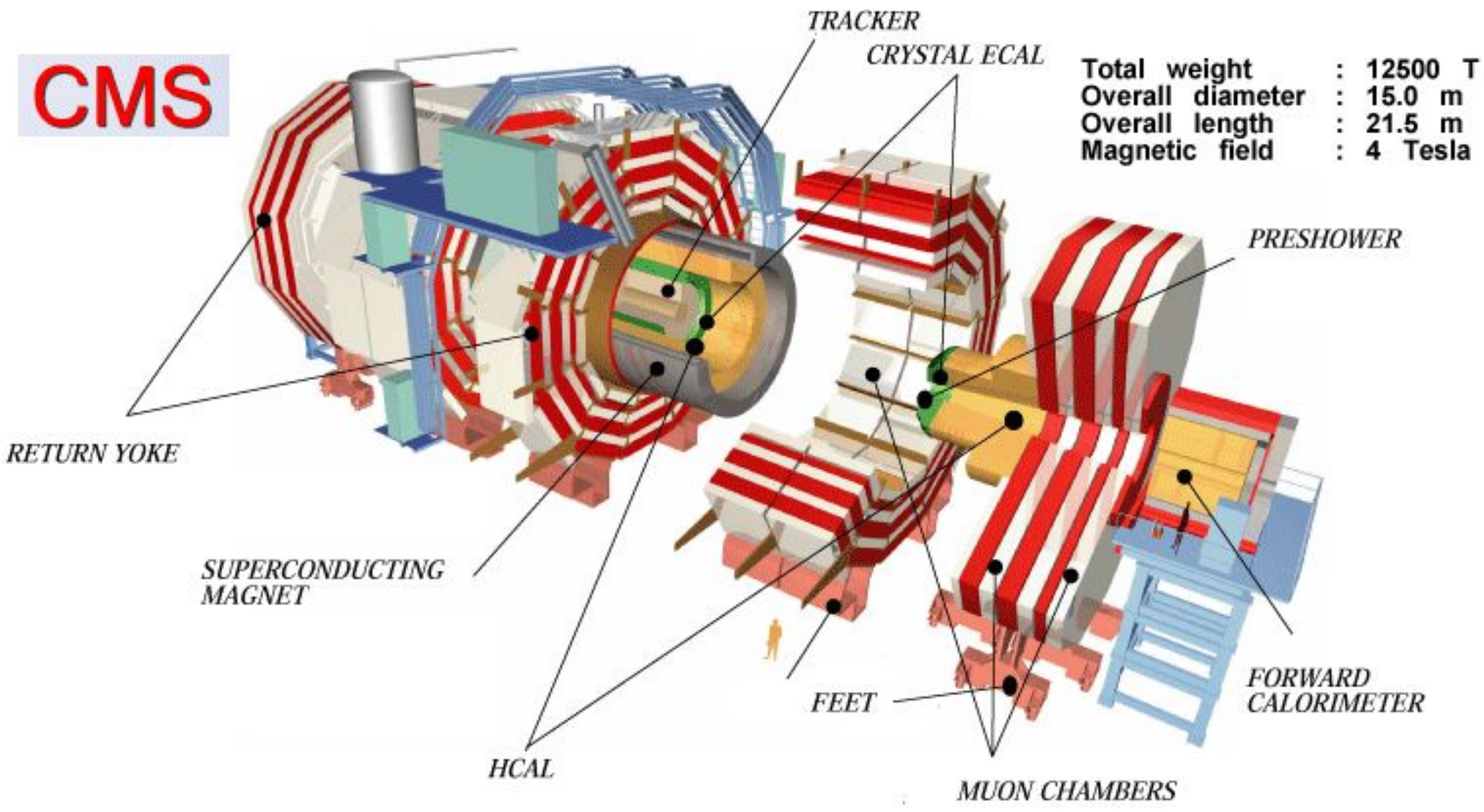
$\sqrt{s} = 7$ TeV | $\sqrt{s} = 8$ TeV

Mass scale [TeV] (10^{-1}, 1, 10)

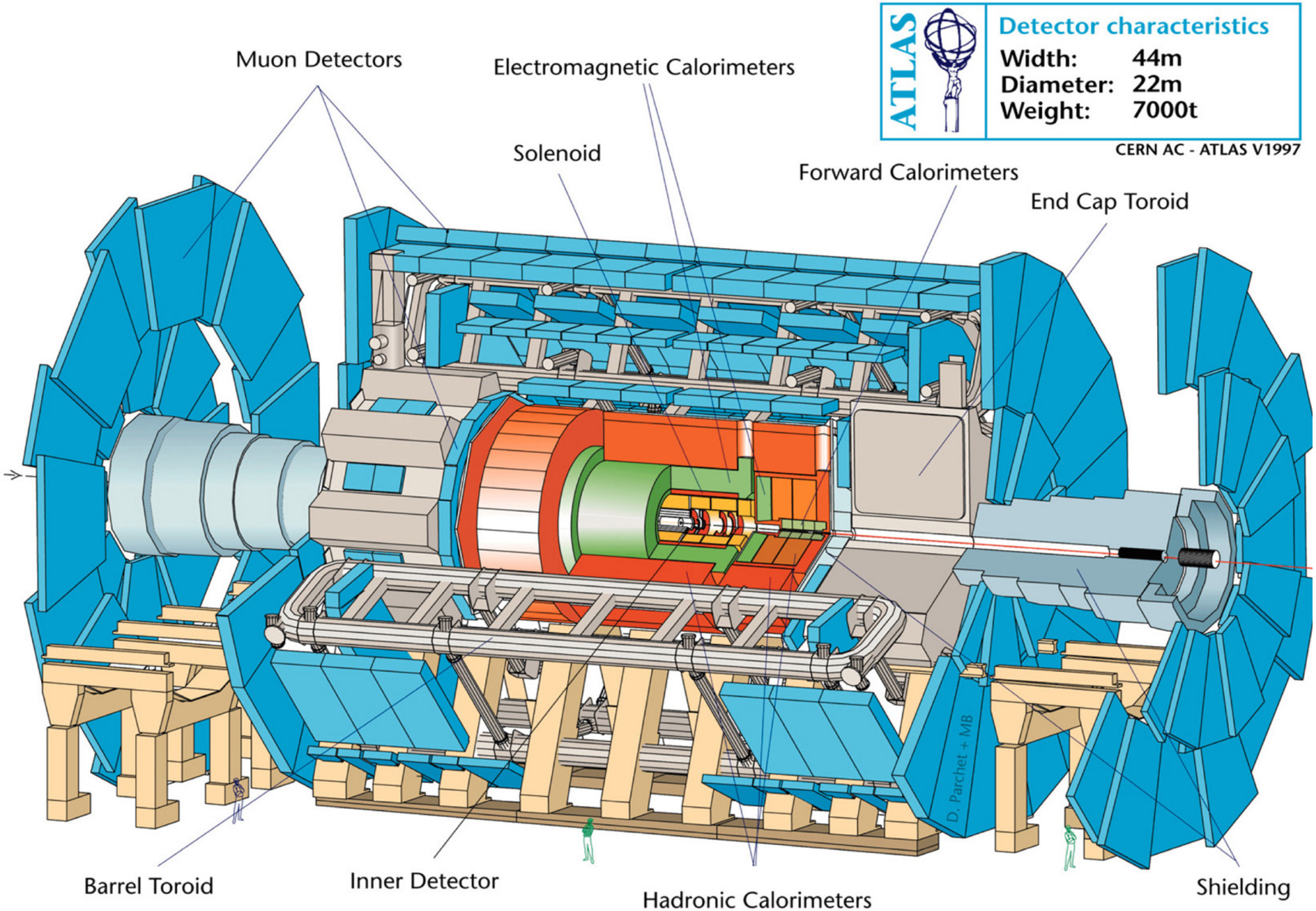
*Only a selection of the available mass limits on new states or phenomena is shown.


Backup
Shift

The CMS Detector

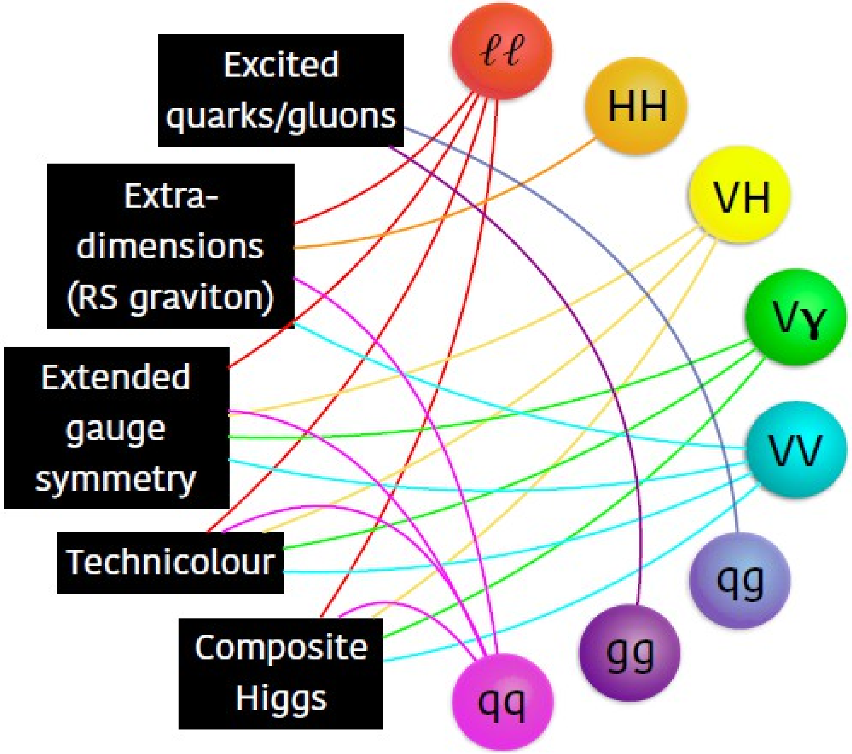


The ATLAS Detector



Other models

- Composite Higgs / Little Higgs → **Vector-like quarks (T,B)**
  - Can cancel Higgs mass divergences from top loops
  - Color-triplet spin-1/2 fermions
  - Left and right handed under SU(2)



- These and other models can also predict **new resonances**
- Great way to find BSM!

*Courtesy Andy Haas

SUSY: 3rd generation squarks in fully hadronic final states

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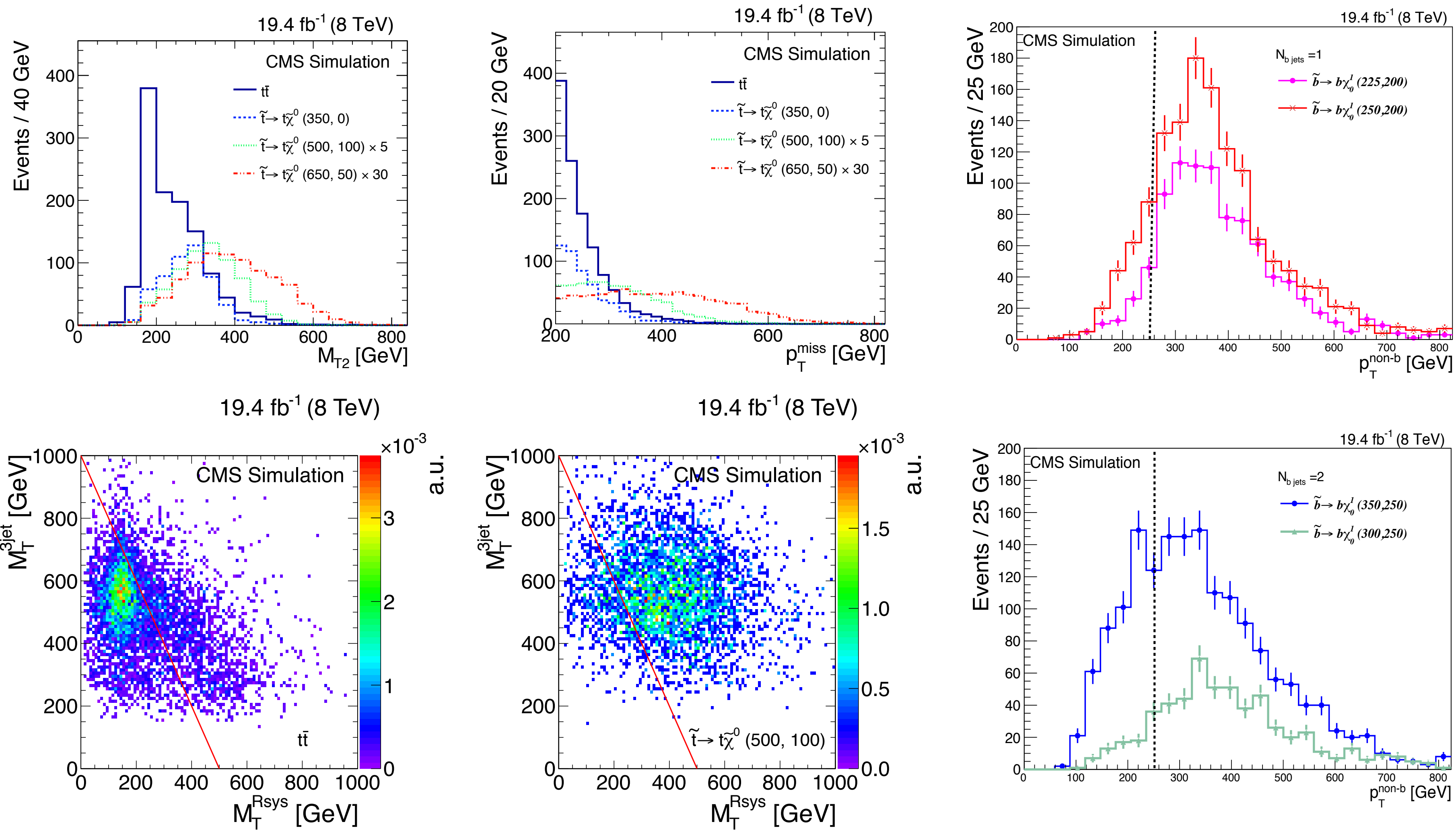

arXiv: 1503.0803
CMS Collaboration

SUSY: 3rd generation squarks in fully hadronic final states

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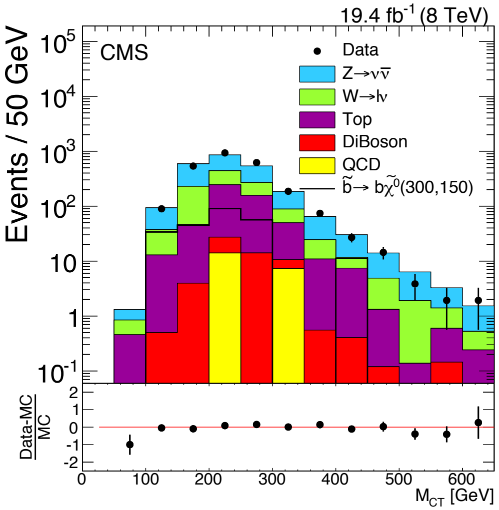

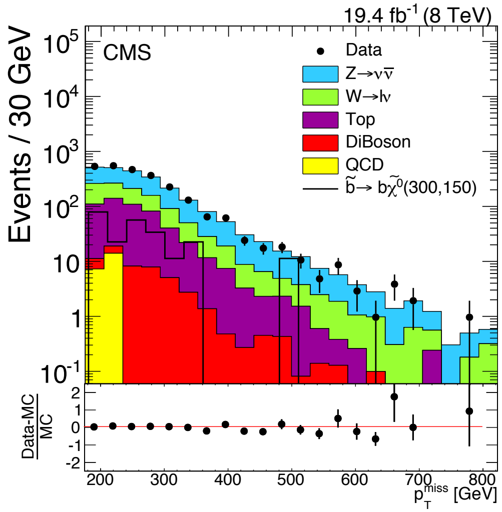

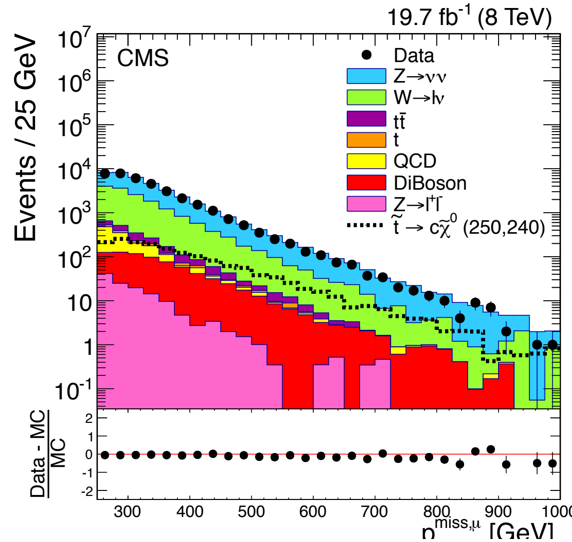

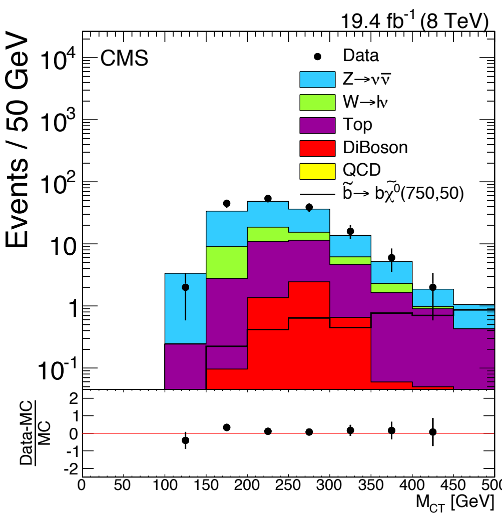

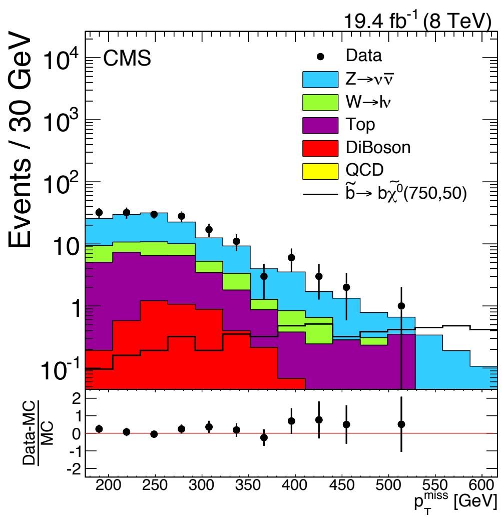

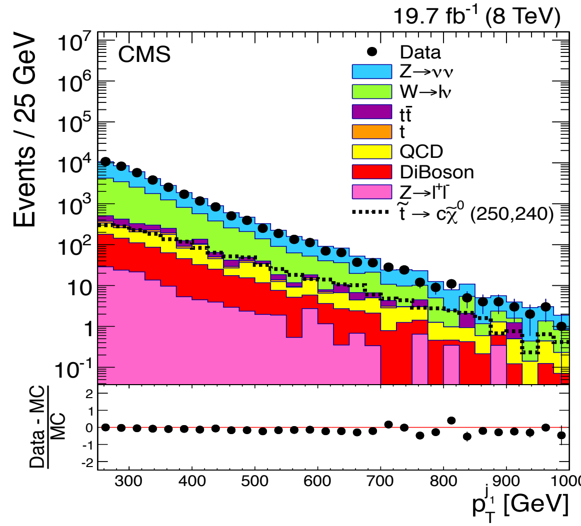

arXiv: 1503.0803
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SUSY: 3rd generation squarks in fully hadronic final states

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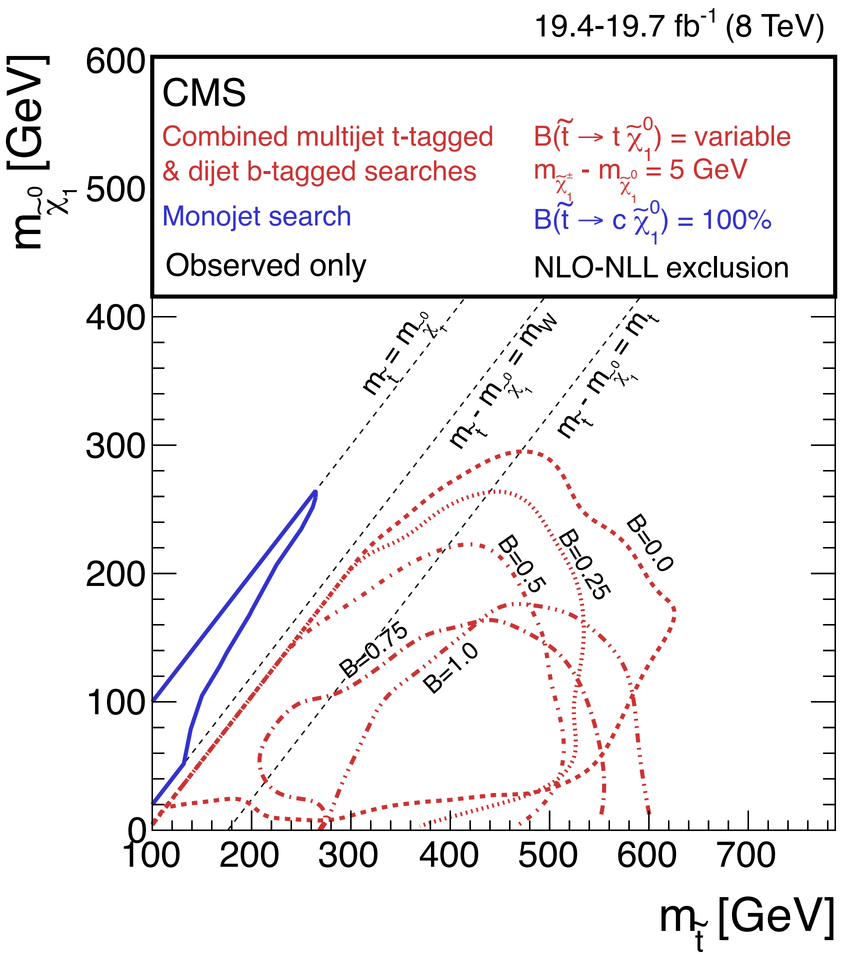

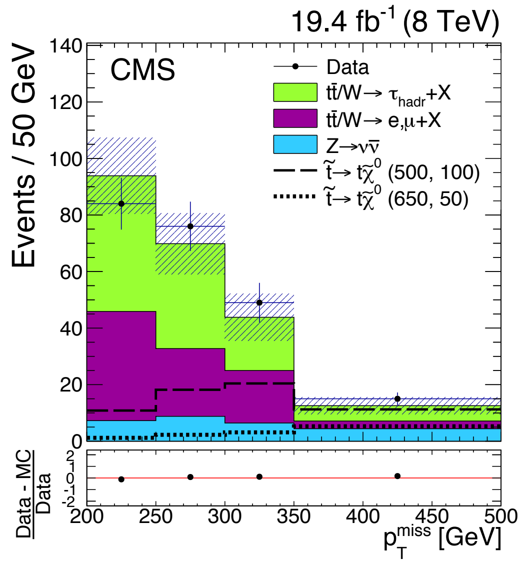

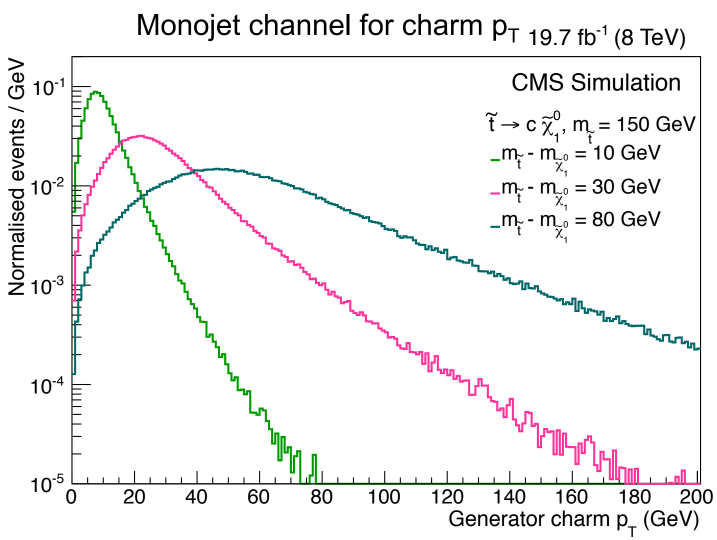

arXiv: 1503.0803
CMS Collaboration

SUSY: Same-flavour opp.-sign dilepton pair, jets, and MET

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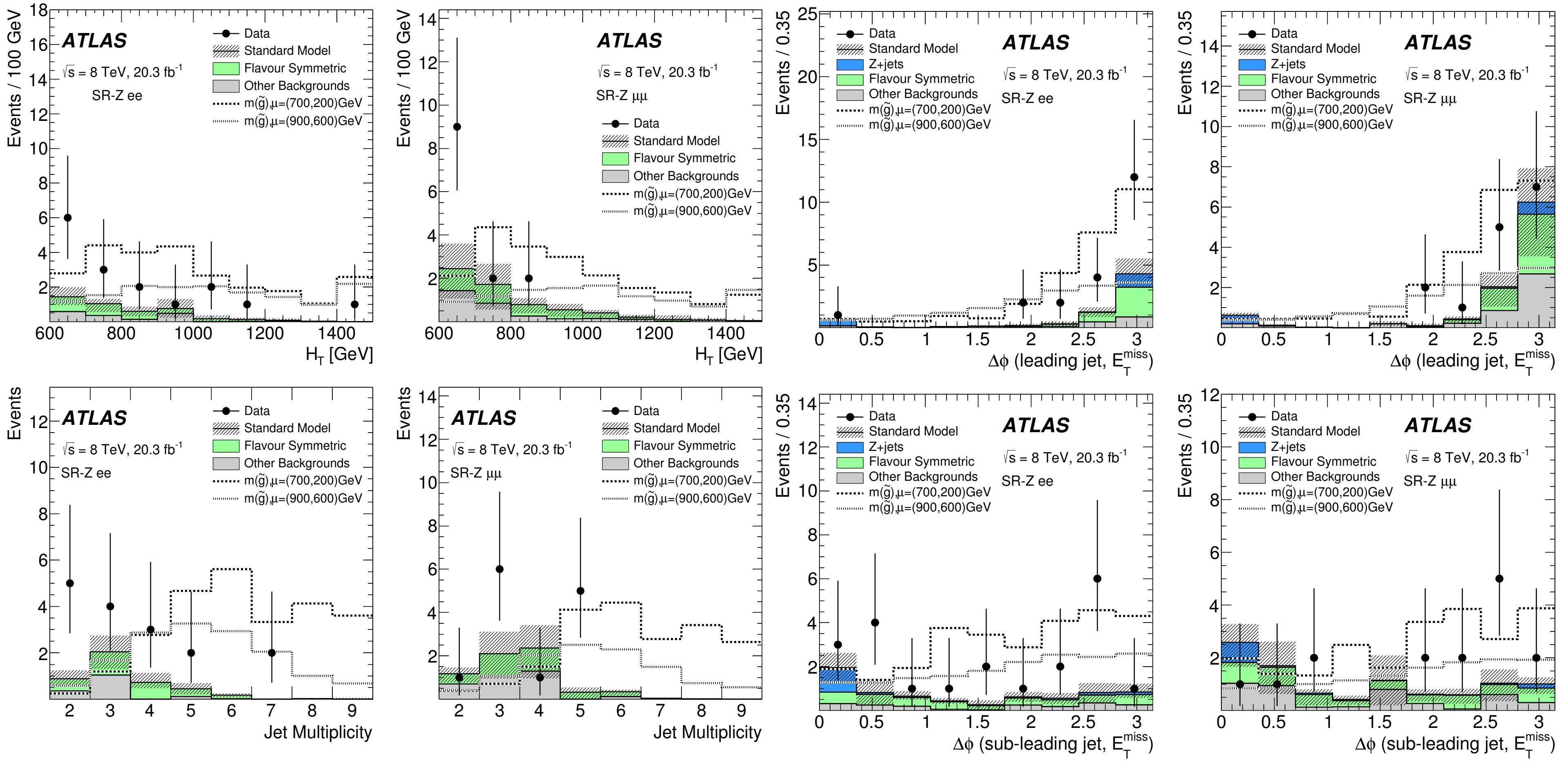

arXiv: 1503.03290
ATLAS Collaboration

SUSY: Same-flavour opp.-sign dilepton pair, jets, and MET

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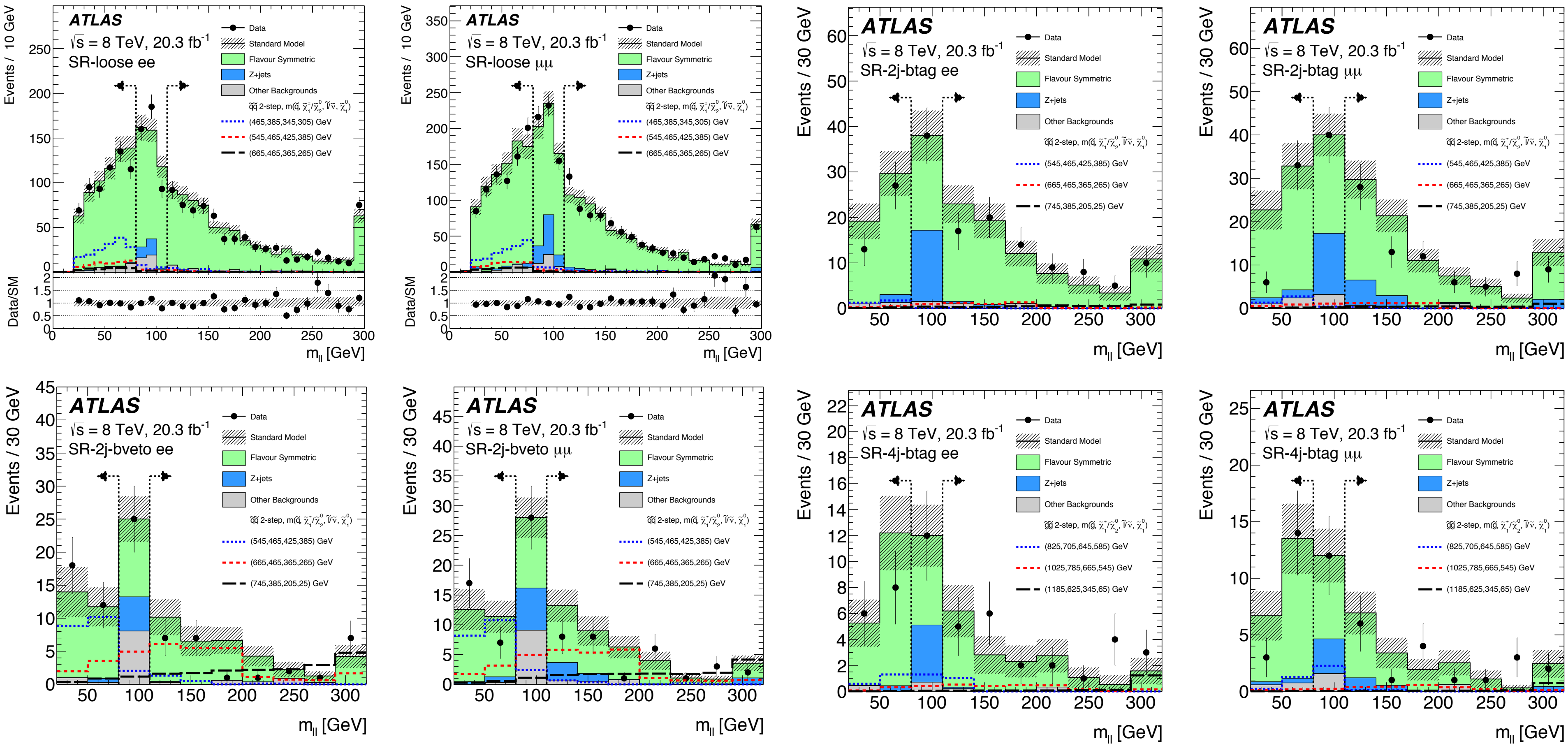

arXiv: 1503.03290
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SUSY: Same-flavour opp.-sign dilepton pair, jets, and MET

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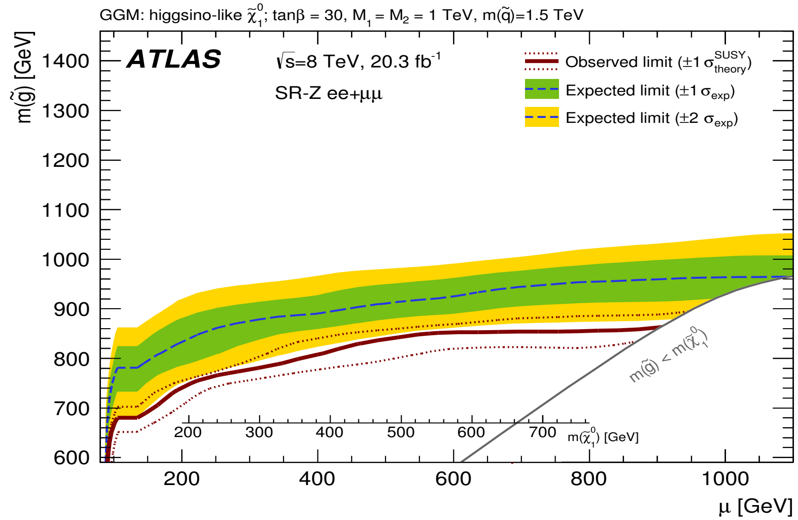
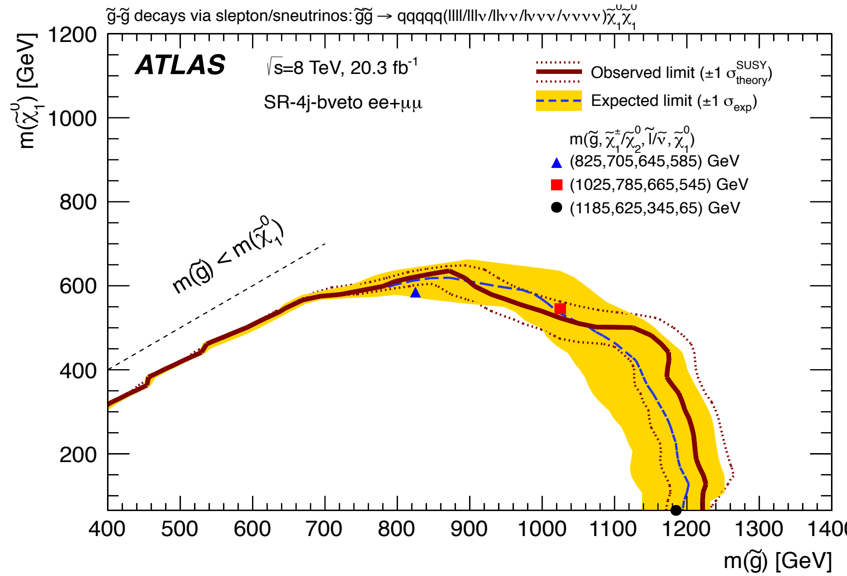
On-Z Region	E_T^{miss} [GeV]	H_T [GeV]	n_{jets}	$m_{\ell\ell}$ [GeV]	SF/DF	E_T^{miss} sig. [$\sqrt{GeV}$]	f_{ST}	$\Delta\phi(jet_{12}, E_T^{miss})$
Signal regions								
SR-Z	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	-	-	> 0.4
Control regions								
Seed region	-	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	< 0.9	< 0.6	-
CReμ	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	DF	-	-	> 0.4
CRT	> 225	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	-	-	> 0.4
Validation regions								
VRZ	< 150	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	-	-	-
VRT	150–225	> 500	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	-	-	> 0.4
VRTZ	150–225	> 500	≥ 2	$81 < m_{\ell\ell} < 101$	SF	-	-	> 0.4

Off-Z Region	E_T^{miss} [GeV]	n_{jets}	$n_{b\text{-}jets}$	$m_{\ell\ell}$ [GeV]	SF/DF
Signal regions					
SR-2j-bveto	> 200	≥ 2	= 0	$m_{\ell\ell} \notin [80, 110]$	SF
SR-2j-btag	> 200	≥ 2	≥ 1	$m_{\ell\ell} \notin [80, 110]$	SF
SR-4j-bveto	> 200	≥ 4	= 0	$m_{\ell\ell} \notin [80, 110]$	SF
SR-4j-btag	> 200	≥ 4	≥ 1	$m_{\ell\ell} \notin [80, 110]$	SF
SR-loose	> (150, 100)	(2, ≥ 3)	-	$m_{\ell\ell} \notin [80, 110]$	SF
Control regions					
CRZ-2j-bveto	> 200	≥ 2	= 0	$80 < m_{\ell\ell} < 110$	SF
CRZ-2j-btag	> 200	≥ 2	≥ 1	$80 < m_{\ell\ell} < 110$	SF
CRZ-4j-bveto	> 200	≥ 4	= 0	$80 < m_{\ell\ell} < 110$	SF
CRZ-4j-btag	> 200	≥ 4	≥ 1	$80 < m_{\ell\ell} < 110$	SF
CRZ-loose	> (150, 100)	(2, ≥ 3)	-	$80 < m_{\ell\ell} < 110$	SF
CRT-2j-bveto	> 200	≥ 2	= 0	$m_{\ell\ell} \notin [80, 110]$	DF
CRT-2j-btag	> 200	≥ 2	≥ 1	$m_{\ell\ell} \notin [80, 110]$	DF
CRT-4j-bveto	> 200	≥ 4	= 0	$m_{\ell\ell} \notin [80, 110]$	DF
CRT-4j-btag	> 200	≥ 4	≥ 1	$m_{\ell\ell} \notin [80, 110]$	DF
CRT-loose	> (150, 100)	(2, ≥ 3)	-	$m_{\ell\ell} \notin [80, 110]$	DF
Validation regions					
VR-offZ	100-150	= 2	-	$m_{\ell\ell} \notin [80, 110]$	SF



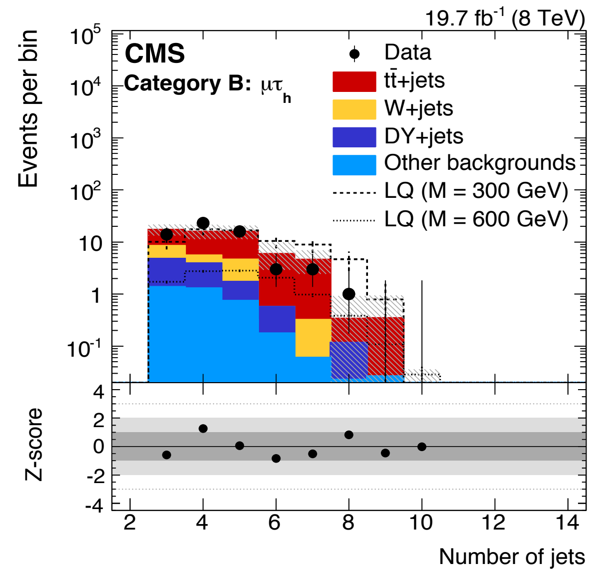


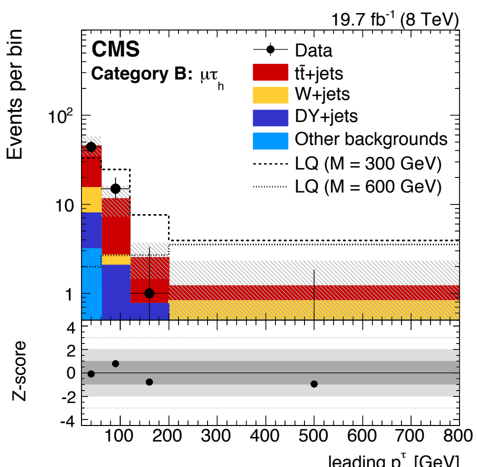
arXiv: 1503.03290
ATLAS Collaboration

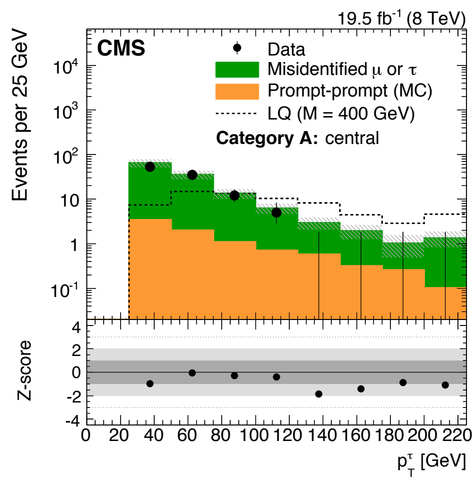
EXO: Third-generation scalar leptoquarks in the $t\tau$ channel

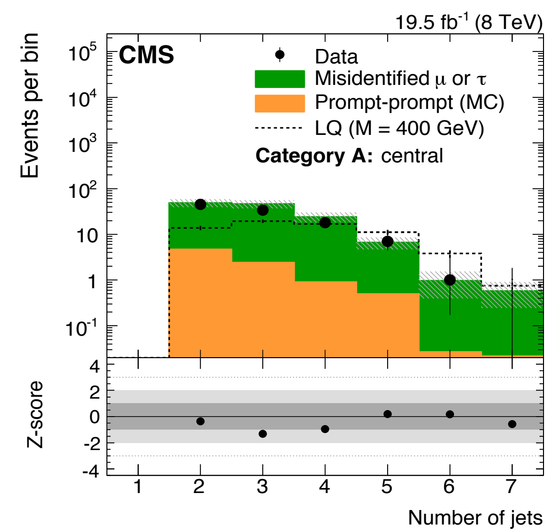
Backup slides

Systematic uncertainty	Magnitude (%)	Category A B (%)	Category A S (%)	Category B $\mu\tau_h$ ch. B (%)	Category B $\mu\tau_h$ ch. S (%)	Category B $e\tau_h$ ch. B (%)	Category B $e\tau_h$ ch. S (%)
Integrated luminosity	2.6	0.4/1.2	2.6	2.6	2.6	2.6	2.6
Electron reco/ID/iso & trigger	p_T, η dependent	—	—	—	—	1.4	2.2
Muon reco/ID/iso & trigger	1.1	0.1/0.5	1.1	0.9	0.9	—	—
τ lepton reco/ID/iso	6.0	0.8/2.8	6.0	1.5	3.0	0.6	3.1
Muon momentum scale & resolution	p_T dependent	0.1/0.3	0.4	—	—	—	—
τ lepton energy scale	3.0	1.2/4.1	2.0	2.3	2.7	0.6	1.5
τ lepton energy resolution	10.0	0.2/0.8	0.9	1.2	1.3	0.2	0.1
Jet energy scale	p_T, η dependent	0.9/3.2	1.9	4.2	1.9	5.6	2.7
Jet energy resolution	η dependent	0.4/1.2	1.0	0.8	0.3	1.6	0.8
Pileup	5.0	0.1/1.2	1.0/2.5	0.8	0.3	0.9	0.5
PDF (on acceptance)	—	—	$^{+2.9}_{-4.3}/^{+2.4}_{-6.2}$	—	0.7	—	0.9
PDF (on background)	—	—	—	8.7	—	8.3	—
Matrix method	—	23.1/15.3	—	—	—	—	—
Jet $\to \tau$ misidentification rate	p_T dependent	—	—	8.2	1.0	10.9	0.8
e $\to \tau$ misidentification rate	η dependent	—	—	0.1	0.1	0.1	0.1
$t\bar{t}$ factorization/renormalization	$^{+100}_{-50}$	—	—	$^{+6.1}_{-5.9}$	—	$^{+2.9}_{-2.7}$	—
Top quark p_T re-weighting	p_T dependent	—	—	0.1	—	0.1	—
W+jets factorization/renormalization	$^{+100}_{-50}$	—	—	4.3	—	0.3	—
W+jets matching threshold	$^{+100}_{-50}$	—	—	1.3	—	2.5	—









arXiv: 1503.09049
CMS Collaboration

EXO: Third-generation scalar leptoquarks in the tτ channel

Backup slides

Category A

M_{LQ_3} (GeV)	p_{T}^{τ} (GeV)	S_{T} (GeV)	$N_{\mathrm{Bkg}}^{\mathrm{PP}}$ ± (stat)	Total $N_{\mathrm{Bkg}}^{\mathrm{Exp}}$ ± (stat) ± (syst)	N^{Obs}	Z-score	$N_{\mathrm{LQ}_3}^{\mathrm{Exp}}$ ± (stat)	ϵ_{LQ_3} (%)
Central channel: $\lvert\widetilde{\eta}\rvert < 0.9$								
200	35	410	8.5 ± 1.0	128 ± 5 ± 25	105	−1.0	53 ± 21	0.04
250	35	410	8.5 ± 1.0	128 ± 5 ± 25	105	−1.0	252 ± 24	0.58
300	50	470	4.2 ± 0.5	39.9 ± 2.9 ± 8.3	27	−1.5	153 ± 11	0.98
350	50	490	4.0 ± 0.5	34.6 ± 2.7 ± 7.1	25	−1.2	92.4 ± 5.6	1.45
400	65	680	0.9 ± 0.2	7.2 ± 1.2 ± 1.7	4	−1.0	28.4 ± 2.1	1.00
450	65	700	0.8 ± 0.2	6.3 ± 1.1 ± 1.6	4	−0.8	17.3 ± 1.1	1.27
500	65	770	0.5 ± 0.2	3.2 ± 0.8 ± 0.8	4	+0.5	9.8 ± 0.6	1.43
550	65	800	0.4 ± 0.1	2.7 ± 0.8 ± 0.6	4	+0.7	6.1 ± 0.3	1.71
600	65	850	0.2 ± 0.1	1.8 ± 0.6 ± 0.4	3	+0.9	3.6 ± 0.2	1.85
650	65	850	0.2 ± 0.1	1.8 ± 0.6 ± 0.4	3	+0.9	2.2 ± 0.1	1.99
700	85	850	0.1 ± 0.1	1.1 ± 0.5 ± 0.3	2	+0.8	1.3 ± 0.1	2.02
750	85	850	0.1 ± 0.1	1.1 ± 0.5 ± 0.3	2	+0.8	0.8 ± 0.1	2.20
800	85	850	0.1 ± 0.1	1.1 ± 0.5 ± 0.3	2	+0.8	0.5 ± 0.1	2.80
Forward channel: $\lvert\widetilde{\eta}\rvert \geq 0.9$								
200	35	410	4.2 ± 0.5	72 ± 4 ± 15	87	+1.1	—	—
250	35	410	4.2 ± 0.5	72 ± 4 ± 15	87	+1.1	50 ± 11	0.11
300	50	470	1.8 ± 0.3	20.3 ± 2.2 ± 3.9	23	+0.5	33.4 ± 5.2	0.21
350	50	490	1.7 ± 0.3	18.2 ± 2.0 ± 3.5	19	+0.2	18.5 ± 2.5	0.29
400	65	680	0.7 ± 0.2	2.7 ± 0.7 ± 0.6	1	−0.9	6.1 ± 1.0	0.21
450	65	700	0.7 ± 0.2	2.3 ± 0.6 ± 0.4	1	−0.7	3.8 ± 0.5	0.28
500	65	770	0.5 ± 0.1	1.2 ± 0.4 ± 0.2	1	0.0	1.6 ± 0.2	0.24
550	65	800	0.4 ± 0.1	0.9 ± 0.4 ± 0.2	1	+0.3	1.2 ± 0.2	0.32
600	65	850	0.3 ± 0.1	0.6 ± 0.3 ± 0.1	1	+0.6	0.6 ± 0.1	0.29
650	65	850	0.3 ± 0.1	0.6 ± 0.3 ± 0.1	1	+0.6	0.3 ± 0.1	0.26
700	85	850	0.1 ± 0.1	0.4 ± 0.2 ± 0.1	0	−0.4	0.2 ± 0.1	0.28
750	85	850	0.1 ± 0.1	0.4 ± 0.2 ± 0.1	0	−0.4	0.1 ± 0.1	0.35
800	85	850	0.1 ± 0.1	0.4 ± 0.2 ± 0.1	0	−0.4	0.1 ± 0.1	0.36

Category B

Process	$p_{\mathrm{T}}^{\tau} < 60\,\mathrm{GeV}$	$60 < p_{\mathrm{T}}^{\tau} < 120\,\mathrm{GeV}$	$120 < p_{\mathrm{T}}^{\tau} < 200\,\mathrm{GeV}$	$p_{\mathrm{T}}^{\tau} > 200\,\mathrm{GeV}$	ϵ_{LQ_3} (%) OS	ϵ_{LQ_3} (%) SS
LQ_3 (200 GeV)	$21 \pm 12^{+7}_{-2}$	0.0 ± 0.1 ± 0.0	0.0 ± 0.1 ± 0.1	0.0 ± 0.1 ± 0.1	0.01	0
LQ_3 (250 GeV)	$31.0 \pm 8.2^{+6.6}_{-3.4}$	$13.1 \pm 5.5^{+1.1}_{-2.9}$	0.0 ± 0.1 ± 0.1	0.0 ± 0.1 ± 0.1	0.09	0.02
LQ_3 (300 GeV)	$33.1 \pm 5.3^{+2.8}_{-3.8}$	$24.6 \pm 4.6^{+2.8}_{-2.1}$	$7.6 \pm 2.6^{+1.1}_{-1.7}$	$3.9 \pm 1.8^{+0.9}_{-0.3}$	0.35	0.08
LQ_3 (350 GeV)	$18.1 \pm 2.6^{+1.8}_{-1.4}$	$13.3 \pm 2.2^{+1.0}_{-1.1}$	$7.2 \pm 1.6^{+0.8}_{-0.7}$	$2.9 \pm 0.9^{+0.5}_{-1.4}$	0.57	0.08
LQ_3 (400 GeV)	$13.9 \pm 1.4^{+1.1}_{-2.6}$	$13.4 \pm 1.4^{+1.0}_{-1.1}$	$7.8 \pm 1.1^{+0.8}_{-0.6}$	$4.1 \pm 0.8^{+0.6}_{-0.8}$	1.30	0.12
LQ_3 (450 GeV)	$10.1 \pm 0.9^{+0.8}_{-1.9}$	$8.6 \pm 0.8^{+0.8}_{-0.8}$	$7.1 \pm 0.7^{+0.5}_{-0.6}$	$5.8 \pm 0.6^{+0.7}_{-0.6}$	2.05	0.27
LQ_3 (500 GeV)	$5.2 \pm 0.4^{+0.5}_{-0.9}$	6.0 ± 0.5 ± 0.5	$5.3 \pm 0.4^{+0.4}_{-0.5}$	$4.4 \pm 0.4^{+0.7}_{-0.5}$	2.75	0.27
LQ_3 (550 GeV)	$3.2 \pm 0.3^{+0.3}_{-0.6}$	$4.4 \pm 0.3^{+0.4}_{-0.3}$	$4.3 \pm 0.3^{+0.5}_{-0.4}$	4.0 ± 0.3 ± 0.4	4.04	0.36
LQ_3 (600 GeV)	$2.0 \pm 0.1^{+0.2}_{-0.5}$	2.7 ± 0.2 ± 0.2	2.7 ± 0.2 ± 0.2	3.5 ± 0.2 ± 0.4	5.11	0.43
LQ_3 (650 GeV)	$1.3 \pm 0.1^{+0.1}_{-0.3}$	$1.8 \pm 0.1^{+0.1}_{-0.2}$	2.0 ± 0.1 ± 0.2	$2.5 \pm 0.1^{+0.3}_{-0.2}$	6.07	0.67
LQ_3 (700 GeV)	0.7 ± 0.1 ± 0.1	1.1 ± 0.1 ± 0.1	1.1 ± 0.1 ± 0.1	$1.6 \pm 0.1^{+0.2}_{-0.1}$	6.66	0.57
LQ_3 (750 GeV)	0.4 ± 0.1 ± 0.1	0.5 ± 0.1 ± 0.1	0.7 ± 0.1 ± 0.1	1.1 ± 0.1 ± 0.1	6.71	0.59
LQ_3 (800 GeV)	0.2 ± 0.1 ± 0.1	0.4 ± 0.1 ± 0.1	0.5 ± 0.1 ± 0.1	0.8 ± 0.1 ± 0.1	7.77	0.61
$\mathrm{t\bar{t}}$+jets	$29.9 \pm 2.9^{+7.3}_{-7.2}$	$8.8 \pm 1.3^{+3.2}_{-3.4}$	$1.7 \pm 0.6^{+0.6}_{-0.6}$	$0.4 \pm 0.3^{+0.9}_{-0.4}$		
W+jets	$7.4 \pm 1.7^{+5.1}_{-5.1}$	0.6 ± 0.5 ± 0.6	0.0 ± 0.1 ± 0.1	0.4 ± 0.4 ± 0.4		
DY+jets	4.8 ± 0.7 ± 2.5	$1.8 \pm 0.4^{+1.1}_{-0.9}$	0.5 ± 0.2 ± 0.3	0.4 ± 0.2 ± 0.2		
Other backgrounds	$3.1 \pm 0.9^{+1.8}_{-1.9}$	$0.2 \pm 0.1^{+0.8}_{-0.3}$	0.2 ± 0.1 ± 0.4	$0.1 \pm 0.1^{+0.1}_{-0.2}$		
Total $N_{\mathrm{Bkg}}^{\mathrm{Exp}}$	$45.2 \pm 3.5^{+9.4}_{-9.3}$	$11.5 \pm 1.4^{+3.4}_{-3.6}$	2.5 ± 0.6 ± 0.8	$1.2 \pm 0.5^{+1.0}_{-0.6}$		
N^{Obs}	44	15	1	0		
Z-score	−0.1	+0.7	+0.8	−1.0		

arXiv: 1503.09049
CMS Collaboration

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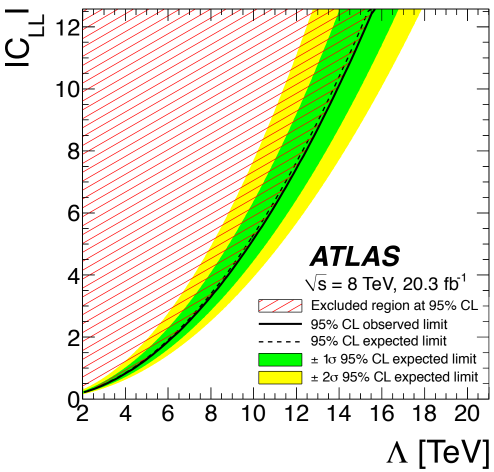
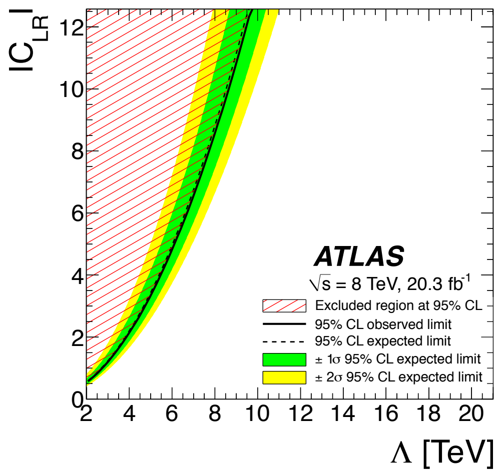
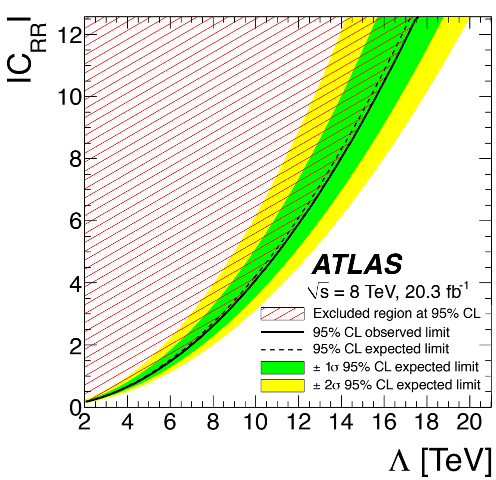
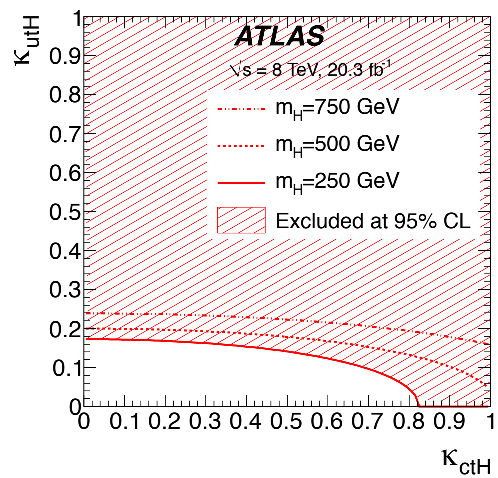




$$\mathcal{L}_{tt} = \frac{1}{2}\frac{C_{\rm LL}}{\Lambda^2}(\bar{u}_{\rm L}\gamma^\mu t_{\rm L})(\bar{u}_{\rm L}\gamma_\mu t_{\rm L}) + \frac{1}{2}\frac{C_{\rm RR}}{\Lambda^2}(\bar{u}_{\rm R}\gamma^\mu t_{\rm R})(\bar{u}_{\rm R}\gamma_\mu t_{\rm R}) - \frac{1}{2}\frac{C_{\rm LR}}{\Lambda^2}(\bar{u}_{\rm L}\gamma^\mu t_{\rm L})(\bar{u}_{\rm R}\gamma_\mu t_{\rm R}) - \frac{1}{2}\frac{C'_{\rm LR}}{\Lambda^2}(\bar{u}_{{\rm L}a}\gamma^\mu t_{{\rm L}b})(\bar{u}_{{\rm R}b}\gamma_\mu t_{{\rm R}a}) + \text{h.c.}$$





$$\mathcal{L}_{\rm FCNC} = \kappa_{utH}\bar{t}Hu + \kappa_{ctH}\bar{t}Hc + \text{h.c.}$$

arXiv: 1504.04605
ATLAS Collaboration

EXO: Third-generation scalar leptoquarks in the tτ channel

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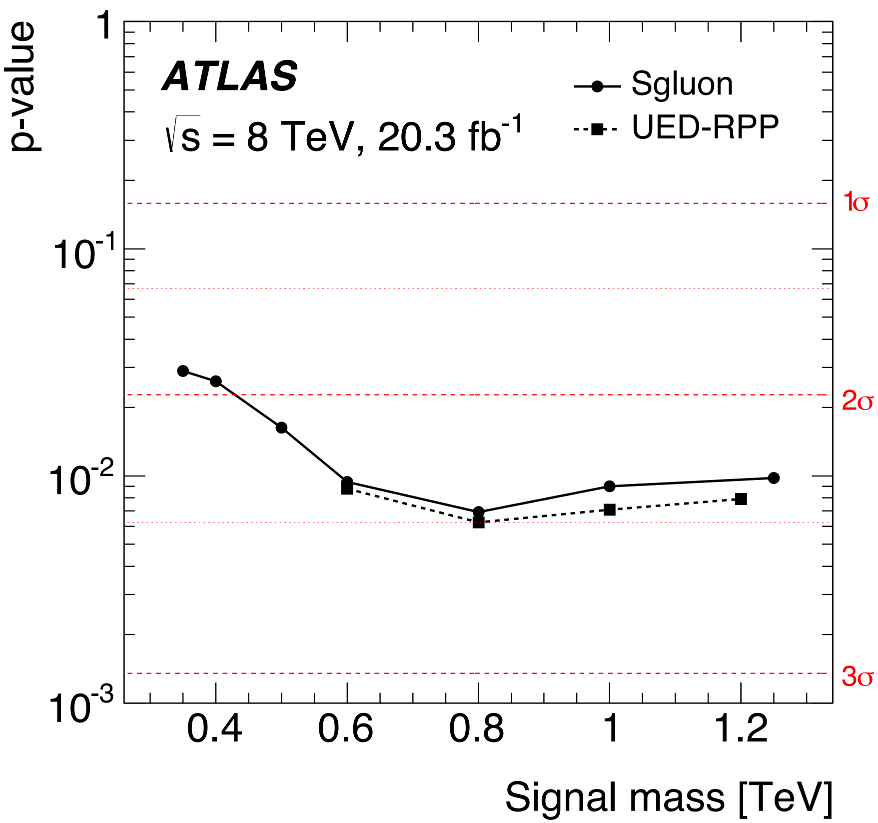

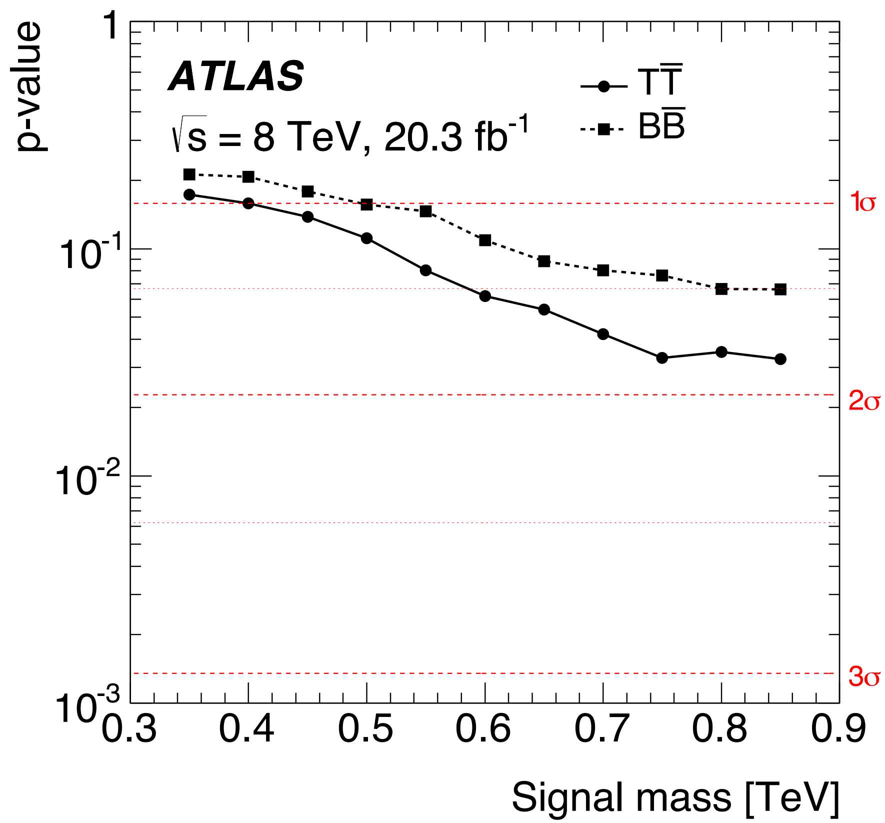

Probability for the data in the four-top-quark signal regions (SR4t0-SR4t4)

arXiv: 1504.04605
ATLAS Collaboration

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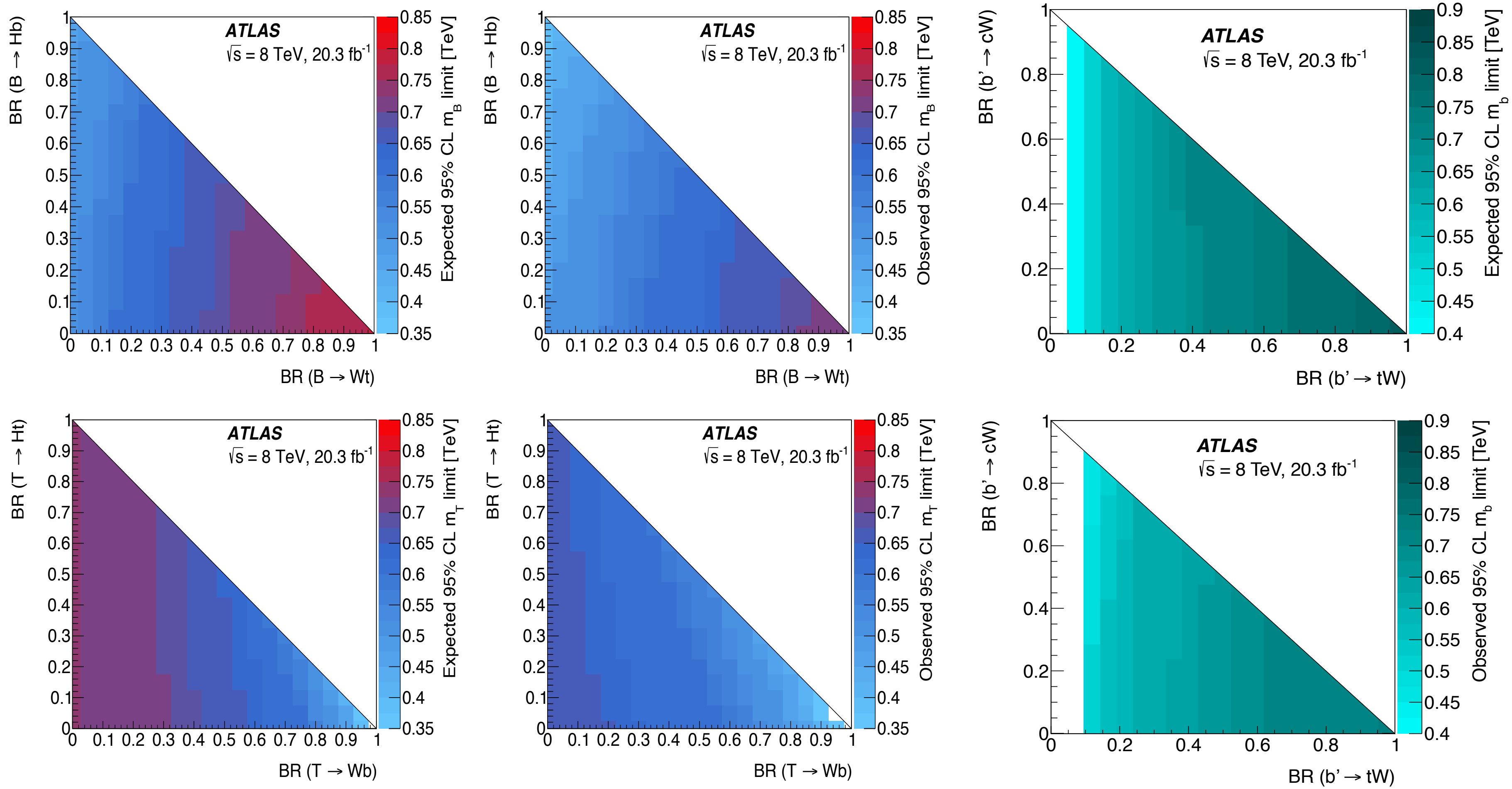

arXiv: 1504.04605
ATLAS Collaboration

EXO: Search for narrow high-mass resonances decaying to Z and Higgs bosons

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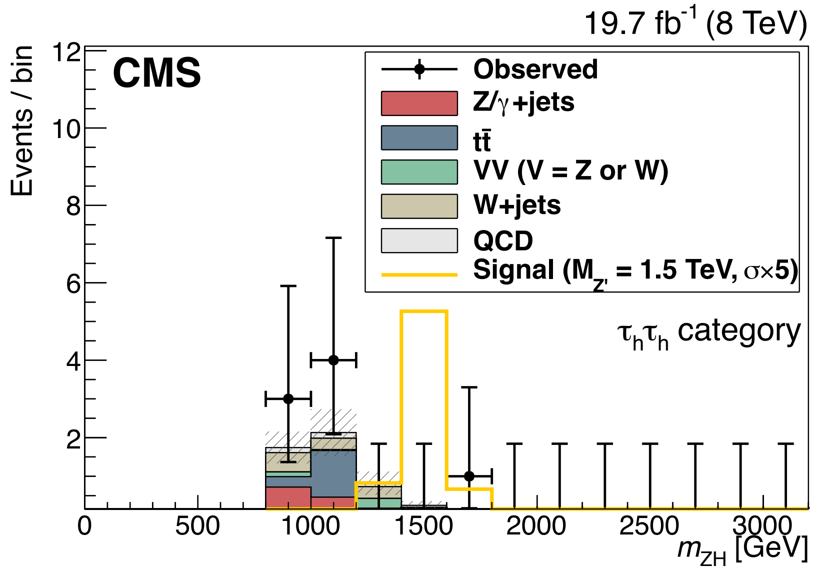
	Mass (TeV)	$\tau_e\tau_e$	$\tau_e\tau_\mu$	$\tau_\mu\tau_\mu$	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_h\tau_h$
$\mathcal{B}(\tau\tau)$		3.2%	6.2%	3.0%	23.1%	22.6%	41.9%
ε_{sig}(%)	0.8	2.8 ± 0.7	3.4 ± 0.5	4.2 ± 0.7	3.3 ± 0.3	4.4 ± 0.3	2.2 ± 0.2
	0.9	11 ± 1	16 ± 1	20 ± 2	14.3 ± 0.5	18.7 ± 0.6	11.5 ± 0.4
	1.0	17 ± 2	24 ± 1	38 ± 2	21.2 ± 0.6	29.3 ± 0.7	18.0 ± 0.5
	1.2	26 ± 2	30 ± 1	39 ± 2	28.3 ± 0.7	35.8 ± 0.7	23.0 ± 0.5
	1.5	30 ± 2	42 ± 2	53 ± 2	29.2 ± 0.8	38.1 ± 0.9	29.1 ± 0.7
	2.0	28 ± 2	39 ± 2	56 ± 3	31.1 ± 0.8	39.2 ± 0.9	31.9 ± 0.7
	2.5	27 ± 2	37 ± 2	42 ± 2	26.8 ± 0.8	37.0 ± 0.8	30.1 ± 0.7
N_{bkg}	0.8	0.3 ± 0.5	1.1 ± 0.8	1.6 ± 1.2	6.1 ± 2.0	6.7 ± 2.1	
	0.9	0.5 ± 0.4	1.7 ± 1.2	3.8 ± 2.1	9.8 ± 3.2	9.2 ± 2.9	
	1.0	1.4 ± 1.4	1.7 ± 1.0	2.0 ± 0.9	9.5 ± 3.5	7.6 ± 2.2	
	1.2	1.2 ± 1.2	1.2 ± 0.8	1.4 ± 0.6	5.0 ± 2.0	6.6 ± 2.3	$6.1^{+3.2}_{-2.5}$
	1.5	0.4 ± 0.4	0.07 ± 0.04	0.9 ± 0.4	4.3 ± 1.8	2.6 ± 0.9	
	2.0	<0.5	<0.4	0.7 ± 0.4	0.1 ± 0.1	<0.4	
	2.5	<2.1	<0.3	0.3 ± 0.1	0.18 ± 0.05	<0.5	
N_{obs}	0.8	1	1	2	3	10	
	0.9	2	2	3	4	13	
	1.0	2	2	5	2	13	
	1.2	0	1	3	5	12	8
	1.5	0	0	1	2	5	
	2.0	0	1	0	0	0	
	2.5	0	0	0	0	0	

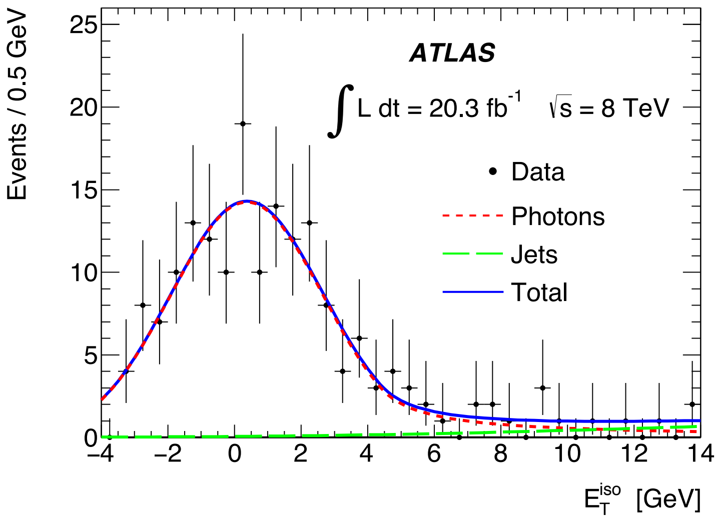


arXiv: 1502.04994
CMS Collaboration

EXO: Search for high-mass diphoton resonances

Backup slides

Source	Uncertainty in signal yield [%]
Integrated luminosity	2.8
MC statistics	1.0
Trigger efficiency	1.0
Photon ID efficiency	3.0
Photon isolation efficiency	0.3–2.1 (for m_{G^*} = 500–3000 GeV)
Total	≈5



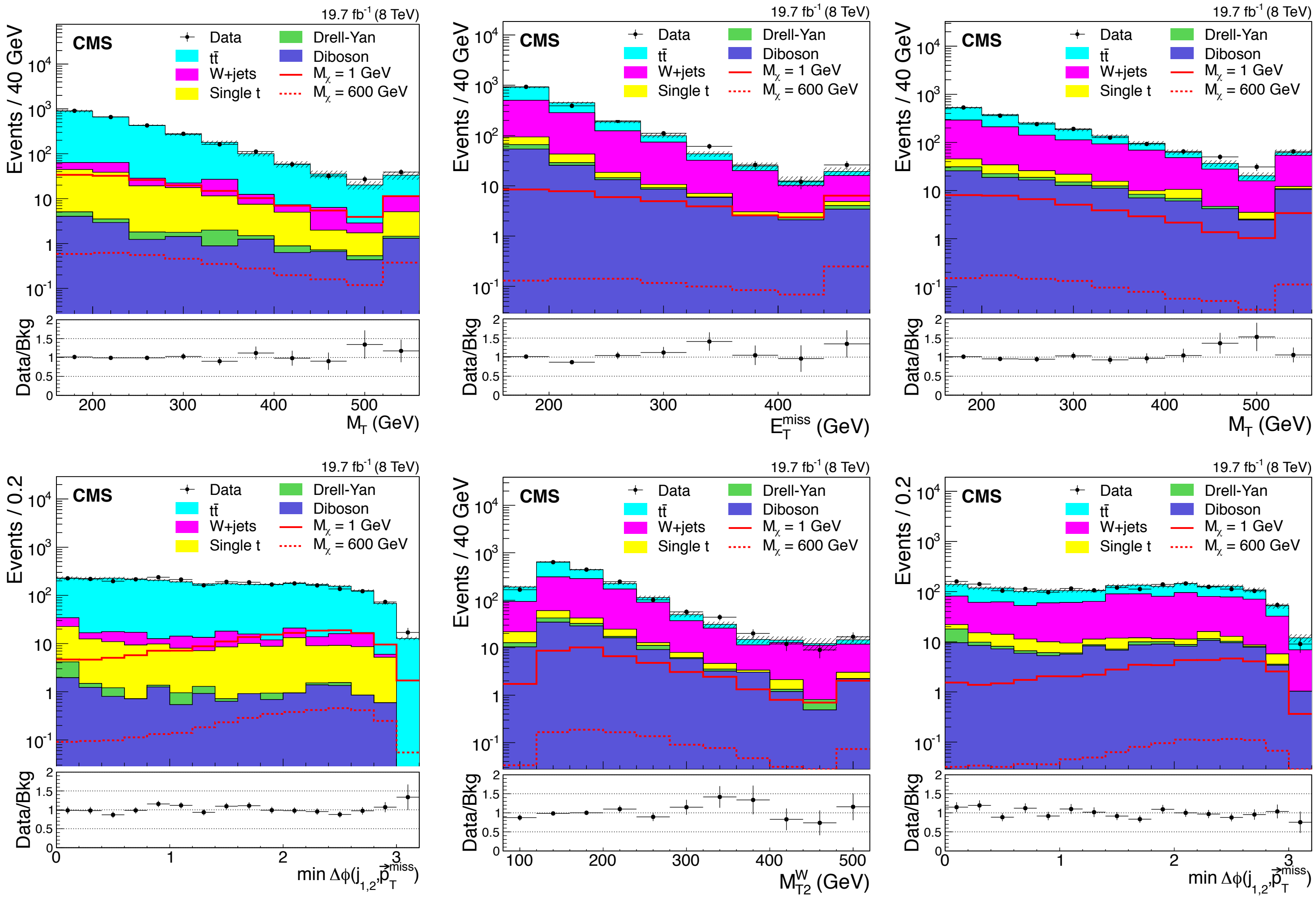
Mass window [GeV]	Background expectation (number of events) Irreducible	Reducible	Total	Observed events
[179, 409] Control region	23800 ± 2400	9100 ∓ 2400	32866	32866
[409, 513]	1070 ± 110	400 ± 100	1463 ± 27	1465
[513, 596]	369 ± 37	129 ± 34	498 ± 12	524
[596, 719]	240 ± 24	74 ± 20	314.4 ± 8.8	335
[719, 805]	75.8 ± 7.7	20.6 ± 5.5	96.4 ± 3.2	99
[805, 901]	46.6 ± 4.8	11.5 ± 3.2	58.1 ± 2.1	60
[901, 1009]	28.2 ± 3.0	6.3 ± 1.8	34.5 ± 1.5	33
[1009, 1129]	16.8 ± 1.9	3.4 ± 1.0	20.2 ± 1.0	15
[1129, 1217]	6.92 ± 0.89	1.35 ± 0.46	8.27 ± 0.45	7
[1217, 1312]	4.85 ± 0.73	0.88 ± 0.39	5.74 ± 0.36	3
[1312, 1415]	3.11 ± 0.54	0.58 ± 0.28	3.69 ± 0.25	0
[1415, 1644]	3.39 ± 0.59	0.61 ± 0.29	4.00 ± 0.32	5
[1644, 3000]	2.12 ± 0.61	0.41 ± 0.22	2.52 ± 0.30	3

$k/\overline{M}_{Pl}$	Expected limit [TeV] -2σ	-1σ	central	$+1\sigma$	$+2\sigma$	Observed limit [TeV]
0.010	1.45	1.38	1.30	1.20	1.11	1.41
0.020	1.80	1.78	1.70	1.60	1.49	1.62
0.030	2.02	2.01	1.96	1.86	1.77	1.92
0.040	2.17	2.16	2.14	2.04	1.94	2.15
0.050	2.29	2.28	2.27	2.17	2.08	2.28
0.060	2.38	2.38	2.37	2.27	2.19	2.38
0.070	2.47	2.46	2.45	2.37	2.27	2.46
0.080	2.54	2.54	2.53	2.46	2.38	2.54
0.090	2.61	2.60	2.60	2.53	2.45	2.60
0.100	2.67	2.66	2.66	2.60	2.51	2.66

arXiv: 1505.05511
ATLAS Collaboration

B2G: Dark Matter in association with top-quark pairs in the single lepton final state

Backup slides



arXiv: 1504.03198
CMS Collaboration

B2G: Dark Matter in association with top-quark pairs in the single lepton final state

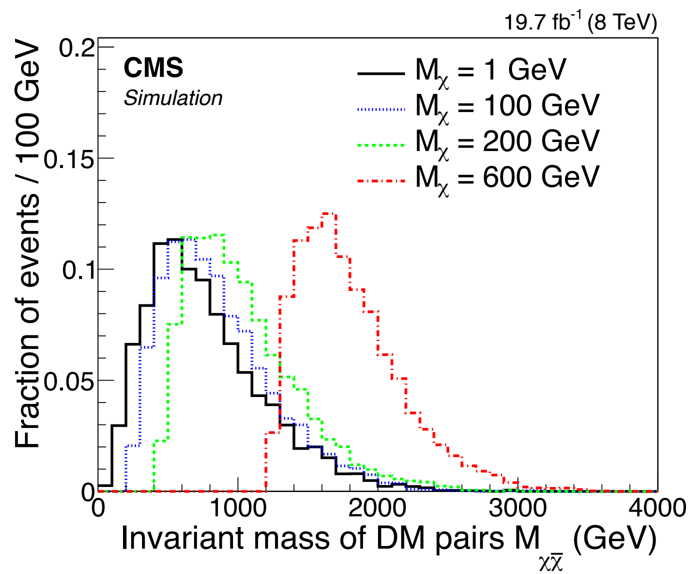
Backup slides

Source of systematic uncertainties	Relative uncertainty on total background (%)
50% normalization uncert. of other bkg in deriving SFs	10
$\mathrm{SF}_{\mathrm{W+jets}}$ (CR tests)	13
$\mathrm{t\bar{t}}$+jets top-quark p_{T} reweighting	3.9
Jet energy scale	4.0
Jet energy resolution	3.0
b-tagging correction factor (heavy flavour)	1.0
b-tagging correction factor (light flavour)	1.8
Pileup model	2.0
PDF	2.6

Source	Yield ($\pm$stat $\pm$syst)
$\mathrm{t\bar{t}}$	$8.2 \pm 0.6 \pm 1.9$
W	$5.2 \pm 1.8 \pm 2.1$
Single top	$2.3 \pm 1.1 \pm 1.1$
Diboson	$0.5 \pm 0.2 \pm 0.2$
Drell–Yan	$0.3 \pm 0.3 \pm 0.1$
Total Bkg	$16.4 \pm 2.2 \pm 2.9$
Signal	$38.3 \pm 0.7 \pm 2.1$
Data	18

$$L_{\mathrm{int}} = \sum_q \sum_i C_{q\,i}\, (\bar{q}\Gamma_i^q \mathrm{q})\, (\bar{\chi}\Gamma_i^\chi \chi)$$

$$L_{\mathrm{int}} = \frac{m_{\mathrm{q}}}{M_*^3}\bar{q}q\bar{\chi}\chi$$



arXiv: 1504.03198
CMS Collaboration