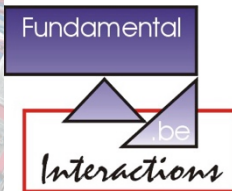
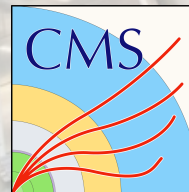


Searches for resonances at the LHC, IAP Summer Solstice



Aidan Randle-Conde
Université Libre de Bruxelles (ULB)



Overview

Introduction to ATLAS and CMS

Resonances and scope

- Dilepton resonances

- t-tbar resonances

- Latest results: ($t+X$)

- Vector boson resonances

- Latest results: Exotica at 2 TeV

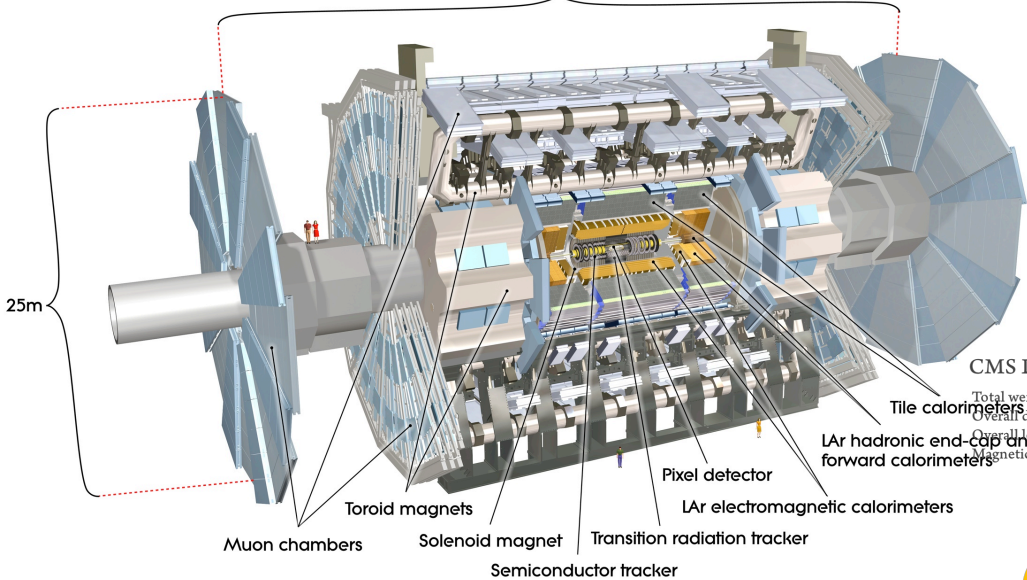
Summary

(More results in backup!)

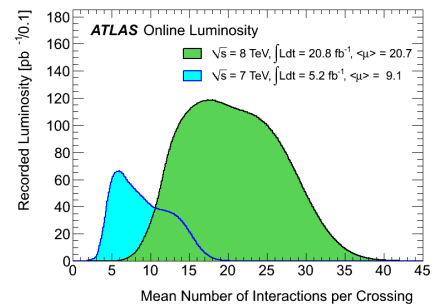
July 2015
Event: 35369265
2012-05-30 20:31:28 CEST

The LHC experiments

- ATLAS and CMS are two general purpose detectors at the LHC



LHC: 27 km, pp collider with $\sqrt{s}=7, 8$ TeV



CMS DETECTOR
 Total weight : 14,000 tonnes
 Overall diameter : 15.0 m
 Overall length : 28.7 m
 Magnetic field : 3.8 T

STEEL RETURN YOKE
 12,500 tonnes

SILICON TRACKERS
 Pixel ($100 \times 150 \mu\text{m}$) $\sim 16\text{m}^2$ - 66M channels
 Microstrips ($80 \times 180 \mu\text{m}$) $\sim 200\text{m}^2$ - 9.6M channels

SUPERCONDUCTING SOLENOID
 Niobium titanium coil carrying $\sim 18,000\text{A}$

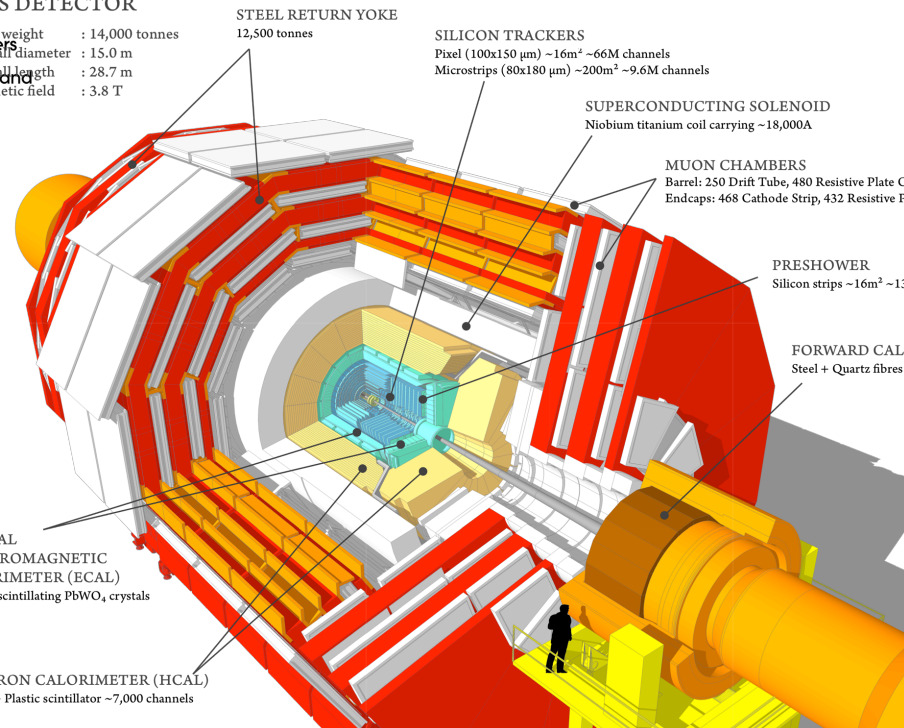
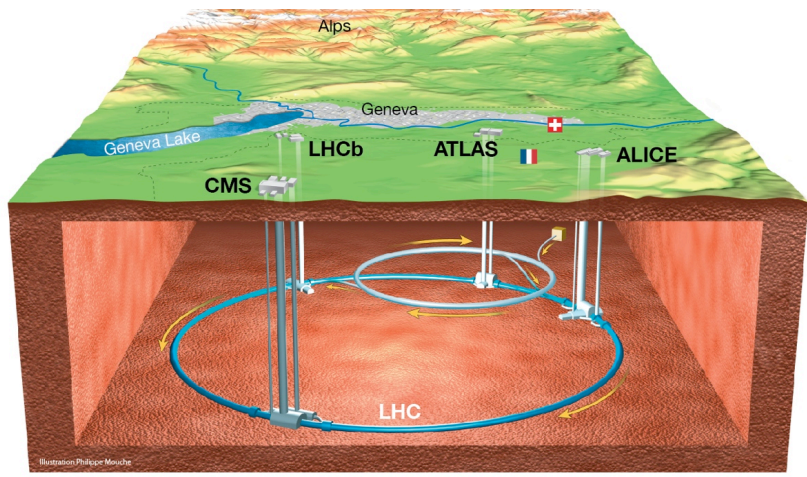
MUON CHAMBERS
 Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
 Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
 Silicon strips $\sim 16\text{m}^2$ - 137M channels

FORWARD CALORIMETER
 Steel + Quartz fibres $\sim 16\text{m}^2$ - 137M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
 $\sim 76,000$ scintillating PbWO₄ crystals

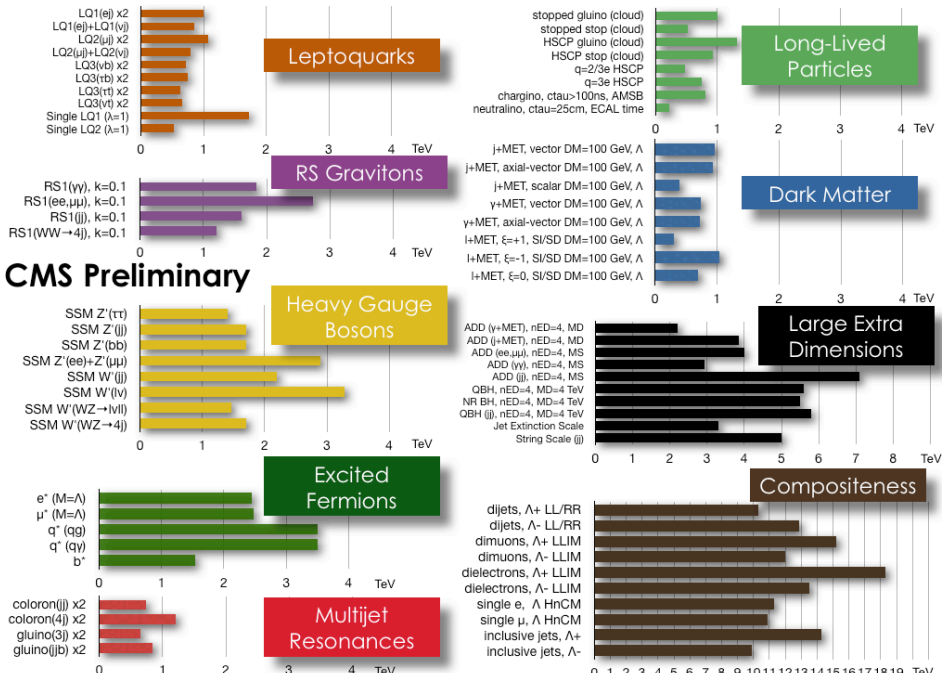
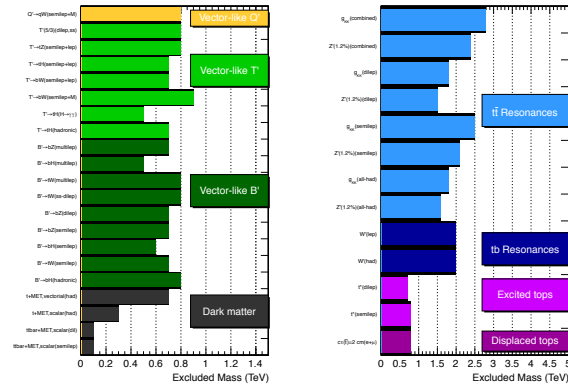
HADRON CALORIMETER (HCAL)
 Brass + Plastic scintillator $\sim 7,000$ channels



Resonances: scope

- A huge number of analyses fit into the topic “resonances”
- I can only cover a fraction of these!
- Mix of simple and complex final states

CMS Searches for New Physics Beyond Two Generations (B2G)
95% CL Exclusions (TeV)



ATLAS Exotics Searches* - 95% CL Exclusion
Status: March 2015

Model	ℓ, γ	Jets	E_{miss}	$[\mathcal{L} dt/dt^{fb}]^{-1}$	Mass limit	Reference
Extra dimensions	ADD $G_{KK} + g/\ell$	≥ 1 J	Yes	20.3	M_{pl} 5.25 TeV	$n=2$ 1502.01518
	ADD non-resonant $\ell\ell$	2e, μ	-	20.3	M_{pl} 4.7 TeV	$n=3$ HLZ 1407.2410
	ADD OBH $\rightarrow f\bar{f}$	1e, μ	-	20.3	M_{pl} 5.2 TeV	$n=6$ 1311.2006
	ADD OBH	-	2]	20.3	M_{pl} 5.82 TeV	1407.1376
	ADD BH high N_{ch}	2e, μ (SS)	-	20.3	M_{pl} 4.7 TeV	$n=6, M_{pl} = 3$ TeV, non-rot BH 1308.4075
	ADD BH high 2^2 pr	≥ 1 e, μ	≥ 2 J	20.3	M_{pl} 5.8 TeV	$n=6, M_{pl} = 3$ TeV, non-rot BH 1405.4254
	ADD BH high multijet	2e, μ	≥ 2 J	20.3	M_{pl} 5.8 TeV	$n=6, M_{pl} = 3$ TeV, non-rot BH Preliminary
	RS1 $G_{KK} \rightarrow \ell\ell$	2e, μ	-	20.3	G_{KK} mass 2.88 TeV	$k/\overline{M}_{pl} = 0.1$ 1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2e, μ	-	20.3	G_{KK} mass 2.88 TeV	Preliminary
	Buk RS $G_{KK} \rightarrow ZZ \rightarrow qq\ell\ell$	2e, μ	2] / 1 J	20.3	G_{KK} mass 740 GeV	$k/\overline{M}_{pl} = 0.1$ 1405.6190
	Buk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\ell$	1e, μ	2] / 1 J	Yes 20.3	G_{KK} mass 700 GeV	$k/\overline{M}_{pl} = 1.0$ 1503.04677
	Buk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	-	4 b	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{pl} = 1.0$ ATLAS-CONF-2014-005
	Buk RS $G_{KK} \rightarrow \ell\ell$	1e, μ	≥ 1 b, $\geq 14\ell$	Yes 20.3	G_{KK} mass 2.2 TeV	$k/\overline{M}_{pl} = 1.0$ ATLAS-CONF-2015-009
	ZUED / RRP	2e, μ (SS)	≥ 1 b, ≥ 1 J	Yes 20.3	G_{KK} mass 900 GeV	Preliminary
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2e, μ	-	20.3	Z' mass 2.9 TeV	1405.4123
	SSM $Z' \rightarrow \tau\tau$	2e, μ	-	19.5	Z' mass 2.02 TeV	1502.07177
	SSM $W' \rightarrow \ell\nu$	1e, μ	-	Yes 20.3	W' mass 3.24 TeV	1407.7484
	EGM $W' \rightarrow WZ \rightarrow \ell\nu\ell'\ell'$	3e, μ	-	Yes 20.3	W' mass 1.52 TeV	1406.4456
	EGM $W' \rightarrow WZ \rightarrow qq\ell\ell$	2e, μ	2] / 1 J	20.3	W' mass 1.89 TeV	1405.6190
	HVT $W' \rightarrow WH \rightarrow \ell\nu b\bar{b}$	1e, μ	2 b	Yes 20.3	W' mass 1.47 TeV	Preliminary
	LRSM $W'_2 \rightarrow \ell\bar{\nu}$	1e, μ	2 b, 0-1 J	Yes 20.3	W' mass 1.82 TeV	1410.4103
	LRSM $W'_2 \rightarrow \ell\nu$	0e, μ	≥ 1 b, 1-1 J	-	W' mass 1.76 TeV	1408.0886
CI	CI $qqqq$	-	2]	-	A 12.0 TeV	Preliminary
	CI $qq\ell\ell$	2e, μ	-	20.3	A 4.35 TeV	1407.2410
	CI $uvtt$	2e, μ (SS)	≥ 1 b, ≥ 1 J	Yes 20.3	A 3.3 TeV	Preliminary
DM	EFT D operator (Dirac)	0e, μ	1 J	Yes 20.3	N 974 GeV	at 90% CL for $m(\chi) < 100$ GeV 1502.01518
	EFT D operator (Dirac)	0e, μ	$1 J, \leq 1$ J	Yes 20.3	M 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV 1309.4017
LQ	Scalar LQ 1 st gen	2e, μ	≥ 2 J	-	LQ mass 660 GeV	$\beta = 1$ 1112.4828
	Scalar LQ 2 nd gen	2e, μ	≥ 2 J	-	LQ mass 685 GeV	$\beta = 1$ 1203.3172
	Scalar LQ 3 rd gen	1e, $\mu, 1\tau$	1 b, 1 J	-	LQ mass 534 GeV	$\beta = 1$ 1303.0526
Heavy quarks	VLO $TT \rightarrow Hb + X, Wb + X$	1e, μ	≥ 1 b, ≥ 3 J	Yes 20.3	T mass 795 GeV	isospin singlet ATLAS-CONF-2015-012
	VLO $TT \rightarrow Zt + X$	2e, μ (SS)	≥ 2 J, 1 b	20.3	T mass 736 GeV	T in (T) doublet 1405.5500
	VLO $BB \rightarrow Zb + X$	2e, μ	≥ 2 J, 1 b	20.3	B mass 795 GeV	B in (B,V) doublet 1409.5500
	VLO $BB \rightarrow Wt + X$	1e, μ	≥ 1 b, ≥ 5 J	Yes 20.3	B mass 840 GeV	isospin singlet 1409.5500
	$T_{3/2} \rightarrow Wt$	1e, $\mu, 1\tau$	≥ 1 b, ≥ 5 J	Yes 20.3	T mass 840 GeV	isospin singlet 1409.5500
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1e, μ	1 J	-	q* mass 3.5 TeV	only u^* and d^* , $\Lambda = m(q^*)$ 1309.3220
	Excited quark $q^* \rightarrow qg$	2e, μ	2]	-	q* mass 4.09 TeV	only u^* and d^* , $\Lambda = m(q^*)$ 1401.13176
	Excited quark $q^* \rightarrow Wq$	1 or 2e, 1b, 2] or 1]	Yes 4.7	-	q* mass 870 GeV	left-handed coupling 1301.1583
	Excited lepton $\ell^* \rightarrow \ell\gamma$	2e, $\mu, 1\gamma$	-	-	l* mass 2.2 TeV	$\Lambda = 2.2$ TeV 1308.1384
	Excited lepton $\ell^* \rightarrow \ell W, \nu Z$	3e, $\mu, 1\tau$	-	-	l* mass 1.6 TeV	$\Lambda = 1.6$ TeV 1411.2921
Other	LSTC $\tau\tau \rightarrow W\gamma$	1e, $\mu, 1\gamma$	-	Yes 20.3	W mass 850 GeV	$m(W_2) = 3$ TeV, no mixing 1407.8150
	LRSM Majorana ν	2e, μ (SS)	2]	-	N mass 551 GeV	1203.3420
	Higgs triplet $H^+ \rightarrow \ell\ell$	2e, μ (SS)	-	20.3	H mass 511 GeV	1412.0207
	Higgs triplet $H^+ \rightarrow \ell\nu$	3e, $\mu, 1\tau$	-	20.3	H mass 400 GeV	DV production, BR(H ⁺ → ℓν)=1 1411.2921
	Monopole (non-res prod)	1e, μ	1 b	Yes 20.3	spin-1 monopole particle mass 657 GeV	$\beta_{non-res} = 0.2$ 1410.5404
	Multi-charged particles	2e, μ	-	20.3	monopole mass 785 GeV	DV production, $g = 1e$ 1207.6411
	Magnetic monopoles	-	-	2.0	monopole mass 882 GeV	DV production, $g = 1e$ 1207.6411

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

Dilepton resonances

- Both ATLAS and CMS have searched for dilepton resonances:

- Simple final states, low backgrounds.
- Look for peak above smoothly falling background.

PRD 90, 052005

- Main selections:

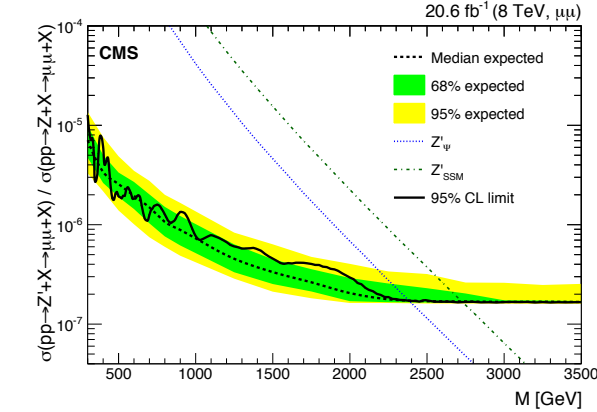
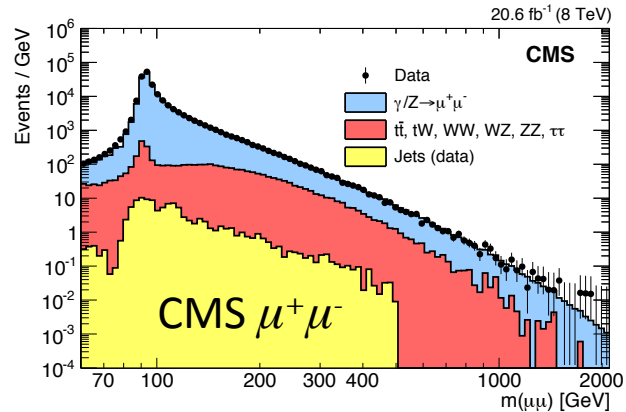
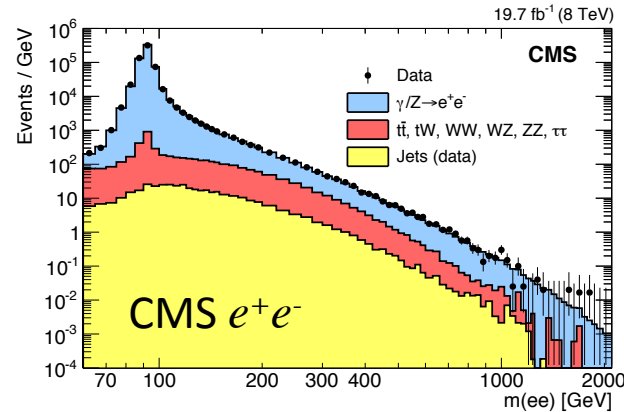
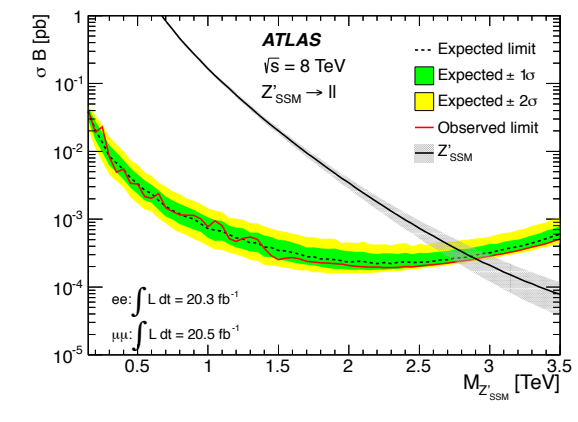
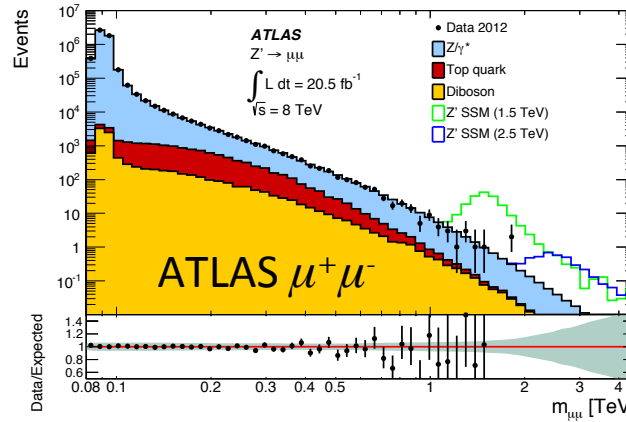
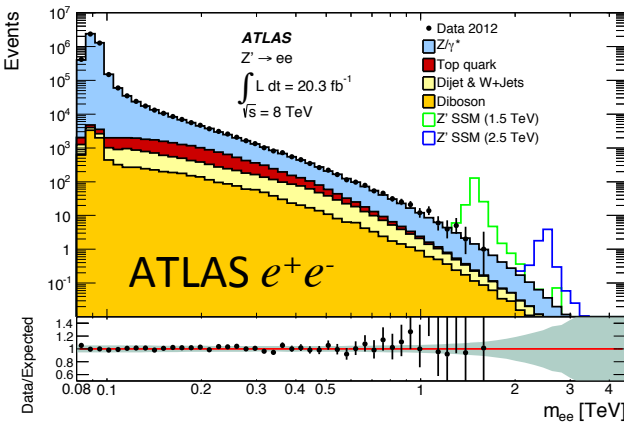
JHEP04(2015)025

	ATLAS	CMS
ee	$E_T > 40, 30 \text{ GeV}$ $ \eta < 1.37$ or $1.52 < \eta < 2.47$	$E_T > 35, 35 \text{ GeV}$ $ \eta < 1.442$ or $1.56 < \eta < 2.5$
$\mu\mu$	$p_T > 25, 25 \text{ GeV}$ $ \eta < 1.05$	$p_T > 45, 45 \text{ GeV}$ $ \eta < 2.4$ ($ \eta < 2.1$ for triggering muon)

- Leading systematic uncertainties come from the PDFs for background modeling (more information in backup slides), and lepton scale factors (statistically limited at high transverse momentum.)
 - ATLAS: 4% for all channels.
 - CMS: 3% for dimuon, 4(6)% for dielectron barrel-barrel (barrel-endcap).
- (Ditau in backup- please ask if you want to see details.)

Dilepton resonances

- Both ATLAS and CMS have searched for dilepton resonances:



- Exclusion limits:

ATLAS: $m(Z'_{SSM}) > 2.90 \text{ TeV}$

CMS: $m(Z'_{SSM}) > 2.90 \text{ TeV}$

t-tbar resonances

- Both ATLAS and CMS search for t-tbar resonances.
- Many complex final states.
- Kinematic selections:

CMS-B2G-13-008

CERN-PH-EP-2015-090

	ATLAS	CMS
<i>jets</i>	anti-kT $\Delta R = 0.4$: $p_T(j) > 25$ GeV, $ \eta(j) < 2.5$ anti-kT $\Delta R = 1.0$: $p_T(j) > 300$ GeV, $ \eta(j) < 2.0$	$p_T(j) > 100, 50$ GeV $ \eta(j) < 2.4$ Top-tagging
<i>e</i>	$E_T(e) > 25$ GeV $ \eta(e) < 1.37$ or $1.52 < \eta(e) < 2.47$	$ \eta(e) < 1.442$ or $1.56 < \eta(e) < 2.5$ $E_T(e) > 85, 20$ GeV (depending on final state)
μ	$p_T(\mu) > 25$ GeV $ \eta(\mu) < 2.5$	$ \eta(\mu) < 2.1, 2.4$ $p_T(\mu) > 85, 45, 20$ GeV (depending on final state)

- Dominant systematic uncertainties:
 - Jet energy scale, t-tbar normalisation, parton shower and fragmentation, luminosity.

t-tbar resonances

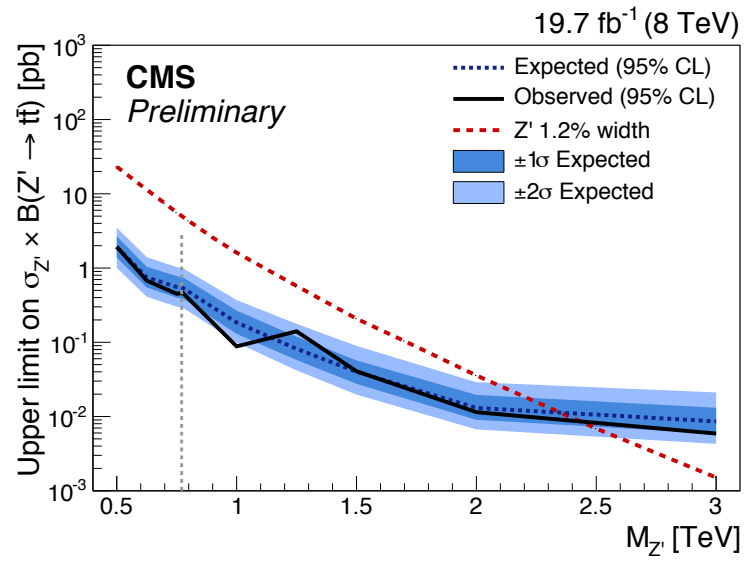
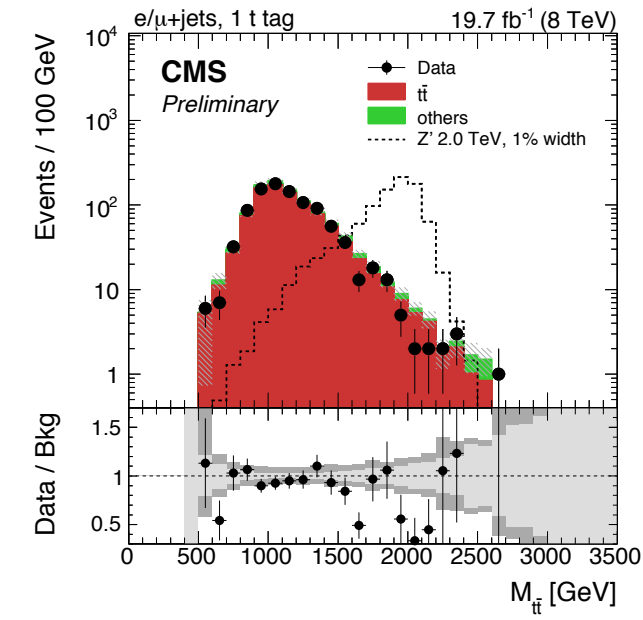
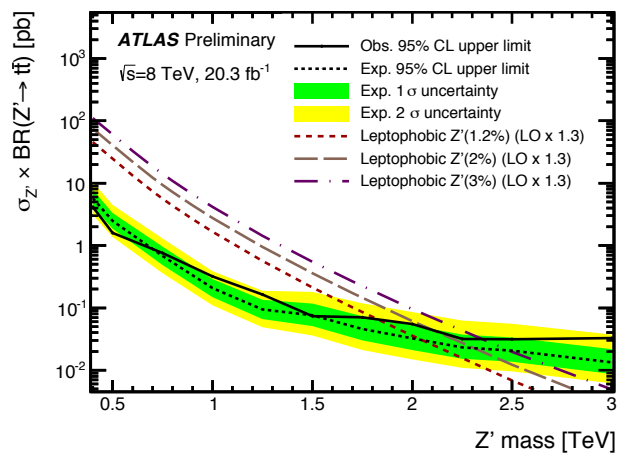
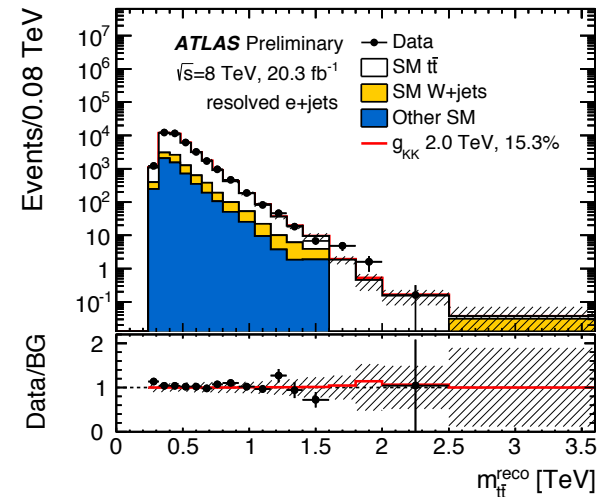
Limits:

ATLAS

$$m(Z') < 0.4 \text{ TeV or } m(Z') > 3.0 \text{ TeV}$$

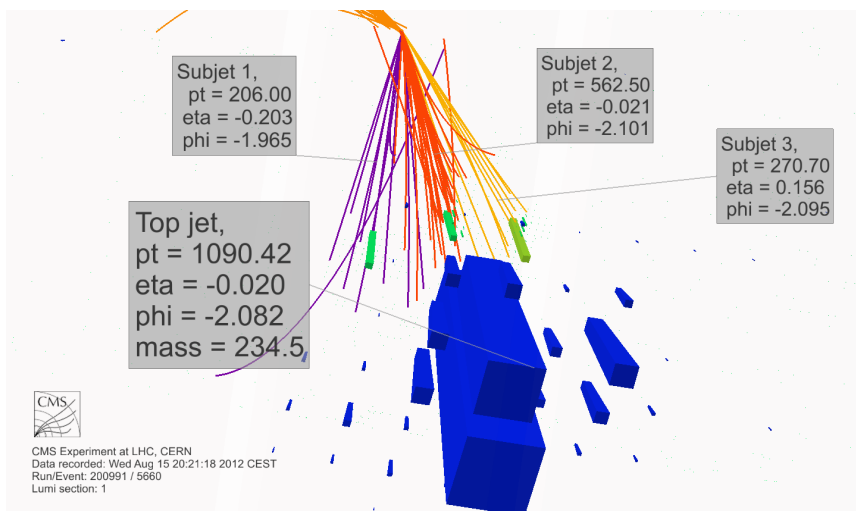
CMS

$$m(Z') > 2.4 \text{ TeV}$$



Top jet tagging

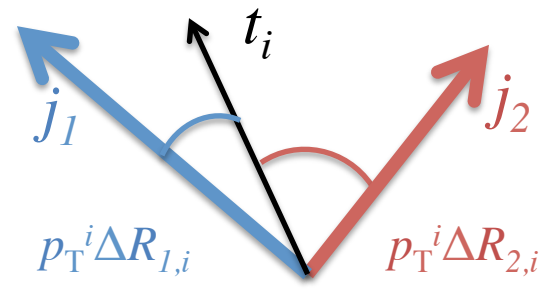
- Searches with boosted top quarks decaying hadronically can give rise to “top jets”, with distinctive substructure.
- ATLAS and CMS have developed “top tagging” algorithms.
- Example from the CMS tagger:
 - $140 < m(j_t) < 250 \text{ GeV}$
 - $N_{\text{sub-jets}} > 2$
 - Minimum pairwise mass, $m_{\text{min}} > 50 \text{ GeV}$



- The “sub-jettiness” is defined as τ_N :

$$\tau_N = \sum_i p_T^i \min\{\Delta R_{1,i} \dots \Delta R_{N,i}\} / \sum_i p_T^i R_0$$
 - R_0 is the characteristic jet radius.
 - τ_N measures consistency with a top decay.
 - τ_i/τ_j are discriminating variables, peaking near 1 for i sub-jets and 0 for j sub-jets.

Track t_i compared to sub-jets j_1, j_2 :



- Further selections per analysis.
- Excellent discussion in the ATLAS paper: Eur. Phys. J. C (2015) 75:165

Latest results: $T \rightarrow tH$

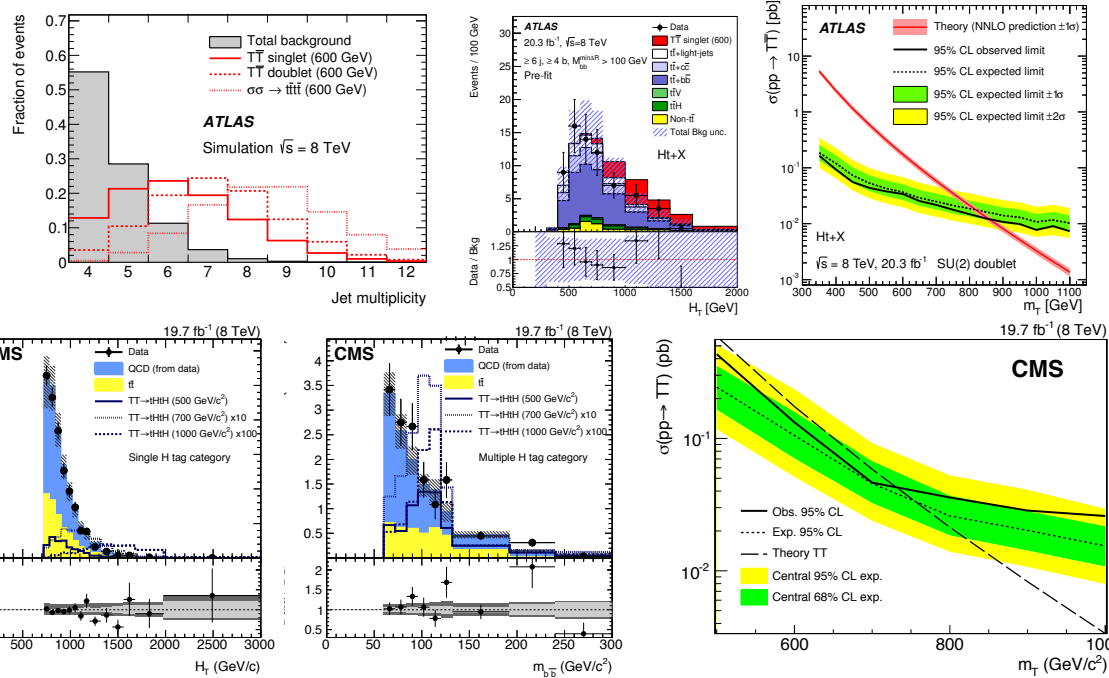
- ATLAS and CMS investigate vector like T quarks decaying to a tH .
- The CMS search makes use of boosted t -jet reconstruction:
 - At least one t -jet with $p_T > 200$ GeV, that contains at least one b tagged jet.
 - At least one jet consistent with a scalar boson (two b tagged jets and $m(j_{CA}) > 60$ GeV).
 - $H_T > 720$ GeV

arXiv: 1505.04306

arXiv: 1503.01952

- For ATLAS there are non trivial kinematic selections and multiple final states.
- Dominant systematic uncertainties:

- QCD estimate
- Flavour tagging
- Jet energy corrections
- H-tagging



- Limits: ATLAS: $m(T \rightarrow tH) > 855$ GeV CMS: $m(T \rightarrow tH) > 745$ GeV

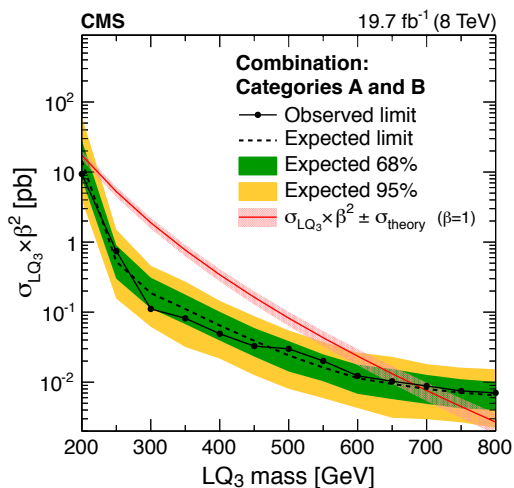
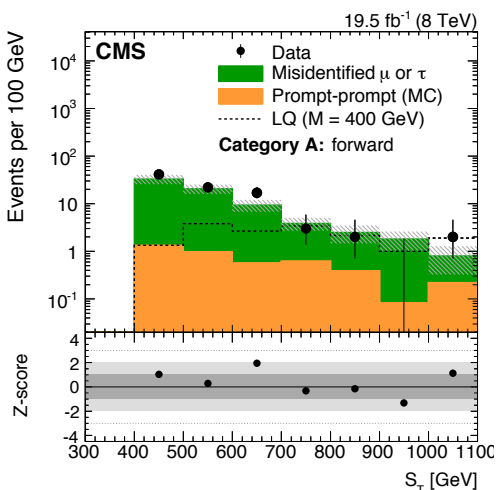
Latest results: $LQ \rightarrow t\tau$

arXiv: 1503.09049

Category A (B)

- CMS investigate leptoquarks decaying to a $t\tau$ final state.
- Two categories A (B) on right:
- S_T is scalar sum of p_T in the event.

τ_{had}	$p_T(\tau_{had}) > 20$ (35) GeV $ \eta(\tau_{had}) < 2.1$ (2.1)
e	$E_T(e) > 15$ (35) GeV $ \eta(e) < 2.5$ (2.1)
μ	$p_T(\mu) > 25$ (30) GeV $ \eta(\mu) < 2.1$ (2.1)
jet	$p_T(j) > 40$ (30) GeV $ \eta(j) < 3.0$ (2.5)
E_T^{Miss}	No selection (>50 GeV)
S_T	Optimised by mass ($S_T > 1000$ GeV)
$p_T(\tau_{had})$	Optimised by mass ($p_T(\tau_{had}) > 20$ GeV)
Leptons	Same sign $\mu\tau_{had}$ ($\mu\tau_{had}$ or $e\tau_{had}$)



- Limits: $m(LQ \rightarrow t\tau) > 685$ GeV
- Dominant systematic uncertainties: t reconstruction, pileup, background estimation.

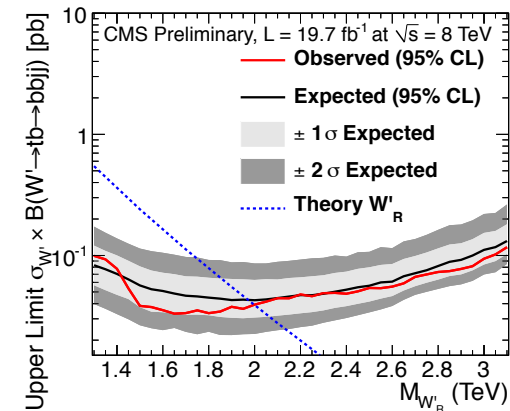
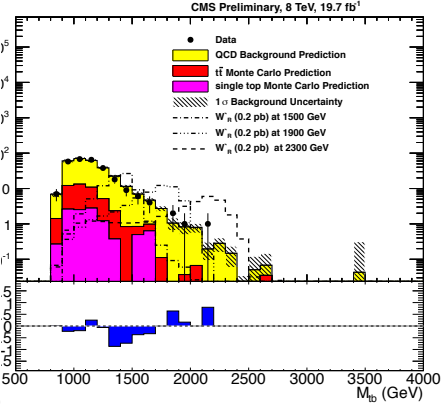
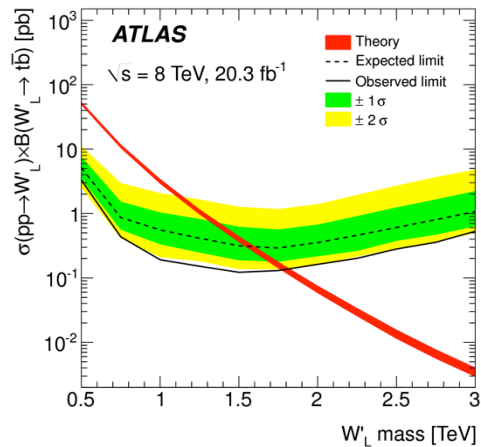
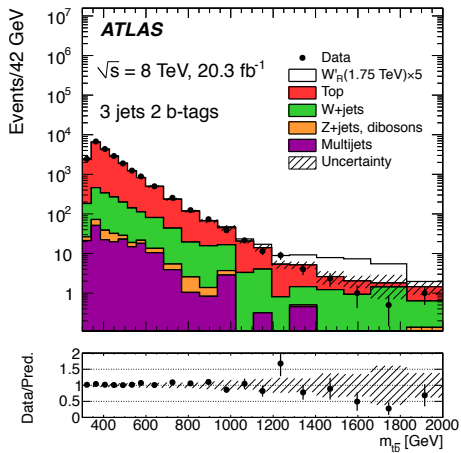
Latest results: $W' \rightarrow tb$

- ATLAS and CMS investigate W' boson decaying to tb final state.
- Dedicated algorithms for top-tagged jets and W' candidates.

Eur. Phys. J. C (2015) 75:165

PLB 743 (2015) 235-255

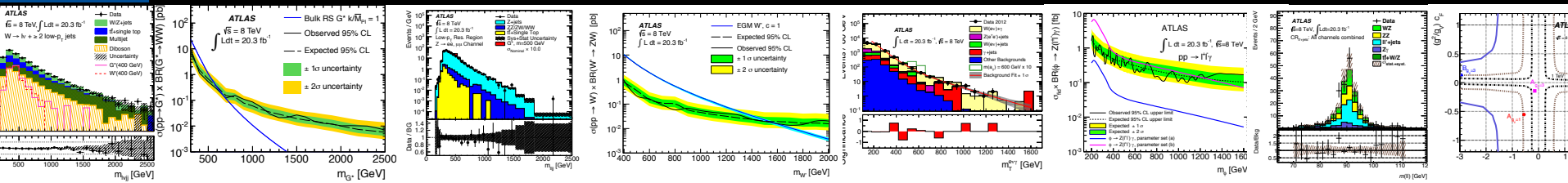
CMS-PAS-B2G-12009



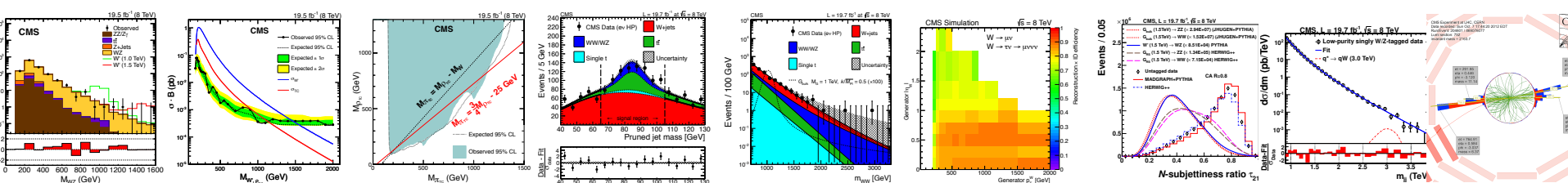
- Dominant systematic uncertainties: t-tbar production, top-tagging.
- Limits:

ATLAS: $m(W')$ right handed > 1.92 TeV CMS: $m(W')$ right handed > 2.15 TeV

ULB Vector boson resonances



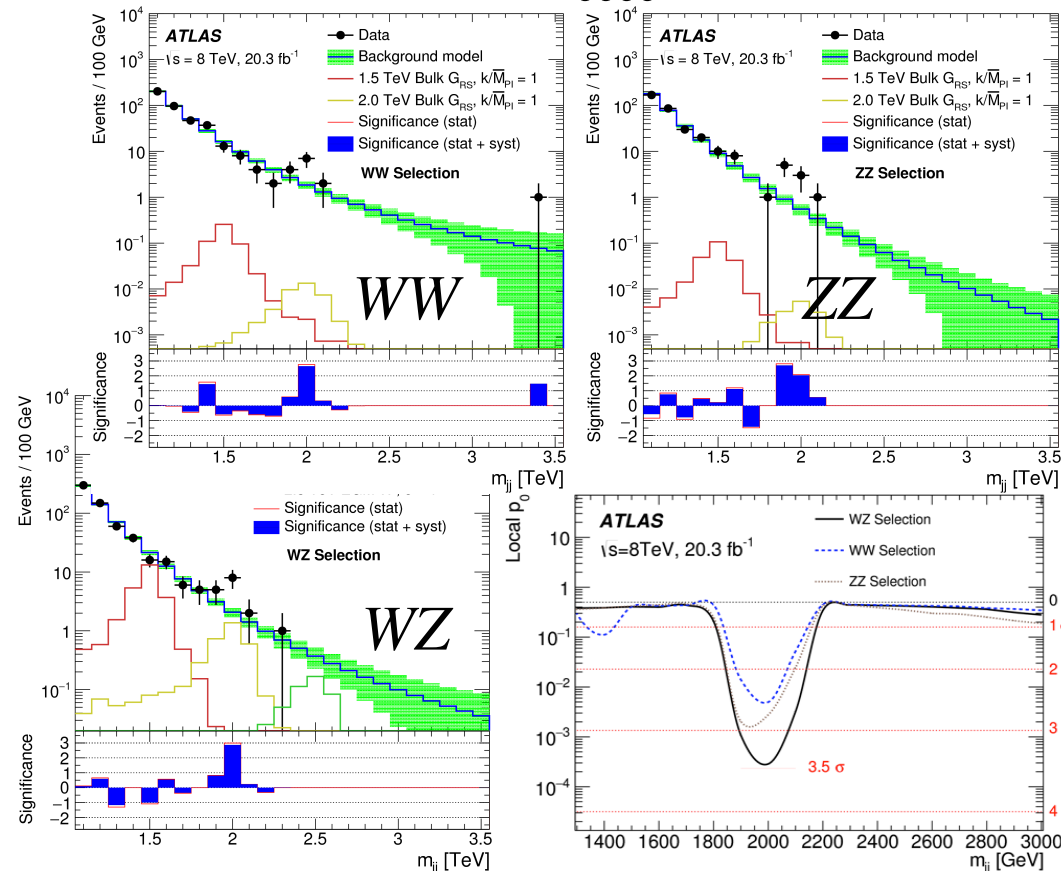
- Many final states ($lljj, llll, ll\nu, jjjj, lvjj$) to consider.
- Benchmark models include W' , Randall-Sundrum Graviton (G_{RS}), Techni-colour.
- Results are not necessarily easy to compare between experiments.
- Leading systematics are usually jet energy scale and jet energy resolution for hadronic final states, lepton scale factors and luminosity for purely leptonic states.
- I cannot cover everything, so I only show the limits!



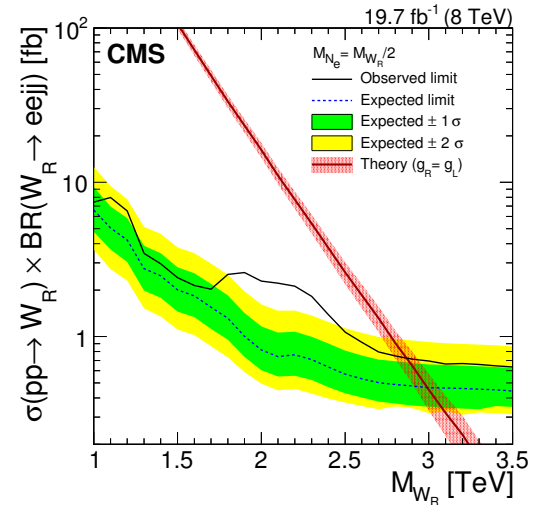
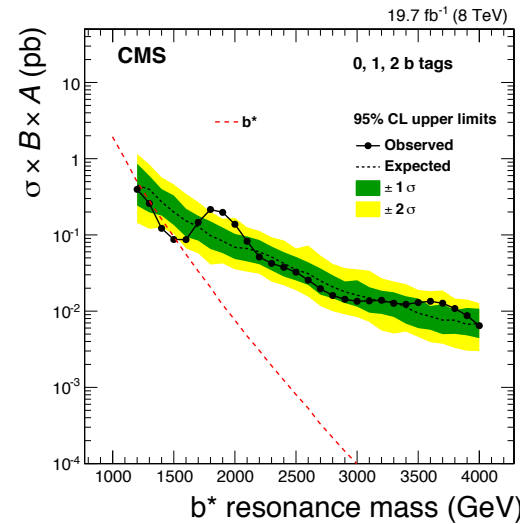
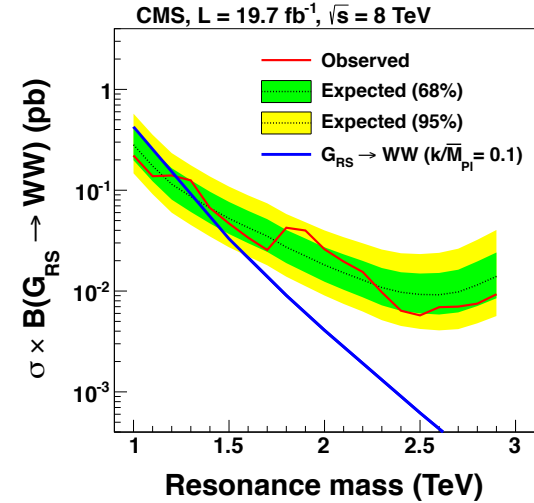
Vector boson resonances

Experiment	Search	Limits	arXiv
ATLAS	$G_{RS} \rightarrow lvjj$	$m(G_{RS}) > 700 \text{ GeV}$	1503.04677
ATLAS	$W' \rightarrow lvjj$	$m(W') > 1490 \text{ GeV}$	1503.04677
ATLAS	$W' \rightarrow WZ \rightarrow lljj$	$m(W') > 1590 \text{ GeV}$	1409.6190
ATLAS	$G_{RS} \rightarrow WZ \rightarrow lljj$	$m(G_{RS}) > 740 \text{ GeV @ k/MPI}=1.0$ $m(G_{RS}) > 540 \text{ GeV @ k/MPI}=0.5$	1409.6190
ATLAS	$\alpha_T \rightarrow lv\gamma$	$m(\alpha_T) > 960 \text{ GeV}$	1407.8150
ATLAS	$\alpha_T \rightarrow ll\gamma$	$m(\alpha_T) > 890 \text{ GeV}$	1407.8150
ATLAS	$W' \rightarrow WZ \rightarrow ll\nu$	$m(W') > 1520 \text{ GeV}$	1406.4456
CMS	$W' \rightarrow WZ \rightarrow ll\nu$	$m(W') > 1550$	1407.3476
CMS	$Q_{TC} \rightarrow WZ \rightarrow ll\nu$	$m(Q_{TC}) > 1140 \text{ GeV}$	1407.3476
CMS	$WZ \rightarrow (lv/ll)+jj$ Graviton bulk	$\sigma(m(G_{RS}) = 600 \text{ GeV}) < 700 \text{ fb}^{-1}$ $\sigma(m(G_{RS}) = 2500 \text{ GeV}) < 10 \text{ fb}^{-1}$	1405.3447
CMS	$q^* \rightarrow qW \rightarrow jjjj$	$m(q^*) > 3200 \text{ GeV}$	1405.1994
CMS	$q^* \rightarrow qZ \rightarrow jjjj$	$m(q^*) > 2900 \text{ GeV}$	1405.1994
CMS	$W' \rightarrow WZ \rightarrow jjjj$	$m(W') > 1700 \text{ GeV}$	1405.1994
CMS	$G_{RS} \rightarrow WW \rightarrow jjjj$	$m(G_{RS}) > 1200 \text{ GeV}$	1405.1994

- Both ATLAS and CMS have recently show results for the $VV \rightarrow jjjj$ final state, where V is a W or Z boson
- Both experiments show an excess around $m(jjjj) = 2$ TeV!
- First, results from ATLAS:
- Most significant excess is $\sim 3.5\sigma$ at $m(VV) = 2$ TeV.
- Jets are “groomed” to reduce QCD backgrounds.



- Equivalent analysis for CMS shows an excess of $\sim 2\sigma$ with an RS graviton model (right).
- There are also excesses around 2 TeV in the dijet spectrum for $b^* \rightarrow bg$ (below left) and right handed W' in the context of $W' \rightarrow eN_e$ (below right).
- Interesting hints of new physics around 2 TeV showing up in several final states!



- LHC Run 1 has seen many very active searches for new resonances.
- ATLAS and CMS have probed new parameter space, setting unprecedented limits, in the range of TeV.
- The experiments have rich programs of physics and diverse searches.
- Tantalising hints of something around $M \sim 2 \text{ TeV}$
 - Fingers crossed for LHC Run 2!

Backup

PDFs and background uncertainties

• Diphoton resonances

• Dijet resonances

• Further multi-jet resonances

• Ditau resonances

• Lepton flavour violating decays

Run: 204153
Event: 35369265
2012-05-30 20:31:28 CEST

ULB PDFs and background uncertainties

- For many searches (dilepton, ditau, diphoton) the dominant systematic uncertainties come from PDF uncertainties on the background
 - Often vary widely as a function of mass
 - Hard to quantify without giving benchmarks
 - Good example from ATLAS dilepton search (arXiv: 1405.4123):

TABLE III. Summary of systematic uncertainties on the expected numbers of events at a dilepton mass of $m_{\ell\ell} = 2$ TeV, where N/A indicates that the uncertainty is not applicable. Uncertainties $< 3\%$ for all values of m_{ee} or $m_{\mu\mu}$ are neglected in the respective statistical analysis.

Source ($m_{\ell\ell} = 2$ TeV)	Dielectrons		Dimuons	
	Signal	Backgr.	Signal	Backgr.
Normalization	4%	N/A	4%	N/A
PDF variation	N/A	11%	N/A	12%
PDF choice	N/A	7%	N/A	6%
α_s	N/A	3%	N/A	3%
Electroweak corr.	N/A	2%	N/A	3%
Photon-induced corr.	N/A	3%	N/A	3%
Beam energy	$< 1\%$	3%	$< 1\%$	3%
Resolution	$< 3\%$	$< 3\%$	$< 3\%$	3%
Dijet and $W +$ jets	N/A	5%	N/A	N/A
Total	4%	15%	4%	15%

TABLE IV. Summary of systematic uncertainties on the expected numbers of events at a dilepton mass of $m_{\ell\ell} = 3$ TeV, where N/A indicates that the uncertainty is not applicable. Uncertainties $< 3\%$ for all values of m_{ee} or $m_{\mu\mu}$ are neglected in the respective statistical analysis.

Source ($m_{\ell\ell} = 3$ TeV)	Dielectrons		Dimuons	
	Signal	Backgr.	Signal	Backgr.
Normalization	4%	N/A	4%	N/A
PDF variation	N/A	30%	N/A	17%
PDF choice	N/A	22%	N/A	12%
α_s	N/A	5%	N/A	4%
Electroweak corr.	N/A	4%	N/A	3%
Photon-induced corr.	N/A	6%	N/A	4%
Beam energy	$< 1\%$	5%	$< 1\%$	3%
Resolution	$< 3\%$	$< 3\%$	$< 3\%$	8%
Dijet and $W +$ jets	N/A	21%	N/A	N/A
Total	4%	44%	4%	23%

2 TeV

3 TeV

Diphoton resonances

- Both ATLAS and CMS investigate diphoton resonances.
- Simple final state.
- Kinematic selections:

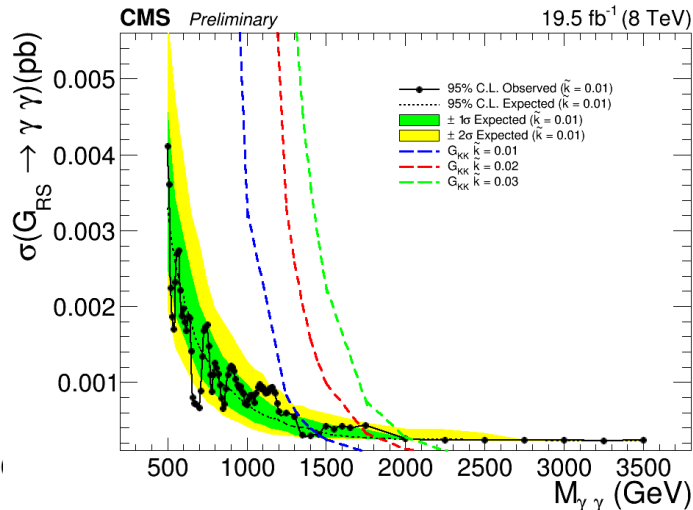
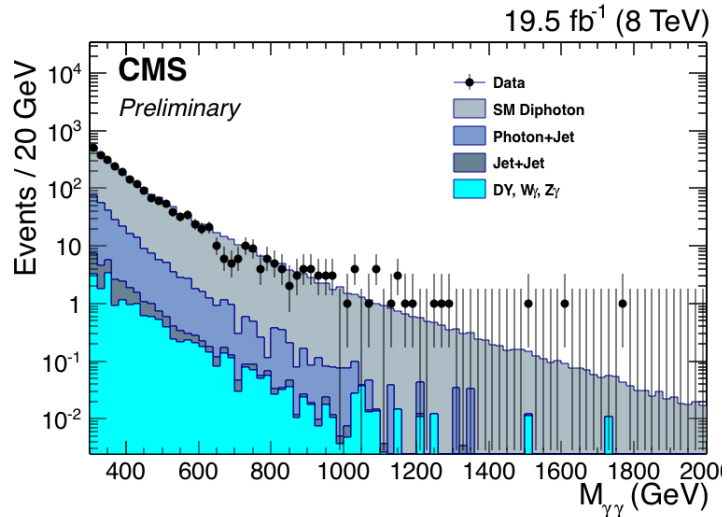
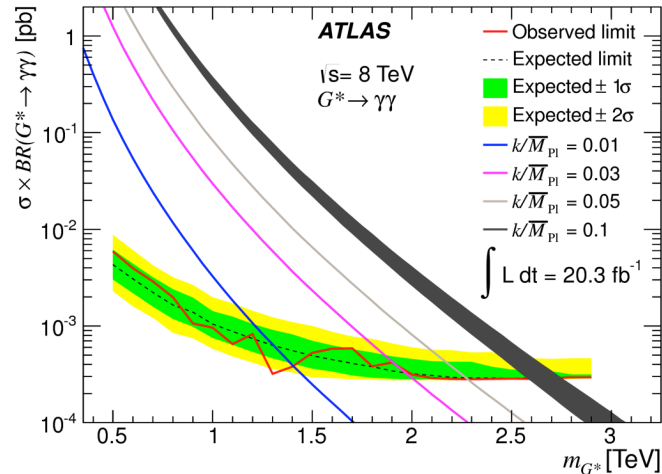
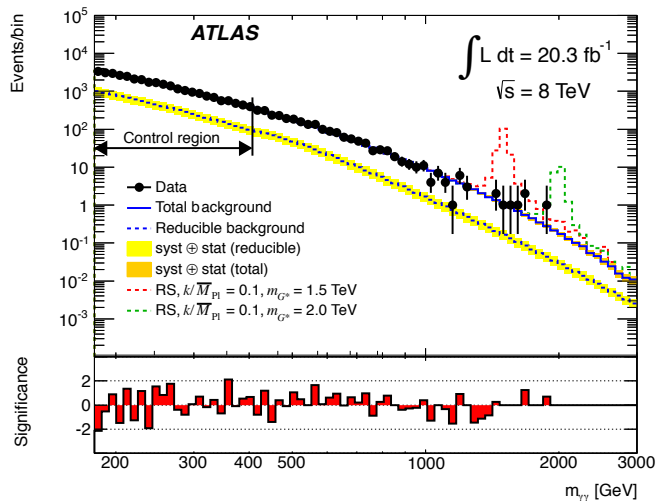
arXiv: 1505.04306

CMS-PAS-EXO-12-045

ATLAS	CMS
$p_T > 50 \text{ GeV}$ $ \eta < 1.37 \text{ or } 1.52 < \eta < 2.47$	$p_T > 80 \text{ GeV}$ $ \eta < 1.4442$ $m(\gamma\gamma) > 300 \text{ GeV}$

- Dominant systematic uncertainties: PDFs for background modeling, photon reconstruction efficiency, luminosity.

Diphoton resonances



Limits for $k/M_{Pl} = 0.1$: ATLAS: $m(G_{RS}) > 2.66 \text{ TeV}$ CMS: $m(G_{RS}) > 2.78 \text{ TeV}$

Dijet resonances

- Both ATLAS and CMS investigate dijet resonances.
- Many possible interpretations, including excited quarks, W' and Z' bosons, black holes etc.
- Kinematic selections:

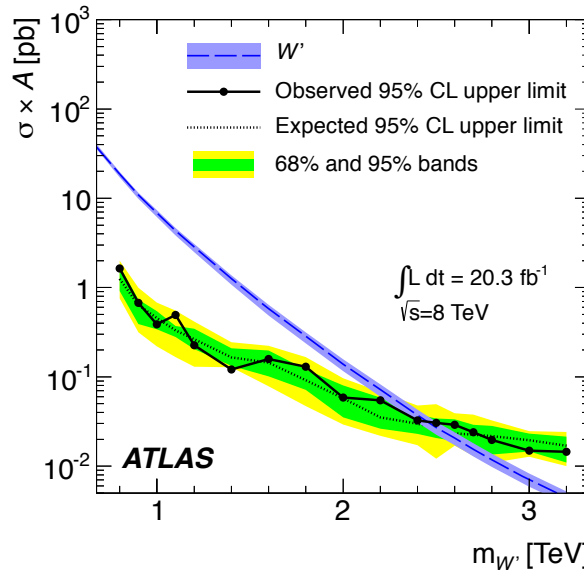
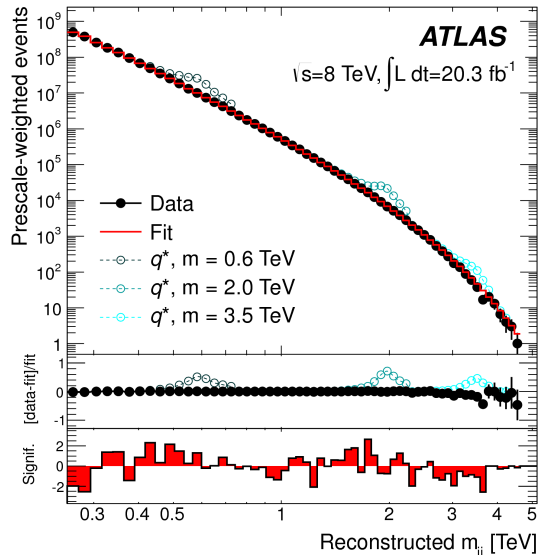
PRD 91, 052007

PRD 91, 052009

ATLAS	CMS
$p_T(j) > 50 \text{ GeV}$ $ \eta(j) < 2.8$ $\frac{1}{2}(\eta(j)_{\text{leading}} - \eta(j)_{\text{subleading}}) < 0.6$ and $m(jj) > 250 \text{ GeV}$ to remove p_T bias	$p_T(j) > 30 \text{ GeV}$ $ \eta(j) < 2.5$ $m(jj) > 890 \text{ GeV}$ to remove trigger bias

- Dominant systematic uncertainties: jet energy scale, jet energy resolution, luminosity.
- (More final states in backup slides.)

Dijet resonances



- Limits on W' , qg searches:

- ATLAS

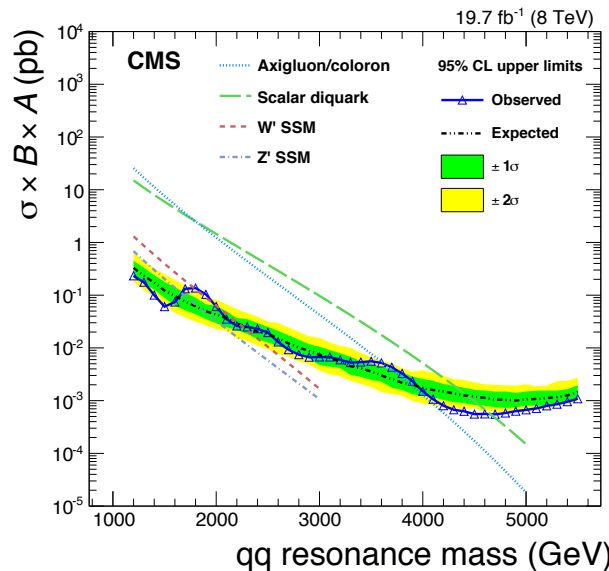
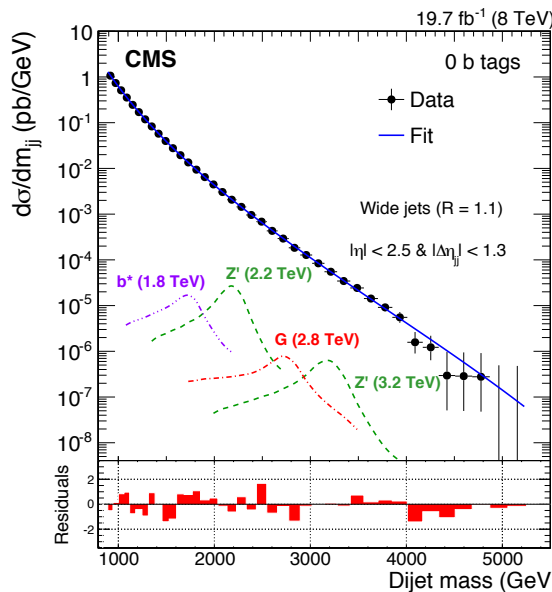
$$m(W') > 2.45 \text{ TeV}$$

$$m(qg) > 4.06 \text{ TeV}$$

- CMS

$$m(W') > 2.2 \text{ TeV}$$

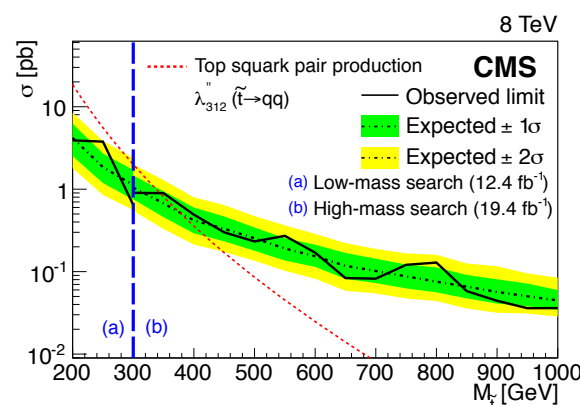
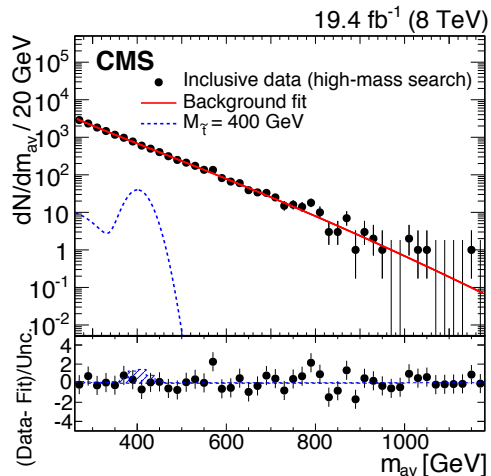
$$m(qg) > 5.0 \text{ TeV}$$



ULB Further multi-jet resonances

- CMS also investigate pair produced resonances decaying to jets, and three-jet final states:

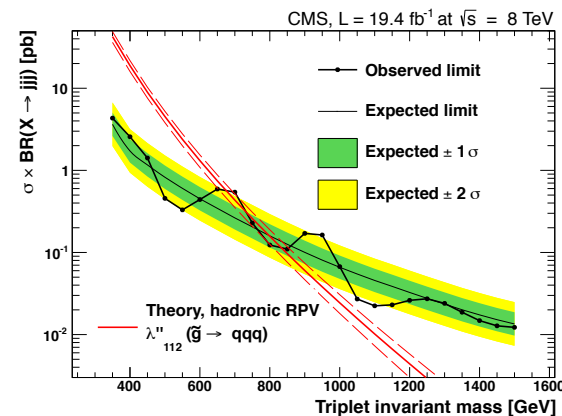
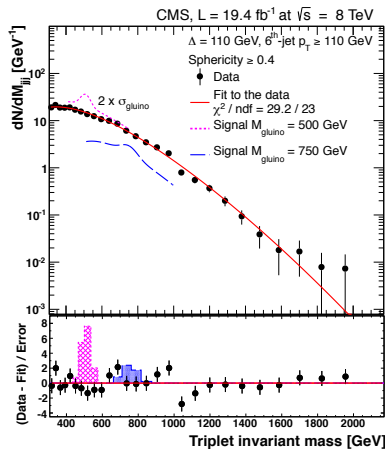
$$X \rightarrow YY, \\ Y \rightarrow jj$$



Phys. Lett. B 730 (2014) 193

Exclude top squark masses for decays to light (heavy) jets in range: $200 < m(jj) < 350$ (385) GeV

$$Z \rightarrow jjj$$



Dominant uncertainties: Jet energy scale, resolution, initial and final state radiation, signal fits

Exclude gluino masses for decays to light (heavy) jets in range: 0 (200) $< m(jjj) < 350$ (835) GeV

arXiv:1412.7706

Ditau resonances

- Results from ATLAS and CMS
- ATLAS considers $\tau_{had}^- \tau_{had}^-$ and $\tau_{had}^- \tau_{lep}$ final states (τ_{had} is a τ jet)
- CMS consider $\tau_e^- \tau_\mu^-$ final states
- Kinematic selections:

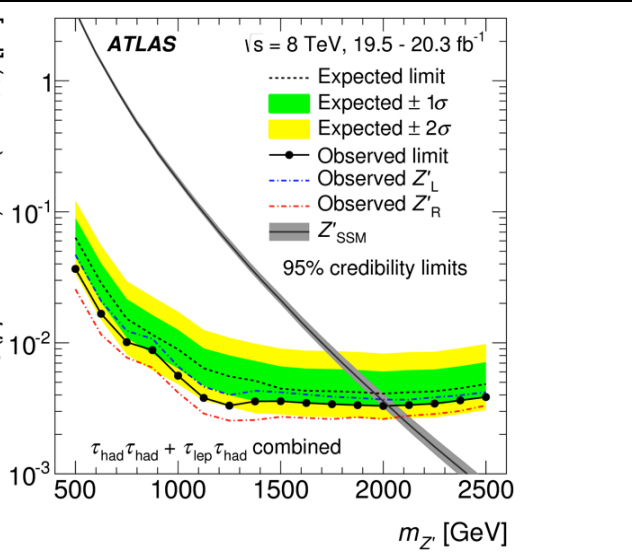
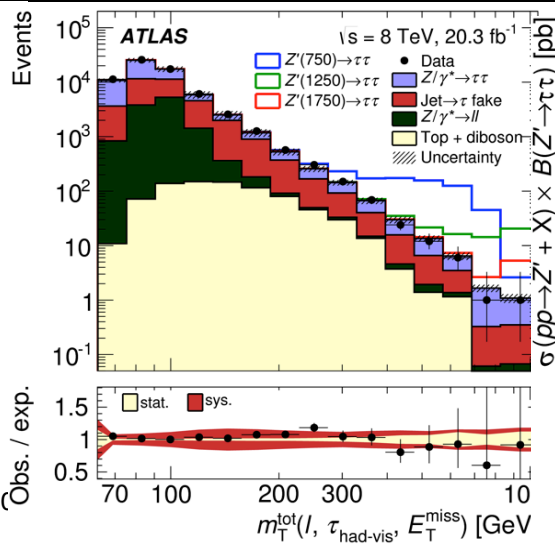
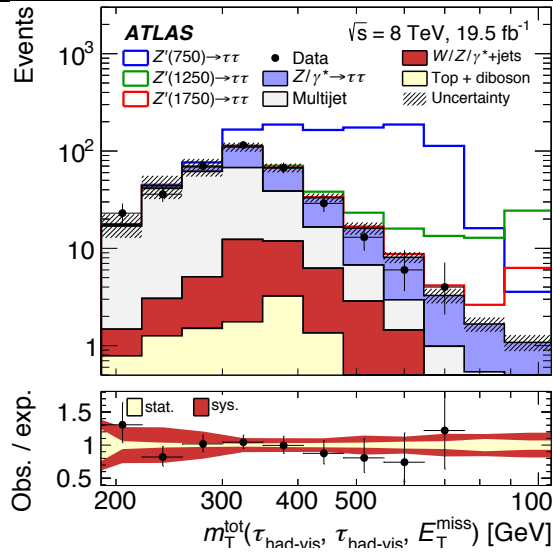
PRD 90, 052005

CMS-PAS-EXO-12-046

	ATLAS	CMS
τ_{had}	$p_T(\tau_{had}) > 30 \text{ GeV}$ $ \eta(\tau_{had}) < 1.37 \text{ or } 1.52 < \eta(\tau_{had}) < 2.47$	
e	$E_T(e) > 15 \text{ GeV}$ $ \eta(e) < 1.37 \text{ or } 1.52 < \eta(e) < 2.47$	$E_T(e) > 20 \text{ GeV}$ $ \eta(e) < 1.442 \text{ or } 1.56 < \eta(e) < 2.5$
μ	$p_T(\mu) > 10 \text{ GeV}$ $ \eta(\mu) < 2.5$	$p_T(\mu) > 20 \text{ GeV}$ $ \eta(\mu) < 2.1$

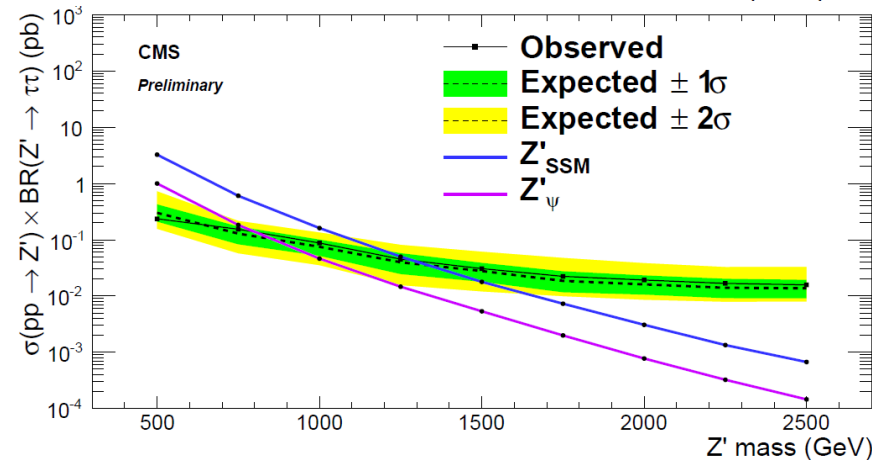
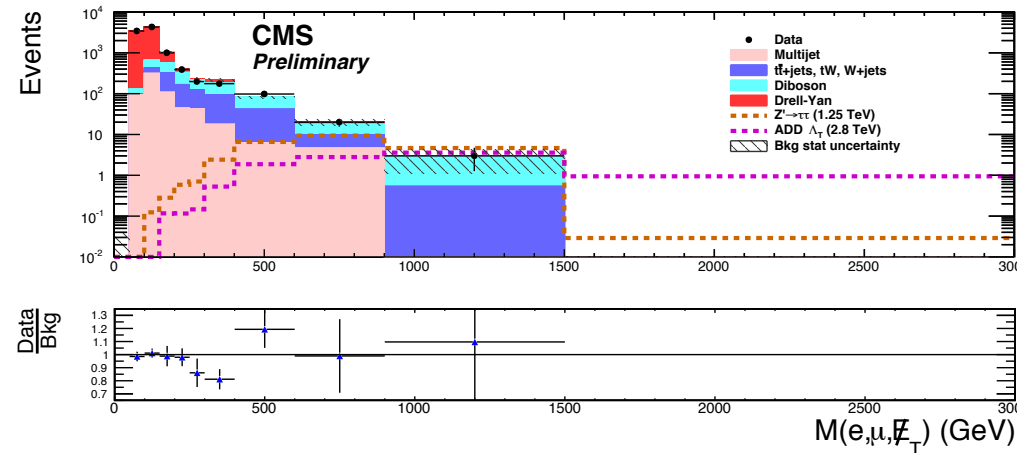
- Dominant systematic uncertainties: PDFs for background modeling, Signal efficiency for ATLAS, data driven background estimates for CMS.

Ditau resonances



19.7 fb⁻¹ (8 TeV)

19.7 fb⁻¹ (8 TeV)



• Exclusion limits:

ATLAS: $m(Z'_{SSM}) > 2.02 \text{ TeV}$

CMS: $m(Z'_{SSM}) > 1.30 \text{ TeV}$

ULB Lepton flavour violating resonances

- Results from ATLAS and CMS
- ATLAS considers $e\text{-}\mu$, $e\text{-}\tau$, and $\mu\text{-}\tau$ final states
- CMS consider $e\text{-}\mu$ final states
- Kinematic selections:

arXiv:1503.054420

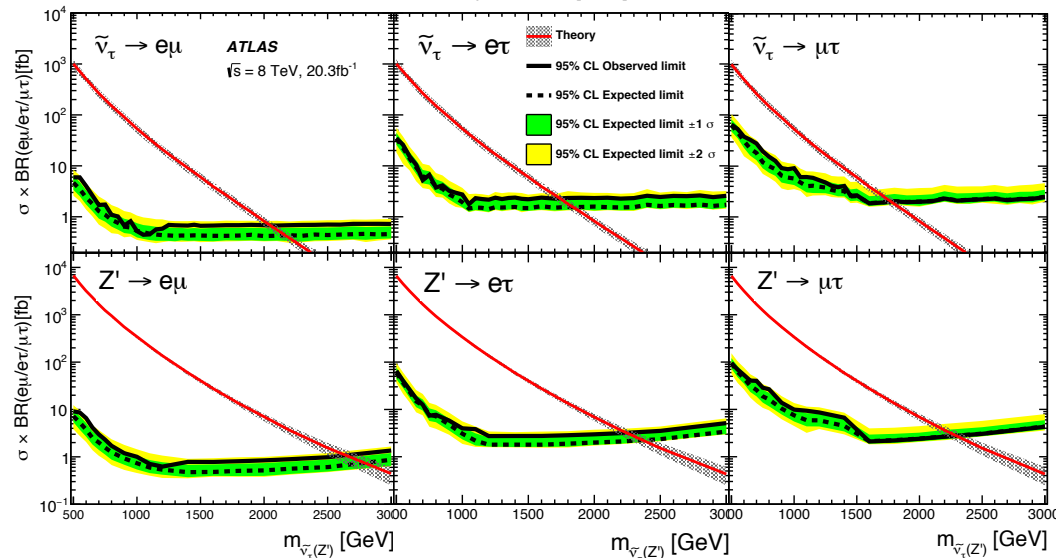
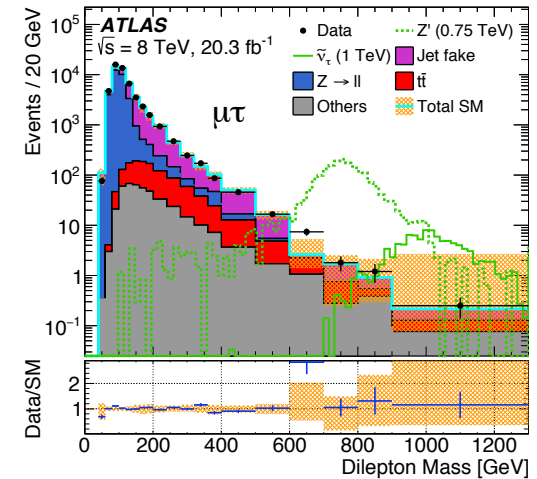
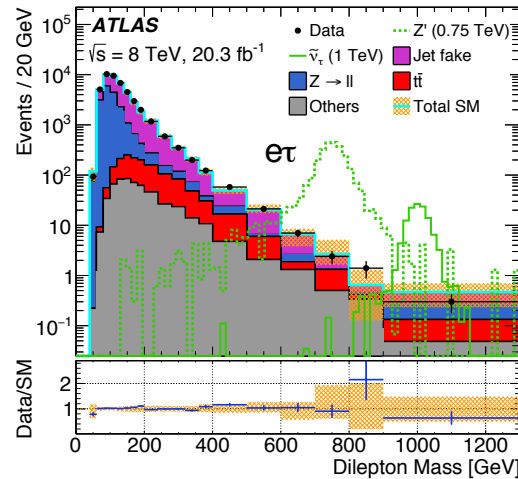
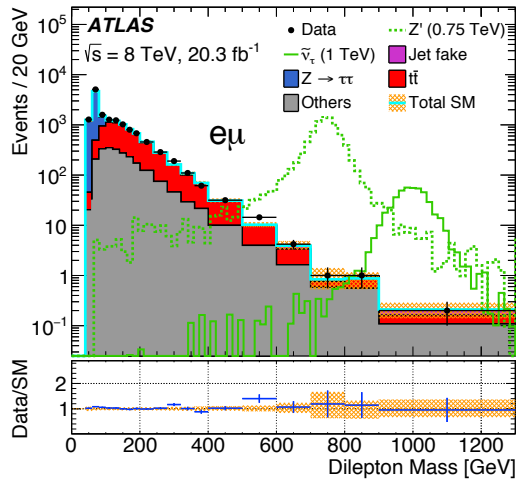
arXiv:1504.055115

ATLAS	CMS
$p_T(\tau_{had}) > 25 \text{ GeV}$ $ \eta(\tau_{had}) < 2.47$ Single track	
$E_T(e) > 25 \text{ GeV}$ $ \eta(e) < 1.37$ or $1.52 < \eta(e) < 2.47$	$E_T(e) > 35 \text{ GeV}$ $ \eta(e) < 1.442$ or $1.56 < \eta(e) < 2.5$
$p_T(\mu) > 25 \text{ GeV}$ $ \eta(\mu) < 2.4$	$p_T(\mu) > 45 \text{ GeV}$ $ \eta(\mu) < 2.1$

- Dominant systematics: Acceptance and efficiency, 3-6% for ATLAS, ~5% for CMS.

ULB Lepton flavour violating resonances

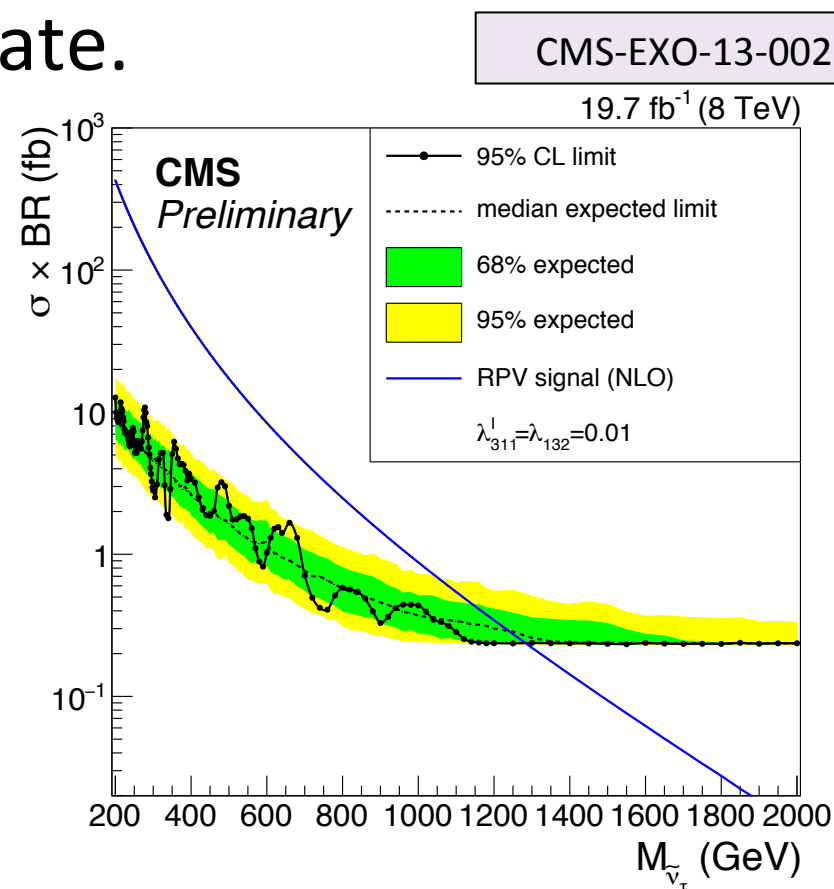
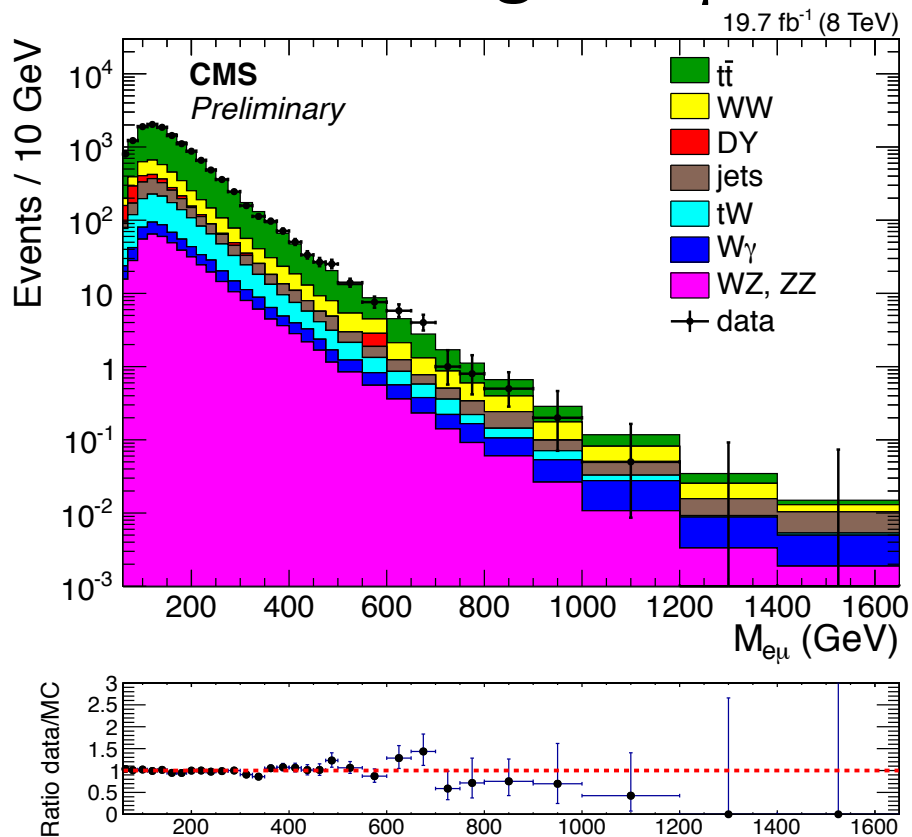
- ATLAS investigates $e\mu$, $e\tau$, $\mu\tau$ final states.



- Limits: \sim
 - $e\mu$: $m(\nu_\tau) > 2.0$ TeV
 - $e\tau$: $m(\nu_\tau) > 1.7$ TeV
 - $\mu\tau$: $m(\nu_\tau) > 1.7$ TeV

ULB Lepton flavour violating resonances

- CMS investigate $e\mu$ final state.



Limit: $m(\tilde{\nu}_\tau) > 2.1$ TeV