Search for low and high mass resonances at ATLAS and CMS

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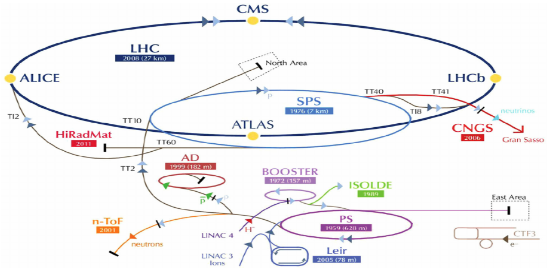
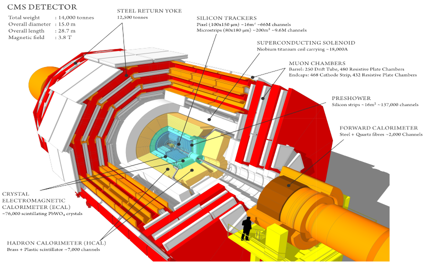
Overview

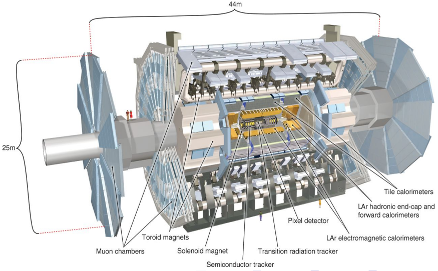
- The search for low and high mass resonances at ATLAS and CMS is quite broad.
- Both collaborations have a very interesting and large physics program on this topic.
- Therefore, I have selected some of the latest results released by both collaborations.
- **On this talk, I will cover:**
  1. Low Mass Resonances ($\mathrm{Z} \to 4\mu$)
  2. Low Mass Resonances ($\mathrm{b\bar{b}}$)
  3. Dijet Resonances
  4. Narrow Resonances to VV
  5. Resonant production of WZ
  6. Combination of searches for heavy resonances to VV
  7. W' and Z'
  8. Pair production of scalar Leptoquarks.
  9. Pair production of Vector-Like fermions.


CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT40
TT41
SPS
1976 (7 km)
TI8
neutrinos
TI2
TT10
ATLAS
CNGS
2006
Gran Sasso
HiRadMat
2011
TT60
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
n-ToF
2001
PS
1959 (628 m)
CTF3
LINAC 4
neutrons
LINAC 3
Ions
Leir
2005 (78 m)

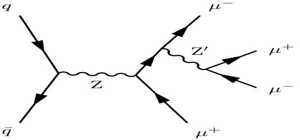
CMS


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 (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

ATLAS

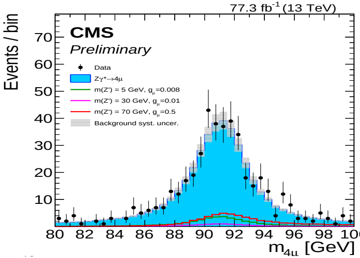

44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

$Z \to 4\mu$ ($77.3\ fb^{-1}$) - CMS-PAS-EXO-18-008



- The inclusion of an additional $U(1)'$ symmetry in the SM, is one of the simplest extensions.
- Such an extension, gives rise to the well known Z' boson.
- "To make the extension anomaly-free, only some generation-dependent couplings are allowed"..
- The analysis uses the $L_\mu - L_\tau$ gauge symmetry: assumes couplings to the 2nd and 3rd generations only.

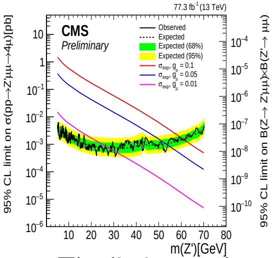
- Event selection criteria:
  1. $n_\mu \geq 4$
  2. $4 < m_{\mu^+\mu^-} < 120$ GeV
  3. $m(Z_1) > 12$ GeV
  4. $80 < m_{4\mu} < 100$ GeV
- Z_1: dimuon pair closest to Z mass.



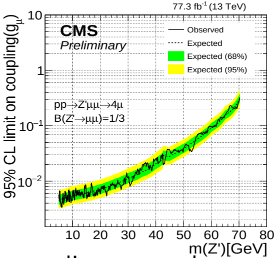
	Background	$m(Z') = 5$ GeV g_μ=0.008	$m(Z') = 15$ GeV g_μ=0.01	$m(Z') = 70$ GeV g_μ=0.5	Observed Data
$80 < m_{4\mu} < 100$ GeV	423.0±39.2	37.1±3.7	31.4±3.1	53.8±5.4	441
$4.9 < m(Z_2) < 5.1$ GeV	9.2±3.1	23.3±2.3	-	-	13
$14.7 < m(Z_2) < 15.3$ GeV	7.7±2.8	-	18.9±1.9	-	6
$68.6 < m(Z_1) < 71.4$ GeV	34.9±6.5	-	-	36.0±3.6	35

$Z \to 4\mu$ (77.3 fb^{-1}) - CMS-PAS-EXO-18-008

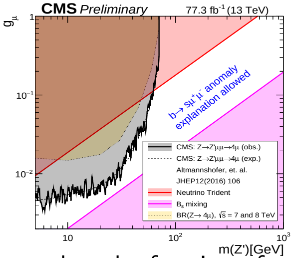
95% CL upper limits on $\sigma(Z'\mu\mu)$ production cross section and branching fraction vs $m(Z')$



95% CL upper limits on the gauge coupling strength as function of $m(Z')$

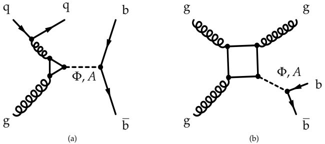


Comparison with other experiments sensitive to the same parameter space



- The limits on the gauge coupling strength, g_μ, assume that the fraction of $B(Z' \to \mu\mu)$ is equal to $1/3$.
- The shaded yellow region shows constraints derived from the ATLAS measurements at 7 and 8 TeV of $Z \to 4\mu$.
- Shaded red: trident cross section by the CCFR Collaboration and magenta from global analysis of B_s mixing.
- **The region in between the red and magenta constrains ,and for $m(Z') > 10$ GeV, is a candidate region to explain the LHCb B-decay anomalies.**

$b\bar{b}$ pairs (35.9 fb^{-1}) - CMS-PAS-EXO-17-024



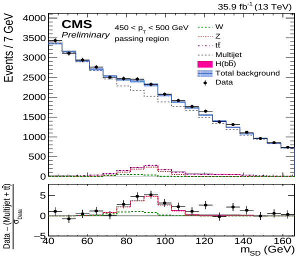
One-loop diagrams of processes exchanging a scalar (Φ) or pseudoscalar (A) mediator, leading to a boosted double b-jet signature.

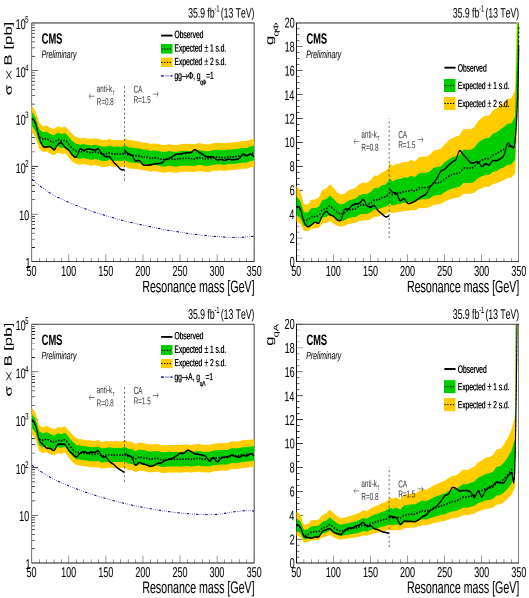
- Depending on the signal hypothesis, the analysis uses two different jet-recon. algorithms (anti-$k_t - AK8$) or Cambridge-Aachen (CA15)).
- The event selection requires a hard ISR jet with $p_T > 450 GeV$ (500 GeV) and $|\eta| < 2.5$ for AK8 (CA15) jets.
- $n_\ell = 0$ and $p_T^{miss} > 140$ GeV.
- The soft-drop algorithm is used to reduce QCD contamination: $\frac{min(p_{T1}, p_{T2})}{p_{T1}+p_{T2}} > z_{cut}(\frac{\Delta R_{1,2}}{R_0})^\beta$
- A dimensionless mass scale variable for QCD multijet jets, $\rho = log(m_{SD}^2/p_T^2)$ is used to characterize the correlation between the jet b tagging discriminator, jet mass, and jet p_T.
- **Events with $\Phi(b\bar{b})$-tag are defined as passing.**

AK8 jets							
m_Φ [GeV]	$p_T > 450$ GeV	$m_{SD} > 40$ GeV	Lepton veto	$p_T^{miss} < 140$ GeV	$N_2^{1,DDT} < 0$	$-6.0 < \rho < 2.1$	double-b tag
50	75.0 ± 0.1	37.5 ± 0.2	36.2 ± 0.2	32.9 ± 0.2	14.7 ± 0.1	14.3 ± 0.1	7.3 ± 0.1
100	75.4 ± 0.1	42.2 ± 0.2	40.6 ± 0.2	37.5 ± 0.2	18.0 ± 0.1	17.5 ± 0.1	7.1 ± 0.1
125	75.5 ± 0.2	42.3 ± 0.2	40.6 ± 0.2	37.5 ± 0.2	18.1 ± 0.1	17.5 ± 0.1	6.1 ± 0.1
CA15 jets							
m_Φ [GeV]	$p_T > 500$ GeV	$m_{SD} > 82$ GeV	Lepton veto	$p_T^{miss} < 140$ GeV	$N_2^{1,DDT} < 0$	$-4.7 < \rho < -1.0$	double-b tag
200	61.0 ± 0.1	35.6 ± 0.1	33.9 ± 0.1	31.1 ± 0.1	13.9 ± 0.1	13.0 ± 0.1	3.3 ± 0.0
300	63.4 ± 0.1	35.7 ± 0.1	34.0 ± 0.1	31.1 ± 0.1	13.2 ± 0.1	11.1 ± 0.1	1.9 ± 0.0
350	64.3 ± 0.1	35.8 ± 0.1	33.9 ± 0.1	31.1 ± 0.1	13.0 ± 0.1	8.6 ± 0.1	1.1 ± 0.0

$b\bar{b}$ pairs ($35.9\ fb^{-1}$) - CMS-PAS-EXO-17-024

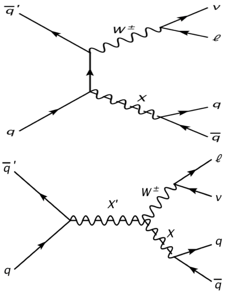
- QCD-multi-jet is the dominant BG (estimated from data).
- The figure below shows the observed and fitted background in one of the p_T categories for the AK8 selection.
- The QCD-multijet BG in the passing region is predicted using the failing region and the pass-fail ratio $R_{p/f}$.





Dijet+ℓ Resonances (79.8 fb^{-1}) - **ATLAS-CONF-2018-015**

- Resonances might have large couplings to partons:
  $q\bar{q}' \rightarrow WX \rightarrow \ell\nu q\bar{q}$
  $q\bar{q}' \rightarrow X' \rightarrow WX \rightarrow \ell\nu q\bar{q}$
- The search focuses in final states where $\ell = \mathrm{e}$ or μ.



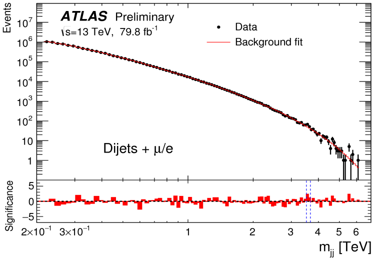
- The analysis searches for an excess, using the m_{jj} distribution: 0.22 GeV $< m_{jj} < 6.3$ TeV.
- Events must have two jets, reconstructed w/ the anti-k_T algorithm, w/ $p_T > 20$ GeV and $|\eta| < 2.4$.
- The two highest p_T jets are used for m_{jj}.
- In addition, an e or μ with $p_T > 60$ GeV is required.
- The m_{jj} distribution for the background is expected to be smooth and to decay monotonically. The following fit function is used to determine the shape of the BG:

$$f(x) = p_1(1-p_2)^{p_2} x^{p_3 + p_4 \ln x + p_5 \ln^2 x}$$

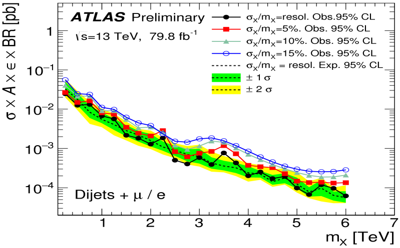
$$x = m_{jj}/\sqrt{s},\ p_i \text{ fit parameters}$$

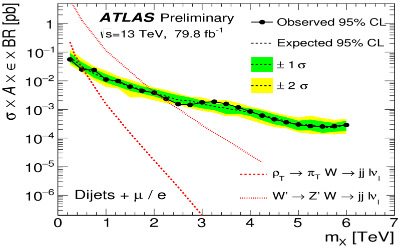
Dijet+ℓ Resonances (79.8 fb^{-1}) - **ATLAS-CONF-2018-015**

- The figures shows the resulting distribution in data and the corresponding fit.
- The BumpHunter test was used to determine the most significant deviation from the background only hypothesis.



Exclusion bounds at 95% CL.

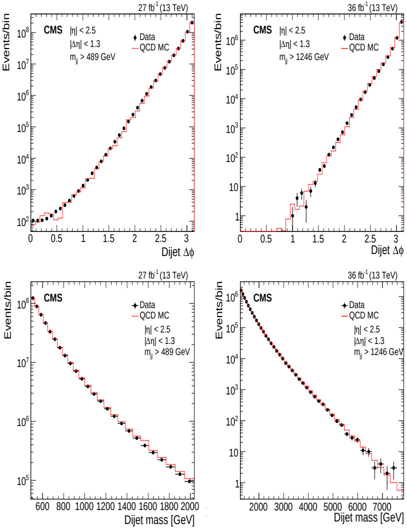




Dijet Resonances (36 fb^{-1}) - **CMS-EXO-16-056**

- CMS divides the search in to narrow and broad resonance spectrums,using wide jets: $p_T > 30$ GeV, $|\eta| < 2.5$.
- The narrow resonance search, separates events in to two m_{jj} regions:
  1. $0.6 < m_{jj} < 1.6$ TeV (27 fb^{-1})
  2. $m_{jj} > 1.6$ TeV (36 fb^{-1})
- The broad resonance search, uses the same events as the high-mass narrow resonance scenario.
- Several benchmark models used: **String resonances, Scalar diquarks, Mass-degenerate excited quarks, Axigluons and colorons, W', Z', Randall-Sundrum, Dark matter mediators**, etc.

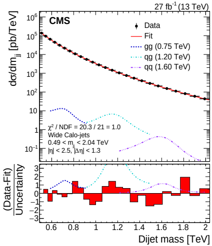
- QCD-multijet events are the dominant source BG.

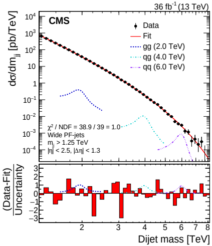


Dijet Resonances ($36\ fb^{-1}$) - **CMS-EXO-16-056**

Narrow dijet

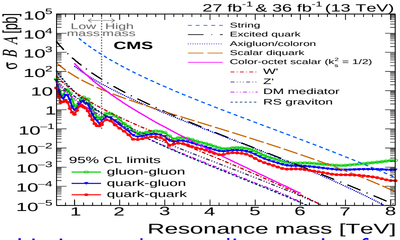
- m_{jj} for the observed number of events in each bin divided by the integrated luminosity and the bin width, with bins of width corresponding to the dijet mass resolution.



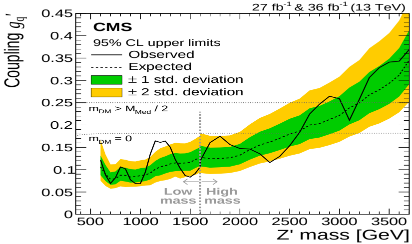


$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\,ln(x)}}\ , \quad \frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\,ln(x)+P_4\,ln^2(x)}}$$

Limits on the resonance mass

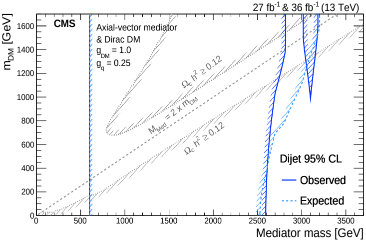


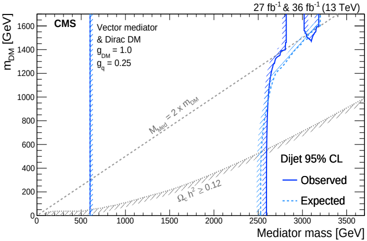
Limits on the coupling to q's of a leptophobic Z'

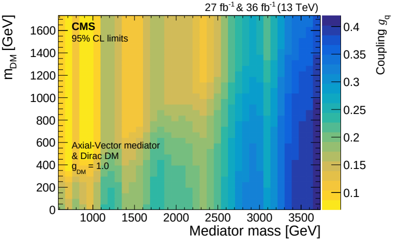


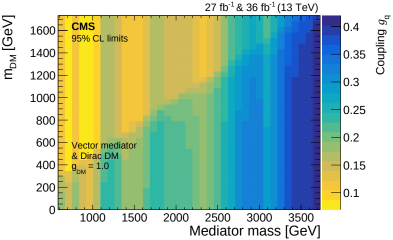
Narrow dijet: Limits on a dark matter mediator

Limits are set to constrain simplified models of DM, with leptophobic vector and axial-vector mediators that couple only to quarks and DM particles.





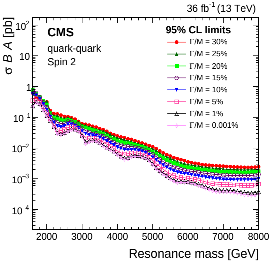




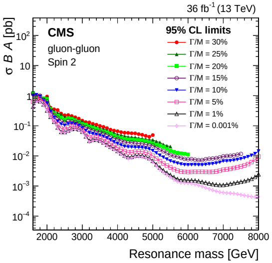
Dijet Resonances (36 fb^{-1}) - CMS-EXO-16-056

- The search for narrow resonances assumes the resonance width, Γ, is negligible compared to the experimental dijet mass resolution.
- The broad resonance search, constrains the width up to 30% of the resonance mass (M). Limits are given as function of Γ/M.
- The shape of a broad resonance depends on the relationship between the width and the resonance mass. The cross section is described by Breit-Wigner:

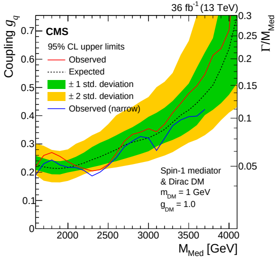
$\hat{\sigma} \propto \frac{\pi}{m^2} \frac{[\Gamma^i M][\Gamma^f M]}{(m^2 - M^2)^2 + [\Gamma M]^2}$, Spin1: $\Gamma M \rightarrow (\frac{m^2}{M^2})\Gamma M$, Spin2: $\Gamma M \rightarrow (\frac{m^4}{M^4})\Gamma M$



95% CL upper limits for spin-2 resonances produced and decaying in the qq channel.



95% CL upper limits for spin-2 resonances produced and decaying in the gg channel.

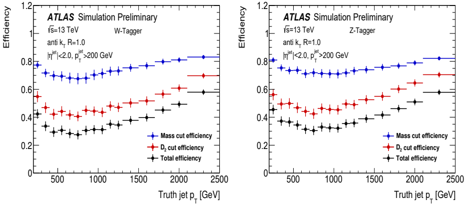


95% CL upper limits on g_q vs resonance mass for a vector mediator.

Narrow Dijet Resonances (79.8 fb^{-1}) ATLAS-CONF-2018-016

- The analysis searches for narrow resonances decaying to a pair of vector bosons (WW, WZ, ZZ).
- Heavy resonances decaying to vector-boson-pairs are predicted in several extensions of the SM, such as: extended gauge symmetry models, GUT theories, theories with warped extra dimensions, two Higgs doublet models, technicolour, etc.
- **The analysis focuses in narrow VV resonances decaying to fully hadronic final states.**
- As expected, the largest BG contribution comes from QCD-multijet events.

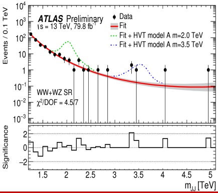
- Event selection criteria:
  1. $N_{jets} \geq 2$ (anti-k_t, $R = 1.0$).
  2. $p_T^{lj1(j2)} > 500(200)$ GeV.
  3. $|\eta^{j1(j2)}| < 2.0$.
  4. $m_{jj} > 1200$ GeV
  5. $|\Delta \mathrm{y}| < 1.2$
  6. $(p_{T1} - p_{T2})/(p_{T1} + p_{T2}) < 0.15$
  7. In addition, to discriminate the jets from the bosons from other jets, the reconstructed jet mass and the D_2 variables are used (D_2: energy correlation functions for jet substructure).

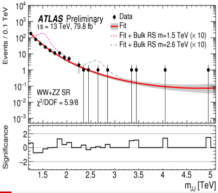


Narrow Dijet Resonances ($79.8\ fb^{-1}$) **ATLAS-CONF-2018-016**

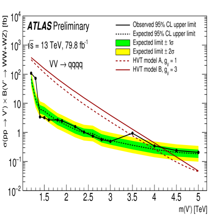
- The BG is expected to have a smooth falling distribution. Therefore, the analysis searches for narrow peaks on top of the BG prediction.
- The analysis uses a binned maximum likelihood fit of a parametrised form to the m_{jj} distribution

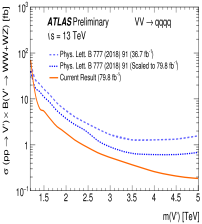
  $\frac{dn}{dx} = p_1(1-x)^{p_2 - \zeta p_3} x^{-p_3}$, where $x = m_{jj}/\sqrt{s}$, p_1 is a normalisation factor, p_2 and p_3 are dimensionless shape parameters, and ζ is a constant.)
- The modelling of the parametric shape is tested in dedicated CRs.



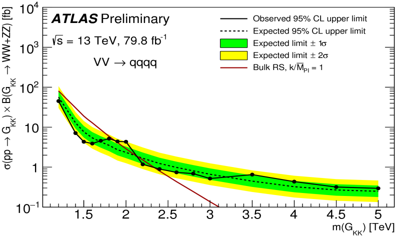


spin-1 Heavy Vector Triplet Model





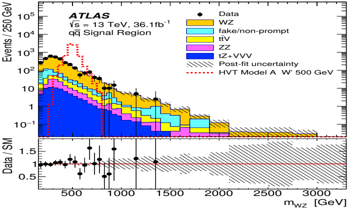
Kaluza-Klein of the RS graviton

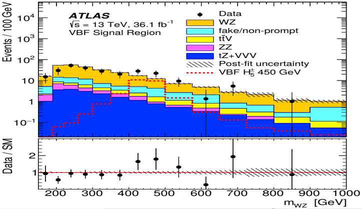


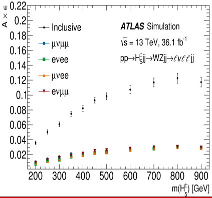
Heavy Resonances WZ (36.1 fb^{-1}) - ATLAS-EXOT-2016-11

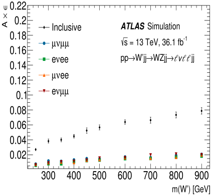
- Resonant production of WZ bosons.
- Basic Selection Criteria:
  1. $N_\ell \geq 3$. At least two from the Z: same flavour, opposite charge, $|m_{\ell\ell} - m_Z| < 20$ GeV.
  2. $E^T_{miss} > 25$ GeV. The third lepton and the E^T_{miss} are assume to come from the W.
- Considers *VBF* and $q\bar{q}$ production.
- For VBF: $N_j \geq 2$, $|\Delta\eta(j_1, j_2)| > 3.5$, $m_{jj} > 500$ GeV, $n_{\mathrm{b-jets}} = 0$.

	$q\bar{q}$ Signal Region	VBF Signal Region
WZ	521 ± 29	87 ± 12
Fake/non-prompt	64 ± 13	15 ± 4
$t\bar{t}V$	29 ± 4	4.9 ± 0.8
ZZ	18.9 ± 2.0	4.4 ± 1.0
$tZ + VVV$	14.1 ± 2.9	8.1 ± 1.8
Total Background	647 ± 25	120 ± 11
Observed	650	114



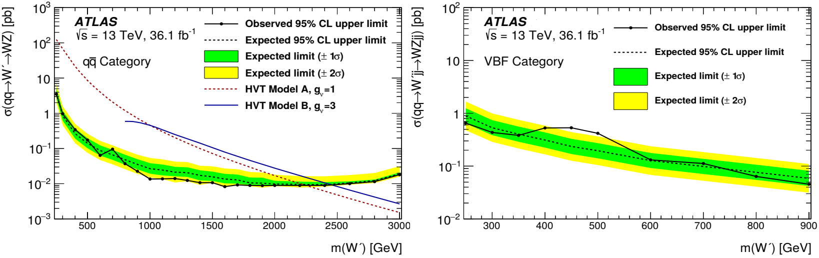




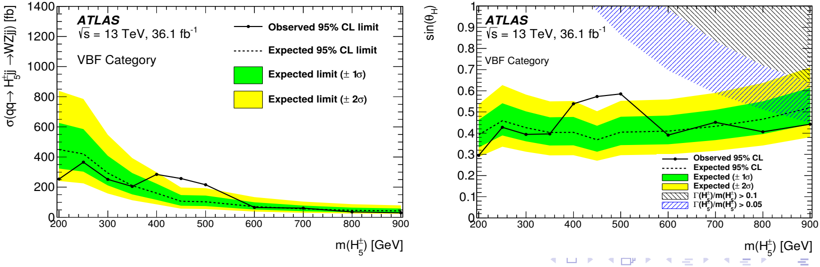


Heavy Resonances WZ (36.1 fb^{-1}) - **ATLAS-EXOT-2016-11**

Upper limits at 95% CL on the $\sigma \times \mathrm{B}(\mathrm{W}' \to \mathrm{W}^{\pm}\mathrm{Z})$ vs $m(\mathrm{W}')$ (heavy vector triplet (HVT) model)

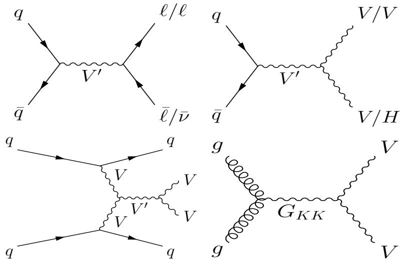


Upper limits at 95% CL on the $\sigma \times \mathrm{B}(\mathrm{H}_5^{\pm} \to\to \mathrm{W}^{\pm}\mathrm{Z})$ and the paramter $\theta_H$vs $m(\mathrm{H}_5^{\pm})$ (GM Model)



Combination of Searches for Heavy Resonances (36.1 fb^{-1})

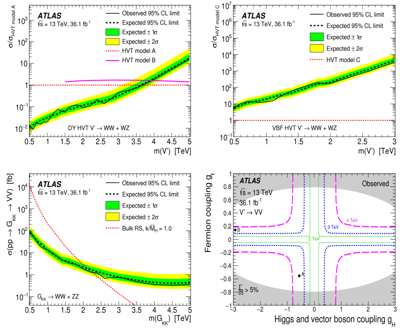
- ATLAS-EXOT-2017-31



Channel	Diboson state	Selection: Leptons	E_T^{miss}	Jets	b-tags	VBF cat.	Reference
$qqqq$	$WW/WZ/ZZ$	0	veto	2J	–	–	[9]
$\nu\nu qq$	WZ/ZZ	0	yes	1J	–	yes	[13]
$\ell\nu qq$	WW/WZ	$1e, 1\mu$	yes	2j, 1J	–	yes	[10]
$\ell\ell qq$	WZ/ZZ	$2e, 2\mu$	–	2j, 1J	–	yes	[13]
$\ell\ell\nu\nu$	ZZ	$2e, 2\mu$	yes	–	0	yes	[14]
$\ell\nu\ell\nu$	WW	$1e+1\mu$	yes	–	0	yes	[12]
$\ell\nu\ell\ell$	WZ	$3e, 2e+1\mu, 1e+2\mu, 3\mu$	yes	–	0	yes	[11]
$\ell\ell\ell\ell$	ZZ	$4e, 2e+2\mu, 4\mu$	–	–	–	yes	[14]
$qqbb$	WH/ZH	0	veto	2J	1, 2	–	[15]
$\nu\nu bb$	ZH	0	yes	2j, 1J	1, 2	–	[16]
$\ell\nu bb$	WH	$1e, 1\mu$	yes	2j, 1J	1, 2	–	[16]
$\ell\ell bb$	ZH	$2e, 2\mu$	veto	2j, 1J	1, 2	–	[16]
$\ell\nu$	–	$1e, 1\mu$	yes	–	–	–	[17]
$\ell\ell$	–	$2e, 2\mu$	–	–	–	–	[18]

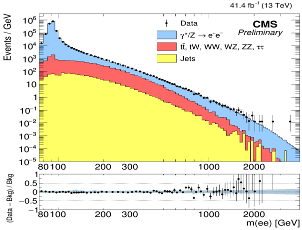
$$L = \prod_c \prod_i \mathrm{Pois}\left(n_{ci}^{obs} \middle| n_{ci}^{sig}(\mu, \vec{\theta}) + n_{ci}^{bkg}(\vec{\theta})\right) \prod_k f_k(\theta_k)$$

Channel	Lower limits on resonance mass [TeV]: HVT model A Obs	HVT model A Exp	HVT model B Obs	HVT model B Exp	Bulk RS Obs	Bulk RS Exp
WW	2.9	3.1	3.6	3.5	1.7	1.9
WZ	3.6	3.6	3.9	3.9	–	–
ZZ	–	–	–	–	1.5	1.7
VV	3.7	3.7	4.0	3.9	2.3	2.2
WH	2.6	2.8	2.8	3.1	–	–
ZH	2.7	2.5	2.8	2.8	–	–
VH	2.8	3.1	3.0	3.4	–	–
$\ell\nu$	4.6	4.6	–	–	–	–
$\ell\ell$	4.5	4.4	–	–	–	–
$\ell\nu/\ell\ell$	5.0	5.0	–	–	–	–
VV/VH	4.3	4.3	4.5	4.4	–	–
$VV/VH/\ell\nu/\ell\ell$	5.5	5.3	–	–	–	–



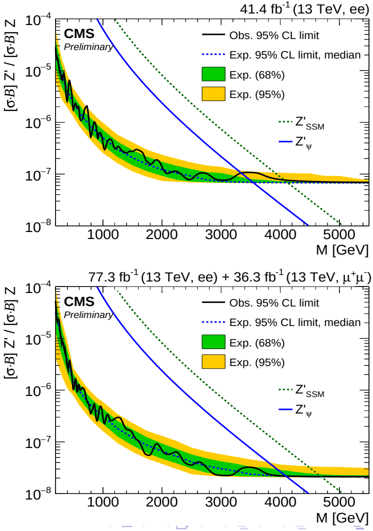
$Z' \to \mathrm{ee}$ ($77.3\ fb^{-1}$) - CMS-PAS-EXO-18-006

- The analysis selects two well reconstructed and isolated electrons, with $E_T > 35$ GeV.
- Electrons are selected in the barrel region using $|\eta| < 1.4442$ or in the endcap region $1.566 < |\eta| < 2.5$.
- The dielectron pair is formed with the highest p_T electrons.



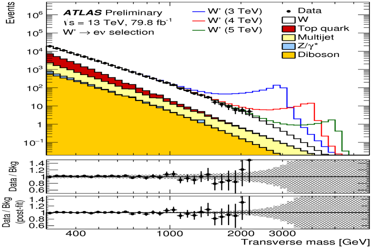
Channel	Model	Obs. limit [TeV]	Exp. limit [TeV]
ee (2017)	Z'_{SSM}	4.10	4.15
	Z'_{ψ}	3.35	3.55
ee (2016 and 2017) + $\mu\mu$ (2016)	Z'_{SSM}	4.7	4.7
	Z'_{ψ}	4.1	4.1

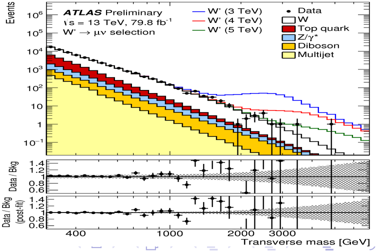
The 95% CL upper limits on $\sigma \times \mathrm{B}$ for a spin-1 resonance with a width equal to 0.6% of the resonance mass, relative to the $\sigma \times \mathrm{B}$ fraction for a Z boson.



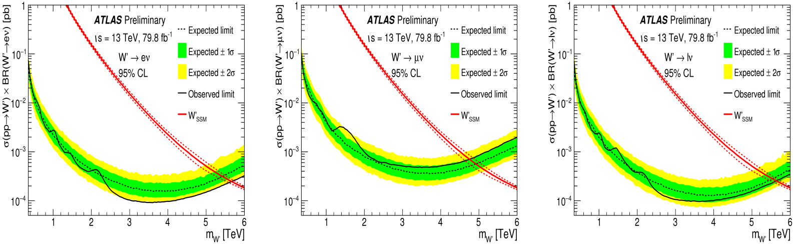
$W' \to \ell + E_T^{miss}$ (79.8 fb^{-1}) - **ATLAS-CONF-2018-017**

- The search for $W' \to \ell + E_T^{miss}$, focuses in final states where $\ell \to \mathrm{e}$ or $\ell \to \mu$.
- m_T is used to search for signal events: $m_T = \sqrt{2 p_T^{\ell} E_T^{miss}(1 - cos\Delta\phi(\ell, E_T^{miss}))}$
- The main source of BG events come from W+jets, $\mathrm{t\bar{t}}$, single-t, and DY+jets.
- Event selection criteria was used:
  1. $N_{\mathrm{e}/\mu} = 1$
  2. ℓ identification: Tight
  3. $p_T^{\mathrm{e}}(p_T^{\mu}) > 65(55)$ GeV
  4. $E_T^{miss}(\mathrm{e}) > 65$ GeV
  5. $E_T^{miss}(\mu) > 55$ GeV
  6. $m_T(\ell, E_T^{miss}) > 300$ GeV
- Main BGs estimated from MC, after applying mass-dependent correction factors.
- multijet, estimated from data: $N_T^{multijet} = \frac{\mathrm{f}}{\mathrm{f\text{-}r}}(r(N_L + N_T) - N_T)$





- 95% CL upper limits on $\sigma \times BR$ as function of W'_{SSM} mass.



Expected and observed 95% CL lower limits

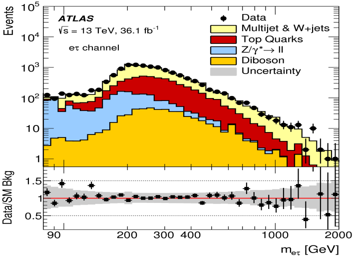
Decay	$m_{W'}$ lower limit [TeV] Expected	Observed
$W' \rightarrow e\nu$	5.4	5.7
$W' \rightarrow \mu\nu$	4.9	4.8
$W' \rightarrow \ell\nu$	5.5	5.6

LFV (79.8 fb^{-1}) - ATLAS-CONF-2018-017

- The search uses as benchmark the production of a Z' boson, assuming same couplings as the SM Z boson.
- Only leptonic decays that violate Lepton Flavour Conservation are allowed.
- The analysis considers final states to $\mathrm{e}\mu$, $\mathrm{e}\tau$, and $\mu\tau$.
- Q_{ij} represents the 3 lepton generation and gives the strength of the LFV couplings, relative to the SM $\ell\ell$.
- Event selection criteria:
  1. Exactly two different-flavour leptons.
  2. All leptons must pass ID criteria.
  3. $p_T(\mathrm{e}, \mu, \tau) > 65$ GeV.
  4. $\Delta\phi(\ell, \ell') > 2.7$.
  5. $N_{\mathrm{b}-jets} = 0$.
  6. $m_{\ell,\ell'}$ discrimination variable.

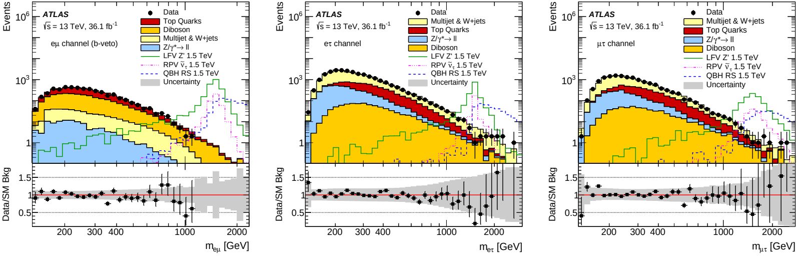
- Irreducible BGs: Z/γ^*, $\mathrm{t\bar{t}}$, single-t, VV (from MC).
- Reducible BG: jets wrongly identified as leptons. Estimated from data.
- The estimation of reducible BGs is verified in dedicated regions, where the BG under estimation has a dominant contribution.

W+jets enriched CR



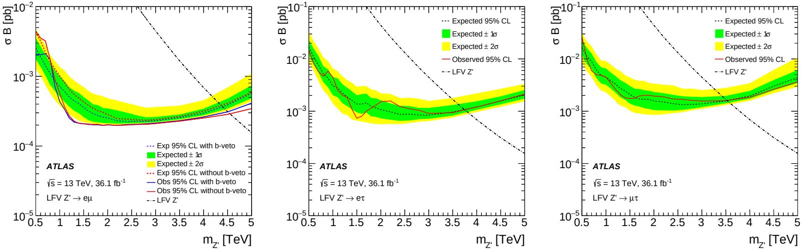
LFV (79.8 fb^{-1}) - ATLAS-CONF-2018-017

- No excess of events is observed above the SM expectation.
- Therefore, the analysis places limits four different models: Z' with SM couplings and chiral structure as the Z, RPV SUSY stau-neutrino production ($\tilde{\nu}_{tau}$), Arkani- Hamed-Dimopoulos-Dvali (ADD) model ($n = 6$), and Randall-Sundrum (RS) model.
- **For the RPV interpretation, the theoretical prediction of the $\sigma \times BR$, the coupling to first-generation quarks is assumed $\lambda'_{311} = 0.11$, for all channels. It is also assumed that $\lambda_{312} = \lambda_{321} = 0.07$ for the $\mathrm{e}\mu$, $\lambda_{313} = \lambda_{331} = 0.07$ for the $\mathrm{e}\tau$, and $\lambda_{323} = \lambda_{332} = 0.07$ for the $\mu\tau$.**

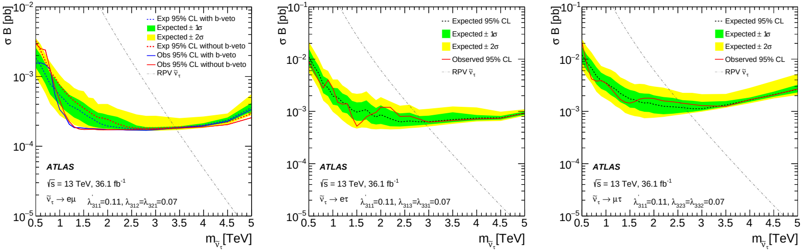


LFV (79.8 fb^{-1}) - **ATLAS-CONF-2018-017**

Limits of LVF Z' with SSM couplings

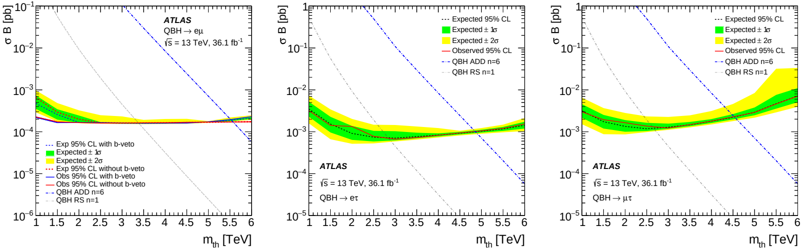


Limits of RPV SUSY $\tilde{\nu}_\tau$



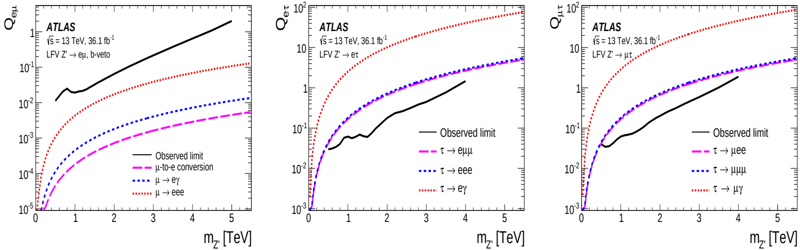
LFV (79.8 fb^{-1}) - ATLAS-CONF-2018-017

- For the ADD and RS models, at short distances there is an increase in the strength of gravity. Therefore, pp collisions at the LHC could produce states exceeding the threshold mass (m_{th}) and form black holes.
- "For masses beyond 3-5m_{th}, it is expected that thermal black holes would be produced, characterised by high-multiplicity final states."

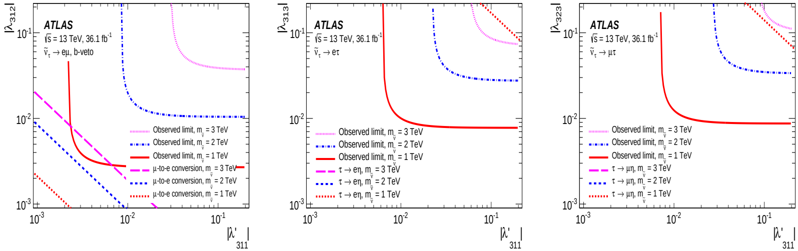


LFV ($79.8\ fb^{-1}$) - **ATLAS-CONF-2018-017**

Limits on the couplings for the LVF Z'

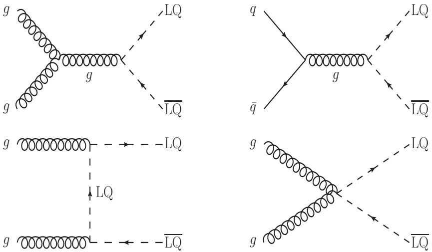


Limits on the couplings for RPV SUSY $\tilde{\nu}_\tau$



LQ_3 ($35.9\ fb^{-1}$) - CMS-B2G-16-028

- Leptoquarks ($\mathrm{LQ}s$) are hypothetical particles that carry both baryon and lepton quantum numbers.
- Third generation $\mathrm{LQ}s$ (LQ_3s) have currently become of great interest since they can explain the anomaly observed in the $\bar{\mathrm{B}} \to \mathrm{D}\tau\bar{\nu}$ and $\bar{\mathrm{B}} \to \mathrm{D}^*\tau\bar{\nu}$ decay rates, announced by the BaBar, LHCb and Belle collaborations.
- **There is a 4σ deviation of these decay rated w.r.t the SM prediction. The difference can be explained assuming large couplings of $\mathrm{LQ}s$ to third generation particles.**



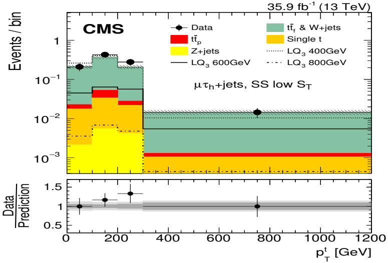
LQ_3 $(35.9\ fb^{-1})$ - CMS-B2G-16-028

- **Two search regions are considered: (1) $\ell\tau_h\tau_h$+jets, which has good sensitivity for LQ_3s masses below 500 GeV, and (2) $\ell\tau_h$+jets, where ℓ is an e or μ.**
- The dominant sources of BGs come from $t\bar{t}$ and W+jets.
- The event selection criteria is shown in the table below. In addition $p_T^{\ell} > 30$ GeV, and at least two jets with $p_T > 50$ GeV and $|\eta| < 2.4$.

Table 1: Summary of selection criteria in event categories A ($\ell\tau_h$ + jets) and B ($\ell\tau_h\tau_h$ + jets), where $\ell = \mu$, e. In category A, the two subcategories, OS and SS, are defined by the charge of the $\ell\tau_h$ pair. The fit variable used in each category is also shown.

	Category A		Category B
	OS $\ell\tau_h$ + jets	SS $\ell\tau_h$ + jets	$\ell\tau_h\tau_h$ + jets
Jet selection	$\geq$4 jets	$\geq$3 jets	$\geq$3 jets
p_T^{miss} selection	$p_T^{miss} > 100$ GeV	$p_T^{miss} > 50$ GeV	$p_T^{miss} > 50$ GeV
τ_h selection	$p_T > 100$ GeV		$p_T^{\tau 1} > 65$ GeV, $p_T^{\tau 2} > 35$ GeV
b tagging	$\geq$1 b tag		—
S_T selection	—		$S_T > 350$ GeV
Fit variable	p_T^t in two S_T bins		number of events

- The p_T of top-quarks (p_T^t) from LQ_3s decays, is expected to be larger w.r.t to the BG process. Therefore, p_T^t, from a t decaying to jets, is used as discrimination variable for events in category A.
- "A kinematic reconstruction of the top quark candidate is performed by building top quark hypotheses using between one and five jets."



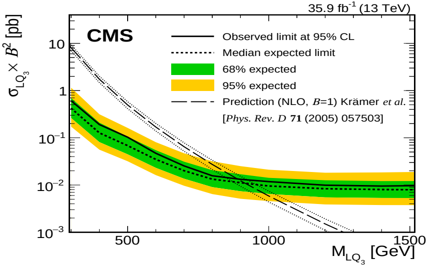
LQ_3 ($35.9\ fb^{-1}$) - CMS-B2G-16-028

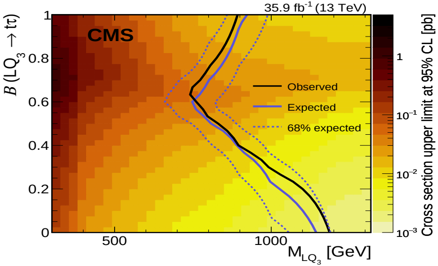
A counting experiment is conducted for events falling in category B

Process	$e\tau_h\tau_h$ + jets	$\mu\tau_h\tau_h$ + jets
LQ_3 (300 GeV)	$97\,^{+25}_{-24}$	$167\,^{+36}_{-37}$
LQ_3 (400 GeV)	$73\,^{+14}_{-13}$	$98\,^{+19}_{-17}$
LQ_3 (500 GeV)	$34.1\,^{+6.6}_{-6.2}$	$44.9\,^{+8.5}_{-7.9}$
LQ_3 (600 GeV)	$14.1\,^{+2.8}_{-2.7}$	$21.1\,^{+4.1}_{-3.8}$
LQ_3 (700 GeV)	$7.3\,^{+1.5}_{-1.4}$	$7.1\,^{+1.5}_{-1.4}$
LQ_3 (800 GeV)	$3.2\,^{+0.7}_{-0.7}$	$4.4\,^{+1.0}_{-0.9}$
LQ_3 (900 GeV)	$1.5\,^{+0.4}_{-0.3}$	$1.9\,^{+0.4}_{-0.4}$
LQ_3 (1000 GeV)	$0.8\,^{+0.2}_{-0.2}$	$0.9\,^{+0.2}_{-0.2}$
$t\bar{t}_f$	$2.5\,^{+0.8}_{-1.2}$	$3.2\,^{+1.5}_{-1.2}$
$t\bar{t}_{p+f}$	$1.5\,^{+0.8}_{-0.8}$	$2.0\,^{+0.8}_{-0.9}$
Single t	$0.3\,^{+0.3}_{-0.3}$	$0.0\,^{+0.2}_{-0.0}$
W+jets	$0.5\,^{+1.2}_{-0.5}$	$0.4\,^{+0.7}_{-0.4}$
Z+jets	$1.4\,^{+0.5}_{-0.5}$	$1.0\,^{+0.4}_{-0.4}$
Diboson	$1.6\,^{+1.7}_{-1.6}$	$1.7\,^{+1.8}_{-1.7}$
Total background	$7.9\,^{+2.4}_{-2.5}$	$8.4\,^{+2.6}_{-2.3}$
Data	9	11

- No excess above the SM expectation is observed in either category.
- Upper limits at 95% CL are set on $\sigma \times B^2$ of LQ_3 pairs.

The theoretical curve corresponds to the NLO cross section with uncertainties from PDF and scale variations.

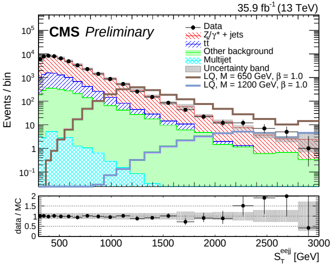


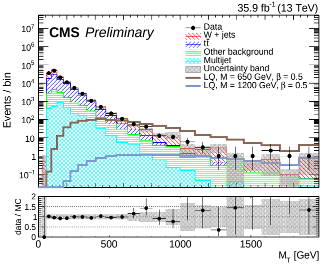


LQ_e ($35.9\ fb^{-1}$) - CMS-PAS-EXO-17-009

- Two final states are considered: (1) eejj and (2) eνjj.
- eejj selection criteria:
  1. $N_j = 2$ (w/ highest p_T).
  2. $N_e = 2$ (w/ highest p_T).
  3. $p_T(e_1 + e_2) > 70$ GeV.
  4. $S_T > 300$ GeV.
- eνjj selection criteria:
  1. e and jj same as eejj.
  2. $p_T^{miss} > 70$ GeV.
  3. $\Delta\phi(p_T^{miss}, j_1) > 0.5$, $\Delta\phi(p_T^{miss}, e) > 0.8$.
  4. $S_T > 300$ GeV.
  5. $m_T(p_T^{miss}, e) > 50$ GeV.
- BG from $W + jets$ and $t\bar{t}$ estimated from MC, but the normalisation corrected using data and MC in dedicated CRs.

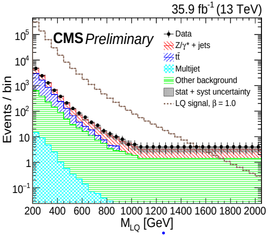
- QCD estimated from data.



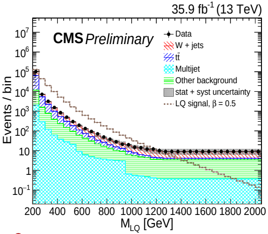


LQ_e $(35.9\ fb^{-1})$ - CMS-PAS-EXO-17-009

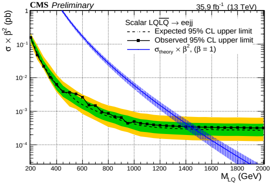
eejj

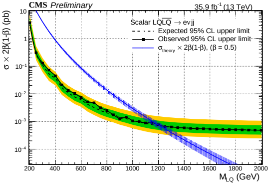


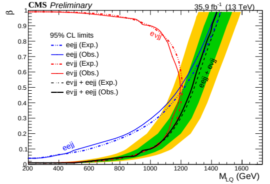
$ee\nu j$



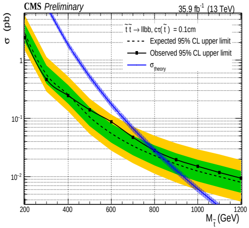
- No excess above the SM. Therefore, 95% CL limits are set.
- β corresponds to $LQLQ \rightarrow$ eejj BF.

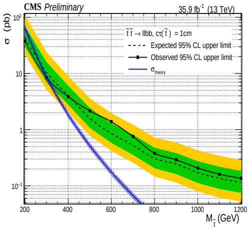






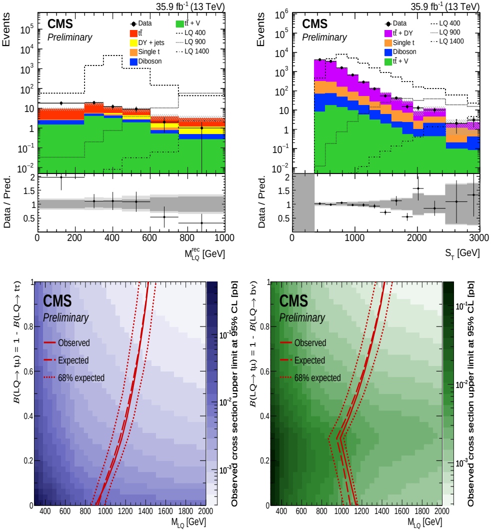
95% CL on the long-lived RPV SUSY $\tilde{t}$ pair production cross section as a function of $\tilde{t}$ mass for $c\tau = 0.1$ cm (top) and 1 cm (bottom).





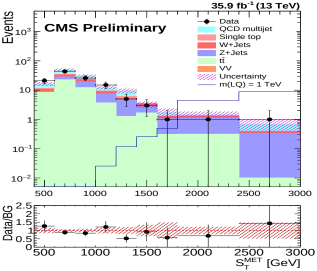
$LQ_{t\mu}$ $(35.9\ fb^{-1})$ - CMS-PAS-B2G-16-027

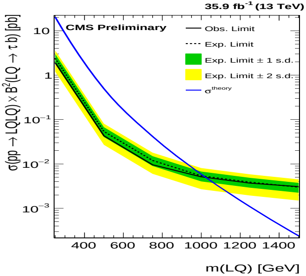
- Search for $LQLQ \to tt\mu\mu$
- The analysis required at least two well isolated muons, with $p_T > 30$ GeV, and two jets (at least 1 b−tagged).
- In addition $S_T^{lep} > 200$ GeV and $S_T^{lep} > 350$ GeV is required.
- The analysis is slitted in two categories:
  1. Additional: μ or e, and $Q(\mu_1) \times Q(\mu_2) < 0$.
  2. No additional μ or e is required.

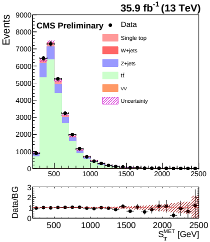


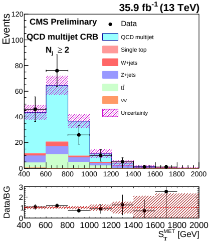
$LQ_{b\tau_h}$ ($35.9\ fb^{-1}$) - CMS-PAS-B2G-16-027

- Search for $LQLQ \rightarrow bb\tau_h\tau_h$
- The analysis selects two hadronic τ leptons, with $p_T > 70$ GeV, and two jets with $p_T > 50$ GeV and $|eta| < 2.4$.
- In addition, $p_T^{miss} > 50$ GeV, and $m(\tau_h, \tau_h) > 100$ GeV, was requested.
- S_T^{miss} is the main discrimination variable.
- $t\bar{t}$ and QCD multijet are the main BGs.



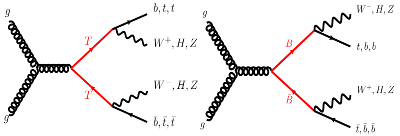




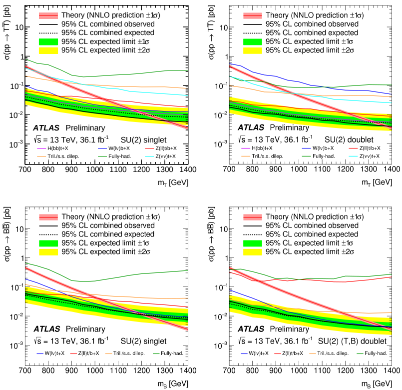


$\mathrm{T} \to \mathrm{Zt/Wb/HT}, \mathrm{B} \to \mathrm{Zb/Ht/Wb}$ (36.1 fb^{-1}) - ATLAS-CONF-2018-032

- The search presents a combination for vector-like partners of the top and bottom quarks.
- Several decay channels are considered: $\mathrm{T} \to \mathrm{Zt/Wb/HT}, \mathrm{B} \to \mathrm{Zb/Ht/Wb}$
- Several BSM models predict the existence of vector-like quarks (VLQs): color-triplet spin-1/2 fermions whose left- and right-handed chiralities transform the same under weak-isospin.



Analysis	$T\bar{T}$ decay	$B\bar{B}$ decay
$H(bb)t + X$ [14]	$HtH\bar{t}$	-
$W(\ell\nu)b + X$ [15]	$WbW\bar{b}$	-
$W(\ell\nu)t + X$ [16]	-	$WtW\bar{t}$
$Z(\nu\nu)t + X$ [17]	$ZtZ\bar{t}$	-
$Z(\ell\ell)t/b + X$ [18]	$ZtZ\bar{t}$	$ZbZ\bar{b}$
tril./s.s. dilepton [19]	$HtH\bar{t}$	$WtW\bar{t}$
fully-hadronic [20]	$HtH\bar{t}$	$HbH\bar{b}$



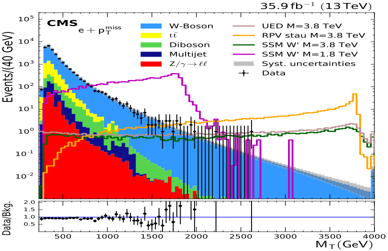
Summary

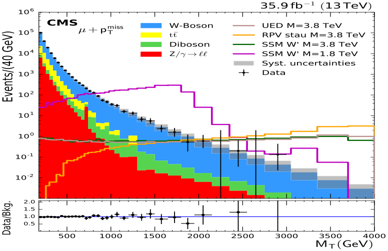
- The physics program to search for high and low mass resonances at ATLAS and CMS is robust and broad.
- **Unfortunately, no signs of new physics have been found until now.**
- ATLAS and CMS have reported some results using combined data from the 2015 up to 2017.
- More analyses are expected to be released soon, so keep your eyes open for more interesting physics to come!

BACKUP

$W' \to \ell + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-16-033

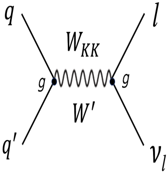
- The search for $W' \to \ell + E_T^{miss}$, focuses in final states where $\ell \to \mathrm{e}$ or $\ell \to \mu$.
- m_T is used to search for signal events:
  $$m_T = \sqrt{2p_T^{\ell} E_T^{miss}(1 - cos\Delta\phi(\ell, E_T^{miss}))}$$
- The main source of BG events come from W+jets, $\mathrm{t\bar{t}}$, single-t, and DY+jets.
- Event selection criteria was used:
  1. $N_{\mathrm{e}/\mu} = 1$
  2. ℓ identification: Tight
  3. $p_T^{\mathrm{e}}(p_T^{\mu}) > 130(53)$ GeV
  4. $E_T^{miss}(\mathrm{e}) > 150$ GeV
  5. $0.4 < p_T/E_T^{miss}(\mu) < 0.15$
  6. $\Delta\phi(\ell, E_T^{miss}) > 2.5$
  7. $m_T(\mathrm{e}, E_T^{miss}) > 250$ GeV
  8. $m_T(\mu, E_T^{miss}) > 100$ GeV
- multijet, estimated from data using isolation templates.

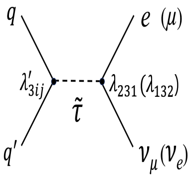




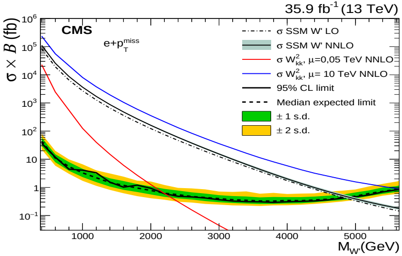
$W' \rightarrow \ell + E_T^{miss}$ $(35.9\ fb^{-1})$ - **CMS-EXO-16-033**

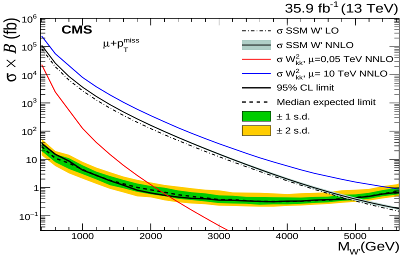
- The analysis sets limits for different models:
  1. **SSM**
  2. **Split-UED:** universal extra dimensions with fermions propagating in the bulk. In this model all SM particles have corresponding Kaluza-Klein (KK) partners.
  3. **RPV SUSY:** The analysis studies the cases where a tau slepton decays to $\mathrm{e} + \nu_\mu$ or $\mu + \nu_\mathrm{e}$.





SSM interpretation

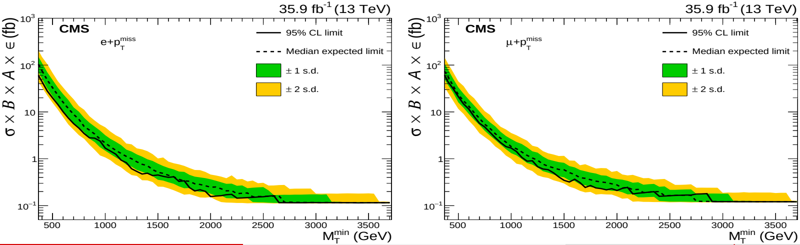




$W' \to \ell + E_T^{miss}$ (35.9 fb^{-1}) - **CMS-EXO-16-033**

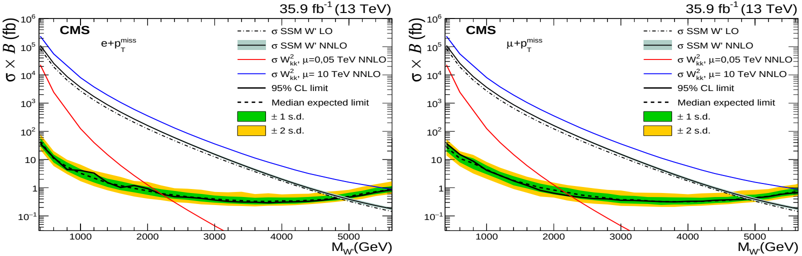
Model-independent cross section limit

- The limit is set using a single bin ranging from a lower threshold on M_T to infinity. For each M_T point, the analysis provides the acceptance A and efficiency ϵ. No other assumptions are made.
- "In order to determine any limit for a specific model from the model-independent limit shown here, only the model-dependent part of the efficiency needs to be applied."
- A factor f_{M_T} that reflects the effect of the threshold M_{min} on the signal is determined by counting the events with $M_T > M_{min}$ and dividing it by the number of generated events.

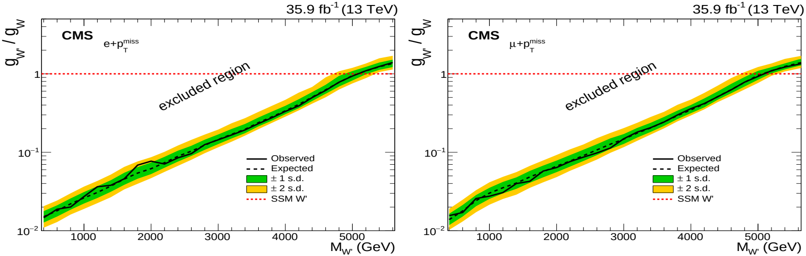


$W' \to \ell + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-16-033

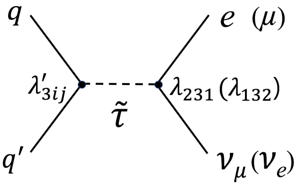
Limits on an SSM W' boson (Combined limit 5.2 TeV)

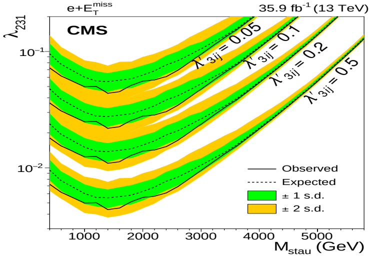


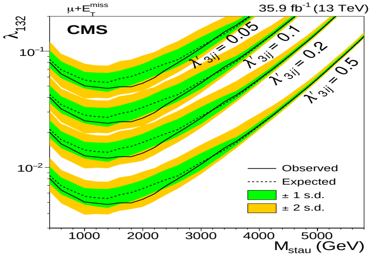
Limits on the coupling strength



Limits on RPV SUSY





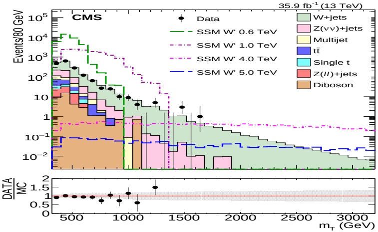


- λ_{231} is used for $\mathrm{e} + \nu_\mu$ and λ_{132} for $\mu + \nu_\mathrm{e}$
- At low masses, the $\tilde{\tau}$ signal has higher efficiency w.r.t the SSM W' scenario.
- The fraction f_{M_T} is determined at generator level and a correction is applied w.r.t the SSM W' model.

$W' \rightarrow \tau_h + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-17-008

- The analysis searches for the production of $\mathrm{W}' \rightarrow \tau_h \nu$.
- Two benchmark models are considered: SSM and nonuniversal gauge interaction (NUGIM).
- NUGIM models predict larger BF for third generation fermions and explain the large mass of the top quark.
- **The NUGIM models propose a $SU(2)_{light} \times SU(2)_{heavy} \times U(1)$ symmetry. Through mixing we get the SM $SU(2)_W$ and an extended group, $SU(2)_E$, from which the W' emerge.**
- There is a mixing angle, θ_E, which allows to modify the couplings to the heavy boson.

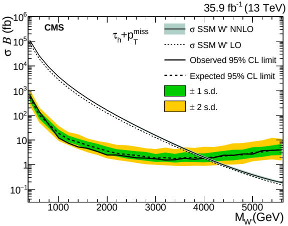
- $m_T(\tau_h, p_T^{miss})$ is used as the main discrimination variable.
- Main event selection criteria:
  1. $p_T(\tau_h) > 80$ GeV
  2. $p_T^{miss} > 200$ GeV
  3. $0.7 < p_T(\tau_h)/p_T^{miss} < 1.3$
  4. $\Delta\phi > 2.4$
  5. $m_T(\tau_h, p_T^{miss}) > 300$ GeV



$W' \to \tau_h + E_T^{miss}$ $(35.9\ fb^{-1})$ - CMS-EXO-17-008

SSM

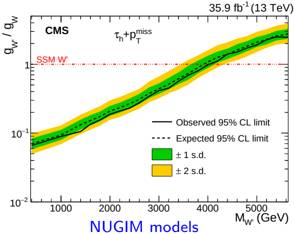
95% CL upper limits on the cross section, considering same couplings as the SM W-boson.



Coupling strength

95% CL upper limits on the ratio of couplings. The values above the observed limit contour are excluded.

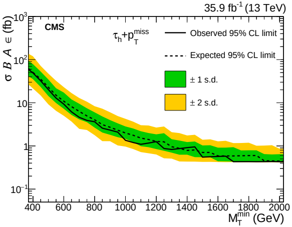
$$\Gamma_{W'} = \Gamma_W (g'_W / g_W)$$



Model-Independent

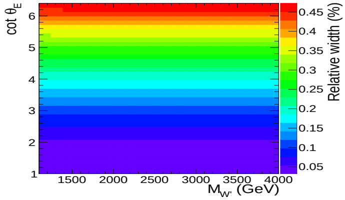
95% CL upper limits on the product of cross section, branching fraction, and acceptance.

$$(\sigma B \epsilon)_{excl} = ((\sigma B \epsilon)_{MI}\, m_T^{mis})/f_{m_T}$$



NUGIM models

Width of the W′ boson as a function of $M_{W'}$ and mixing



95% CL upper limits on the mixing angle $cot\theta_E$ as a function

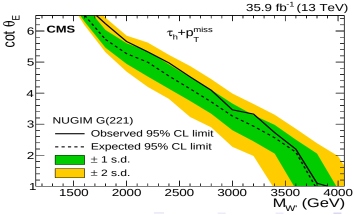


Table 2: Systematic uncertainties in the expected number of events as estimated for the total background and for signal with a W'_{SSM} mass of 2 (4) TeV. The uncertainty is estimated with the binning shown in Figure 1 at $m_T = 2$ (4) TeV for the background and in a three-bin window around $m_T = 2$ (4) TeV for the signal. Uncertainties that are not applicable are denoted "N/A", and "negl." means that the uncertainty is not included in the statistical analysis. Sources of uncertainties not included in the table are neglected in the statistical analysis.

Source	Electron channel		Muon channel	
	Background	Signal	Background	Signal
Trigger	negl. (negl.)	negl. (negl.)	1% (1%)	2% (2%)
Lepton reconstruction and identification	negl. (negl.)	negl. (negl.)	7% (21%)	5% (29%)
Lepton momentum scale and resolution	4% (3%)	4% (3%)	3% (12%)	7% (10%)
Multijet background	7% (113%)	N/A (N/A)	1% (1%)	N/A (N/A)
Top extrapolation	2% (5%)	N/A (N/A)	3% (3%)	N/A (N/A)
Top normalization	$< 0.5\%$ ($< 0.5\%$)	N/A (N/A)	$< 0.5\%$ ($< 0.5\%$)	N/A (N/A)
Diboson extrapolation	2% (9%)	N/A (N/A)	3% (10%)	N/A (N/A)
PDF choice for DY	1% (14%)	N/A (N/A)	$< 0.5\%$ ($< 0.5\%$)	N/A (N/A)
PDF variation for DY	8% (12%)	N/A (N/A)	7% (11%)	N/A (N/A)
EW corrections for DY	4% (5%)	N/A (N/A)	4% (6%)	N/A (N/A)
Luminosity	2% (1%)	2% (2%)	2% (2%)	2% (2%)
Total	13% (115%)	4% (4%)	12% (29%)	9% (31%)