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Experimental overview of Exotics Searches

8th Edition of the Large Hadron Collider Physics Conference

May 28th

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ATLAS and CMS Collaborations

ATLAS EXPERIMENT

CMS Compact Muon Solenoid

Introduction

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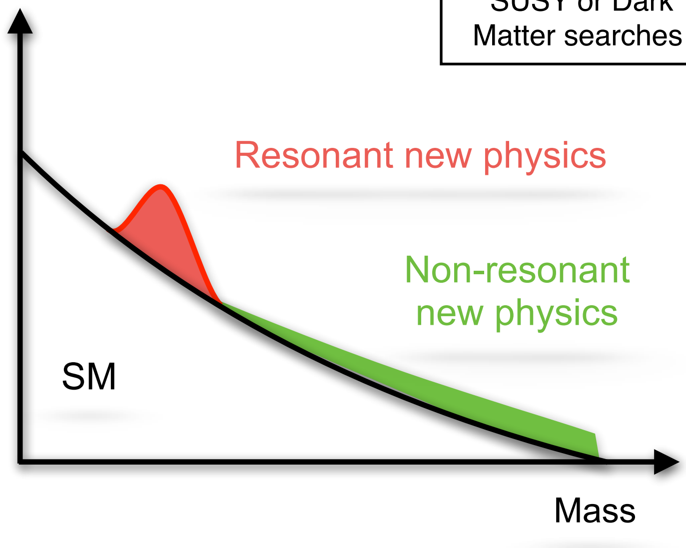
Not covering SUSY or Dark Matter searches!

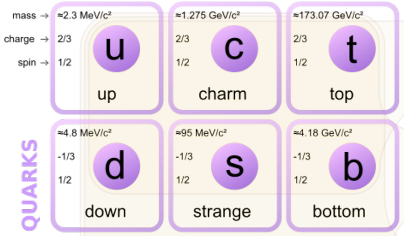
- A rich program of new physics searches by ATLAS and CMS has been underway, to address the many questions left unanswered by the Standard Model.
- Under a myriad of new physics scenarios, new phenomena could manifest itself via resonant or non-resonant effects in a wide energy range.



- **This overview covers new results by ATLAS and CMS, targeting:**
  - Hadronic, dilepton and lepton+jets, and diboson final states.
- Wide variety of final states that are generic probes for many models of new physics…
- …as well as final states that are motivated by particular classes of models.
- Powerful programs with large focus on re-interpretability of results.
- Many results include excellent LHC full Run 2 dataset: 140-150/fb of 13 TeV collisions.

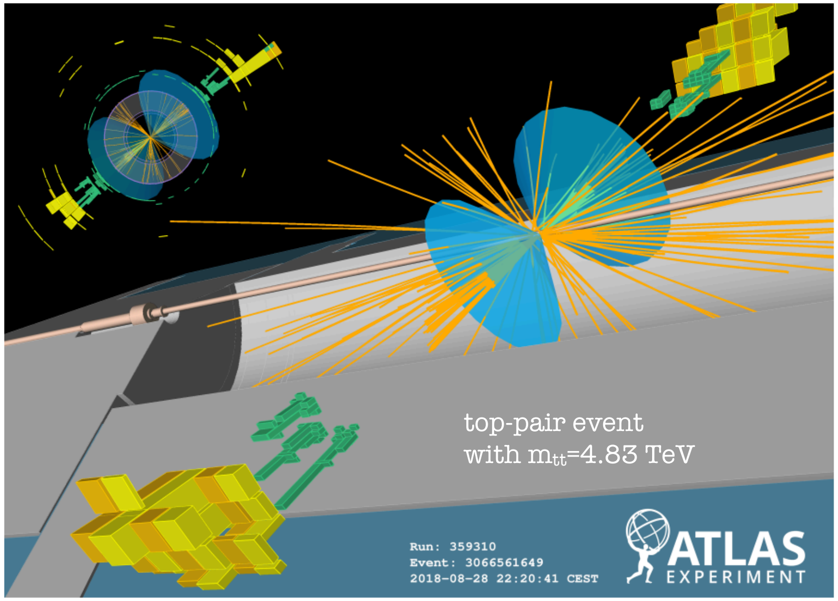
Searches for hadronic resonances

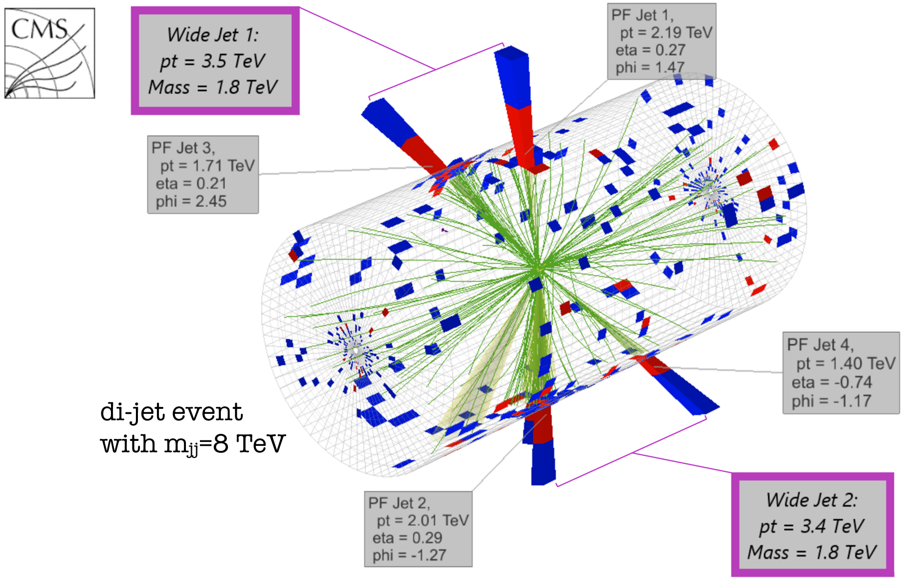
- A probe for heavy gauge bosons, excited quarks, quantum black holes, Kaluza-Klein gravitons, chiral excitations of the W boson, SSM Z', top-assisted-technicolor Z', Z' dark matter mediators, …
    - A wide range of masses, from 350 GeV to 10 TeV.



Highlights:

- New trigger technique for low mass acceptance.
- New and improved b-tagging algorithms at high-p_T.
- Dedicated techniques to identify high-p_T (boosted) top-jets.





di-jet event
with m_{jj}=8 TeV

Di-jet resonances

Full Run 2 dataset

ATLAS: JHEP03(2020)145

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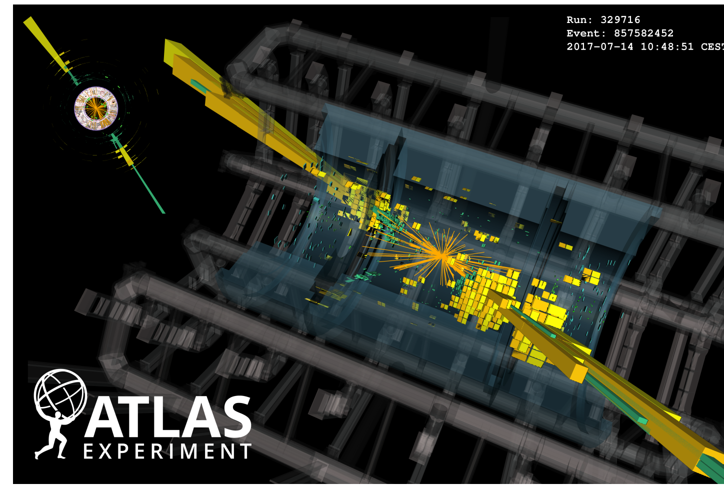
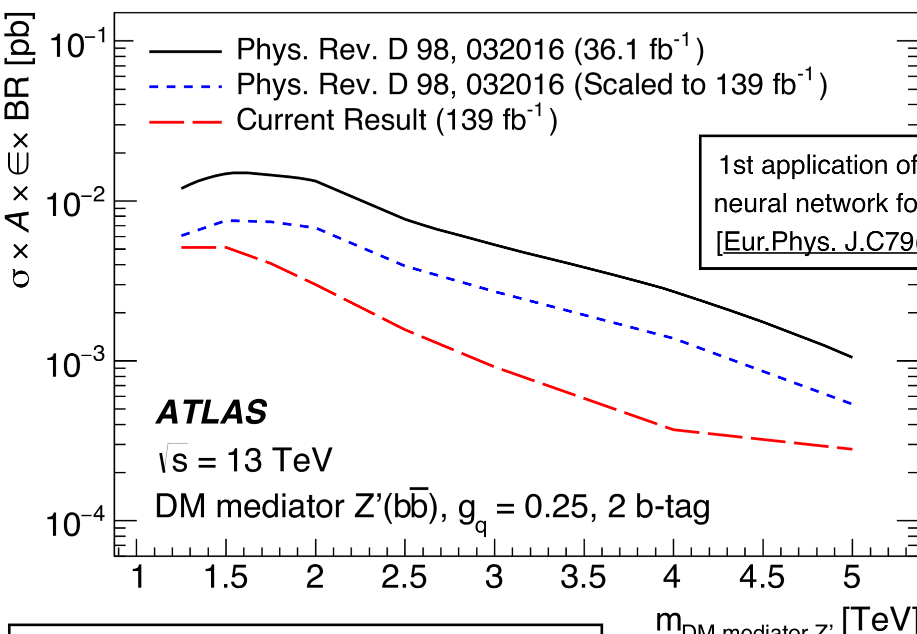
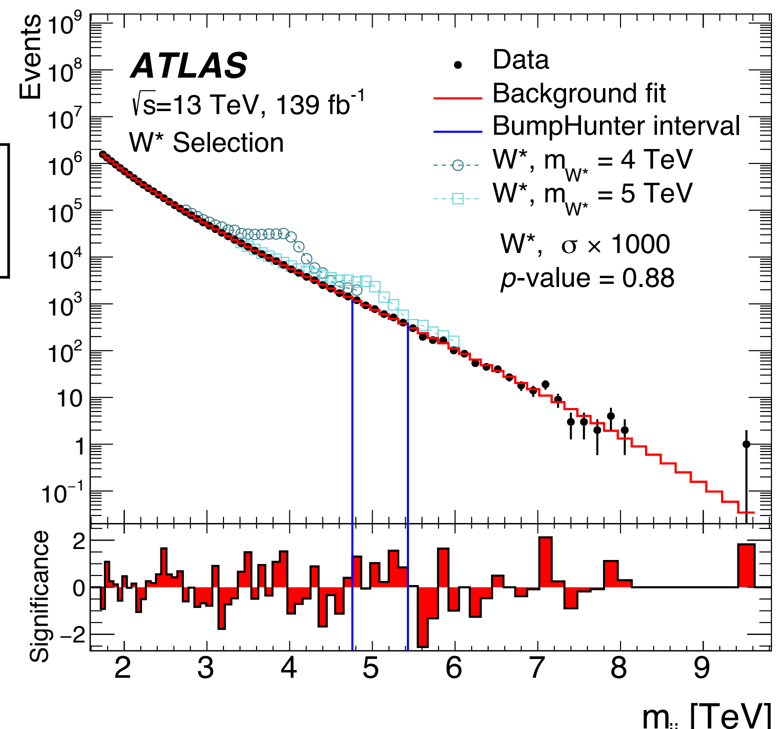
- **Inclusive** result and **in events with 1 or 2 b-jets.**
- Jets close in $|\Delta y|$ (to reject background).
- Background from sliding-window fit to data.
- Exclusions on several benchmarks: e.g. excited quarks, chiral excitation of the W, leptophobic Z' DM mediator.
- For reinterpretation: 95% CL cross-section limits on gaussian-shaped signals of various widths (up to 15%) as a function of the mass.

Dijet event with m_{jj}=9.5 TeV





1st application of new deep neural network for b-tagging [Eur.Phys. J.C79(2019)970]



A search for di-jet resonances in events with a charged lepton not covered here: EXOT-2018-32

Di-jet resonances

Full Run 2 dataset

CMS: JHEP05(2020)033

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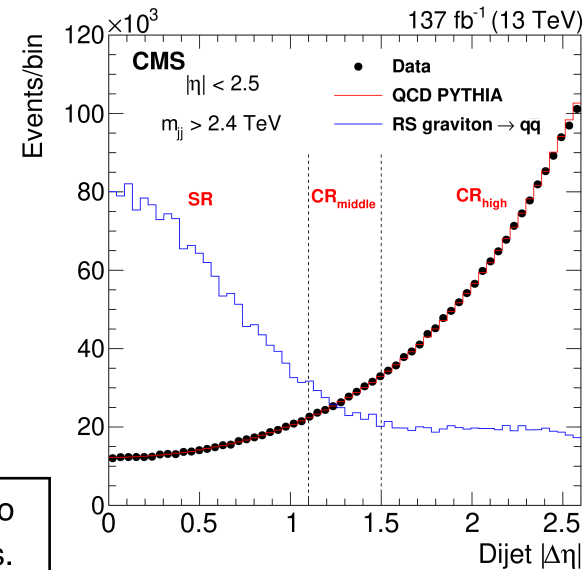
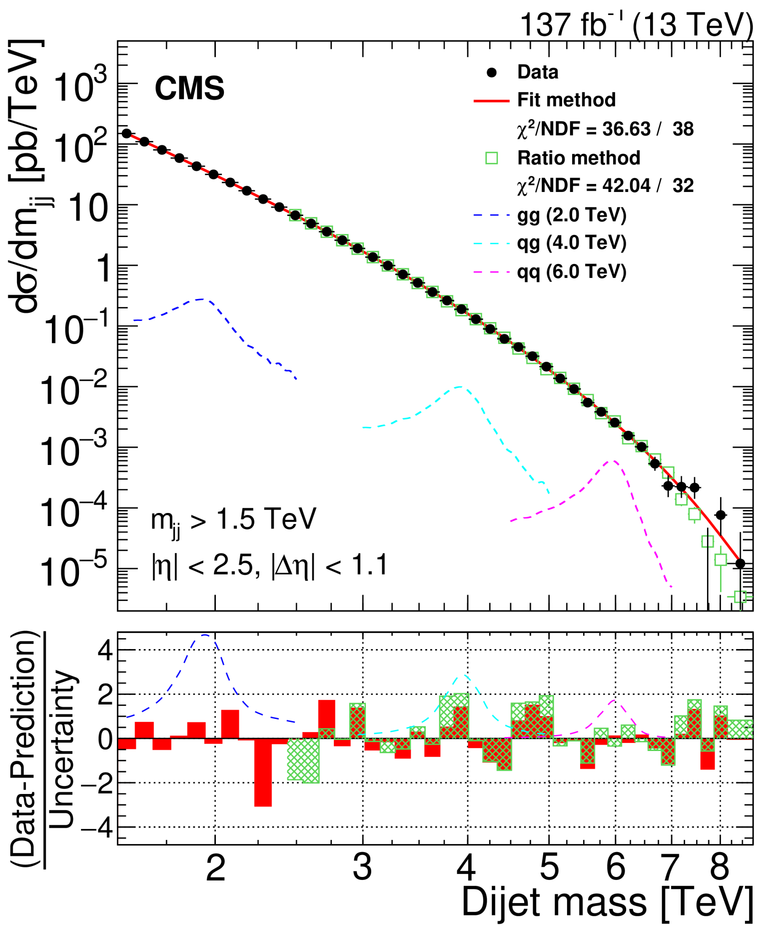
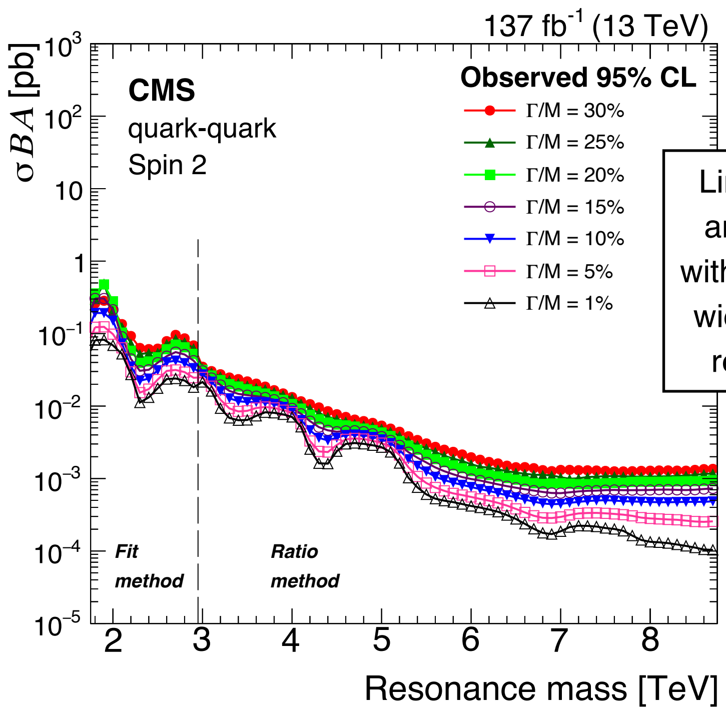
- "Wide" jets by combining R=0.4 close-by jets: reduce analysis sensitivity to final state radiation.
- Parametric fit to signal region data for $1.5 < m_{jj} < 2.4$ TeV.
- New "ratio method" for $m_{jj} > 2.4$ TeV: using control regions with larger $\Delta\eta$ values and MC-to-data transfer factors.





Enhanced sensitivity with ratio method for broad resonances.



Limits set for qq, qg and gg final states, with narrow and broad widths (up to 30% of resonance mass).

Di-jet resonances

CMS: PhysLettB(2020)135448

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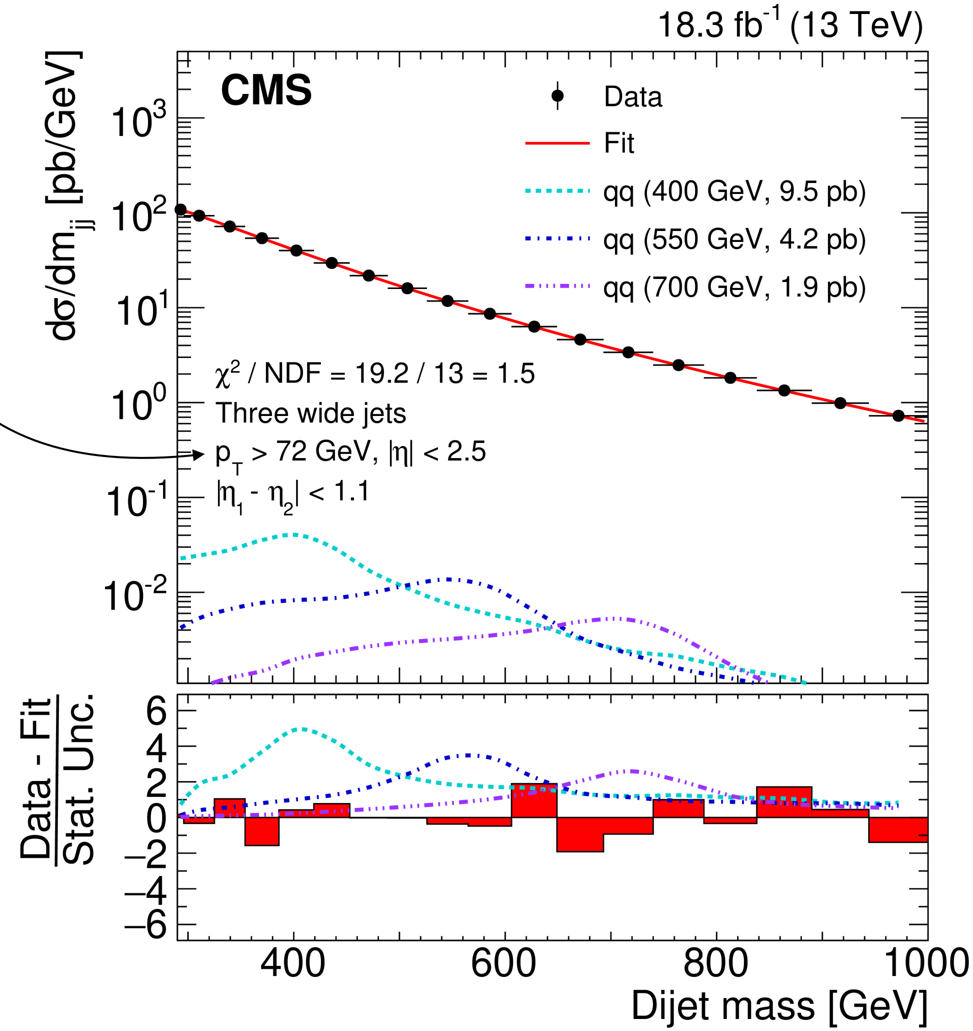
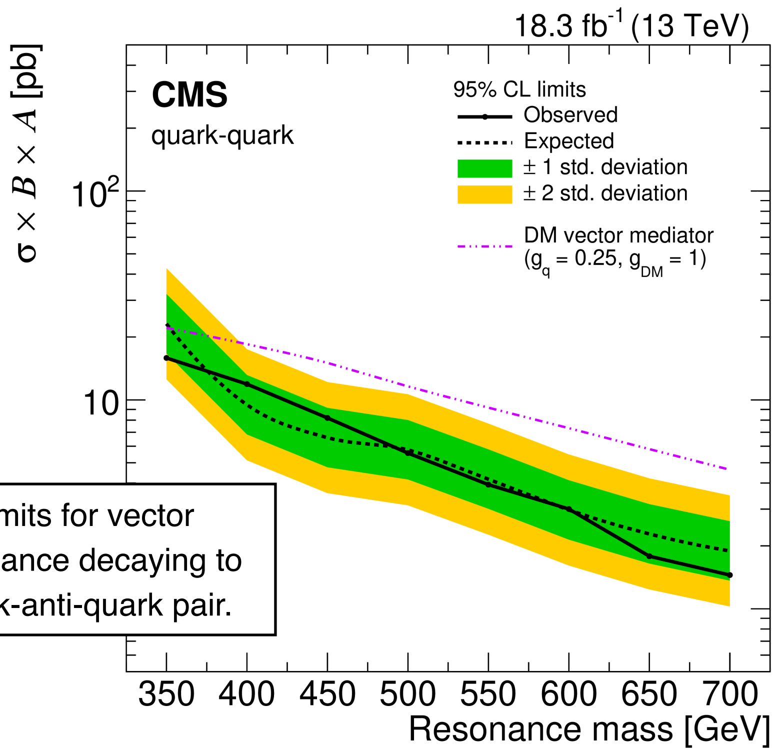
- How to get sensitivity at lower masses?
  - E.g. to dark matter mediators.
- **Data-scouting:** 3-jet events reconstructed and recorded at higher rate in a compact form (only calorimeter-based jets) with lower p_T thresholds.
- Background from parametric fit to data.



Dijet mass from the two p_T leading jets in the event.



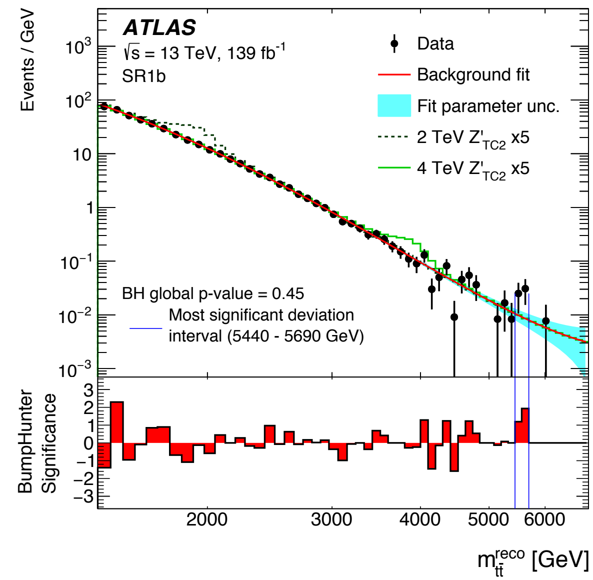
Limits for vector resonance decaying to quark-anti-quark pair.

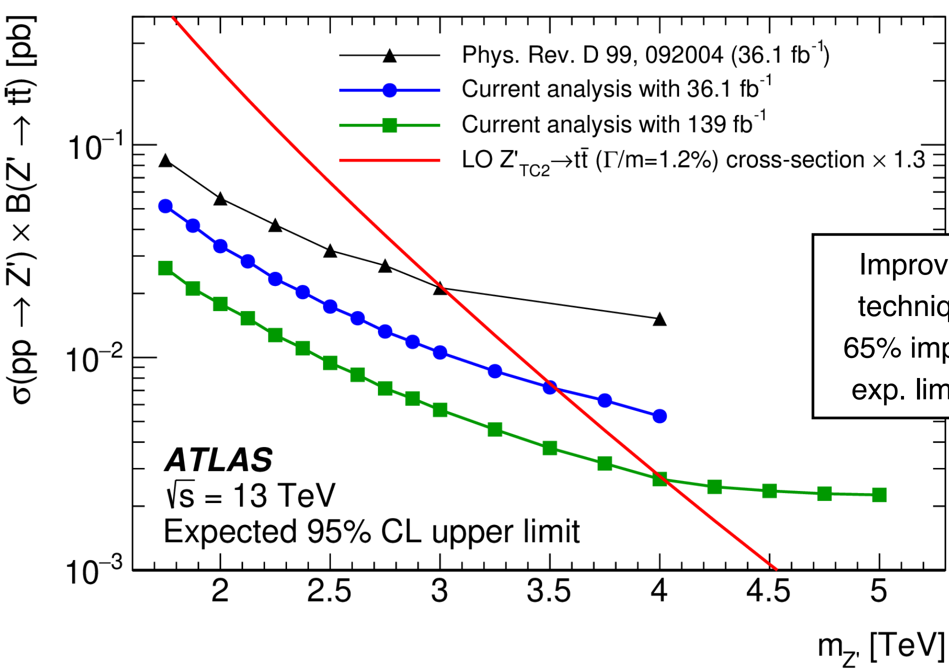
Fully-hadronic top-pair resonances

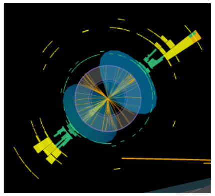
ATLAS: EXOT-2018-48

Full Run 2 dataset

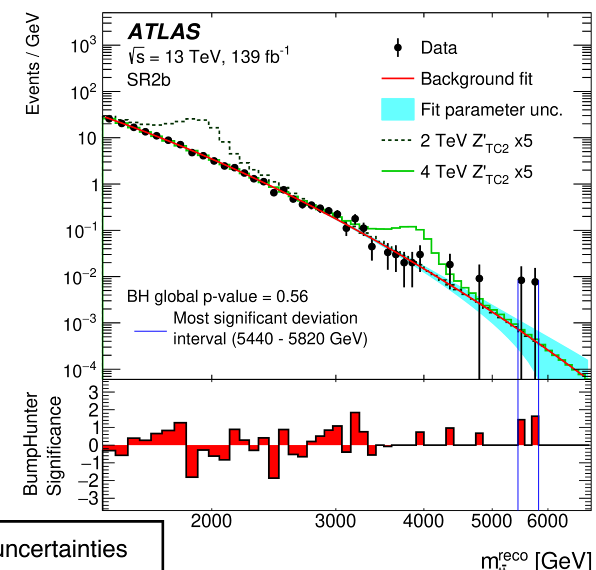
- What if couplings to third generation are favored?
  - Search for resonances from top-pairs with masses > 1.4 TeV.
- Fully-hadronic top decays are captured in a large-radius jet.
- **New DNN top tagger:** substructure variables as features.
- **b-tagging with variable-radius track-jets:** two signal regions with 1 or 2 b-tagged jets.
- Background from SM multijet and top-pair production from fit to data.
- Z'_{TC2} with Γ/m=1%(3%) excluded for masses up to 3.9 (4.7) TeV.







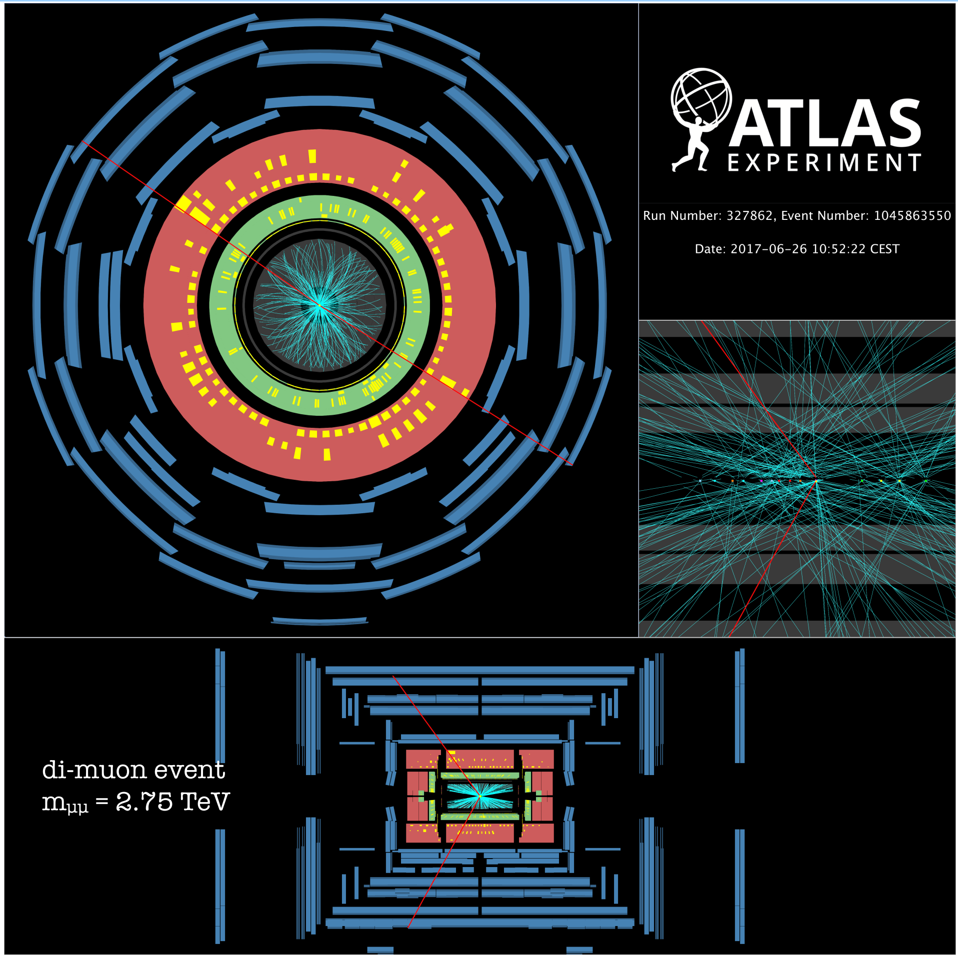
Improved analysis techniques lead to 65% improvement in exp. limits at 4 TeV.



Spurious-signal uncertainties dominate above 4.5 TeV.

Dilepton and lepton+jets final states

- Dilepton signatures: the cleanest final states to probe for new physics!
- Typical benchmarks: Z' bosons in the Sequential Standard Model (SSM), Heavy Vector Triplet (HVT) and E6 GUT models.
- Lepton+jets as probes for excited leptons and leptoquarks.



Highlights:

- Increasing use of generator-only MC samples or fully data-driven approaches for background estimation.
- More data leads to better understanding of the detector: e.g. improved treatment of relative alignment of sub-detectors, critical for high-p_T muons.

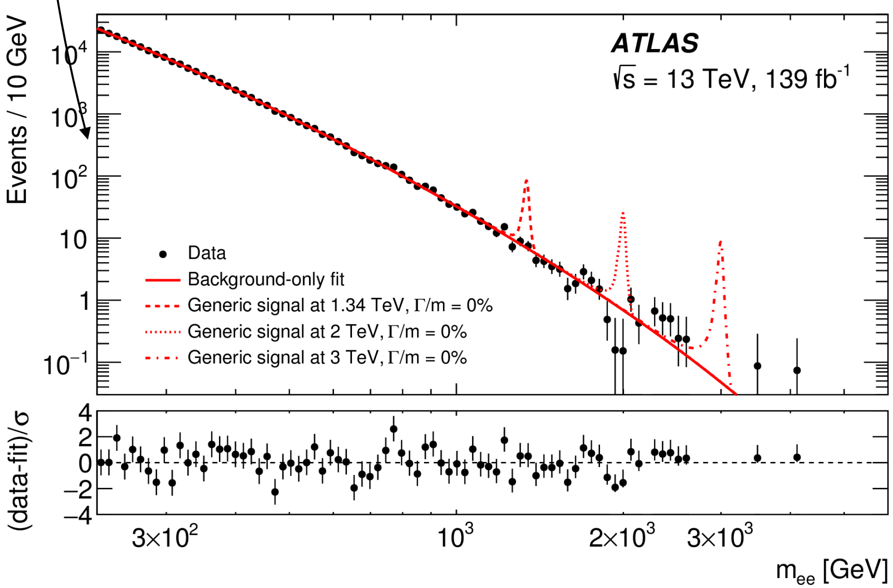
Searches in $\ell^{\pm}\nu$ final states not covered here: EXOT-2018-30 (ATLAS) and EXO-16-033 (CMS)

Dilepton resonances

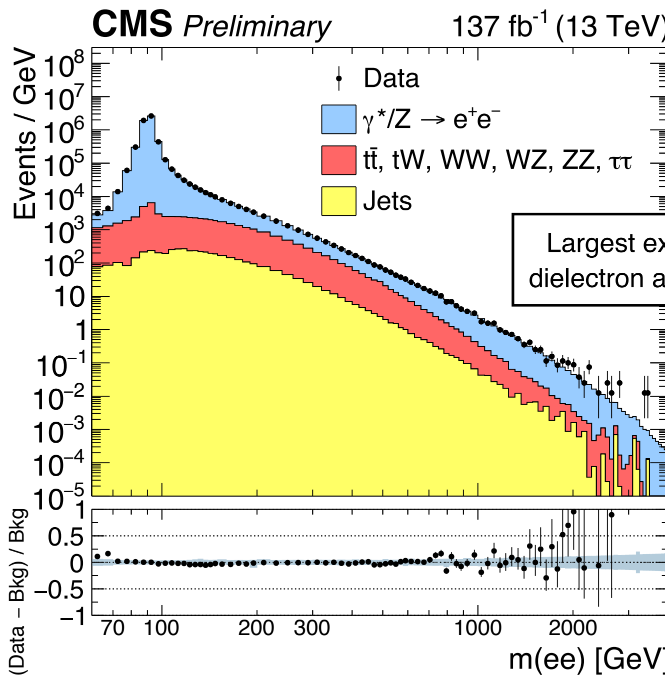
Full Run 2 dataset

ATLAS: PhysLettB796(2019)68

- Narrow and broad in range: 250 GeV to 6 TeV.
- Data-driven background estimation above Z peak.
- Generic signal shape at various widths: Breit-Wigner convolved with detector resolution.
- Cross-sections for spin-0, 1 and 2 benchmarks obtained in fiducial volume for compatibility with the definition of the generic signal model.



CMS: EXO-19-019



Largest excess in dielectron at 1.8 TeV

- Narrow resonances in range 200 GeV to 5.5 TeV.
- Main backgrounds from simulation.
- Search in mass window of assumed Z'_{SSM} or Z'_{ψ} resonance mass.
- 95% CL limits on ratio of cross-section for new signal wrt SM Z boson: cancels experimental and theoretical uncertainties common to both.

ee+μμ fit ➜ most stringent limits to data on Z'_{ψ} (Z'_{SSM}): ATLAS excluded at 4.5 (5.1) TeV and CMS at 4.6 (5.2) TeV.

Dilepton non-resonant

ATLAS: EXOT-2019-16

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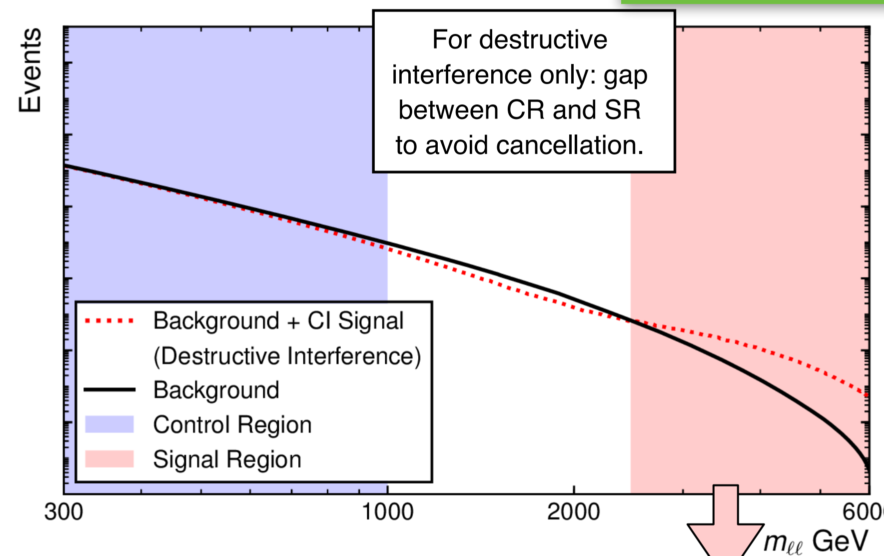
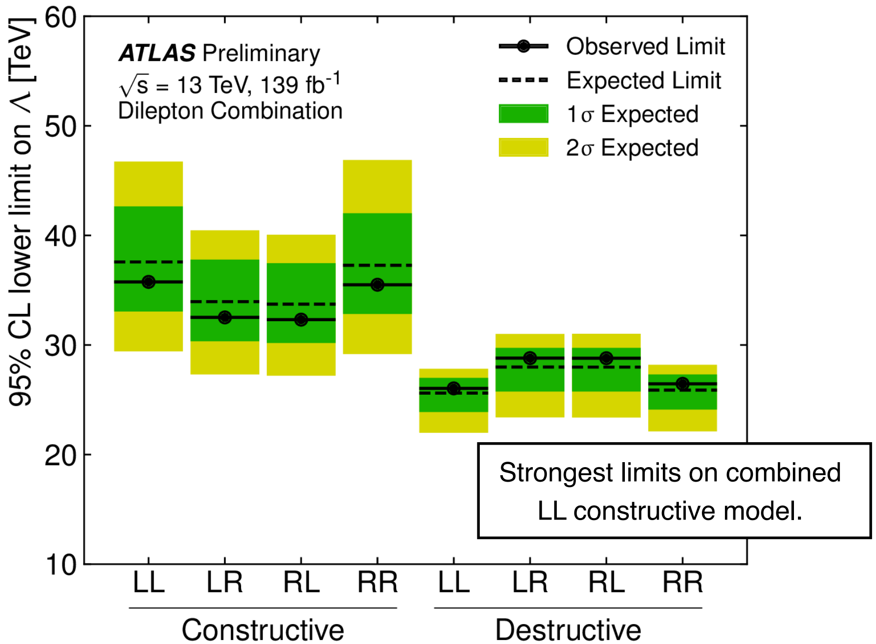
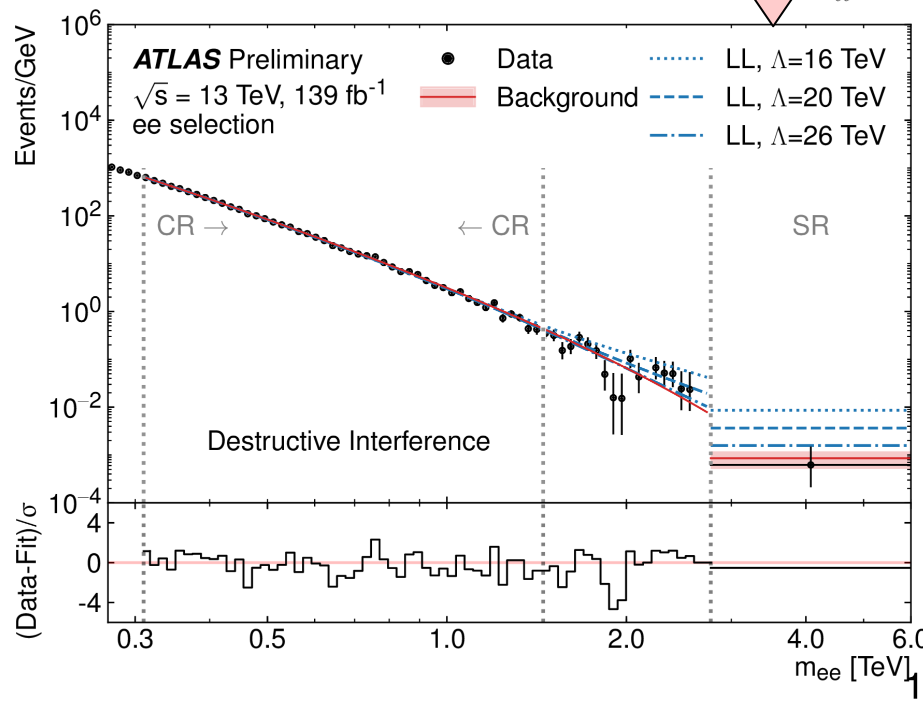
Full Run 2 dataset

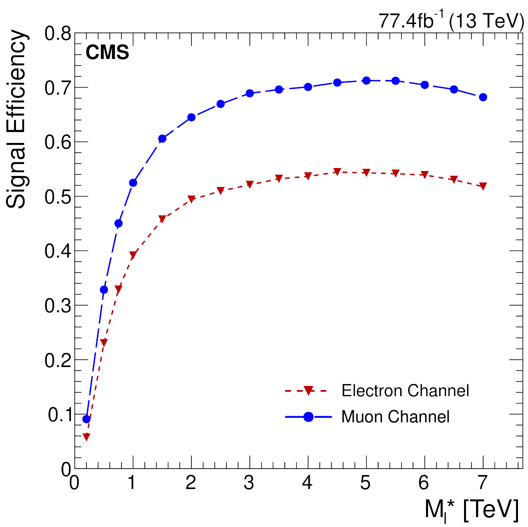
- Search for enhanced dilepton rates for masses above 2 TeV: can be interpreted with 2q2l contact interaction (CI) framework.
- First use of data-driven background estimate and single-bin high-mass signal region.
- Functional form fit to data in control region and extrapolated to signal region.
- Lower limits on the CI scale for different chiral structure and interference sign.

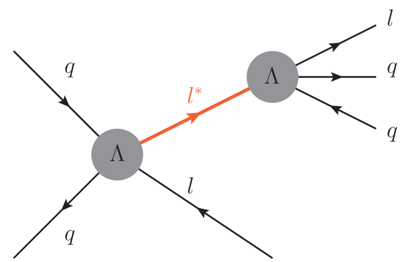




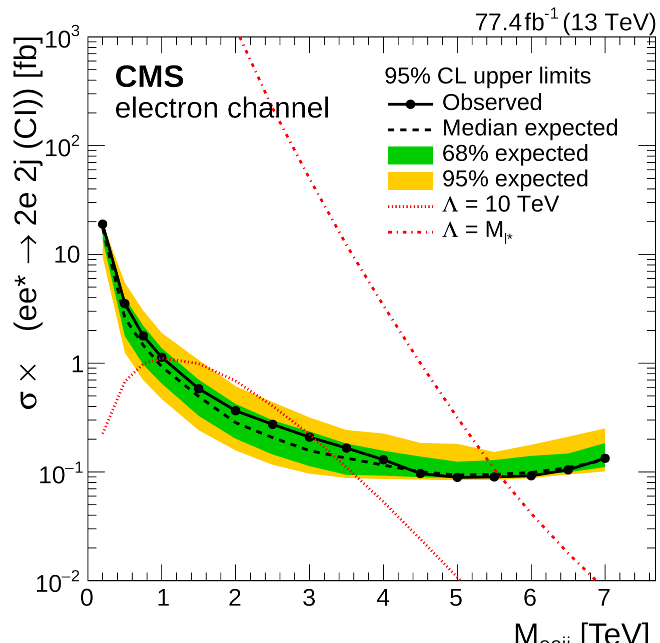


- Search for excited muon or electron decaying to 1l + 2jets.
- Contact interaction for production and decay with energy scale Λ.
- Main backgrounds (top-pair and DY) from simulation, validated in dedicated regions in low M_{ll} events.



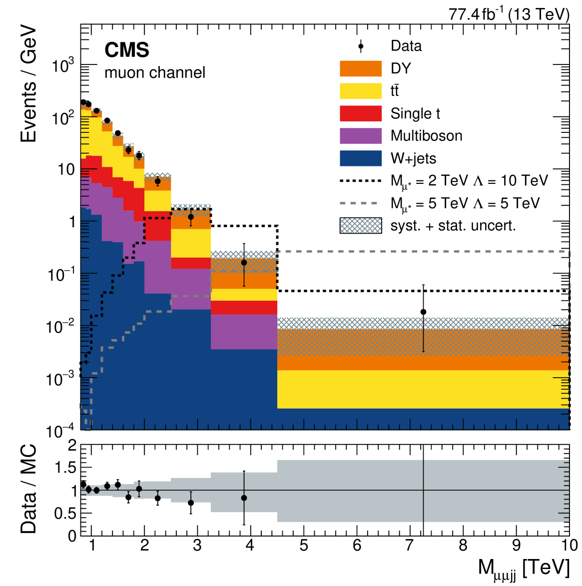


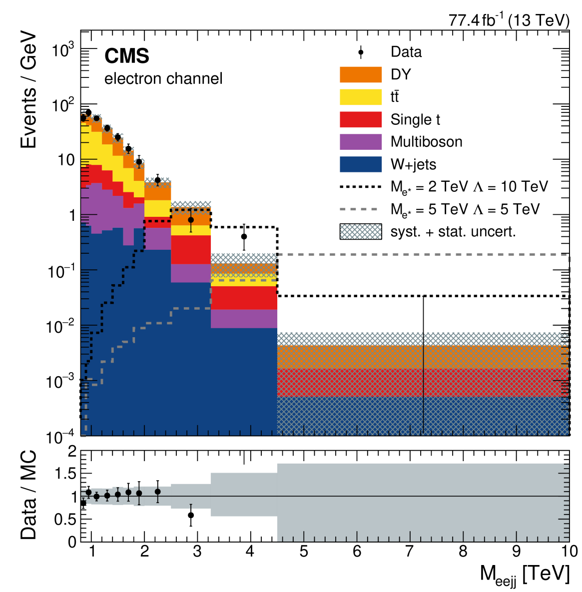
l* produced in association with a lepton of the same flavour.



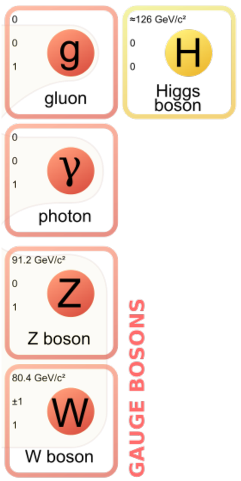
Excited electrons (muons) excluded up to masses of 5.6 (5.7) TeV, under $M_{l^*} = \Lambda$.

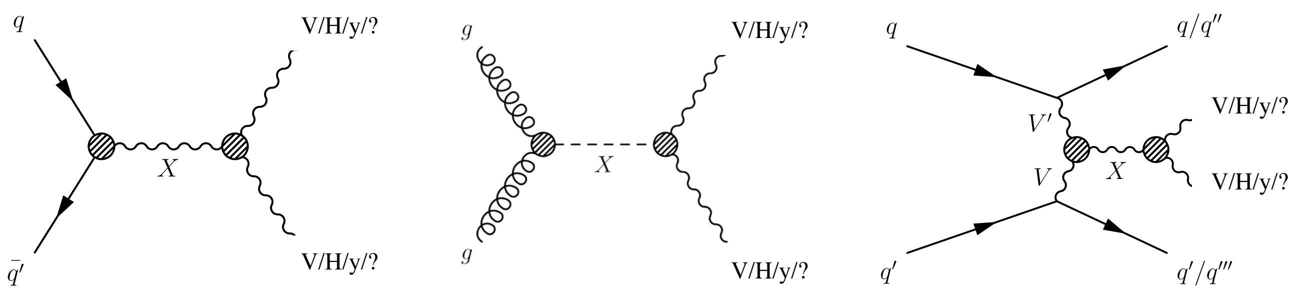
In terms of substructure scale Λ, limits of 11 (12) TeV for excited electrons (muons) of mass ~2 TeV.





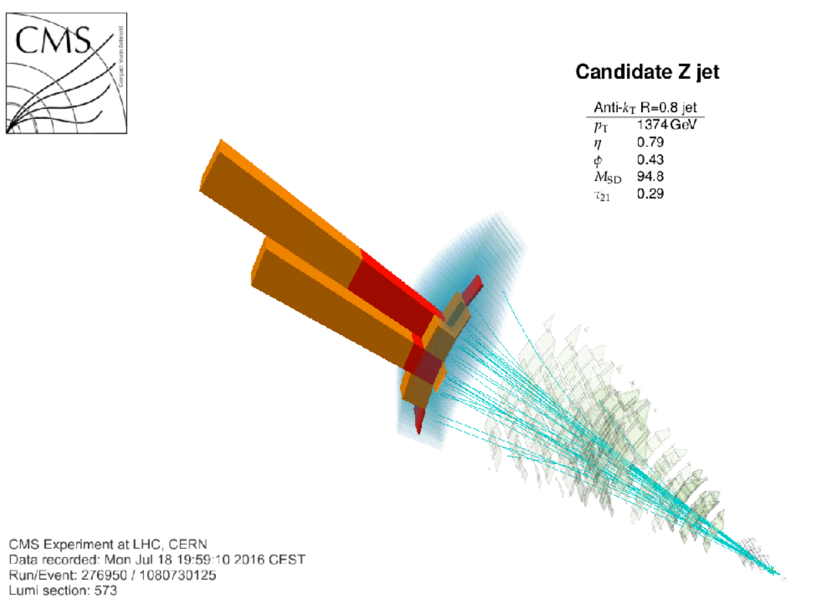
- Targeting O(100 GeV) to multi-TeV resonances (radions, gravitons, new vector bosons, extended Higgs sector) in different BSM scenarios:
    - Warped extra-dimensions, composite Higgs, technicolor, …





Highlights:

- Improved tagging algorithms for high-p_T $V \to qq$, $H \to bb$, $H \to \tau\tau$ decays:
    - Dense environment: critical to combine calorimeter with superior angular resolution of trackers.
- Novel analysis methods: 3D likelihood fits and anomaly detection techniques for broadening scope of the searches.



VV→qqqq resonances

CMS: EurPhysJC80,237(2020)

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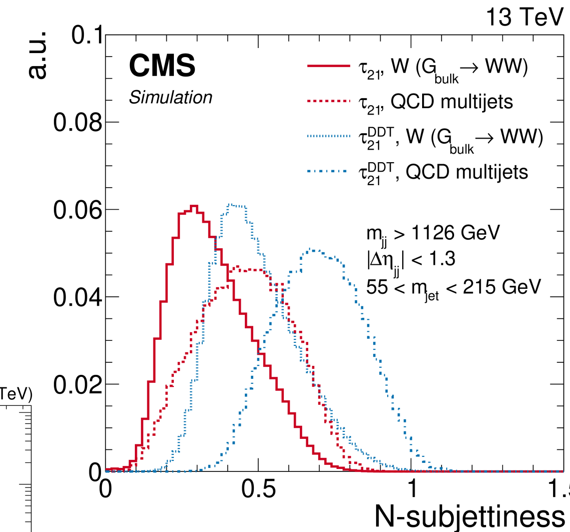
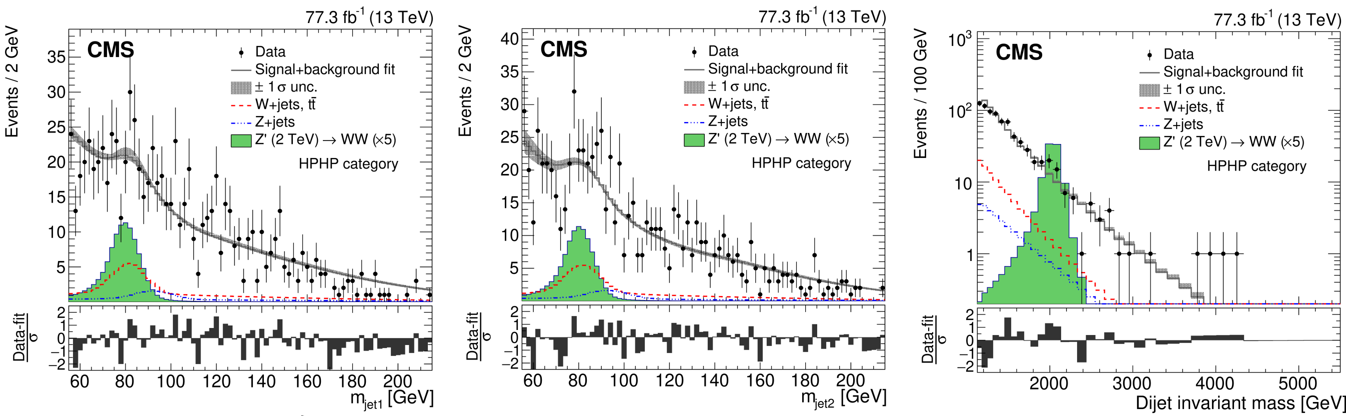
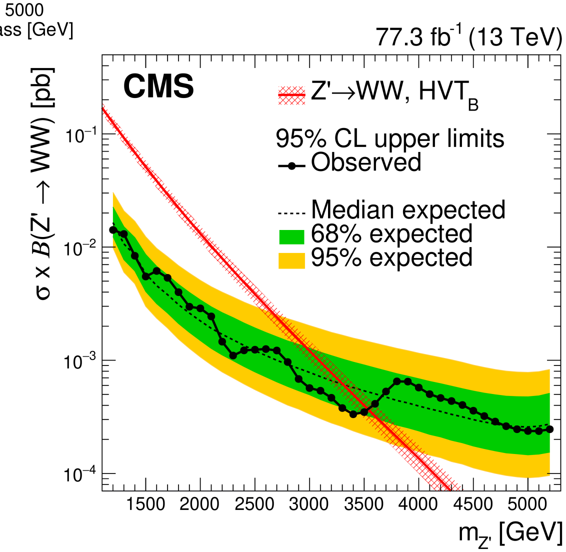
- Search for massive resonances decaying to WW, WZ or ZZ.
- Boosted W/Z decaying into single large-radius jets and within $|\Delta\eta|<1.3$.
- W/Z tagging with high-purity and low-purity selections: recovering acceptance where background is small.



W/Z-tagging with N-subjettiness, after mass decorrelation.



- **New analysis method:** 3D fit to masses of the two jets and dijet invariant mass ⇒ up to 30% improvement in sensitivity.
- Benchmarks: Randall-Sundrum gravitons and Heavy Vector Triplets
  - Under HVT Model B, exclusions for W' (Z') resonances with masses below 3.8 (3.5) TeV.



Semi-leptonic VV resonances (I)

ATLAS: HDBS-2018-10

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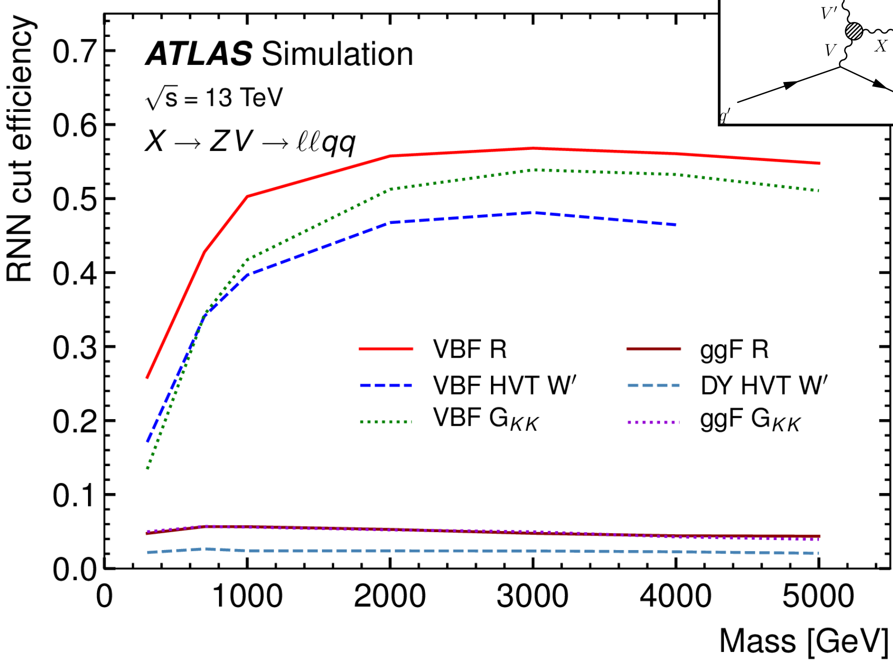
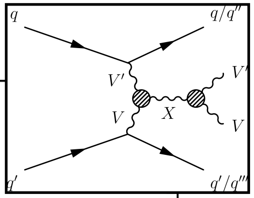
Full Run 2 dataset

- Search for massive resonances decaying to WW, WZ or ZZ boson pairs via gg fusion (ggF), Drell-Yan (DY) or vector boson fusion (VBF).
- Wide mass range: 300 GeV to 5 TeV.
  - V → qq reconstructed as 2 small-R jets or a single large-R jet depending on $p_T(V)$.
- **Recurrent neural network with 4-momentum of small-radius jets for categorizing between ggF/DY or VBF:**
  - VBF production typically accompanied of well-separated jets with large dijet invariant mass.

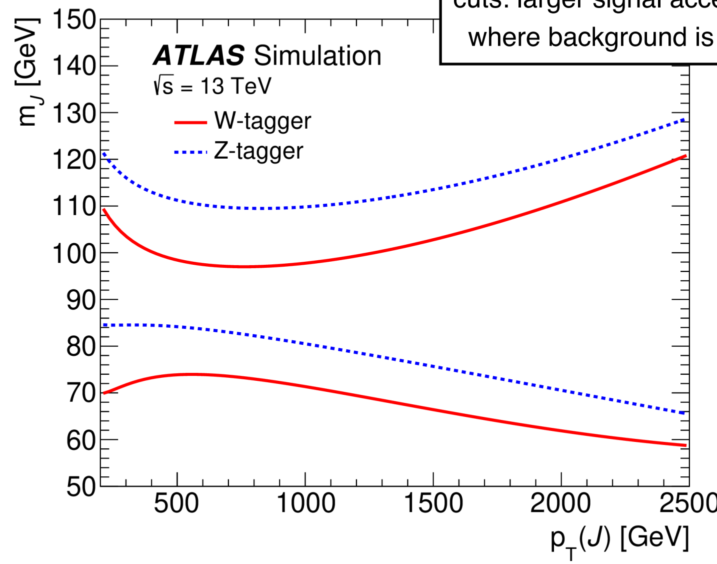
Three distinct channels:

- ZV → ννqq (0-lepton)
- WV → lνqq (1-lepton)
- ZV → llqq (2-lepton)





Boosted W/Z tagging via mass and substructure (D_2) cuts: larger signal acceptance where background is small.



Semi-leptonic VV resonances (II)

ATLAS: HDBS-2018-10

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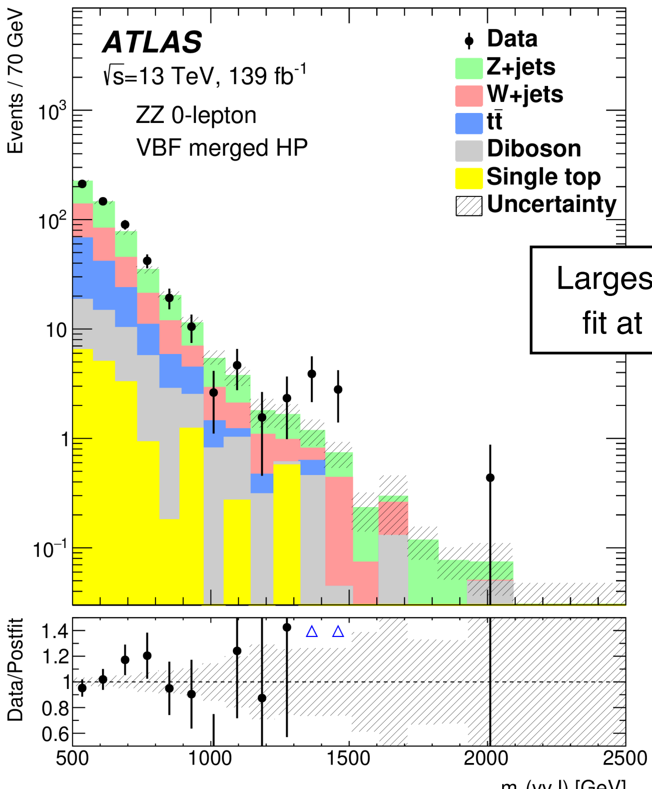
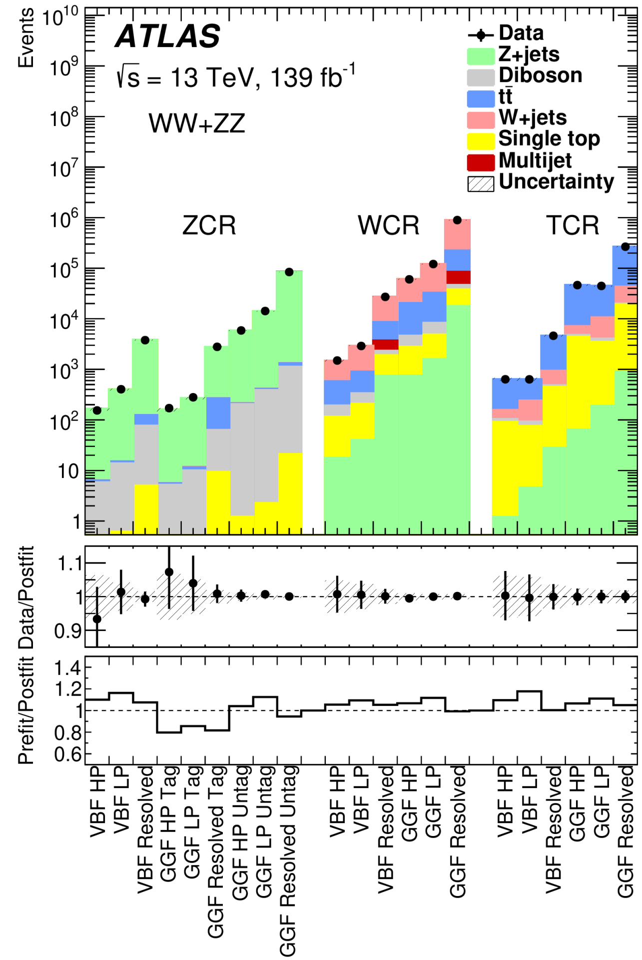
Full Run 2 dataset

- Separate WW+ZZ and WZ fits are performed for the ggF/DY and VBF production modes, but including signal and control regions from both categories.
- Dominant backgrounds from simulation: simultaneous fit to m_{VV} (or $m_{T,VV}$) in signal regions and Z+jets, W+jets and top-pair control regions.





Largest excess in RS radion fit at m_T ~ 1.5 TeV (2.8σ)

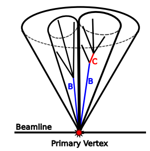
Obs (exp) 95% CL lower limits on the mass in TeV:

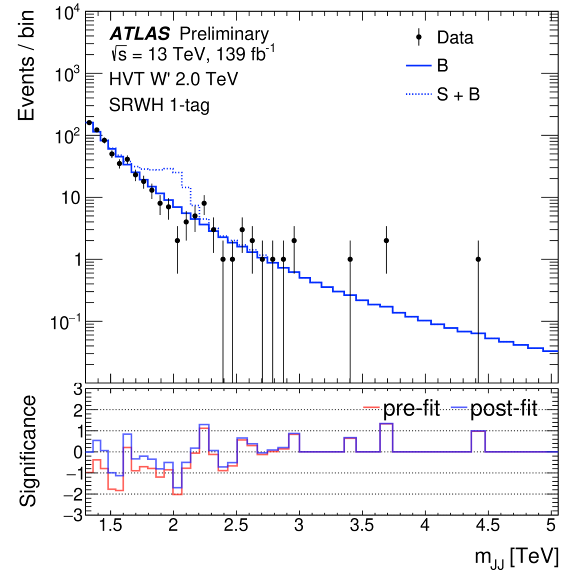
Production process	RS radion	HVT			RS graviton
			W'	Z'	
ggF/DY	3.2 (2.9)	Model A	3.9 (3.8)	3.5 (3.4)	2.0 (2.2)
		Model B	4.3 (4.0)	3.9 (3.7)	
VBF	–	Model C	–	–	0.76 (0.77)

VH→qqbb resonances

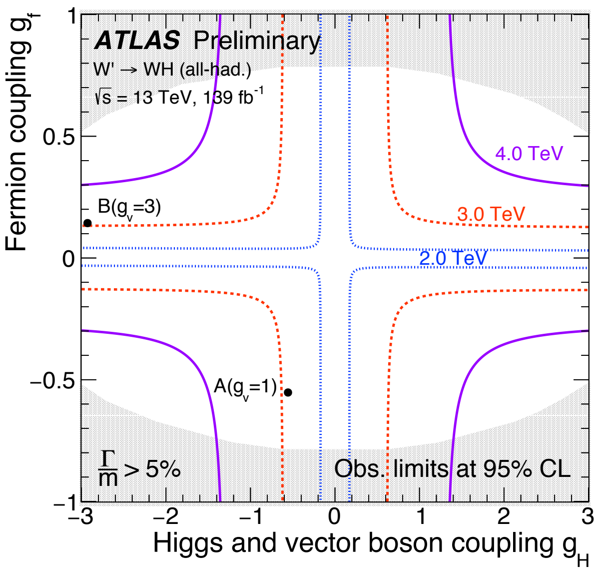
Full Run 2 dataset | ATLAS: HDBS-2018-11

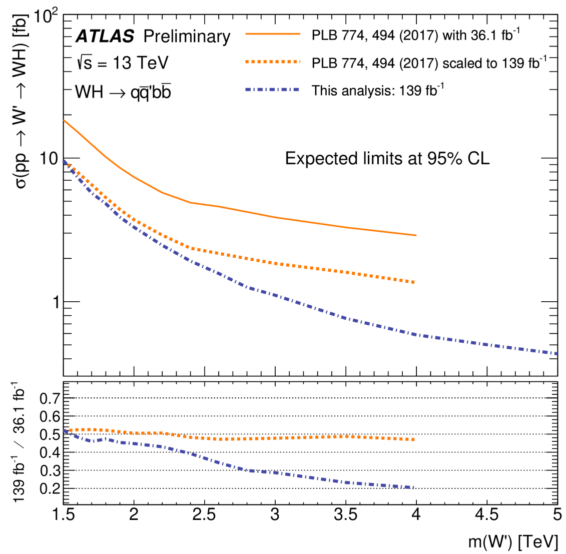
- Fully-hadronic final state: two large-radius jets, jet substructure, track multiplicity and b-tagging to identify H→bb and V→qq(') candidates.
- **Variable-radius track-jets for b-tagging**: p_T-dependent radius to resolve highly boosted bb pairs from Higgs boson decay.
- Signal regions with 1 or 2 b-tagged jets.
- Background (dominated by multijet) estimated from region with 0-tag: BDT trained on control region data to estimate extrapolation corrections to 1 and 2-tag.

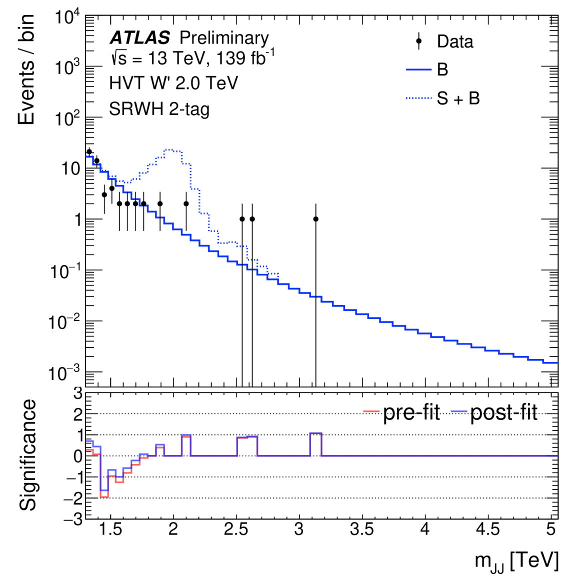




Limits in coupling plane for HVT framework.







Substantial improvement in sensitivity at high masses (e.g. due to improved H→bb tagging)

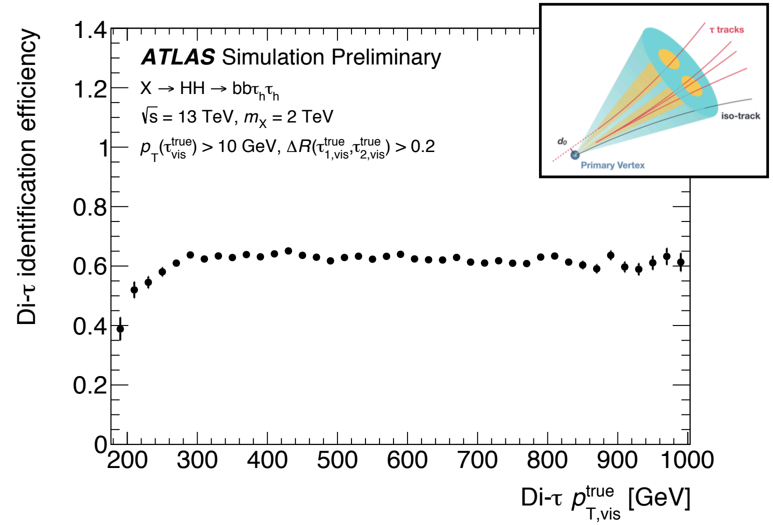
HVT Model B exclusions of W' (Z') up to 3.20 (2.65) TeV.

HH→bbττ resonances

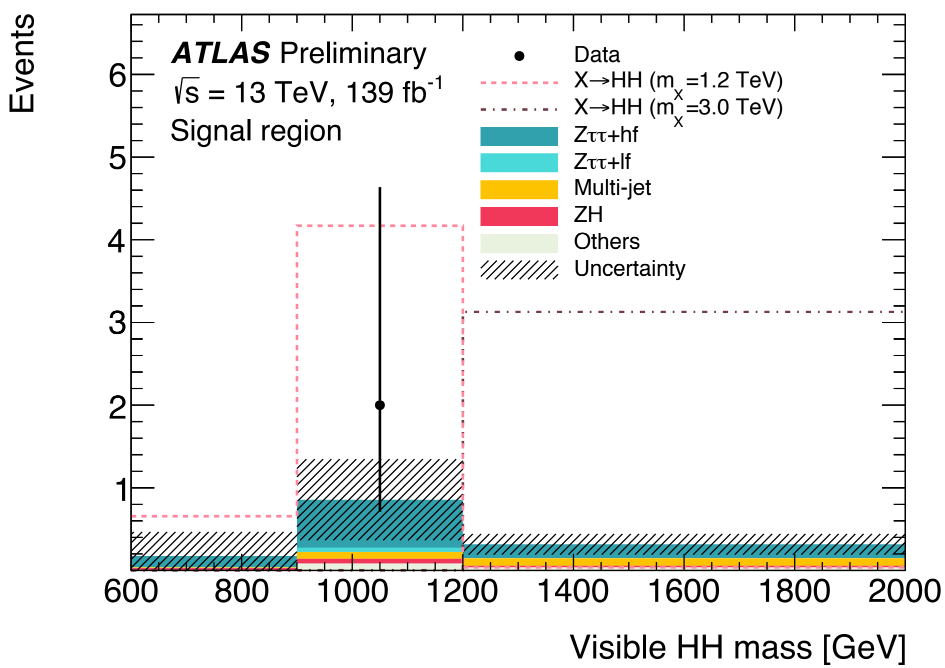
Full Run 2 dataset

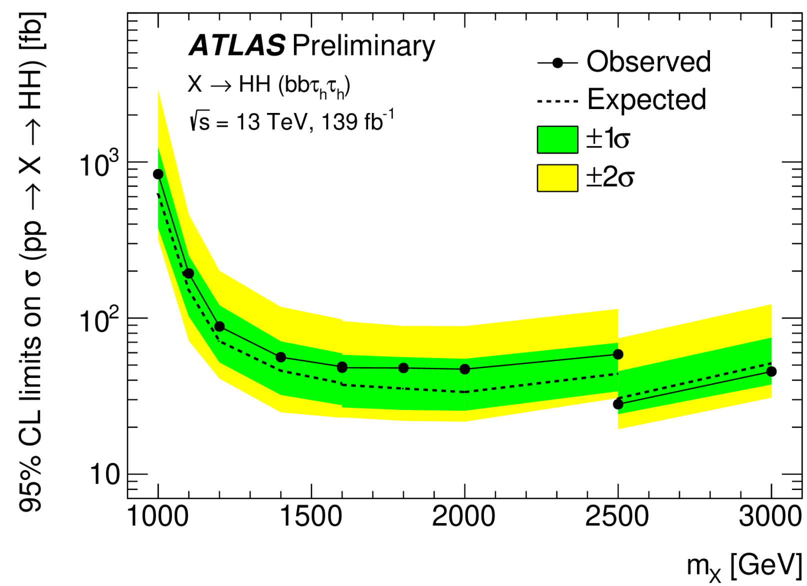
ATLAS: CONF-2020-012

- Targets boosted Higgs boson decays into bb-pair and two hadronically decaying τ-leptons.
- **New method** for reconstructing and identifying the ττ pair.
- **b-tagging of variable-radius track-jets** for H→bb.
- Relative fractions of Z+jets (light vs heavy flavor) adjusted from control region in data.
- Observed cross-section limits on heavy, narrow-width, scalar resonance between 88 and 46 fb (1.2-3 TeV).



BDT with calorimeter, tracking and vertexing information, trained on G→HH→ττττ simulation vs multi-jet enriched data.





A→BC with weak supervision

ATLAS: HDBS-2018-59

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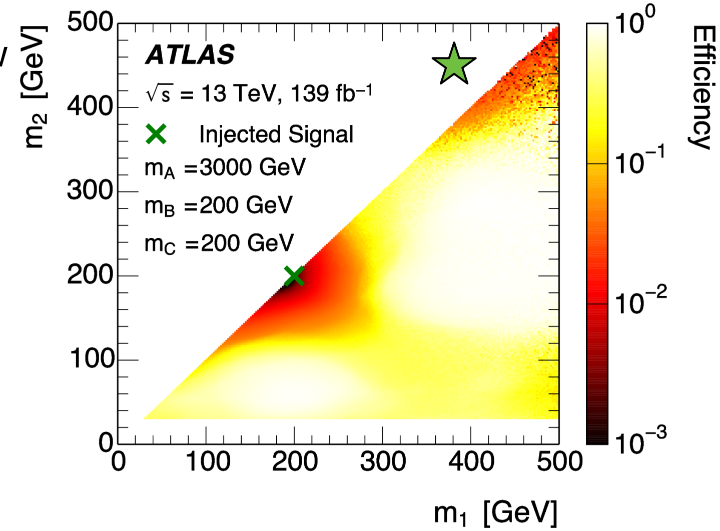
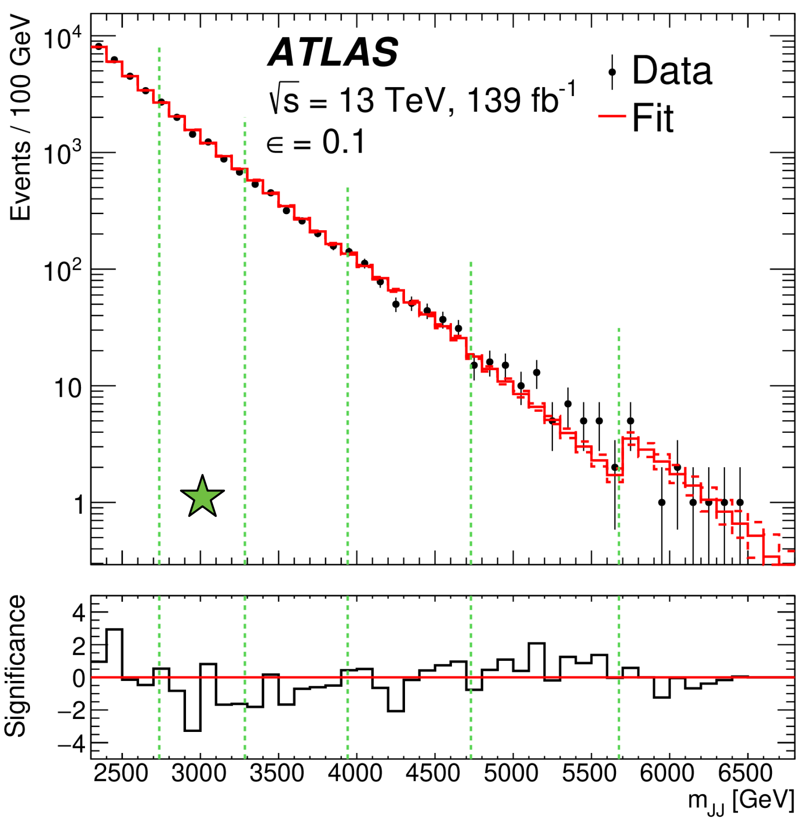
m_A: O(1 TeV)

m_B, m_C: O(100 GeV)

Full Run 2 dataset

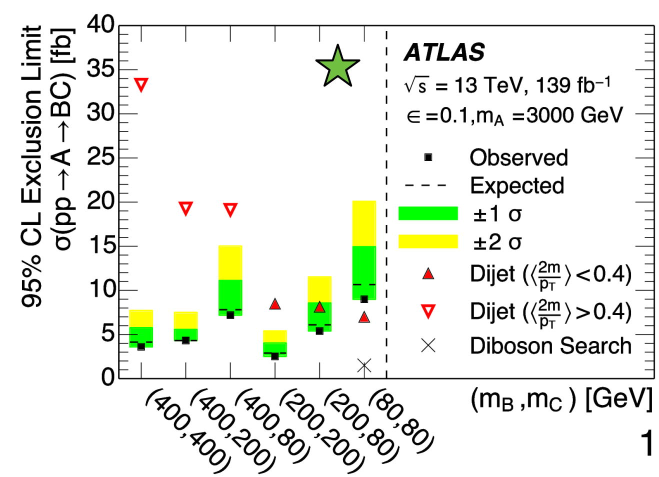
- Generic search for new resonances via anomaly detection procedure, targeting dijet topology with large-radius jets.
- **CWoLa method:** Classification WithOut LAbels for generic new physics in A→BC topology.
- Using data in a series of m_{jj} regions, train NNs to distinguish signal region from sidebands (jet masses as input features).



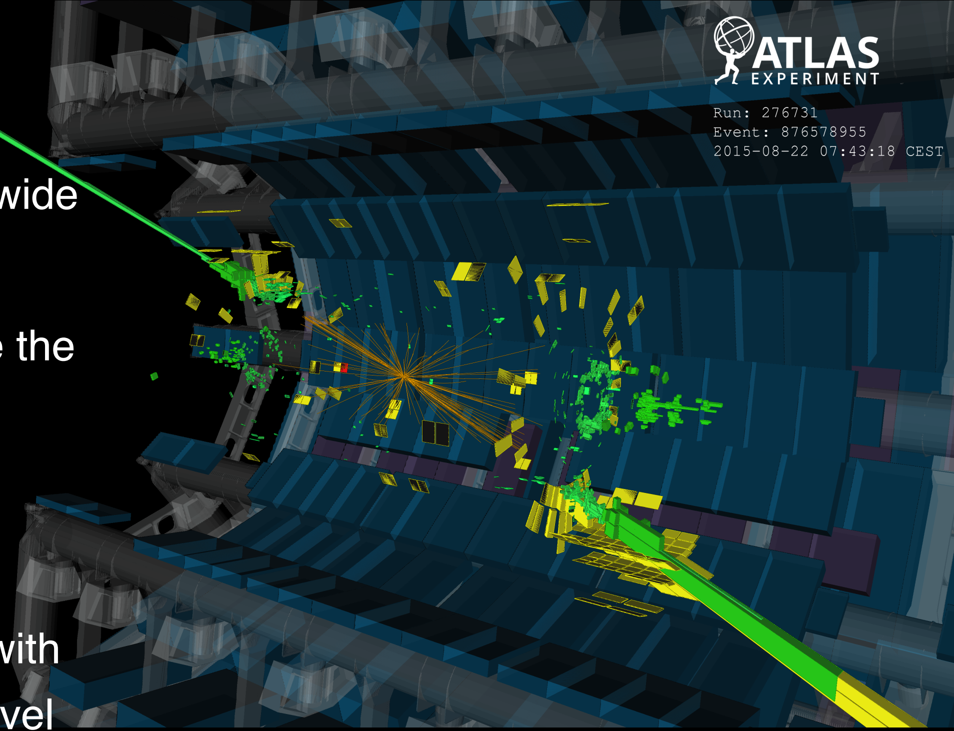


- Fits performed to a portion of the m_{jj} distribution after cut on NN outputs (one per signal region) at selection efficiencies of 1% and 10%.

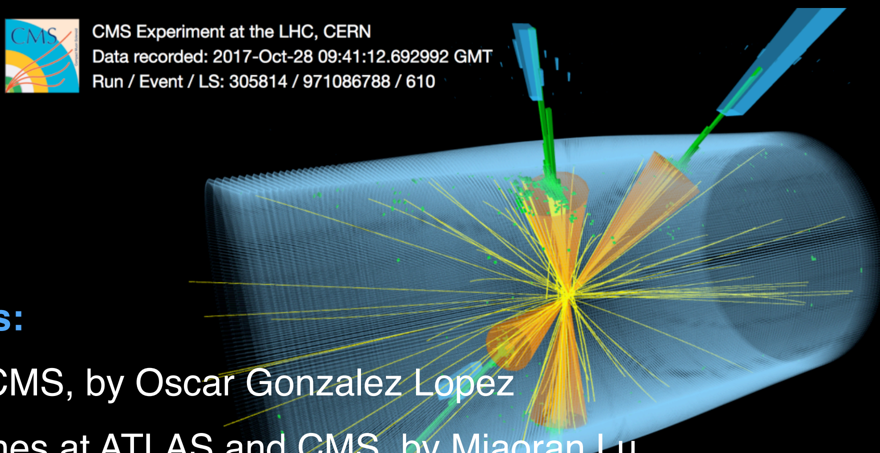
Cross section limits for narrow-width A, B, and C particles for different values of m_A, m_B, m_C.



Summary and outlook



- Huge effort by CMS and ATLAS to cover a wide kinematic range and final states.
- Producing re-interpretable limits to increase the longevity of each result.
- Broadening the scope by minimizing direct theory biases.
- **Making the most out of the full dataset**, with improved knowledge of the detector and novel analysis techniques leading to improved sensitivity.



Many more details will be covered in parallel talks:

- Searches for heavy resonances at ATLAS and CMS, by Oscar Gonzalez Lopez
- Diboson resonance and vector-like quark searches at ATLAS and CMS, by Miaoran Lu
- Boosted object identification in searches in ATLAS and CMS, by Pantelis Kontaxakis
- Search for heavy resonances decaying to Higgs bosons at ATLAS & CMS, by Ke Li

Backup

ATLAS summary plot

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2020

ATLAS Preliminary

$\int \mathcal{L}\,dt = (3.2 - 139)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 8, 13 TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK}+g/q$	0 e,μ	1 – 4 j	Yes	36.1	M_D 7.7 TeV	$n=2$	1711.03301
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n=3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n=6$	1703.09127
	ADD BH high $\sum p_T$	≥ 1 e,μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n=6$, $M_D=3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n=6$, $M_D=3$ TeV, rot BH	1512.02586
	RS1 $G_{KK}\to\gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl}=0.1$	1707.04147
	Bulk RS $G_{KK}\to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl}=1.0$	1808.02380
	Bulk RS $G_{KK}\to WV\to \ell\nu qq$	1 e,μ	2 j / 1 J	Yes	139	G_{KK} mass 2.0 TeV	$k/\overline{M}_{Pl}=1.0$	2004.14636
	Bulk RS $g_{KK}\to tt$	1 e,μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m=15\%$	1804.10823
	2UED / RPP	1 e,μ	≥ 2 b, ≥ 3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)}\to tt)=1$	1803.09678
Gauge bosons	SSM $Z'\to\ell\ell$	2 e,μ	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z'\to\tau\tau$	2 τ	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z'\to bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z'\to tt$	0 e,μ	≥ 1 b, ≥ 2 J	Yes	139	Z' mass 4.1 TeV	$\Gamma/m=1.2\%$	2005.05138
	SSM $W'\to\ell\nu$	1 e,μ	–	Yes	139	W' mass 6.0 TeV		1906.05609
	SSM $W'\to\tau\nu$	1 τ	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $W'\to WZ\to\ell\nu qq$ model B	1 e,μ	2 j / 1 J	Yes	139	W' mass 4.3 TeV	$g_V=3$	2004.14636
	HVT $V'\to WV\to qqqq$ model B	0 e,μ	2 J	–	139	V' mass 3.8 TeV	$g_V=3$	1906.08589
	HVT $V'\to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V=3$	1712.06518
	HVT $W'\to WH$ model B	0 e,μ	≥ 1 b, ≥ 2 J		139	W' mass 3.2 TeV	$g_V=3$	CERN-EP-2020-073
	LRSM $W_R\to tb$	multi-channel			36.1	W_R mass 3.25 TeV		1807.10473
	LRSM $W_R\to\mu N_R$	2 μ	1 J	–	80	W_R mass 5.0 TeV	$m(N_R)=0.5$ TeV, $g_L=g_R$	1904.12679
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η_{LL}^-		1703.09127
	CI $\ell\ell qq$	2 e,μ	–	–	139	Λ 35.8 TeV η_{LL}^-		CERN-EP-2020-066
	CI $tttt$	$\geq$1 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t}\rvert=4\pi$	1811.02305
DM	Axial-vector mediator (Dirac DM)	0 e,μ	1 – 4 j	Yes	36.1	m_{med} 1.55 TeV	g_q=0.25, g_χ=1.0, $m(\chi)=1$ GeV	1711.03301
	Colored scalar mediator (Dirac DM)	0 e,μ	1 – 4 j	Yes	36.1	m_{med} 1.67 TeV	g=1.0, $m(\chi)=1$ GeV	1711.03301
	$VV\chi\chi$ EFT (Dirac DM)	0 e,μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi)<150$ GeV	1608.02372
	Scalar reson. $\phi\to t\chi$ (Dirac DM)	0-1 e,μ	1 b, 0-1 J	Yes	36.1	m_ϕ 3.4 TeV	$y=0.4$, $\lambda=0.2$, $m(\chi)=10$ GeV	1812.09743
LQ	Scalar LQ 1st gen	1,2 e	≥ 2 j	Yes	36.1	LQ mass 1.4 TeV	$\beta=1$	1902.00377
	Scalar LQ 2nd gen	1,2 μ	≥ 2 j	Yes	36.1	LQ mass 1.56 TeV	$\beta=1$	1902.00377
	Scalar LQ 3rd gen	2 τ	2 b	–	36.1	LQ_3^u mass 1.03 TeV	$\mathcal{B}(LQ_3^u\to b\tau)=1$	1902.08103
	Scalar LQ 3rd gen	0-1 e,μ	2 b	Yes	36.1	LQ_3^d mass 970 GeV	$\mathcal{B}(LQ_3^d\to t\tau)=0$	1902.08103
Heavy quarks	VLQ $TT\to Ht/Zt/Wb+X$	multi-channel			36.1	T mass 1.37 TeV	SU(2) doublet	1808.02343
	VLQ $BB\to Wt/Zb+X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3}T_{5/3}\lvert T_{5/3}\to Wt+X$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3}\to Wt)$= 1, $c(T_{5/3}Wt)$= 1	1807.11883
	VLQ $Y\to Wb+X$	1 e,μ	≥ 1 b, $\geq$ 1j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y\to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B\to Hb+X$	0 e,μ, 2 γ	≥ 1 b, $\geq$ 1j	Yes	79.8	B mass 1.21 TeV	κ_B= 0.5	ATLAS-CONF-2018-024
	VLQ $QQ\to WqWq$	1 e,μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^*\to qg$	–	2 j	–	139	q^* mass 6.7 TeV	only u^* and d^*, $\Lambda=m(q^*)$	1910.08447
	Excited quark $q^*\to q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda=m(q^*)$	1709.10440
	Excited quark $b^*\to bg$	–	1 b, 1 j	–	36.1	b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	3 e,μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda=3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e,μ,τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda=1.6$ TeV	1411.2921
Other	Type III Seesaw	1 e,μ	≥ 2 j	Yes	79.8	N^0 mass 560 GeV		ATLAS-CONF-2018-020
	LRSM Majorana ν	2 μ	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R)=4.1$ TeV, $g_L=g_R$	1809.11105
	Higgs triplet $H^{\pm\pm}\to\ell\ell$	2,3,4 e,μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm}\to\ell\tau$	3 e,μ,τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm}\to\ell\tau)=1$	1411.2921
	Multi-charged particles	–	–	–	36.1	multi-charged particle mass 1.22 TeV	DY production, $\lvert q\rvert=5e$	1812.03673
	Magnetic monopoles	–	–	–	34.4	monopole mass 2.37 TeV	DY production, $\lvert g\rvert=1g_D$, spin 1/2	1905.10130

$\sqrt{s}$ = 8 TeV | $\sqrt{s}$ = 13 TeV partial data | $\sqrt{s}$ = 13 TeV full data

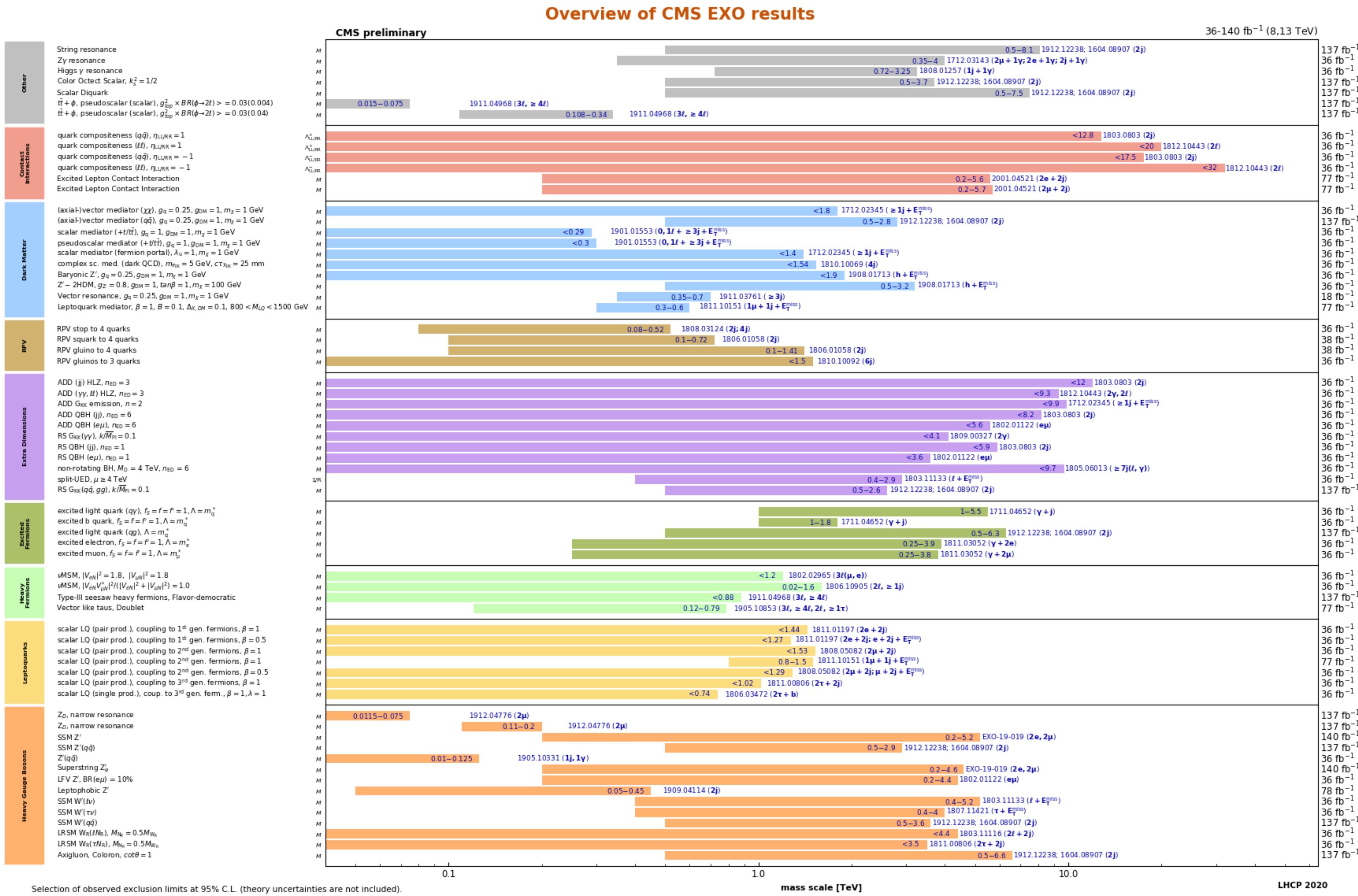
Mass scale [TeV] (10^{-1}, 1, 10)

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

†Small-radius (large-radius) jets are denoted by the letter j (J).

CMS summary plot

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK



ATLAS: di-jet resonances

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

ATLAS: JHEP03(2020)145

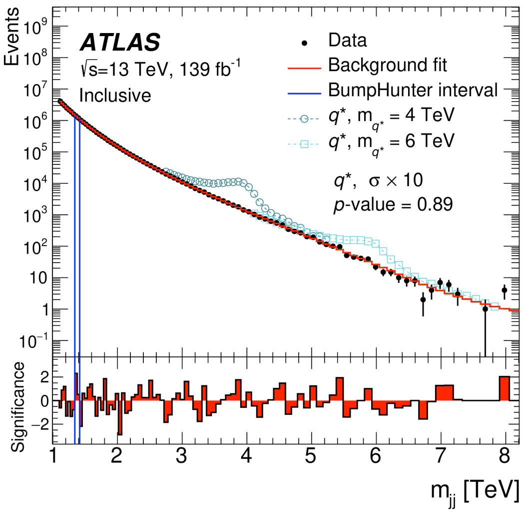
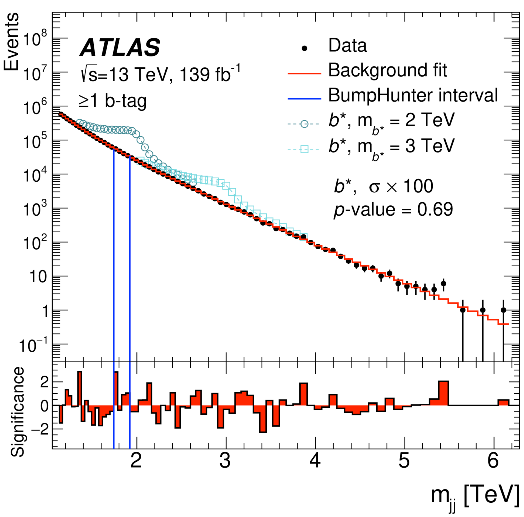
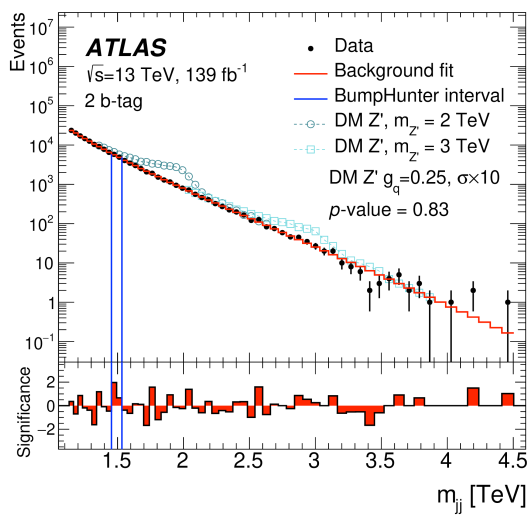
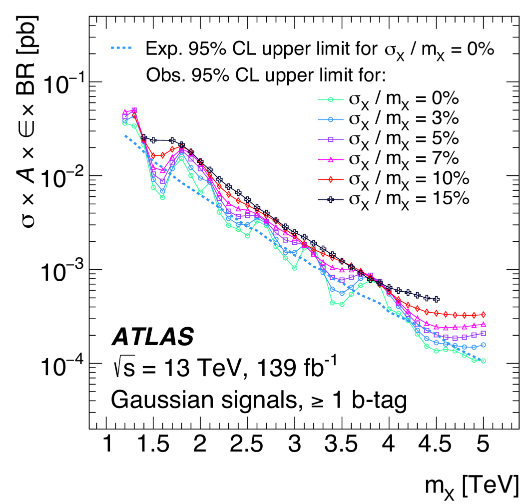


Table 2: The lower limits on the masses of benchmark signals at 95% CL.

Category	Model	Lower limit on signal mass at 95% CL	
		Observed	Expected
Inclusive	q^*	6.7 TeV	6.4 TeV
	QBH	9.4 TeV	9.4 TeV
	W'	4.0 TeV	4.2 TeV
	W^*	3.9 TeV	4.1 TeV
	DM mediator Z', $g_q = 0.20$	3.8 TeV	3.8 TeV
	DM mediator Z', $g_q = 0.50$	4.6 TeV	4.9 TeV
$1b$	b^*	3.2 TeV	3.1 TeV
$2b$	DM mediator Z' $g_q = 0.20$	2.8 TeV	2.8 TeV
	DM mediator Z', $g_q = 0.25$	2.9 TeV	3.0 TeV
	SSM Z',	2.7 TeV	2.7 TeV
	graviton, $k/\overline{M}_{PL} = 0.2$	2.8 TeV	2.9 TeV

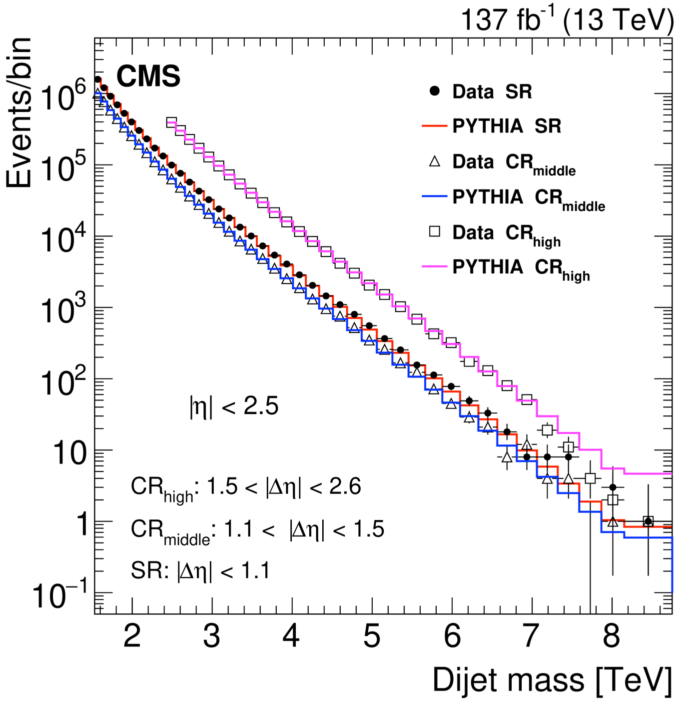


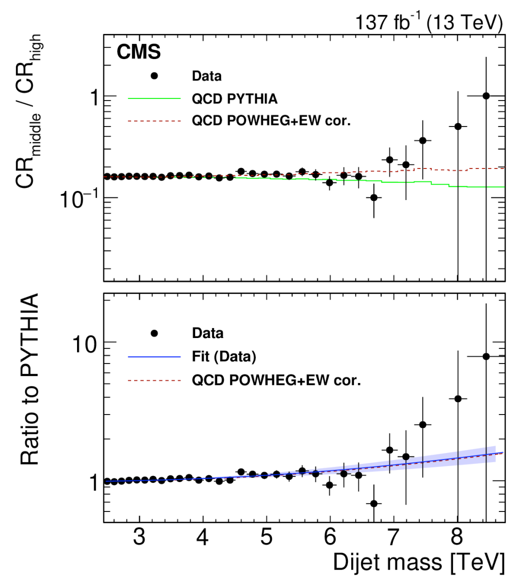


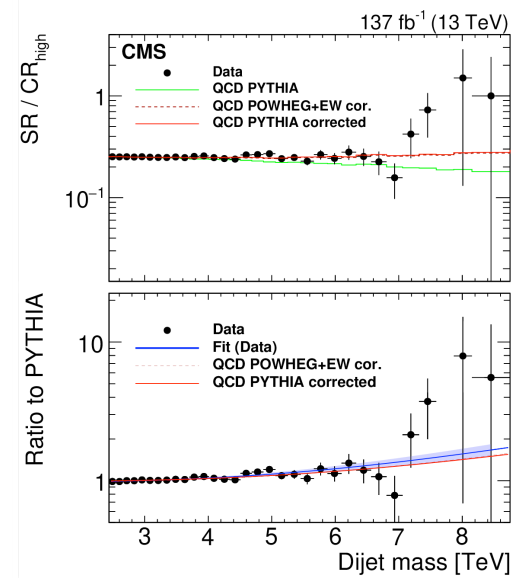


CMS: di-jet resonances

CMS: JHEP05(2020)033







Ratio method:

$$N_{SR}^{Prediction} = R \times N_{CR_{high}}^{Data}$$

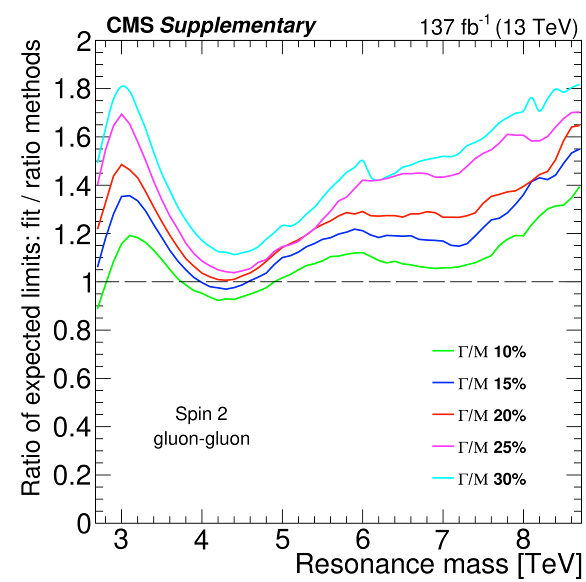
$$R = C \times N_{SR}^{Simulation} / N_{CR_{high}}^{Simulation}$$

$$R_{aux.} = N_{CR_{middle}} / N_{CR_{high}}$$

$$C = \frac{R_{aux.}^{Data}}{R_{aux.}^{Simulation}} = p_0 + p_1 \times (m_{jj}/\sqrt{s})^3$$

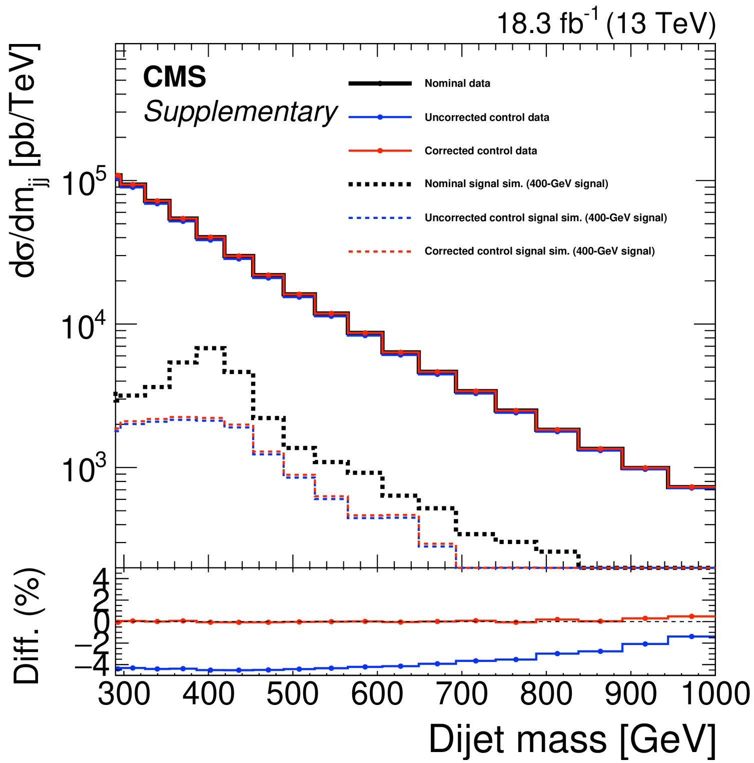
Fit method: $$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3 \ln(x)}}$$

Model	Final state	Observed (expected) mass limit [TeV]
String	q g	7.9 (8.1)
Scalar diquark	q q	7.5 (7.9)
Axigluon/coloron	$q\bar{q}$	6.6 (6.4)
Excited quark	q g	6.3 (6.2)
Color-octet scalar ($k_s^2 = 1/2$)	g g	3.7 (3.9)
W′ SM-like	$q\bar{q}$	3.6 (3.9)
Z′ SM-like	$q\bar{q}$	2.9 (3.4)
RS graviton ($k/\overline{M}_{Pl} = 0.1$)	$q\bar{q}$, g g	2.6 (2.6)
DM mediator ($m_{DM} = 1$ GeV)	$q\bar{q}$	2.8 (3.2)



CMS: low mass di-jet resonances

CMS: PhysLettB(2020)135448



Selection	Data after trigger sel.	Signal (800 GeV)	Signal (600 GeV)	Signal (500 GeV)	Signal (400 GeV)	Signal (300 GeV)
Trigger	(100%)	91.1% ± 0.1%	85.9% ± 0.1%	82.2% ± 0.1%	68.1% ± 0.1%	43.3% ± 0.1%
$\|\Delta\eta(jj)\| < 1.1$	45.2% ± 0.2%	52.4% ± 0.1%	52.6% ± 0.1%	52.6% ± 0.1%	47.1% ± 0.1%	34.2% ± 0.1%
Three jets $p_T > 72$ GeV	7.8% ± 0.1%	13.6% ± 0.1%	10.9% ± 0.1%	9.2% ± 0.1%	6.68% ± 0.05%	4.04% ± 0.03%
$290 < mjj < 1000$ GeV	3.6% ± 0.1%	12.3% ± 0.1%	10.1% ± 0.1%	8.3% ± 0.1%	5.39% ± 0.05%	2.70% ± 0.03%

Fully-hadronic top-pair resonances

Columbia University
in the City of New York

ATLAS: EXOT-2018-48

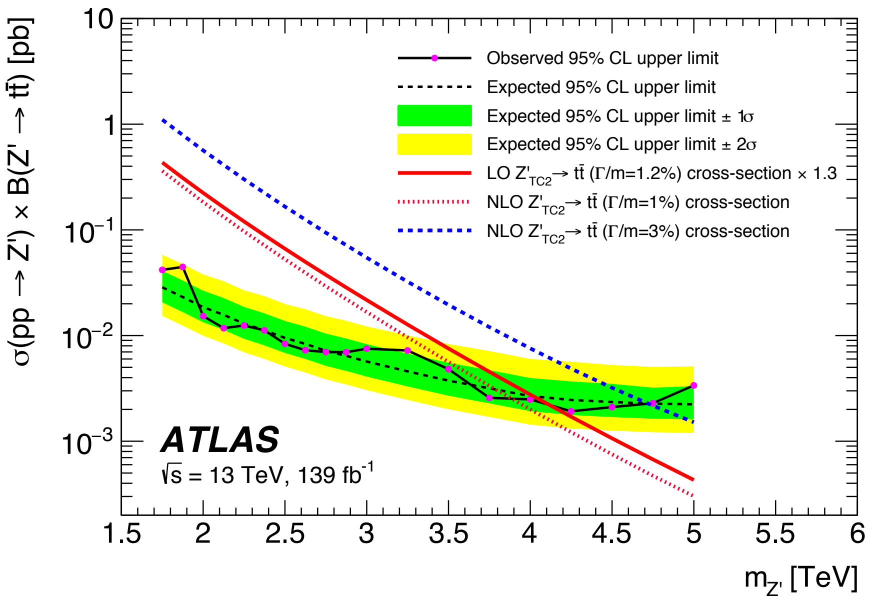
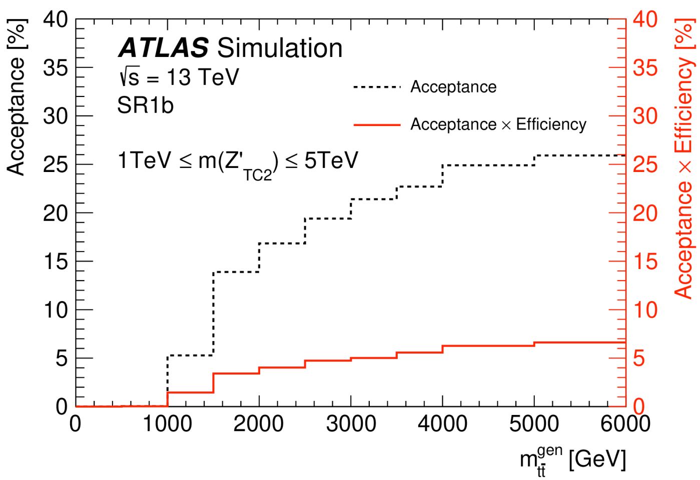
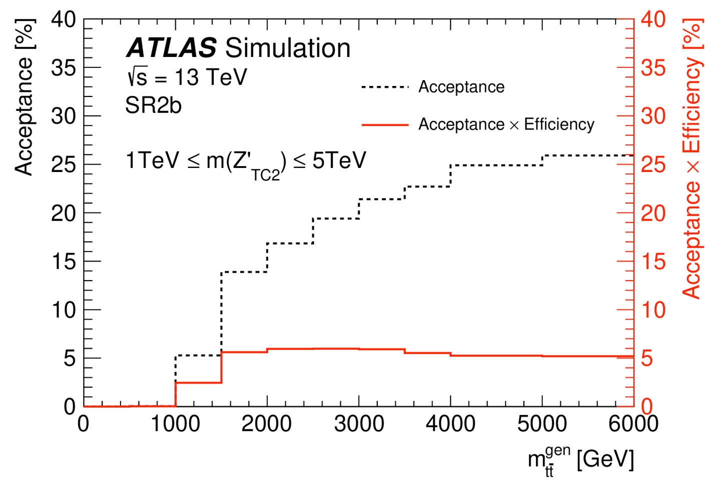


Table 1: Event categorization used to model the multijet background from data according to whether the leading and subleading large-R jets are top-tagged or b-tagged. If the large-R jet is top-tagged, it is denoted by t, and otherwise by $\not{t}$, as indicated in the left column or in the bottom row. Similarly, if the large-R jet is b-tagged, it is denoted by b, and otherwise by $\not{b}$. The percentages in parentheses show the expected fractions of SM $t\bar{t}$ events obtained using the $t\bar{t}$ and multijet simulation samples. Non-$t\bar{t}$ or non-multijet background events are negligible. The signal regions, SR1b and SR2b, are coloured in red, the template region (TR) in grey and the rest of the control regions A-I in light blue.

Subleading large-R jet	Leading large-R jet: $\not{t}\not{b}$	$\not{t}b$	$t\not{b}$	tb
tb	A (6.1%)		SR1b (23%)	SR2b (90%)
$t\not{b}$	B (0.5%)	E (1.8%)	TR (2.6%)	SR1b (28%)
$\not{t}b$	C (0.4%)		G (2.3%)	
$\not{t}\not{b}$	D (< 0.1%)	F (0.3%)	H (0.4%)	I (6.7%)





CMS: dilepton resonances

CMS: EXO-19-019

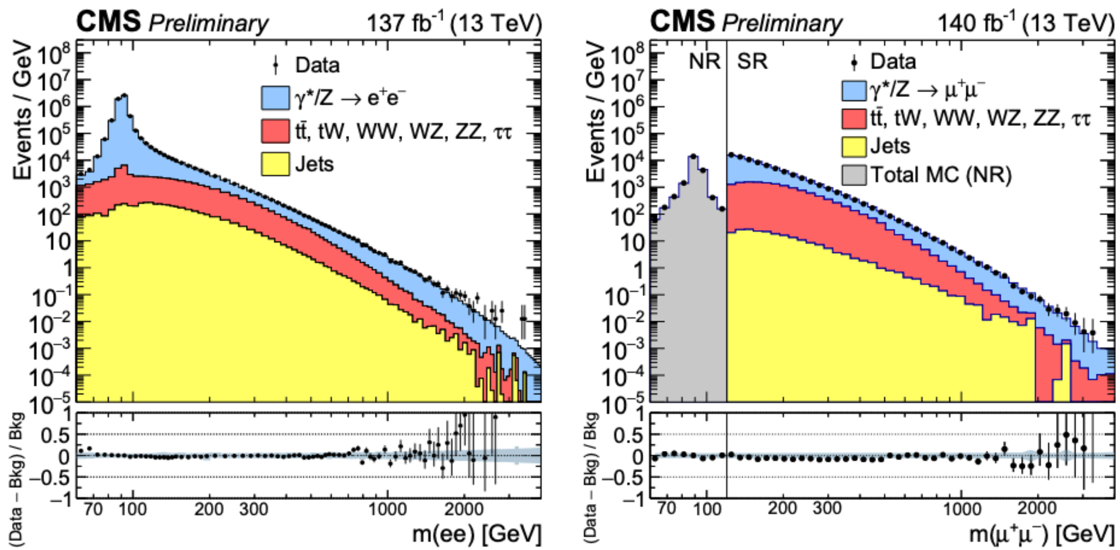


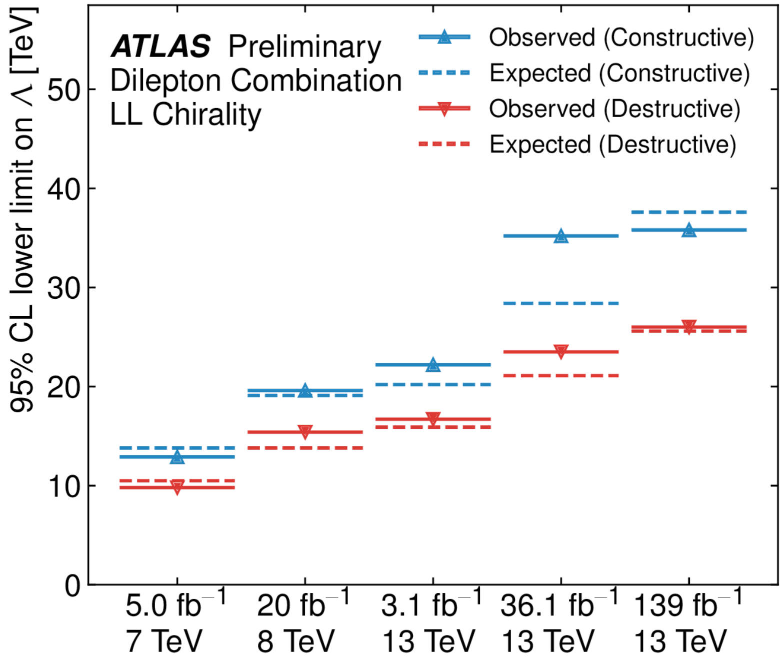
Figure 1: The invariant mass distribution of pairs of (left) electrons and (right) muons observed in data (black dots with statistical error bars) and expected from the SM processes (stacked histograms). For the dimuon channel, a prescaled trigger with a p_T threshold of 27 GeV was used to collect events in the normalization region (NR) with $m_{\mu\mu} < 120$ GeV. The corresponding offline threshold is 30 GeV. Events in the signal region (SR) corresponding to masses above 120 GeV are collected using an unprescaled single muon trigger. The bin width gradually increases with mass. The ratio of the data yields after background subtraction to the background yields is shown on the bottom plots. The blue band represents the various statistical and systematic uncertainties on the background.

Channel	Z'_{SSM}		Z'_{ψ}	
	Obs. [TeV]	Exp. [TeV]	Obs. [TeV]	Exp. [TeV]
ee	4.72	4.72	4.11	4.13
$\mu^+\mu^-$	4.89	4.90	4.29	4.30
ee + $\mu^+\mu^-$	5.15	5.14	4.56	4.55

ATLAS: dilepton non-resonant

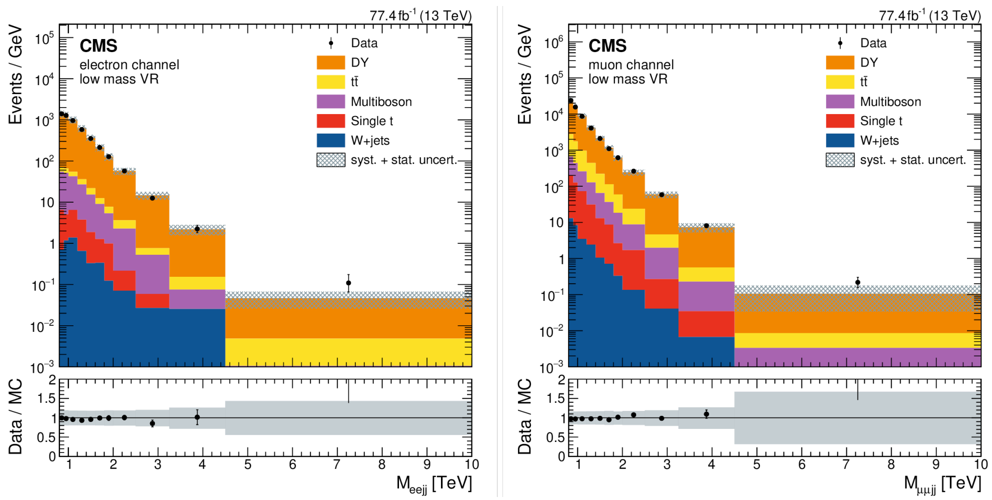
Channel	Constructive interference			Destructive interference		
	CR_{min}	CR_{max}	SR_{min}	CR_{min}	CR_{max}	SR_{min}
e^+e^-	280	2200	2200	310	1450	2770
$\mu^+\mu^-$	310	2070	2070	320	1250	2570

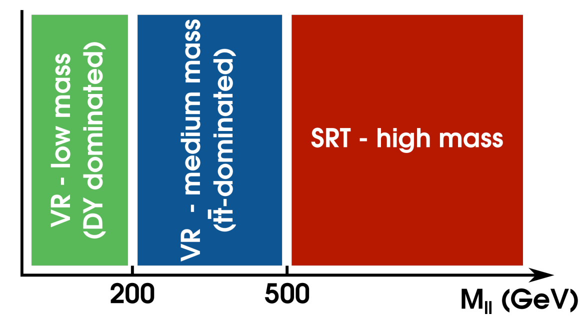
Int.	Channel	Exp./Obs.	LL	LR	RL	RR
Constructive	ee	Expected	31.1	28.9	28.7	30.9
		Observed	26.1	24.7	24.6	26.0
	$\mu\mu$	Expected	29.2	27.1	27.0	29.0
		Observed	32.7	30.0	29.8	32.6
	$\ell\ell$	Expected	37.6	34.0	33.7	37.3
		Observed	35.8	32.5	32.3	35.5
Destructive	ee	Expected	23.0	24.4	24.4	23.2
		Observed	23.5	25.1	25.1	23.7
	$\mu\mu$	Expected	22.0	23.6	23.6	22.2
		Observed	22.3	23.9	23.9	22.5
	$\ell\ell$	Expected	25.6	28.0	28.0	25.9
		Observed	26.0	28.8	28.8	26.5

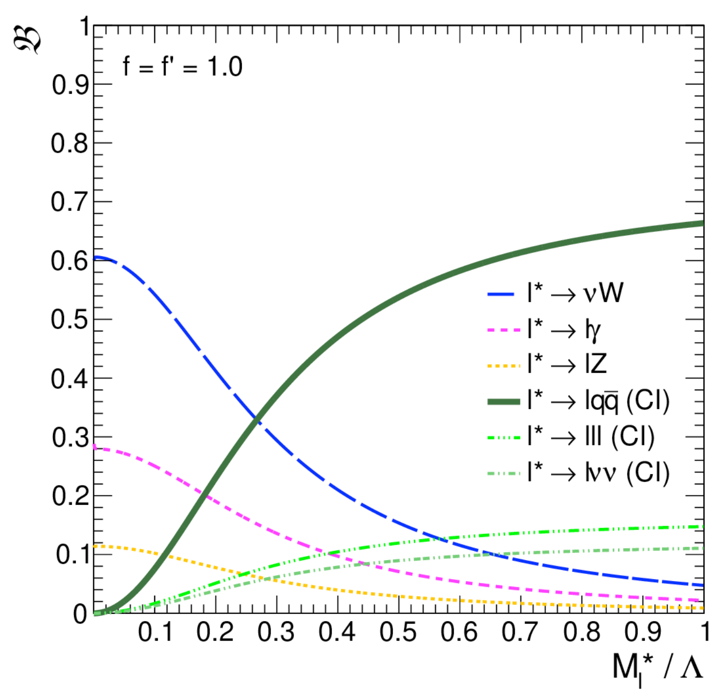


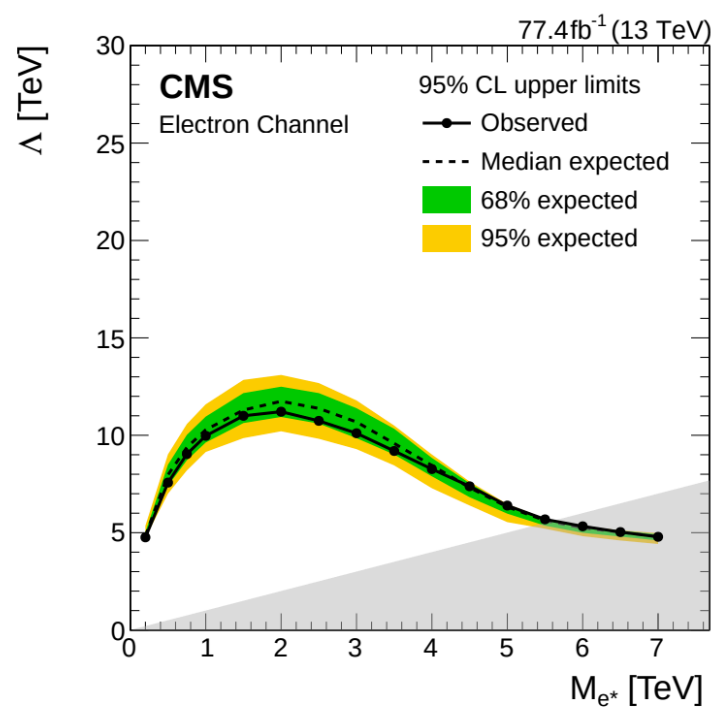
CMS: lepton+jets

CMS: EXO-18-013



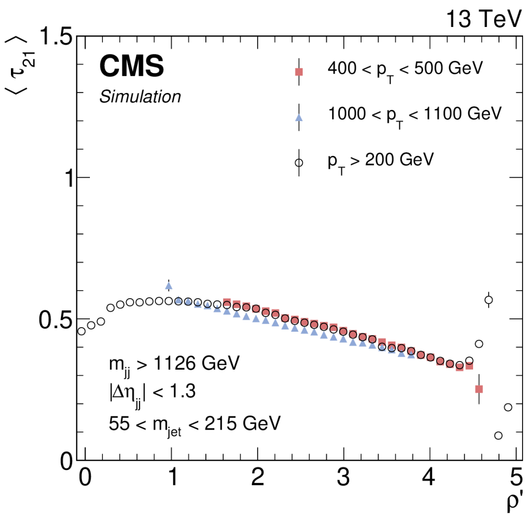


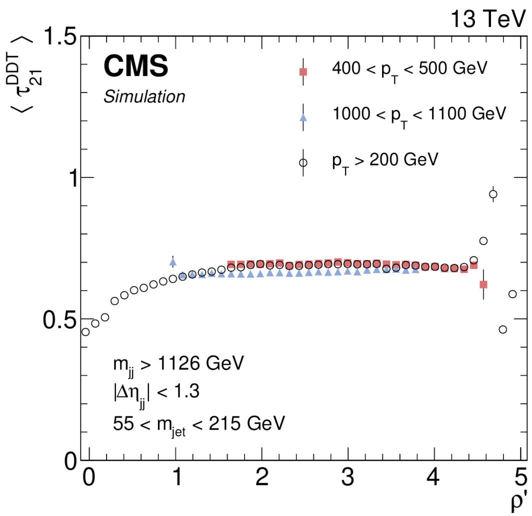


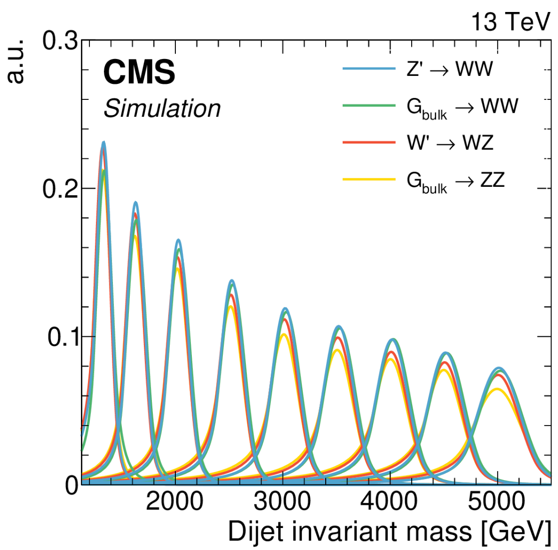


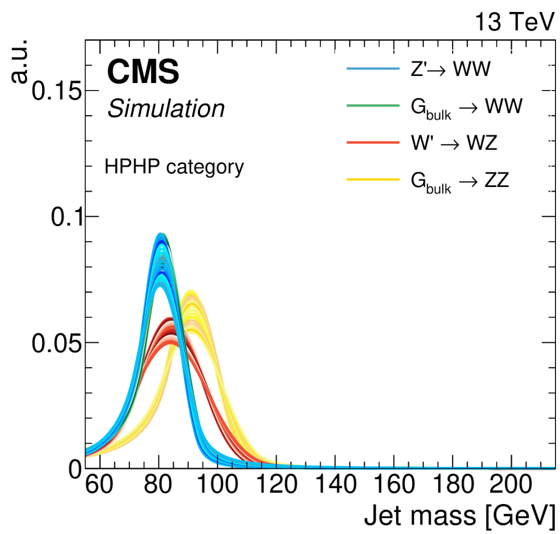
CMS: VV→qqqq resonances (I)

CMS: EurPhysJC80,237(2020)





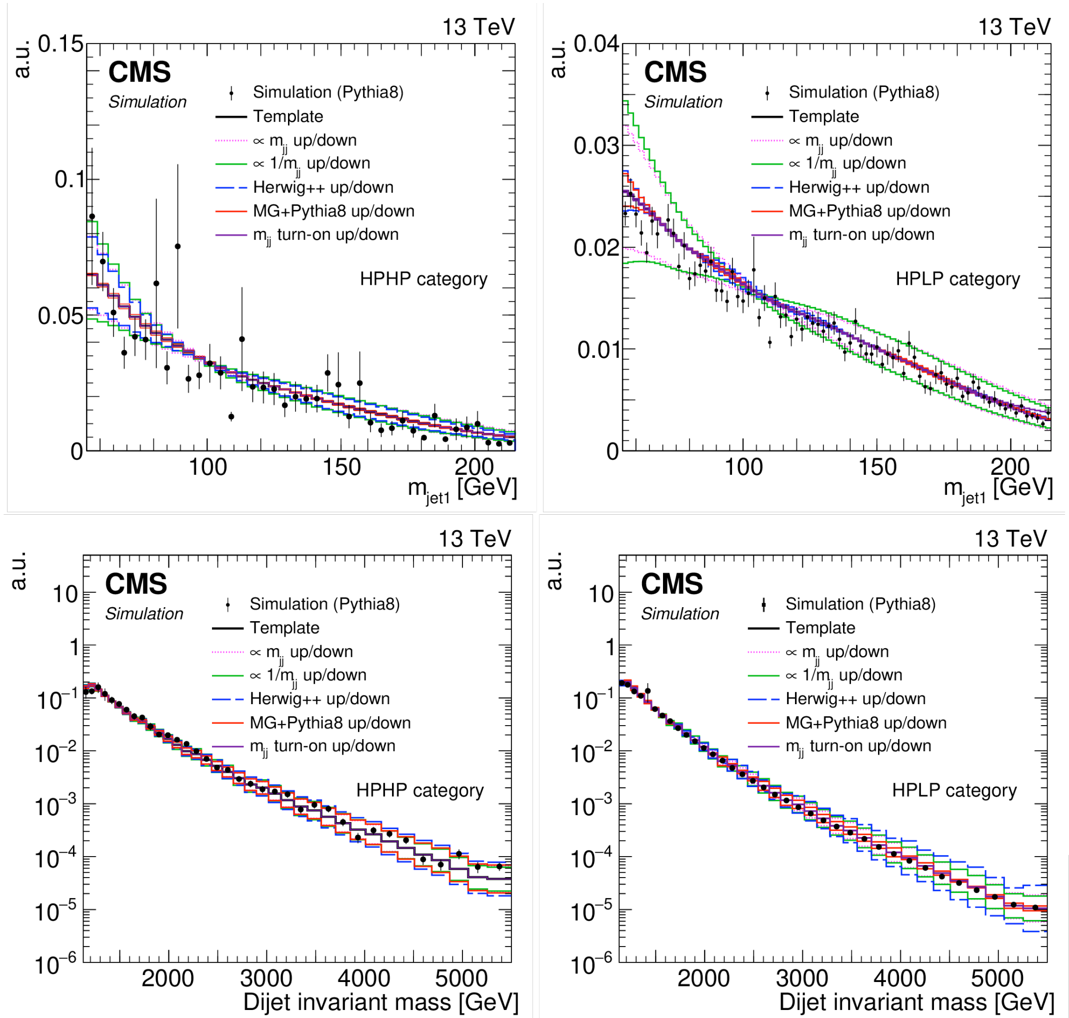


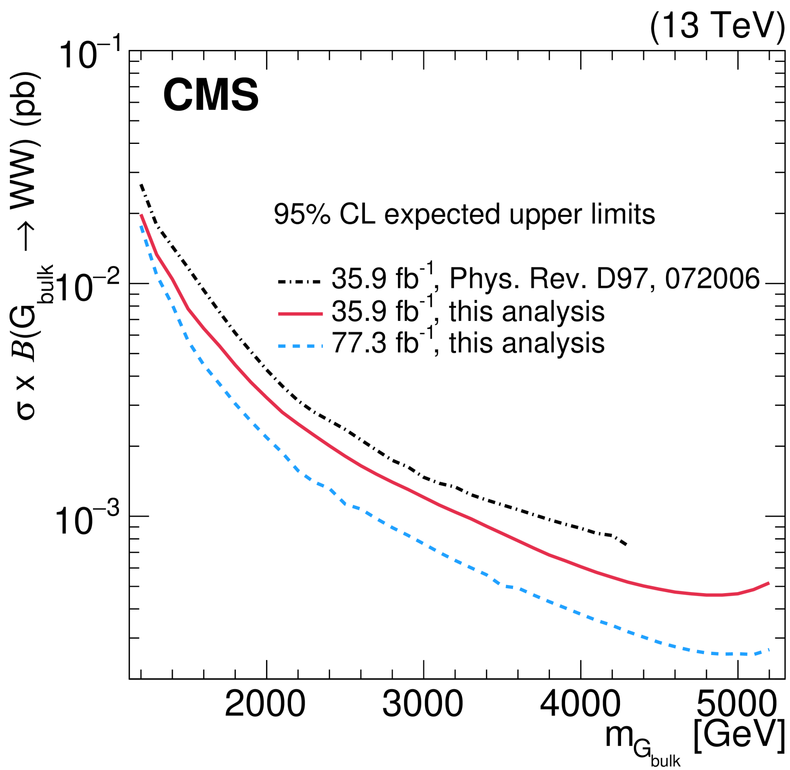


Source	Relevant quantity	HPHP unc. (%)	HPLP unc. (%)
PDFs	Signal yield	3	
Wboson tagging efficiency	Signal + V+jets yield	25 (21)	13 (11)
Wboson tagging p_T dependence	Signal + V+jets yield	8–23	9–25
Integrated luminosity	Signal + V+jets yield	2.3 (2.6)	
QCD normalization	Background yield	50	
W+jets normalization	Background yield	20	
Z+jets normalization	Migration	20	
PDFs	Signal m_{jj}/m_{jet} mean and width	<1	
Jet energy scale	Signal m_{jj} mean	2	
Jet energy resolution	Signal m_{jj} width	5	
Jet mass scale	Signal + V+jets m_{jet} mean	2	
Jet mass resolution	Signal + V+jets m_{jet} width	8	
QCD HERWIG++	QCD shape	—	
QCD MADGRAPH+PYTHIA8	QCD shape	—	
p_T variations	QCD shape	—	
Scale variations	QCD shape	—	
High-m_{jet} turn-on	QCD shape	—	
p_T variations	V+jets m_{jj} shape	—	

CMS: VV→qqqq resonances (II)

CMS: EurPhysJC80,237(2020)





ATLAS: semi-lep VV resonances

ATLAS: HDBS-2018-10

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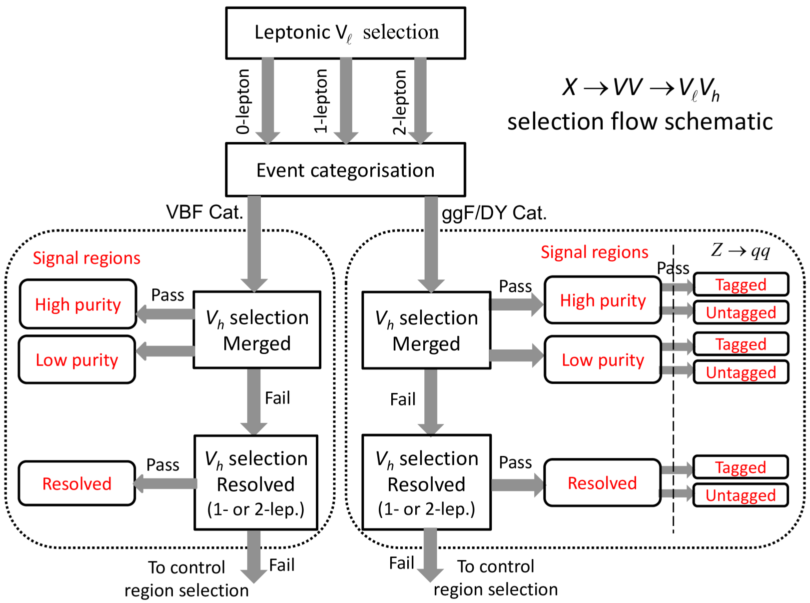
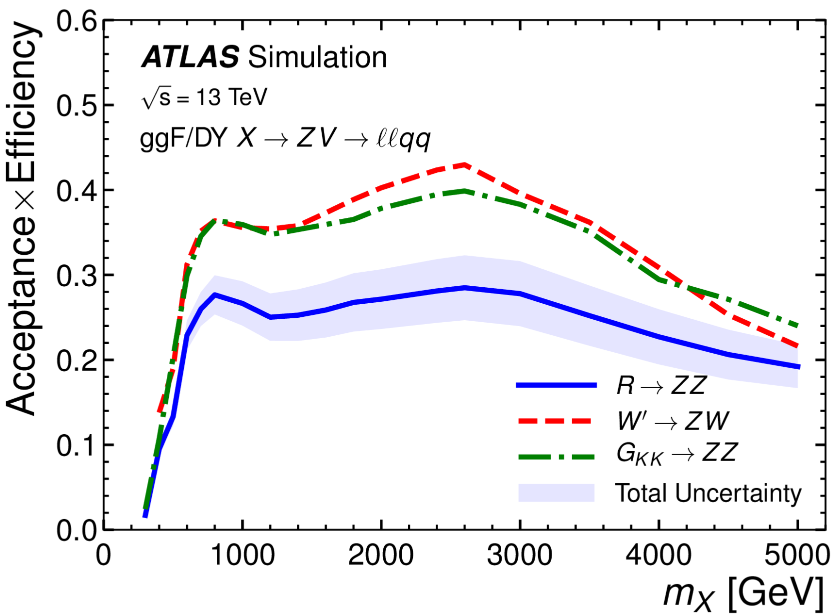


Table 2: Overview of the main $X \to VV \to V_\ell V_h$ selection criteria; the text gives more details. $\mathcal{R}_{p_T/m}$ stands for $\min(p_T^{V_\ell}, p_T^{V_h})/m_{VV}$.

Event selection	0-lepton ($ZV \to \nu\nu V_h$)	1-lepton ($WV \to \ell\nu V_h$)	2-lepton ($ZV \to \ell\ell V_h$)
V_ℓ selection	No *Loose* lepton $E_T^{miss} > 250$ GeV $p_T^{miss} > 50$ GeV	1 *Tight* electron or 1 *Medium* muon with $p_T^\ell > 30$ GeV $E_T^{miss} > 60$ GeV $p_T^{V_\ell} > 75$ GeV	2 *Loose* leptons with $p_T^\ell > 30$ GeV from the $Z \to \ell\ell$ candidate
Event veto	No additional *Loose* leptons Veto events with b-jets not associated with the $Z \to qq$ candidate		
Event categorisation	≥ 1 large-R jets or ≥ 2 small-R jets VBF and ggF/DY classification according to RNN score		
V_h selection (Merged)		$E_T^{miss} > 100$ GeV $p_T^{V_\ell} > 200$ GeV	
	≥ 1 large-R jets The leading jet passing p_T-dependent m_J requirement		
		$\mathcal{R}_{p_T/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_T/m} > 0.25$ (VBF)	$\mathcal{R}_{p_T/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_T/m} > 0.25$ (VBF)
V_h selection (Resolved)	Not Performed	Failed merged selection ≥ 2 small-R jets with $\|\eta\| < 2.5$ $62 < m_{jj} < 97$ GeV for $W \to jj$ $70 < m_{jj} < 105$ GeV for $Z \to jj$	
		$\mathcal{R}_{p_T/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_T/m} > 0.25$ (VBF)	$\mathcal{R}_{p_T/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_T/m} > 0.35$ (VBF)



VH→qqbb resonances

ATLAS: HDBS-2018-11

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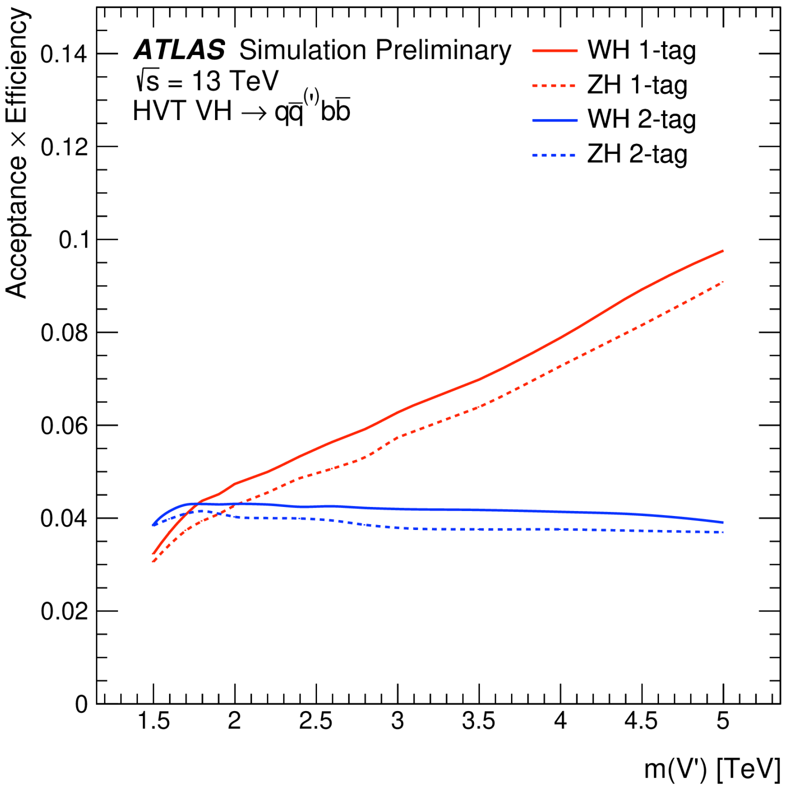

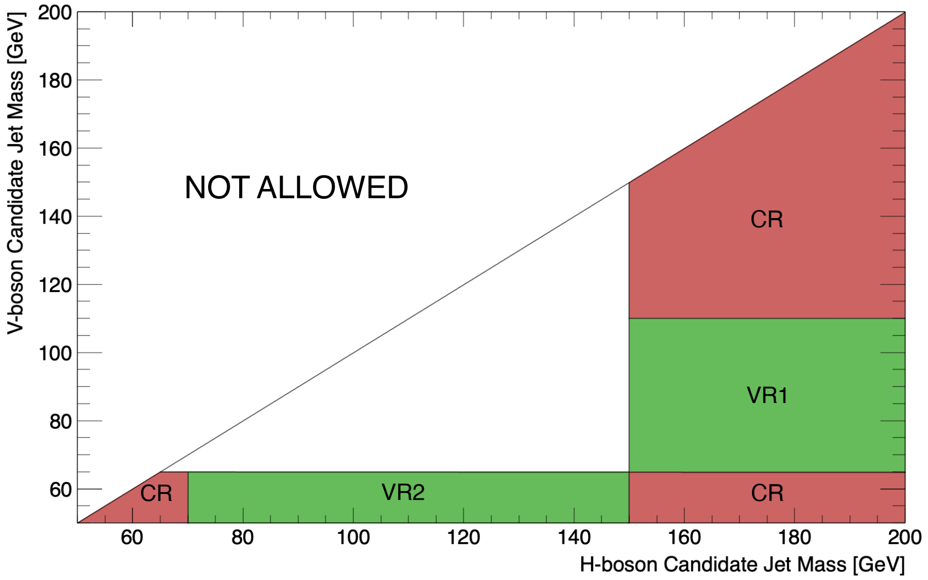

HH→bbττ resonances

ATLAS: CONF-2020-012

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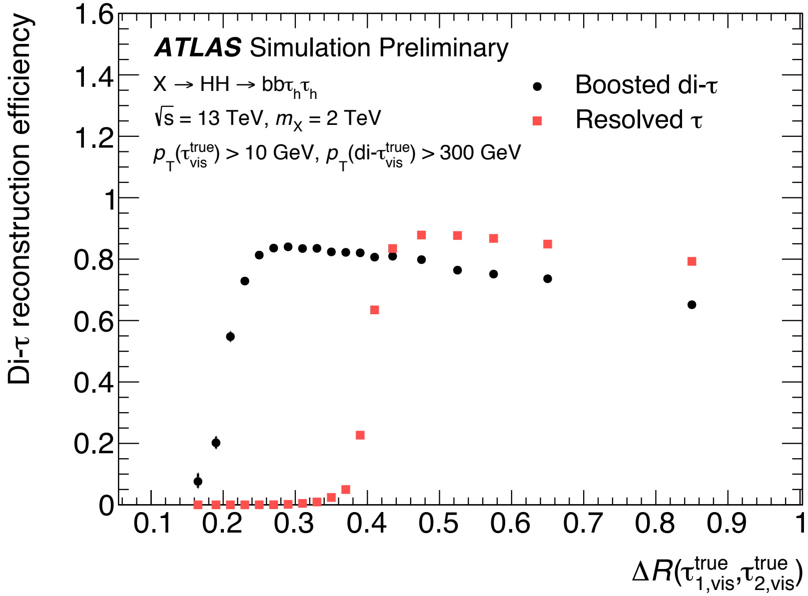

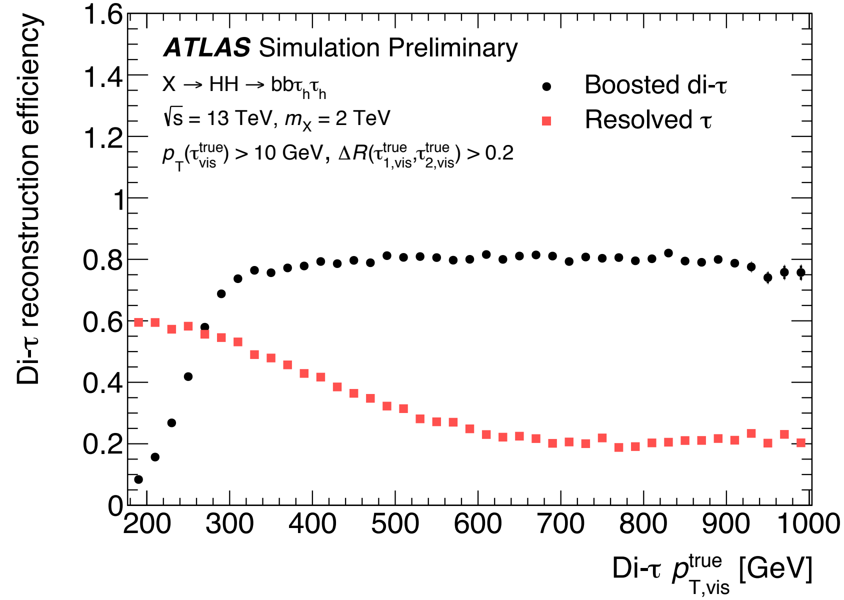

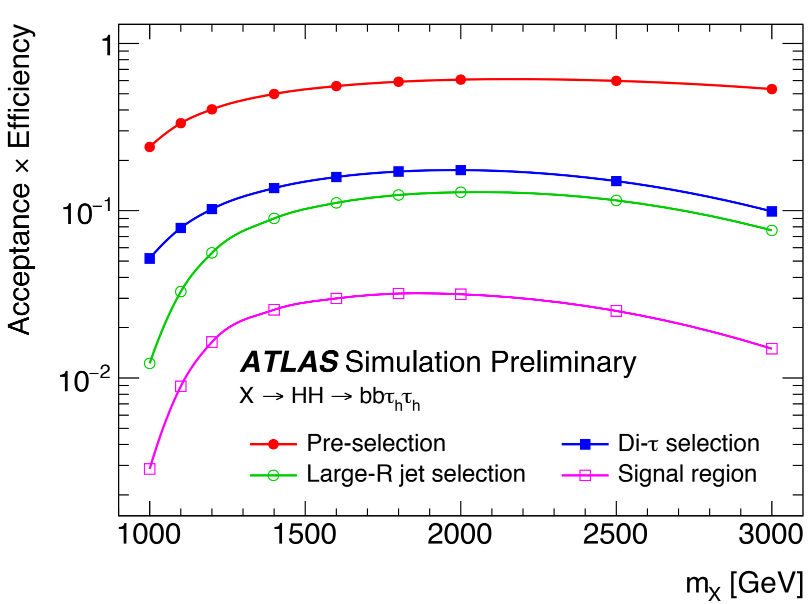

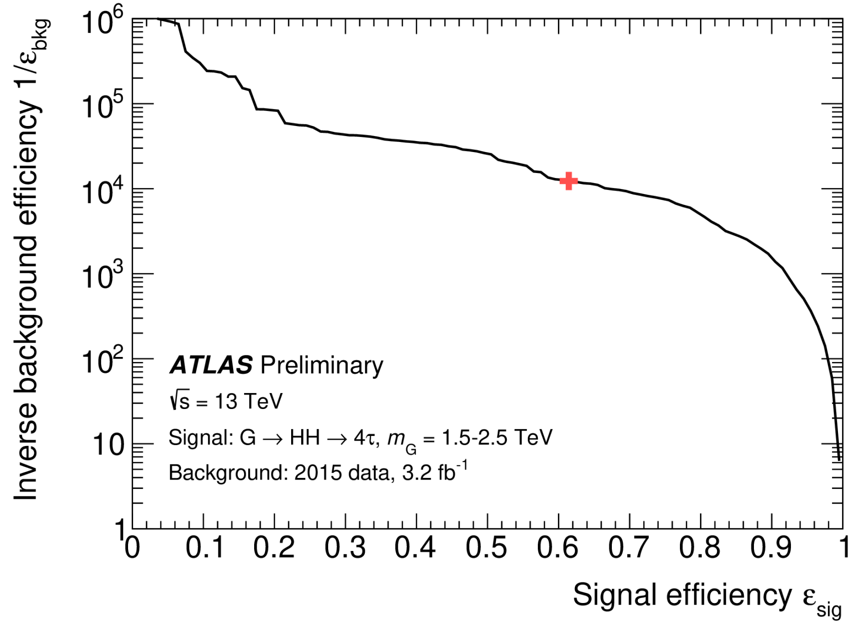

A→BC with weak supervision

ATLAS: HDBS-2018-59

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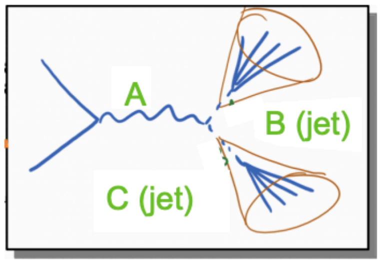
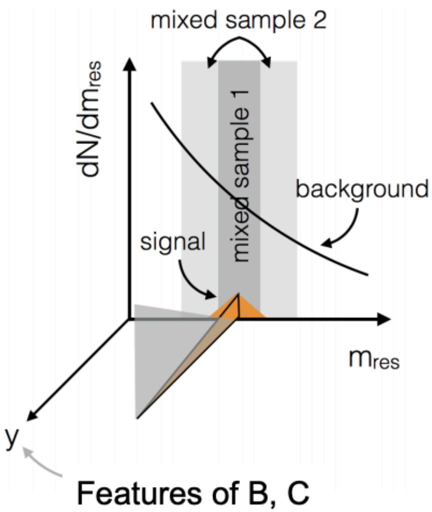
Non-ATLAS figures taken from CERN seminar.





CWoLa

Classification Without Labels