



Searches for Exotic Heavy Resonances with the ATLAS detector

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Introduction



- BSM physics at the TeV scale is a major goal for LHC.
- Exotics group covers a big part of ATLAS new searches
- Many extensions of the Standard Model predict new heavy particles that could appear as resonances decaying into quarks, leptons or photons.
- Using 13 (Run 2) and 13.6 TeV (Run 3) pp collision data from the LHC, ATLAS explores these signatures
- This talk covers two recently published results:
 - $X \rightarrow t\bar{t}$, 1/2 lepton, in full Run 2 data
 - Quantum Black Hole resonances in lepton + jet final states in Partial Run 3 data

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: March 2023

ATLAS Preliminary
 $\int \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$
 $\sqrt{s} = 13 \text{ TeV}$

Model	ℓ, γ	Jets†	E_{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimen.	ADD $G_{KK} + g/q$	$0 e, \mu, \tau, \gamma$	$1-4j$	Yes	139	M_{pl}
	ADD non-resonant $\gamma\gamma$	2γ	-	-	36.7	M_{pl}
	ADD OBH	-	$2j$	-	139	M_{pl}
	ADD BH multijet	-	$\geq 3j$	-	3.6	M_{pl}
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	139	$G_{KK} \text{ mass}$
Gauge bosons	Bulk RS $G_{KK} \rightarrow WW/ZZ$	multi-channel	-	-	36.1	$G_{KK} \text{ mass}$
	Bulk RS $G_{KK} \rightarrow t\bar{t}$	$1 e, \mu$	$\geq 1 b, \geq 1/2j$	Yes	36.1	$G_{KK} \text{ mass}$
	2UED/PPP	$1 e, \mu$	$\geq 2 b, \geq 3j$	Yes	36.1	$KK \text{ mass}$
	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	139	$Z' \text{ mass}$
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	36.1	$Z' \text{ mass}$
CI	Leptophobic $Z' \rightarrow b\bar{b}$	-	$2b$	-	36.1	$Z' \text{ mass}$
	Leptophobic $Z' \rightarrow t\bar{t}$	$0 e, \mu$	$\geq 1 b, \geq 2j$	Yes	139	$Z' \text{ mass}$
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	-	139	$W' \text{ mass}$
	SSM $W' \rightarrow \tau\nu$	1τ	-	-	139	$W' \text{ mass}$
	SSM $W' \rightarrow \nu\bar{\nu}$	1τ	$\geq 1 b, \geq 1j$	Yes	139	$W' \text{ mass}$
DM	HVT $W' \rightarrow WZ$ model B	$0, 2 e, \mu$	$2j/1j$	Yes	139	$W' \text{ mass}$
	HVT $W' \rightarrow WZ$ model C	$0 e, \mu$	$2j/1j$	Yes	139	$W' \text{ mass}$
	HVT $W' \rightarrow WW$ model B	$1 e, \mu$	$2j/1j$	Yes	139	$W' \text{ mass}$
	LRSM $W_{\mu} \rightarrow \mu N_{\mu}$	2μ	$1j$	-	80	$W_{\mu} \text{ mass}$
	CI $\ell\ell q\bar{q}$	-	$2j$	-	37.0	A
LQ	CI $\ell\ell b\bar{b}$	$2 e, \mu$	$1b$	-	139	A
	CI $\ell\ell b\bar{s}$	$2 e, \mu$	$1b$	-	139	A
	CI $\ell\ell b\bar{c}$	$2 e, \mu$	$1b$	-	139	A
	CI $\ell\ell t\bar{t}$	$\geq 1 e, \mu$	$\geq 1 b, \geq 1j$	Yes	36.1	A
	Axial-vector med. (Dirac DM)	-	$2j$	-	139	m_{DM}
Vector-like fermions	Pseudo-scalar med. (Dirac DM)	$0 e, \mu, \tau, \gamma$	$1-4j$	Yes	139	m_{DM}
	Vector med. Z' -2HDM (Dirac DM)	$0 e, \mu$	$2b$	Yes	139	m_{DM}
	Pseudo-scalar med. 2HDM+a	multi-channel	-	-	139	m_{DM}
	Scalar LQ 1 st gen	$2 e$	$\geq 2j$	Yes	139	LQ mass
	Scalar LQ 2 nd gen	2μ	$\geq 2j$	Yes	139	LQ mass
Other	Scalar LQ 3 rd gen	1τ	$2b$	Yes	139	LQ mass
	Scalar LQ 3 rd gen	$0 e, \mu$	$\geq 2j, \geq 2b$	Yes	139	LQ mass
	Scalar LQ 3 rd gen	$\geq 2 e, \mu, \geq 1 \tau, \geq 1 b$	-	-	139	LQ mass
	Scalar LQ 3 rd gen	$0 e, \mu, \geq 1 \tau, 0-2j, 2b$	-	-	139	LQ mass
	Vector LQ mix gen	multi-channel $\geq 1j, \geq 1b$	-	-	139	LQ mass
Exact ferm.	Vector LQ 3 rd gen	$2 e, \mu, \tau$	$\geq 1 b$	Yes	139	LQ mass
	VLO $T\bar{T} \rightarrow Zt + X$	$2e2\mu/3e\mu$	$\geq 1 b, \geq 1j$	-	139	T mass
	VLO $B\bar{B} \rightarrow WtZ\bar{b} + X$	multi-channel	-	-	36.1	B mass
	VLO $T \rightarrow Ht/Zt$	$2(SS)/23 e\mu$	$\geq 1 b, \geq 1j$	Yes	36.1	T mass
	VLO $Y \rightarrow Wb$	$1 e, \mu$	$\geq 1 b, \geq 3j$	Yes	139	Y mass
Excited ferm.	VLO $B \rightarrow Hb$	$0 e, \mu$	$\geq 2b, \geq 1j, \geq 1j$	Yes	139	B mass
	VLL $\nu' \rightarrow Zt/Ht$	multi-channel $\geq 1j$	-	-	139	$\nu' \text{ mass}$
	Excited quark $q' \rightarrow qg$	-	$2j$	-	139	$q' \text{ mass}$
	Excited quark $q' \rightarrow q\gamma$	1γ	$1j$	-	36.7	$q' \text{ mass}$
	Excited quark $b' \rightarrow bg$	-	$1 b, 1j$	-	139	$q' \text{ mass}$
Other	Excited lepton τ'	2τ	$\geq 2j$	-	139	$\tau' \text{ mass}$
	Type III Seesaw	$2, 3, 4 e, \mu$	$\geq 2j$	Yes	139	N^{e} mass
	LRSM Majorana ν	2μ	$2j$	Yes	36.1	$N_{\nu} \text{ mass}$
	Higgs triplet $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$	$2, 3, 4 e, \mu$ (SS)	various	Yes	139	$H^{\pm\pm} \text{ mass}$
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2, 3, 4 e, \mu$ (SS)	-	-	139	$H^{\pm\pm} \text{ mass}$
Other	Multi-charged particles	-	-	-	139	multi-charged particle mass
	Magnetic monopoles	-	-	-	34.4	monopole mass
	$\sqrt{s} = 13 \text{ TeV}$ partial data	-	-	-	-	910 GeV
	$\sqrt{s} = 13 \text{ TeV}$ full data	-	-	-	-	350 GeV
	-	-	-	-	-	1.08 TeV

*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).

Summary Plots for Heavy Particle Searches and Long-lived Particle Searches - March 2023

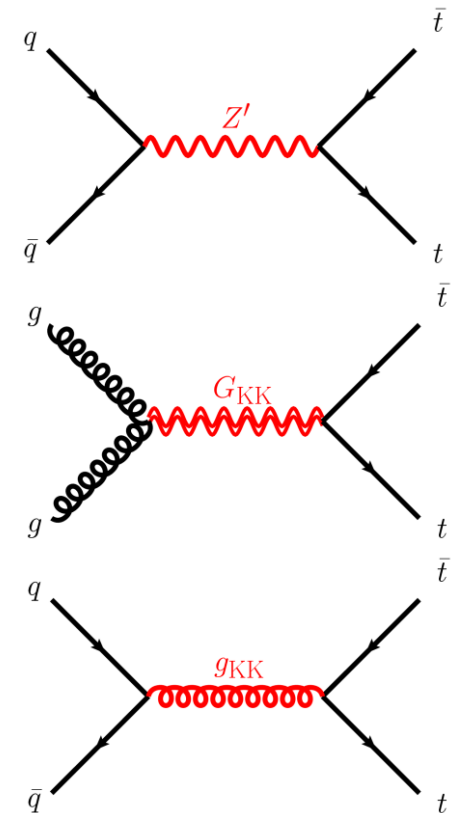
$X \rightarrow t\bar{t}$ 1/2 lepton

<https://arxiv.org/pdf/2512.17856>



Title: Search for $t\bar{t}$ resonances in final states with exactly one or two leptons using 140 fb⁻¹ of pp collision data at $\sqrt{s} = 13$ TeV with the ATLAS experiment

- model agnostic search for an s-channel resonance decaying to $t\bar{t}$
- two orthogonal 1 and 2 lepton channels.
- Wide range of BSM models considered for benchmarking:
 - spin-1 Z'_{TC2} from top-color assisted technicolor models.
 - Spin-2 Kaluza-Klein gravitons from Randall-Sundrum model
 - Spin-1 color octet: g_{kk} Kaluza-Klein excitations of gluons predicted by models with extra dimensions. Previous search excluded g_{kk} lower than 3.7 TeV
- **Trigger selection:**
 - Candidate events for both the 1- and 2-lepton channels are selected using single-muon and single electron triggers.
- **Backgrounds:**
 - W + jets and fake leptons in the 1-lepton channel
 - Z + jets in the 2-lepton channel
 - Data driven correction factors

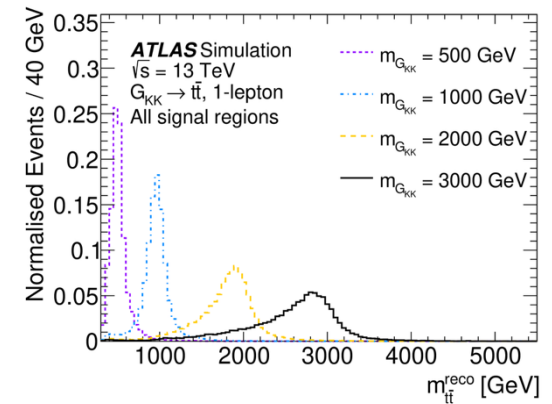
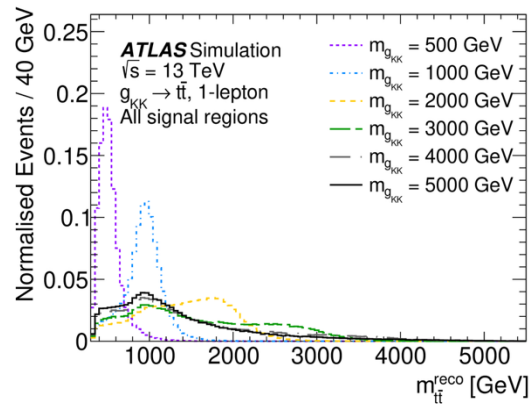
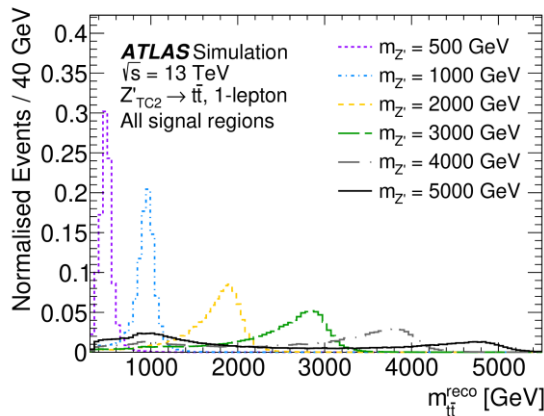


$X \rightarrow t\bar{t}$ 1 lepton channel

<https://arxiv.org/pdf/2512.17856>



- $m_{t\bar{t}}$ constructed from:
 1. small-R jets, lepton and missing transverse momentum in the **resolved topology**.
 2. top-tagged large-R jet, small -R jet, lepton and MET in the **merged topology**.
- At larger resonance masses, a tail towards masses lower than the generated mass is visible, which arises from off-shell production of the signal



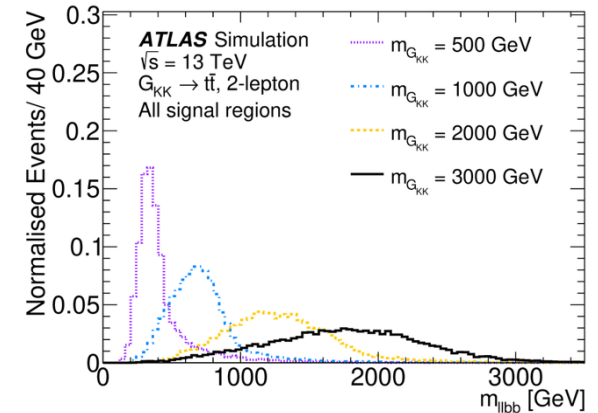
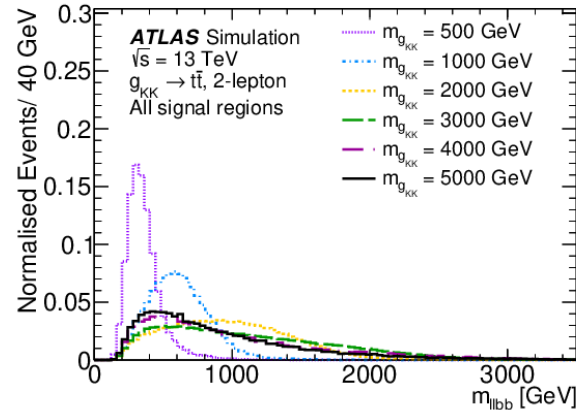
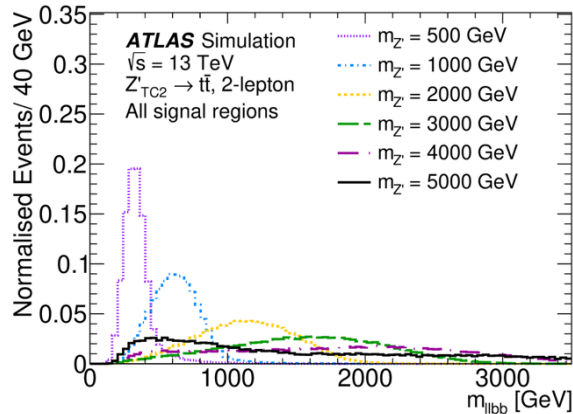
Public plots: Signal distributions in m_{tt} after the signal region selection of the 1-lepton channel for the (a) Z' , (b) G_{KK} , and (c) g_{KK} signals for various representative values of the resonance mass. Events from the Resolved 1b, Resolved 2b, and Merged signal regions are included.

$X \rightarrow t\bar{t}$ 2 lepton channel

<https://arxiv.org/pdf/2512.17856>



- $m_{t\bar{t}}$ can't be constructed unambiguously due to presence of two neutrinos
- m_{llbb} used instead.
- The same trend of low-mass tails for the high-mass signals that were seen in the $m_{t\bar{t}}$ distributions are also visible in the m_{llbb} distributions



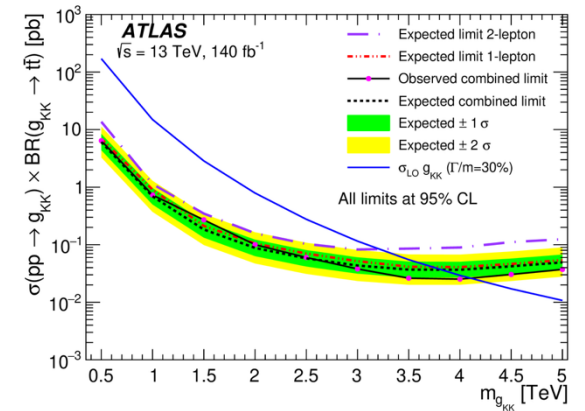
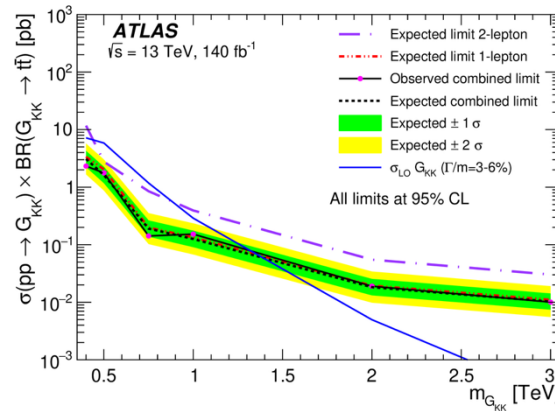
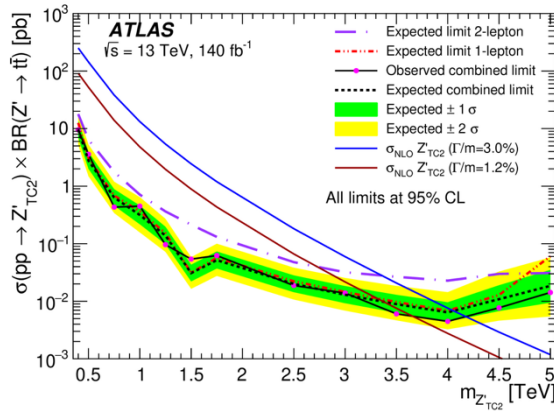
Public plots: Signal distributions in m_{llbb} after the signal region selection of the 2-lepton channel for the (a) Z' , (b) G_{KK} , and (c) g_{KK} signals for various representative values of the resonance mass. Events from the five signal regions are combined.

$X \rightarrow t\bar{t}$ Results

<https://arxiv.org/pdf/2512.17856>



- best limits on the cross-section times branching fraction to $t\bar{t}$ for the Z'_{TC2} signal for $m_{t\bar{t}} < 1.5$ TeV:
- Z'_{TC2} relative $\Gamma = 3\%$ excluded for masses below **4.2 TeV**.
- Z'_{TC2} relative $\Gamma = 1.2\%$ excluded for masses below **3.65 TeV**.
- Slightly weaker than previous search on fully hadronic final states which excluded Z'_{TC2} bosons with 1% and 3% relative widths with masses up to 3.9 TeV and 4.7 TeV, respectively [1],
- best limits the full $m_{t\bar{t}}$ range for :
 1. g_{kk} with a relative width of 30% (4.1 TeV)
 2. G_{kk} (1.3 TeV)



Quantum Black Hole resonances in lepton + jet final states

<https://arxiv.org/pdf/2604.19495>



Title: Search for quantum black holes in lepton and jet final states using $p p$ collisions at $\sqrt{s} = 13.6$ TeV with 4 the ATLAS detector

- **Low scale quantum gravity models predict quantum black holes:**
 - ADD model: the gravitational field is allowed to propagate in n extra dimensions
 - RS1 model: a single extra dimension separates two 3D branes by some distance
- This analysis was previously done with Run2 data: [Search for quantum black hole production in final states using proton-proton collisions at with the ATLAS detector | Phys. Rev. D](#)

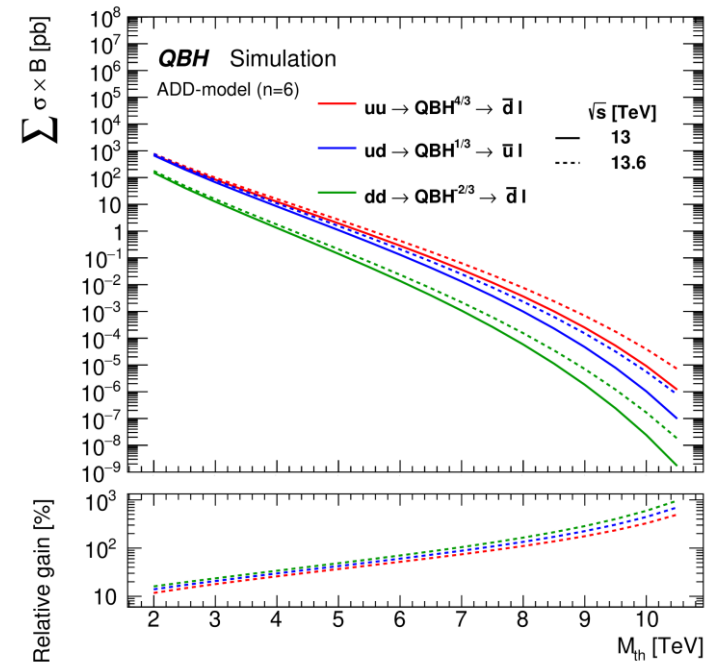
Quantum Black Hole resonances in lepton + jet final states

<https://arxiv.org/pdf/2604.19495>



• What's new in Run3

- Increase in production cross section by up to an order of magnitude with COM energy increase of 0.6 TeV due to power law dependence.
- Partial Run 3 data corresponding to an integrated luminosity of 164 fb^{-1} vs 140 fb^{-1} in full Run2
- Looking at ADD models for $n=2,4$, and 6 vs only $n=6$ for the run 2 analysis.



[Public plots: Search for quantum black holes in lepton+jet final states using proton-proton collisions at \$\sqrt{s}=13.6\$ TeV with the ATLAS detector](#)



- **Previous results in Run2 analysis:**
 - lower mass threshold limits in the ADD = 9.2 TeV.
 - lower mass threshold limits in RS1 = 6.8 TeV.

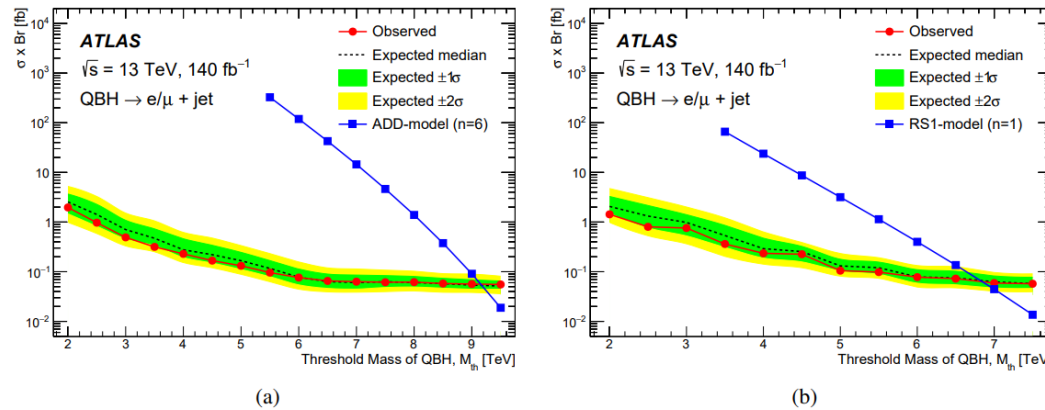


Figure 4: The combined 95% C.L. upper limits on $\sigma \times Br$ as a function of M_{th} for QBH production at $M_{th} = M_D$ with decay into lepton+jet for (a) ADD (extra dimensions $n = 6$) and (b) RS1 (extra dimensions $n = 1$). The limits take into account statistical and systematic uncertainties. Circles along the solid red line indicate the mass M_{th} of the signal where the observed limit is computed. The expected limits are shown by the dashed line. The $\pm 1\sigma$ and $\pm 2\sigma$ bands are shown in green and yellow, respectively. The theoretically predicted $\sigma \times Br$ for the QBH production and decay is shown as the solid blue curve with squares. The limits are obtained with pseudoexperiments.



- Signal Region starting at 3 TeV, with QBH threshold mass range of 6–10.5 TeV.
- Two channels – e+j and μ +j
- Signal region: Candidate events in the signal region (SR) require exactly one signal lepton and at least one signal jet with invariant mass $m_{lj} > 3$ TeV.
- $\Delta\phi_{\ell j} > 2.8$ and $\Delta\eta_{lj} < 3.25$ to exploit the back-to-back topology of the QBH decay
- Sensitivity driven by highest m_{lj} bin of SR

Table 1: Analysis regions definitions. The control (validation) regions used to estimate the leading backgrounds, fake electrons and V +jets, are indicated. The label $ej(\mu j)$ refers to the electron (muon) channel. The “signal” subscript denotes the different lepton and jet signal definitions in the text. The dash (—) indicates a selection criterion not applied, where N/A indicates a criterion cannot be applied, in regions which require exactly one signal lepton. Selections on $m_{\ell j}$ and $S(p_T^{\text{miss}})$ orthogonalise analysis regions from one another. The f CR and f VVR are only relevant in the context of the electron channel. The $m_{\ell\ell}$ criterion in the f CR is only applied in the presence of a second electron.

Variable	WCR (WVR)	f CR (f VVR) (electron channel only)	ZCR (ZVR)	SR
N_{signal}^j	≥ 1	≥ 1	≥ 1	≥ 1
N_{signal}^ℓ	1	1	2	1
$m_{\ell j}$ [TeV]	1.0–2.0 (2.0–3.0)	1.0–3.0	1.0–2.0 (2.0–3.0)	>3.0
p_T^ℓ [GeV]	>150	>150	>150	>150
p_T^j [GeV]	>130	>130	>130	>130
$S(p_T^{\text{miss}})_{ej, \mu j}$	>5.0, 3.0	<3.0 (3.0–5.0)	—	—
$m_{\ell\ell}$ [GeV]	N/A	>120	60–120	N/A
$\Delta\eta_{\ell j}$	<3.25	—	—	<3.25
$\Delta\phi_{\ell j}$	>2.8	—	—	>2.8

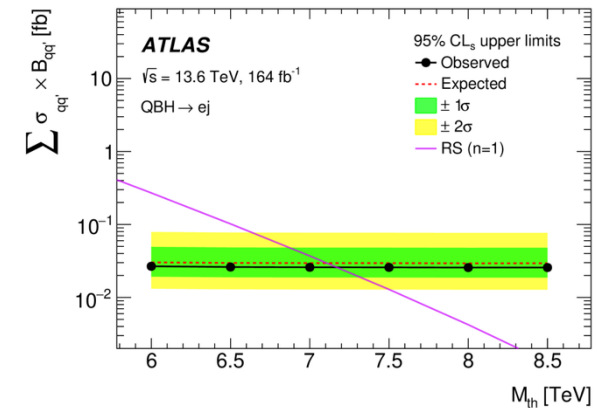
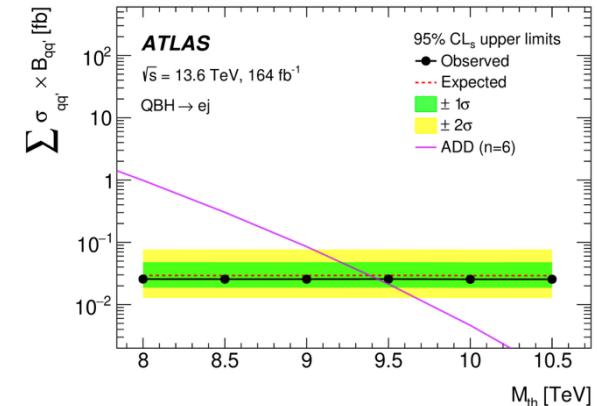


Improved exclusion limits!

- lower mass threshold limits in the ADD (n=6) = **9.4 TeV** (compared to 9.2 TeV for Run2)
- lower mass threshold limits in RS1 = **7.2 TeV** (compared to 6.8 TeV for Run2)
- Electron channel surpasses muon channel in sensitivity by a factor of ~ 3 due to better p_T resolution so the two channels are not combined.

Table 2: Expected and observed exclusion limits at 95% confidence level on the QBH mass threshold M_{th} for RS and ADD models with different number of extra dimensions n , in the electron and muon channels, using Run 3 data at a centre-of-mass energy of 13.6 TeV.

Model	RS		ADD					
	1		2		4		6	
Channel	$e+j$	$\mu+j$	$e+j$	$\mu+j$	$e+j$	$\mu+j$	$e+j$	$\mu+j$
Exclusion limit	Expected							
M_{th} [TeV]	7.1	6.6	8.5	8.1	9.1	8.7	9.4	9.0
Exclusion limit	Observed							
M_{th} [TeV]	7.2	6.6	8.6	8.2	9.1	8.7	9.4	9.0



Conclusion



In this talk I presented some recent results in heavy exotic resonances:

1. $X \rightarrow t\bar{t}$, 1/2 lepton in full Run 2 data
2. Quantum Black Hole resonances in lepton + jet final states in Partial Run 3 data

Although no new BSM excesses were found, we were able to improve limits on various benchmark models!

This is only a part of a large ATLAS exotic heavy resonances effort. More results to come!



Appendix

QBH I+j Partial Run 3 Results muon

