

# **Exotic Searches with ATLAS**

Ellis Kay On Behalf of the ATLAS Collaboration Moriond EW 2024

#### **ATLAS Exotic Searches**





#### **ATLAS Exotic Searches @ Moriond EW**





#### Leptoquarks



#### What?

- → Hypothetical scalar/vector particles with non-zero baryon & lepton number, carrying colour charge & fractional electric charge
- ➡ Decay into quark-lepton pair

#### Why?

- ➡ Appear in many BSM scenarios (e.g. SU(5), SO(10) GUTs)
- → Connect quark & lepton sector
- → May explain certain anomalies, such as  $b \rightarrow s \mu \mu$ ,  $b \rightarrow c \ell v$



Input from 9 analyses, including dedicated searches, SUSY re-interpretations (★) & SUSY re-optimisation (★)

	Scalar				Vector		SR		
Final State	LQ <sup>u</sup> <sub>3</sub>	LQ <sup>d</sup> <sub>3</sub>	LQ <sup>u</sup> <sub>mix</sub>	LQ <sup>d</sup> <sub>mix</sub>	U <sub>1</sub> YM/MC	$\tilde{U}_{1}^{\text{YM/MC}}$	N <sub>e</sub>	$N_{ au had}$	N <sub>b-jet</sub>
<u> τνbτ</u>	~	~			~		0	1	≥2
<u>bτbτ</u>	~				~		{0,1}	{1,2}	{1, 2}
<u>tτtτ</u>		~				~	{1, 2, 3}	≥1	≥1
<u>tvb<b>l</b></u>			~	~			1		≥1
<u>b<b>l</b>b</u> l			~				2		{0, 1, 2}
<u>tete</u>				~			2		
<u>tete</u>				~			{3, 4}		≥2
<u>☆ tvtv</u>	~		~		~		0	0	≥2
☆ <u>bvbv</u>		~		~			0		≥2

- Aim to improve sensitivity through statistical combination of analyses
- ➡ Signal regions designed to be orthogonal
  - Overlapping events identified & removed
- → All final states from ℓ (e/μ),
   τ<sub>had</sub>, (b-)jets and E<sub>T</sub><sup>miss</sup>
   → With different selection

criteria, based on analysis



- Pairs of LQ produced mainly via ggF or qq annihilation
- → Scalar LQ: up (±⅔e) and down (±⅓e), flavour-diagonal or cross-generational ("mix")



 $\overline{\nu}_{\tau}$ 

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- $\rightarrow$  Vector LQ: stronger model dependence pair-production  $\sigma$  dependent on coupling to gluons
- → Yang-Mills (YM,  $\kappa = 0$ ) & Minimal Coupling (MC,  $\kappa = \pm 1$ ) scenarios

		Sca	alar		Vec	tor:	SR			
Final State	LQ <sup>u</sup> <sub>3</sub>	LQ <sup>d</sup> <sub>3</sub>	LQ <sup>u</sup> <sub>mix</sub>	LQ <sup>d</sup> <sub>min</sub>	U <sup>YM/MC</sup>	$\tilde{\textbf{U}}_{1}^{\text{YM/MC}}$	N <sub>e</sub>	$N_{\tauhad}$	N <sub>b-jet</sub>	
<u>tvbτ</u>	V	V			~		0	1	≥2	
<u>bτbτ</u>	V				~		$\{0, 1\}$	{1,2}	{1, 2}	
<u>tttt</u>		V					{ <u>1</u> , 2, 3}	≥1	≥1	
<u>tvb<b>l</b></u>			~	~			1		≥1	II
<u>b<b>l</b>b</u> l			~				2		$\{0, 1, 2\}$	
<u>t lt l</u>				~			2			
<u>t lt l</u>				~			{3, 4}		≥2	
<u>tvtv</u>	V		~		~		0	0	≥2	
<u>bvbv</u>		~		~			0		≥2	

→ U<sub>1</sub>: favoured explanation for R(D<sup>(\*)</sup>) and R(K<sup>(\*)</sup>) 1903.11517

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 → Additional
 reinterpretation of tτtτ search in context of Ũ<sub>1</sub><sup>YM/MC</sup>
 → Ũ<sub>1</sub> carries ±5/3 e

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#### **Heavy Gauge Boson Searches**



- → Many BSM scenarios predict new heavy gauge bosons (Extra dimensions, Little Higgs, LRSM...)
- → The LHC allows us to probe increasingly higher masses
- → Many searches undertaken, often in the context of simplified benchmark models, e.g. Sequential Standard Model (SSM) <u>1107.5830</u>, Heavy Vector Triplet (HVT) <u>1402.4431</u>, <u>2207.05091</u>

TLAS Heavy Pa	rticle	Searc	ches	s* - 9	5% CL l	Jpper Exclusion	Limits	ATL	AS Preliminary
atus: March 2023							ſL	$dt = (3.6 - 139) \text{ fb}^{-1}$	$\sqrt{s} = 13 \text{ TeV}$
Model	$\ell, \gamma$	Jets†	E <sup>miss</sup> T	∫£ dt[fb	p <sup>-1</sup> ]	Limit	-		Reference
ADD $G_{KK} + g/q$ ADD non-resonant $\gamma\gamma$ ADD DBH multijet RS1 $G_{KK} \rightarrow \gamma\gamma$ Bulk RS $G_{KK} \rightarrow tt$ Bulk RS $g_{KK} \rightarrow tt$	$\begin{array}{c} 0 \ e, \mu, \tau, \gamma \\ 2 \ \gamma \\ - \\ 2 \ \gamma \\ \end{array}$ multi-channa 1 e, $\mu \\ 1 \ e, \mu \end{array}$	1 - 4j -2j $\geq 3j$ - el $\geq 1 b, \geq 1J/2$ $\geq 2 b, \geq 3j$	Yes - - - !j Yes Yes	139 36.7 139 3.6 139 36.1 36.1 36.1	M <sub>D</sub> M <sub>S</sub> M <sub>th</sub> G <sub>KK</sub> mass G <sub>KK</sub> mass KK mass		8.0 9 2.3 TeV 3.8 TeV 1.8 TeV	$\begin{array}{l} \textbf{11.2 TeV} & n=2 \\ \textbf{6 TeV} & n=3 \ \text{H2 NLO} \\ \textbf{9.4 TeV} & n=6 \\ \textbf{N} & \textbf{6} \\ \textbf{n} & \textbf{6} \\ \textbf{n} & \textbf{6} \\ \textbf{m} & \textbf{10.1} \\ \textbf{k} / \overline{M}_{Pl} = 0.1 \\ \textbf{k} / \overline{M}_{Pl} = 1.0 \\ \textbf{G} \\ \textbf{F} / \textbf{m} = 15\% \\ \textbf{Tier} (1.1) \ \textbf{g} / \textbf{G} (1.1) \rightarrow tt) = 1 \end{array}$	2102.10874 1707.04147 1910.08447 1512.02586 2102.13405 1808.02380 1804.10823 1803.09678
$\begin{array}{l} \mathrm{SSM}\ Z' \to \ell\ell \\ \mathrm{SSM}\ Z' \to \tau\tau \\ \mathrm{Leptophobic}\ Z' \to bb \\ \mathrm{Leptophobic}\ Z' \to tt \\ \mathrm{SSM}\ W' \to \ell\nu \\ \mathrm{SSM}\ W' \to \tau\nu \\ \mathrm{SSM}\ W' \to \tau\nu \\ \mathrm{SSM}\ W' \to \psi \\ \mathrm{HVT}\ W' \to WZ \ \mathrm{model}\ B \\ \mathrm{HVT}\ W' \to WZ \ \mathrm{model}\ B \\ \mathrm{HVT}\ Z' \to WW \ \mathrm{model}\ B \\ \mathrm{LRSW}\ W_R \to \mu M_R \end{array}$	$\begin{array}{c} 2 \ e, \mu \\ 2 \ \tau \\ - \\ 0 \ e, \mu \\ 1 \ e, \mu \\ 1 \ \tau \\ - \\ 0 - 2 \ e, \mu \\ 1 \ e, \mu \\ 1 \ e, \mu \\ 2 \ \mu \end{array}$	2 b ≥1 b, ≥2 J 	- Yes Yes Yes Yes Yes Yes	139 36.1 36.1 139 139 139 139 139 139 139 80	Z' mass Z' mass Z' mass W' mass W' mass W' mass W' mass Z' mass Z' mass	340 GeV	5.1 TeV 2.42 TeV 2.1 TeV 4.1 TeV 5.0 TeV 4.4 TeV 4.3 TeV 3.9 TeV 5.0 TeV 5.0 TeV	$\Gamma/m = 1.2\%$ $g_{V} = 3$ $g_{V} c_{H} = 1, g_{f} = 0$ $g_{V} = 3$ $m(N_{R}) = 0.5 \text{ TeV}, g_{L} = g_{R}$	1903.06248 1709.07242 1806.09299 2005.05138 1906.056075-2021-025 ATLAS-CONF-2021-025 ATLAS-CONF-2021-043 2004.14636 2207.03925 2004.14636 1904.14636
Cl qqqq Cl ℓℓqq Cl eebs Cl μμbs Cl tttt	2 e,μ 2 e 2 μ ≥1 e,μ	2 j - 1 b ≥1 b, ≥1 j	- - - Yes	37.0 139 139 139 36.1	Λ Λ Λ Λ		1.8 TeV 2.0 TeV 2.57 TeV	$\begin{array}{c c} \textbf{21.8 TeV} & \eta_{LL}^-\\ \textbf{35.8 TeV} \\ \textbf{g}_* = 1\\ \textbf{g}_* = 1\\  C_{4t}  = 4\pi \end{array} \qquad \eta_{LL}^-$	1703.09127 2006.12946 2105.13847 2105.13847 1811.02305
Axial-vector med. (Dirac DM) Pseudo-scalar med. (Dirac DM) Vector med. Z'-2HDM (Dirac DI Pseudo-scalar med. 2HDM+a	0 e, μ, τ, γ M) 0 e, μ multi-chann	2 j 1 - 4 j 2 b el	- Yes Yes	139 139 139 139	m <sub>med</sub> m <sub>med</sub> m <sub>Z'</sub> m <sub>a</sub>	376 GeV 800 GeV	3.8 TeV 3.0 TeV	$\begin{array}{l} g_q{=}0.25, \ g_\chi{=}1, \ m(\chi){=}10 \ {\rm TeV} \\ g_q{=}1, \ g_\chi{=}1, \ m(\chi){=}1 \ {\rm GeV} \\ {\rm tan} \beta{=}1, \ g_\chi{=}0.8, \ m(\chi){=}100 \ {\rm GeV} \\ {\rm tan} \beta{=}1, \ g_\chi{=}1, \ m(\chi){=}10 \ {\rm GeV} \end{array}$	ATL-PHYS-PUB-2022-03 2102.10874 2108.13391 ATLAS-CONF-2021-036
	TLAS Heavy Pa atus: March 2023 Model ADD $G_{KK} + g/q$ ADD OBH ADD OB	TLAS Heavy Particle atus: March 2023Model $\ell, \gamma$ ADD $G_{KK} + g/q$ $0 e, \mu, \tau, \gamma$ ADD 00BHADD OBH $2\gamma$ ADD BH multijet $-$ RS1 $G_{KK} + \gamma\gamma$ $2\gamma$ multi-channBulk RS $g_{KK} \rightarrow tr$ $2\gamma$ multi-channBulk RS $g_{KK} \rightarrow tr$ $2\gamma$ multi-channSSM $Z' \rightarrow \ell\ell$ $2e, \mu$ SSM $Z' \rightarrow t\ell$ SSM $Z' \rightarrow \ell\ell$ $2e, \mu$ sSM $Z' \rightarrow t\ell$ SSM $Z' \rightarrow \ell\ell$ $2e, \mu$ sSM $Y' \rightarrow tr$ SSM $Y' \rightarrow \ell\ell$ $1 e, \mu$ sSM $W' \rightarrow tr$ SSM $W' \rightarrow tr$ $1 e, \mu$ sSM $W' \rightarrow tr$ SSM $W' \rightarrow tr$ $1 e, \mu$ sSM $W' \rightarrow tr$ HTT $W' \rightarrow WZ \rightarrow 6\nu' \ell''$ model B $1 e, \mu$ LRSM $W_R \rightarrow \mu N_R$ Cl $qqq$ $-$ $(l eds)$ Cl $qedq$ $-$ $2\mu$ cl tttAddu-detr med. (Dirac DM) $-$ Pseudo-scalar med. (Dirac DM)Pseudo-scalar med. 2HDM-a rulti-chann	TLAS Heavy Particle Searce atus: March 2023Model $\ell, \gamma$ Jets†ADD $G_{KK} + g/q$ $0 e, \mu, \tau, \gamma$ $1-4j$ ADD OBH $2\gamma$ $2j$ ADD OBH $2\gamma$ $2j$ ADD BH multipit $2j$ $2j$ Bulk RS $G_{KK} \rightarrow tW/ZZ$ multi-channelBulk RS $G_{KK} \rightarrow tW/ZZ$ $1e, \mu \ge 2b, \ge 3j$ SSM Z' $\rightarrow \ell\ell$ $2e, \mu$ $-$ Leptophobic Z' $\rightarrow tt$ $0e, \mu, z, \gamma$ $2j$ SSM Z' $\rightarrow \ell\ell$ $1e, \mu \ge 2b, \ge 3j$ SSM Z' $\rightarrow \ell\ell$ $2e, \mu$ $-$ SSM W' $\rightarrow tr$ $1e, \mu \ge 2b, \ge 3j$ SSM W' $\rightarrow tr$ $1e, \mu \ge 2b, \ge 3j$ SSM W' $\rightarrow tr$ $1e, \mu \ge 2b, \ge 3j$ SSM W' $\rightarrow tr$ $1e, \mu \ge 1b, \ge 2J/Z$ SSM W' $\rightarrow tr$ $1e, \mu \ge 1b, \ge 2J/Z$ SSM W' $\rightarrow tr$ $1e, \mu \ge 1b, \ge 2J/Z$ SSM W' $\rightarrow tr$ $1e, \mu \ge 1b, \ge 1J$ HTT W' $\rightarrow WZ$ model B $1e, \mu \ge 1/J$ HTW W' $\rightarrow WZ$ $2\mu \ell'$ LRSM W_R $\rightarrow \mu N_R$ $2\mu$ Cl (qag $ 2i$ $1b, \ge 1J$ Cl $pubs$ $2u$ Cl $pubs$ $2\mu$ <tr< td=""><td>TLAS Heavy Particle Searches atus: March 2023Model<math>\ell, \gamma</math>Jets†<math>E_T^{miss}</math> TADD <math>G_{KK} + g/q</math><math>0 e, \mu, \tau, \gamma</math><math>1 - 4j</math>YesADD OBH<math>2\gamma</math><math>2\gamma</math><math>-2j</math>ADD OBH<math>2\gamma</math><math>2j</math><math>-2j</math>ADD BH multipit<math>2\gamma</math><math>-2j</math>Bulk RS <math>G_{KK} \rightarrow tW/ZZ</math> Bulk RS <math>G_{KK} \rightarrow tt</math><math>1 e, \mu \geq 21 b, \geq 13/21</math>YesSSM Z' <math>\rightarrow \ell \ell</math><math>2e, \mu</math><math>-</math>SSM Z' <math>\rightarrow \ell \ell</math><math>2e, \mu</math><math> -</math>Leptophobic Z' <math>\rightarrow bb</math><math> 2b \geq 3j</math>YesSSM Z' <math>\rightarrow \ell \ell</math><math>2e, \mu</math><math> -</math>Leptophobic Z' <math>\rightarrow tt</math><math>0e, \mu</math><math>21 b, \geq 2J</math>YesSSM W' <math>\rightarrow \ell \gamma</math><math>1e, \mu</math><math>-</math>YesSSM W' <math>\rightarrow \ell \gamma</math><math>1r</math><math>-</math>YesSSM W' <math>\rightarrow \ell \gamma</math><math>1e, \mu</math><math>21 b, \geq 1J</math><math>-</math>HTT W' <math>\rightarrow WZ</math> model B<math>0e, \mu</math><math>2 \ell JJ</math>YesHTT W' <math>\rightarrow WZ</math> model B<math>1e, \mu</math><math>2 j/1J</math>YesHTW W' <math>\rightarrow \ell \ell'</math> model B<math>1e, \mu</math><math>2 j/1J</math>YesLBSM W<sub>R</sub> <math>\rightarrow \mu N_R</math><math>2\mu</math><math>1J</math><math>-</math>Cl qaqq<math> 2 </math><math> -</math>Cl qapa<math>2e, \mu</math><math>  -</math>Cl qapa<math>2e, \mu</math><math>  -</math>Cl qapa<math>2\mu</math><math>1b</math><math> -</math>Cl qapa<math> 2 </math><math> -</math>Cl qapa<math>2e, \mu</math><math>  -</math>Cl qapa<math>2e, \mu</math><math>  -</math>Cl qapa<math>2e, \mu</math><!--</td--><td>TLAS Heavy Particle Searches* - 9atus: March 2023Model<math>\ell, \gamma</math>Jets†<math>E_{T}^{miss}</math><math>\int \mathcal{L} dt[ft]</math>ADD <math>G_{KK} + g/q</math><math>0 e, \mu, \tau, \gamma</math><math>1-4j</math>Yes139ADD OBH<math>2\gamma</math><math>-</math>36.7ADD OBH<math>2\gamma</math><math>-</math>139ADD BH multipit<math>2\gamma</math><math>-</math>139Bulk RS <math>G_{KK} \rightarrow tW/ZZ</math>multi-channel36.1Bulk RS <math>G_{KK} \rightarrow tt</math><math>1 e, \mu \ge 1b, \ge 1J/2l</math>Yes2DU / RPP<math>1 e, \mu \ge 1b, \ge 1J/2l</math>YesSSM Z' <math>\rightarrow \ell \ell</math><math>2e, \mu</math><math>-</math>139SSM Z' <math>\rightarrow \ell \ell</math><math>2e, \mu</math><math>-</math>36.1SSM Z' <math>\rightarrow \ell \ell</math><math>2e, \mu</math><math>-</math>36.1SSM Z' <math>\rightarrow \ell \ell</math><math>2e, \mu</math><math>-</math>78SSM W' <math>\rightarrow \ell r</math><math>1e, \mu</math><math> 2b, \ge 3j</math>SSM W' <math>\rightarrow \ell r</math><math>1e, \mu</math><math> 2b, \ge 139</math>SSM W' <math>\rightarrow \ell r</math><math>1e, \mu</math><math> 189</math>HYT W' <math>\rightarrow WZ</math><math>0e' \ell' \ell'</math><math>0e, \mu, 2l/(FF)</math>YesSSM W' <math>\rightarrow \ell r</math><math>1e, \mu</math><math>2l/(FF)</math>YesSSM W' <math>\rightarrow \ell r</math><math>1e, \mu</math><math>2l/(FF)</math>YesCl qaga<math> 2l</math><math> 139</math>HYT W' <math>\rightarrow WZ</math><math>2e' \ell' \ell'</math><math>1J</math><math> 80</math>Cl qaga<math> 2l</math><math> 139</math>HYT W' <math>\rightarrow WZ</math><math>2e' \ell' \ell'</math><math>1j</math><math>-</math></td><td>TLAS Heavy Particle Searches* - 95% CL L atus: March 2023Model<math>\ell, \gamma</math>Jets†<math>E_{T}^{miss}</math><math>f\mathcal{L}dt[fb^{-1}]</math>ADD GGRK+ g/q<math>0 e, \mu, \tau, \gamma</math><math>1 - 4j</math>Yes139ADD OBH ADD DH multijet<math>2\gamma</math><math>-139</math>MaRS1 GKK <math>\rightarrow \gamma\gamma</math><math>2\gamma</math><math>-139</math>GKK massBulk RS <math>G_{KK} \rightarrow \gamma\gamma</math><math>2\gamma</math><math>-139</math>GKK massBulk RS <math>G_{KK} \rightarrow \gamma\gamma</math><math>2\gamma</math><math>-139</math>GKK massSSM Z' <math>\rightarrow \ell\ell</math><math>2e, \mu</math><math>-139</math>GKK massSSM Z' <math>\rightarrow \ell\ell</math><math>2e, \mu</math><math>-139</math>GKK massSSM Z' <math>\rightarrow \ell\ell</math><math>2e, \mu</math><math>-139</math>Z' massSSM Z' <math>\rightarrow \ell\ell</math><math>2e, \mu</math><math>-139</math>Z' massSSM Z' <math>\rightarrow \ell\ell</math><math>2e, \mu</math><math>-139</math>Z' massSSM Z' <math>\rightarrow \ell\ell</math><math>2e, \mu</math><math>-161</math>Z' massSSM Z' <math>\rightarrow \ell\ell</math><math>2e, \mu</math><math>-163</math>YesSSM W' <math>\rightarrow tr</math><math>1e, \mu</math><math>210, 23</math>YesSSM W' <math>\rightarrow tr</math><math>1e, \mu</math><math>21/13</math>YesSSM W' <math>\rightarrow tr</math><math>1e, \mu</math><math>21/13</math>YesHYT W' <math>\rightarrow WZ</math> model B<math>1e, \mu</math><math>21/13</math>YesHYT W' <math>\rightarrow WZ</math><math>2e, \mu</math><math>13</math><math>-80.1</math>HYT W' <math>\rightarrow WZ</math><math>2e, \mu</math><math>2e, \mu</math><math>210, 21</math>HYT W' <math>\rightarrow WZ</math><math>2e, \mu</math><math>2e, \mu</math><math>210, 21</math>HYT W' <math>\rightarrow WZ</math><math>2e, \mu</math><math>2e, \mu</math><math>21/13</math>HYT W' <math>\rightarrow WZ</math><math>2e, \mu</math><math>2e, \mu</math><math>210, 21</math>HYT W' <math>\rightarrow WZ</math><math>2e, \mu</math><math>2e, \mu</math><math>210, 21</math>HYT W' <math>\rightarrow WZ</math><math>2e, \mu</math><math>2e, 199</math>HYT W' <math>\rightarrow WZ</math>&lt;</td><td>TLAS Heavy Particle Searches* - 95% CL Upper Exclusion atus: March 2023Model<math>\ell, \gamma</math>Jets†<math>\mathbb{F}_{T}^{miss}</math><math>\int \mathcal{L} dt[fb^{-1}]</math>LimitADD GKK+ £/q<math>0 e, \mu, \tau, \gamma</math><math>1 - 4i</math>Yes139ADD OBH ADD OBH ADD OBH multiple<math> 2i</math><math>-</math>367ADD OBH ADD OBH ADD BH multiple<math> 2i</math><math>-</math>139ADD GBH ADD OBH ADD BH multiple<math> 2i</math><math>-</math>139Bulk RS <math>G_{KK} \rightarrow TY</math><math>2\gamma</math><math> 139</math>Bulk RS <math>G_{KK} \rightarrow TY</math><math>2\gamma</math><math> 139</math>Bulk RS <math>G_{KK} \rightarrow TY</math><math>2\gamma</math><math> 139</math>SM Z' <math>\rightarrow \ell\ell</math><math>1 e, \mu \geq 1J/2</math>Yes36.1SSM Z' <math>\rightarrow \ell\ell</math><math>2e, \mu</math><math> 139</math>SSM Z' <math>\rightarrow \ell\ell</math><math>1 e, \mu \geq 1J/2</math>Yes139SSM Z' <math>\rightarrow \ell\ell</math><math>- 2b</math><math>- 36.1</math>Leptophobic Z' <math>\rightarrow bb</math><math>- 2b</math><math>- 36.1</math>Z' mass<math>2j L j 1 J</math>Yes139SSM W' <math>\rightarrow tr</math><math>1 e, \mu \geq 2j/1J 2</math>YesSSM W' <math>\rightarrow tr</math><math>1 e, \mu \geq 2j/1J 3</math>YesHTT W' <math>\rightarrow WZ = \delta t/\ell'\ell'</math> model B<math>1 e, \mu \geq 2j/1J 3</math>HT W' <math>\rightarrow WZ = \delta t/\ell'\ell'</math><math>1 e, \mu \geq 2j/1J 3</math>HT W' <math>\rightarrow WZ = \delta t/\ell'\ell'</math><math>1 e, \mu \geq 2j/1J 3</math>HT W' <math>\rightarrow WZ = \delta t/\ell'\ell'</math><math>1 e, \mu \geq 2j/1J 3</math>HT W' <math>\rightarrow WZ = \delta t/\ell'\ell'</math><math>1 e, \mu \geq 2j/1J 3</math>HT W' <math>\rightarrow WZ = \delta t/\ell'\ell'</math><math>1 e, \mu \geq 2j/1J 3</math>HT W' <math>\rightarrow WZ = \delta t/\ell'\ell'</math><math>1 e, \mu \geq 2j/1J 3</math>HT W' <math>\rightarrow WZ = \delta t/\ell'\ell'</math><math>1 e, \mu \geq 2j/1J 3</math>HT W' <math>\rightarrow WZ = \delta t/\ell'\ell'</math></td><td>TLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits         from the second of the second o</td><td>TLAS Heavy Particle Searches* - 95% CL Upper Exclusion LimitsATLatus: March 2023<math>\int \mathcal{L} dt = (3.6 - 139) fb^{-1}</math>Model<math>i, \gamma</math><math>j \neq 1</math><math>j \neq 1</math>&lt;</td></td></tr<>	TLAS Heavy Particle Searches atus: March 2023Model $\ell, \gamma$ Jets† $E_T^{miss}$ TADD $G_{KK} + g/q$ $0 e, \mu, \tau, \gamma$ $1 - 4j$ YesADD OBH $2\gamma$ $2\gamma$ $-2j$ ADD OBH $2\gamma$ $2j$ $-2j$ ADD BH multipit $2\gamma$ $-2j$ Bulk RS $G_{KK} \rightarrow tW/ZZ$ Bulk RS $G_{KK} \rightarrow tt$ $1 e, \mu \geq 21 b, \geq 13/21$ YesSSM Z' $\rightarrow \ell \ell$ $2e, \mu$ $-$ SSM Z' $\rightarrow \ell \ell$ $2e, \mu$ $ -$ Leptophobic Z' $\rightarrow bb$ $ 2b \geq 3j$ YesSSM Z' $\rightarrow \ell \ell$ $2e, \mu$ $ -$ Leptophobic Z' $\rightarrow tt$ $0e, \mu$ $21 b, \geq 2J$ YesSSM W' $\rightarrow \ell \gamma$ $1e, \mu$ $-$ YesSSM W' $\rightarrow \ell \gamma$ $1r$ $-$ YesSSM W' $\rightarrow \ell \gamma$ $1e, \mu$ $21 b, \geq 1J$ $-$ HTT W' $\rightarrow WZ$ model B $0e, \mu$ $2 \ell JJ$ YesHTT W' $\rightarrow WZ$ model B $1e, \mu$ $2 j/1J$ YesHTW W' $\rightarrow \ell \ell'$ model B $1e, \mu$ $2 j/1J$ YesLBSM W <sub>R</sub> $\rightarrow \mu N_R$ $2\mu$ $1J$ $-$ Cl qaqq $ 2 $ $ -$ Cl qapa $2e, \mu$ $  -$ Cl qapa $2e, \mu$ $  -$ Cl qapa $2\mu$ $1b$ $ -$ Cl qapa $ 2 $ $ -$ Cl qapa $2e, \mu$ $  -$ Cl qapa $2e, \mu$ $  -$ Cl qapa $2e, \mu$ </td <td>TLAS Heavy Particle Searches* - 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#### ATL-PHYS-PUB-2023-008

#### $W' \rightarrow \tau \nu$





- → Also motivated by models which favour τν: Non-Universal Gauge Interaction Models (NUGIM)
  - Non universality of couplings to SM fermions parameterised as θ<sub>NU</sub>







CERN-EP-2023-298

- Also derive model-independent limits on visible σ for m<sub>T</sub> thresholds of 200 - 2950 GeV
  - Improvement of up to 5x w.r.t previous results

#### **Heavy Resonance Combination**

- Combine searches for diboson, di-quark, dilepton resonances
  - Fully leptonic, semileptonic, fully hadronic
  - Including  $\tau v, \tau \tau$
- → Validate individual results, check for overlaps, combine analyses
- Set limits on couplings of HVT model (g<sub>a</sub>, g<sub>ℓ</sub>, g<sub>H</sub>...)
  - Consider benchmark coupling points, e.g. HVT model C (g<sub>H</sub> = 1, g<sub>f</sub> = 0) targets VBF production channels







### **Searches for Heavy Scalars**

- New massive (pseudo-) scalar states with strong couplings to top quarks predicted in September 2022 numerous BSM models 60
- e.g. Two-Higgs-Doublet Models (2HDMs)
  - Introduce 5 physical states:  $h^0$ ,  $H^0$ ,  $A^0$ ,  $H^+$ ,  $H^-$
  - Ratio of VEVs for two doublets: tanß
  - Mixing angle of  $h^0$  and  $H^0$ :  $\alpha$
  - Precision measurements dictate  $cos(\beta \alpha) = 0$ if h<sup>0</sup> is SM Higgs (alignment limit)

Dominant production mode for A/H is ggF





#### A/H → t₹





### tt H/A -> tttt

- H/A production in association with tt is much less susceptible to interference with SM
- → Latest search focuses on 1-lepton / 2 Opposite-Sign (OS) lepton final states
- ➡ High jet & b-jet multiplicities in final state
- Use data-driven approach with neural network to correct known mismodelling of tt+jets BG

ATLAS-CONF-2024-002

Use Graph Neural Network (GNN) to distinguish signal from BG



### **Conclusions & Outlook**



- ➡ ATLAS has an diverse BSM search programme, with many new results published and in progress for the full LHC Run-2 dataset
  - Only a handful of the latest results presented here
  - See the list of all public results on the <u>AtlasPublic twiki</u>, and catch up on latest news with ATLAS <u>briefings</u>
- → We unfortunately did not detect BSM physics... but not for lack of trying
- → On top of performing many analyses, there have been huge efforts to make the most of our results by combining them
- And huge improvements have been made thanks to novel analysis techniques, such as employment of neural networks
- Run-3 of the LHC is ongoing, with 13.6 TeV collision energy and the inclusion of <u>multiple upgrades</u>
  - Looking forward to new searches with this dataset



# Backup



### **The Large Hadron Collider Complex**





#### **The ATLAS Detector**





#### **ATLAS Coordinate System**



$$\eta = -\ln \tan\left(\frac{\theta}{2}\right)$$

$$\Delta R = \sqrt{\left(\Delta\phi\right)^2 + \left(\Delta\eta\right)^2}$$





#### **LHC Schedule**

https://hilumilhc.web.cern.ch/content/hl-lhc-project





#### LHC / HL-LHC Plan





### **Upgrades for Run-3**

#### https://home.cern/press/2022/ATLAS-upgrades-LS2



#### MUON NEW SMALL WHEELS (NSW)

Installed new muon detectors with precision tracking and muon selection capabilities. Key preparation for the HL-LHC.

#### NEW READOUT SYSTEM FOR THE NSWs

The NSW system includes two million micromega readout channels and 350 000 small strip thin-gap chambers (sTGC) electronic readout channels.

#### LIQUID ARGON CALORIMETER

New electronics boards installed, increasing the granularity of signals used in event selection and improving trigger performance at higher luminosity.



#### TRIGGER AND DATA ACQUISITION SYSTEM (TDAQ)

Upgraded hardware and software allowing the trigger to spot a wider range of collision events while maintaining the same acceptance rate.

#### NEW MUON CHAMBERS IN THE CENTRE OF ATLAS

Installed small monitored drift tube (sMDT) detectors alongside a new generation of resistive plate chamber (RPC) detectors, extending the trigger coverage in preparation for the HL-LHC.

#### ATLAS FORWARD PROTON (AFP)

Re-designed AFP time-of-flight detector, allowing insertion into the LHC beamline with a new "out-of-vacuum" solution.

#### **LHC Proton Beams**





- ◊ > 50 kinds of magnets
- 1232 superconducting dipole magnets operating at -271.3°C
  - Sextupole, octupole & decapole magnets correct the beam
- 8 RadioFrequency (RF) cavities per beam

- ♦ Proton beam energy = 6.5 TeV
- $\diamond$  1.2 x 10<sup>11</sup> protons/bunch
- ◊ ~ 2800 bunches/beam
- ◊ 25ns bunch spacing
  - ➡ 40,000,000 collisions per second



# The Elephant in the Room

LHCb-PAPER-2022-045 LHCb-PAPER-2022-046



- → Results of LHCb Run-1 + Run-2 measurement of R<sub>k</sub> and R<sub>k\*</sub> presented in recent LHC seminar
  - Simultaneously analysing B<sup>+</sup>→K<sup>+</sup>ℓ<sup>+</sup>ℓ<sup>-</sup> and B<sup>0</sup>→K<sup>\*0</sup>ℓ<sup>+</sup>ℓ<sup>-</sup>, data-driven modelling of mis-ID backgrounds, MVA in two mass (q<sup>2</sup>) ranges...



→ What does this mean for our analyses motivated by LFU?

## The Elephant in the Room



