

# Recent searches for new phenomena with the ATLAS detector

Sébastien Rettie, on behalf of the ATLAS collaboration

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#### The Standard Model (SM) of Particle Physics

- Excellent description of nature
- Experimentally verified to extremely high degrees of precision
- However, known to be incomplete









#### **Physics Beyond The Standard Model**

- What is **Dark Matter**?
  - Candidates for Dark Matter could be produced at the LHC
- Grand Unified Theory (GUT)?
  - Unify all forces to a super force
- Are there **extra dimensions** of space?
  - Could explain why gravity is so weak
- Explore the unknown
  - Surprises can happen at any time





- The LHC is **performing very well overall**
- Achieved and surpassed design instantaneous luminosity

• Over 139 fb<sup>-1</sup> of *pp* data recorded by ATLAS at  $\sqrt{s} = 13$  TeV



#### **Results Covered Today**

- Several exciting results searching for BSM physics in ATLAS
- Focusing on latest relevant results for this talk
- Leptoquarks (LQ) couple to both leptons and quarks
  - Pair produced
  - Singly produced: scalar leptoquarks in the b au au final state
- Vector-like leptons (VLL) and vector-like quarks (VLQ) couple to both vector bosons and leptons/quarks
- Generic searches: lepton + 2 jets
- **Dark matter**: semi-visible jets (SVJ), particles invisible to the ATLAS detector





#### ATLAS-CONF-2022-052

#### **Pair-produced Leptoquarks**

- Searching for down-type scalar LQ with cross-generational decays  $LQ^{\rm d}_{\rm mix}$  and vector LQ  $\tilde{U}_1$
- Final state:  $LQLQ \rightarrow t\ell t\ell$  (multileptons)
- Require two or more light leptons (e or μ) and at least two jets (at least one of which is identified as coming from a *b*-hadron)
- Main backgrounds:  $t\overline{t}$  production in association with a vector boson, and diboson production





3CSR\_F

38SR-U

48SR\_

48SR\_U



#### **Pair-produced Leptoquarks Results**

- Effective mass  $(m_{\rm eff})$  used as discriminating variable: sum of  $p_{\rm T}$  of light leptons and jets and  $E_{\rm T}^{\rm miss}$
- Additional background-enriched categories are used in the fit to improve the modelling of several leading backgrounds
- For LQ decaying to  $te(t\mu)$ , masses excluded up to
  - 1.6 TeV (1.64 TeV) for scalar LQ
  - 1.71 TeV (1.73 TeV) for vector LQ  $\tilde{U}_1$  in minimal coupling scenario
  - 2.0 TeV (2.0 TeV) for vector LQ  $\tilde{U}_1$  in Yang-Mills scenario









e

*b*-jet

#### Singly-produced Scalar Leptoquarks

- Final state:  $b\tau\tau$
- Select a pair of opposite charge taus produced in association with a *b*-tagged jet
- Two channels, depending on the decay mode of the  $\tau$  are considered:  $\tau_{\rm lep}\tau_{\rm had}$  and  $\tau_{\rm had}\tau_{\rm had}$
- Main backgrounds:  $t\bar{t}$ , single top-quark,  $Z( \rightarrow \tau \tau) + jets$  and multi-jet events



ATLAS-CONF-2022-037





#### Singly-produced Scalar Leptoquarks Results

- Discriminating variable is  $S_T$ : scalar  $p_T$  sum of the two  $\tau$  and leading- $p_T$  *b*-jet
- Masses of **singly-produced** LQ excluded for various coupling scenarios: 0.89 TeV for  $\lambda = 1.0$ , 1.01 TeV for  $\lambda = 1.7$ , and 1.28 TeV for  $\lambda = 2.5$ , where  $\lambda$  is the LQ to  $\tau b$ Yukawa coupling
- Results also interpreted in the context of the  $\tilde{S}_1$  model for single plus pair LQ production (LQ+LQLQ)
- Lower observed limits driven by the highest  $S_T$  bin in the  $\tau_{\rm had}\tau_{\rm had}$  channel





#### **3rd Generation Vector-like Leptons (VLL)**

- VLL doublet couple only to 3<sup>rd</sup> generation leptons
- Final state: 2, 3, or ≥4 light leptons (e or µ), and zero or more hadronically decaying tau leptons
- Events classified using **Boosted Decision Tree** (BDT)



ATLAS-CONF-2022-044

Variables			BDT Train	ning Regions			
BDT	$2\ell$ SSSF, $1\tau$	$2\ell$ SSOF, $1\tau$	$2\ell$ OSSF, $1\tau$	$2\ell$ OSOF, $1\tau$	$2\ell, \geq 2\tau$	$3\ell, \geq 1\tau$	$4\ell, \geq 0\tau$
$N_\ell$	2	2	2	2	2	3	$\geq 4$
Charge/Flavor	$\mathbf{SSSF}$	SSOF	OSSF	OSOF	-	-	-
$N_{ au}$	1	1	1	1	$\geq 2$	$\geq 1$	$\geq 0$
$N_{ m iet}$				> 0			
$\tilde{E_{\mathrm{T}}^{\mathrm{miss}}}$ [GeV]	$\geq 120$	$\geq 90$	$\geq 60$	$\geq 100$	$\geq 60$	$\geq 90$	$\geq 60$



#### **3rd Generation Vector-like Leptons (VLL) Results**

- Seven signal regions require the same selection as BDT training regions (see previous slide), with an additional cut on the BDT score
- VLL masses
   excluded up to
   900 GeV for
   VLL coupling to
   3<sup>rd</sup> generation
   SM leptons

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### Vector-like Quarks (VLQ)

EXOT-2018-58 T/B t/b T/B T/B V (or H)

- Search for pair production of VLQ
- Require high-p<sub>T</sub> Z boson decaying to two same-flavour opposite-sign leptons (e or μ), and at least one b-tagged jet
- Additional leptons from the V (W/Z) or H decay define 2lepton vs ≥3-lepton channels
- Deep neural network (DNN) used to classify large-radius jets originating from hadronically decaying Z/W bosons, H boson, or top quark
- 19 fit categories based on lepton multiplicity, number of btagged jets, and DNN tags







#### **Vector-like Quarks (VLQ) Results**

- Binned likelihood fit of the discriminating variables in the categories of each individual channel carried out
- Limits set for various VLQ models

Model	Observed (E $2\ell$	expected) Mas $3\ell$	s Limits [TeV] Combination
$T\overline{T}$ Singlet	1.14 (1.16)	1.22 (1.21)	1.27 (1.28)
$T\overline{T}$ Doublet	1.34 (1.32)	1.38 (1.37)	1.46 (1.44)
$100\% T \rightarrow Zt$	1.43 (1.43)	1.54 (1.50)	1.60 (1.56)
$B\overline{B}$ Singlet	1.14 (1.21)	1.11 (1.10)	1.20 (1.25)
$B\overline{B}$ Doublet	1.31 (1.37)	1.07 (1.04)	1.32 (1.38)
$100\% B \rightarrow Zb$	1.40 (1.47)	1.16 (1.18)	1.42 (1.48)





#### **Generic Searches**

- Final state: at least one light lepton (e or μ) and two jets
- Search for deviations from a smoothly falling background hypothesis
- Use three- and four-body invariant mass distributions constructed from leptons and jets: m<sub>jjl</sub>, m<sub>jjll</sub>, m<sub>jbl</sub>, m<sub>bbl</sub>
- Background is estimated with:  $f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x + p_5 \ln^2 x}$ , where  $x \equiv m/\sqrt{s}$  and  $p_i$  are free parameters
- No significant excess observed above the background expectation





#### ATLAS-CONF-2022-048

#### **Generic Searches Results**

 Limits set on BSM models, e.g. the sequential standard model (same couplings as the SM, but larger masses for W'/Z' bosons)



 Model-independent limits also provided for generic Gaussian-like signals with different widths





### Semi-visible Jets (SVJ)

- Semi-visible jets signature can arise in strongly-interacting dark sectors
- Final state: SM hadrons and dark hadrons produced by **t-channel** mediator  $\boldsymbol{\Phi}$
- Pythia8 **Hidden Valley** (HV) module used to simulate interactions connecting the dark sector with the SM sector
- Search exploits two largely uncorrelated variables:

• 
$$p_{\mathrm{T}}^{\mathrm{bal}} = \frac{\left| \vec{p}_{\mathrm{T}}(j_{1}) + \vec{p}_{\mathrm{T}}(j_{2}) \right|}{\left| \vec{p}_{\mathrm{T}}(j_{1}) \right| + \left| \vec{p}_{\mathrm{T}}(j_{2}) \right|}$$

• Difference in the azimuthal angle between  $j_1$  and  $j_2$ :  $\left| \phi_{\max} - \phi_{\min} \right|$ 





#### Semi-visible Jets (SVJ) Results

- Signal region requires  $E_{\rm T}^{\rm miss} \ge 600$  GeV and  $H_{\rm T} \ge 600$  GeV, with  $H_{\rm T}$  being the scalar sum of jet  $p_{\rm T}$
- **Control regions**, used to estimate backgrounds more accurately, require additional selections:
  - **1L** (W+jets): exactly one µ, no *b*-tagged jet
  - **1L1B** ( $t\bar{t}$  and single top): exactly one  $\mu$ , exactly one *b*-tagged jet
  - 2L (Z+jets): two opposite charged µ with invariant mass between 66 GeV and 116 GeV, no *b*-tagged jet
- Upper limits on mediator mass range from 2.4 TeV to 2.7 TeV, depending on the values of  $R_{inv} = \left\langle \frac{\# \text{ of stable hadrons}}{\# \text{ of hadrons}} \right\rangle$

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ATLAS-CONF-2022-038





0.2





1.0

- Final state: top quark and missing transverse momentum ( $E_{\rm T}^{\rm miss}$ )
- Require lepton veto,  $E_{\rm T}^{\rm miss} > 250$  GeV, and at least one top-tagged large-R jet with  $p_{\rm T} \in [350,2500]$  GeV and mass  $\in [40,600]$  GeV
- Exploit event topology by reconstructing boosted top quark from decay products

• "T" 
$$\rightarrow t\bar{t}$$
, "V"  $\rightarrow V + jets$ , "f"  $\rightarrow$  forward jet

 $\Delta \phi_{min} (j, E_T^{miss})$ 

20

ATLAS-CONF-2022-036



#### **Invisible Particles Results**

- XGBoost used to discriminate signal from background
- SR0b expected to account for *b*-tagging inefficiencies, increasing signal selection efficiency by 30 to 60%
- VLQ masses excluded up to 2.2 TeV assuming coupling to the top quark  $\kappa_T = 0.5$  and branching ratio for  $T \rightarrow Zt$  of 25%
- Dark Matter candidate masses excluded for scalar (vector) mediators up to 5.0 (2.8) TeV assuming a resonant (non-resonant) model





#### **A Promising Road Ahead**

- Broad physics programme searching for new phenomena with ATLAS; many searches not covered today!
- So far, no significant deviation from the Standard Model expectation
- Run 3 data currently being collected; expect new results soon!







#### Thank you! Merci!

#### **Questions?**





#### **Summary Plot**

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

Status: July 2022

ATLAS Preliminary  $\sqrt{s} = 8.13$  TeV

Sta	atus: July 2022						$\int \mathcal{L} dt = (3)$	3.6 − 139) fb <sup>−1</sup>	$\sqrt{s} = 8, 13 \text{ TeV}$
	Model	l,γ Je	ets† E	niss T∫£ dt[fb	-1]	Limit			Reference
Extra dimensions	$ \begin{array}{llllllllllllllllllllllllllllllllllll$	$e, \mu, \tau, \gamma = 1$ $2\gamma$ $-$ $2\gamma$ ti-channel $1e, \mu = 2$ $1e, \mu \ge 1t$ $1e, \mu \ge 2$	$\begin{array}{c} -4j \\ \hline 2j \\ \geq 3j \\ \hline , \geq 1J/2j \\ b, \geq 3j \end{array}$	Yes 139 - 36.7 - 139 - 3.6 - 139 36.1 Yes 139 Yes 36.1 Yes 36.1	М <sub>D</sub> M <sub>S</sub> M <sub>th</sub> M <sub>th</sub> G <sub>KK</sub> mass G <sub>KK</sub> mass G <sub>KK</sub> mass KK mass KK mass	2.3 2.0 Tr 1.8 TeV	11.2 Te 8.6 TeV 9.4 TeV 9.55 TeV 4.5 TeV 8 TeV eV 3.8 TeV	$ \begin{array}{l} V & n = 2 \\ n = 3 \; \text{HLZ NLO} \\ n = 6 \; , M_D = 3 \; \text{TeV, rot BH} \\ k/M_{Pl} = 0.1 \\ k/M_{Pl} = 1.0 \\ k/M_{Pl} = 1.0 \\ F/m = 15\% \\ \hline \Gamma \text{ier} (1,1), \mathcal{B}(\mathcal{A}^{(1,1)} \to tt) = 1 \end{array} $	2102.10874 1707.04147 1910.08447 1512.02586 2102.13405 1808.02380 2004.14636 1804.10823 1803.09678
Gauge bosons	$\begin{array}{llllllllllllllllllllllllllllllllllll$	$\begin{array}{cccc} 2 \ e, \mu & & \\ 2 \ \tau & & \\ 0 \ e, \mu & \geq 1 \\ 1 \ e, \mu & & \\ 1 \ \tau & & \\ - & & \geq 1 \\ 3 \ e, \mu & & 2 \\ 3 \ e, \mu & & 2 \\ 1 \ e, \mu & & 1-2 \\ 0, 2 \ e, \mu & & 1-2 \\ 2 \ \mu & & \end{array}$	$\begin{array}{c} - & - \\ 2 b \\ b, \geq 2 J \\ - & \\ y/1 J \\ (VBF) \\ b, 1-0 j \\ 1 J \end{array}$	- 139 - 36.1 - 36.1 /es 139 /es 139	Z' mass Z' mass Z' mass W' mass W' mass W' mass W' mass W' mass W' mass Z' mass Z' mass	2.4 2.1 340 GeV	5.1 TeV 2 TeV 4.1 TeV 5.0 TeV 4.4 TeV 4.4 TeV 4.3 TeV 3.3 TeV 3.2 TeV 5.0 TeV 5.0 TeV	$\Gamma/m = 1.2\%$ $g_V = 3$ $g_V c_{H} = 1, g_f = 0$ $g_V = 3$ $g_V = 3$ $g_V = 3$ $m(N_R) = 0.5$ TeV, $g_L = g_R$	1903.06248 1709.07242 1805.09299 2005.05138 1906.05609 ATLAS-CONF-2021-025 ATLAS-CONF-2021-025 ATLAS-CONF-2021-036 ATLAS-CONF-2022-005 2207.00230 2207.00230 1904.12679
C	Cl qqqq         Cl {l{qq}         Cl {l{qq}         Cl {l{pq}         Cl {l{pq}	_ 2 e,μ 2 e 2 μ ≥1 e,μ ≥1	2 j - 1 b 1 b b, ≥1 j	- 37.0 - 139 - 139 - 139 rés 36.1	Λ Λ Λ	1.8 TeV 2.0 Ti 2.	/ eV .57 TeV	<b>21.8 TeV</b> $\eta_{LL}^{-}$ <b>35.8 TeV</b> $\eta_{LL}^{-}$ $g_{*} = 1$ $g_{*} = 1$ $g_{C_{4t}}^{-} = 4\pi$	1703.09127 2006.12946 2105.13847 2105.13847 1811.02305
MQ	Axial-vector med. (Dirac DM) 0 e Pseudo-scalar med. (Dirac DM) 0 e Vector med. Z'-2HDM (Dirac DM) Pseudo-scalar med. 2HDM+a mult	$e, \mu, \tau, \gamma = 1$ $e, \mu, \tau, \gamma = 1$ $0 e, \mu$ ti-channel	-4j -4j 2b	rés 139 rés 139 rés 139 rés 139 139	m <sub>med</sub> m <sub>med</sub> m <sub>med</sub>	2.1 1 376 GeV 560 GeV	GeV 3.1 TeV	$\begin{array}{l} g_{q}{=}0.25,  g_{\chi}{=}1,  m(\chi){=}1  {\rm GeV} \\ g_{q}{=}1,  g_{\chi}{=}1,  m(\chi){=}1  {\rm GeV} \\ {\rm tan}  \beta{=}1,  g_{\chi}{=}0.8,  m(\chi){=}100  {\rm GeV} \\ {\rm tan}  \beta{=}1,  g_{\chi}{=}1,  m(\chi){=}10  {\rm GeV} \end{array}$	2102.10874 2102.10874 2108.13391 ATLAS-CONF-2021-036
ГØ	Scalar LQ 1 <sup>st</sup> gen       Scalar LQ 2 <sup>rd</sup> gen       Scalar LQ 3 <sup>rd</sup> gen       Vector LQ 3 <sup>rd</sup> gen	$2 e 2 \mu 1 \tau 0 e, \mu \ge 2 e, \mu, \ge 1 \tau \ge 1 e, \mu, \ge 1 \tau 0 - 1 \tau$	≥2j 2b j, ≥2b j, ≥2b j, ≥1b 2j, 2b 2b	res 139 res 139 res 139 res 139 res 139 res 139 res 139 res 139	LQ mass LQ mass LQ <sup>4</sup> mass LQ <sup>3</sup> mass LQ <sup>3</sup> mass LQ <sup>3</sup> mass LQ <sup>3</sup> mass	1.8 TeV 1.7 TeV 1.2 TeV 1.24 TeV 1.24 TeV 1.43 TeV 1.26 TeV 1.77 TeV		$\begin{array}{l} \beta=1\\ \beta=1\\ \mathcal{B}(LQ_3^\circ\rightarrow b\tau)=1\\ \mathcal{B}(LQ_3^\circ\rightarrow t\nu)=1\\ \mathcal{B}(LQ_4^\circ\rightarrow t\tau)=1\\ \mathcal{B}(LQ_4^\circ\rightarrow b\nu)=1\\ \mathcal{B}(LQ_3^\circ\rightarrow b\nu)=1\\ \mathcal{B}(LQ_3^\circ\rightarrow b\tau)=0.5, \mbox{Y-M coupl.} \end{array}$	2006.05872 2006.05872 2108.07665 2004.14060 2101.11582 2101.12527 2108.07665
Vector-like fermions	$\begin{array}{ll} VLQ\;TT\to Zt+X & 2e^{t/t}\\ VLQ\;BB\to Wt/Zb+X & \text{mult}\\ VLQ\;T_{57}T_{57}I_{57}J_{53}\to Wt+X & 2(St)\\ VLQ\;T\to Ht/Zt & VLQ\;Y\to Wb \\ VLQ\;Y\to Wb & VLQ\;Y\to Hb & VLQ\;Y\to Hb \\ VLQ\;T\to Z\tau/H\tau & \text{mult} \end{array}$	$\begin{array}{l} 2\mu/\geq 3e,\mu\geq 1\\ \text{ti-channel}\\ S)/\geq 3\ e,\mu\geq 1\\ 1\ e,\mu\geq 1\\ 1\ e,\mu\geq 1\\ 0\ e,\mu\geq 2b,\\ \text{ti-channel} \end{array}$	b, ≥1 j b, ≥3 j b, ≥3 j b, ≥1 j ≥1 j, ≥1 J ≥1 j	- 139 36.1 Yes 36.1 Yes 139 Yes 36.1 - 139 Yes 139	T mass           B mass           T <sub>5/3</sub> mass           T mass           Y mass           B mass           τ' mass	1.4 TeV 1.34 TeV 1.64 TeV 1.8 TeV 1.8 TeV 1.85 Te 2.0 Tr 898 GeV	V V V	$\begin{array}{l} {\rm SU(2) \ doublet} \\ {\rm SU(2) \ doublet} \\ {\rm SU(2) \ doublet} \\ {\rm SU(2) \ singlet, \ \kappa_T = 0.5} \\ {\rm SU(2) \ singlet, \ \kappa_T = 0.5} \\ {\rm SU(2) \ singlet, \ \kappa_B = 0.3} \\ {\rm SU(2) \ doublet \ \kappa_B = 0.3} \\ {\rm SU(2) \ doublet} \end{array}$	ATLAS-CONF-2021-024 1808.02343 1807.11883 ATLAS-CONF-2021-040 1812.07343 ATLAS-CONF-2021-018 ATLAS-CONF-2022-044
Excited fermions	Excited quark $q^* \rightarrow qg$ Excited quark $q^* \rightarrow q\gamma$ Excited quark $b^* \rightarrow bg$ Excited lepton $l^*$ Excited lepton $v^*$	- 1 γ - 1 3 e, μ s e, μ, τ	2 j 1 j b, 1 j -	- 139 - 36.7 - 139 - 20.3 - 20.3	q* mass q* mass b* mass <i>t</i> * mass y* mass	1.6 TeV	6.7 TeV 5.3 TeV 3.2 TeV 3.0 TeV	only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ $\Lambda = 3.0 \text{ TeV}$ $\Lambda = 1.6 \text{ TeV}$	1910.08447 1709.10440 1910.0447 1411.2921 1411.2921
Other	Type III Seesaw 2; LRSM Majorana $\nu$ Higgs triplet $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$ 2,3,4 Higgs triplet $H^{\pm\pm} \rightarrow \ell \ell$ 3,3,4 Higgs triplet $H^{\pm\pm} \rightarrow \ell \ell$ 3 Multi-charged particles Magnetic monopoles	3,4 e, μ 2 μ 4 e, μ (SS) va 4 e, μ (SS) 6 e, μ, τ - - 3 TeV	≥2 j 2 j arious - - - - -	res 139 - 36.1 res 139 - 139 - 20.3 - 139 - 34.4	N <sup>0</sup> mass N <sub>R</sub> mass H <sup>±±</sup> mass H <sup>±±</sup> mass H <sup>±±</sup> mass multi-charged particle mass monopole mass	910 GeV 350 GeV 400 GeV 5 1.59 TeV 2.3	3.2 TeV 7 TeV	$\begin{split} m(W_R) &= 4.1 \text{ TeV}, g_L = g_R \\ \text{DY production} \\ \text{DY production} \\ \text{DY production}, & \mathcal{B}(H_L^{i+} \to \ell \tau) = 1 \\ \text{DY production}, &  \mathcal{G}  = 5e \\ \text{DY production}, &  g  = 1g_D, \text{spin } 1/2 \end{split}$	2202.02039 1809.11105 2101.11961 ATLAS-CONF-2022-010 1411.2921 ATLAS-CONF-2022-034 1905.10130
	ys = 8 fev partial	data	full data		10 <sup>-1</sup>	1	10	Mass scale [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).



## <u>A Toroidal LHC ApparatuS</u>







#### **Particle Detection in ATLAS**

- Different particles leave different signatures in the detector
- Solenoid and toroid magnetic fields bend particles to measure momenta









Bourses postdoctorales

Postdoctoral Fellowships

Nanting

CÉRN





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#### **Singly-produced Scalar Leptoquarks**

• Quark-gluon scattering





#### **3rd Generation Vector-like Leptons (VLL)**





#### **3rd Generation Vector-like Leptons (VLL)**

• BDT training variables

Variable	Description
$E_{\rm T}^{\rm miss}$	The missing transverse momentum in the event
$S(E_T^{\text{miss}})$	The missing transverse momentum significance in the event
$L_T$	The scalar sum of light leptons $p_T$ in the event
$L_T + E_T^{\text{miss}}$	The scalar sum of light leptons $p_T$ and the missing transverse momentum in the event
$L_T + p_T(\tau)$	The scalar sum of light leptons $p_T$ and sum of taus $p_T$ in the event
$p_T(l_1)$	The leading light lepton $p_T$ in the event
$p_T(l_2)$	The sub-leading light lepton $p_T$ in the event
$p_T(j_1)$	The leading jet $p_T$ in the event
$p_T(\tau_1)$	The leading $\tau p_T$ in the event
$N_j$	The number of jets in the event
$N_b$	The number of $b$ -jets in the event
$H_T$	The scalar sum of jet $p_T$ in the event
$L_T + H_T$	The scalar sum of light leptons $p_T$ and sum of jets $p_T$ in the event
$M_{ll}$	The invariant mass of all light leptons in the event
$M_{l\tau}$	The invariant mass of all light leptons and taus in the event
$M_{lj}$	The invariant mass of all light leptons and jets in the event
$M_{jj}$	The invariant mass of all jets in the event
$M_{j\tau}$	The invariant mass of all jets and taus in the event
$M_T$	The transverse mass of the leading light lepton in the event
M <sub>OSSF</sub>	The invariant mass the opposite sign same flavor pair of light leptons closest to the Z mass in the even
$\Delta \phi(j_1 E_T^{\text{minss}})$	$\Delta \phi$ between $E_T^{\text{mins}}$ and the leading $p_T$ jet in the event
$\Delta \phi(l_1 E_T^{\rm miss})$	$\Delta \phi$ between $E_T^{\text{miss}}$ and the leading $p_T$ light lepton in the event
$\Delta\phi(l_1l_2)$	$\Delta \phi$ between the leading and sub-leading $p_T$ light lepton in the event
$\Delta \phi(l_1 j_1)$	$\Delta \phi$ between the leading $p_T$ light lepton and jet in the event
$\Delta\phi(\tau_1 E_T^{\rm miss})$	$\Delta \phi$ between $E_T^{\text{miss}}$ and the leading $p_T \tau$ in the event
$\Delta \phi(l_1 \tau_1)$	$\Delta \phi$ between the leading $p_T$ light lepton and $\tau$ in the event
$\Delta \phi(j_1 \tau_1)$	$\Delta \phi$ between the leading $p_T$ jet and $\tau$ in the event
$\Delta R(j_1 E_{T_{.}}^{\text{miss}})$	$\Delta R$ between $E_T^{\text{miss}}$ and the leading $p_T$ jet in the event
$\Delta R(l_1 E_T^{\rm miss})$	$\Delta R$ between $E_T^{\text{miss}}$ and the leading $p_T$ light lepton in the event
$\Delta R(l_1 l_2)$	$\Delta R$ between the leading and sub-leading $p_T$ light lepton in the event
$\Delta R(l_1 j_1)$	$\Delta R$ between the leading $p_T$ light lepton and jet in the event
$\Delta R(\tau_1 E_T^{\rm miss})$	$\Delta R$ between $E_T^{\text{miss}}$ and the leading $p_T \tau$ in the event
$\Delta R(l_1\tau_1)$	$\Delta R$ between the leading $p_T$ light lepton and $\tau$ in the event
$\Delta R(j_1 \tau_1)$	$\Delta R$ between the leading $p_T$ jet and $\tau$ in the event



#### **Vector-like Quarks (VLQ)**

								$2\ell$ channel						$3\ell$ channel			
							Category		1 <i>b</i> SR			2 <i>b</i> SR			_		
							-	V-tags	H-tags	top-tags	V-tags	H-tags	top-tags	V-tags	H-tags	top-tags	
Preselection	> 2 central jets						No tag	0	0	0	0	0	0	0	0	0	
Tieselection	at least two SF leptons with $p_{\rm T} > 28 {\rm GeV}$					V tag	1	0	0	1	0	0	$\geq 1$	0	0		
		at least one pai	r of OS-SF lept	ons $ m(\ell \ell) - m$	Z  < 10 GeV		H tag	0	1	0	0	1	0	0	≥ 1	0	
Channel definitions		2	2ℓ 2ℓ		$\begin{array}{c} 3\ell\\ \geq 3\ell\end{array}$		Top tag	0	0	1	0	0	1	0	0	≥ 1	
	$p_{\mathrm{T}}\left(\ell\ell\right) > 300\mathrm{GeV}$		$p_{\mathrm{T}}\left(\ell\ell\right) > 200\mathrm{GeV}$			2	0	0	2	0	0		_				
$H_{\rm T}({\rm jet}) + E_{\rm T}^{\rm miss} > 920 {\rm GeV}$		$H_{\rm T}(\text{jet} + \text{lep}) > 300 \text{GeV}$		Devilite to a 1	0	2	0	0	2	0		_					
Region	1 <i>b</i> SR	2 <i>b</i> SR	1 <i>b</i> CR	2 <i>b</i> CR	SR	VV CR	Double tag 1	1	0	1	1	1	0		_		
definitions	$H_{\rm T}({\rm jet}) + E_{\rm T}^{\rm mi}$	ss > 1380 GeV	$H_{\rm T}({\rm jet}) + E_{\rm T}^{\rm min}$	iss < 1380 GeV	-	_			_		0	0	2		_		
	= 1 b-jet	$\geq 2 b$ -jet	= 1 b-jet	$\geq 2 b$ -jet	$\geq 1 b$ -jet	= 0 b-jet	Deathle tex 2	0	1	1	0	1	1		_		
MCBOT categories	$7$ $m(Zh_1)$	$7 m(Zh_2)$	– Hrr(iet)	- 5 $-$	– t⊥len)	Double tag 2	0	0	2		_			_			
	$m(Lb_1)$	$\frac{1}{1} \qquad m(2b_2) \qquad m(b_1) + L_T \qquad m(b_1) + h(b_1) = \frac{1}{1}$		1	1	0	1	0	1	0	≥ 1	≥ 1					
							$O_{\rm Warflow}$ (OE)		or $> 2$ ta	gs		or $> 2$ tag	gs	$\geq 1$	0	$\geq 1$	
							Overnow (OF)		_			_		≥ 1	≥ 1	0	



 $\geq 1$ 

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#### **Invisible Particles**







#### **Invisible Particles**

• BDT training variables

Variable	Description	Resonant DM model	Non-resonant DM model	VLQ
$\overline{E_{\mathrm{T}}^{\mathrm{miss}}}$	Missing transverse momentum	$\checkmark$	$\checkmark$	$\checkmark$
Ω	$E_{\mathrm{T}}^{\mathrm{miss}}$ and large-R jet $p_{\mathrm{T}}$ balance: $\frac{E_{\mathrm{T}}^{\mathrm{miss}} - p_{\mathrm{T}}(J)}{E_{\mathrm{T}}^{\mathrm{miss}} + p_{\mathrm{T}}(J)}$	$\checkmark$	$\checkmark$	$\checkmark$
$N_{jets}$	Small- $R$ jet multiplicity	$\checkmark$	$\checkmark$	$\checkmark$
$\Delta R_{ m max}$	Maximum $\Delta R$ between two small- $R$ jets	$\checkmark$	$\checkmark$	$\checkmark$
$m_{\rm T,min}(E_{\rm T}^{\rm miss},\!b\!\!-\!{\rm jet})$	Transverse mass of $E_{\rm T}^{\rm miss}$ and the closest $b\text{-tagged jet}.$	$\checkmark$	$\checkmark$	$\checkmark$
$m_{\rm top-tagged \ jet}$	Mass of the large- $R$ top-tagged jet	$\checkmark$		$\checkmark$
$\Delta p_{\mathrm{T}}$ (J,jets)	Scalar difference of large- $R$ jet $p_{\rm T}$ and the sum of $p_{\rm T}$ of all small- $R$ jets.	$\checkmark$	$\checkmark$	
$H_{\mathrm{T}}$	Sum of all small- $R$ jet $p_{\rm T}$		$\checkmark$	$\checkmark$
$H_{\rm T}/E_{\rm T}^{\rm miss}$	Ratio of $H_{\rm T}$ and $E_{\rm T}^{\rm miss}$		$\checkmark$	$\checkmark$
$\Delta E(E_{\rm T}^{\rm miss},J)$	Energy difference between $E_{\mathrm{T}}^{\mathrm{miss}}$ and the large- $R$ jet		$\checkmark$	$\checkmark$
$\Delta \phi(E_{\mathrm{T}}^{\mathrm{miss}},J)$	Angular distance in the transverse plane between $E_{\rm T}^{\rm miss}$ and large- $R$ jet		$\checkmark$	$\checkmark$
$p_{\mathrm{T}}(\mathrm{J})$	Large- $R$ jet $p_{\rm T}$			$\checkmark$
$m_{\rm T}(E_{\rm T}^{\rm miss},\!J)$	Transverse mass of the $E_{\rm T}^{\rm miss}$ and large- $R$ jet			$\checkmark$
$\Delta \phi(b\text{-tagged jet},J)$	Angular distance in the transverse plane between the large- $R$ jet and the leading $b$ -jet			$\checkmark$



#### **Abstract**

 Many theories beyond the Standard Model (BSM) have been proposed to address several of the Standard Model shortcomings, such as the origin of dark matter and neutrino masses, the fine-tuning of the Higgs boson mass, or the observed pattern of masses and mixing angles in the quark and lepton sectors. Many of these BSM extensions predict new particles or interactions directly accessible at the LHC. This talk will present some highlights on recent searches based on the the full Run 2 data collected by the ATLAS detector at the LHC with a centre-of-mass energy of 13 TeV. These include searches for leptoquarks and vector-like fermions, new high mass resonances and lepton flavour violating decays, dark sector searches, as well as searches for new phenomena giving unconventional and/or long-lived particle signatures.

