### Exotic Searches at ATLAS

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## Introduction and Outline

> Exotic physics at ATLAS:

- ✓ Searches for new physics (NP) beyond the SM: Many well motived theories
- ✓ Many diverse & broad topics
  - Large overlap with SYSY searches
- > Only a few selected results from ATLAS Analyses after summer 2018
  - ✓ Heavy neutrio + right-handed W
    - arXiv: 1809.11105 [hep-ex]
  - $\checkmark$  4 Top production
    - arXiv: 1811.02305 [hep-ex]
  - ✓ Single Long-lived neutral particle
    - arXiv: 1811.02542 [hep-ex]
  - ✓ All based on 36.1fb<sup>-1</sup> data at 13TeV pp collisions (149fb<sup>-1</sup> recorded)
  - ✓ Not include SUSY, dark matter searches & BSM Higgs, Eg:
    - Invisible Higgs decays, arXiv: 1809.06682 [hep-ex]
    - BSM H->hh arXiv:1811.04671 [hep-ex] •

> Focus on basic search strategy without too much technical details



exotic physics at ATLAS

# Heavy Neutrino and Right Handed W



- > Left-right symmetric models: Keung-Senjanovic (KS) process
  - ✓ Assuming no mixing between flavors: two same flavor leptons (e,µ) + 2 jets final states
  - ✓ Heavy Dirac neutrino N<sub>R</sub>: opposite signed leptons
  - $\checkmark$  Heavy Majorana neutrino N<sub>R</sub>: 50% same (SS) and 50% opposite (OS) signed leptons
- > Background in OS final state:
  - ✓ Dominated by SM top & Z+jets: estimated using MC
  - ✓ Small contribution from diboson and W+jets
- Background in SS final state:
  - ✓ SM diboson and SM Z+jets (for ee only due to charge misidentification)
    - Charge misidentification from control sample
  - ✓ Largest bg from fake leptons (~60%)
    - estimated using fake factors from data

# Heavy Neutrino and Right Handed W

- > Defined signal (SR) and control (CR) region:
  - ✓ Events in CR to constrain the background estimation
- Signal extraction: Simultaneous binned likelihood fits to various kinematic variables of selected events in the signal and control regions
  - ✓ Simultaneous fit to SS and OS events for Majorana neutrino senario
- Systematic uncertainties taken into account as nuisance parameters in fits



## Heavy Neutrino and Right Handed W



SILAFAE2018, Nov 26-30, 2018

# Four Top Quark Production

- > SM 4 quark production ( $\sigma$ ~9.2fb), can be significantly enhanced by NP
- > Final state: 1 or 2 W boson decay leptonically
  - ✓ Single or dilepton + MET
  - high multiplicity of jets & b-jets
  - ✓ Hadronic top candidates tagged with large-R jets
- Dominated by SM top+jets production
  - ✓ Based on b-jet fake probability: assuming no correlation with jet multiplicity
- $\succ$  Distinguish signal from background using H<sub>T</sub>
  - $\checkmark$  H<sub>T</sub>: scalar sum of the jet P<sub>T</sub>
- > See talk by Leonid Serkin at this workshop for details



# Long-lived Neutral Particles (LLP)



Long lived neutral particles predicted by NP: Hidden/Dark sectors, SUSY ......
 Very unconventional experimental signatures, Eg:

- Jets associated with vertice significant away from the collision point
- Narrow jets with little energy deposition in the EM calorimeter, and no inner detector tracks
- Lepton jet: collinear jet-like structure containing leptons/pions

### Searches for LLP at ATLAS

A.	ATLAS Long-lived Particle Searches* - 95% CL Exclusion								ATLAS Preliminary		
Sta	atus: July 2018							ſĹ	$dt = (3.2 - 36.1) \text{ fb}^{-1}$	$\sqrt{s}$ = 8, 13 TeV	
	Model	Signature	∫£ dt [fl	p <sup>-1</sup> ]	Lifetime lim	it				Reference	
	$\operatorname{RPV} \chi_1^0 \rightarrow eev/e\mu v/\mu\mu v$	displaced lepton pair	20.3	$\chi_1^0$ lifetime		7-740 m	m		$m(\tilde{g})=$ 1.3 TeV, $m(\chi_1^0)=$ 1.0 TeV	1504.05162	
	$\operatorname{GGM}_{\chi_1^0} \to Z\tilde{G}$	displaced vtx + jets	20.3	$\chi_1^0$ lifetime		6-480 mm			$m(\tilde{g}) = 1.1 \text{ TeV}, \ m(\chi_1^0) = 1.0 \text{ TeV}$	1504.05162	
	$\operatorname{GGM}_{\mathcal{X}_1^0} \to Z\tilde{G}$	displaced dimuon	32.9	$\chi_1^0$ lifetime				0.029-18.0 m	$m(\tilde{g}) = 1.1 \text{ TeV}, m(\chi_1^0) = 1.0 \text{ TeV}$	CERN-EP-2018-173	
USY	GMSB	non-pointing or delayed 3	20.3	$\chi_1^0$ lifetime			0.08-5.4 m	1	SPS8 with $\Lambda{=}200\text{TeV}$	1409.5542	
	AMSB $\rho \rho \rightarrow \chi_1^{\pm} \chi_1^0, \chi_1^+ \chi_1^-$	disappearing track	20.3	$\chi_1^{\pm}$ lifetime			0.22-3.0 m		$m(\chi_1^{\pm})=450~{ m GeV}$	1310.3675	
	AMSB $\rho \rho \rightarrow \chi_1^{\pm} \chi_1^0, \chi_1^+ \chi_1^-$	disappearing track	36.1	$\chi_1^{\pm}$ lifetime		0.05	57-1.53 m		$m(\chi_1^{\pm})=450~{ m GeV}$	1712.02118	
ŝ	AMSB $\rho \rho \rightarrow \chi_1^{\pm} \chi_1^0, \chi_1^+ \chi_1^-$	large pixel dE/dx	18.4	$\chi_1^{\pm}$ lifetime			1.31-	9.0 m	$m(\chi_1^{\pm})=450~{ m GeV}$	1506.05332	
	Stealth SUSY	2 ID/MS vertices	19.5	<b>Š</b> lifetime				0.	<b>12-90.6 m</b> $m(\tilde{g}) = 500 \text{ GeV}$	1504.03634	
	Split SUSY	large pixel dE/dx	36.1	ĝ lifetime			> 0.9 m		$m(\tilde{g}) = 1.8 \text{ TeV}, m(\chi_1^0) = 100 \text{ GeV}$	CERN-EP-2018-198	
	Split SUSY	displaced vtx + $E_T^{miss}$	32.8	<b>ğ</b> lifetime			0.	03-13.2 m	$m(\tilde{g}) = 1.8 \text{ TeV}, \ m(\chi_1^0) = 100 \text{ GeV}$	1710.04901	
	Split SUSY	0 $\ell$ , 2 – 6 jets + $E_T^{miss}$	36.1	ĝ lifetime	-	-	0.0-2.1 m		$m( ilde{g}) =$ 1.8 TeV, $m(\chi_1^0) =$ 100 GeV	ATLAS-CONF-2018-0	
liggs BR = 10%	$H \rightarrow s s$	2 low-EMF trackless jets	20.3	s lifetime			0.41-7.5	7 m	m(s)= 25 GeV	1501.04020	
	$H \rightarrow s s$	2 ID/MS vertices	19.5	s lifetime				0.31-25.4 m	m(s)= 25 GeV	1504.03634	
	FRVZ $H \rightarrow 2\gamma_d + X$	2 e-, µ-jets	20.3	γd lifetime 0-3 mm					$m(\gamma_d) = 400 \text{ MeV}$	1511.05542	
	FRVZ $H \rightarrow 2\gamma_d + X$	2 <i>e</i> -, μ-, π-jets	3.4	γd lifetime		0.022-1.	113 m		$m(\gamma_d) = 400 \text{ MeV}$	ATLAS-CONF-2016-0	
	FRVZ $H \rightarrow 4\gamma_d + X$	2 <i>e</i> -, μ-, π-jets	3.4	$\gamma_d$ lifetime		0.0	38-1.63 m		$m(\gamma_d) = 400 \text{ MeV}$	ATLAS-CONF-2016-0	
•	$H \rightarrow Z_d Z_d$	displaced dimuon	32.9	Z <sub>d</sub> lifetime				0.009-24.0 m	$m(Z_d) = 40 \text{ GeV}$	CERN-EP-2018-173	
	$VH$ with $H \rightarrow ss \rightarrow bbbb$	$1-2\ell$ + multi-b-jets	36.1	s lifetime 0-3 mm				_	$\mathcal{B}(H \rightarrow ss) = 1, m(s) = 60 \text{ GeV}$	1806.07355	
	$\Phi(300 \text{ GeV}) \rightarrow s  s$	2 low-EMF trackless jets	20.3	s lifetime			0.29-7	.9 m	$\sigma \times \mathcal{B} = 1 \text{ pb}, m(s) = 50 \text{ GeV}$	1501.04020	
	$\Phi(300 \text{ GeV}) \rightarrow s  s$	2 ID/MS vertices	19.5	s lifetime				0.19-31.9 m	$\sigma \times \mathcal{B} = 1 \text{ pb}, m(s) = 50 \text{ GeV}$	1504.03634	
calar	$\Phi(\text{600 GeV}) \rightarrow ss$	2 low-EMF trackless jets	3.2	s lifetime			0.09-2.7 m		$\sigma \times \mathcal{B} = 1 \text{ pb, } m(s) = 50 \text{ GeV}$	ATLAS-CONF-2016-1	
ν.	$\Phi(900~\text{GeV}) \rightarrow ss$	2 low-EMF trackless jets	20.3	s lifetime			0.15-4.1 m		$\sigma \times \mathcal{B} = 1 \text{ pb}, m(s) = 50 \text{ GeV}$	1501.04020	
	$\Phi(900 \text{ GeV}) \rightarrow s s$	2 ID/MS vertices	19.5	s lifetime				0.11-18.3 m	$\sigma \times \mathcal{B} = 1 \text{ pb, } m(s) = 50 \text{ GeV}$	1504.03634	
	$\Phi(1 \text{ TeV}) \to s  s$	2 low-EMF trackless jets	3.2	s lifetime				0.78-16.0 m	$\sigma \times \mathcal{B} = 1 \text{ pb, } m(s) = 400 \text{ GeV}$	ATLAS-CONF-2016-1	
Other	HV $Z'(1 \text{ TeV})  ightarrow q_{ m v} q_{ m v}$	2 ID/MS vertices	20.3	s lifetime			0.1-4.9 m		$\sigma \times \mathcal{B} = 1 \text{ pb, } m(s) = 50 \text{ GeV}$	1504.03634	
	HV $Z'$ (2 TeV) $ ightarrow q_{ m v} q_{ m v}$	2 ID/MS vertices	20.3	s lifetime			0.1-	10.1 m	$\sigma \times \mathcal{B} = 1 \text{ pb, } m(s) = 50 \text{ GeV}$	1504.03634	
					0.01	0.1	1	10	<sup>100</sup> cτ [m]		
On	$\sqrt{s} = 8$ ly a selection of the av	vs = 13 TeV	on new	states is shown.					$(\gamma\beta=1)$		

#### All searches are for pair production of LLP so far

# Single LLP production with Z boson



- Single production of LLP predicted in NP scenarios
- General search with a very unique experiment signature: Displaced jet
- Dominated bg from Z+jets (jet fakes LLP signal)
  - ✓ Data driven approach for bg estimate
  - ✓ Measuring fake jet fake probability using W+jets
- > Counting experiment, different  $E_T$  cut for  $m_{\Phi}$ 
  - $\checkmark\,$  UL as a function of  $m_{\Phi_{\!_{\! T}}}m_{Zd}$  and lifetime of Zd





# Single LLP production with Z boson

Minimum jet $E_{\rm T}$	$40\mathrm{GeV}$	$60{ m GeV}$	$80\mathrm{GeV}$
Background	$175 \pm 22$	$33.0 \pm 4.4$	$13.2 \pm 3.5$
Data	158	35	16
Expected UL	65	17	10
Observed UL	50	18	13

[Ref] arXiv:1811.02542 [hep/ex]





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## Conclusion

- Very broad and rich exotic physics program at ATLAS
  - ✓ Only a few selected new results were reported here
  - ✓ Start to probe many possible new particles/NP scenario at TeV scale
  - ✓ Strong constraint for some NP scenario
- Current results still dominated by statistical limitation
  - ✓ Expect significantly better physics reach with more data (HL-LHC)



Sta	itus: July 2018								$\int \mathcal{L} dt = (1 - 1)^{2}$	3.2 – 79.8) fb <sup>-1</sup>	$\sqrt{s} = 8, 13 \text{ Te}$
	Model	$\ell, \gamma$	Jets†	E <sup>miss</sup>	∫£ dt[fb	-1]	Limit				Reference
	ADD Group data	0.6.4	1-41	Vac	26.1	Ma			7.7.701	2	1711.02201
2	ADD non-reconant w	2.4		100	26.7	Me.			7.7 TeV // = 2	* - * * * 7 NI O	1707 04147
tra dimension	ADD OBH	- /	21		37.0	Ma			8.9 TeV	n = 5 mil 1400	1703.09127
	ADD BH high Y av	>1.c.u	> 2 i		3.2	Ma			8.2 TeV	e = 6 Mo = 3 TeV rot BH	1606.02265
	ADD BH multijet		> 3 i	-	3.6	Ma			9.55 TeV	e = 6 Mo = 3 TeV rot BH	1512 02586
	BS1 $G_{KK} \rightarrow \gamma\gamma$	2 v		-	36.7	Gyv mass		4.1 TeV	0.00 101	$k(\overline{M}_{ci} = 0.1$	1707.04147
	Bulk BS $G_{WW} \rightarrow WW/ZZ$	multi-channe	મ		36.1	Gev mass		2.3 TeV		$k/\overline{M}_{ci} = 1.0$	CERN-EP-2018-17
1	Bulk RS $g_{KK} \rightarrow tt$	1 e, µ	≥ 1 b, ≥ 1J.	2i Yes	36.1	BKK MASS		3.8 TeV		$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	1 e, µ	$\geq 2 \text{ b}, \geq 3$	j Yes	36.1	KK mass		1.8 TeV		$Tier(1,1),\mathcal{B}(A^{(1,1)}\to tt)=1$	1803.09678
	$\operatorname{SSM} Z' \to \ell \ell$	2 e, µ	-	-	36.1	Z' mass		4.5 TeV			1707.02424
ons	SSM $Z' \rightarrow \tau \tau$	27		-	36.1	Z' mass		2.42 TeV			1709.07242 1805.09299
	Leptophobic $Z' \rightarrow bb$	-	2 b	-	36.1	Z' mass		2.1 TeV			
	Leptophobic $Z' \rightarrow tt$	1 e, µ	$\geq 1 \text{ b}, \geq 1 \text{J}$	2j Yes	36.1	Z' mass		3.0 TeV		$\Gamma/m = 1\%$	1804.10823
	SSM $W' \rightarrow \ell \gamma$	1 e, µ	-	Yes	79.8	W' mass		5.6	TeV		ATLAS-CONF-2018-
•	SSM $W' \rightarrow \tau v$	1 7	-	Yes	36.1	W' mass		3.7 TeV			1801.06992
	HVT $V' \rightarrow WV \rightarrow qqqq \mod q$	iΒ 0 <i>e</i> ,μ	2 J	-	79.8	V' mass		4.15 TeV		$g_V = 3$	ATLAS-CONF-2018-
	$HVT V' \rightarrow WH/ZH \mod B$	multi-channe	ы		36.1	V' mass		2.93 TeV		$g_V = 3$	1712.06518
	LRSM $W'_R \rightarrow tb$	multi-channe	ы		36.1	W' mass		3.25 TeV			CERN-EP-2018-14
0	CI qqqq	-	2 j	-	37.0	٨				21.8 TeV n <sub>LL</sub>	1703.09127
	Cliriqq	2 e, µ			36.1	A				40.0 TeV 7/12	1707.02424
	Citter	≥1 eµ	210, 21	Yes	36.1	٨		2.57 TeV		$ G_{4\ell}  = 4\pi$	CERN-EP-2018-1
M	Axial-vector mediator (Dirac DI	Λ) 0 e, μ	1 – 4 j	Yes	36.1	mined	1,	55 TeV		$g_q=0.25, g_q=1.0, m(\chi) = 1 \text{ GeV}$	1711.03301
	Colored scalar mediator (Dirac	DM) 0 e, µ	1 – 4 j	Yes	36.1	mixed		1.67 TeV		$g=1.0, m(\chi) = 1 \text{ GeV}$	1711.03301
	VV XX EFT (Dirac DM)	0 e, µ	1 J, ≤ 1 j	Yes	3.2	м,	700 GeV			m(χ) < 150 GeV	1608.02372
	Scalar LQ 1 <sup>st</sup> gen	2 e	≥ 2 j	-	3.2	LQ mass	1.1 Te)	/		$\beta = 1$	1605.06035
í -	Scalar LQ 2 <sup>nd</sup> gen	2 μ	≥ 2 j	-	3.2	LQ mass	1.05 TeV			$\beta = 1$	1605.06035
	Scalar LQ 3 <sup>rd</sup> gen	1 e, µ	≥1 b, ≥3	Yes	20.3	LQ mass	640 GeV			$\beta = 0$	1508.04735
	VLQ $TT \rightarrow Ht/Zt/Wb + X$	multi-channe	ы		36.1	T mass	1.37	TeV		SU(2) doublet	ATLAS-CONF-2018
	$VLQ BB \rightarrow Wt/Zb + X$	multi-channe	ы		36.1	B mass	1.34	TeV		SU(2) doublet	ATLAS-CONF-2018-
•	VLQ $T_{5/3} T_{5/3}   T_{5/3} \rightarrow Wt + \lambda$	2(SS)/≥3 e <sub>4</sub>	u ≥1 b, ≥1	Yes	36.1	T <sub>5/3</sub> mass	1	.64 TeV		$S(T_{5/3} \rightarrow Wt) = 1, c(T_{5/3}Wt) = 1$	CERN-EP-2018-1
	$VLQ Y \rightarrow Wb + X$	1 e, µ	≥ 1 b, ≥ 1	i Yes	3.2	Y mass	1.4	4 TeV		$\mathcal{D}(Y \rightarrow Wb) = 1, c(YWb) = 1/\sqrt{2}$	ATLAS-CONF-2016-
	$VLQ B \rightarrow Hb + X$	0 e,μ, 2 γ	≥ 1 b, ≥ 1	i Yes	79.8	B mass	1.21 T	eV		κ <sub>B</sub> = 0.5	ATLAS-CONF-2018-
	$VLQ QQ \rightarrow WqWq$	1 e, µ	≥ 4 j	Yes	20.3	Q mass	690 GeV				1509.04261
2	Excited quark $q^* \rightarrow qg$	-	2 j	-	37.0	q* mass		6.0	TeV	only $u^*$ and $d^*$ , $\Lambda = m(q^*)$	1703.09127
5	Excited quark $q^* \rightarrow q\gamma$	1γ	1 j	-	36.7	q* mass		5.3 T	eV	only $u^*$ and $d^*$ , $\Lambda = m(q^*)$	1709.10440
;	Excited quark $b^* \rightarrow bg$	-	1 b, 1 j	-	36.1	b* mass		2.6 TeV			1805.09299
2	Excited lepton l*	3 e, µ		-	20.3	l* mass		3.0 TeV		A = 3.0 TeV	1411.2921
S.	Excited lepton v*	3 e, µ, τ	-	-	20.3	y" mass		1.6 TeV		A = 1.6 TeV	1411.2921
	Type III Seesaw	1 e, µ	≥ 2 j	Yes	79.8	N <sup>®</sup> mass	560 GeV	0.07-14		(M/ ) 2.4.768 ex min	ATLAS-CONF-2018
	Linow majorana v	234 e. µ	2]		20.3	N* mass	970 CeV	2.0 164		m(vrg) = 2.4 kW, no moving	1710.00748
	Higgs triplet $H^{\pm\pm} \rightarrow \ell \tau$	3 e u T	-		20.1	Mill man	400 GeV			DY production $\mathcal{B}(H^{*+} \rightarrow \ell^{-1}) = 1$	1411 2924
	Monoton (non-res prod)	1.0.4	1.h	Vae	20.3	spin-1 invisible particle mass	657 GeV			$a_{11} = 0.2$	1410 5404
	Multi-charged particles	-	-	- 100	20.3	multi-charged particle mass	785 GeV			DY production, [c] - 5e	1504.04188
	Magnetic monopoles	_	_		7.0	monopole mass	1 24	TeV		DY production, $ g  = 1g_0$ , spin 1/2	1509.08059
	magnese menopolea		-		2.0	a contract of the second se	1.04				1038,00008
-		$\sqrt{s} = 8 \text{ TeV}$	$\sqrt{s} = 1$	3 TeV		10-1					



## The ATLAS Detector

