

14th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2022)

Searches for new physics with leptons using the ATLAS detector



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31/08/2022



- Light charged leptons have a very clean detector signature and are "easy" to reconstruct and identify.
 - \star ATLAS is adding more and more of analyses with challenging τ in the final state.
- There are multiple open questions regarding lepton properties, e.g.
 Which mechanism generates neutrino masses?
 How to explain the flavour dependence of Yukawa coupling strength?
- ★ Recent observations provide some hints on new physics, e.g.
 - ★ Lepton Flavour Universality (LFU) violation in B meson decays (<u>Eur. Phys.</u> <u>J. C 81, 226 (2021)</u>),
 - ★ Muon anomalous magnetic moment $(g 2)_{\mu}$ discrepancy (<u>Phys. Rev.</u> Lett. 126, 141801).

Searches with ATLAS



... with leptons in the final states (typically isolated, high-pt e, μ, τ)

Direct searches

- ★ W' search,
- \star Vector like au's
- ★ Type-III seesaw (heavy leptons),
- ★ Doubly Charged Higgs boson (covered by Christian Weber),

full Run 2 ATLAS dataset (139 fb⁻¹)

Indirect searches

- ★ General multilepton,
- ★ Lepton Flavour Violation (LFV) in Z boson decays,
- ★ Charge/flavour x-sec asymmetry.



Searches for heavy gauge bosons

★ ATLAS performed searches for the new gauge bosons within the Sequential Standard Model (SSM), which is the flavour-universal benchmark model.



- ★ Past analyses provided upper mass limits of 6 TeV for the W' boson and 5.1 TeV for the Z' boson at 95% CL from the:
 - ★ [EXOT-2018-30]: $W' \rightarrow \ell \nu$ decay, where $\ell = e, \mu$;
 - ★ [EXOT-2018-08]: $Z' \rightarrow \ell \ell$ decay.

★ These results have now been complemented with analysis of $W' \rightarrow \tau \nu$ decays: [ATLAS-CONF-2021-025]



visible decay products, typically one or three charged pions and up to two neutral pions.

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Search for $W' \to \tau_{had} \nu$ decays I

- ★ Only hadronic \u03c6 decay modes that are identified with a Recurrent Neural Network (RNN) are considered (~65% of all \u03c6 decays):
 - ★ RNN uses <u>calorimeter shower shape</u> and <u>tracking</u> <u>information</u> to suppress background.

★ Signature of the $W' \rightarrow \tau \nu$ decays:

- \star High transverse momentum of au decays,
- \star Large missing transverse momentum, E_T^{miss} .
- \star Discriminant variable:

$$m_T = \sqrt{2 \ E_T^{miss} p_T \ (1 - \cos \Delta \phi)}.$$

- ★ Main backgrounds:
 - \star off-shell $W \rightarrow \tau \nu$ (simulation),
 - ★ QCD jets (*data-driven*),
 - ★ Other: $W/Z/\gamma^*$ decays, $t\overline{t}$, single top-quark, VV.











Search for $W' \to \tau_{had} \nu$ decays II

- ★ No significant excess over SM prediction observed.
- ★ Investigated models and their corresponding limits:
 - ★ Sequential Standard Model (SSM): Heavy W' bosons with masses up to 5.0
 TeV are excluded at 95% CL (SSM assumes the same couplings as for SM W boson).
 - Non-Universal Gauge Interaction Model (NUGIM):

For non-universal couplings, W' bosons are excluded for masses less than **3.5 – 5.0 TeV**, depending on the model parameters. Values of $\cot \theta_{NU} > 1$ enhance the couplings to the third generation.







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Vector like τ 's II



★ No excess of events above SM expectation.



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Type-III seesaw heavy leptons I

- \star At least one extra fermionic SU(2) triplet predicted by the type-III seesaw mechanism:
 - \star Pair production of new heavy charged (L^{\pm}) and neutral (N^{0}) leptons.



★ A heavy Majorana neutrino could explain the small masses of SM neutrinos.



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Type-III seesaw heavy leptons II

- ★ Only **light leptons** (e, μ) considered in the final states with **democratic scenario** $\mathscr{B}_e = \mathscr{B}_\mu = \mathscr{B}_\tau = 1/3.$
- ★ Main backgrounds:
 - Reducible: fake/non-prompt (FNP) leptons,
 - ★ Irreducible: diboson (VV), rare top ($t\bar{t}V$).

 The measurement is statistically limited.





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Type-III seesaw heavy leptons III

- ★ No significant excess over SM prediction observed.
- ★ Most stringent limits on type-III seesaw models at LHC:







- ★ As seen in previous slides, several BSM theories give multi-lepton $(3\ell +, \ell = e, \mu)$ final states.
- ★ A search with minimal model dependence of BSM physics aimed to cover wide range of potential new-physics simultaneously in three- and four-lepton final states.
- ★ 22 signal regions were constructed according to number of the leptons, invariant mass of the leptons, the missing transverse momentum and the presence of leptons originating from Z boson decay.



Model specific limits

Model	Mass [GeV]	$\sigma_{ m exp}^{95}$	[fb]	$\sigma_{\rm obs}^{95}$ [fb]		
Type-III Seesaw	400	41	+17 -11	27		
	700	12	+5 -3	8.8		
$H^{\pm\pm}$	300	0.18	$^{+0.08}_{-0.05}$	0.12		
	500	0.16	$^{+0.07}_{-0.05}$	0.11		

 3ℓ and 4ℓ final states considered, where $\ell = e, \mu$.





- ★ Lepton Flavour Violation (LFV) is extremely rare within the SM:
 - ★ e.g. possible through neutrino oscillations with $\mathscr{B}(Z \to e\mu) < \sim 10^{-54}$,
 - excellent probe of new physics deviation would immediately indicate new physics,
 - \star very small signal in a huge background.
- ★ ATLAS analyses have been published recently:
 - ★ $Z \rightarrow e\tau$ and $Z \rightarrow \mu\tau$: [EXOT-2018-36] hadronic τ decays results and [EXOT-2020-28] leptonic ones,
 - ★ $Z \rightarrow e\mu$: [EXOT-2018-35].
- ★ Machine learning methods have been used to discriminate between signal and background.



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LFV in $Z \rightarrow e\tau$ and $Z \rightarrow \mu\tau$ decays I

 \star Previous search for Z boson LFV decays involving τ leptons done with τ decaying hadronically [EXOT-2018-36]:

 $\star \mathscr{B}(Z \to e \tau_{had}) < 8.1 \times 10^{-6} \text{ and } \mathscr{B}(Z \to \mu \tau_{had}) < 9.5 \times 10^{-6}.$

 \star ... were complemented with inclusion of **leptonically** decaying τ , which significantly improved the sensitivity reach for the $Z \rightarrow \ell \tau$ decays [EXOT-2020-28].

★ Signal signature $Z \rightarrow \ell^{\pm} \ell^{\prime \mp} + 2\nu$:

- ***** two light charged leptons (different flavour + opposite charge) and two neutrinos,
- \star Invariant mass of the final state close to the Z boson mass,
- **two leptons** emitted approximately **back-to-back**,
- $\star \tau$ is typically **boosted** \rightarrow two neutrinos collinear with the light lepton from the au decay.
- ★ Main backgrounds:
 - ★ lepton flavor conserving $Z \rightarrow \tau \tau \rightarrow \ell \ell' + 4\nu$,
 - $\star t\bar{t}, VV$, Higgs production,
 - \star small contribution of $Z \to \ell \ell$ with flavour of one ℓ being misidentified.





background

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signal





LFV in $Z \rightarrow e\tau$ and $Z \rightarrow \mu\tau$ decays II

Events / 0.025



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arXiv:2105

- ★ Signal was optimised using deep neural network:
 - ★ It was individually trained on main backgrounds: $Z \rightarrow \tau \tau; t\bar{t}; VV.$
- ★ Search is dominated by the statistical uncertainty.
- ★ Upper limits improved and are now by a factor of 2 better compared to LEP limits



LFV Z decay	previous UL	only τ_{lep} decays UL	new combined UL
$ \begin{array}{l} \mathcal{B}(Z \to e\tau) \\ \mathcal{B}(Z \to \mu\tau) \end{array} $	9.8×10^{-6} [OPAL] 12×10^{-6} [DELPHI]	7.0×10^{-6} 7.2×10^{-6}	5.0×10^{-6} 6.5×10^{-6}

@ 95% CL



LFV in $Z \rightarrow e\mu$ decays



- ★ Search for a $Z \rightarrow e\mu$ peak in the $m_{e\mu}$ invariant mass distribution.
- ★ Main backgrounds:

 $\star Z \to \tau \tau \to e \mu \nu_e \nu_\mu \nu_\tau \nu_\tau,$

 $\star Z \rightarrow \mu \mu$ with μ misidentified as an electron,

 $\star t\bar{t} \to e\mu\nu\bar{\nu}b\bar{b}$ and $WW \to e\mu\nu\bar{\nu}$.

flat polynomial fit

estimated from MC

- \star Analysis strategy:
 - \star Veto events with high- p_T jets and large E_T^{miss} ,
 - ★ Further signal optimisation and background rejection by BDT and b-veto.
- ★ Analysis is statistically limited both in data and simulation.



 $\mathscr{B}(Z \to e\mu) < 2.62 \ (2.37) \times 10^{-7}$ observed (expected) @ 95% CL.

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★ Novel search at ATLAS compares production cross-sections for $e^+\mu^-$ and $e^-\mu^+$ pairs to constrain BSM physics processes [EXOT-2018-29].

Search for $e^+\mu^-$ to $e^-\mu^+$ asymmetry I

- ★ Standard Model predicts the ratio to be 1, but several BSM theories predict ρ to be significantly greater than one:
 - ★ **R-parity-violating (RPV) SUSY** models with smuons $\tilde{\mu}_{L}$,
 - ★ scalar leptoquark with couplings permitting $S_1 \rightarrow ue^-, c\mu^-$.

$$\rho \equiv \frac{\sigma(pp \to e^+\mu^- + X)}{\sigma(pp \to e^-\mu^+ + X)}$$

arXiv:2112.08090

 \star Signal regions designed to address these scenarios:



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Search for $e^+\mu^-$ to $e^-\mu^+$ asymmetry II

- ★ Experimental effects bias the measured ratio (ρ) downwards, e.g. mis-ID e vs. μ , $\sigma(W^+j) > \sigma(W^-j)$ analysis is searching for positive deviations of ρ .
- Analysis is almost completely data-driven (mis-ID leptons, detector effects in muon reconstruction).
- ★ Data is consistent with the SM hypothesis, so upper limits on RPV SUSY and LQ models are set.







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Leptoquarks I

- ★ Good candidates to explain observed *B*-anomalies and $(g-2)_{\mu}$ predictionmeasurement discrepancy.
- ★ Search for scalar and vector leptoquarks singly-produced or pair-produced with the ATLAS detector

$$\star LQ_s \to b\tau_{had}/b\tau_{lep}\dots + \tau_{had}$$

$$(4/3e, 3B + L = -2)$$

$$\star LQ_{mix}^{u(d)}LQ_{mix}^{u(d)} \to t\nu b\ell/t\ell b\nu$$

(s:-1/3e, s & v: 2/3e, $\ell = e, \mu$)

$$\star LQ^{d}_{mix}LQ^{d}_{mix} \to t\ell t\ell (-1/3e, \ell = e, \mu)$$



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Leptoquarks II

- \star Event selections:
 - \star lepton+ τ or $\tau\tau$, opposite charge, $\geq 1 b$ -jets...
 - \star MET trigger, ≥ 4 jets, ≥ 1 b-jets
 - \star Single and di-lepton triggers, ≥ 2 jets, $\geq 1 b$ -jets
- ★ Main backgrounds:
 - $\star t\bar{t}$, single t, fake τ
 - \star W + jets, $t\bar{t}$, single t
 - \star $t\bar{t}W$, $t\bar{t}Z$, VV, non-prompt ℓ
- ★ No significant excess above SM predictions
- ★ The limits for masses excluded set for different decay scenarios, branching ratios and coupling strengths





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Summary



- No evidence was found (yet) looking at many final states containing leptons.
- ★ The lower/upper limits are still improving with more and more data being available and new analysis techniques developed.
- ★ We are all excited to see new fresh 'Run 3' data being already recorded!

Model Status ADD Grkt + 1 ADD OBH ADD OBH ADD BD BH BUK RS Grkt - 1 Buk RS Grkt - 1 SSM Z' - 1 SSM Z' - 1 SSM Z' - 1 SSM Z' - 1 SSM W' - 1 SSM W' - 1 SSM W' - 1 SSM W' - 1 SSM W' - 1 Laptophobic SSM W' - 1 LRSM W _R C (1 agag C (1 agag C (1 agag	g/q sonant $\gamma\gamma$ ittijet $\gamma\gamma$ WW/ZZ $\kappa \rightarrow WV \rightarrow \ell \nu qq$ $\kappa \rightarrow tt$ $Z' \rightarrow bb$ $Z' \rightarrow tt$ $\ell \ell$ $\ell \ell$ t' t'' t''' t''''''''''''''''''	ℓ, γ $0 e, \mu, \tau, \gamma$ 2γ multichanne $1 e, \mu$ $1 e, \mu$ 1	Jets† 1-4j 2j 2j/1J ≥jt, ≥1J/2 ≥2b, ≥3j - 2b ≥1b, ≥2J - 2b	Emiss Tes - - - Yes Yes Yes Yes	∫£ dt[fb 139 36.7 37.0 3.6 139 36.1 139 36.1 139 36.1 139 36.1 36.1 36.1 139 36.1	⁻¹] Mb Ms Mth Mth G _{KK} mass G _{KK} mass G _{KK} mass KK mass KK mass Z' mass Z' mass	Limit	4.5 Te 2.3 TeV 2.0 TeV 3.8 TeV 1.8 TeV	11.2 Te ¹ 8.6 TeV 8.9 TeV 9.55 TeV V		2102.10874 1707.04147 1703.09127 1512.02586 2102.13405 1808.02380 2004.14638 1804.10823
ADD G_{KK} + ADD QBH ADD QBH ADD QBH RS1 G_{KK} - Bulk RS G_{K} Bulk RS G_{K}	\mathcal{E}/q sonant $\gamma\gamma$ withjet $\gamma\gamma$ WW/ZZ $\kappa \rightarrow WV \rightarrow \ell\nu qq$ $\kappa \rightarrow tt$ $\mathcal{E}' \rightarrow bb$ $\mathcal{E}' \rightarrow bb$ $\mathcal{E}' \rightarrow bb$ $\mathcal{E}' \rightarrow bb$ $\mathcal{E}' \rightarrow bb$ $\mathcal{E}' \rightarrow bb$ $\mathcal{E}' \rightarrow \mathcal{E}' q model$ $WZ \rightarrow \ell\kappa^2 \ell'' model B$	$\begin{array}{c} 0 \ e, \mu, \tau, \gamma \\ 2 \ \gamma \\ - \\ 2 \ \gamma \\ \end{array}$ multi-channe 1 \ e, \mu 1 \ e, \mu \\ 1 \ e, \mu \\ 2 \ \tau \\ - \\ 0 \ e, \mu \\ 1 \ e, \mu \\ 1 \ r \\ \end{array}	1 - 4j -2j $\ge 3j$ $\ge 1b, \ge 1J/2$ $\ge 2b, \ge 3j$ -2b $\ge 1b, \ge 2J$ -2b $\ge 1b, \ge 2J$	Yes - - Yes Yes Yes - - - Yes	139 36.7 37.0 3.6 139 36.1 139 36.1 36.1 139 36.1 36.1	М _D Ms Mth G _{KK} mass G _{KK} mass G _{KK} mass KK mass KK mass Z' mass Z' mass		4.5 Te 2.3 TeV 2.0 TeV 3.8 TeV 1.8 TeV	11.2 Te ¹ 8.6 TeV 8.9 TeV 9.55 TeV V	$ \begin{array}{l} n = 2 \\ n = 3 \; \text{HIZ NLO} \\ n = 6 \\ m = 6, \; M_0 = 3 \; \text{TeV, rot BH} \\ k \; M_{P } = 0.1 \\ k \; M_{P } = 1.0 \\ \Gamma m = 15\% \\ \Gamma m = 15\% \end{array} $	2102.10874 1707.04147 1703.09127 1512.02586 2102.13405 1808.02380 2004.14636 1804.10823
SSM $Z' \rightarrow$ SSM $Z' \rightarrow$ Leptophobic Leptophobic SSM $W' \rightarrow$ SSM $W' \rightarrow$ HVT $W' \rightarrow$ HVT $W' \rightarrow$ LRSM W_R Cl qqqq	$ \begin{array}{l} \ell\ell \\ \tau\tau \\ \geq Z' \rightarrow bb \\ \ell\nu \\ \ell\nu \\ \tau b \\ WZ \rightarrow \ell\nu \ell'\ell' \text{ model} \\ WZ \rightarrow \ell\nu \ell'\ell' \text{ model} \\ WH \text{ model} \\ B \\ \rightarrow Wh \end{array} $	2 e, µ 2 r - 0 e, µ 1 e, µ 1 r - B 1 e, µ	- 2 b ≥1 b, ≥2 J -	- - Yes	139 36.1 36.1	Z' mass Z' mass				$(101(1,1), D(A^{*})^{\prime} \rightarrow tt) = 1$	1803.09678
CI qqqq CI ℓℓqq	· /····	10 3 e, μ 0 e, μ 2 μ	≥1 b, ≥1 J 2 j / 1 J 2 j (VBF) ≥1 b, ≥2 J 1 J	Yes - Yes Yes -	139 139 139 139 139 139 139 139 139 80	Z' mass Z' mass W' mass W' mass W' mass W' mass W' mass W' mass W' mass	340 GeV	5.1 2.42 TeV 2.1 TeV 4.1 TeV 5.0 4.4 Te 4.3 TeV 3.2 TeV 5.0	IEV IO TEV IEV I	$\Gamma/m = 1.2\%$ $g_V = 3$ $g_V c_{1f} = 1, g_f = 0$ $g_V = 3$ $m(N_R) = 0.5$ TeV, $g_L = g_R$	1903.06248 1709.07242 1805.09299 2005.05138 1906.05609 ATLAS-CONF-2021-0 2004.14636 ATLAS-CONF-2022-0 2007.05293 1904.12679
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		$\begin{array}{c c} \textbf{21.8 TeV} & \eta_{LL}^- \\ \textbf{35.8 TeV} \\ \textbf{g}_* = 1 \\ \textbf{g}_* = 1 \\ C_{4t} = 4\pi \end{array} \eta_{LL}^-$	1703.09127 2006.12946 2105.13847 2105.13847 1811.02305
Axial-vector Pseudo-sca Vector med. Pseudo-sca	med. (Dirac DM) lar med. (Dirac DM) . Z'-2HDM (Dirac DM) lar med. 2HDM+a	0 e, μ, τ, γ 0 e, μ, τ, γ M) 0 e, μ multi-channe	1 – 4 j 1 – 4 j 2 b	Yes Yes Yes	139 139 139 139	m _{med} m _{med} m _{med}	376 GeV 560 GeV	2.1 TeV 3.1 TeV		$\begin{array}{l} g_{q}=0.25, g_{\chi}=1, \ m(\chi)=1 \ {\rm GeV} \\ g_{q}=1, \ g_{\chi}=1, \ m(\chi)=1 \ {\rm GeV} \\ \tan\beta=1, \ g_{Z}=0.8, \ m(\chi)=100 \ {\rm GeV} \\ \tan\beta=1, \ g_{\chi}=1, \ m(\chi)=10 \ {\rm GeV} \end{array}$	2102.10874 2102.10874 2108.13391 ATLAS-CONF-2021-0
Scalar LQ 1 Scalar LQ 2 Scalar LQ 3 Scalar LQ 3 Scalar LQ 3 Scalar LQ 3 Scalar LQ 3 Vector LQ 3	st gen nd gen rd gen rd gen rd gen rd gen	$\begin{array}{c} 2 \ e \\ 2 \ \mu \\ 1 \ \tau \\ 0 \ e, \mu \\ \geq 2 \ e, \mu, \geq 1 \ \tau \\ 0 \ e, \mu, \geq 1 \ \tau \\ 1 \ \tau \end{array}$	$\geq 2 j$ $\geq 2 j$ $\geq 2 j$ $\geq 2 j$, $\geq 2 b$ $r \geq 1 j$, $\geq 1 b$ 0 - 2 j, $2 b2 b$	Yes Yes Yes - Yes Yes Yes	139 139 139 139 139 139 139 139	LQ mass LQ mass LQ" mass LQ" mass LQ ⁴ mass LQ ⁴ mass LQ ⁴ mass		1.8 TeV 1.7 TeV 1.2 TeV 1.24 TeV 1.43 TeV 1.43 TeV 1.66 TeV 1.77 TeV		$\begin{array}{l} \beta = 1 \\ \beta = 1 \\ \mathcal{B}(\mathrm{ILQ}_3^{\mathrm{c}} \rightarrow \mathrm{br}) = 1 \\ \mathcal{B}(\mathrm{IQ}_3^{\mathrm{c}} \rightarrow \mathrm{tr}) = 1 \\ \mathcal{B}(\mathrm{IQ}_3^{\mathrm{c}} \rightarrow \mathrm{tr}) = 1 \\ \mathcal{B}(\mathrm{IQ}_3^{\mathrm{c}} \rightarrow \mathrm{br}) = 1 \\ \mathcal{B}(\mathrm{IQ}_3^{\mathrm{c}} \rightarrow \mathrm{br}) = 0.5, \mbox{ YM coupl.} \end{array}$	2006.05872 2006.05872 2108.07665 2004.14060 2101.11582 2101.12527 2108.07665
VLQ $TT \rightarrow$ VLQ $BB \rightarrow$ VLQ $T_{5/3}T_{7}$ VLQ $T \rightarrow F$ VLQ $T \rightarrow F$ VLQ $Y \rightarrow 1$ VLQ $B \rightarrow F$	$\begin{array}{c} Zt + X \\ Wt/Zb + X \\ S_{3} T_{5/3} \rightarrow Wt + X \\ t/Zt \\ Wb \\ tb \end{array}$	$\begin{array}{c} 2e/2\mu/{\geq}3e,\mu\\ \text{multi-channe}\\ 2(SS)/{\geq}3\ e,\mu\\ 1\ e,\mu\\ 1\ e,\mu\\ 0\ e,\mu\end{array}$	$i \ge 1 b, \ge 1 j$ $i \ge 1 b, \ge 1 j$ $i \ge 1 b, \ge 1 j$ $i \ge 1 b, \ge 3 j$ $i \ge 1 b, \ge 1 j$ $i \ge 2b, \ge 1j, \ge 1$	- Yes Yes J -	139 36.1 36.1 139 36.1 139	T mass B mass T _{5/3} mass T mass Y mass B mass		1.4 TeV 1.34 TeV 1.64 TeV 1.8 TeV 1.85 TeV 2.0 TeV		$\begin{array}{l} SU(2) \mbox{ doublet} \\ SU(2) \mbox{ doublet} \\ \mathcal{B}(T_{5/3} \to Wt) = 1, \ c(T_{5/3} \ Wt) = 1 \\ SU(2) \mbox{ singlet}, \ \kappa_T = 0.5 \\ \mathcal{B}(Y \to Wb) = 1, \ c_R(Wb) = 1 \\ SU(2) \mbox{ doublet}, \ \kappa_B = 0.3 \end{array}$	ATLAS-CONF-2021-0 1808.02343 1807.11883 ATLAS-CONF-2021-0 1812.07343 ATLAS-CONF-2021-0
Excited qua Excited qua Excited qua Excited lept Excited lept Excited lept	$\operatorname{rk} q^* \rightarrow qg$ $\operatorname{rk} q^* \rightarrow q\gamma$ $\operatorname{rk} b^* \rightarrow bg$ $\operatorname{on} \ell^*$ $\operatorname{on} \nu^*$	1γ 3 e, μ 3 e, μ, τ	2j 1j 1b,1j - -		139 36.7 36.1 20.3 20.3	q* mass q* mass b* mass t* mass r* mass		5.3 2.6 TeV 3.0 TeV 1.6 TeV	6.7 TeV 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 1805.09299 1411.2921 1411.2921
Type III See LRSM Majo Higgs triplet Higgs triplet Higgs triplet Multi-charge Magnetic m	saw rana v $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$ $H^{\pm\pm} \rightarrow \ell \ell$ $H^{\pm\pm} \rightarrow \ell \tau$ solutions onopoles	2,3,4 e, µ 2 µ 2,3,4 e, µ (SS 3 e, µ, τ - -	≥2 j 2 j 3) various 3) - - -	Yes - Yes - - -	139 36.1 139 139 20.3 36.1 34.4	N ⁰ mass N _R mass H ^{±±} mass H ^{±±} mass H ^{±±} mass multi-charged partit monopole mass	9 350 GeV 400 GeV cle mass	10 GeV 3.2 TeV 1.08 TeV 1.22 TeV 2.37 TeV		$\begin{split} m(W_R) &= 4.1 \text{ TeV}, g_L = g_R \\ \text{DY production} \\ \text{DY production} \\ \text{DY production}, & \text{S}(H_L^{t*} \to \ell \tau) = 1 \\ \text{DY production}, g = 5e \\ \text{DY production}, g = 1 g_D, \text{ spin } 1/2 \end{split}$	2202.02039 1809.11105 2101.11961 ATLAS-CONF-2022-0 1411.2921 1812.03673 1905.10130

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



Backup

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Doubly charged Higgs I

- \star Searching for $H^{\pm\pm}$ pair production in all lepton flavour and charge combinations: $H^{\pm\pm} \rightarrow \ell^{\pm} \ell^{\prime\pm}$, $\ell, \ell' = e, \mu, \tau$.
- ★ Left-Right Symmetric Model (LRSM) within type-II seesaw mechanism: two chiralities $H_I^{\pm\pm}$ and $H_R^{\pm\pm}$ (different production cross-section due to different coupling to Z).
- ★ Type-II seesaw mechanism: arguably simplest known way to account for the smallness of the neutrino masses.
- ★ Lepton-Flavour Violation is allowed.
- \star Three possible $H^{\pm\pm}$ decay modes:
 - ★ leptonic: $H^{\pm\pm} \rightarrow \ell^{\pm} \ell^{'\pm}$.
 - \star bosonic: $H^{\pm\pm} \to W^{\pm}W^{\pm}$,
 - \star mixed: $H^{\pm\pm} \rightarrow H^{\pm}W^{\pm}$.

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★ The value of the free model parameter $v_{\Lambda} \rightarrow 0$ GeV: exclude decays to bosons.



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ATLAS-CONF

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Doubly charged Higgs II

★ Only **light leptons** (e, μ) considered in the final states with democratic scenario:

$$\mathscr{B}_{ee} = \mathscr{B}_{e\mu} = \mathscr{B}_{e\tau} = \mathscr{B}_{\mu\mu} = \mathscr{B}_{\mu\tau} = \mathscr{B}_{\tau\tau} = 1/6.$$

- ★ Analysis signature: prompt, isolated, same-charge, high-p_T
 lepton pairs.
- ★ Main backgrounds:
 - Reducible: fake/non-prompt (FNP) leptons,
 - \star Irreducible: diboson (VV), Drell-Yan.
- The measurement is statistically limited.







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Doubly charged Higgs III

★ No significant excess, $H_L^{\pm\pm}$ with masses below **1010 GeV** and $H_R^{\pm\pm}$ with masses below **880 GeV** are excluded at 95% CL.

★ Can be interpreted in multiple models.



 $m(H^{\pm\pm}) > 1080 \ (1040^{+40}_{-60}) \ GeV$ observed (expected) @ 95% CL.

observed combined lower limit



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