



Searches for new phenomena in leptonic final states using the ATLAS detector

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What lies beyond Standard Model?



Although SM is complete and self-consistent, it does not describe all the phenomena we observe (gravity, dark matter).



A Belov Fire from collection In the darkness

In the darkness: searching for BSM phenomena



This talk focuses on NEW results in final states with leptons which provide excellent sensitivity to new phenomena through clean signals and good background discrimination



A Belov Fire from collection In the darkness

Talk Outline

- Lepton performance at high transverse energy/momentum (E_T/p_T)
- Search for periodic signals in ee/yy
- Resonant searches in $e\mu$, $e\tau_{had}$, $\mu\tau_{had}$
- Quantum black hole search in e/µ+jet
- Excited τ search
- Searches for heavy neutrinos in
 - in same sign WW scattering
 - charged leptons and jets

Results based on 139-140 fb⁻¹ of proton-proton collision data collected in 2015-2018



Electron performance in offline and trigger



Muon performance in offline and trigger

Combine track reconstructed in the muon spectrometer and the inner detector Single muon trigger efficiency: 12 m

MDT



0.4 0.3

500

1000

1500

True muon p₊ [GeV]

STAND WITH

Tau performance in offline and trigger

- $\begin{array}{c} \pi^{-} \\ \pi^{0} \\ \pi^{+} \\ \pi^{+} \end{array}$
- <u>Track classifier efficiency</u> is 95% (93%) for 1 (3)-prong taus.
- Average <u>track association efficiency</u> improved ~70% => >90% (65% => 75%) for 1(3)-prong taus compared to early Run 2.
- Identification efficiency 60-95% (45-95%) for 1 (3)-prong taus.
- <u>Rejection of misidentified tau-had candidates</u> improved by 50–100% wrt RNN deployed in the end of Run 2.
- <u>Rejection of electrons</u> improved by 3 wrt the previous
 BDT-based algorithm: 85%–95% (90%–98%) for 1-prong
 (3-prong) tau had-vis for rejection of 2000–300 (200–90)
- <u>Decay mode classification</u>, based on a Neural Network algorithm, achieves a diagonal efficiency of about 82%, ~9% higher than BDT algorithm used during Run 2.
- <u>Energy resolution</u> 4.5%–6% (4%–5%) for 1 (3)-prong tau
- Trigger improvements closely follow offline developments



Truth $p_{\tau}(\tau_{had-vis})$ [GeV]





Not all improvements included in searches presented. Only hadronic tau decays.

Truth $p_{T}(\tau_{had-vis})$ [GeV]

Searches for periodic signals (ee/yy)



(Non)resonant searches <u>ee/yy</u> have no sensitivity to such small signals =>

Novel search technique based on continuous wavelet transforms.

Infer the frequency of periodic signals from the invariant mass spectra:



x=(m-β)/ α , α is inversely proportional to frequency, β is translational parameter

Quantum gravity models, e.g. Clockwork/Linear dilaton, result in towers of resonances w/ small splittings in mass spectrum

k, onset of Kaluza-Klein graviton spectrum

 M_5 , 5D reduced Planck mass, cross-section $\propto 1/M_5^3$ (small)



Submitted to JHEP arxiv:2305.10894

Results of the Clockwork search

 $W(\alpha,\beta) = \frac{1}{\sqrt{\alpha}} \int_{-\infty}^{+\infty} f(m) \psi^*\left(\frac{m-\beta}{\alpha}\right) dm$

Neural network classifier enhances sensitivity to periodic resonances NN score => test-statistic

No excess is observed: limits are set



ATLAS

[GeV] α 1000

300

100

30

Mass-frequency scalograms



More resonant dilepton searches: eµ, e τ_{had} , $\mu \tau_{had}$

Models: LFV Z', scalar neutrinos in RPV SUSY, Quantum Black Holes (QBH ADD/RS) Signature 2 back-to-back leptons, no b-jets Bkgs: W+jets/multijet (FNP) data-driven; ttbar and WW use CR for normalization; the rest is MC-only Result: No significant excesses observed.



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Search for QBH \rightarrow ej, μ j

<u>Signature</u>: 1 light lepton & 1 jet p_T >130GeV each, no other light leptons >10GeV or jets >130GeV <u>Bkgs</u>: multijet data-driven; ttbar, Z/W+jets CR for normalization; the rest from MC <u>Result</u>: No significant excesses observed.

95% CL on threshold mass of QBH >9.2TeV in ADD n = 6 (was 5.3 TeV in 20.3fb⁻¹ @ 8 TeV)





Search for excited tau-leptons

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ттjj final state: 4-fermion contact interaction production and decay <u>Fit</u> on $S_T = \sum p_T(\tau_{had} \tau_{had}, j^1 j^2)$ Bkg: $Z \rightarrow \tau \tau$, ttbar and single-top use CR τ^{-} Λ No excess over SM observed. Excluded: m_{r*} up to 4.6 TeV Events / 200 GeV 95% CL limit on σ [fb] **ATLAS** 13 TeV, 139.0 fb⁻¹ 95% CL lower limit on Λ [TeV] ATLAS Exp.sig Obs.sig ATLAS $\Lambda = m_{r^*}$ 10⁴ = 13 TeV 139 fb⁻¹ Top 13 TeV, 139.0 fb⁻¹ Observed Other SR Fakes $q\bar{q} \rightarrow \tau \tau^* \rightarrow \tau \tau i j$ 10^{2} $q\bar{q} \rightarrow \tau \tau^* \rightarrow \tau \tau \parallel$ Theo. uncert. WUncert. • Data Expected Expected $\pm 1\sigma$ 10 Expected $\pm 2\sigma$ 10² 10 10 Data / SM heoretical $\Lambda = 10 \text{TeV}$ 1.4E 1.2Ē Observed 10^{-2} Expected 1.0 Expected $\pm 1\sigma$ 0.8Ē Expected $\pm 2\sigma$ 0.6Ē 500 1000 10^{-3} 2000 3000 4000 5000 1000 2000 3000 4000 1000 S_{T} [GeV] m, [GeV] m_{7*} [GeV]



Search for majorana neutrinos in same-sign (ss) WW arXiv:2305.14931

Benchmark: Phenomenological Type-I Seesaw model Selection: 2 ss muons & 2 jets: |y_{jj}|>4 & m_{jj} > 300GeV Bkgs: ssWW and WZ - CR; non-prompt - data-driven, the rest - MC No excess is seen. Complementary to resonant production searches



Search for heavy neutrinos N_{R} and W_{R} (leptons+jets)

arXiv:2304.09553



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Summary

Results presented are only based Run 2 data @ 13TeV and not Run 3 yet

- explore new ideas: e.g. opposite sign dilepton analysis has multiple search publications
 (1) <u>inclusive resonant</u> 2019, (2) <u>non-resonant</u> 2020, (3) <u>non-resonant with/wo b-jets</u> 2021, (4) <u>periodic signals</u> 2023 and (5) NEW <u>dilepton+MET exclusive search</u>* 2023
- benefit from best possible object performance for the final Run 2 publication (e.g. LVF Z')
- COVID, wars, threats to democracy, natural disasters which all take toll on our time

* See talk by Giulia Ripellino









Triptych "Hadron Collider" Ye. Zhemchuzhnikova

Outlook

ATLAS Run 3 search reach is boosted by:

- increase in the centre of mass energy to 13.6 TeV and integrated luminosity (66 fb⁻¹ of proton-proton collision data collected already)

- upgraded hardware trigger

- lepton performance improvements: e.g. deep neural network identification for electrons (<u>ATL-PHYS-PUB-2022-022</u>)

- and many new search ideas

Stay tuned to new results to come...

THANK YOU FOR YOUR ATTENTION!



Ye. Zhemchuzhnikova, Institute of single crystals ¹⁶



Back-up



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

Status: March 2023

Sta	atus: March 2023							$\int \mathcal{L} dt = (3)$	$3.6 - 139) \text{ fb}^{-1}$	$\sqrt{s} = 13 \text{ TeV}$
	Model	ℓ, γ	Jets†	$\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}$	∫£ dt[fb	-1]	Limit	5		Reference
Extra dimen.	$\begin{array}{l} \text{ADD } G_{KK} + g/q \\ \text{ADD non-resonant } \gamma\gamma \\ \text{ADD OBH} \\ \text{ADD BH multijet} \\ \text{RS1 } G_{KK} \to \gamma\gamma \\ \text{Bulk RS } G_{KK} \to WW/ZZ \\ \text{Bulk RS } g_{KK} \to tt \\ \text{2UED / RPP} \end{array}$	$\begin{array}{c} 0 \ e, \mu, \tau, \gamma \\ 2 \ \gamma \\ - \\ 2 \ \gamma \\ multi-channe \\ 1 \ e, \mu \\ 1 \ e, \mu \end{array}$	1 - 4j -2j $\ge 3j$ -1 $\ge 1 b, \ge 1J/2$ $\ge 2 b, \ge 3j$	Yes - - - ?j Yes Yes	139 36.7 139 3.6 139 36.1 36.1 36.1	M _D Ms Mth Mth Gкк mass Gкк mass gкк mass KK mass		11.2 Te 8.6 TeV 9.4 TeV 9.55 TeV 2.3 TeV 3.8 TeV 1.8 TeV	$ \begin{array}{l} V & n=2 \\ n=3 \ \text{HZ NLO} \\ n=6 \\ m=6, \ M_D=3 \ \text{TeV}, \ \text{rot BH} \\ k/\overline{M}_{Pl}=0.1 \\ k/\overline{M}_{Pl}=1.0 \\ \Gamma/m=15\% \\ Tire(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 1804.10823 1803.09678
Gauge bosons	$\begin{array}{l} \mathrm{SSM}\ Z' \to \ell\ell \\ \mathrm{SSM}\ Z' \to \tau \\ \mathrm{Leptophobic}\ Z' \to bb \\ \mathrm{Leptophobic}\ Z' \to tt \\ \mathrm{SSM}\ W' \to tr \\ \mathrm{SSM}\ W' \to tr \\ \mathrm{SSM}\ W' \to tr \\ \mathrm{VT}\ W' \to WZ \ \mathrm{model}\ B \\ \mathrm{HVT}\ W' \to WZ \to \ell\nu\ \ell'\ell' \ \mathrm{model}\ B \\ \mathrm{HVT}\ W' \to WZ \to ch\ \ell'\ell' \ \mathrm{model}\ B \\ \mathrm{HSM}\ W_R \to nM_R \end{array}$	$\begin{array}{c} 2 \ e, \mu \\ 2 \ \tau \\ 0 \ e, \mu \\ 1 \ e, \mu \\ 1 \ \tau \\ 0 \ -2 \ e, \mu \\ 1 \ e, \mu \\ 1 \ r \\ 0 \ -2 \ e, \mu \\ 1 \ e, \mu \\ 2 \ \mu \end{array}$	- 2 b ≥1 b, ≥2 J - ≥1 b, ≥1 J 2 j/1 J 2 j/VBF) 2 j/1 J 1 J	- Yes Yes Yes Yes Yes Yes	139 36.1 36.1 139 139 139 139 139 139 139 139 80	Z' mass Z' mass Z' mass Z' mass W' mass W' mass W' mass W' mass Z' mass Z' mass W _R 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	$\label{eq:gamma} \begin{split} & \Gamma/m = 1.2\% \\ & g_V = 3 \\ & g_V c_H = 1, g_F = 0 \\ & g_V = 3 \\ & m(N_G) = 0.5 \text{TeV}, g_L = g_R \end{split}$	1903.06248 1709.07242 1805.09299 2005.05138 1906.05609 ATLAS-CONF-2021-025 ATLAS-CONF-2021-043 2004.14636 2207.03925 2004.14636 1904.12679
CI	Cl qqqq Cl ℓℓqq Cl eebs Cl μμbs Cl tttt	− 2 e,μ 2 e 2μ ≥1 e,μ	2 j - 1 b 1 b ≥1 b, ≥1 j	- - - Yes	37.0 139 139 139 36.1	Λ Λ Λ Λ Λ		1.8 TeV 2.0 TeV 2.57 TeV	$\begin{array}{c} \textbf{21.8 TeV} \eta_{LL}^- \\ \textbf{35.8 TeV} \\ \textbf{g}_* = 1 \\ \textbf{g}_* = 1 \\ C_{4t} = 4\pi \end{array} \boldsymbol{\eta}_{LL}^- \end{array}$	1703.09127 2006.12946 2105.13847 2105.13847 1811.02305
MQ	Axial-vector med. (Dirac DM) Pseudo-scalar med. (Dirac DM) Vector med. Z'-2HDM (Dirac D Pseudo-scalar med. 2HDM+a) 0 e, μ, τ, γ M) 0 e, μ multi-channe	2j 1-4j 2b	Yes Yes	139 139 139 139	m _{med} m _{med} m _{Z'} m _a	376 GeV 800 GeV	3.8 TeV 3.0 TeV	$\begin{array}{l} g_q{=}0.25, g_{\chi}{=}1, m(\chi){=}10 {\rm TeV} \\ g_q{=}1, g_{\chi}{=}1, m(\chi){=}1 {\rm GeV} \\ {\rm tan} \beta{=}1, g_Z{=}0.8, m(\chi){=}100 {\rm GeV} \\ {\rm tan} \beta{=}1, g_{\chi}{=}1, m(\chi){=}10 {\rm GeV} \end{array}$	ATL-PHYS-PUB-2022-036 2102.10874 2108.13391 ATLAS-CONF-2021-036
07	Scalar LQ 1 st gen Scalar LQ 2 rd gen Scalar LQ 3 rd gen Scalar LQ 3 rd gen Scalar LQ 3 rd gen Scalar LQ 3 rd gen Vector LQ mix gen Vector LQ 3 rd gen	$\begin{array}{c} 2 \ e \\ 2 \ \mu \\ 1 \ \tau \\ 0 \ e, \mu \\ \geq 2 \ e, \mu, \geq 1 \ \tau \\ 0 \ e, \mu, \geq 1 \ \tau \\ \text{multi-channe} \\ 2 \ e, \mu, \tau \end{array}$	$ \begin{array}{c} \geq 2 j \\ \geq 2 j \\ 2 b \\ \geq 2 j, \geq 2 b \\ r \geq 1 j, \geq 1 b \\ 0 - 2 j, 2 b \\ q \geq 1 j, \geq 1 b \\ \geq 1 b \end{array} $	Yes Yes Yes Yes Yes Yes Yes	139 139 139 139 139 139 139 139	LQ mass LQ mass LQ ⁴ mass LQ ⁴ mass LQ ⁴ mass LQ ⁴ mass LQ ⁴ mass LQ ⁵ mass LQ ⁵ mass	1.2 1 1.2	1.8 TeV 1.7 TeV 1.49 TeV 4 TeV 4 TeV 6 TeV 2.0 TeV 1.96 TeV	$\begin{array}{l} \beta = 1 \\ \beta = 1 \\ \mathcal{B}(\mathrm{LQ}_{3}^{o} \rightarrow b\tau) = 1 \\ \mathcal{B}(\mathrm{LQ}_{3}^{o} \rightarrow t\tau) = 1 \\ \mathcal{B}(\mathrm{LQ}_{3}^{o} \rightarrow t\tau) = 1 \\ \mathcal{B}(\mathrm{LQ}_{3}^{o} \rightarrow b\tau) = 1 \\ \mathcal{B}(\mathrm{LQ}_{3}^{o} \rightarrow b\tau) = 1 \\ \mathcal{B}(\mathrm{LQ}_{3}^{o} \rightarrow b\tau) = 1 , \mathrm{YM} \ \mathrm{coupl.} \end{array}$	2006.05872 2006.05872 2303.01294 2004.14060 2101.11582 2101.12527 ATLAS-CONF-2022-052 2303.01294
Vector-like fermions	$ \begin{array}{l} VLQ \ TT \to Zt + X \\ VLQ \ BB \to Wt/Zb + X \\ VLQ \ T_{5/3}T_{5/3} \to Wt + X \\ VLQ \ T \to Ht/Zt \\ VLQ \ Y \to Wb \\ VLQ \ Y \to Hb \\ VLQ \ K \to Hb \\ VLL \ \tau' \to Z\tau/H\tau \end{array} $	$\begin{array}{c} 2e/2\mu/\geq 3e, \mu\\ \text{multi-channe}\\ 2(SS)/\geq 3e, \mu\\ 1e, \mu\\ 1e, \mu\\ 0e, \mu\geq\\ \text{multi-channe} \end{array}$	$x \ge 1 \ b, \ge 1 \ j$ $u \ge 1 \ b, \ge 1 \ j$ $u \ge 1 \ b, \ge 3 \ j$ $u \ge 1 \ b, \ge 1 \ b, \ge 1 \ b$	- Yes Yes IJ - Yes	139 36.1 36.1 139 36.1 139 139	T mass B mass T _{5/3} mass T mass Y mass B mass τ' mass	1. 898 GeV	1.46 TeV 34 TeV 1.64 TeV 1.8 TeV 1.85 TeV 2.0 TeV	$\begin{array}{l} {\rm SU(2)\ doublet} \\ {\rm SU(2)\ doublet} \\ {\rm SU(2)\ doublet} \\ {\rm SU(2)\ singlet,\ } \kappa_T=0.5 \\ {\rm SU(2)\ singlet,\ } \kappa_T=0.5 \\ {\rm SU(2)\ oublet,\ } \kappa_B=0.3 \\ {\rm SU(2)\ doublet,\ } \kappa_B=0.3 \\ {\rm SU(2)\ doublet} \end{array}$	2210.15413 1808.02343 1807.11883 ATLAS-CONF-2021-040 1812.07343 ATLAS-CONF-2021-018 2303.05441
Exctd ferm.	Excited quark $q^* \rightarrow qg$ Excited quark $q^* \rightarrow q\gamma$ Excited quark $b^* \rightarrow bg$ Excited lepton τ^*	1γ - 2τ	2j 1j 1b,1j ≥2j	-	139 36.7 139 139	q * mass q * mass b * mass τ* mass		6.7 TeV 5.3 TeV 3.2 TeV 4.6 TeV	only u^* and $d^*, \Lambda = m(q^*)$ only u^* and $d^*, \Lambda = m(q^*)$ $\Lambda = 4.6 \text{ TeV}$	1910.08447 1709.10440 1910.08447 2303.09444
Other	Type III Seesaw LRSM Majorana v Higgs triplet $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$ Higgs triplet $H^{\pm\pm} \rightarrow \ell \ell$ Multi-charged particles Magnetic monopoles	$2,3,4 e, \mu$ 2 μ 2,3,4 e, μ (SS 2,3,4 e, μ (SS	$2j$ $2j$ $2j$ $-$ $-$ $-$ $\sqrt{s} = 13$ full d	Yes - Yes - - 3 TeV ata	139 36.1 139 139 139 34.4	N ⁰ mass N _R mass H ^{±±} mass H ^{±±} mass multi-charged pa monopole mass	910 GeV 350 GeV 1.08 T rticle mass	3.2 TeV TeV 1.59 TeV 2.37 TeV 1 1 1	$m(W_R) = 4.1$ TeV, $g_L = g_R$ DY production DY production DY production, $ q = 5e$ DY production, $ g = 1g_D$, spin 1/2	2202.02039 1809.11105 2101.11961 2211.07505 ATLAS-CONF-2022-034 1905.10130
	4	and an and	Tun u	ura		10			Mass scale [TeV]	

Most of the limits are ~1TeV scale or beyond

ATLAS Preliminary

*Only a selection of the available mass limits on new states or phenomena is shown.



Electron reconstruction





Clockwork search





Search for heavy neutrinos N_R and W_R (leptons+jets)

arXiv:2304.09553









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