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

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on behalf of the ATLAS Collaboration

EPS 2023 - Hamburg
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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

A Belov Fire from collection In the darkness

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

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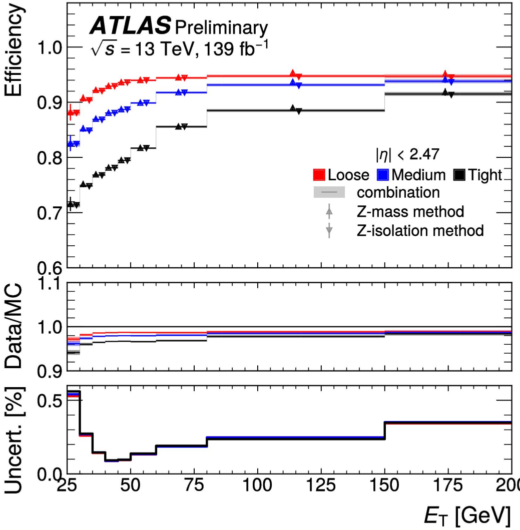
Talk Outline

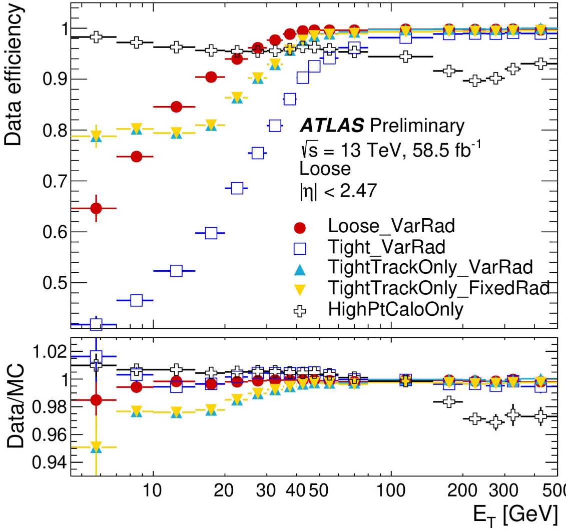
- Lepton performance at high transverse energy/momentum (E_T/p_T)
- Search for periodic signals in ee/ɣɣ
- Resonant searches in eμ, eτ_{had}, $\mu\tau_{had}$
- Quantum black hole search in e/μ+jet
- Excited τ search
- Searches for heavy neutrinos in
  - in same sign WW scattering
  - charged leptons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

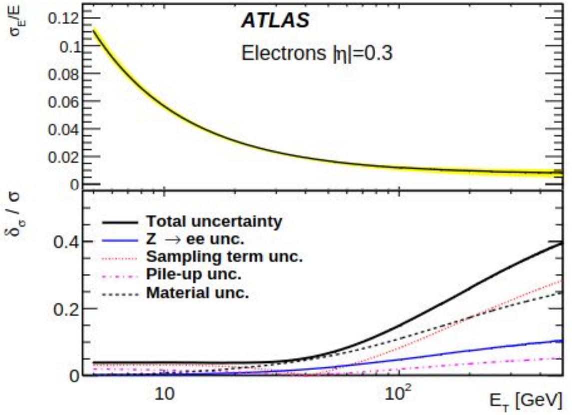
Results
based on 139-140 fb^{-1} of
proton-proton collision data
collected in 2015-2018

Electron performance in offline and trigger

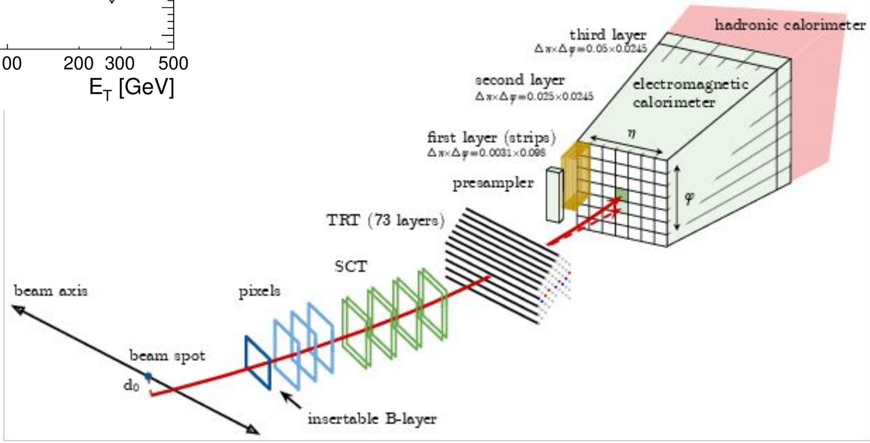
EGAM-2022-02







JINST **14** P03017



- Offline efficiencies at high E_T: identification >90%, isolation ~100%
- Electron resolution is better than 1% at high E_T
- Single electron trigger efficiency [Eur. Phys. J. C 80 (2020) 47]: ~97% for E_T>80GeV

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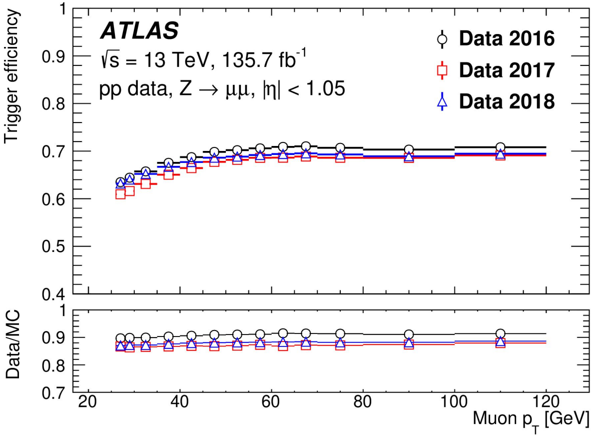
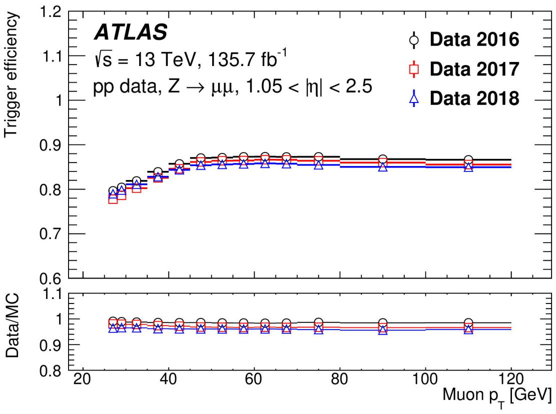
Also see poster by Filip Nechansky

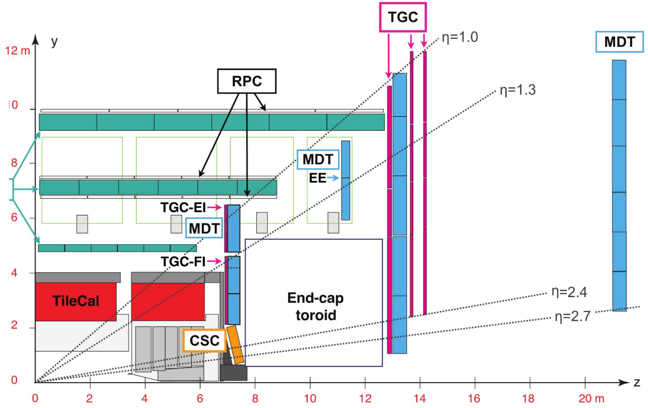
Muon performance in offline and trigger

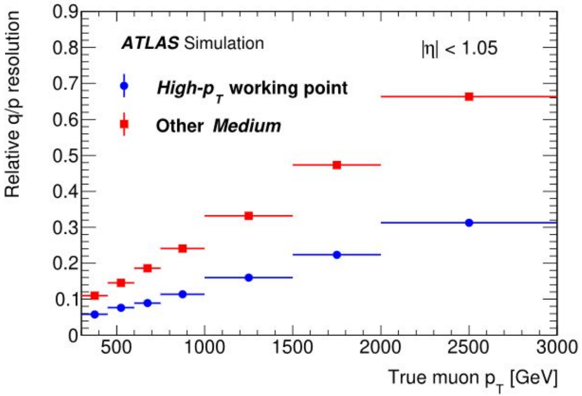
Combine track reconstructed in the muon spectrometer and the inner detector

Single muon trigger efficiency:









High p_T identification point (vs medium)

- maximizes p_T resolution for p_T>100GeV
- minimize background efficiency: 0.05 vs 0.07
- at cost of muon efficiency: 80% vs 97%

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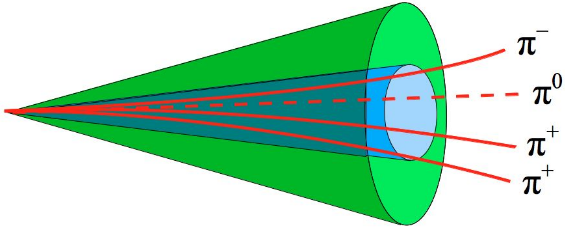
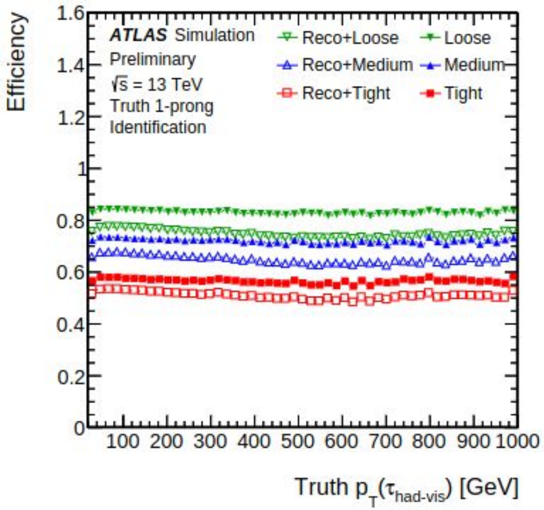
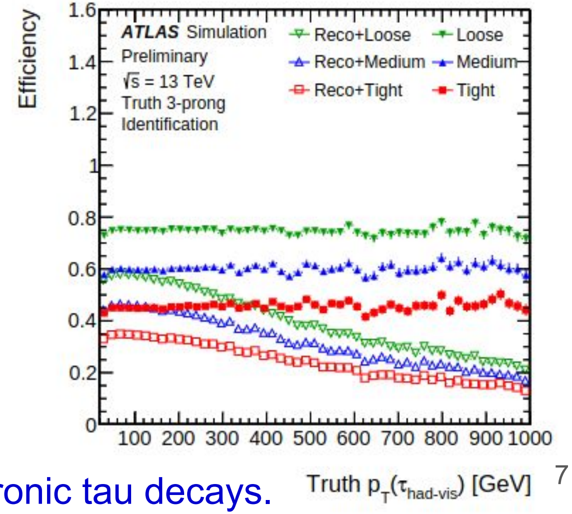
[Eur. Phys. J. C 81 (2021) 578](), [JINST 15 (2020) P09015]()

Tau performance in offline and trigger



- Track classifier efficiency is 95% (93%) for 1 (3)-prong taus.
- Average track association efficiency 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.
- Rejection of misidentified tau-had candidates improved by 50–100% wrt RNN deployed in the end of Run 2.
- Rejection of electrons 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)
- Decay mode classification, based on a Neural Network algorithm, achieves a diagonal efficiency of about 82%, ~9% higher than BDT algorithm used during Run 2.
- Energy resolution 4.5%–6% (4%–5%) for 1 (3)-prong tau
- Trigger improvements closely follow offline developments





ATL-PHYS-PUB-2022-044

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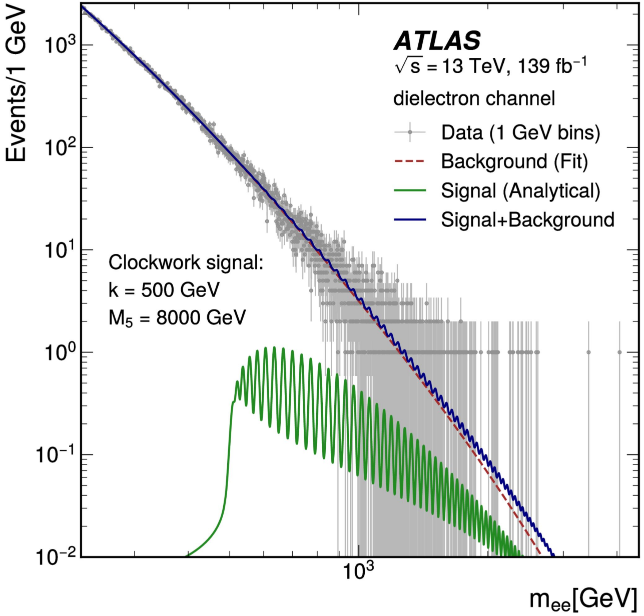
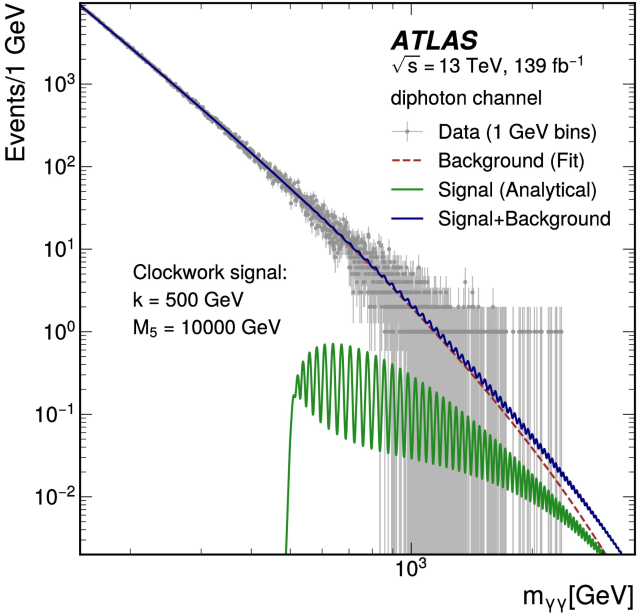
Not all improvements included in searches presented. Only hadronic tau decays.

Searches for periodic signals (ee/γγ)

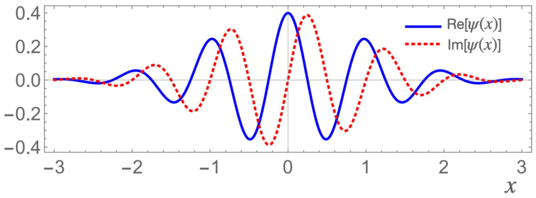




(Non)resonant searches ee/γγ have no sensitivity to such small signals =>

Novel search technique based on continuous wavelet transforms.

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



$x=(m-\beta)/\alpha$, 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 ∝ $1/M_5^3$(small)

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Submitted to JHEP arxiv:2305.10894

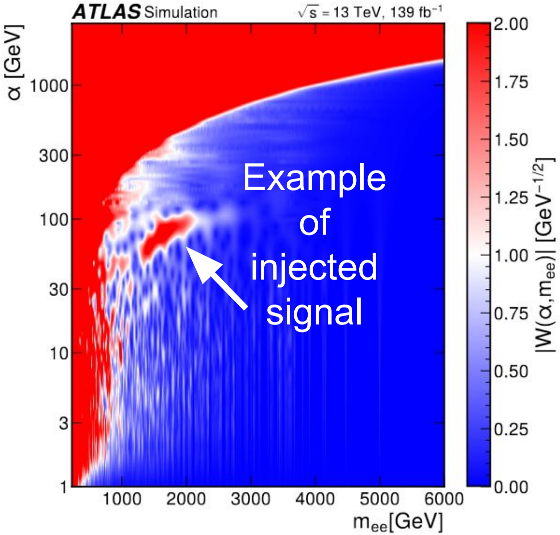
Results of the Clockwork search

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

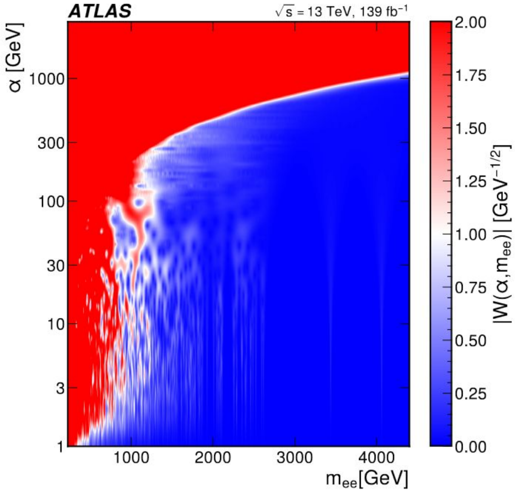
Neural network classifier enhances sensitivity to periodic resonances

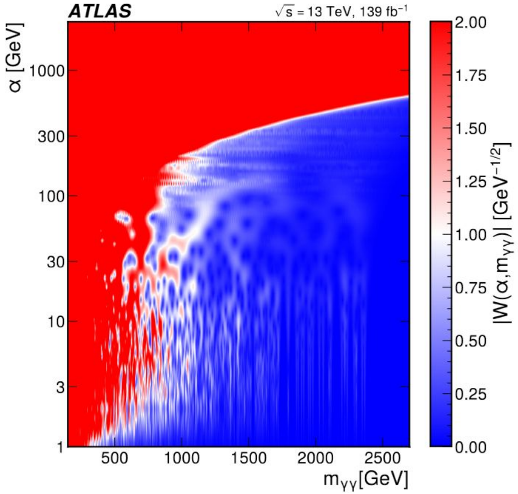
NN score => test-statistic

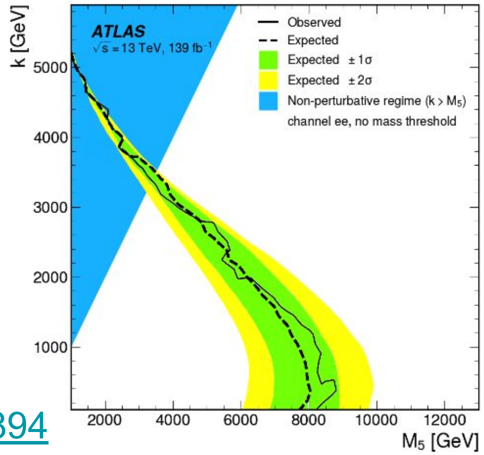
No excess is observed: limits are set

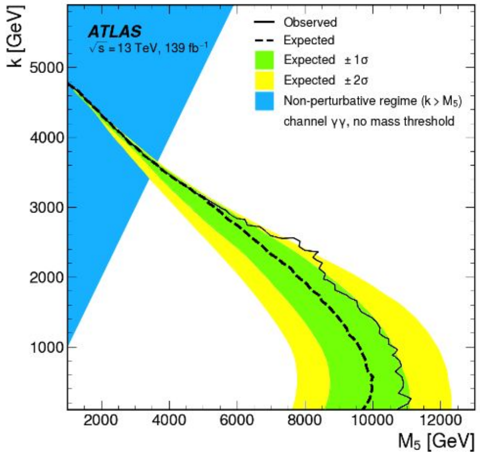


Mass-frequency scalograms









Submitted to JHEP arxiv:2305.10894

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

Models: LFV Z’, scalar neutrinos in RPV SUSY, Quantum Black Holes (QBH ADD/RS)

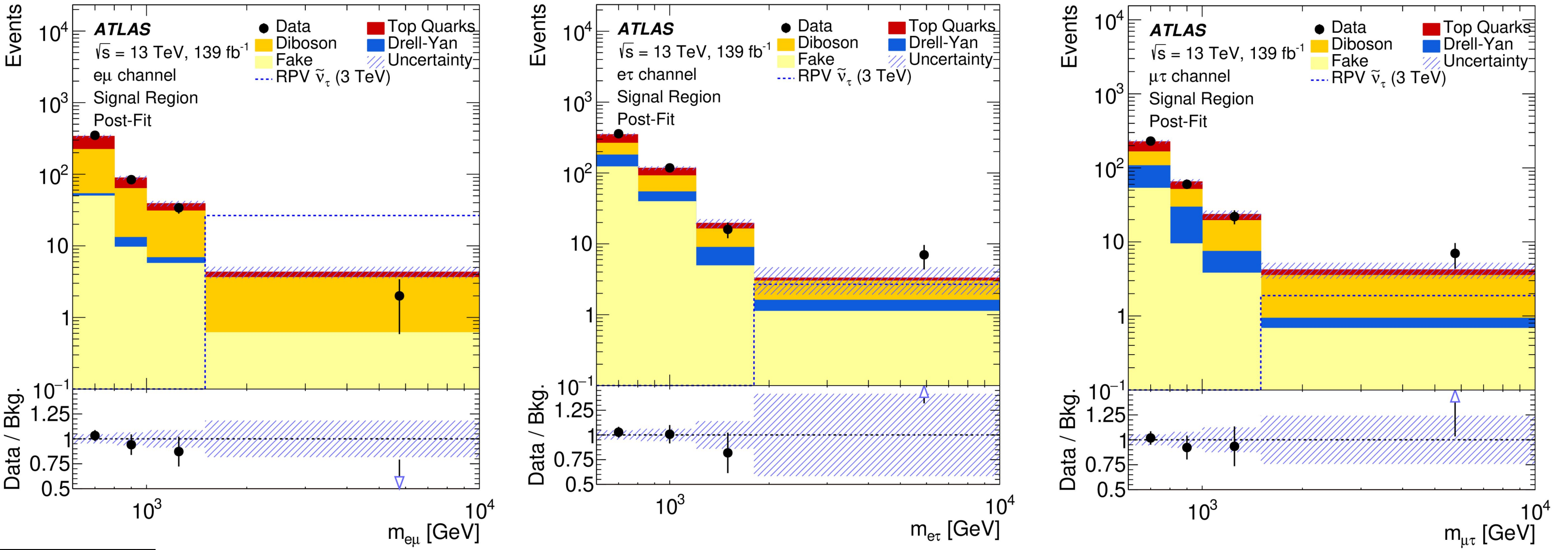
Signature 2 back-to-back leptons, no b-jets

Bkgs: W+jets/multijet (FNP) data-driven; ttbar and WW use CR for normalization; the rest is MC-only

Result: No significant excesses observed.

Model	Observed (expected) 95% CL lower limit [TeV]		
	$e\mu$ channel	$e\tau$ channel	$\mu\tau$ channel
LFV Z'	5.0 (4.8) **+0.6***	4.0 (4.3) **+0.3***	3.9 (4.2) **+0.4***
RPV SUSY $\tilde{\nu}_\tau$	3.9 (3.7)	2.8 (3.0)	2.7 (2.9)
QBH ADD $n = 6$	5.9 (5.7)	5.2 (5.5)	5.1 (5.2)
QBH RS $n = 1$	3.8 (3.6)	3.0 (3.3)	3.0 (3.1)

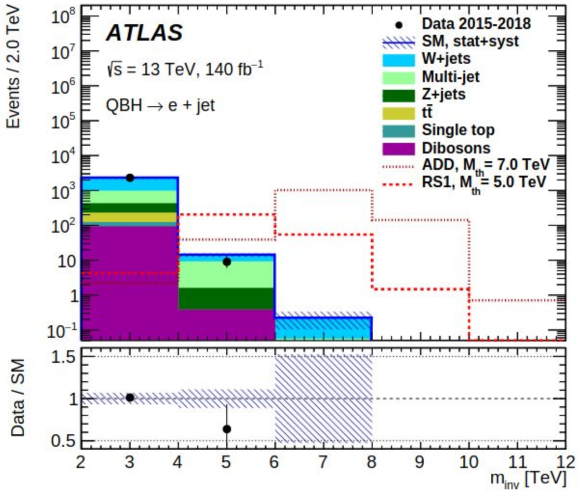
wrt 36.1 fb^{-1} ATLAS result

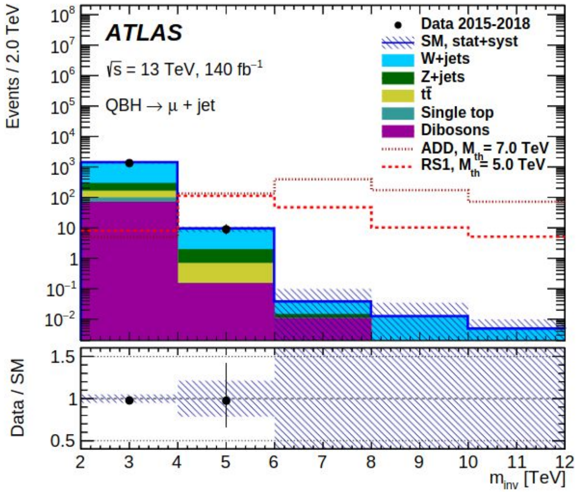


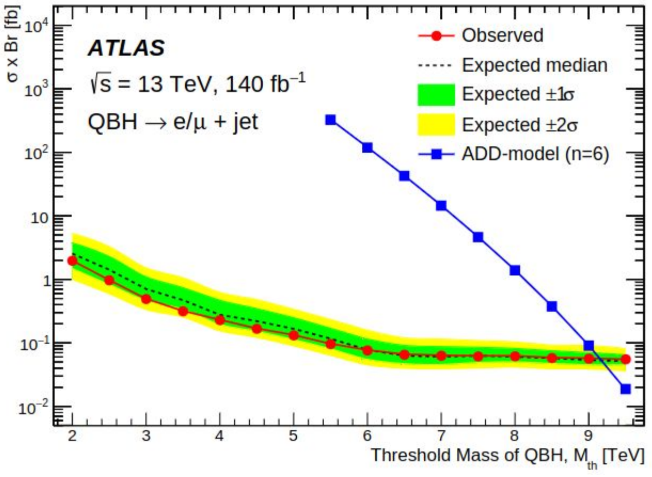
arxiv:2307.08567 submitted to JHEP

Search for QBH →ej, μj

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



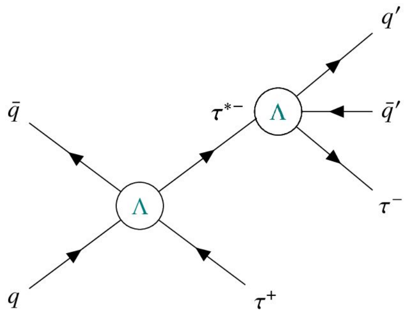




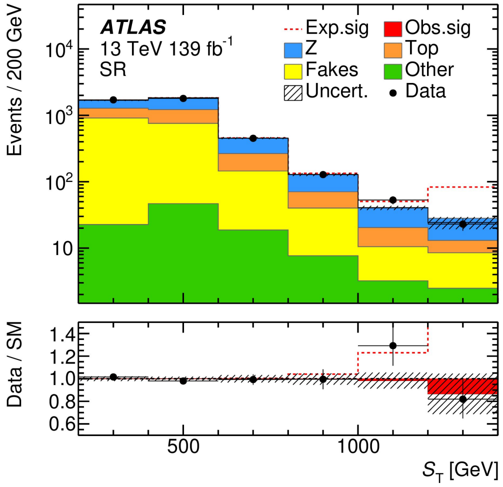
arxiv:2307.14967 submitted to PRD

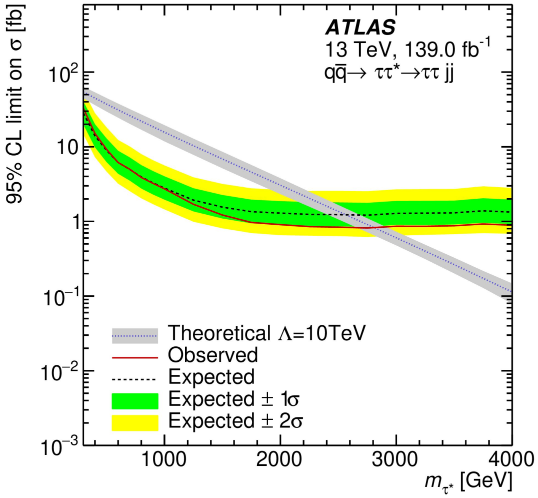
Search for excited tau-leptons

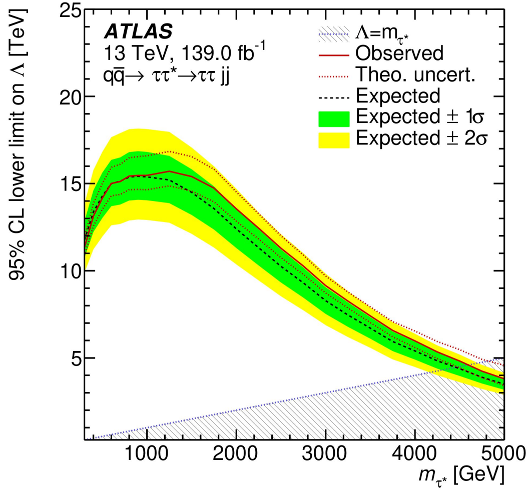
JHEP 06 (2023) 199



- ττjj final state: 4-fermion contact interaction production and decay
- Fit on $S_T=\sum p_T(\tau_{had}\tau_{had},j^1j^2)$
- Bkg: Z→ττ, ttbar and single-top use CR
- No excess over SM observed. Excluded: m_{τ^*} up to 4.6 TeV







This final state is also sensitive to LQ pair production. See talk by Ch. Appelt

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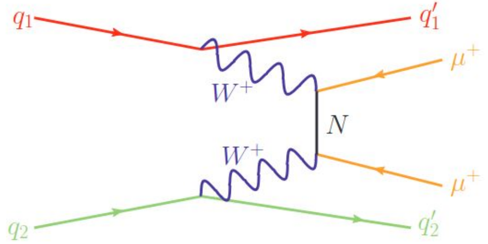
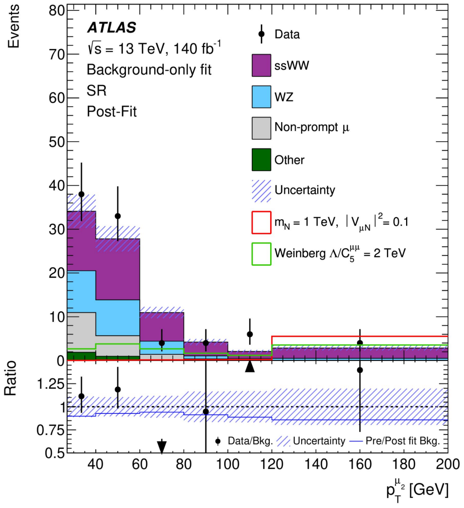
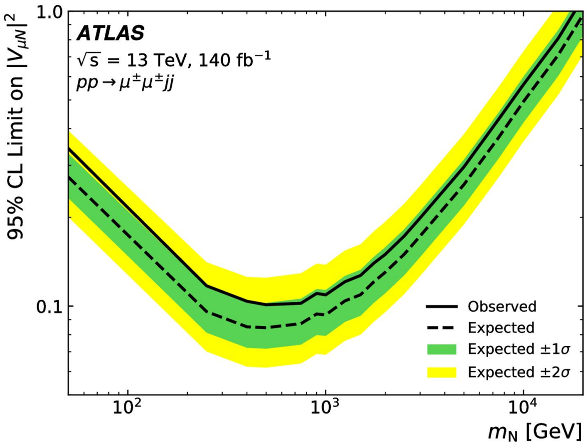
Search for majorana neutrinos in same-sign (ss) WW

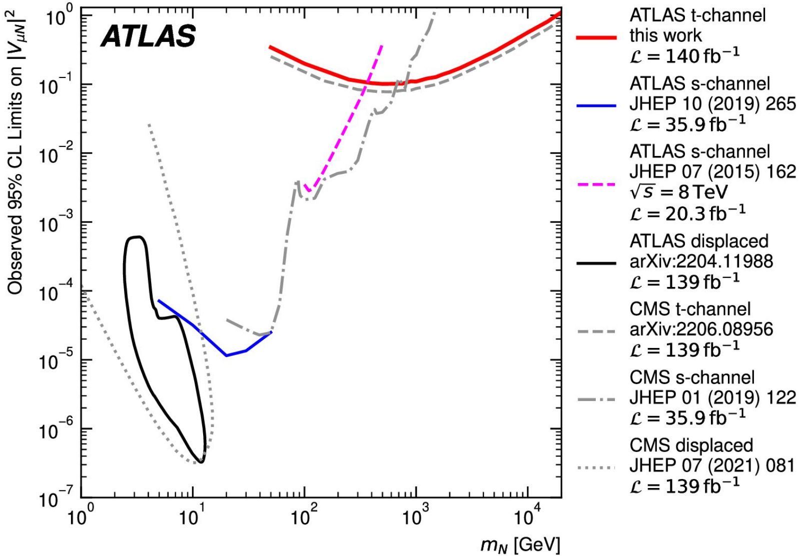
arXiv:2305.14931



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







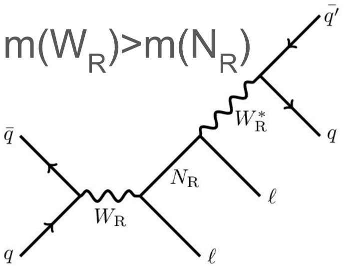
$|V_{\mu N}|^2$, the only entry into the mass-mixing matrix:
muon-neutrino–heavy-neutrino mass-mixing matrix element

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

arXiv:2304.09553

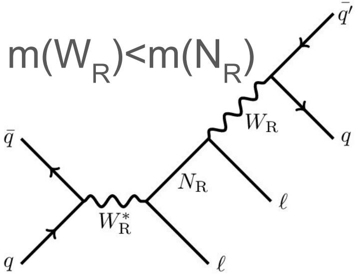
Channels: Resolved/boosted ($m(W_R) \gg m(N_R)$), same/opposite sign (SS/OS)
Backgrounds: Z+jets/VV/ttbar CRs; non-prompt - data-driven
Left-Right Symmetric Model with Majorana N_R (SS/OS) or Dirac N_R (OS)

$m(W_R) > m(N_R)$

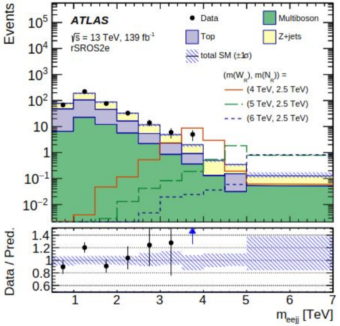


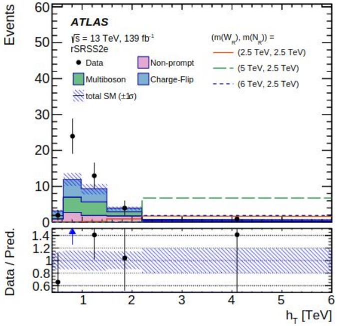
$m_{jj\ell\ell}$ (resolved, OS)
h_T (resolved, SS)
$m_{J\ell\ell}$ (boosted 1e/2e/2μ)

$m(W_R) < m(N_R)$

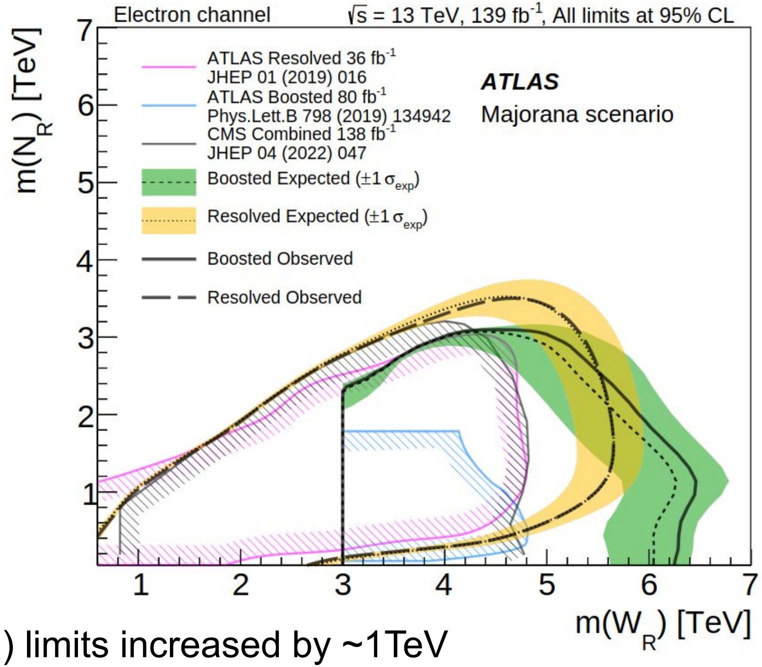


m_{jj} (resolved, OS)
h_T (resolved, SS)





No excess observed in 9 signal regions



$m(W_R)$ limits increased by ~1TeV
Limits in other channels/scenarios in backup

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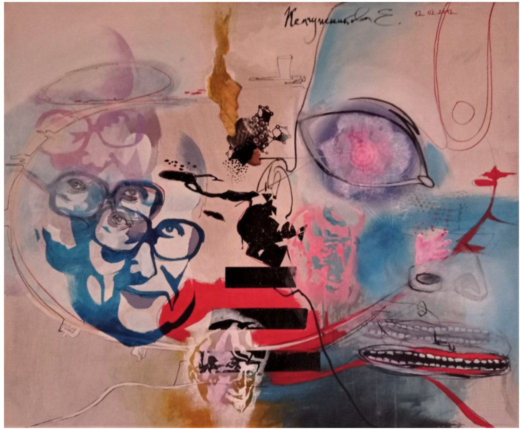
Summary

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) inclusive resonant 2019, (2) non-resonant 2020, (3) non-resonant with/wo b-jets 2021, (4) periodic signals 2023 and (5) NEW dilepton+MET exclusive search* 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

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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 (ATL-PHYS-PUB-2022-022)

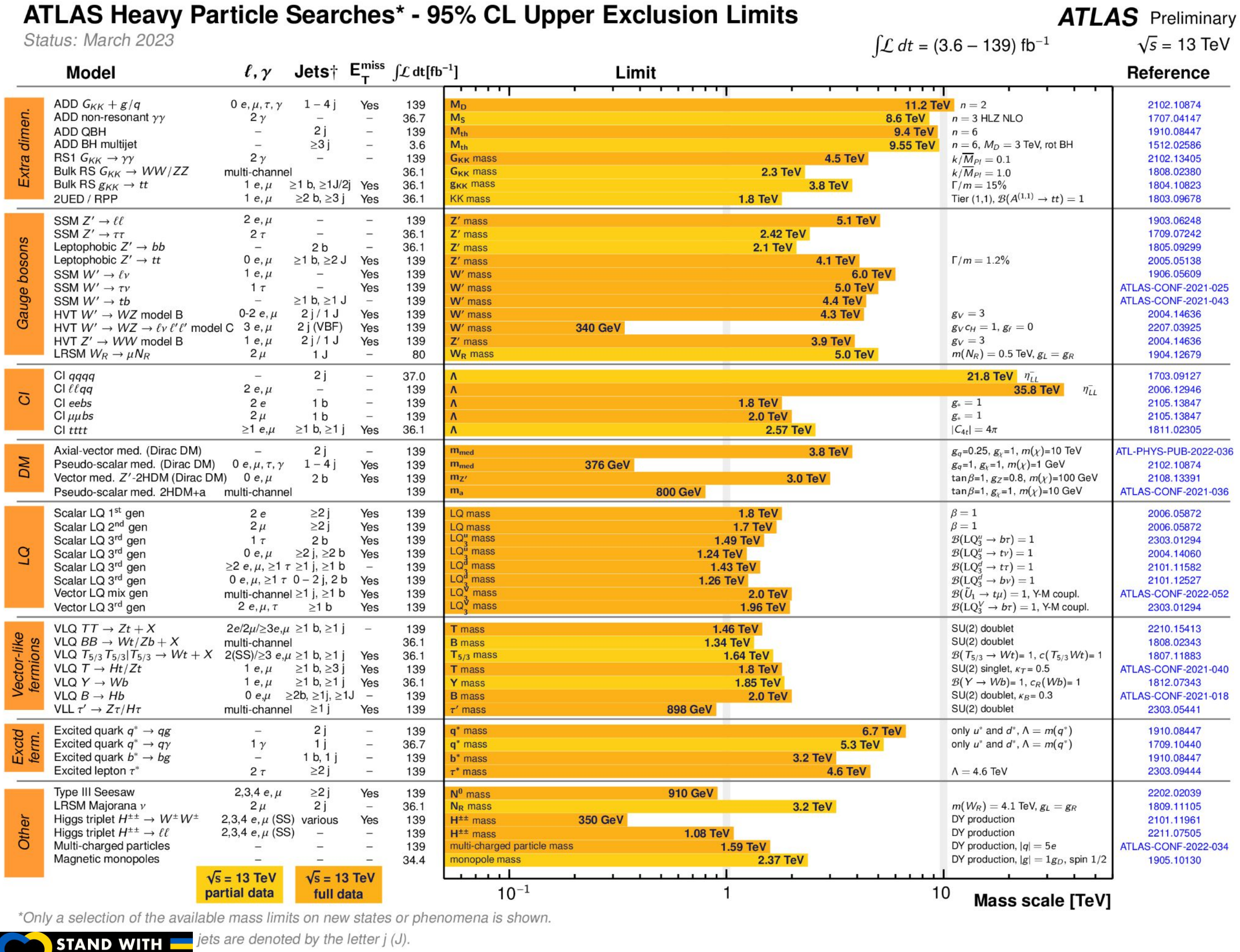
- and many new search ideas

Stay tuned to new results to come…

THANK YOU FOR YOUR ATTENTION!

Ye. Zhemchuzhnikova, Institute of single crystals

Back-up



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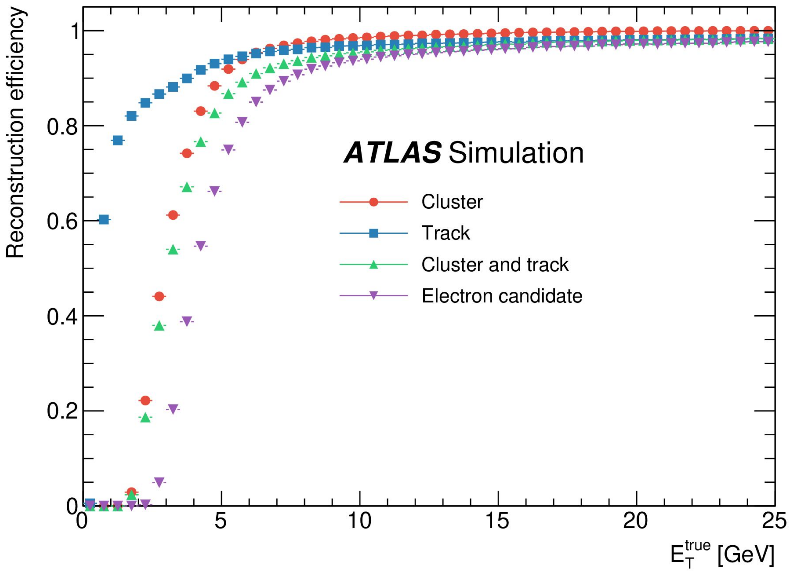
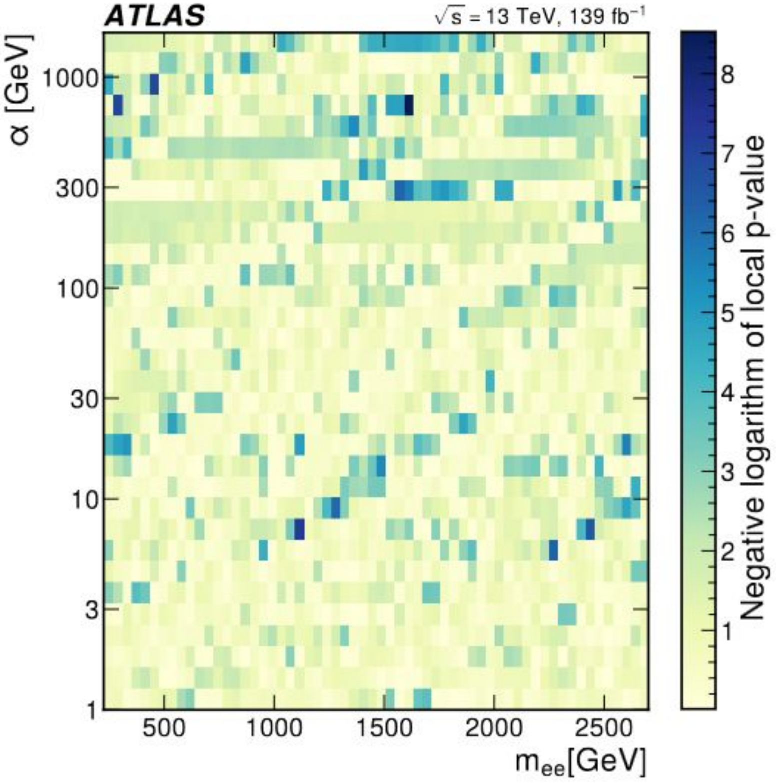
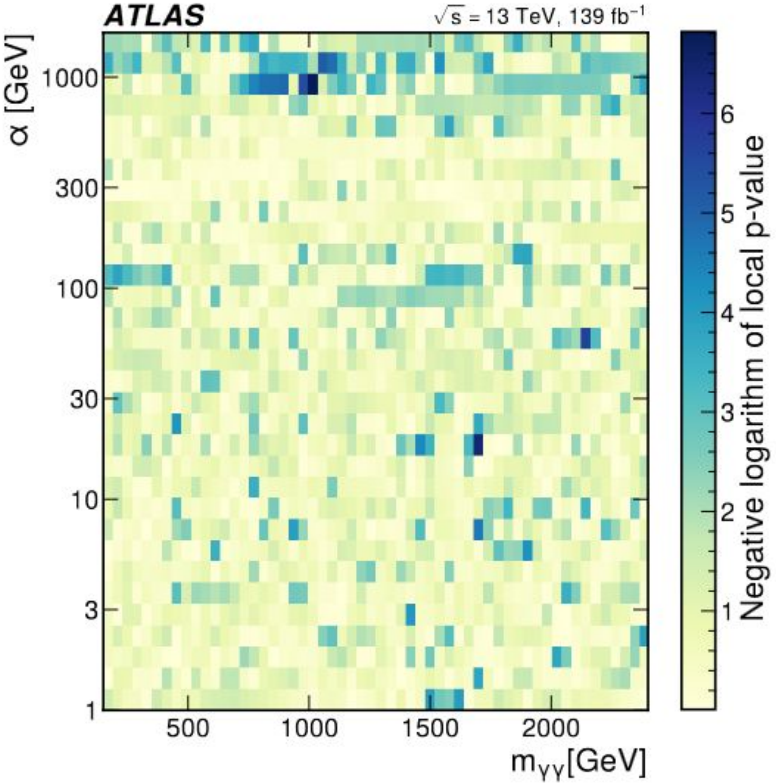
Most of the limits are ~1TeV scale or beyond

Electron reconstruction



Clockwork search





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

[arXiv:2304.09553]