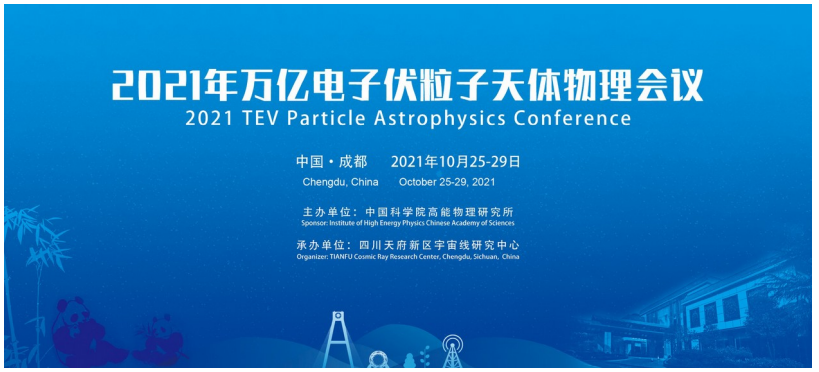
Searches for new physics with leptons using the ATLAS detector



TeV Particle Astrophysics 2021

Antonio Sidoti
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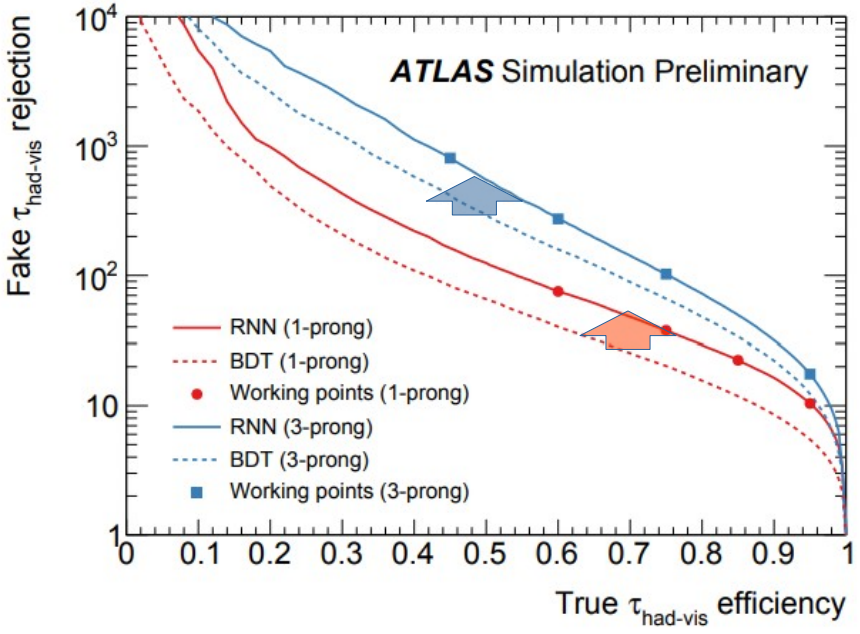
Istituto Nazionale Fisica Nucleare – Sezione di Bologna
on behalf of the ATLAS Collaboration

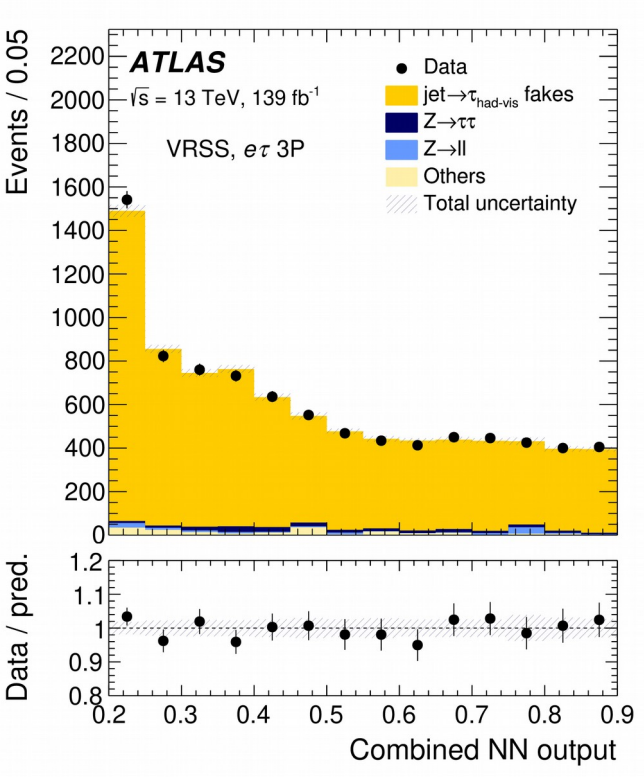
Beyond Standard Model Searches in ATLAS

So far, lepton flavor universality tests in b-physics sector and (g-2)μ anomalies could hint to BSM in particle physics.
Exploit ATLAS exceptional lepton identification capabilities (electrons, muons and taus)



Tau ID rejection vs efficiency

ATLAS-PHYS-PUB-2019-033



Tau Fake estimations

Nature Phys. 17 (2021) 819

… and for electrons and muons as well

Outline

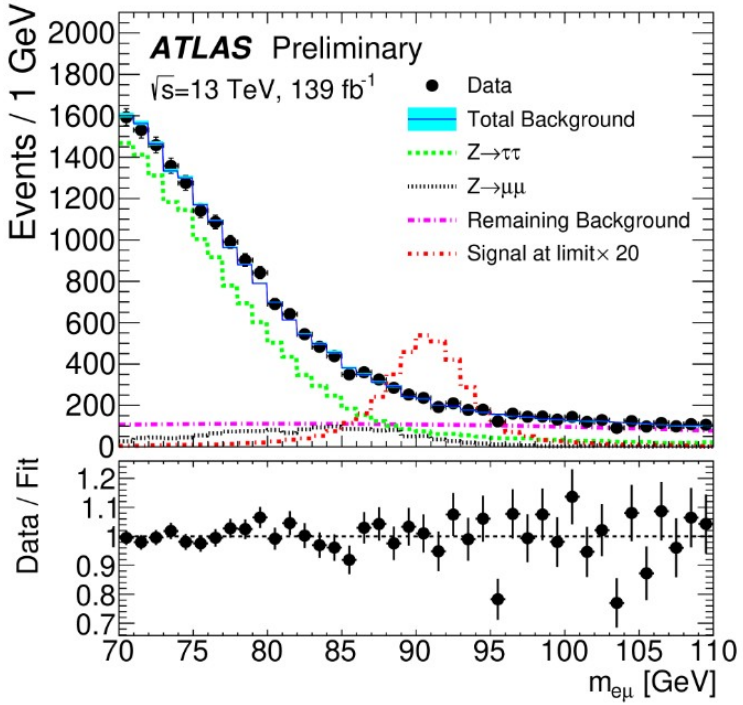
- Test of SM symmetries (indirect):
  - Lepton flavor violation in Z boson decays
  - Measurement of eμ charge asymmetry
  - bsll contact interactions
- Direct searches of BSM heavy particles
  - TypeIII Seesaw heavy leptons
  - Heavy gauge bosons Z' and W'

Other ATLAS talks related to BSM searches:

- For Leptoquark searches → Talk from P. Baur
- For resonances decaying in pairs of heavy boson → Talk from S. Li
- For LFV in Higgs boson → Talk from K. Ran
- For BSM in 3rd generation quarks → Talk from A. Burger
- For additional scalar particles → Talk E. Reynolds
- Dark matter searches → Talk from C. Li
- Searches with challenging and long lived signatures → S. Grancagnolo

Lepton Flavor Violation Searches

- Exploit huge statistics of Z bosons produced and look for LFV in Z decays
- LFV very rare from SM (neutrino mixing) BR~10^{-50}
- Positive signal would be a clear indication of BSM physics



LFV in Z → eμ search

ATLAS-CONF-2021-042

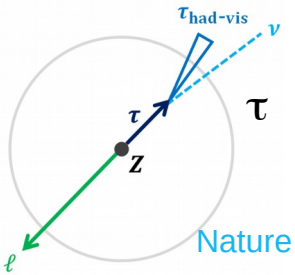
- Signal optimization and background rejection using BDT
- Fit peak in M(eμ) invariant mass distribution
- Statistics dominated measurement

ATLAS Run1 Result:
Br(Z→ eμ)<7.5 x10^{-7} at 95% CL

New Run2 Result:
Observed (Expected) limit
Br(Z→ eμ)<3.04 (2.75)x10^{-7} at 95% CL

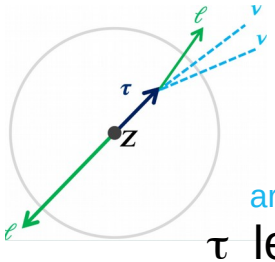
Lepton Flavor Violation searches Z → e/μ τ

- Deep Neural Network with full kinematic information to discriminate signal from different background
- Low and High P_T categorization to optimize sensitivity



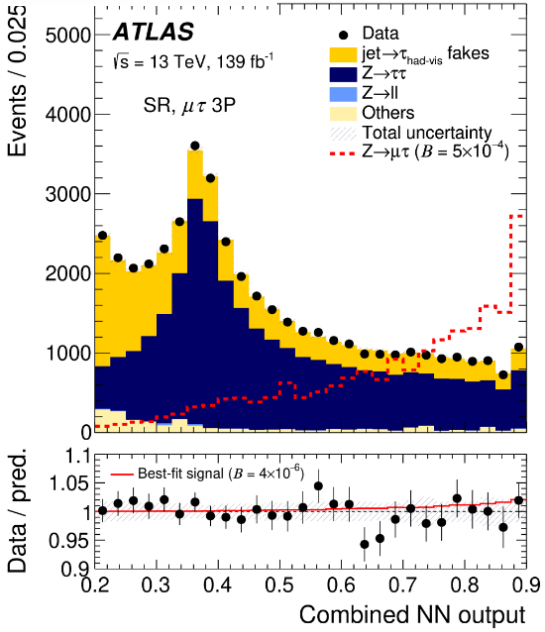
τ hadronic

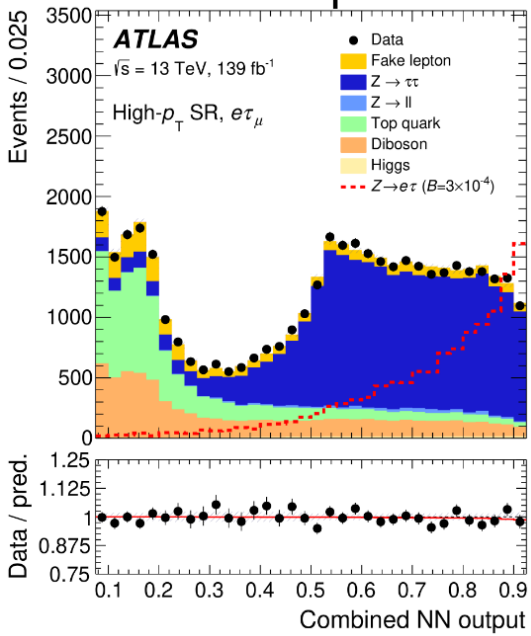
Nature Phys. 17 (2021) 819



arXiv: 2105.12491

τ leptonic





Previous best limits at LEP:
Br(Z→ eτ)<12 x10^{-6} at 95% CL
Br(Z→ μτ)<9.8 x10^{-6} at 95% CL

New Run2 Results:
(marginal dependence on unpolarized and maximally polarized τ leptons hypothesis)
Observed limit τ had
Br(Z→ eτ)<8.1 x10^{-6} at 95% CL
Br(Z→ μτ)<9.9 x10^{-6} at 95% CL
Observed limit τ lep
Br(Z→ eτ)<7.0 x10^{-6} at 95% CL
Br(Z→ μτ)<7.2 x10^{-6} at 95% CL
Observed limit Run1 + Run2
Br(Z→ eτ)<5.0x10^{-6} at 95% CL
Br(Z→ μτ)<6.5x10^{-6} at 95% CL

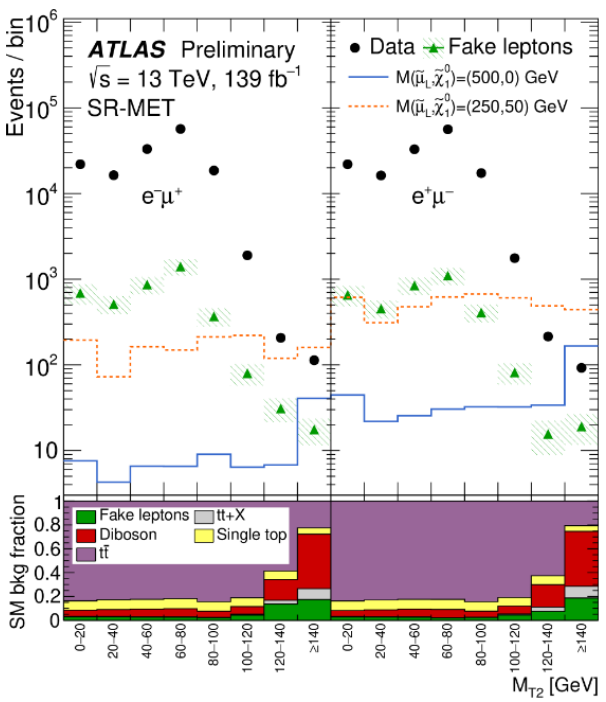
e μ asymmetry

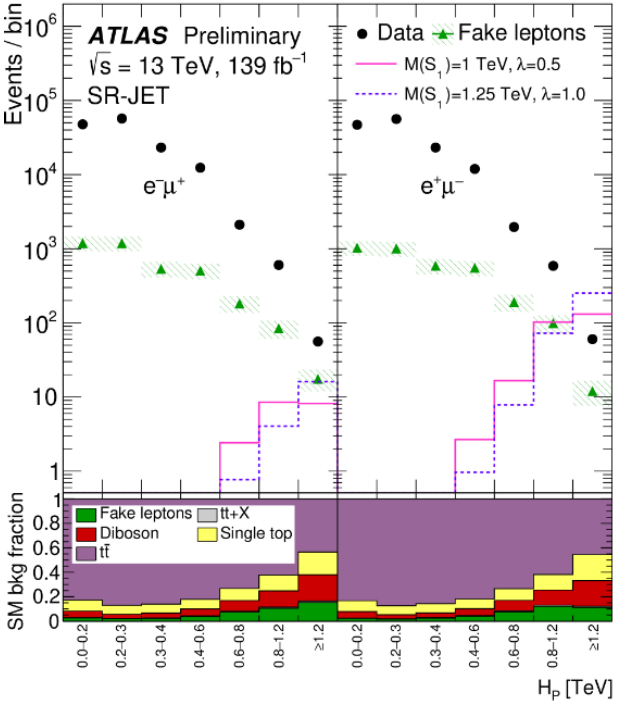
ATLAS-CONF-2021-045

Measure the ratio $\rho = \frac{\sigma(pp \to e^+\mu^- + X)}{\sigma(pp \to e^-\mu^+ + X)}$

Ideally ρ_{SM}=1. Detector effects could ρ_{SM}<1 A measurement of ρ>1 → Hint of new physics

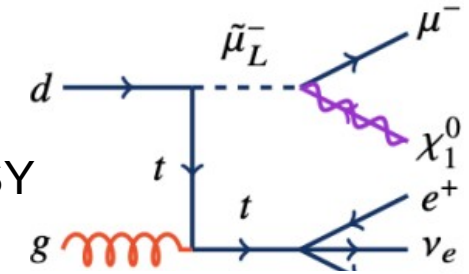
- Events separated in independent signal regions: large MET and jet regions
- Mis-identified leptons estimated with data driven method
- In ratio many uncertainties cancel out → Muon charge bias (trigger, reconstruction) carefully estimated and validated



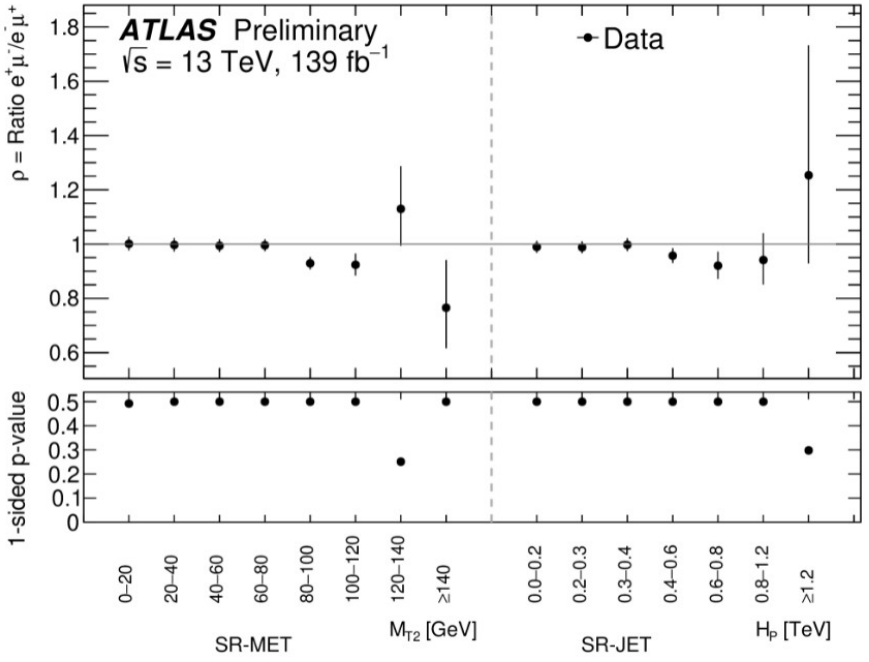


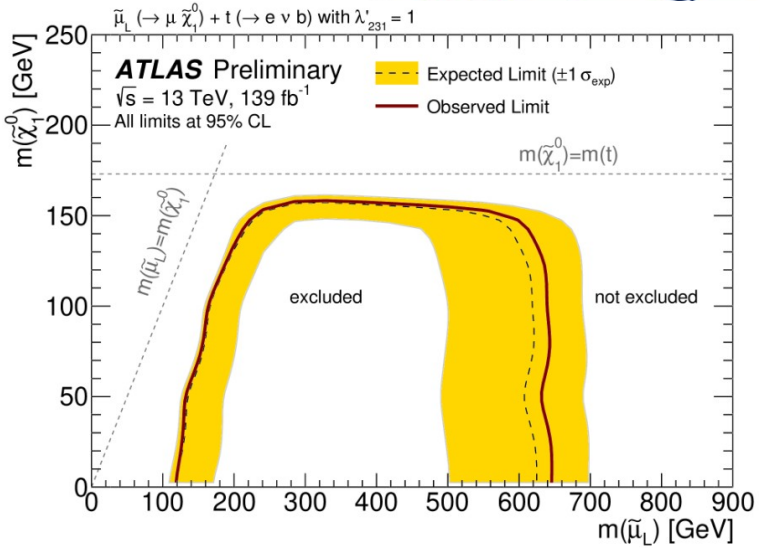
e μ asymmetry

RPV SUSY

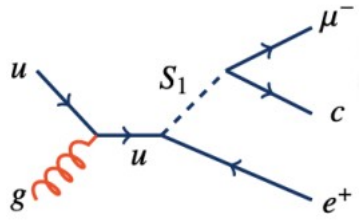


No significant excess observed in ρ measurement

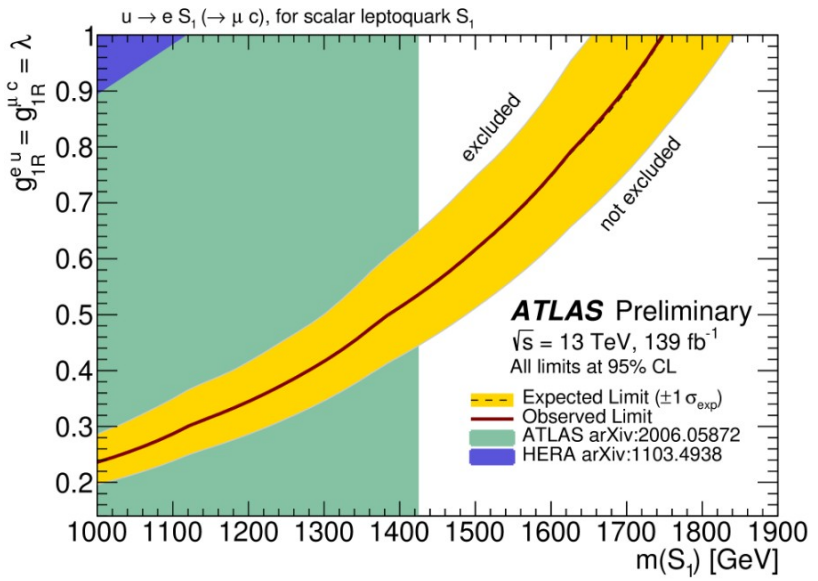




Limits extracted at 95% CL
for specific models



Single LQ production

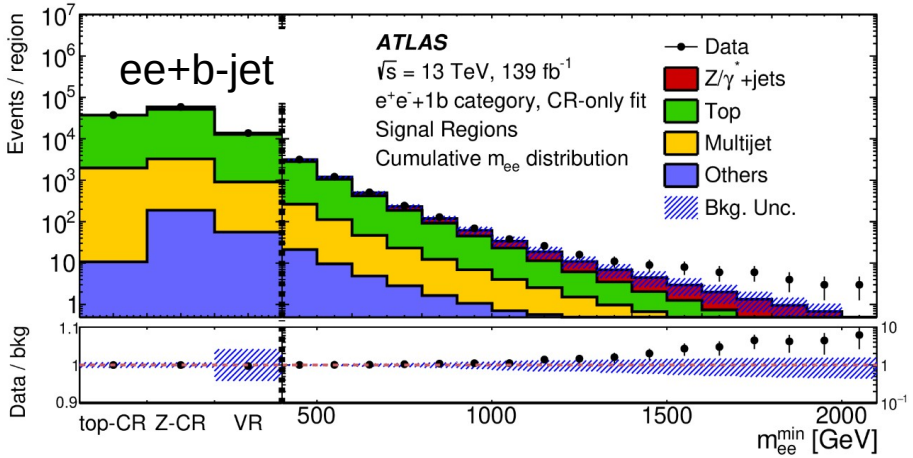


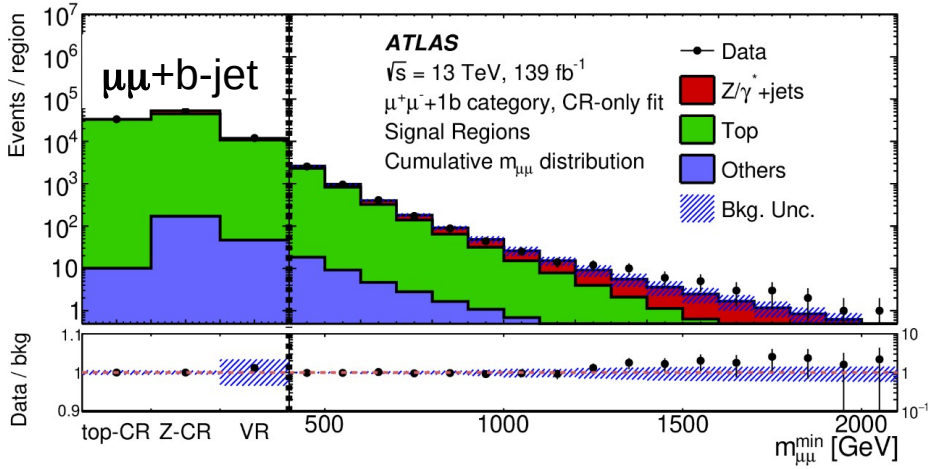
bsll contact interaction

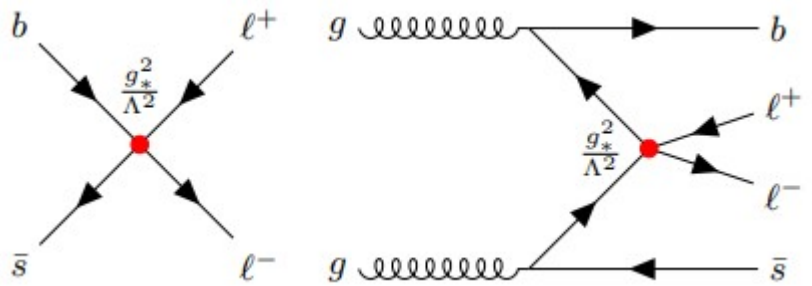
PRL 127 (2021) 141801

Direct probe of *bsll* interaction at high momentum
Four categories: $e^+e^-/\mu^+\mu^-$ + 0/1 b-jets

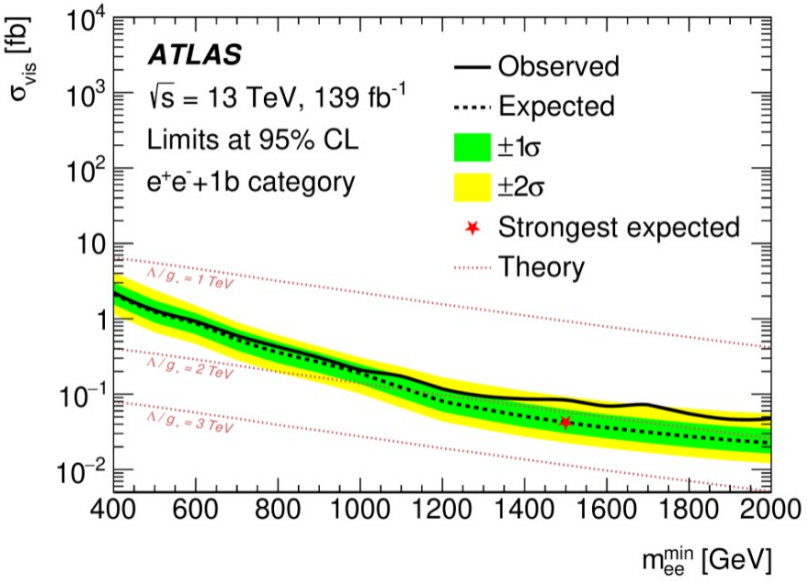
Background: Z/γ + jets, tt̄/Wt/tt̄V, QCD





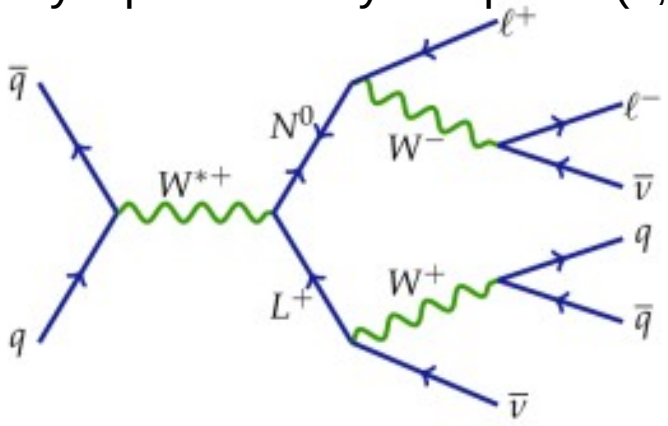


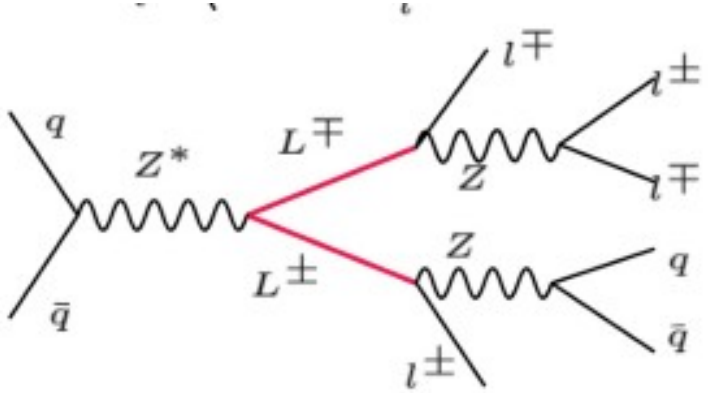
Limit interpreted with CI framework



Type III SeeSaw

Search for charged and neutral heavy leptons predicted by TypeIII Seesaw models → motivated by small SM neutrino mass
Heavy leptons decay in leptons (ν, e/μ) + SM bosons (W, Z or H)





Search in 2, 3 and 4 leptons final state and combination

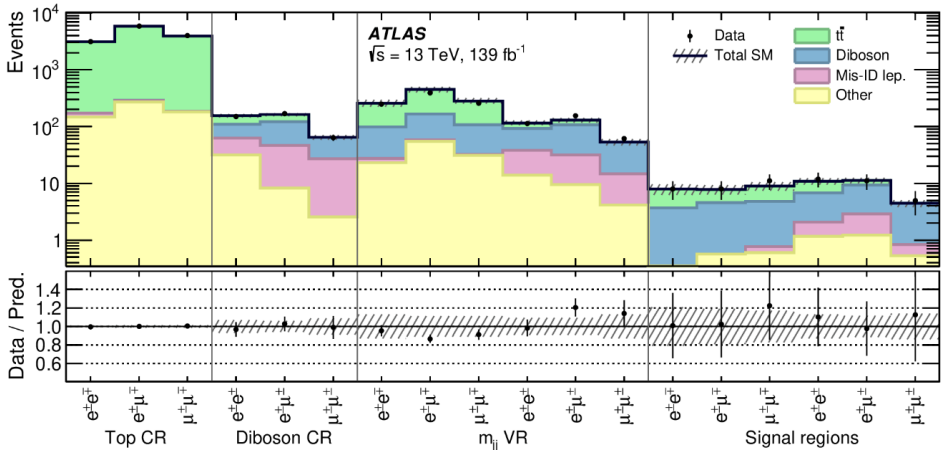
Two leptons + jets

Eur. Phys. J. C 81 (2021) 218

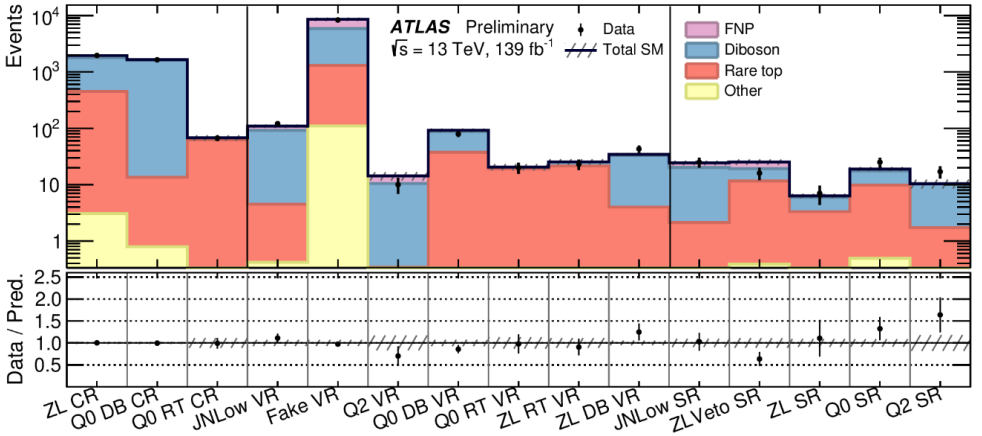
Three, four leptons + combination with two leptons

ATLAS-CONF-2021-023

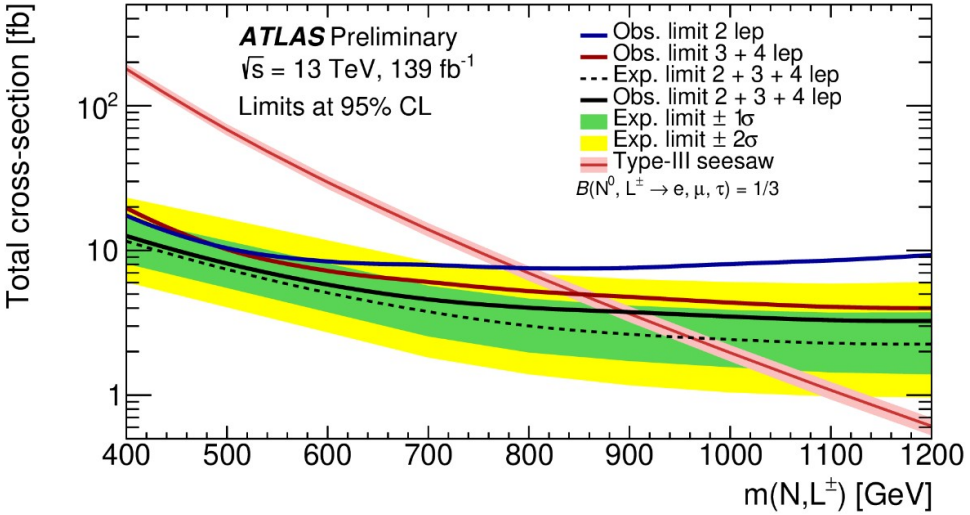
Heavy leptons in TypeIII SeeSaw



Two leptons final state



Three and Four leptons final state



Statistics limited measurement

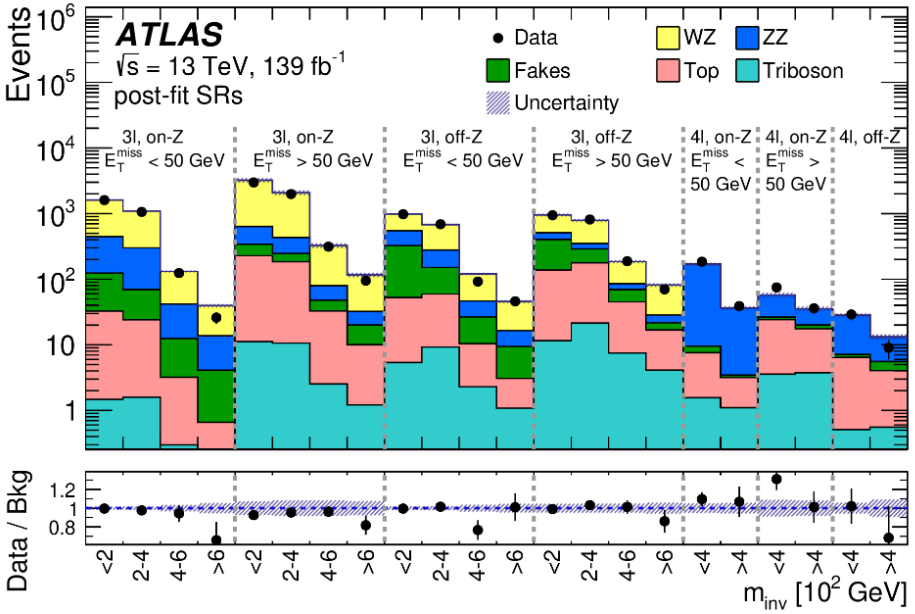
Heavy lepton mass below 910 GeV excluded at 95% CL

Multilepton General Search

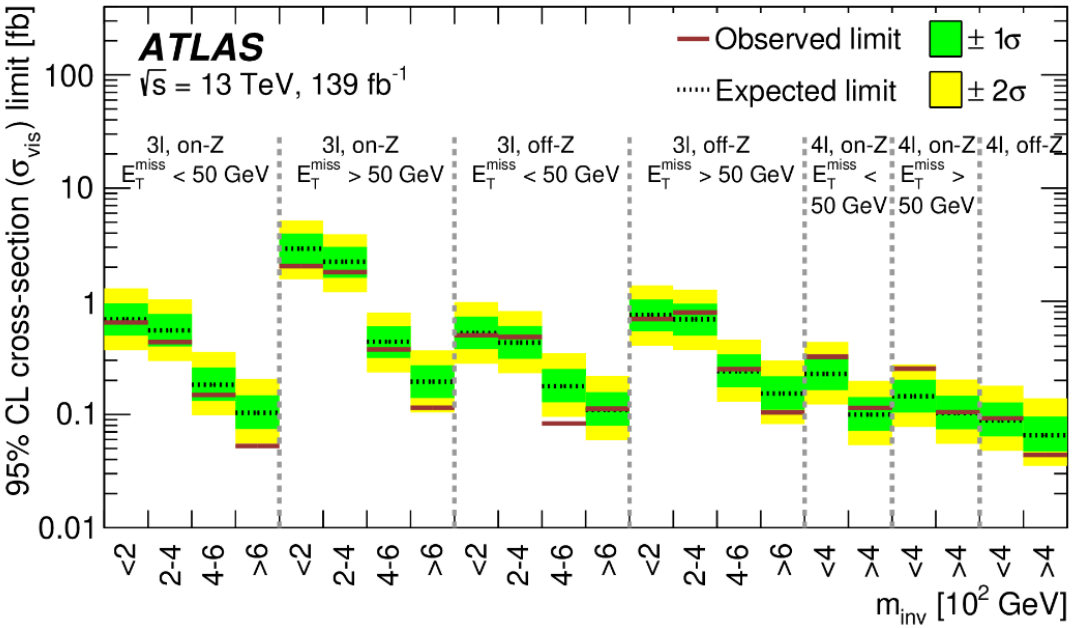
arXiv:2107.00404

- Exclude cross section for 3 and 4 lepton final states with additional requirements (small or large E_T^{miss} presence or not of a Z boson)
- Upper limits derived for specific models: Doubly charged Higgs and TypeIII Seesaw

Event Yields



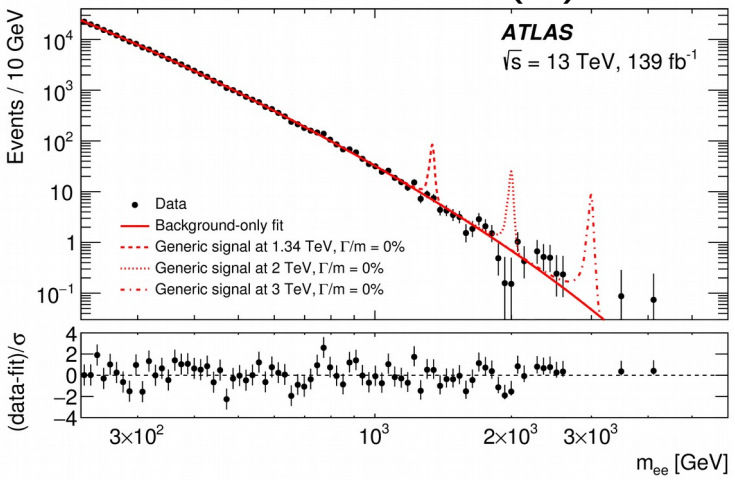
Excluded Cross Sections



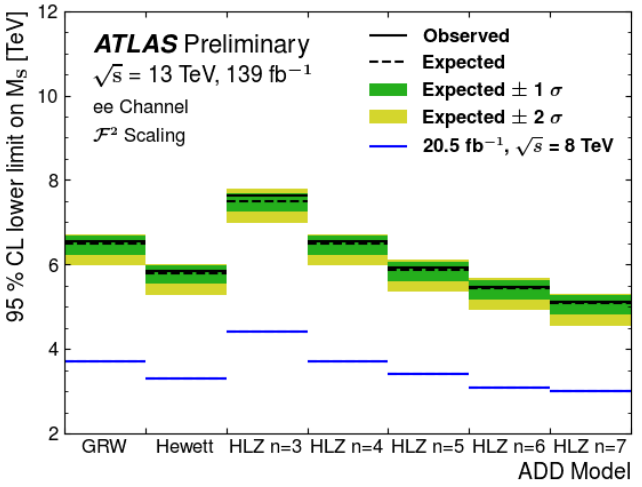
Non resonant dilepton search

From resonant search (Z') and non-resonant search in dilepton invariant mass distributions.

Resonant search (Z')



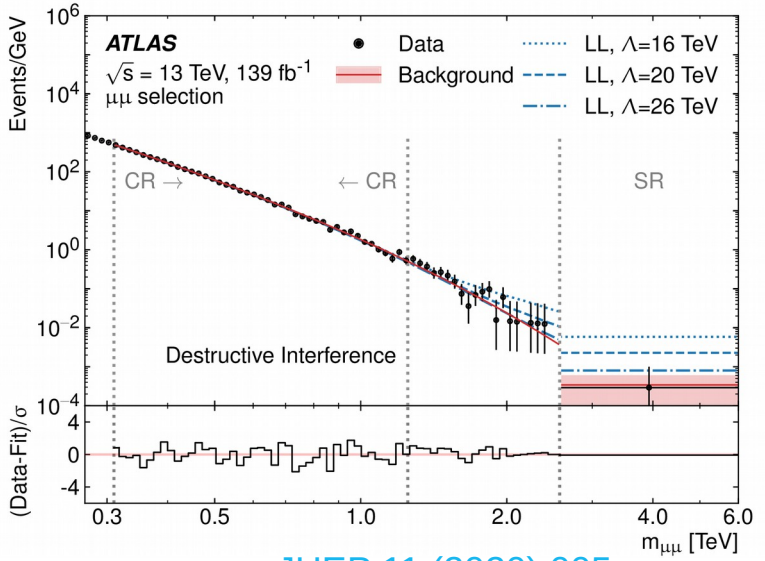
Phys Lett B 796 (2019) 68



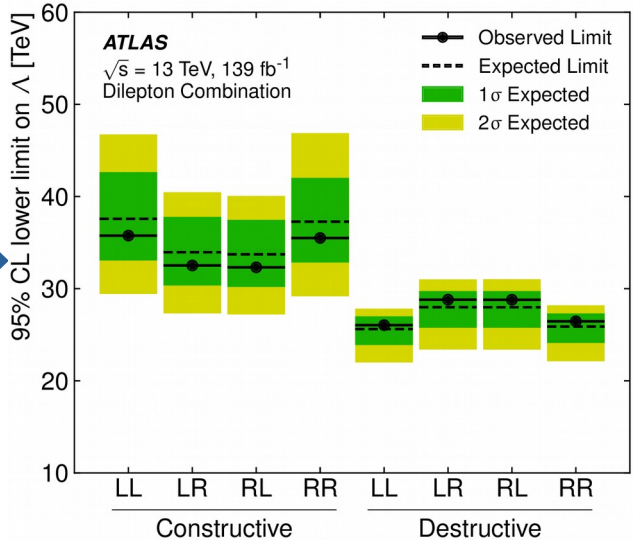
Graviton mass excluded limits for ADD models

ATL-PHYS-PUB-2021-021

Non resonant search



$$\frac{d\sigma}{dm_{\ell\ell}} = \frac{d\sigma_{DY}}{dm_{\ell\ell}} - \eta_{ij}\frac{F_I}{\Lambda^2} + \frac{F_C}{\Lambda^4}$$



JHEP 11 (2020) 005

Search for Heavy W’

Select events with large E_T^{miss}

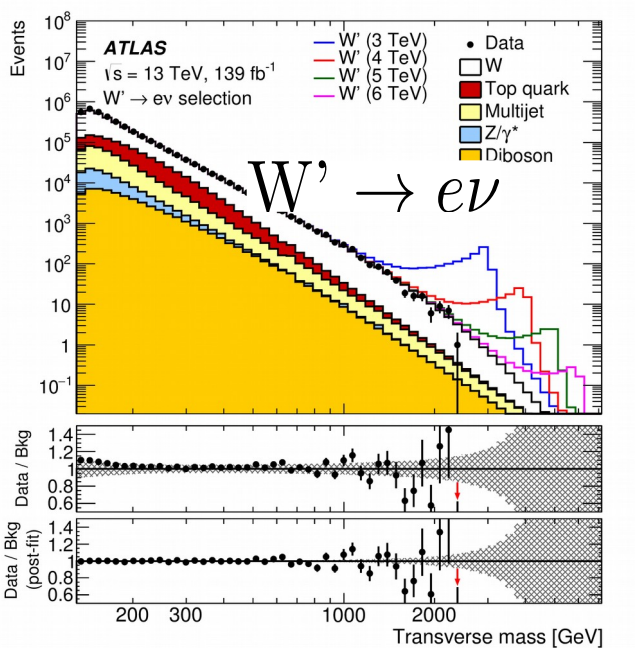
and exactly one lepton ($e/\mu/\tau_h$)

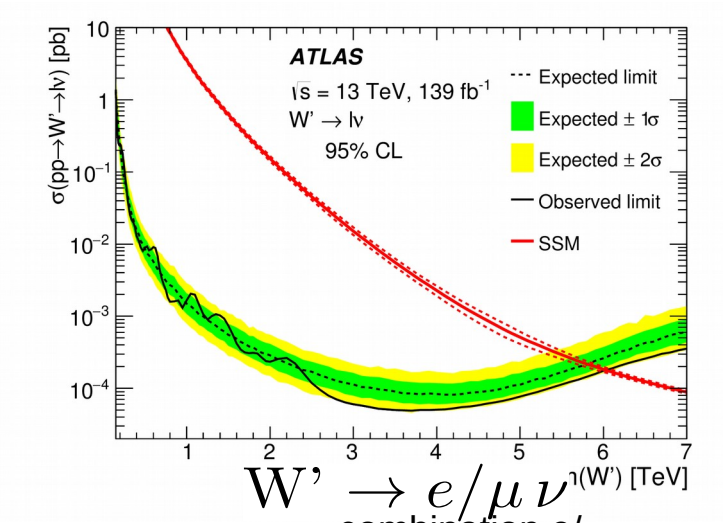
Transverse mass M_T as the discriminant

Inpterpretation as exclusion limits with SSM Sequential model

M(W’)>6 TeV (e and μ)
M(W’)> 5 TeV (τ)
@95% CL

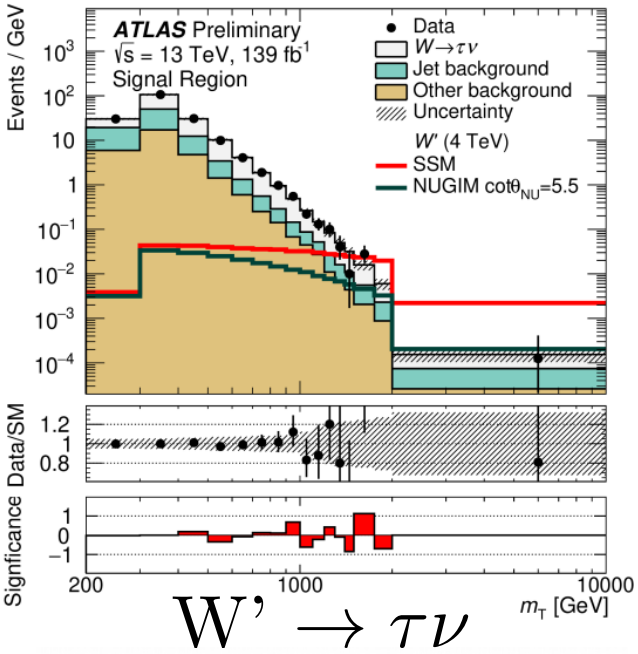
electron channel

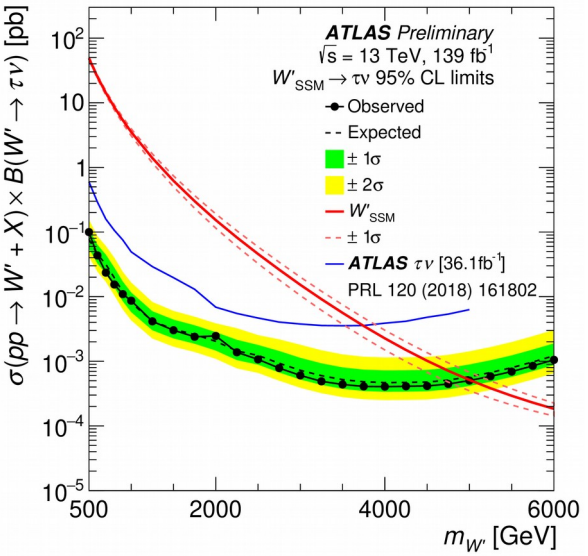




Phys. Rev. D 100 (2019) 052013

τ channel

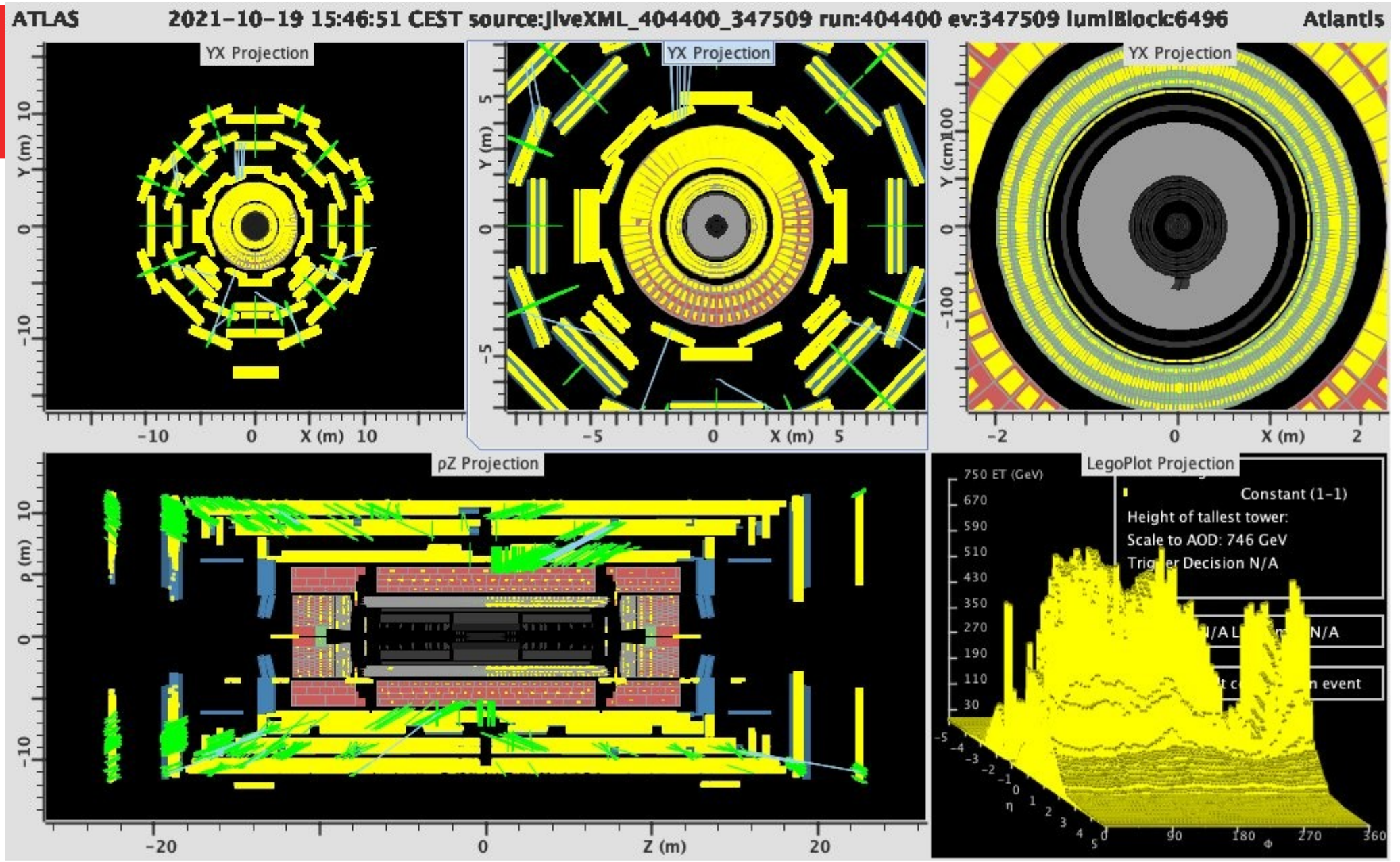




ATLAS-CONF-2021-025

Conclusions

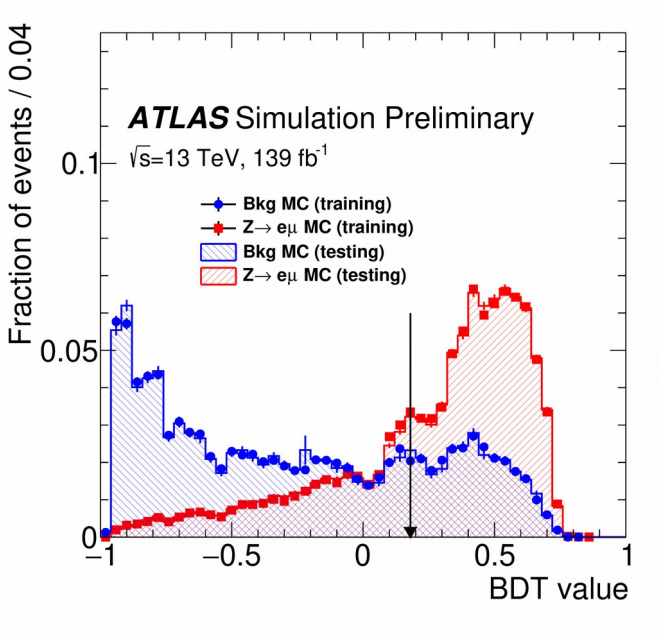
- Searches of BSM physics with leptonic final state well established in ATLAS
- No evidence for BSM deviations
- Limits on LFV and direct searches constantly improving thanks to increased statistics and better analysis techniques
- One of the most promising sector to look for confirmation of hints of LFU violations (LHCb, Babar and Belle) and muon (g-2)
- …..



RUN 3 IS COMING

BackUp

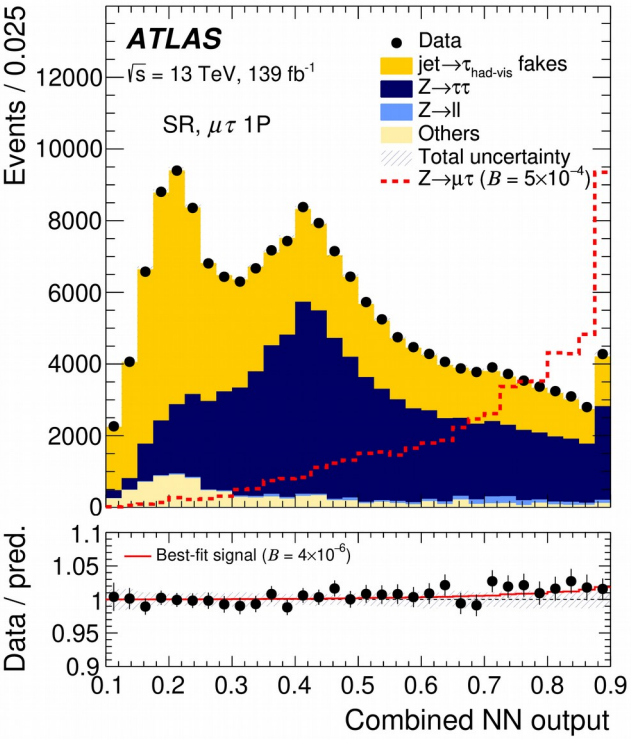
LFV Z→ eμ



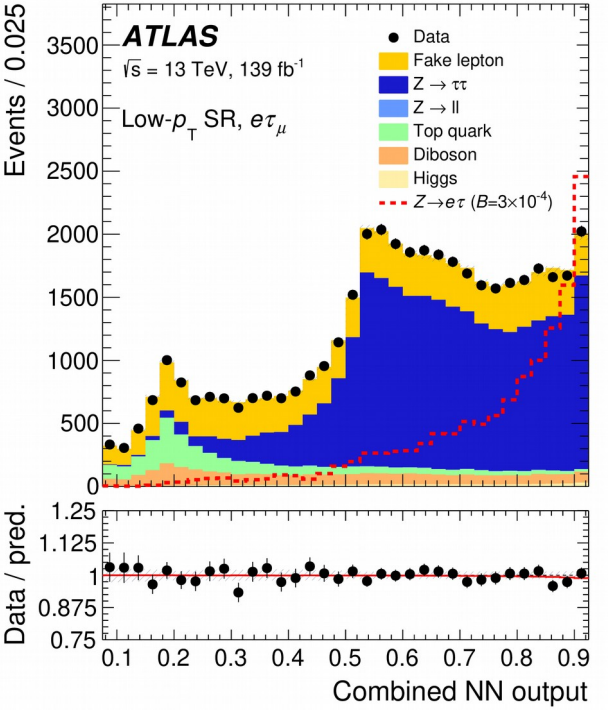
Source of uncertainty	Degradation of $\mathcal{B}^{95\%\mathrm{CL}}(Z \to e\mu)$
Limited simulated events	9.5%
$Z \to \tau\tau$	4.7%
$Z \to \mu\mu$	6.1%
All other sources	2.4%
Jet energy scale and resolution	1.2%
Pile-up	1.2%
Electron energy scale and resolution	0.8%
Lepton efficiency	0.7%
b-tagging	0.6%
Muon resolution and bias correction	0.6%

LFV Z→ τ e/μ

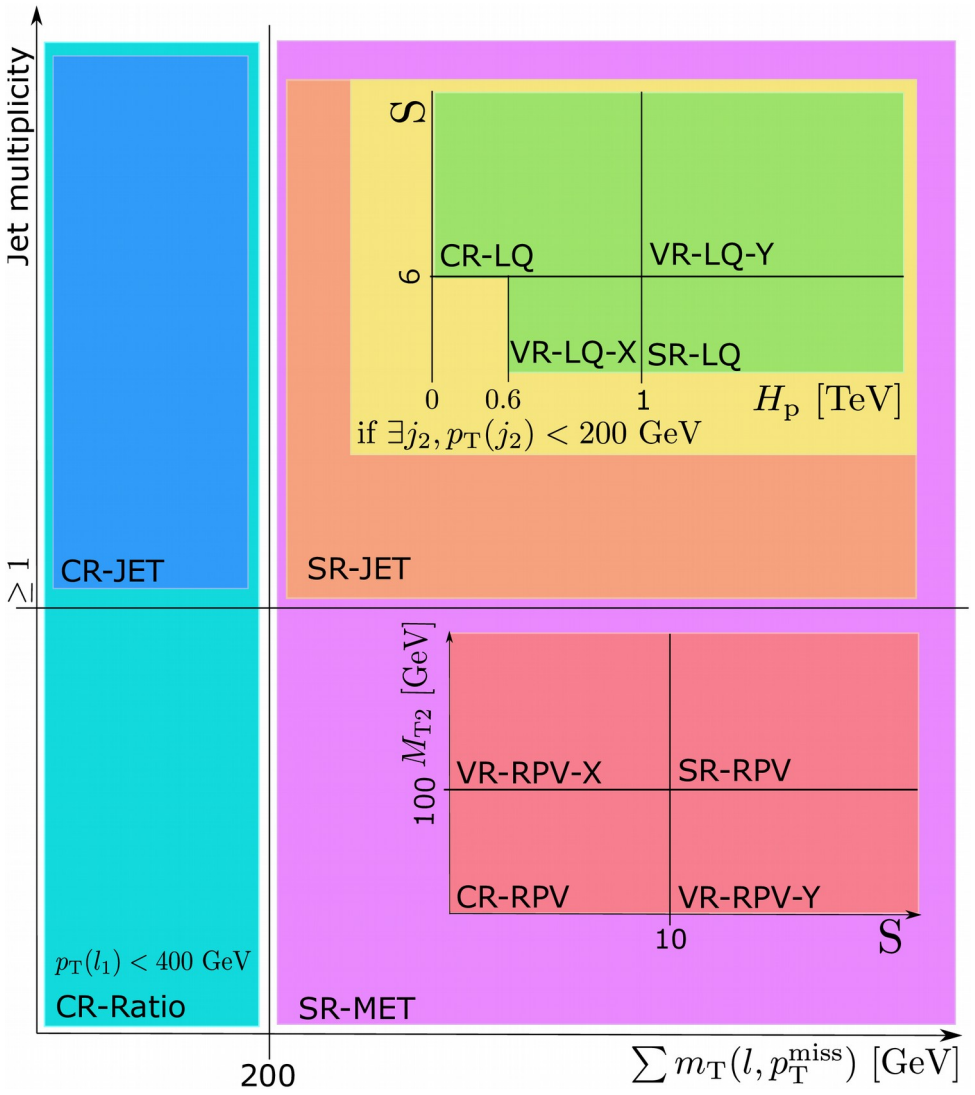
Experiment, polarization assumption	Observed (expected) upper limit on $\mathcal{B}(Z \to \ell\tau)$ [$\times 10^{-6}$] $e\tau$	$\mu\tau$
ATLAS Run 2, unpolarized τ	8.1 (8.1)	9.9 (6.3)
ATLAS Run 2, left-handed τ	8.2 (8.6)	9.5 (6.7)
ATLAS Run 2, right-handed τ	7.8 (7.6)	10 (5.8)
ATLAS Run 1, unpolarized τ		17 (26)
ATLAS Run 1+Run 2 combination, unpolarized τ		9.5 (6.1)
LEP OPAL, unpolarized τ	9.8	17
LEP DELPHI, unpolarized τ	22	12



Final state, polarization assumption	Observed (expected) upper limit on $\mathcal{B}(Z \to \ell\tau)$ [$\times 10^{-6}$] $e\tau$	$\mu\tau$
$\ell\tau_{\text{had}}$ Run 1 + Run 2, unpolarized τ	8.1 (8.1)	9.5 (6.1)
$\ell\tau_{\text{had}}$ Run 2, left-handed τ	8.2 (8.6)	9.5 (6.7)
$\ell\tau_{\text{had}}$ Run 2, right-handed τ	7.8 (7.6)	10 (5.8)
$\ell\tau_{\ell'}$ Run 2, unpolarized τ	7.0 (8.9)	7.2 (10)
$\ell\tau_{\ell'}$ Run 2, left-handed τ	5.9 (7.5)	5.7 (8.5)
$\ell\tau_{\ell'}$ Run 2, right-handed τ	8.4 (11)	9.2 (13)
Combined $\ell\tau$ Run 1 + Run 2, unpolarized τ	5.0 (6.0)	6.5 (5.3)
Combined $\ell\tau$ Run 2, left-handed τ	4.5 (5.7)	5.6 (5.3)
Combined $\ell\tau$ Run 2, right-handed τ	5.4 (6.2)	7.7 (5.3)



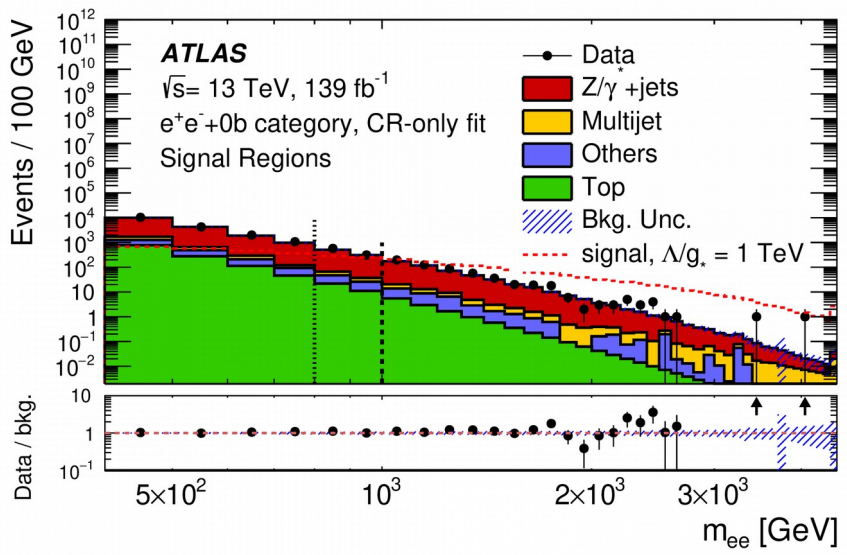
eμ Asymmetry

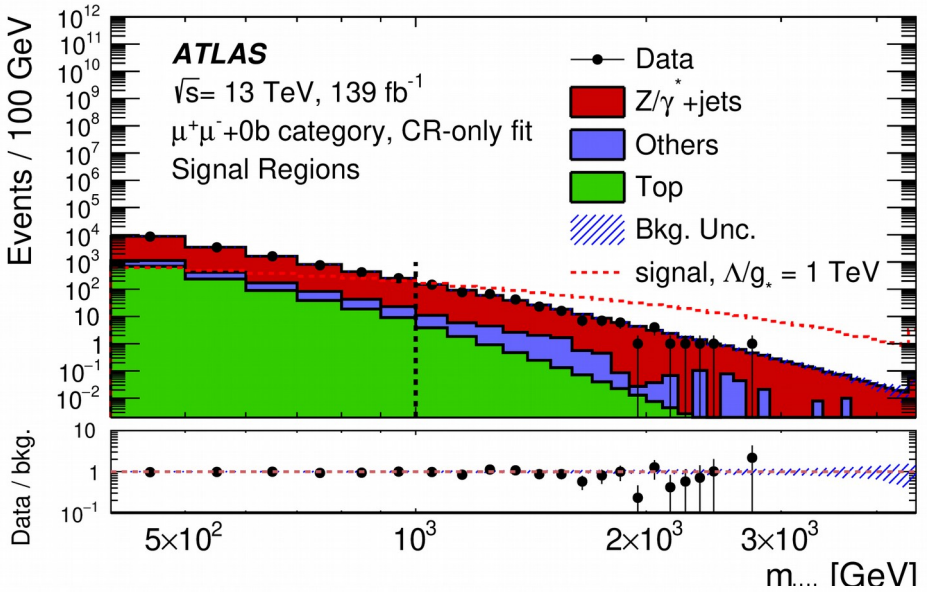


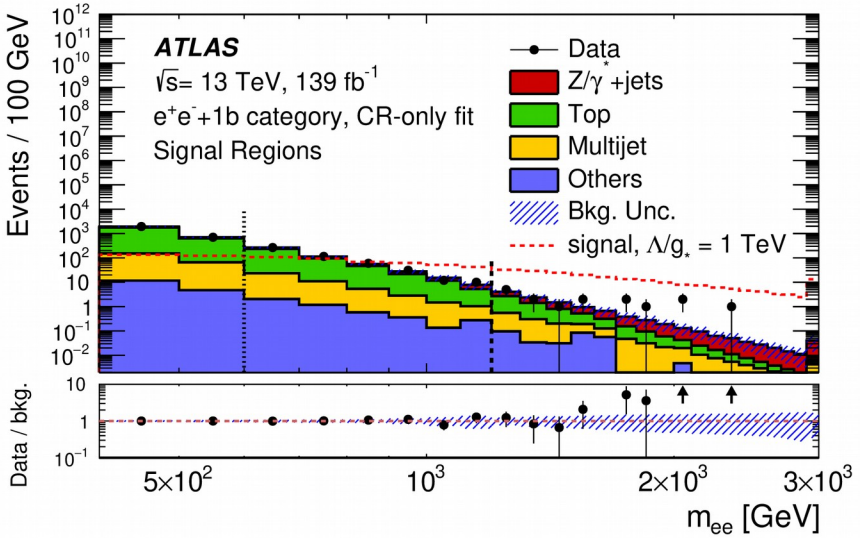
	SR-RPV	
	$e^+\mu^-$	$e^-\mu^+$
$m(\tilde{\chi}_1^0, \tilde{\mu}) = (\ 0, 500)$ GeV, $\lambda'_{231} = 1$	191 ± 19	46.8 ± 3.9
$m(\tilde{\chi}_1^0, \tilde{\mu}) = (50, 250)$ GeV, $\lambda'_{231} = 1$	1 160 ± 88	361 ± 92
$m(S_1) = 1000$ GeV, $\lambda = 0.5$		
$m(S_1) = 1250$ GeV, $\lambda = 1.0$		
Data	489 ± 22	510 ± 23
Total SM expectation	503 ± 48	510 ± 26
• part due to real leptons	473 ± 47	479 ± 24
• part due to fake leptons	29.4 ± 8.2	30.3 ± 8.3

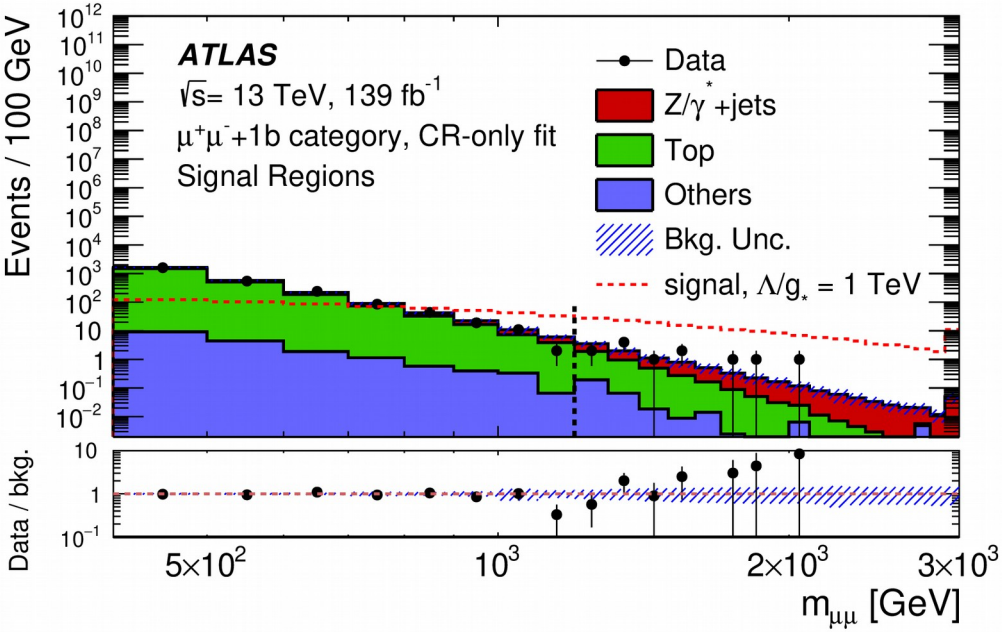
	SR-LQ	
	$e^+\mu^-$	$e^-\mu^+$
$m(\tilde{\chi}_1^0, \tilde{\mu}) = (\ 0, 500)$ GeV, $\lambda'_{231} = 1$		
$m(\tilde{\chi}_1^0, \tilde{\mu}) = (50, 250)$ GeV, $\lambda'_{231} = 1$		
$m(S_1) = 1000$ GeV, $\lambda = 0.5$	157 ± 26	10.6 ± 2.3
$m(S_1) = 1250$ GeV, $\lambda = 1.0$	244 ± 38	15.9 ± 3.4
Data	60.9 ± 7.8	69.1 ± 8.3
Total SM expectation	61 ± 13	69 ± 12
• part due to real leptons	46 ± 12	47 ± 11
• part due to fake leptons	14.1 ± 4.8	22.1 ± 6.6

bsll

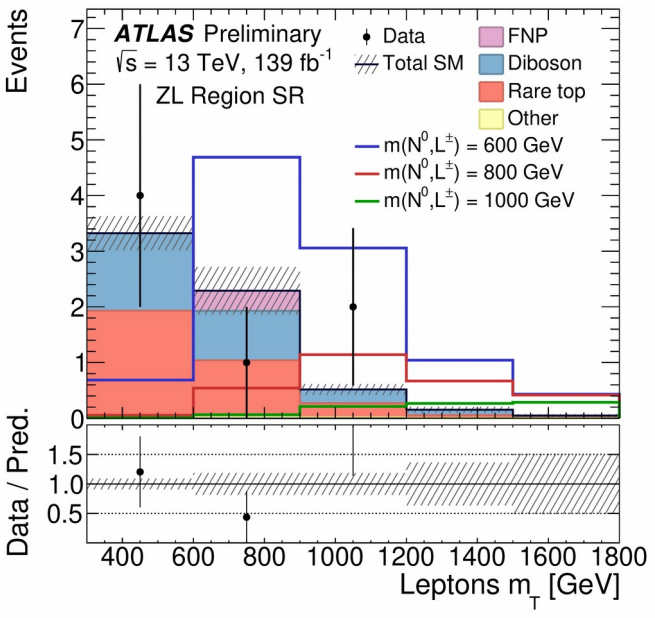

ATLAS
√s= 13 TeV, 139 fb-1
e+e-+0b category, CR-only fit
Signal Regions
Data
Z/γ* +jets
Multijet
Others
Top
Bkg. Unc.
signal, Λ/g* = 1 TeV
Events / 100 GeV
Data / bkg.
mee [GeV]

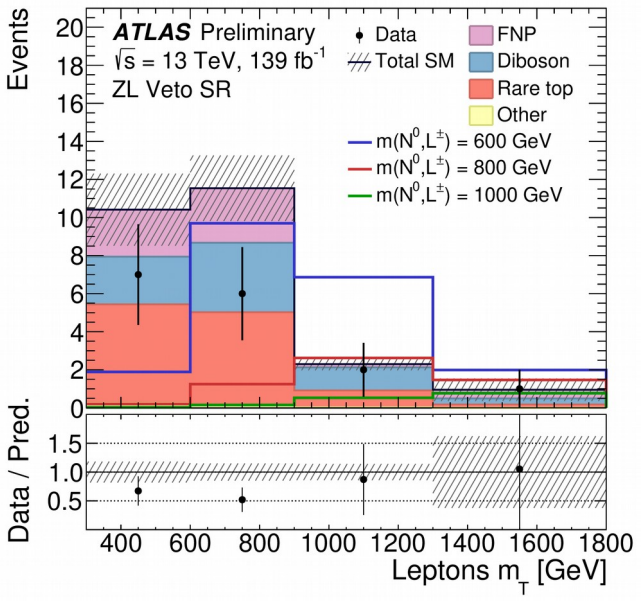

ATLAS
√s= 13 TeV, 139 fb-1
μ+μ-+0b category, CR-only fit
Signal Regions
Data
Z/γ* +jets
Others
Top
Bkg. Unc.
signal, Λ/g* = 1 TeV
Events / 100 GeV
Data / bkg.
mμμ [GeV]

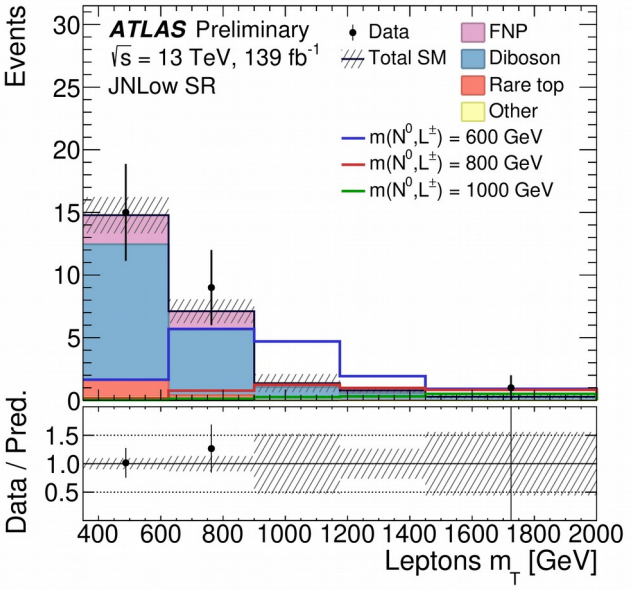

ATLAS
√s= 13 TeV, 139 fb-1
e+e-+1b category, CR-only fit
Signal Regions
Data
Z/γ* +jets
Top
Multijet
Others
Bkg. Unc.
signal, Λ/g* = 1 TeV
Events / 100 GeV
Data / bkg.
mee [GeV]

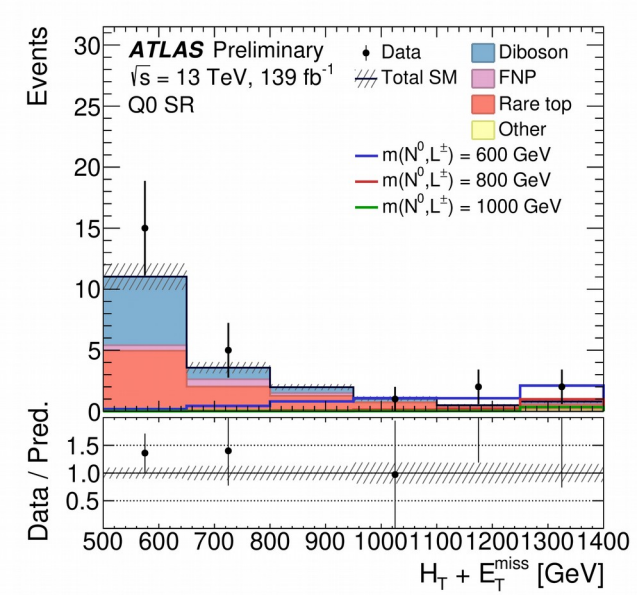

ATLAS
√s= 13 TeV, 139 fb-1
μ+μ-+1b category, CR-only fit
Signal Regions
Data
Z/γ* +jets
Top
Others
Bkg. Unc.
signal, Λ/g* = 1 TeV
Events / 100 GeV
Data / bkg.
mμμ [GeV]

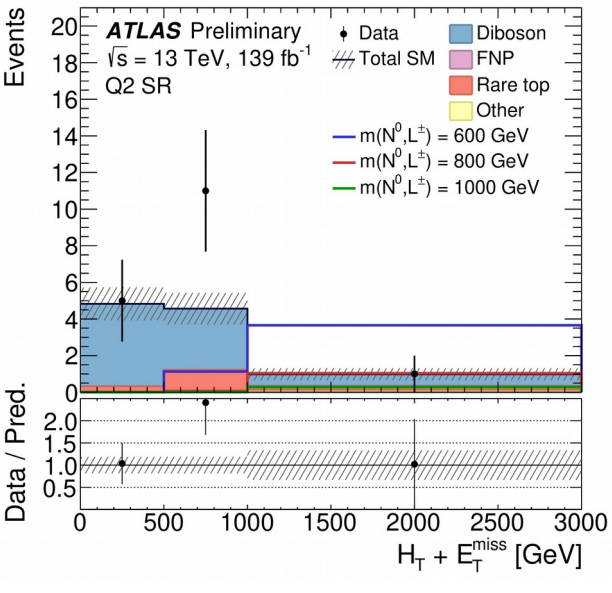
Type3 SeeSaw



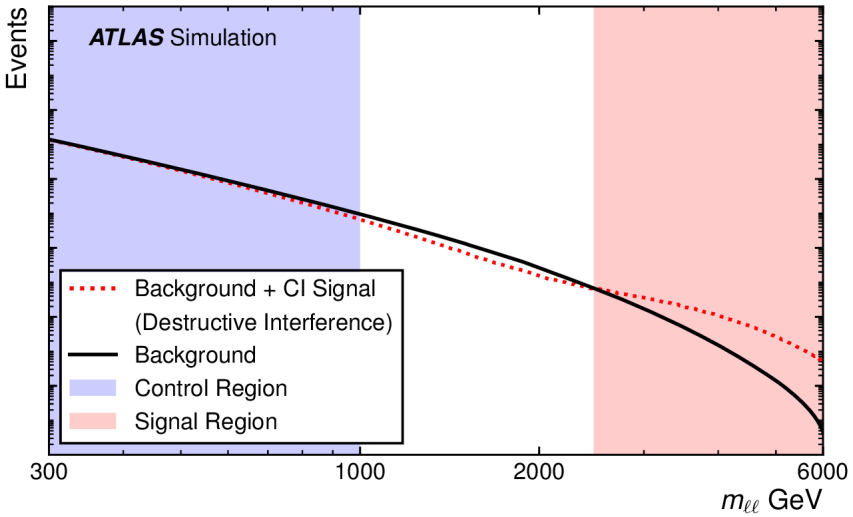


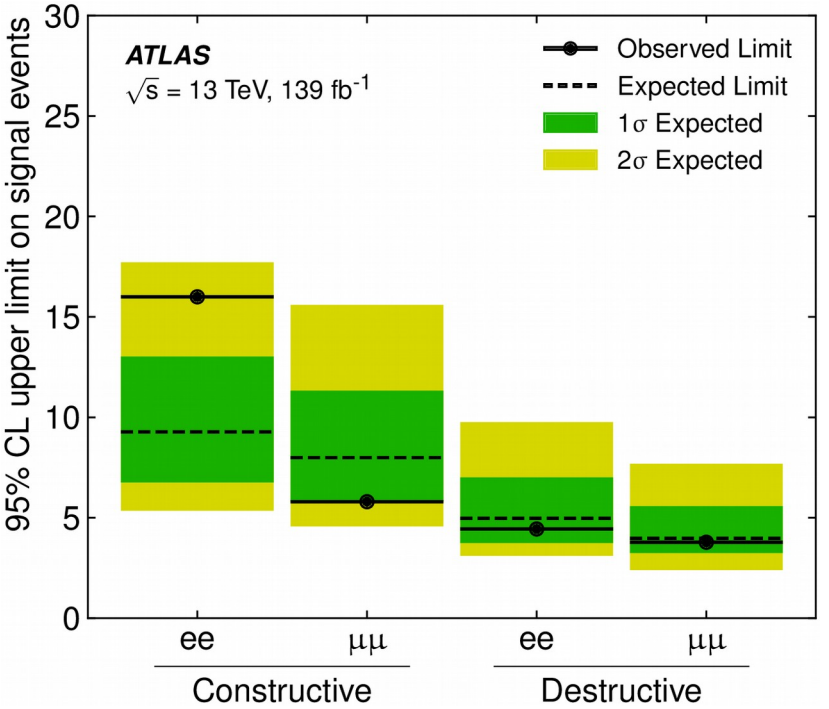


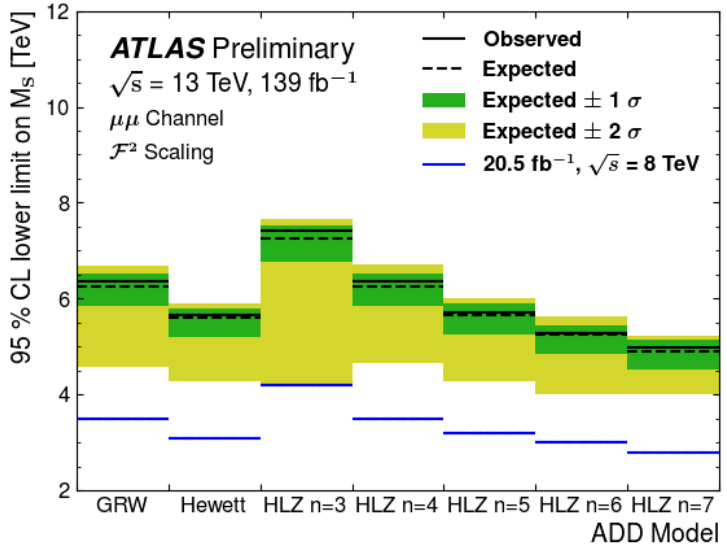




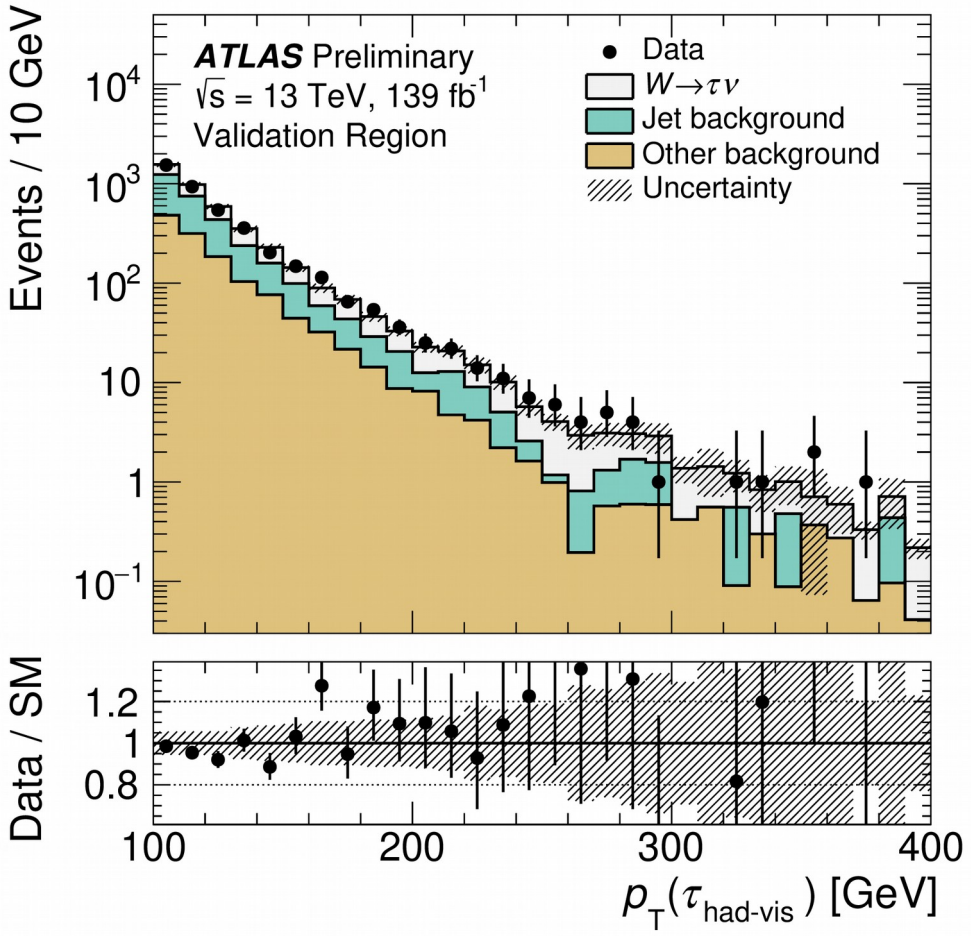
Dilepton search

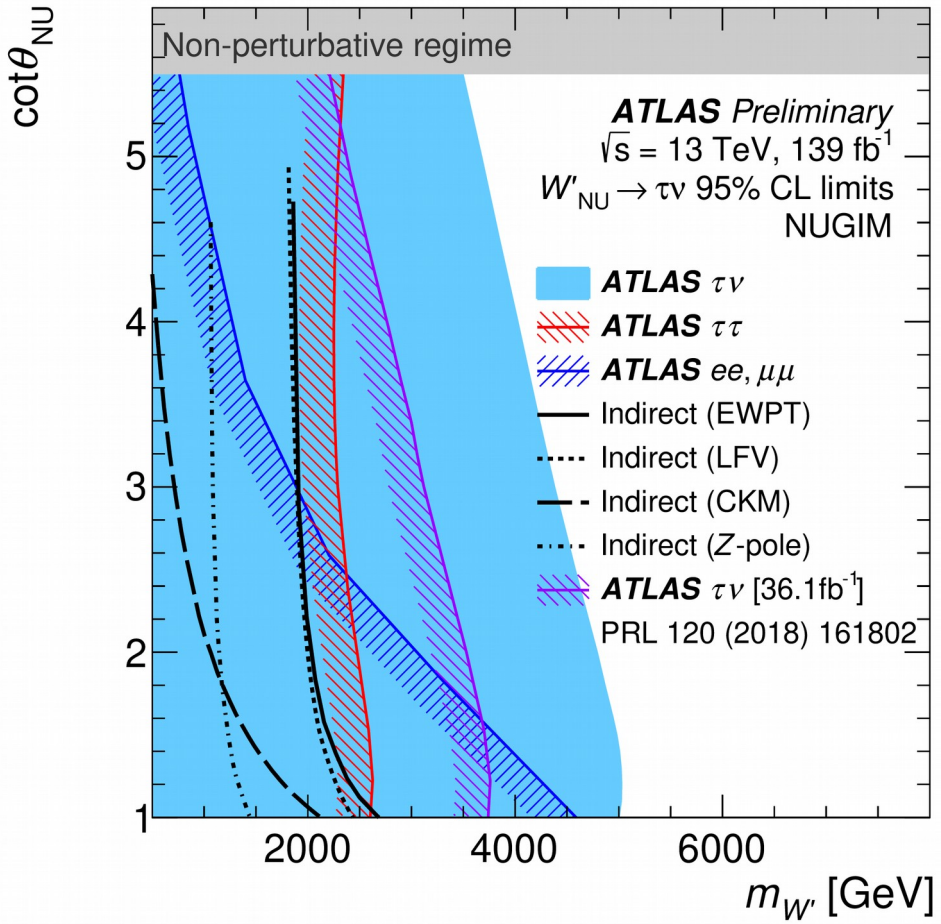






W’ → τ ν


ATLAS Preliminary
√s = 13 TeV, 139 fb-1
Validation Region
Data
W→τν
Jet background
Other background
Uncertainty
Events / 10 GeV
Data / SM
pT(τhad-vis) [GeV]


Non-perturbative regime
ATLAS Preliminary
√s = 13 TeV, 139 fb-1
W'NU → τν 95% CL limits
NUGIM
ATLAS ττ
ATLAS ee, μμ
Indirect (EWPT)
Indirect (LFV)
Indirect (CKM)
Indirect (Z-pole)
ATLAS τν [36.1fb-1]
PRL 120 (2018) 161802
cotθNU
mW' [GeV]