Tests of Neutrino Mass Models at ATLAS

The 22nd International Workshop on Neutrinos from Accelerators

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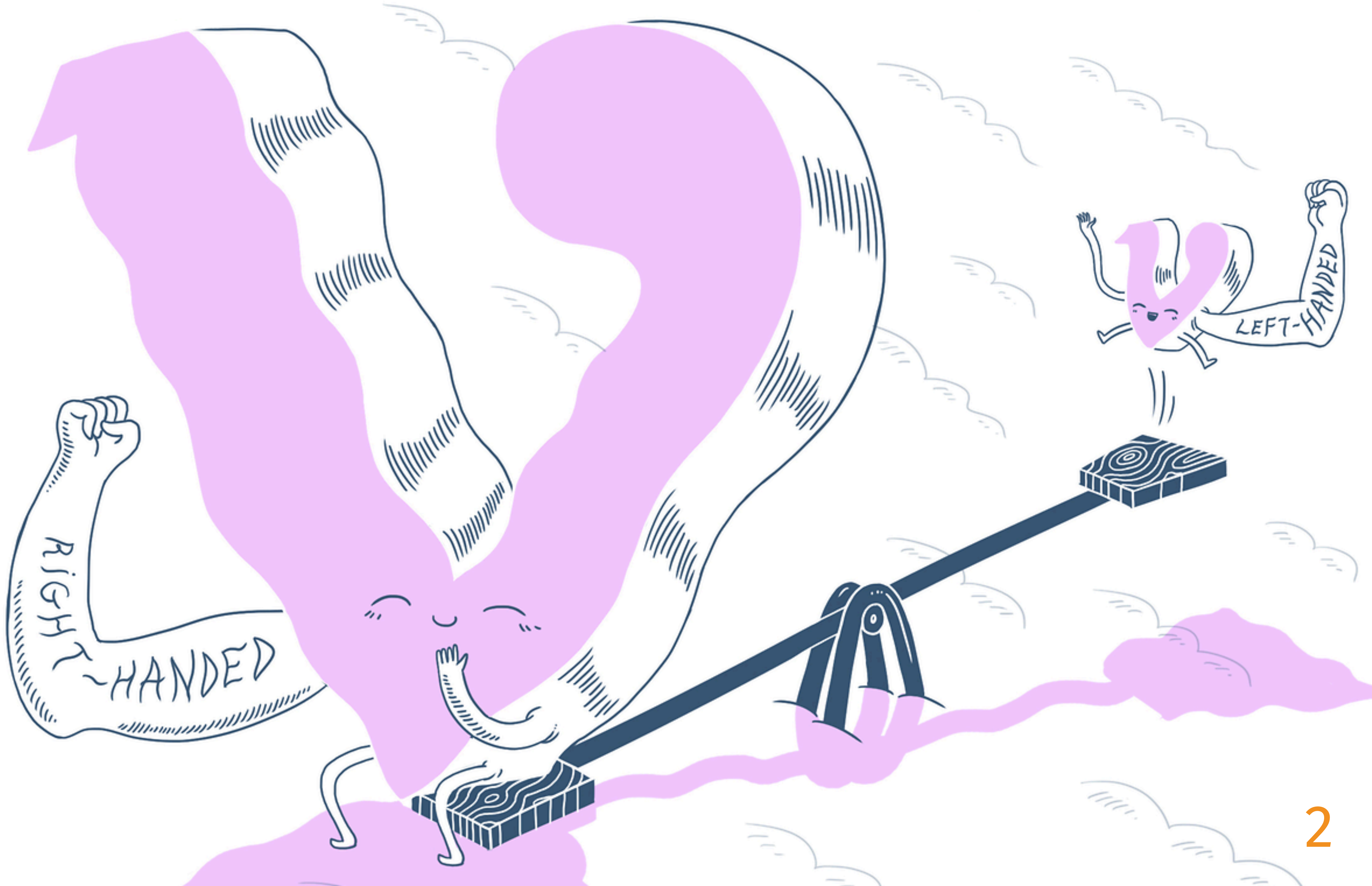
on behalf of the ATLAS collaboration

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

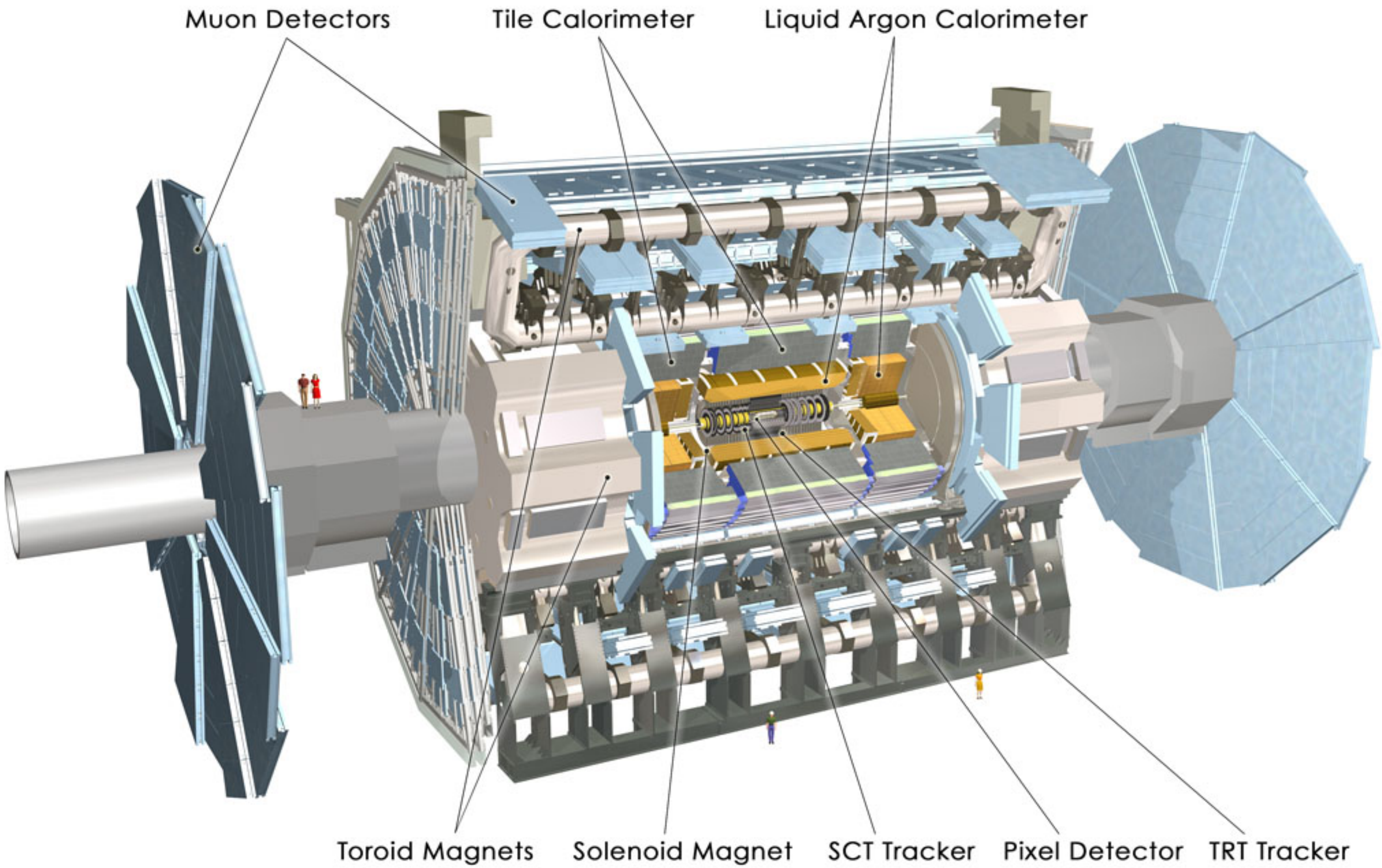
- Neutrino oscillations observed experimentally — at least two SM neutrinos have non-zero mass.
- Neutrinos may be Dirac or Majorana particles.
- The seesaw mechanism might explain the relative smallness of the neutrino masses.
- Connects SM left-handed neutrino masses with the masses of new right-handed neutrino-like particles.

Source: Symmetry Magazine, artwork by Sandbox Studio, Chicago with Ana Kova



Three types:

1. type-I seesaw (fermionic singlets)
2. type-II seesaw (a scalar triplet)
3. type-III seesaw (fermionic triplets)



- General purpose detector at the Large Hadron Collider.
  - Precision measurement of the Standard Model.
  - Searches beyond the SM — particles with masses greater than M ~ 1 TeV.
- Analysed full 139 fb^{-1} of Run 2 data.

Type-I Seesaw Heavy Neutral Leptons (1)

ATLAS-EXOT-2017-26 36 fb^{-1}
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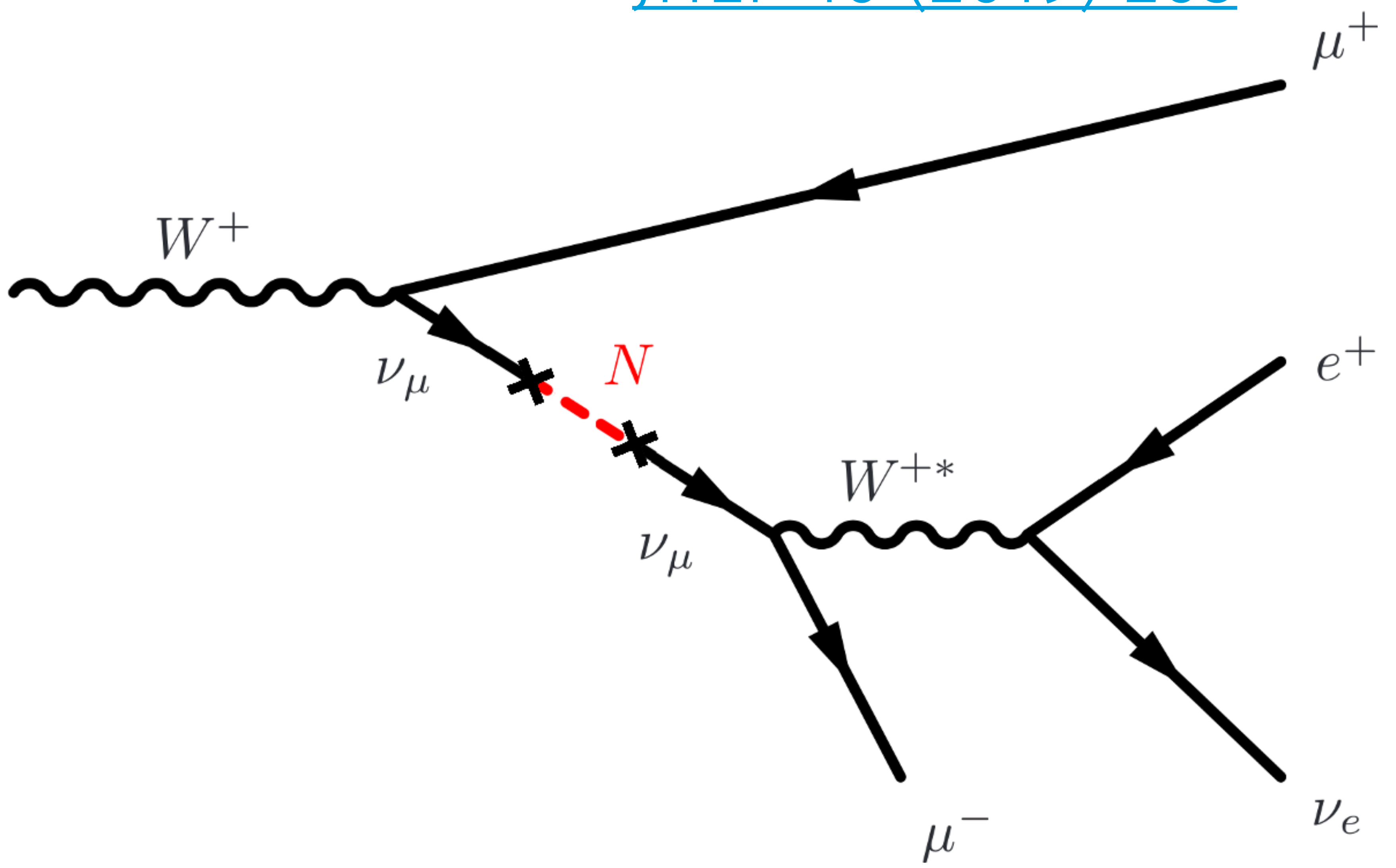
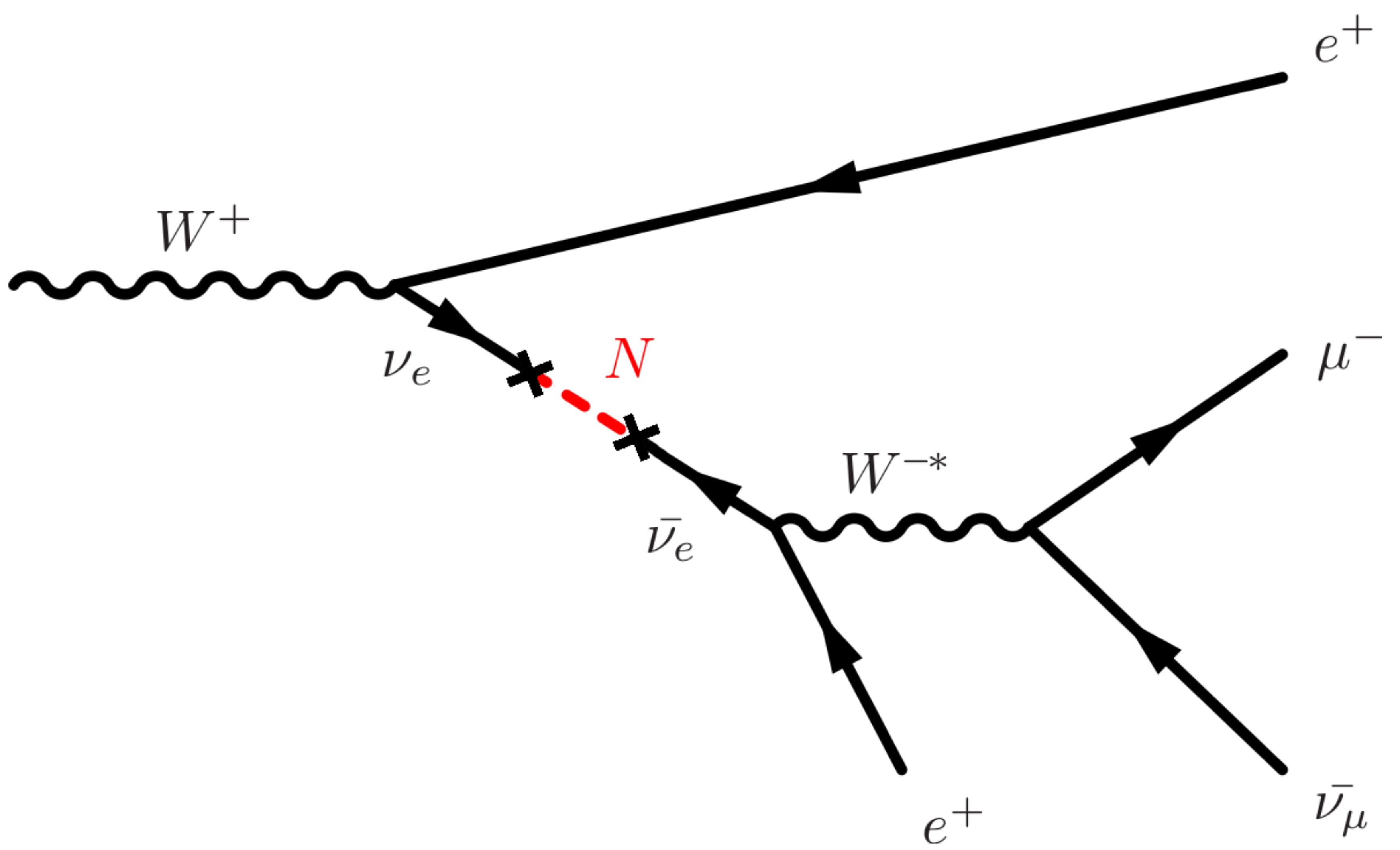
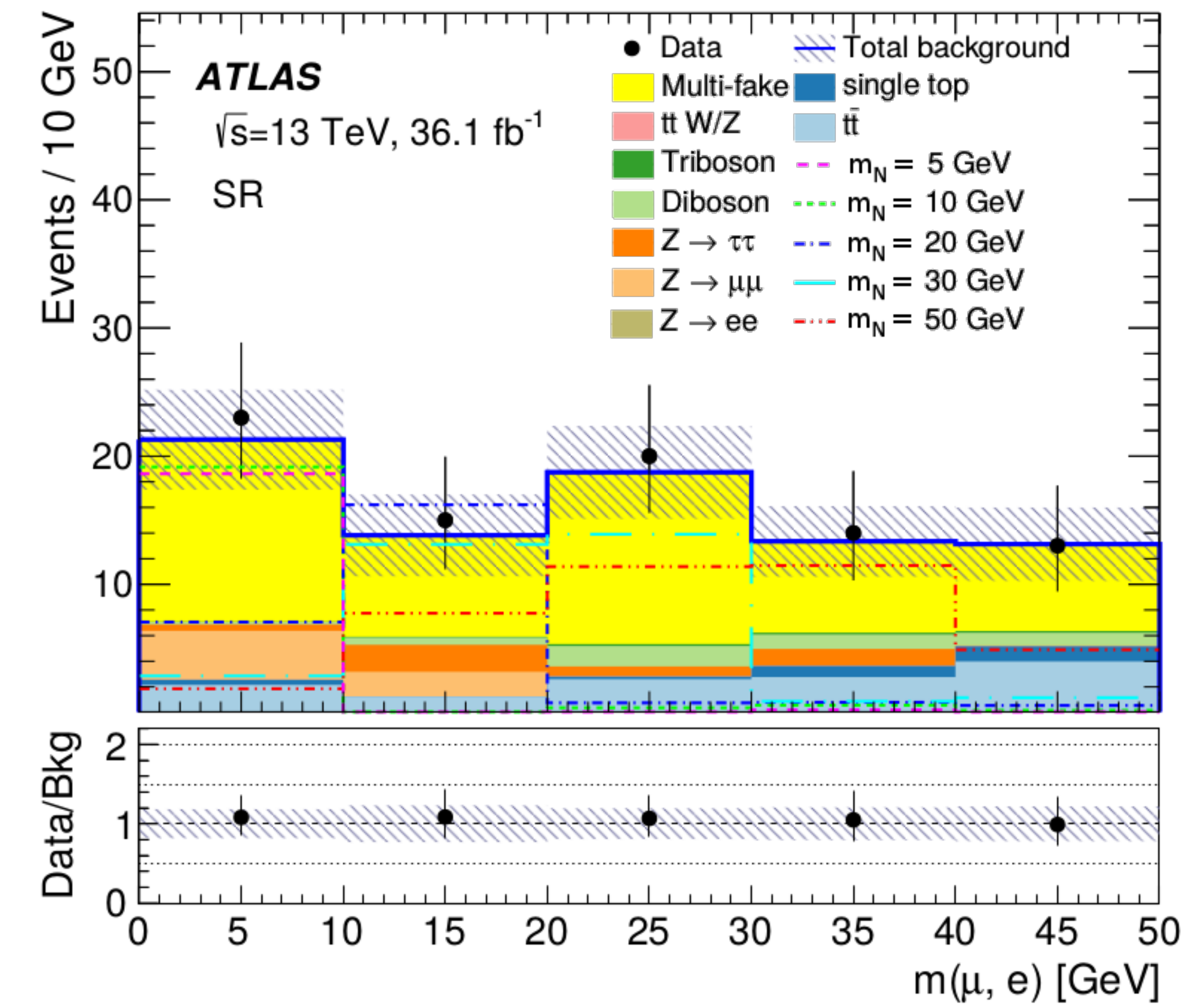
- Type-I seesaw introduces a right-handed Majorana neutrino N, also called Heavy Neutral Lepton (HNL), Prog. Theor. Phys. 64 (1980) 1103.
- Depending on the mixing and mass parameters, the HNL may decay promptly or be long-lived.
  - Mass range explored: $1.4 < m_N < 50$ GeV
  - Displaced vertices up to 300 mm in the transverse plane have been investigated.
- Both lepton number conserving (LNC) and lepton number violating (LNV) final states possible.
- Signatures
  - prompt: $W^\pm \to e^\pm e^\pm \mu^\mp \nu_\mu$ & $W^\pm \to \mu^\pm \mu^\pm e^\mp \nu_e$
  - displaced: prompt μ, displaced vertex with opposite charge $e\mu$ or $\mu\mu$





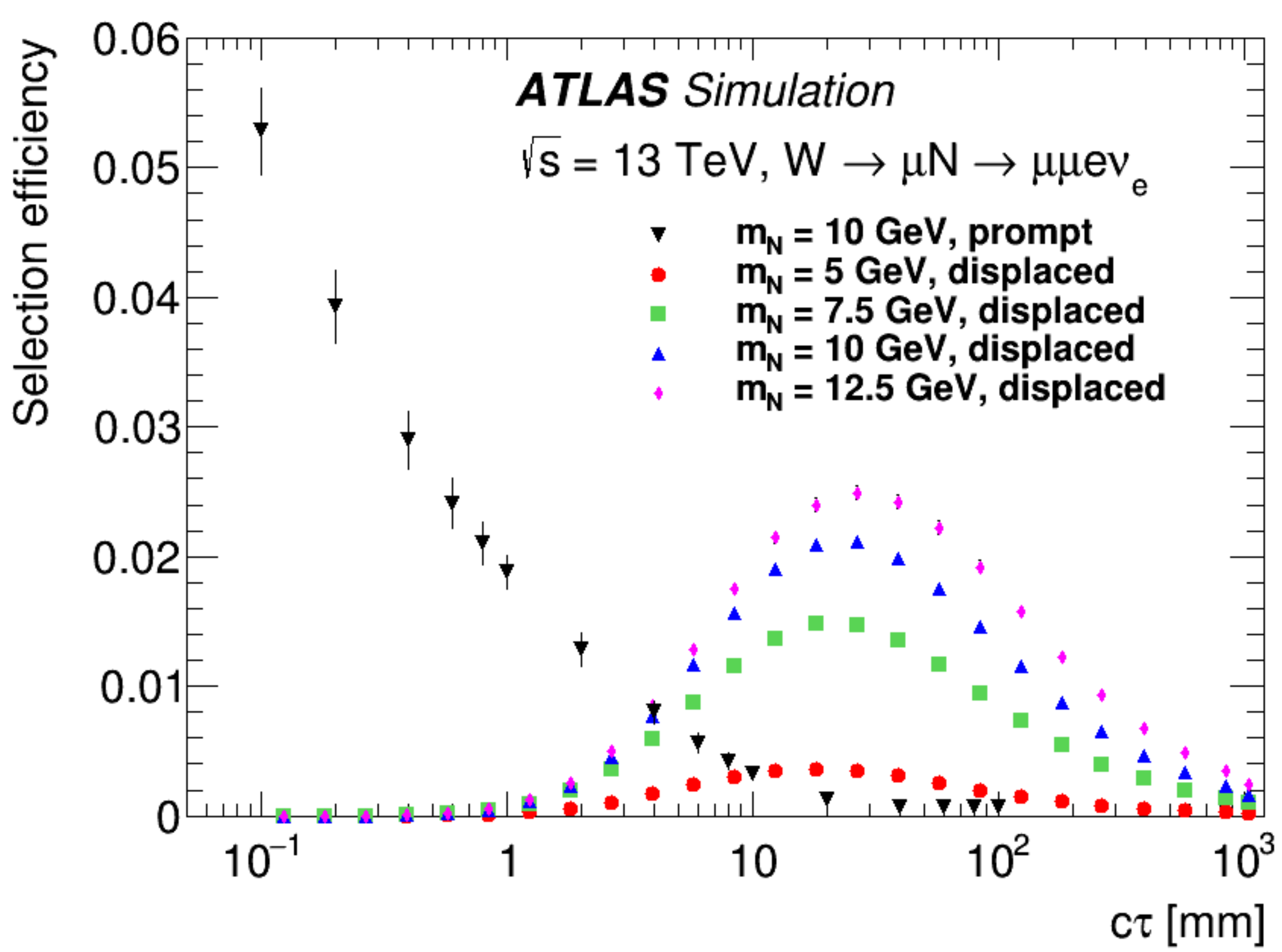
Prompt signatures

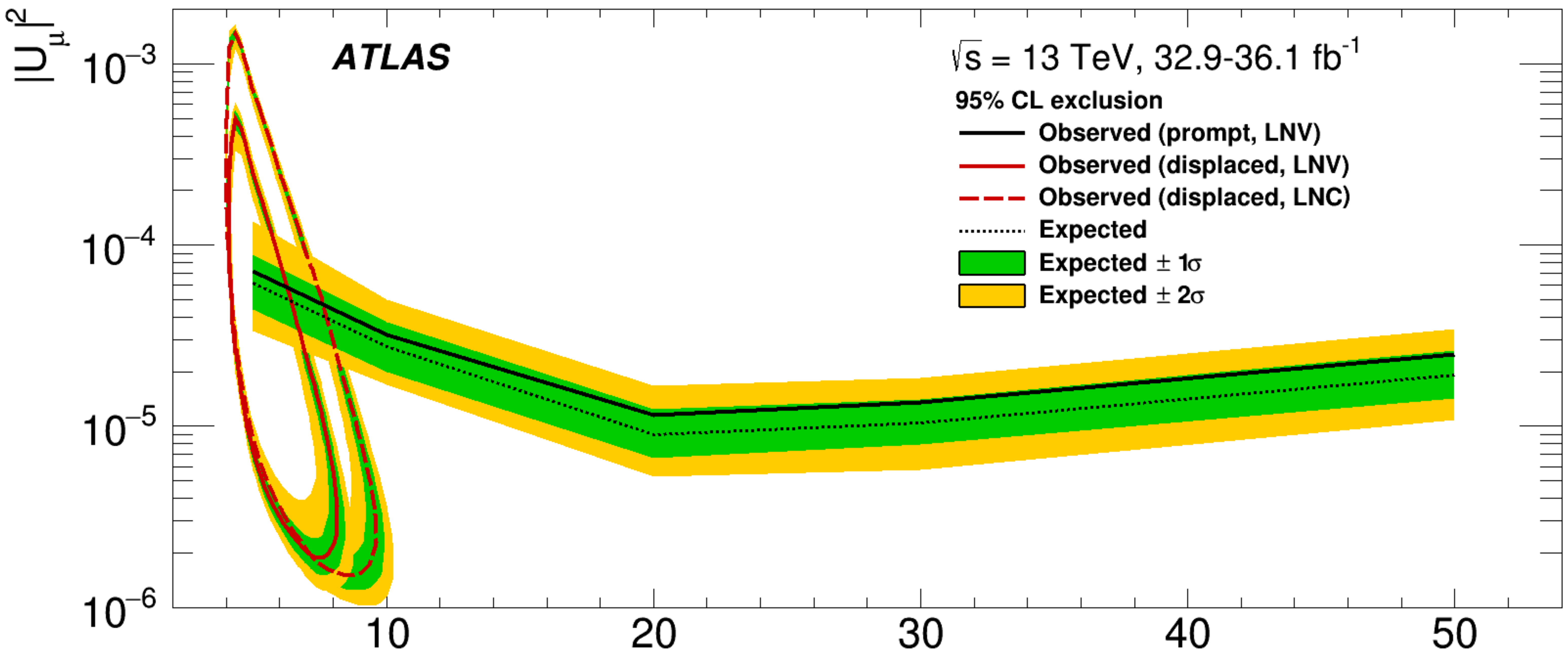
- W decay constraint: $40 < m(l, l, l') < 90$ GeV
- Reduce leptons with misreconstructed charge: $m(e, e) < 78$ GeV
- $E_T^{miss} < 60$ GeV
- Fitted variable: $m(l, l')$

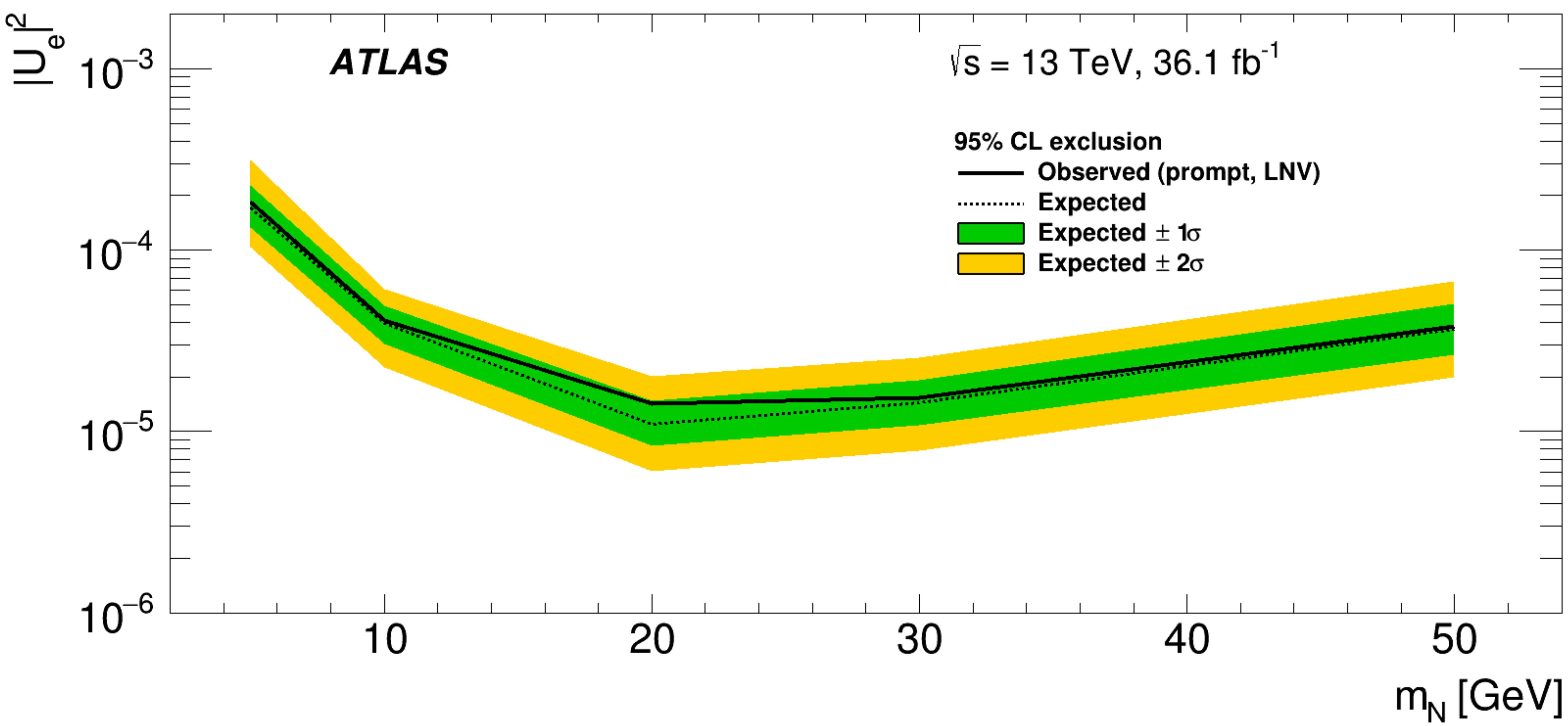


Displaced signatures

- background sources:
  - hadronic interactions in material
  - decays of metastable particles (hadrons)
  - accidental crossings of charged particles
  - cosmic-ray muons
- No events observed in the signal region.







Prompt signature limits

- Cover the mass range 5–50 GeV.
- $|U_\mu|^2$ and $|U_e|^2$ above 1.4×10^{-5} are excluded in for masses 20–30 GeV.

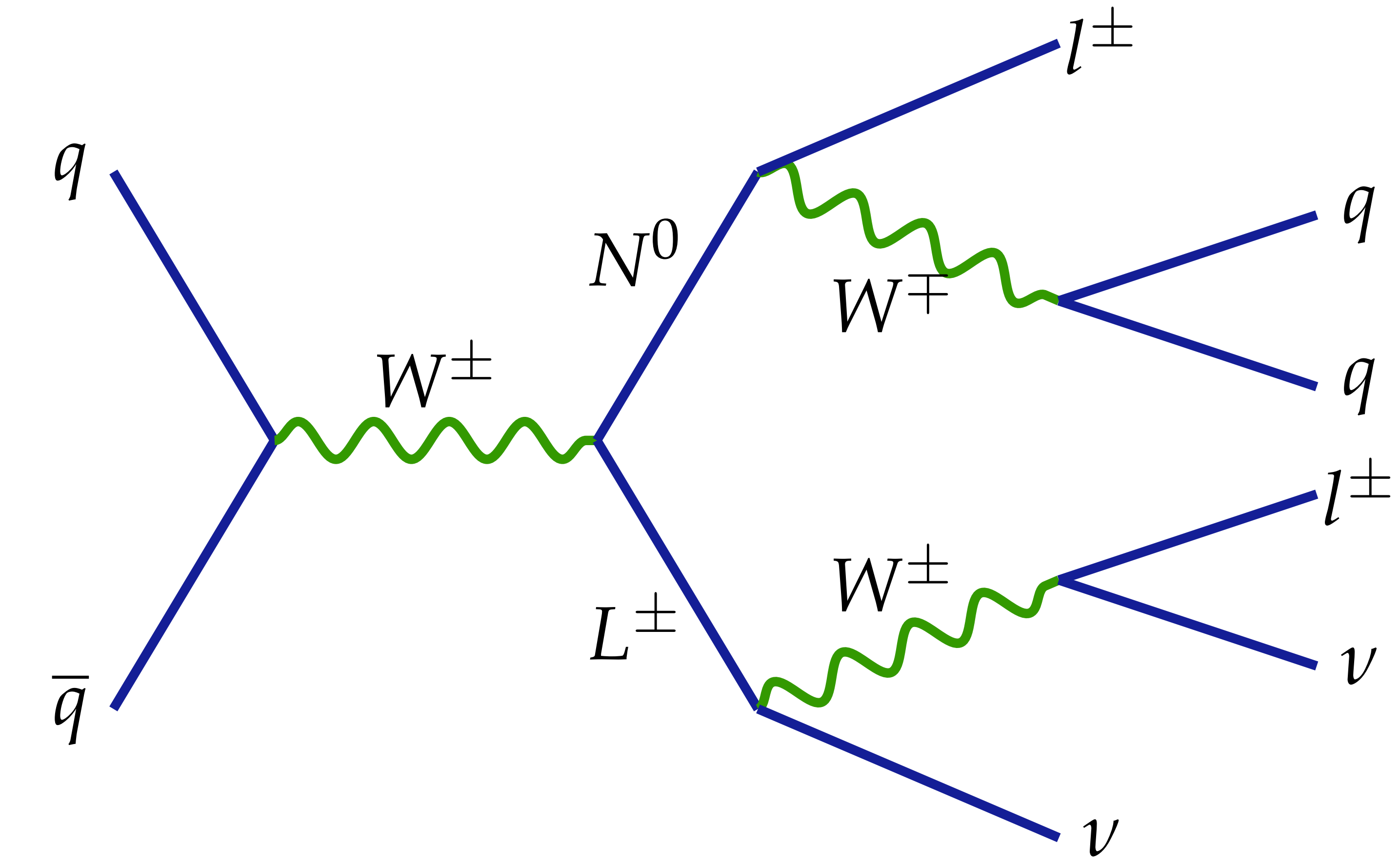
Displaced signature limits

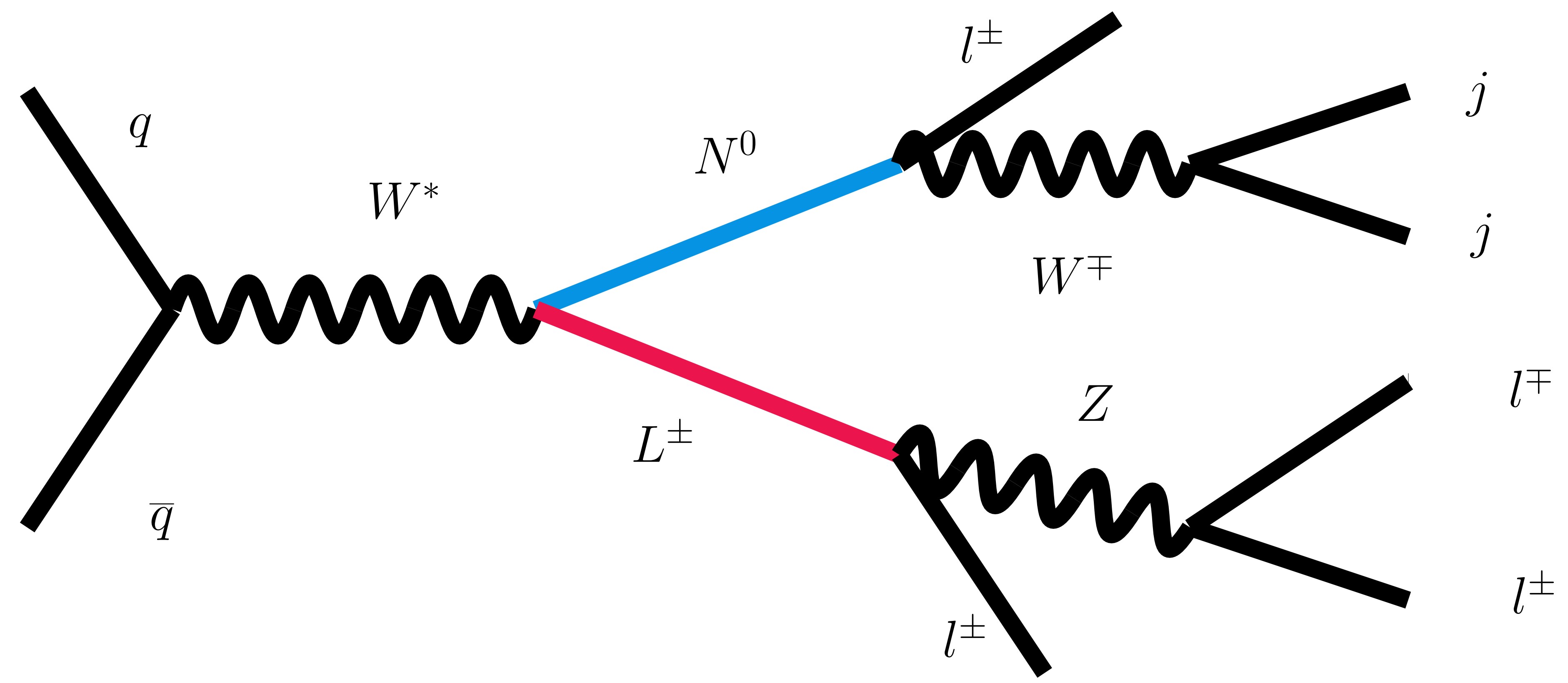
- Cover the mass range 4.5–10 GeV.
- $|U_\mu|^2$ excluded above 2.0×10^{-6} (1.5×10^{-6}) assuming LNV (LNC).

ATLAS-CONF-2021-023
ATLAS-EXOT-2018-33
Eur. Phys. J. C 81 (2021) 218

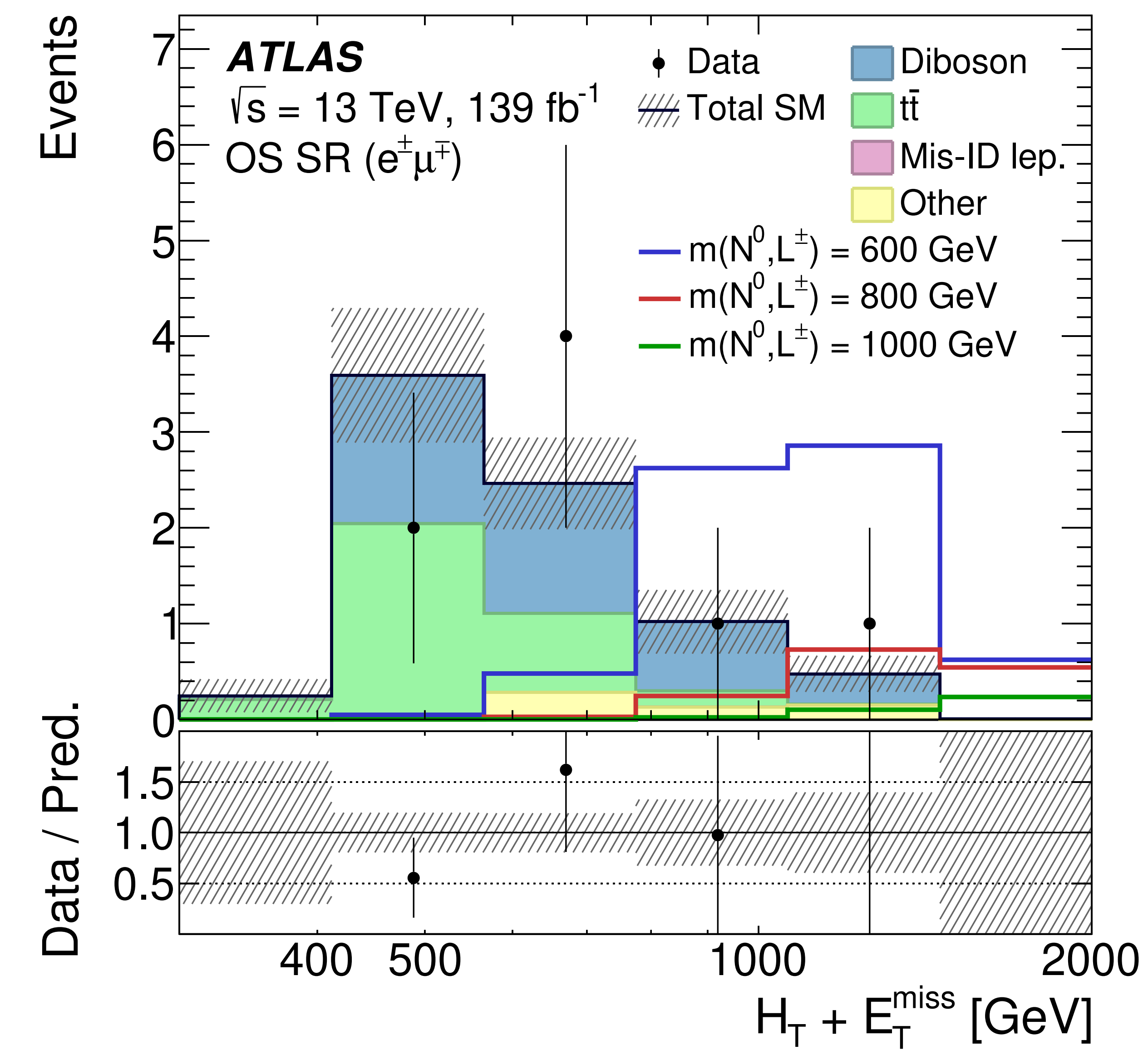
139 fb^{-1}

- Minimal type-III seesaw — an extra fermionic triplet:
  one neutral (N^0) and two oppositely-charged leptons (L^+, L^-),
  Phys. C - Particles and Fields (1989) 44, 441, Eur. Phys. J. C (2012) 72, 1899.
- Decays into a SM lepton and a W, Z or H boson, the highest branching ratio into W.
- Probed a few possible lepton/jet multiplicities:
  - two light leptons, at least two jets
  - three light leptons, zero or one jet
  - three light leptons, at least two jets
  - four light leptons, any number of jets

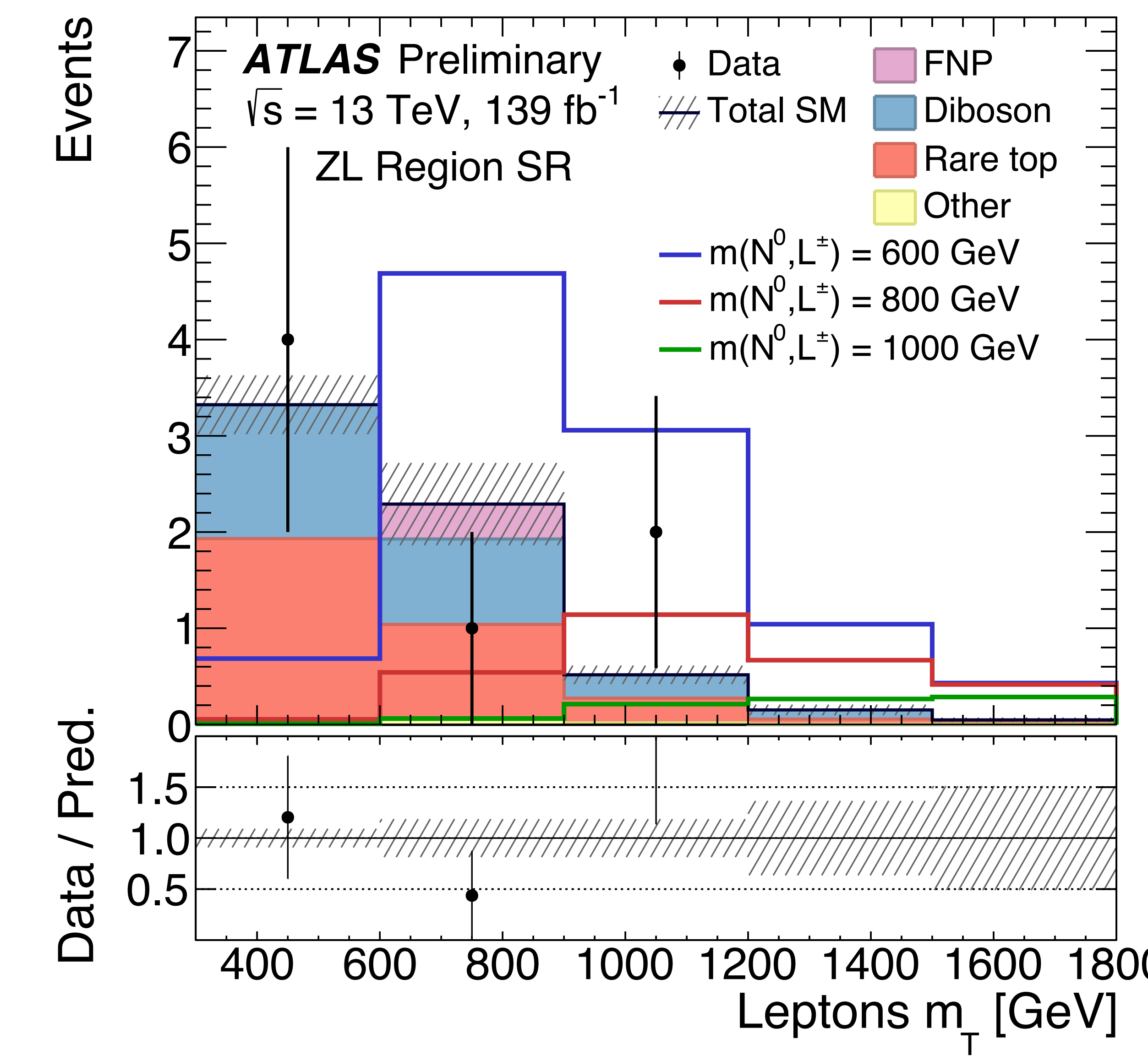




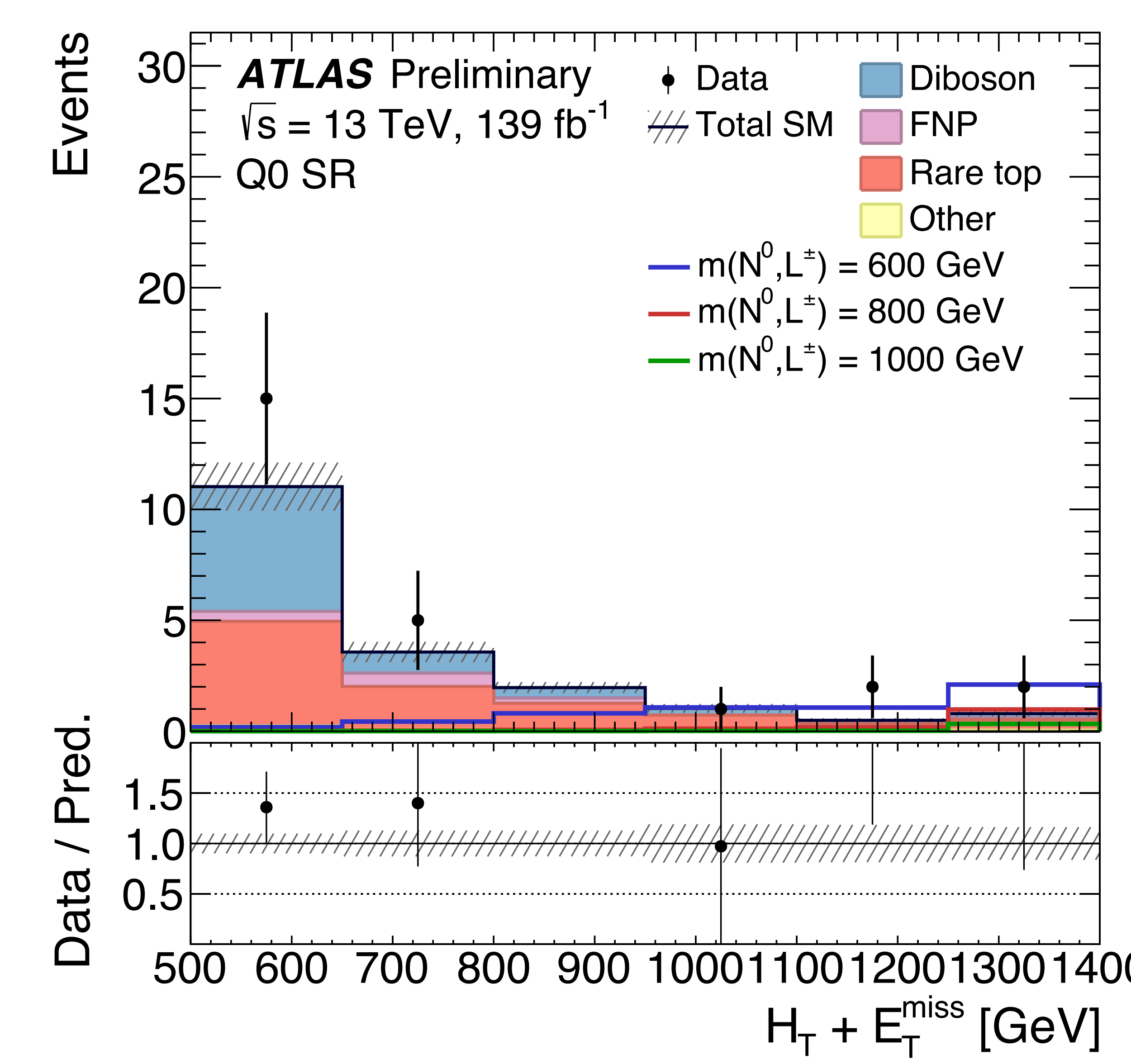
- 11 signal regions (SR) in total:
  - 6 dilepton SRs: all lepton flavour and charge combinations
  - 3 trilepton SRs: on-Z and off-Z with 2+ jets, inclusive with 0-1 jets
  - 2 four lepton SRs: sum of lepton charge 0 or 2
- High E_T^{miss} with good reconstruction significance required — neutrinos.
- Demanding background estimation: large fraction of non-prompt and fake leptons, leptons with misreconstructed charge.



dilepton OS $e\mu$

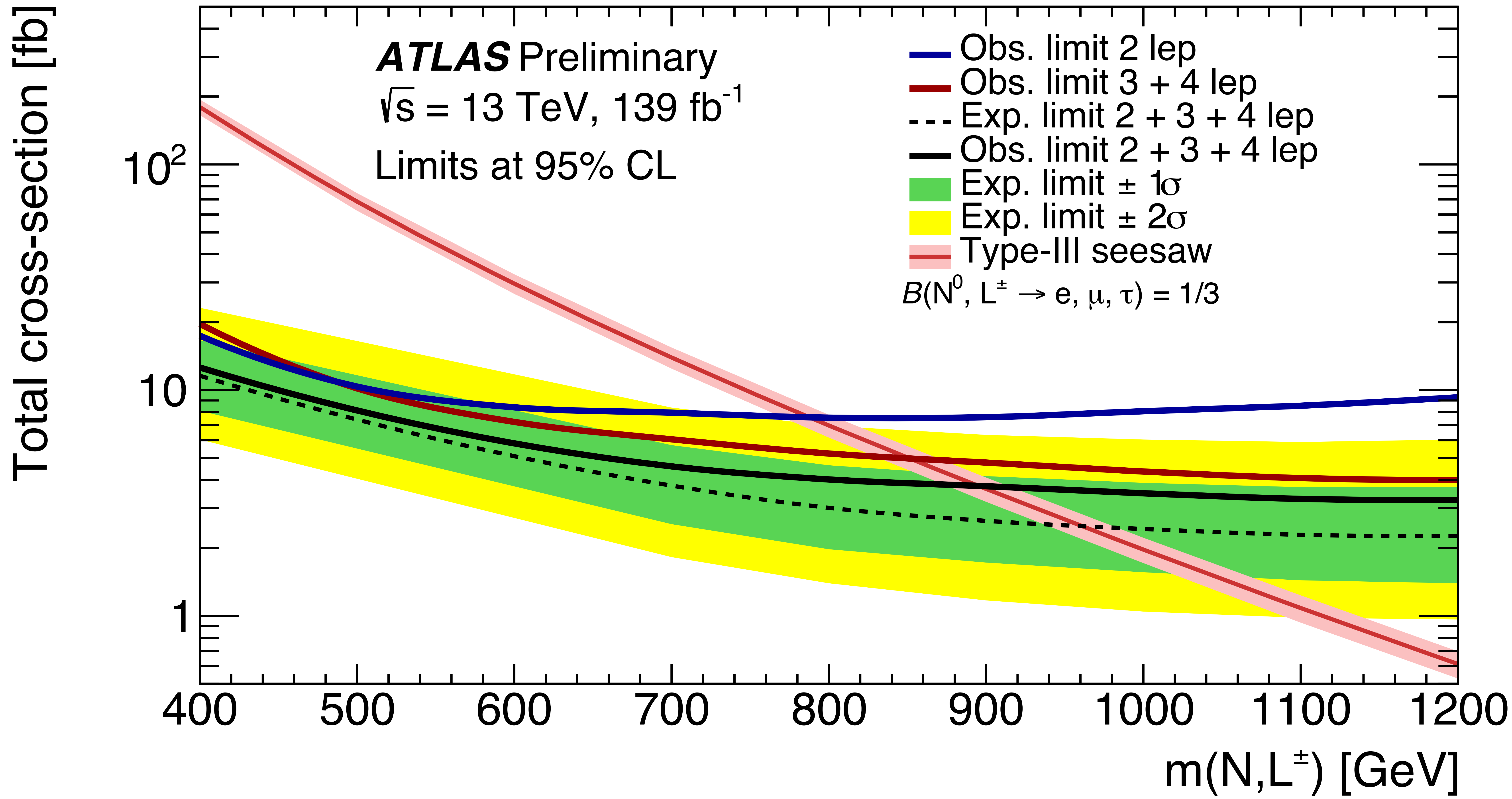


trilepton on-Z, 2+ jets



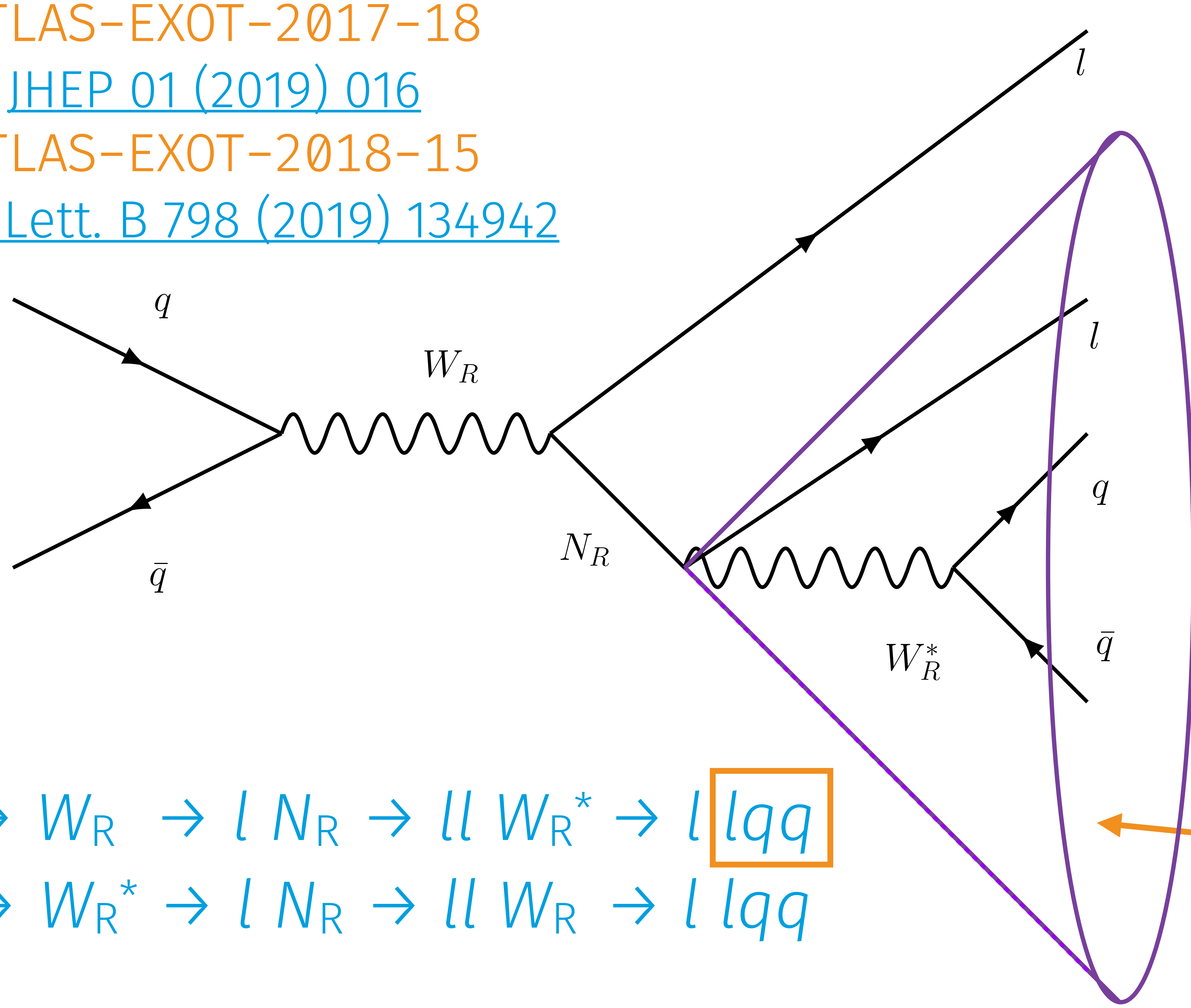
four lepton, charge = 0

Type-III Seesaw Heavy Leptons (3)



- Heavy leptons with masses below 910 GeV are excluded.
  - Dilepton channel limit: 790 GeV
  - Tri- and four-lepton channel limit: 870 GeV

ATLAS-EXOT-2017-18
JHEP 01 (2019) 016
ATLAS-EXOT-2018-15
Phys. Lett. B 798 (2019) 134942



$pp \to W_R \to l\, N_R \to ll\, W_R^* \to l\, \boxed{lqq}$

$pp \to W_R^* \to l\, N_R \to ll\, W_R \to l\, lqq$

resolved channel	boosted channel
2 leptons (e, μ)	1 lepton (e, μ)
2 small-radius jets	1 large-radius jet
36.1 fb^{-1}	80 fb^{-1}

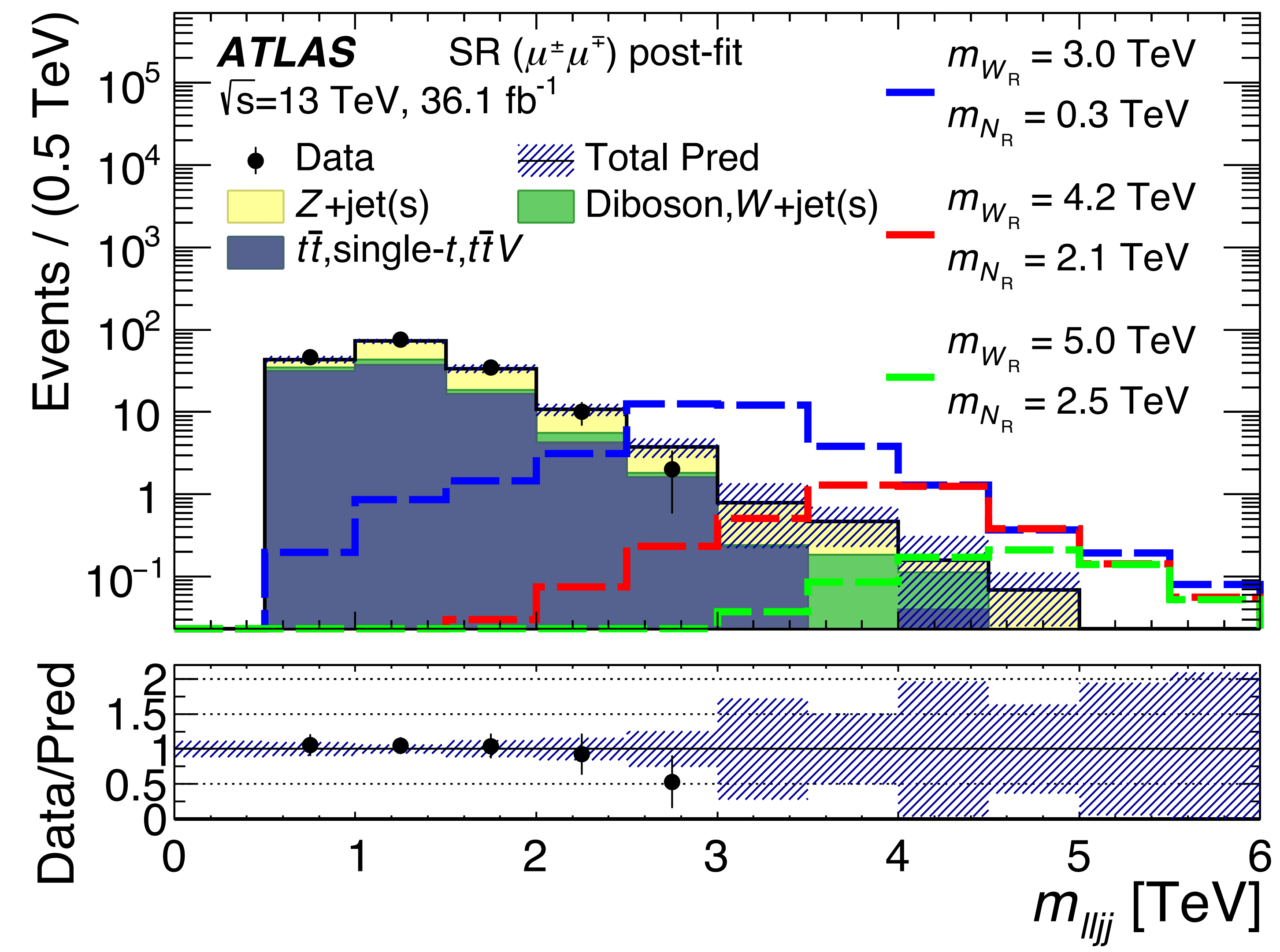
- Left–right symmetric models (LRSMs) attempt to explain the broken parity symmetry of the SM weak interaction.
- Can introduce right-handed counterparts to the *W* and *Z* bosons (W_R and Z_R) and right-handed heavy neutrinos (N_R), Phys. Rev. Lett. 50, 1427.
- N_R decay can result in a large-radius jet after the boost due to a heavy W_R.
- Lepton flavour conserving.
- Heavy neutrinos can either be Dirac (only opposite-charge leptons) or Majorana particles (same-charge final state leptons allowed).

ATLAS-EXOT-2017-18 36 fb^{-1}

[JHEP 01 (2019) 016]

Opposite-charge channel:

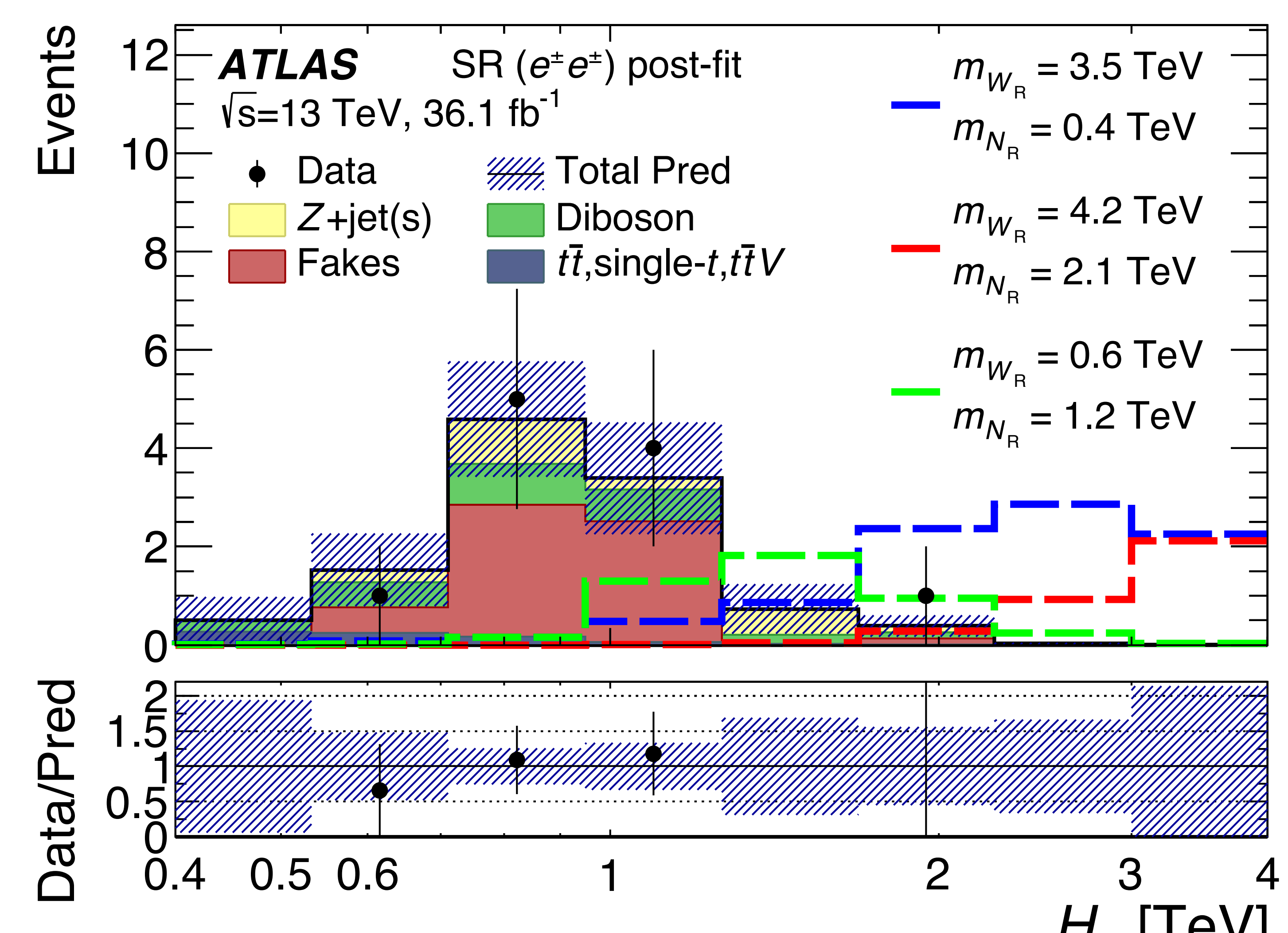
- Background: top-quark events and Z+jets.
- Data-driven m_{jj} reweighting.
- Fit: m_{lljj} for $m(W_\mathrm{R}) > m(N_\mathrm{R})$, else m_{jj}.

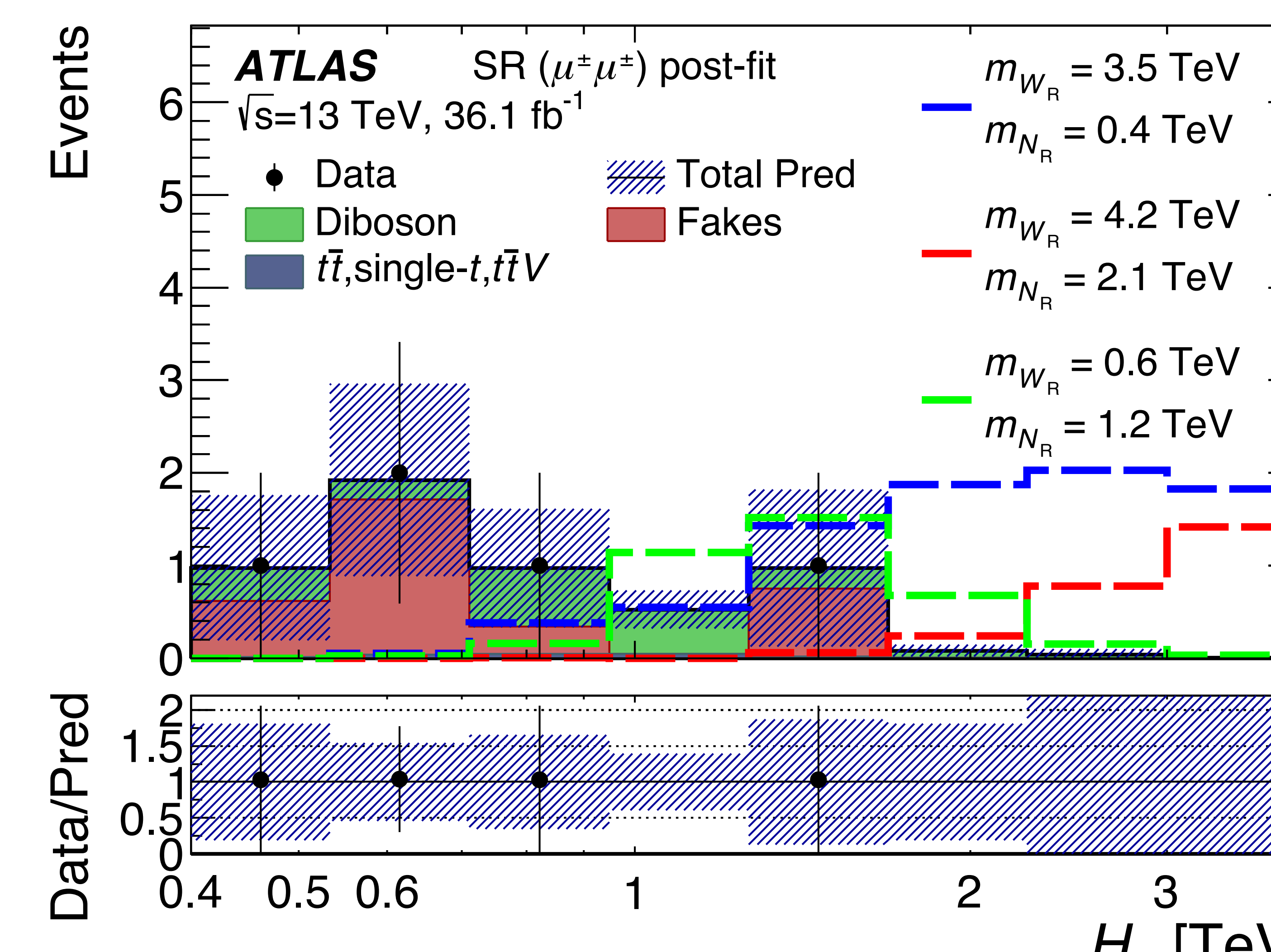


	SR($\ell^\pm\ell^\mp$)	SR($\ell^\pm\ell^\pm$)
m_{ee} [GeV]	> 400	> 400
$m_{\mu\mu}$ [GeV]	> 400	> 400
$m_{e\mu}$ [GeV]	—	—
H_T [GeV]	> 400	> 400
m_{jj} [GeV]	> 110	> 110
Jet p_T [GeV]	> 100	> 100

Same-charge channel:

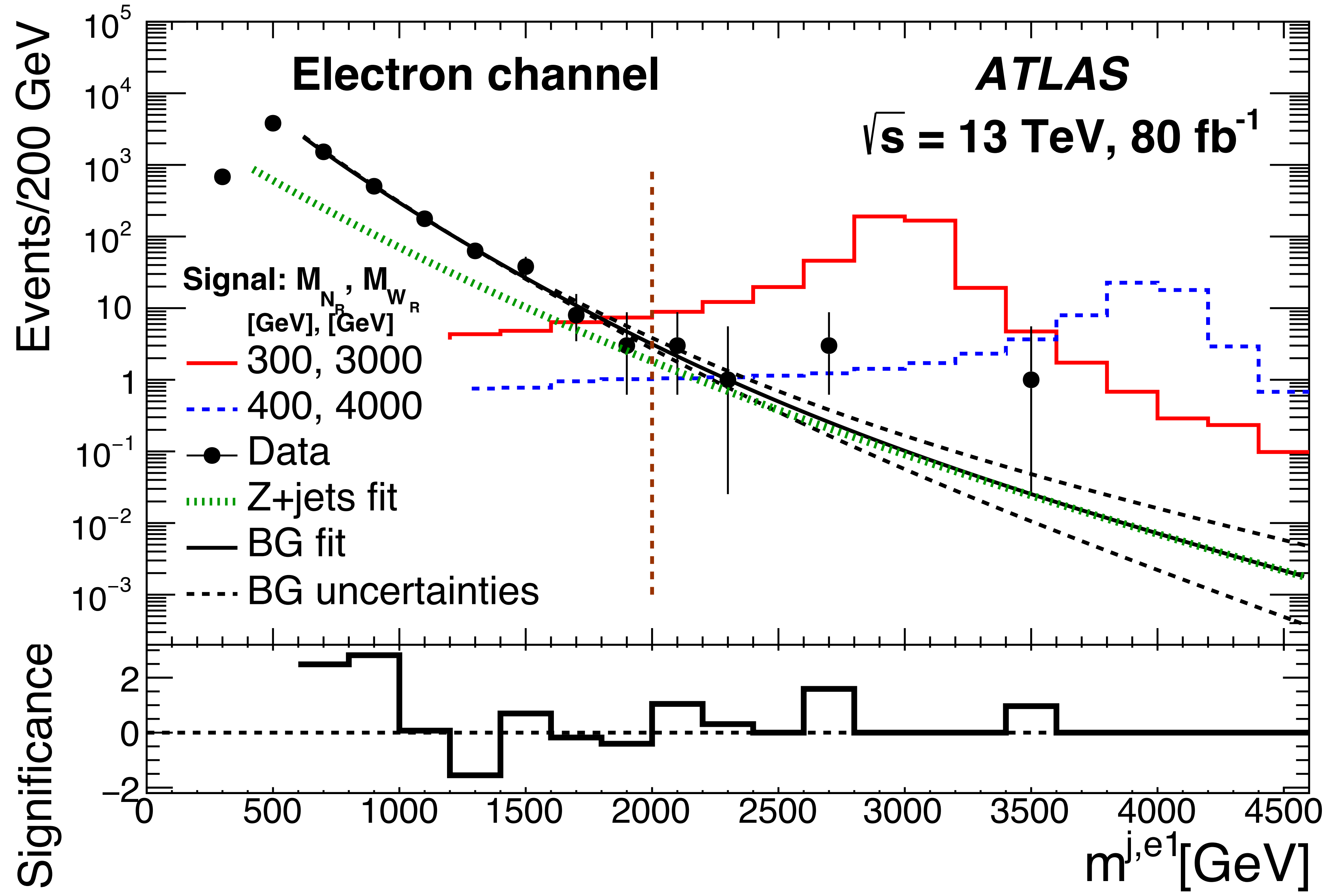
- Charge misidentification precisely evaluated.
- Data-driven fake lepton estimation.
- Fit: H_T = scalar sum of p_T (2 leptons and 2 leading jets).

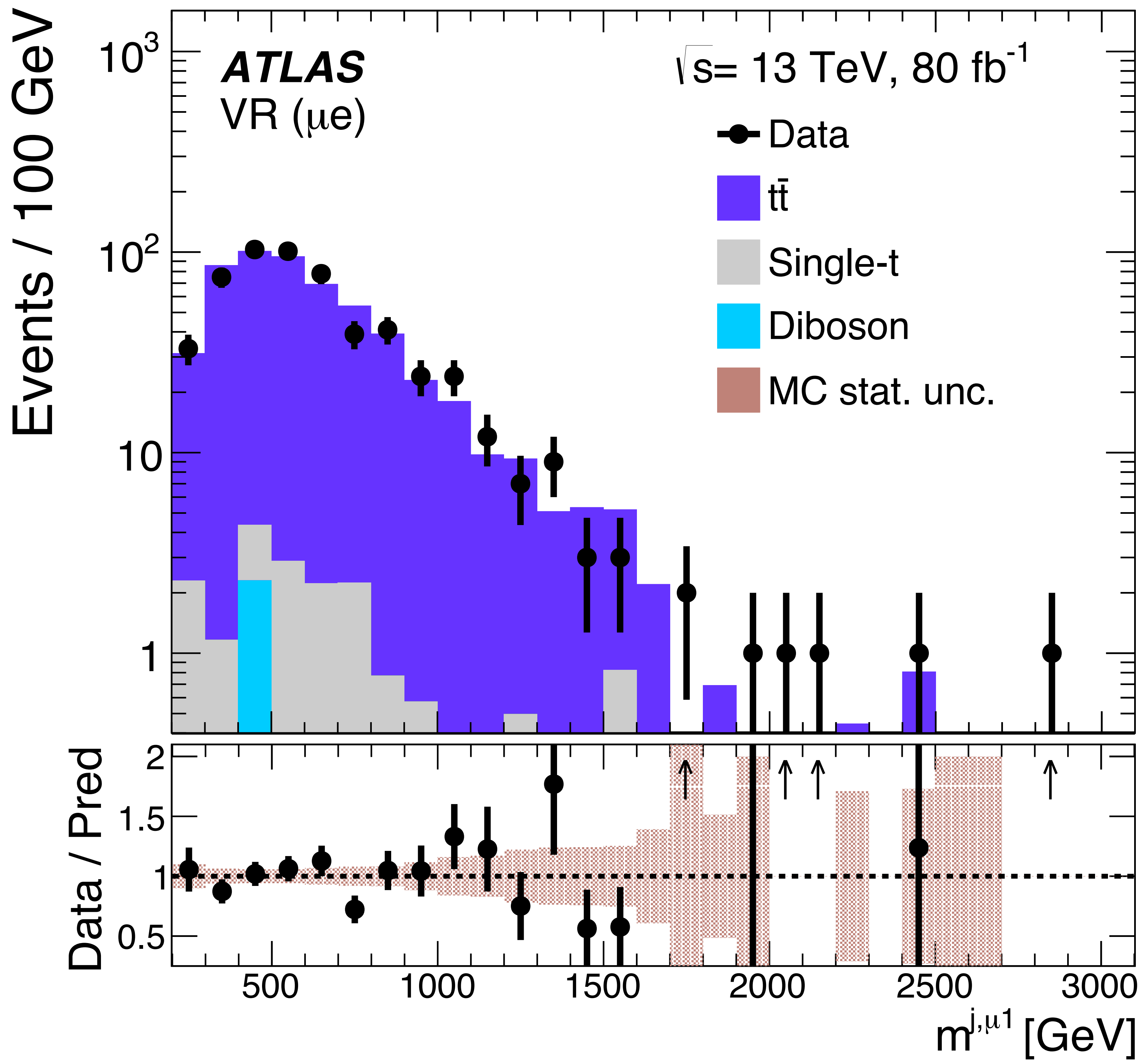




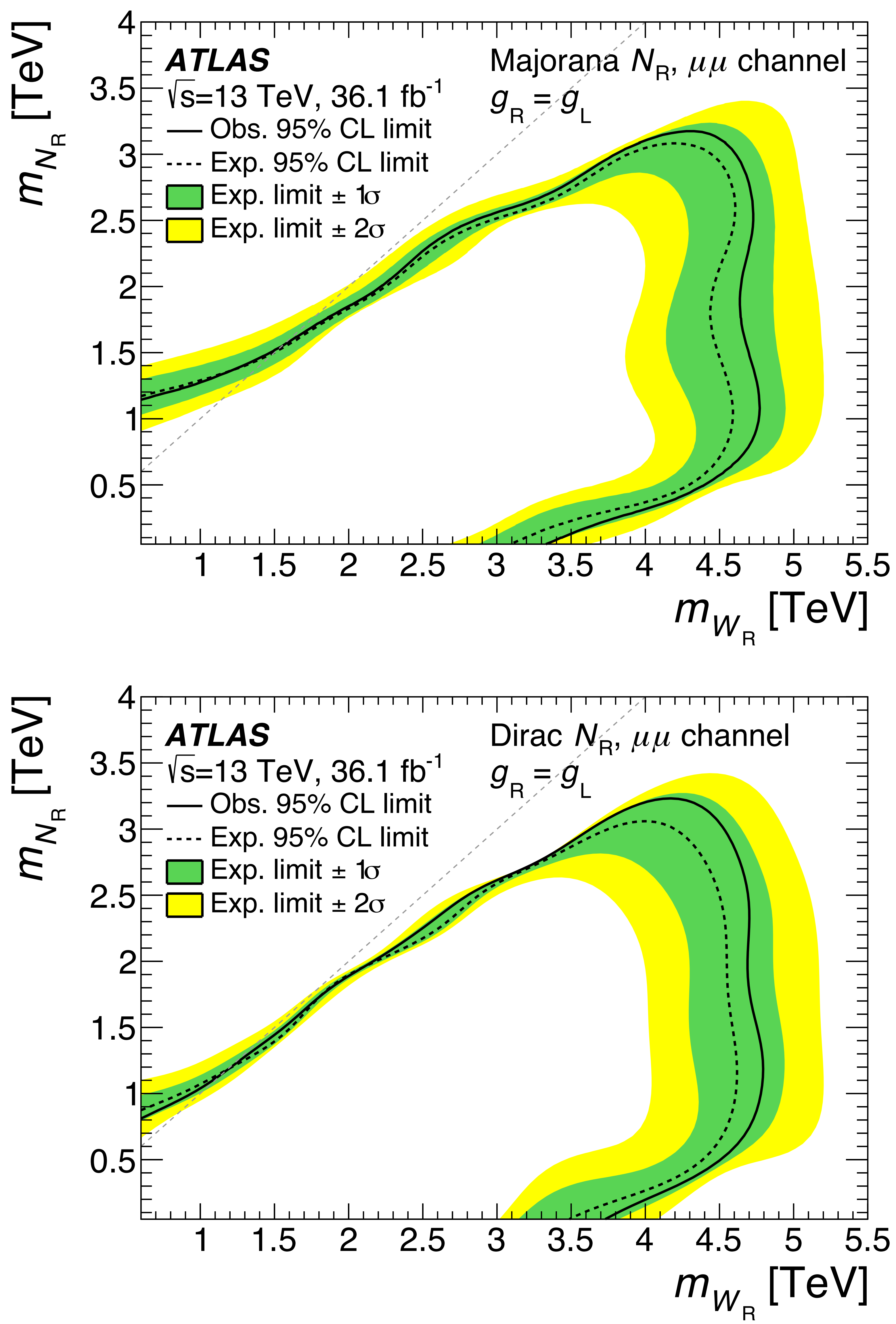
ATLAS-EXOT-2018-15 80 fb^{-1}
Phys. Lett. B 798 (2019) 134942

- Isolated lepton and large-radius jet back-to-back.
- Subleading lepton contained in the jet, 30% uncertainty on electron identification.
  - Different-flavour validation region to estimate it.
- Trying to reconstruct W_R mass, signal region with masses above 2 TeV.
- *Z*+jets background fitted on MC (full range),
- ttbar events fitted on data with *Z*+jets fixed, fit up to 2 TeV and extrapolated to SR.

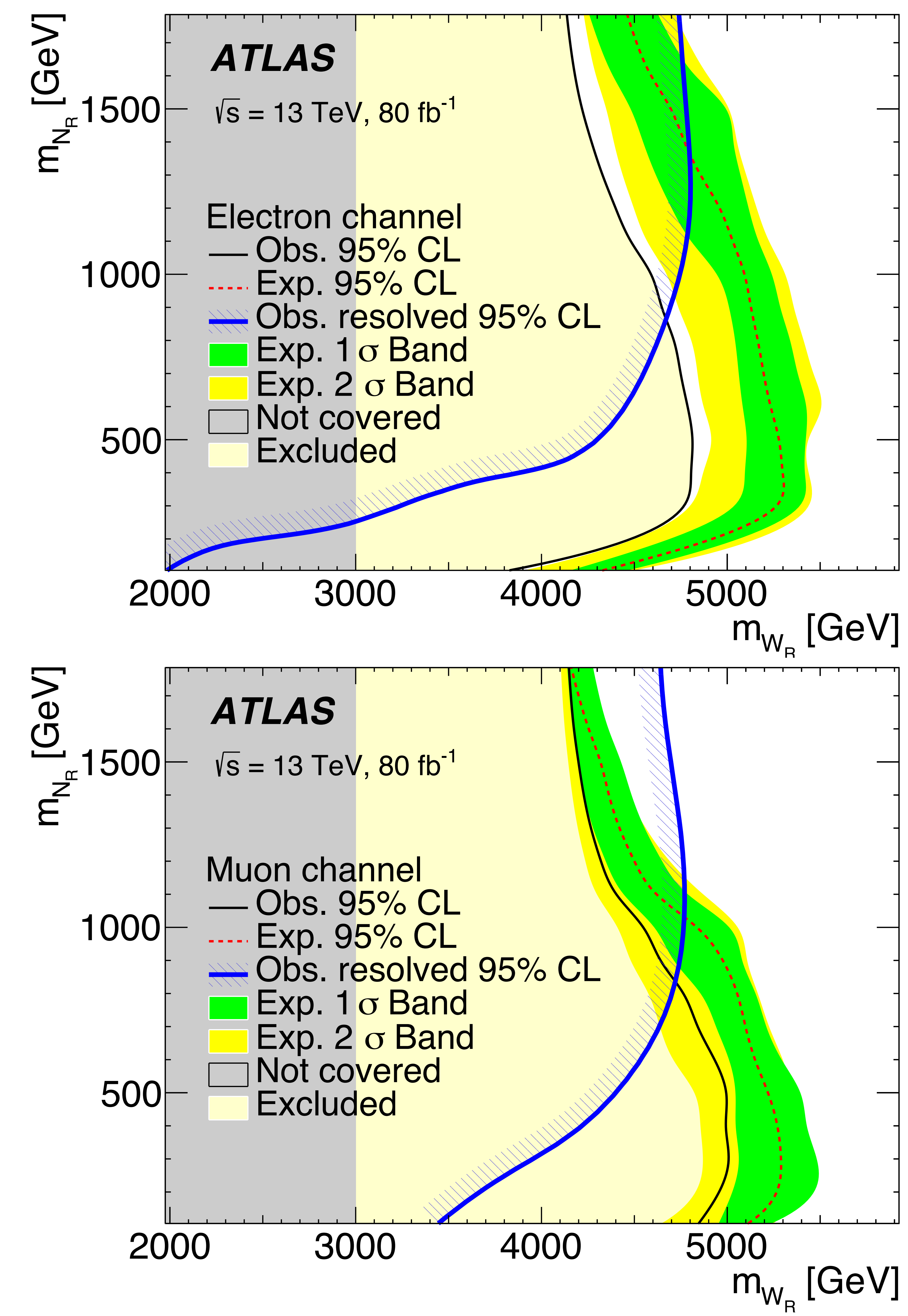




Resolved channel



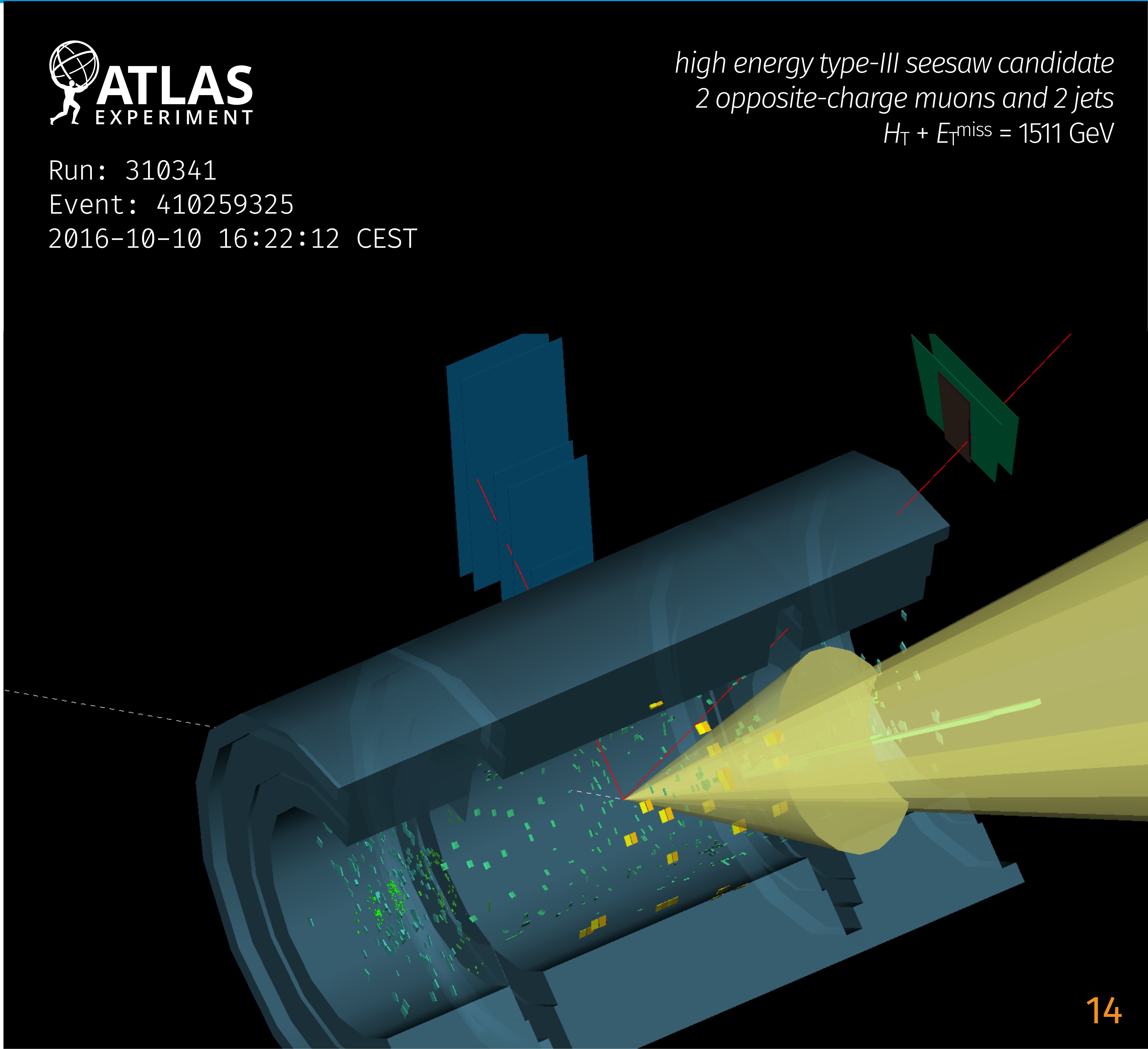
Boosted channel



- Binned likelihood fit performed (one bin in boosted channel) to obtain limits on masses of N_R and W_R.
- Resolved channel: excluded up to $m(W_R) = 4.7$ TeV and $m(N_R) = 3.2$ TeV, tested also $m(N_R) > m(W_R)$.
- Boosted channel improves limits on $m(W_R)$ for low N_R masses up to 5 TeV.

Conclusions

- ATLAS performed several searches for models that could explain neutrino masses.
- No significant excess from the Standard Model has been observed.
- Many searches of full Run 2 data still being completed.
- Run 3 just around the corner.



DESY.