Search for heavy right-handed gauge bosons decaying into boosted heavy neutrinos with the ATLAS detector at $\sqrt{s} = 13$ TeV

Debarati Roy
on behalf of the ATLAS Collaboration

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Standard Model (SM) and beyond

- SM :

=> Extremely successful theory.
=> Guided through new particle discoveries (Higgs boson glorifies its success in 2012!)

- Couple of experimental observations SM cannot explain direct towards new Physics ✨✨👻 ✨✨

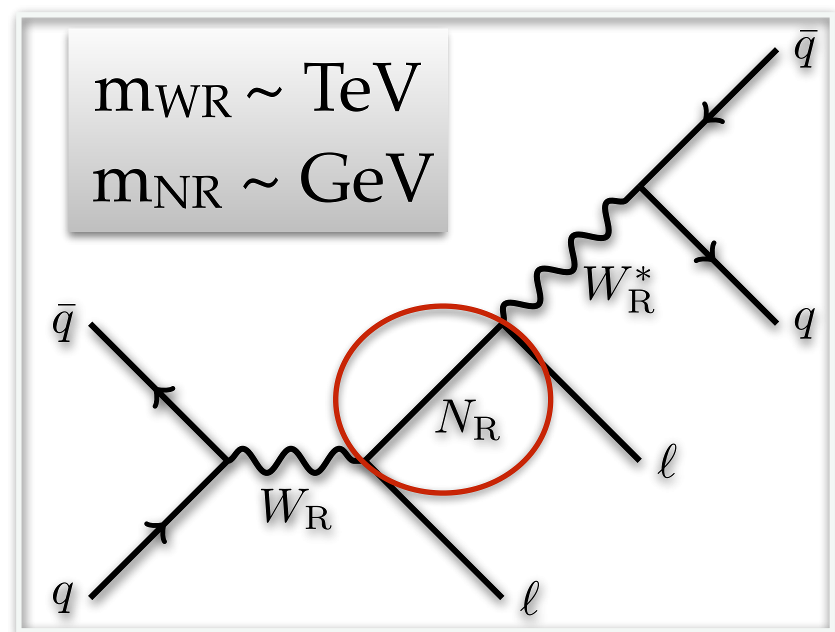
=> Neutrino oscillation concludes neutrino has a very small mass.

=> Several searches performed in LHC to explain origin of a very small neutrino mass!

- Left Right Symmetric Model (LRSM) :

=> Restores parity by introducing right-handed gauge bosons (W_R) & right-handed neutrinos (N_R).

=> Small neutrino mass can be explained via its coupling to N_R via mass mixing matrix.

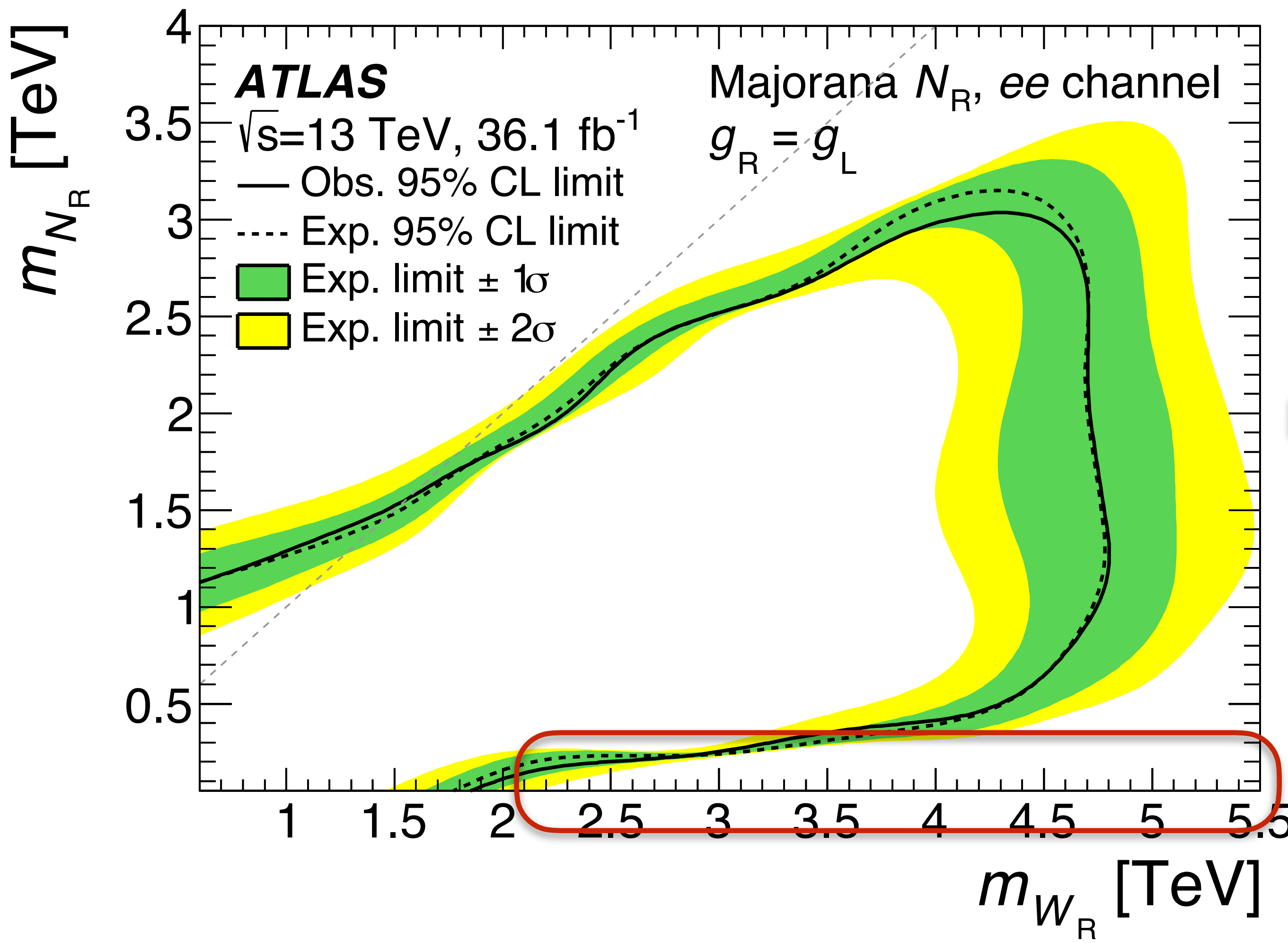


Final state => 2 jets + 2 leptons (resolved topology)

Extending phase space with boosted topology

Several searches performed in ATLAS (& in CMS) with resolved topology.

Latest ATLAS result in resolved scenario

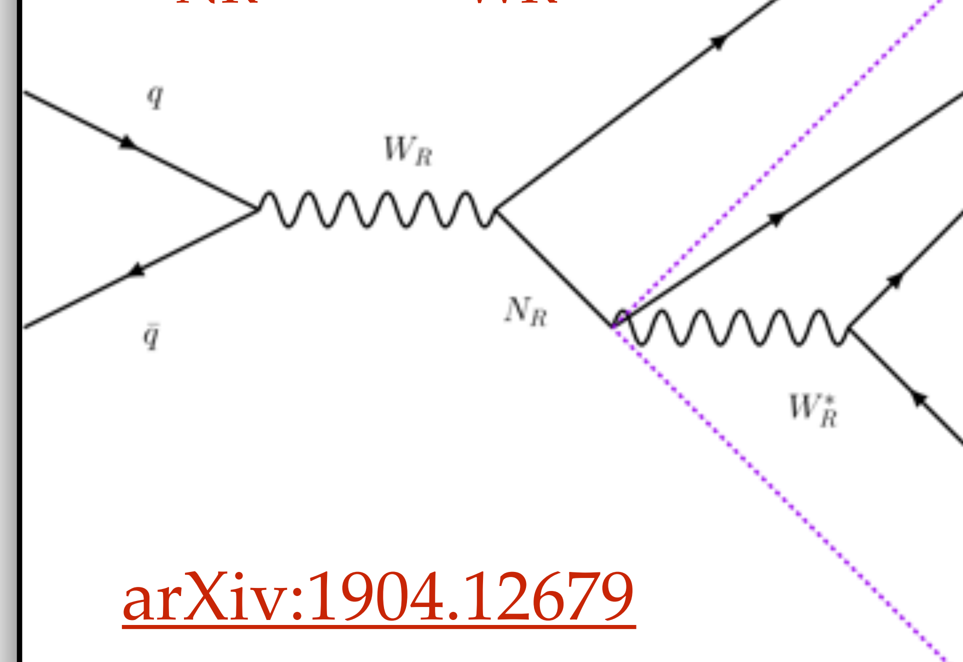


$m_{NR} << m_{WR}$:

- Less explored phase space with limited discovery potential estimation => Sensitivity drops with resolved topology.
- More efficient to consider boosted scenario!

- First time we looked at possibility for boosted heavy neutrinos in ATLAS with 80 fb^{-1} of data at 13 TeV.

$m_{NR} << m_{WR}$



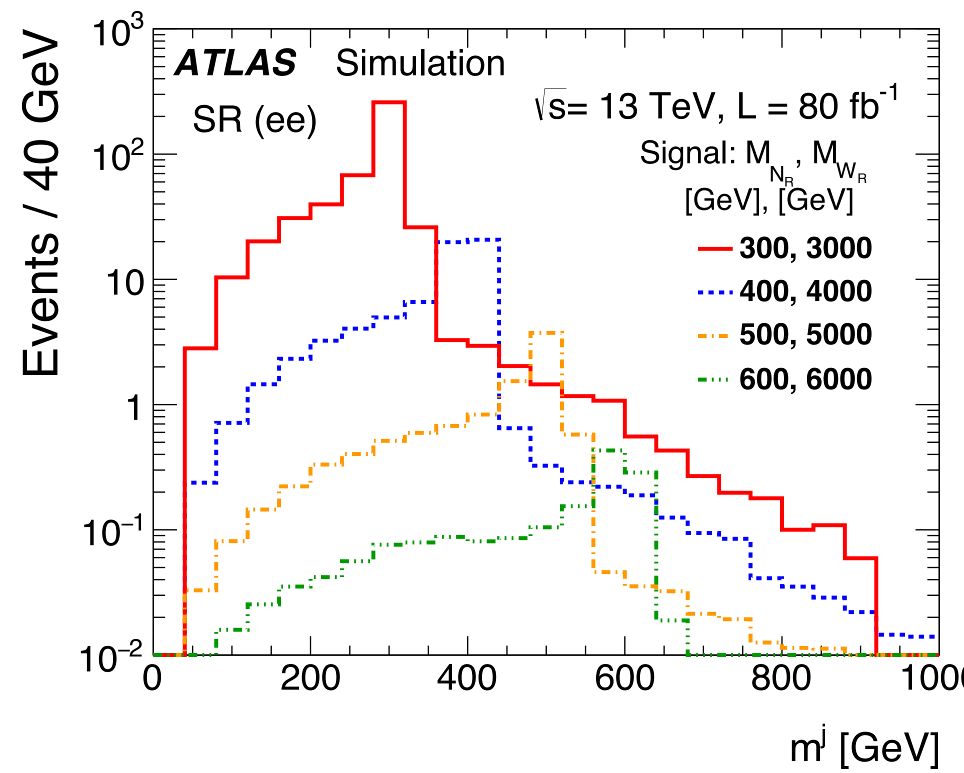
arXiv:1904.12679

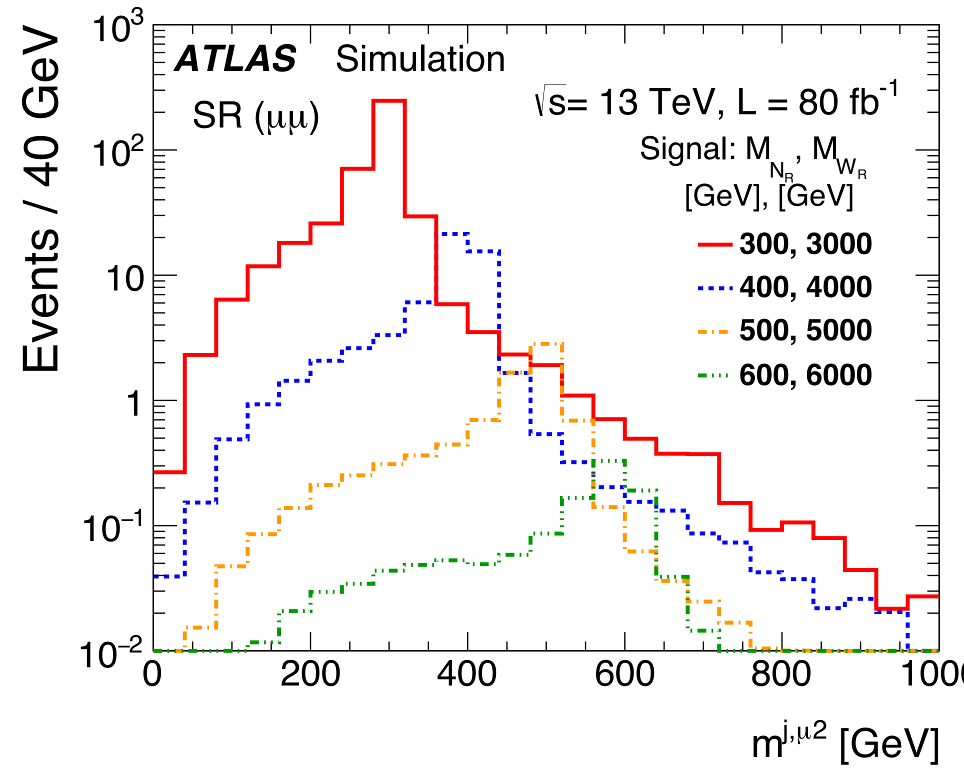
Boosted heavy neutrino search : Introduction

- Final state consists of a large radius jet & two leptons.
- Electron (e) & muon (μ) final states looked at separately with no flavour mixing.
- A balancing topology between hardest e (e1) or μ (μ1) & highest mass large radius jet (j) along with 2nd hardest e (e2) or μ (μ2) inside that large radius jet gives well shaped detector level variables.
- Different N_R mass computation performed between e & μ final states due to nature of jet reconstruction :

  e channel : Mass of large radius jet (e energy part of j energy, **a distinguishing feature of this search**)

  μ channel : Mass of large radius jet & μ2.





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Boosted heavy neutrino search : Analysis Selection

Object Selection :

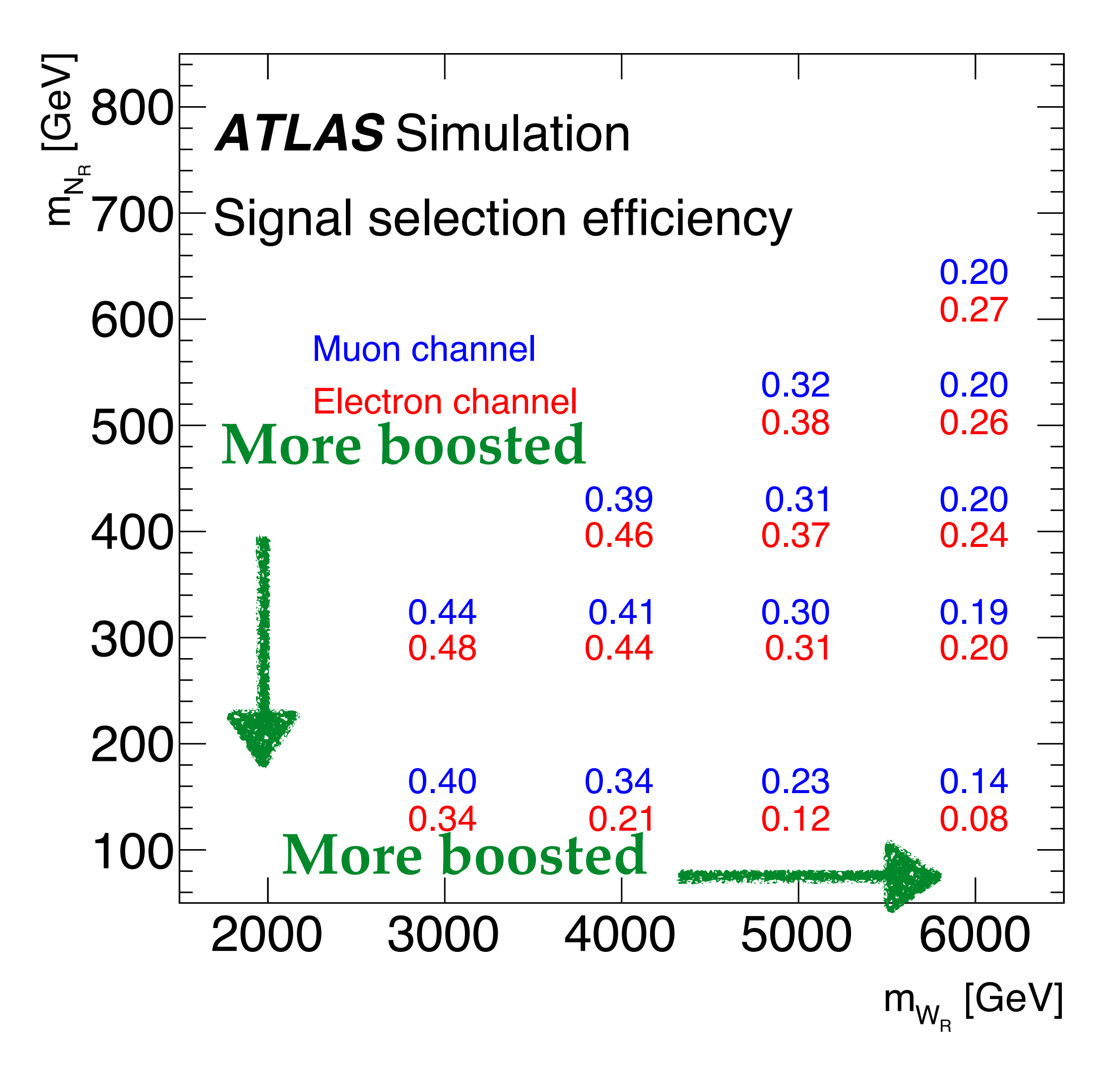
- Exactly 2 leptons & at least 1 large radius trimmed jet.
- Isolated e1/μ1 & non-isolated e2/μ2 (2^{nd} hardest leptons allowed to be close to large radius jet).
- Highest mass large radius (R = 1.0) jet (j) used with $p_T > 200$ GeV, $|\eta| < 2.0$ ($m_j > 50$ GeV in e final state).
- $p_{T,e1/e2} > 26$ GeV, $|\eta| < 2.47$ excluding crack region. $p_{T,\mu1/\mu2} > 28$ GeV, $|\eta| < 2.5$.

Topological Cuts :

- Azimuthal separation (dΦ) between e1/μ1 & j > 2.0.
- ΔR between e2/μ2 & j < 1.0.

Further Background Reduction Cuts :

- Dilepton invariant mass (m_{ll}) > 200 GeV.
- dΦ between e1(μ1) & e2(μ2) > 1.5.



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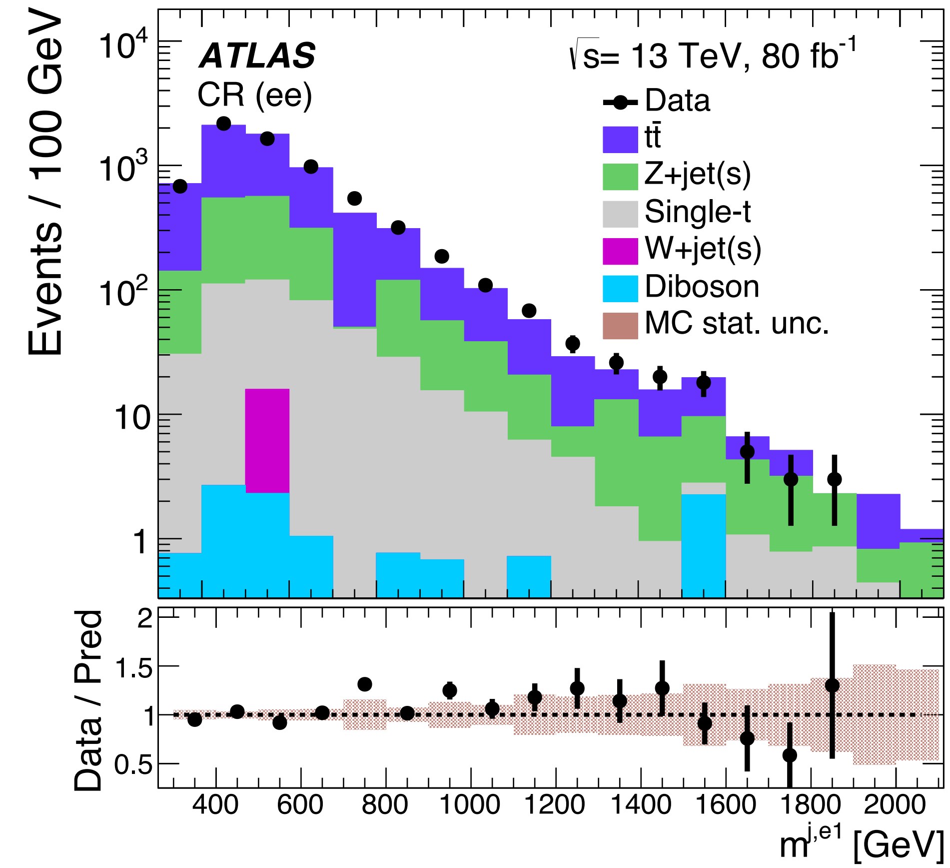
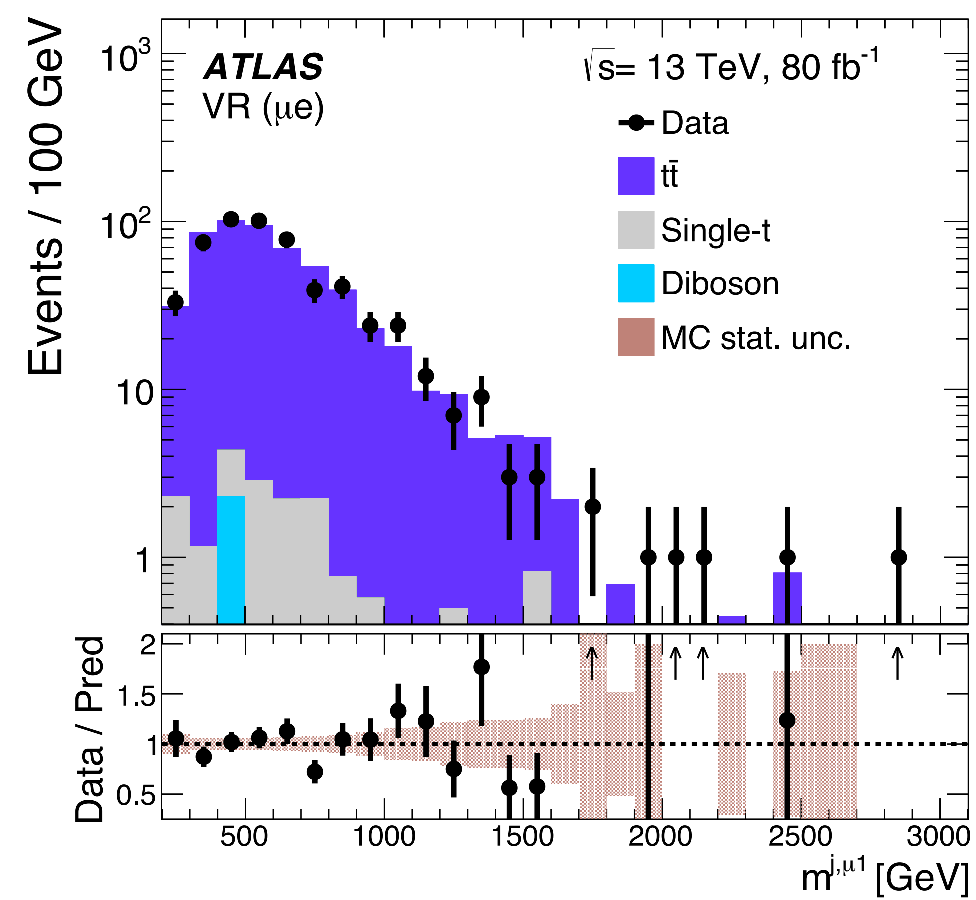
m_{WR} : The discriminating variable for region definition

- m_{WR} Computation in e final state : Invariant mass of j + e1.
- m_{WR} Computation in μ final state : Invariant mass of j + μ1 + μ2.
- Control Region (CR : $m_{WR} < 2$ TeV) shows reasonable data-mc agreement including statistical uncertainty.
- Signal Region (SR : $m_{WR} > 2$ TeV).
- A Validation Region (VR) studied with a hard e inside j balanced by a μ to conclude that data can be well predicted by mc (when a hard e inside j).





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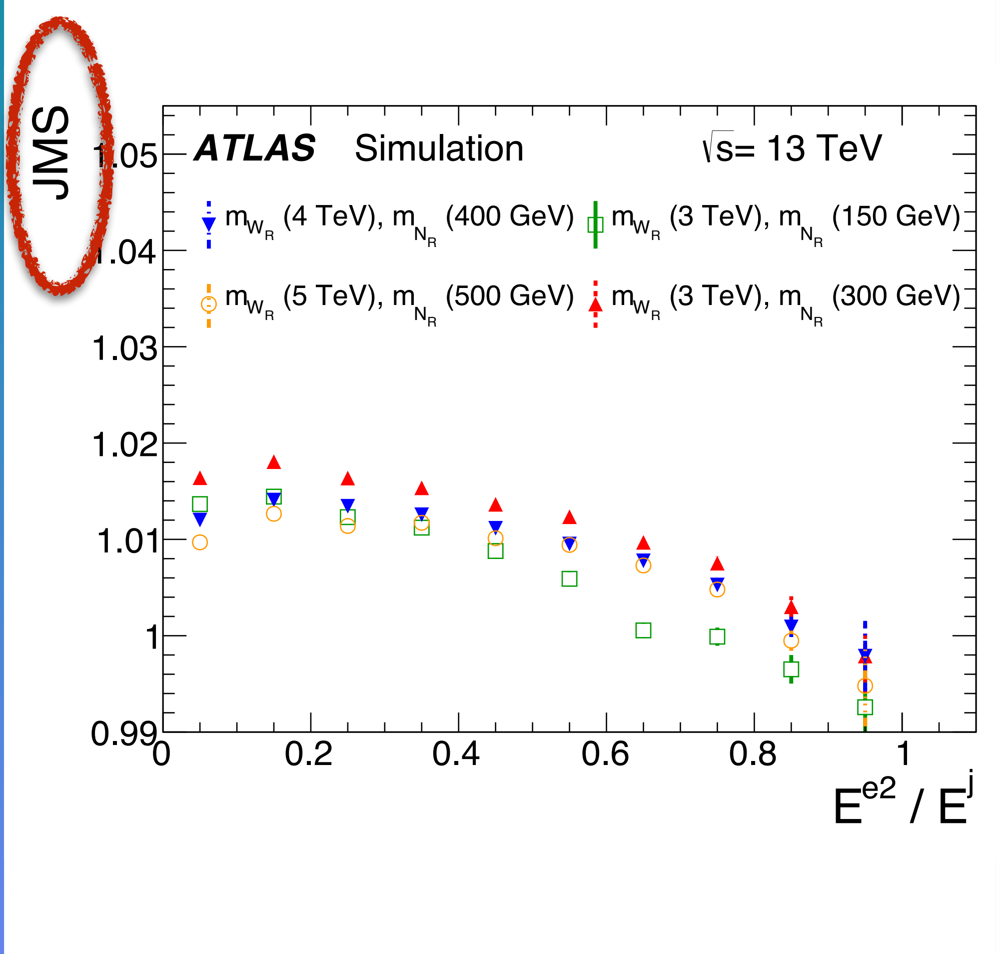
Performance of large radius jet with a hard e inside

- Large radius jet reconstruction in ATLAS based on energy clusters calibrated at hadronic scale.

- Effect of a non-negligible fraction of EM clusters in j investigated in terms of jet energy scale (JES) & jet mass scale (JMS) as a function of ratio of energy of e to the energy of j.



- A weak dependence (within scale expected uncertainty range) concludes no additional correction factor needs to be implemented.

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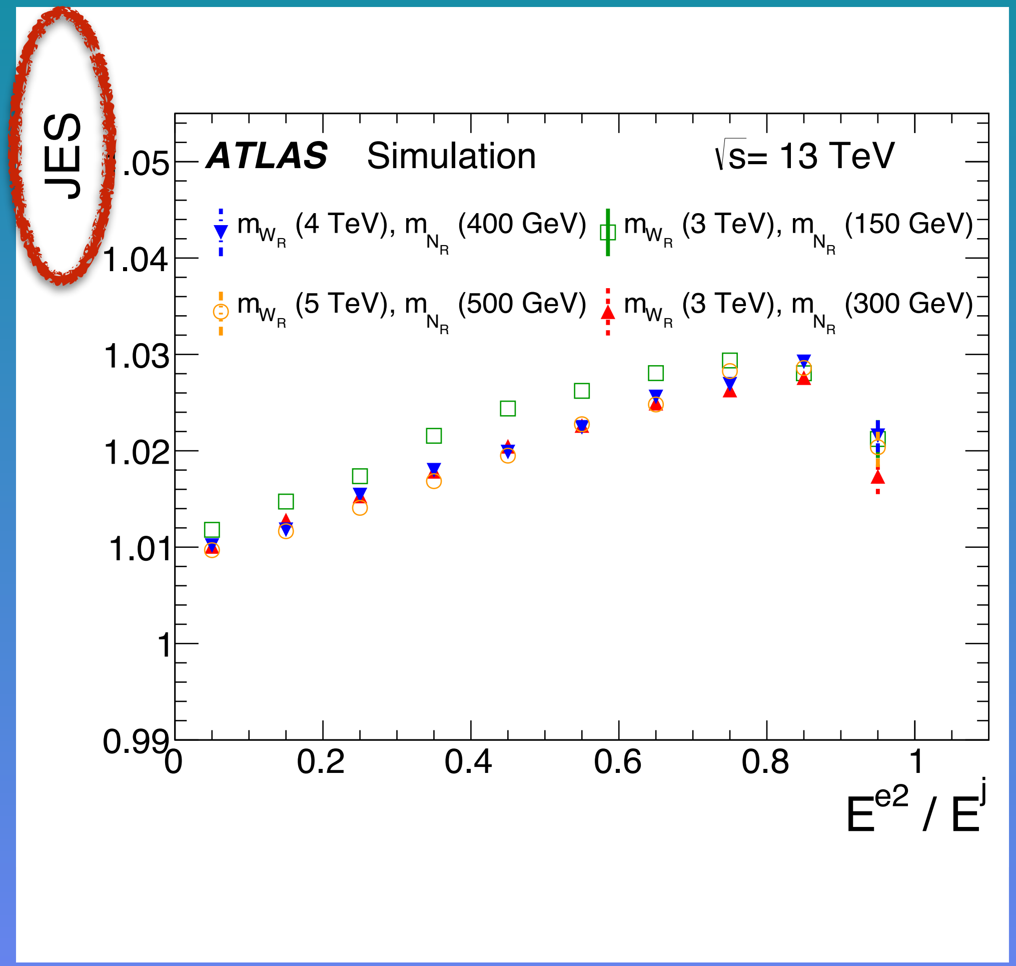

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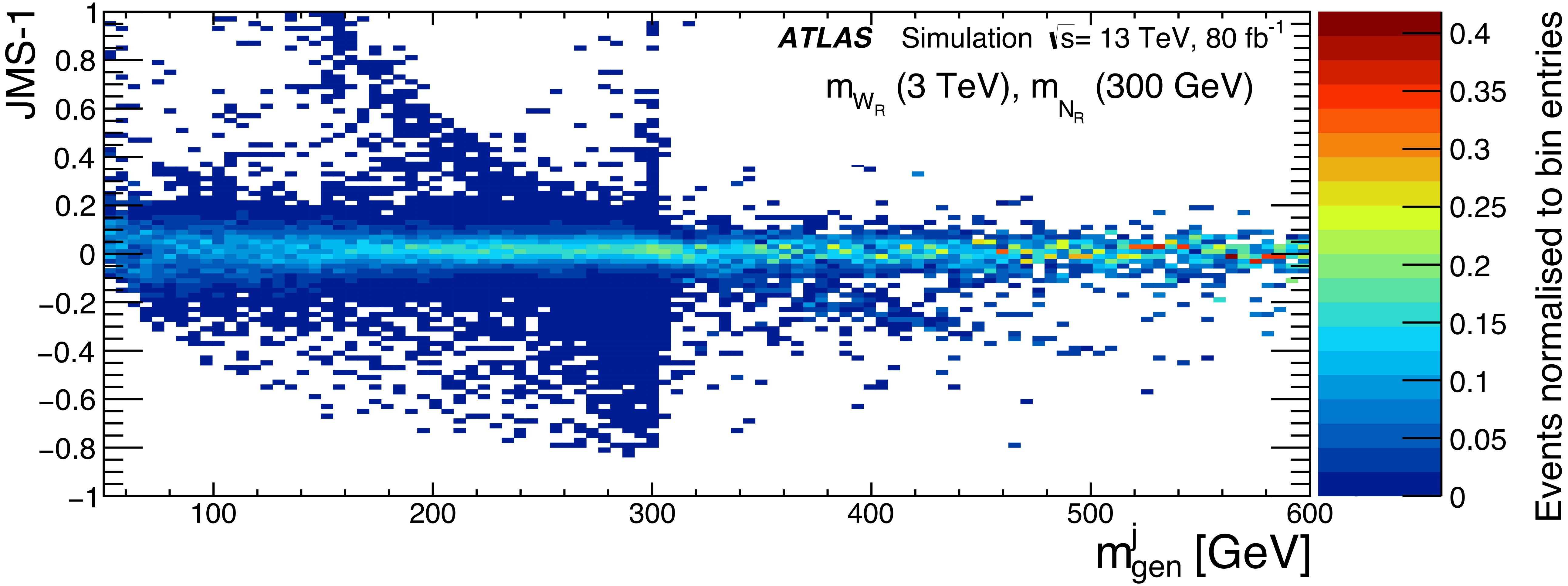
Performance of large radius jet with a hard e inside

- JMS as a function of generator level large radius jet mass shows reasonable behaviour :



Events mostly concentrated at the JMS expected value equal to unity.

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Overlap Removal (OR) Strategy for e close to hadronic activity

- In signal topology e2 always close to a real jet

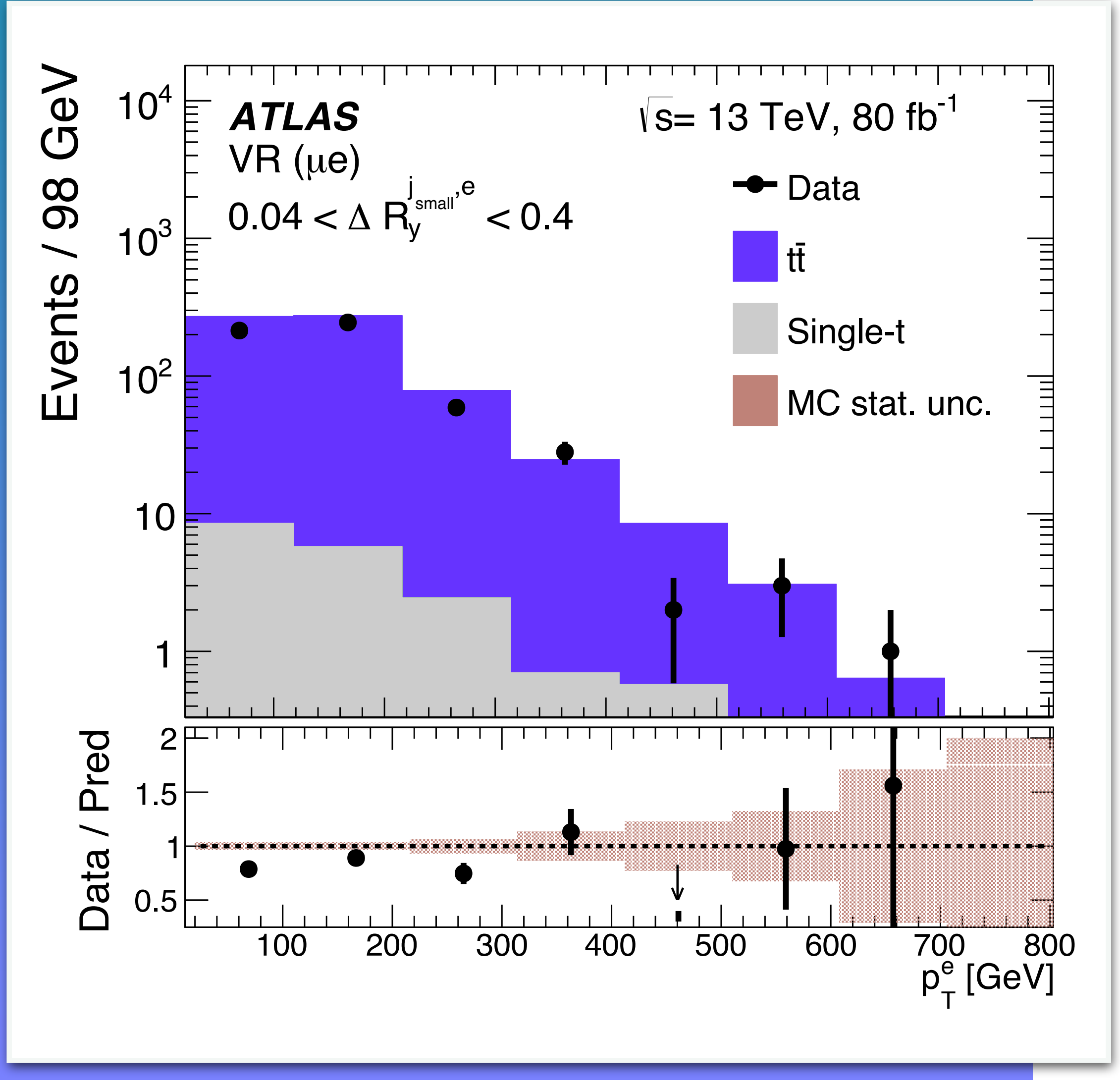
=> Standard OR in ATLAS removes jet or e if within $\Delta R < 0.4$: Thus signal efficiency drops off !

=> A modified OR approach followed for e2 :

Within $\Delta R \sim 0.04$ of e & jet, events dominated with a true e mis-reconstructed as a jet. Thus events with $\Delta R > 0.04$ selected.

=> Further standard e efficiency correction factor cannot be used.

Thus in VR additional criterion applied : a b-tagged jet & data-mc comparison done within $0.04 < \Delta R < 0.4$.



Residual disagreement in addition to statistical, theory & b-tagging uncertainties quantified as an additional efficiency correction factor uncertainty.

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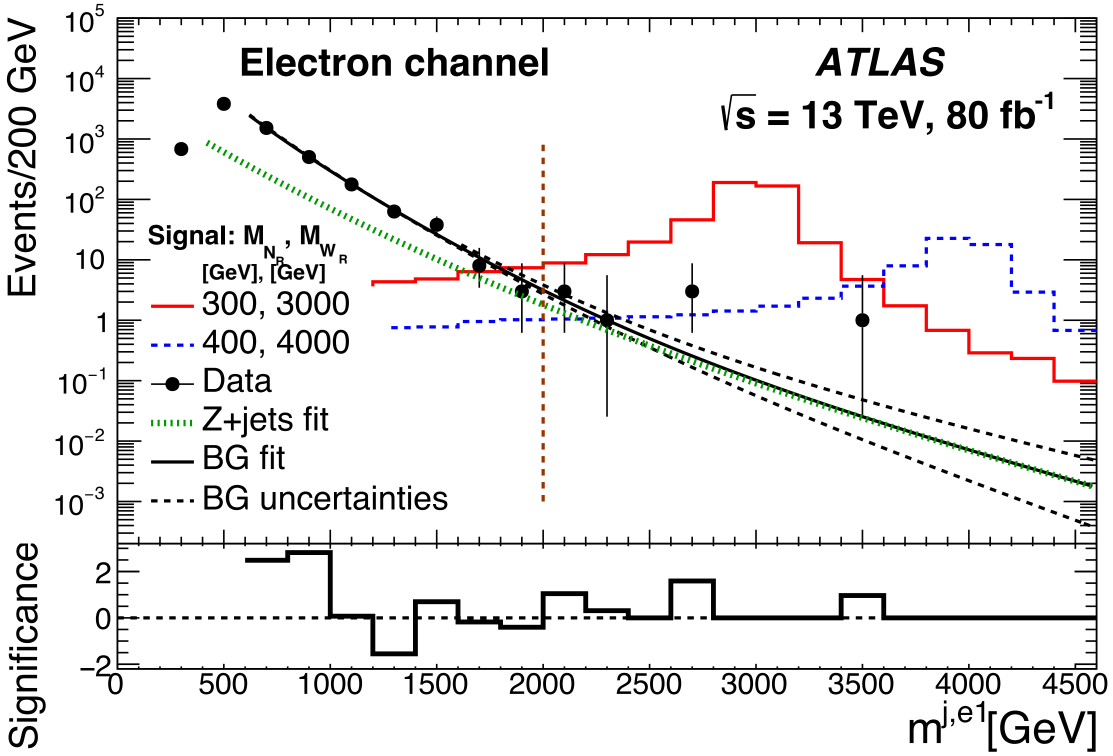
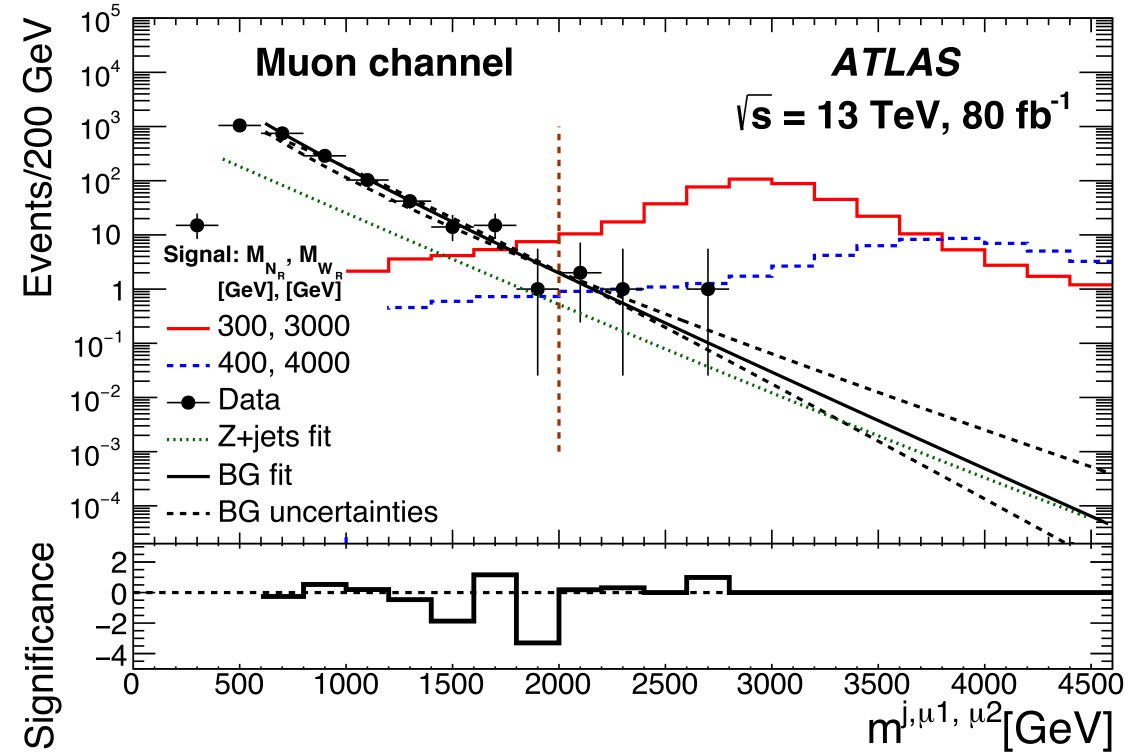
Background Estimation : A fit extrapolation from CR to SR





- A data-driven CR fit (range 600-1800GeV) performed & extrapolated to SR.
- Different steeply falling functional forms tested in CR, best taken with respect to mc closure (in CR & VR) & GOF.
- As Zjets dominates in higher mass range, a Zjets mc fit (range 400-4000GeV) parameters used in resultant fit to data.
- Fitted uncertainty includes extreme variations in SR yield using different fit ranges in CR as well as modelling uncertainty in Zjets mc & statistical uncertainty of fit.

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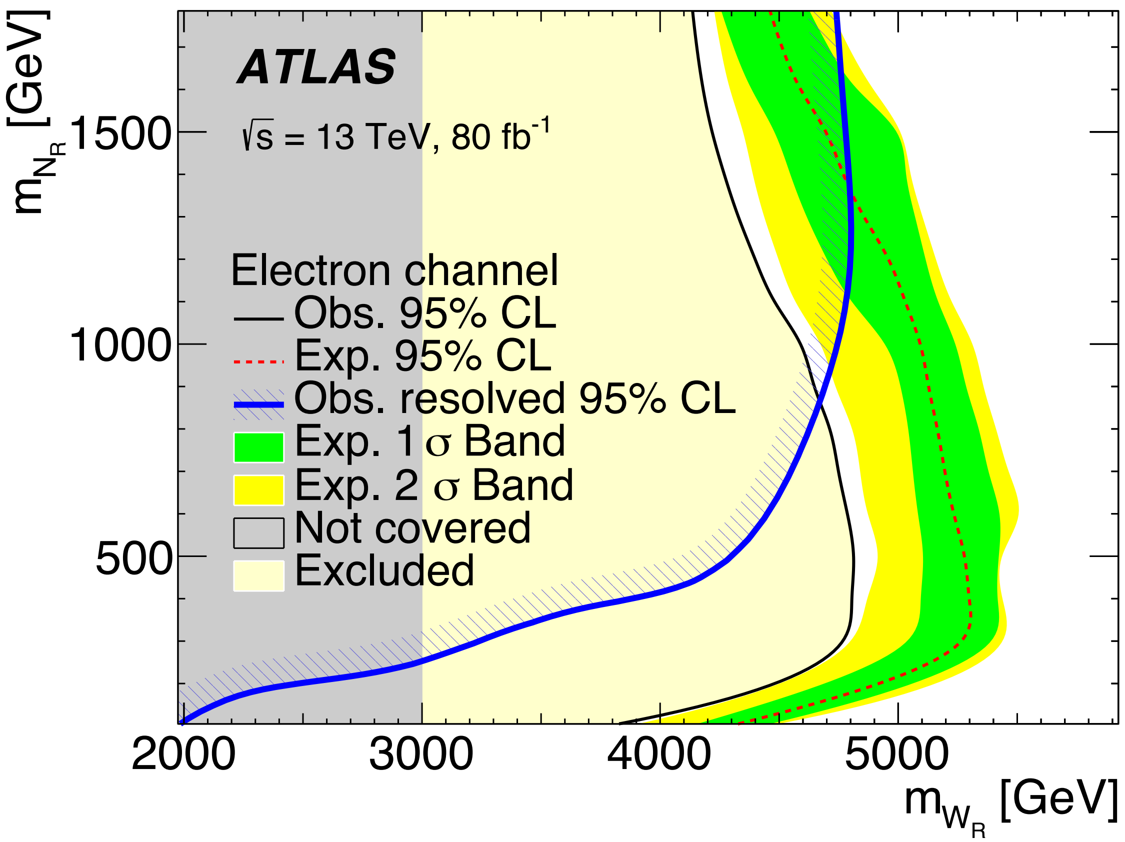
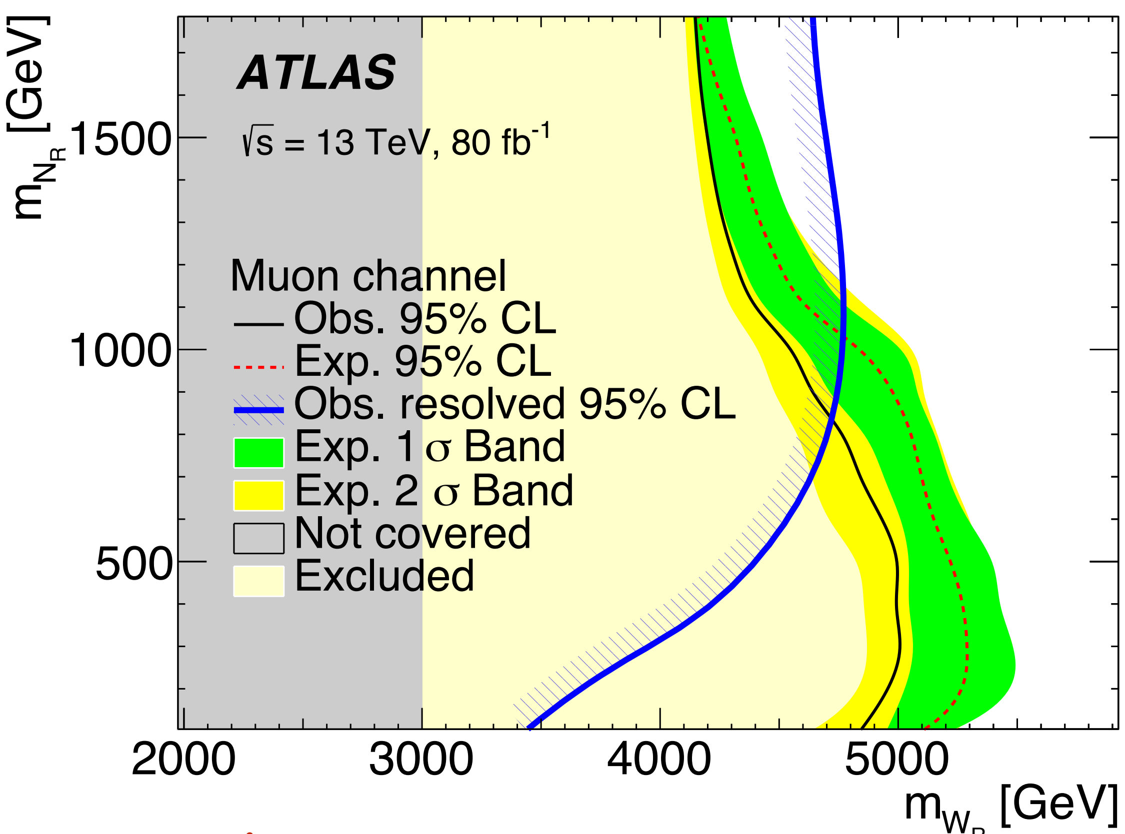
Estimation of limit with a single bin Poissonian counting expt.





	Electron Channel	Muon Channel
Signal ($m_{W_R} = 3$ TeV, $m_{N_R} = 150$ GeV)	346^{+48}_{-75}	411^{+36}_{-48}
Signal ($m_{W_R} = 3$ TeV, $m_{N_R} = 300$ GeV)	471^{+42}_{-69}	429^{+29}_{-40}
Signal ($m_{W_R} = 4$ TeV, $m_{N_R} = 400$ GeV)	66^{+6}_{-10}	57^{+4}_{-4}
Expected background	$2.8^{+0.5}_{-0.7}$	$1.9^{+0.5}_{-0.7}$
Observed events	8	4
Significance	2.4σ	1.2σ
p-value	0.0082	0.12

- SR yields from signal, background & systematic uncertainties as a set of nuisance parameters used for likelihood fit to data as a single bin.
- Lower limits on masses of N_R & W_R determined by profiled likelihood test statistic with CLs method.
- Excluded region extends upto m_{WR} ~ 4.8 TeV in e & 5 TeV in μ (m_{NR} ~ 0.4-0.5 TeV).

Assumptions : $g_{WR} = g_{WL}$

N^e_R, N^μ_R, N^τ_R at same mass

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Summary & Outlook

- As LHC energy & luminosity increase extended phase space becoming more suitable to explore massive resonances & thus more crucial to study boosted topologies => boosted heavy neutrinos looked into for the first time!

- Till now as no new physics can be reached in LHC with standard topologies & reconstructed standard objects we need to focus more on unusual topologies & objects which present a challenge to standard reconstruction techniques => a large radius jet with a hard electron inside an example (a common final state for many BSM physics to explore in boosted scenario) that also results into small background.

- Further tuning for this search in order to gain more signal efficiency for near future is underway => mainly working on to bring up a lepton identification menu in dense hadronic environment & in high p_T regime.