Search for a new heavy boson W′ decaying to a top and a bottom quark with the ATLAS detector

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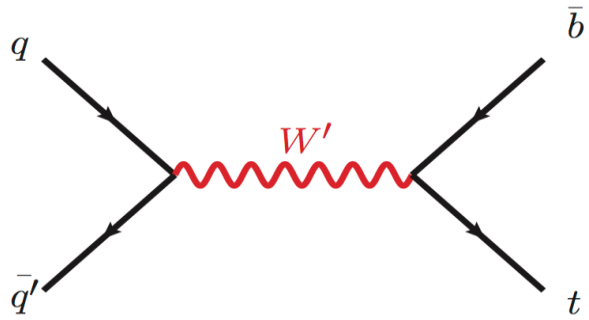
Outline

- Introduction
- $W' \to tb \to qqbb$ channel
- $W' \to tb \to l\nu bb$ channel
- Latest Result

Introduction

W' appears in several BSM scenarios: Extra dimensions, strong dynamics or composite Higgs. Some with preferential 3rd generation couplings

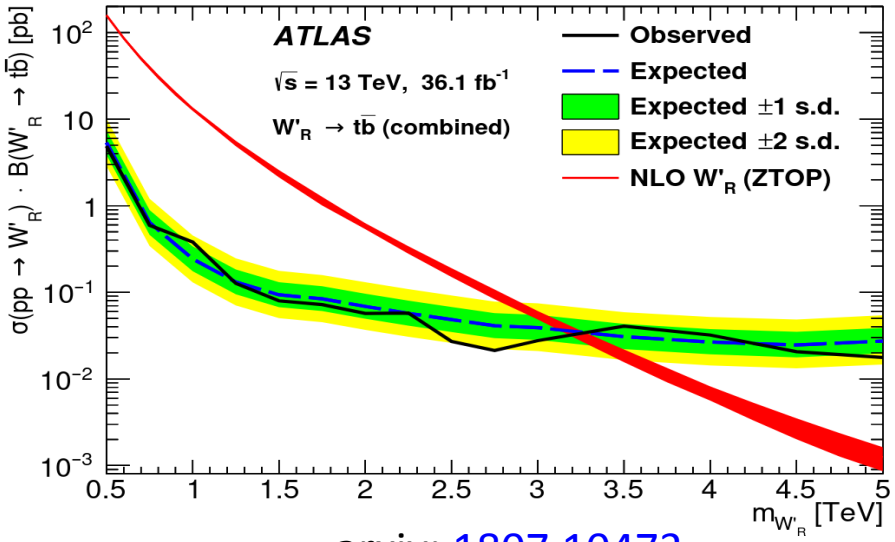
- **Benchmark Model**
- SSM-like with free mass, coupling to 3rd generation and width
- Two possible Chiralities. Right handed or Left-handed W'
- Assumption: RH Neutrino mass > Mass of W'



- **General Information**

- Two channels are studied separately, combined at the end
  - 0L: public (CONF note)
  - 1L: work in progress
- Final states:
  - 0L: 1 top-quark (AntiKt10 jet) and 1 b-quark (AntiKt4 jet)
  - 1L: 2 b-quark (AntiKt4 jet), 1 lepton and 1 neutrino (E_T^{miss})
- Reconstruct mass of tb
- MC + Data-driven estimated background
- Profile-likelihood fit on the m_{tb} spectrum

Previous Result



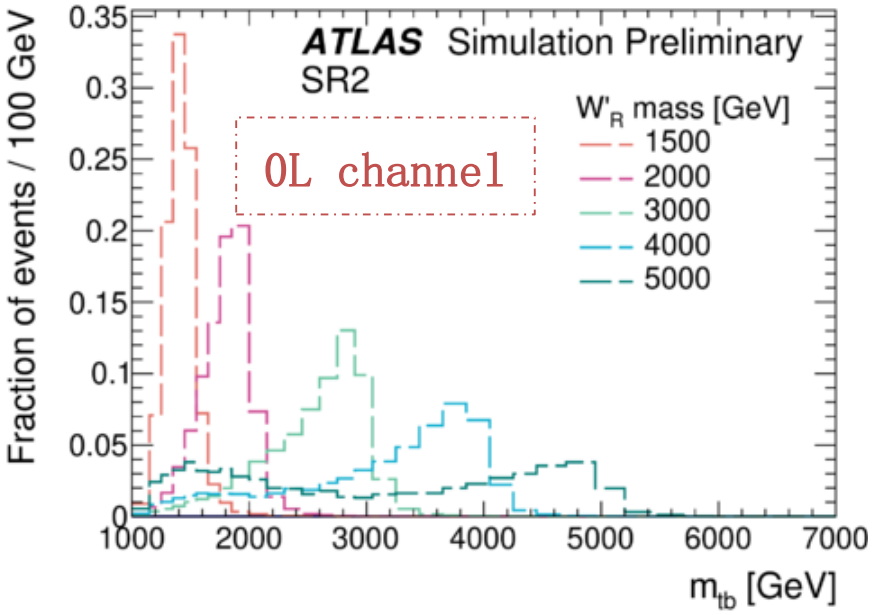
arxiv: 1807.10473

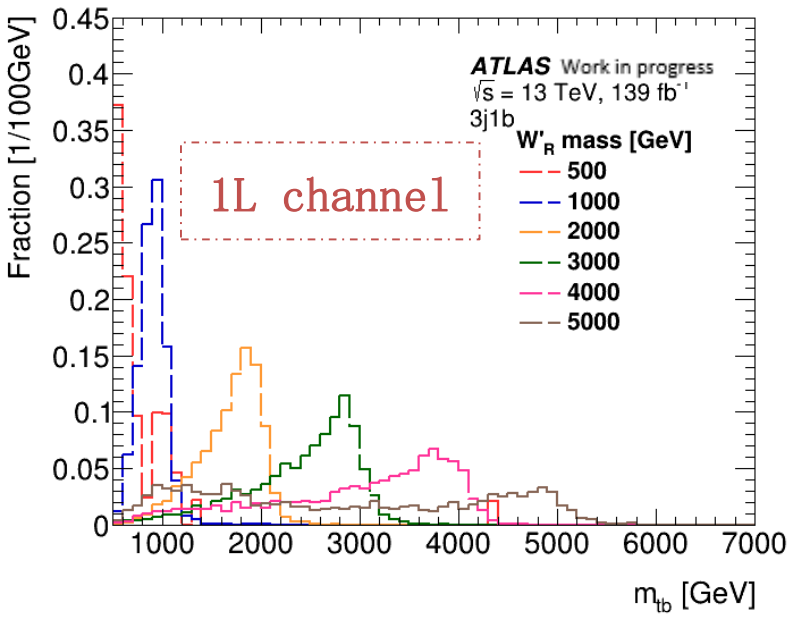
$W' \rightarrow tb$: Signal

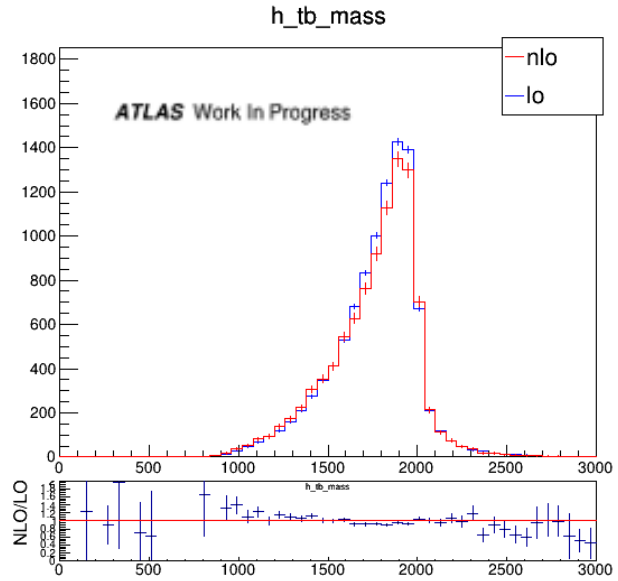
- Signal: pp -> w' -> tb
  - Generated with Madgraph + Pythia at LO
  - Scaled to NLO using ZTOP: Phys.Rev.D86 (2012) 075018, arXiv: 1208.4858
  - RH W' with 3.5% relative Width

$$\mathcal{L} = \frac{V'_{ij}}{2\sqrt{2}} \bar{f}_i \gamma_\mu \left(g'^R_{i,j}(1+\gamma^5) + g'^L_{i,j}(1-\gamma^5) \right) W'^\mu f_j + h.c.$$

Reconstructed tb mass







2 TeV signal, 0L channel, LO already scaled with the factor

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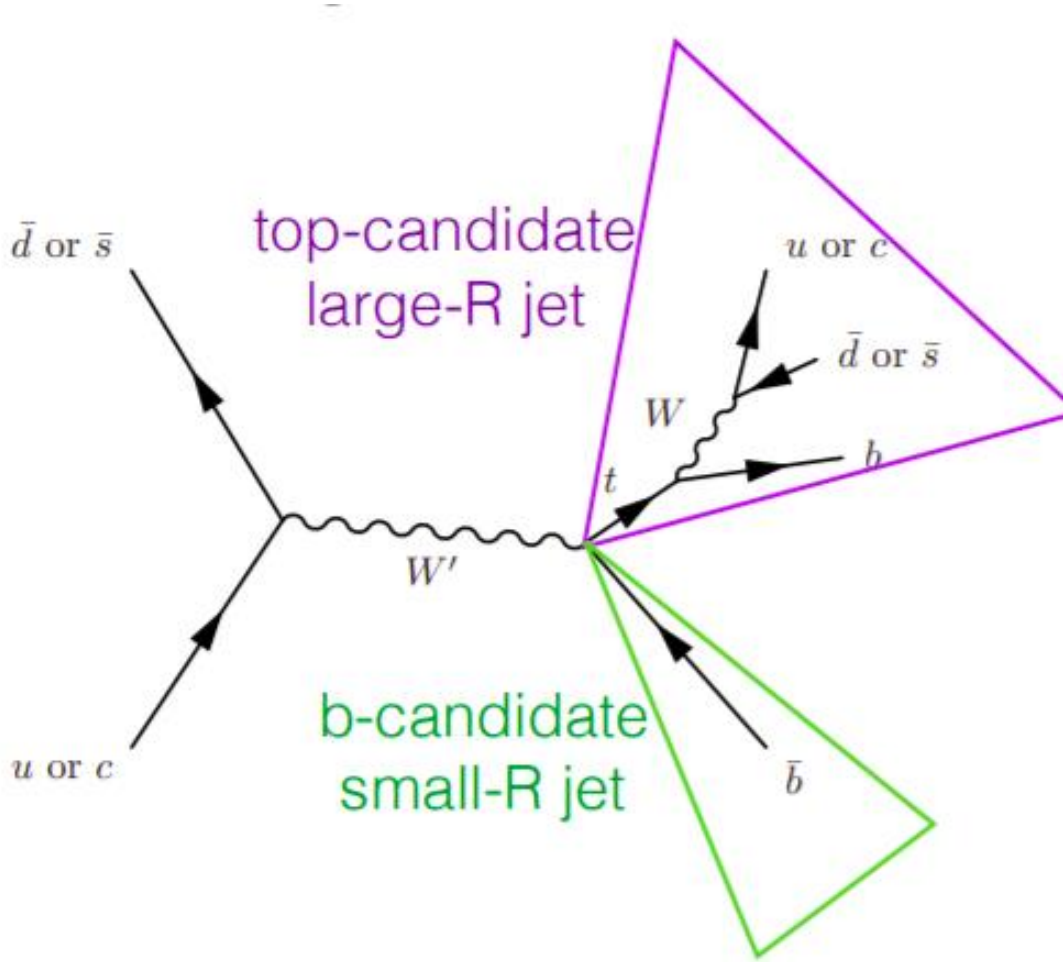
$W' \to tb \to qqbb$: Analysis strategy

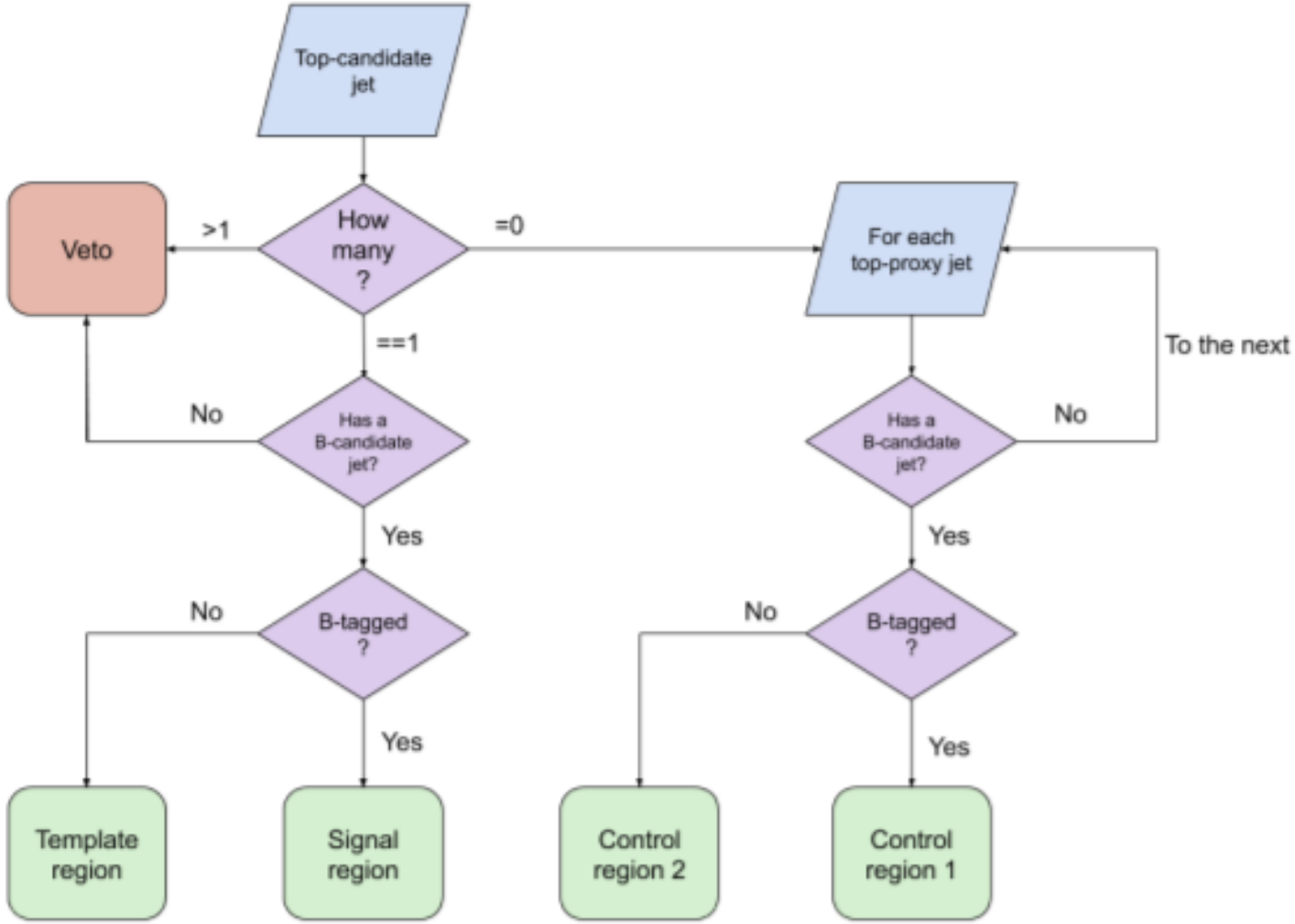
- Boosted hadronically decaying top-quark
  -> one large-R jet (AntiKt10) as top-candidate
- b-quark from W'
  -> small-R jet (AntiKt4) as b-candidate
- Categorization based on top-tagging and b-tagging

  top-tagging: large-R jets identified as coming from a top-quark
  b-tagging: small-R jets identified as coming from b-quark
  Both are DNN based
- Backgound:
  - MC ttbar
  - Data-driven QCD multi-jet



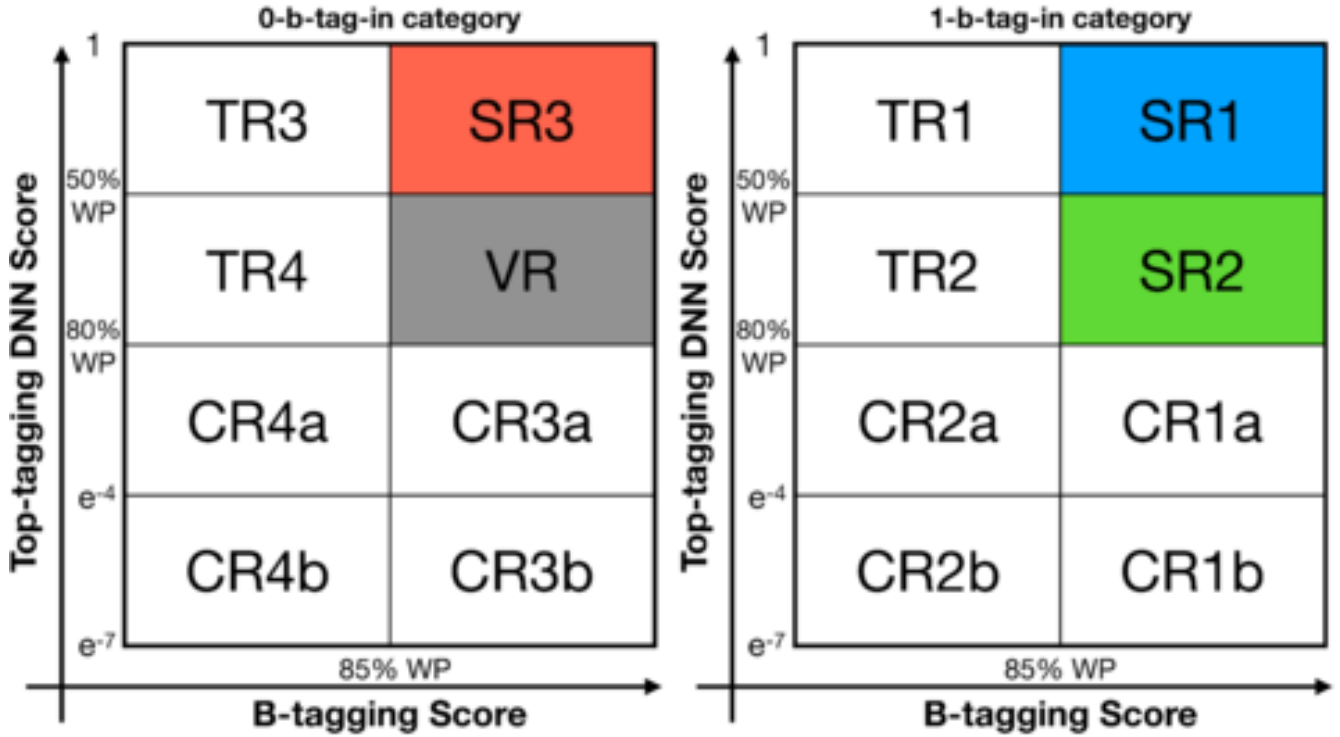
$W' \to tb \to qqbb$: Event selection

- Consider all the top-proxy jet and b-candidate jet pairs
  - One event can contain more than one candidate pair
- Veto events with two or more top-tagged candidates
- Control regions for data-driven estimation background
- 500 GeV cut for top- and b-candidates $\Delta\eta(tb) > 2.0$



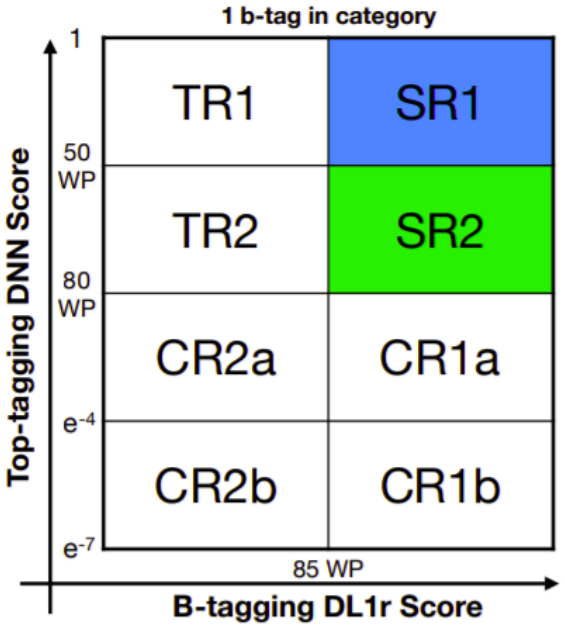
$W' \to tb \to qqbb$: Categorization

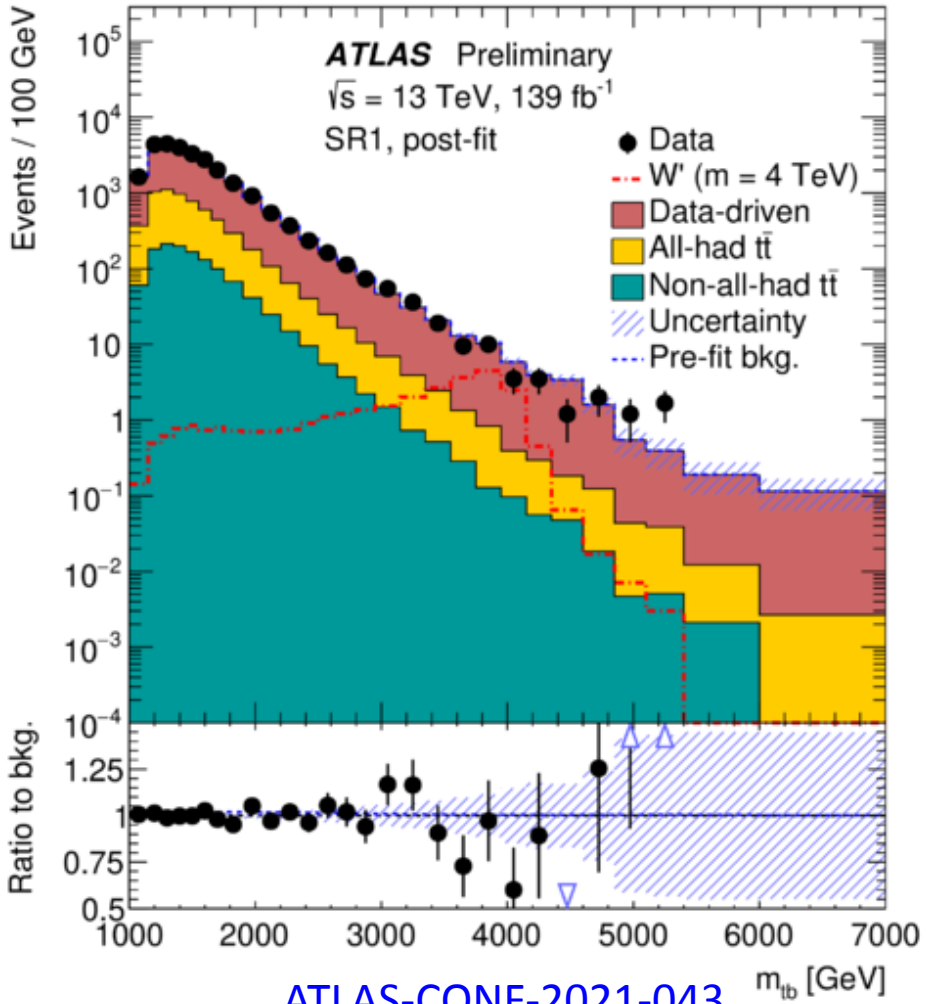
- 2 categories: 0 or 1+ b-tagged small-R jet inside the top-candidate
- Signal/template region: pass 80% WP top-tag
  - top-candidate pass (fail) 50% WP top-tag -> SR1/SR3 (SR2/VR)
- ABCD-like categorization:
  - B-tagging score: 85WP
  - top-tagging DNN score: 50/80/e^{-4}/e^{-7}



$W' \to tb \to qqbb$: Background estimation

- CRa: nominal data-driven estimation
- Subtract ttbar from data in TR
- SR1 = TR1*(CR1/CR2), bin-by-bin
- Systematic: |(CR1a/CR2a)/(CR1b/CR2b)-1|





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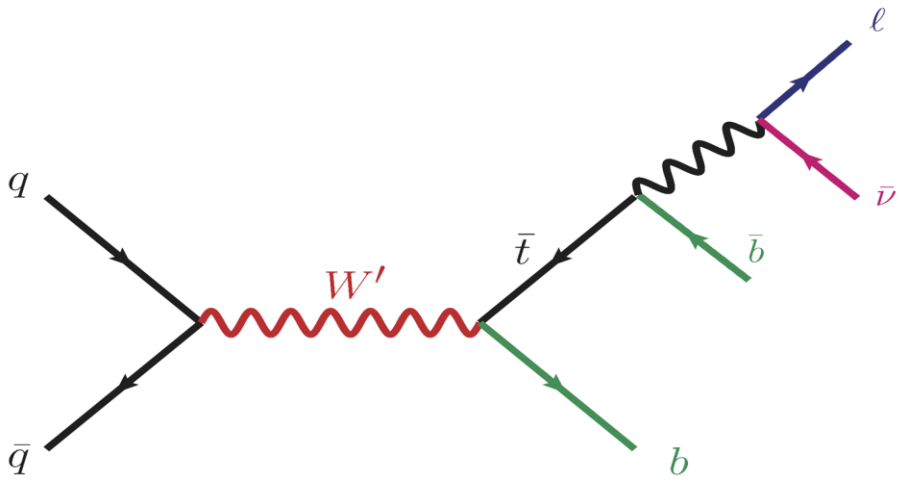
$W' \to tb \to l\nu bb$: Analysis strategy

- Final states: leptons (el or mu), MET and small-R jets (2 or more)
- Reconstructed m_{tb}:
  lep + MET -> W boson, W boson + b-jet -> top, top + b-jet -> W'
- Template fit (Multijet) + MC (anything else) for background estimation
- Profile-likelihood fit on the m_{tb} spectrum in 4 signal regions and 2 control regions



$W' \to tb \to l\nu bb$: Reconstruction

Reconstruction

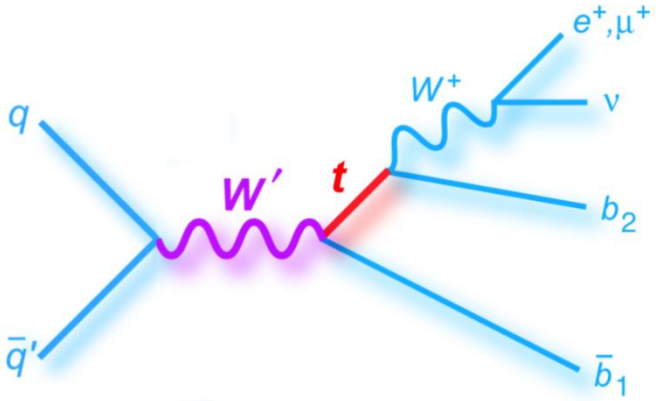
- Neutrino reconstruction algorithm using m_w (80.4 GeV) and the missing energy
- W reconstruction: Single lepton + neutrino
- Top reconstruction: jet that provides the closest m_{top} = 172.5 GeV -> b_{top}
- W' reconstruction: Remaining jet with highest P_T -> $b_{W'}$

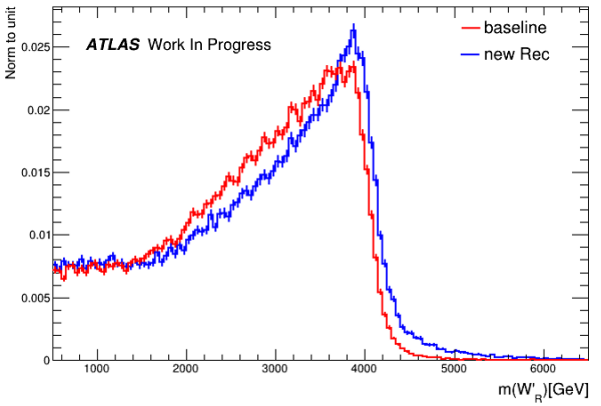
$$p_{z,\nu}^{\pm} = \frac{\mu \cdot p_{z,l}}{p_{T,l}^2} \pm \sqrt{\frac{\mu^2 \cdot p_{z,l}^2}{p_{T,l}^4} - \frac{E_l^2 \cdot p_{T,\nu}^2 - \mu^2}{p_{T,l}^2}}$$

Alternative method

- Consider the neutrino momentum should satisfy both of the W boson and top reconstruction at same time
- Solution should be a group of points (if exist) on the intersection of these two ellipsoids described by the equations
- Choose the point closest to the MET and the projection of the ellipse onto the transverse plane, define the distance as D_ν
- Choose the jet with smallest D_ν as b-candidate
- Better resolution, but less events,
  hurt the significance, especially at high mass region

$$m_W^2 = (P_\nu + P_l)^2$$
$$m_t^2 = (P_\nu + P_l + p_{b_2})^2$$





$W' \to tb \to l\nu bb$: Categorization

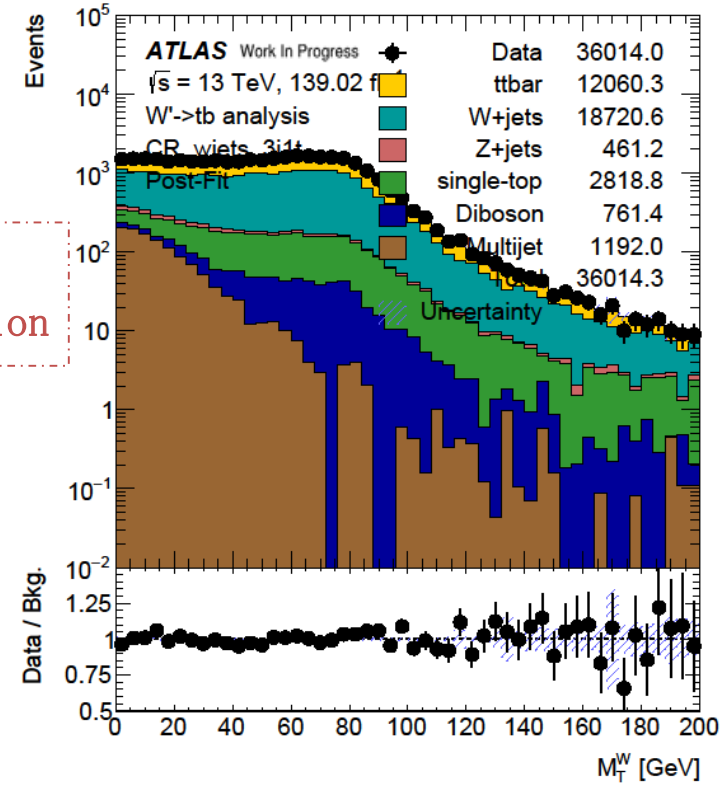
- Exactly 2/3 jets, exactly 1/2 b-tagged in those jets
- Angular cut keep SR/VR/CR orthogonal
- Additional cut in SR
  - Based on b-tagging
    - In the 2-jet 1-b region: b_{top} is b-tagged
    - In the 3-jet 1-b region and 3-jet 2-b regions: J_3 is not b-tagged
  - Based on top-tagging
    - Simple top tagging based on the mass of re-clustered jets from small-R jets
    - Remove events with an hadronic top-tagged jet

Region	SR	$VR_{w\,jets}$	$CR_{w\,jets}$
Trigger	E_T^{miss} OR one-lepton		
N_{jets}	$= 2, = 3$		
$N_{b\,jets}$	$= 1, = 2$	$= 1$	
p_T^{lep}	>50GeV		
E_T^{miss}	>100GeV		
m_T^W (in 1-tag)	>20GeV		
$p_T^{bw'}$	>200GeV		
p_T^{top}	>200GeV		
m_{tb}	>400GeV		
$\Delta\eta(t, b_{W'})$	<2.0		
$\Delta R(l, b_{top})$	<1.0	>1.0, <=2.0	>2.0

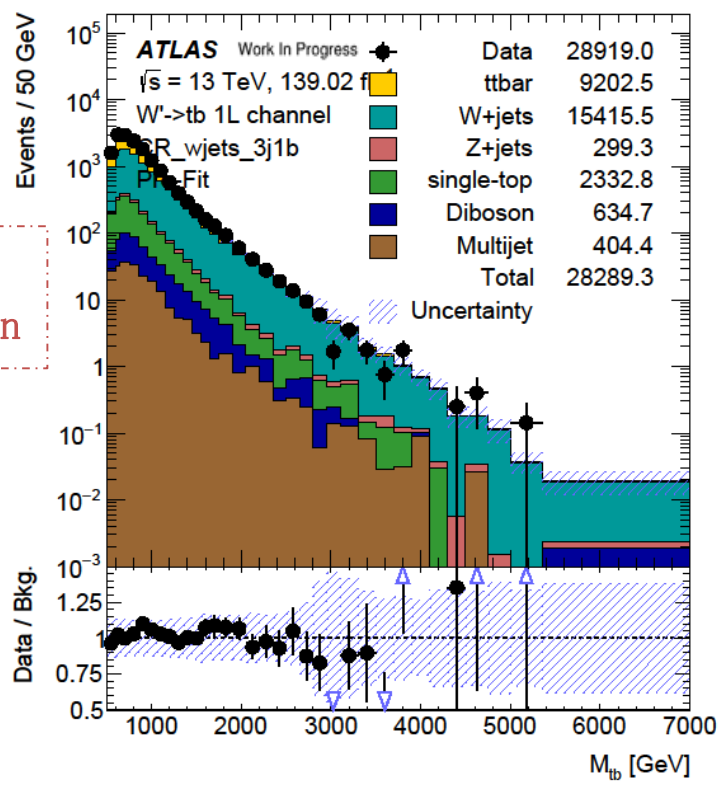
$W' \to tb \to l\nu bb$: Multijet estimation

- MC for ttbar/Wjets/single-top/diboson/Zjets
- m_T^W and m_{tb} distribution from loose-not-tight regions (same selection otherwise), multijet_template = Data – MC
- Fit m_T^W with normal MC and Data (tight), get initial norm_SF for multijet
- Implement the norm_SF on m_{tb} distribution. And include in the final fit
- Multijet small in all regions

CR
m_T^W distribution



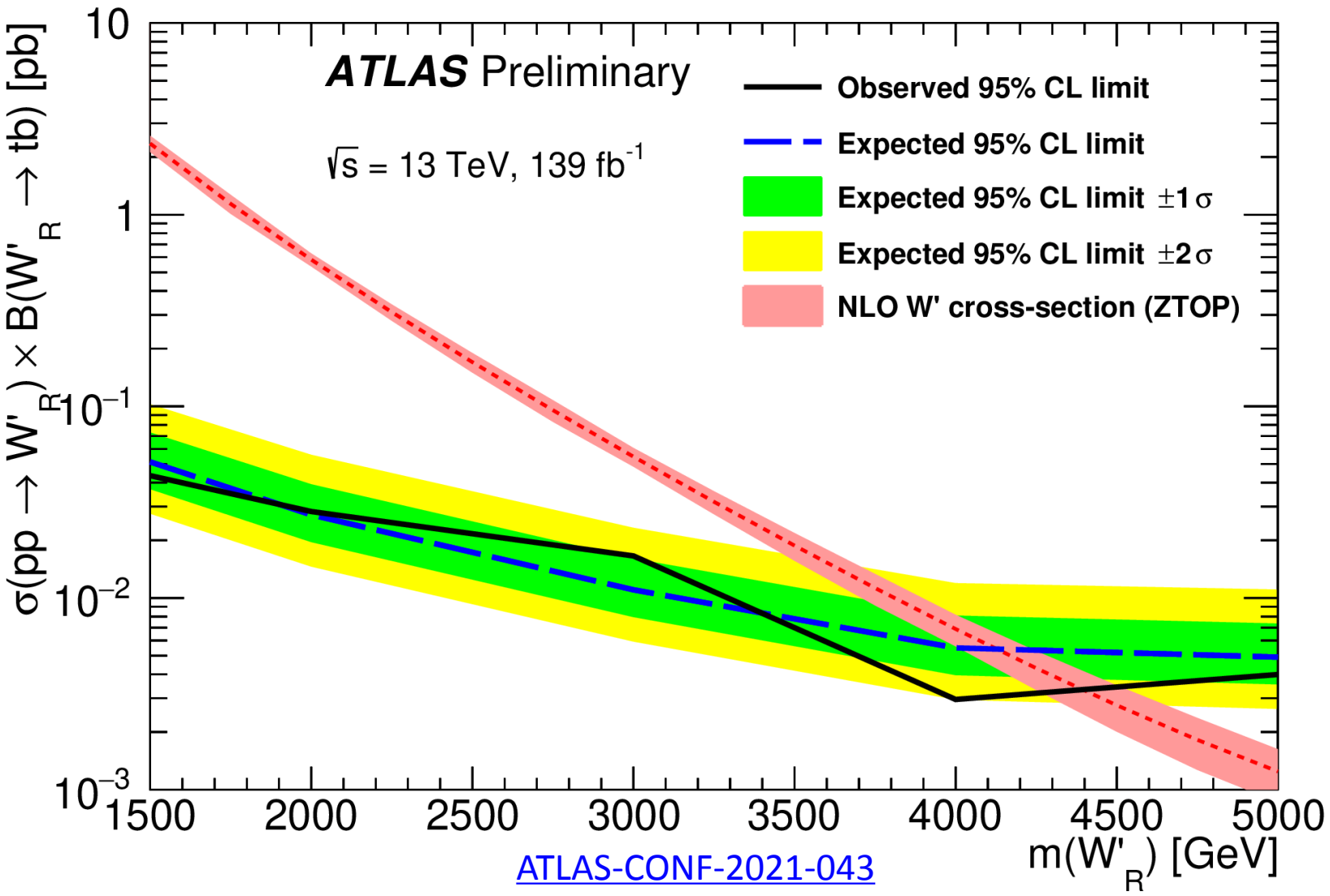
CR
m_{tb} distribution



$W' \rightarrow tb \rightarrow qqbb$: result

The search is performed in the m_{tb} distribution of the 3 signal regions simultaneously

Mass excluded
4.4 TeV (4.2 TeV) for obs (exp)at 95% CL



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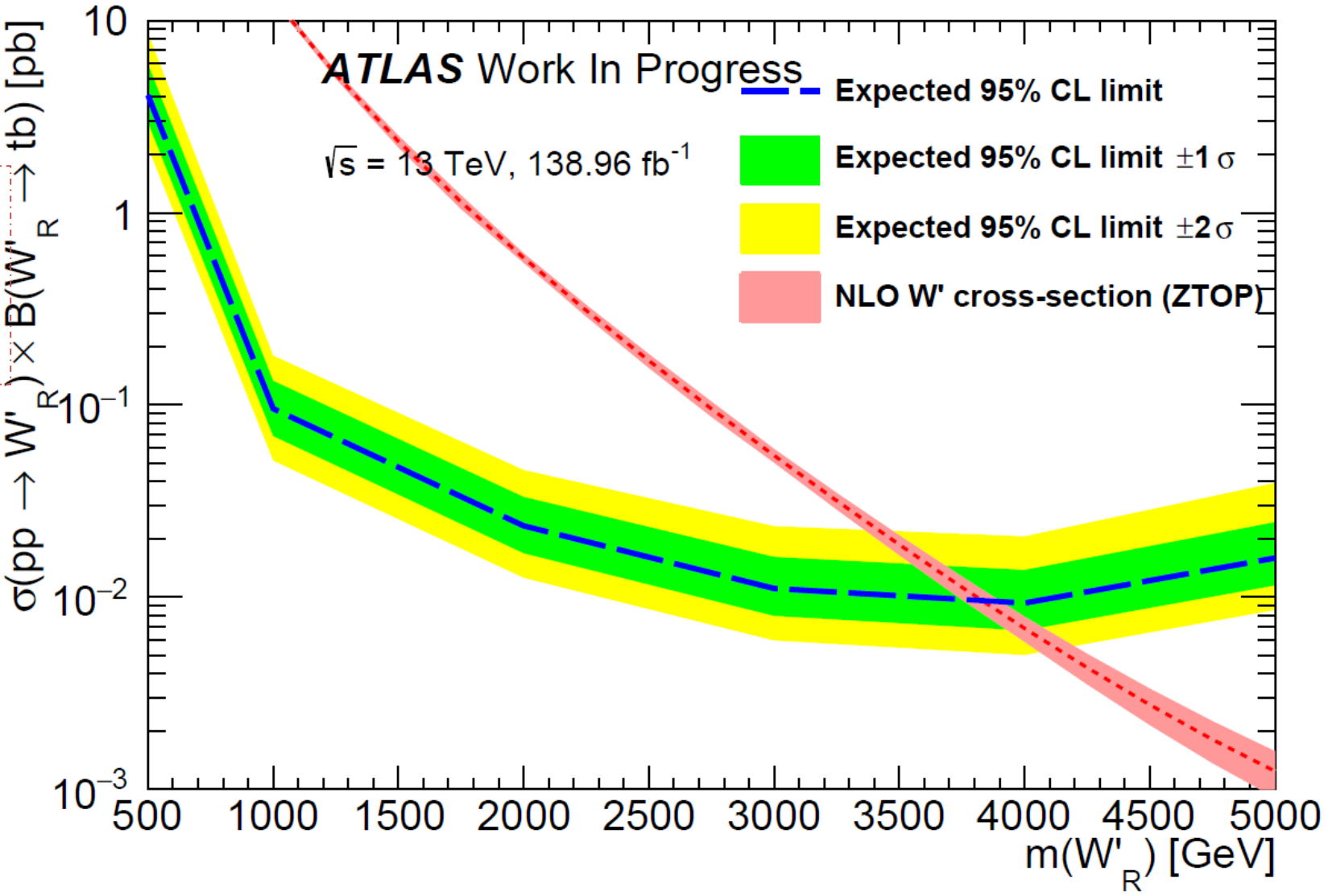
$W' \to tb \to l\nu bb$: Expected result

The search is performed in the m_{tb} distribution of the 4 SR and 2 CR simultaneously

Mass excluded 3.85 TeV for exp at 95% CL

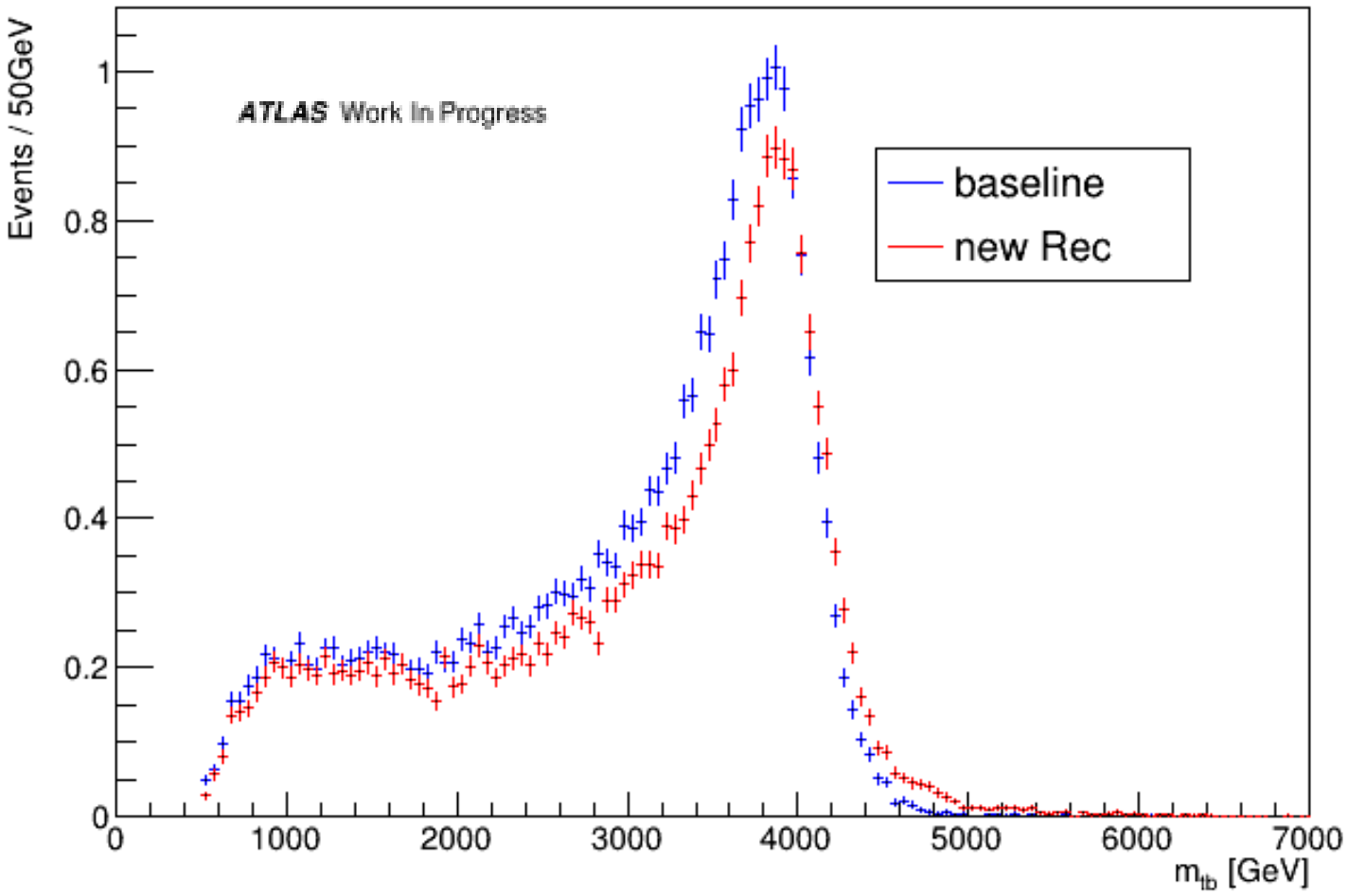


Summary

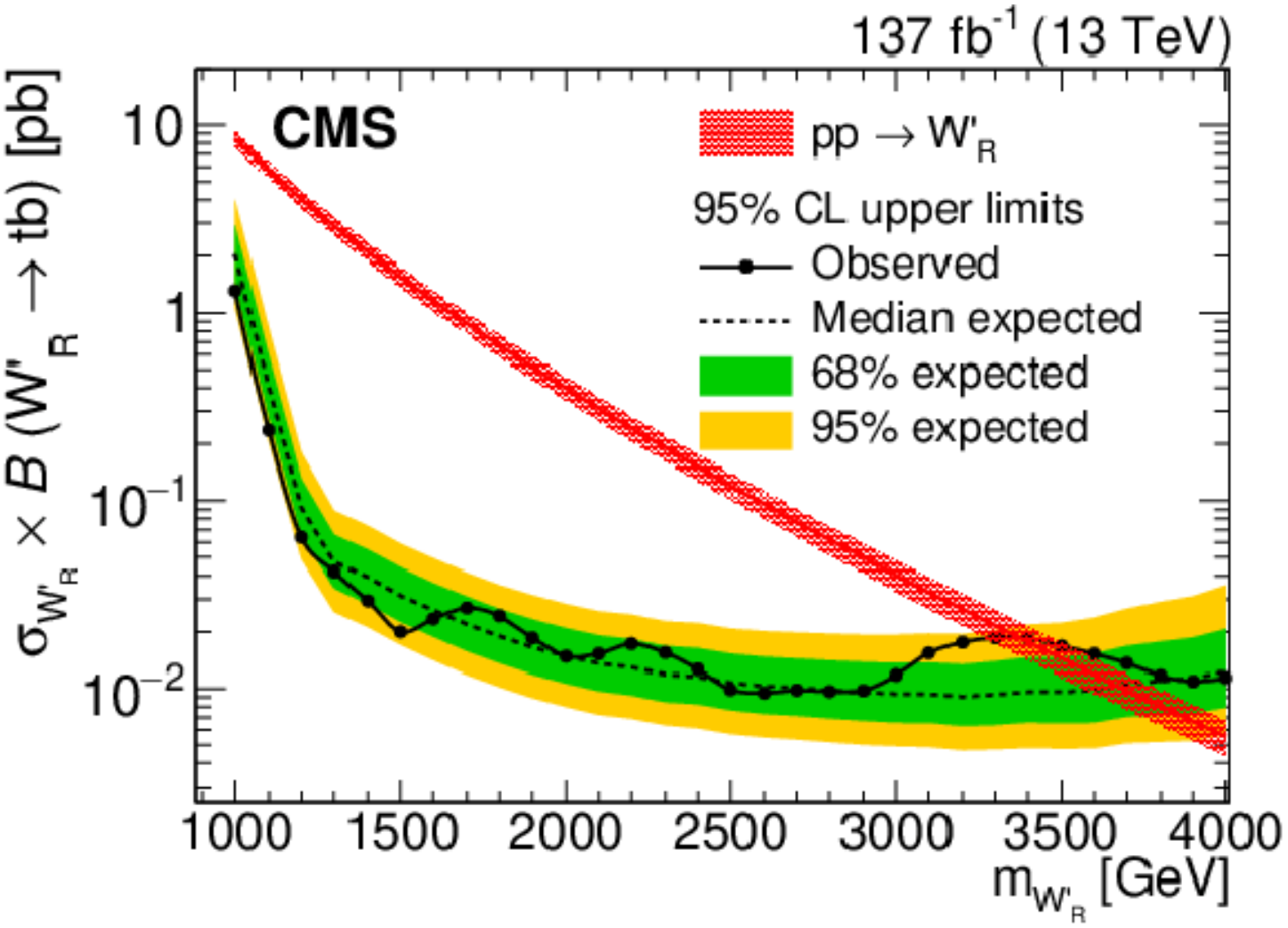
- Present the studies of the heavy boson W’ decaying to a top and a bottom quark
- Large improvement from 36.1 fb^{-1} results
- Observed limit mass excluded up to 4.4 TeV in 0L channel, right-handed
- Expected limit mass excluded up to 4.2 (3.85) TeV in 0L (1L) channel, right handed

Backup

Neutrino Rec comparison



CMS result



arxiv: [2104.04831]