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# Search for $W' \rightarrow tb$

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on behalf of ATLAS and CMS collaborations

# Outline

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Introduction

$W'$  models

Event selection

Analyses summary

Run 1 results

Run 2 results

Results on couplings

Conclusion and Outlook

# Introduction

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Massive charged gauge bosons  $W'$

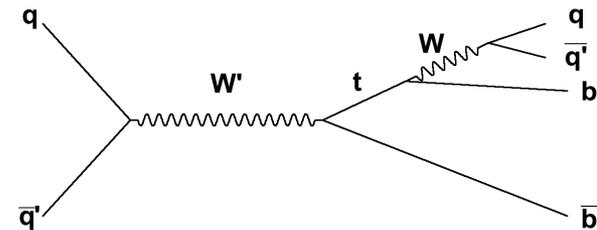
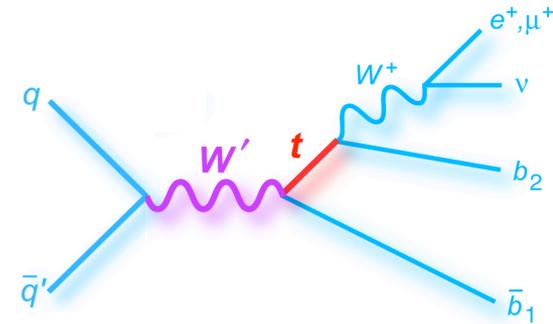
- Predicted by several Beyond Standard Model theories
  - Effective Left-Right model ([Phys.Rev.D66:075011](#), [PhysRevD.86.075018](#))
- Arise from additional symmetries

$W' \rightarrow tb$  is an interesting channel:

- More model independent than leptonic decay
- Probe leptophobic sector
- BSM dynamics could explain high top mass
- Directly probes coupling to third generation
- Complementary to  $W' \rightarrow \nu e$  and  $W' \rightarrow VV$  searches

$W'$  signal samples generation:

- ATLAS: MadGraph5 (LO) using FeynRules, with CTQ6L1 PDF
- CMS: CompHEP (LO) with CTQ6M PDF



# W' models

$$\mathcal{L} = \frac{V_{fifj}}{2\sqrt{2}} g_w \bar{f}_i \gamma_\mu [a_R(1 + \gamma^5) + a_L(1 - \gamma^5)] W'^\mu f_j + \text{h.c.}$$

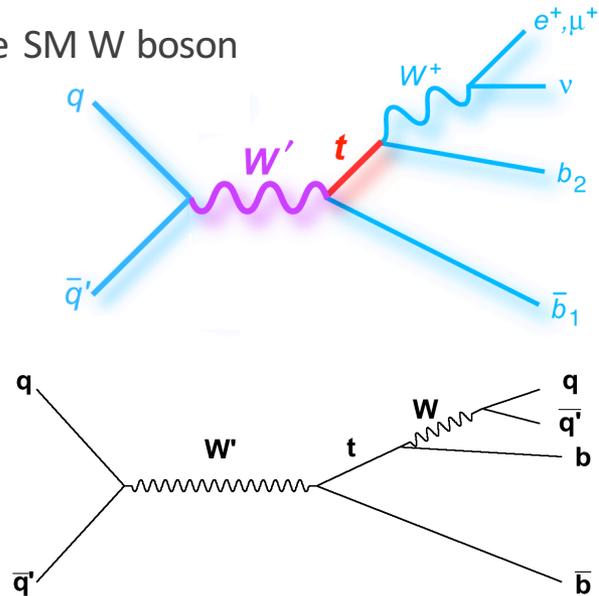
$V_{fifj}$  CKM matrix for quarks,  $\delta_{ij}$  for leptons

$g_w$  Standard Model weak coupling constant

$a_R$  coupling strength to right-handed fermions

If  $a_L > 0$ , one must take into account interference with the SM W boson

- $W'$  with left and right handed couplings
- $m(W_{R'}) \gg m(\nu_R)$
- $m(W_{R'}) < m(\nu_R)$ :  $W_{R'} \rightarrow l\nu_R$  forbidden
  - $W_{R'}$  cross section \* branching ratio is enhanced



# Event selection - leptonic

## Preselection:

- ==1 lepton (e or  $\mu$ ), (dilepton veto)
- $\geq 2$  central jets
- High  $E_T^{\text{miss}}$

## Final state:

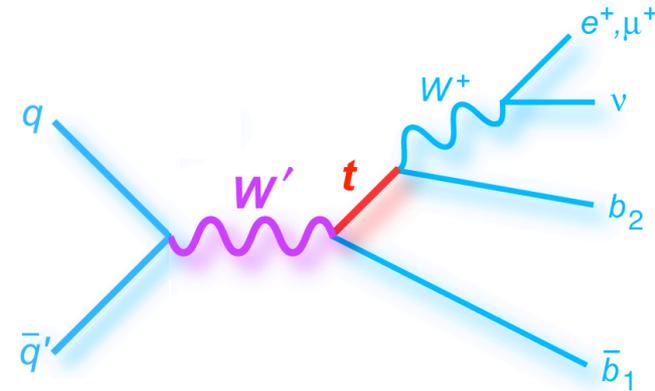
- high  $p_T$  lepton (e or  $\mu$ ),  $E_T^{\text{miss}}$ , 2 high  $p_T$  b-jets
- Backgrounds:
  - $t\bar{t}$ , W+jets, single top (s-, t-channel, Wt), Z+jets, diboson (WW, WZ, ZZ), multijet

## Neutrino $p_z$ calculation

- Estimated from  $E_T^{\text{miss}}$  and W mass constraint
- Neutrino  $p_z$  reconstruction

## Top and $W'$ reconstruction

- Find jet that gives  $m(l\nu b)$  mass closest to top-quark
- Assign highest  $p_T$  remaining jet to  $W'$  decay



# Event selection - hadronic

## Preselection:

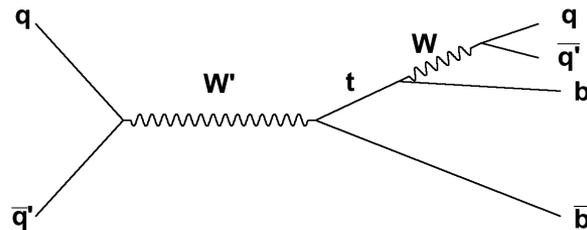
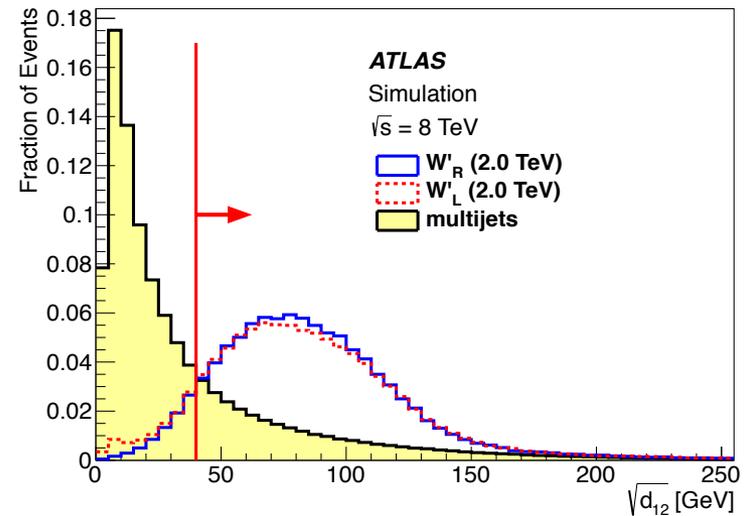
- Veto events with leptons (e or  $\mu$ )
- One large-R jet (ATLAS:  $R=1.$ , CMS:  $R=0.8$ )

## Final state:

- No leptons, one large-R jet
- Backgrounds:
  - Multijet,  $t\bar{t}$ , single top (s-, t-channel,  $Wt$ )

## Top-tagger

- Use of jet substructure to distinguish between top quark jet and QCD jet



# Leptonic analyses summary

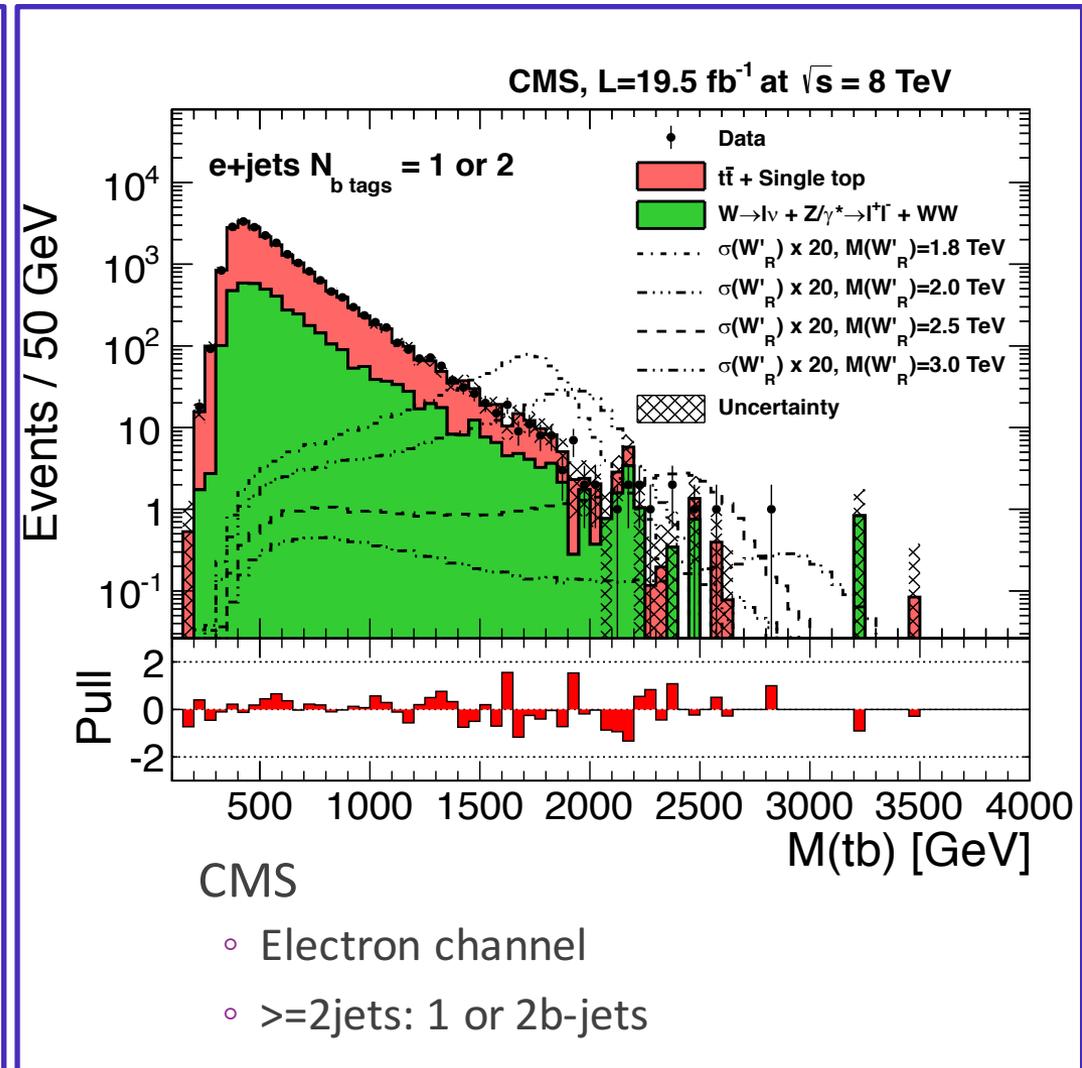
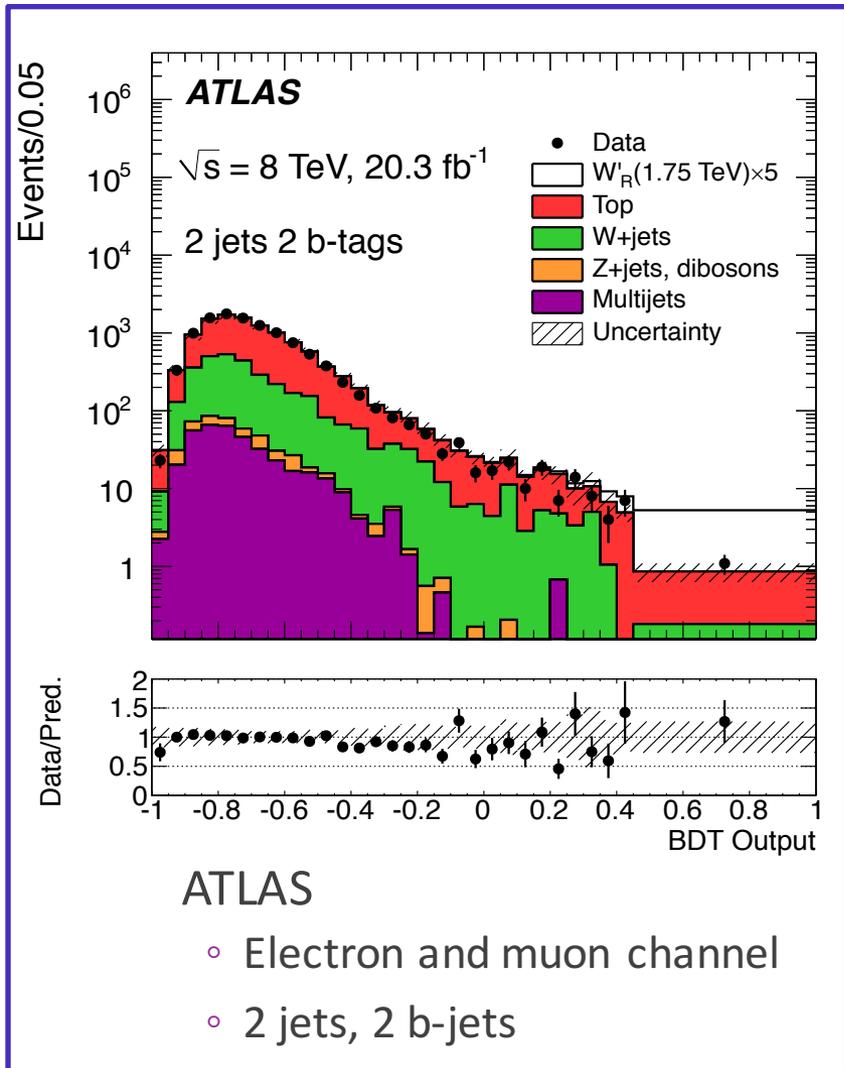
	$m(W'_R)$ [TeV]	$m(W'_L)$ [TeV]	coupling $a_R = g'_R/g$
ATLAS leptonic 8TeV ( $20.3\text{fb}^{-1}$ ): <ul style="list-style-type: none"> <li>◦ Electron and muon channels</li> <li>◦ 2 or 3jets, 2 b-jets</li> <li>◦ 2 BDT</li> <li>◦ <a href="#">Phys. Lett. B743 (2015) 235</a></li> </ul>	1.92	1.70	$0.2$ $m(W'_R) = 750 \text{ GeV}$
CMS leptonic 8TeV ( $19.5\text{fb}^{-1}$ ): <ul style="list-style-type: none"> <li>◦ Electron and muon channels</li> <li>◦ <math>\geq 2</math>jets: 1 or 2b-jets</li> <li>◦ <math>p_T(\text{top}), m(\text{top}), p_T(\text{jet1}, \text{jet2})</math></li> <li>◦ <a href="#">JHEP05 (2014) 108</a></li> </ul>	2.05	2.02	$0.2$ $m(W'_R) = 800 \text{ GeV}$
CMS leptonic 13TeV ( $35.9\text{fb}^{-1}$ ): <ul style="list-style-type: none"> <li>◦ Electron and muon channels</li> <li>◦ <math>\geq 2</math>jets: 1 or 2 b-jets               <ul style="list-style-type: none"> <li>◦ TypeA, TypeB</li> </ul> </li> <li>◦ <math>p_T(\text{top}), m(\text{top}), p_T(\text{jet1}, \text{jet2})</math></li> <li>◦ <a href="#">PAS B2G-17-010</a></li> </ul>	3.5		$0.3$ $m(W'_R) = 1200 \text{ GeV}$

# Hadronic analyses summary

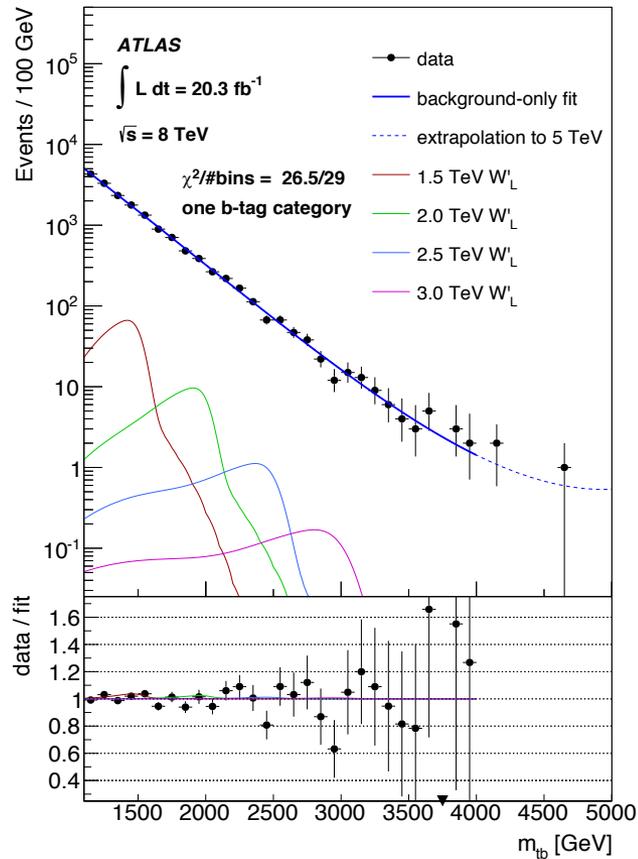
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	$m(W'_R)$ [TeV]	$m(W'_L)$ [TeV]	coupling $a_R = g'_R/g$
ATLAS hadronic 8TeV ( $20.3\text{fb}^{-1}$ ): <ul style="list-style-type: none"> <li>◦ Large R jet, top tagging</li> <li>◦ 1tag, 2tag regions</li> <li>◦ <a href="#">Eur. Phys. J. C (2015) 75: 165</a></li> </ul>	1.8	1.7	0.5 $m(W'_R) = 1500$ GeV
CMS hadronic 8TeV ( $19.7\text{fb}^{-1}$ ): <ul style="list-style-type: none"> <li>◦ Large R jet, top tagging</li> <li>◦ 2jets, 2tag region</li> <li>◦ <a href="#">JHEP02 (2016) 122</a></li> </ul>	2.02		0.35 $m(W'_R) = 1300$ GeV
CMS hadronic 13TeV ( $2.55\text{fb}^{-1}$ ): <ul style="list-style-type: none"> <li>◦ Large R jet, top tagging</li> <li>◦ 2jets, 2tag region</li> <li>◦ <a href="#">PAS B2G-16-009</a></li> </ul>	2.0		

# m(tb) leptonic analyses 8 TeV

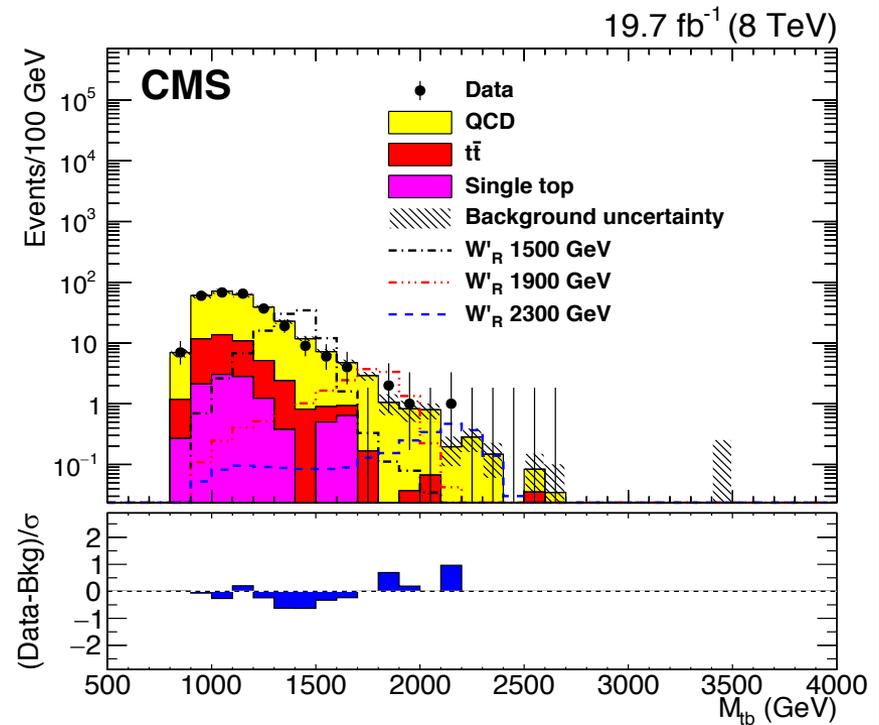


# m(tb) hadronic analyses 8 TeV



ATLAS

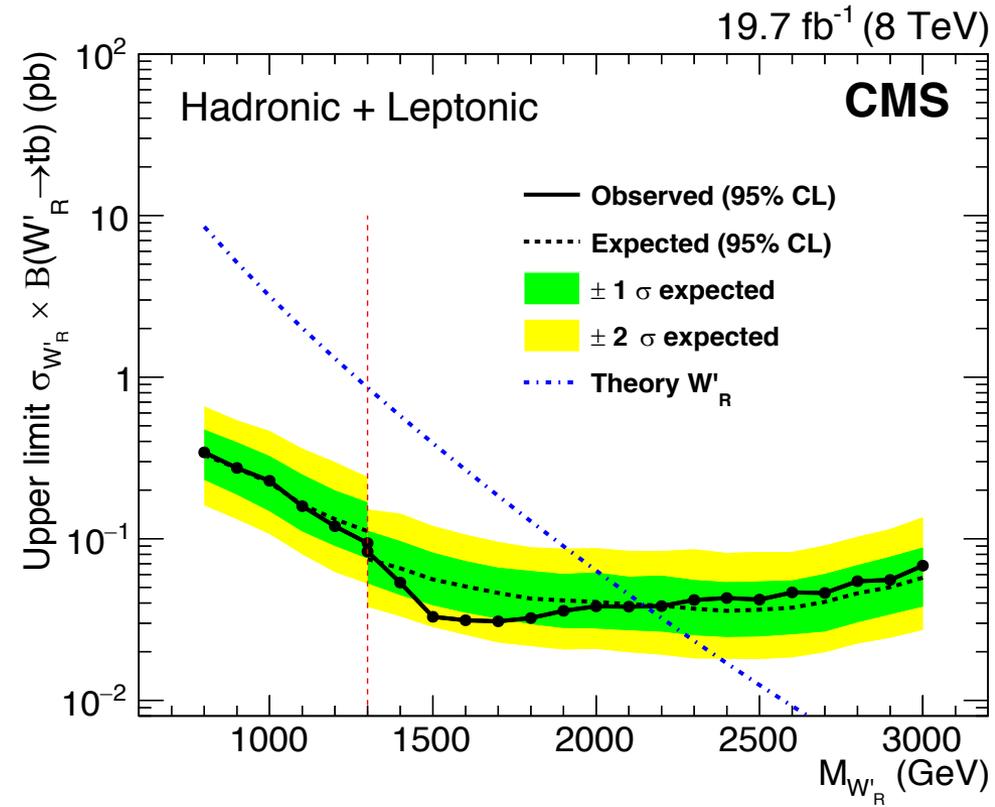
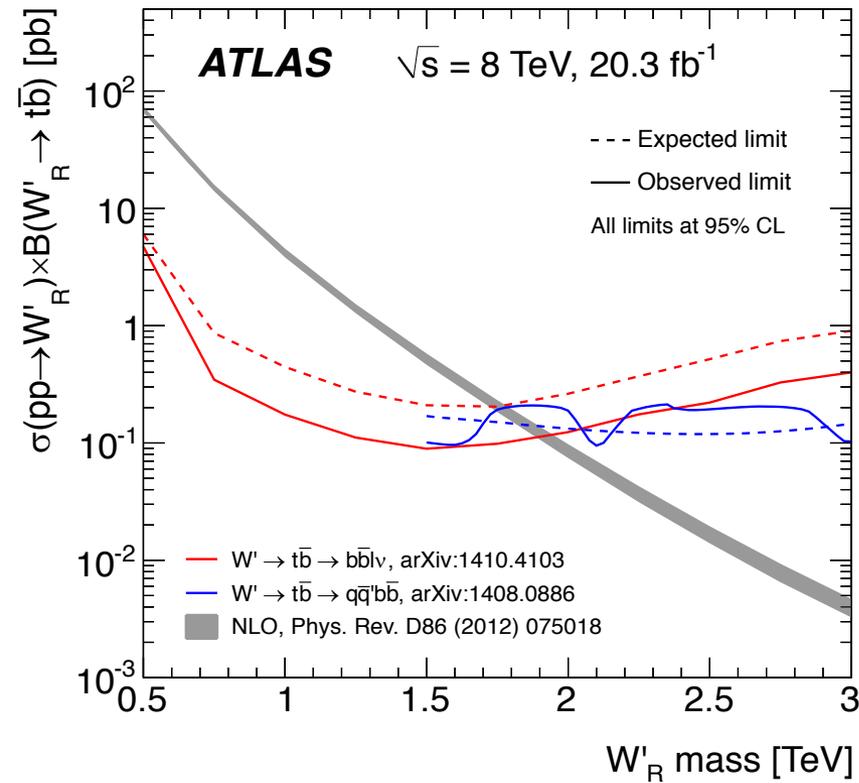
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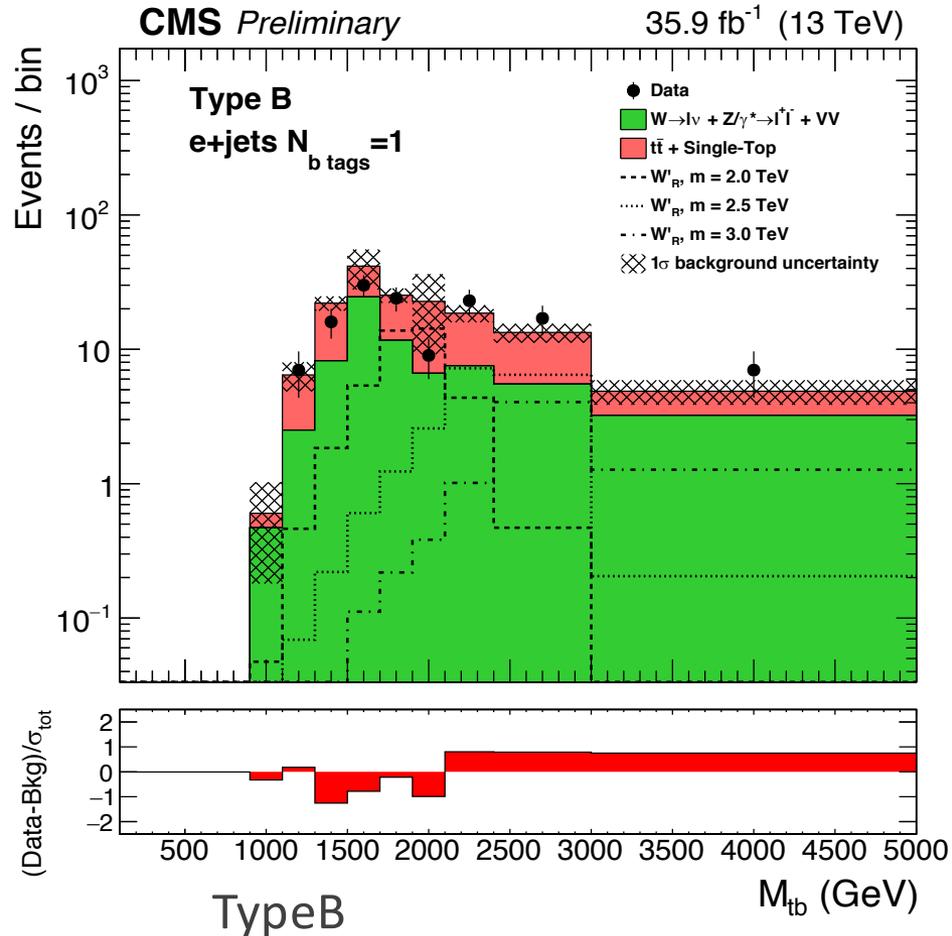
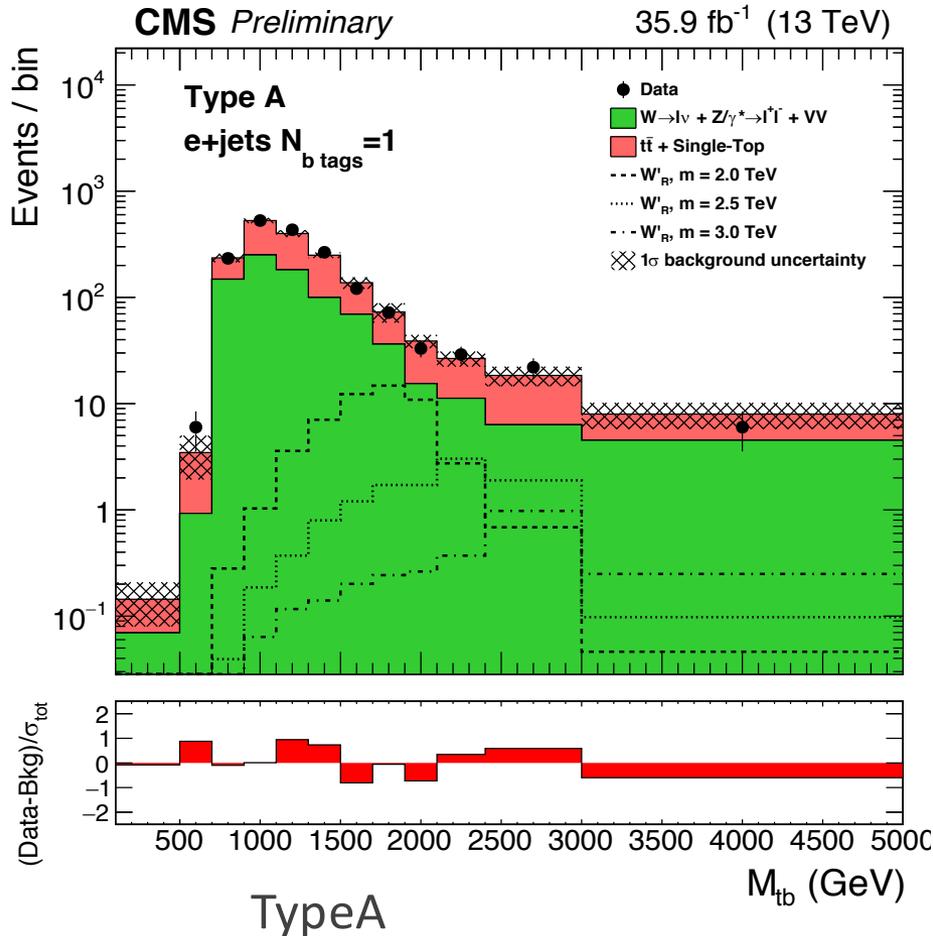
CMS

- Large R jet, top tagging
- 2jets, 2tag region

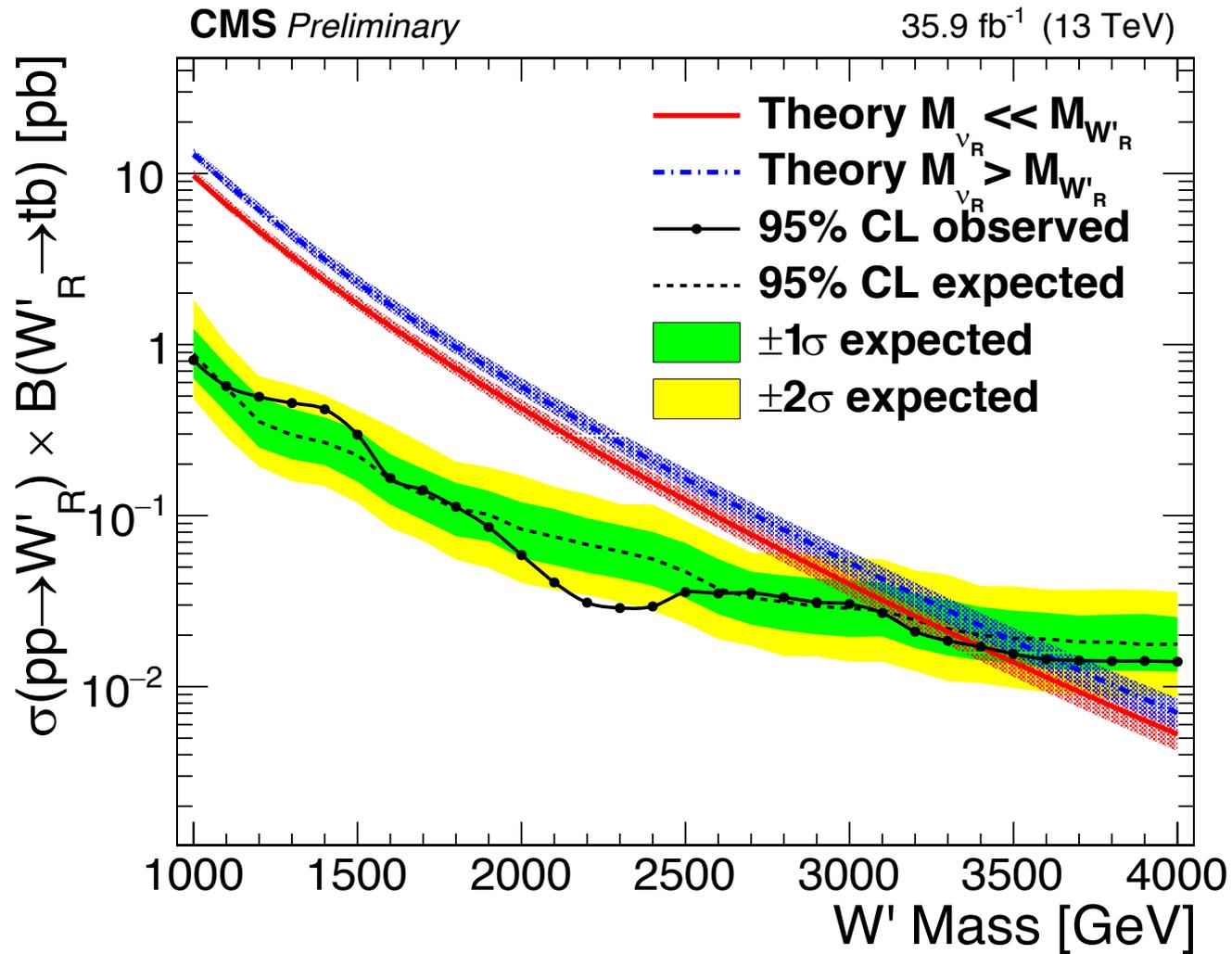
# $W'_R$ – combined 8 TeV



# m(tb) leptonic channel 13 TeV



# $W'_R$ – leptonic channel 13 TeV



# Leptonic analyses summary

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# Interference

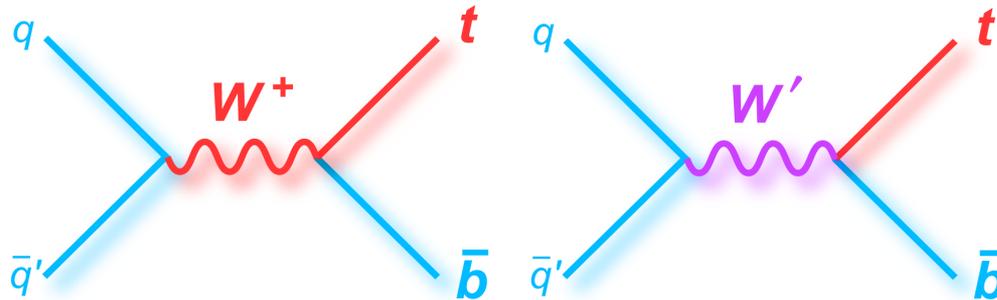
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$W'_L$  couple to same fermion multiplets as Standard Model  $W$  boson

- Interference between s-channel single top production via  $W$  and  $W'_L$  bosons
- Interference can be constructive and destructive
  - We consider only destructive interference
- In principle these processes must be generated together

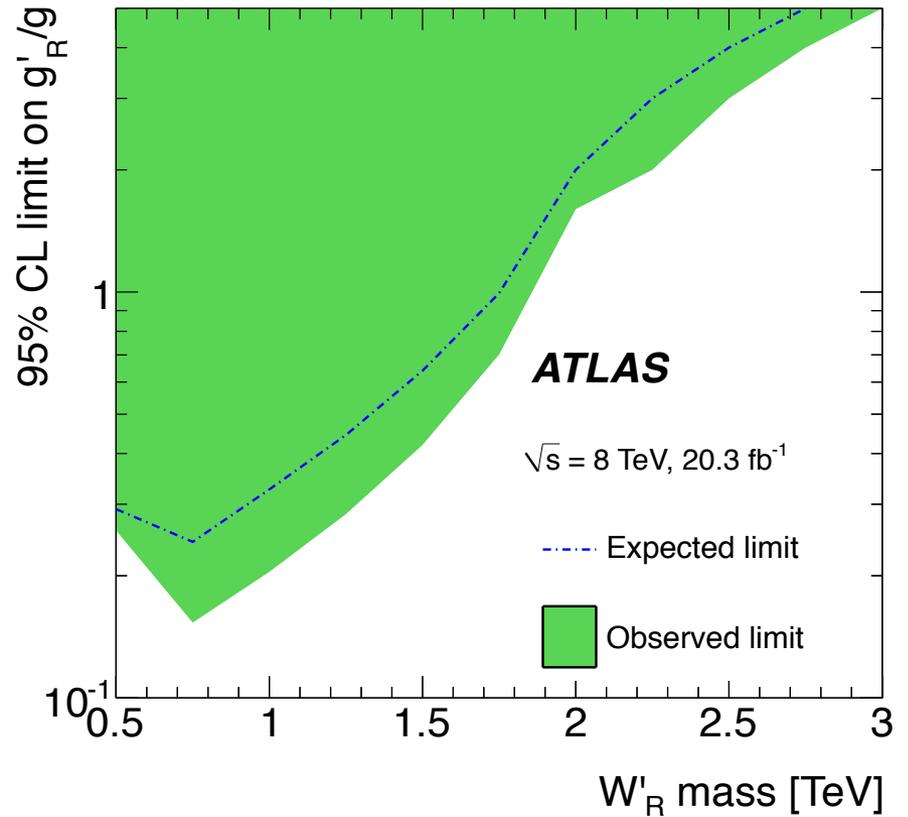
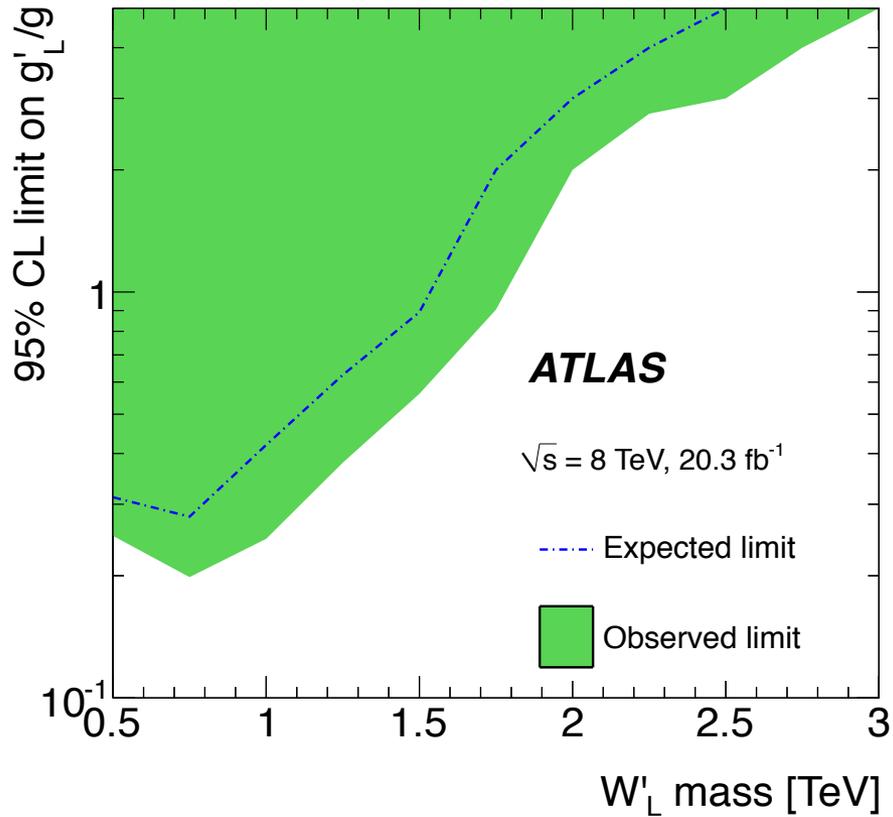
For  $W'_L$  search s-channel single top production enters into signal

- $Wt$  and t-channel single top productions are considered as backgrounds
- Limits are set on the  $pp \rightarrow W'_L/W \rightarrow tb$  process considered as unique signal

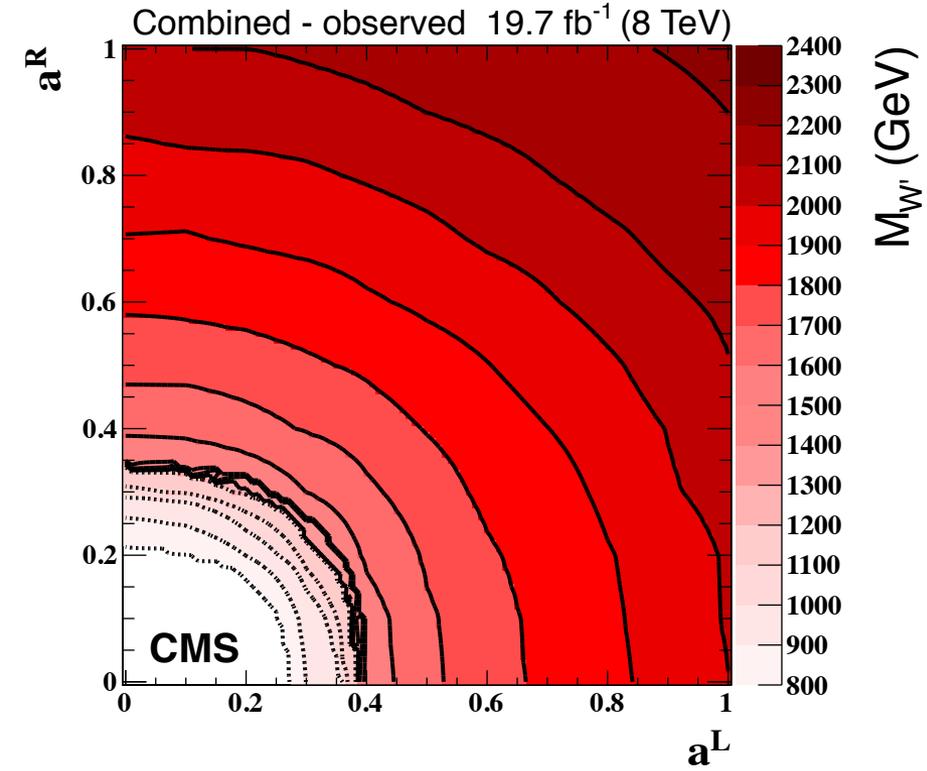
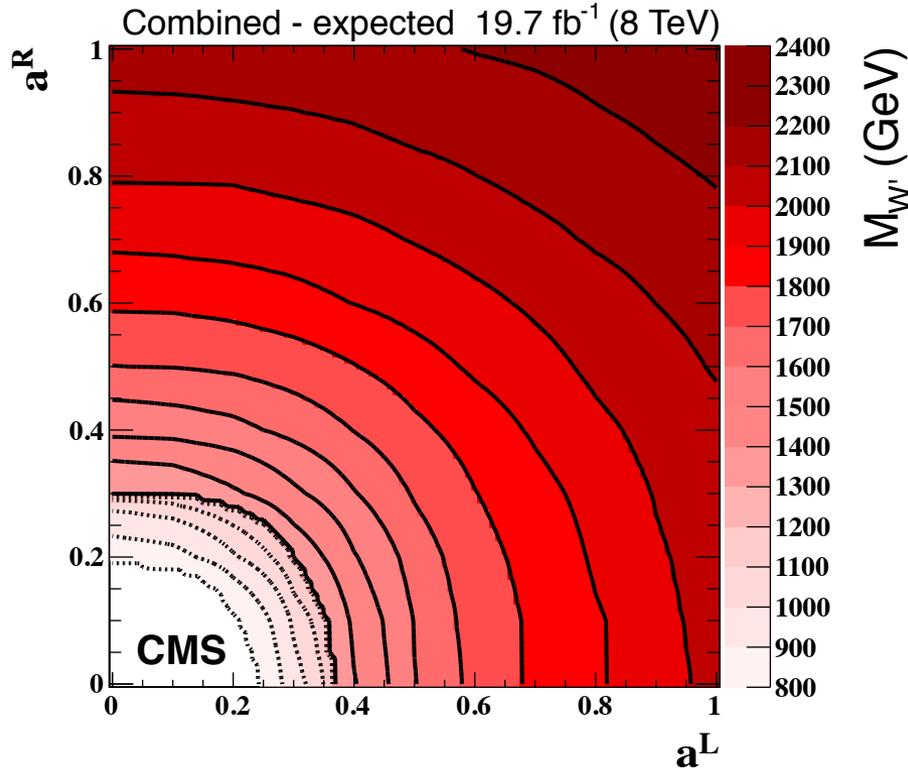


$$|\mathcal{M}|^2 = |\mathcal{M}_{SM}|^2 + |\mathcal{M}_{BSM}|^2 + 2\Re(\mathcal{M}_{SM}^* \mathcal{M}_{BSM})$$

# Couplings ATLAS 8 TeV

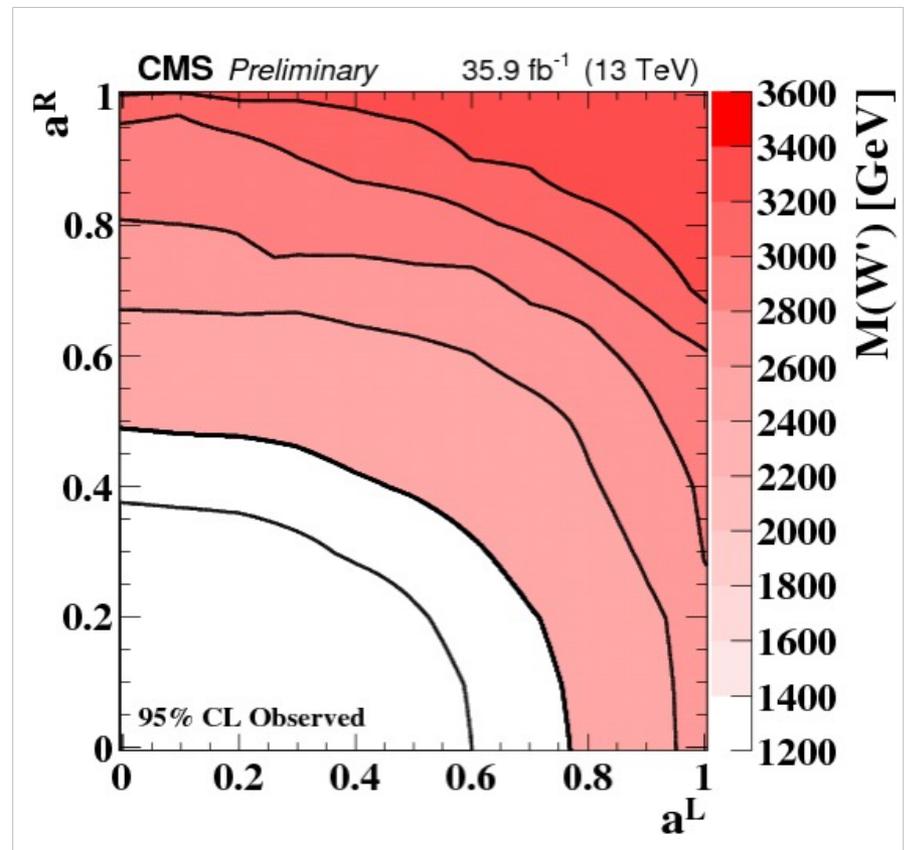
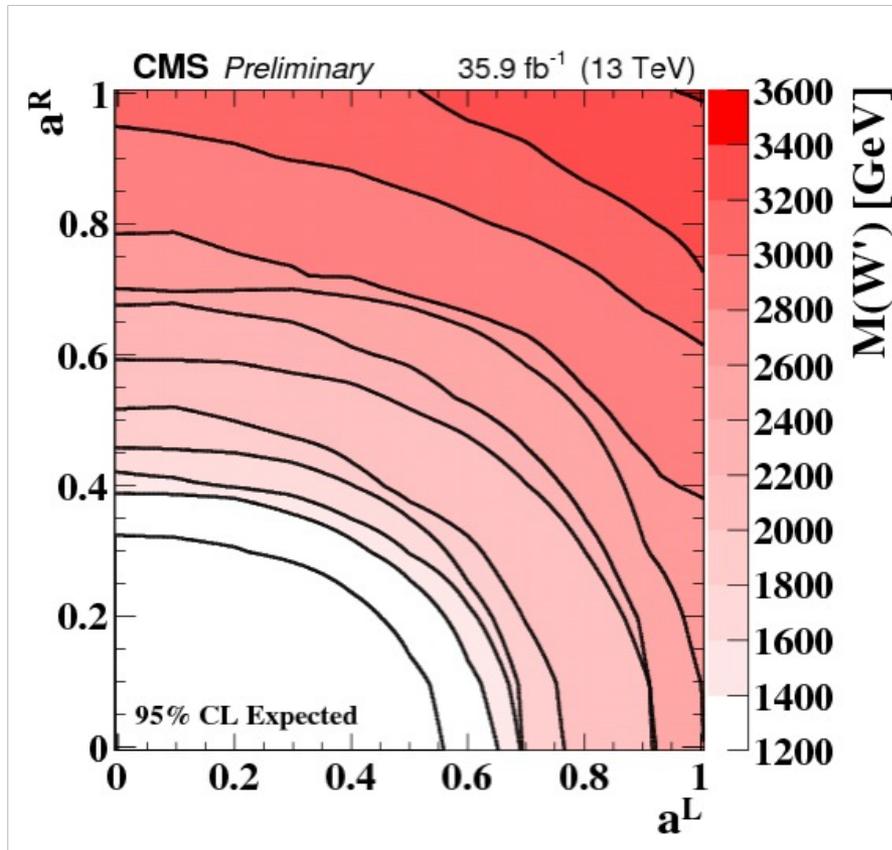


# Couplings CMS 8 TeV



$$\sigma_{a_{ud}^L a_{ud}^R a_{tb}^L a_{tb}^R} = \left(1 - a_{ud}^L a_{tb}^L\right) \sigma_t + a_{ud}^R a_{tb}^R \frac{a_{ud}^R a_{tb}^R - a_{ud}^L a_{tb}^L}{a_{ud}^L a_{tb}^L + a_{ud}^R a_{tb}^R} \sigma_{W'_R} + a_{ud}^L a_{tb}^L \frac{a_{ud}^L a_{tb}^L - a_{ud}^R a_{tb}^R}{a_{ud}^L a_{tb}^L + a_{ud}^R a_{tb}^R} \sigma_{W'_L} + 2 \frac{a_{ud}^R a_{tb}^R a_{ud}^L a_{tb}^L}{a_{ud}^L a_{tb}^L + a_{ud}^R a_{tb}^R} \sigma_{W'_{LR}}$$

# Couplings CMS 13 TeV



$$\sigma = (1 - a_L^2)\sigma_{SM} + \frac{1}{a_L^2 + a_R^2} (a_L^2(a_L^2 - a_R^2)\sigma_L + a_R^2(a_R^2 - a_L^2)\sigma_R + 4a_L^2 a_R^2 \sigma_{LR} - 2a_L^2 a_R^2 \sigma_{SM})$$

# Conclusion and Outlook

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## Presented ATLAS and CMS results for $W'$ searches

- CMS performed search in leptonic channel for Run2
- Both experiments performed hadronic searches for Run 1
  - Expect updates soon
- Combination of leptonic and hadronic searches

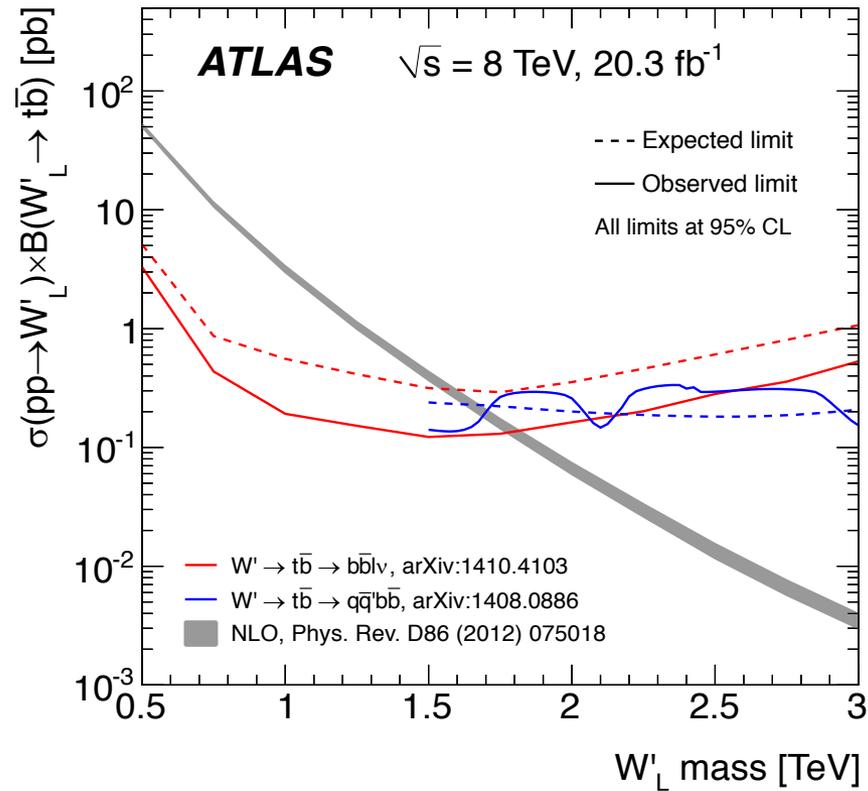
## No excess found

- Results are interpreted as limits on several  $W'$  models
- $W'_R, W'_L$
- Limits on couplings

# Back up

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# $W'_L$ - combined 8 TeV



# Right-handed $W'$ - hadronic

