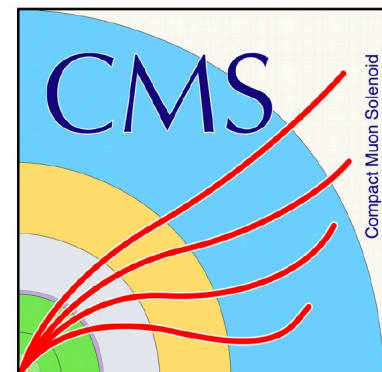




# Searches for new BSM resonances (experimental overview)



Workshop on HL-LHC physics and  
perspectives at HE-LHC  
CERN, June 18-20, 2018

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on behalf of the ATLAS and CMS  
collaborations

# Introduction

- Many ongoing activities by ATLAS and CMS
  - Mainly aimed at HL-LHC but also few studies for HE-LHC and running at different cm energies
- Analyses centre on
  - Searches for heavy  $Z'/W'$  bosons
  - $t\bar{t}$  and diboson resonances
  - Heavy composite Majorana neutrinos
  - Leptoquarks
  - Vector-like quarks
- New CMS results on  $HH \rightarrow 4b$  resonances covered in separate talk this morning

# $W' \rightarrow tb \rightarrow l\nu bb$

## Signature

- High- $p_T$  lepton, significant  $E_{T^{miss}}$ , 2 b-jets

## CMS

- Extrapolation of Run-2 (CMS B2G-16-017)

## Systematics

- Run-2 or no systematic uncertainties
- Reduce most experimental to O(%), top  $p_T$  reweighting by factor 3, theory uncertainty by factor 2

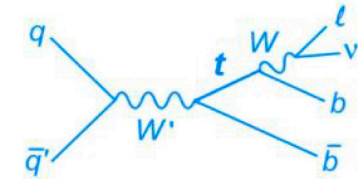
- Exclude  $m(W') > 4 \text{ TeV}$  @ 95% CL

- Current limit: 2.67 TeV

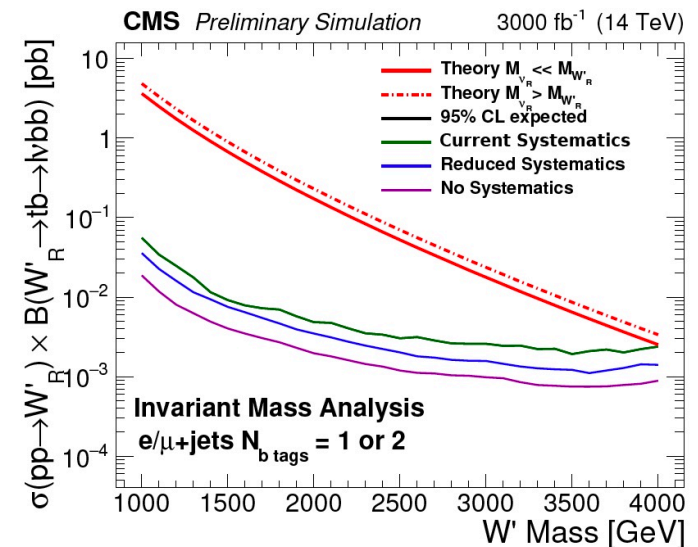
- No updates planned

## ATLAS

- Similar study ongoing using MC truth and smearing functions



Source	Current systematics	Reduced systematics	Shape?
Luminosity	6.2%	1.5%	No
Trigger Efficiency ( $e/\mu$ )	2%/5%	1%/1%	No
Lepton ID Efficiency ( $e/\mu$ )	5%/2%	1%/1%	No
Jet Energy Scale	3.8%	1%	Yes
Jet Energy Resolution	1%	0.07%	Yes
b/c-tagging	2.7%	1%	Yes
light quark mis-tagging	1.2%	1.2%	Yes
W-tjets Heavy Flavor Fraction	2.3%	1.1%	Yes
Top $p_T$ Reweighting	18%	6%	Yes
PDF	6.1%	3%	Yes
Matrix element $Q^2$ scale	18.9%	9.5%	Yes
$t\bar{t}$ Parton matching $Q^2$ scale	1.7%	0.9%	Yes
Theoretical top cross section	15%	7.5%	No
Theoretical bosonic cross section	10%	5%	No



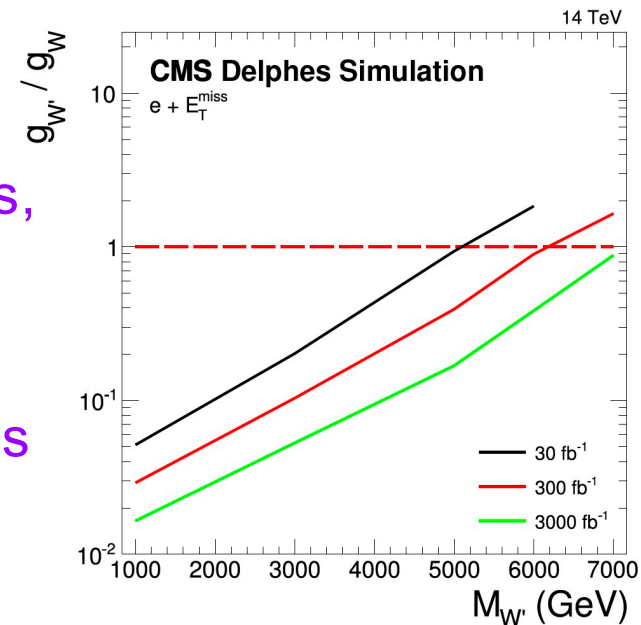
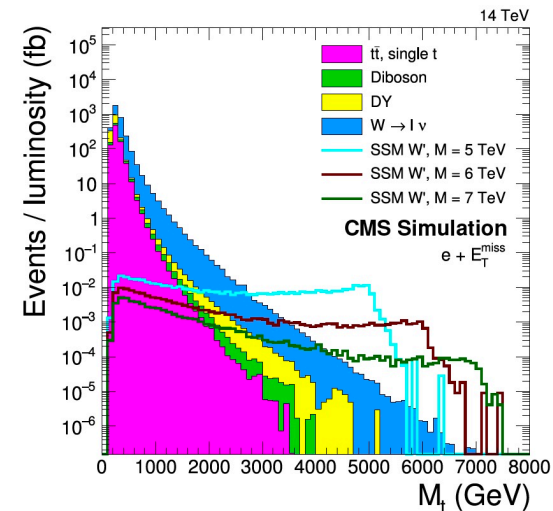
$$W' \rightarrow \ell \nu$$

## • CMS (CMS-PAS-EXO-14-007)

- Looking at  $e + E_T^{\text{miss}}$  final state using Delphes
- Can discover SSM  $W'$  signal up to  $\sim 7$  TeV
  - Currently  $W'$  excluded up to 5.6 TeV (ATLAS-CONF-2018-017)
- High luminosity needed to reach low couplings of  $O(0.1 - 0.01)$  for  $5\sigma$  discovery
- Also separation power between different models (CI, obsolete EFT DM) studied
- No plan to update electron channel results, but study to be extended to tau channel

## • ATLAS

- Studying  $e + E_T^{\text{miss}}$  and  $\mu + E_T^{\text{miss}}$  final states using MC truth + smearing
- Plan to show discovery/exclusion limits



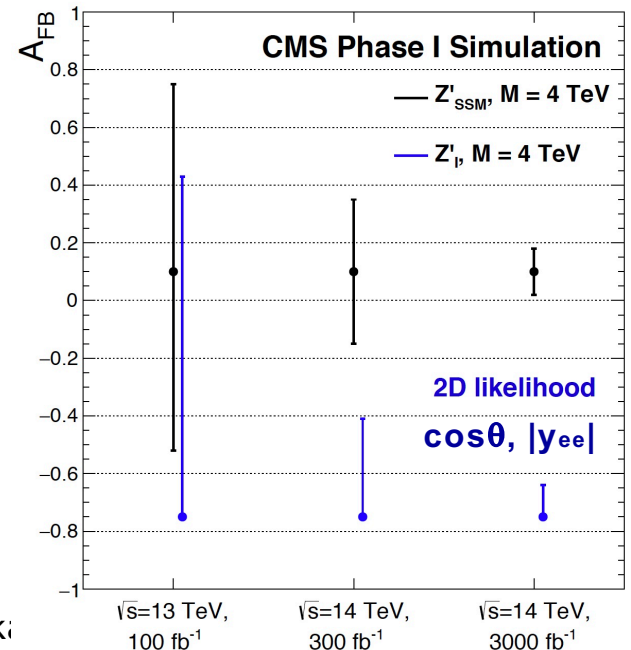
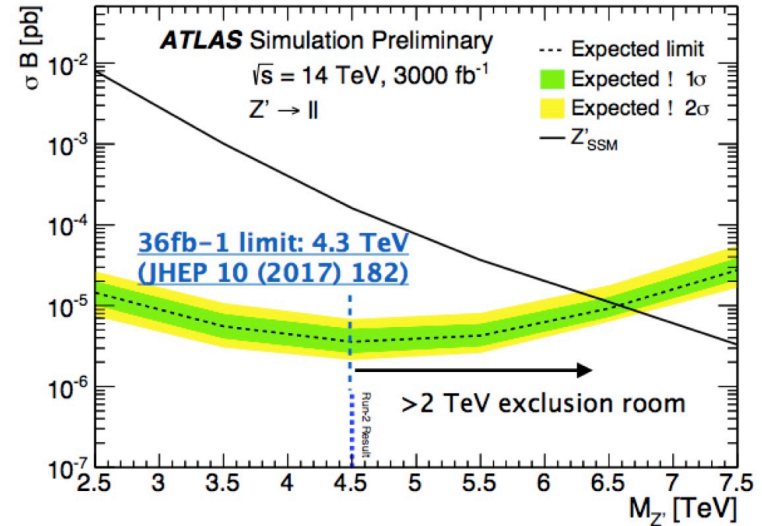
# $Z' \rightarrow \ell\ell$

## ATLAS

- Studying  $ee$  and  $\mu\mu$  final states using MC truth + smearing
- Exclusion limits shown in LAr TDR
- Plan to show exclusion and discovery limits for various  $Z'$  models for  $\sqrt{s} = 13, 14, 15, 27$  TeV
- Also plans for property studies

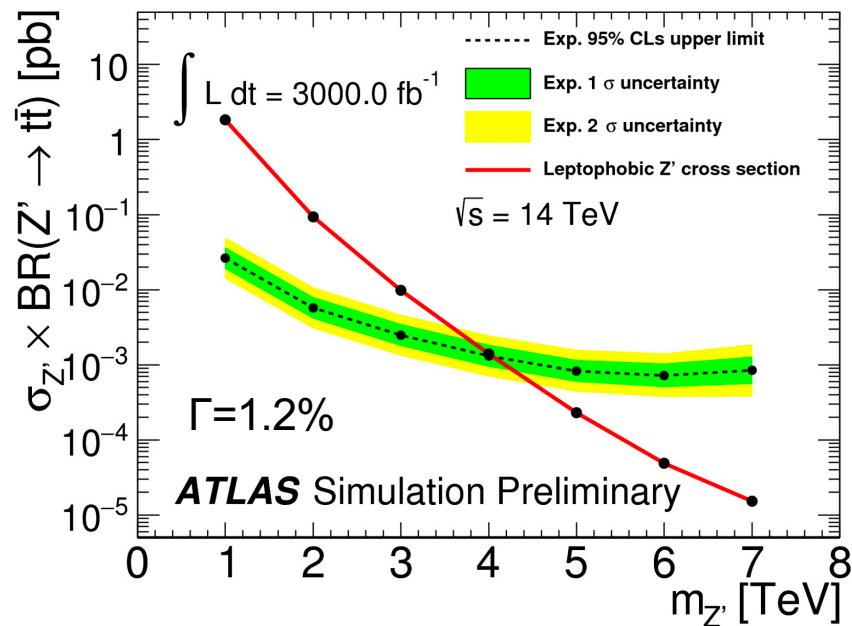
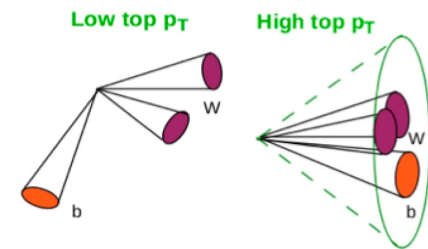
## CMS (CMS-PAS-EXO-14-007)

- Study  $ee$  final state
- Existing full sim property study using AFB in 2014
- No plan to update results



# ATLAS $t\bar{t}$ resonances

- Study  $Z' \rightarrow t\bar{t} \rightarrow \ell\nu b \text{ } qq'b$  (mult. small-R or large-R jets)
- Approach: MC truth + smearing approach
- Results from ATL-PHYS-PUB-2017-02
- Exclude top-colour  $Z'$  at 95% CL (no systematic uncertainties) with
  - $m_{Z'} < 3$  TeV after Run-3
  - $m_{Z'} < 4$  TeV after the HL-LHC
  - Run-1 paper with  $20.3 \text{ fb}^{-1}$  (JHEP 08 (2015) 053):  $m_{Z'} < 2.1$  TeV
- Results now updated with recent smearing functions (not yet public)
  - No additional updates planned



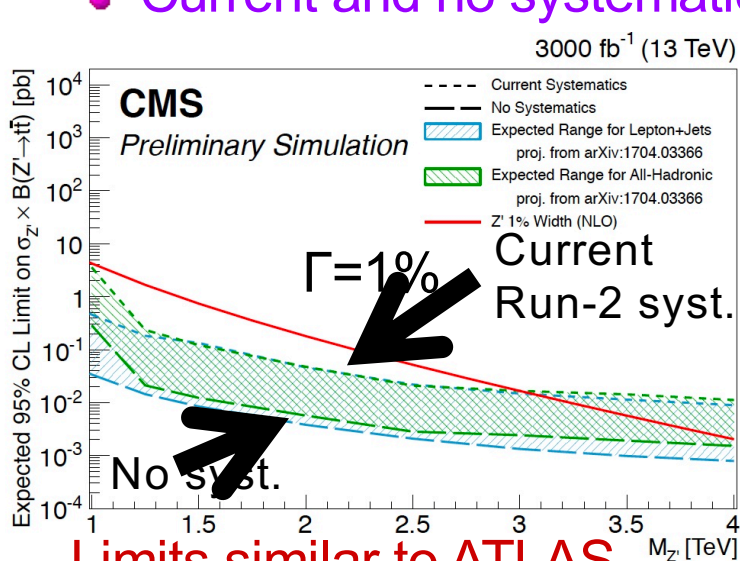
# CMS $t\bar{t}$ resonance search

- Projected results from Run-2

- Study both lepton+jet and all hadronic final states

- Two scenarios for systematic uncertainties considered:

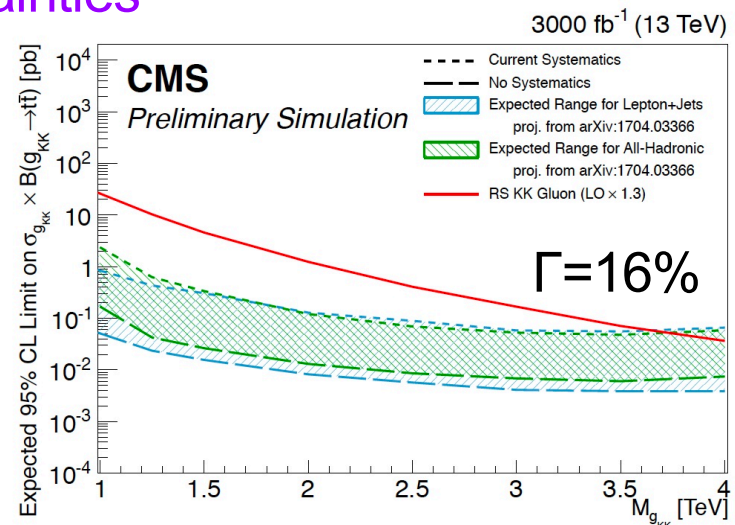
- Current and no systematic uncertainties



- Limits similar to ATLAS
- Similar limits on  $m(Z')$  for both final states

- Results to be superseded by upcoming new Delphes study

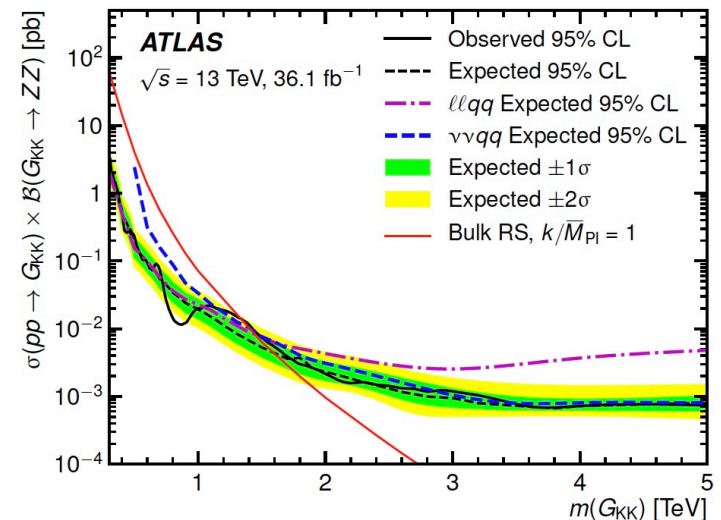
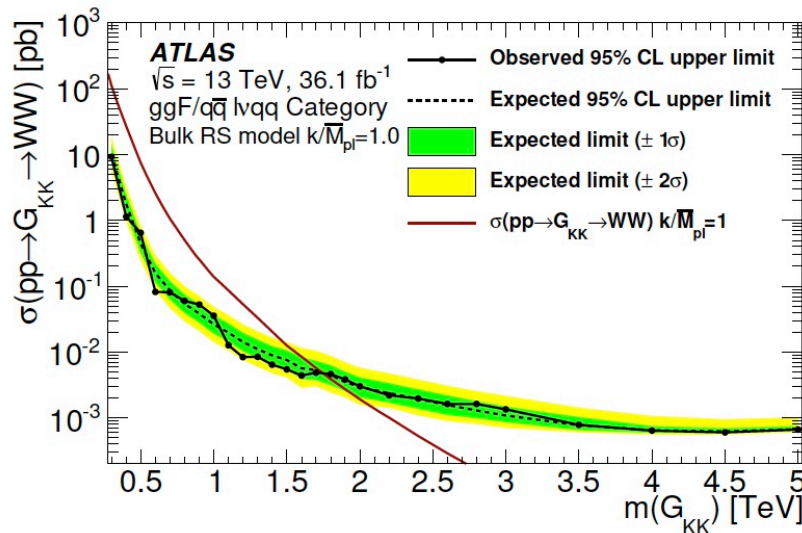
- Adapt analysis strategy for  $m(Z') > 4$  TeV (offshell prod. important)
  - Concentrate on wider (theoretically more correct) resonances



Exclusion limits with broader resonance few 100 GeV lower

# ATLAS $W$ resonance search

- Look at  $WW/WZ \rightarrow \ell\nu qq$  and  $ZW/ZZ \rightarrow \ell\ell qq, \nu\nu qq$  final states
  - Both resolved and boosted channels
- Analysis done similar to Run 2 ([JHEP 03 \(2018\) 042](#), [JHEP 1803 \(2018\) 009](#))
- Approach:
  - MC truth + smearing approach for HL-LHC
  - Delphes for HE-LHC
- Several studies done comparing Delphes with smearing approach





# HH→4b

## • CMS (CMS-PAS-FTR-18-003)

• New result!

• Look at VBF HH channel

• VBF signature has higher significance w.r.t. to presently studied s-channel

• See talk by Devdatta Majumber

## • ATLAS (CERN-LHCC-2015-020)

• Old truth+smearing-based study of  $G^*_{\text{KK}} \rightarrow \text{HH}$  production

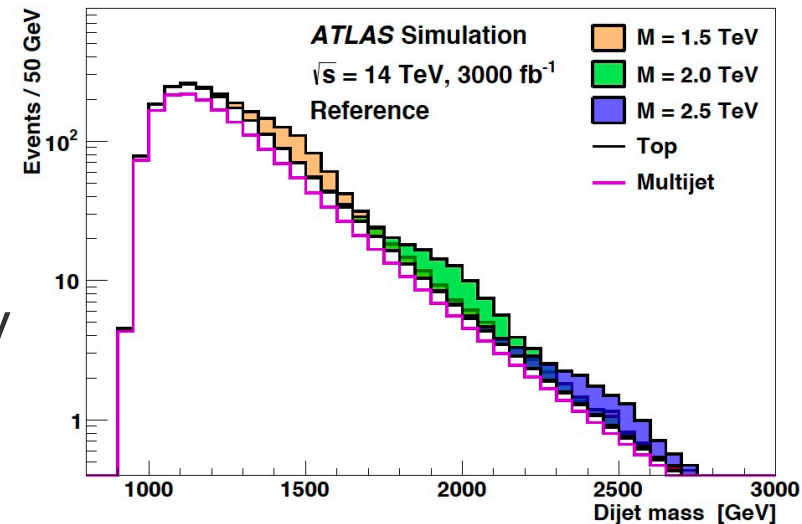
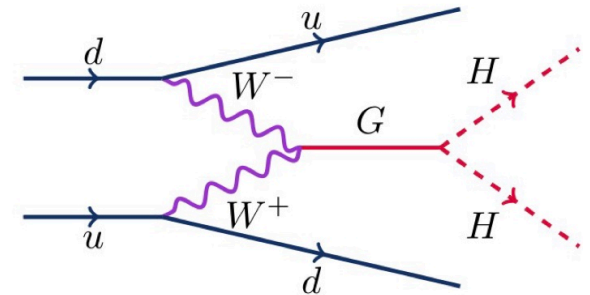
• bb-system from H highly boosted

• Exclude  $G^*_{\text{KK}} \rightarrow \text{HH}$  for  $m < 2.2$  TeV

• Update analysis

• Improved selections

• bootstrap bkd estimate from Run 2

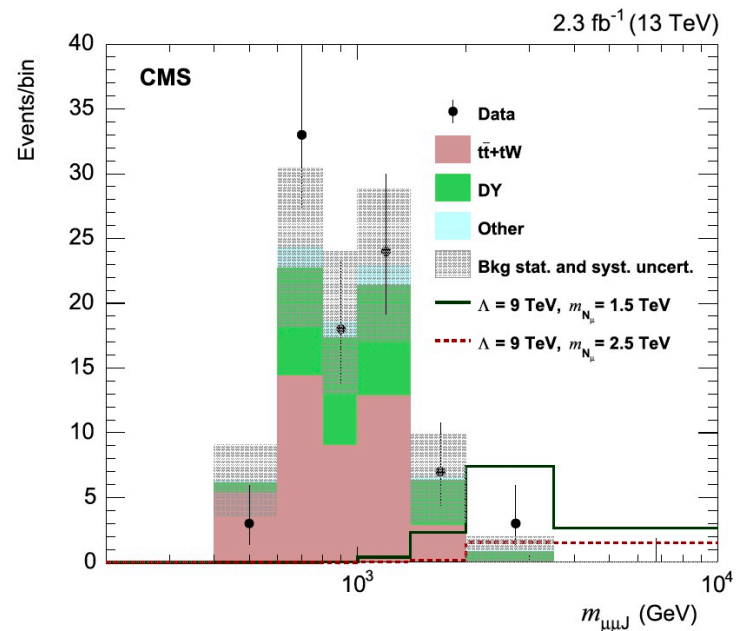
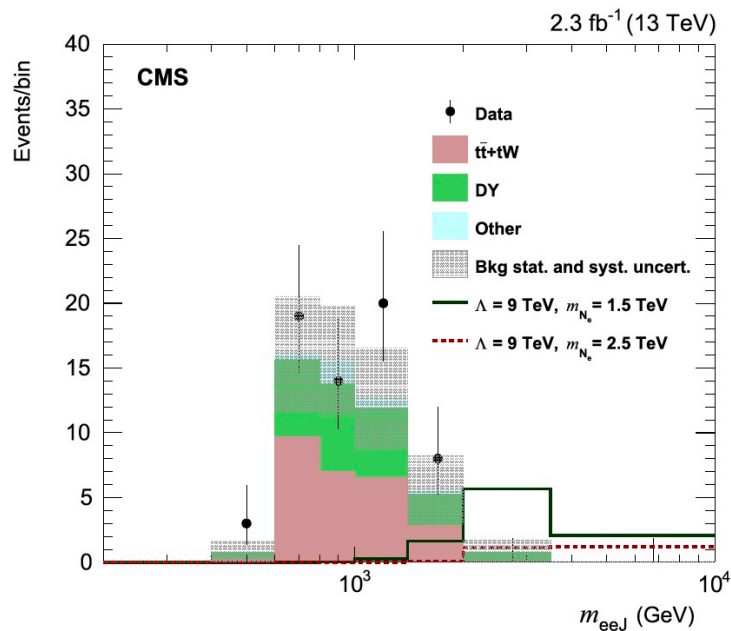
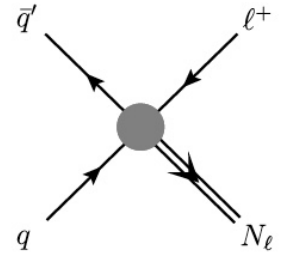


# CMS: Heavy composite Majorana neutrino

- Look at  $N \rightarrow \ell q q'$  decays

  - $ee + 2 \text{ jets}$  or  $\mu\mu + 2 \text{ jets}$  final state

- Run 2 analysis in Phys. Lett. B 775 (2017) 315



- Plan

  - Do similar study for HL-LHC using Delphes

  - Calculate discovery/exclusion limits

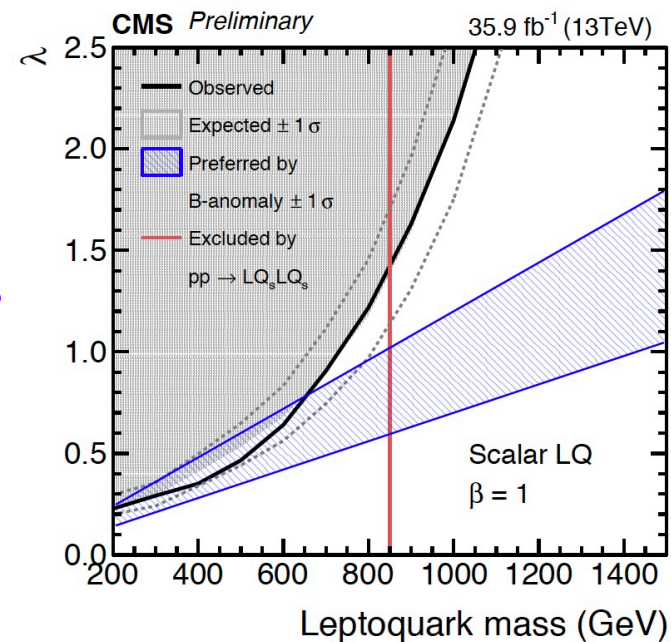
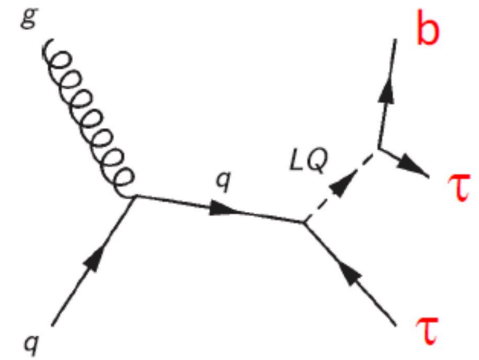
# CMS: $LQ_3 \rightarrow \tau b$

## Run 2 result in CMS-PAS-EXO-17-029

- LQ could explain anomalies seen in B factories
- $BR(LQ_3 \rightarrow \tau b) = 1$
- Model R2 ~ as described in Phys. Rep. 641 (2016)
- Look at  $e\tau hb$ ,  $\mu\tau hb$  and  $\tau\tau hb$  final states

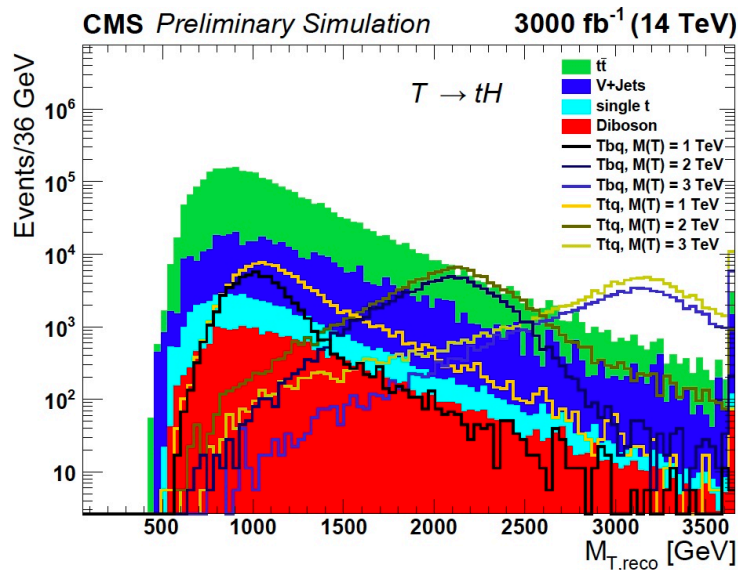
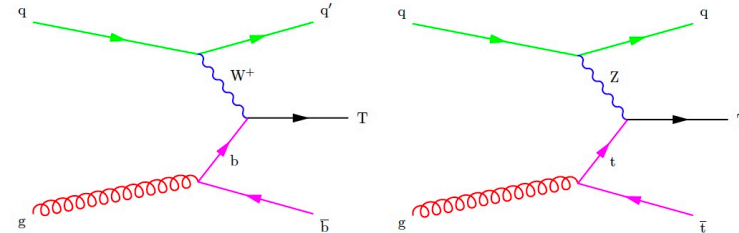
## Plans

- Redo analysis for HL-LHC using Delphes
- Sensitive to high-mass/coupling region



# CMS: single VLQ: $T \rightarrow tH$

- Look at  $T \rightarrow tH \rightarrow (\ell\nu b)$  (bb) final state
- Delphes-based study
- Study sensitivity to left- and right-handed VLQ



Mass (GeV)	Expected cross section upper limit (fb)	
	Tbq (LH)	Ttq (RH)
1000	85.9	54.7
1500	28.4	20.3
2000	12.8	9.06
2500	7.20	4.64
3000	4.69	4.69

## Plans

- Updated results hopefully available in time

# Instead of summary: expected studies

Analysis	Exp.	method	status	comments
$W' \rightarrow tb$	ATLAS	MC truth + smearing	On track	discovery and exclusion reach in semilep channel
	CMS	Projection	Previous study, done	Done for ECFA 2016. discovery and exclusion reach in semilep + had channels. Systematics impact
$W' \rightarrow \ell, \nu$	ATLAS	MC truth + smearing	On track	Discovery / exclusion limits in $e/\mu$ channel
	CMS	Delphes	Previous+ study for $e$ , new for $\tau$	Discovery reach and weak couplings for $W'$ in $e/\tau$ channel. Separation power between models
$Z' \rightarrow \ell\ell$	ATLAS	MC truth + smearing	On track	Study limits for $\sqrt{s} = 13, 14, 15, 27$ TeV, distinction between models
	CMS	Fullsim version 2014	Previous study, done	$Z'$ properties (AFB) for diff dilepton resonance models. Upgrade impact.
ttbar resonances	ATLAS	MC truth + smearing	Nearly finished	Update of <a href="#">ATL-PHYS-PUB-2017-02</a> with recent smearing functions
	CMS	Delphes	On track	Semilep + had comb., narrow and wide widths. Updates ECFA study

# Instead of summary: expected studies

Analysis	Exp.	method	status	comments
VV resonances	ATLAS	MC truth + smearing	On track	WW/WZ $\rightarrow$ $\ell\nu qq$ , $\ell\ell qq$ , $\nu\nu qq$ final states, boosted and non-boosted jets
HH $\rightarrow$ 4b	ATLAS	MC truth + smearing	On track	Update of result in CERN-LHCC-2015-020
VBF + heavy reson. $\rightarrow$ 4b	CMS	Full sim	Brand-new public result	PAS-FTR-18-003
Heavy composite Majorana $\nu$	CMS	Delphes	On track	Limits in $e e j j$ , $\mu\mu j j$ channels
LQ <sub>3</sub> $\rightarrow$ $\tau b$	CMS	Delphes	On track	
VLQ	CMS	Delphes	Previous study, done	ECFA 2016. Exclusion sensitivity for left- and right-handed VLQ

# Backup

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