中国科学院高能物理研究所
Institute of High Energy Physics
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LHCP 2017 - 15-20 May, Shanghai

Searches for new physics in lepton plus jet final states in ATLAS and CMS

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On behalf of the ATLAS and CMS collaborations

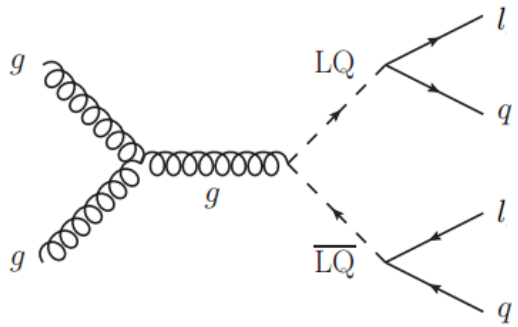
Lepton plus jet searches in ATLAS and CMS

Lepton plus jet signature is expected in many scenarios beyond the SM.
Some examples are:

- Leptoquarks, heavy neutrinos, microscopic black holes (discussed in this talk)
- Diboson searches
  → Talks by Ljiljana Morvaj and Huang Huang
- Vector-like quarks, heavy top-quark partner ($X_{5/3}$)
  → Talks by Andrew Ivanov, Huaqiao Zhang, Sophio Pataraia
- SUSY 3rd generation
  → Talks by Loukas Gouskos and Caroline Collard
- SUSY RPV:
  → Talk by Xuai Zhuang

Leptoquark model

- Leptoquarks are bosons that carry both lepton and baryon numbers and are predicted in many theories beyond the SM
- Exact properties (spin, weak isospin, electric charge) depend on specific model $\rightarrow$ direct LQ searches at the LHC in the context of an effective model: Buchmüller-Rückl-Wyler model (BRW). Three generations: LQ1, LQ2, LQ3
- σ depends only on LQ masses (for scalar LQ, discussed here) BR($LQ \rightarrow \ell q$) = β; BR($LQ \rightarrow \nu q$) = 1-β



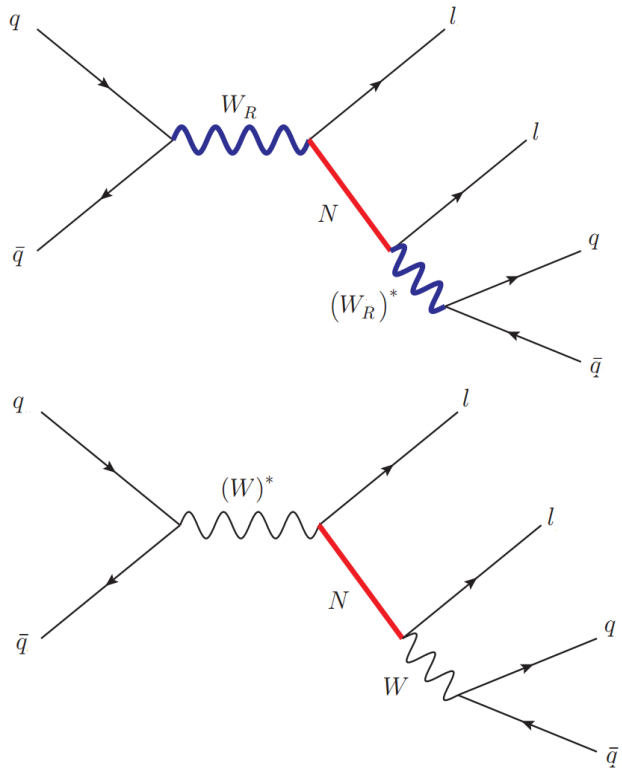
$LQ\bar{LQ}$	β^2	$\beta(1-\beta)$	$(1-\beta)^2$
1st gen	$ee + jj$	$e\nu + jj$	n/a
2nd gen	$\mu\mu + jj$	$\mu\nu + jj$	n/a
3rd gen	$\tau\tau$+bb,tt	n/a	$\nu\nu$+bb,tt

β generally unknown, but $\{\ell\ell, \ell\nu, \nu\nu\} + qq$ maximally produced for $\beta = 1$, 0.5, and 0 (as required in the BRW model and assumed in the results of this talk)

(Some) models with heavy Majorana neutrino

Left-right: $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)$

- provides explanation of parity violation in weak interactions
- $SU(2)_R \rightarrow$ 3 additional gauge bosons: $W_R^{\pm}$ and Z' $\rightarrow$ heavy right-handed neutrino states N_ℓ ($\ell = e, \mu, \tau$)
- σ ruled by $\mathbf{m(W_R)}$ and $\mathbf{N_\ell / m(W_R)}$ relationship

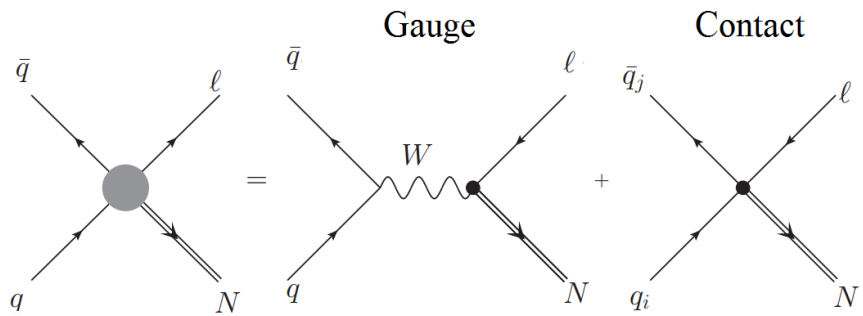


Seesaw: introduces new heavy states

- neutrino masses given by $m_\nu \sim y_\nu^2 v^2 / m_N$
- **Type I** implemented through fermion singlet (3 right-handed neutrino states, N_ℓ)
- σ depends on $\mathbf{V_{\ell N}}, \mathbf{m_N}$

Compositeness: quarks and leptons have internal substructure (at the compositeness scale, Λ)

- SM fermions thought as bound states of more fundamental constituents
- $\rightarrow$ excited fermions, among which N_ℓ
- σ function of $\mathbf{\Lambda}, \mathbf{m_{N_\ell}}$



LQ1 and LQ2 in $\ell\ell jj$ channels with ATLAS and CMS (13 TeV; 3 fb^{-1})

ATLAS LQ1 - LQ2: New J. Phys. 18 (2016) | CMS LQ1: EXO-16-007 | CMS LQ2: EXO-16-043

- ℓ: pT>50 (CMS), 30 (ATLAS) GeV, $|\eta|$ <2.5
- $\geq$ 2 jets: pT>50 GeV, $|\eta|$ <2.5
- $M_{\ell\ell}$ >50 (CMS), 130 (ATLAS)
- S_T > 300 (CMS), 600 (ATLAS)

$M_{\ell\ell}$, S_T cuts optimized for each signal mass point in CMS including $M_{min}(\ell, jet)$, used for signal extraction in ATLAS

Z+Jets

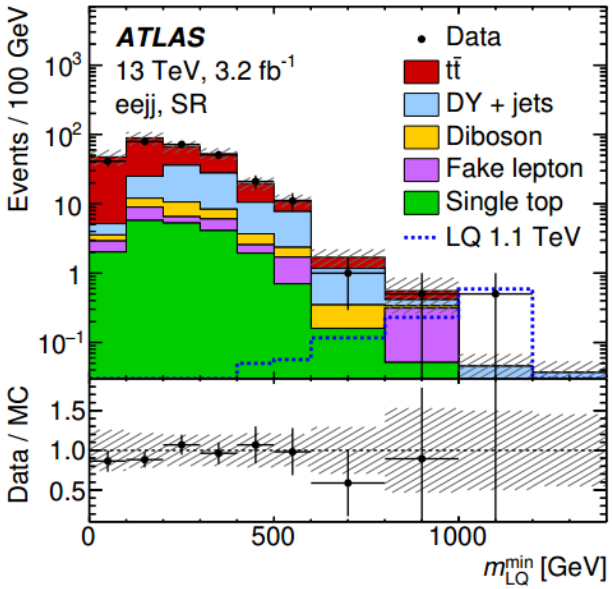
from MC, normalized to data around the Z-peak

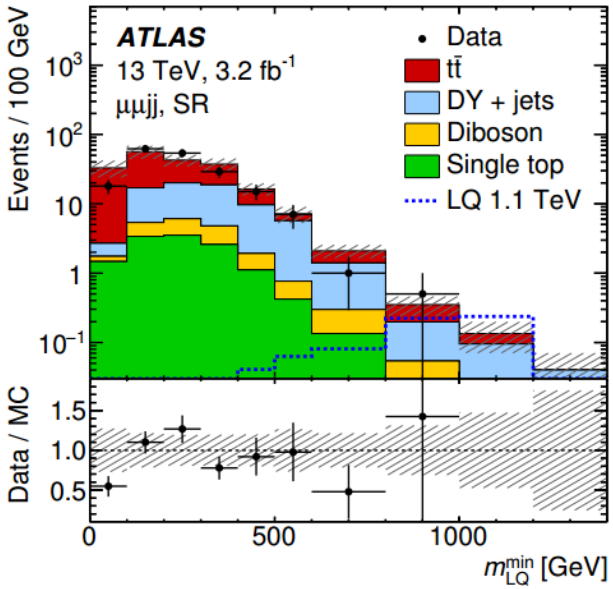
$t\bar{t}$

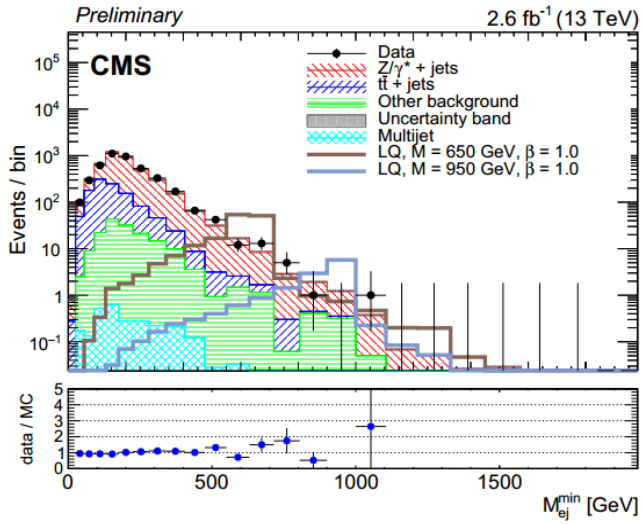
ATLAS, CMS LQ1: from MC corrected by SF in $e\mu$ CR

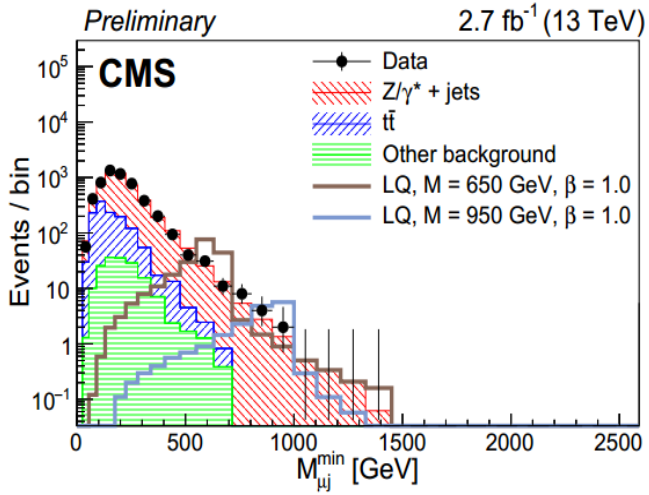
CMS LQ2: from data $e\mu$ events correcting by different BR and object efficiencies

Results for LQ1 and LQ2 with ATLAS and CMS





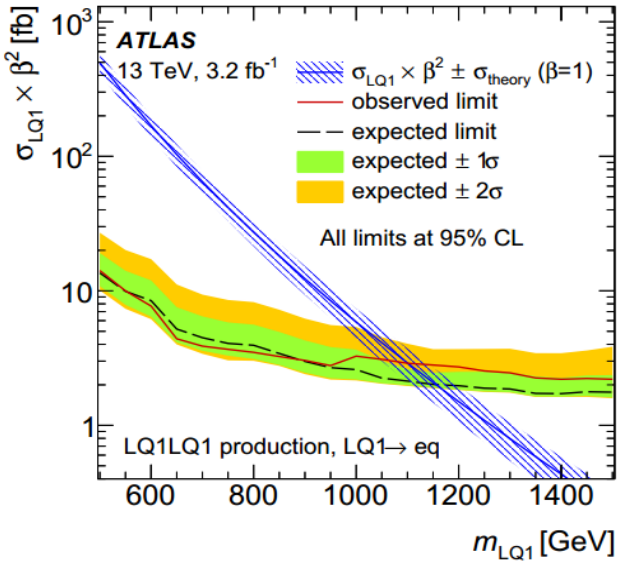




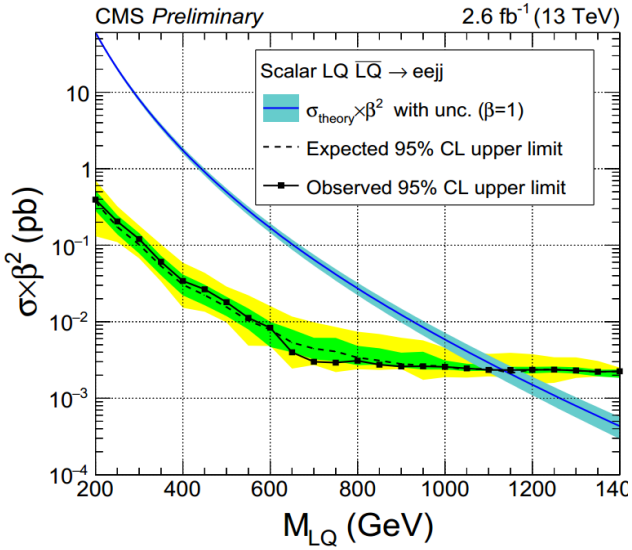
Limits for LQ1 and LQ2 with ATLAS and CMS

eejj $[\beta^2; \beta = 1]$

$<$1100 GeV at 95% CL

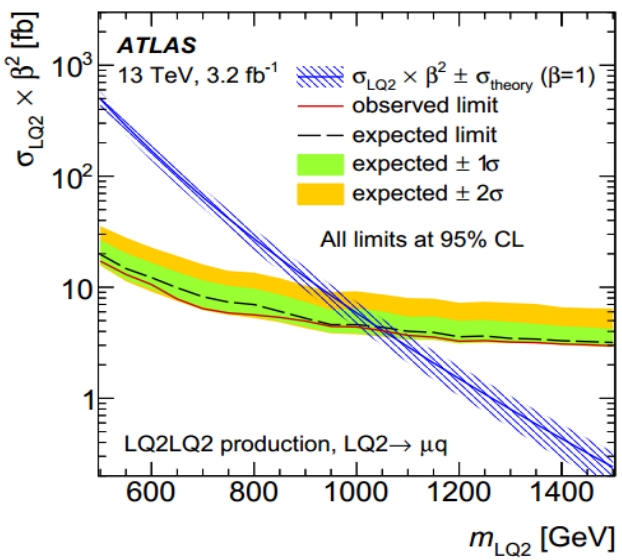


$<$1130 GeV at 95% CL

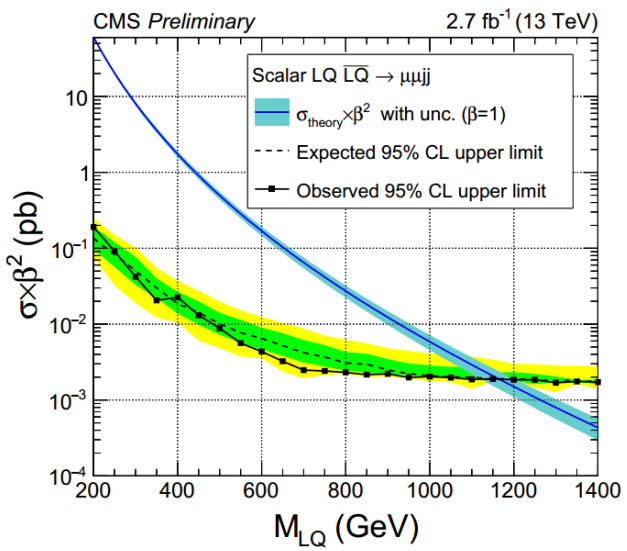


$\mu\mu$jj $[\beta^2; \beta = 1]$

$<$1050 GeV at 95% CL



$<$1165 GeV at 95% CL

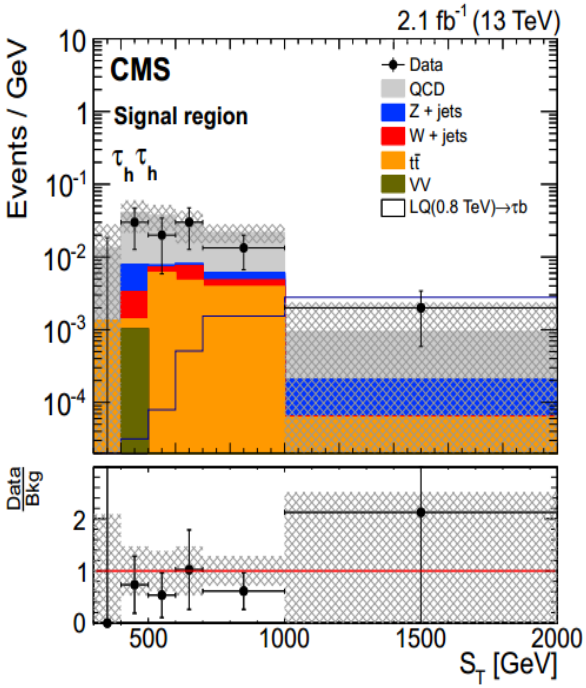


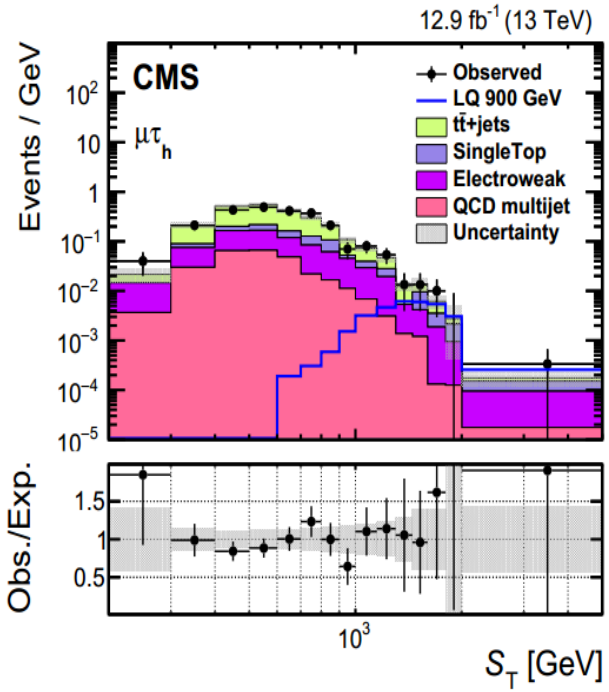
Searches with 2 taus and 2 jets in CMS (13 TeV; 3 - 13 fb^{-1})

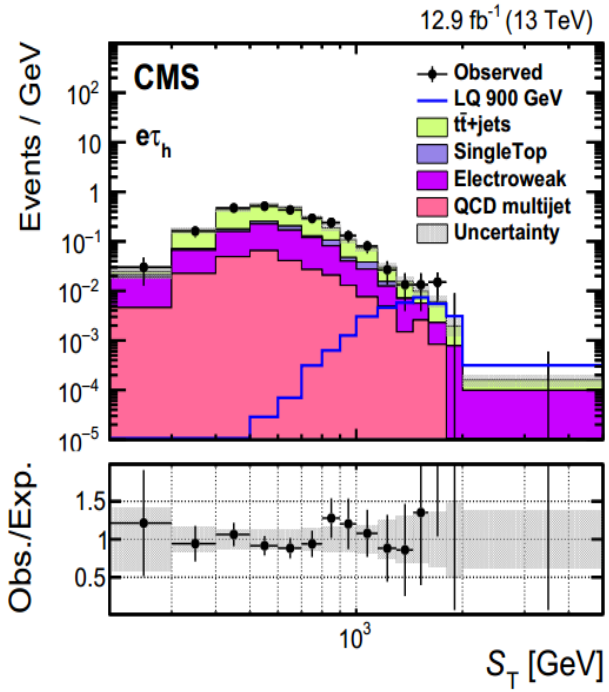
JHEP 03 (2017) EXO-16-023

Consider $\tau_h(\tau_h, e, \mu)$ jj channel
- τ_h: pT>60 GeV, $|\eta|$ <2.1
- e, μ: pT>50 GeV, $|\eta|$ <2.1
- j: pT>50 GeV, $|\eta|$ <2.4
- $\not{E}_T$ > 50 GeV
- $M(\tau_h, ((\tau_h), (e, \mu)))$ >(100),(150) GeV

- Multijet data with loose τ_h isolation weighted by tight-to-loose τ_h efficiencies measured with $\not{E}_T$ <30
- $t\bar{t}$ From simulation, after validation in dilepton plus b-jet region
- Z,W+jets From simulation, after normalization to data in control regions



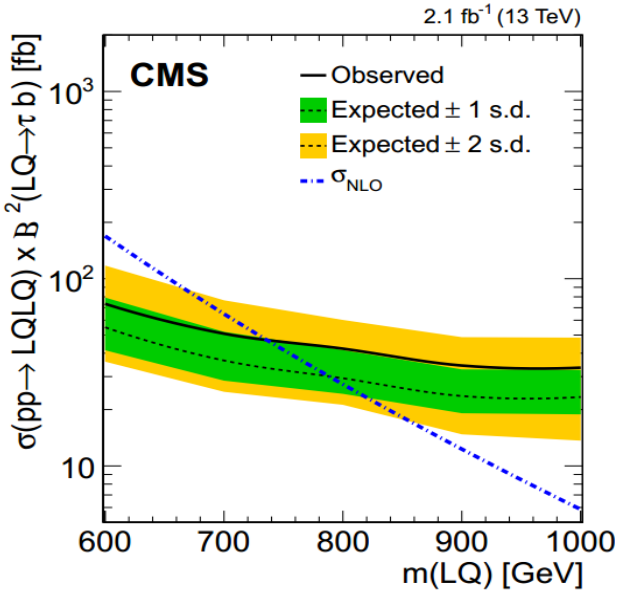




Limits for LQ3 and LR heavy neutrinos in CMS

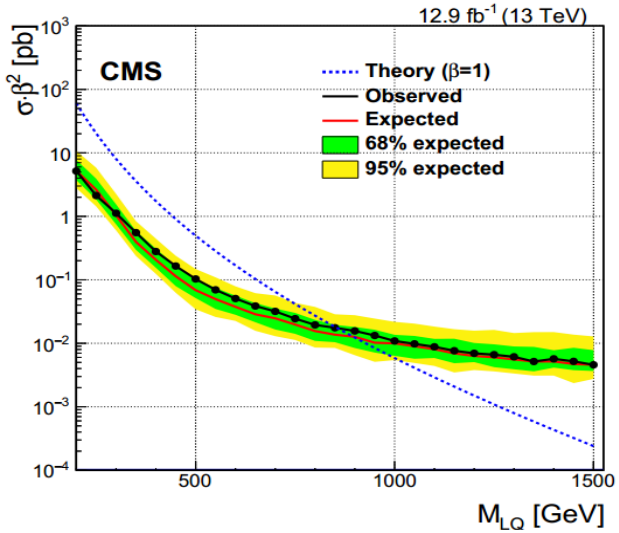
$\tau_h\tau_h$bb $[\beta^2; \beta = 1]$

<740 GeV at 95% CL

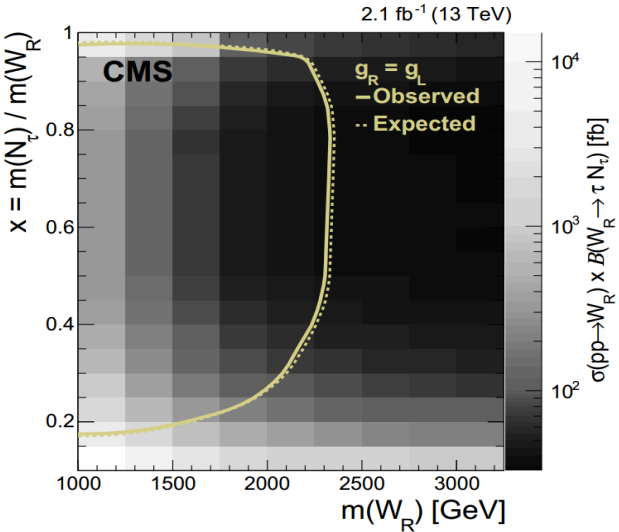


$\tau_h\ell$bb $[\beta^2; \beta = 1]$

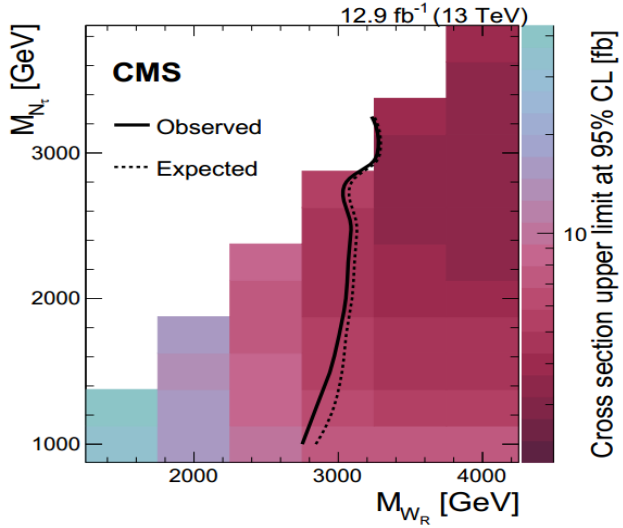
<850 GeV at 95% CL



<2.35 (1.63) GeV at 95% CL, $N_\tau = 0.8$ (0.2) W_R



<2.9 GeV at 95% CL, $N_\tau = 0.5$ W_R



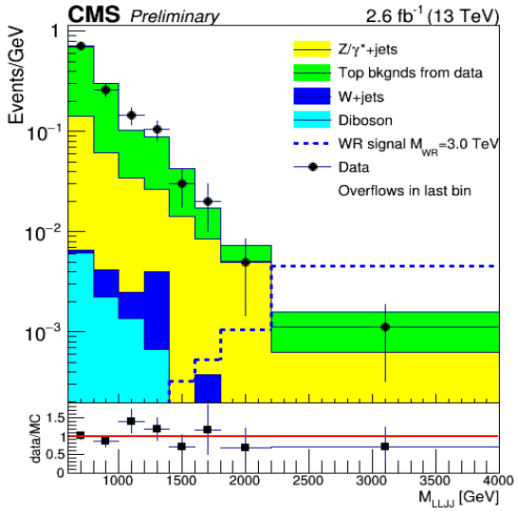
Left-right W_R and heavy neutrino search with 2 leptons and 2 jets in CMS (13 TeV, 2.6 fb^{-1})

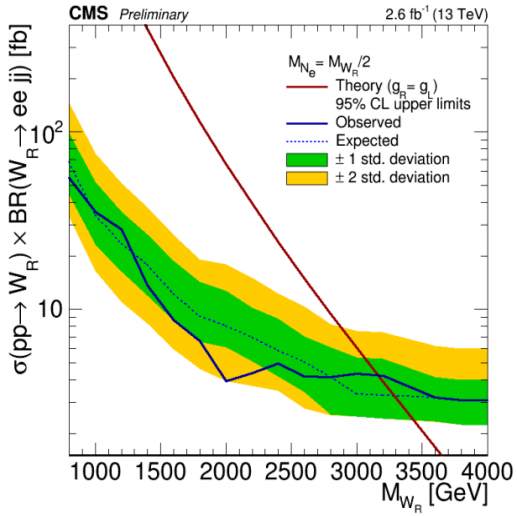
Consider ee,$\mu\mu$+jj channels EXO-16-045

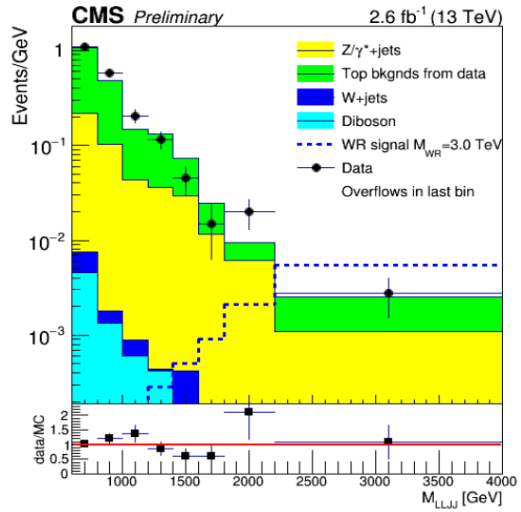
- ℓ, ℓ: pT>60,53 GeV and $|\eta| < 2.4$
- $\geq$2 jets:pT>40 GeV and $|\eta| < 2.4$
- $M_{\ell,\ell}$ >200 GeV, $M_{\ell\ell jj}$ >600 GeV

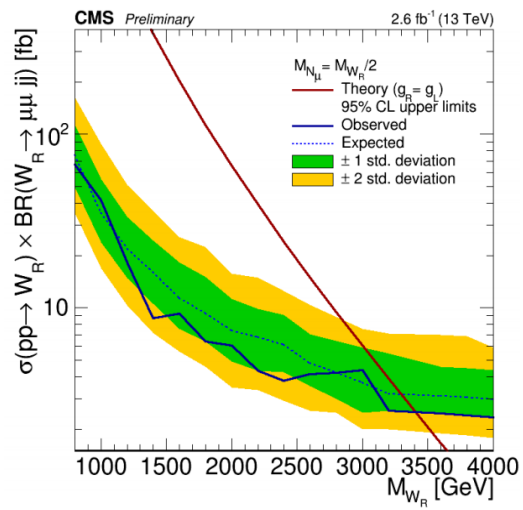
- $t\bar{t}$ from eμ data scaled to the 2lep same-flavor region
- Drell-Yan from simulation after data/MC correction taken from Z-peak

Observation in agreement with SM expectation









Heavy composite Majorana neutrino with 2 leptons and 2 quarks in CMS (13 TeV, 2 fb^{-1})

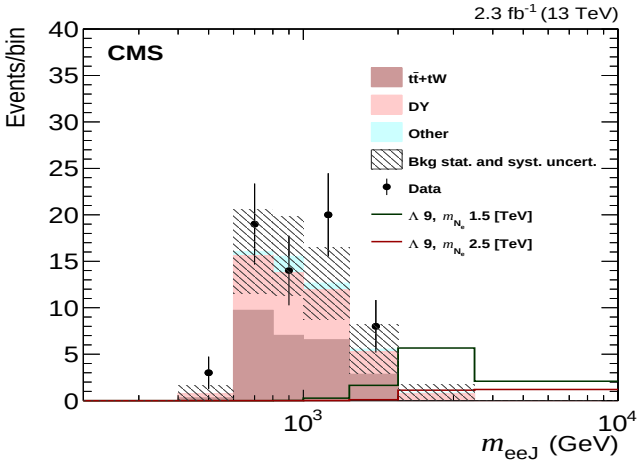
EXO-16-026

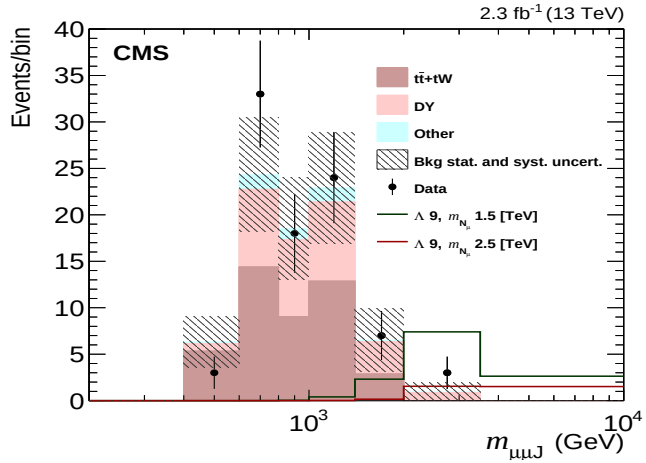
Consider ee+qq, $\mu\mu$+qq channels
- $\ell\ell$: pT>110,35(50,30) GeV

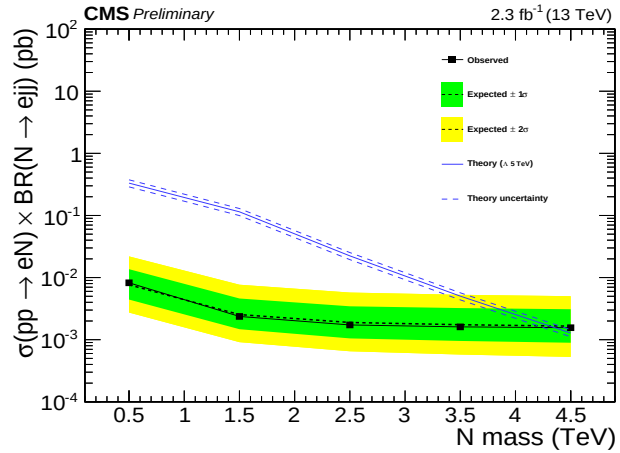
for ee($\mu\mu$), $|\eta| < 2.4$
- $\geq$1 large-radius jet: pT>190 GeV, $|\eta| < 2.4$

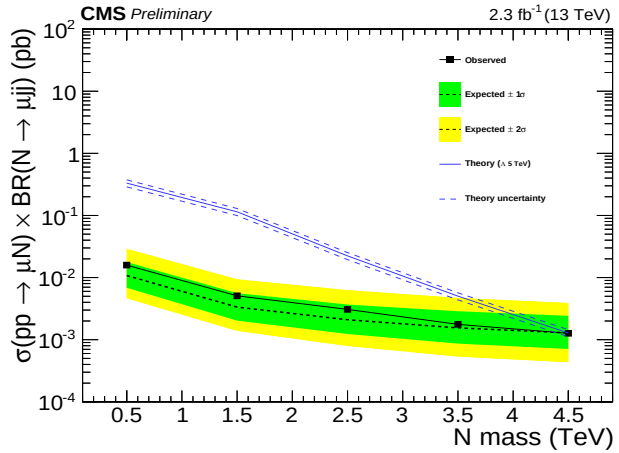
(for N decays with gauge/contact interaction)

Bkg estimation done consistently among channels
- $t\bar{t}$ from eμ data scaled to the 2lep same-flavor region
- Drell-Yan from simulation after data/MC correction taken from Z-peak









Type I Seesaw (SS) N and left-right and in ATLAS and CMS (8 TeV, 20 fb^{-1})

Phys. Lett. B 748 (2015) | JHEP 04 (2016) | JHEP07(2015)

Signal selection

	CMS		ATLAS	
	$ee, \mu\mu, e\mu + jj$ channels • **same-sign lepton selection** • 3rd ℓ veto, Z-peak veto, no b-jet, $E_T^{miss} < 30$		$ee, \mu\mu + jets$ channels • **same-sign lepton selection** • 3rd ℓ veto, Z-peak veto, $E_T^{miss} < 40$ GeV	
Model	**Type I SS** ($m_N < 80$)	**Type I SS** ($m_N > 80$)	**Type I SS**	**Left-right** N
# jet	≥ 2	≥ 2	≥ 2	≥ 1
$\mathbf{m_{\ell\ell jj}}$	<200 GeV	>80 GeV	-	>400 (200)
$\mathbf{m_{jj}}$	<120 GeV	[50, 110] GeV	[50, 110] GeV	>110 GeV

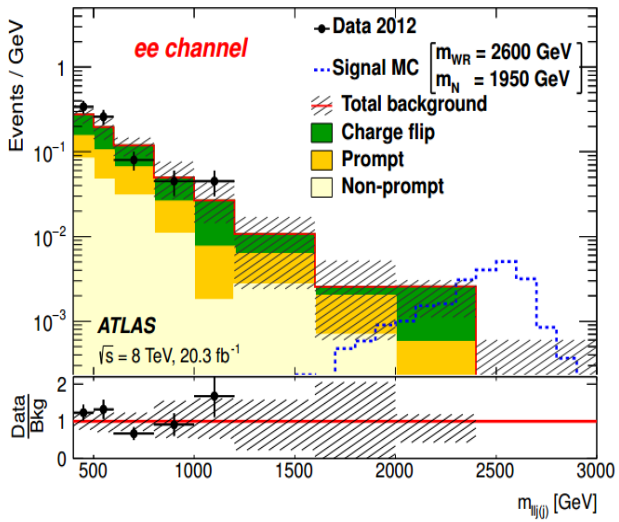
Background estimation

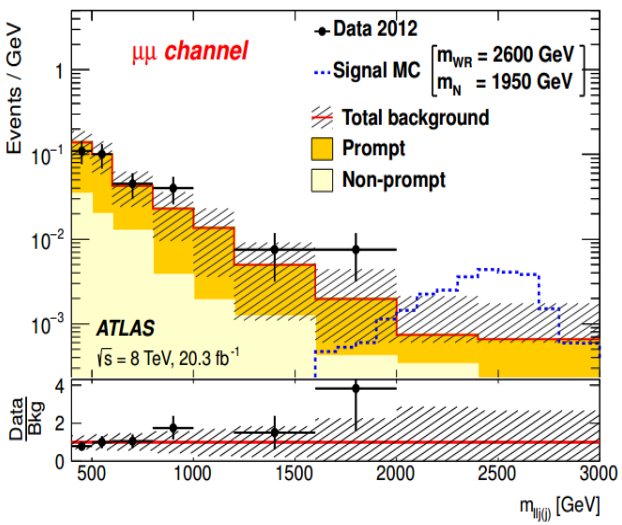
Irreducible
• Diboson processes
• Taken from simulation (Validated in 3/4 lep region)

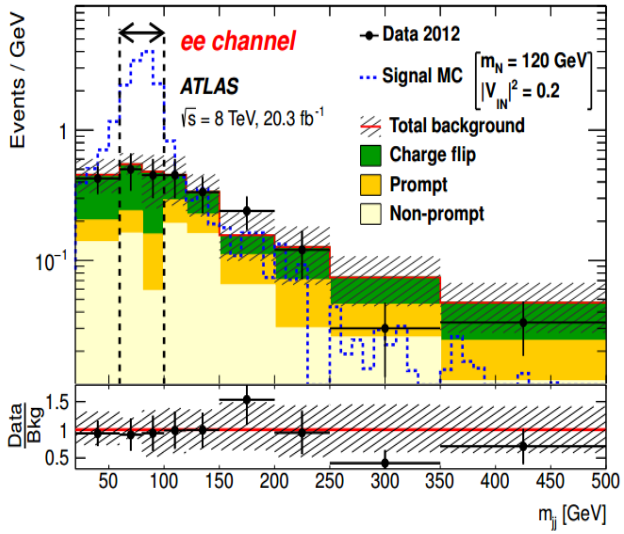
ℓ MisIdentification
• Weight data events selected with loose ID by P(pT,η,ℓ)
• P(pT,η,ℓ) measured from data in multijet and Z+jets events

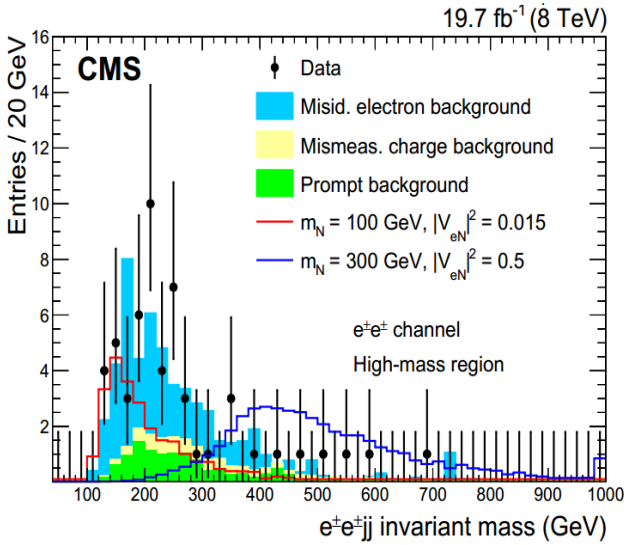
Charge flip
• Charge mismeasurement from simulation (corrected with $Z \to ee$ data)

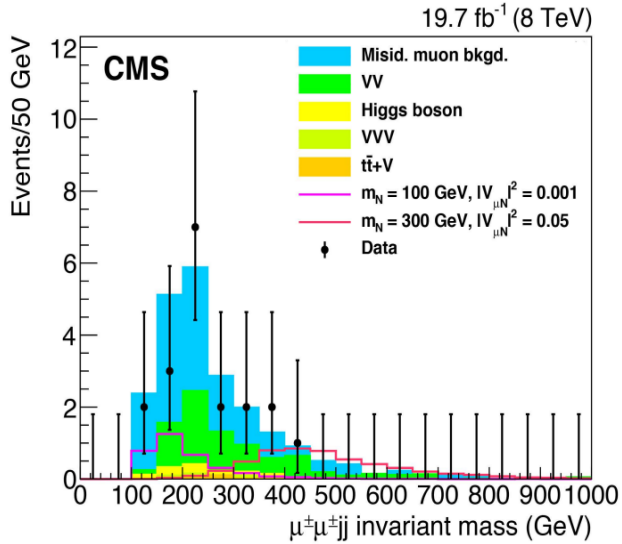
Results for type I Seesaw (SS) N and left-right and in ATLAS and CMS

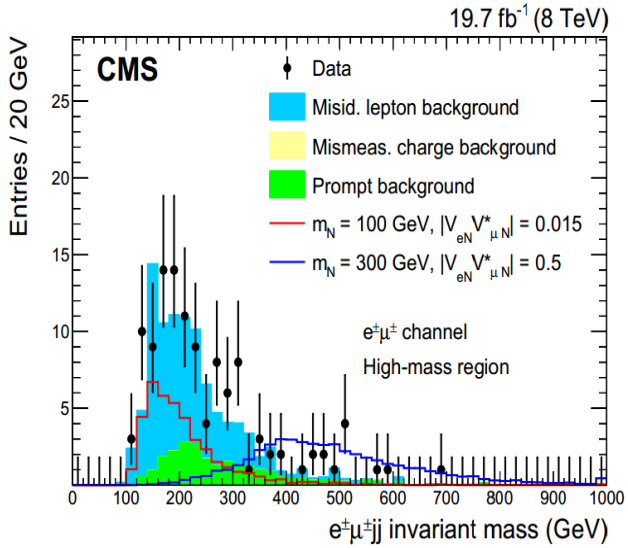




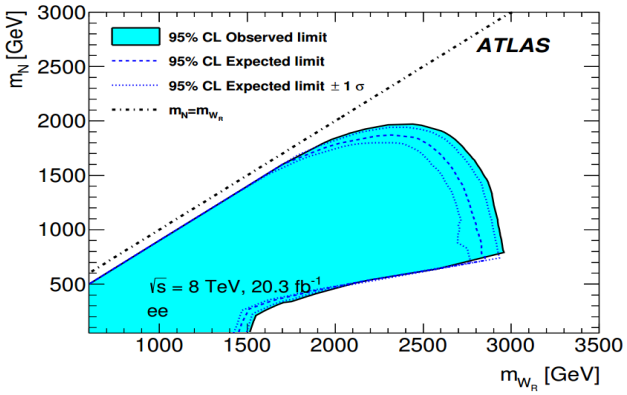


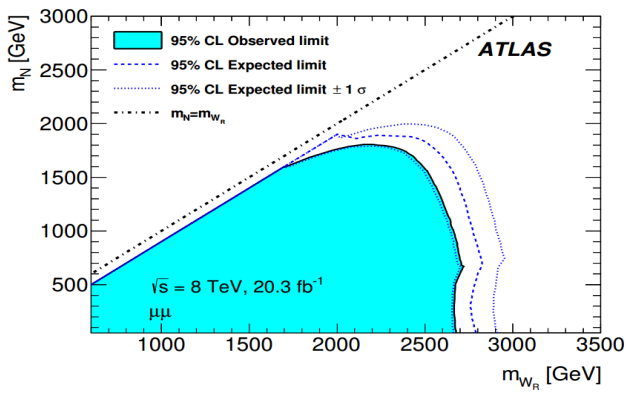


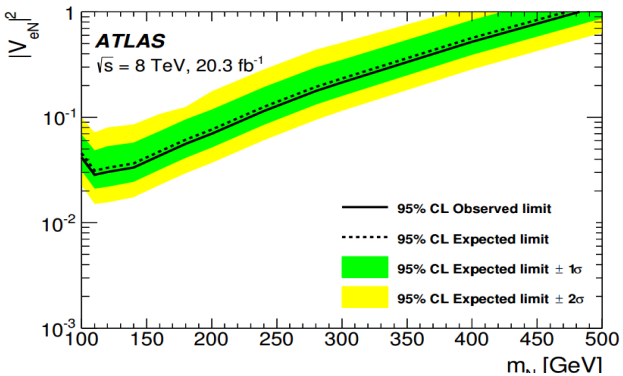


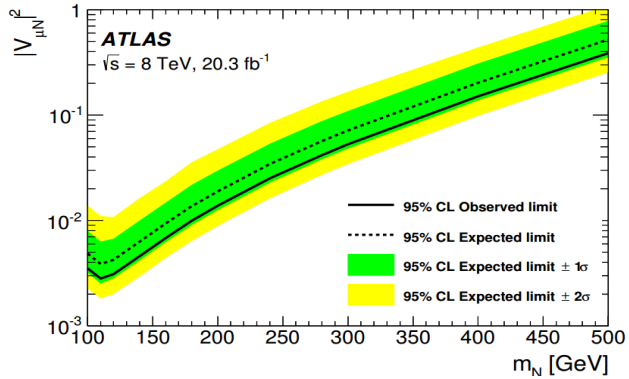


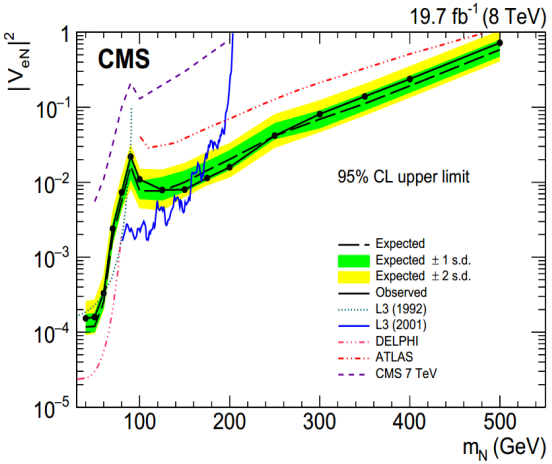
Limits for type I Seesaw (SS) N and left-right and in ATLAS and CMS

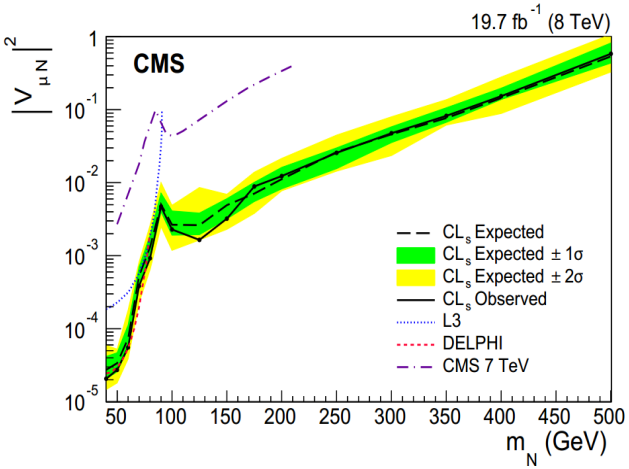


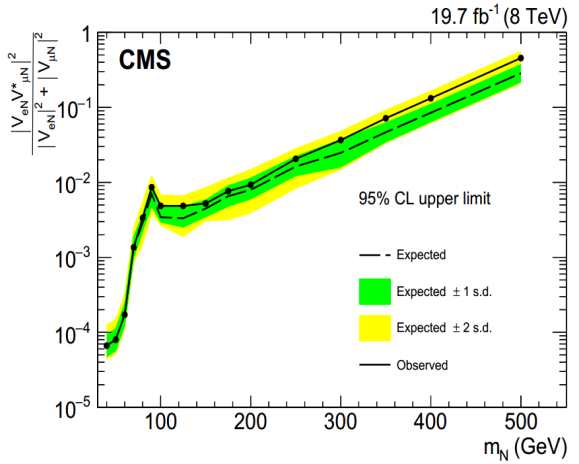












TeV-scale gravity signature in ATLAS (13 TeV, 3 fb^{-1})

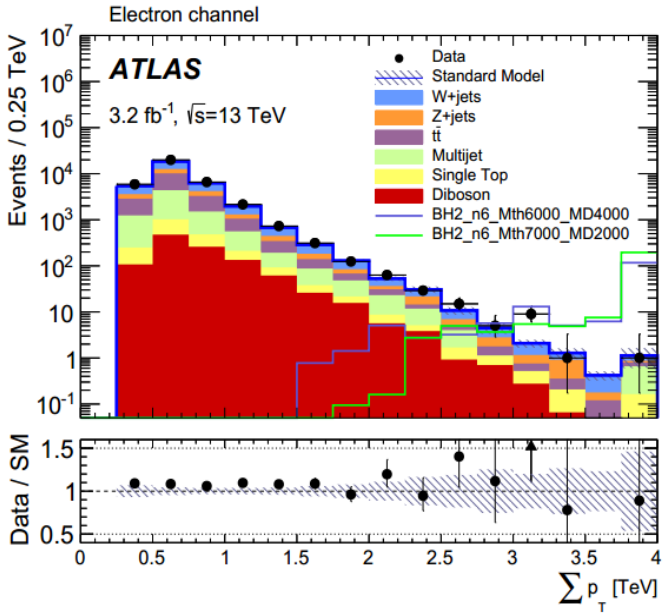
Fundamental scale of gravity ($\mathbf{M_D}$) lowered up to TeV scale in some extra dimentions models (ADD, RS) $\rightarrow$ microscopic black holes

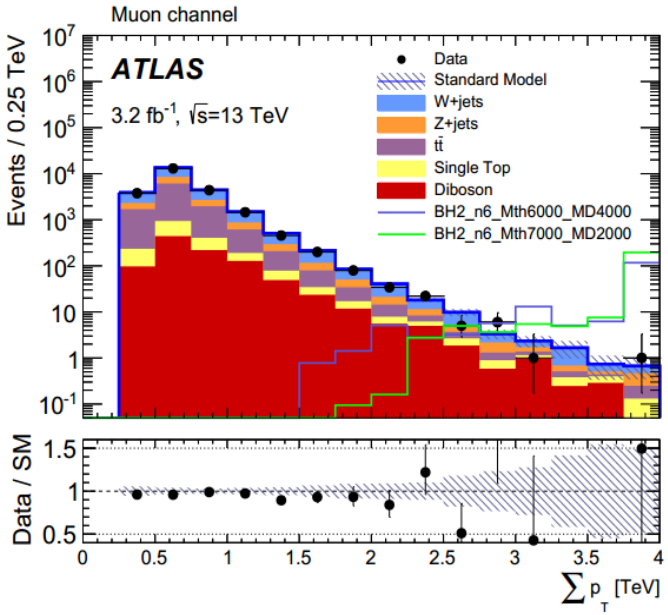
Investigate ℓjj ($\ell\ell\ell$) channels

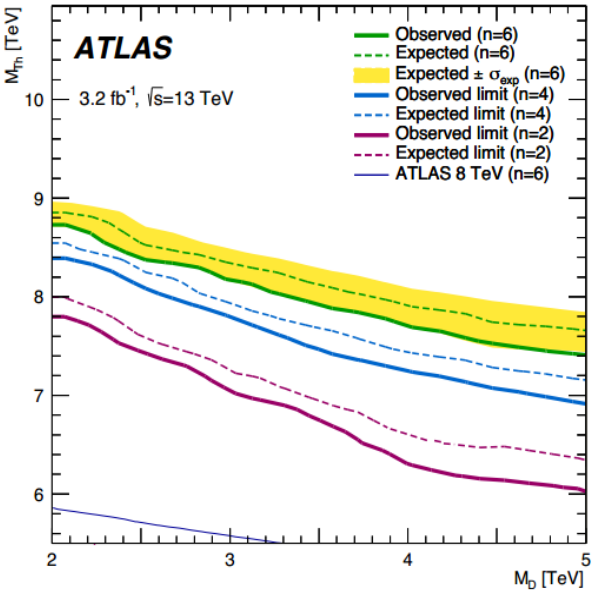
- pT>100 GeV
- $\sum$ pT > 3 TeV

Main bkg taken from simulation normalized to data in $750 < \sum \text{pT} < 1500$ GeV

- Z+jets: evt around the Z-peak
- W+jets: 1 ℓ, $E_T^{miss} > 40$ GeV, no b-jet
- $t\bar{t}$: 1 ℓ, # jet$\geq$ 4 GeV, 2 b-jet







Summary

- ATLAS and CMS have a wide program for search with lepton plus jet final states
  → we focused on leptoquark, heavy neutrino searches, and microscopic black holes
- Leptoquark are investigated within the BRW model with
  searches in all the 3 generations at 13 TeV

	LQ1	LQ2	LQ3
ATLAS	<1100 GeV ($ee + jj$)	<1050 GeV ($\mu\mu + jj$)	<640 GeV ($t\bar{t} + E_T^{miss}$, 8 TeV)
CMS	<1130 GeV ($ee + jj$)	<1165 GeV ($\mu\mu + jj$)	<740 GeV ($\tau_h\tau_h + bb$) <850 GeV ($\tau_h\ell + bb$)

- Heavy neutrinos investigated with different models with
  searches in all the 3 generations at 13 TeV and 8 TeV

	Left-right	Type I seesaw	Composite
ATLAS	50 GeV to 2000 GeV $m_{W_R} > 400$ GeV	$\|V_{eN}\|^2 < 0.029$ $\|V_{\mu N}\|^2 < 0.0028$ for $m_N = 110$ GeV	n/a
CMS	200 GeV to 2150 GeV $m_{W_R} > 600$ GeV	$\|V_{eN}\|^2 < 0.00015$-0.71 $\|V_{\mu N}\|^2 < 2.1\times10^{-5}$-$0.583$ $\|V_{eN}V^*_{\mu N}/(\|V_{eN}\|^2 + \|V_{\mu N}\|^2)\| < 6.6\times10^{-5}$-$0.47$ for m_N in [40-500] GeV	4.35 $eeqq$ TeV 4.50 $\mu\mu qq$ TeV for $\Lambda = 5$ TeV

- Production of microscopic black holes excluded in models with two to six extra space dimensions in the (M_D, M_{th}) plane
- In all searches good agreement between observation and SM expectaion
  → mild deviation observed in searches for LQ1 and heavy neutrinos in the $ee + jj$ channel in CMS at 8 TeV not confirmed