Searches for heavy resonances at the LHC

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on behalf of
the ATLAS & CMS Collaborations

LaThuile2019
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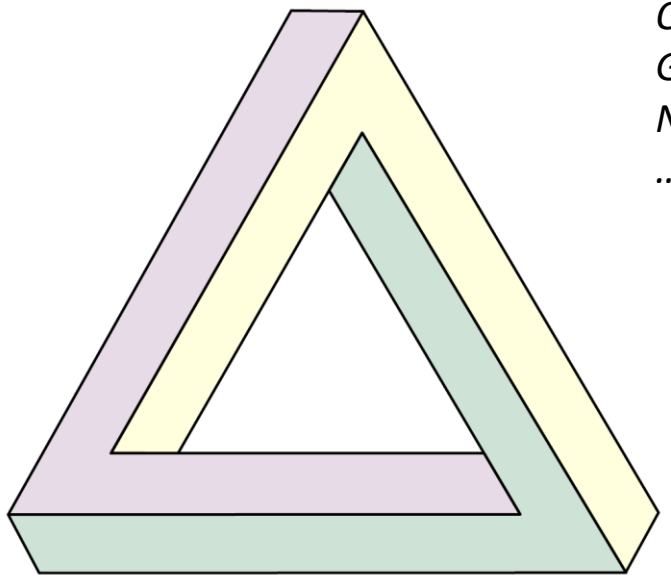
10-16 March 2019

… current status …

the Questions



Hierarchy problem
Unification of forces
New fundamental forces
Origin of flavor
Origin of dark matter
Gravity, dark energy
Neutrino masses
…

the SM extensions

SUSY, Extra-Dimensions, New Gauge Bosons, Contact Interactions, Leptoquarks, Excited fermions, 4th generation, Type III seesaw,…

the Proofs (experiments)

(jets, lepton, γγ, Z)+E_T^{miss} , (ee, μμ, ττ, γγ, jj, lepton-jet, lepton-γ, γ-jet, VV, tt) resonances, slow-moving or long-lived particles, …

RUN-2 completed: ~ 140 fb^{-1} per experiment at 13 TeV

Overview of EXOTIC searches (ATLAS)

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2018

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 79.8)$ fb^{-1} $\sqrt{s} = 8, 13$ TeV

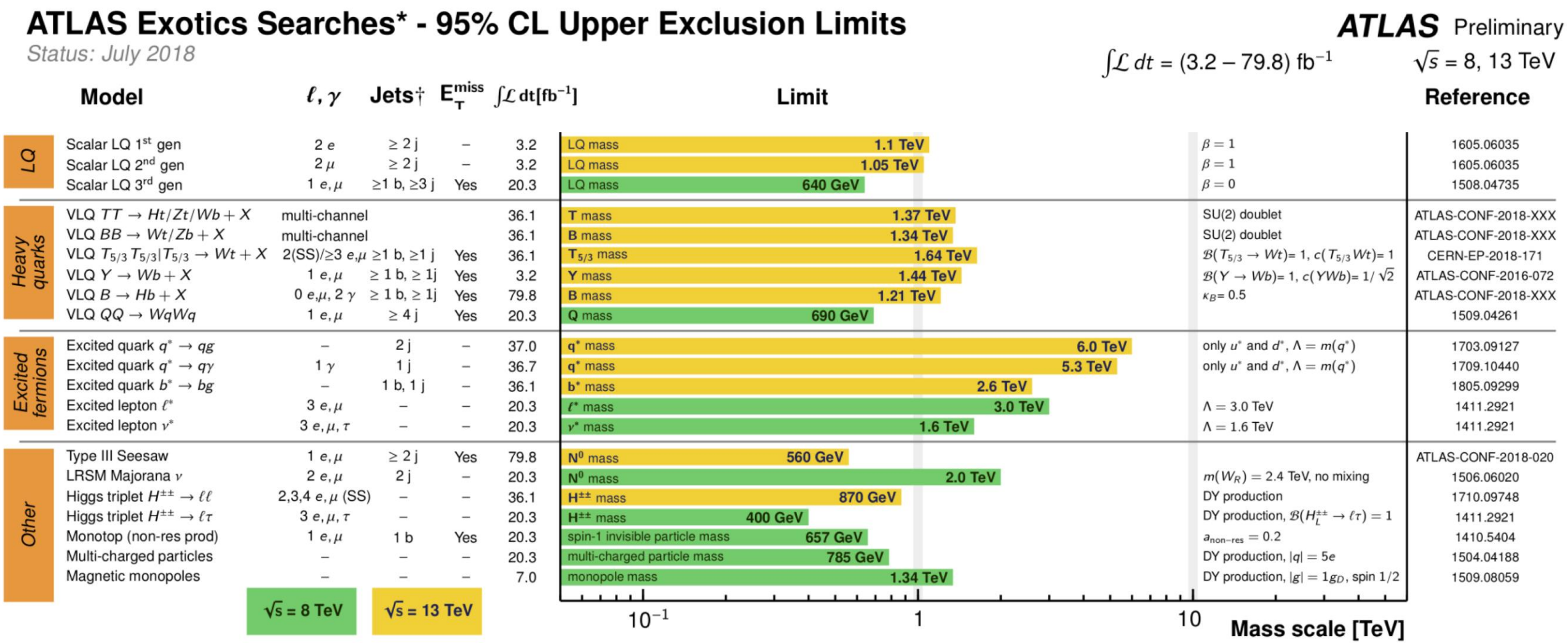
	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	M_D 7.7 TeV	$n = 2$	1711.03301
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	1707.04147
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	CERN-EP-2018-179
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	36.1	Z' mass 4.5 TeV		1707.02424
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z' \to bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z' \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	Z' mass 3.0 TeV	$\Gamma/m = 1\%$	1804.10823
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	79.8	W' mass 5.6 TeV		ATLAS-CONF-2018-017
	SSM $W' \to \tau\nu$	1 τ	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	2 J	–	79.8	V' mass 4.15 TeV	$g_V = 3$	ATLAS-CONF-2018-016
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	1712.06518
	LRSM $W'_R \to tb$	multi-channel			36.1	W' mass 3.25 TeV		CERN-EP-2018-142
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV	η_{LL}^-	1703.09217
	CI $\ell\ell qq$	2 e, μ	–	–	36.1	Λ 40.0 TeV	η_{LL}^-	1707.02424
	CI $tttt$	≥1 e,μ	≥1 b, ≥1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t}\rvert = 4\pi$	CERN-EP-2018-174
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	m_{med} 1.55 TeV	g_q=0.25, g_χ=1.0, $m(\chi) = 1$ GeV	1711.03301
	Colored scalar mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	m_{med} 1.67 TeV	g=1.0, $m(\chi) = 1$ GeV	1711.03301
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

**Only a selection of the available mass limits on new states or phenomena is shown.*

†Small-radius (large-radius) jets are denoted by the letter j (J).

Overview of EXOTIC searches (ATLAS)



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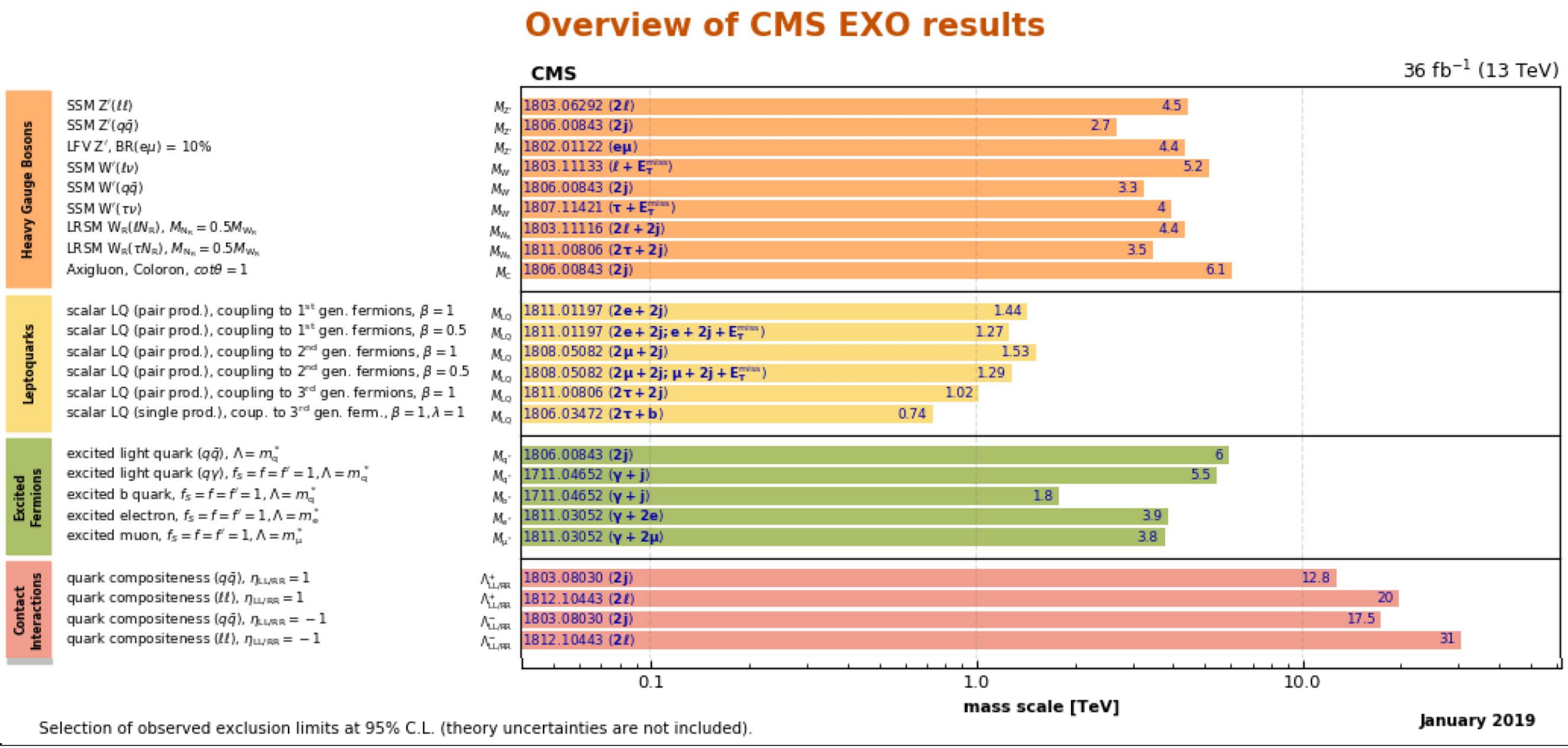
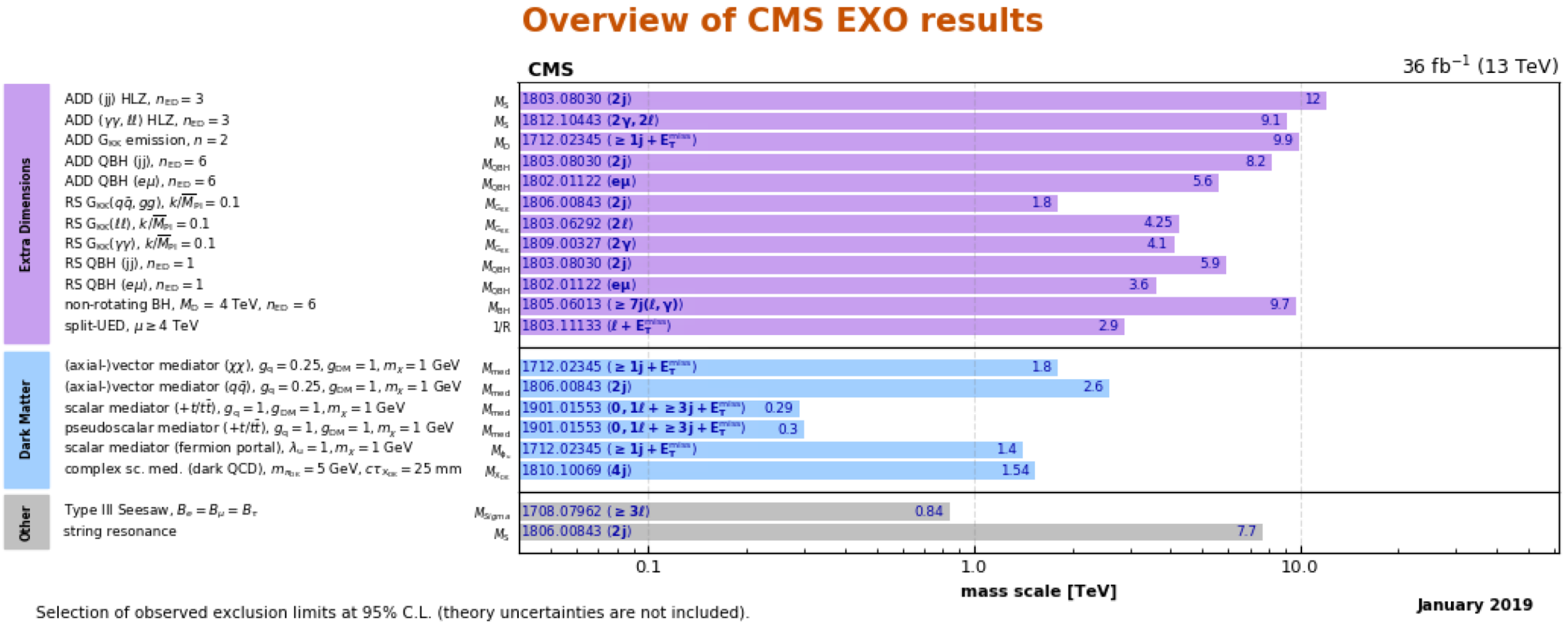
Overview of EXOTIC searches (CMS)



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

Overview of EXOTIC searches (CMS)



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

… today's menu …

some recent results from RUN-2

Heavy Gauge Bosons & Extra Dimensions

$X \rightarrow e^+e^-$, $\mu^+\mu^-$, $X \rightarrow e\nu$, $\mu\nu$, $\tau\nu$

$X \rightarrow$ dijet , $X \rightarrow tt$

$X \rightarrow \gamma\gamma$, $X \rightarrow WW, WZ, ZZ$

excited leptons

$e^* \rightarrow e\gamma$, $\mu^* \rightarrow \mu\gamma$

Vector-Like Quarks

$B \rightarrow Hb$, $Z' \rightarrow tT$ $(T \rightarrow Ht, Zt, Wb)$

3rd generation scalar LQ

$LQ^u_3 \rightarrow t\nu, b\tau$ & $LQ^d_3 \rightarrow b\nu, t\nu$

type-III seesaw heavy leptons

$qq \rightarrow W^{\pm} \rightarrow N^0 L^{\pm} \rightarrow (\ell^{\pm} W)(W^{\pm} \nu)$

More material:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/EXO/index.html
http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G/index.html
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/B2G/index.html

dark matter
and
long-lived particles
at the LHC
from Alex Kastanas
(next talk)

… how we do it …

Search for **deviations** from SM background;
Use an **optimal observable** with maximum signal – background separation

- Bump hunting
- Excess in tails of distributions
- Special structures (peaks/dips) due to *interference*

Final states contain :

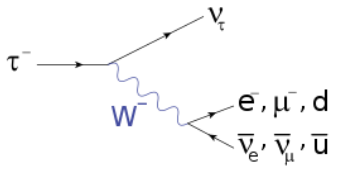
Physics Objects

leptons

electrons

muons

taus



$\tau_{hadronic}$ *: tau jets*

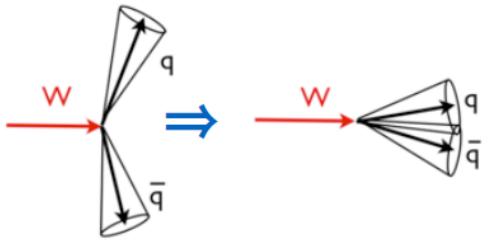
missing $\vec{p}_T$

$$\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}} = -\sum_{\text{visible particles}} \vec{p}_{\mathrm{T}}$$

sensitive to multiple p-p interactions (**pileup**)

***pileup suppression** is fundamental for ATLAS & CMS*

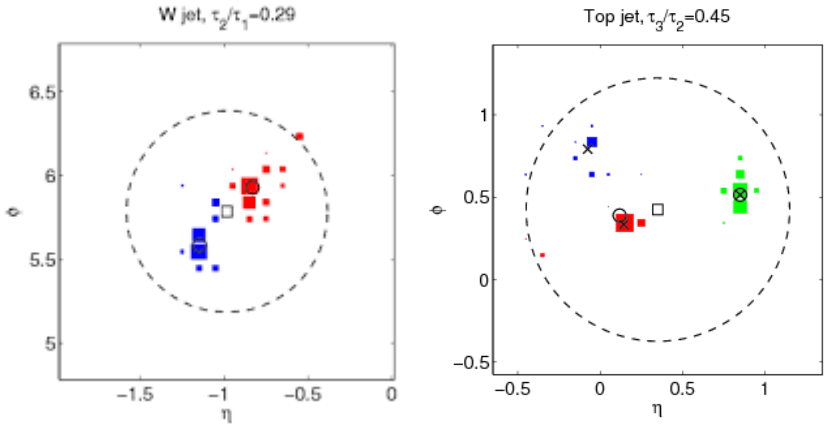
jets



Resolved anti-kT (R=0.4)

Boosted anti-kT (R=0.8,1.0)

b/t - tagging



jet substructure

N-subjetiness [JHEP 1103:015, 2011]

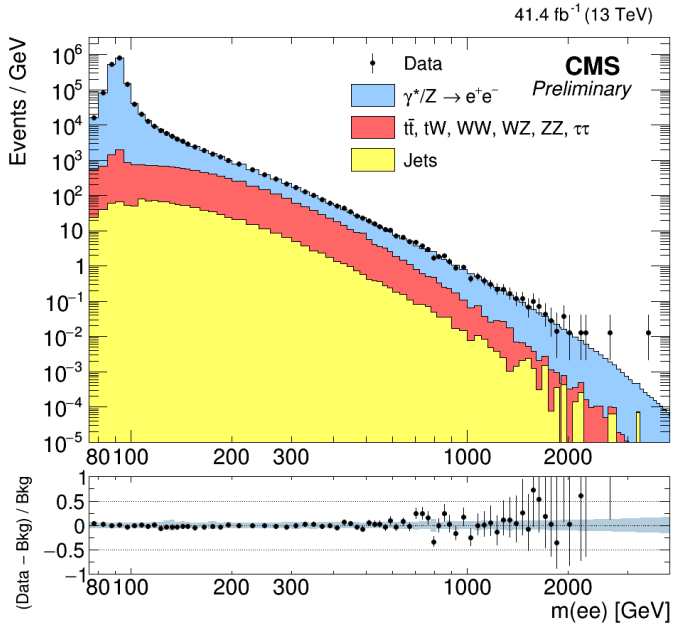
$$\tau_N = \frac{1}{d_0}\sum_k p_{T,k}\min\{\Delta R_{1,k}, \Delta R_{2,k}, \cdots, \Delta R_{N,k}\}$$

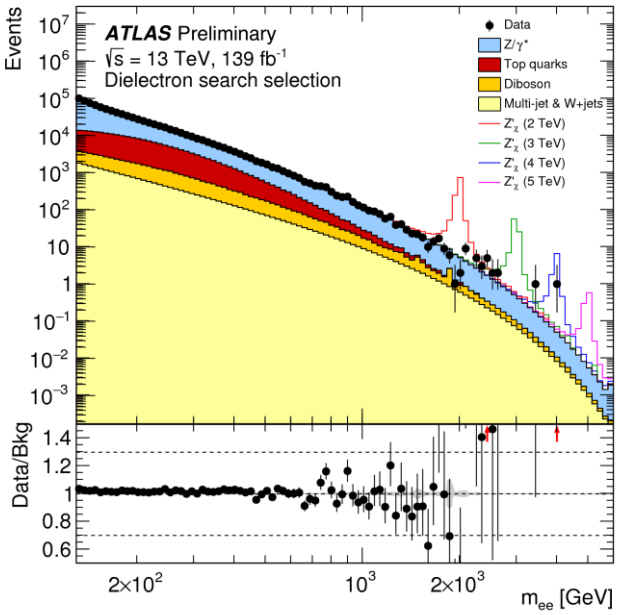
jet grooming (jet mass)

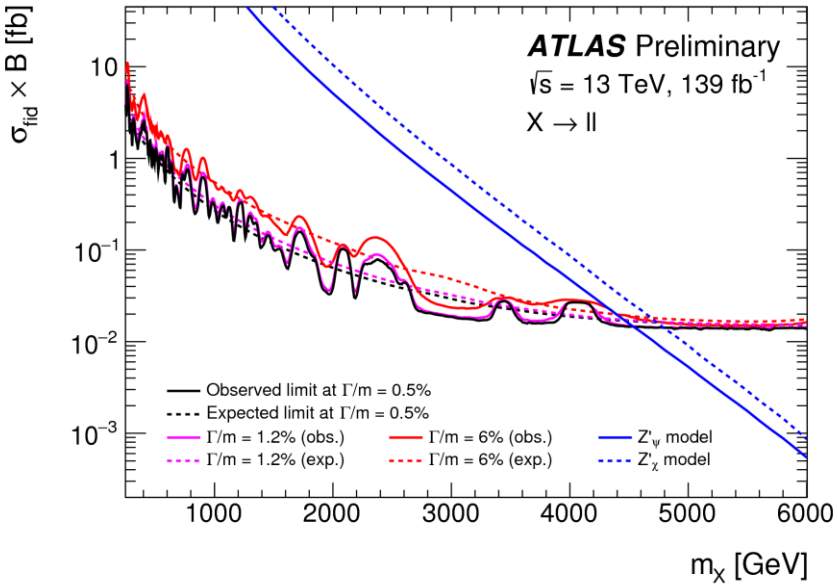
Trimming [JHEP 1002:084,2010]
Pruning [Phys.Rev.D80, 051501 (2009)]
Softdrop [JHEP05(2014),146]

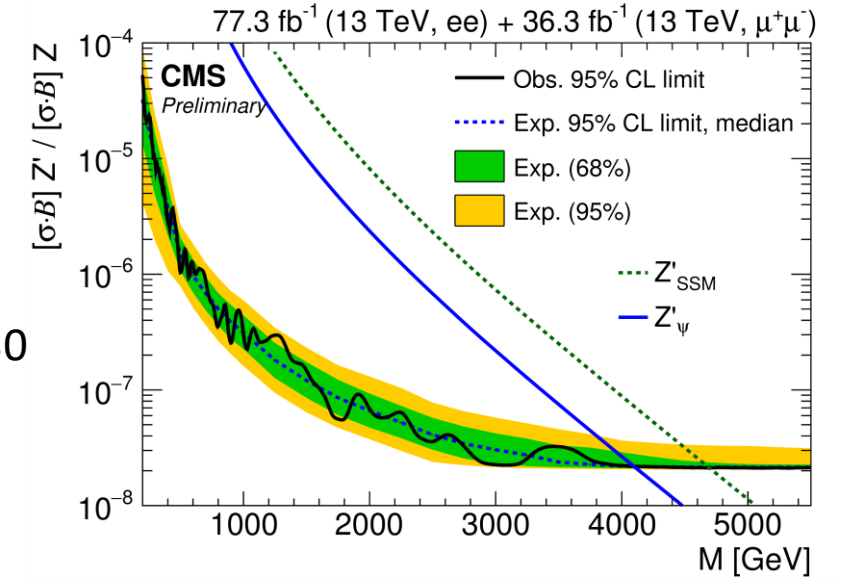
Z’→ e⁺e⁻ , μ⁺μ⁻

77/139 fb^{-1}





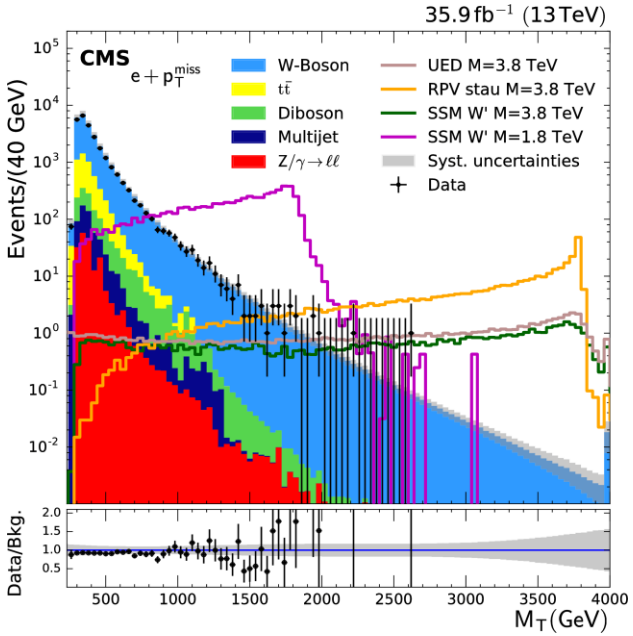


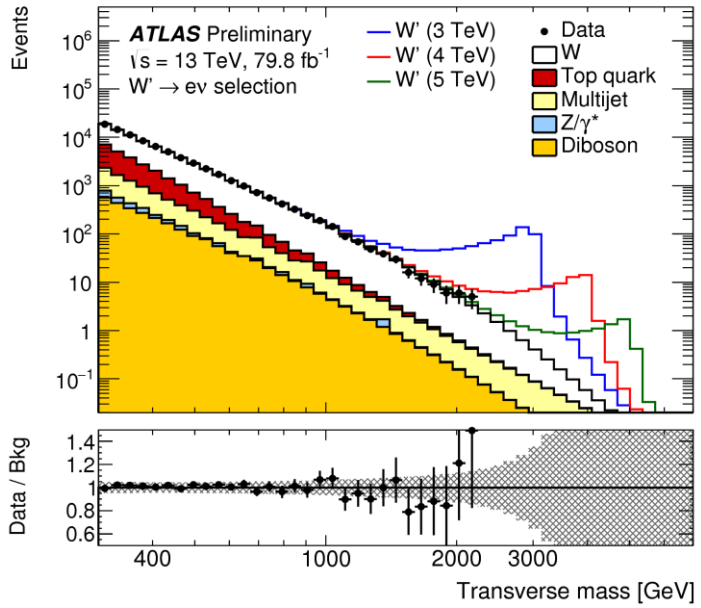


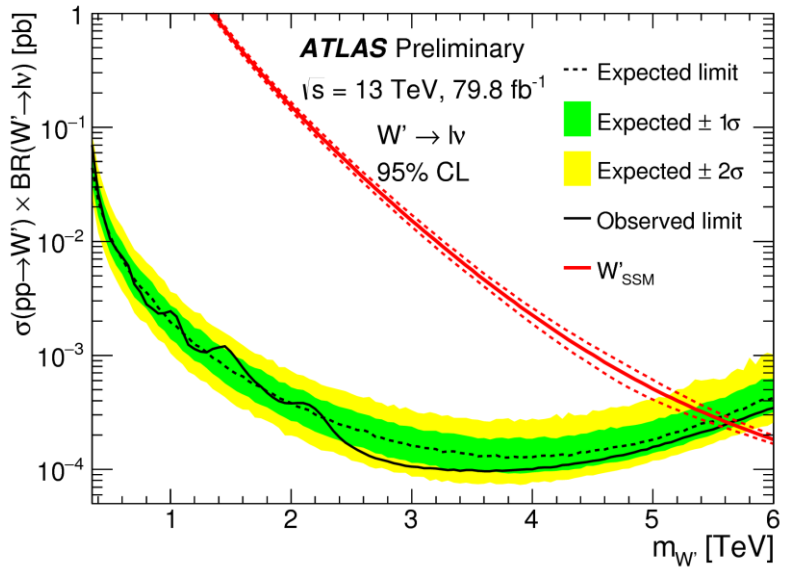
- Search separately in e⁺e⁻ & μ⁺μ⁻ final states; then combine results
- High signal selection efficiencies
- σ(Z’)/σ(Z) ratio limits
  - No dependence on luminosity
  - suppress correlated experimental uncertainties
- Limits for narrow Z’

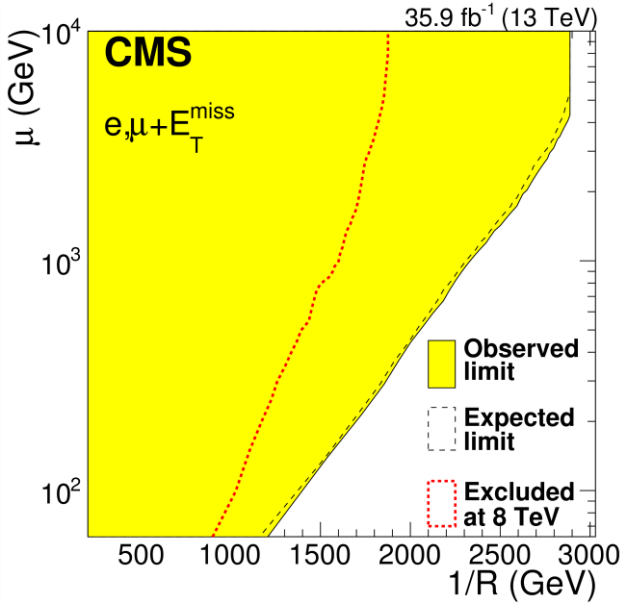
- Upper (lower) limits on σ·B (mass) for various Z’ models
  - limits on couplings (HVT models)
- model-independent limits on A·σ·B by applying fiducial cuts (lepton p_T > 30 GeV, and lepton |η| < 2.5)
- results for various resonance width hypotheses

W'→ eν , μν









search : separately in eν & μν final states; then combine results

interference : The W' boson is assumed not to couple to the SM W and Z.

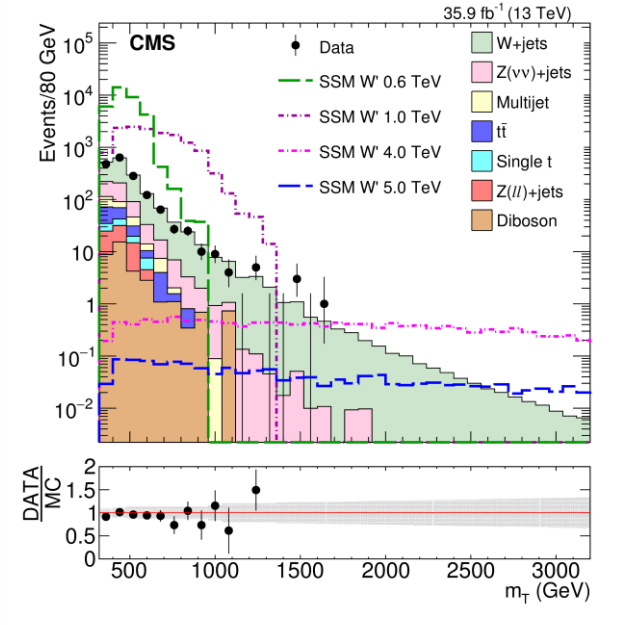
backgrounds : from simulation except multijets (data-driven)

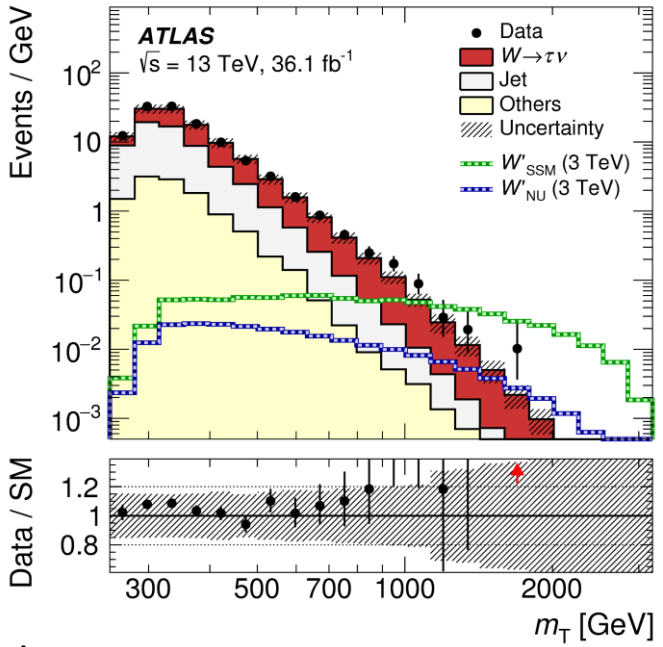
uncertainties : lepton & E_T^{miss} reconstruction, background modelling, PDFs , luminosity

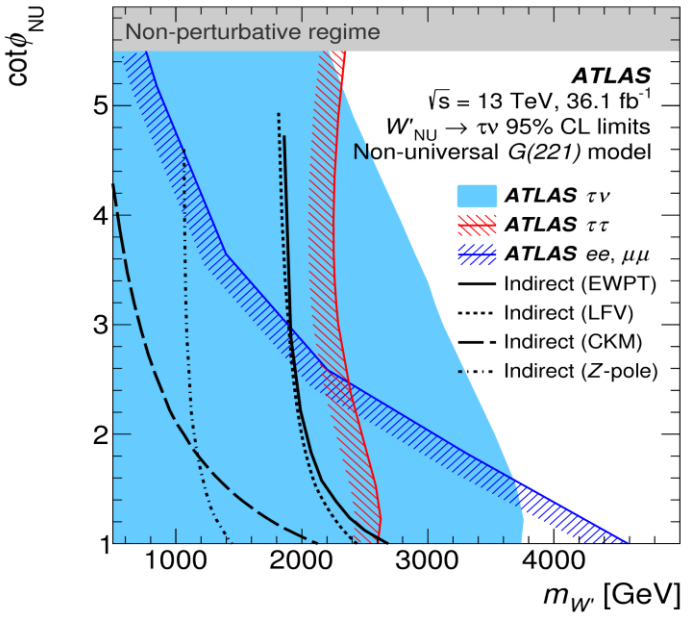
The results are interpreted in the context of the **SSM** (ATLAS/CMS), **split UED** & **RPV stau** (CMS)

W'→τν

36 fb^{-1}







search : charged heavy gauge bosons decaying to $\tau_{hadronic}$ + ν

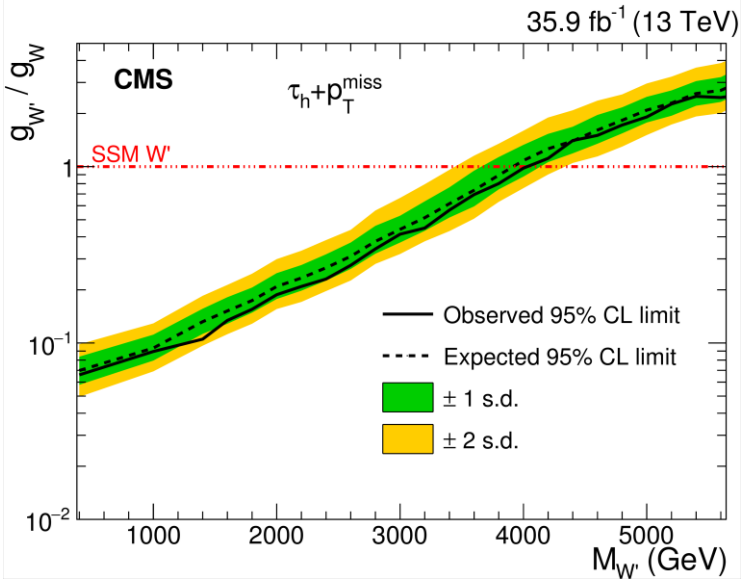
reconstruction: $\tau_{hadronic}$ is a tau jet seeded from a jet (anti-kT , R=0.4)

backgrounds : off-shell tail of the m_T distribution from the SM W.

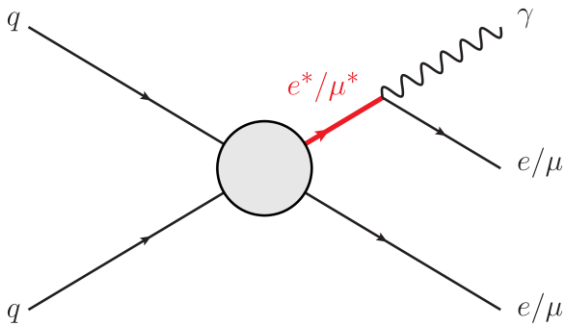
models: SSM, Non-universal G(221) enhanced BRs to 3rd generation fermions
G(221): cotϕ_{NU} mixing angle, related to W'$_{NU}$ couplings to heavy fermions.

For $M_{W'}$>180 GeV, **W'→ tb** opens, affects BR(W' →τν)=8.5% in SSM
W'→ tb searches: Phys. Lett. B 788 (2019) 347 , Phys. Lett. B 777 (2017) 39

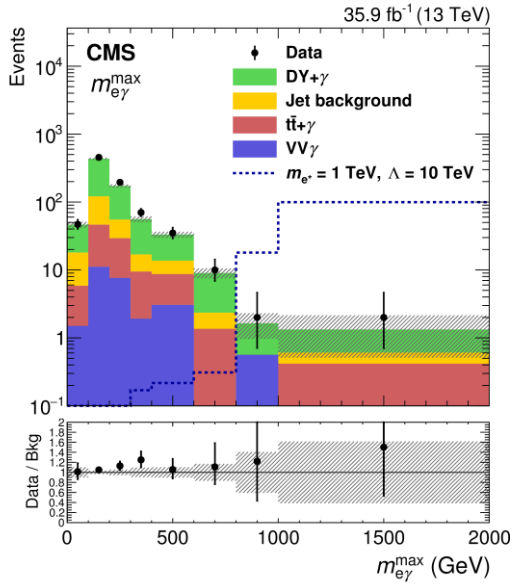
talk from
Emery Nibigira

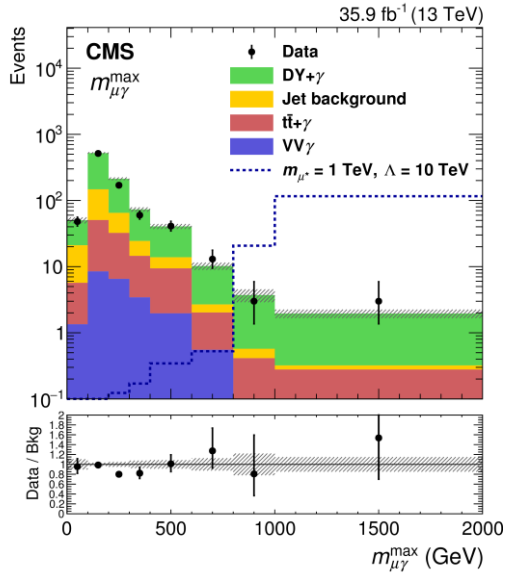


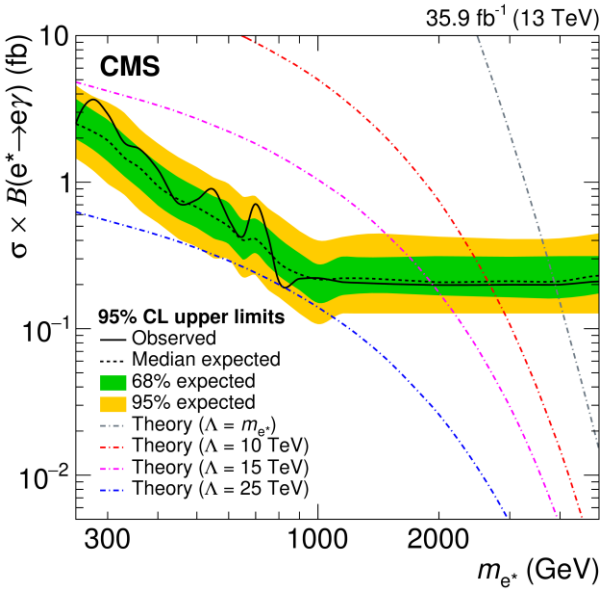
ee*,μμ* → eeγ, μμγ



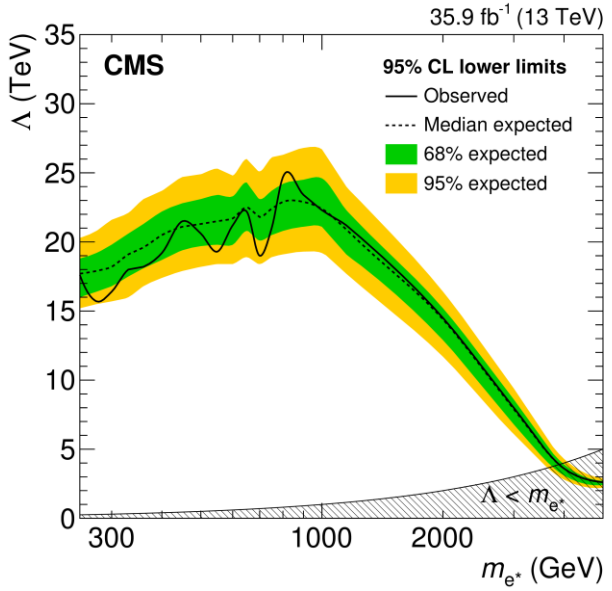
New strong force with characteristic energy scale **Λ (compositeness scale)**







Compositeness models predict **excited** leptons : **e*** (**μ***)→ eγ (μγ)
Production through **Contact Interactions (CI)**, decay via **SM gauge interactions**

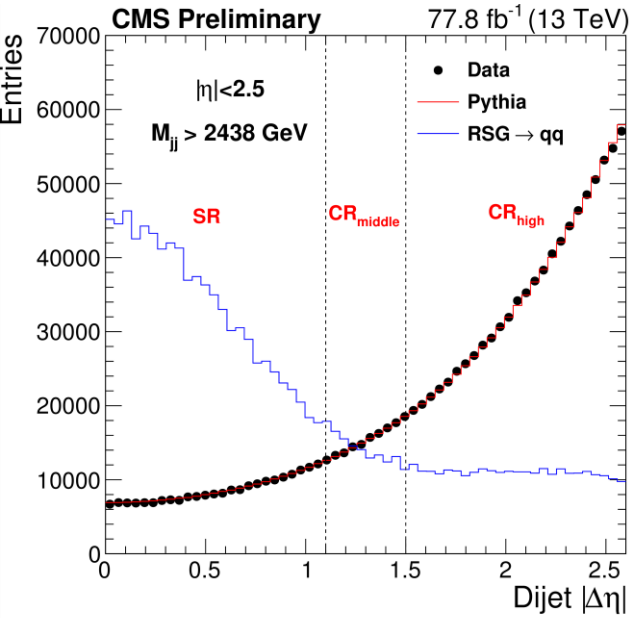


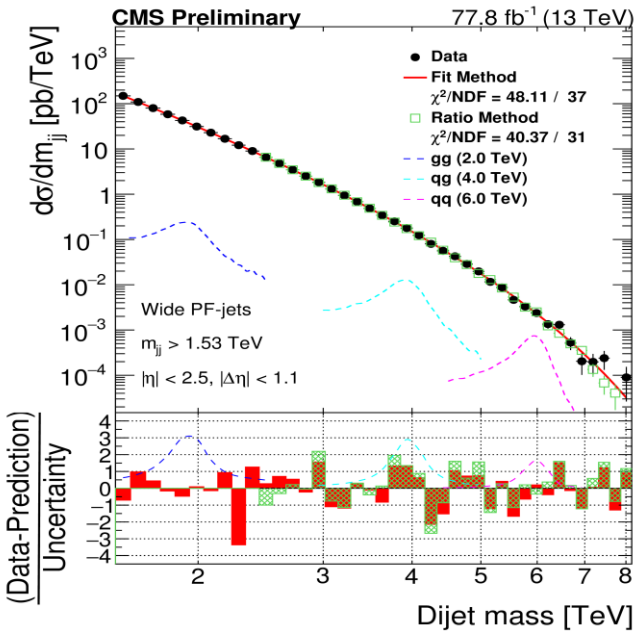
final state: same-flavor lepton pair → low bkgd but **ambiguity** in the **e*/μ*** reconstruction.
thresholds: eeγ , μμγ [e,μ,γ p_T>35 GeV and ΔR(ℓ,γ)>0.7]. Both pairings are used.
Bkgd rejection : 2D cut on ($m_{\ell\gamma}^{max}$, $m_{\ell\gamma}^{min}$) plane.

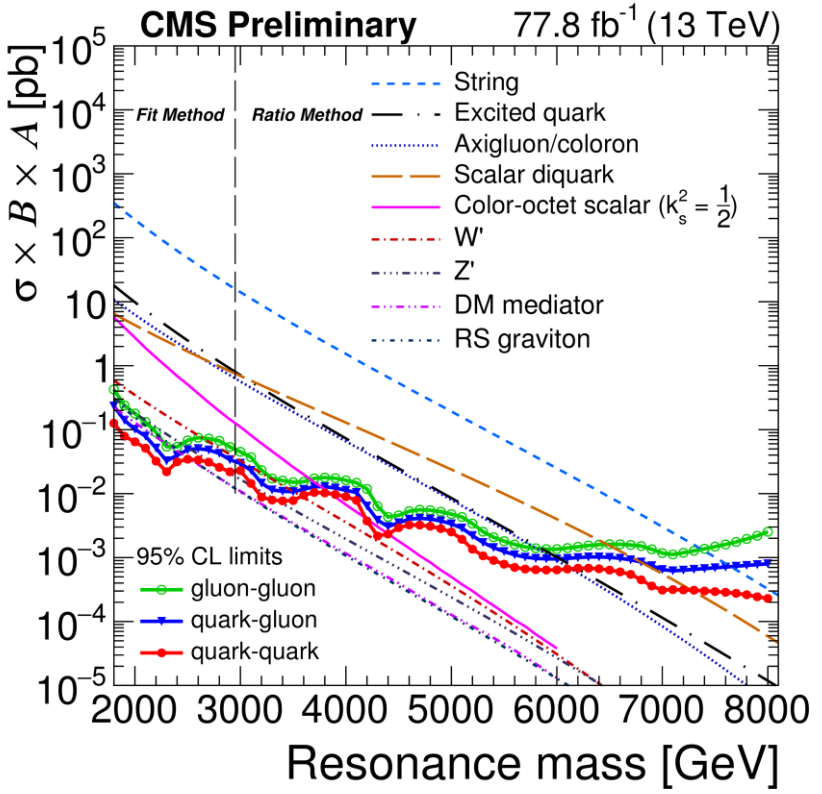
Channel	Observed (expected) limit on m_{ℓ^*} for $m_{\ell^*} = \Lambda$, TeV	Observed (expected) limit on Λ for $m_{\ell^*} \approx 1$ TeV, TeV
eeγ	3.9 (3.8)	25 (23)
μμγ	3.8 (3.9)	25 (23)

dijet resonances – high mass region

78 fb^{-1}







search: high mass dijet resonances using wide PF-jets
(ΔR < 1.1 , reduced sensitivity to gluon radiation from the final-state partons)

QCD background : t-channel production

a) fitting an empirical functional form

b) data-driven method via a |Δη| sideband.

$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)}}$$

models : s-channel dijet resonances

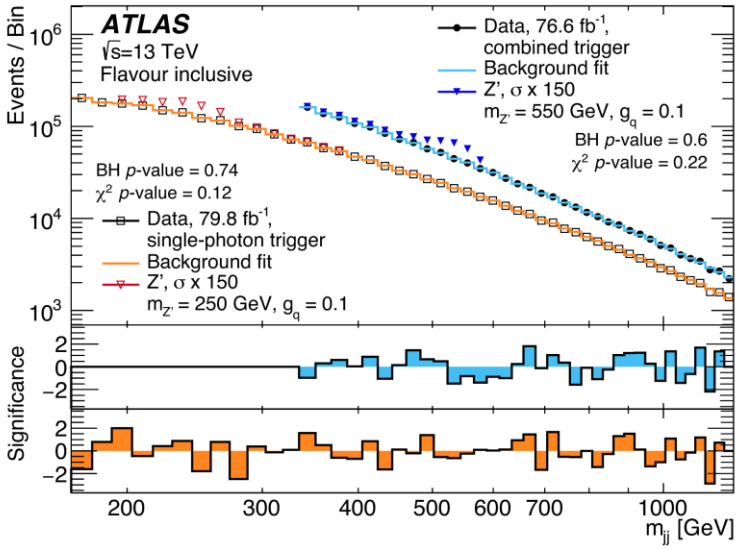
widths and line shapes depend on the parton content of the resonance (qq, qg, or gg).

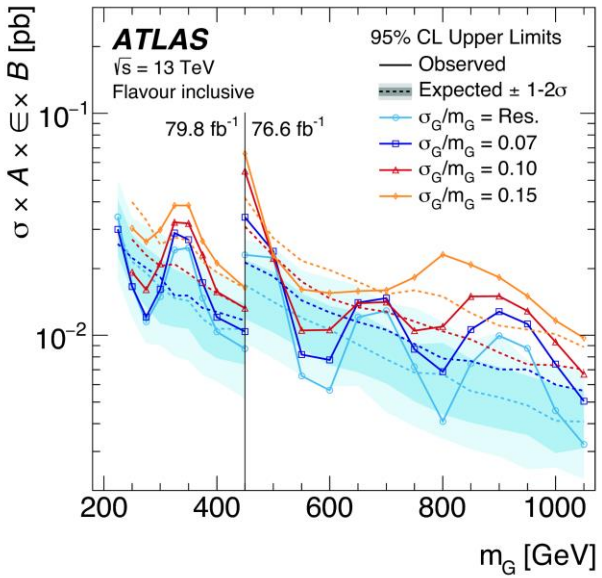
ATLAS [37 fb^{-1} , Phys. Rev. D 96, 052004 (2017)]

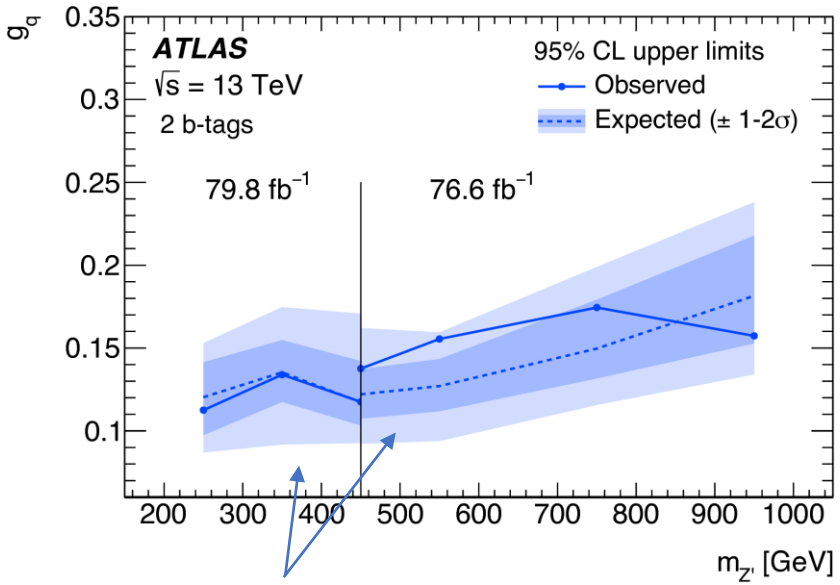
Model	Final State	Observed (expected) mass limit [TeV] 36 fb^{-1} 13 TeV	77.8 fb^{-1} 13 TeV
String	qg	7.7 (7.7)	7.6 (7.9)
Scalar diquark	qq	7.2 (7.4)	7.3 (7.5)
Axigluon/coloron	$q\bar{q}$	6.1 (6.0)	6.2 (6.3)
Excited quark	qg	6.0 (5.8)	6.0 (6.0)
Color-octet scalar ($k_s^2 = 1/2$)	gg	3.4 (3.6)	3.7 (3.8)
W'	$q\bar{q}$	3.3 (3.6)	3.6 (3.8)
Z'	$q\bar{q}$	2.7 (2.9)	2.9 (3.1)
RS graviton ($k/M_{PL} = 0.1$)	$q\bar{q}$, gg	1.8 (2.3)	2.4 (2.4)
DM mediator ($m_{DM} = 1$ GeV)	$q\bar{q}$	2.6 (2.5)	2.5 (2.8)

dijet resonances – low mass region

80 fb^{-1}







different acceptances

search : dijet resonance produced in association with a high E_T photon.
variants: *jet flavor inclusive* & *2 b-tags*

the problem : low mass dijet searches suffer from high multi-jet bkgd
$\Rightarrow$ high P_T^{trig} jet trigger thresholds $\Rightarrow$ low sensitivity bound at $M_{jj} \sim 2\times P_T^{trig}$

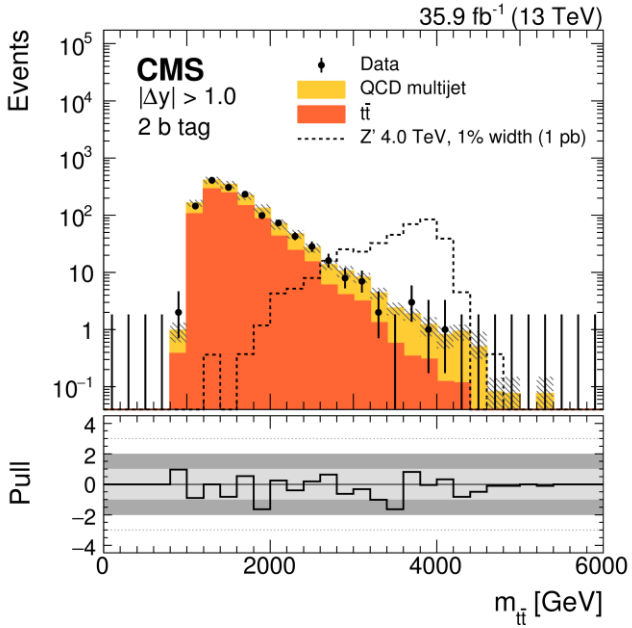
solutions: - record partial event information [PLB**769**(2017)520 , Phys.Rev.Lett.**121**(2018)081801]
- resonance produced in association with **γ** or **jet** , dedicated b-jet triggers

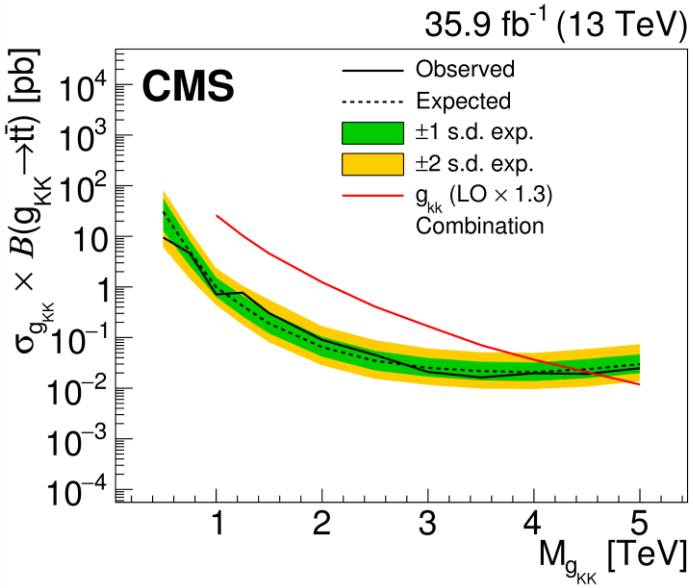
models

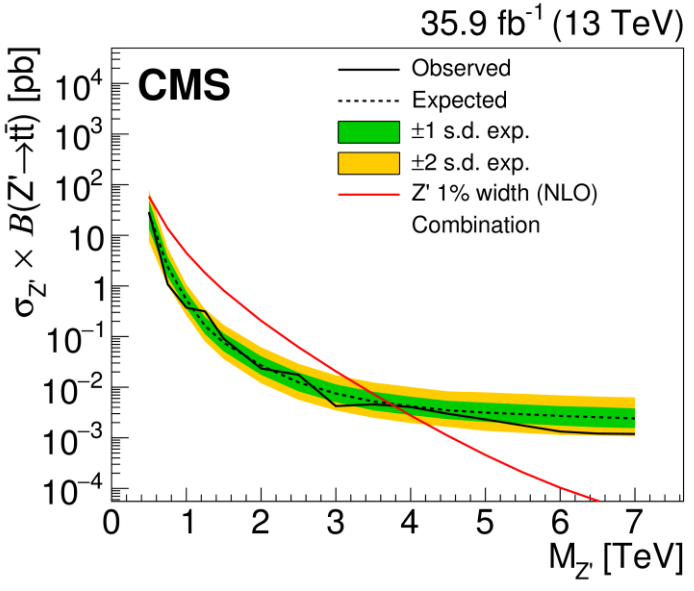
leptophobic Z' resonance
- axial-vector couplings to quarks (g_q) universal in quark flavour.
- negligible mixing with the SM Z

generic Gaussian-shape signal
- upper limits on fiducial cross section

resonant $t\bar{t}$ production







search : spin-1 resonance X→ **$t\bar{t}$** , no interference with SM $t\bar{t}$ production assumed.
$t\bar{t}$ modes: fully-leptonic, semi-leptonic, hadronic , *leptons* = e , μ

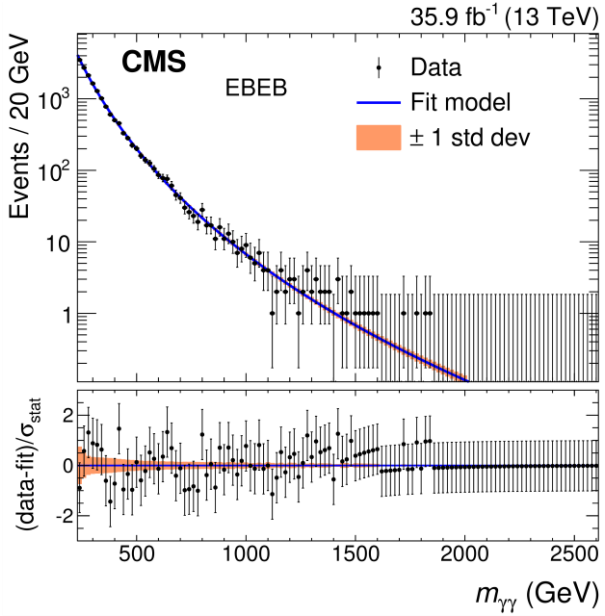
strategy : optimized for top-quarks with high Lorentz boosts;
requires non-isolated leptons and jet substructure techniques.
simult. measurement of the bkgds and t-tagging efficiency from data.

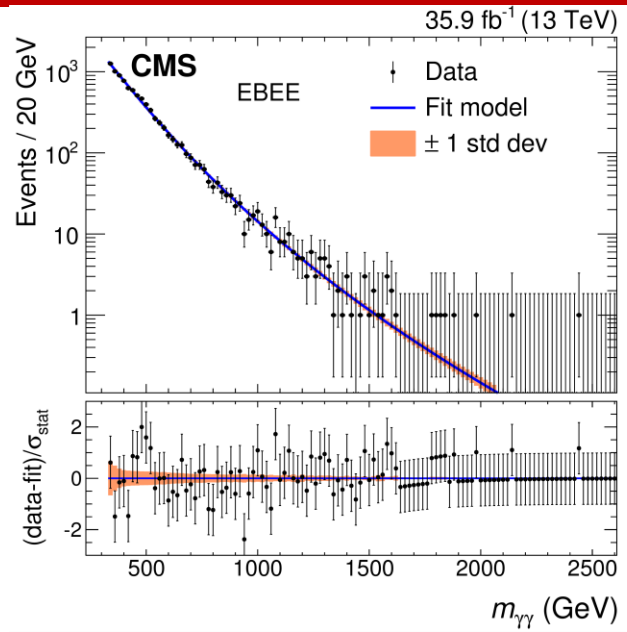
ATLAS : probe also low top-quark boosts (resolved decay topology)
[36 fb^{-1} , CERN-EP-2018-350 , Eur. Phys. J. C 78 (2018) 565]

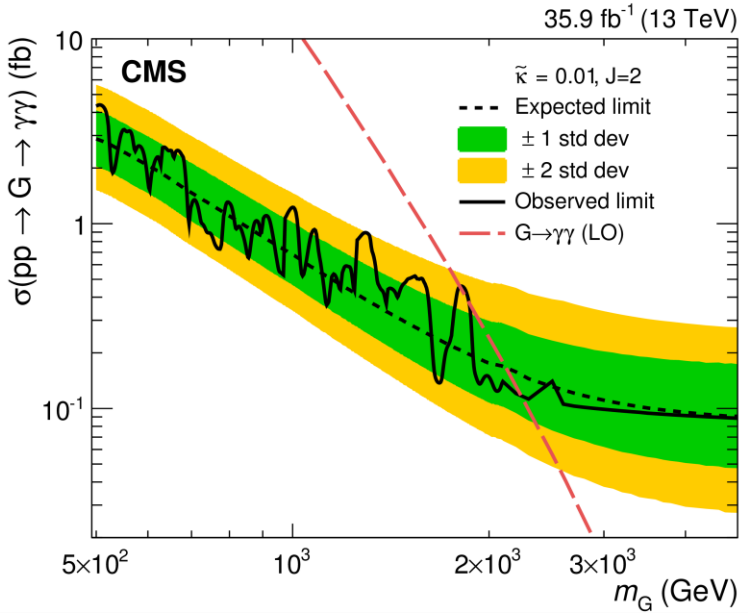
leptophobic topcolor Z'			
Width	1%	10%	30%
Exclusion (TeV)	0.50 - 3.80	0.50 - 5.25	0.50 - 6.65

1^{rst} Kaluza-Klein excitation of the gluon in the RS scenario (g$_{KK}$)	
Exclusion (TeV)	0.5 - 4.55

Heavy resonances in γγ







search : resonant new physics signatures with high-mass diphoton events

advantages :
lower SM backgrounds / better mass resolution w.r.t. dijets
larger branching fraction w.r.t. dileptons

background estimation : $m_{\gamma\gamma}$ fit to a parametrized functional form → fully data-driven description of the shape

limits : on heavy spin-0/spin-2 resonances

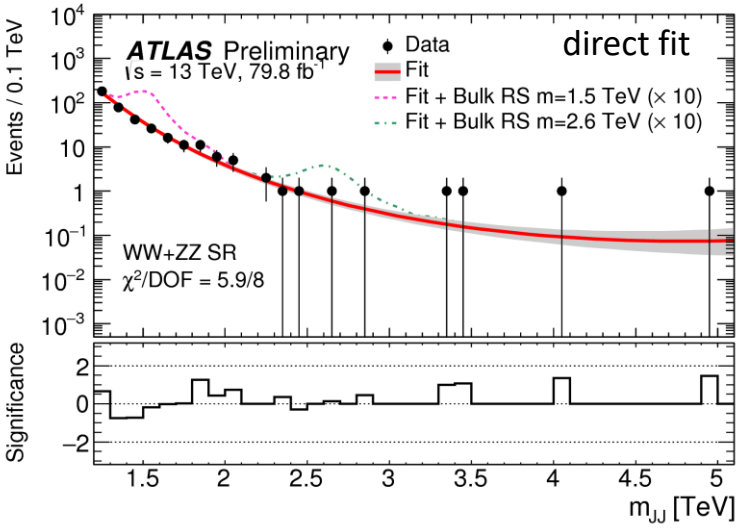
ATLAS [36 fb^{-1} , Phys. Lett. B 775 (2017) 105]

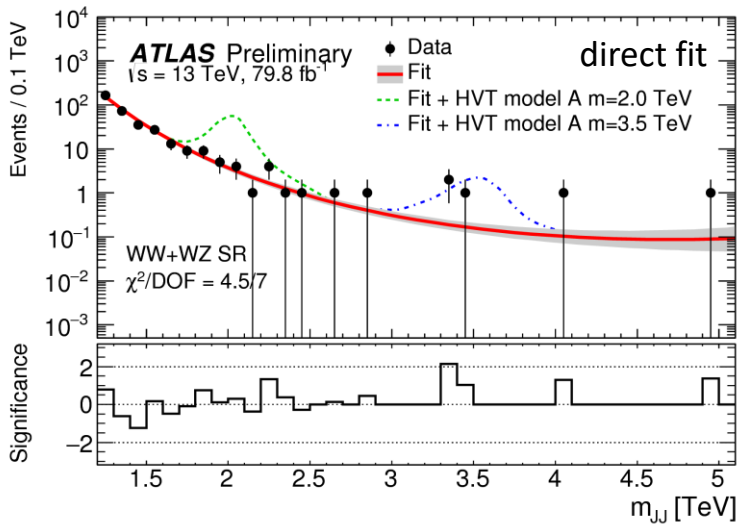
RS graviton			
$\tilde{\kappa}$	0.01	0.1	0.2
Γ/M	1.4×10^{-4}	1.4×10^{-2}	5.6×10^{-2}
Exclusion (TeV)	2.3	4.1	4.6

Also, model independent limits on cross sections in the fiducial volume (P_T^{γ}>75 GeV) for **resonant** pp →γγ processes.

X→WW,WZ,ZZ

80 fb^{-1}





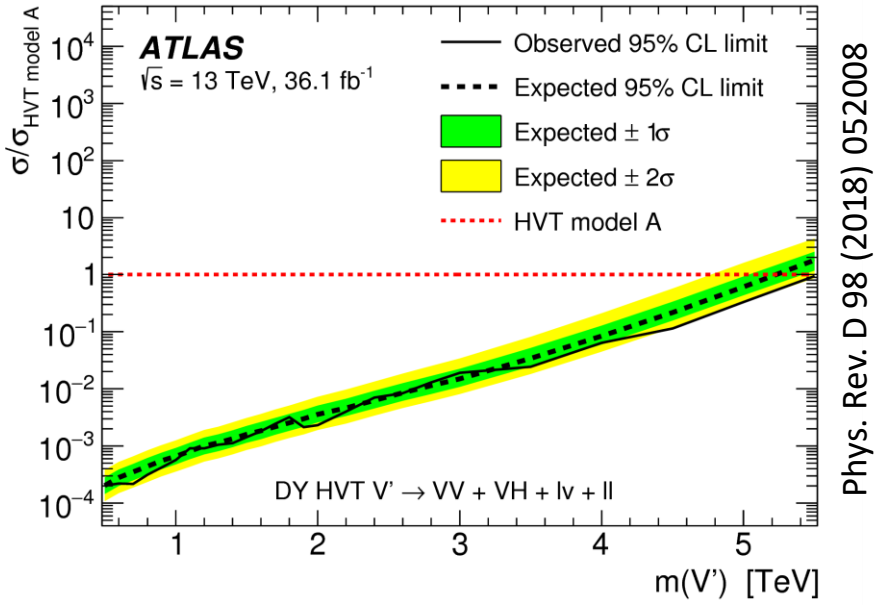
Model	Signal Region	Excluded mass range [TeV]
HVT model A, $g_V = 1$	WW	$1.30 - 2.80$
	WZ	$1.20 - 3.10$
	$WW + WZ$	$1.20 - 3.40$
HVT model B, $g_V = 3$	WW	$1.30 - 3.10$
	WZ	$1.20 - 3.30$
	$WW + WZ$	$1.20 - 4.15$
Bulk RS, $k/\overline{M}_{\mathrm{Pl}} = 1$	WW	$1.30 - 1.60$
	ZZ	*None*
	$WW + ZZ$	$1.20 - 1.90, 2.10 - 2.30$

Search : narrow diboson resonances decaying to fully hadronic final states

models :
spin-1 Heavy Vector Triplet Model (HVT) , X→WZ , WW
spin-2 graviton G_{KK} → WW, ZZ (bulk RS)

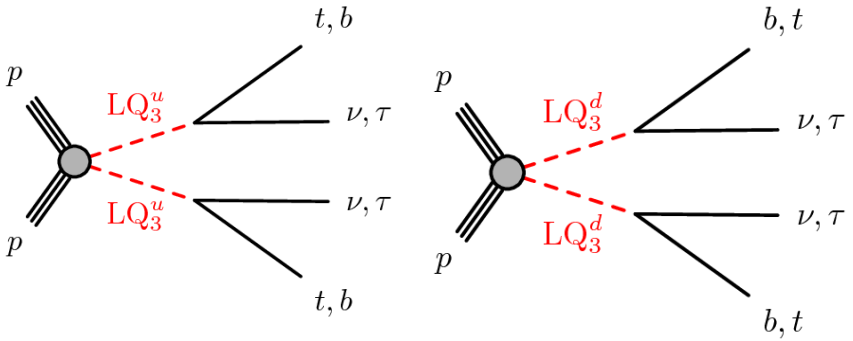
diboson system : pairs of high transverse momentum, **large-radius** (R=1.0) jets tagged as compatible with the hadronic decay of a boosted W or Z boson, using **jet mass** and **substructure** properties.

background : from multijet production suppressed by the characteristic jet substructure of W/Z bosons

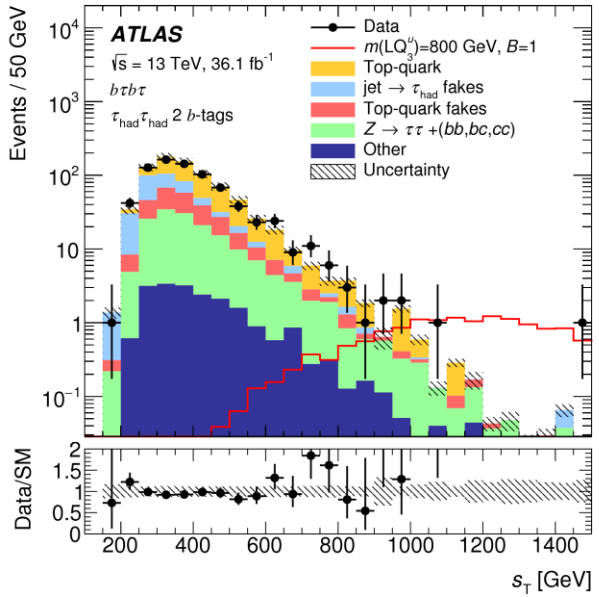


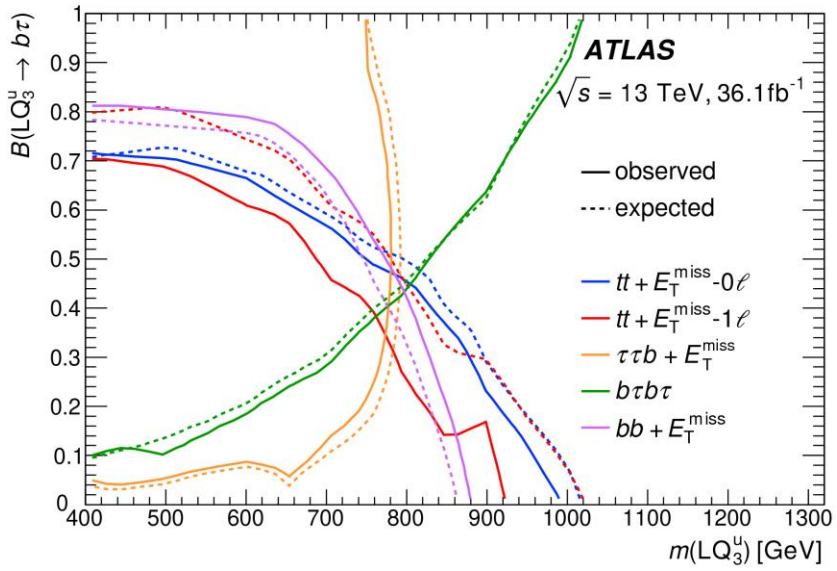
CMS [36 fb^{-1}]
JHEP 07 (2018) 075 , Phys. Rev. D 97, 072006

3rd - generation scalar LQ



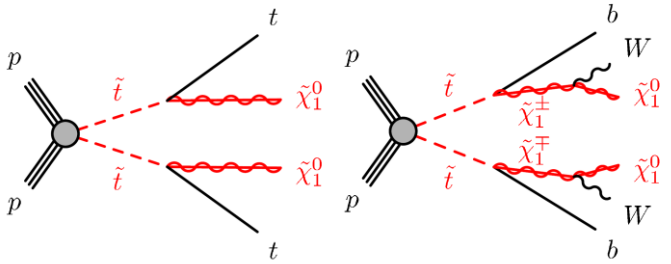
assumption : LQs decay only to fermions of the same family (minimal Buchmüller–Rückl–Wyler model Phys. Lett. B **191** (1987) 442)

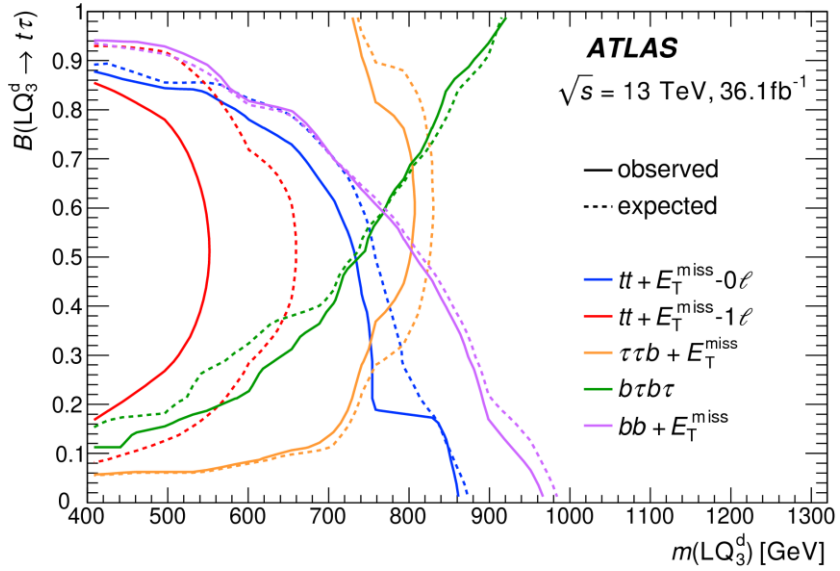




Exchange of LQs might explain the potential violation (if confirmed) of lepton universality in measurements of B-meson decays [arXiv:1706.07808]

reinterpretations of previously published ATLAS searches :
- HH→bbττ
- pair production of top/bottom squarks



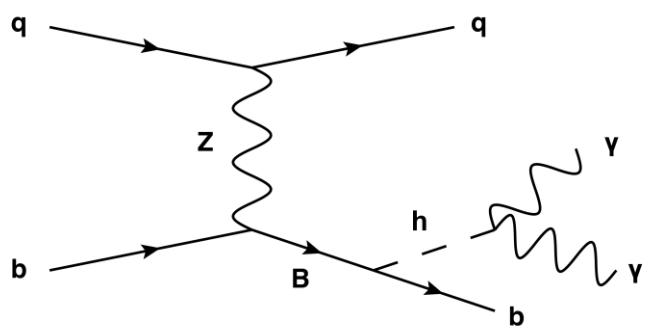


CMS [36 fb^{-1}]

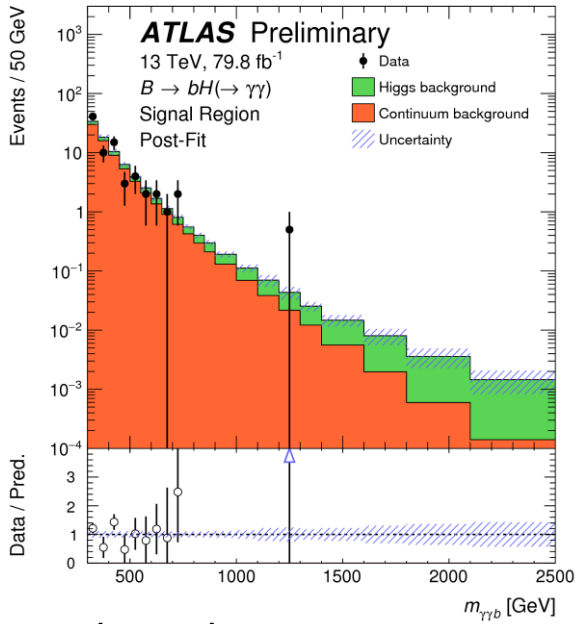
LQ_3^u, LQ_3^d (B=0), Phys. Rev. D **98** (2018) 032005
LQ_3^u (B=1), 1811.00806
LQ_3^d (B=1), Eur. Phys. J. C **78** (2018) 707

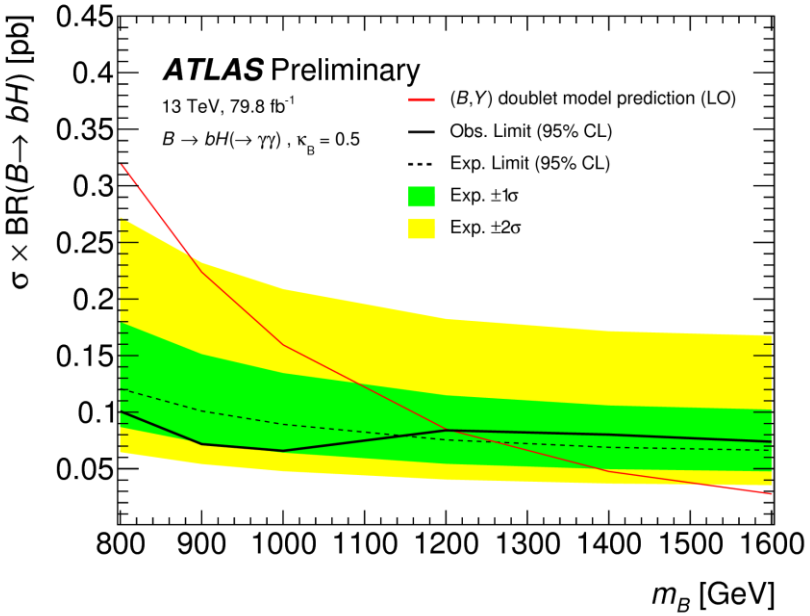
Vector Like B→Hb

80 fb^{-1}



t-channel production of the signal





search : single-production of VLQ B that couples exclusively to third-generation SM quarks via the flavor-changing neutral current interaction B→Hb→(γγ)b.

- cross section explicitly depends on the coupling, κ_B, of the VLQ to SM quarks

model : assume a generalized coupling κ_B=0.5 and doublet branching ratios of 50% for B→Hb and B → Zb

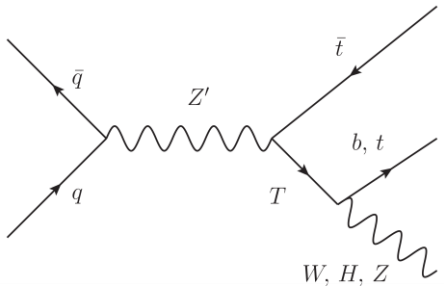
M_B < 1210 GeV excluded at 95% CL

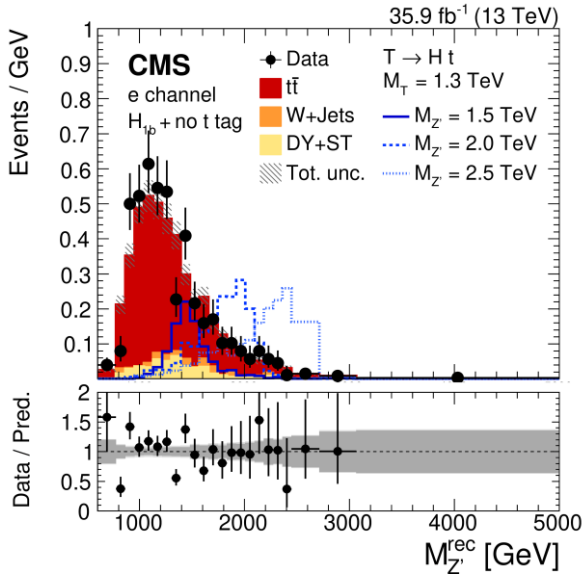
final state : two photons from the Higgs boson decay, a b-quark, and an additional light-flavor forward quark.

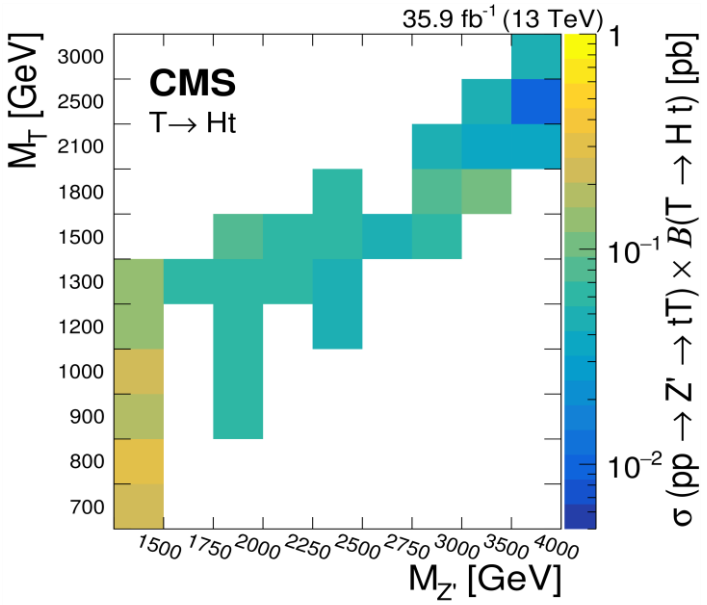
main background : non-resonant diphoton production estimated from the data sidebands in $m_{\gamma\gamma}$

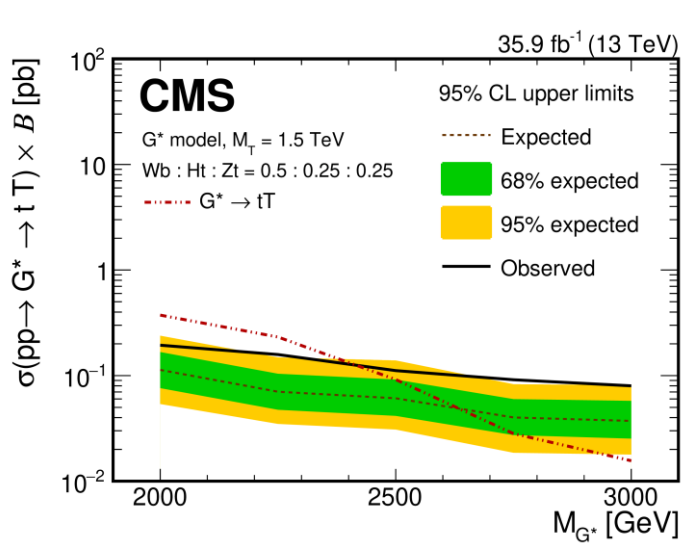
CMS [36 fb^{-1} , JHEP 06 (2018) 031]
B→Hb→(bb)b
singlet/doublet representation
various B widths (Γ/M = 1,10,20,30%)

Z'→tT (T→Ht,Zt,Wb)







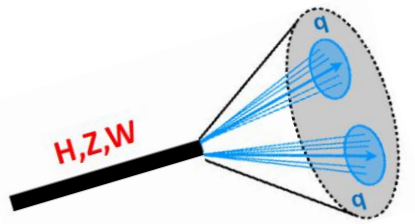


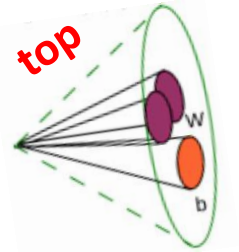
Extra dimension model
heavy spin-1 resonance G*
M_{G^*} excluded in
[1.5,2.3] TeV & [2.0,2.4] TeV
for M_T of 1.2 and 1.5 TeV.
arXiv:1110.6058

search : heavy spin-1 resonance Z' → **t T** (**vector-like** top-quark partner)
dominant decay mode if $M_t + M_T < M_{Z'} < 2M_T$.

final state:
optimized for Z'→ tHt , tZt → monolepton + jets (leptonic decay of **one** top quark)

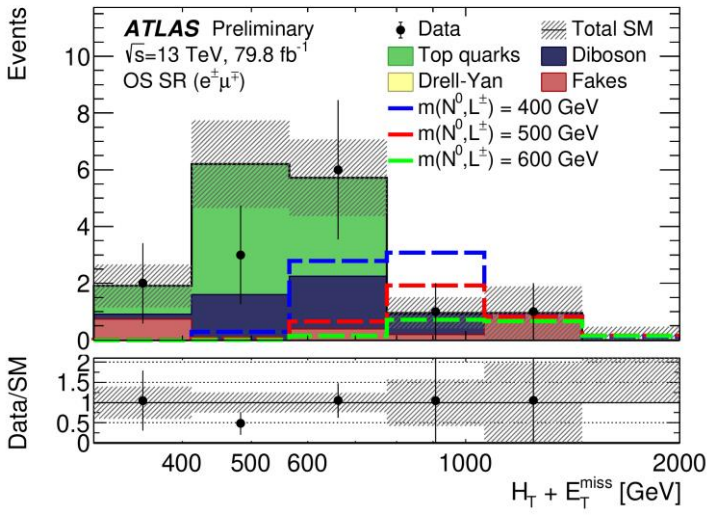
Use of **resolved** (R=0.4) and **merged** (R=0.8) top quark hadronic decay products.
Highly boosted H, Z and W bosons identified using **jet substructure** techniques.

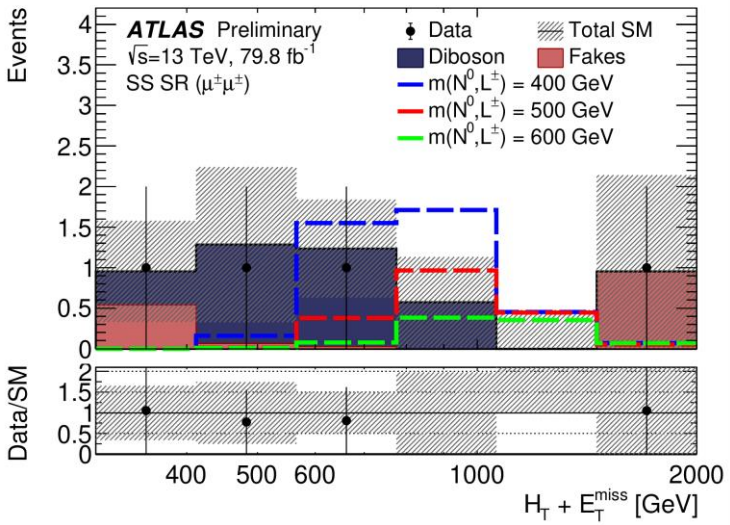


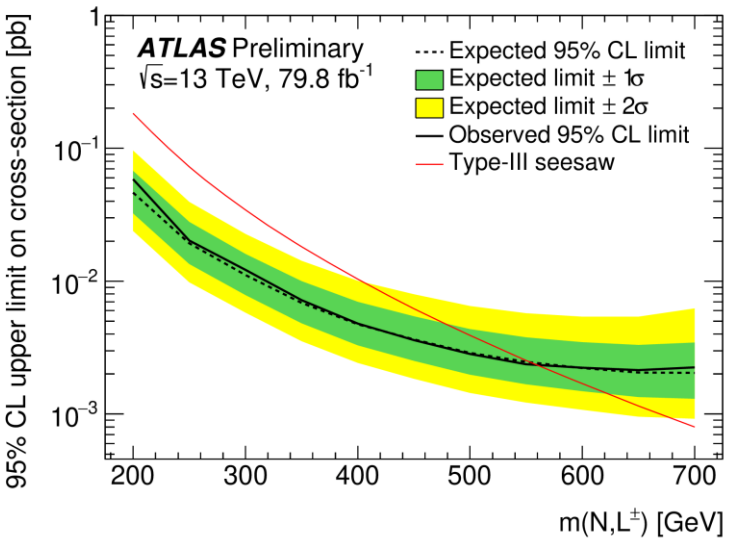


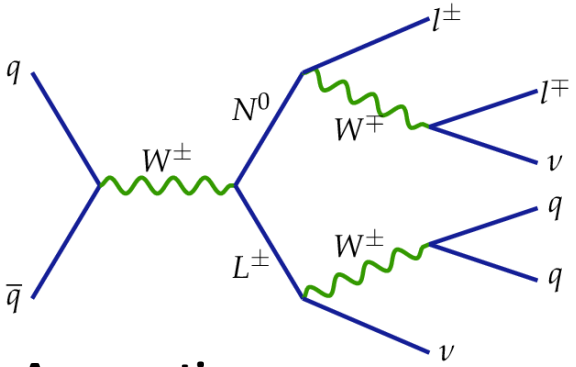
type-III seesaw heavy leptons

80 fb^{-1}









type-III model : new **charged** and **neutral** heavy leptons could be produced in EW processes LHC

final state: six channels defined by the lepton pairs (ee,μμ,eμ × SS,OS)

observable: the sum of the E_T^{miss} + H_T (scalar sum of the transverse momenta)

main systematics:

experimental (uncertainty in the simulation of physics object efficiencies)
theoretical (uncertainty in the physics model used for simulation e.g. cross sections),
yields (uncertainty arising from fitting the yield of top and diboson backgrounds)

Assumptions:

- N^0 and $L^\pm$ are considered mass-degenerate.
- BR to all lepton flavors are assumed to be equal (1/3)

CMS [36 fb^{-1} , Phys. Rev. Lett. 119, 221802]

Epilogue

- Many beautiful results from ATLAS and CMS. More to come soon including the full RUN-2 luminosity.
- Observations are in agreement with standard model expectations.
- Upper limits on production cross section of new heavy resonances calculated in a model-independent manner.
- Limits are interpreted as constraints on model parameters (masses, couplings …).

Necessary to continue the broad search program for New Physics

Up to now the EXOTICA papers have (almost) the same sentence in the abstract:

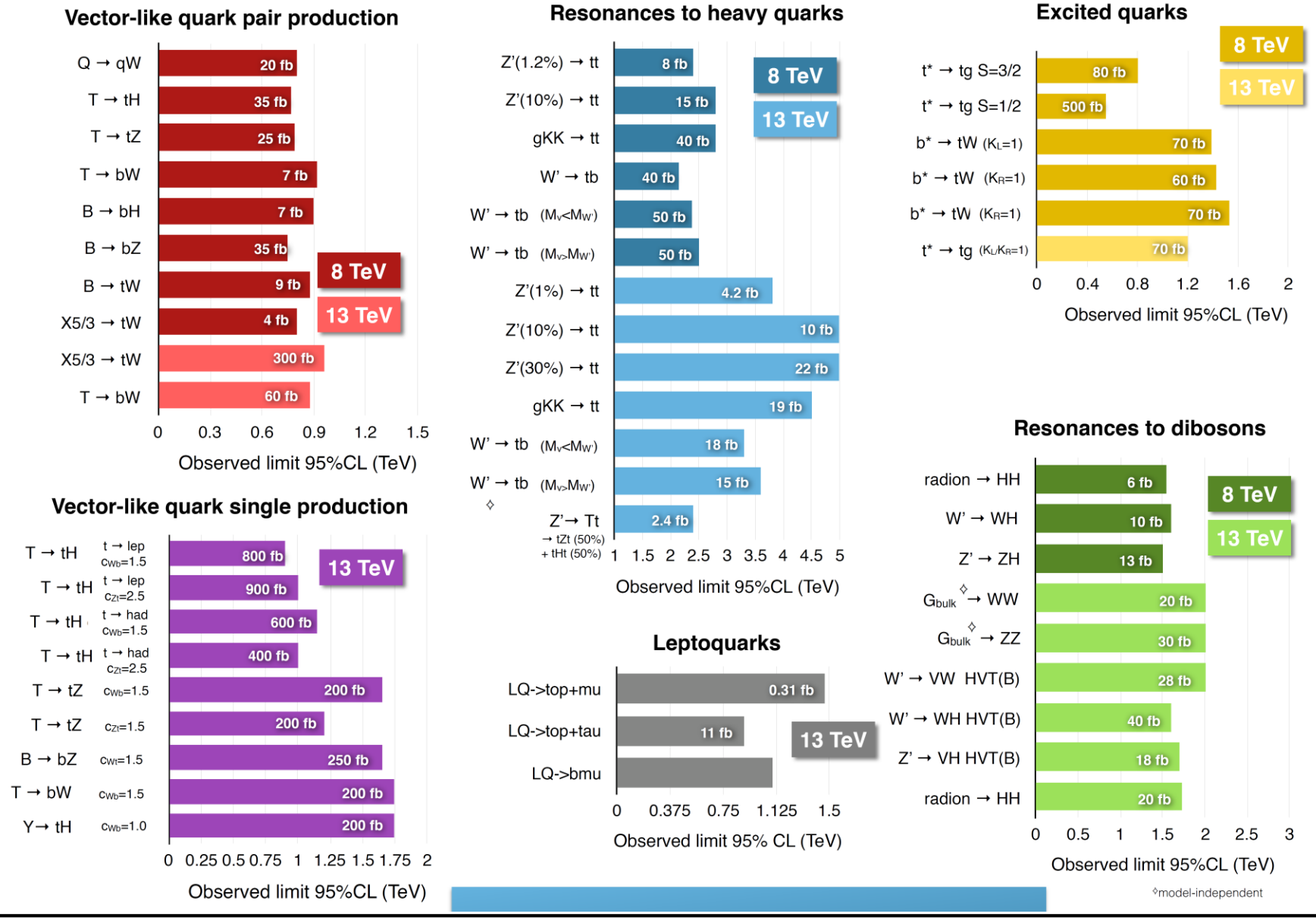
… No significant excess above the background expectation is observed, and upper limits on ….

Lets **hope** that in the near future, at least one (or more) EXOTICA abstract(s) will contain the magic sentence:

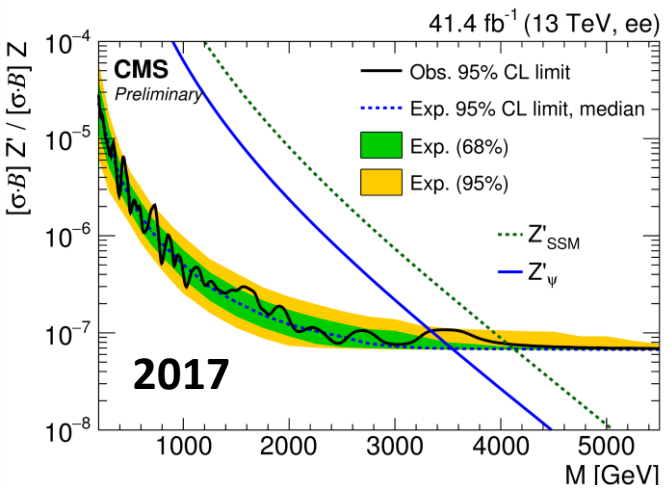
… An excess of events is observed above the expected background, with a local significance of 5.0 standard deviations, at a mass near ….

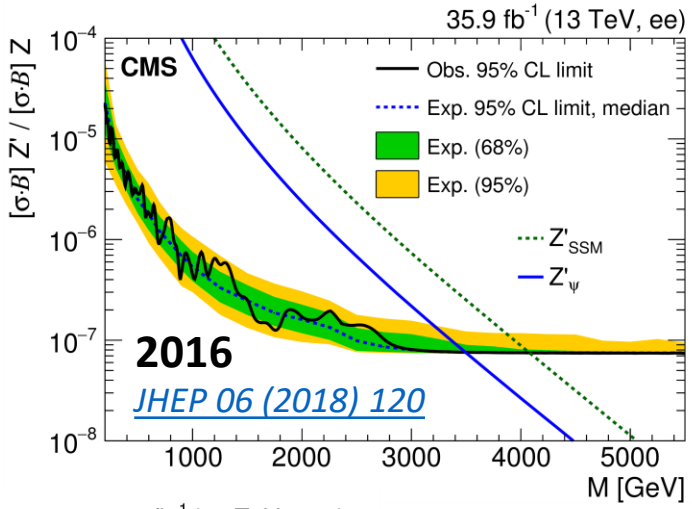
BACKUP

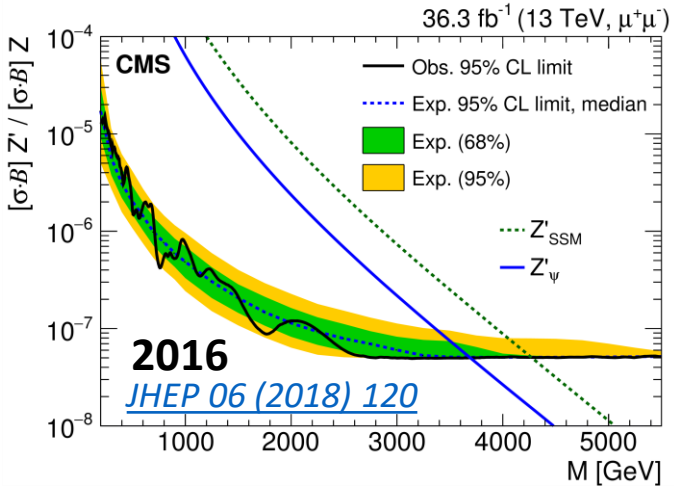
Overview of EXOTIC searches (CMS-heavy SM particles)



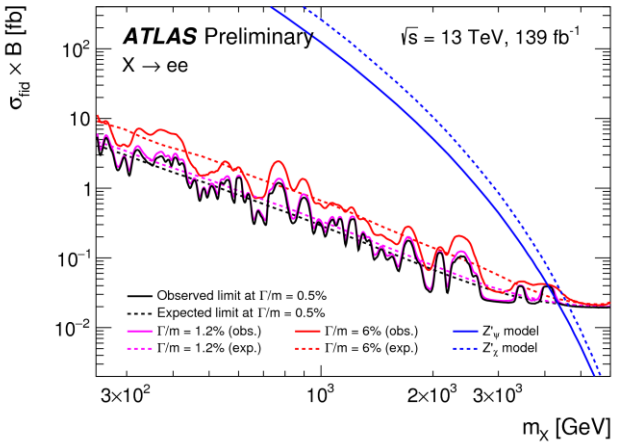
$Z' \rightarrow e^+e^-$, $\mu^+\mu^-$

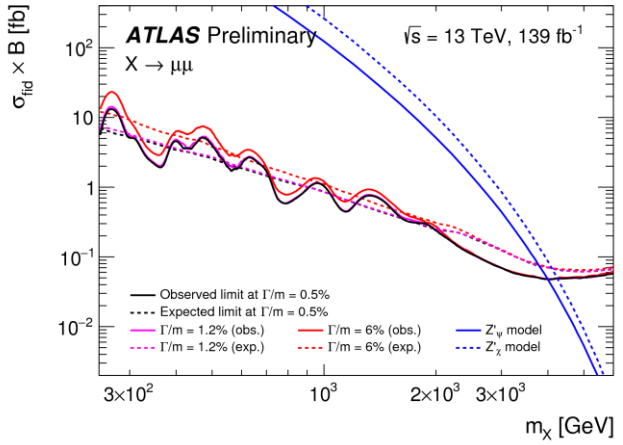






Channel	Model	Obs. limit [TeV]	Exp. limit [TeV]
ee (2017)	Z'_{SSM}	4.10	4.15
	Z'_{ψ}	3.35	3.55
ee (2016 and 2017) + $\mu\mu$ (2016)	Z'_{SSM}	4.7	4.7
	Z'_{ψ}	4.1	4.1

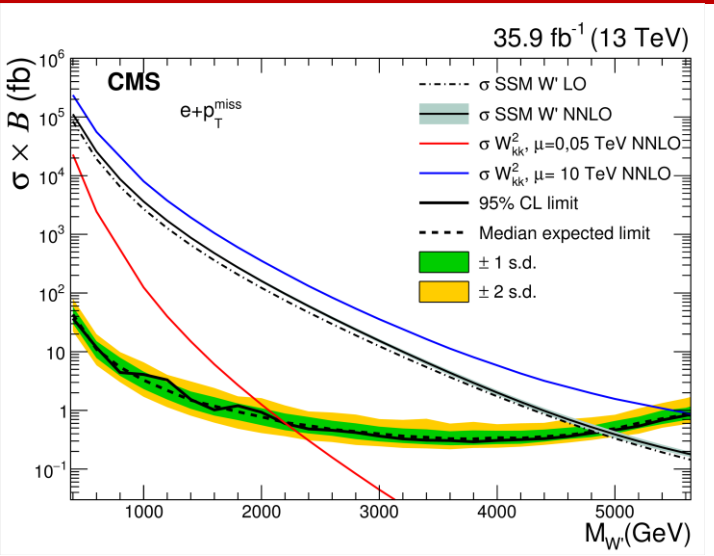




Model	Lower limits on $m_{Z'}$ [TeV]					
	ee		$\mu\mu$		$\ell\ell$	
	obs	exp	obs	exp	obs	exp
Z'_{ψ}	4.3	4.3	4.0	3.8	4.5	4.5
Z'_{χ}	4.6	4.6	4.2	4.1	4.8	4.7
Z'_{SSM}	4.9	4.9	4.5	4.4	5.1	5.0

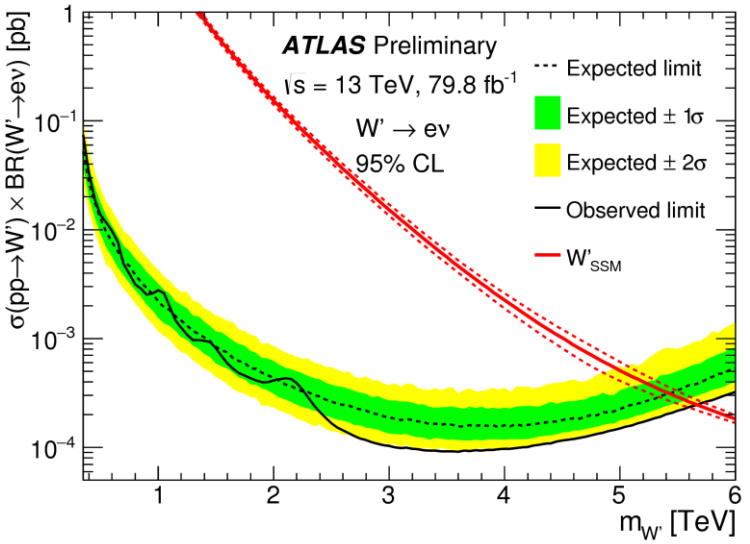
W'→ eν , μν

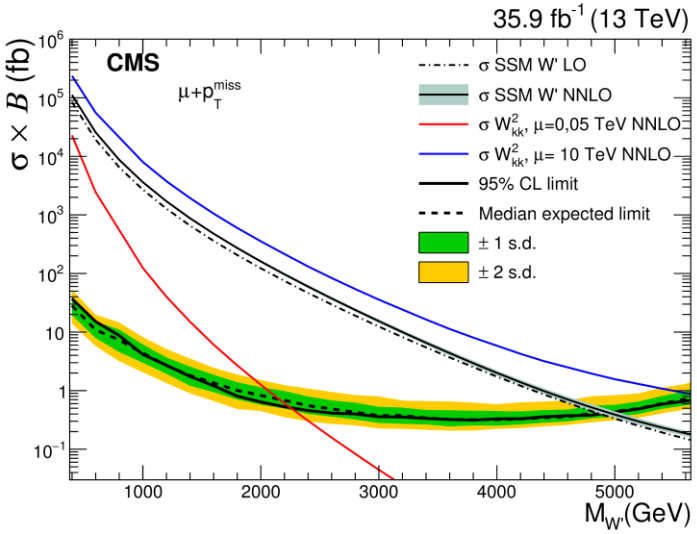
36/80 fb^{-1}



ATLAS (SSM model)

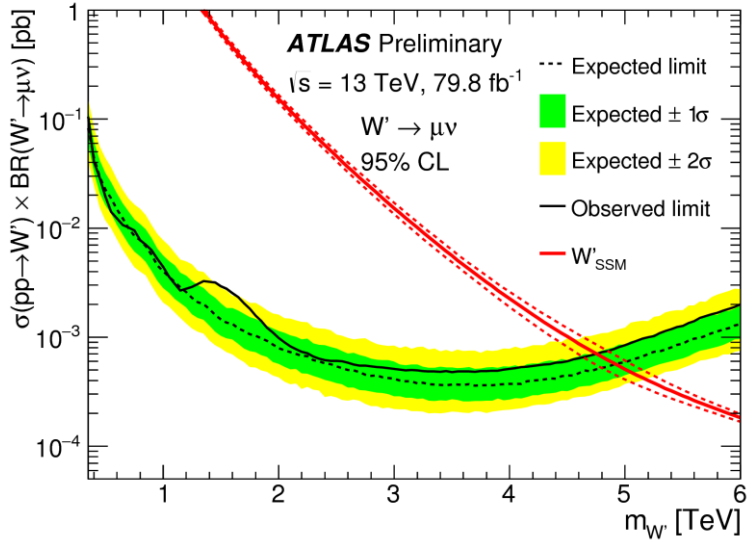
Decay	$m_{W'}$ lower limit [TeV] Expected	Observed
$W' \to e\nu$	5.4	5.7
$W' \to \mu\nu$	4.9	4.8
$W' \to \ell\nu$	5.5	5.6





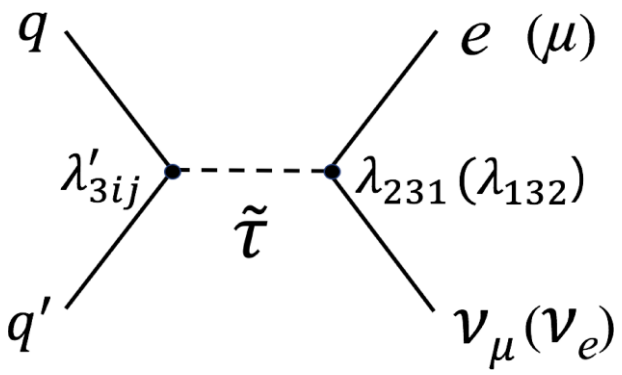
CMS (SSM model)

Decay	$m_{W'}$ lower limit [TeV] Expected	Observed
$W' \to e\nu$	5.0	4.9
$W' \to \mu\nu$	4.9	4.9
$W' \to \ell\nu$	5.2	5.2



W'→ eν , μν

36 fb^{-1}

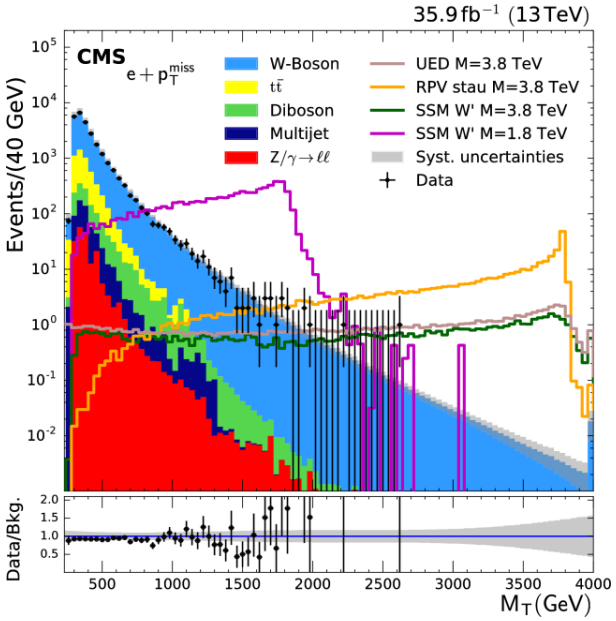


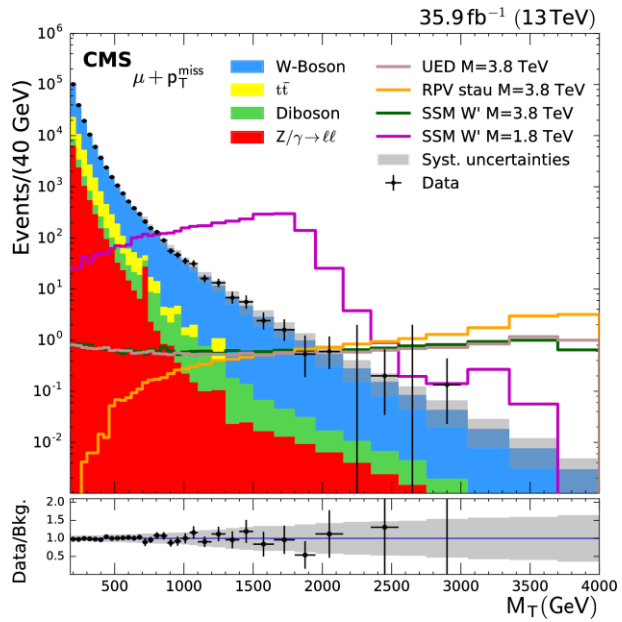
RPV SUSY :
scalar stau ($\tilde{\tau}$) could act as a **mediator** with couplings λ_{231} (λ_{132}) for the electron (muon) final states.

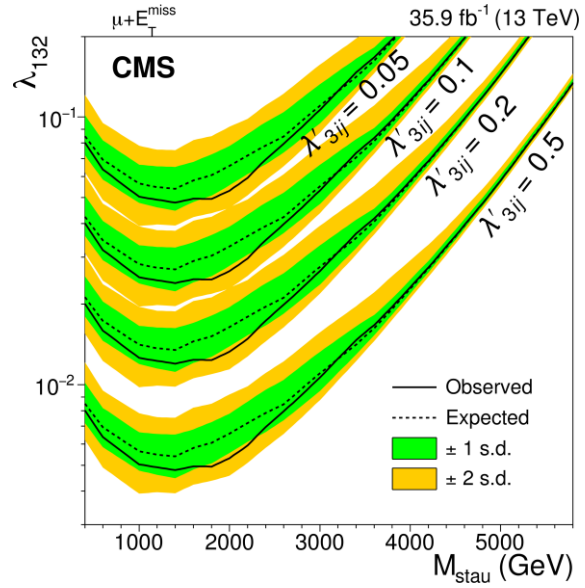
R-parity and lepton flavor violating decay to a charged lepton and a neutrino [Phys. Rev. D **86** (2012) 055010, Phys. Lett. B **76** (1978) 575]

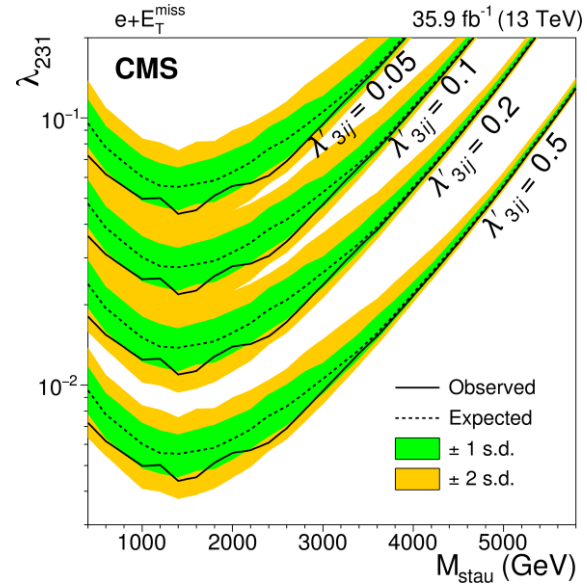
λ'_{3ij} : hadronic-leptonic RPV coupling to the 3rd generation

Signal samples : MadGraph 5 (v1.5.14) at LO
M_{stau} in the range 400-6000 GeV





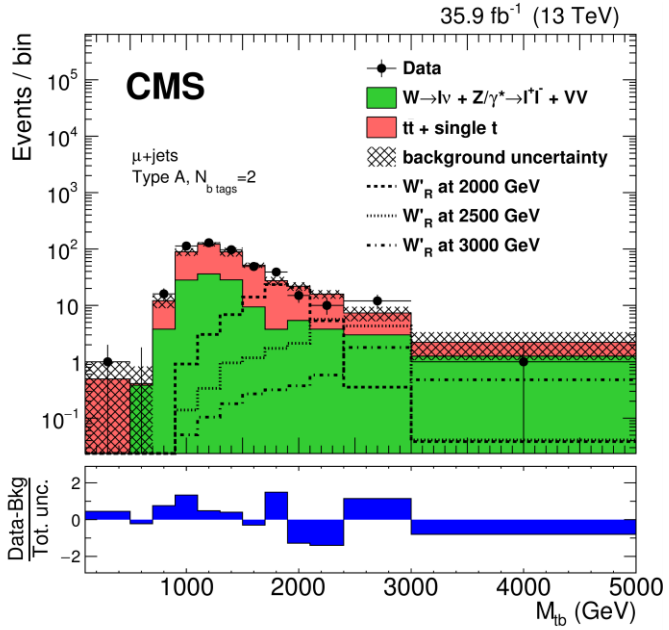


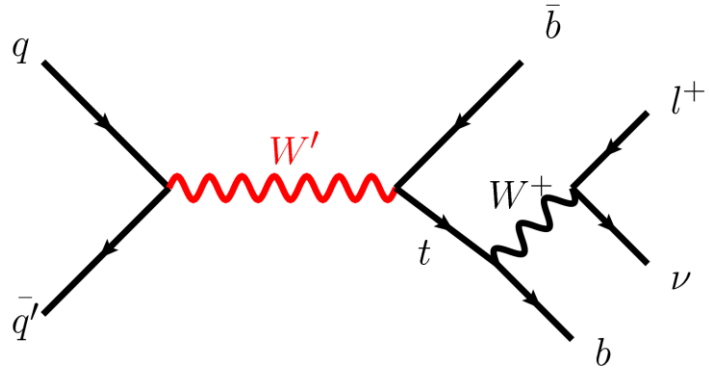


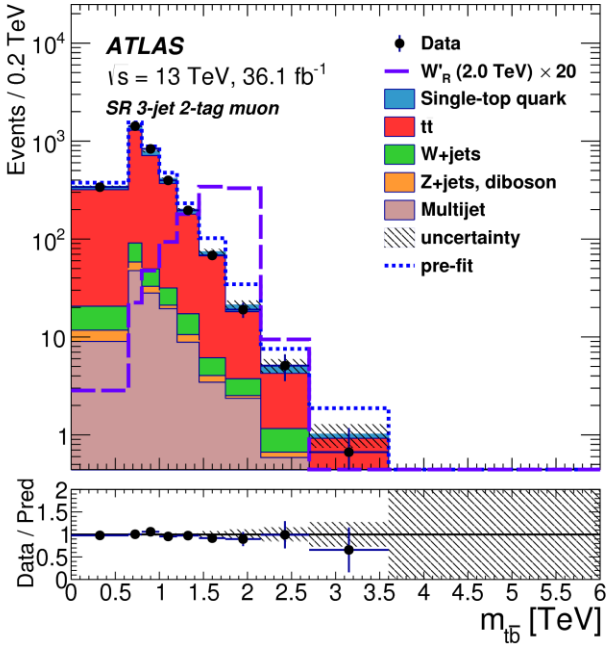
Phys. Lett. B 788 (2019) 347
Phys. Lett. B 777 (2017) 39

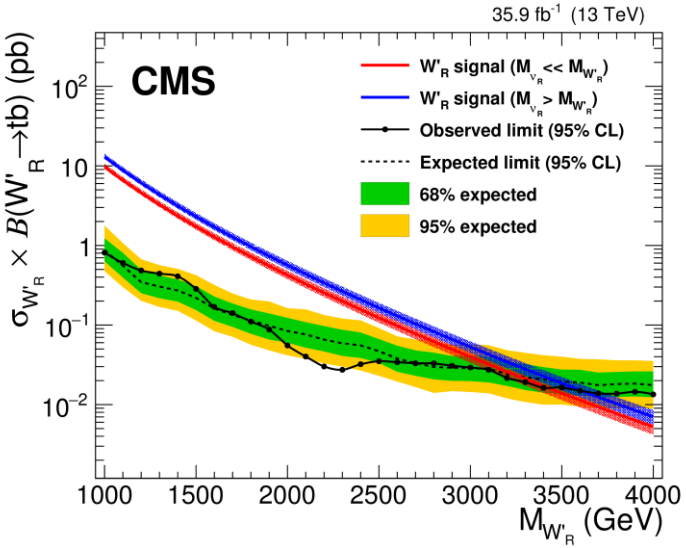
W'→tb

36 fb^{-1}

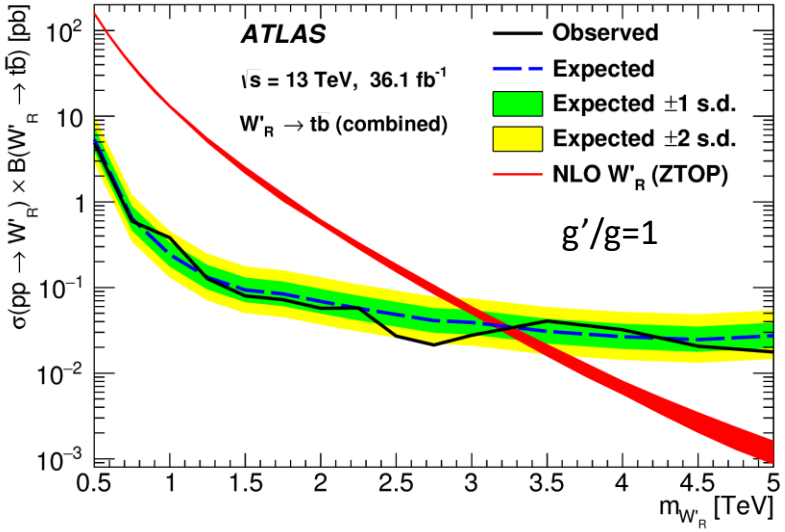






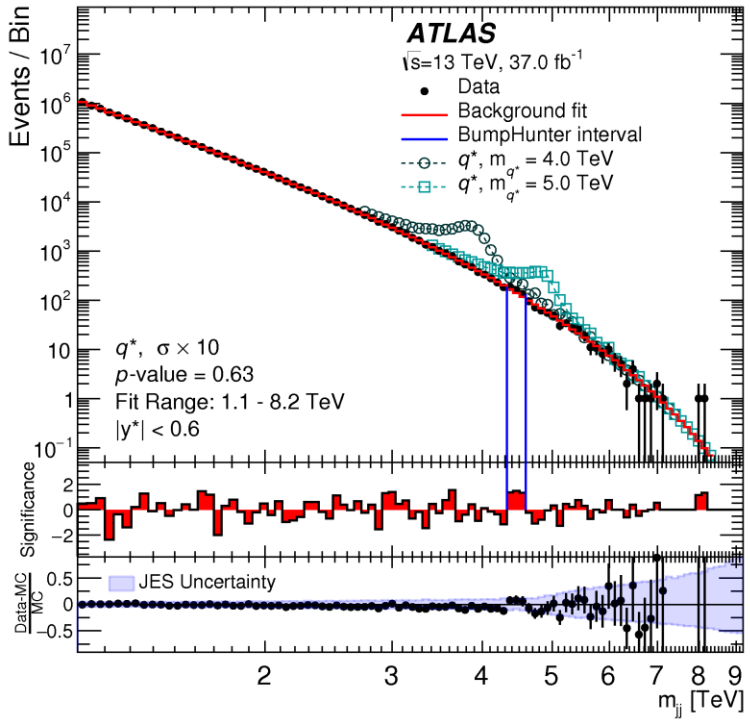


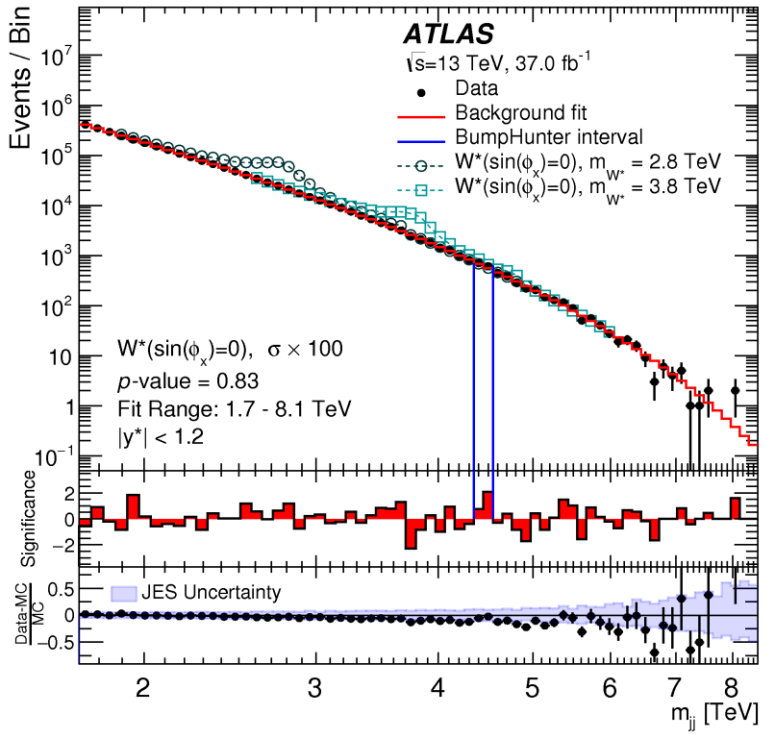
limits on the production of a right-handed W'$_R$ boson

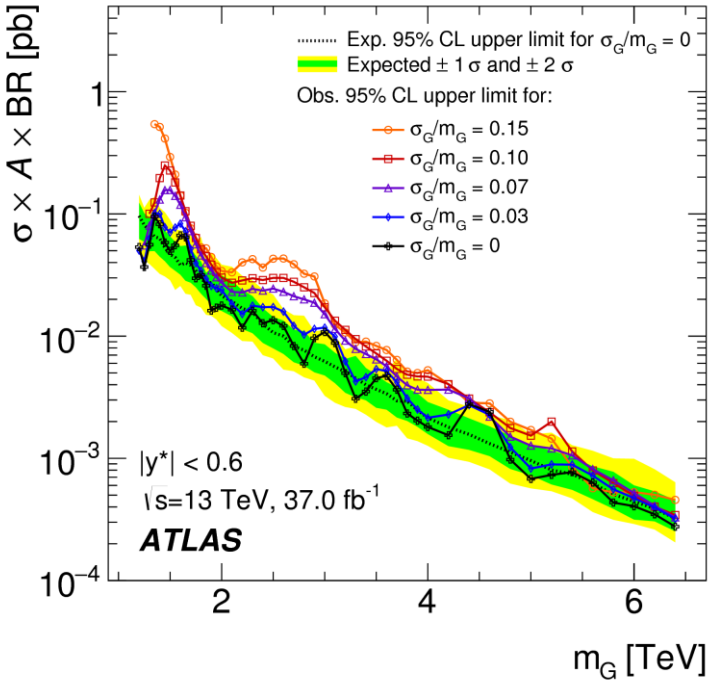


dijet resonances – high mass region

37 fb^{-1}







- jets : anti-k_T, R = 0.4

High-level trigger : at least one jet with p_T> 380 GeV

Offline : p_T>440 (60) GeV for the leading (subleading) jet.

rapidity difference : $y^* = (y_{jet1} - y_{jet2})/2$

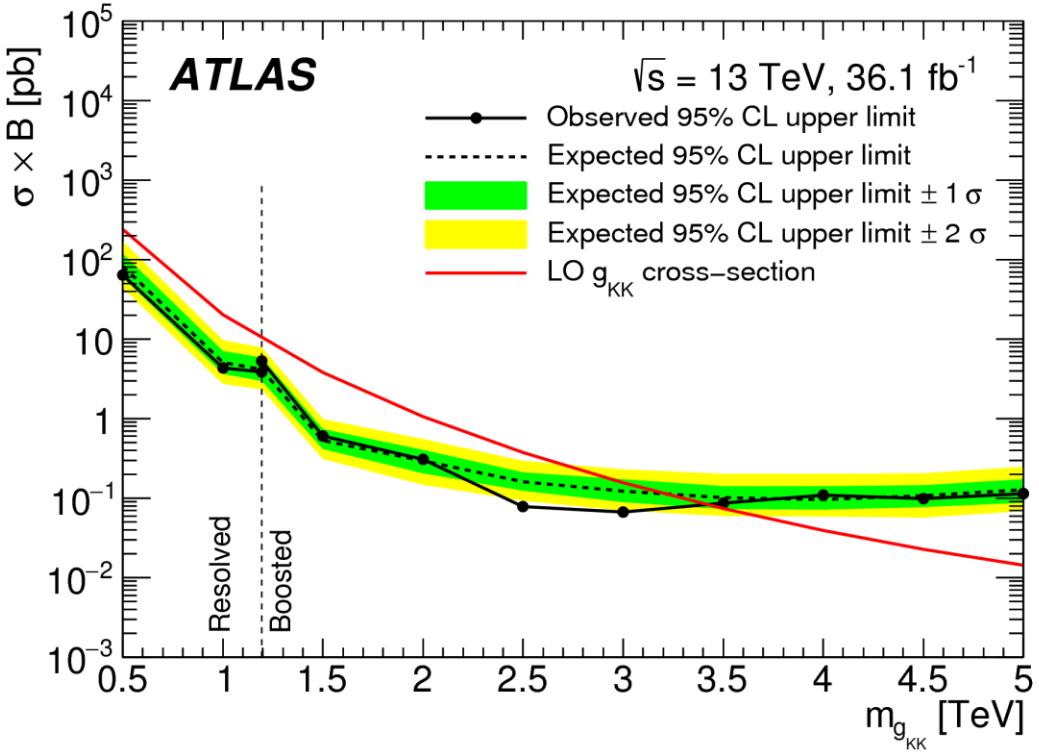
- background estimate : sliding-window fitting method

- Model-independent limits on signals with a Gaussian shape

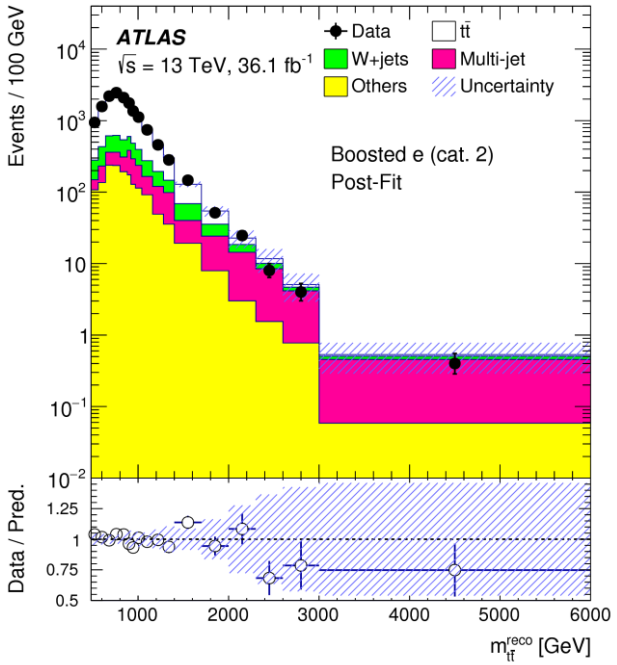
Model	95% CL exclusion limit	
	Observed	Expected
Quantum black hole	8.9 TeV	8.9 TeV
W'	3.6 TeV	3.7 TeV
W^*	3.4 TeV 3.77 TeV – 3.85 TeV	3.6 TeV
Excited quark	6.0 TeV	5.8 TeV
Z' ($g_q = 0.1$)	2.1 TeV	2.1 TeV
Z' ($g_q = 0.2$)	2.9 TeV	3.3 TeV
Contact interaction ($\eta_{LL} = -1$)	21.8 TeV	28.3 TeV
Contact interaction ($\eta_{LL} = +1$)	13.1 TeV 17.4 TeV – 29.5 TeV	15.0 TeV

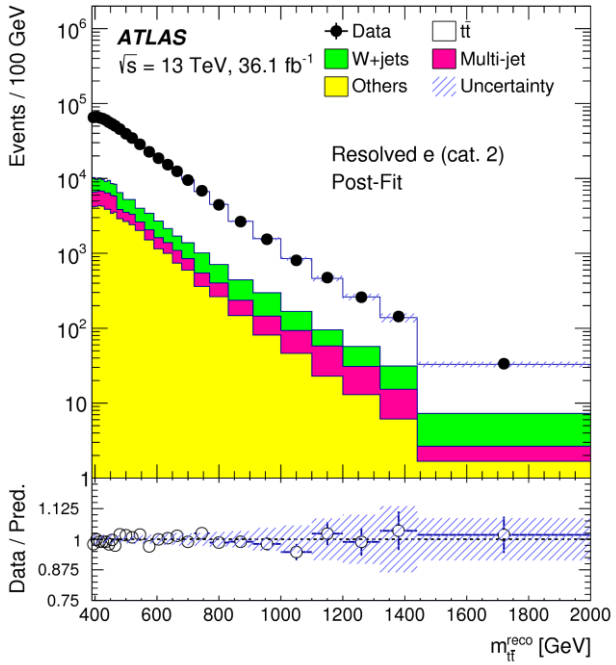
resonant tt̄ production

fully hadronic final state



lepton-plus-jets final state





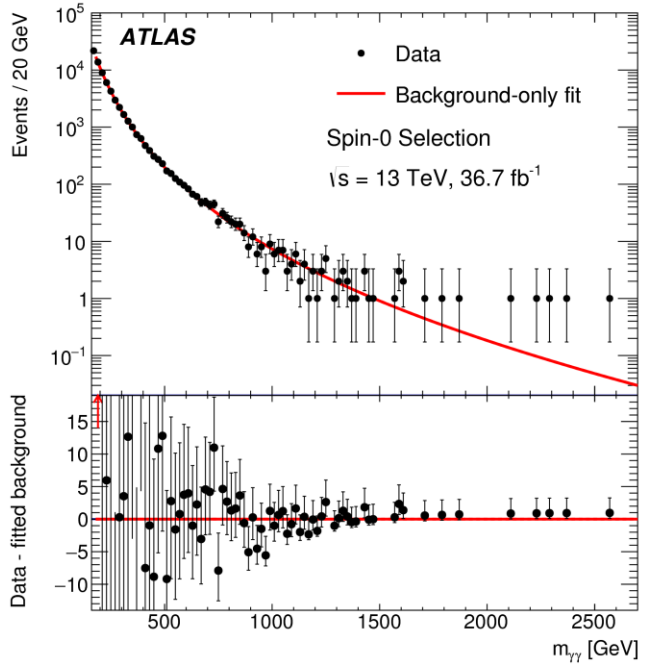
Signal		Expected excluded mass [TeV]	Observed excluded mass [TeV]
Z'_{TC2}	($\Gamma = 1\%$)	$[0.57, 2.8]$	$[0.58, 3.1]$
	($\Gamma = 3\%$)	$[0.51, 3.6]$	$[0.53, 3.6]$
Z'_{med}	(vector)	$[0.75, 1.07] \cup [2.0, 2.1]$	$[0.74, 0.97] \cup [2.0, 2.2]$
	(axial-vector)	$[1.99, 2.04]$	$[0.80, 0.92] \cup [2.0, 2.2]$
g_{KK}	($\Gamma = 10\%$)	< 3.5	< 3.4
	($\Gamma = 20\%$)	< 3.4	< 3.4
	($\Gamma = 30\%$)	< 3.3	< 3.4
	($\Gamma = 40\%$)	< 3.2	< 3.4

Summary of 95 % Confidence Level mass exclusion ranges on benchmark models

Model	Observed excluded mass [TeV]	Expected excluded mass [TeV]
Z'_{TC2} (1% width)	< 3.0	< 2.6
$Z'_{\mathrm{DM,ax}}$	< 1.2	< 1.4
$Z'_{\mathrm{DM,vec}}$	< 1.4	< 1.6
G_{KK}	[0.45, 0.65]	[0.45, 0.65]
g_{KK} (15% width)	< 3.8	< 3.5
g_{KK} (30% width)	< 3.7	< 3.2

Heavy resonances in γγ

37 fb^{-1}



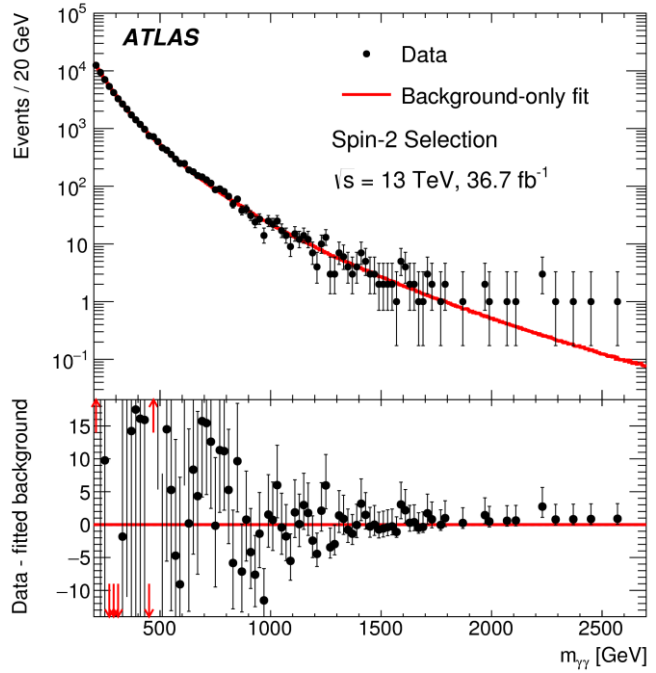
searches :
spin 0 resonances
(predicted by theories with an extended Higgs sector)

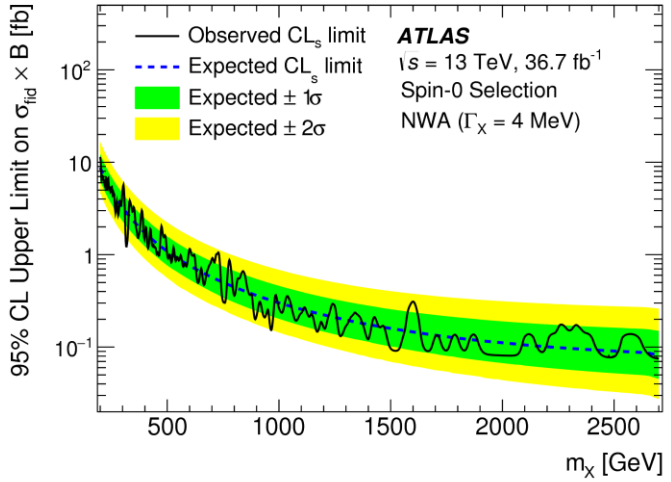
spin 2 resonances
(a warped extra-dimension Model is used as benchmark)

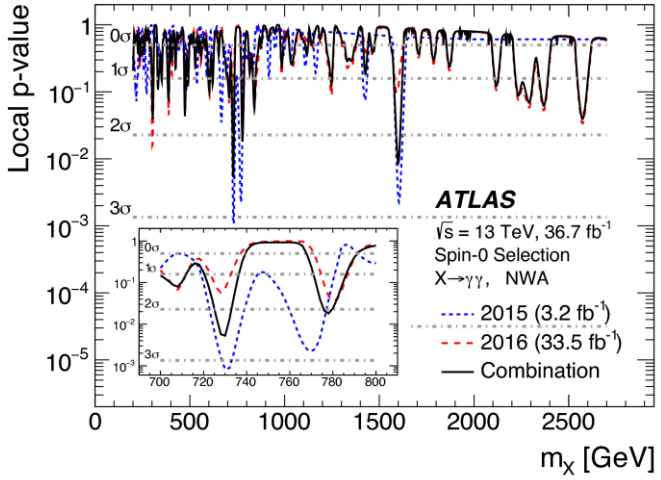
Kinematic selection

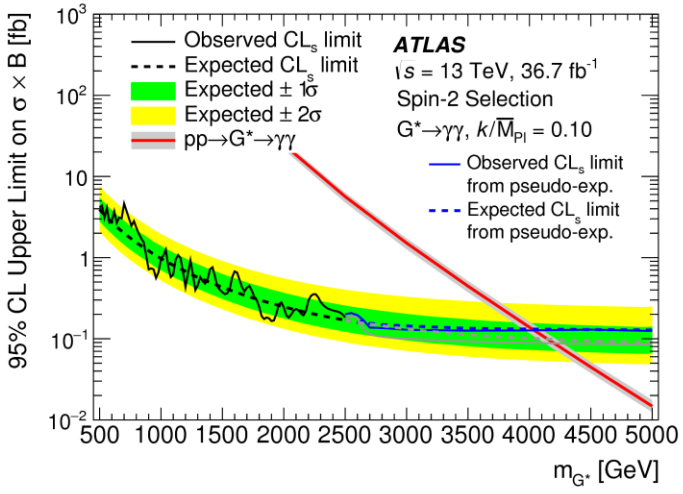
spin-0 resonance : E_T>0.4 $m_{\gamma\gamma}$ (leading photon) ,
E_T>0.3 $m_{\gamma\gamma}$ (subleading photon)

spin-2 resonance : E_T> 55 GeV for each photon





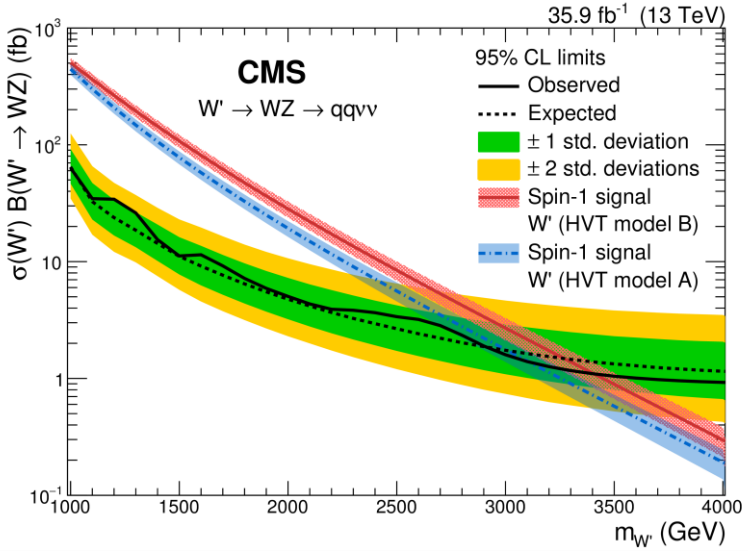


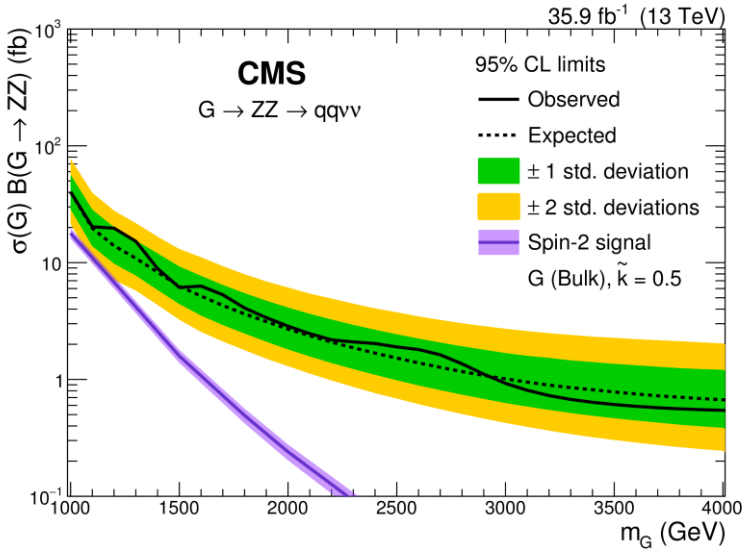


X→WW,WZ,ZZ

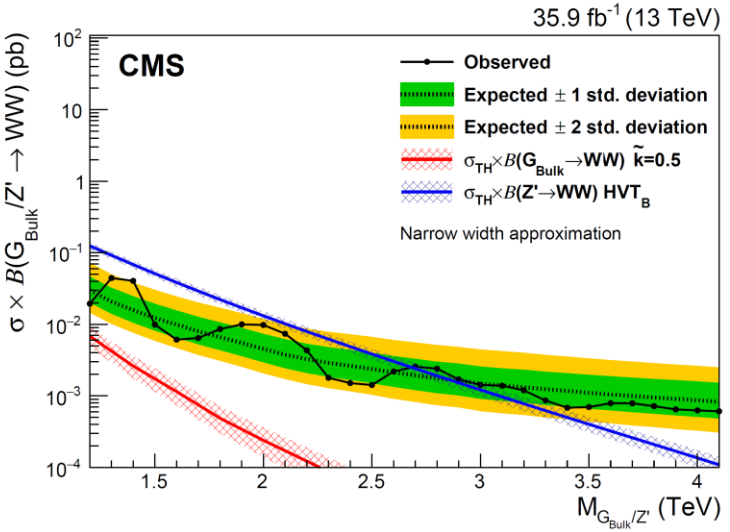
36 fb^{-1}

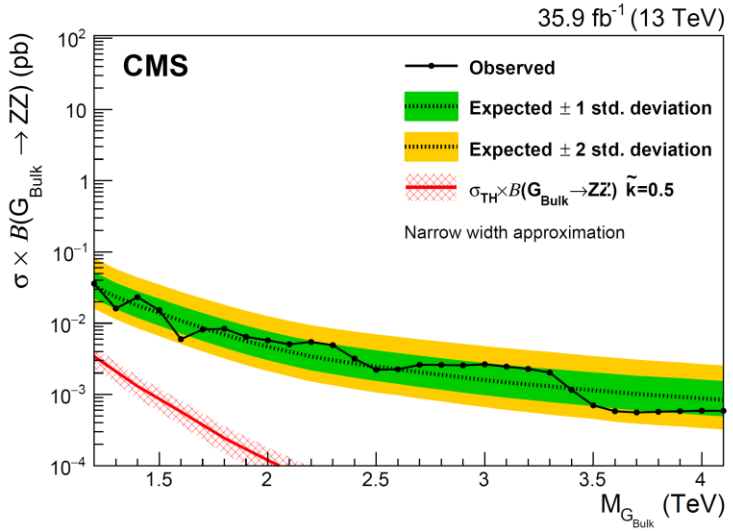
X → VZ → qqνν

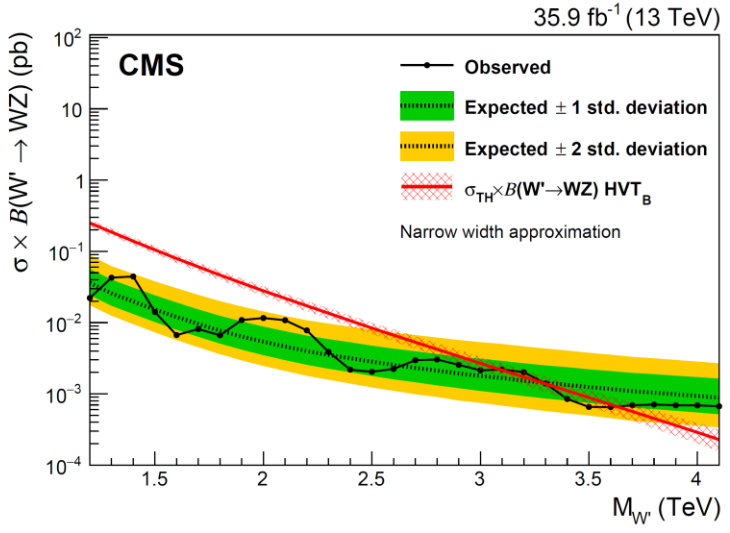


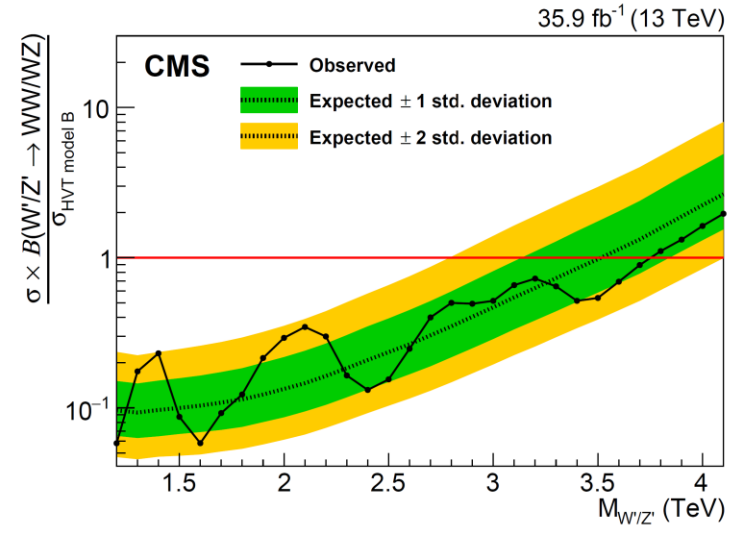


X→ WW, WZ, ZZ, qW, qZ W,Z→ dijet









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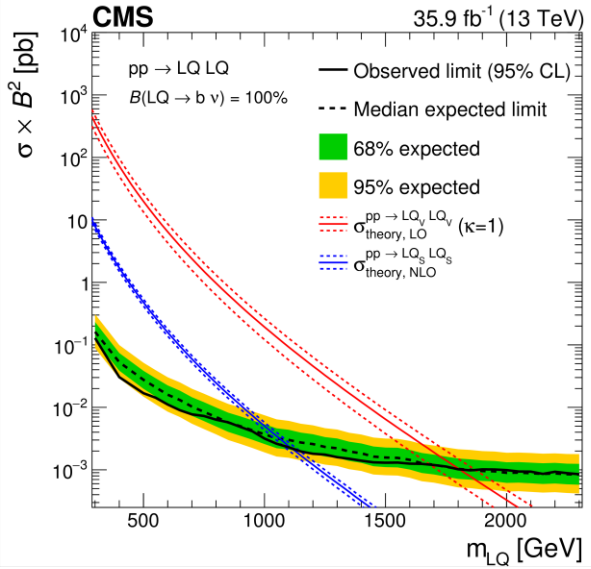
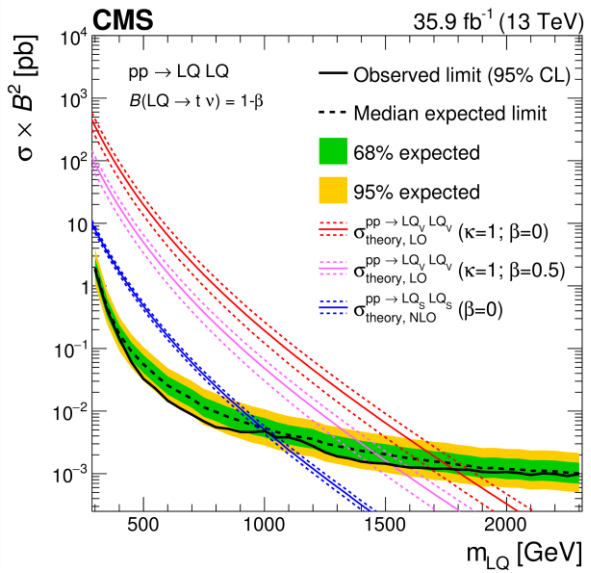
3rd - generation scalar LQ

36 fb^{-1}





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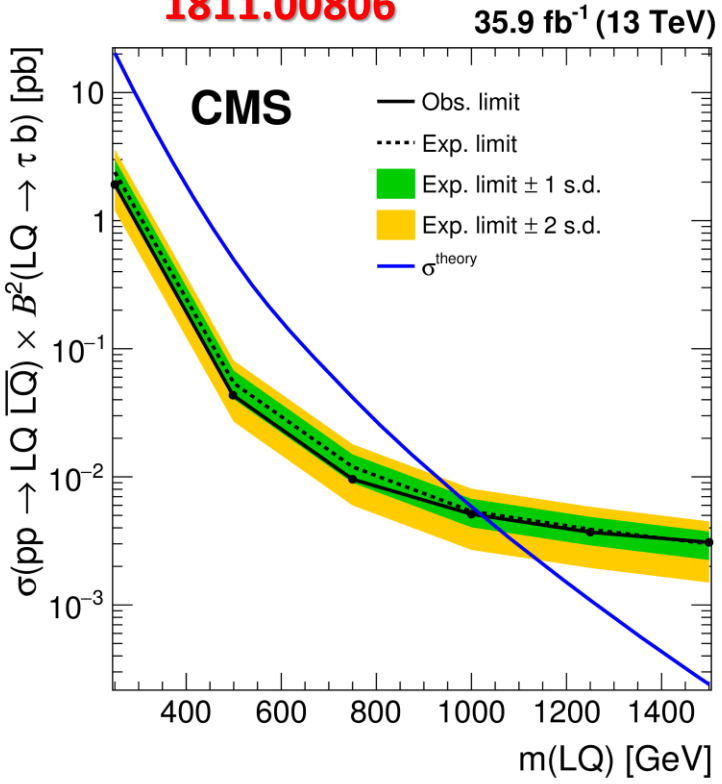

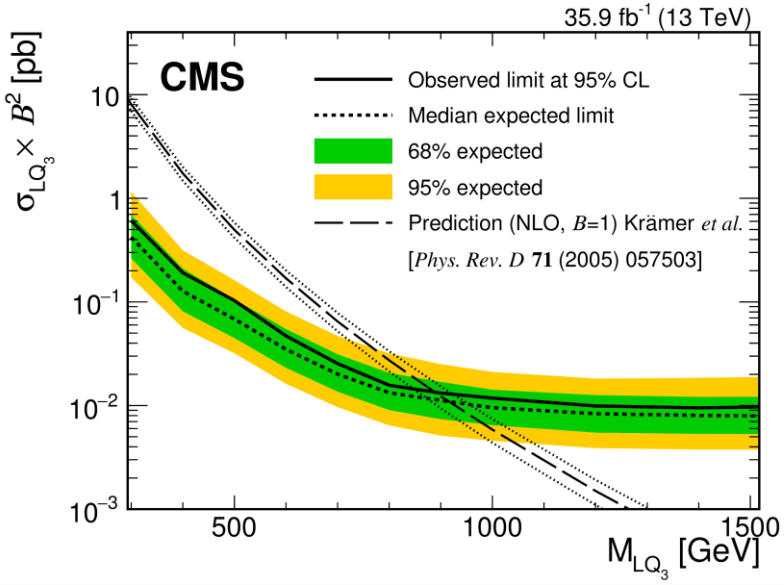

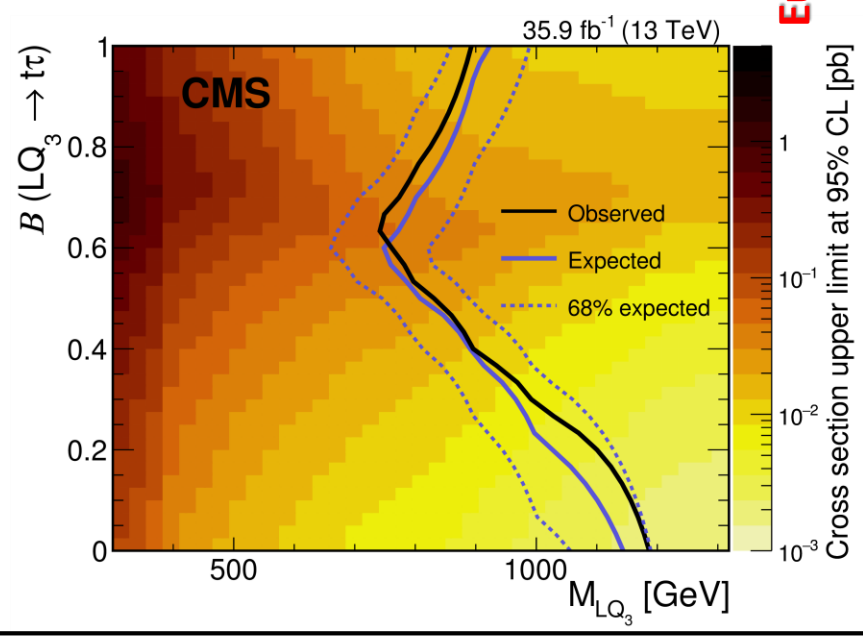

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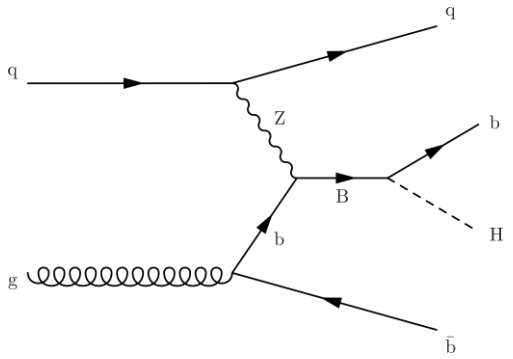
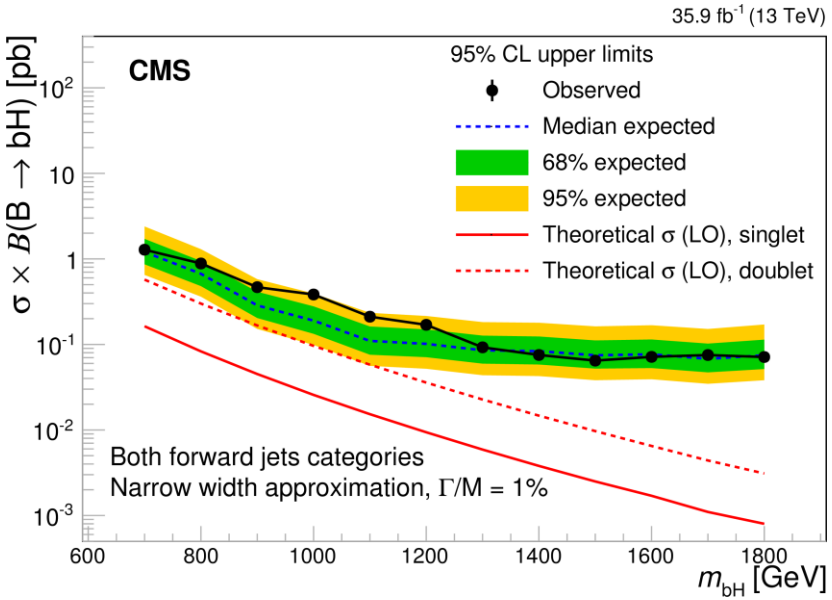
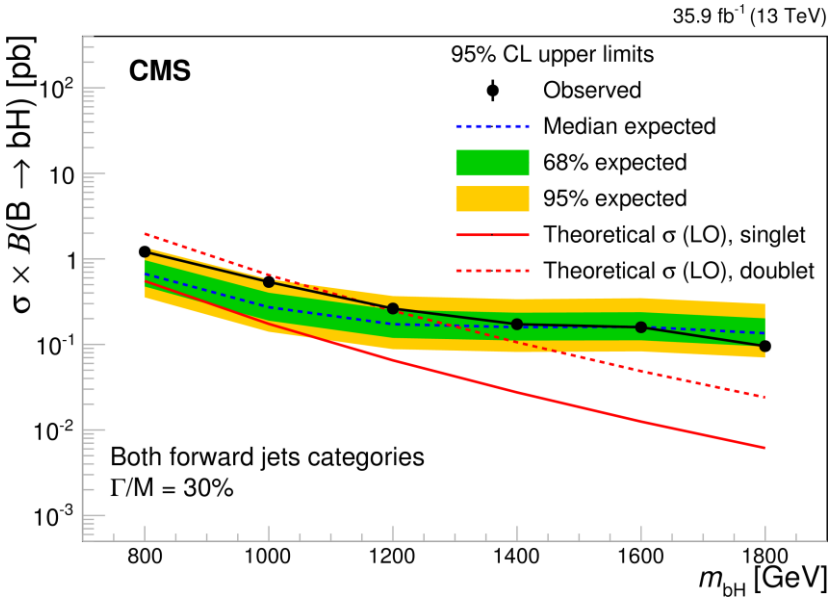
Vector Like B→Hb →(bb)b

36 fb^{-1}







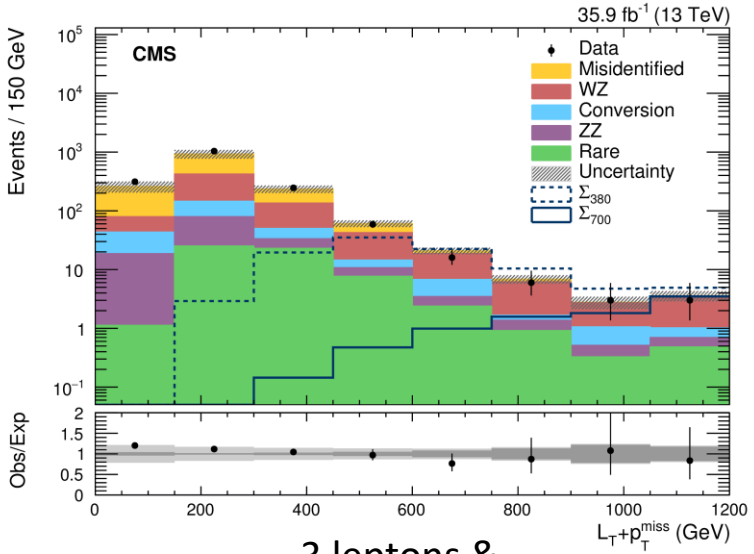
H→ bb : highly boosted pair reconstructed as a single collimated jet

assumptions : B quark belongs to a singlet or doublet representation. It decays exclusively to SM particles.

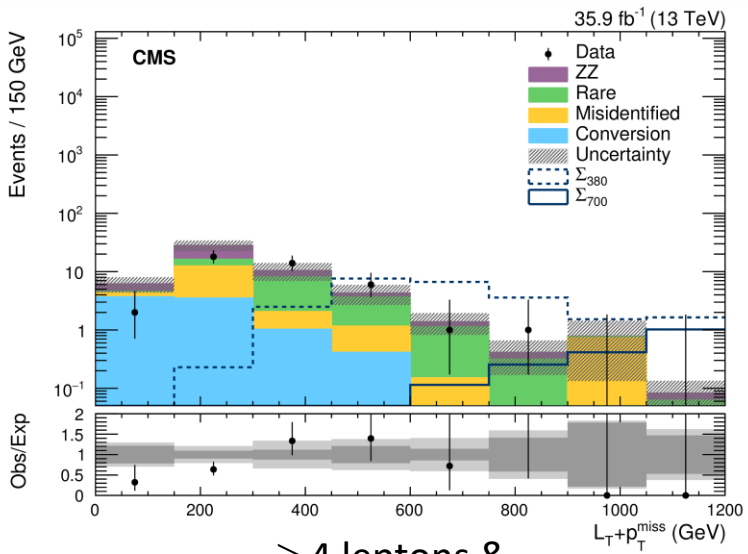
singlet BRs of B → Hb, Zb, Wt are 25%, 25%, 50%,
doublet BRs of B → Hb, Zb, Wt are 50%, 50%, 0%

BRs depend on the VLQ mass m_B

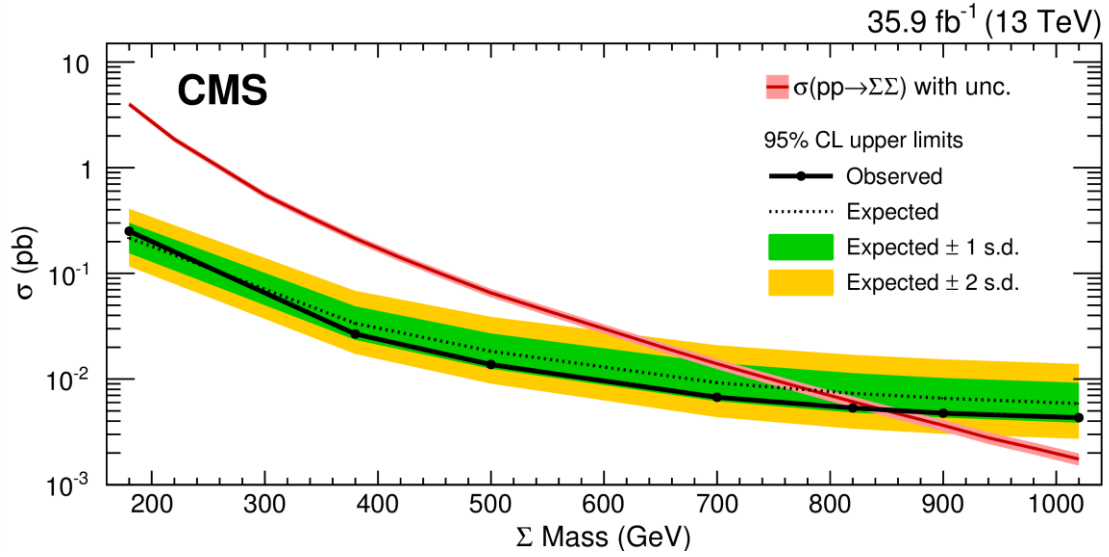
type-III seesaw heavy leptons



3 leptons &
1 OSSF pair with mass above-Z



$\geq$ 4 leptons &
1 OSSF pair



type-III model : new **charged** (**Σ$^{\pm}$**) and **neutral** (**Σ^{0}**) heavy leptons could be produced in EW processes

$$\Sigma^{\pm} \to W^{\pm}\nu_{\ell},\ \Sigma^{\pm} \to Z\ell^{\pm},\ \Sigma^{\pm} \to H\ell^{\pm}$$

$$\Sigma^{0} \to W^{\pm}\ell^{\mp}\quad \Sigma^{0} \to Z\nu_{\ell}\quad \Sigma^{0} \to H\nu_{\ell}$$

$$\ell = e, \mu, \text{ or } \tau$$

All combination are considered

Σ$^{\pm}$, **Σ^{0}** degenerate in mass at tree level

$$B_{\ell} \sim |V_{\ell}|^2 / (|V_e|^2 + |V_{\mu}|^2 + |V_{\tau}|^2$$

V_{ℓ} : heavy-light fermion mixing angle

excluded M_{Σ} [GeV] at 95% CL

$B_e=B_{\mu}=B_{\tau}$	:	< 840
$B_e+B_{\mu}=1$, $B_{\tau}=0$	:	< 900-930
$B_e+B_{\mu}=0$, $B_{\tau}=1$	:	< 390