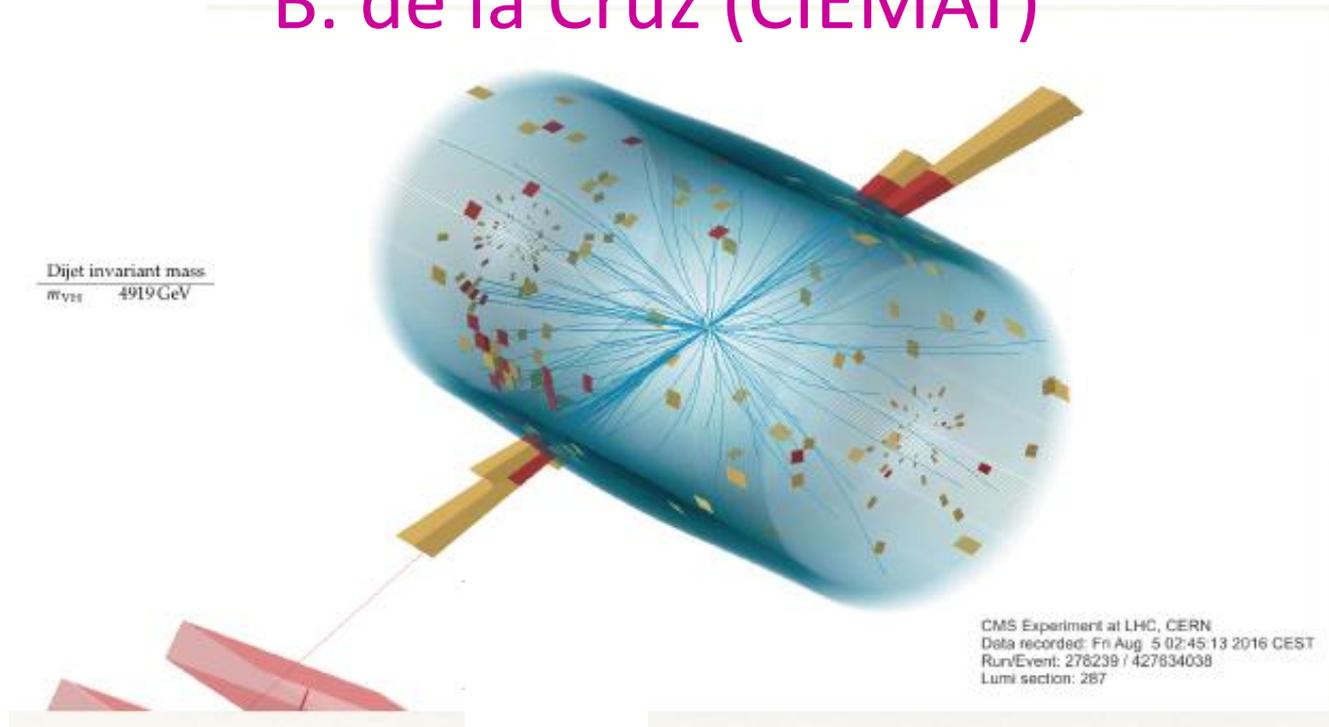




Searches for high mass resonances using leptonic final state evts at 13 TeV in CMS

B. de la Cruz (CIEMAT)



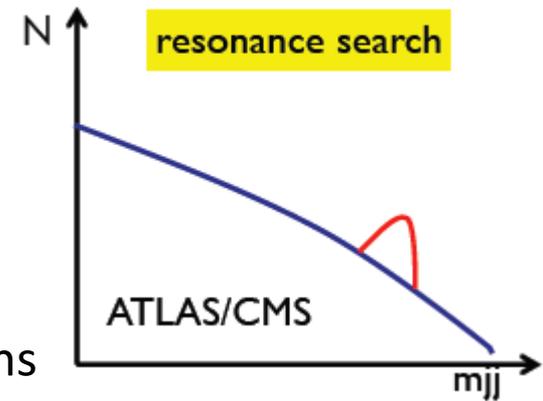
Red LHC – CIEMAT (Madrid)

10th May 18

Searches in final states with leptons

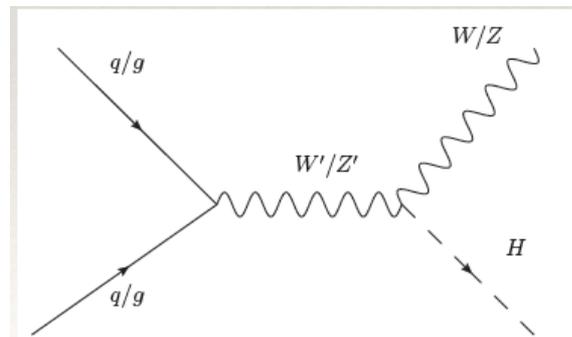
New physics searches benefit from:

- Highest energies/masses → region in phase space in the kinematical limit, basically free of SM background → “easy” bump hunting search, though control region?
- Highest statistics → Precision knowledge of SM background, sensitive to small deviations from predictions



Experimental clean events: inclusive final states with leptons: $l+p_T^{\text{miss}}, e\mu, l^+l^-$

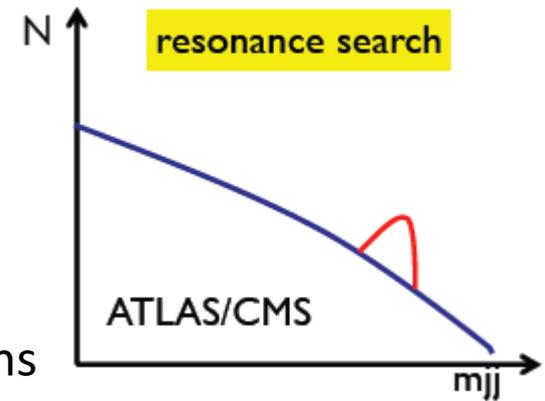
Motivation: new (vector) bosons not a necessary ingredient to extend SM into a more general theory, but many models predict their existence. → Look for them!



Searches in final states with leptons

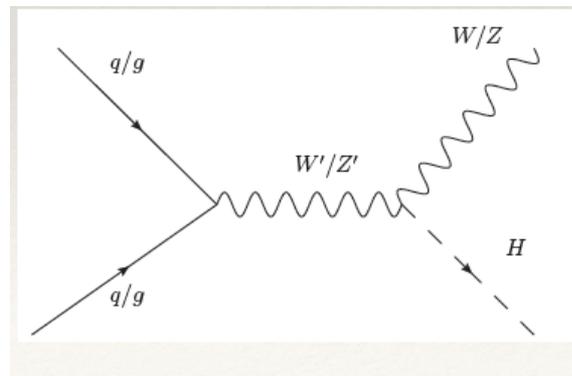
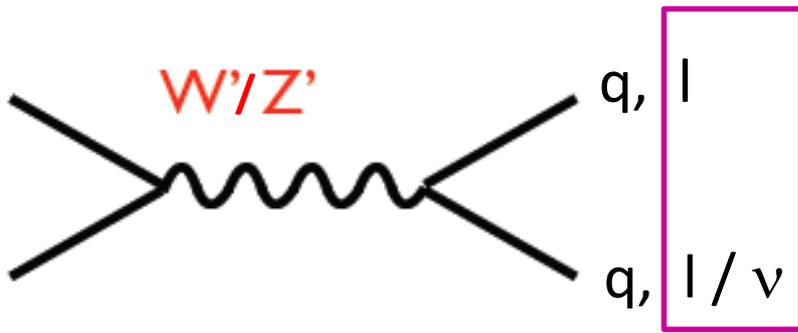
New physics searches benefit from:

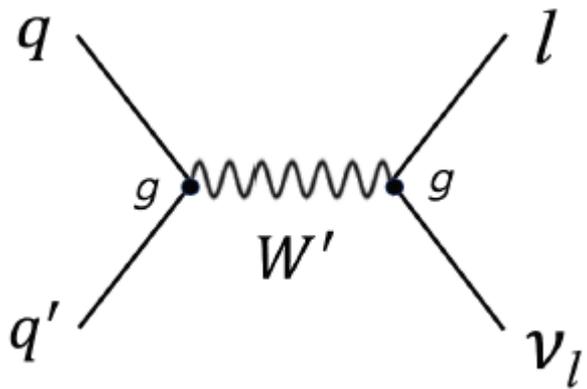
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Motivation: new (vector) bosons not a necessary ingredient to extend SM into a more general theory, but many models predict their existence. → Look for them!

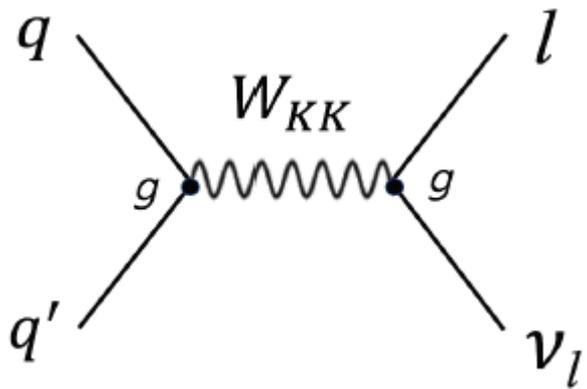




Benchmark scenario: **SSM**

W' / Z' : copy of SM W / Z (same couplings, decay modes)

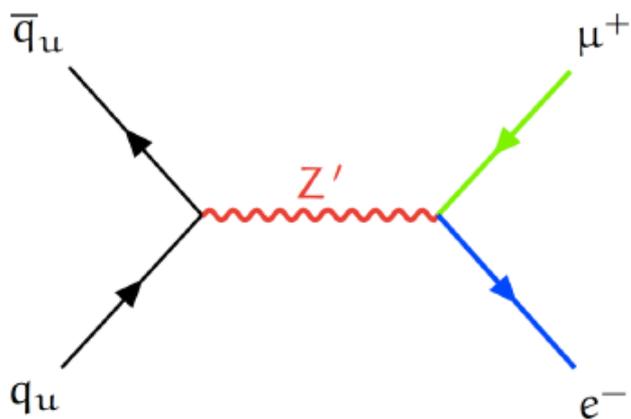
Experimental final state	SSM V'	LFV V'	RPV Slepton	Extra-dim (RS-ADD)	DM
Dilepton ($\mu\mu, ee$)	X			X	X
Dilepton $e\mu$		X	X	X	
Single lepton ($\mu/e + p_T^{\text{miss}}$)	X		X	X	X



Models assuming extra spatial dimensions (KK, RS, ADD)

Experimental final state	SSM V'	LFV V'	RPV Slepton	Extra-dim (RS-ADD)	DM
Dilepton ($\mu\mu, ee$)	X			X	X
Dilepton $e\mu$		X	X	X	
Single lepton ($\mu/e + p_T^{\text{miss}}$)	X		X	X	X

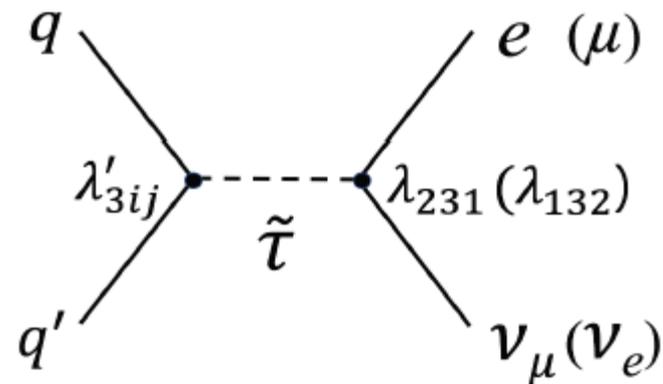
Experimental final state	SSM V'	LFV V'	RPV Slepton	Extra-dim (RS-ADD)	DM
Dilepton ($\mu\mu, ee$)	X			X	X
Dilepton $e\mu$		X	X	X	
Single lepton ($\mu/e + p_T^{\text{miss}}$)	X		X	X	X



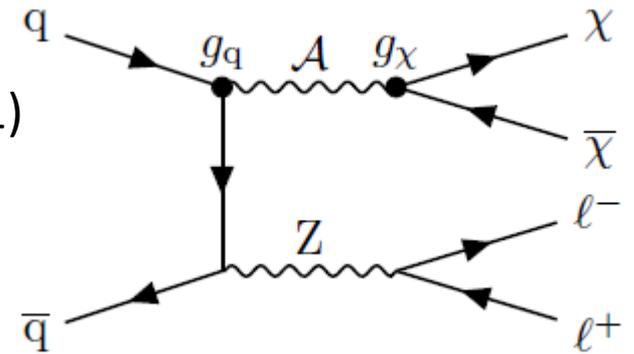
Models assuming Lepton Flavour Violation

Experimental final state	SSM V'	LFV V'	RPV Slepton	Extra-dim (RS-ADD)	DM
Dilepton ($\mu\mu, ee$)	X			X	X
Dilepton $e\mu$		X	X	X	
Single lepton ($\mu/e + p_T^{\text{miss}}$)	X		X	X	X

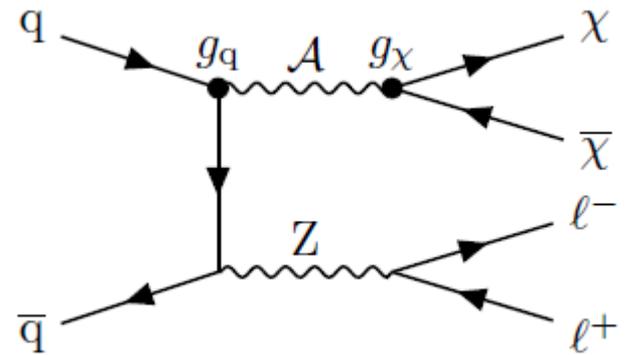
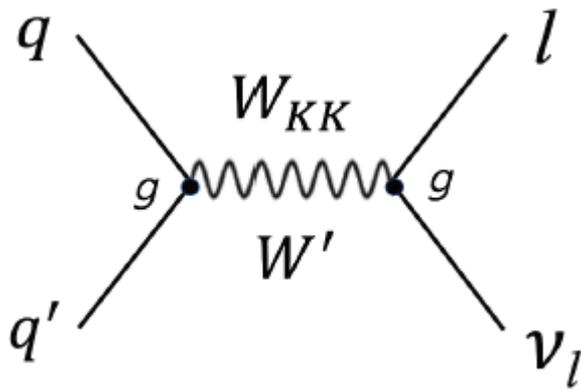
RPV SUSY model assuming sleptons as mediators, which can be LSP.
Lepton flavour and lepton number are violated



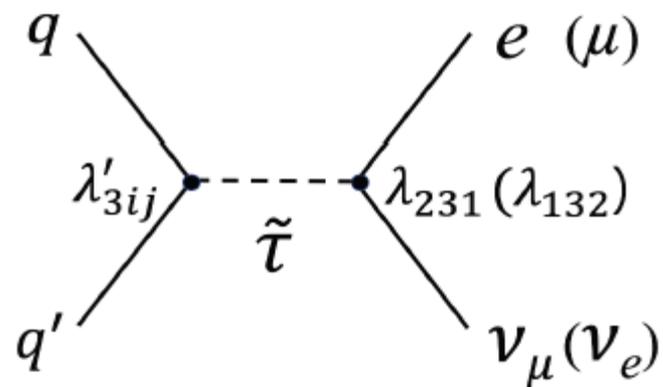
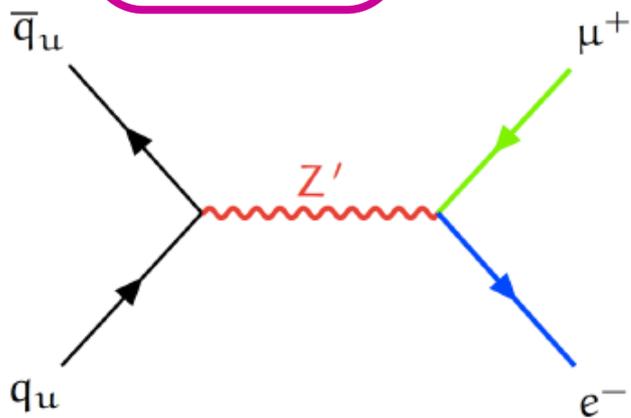
- Simplified model, with a high mass Mediator ($s=1$) (vector/axial-vector boson) exchanged.
- DM particle assumed a Dirac fermion
- Parameters: $m_{\text{Med}}, m_{\chi}, g_{\chi}, g_q$



Experimental final state	SSM V'	LFV V'	RPV Slepton	Extra-dim (RS-ADD)	DM
Dilepton ($\mu\mu, ee$)	X			X	X
Dilepton $e\mu$		X	X	X	
Single lepton ($\mu/e + p_T^{\text{miss}}$)	X		X	X	X



Experimental final state	SSM V'	LFV V'	RPV Slepton	Extra-dim (RS-ADD)	DM
Dilepton $(\mu\mu, ee)$	X			X	X
Dilepton $e\mu$		X	X	X	
Single lepton $(\mu/e + p_T^{\text{miss}})$	X		X	X	X



Experimental final state	SSM V'	LFV V'	RPV Slepton	Extra-dim (RS-ADD)	DM
Dilepton ($\mu\mu, ee$)	X			X	X
Dilepton $e\mu$		X	X	X	
Single lepton ($\mu/e + p_T^{\text{miss}}$)	X		X	X	X

- Studying different parameters (mass, couplings, etc) in each case
- Different signal widths assumed when possible
- Model “independent” studies, or benchmark scenarios (SSM, etc) assumed
- No interference effects, no offshell contributions from PDF

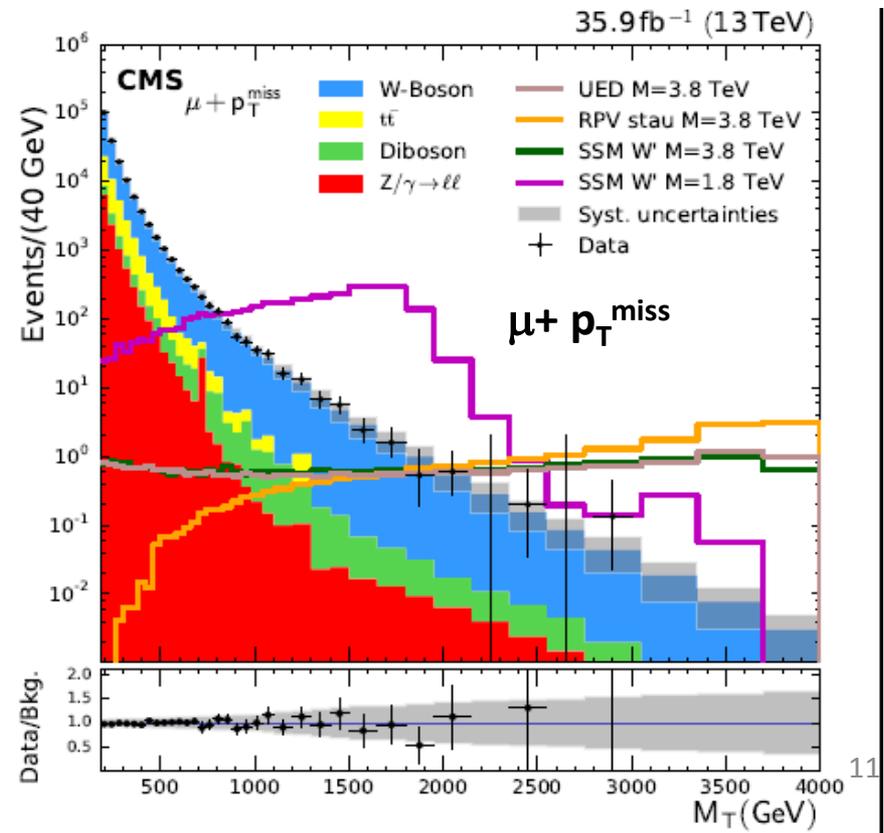
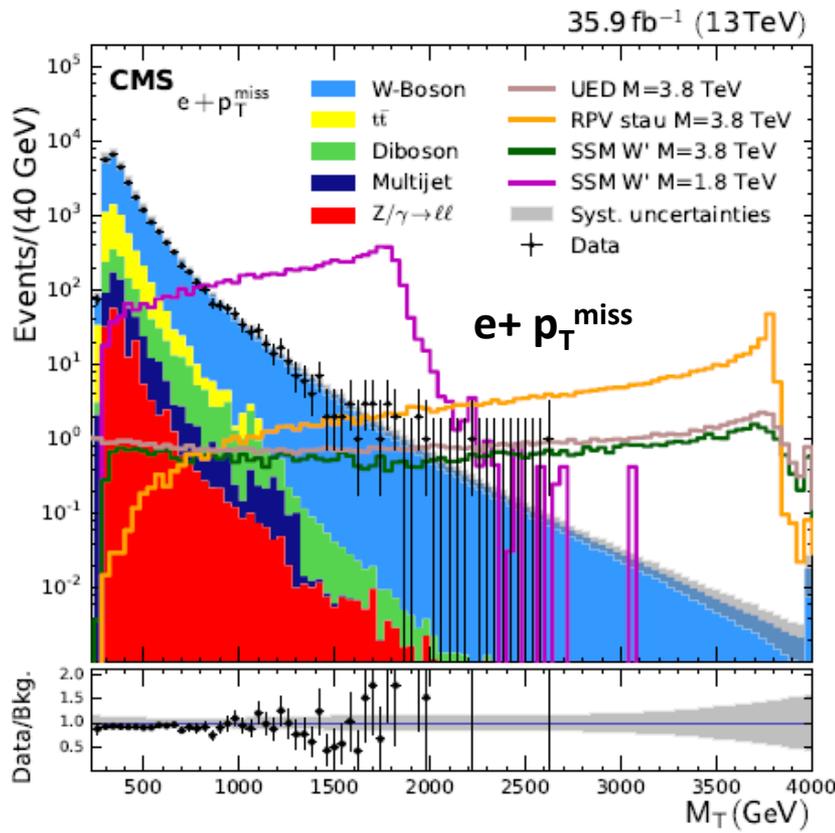
$pp \rightarrow l(e, \mu) + p_T^{\text{miss}}$

arXiv:1803.11133

Experimental key points at high p_T/M_T region

- Lepton p_T measurement: scale & resolution (especially μ -bremstrahlung in detector material)
- Fake leptons : especially electrons.
- Missing p_T resolution: - Σp_T over all particles in evt

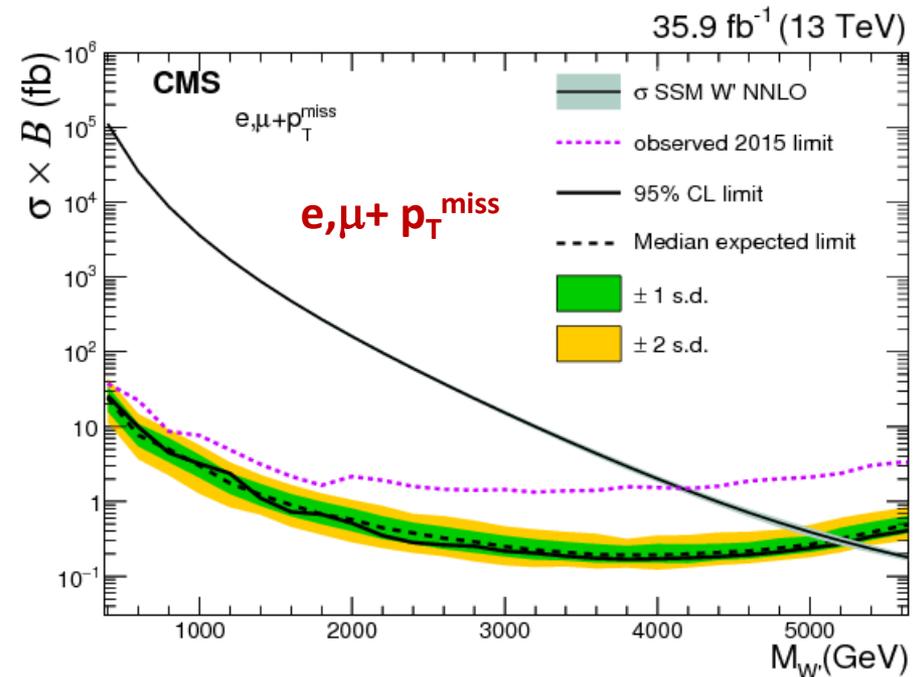
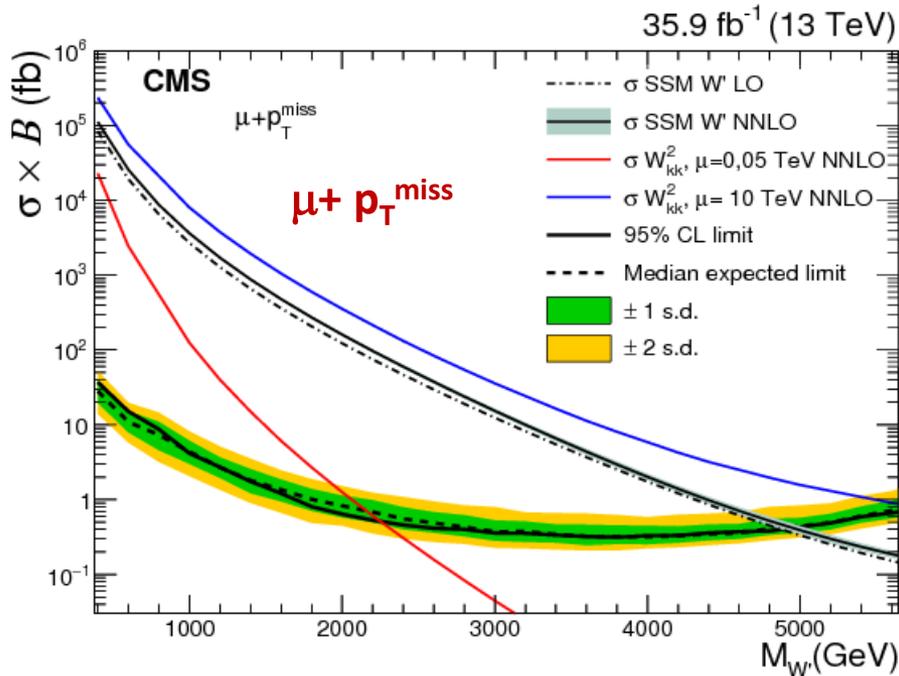
Typical signal efficiencies $\sim 75\%$



$pp \rightarrow l(e,\mu) + p_T^{\text{miss}}$

arXiv:1803.11133

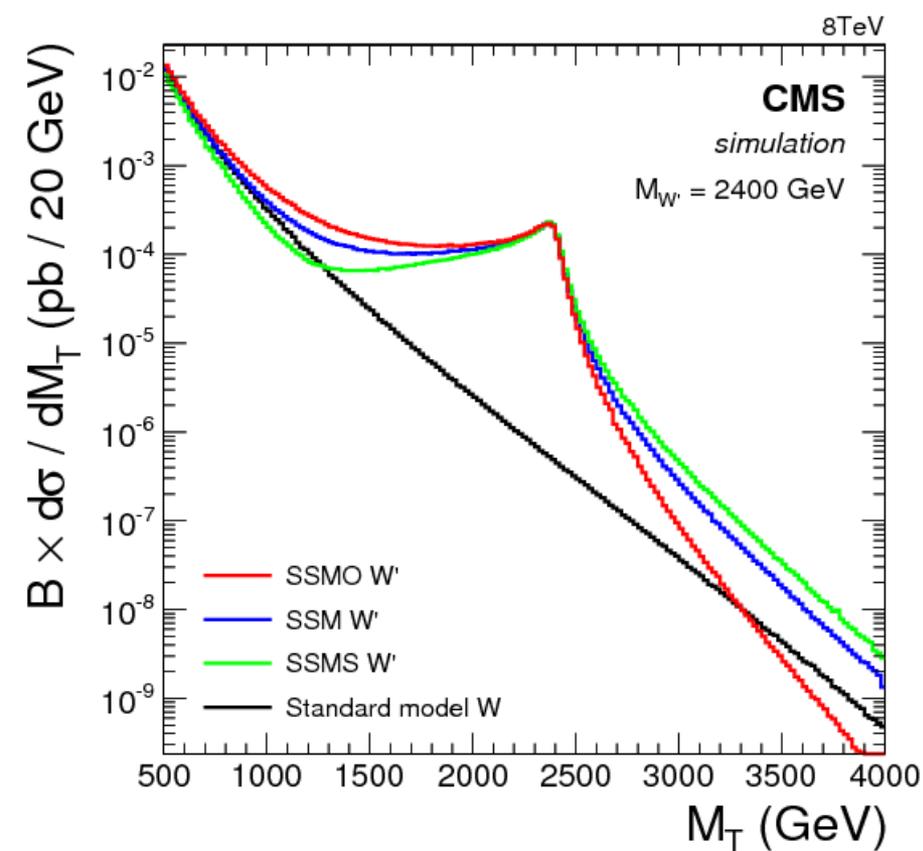
Comparison of M_T distribution for data and SM predictions in the context of several models, allow to place 95% CL on σB using Bayesian statistics



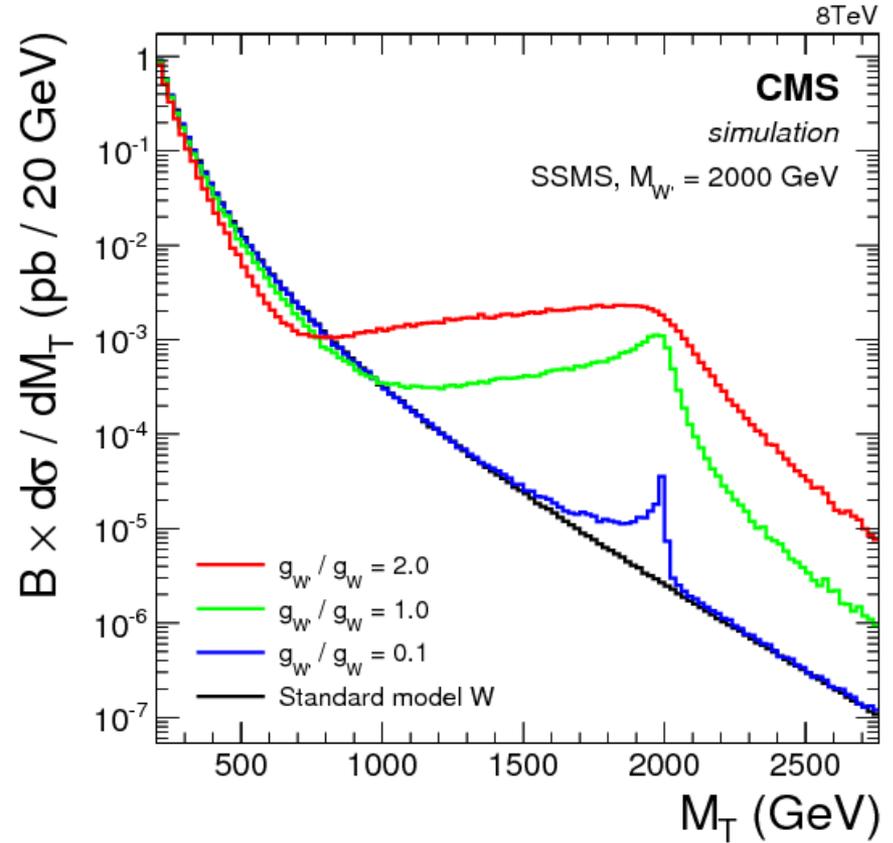
Individual channels (e/ μ + MET) have very similar sensitivity.

SSM W' production disfavoured by data, at 95% CL, for W' mass < 5.2 TeV, combining e/ μ + MET channels

$pp \rightarrow l(e, \mu) + p_T^{\text{miss}}$



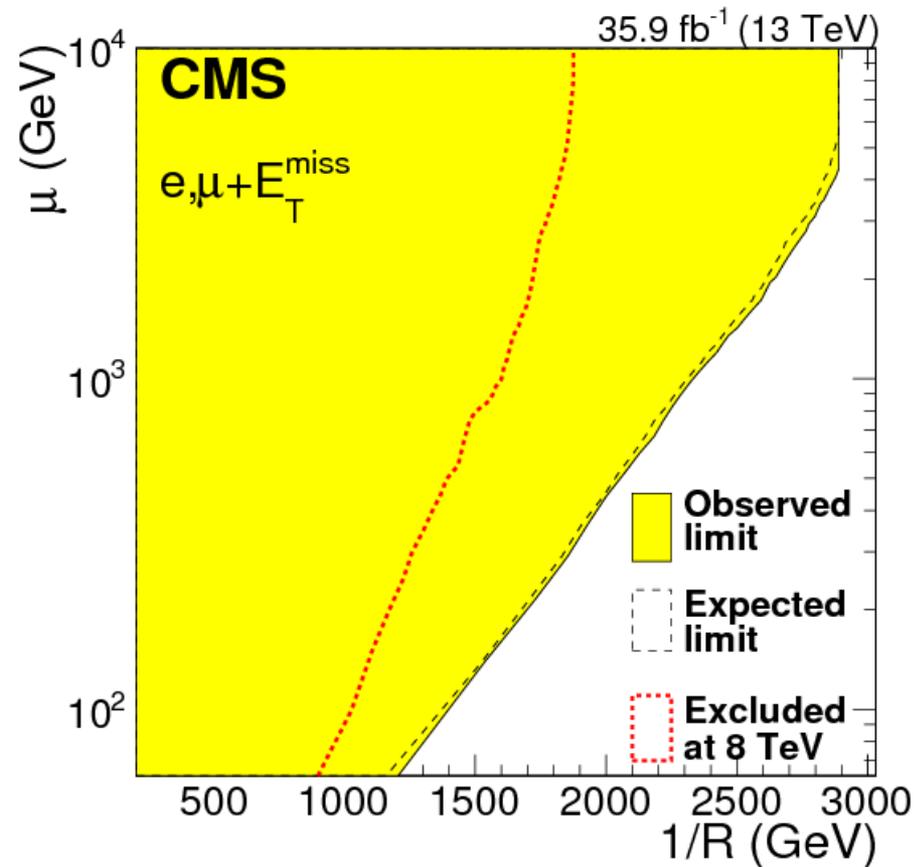
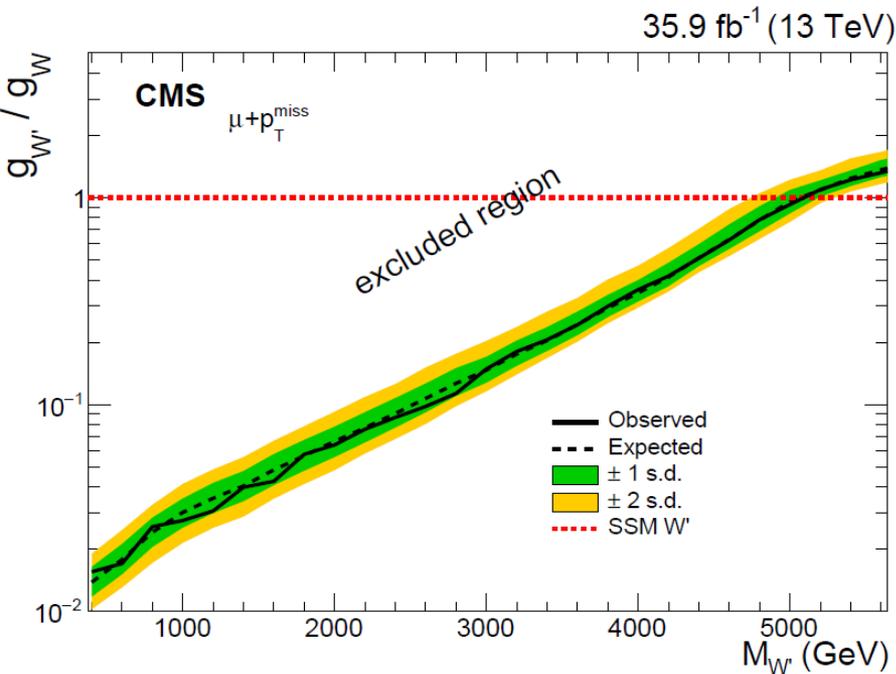
Effect of interference on cross section



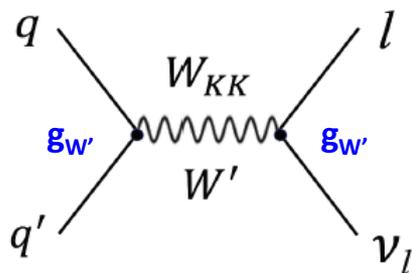
Effect of different couplings
 → impact on signal width

$pp \rightarrow l(e, \mu) + p_T^{\text{miss}}$

arXiv:1803.11133



Dependence with coupling value



Interpretation in terms of extra dimensions
in the plane $(\mu, 1/R)$

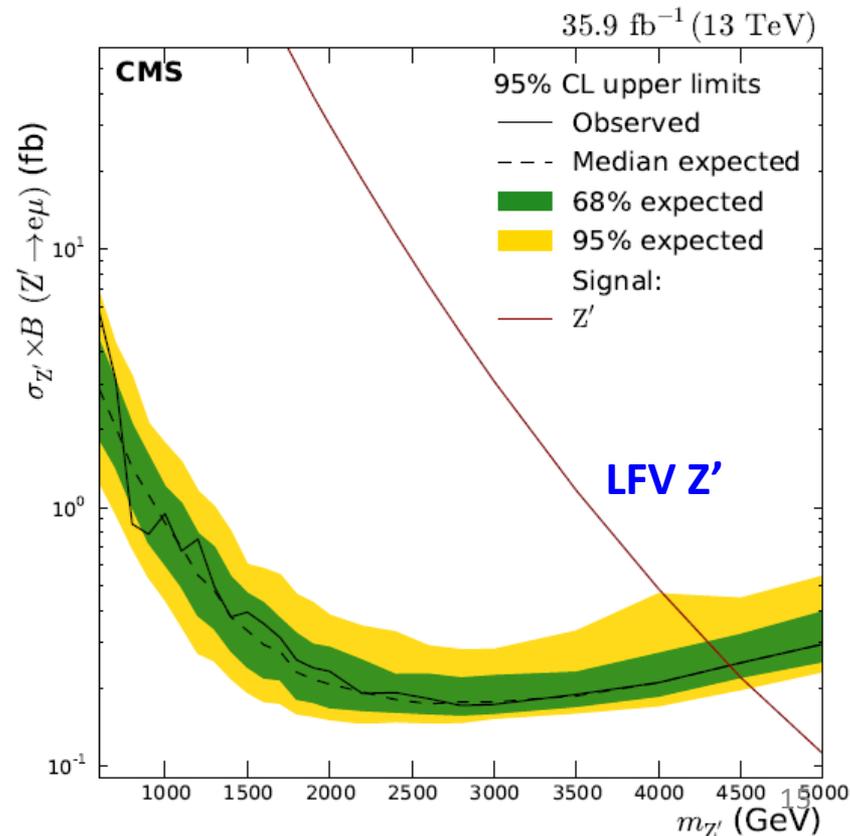
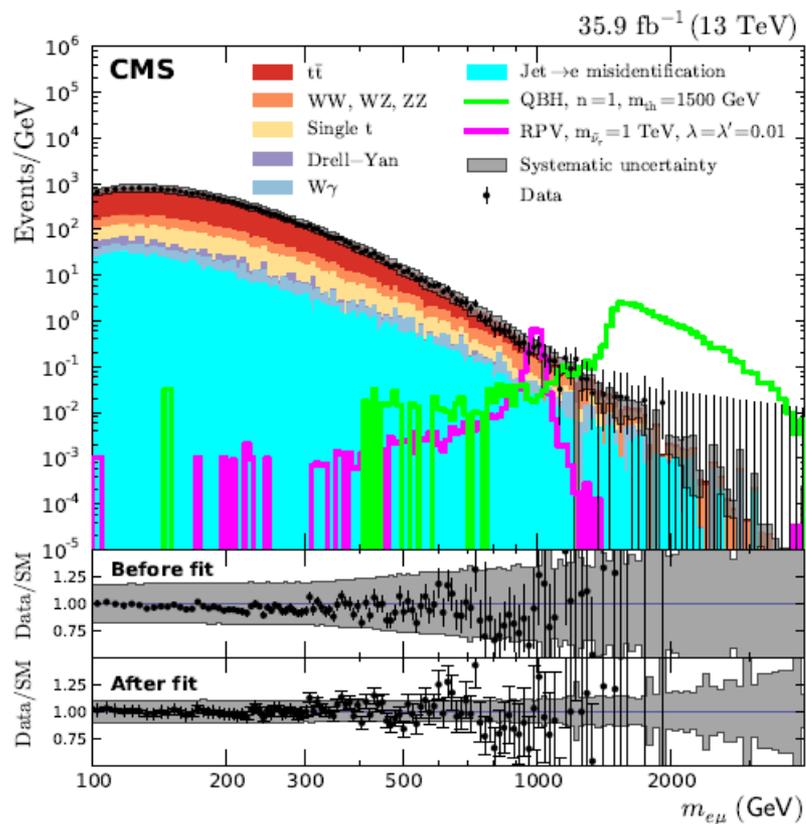
R = radius of extra dimension

μ : related to mass of 2nd KK excitation of W boson

pp $\rightarrow e\mu$ final states

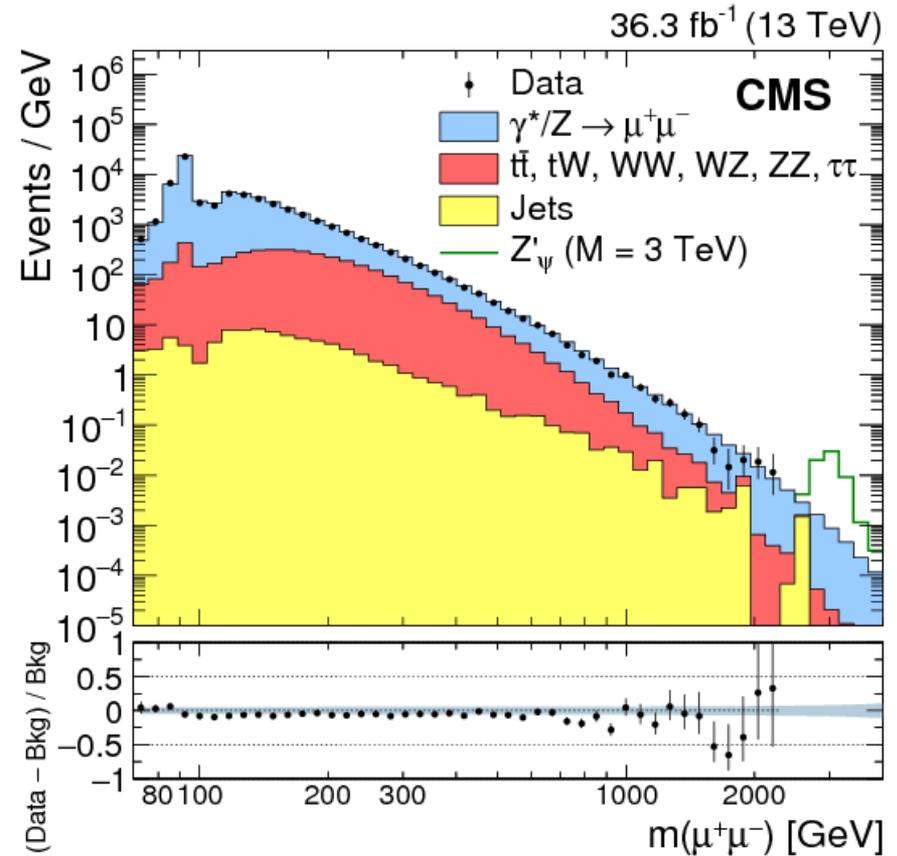
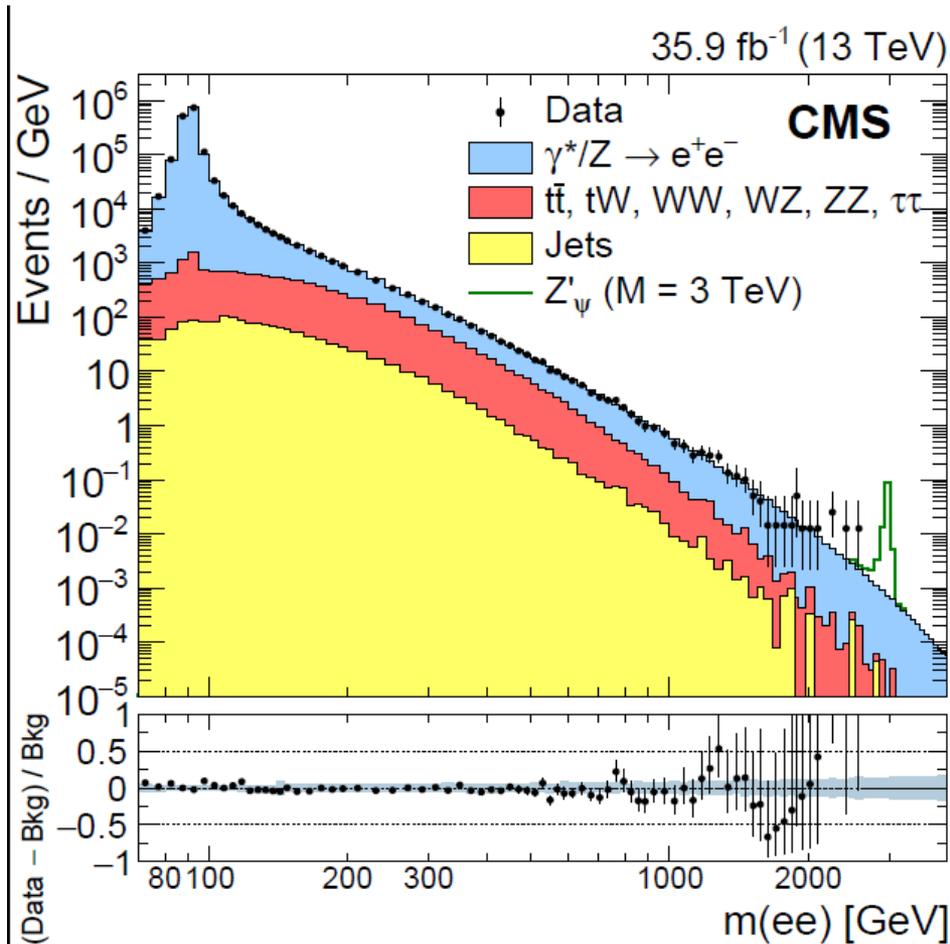
arXiv:1802.01122
Accepted JHEP

- Reconstruction of invariant mass $e\mu$ system
- Interpretation as LFV Z' resonance: same couplings as SM, but possible LFV decays ($Z' \rightarrow e\mu$).
- No interference Z'/Z



$pp \rightarrow e^+e^- / \mu^+\mu^-$ final states

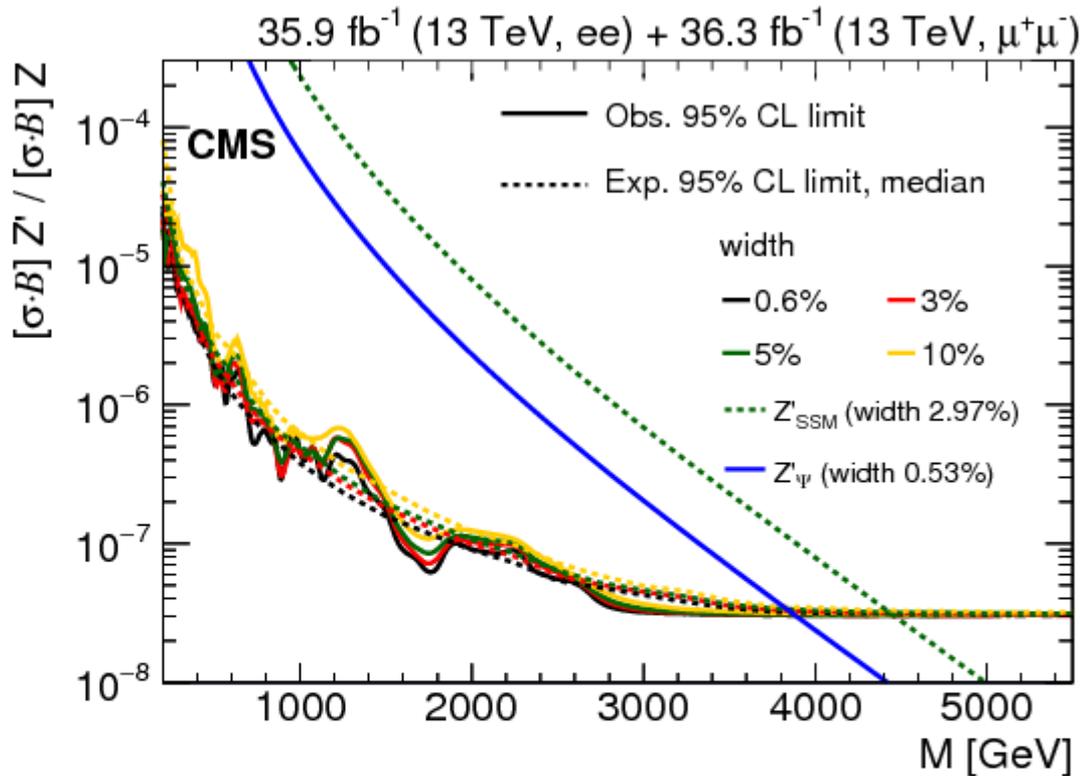
arXiv:1803.06292



$pp \rightarrow e^+e^- / \mu^+\mu^-$ final states

arXiv:1803.06292

Interpretation as Z' resonance in a general frame covering SSM (hard copy of SM Z) and other models with different couplings/widths

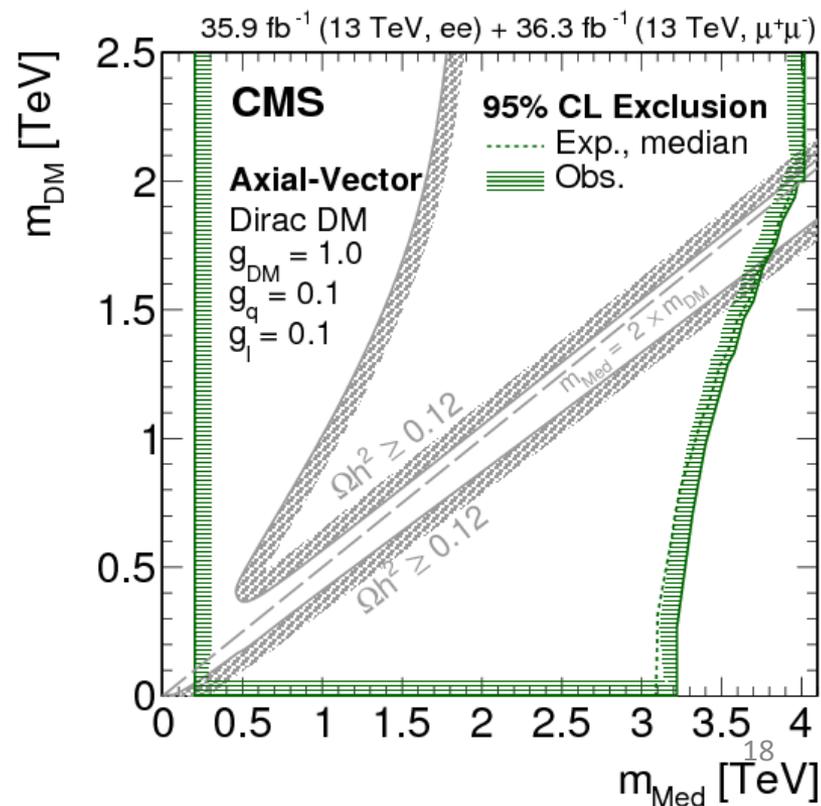
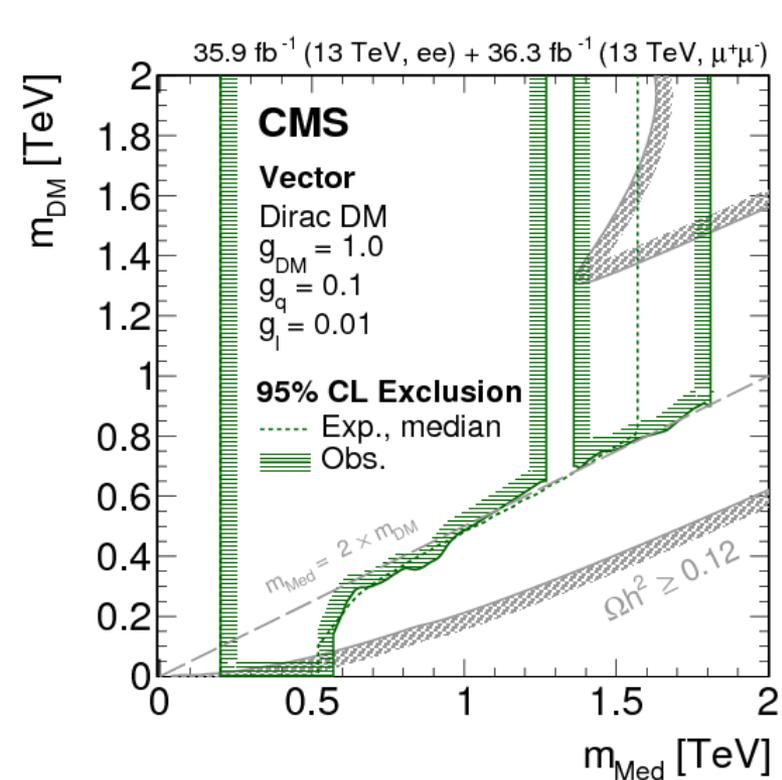


pp $\rightarrow ee / \mu\mu$ final states

arXiv:1803.06292

- DM Simplified model, with a high mass Mediator ($s=1$) which is vector/axial-vector boson exchanged in the s-channel.
- DM particle assumed a Dirac fermion
- 5 parameters: m_{Med} , m_{DM} , g_{DM} , g_l , g_q

Interference Mediator/Z well under 5%, so neglected.

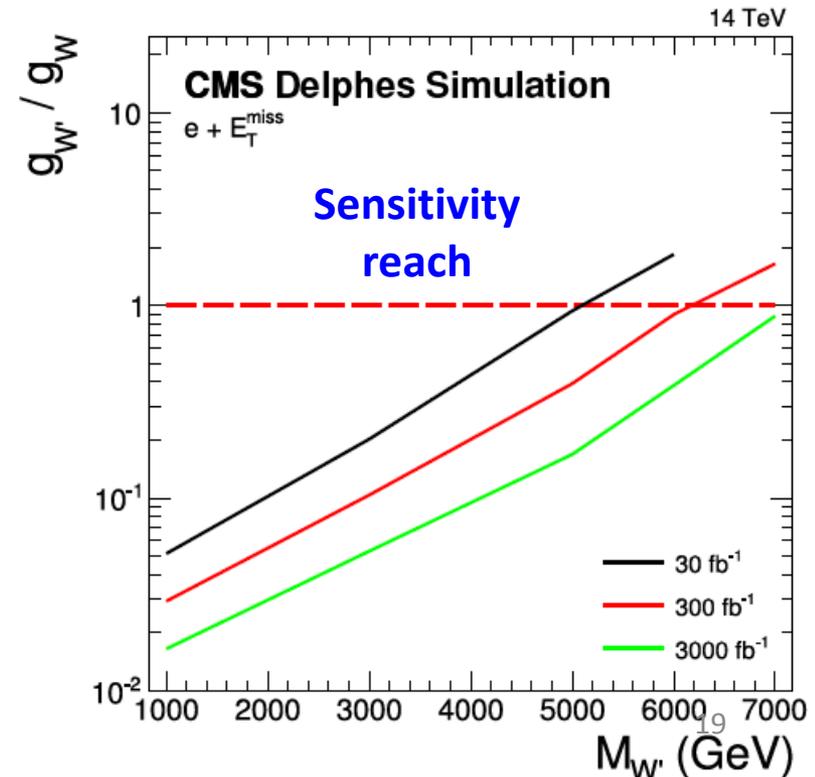
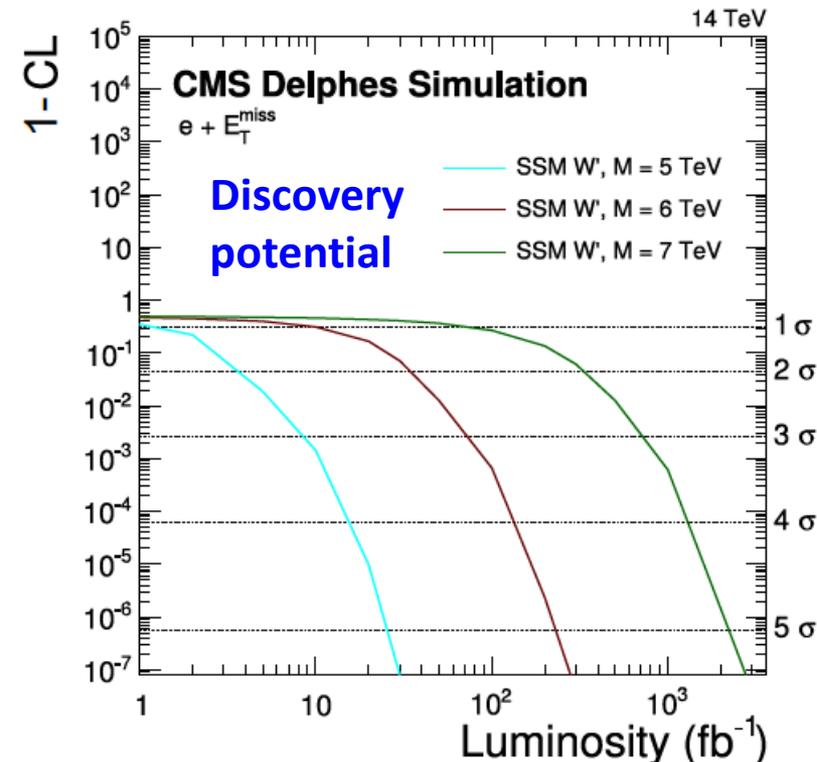


Prospects for HL-LHC

How will these searches improve with statistics from HL-LHC?

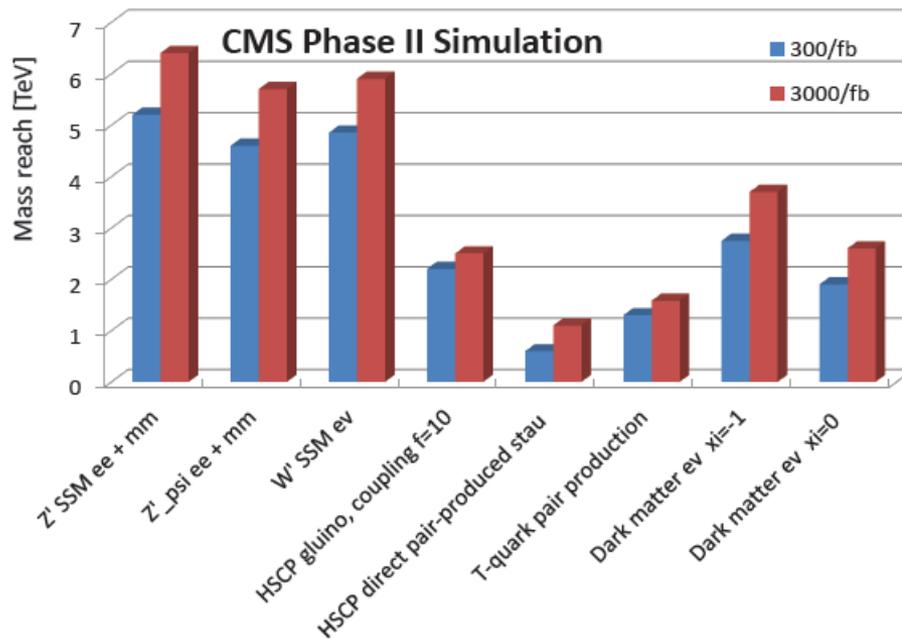
Direct “bump-search” sensitivity saturating after big jump in \sqrt{s} (2015) and Lumi (2016)

After Run 3 (~300 fb⁻¹ expected), HL-LHC is expected to deliver 3000 fb⁻¹



Prospects for HL-LHC

- Need to exploit (as already doing) other phase space parameters besides mass (couplings, prompt/non-prompt decays, etc).
- Obtain model independent limits as much as possible, based on experimental signatures, making generic assumptions (eg. kinematics)
- Systematically look for corners never looked at before (VX),...

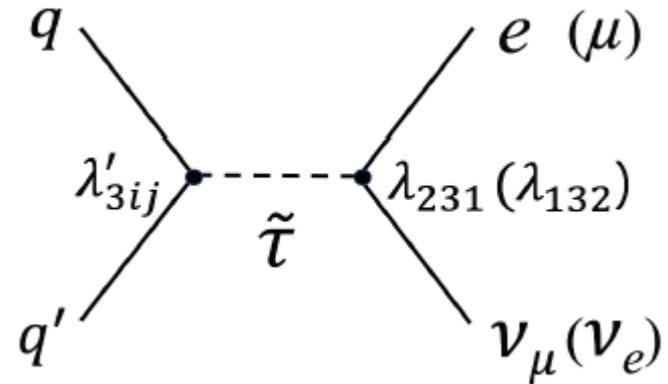
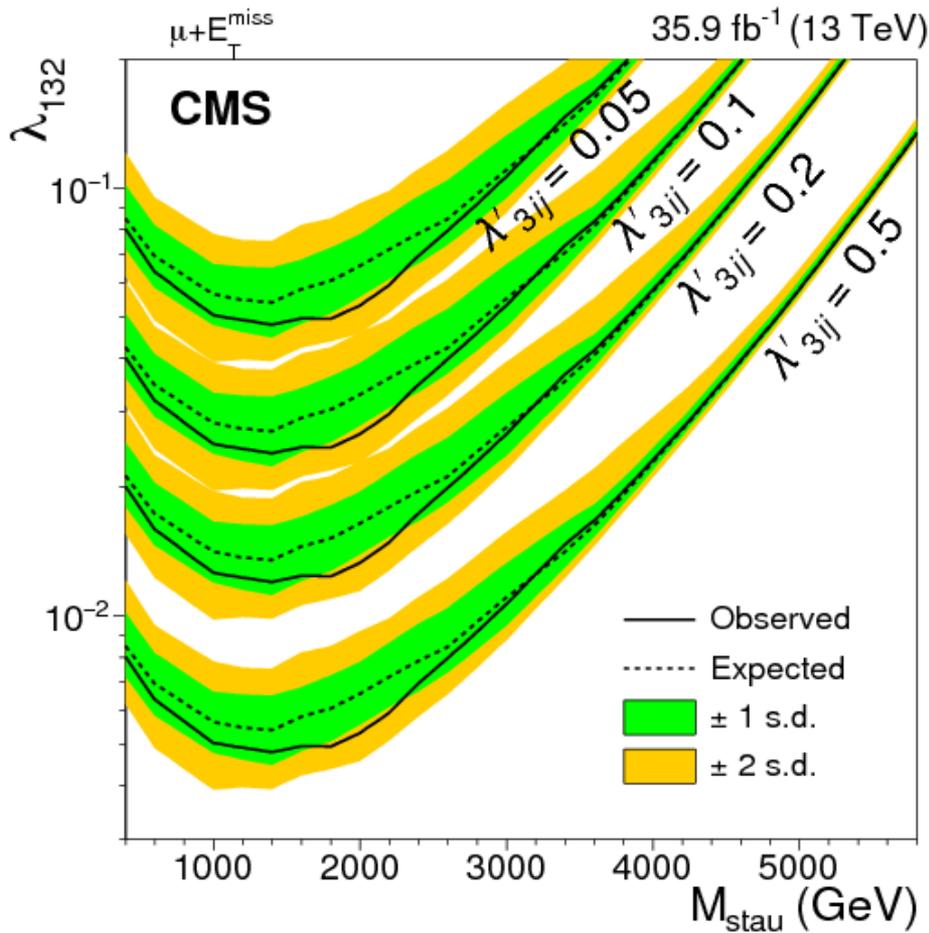


Projections using Delphes,
parametrizing CMS
performance

Thank you

$pp \rightarrow l(e, \mu) + \text{Missing } p_T$

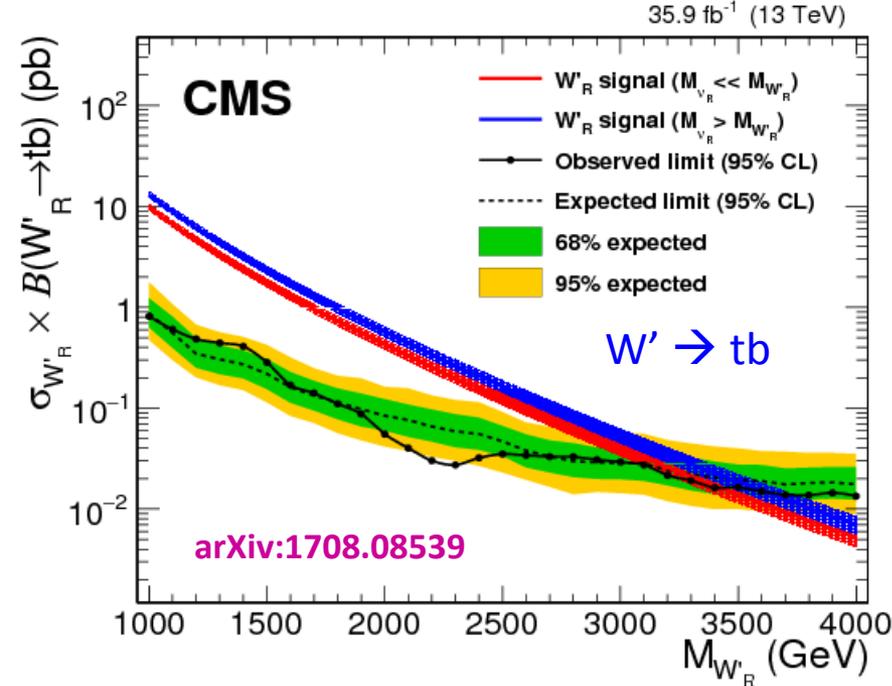
arXiv:1803.11133



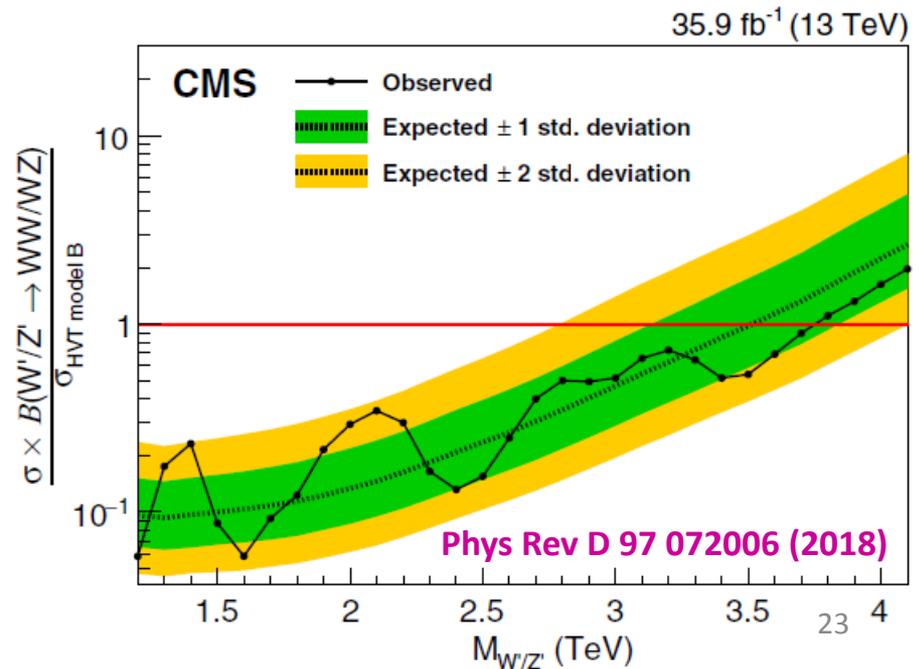
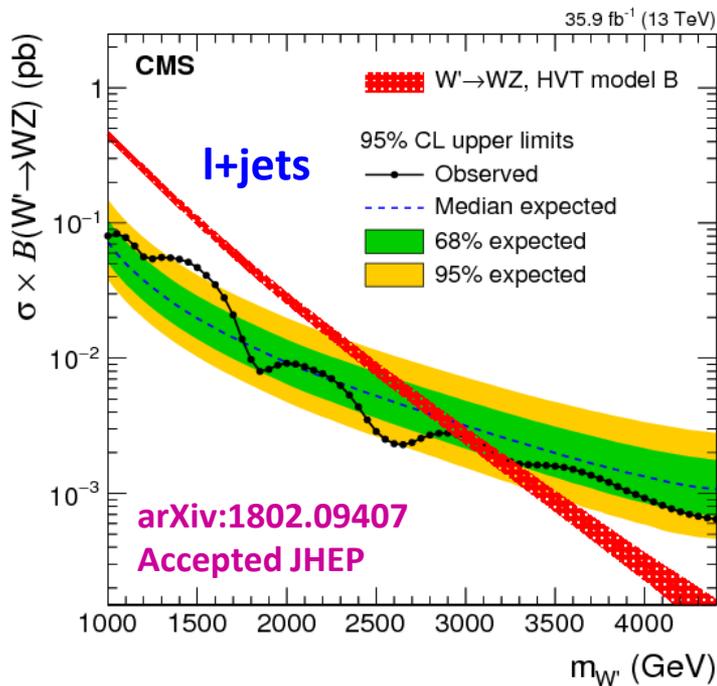
Interpretation in terms of τ slepton production as a mediator

Limits on λ_{132} (decay) as a function of the stau mass, for several values of λ'_{3ij} (production)

Other W' / Z' searches



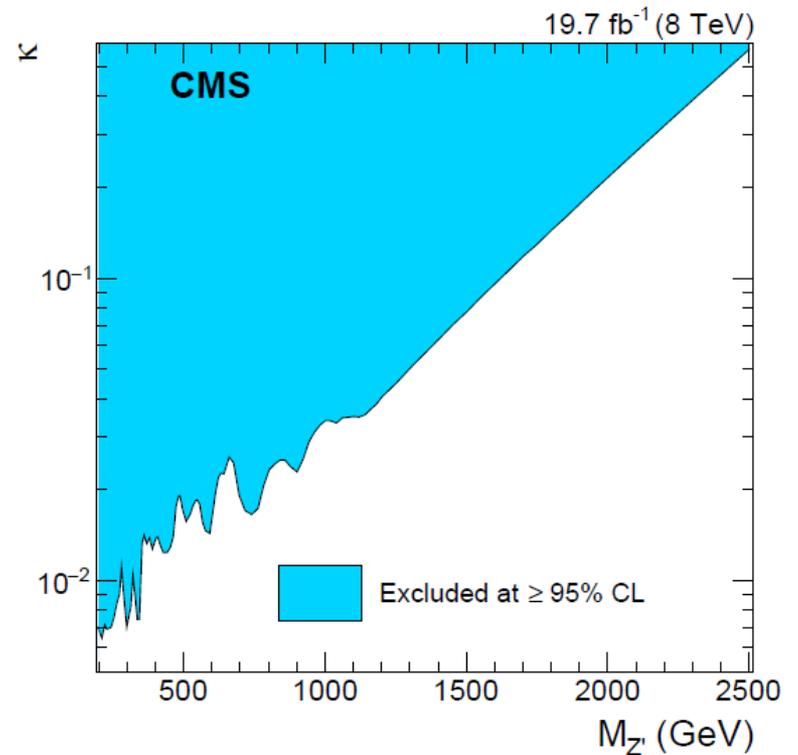
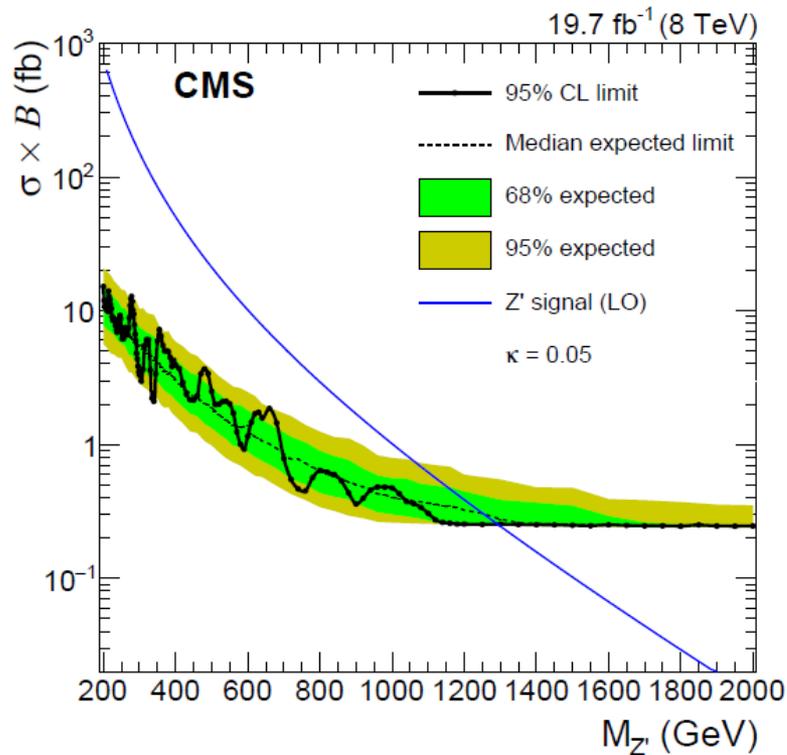
$W'/Z' \rightarrow WW, WZ, ZZ$
using dijets



$pp \rightarrow e\mu$ final states

Eur. Phys. J. C 76 (2016) 317

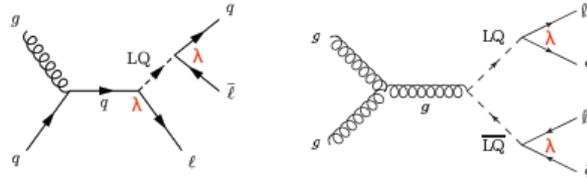
- Reconstruction of invariant mass $e\mu$ system
- Interpretation as LFV Z' resonance: possible LFV decays ($Z' \rightarrow e\mu$).



Bonus: Leptoquarks (l+jets)

- New scalar (spin 0) or vector (spin 1) particle
 - Carry both lepton and baryon number
 - Carry fractional electric charge $\pm(1/3, 2/3, 4/3, 5/3)e$
- Appear in GUTs, technicolor, composite models, RPV SUSY...
- Searches assume no inter-generational mixing (FCNC, proton decay)

- LQs can be singly or pair produced

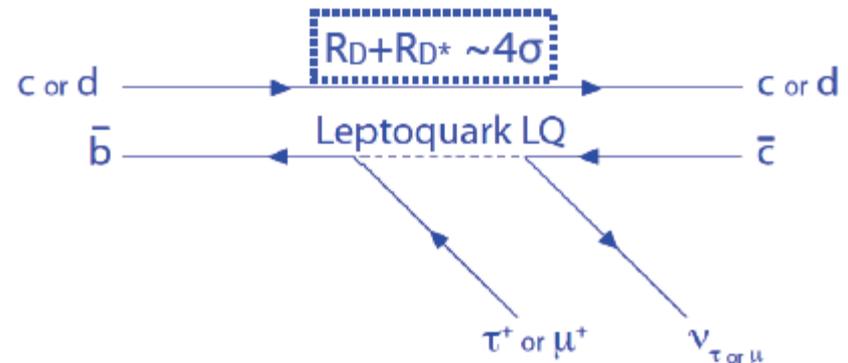
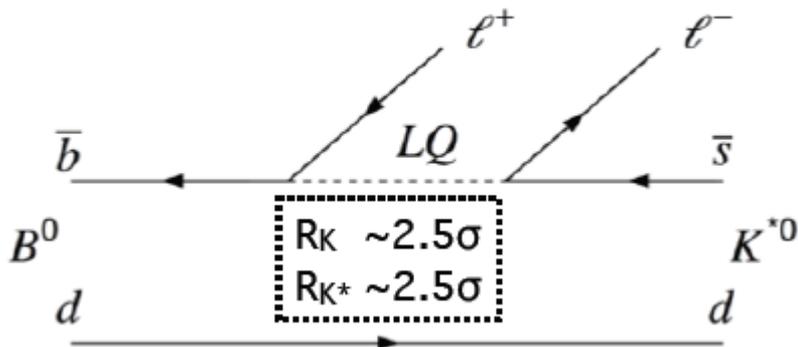


- Free parameters:
 - LQ mass
 - LQ $\rightarrow \ell q$ coupling λ
 - $\beta = \text{BF}(LQ \rightarrow \ell^\pm q) = 1 - \text{BF}(LQ \rightarrow \nu q)$
- Single LQ production cross section depends on λ , pair production does not

From <http://moriond.in2p3.fr/QCD/2018/WednesdayMorning/Morse.pdf>

Anomalies in decays of B mesons at LHCb (Babar, Belle) hint at possible sector with LFV

Possible new physics scenarios



Bonus: Leptoquarks

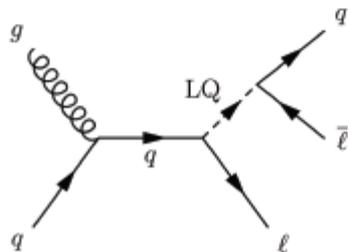
CMS Searches



All using 35.9 fb⁻¹

Single Production

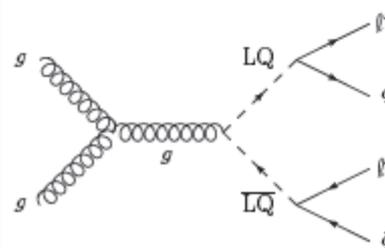
	1st /2nd Generation	3rd Generation
llq	$ee j$ $\mu\mu j$	$\tau\tau b$



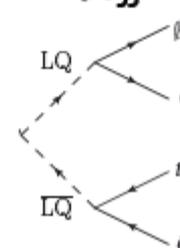
Pair Production

	1st Generation	2nd Generation	3rd Generation
$llqq$	$ee jj$	$\mu\mu jj$	$\tau\tau tt$ $\tau\tau bb$
$lvqq$	$ev jj$	$\mu\nu jj$	$\tau\nu tt$ $\tau\nu bb$
$vvqq$	$\nu\nu jj$		$\nu\nu tt$ $\nu\nu bb$

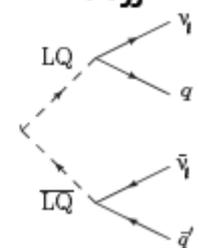
$lljj$ final state



$lvjj$



$vvjj$

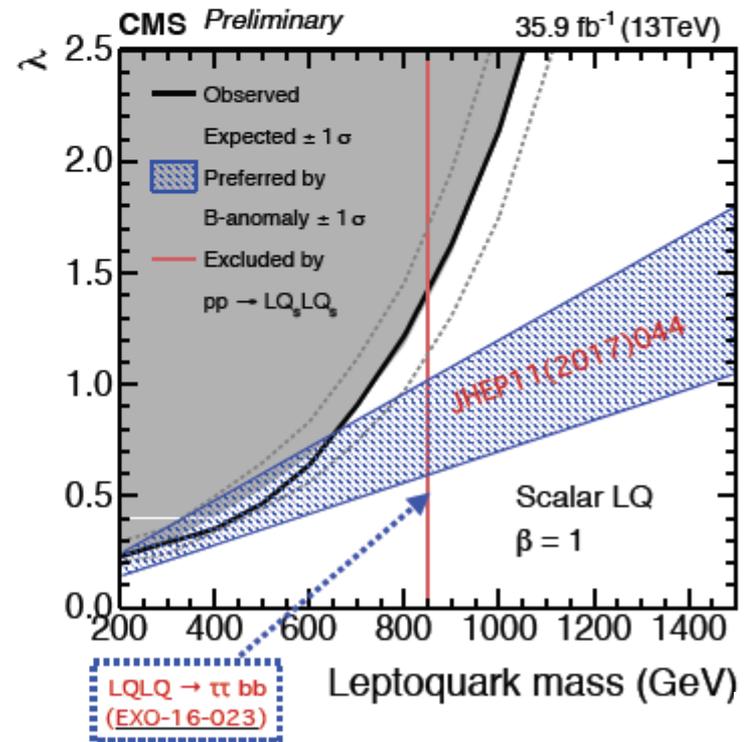
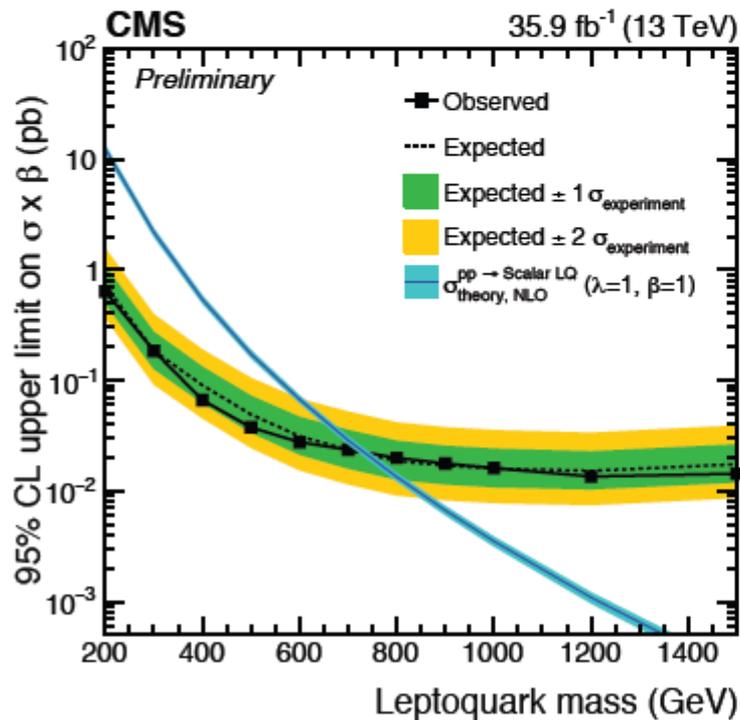


Bonus: Leptoquarks

3rd gen. Single LQ - $\tau\tau b$ (CMS-PAS-EXO-17-029)

- Exclude $M_{LQ} < 744$ GeV for $\beta=1, \lambda=1$
- Scan $0 < \lambda < 2.5$
 - Upper value of λ bounded by resonance width and LEP constraints

First search for
3rd gen. single LQ
production



Bonus: Leptoquarks

CMS LQ Limit Overview

NEW 2016 All using 35.9 fb⁻¹

