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Chasing light vector-like leptons from the SM Higgs to ZZ* search

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Work in progress with R. Dermisek, A. Raval

Contents

- SM Higgs discovery and new physics BSM
- Vector-like lepton (VLL)
  : mixing with SM μ for $(g\text{-}2)_\mu$
- Constraint of light VLL parameters from $h_{SM} \to ZZ^* \to 4\ell$
- Conclusions

SM Higgs discovery

SM Higgs-like particle was discovered

- An important quest of the LHC

5σ	$h \to \gamma\gamma$	$h \to ZZ^* \to 4\ell$
4σ	$h \to WW \to 2\ell 2\nu$	$h \to 2\tau$

- Fundamental scalar in the nature!!
- Higgs boson mass : Large quantum correction from UV physics around Λ_{SM}
  - Discovery of Higgs : main theoretical motivation of NP BSM at TeV (or > ?)
- No direct NP signal found : prepare the next LHC running

Search of BSM signal at the LHC

Top-down approach : From well-motivated models (e.g., SUSY SM scenarios)

- Gauge hierarchy problem & DM candidate : attractive for theorists
- Easy to expect collider signals
  : New particle spectrum and interactions are correlated by model parameters
- Signals are (too much) model dependent : Not easy to apply the LHC null results

Bottom-up approach : Simple extensions of SM (motivated by experiment results)

- Independent parameters : easy to directly apply the LHC results (useful for exp.)
- Hard to combine experimental results (e.g. + DM, B-physics, ..)
- Higgs extensions : 2HDM, .. + α Dermisek, Hall, Lunghi, Shin JHEP 1404, 140 and various talks here
  Matter extensions : DM, new fermions, matter scalars, ….

Vector-like leptons (new matter)

- Mass term arbitrarily set theoretically
- Weak direct bound LEPII
- Contribute to Higgs to VV channel ($h \to \gamma\,\gamma$ ATLAS) Carena, Low, Wagner JHEP 1208, 060
- No in the Higgs production process
- Raise Higgs mass : MSSM Martin PRD81, 035004 (2010)
  Composite models Bae, Jung, Kim PRD87, 015014 (2013)
- Affect the RG evolution of couplings Dermisek PLB713, 469 (2012) PRD87, 055008 (2013)

Minimal

	$L_{L,R}$	$E_{L,R}$
$SU(2)_L$	2	1
$U(1)_Y$	-1/2	-1

+ SM singlet (DM with Z_2) ?

Joglekar, Schwaller, Wagner JHEP 1212, 064

Vector-like lepton mixing with SM ℓ

- Decay signals contain SM leptons (Good for collider search)
- Non-standard leptonic SM Higgs decays (Large decay width, LFV decays)
- Precision measurements
  1) Radiative lepton decays (lepton flavour violation)
  2) Electron EDM
  3) Muon anomalous magnetic moment (motivated in this work)
- Model dependent issue : how the mixing is realised
  e.g., Yukawa type Dermisek, Raval PRD88, 013017 (2013) vector-like Falkowski, Straub, Vicente, 1312.5329

Production : EW processes

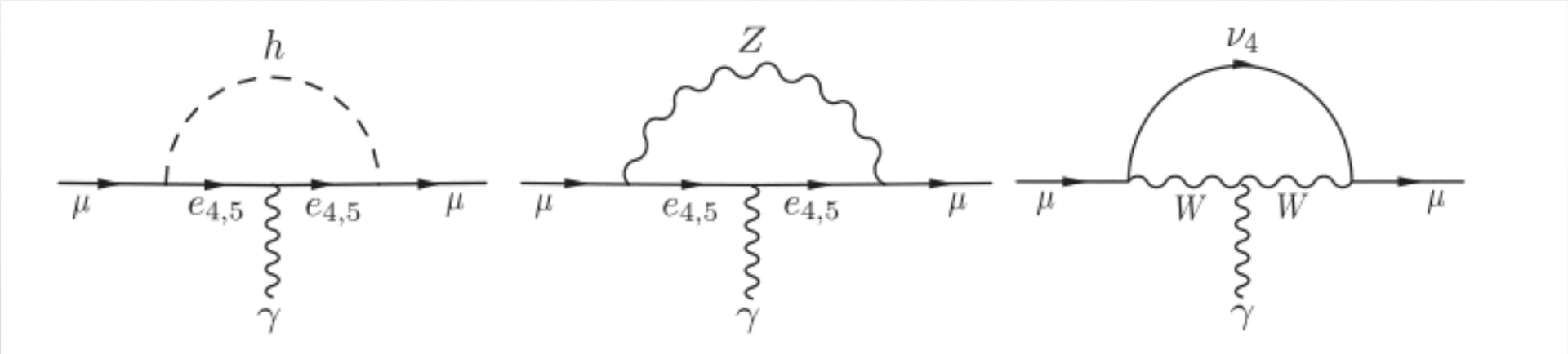
Weak direct bounds so far

- DY process : pair production < O(pb) 8TeV
- Higgs decay : depends on Br. (**light VLL**)

Vector-like lepton mixing with SM μ

Muon anomalous magnetic moment

Minimally



Large for heavy leptons

Large for light leptons

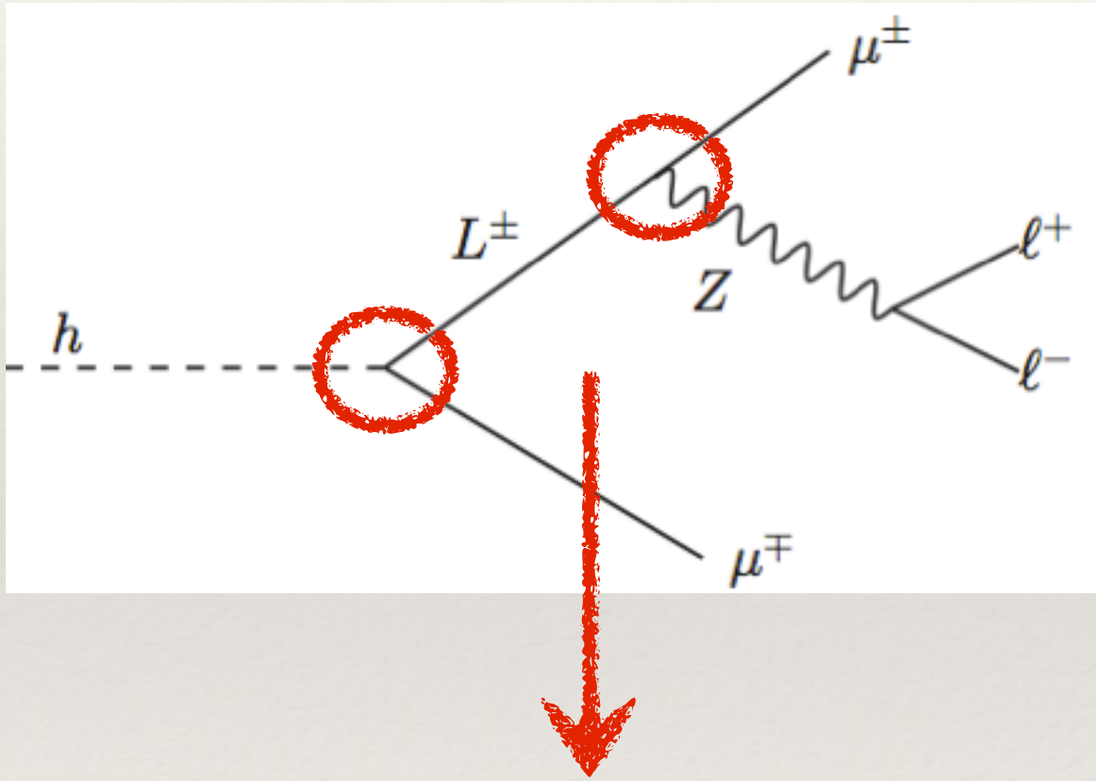
- Heavy new leptons ≫ M_Z Kannike, Raidal, Straub, Strumia JHEP 1202, 106
- Light new leptons ≳ M_Z Dermisek, Raval PRD88, 013017 (2013)

Correlated with the physical <u>muon mass</u> &

$$R_{\mu\mu} \equiv \frac{\Gamma(h \to \mu^+\mu^-)}{\Gamma(h \to \mu^+\mu^-)_{\rm SM}}.$$

Light Vector-like lepton signal from $h_{SM} \to ZZ^* \to 4\ell$

Considering light VLL mixing with SM μ motivated from $(g\text{-}2)_\mu$



L : lightest charged vector-like lepton
(assume only one lepton is involved)

$\ell = \mu$ or e

Contribute to 4μ or 2e2μ final states of

$h_{SM} \to ZZ^* \to 4\ell$

FCNC

Flavour violating Yukawa

$$\mathcal{L} \supset (g_Z^L \bar{L}_L \gamma^\mu \mu_L + g_Z^R \bar{L}_R \gamma^\mu \mu_R) Z_\mu - \frac{1}{\sqrt{2}} (g_h^L \bar{L}_L \mu_R + g_h^R \bar{L}_R \mu_L) h \ + \text{h.c.} \ ,$$

General parameters (can be effective couplings)

Light Vector-like lepton signal from $h_{SM} \to ZZ^* \to 4\ell$

$h_{SM} \to ZZ^* \to 4\ell$ 5σ discovery $\sigma/\sigma_{SM} \sim 1$: strong constraint on light VLL

Kinematic topology of VLL contributed process different from SM h

: The efficiency of 4ℓ selection cut (for SM h) is different

- Define kinematic acceptance $\xi = \eta/\eta_{SM}$ (relative cut eff.)

NP + SM : $h \to 4\mu$ (2e2μ)

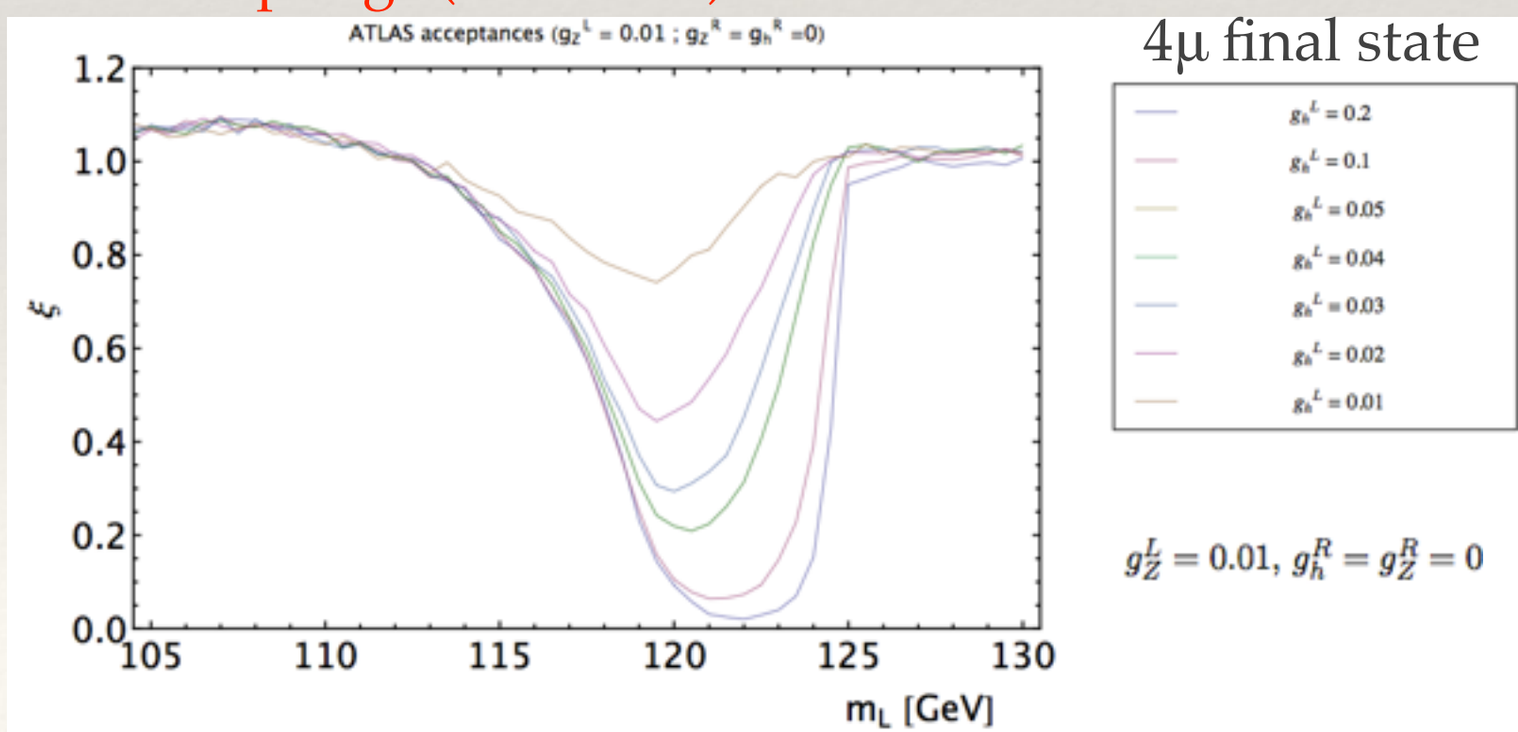
- More than two processes in ξ (SM + NPonly + interference)

: depends on masses + couplings (relative σ)

ξ by MadGraph5 + Pythia6

$m_h = 125$ GeV

$$\mathrm{Br}(L^\pm \to Z\mu^\pm) = 1.$$



4μ final state

$g_Z^L = 0.01,\ g_h^R = g_Z^R = 0$

Light Vector-like lepton signal from $h_{SM} \to ZZ^* \to 4\ell$

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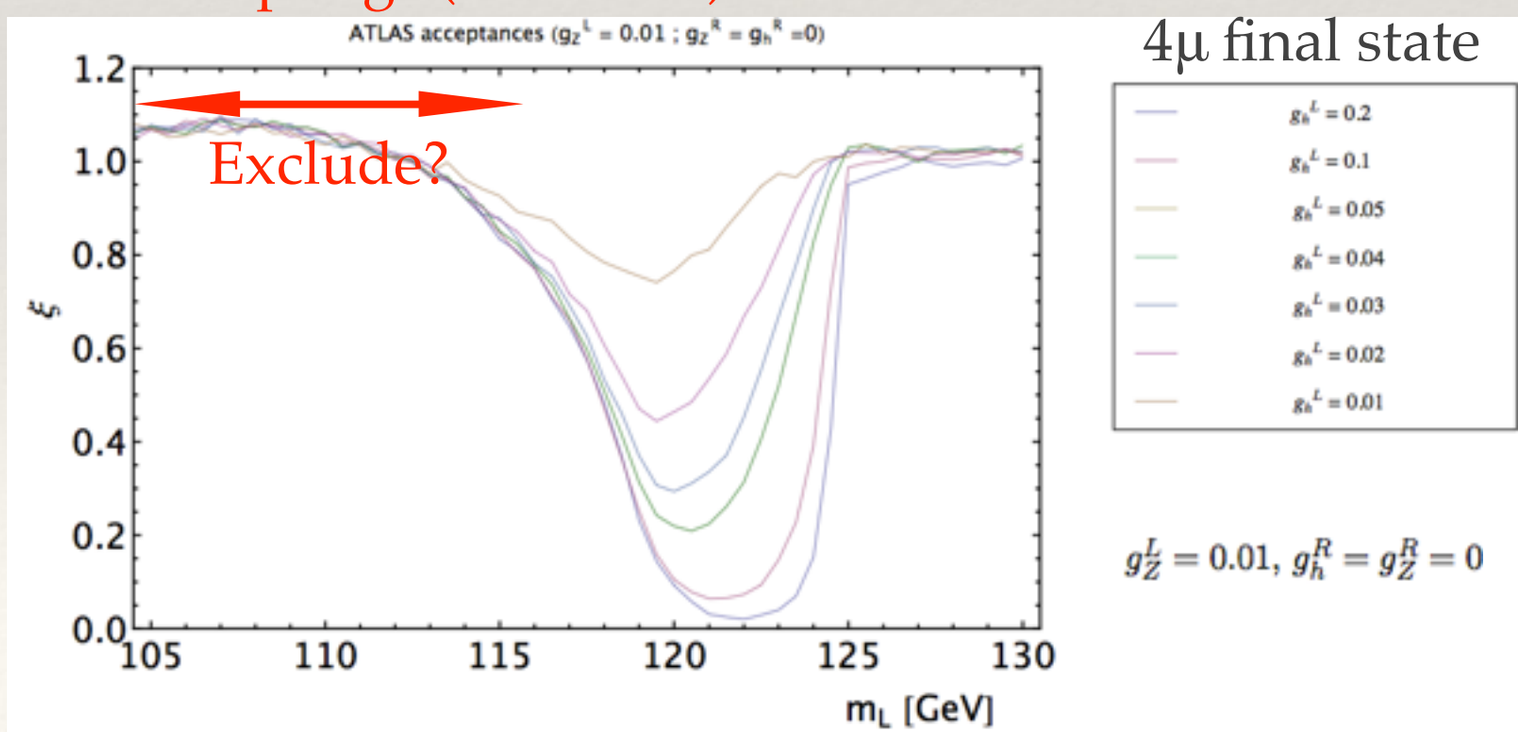

4μ final state

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Light Vector-like lepton signal from $h_{SM} \to ZZ^* \to 4\mu$

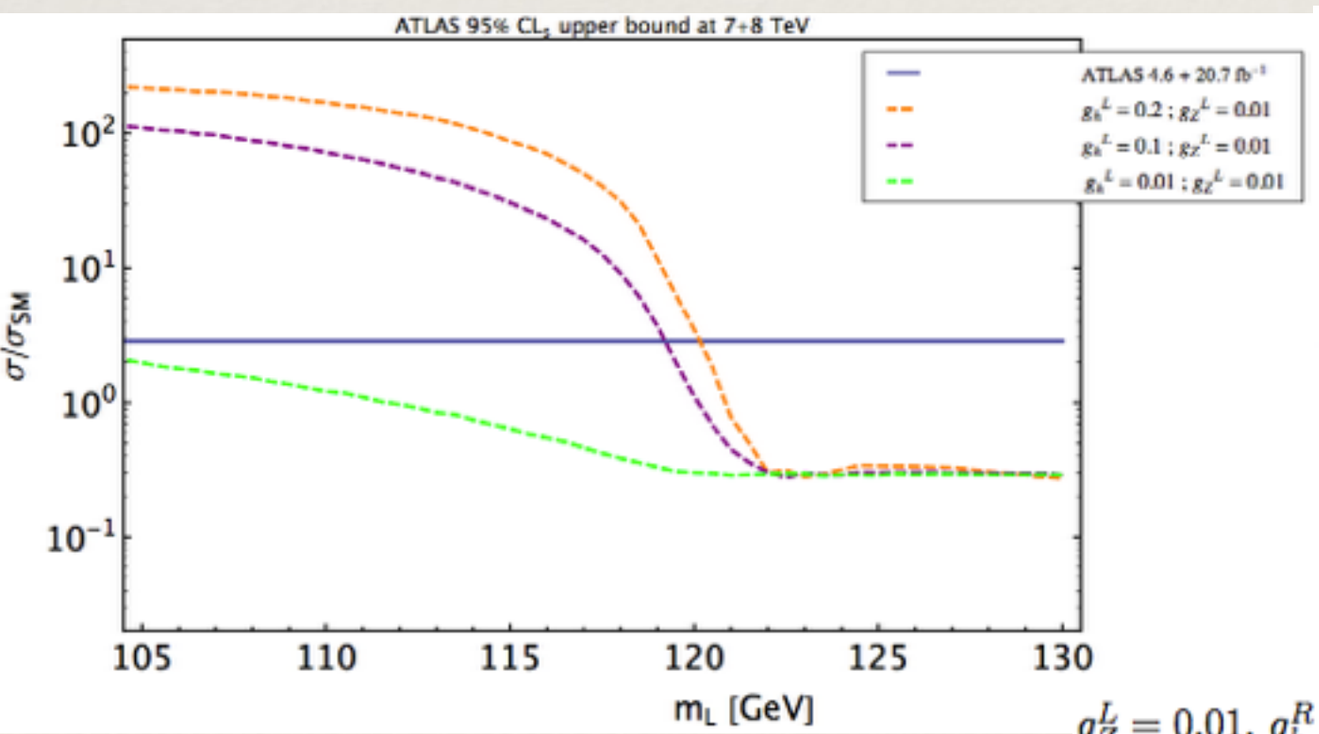
Apply modified frequentist construction 95% C.L. exclusion limit σ/σ_{SM}

$\mathrm{Br}(L^\pm \to Z\mu^\pm) = 1.$

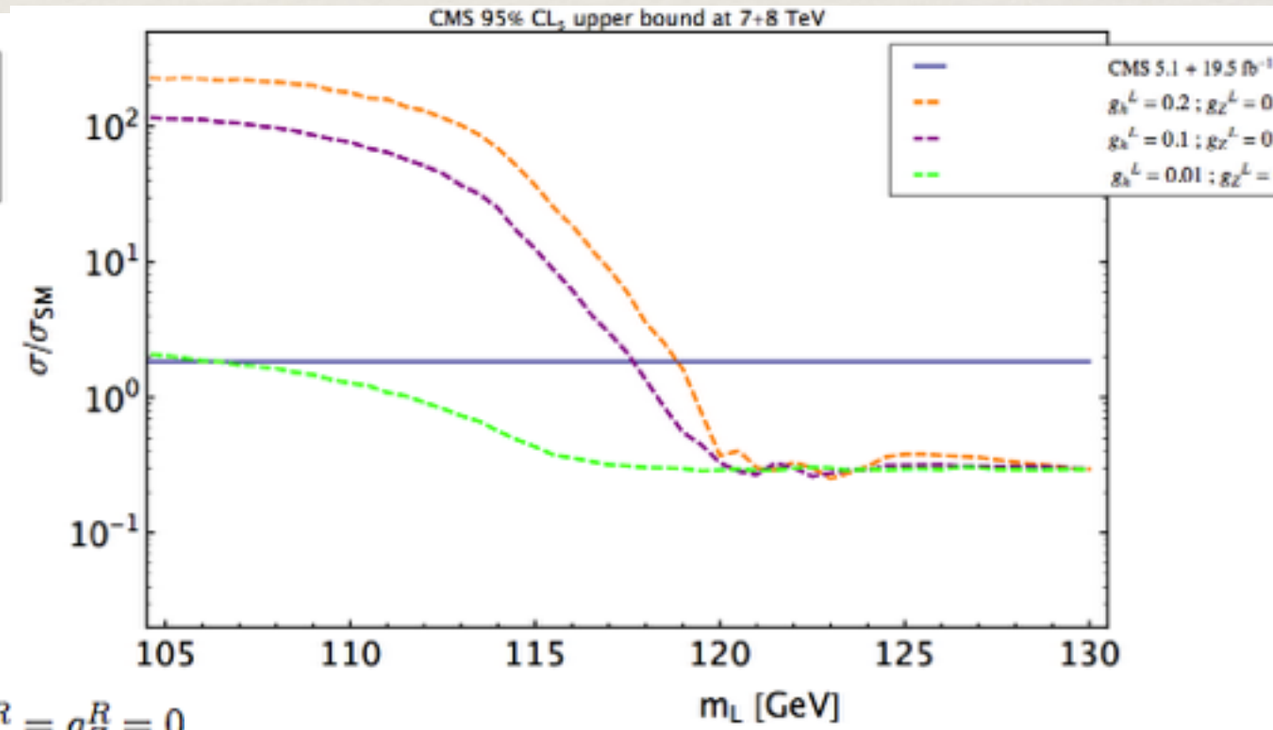
4μ final state

$m_h = 125$ GeV

ATLAS



CMS



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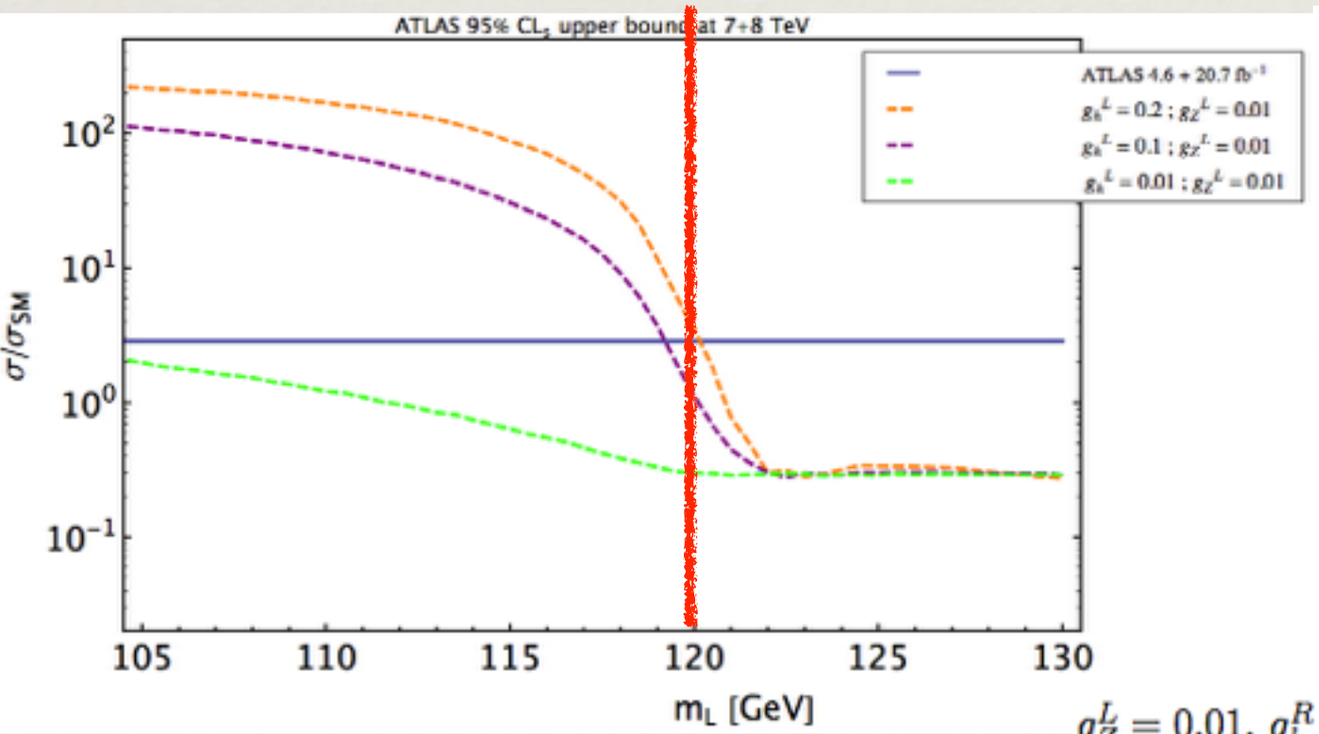
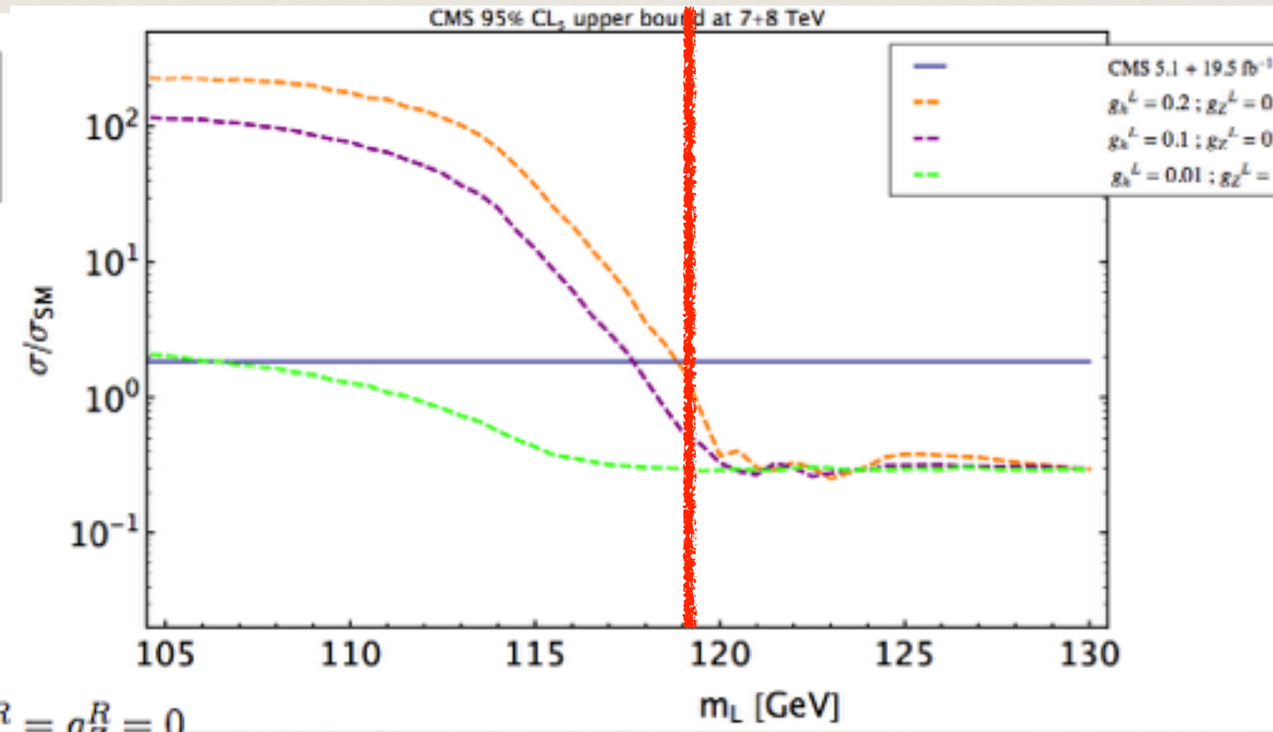


CMS



$g_Z^L = 0.01,\ g_h^R = g_Z^R = 0$

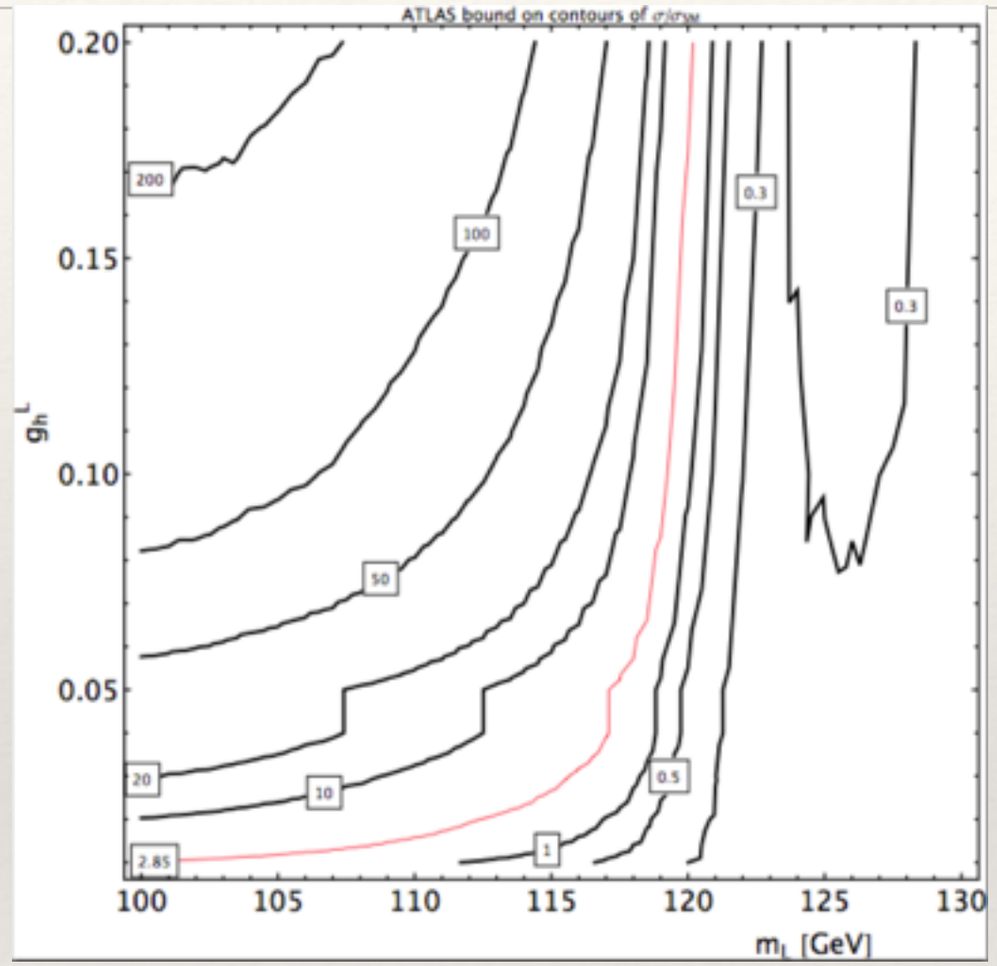
Lower limit m_L ~120 GeV for large FV Yukawa couplings ≳ 0.1 ?

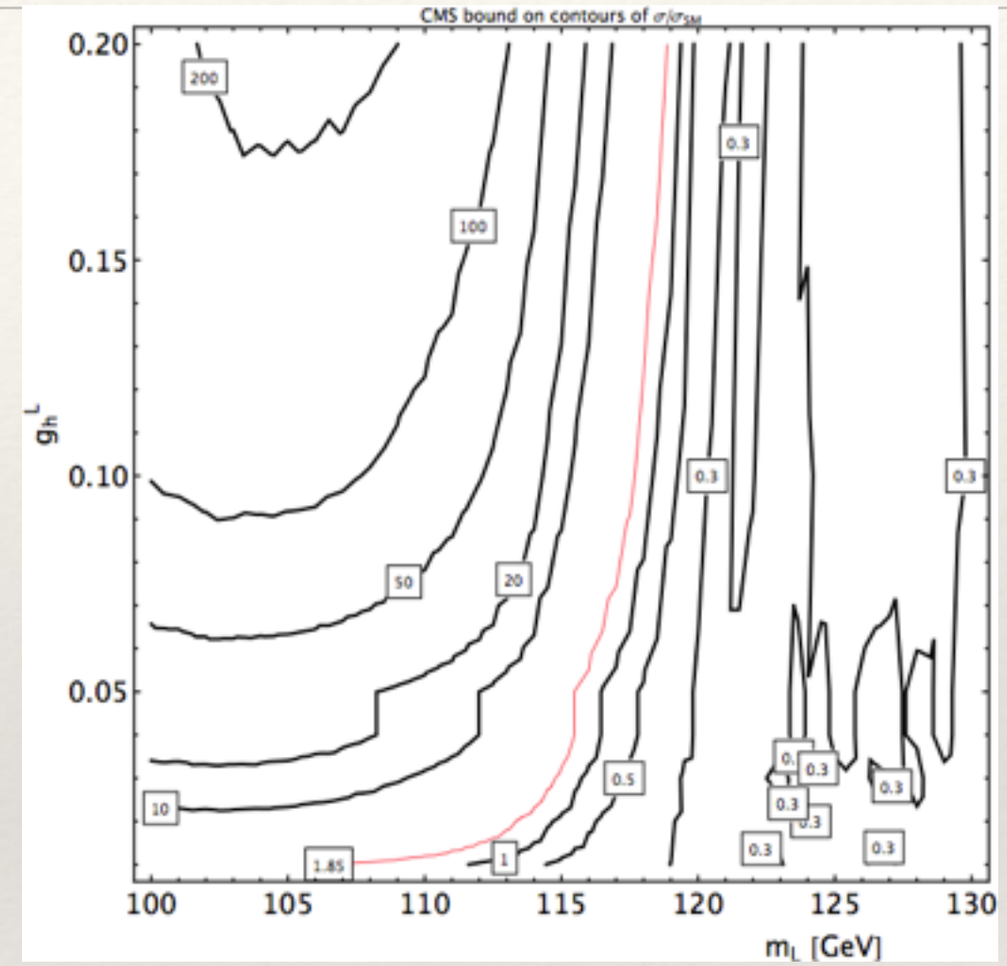
4μ final state

Contours of $\mu = \sigma / \sigma_{SM}$

$m_h = 125$ GeV

$\mathrm{Br}(L^{\pm} \to Z\mu^{\pm}) = 1.$





- Red line : 95% CLs upper bound $g_Z^L = 0.01,\ g_h^R = g_Z^R = 0$
- VLL ≲ 120 GeV & FV Yukawa $g_h \gg 0.05$ excluded in our ref. : powerful!!! (general param.)
- FCNC coupling $g_z \lesssim 0.01$ from EWP data & $\mathrm{Br}(L \to Z\mu) = 1$: Results similar

Light Vector-like lepton signal from $h_{SM} \to ZZ^* \to 4\ell$

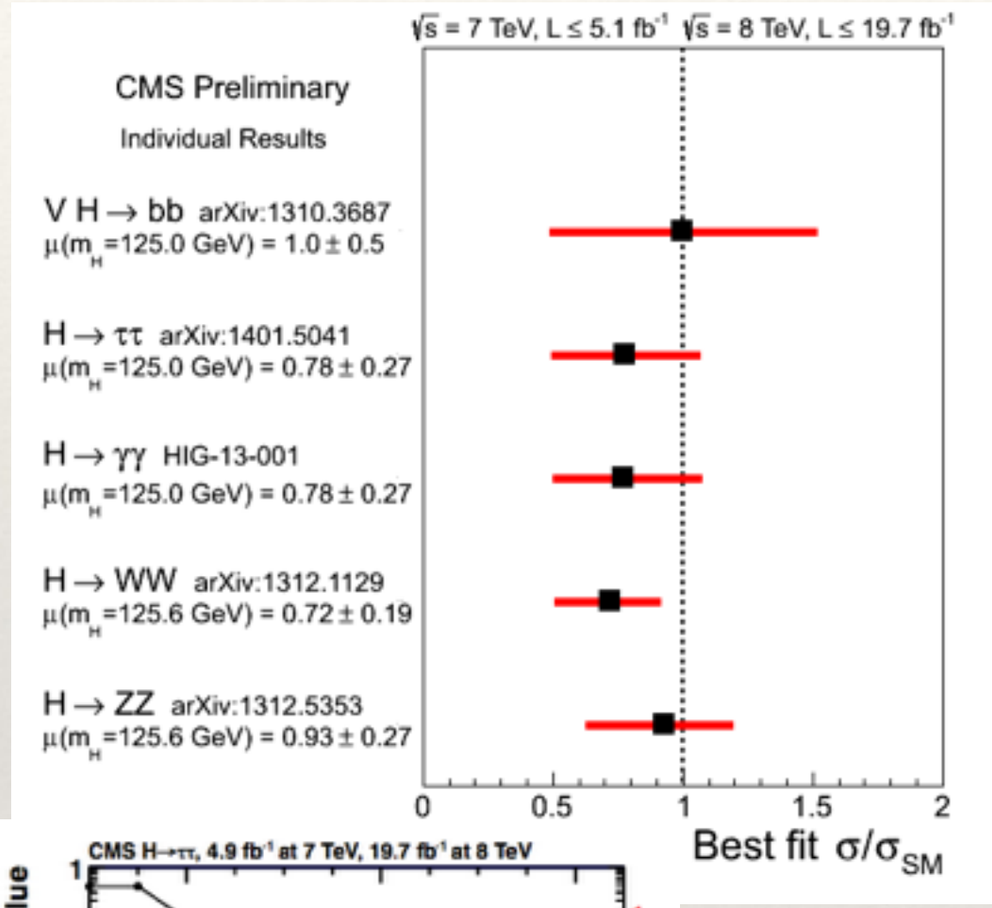
Still not enough….

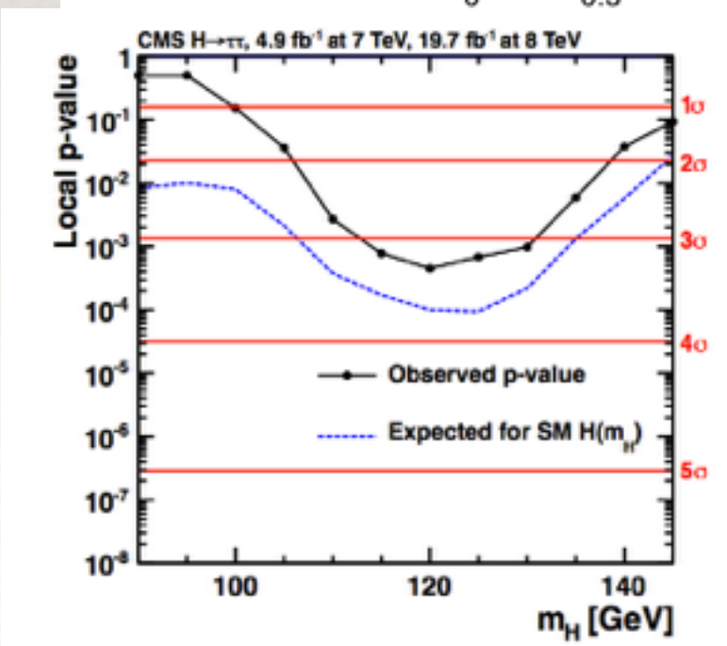
- More parameter scan to provide exact bound and contours
- Add analysis on 2e2μ final state
  : expect similar contours of σ/σ_{SM} and bound 3.02 from ATLAS
- Analyse $h_{SM} \to WW^* \to 2\ell 2\nu$, σ/σ_{SM} closer to ~ 1
  : stronger bound? Work in progress with R. Dermisek, J. Hall, E. Lunghi

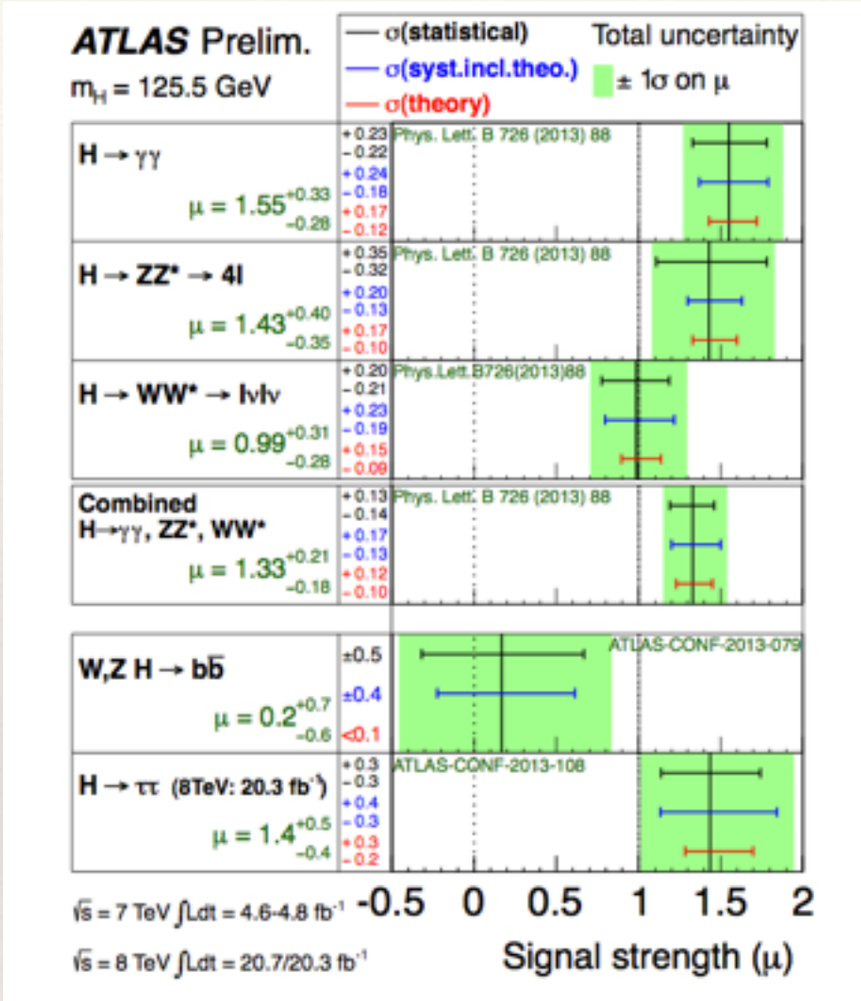
Conclusions

- Vector-like leptons at the LHC bottom-up toward NP BSM expecting non-standard phenomena.
- Mixing with SM μ, light charged VLL parameters can be constrained from the well-observed SM $h \to ZZ^* \to 4\ell$ search. (4μ, 2e2μ)
- In terms of general parameters, 95% CL excl. obtained from 7+8 TeV LHC results of 4μ final state. Powerful!
  (roughly VLL ≲ 120 GeV & FV Yukawa $g_h \gg 0.05$ at our ref. parameters)
- More analyses are needed : 2e2μ and $h_{SM} \to WW^* \to 2\ell 2\nu$

Back-up





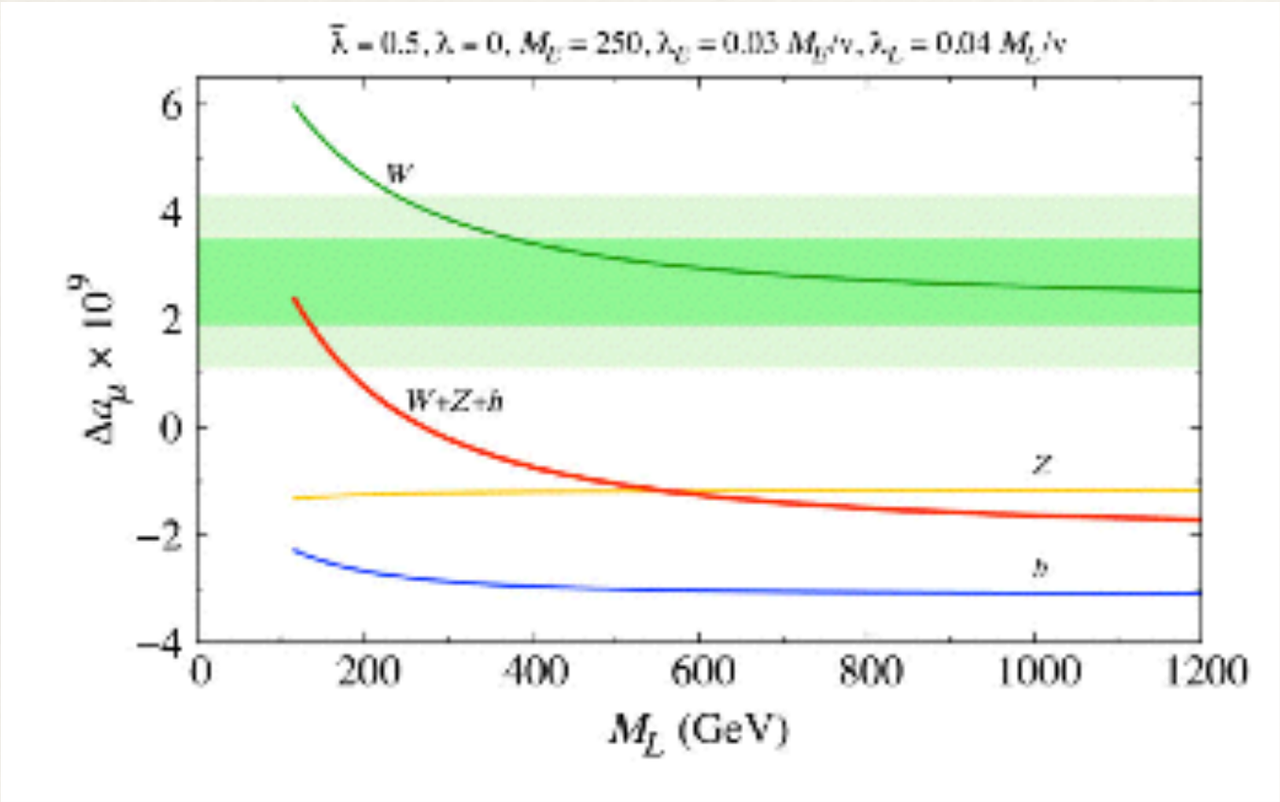


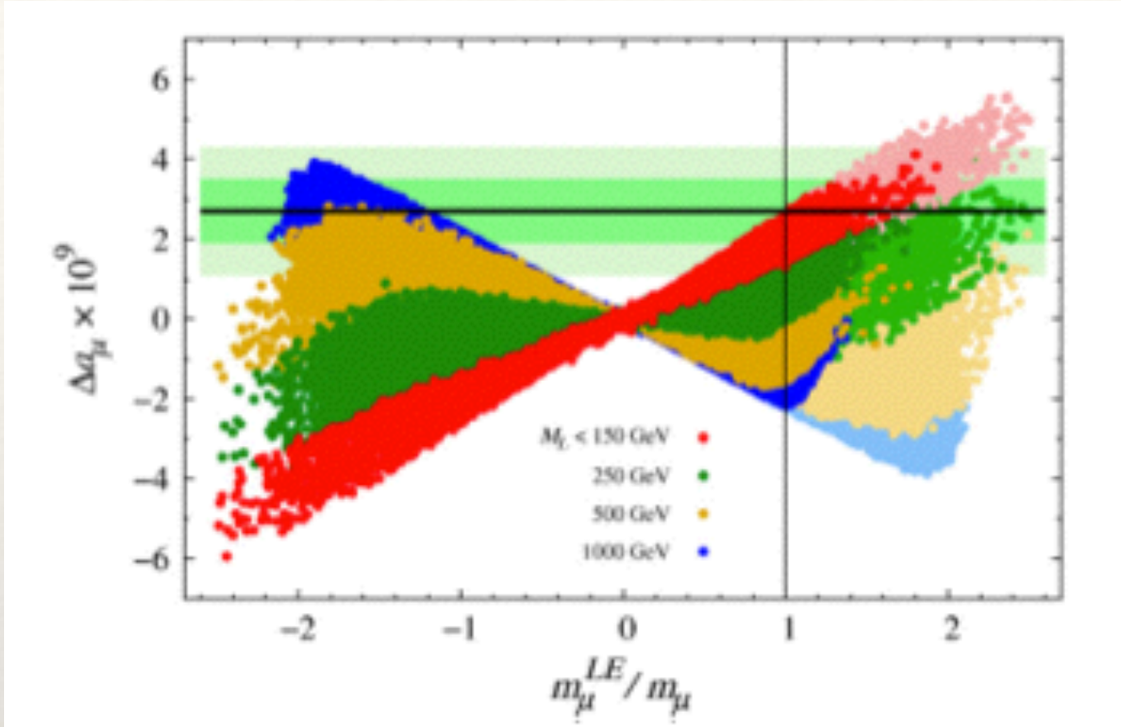
ATLAS-CONF-2013-108

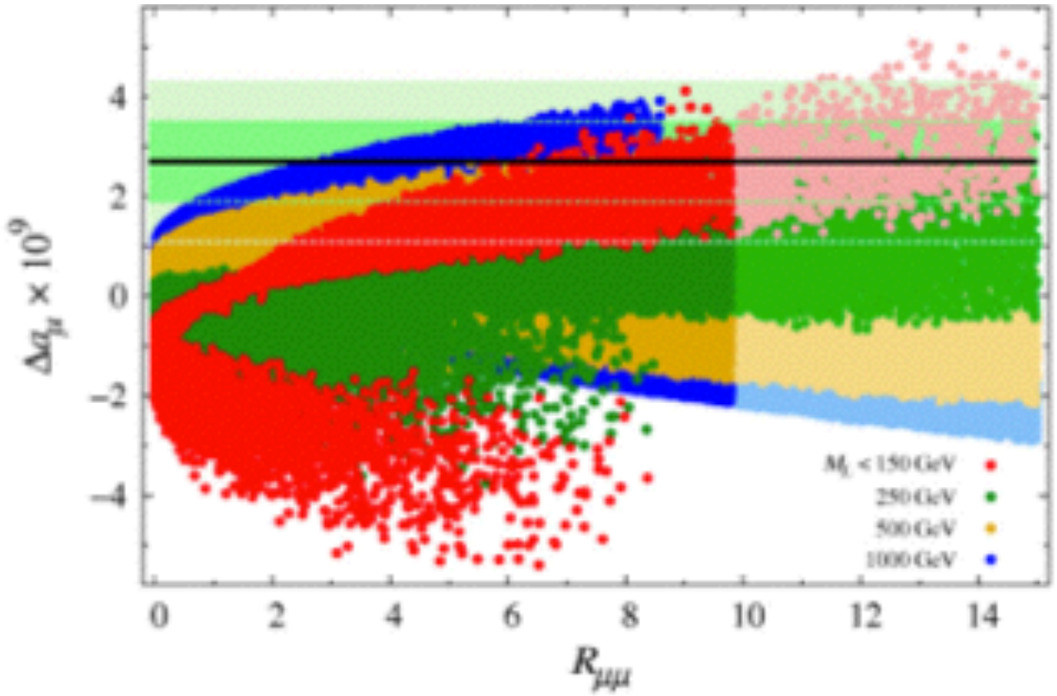
CMS 1401.5041, background includes H→WW

Back-up

Dermisek, Raval PRD88, 013017 (2013)







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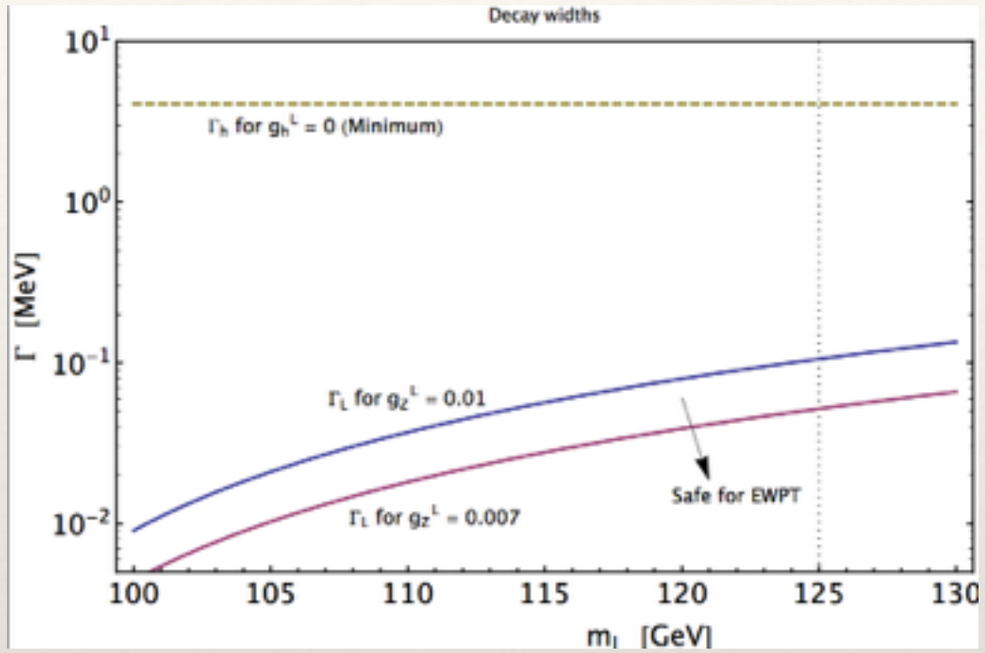

$$\mu \equiv \sigma/\sigma_{\rm SM} \equiv \xi\sigma^0/\sigma^0_{\rm SM} < \frac{\ell_{95}}{E_{\rm SM}}$$

$$\sigma^0/\sigma^0_{\rm SM} < \frac{\ell_{95}}{\xi \cdot E_{\rm SM}}$$