ANL workshop NPI

DIBOSON EXCESS THEORY UPDATES

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(Fermilab)

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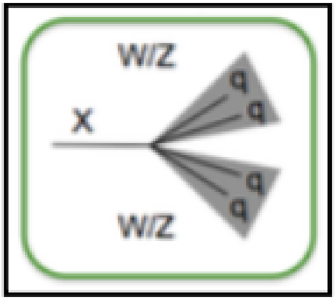
Selected updates since my work with B. Dobrescu:
arXiv:1506.06736, **arXiv:1507.01923**

Diboson Excess (why people are(were?) excited)

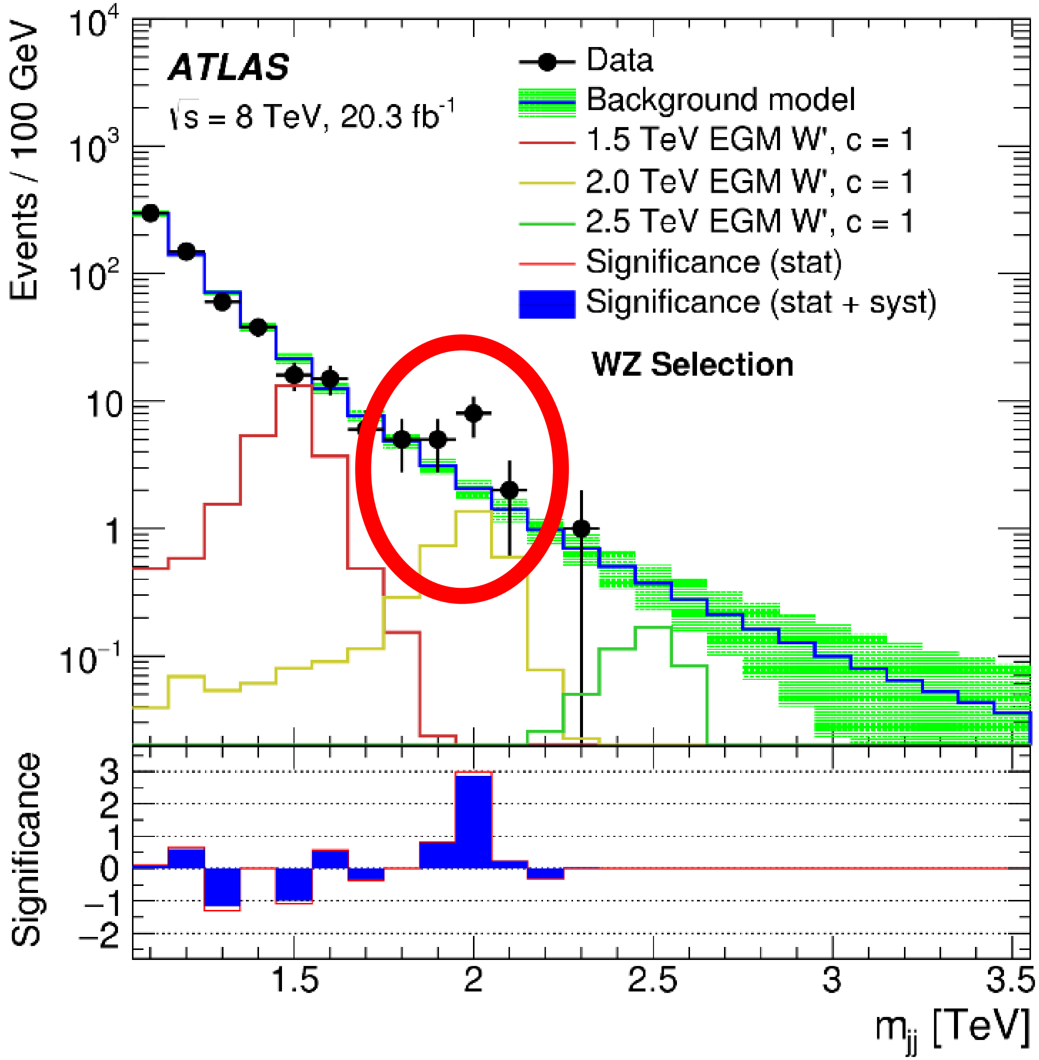
V-jet + V-jet

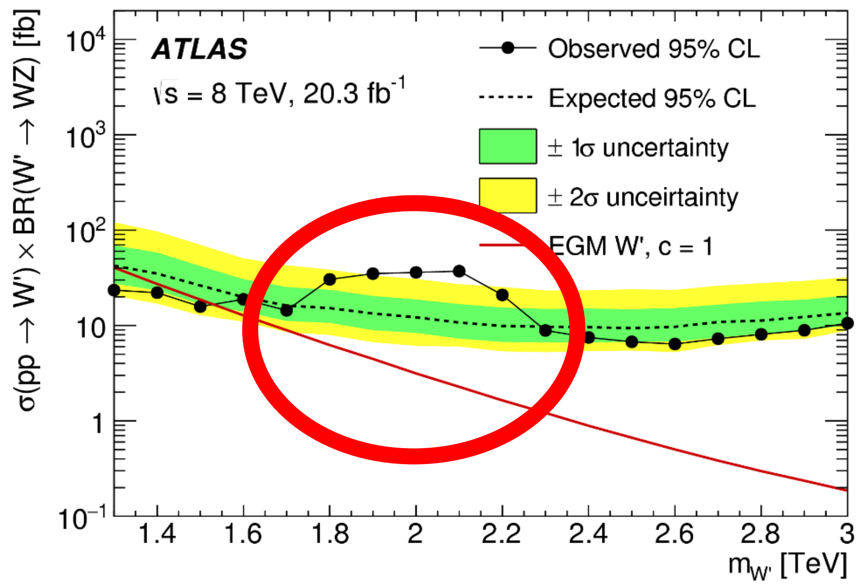


- Searched for a pair of boosted fat jets.
- Using jet substructure to suppress QCD background.
- Mass window for jets are weak boson mass ± 13 GeV. WW, ZZ, WZ signal regions overlap, including some uncoventional cut on number of tracks (more discussion later)

arXiv:1506.00962, more details and additional material, see http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2013-08/#auxstuff

Diboson Excess (why people are excited)

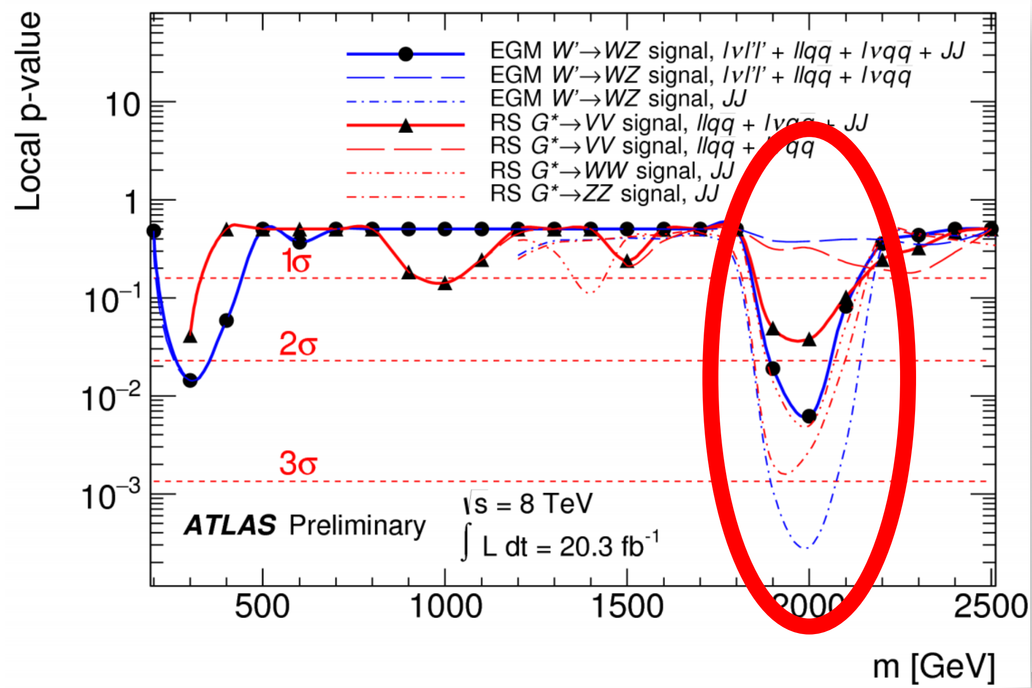


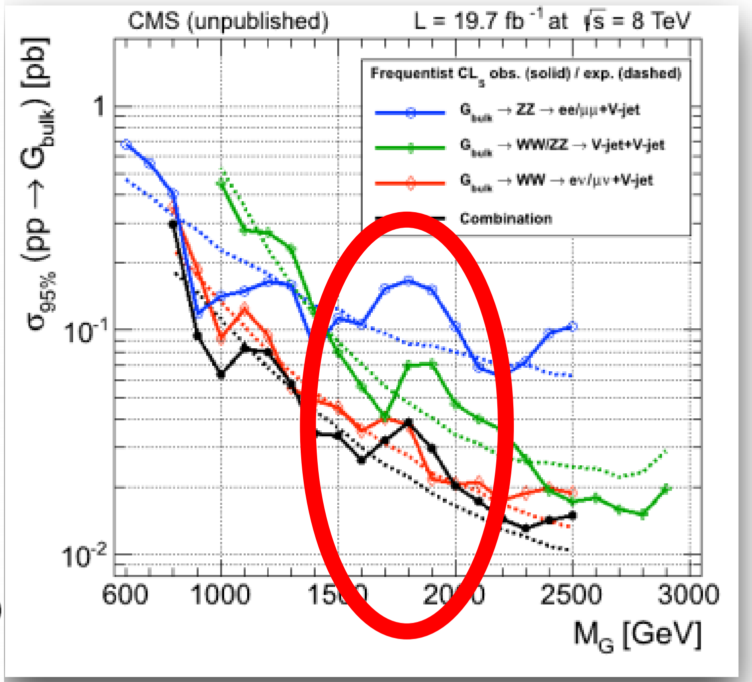


Local significance 3.4 sigma
Global significance 2.5 sigma

An “obvious” bump near 2 TeV. Due to resolution, anywhere between ~1.8-2.1 TeV has more than 2 sigma significance.

Diboson-Other channels

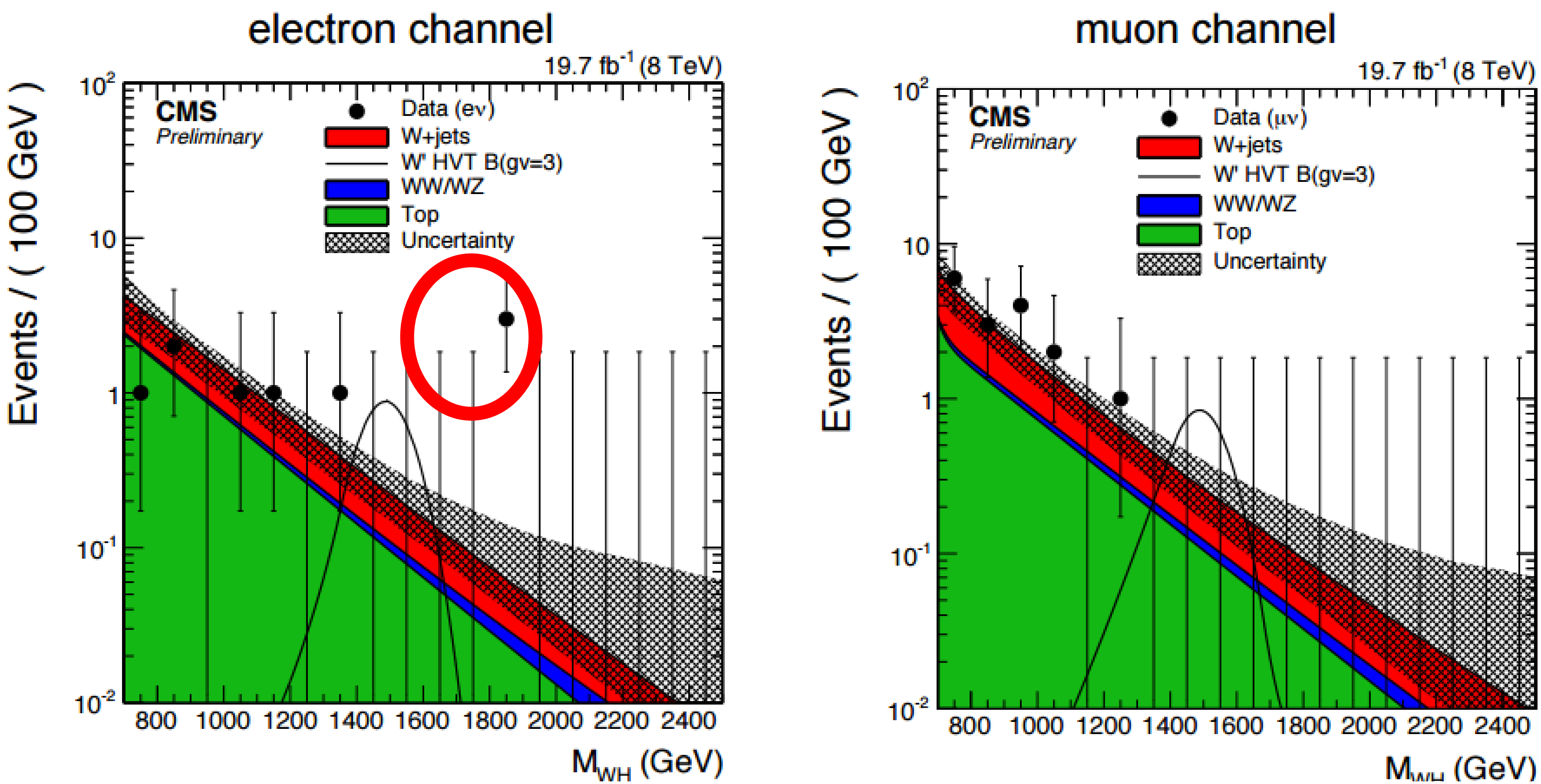




EXO-13-009 public twiki

(Recent update) ATLAS shows combined analysis for W'->WZ, G*->VV in hadronic, leptonic and semi-leptonic channels, still get ~2.5σ at 2 TeV.

WH->lv bb (3rd excess)



CMS-PAS-EXO-14-010

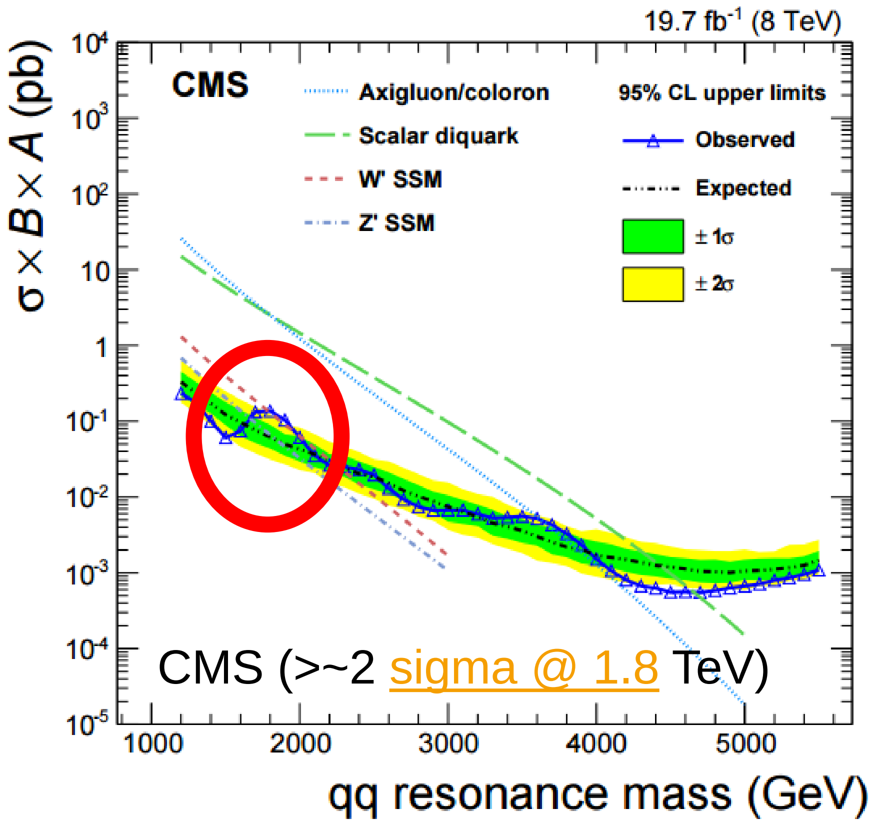
Same search techniques as W(lv)V(qq) search

Lower backgrounds due to better background rejection of H(bb)-tagger compared to W(qq)/Z(qq)-tagger

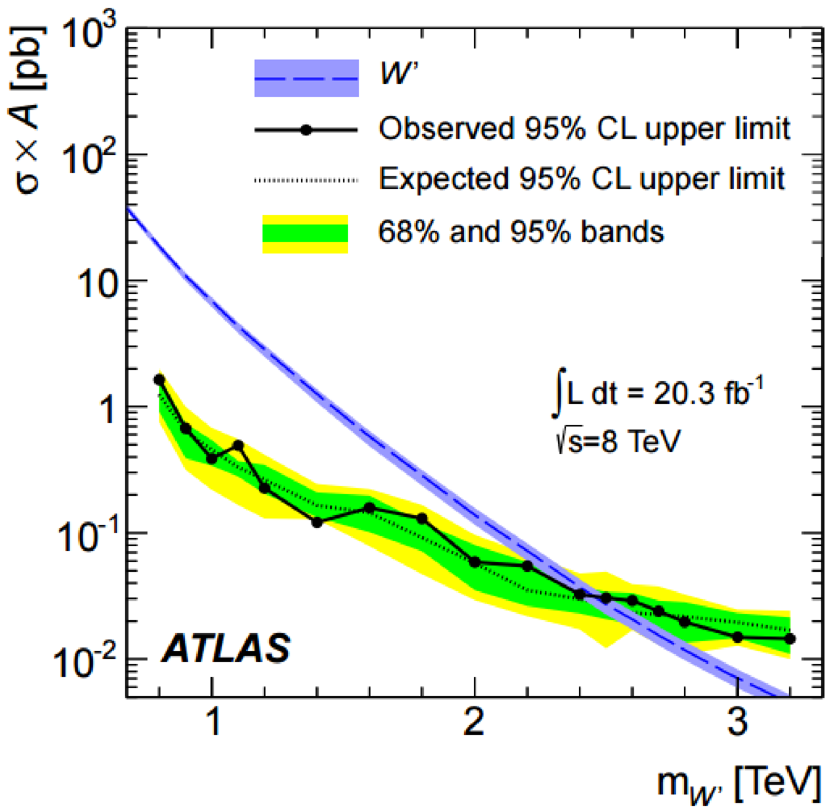
Excess in W(lv)H(bb) at 1.8 TeV has a global significance of 2.2 s.d.

Dijets (4th excess)

CMS (1501.04198):



ATLAS (1407.1376):

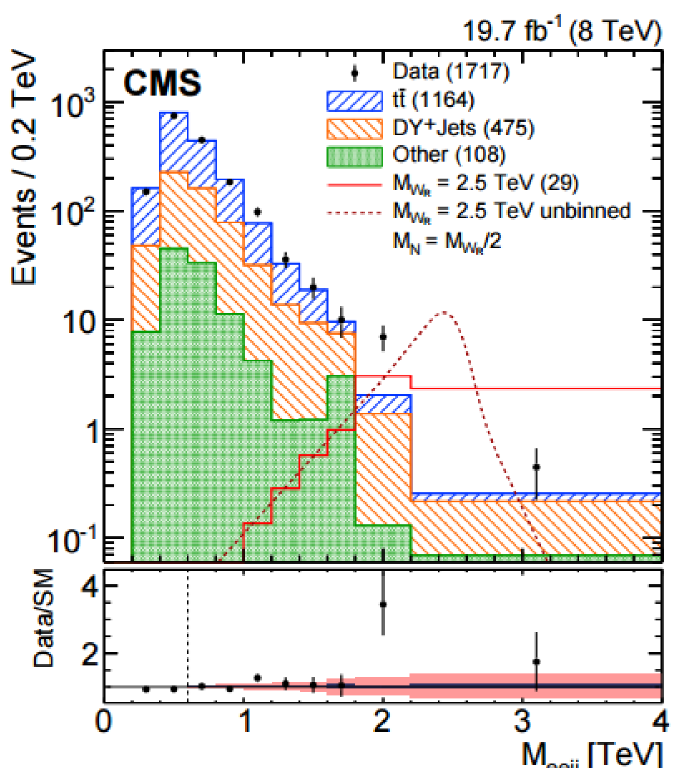


eejj (5th excess)

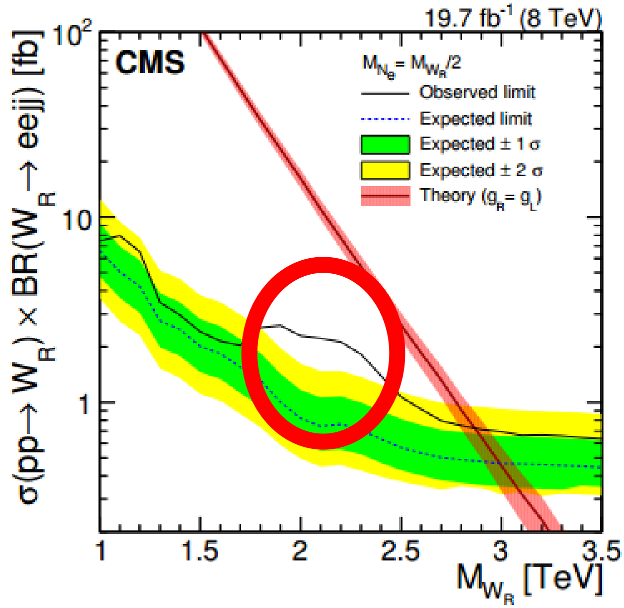
Z-dilepton peak vetoed.

$\underline{W' \to eN \to e^+e^-jj}$ (no e^+e^+jj signal $\to$ Dirac mass for N)

CMS (1407.3683):



14 observed with 5 expected bkg.
2.8σ significance.
One event has same-sign dilepton.



Gauge Boson

e^+e^-jj (CMS) 2.8σ "peak" @ 1.8–2.2 TeV	1~2 fb
jj (CMS) $\sim 2\sigma$ "peak" @ 1.8–1.9 TeV	50~100 fb
JJ (ATLAS) 2.5σ (global) peak @ 1.8–2.1 TeV	3~10 fb
$J(\ell^+\ell^-)$ (CMS) $\sim 2\sigma$ "peak" @ 1.8–1.9 TeV	~few fb
$Wh \to (\ell\nu)(b\bar{b})$ (CMS) 2.2σ "peak" @ 1.8–1.9 TeV	~few fb

Many aspects point us toward a charged gauge boson explanation:

- Sizable production, dominant decays into dijet
- Decays to Wh
- accommodates eejj

Cherry picking?
For these excesses, other experiments see compatible excesses with less significance (jj, JJ), or not explicit search result not available (eejj), or no excesses seen but sensitivity is worse with little tension (lvbb, lvjj).

W_R—works out of the box

Due to constraints from lepton+Missing Energy search, W' should have little/no couplings to SM lepton and neutrino.

Right-handed W' is a very straight forward choice and works out of the box.

Simply count by degree of freedom, ignoring the phase space factors, partial widths

$$jj : tb : lN : WZ : Wh = 24 : 12 : 4 : 1 : 1$$

and branching fractions

$$jj : tb : WZ : Wh = \sim 60\% : 30\% : 3\% : 3\%$$

*assuming W-W' mass mixing; WZ and Wh only longtitugonal modes counts; lN has a bit more complexities.

$SU(2)_R$ extension (LR-symmetric model)

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

$$\Big\downarrow W_R, Z' \qquad g_R, g_{B-L} \to g'$$
$$g_L \to g$$

$$SU(2)_L \times U(1)_Y$$

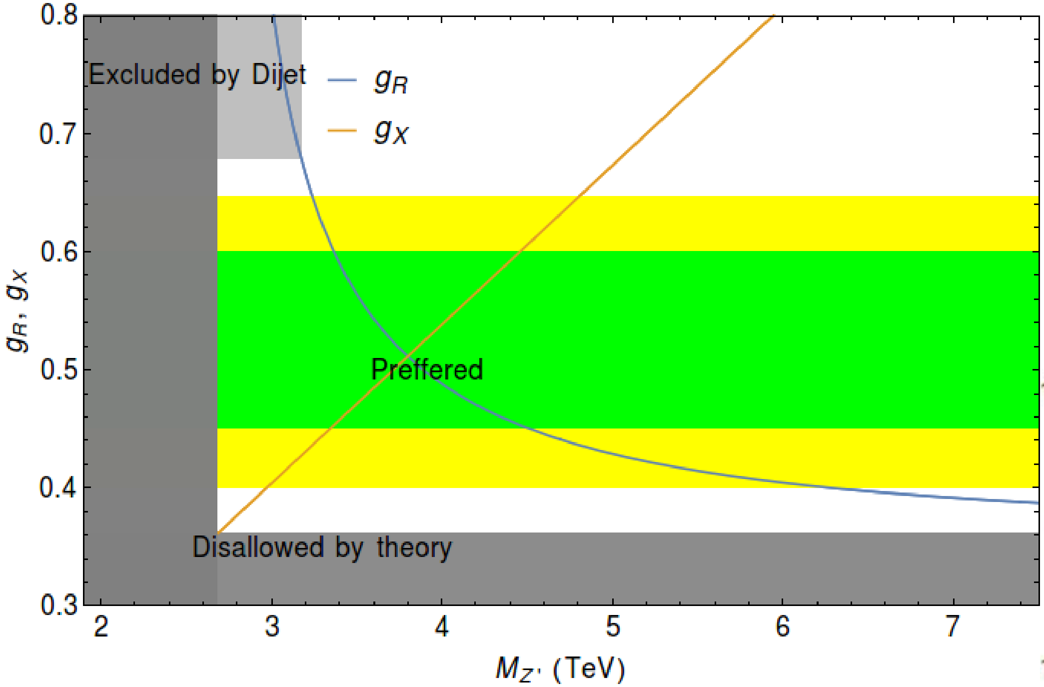
$$\Big\downarrow W, Z$$

$$U(1)_{em}$$

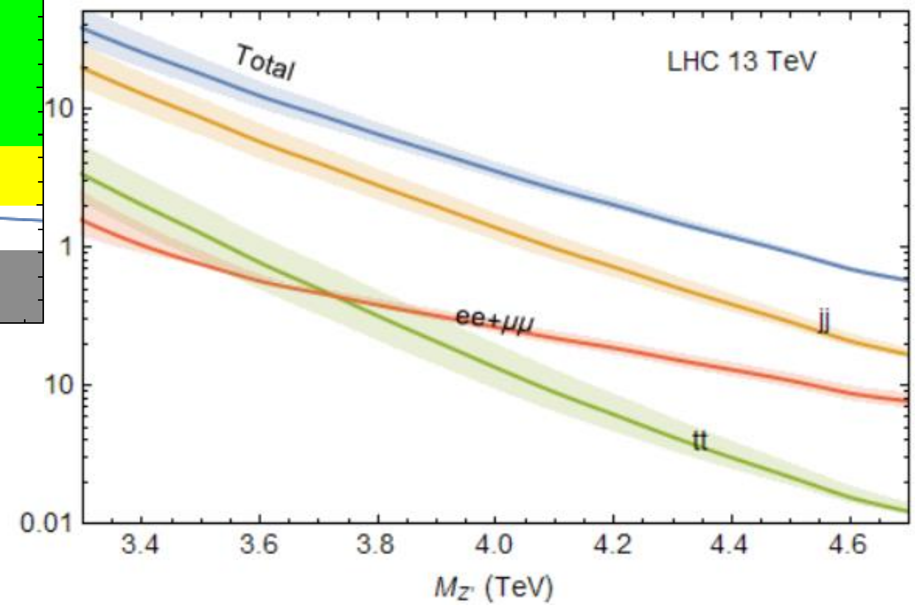
g_R is the only free parameter in gauge couplings, others are fixed by SM condition. Masses and mixings determined by details of the symmetry breaking.

LR-symmetric standard model as very long history. Our proposal is one variation. See earlier works by J. Pati, A. Salam, PhysRevLett.31.661 (1973), PhysRevD.10.275(1974), R. Mohapatra, J. Pati PhysRevD.11.2558(1975), PhysRevD.11.566 (1975), G. Senjanovic and Mohapatra PhysRevD.12.1502(1975) and many more. For many detailed properties of this model, see **Mohapatra's book**, and phenomenological studies, see, e.g., Q.-H. Cao, Z. Li, J.-H. Yu and C.P. Yuan **arXiv:1205.3769**.

Preferred values



For fixed W' mass (as observed), only one free-parameter left g_R, which can be represented by Z' mass.

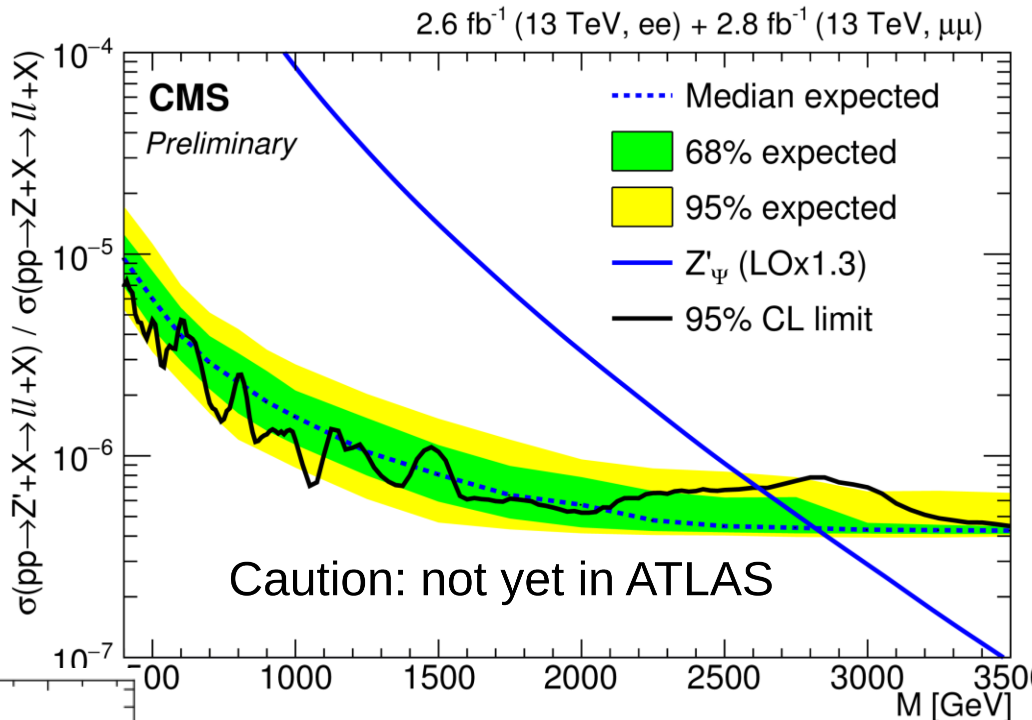


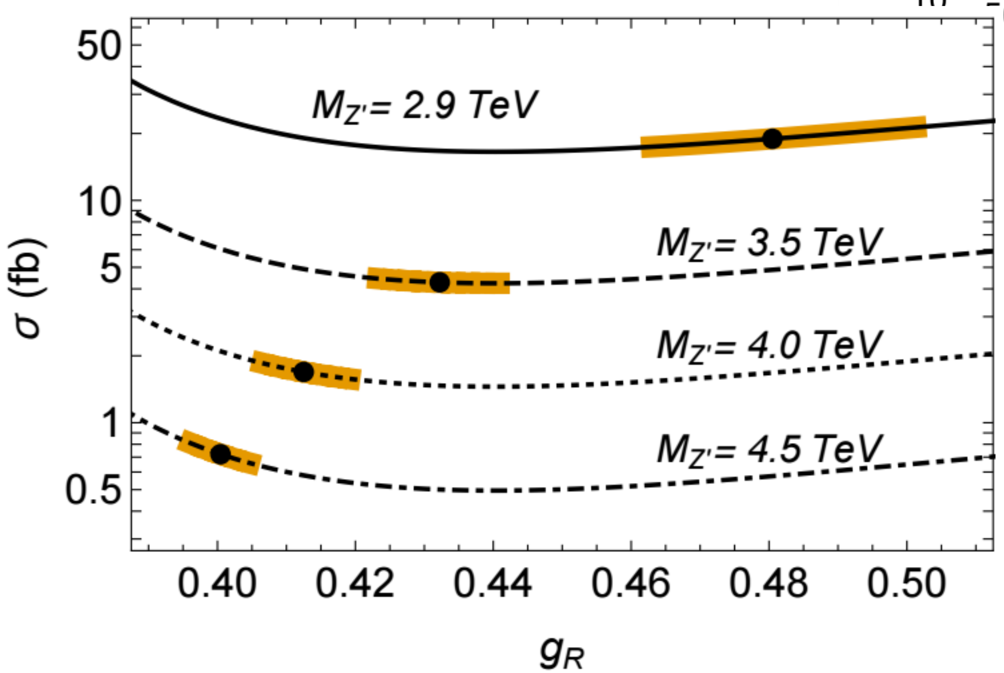
Z' properties predicted, up to heavy neutrino sector, vector fermions and heavy Higgs boson branching fractions.

Note here, lower value of g_R corresponds to heavier Z' mass. The preferred range of g_R has large uncertainty, depending on details of background subtraction and many other factors.

Z' properties

One can break the $SU(2)_R$ by a scalar doublet instead of a triplet; the g_R value (lower than g) could push Z' mass high enough to avoid dilepton constraints from 8 TeV while compatible with the excess in 13 TeV.

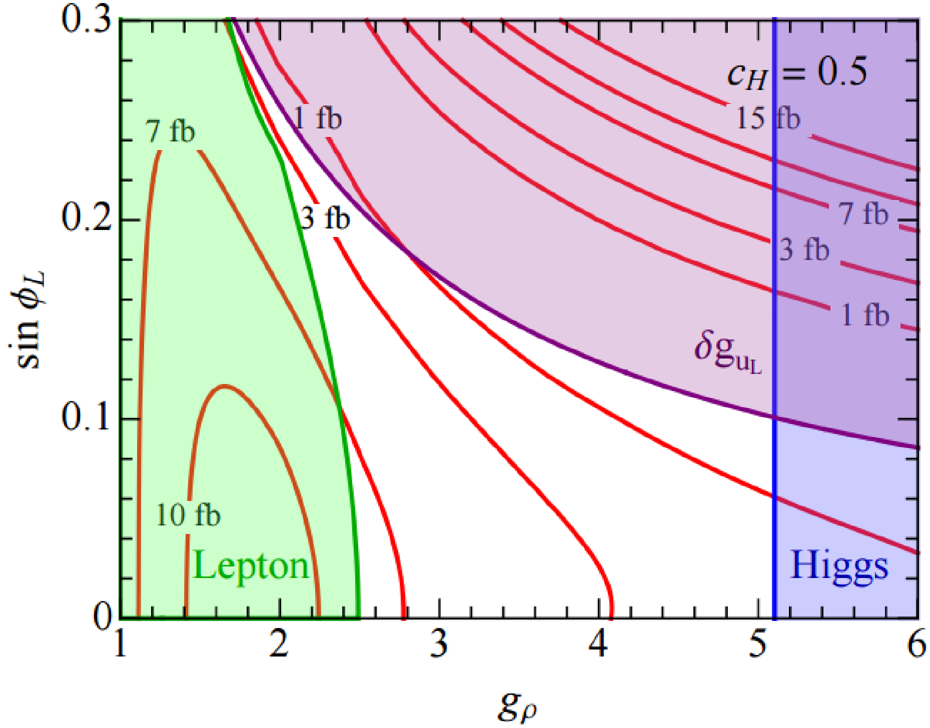


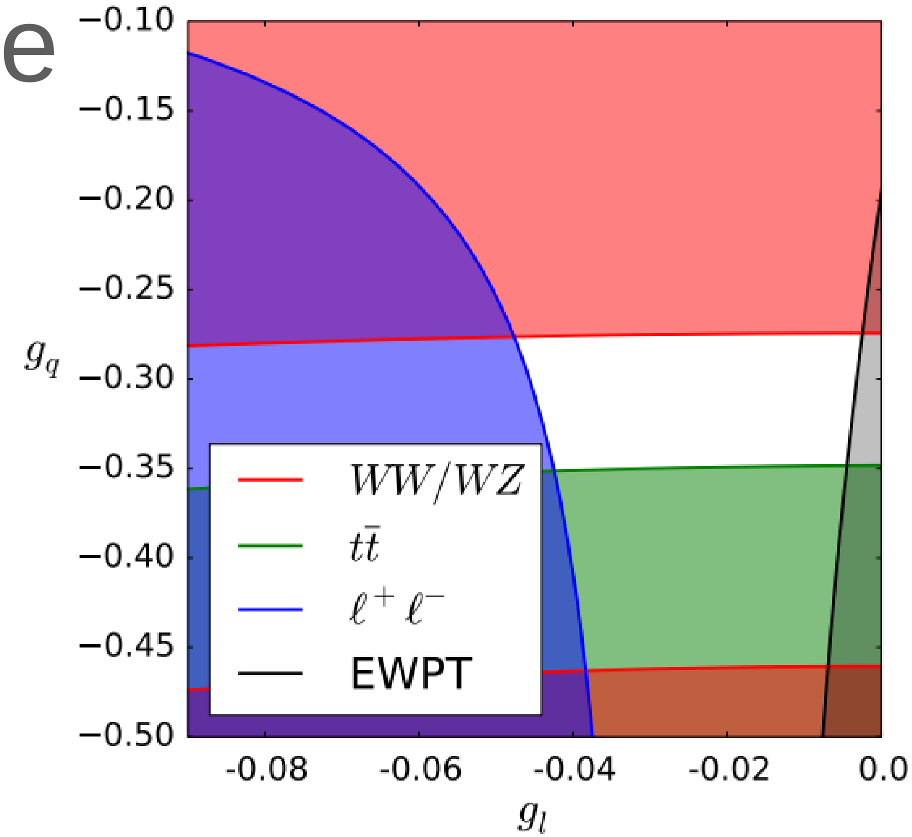


B. Dobrescu and P. Fox, arXiv:1511.02148 (a model file for event generation is also available from this paper.)

M. Buen-Abad, A. G. Cohen and M. Schmaltz, arXiv:1604.03578

Composite Resonance





Composite resonances, unitarize weak boson scattering, decay dominantly to weak boson pairs.

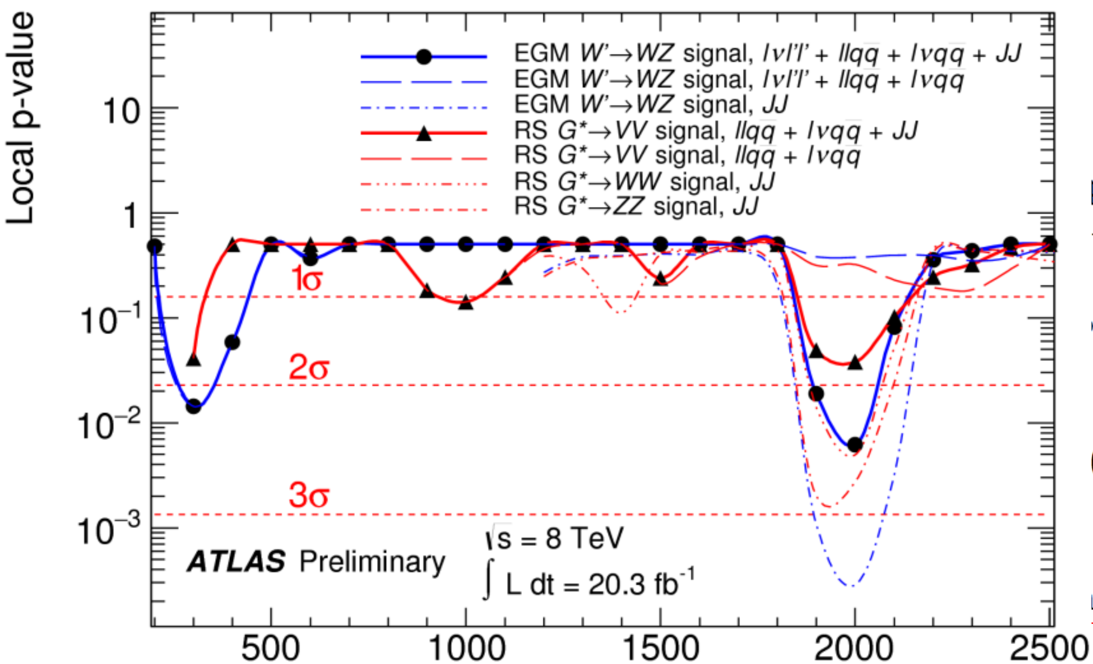
Production are mainly from quark-heavy quark mixing. (receives constrains from EWPO)

An argument for composite resonance is in composite Higgs models, the tuning is large if not the composite scalar below a few TeV.

Left figure from M. Low, A. Tesi, L.-T. Wang, arXiv:1507.07557.
Right figure from A. Carmona, A. Delgado, M. Quiros, J. Santiago, arXiv:1507.01914.
Similar result from other composite interpretations.

8 TeV combination and 13 TeV

Signal hypothesis	m_X (TeV)	Significance	p-value	Best-fit cross section (fb)	
$\mathrm{W}' \to \mathrm{W}_L\,\mathrm{Z}_L$	1.9	2.5 (3.1)	6.5 (1.0) $\times 10^{-3}$	$5.3^{+2.3}_{-2.0}$	$(5.5^{+2.0}_{-1.6})$
	2.0	2.5 (3.2)	7.0 (0.8) $\times 10^{-3}$	$4.3^{+2.1}_{-1.5}$	$(4.7^{+1.8}_{-1.3})$



production cross section from 8 to 13 TeV. We
viation in the Run-2 data

est-fit cross section derived in this paper in the

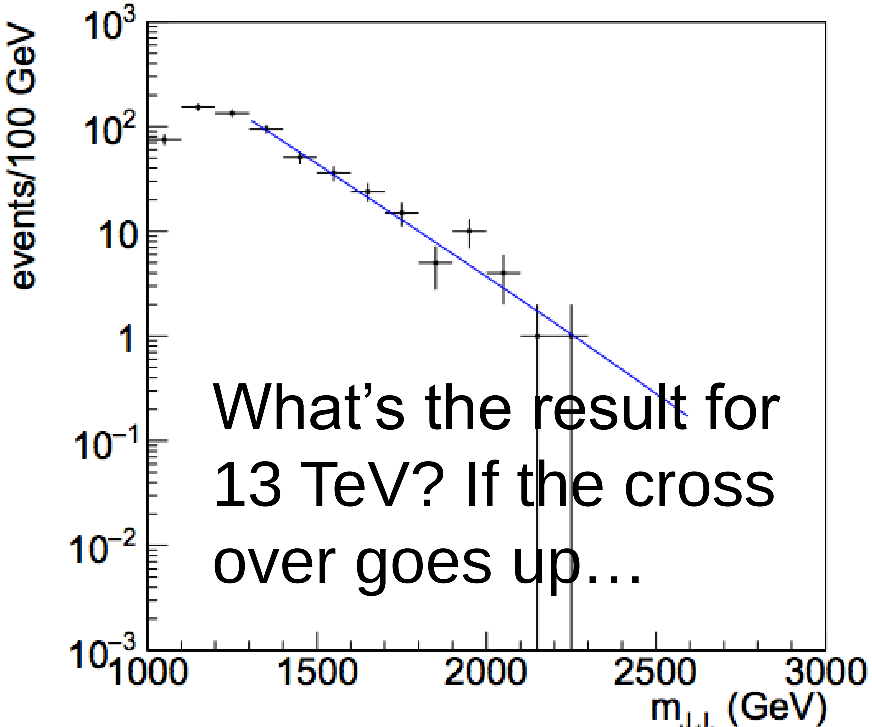
(consistent-with-zero) result we obtain in the

e best-fit cross section that we have derived in

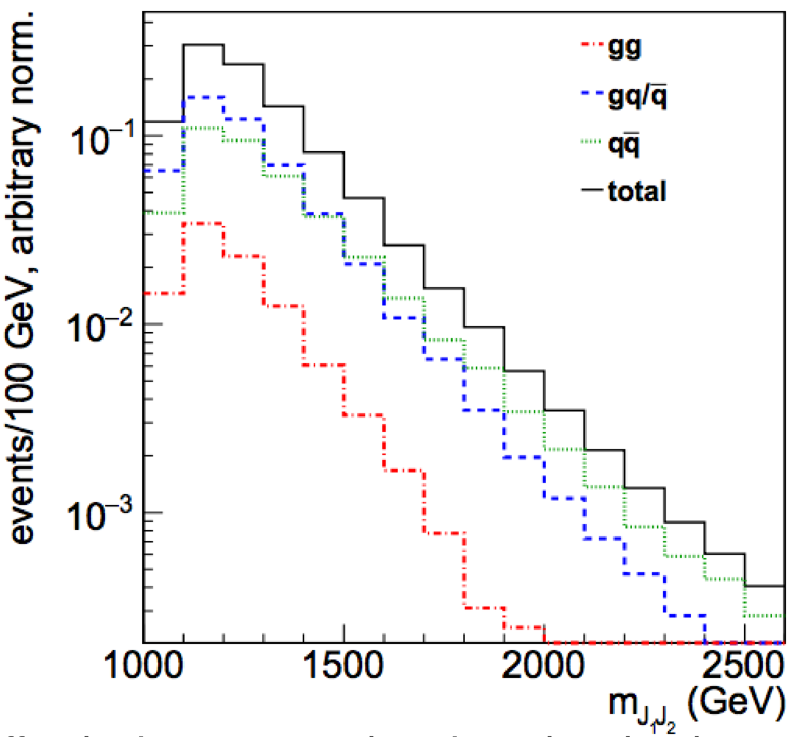
F. Dias, S. Gadatsch, M. Gouzevich, C.Leonidopoulos, S. Novaes, A. Oliveira, M. Pierini, T. Tomei, arXiv:1512.03371

Biboson Excess from SM?

A. Martin and T. S. Roy, arXiv:1604.05728
See also in for other efforts, D. Goncalves, F. Krauss and M. Spannowsky arXiv:1508.04162



What's the result for 13 TeV? If the cross over goes up…



Left: before the # of tracks cut
Right: after the # of tracks cut

Then all one need to get a fake bump is to have downward fluctuations before and after the bump…

# of tracks cut effectively removes the gluon-jets background for hadronic boson, raising the relative importance of QCD background form qqbar comparing to qg.
Modeling the background from qg dominances low invariant mass regions may lead to undershoot of the background at high mass tail.

Summary and outlook

- We propose a very compelling and coherent interpretation of recent observed excesses with simple extension of the SM gauge symmetry

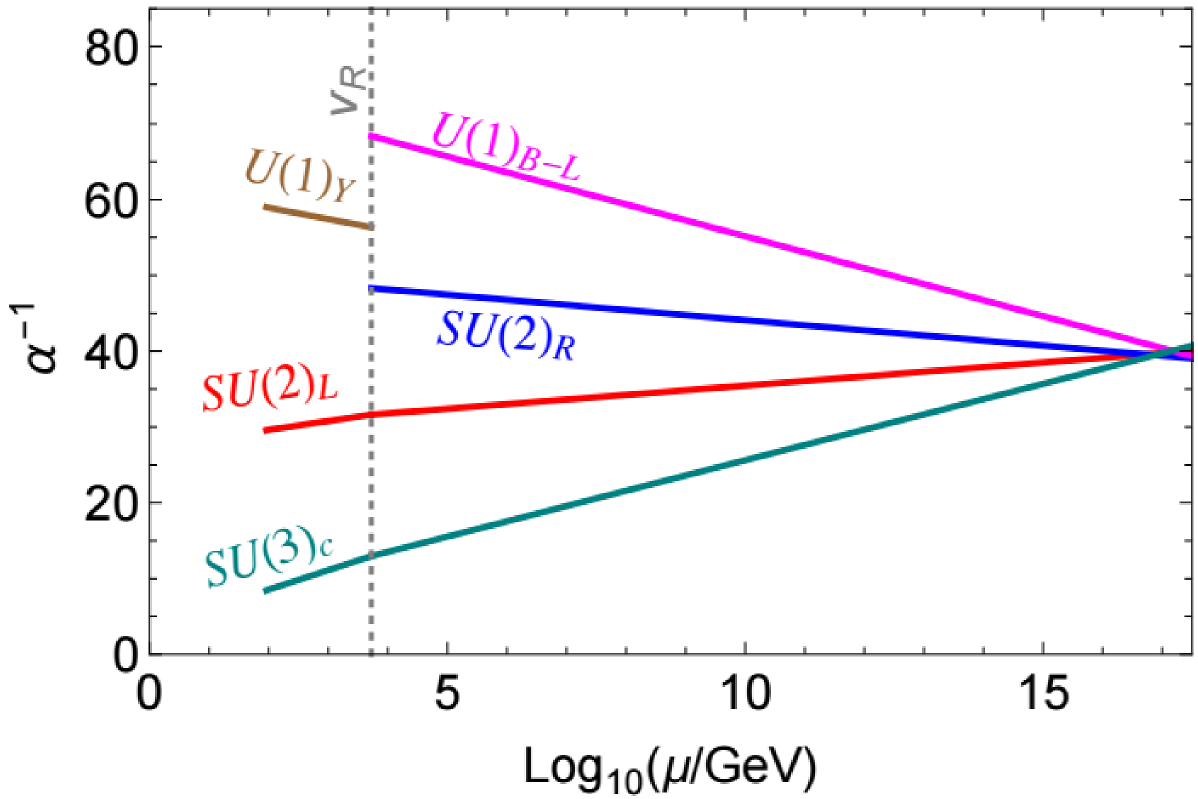
- Exciting opportunity for Run2, will get definite answer for these excesses. Hopefully we will see consistent $\sim 2\sigma$ excesses with $\sim 5\ fb^{-1}$ of data, and establish discovery with $\sim 30\ fb^{-1}$.

Thank you!

- Many other aspects of the models can be tested: including chiral structures of the gauge couplings (from tb, and lljj angular distributions, work by T. Han et al arXiv:1211.6447, arXiv:1008.3508), heavy neutrino nature, Higgs physics (B. Dorescu, ZL arXiv:1507.01923) and heavy Z' (B. Dorescu, ZL arXiv:1506.06736, Brehmer, Hewett, Kopp, Rizzo, Tattersall, arXiv:1507.00013), higher order corrections, precision tests, alternative production modes (E. Berger, Q.-H. Cao, J.-H. Yu, C.-P. Yuan, arXiv:1108.3613), connections to DM (A. Berlin, P. J. Fox, D. Hooper, G. Mohlabeng, arXiv:1604.06100), model building of fermion masses, connection with \digamma excess (many, some helps from charged scalars augumenting diphoton Br.), etc.

- Alternatively, all these excess may not persist simultaneously. In this case, many other possibilities will be open. Many tests, including color, width, initial state, and so on need to be performed to identify its physical origin (T. Han, I. Lewis, Z. Liu arXiv:1010.4309 , S. Chivukula, E. Simmons, N. Vignaroli, P. Ittisamai, K. Mohan, arXiv:1406.2003, arXiv:1412.3094, arXiv:1507.06676, M.Buschmann and F. Yu arXiv:1604.06096)

Gauge coupling unification



With slightly modified scalar sector and out preferred values of the gauge couplings, gauge coupling unification can be achieved, by B. Dev., R. Mohapatra, **arXiv:1508.02277**.

See also early works on low intermediate scale gauge coupling unification without SUSY, T. Rizzo and G. Senjanovic, **PRL 46 1315,**(1981).

and many related studies on best fit coupling strength and dark matter (Brehmer, Hewett, Kopp, Rizzo, Tattersall, **arXiv:1507.00013**), alternative setup for eejj excess (J. Gluza, T. Jelinski, **arXiv:1504.05568**, Coloma, Dobrescu and Lopez-Pavon, **arXiv:1508.04129**), electroweak precision Q.-H. Cao, B. Yan and D.M. Zhang, **arXiv:1507.00268**), and many efforts from different groups.