Anatomy of the ATLAS diboson anomaly

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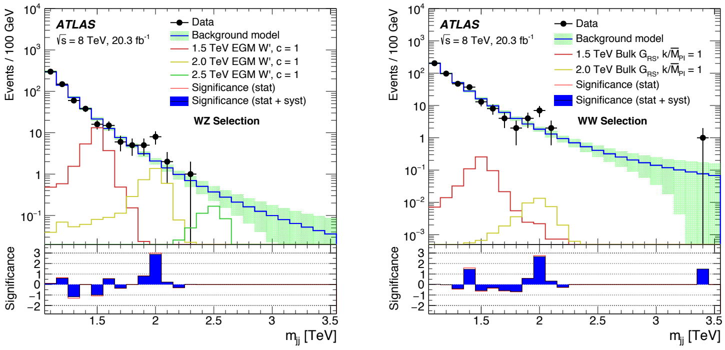
1507.01638, to appear in PRD

Outline

- The anomaly in a nutshell
- Likelihood analysis
- New physics desiderata
- Models

ATLAS

- seeks 2, 2-prong fat jets with $m_j \in [69.4, 95.4]$ (a ‘ W’) or $\in [79.8, 105.8]$ (a ‘ Z’)
- finds bumps at 2 TeV in ‘WW’, ‘WZ’, & ‘ZZ’ of 2.6, 3.4, & 2.9 σ bzw.



(a) (b)

ATLAS, 1506.00962

More questions than answers ...

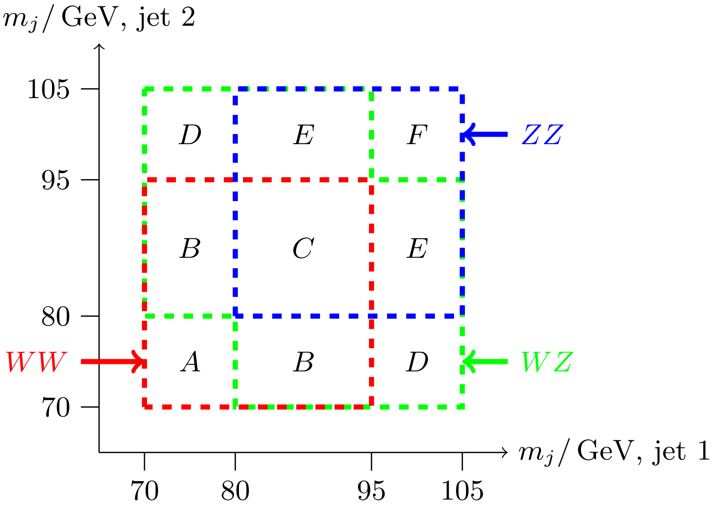
- $m_j \in [69.4, 95.4]$ (a ‘ W’) or $\in [79.8, 105.8]$ (a ‘ Z’) $\Longrightarrow$ signals overlap
- How many events are common?
- What is the true global significance?
- Are these (likely) Ws or Zs?
- ...

Start by trying to answer some of these qq ...

... by a poor man's (i.e. theorist's) likelihood analysis.

cf. Brehmer & al., 1507.00013
Fichet & von Gersdorff, 1508.04814

1. In an ancillary file far, far away, we are told the numbers in the ‘WW+ZZ’ and ‘WW+WZ+ZZ’ regions



$$WW = A + B + C,$$
$$ZZ = C + E + F,$$
$$WZ = B + C + D + E,$$
$$WW + ZZ = A + B + C + E + F,$$
$$WW + WZ + ZZ = A + B + C + D + E + F.$$

Even a theorist can't solve 5 eqns in 6 unknowns!
For the 3 bins around 2 TeV:

	A	B	C	D	E	F
$n_i^{\mathrm{obs},1}$	2	6	5	0	4	0
$n_i^{\mathrm{obs},2}$	1	7	5	0	3	1
$n_i^{\mathrm{obs},3}$	0	8	5	0	2	2
μ_i^{SM}	2.09	2.72	1.00	2.43	0.46	0.34

2. Read off probabilities (from ATLAS model simulation) for bosons from a 2 TeV resonance to fall in the signal regions:

	W jet tag only	W and Z jet tag	Z jet tag only
true W	0.25	0.36	0.04
true Z	0.11	0.39	0.21

M_{ji}	A	B	C	D	E	F
true WW	0.063	0.182	0.132	0.018	0.025	0.001
true WZ	0.028	0.139	0.143	0.057	0.090	0.007
true ZZ	0.012	0.087	0.155	0.047	0.165	0.044

3. Use ATLAS' reported efficiencies, branching ratios, etc, to compute a final Poisson likelihood:

$$p(\{n_i^{\mathrm{obs},\alpha}\}|s_{WW},\ s_{WZ},\ s_{ZZ}) =$$

$$\sum_{\alpha=1}^{3} \frac{\exp\left[-\sum_{i\in\{A,B,C,D,E,F\}}\left(\mu_i^{SM}+\epsilon\sum_{j=1}^{3} b_i s_j M_{ji}\right)\right]}{\prod_{i\in\{A,B,C,D,E,F\}} n_i^{\mathrm{obs},\alpha}!}$$

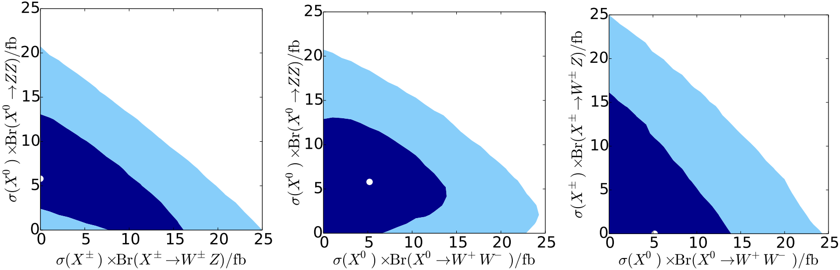
$$\prod_{i\in\{A,B,C,D,E,F\}} \left(\mu_i^{SM}+\epsilon\sum_{j=1}^{3} b_i s_j M_{ji}\right)^{n_i^{\mathrm{obs},\alpha}},$$

Caveats:

- No background uncertainty (ATLAS says it's small)
- ATLAS model is RS KK graviton - W and Z are long. polarized.
- Background expectation ad hoc
- ...

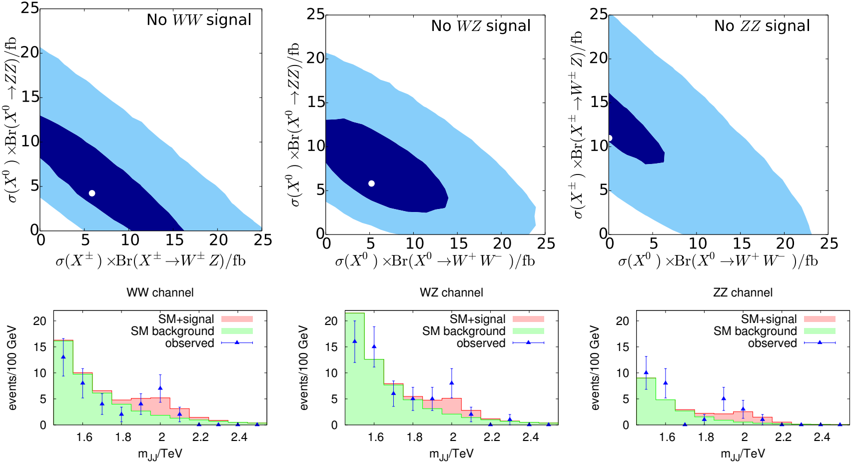
Likelihood results:

- In terms of $\sigma \times BR$ of WW, WZ, and ZZ components
- Best fit at 5.2, 0, 5.8 fb, bzw.
- But pretty flat!



Likelihood results II:

- SM has p-value of 6×10^{-4} ($4\ \sigma$)
- Likelihood with one channel forced to vanish ($\Delta\chi^2 < 1$)



More questions than answers ...

- How many events are common? 13/17, 15/17, 9/17.
- What is the true global significance? 4σ $(3.4 < 4 < 5.2)$
- Are these (likely) Ws or Zs? Likely equal *WW* and *ZZ* with no *WZ*

New physics desiderata . . .

. . . from an EFT perspective.

Desiderata I

- $SU(2) \times U(1)$ plus $H \in 2_{\frac{1}{2}}$ plus new resonance
- Dimension ≤ 4 couplings for production and decay
- Integer spin; ≤ 1
- (Spin 0 $\implies$ tune couplings to prevent vev) $\implies$ spin 1

Desiderata II

- Resonance ρ^{μ} with EW charge can couple to quarks and W/Z/H.
- ρ-parameter $\implies$ custodial $SU(2)_L \times SU(2)_R$ symmetry
- Coupling to quarks $\implies$ 1 or 3 of $SU(2)_L$ or $SU(2)_R$
- 3 allows diboson coupling via $\sim \rho^{\mu} H^{\dagger} D_{\mu} H$

Desiderata III

- Coupling to quarks $\implies$ EWPT non-universal
- LH coupling affects $Z \to h$ and CKM unitarity
- Flavour: couple universally to light generations

We have arrived at 2 models: EFTs of an $SU(2)_L$ or an $SU(2)_R$ triplet.

Can either explain the anomaly without conflict with other searches?

e.g. *SU*(2)$_L$ triplet.

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4}\rho^a_{\mu\nu}\rho^{a\mu\nu} + (\frac{1}{2}m_\rho^2 + \frac{1}{4}g_m^2 H^\dagger H)\rho^a_\mu \rho^{a\mu}$$
$$-2g\epsilon^{abc}\partial_{[\mu}\rho^a_{\nu]}W^{b\mu}\rho^{c\nu} - g\epsilon^{abc}\partial_{[\mu}W^a_{\nu]}\rho^{b\mu}\rho^{c\nu}$$
$$+(\frac{1}{2}ig_\rho \rho^a_\mu H^\dagger \sigma^a D^\mu H + \text{h.c.}) + g_q \rho^a_\mu \overline{Q_L}\gamma^\mu \sigma^a Q_L$$

Callan, Coleman, Wess & Zumino

e.g. $SU(2)_L$ triplet.

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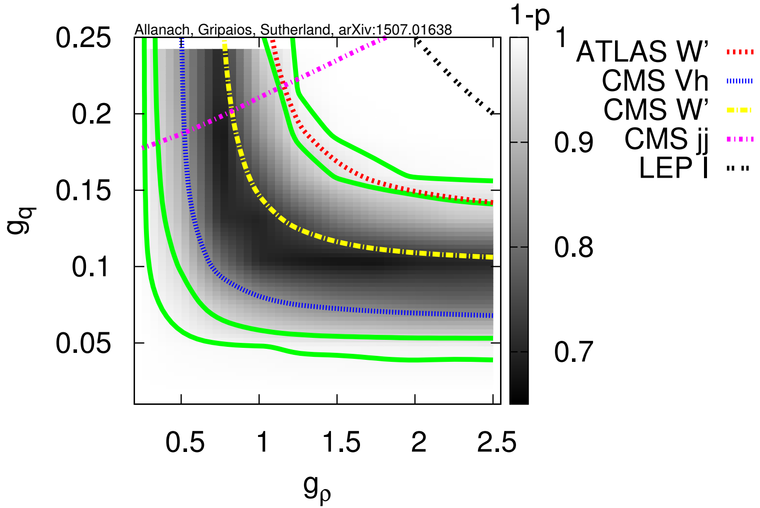

ATLAS, 1409.6190
CMS, 1506.01443
CMS, 1405.1994
CMS, 1501.04198
Pomarol & Riva, 1308.2803

Summary

- ATLAS anomalies not inconsistent
- Could be WW, WZ, or ZZ
- L- or R-triplet models make sense as bona fide EFTs
- Higgs compositeness?

Thamm & al., 1506.08688

Low & al., 1507.07557

Niehoff & al., 1508.00569

- Tension with CMS Vh
- We wait with bated breath for an update . . .