RESONANCE INTERPRETATIONS OF THE ATLAS DIBOSON EXCESS

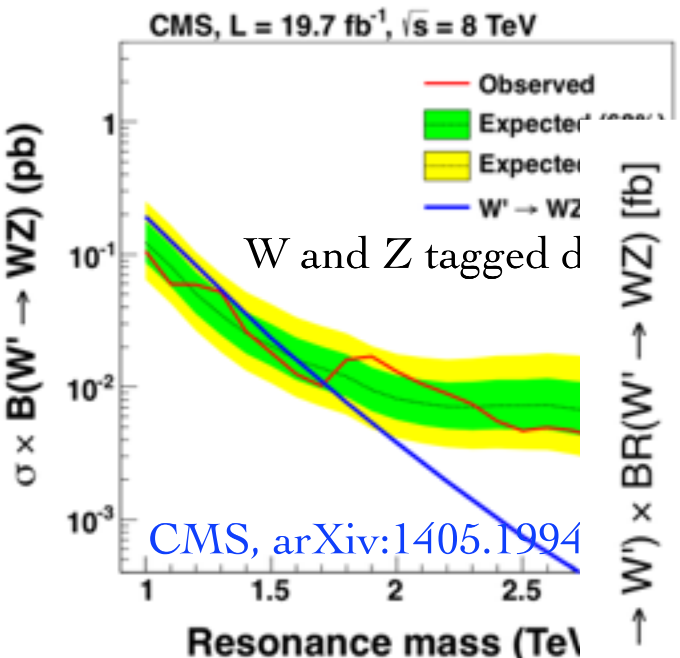
Riccardo Torre

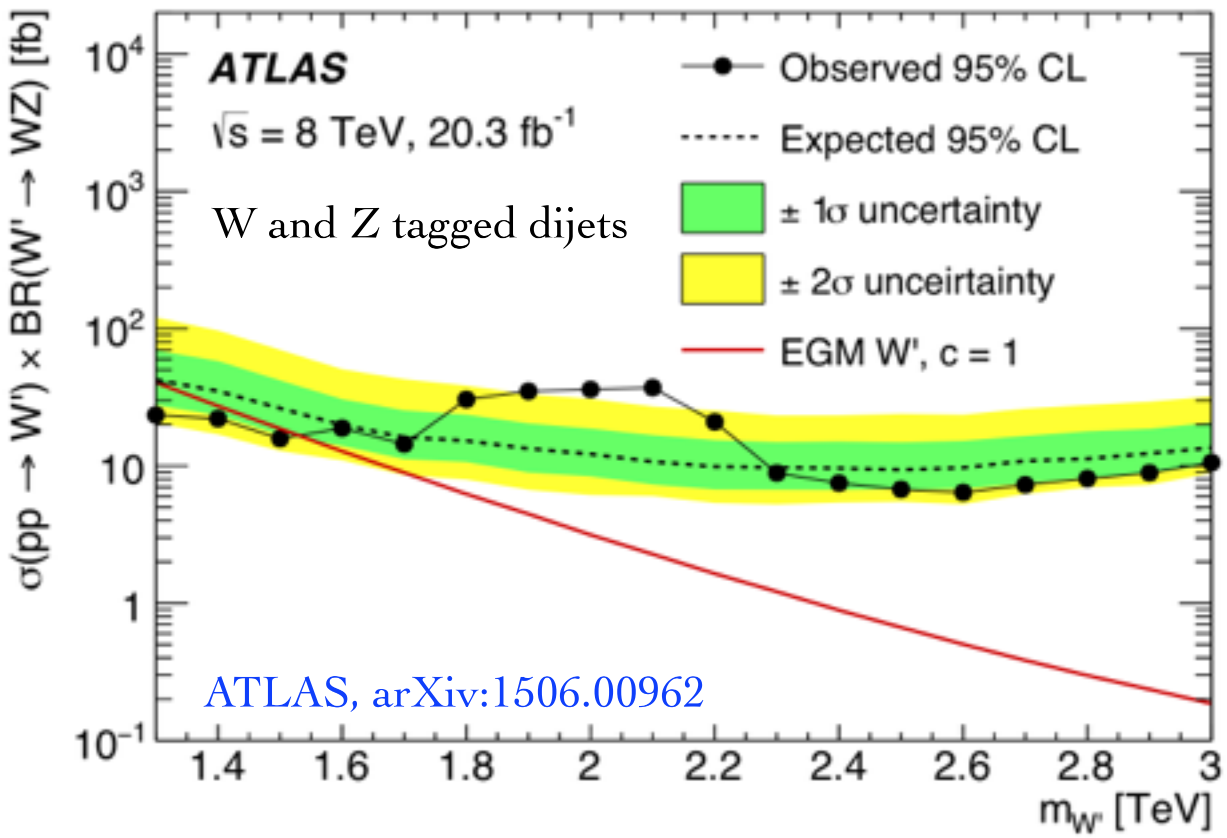
Padova University / EPFL Lausanne

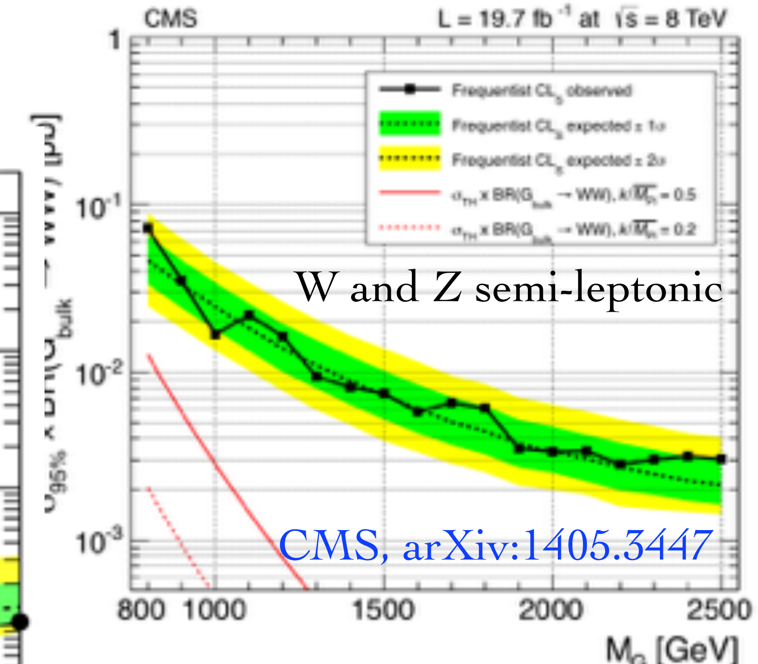
St. Petersburg - 01 September 2015

A. Thamm, R. Torre, A. Wulzer, 1506.08688, C. Petersson, R. Torre, 1508.05632

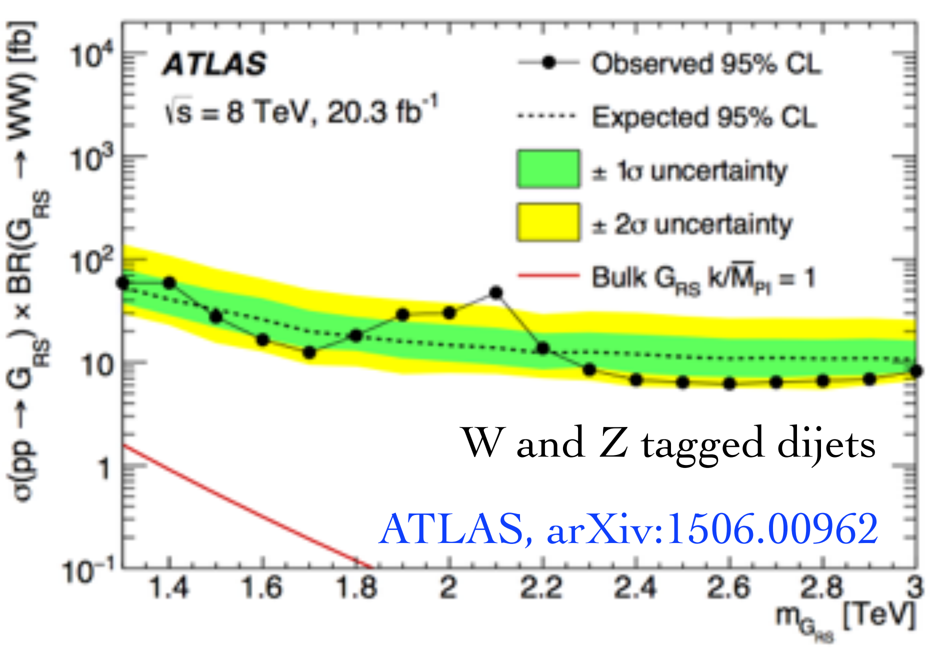
HINTS FOR NEW PHYSICS?

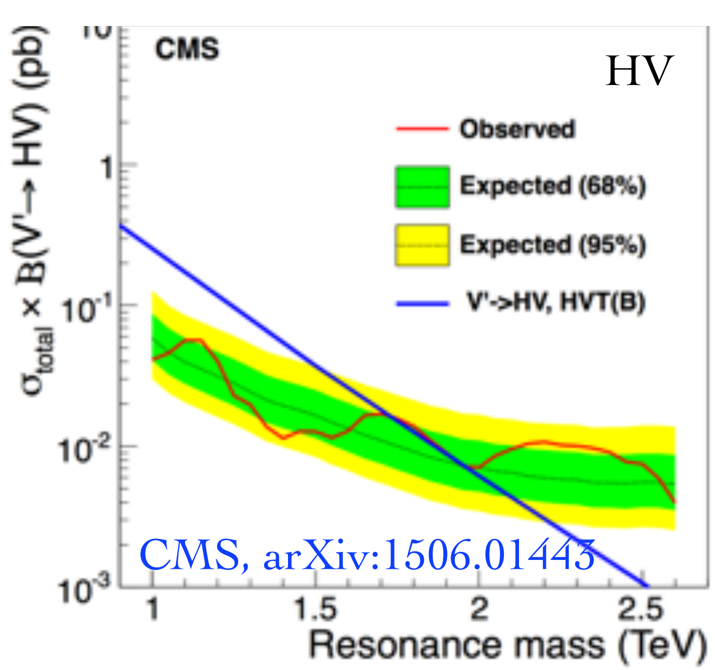


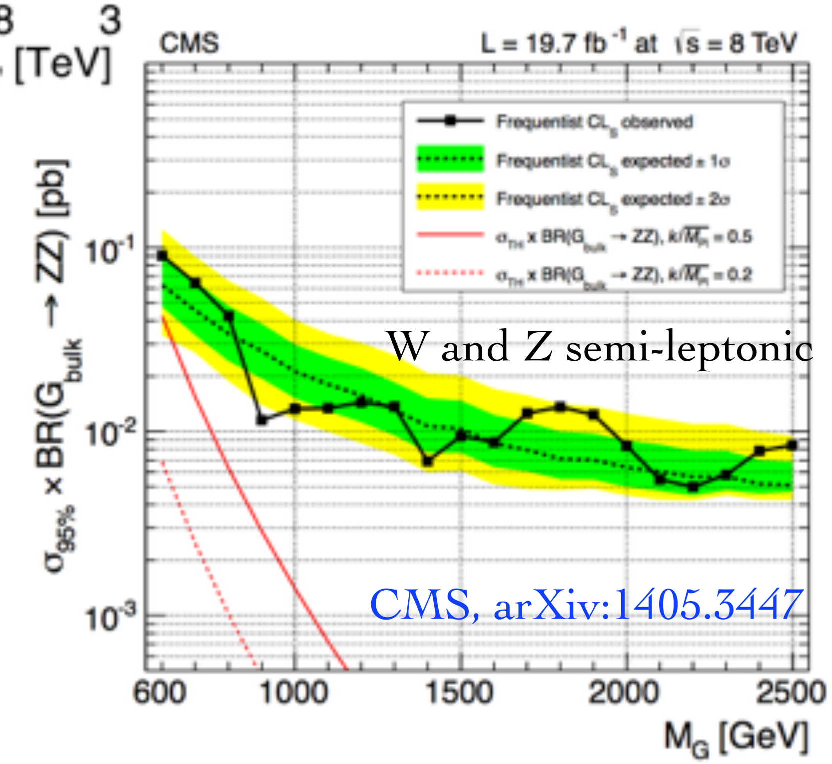




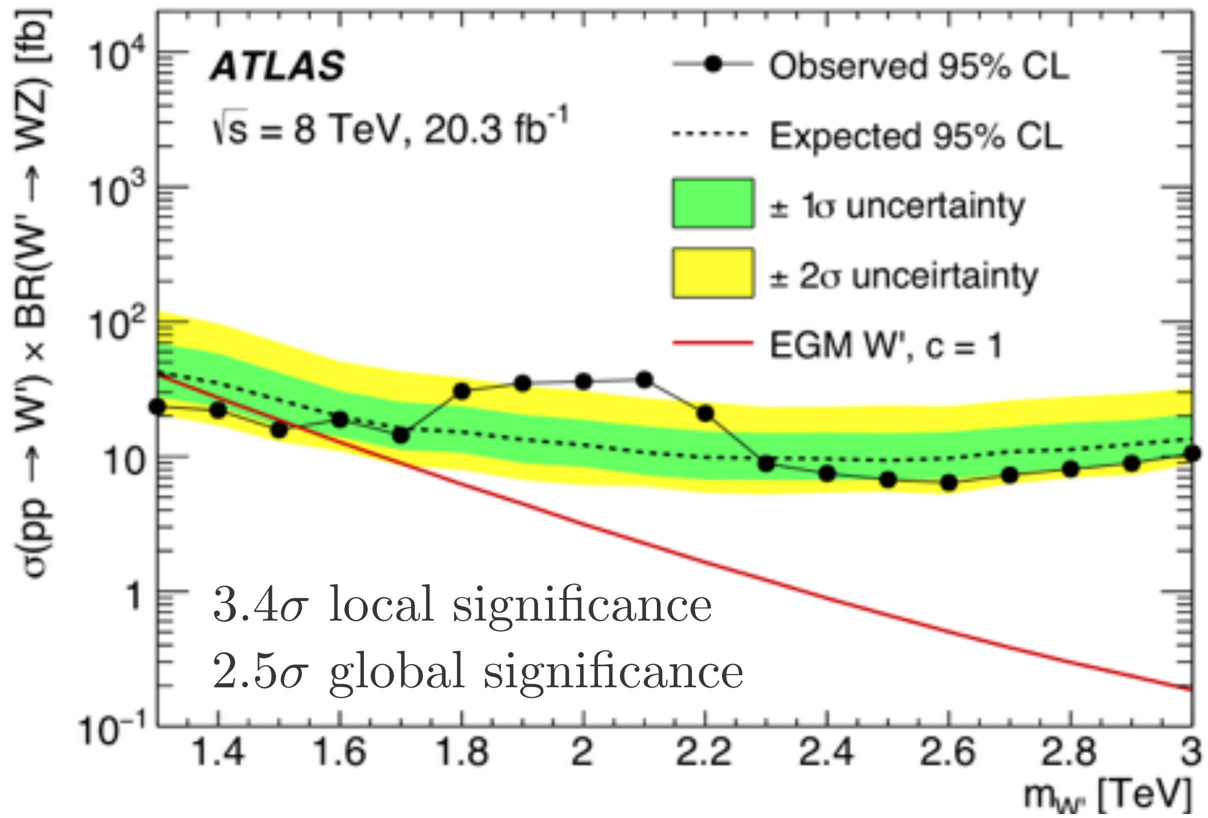
see also Junjie Zhu talk

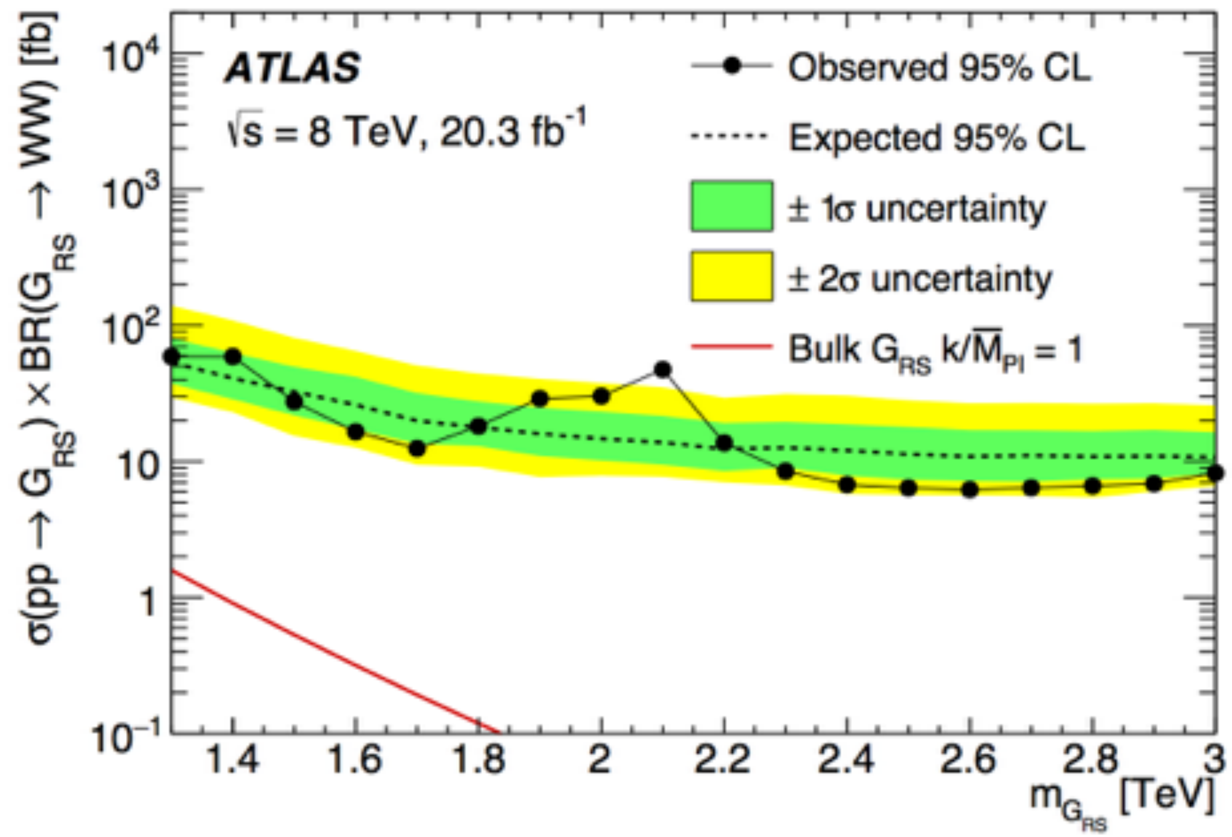


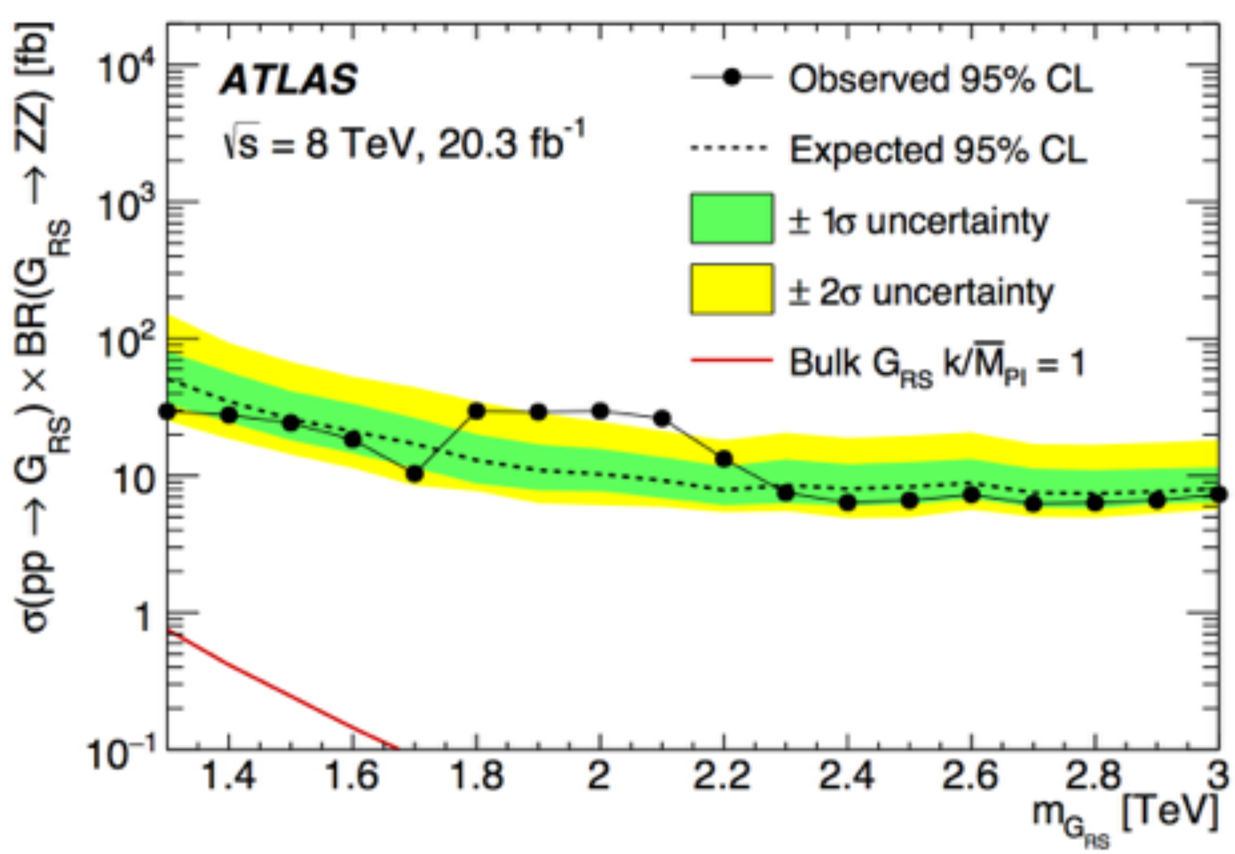




HINTS FOR NEW PHYSICS?



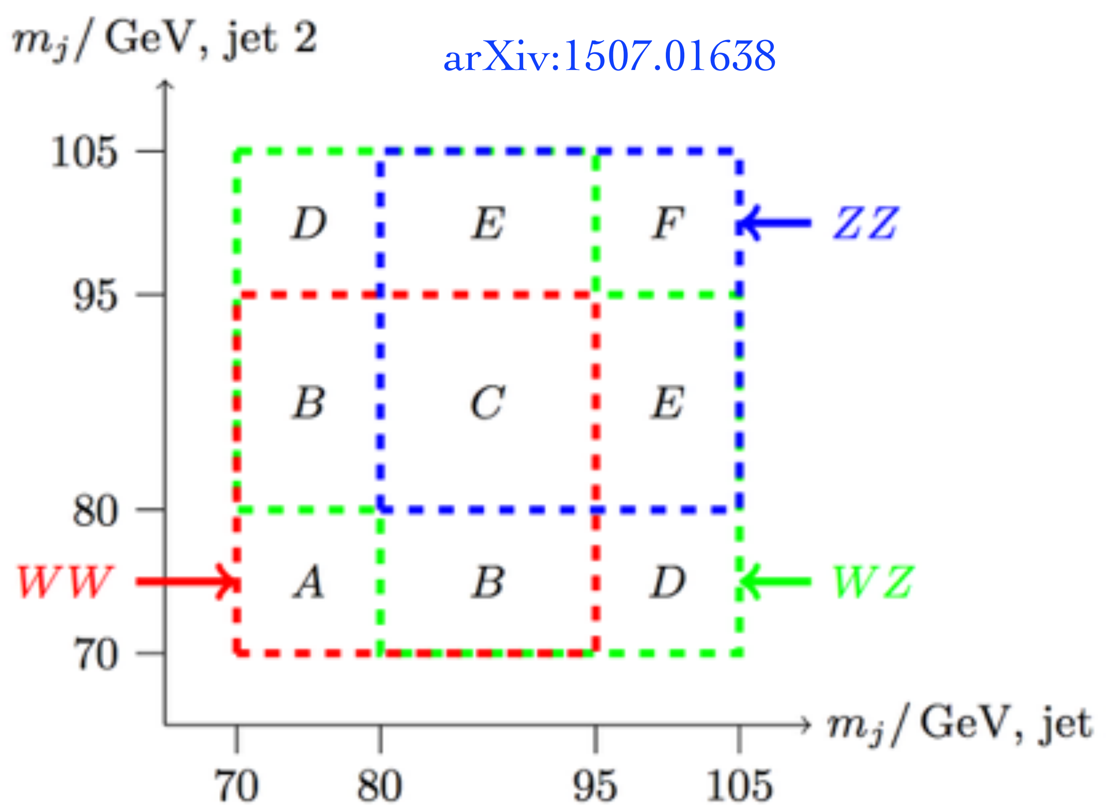


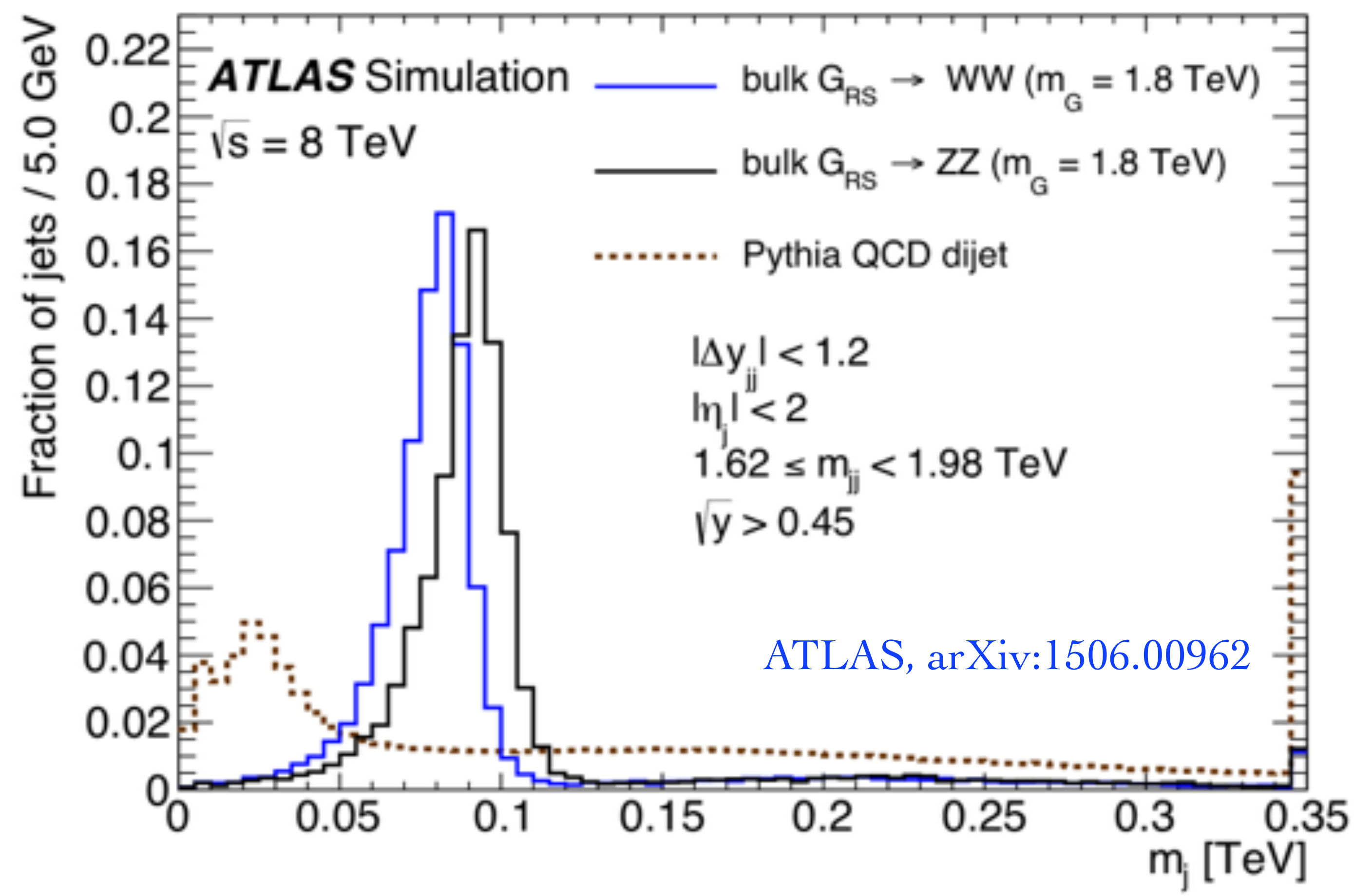


ATLAS, arXiv:1506.00962

BOOSTED VECTORS TAGGING EFFICIENCIES

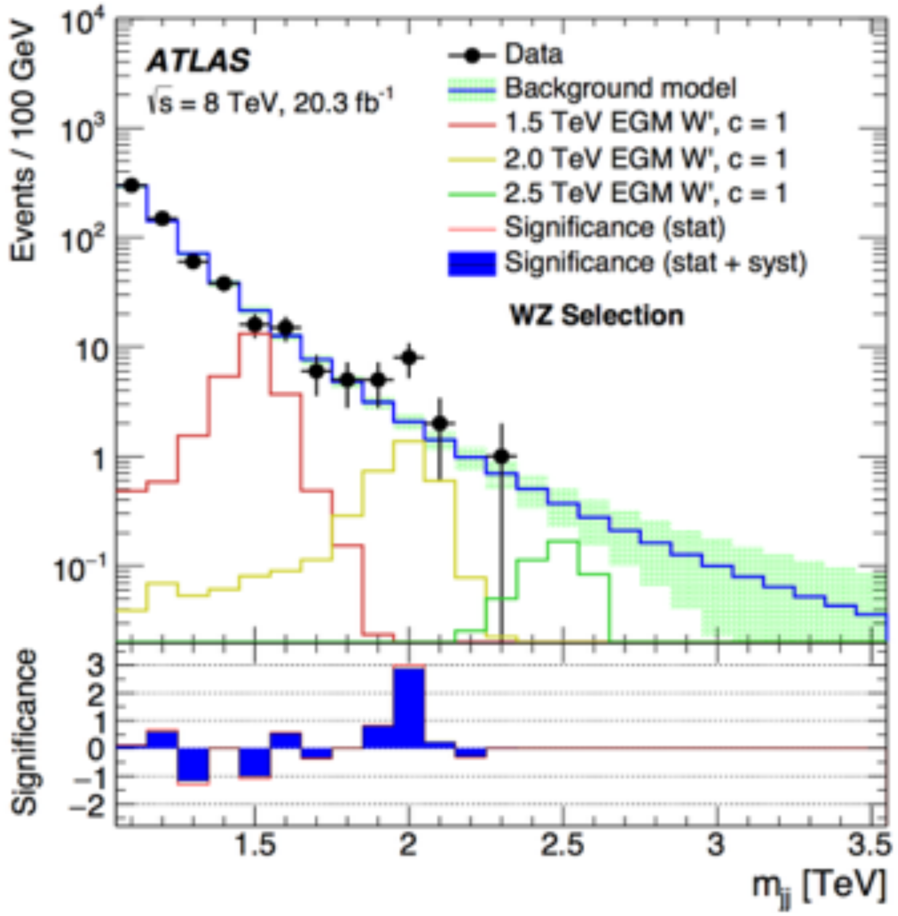
- W-jet: 69.4 GeV < m < 95.4 GeV
- Z-jet: 79.8 GeV < m < 105.8 GeV

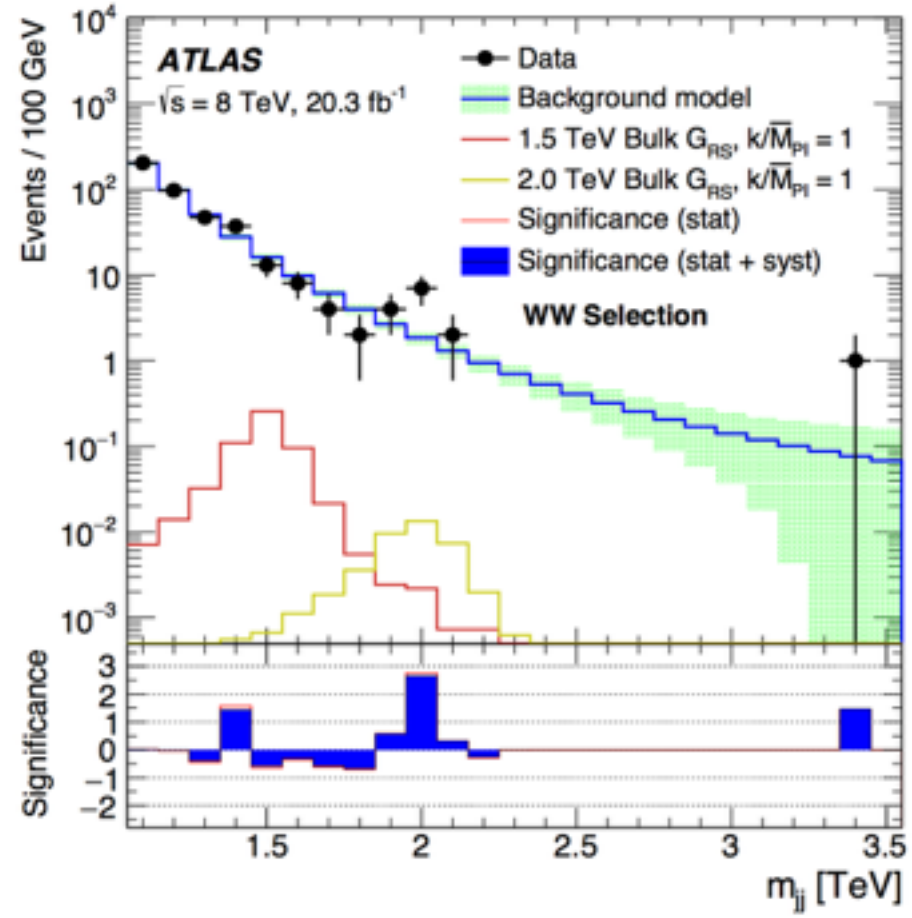


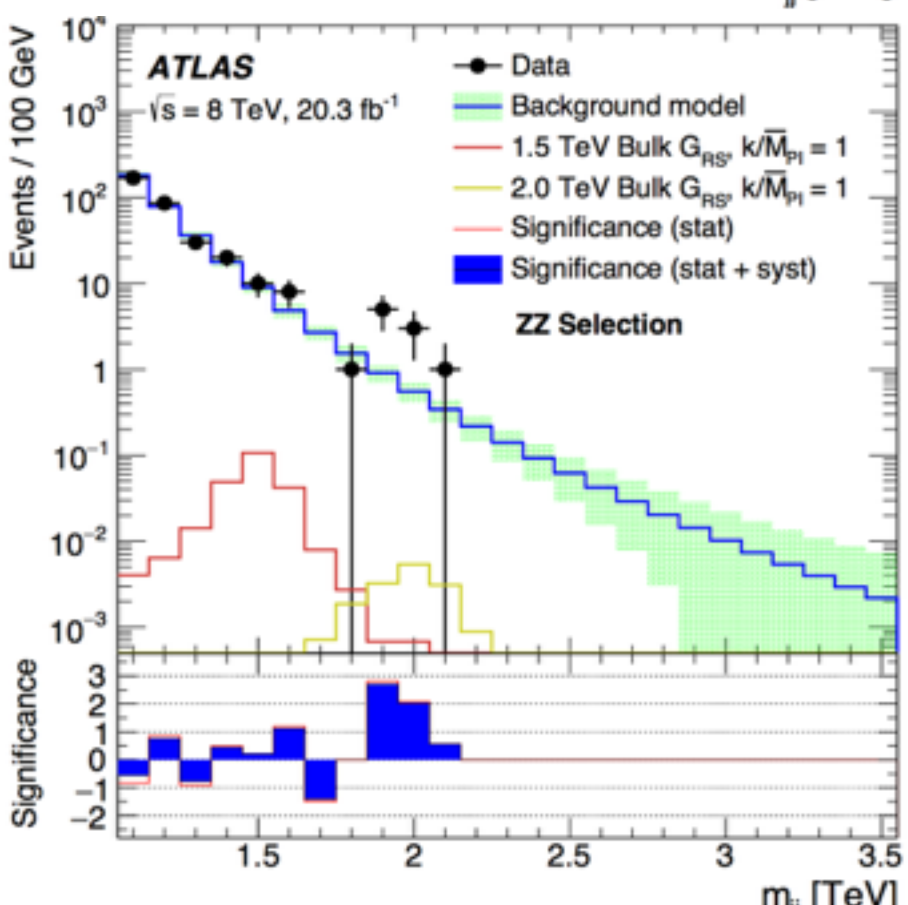


selection region / final state	WW	WZ	ZZ
WW	0.39	0.37	0.16
WZ	0.33	0.44	0.25
ZZ	0.27	0.47	0.37

EXCESS EVENTS

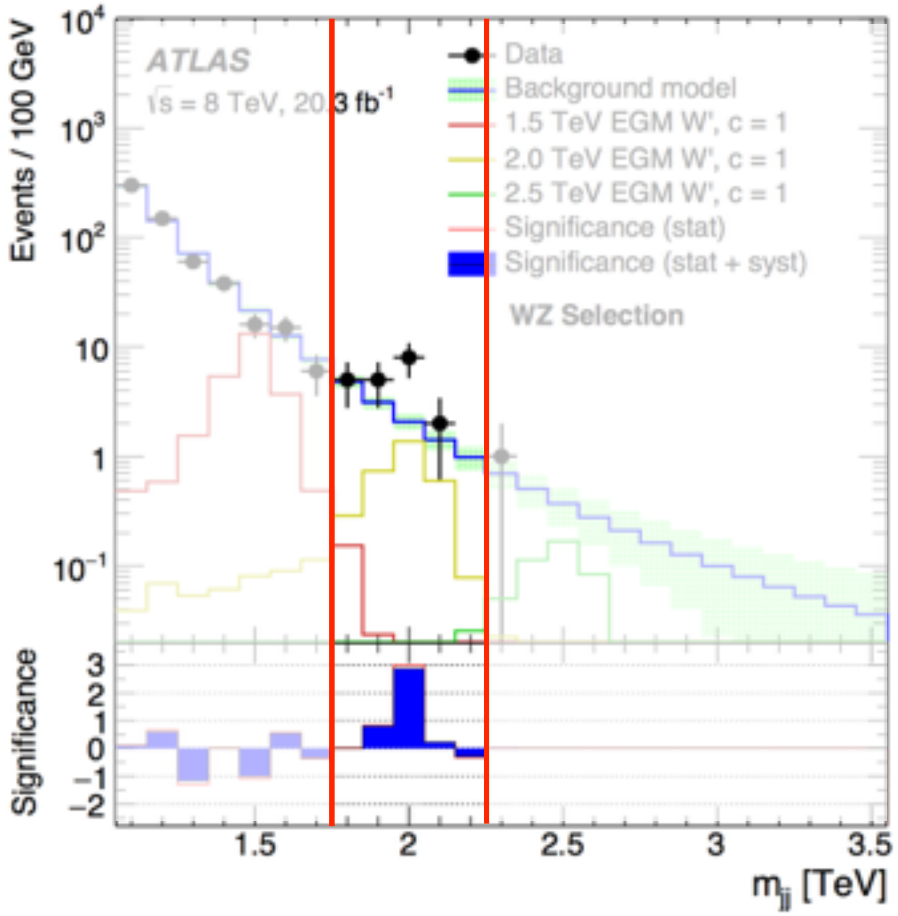


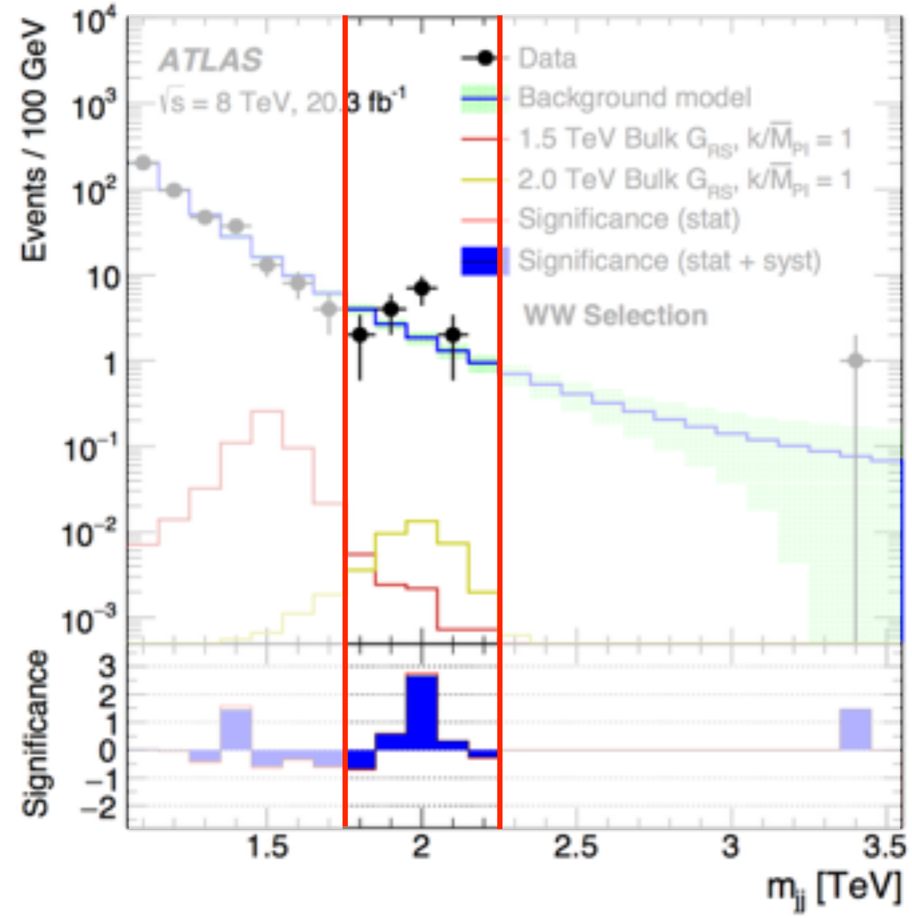




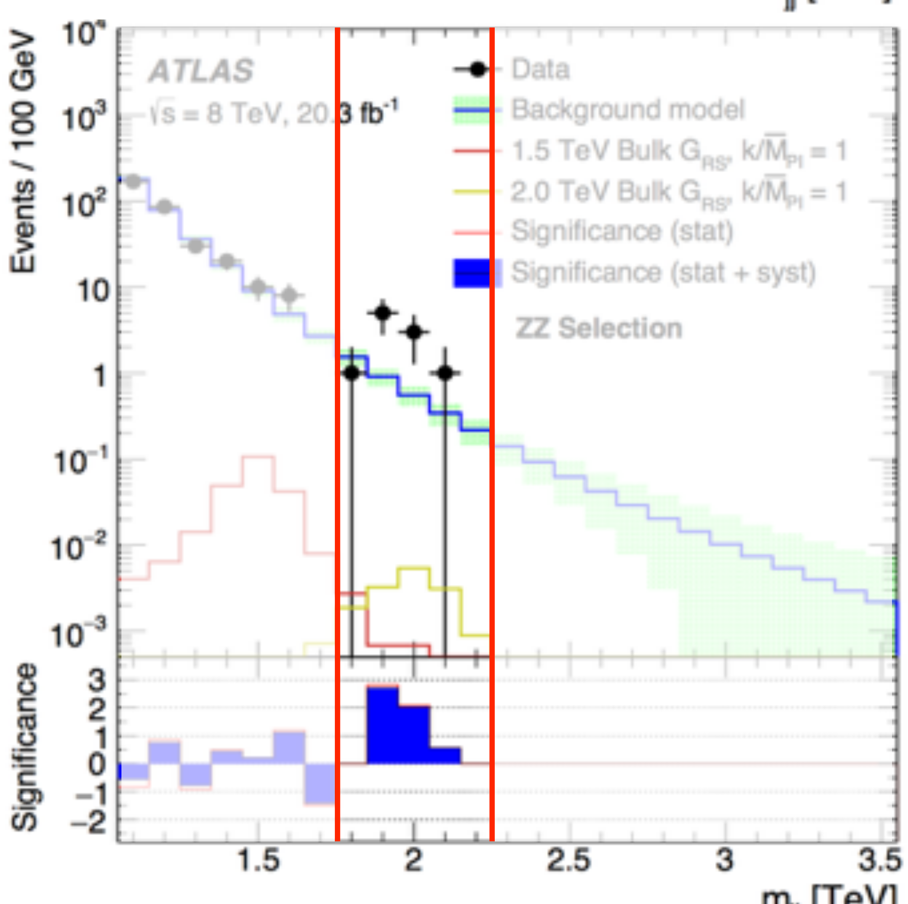
ATLAS, arXiv:1506.00962

EXCESS EVENTS

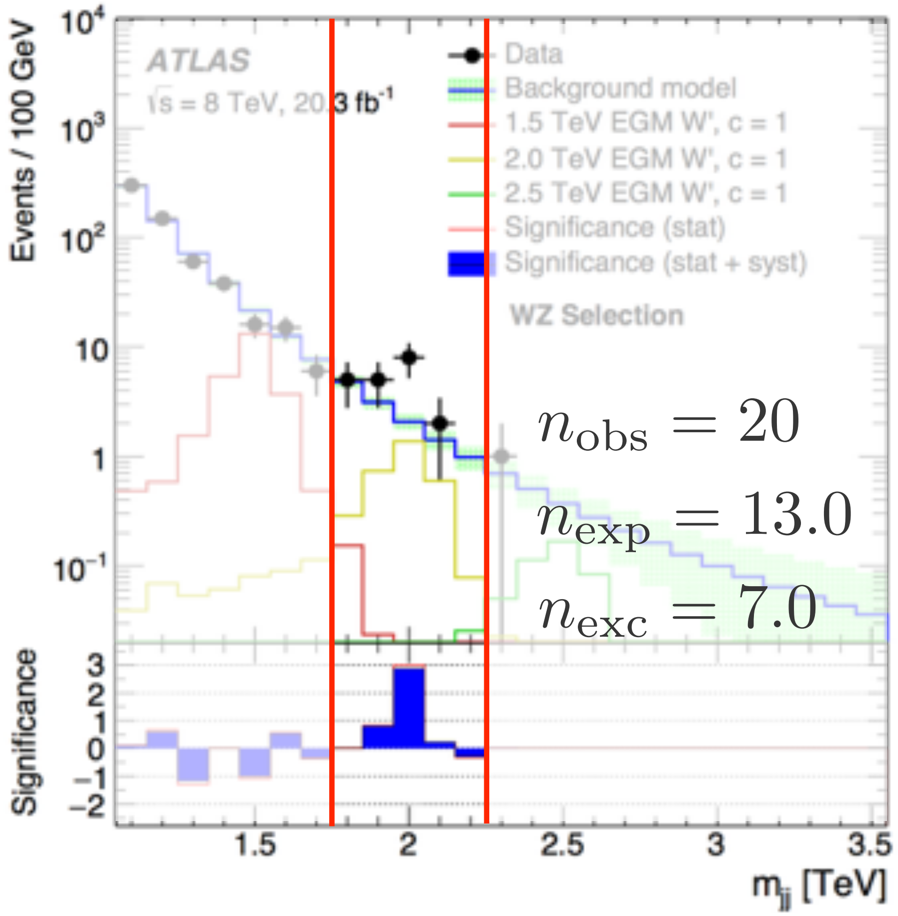


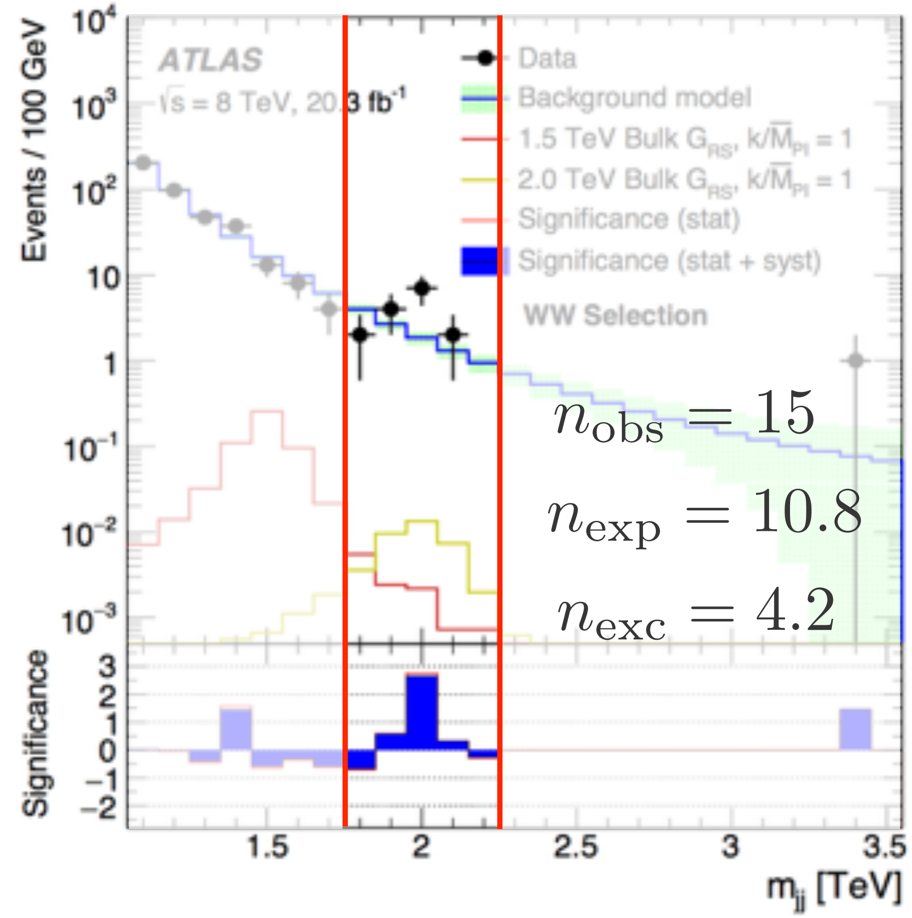


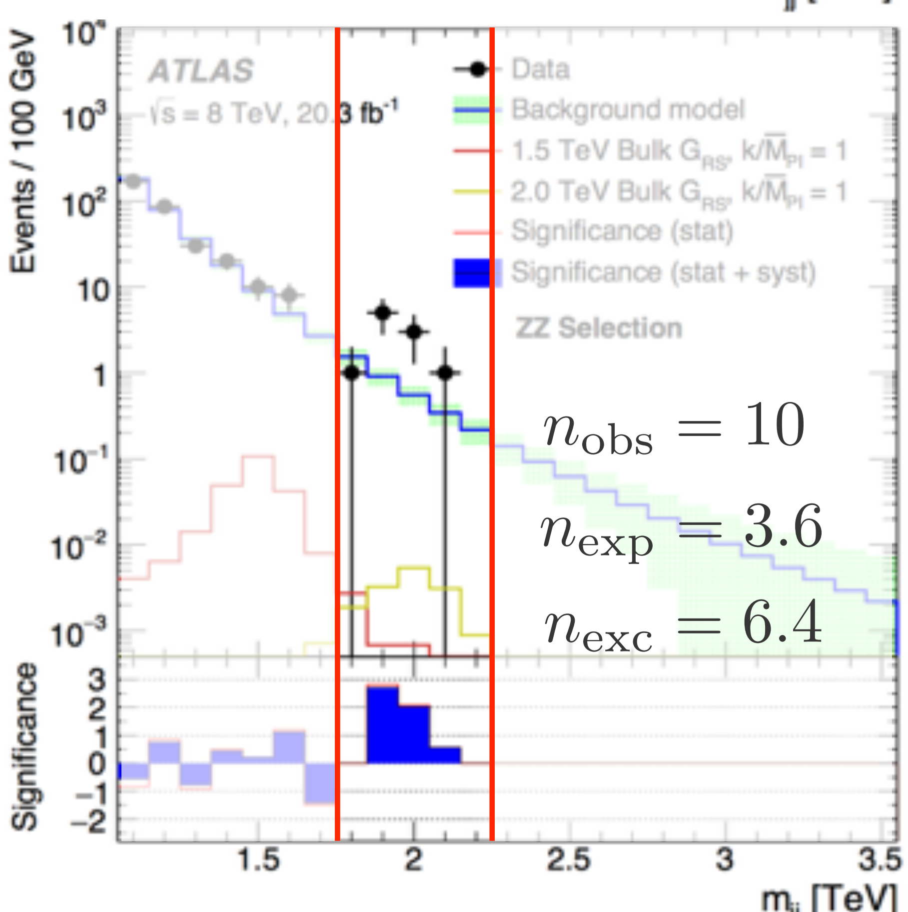
ATLAS, arXiv:1506.00962



EXCESS EVENTS







ATLAS, arXiv:1506.00962

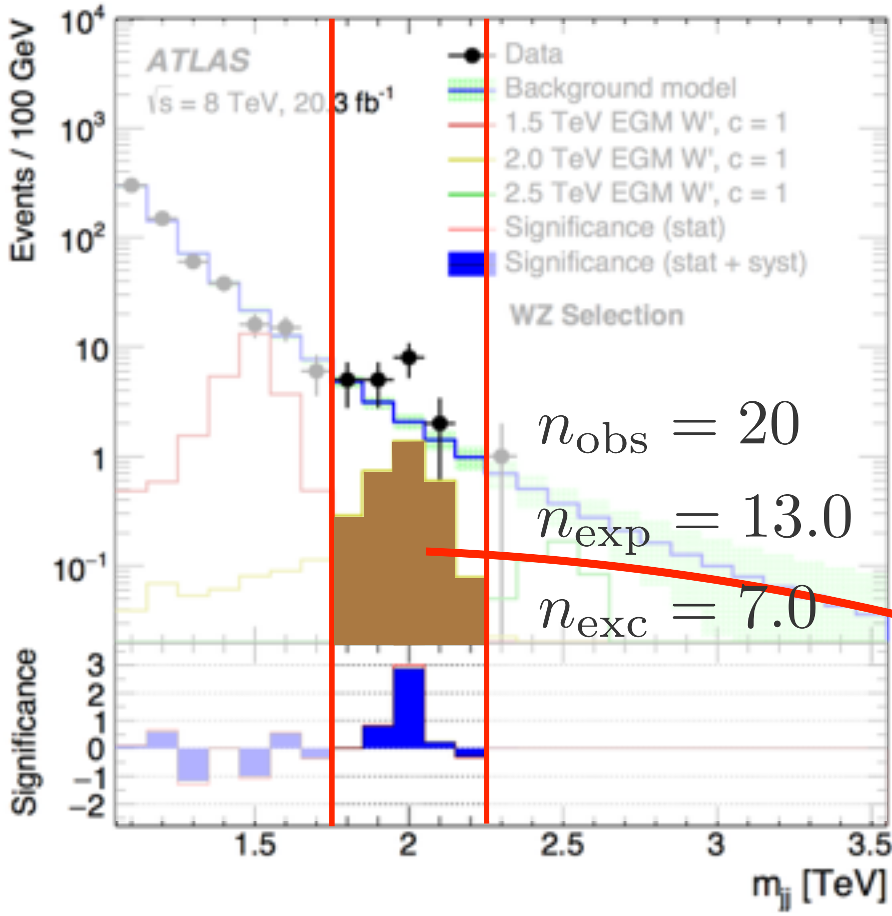
Big statistical uncertainties:

$$S_{WZ} = 7.0^{+3.8}_{-2.6}$$
$$S_{WW} = 4.2^{+3.2}_{-2.0}$$
$$S_{ZZ} = 6.4^{+3.6}_{-2.4}$$

A combined fit to all these channels is impossible to do since we lack any information about the correlation of the big systematic uncertainties (~50% for the signal)!

We will just extract the signal CS from a single channel and confront with the others

SIGNAL CROSS SECTION (E.G. W')



$n_{\text{obs}} = 20$

$n_{\text{exp}} = 13.0$

$n_{\text{exc}} = 7.0$

$\text{BR}_{WZ\to\text{had}} \approx 0.47$

m [TeV]	$\Gamma_{W'}$ [GeV]	$\Gamma_{G_{RS}}$ [GeV]	$W' \to WZ$ $\sigma\times$BR [fb]	$f_{10\%}$	$G_{RS} \to WW$ $\sigma\times$BR [fb]	$f_{10\%}$	$G_{RS} \to ZZ$ $\sigma\times$BR [fb]	$f_{10\%}$
1.3	47	76	19.1	0.83	0.73	0.85	0.37	0.84
1.6	58	96	6.04	0.79	0.14	0.83	0.071	0.84
2.0	72	123	1.50	0.72	0.022	0.83	0.010	0.82
2.5	91	155	0.31	0.54	0.0025	0.78	0.0011	0.78
3.0	109	187	0.088	0.31	0.00034	0.72	0.00017	0.71

$$\frac{(\sigma\times\text{BR})_{\text{ATLAS}}}{\text{BR}_{WZ\to\text{had}}} = 3.17\ \text{fb} \quad\Longrightarrow\quad 3.4\ \text{events}$$

$$\sigma_{W'}\times\text{BR}_{W'\to WZ} = 6.5^{+5.1}_{-4.1}\ \text{fb} \quad\Longleftarrow\quad S_{WZ} = 7.0^{+3.8}_{-2.6}$$

The order of magnitude of the cross section for a signal that can give rise to the observed excess is a few fb, despite the exclusion limit fluctuates over 40fb
This is the (non-trivial!) result of big statistical and systematic uncertainties

INTERPRETATIONS OF THE EXCESS

1. Heavy Vector Triplet in CH models

   Thamm, Torre, Wulzer, arXiv:1506.08688

2. Scalar sgoldstino in SUSY

   Petersson, Torre, arXiv:1508.05632

INTERPRETATIONS OF THE EXCESS

1. Heavy Vector Triplet in CH models

Thamm, Torre, Wulzer, arXiv:1506.08688

2. Scalar sgoldstino in SUSY

Petersson, Torre, arXiv:1508.05632

HVT FROM COMPOSITE HIGGS MODELS

- Heavy vector resonances are one of the most robust predictions of models where the Hierarchy Problem is solved by Higgs compositeness
- They are associated to the global current operators corresponding to the SM gauge group

Pappadopulo, Thamm, Torre, Wulzer, arXiv:1402.4431

Interactions

$$\mathcal{L}_V = -\frac{1}{4} D_{[\mu} V_{\nu]}^a D^{[\mu} V^{\nu]\,a} + \frac{m_V^2}{2} V_\mu^a V^{\mu\,a} + i\, g_V c_H V_\mu^a H^\dagger \tau^a \overleftrightarrow{D}^\mu H + \frac{g^2}{g_V} c_F V_\mu^a J_F^{\mu\,a}$$

$$c_H(g_V) \sim O(1) \qquad c_F(g_V) \sim O(1) \qquad m_V = g_V f$$

Partial Widths

$$\Gamma_{V_\pm \to f \bar{f}'} \simeq 2\,\Gamma_{V_0 \to f \bar{f}} \simeq N_c[f] \left(\frac{g^2 c_F}{g_V} \right)^2 \frac{m_V}{48\pi}$$

$$\Gamma_{V_0 \to W_L^+ W_L^-} \simeq \Gamma_{V_\pm \to W_L^\pm Z_L} \simeq \frac{g_V^2 c_H^2 m_V}{192\pi}$$

$$\Gamma_{V_0 \to Z_L h} \simeq \Gamma_{V_\pm \to W_L^\pm h} \simeq \frac{g_V^2 c_H^2 m_V}{192\pi}$$

Production Cross Section (NWA)

$$\sigma = \frac{4\pi^2}{3 s m_V} \sum \Gamma\left(V \to q_i q_j\right) \times \int_{\frac{m_V^2}{s}}^{1} \frac{dx}{x} f_{p/q_i}\left(x, m_V^2\right) f_{p/q_j}\left(\frac{m_V^2}{x s}, m_V^2\right),$$

CONSTRAINTS

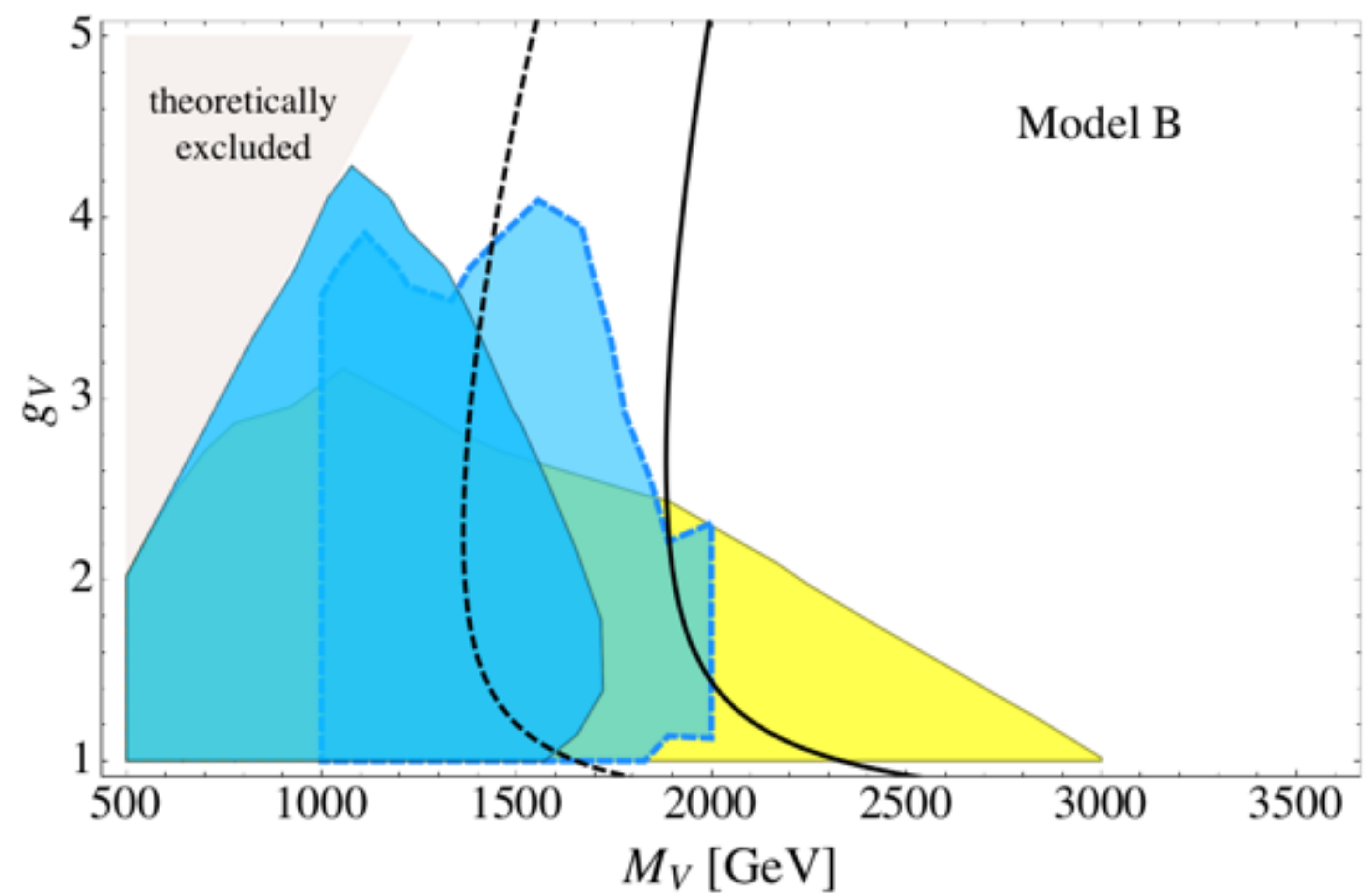
Partial Widths

$$\Gamma_{V_{\pm}\to f\bar{f}'} \simeq 2\,\Gamma_{V_0\to f\bar{f}} \simeq N_c[f]\left(\frac{g^2 c_F}{g_V}\right)^2 \frac{m_V}{48\pi}$$

$$\Gamma_{V_0\to W_L^+ W_L^-} \simeq \Gamma_{V_{\pm}\to W_L^{\pm} Z_L} \simeq \frac{g_V^2 c_H^2 M_V}{192\pi}\,,$$

$$\Gamma_{V_0\to Z_L h} \simeq \Gamma_{V_{\pm}\to W_L^{\pm} h} \simeq \frac{g_V^2 c_H^2 M_V}{192\pi}$$

- Mostly DY production
- SU(2)$_L$ triplet (degenerate)
- $l\nu$ dominant for large masses (low couplings)
- di-bosons dominant for large couplings (low masses)
- strong constraints from EWPT (oblique parameters)
- **HVT predict same rates in di-bosons and VH final states**



Pappadopulo, Thamm, Torre, Wulzer, arXiv:1402.4431

CONSTRAINTS

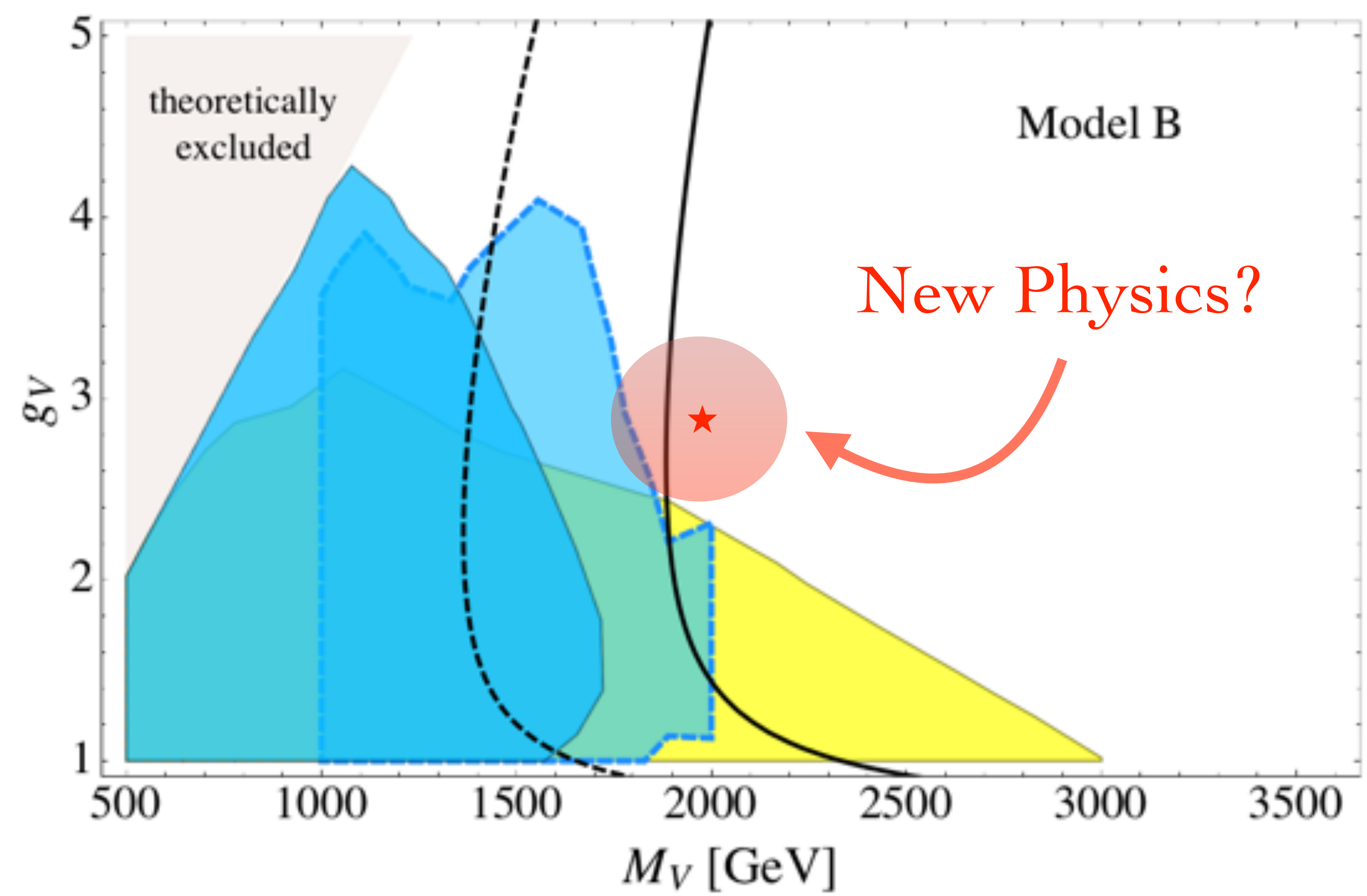
Partial Widths

$$\Gamma_{V_\pm \to f\bar{f}'} \simeq 2\,\Gamma_{V_0 \to f\bar{f}} \simeq N_c[f] \left(\frac{g^2 c_F}{g_V}\right)^2 \frac{m_V}{48\pi}$$

$$\Gamma_{V_0 \to W_L^+ W_L^-} \simeq \Gamma_{V_\pm \to W_L^\pm Z_L} \simeq \frac{g_V^2 c_H^2 M_V}{192\pi},$$

$$\Gamma_{V_0 \to Z_L h} \simeq \Gamma_{V_\pm \to W_L^\pm h} \simeq \frac{g_V^2 c_H^2 M_V}{192\pi}$$

- Mostly DY production
- SU(2)$_L$ triplet (degenerate)
- $l\nu$ dominant for large masses (low couplings)
- di-bosons dominant for large couplings (low masses)
- strong constraints from EWPT (oblique parameters)
- **HVT predict same rates in di-bosons and VH final states**



Pappadopulo, Thamm, Torre, Wulzer, arXiv:1402.4431

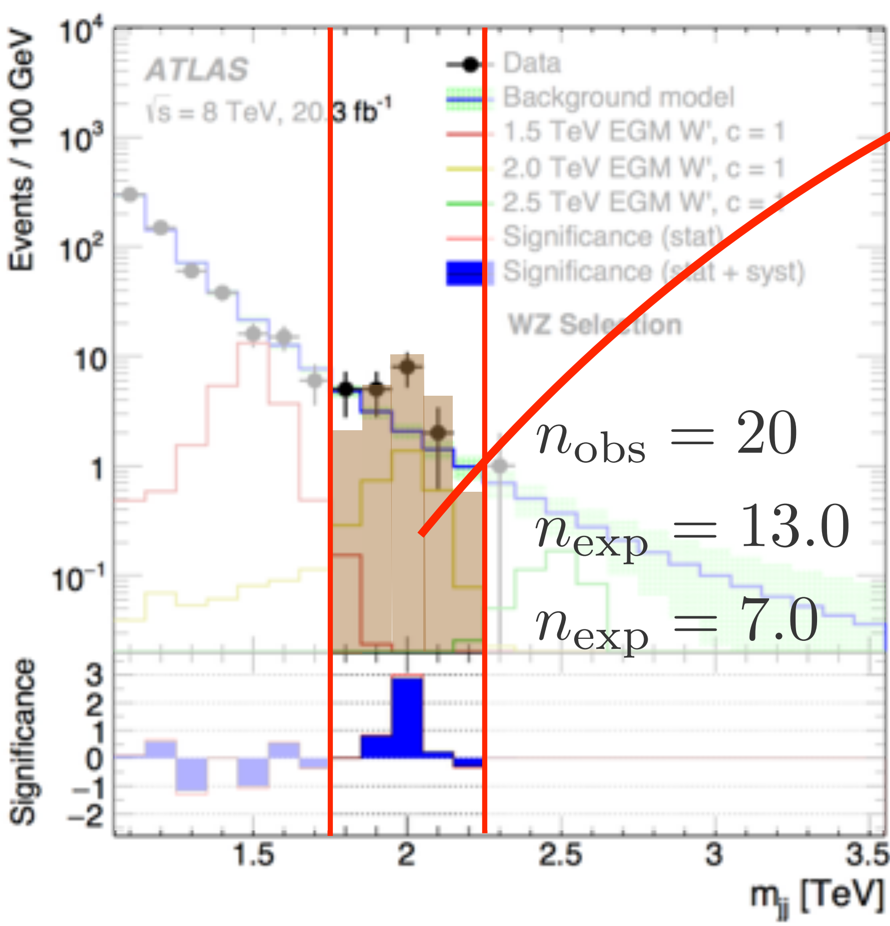
HVT SIGNAL CROSS SECTION

- Both the neutral and charged components of the triplet contribute to the the various selection regions

Thamm, Torre, Wulzer, arXiv:1506.08688

$$S_{WZ} = \mathcal{L} \times \mathcal{A} \times \left[(\sigma \times \text{BR})_{V^\pm} \, \text{BR}_{WZ\to\text{had}} \epsilon_{WZ\to WZ} + (\sigma \times \text{BR})_{V^0} \, \text{BR}_{WW\to\text{had}} \epsilon_{WW\to WZ} \right]$$

- Once we fix the mass there is only one parameter g_V



$$n_{\text{obs}} = 20$$

$$n_{\text{exp}} = 13.0$$

$$n_{\text{exp}} = 7.0$$

$$S_{WZ} = 7.0^{+3.8}_{-2.6}$$

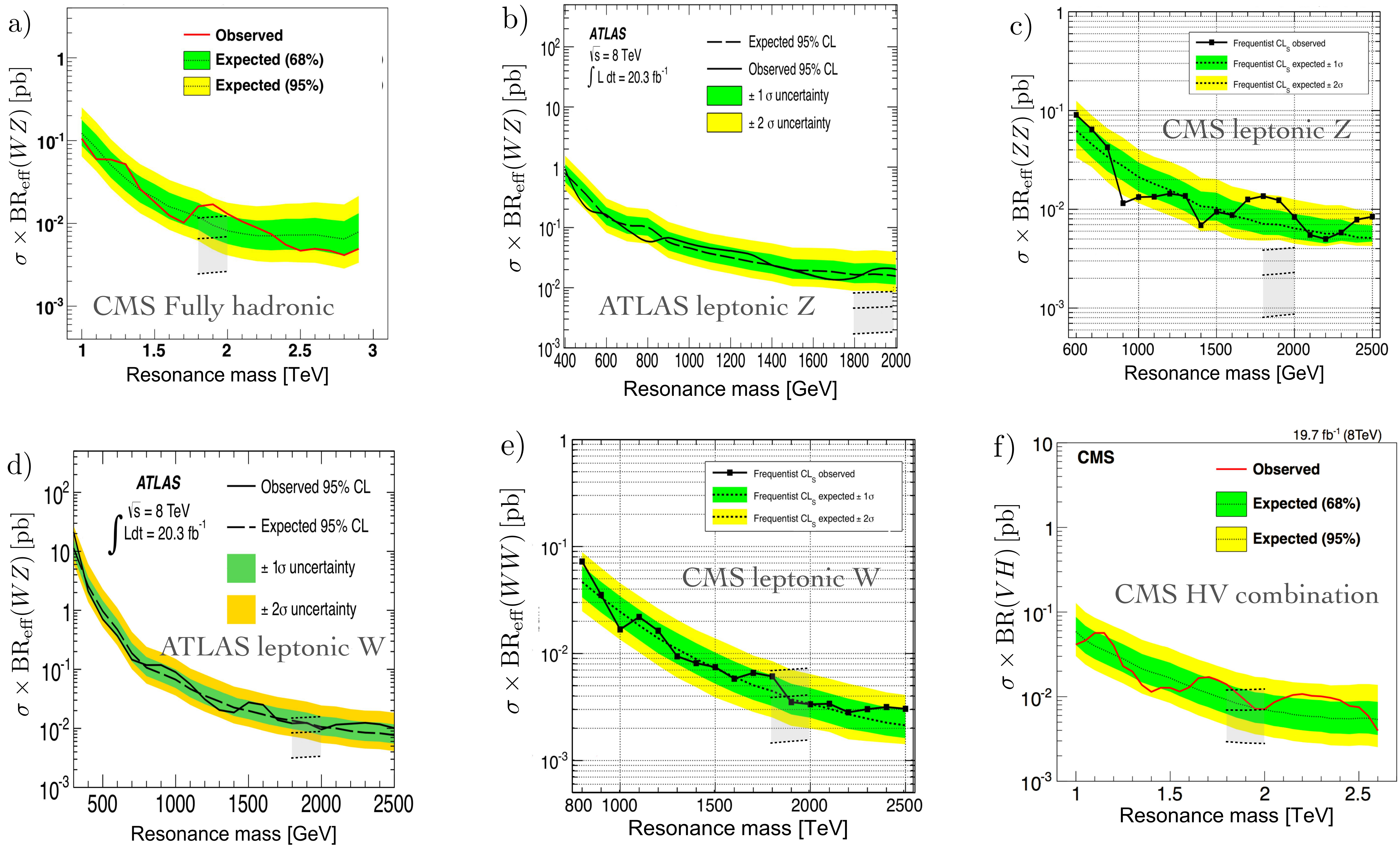
m_V [TeV]	g_V	$(\sigma \times \text{BR})_{V^\pm}$ [fb]	$(\sigma \times \text{BR})_{V^0}$ [fb]
1.8	$3.95^{+1.65}_{-0.88}$	4.51	2.04
1.9	$3.37^{+1.63}_{-0.83}$	4.63	2.09
2.0	$2.81^{+1.54}_{-0.82}$	4.79	2.16

$$S_{WW} \in [2.2, 10.3] \qquad S_{ZZ} \in [1.4, 6.6]$$

$$S_{WW} = 4.2^{+3.2}_{-2.0} \qquad S_{ZZ} = 6.4^{+3.6}_{-2.4}$$

COMPATIBILITY WITH OTHER SEARCHES

Thamm, Torre, Wulzer, arXiv:1506.08688



INTERPRETATIONS OF THE EXCESS

1. Heavy Vector Triplet in CH models

Thamm, Torre, Wulzer, arXiv:1506.08688

2. Scalar sgoldstino in SUSY

Petersson, Torre, arXiv:1508.05632

SCALAR SGOLDSTINO IN SUSY

- If SUSY is linearly realized SUSY breaking can be parametrised through

$$X = x + \sqrt{2}\theta\tilde{G} + \theta^2 F_X$$

- The fermion component is the Goldstone fermion of spontaneously broken SUSY (the Goldstino), while the complex scalar $x = (\phi + ia)/\sqrt{2}$ is not protected by the Goldstone symmetry and generally acquires a model dependent mass
- These degrees of freedom in X couple to SM particles and their superpartners with couplings suppressed by $f \equiv \langle F_X \rangle$
- The interactions of X with SM particles and their superpartners can be obtained by promoting the usual soft terms to supersymmetric operators, e.g.

$$\frac{m_i}{2}\lambda^{\alpha}_{(i)}\lambda_{(i)\,\alpha} \longrightarrow \frac{m_i}{2f}\int d^2\theta X W^{\alpha}_{(i)} W_{(i)\,\alpha}$$

- To interpret the ATLAS excess we take the masses of the CP-even and CP-odd scalars degenerate (not necessary)

$$\frac{m_\phi^2}{4f^2}\int d^4\theta (X^\dagger X)^2 \qquad \Longrightarrow \qquad m_\phi = m_a = 2\ \text{TeV}$$

SGOLDSTINO PRODUCTION/DECAY

Perazzi, Ridolfi, Zwirner, hep-ph/0001025

Interactions

$$\mathcal{L}_{gg} = \frac{m_3}{2\sqrt{2}f}\left(-\phi G^{a\,\mu\nu}G^a_{\mu\nu} + aG^{a\,\mu\nu}\widetilde{G}^a_{\mu\nu}\right),$$

$$\mathcal{L}_{WW} = \frac{m_2}{\sqrt{2}f}\left(-\phi W^{+\,\mu\nu}W^-_{\mu\nu} + aW^{+\,\mu\nu}\widetilde{W}^-_{\mu\nu}\right),$$

$$\mathcal{L}_{ZZ} = \frac{m_1 s^2_{\theta_W} + m_2 c^2_{\theta_W}}{2\sqrt{2}f}\left(-\phi Z^{\mu\nu}Z_{\mu\nu} + aZ^{\mu\nu}\widetilde{Z}_{\mu\nu}\right),$$

$$\mathcal{L}_{\gamma\gamma} = \frac{m_1 c^2_{\theta_W} + m_2 s^2_{\theta_W}}{2\sqrt{2}f}\left(-\phi F^{\mu\nu}F_{\mu\nu} + aF^{\mu\nu}\widetilde{F}_{\mu\nu}\right),$$

$$\mathcal{L}_{Z\gamma} = \frac{(m_2 - m_1)s_{\theta_W}c_{\theta_W}}{\sqrt{2}f}\left(-\phi F^{\mu\nu}Z_{\mu\nu} + aF^{\mu\nu}\widetilde{Z}_{\mu\nu}\right),$$

$$\mathcal{L}_{GG} = \frac{m^2_\phi}{2\sqrt{2}f}\left(-\phi\,\widetilde{G}\,\widetilde{G} + i\,a\,\widetilde{G}\,\widetilde{G}\right) + \text{h.c.}\,,$$

Partial Widths

$$\Gamma(\phi \to gg) = \frac{m_3^2 m_\phi^3}{4\pi f^2}\,,$$

$$\Gamma(\phi \to WW) = \frac{m_2^2 m_\phi^3}{16\pi f^2}k\left(\frac{m_W}{m_\phi}\right),$$

$$\Gamma(\phi \to ZZ) = \frac{(m_1 s^2_{\theta_W} + m_2 c^2_{\theta_W})^2 m_\phi^3}{32\pi f^2}k\left(\frac{m_Z}{m_\phi}\right),$$

$$\Gamma(\phi \to \gamma\gamma) = \frac{(m_1 c^2_{\theta_W} + m_2 s^2_{\theta_W})^2 m_\phi^3}{32\pi f^2}\,,$$

$$\Gamma(\phi \to Z\gamma) = \frac{(m_2 - m_1)^2 s^2_{\theta_W} c^2_{\theta_W} m_\phi^3}{16\pi f^2}\left(1 - \frac{m_Z^2}{m_\phi^2}\right)^3,$$

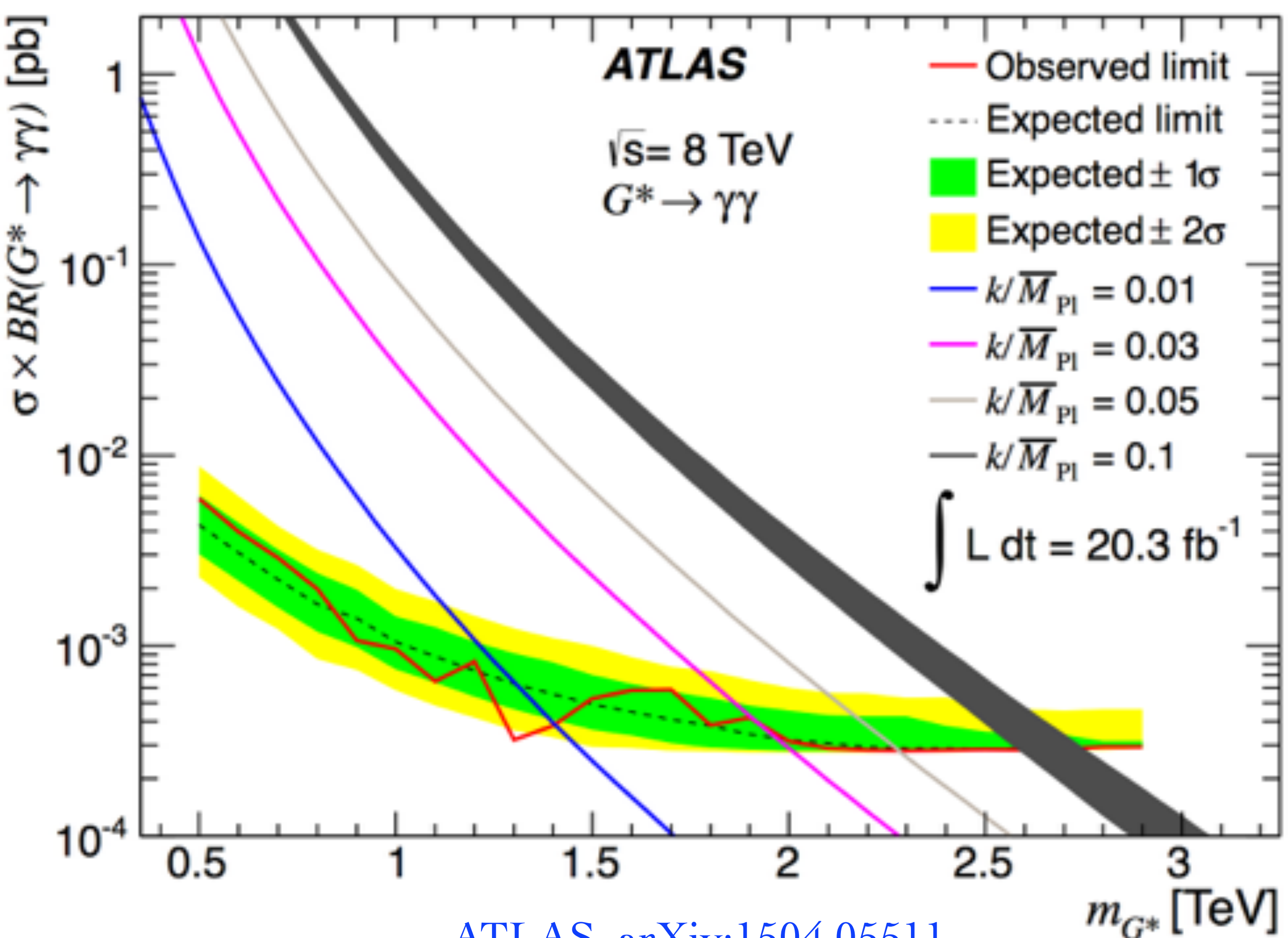
$$\Gamma(\phi \to GG) = \frac{m_\phi^5}{32\pi f^2}\,,$$

Production Cross Section (NWA)

$$\sigma = \frac{\pi^2\Gamma\left(\phi \to gg\right)}{4sm_\phi} \times \int_{\frac{m_\phi^2}{s}}^1 \frac{dx}{x} f_{p/g}(x, m_\phi^2)\, f_{p/g}\left(\frac{m_\phi^2}{xs}, m_\phi^2\right)$$

SGOLDSTINO PRODUCTION/DECAY

Constraints



ATLAS, arXiv:1504.05511

Partial Widths

$$\Gamma(\phi \to gg) = \frac{m_3^2 m_\phi^3}{4\pi f^2},$$

$$\Gamma(\phi \to WW) = \frac{m_2^2 m_\phi^3}{16\pi f^2} k\left(\frac{m_W}{m_\phi}\right),$$

$$\Gamma(\phi \to ZZ) = \frac{(m_1 s_{\theta_W}^2 + m_2 c_{\theta_W}^2)^2 m_\phi^3}{32\pi f^2} k\left(\frac{m_Z}{m_\phi}\right),$$

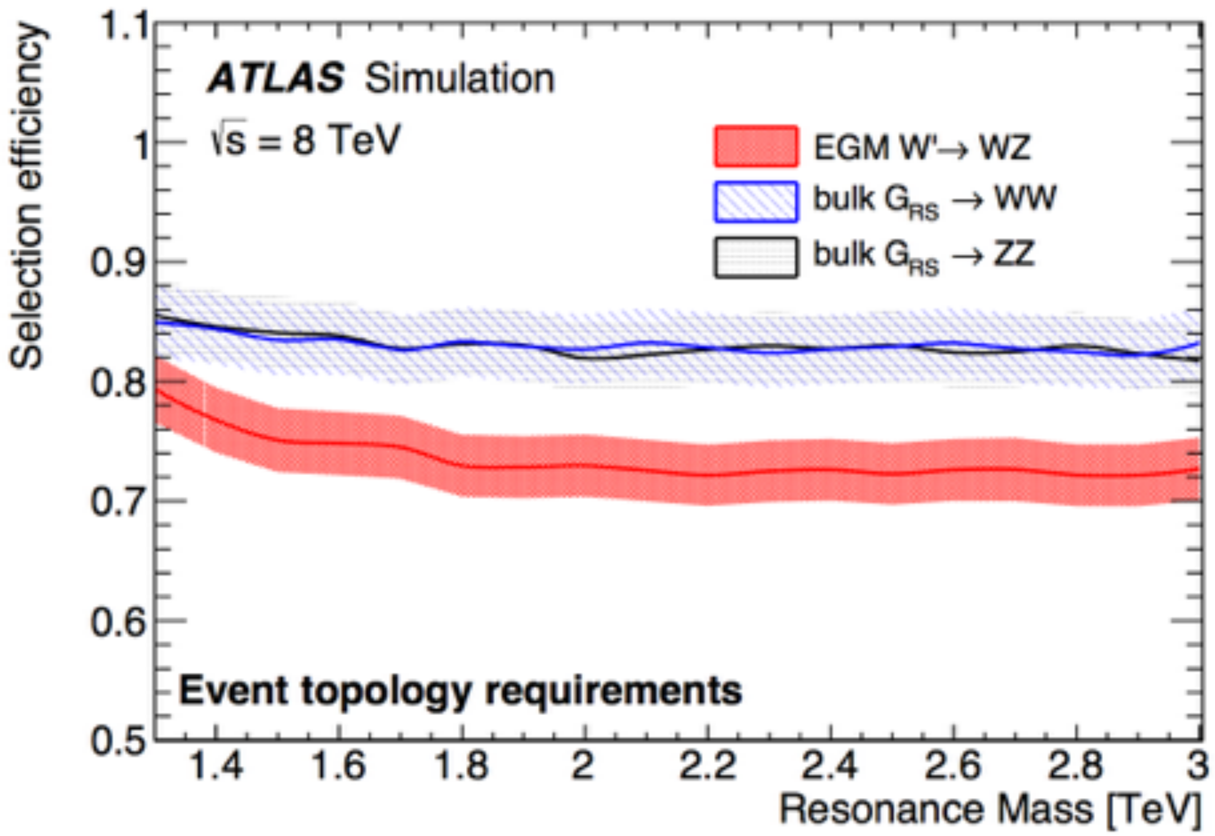
$$\Gamma(\phi \to \gamma\gamma) = \frac{(m_1 c_{\theta_W}^2 + m_2 s_{\theta_W}^2)^2 m_\phi^3}{32\pi f^2},$$

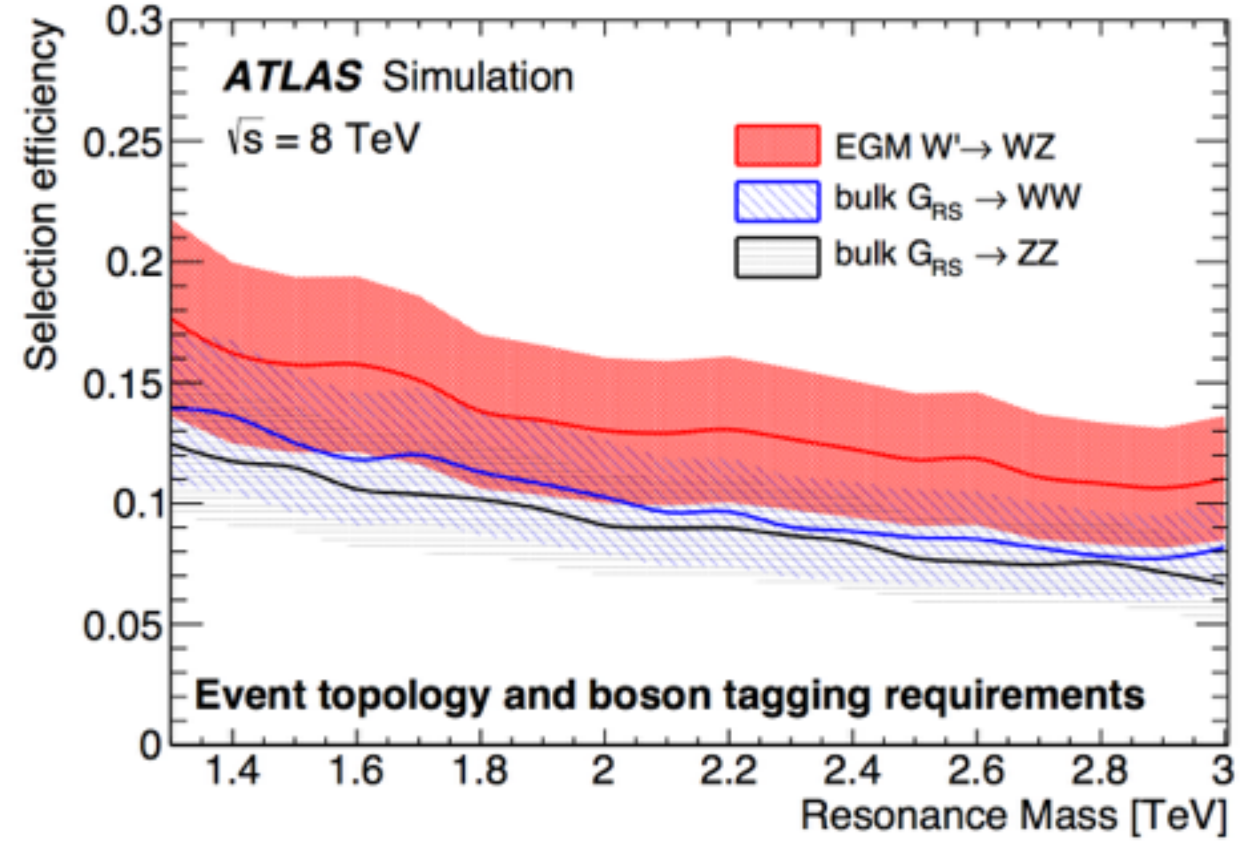
$$\Gamma(\phi \to Z\gamma) = \frac{(m_2 - m_1)^2 s_{\theta_W}^2 c_{\theta_W}^2 m_\phi^3}{16\pi f^2} \left(1 - \frac{m_Z^2}{m_\phi^2}\right)^3,$$

$$\Gamma(\phi \to GG) = \frac{m_\phi^5}{32\pi f^2},$$

The bound can be completely evaded taking $m_1 \approx -m_2 \tan^2\theta_W$
However there is a large range of m_1 where the constraint is satisfied
Moreover the excess will depend very weakly on m_1, that we fix to a reference value $m_1 = 100$ GeV

AN ISSUE WITH EFFICIENCIES

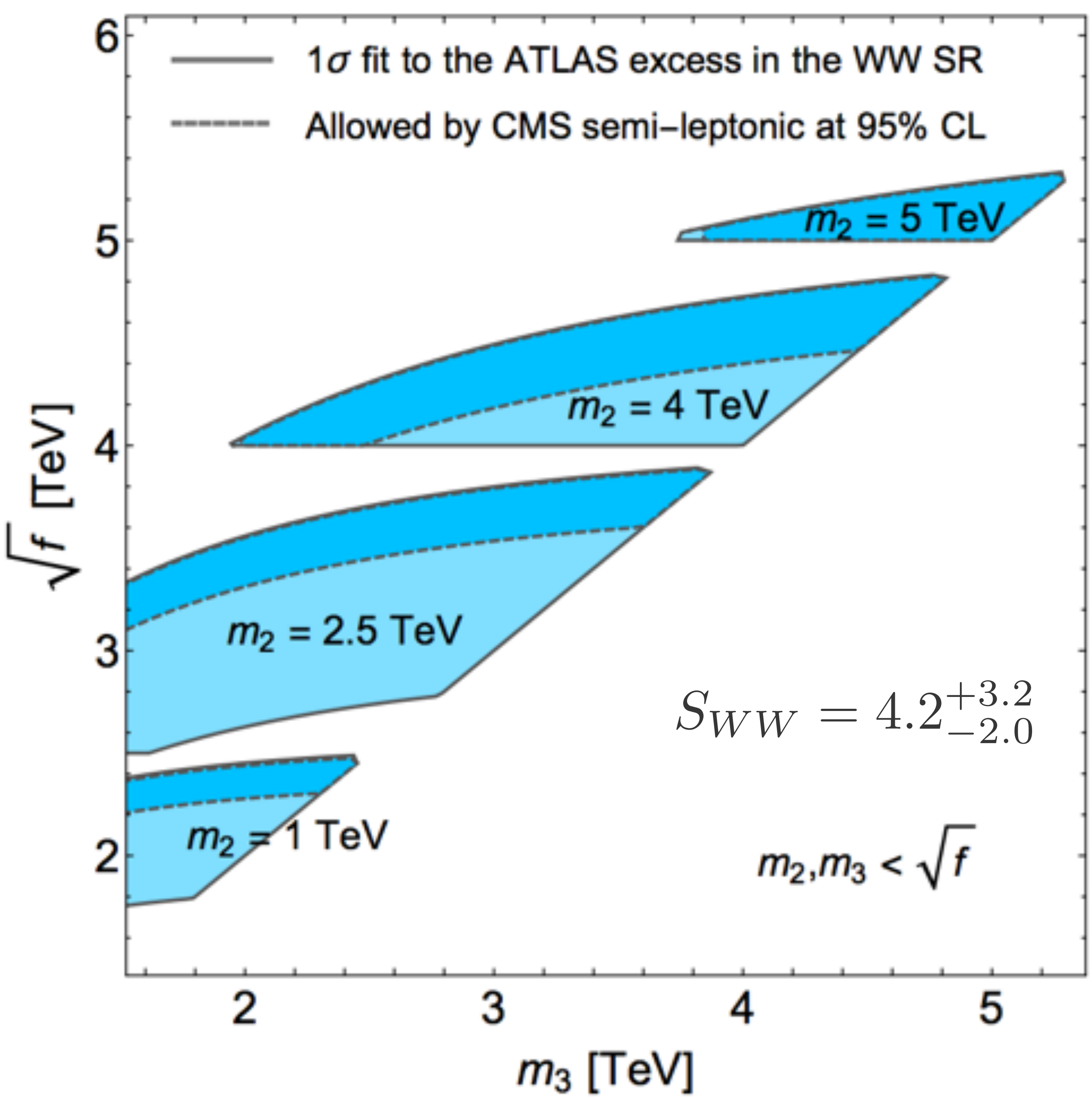




- ATLAS only gives interpretation (and computes efficiencies) for spin-1 and -2 hypotheses decaying to longitudinal W/Z
- Most of the other relevant analyses also only consider spin-1 and -2 mostly coupling to longitudinal W/Z
- The efficiency for a spin-2 decaying to transverse is expect to be around 50% less (CMS RS graviton)
- For spin-0 is also expected to be reduced (no way of reliably estimate them)
- To be able to compare with other analyses in a consistent way we assume for the sgoldstino the same efficiencies as for the bulk graviton

PARAMETER SPACE

- The only relevant parameters for the diboson excess are f, m_2, m_3
- Fixing m_2 we get allowed regions in the $(m_3, \sqrt{f})$ plane
- We extract the signal CS from the WW channel and compare with the other channels and relevant searches



For the WZ and ZZ selections we predict

$$S_{WZ} \in [2.4, 8.0]$$

$$S_{ZZ} \in [1.3, 4.2]$$

To be compared with the observed excess events in these channels

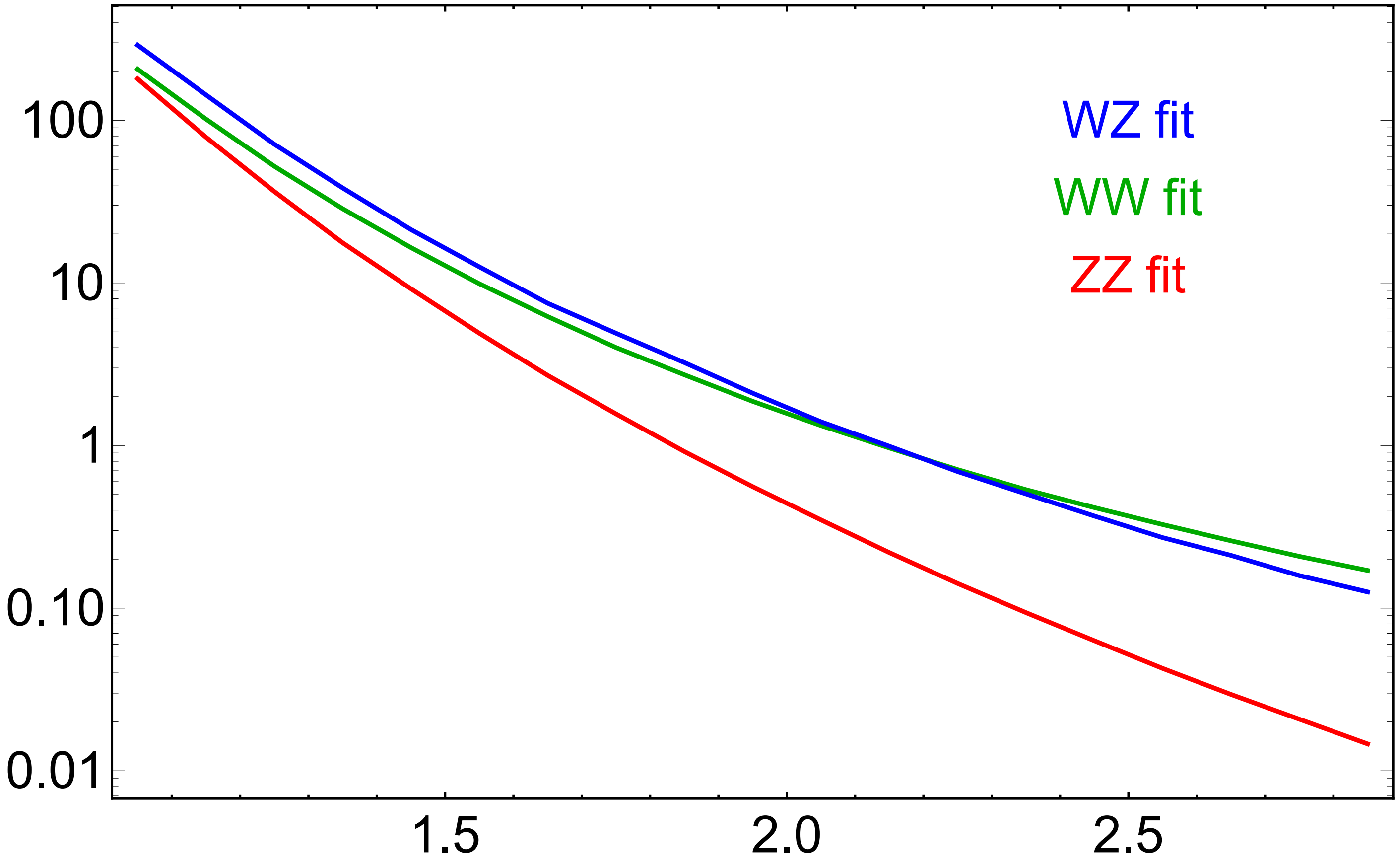
$$S_{WZ} = 7.0^{+3.8}_{-2.6}$$

$$S_{ZZ} = 6.4^{+3.6}_{-2.4}$$

The analysis which sets the strongest constraint in this channel is the semi-leptonic search by CMS (arXiv:1405.3447)

A wide region of the parameter space still remains viable!

AN ISSUE WITH ZZ?

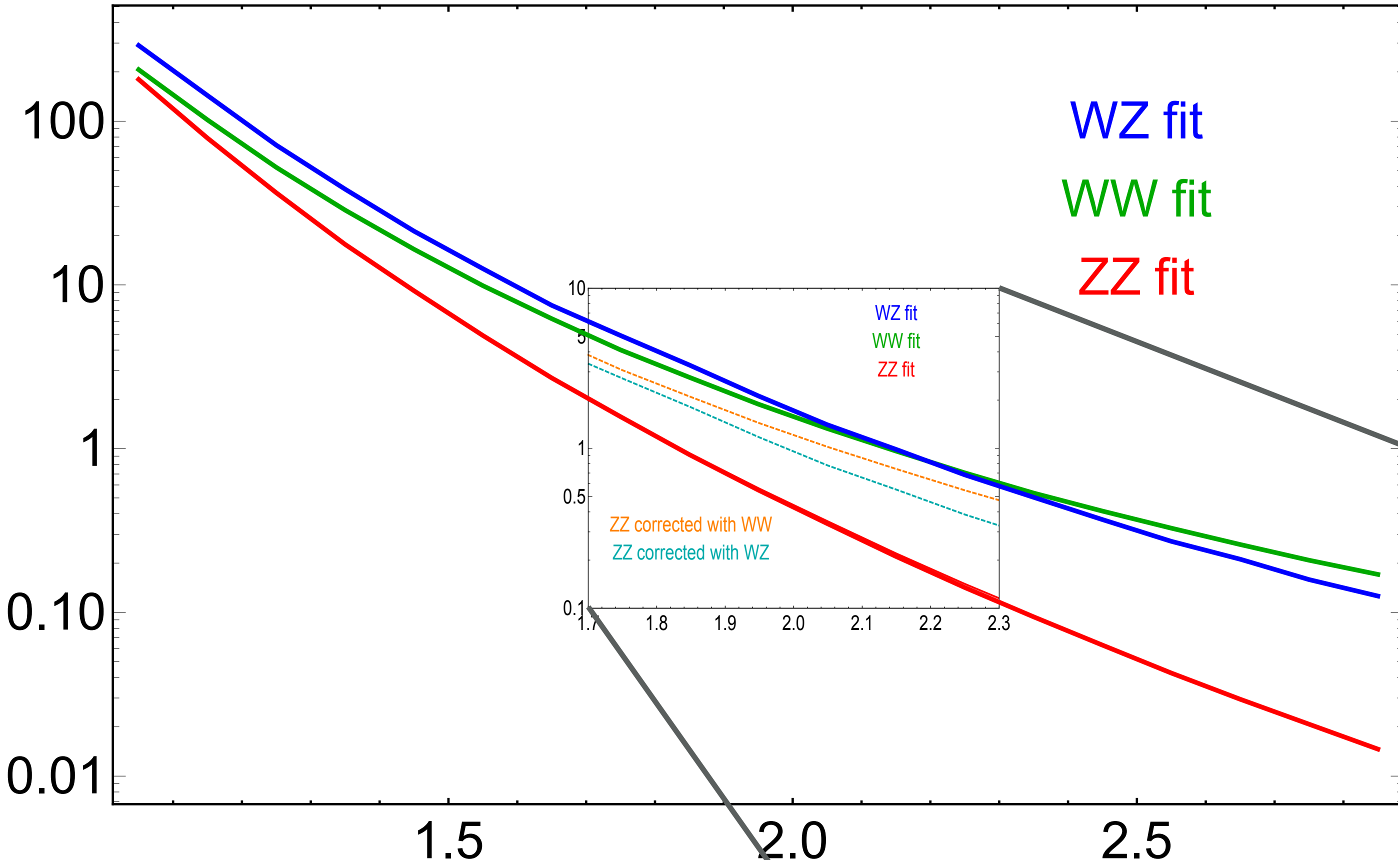


The ZZ background fit of ATLAS falls off much faster than the WW and WZ background

Statistics is more limited in ZZ (no events above the bump)

In the SM one would (naively) not expect such a difference in shape

AN ISSUE WITH ZZ?



The ZZ background fit of ATLAS falls off much faster than the WW and WZ background

Statistics is more limited in ZZ (no events above the bump)

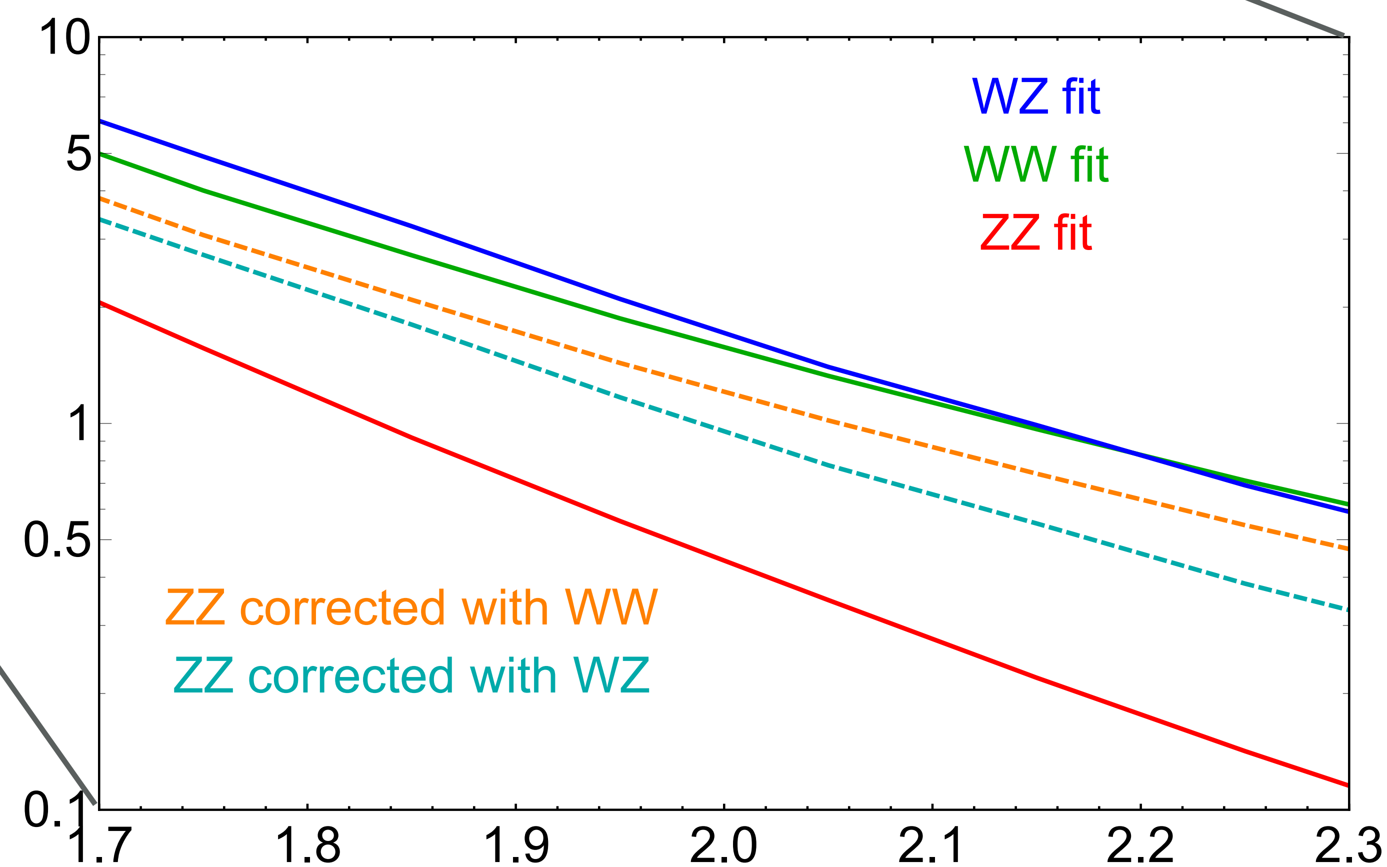
In the SM one would (naively) not expect such a difference in shape

One can try to mimic the ZZ background using the WZ and WW shape with the ZZ normalisation

The number of excess events in ZZ radically changes

$$S_{ZZ}^{(WZ)} = 3.0 \qquad S_{ZZ}^{(WW)} = 1.7$$

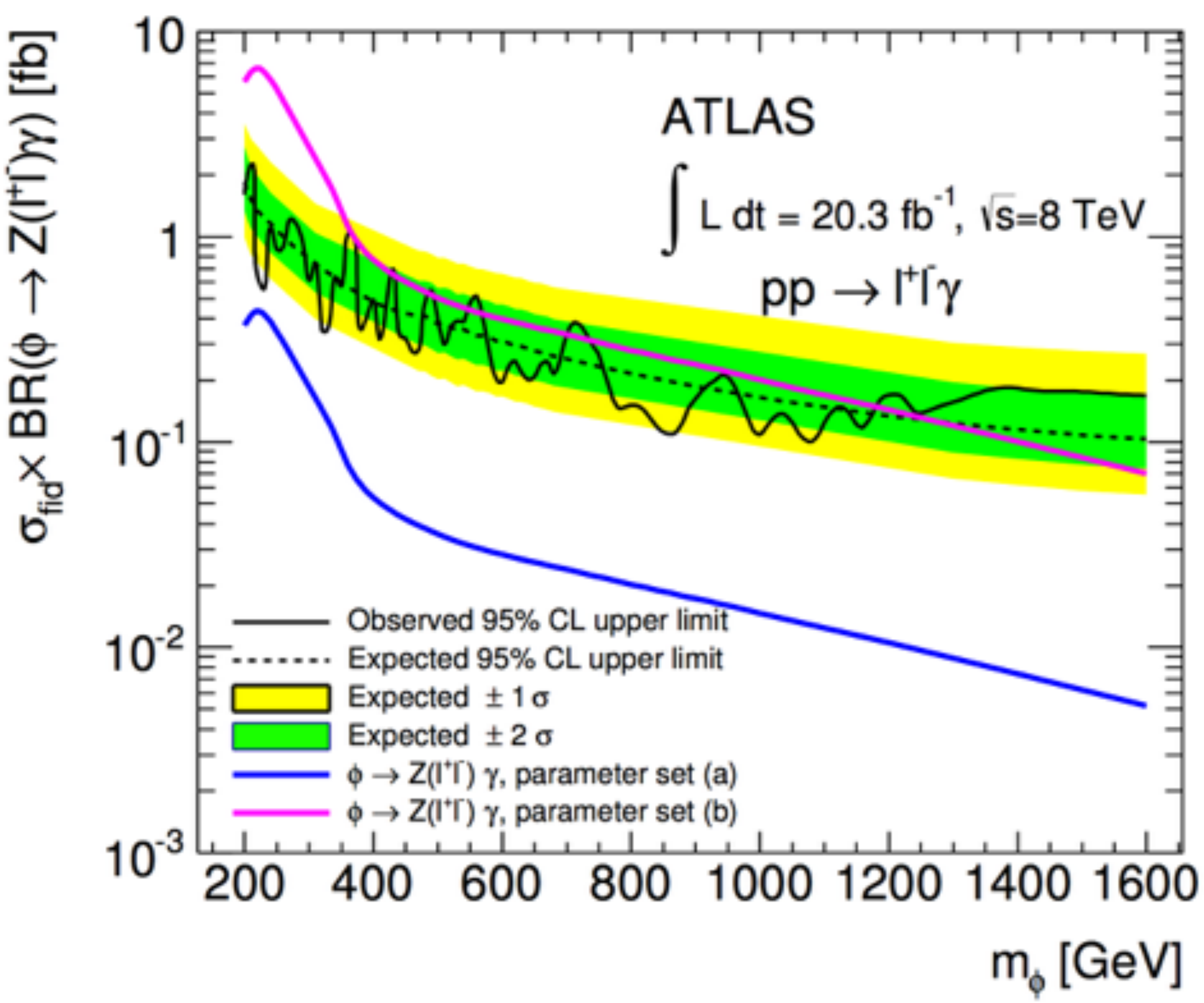
To be compared with $S_{ZZ} = 6.4$



PROSPECTS FOR RUN 2

$$\frac{\sigma_{gg}^{13\mathrm{TeV}}}{\sigma_{gg}^{8\mathrm{TeV}}} \sim 15 \qquad \text{vs} \qquad \frac{\sigma_{q\bar{q}}^{13\mathrm{TeV}}}{\sigma_{q\bar{q}}^{8\mathrm{TeV}}} \sim 7$$

This difference may even allow immediately to understand the production mechanism
Di-boson searches at 13 TeV should be effective already with few inverse fb



The main prediction in the case of the sgoldstino is a signal in the $Z\gamma$ channel that also depends on m_1

$$\sigma \times \mathrm{BR}_{Z\gamma} \sim 0.01 - \text{few fb}$$

At Run2 this can be the smoking gun in the sgoldstino case!

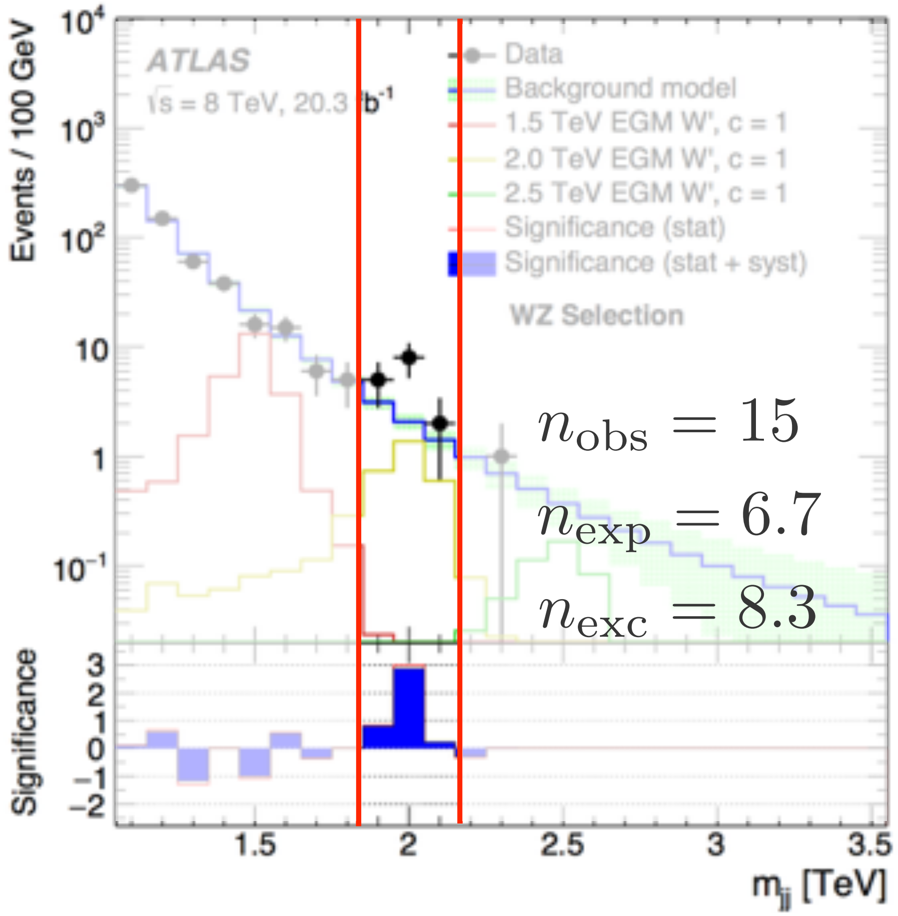
CONCLUSION

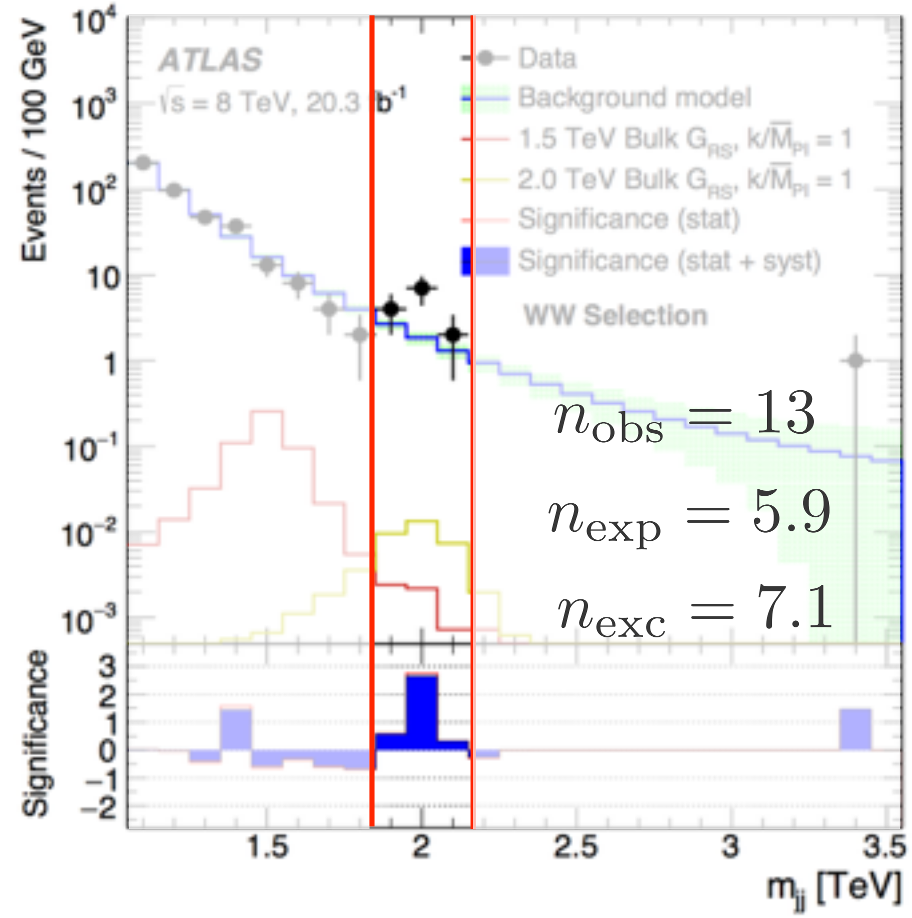
- Some interesting excesses show up in Run 1 searches for heavy resonances
- We took the largest such excess from ATLAS and tried to interpret it in two different new physics scenarios
- The excess requires a cross section times BR around 5 to 10 fb
- This signal hypothesis has a slight tension with strong bounds from semi-leptonic analyses, but everything is still compatible within uncertainties
- Already by the end of the year it should be possible to definitely exclude the new physics origin of these fluctuations
- But in the case of a persisting excess…

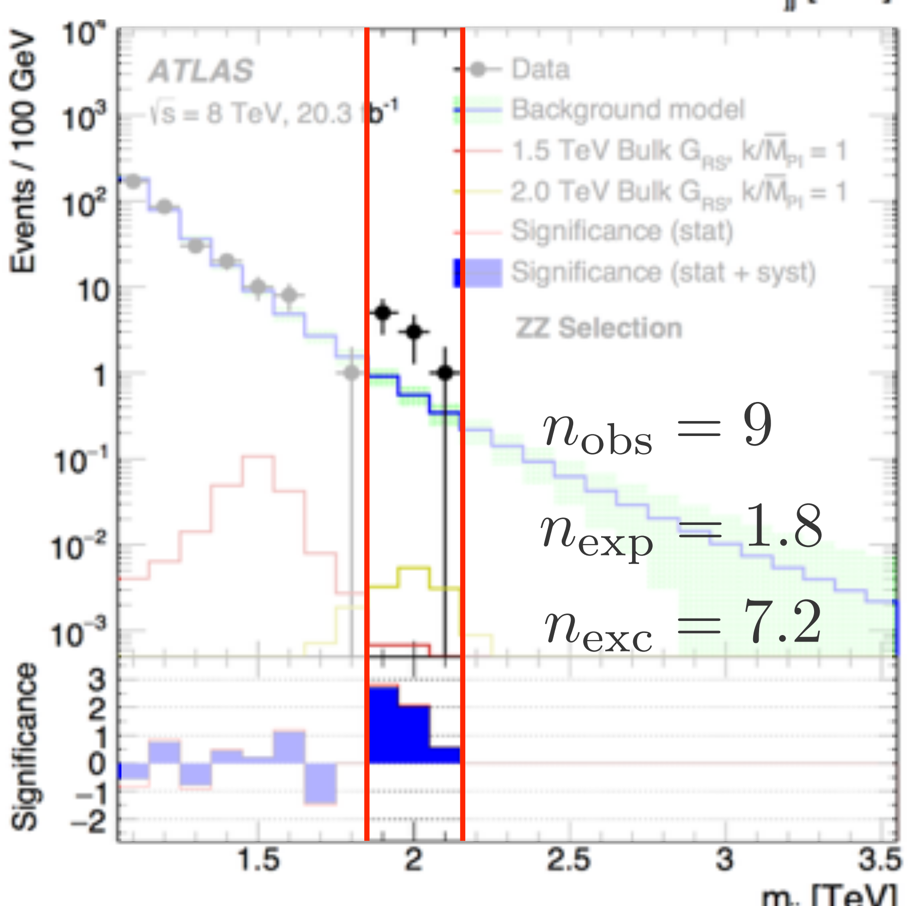
… stay ready for champagne!

THANK YOU

EXCESS EVENTS







Big statistical uncertainties:

$$S_{WZ} = 8.3^{+4.0}_{-2.8}$$
$$S_{WW} = 7.1^{+3.8}_{-2.6}$$
$$S_{ZZ} = 7.2^{+3.8}_{-2.6}$$

A combined fit to all these channels is impossible to do since we lack any information about the correlation of the big systematic uncertainties (~50% for the signal)!

We will just extract the signal hypothesis from a single channel and confront with the others