The undead 2 TeV diboson excess

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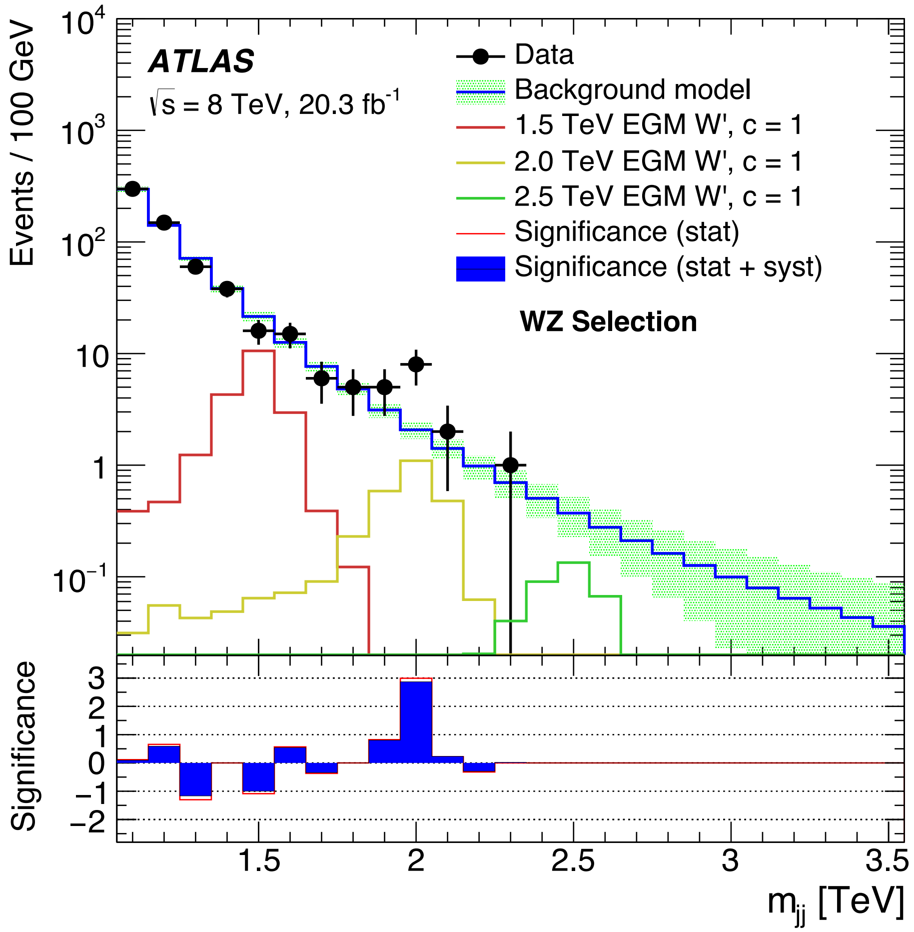
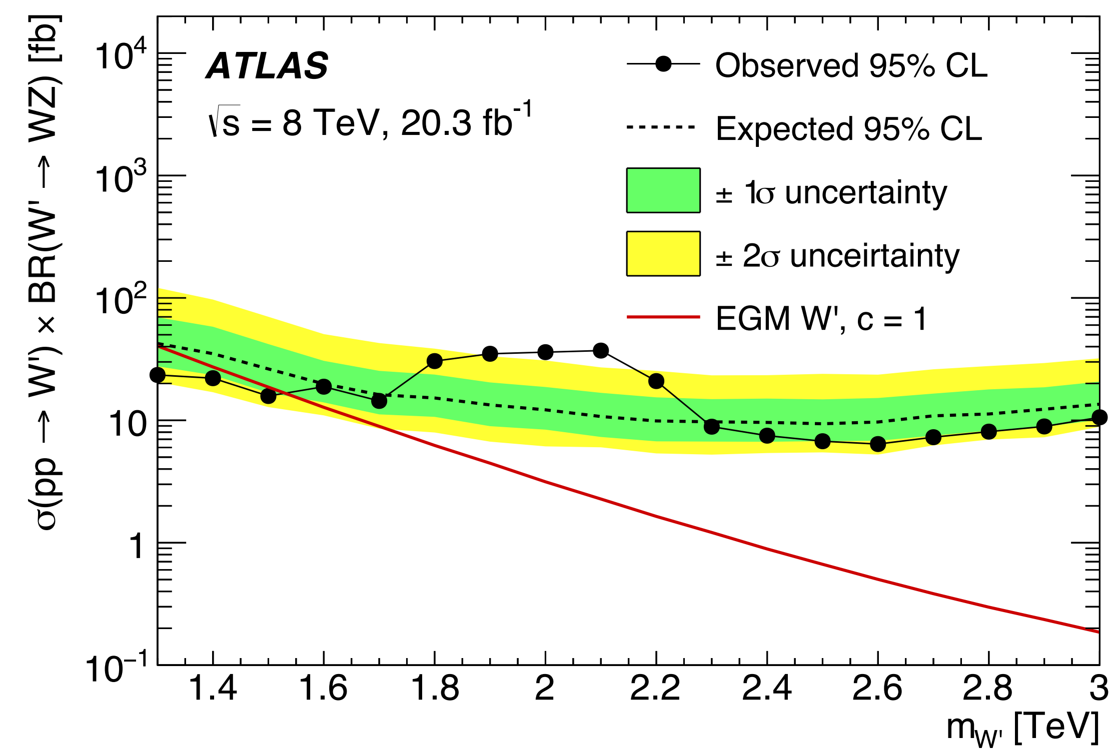
PASCOS 2017, Madrid, June 22nd 2017

The excess

Search for VV (V = W or Z) diboson resonances in boson-tagged jets, Run 1





- Fat jets of radius R=1.2 tagged as `$W$′ or `Z′ depending on mass
- Samples tagged as `$WW$′, `WZ′ or `ZZ′
- Excess largest in `WZ′: 3.4σ

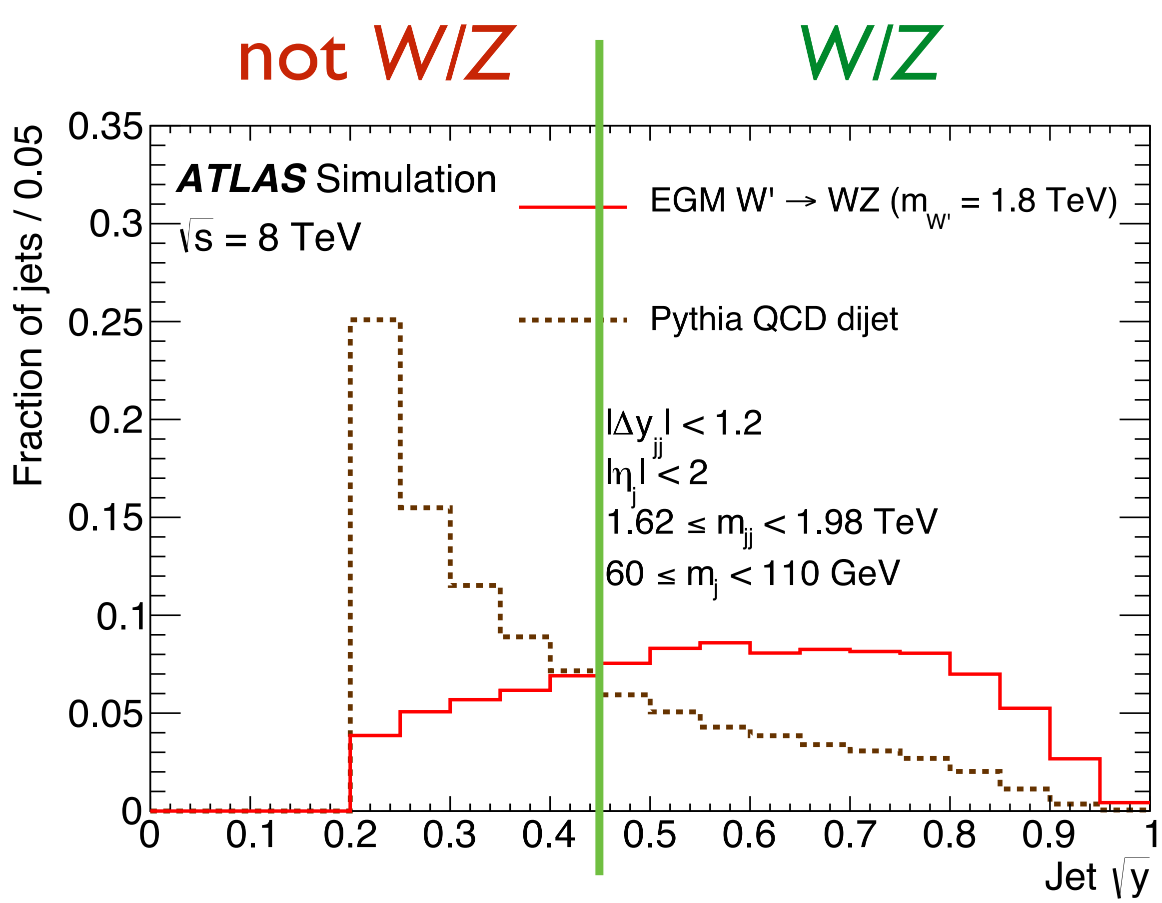
I will consider this sample all the presentation, for consistency, but excesses in other samples too

Dictionary for non-experts…

The `hadronically decaying *W* and *Z* bosons´ in this ATLAS analysis — and analogous analyses by CMS — are not necessarily *W* or *Z* bosons.

They are some particle(s) decaying hadronically, giving a fat jet with a mass ~ M_W, M_Z, and with a certain value for some `boson tagging´ variable that is used to try to distinguish jets from *W*/*Z* bosons from quark and gluon jets.

ATLAS uses at Run 1 a variable called `*y*´, requiring $sqrt(y) \geq 0.45$.

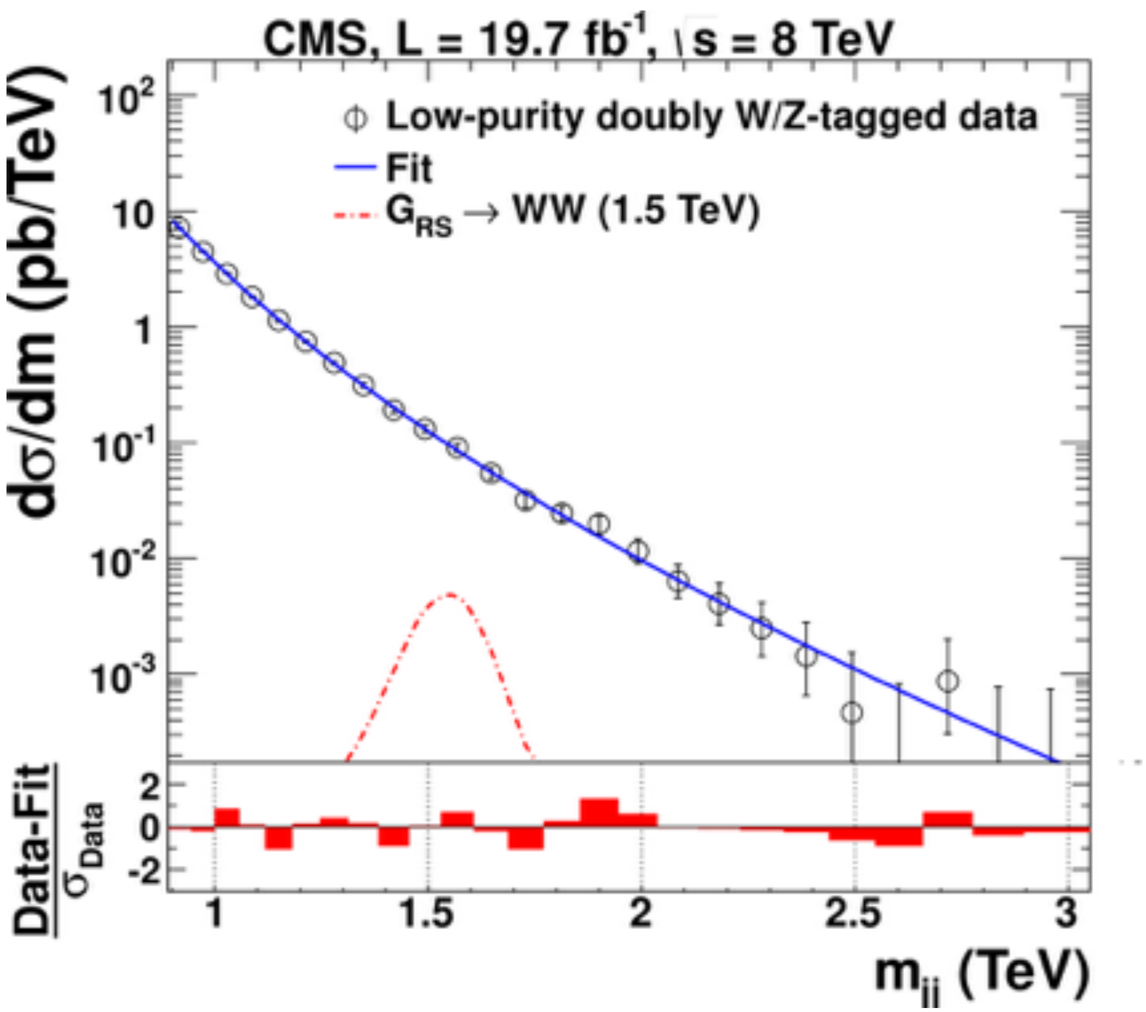


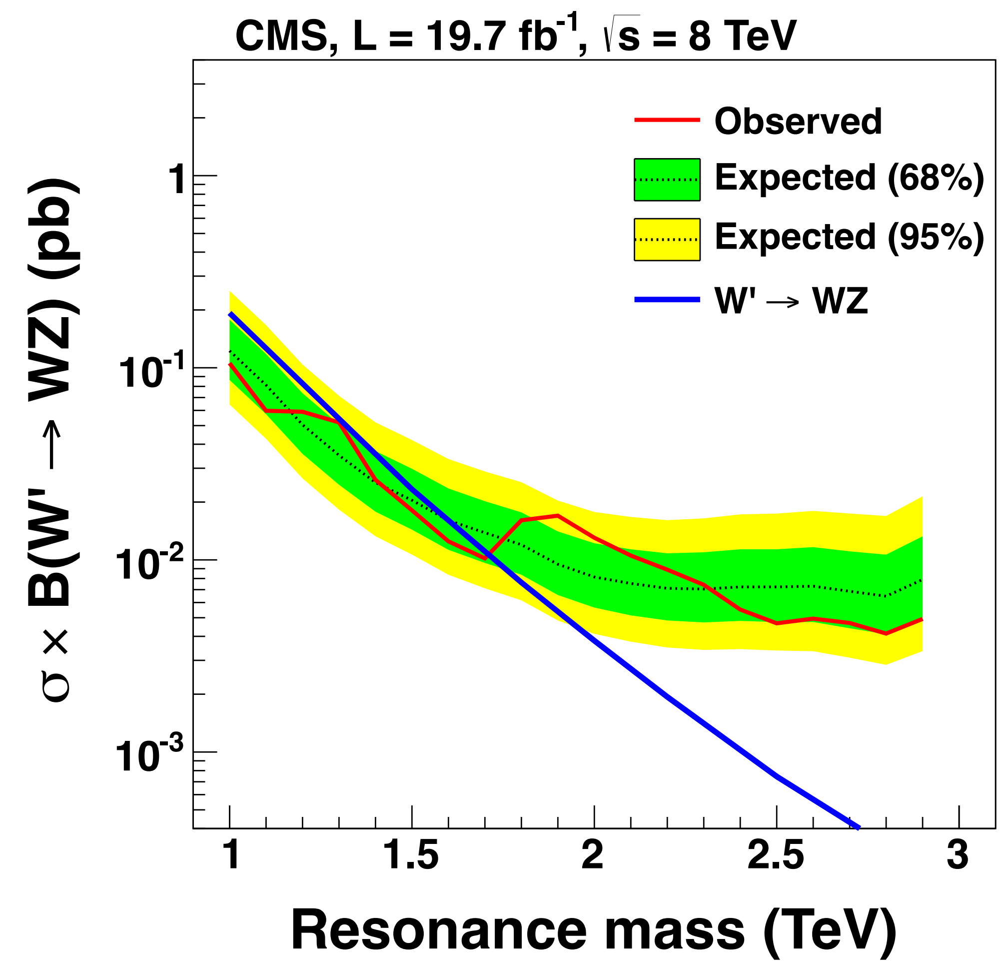
ATLAS [Run 1 and Run 2]
`*W*´: mass window $M_W \pm 15$ GeV
`*Z*´: mass window $M_Z \pm 15$ GeV
[Can be *W* and *Z* simultaneously]

CMS [Run 2]
`*W*´: 65-85 GeV
`*Z*´: 85-105 GeV

The `diboson excess´ is actually an excess in the production of a pair of objects with a mass not far from ~100 GeV giving fat jets that pass some requirement of compatibility with W or Z bosons

Meanwhile in CMS…





Compatible with ATLAS excess within uncertainties

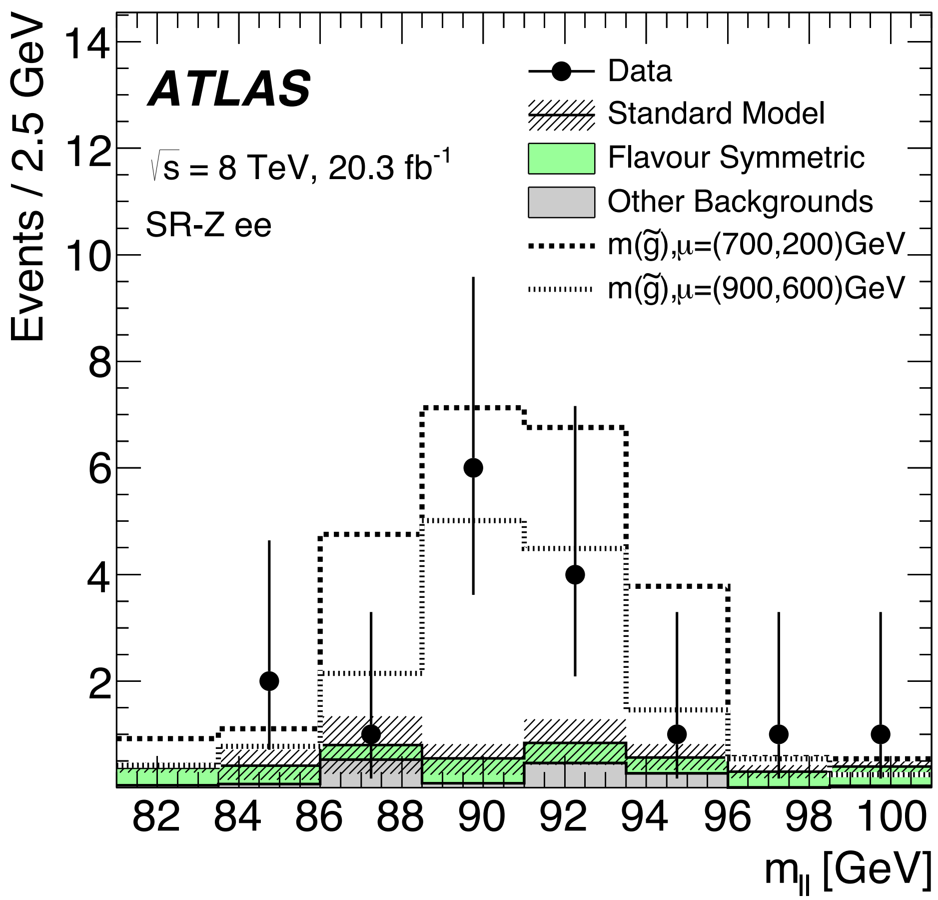
[remember when Higgs mass was not the same in *ZZ* and γγ]

Analysis different from ATLAS: different jets, \`boson tagger´ τ_{21}, etc.

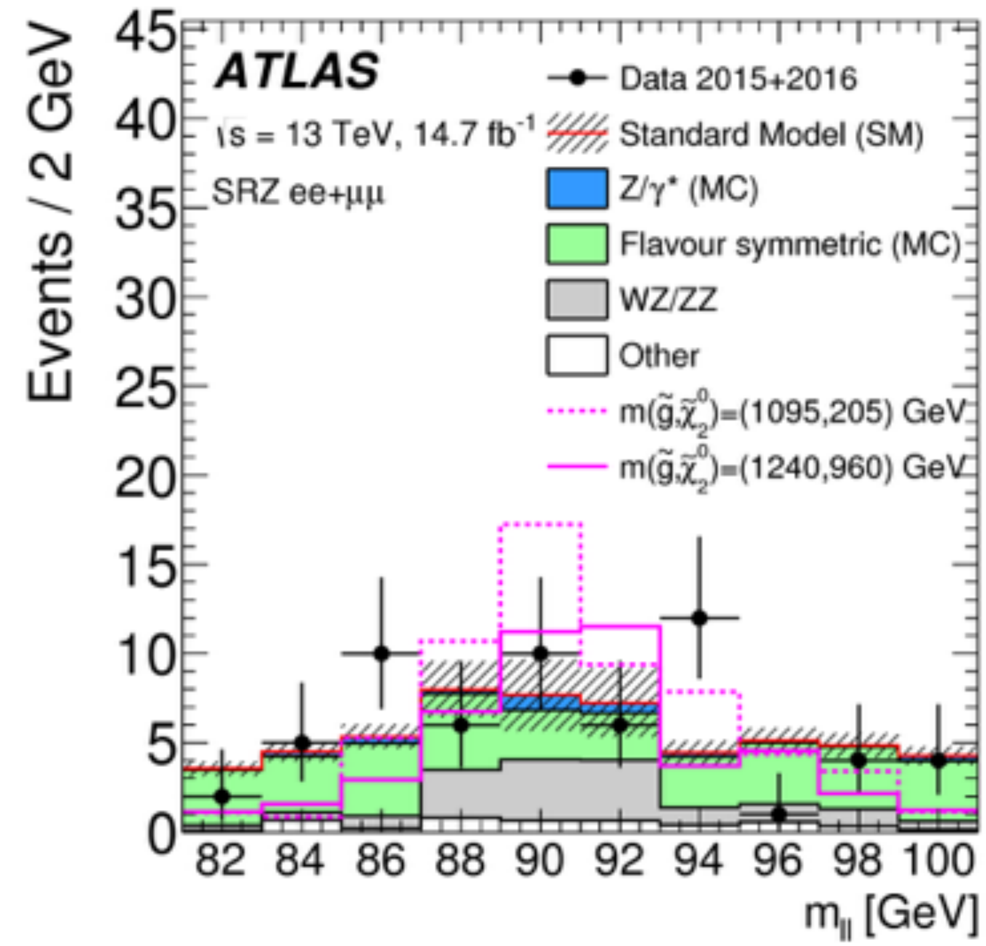
What should have been done with the excess…

Example: ATLAS excess in *Z*+MET events in SUSY search

Run 1: 3σ



Run 2: no excess

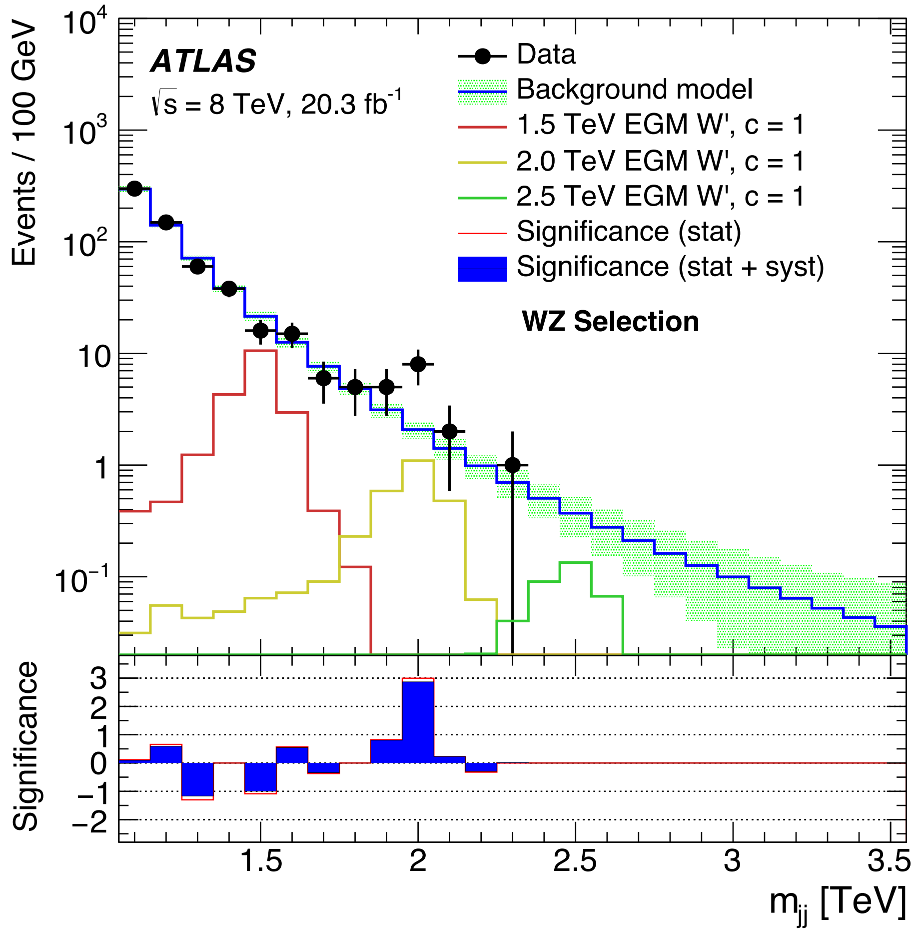


Keep same event selection, except for slightly different definitions for leptons and jets, due to harder Run 2 environment.

No excess in Run 2 → quite conclusive!

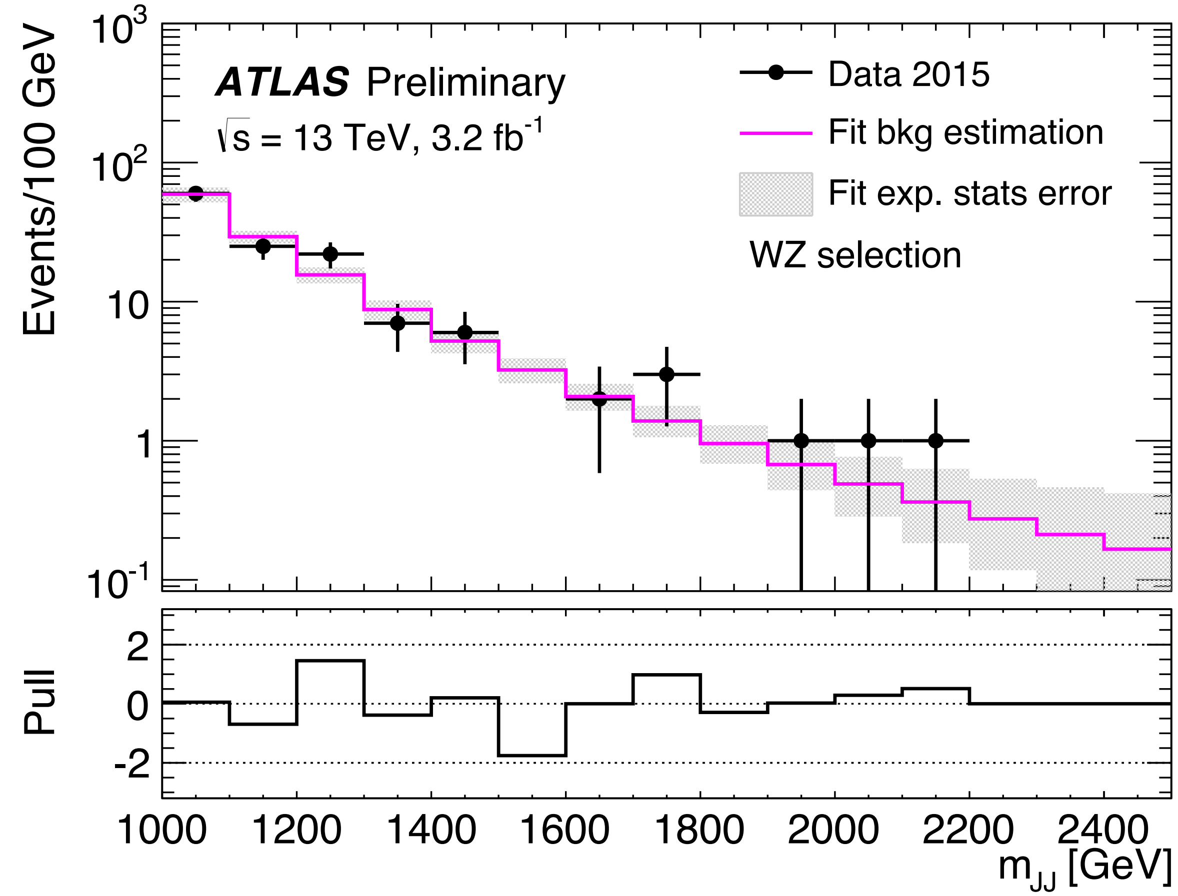
What it was actually done…

Run 1 20.3 fb^{-1}



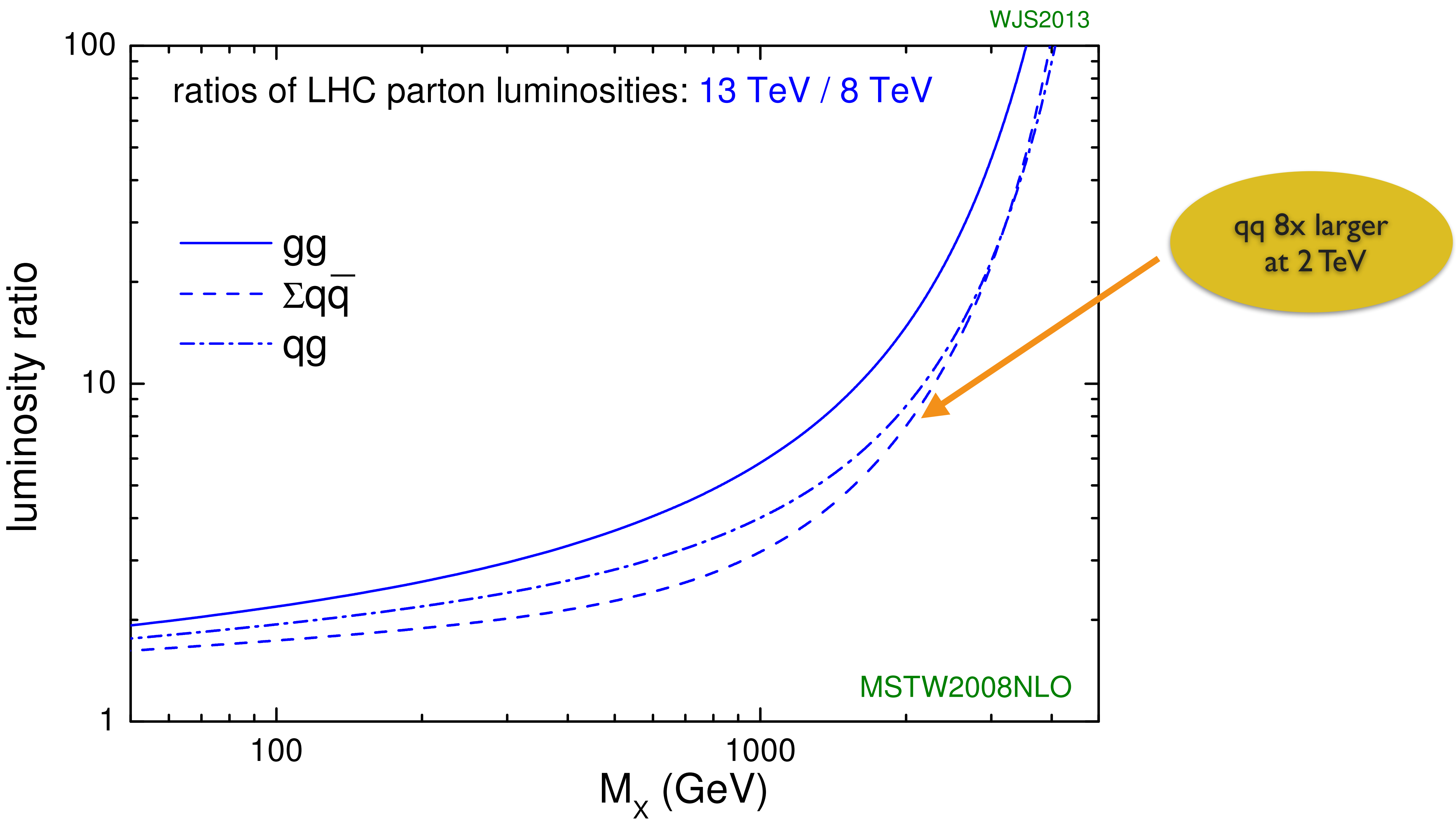
- jets with radius *R*=1.2
- C/A algorithm
- variable `y´ to analyse jet two-prong substructure and reject quark/gluon jets
- …

Run 2 3.2 fb^{-1}



- jets with radius *R*=1.0
- anti-k_T algorithm
- variable `D_2´ to analyse jet two-prong substructure and reject quark/gluon jets
- …

If the excess had been precisely a *VV* diboson resonance, it should have appeared in Run 2 data, even with a smaller luminosity, because of the larger parton distribution functions at 13 TeV than at 8 TeV.

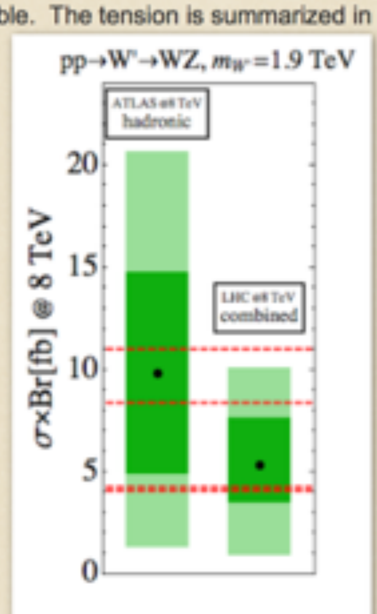


… so bloggers & influencers spread news of the `decease´…

Saturday, 9 January 2016

Weekend Plot: The king is dead (long live the king)

The new diphoton king has been discussed at length in the blogoshpere, but the late diboson king also deserves a word or two. Recall that last summer ATLAS announced a 3 sigma excess in the dijet invariant mass distribution where each jet resembles a fast moving W or Z boson decaying to a pair of quarks. This excess can be interpreted as a 2 TeV resonance decaying to a pair of W or Z bosons. For example, it could be a heavy cousin of the W boson, W' in short, decaying to a W and a Z boson. Merely a month ago this paper argued that the excess remains statistically significant after combining several different CMS and ATLAS diboson resonance run-1 analyses in hadronic and leptonic channels of W and Z decay. However, the hammer came down seconds before the diphoton excess announced: diboson resonance searches based on the LHC 13 TeV collisions data do not show anything interesting around 2 TeV. This is a serious problem for any new physics interpretation of the excess since, for this mass scale, the statistical power of the run-2 and run-1 data is comparable. The tension is summarized in this plot:



The green bars show the 1 and 2 sigma best fit cross section to the diboson excess. The one on the left takes into account only the hadronic channel in ATLAS, where the excess is most significant; the one on the right is bases on the combined run-1 data. The red lines are the limits from run-2 searches in ATLAS and CMS, scaled to 8 TeV cross sections assuming W' is produced in quark-antiquark collisions. Clearly, the best fit region for the 8 TeV data is excluded by the new 13 TeV data. I display results for the W' hypothesis, however conclusions are similar (or more pessimistic) for other hypotheses leading to WW and/or ZZ final states. All in all, the ATLAS diboson excess is not formally buried yet, but at this point any a reversal of fortune would be a miracle.

The 750 GeV Diphoton Bump: What It Cannot Be

By Tommaso Dorigo | December 30th 2015 09:57 AM | 49 comments | Print | E-mail | Track Comments

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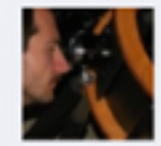

Tommaso Dorigo

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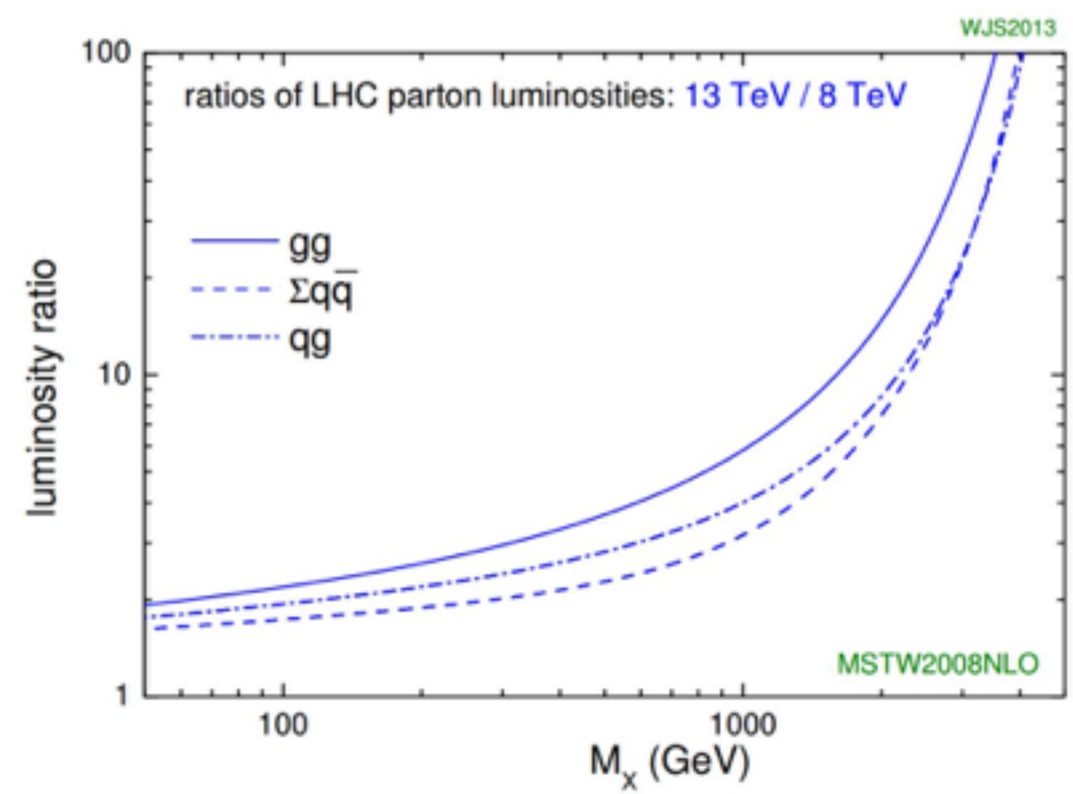
Two weeks have passed since the CERN Jamboree of December 15th, which will be always remembered for the spurious 750 GeV signal observed by ATLAS and CMS in their mass spectra of photon pairs. It is unfortunate, as dozens of very important new measurements and search results were shown by the experiments on that occasion, but they all got overshadowed by a fluctuation.

Even more annoying to some is the fact that the press picked up and overhyped the news, as is quite common in similar circumstances. I personally do not mind, as I belong to the minority who considers this in general a good thing in almost all cases, as it gives some visibility to particle physics and a chance to make our science more understandable to the general public, whatever the claim that is made and however true or fake it is. However, at some point we need to clean up the mess and sweep the floor of all the useless paper clips. We will have to wait for 2016 data to do that, unfortunately, as there is no way to convince the enthusiasts that this is no different from all the other spurious signals that ATLAS and CMS have seen in the past.

Maybe what I can do here is to just remind you of one similar anomaly that got people very excited but went away in 2015 data. That is of course the diboson bump that was seen by ATLAS and CMS at 1.8-2 TeV. It was an over-3-sigma observation by ATLAS, and a 2-sigmaish thing in CMS. The experiments cannot see anything similar in their higher-energy data - granted, the studied luminosity is only a fifth of the 2012 one, but the energy is over 60% higher so any massive object should show up more frequently now, as shown by the graph below.



But, do you think that an anomaly is really tested by doing a different search with more luminosity?

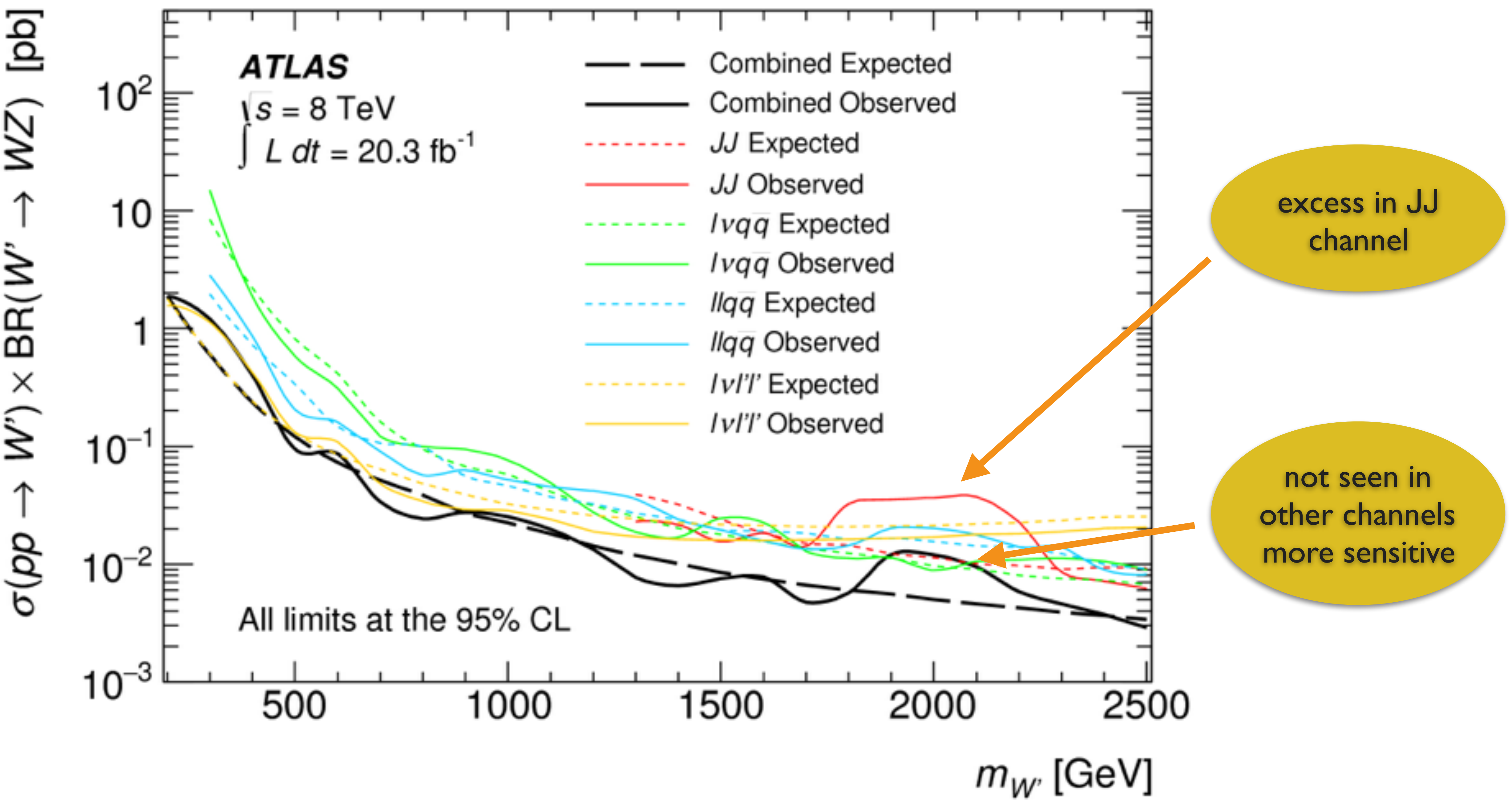
(if you do, you will change your mind soon: look out for the rest of the talk)

And do you think that new physics will manifest as precisely one of the simple benchmark models looked for at the LHC?

(if you do, you can safely open your laptop if you already didn't so and ignore the rest of the talk)

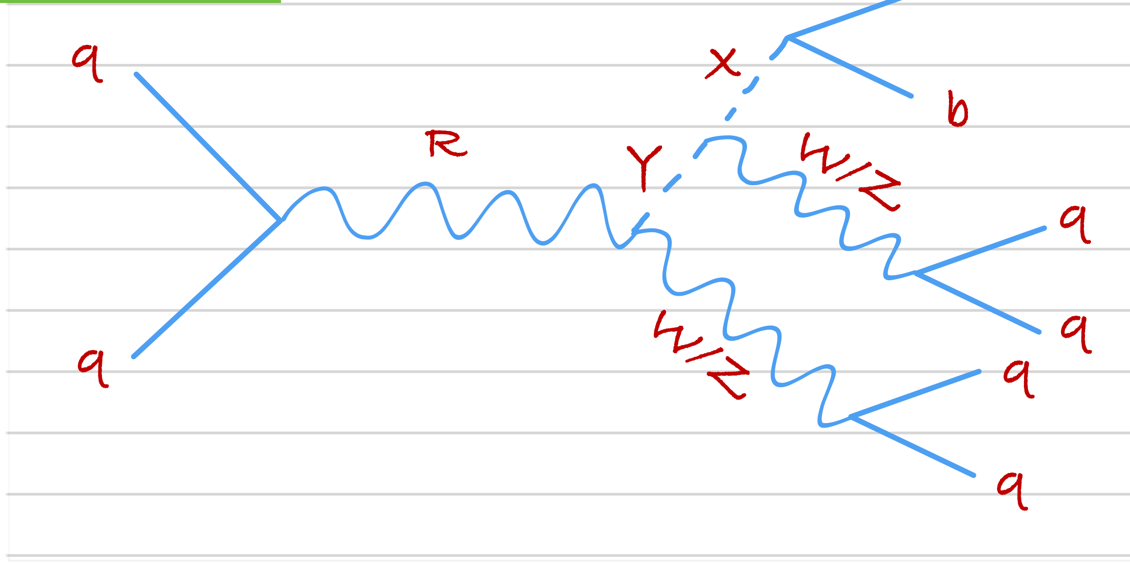
Dissecting the anomaly

By the time the excess appeared, it should have been clear that this excess, if not a fluctuation, was not a VV diboson resonance…



… and actually, there were alternative proposals to explain the JJ hadronic excess and the absence of signals in semileptonic final states.

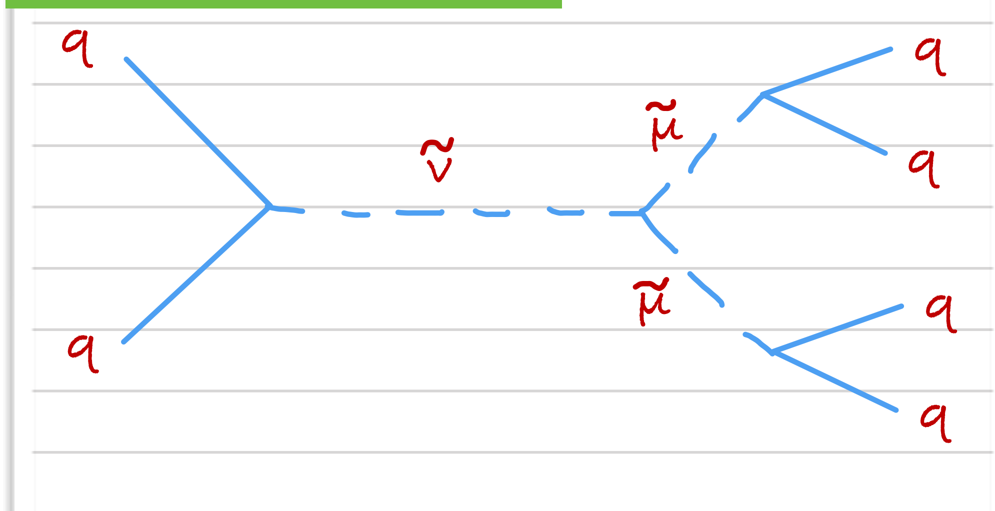
triboson



JAAS 1506.06739

extra particle *X* causes efficiency drop in semileptonic final states

di(nonSM)boson



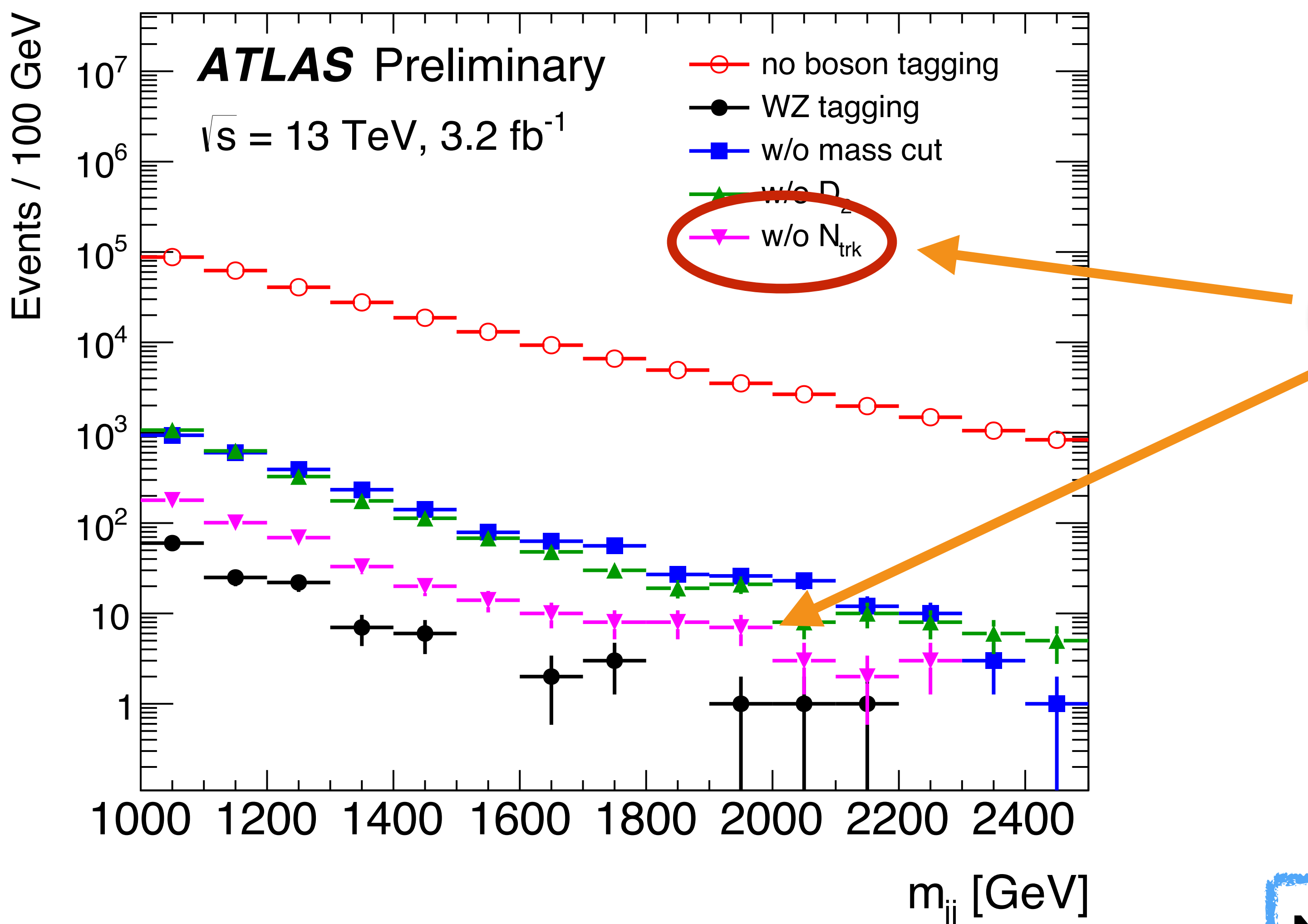
Allanach et al. 1511.01483

simply, there are no semileptonic final states

Buried alive? Hint #1

December 2015

ATLAS Run 1 3.2 fb^{-1}

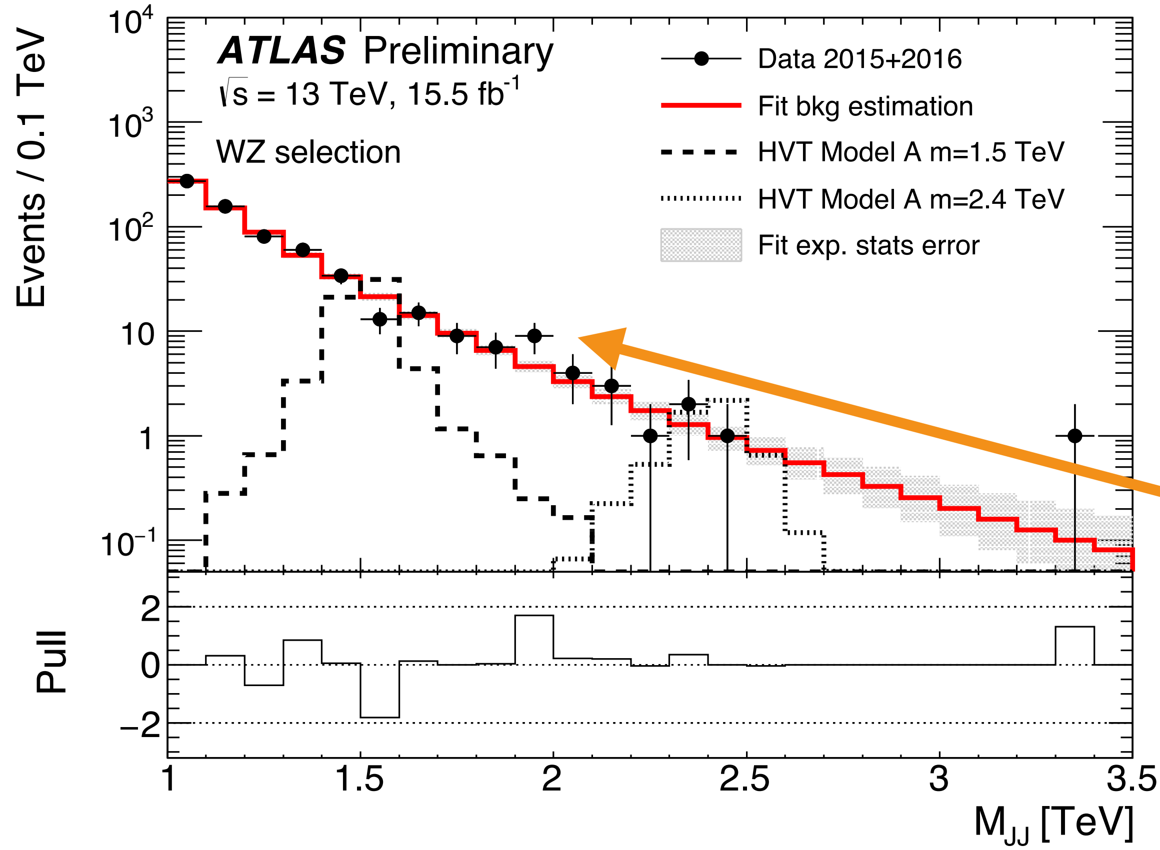


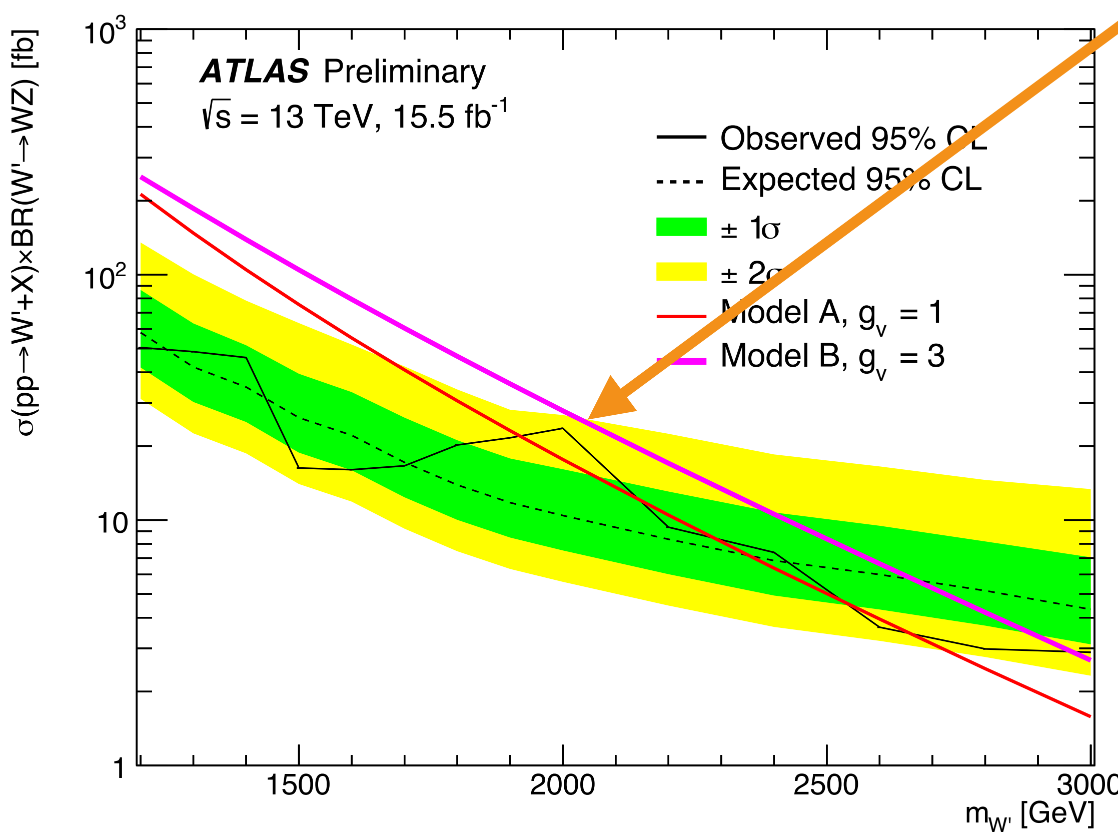
small 2.4σ bump appears with looser event selection (pink)

Maybe the new event selection is `cutting too hard´?

Buried alive? Hint #2

August 2016





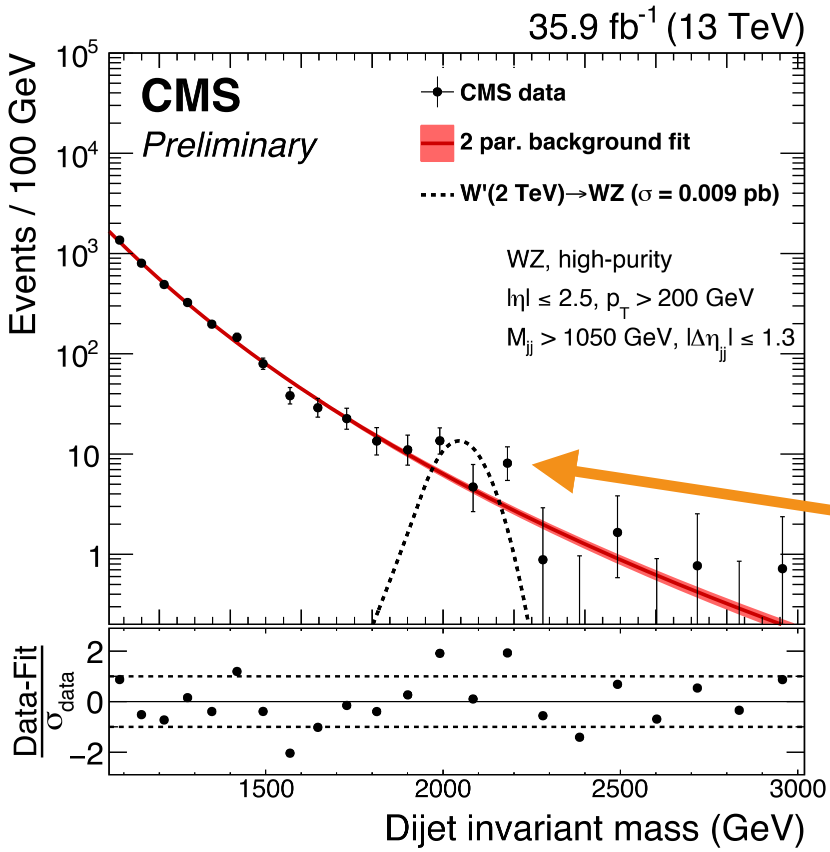
ATLAS Run 2 15.5 fb^{-1}

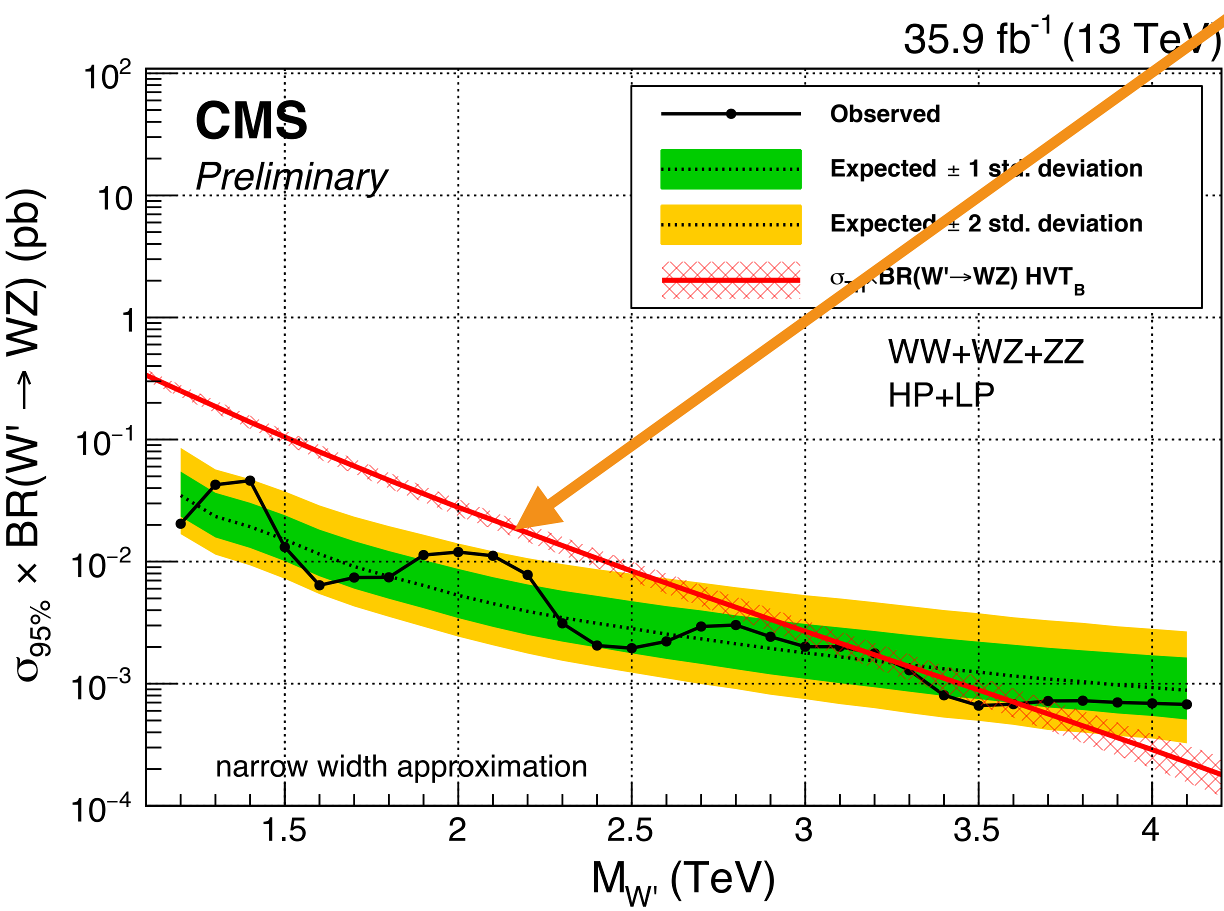
with more luminosity small 2σ bump appears

Maybe the new event selection is `cutting too hard´???!!!

Buried alive? Hint #3

March 2017





CMS Run 2 35.9 fb^{-1}

at the `right place´, a small 2σ bump appears

Another coincidence???!!!

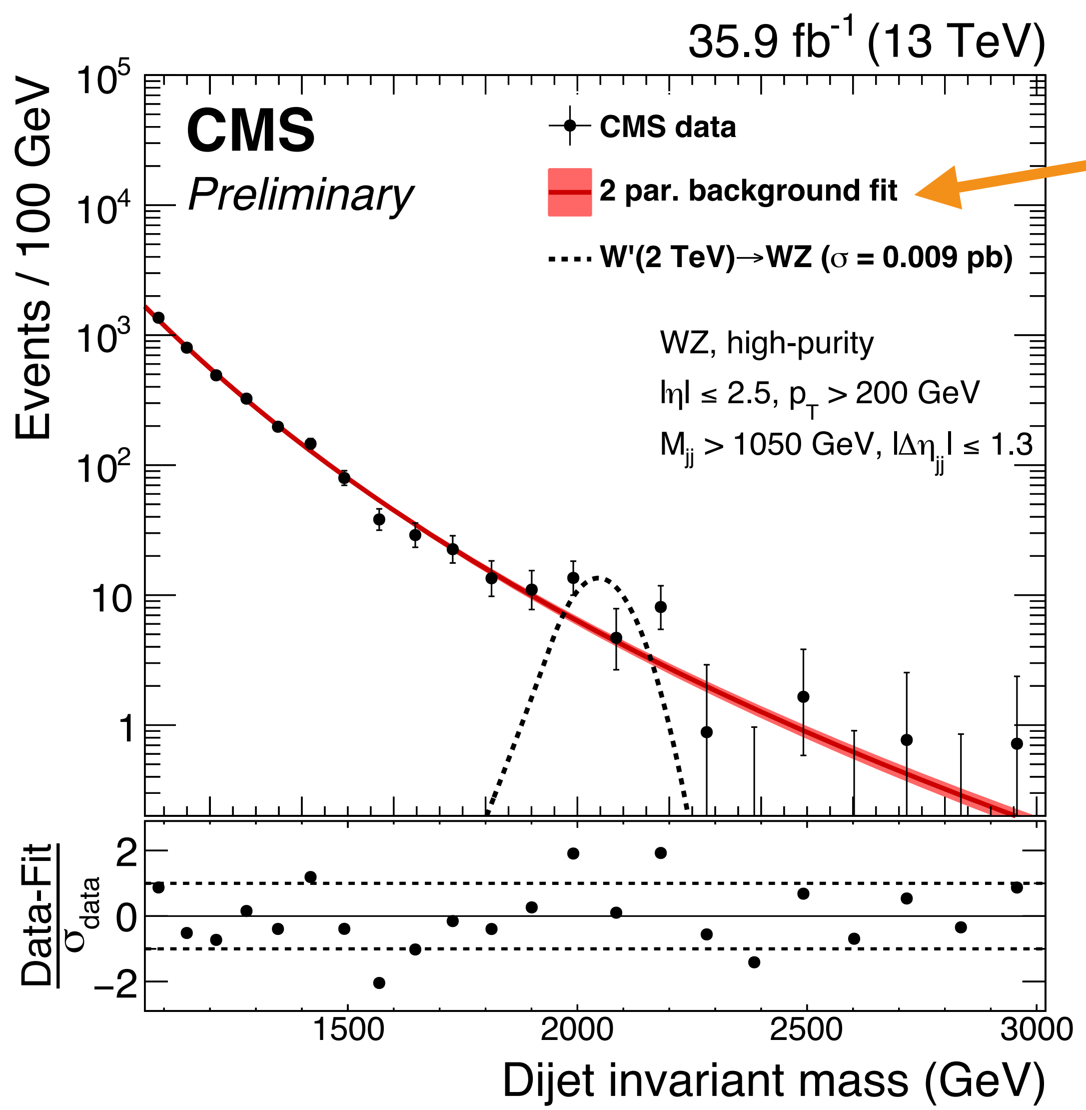
Do you think that it is a coincidence to have these five little bumps around 2 TeV?

(I don’t, but in any case, Nature doesn’t care about our beliefs)

Achiles' heel of diboson searches

The main background is QCD dijet production, which cannot be accurately predicted by Monte Carlo calculations.

Therefore, the background is determined by a fit to data in the signal region using some smooth functional form.



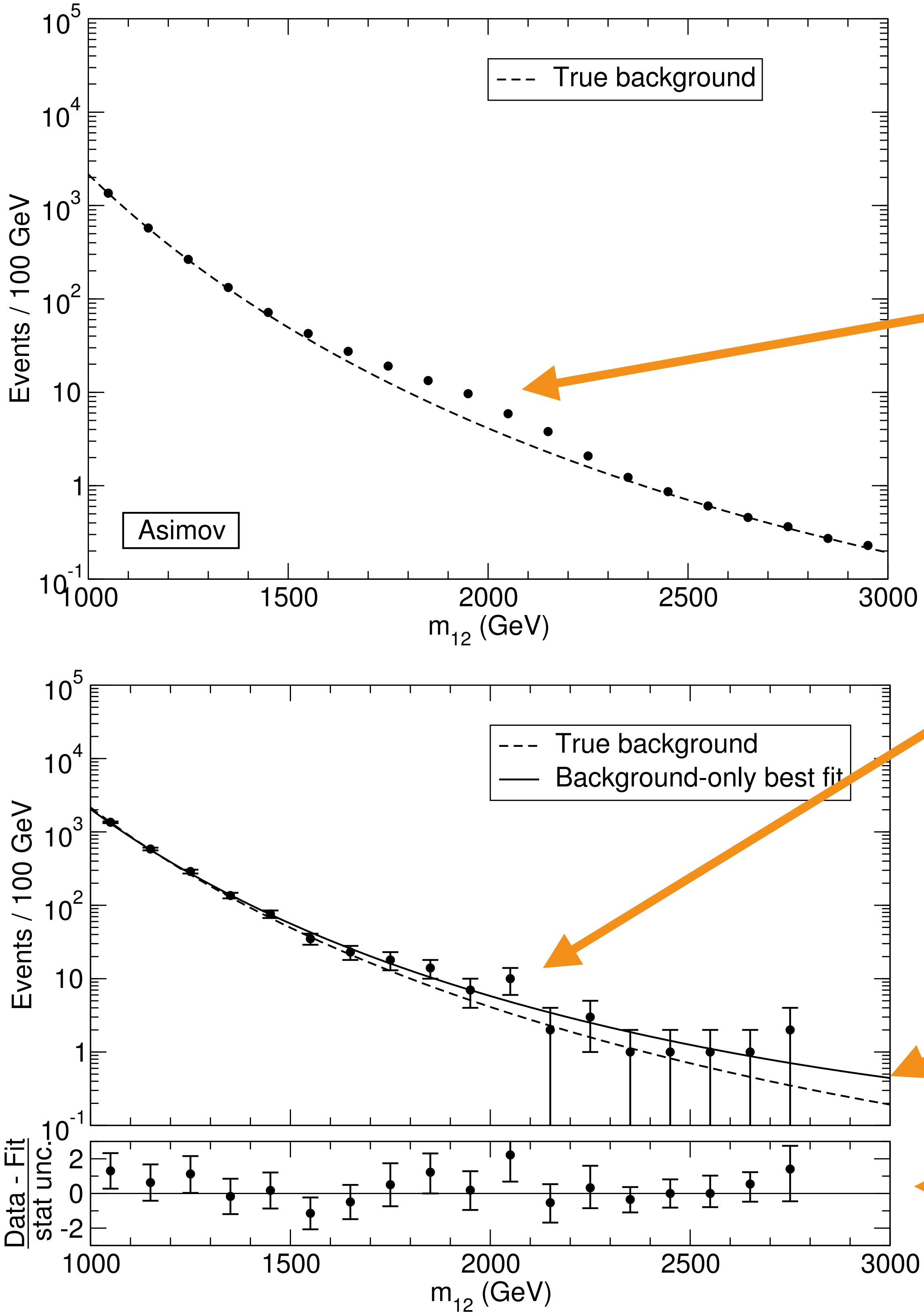
$$\frac{dN}{dm_{JJ}} = \frac{P_0(1 - m_{JJ}/\sqrt{s})^{P_1}}{(m_{JJ}/\sqrt{s})^{P_2}}$$

P₁, *P₂* free parameters

P₀ normalisation

This may be fine for narrow resonances, but new physics signals giving wide bumps are mostly absorbed by the background fit if statistics are small.

JAAS 1703.06153



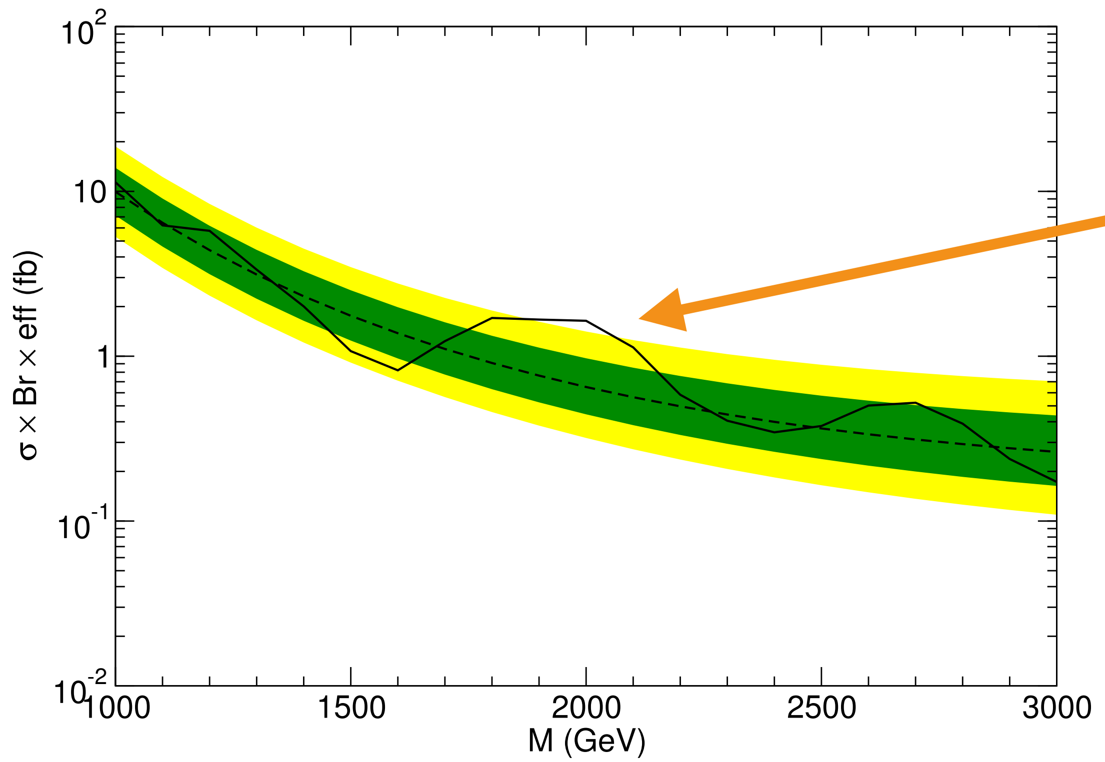
new physics signal is a large wide bump on top of smooth background

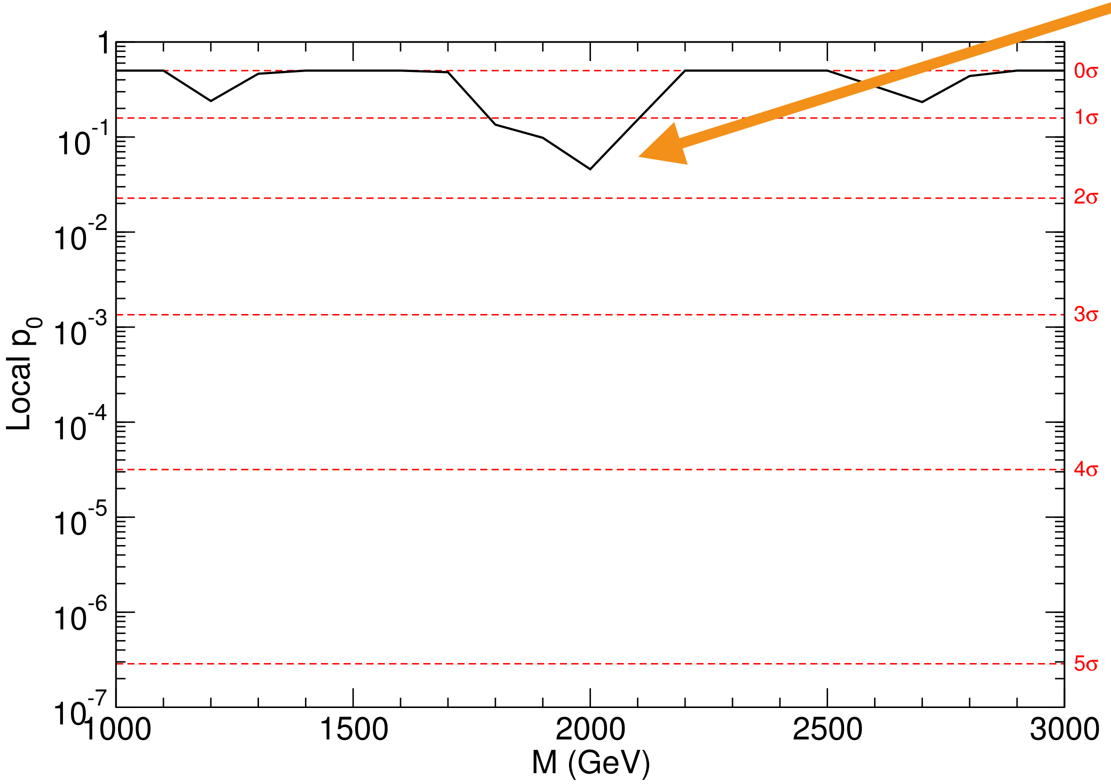
in pseudo-experiment, many extra `signal´ events and also some fluctuations

the `best background-only fit´ absorbs part of the bump

data exhibits smallish deviations w.r.t. best fit

Therefore…



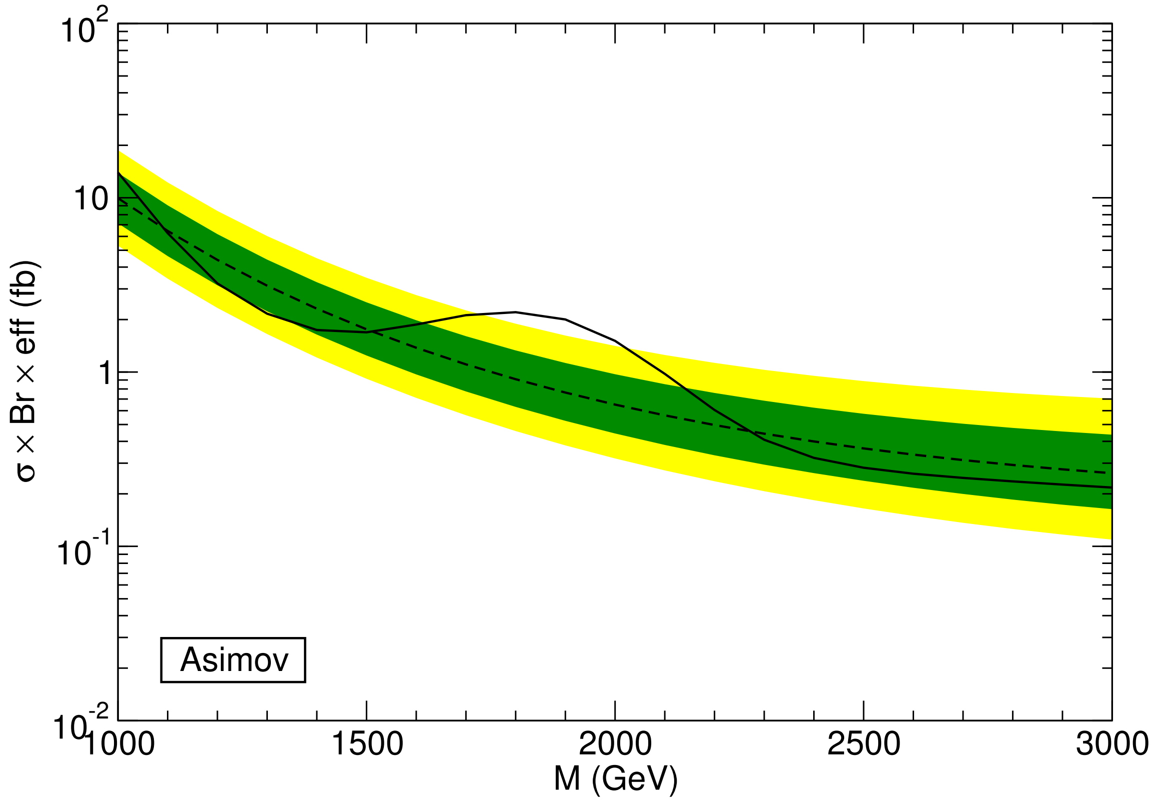


upper limit does not show anything remarkable

P-value calculated assuming narrow resonance does not either

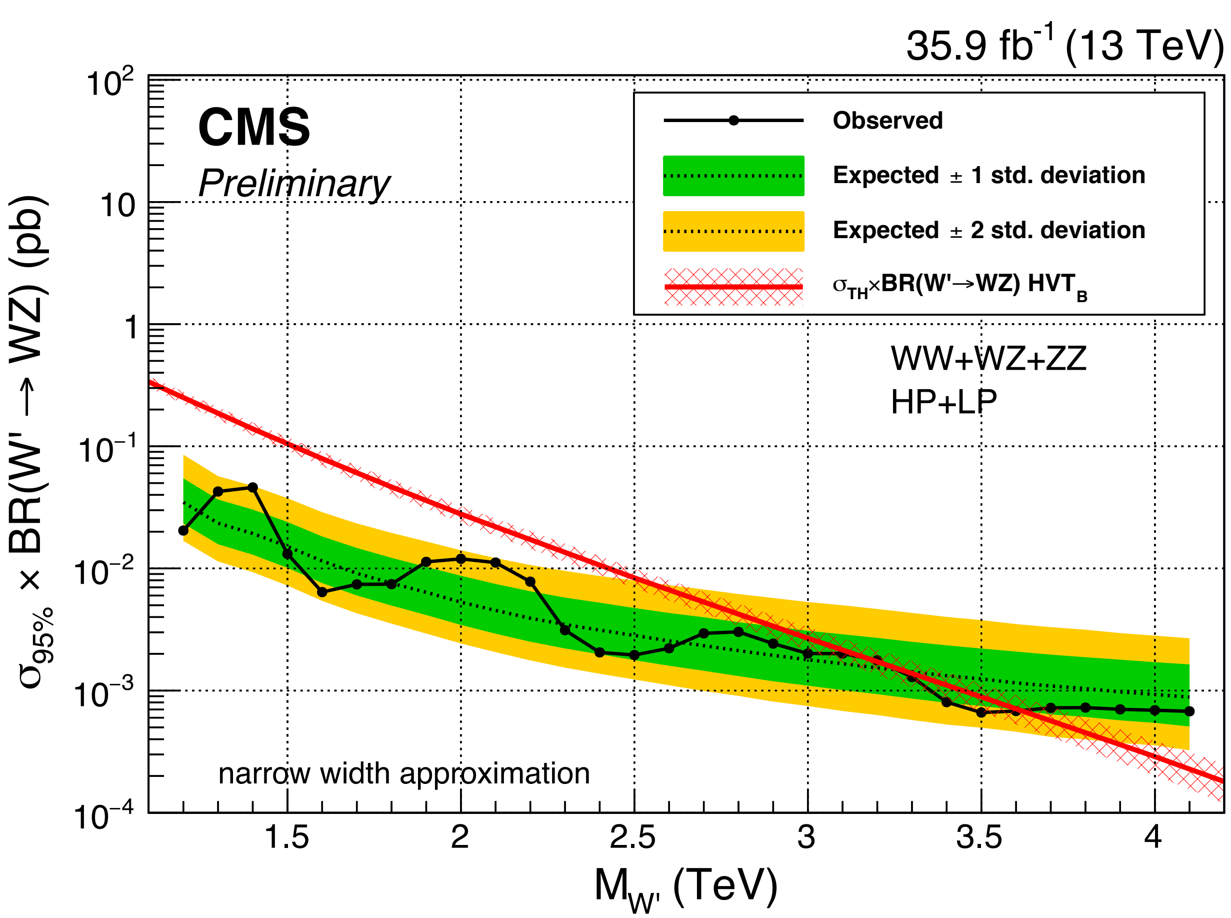
`No significant excess is observed´

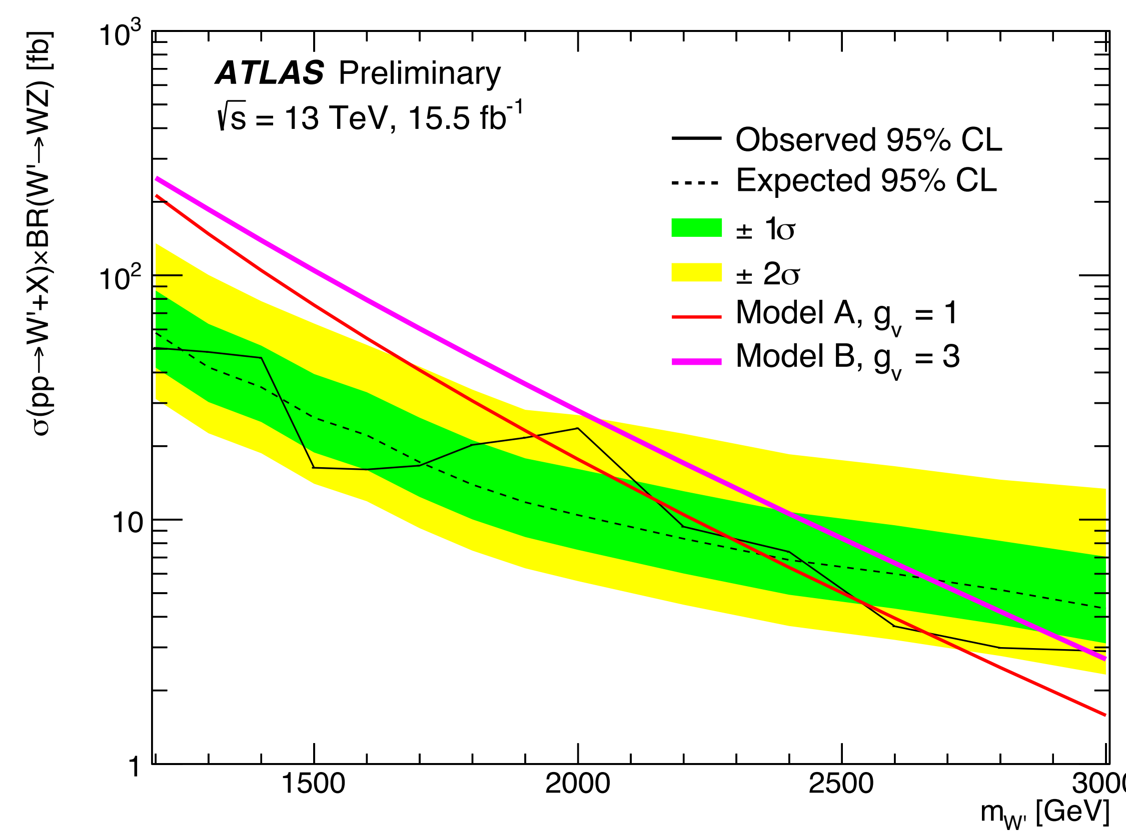
Just for fun…



Expected features for wide bump absorbed by background fit:

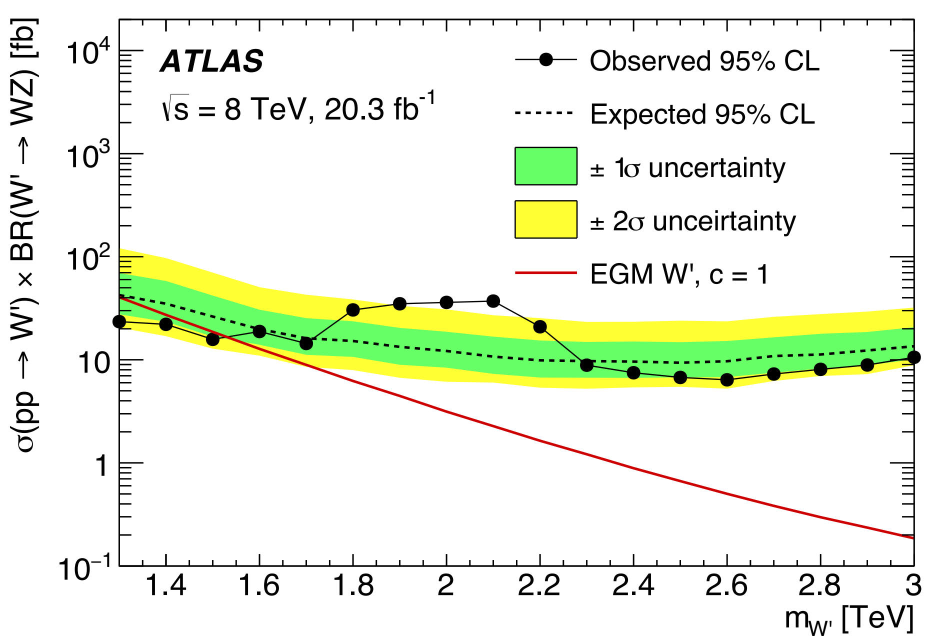
- the bump ✔
- small dips at both sides ✔
- small excess at low mass ✔
- deficit at high mass ✔



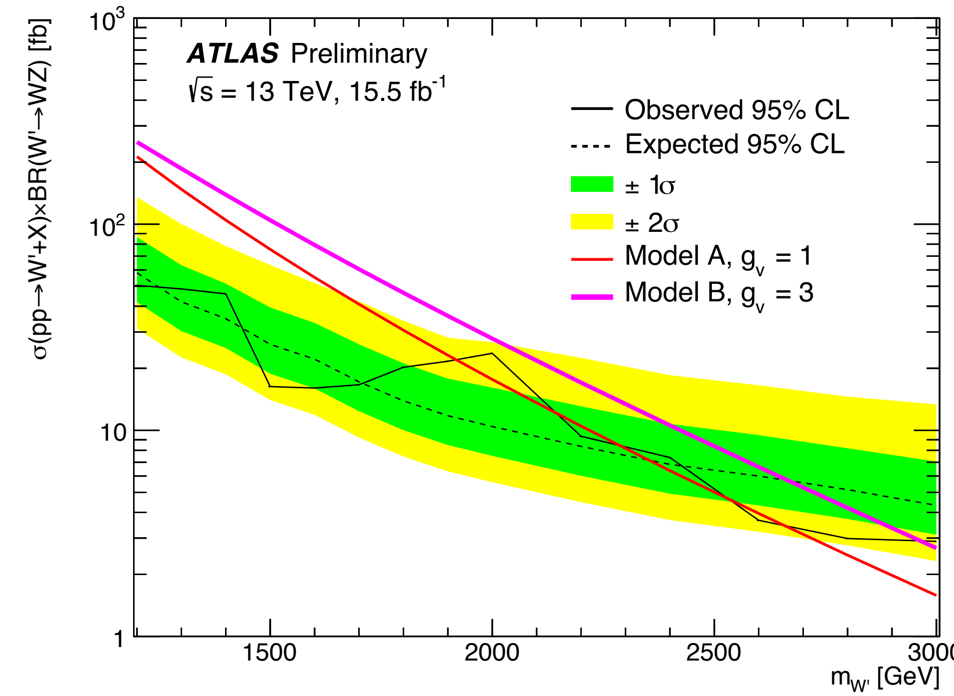


Still, a serious concern is that the excess *should be larger* in Run 2 if it was something at Run 1.

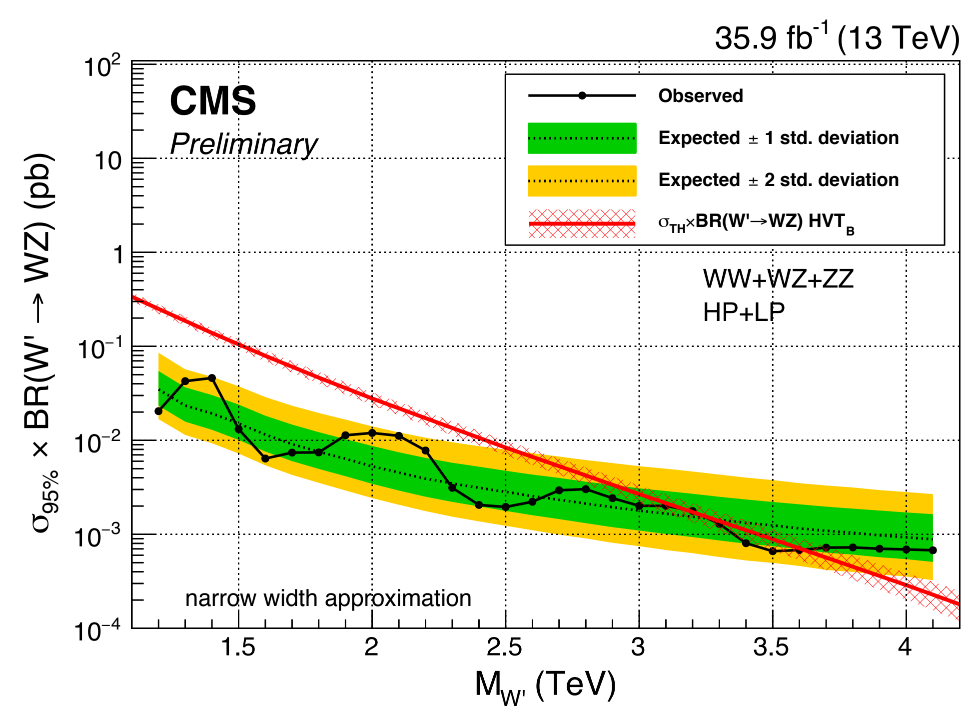
Tribosons and di(nonSM)bosons cannot fully explain that point. [unless fast detector simulations used by theorists miss some crucial detector features]



~ same luminosity
~ 8x PDFs



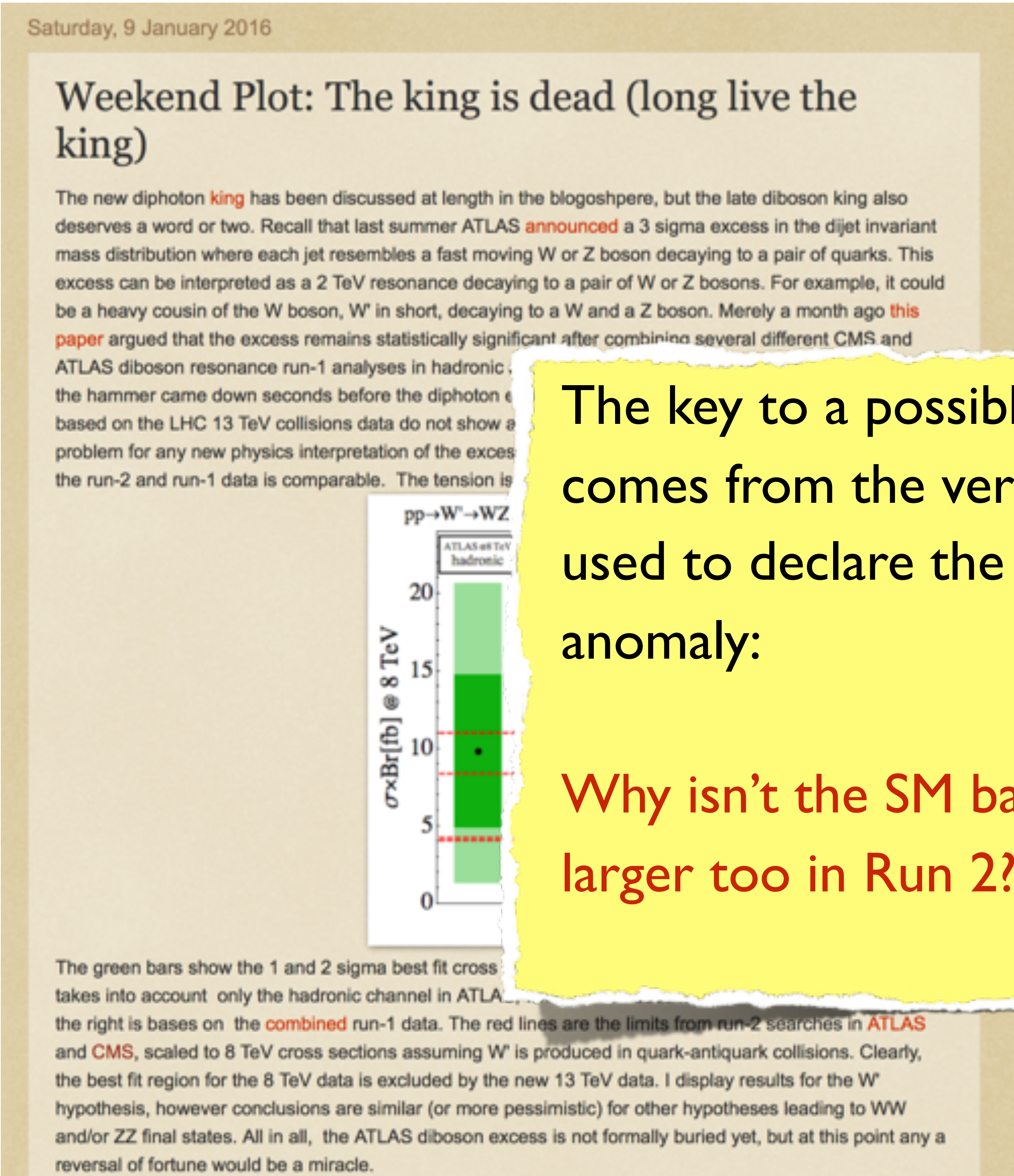
????



~ 2x luminosity
~ 8x PDFs

Nature does not care if we have a model to understand it.

But we would be happier if we have one.



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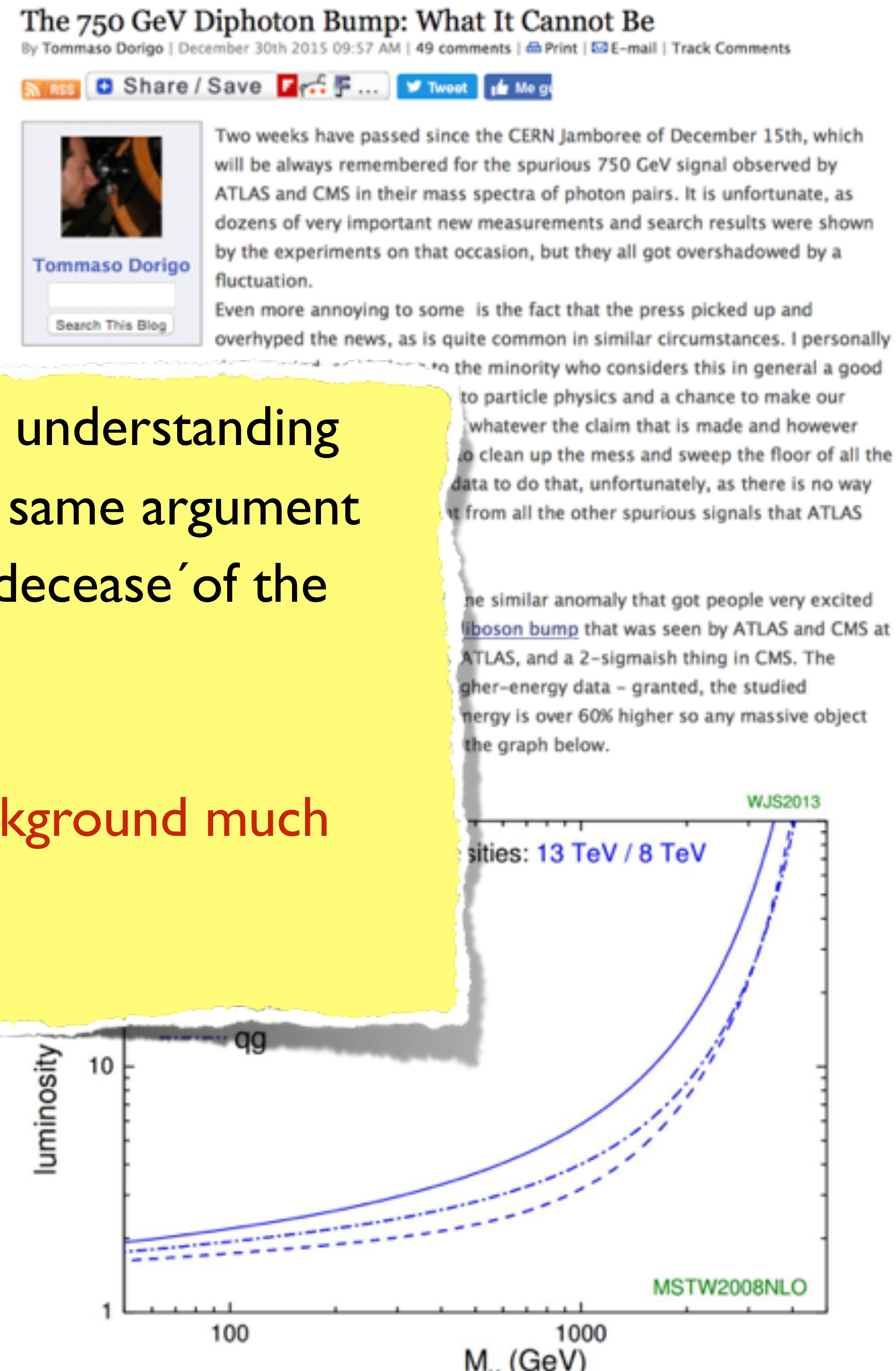
The green bars show the 1 and 2 sigma best fit cross ... takes into account only the hadronic channel in ATLA... the right is bases on the combined run-1 data. The red lines are the limits from run-2 searches in ATLAS and CMS, scaled to 8 TeV cross sections assuming W' is produced in quark-antiquark collisions. Clearly, the best fit region for the 8 TeV data is excluded by the new 13 TeV data. I display results for the W' hypothesis, however conclusions are similar (or more pessimistic) for other hypotheses leading to WW and/or ZZ final states. All in all, the ATLAS diboson excess is not formally buried yet, but at this point any a reversal of fortune would be a miracle.



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Tommaso Dorigo

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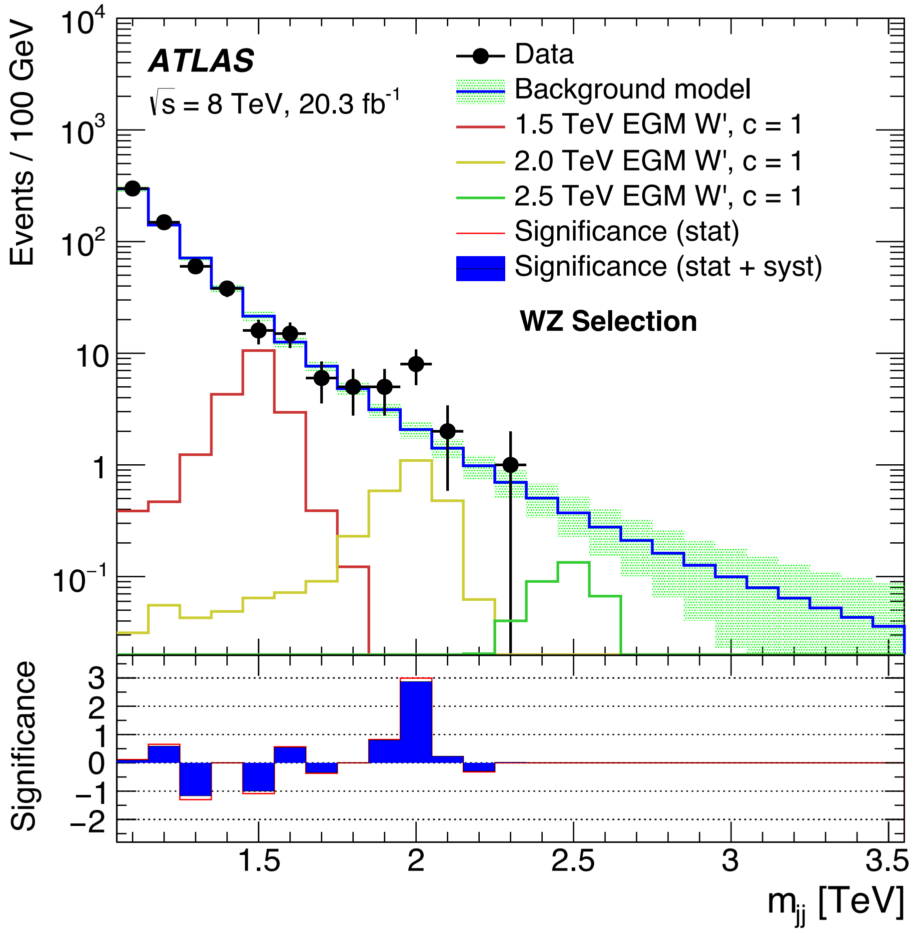
...he similar anomaly that got people very excited ... iboson bump that was seen by ATLAS and CMS at ... TLAS, and a 2-sigmaish thing in CMS. The ... gher-energy data - granted, the studied ... nergy is over 60% higher so any massive object ... the graph below.

The key to a possible understanding comes from the very same argument used to declare the `decease´of the anomaly:

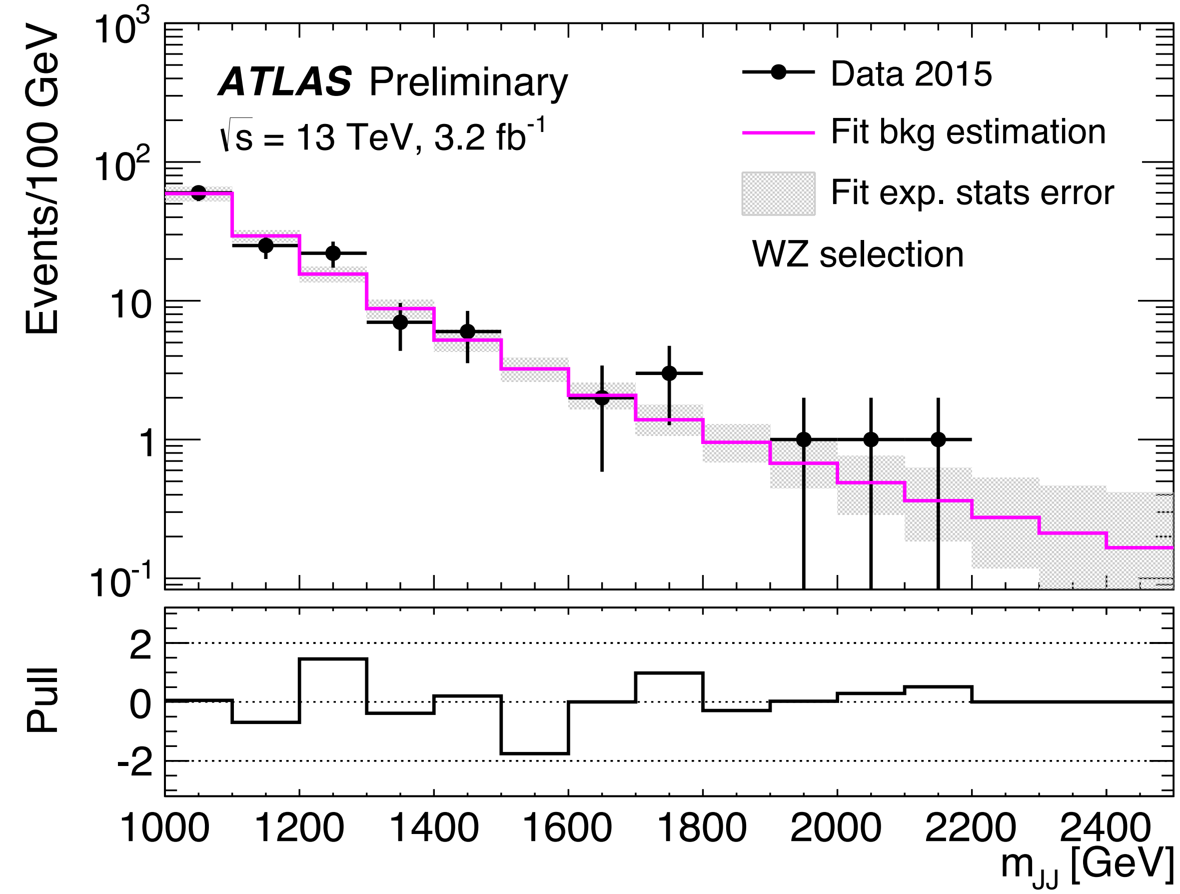
Why isn't the SM background much larger too in Run 2?

Evolution of ATLAS analyses

Run 1 20.3 fb^{-1}



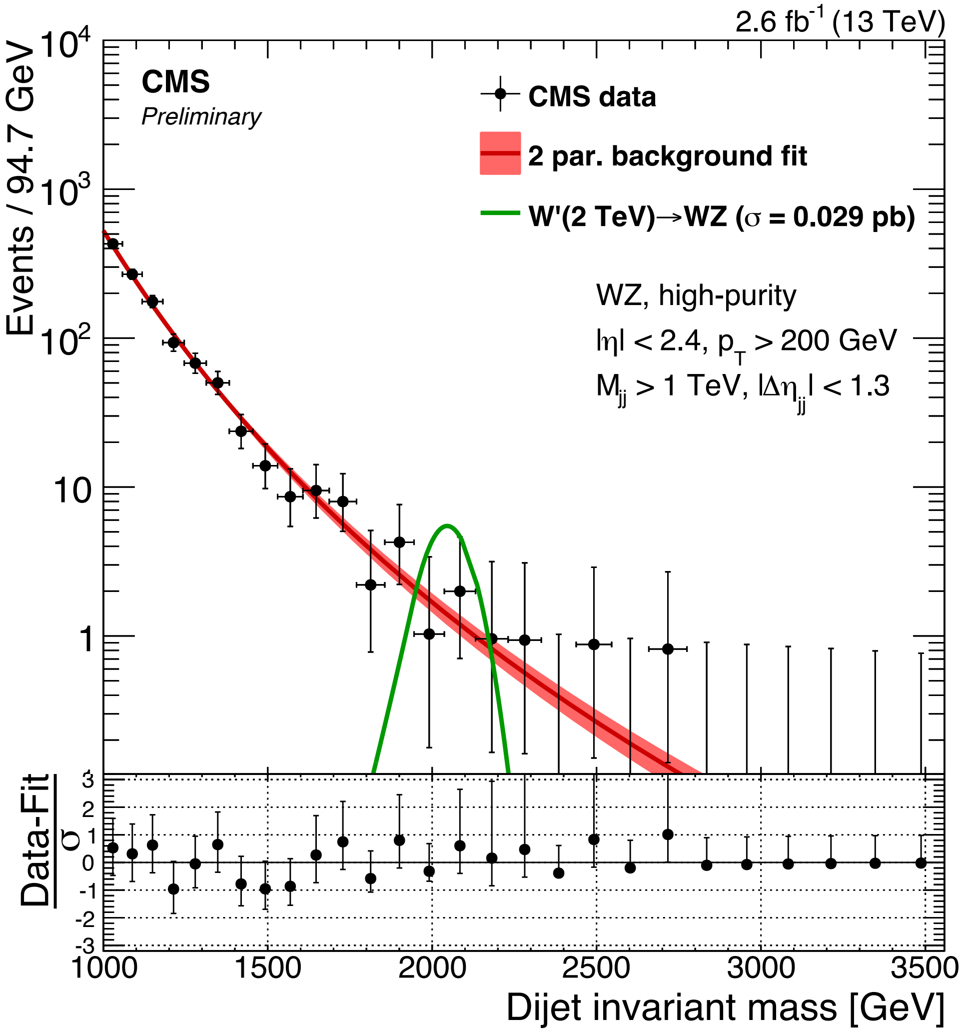
Run 2 3.2 fb^{-1}



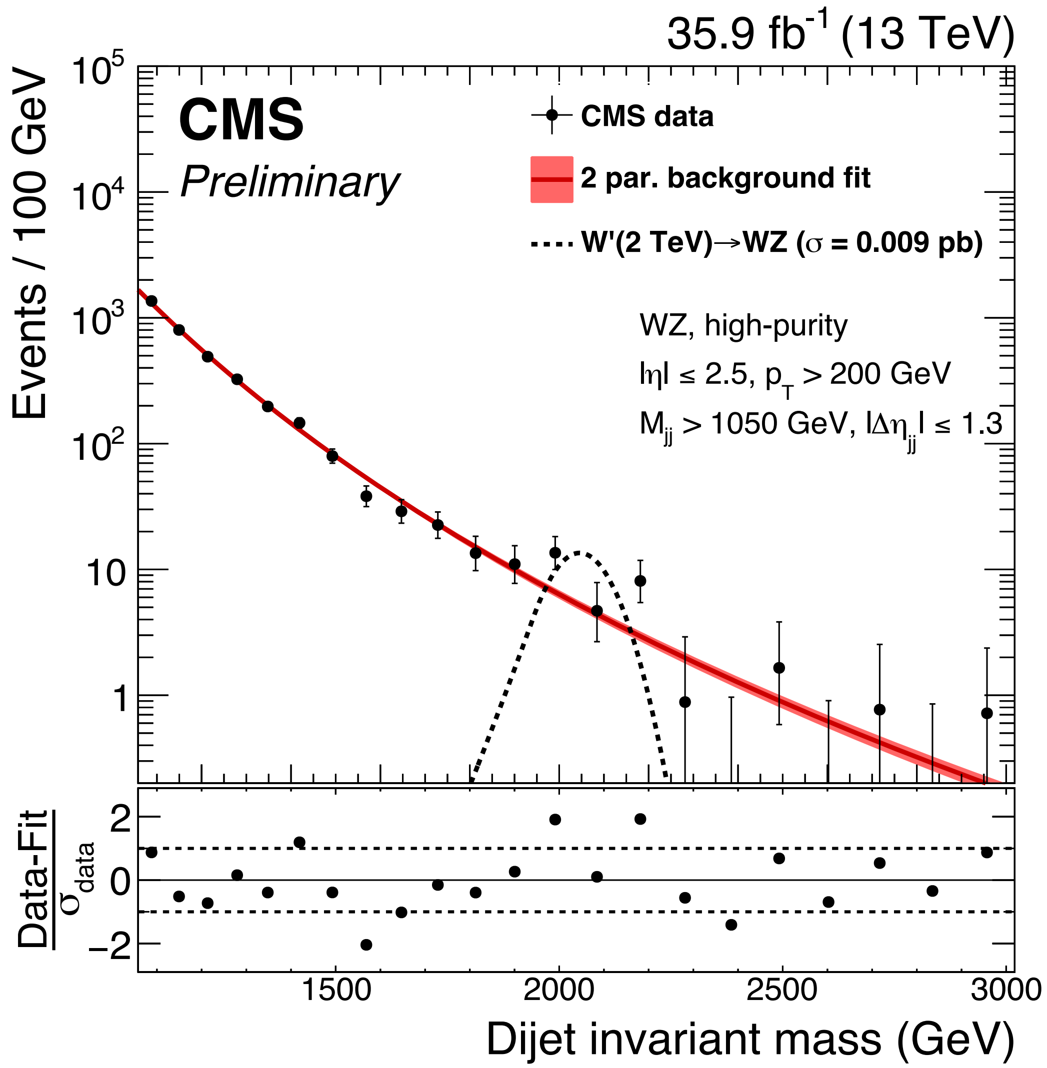
Background of ~ 2 events around 2 TeV should have become ~ 3–5 events, but is smaller than one event. Indeed, the new event selection is harsher.

Evolution of CMS analyses

Run 2 2.6 fb^{-1}



Run 2 35.9 fb^{-1}



The cut on the \`boson tagging´ variable τ_{21} to tag *W* and *Z* bosons changes from $\tau_{21} \leq 0.45$ to $\tau_{21} \leq 0.35$. The new event selection is much harsher. Background: 2 → 7 events with 14x more luminosity.

Why change?

ATLAS and CMS are looking for dibosons, the whole dibosons and nothing but dibosons.

Then, it makes sense — under that point of view — to optimise the expected sensitivity for dibosons when the luminosity is increased, by making the event selection more and more stringent.

The problem with that approach is twofold:

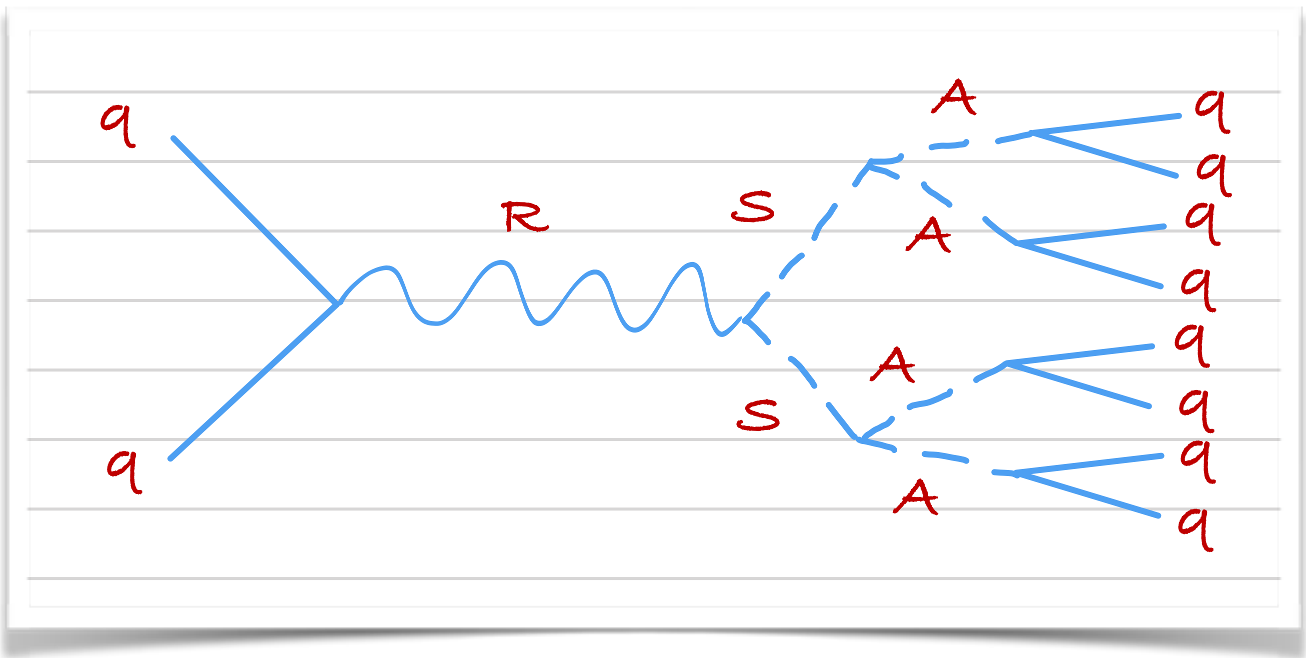
- With small statistics, one is not sensitive to wide bumps.
- Obviously the potential excess is not a diboson.

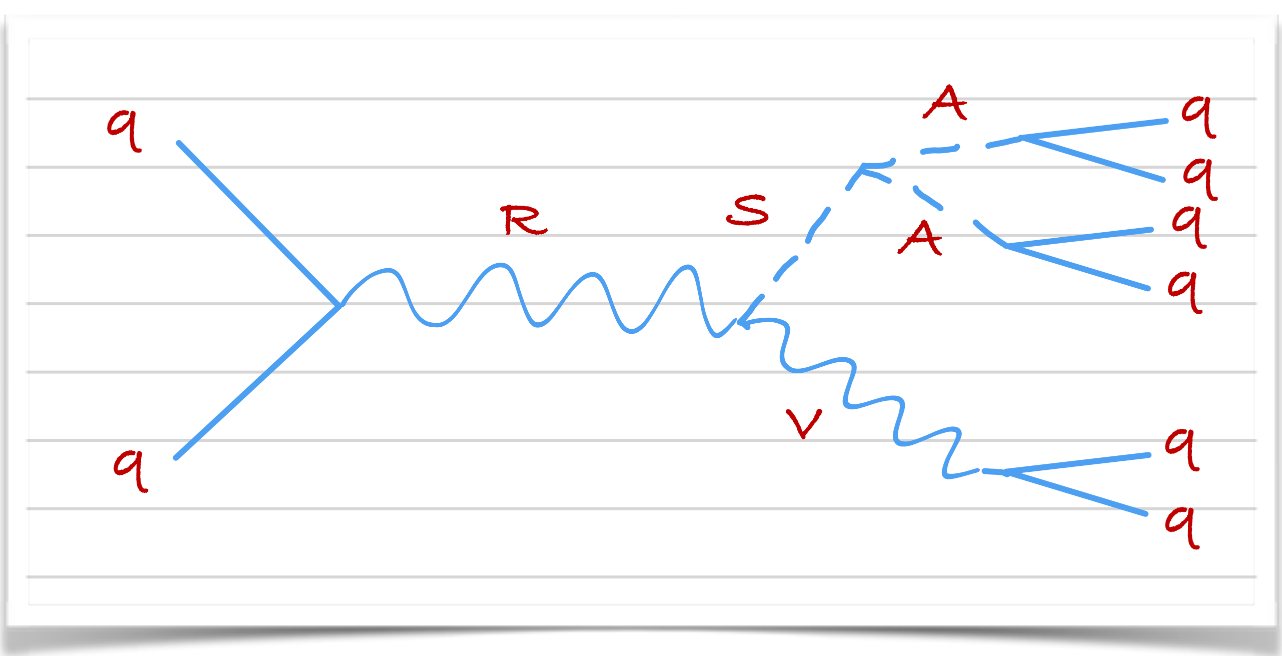
Moreover, the focus of LHC searches should be on exploring Nature, not on excluding benchmark models with the highest possible mass reach. With that ultimate goal, the strategy followed does not seem optimal.

Desperate hypothesis: may it be possible to have some new physics signal that is `seen´ by the `boson taggers´ y, D_2, τ_{21}, like QCD dijets?

Yes, and I call it `stealth boson´

Proof of principle!





JAAS 1705.07885

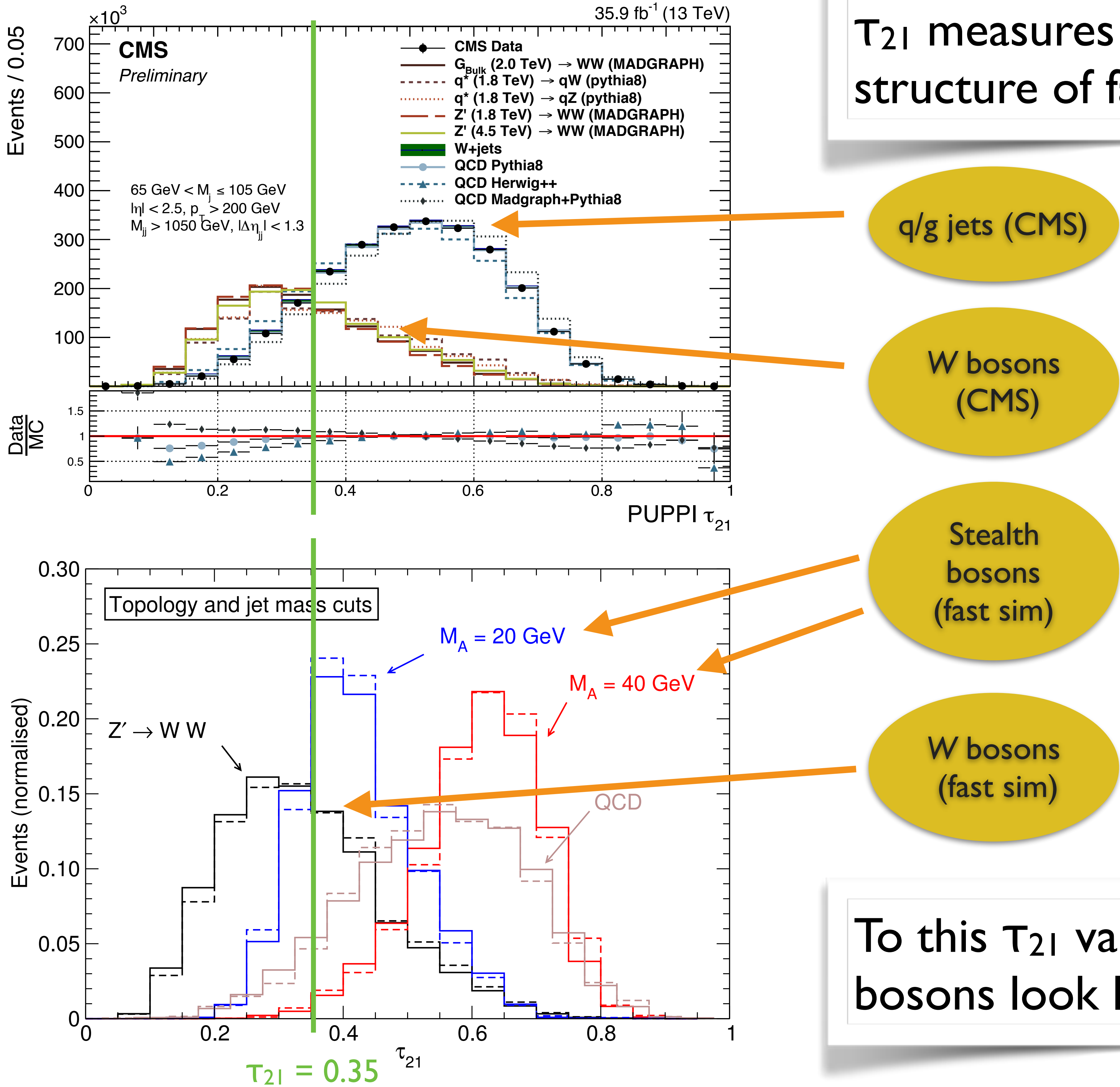
Boosted `stealth boson´ S with mass similar to M_W, M_Z and cascade decay

$S \to AA \to qqqq$

single merged jet.

[S = H_1, a new light scalar; A = light pseudo-scalar, for example]

Example: how do standard CMS analyses see stealth bosons?

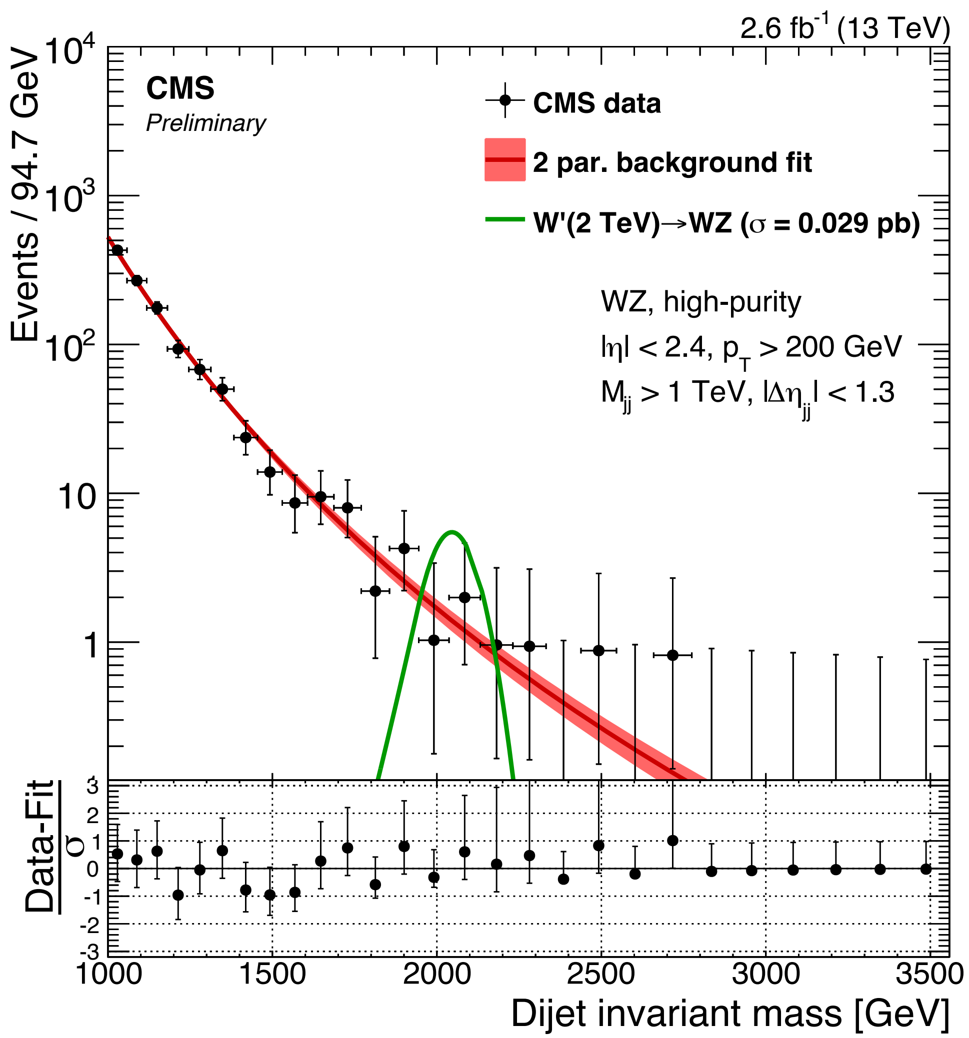


τ_{21} measures two-prong structure of fat jets

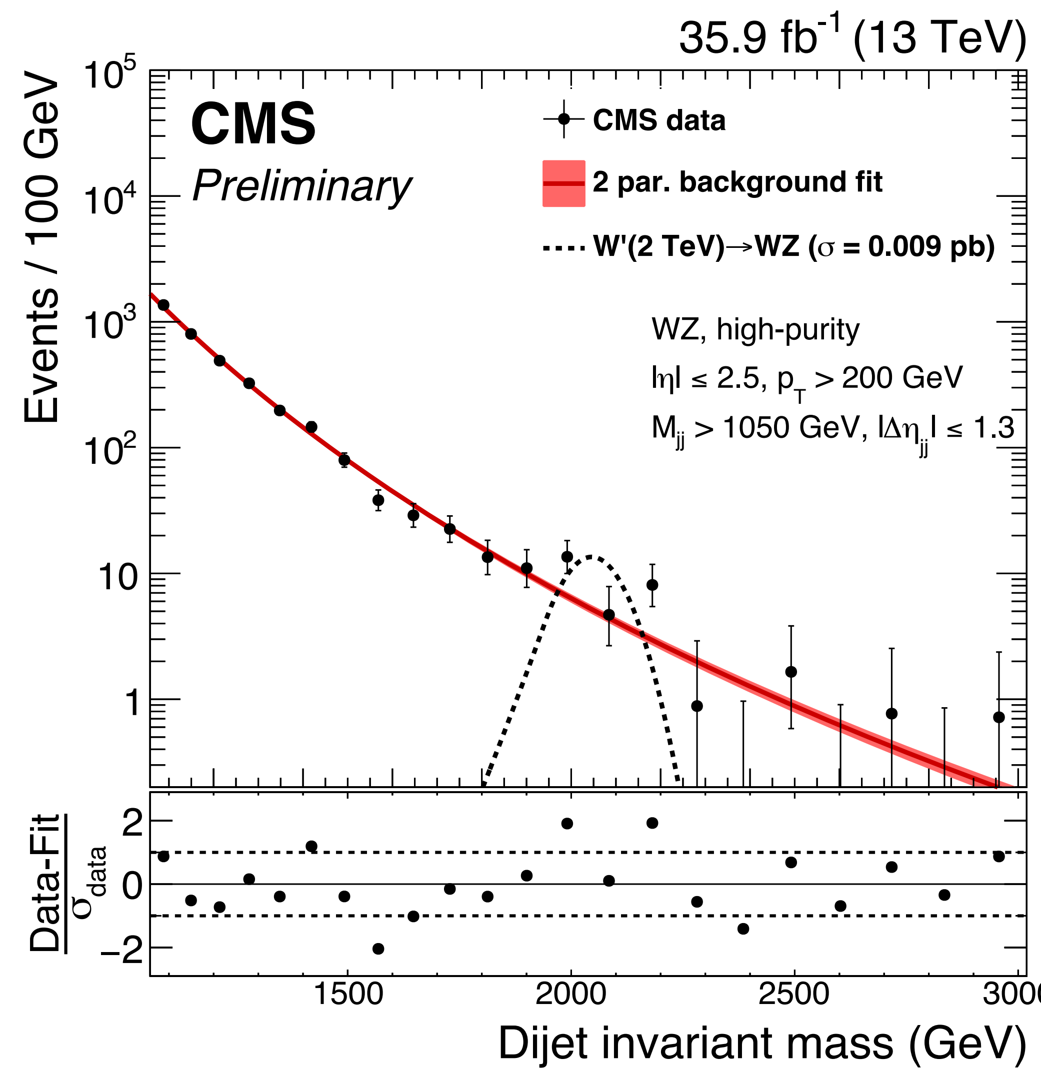
To this τ_{21} variable, stealth bosons look like q/g jets

Stealth bosons at work (1)

Run 2 2.6 fb^{-1}



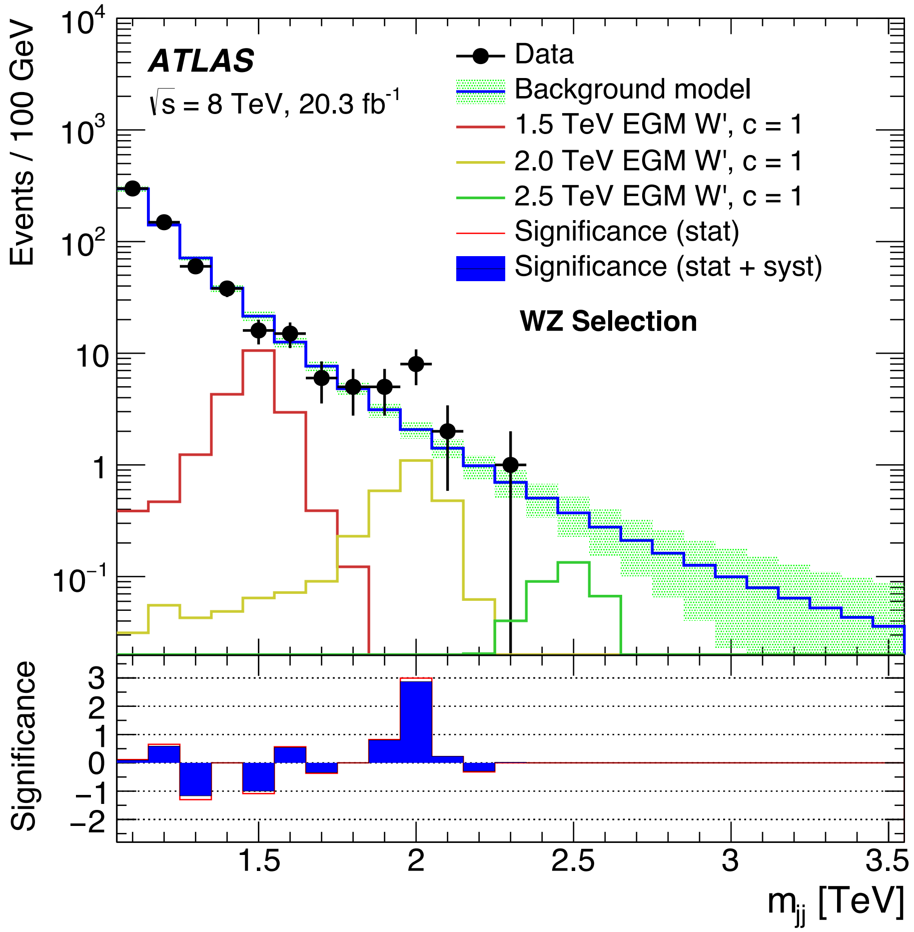
Run 2 35.9 fb^{-1}



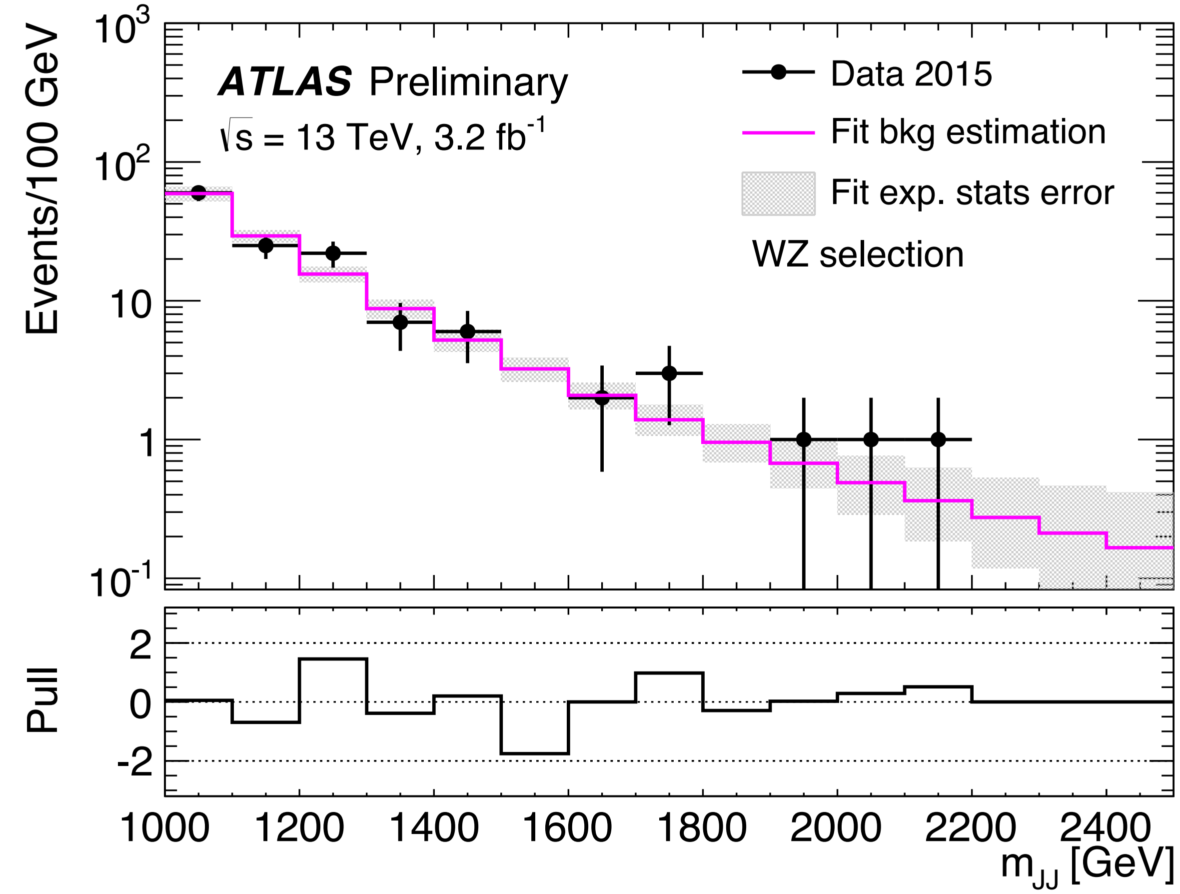
For $R \to SS$ signal, changing $\tau_{21} \leq 0.45$ to $\tau_{21} \leq 0.35$ reduces efficiency by a factor 1/10 or less [compared to 1/2 for dibosons].

Stealth bosons at work (II)

Run 1 20.3 fb^{-1}

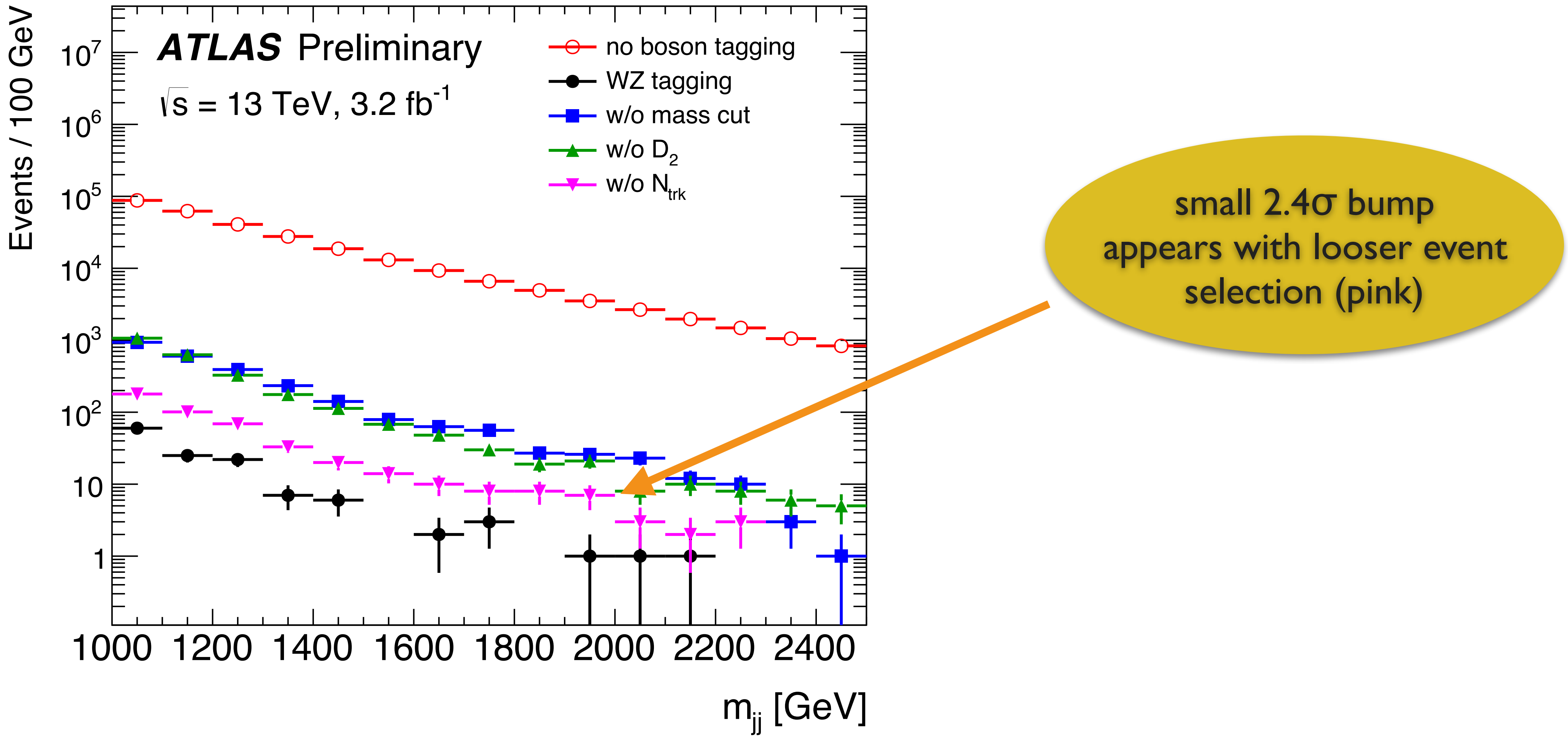


Run 2 3.2 fb^{-1}



For $R \to SS$ signal, the ATLAS Run 2 efficiency is 0.6x smaller than at Run 1 [compared to 1.15 larger for dibosons].

Stealth bosons at work (III)



For $R \to SS$ signal, the `loose selection´ has 1.5x - 7x larger efficiency than nominal selection [compared to 1.1x larger for dibosons].

Testing the excess: Proposals

- Measurements should be done with more statistics at least in some signal region. Revert to previous $\tau_{21} \leq 0.45$ cut and see what happens with more data.

- Use additional substructure variables: τ_{31}, τ_{41}, etc.

- Remove jet mass requirements in order to be more sensitive to new particles at the weak scale.

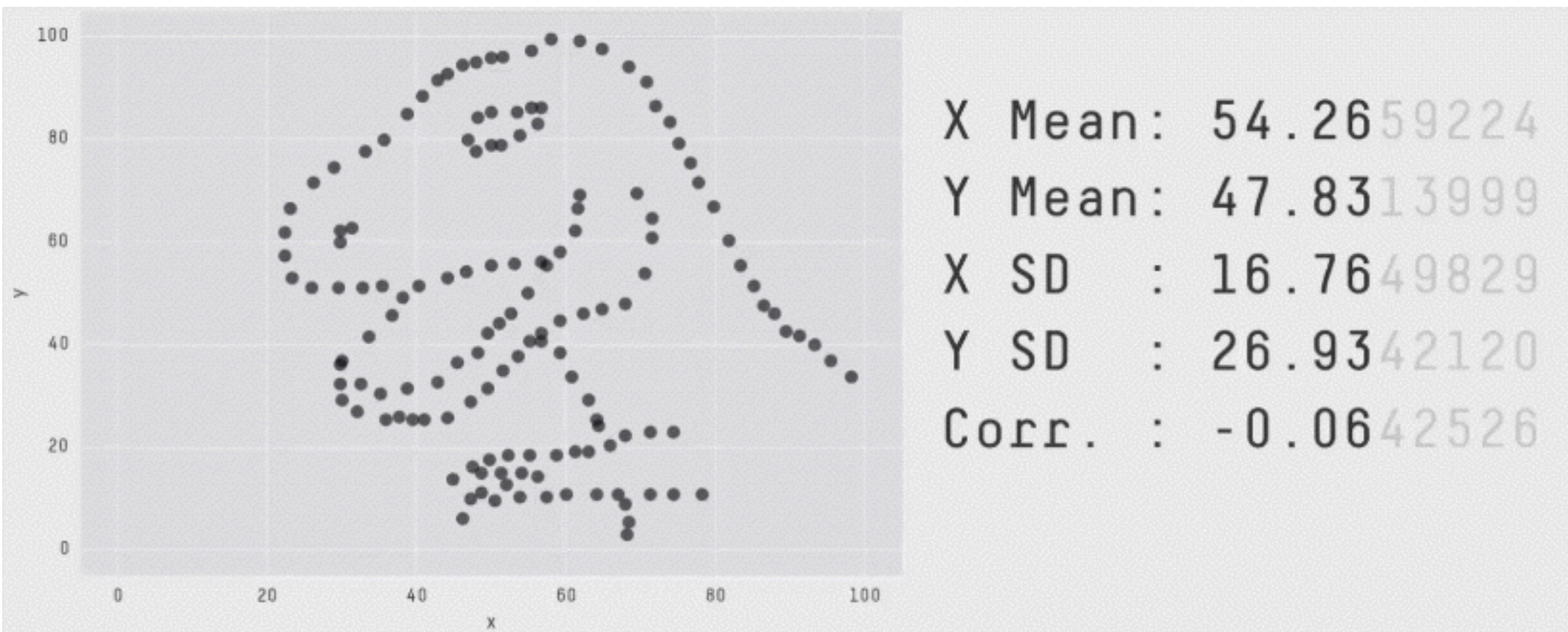
Summary — Physics aspects

- Five little bumps appear in hadronic diboson resonance searches by ATLAS and CMS at 8 and 13 TeV. I think it is too much for a coincidence.
- These searches are tricky because the background is not predicted from Monte Carlo. The background `calculation´ by a fit can absorb large wide bumps if statistics are small.
- Yet, the size of these small excesses seems inconsistent at first sight, given the PDF and luminosity scaling between analyses.
- As a last desperate proposal, one can think that new physics causing the excesses might look like the QCD background to current searches, which have increasing luminosity but also increasing background rejection.
- There is a proof of principle that this may be the case.

Summary — Philosophy aspects

- One does not need to believe in the 2 TeV excess to realise that there are serious shortcomings in some LHC searches, as shown in this talk.
- Any excess should be tested with more statistics, not with a different analysis. Such tests are model-dependent and inconclusive if the excess is not confirmed.
- The continuous optimisation of the sensitivity keeps statistics always low. This is not a good idea especially if the background is obtained by a fit, as one may miss \`features´ in data, such as wide bumps.
- The continuous optimisation of the sensitivity for specific models is also a bad idea if one wants to probe more general new physics that is not exactly one of the few simple benchmark models under study.
- And, to have an informed opinion, please, don't just read the headlines.

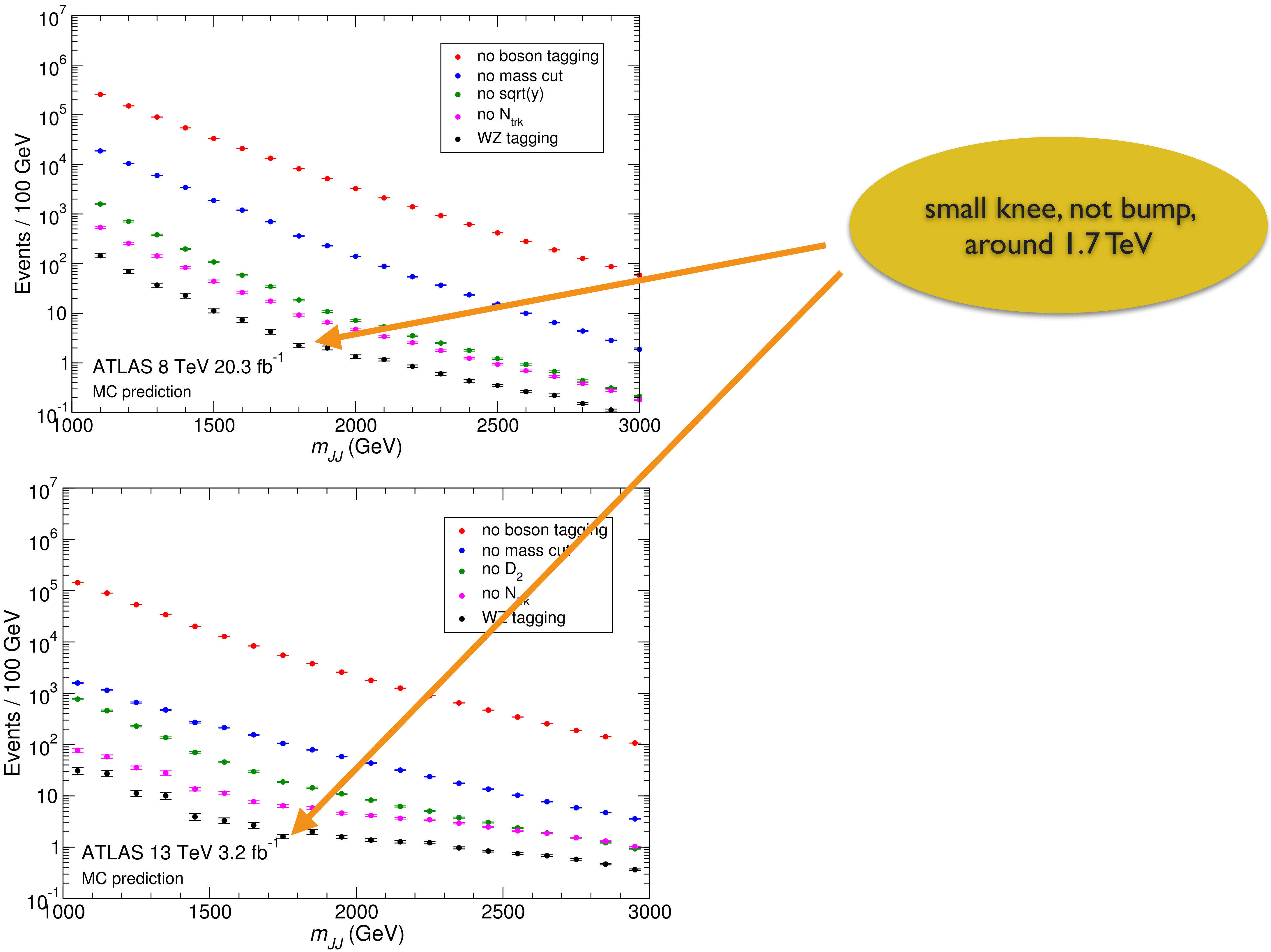
Thanks!



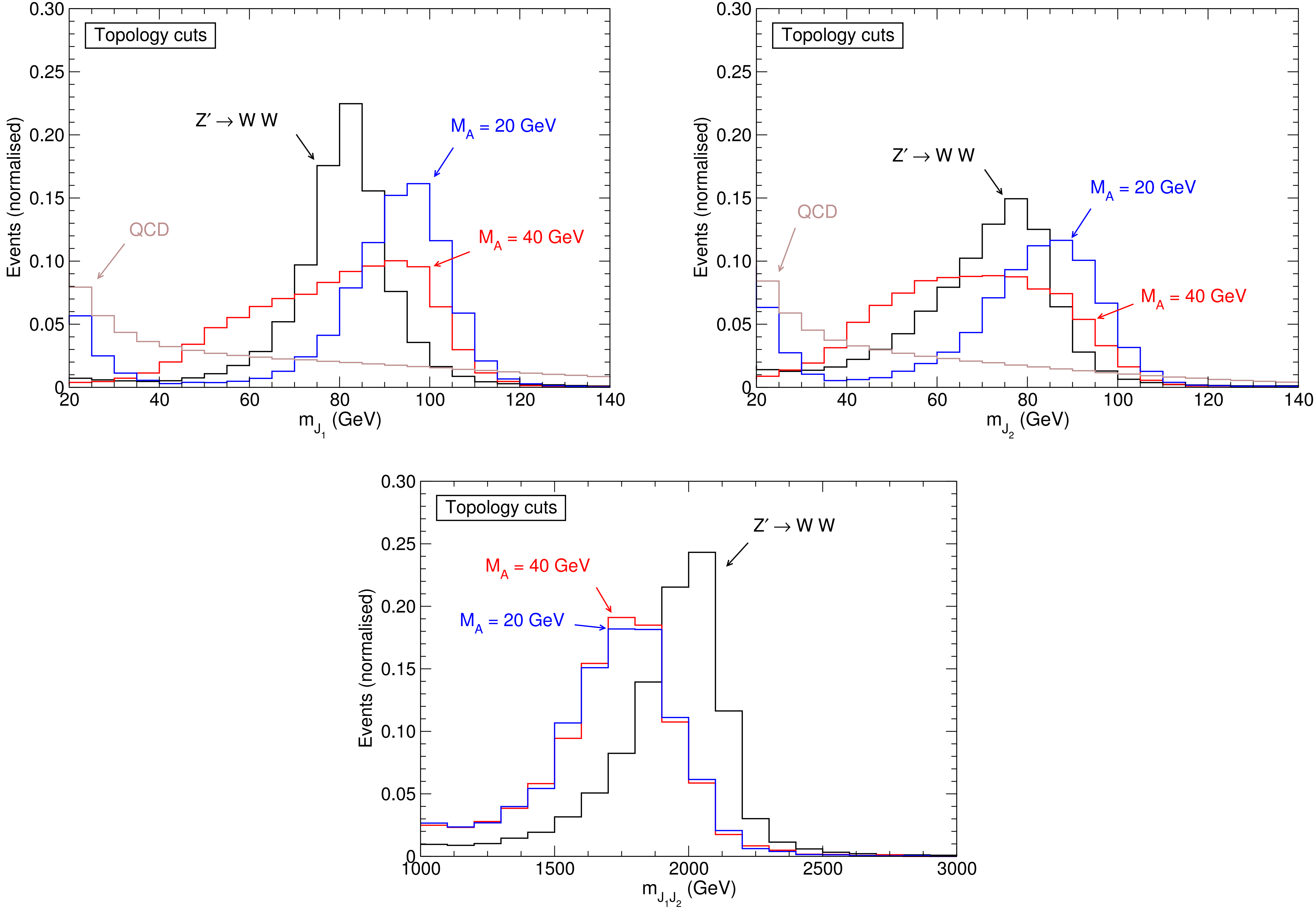
100
80
60
40
20
0
y
0
20
40
60
80
100
x
X Mean: 54.2659224
Y Mean: 47.8313999
X SD : 16.7649829
Y SD : 26.9342120
Corr. : -0.0642526

Extra!

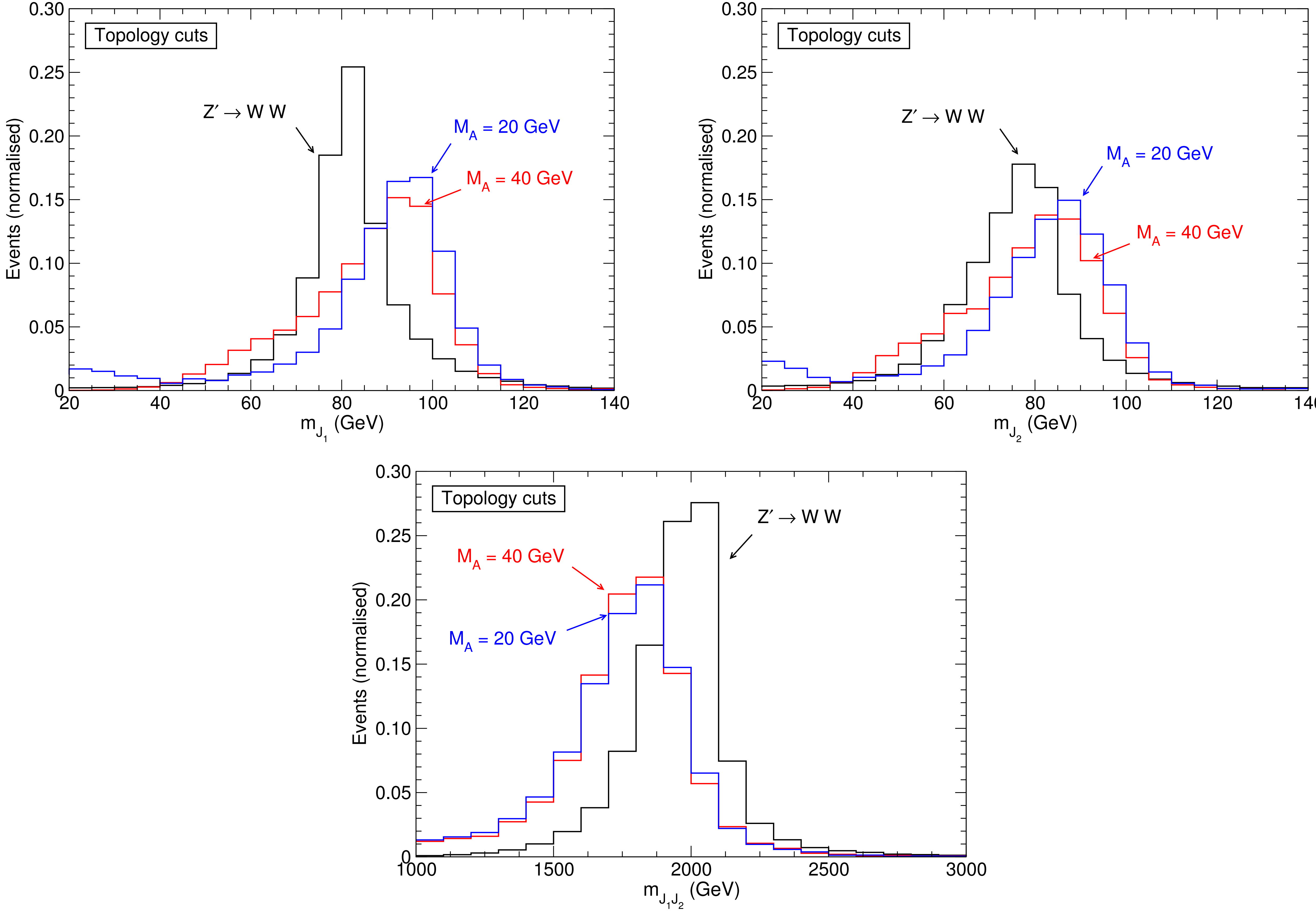
Background shaping?



Mass distributions — CMS

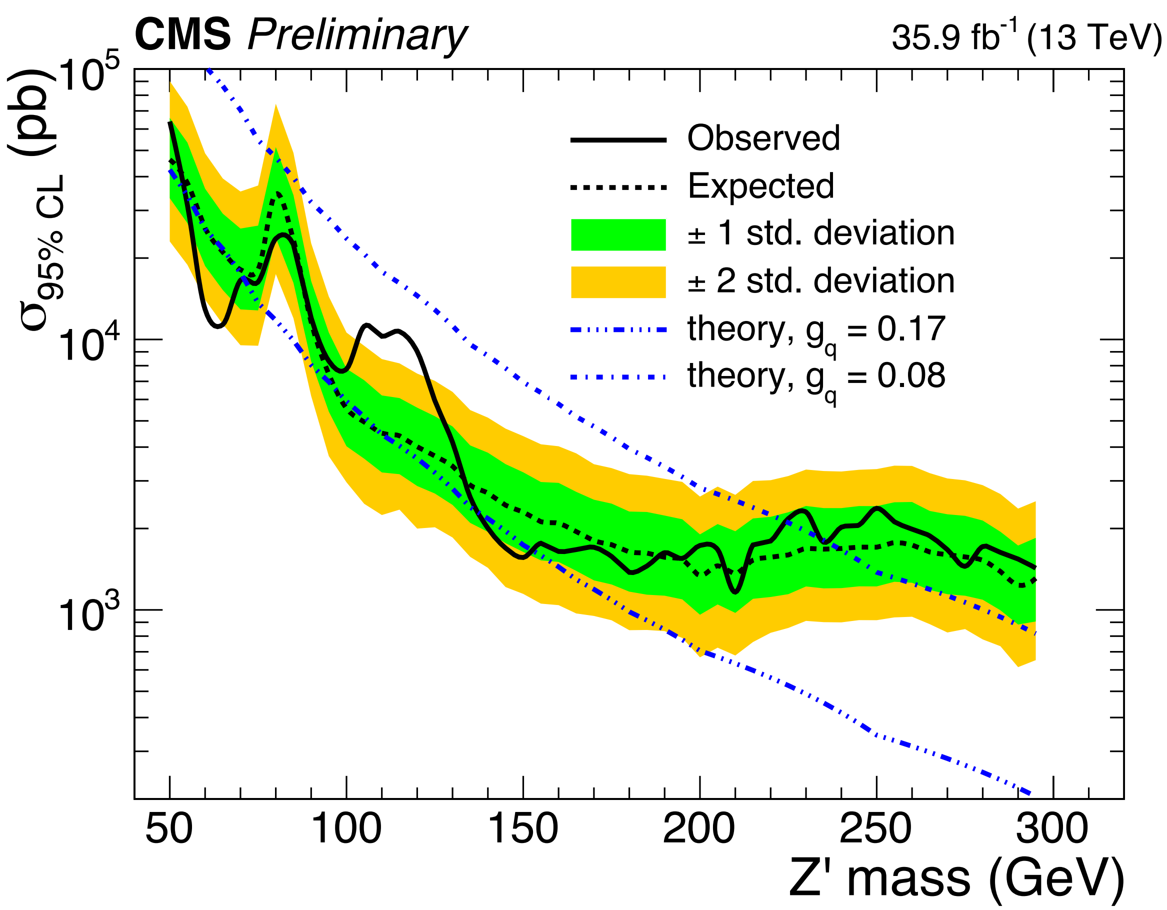


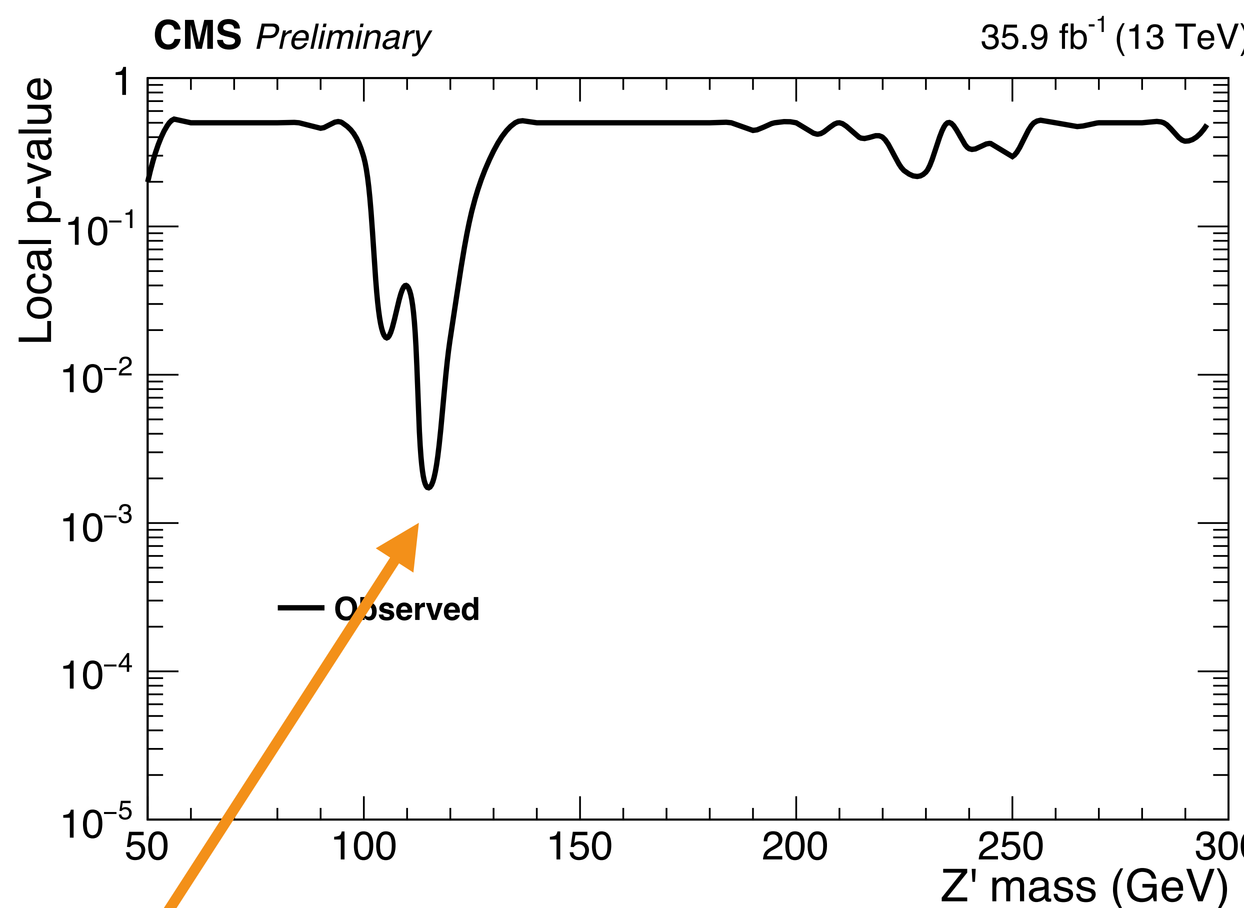
Mass distributions — ATLAS



Other hints? (I)

CMS search for light resonances decaying to *qq*, produced in association with a jet





2.9σ at 115 GeV

Other hints? (II)

High Energy Physics – Experiment

Localized 4σ and 5σ Dijet Mass Excesses in ALEPH LEP2 Four-Jet Events

Jennifer Kile, Julian von Wimmersperg-Toeller

(Submitted on 7 Jun 2017)

We investigate an excess observed in hadronic events in the archived LEP2 ALEPH data. This excess was observed unexpectedly at preselection level during data-MC comparisons of four-jet events. The events are clustered into four jets and paired such that the mass difference between the two dijet systems is minimized. The excess occurs in the region $M_1 + M_2 \sim 110$ GeV; about half of the excess is concentrated in the region $M_1 \sim 80$ GeV, $M_2 \sim 25$ GeV, with a local significance between 4.8σ and 5.6σ, depending on assumptions about hadronization uncertainties. The other half of the events are in a broad excess near $M_1 \sim M_2 \sim 55$ GeV; these display a local significance of $4.1 - 4.5\sigma$. We investigate the effects of changing the SM QCD Monte Carlo sample, the jet-clustering algorithm, and the jet rescaling method. We find that the excess is remarkably robust under these changes, and we find no source of systematic uncertainty that can explain the excess. No analogue of the excess is seen at LEP1.

Comments: 39 pages, 16 figures
Subjects: **High Energy Physics – Experiment (hep-ex)**; High Energy Physics – Phenomenology (hep-ph)
Cite as: arXiv:1706.02255 **[hep-ex]**
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