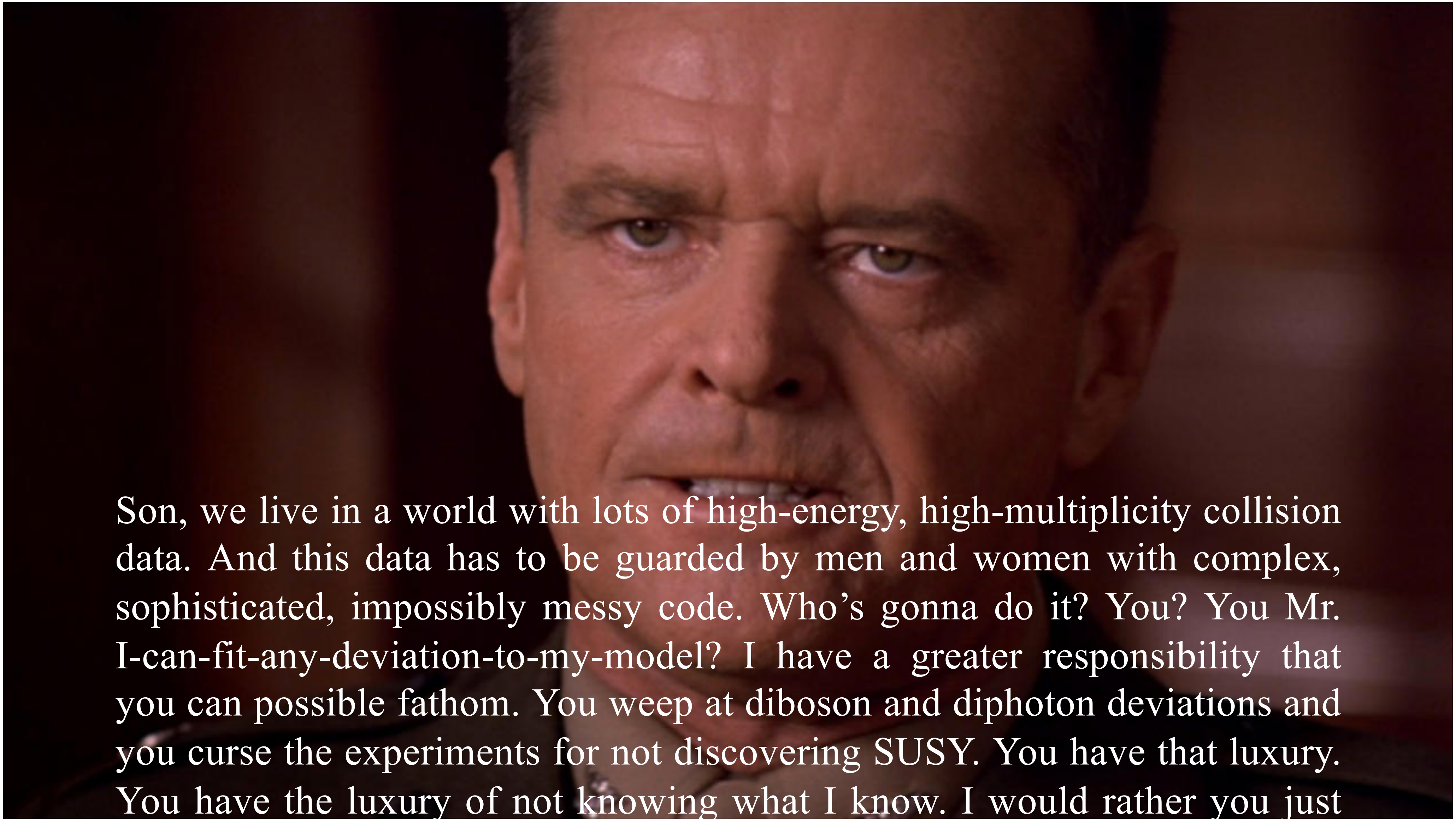
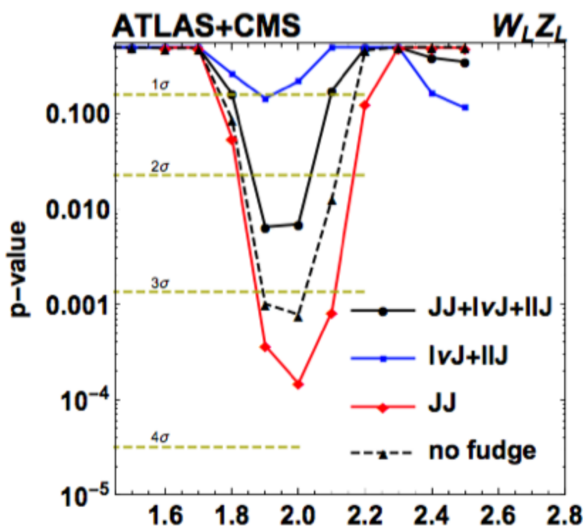
You can’t handle the 2016 results!

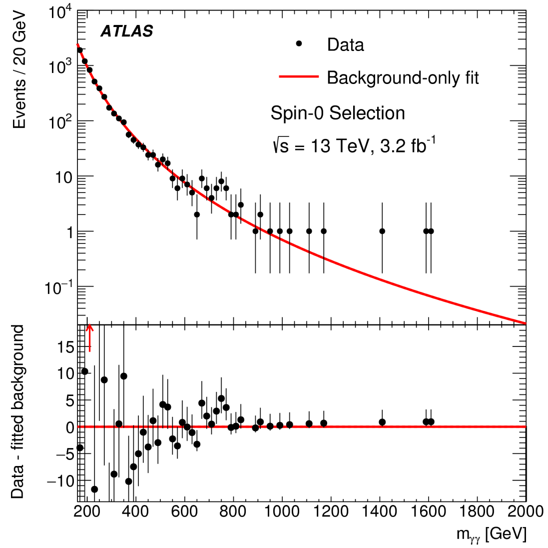


Son, we live in a world with lots of high-energy, high-multiplicity collision data. And this data has to be guarded by men and women with complex, sophisticated, impossibly messy code. Who’s gonna do it? You? You Mr. I-can-fit-any-deviation-to-my-model? I have a greater responsibility that you can possible fathom. You weep at diboson and diphoton deviations and you curse the experiments for not discovering SUSY. You have that luxury. You have the luxury of not knowing what I know. I would rather you just said thank you and went on your way. Otherwise, I suggest you pick up an application form and join one of the LHC experiments. Either way, I don’t give a damn what you think you are entitled to.

Bump Hunting at the LHC

An Experimentalist's Perspective





Christos Leonidopoulos

THE UNIVERSITY *of* EDINBURGH

"Holography, conformal field theories, and lattice"

Higgs Centre for Theoretical Physics , University of Edinburgh – June 2016

Disclaimer

I will only be discussing **public** ATLAS and CMS results today

The bulk of 2016 results from LHC are to be presented at ICHEP (August, Chicago)

4 July 2012

8 October 2013

Nobelprize.org
The Official Web Site of the Nobel Prize

Educational | Video

Home | Nobel Prizes and Laureates | Nomination | Ceremonies | Al

Nobel Prizes and Laureates

Physics Prizes | 2013

▼ About the Nobel Prize in Physics 2013

- Summary
- Prize Announcement
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- Advanced Information
- Popular Information
- Greetings
- Award Ceremony Video
- Award Ceremony Speech

▶ François Englert
▶ Peter Higgs

All Nobel Prizes in Physics
All Nobel Prizes in 2013

The Nobel Prize in Physics 2013
François Englert, Peter Higgs

The Nobel Prize in Physics 2013

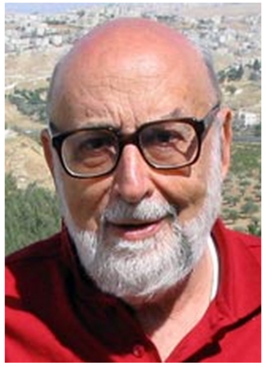


Photo: Pnicolet via Wikimedia Commons
François Englert

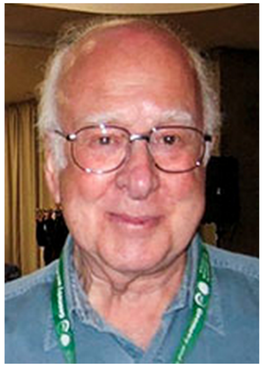


Photo: G-M Greuel via Wikimedia Commons
Peter W. Higgs

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

The Completion of the Standard Model

- We have managed to consolidate the SM
  - Detailed studies at the LHC ($\sqrt{s}$=7, 8, 13 TeV)

- Complements & completes a decades-long programme of work

- It works beautifully!


IS THAT ALL THERE IS ?

LHC:
The only approved collider physics programme for the next 20 years

LHC: Run 2 at $\sqrt{s} = 13$ TeV

Two axes of work:

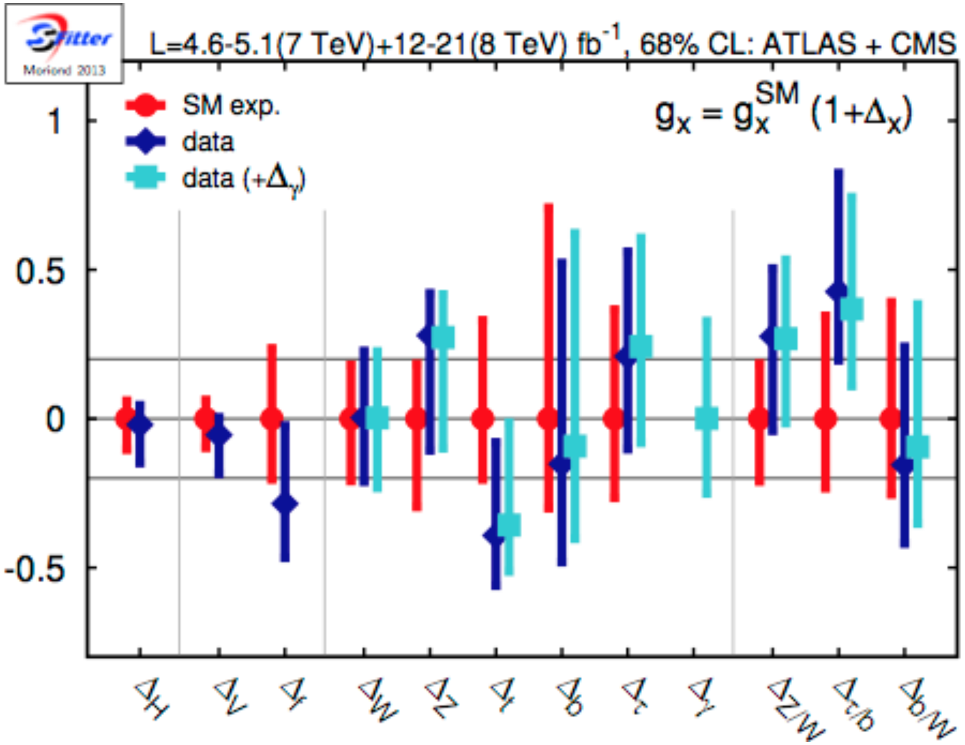
- Measurement of the Higgs properties
  - (Precise determination of) Couplings
  - Spin/CP: CP-odd component? CP violation?
  - Width: window into invisible matter

  - Huge momentum and detailed work plan

- Exotic (~~and SUSY~~) Searches
  - Exploit the increase in collision energy

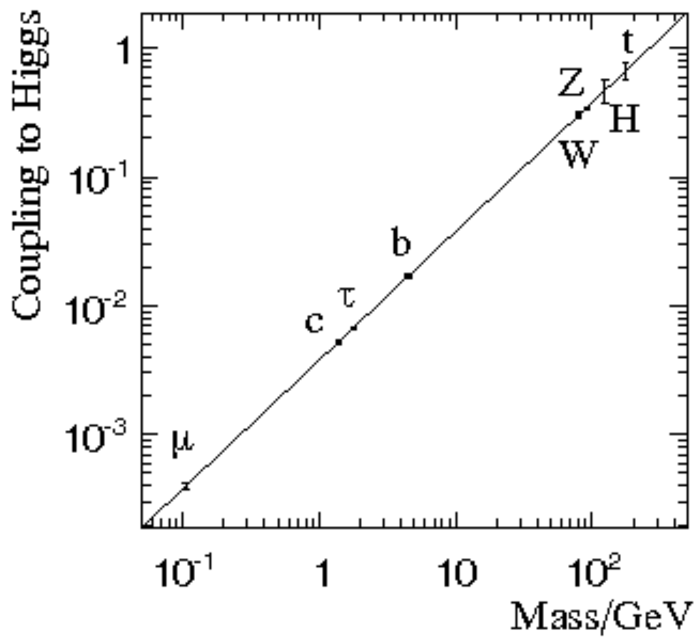
Why Higgs Physics?

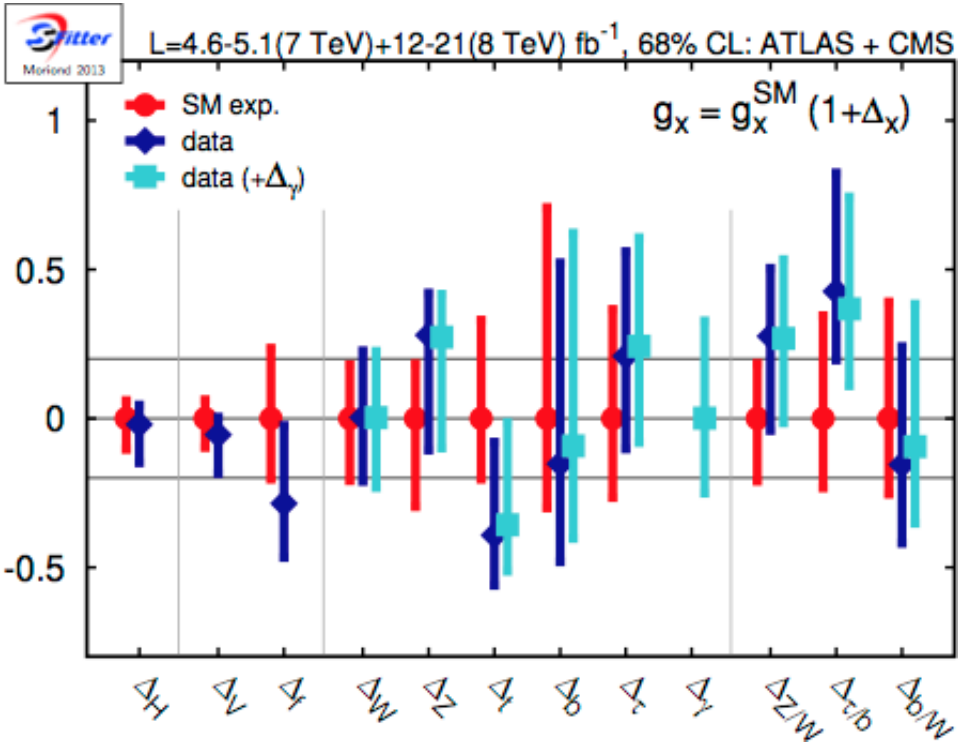
Measurement of Higgs properties



One way of looking for New Physics is via the measurement of Higgs couplings and their comparison to the SM predictions

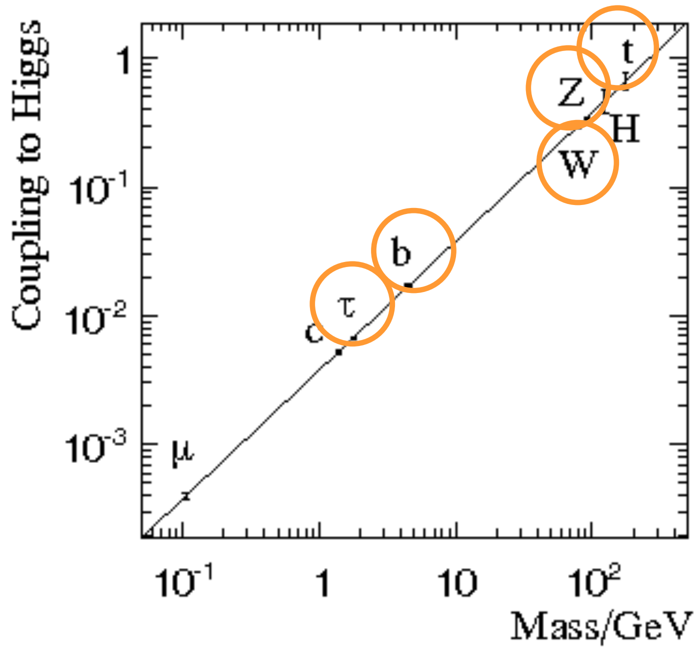
Measurement of Higgs properties

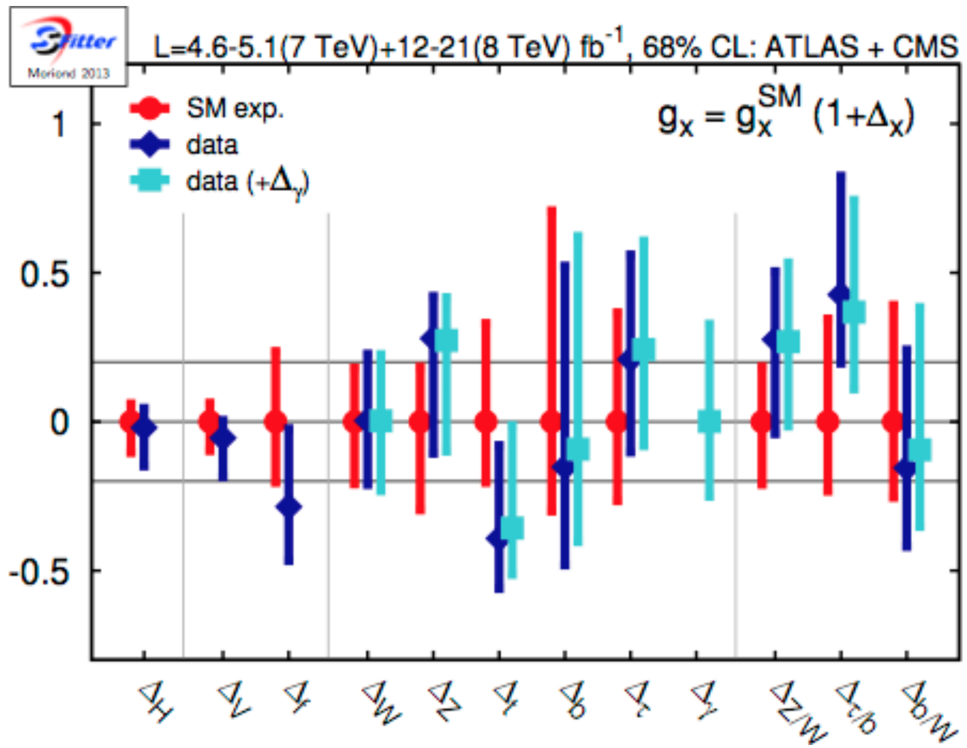




Measuring the Higgs decay rate to different final states is a stringent test of the EWK breaking mechanism & SM

Measurement of Higgs properties

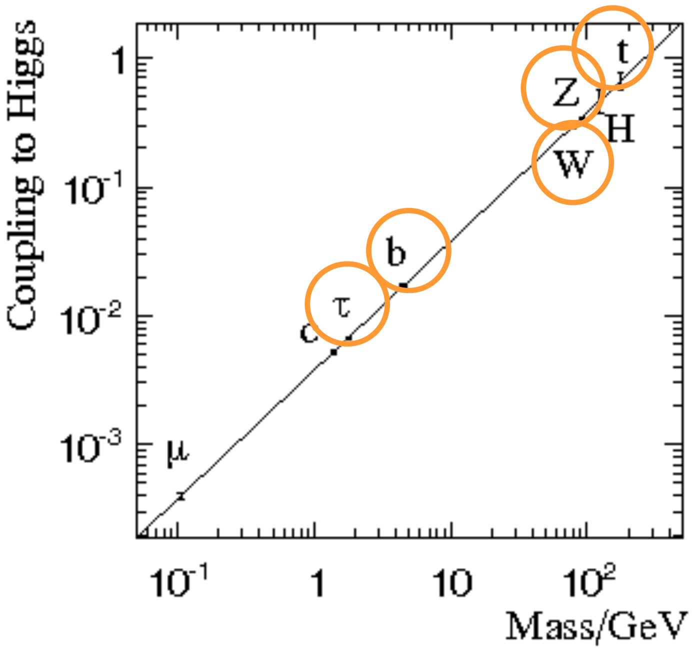


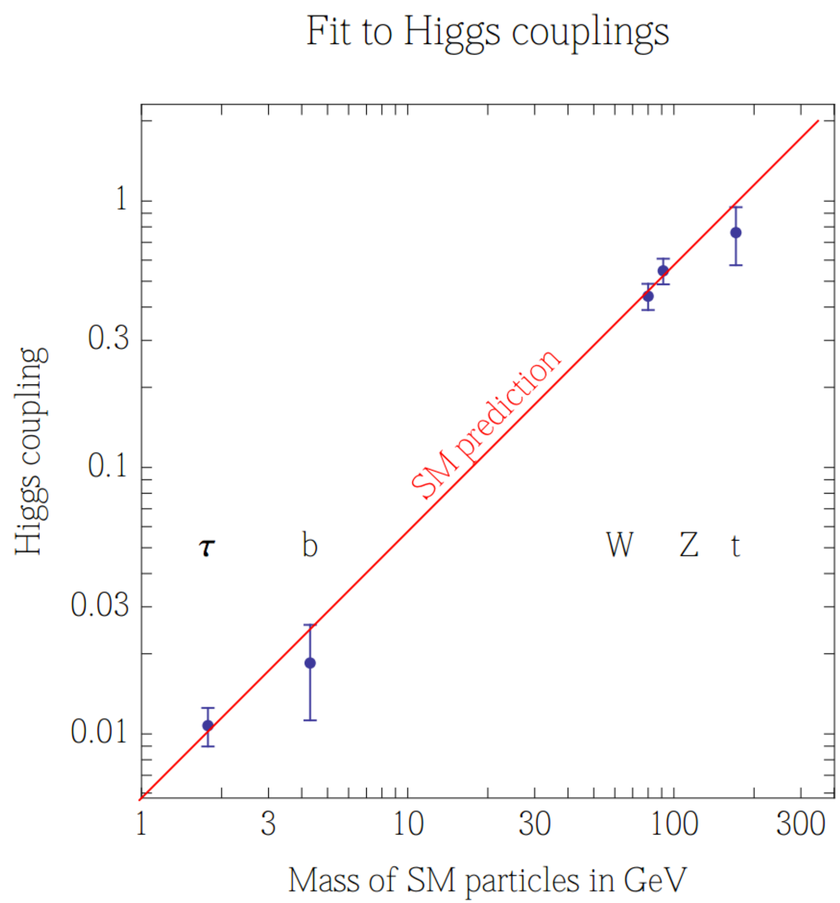


Measuring the Higgs decay rate to different final states is a stringent test of the EWK breaking mechanism & SM

Measurement of Higgs properties

P.P. Giardino et al: arXiv:1303.3570





Measuring the Higgs decay rate to different final states is a stringent test of the EWK breaking mechanism & SM

"Nearly impossible to reproduce by accident"
Guido Altarelli

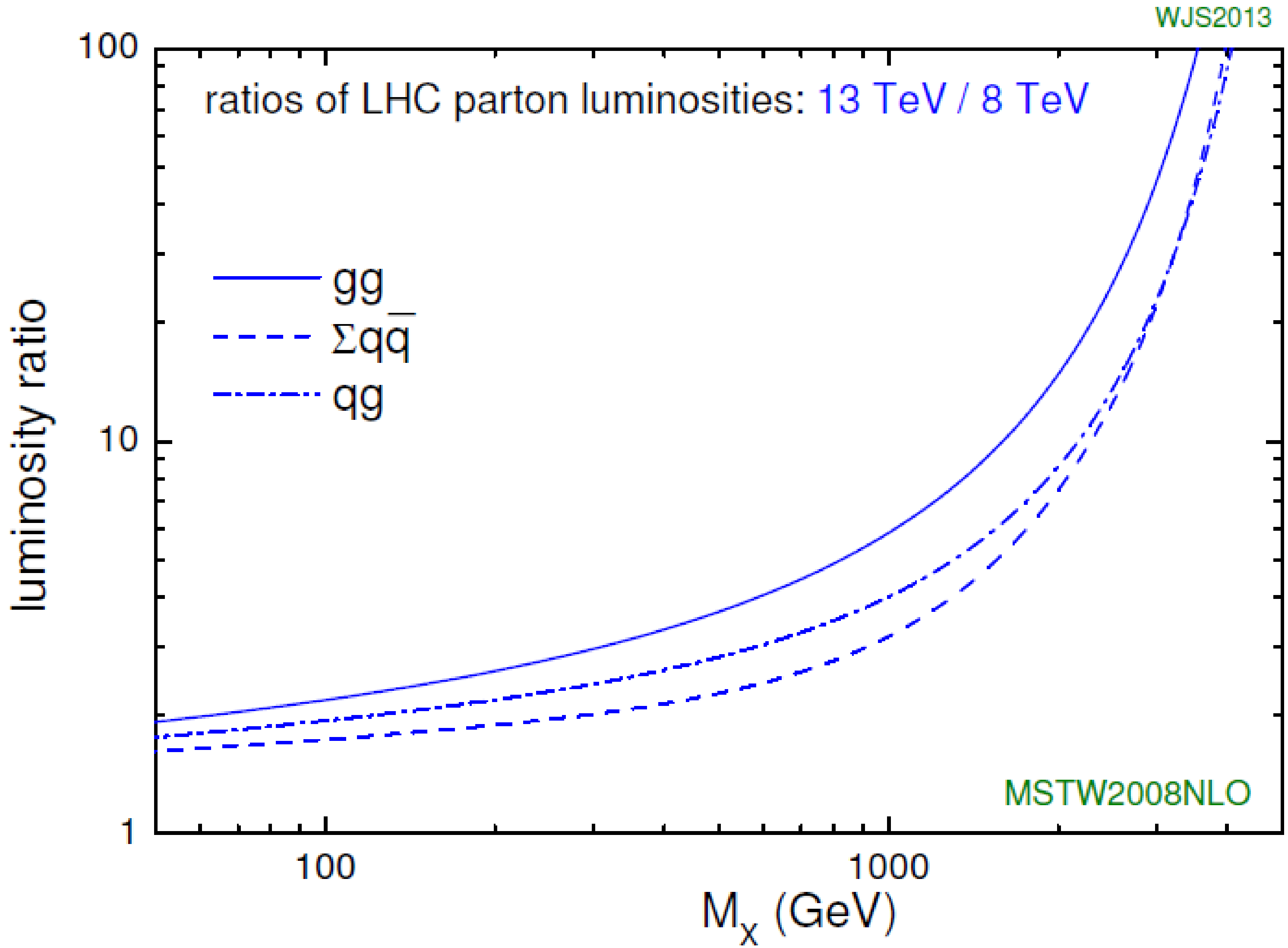
Is Higgs the answer?

(On the measurement of Higgs properties and couplings) Important & nice to see progress, but “this question carries a similar potential for surprise as a football game between Brazil and Tonga”

http://resonaances.blogspot.jp/2012/10/higgs-new-deal.html

Why Searches?

Parton Luminosity Ratio: LHC13/LHC8



"You can run but you cannot hide"

Exotic Searches: Personal Philosophy

- Try to be as agnostic as humanly possible
- Try to calibrate your “excitement-meter” with common sense

Three personal rules on deviations at the LHC:
- Persistence: does it survive time & more data?
- Does it appear on both experiments?
- Does it appear in more than one channels?

Exotic Searches: LHC results

Will be discussing (mostly) "di-boson" searches today

- VV
- VH
- HH
- $\gamma\gamma$

where $V = W, Z$ is a vector boson decaying hadronically or leptonically

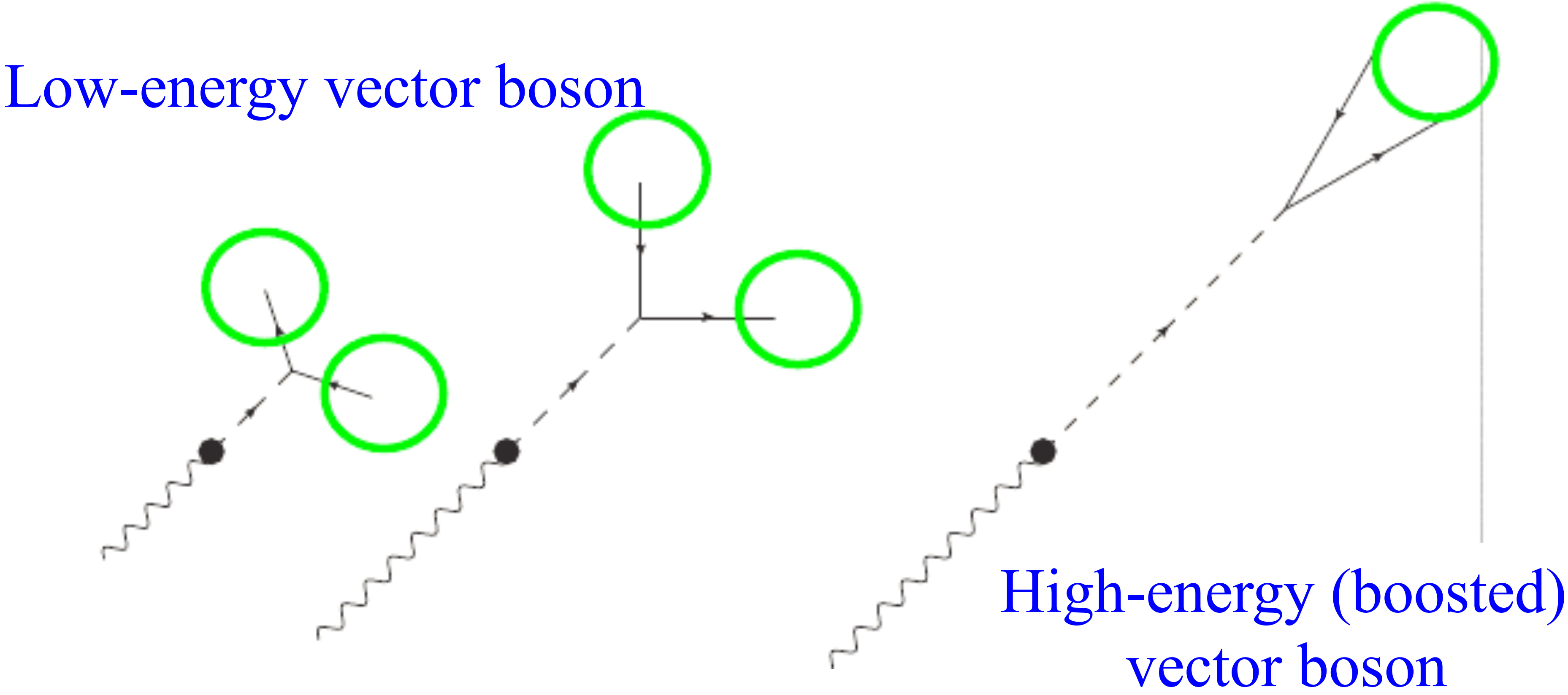
Bonus searches:

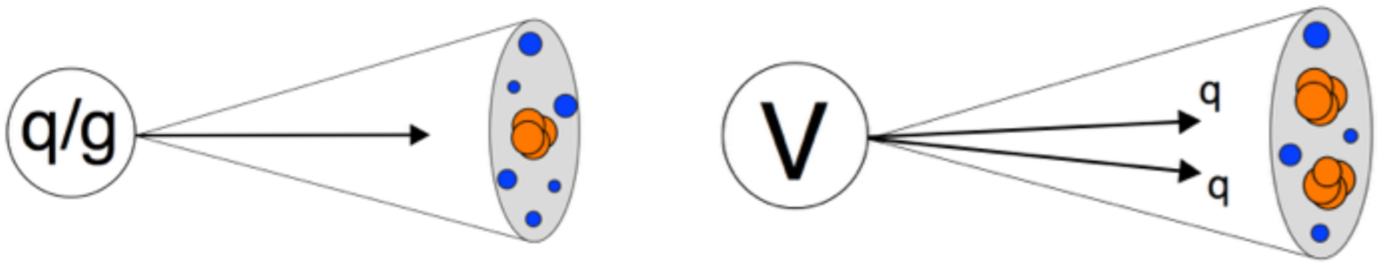
- $q\bar{q}$ (dijets)
- W_R/N_R

Will *not* be discussing dileptons:

- $\ell\nu$, $\ell\ell$

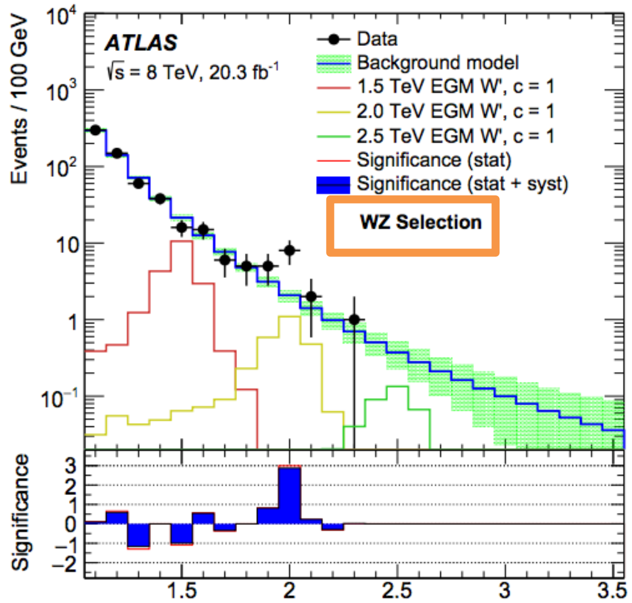
Boosted hadronic vector bosons

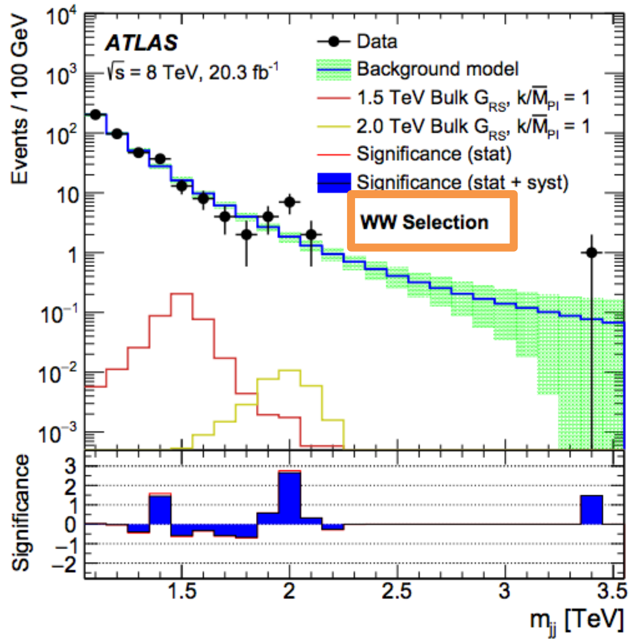




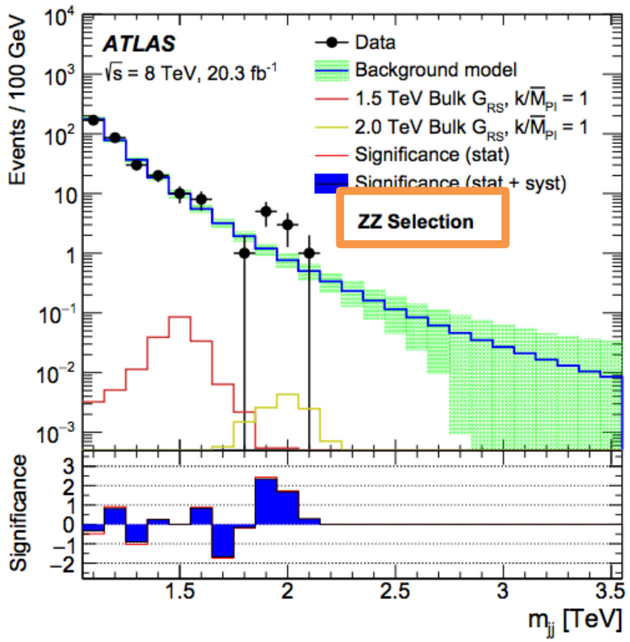
Run-1 Searches

Run-1: The "ATLAS" dijet diboson excess



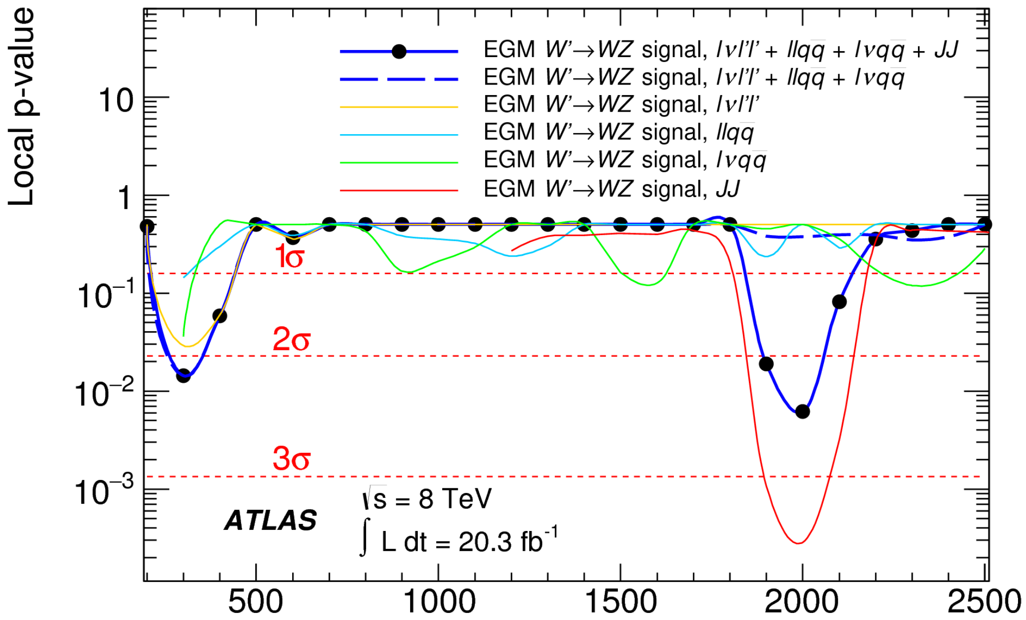


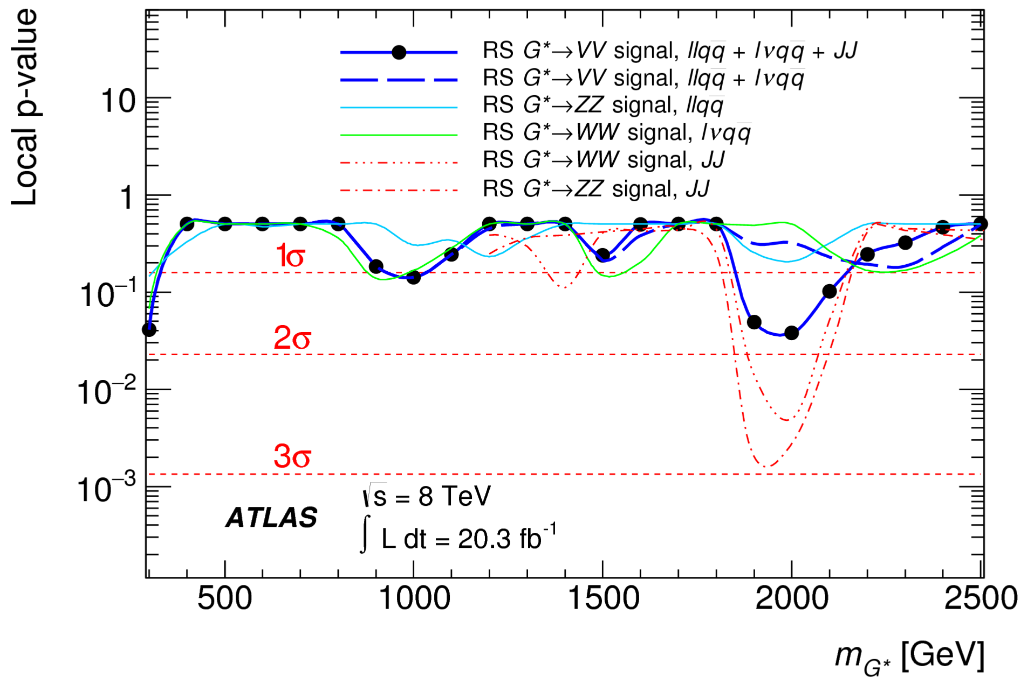
arxiv1506.00962
JHEP12(2015)055



- Deviations of 3.4 σ (WZ), 2.6σ (WW) and 2.9σ (ZZ) at 2 TeV (local significance)
- _Not_ statistically independent (W/Z tagging has overlaps)
- Global significance: 2.5σ (after LEE correction)

Run-1 ATLAS dibosons: other channels?





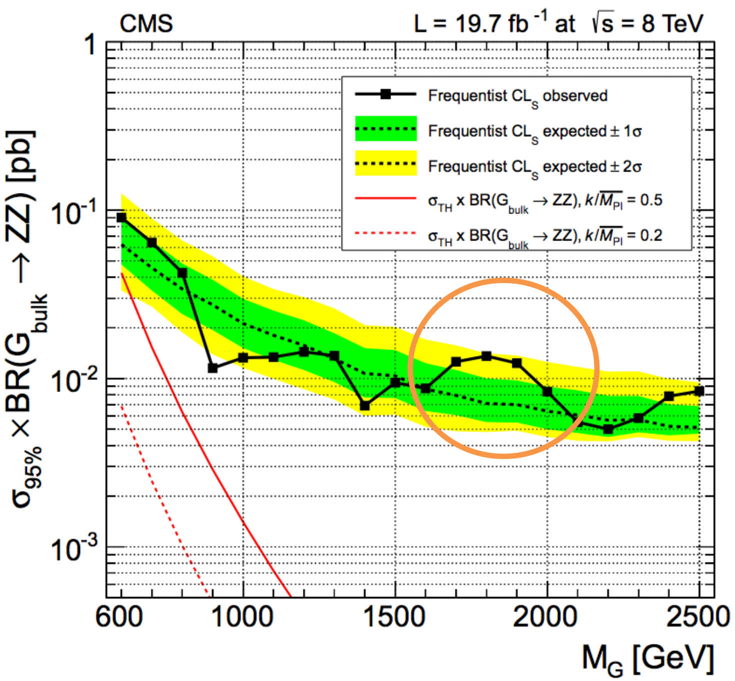
arxiv:1512.05099
Phys. Lett. B 755 (2016) 285

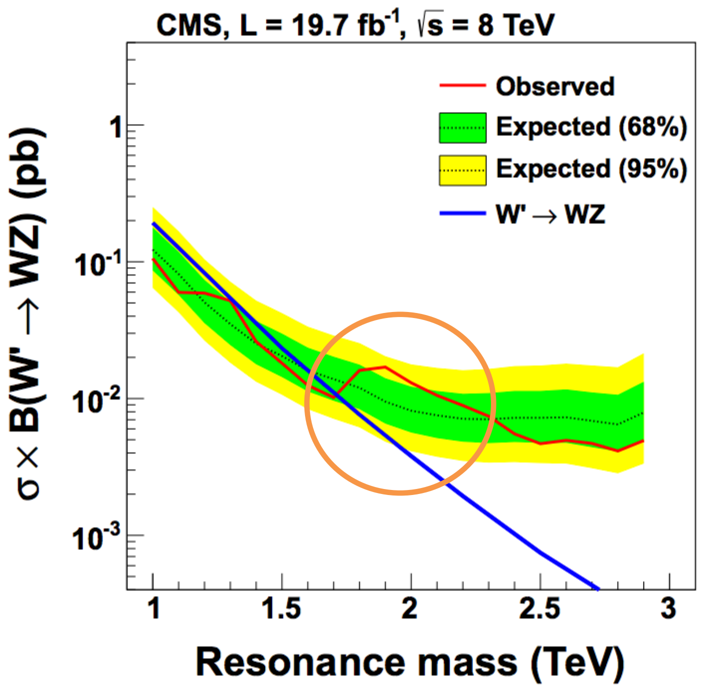
W'-like (spin-1) interpretation

RS G*-like (spin-2) interpretation

No interesting deviation in non-hadronic channels

Run-1 CMS dibosons





RS G*-like (spin-2) interpretation

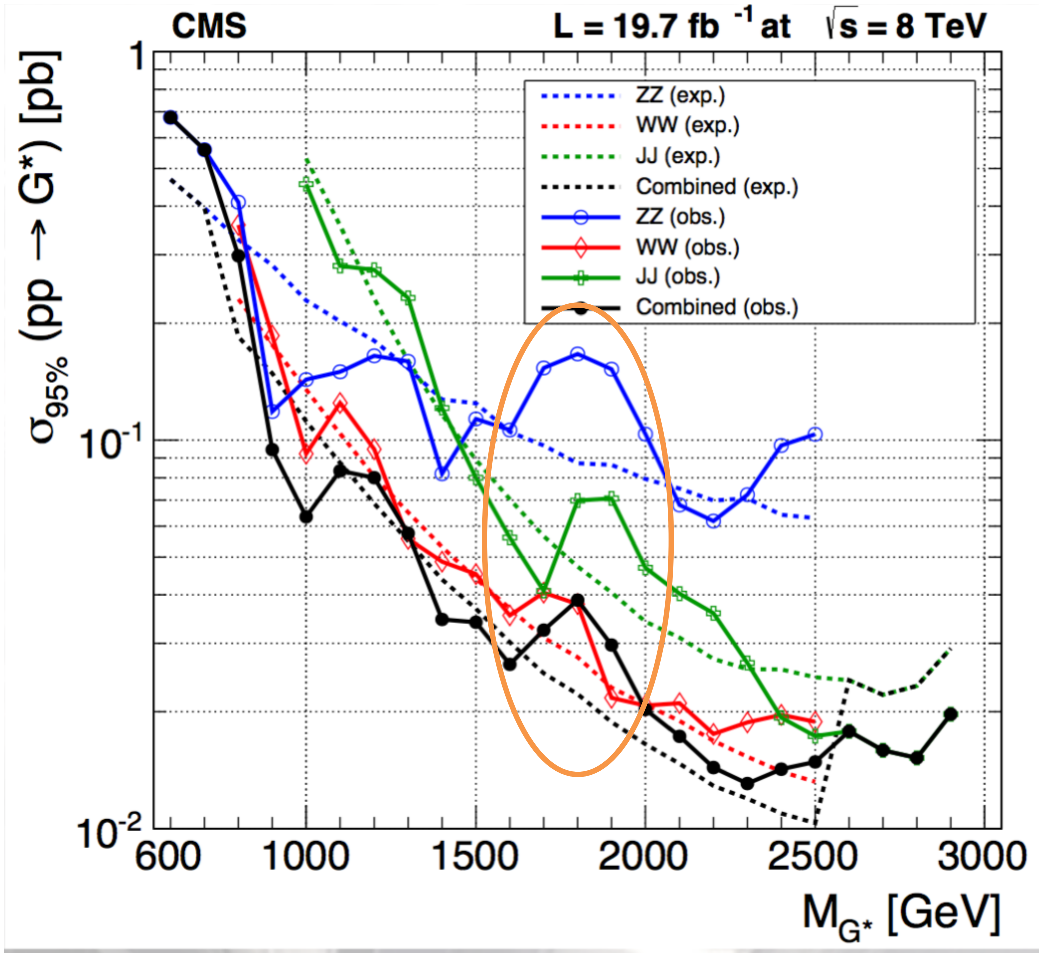
arxiv1405.3447
JHEP 08 (2014) 174

W'-like (spin-1) interpretation

arXiv:1405.1994
JHEP08(2014)173

Deviations more modest than in ATLAS, but: at same mass and in several channels. Coincidence?

Run-1 CMS dibosons



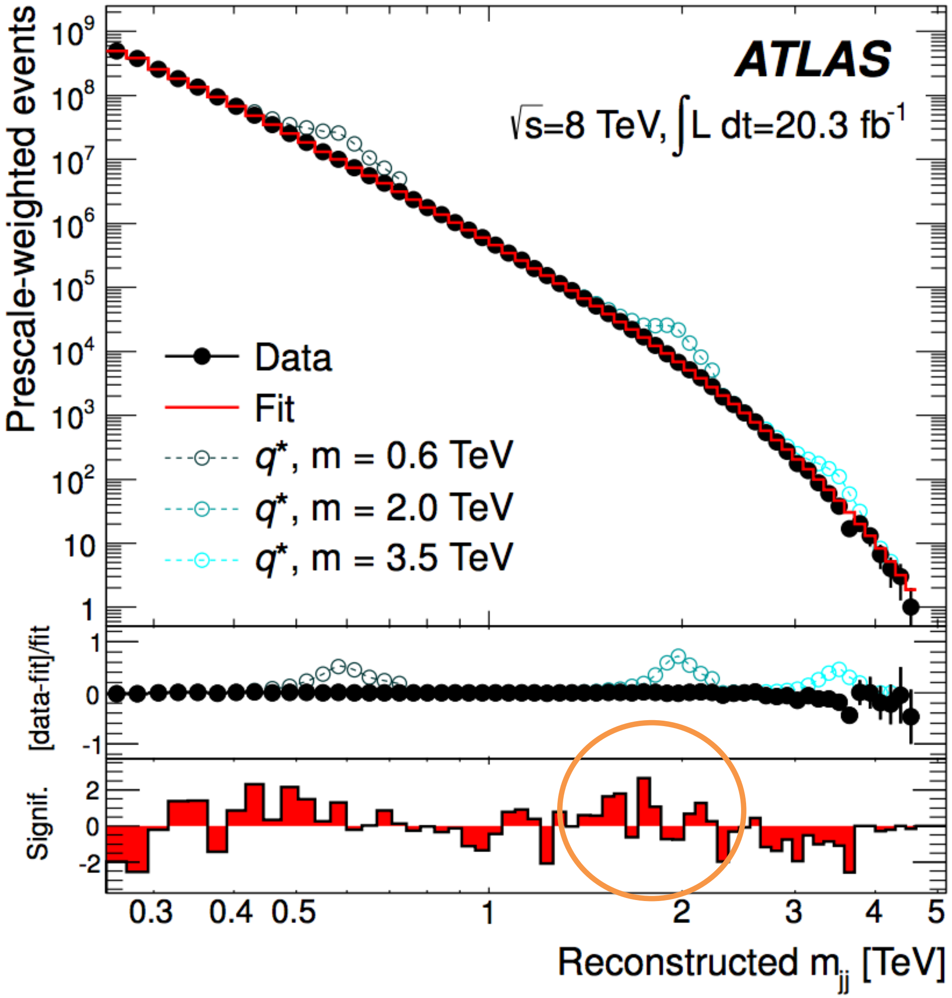
arxiv1405.3447
JHEP 08 (2014) 174

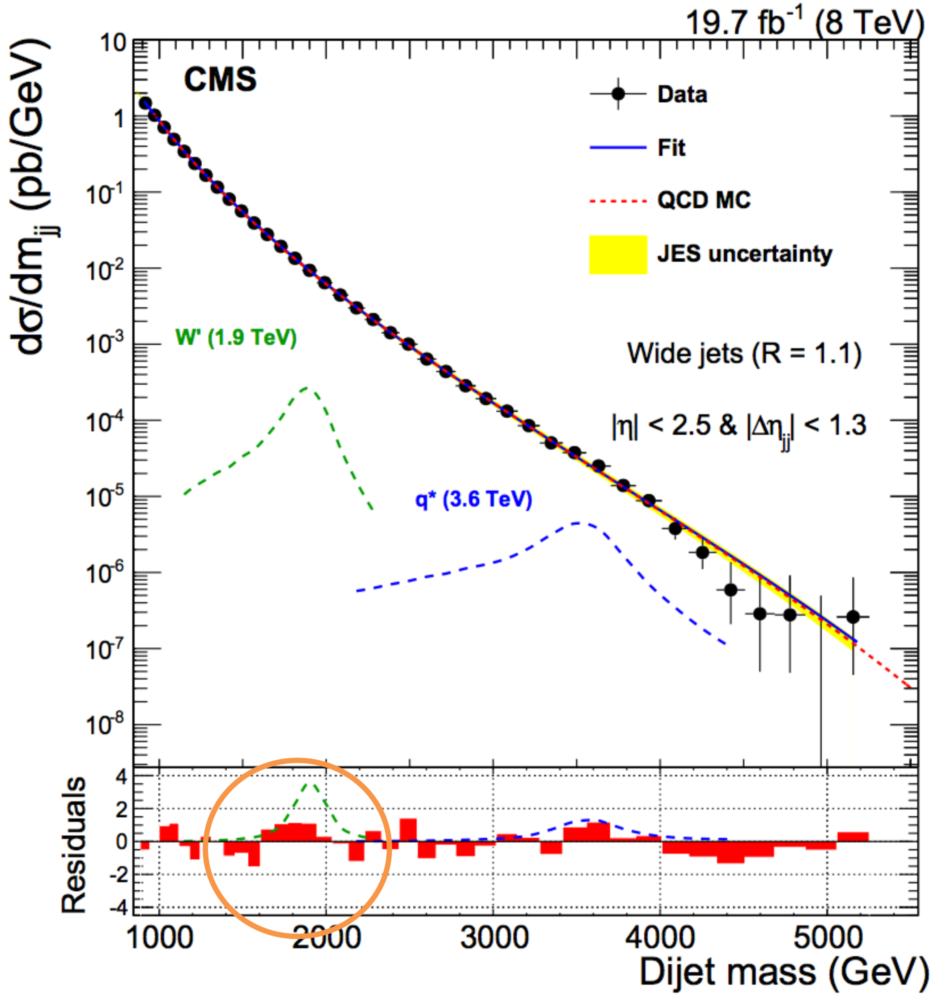
arXiv:1405.1994
JHEP08(2014)173

RS G*-like (spin-2) interpretation

Deviations more modest than in ATLAS, but: at same mass and in several channels. Coincidence?

Run-1: ATLAS + CMS dijets



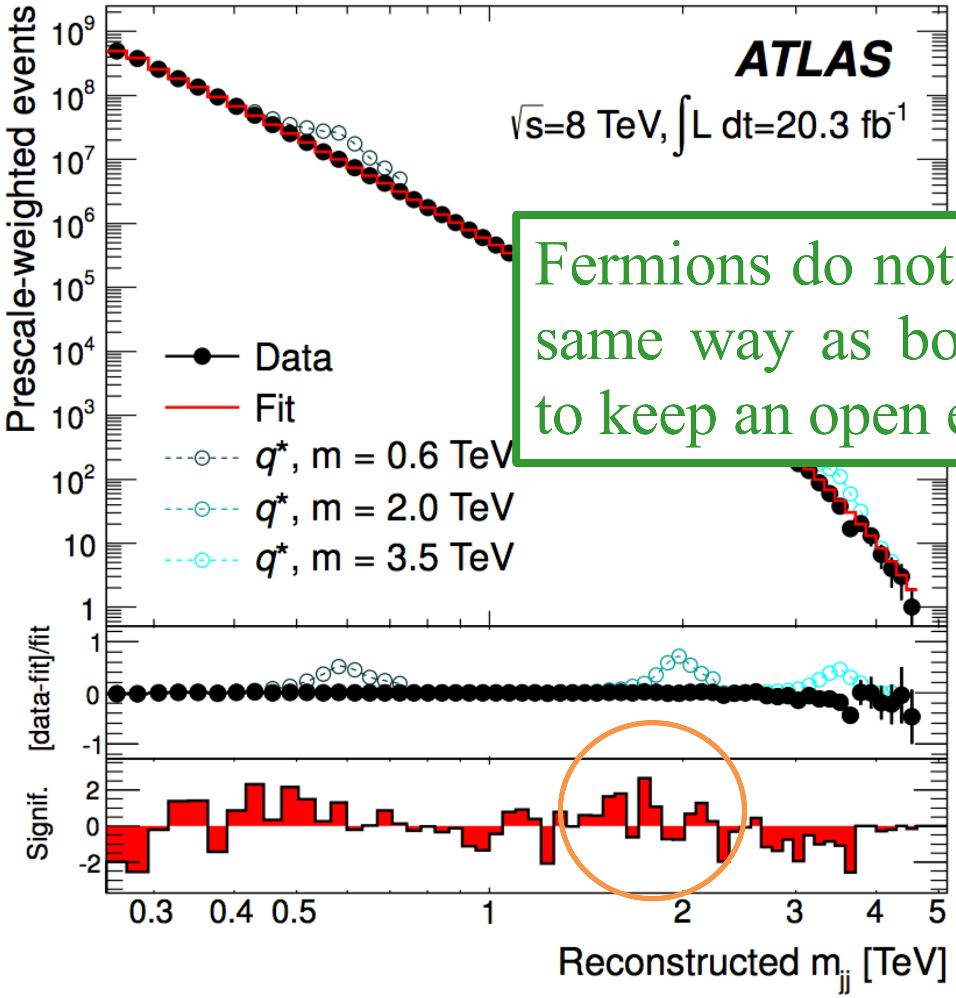


arXiv1407.1376
Phys. Rev. D 91, 052007 (2015)

arXiv:1501.04198
Phys. Rev. D 91, 052009 (2015)

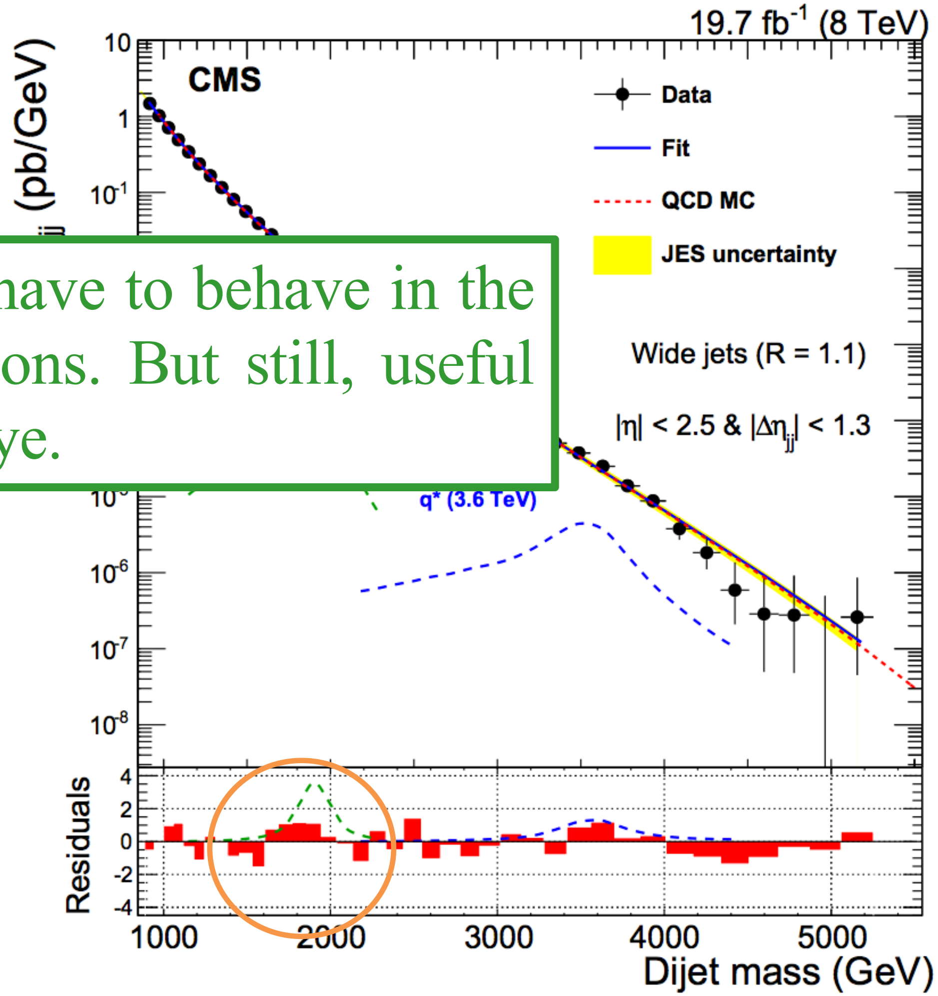
Nothing terribly exciting, but: keep an open eye

Run-1: ATLAS + CMS dijets



arXiv1407.1376
Phys. Rev. D 91, 052007 (2015)

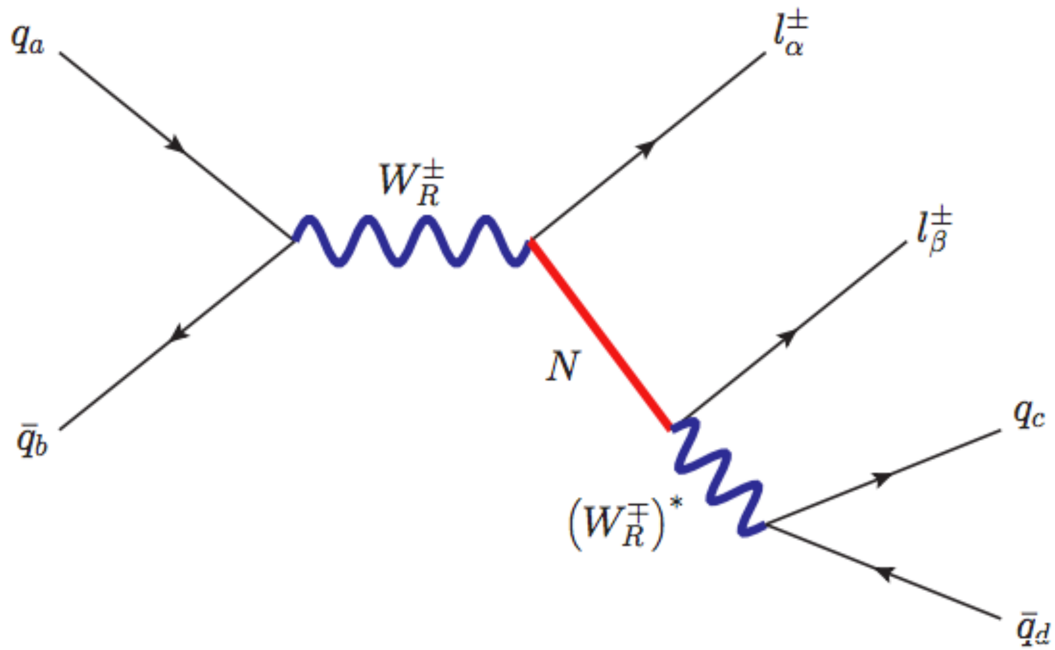
Fermions do not have to behave in the same way as bosons. But still, useful to keep an open eye.



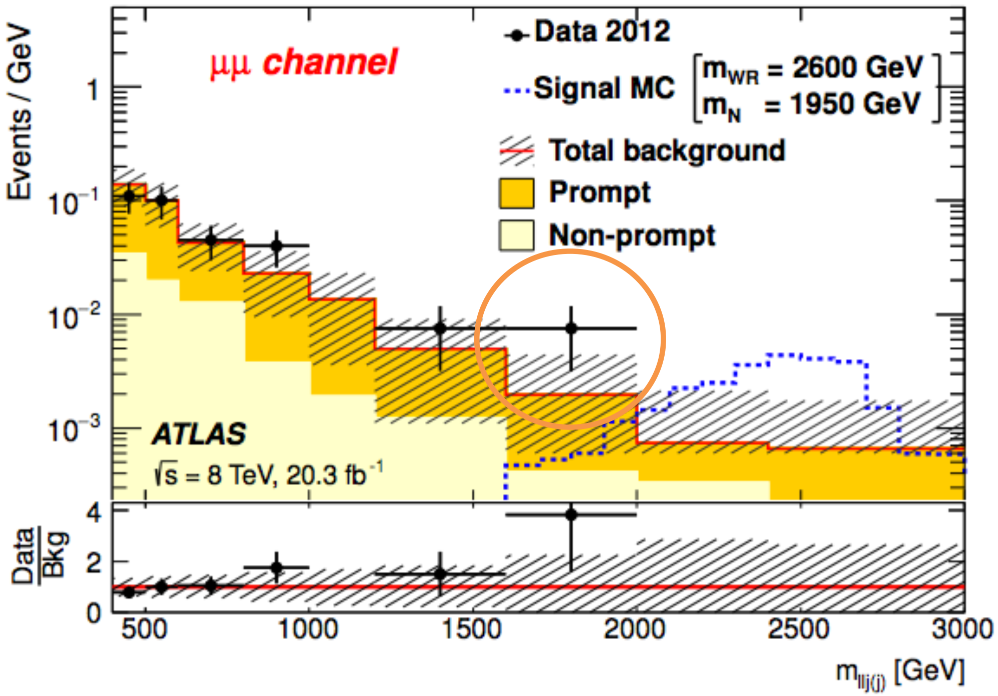
arXiv:1501.04198
Phys. Rev. D 91, 052009 (2015)

Nothing terribly exciting, but: keep an open eye

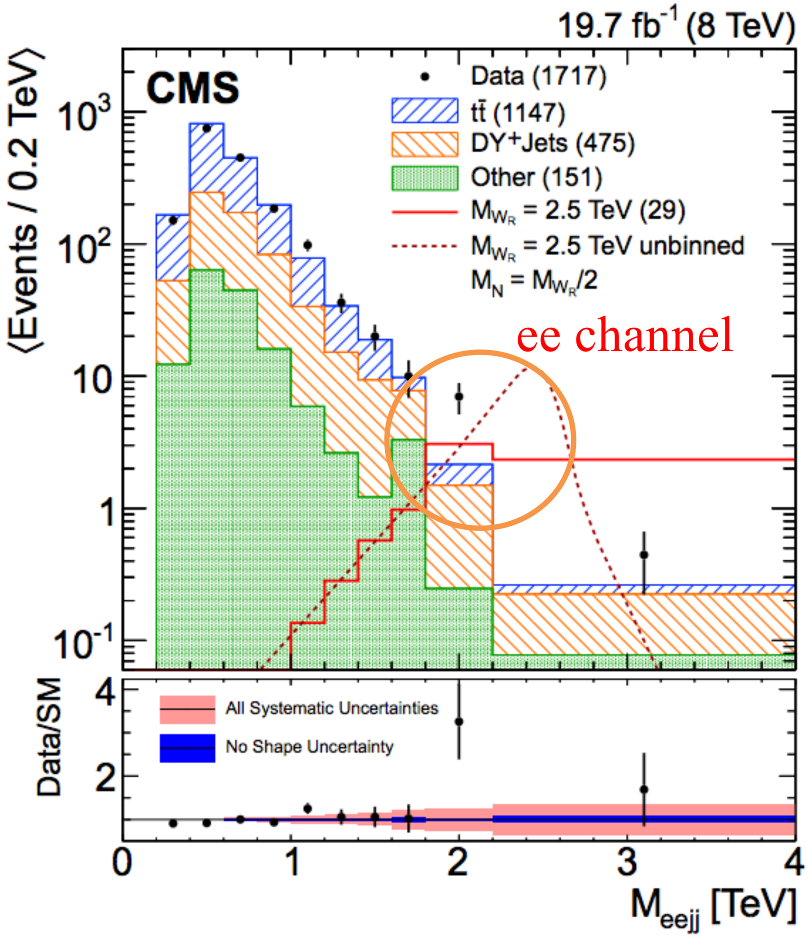
Run-1: ATLAS + CMS W_R/N_R



Run-1: ATLAS + CMS W_R/N_R



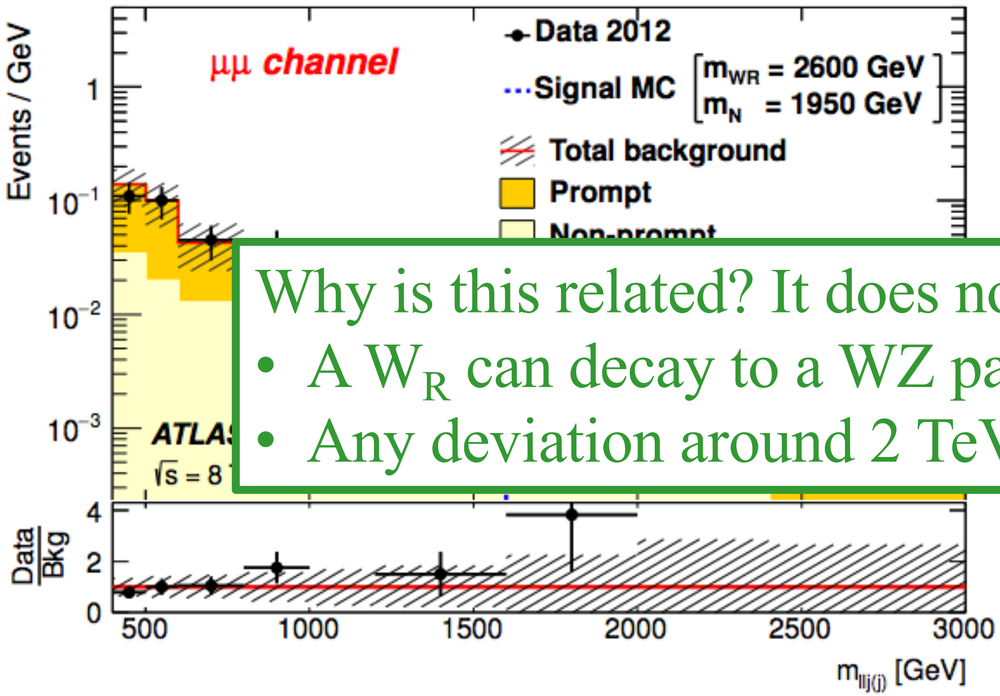
arXiv:1506.06020
JHEP07(2015)162



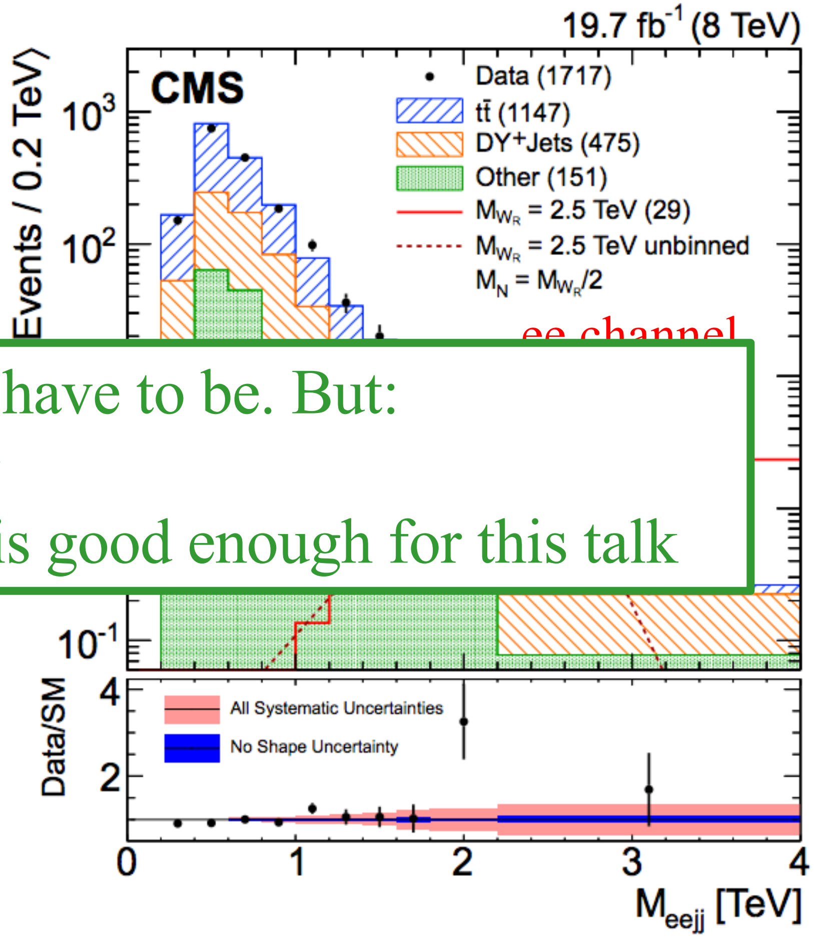
arXiv:1407.3683
Eur. Phys. J. C 74 (2014) 3149

Nothing terribly exciting, but: keep an open eye

Run-1: ATLAS + CMS W_R/N_R



arXiv:1506.06020
JHEP07(2015)162



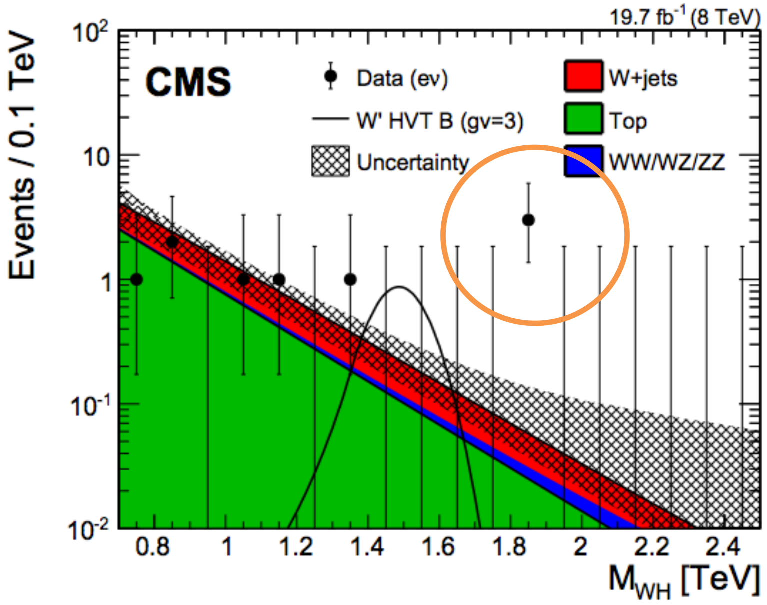
arXiv:1407.3683
Eur. Phys. J. C 74 (2014) 3149

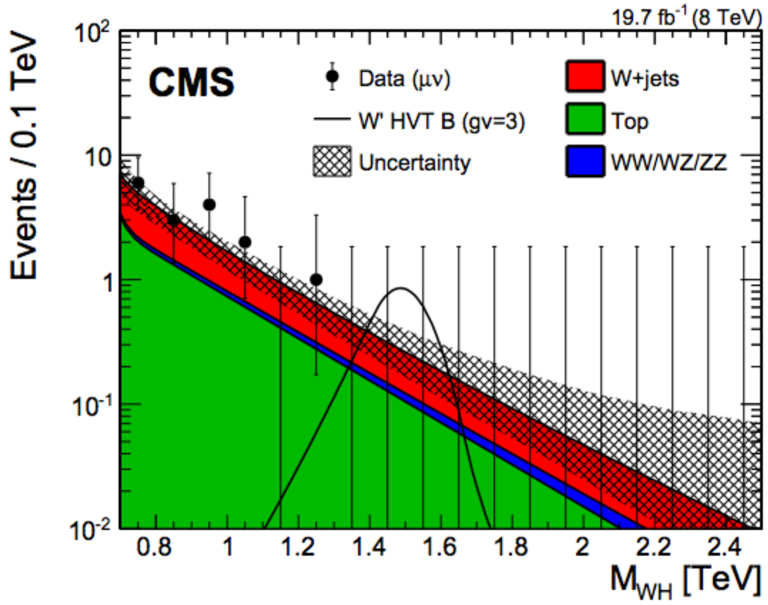
Why is this related? It does not have to be. But:

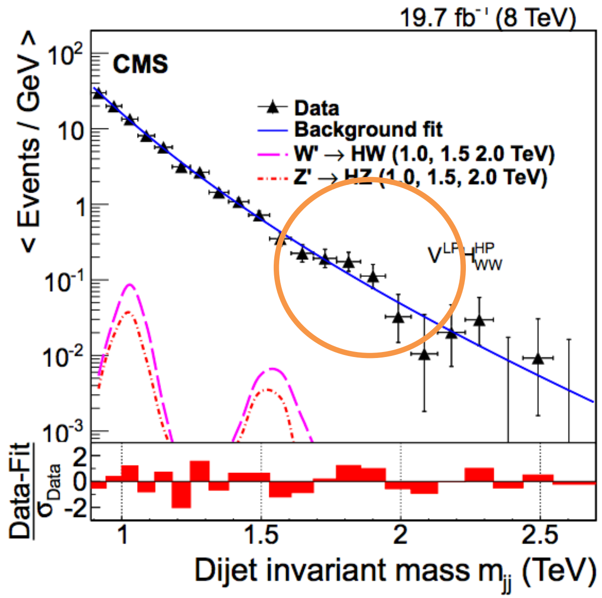
- A W_R can decay to a WZ pair
- Any deviation around 2 TeV is good enough for this talk

Nothing terribly exciting, but: keep an open eye

Run-1: CMS W/Z+H







arXiv:1601.06431
EPJC 76 (2016) 237

arXiv:1506.01443
JHEP 02 (2016) 145

4 events in electron channel (3 sigma); nothing in the muon channel (reduces deviation to 2 sigma)

Unofficial Combination of Run-1 diboson results

Combination of Run-1 Exotic Searches in Diboson Final States at the LHC

F. Dias,[a] S. Gadatsch,[b] M. Gouzevich,[c] C. Leonidopoulos,[a] S.F. Novaes,[d] A. Oliveira,[e] M. Pierini,[b] T. Tomei[d]

arXiv:1512.03371
JHEP04(2016)155

ABSTRACT: We perform a statistical combination of the ATLAS and CMS results for the search of a heavy resonance decaying to a pair of vector bosons with the $\sqrt{s} = 8$ TeV datasets collected at the LHC. We take into account six searches in hadronic and semileptonic final states carried out by the two collaborations. We consider only public information provided by ATLAS and CMS in the HEPDATA database and in papers published in refereed journals. We interpret the combined results within the context of a few benchmark new physics models, such as models predicting the existence of a W′ or a bulk Randall-Sundrum spin–2 resonance, for which we present exclusion limits, significances, p-values and best-fit cross sections. A heavy diboson resonance with a production cross section of ∼4-5 fb and mass between 1.9 and 2.0 TeV is the exotic scenario most consistent with the experimental results. Models in which a heavy resonance decays preferentially to a WW final state are disfavoured.

Unofficial

Combination of Run-1 diboson results

$\ell\ell$J channel is $\approx$ 2 fb and increases to $\approx$ 9 fb for the JJ channel. When combined, the estimated cross section is 5 fb. The combination of the two channels reduces the exotic cross section favoured by the JJ results, and alleviates the potential disagreement between different channels, without reducing the overall significance of the excess. In other words, the combination of the two channels leads to a more coherent picture of the results by the two experiments. This is also evident from the profile likelihood scans shown in Fig. 21: given the uncertainty on the best-fit exotic production cross section, and contrary to what one might expect by considering the individual exclusion limits, the results obtained in different final states are not in tension with each other. In addition, the combination pushes the excess to mass values below 2 TeV.

Signal hypothesis	m_X (TeV)	Significance	p-value	Best-fit cross section (fb)	
$W' \to W_L Z_L$	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) $\times 10^{-3}$	$4.3^{+2.1}_{-1.5}$	$(4.7^{+1.8}_{-1.3})$
$G_{bulk} \to W_L W_L$	1.9	0.49 (0.83)	0.30 (0.20)	$0.75^{+1.67}_{-0.75}$	$(1.4^{+1.7}_{-1.4})$
	2.0	0.88 (1.33)	0.20 (0.092)	$1.1^{+1.4}_{-1.1}$	$(1.8^{+1.8}_{-1.4})$
$G_{bulk} \to Z_L Z_L$	1.9	3.4 (3.8)	3.2 (0.65) $\times 10^{-4}$	$5.2^{+2.1}_{-1.6}$	$(4.7^{+1.8}_{-1.2})$
	2.0	3.0 (3.5)	1.2 (0.24) $\times 10^{-3}$	$4.2^{+1.9}_{-1.2}$	$(3.9^{+1.6}_{-1.0})$
G_{bulk} (r=2)	1.9	2.6 (3.4)	5.2 (0.40) $\times 10^{-3}$	$3.9^{+2.4}_{-1.5}$	$(4.9^{+2.0}_{-1.7})$
	2.0	2.4 (3.1)	8.8 (0.89) $\times 10^{-3}$	$3.1^{+1.8}_{-1.3}$	$(3.9^{+1.6}_{-1.4})$

Unofficial

Combination of Run-1 diboson results

$\ell\ell$J channel is ≈ 2 fb and increases to ≈ 9 fb for the JJ channel. When combined, the estimated cross section is 5 fb. The combination of the two channels reduces the exotic cross section favoured by the JJ results, and alleviates the potential disagreement between different channels, without reducing the overall significance of the excess. In other words, the combination of the two channels leads to a more coherent picture of the results by the two experiments. This is also evident from the profile likelihood scans shown in Fig. 21: given the uncertainty on the best-fit exotic production cross section, and contrary to what one might expect by considering the individual exclusion limits, the results obtained in different final states are not in tension with each other. In addition, the combination pushes the excess to mass values below 2 TeV.

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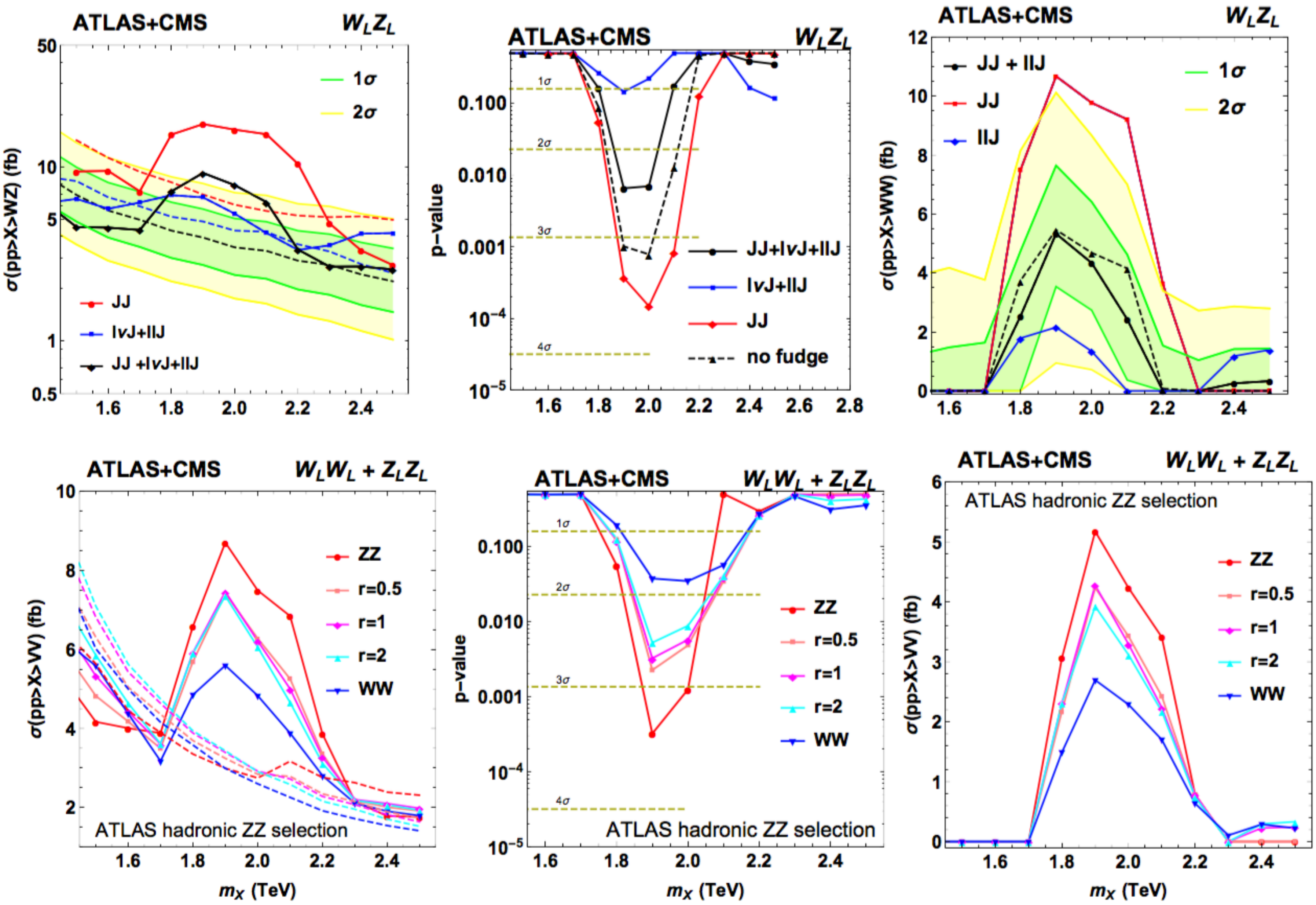
	2.0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
G_{bulk} (r=2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	2.0	2.4 (3.1)	8.8 (0.89) $\times 10^{-3}$	$3.1^{+1.8}_{-1.3}$	$(3.9^{+1.6}_{-1.4})$

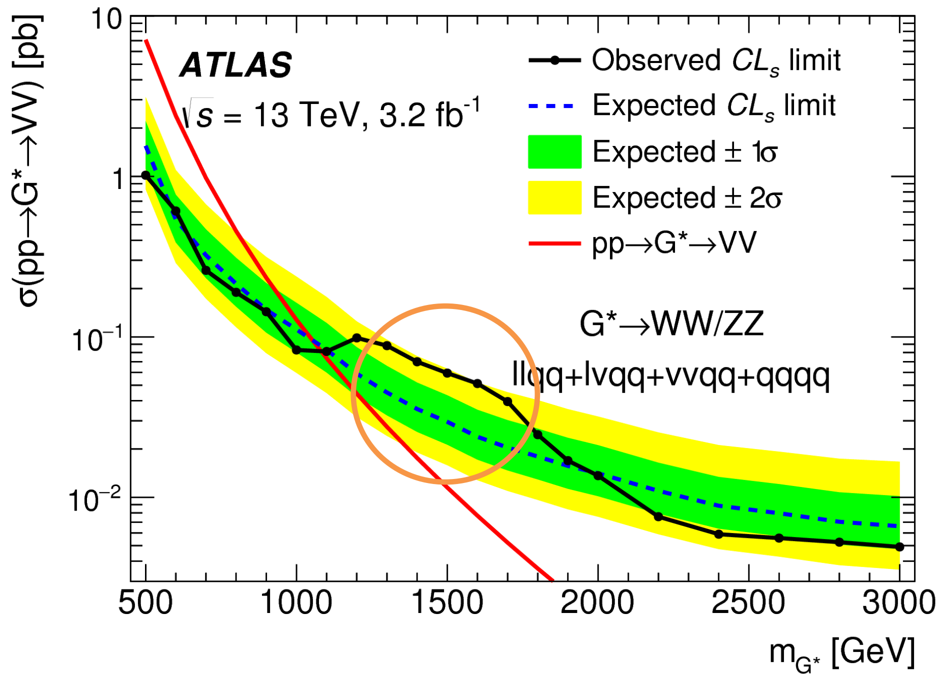
By combining all channels from two experiments, we knew right away that ATLAS hadronic result was 'exaggerated': combination of searches gave more coherent picture, still consistent with non-zero cross section for exotic signal

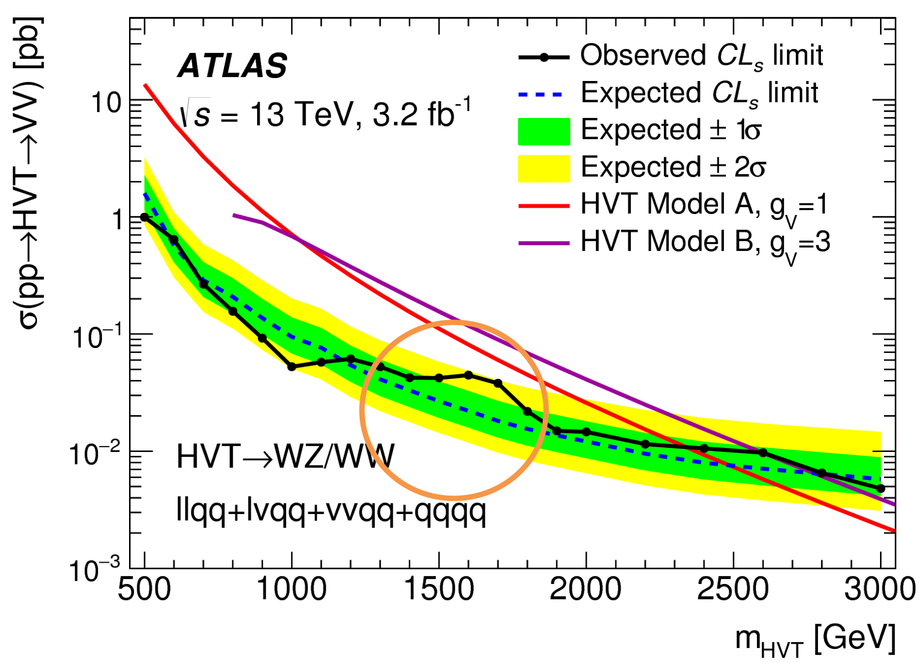
Unofficial Combination of Run-1 diboson results



Run-2 Searches

Run-2 ATLAS dibosons





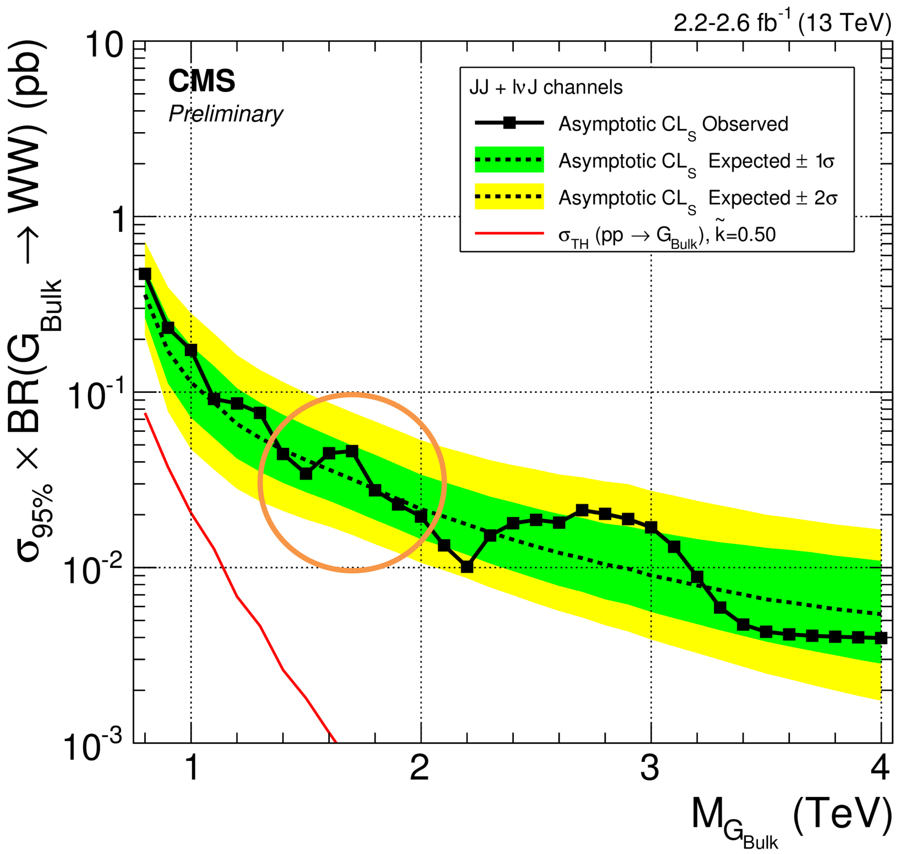
RS G*-like (spin-2) interpretation

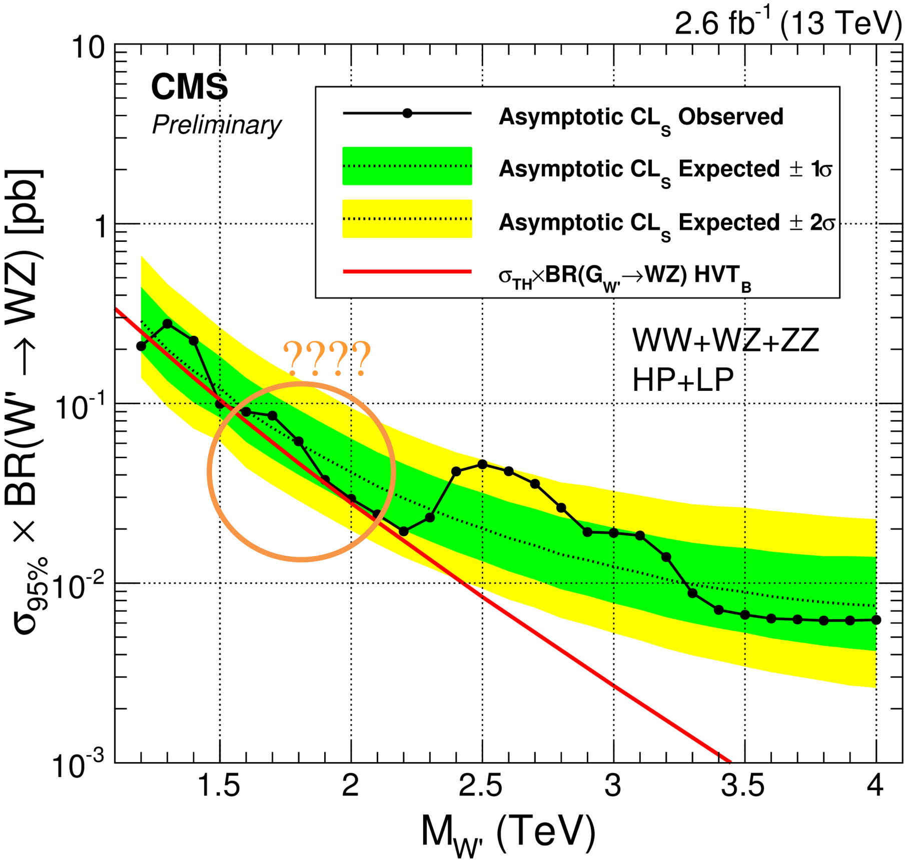
HVT/W'-like (spin-1) interpretation

arxiv:1606.04833
submitted to JHEP

Deviations smaller than in Run-1 (but: not same sensitivity, not enough data to rule out Run-1 deviation)

Run-2 CMS dibosons





RS G*-like (spin-2) interpretation

Preliminary
PAS EXO-15-002

W'-like (spin-1) interpretation

Deviations smaller than in Run-1 (but: not same sensitivity, not enough data to rule out Run-1 deviation)

Unofficial Combination of Run-1 diboson results

In assessing the compatibility of the Run-2 exclusion limits with the results obtained in this study (summarised in Table 3) we use parton luminosity ratio values of 13 (15) for $m_X = 1.9$ TeV (2.0 TeV) for gg production ($\mathrm{G_{bulk}} \to \mathrm{W}_L\mathrm{W}_L$ and $\mathrm{G_{bulk}} \to \mathrm{Z}_L\mathrm{Z}_L$ channels) and 8 (8.5) for $m_X = 1.9$ TeV (2.0 TeV) for $q\bar{q}$ production ($\mathrm{W}' \to \mathrm{W}_L\mathrm{Z}_L$ channels) [88] to calculate the increase in the exotic signal production cross section from 8 to 13 TeV. We observe that the absence of a significant deviation in the Run-2 data

- creates a $\sim 2-3\sigma$ tension with the best-fit cross section derived in this paper in the $\mathrm{G_{bulk}} \to \mathrm{Z}_L\mathrm{Z}_L$ channel,
- is consistent (within 1σ) with the (consistent-with-zero) result we obtain in the $\mathrm{G_{bulk}} \to \mathrm{W}_L\mathrm{W}_L$ channel, and
- is also consistent (within 1σ) with the best-fit cross section that we have derived in the $\mathrm{W}' \to \mathrm{W}_L\mathrm{Z}_L$ channel.

We, therefore, conclude that the preliminary analysis of the Run-2 data by ATLAS and CMS does not rule out the small deviation reported in the $\mathrm{W}' \to \mathrm{W}_L\mathrm{Z}_L$ channel of the Run-1 diboson searches. It is widely expected that a clear picture will emerge with the analysis of the larger 13 TeV datasets.

Unofficial

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- Tension with gg/G^* result from Run-1
- $q\bar{q}/W'$ interpretation still alive

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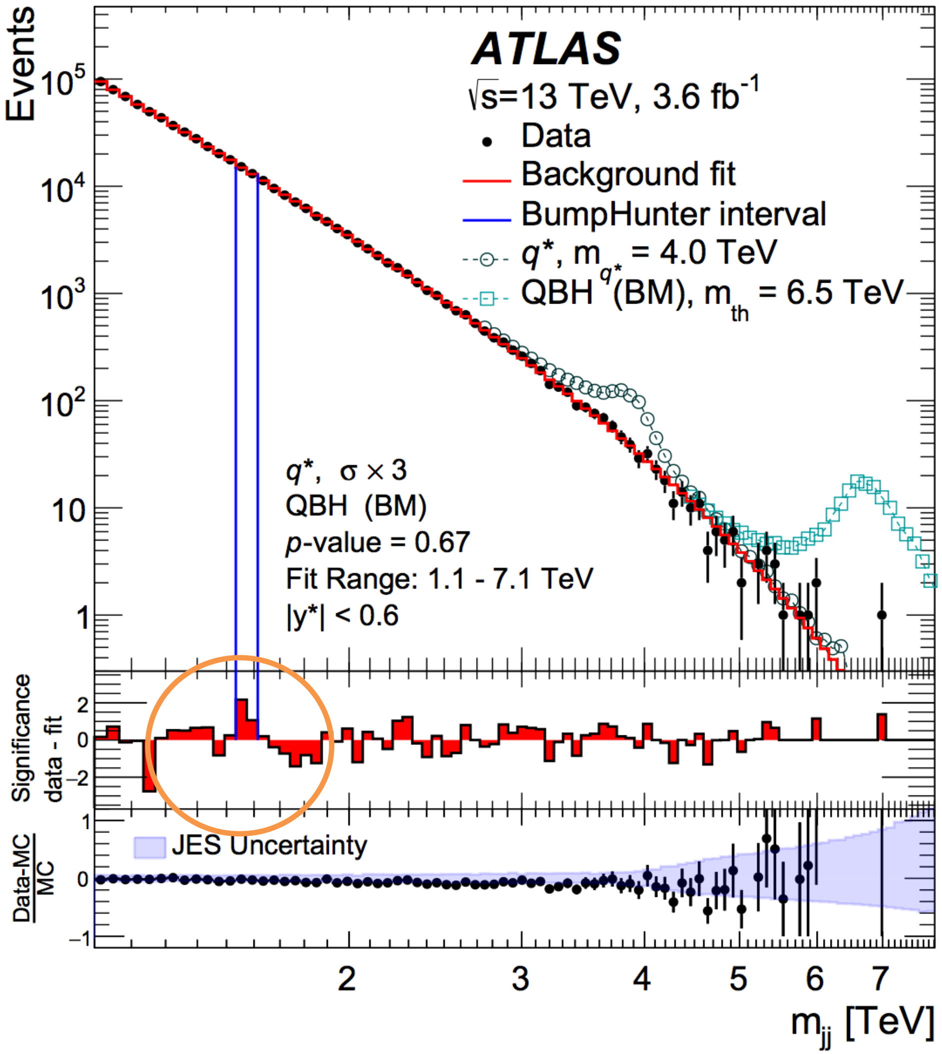
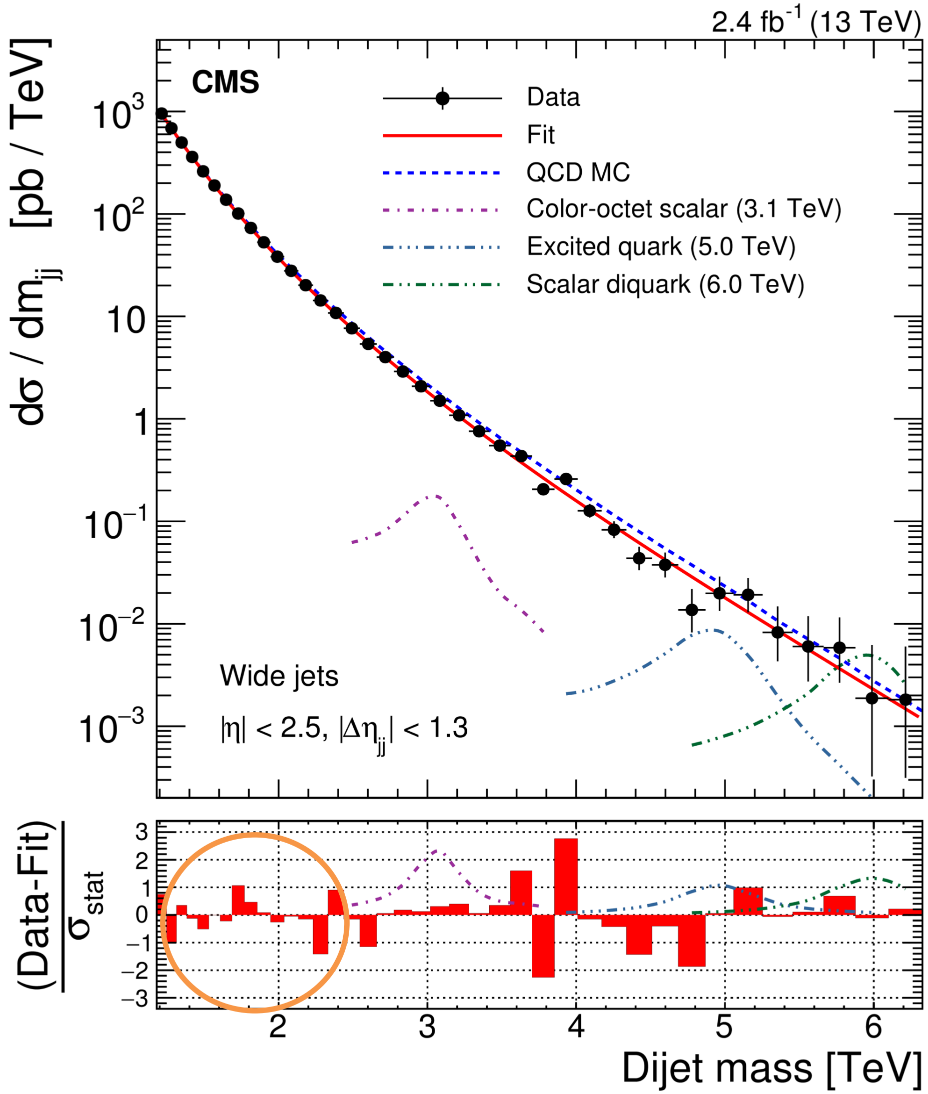
Run-2: ATLAS + CMS dijets



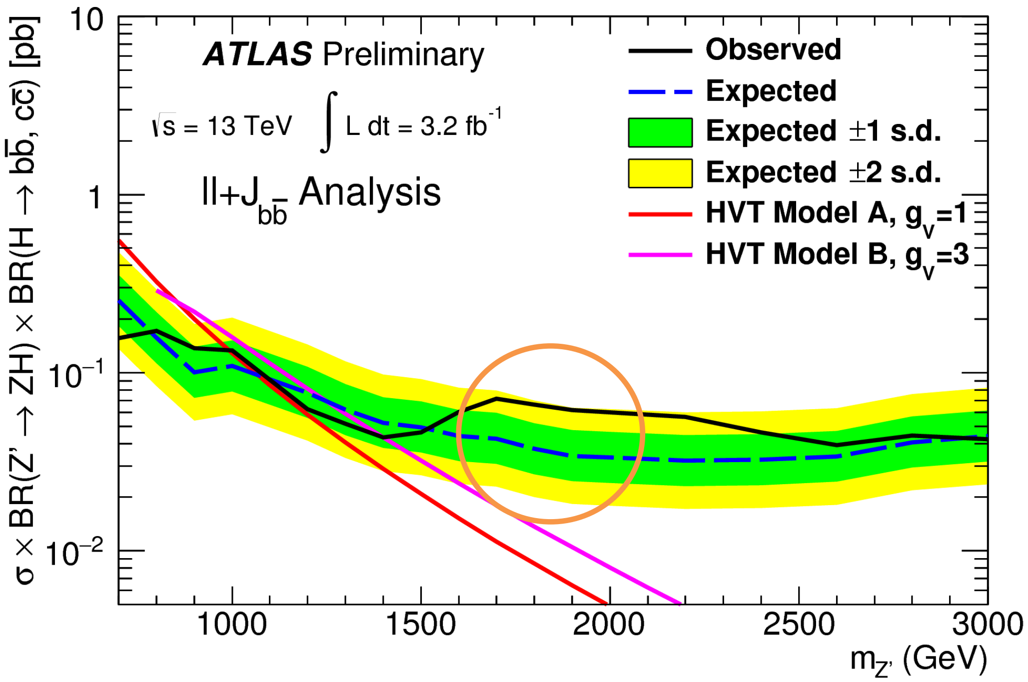
arxiv:1512.01530
PLB 754 (2016) 302-322

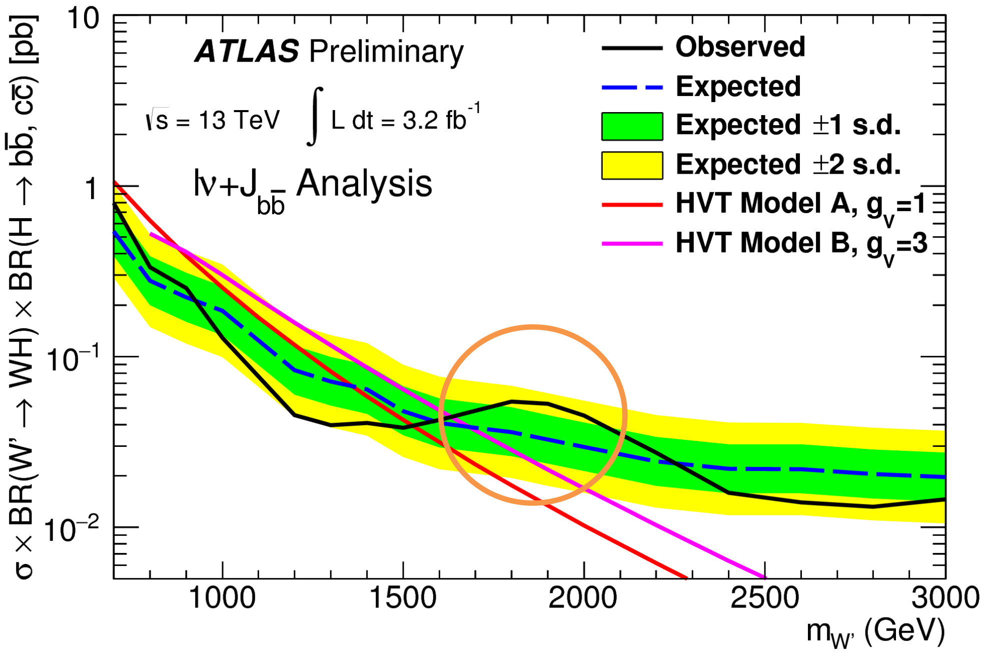


arXiv:1512.01224
PhysRevLett.116.071801

Nothing terribly exciting, but: keep an open eye
(Conclusions: very similar to Run-1)

Run-2: ATLAS W/Z+H

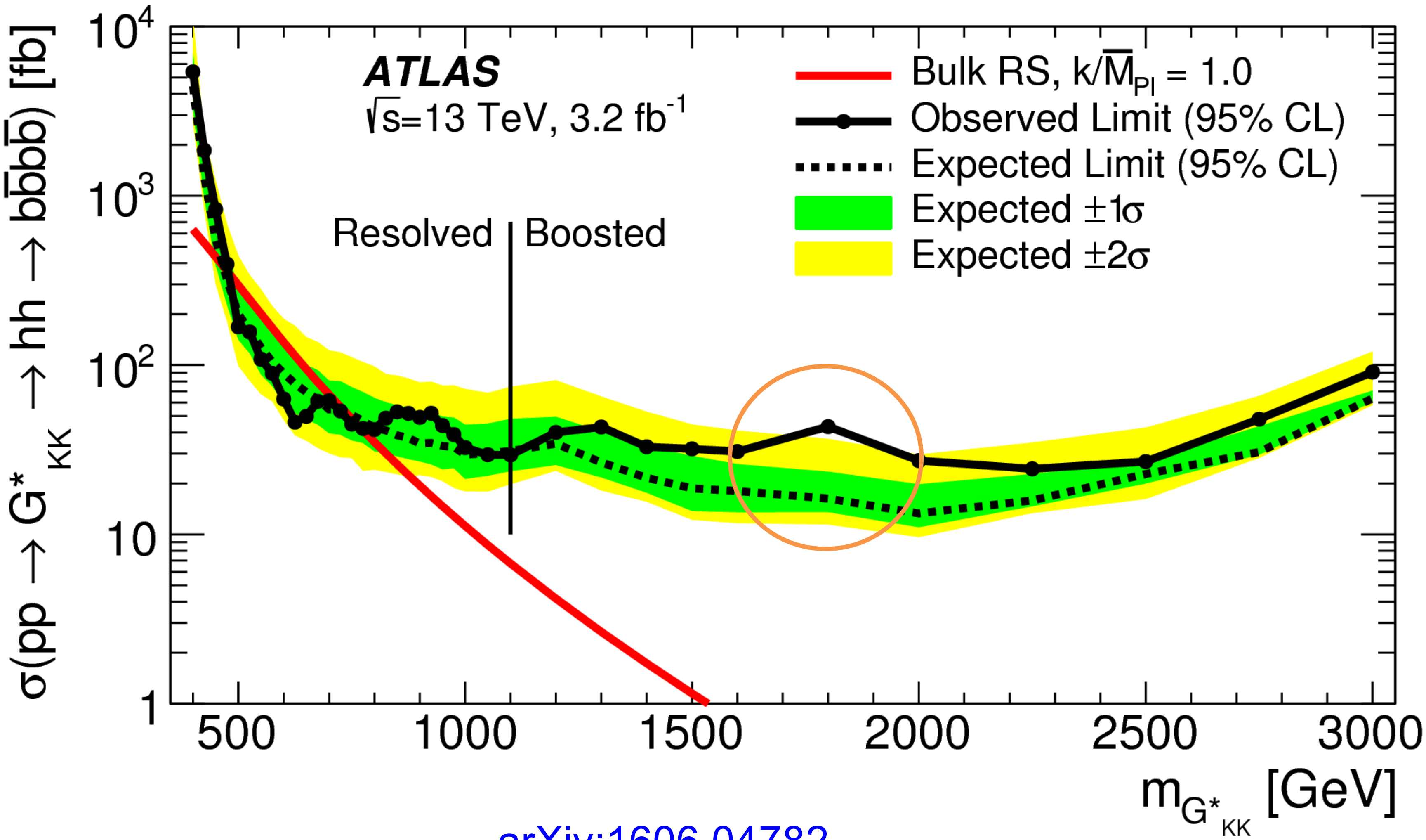




Preliminary
ATLAS-CONF-2015-074

Nothing terribly exciting, but: keep an open eye

Run-2: ATLAS H+H

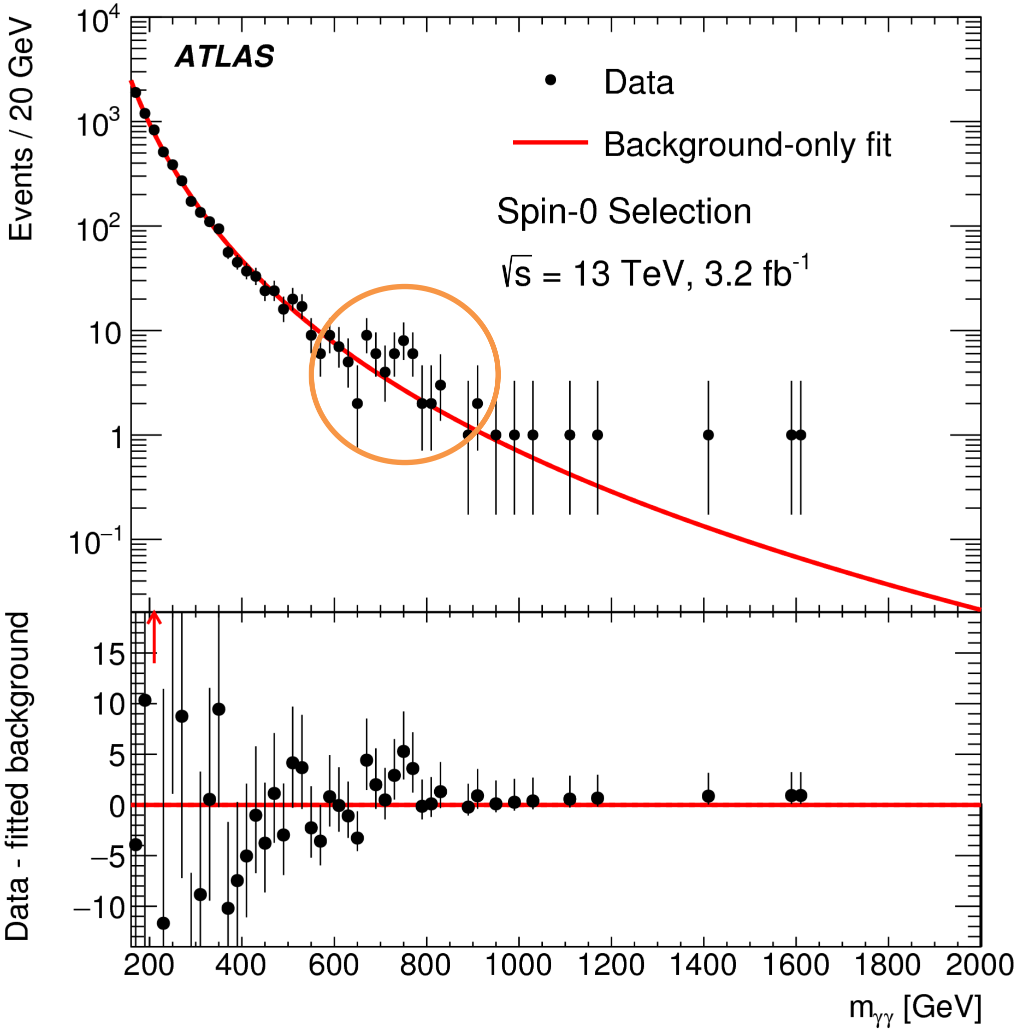


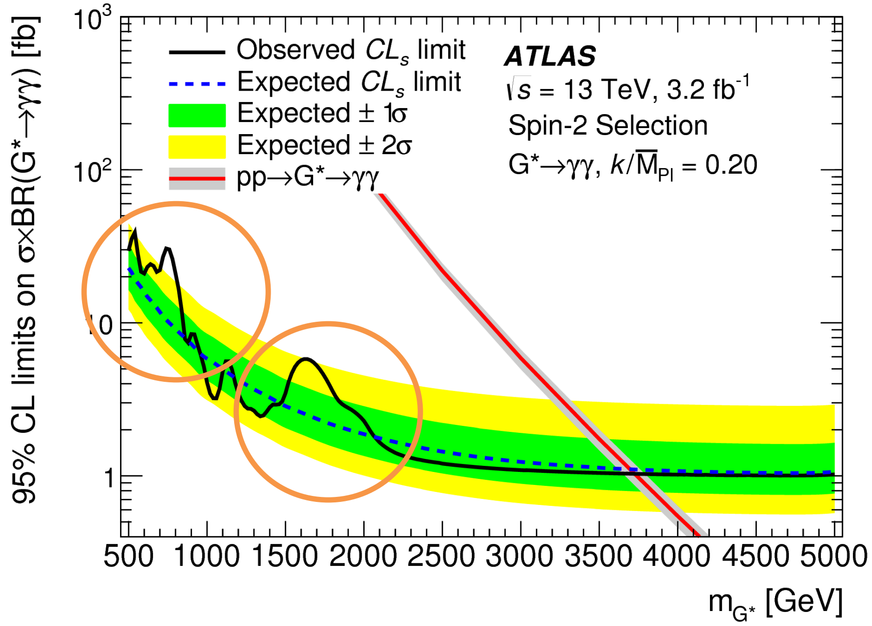
arXiv:1606.04782
Submitted to PRD

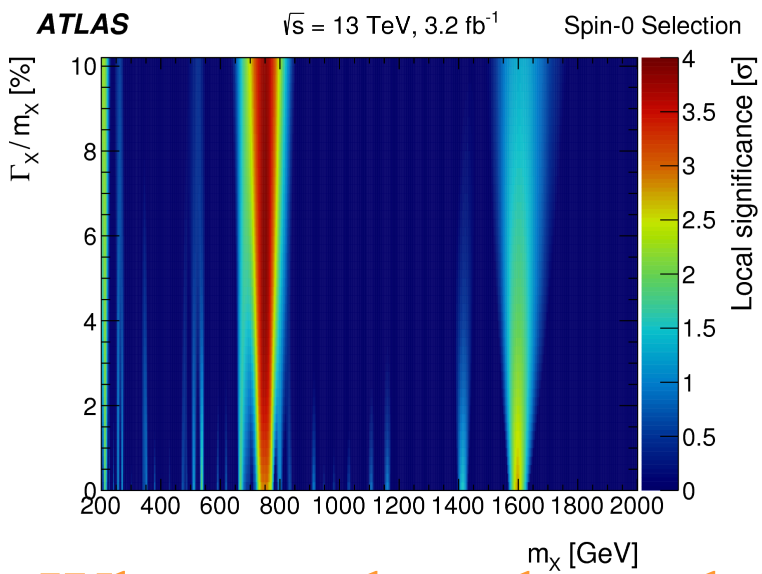
Nothing terribly exciting, but: keep an open eye

Diphotons

Run-2: ATLAS γγ



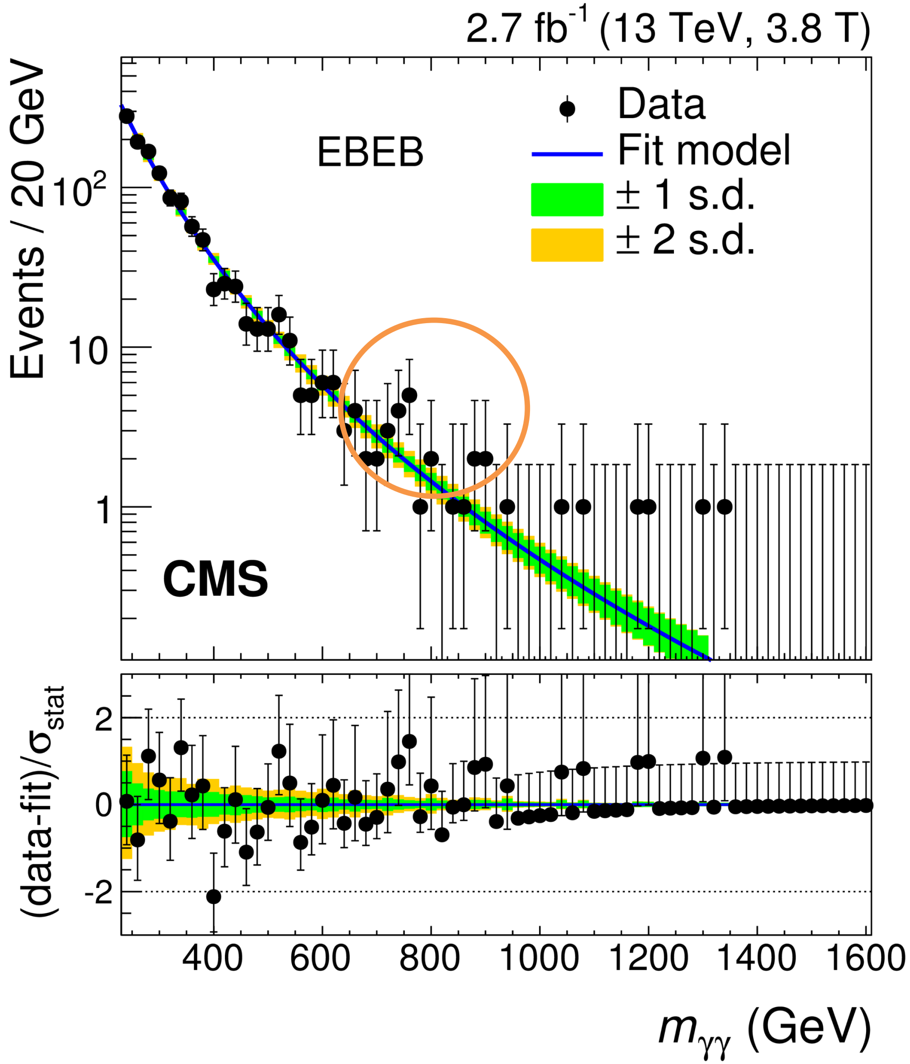


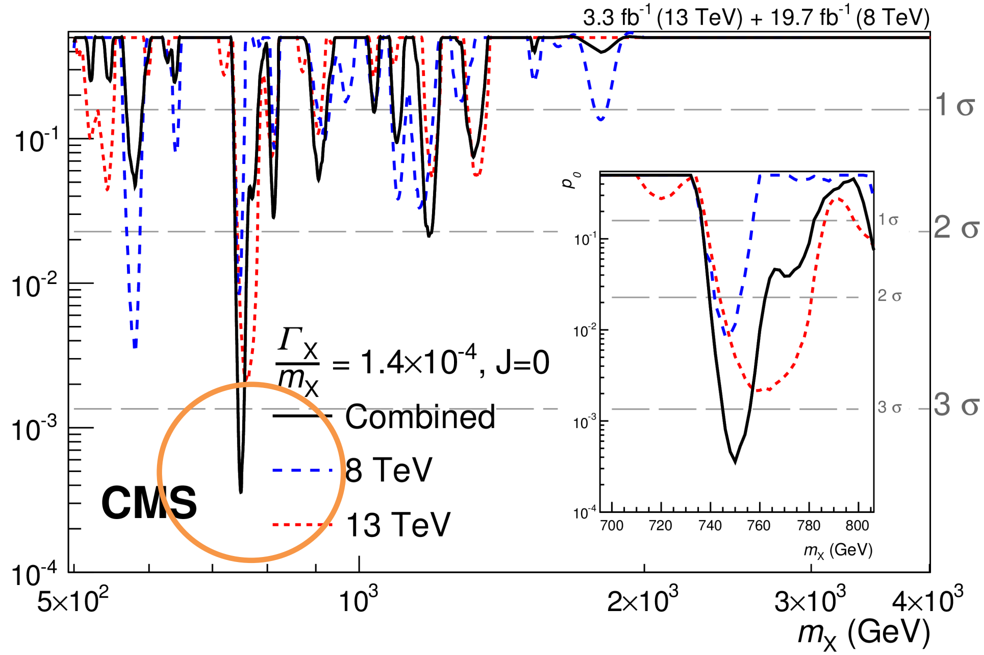


arXiv:1606.03833
Submitted to JHEP

Most exciting deviation in Run-2. Why no other channels?

Run-2: CMS γγ

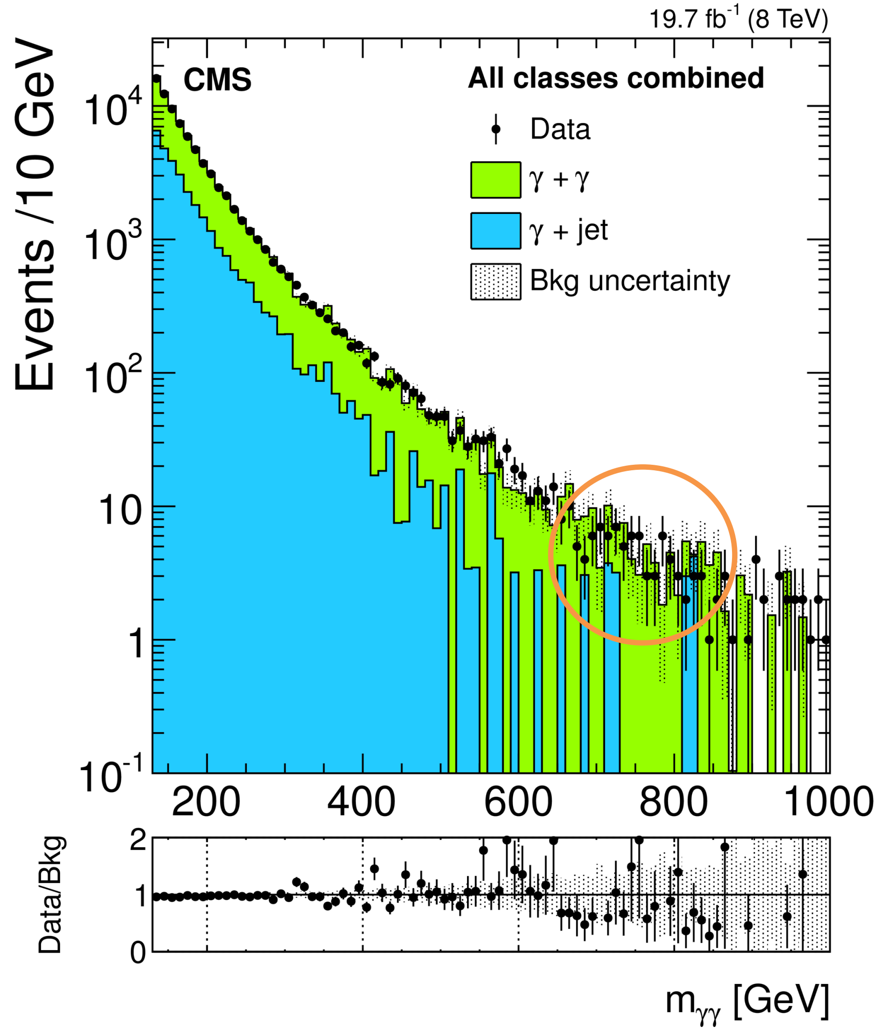


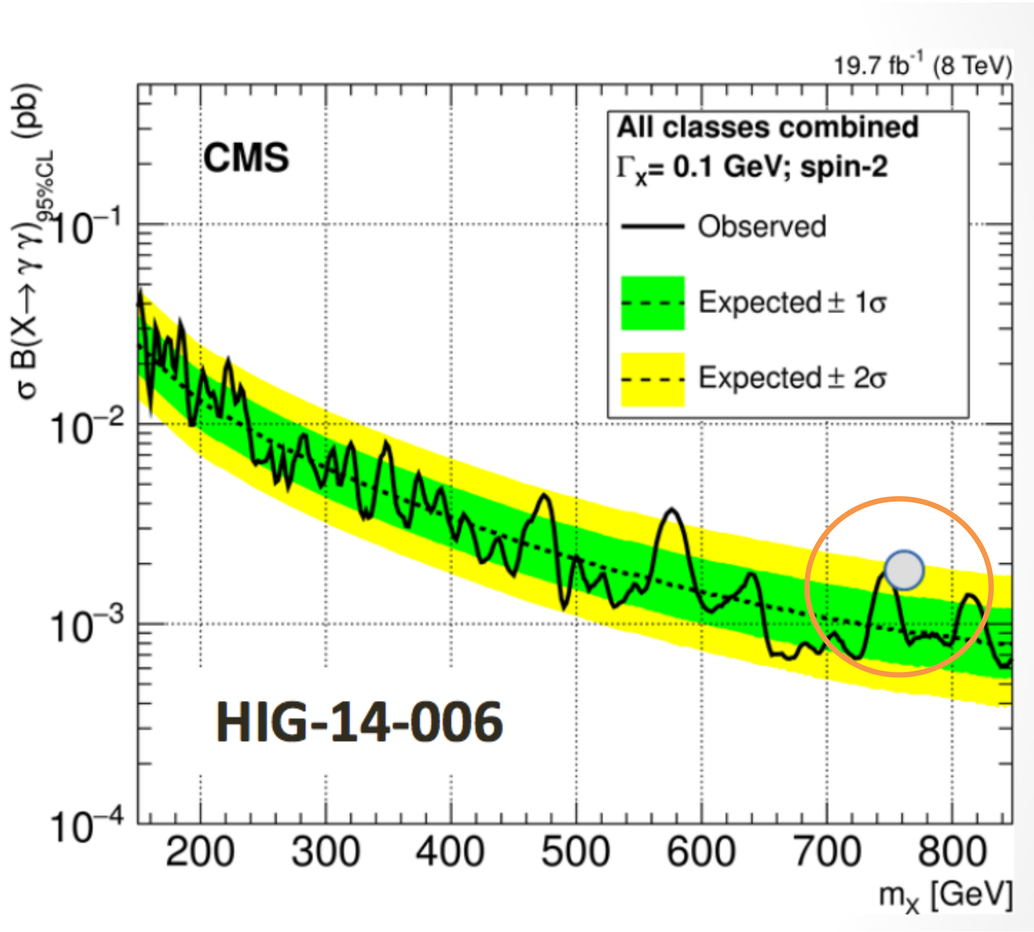


arXiv:1606.04093
Submitted to PRL

Most exciting deviation in Run-2. Why no other channels?

Run-1: CMS γγ





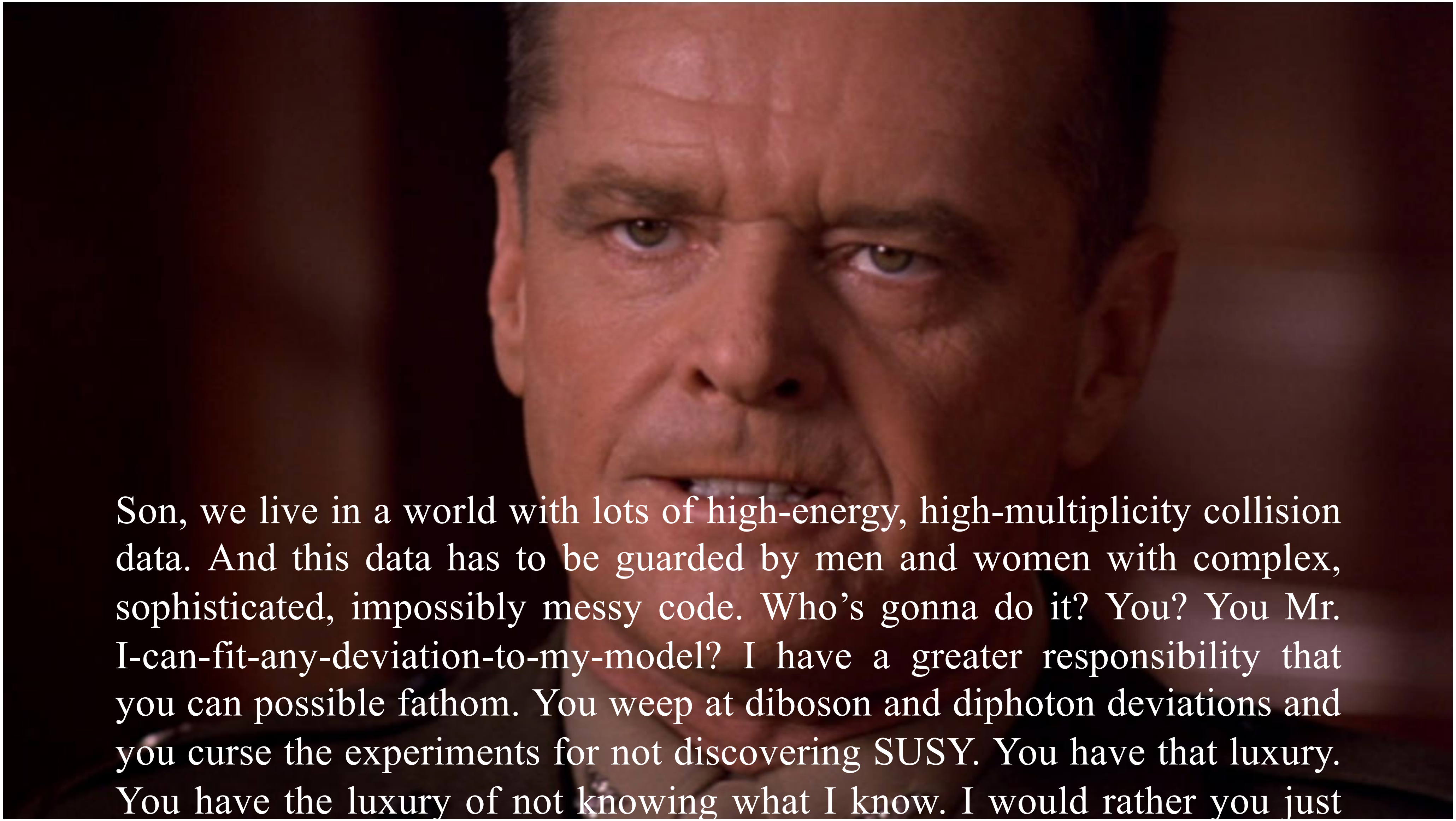
arXiv:1506.02301
Phys. Lett. B 750 (2015) 494

Excess not excluded by Run-1. Why no other channels?

What about new, unpublished 2016 results?!

You want new results? You want to know what the experiments see in the 2016 collision data?

You can't handle the 2016 results!



Son, we live in a world with lots of high-energy, high-multiplicity collision data. And this data has to be guarded by men and women with complex, sophisticated, impossibly messy code. Who's gonna do it? You? You Mr. I-can-fit-any-deviation-to-my-model? I have a greater responsibility that you can possible fathom. You weep at diboson and diphoton deviations and you curse the experiments for not discovering SUSY. You have that luxury. You have the luxury of not knowing what I know. I would rather you just said thank you and went on your way. Otherwise, I suggest you pick up an application form and join one of the LHC experiments. Either way, I don't give a damn what you think you are entitled to.

Summary #1

- Most exciting result from Run-1: deviation around 1.8 TeV in several channels with vector boson pairs by both ATLAS+CMS

- Small deviations V+H and HH channels around the same mass region

- Excesses not confirmed (yet) in Run-2. However, Run-2 sensitivity not as good as in Run-1 yet.

Summary #2

- Most exciting result from Run-2: deviations around 750 GeV in diphoton channel by both ATLAS+CMS

- No deviation around 750 GeV in any other channel

Summary #3

- Both of these cases should be resolved one way or another by this summer: ATLAS+CMS to present results with 3 fb^{-1} (2015)+ 7 fb^{-1} (2016) ~ 10 fb^{-1} of data at $\sqrt{s}$ = 13 TeV

- If either of these deviations is due to New Physics, it is extremely hard to not have it appear emphatically at ICHEP!

- Hang in there. We will know Soon™.

Thanks for coming to Edinburgh!

Have a safe trip back home