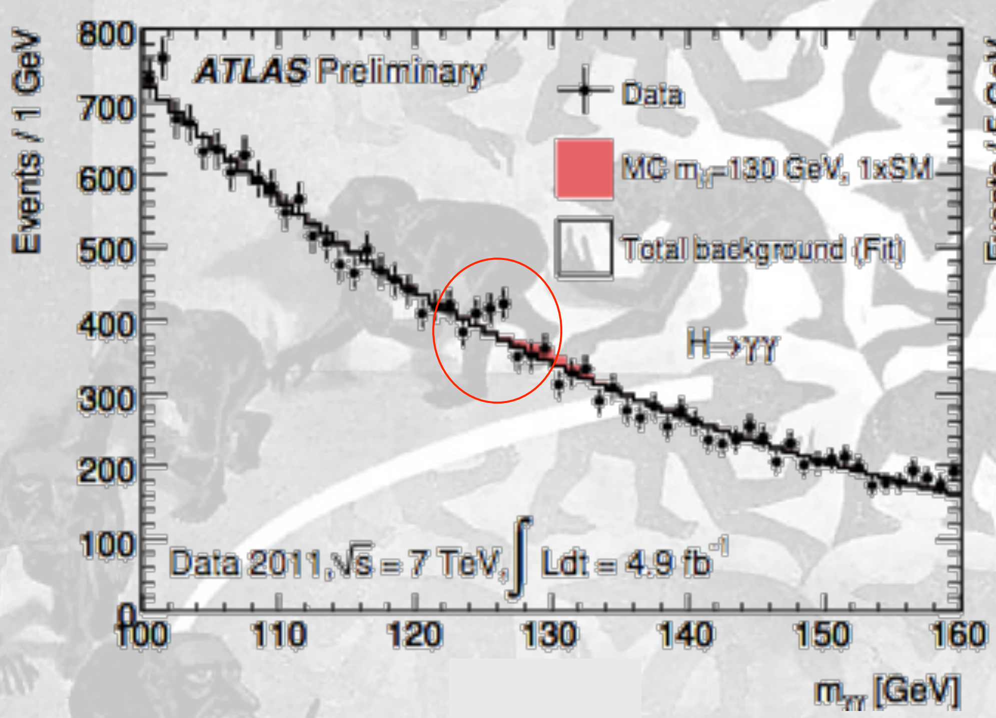
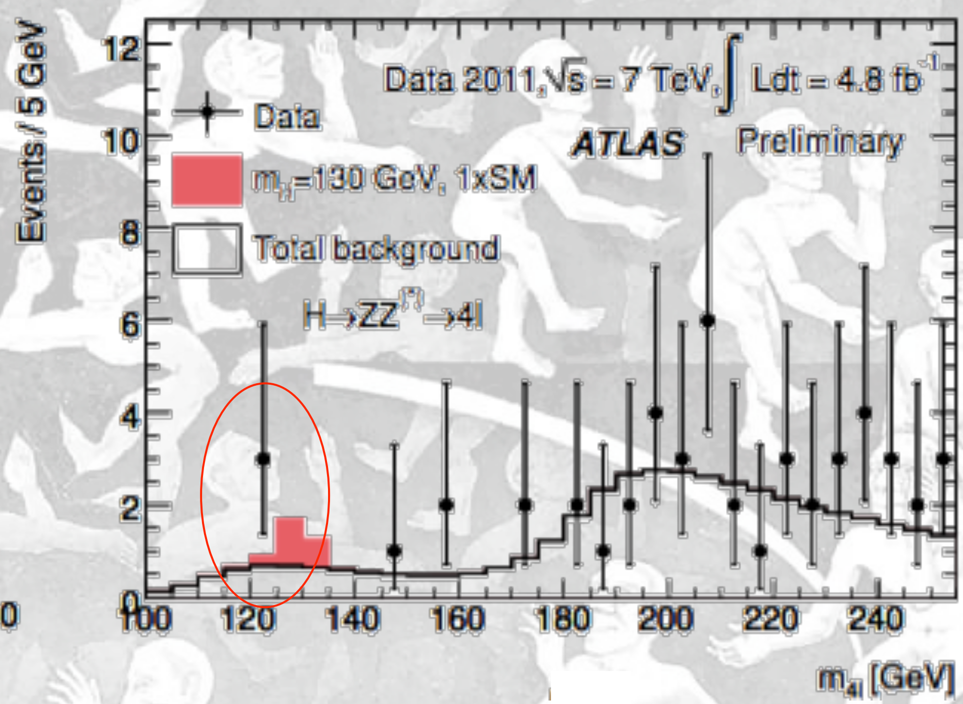
Is this the Standard Model Higgs??





Justin Albert

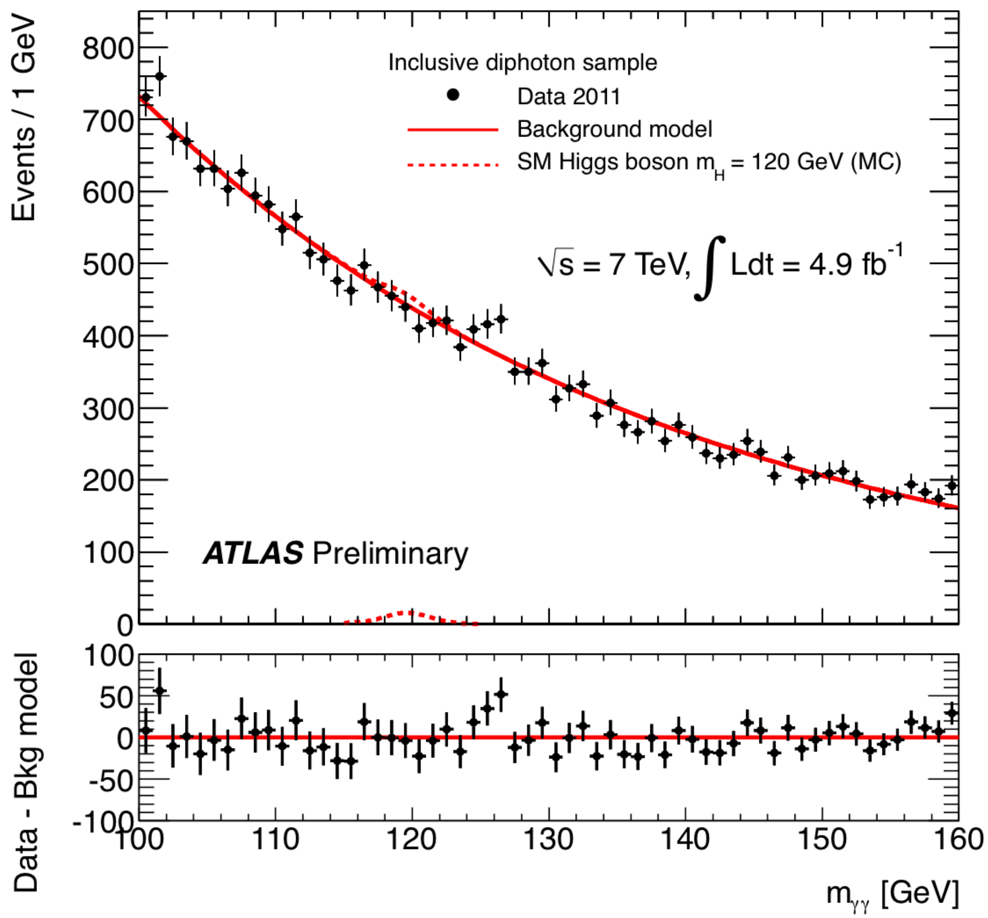
Univ. of Victoria

TRIUMF Workshop on LHC Results

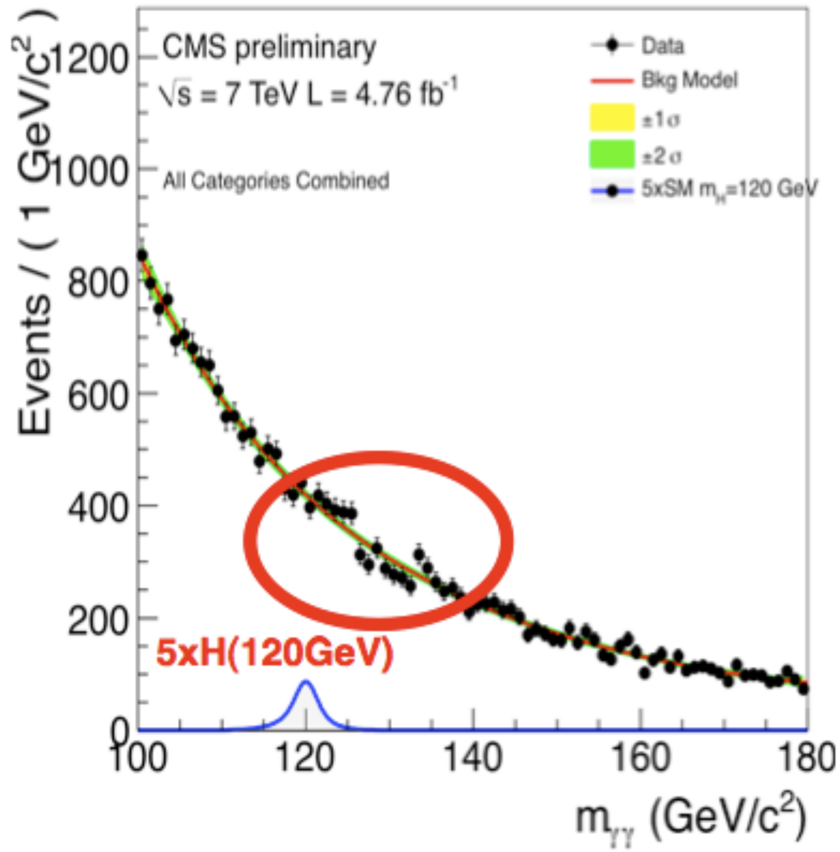
Dec. 14, 2011

What do we know about these bumps?

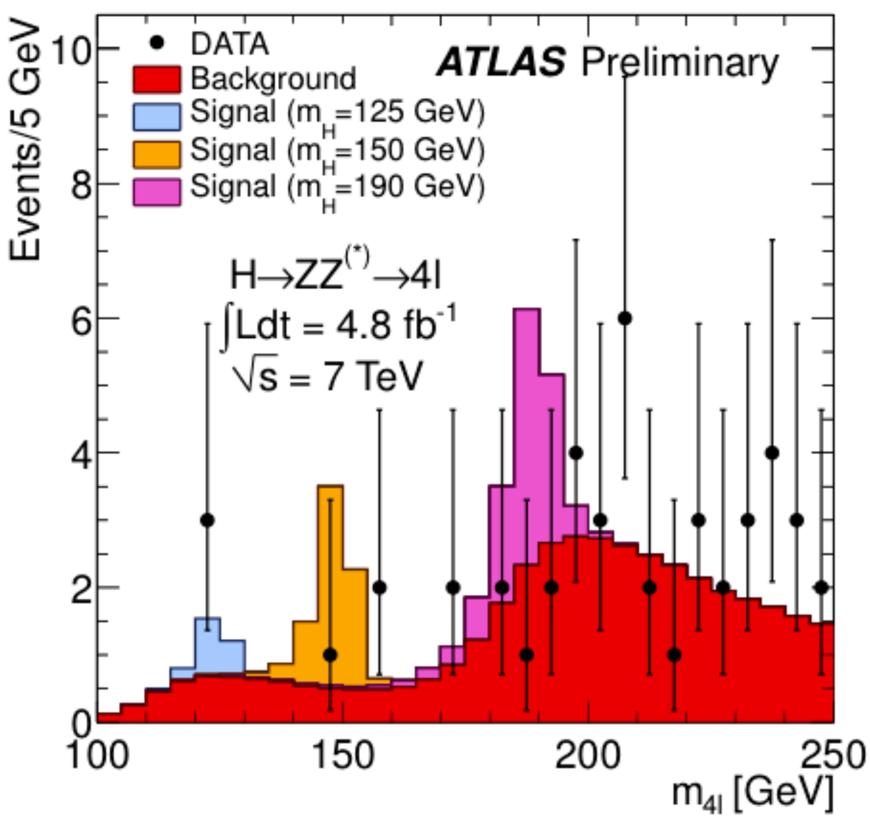
ATLAS

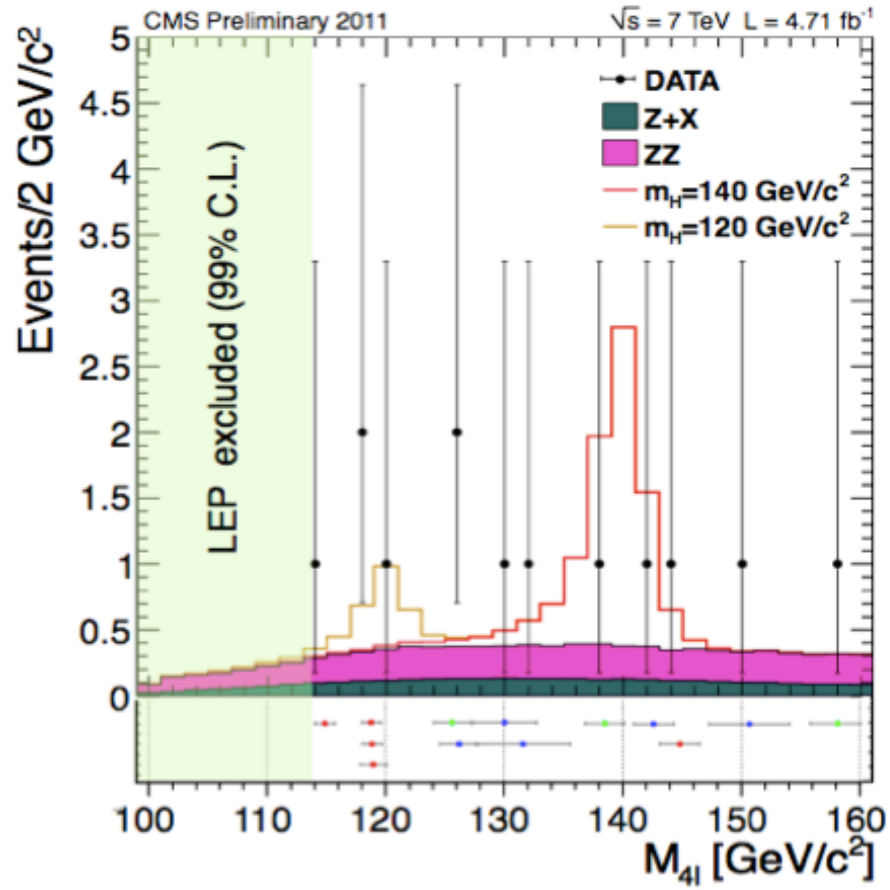


CMS

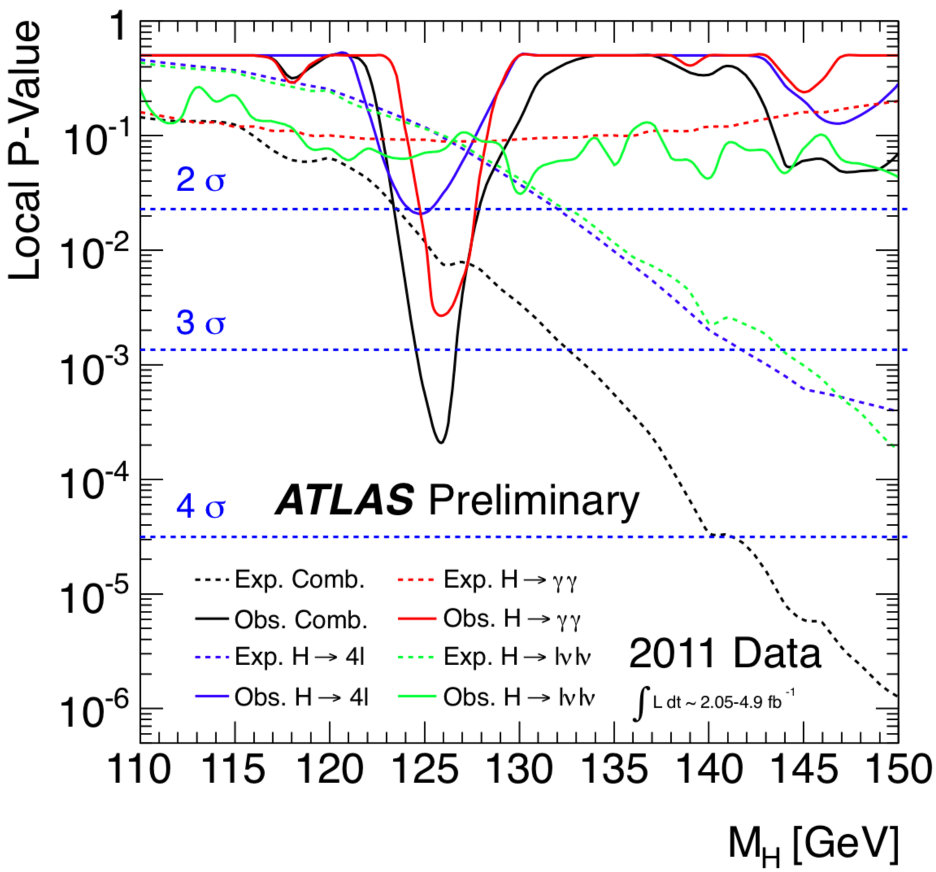


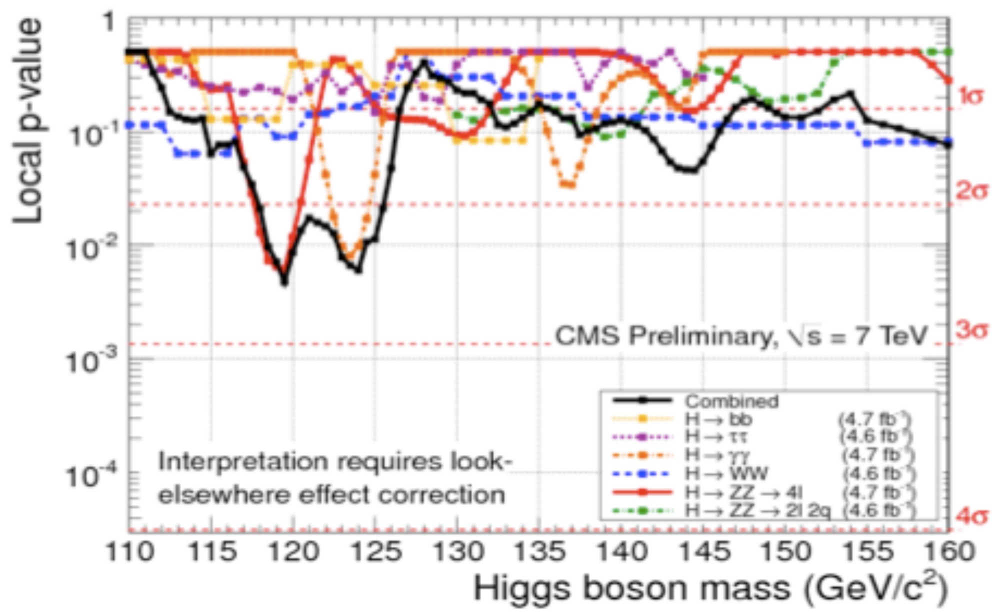
What do we know about these bumps?





What do we know about these bumps?

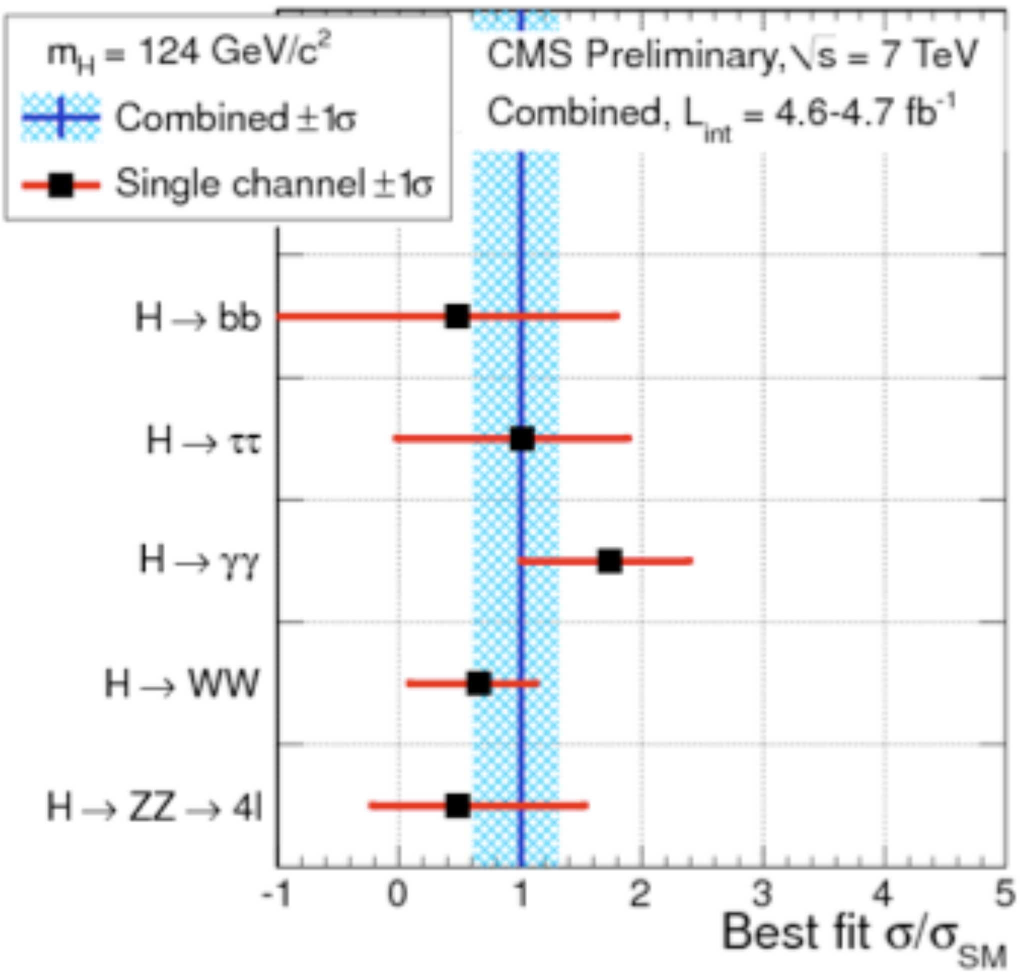




What do we know about these bumps?

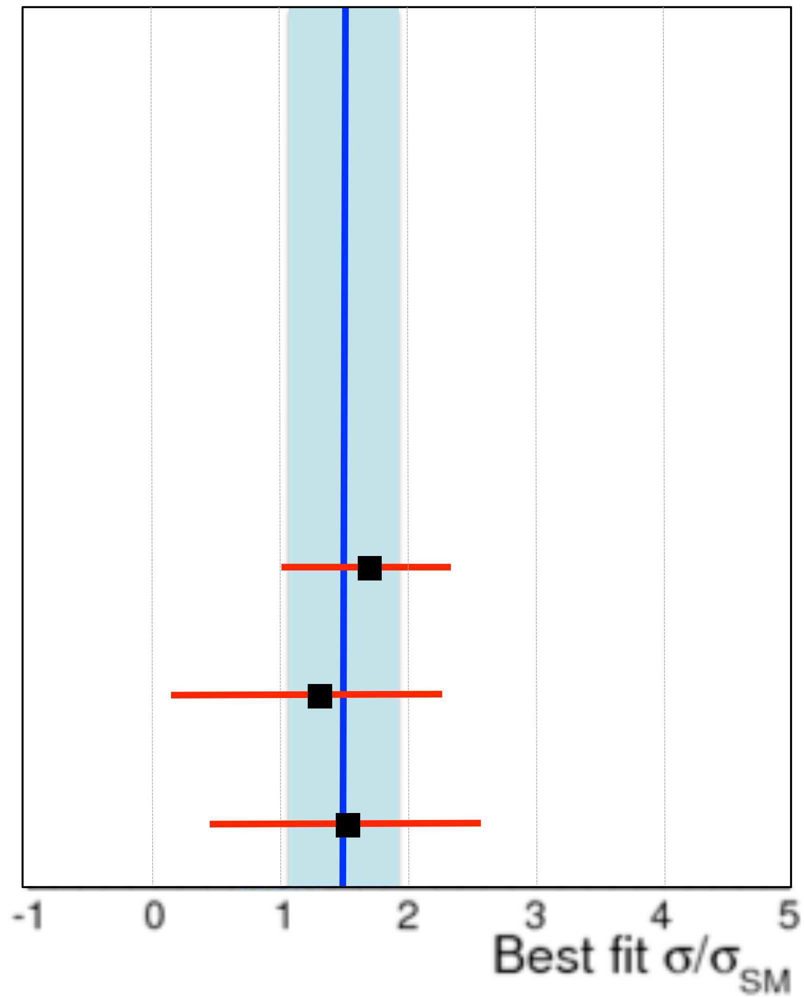
CMS

124 GeV



ATLAS approximate

125 GeV



What do we want to know?

- Under the hypothesis that the peaks at ~125 GeV are the signal of a particle decay, rather than a statistical fluctuation (nor are from the decay of more than one different particle), we would like to know this particle's:

  1) **Spin**, **CP**, and **effective couplings to each decay channel**

  2) *and are these consistent with expectations from a SM Higgs*,

  (in addition, of course, to its exact mass).

What can we say already?

- Since it appears to decay to $\gamma\gamma$, we know that it cannot be spin 1, and we also know that it cannot be a fermion =>
  - it *must* be **spin 0** or **2**

- Spin 2 (for example, a Randall-Sundrum graviton) is certainly still a conceivable possibility. In most such models, such particles also would decay to dileptons with a significant branching fraction – this certainly cannot be the case here (there are no bumps in dilepton mass spectra at this mass). But there is no fundamental reason for a tensor particle not to be fermiophobic.
  - *We need to exclude spin 2 experimentally.*

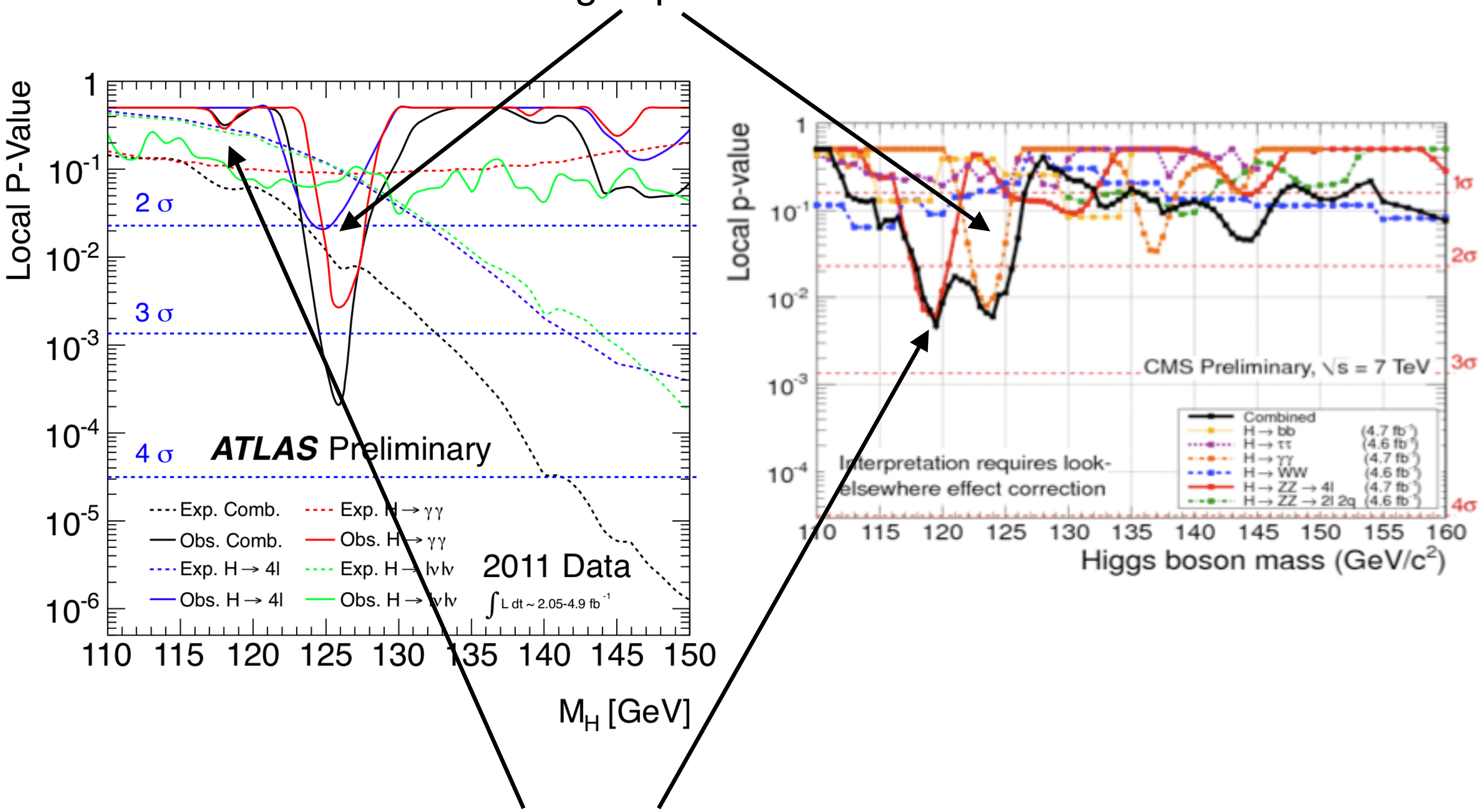
What can we say already?

- What do we know about its ***CP***?
  - Not much. Since it decays to two photons (and because it has even spin), its *C*-parity must be +1 *if* *C* happens to be conserved in the decay – but we don't know its parity. Must be measured experimentally as well.

- So far, the effective **couplings** of our possible particle appear consistent with an SM Higgs, but obviously be need quite a bit more data before effective couplings can be measured with any level of precision.

And might there be two particles?

god particle



dog particle

What info do we have?

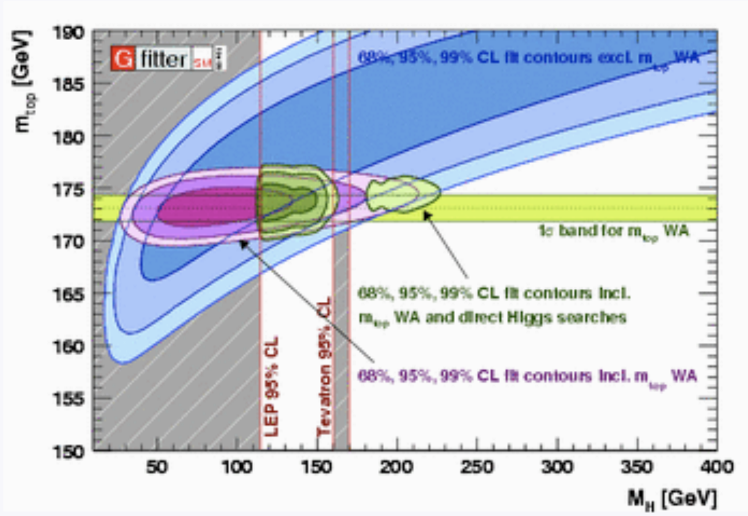
- With sufficient data, we can do an angular analysis of the 4 leptons from the ZZ^* decays, and thus obtain info on spin and *CP*.
- Once we have data in VBF channels, angular analysis of the jets (+ Higgs) can also give us information. (And analogously for $t\bar{t}$"*H*" channels.)
- Associated production channels (also, once we have data in them) can also help us exclude spin 2.
- The jet properties in "*H*" $\rightarrow$ *bb* and "*H*" $\rightarrow \tau\tau$ (again, once we have data in these channels) may also give some information.

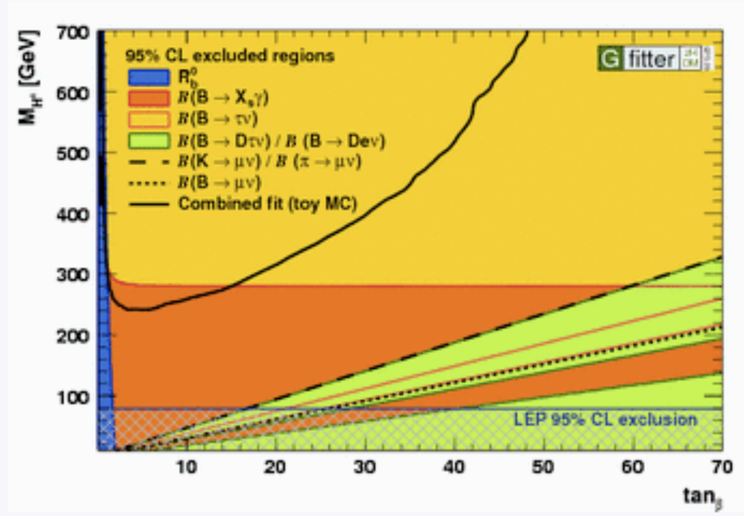
Combining info from different sources…

- And additionally, **ratios of observed yields** of the signal channels, and even **limits**, can also *all* contribute information on spin and *CP*.
- Information from these sources on Higgs spin and *CP* is coupled to and *correlated with* information on Higgs couplings and mass, as well as with other (less interesting) parameters.
- Need a system for combining all information into a **global fit** for Higgs spin and *CP* (as well as couplings)…
- Two general ways to do this:
  - a) Directly fit actual events (that pass signal selection for the various Higgs decays) into an event-by-event global fit for Higgs properties.
  - b) Combine already-experimentally-fitted information (constraints on spin, *CP*, and couplings, perhaps all as functions of Higgs mass) into world-average fits.
- Both are necessary. Let's start with b)

G fitter A Generic Fitter Project for HEP Model Testing

- **Home**
- Publications
- Talks
- *Packages*
  - SM Results
  - 2HDM Results
  - Oblique Parameters
  - GCombo
- License





- ↓ News
- ↓ Introduction
- ↓ Gfitter Features
- ↓ Gfitter Plugin Packages

(*) M.B. (CERN), H. Flächer (CERN), M. Goebel (Univ. Hamburg, DESY), J. Haller (Univ. Hamburg), A. Höcker (CERN), D. Ludwig (Univ. Hamburg, DESY), K. Mönig (DESY), M. Schott (CERN), J. Stelzer (DESY)

Gfitter

A *Generic Fitting Project for HEP Model Testing*

Goal: provide state-of-the-art model testing tool for LHC era

- Tools used by LEP written in outdated programming language, difficult to maintain in line with theoretical and experimental progress, difficult to include beyond-SM scenarios, limited fitting and statistics capabilities, …

Gfitter software

- Modular, object-oriented C++ relying on ROOT, XML and python
- Core package with data handling, fitting and statistics tools
- Independent physics libraries: SM, 2HDM, Oblique parameters, …

Gfitter features

- Consistent treatment of theoretical uncertainties in fit using *R*fit prescription (CKMfitter)
- Various fitting tools: Minuit, Genetic Algorithm and Simulated Annealing (via *T*MVA)
- Full statistics analysis: parameter scans, p-values, MC analyses, goodness-of-fit tests

Main publication: EPJ C60, 543-583,2009 [arXiv:0811.0009]

Higgs Mass Constraints

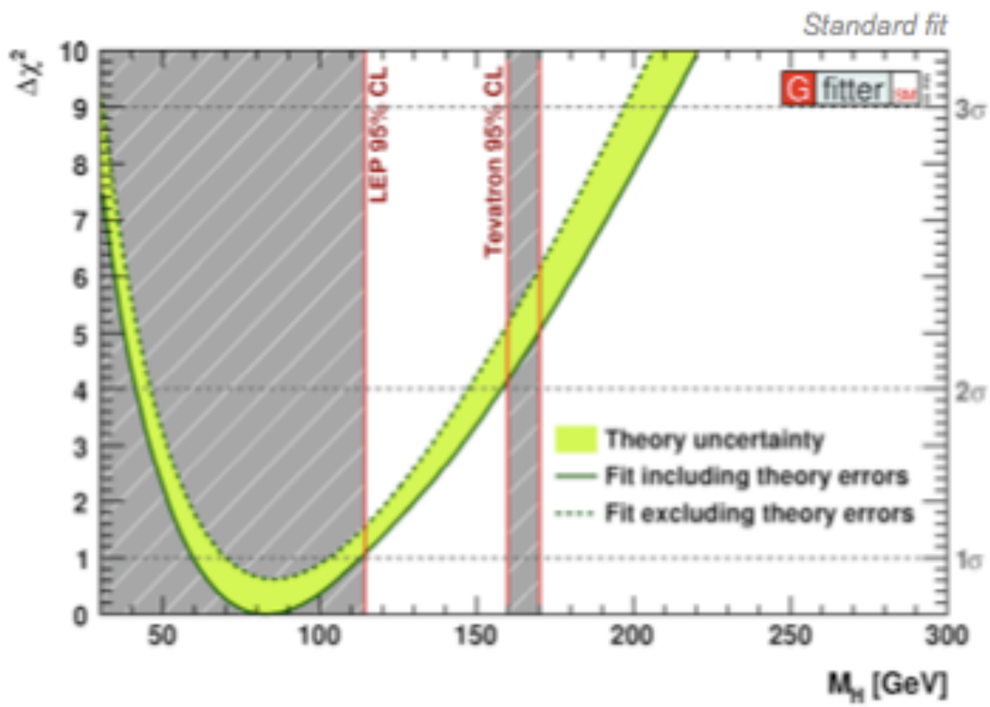
M_H from *Standard fit*:

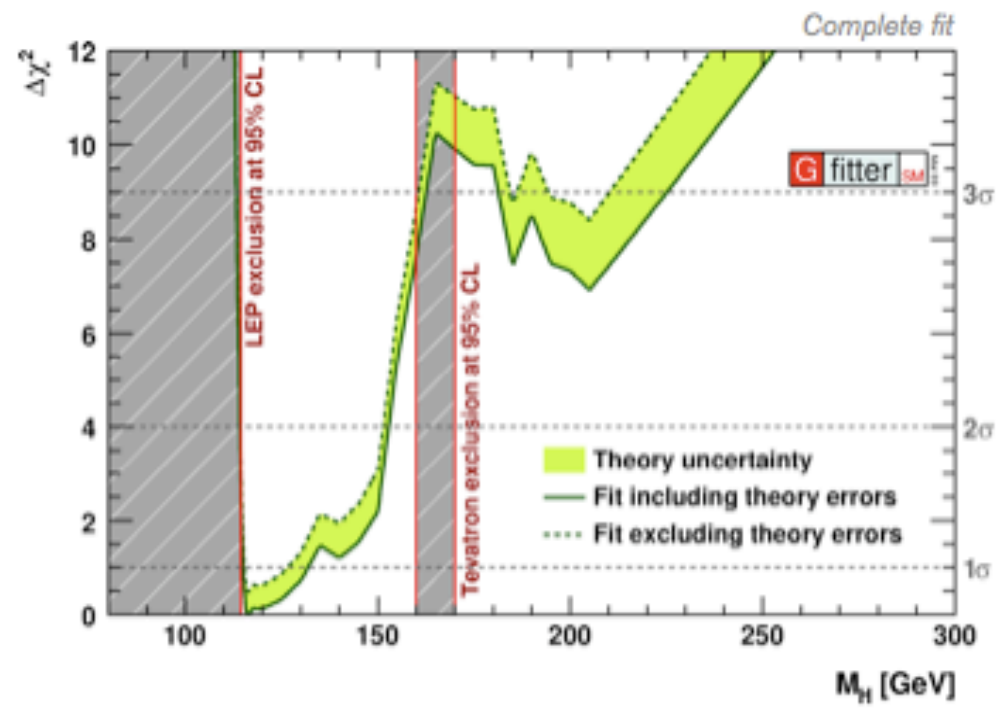
- Central value $\pm 1\sigma$: $M_H = 83^{+30}_{-23}$ GeV
- 2σ interval: [42, 158] GeV

Green band due to *R*fit treatment of theory errors, fixed errors lead to larger χ^2_{min}

M_H from *Complete fit*:

- Central value $\pm 1\sigma$: $M_H = 116^{+16}_{-1.3}$ GeV
- 2σ interval: [114, 153] GeV





A Generic, Model-Independent Parametrization

- Based on De Rujula et al. (“DLPRS”), arXiv: 1001.5300 (extend to additional Higgs decay modes) -- thanks to Adam Ritz & Heather Logan for discussions:

Higgs look-alikes at the LHC

A. De Rújula[a,b,c], Joseph Lykken[d], Maurizio Pierini[c], Christopher Rogan[e], and Maria Spiropulu[c,e]

[a] *Instituto de Física Teórica, Univ. Autónoma de Madrid, Madrid, and CIEMAT, Madrid, Spain,*
[b] *Physics Dept., Boston University, Boston, MA 02215,*
[c] *Physics Department, CERN, CH 1211 Geneva 23, Switzerland,*
[d] *Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510,*
[e] *Lauritsen Laboratory of Physics, California Institute of Technology, Pasadena, CA 91125*

The discovery of a Higgs particle is possible in a variety of search channels at the LHC. However, the true identity of any putative Higgs boson will, at first, remain ambiguous until one has experimentally excluded other possible assignments of quantum numbers and couplings. We quantify the degree to which one can discriminate a Standard Model Higgs boson from “look-alikes” at, or close to, the moment of discovery at the LHC. We focus on the fully-reconstructible “golden” decay mode to a pair of Z bosons and a four-lepton final state. Considering both on-shell and off-shell Z's, we show how to utilize the full decay information from the events, including the distributions and correlations of the five relevant angular variables. We demonstrate how the finite phase space acceptance of any LHC detector sculpts the decay distributions, a feature neglected in previous studies. We use likelihood ratios to discriminate a Standard Model Higgs from look-alikes with other spins or nonstandard parity, CP, or form factors. For a resonance mass of 200 GeV/c^2, we achieve a median discrimination significance of 3σ with as few as 19 events, and even better discrimination for the off-shell decays of a 145 GeV/c^2 resonance.

- General <u>spin 0</u> “Higgs” coupling to two vectors or two fermions:

$$L_{\mu\alpha} = X\, g_{\mu\alpha} - (Y + i\, Z)\, \frac{k_\alpha k_\mu}{M_X^2} + (P + i\, Q)\, \epsilon_{\mu\alpha} \frac{p_1 p_2}{M_X^2}$$

- Spin 1: $L^{\rho\mu\alpha} = X\,(g^{\rho\mu}\, p_1^\alpha + g^{\rho\alpha}\, p_2^\mu) + (P + i\, Q)\, \epsilon^{\rho\mu\alpha}(p_1 - p_2)$

- Spin 2$^+$:

$$\begin{aligned} L^{\rho\sigma\mu\alpha} = \; & X_0\, m_H^2\, g^{\mu\rho}\, g^{\alpha\sigma} \\ & + (X_1 + i\, Y_1)\,(p_1^\alpha\, p_2^\rho\, g^{\sigma\mu} + p_1^\rho\, p_2^\mu\, g^{\sigma\alpha}) \\ & + (X_2 + i\, Y_2)\, p_1^\rho\, p_2^\sigma\, g^{\mu\alpha}, \end{aligned}$$

(Lots of) Experimental Inputs

Measured rates (or limits on rates):

production	decay	mode #
gg -> H	ZZ	1
qqH	ZZ	2
gg -> H	WW	3
qqH	WW	4
ttH	WW	5
gg -> H	gam gam	6
qqH	gam gam	7
ttH	gam gam	8
WH	gam gam	9
ZH	gam gam	10
qqH	tau tau	11
ttH	b bbar	12
WH	b bbar	13
qqH	b bbar	14
qqH gamma	b bbar	15
gg -> H	Z gam	16

Decay width

The measured width of the Higgs decay (this is certain to be just an upper limit if we have an SM Higgs -- nevertheless, an upper limit gives information and potential constraints).

Angular variables

In modes 5, 8, 12 (ttH modes): the Gunion-He parameters (see hep-ph/9602226):
a_1, a_2, b_1, b_2, b_3, b_4

In those same modes: modified Gunion-He parameters (replacing the momentum of the antitop with the momentum of the reconstructed Higgs in the lab frame):
a_1', a_2', b_1', b_2', b_3', b_4'

In modes 2, 4, 7, 11, 14, 15 (VBF modes):
delta_phijj (the azimuthal angle between the two tagging jets, see hep-ph/0105325)
And the other phase space variable.
[
In modes 1 and 2 (H -> ZZ):
the phi & theta decay angles

In modes 3, 4, 5 (H -> WW):
the angle between the leptons (in the lab frame)

In mode 15:
the phase space variables

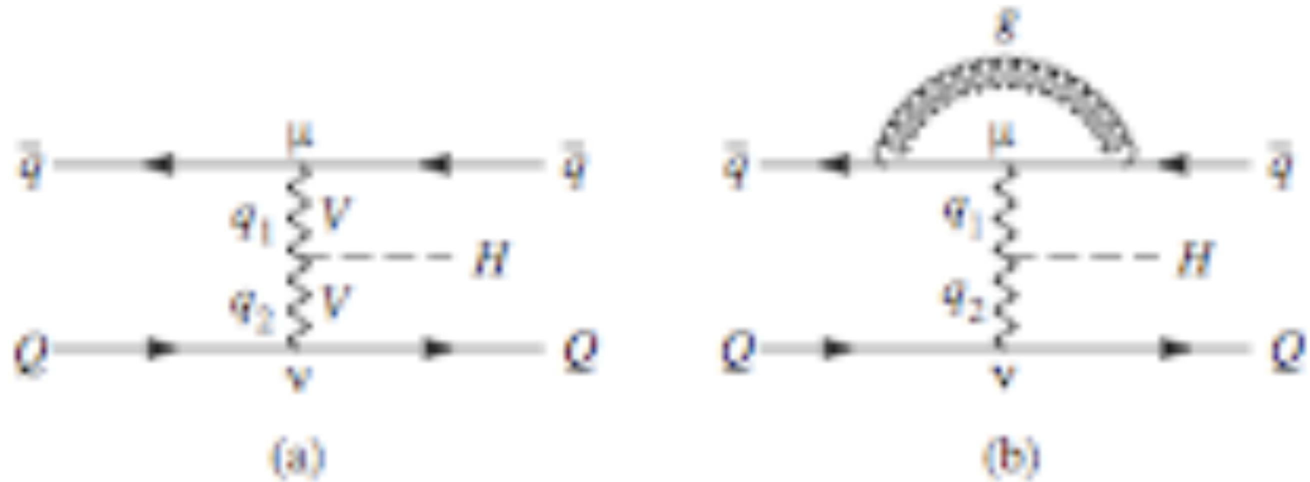
In modes 2, 4, 5:
angular correlations between the decay angles and the angles of the tagging jets?

Indirect Higgs information:

top mass, W mass, etc. ....

VBF $H \to b\bar{b}$

Eric Ouellette



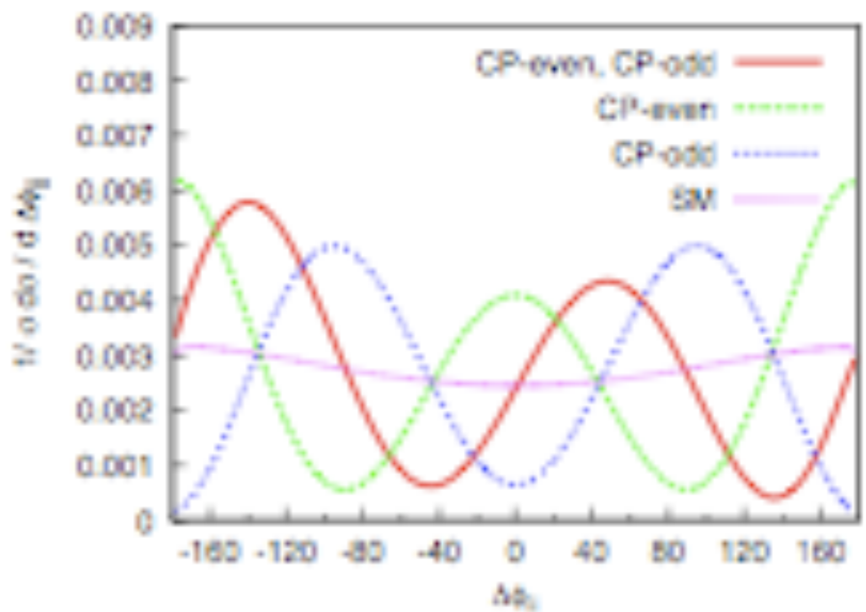
looking at most general tensor structure of this process:

$$T^{\mu\nu}(q_1, q_2) = a_1(q_1, q_2)g^{\mu\nu} + a_2(q_1, q_2)[q_1 \cdot q_2 g^{\mu\nu} - q_2^\mu q_1^\nu] + a_3(q_1, q_2)\epsilon^{\mu\nu\rho\sigma} q_{1\rho} q_{2\sigma}$$

VBF $H \to b\bar{b}$

Eric Ouellette

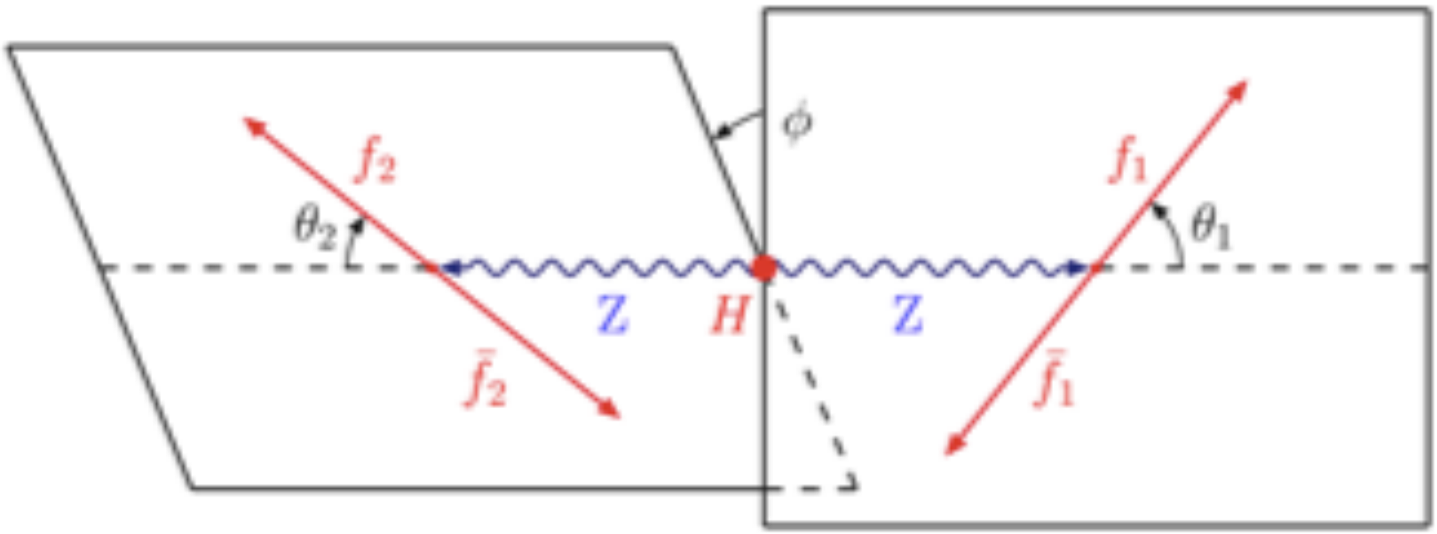
- An anomalous coupling will have several effects: Higgs production x-section, Higgs branching ratio, various final state distributions, etc.
- Observable most sensitive to anomalous coupling: azimuthal angle difference (azimuthal angle of "away" jet minus azimuthal angle of "toward" jet).



(Plehn, Rainwater, & Zeppenfeld, hep-ph/0105325)

$H \to ZZ^*$

Mike Jarrett

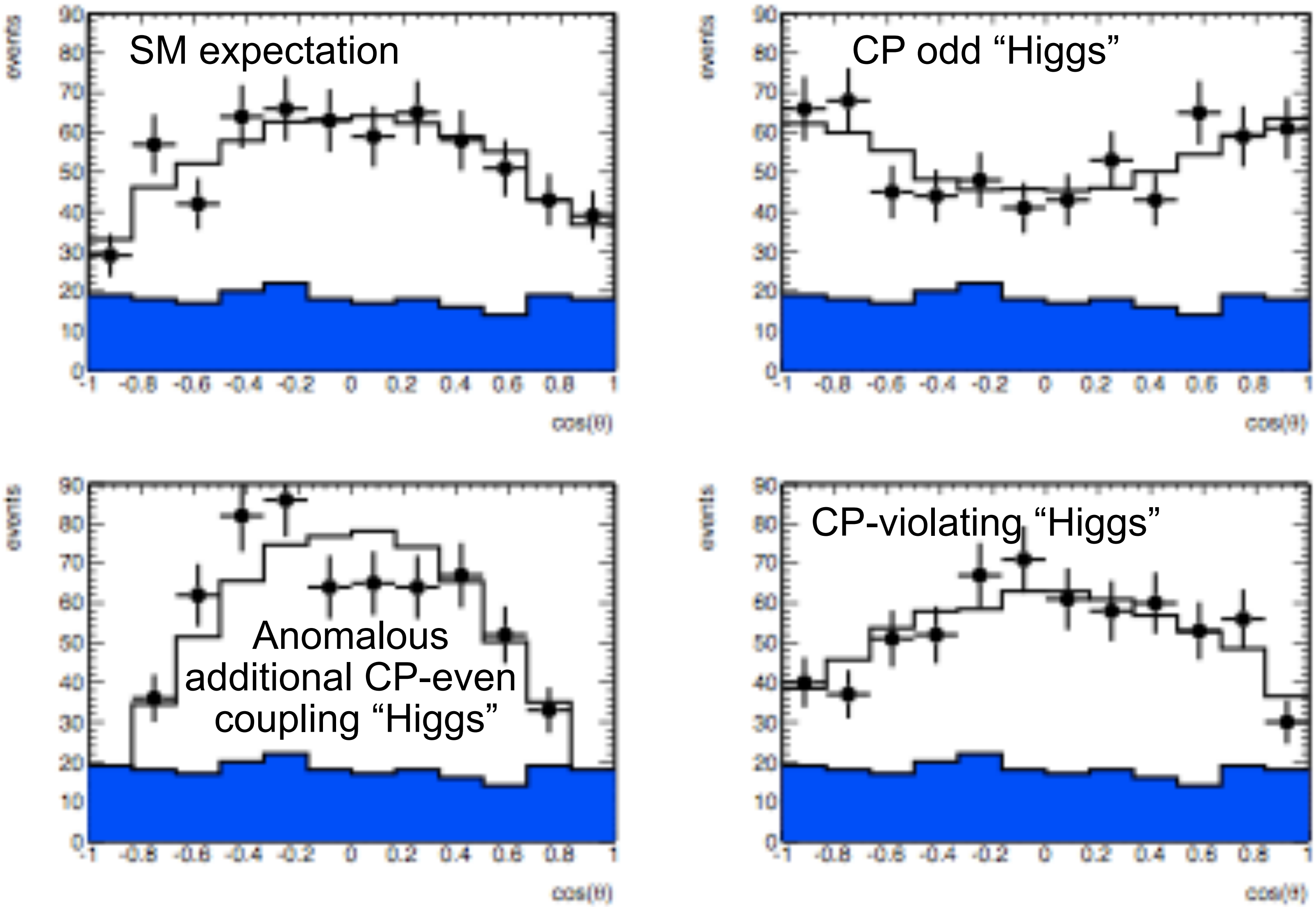


Eta	$\lesssim 2.5$
Leading Lepton Pt	20 GeV
Following Lepton Pt	7 GeV
Z Mass Acceptance	15 GeV

$H \rightarrow ZZ^*$

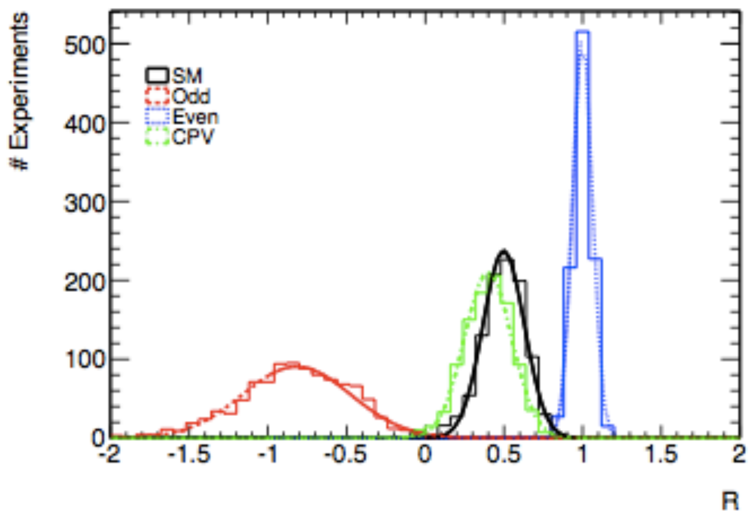
Mike Jarrett

$100\ fb^{-1}$

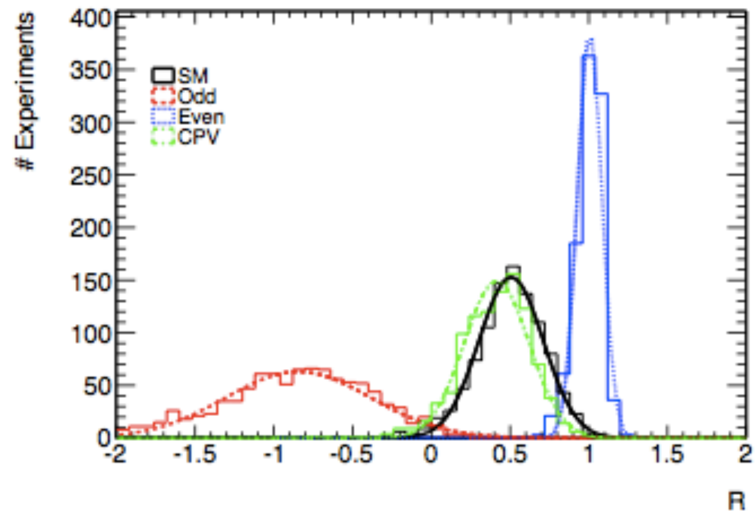


$H \rightarrow ZZ^*$

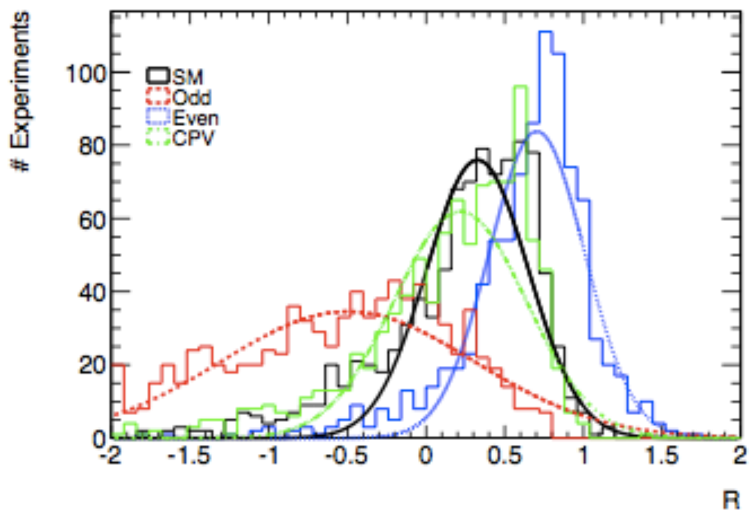
Mike Jarrett



(a) 100 fb^{-1}



(b) 50 fb^{-1}



(c) 10 fb^{-1}

Properties Fitting

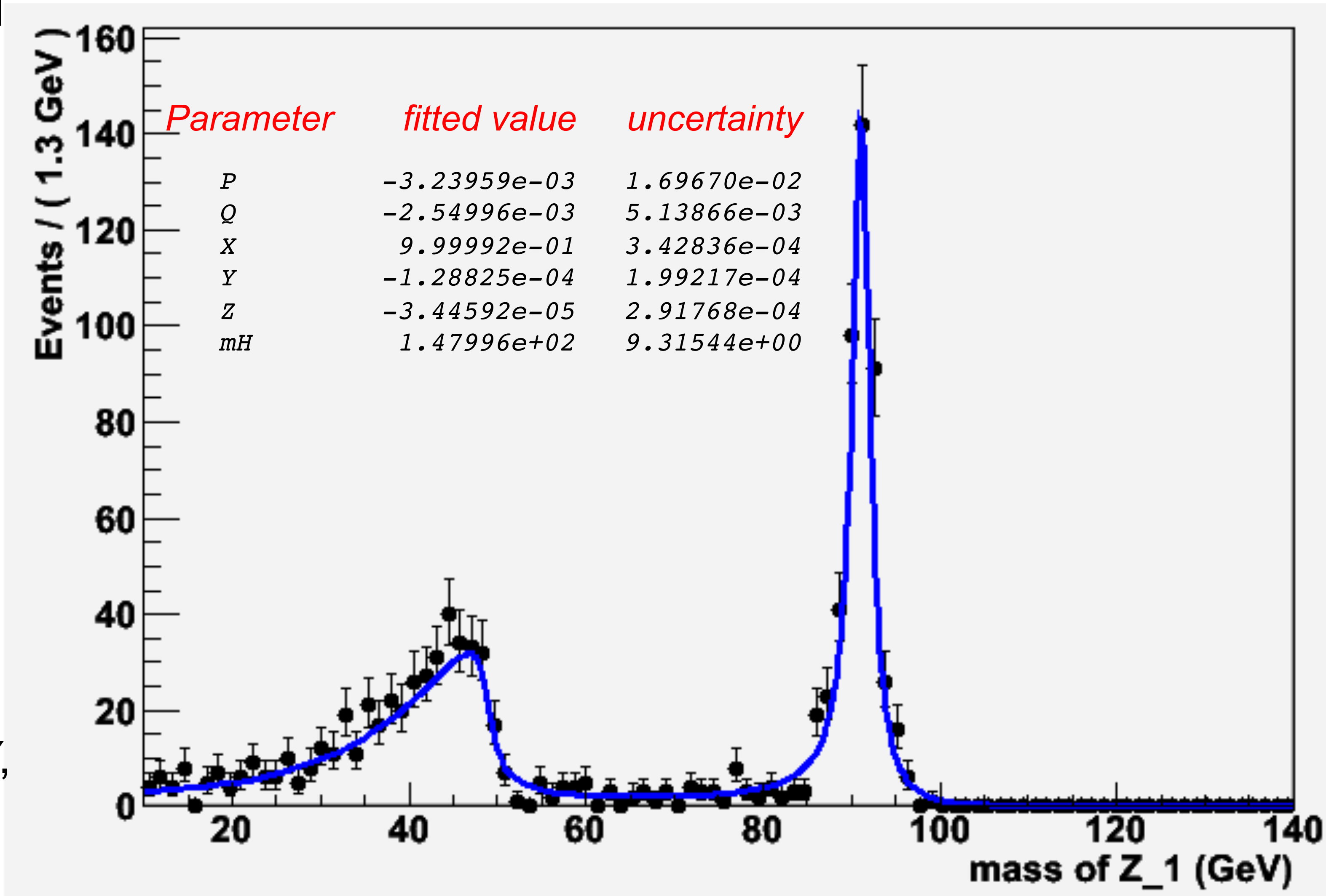
- Use best-fit values (with uncertainties) for other SM parameters.
- 21 parameter fit
- New package added to Gfitter.
- **BUT FIRST!**
  1) Before one can really utilize a package like Gfitter, one needs to do an experimental fit for signal and background in the individual modes, etc., to fit for the physical constraints that can then be used in the Gfitter fit.
  2) Gfitter ***does not (and can not)*** do an experimental fit for those physical constraints.
  3) An event-by-event experimental fit, combining all the individual modes, can in principle provide a lot more information than first fitting for constraints, then doing a separate fit to combine those constraints.

⇒ Need to start with an event-by-event experimental fit, with signal and background in each mode, for Higgs properties…

Higgs Properties Fit of 1000 $H \rightarrow ZZ^*$ events: Projection onto $m_{Z^{(*)}}$

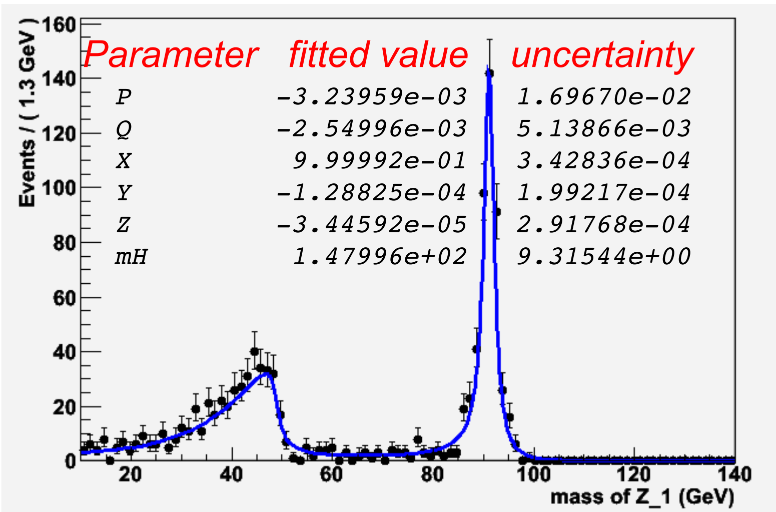
- RooFit-based fit to fully general PDF (as per the DLPRS paper).
- 1000 events (just signal, and just one decay mode, so far…).
- Fit for BSM parameters Y, Z, P, Q (as well as m_H).

m_H = 140 GeV

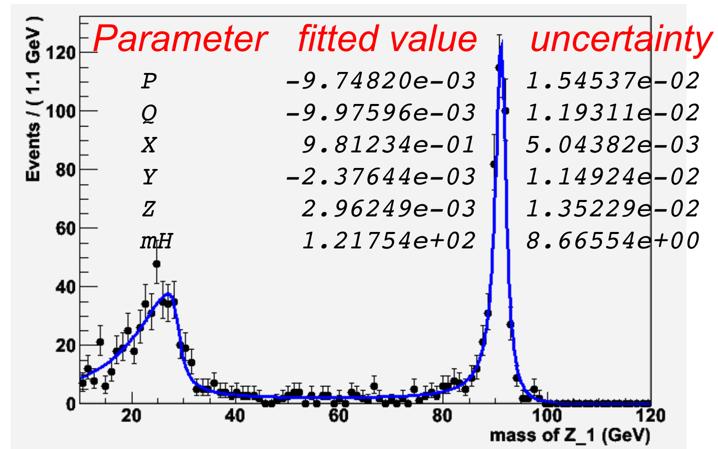


Higgs Properties Fit of 1000 $H \rightarrow ZZ^{(*)}$ events: Projection onto $m_{Z^{(*)}}$

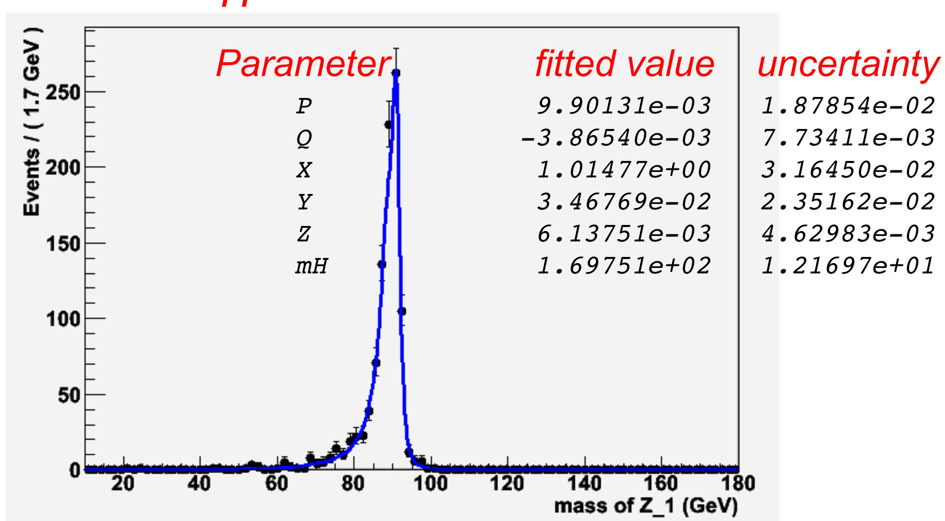
m_H = 140 GeV



m_H = 120 GeV



m_H = 180 GeV



Is this the SM Higgs??

Summary

- We already know a few things about this "Higgs," assuming it's not a fluctuation: it *must be spin 0 or 2*, and – so far… – the *couplings are consistent with SM* expectation.

- Other properties will need a little more time, but note that although individual Higgs decay modes require large amounts of data to determine Higgs properties, a global fit using all available info will start seeing results *much* sooner.

- Begun global Higgs properties fit, both event-by-event, as well as in the Gfitter framework – but **urgently need help from / collaboration with theorists**!
  - Thanks so far to Heather Logan and Adam Ritz for much helpful advice!

- With your (theorists') help, we should have much more info on the properties of our "possible Higgs" very soon.

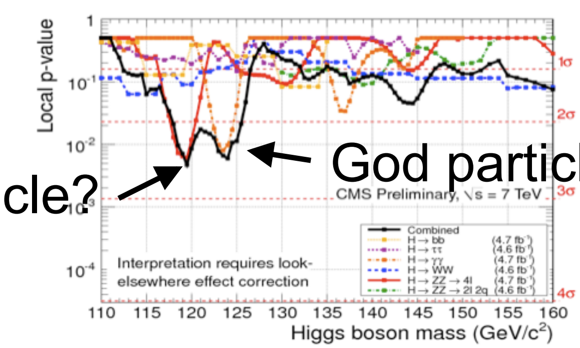
BACKUP

What do we know about these bumps?

- Before look-elsewhere-effect is considered, we have:
  - $\gamma\gamma$ channel: *ATLAS: 2.7σ signal, (2.0 ± 0.8) x SM @ (126 ± 2) GeV*
    - *CMS: 2.3σ signal, (1.8 ± 0.8) x SM @ (123 ± 3) GeV*
  - 4ℓ channel: *ATLAS: 2.0σ signal, (1.5 ± 1.1) x SM @ (124 ± 2) GeV*
    - *CMS: 0.7σ signal, (0.5 ± 0.7) x SM @ (125 ± 6) GeV*
  - $2\ell 2\nu$ channel: *ATLAS: 1.8σ signal, (2.1 ± 1.6) x SM @ (120 ± 15) GeV*
    - *CMS: 1.0σ signal, (0.7 ± 0.7) x SM @ (126 ± 2) GeV*

- After LEE is considered, we have
  - *ATLAS* combined: *2.3σ signal, (1.5 ± 0.6) x SM @ (125 ± 2) GeV*
  - *CMS* combined: *1.9σ signal, (1.2 ± 0.6) x SM @ (122 ± 3) GeV*

- Could there be two separate bumps (at 119 and 125 GeV)?



Dog particle?

God particle