Search for degenerate Higgs bosons

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Searching for another resonance - why?

- The peak we saw: what if it contains two particles with the same mass? What if there are two Higgs bosons with very similar masses (or the same mass) but different branching ratios or production cross sections?
- How to test this? Mass resolution is not good enough for one to see two peaks almost on top of each other...
- My summer student project: find out if there is more than one Higgs bosons with the almost same masses by looking at the cross section times branching ratio $(\sigma B)_{meas.}$ in different modes.
- I will show how to search for another resonance using simplified ("toy") data. Work with real data is ongoing.

Searching for another resonance - theory

- Suggestion in articles (Arxiv: 1301.0328 and 1208.1817): calculate the rank of the matrix of the measured $(\sigma B)_{meas.}$. If there is only one Higgs boson, the rank is one. If the rank is two, then there are two or more Higgs bosons.
- Simple example: 2x2 matrix, only one Higgs boson.

	$H\gamma\gamma$	HW^+W^-
ggH	$\sigma_{gg} B_{\gamma\gamma}$	$\sigma_{gg} B_{ww}$
qqH	$\sigma_{qq} B_{\gamma\gamma}$	$\sigma_{qq} B_{ww}$

$\rightarrow$ Determinant is
$(\sigma_{gg} B_{\gamma\gamma})(\sigma_{qq} B_{ww}) - (\sigma_{gg} B_{ww})(\sigma_{qq} B_{\gamma\gamma}) = 0$
$\rightarrow$ double ratio $\rho = \frac{(\sigma_{gg} B_{\gamma\gamma})(\sigma_{qq} B_{ww})}{(\sigma_{gg} B_{ww})(\sigma_{qq} B_{\gamma\gamma})} = 1$
$\rightarrow$ rank is 1.

Searching for another resonance - example

- Simple example: 2x2, two Higgses.

	$H\gamma\gamma$	HW^+W^-
ggH	$\sigma_{gg1}B_{\gamma\gamma1} + \sigma_{gg2}B_{\gamma\gamma2}$	$\sigma_{gg1}B_{ww1} + \sigma_{gg2}B_{ww2}$
qqH	$\sigma_{qq1}B_{\gamma\gamma1} + \sigma_{qq2}B_{\gamma\gamma2}$	$\sigma_{qq1}B_{ww1} + \sigma_{qq2}B_{ww2}$

$\rightarrow$ Determinant is

$(\sigma_{gg1}B_{\gamma\gamma1} + \sigma_{gg2}B_{\gamma\gamma2})(\sigma_{qq1}B_{ww1} + \sigma_{qq2}B_{ww2})$
$-(\sigma_{gg1}B_{ww1} + \sigma_{gg2}B_{ww2})(\sigma_{qq1}B_{\gamma\gamma1} + \sigma_{qq2}B_{\gamma\gamma2})$
$= \sigma_{gg1}B_{\gamma\gamma1}\sigma_{qq2}B_{ww2} + \sigma_{gg2}B_{\gamma\gamma2}\sigma_{qq1}B_{ww1}$
$-\sigma_{gg1}B_{\gamma\gamma2}\sigma_{qq2}B_{ww1} - \sigma_{gg2}B_{\gamma\gamma1}\sigma_{qq1}B_{ww2}$
$\neq 0$

$\rightarrow$ in general, double ratio $\rho \neq 1$.

$\rightarrow$ rank is 2.

Searching for another resonance - how?

- Start from a toy data matrix (2x2).
- Elements in this matrix are signal strengths: $\frac{(\sigma B)_{meas.}}{(\sigma B)_{SM}}$.
  Following values are the latest public CMS results (CMS-PAS-HIG-13-005):

	$\mathrm{H}\gamma\gamma$	$\mathrm{H}W^+W^-$
ggH	0.70 ± 0.31	0.73 ± 0.21
qqH	1.01 ± 0.58	-0.047 ± 0.65

- Because of the uncertainties, computing the double ratio is not straightforward.
  Solution: evaluate the statistical compatibility of the observed data with a matrix of double ratio 1.

Searching for another resonance - statistical treatment

- Scan the likelihood as function of the double ratio ρ, profiling the other parameters.
- A model in which the double ratio ρ is the parameter of interest must be defined:
  for (ggH, qqH $\to \gamma\gamma$, W^+W^-) the model is following

	$\mathrm{H}\gamma\gamma$	$\mathrm{H}W^+W^-$
ggH	$\mu_{\gamma\gamma}$	μ_{ww}
qqH	$\lambda \cdot \mu_{\gamma\gamma}$	$\lambda \cdot \mu_{ww} \cdot \rho$

- For testing the hypothesis of one Higgs ($\rho = 1$) we define the profile likelihood ratio

$$q(\rho) = -2 \ln \frac{L(\rho)}{L(\hat{\rho})} = -2 \ln L(\rho) + 2 \ln L(\hat{\rho}).$$

- A p-value is obtained from the fact that approximately

$$q(\rho = 1) = \chi^2(1 \text{ d.o.f}),$$

  which is a test against the hypothesis of rank one.

Plot of the case 1 (ggH, qqH $\rightarrow \gamma\gamma$, W^+W^-)

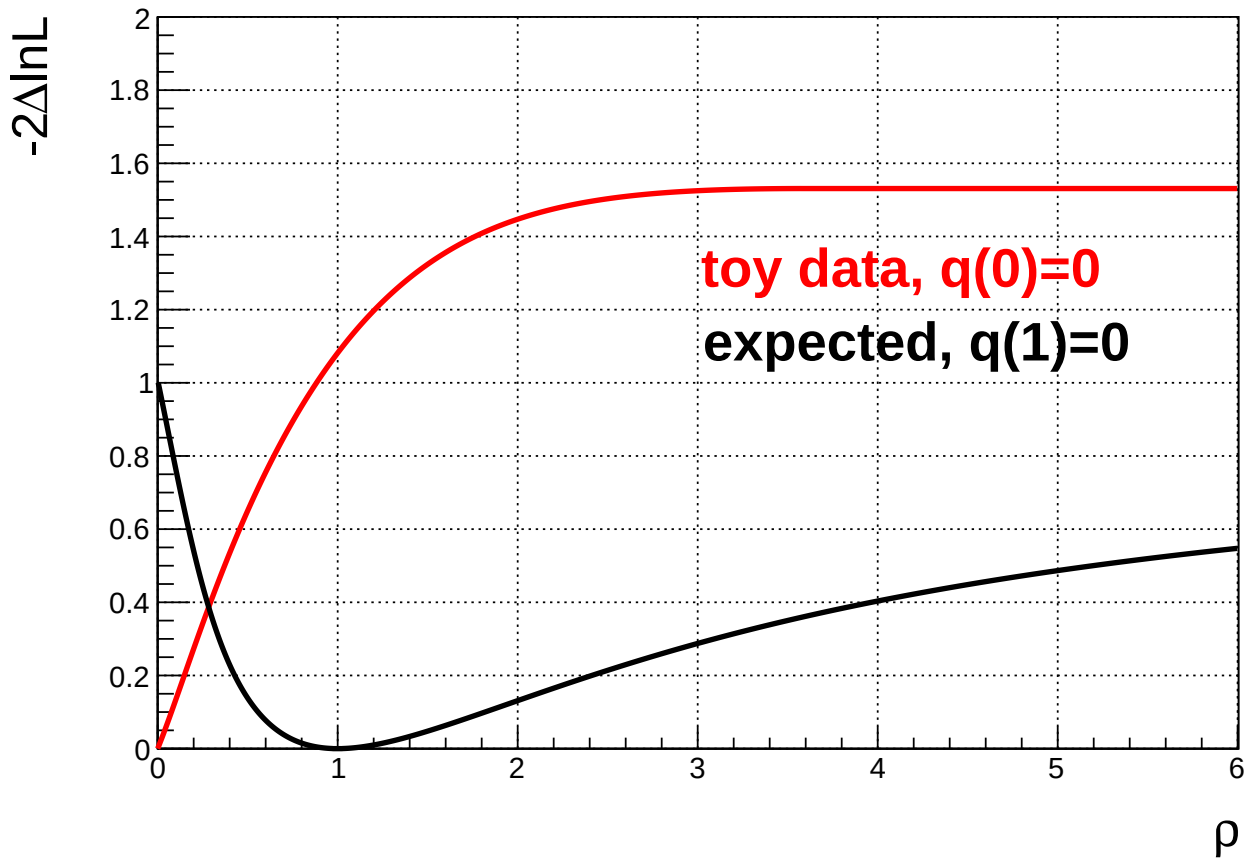

Figure: (ggH, VBF $\rightarrow \gamma\gamma$, W^+W^-). Fitting of the double ratio ρ (best fit value $\hat{\rho} = -0.21$). The p-value in this case is 0.30 - this means that there is approximately 30 % probability to measure q(1)>1.075 by accident if the matrix has rank one.

Conclusion

- A method to test for the presence of multiple Higgs bosons has been developed.
- Using simplified CMS data from the W^+W^- and $\gamma\gamma$ decay channels, we obtain a result compatible with a single Higgs boson at the level of 30%.
- The analysis is now being done using the full data and the other production and decay modes.

References for further reading

- Yuval Grossman, Ze'ev Surujon, Jure Zupan:
  How to test for mass degenerate Higgs resonances
  (`http://arxiv.org/abs/1301.0328`)
- John F. Gunion, Yun Jiang, Sabine Kraml:
  Diagnosing Degenerate Higgs Bosons at 125 GeV
  (`http://arxiv.org/abs/1208.1817`)
- CMS Collaboration:
  Combination of standard model Higgs boson searches and measurements of the properties of the new boson with a mass near 125 GeV
  (`http://cds.cern.ch/record/1542387`).