Higgs spin and parity measurements from CMS

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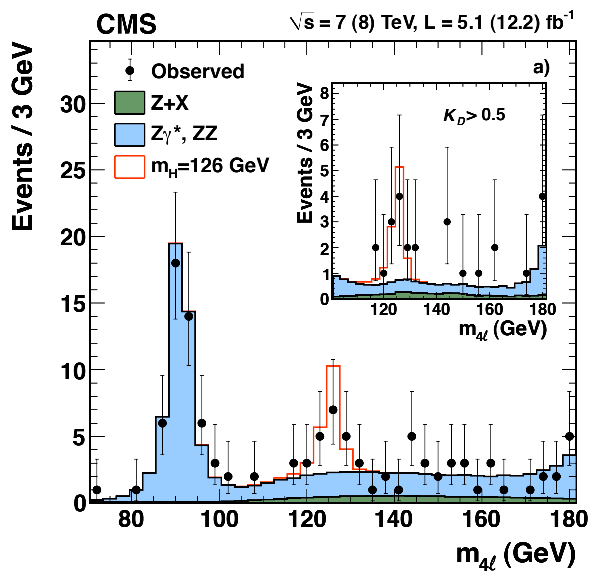
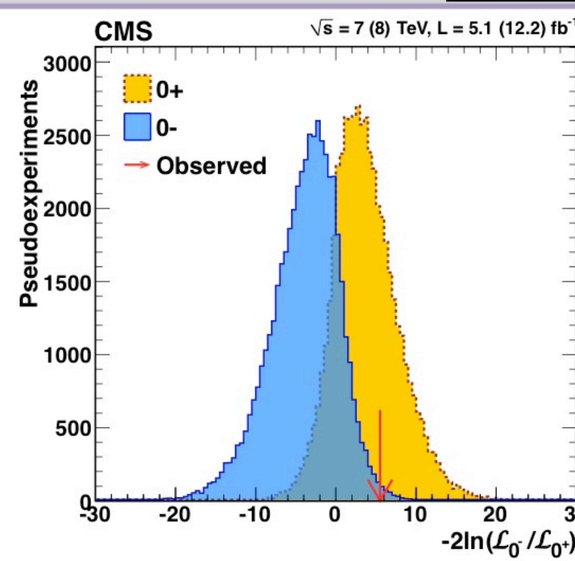
Physics reach

- CMS and ATLAS discovered a Higgs-like boson
- The next big question: is this *the* standard model Higgs?
  - What is the J^{CP} property?
  - If there is a small deviation from SM, are we able to detect it?
  - Interference effects deepens amount of phenomenology in this channel
- H→ZZ→4l channel allows us to probe the HZZ vertex very cleanly
  - Great S/B ratio, very clean sample for property measurement



Hypothesis testing and f_{a3}

- We are able to distinguish different cases through hypothesis testing
  - Excluded a lot of models!
- As well as measure the amount of mixture from CP-odd coupling to ZZ through higher-order operator on top of SM

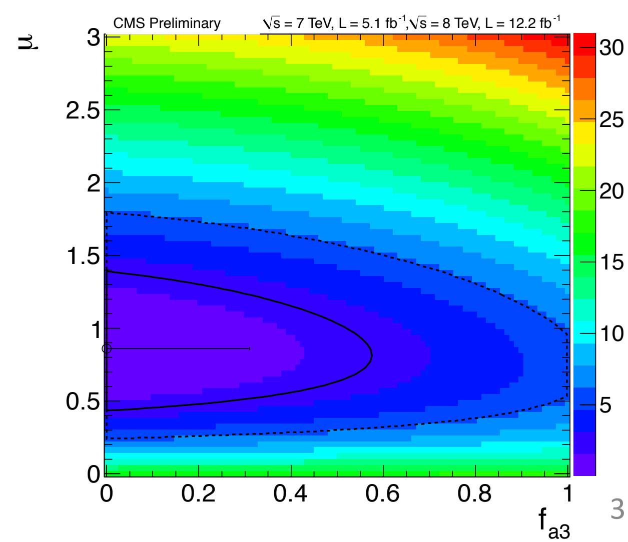


$$L \sim v^{-1} X (A_1^{ZZ} m_z^2 Z_\mu Z^\mu + A_2^{ZZ} Z_{\mu\nu} Z^{\mu\nu} + A_3^{ZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu}$$

$$+ A_2^{ZA} Z_{\mu\nu} F^{\mu\nu} + A_3^{ZA} Z_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$+ A_2^{AA} F_{\mu\nu} F^{\mu\nu} + A_3^{AA} F_{\mu\nu} \tilde{F}^{\mu\nu})$$

* Couplings involving photons are usually not considered in the 4l channel



Possible next steps

arxiv: 1309.4819
arxiv: 1310.1397
…

- One natural extension is to measure other couplings
- Some complementary approaches are possible
  - Extending fa3 measurement to measure other pairs of couplings
    - Having advantage of being a natural extension of a well-established analysis
    - Easier to implement, but has some limitations
  - Construct likelihood and perform a fit to data to directly extract all effective couplings
    - A novel approach: requires a lot of work and thinking
    - Would allow us to extract as many parameters as we want at once
    - More details in the next page

Documentation: in preparation, coming soon

Direct extraction of couplings

- It's a very ambitious project
  - Both in terms of physics reach and computing
- Construct a continuous detector-level likelihood function as a continuous function of Lagrangian parameters
  - The function is 12 dimensional
  - It includes all interference effects between different couplings
- This is done by convoluting differential cross section with detector effects $P(\vec{X}^{reco} \mid \vec{A}^{lagrangian}) = Differential\ cross\ section \otimes Detector$
  - Through numerical integration (not MC integration)
- Once the likelihood is built it is conceptually straightforward to perform unbinned fit to data and extract parameters

Example – proof of principle

- We take lepton response functions roughly similar to CMS, and smear samples (+efficiency) generated by Madgraph
- Construct likelihood and perform fits to extract result for one pseudo-experiment of 5000 events, floating all parameters at the same time

Parameter	True value	Fitted value
A_2^{ZZ}/A_1^{ZZ}	3.85	3.754 ± 0.073
A_3^{ZZ}/A_1^{ZZ}	5.05	5.08 ± 0.20
A_2^{ZA}/A_1^{ZZ}	0	-0.005 ± 0.013
A_3^{ZA}/A_1^{ZZ}	0	0.0006 ± 0.018
A_2^{AA}/A_1^{ZZ}	0	-0.0012 ± 0.0048
A_3^{AA}/A_1^{ZZ}	0	-0.0013 ± 0.0042

Covariance and correlation matrices

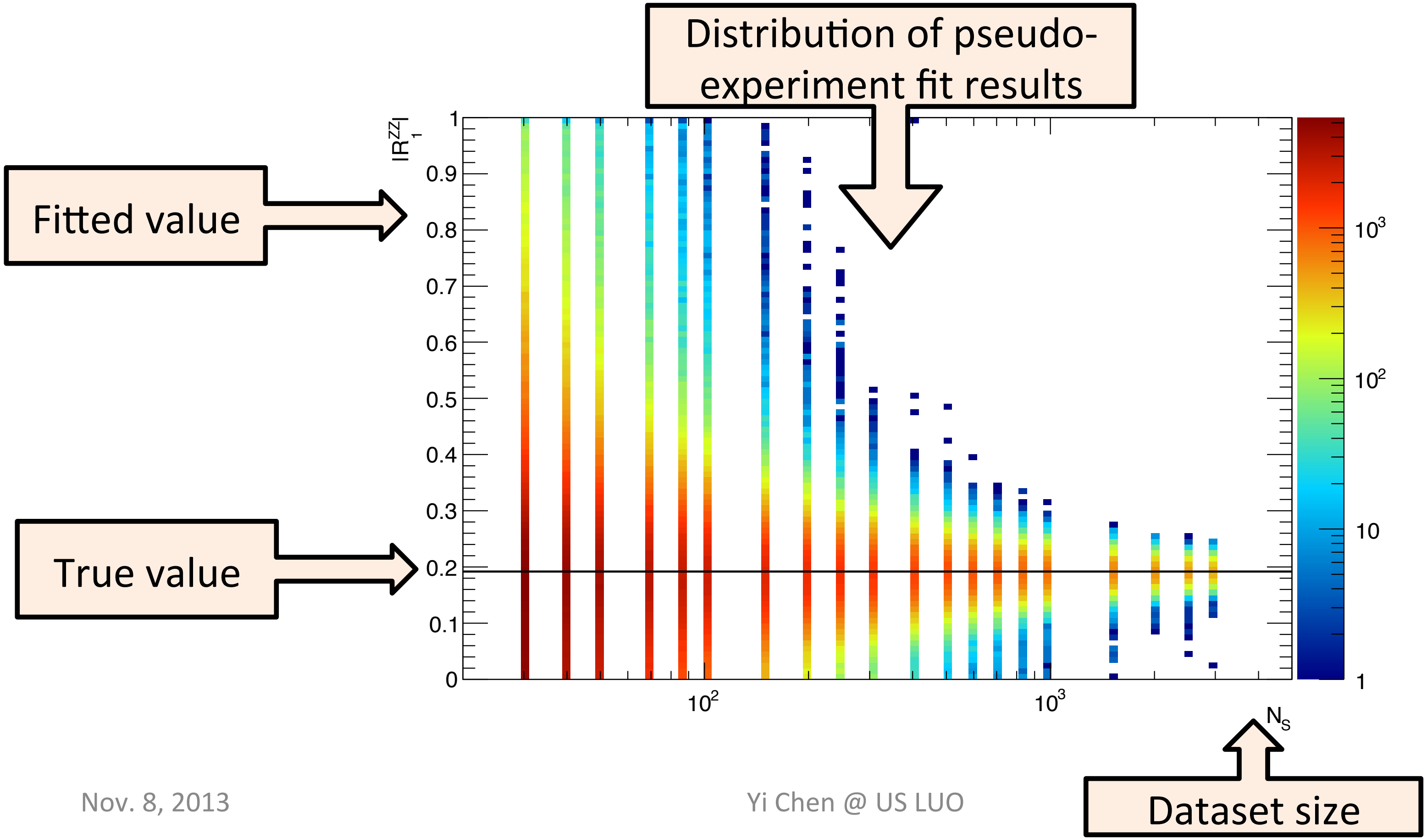
5.380e-03	2.042e-03	2.120e-04	-1.556e-04	2.319e-05	-1.502e-05
2.042e-03	4.053e-02	-2.874e-04	1.199e-04	-5.645e-05	1.361e-06
2.120e-04	-2.874e-04	1.736e-04	-4.836e-05	1.712e-05	-4.103e-06
-1.556e-04	1.199e-04	-4.836e-05	3.325e-04	-4.654e-06	2.357e-05
2.319e-05	-5.645e-05	1.712e-05	-4.654e-06	2.279e-05	-2.889e-06
-1.502e-05	1.361e-06	-4.103e-06	2.357e-05	-2.889e-06	1.728e-05

PARAMETER CORRELATION COEFFICIENTS

NO.	GLOBAL	1	3	5	7	9	11
1	0.28386	1.000	0.138	0.219	-0.116	0.066	-0.049
3	0.20259	0.138	1.000	-0.108	0.033	-0.059	0.002
5	0.39476	0.219	-0.108	1.000	-0.201	0.272	-0.075
7	0.36730	-0.116	0.033	-0.201	1.000	-0.053	0.311
9	0.30440	0.066	-0.059	0.272	-0.053	1.000	-0.146
11	0.33779	-0.049	0.002	-0.075	0.311	-0.146	1.000

Example – proof of principle

- The fit is seen to be stable in toy studies, and uncertainty is seen to behave reasonably as a function of dataset size



Summary

- We have reached the milestone of discovering the new particle, now it's time to characterize it
- A lot has been learned about it so far
- We strive to learn as much as we can from data, and with different novel approaches we can do a lot more than before
  - For example study if SM fluctuations can be faked by combinations of different operators
  - Many interesting features in this model space can be probed for the first time with full detector effects

- Exciting physics awaits!