Property Measurements of Higgs-like Single Resonance at LHC

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On behalf of CMS+

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Outline

- Review of CMS spin/parity methods and HCP results
  - http://arxiv.org/pdf/1212.6639v1.pdf
- Review the pp→X→VV interactions
  - The JHU Generator is used to simulate the pp→X→VV interactions
    - Phys. Rev. D 86, 095031
  - See previous talk at this meeting
    - https://indico.cern.ch/getFile.py/access?contribId=2&resId=0&materialId=slides&confId=202154
- Summary and Discussions

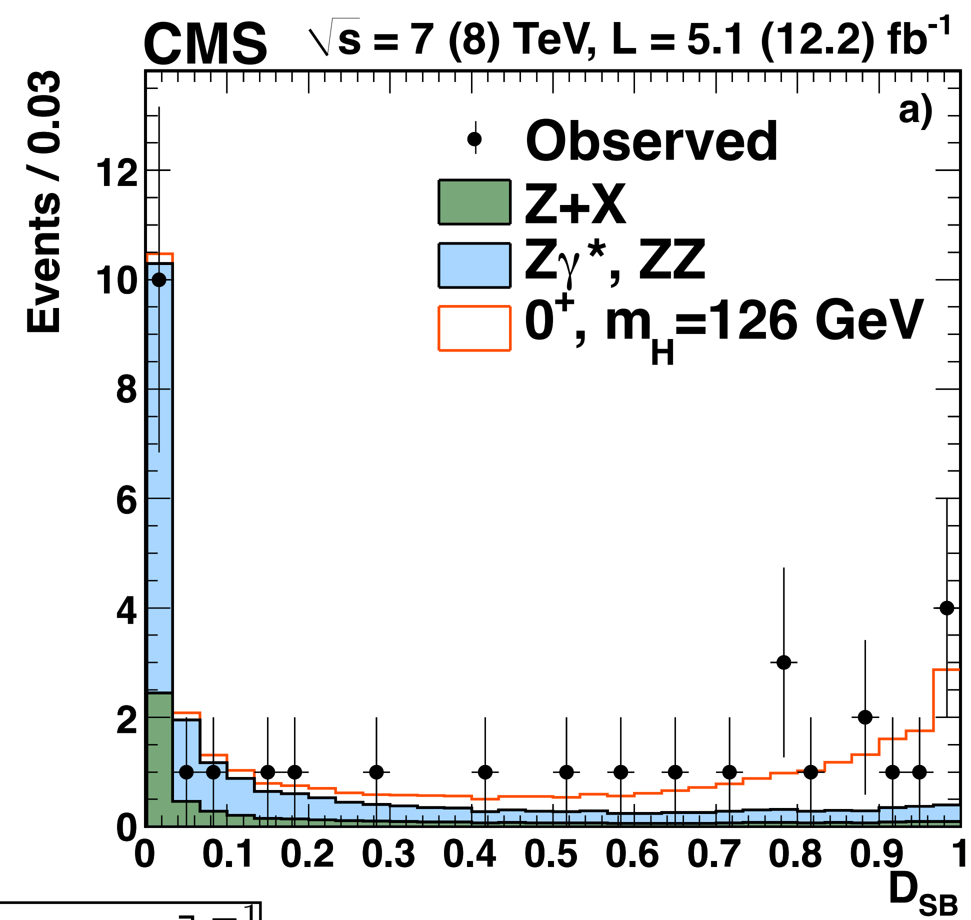
A family of MELAs in CMS

- To describe a given 4l events at the c.o.m, we need a set of 8 variables
  - 3 masses, 2 production angles and 3 decay angles: m(4l), m(z1), m(z2), θ^*, Φ_1, θ_1, θ_2, Φ
  - The PDF of these 8 variables can be calculated analytically/numerically for given a particular model and thus used fully in a 8D fit
- With limited statistics, we combine the non-m(4l) variables into kinematic discriminants

$$\text{MELA} \equiv \frac{\mathcal{P}_{\rm sig}}{\mathcal{P}_{\rm sig}+\mathcal{P}_{\rm bkg}} = \left[1+\frac{\mathcal{P}_{\rm bkg}(m_{Z_1},m_{Z_2},\vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\rm sig}(m_{Z_1},m_{Z_2},\vec{\Omega}|m_{4\ell})}\right]^{-1}$$

For Spin/parity, we use as input 2-D templates

1. One distinguishes SMHiggs over background (superMELA)
2. The other distringuish SM Higgs with other spin/parity models(pseduoMELA, gravi-MELA) shown later



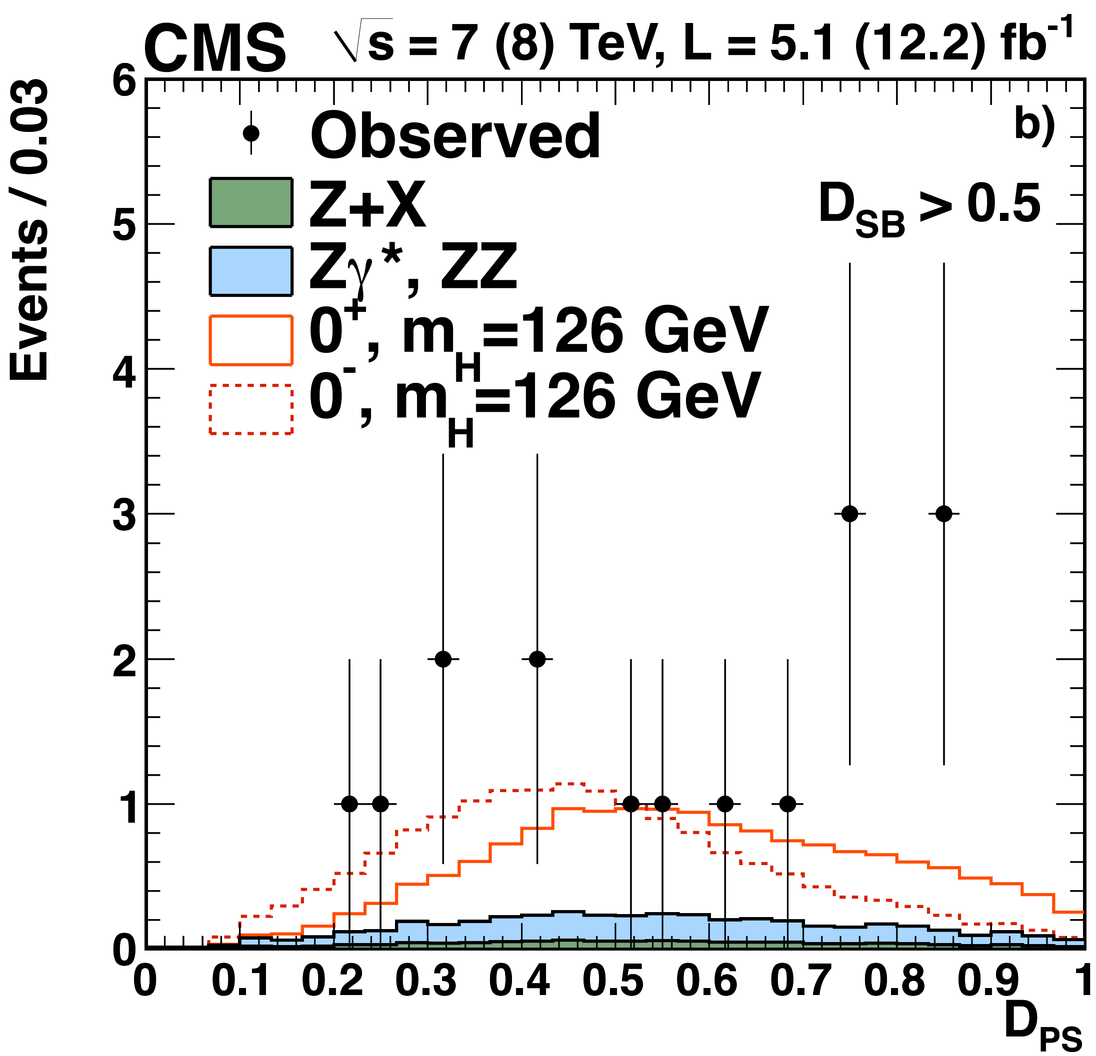
$$\text{superMELA} \equiv \frac{\mathcal{P}_{\rm sig}}{\mathcal{P}_{\rm sig}+\mathcal{P}_{\rm bkg}} = \left[1+\frac{\mathcal{P}_{\rm bkg}(m_{Z_1},m_{Z_2},\vec{\Omega}|m_{4\ell})\mathcal{P}_{\rm bkg}(m_{4\ell})}{\mathcal{P}_{\rm sig}(m_{Z_1},m_{Z_2},\vec{\Omega}|m_{4\ell})\mathcal{P}_{\rm sig}(m_{4\ell})}\right]^{-1}$$

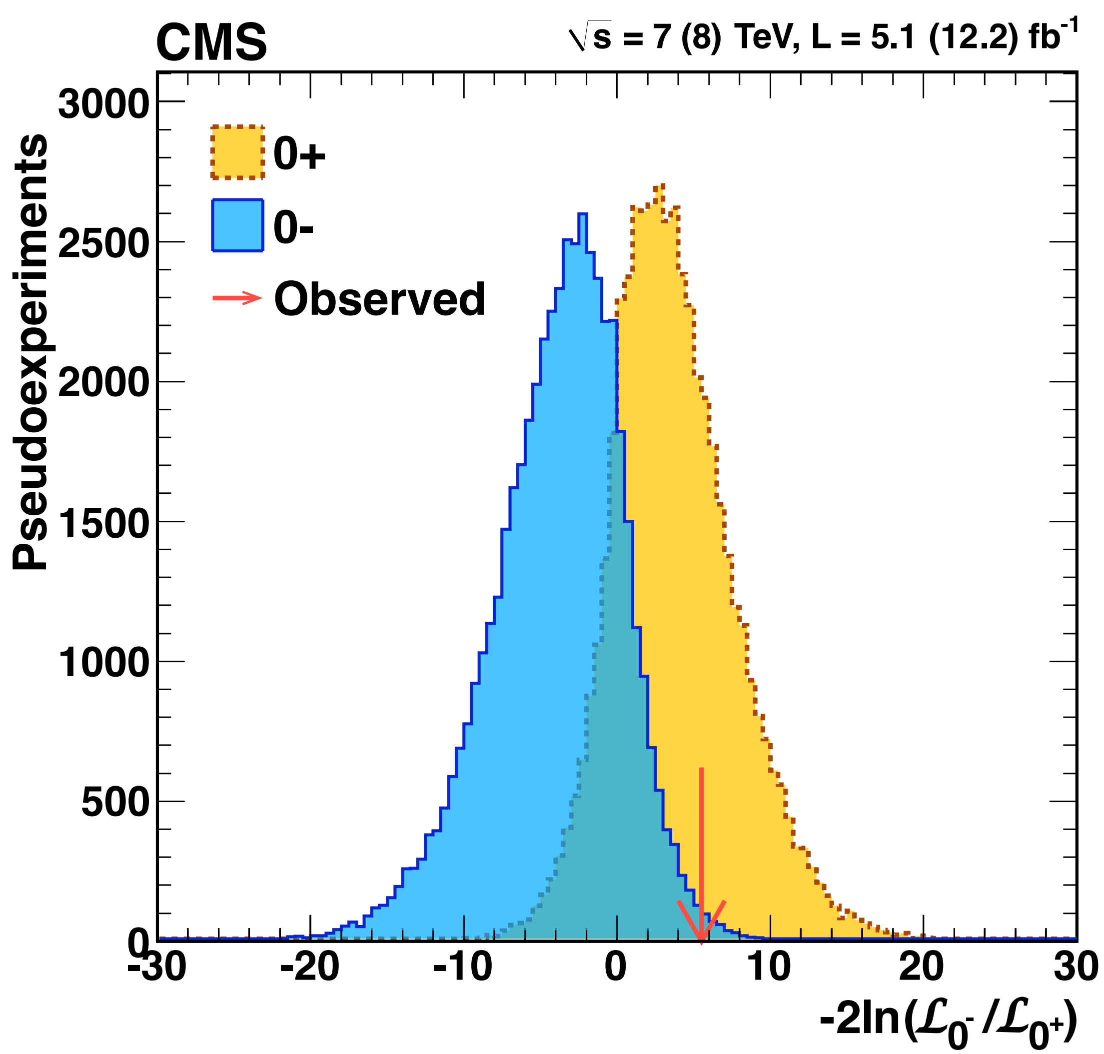
CMS Parity Results (I)

- CMS excludes the presence of a pure CP odd state at the level of ~95%

$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{\rm SM}}{\mathcal{P}_{\rm SM} + \mathcal{P}_{J^P}} = \left[1 + \frac{\mathcal{P}_{J^P}(m_1, m_2, \vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\rm SM}(m_1, m_2, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

$\downarrow$





CMS Parity Results (II)

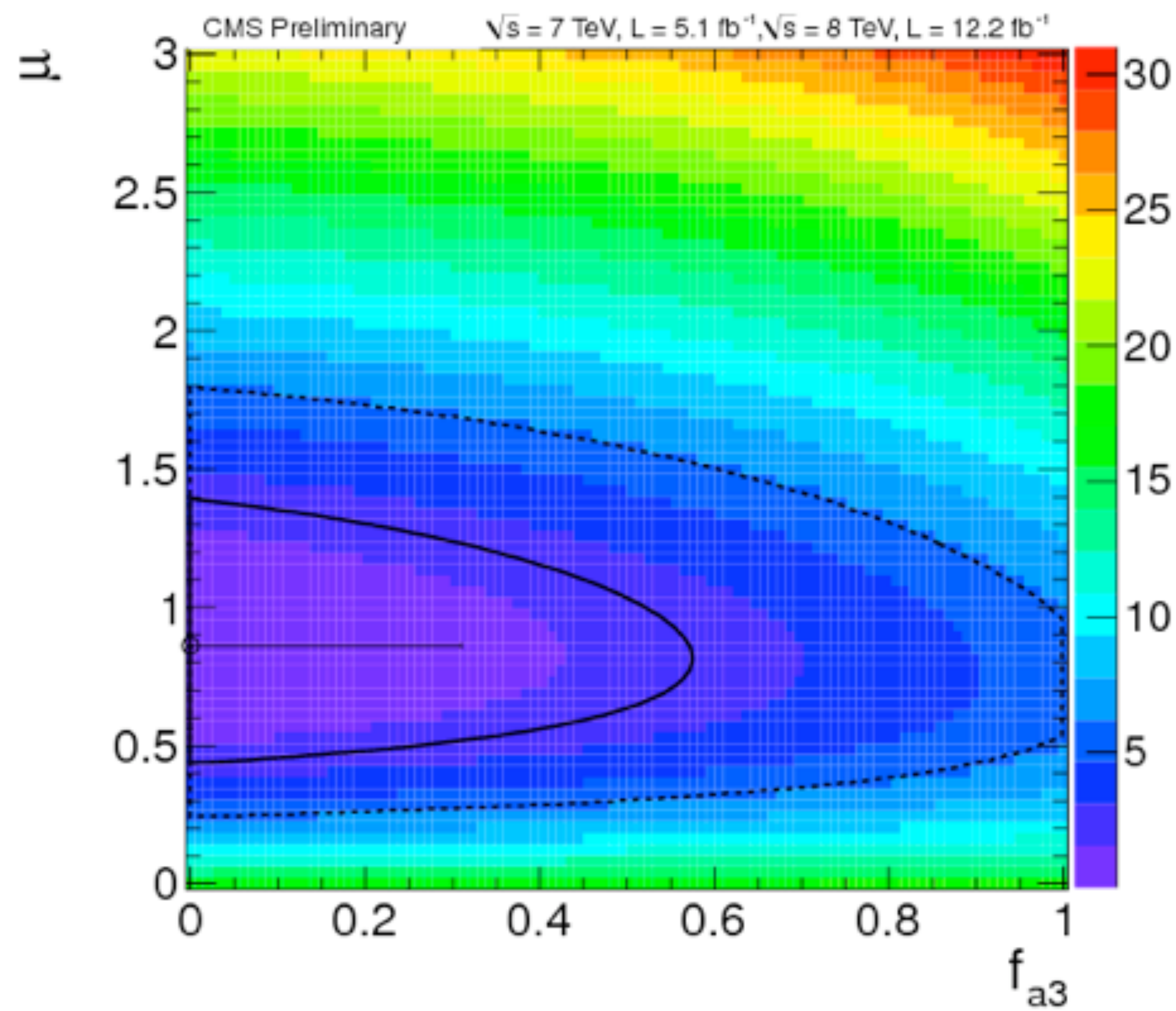
- A preliminary result on the fraction of CP state

$$A = v^{-1}\epsilon_1^{*\mu}\epsilon_2^{*\nu}\left(a_1 g_{\mu\nu} m_H^2 + a_2\, q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta\right) = A_1 + A_2 + A_3$$

$$f_{a3} = |A_3|^2/(|A_1|^2 + |A_3|^2)$$

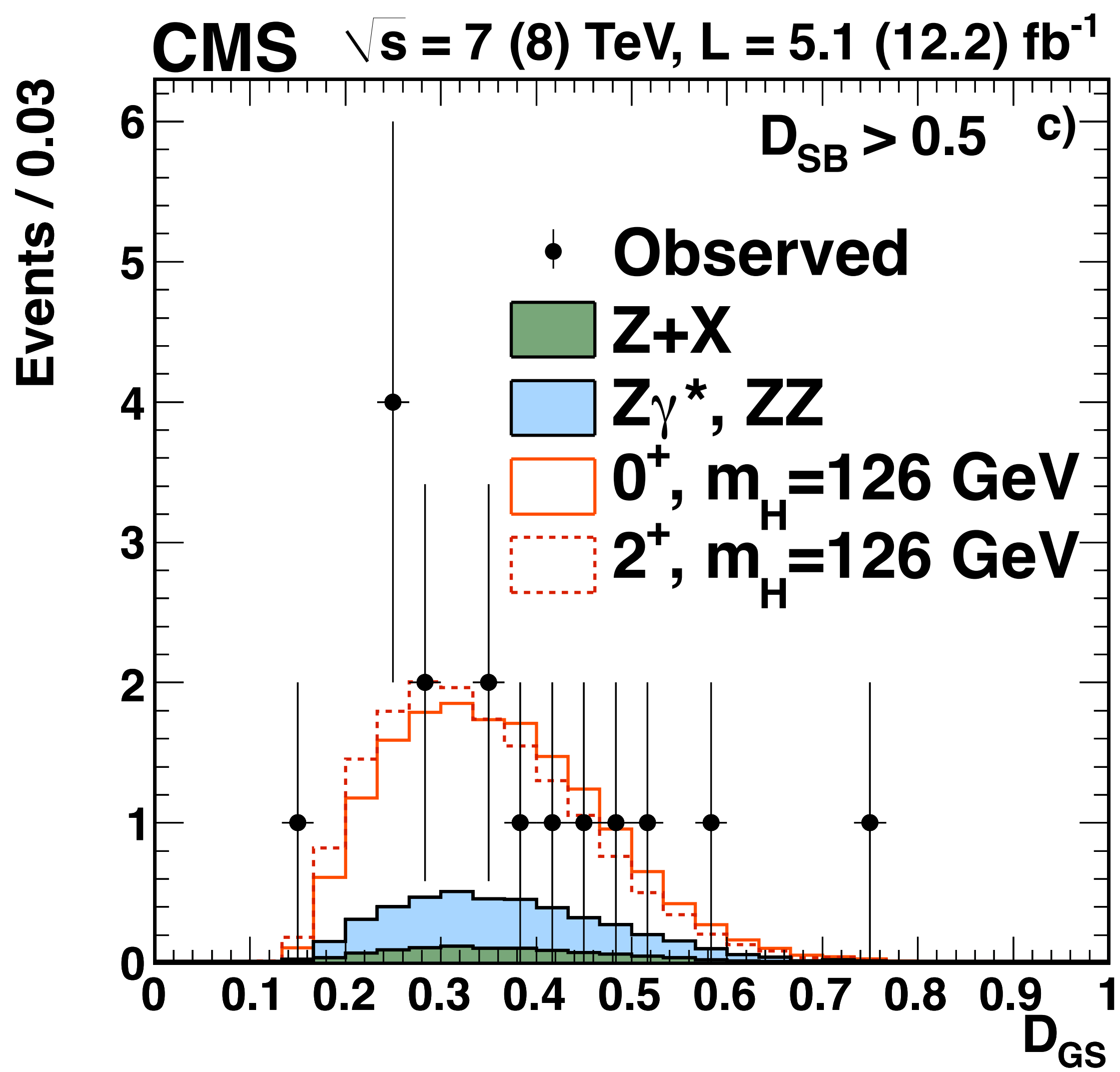
- The measurement is statistically limited

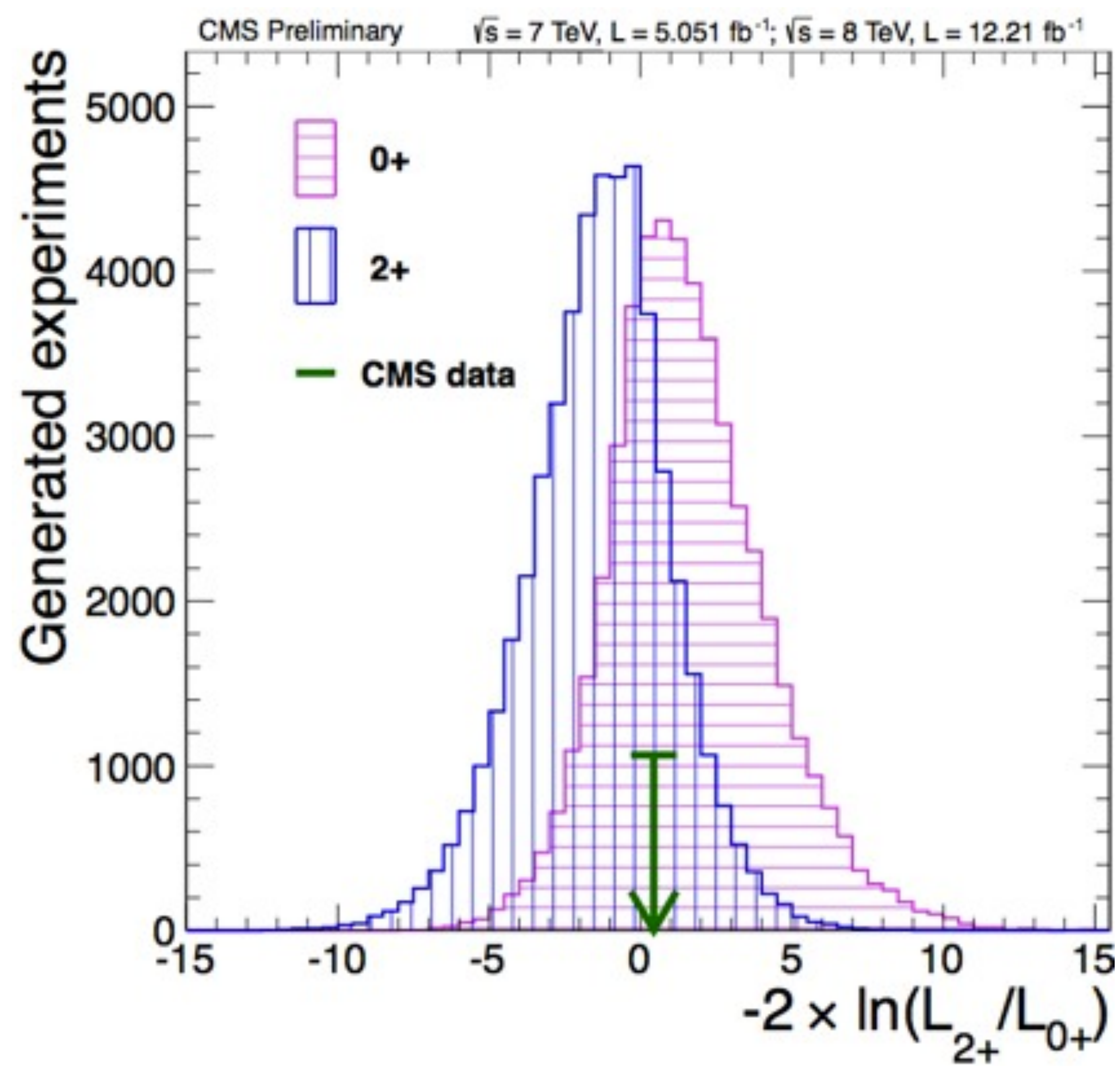
$$f_{a3} = 0.00^{+0.31}_{-0.00}$$



CMS Spin Results

- CMS considers the minimal coupling spin 2 model (details later)
  - The result is not sensitive yet to distinguish against the SM Higgs





Describe pp→X→VV Interactions

Phys. Rev. D 86. 095031

or

http://arxiv.org/abs/1208.4018

The JHU Generator

- A MC program developed to simulate production and decay of X→VV with X spin <= 2
  - X→ZZ→ 4l, 2l2τ, 2l2ν, 2l2q
  - X→WW → 2l2ν, lντν, lνqq
  - X→γγ
- Includes all spin correlations and all possible couplings
  - Inputs are general dimensionless couplings - calculates matrix elements
- For the production of X, both gg and qq are considered
- Output in LHE format; e.g. can interface to Pythia for hadronization
- All code publicly available: www.pha.jhu.edu/spin

XVV Amplitudes

$$A_{J=0}(X \to V_1 V_2) = v^{-1}\left(g_1^{(0)} m_V^2 \epsilon_1^* \epsilon_2^* + g_2^{(0)} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + g_3^{(0)} f^{*(1),\mu\nu} f_{\mu\alpha}^{*(2)} \frac{q_\nu q^\alpha}{\Lambda^2} + g_4^{(0)} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu} \right)$$

$$A_{J=1}(X \to V_1 V_2) = b_1 \left[(\epsilon_1^* q)(\epsilon_2^* \epsilon_X) + (\epsilon_2^* q)(\epsilon_1^* \epsilon_X) \right] + b_2\, \epsilon_{\alpha\mu\nu\beta} \epsilon_X^\alpha \epsilon_1^{*,\mu} \epsilon_2^{*,\nu} \tilde{q}^\beta$$

$$\begin{aligned} A_{J=2}(X \to V_1 V_2) = \Lambda^{-1} \Big[& 2 g_1^{(2)} t_{\mu\nu} f^{*(1)\mu\alpha} f^{*(2)\nu\alpha} + 2 g_2^{(2)} t_{\mu\nu} \frac{q_\alpha q_\beta}{\Lambda^2} f^{*(1)\mu\alpha} f^{*(2)\nu\beta} \\ & + g_3^{(2)} \frac{\tilde{q}^\beta \tilde{q}^\alpha}{\Lambda^2} t_{\beta\nu} \left(f^{*(1)\mu\nu} f_{\mu\alpha}^{*(2)} + f^{*(2)\mu\nu} f_{\mu\alpha}^{*(1)} \right) + g_4^{(2)} \frac{\tilde{q}^\nu \tilde{q}^\mu}{\Lambda^2} t_{\mu\nu} f^{*(1)\alpha\beta} f_{\alpha\beta}^{*(2)} \\ & + m_V^2 \left(2 g_5^{(2)} t_{\mu\nu} \epsilon_1^{*\mu} \epsilon_2^{*\nu} + 2 g_6^{(2)} \frac{\tilde{q}^\mu q_\alpha}{\Lambda^2} t_{\mu\nu} \left(\epsilon_1^{*\nu} \epsilon_2^{*\alpha} - \epsilon_1^{*\alpha} \epsilon_2^{*\nu} \right) + g_7^{(2)} \frac{\tilde{q}^\mu \tilde{q}^\nu}{\Lambda^2} t_{\mu\nu} \epsilon_1^* \epsilon_2^* \right) \\ & + g_8^{(2)} \frac{\tilde{q}_\mu \tilde{q}_\nu}{\Lambda^2} t_{\mu\nu} f^{*(1)\alpha\beta} \tilde{f}_{\alpha\beta}^{*(2)} + g_9^{(2)} m_V^2 \frac{t_{\mu\alpha} \tilde{q}^\alpha}{\Lambda^2} \epsilon_{\mu\nu\rho\sigma} \epsilon_1^{*\nu} \epsilon_2^{*\rho} q^\sigma \\ & + g_{10}^{(2)} m_V^2 \frac{t_{\mu\alpha} \tilde{q}^\alpha}{\Lambda^4} \epsilon_{\mu\nu\rho\sigma} q^\rho \tilde{q}^\sigma \left(\epsilon_1^{*\nu} (q \epsilon_2^*) + \epsilon_2^{*\nu} (q \epsilon_1^*) \right) \Big] \end{aligned}$$

scenario	X production	$X \to VV$ decay	comments
0_m^+	$gg \to X$	$g_1^{(0)} \neq 0$	SM Higgs boson scalar
0_h^+	$gg \to X$	$g_2^{(0)} \neq 0$	scalar with higher-dimension operators
0^-	$gg \to X$	$g_4^{(0)} \neq 0$	pseudo-scalar
1^+	$q\bar{q} \to X$	$b_2 \neq 0$	exotic pseudo-vector
1^-	$q\bar{q} \to X$	$b_1 \neq 0$	exotic vector
2_m^+	$g_1^{(2)} \neq 0$ in	$g_1^{(2)} = g_5^{(2)} \neq 0$	graviton-like tensor with minimal couplings
2_h^+	$g_4^{(2)} \neq 0$	$g_4^{(2)} \neq 0$	tensor with higher-dimension operators
2_h^-	$g_8^{(2)} \neq 0$	$g_8^{(2)} \neq 0$	"pseudo-tensor"

Summary and Discussions

- We have discovered a new particle
  - However little is known so far about its spin and parity or its role in the EWSB
    - CMS is able to disfavor a pure parity odd state at ~95% confidence level
  - It is important to keep open minded as we step into the unknown
    - Experimental exclusion of other benchmark spin parity models are important to either confirm or disfavor the SM Higgs mechanism
- It is also feasible to carry on spin/parity measurements with 25/fb data in each exp.
  - Spin 0
    - We need to measure the even/odd mixture fractions
  - Spin 2
    - minimal coupling model can be used as a benchmark and it is implemented in multiple frameworks and productions
    - We can also test other high dimensional operators and different production mechanism

Backup Slides

Connect to VBF@NLO for 2m+

- We compare the equations 1-2 to the VBF@NLO release note
  - http://www-itp.particle.uni-karlsruhe.de/~vbfnloweb/wiki/lib/exe/fetch.php?media=documentation:vbfnlo_releasenote26.pdf

For the singlet spin-2 field, $T^{\mu\nu}$, the effective Lagrangian is

$$\mathcal{L}_{\text{singlet}} = \frac{1}{\Lambda} T_{\mu\nu} \left(\boxed{f_1 B^{\alpha\nu} B^{\mu}_{\alpha} + f_2 W_i^{\alpha\nu} W^{i,\mu}_{\alpha}} + \boxed{f_3 \widetilde{B}^{\alpha\nu} B^{\mu}_{\alpha} + f_4 \widetilde{W}_i^{\alpha\nu} W^{i,\mu}_{\alpha}} + \boxed{2 f_5 (D^\mu \Phi)^\dagger (D^\nu \Phi)} \right), \quad (1)$$

and for the spin-2 triplet field, $T_j^{\mu\nu}$, the effective Lagrangian is given by

$$\mathcal{L}_{\text{triplet}} = \frac{1}{\Lambda} T_{\mu\nu j} \left(\boxed{f_6 (D^\mu \Phi)^\dagger \sigma^j (D^\nu \Phi) + f_7 W^{j,\mu}_{\alpha} B^{\alpha\nu}} \right), \quad (2)$$

- The approximate corresponding couplings in the JHUGen

g1 g5 g9

- Technical parameters for generating the 2m+
  - JHUGen: g1 = g5 = 1
  - VBF@NLO: F1=F2=F5 = 1