Can the 126GeV Boson be a Pseudoscalar?

Baradhwaj Coleppa, Kunal Kumar and Heather E. Logan

GK Block Course, Oct. 2012

RADUIERTEN
KOLLEG
Masse-Spektrum-Symmetrie

Introduction

- Discovery of a new resonance at about 126 *GeV* at ATLAS & CMS

Decay	Significance
$\gamma\gamma$	$4.1 - 4.5\sigma \rightarrow$ Spin-0,2
$ZZ^* \rightarrow 4\ell$	$3.2 - 3.4\sigma$
$WW^* \rightarrow \ell\nu\ell\nu$	$1.6 - 2.8\sigma$
$\tau\tau$, $b\bar{b}$	inconclusive

- CP determination possible through angular distribution of decay product, hadronic event shapes, $\tau\tau$ spin correlation
- Alternative: examining correlations among decay channels including contribution from $Z\gamma^* \rightarrow 4\ell$
- Parametrize pseudoscalar couplings to gauge bosons, fit them to experiment and detect discrepencies

Introduction

- Discovery of a new resonance at about 126 *GeV* at ATLAS & CMS

Decay	Significance
$\gamma\gamma$	$4.1 - 4.5\sigma \rightarrow$ Spin-0,2
$ZZ^* \rightarrow 4\ell$	$3.2 - 3.4\sigma$
$WW^* \rightarrow \ell\nu\ell\nu$	$1.6 - 2.8\sigma$
$\tau\tau$, $b\bar{b}$	inconclusive

- CP determination possible through angular distribution of decay product, hadronic event shapes, $\tau\tau$ spin correlation
- Alternative: examining correlations among decay channels including contribution from $Z\gamma^* \rightarrow 4\ell$
- Parametrize pseudoscalar couplings to gauge bosons, fit them to experiment and detect discrepencies

Introduction

- Discovery of a new resonance at about 126 GeV at ATLAS & CMS

Decay	Significance
$\gamma\gamma$	$4.1 - 4.5\sigma \rightarrow$ Spin-0,2
$ZZ^* \rightarrow 4\ell$	$3.2 - 3.4\sigma$
$WW^* \rightarrow \ell\nu\ell\nu$	$1.6 - 2.8\sigma$
$\tau\tau$, $b\bar{b}$	inconclusive

- CP determination possible through angular distribution of decay product, hadronic event shapes, $\tau\tau$ spin correlation
- Alternative: examining correlations among decay channels including contribution from $Z\gamma^* \rightarrow 4\ell$
- Parametrize pseudoscalar couplings to gauge bosons, fit them to experiment and detect discrepencies

Introduction

- Discovery of a new resonance at about 126 GeV at ATLAS & CMS

Decay	Significance
$\gamma\gamma$	$4.1 - 4.5\sigma \to$ Spin-0,2
$ZZ^* \to 4\ell$	$3.2 - 3.4\sigma$
$WW^* \to \ell\nu\ell\nu$	$1.6 - 2.8\sigma$
$\tau\tau$, $b\bar{b}$	inconclusive

- CP determination possible through angular distribution of decay product, hadronic event shapes, $\tau\tau$ spin correlation
- Alternative: examining correlations among decay channels including contribution from $Z\gamma^* \to 4\ell$
- Parametrize pseudoscalar couplings to gauge bosons, fit them to experiment and detect discrepencies

Introduction

- Discovery of a new resonance at about 126 *GeV* at ATLAS & CMS

Decay	Significance
$\gamma\gamma$	$4.1 - 4.5\sigma \rightarrow$ Spin-0,2
$ZZ^* \rightarrow 4\ell$	$3.2 - 3.4\sigma$
$WW^* \rightarrow \ell\nu\ell\nu$	$1.6 - 2.8\sigma$
$\tau\tau$, $b\bar{b}$	inconclusive

- CP determination possible through angular distribution of decay product, hadronic event shapes, $\tau\tau$ spin correlation
- Alternative: examining correlations among decay channels including contribution from $Z\gamma^* \rightarrow 4\ell$
- Parametrize pseudoscalar couplings to gauge bosons, fit them to experiment and detect discrepencies

Pseudoscalar Couplings

$$\mathcal{L} = c\frac{\alpha_s}{4\pi v}\phi G^a_{\mu\nu}\widetilde{G}^{a\mu\nu} + a\frac{\alpha}{4\pi v}\phi\left[B_{\mu\nu}\widetilde{B}^{\mu\nu} + bW^i_{\mu\nu}\widetilde{W}^{i\mu\nu}\right]$$

with the dual field strength tensor

$$\widetilde{W}^i_{\mu\nu} = \epsilon_{\mu\nu\alpha\beta}W^{i\alpha\beta}$$

and field strength tensor

$$W^i_{\mu\nu} = \partial_\mu W^i_\nu - \partial_\nu W^i_\mu + g\epsilon^{ijk}W^j_\mu W^k_\nu$$

$$W^1_\mu = \frac{1}{\sqrt{2}}(W^+_\mu + W^-_\mu)$$

$$W^2_\mu = \frac{i}{\sqrt{2}}(W^+_\mu - W^-_\mu)$$

$$\begin{pmatrix} W^3_\mu \\ B_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix}\begin{pmatrix} Z^0_\mu \\ A_\mu \end{pmatrix}$$

Pseudoscalar Couplings

$$\mathcal{L} = c\frac{\alpha_s}{4\pi v}\phi G^a_{\mu\nu}\widetilde{G}^{a\mu\nu} + a\frac{\alpha}{4\pi v}\phi\left[B_{\mu\nu}\widetilde{B}^{\mu\nu} + bW^i_{\mu\nu}\widetilde{W}^{i\mu\nu}\right]$$

Dependence of the decay amplitudes on b

$$\mathcal{M}(\phi \to WW) \propto b$$
$$\mathcal{M}(\phi \to ZZ) \propto (b\cos^2\theta_W + \sin^2\theta_W)$$
$$\mathcal{M}(\phi \to \gamma\gamma) \propto (\cos^2\theta_W + b\sin^2\theta_W)$$
$$\mathcal{M}(\phi \to Z\gamma) \propto (b-1)$$

Matching the Observed Rates

- determine b by the requirement to fit the observed rates for $\gamma\gamma$ and 4ℓ decays
- complication: admixture to 4ℓ final state from $\phi \to Z\gamma^* \to 4\ell$
- take prediction for

$$R^{SM}_{ZZ/\gamma\gamma} \equiv \frac{\Gamma(H \to ZZ^*)}{\Gamma(H \to \gamma\gamma)} \simeq 12.7$$

- ZZ is not final state $\to$ rewrite $R^{SM}_{ZZ/\gamma\gamma}$ in terms of partial width after cuts in the $4e$ final state: $\Gamma^c(H \to ZZ^* \to 4e)$;
  also using

$$\Gamma(H \to ZZ^*) = \frac{\Gamma(H \to ZZ^* \to 4e)}{[BR(Z \to ee)]^2}$$

Matching the Observed Rates

$R^{SM}_{ZZ/\gamma\gamma} =$

Term : from Monte Carlo Simulation (CalcHEP)

Term : computed at leading order

Term : Measurement form ATLAS and CMS

Matching the Observed Rates

$$R^{SM}_{ZZ/\gamma\gamma} = \frac{\Gamma(H \to ZZ^* \to 4e)}{\Gamma^c(H \to ZZ^* \to 4e)}$$

Term : from Monte Carlo Simulation (CalcHEP)

Term : computed at leading order

Term : Measurement form ATLAS and CMS

Matching the Observed Rates

$$R^{SM}_{ZZ/\gamma\gamma} = \frac{\Gamma(H \to ZZ^* \to 4e)}{\Gamma^c(H \to ZZ^* \to 4e)} \times \frac{1}{[BR(Z \to ee)]^2}$$

Term : from Monte Carlo Simulation (CalcHEP)

Term : computed at leading order

Term : Measurement form ATLAS and CMS

Matching the Observed Rates

$$R^{SM}_{ZZ/\gamma\gamma} = \frac{\Gamma(H \to ZZ^* \to 4e)}{\Gamma^c(H \to ZZ^* \to 4e)} \times \frac{1}{[BR(Z \to ee)]^2} \times \frac{\Gamma^c(H \to ZZ^* \to 4e)}{\Gamma(H \to \gamma\gamma)}$$

Term : from Monte Carlo Simulation (CalcHEP)

Term : computed at leading order

Term : Measurement form ATLAS and CMS

Matching the Observed Rates

$$R^{SM}_{ZZ/\gamma\gamma} = \frac{\Gamma(H \to ZZ^* \to 4e)}{\Gamma^c(H \to ZZ^* \to 4e)} \times \frac{1}{[BR(Z \to ee)]^2} \times \frac{\Gamma^c(H \to ZZ^* \to 4e)}{\Gamma(H \to \gamma\gamma)}$$

Term : from Monte Carlo Simulation (CalcHEP)

Term : computed at leading order

Term : Measurement form ATLAS and CMS

Matching of the observed rates:

$$\frac{\Gamma^c(H \to ZZ^* \to 4e)}{\Gamma(H \to \gamma\gamma)} \to \frac{\Gamma^c(\phi \to 4e)}{\Gamma(\phi \to \gamma\gamma)}$$

Matching the Observed Rates

$$R^{SM}_{ZZ/\gamma\gamma} = \frac{\Gamma(H \to ZZ^* \to 4e)}{\Gamma^c(H \to ZZ^* \to 4e)} \times \frac{1}{[BR(Z \to ee)]^2} \times \frac{\Gamma^c(H \to ZZ^* \to 4e)}{\Gamma(H \to \gamma\gamma)}$$

Term : from Monte Carlo Simulation (CalcHEP)

Term : computed at leading order

Term : Measurement form ATLAS and CMS

Matching of the observed rates:

$$\frac{\Gamma^c(H \to ZZ^* \to 4e)}{\Gamma(H \to \gamma\gamma)} \to \frac{\Gamma^c(\phi \to 4e)}{\Gamma(\phi \to \gamma\gamma)}$$

Result of Matching

$$b = -\cot^2\theta_W(1+\epsilon), \quad \text{where } \epsilon = -0.092$$

Predictions for WW^* and $Z\gamma$ Final States

b is fixed now an gives us the pseudoscalar decay width to $WW*$ and $Z\gamma$

$$R^{\phi}_{WW/\gamma\gamma} \equiv \frac{\Gamma(\phi \to WW^*)}{\Gamma(\phi \to \gamma\gamma)} = 0.229$$

$$R^{\phi}_{Z\gamma/\gamma\gamma} \equiv \frac{\Gamma(\phi \to Z\gamma)}{\Gamma(\phi \to \gamma\gamma)} = 121$$

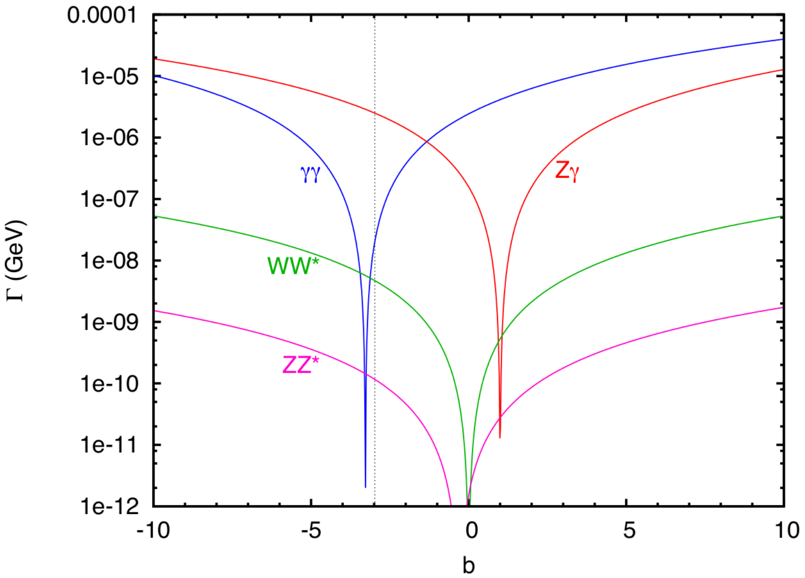
Values for SM Higgs at 126 GeV

$$R^{SM}_{WW/\gamma\gamma} \simeq 101, \quad R^{SM}_{Z\gamma/\gamma\gamma} \simeq 0.711$$

Consequences:

- $\frac{R^{\phi}_{WW/\gamma\gamma}}{R^{SM}_{WW/\gamma\gamma}} = \frac{1}{440}$ disfavours pseudoscalar since ATLAS and CMS have measured rates
- stronger exclusion by very high $\phi \to Z\gamma$ rate:
  investigating the channel $\phi \to Z\gamma \to \ell\ell\gamma$ should lead to upper bound $\sigma/\sigma_{SM} \simeq 8$ at 95% CL with the 8 TeV/5 fb^{-1} data sample which should exclude pseudoscalar prediction of $\sigma/\sigma_{SM} = 170$!

Figures



0.0001
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
1e-12
-10
-5
0
5
10
b
Γ (GeV)
γγ
Zγ
WW*
ZZ*