Exotic $Z\gamma$ Search with the ATLAS Detector and Implication to the 750 GeV $\gamma\gamma$ Excess

Dart-yin A. Soh

Institute of Physics, Academia Sinica

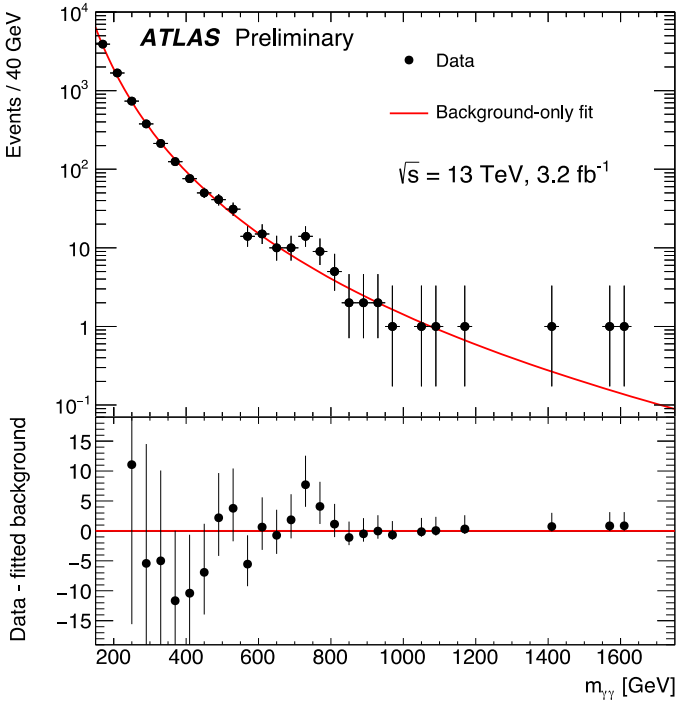
Content

- The 750 GeV excess: VBF Production?
- $Z\gamma/W\gamma$ exotic search at 8 TeV
- $Z\gamma$ exotic search at 13 TeV
- Implication to the 750 GeV $\gamma\gamma$ excess
- Conclusions

With the lastest results presented in Moriond 2016

The 750 GeV Excess

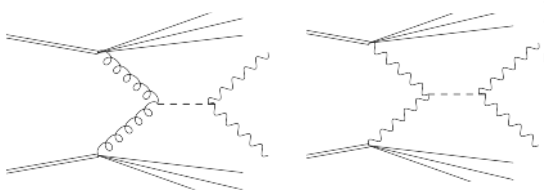
- The exciting news that the ~750 GeV excess at 13 TeV (2015) LHC collisions with both the ATALS and CMS detectors.
- The first up to >3σ BSM excess

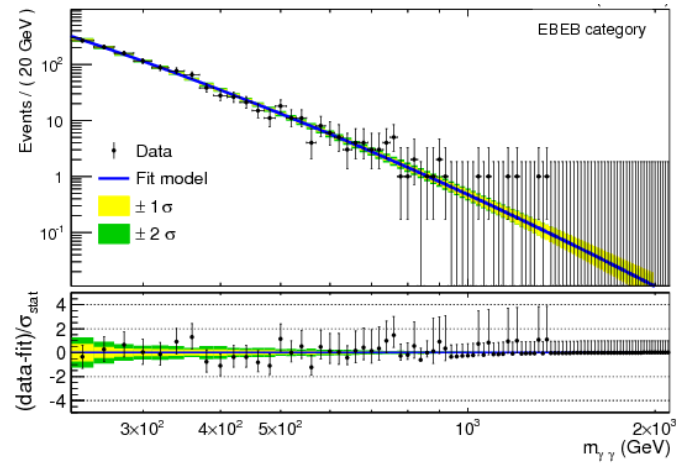


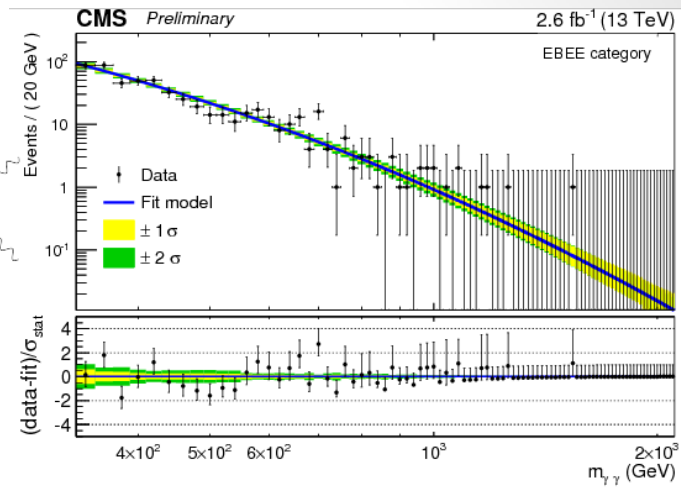
spin-0 or spin-2?

real γ, collimated γ or fake γ?

ggF or VBF productions?







- **In the NWA search**, an excess of **3.6**σ (local) is observed at a mass hypothesis of minimal p_0 of 750 GeV

VBF v.s. Simpleness

- SM-like 750 GeV Higgs: $\sigma^{VBF}_{proc} \big/ \sigma^{ggF}_{proc} \simeq \frac{620\,fb}{220\,fb} \sim \frac{1}{3}$, $\frac{G(f\to gg)}{G(f\to gg)} = \frac{2.55\times10^{-4}}{1.2}$, so $d\mathcal{L}^{VBF}_{pp} \big/ d\mathcal{L}^{ggF}_{pp} = \frac{3}{2}\times 10^{-4}$
- Minimal BSM: 2HDM, Georgi-Machacek triplet model… fail (custodial symmetry) $c_{fVV}\,\mu\, v_T, c_{fgg}\,\mu\, v$, unless introducing huge muber of charge scalars

  arXiv:1512.04921, arXiv:1601.06394…
- SM+new gauge symmetries: VBF (simpler) v.s. ggF (new quarks/leptons)

  many many models
- dim-5 effective couplings of scalars/axions:

$$\kappa_S \frac{\alpha_S}{4\pi v}\varphi \sum_a G^a_{\mu\nu}\tilde{G}^{a\mu\nu} + \kappa_W \frac{\alpha}{4\pi v}\varphi\, B_{\mu\nu}\tilde{B}^{\mu\nu} + \sum_c W^c_{\mu\nu}\tilde{W}^{c\mu\nu}$$

if $k_g \sim 0$ no underlying colored particle, VBF is dominant, otherwise VBF cannot compete with ggF

using effective W/Z approximation

$$\hat{\sigma}_{in\to\Phi,incl.} m_\Phi^2 \frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}+\Gamma_{other}} \frac{d\mathcal{L}}{dm_\Phi^2} \sim \frac{\Gamma_{in}}{m_\Phi} \frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}+\Gamma_{other}} \frac{d\mathcal{L}}{dm_\Phi^2}$$

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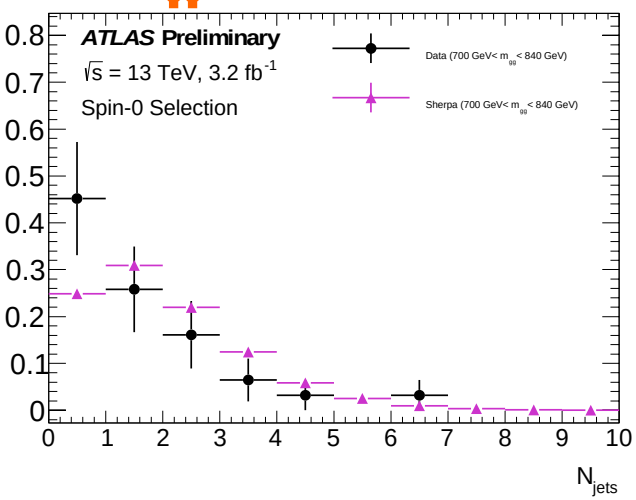
- Atlas: no other activity, Jet multiplicity

m_{WW} = [700-840] GeV



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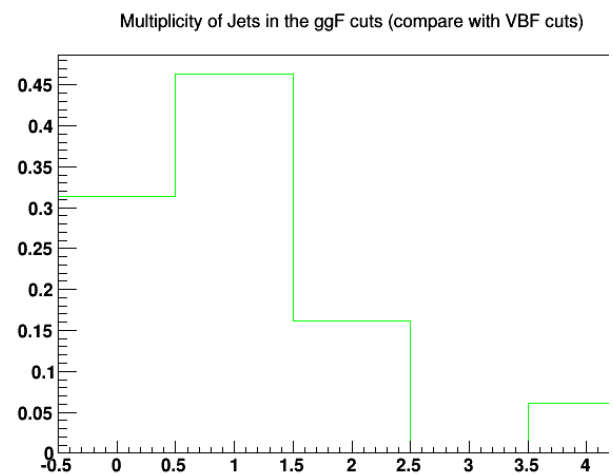
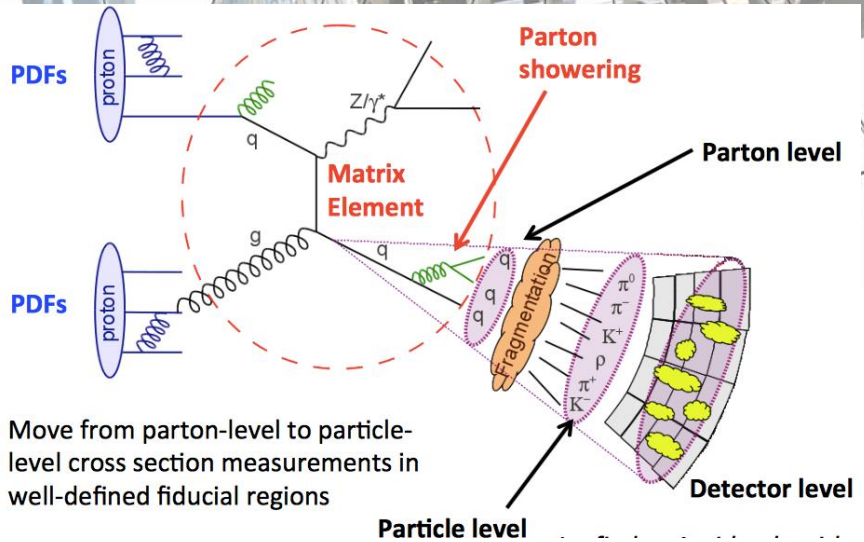
effective scalar with MadGraph5 at parton level, using the fiducial cuts:

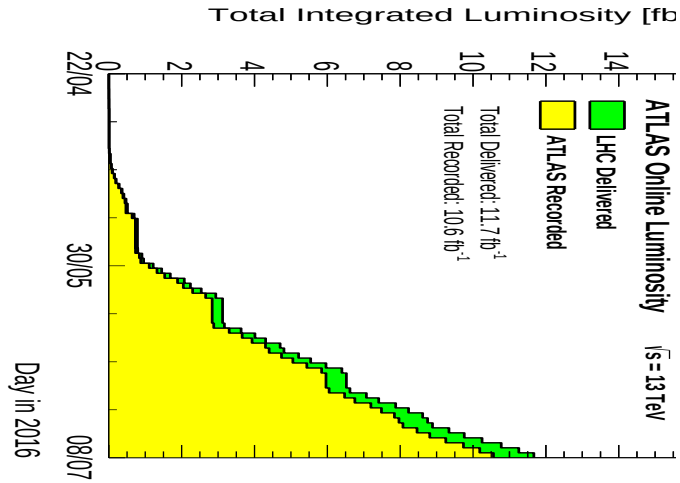


We cannot exclude the VBF yet due to low statistics!

2016 Collisions at the LHC & the Atlas Detector

- 13TeV Run2 started in 2015 and 2016!
- Luminosities in physics
  - 20.3 fb^{-1} (8 TeV, 2012) peak lumi 7.7x10^{33}
  - 3.2 fb^{-1} (13 TeV 2015) Good data
  - Atlas recorded 6.0 fb^{-1} until 21 June and ~10 fb^{-1} in 2016!!
- Models of hard process->MC generator->detector simulation



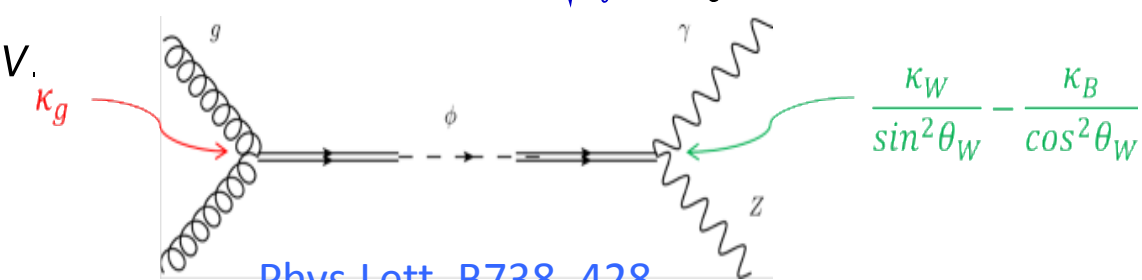


Effective Model for the $Z\gamma$ Exotic Search

- Model-independent, depend on spin(-1 & -0) and CP (NWA)
- A new search for spin-0 Zγ resonance up to 2TeV using the generic effective dimension-5 phenomenological model of the singlet scalar as a benchmark

$$L_{eff} = c_g \frac{4\pi\alpha_S}{\Lambda}\phi G^a_{\mu\nu}G^{a\mu\nu} + c_W \frac{4\pi\alpha_{em}}{\Lambda\cdot\sin^2\theta_W}\phi W^a_{\mu\nu}W^{a\mu\nu} + c_B \frac{4\pi\alpha_{em}}{\Lambda\cdot\cos^2\theta_W}\phi B_{\mu\nu}B^{\mu\nu}$$

- Large vector-like fermions of new strong dynamics and electroweak run in the loops underly the couplings and thus can be estimated in NDA (and only ggF)
- Set (a): $c_g = c_W = -c_B = 1/4\pi$ for the n−loop corrections $c_V \leq O(1)/4\pi$.
- Set (b): $c_g = 1/2\pi, c_W = -c_B = 1/\pi$ when $c_V \leq a_f\sqrt{N'_c}$ $N'_c = 4$ and $a_f = 2$
- scale $\Lambda = 6TeV$. $m_Q = 750GeV$.



Phys.Lett. B738, 428

$Z\gamma$ Exotic Leptonic Search at 8 TeV

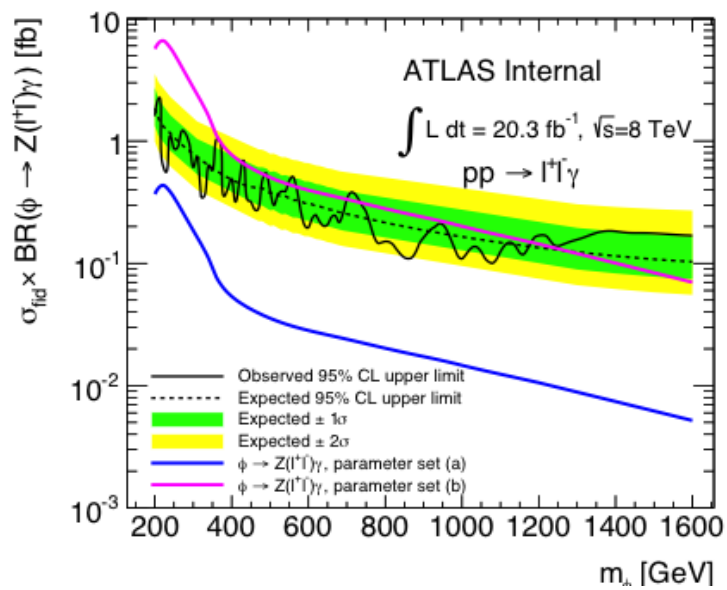
- Using the LO Higgs process in MadGraph5 interfaced to Pythia8 with MSTW2008LO to simulate the signals for singlet scalar

Event Selection

Cuts applied in the $Z\gamma$ searches		
Cuts	$e^+e^-\gamma$	$\mu^+\mu^-\gamma$
Lepton p_T	$p_T^e > 25GeV$	$p_T^\mu > 25GeV$
Lepton η	$\lvert\eta_e\rvert < 2.47$	$\lvert\eta_\mu\rvert < 2.7$
Boson mass	$[65, 115]$GeV	$[65, 115]$ GeV
l track isolation	< 0.15	< 0.15
l calo isolation	< 0.20	< 0.30
Photon	$E_T^\gamma > 40GeV$, $\Delta R(l,\gamma) > 0.7$ $\lvert\eta_\gamma\rvert < 2.37$ photon isolation < 4 GeV	
impact parameter significance	< 6.5	< 3.5

Cuts	$e^+e^-\gamma$
Lepton	$p_T^e > 25GeV$ $\lvert\eta_{e(\mu)}\rvert < 2.47(2.7)$ $N_{e^+} = 1, N_{e^-} = 1$
Boson	$65 < m_{inv}(Z) < 115\ GeV$
Photon	$E_T^\gamma > 40\ GeV$ $\lvert\eta^\gamma\rvert < 2.37$, $\Delta R(e,\gamma) > 0.7$ $\epsilon_h^p < 0.5$

- Uncertainties from the expected limits
- Set (a) no sensitivity
- Set (b) excluded in the range $[200, 1180]GeV$
- All fluctuations within the 2σ band



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Zγ Exotic Search at 13 TeV of 2015 Data

- Search for a spin-0 resonance with larger mass range
- Both **leptonic** and **hadronic** Z decay modes are analyzed at 13TeV

leptonic channel ($Z\gamma \rightarrow l^+l^-\gamma$)

- Photon: **P_T>0.3*$M_{ll\gamma}$**, where $M_{ll\gamma}$>200 GeV
- 2 leptons (e+e-/μ+μ-) selection:
  - **|d0|, |η| cut, P_T (>10 GeV), Medium ID, Isolation**
  - **Z mass window**
- Main background: Z+γ, Z+Jet

hadronic channel ($Z\gamma \rightarrow q\bar{q}\gamma$)

- Photon selection: **P_T > 200 GeV**
- Boosted large-R jet selection:
  - **anti-kt, R=1.0, P_T(> 200GeV), |η|<2**
  - **Z-boson-tagged**
- Main background: γ+Jet

Fit in **0.2-1.6TeV**, signal search in **0.25 -1.5 TeV**

- Signal: **Double-sided crystal ball**
- Background: analytic parametrization
- Largest deviation: **Local Z0 = 2σ at 350GeV**

Fit in **0.64-3TeV**, signal search in **0.7-2.75 TeV**

- Signal: **Crystal ball + Gaussian**
- Background: analytic parametrization
- Largest deviation: **Local Z0 = 1.8σ at 1.9TeV**

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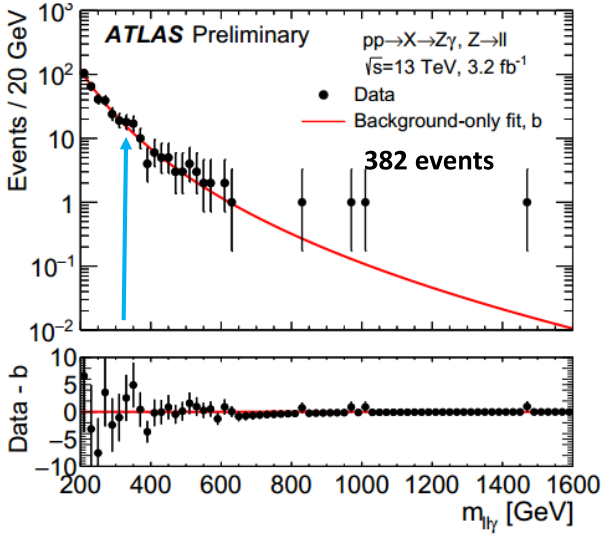
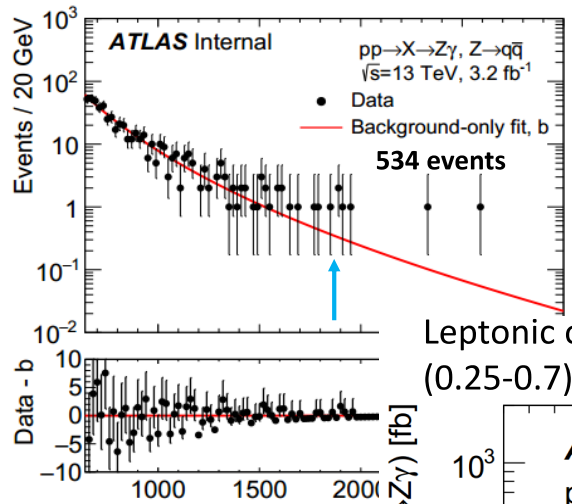
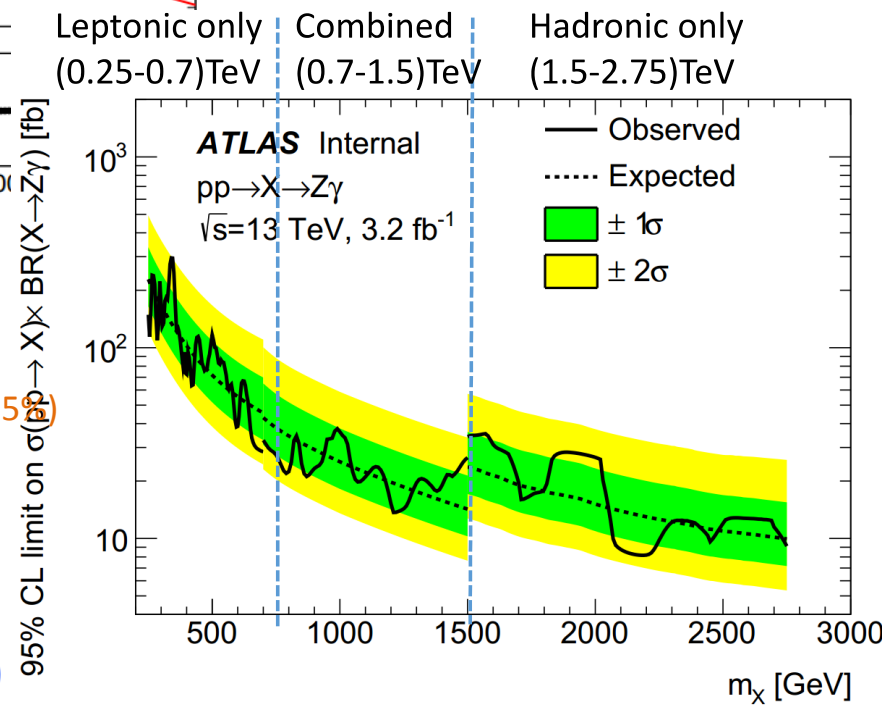
Zγ Exotic Search at 13 TeV of 2015 Data

❖Signal: POWHEG-BOX+Pythia8 with effective scalar model





No significant excess found



- dominant by statistic uncertainties
- Leptonic channel:

γ/e resolution (4.0-0.5%), spurious signal (3.0-2.0%), Luminosity (0.5%)

- Hadronic channel:

jet mass resolution (4.3-2.1%) & jet energy resolution (5.3-1.0%)

ATALS-CONF-2016-010 (Moriond 2016)

Implication to the 750 GeV $\gamma\gamma$ excess

- Can we make constraints on the models of 750 GeV resonance using the $Z\gamma$ search? The effective Lagrangian is for singlet

$$L_{eff} = c_g \frac{4\pi\alpha_s}{\Lambda} \phi G^a_{\mu\nu} G^{a\mu\nu} + c_W \frac{4\pi\alpha_{em}}{\Lambda \cdot \sin^2\theta_W} \phi W^a_{\mu\nu} W^{a\mu\nu} + c_B \frac{4\pi\alpha_{em}}{\Lambda \cdot \cos^2\theta_W} \phi B_{\mu\nu} B^{\mu\nu}$$

- We can constrain only parameters c_B, c_W but not c_g
- The 13 TeV limit ~40 fb, roughly same as that extrapolated from 8 TeV observed limit
- ZZ search is too loose to constrain any parameter
- $Z\gamma$ search and WW search are essential constraints

$$g_{f\,gg} = \kappa_g \frac{\alpha_s}{4\pi},$$

$$g_{f\,WW} = \kappa_W \frac{\alpha_{em}}{4\pi s_w^2},$$

$$g_{f\,ZZ} = \frac{\alpha_{em}}{4\pi}\left(\kappa_W \frac{c_w^2}{s_w^2} + \kappa_B \frac{s_w^2}{c_w^2}\right),$$

$$g_{f\,Z\gamma} = \frac{\alpha_{em}}{4\pi} c_w s_w \left(\frac{\kappa_W}{s_w^2} - \frac{\kappa_B}{c_w^2}\right),$$

$$g_{f\,\gamma\gamma} = \frac{\alpha_{em}}{4\pi}(\kappa_W + \kappa_B).$$

the exclusion limit of 8 TeV rescaled to 13 TeV rates

Final State	95% CL U.L. on $\sigma \times$ BR [fb]
WW (gluon fusion)	174
ZZ (gg prod.)	89
$Z\gamma$	42

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- $Z\gamma$ search and WW search are essential constraints

$$c_B < -(3.6226 \sim 2.5833)|c_W| \quad c_B > (0.03867 \sim 0.4689)|c_W|$$

- We can also constrain the models that the resonance is not singlet, but more complicate
- The data we need to find it in $Z\gamma$ channel? model dependent

$$g_{f\,gg} = \kappa_g \frac{\alpha_s}{4\pi},$$

$$g_{f\,WW} = \kappa_W \frac{\alpha_{em}}{4\pi s_w^2},$$

$$g_{f\,ZZ} = \frac{\alpha_{em}}{4\pi}\left(\kappa_W \frac{c_w^2}{s_w^2} + \kappa_B \frac{s_w^2}{c_w^2}\right),$$

$$g_{f\,Z\gamma} = \frac{\alpha_{em}}{4\pi} c_w s_w \left(\frac{\kappa_W}{s_w^2} - \frac{\kappa_B}{c_w^2}\right),$$

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arXiv:1512.04928

Conclusions

- We consider the tension between VBF production and simpleness of the 750 GeV excess
- We use an EFT model to search for the heavy exotic resonance of Z boson+photon in leptonic channels at 8 TeV at ATLAS
- The same search for the heavy scalar resonance of Z boson+photon in both leptonic and hadronic channels at 13 TeV is presented
- We use the exotic $Z\gamma$ search to constrain the EFT parameters of the scalar 750 GeV resonance

Thank you!

Backup: Model Parameter Constraint of 8TeV

Only exclusions on the two particular parameter sets were attained from data. However, the coupling coefficients c_V can be any values below the upper bounds. We can go further to constrain the parameter space.

- Only cross sections $\sigma_{th}(c_V; m_\phi, \cdots)$ are needed
- High-dimensional parameter space: assuming constraint $c_W = -c_B$
- Interesting parameters: $c \equiv c_g =\propto \sqrt{N'_c}$ and ratio $\rho = c_g/c_W = 1/a_f$
- Two special $\rho_a = 1$ and $\rho_b = 1/2$, constraint of c