Interpreting the 750 GeV Diphoton Resonance using photon jets in Hidden-Valley-like models

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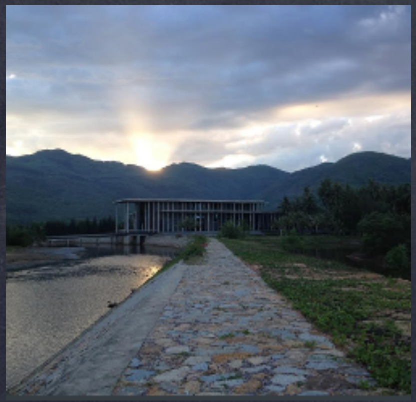

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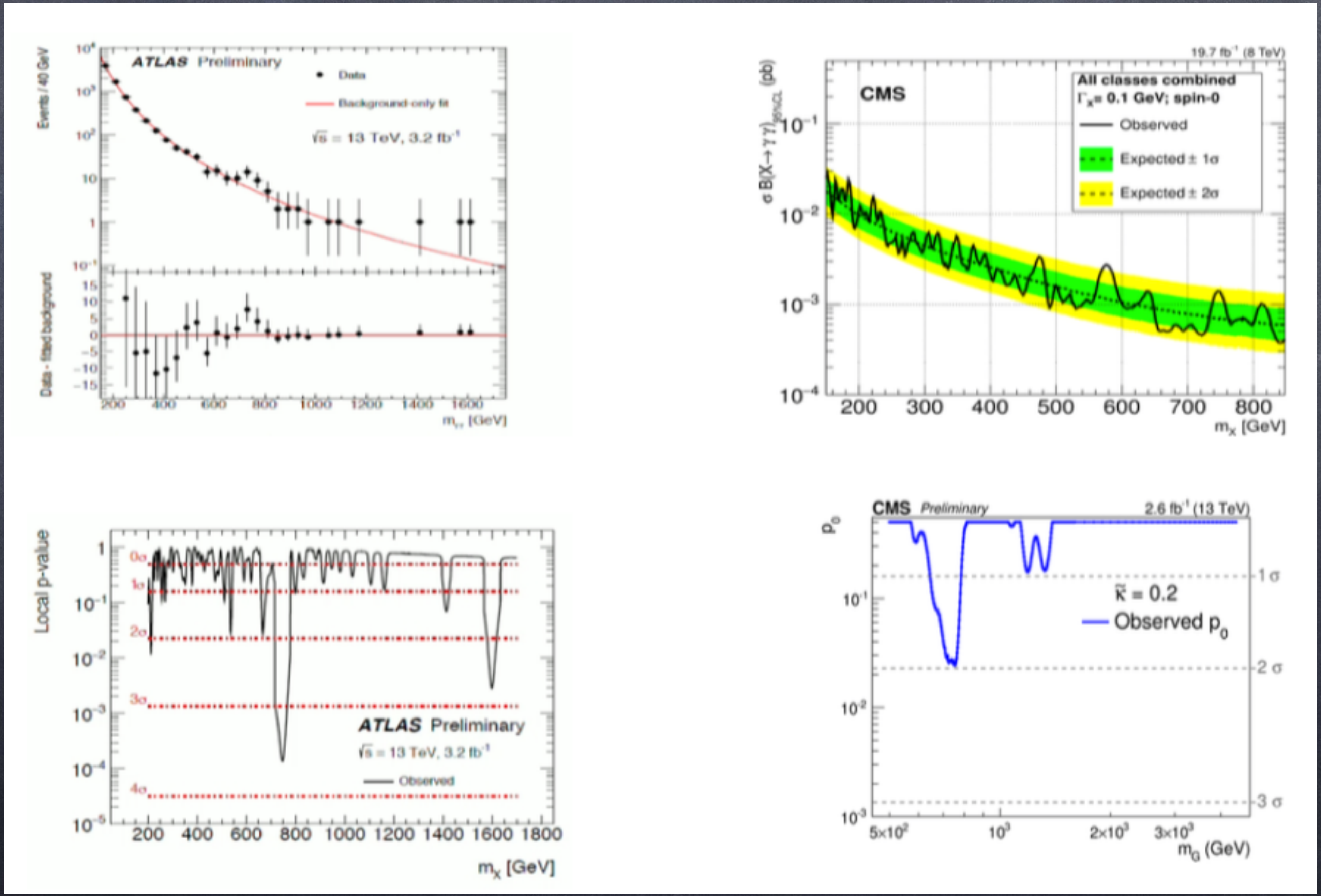
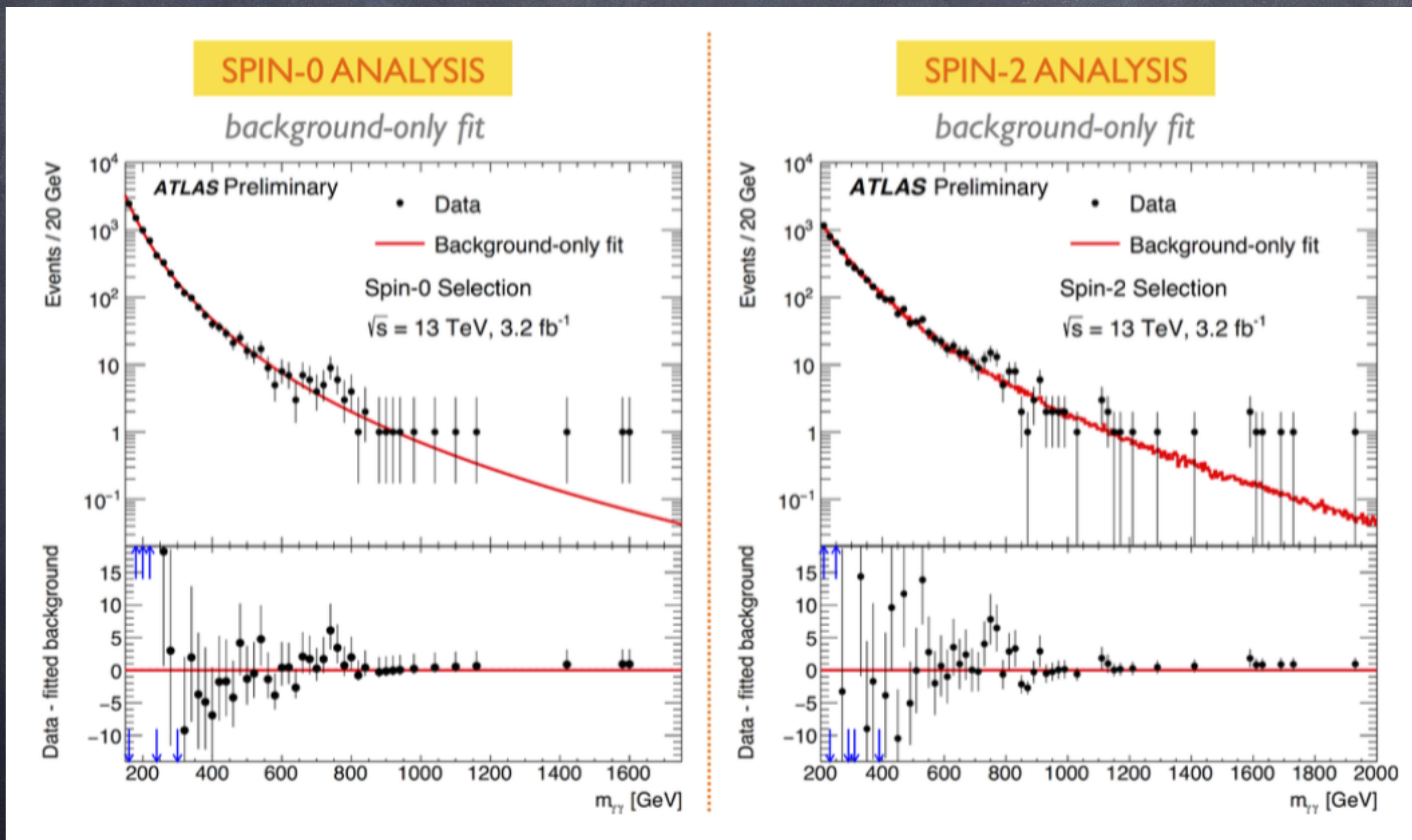
The big news on 12/15, 2015 750 GeV Diphoton Resonance ? ?



Still there... and more consistent than before... on 3/17, 2016



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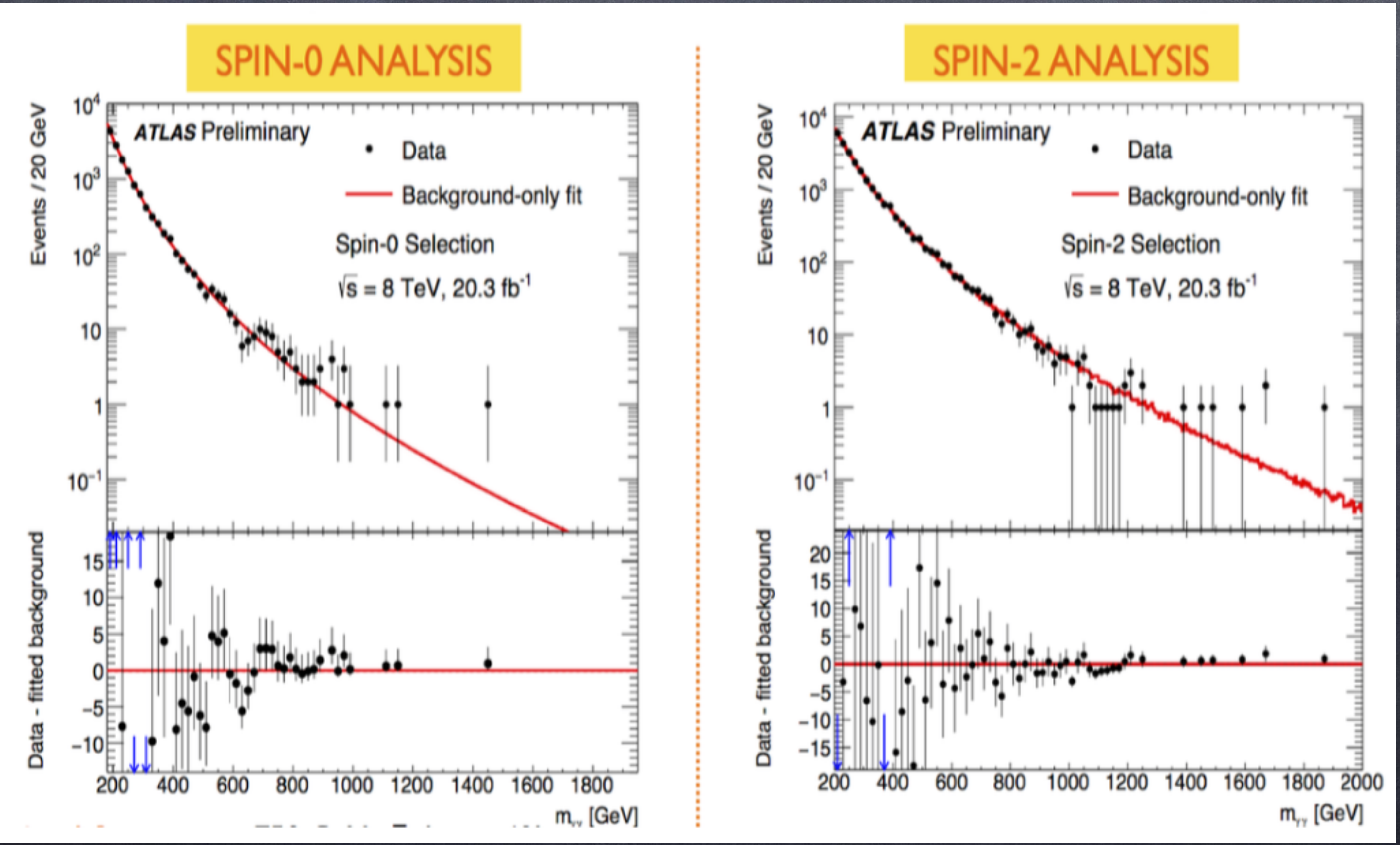

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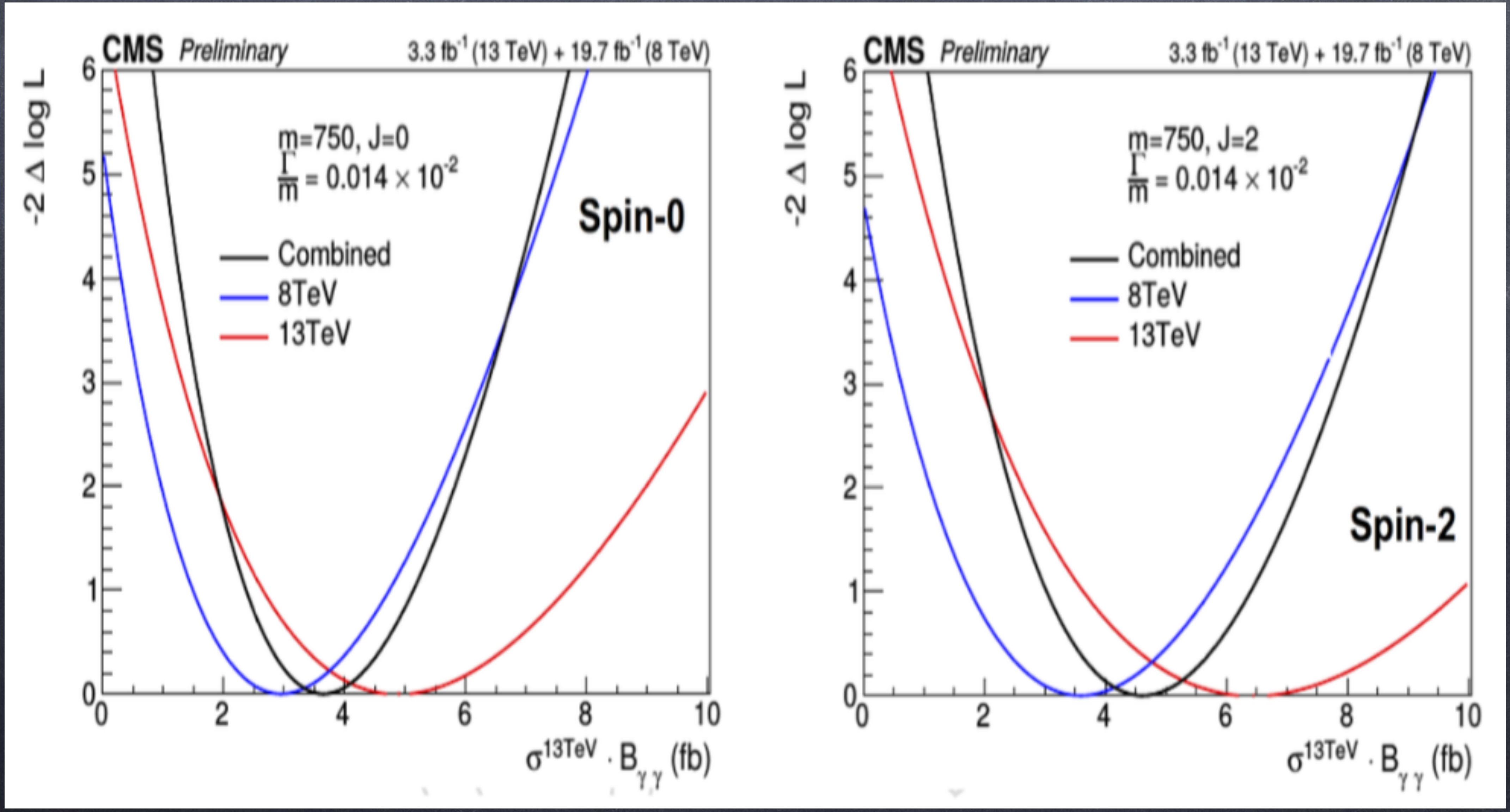
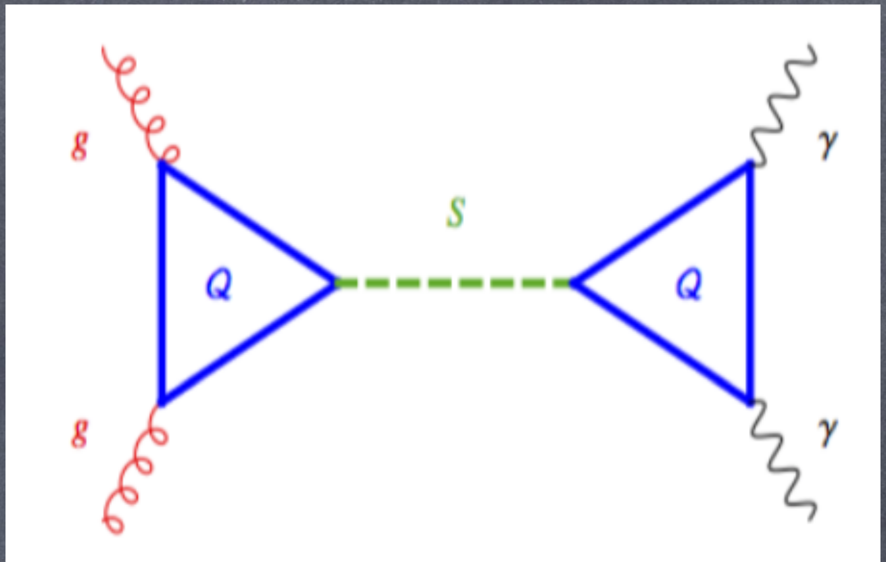


How to explain these data ?

- The Standard Way :



- More than 1/3 of papers (>150) are belong to this kind ! !

$$\mathcal{L}_{\rm eff} = \frac{\alpha}{4\pi}\frac{k_\gamma}{\Lambda_\gamma}\phi F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{\alpha_s}{4\pi}\frac{k_g}{\Lambda_g}\phi G^a_{\mu\nu}\tilde{G}^{a\mu\nu}$$

- Some effective models, composite models, extra- dimensional models, ... are belong to this kind !

How to explain these data ?

- Some exotic proposals :
- Ex :
- collimated photons (photon jets)
- fake photon (dark photon)
- diphoton excess w/o resonance at 750 GeV
- ...

What is the photon-jet ?

A photon-jet $(\gamma - jet)$ is a special feature that consists of a cluster of collinear photons from the decay of a fast moving light particle (O (1GeV)).

- Does it work to explain the 750 GeV diphoton excess data ?

- <1> We interpret the resonance as a scalar boson X(750) in Hidden-Valley-like models.
- <2> The scalar boson X can mix with the standard model Higgs boson and thus can be produced via gluon fusion.
- <3> It then decays into a pair of very light hidden particles Y of O(1GeV), each of which in turn decays to a pair of collimated π^0's, and these two π^0's decay into photons which then form photon-jets.
- <4> Because these photons inside the photon-jet are so collimated that it cannot be distinguished from a single photon, and so in the final state of the decay of X(750) a pair of photon-jets look like a pair of single photons, which the experimentalists observed and formed the 750 GeV diphoton resonance.

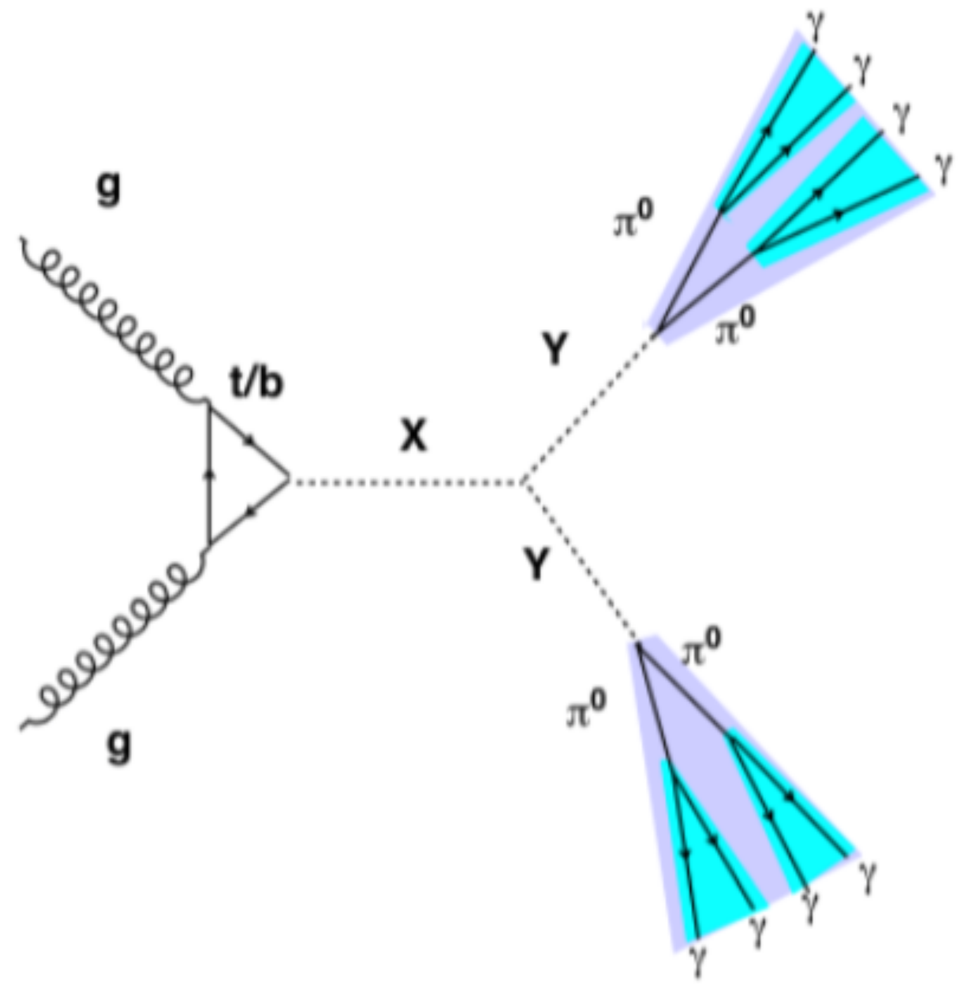


FIG. 2. The Feynman diagram for $pp \to X \to YY \to (\pi^0\pi^0)(\pi^0\pi^0) \to (4\gamma)(4\gamma)$ (2 γ-jets in the final state)

The advantages of this idea :

- 1. We separate the production mode and final state to two different particles : X and Y which will ease the tension of the production rate about $\sigma \sim O(10\,fb)$ naturally.
- 2. We can explain the width relative to the mass of the resonance is rather large $(\Gamma/M \approx 0.06)$ by the stronger coupling of X→YY but not $X \to \gamma\gamma$ which is just tree-level and both X and Y are in the hidden sector, so the coupling of them could be large naturally.
- 3. Our scenario is somewhat more economical which means we just invite two new particles : X(750 GeV) and Y(O(1GeV)) to interpret the 750 GeV diphoton excess data.

Hidden-Valley-like simplified model

$$\mathcal{L} = \frac{1}{2}\partial_\mu \chi_1 \partial^\mu \chi_1 + \frac{1}{2}\partial_\mu \chi_2 \partial^\mu \chi_2 + \frac{1}{2}\mu_1^2 \chi_1^2 + \frac{1}{2}\mu_2^2 \chi_1^2 + \mu_3^2 \chi_1 \chi_2$$
$$+ (\lambda_1 \chi_1 + \lambda_2 \chi_2)[M(\Phi^\dagger \Phi) + N(\lambda_1 \chi_1 + \lambda_2 \chi_2)^2]$$
$$+ \mathcal{L}_{SM} \, ,$$

Hidden-Valley-like simplified model

$$
\begin{aligned}
m_h^2 &\simeq 2\lambda\langle\phi\rangle^2 - (\mu_1^2 sin^2\theta_1 + \mu_2^2 sin^2\theta_2) - M\langle\phi\rangle(\lambda_1 sin2\theta_1 + \lambda_2 sin2\theta_2) \\
&= (125\ \mathrm{GeV})^2 \\
m_X^2 &\simeq -\mu_1^2 cos^2\theta_3 - \mu_2^2 sin^2\theta_3 - \mu_3^2 sin2\theta_3 + 2\lambda\langle\phi\rangle^2 sin^2\theta_1 + \lambda_1 M\langle\phi\rangle \sin 2\theta_1 \\
m_Y^2 &\simeq -\mu_1^2 sin^2\theta_3 - \mu_2^2 cos^2\theta_3 + \mu_3^2 sin2\theta_3 + 2\lambda\langle\phi\rangle^2 sin^2\theta_2 + \lambda_2 M\langle\phi\rangle \sin 2\theta_2 \\
\mathcal{L}_{Xhh} &\simeq \frac{1}{2}[2\lambda\langle\phi\rangle cos^2\theta_1 \sin\theta_1 + 6N\lambda_1^3 cos\theta_1 sin^2\theta_1 \\
&\quad +\lambda_1 M(\cos^3\theta_1 - 2\cos\theta_1\sin^2\theta_1)]Xhh \equiv \frac{\mu_{Xhh}}{2}Xhh \\
\mathcal{L}_{XYY} &\simeq \frac{6N}{2}[\lambda_2^3\cos^2\theta_3\sin\theta_3 + \lambda_1^3\cos\theta_3\sin^2\theta_3 + \lambda_1\lambda_2^2(\cos^3\theta_3 - 2\cos\theta_3\sin^2\theta_3) \\
&\quad +\lambda_2\lambda_1^2(\sin^3\theta_3 - 2\cos^2\theta_3\sin\theta_3)]XYY \equiv \frac{\mu_{HS}}{2}XYY\ ,
\end{aligned}
$$

Hidden-Valley-like simplified model

$$\Gamma(X \to W^+W^-) = \sin^2\theta_1 \frac{g^2}{64\pi}\frac{m_X^3}{m_W^2}\sqrt{1-\frac{4m_W^2}{m_X^2}}\left(1-\frac{4m_W^2}{m_X^2}+\frac{12m_W^4}{m_X^4}\right) ,$$

$$\Gamma(X \to ZZ) = \sin^2\theta_1 \frac{g^2}{128\pi}\frac{m_X^3}{m_Z^2}\sqrt{1-\frac{4m_Z^2}{m_X^2}}\left(1-\frac{4m_Z^2}{m_X^2}+\frac{12m_Z^4}{m_X^4}\right) ,$$

$$\Gamma(X \to t\bar{t}) = \sin^2\theta_1 \frac{N_c g^2 m_t^2}{32\pi m_W^2}\left(1-\frac{4m_t^2}{m_X^2}\right)^{3/2}(1+\triangle_{QCD}) ,$$

$$\Gamma(X \to YY) = \frac{\mu_{HS}^2}{32\pi m_X} \times \sqrt{1-4\left(\frac{m_Y}{m_X}\right)^2} .$$

$$\Gamma(X \to hh) = \frac{\mu_{Xhh}^2}{32\pi m_X} \times \sqrt{1-4\left(\frac{m_h}{m_X}\right)^2} .$$

Hidden-Valley-like simplified model

FIG. 1. The branching ratios of the scalar boson $X(750)$ with $\Gamma = 45GeV$ for the four most dominant modes YY, W^+W^-, ZZ, and $t\bar{t}$

Hidden-Valley-like simplified model

$$\Gamma(Y \to \ell^+\ell^-) = \sin^2\theta_2 \frac{m_\ell^2 m_Y}{8\pi\langle\phi\rangle^2}\left(1 - \frac{4m_\ell^2}{m_Y^2}\right)^{3/2},$$

$$\Gamma(Y \to \pi\pi) = \sin^2\theta_2 \frac{m_Y^3}{216\pi\langle\phi\rangle^2}\left(1 - \frac{4m_\pi^2}{m_Y^2}\right)^{1/2}\left(1 + \frac{11m_\pi^2}{2m_Y^2}\right)^2,$$

$$\Gamma_Y = \frac{1}{\tau_Y} = \sum_{\ell=e,\mu}\Gamma(Y \to \ell^+\ell^-) + \sum_{\pi=\pi^+,\pi^0}\Gamma(Y \to \pi\pi),$$

Here $\pi\pi$ includes $\pi^+\pi^-$, $\pi^0\pi^0$ and $\Gamma(Y \to \pi^+\pi^-) = 2\Gamma(Y \to \pi^0\pi^0)$.

Hidden-Valley-like simplified model

For a 1 GeV scalar boson Y, the branching ratio into $\pi\pi$ is almost 100% and for $\mu^+\mu^-$ is just about 0.4%

For a 1 GeV scalar boson Y with $\sin\theta_2 = 1.6 \times 10^{-2}$, we have

$\Gamma_Y \approx 4.25 \times 10^{-10}$ GeV and so $\tau_Y = \frac{1}{\Gamma_Y} \approx 1.55 \times 10^{-15}$ (s).

$$\sigma(pp \to gg \to X(750)) = \sin^2\theta_1 \times \sigma_{\rm SM}(pp \to gg \to H_{\rm SM}) .$$

Fitting the width for X(750)

In order to fit the width of $X(750)$ to 45 GeV with the mixing angle $\sin\theta_1 = 0.3$, we need a very strong coupling for X with a pair of Y's

$$|\mu_{HS}| \gtrsim 1308 \text{ GeV} . \quad (29)$$

	YY	W^+W^-	ZZ	$t\bar{t}$
BR	50.45%	29.07%	14.38%	6.10%
Γ_i (GeV)	22.70	13.08	6.47	2.75

TABLE I. The branching ratios and partial widths for $X(750)$ into the four most dominant modes YY, W^+W^-, ZZ, and $t\bar{t}$ with the mixing angle fixed at $\sin\theta_1 = 0.3$.

Fitting the production rate for X(750)

$$\sigma\left(pp \to X \to YY \to (\pi^0\pi^0)(\pi^0\pi^0) \to (4\gamma)(4\gamma)\right)$$

$$= \sigma(pp \to X) \times B(X \to YY) \times \left[B(Y \to \pi^0\pi^0)\right]^2 \times \left[B(\pi^0 \to \gamma\gamma)\right]^4$$

$$\approx \left[736 \text{ fb} \times (0.3)^2\right] \times [50.45\%] \times \left[100\% \times \frac{1}{3}\right]^2 \times [100\%]^4$$

$$\approx 3.71 fb$$

Fitting the production rate for X(750)

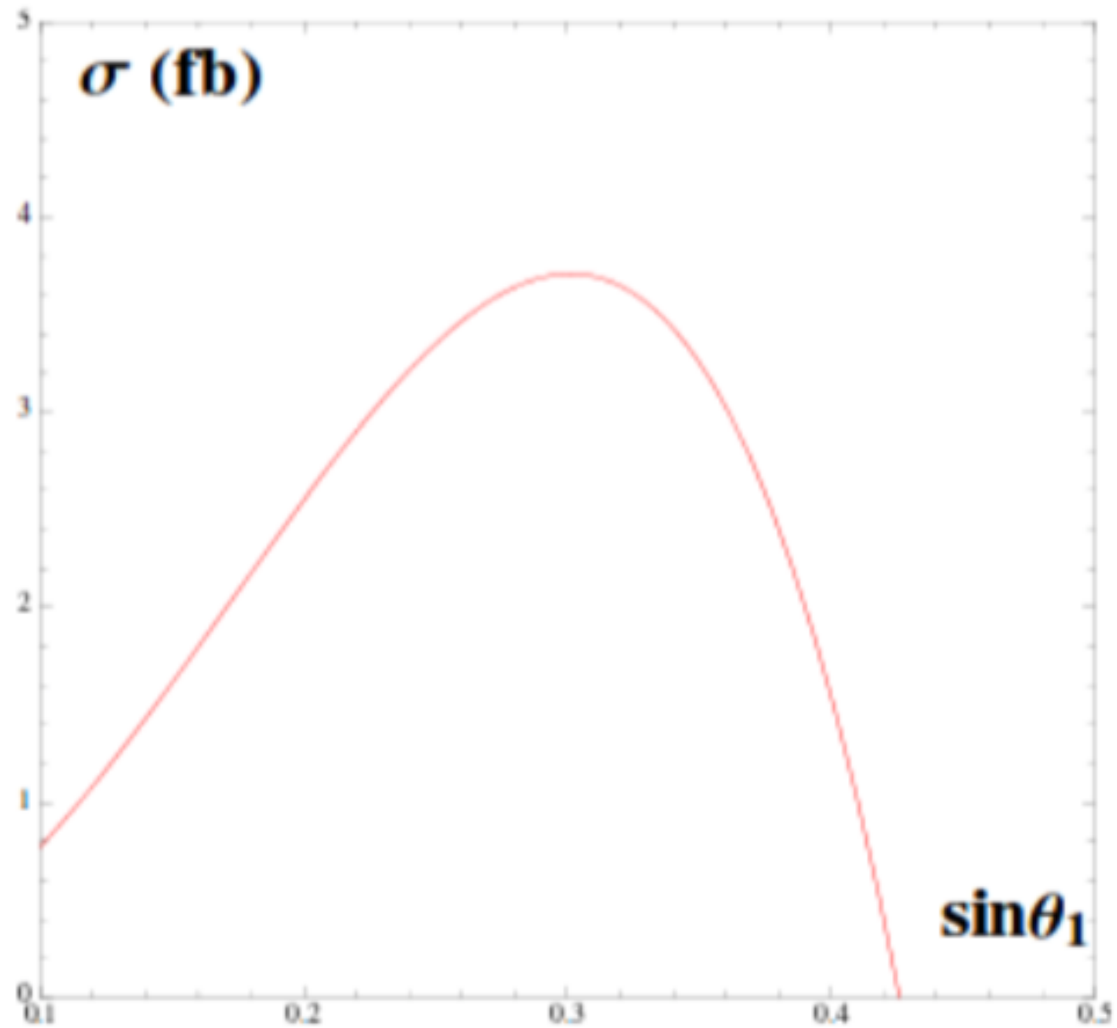
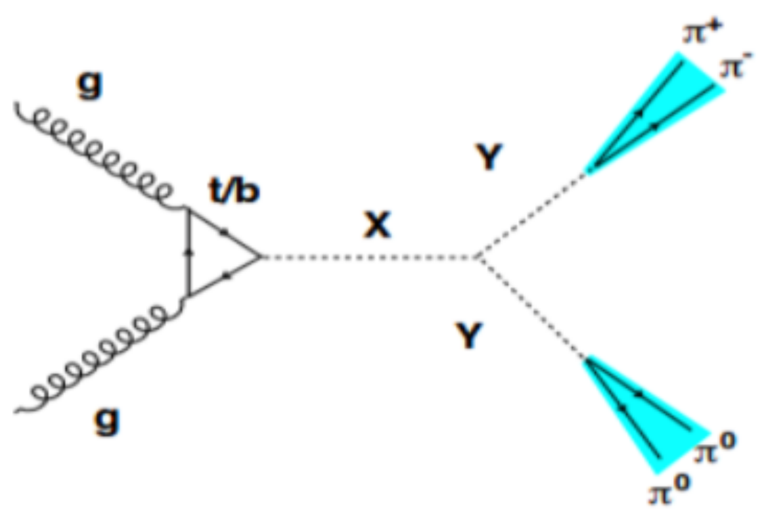


FIG. 4. The variation of production rate of $\sigma\left(pp \to X \to YY \to (\pi^0\pi^0)(\pi^0\pi^0) \to (4\gamma)(4\gamma)\right)$ versus $\sin\theta_1$

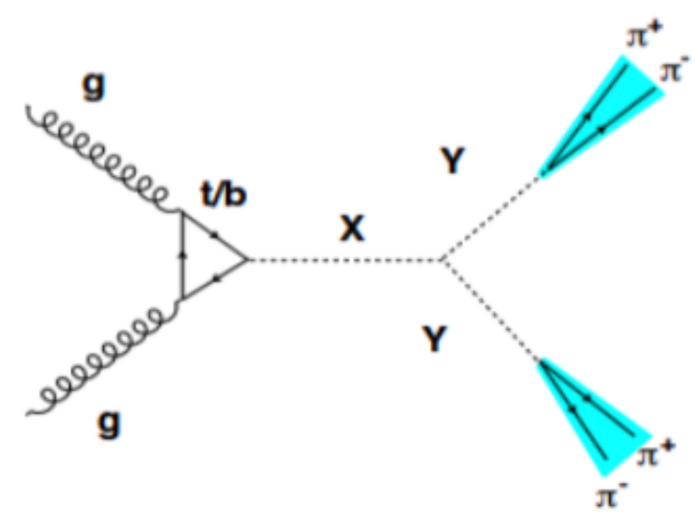
DISCUSSION

$\mathcal{O}(15\text{ fb})$

$pp \to X \to YY \to (\pi^0\pi^0)(\pi^+\pi^-)$



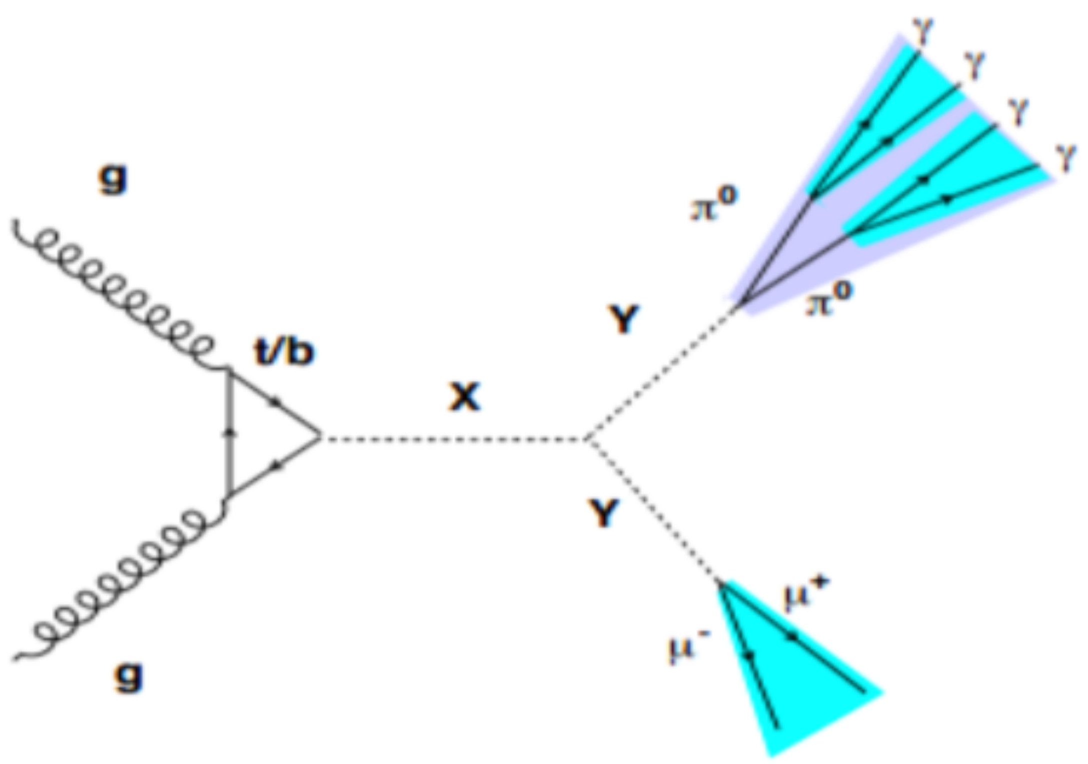
$pp \to X \to YY \to (\pi^+\pi^-)(\pi^+\pi^-)$



DISCUSSION

$\mathcal{O}(0.1\ \text{fb})$

$$pp \to X \to YY \to (\pi^0\pi^0)(\mu^+\mu^-)$$



Conclusion

If the 750 GeV Diphoton Resonance comes to be true, except for testing other decay channels to confirm the predictions of different type of models in the market, one important issue comes out : Could we interpret the large production rate of O(10 fb) and large width relative to the mass $\Gamma/M \approx 6\%$ naturally ??

We try to use our idea as a smoking gun to induce other more natural way but not traditional way to explain the 750 GeV Diphoton Resonance data !

- ***Thank you very much for your listening ! !***