Implication of a 750 GeV Diphoton Resonance for Heavy Quark Searches

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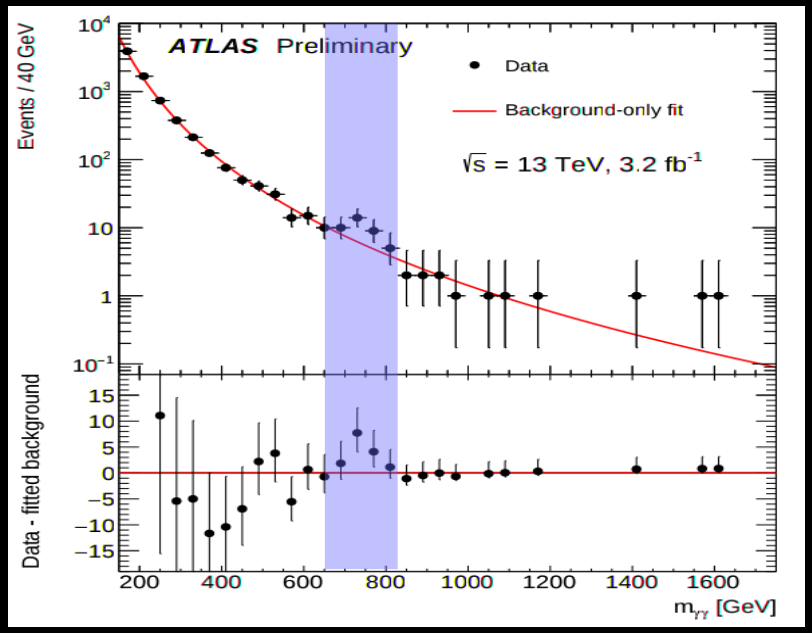
with S. Banerjee, G. Belanger and C. Delaunay arXiv:1606.09013

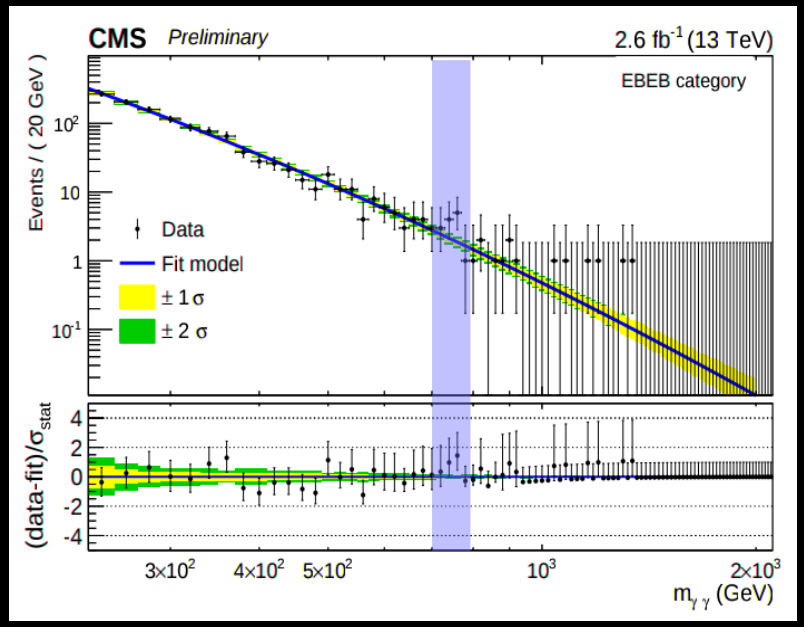
Outline

- A 750 GeV resonance in the early 13 TeV data?
- Heavy quarks mediating the resonance production
- Consequences for heavy quark searches
- Conclusions

A 750 GeV $\gamma\gamma$ resonance?

The Christmas present





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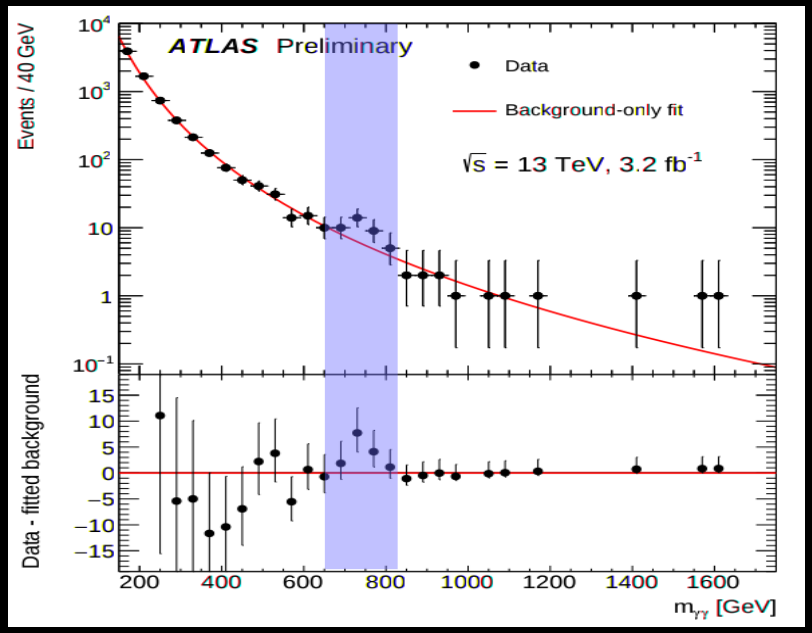

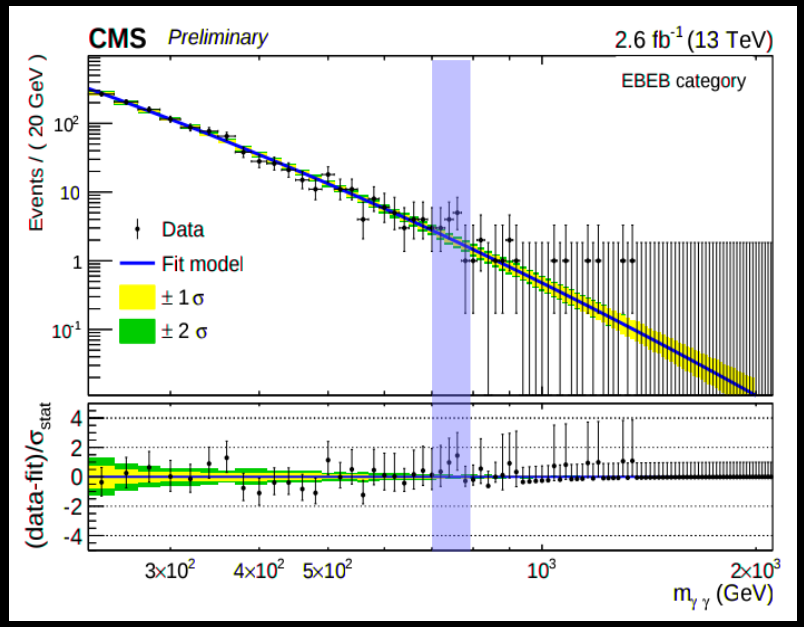

Huge excitement and many questions

- Is it true? Are we this lucky?
- What's the production cross section?
- What is it? Is it related with naturalness? And if not, why is it?
- Large width or small width?
- Spin 0 or higher spin?
- What's the production mechanism?

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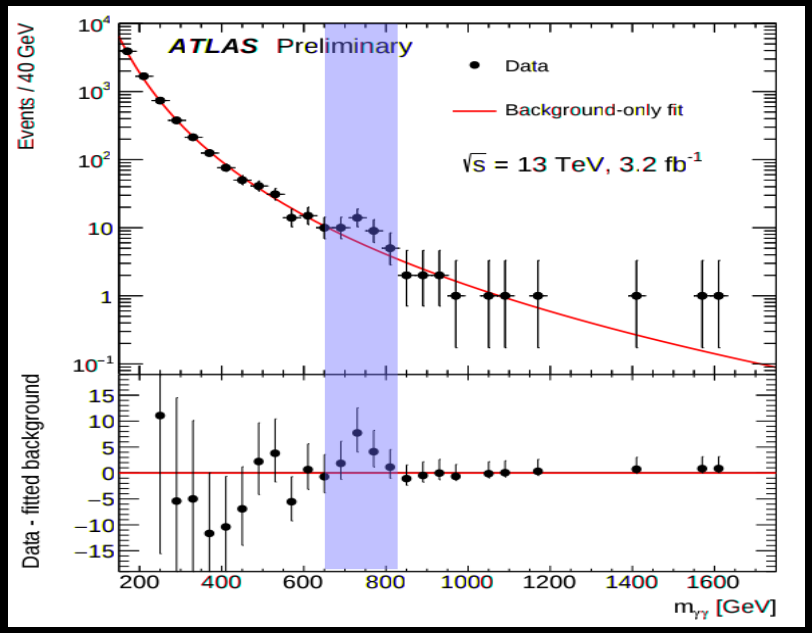

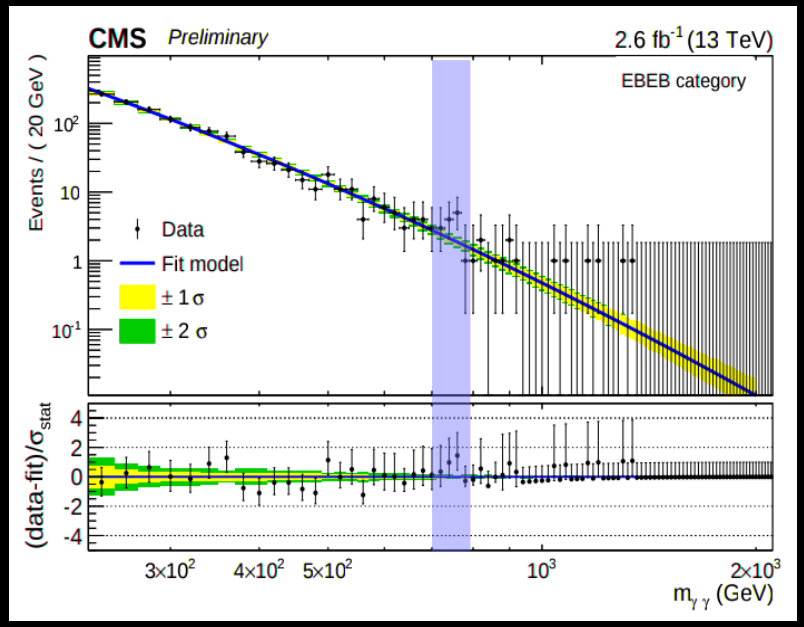

Huge excitement and many questions

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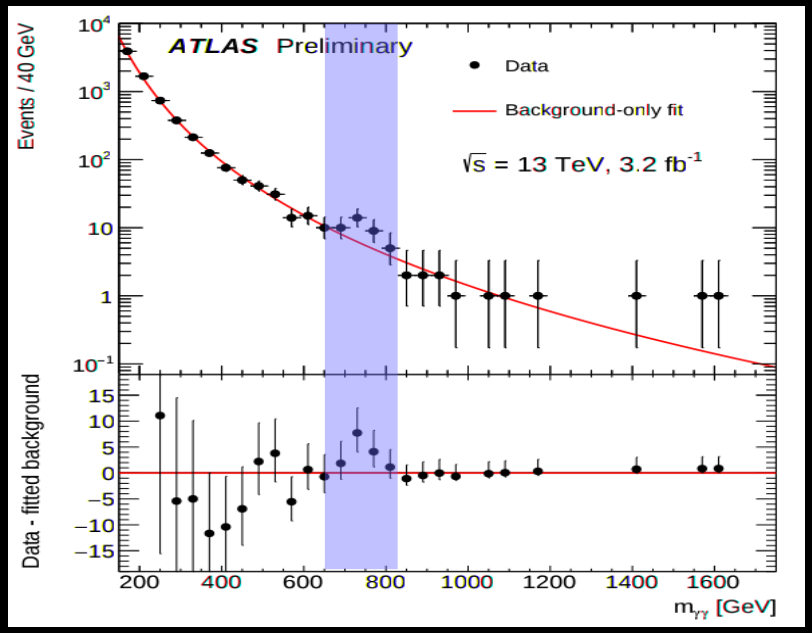

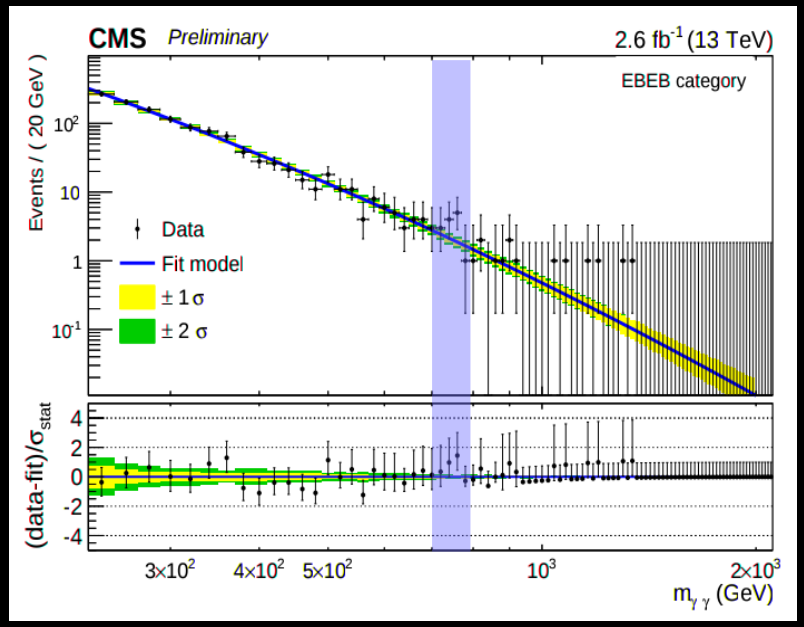

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- Is it true? Are we this lucky?
- What's the production cross section? Large, around 5 fb
- What is it? Is it related with naturalness? And if not, why is it?
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A 750 GeV $\gamma\gamma$ resonance?

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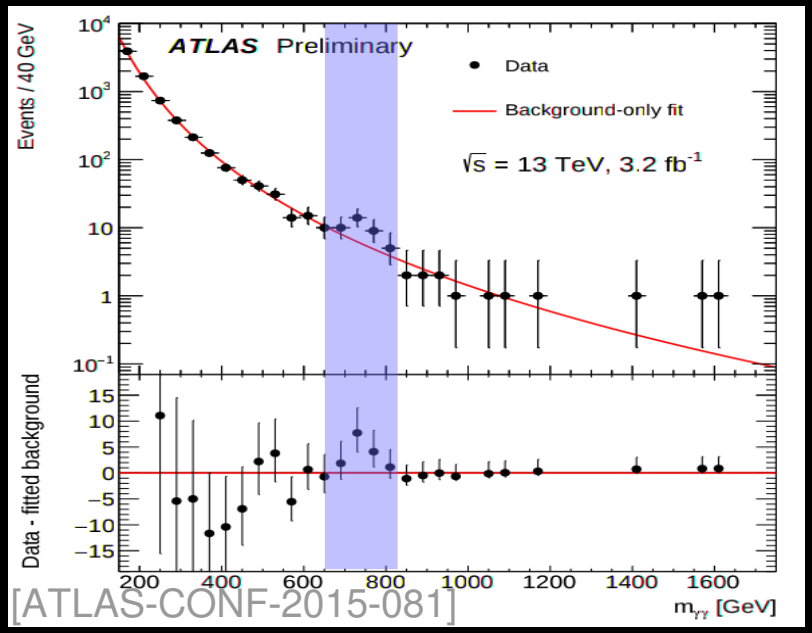
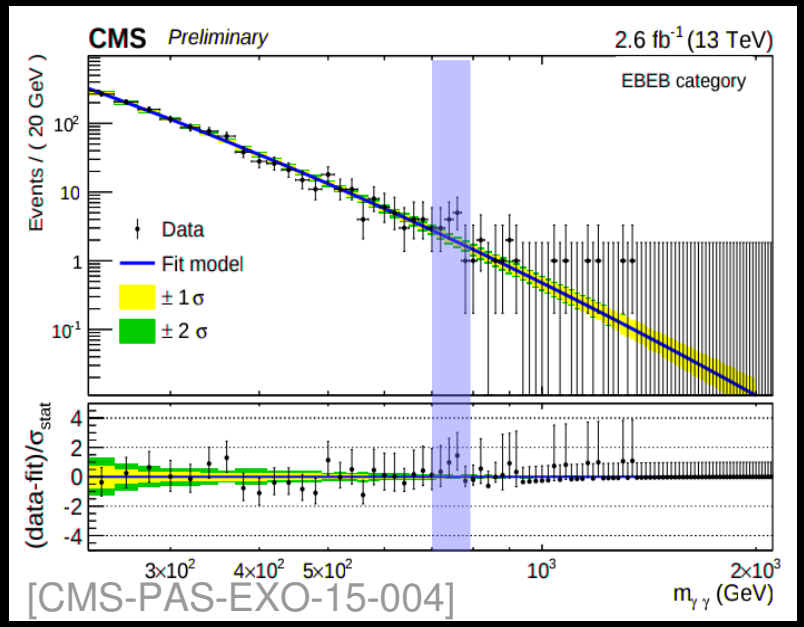


[ATLAS-CONF-2015-081]



[CMS-PAS-EXO-15-004]

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~ no clue!
(but ~400 ideas)

A 750 GeV $\gamma\gamma$ resonance?

The Spring impatience

How much data they have?

When are they going to unblind?

When we theorist will know?

A 750 GeV $\gamma\gamma$ resonance?

The Spring impatience

How much data they have?

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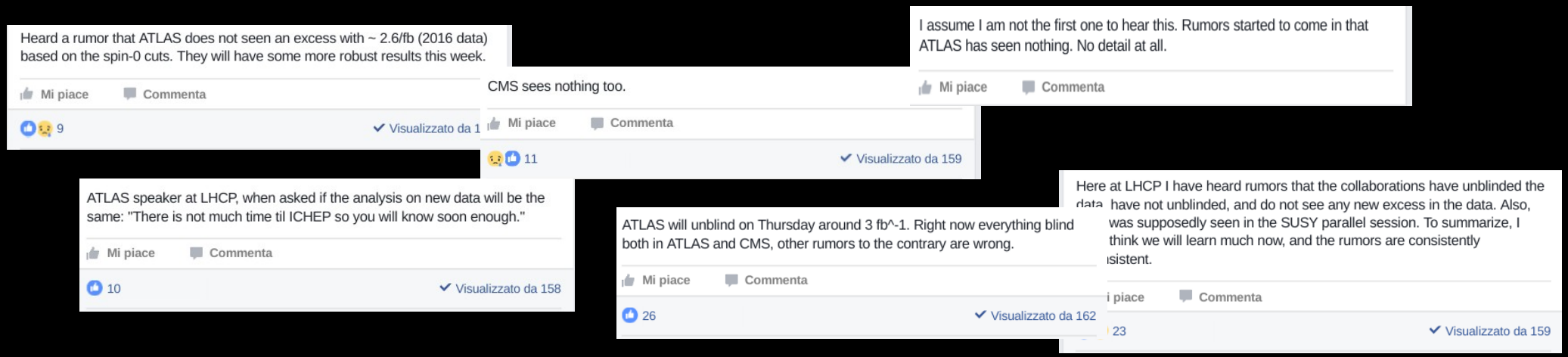
When we theorist will know?

Meanwhile on the web...



Rumours, rumours, rumours... All negative, but nothing conclusive yet

ICHEP is not far, and for the moment we still have an excess in 2015 data

Let's go back to theory interpretation and implications

A 750 GeV $\gamma\gamma$ resonance?

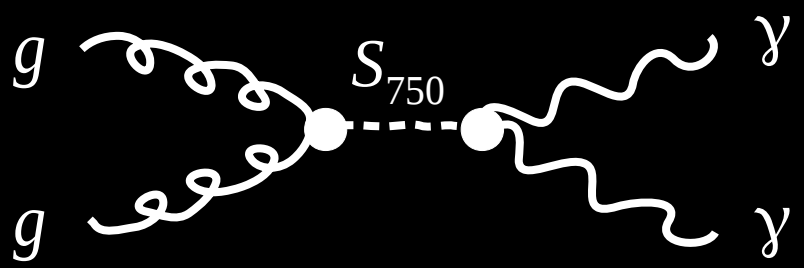
What do we know, assuming is a resonance undergoing a 2 body decay?

- It's a boson and it cannot be spin 1
- It's neutral, and thus decays into two photons via a loop diagram

Compatibility with run-1 limits requires $\sigma_{13\,TeV}/\sigma_{8\,TeV} \sim 5$ [Franceschini et al. '15]

- It hints to production via gluons fusion or sea quarks

The easiest possibility is a scalar singlet coupled to gluons and photons



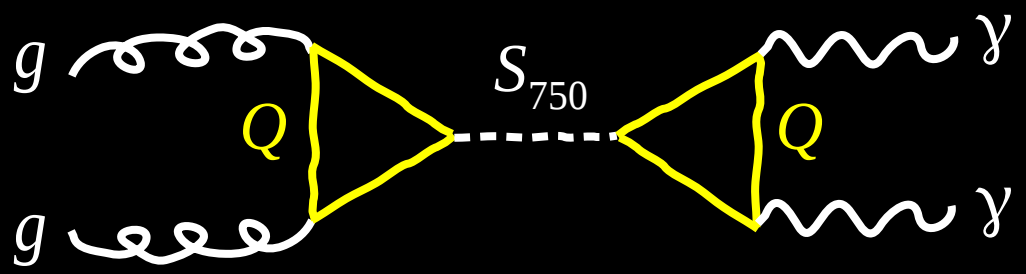
This interactions be parametrised by the "everybody's model"

$$L = \Lambda_g^{-1} S G^{\mu\nu} G_{\mu\nu} + \Lambda_\gamma^{-1} S F^{\mu\nu} F_{\mu\nu}$$

Question: What's the underling structure of the everybody's model?

Heavy Quarks and the $\gamma\gamma$ resonance

- Extra matter content it's generally necessary to achieve large σ
- Vector like quarks invoked in models compatible with the $\gamma\gamma$ excess



Q { Charged under $SU(3)_c$

Can be an $SU(2)_L$ singlet, only charged under $U(1)_Y$

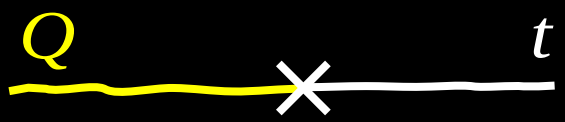
Possible underling structure of the "everybody's model"

$$L = y_S S\bar{Q}Q + M\bar{Q}Q + m\bar{Q}t_R + \frac{\lambda_t v}{\sqrt{2}}\bar{t}_L t_R + \Lambda_g^{-1} S G^{\mu\nu} G_{\mu\nu} + \Lambda_\gamma^{-1} S F^{\mu\nu} F_{\mu\nu}$$

Heavy Quarks and the $\gamma\gamma$ resonance

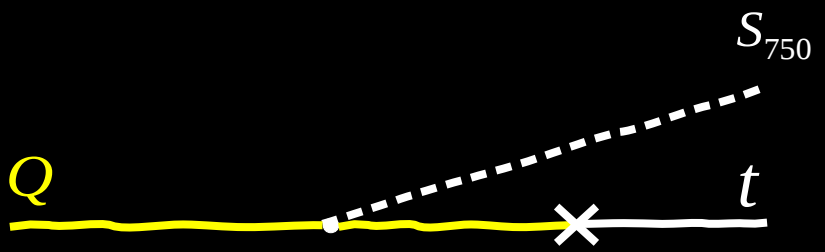
- The heavy quark mixes with the SM top

$m\bar{Q}t_R$



$$tg_{2\theta_R} \sim 2\frac{m}{M}\left(1+\frac{m^2}{M^2}+\frac{\lambda_t^2 v^2}{2M^2}\right)$$

$$\frac{tg_{2\theta_L}}{tg_{2\theta_R}} \sim \frac{\lambda_t v}{\sqrt{2}M}\left(1-2\frac{m^2}{M^2}\right)$$



$$m_{S_{750}} + m_t \sim 920\,GeV$$

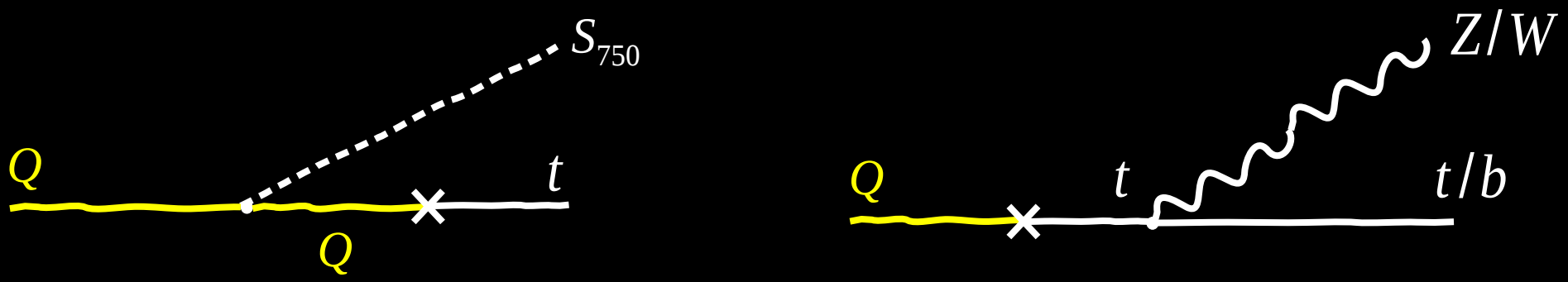
- This is the kinematic region that the LHC has just started to probe

LHC 8 limits on VLQs ATLAS ~ CMS ~ 750-950 GeV

- The heavy quark can decay into the 750 GeV resonance!

Heavy Quarks and the $\gamma\gamma$ resonance

- The mixing term intervenes also into the decay into SM states

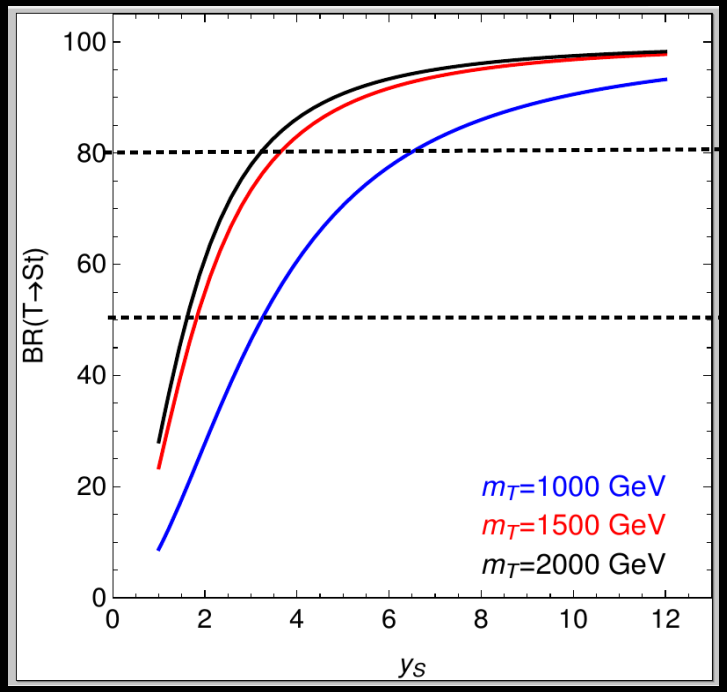


- The rate into St it's independent of the mixing, and depends only on y_S
  [Csaki et al. '16]

$$\Gamma_{T\to Vq} \sim g^2 s_L^2 m_T$$

$$\Gamma_{T\to Ht} \sim \lambda_t^2 s_L^2 m_T$$

$$\Gamma_{T\to St} \sim y_S^2 s_L^2 m_T$$



$y_S \in [2.5,6]$

$y_S \in [1.5,3.5]$

Large rates attainable with $y_S < 4\pi$

Heavy Quarks and the $\gamma\gamma$ resonance

- The S resonance can decay to $\gamma\gamma$, gg and $t\bar{t}$

$$\begin{cases} \Gamma_{S\to gg} \sim \alpha_s \dfrac{m_S^3}{m_T^2} y_S^2 c_L^2 c_R^2 \\ \Gamma_{S\to\gamma\gamma} \sim \alpha_{em} \dfrac{m_S^3}{m_T^2} y_S^2 c_L^2 c_R^2 \\ \Gamma_{S\to t\bar{t}} \sim m_S y_S^2 s_L^2 s_R^2 \end{cases}$$

- Branching ratios independent of y_S
- Small mixing necessary to suppress $t\bar{t}$

$$\sigma_{\gamma\gamma} \sim \frac{1}{s M_S} \Gamma_{S\to gg} BR_{S\to\gamma\gamma}$$

- The $\gamma\gamma$ rate depends on y_S

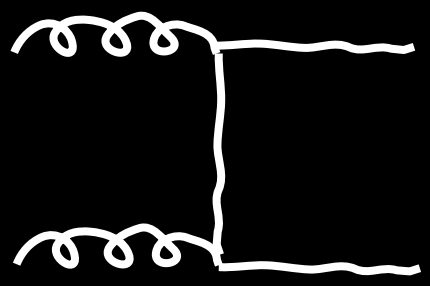
$$BR^T_{S\to\gamma\gamma} \sim \frac{\alpha_{em}^2}{\alpha_s^2} \sim 4\times 10^{-3}$$

Possible enhancement with heavy leptons VLL
[Angelescu et al. '15]

- Keep $BR_{S\to\gamma\gamma}$ free to parametrise contributions from extra matter

Heavy Quarks and the $\gamma\,\gamma$ resonance

- 8 TeV stronger limits on VLQs come from pair production



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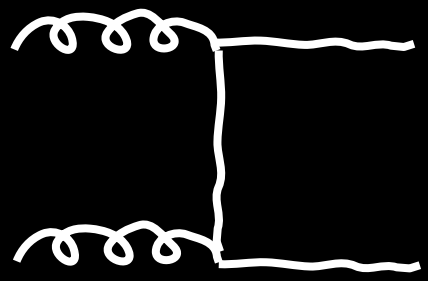
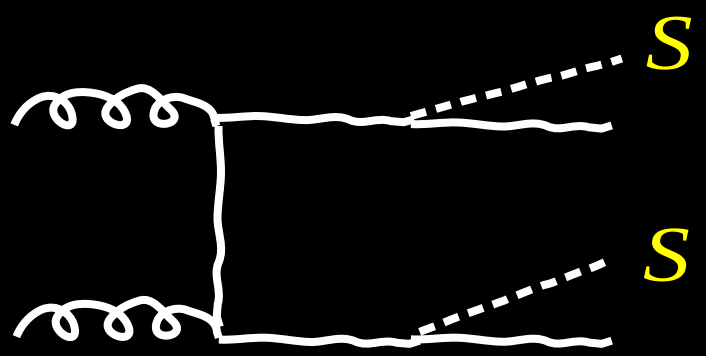


$$BR_{T \to St} \sim O(1)$$



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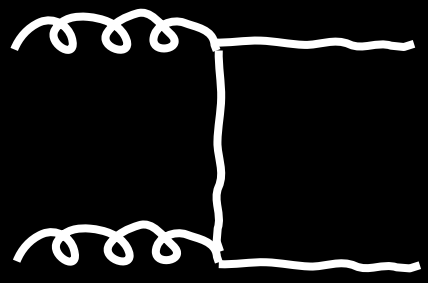

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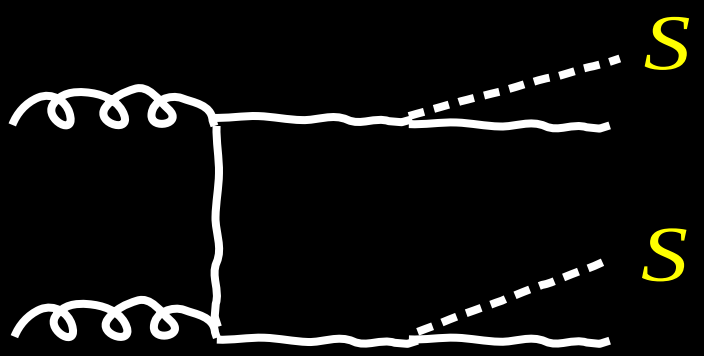


$$p\,p \to T\,\bar{T} \to S\,t\,S\,\bar{t} \to S\,S\,W\,W\,b\,\bar{b}$$

- Taking one S to decay into a $\gamma\gamma$ pair and one leptonic W

$$p\,p \to T\,\bar{T} \to 2\,\gamma + l + 6\,j$$

- CMS performed a similar 8 TeV analysis for the case of $T \to Ht$ [CMS-B2G-13-005]
  - Good sensitivity, despite $BR^{SM}_{H \to \gamma\gamma} \sim 2 \times 10^{-3}$
  - Limit of ~600 GeV for $BR_{T \to Ht} = 1$

- What can LHC run-2 say on this process?

A new search channel for heavy quarks

- Selection requirements
  - 2 isolated photons, with $m_{\gamma\gamma} \in [700, 800]\, GeV$
  - Leading photon $p_T^{\gamma_1} > m_{\gamma\gamma}/2$
  - One isolated lepton
  - $ST = MET + HT + p_T^l > 770\, GeV$

  } 8 TeV-like selections

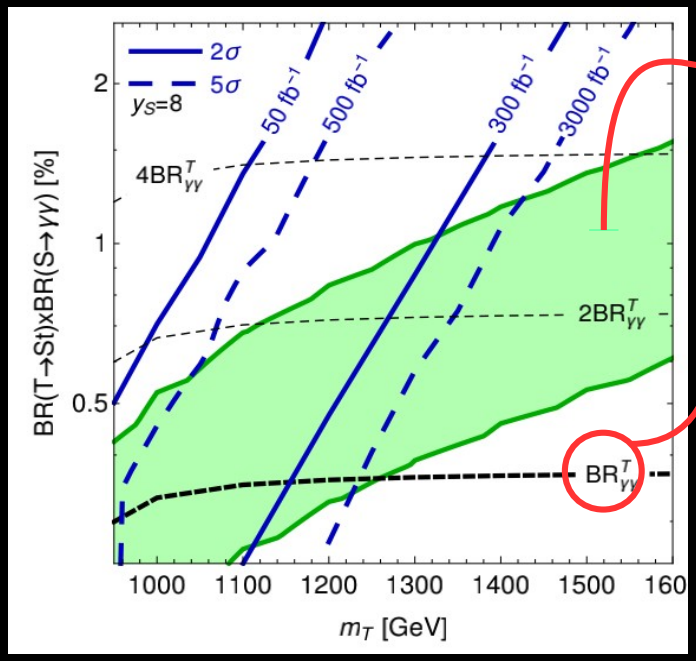
- Main backgrounds from non resonant processes
  - $\gamma\gamma t\bar{t}$, $\gamma\gamma t$, $\gamma\gamma + jets$
  - Difficult to model with Montecarlo
  - We rescale the 8 TeV rate for $\sqrt{s}$ increase and acceptance differences

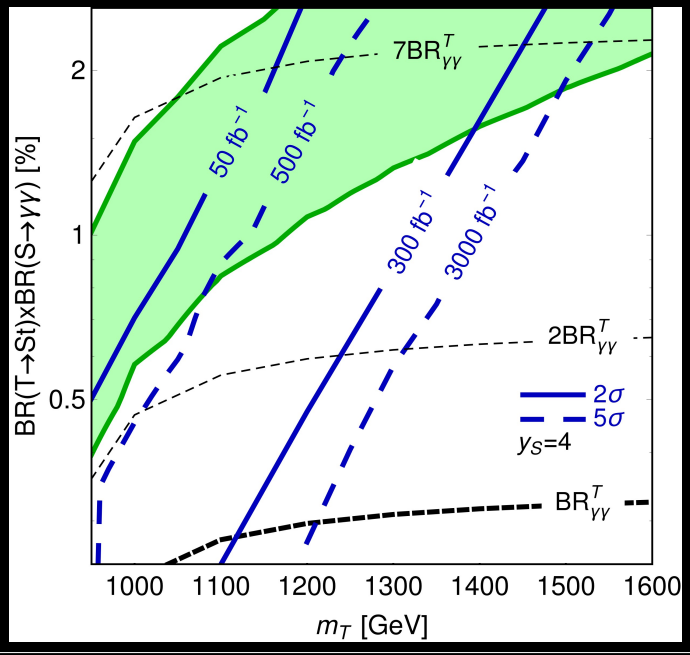
$$B^{8\,TeV}_{19.7\,fb^{-1}} = 0.11\, events$$

$$B^{13\,TeV}_{L} = 0.04 \frac{L}{19.7}\, events$$

- Define a statistical measure $\alpha = \frac{S}{\sqrt{S+B}}$

A new search channel for heavy quarks





Region compatible with the diphoton signal

Nominal model Branching Ratio

LHC 13 reach

- 2σ reach extends up to 1.3 TeV for $L = 300\, fb^{-1}$
- 5σ reach extends up to 1.4 TeV for $L = 3000\, fb^{-1}$
- Results in the $m_T - BR$ plane are model independent. Easy reinterpretation
- Large region of the $\gamma\gamma$ excess regions accessible during run-2
- Unique probe of the Tt mixing, due to the reconstruction of $m_{\gamma\gamma}$

Impact on standard heavy quark searches

$$
\left.
\begin{array}{r}
p\,p \to T\,\bar{T} \to W\,W\,b\,\bar{b} \\
p\,p \to T\,\bar{T} \to Z\,t\,Z\,\bar{t} \to W\,W\,b\,\bar{b}\,Z\,Z \\
p\,p \to T\,\bar{T} \to H\,t\,H\,\bar{t} \to W\,W\,b\,\bar{b}\,H\,H \\
\hline
p\,p \to T\,\bar{T} \to S\,t\,S\,\bar{t} \to W\,W\,b\,\bar{b}\,S\,S
\end{array}
\right\}
$$

Similar final stats when $S \to jj$

Softer leptons, due to non boosted T decay products
Higher hadronic activity, due two jets coming from the S decay

BP1 $\begin{cases} m_T = 1000\,GeV \\ BR(S \to \gamma\,\gamma) = 2 \times BR^T_{\gamma\,\gamma} \end{cases}$

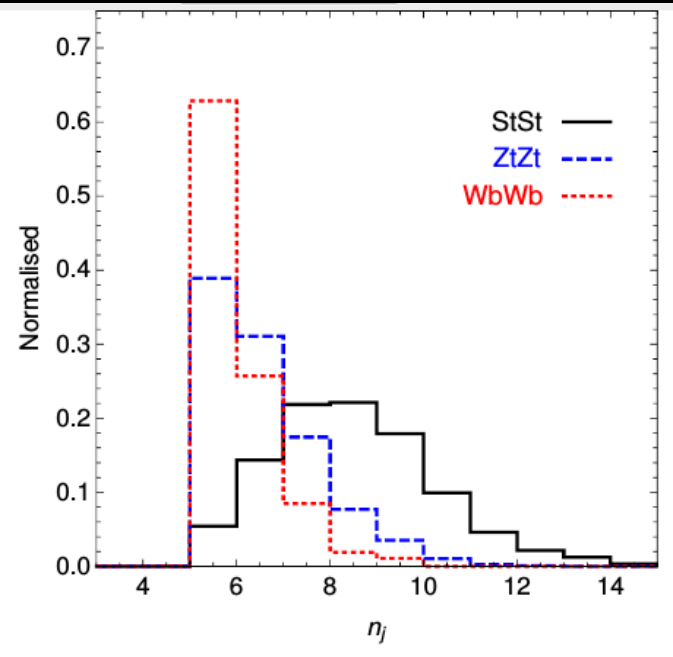
BP2 $\begin{cases} m_T = 1100\,GeV \\ BR(S \to \gamma\,\gamma) = BR^T_{\gamma\,\gamma} \end{cases}$

$ZtZt$ selection
- 2 opposite sign leptons
- 5 jets (2 b-tag)
- $HT > 1200\,GeV$, $ST > 1700\,GeV$

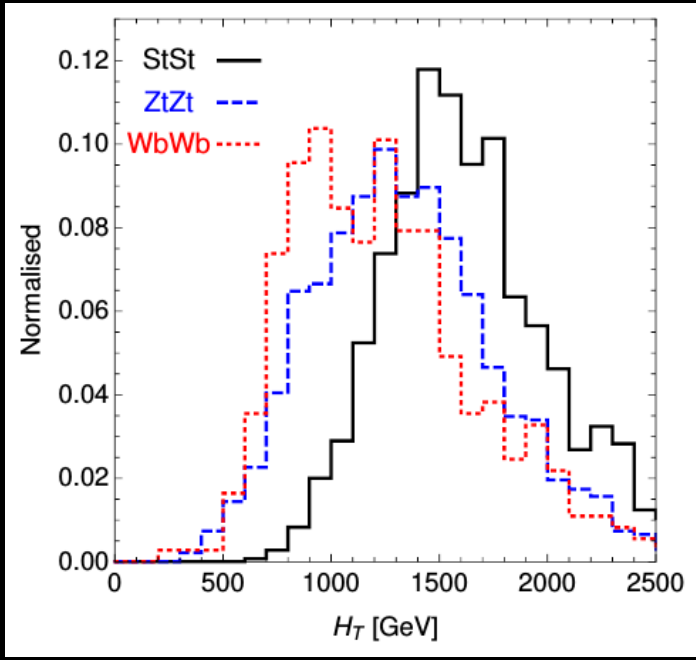
$\mathcal{L}$ [fb^{-1}]	$N_{bkg.}$	N_{BP_1}	α_{BP_1}	N_{BP_2}	α_{BP_2}
100	439	26	1.2σ	22	1.0σ
300	1317	79	2.1σ	67	1.8σ
1000	4390	262	3.8σ	222	3.3σ
3000	13170	786	6.7σ	674	5.8σ

Impact on standard heavy quark searches

If a signal is observed in a selection targeting VLQs, can we disentangle the decay mode of the heavy quark?



$$m_T = 1000\,GeV$$



- Heavy quarks decaying into St feature higher jet multiplicity and higher hadronic activity
- Possible in principle to disentangle the origin of the signal

Conclusions

- Hint of a 750 GeV diphoton resonance in early 13 TeV data
- The large production cross section seems to require the presence of extra matter, for example VLQs, coupled to the resonance
- Mixing effects will induce the decay of the heavy quarks into the resonance and a SM quark, which can be the dominant channel

Consequences

- Complementary probe of new physics through this new VLQs decay mode. Strong sensitivity with the $\mathcal{Y}\,\mathcal{Y}$ final state at LHC 13
- Impact on standard VLQ searches: tighter kinematic cuts will ensure sensitivity to this decay mode with current selections
- Exploit the differences in hadronic activity to discriminate between various decay modes once a signal is observed

- Results applicable to any diphoton resonance lighter than T

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Thank you!