DIPHOTON EXCESS: 750 GEV SCALAR OR THE KITCHEN SINK?

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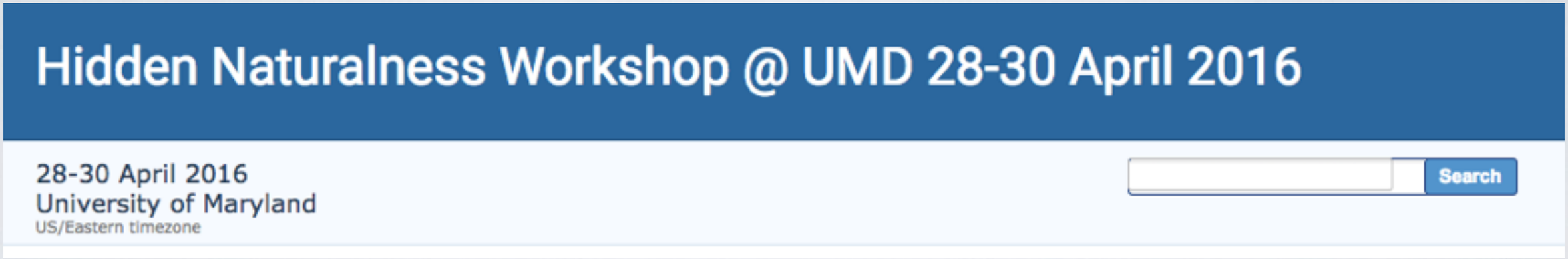
Based on 1512.05295 with
Sam McDermott and Harikrishnan Ramani

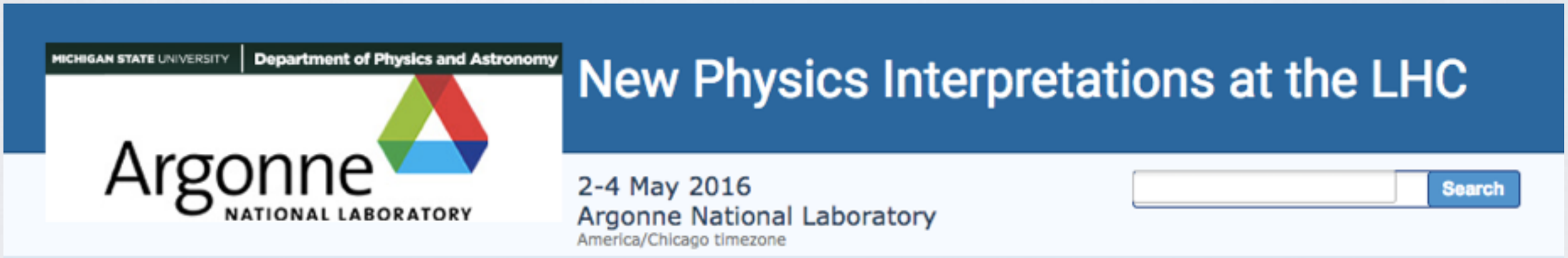
A BIT OF A STRANGE TIME IN THE FIELD…

A BIT OF A STRANGE TIME IN THE FIELD…

Luckily our field isn't the only one having issues…

A TALE OF TWO CITIES…





WHAT'S ALL THE FUSS?

- Dec 15 ATLAS and CMS release first results from 13 TeV
- slight excess in a search for a Higgs-like object found in both experiments - 3.6 sigma local, 2.0 global (ATLAS), 2.6 local, 1.2 global (CMS)
- What's this mean?
  - roughly 1/100-1/1000 chance local or 1/20 to 1/3 with LEE
  - but there's two experiments…
  - AND it would be the first particle ever beyond the SM, so the stakes are high!

SO WHAT HAPPENED?

SO WHAT HAPPENED?

Composite Models for the 750 GeV Diphoton Excess

Keisuke Harigaya, Yasunori Nomura

(Submitted on 15 Dec 2015 (v1), last revised 16 Dec 2015 (this version, v2))

We present composite models explaining the diphoton excess of mass around 750 GeV recently reported by the LHC experiments.

Comments: 7 pages, 1 figure
Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Physics - Experiment (hep-ex)
DOI: 10.1016/j.physletb.2016.01.026
Report number: UCB-PTH-15/15
Cite as: arXiv:1512.04850 **[hep-ph]**
(or arXiv:1512.04850v2 **[hep-ph]** for this version)

Submission history

From: Keisuke Harigaya [view email]
[v1] Tue, 15 Dec 2015 16:47:58 GMT (215kb)
[v2] Wed, 16 Dec 2015 08:19:11 GMT (183kb)

Not more than an hour or so after the talks at CERN…

SO WHAT HAPPENED?

band·wag·on

/ˈbandˌwagən/

noun

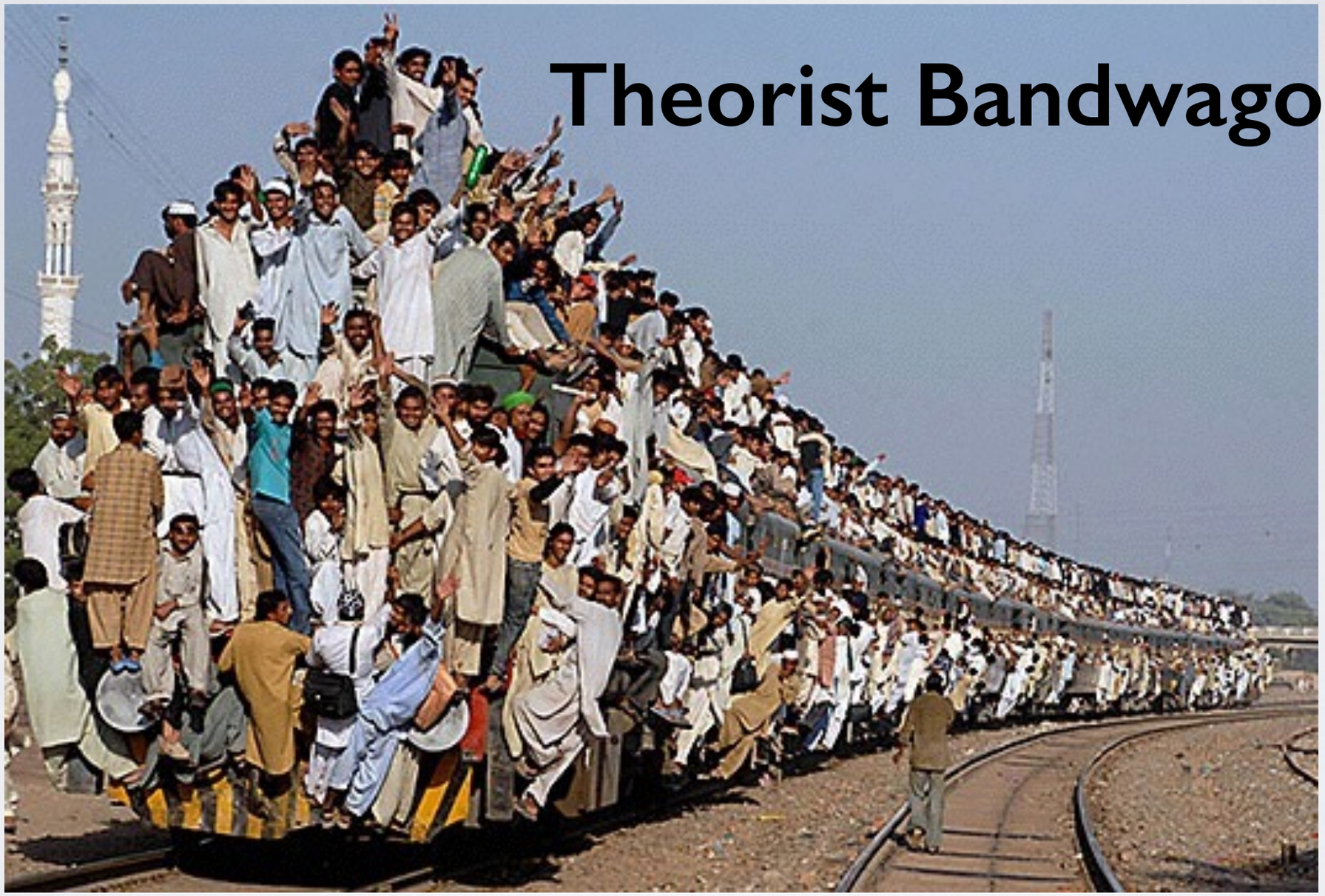
1. a wagon used for carrying a band in a parade or procession.
2. a particular activity or cause that has suddenly become fashionable or popular.
   "the local deejays are on the home-team bandwagon"

SO WHAT HAPPENED?

http://astrumia.web.cern.ch/astrumia/InstantPaper.html

December 2015: the Gold Rush			
0	ATLAS and CMS	seminar	15 Dec 2015 14-16
1	K. Harigaya, Y. Nomura, 7 pages	1512.04850	v1: 15 Dec 2015 16:47:58 v2: 16 Dec 2015 08:19:11
2	Y. Mambrini, G. Arcadi, A. Djouadi, 9 pages	1512.04913	15 Dec 2015 20:05:04
3	M. Backovic, A. Mariotti, D. Redigolo, 17 pages	1512.04917	15 Dec 2015 20:26:16
4	A. Angelescu, A. Djouadi, G. Moreau, 15 pages	1512.04921	15 Dec 2015 20:32:58
5	Y. Nakai, R. Sato, K. Tobioka, 6 pages	1512.04924	15 Dec 2015 20:39:32
6	S. Knapen, T. Melia, M. Papucci, K. Zurek, 20 pages	1512.04928	15 Dec 2015 20:44:08
7	D. Buttazzo, A. Greljo, D. Marzocca, 16 pages	1512.04929	15 Dec 2015 20:49:36
8	A. Pilaftsis, 6 pages	1512.04931	15 Dec 2015 20:50:27
9	R. Franceschini, G. Giudice, J.F. Kamenik, M. McCullough, A. Pomarol, R Rattazzi, M. Redi, F. Riva, A. Strumia, R. Torre, 32 pages	1512.04933	15 Dec 2015 20:53:14
10	S. Di Chiara, L. Marzola, M. Raidal, 5 pages	1512.04939	15 Dec 2015 20:59:17
11	T. Higaki, K.S. Jeong, N. Kitajima, F. Takahashi, 8 pages	1512.05295	16 Dec 2015 19:36:36
12	S.D. McDermott, P. Meade, H. Ramani, 6 pages	1512.05295	16 Dec 2015 20:48:16
13	J. Ellis, S.A.R. Ellis, J. Quevillon, V. Sanz, T. You, 36 pages	1512.05327	16 Dec 2015 20:49:44
14	M. Low, A. Tesi, L.T. Wang, 23 pages	1512.05328	16 Dec 2015 20:50:26
15	B. Bellazzini, R. Franceschini, F. Sala, J. Serra, 15 pages	1512.05330	16 Dec 2015 20:52:53
16	R.S. Gupta, S. Jager, Y. Kats, G. Perez, E. Stamou, 26 pages	1512.05332	16 Dec 2015 20:55:11
17	C. Petersson, R. Torre, 3 pages	1512.05333	16 Dec 2015 20:57:47
18	E. Molinaro, F. Sannino, N. Vignaroli, 5 pages	1512.05334	16 Dec 2015 20:58:23
>19	19.5 papers more		17 Dec 2015
>40	6 papers more		21 Dec 2015
>46	27 papers more, mention d'honneur to dark matter decaying to gamma gamma (1512.06562) and to the D3-brane (1512.06773)		22 Dec 2015

SO WHAT HAPPENED?



Theorist Bandwagon…

SO WHAT HAPPENED?

HEP **2** records found Search took 0.09 seconds.

1. **Search for resonances decaying to photon pairs in 3.2 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector**
   The ATLAS collaboration. Dec 15, 2015.
   ATLAS-CONF-2015-081
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   CERN Document Server ; Link to Fulltext
   Detailed record - Cited by 320 records 250+

2. **Search for new physics in high mass diphoton events in proton-proton collisions at 13TeV**
   CMS Collaboration. 2015. 17 pp.
   CMS-PAS-EXO-15-004
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   CERN Document Server ; Link to Fulltext
   Detailed record - Cited by 309 records 250+

$\mathcal{O}(2)$ citations per day for over 4 months…

UNPRECEDENTED even beyond the ACTUAL Higgs

MULTIPLE THEORY PAPERS FROM THE SAME AUTHORS EVEN…

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find j "Phys.Rev.Lett.,105" :: more

Sort by: earliest date | desc. | - or rank by - | Display results: 25 results | single list

HEP **134** records found 1 - 25 ▸▸ jump to record: 1 Search took 0.14 seconds.

1. **Novel kinematics from a custodially protected diphoton resonance**
   Jack H. Collins, Csaba Csaki, Jeff Asaf Dror, Salvator Lombardo (Cornell U., Phys. Dept. & Cornell U., LEPP). Mar 30, 2016. 24 pp.
   e-Print: arXiv:1603.09350 [hep-ph] | PDF
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record - Cited by 1 record

2. **A Diphoton Resonance from Bulk RS**
   Csaba Csaki (Cornell U., LEPP & Cornell U., Phys. Dept.), Lisa Randall (Harvard U., Phys. Dept.). Mar 23, 2016. 15 pp.
   e-Print: arXiv:1603.07303 [hep-ph] | PDF
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record - Cited by 4 records

3. **Gluon vs. Photon Production of a 750 GeV Diphoton Resonance**
   Csaba Csaki (Cornell U., LEPP), Jay Hubisz (Syracuse U.), Salvator Lombardo (Cornell U., LEPP), John Terning (UC, Davis). Jan 4, 2016. 15 pp.
   e-Print: arXiv:1601.00638 [hep-ph] | PDF
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record - Cited by 69 records 50+

4. **Minimal model of a diphoton resonance: Production without gluon couplings**
   Csaba Csáki (Cornell U., LEPP), Jay Hubisz (Syracuse U.), John Terning (UC, Davis). Dec 17, 2015. 4 pp.
   Published in **Phys.Rev. D93 (2016) no.3, 035002**
   DOI: 10.1103/PhysRevD.93.035002
   e-Print: arXiv:1512.05776 [hep-ph] | PDF
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   ADS Abstract Service
   Detailed record - Cited by 160 records 100+

THIS WOULDN'T BE THE FIRST TIME THEORISTS DISCOVERED A BOSON IN DECEMBER…

ATLAS Note

Report number	ATLAS-CONF-2011-161
Title	**Search for the Standard Model Higgs boson in the diphoton decay channel with 4.9 fb-1 of ATLAS data at sqrt(s)=7TeV**
Corporate Author(s)	The ATLAS collaboration
Collaboration	ATLAS Collaboration
Imprint	13 Dec 2011. - mult. p.
In:	108th LHCC Meeting, CERN, Geneva, Switzerland, 7 - 8 Dec 2011
Subject category	Detectors and Experimental Techniques
Accelerator/Facility, Experiment	CERN LHC ; ATLAS
Free keywords	Standard Model Higgs ; Diphotons
Abstract	This note presents a search for the Standard Model Higgs boson in the diphoton decay channel in proton-proton collisions at a centre-of-mass energy of sqrt(s)=7 TeV using data corresponding to an integrated luminosity of 4.9 fb-1 collected with the ATLAS detector at the LHC. Over the diphoton mass range 110-150 GeV the maximum deviation from the background-only expectation is observed at 126 GeV with a local significance of 2.8 standard deviations. Taking the look-elsewhere effect into account, the significance is 1.5 standard deviations. The expected cross section exclusion at 95% confidence level varies between 1.6 and 2.9 times the Standard Model cross section over the mass range 110-150 GeV. The observed exclusions lie between 0.9 and 4.0 times the Standard Model cross section, and a Standard Model Higgs boson is excluded at 95% confidence level in the mass range of 114-115 GeV and 135-136 GeV.

Corresponding record in: Inspire

Back to search

Record created 2011-12-13, last modified 2015-01-14

THIS WOULDN'T BE THE FIRST TIME THEORISTS DISCOVERED A BOSON IN DECEMBER…

Implications of a 125 GeV Higgs for the MSSM and Low-Scale SUSY Breaking

Patrick Draper, Patrick Meade, Matthew Reece, David Shih

(Submitted on 13 Dec 2011)

Recently, the ATLAS and CMS collaborations have announced exciting hints for a Standard Model-like Higgs boson at a mass of approximately 125 GeV. In this paper, we explore the potential consequences for the MSSM and low scale SUSY-breaking. As is well-known, a 125 GeV Higgs implies either extremely heavy stops (>~ 10 TeV), or near-maximal stop mixing. We review and quantify these statements, and investigate the implications for models of low-scale SUSY breaking such as gauge mediation where the A-terms are small at the messenger scale. For such models, we find that either a gaugino must be superheavy or the NLSP is long-lived. Furthermore, stops will be tachyonic at high scales. These are very strong restrictions on the mediation of supersymmetry breaking in the MSSM, and suggest that if the Higgs truly is at 125 GeV, viable models of gauge-mediated supersymmetry breaking are reduced to small corners of parameter space or must incorporate new Higgs-sector physics.

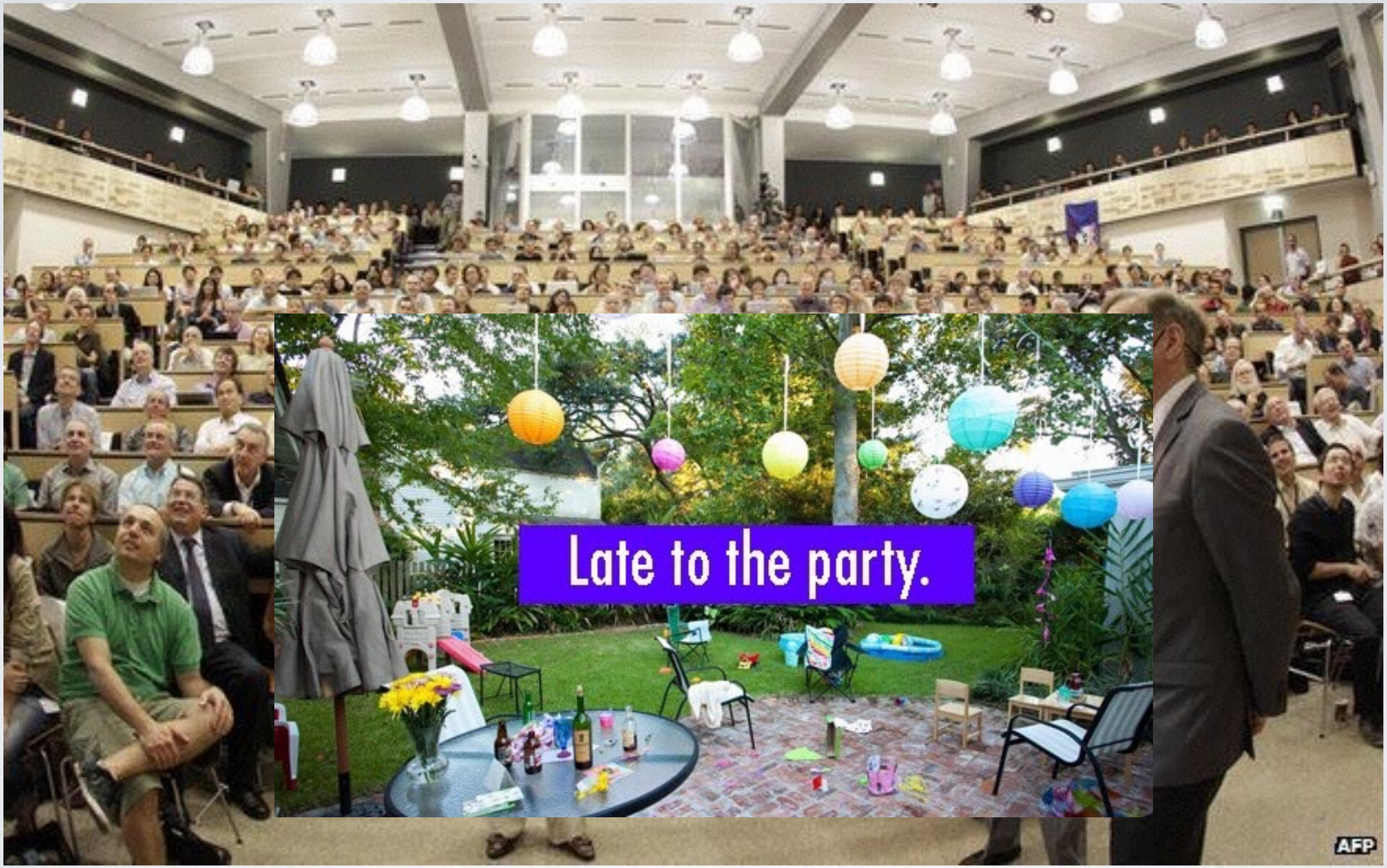
Comments: 6 pages, 6 figures
Subjects: **High Energy Physics - Phenomenology (hep-ph)**
DOI: 10.1103/PhysRevD.85.095007
Cite as: **arXiv:1112.3068 [hep-ph]**
(or **arXiv:1112.3068v1 [hep-ph]** for this version)

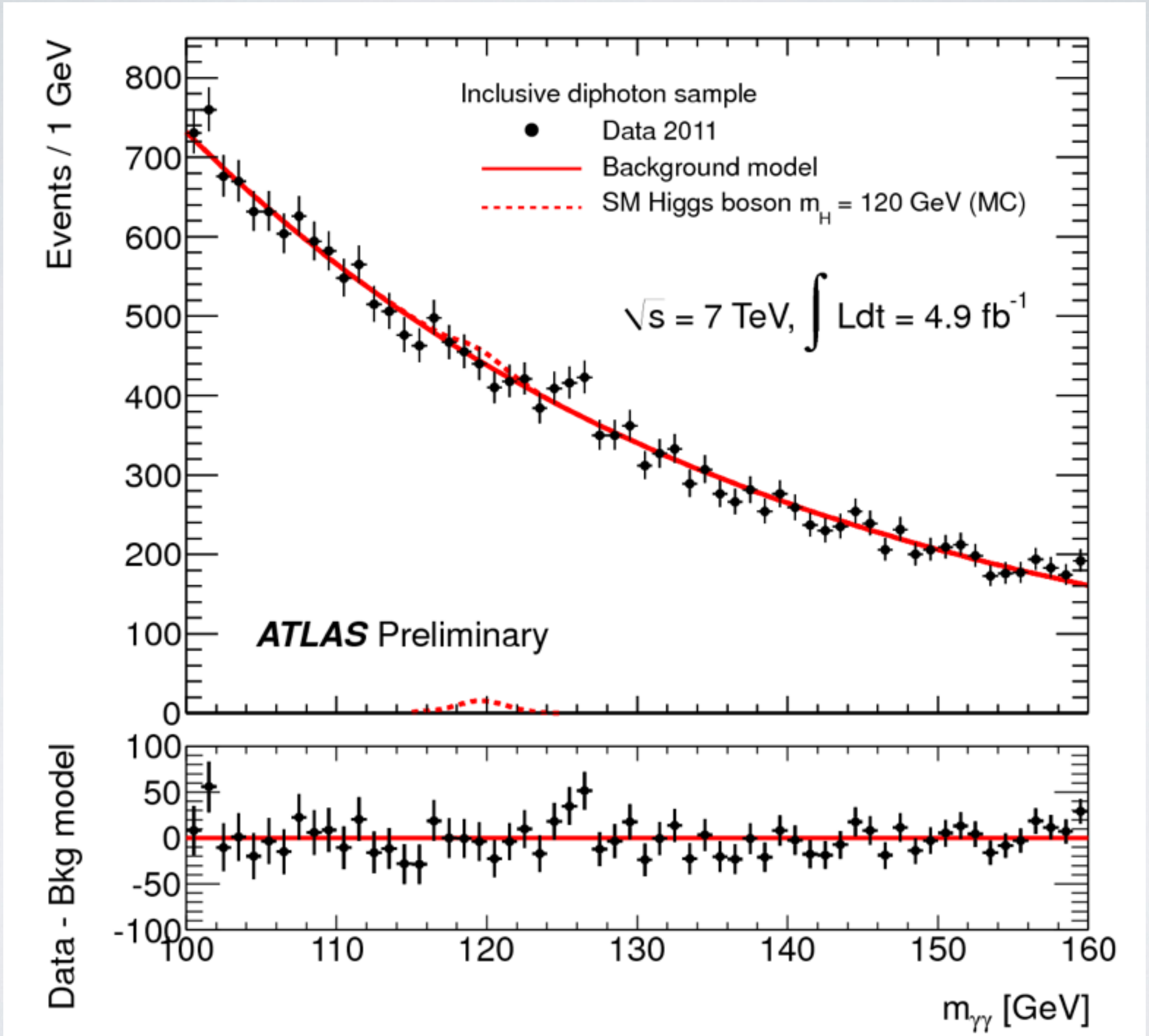
Submission history

From: Matthew Reece [view email]
[v1] Tue, 13 Dec 2011 23:05:02 GMT (484kb,D)

Experimentalists…

Experimentalists…

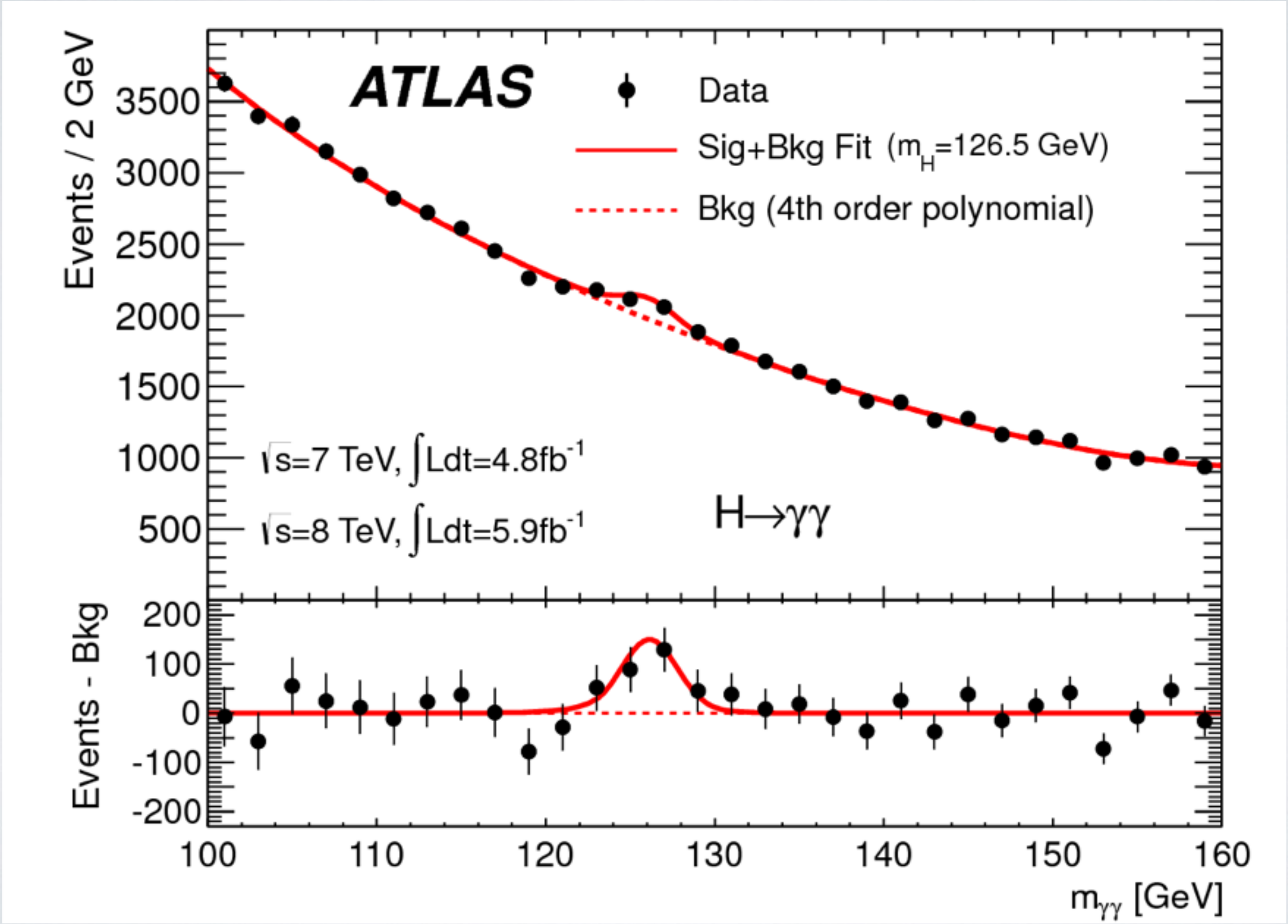



Inclusive diphoton sample
Data 2011
Background model
SM Higgs boson m_H = 120 GeV (MC)
√s = 7 TeV, ∫ Ldt = 4.9 fb^-1
ATLAS Preliminary
Events / 1 GeV
Data - Bkg model
m_γγ [GeV]

RIDICULOUS! WHY WOULD YOU WRITE A PAPER?

BECAUSE THERE WAS A HINT IN ZZ AS WELL!

Eventually turned into 5 sigma… but even this at first is not blatantly obvious if you just go by the distribution



WHAT'S THIS EXCESS LOOK LIKE?

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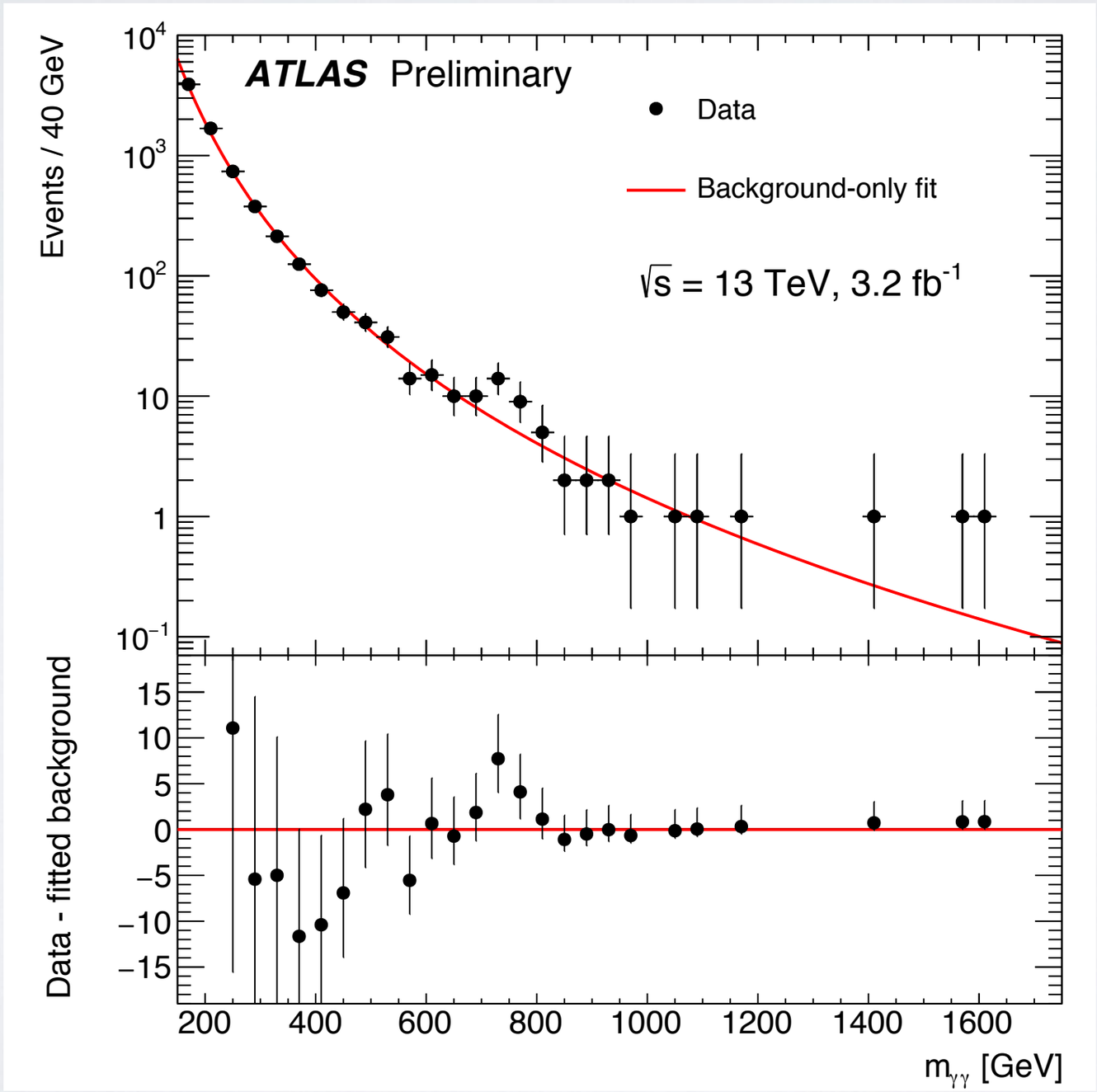

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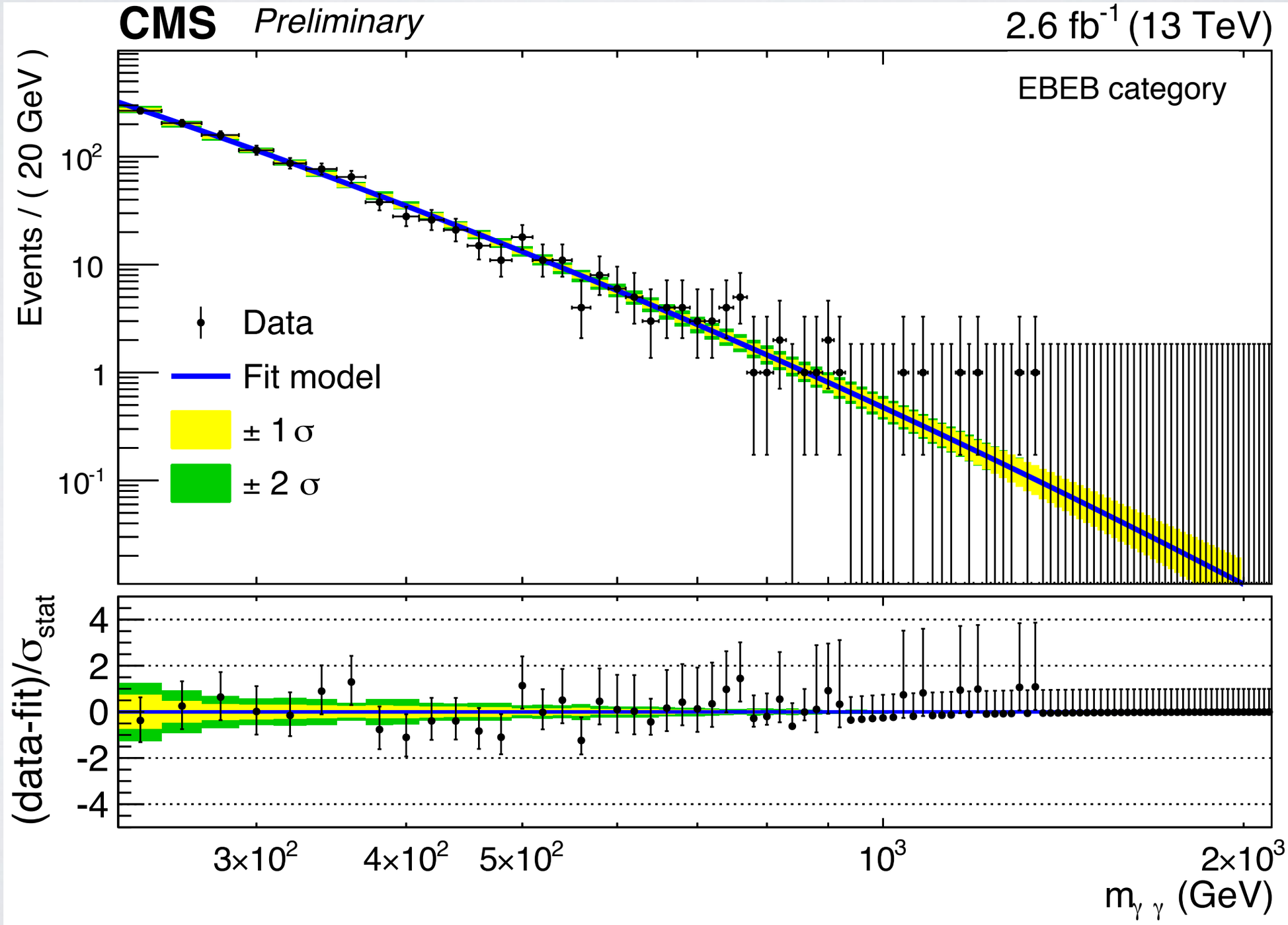


WHAT COULD IT BE?

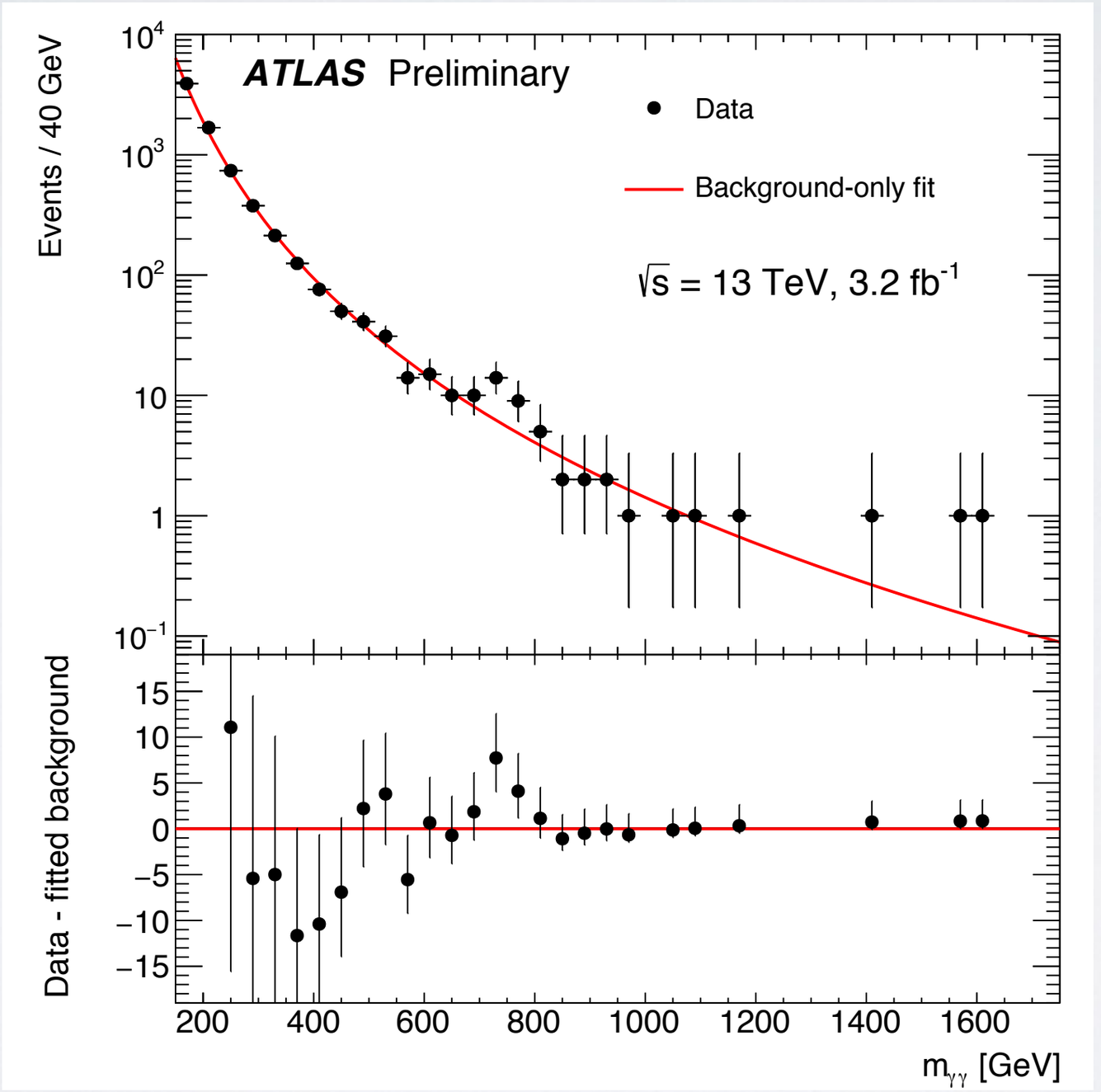
- Statistical fluctuation? Most likely explanation…
- Experimentalists screwed up? poor background modeling? Very very unlikely, but yet not impossible…
- New Physics? ehhhh…

NEW PHYSICS OPTIONS THERE ARE BROADLY 2 CATEGORIES

Resonance

Non-Resonance

NON-RESONANT OPTION

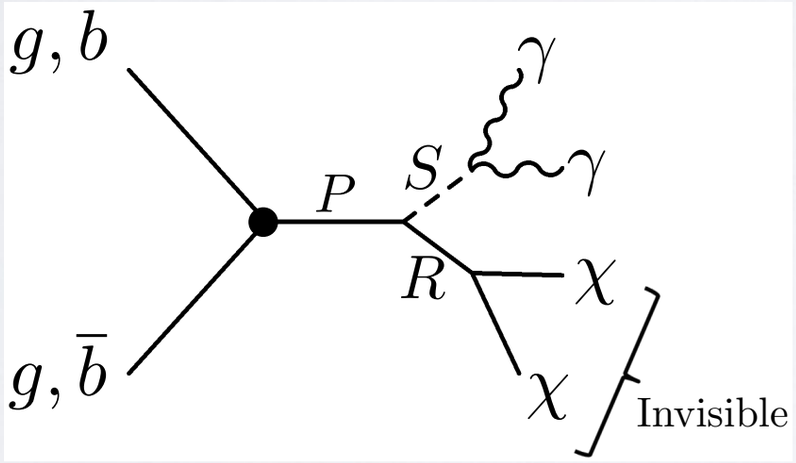


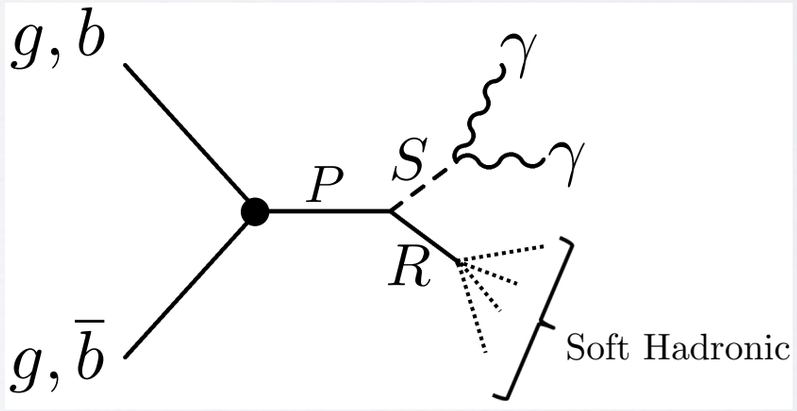
NON-RESONANT OPTION

"We have testimony that you walk like a duck and you quack like a duck. Tell the court—are you a duck?"

MAYBE THAT'S A BIT HARSH…

- However… if you have non resonant production you have other things in the event





MAYBE THAT'S A BIT HARSH…

- However… if you have non resonant production you have other things in the event

- Both experiments explicitly said that the events look like the events in their sideband regions, i.e. pp to diphoton in the SM which doesn't contain other objects…

- Not an impossible option, but no indications, this is something that ***could*** be cleared up with the existing data quite a bit

RESONANCE

- Spin 0 - Likely - could be different types of production and decay

- Spin 1 - No

- Spin 2 - Unlikely

    - couple to stress-energy so you have bounds right away from other channels

What is the $\gamma\gamma$ resonance at 750 GeV?

Roberto Franceschini[a], **Gian F. Giudice**[a],
Jernej F. Kamenik[a,b,c], **Matthew McCullough**[a], **Alex Pomarol**[a,d],
Riccardo Rattazzi[e], **Michele Redi**[f], **Francesco Riva**[a],
Alessandro Strumia[a,g], **Riccardo Torre**[e]

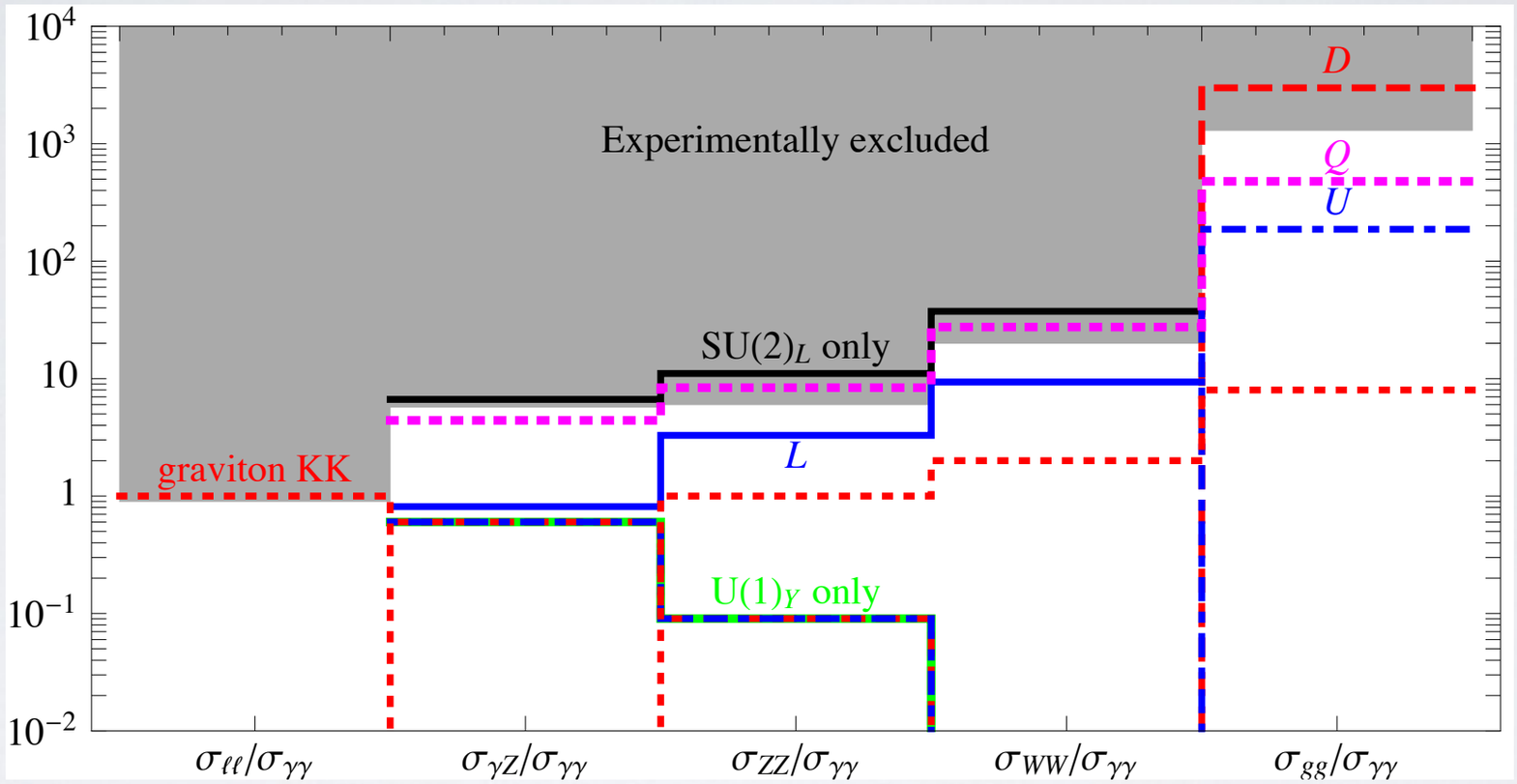


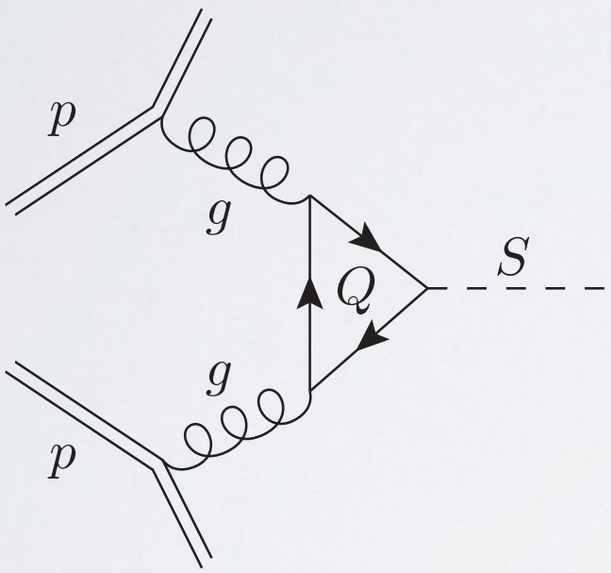
Figure 3: *Predicted cross section into various final states in units of* $\sigma(pp \to S \to \gamma\gamma)$ *compared to the experimental bounds. The models that satisfy all bounds are: a loop of vector-like right-handed up quarks* U *(blue dot-dashed), a loop of vector-like left-handed* L *weak doublets (blue) or of any lepton with* $\mathrm{U}(1)_Y$ *charges only (green), provided that a production mechanism is found. The models that violate some bounds are: a loop of particles with* $\mathrm{SU}(2)_L$ *charges only (black), a loop of vector-like right-handed down quarks* D*, of vector-like left-handed quarks* Q *(red dashed and magenta dotted), and a KK graviton (red dotted).*

WHAT DOES A MODEL NEED TO ACCOMPLISH?

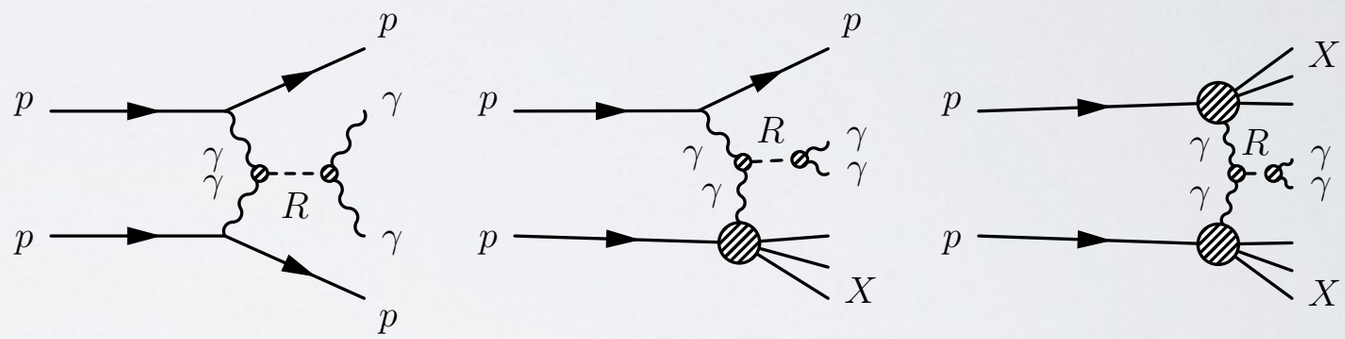
- You need sufficient diphoton events
- You need to not screw up other channels…
- You need a large enough width?

SPIN 0

Colored or Uncolored Production?



Can do easily*
in weak coupling



May be possible but ***needs*** strong coupling

Effective Operators?

OUR SINGLET EXAMPLE

Basically the signal is the same as the Higgs… except you don't want the tree-level decays!

Add a scalar singlet under the SM, but you need to couple it somehow to photons so this isn't sufficient on it's own.

$$\mathcal{L}_{QL} \supset \frac{1}{2} m_S^2 S^2 + y_Q \bar{Q} Q S + m_Q \bar{Q} Q + y_L \bar{L} L S + m_L \bar{L} L$$

Minimal model: Scalar Singlet + Vector-like Fermions

PRODUCTION AND DECAY

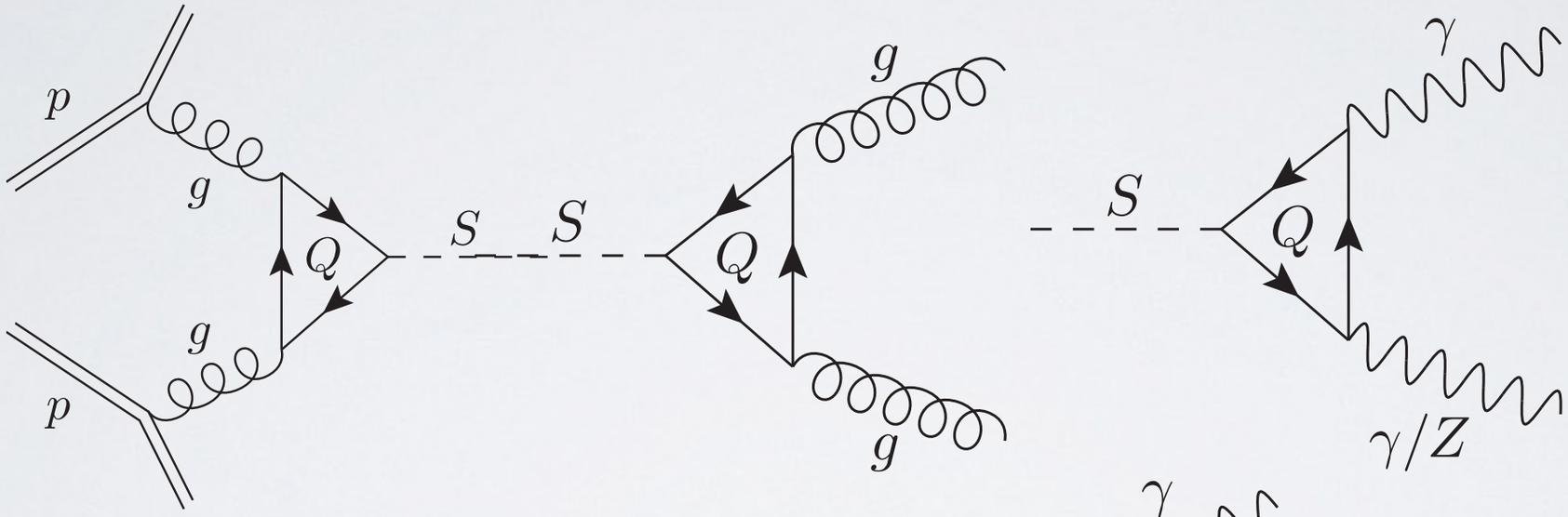
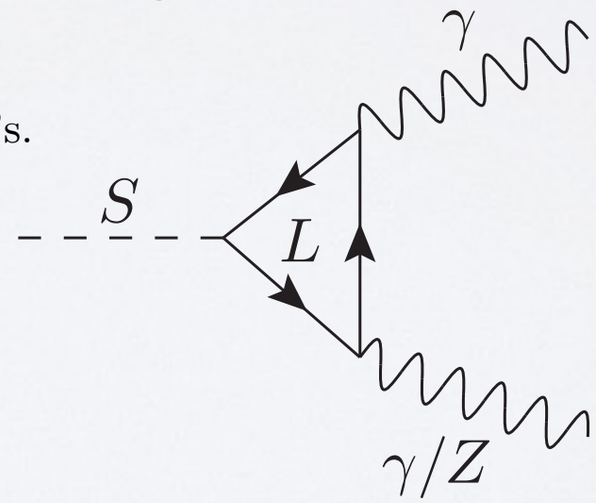


FIG. 1. Production of S particles from a loop of Q's.



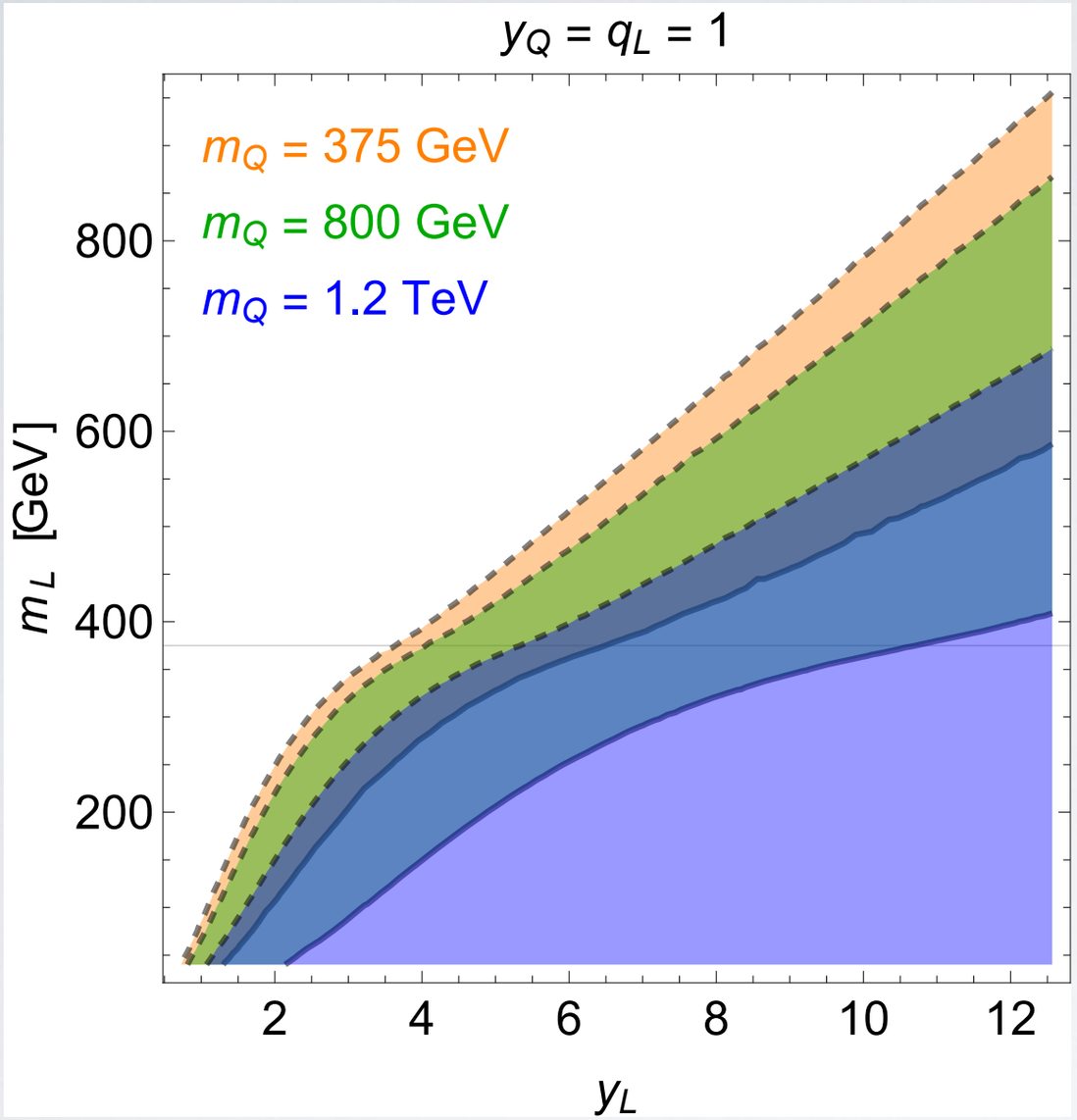


FIG. 3. Contours of $N_{\gamma\gamma}$ for the model in Eq. (5) with $y_Q = q_L = 1$. On the dashed (solid) lines we get 5 (15) events with $\mathcal{L} = 3.2\,\text{fb}^{-1}$ and $\epsilon \times A = 0.5$. The colored particle mass is fixed by the color coding; $m_Q = 375\,\text{GeV}$ is ruled out by direct searches, but is included for illustration. Below the faint solid line the S has on-shell decays to L.

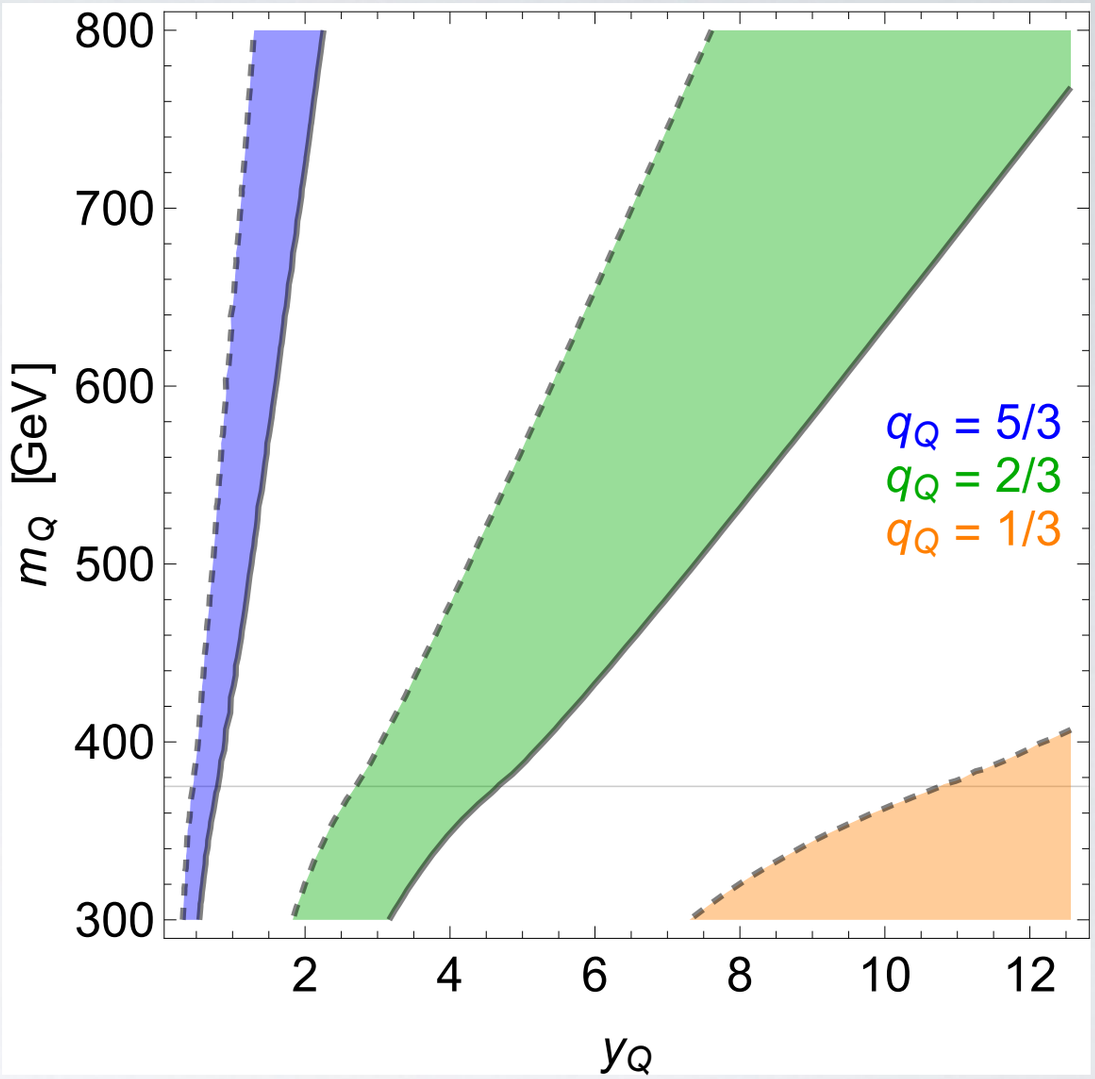


FIG. 4. Contours of $N_{\gamma\gamma}$ for the model in Eq. (7). On the dashed (solid) lines we get 5 (15) events with $\mathcal{L} = 3.2\,\text{fb}^{-1}$ and $\epsilon \times A = 0.5$. The quark electric charge is fixed by the color coding; $q_Q = 1/3$ is ruled out by direct searches, but is included for illustration. Below the faint solid line, the S has on-shell decays to Q.

Colored particles can be decently heavy

LARGE WIDTH?

$$\Gamma_{tot} = \Gamma_{SM} + \Gamma_X$$

ATLAS definitely prefers a larger width at LEAST of the experimental resolution and best fit is 45 GeV

$$\Gamma_{SM} \sim \mathcal{O}(\mathrm{MeV}) \qquad \Gamma_{det} \sim \mathcal{O}(5\,\mathrm{GeV})$$

We'll start by being agnostic about what X is and just fix the total width, but of course that changes the branching fractions!

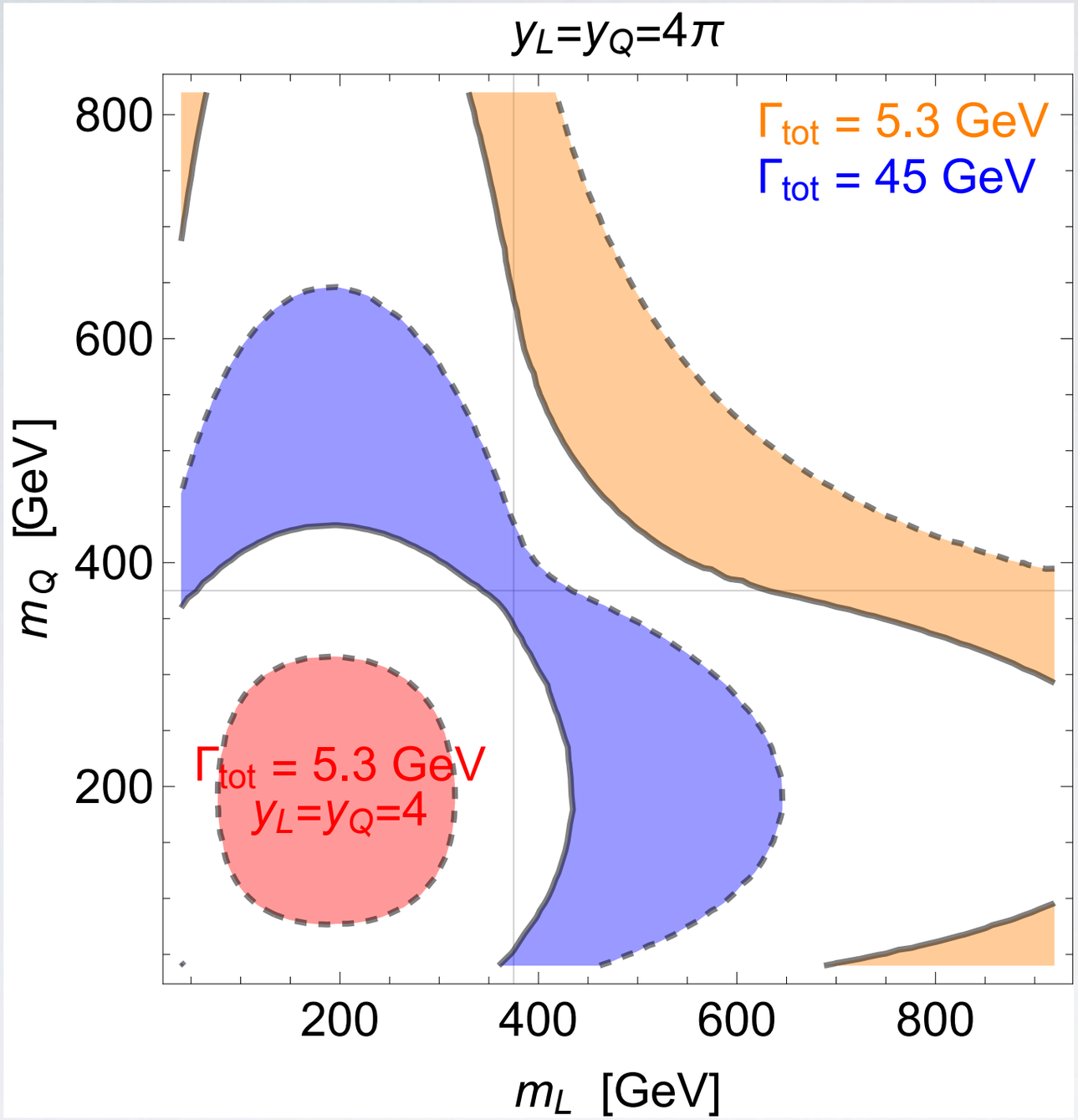


FIG. 5. Contours of $N_{\gamma\gamma}$ in the $m_L - m_Q$ plane for a fixed width. On the dashed (solid) lines, we get 5 (15) events with $\mathcal{L} = 3.2\,\text{fb}^{-1}$ and $\epsilon \times A = 0.5$, assuming the total width to be fixed to the amount suggested by the color coding. Below and to the left of the faint solid lines, the S has on-shell decays to the new fermions. The 5.3 GeV width is motivated by the diphoton invariant mass resolution at ATLAS [1].

Can't accommodate it w/o strong coupling and light masses…

WHAT CAN THE REST OF THE WIDTH BE? INVISIBLE?

$$y_\chi S \bar{\chi} \chi$$

There will be monojet constraints! It will decay to MET most of the time in this sort of scenario!

45 GeV width implies $\sigma(p\bar{p} \to S \to \text{invisible}) \sim 9\,\text{pb}$

5.3 GeV width implies $\sigma(pp \to S \to \text{invisible}) > 1\ \text{pb}.$

$\not{E}_T$ threshold [GeV]	$\sigma_{\text{invisible}}$[pb]
250	3
300	1.78
350	0.75
400	0.65
450	0.52

CMS monojet

TABLE I. Bounds from searches for mono-jet plus $\not{E}_T$ in 8 TeV data [8].

PREDICTIONS OF THE MODEL?

- It should show up in diphotons again…
- γZ you would need 50 fb^{-1} for 5 events w/o background and 600 fb^{-1} if you scaled up with current backgrounds to get to 3 sigma
- Depending on the width…

WHAT NEXT?

- Wait for more data, or…

THROW EVERYTHING INCLUDING THE KITCHEN SINK AT IT…

Pseudoscalars are nice from the POV of strong dynamics
Scalars can fit anywhere (hence the RS interpretations)
The rest is up to nature and ATLAS and CMS…