Particle physics going 'gaga'.

Kai Schmidt-Hoberg

Overview of theoretical interpretations of the diphoton excess

Current count ~ 175 papers

No paper out today

~170 spin-0 resonance
~5 spin-2 resonance
~1 spin-1 resonance
~5 parent resonance/kinematic edge

HELMHOLTZ ASSOCIATION

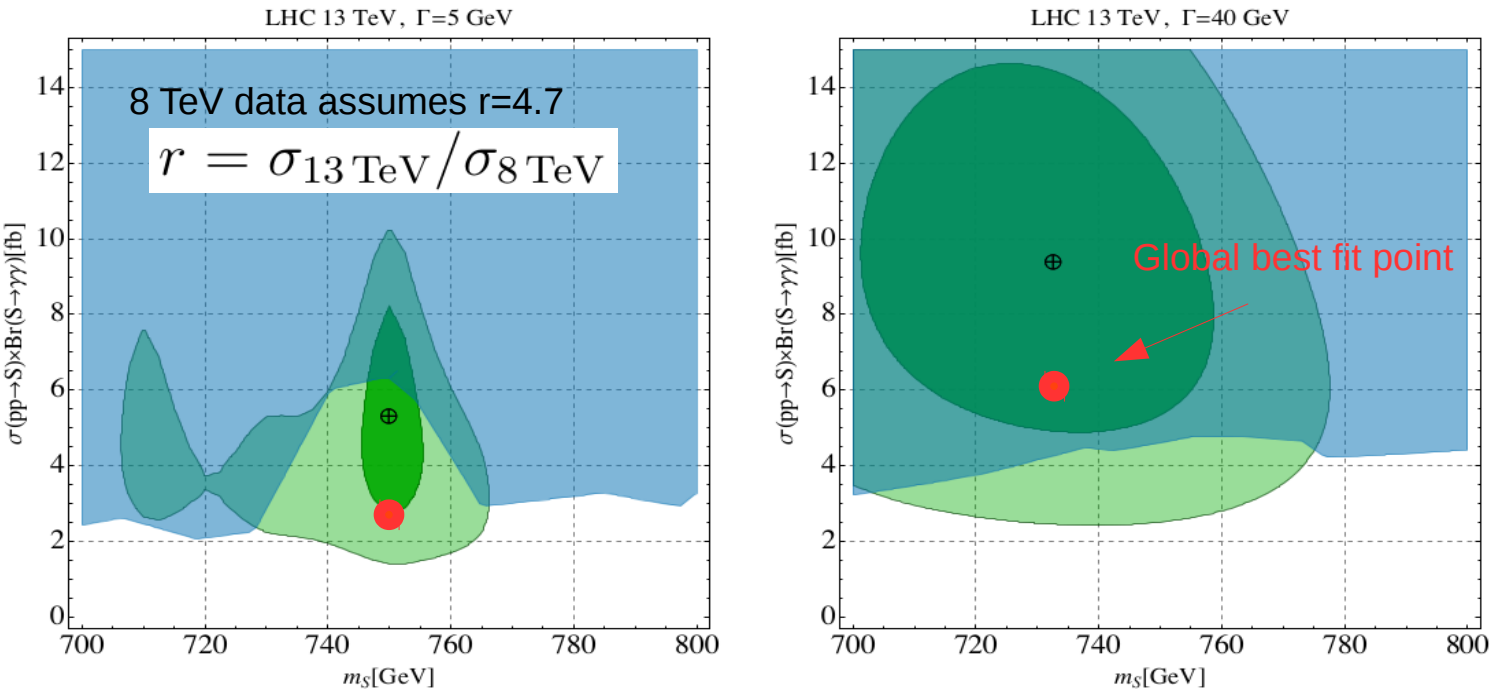
erc

DESY

Observation (ATLAS + CMS).

Inferred **cross section** (combined):

1512.05777



Some tension with run 1 data...

Signal cross section should grow significantly to be consistent

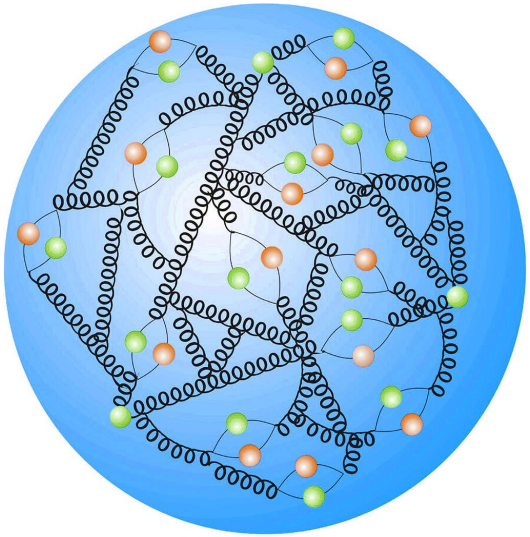
Width: largish width of ~ 40 GeV slightly preferred (not significant)

A resonance at 750 GeV.

Simplest explanation: A **resonance at 750 GeV**

Narrow width approximation OK

$$\sigma(pp \to \gamma\gamma) \approx \sigma(pp \to \Phi) \cdot BR(\Phi \to \gamma\gamma)$$



Possible parton initial states are qq, gg, VV

Increase in cross section depends on initial state:

$r_{b\bar{b}}$	$r_{c\bar{c}}$	$r_{s\bar{s}}$	$r_{d\bar{d}}$	$r_{u\bar{u}}$	r_{gg}	$r_{\gamma\gamma}$
5.4	5.1	4.3	2.7	2.5	4.7	1.9

<3.9 from finite size

Other resonance searches at 8 TeV.

1512.04933

final state f	σ at $\sqrt{s} = 8\,\text{TeV}$ observed	implied bound on $BR(S \to f)/BR(S \to \gamma\gamma)$
$e^+e^- + \mu^+\mu^-$	< 1.2 fb	$< 0.6\ (r/5)$
$\tau^+\tau^-$	< 12 fb	$< 6\ (r/5)$
$Z\gamma$	< 4.0 fb	$< 2\ (r/5)$
ZZ	< 12 fb	$< 6\ (r/5)$
Zh	< 19 fb	$< 10\ (r/5)$
hh	< 39 fb	$< 20\ (r/5)$
W^+W^-	< 40 fb	$< 20\ (r/5)$
$t\bar{t}$	< 550 fb	$< 300\ (r/5)$
$b\bar{b}$	$\lesssim 1\,\text{pb}$	$< 500\ (r/5)$
jj	$\lesssim 2.5$ pb	$< 1300\ (r/5)$

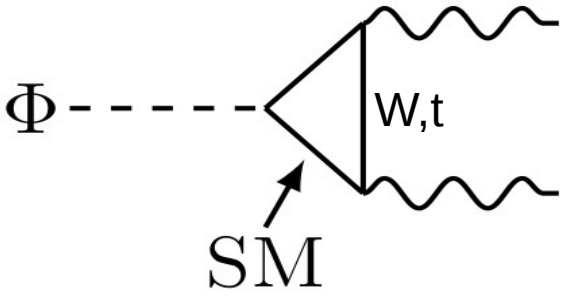
$$BR(\Phi \to \gamma\gamma)/BR(\Phi \to \text{SM SM})) \gtrsim 10^{-3}$$

Could it be the SM + 750 GeV resonance?

1512.04928

Is it possible to have **only** SM states contributing to the effective couplings?

Decay: loop induced!



Decay to WW, tt, open:

Can estimate:

$$\frac{BR(\Phi \to \gamma\gamma)}{BR(\Phi \to W^+W^-/t\bar{t})} \sim \left(\frac{\alpha}{4\pi}\right)^2 \sim 5 \times 10^{-5}$$

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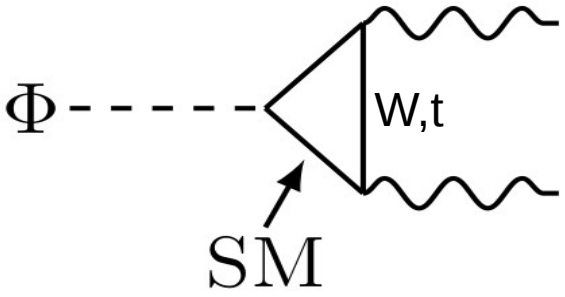

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Excluded by bounds from resonance searches in WW, tt, …

Need additional BSM states!

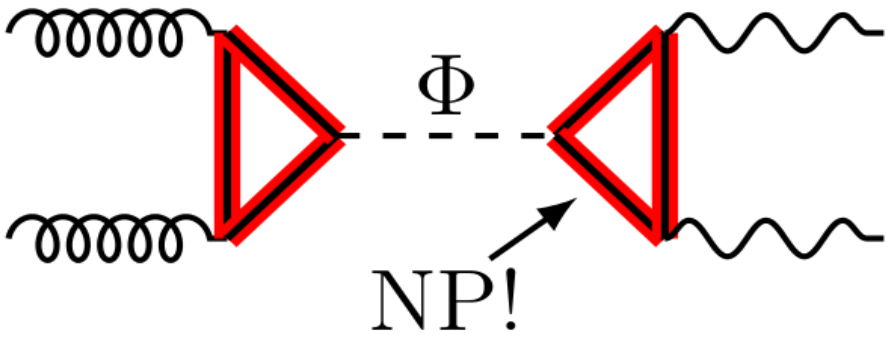
What is the spin of the resonance?

Landau-Yang theorem:

For a two photon final state the resonance could have **spin 0 or spin 2**.

98% of papers have considered spin 0

Natural production process: gluon fusion

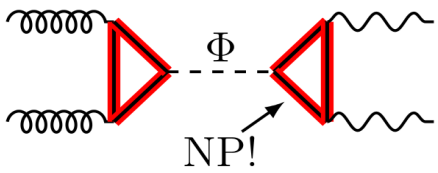


Very simple working model (narrow width): Resonance + vector-like fermions

M > 375 GeV

How to test this setup?

The extra fermions induce effective couplings



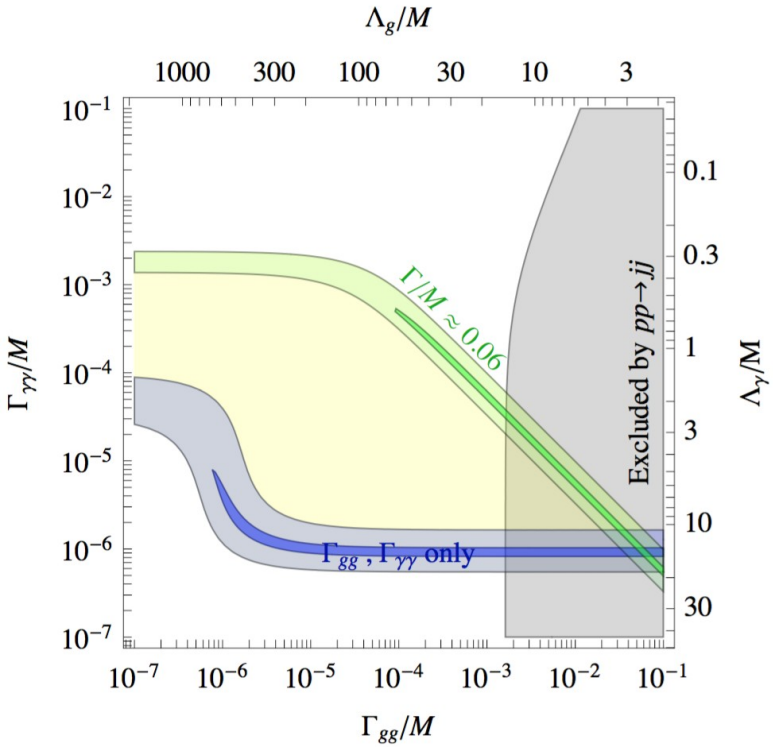
$$\mathcal{L}^{\mathrm{d=5}}_{\mathrm{(int)}} = \frac{S}{\Lambda}\left[c_{GG}\, G^{A\,\mu\nu} G^{A}_{\mu\nu} + c_{WW}\, W^{I\,\mu\nu} W^{I}_{\mu\nu} + c_{BB}\, B^{\mu\nu} B_{\mu\nu}\right]$$

What are promising search channels?

If couplings are large enough → dijets

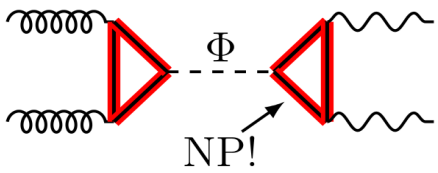
Gluon couplings can be much smaller (cancels out of production * BR)

Cannot be tested at LHC?!



How to test this setup?

Fermions in the loop are charged under
SM gauge group (not electromagnetism) → mixing



Irreducible contributions to ZZ, WW, Zgamma

Can have cancellations, but only two operators for four couplings

	operator	$\frac{\Gamma(S\to Z\gamma)}{\Gamma(S\to\gamma\gamma)}$	$\frac{\Gamma(S\to ZZ)}{\Gamma(S\to\gamma\gamma)}$	$\frac{\Gamma(S\to WW)}{\Gamma(S\to\gamma\gamma)}$
excluded	WW only	$2/\tan^2\theta_W \approx 7$	$1/\tan^4\theta_W \approx 12$	$2/\sin^4\theta_W \approx 40$
	BB only	$2\tan^2\theta_W \approx 0.6$	$\tan^4\theta_W \approx 0.08$	0

Direct searches for the extra fermions, m > 375 GeV

What about the MSSM?

How does this fit into known models?

$$BR(\Phi \to \gamma\gamma)/BR(\Phi \to \text{SM SM})) \gtrsim 10^{-3}$$

Large BR into photons - **problematic for 2HDM, MSSM!**

For **R-parity conservation**, candidates are heavy Higgses H,A

→ does not work 1512.05332

Again need additional states…

If you love SUSY and signal genuine→ beyond MSSM ?!

A MSSM solution?

G Weiglein: with R parity violation everything possible :-)

Possible interpretation in the MSSM with R parity violation:

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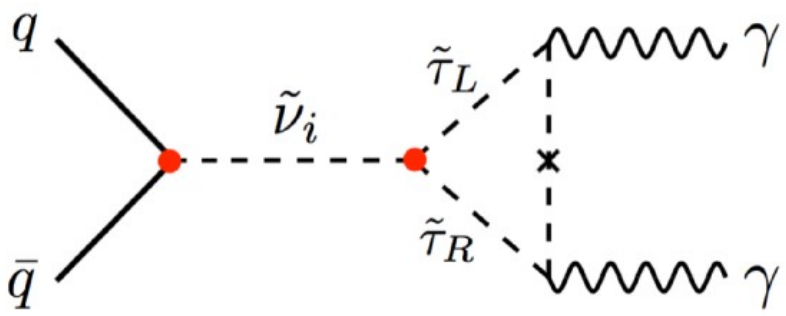

Large enough rate: Mass of stau 375 GeV < m < 388 GeV

In the given model: dd initial state → strong tension with run 1 data

Even with R parity violation challenging to explain in MSSM!

The minimal model

- The minimal case: only effective couplings to photons (well, not only...)

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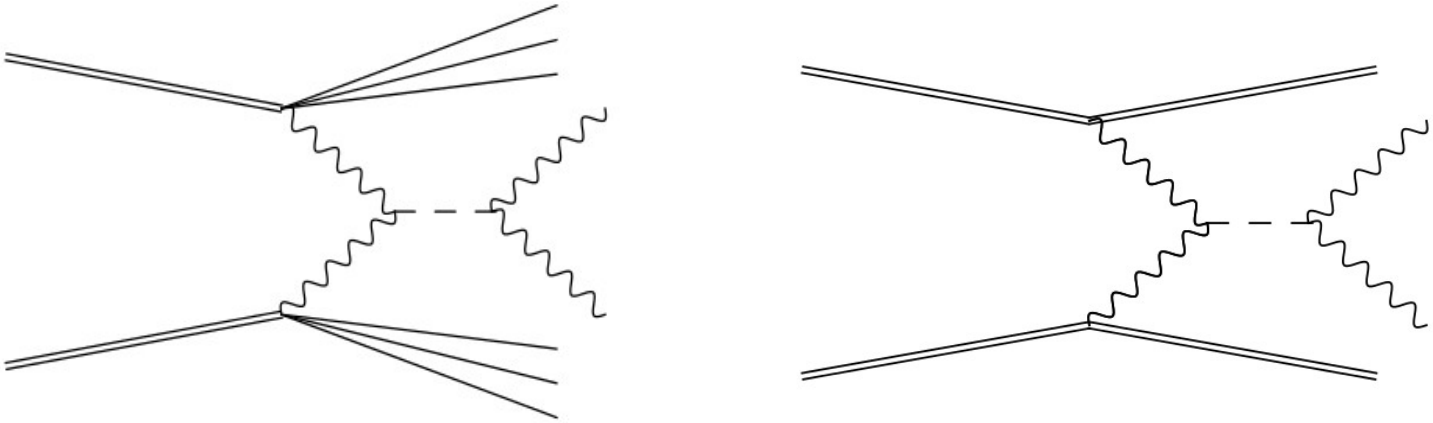


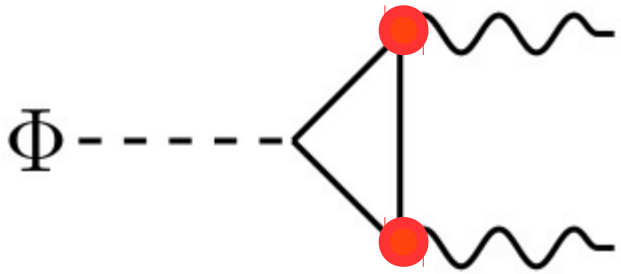
- No new colored states needed
- possible detection of forward protons from elastic photoproduction
- Tension with run 1 data

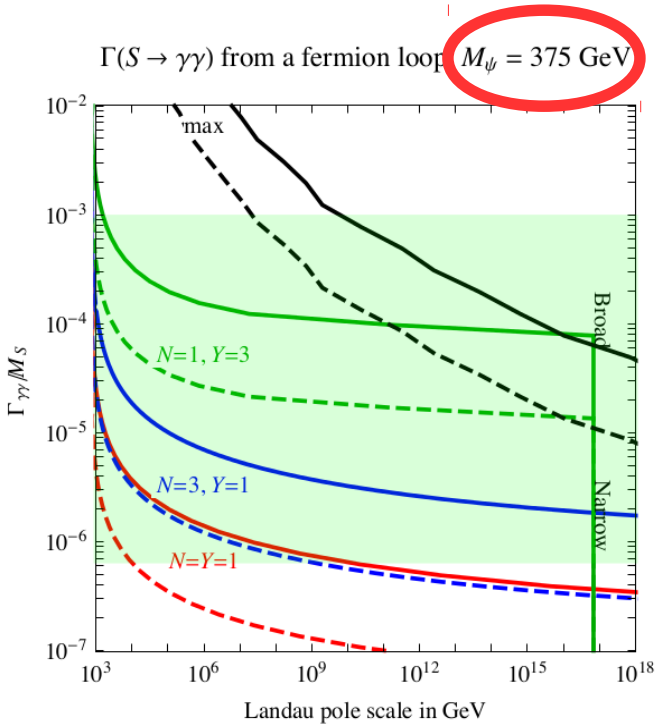
What if the width is large?

Large width is difficult to achieve in the simple model with gg initial state (only loop induced decay modes) → also ruled out by dijets...

Need additional annihilation channels (tree-level)

But then also need to increase partial width into two photons

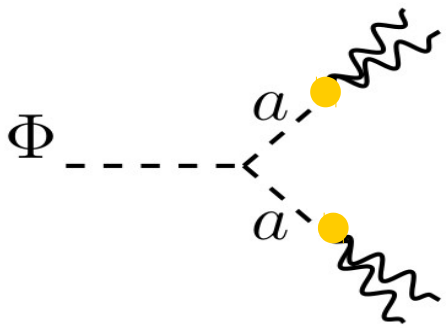




What if the width is large?

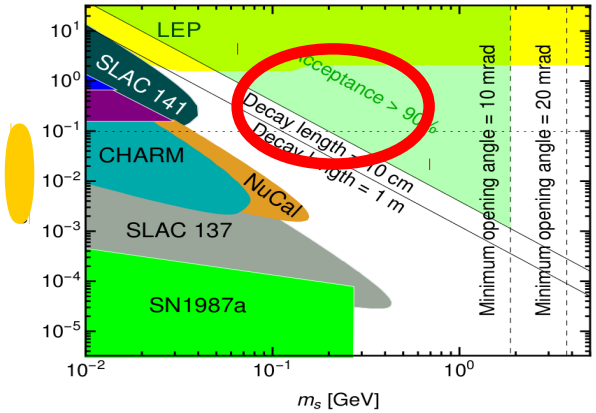
Option for a large width (if not several states at 750 GeV):

- New strong dynamics (similar to QCD) 1512.04850
- Large invisible width ('dark matter mediator')?
  → Constraints from monojet searches, but not excluded 1512.06842
  Journal club by Felix next week (18/02, 12am, theory common room)
- Tree-level decays 1512.04928



Could be very collimated photons (not resolved)

Depends on mass and coupling of a



Spin-2

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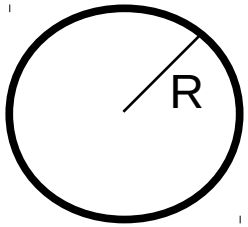
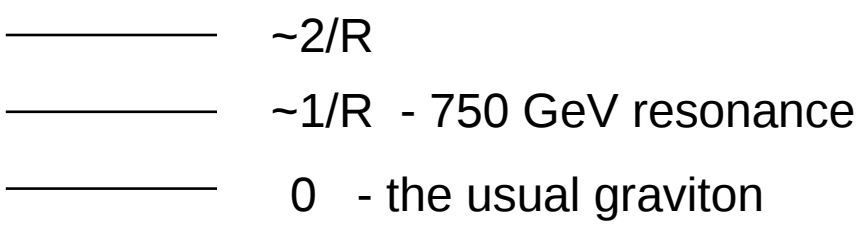
Spin-2 resonance much less studied

Only fundamental spin-2 particle: graviton

Candidate: KK excitation of graviton in extra dimensions



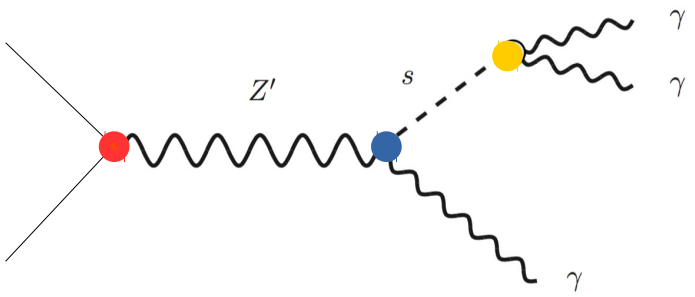


Couplings to SM states depend on localization in extra dimensions

Difference to spin 0 → different angular distributions

Spin 1 - Evading Landau-Yang

Could it be a vector resonance despite Landau-Yang? 1512.06833



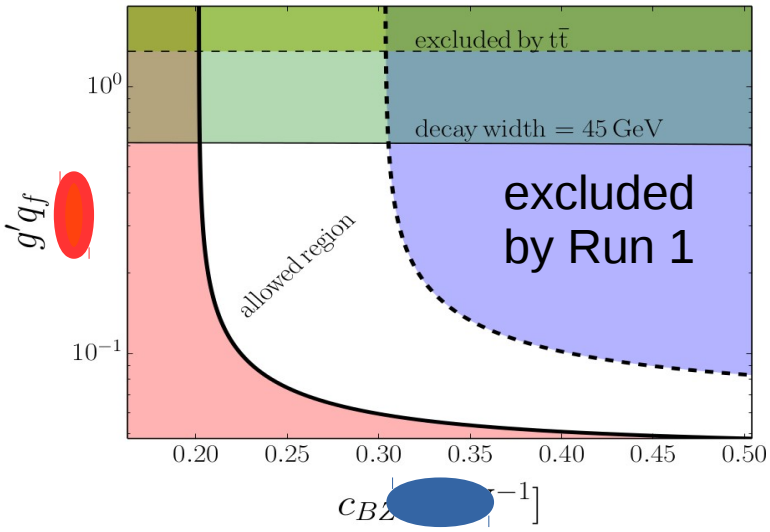
collimated

Ingredients naturally present in Z' models:

- Higgs boson to break the U(1)'
- Anomalies: Extra fermions (non-colored) will generate couplings

3rd generation couplings (bb initial state)

Naturally large width (strongest constraint)



A parent resonance → JRR

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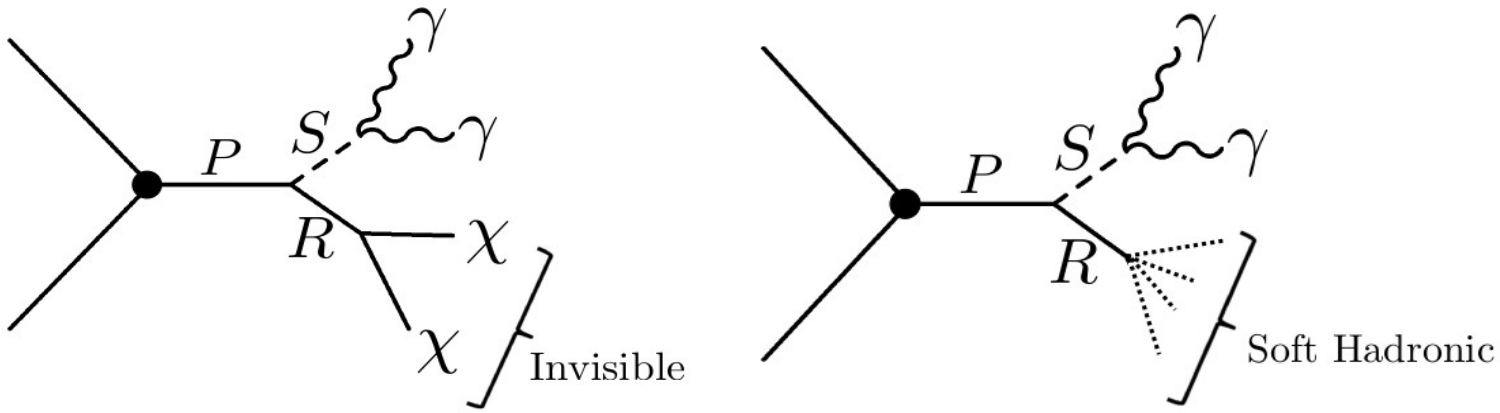
A parent resonance would allow for better Run-1/Run-2 compatibility



Naturally additional signatures such as etxra jets, MET, …

Search is inclusive, but nothing suspicious seen...

To suppress MET need $\Delta = m_P - m_S - m_R$ small

Summary

- Large number of possible interpretations of the 750 GeV excess
- Spin 0,1,2 resonance as well as non-resonant physics could work
- Almost too simple to write down a working model (unlike a number of other anomalies - say top forward backward asymmetry)

- However, vanilla MSSM or 2HDM don't work
- Need additional new states, which should be accessible!

- Overall: many theorists in excited state (at least until summer)

Thank you!