The Compatibility of LHC Data with a New Heavy Scalar

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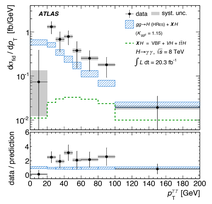
Observations

Most Run 1 results matched Standard Model predictions, there were a number of small excesses:

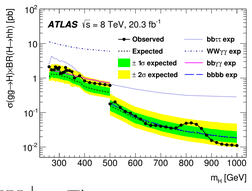
Higgs p_T spectrum:

JHEP **09**, 112 (2014)



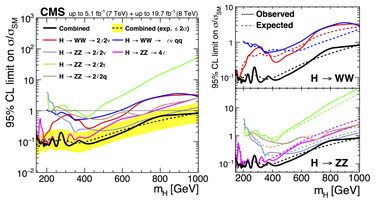
Di-Higgs rate:

Phys.Rev. **D92** (2015) 092004



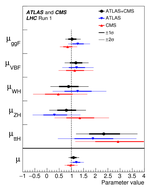
VV production ($V = W^{\pm},\ Z$):

JHEP **1510** (2015) 144



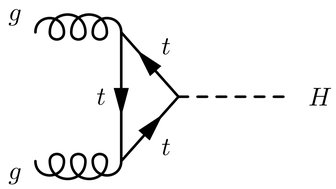
Top associated Higgs production:

arXiv:1606.02266

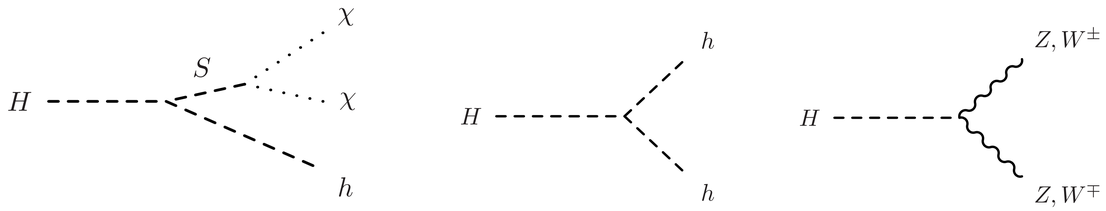


The Model

These excesses can all explained by the existence of a Heavy Scalar, the *Madala boson*, produced through gluon fusion (arXiv:1506.00612, arXiv:1603.01208):



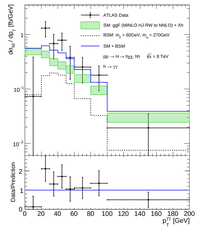
With the following decay modes:



- The intermediate scalar S can explain a large $H \to h\chi\chi$ branching ratio
- Phenomenologically interesting in the range $m_h < m_S < m_H - m_h$
- H can be identified as a part of a *Two Higgs Doublet Model* (2HDM)
- *If* H is the CP-even component of a 2HDM, we would expect more particles: A and $H^{\pm}$

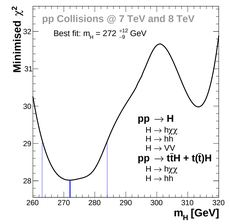
Explaining the Excesses

- Heavy scalar decays to Higgs $\Longrightarrow$ distorted Higgs p_T spectrum



- Di-Higgs production is enhanced through a resonance ($pp \to H \to hh$)
- Resonant production of VV pairs ($pp \to H \to VV$)
- Small $H \to VV$ branching fraction $\Longrightarrow$ enhanced $pp \to tH$ cross section

A statistical combination is performed leaving the mass of this heavy scalar as a free parameter:

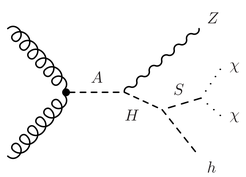


Signatures

Search for A:

$$\mathcal{L}_{V\phi\phi} = \boxed{\frac{M_W}{v\cos\theta_W}\sin(\beta-\alpha)Z_\mu\left(A\partial_\mu H - H\partial_\mu A\right)} + \boxed{\frac{M_W}{v\cos\theta_W}\cos(\beta-\alpha)Z_\mu\left(A\partial_\mu h - h\partial_\mu A\right)}$$
$$+ i\frac{M_W}{v}\frac{(2\cos^2\theta_W - 1)}{\cos\theta_W}Z_\mu\left(H^-\partial_\mu H^+ - H^+\partial_\mu H^-\right) + ieA_\mu\left(H^-\partial_\mu H^+ - H^+\partial_\mu H^-\right)$$
$$+ \left[i\frac{M_W}{v}\sin(\beta-\alpha)\left(W^{-\mu}H\partial_\mu H^+ - W^{-\mu}H^+\partial_\mu H\right) + \text{h.c}\right]$$
$$+ \left[i\frac{M_W}{v}\cos(\beta-\alpha)\left(W^{-\mu}h\partial_\mu H^+ - W^{-\mu}H^+\partial_\mu h\right) + \text{h.c}\right]$$
$$+ \left[\frac{M_W}{v}\left(W^{-\mu}A\partial_\mu H^+ - W^{-\mu}H^+\partial_\mu A\right) + \text{h.c}\right].$$

Red term is small since $\cos(\beta-\alpha)$ is small, so h is SM-like. Blue term has large coupling since $\sin(\beta-\alpha) \sim 1$. Leads to the diagram:



Experimental Searches

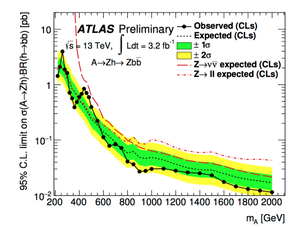
- Tag the Higgs h using any channel
- Tag the Z boson by searching for di-lepton pairs
- Requirement on missing energy

There are two current experimental searches which do this:

- The $A \to Zh$ search channel: ATLAS and CMS search for A using the $h \to b\bar{b}$ decay channel. The mass of Zh is used as a discriminant here.
- $Z + E_T^{\text{miss}}$: the SUSY search, ATLAS and CMS searches for 2 same-flavour opposite-sign leptons, with missing energy.

Illustrative Results

ATLAS-CONF-2016-015



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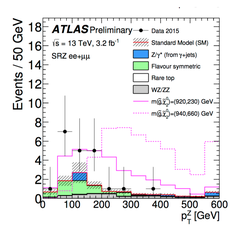

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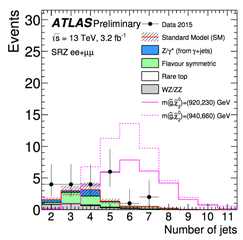

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