How to understand anomalous di-Higgs production in ATLAS in the $b\bar{b}b\bar{b}$ final state

Based on ATLAS-CONF-2022-035 [1]

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**Signal Processes**

- **ggF Production**
  - Observed coupling
  - $K = K_{\text{SM}}$
  - $K'_{VH} = \text{HHH coupling modifier}$
  - $b\bar{b}b\bar{b}$ final state
  - Largest branching fraction
  - Fully hadronic final state
  - $\Delta R \sim 35\%$

- **VBF Production**
  - $\sigma_{\text{SM}} = 1.73 \text{ fb}$
  - $\sigma_{\text{ggF}} = 31.05 \text{ fb}$

**Event Selection**

- **Pairing Strategy**
  - Minimize $\Delta R$ between jets in leading Higgs Candidate
  - Smooth $m_{H_1} - m_{H_2}$ mass plane
  - Lower accuracy at low $m_{H_1}$
  - Strong $K$ dependance

- **Construct Higgs Candidates**
  - Central jet [$\eta < 2.5, p_T \geq 40 \text{ GeV}$]
  - $b$-tagged jet [DL1r @77% WP]

- **Background Estimation**
  - Fully data-driven background estimation
  - $2b + 4b$ events used in all regions
  - ~center of $m_H$ distributions
  - Profile likelihood ratio used to obtain 2$\sigma$ level constraints

**Kinematic Regions**

- Signal Region: $X_{HH} < 1.6$
  - $X_{HH}$ non-SM
  - $X_{HH}$ stabilised
  - $X_{HH}$ metastable
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  - $X_{HH}$ metastable

**Background Composition**

- $\sim 90\%$ QCD
- $\sim 10\%$ $tt$

**Additional Categorization**

- $ggF$ in $\Delta H_H$ and $X_{HH}$ (3x2) per year
- $VBF$ in $\Delta H_H$ (2) all years together

**Background Estimation**

- $2\sigma$ constraints: $K_x = [-3.5, 11.3]$ ($[-5.4, 11.4]$)
- $K_{\text{ggF}} = [-0.0, 2.1]$ ($[-0.1, 2.1]$)

**Sketch Inspired by [2]**

How stable is the vacuum?

Can VH1’s thermal evolution account for baryon excess?

H self-coupling impacts the shape of V(H)

Additional categorization:

- $ggF$ in $\Delta H_H$ and $X_{HH}$ (3x2) per year
- $VBF$ in $\Delta H_H$ (2) all years together

Profile likelihood ratio used to obtain 2$\sigma$ level constraints

$$-2\Delta \ln (\hat{L}) = -2\ln \left( \frac{\hat{L}(\hat{\lambda}, \hat{\theta})}{\hat{L}(\hat{\lambda}, \hat{\theta})} \right)$$

Conditional likelihood

Unconditional likelihood

**V(H)**

- Impacts on the shape of $V(H)$
- Can account for baryon excess?

**V(H)** needs to be measured!