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

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ATLAS EXPERIMENT

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

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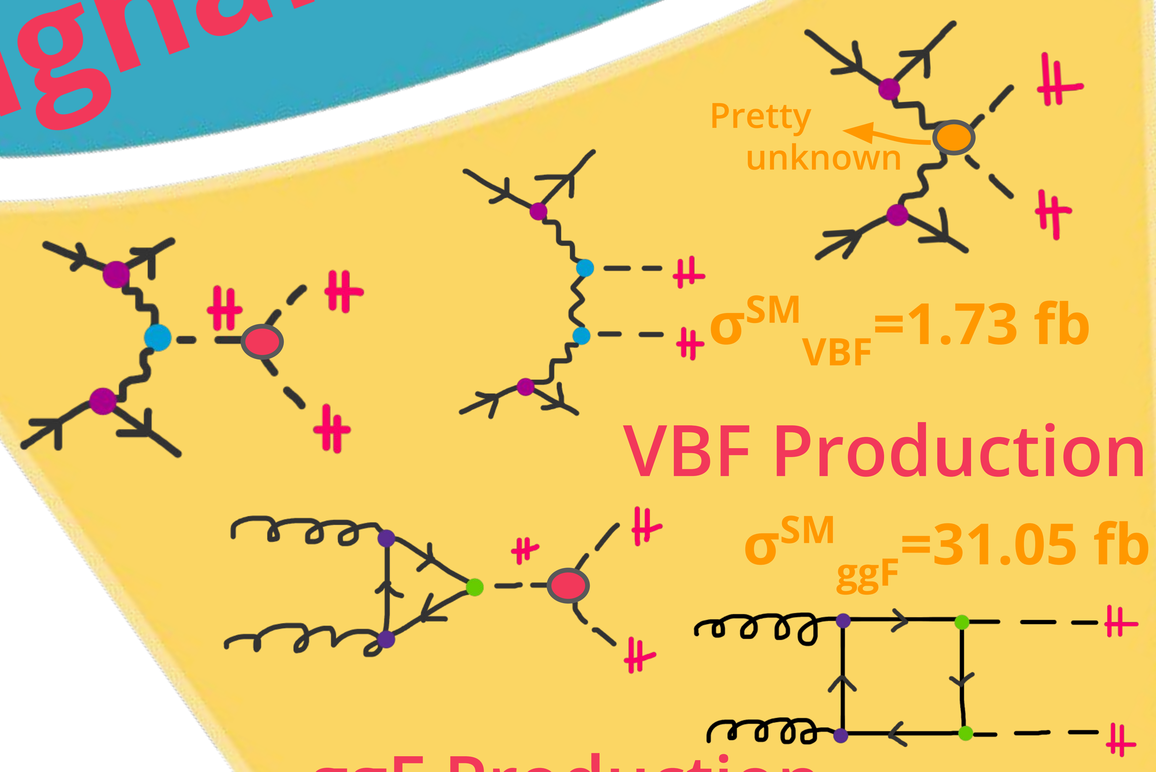
Signal Processes



σ^{SM}_{VBF}=1.73 fb

VBF Production

σ^{SM}_{ggF}=31.05 fb

ggF Production

K = Observed coupling / SM coupling

K_λ - HHH coupling modifier

K_{2V} - HHVV coupling modifier

bbbb final state

✓ Largest branching fraction

━ Fully hadronic final state

Br ~ 35%

B

✓ Central jet [η < 2.5, $p_T \geq$ 40 GeV]

✓ b-tagged jet [DL1r @77% WP]

4x

Construct Higgs Candidates

Pairing Strategy

Minimize ΔR between jets in leading Higgs Candidate

✓ Smooth m_{H1}- m_{H2} mass plane

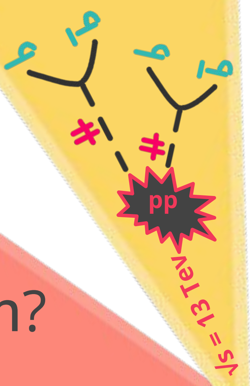
━ Lower accuracy at low m_{HH}

━ Strong κ dependance

H1 Leading Higgs Candidate

ΔR

H2 - sub-leading Higgs Candidate



Event Selection

126 fb^{-1} pp collision data @ √s = 13 Tev

✓ Pass combination of multi-b-jet triggers

✓ 4x b-tagged jet

✓ $t\bar{t}$ suppression, Xwt > 1.5,

$$X_{Wt} = \sqrt{\left(\frac{m_W - 80.4\,\text{GeV}}{0.1 m_W}\right)^2 + \left(\frac{m_t - 172.5\,\text{GeV}}{0.1 m_t}\right)^2}$$

VBF?

+ m_{HH} > 400 GeV

✓ VBF Jets:

✓ 2x untagged jet

✓ m_{jj} > 1 TeV

✓ $|\eta_{jj}|$ > 3

ggF?

✗ VBF Jets

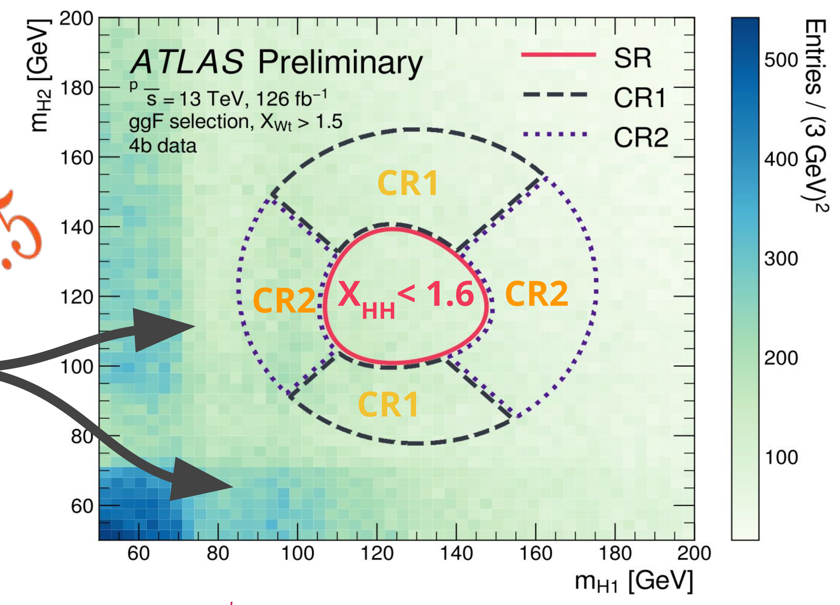
+ $|\eta_{HH}|$ < 1.5

ggF & VBF channels are orthogonal!

2b & 4b events used in all

Kinematic Regions

Feature from top veto cut $X_{Wt} > 1.5$



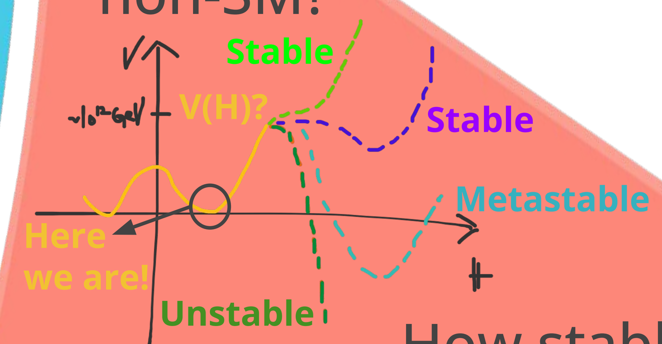
$$X_{HH} = \sqrt{\left(\frac{m_{H1} - 124\,\text{GeV}}{0.1 m_{H1}}\right)^2 + \left(\frac{m_{H1} - 117\,\text{GeV}}{0.1 m_{H1}}\right)^2}$$

Signal Region: X_{HH}< 1.6

~center of m_H distributions

Higgs Potential

Is V(H) non-SM?



Sketch inspired by [2]

How stable is the vacuum?

Can V(H)'s thermal evolution account for baryon excess?

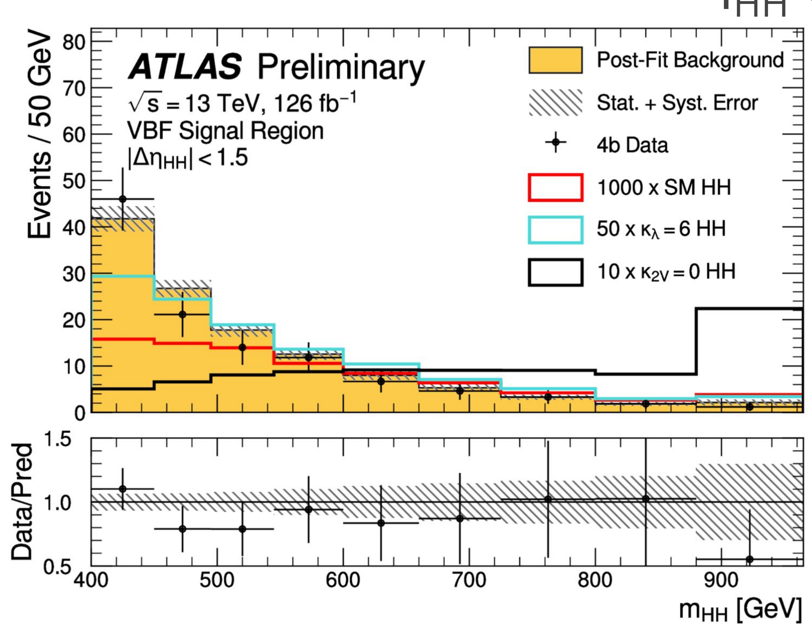
V(H) needs to be measured!

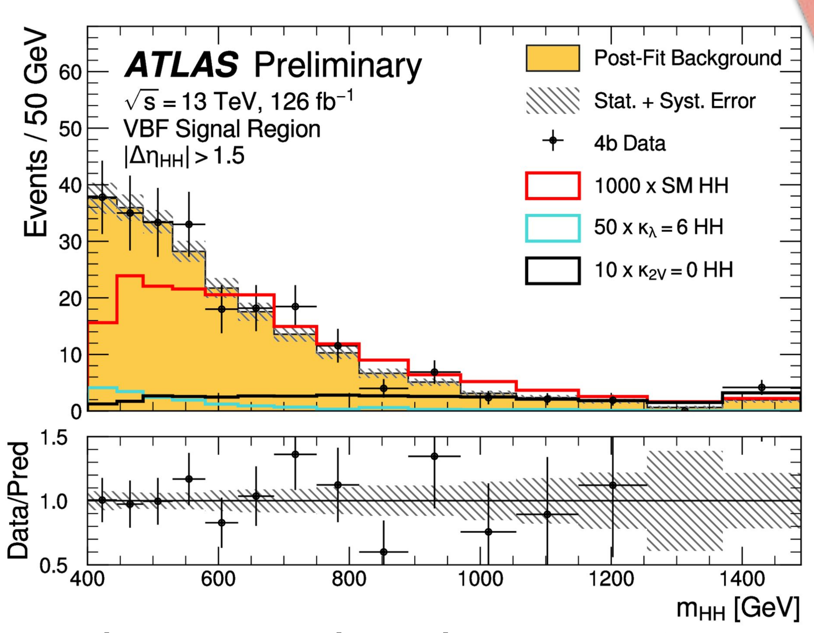
H self-coupling impacts the shape of V(H)!

Additional categorization:

✓ ggF in $\Delta\eta_{HH}$ and X_{HH} (3x2) per year

✓ VBF in $\Delta\eta_{HH}$ (2) all years together





Profile likelihood ratio used to obtain 2σ level constraints

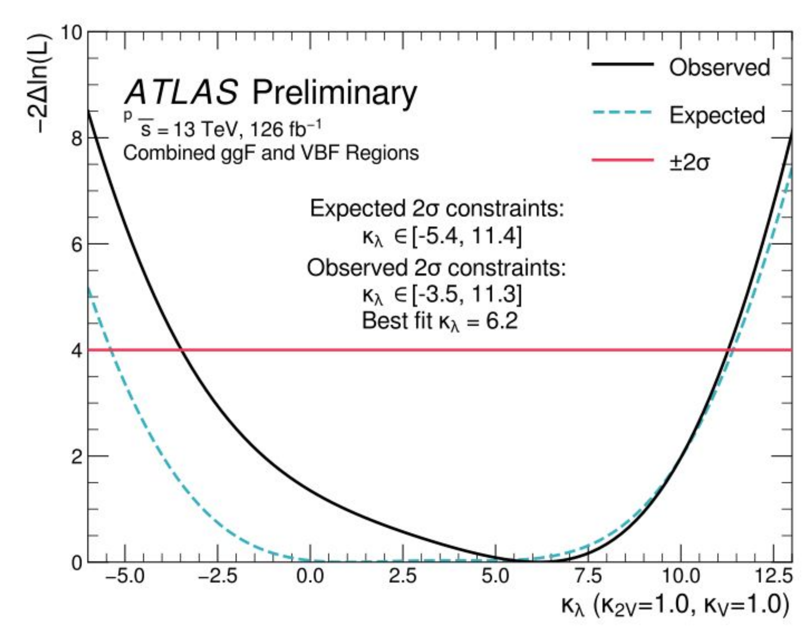
$$-2\Delta\ln\lambda(\tilde{\kappa}) = -2\ln\left(\frac{L(\tilde{\kappa}, \hat{\hat{\theta}})}{L(\hat{\tilde{\kappa}}, \hat{\theta})}\right)$$

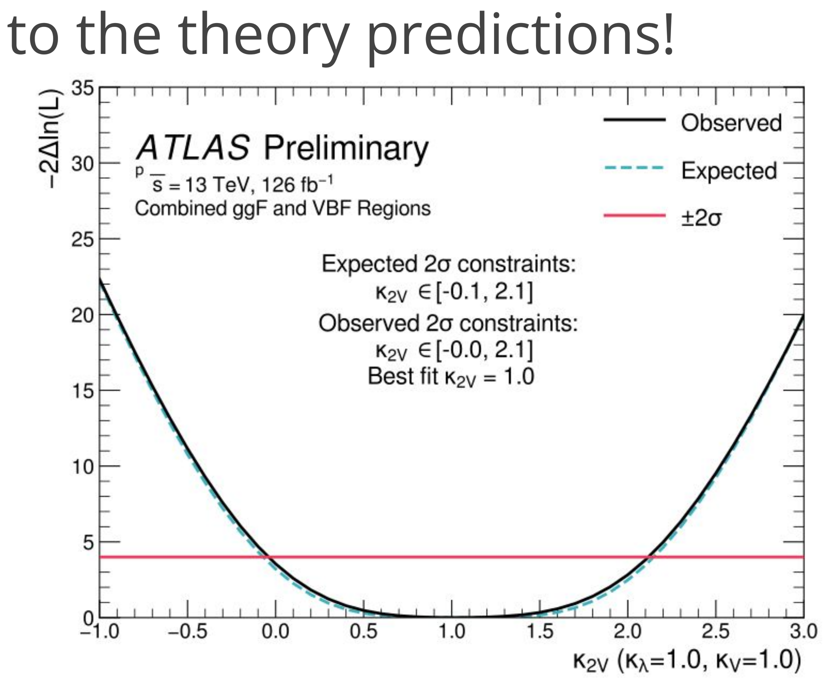
Conditional likelihood

Unconditional likelihood

POI = K_λ (K_{2V})

ggF signal included in VBF regions and vice versa with the signal strengths fixed to the theory predictions!





Simultaneously fit in ggF & VBF regions!

Observed (expected) 2σ constraints:

K_λ= [-3.5,11.3] ([-5.4,11.4])

K_{2V}= [-0.0,2.1] ([-0.1,2.1])

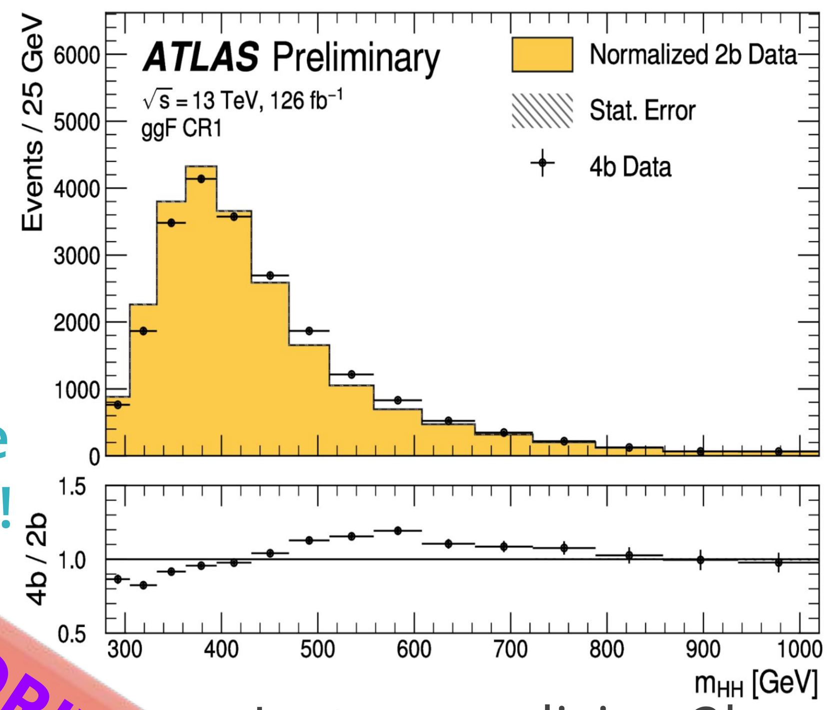
Background Estimation

Background composition

~90% QCD

~10% tt

Can't use MC!



Just normalising 2b cannot mimic 4b kinematics!

FULLY DATA-DRIVEN BACKGROUND ESTIMATION

Neural Network (NN) trained to map 2b kinematics into 4b kinematics

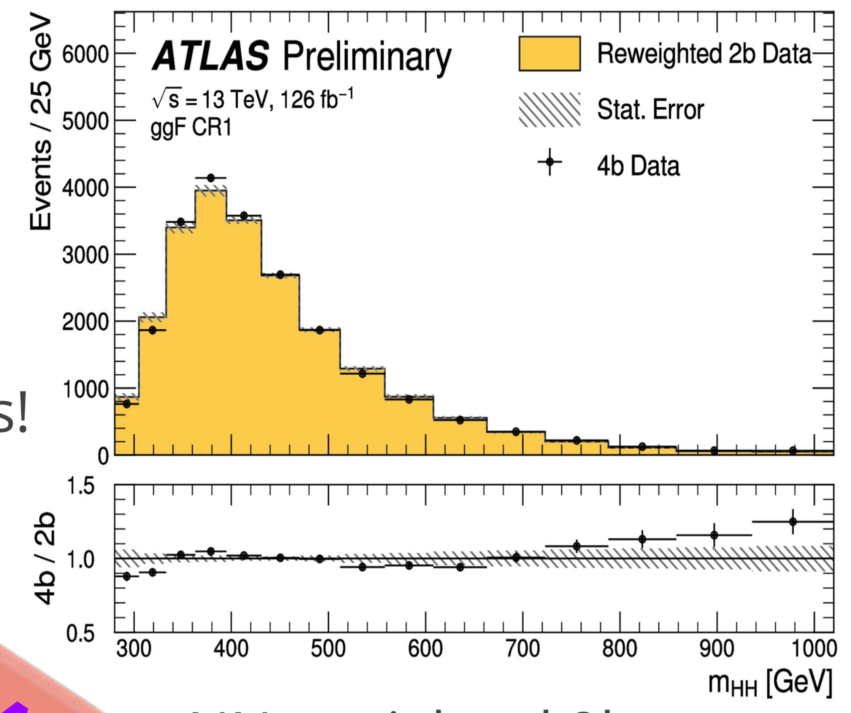
Need to learn the reweighting function

$$w(\tilde{x}) = \frac{p_{4b}(\tilde{x})}{p_{2b}(\tilde{x})}$$

Kinematic variables [different for ggF & VBF]

$$\mathcal{L}(w(\tilde{x})) = \int d\tilde{x}\left[\sqrt{w(\tilde{x})}\,p_{2b}(\tilde{x}) + \frac{1}{\sqrt{w(\tilde{x})}}\,p_{4b}\right]$$

Minimised by the NN



NN rewighted 2b successfully models 4b kinematics!

CR1 - train nominal background prediction

CR2 - train alternative background prediction

Source of the dominant uncertainty

Bibliography

[1] "Search for non-resonant pair production of Higgs bosons in the $b\bar{b}b\bar{b}$ final state in pp collisions at √s = 13 TeV with the ATLAS detector". Technical report, CERN, Geneva (2022). All figures including auxiliary figures are available at https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2022-035. https://cds.cern.ch/record/2811390

[2] Alexander Kusenko. Physics, 8 (2015) 108.