Search for Di-Higgs Production via Vector Boston Fusion

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Understanding the SM with Di-Higgs

The SM Higgs potential is:

$$V(\phi) = -\mu^2\phi^2 + \lambda\phi^4$$

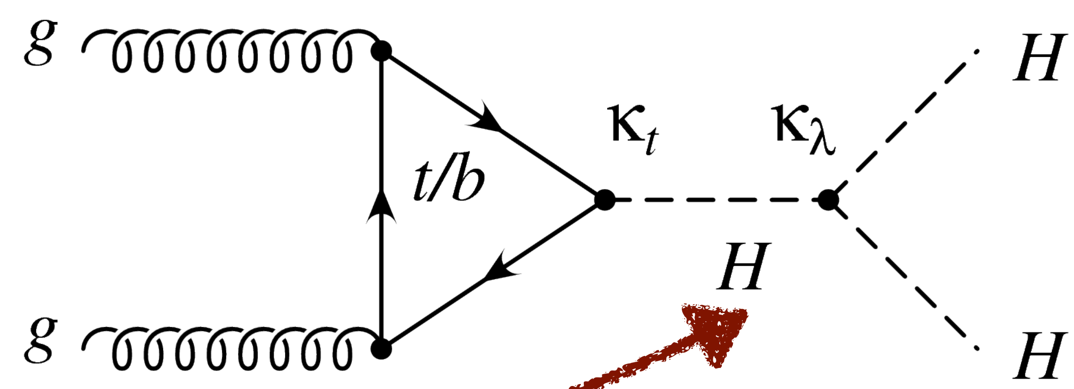
$$\frac{\mu}{\sqrt{\lambda}} = v = 246\ \mathrm{GeV}$$

Expand around the minimum, get:

$$V = V_0 + \lambda v^2 h^2 + \lambda v h^3 + \ldots$$

$$= V_0 + \frac{1}{2} m_H^2 h^2 + \frac{m_h^2}{2v^2} v h^3 + \ldots$$

This term allows di-Higgs production!



$$k_\lambda = \frac{m_h^2}{2v^2}$$

The SM predicts di-Higgs production!

This higher-order term tells us more about the shape of the potential!

Why Study the Shape?

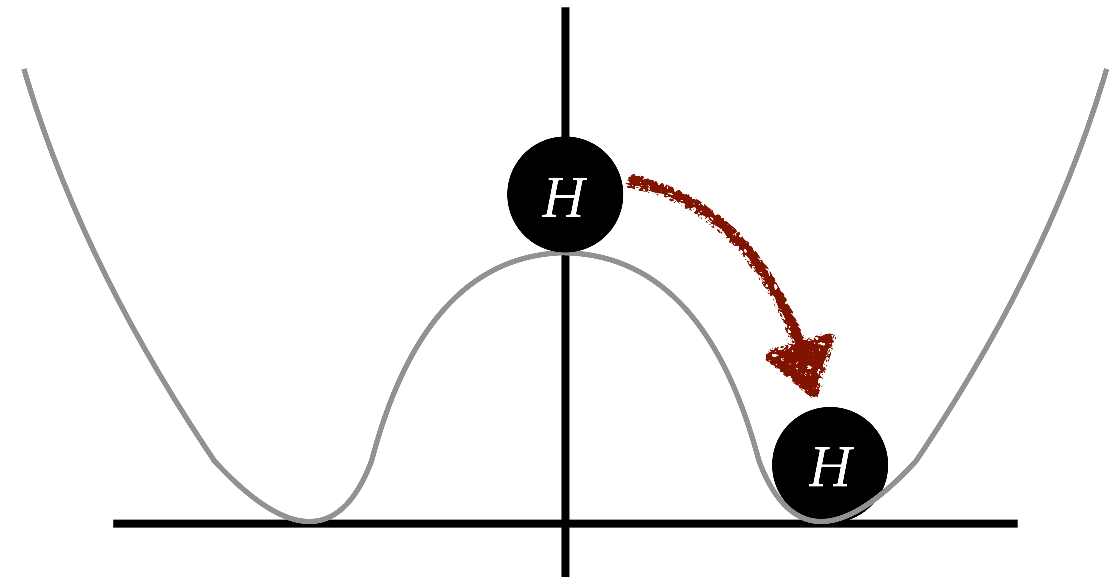
Many models alter the Higgs potential!

Inflation— one of the best models for early universe evolution— requires a scalar … just like the Higgs!

Need couplings to gravity: $\frac{\xi h^2}{2} R$

which modify the shape of the potential!

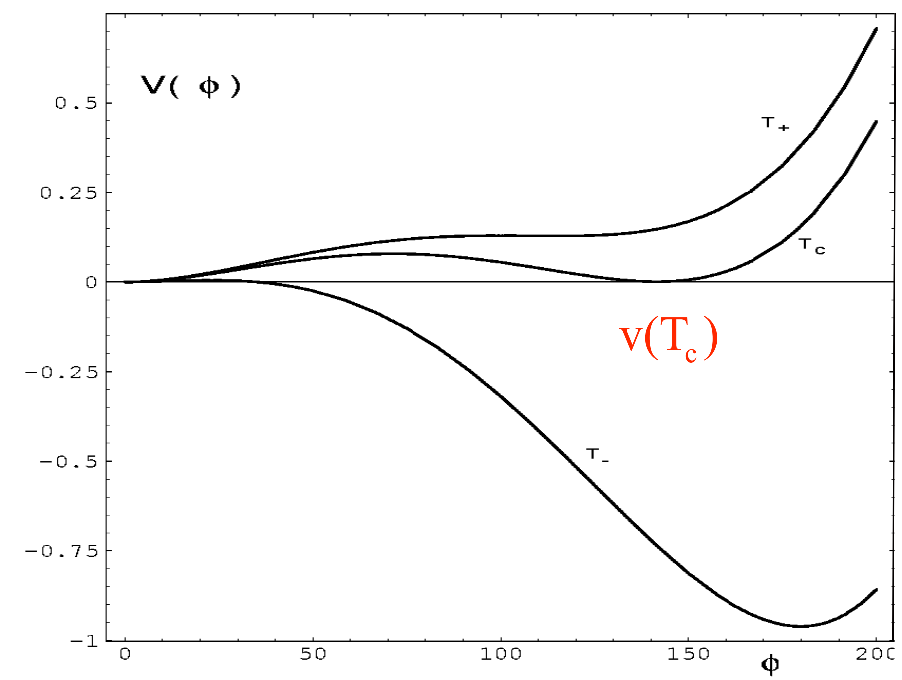
Bezrukov and Shaposhnikov



Other models have the Higgs potential undergo a phase transition, which could explain matter-antimatter asymmetry

This phase transition requires modifications to the SM potential!

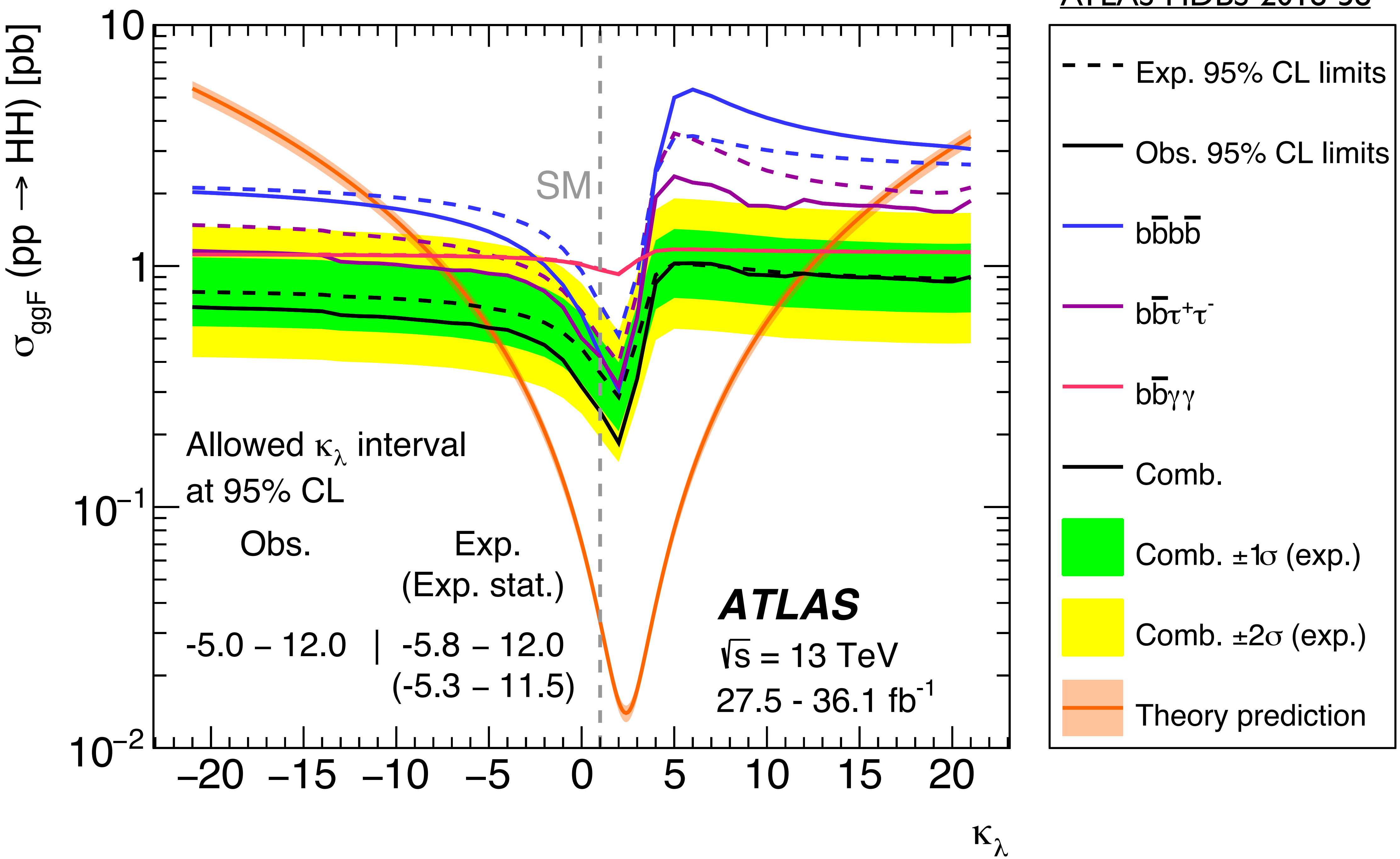
C. Wagner



These are just some examples:
If we can measure the shape of the potential, we can find hints of new physics!

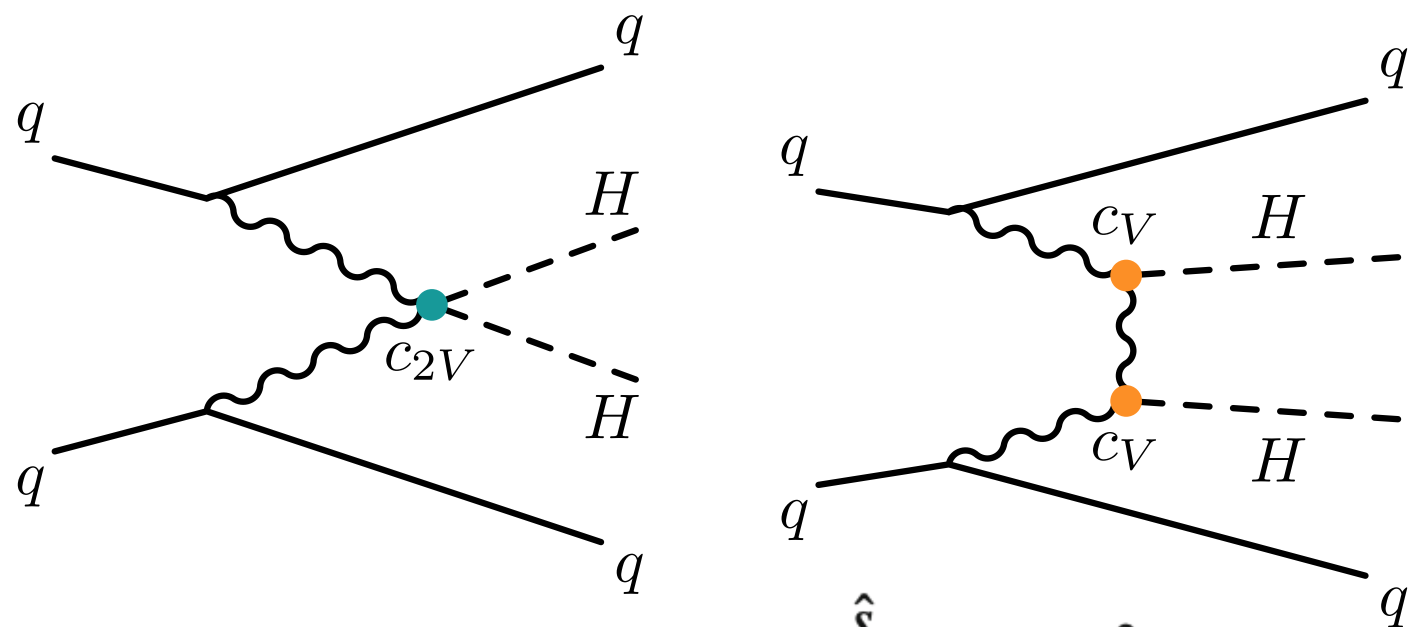
Results on DiHiggs

ATLAS-HDBS-2018-58



Existing searches can probe κ_λ, and set constraints on the shape of the Higgs potential!

But This Isn't the Only Thing



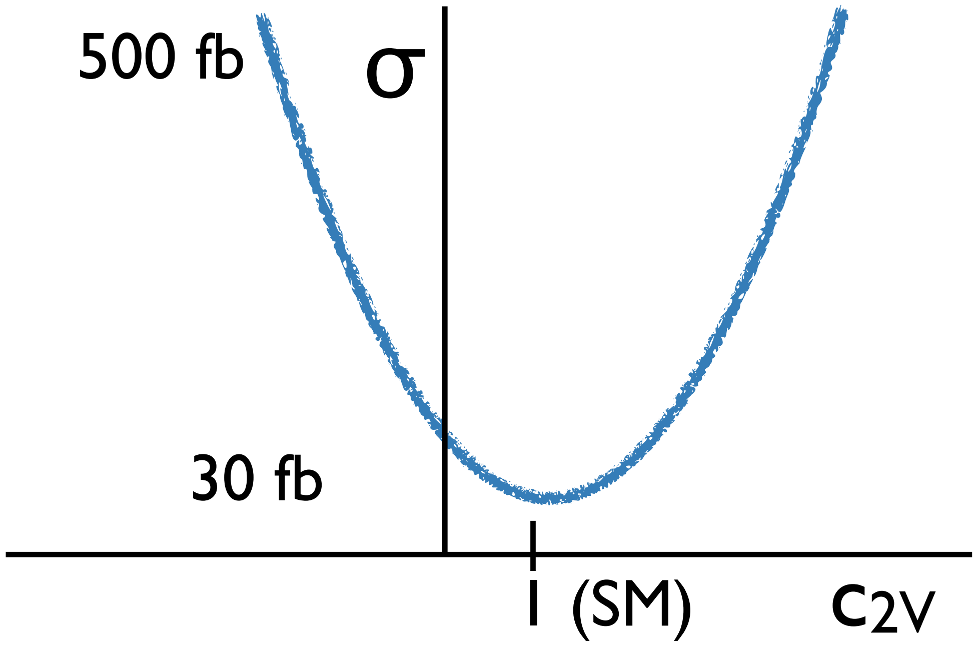
$$\mathscr{A}(V_L V_L \to hh) \simeq \frac{\hat{s}}{v^2}(c_{2V} - c_V^2)$$

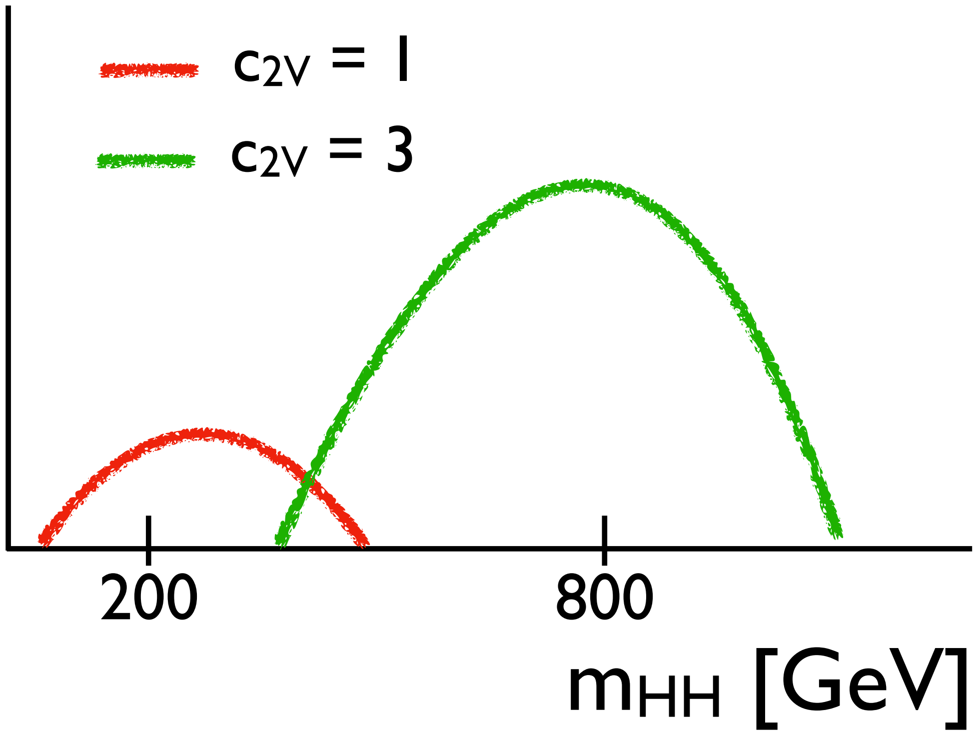
- Deviations in the shape aren't the only thing we can measure with di-Higgs
  - We can also access some fundamental interactions in the Standard Model, which are currently unmeasured!
- c_{2V} is one **first example**: the coupling between two vector bosons and two Higgs bosons has no current constraints!
  - This is just the start of a program where we can explore many other couplings which can be measured with di-Higgs final states: will be part of a global EFT program

What Can We Measure?

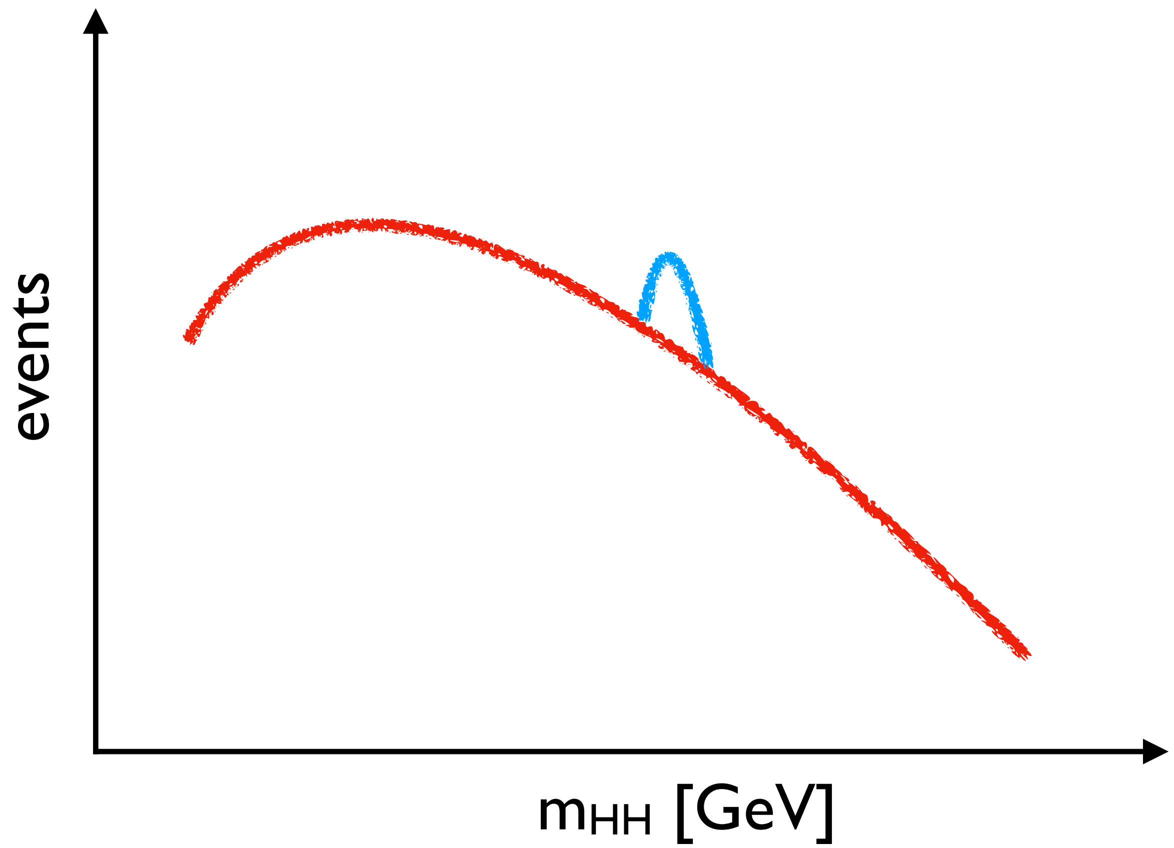
$$\mathscr{A}(V_L V_L \rightarrow hh) \simeq \frac{\hat{s}}{v^2}(c_{2V} - c_V^2)$$

- What does this amplitude actually say?
- Two important things:
  - The cross-section will grow when c_{2V} != c_V
  - But the cross-section is also dependent on s^!



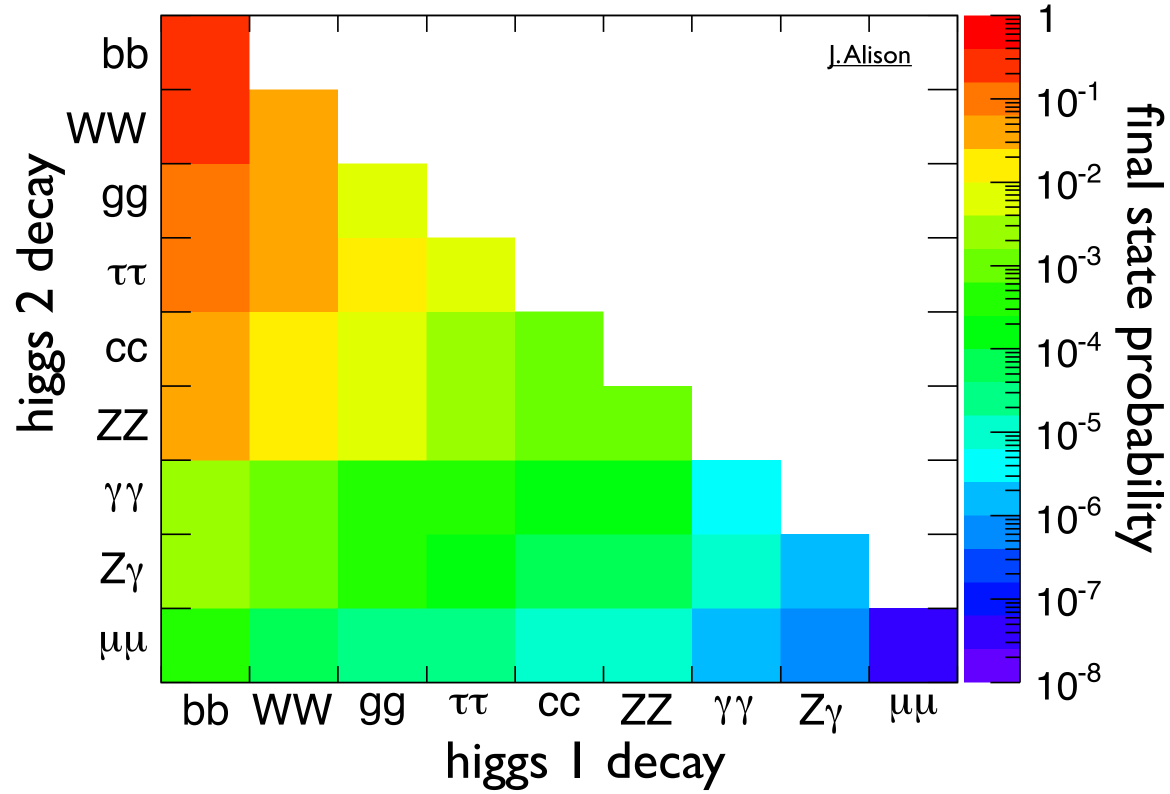


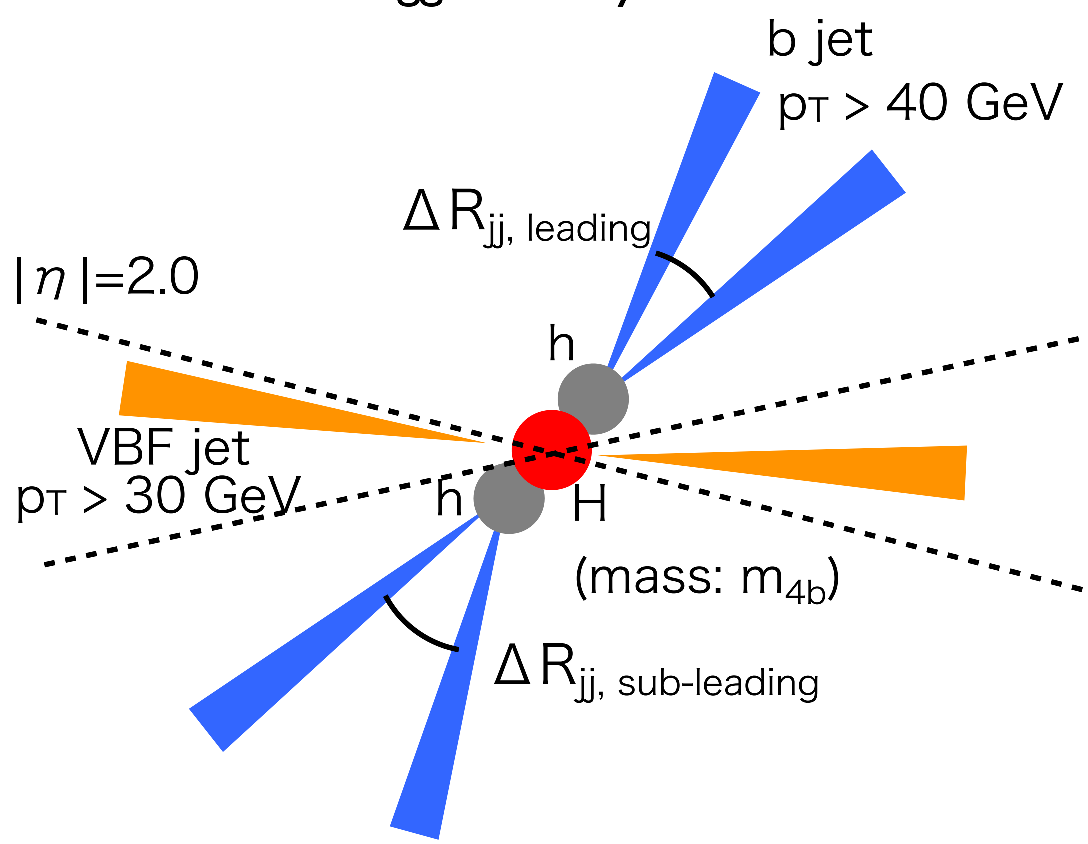
What Else?



- Can also search for resonances decaying to di-Higgs final states
- These are predicted by many models: e.g. 2HDM models, where "heavy Higgs" decays to pairs of our Higgs
  - In some parameter corners, VBF is the highest cross-section process for these signals!

How Do You Measure This?

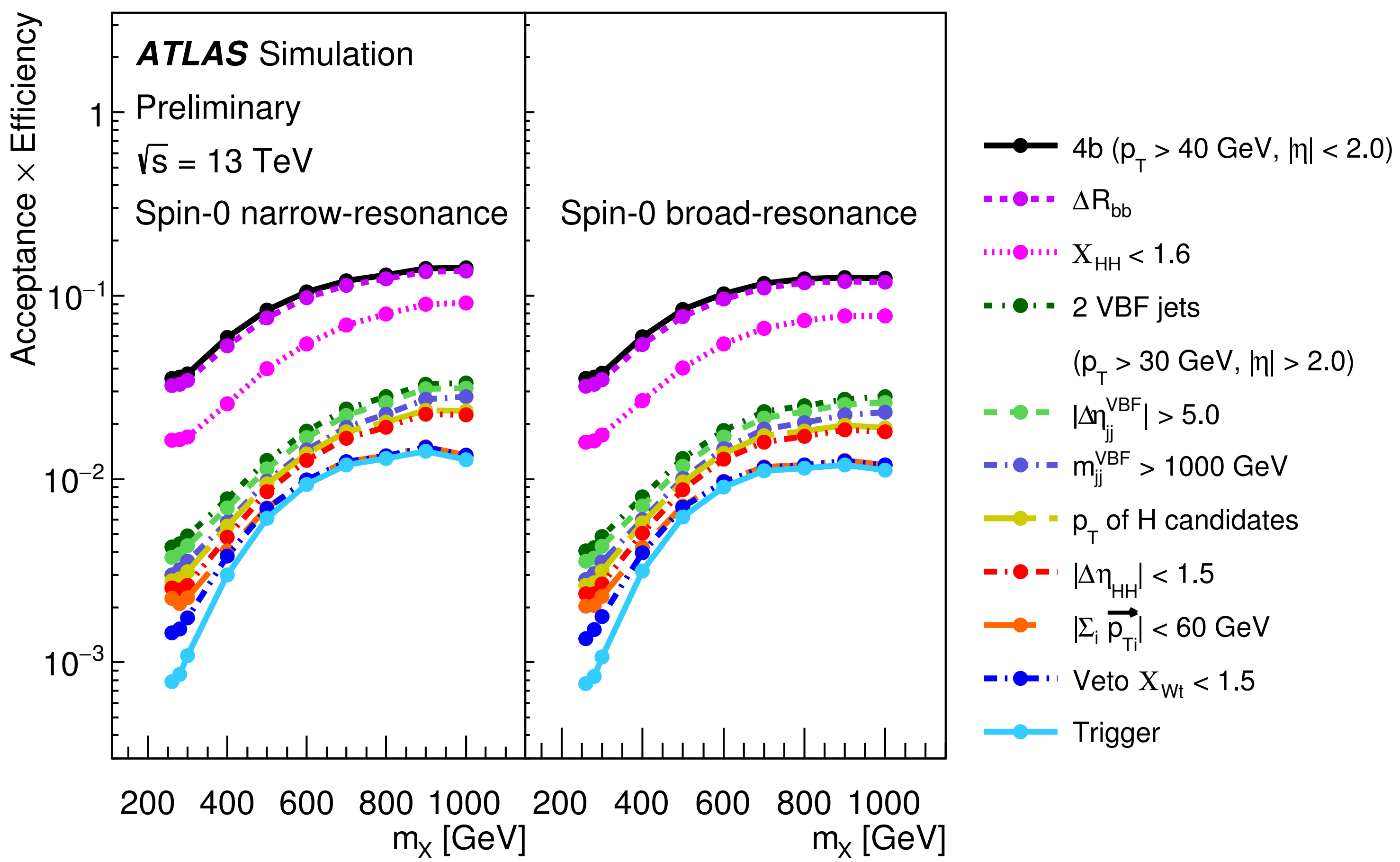




- Look for two Higgs bosons
  - We like to do this with the 4 b-jet final state: the largest branching ratio, but a challenging background
- Select two forward jets to tag the VBF process

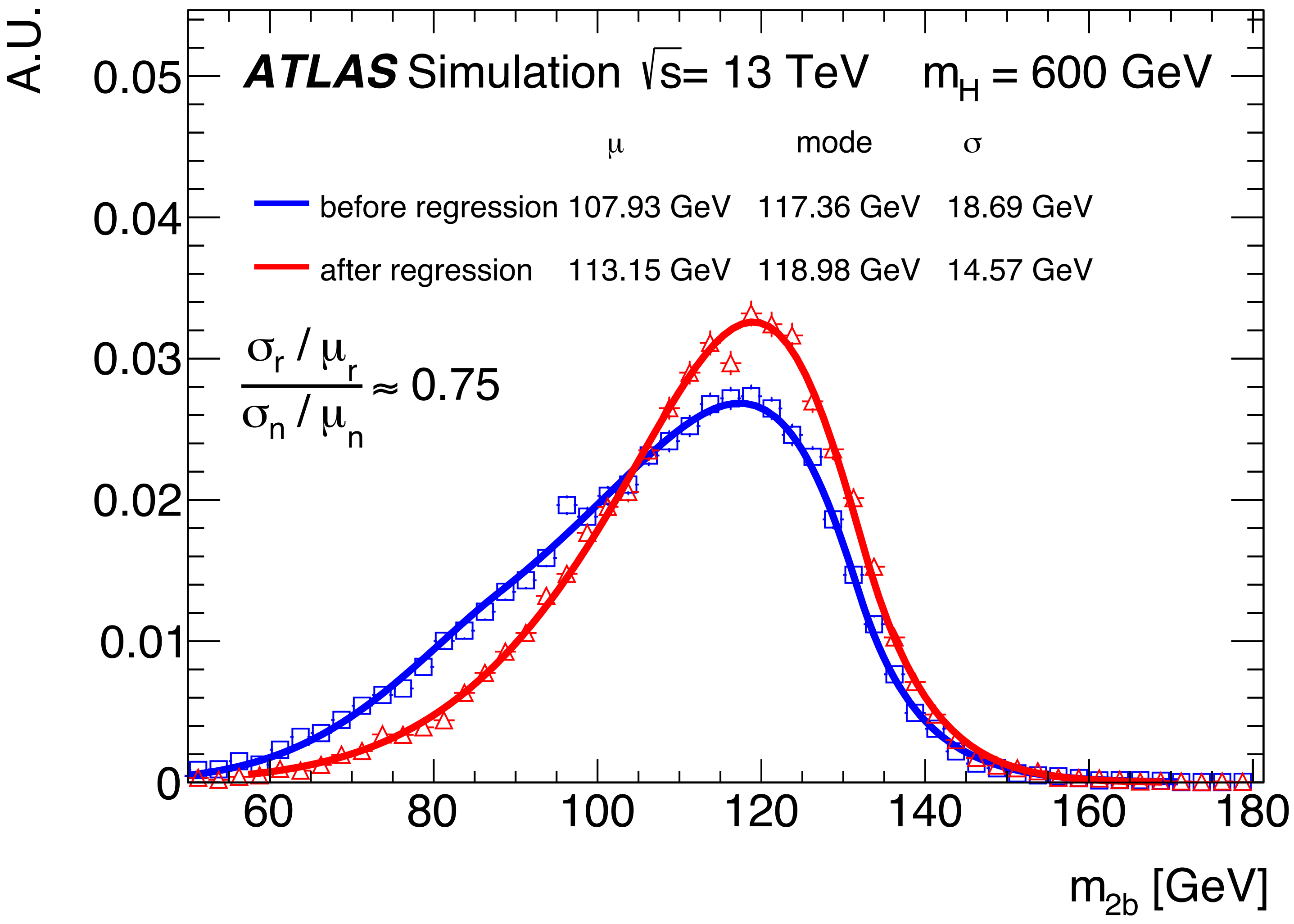
Analysis Selections

- Several sets of cuts used to enhance selection to the signal and reduce backgrounds
- Triggers require 2 b-tags: use fast tracking in the HLT to significantly reduce the rate, keep most of the signal

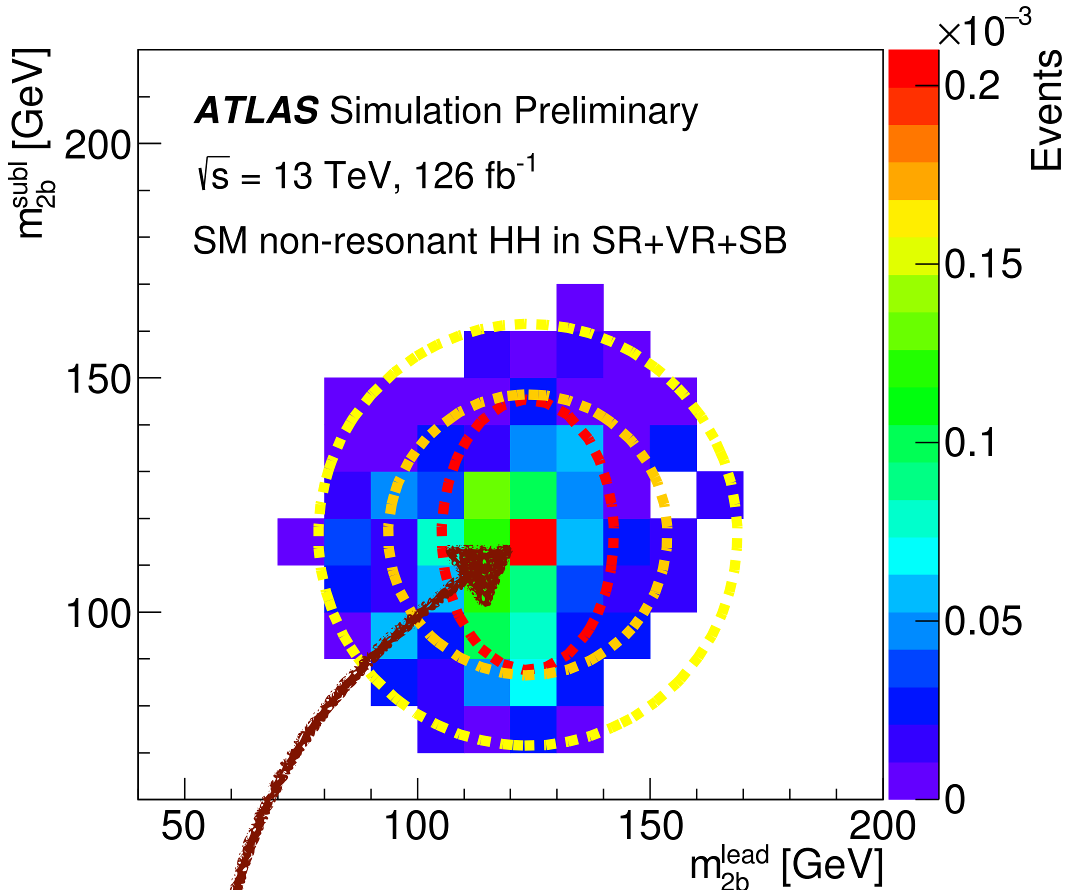


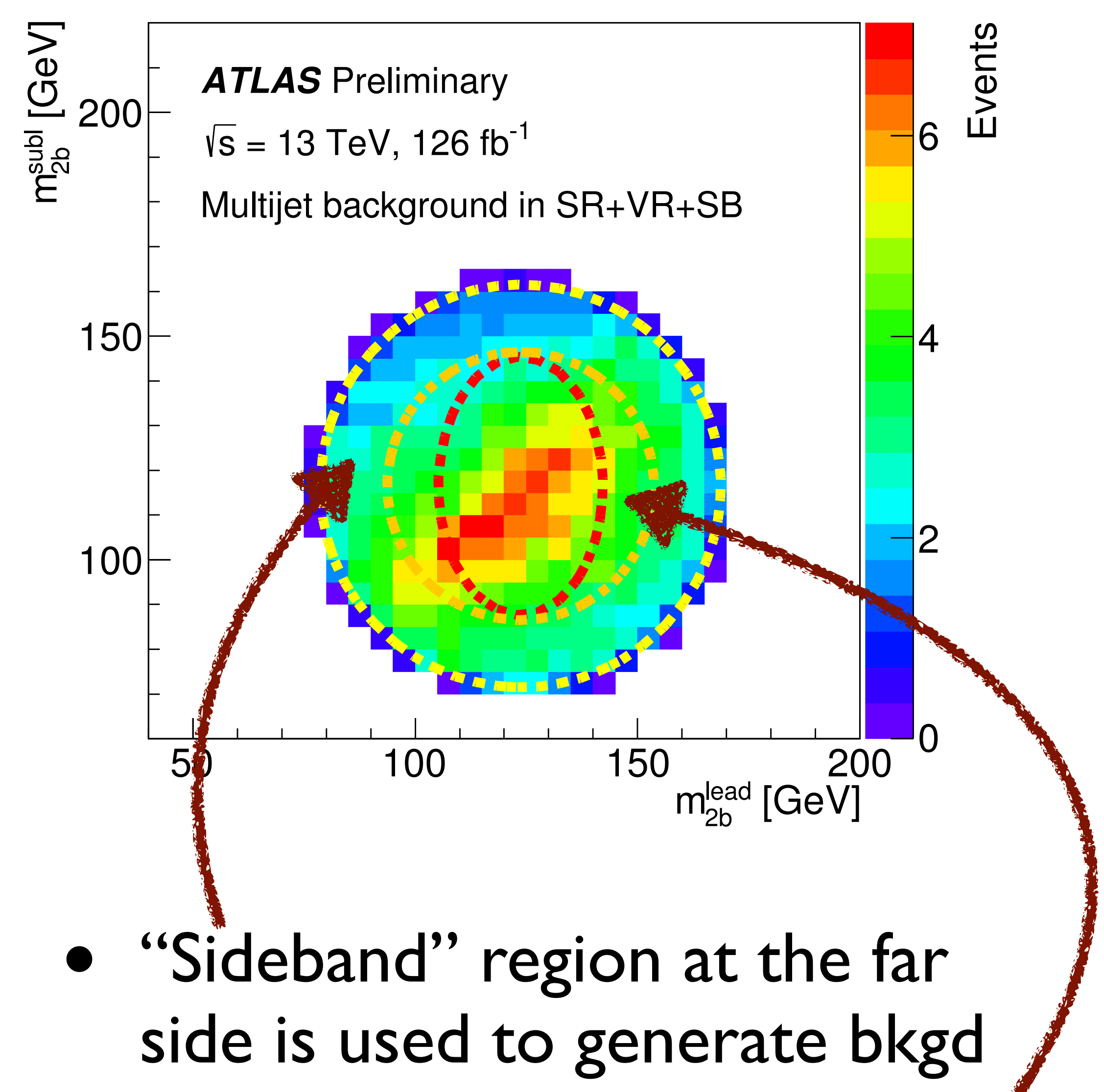
B-Jet Regression

- For the first time in ATLAS (!) use a b-jet energy regression with a BDT: use several track-based variables to correct b-jet energies to closer to true value
- Leads to a 25% improvement in the sharpness of Higgs peaks!
- Tested in data and MC: no mismodelings observed, no new systematic assigned
  - (nb: most bkgd is data-driven, so impact of any uncertainties would be small)



Background Model



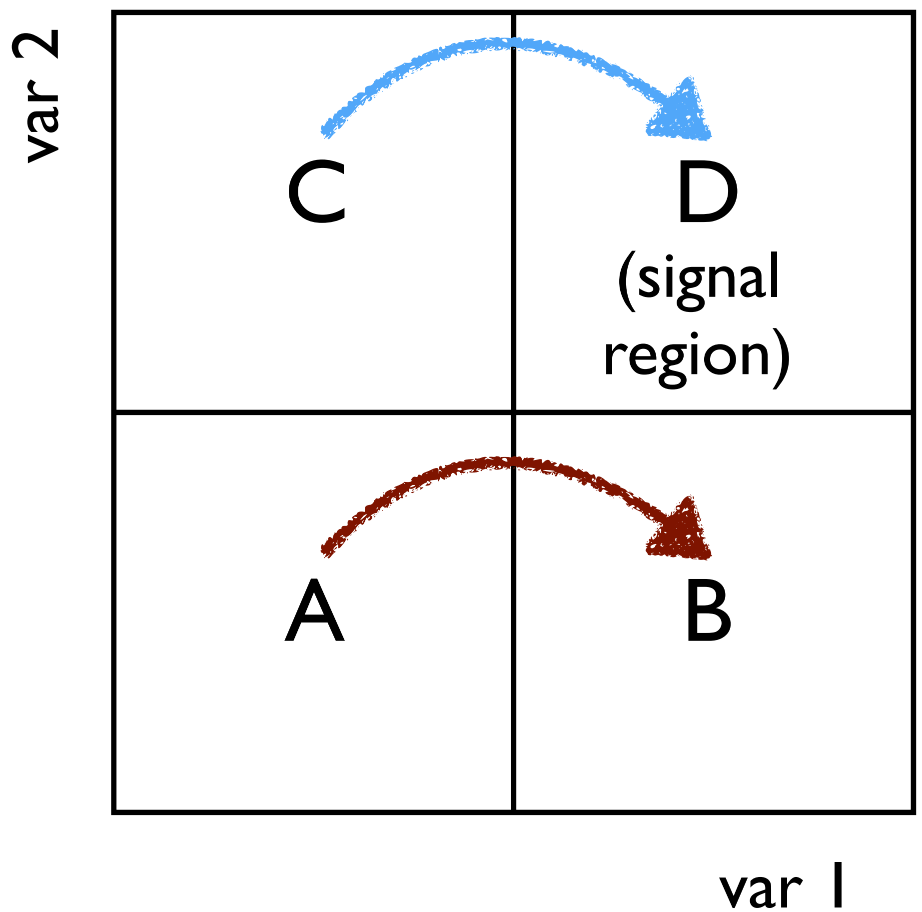


- Signal is concentrated at the center of the m_H m_H plane: use the surrounding regions to model the bkgd

- "Sideband" region at the far side is used to generate bkgd model, and "validation" region in orange used to assign uncertainties and check quality

Background Model Details

Generically:



1. Measure a transfer factor
2. Apply the transfer factor to another region

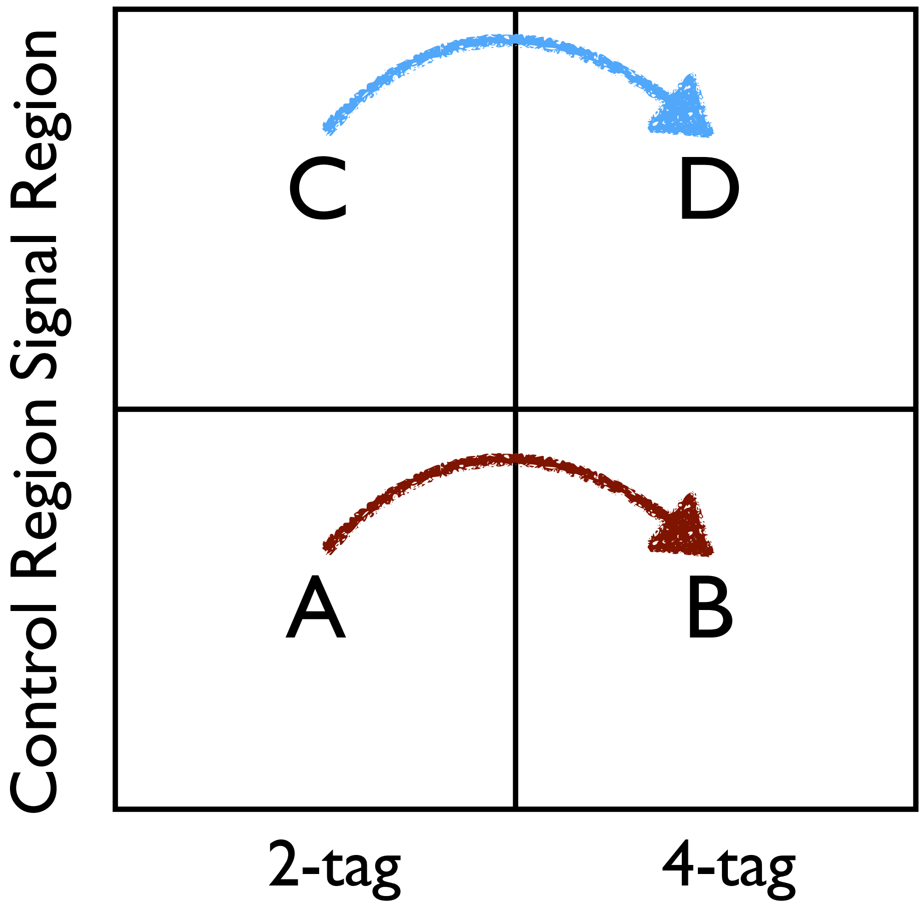
$$D = C\frac{B}{A}$$

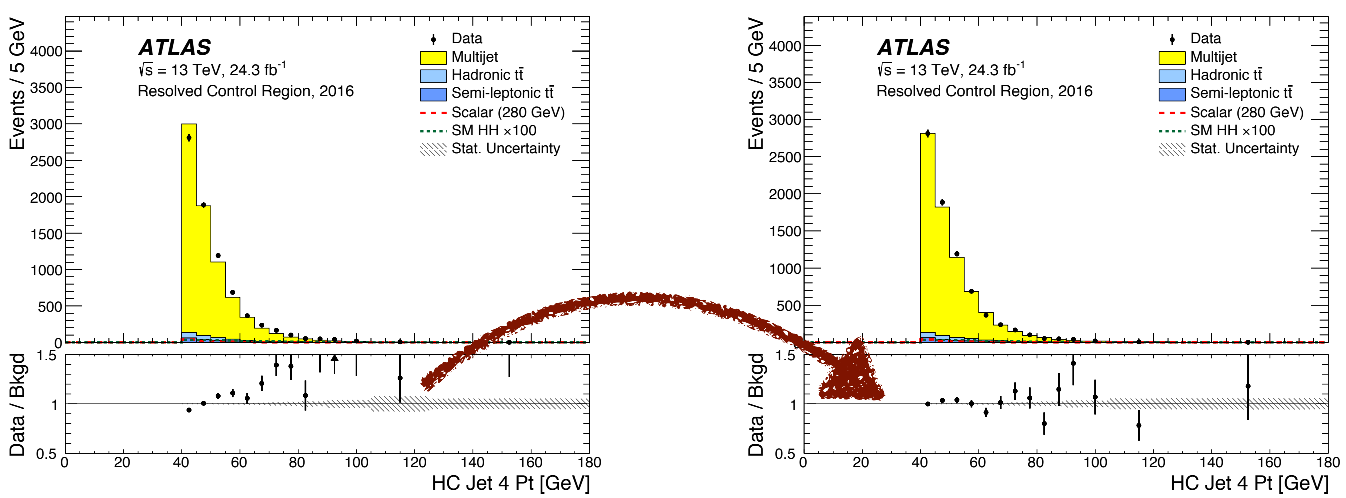
Background Model Details

In our case:

1. Measure a transfer factor

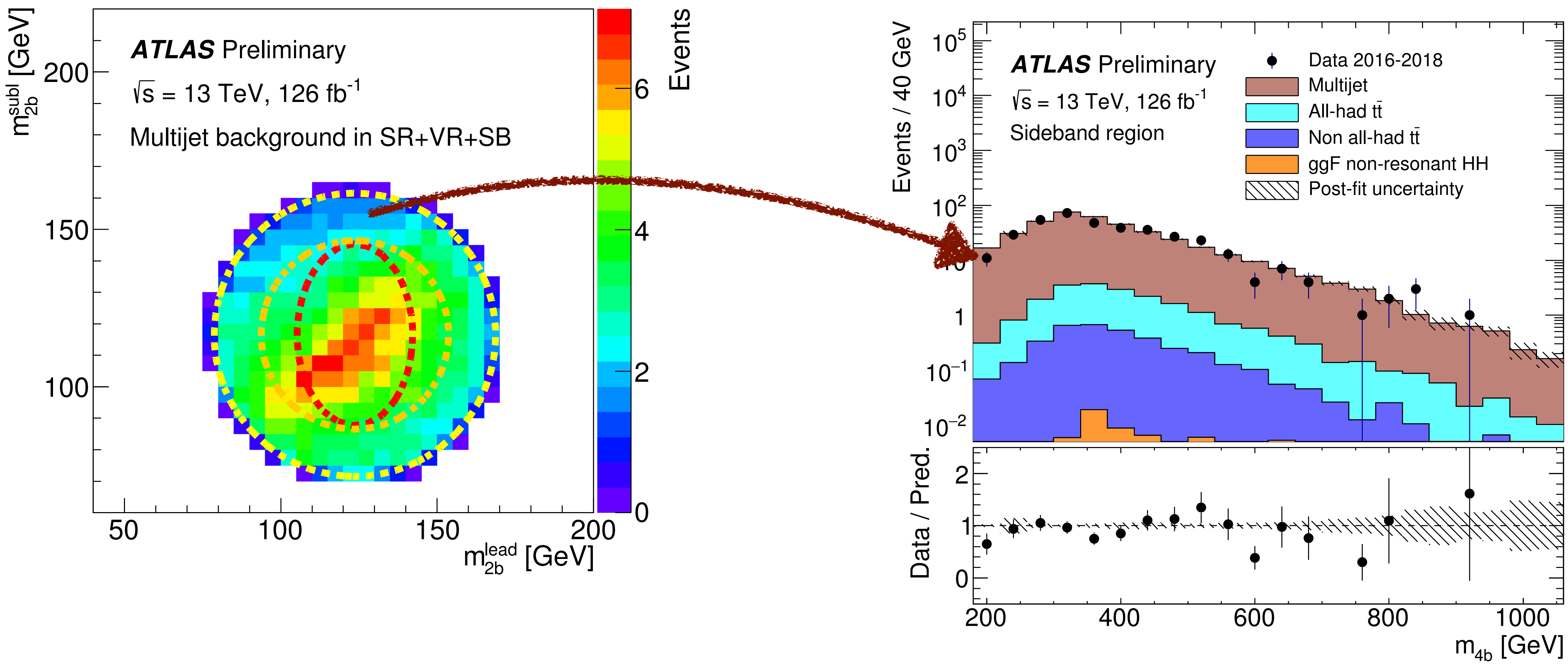
This time the transfer factor is more complicated: iteratively reweight kinematic distributions to get agreement





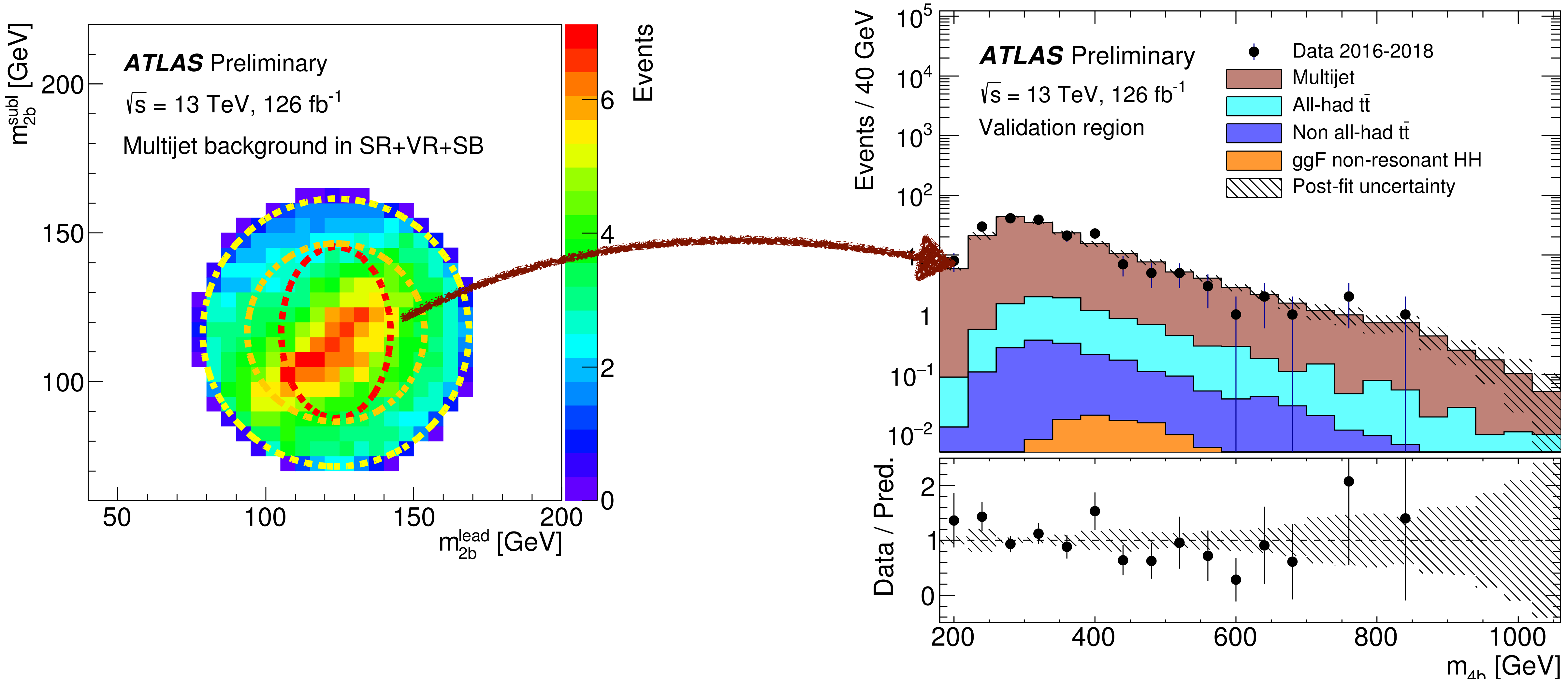
2. Apply the transfer factor to another region

Control Region



- Data on the right plot is 4-btag data
- Multijet bkgd is 2-btag, reweighted iteratively to match 4-btag data
- After reweighting, see good agreement in the control region!

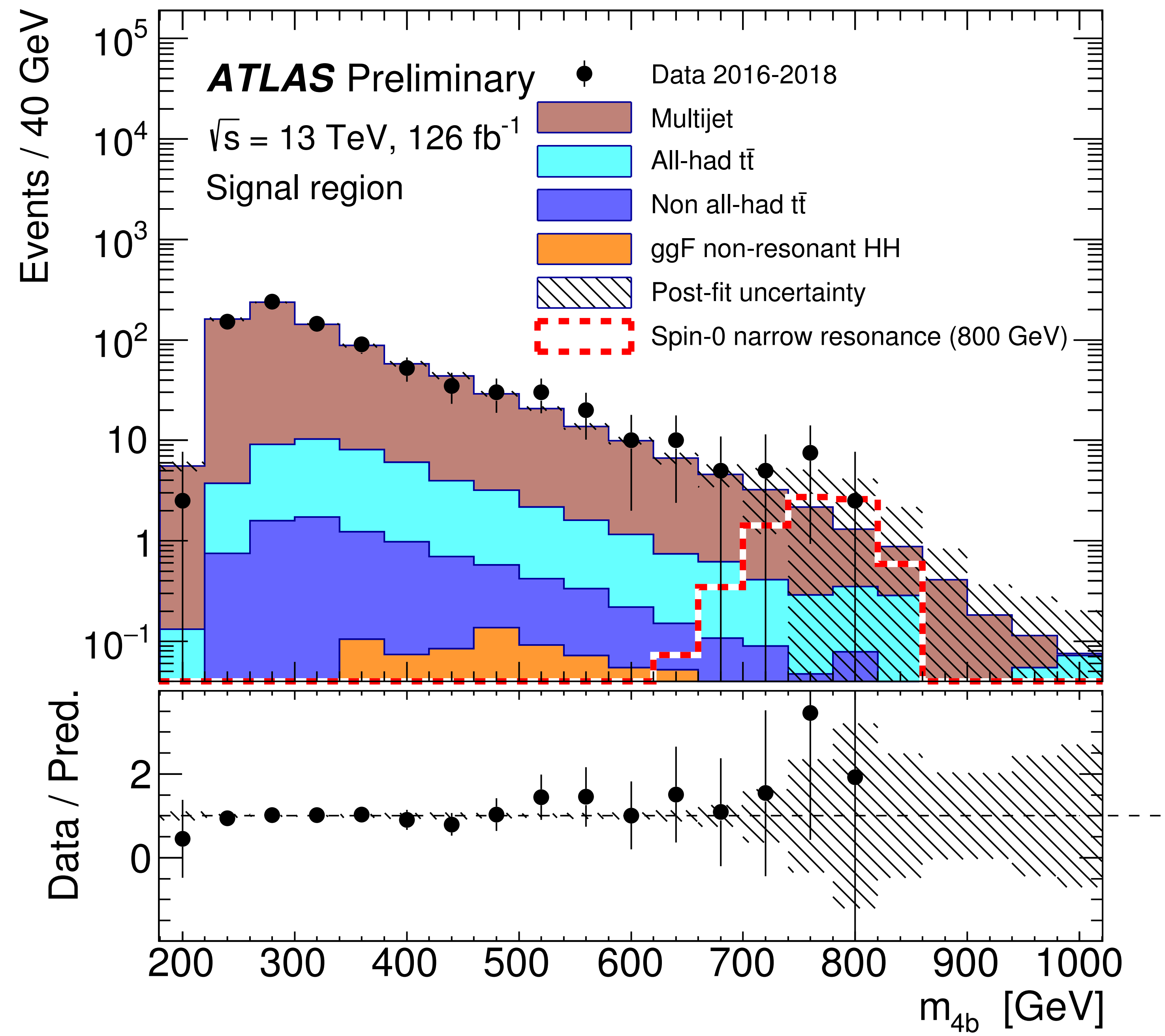
Validation Region



- Same story here: data is 4-btag, and multijet bkgd is 2-btag, reweighted using functions derived in control region
- See good agreement in validation region!

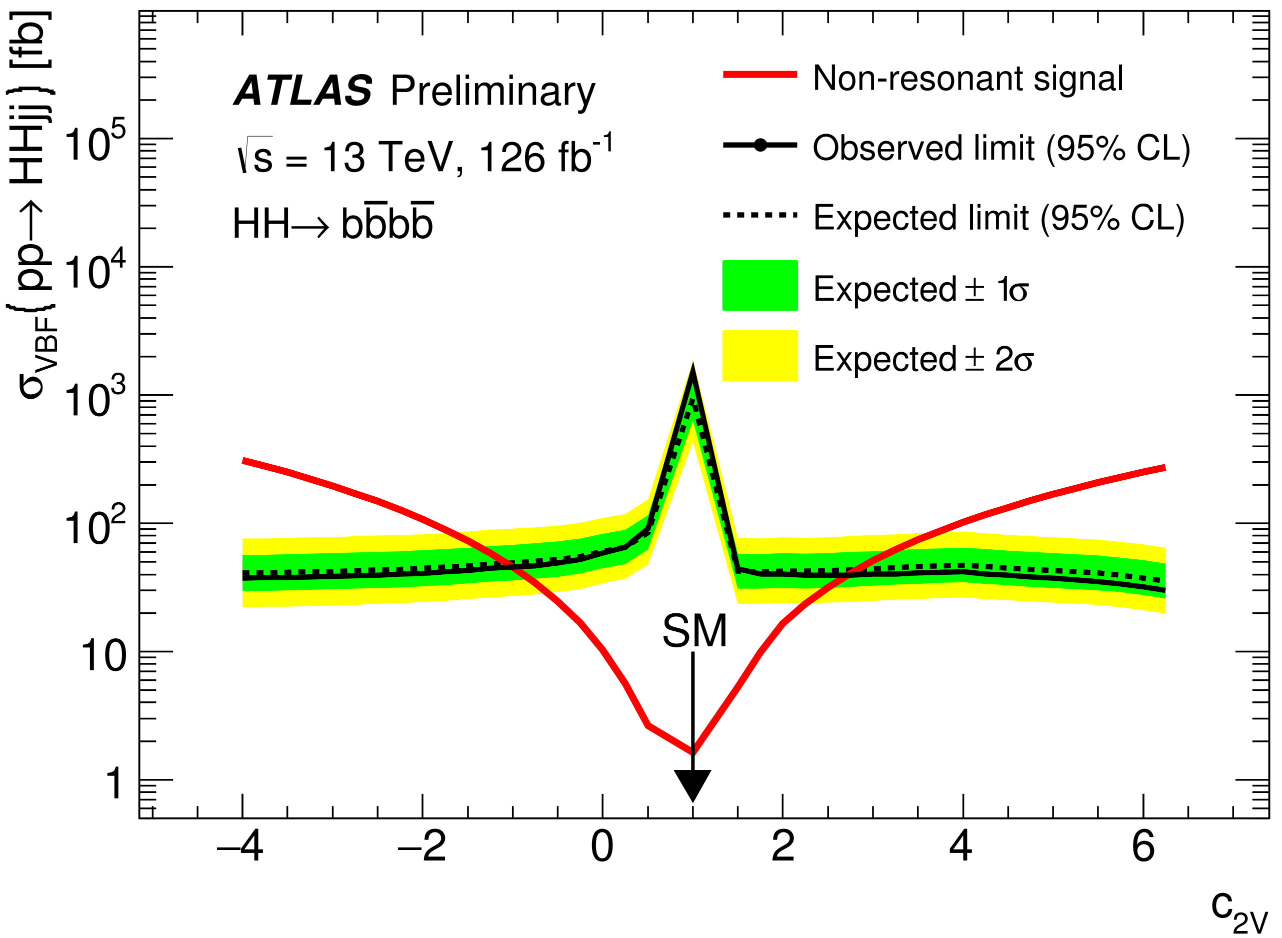
Signal Region

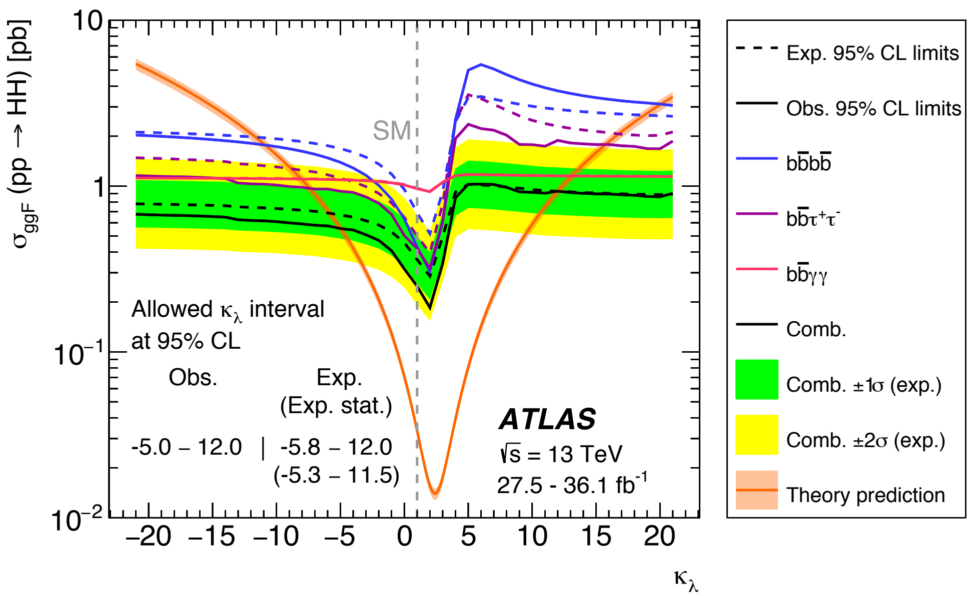
- Signal region shows no significant excess
  - Largest deviation is 1.5σ at 550 GeV, and < 1σ at 750 GeV
- So we set limits



Limits on c_{2V}

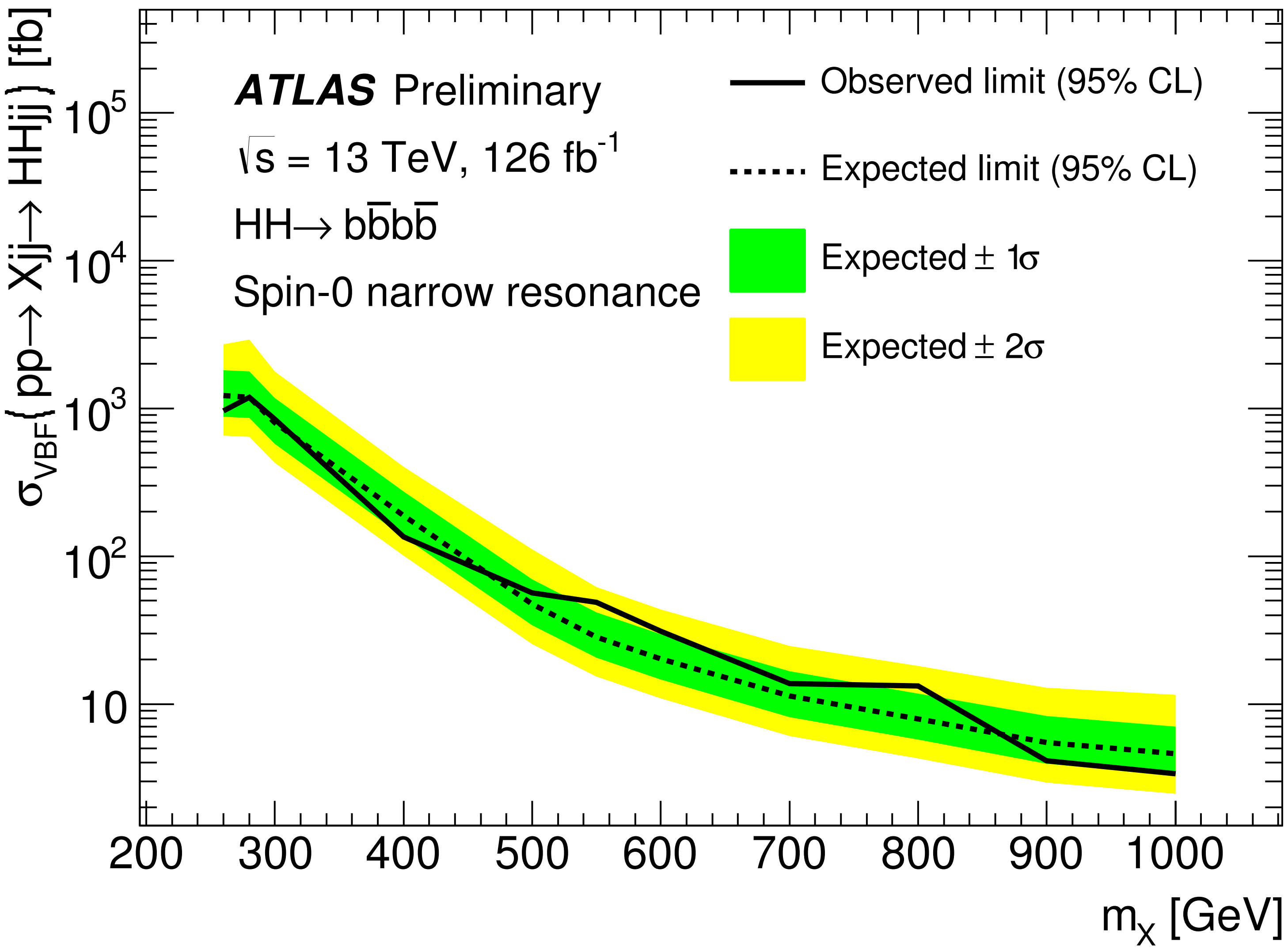
- Non-resonant signal cross-section has a strong dependence on c_{2V}, as expected
- But also notice that moving away from the SM value, the limit becomes much lower: this means the shape is easier to observe (higher m_{HH}) values
- This is opposite of the case of κ_λ like for the ggF analysis!





Resonant Limits

- Also set limits on new resonances decaying to pairs of Higgs bosons, produced via VBF
- First limits on this type of new physics model!



Conclusions

- di-Higgs analyses are a critical part of the physics programs of the LHC for run 2 and beyond
- Traditionally these are used to measure properties of the Higgs potential, but modifications can tell us even more about the SM
  - These can be rare signatures, but BSM deviations give huge cross-sections
- Here, we present the first measurement of the c_{2V} parameter by studying di-Higgs produced by VBF
- No excess is observed, and we set limits on resonances and the first limits on the c_{2V} parameter
- More in ATLAS-CONF-2019-030

Thank you!