Extracting Higgs boson couplings using a jet veto

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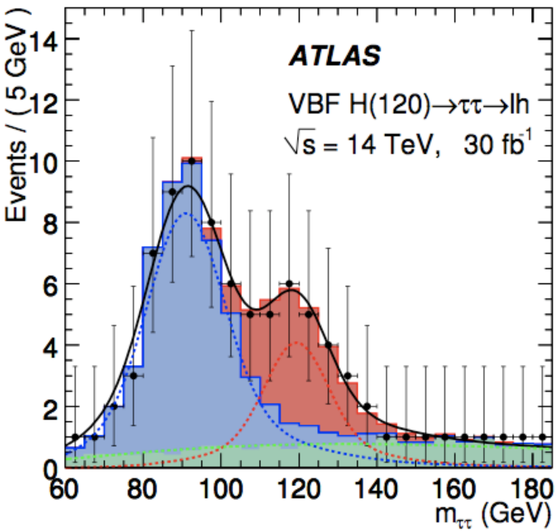
Overview

1) Introduction/reminder standard VBF analyses
2) Using a jet veto as a tool to probe the Higgs + 2 jet.
3) Simultaneous extraction of gluon and W couplings using a jet veto

VBF analyses at the LHC

- Many decay channels studied in literature, here focus on 120GeV Higgs decaying to taus.
- After main analysis cuts on tag-jets (widely separated, large invariant mass), the analyses typically veto on third jet activity in the central region between the tag jets.
- This veto is set very low, not only to reduce backgrounds, but to suppress Higgs production from gluon-gluon fusion (GF).



Signal is extracted from the $m_{\tau\tau}$ distribution.

The shape of the background is dominated by instrumental effects and can be determined from in-situ methods.

Long term goal: Extract cross-section x branching ratio. Assume that VBF dominates over GF. Feed result into global fits to extract Higgs couplings.

Measuring VBF and GF at the same time?

- Crucial component is the veto on additional jets above Q_0 in the central region between the two tag jets.
- The excess of events in the di-tau invariant mass spectrum contains contributions from both GF and VBF:

$$\sigma(Q_0) = \Lambda_{\rm g}\sigma_{\rm g}^{\rm SM}(Q_0) + \Lambda_{\rm V}\sigma_{\rm V}^{\rm SM}(Q_0)$$

here, Λ_i is the ratio of the actual Higgs coupling to 'i' to the SM value, i.e. $\Lambda_g = \Lambda_V = 1$ in the SM.

- Instead of cutting at low veto-scales, to suppress GF contribution, can in principle measure the size of the Higgs cross-section as a function of Q_0 and extract contributions for GF and VBF separately.
  - Advantage that it does not assume a SM-like coupling to vector bosons, applicable to BSM Higgs
  - Can we do this in practice, given the likely event rate at LHC and the theory/ experimental uncertainties?

Basic VBF analysis details

MC samples

SHERPA 1.2 used with CTEQ6L PDFs to generate samples of GF and VBF events at $\sqrt{s}$=14TeV. Specifically generate H+nj, with n=2,3.

K-factors invoked to account for missing virtual corrections by normalizing dedicated samples to the NLO calculation of Campbell, Ellis & Zanderighi (2006). This is needed to get the ratio of GF and VBF events correct.

VBF analysis cuts

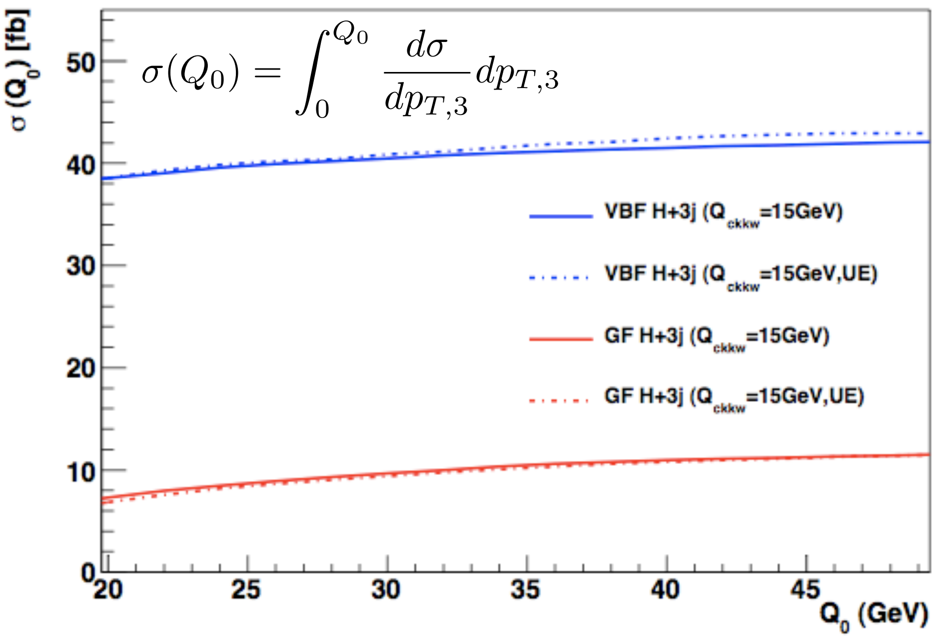
Jets found using Anti-k_T algorithm with R=0.4.

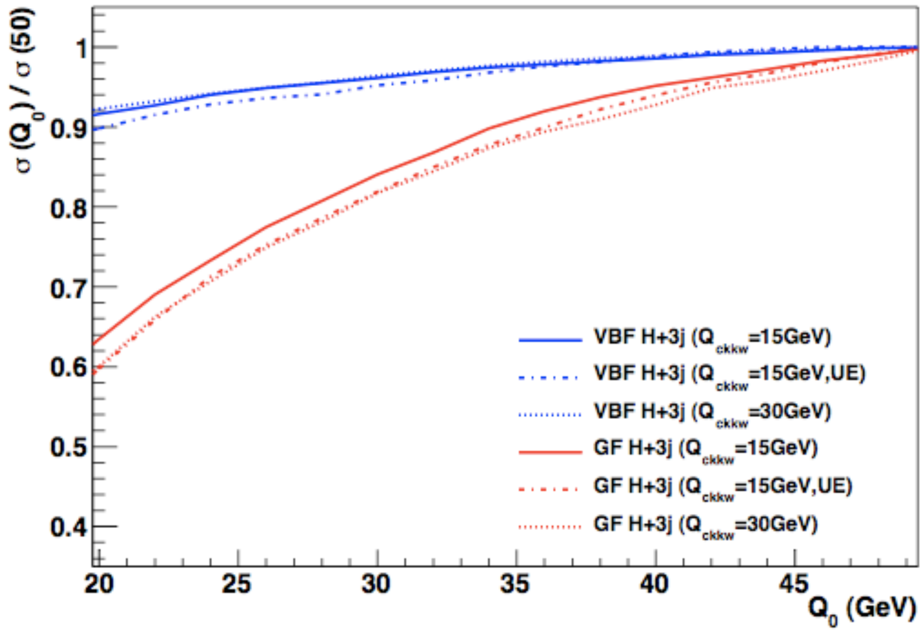
Then, follow explicitly the ATLAS standard VBF analysis:

1) Tag jets: $E_{T,1} > 40$GeV and $E_{T,2} > 20$GeV
2) Tag jets: $M_{jj} > 700$GeV, $\Delta\eta_{jj} > 4.4$ and $\eta_1.\eta_2 < 0$
3) Tau candidates: $\cos(\Delta\phi) > -0.9$
4) Missing $E_T > 30$GeV

After these kinematic cuts, we have a reasonable jet/Higgs topology

The jet veto dependence





- Left plot shows the size of the VBF and GF cross-section as a function of Q_0 after the kinematic cuts (still missing experimental efficiencies for taus, such as trigger, reconstruction…)
- Right plot highlights the different Q_0 dependence of VBF and GF events.
  - CKKW matching scale in SHERPA is important in GF shape – in a way this reflects the large theory uncertainty in the prediction, will return to this later.
  - Underlying event also cause a shape uncertainty between Q_0=20 and Q_0=50 for GF and VBF

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Estimating the fit accuracy for 60fb^{-1} of data

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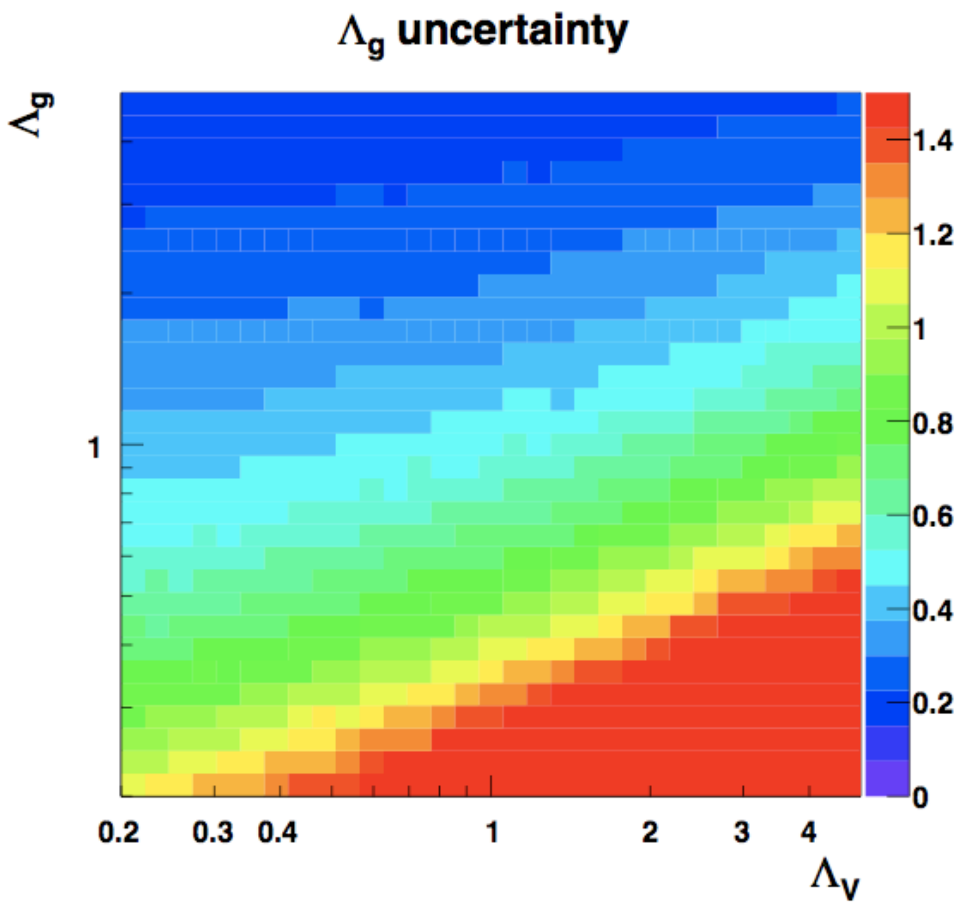
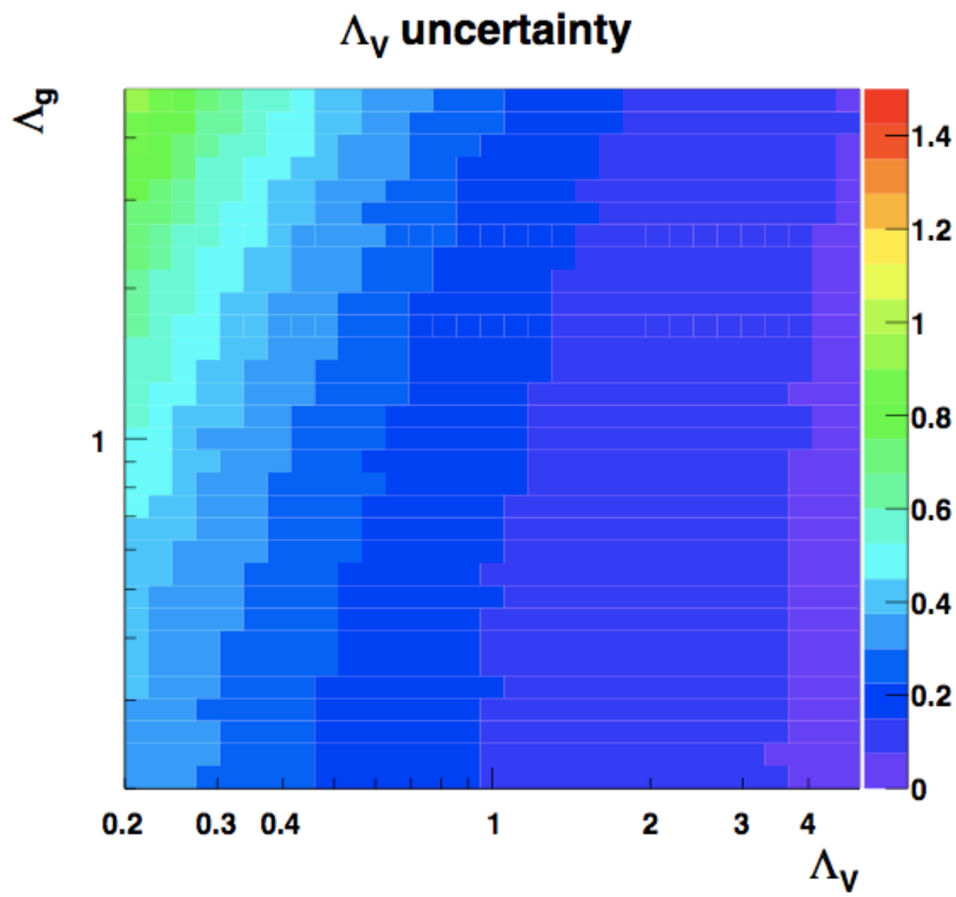
- Need to account for ATLAS experimental efficiency, ε, for tau-tau measurements (trigger, reconstruction, id…..)
  - Efficiency will be similar for GF and VBF events because we have already cut on the topology of the H+2j system. Take ε=0.036 (corresponds to all decay channels).

- Using SHERPA cross-sections and experimental efficiency, predict number of Higgs events for 60fb^{-1} of data. Find N_{GF}=25 and N_{VBF}=90 for Q_0=50.

- Perform 1000 pseudo-experiments for each value of Λ_g and Λ_V.
  - (Poisson distributed) GF and VBF events chosen at random from reduced MC samples (i.e. samples after kinematic cuts),
  - Smear/shift Q_0 distribution by systematic uncertainties
  - Perform fits in each experiment to extract Λ_g and Λ_V
  - Take uncertainty in method to be the RMS of fit values.

Results without systematics





- Colours represent the fractional uncertainty in the fit, across BSM parameter space.
  - Yellow, orange, red mean a very large final uncertainty on Λ
  - Dark blue represents a very well measured uncertainty.

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Impact of systematic uncertainties

What we are trying to measure: $\sigma(Q_0) = \sigma_{\rm jj}(1 - P_{\rm veto}(Q_0))$

H+2j cross-section (after cuts on tag jets)
i.e. A normalization uncertainty

Probability of additional jet above Q_0
i.e. a shape dependence

Take all theory/experimental uncertainties from vast literature:

1) VBF: Normalization of H+2j is known to about ±4% and (1-P_{veto}) is known to ±1% at all Q_0.
2) GF: Normalization of H+2j is known to about ±20%. Additional uncertainty from (1-P_{veto}) is not well known. Assign additional, uncorrelated, uncertainty of ±20% at Q_0=20 and 50 GeV.
3) Add in UE uncertainty in (1-P_{veto}), found from SHERPA after turning UE on/off.

4) VBF systematic (20%) on acceptance/normalization is mainly from JES. We find that corresponding systematic for GF is larger (~30%), due to steeper tag-jet distributions.
5) Find mild effect of JES on (1-P_{veto}) -- 0% for VBF and (max) ±3% for GF.
6) Background fluctuations affecting signal extraction is taken into account across Q_0 distribution by adding/removing events based on poisson fluctuation of background.

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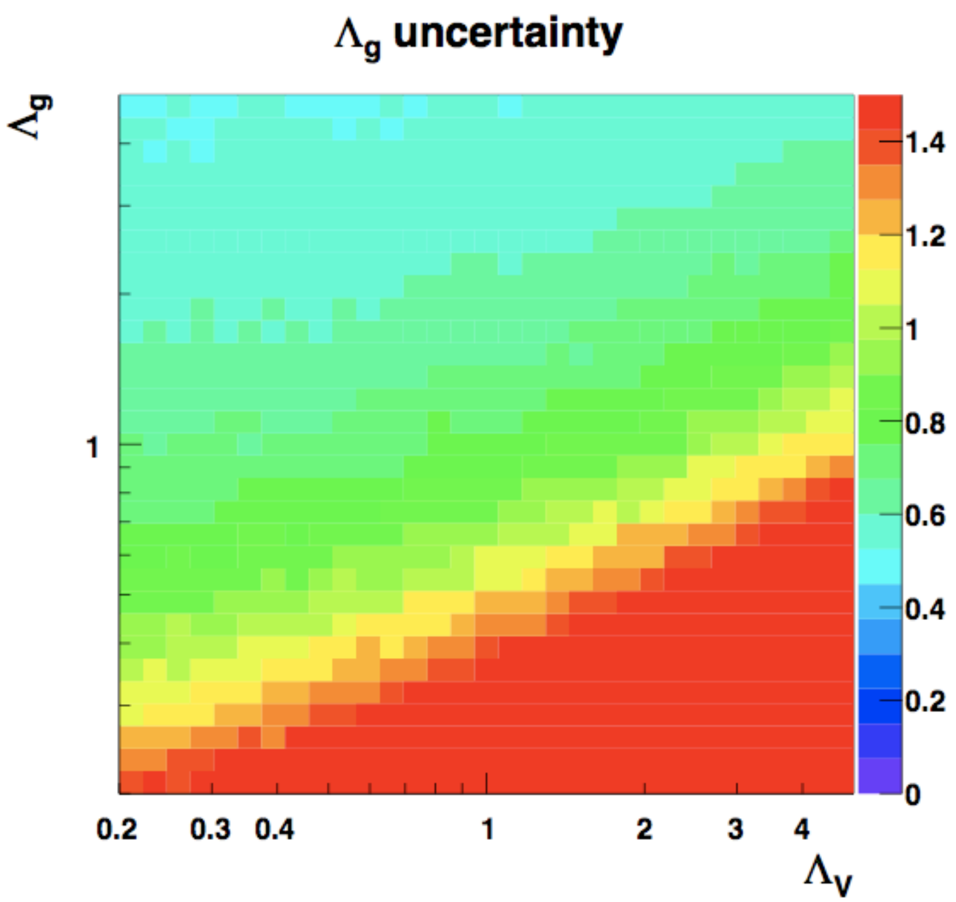
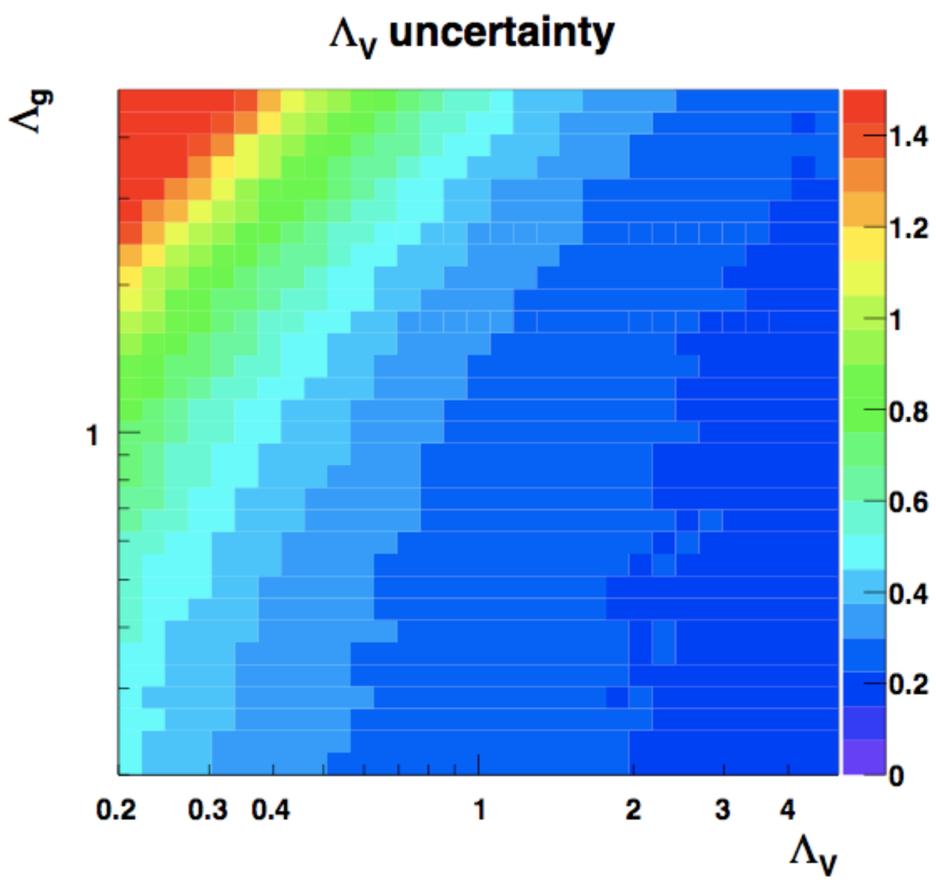
Results with systematics





Breakdown of systematic effects

Error	SM ($\Lambda_{g,V} = 1$) $\sigma_{\Lambda_g}/\Lambda_g$	SM ($\Lambda_{g,V} = 1$) $\sigma_{\Lambda_V}/\Lambda_V$	BSM ($\Lambda_g = 4$, $\Lambda_V = 1/4$) $\sigma_{\Lambda_g}/\Lambda_g$	BSM ($\Lambda_g = 4$, $\Lambda_V = 1/4$) $\sigma_{\Lambda_V}/\Lambda_V$
Stat. only	0.51 [0.23]	0.16 [0.07]	0.19 [0.08]	0.72 [0.33]
Backgd.	0.56 [0.25]	0.18 [0.08]	0.20 [0.09]	0.79 [0.35]
VBF	0.52 [0.25]	0.17 [0.08]	0.19 [0.08]	0.75 [0.33]
GF	0.65 [0.45]	0.19 [0.11]	0.43 [0.40]	1.56 [1.40]
Expt.	0.62 [0.39]	0.26 [0.21]	0.35 [0.31]	0.89 [0.52]
All	0.77 [0.57]	0.28 [0.23]	0.53 [0.50]	1.66 [1.49]

Middle columns show effect of statistical uncertainty + specific systematic
i.e. statistical uncertainty in fitting procedure is always present.
Numbers in square brackets correspond to $300 fb^{-1}$

Summary and outlook

- Jet veto dependence of the signal excess can be used to extract the different mechanisms of Higgs production:
  - Simultaneous extraction of effective coupling of Higgs to gluons and vector bosons should be possible.
  - More information in arXiv:1006:0986

- At the moment large theoretical uncertainty in both the normalization and shape of the GF cross-section, which will impact on the standard VBF approach as well.
- The JES uncertainty dominates the measurement from experimental perspective – understanding JES in the presence of pile-up will be crucial in H+2j analyses.

- Can study jet veto dependence in early LHC data, i.e. jet-gap-jet topology, W/Z + nj production – use to feed back into theory calculations