The University of Manchester

MANCHESTER 1824

University of Durham

# Probing New Physics using jet vetoes

Andy Pilkington – Manchester and IPPP Durham

*Presented at Low-x 2012, Paphos, 30th June 2012*

**Overview**

1) Extracting Higgs boson couplings
2) Understanding TeV-scale resonances

MANCHESTER 1824

The University of Manchester

University of Durham

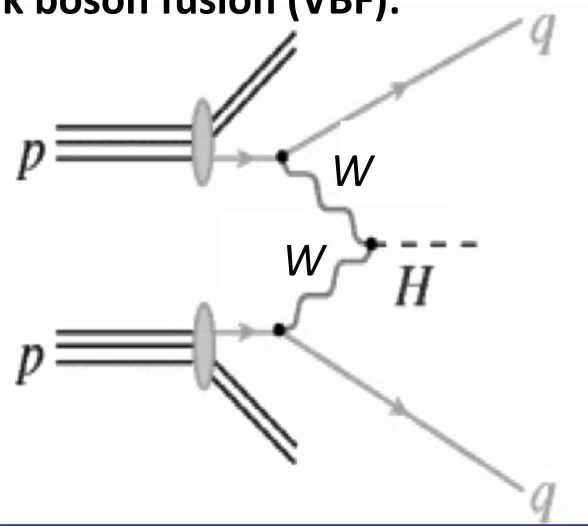
IP3

**Overview**

1) Extracting Higgs boson couplings and quantum numbers
2) Identifying the colour of TeV-scale resonances

# Higgs-plus-two-jet production

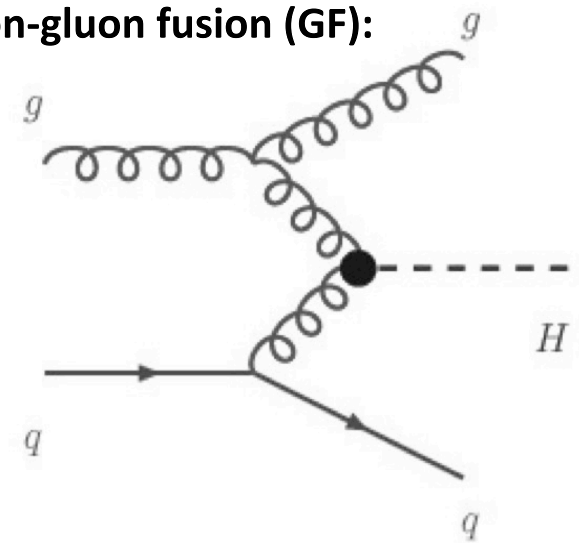
**Weak boson fusion (VBF):**




Quarks in proton radiate W's. Naturally produces two tag jets with large transverse momentum , O($M_W$)

No colour flow between quark lines – expect that QCD radiation between quark-jets will be suppressed.

**Gluon-gluon fusion (GF):**

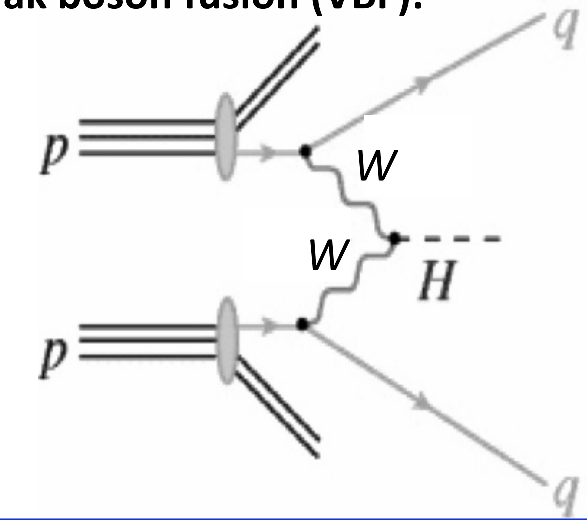



Higgs production via gluon-gluon fusion. Tag jet production not typical, but does occur.

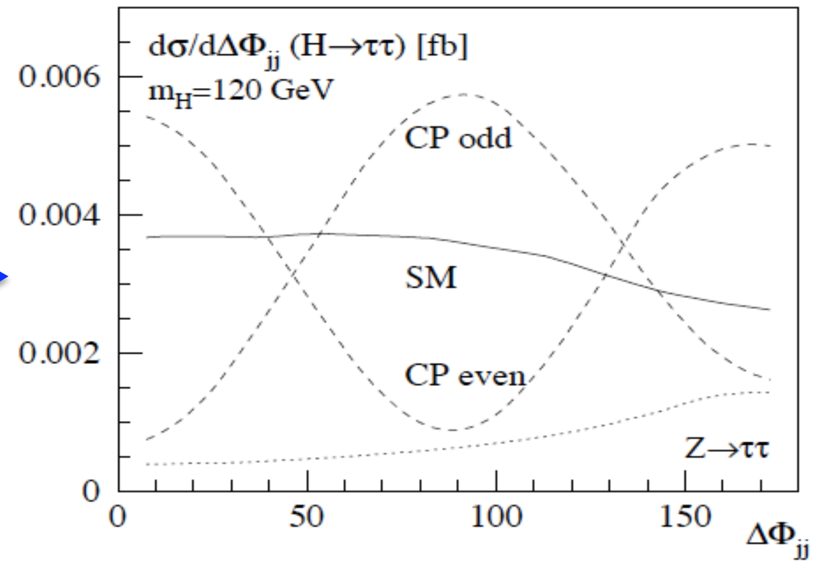
Colour octet flow between tag jets – expect more radiation in the region between the tag jets.

# H+2j = a probe of CP quantum numbers

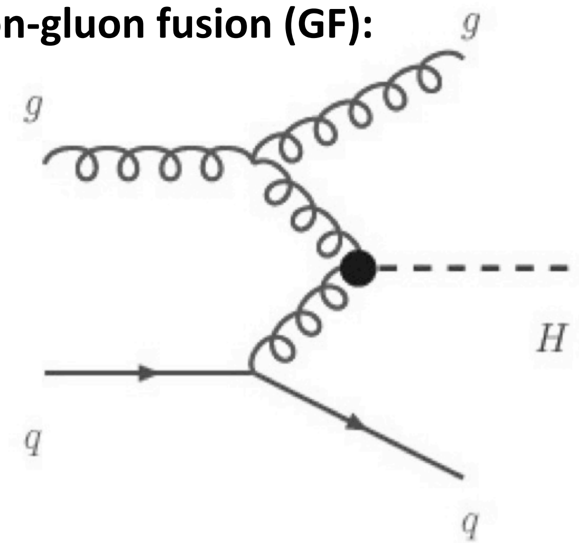
**Weak boson fusion (VBF):**



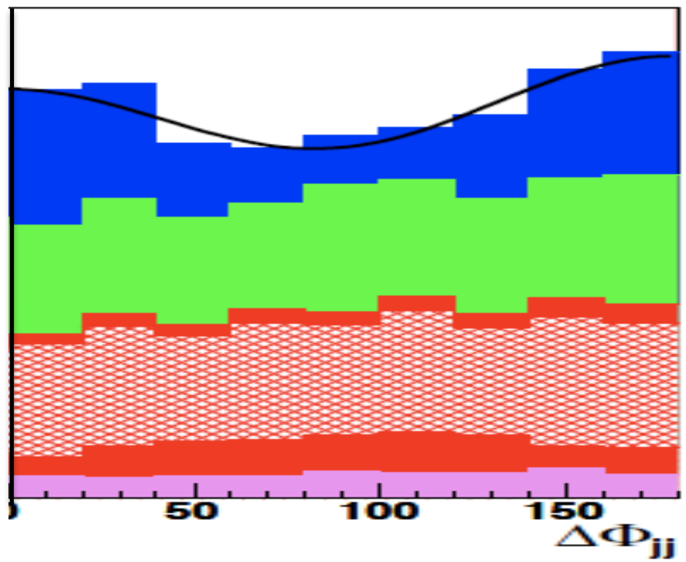

PRL 88, 051801 (2001)




**Gluon-gluon fusion (GF):**




JHEP 04, 052 (2007)



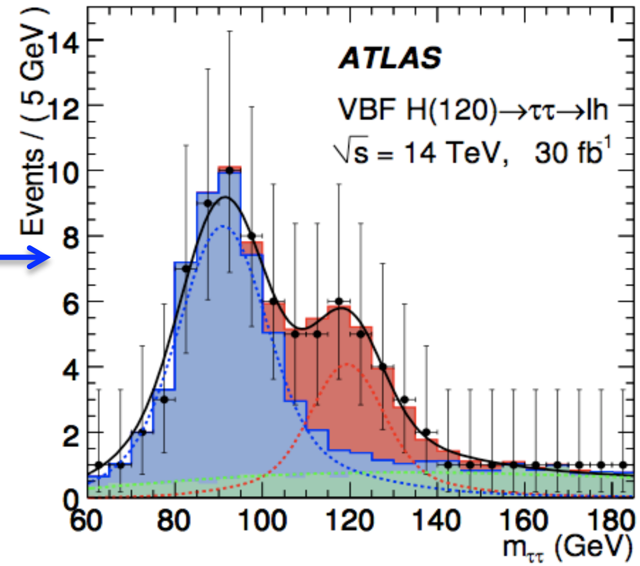
The University of Manchester

MANCHESTER 1824

University of Durham

# Example: H→ττ 'VBF-style' analysis

arXiv:0901.0512




**VBF analysis as per ATLAS CSC analysis** [arXiv:0901.0512]

Jets found using anti-$k_T$ algorithm with R=0.4.

Kinematic cuts on jets and taus:

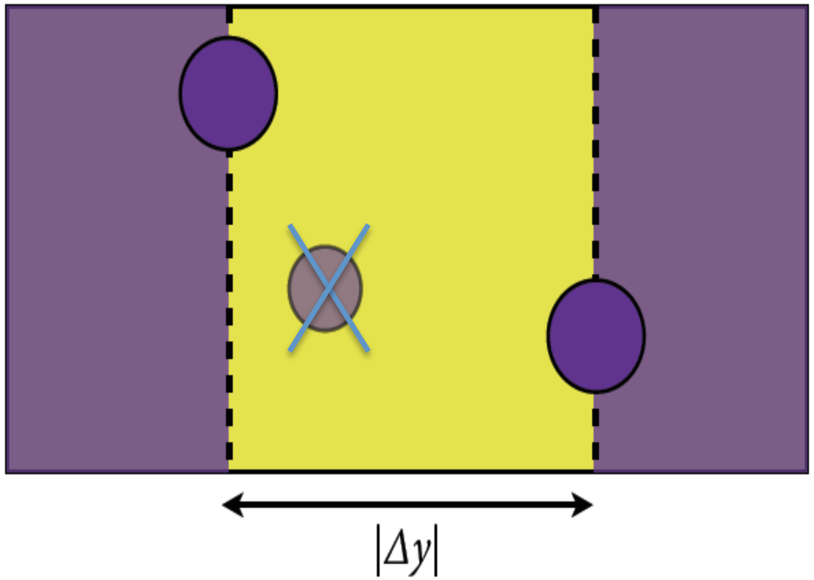
1) Tag jets: $E_{T,1} > 40$GeV and $E_{T,2} > 20$GeV
2) Tag jets: $M_{jj} > 700$GeV, $\Delta\eta_{jj} > 4.4$ and $\eta_1.\eta_2 < 0$
3) 2 tau candidates with $\cos(\Delta\phi) > -0.9$
4) Missing $E_T > 30$GeV

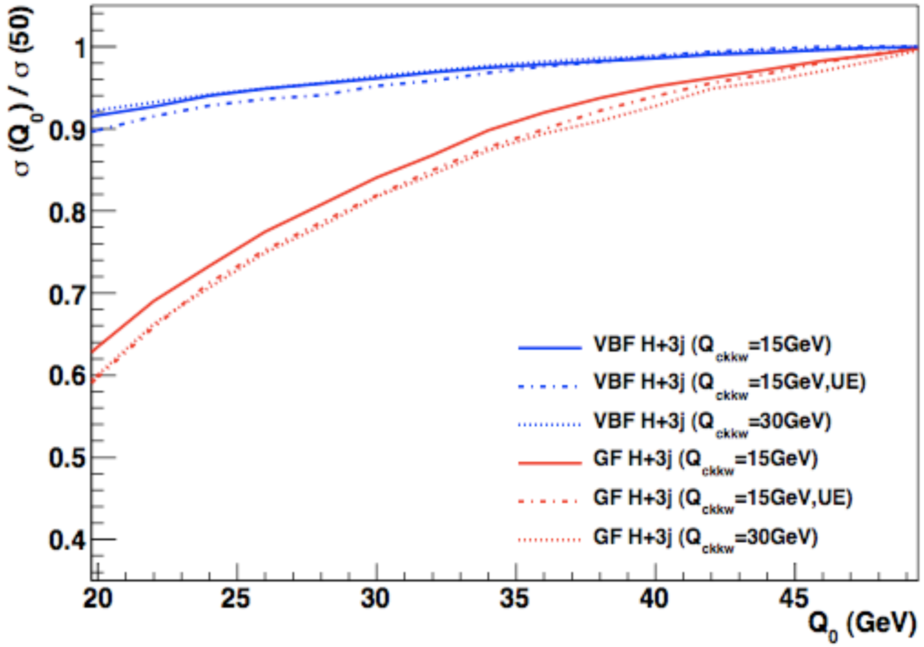
After these cuts *and* expected experimental efficiency, expect ~90 VBF events and ~25 GF events with 60 $fb^{-1}$ for a *Standard Model* Higgs boson of 120 GeV at √s = 14TeV.

In BSM models, the Higgs couplings are typically different than the SM Higgs couplings:

- GF could be very important if the couplings to vector bosons are heavily suppressed
- If we want to extract the CP using the tagging-jers, need to have a model independent handle on the 'contamination' between GF and VBF channels.

# The jet veto efficiency




- A typical approach is to reject events if they contain a jet in the rapidity interval between the tagging jets -> events are rejected if they contains 'in-gap' jets with $p_T > Q_0$
- The difference in colour flow between the tag jets for GF and VBF means that GF events are much less likely to survive the veto

# Measuring VBF and GF at the same time?

- In principle, can measure the size of the Higgs cross-section as a function of $Q_0$ and extract contributions for GF and VBF separately:

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

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

- Knowing $\Lambda_g$ and $\Lambda_W$ allows us to interpret the $\Delta\phi_{jj}$ distribution and extract the CP quantum numbers of the Higgs boson
- The ratio $\Lambda_W / \Lambda_g$ is equivalent to a the ratio of effective Higgs couplings to W's and gluons.
- Model independent: does not assume a SM-like coupling to vector bosons.

Cox, Forshaw and AP, **PLB 696 (2011) 87-91**

The University of Manchester
MANCHESTER 1824

IP3 University of Durham

# 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

Can find most theory/experimental uncertainties in the literature.

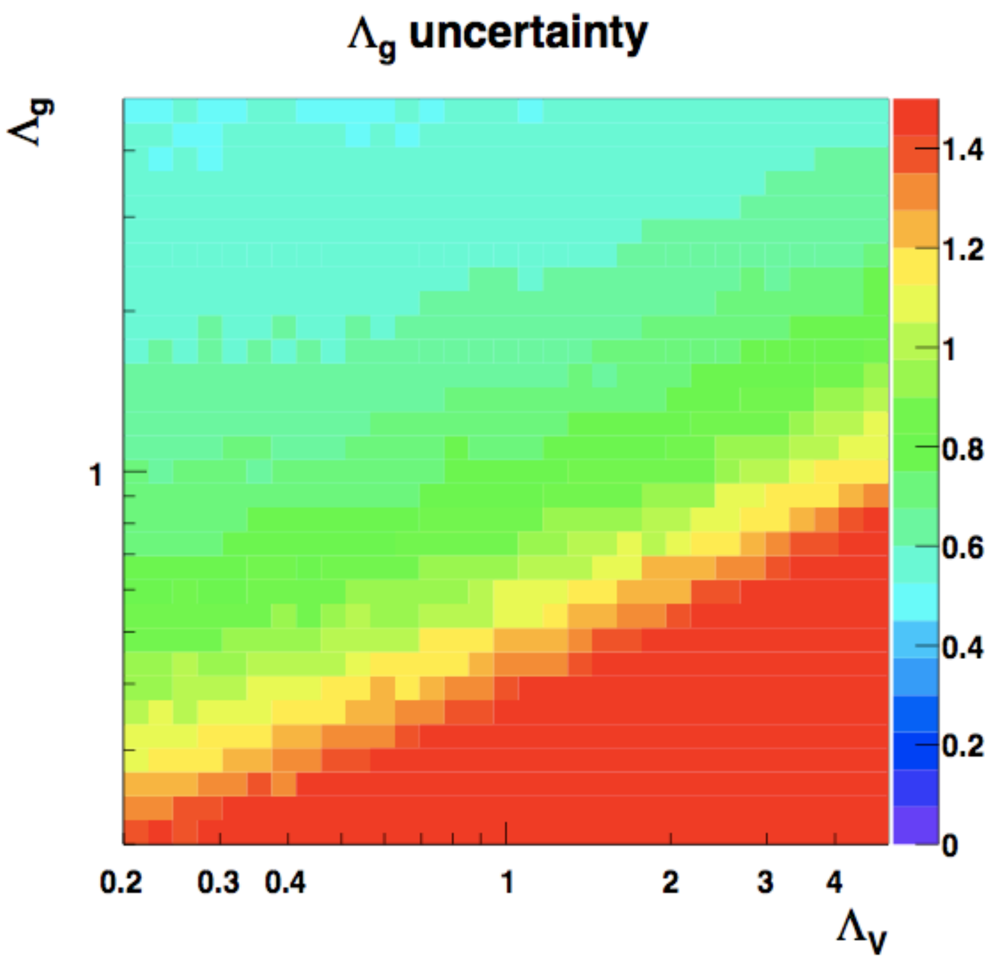
**Uncertainties in theoretical prediction:**

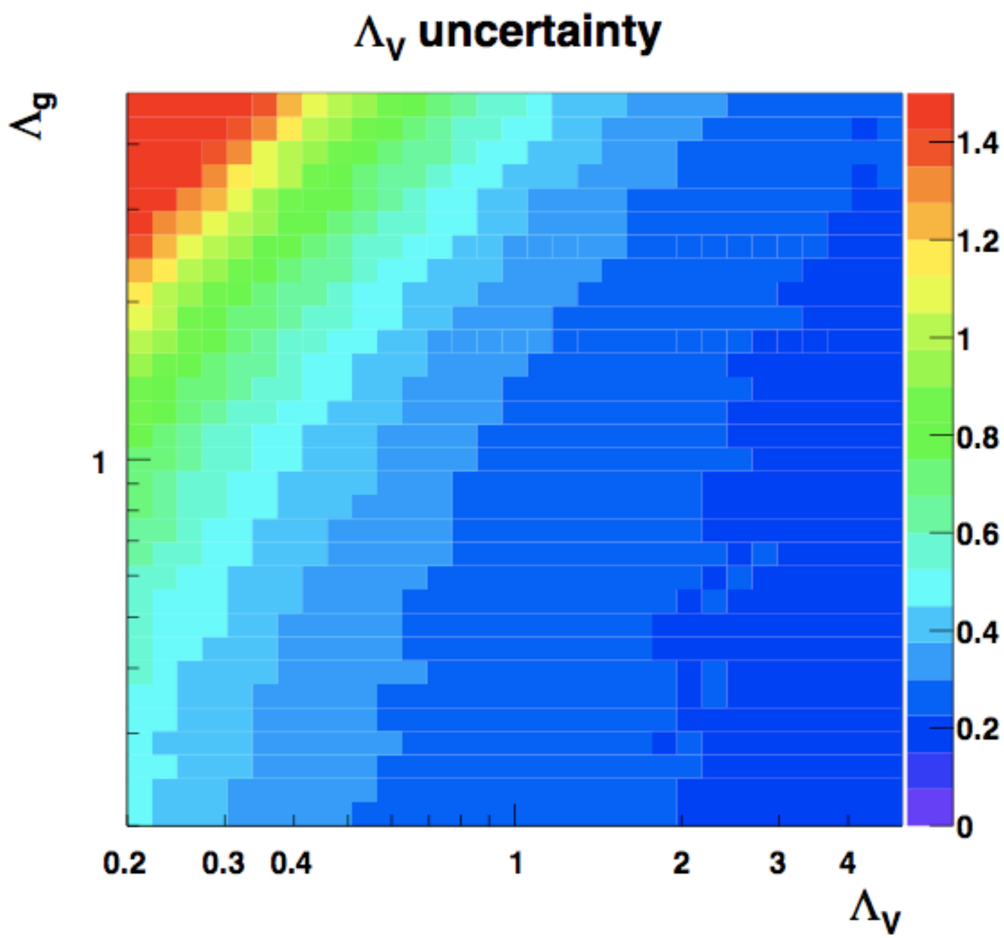
1) VBF: Normalization of H+2j is known to about ±4% and (1-$P_{veto}$) is known to ±1% at all $Q_0$.
2) GF: Normalization of H+2j is known to about ±20%. Additional uncertainty from (1-$P_{veto}$) is not well known. Asume additional, uncorrelated, uncertainty of ±20% at $Q_0$=20 and 50 GeV.
3) UE uncertainty in (1-$P_{veto}$), approximately 2% and 5% for VBF and GF respectively,

**Uncertainties from experimental measurement:**

1) VBF systematic (20%) on acceptance/normalization is mainly from JES. JES systematic for GF is larger (~30%), due to steeper tag-jet distributions.
2) Find mild effect of JES on (1-$P_{veto}$) -- 0% for VBF and (max) ±3% for GF.
3) Background normalisation / statistical fuctuations

# Results with systematic uncertainties included




80% uncertainty in $\Lambda_g$ measurement for a SM Higgs boson. This is competitive with the global extraction across all channels (**PRD 70:113009,2004**).

The University of Manchester
MANCHESTER 1824

IP3 University of Durham

# Breakdown of systematic uncertainty

| Error | SM ($\Lambda_{g,V} = 1$) | | BSM ($\Lambda_g = 4,\ \Lambda_V = 1/4$) | |
|---|---|---|---|---|
| | $\sigma_{\Lambda_g}/\Lambda_g$ | $\sigma_{\Lambda_V}/\Lambda_V$ | $\sigma_{\Lambda_g}/\Lambda_g$ | $\sigma_{\Lambda_V}/\Lambda_V$ |
| 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] |

Largest uncertainty arises from the theoretical modelling of the GF cross-section and kinematics.

Experimental uncertainty mainly due to JES.
- Actually, this is overestimated: the current JES@ATLAS is about 2x smaller than the values used in this study.

Numbers represent the fractional uncertainty given 60 [300] fb$^{-1}$ of data.
Middle rows show effect of statistical uncertainty + specific systematic
- statistical uncertainty in fitting procedure is always present.

The University of Manchester

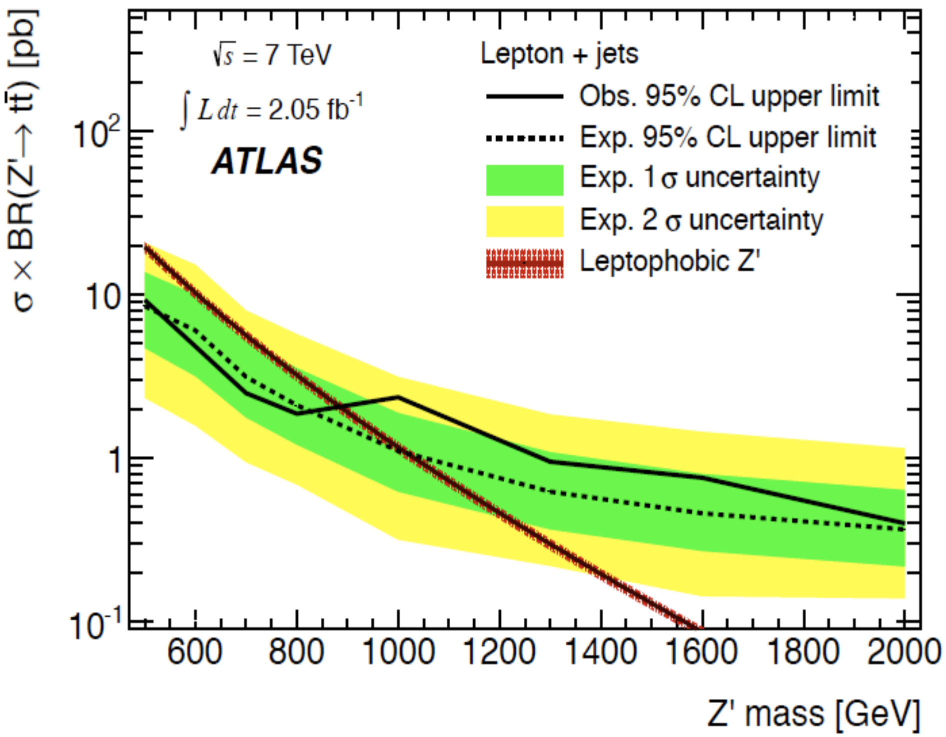
MANCHESTER 1824

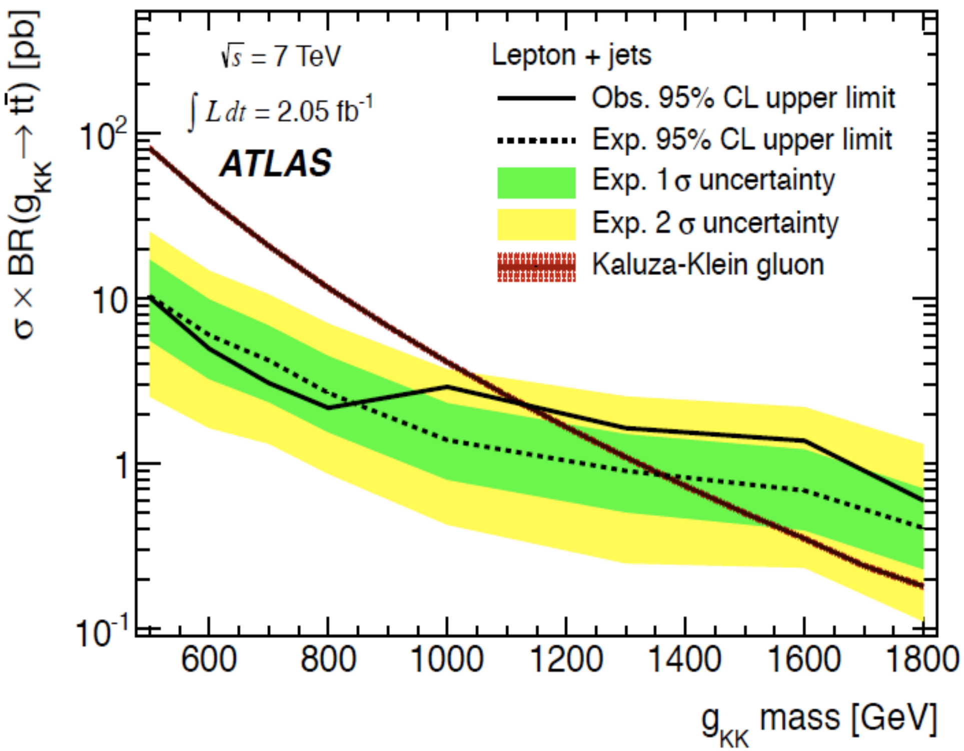
University of Durham

**Overview**

1) Extracting Higgs boson couplings and quantum numbers
2) Identifying the colour of TeV-scale resonances

# BSM resonance decaying to top-antitop pair

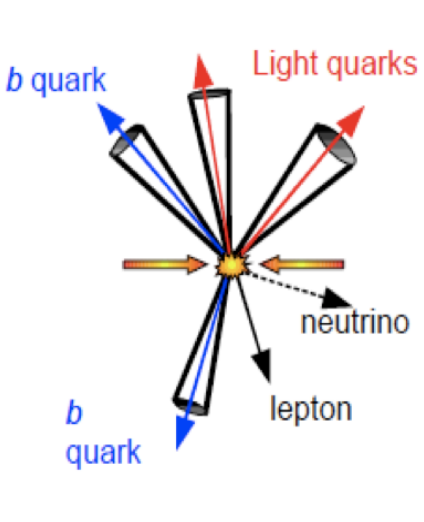


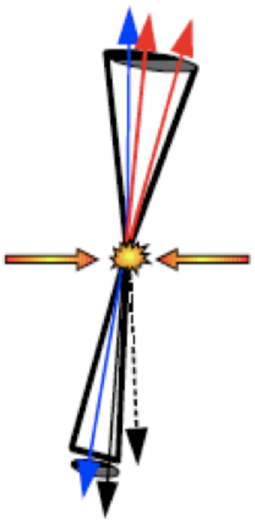

arXiv:1205.5371

- ATLAS/CMS are both searching for a heavy resonance decaying to top-pairs
- Exclude models of *heavy colour singlets* and *heavy colour octets* up to approximately 1.2-1.5TeV.
- But….how would we tell which model was correct if we actually saw a resonance?

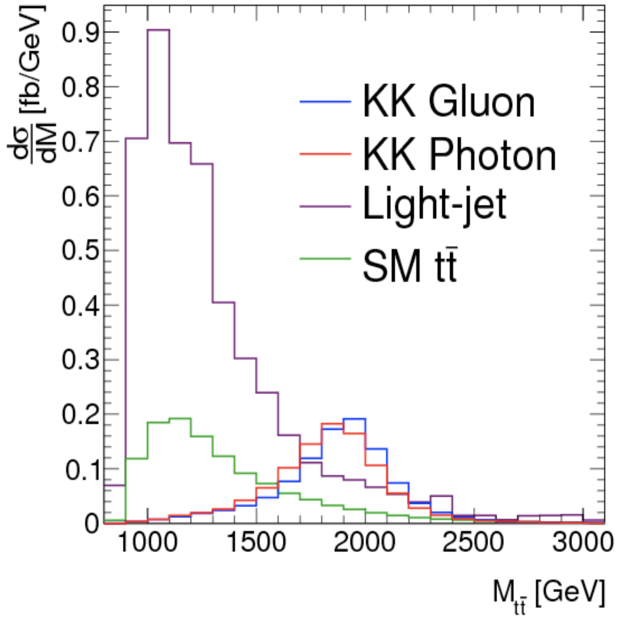
# Searching for heavy resonances with boosted top-jets

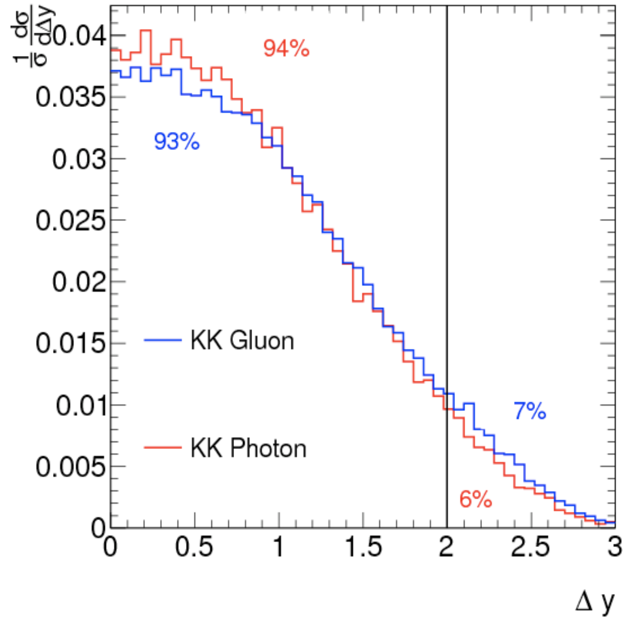



Low mass resonance



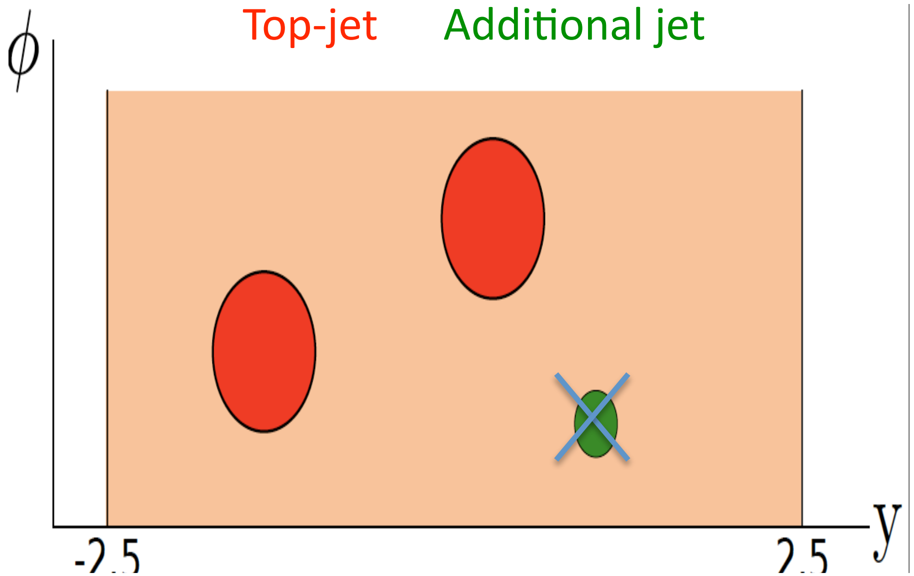
High mass resonance

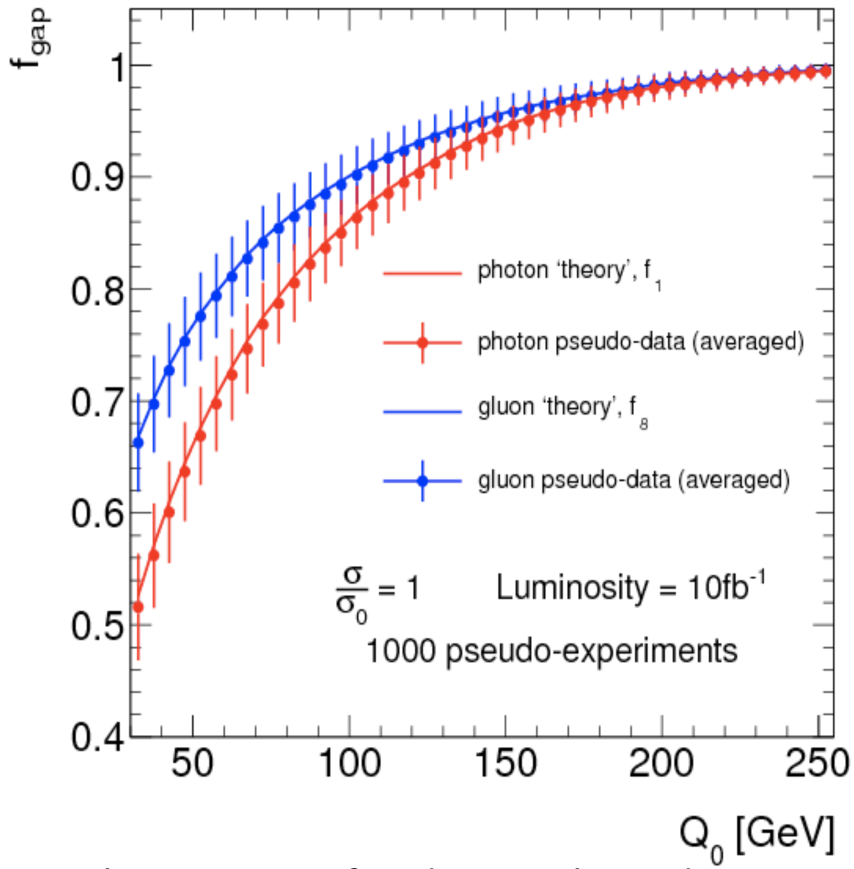



- For very heavy resonances, decay products of top quarks are quasi-collinear
- Use ‘standard’ top-tagging algorithms to identify top-antitop dijet system
- For identical spins the dijet mass and rapidity separation will be ~identical for colour singlet / octets.

# The jet veto efficiency




- In this case, define the jet veto as no additional jets with $p_T > Q_0$ in a fixed central rapidity interval
- If resonance observed could fit the observed gap-fraction with two curves:

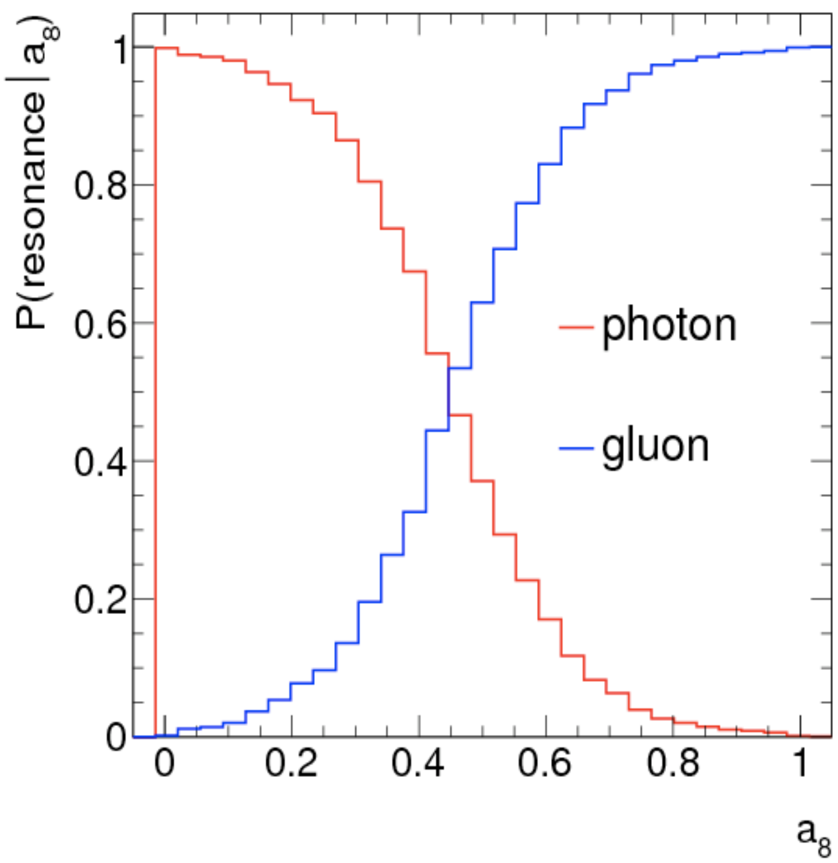
$$f_{gap} = a_1 f_1 + a_8 f_8$$

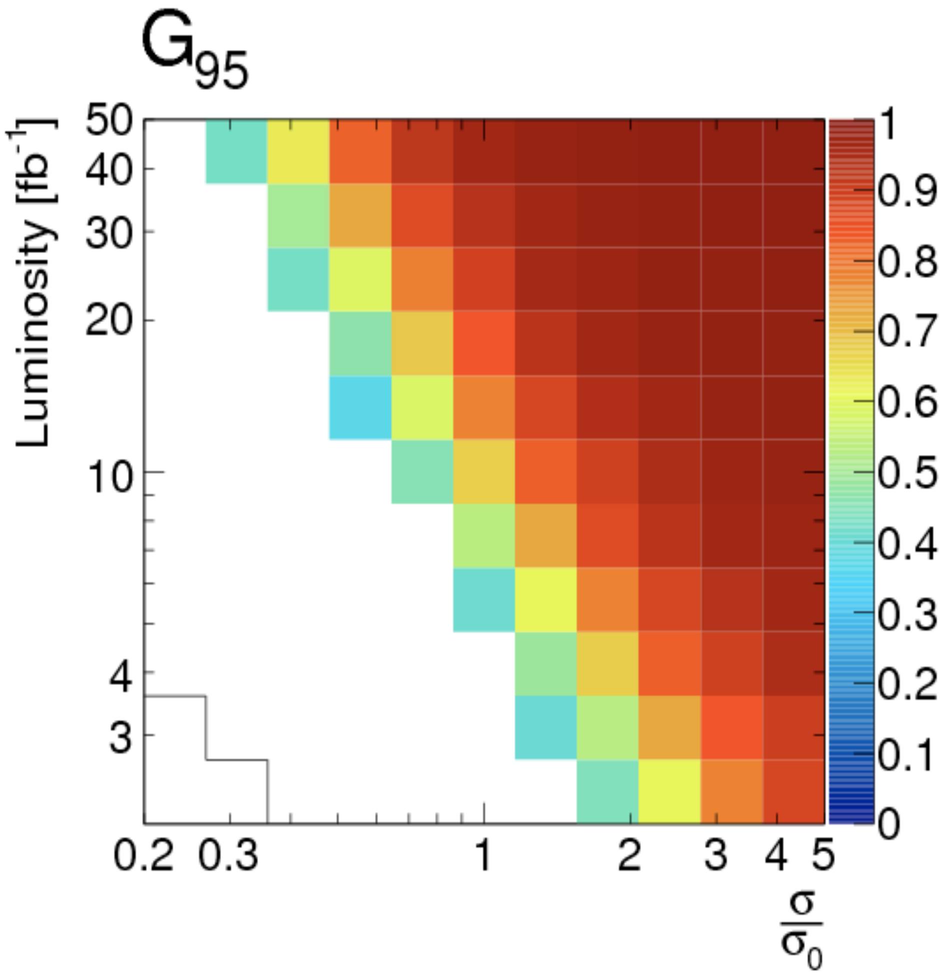
fraction of singlet events

Fraction of octet events

Ask, Collins, Forshaw, Joshi and AP,
**JHEP 1201 (2012) 018**

# Probability of correctly identifying a heavy gluon




- Left plot: Probability of a 2TeV resonance being a heavy gluon (or heavy photon) given a specific measured value of $a_8$ ($10fb^{-1}$ at $\sqrt{s}$=14TeV)

- Right plot: Fraction of experiments that would rule out the wrong resonance at 95% confidence level, for a given luminosity and signal cross-section. Includes 10% uncertainty (theory+expt).

# Summary

**Jet vetoes and colour flow**

- The dependence of a particular signal on the jet veto scale can be used to identify the colour flow in the signal topology. This can be used to extract fundamental properties of New Physics signals observed at the LHC.

**Higgs-plus-two-jet events**

- Jet vetoes can be used to extract the VBF and GF components in H+2j event
- Allows the CP quantum numbers and ratio of Higgs couplings to W's and gluons to be obtained

**Heavy resonances**

- Jet vetoes can be used to determine the colour structure of a heavy resonance decaying to quark pairs.