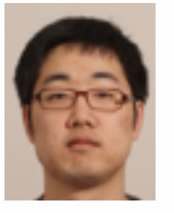
Observation and measurement of $H \to WW^* \to \ell\nu\ell\nu$

ATLAS-CONF-2014-060

University of Illinois
Philip Chang



USLUA 2014

November 13, 2014

Why H→WW* channel?

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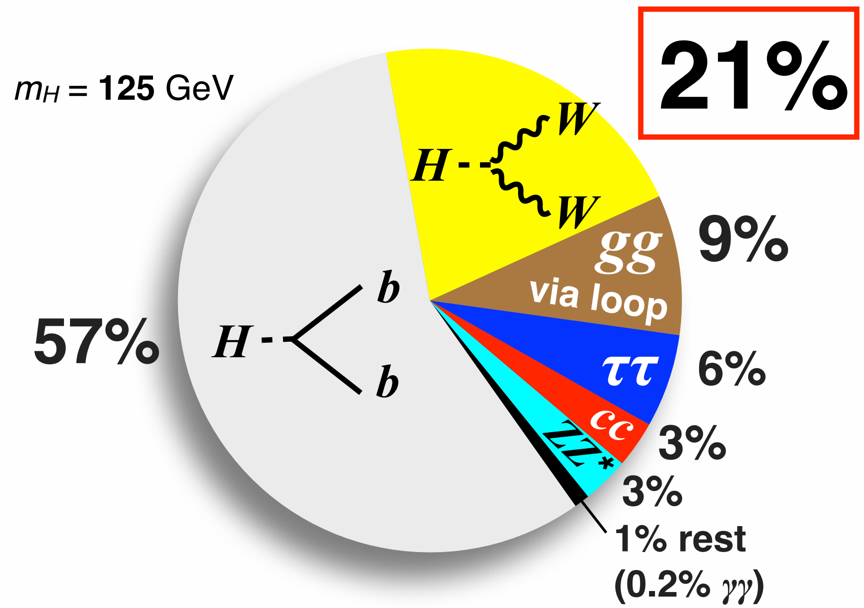
Branching ratio of SM Higgs boson of 125 GeV



Second largest BR

H→WW* channel currently provides the most precise signal strength measurement in a single decay channel

Signal characteristics

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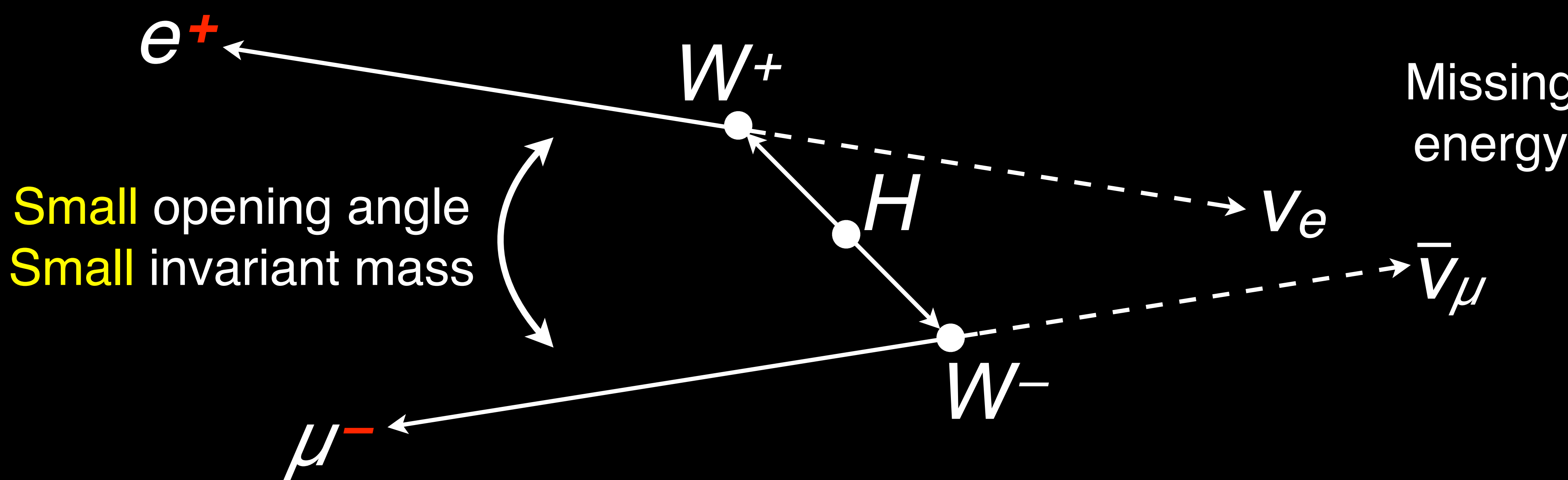

Higgs boson is a neutral and spin-0 particle

Candidate event

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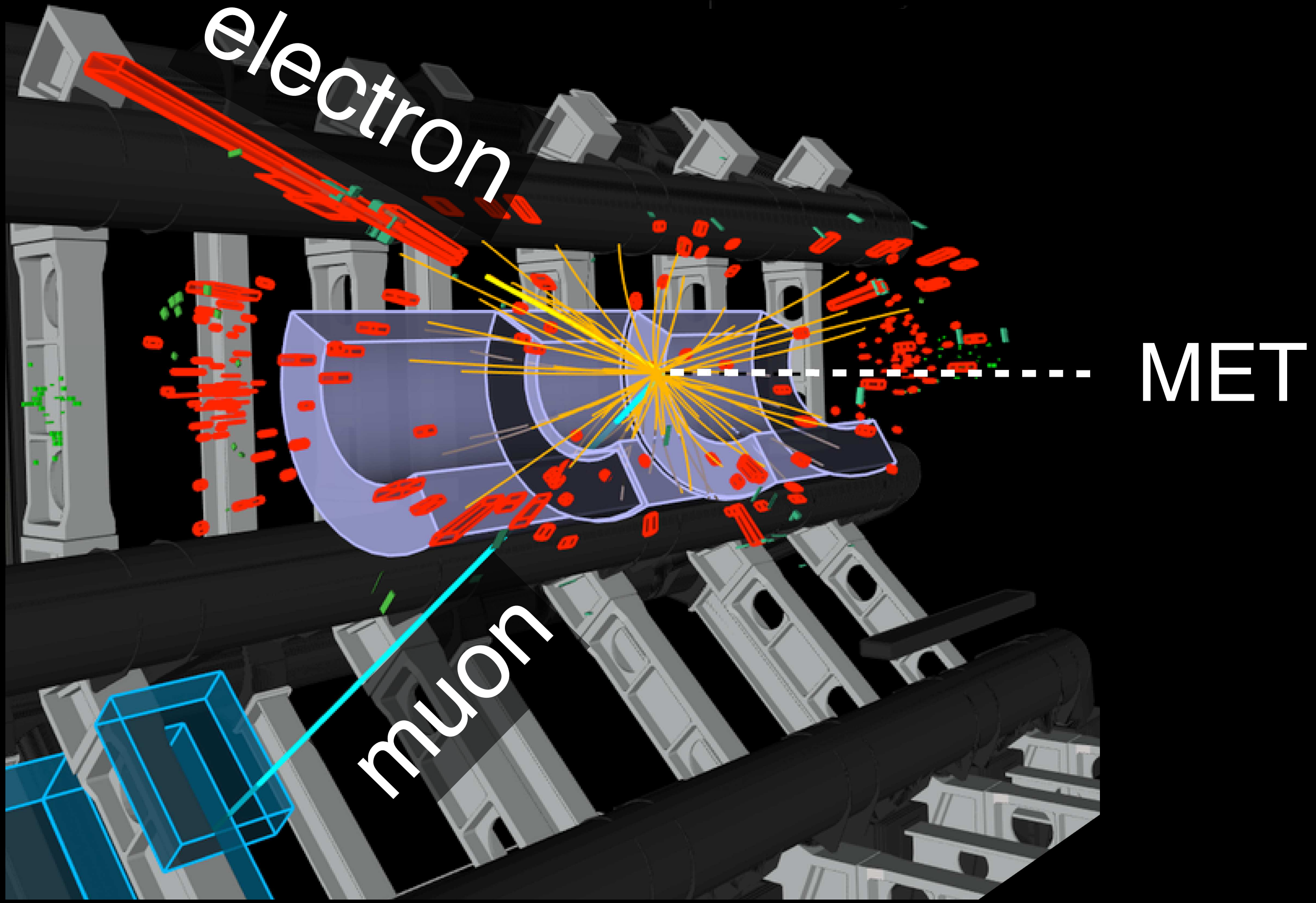
Run 189483, Ev. no. 90659667
Sep. 19, 2011, 10:11:20 CEST



Candidate event

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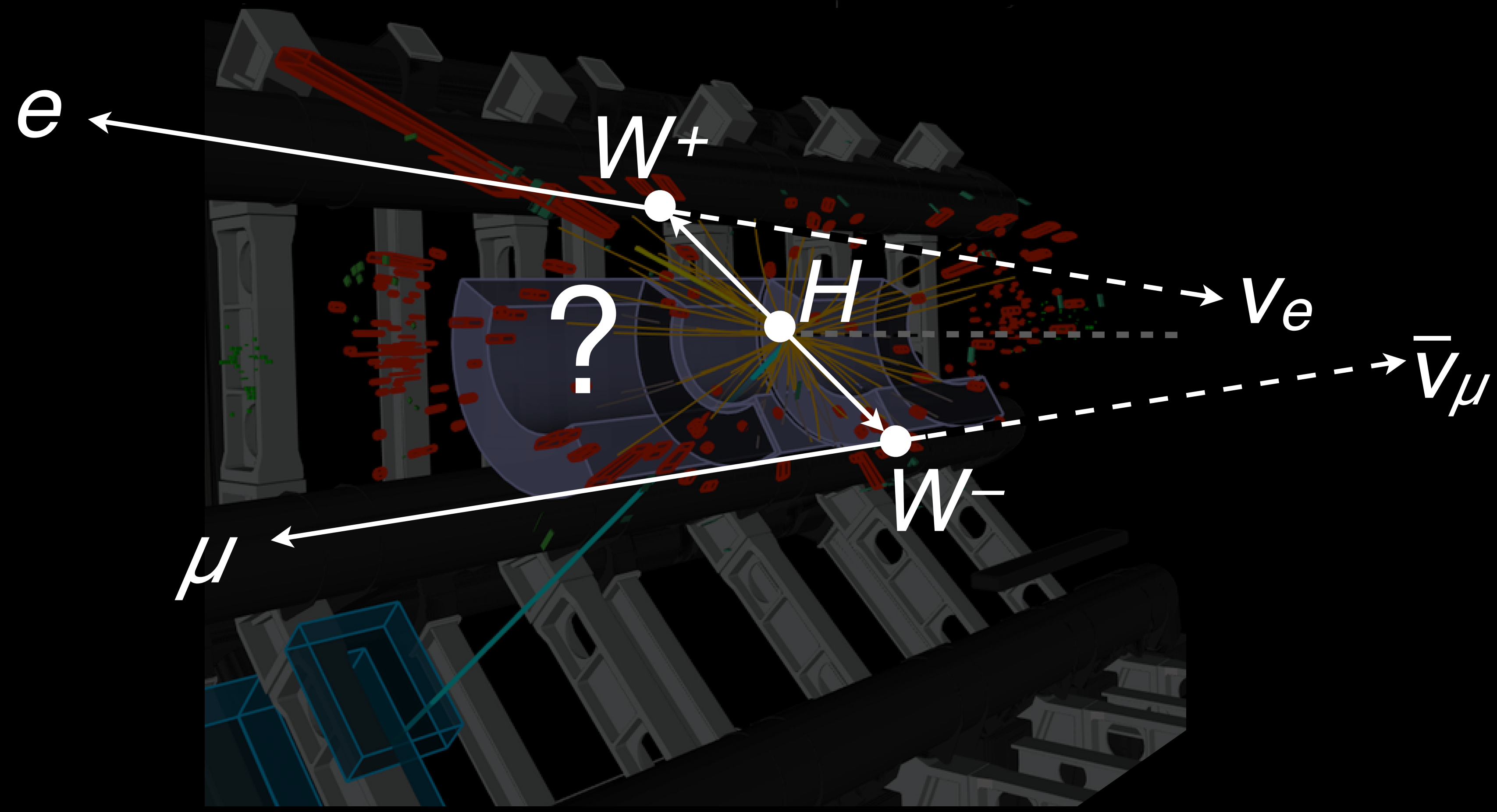

Categorizing ggF and VBF events

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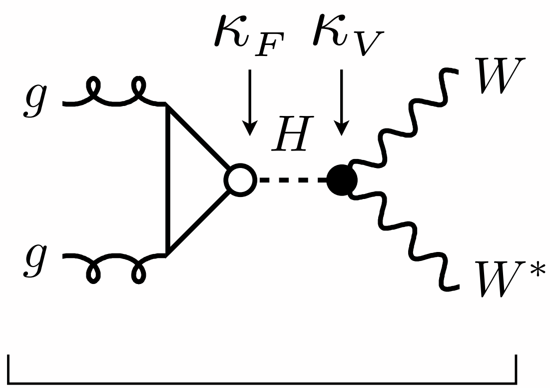
Pre-selection

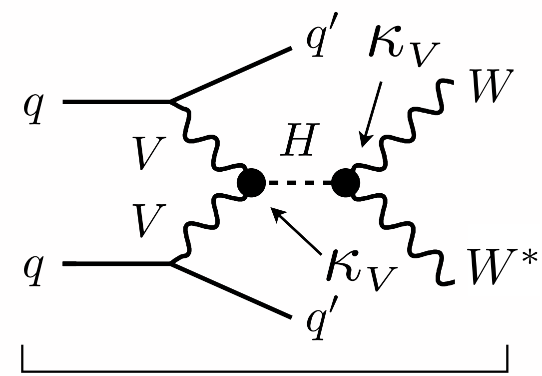
Two lepton + MET

ggF enriched region



ggF production

VBF enriched region



VBF production

Many improvements since last result

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- Dilepton trigger → lower leading lepton p_T
- **MET resolution improvement**
- Better understanding of Top background
- QCD estimation
- Better fake factor measurement for jets faking leptons
- Sub-threshold b-tagging
- Re-optimized selections
- More refined fit procedure
- Addition of ggF + 2 jet category
- Same sign control region is added
- Reweighting of p_T of Z boson
- **Adopted BDT analysis for VBF enriched region**

$O(50\%)$ improvement in sensitivity
Uncertainty reduced by $O(30\text{-}50\%)$

MET resolution improvement

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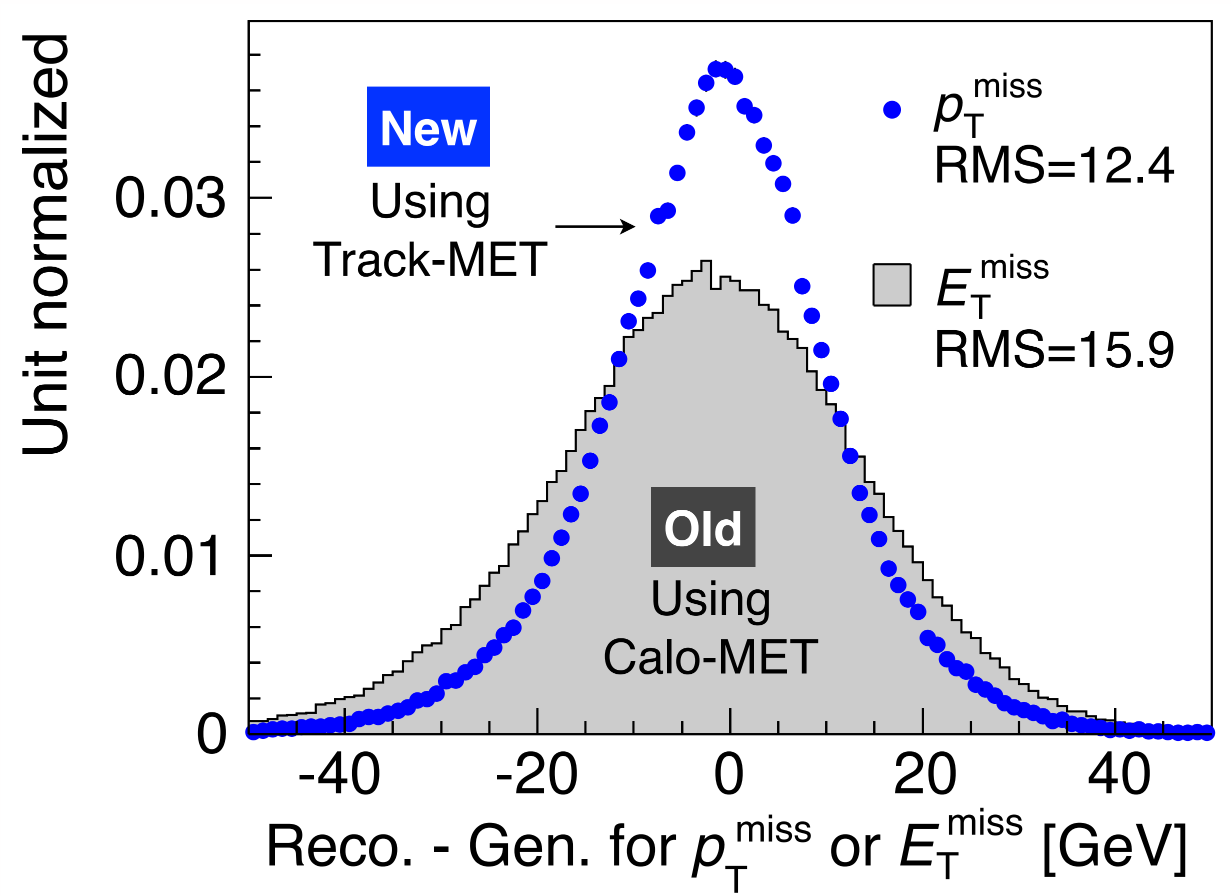
Better MET resolution → Better background separation

MET resolution



***O*(20%) improvement in resolution**

MVA for VBF region

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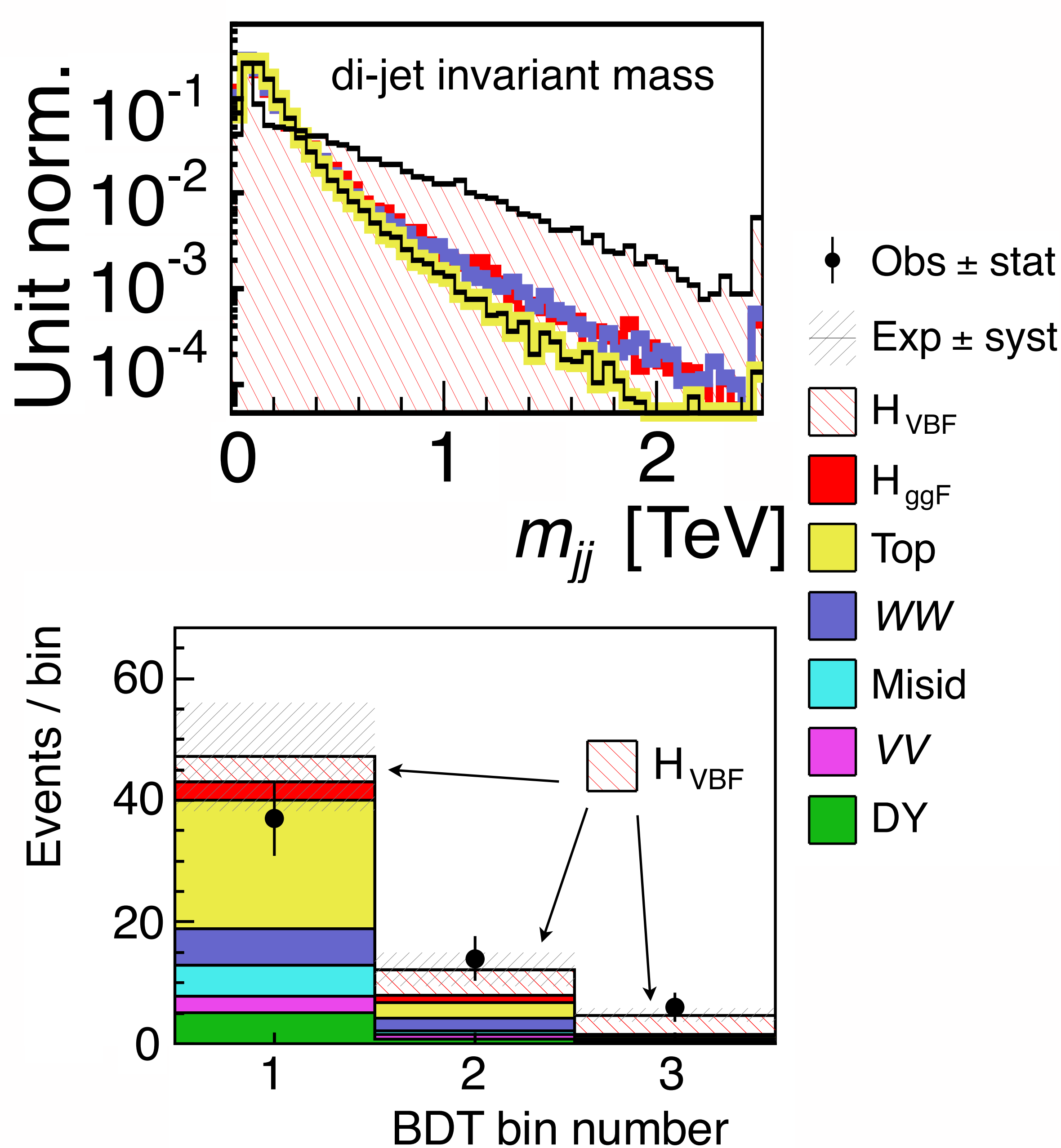
Train boosted decision tree (BDT) multivariate method using 8 discriminating variables



$\boldsymbol{O}$(30%) improvement in significance over cut-based analysis

Results

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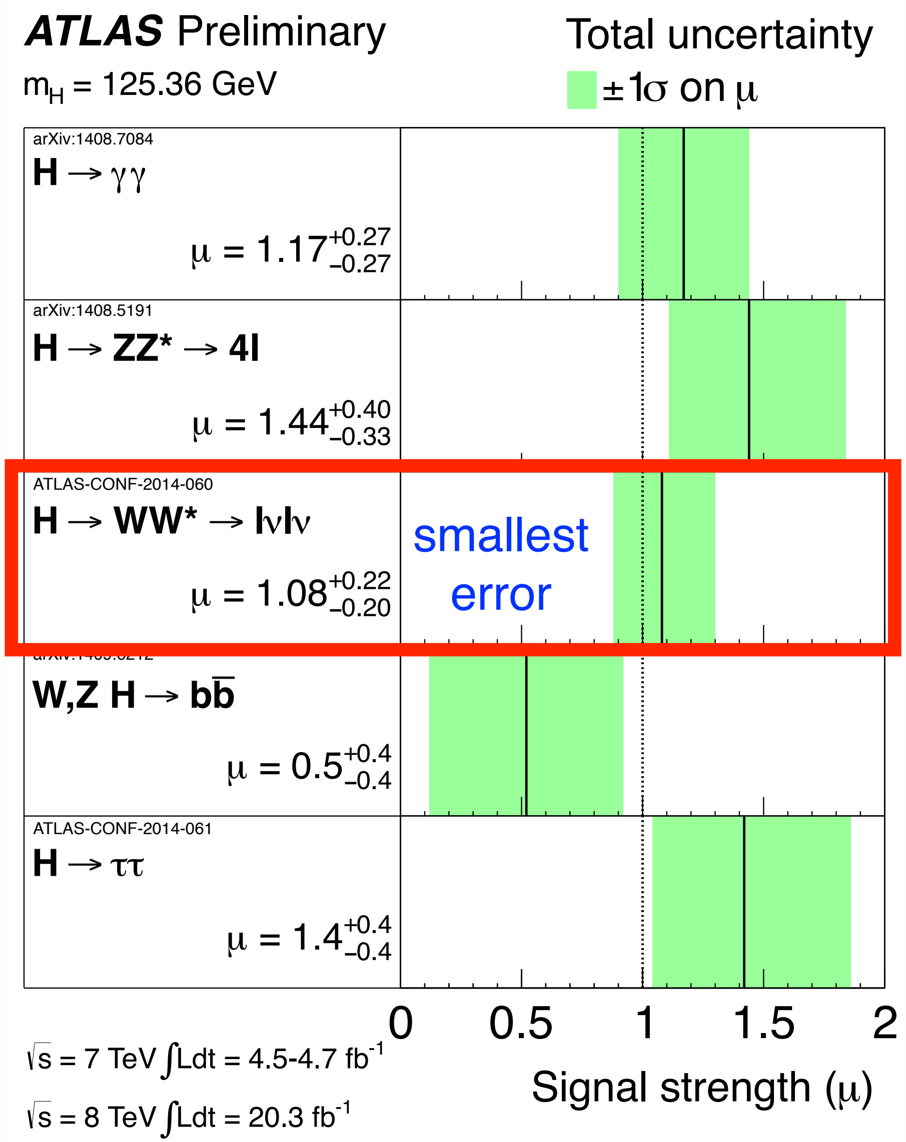
1. Observation of H→WW* decay
   6.1σ significance

2. Evidence for VBF production
   3.2σ significance

3. Combined signal strength
   $\boldsymbol{\mu = 1.08^{+0.22}_{-0.20}}$ →

4. Coupling measurement
   $\boldsymbol{\kappa_F = 0.92^{+0.31}_{-0.23}\ ,\ \kappa_V = 1.04^{+0.10}_{-0.11}}$

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/HIGGS/



Leading systematic uncertainty sources:
- ~10% : ggF signal theory uncertainty
- ~6% : WW modeling
- ~6% : Object mis-ID bkg. modeling

Summary

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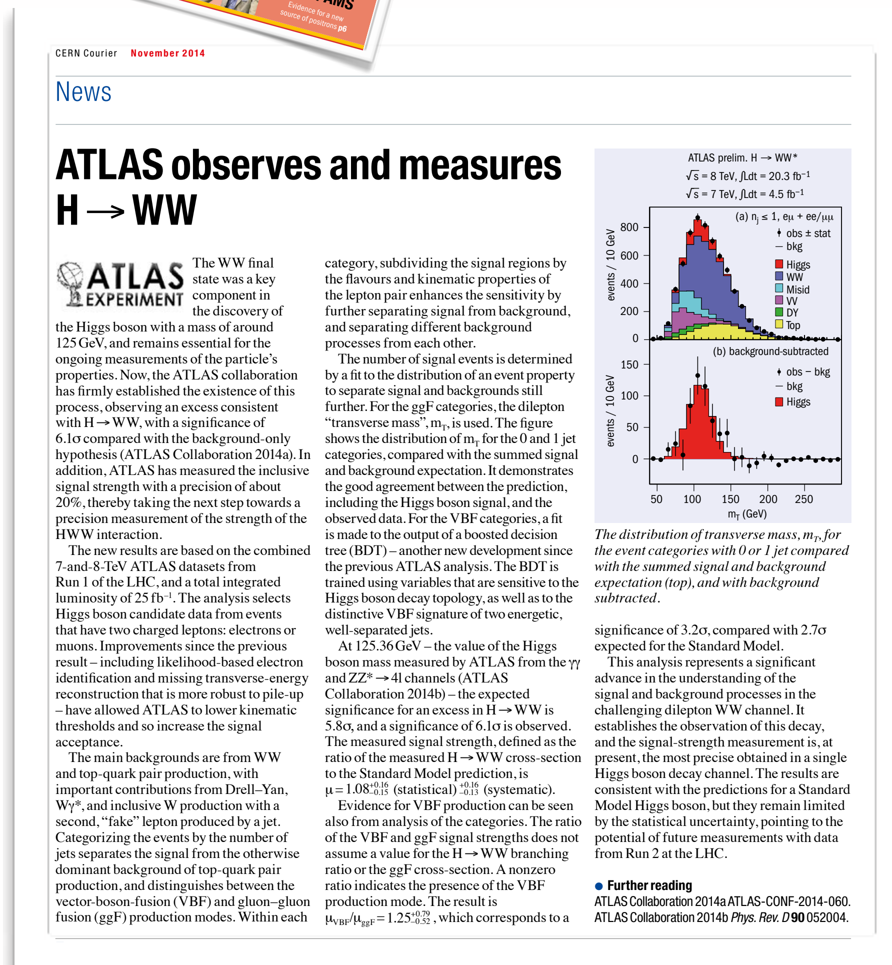
- **6.1σ** observation of H→WW*
- **3.2σ** evidence of VBF H→WW*
- Most precise μ measurement
- No significant deviation from SM
- Coupling combination being finalized
- Run-2 (2015 – 2018) will increase statistics by ×10

Featured on CERN courier, Nov. 2014 Volume 54 Issue 9



CERN Courier November 2014

News

ATLAS observes and measures H → WW

The WW final state was a key component in the discovery of the Higgs boson with a mass of around 125 GeV, and remains essential for the ongoing measurements of the particle's properties. Now, the ATLAS collaboration has firmly established the existence of this process, observing an excess consistent with H → WW, with a significance of 6.1σ compared with the background-only hypothesis (ATLAS Collaboration 2014a). In addition, ATLAS has measured the inclusive signal strength with a precision of about 20%, thereby taking the next step towards a precision measurement of the strength of the HWW interaction.

The new results are based on the combined 7-and-8-TeV ATLAS datasets from Run 1 of the LHC, and a total integrated luminosity of 25 fb^{-1}. The analysis selects Higgs boson candidate data from events that have two charged leptons: electrons or muons. Improvements since the previous result – including likelihood-based electron identification and missing transverse-energy reconstruction that is more robust to pile-up – have allowed ATLAS to lower kinematic thresholds and so increase the signal acceptance.

The main backgrounds are from WW and top-quark pair production, with important contributions from Drell–Yan, Wγ*, and inclusive W production with a second, "fake" lepton produced by a jet. Categorizing the events by the number of jets separates the signal from the otherwise dominant background of top-quark pair production, and distinguishes between the vector-boson-fusion (VBF) and gluon–gluon fusion (ggF) production modes. Within each category, subdividing the signal regions by the flavours and kinematic properties of the lepton pair enhances the sensitivity by further separating signal from background, and separating different background processes from each other.

The number of signal events is determined by a fit to the distribution of an event property to separate signal and backgrounds still further. For the ggF categories, the dilepton "transverse mass", m_T, is used. The figure shows the distribution of m_T for the 0 and 1 jet categories, compared with the summed signal and background expectation. It demonstrates the good agreement between the prediction, including the Higgs boson signal, and the observed data. For the VBF categories, a fit is made to the output of a boosted decision tree (BDT) – another new development since the previous ATLAS analysis. The BDT is trained using variables that are sensitive to the Higgs boson decay topology, as well as to the distinctive VBF signature of two energetic, well-separated jets.

At 125.36 GeV – the value of the Higgs boson mass measured by ATLAS from the γγ and ZZ* → 4l channels (ATLAS Collaboration 2014b) – the expected significance for an excess in H → WW is 5.8σ, and a significance of 6.1σ is observed. The measured signal strength, defined as the ratio of the measured H → WW cross-section to the Standard Model prediction, is $\mu = 1.08^{+0.16}_{-0.15}$ (statistical) $^{+0.16}_{-0.13}$ (systematic).

Evidence for VBF production can be seen also from analysis of the categories. The ratio of the VBF and ggF signal strengths does not assume a value for the H → WW branching ratio or the ggF cross-section. A nonzero ratio indicates the presence of the VBF production mode. The result is $\mu_{VBF}/\mu_{ggF} = 1.25^{+0.79}_{-0.52}$, which corresponds to a significance of 3.2σ, compared with 2.7σ expected for the Standard Model.

This analysis represents a significant advance in the understanding of the signal and background processes in the challenging dilepton WW channel. It establishes the observation of this decay, and the signal-strength measurement is, at present, the most precise obtained in a single Higgs boson decay channel. The results are consistent with the predictions for a Standard Model Higgs boson, but they remain limited by the statistical uncertainty, pointing to the potential of future measurements with data from Run 2 at the LHC.

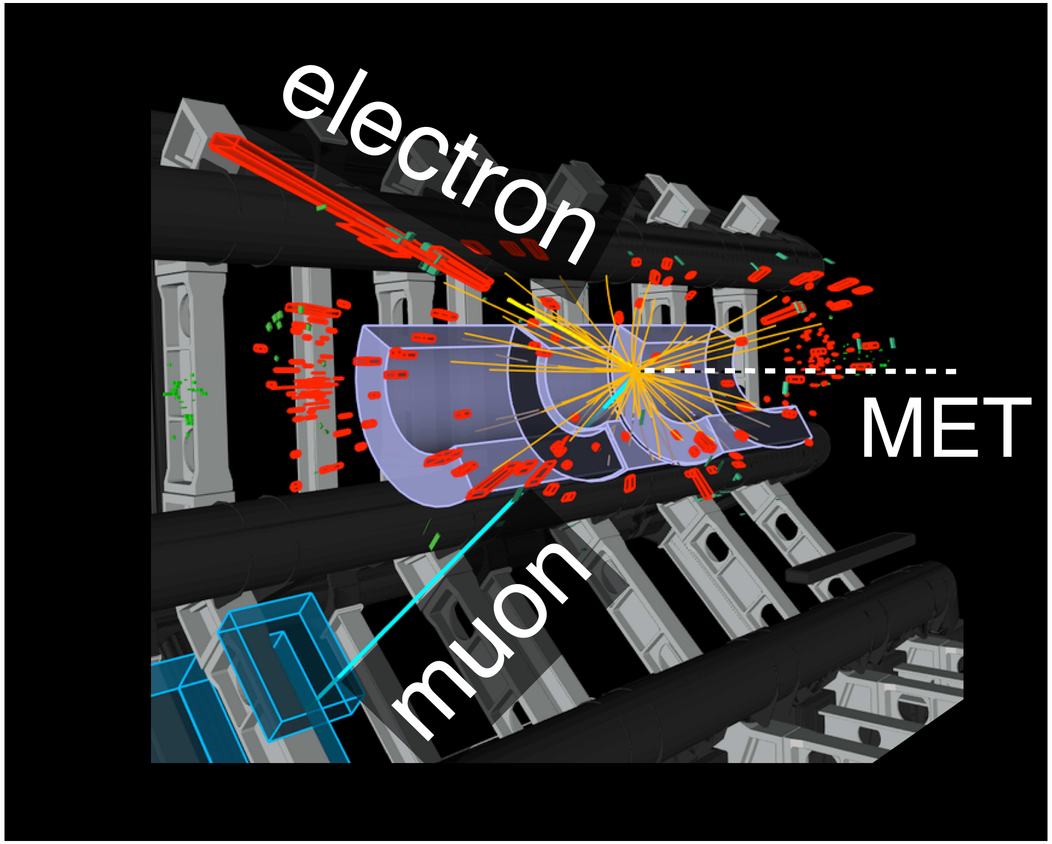
The distribution of transverse mass, m_T, for the event categories with 0 or 1 jet compared with the summed signal and background expectation (top), and with background subtracted.

Further reading
ATLAS Collaboration 2014a ATLAS-CONF-2014-060.
ATLAS Collaboration 2014b *Phys. Rev. D* **90** 052004.

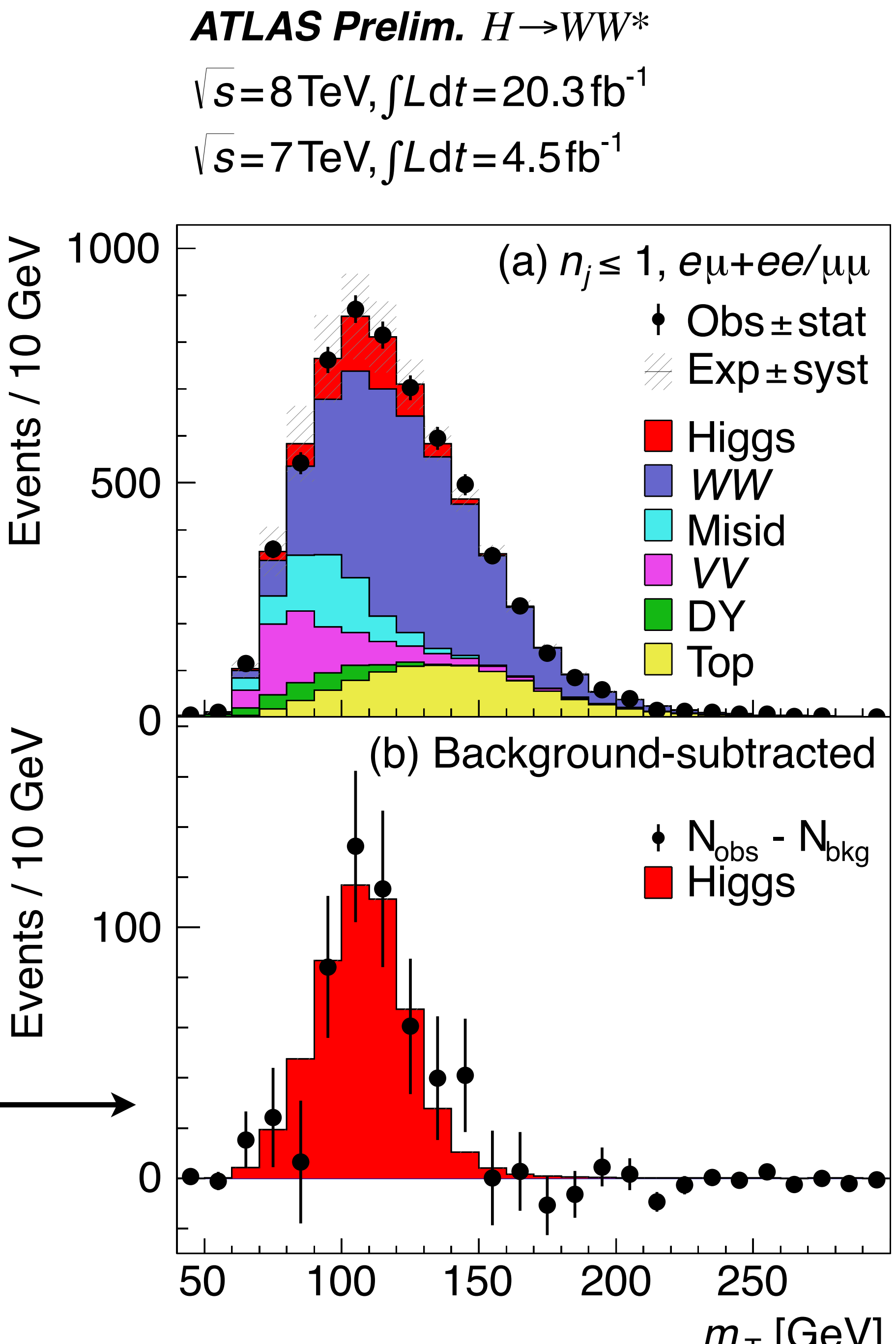
Stay tuned!

Back Up

Transverse mass, m_T distribution



Compute transverse mass of $\ell\ell$+MET system



Categorizing ggF and VBF events

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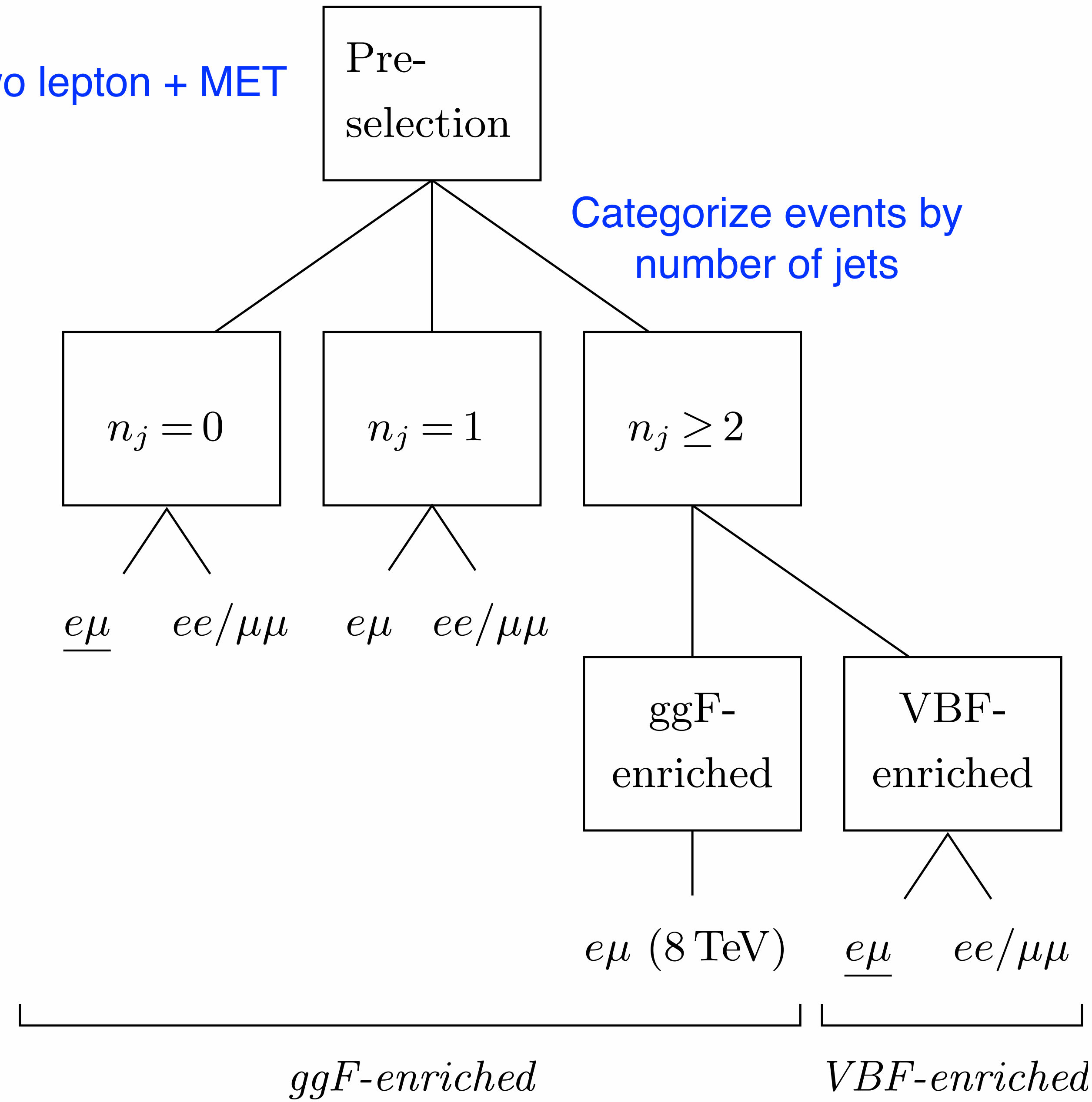
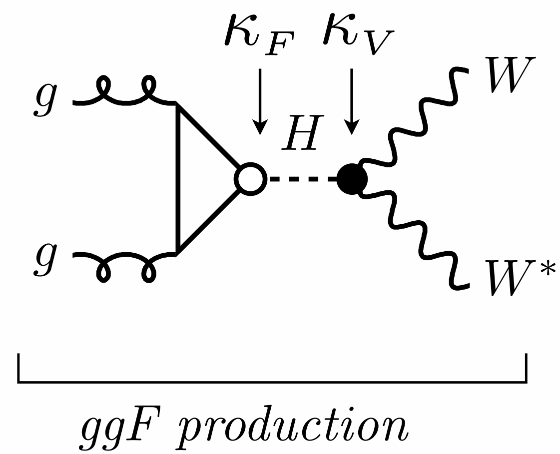
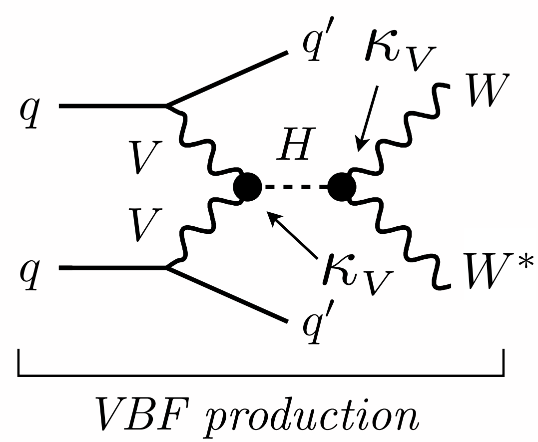
Two lepton + MET

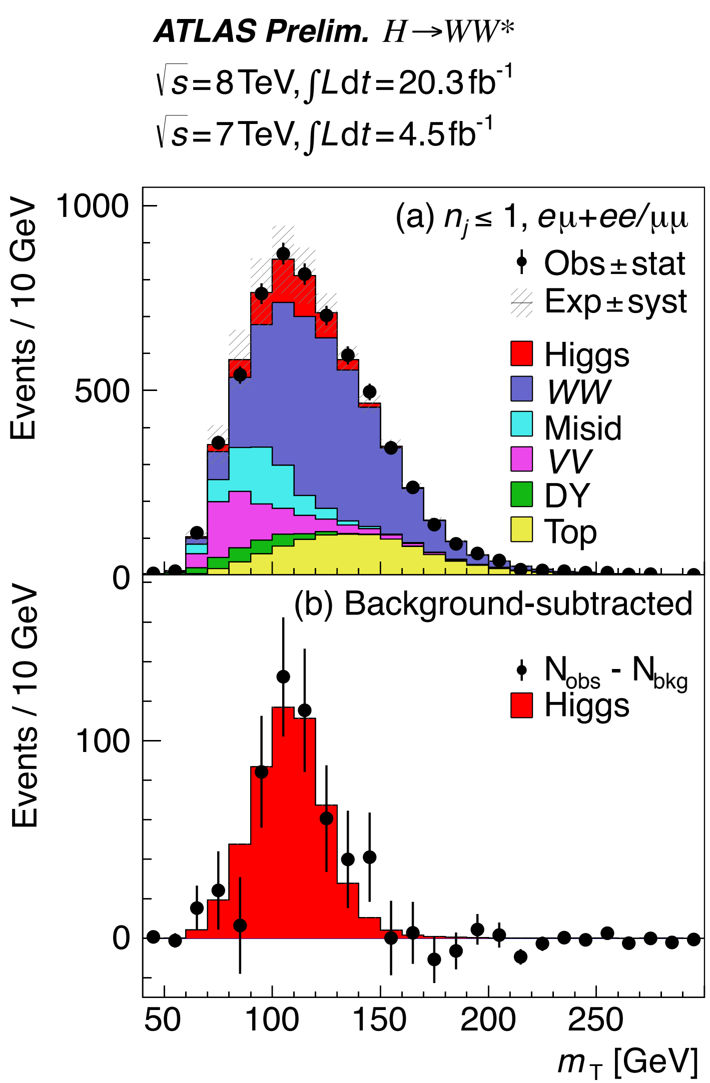
Categorize events by number of jets

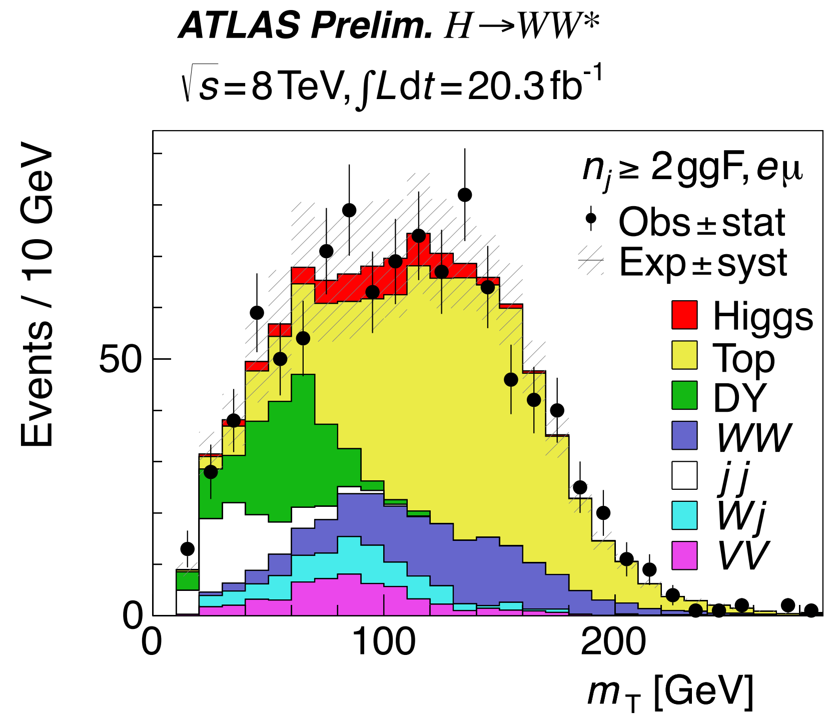


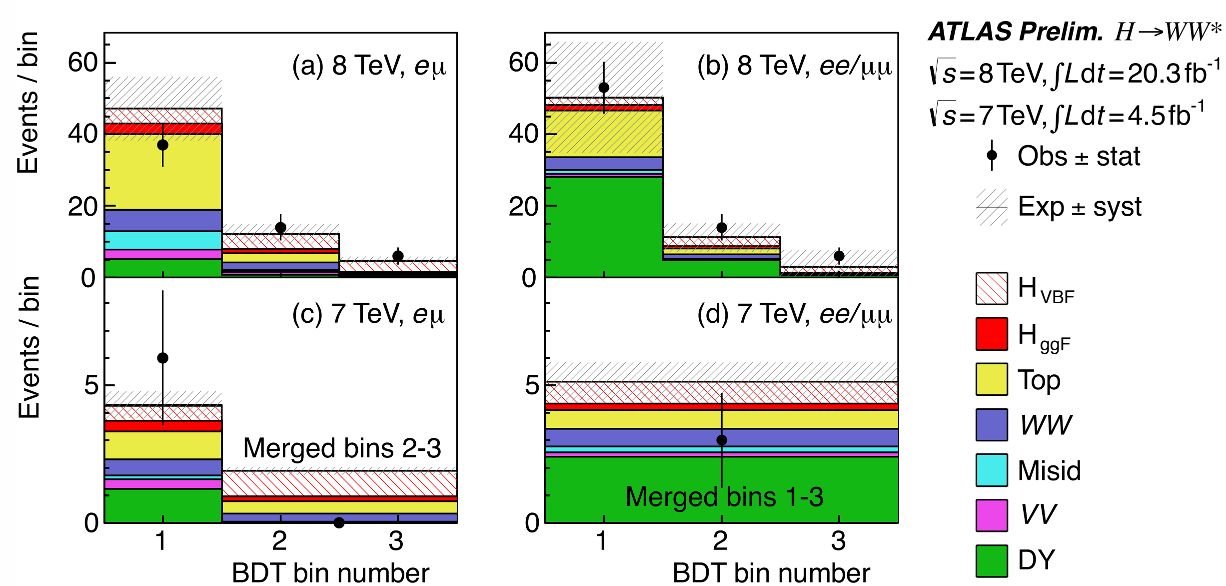




Key discriminant distribution







Previous results

Phys. Lett. B 726 (2013), pp. 88-119

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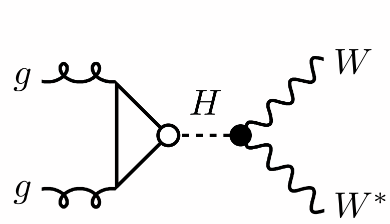
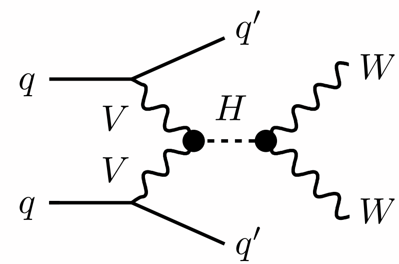
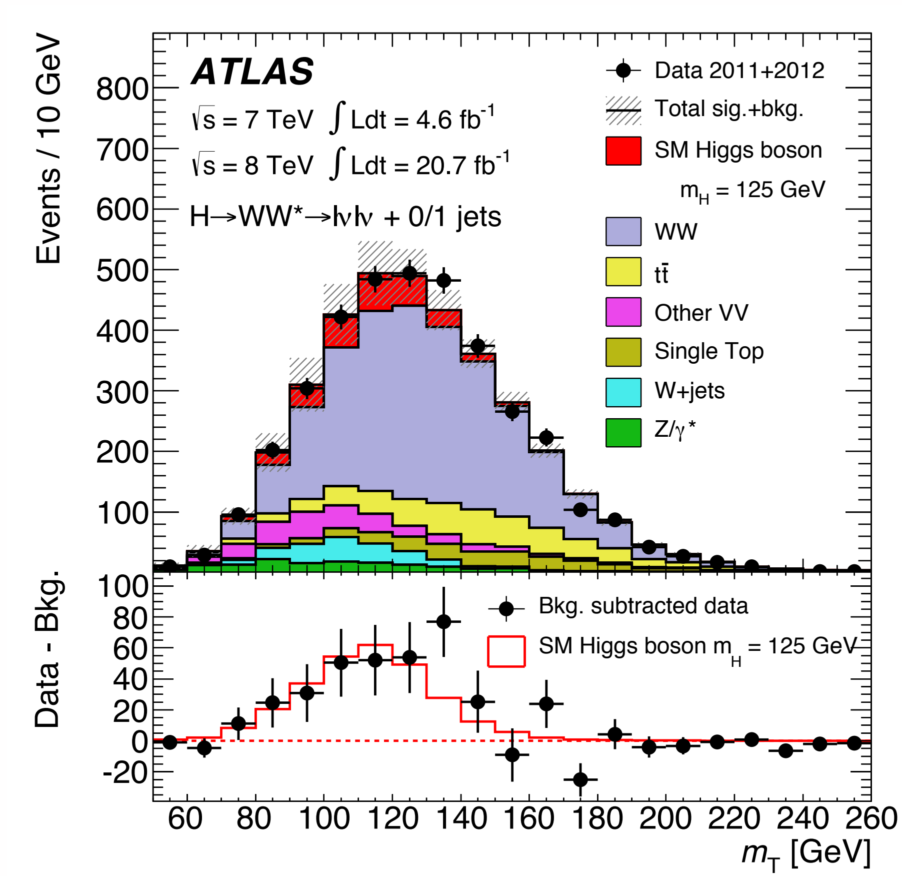
expected significance = 3.8σ

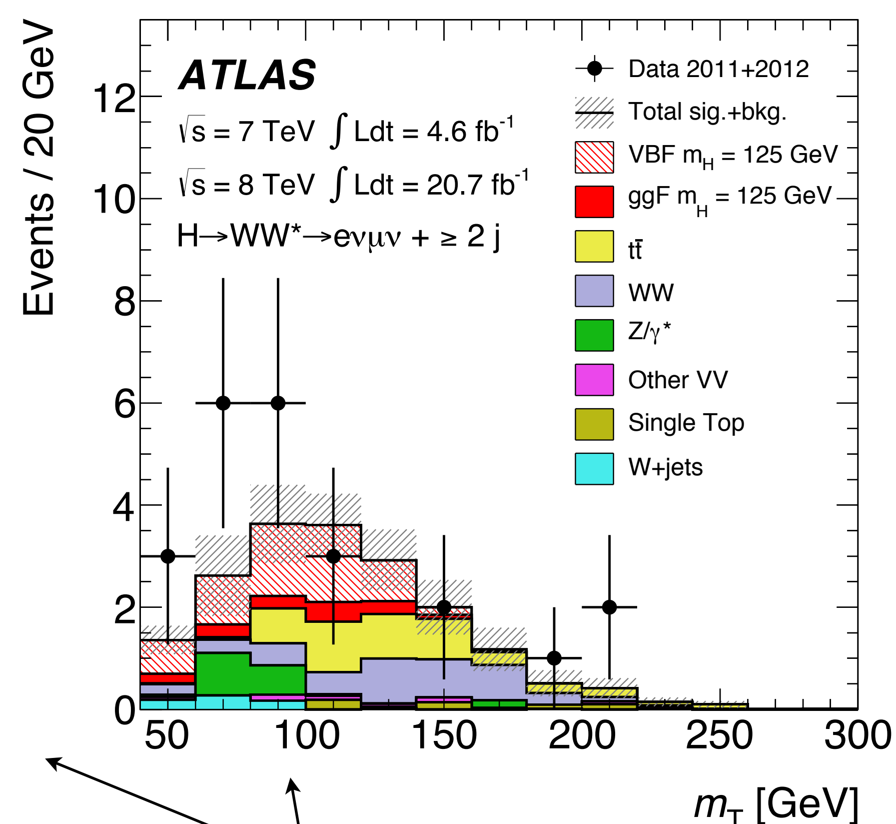


ggF enriched



VBF enriched





Key discriminating variable, the transverse mass of the Higgs boson, m_T

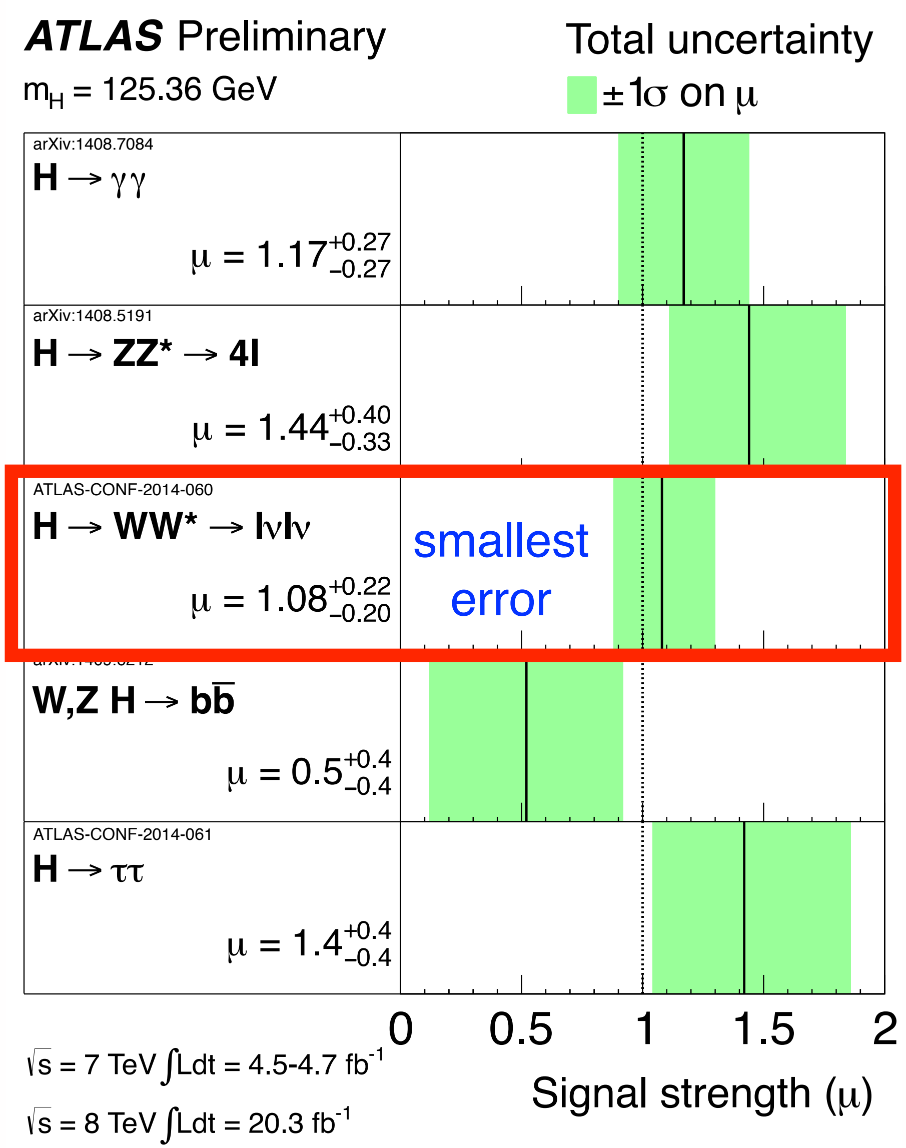
Results

w.r.t last year's result

1. Observation of H→WW* decay
   Obs (Expt) = 6.1σ (5.8σ)
   ~50% improv.
2. Evidence for VBF production
   Obs (Expt) = 3.2σ (2.7σ)
   ~70% improv.
3. Combined signal strength
   $\mu = 1.08^{+0.22}_{-0.20}$ →
   uncertainty reduced by ~1/3
4. Coupling measurement
   $\kappa_F = 0.92^{+0.31}_{-0.23}$, $\kappa_V = 1.04^{+0.10}_{-0.11}$
   uncertainty reduced by ~1/2

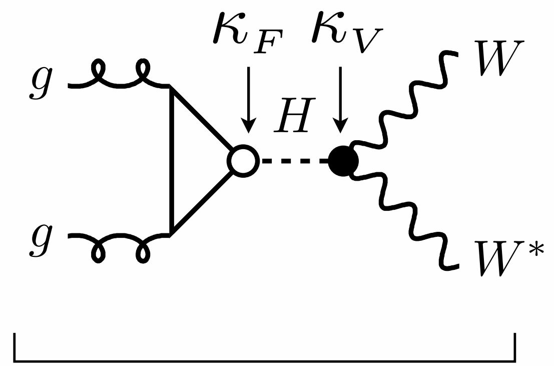
Leading systematic uncertainty sources:
~10% : ggF signal theory uncertainty
~6% : WW modeling
~6% : Object mis-ID bkg. modeling

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/HIGGS/

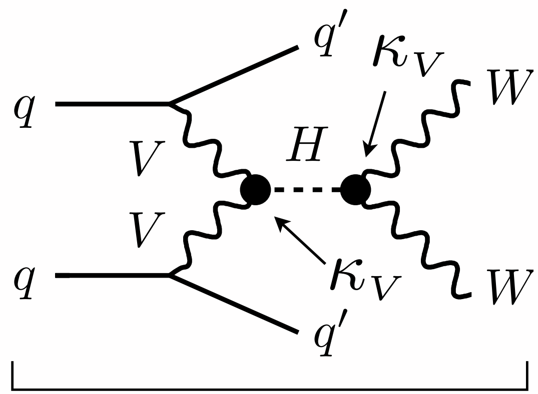


Coupling measurement

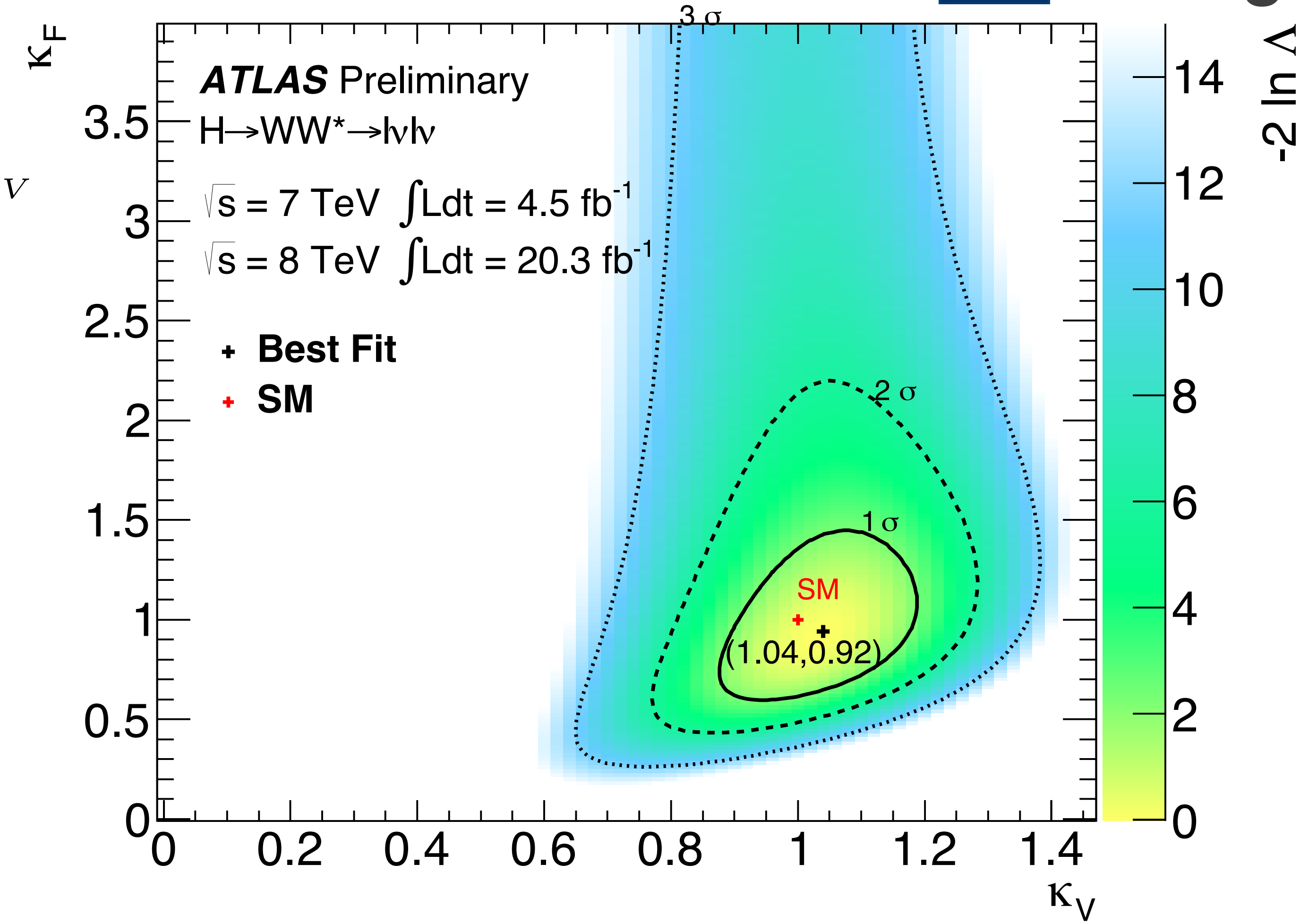
Fermion, vector boson couplings deviate by a common factor, κ_F, κ_V



ggF production



VBF production



$$\kappa_F = 0.92 \begin{array}{l} +0.31 \\ -0.23 \end{array}$$

$$\kappa_V = 1.04 \begin{array}{l} +0.10 \\ -0.11 \end{array}$$

H→WW* is one of the strongest constraining channel

Title

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m_T resolution