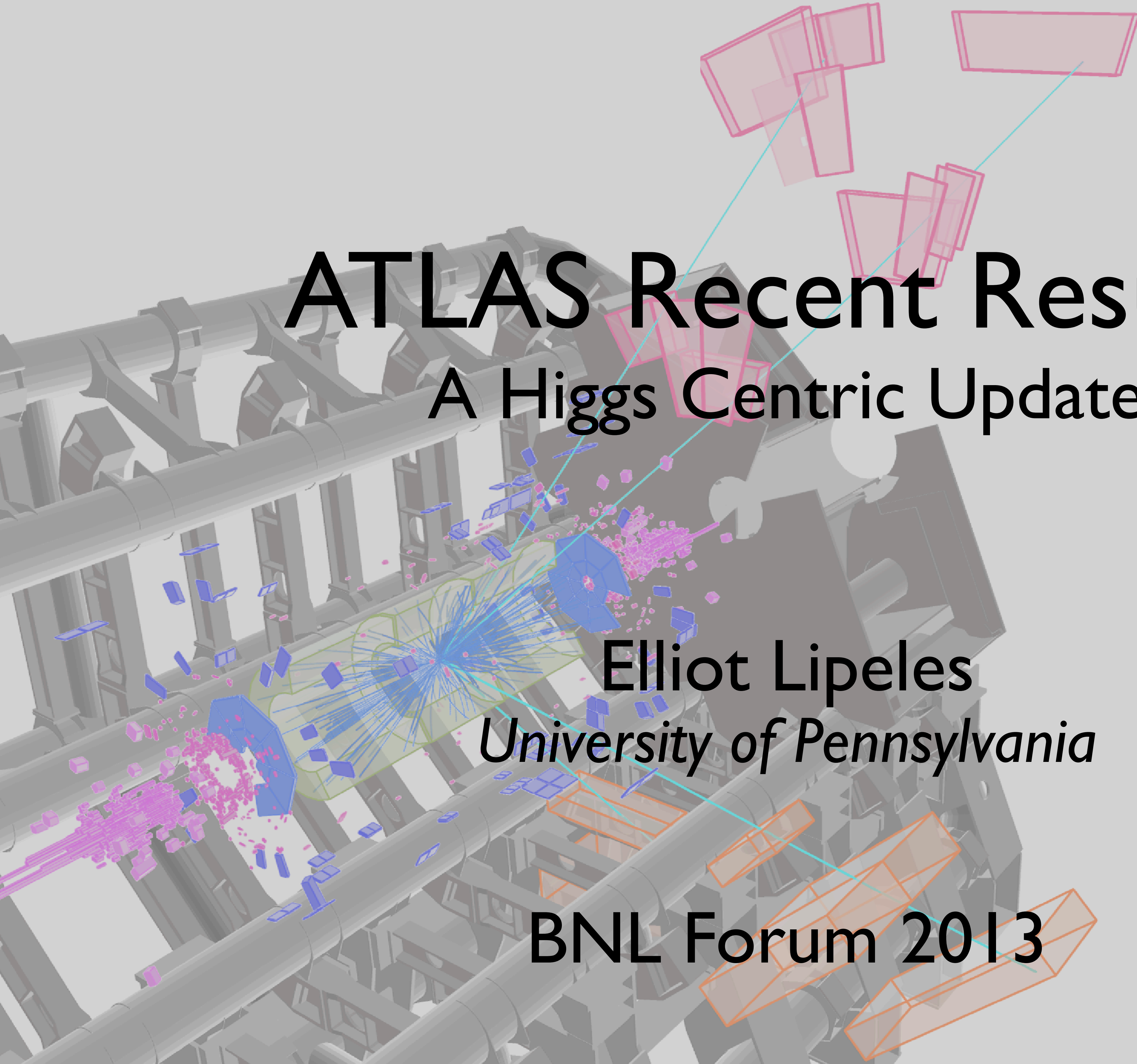


ATLAS Recent Results

A Higgs Centric Update

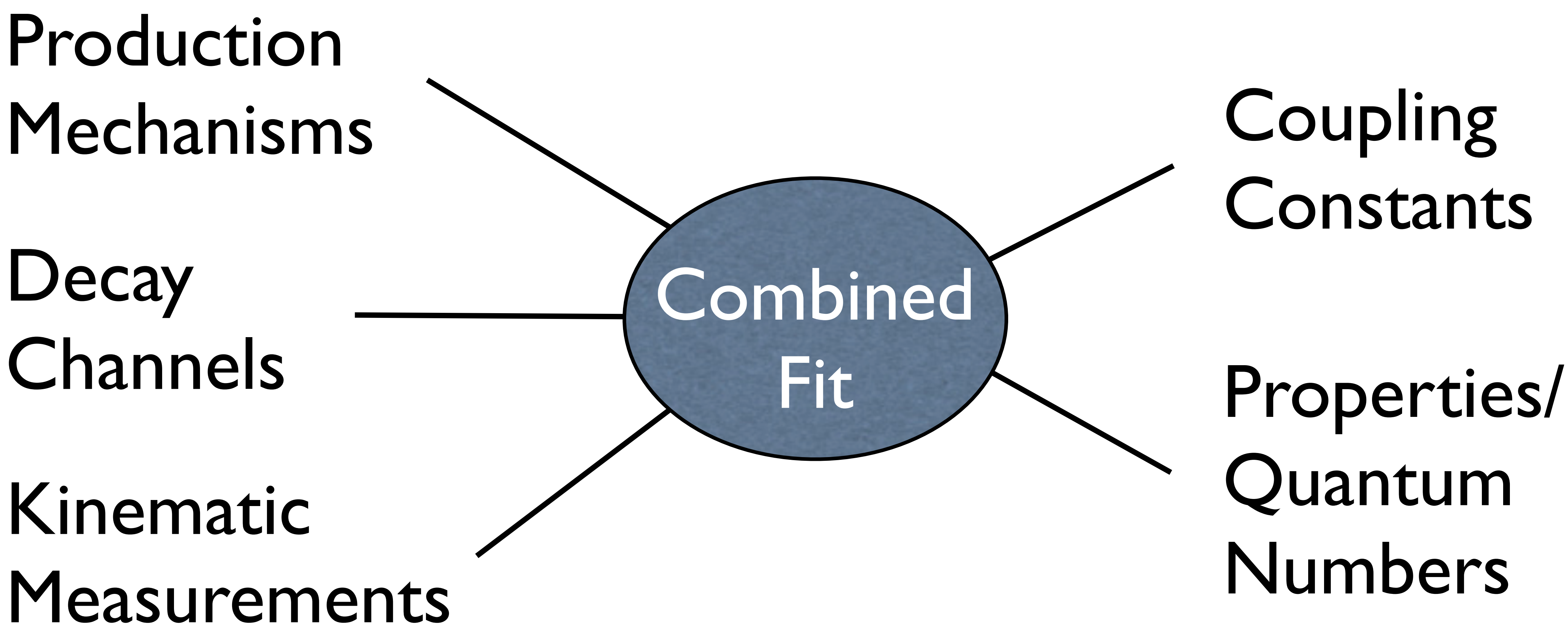
Elliot Lipeles

University of Pennsylvania

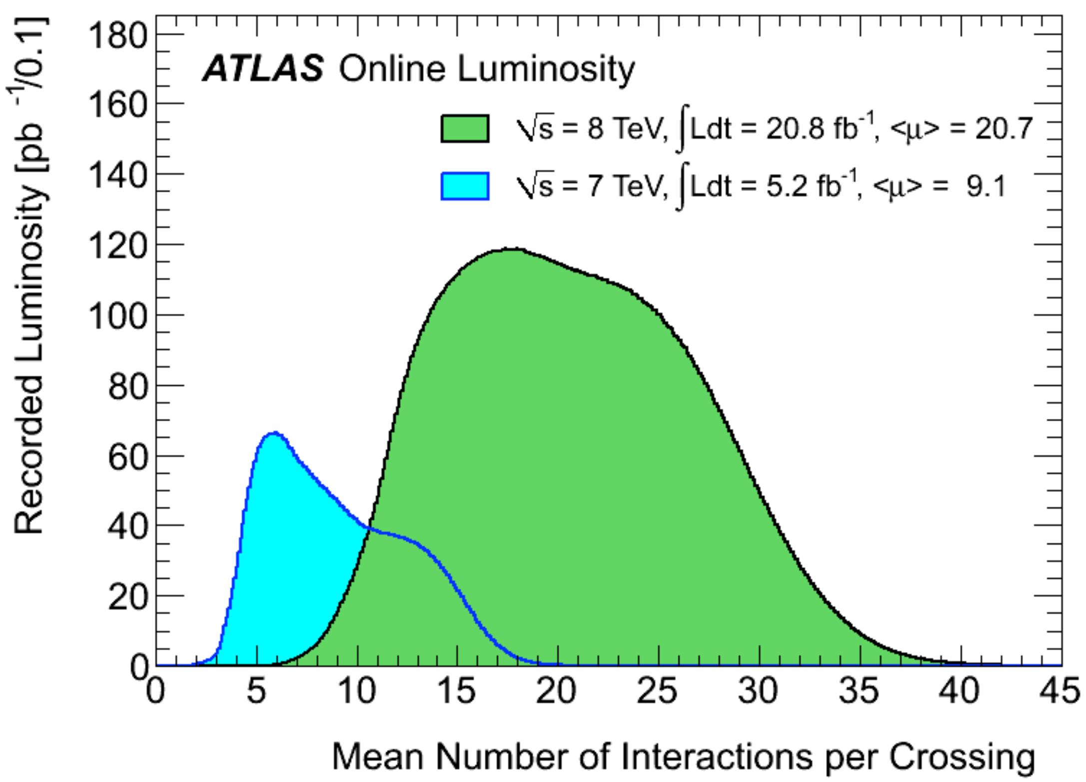
BNL Forum 2013

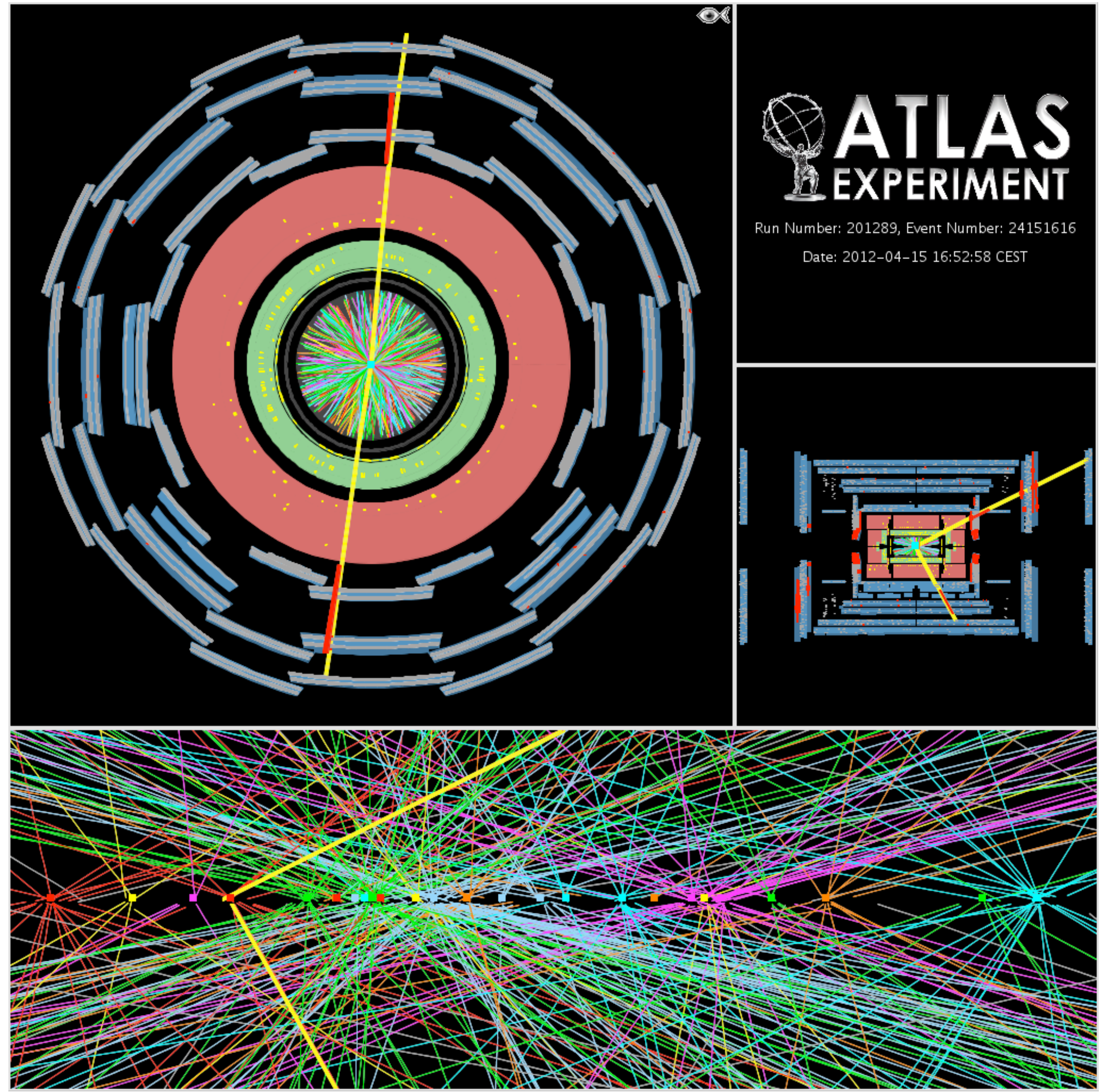
A “Higgs” Boson has been Observed

Higgs: Understanding what have we found



The 2011 and 2012 Datasets

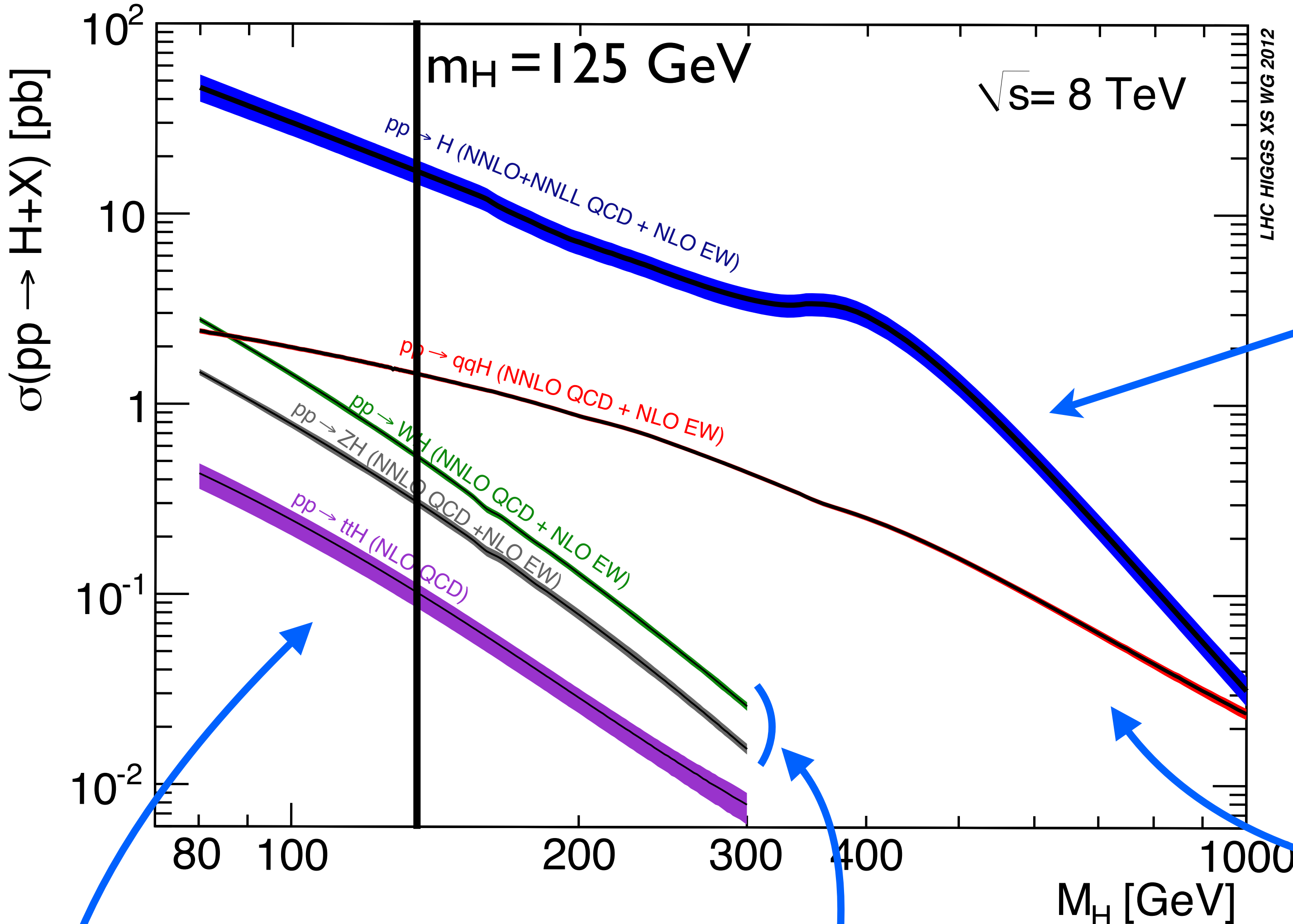




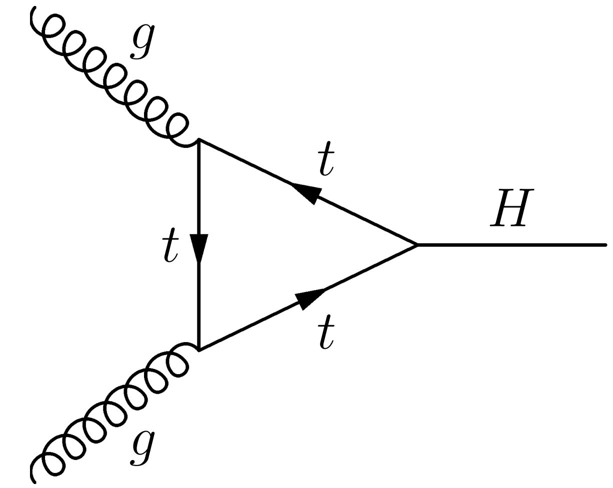
Data used in analysis:

- 2011 5fb^{-1} 7 TeV
- 2012 20fb^{-1} 8 TeV

Higgs Production Summary

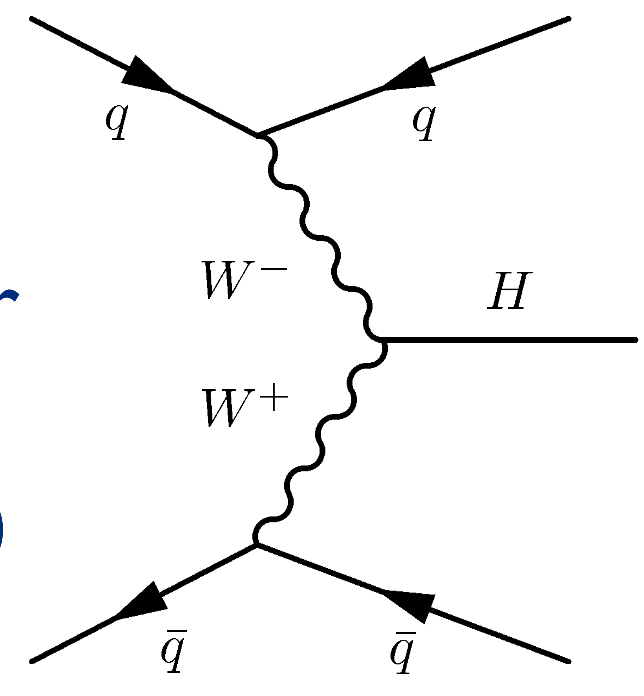


ggF

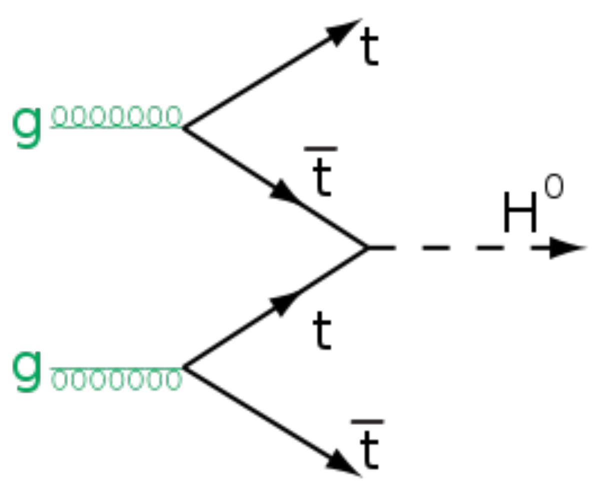


Large QCD Uncertainties
Sensitive to new physics in the loop

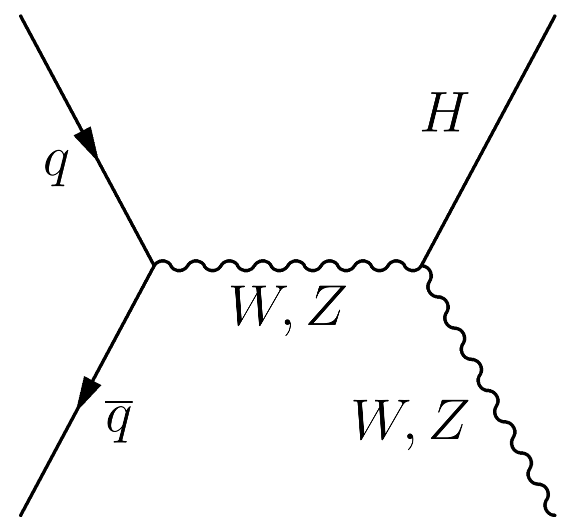
VBF (vector boson fusion)



ttH



VH

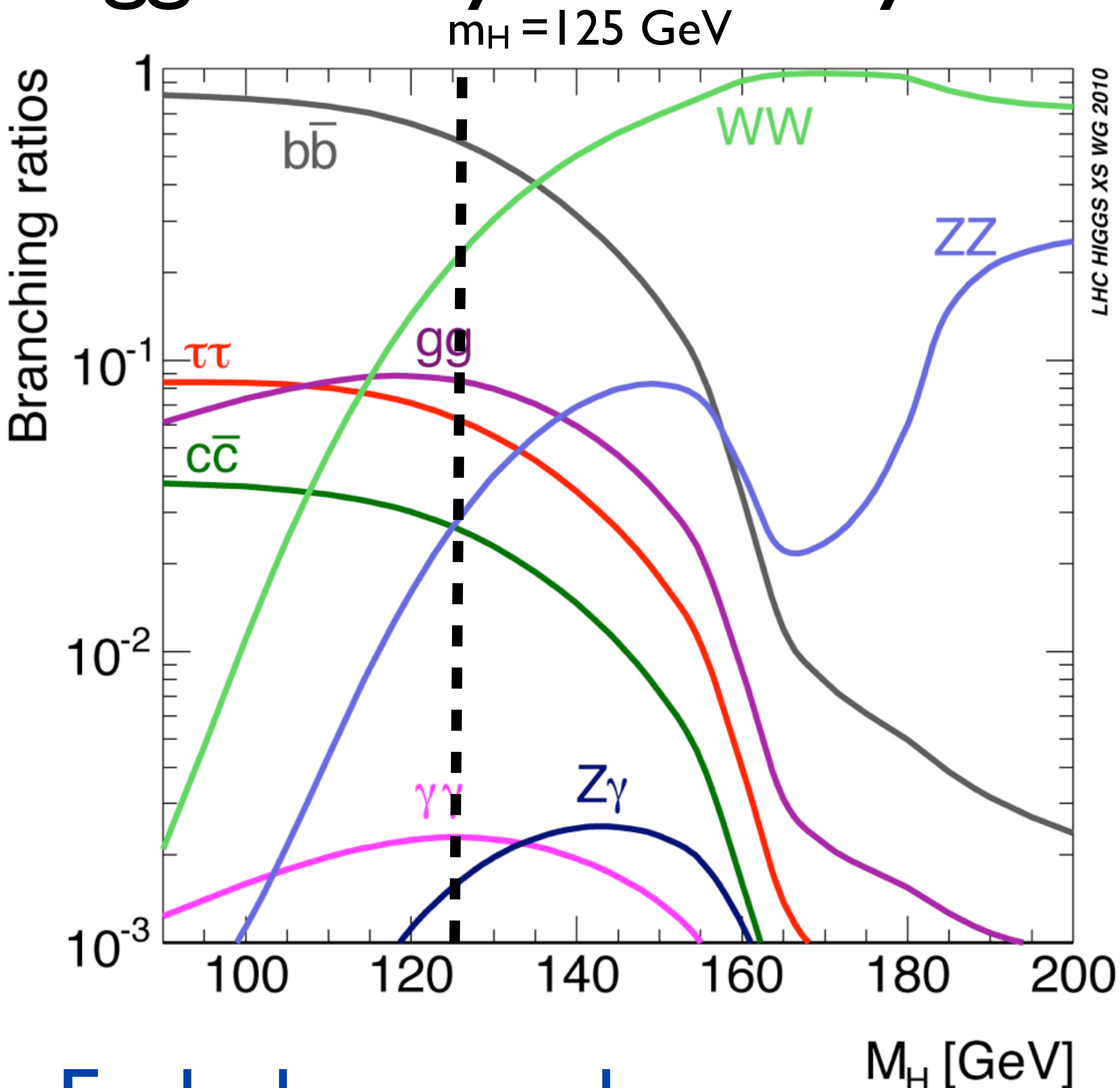


Access to top coupling

Usually tagged w/ W/Z decay to leptons (inc. neutrinos)

Small QCD Uncertainties
Distinctive forward jet tags

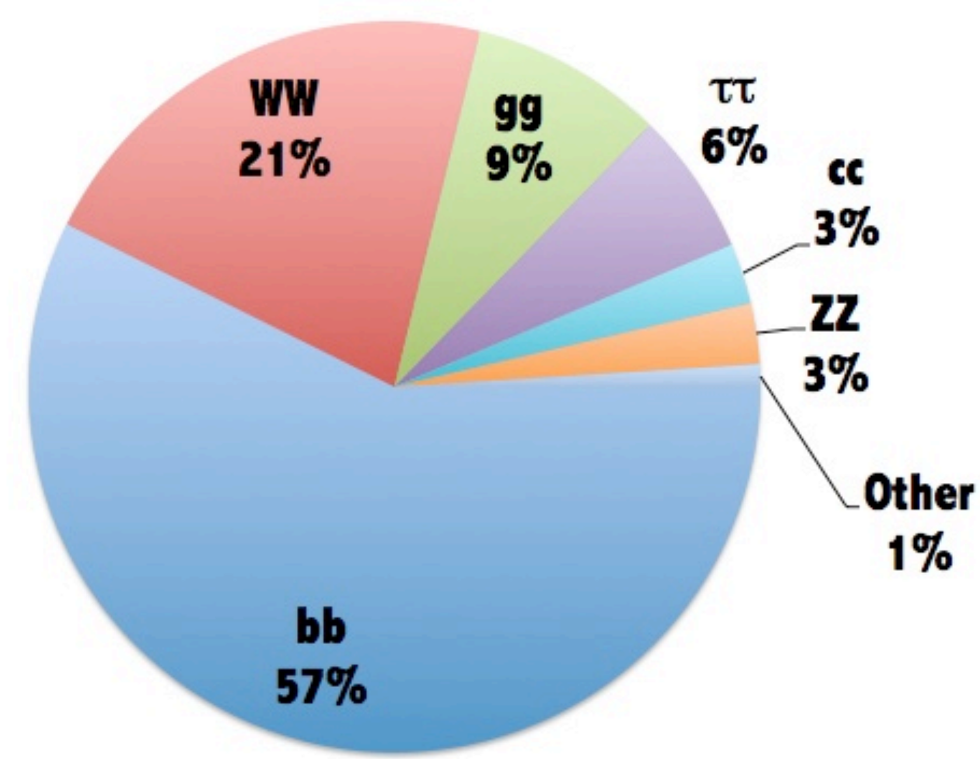
Higgs Decay Summary



Observed:
WW, ZZ, and $\gamma\gamma$

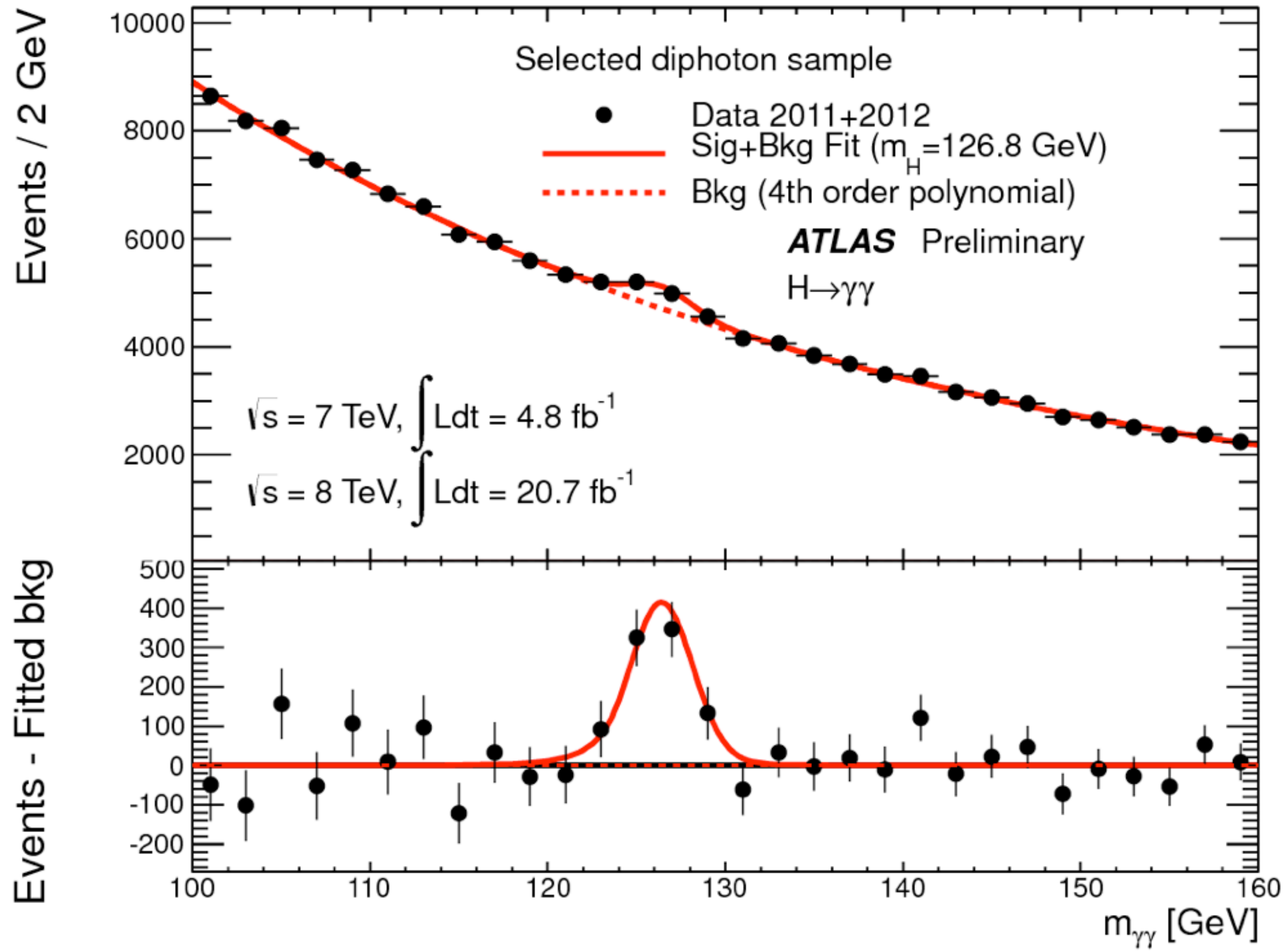
Searches:
bb, $\tau\tau$, $Z\gamma$, and $\mu\mu$

Higgs decays at m_H=125GeV



Each decay probes a different Higgs (Yukawa) coupling

$H \to \gamma\gamma$ Signal

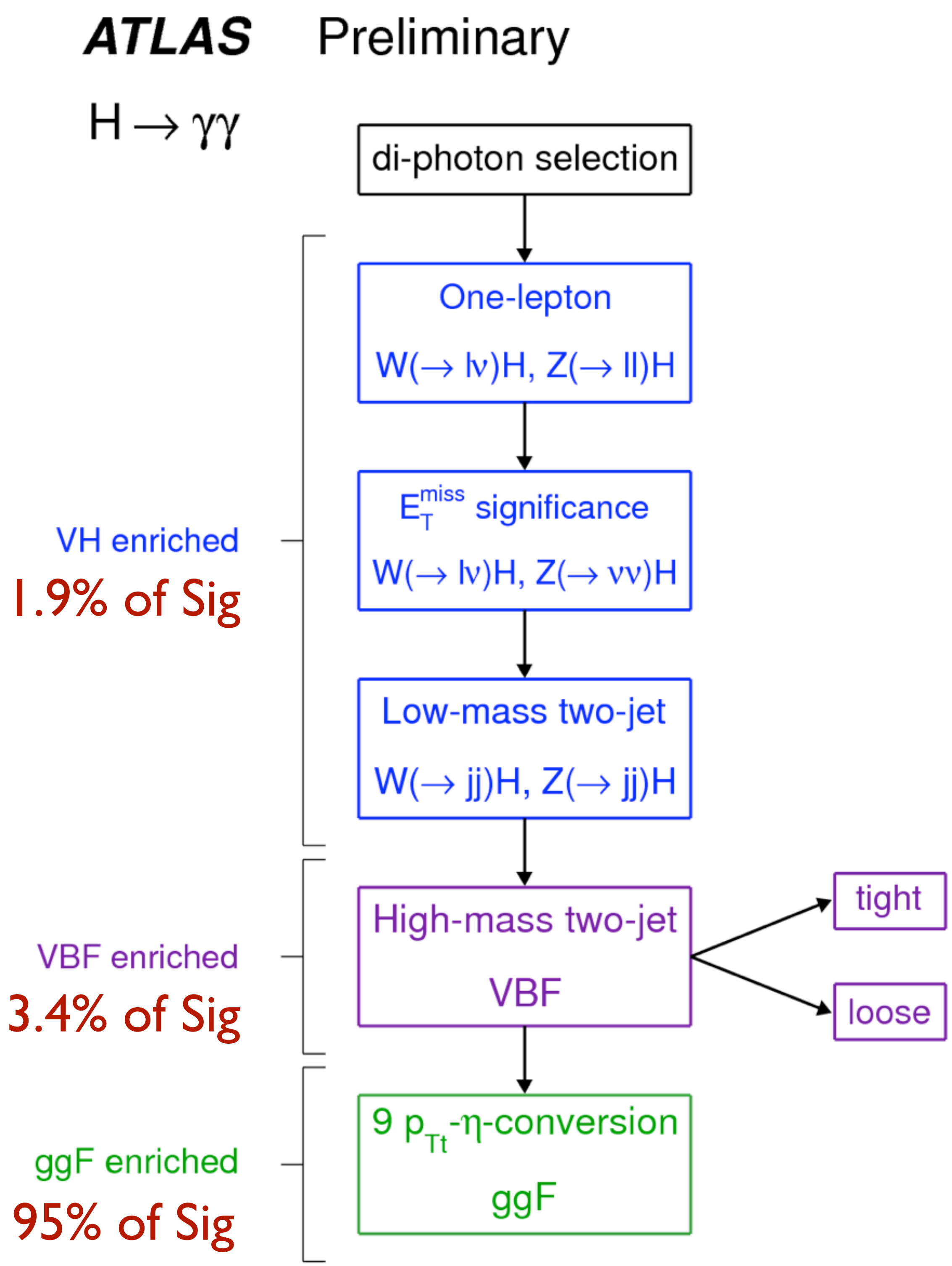


Inclusive: All production modes with $\gamma\gamma$ final state

Signal strength relative to SM: $1.65 \pm 0.24(\text{stat})^{+0.25}_{-0.18}(\text{syst})$

ATLAS-CONF-2013-012

$H \to \gamma\gamma$ by Production Channel



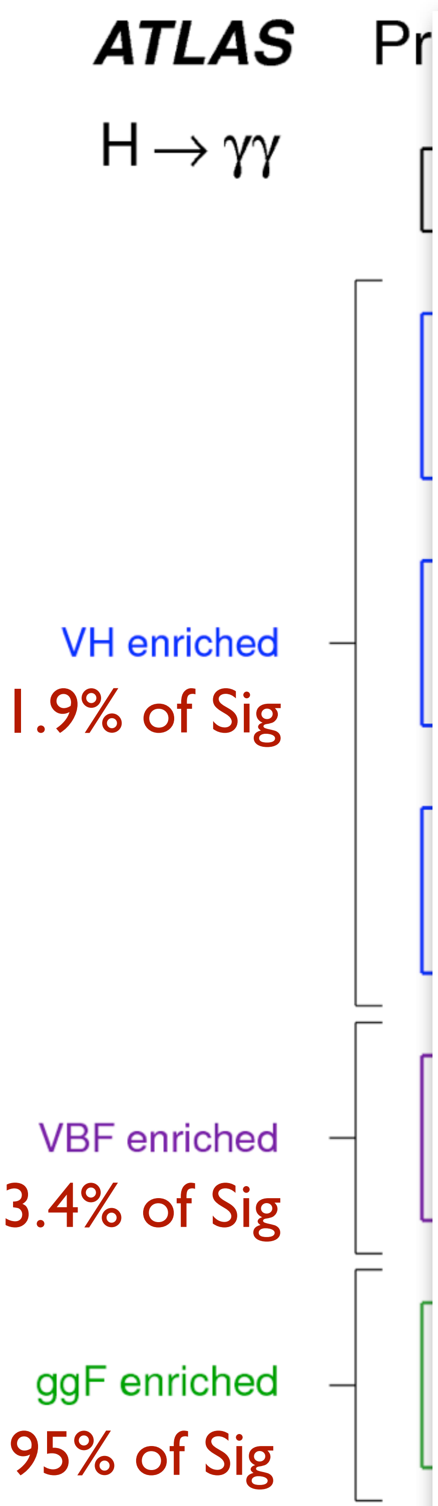
Diphoton sample divided into exclusive subsets for different production mechanisms

- 80-90% leptonic WH and ZH remainder ttH
- 50% hadronic WH and ZH remainder ggF
- 54(76)%VBF for loose(tight) remainder ggF
- 75-95% ggF depending on category

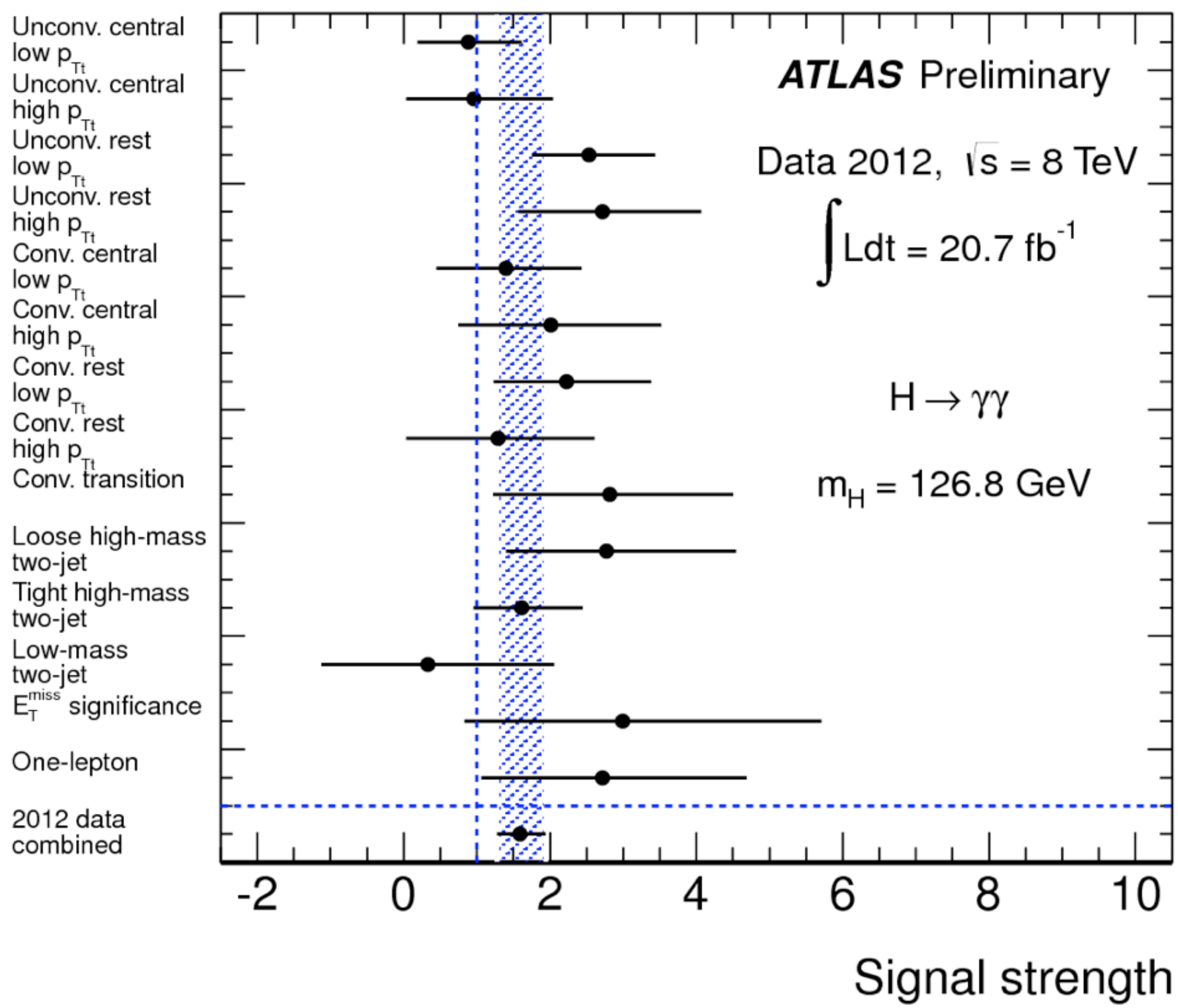
Most categories not very pure in one production mode

ATLAS-CONF-2013-012

$H \to \gamma\gamma$ by Production Channel



Result is yield in each category



into
rent

and ZH

d ZH

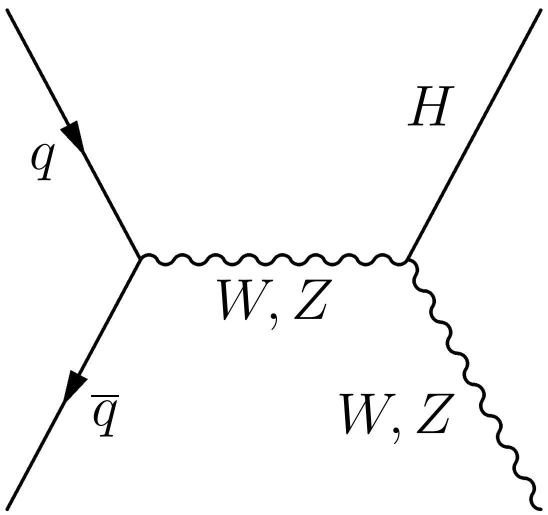
(tight)

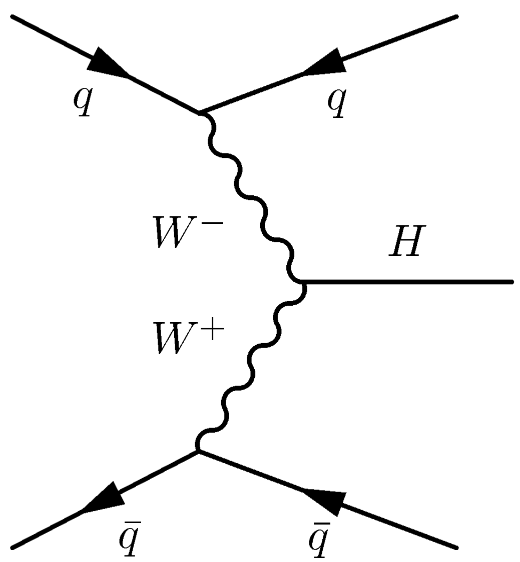
g on

Most cat ... on mode

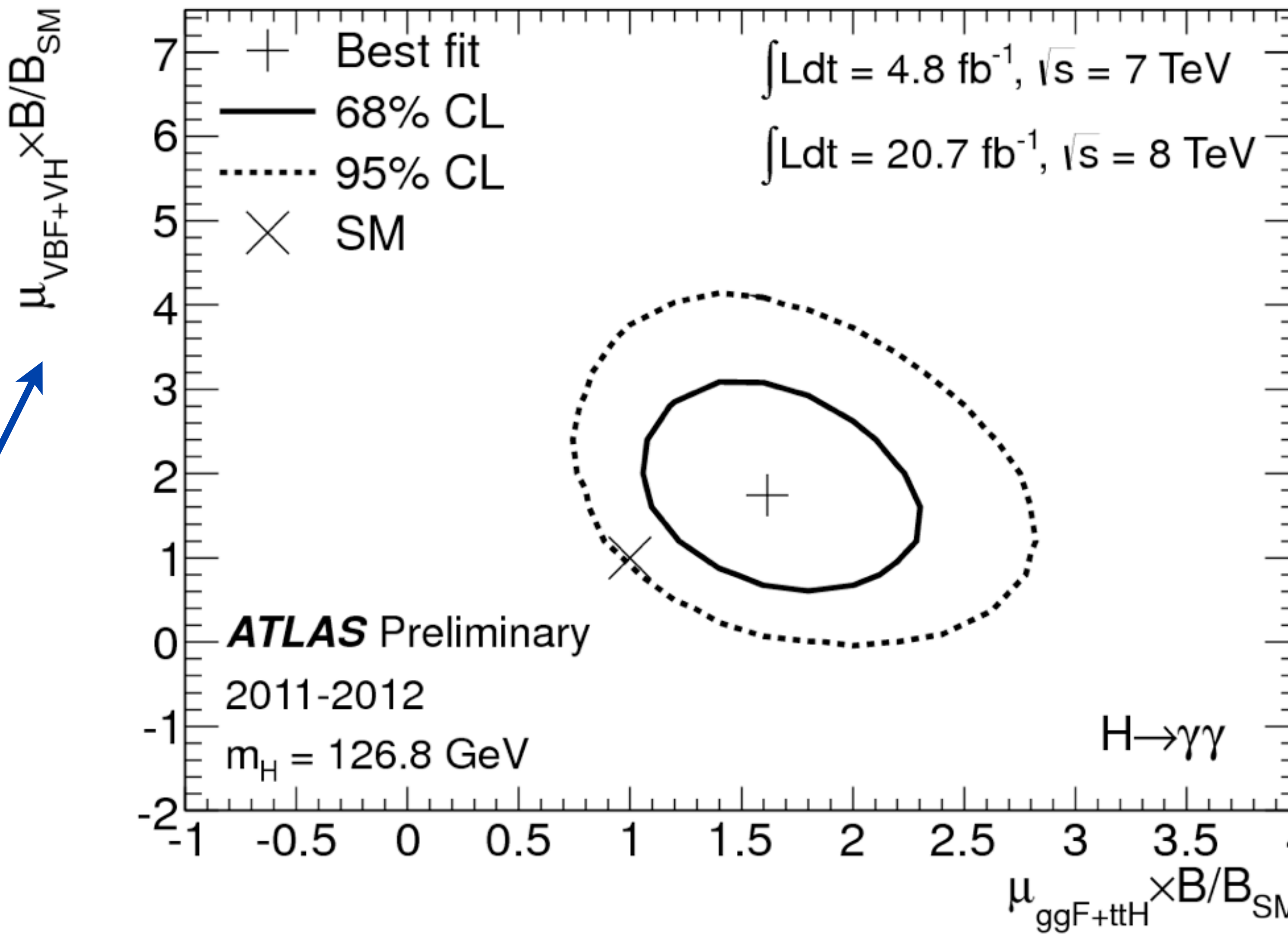
ATLAS-CONF-2013-012

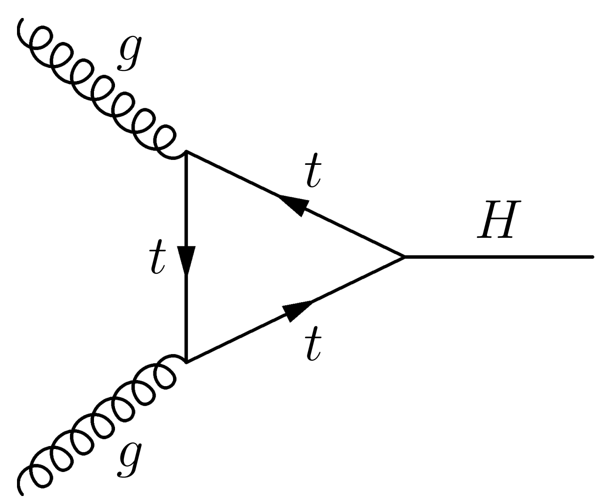
$H \to \gamma\gamma$ by Production Channel

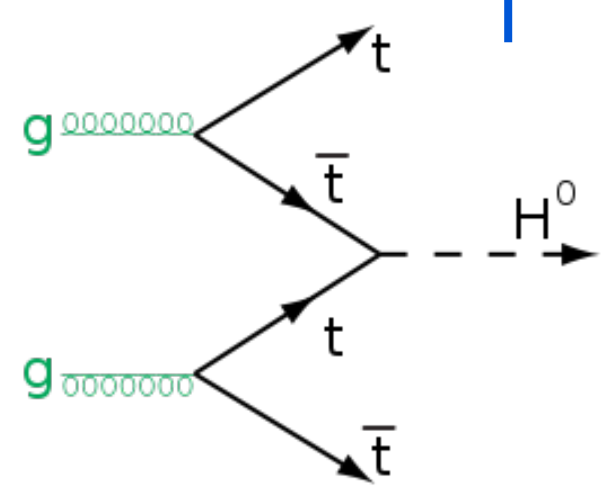




Involved the WWH and ZZH couplings in SM



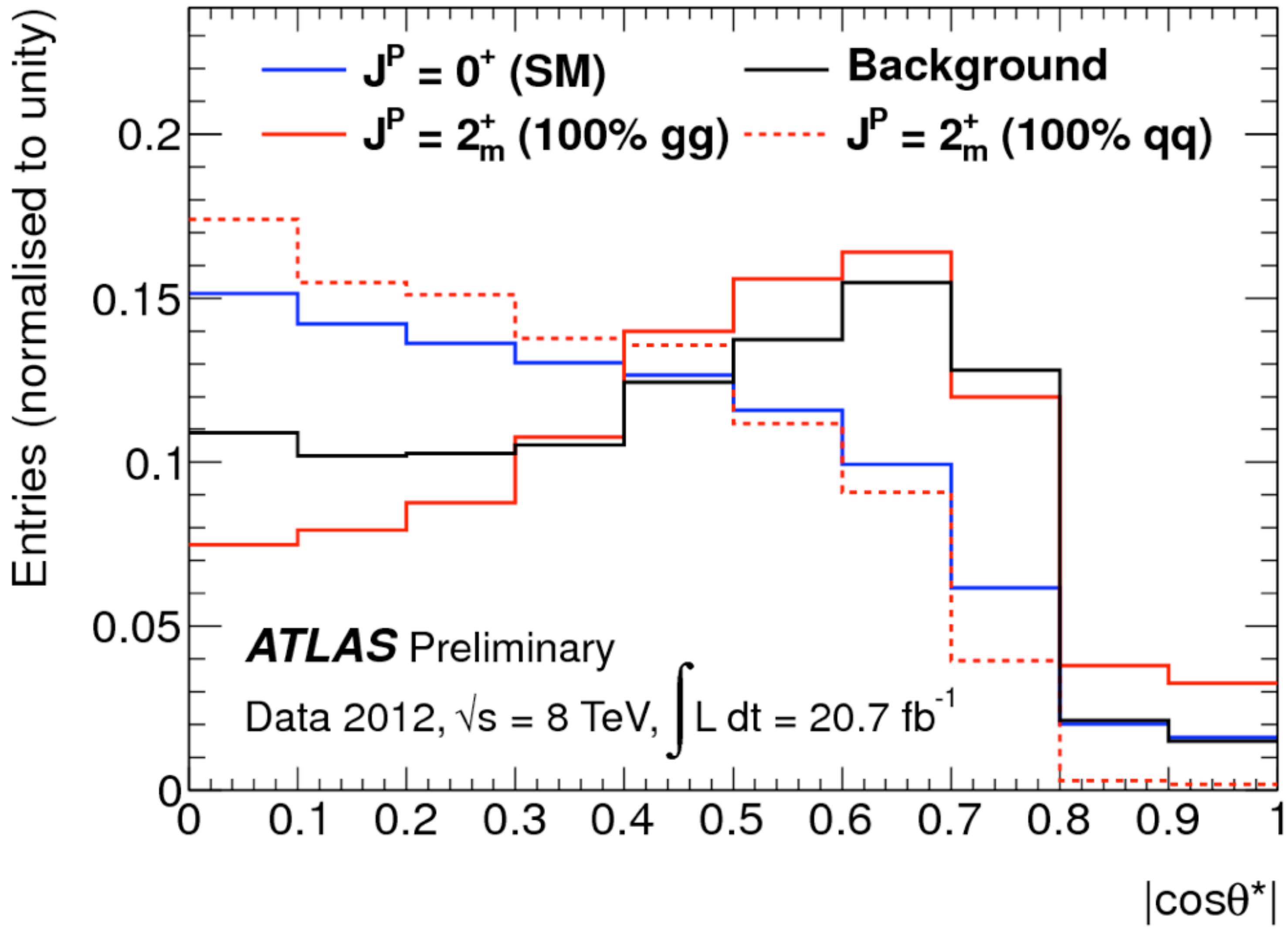




Involved the ttH coupling in SM

ATLAS-CONF-2013-012

$H \to \gamma\gamma$ Spin



A spin-1 resonance cannot decay to two photons
so spin-1 is excluded

Photon spins are not observed

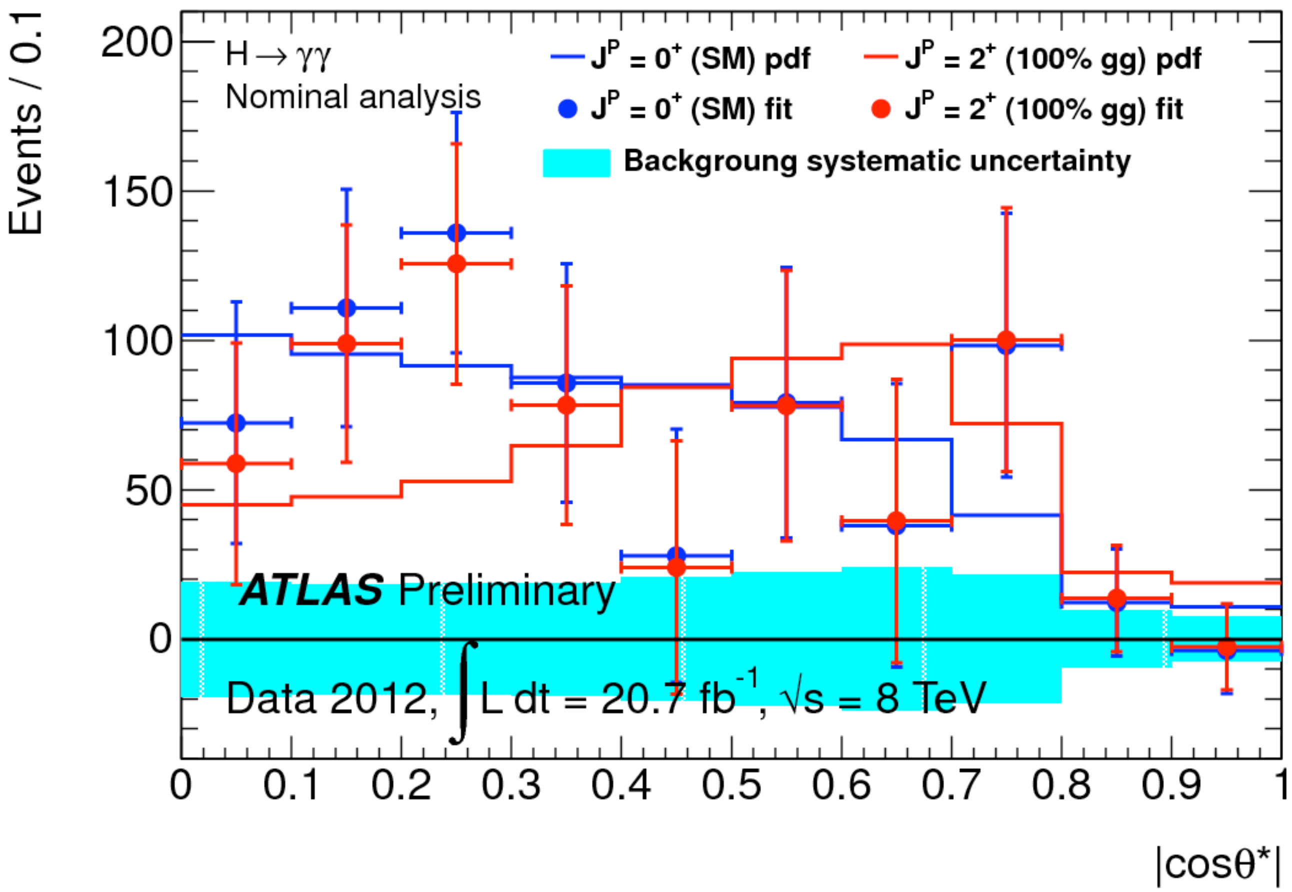
Spin-2 with initial state of gg or $q\bar{q}$ will have different decay kinematics

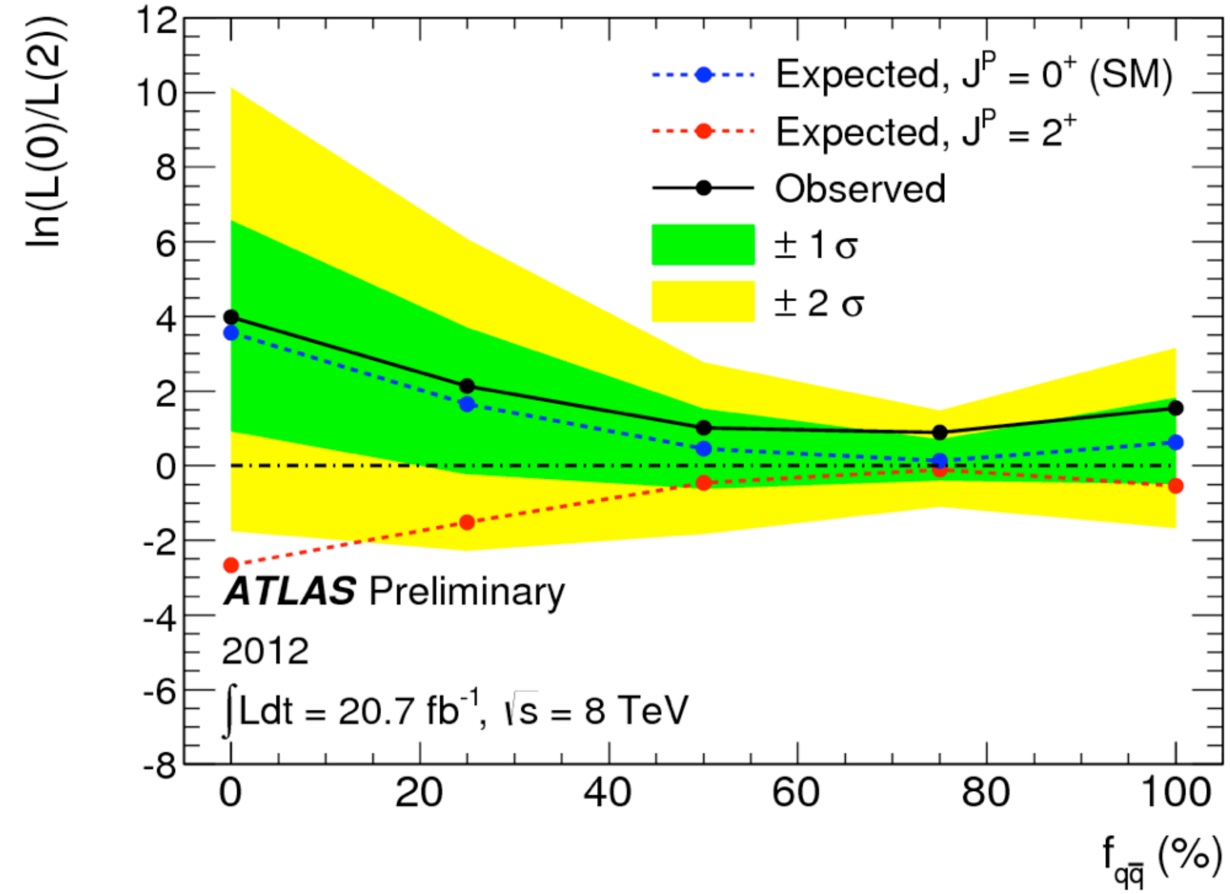
$\cos\theta^*$ is the angle of photons relative to beam direction with a correction for the boost of the $\gamma\gamma$ system

Selection modified to reduce $m_{\gamma\gamma} - \cos\theta^*$ correlation

ATLAS-CONF-2013-029

$H \to \gamma\gamma$ Spin





The data are fit for signal and background yields for spin-0 and spin-2

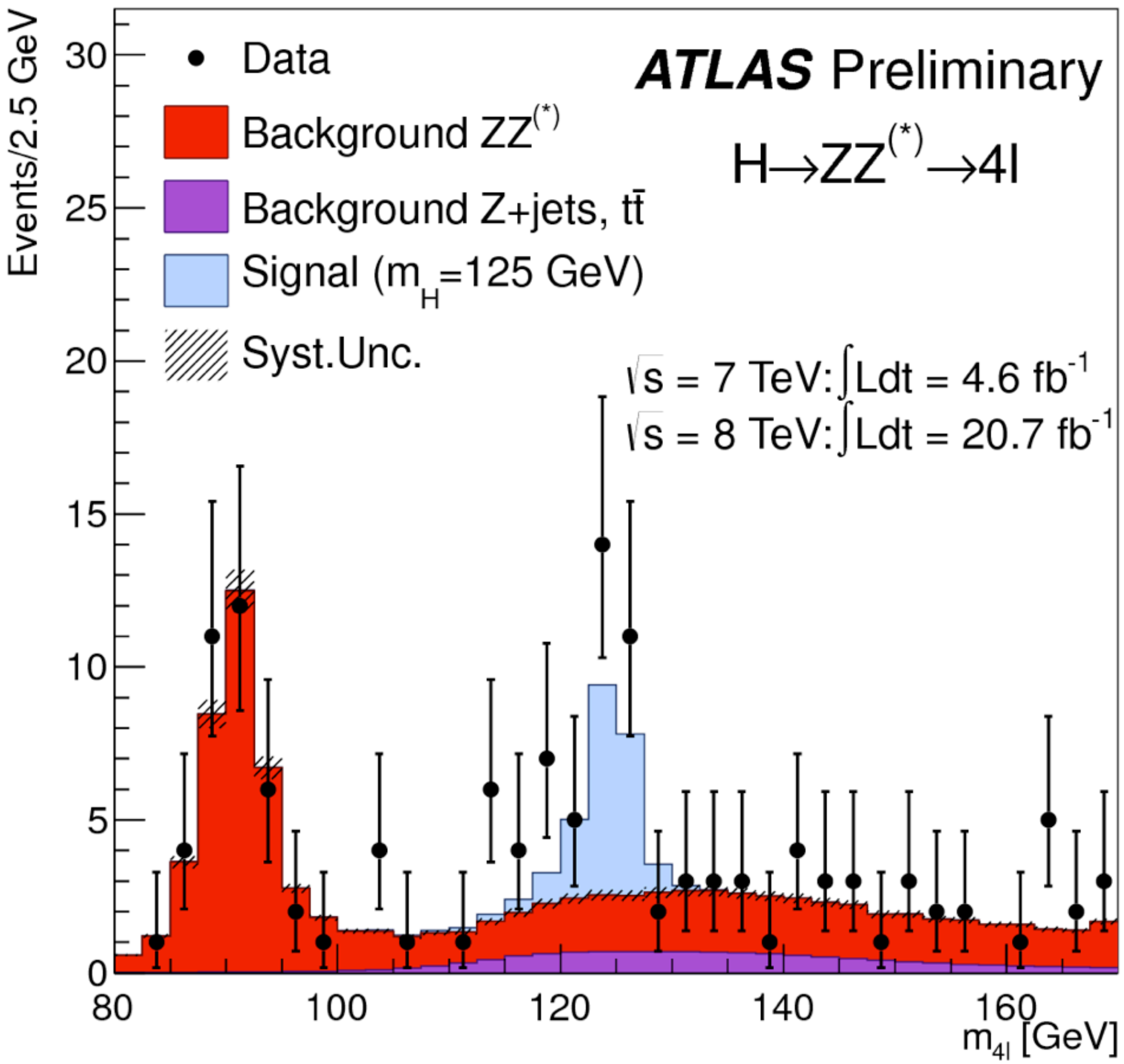
The ratio of the best fit likelihoods is used as a test statistic to set limits

Only 8 TeV data are used at this point

Spin-2 produced by gluon fusion is excluded at 99% CL

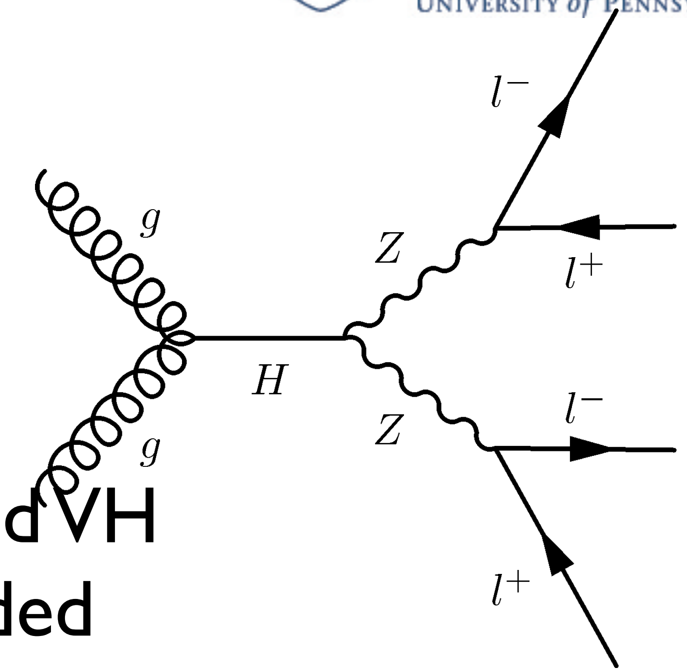
ATLAS-CONF-2013-029

$H \to ZZ$ Production

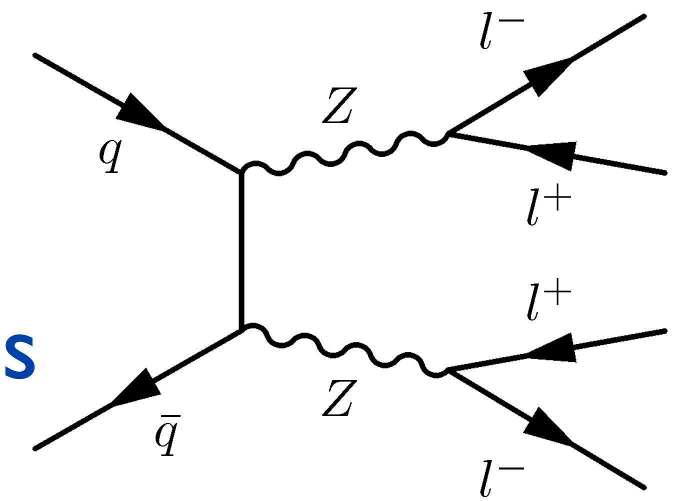


Signal + VBF, VH, ttH

Separate VBF and VH categories added

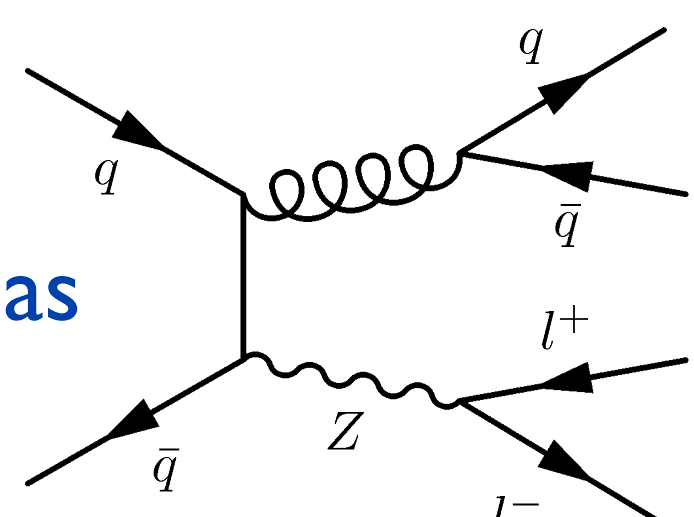


Irreducible background: 4 real leptons



Main Issue is getting the highest efficiency without letting this get out of control

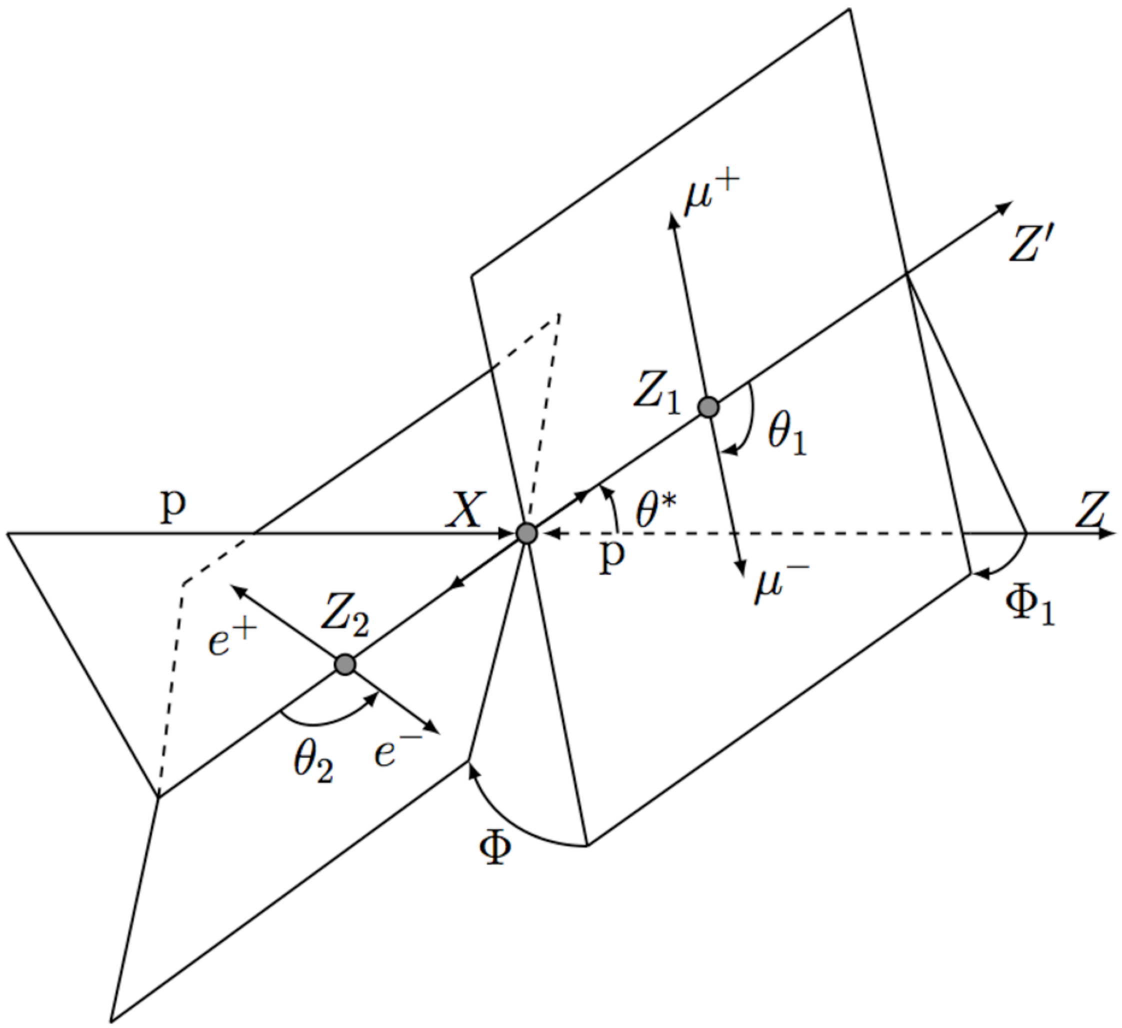
Z+2 jets misidentified as leptons



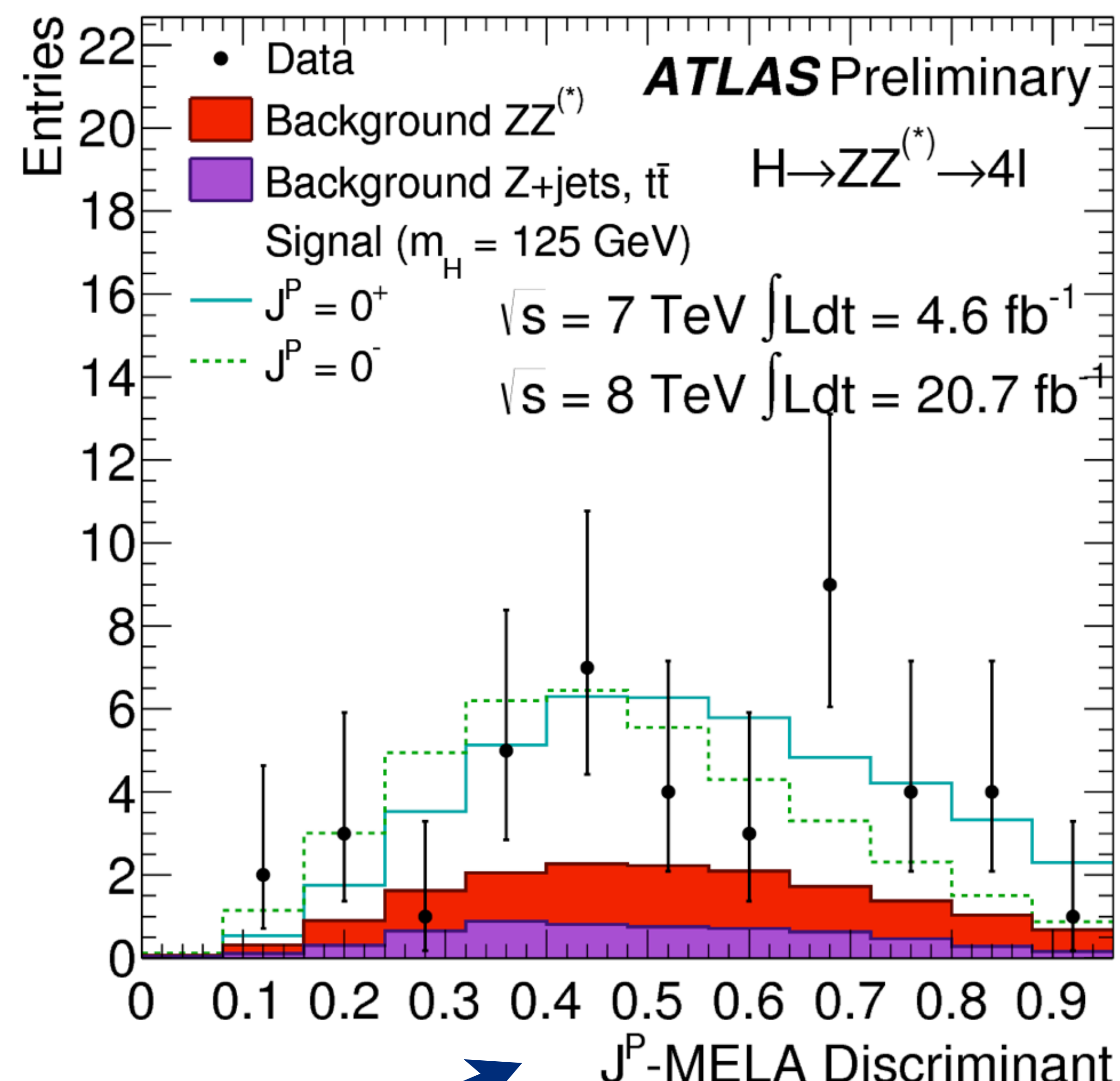
Acceptance:

39% 4μ, 26% $2e2\mu/2\mu2e$, 19% $4e$

$H \to ZZ$ Spin



Considered J^P: 0^+, 0^-, 1^+, 1^-, 2^+, 2^-



Full kinematics measured = 5 angles

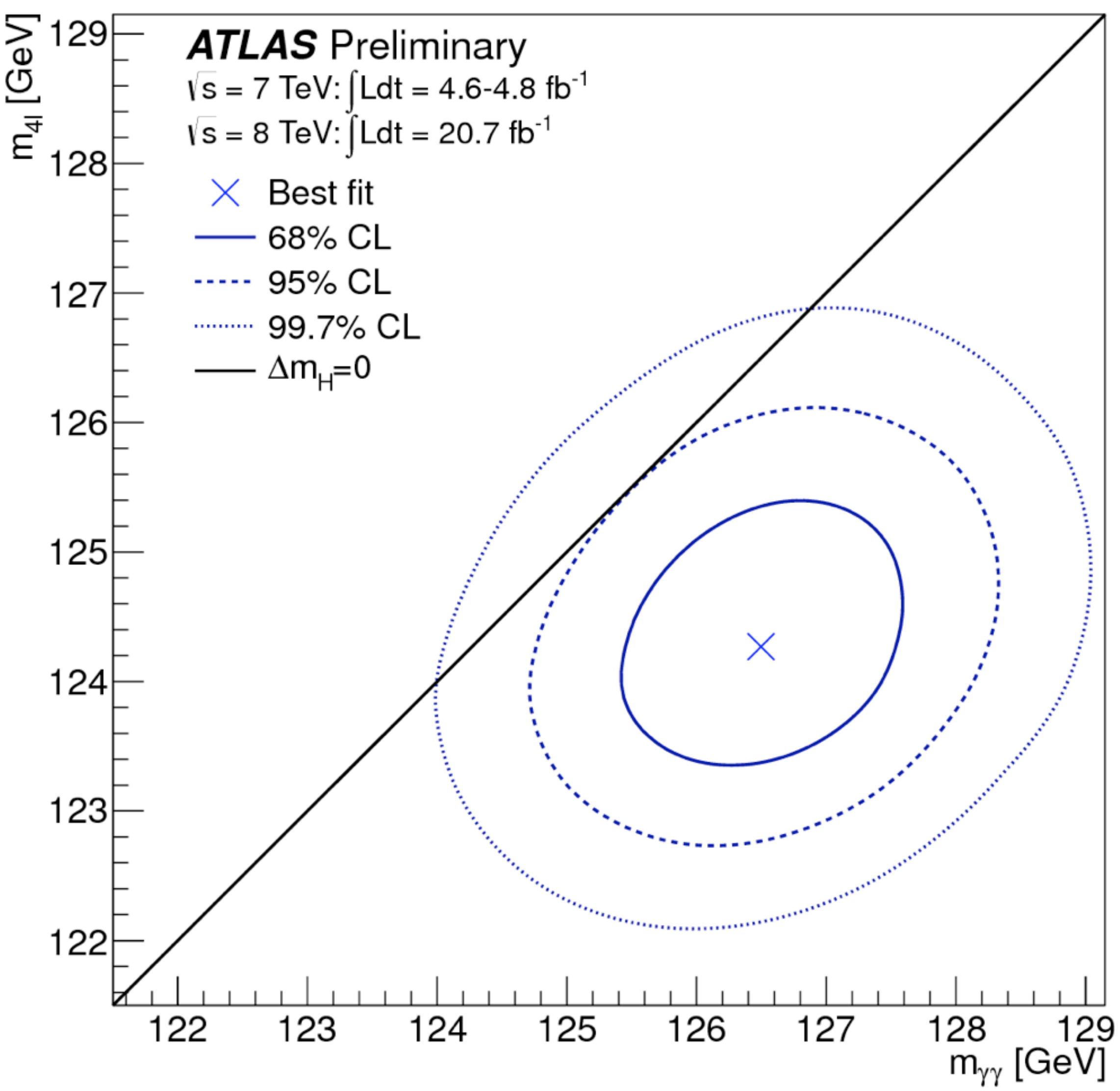
Decay products sensitive to Z spins

Two analysis methods:

- BDT with MC for input
- MELA = an analytic probability based on field theory matrix element

0^-, 1^+ excluded at 97.8% CL

Mass from $H \to \gamma\gamma$ and $H \to ZZ$



Some tension between $\gamma\gamma$ and ZZ mass determinations

Main systematics on $\gamma\gamma$ mass

- Photon energy scale (from $Z \to ee$ data)
- Material modeling (validated with γ conversions)

Main systematics on ZZ mass

- Electron energy scale
- Muon momentum scale (both validated with J/ψ data)

Mass combined including systematic correlations

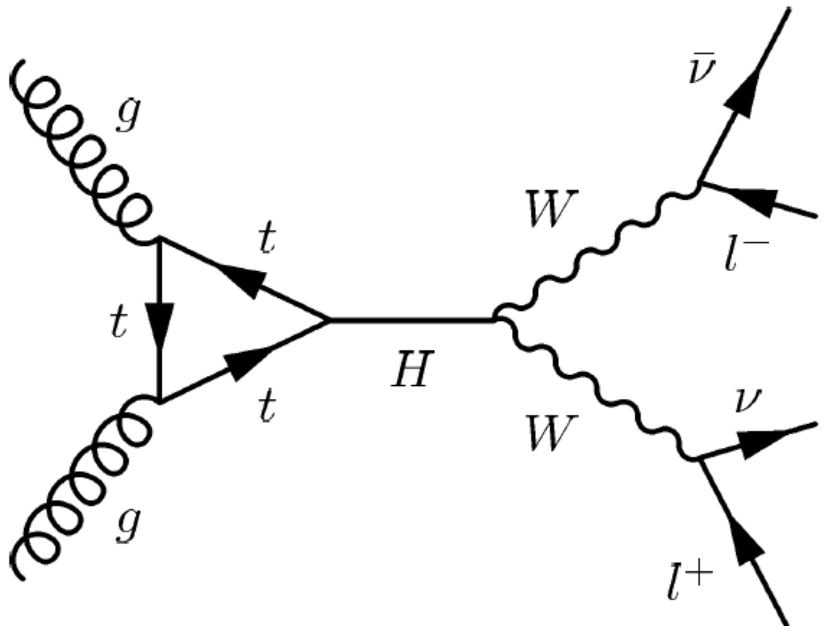
$$m_H = 125.5 \pm 0.2\,(\text{stat})\,^{+0.5}_{-0.6}\,(\text{sys})\ \text{GeV}$$

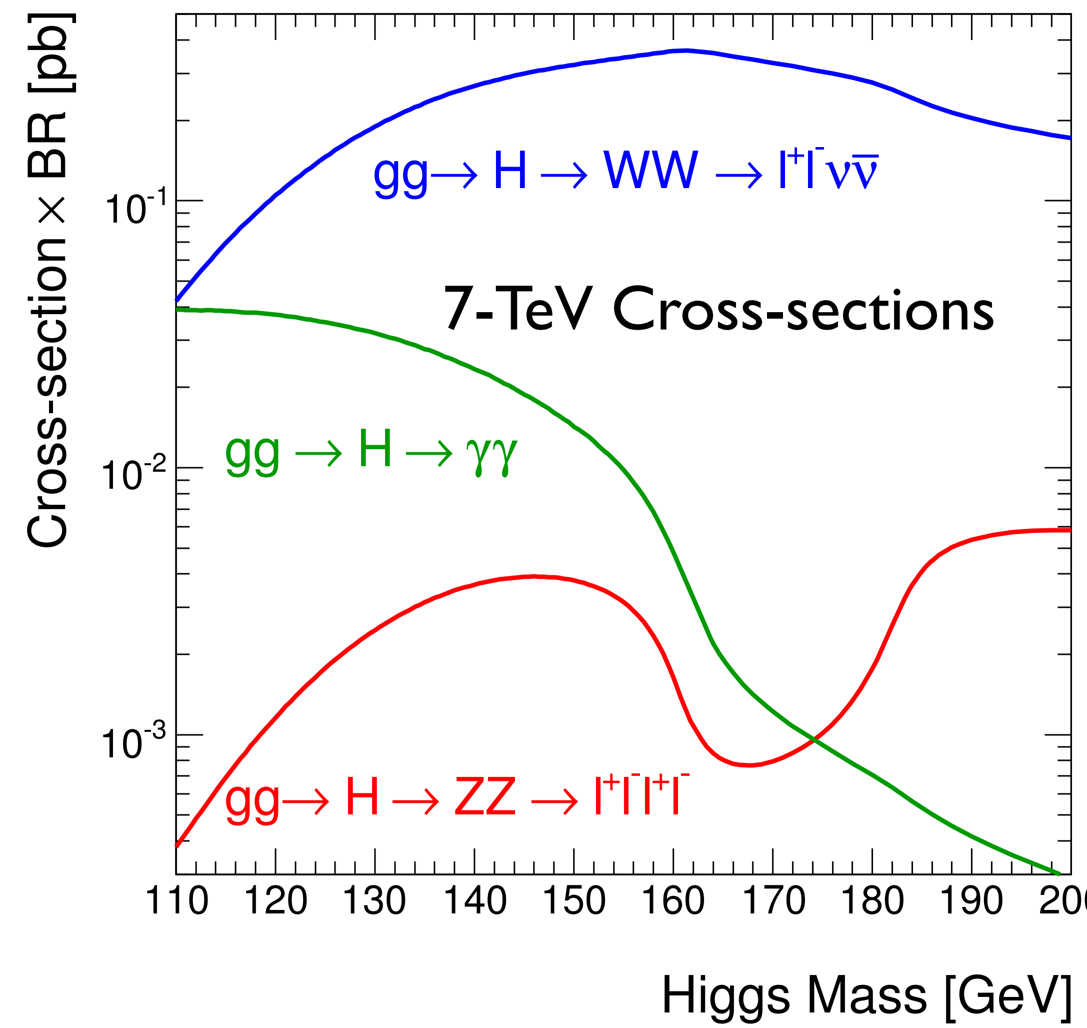
Many detailed cross-checks have been performed

Consistency is at the 2.5 sigma level

$H \to WW$ Overview

High yield channel

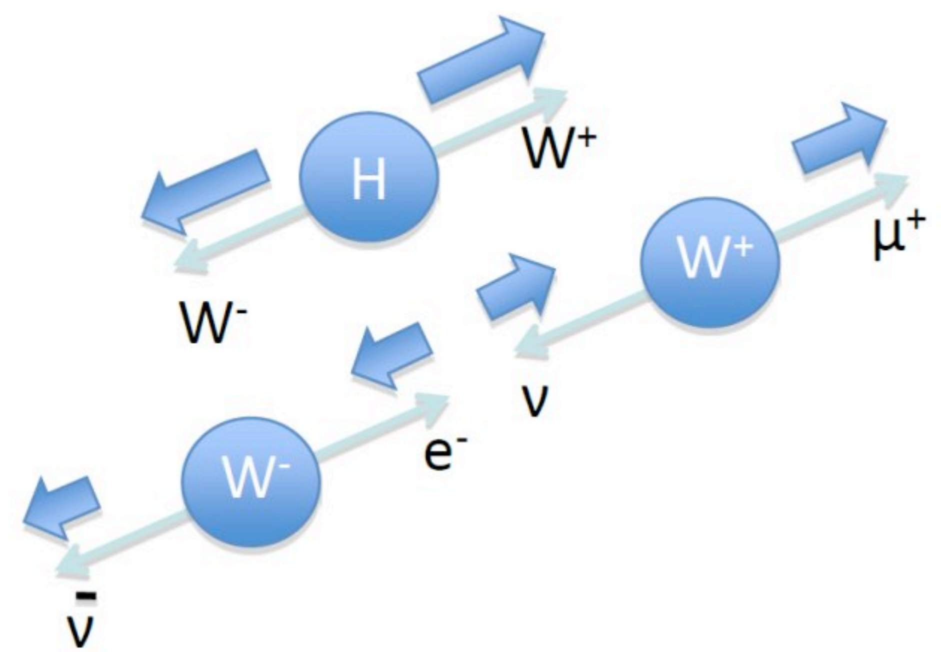




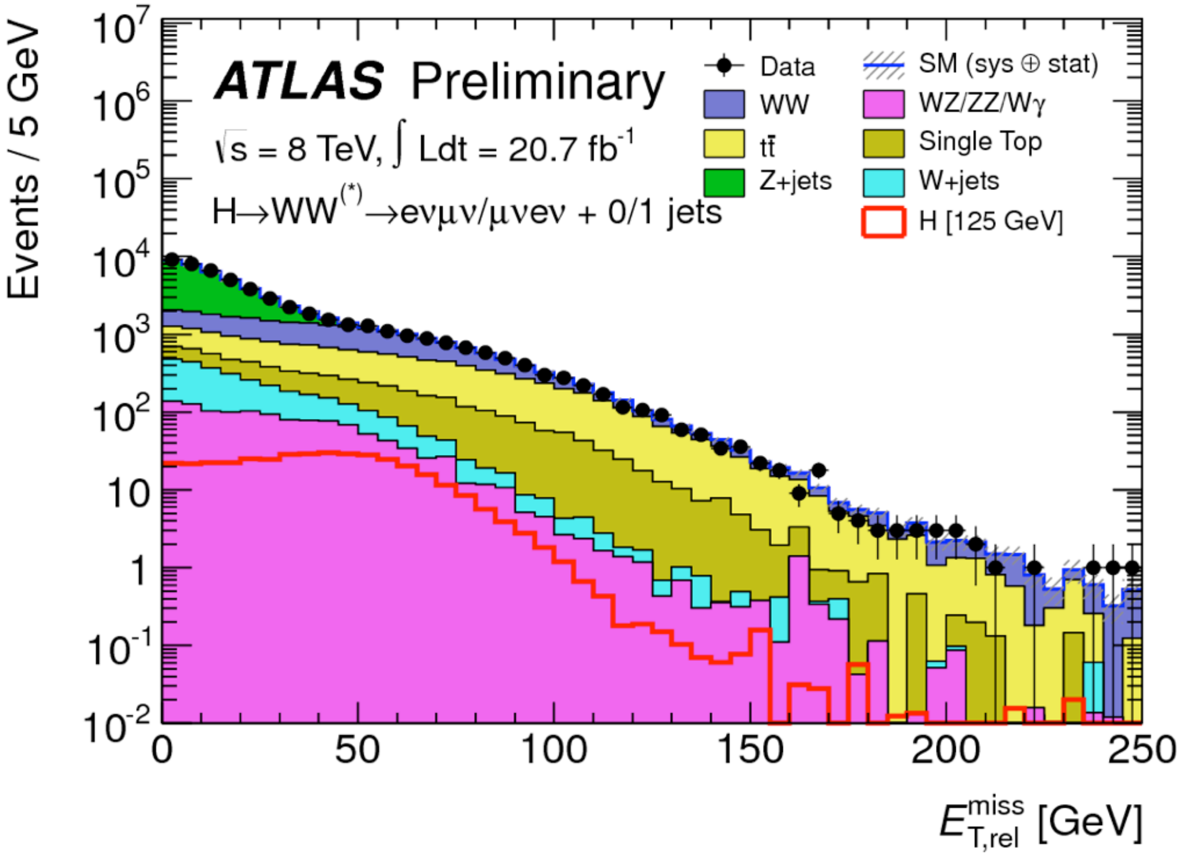
The problem is that we can only work with the leptonic W decay which has a neutrino in it

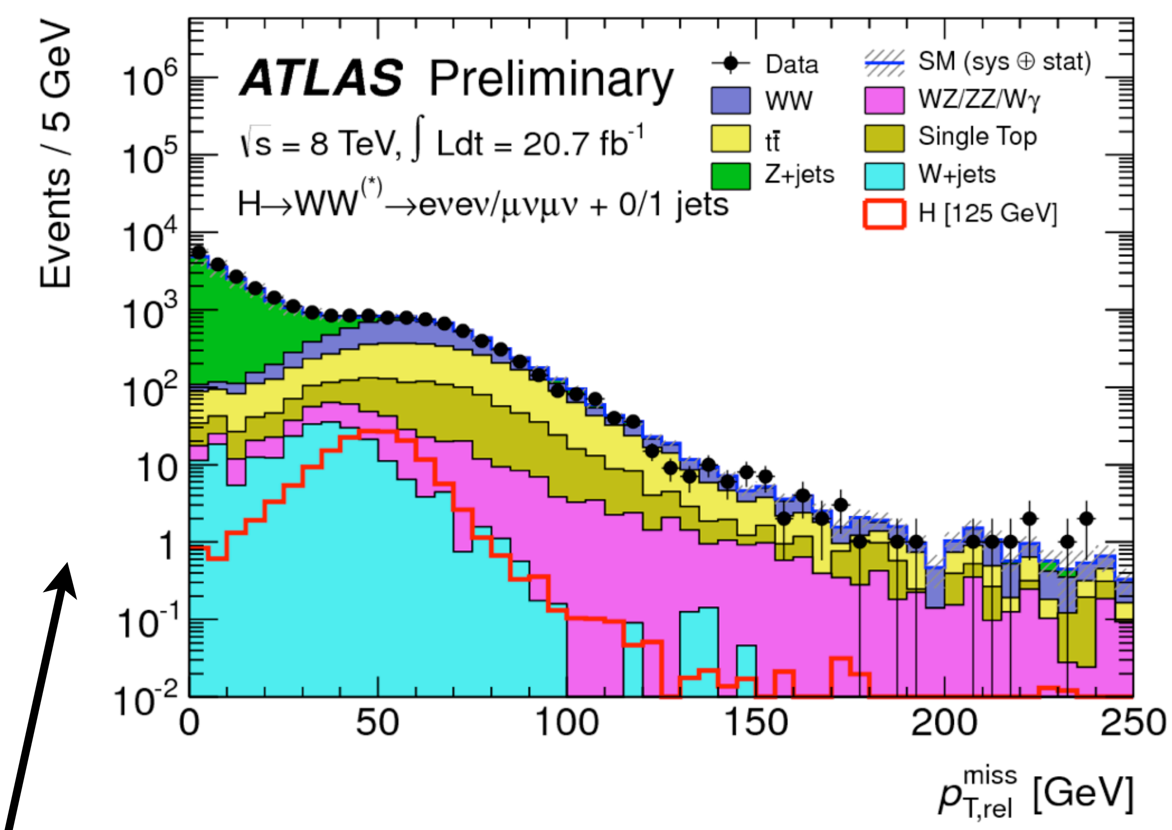
$W \to \ell\nu$ is a spin analyzer because of the parity violation in the W decay

Also get approximate mass from missing momentum



$H \to WW$: Even finding WW is hard

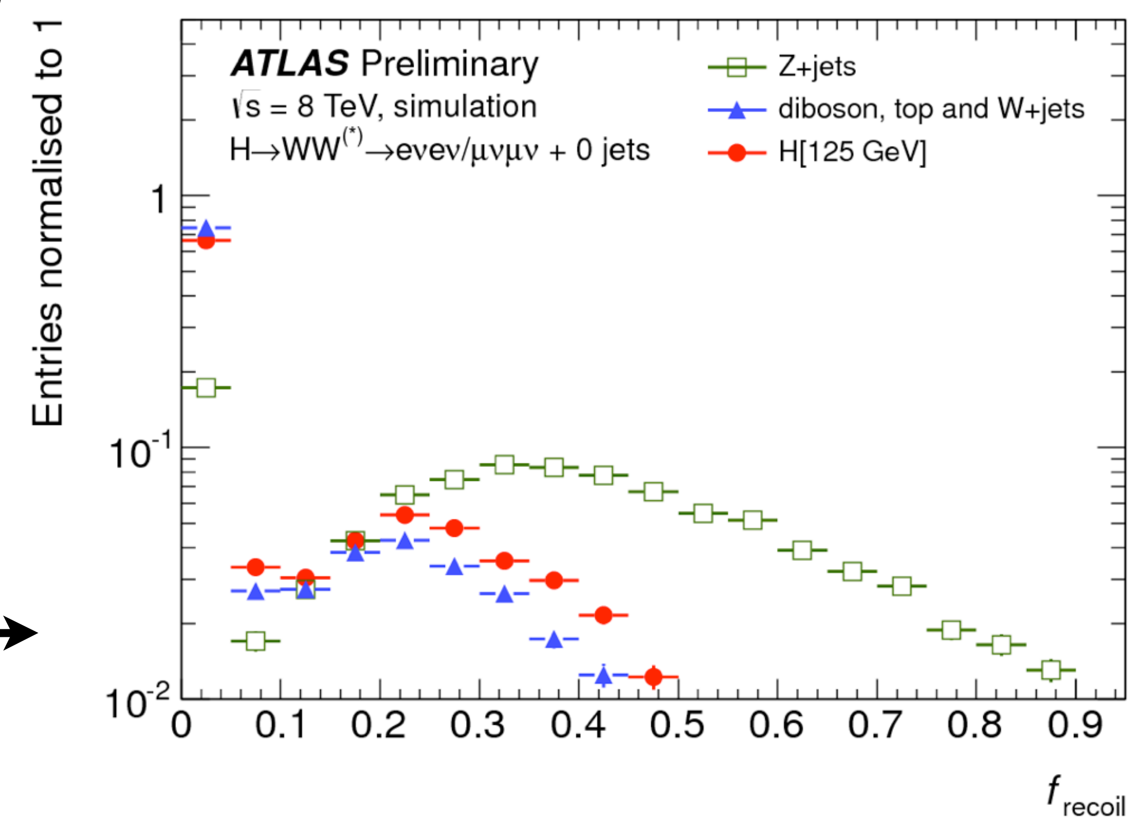




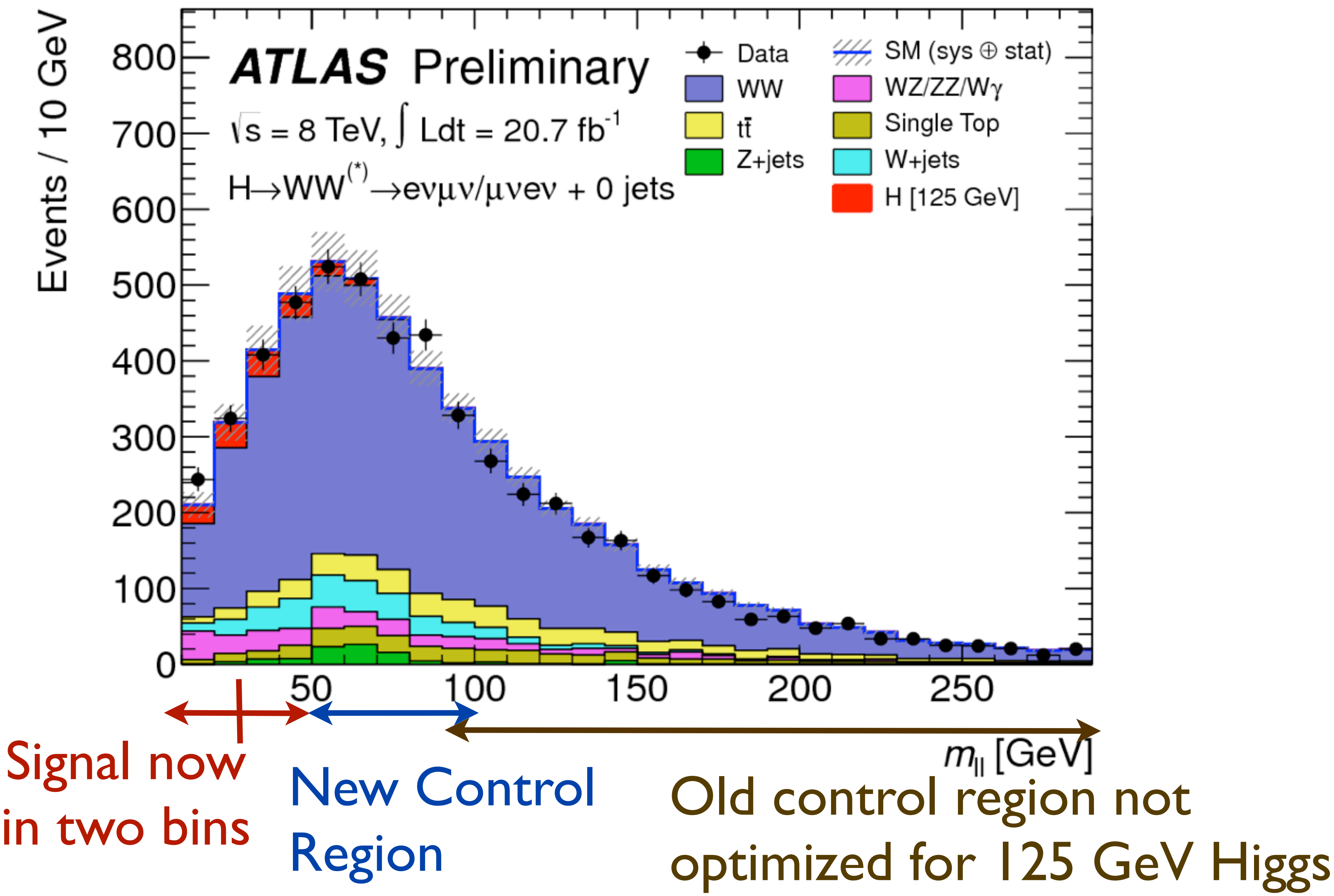
HCP result only used $e\mu$ events

Moriond results add the same flavor ($ee/\mu\mu$) using two new variables

- Track-based missing momentum
- Low energy hadronic recoil from calorimeter



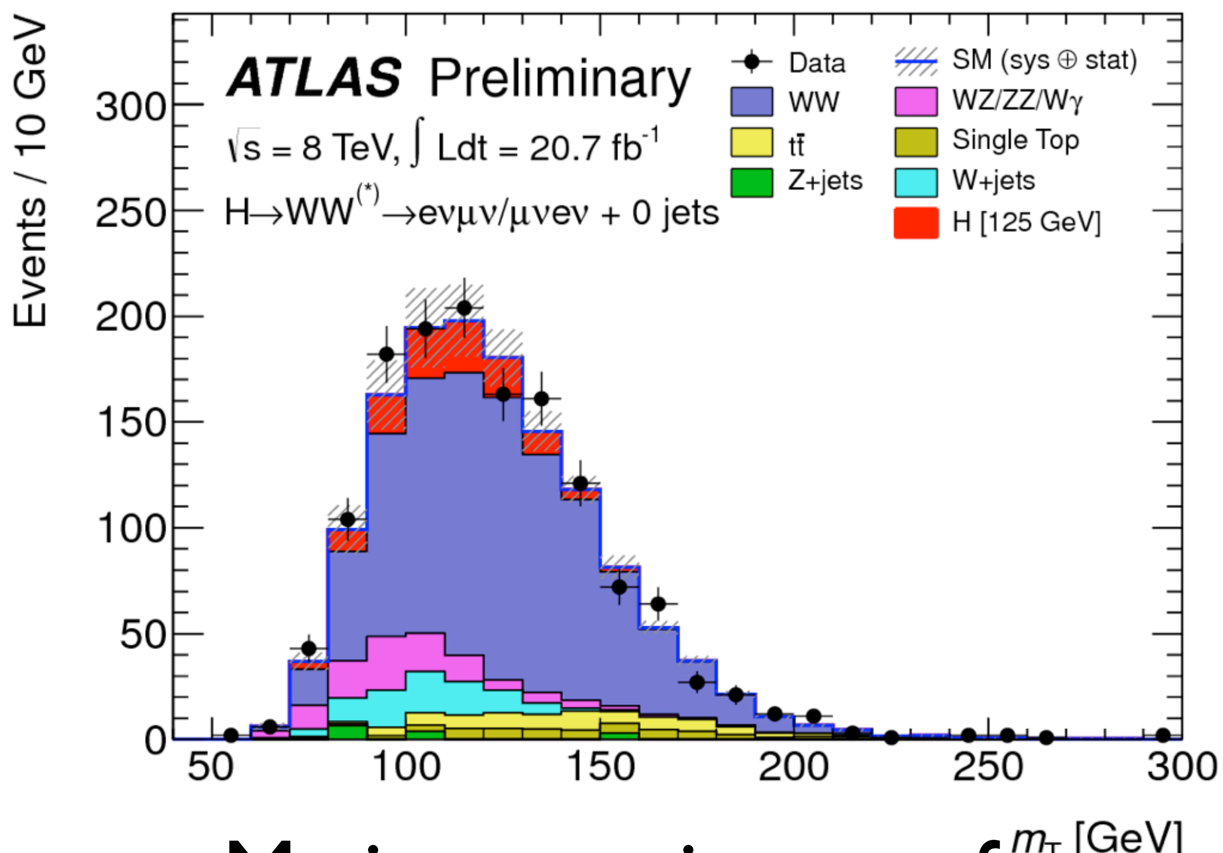
$H \rightarrow WW$ Improvements

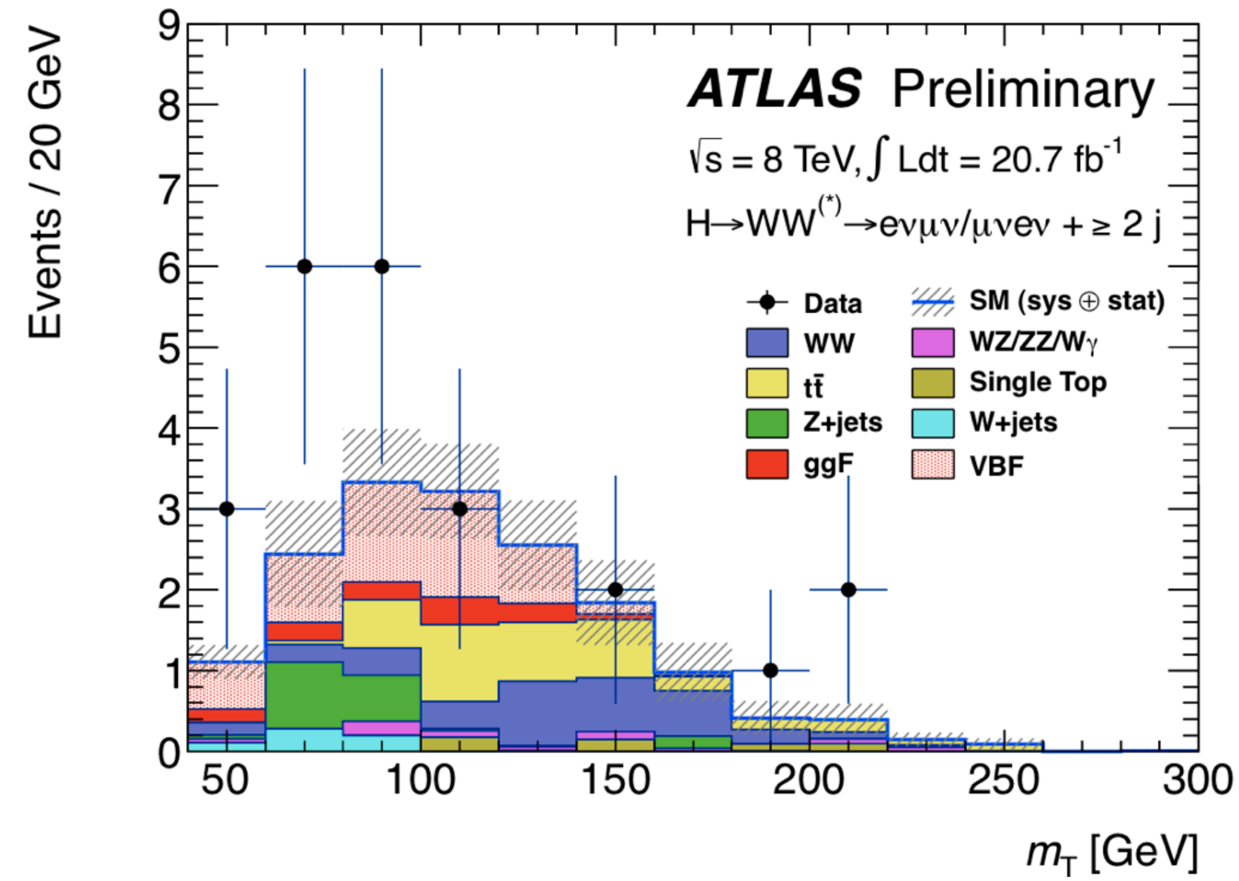


Many improvements in Moriond result

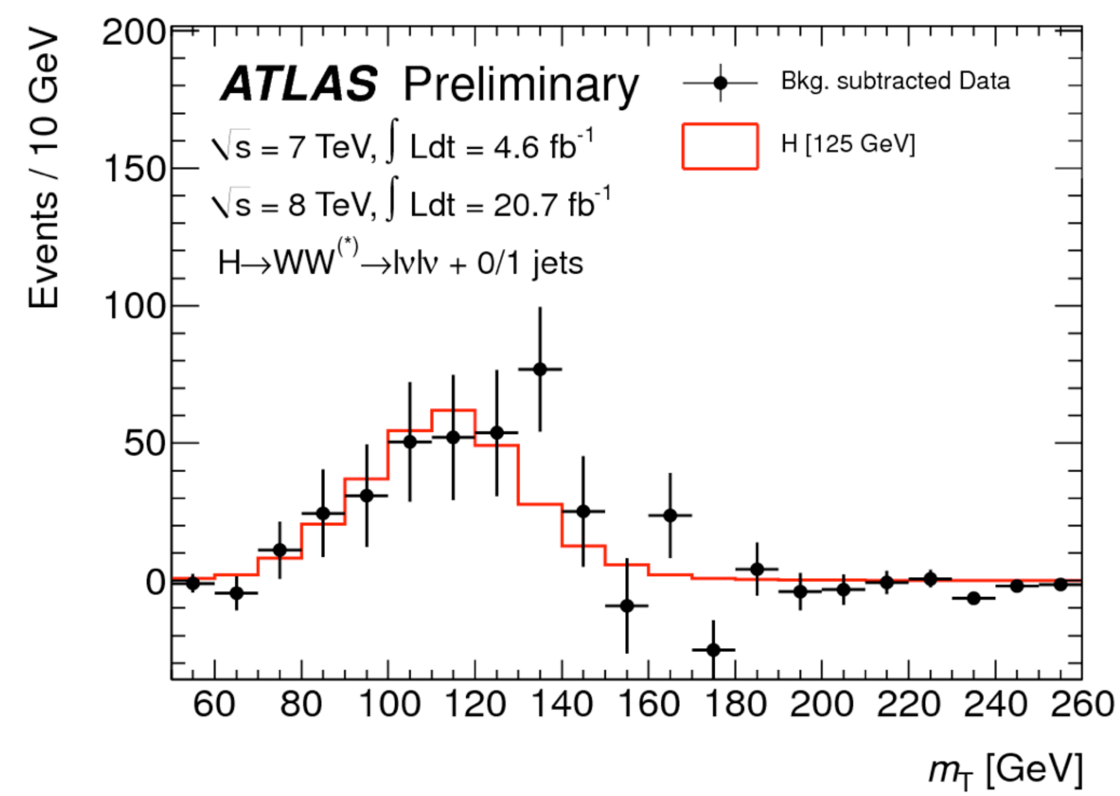
- Inclusion of same-flavor
- Better control regions
- Better signal categorization
- Update of VBF category
- Reanalysis of 2011 data

$H \to WW$ Result Plots





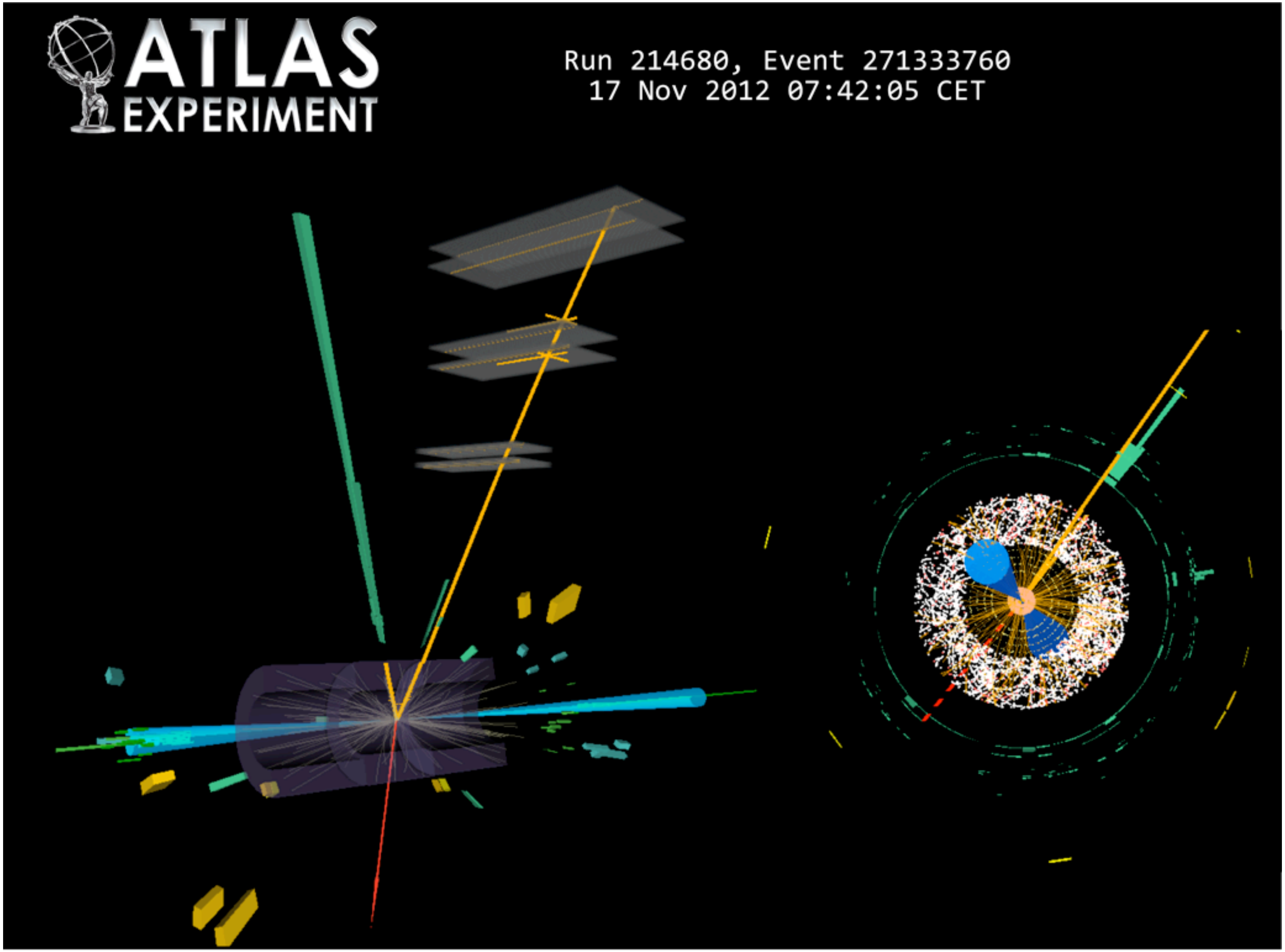
M_T is an estimate of the llnn mass



Analysis bins:

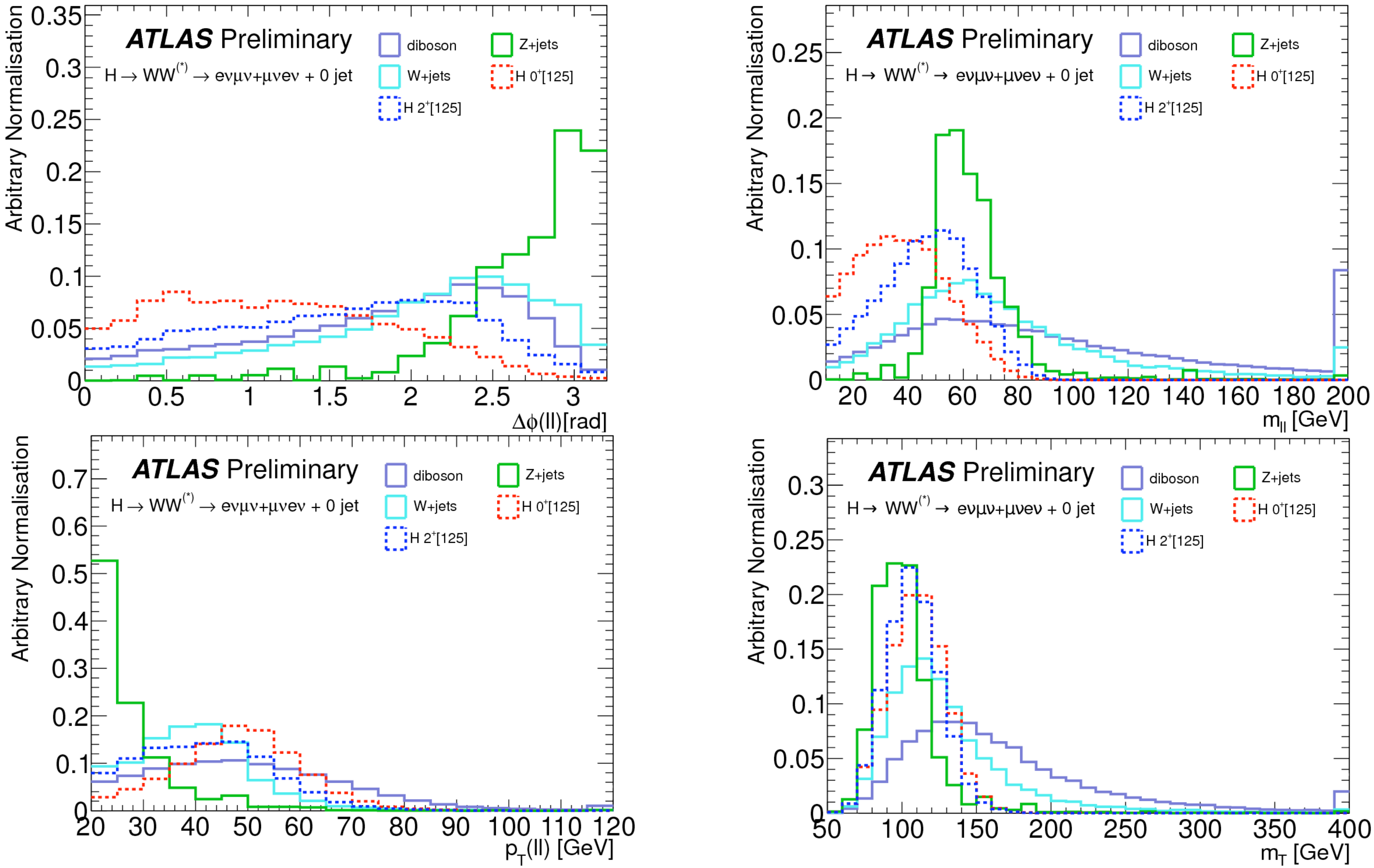
- 0-jet (ggF), 1-jet(ggF), 2-jet(VBF)
- Same-flavor, opposite-flavor
- 2011, 2012

$H \to WW$ VBF event

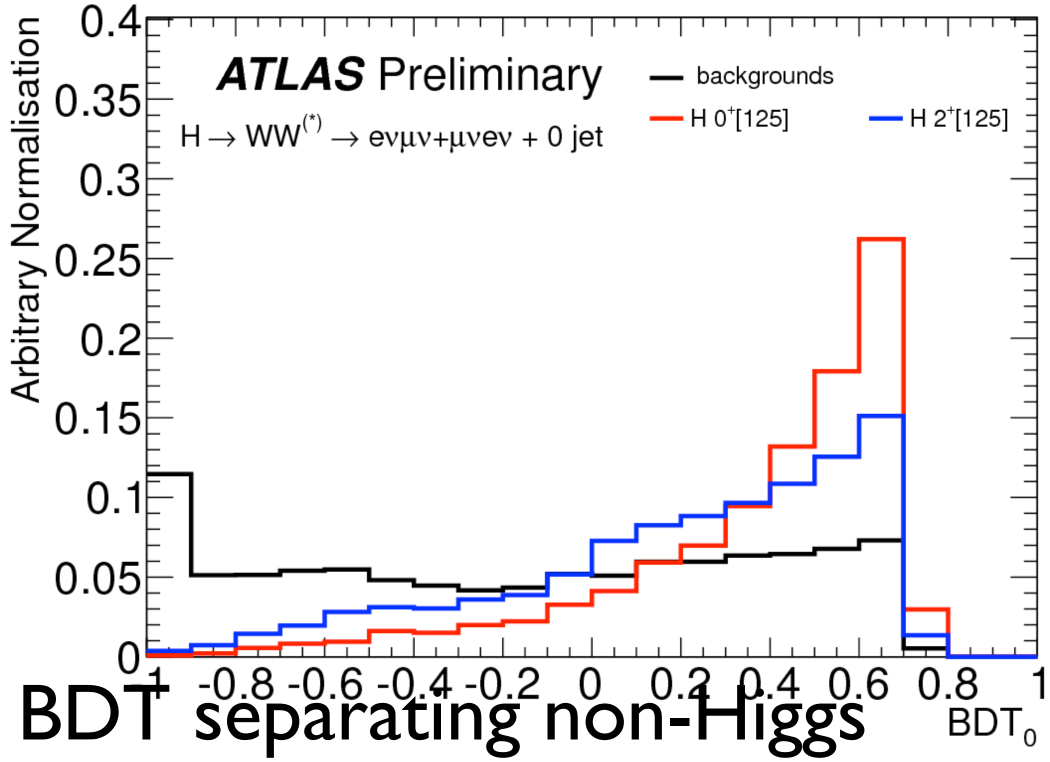


$H \to WW$ Spin

Discriminating variables: spin-2 looks more like background

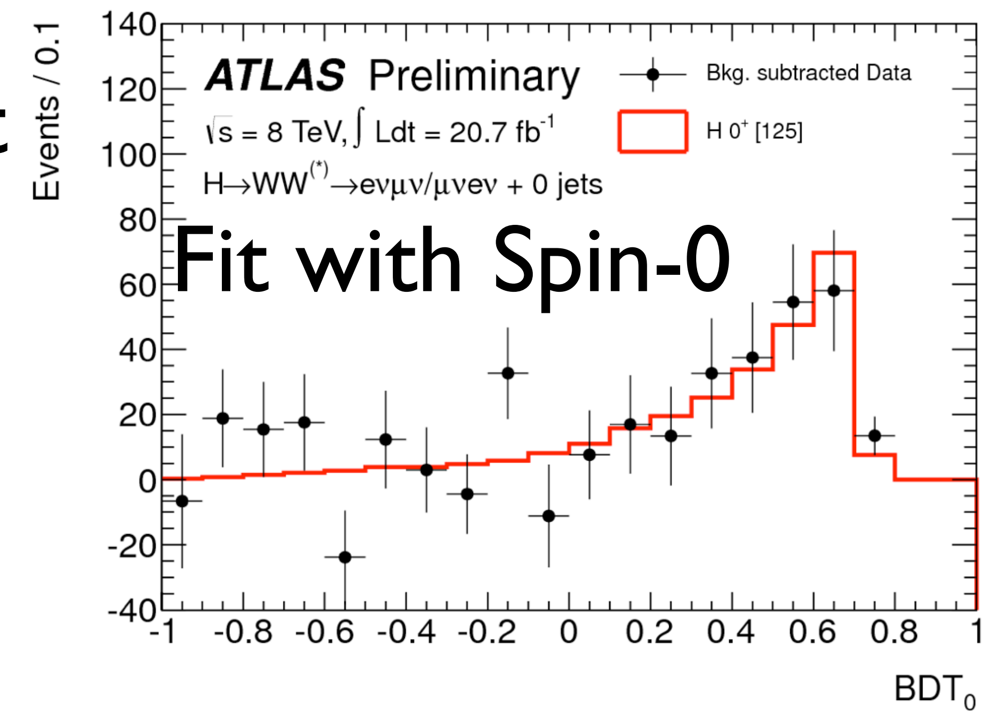


$H \to WW$ Spin

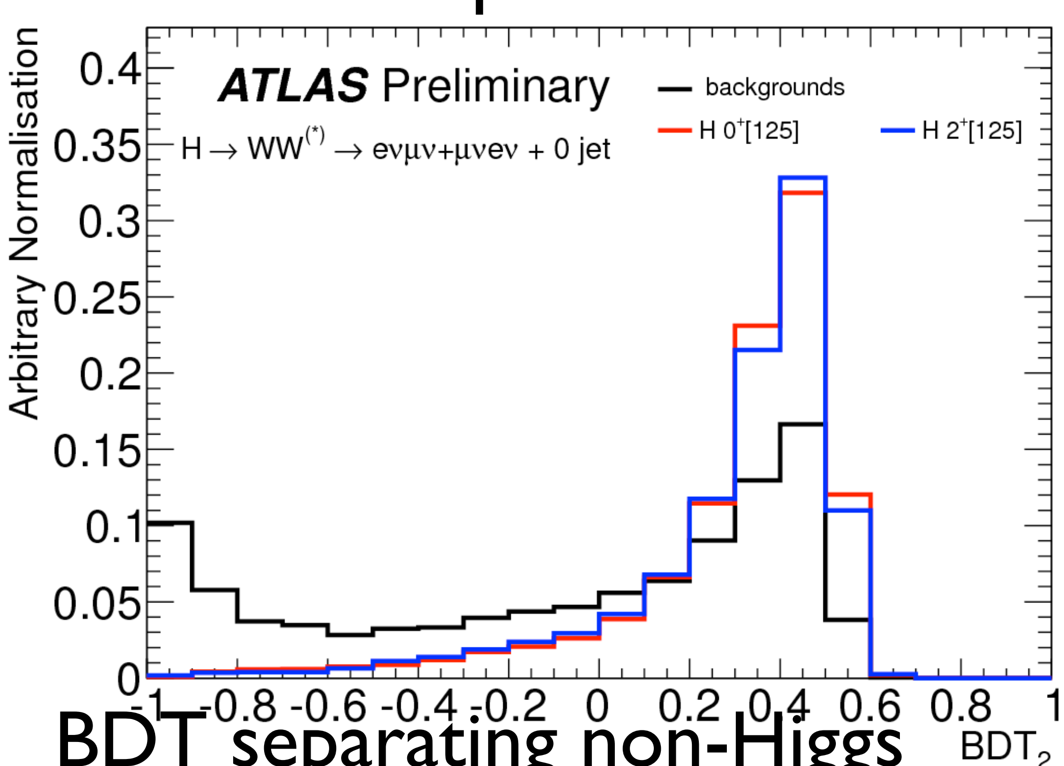


BDT separating non-Higgs from spin-0

2d binned fit BDT0 vs BDT2

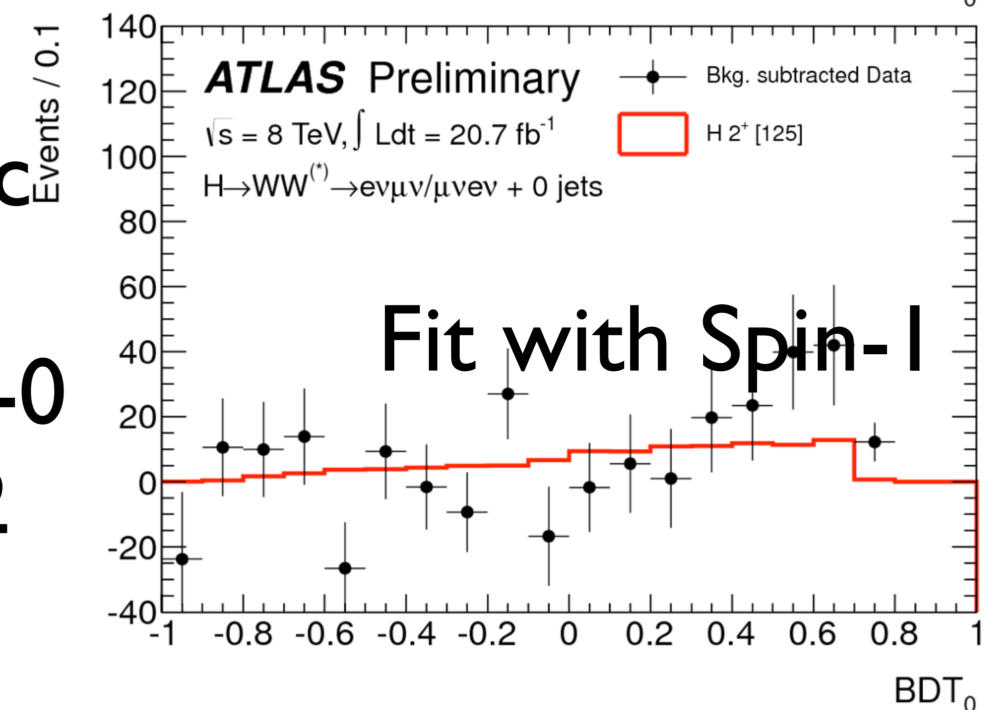


Fit with Spin-0



BDT separating non-Higgs from spin-1

Test statistic likelihood ratio of spin-0 over spin-2

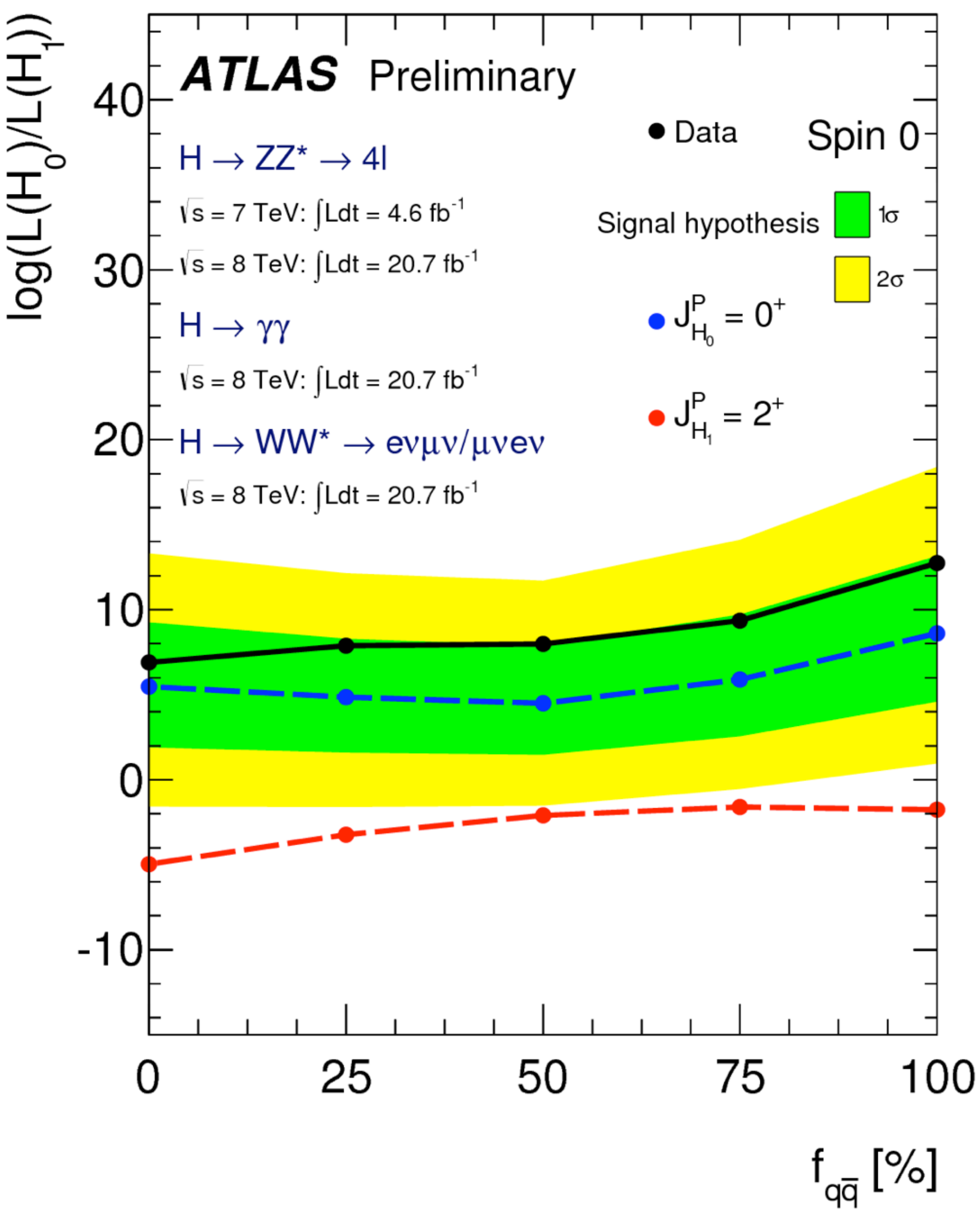


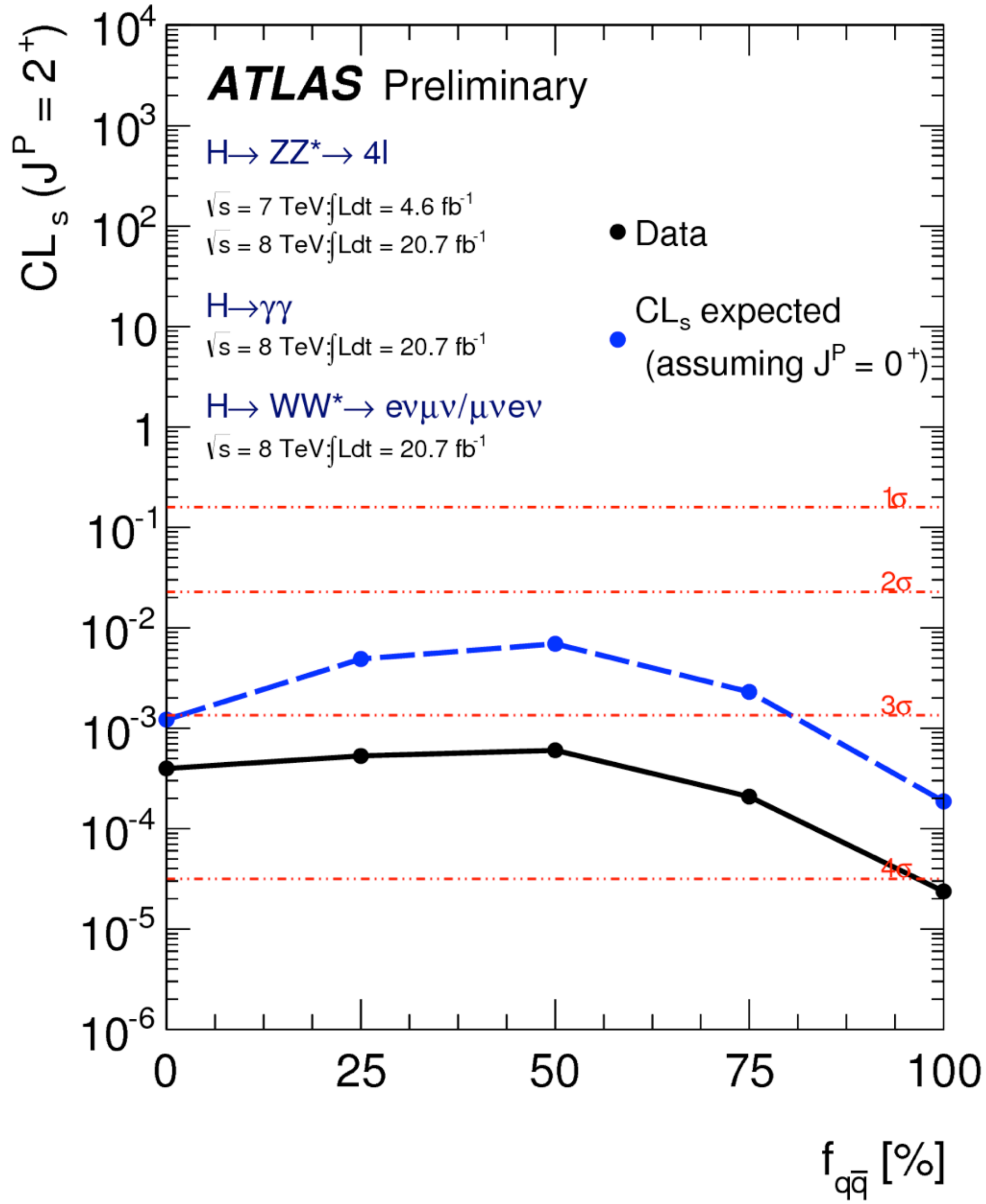
Fit with Spin-1

Exclusion of 2+ varies from 99% for 100% $q\bar{q}$ to 95% for 100% gg production

Spin Combination

Spin results from WW, ZZ, and $\gamma\gamma$ combined



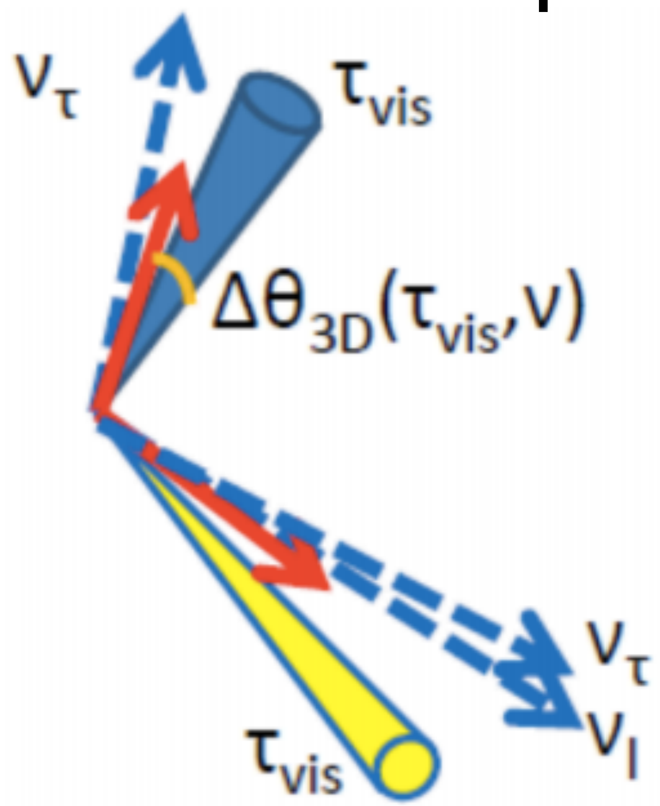


$J^P=2^+$ excluded at 99.9% CL independent of $f_{q\bar{q}}$

$H \to \tau\tau$ Search

Problem is tau decays involve neutrinos

- $\tau \to \ell\nu\nu$
- $\tau \to h\nu$ where h is some number of pions

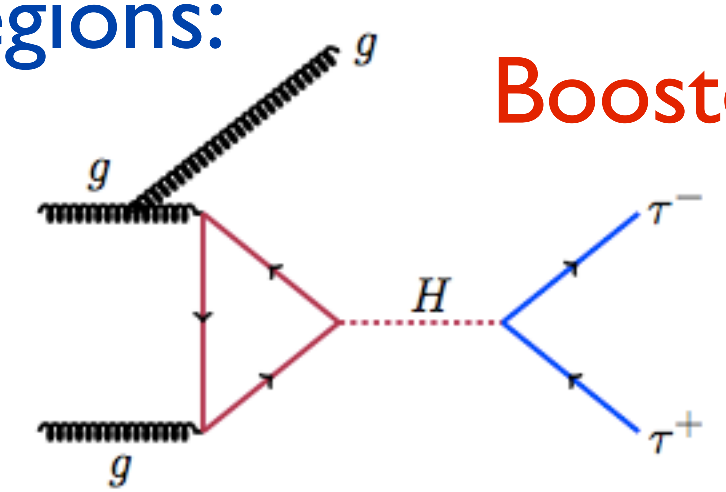


Make best estimate using measured constrains of tau mass and measured missing momentum

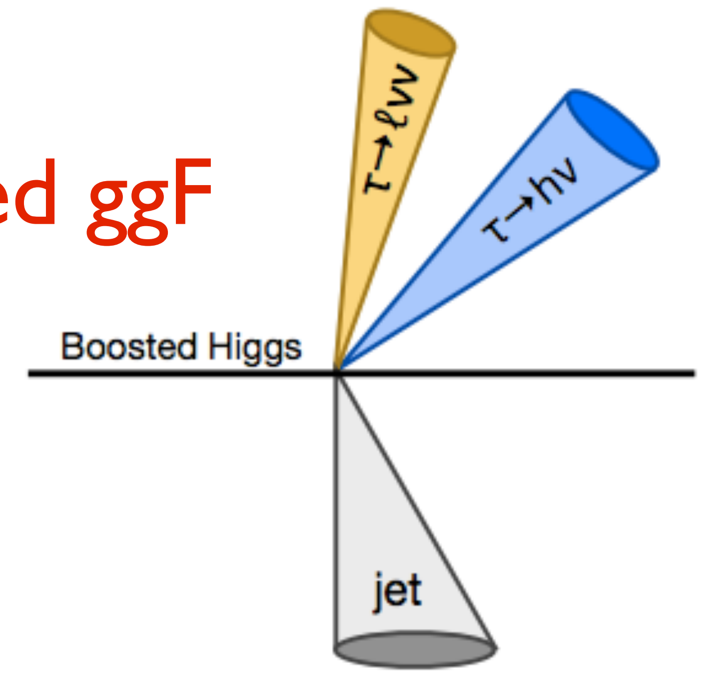
Large Backgrounds

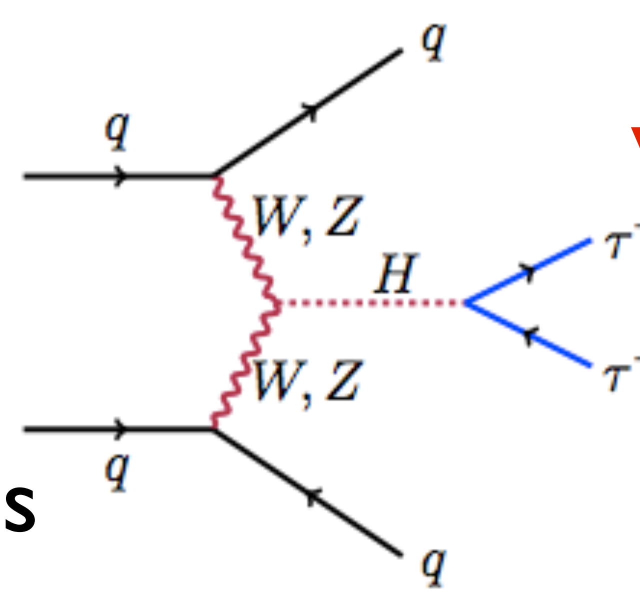
- Multijet QCD
- $Z \to \tau\tau$

Two viable signal regions:

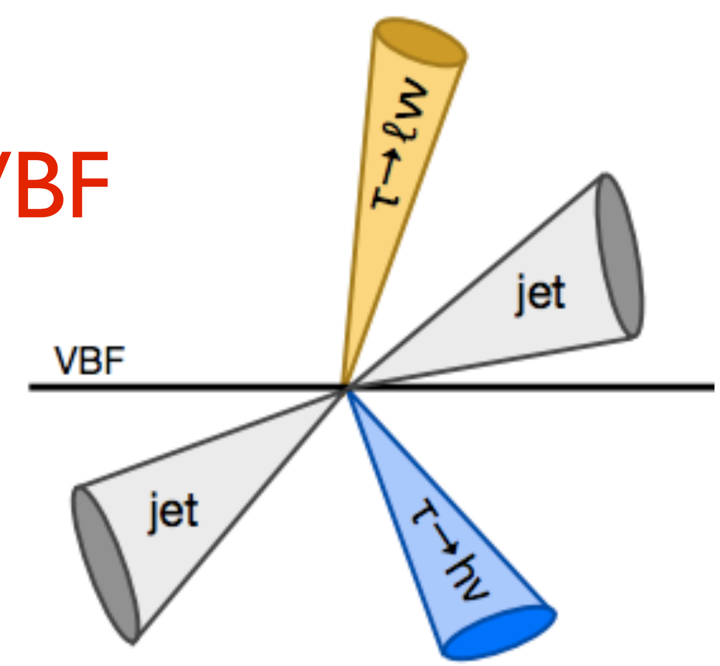


Boosted ggF





VBF



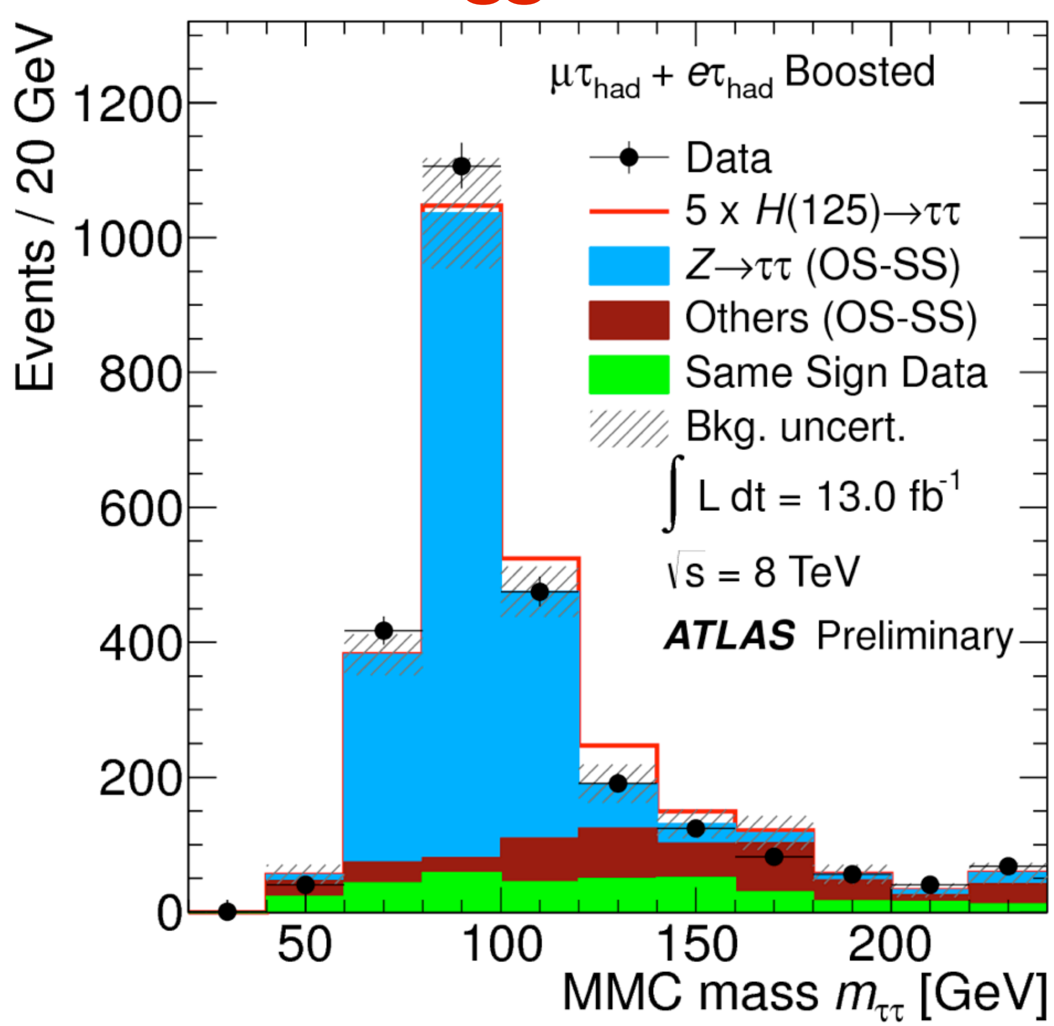
$H \rightarrow \tau\tau$ Search

Analysis divided by (tau decay) x (VBF, ggF, Boosted ggF):

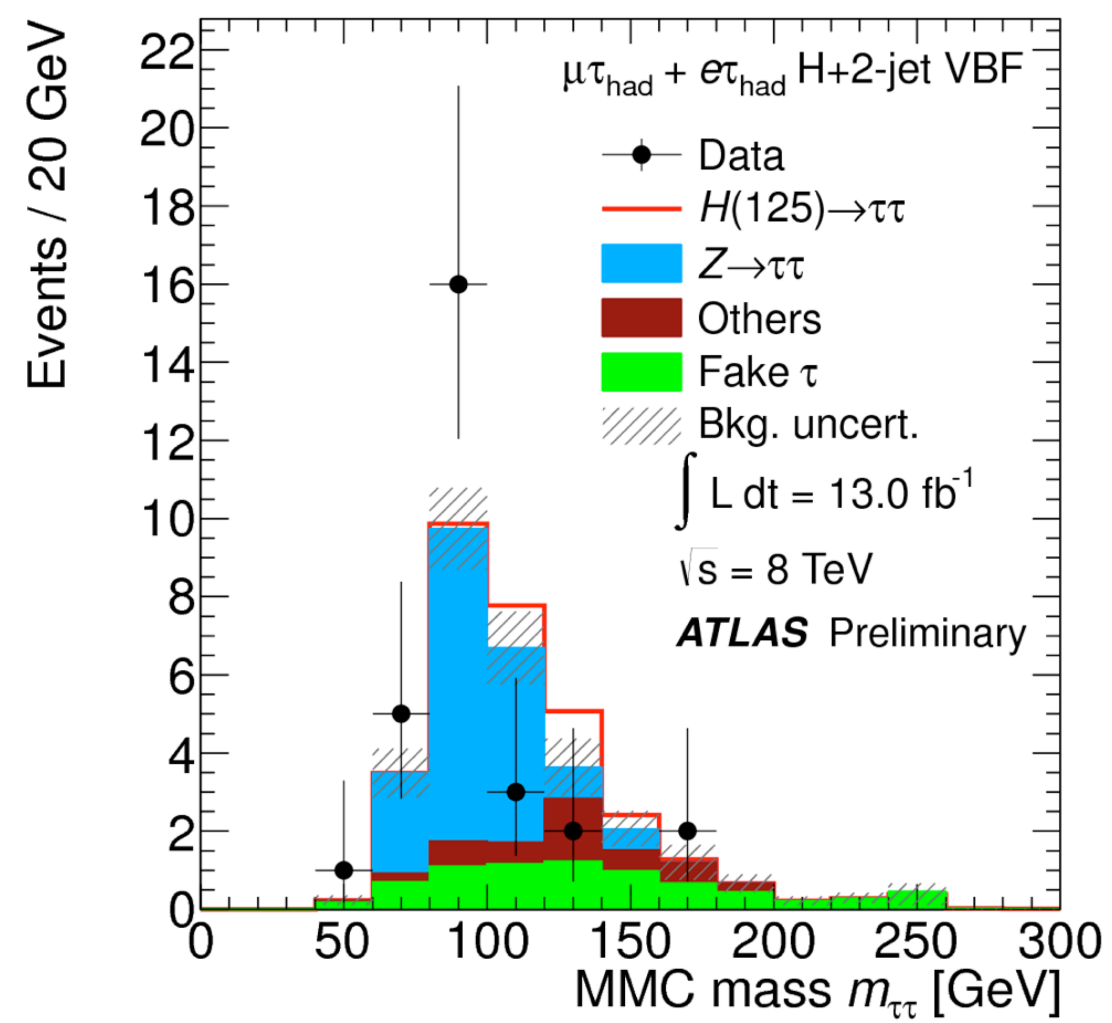
- lepton-lepton
- lepton-hadron
- hadron-hadron

Two of the most sensitive categories

Boosted ggF



VBF



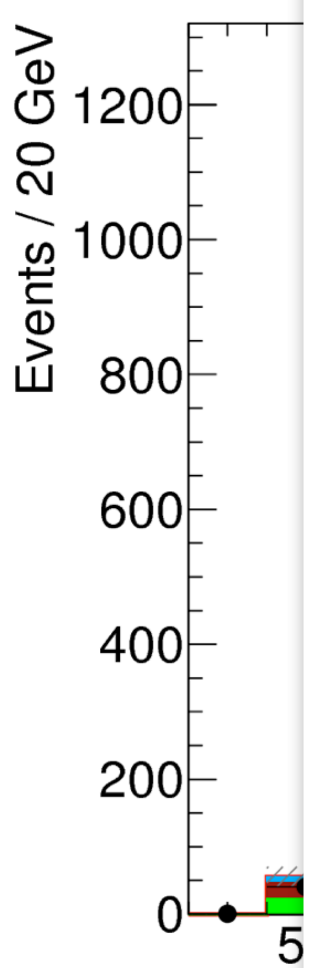
Not updated since HCP (Nov 2012)

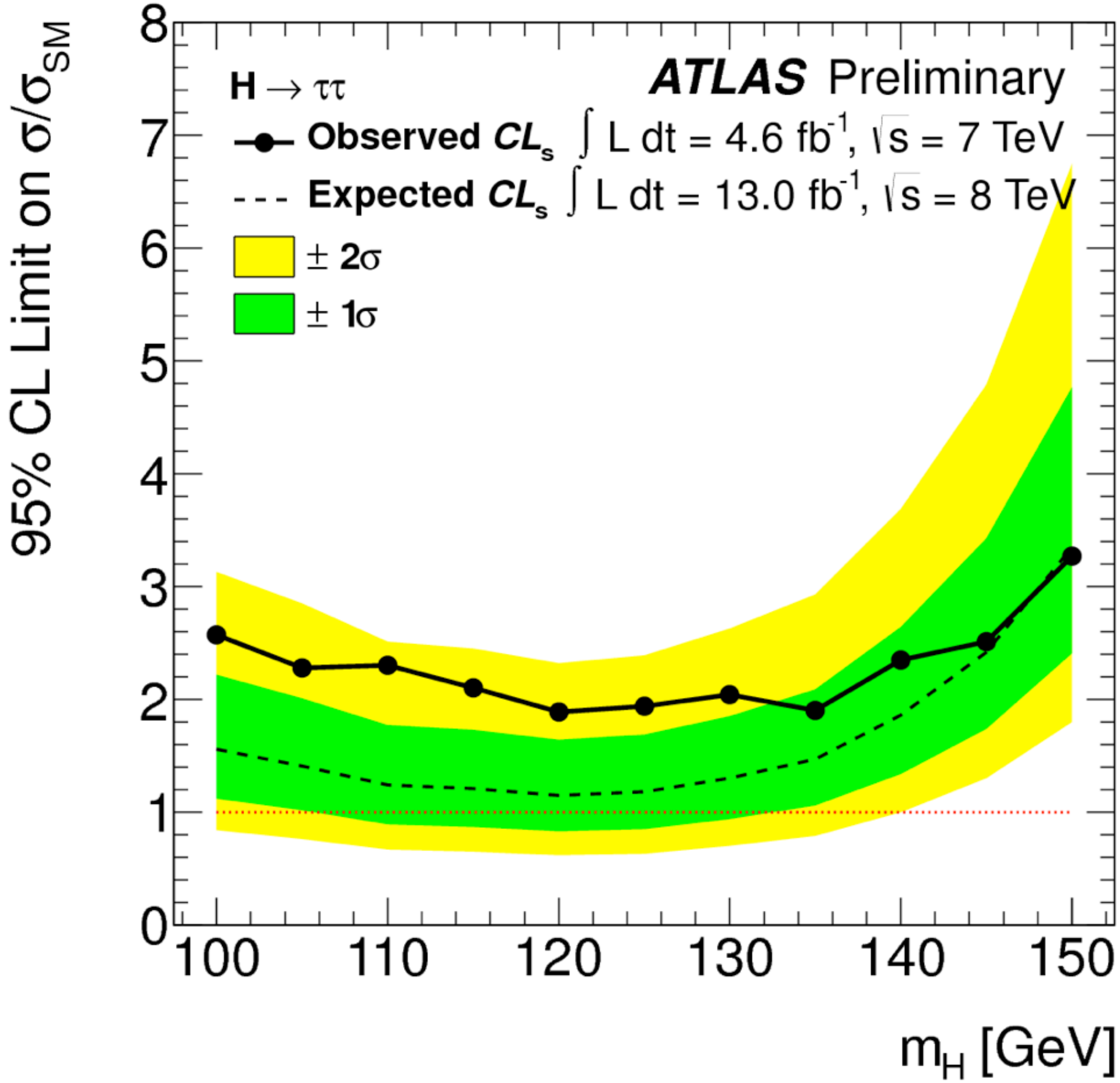
$H \to \tau\tau$

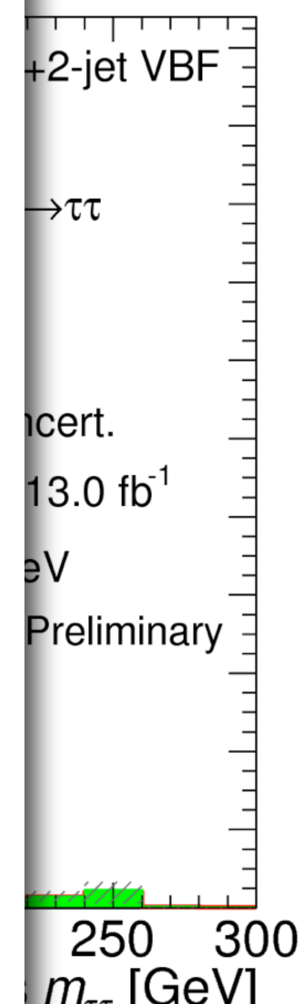
Analysis ... F):

- lepton-lep
- lepton-had
- hadron-ha

Boos







Upper limit: 1.9xSM (1.2xSM expected)

Significance: 1.1 sigma (1.9 sigma expected)

Signal Stength/SM: $\mu = 0.7 \pm 0.7$

Not update

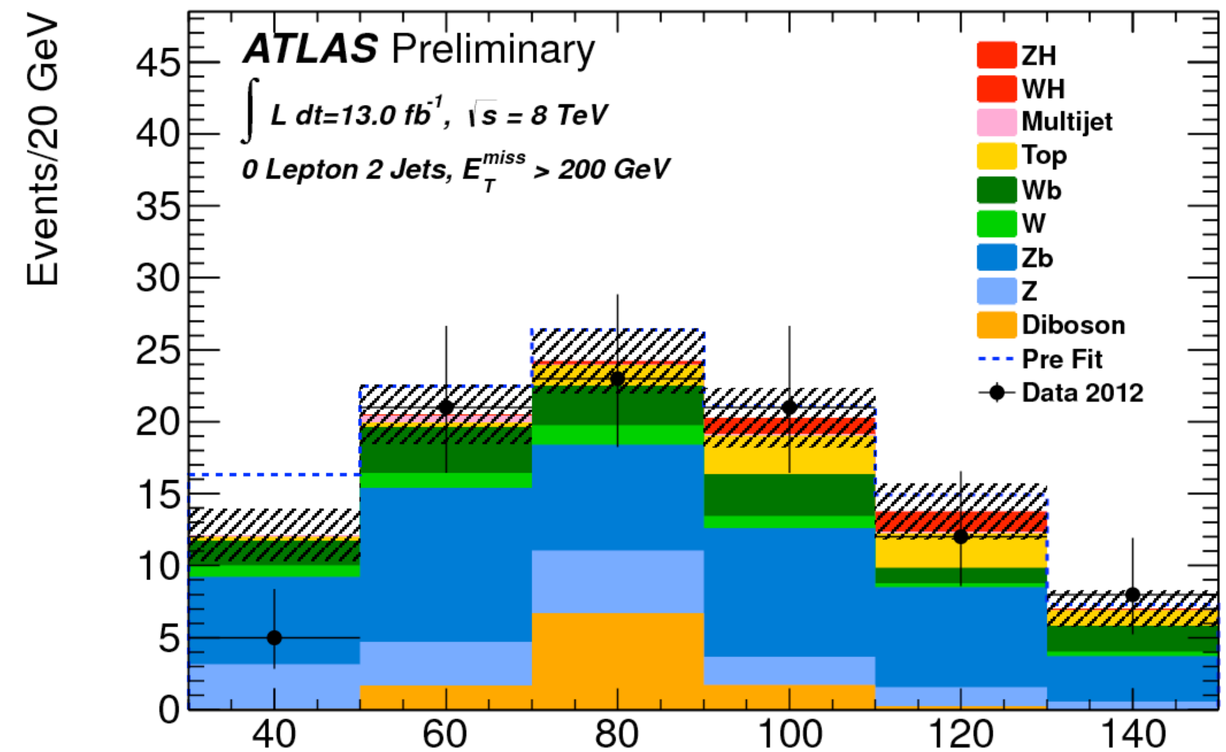
$H \to bb$ Search

Extremely difficult because
- b-jets are common
- jet resolutions are not so great
- jet distributions hard to model

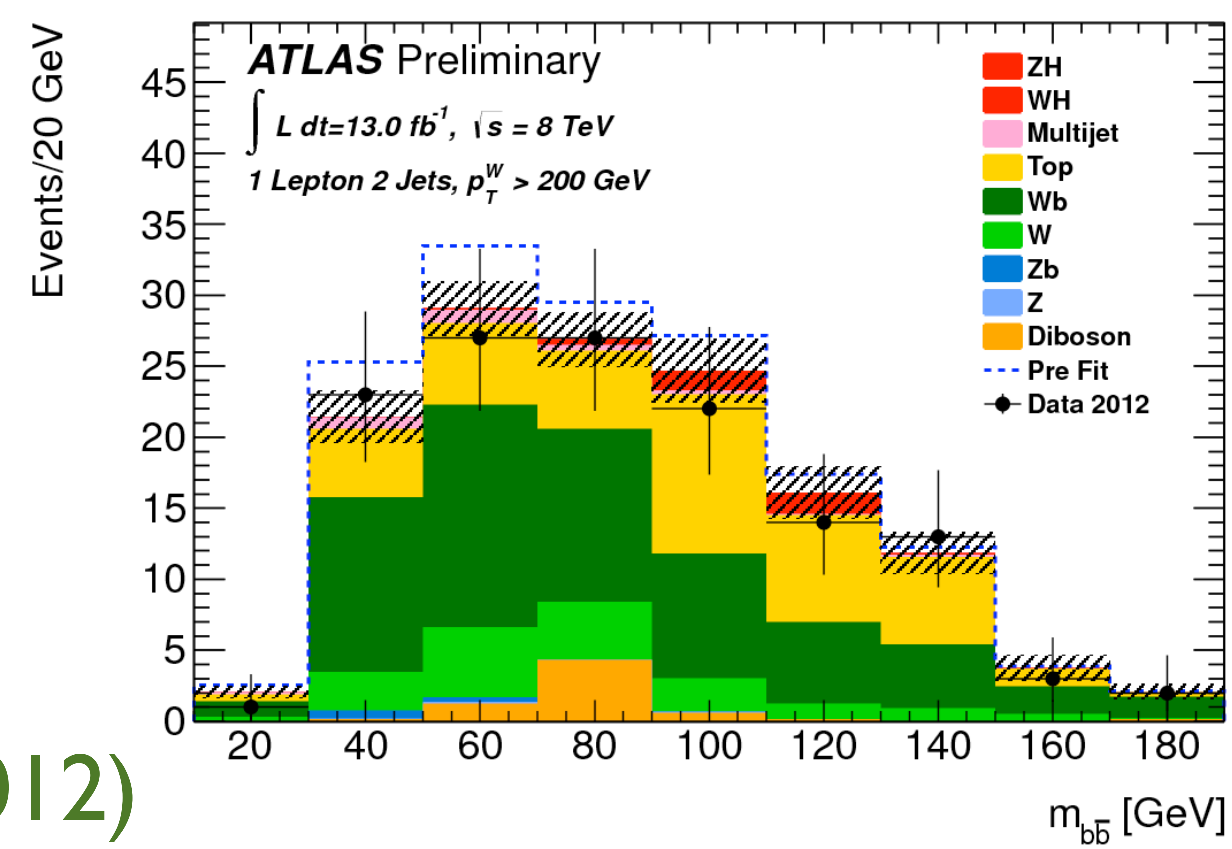
Abandon gluon fusion (ggF) and focus on VH production
- V= $W \to \ell\nu$, $Z \to \ell\ell$, $Z \to \nu\nu$
- Focus on high P_T V systems

Analysis very complex
- Signal regions sliced based on 0, 1, or 2 leptons, and based on P_T V
- Use lower P_T V to control background modeling

Not updated since HCP (Nov 2012)

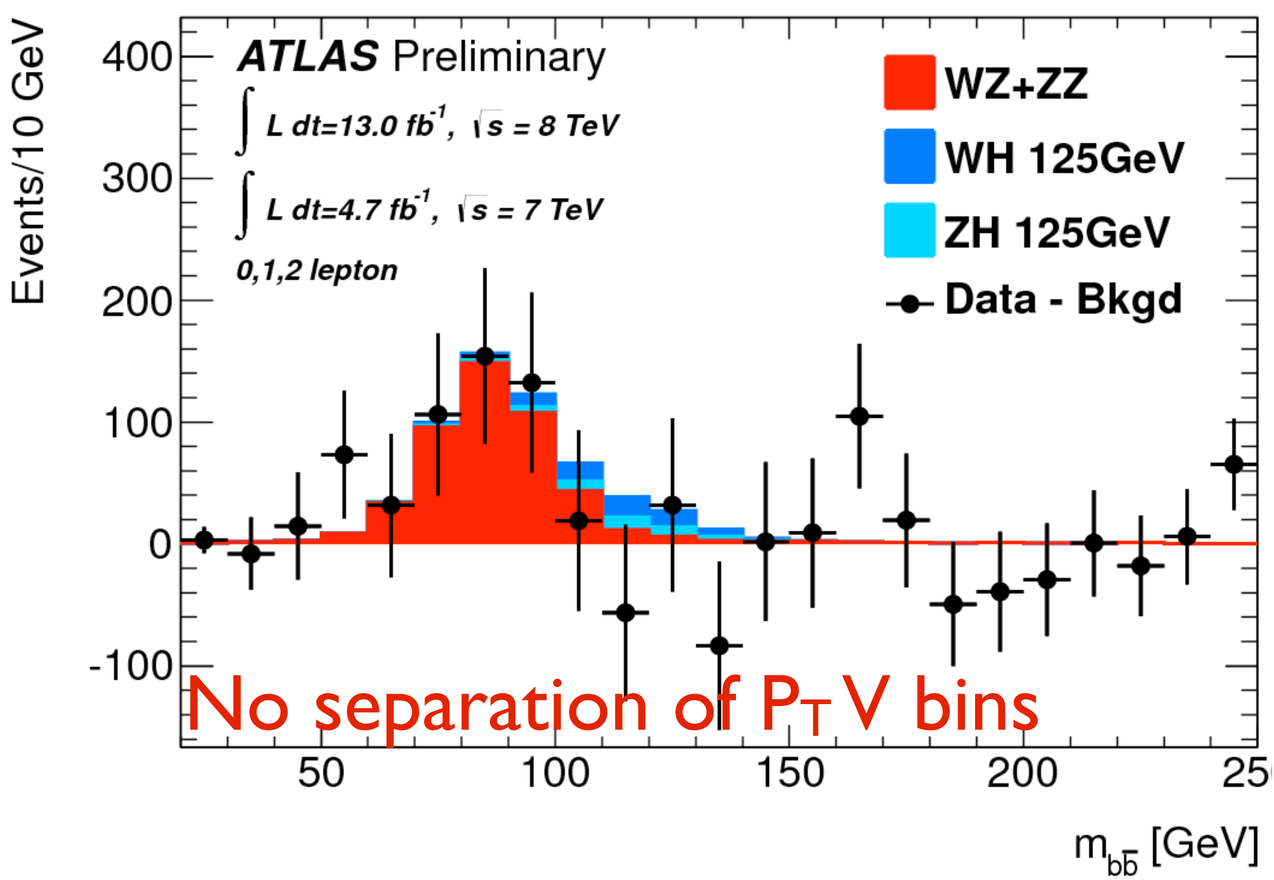


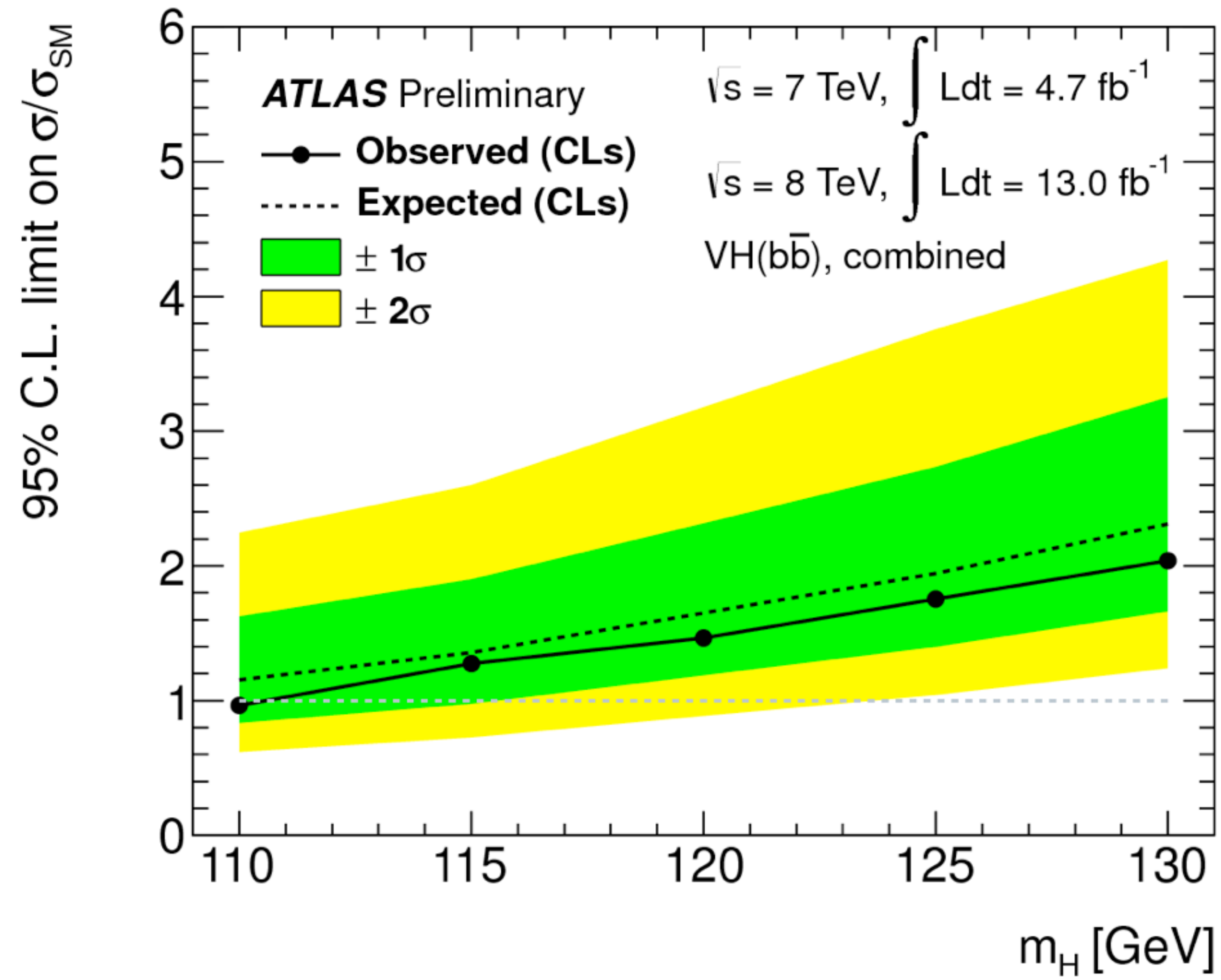
Highest S/B categories



$H \to bb$ Search

Even find the
$WZ + ZZ \to Wb\bar{b} + Zb\bar{b}$
background was hard





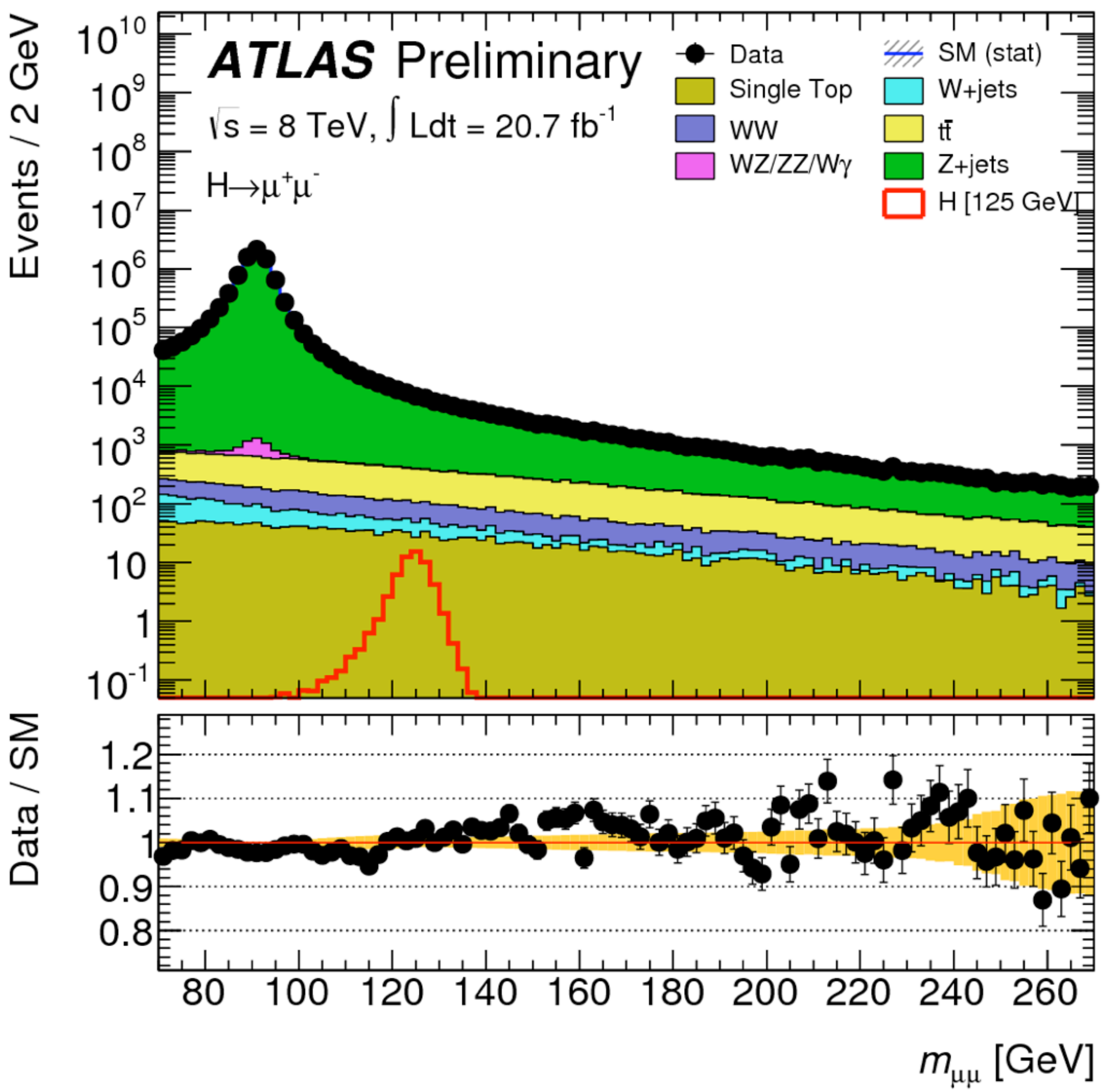
Now 4.0 sigma signal for
WZ+ZZ with one $Z \to b\bar{b}$

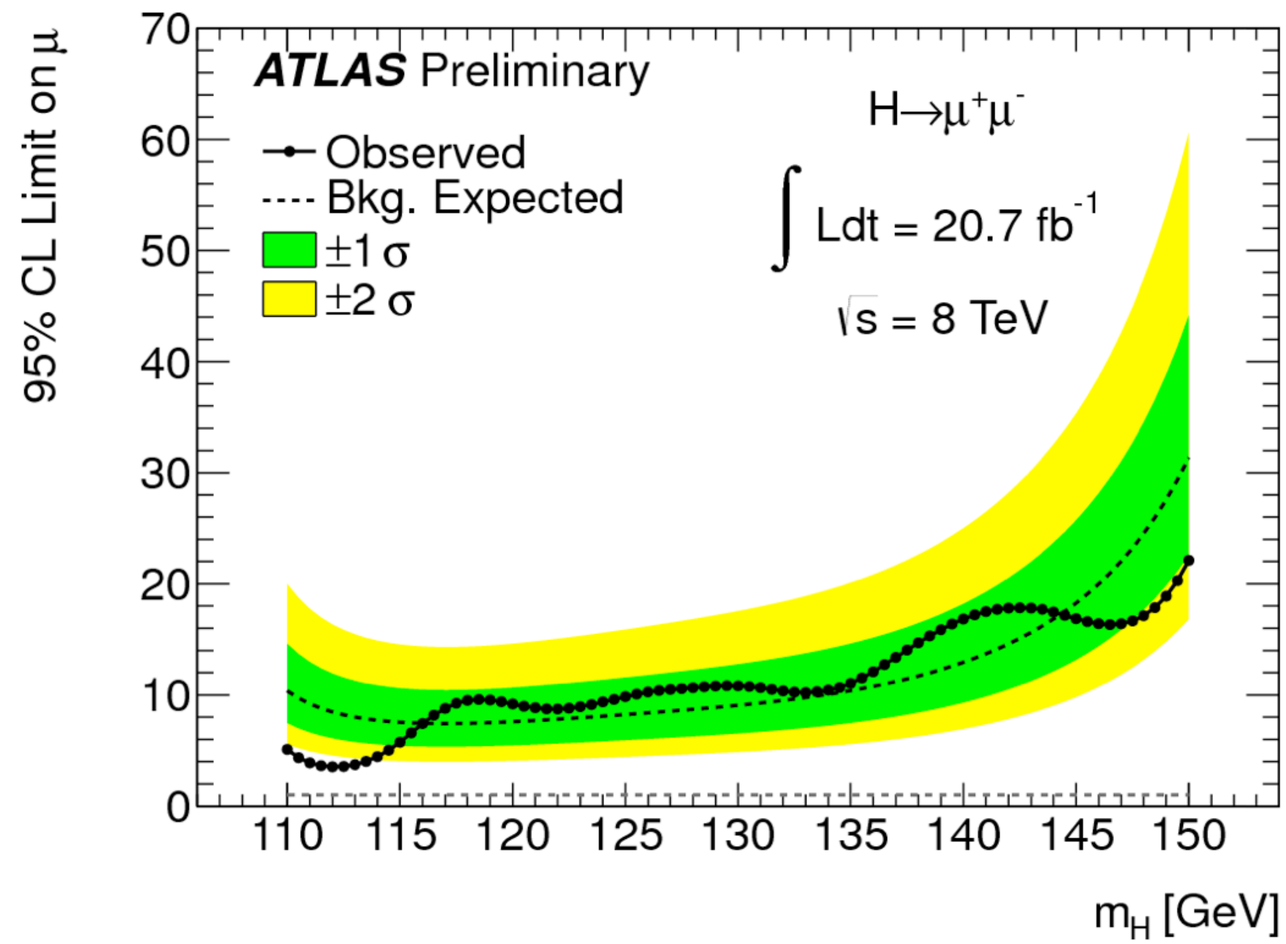
Exclusion is 1.8 times the SM

WZ+ZZ (to bb) is ~5
times the Higgs signal

$H \to \mu\mu$ Search

If it is really the Higgs it couples to mass, so $H \to \mu\mu$ should be very small



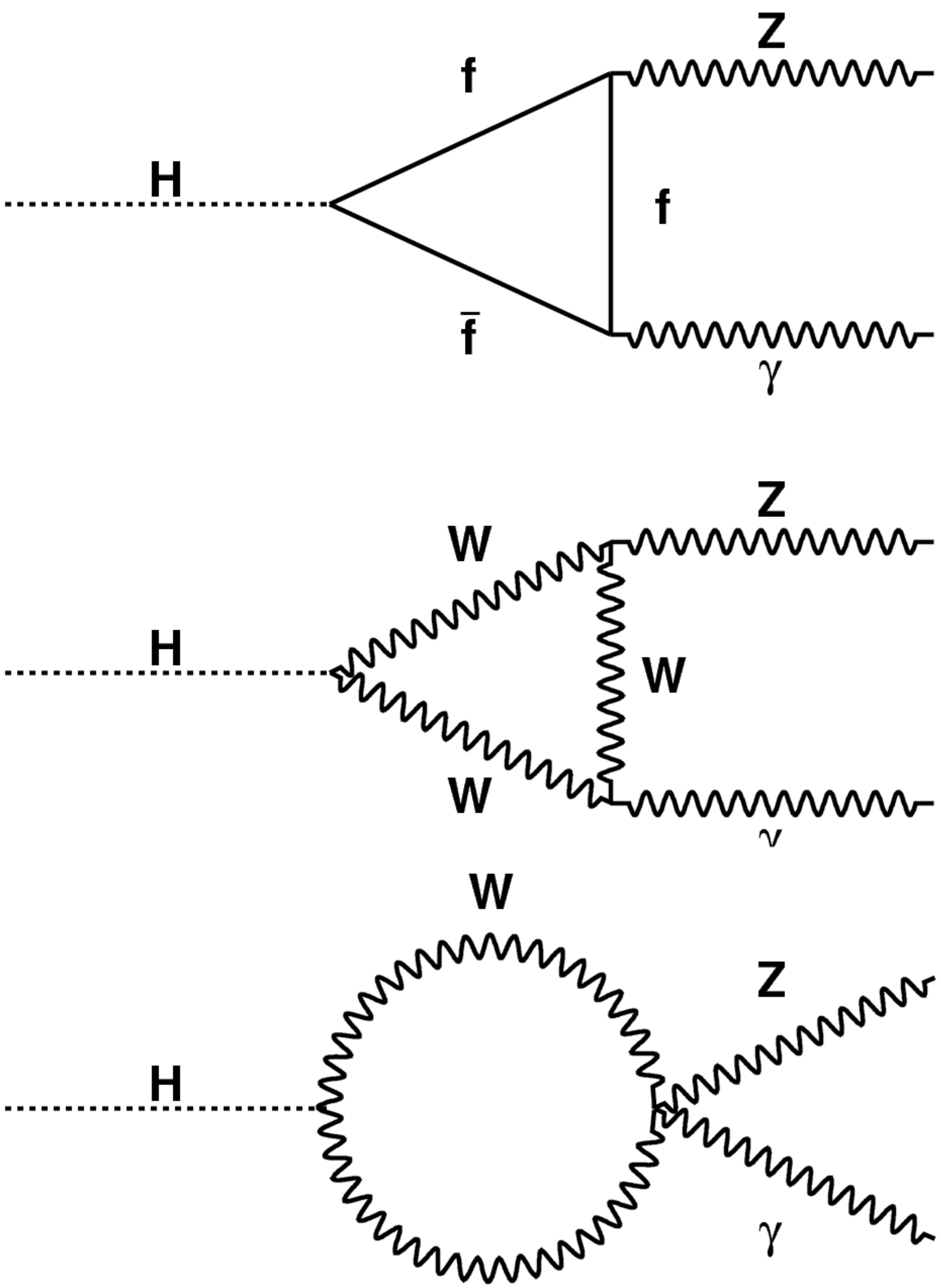


Limit is 9.8 times SM at m_H = 125 GeV

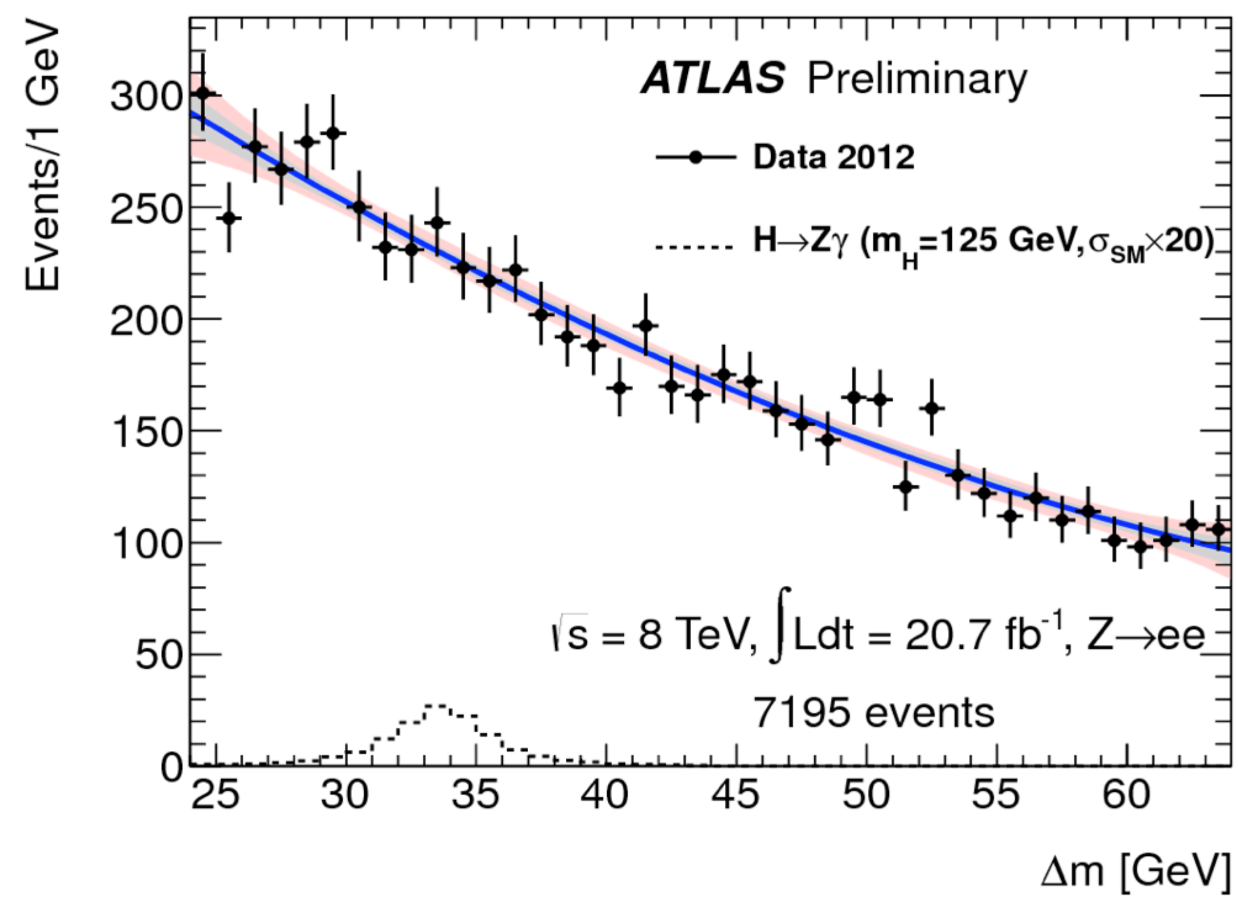
Predicted signal is under a sea of Drell-Yan

$H \to Z\gamma$ Search

Another loop induced coupling



Reconstructed in the $H \to Z\gamma \to \ell^+\ell^-\gamma$ channel



Observed limit is18.2xSM with 13.5xSM expected

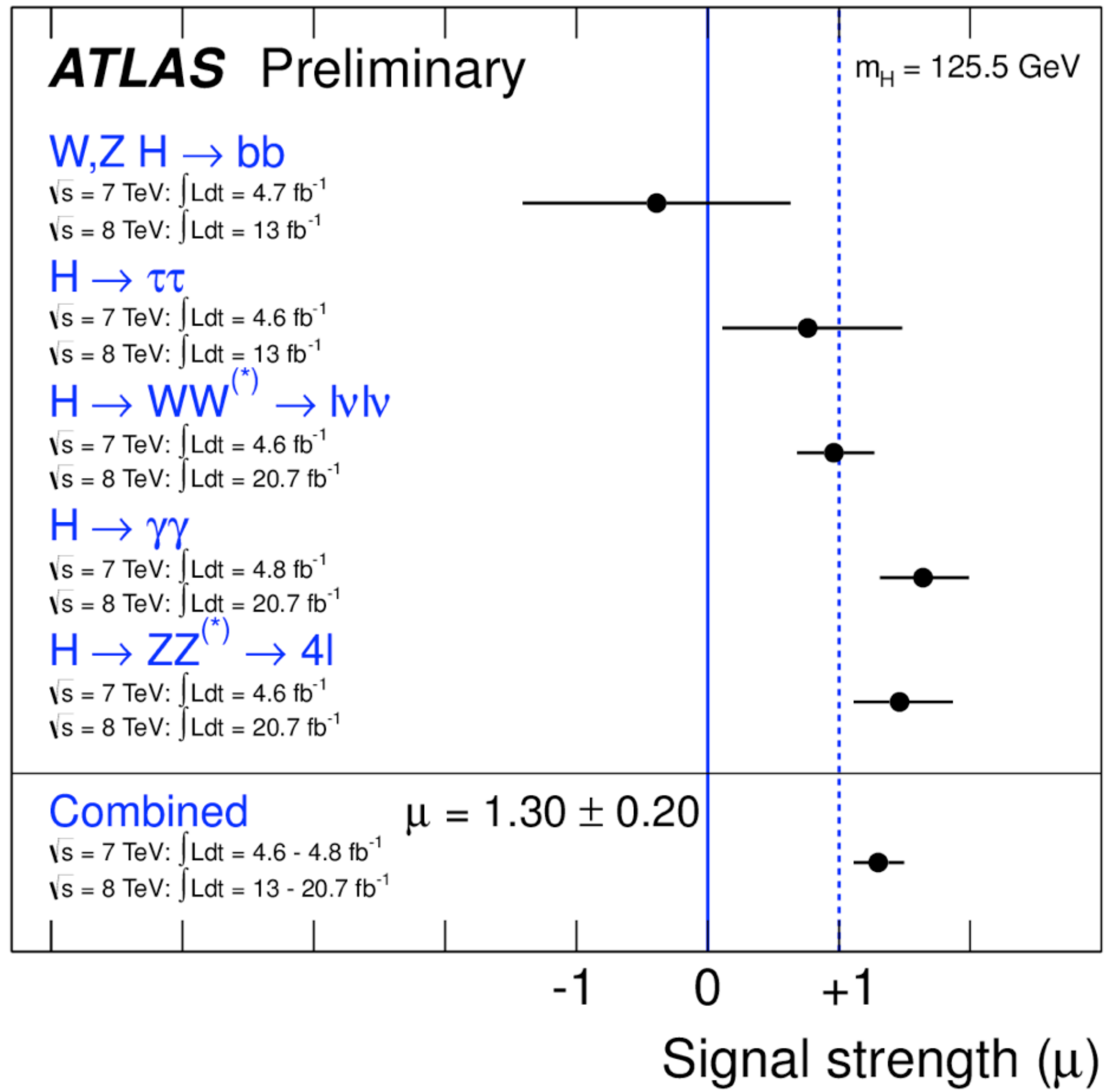
Grand Combination

We combine all the inputs just discussed into global likelihood fit

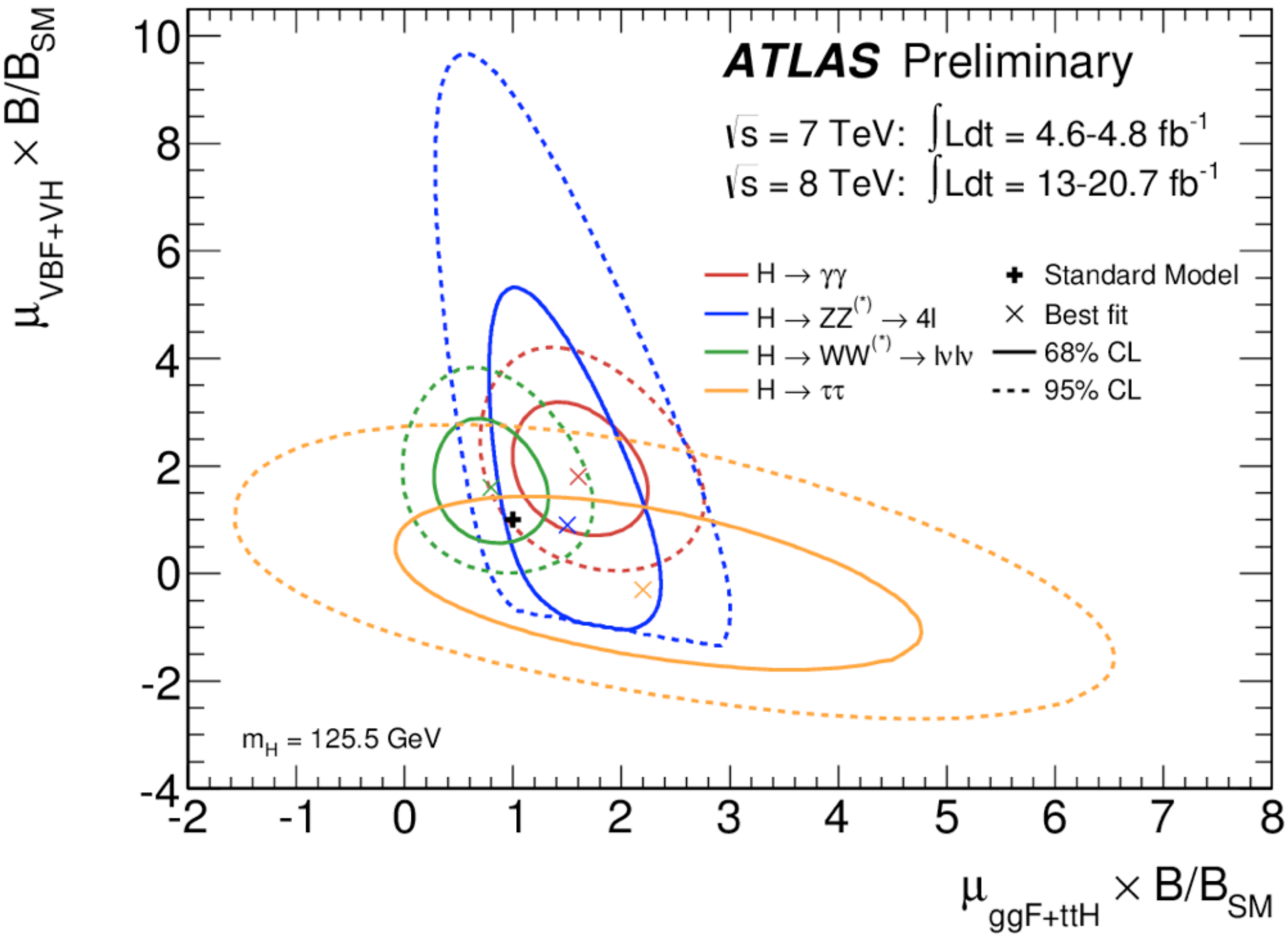
- includes correlations of systematics

Summary of Production Modes

	ggF	VBF	VH	ttH
$\gamma\gamma$	✓	✓	✓	✓
WW	✓	✓		
ZZ	✓	✓	✓	
$\tau\tau$	✓	✓	✓	
$b\bar{b}$			✓	✓



Evidence of VBF production

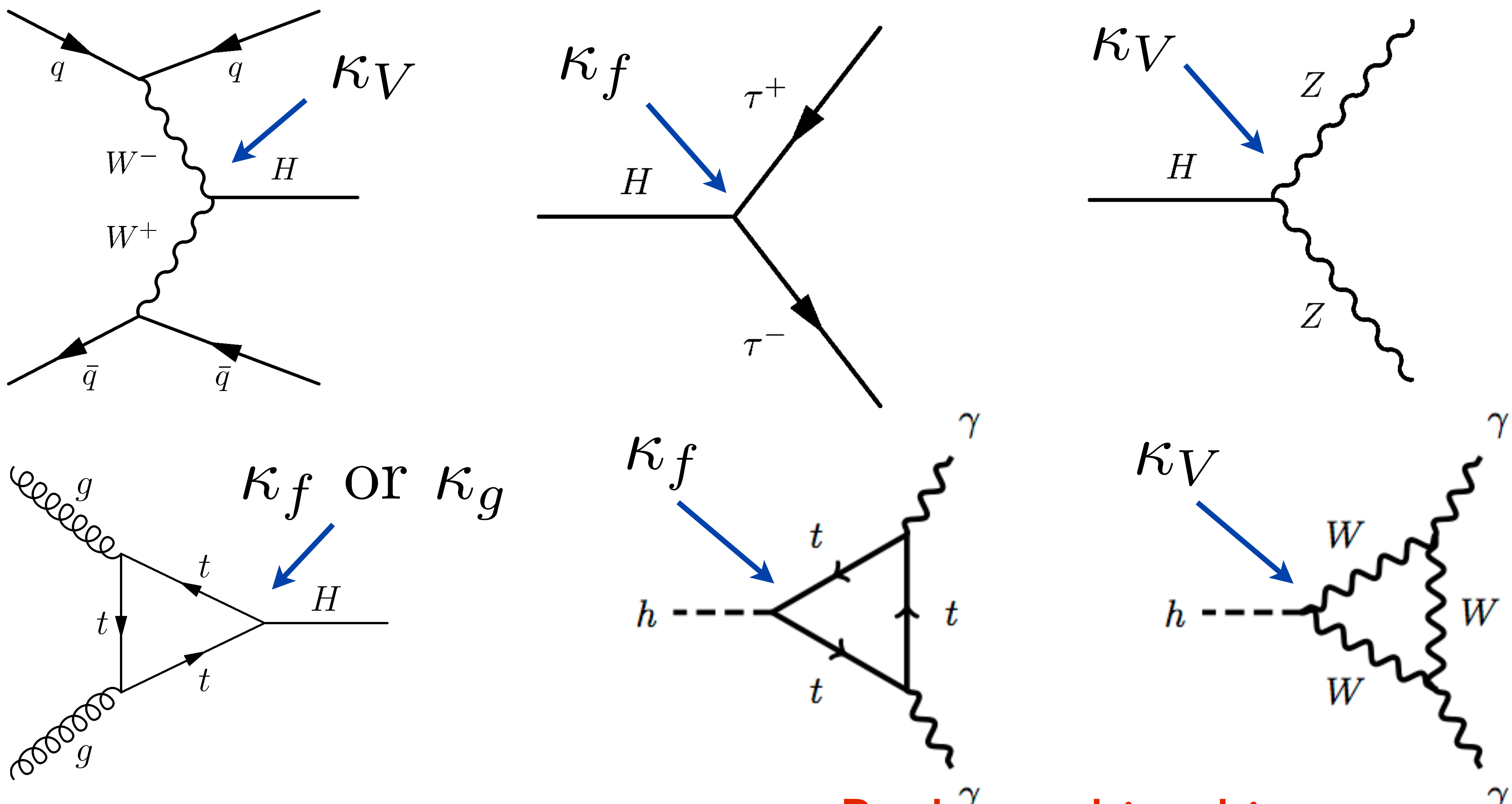


3.1σ evidence of VBF production

Coupling Interpretation

Several different models depending on assumptions:

- New particles in loops?
- BSM contributions to total width (invisible decays, other decays to BSM)?



Both combined in κ_γ

Coupling Interpretation

Example looking for new physics in loops

Only decays to SM particles

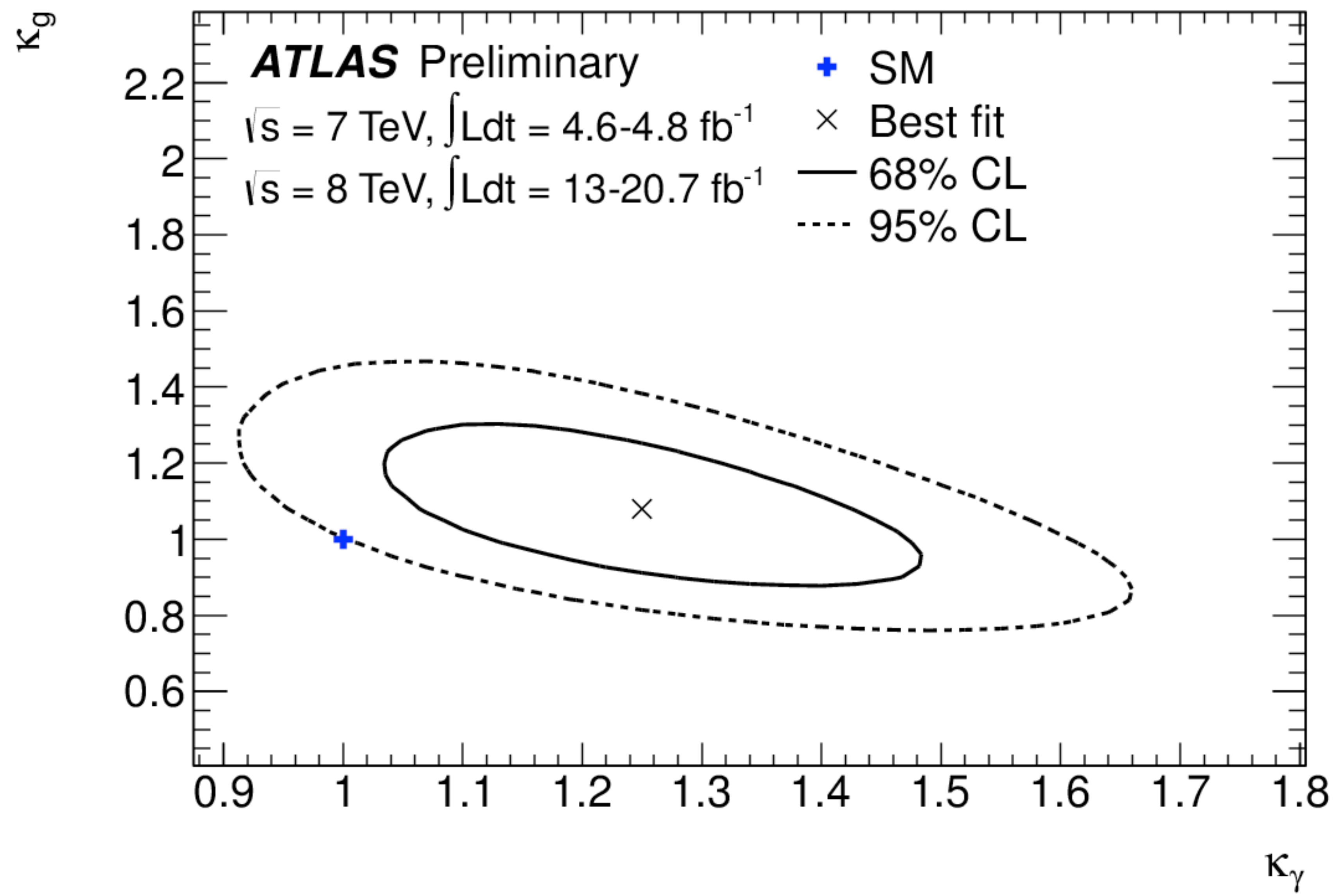
$$\kappa_g = 1.08 \pm 0.14$$

$$\kappa_\gamma = 1.23^{+0.16}_{-0.13}$$

Include invisible or other BSM

$$\kappa_g = 1.08^{+0.32}_{-0.14}$$

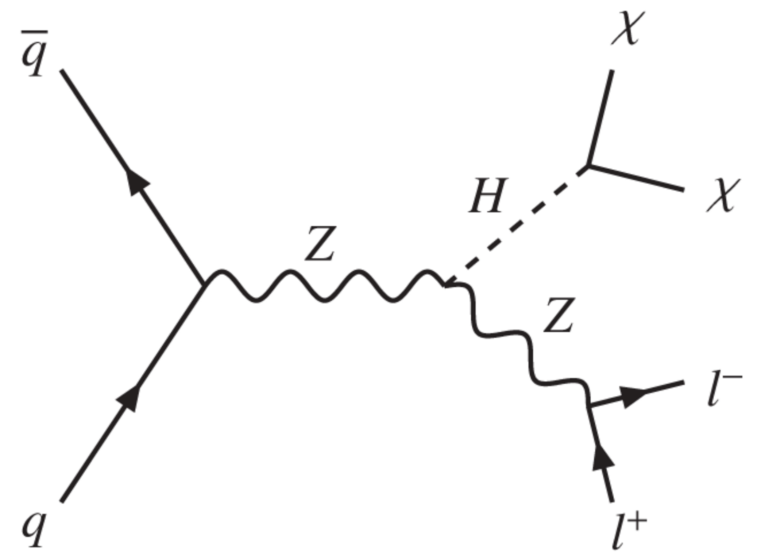
$$\kappa_\gamma = 1.24^{+0.16}_{-0.14}$$



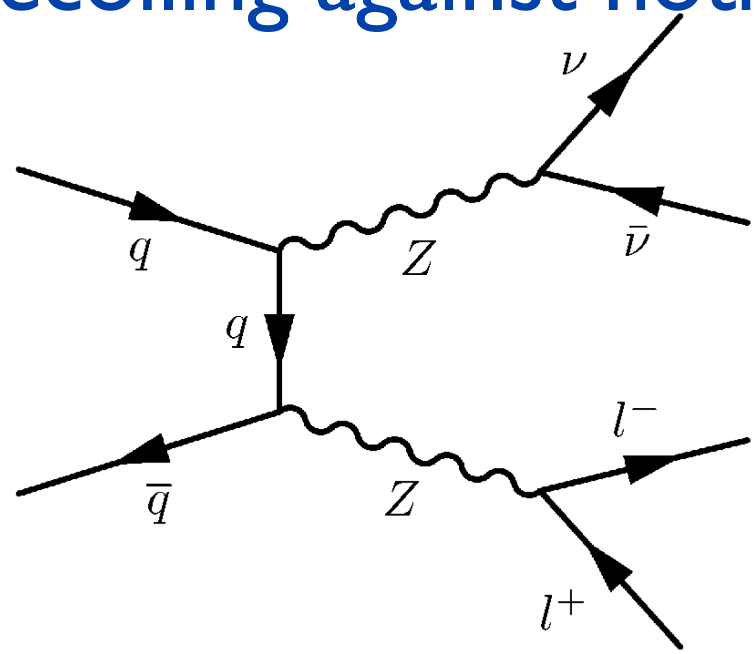
$BR_{\text{invisible or non-SM}} < 0.6$ at 95% CL

Higgs to Invisible

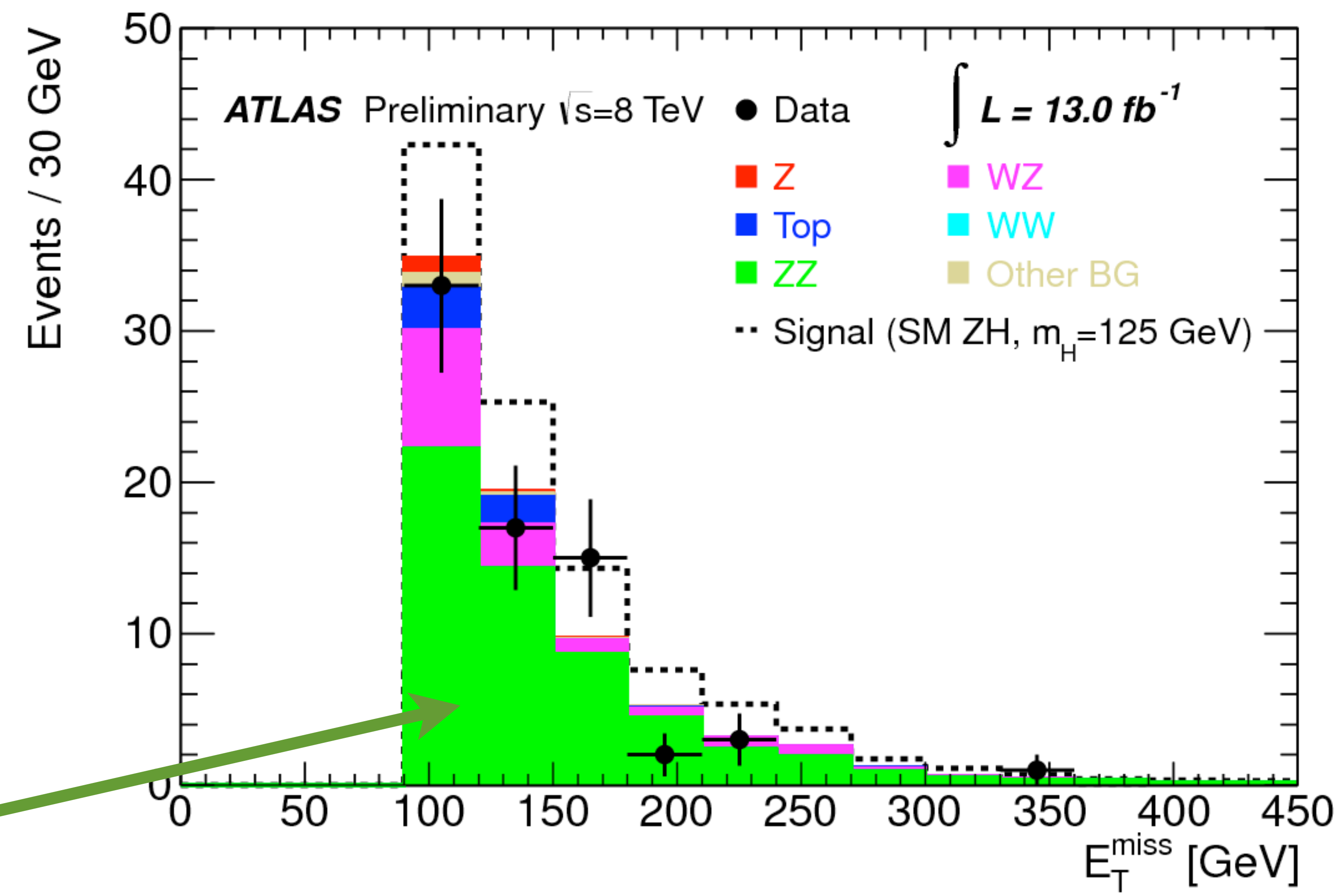
We have also searched directly for Higgs to invisible...



Z recoiling against nothing



SM source of Z recoiling against nothing

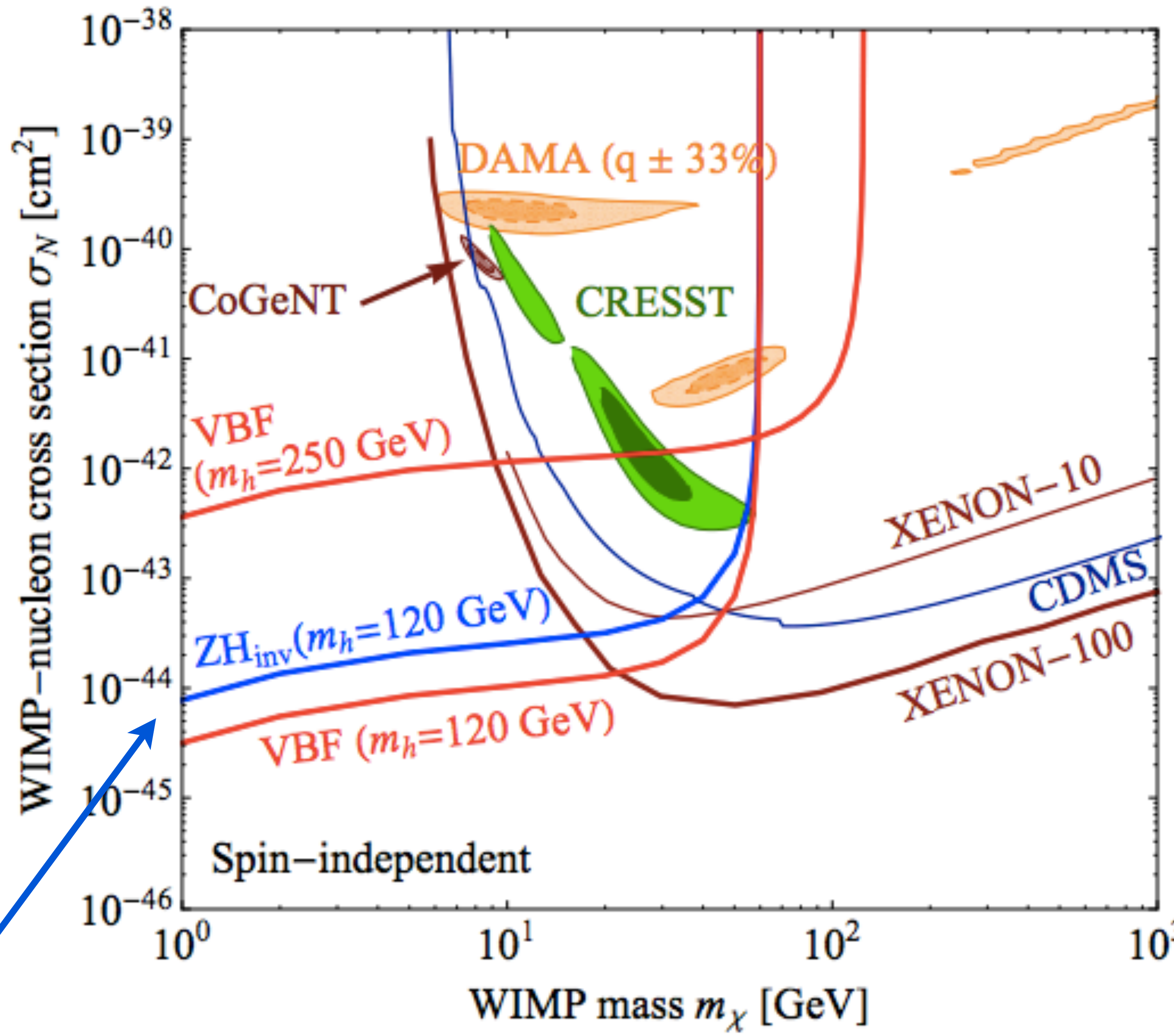


$BR_{invisible} < 0.65$ (observed) at 95% CL, (0.84 expected)

Higgs to Invisible Interpretation

Implications for dark matter searches if DM to nucleon couplings is entirely Higgs

from arXiv:1109.4398v1 [hep-ph]



Based on expected sensitivity (BR_{inv}<0.75) very close to observed

Summary

There is definitely something there that strongly resembles the SM Higgs

Spin:

•various combinations of 0^-, 1^+, 1^-, and 2^+ excluded

Couplings:

•order 20-30% constraints on vectors, fermions just crossing the sensitivity thresholds

•Interesting sensitivity to dark matter and other BSM