Search for the Higgs boson in fermionic channels using the ATLAS detector

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for the ATLAS Collaboration

2013 PASCOS 19th International Symposium on Particles, Strings and Cosmology

Where we stand

$$\mathcal{L} = \frac{1}{2}(\partial_\mu\phi\partial^\mu\phi - m_H^2\phi^2)$$

←scalar

$$+ \frac{vg^2}{2}\phi W_\mu^+ W^{-\mu} + \frac{v(g^2+g'^2)}{4}\phi Z_\mu Z^\mu$$

←coupling to W/Z

$$- \sum_f Y_f \phi \bar{f} f$$

←coupling to fermion

$$- \lambda v\phi^3 - \lambda\frac{\phi^4}{4}$$

←self coupling
(at future experiment)

$$+\frac{g^2}{2}\phi^2 W_\mu^+ W^{-\mu} + \frac{(g^2+g'^2)}{4}\phi^2 Z_\mu Z^\mu$$

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←coupling to fermion?

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(at future experiment)

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Motivation

- ❖ Gauge invariance as guiding principle of gauge sector in Standard Model (SM)
- ❖ No guiding principle in Higgs sector
  - ▸ especially true for Yukawa coupling

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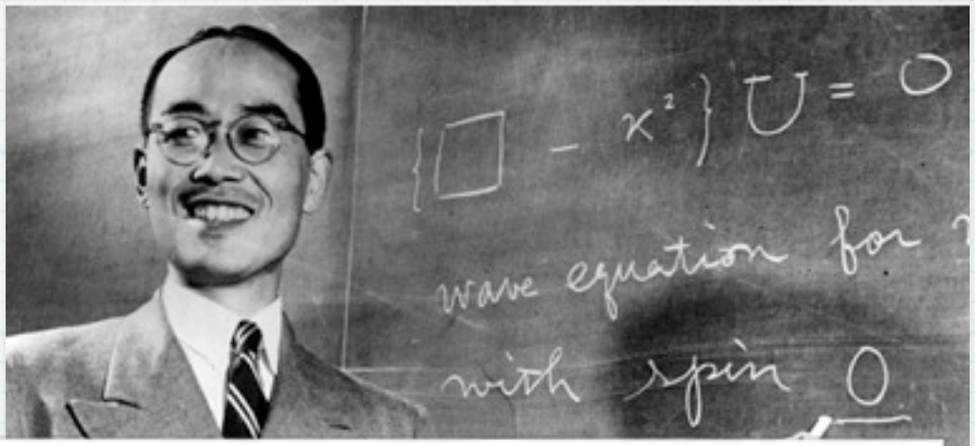
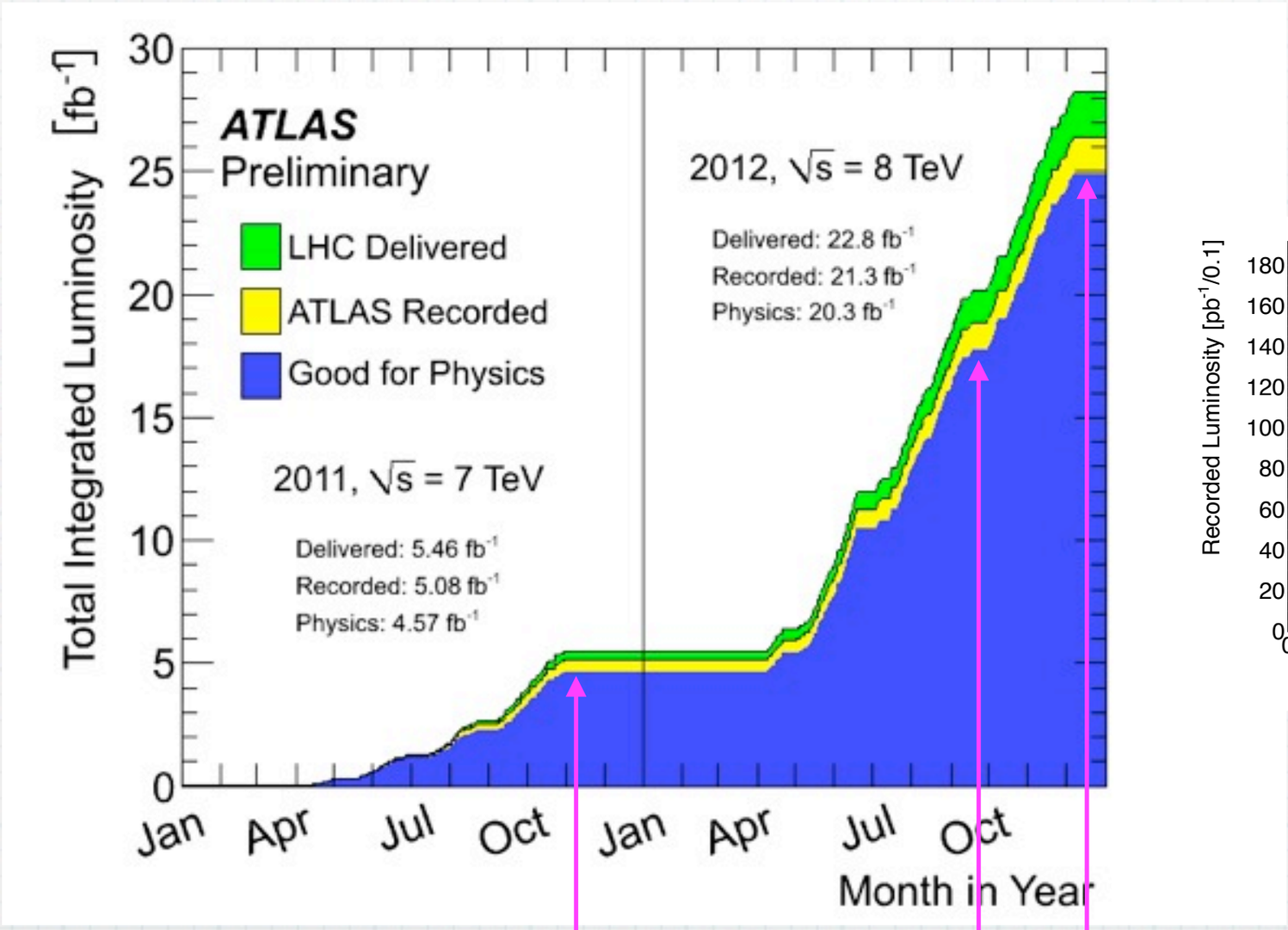
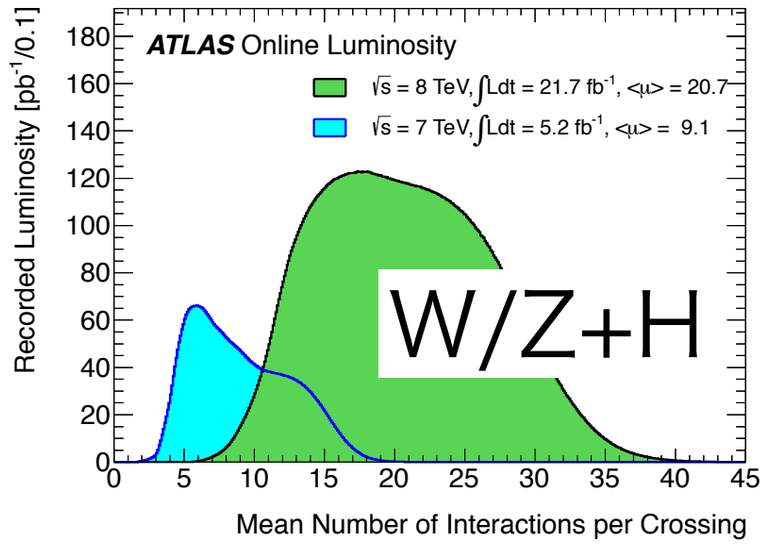


Direct experimental confirmation is essential

Dataset & Search channels



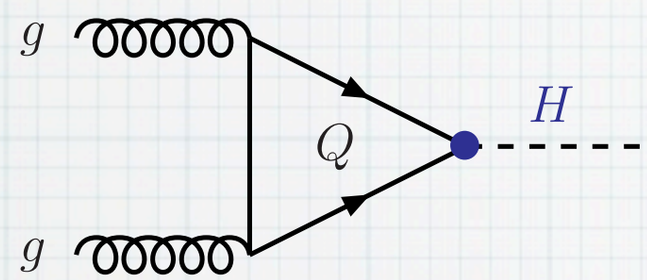


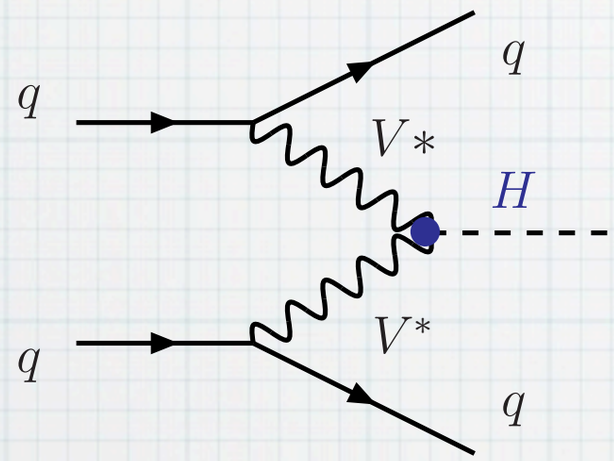
ttH(→bb)
ATLAS-CONF-2012-135

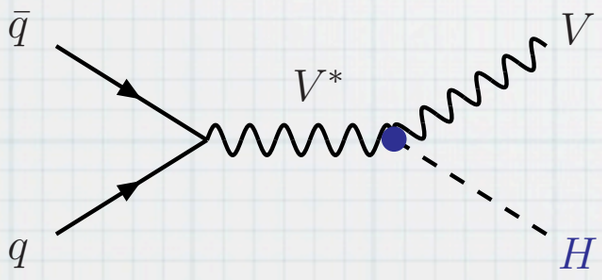
H→ τ τ
ATLAS-CONF-2012-160

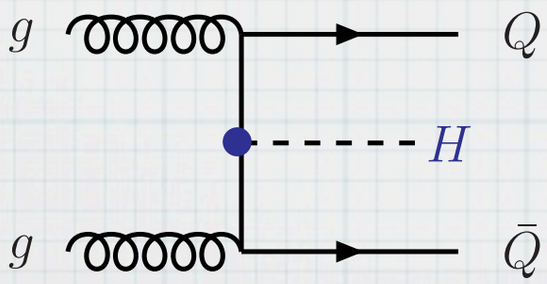
W/Z+H(→bb)
ATLAS-CONF-2013-079

Higgs Production and Decay (SM)

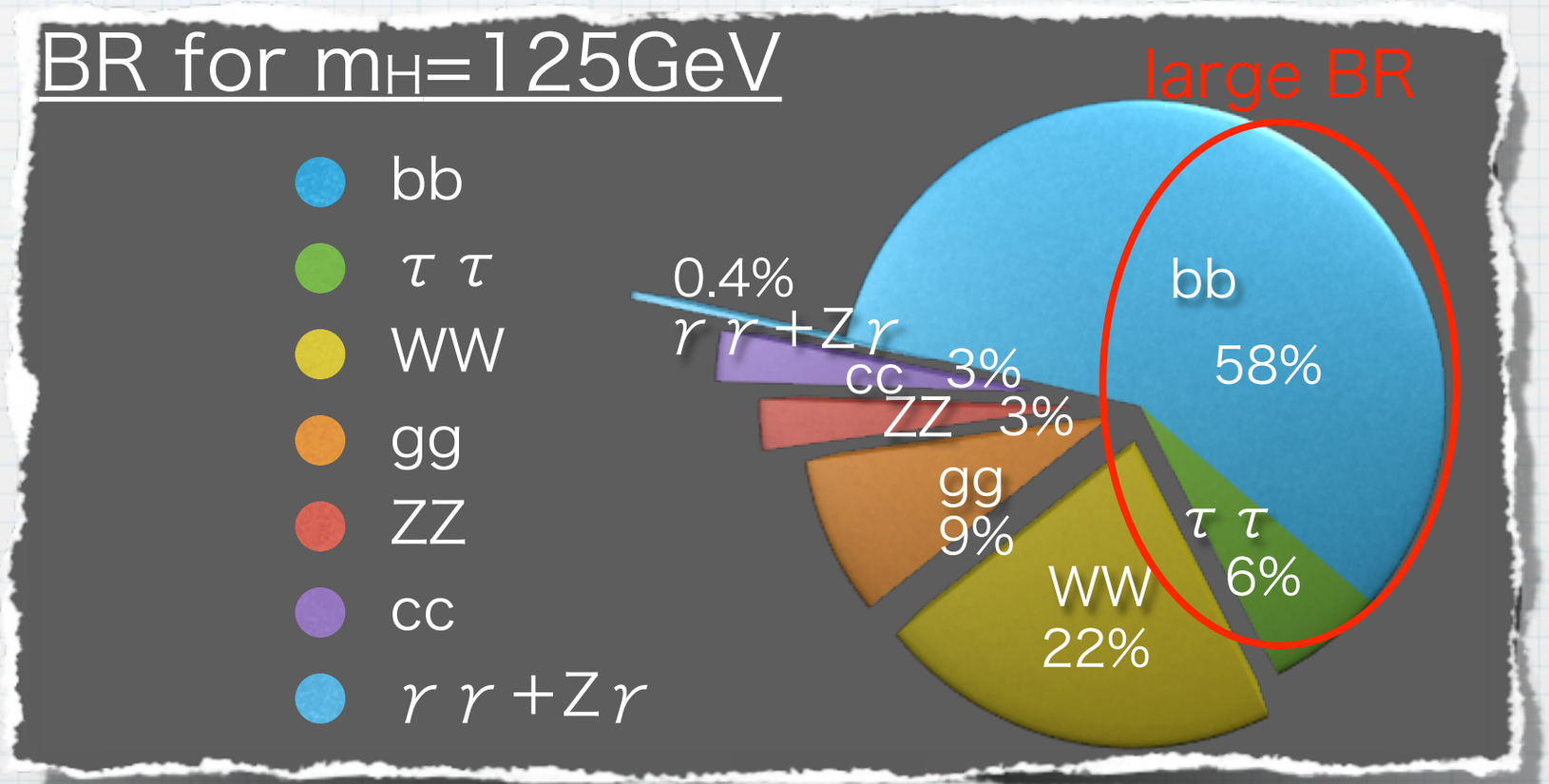




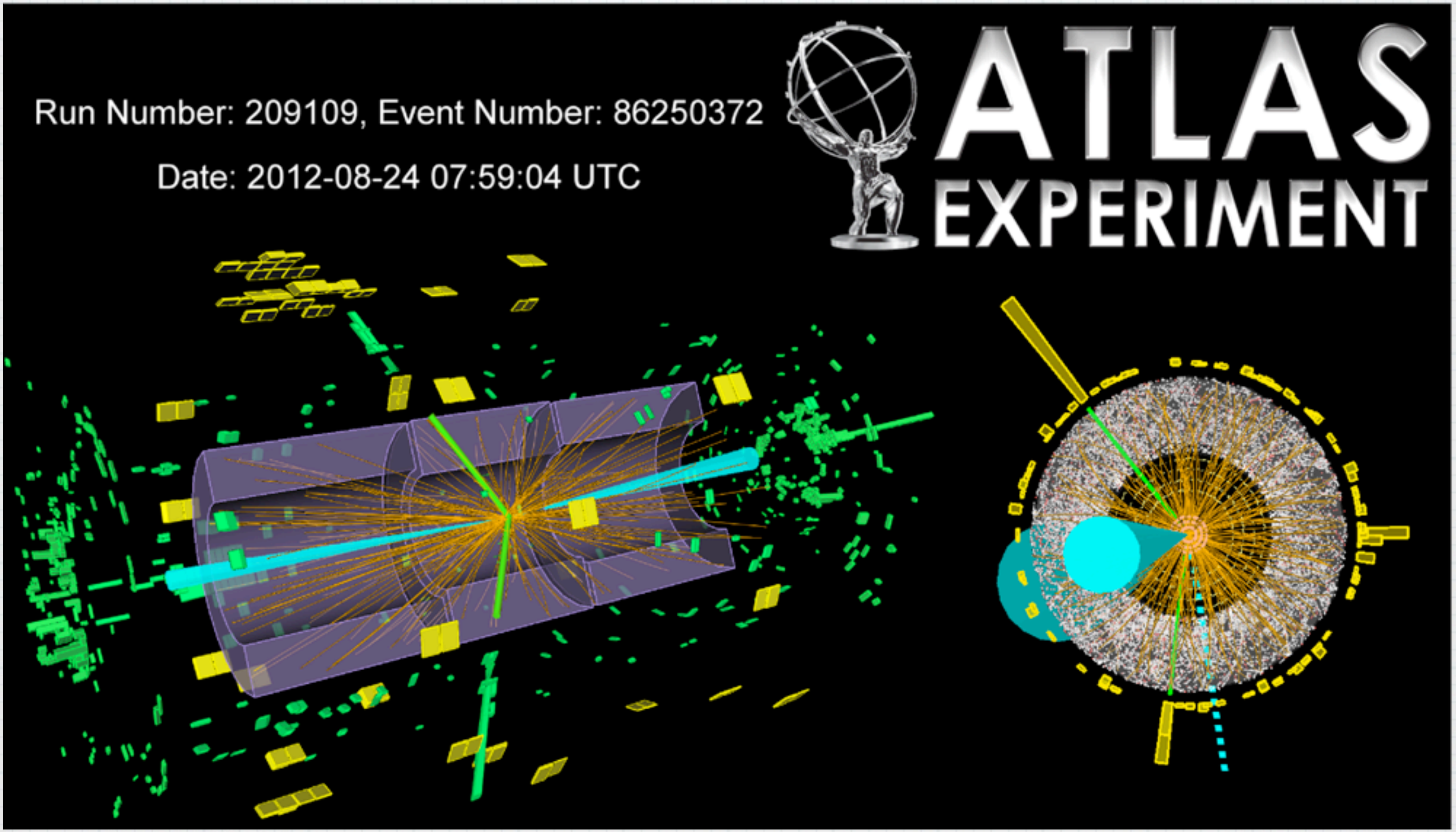




m_H=125GeV	σ (pb) @7TeV	σ (pb) @14TeV	14TeV / 7TeV
Gluon Fusion (gF)	15.3	50.0	3.3
Vector Boson Fusion (VBF)	1.2	4.2	3.5
WH ZH	0.6 0.3	1.5 0.9	2.5 3.0
ttH	0.1	0.6	6.0



$H \rightarrow \tau\ \tau$

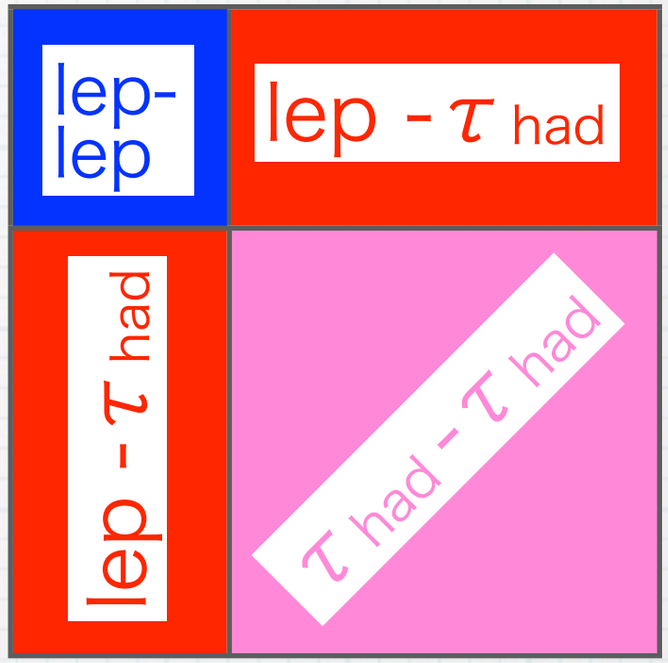


H→ τ τ sub-channels & τ ID

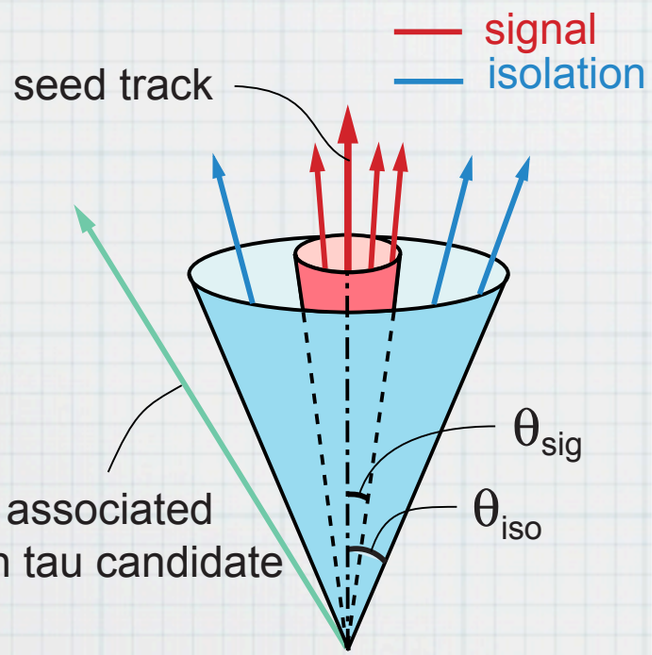
- τ decay split into 3 channels
  - l ν ν + l ν ν (lep - lep)
  - l ν ν + had ν (lep - τ had)
  - had ν + had ν (τ had - τ had)

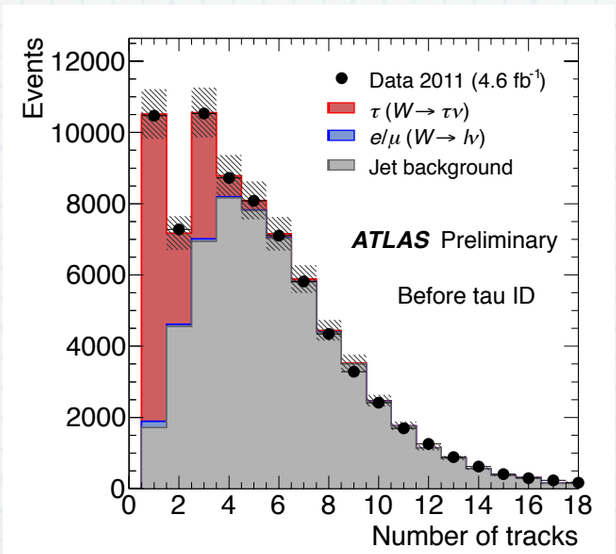
lν ν
BR~35%

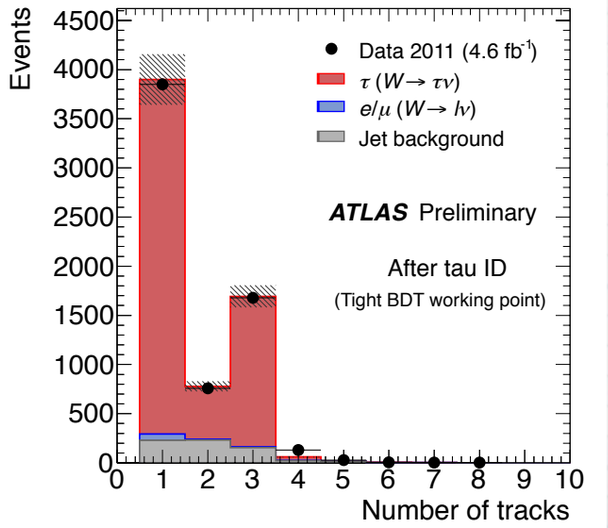
had ν
BR~65%

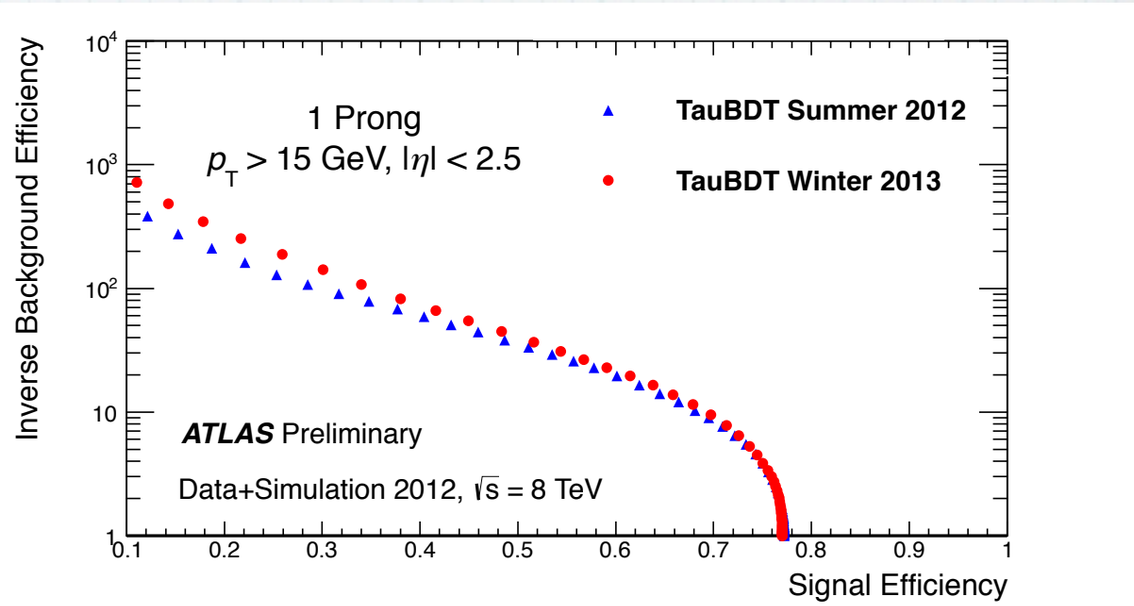


pT of lepton
or τ had
> 10-25 GeV





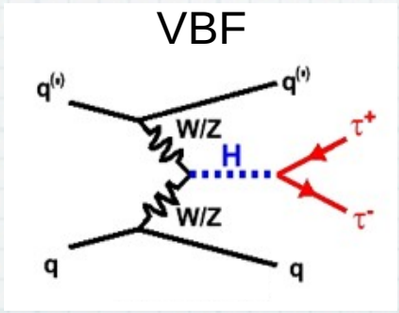




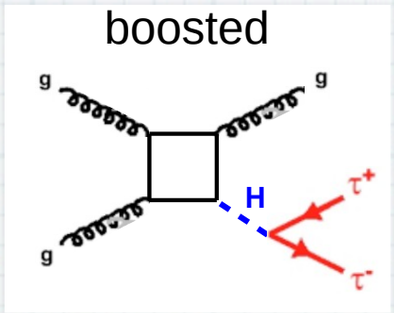
Classification

classification

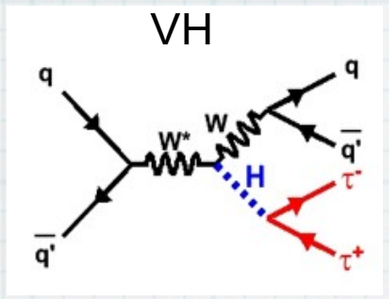
sensitivity (high S/N or better $m_{\tau\tau}$ resolution)



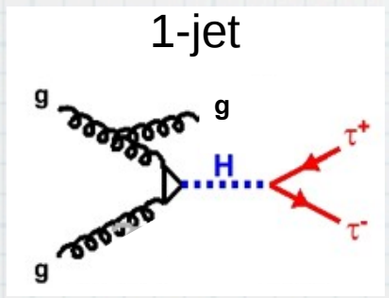
- VBF
  - 2 forward jets w/ large rapidity gap



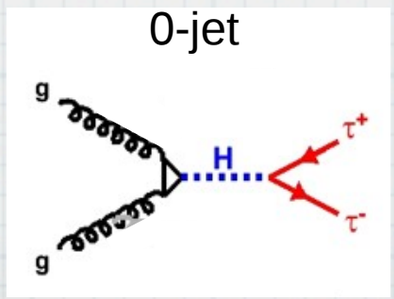
- Boosted
  - [not VBF] high p_T τ τ system



- W/Z+H 2jet
  - [not VBF nor boosted] hadronic W/Z

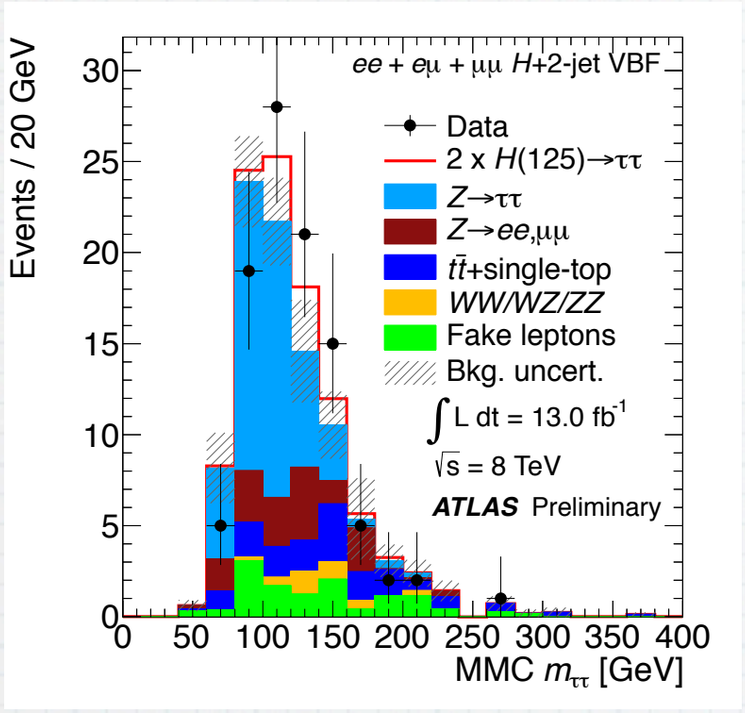


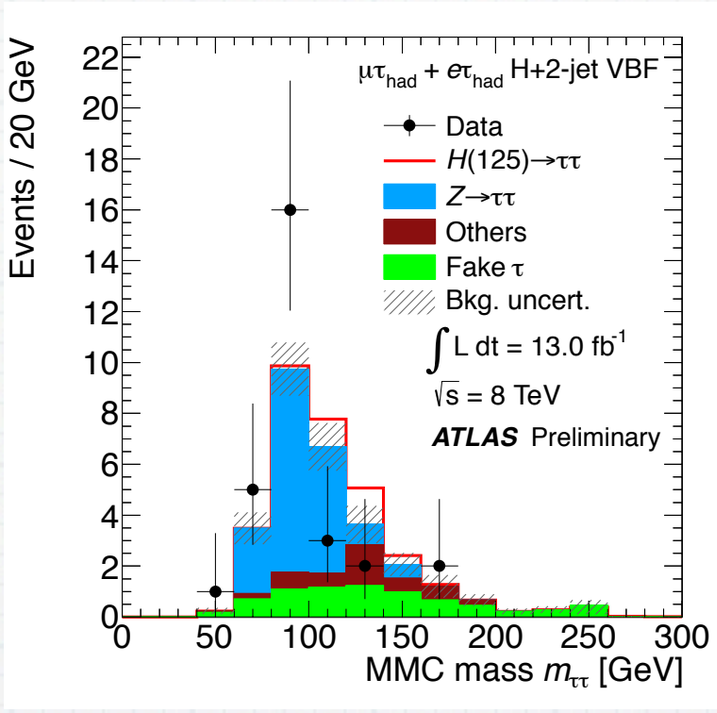
- 1jet
  - [not VBF, boosted, nor W/Z+H] 1 jet

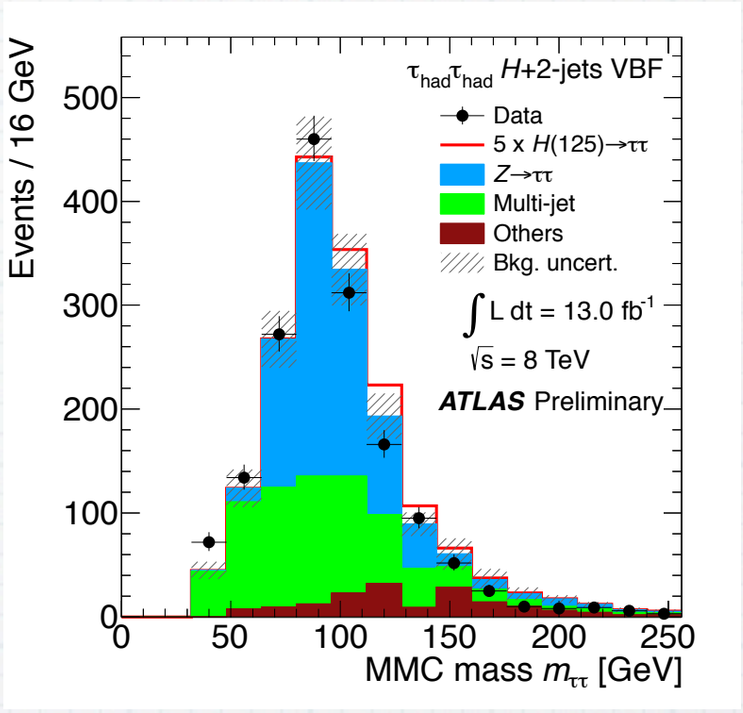


- 0jet
  - [not VBF, boosted, nor W/Z+H] 0 jet

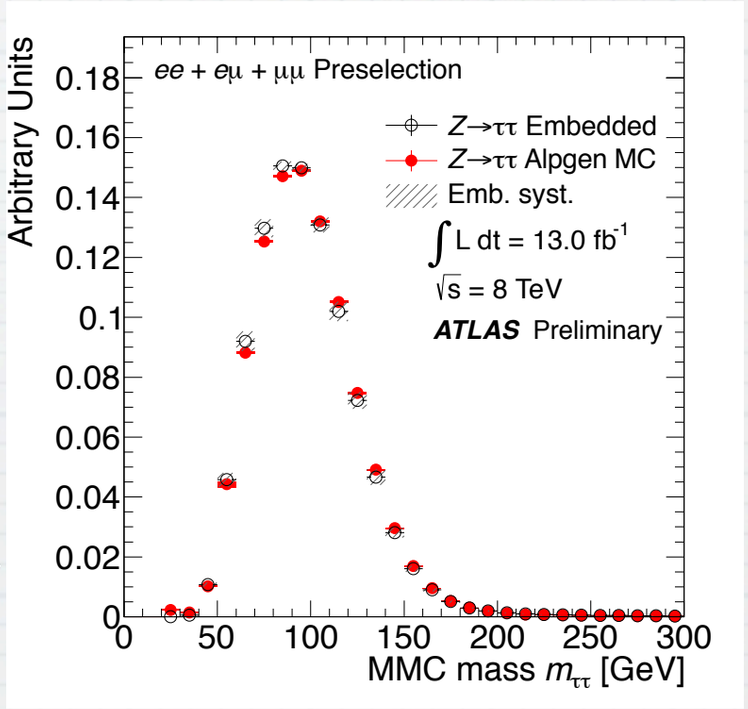
Mass reconstruction & Background







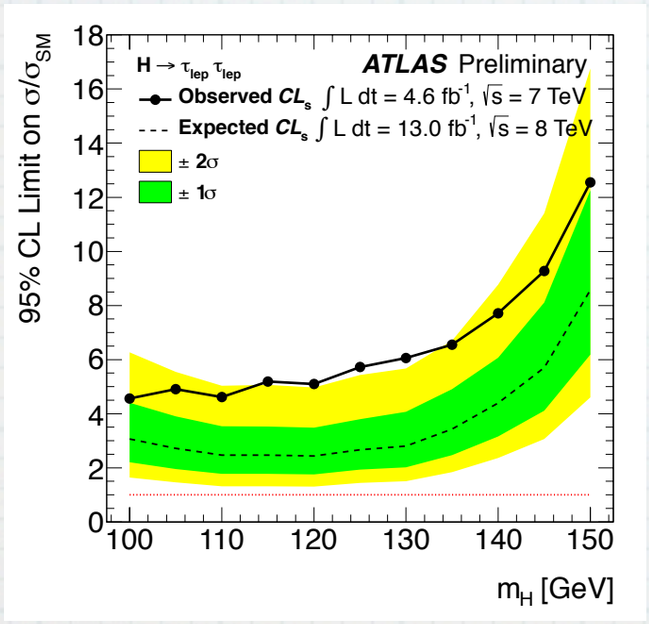
- Missing Mass Calculator
  - probabilistic approach to solve for missing momentum and mass
- $Z \rightarrow \tau\ \tau$ the major background (BG) evaluated by data
  - μ in $Z \rightarrow \mu\ \mu$ real data replaced by MC τ

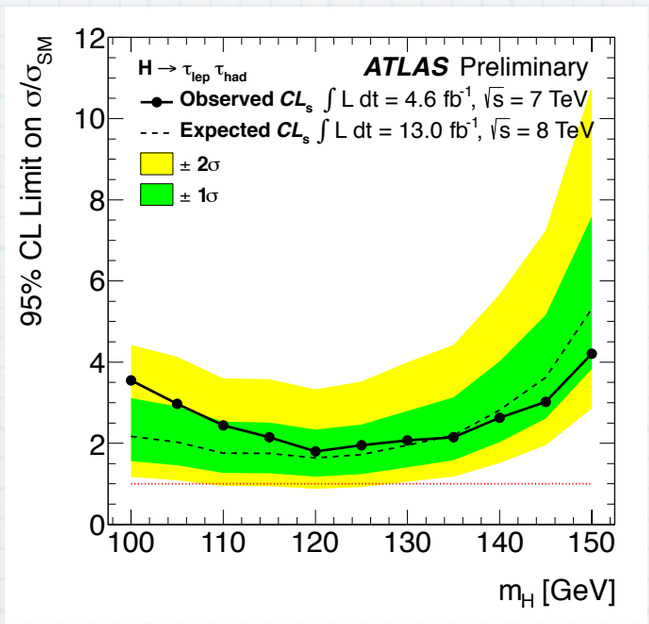


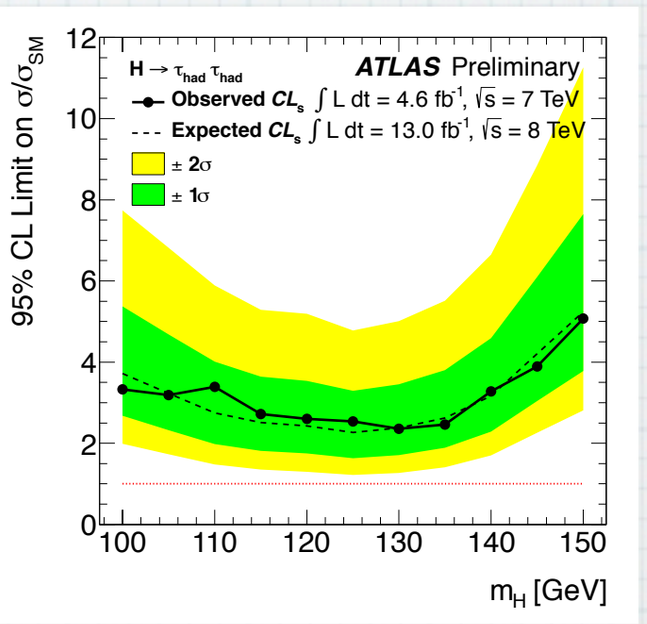
$H \to \tau\ \tau$ channel by channel

lep-had	VBF	boosted	1jet	0jet
gF:VBF:VH	17:83:0	72:19:9	78:15:7	98:1:1
signal	~3	~28	~107	~61
BG	~29	~2530	~22400	~13960
Observed	29	2602	21782	13312

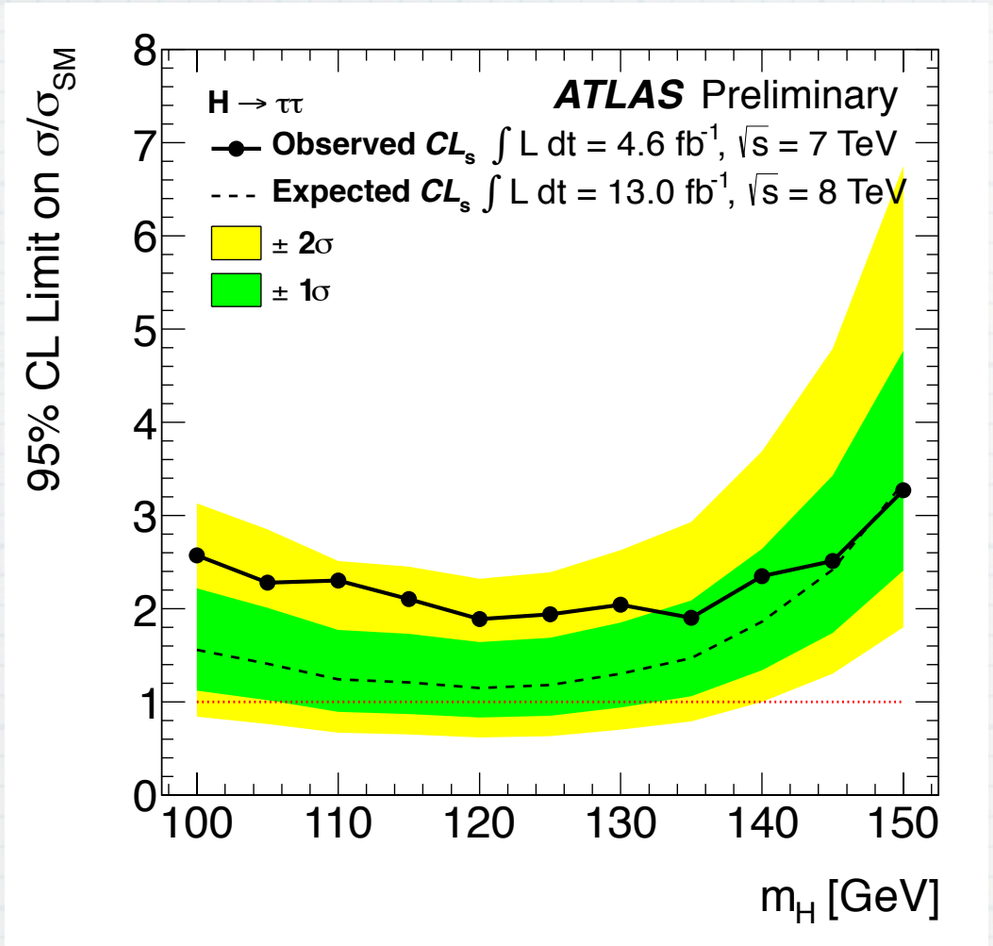
Table is only for 8 TeV







$H \to \tau\,\tau$ Combined Result



$(\sigma \times BR)/(\sigma \times BR)_{SM} < 1.9$
(1.2 expected) @95% C.L.
at $m_H = 125$ GeV

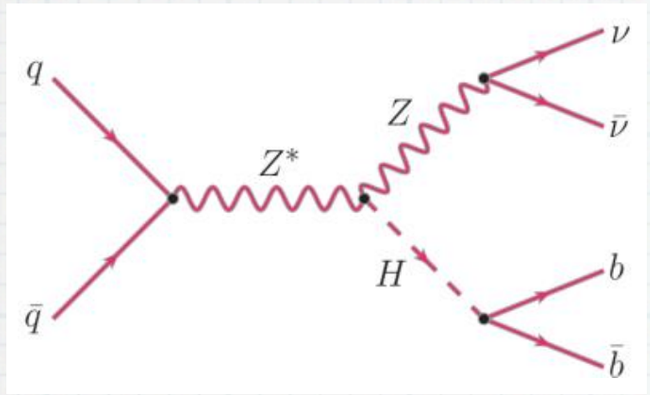
$\mu \equiv$ signal yield relative to SM Higgs expectation

$$\mu = 0.7 \pm 0.7$$

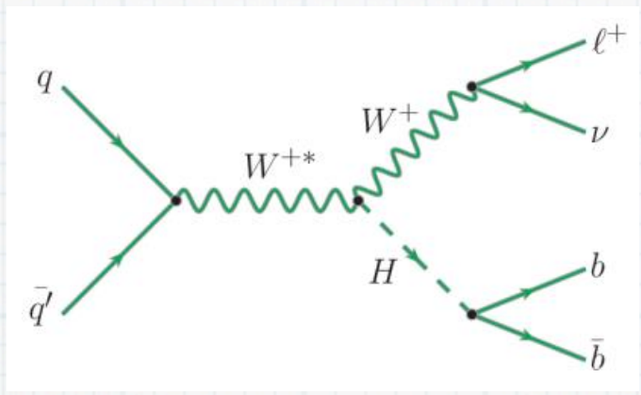
❖ No significant excess over SM BG observed

H→bb

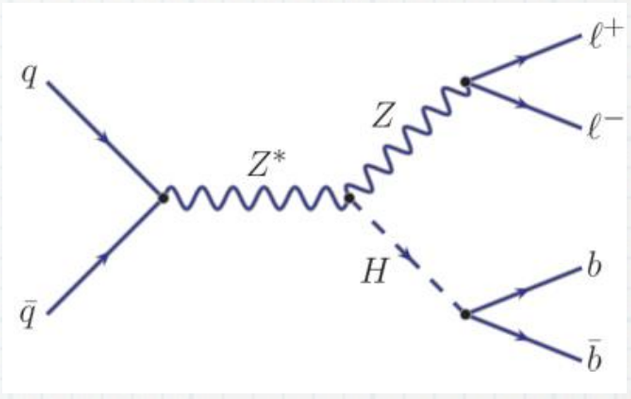
W/Z+H(→bb)



0 lepton
- E_T^{miss} > 120 GeV
- p_T^{miss} > 30 GeV



1 lepton
- E_T^{miss} > 25 GeV
- m_T^W > 40 GeV

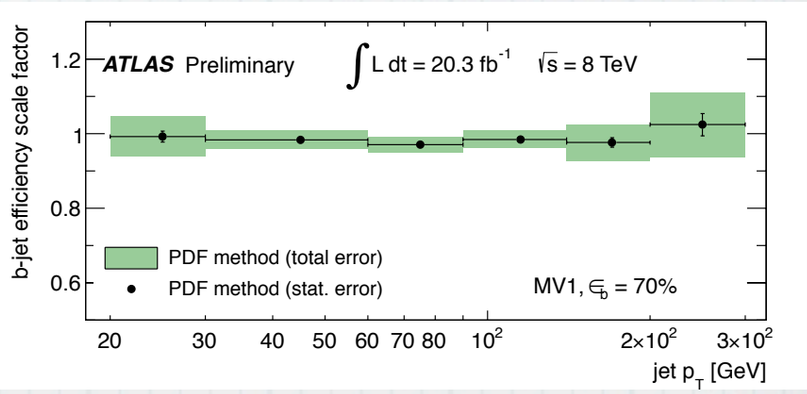


2 lepton
- E_T^{miss} < 60 GeV
- 83 < m_{ll} < 99 GeV

- 2 b-tagged jets ⇐ b-tag key ingredient
  - p_T > 45, and 20 GeV
- Look for m_{bb} peak
  ⇐ dijet mass crucial
- Classification for better sensitivity
  - bins of $p_T^{W/Z}$ & #jets (2 or 3)

$p_T^{W/Z}$ (GeV)	0-90	90-120	120-160	160-200	>200
0 lepton	×	×	○	○	○
1or2 lepton	○	○	○	○	○

b-tag efficiency data/MC



ε_b~70%, ε_c~20%,
ε_l~0.6%

Background & Fitting

0 lepton major BG
- Z+jet
- t-tbar
- diboson
- W+jet

1 lepton major BG
- t-tbar
- W+jet
- QCD multijet
- diboson

2 lepton major BG
- Z+jet
- t-tbar
- diboson

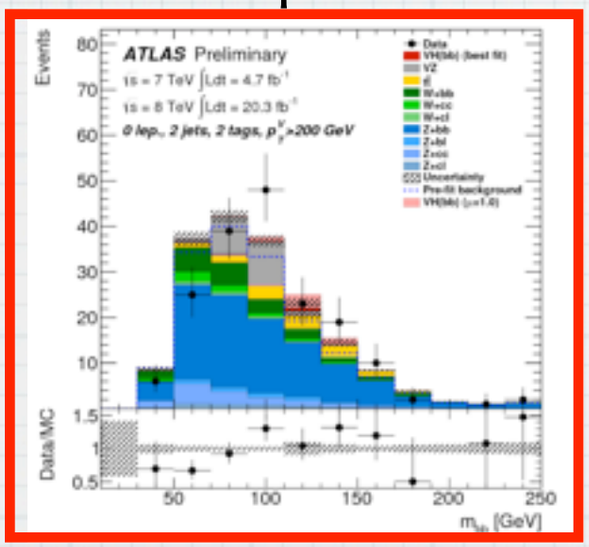
Reliable estimate of BG crucial

- Fitting M_{bb} distribution in 26 signal and 31 control regions to get the yield
  - shape template from MC
    - shape also adjusted within systematics
  - normalization of t-tbar, W/Z+b/c are floated
  - single top, diboson, W/Z+light constrained by theory within systematics
- QCD multijet estimated separately from data

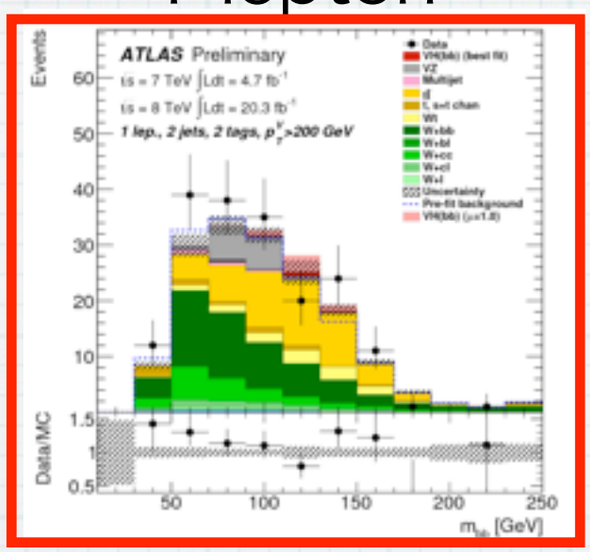
Fitting

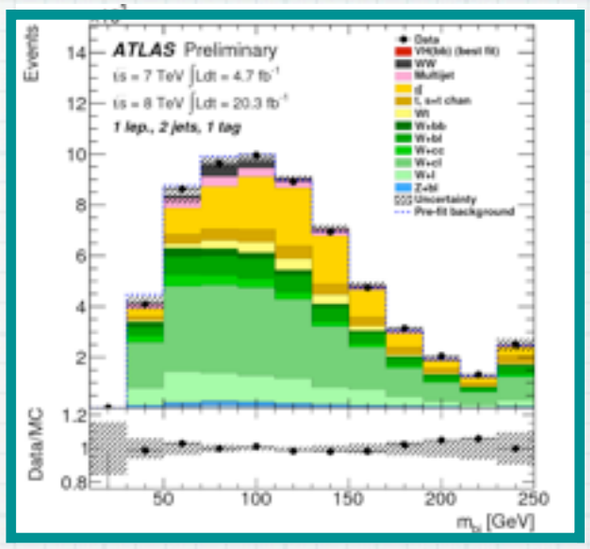
	2jet, 2tag	3jet, 2tag	2jet, 1tag	3jet, 1tag	eμ, 2tag
0 lepton (x3 $p_T^{W/Z}$)	signal	signal	control	control	×
1 lepton (x5 $p_T^{W/Z}$)	signal	signal	control	control	×
2 lepton (x5 $p_T^{W/Z}$)	signal	signal	control	control	control

0 lepton

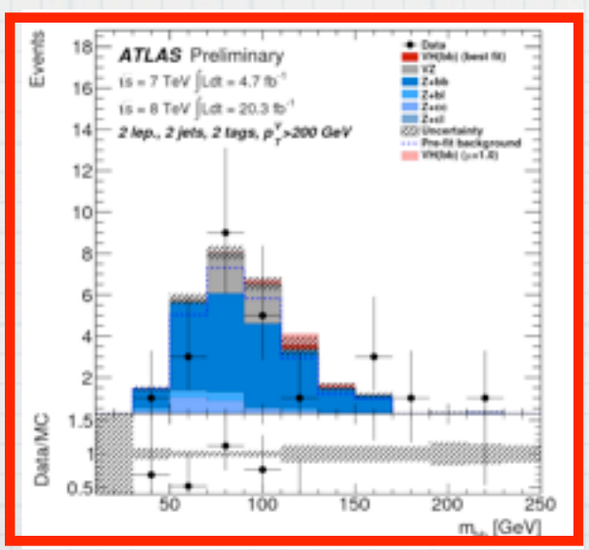


1 lepton





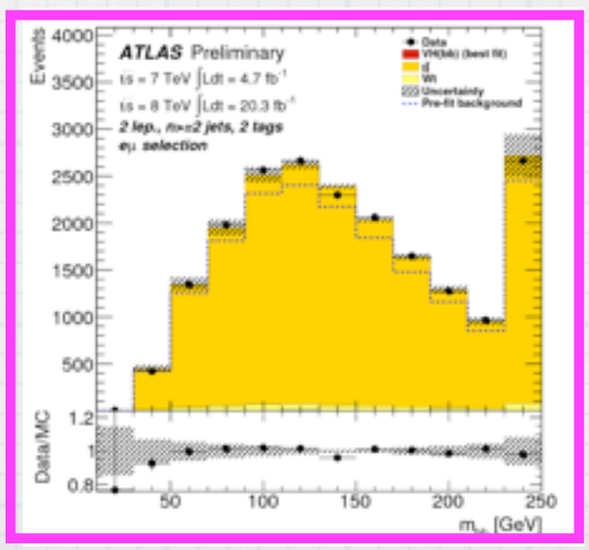
W+jet
control region



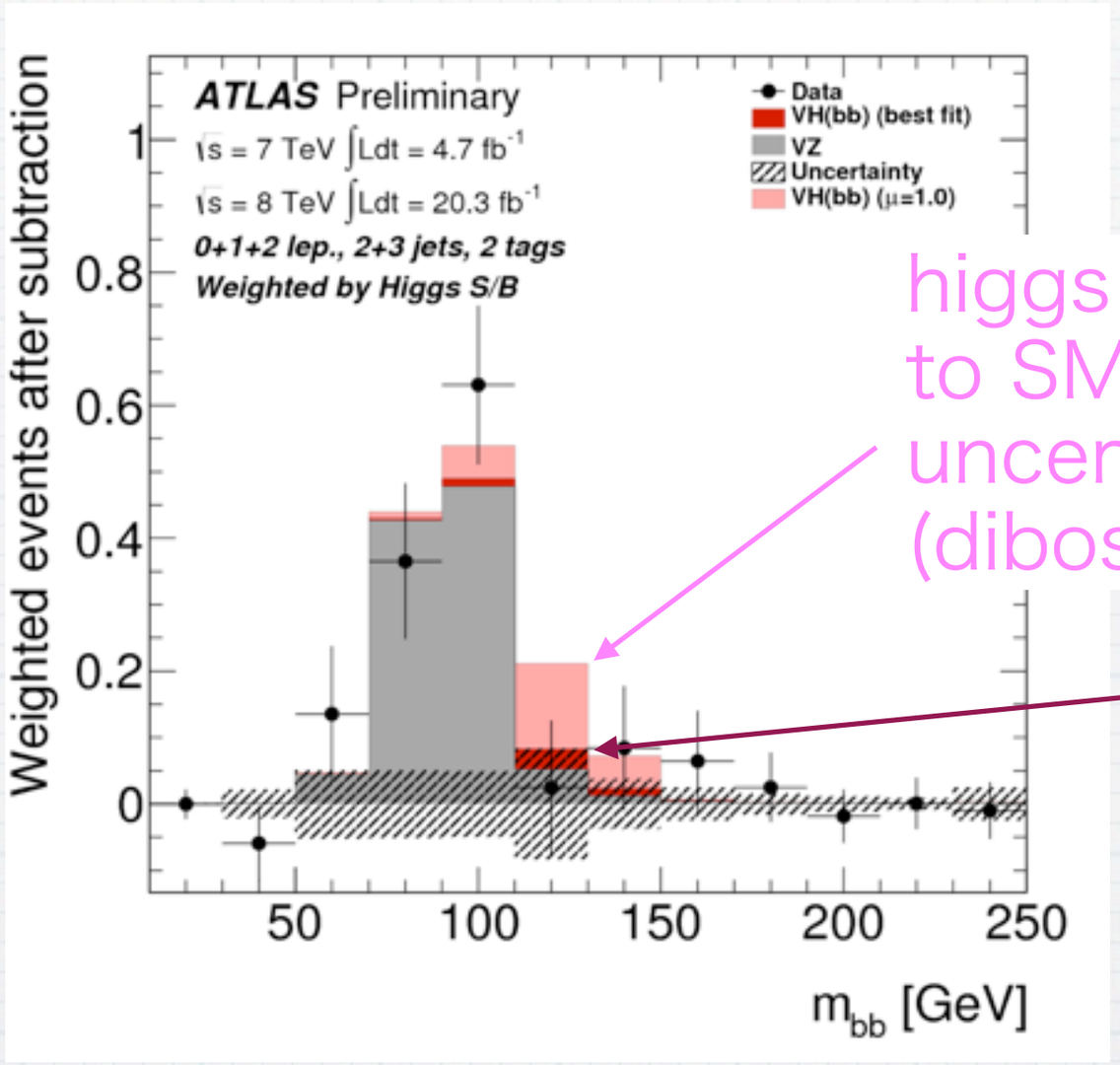
2jet, 2tag,
$p_T^{W/Z}$ >200GeV

2 lepton

t-tbar
control region



After fitting

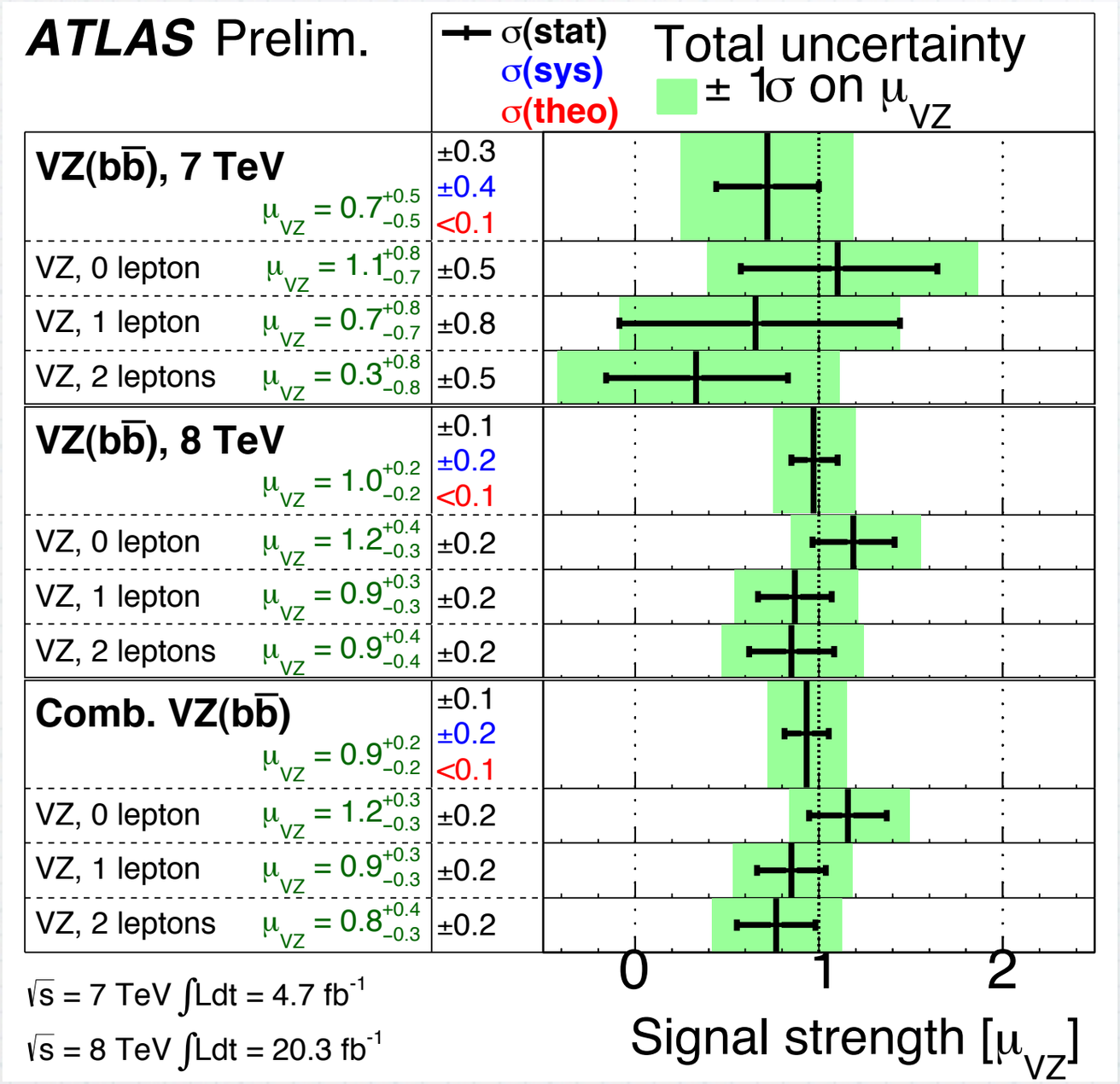


higgs yield fixed to SM w/ large uncertainty (diboson fitting)

higgs yield free in fitting

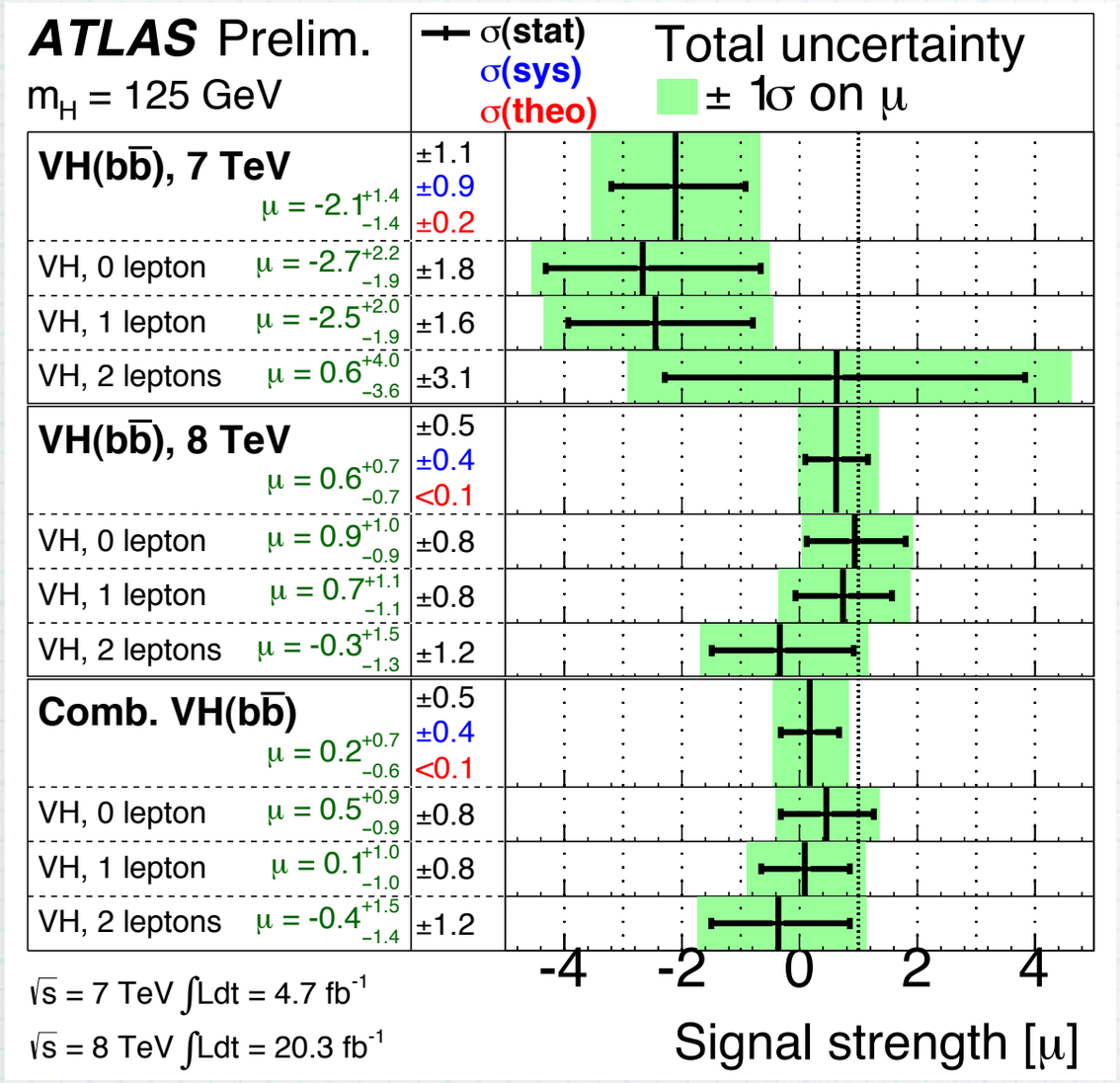
- No significant excess of H→bb
- Clear peak of W/Z + Z(→bb)
  - mass resolution under control

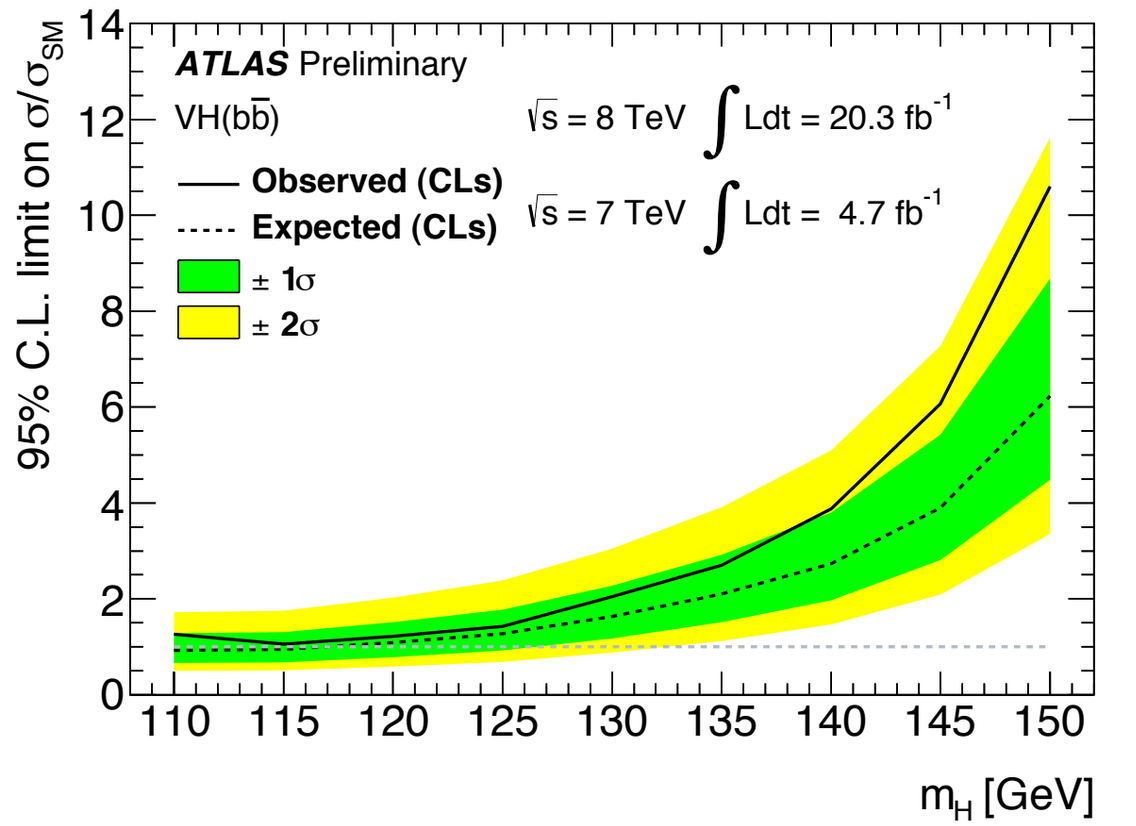
W/Z+Z(→bb) Result



- 4.8σ significance (5.1σ expected)
- Demonstration of validation of analysis and potential to observe H→bb

W/Z+H(→bb) Result





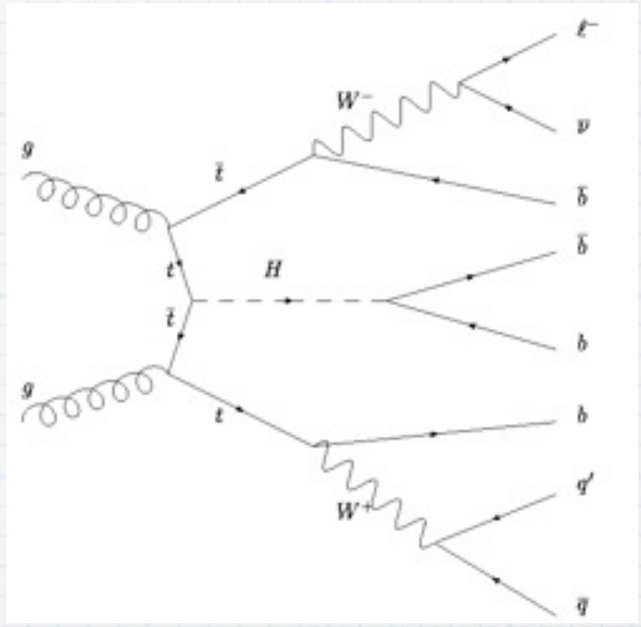
$(\sigma \times BR)/(\sigma \times BR)_{SM} < 1.4$
(1.3 expected) @95% C.L.
at $m_H = 125$ GeV

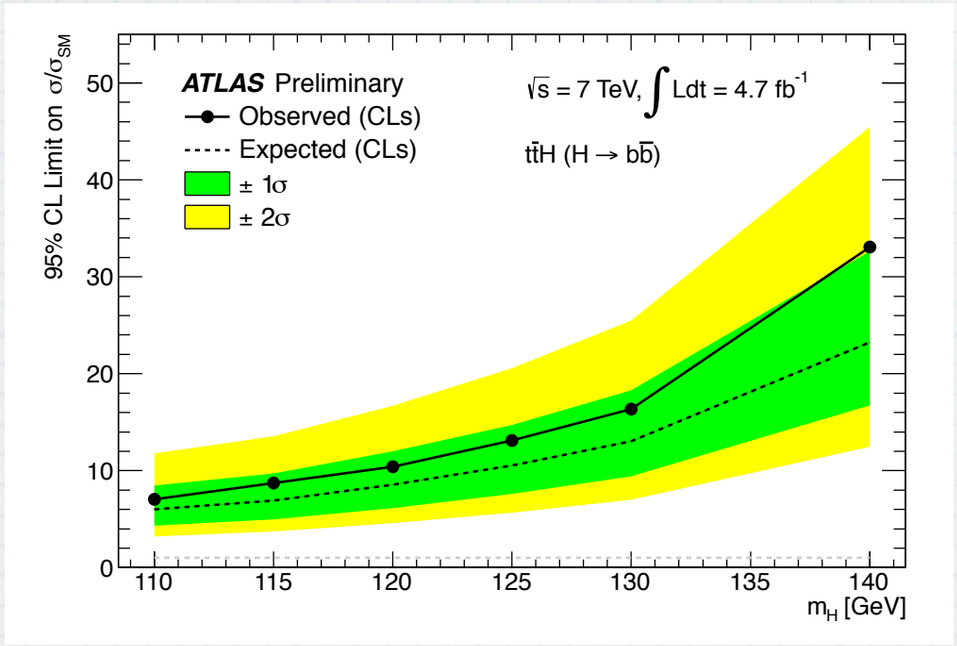
$$\mu_{\mathrm{comb}} = 0.2^{+0.7}_{-0.6}$$

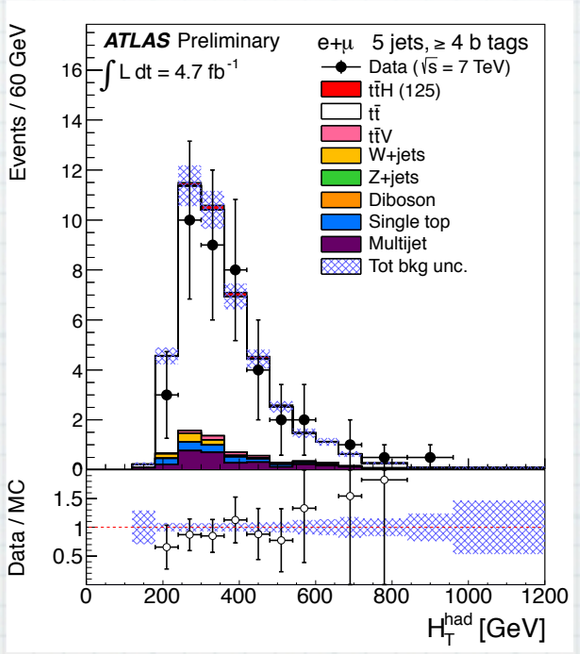
$$\mu_{\,7\mathrm{TeV}} = -2.1 \pm 1.4 \qquad \mu_{\,8\mathrm{TeV}} = 0.6 \pm 0.7$$

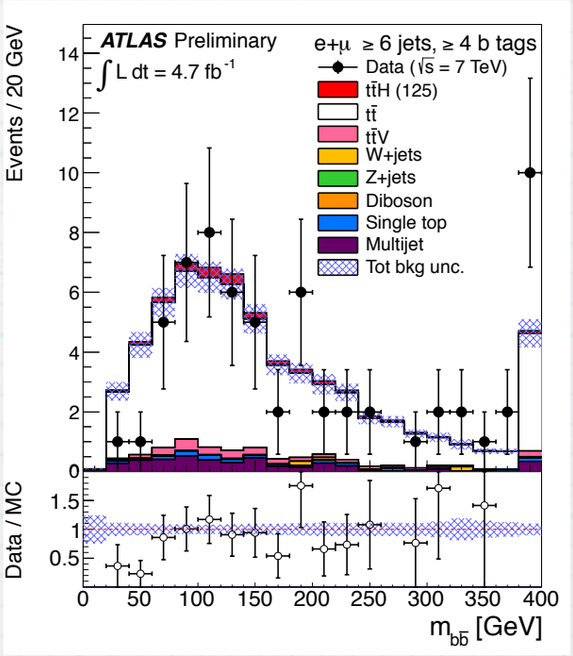
ttH(→bb)

- Important window to access Y_t
- $W \to l\nu$ + $W \to qq'$ is considered
  - One lepton, ≥4jets, E_T^{miss} > 20-30 GeV
- Nine categories used









$(\sigma \times BR)/(\sigma \times BR)_{SM} < 13.1$ (10.5 expected) @95% C.L. at $m_H = 125$ GeV

Conclusions

- Exciting time is coming to fully examine the Higgs sector by experiment
  - Direct verification of existence of Yukawa coupling is important
    - $\mu = 0.7 \pm 0.7$ in H→τ τ
    - $\mu = 0.2^{+0.7}_{-0.6}$ in W/Z+H(→bb)
    - ttH(→bb) search is also ongoing