Search for Standard Model Higgs Bosons produced in association with top quarks with the ATLAS detector

Yang Qin (Quake)

On behalf of the ATLAS Collaboration

Introduction

- Higgs boson discovery → property measurement

Introduction

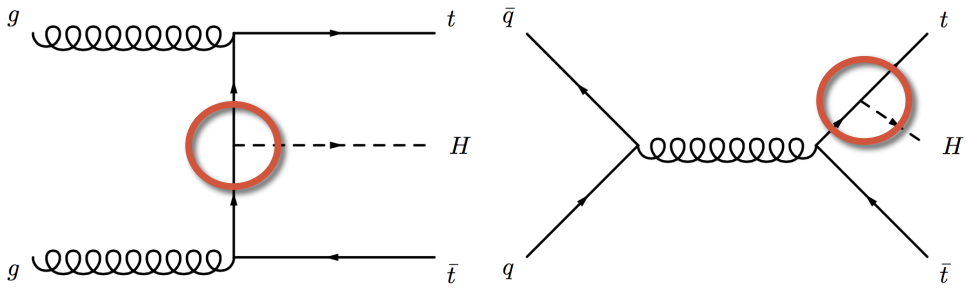
- Higgs boson discovery → property measurement: coupling to fermions

Introduction

- Higgs boson discovery → property measurement: coupling to fermions
- Top Yukawa coupling: strongest Yukawa coupling $Y_t \sim 1$
  - Understanding SM EWSB
  - Test BSM theories

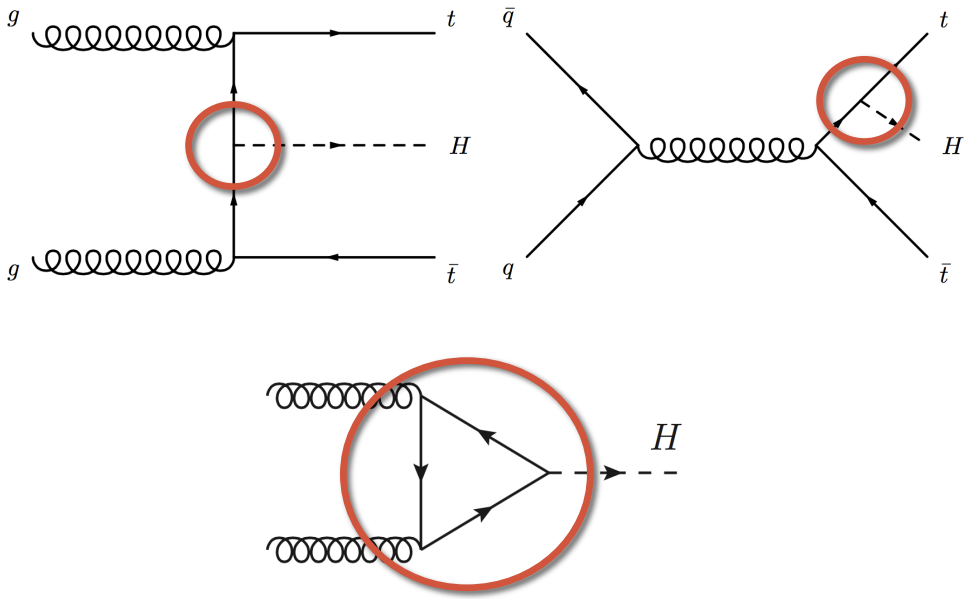
Introduction

- Higgs boson discovery → property measurement: coupling to fermions
- Top Yukawa coupling: strongest Yukawa coupling $Y_t \sim 1$
  - Understanding SM EWSB
  - Test BSM theories
- $t\bar{t}H$:
  - Direct probe to $|Y_t|$



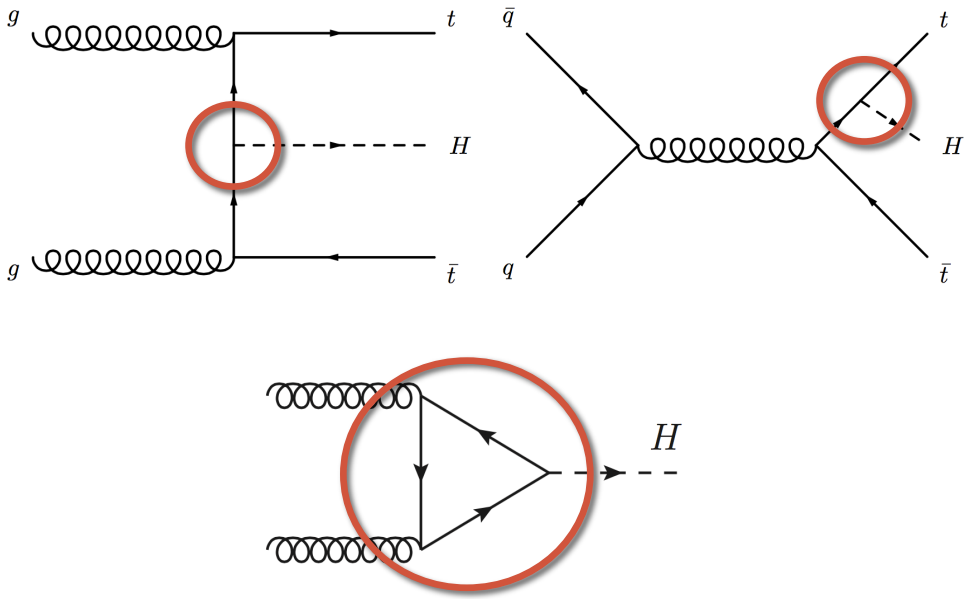
Introduction

- Higgs boson discovery → property measurement: coupling to fermions
- Top Yukawa coupling: strongest Yukawa coupling $Y_t \sim 1$
  - Understanding SM EWSB
  - Test BSM theories
- $t\bar{t}H$:
  - Direct probe to $|Y_t|$



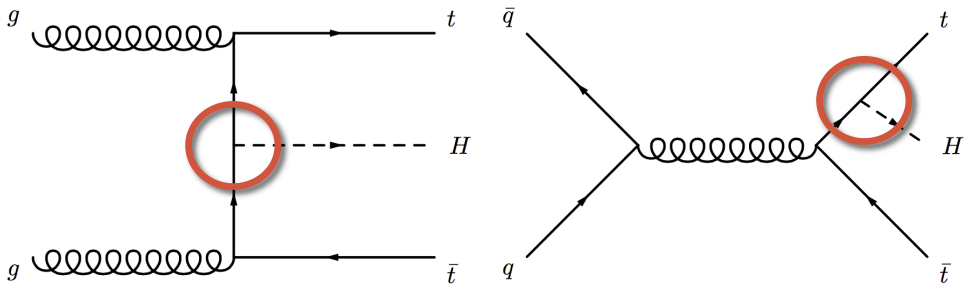
Introduction

- Higgs boson discovery → property measurement: coupling to fermions
- Top Yukawa coupling: strongest Yukawa coupling $Y_t \sim 1$
  - Understanding SM EWSB
  - Test BSM theories
- $t\bar{t}H$:
  - Direct probe to $|Y_t|$
  - Small production rate in SM

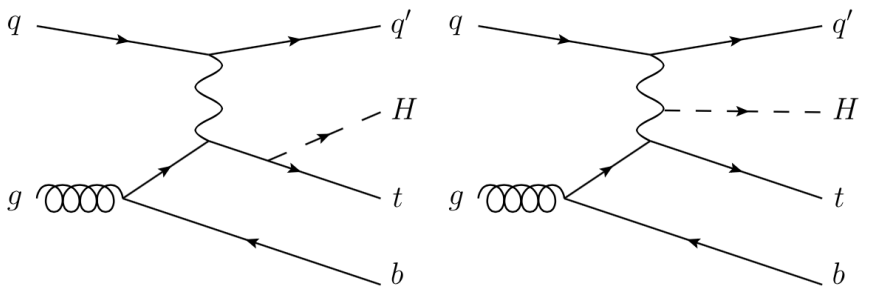


Introduction

- Higgs boson discovery → property measurement: coupling to fermions
- Top Yukawa coupling: strongest Yukawa coupling $Y_t \sim 1$
  - Understanding SM EWSB
  - Test BSM theories
- $t\bar{t}H$:
  - Direct probe to $|Y_t|$
  - Small production rate in SM

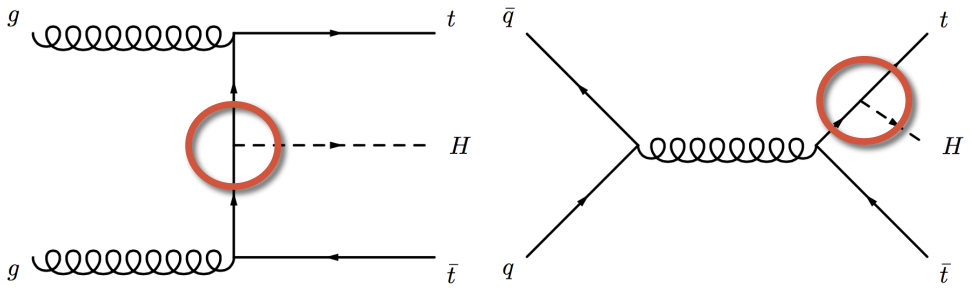


- tH:

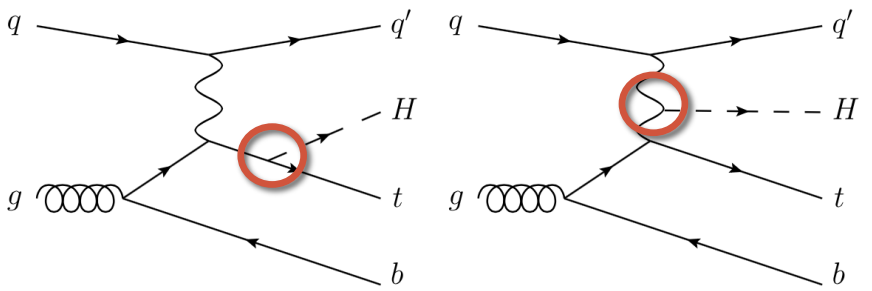


Introduction

- Higgs boson discovery → property measurement: coupling to fermions
- Top Yukawa coupling: strongest Yukawa coupling $Y_t \sim 1$
  - Understanding SM EWSB
  - Test BSM theories
- $t\bar{t}H$:
  - Direct probe to $|Y_t|$
  - Small production rate in SM

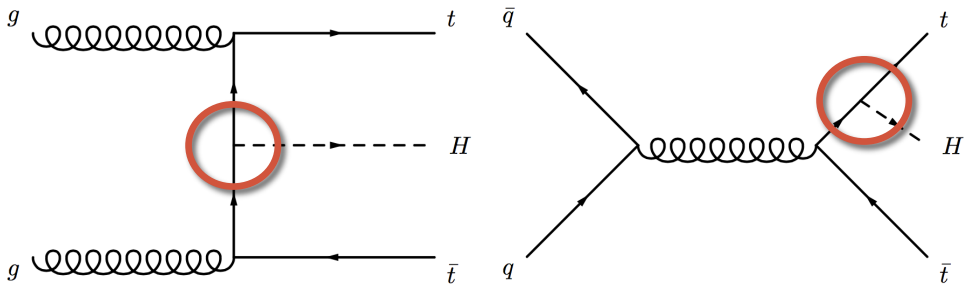


- tH:

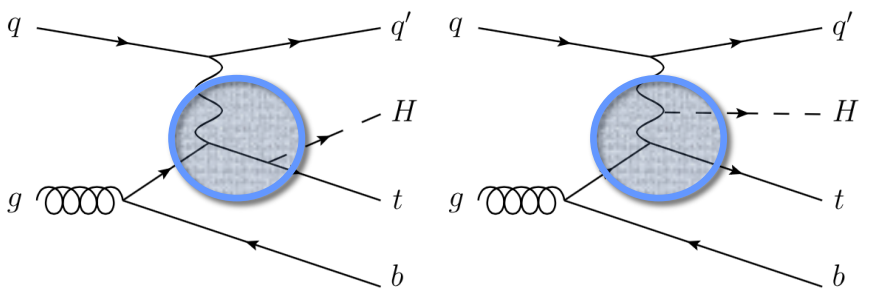


Introduction

- Higgs boson discovery → property measurement: coupling to fermions
- Top Yukawa coupling: strongest Yukawa coupling $Y_t \sim 1$
  - Understanding SM EWSB
  - Test BSM theories
- $t\bar{t}H$:
  - Direct probe to $|Y_t|$
  - Small production rate in SM

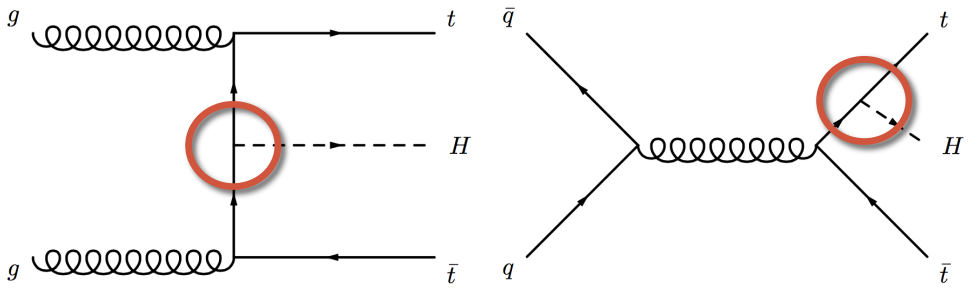


- tH:
  - Sensitive to the relative sign of Y_t given the interference with g_{HWW}

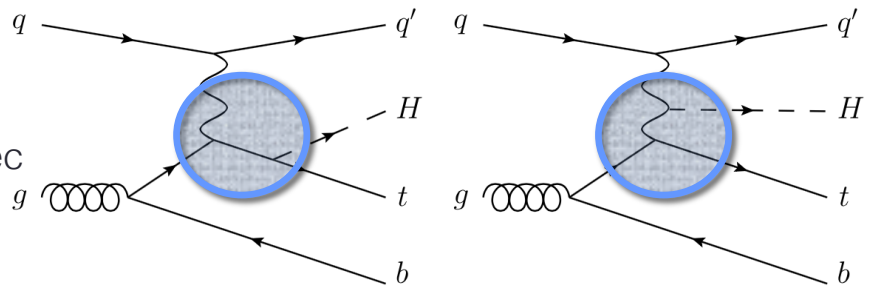


Introduction

- Higgs boson discovery → property measurement: coupling to fermions
- Top Yukawa coupling: strongest Yukawa coupling $Y_t \sim 1$
  - Understanding SM EWSB
  - Test BSM theories
- $t\bar{t}H$:
  - Direct probe to $|Y_t|$
  - Small production rate in SM



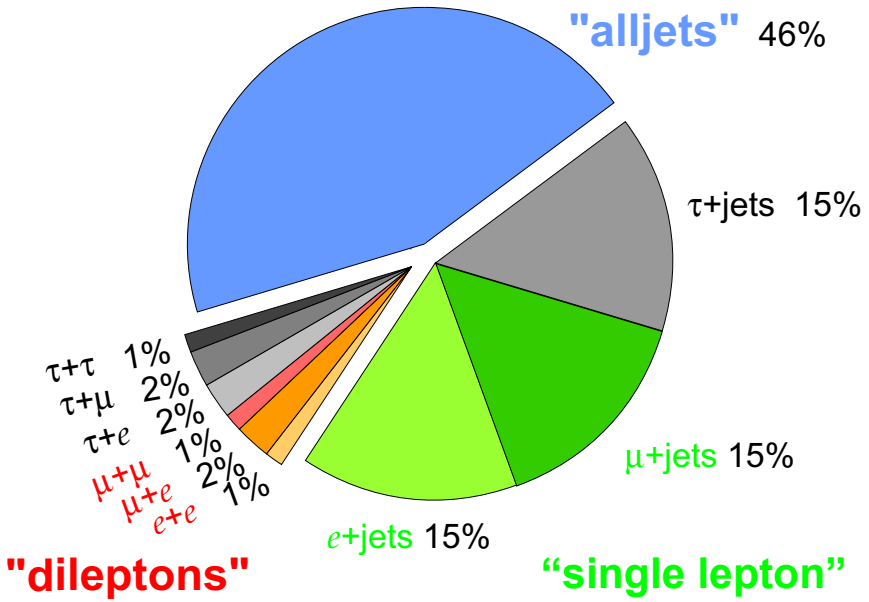
- tH:
  - Sensitive to the relative sign of Y_t given the interference with g_{HWW}
  - Destructive interference in SM → small x-sec



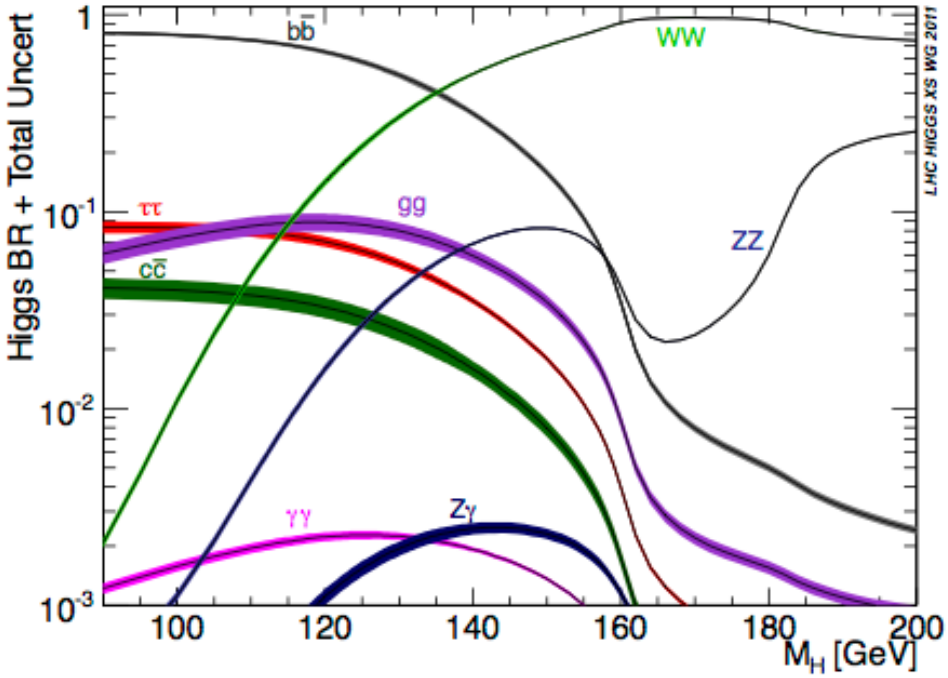
Introduction

- Combination of the $t\bar{t}$ and H decay produces large number of possible final states

Top Pair Branching Fractions

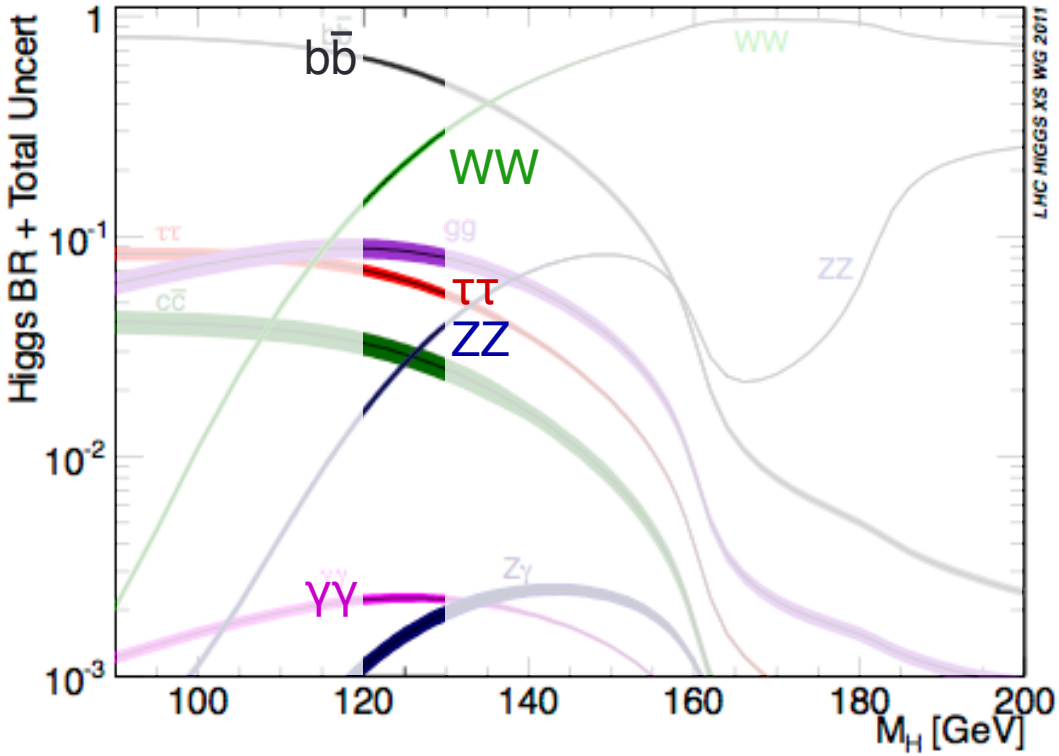


Higgs Branching Fractions



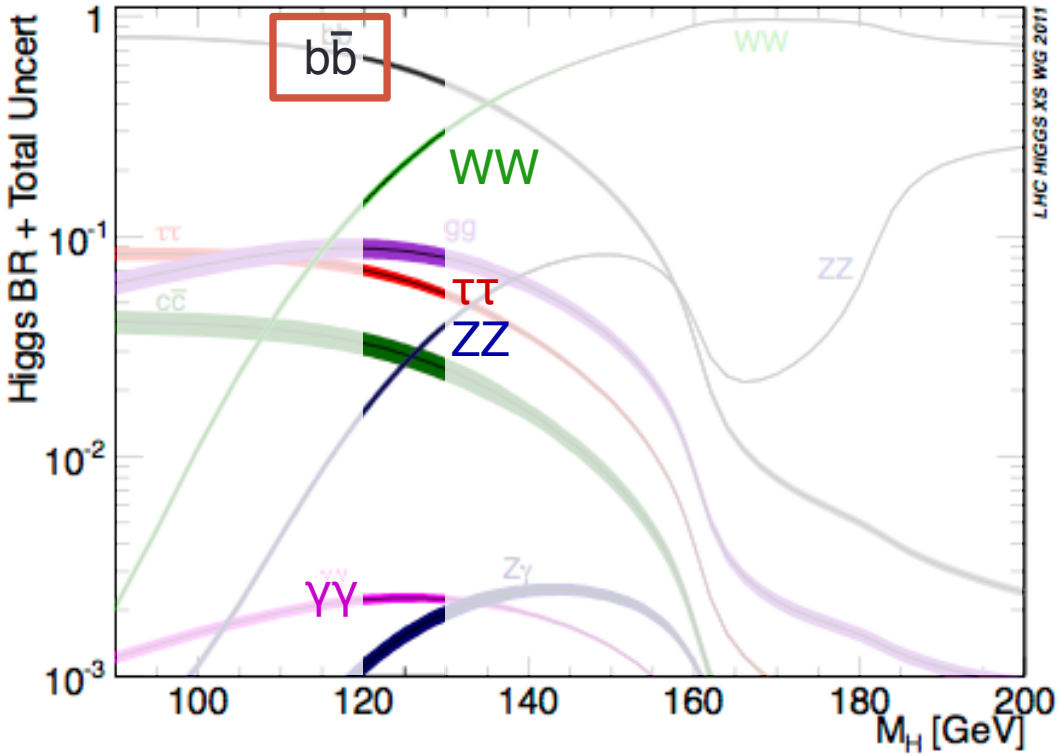
Outline

- $t\bar{t}H$ ($H \rightarrow b\bar{b}$) @ 8 TeV — Eur. Phys. J. C (2015) 75:349
- $t\bar{t}H$ (Multilepton) @ 8 TeV — Accepted by Phys. Lett. B
  - Sensitive to $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, $H \rightarrow ZZ^*$
- $t\bar{t}H$ ($H \rightarrow \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$) @ 7 / 8 TeV — Phys. Lett. B 740 (2015) 222-242



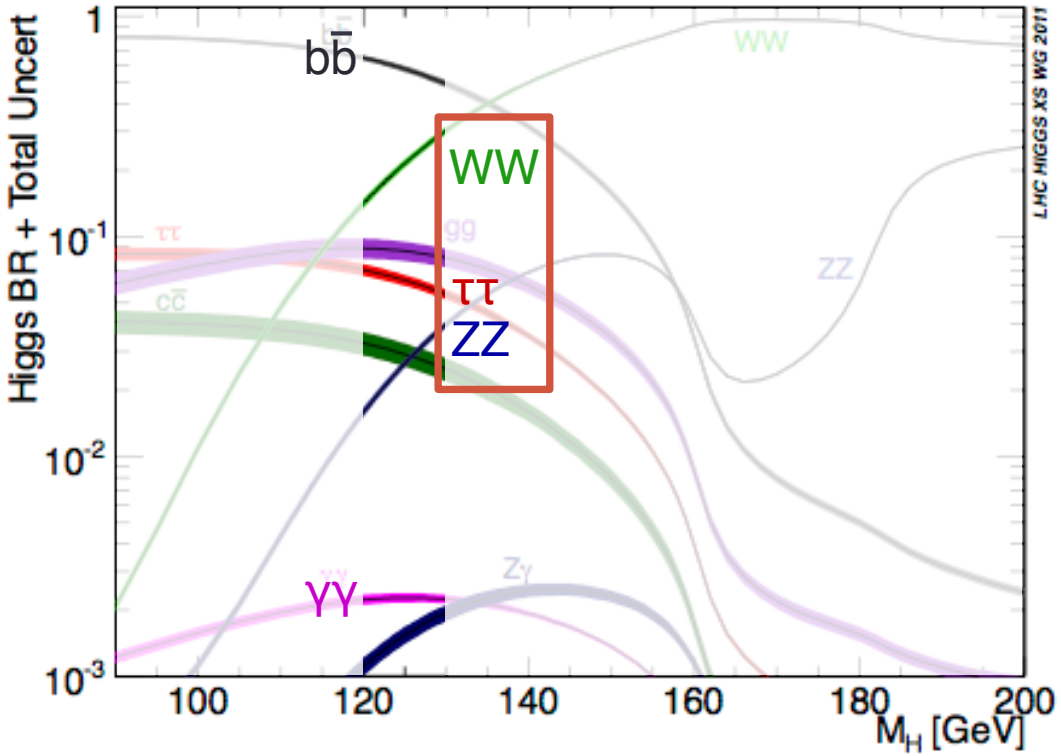
Outline

- $t\bar{t}H$ ($H \rightarrow b\bar{b}$) @ 8 TeV — Eur. Phys. J. C (2015) 75:349
- $t\bar{t}H$ (Multilepton) @ 8 TeV — Accepted by Phys. Lett. B
  - Sensitive to $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, $H \rightarrow ZZ^*$
- $t\bar{t}H$ ($H \rightarrow \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$) @ 7 / 8 TeV — Phys. Lett. B 740 (2015) 222-242



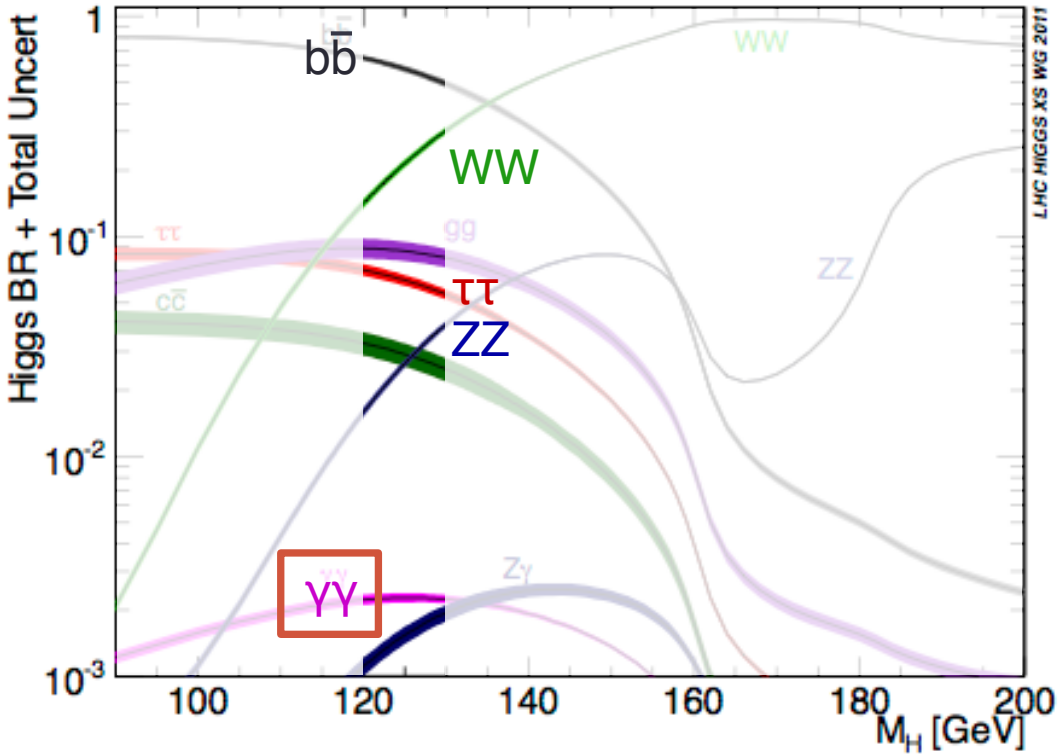
Outline

- $t\bar{t}H$ ($H \rightarrow b\bar{b}$) @ 8 TeV — Eur. Phys. J. C (2015) 75:349
- $t\bar{t}H$ (Multilepton) @ 8 TeV — Accepted by Phys. Lett. B
  - Sensitive to $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, $H \rightarrow ZZ^*$
- $t\bar{t}H$ ($H \rightarrow \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$) @ 7 / 8 TeV — Phys. Lett. B 740 (2015) 222-242



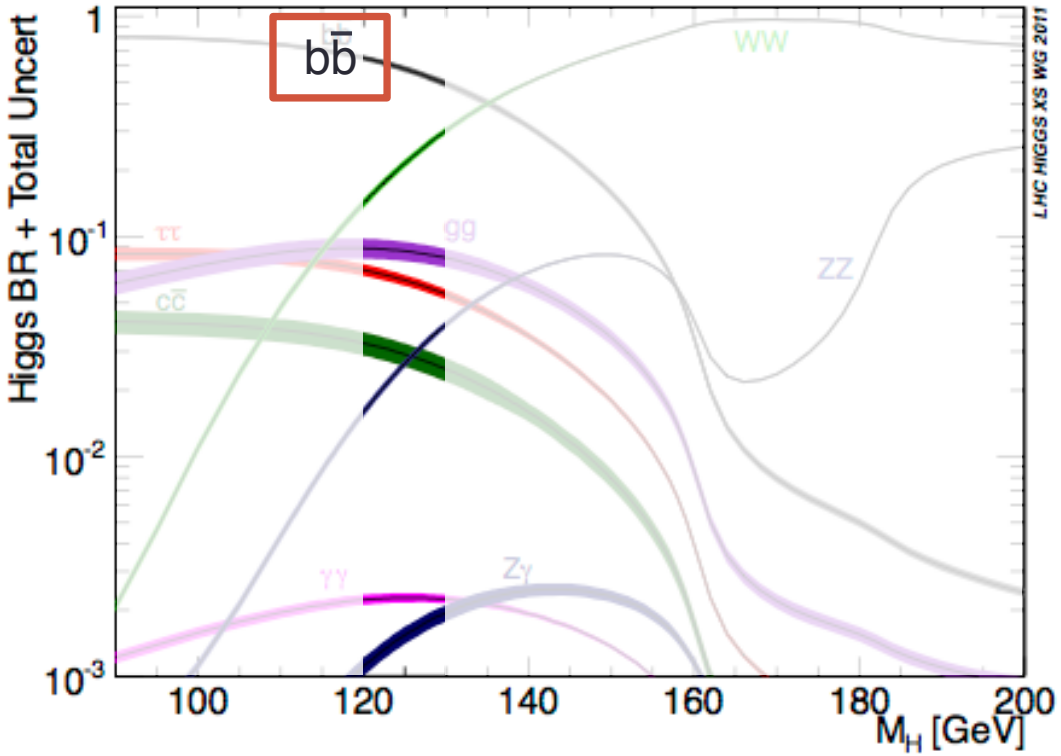
Outline

- $t\bar{t}H$ ($H \rightarrow b\bar{b}$) @ 8 TeV — Eur. Phys. J. C (2015) 75:349
- $t\bar{t}H$ (Multilepton) @ 8 TeV — Accepted by Phys. Lett. B
  - Sensitive to $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, $H \rightarrow ZZ^*$
- $t\bar{t}H$ ($H \rightarrow \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$) @ 7 / 8 TeV — Phys. Lett. B 740 (2015) 222-242

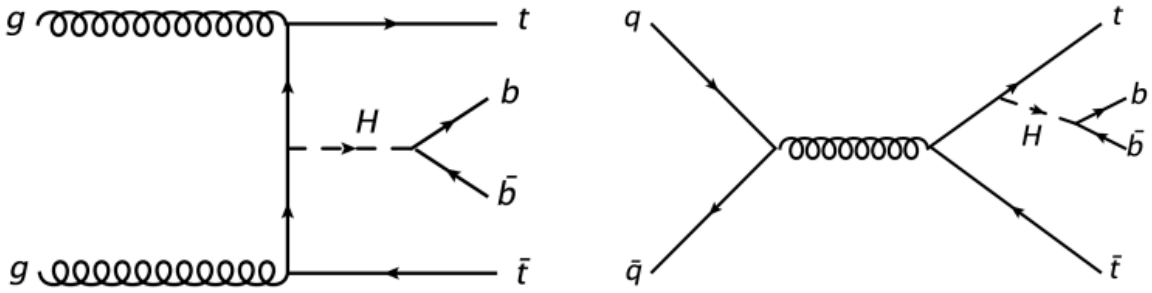


Outline

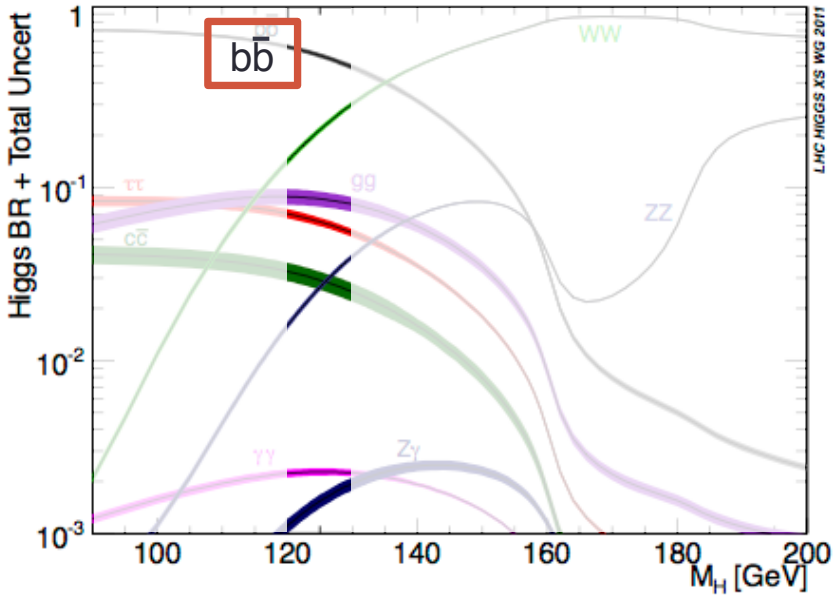
- $t\bar{t}H$ ($H \rightarrow b\bar{b}$) @ 8 TeV — Eur. Phys. J. C (2015) 75:349
- $t\bar{t}H$ (Multilepton) @ 8 TeV — Accepted by Phys. Lett. B
  - Sensitive to $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, $H \rightarrow ZZ^*$
- $t\bar{t}H$ ($H \rightarrow \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$) @ 7 / 8 TeV — Phys. Lett. B 740 (2015) 222-242



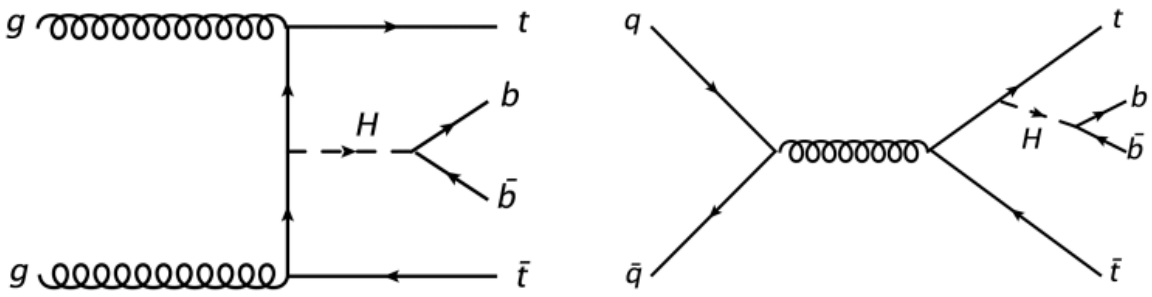
$t\bar{t}H$ ($H \rightarrow b\bar{b}$)



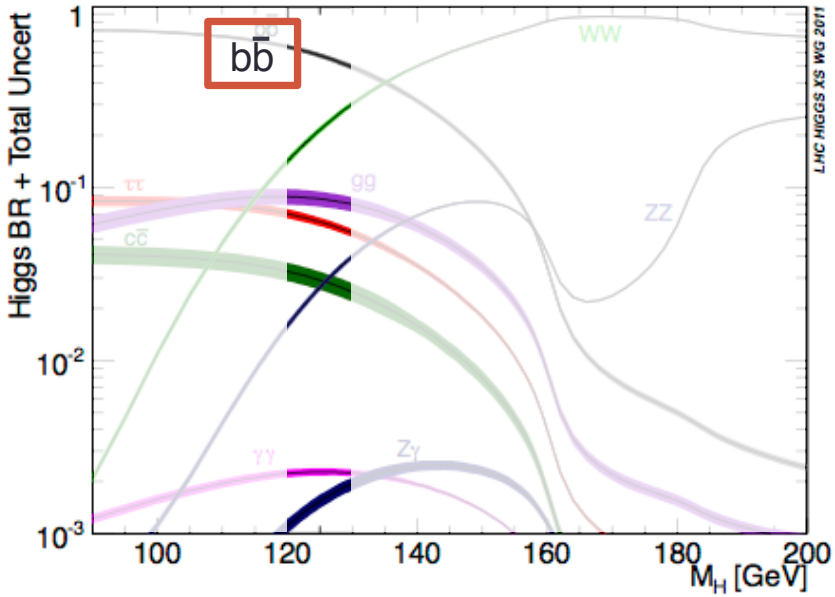
- Highest branching ratio (58%)



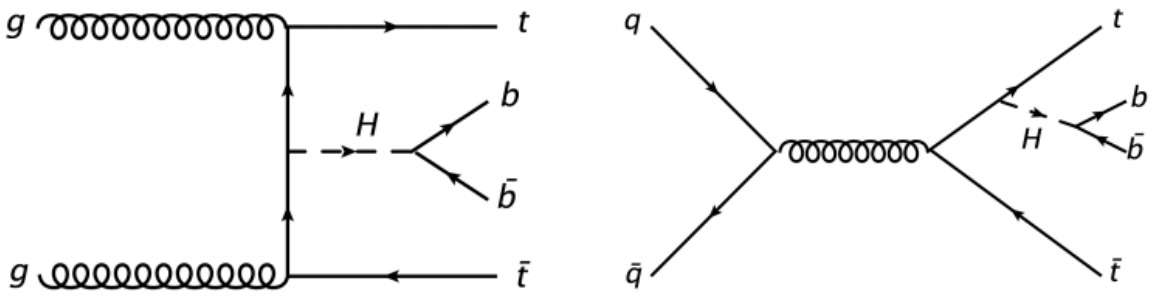
$t\bar{t}H$ ($H \rightarrow b\bar{b}$)



- Highest branching ratio (58%)
- Large $t\bar{t}+b\bar{b}$ background – irreducible

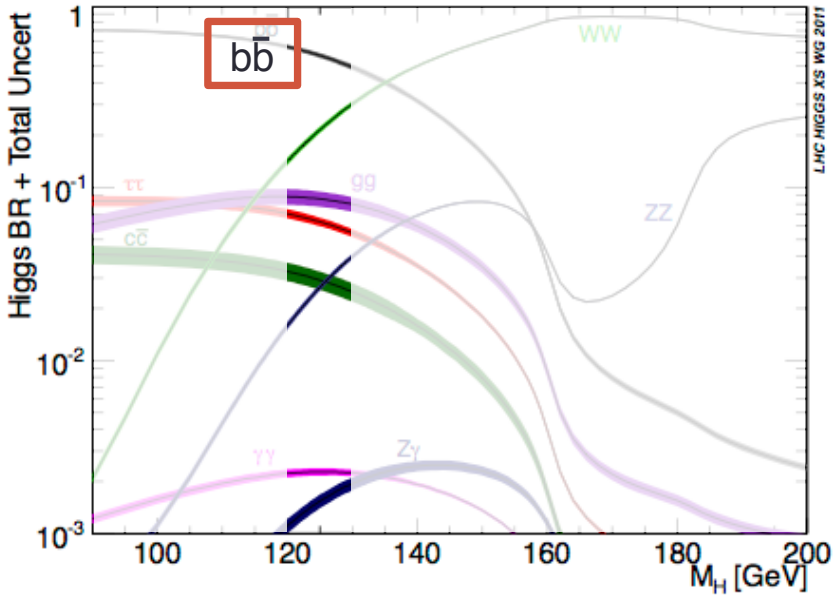


$t\bar{t}H$ ($H \rightarrow b\bar{b}$)



- Highest branching ratio (58%)
- Large $t\bar{t}$+$b\bar{b}$ background – irreducible

- 2 channels based on decay of $t\bar{t}$
  - Single lepton channel
  - Dilepton channel

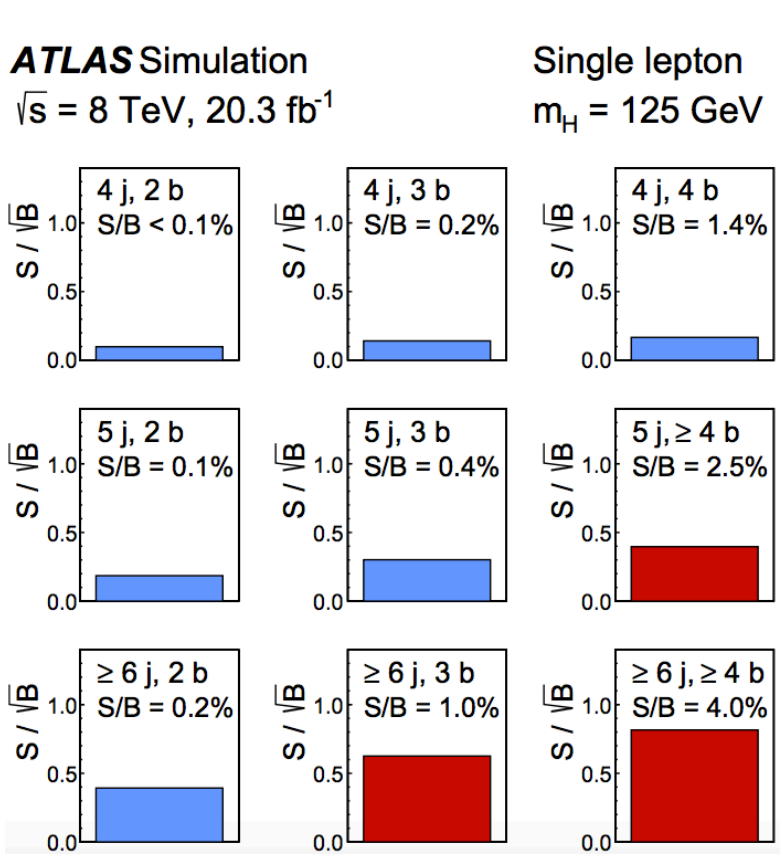


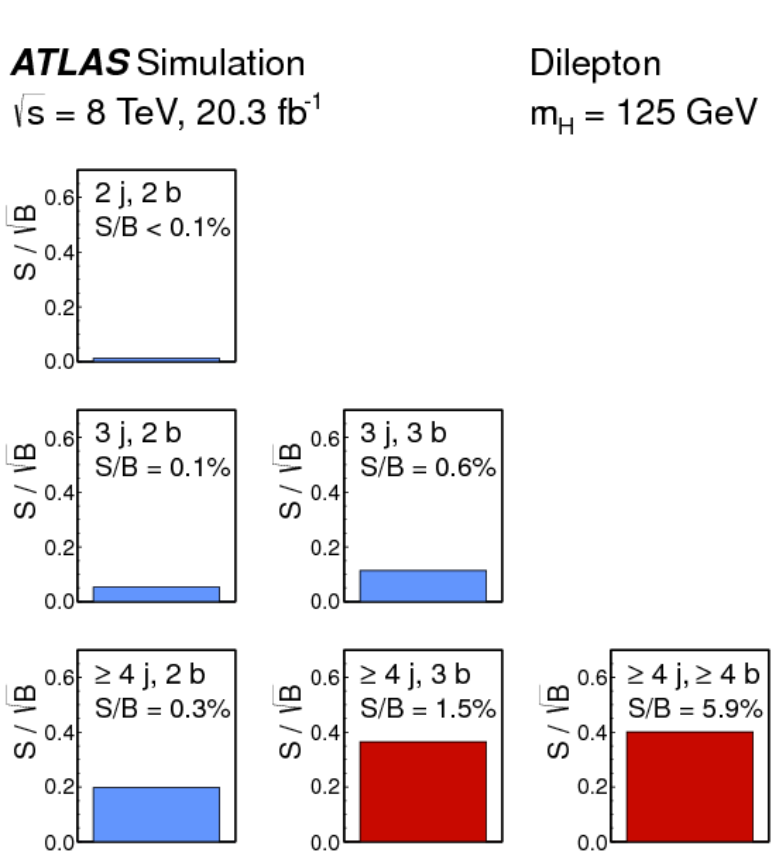
Analysis Strategy

- **Heavily background dominated** –
  - Categorise events into different regions according to $\mathbf{N_{jets}}$ and $\mathbf{N_{tags}}$ to improve the sensitivity

Analysis Strategy

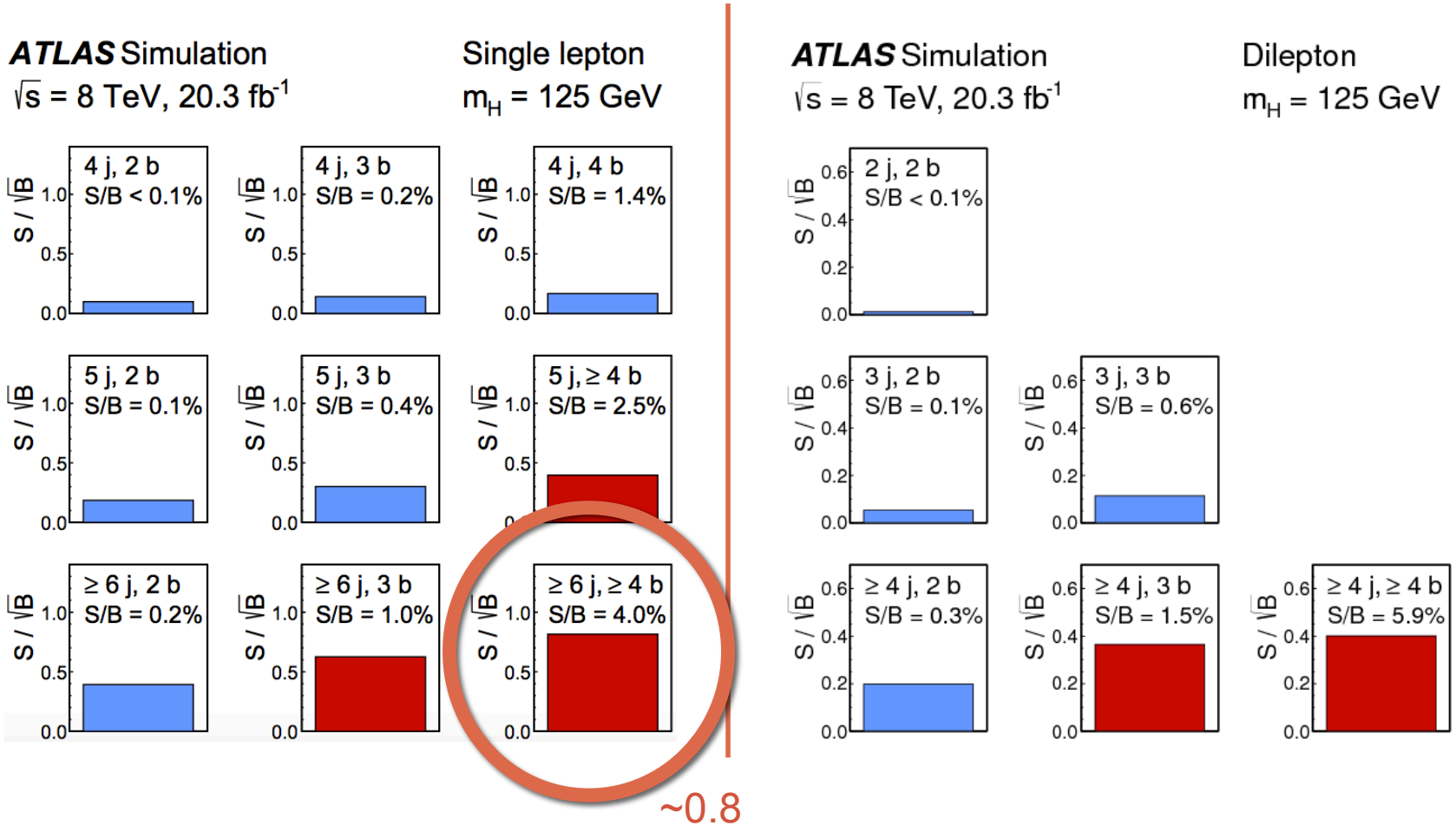
- **Heavily background dominated** –
  - Categorise events into different regions according to $\mathbf{N_{jets}}$ and $\mathbf{N_{tags}}$ to improve the sensitivity





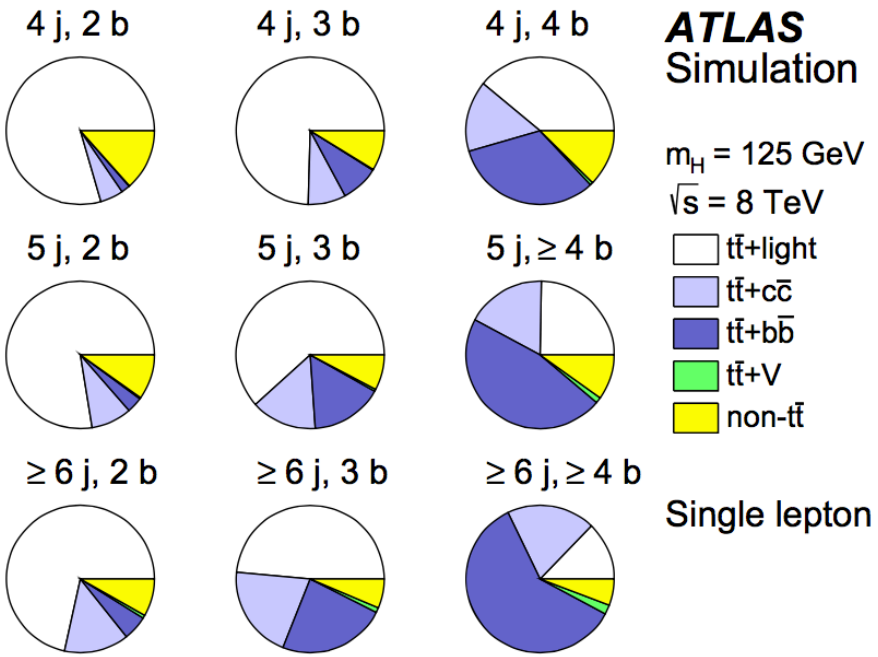
Analysis Strategy

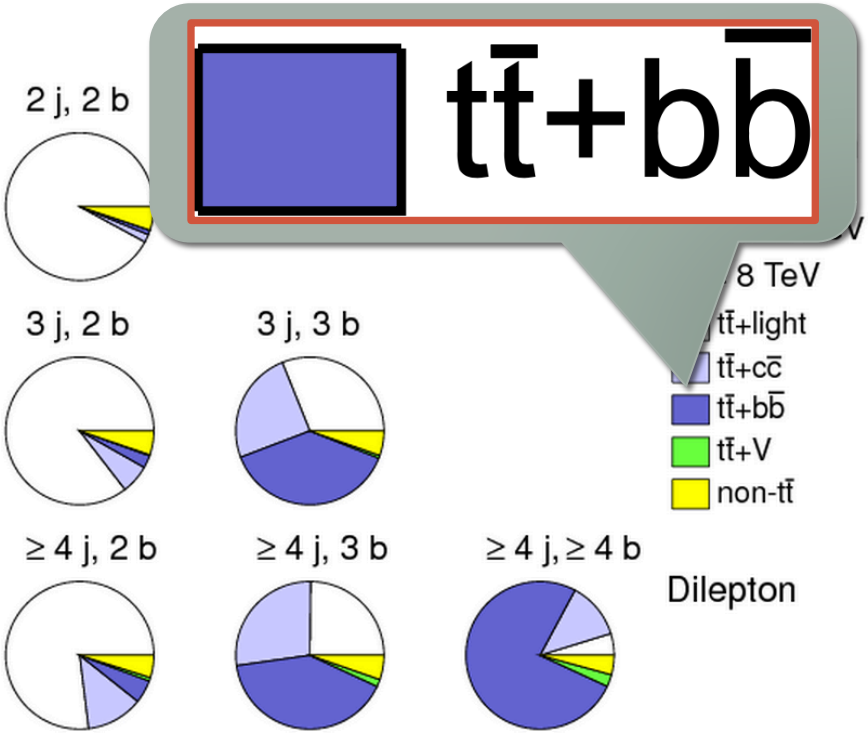
- **Heavily background dominated** –
  - Categorise events into different regions according to $\mathbf{N_{jets}}$ and $\mathbf{N_{tags}}$ to improve the sensitivity



Analysis Strategy

- **Heavily background dominated** –
  - Categorise events into different regions according to $\mathbf{N_{jets}}$ and $\mathbf{N_{tags}}$ to improve the sensitivity
- Dominant background: $t\bar{t}+b\bar{b}$
  - modelled with inclusive $t\bar{t}$ Powheg+Pythia6; reweighted to Sherpa+OpenLoops ($t\bar{t}+b\bar{b}$ @ NLO)





Analysis Strategy

- **Heavily background dominated** –
  - Categorise events into different regions according to $\mathbf{N_{jets}}$ and $\mathbf{N_{tags}}$ to improve the sensitivity
- Dominant background: $t\bar{t}+b\bar{b}$
  - modelled with inclusive $t\bar{t}$ Powheg+Pythia6; reweighted to Sherpa+OpenLoops ($t\bar{t}+b\bar{b}$ @ NLO)
- Simultaneous fit is performed in all regions to reduce the impact of the systematic uncertainties in signal regions

	2 tags	3 tags	≥ 4 tags
4 jets	H_T^{had}	H_T^{had}	H_T^{had}
5 jets	H_T^{had}	NNHF	NN
≥ 6 jets	H_T^{had}	NN	NN

* H_T^{had}: scalar sum of jet p_T

	2 tags	3 tags	≥ 4 tags
2 jets	H_T		
3 jets	H_T	NN	
≥ 4 jets	H_T	NN	NN

* H_T: scalar sum of all object p_T

Analysis Strategy

- **Heavily background dominated** –
  - Categorise events into different regions according to $\mathbf{N_{jets}}$ and $\mathbf{N_{tags}}$ to improve the sensitivity
- Dominant background: $t\bar{t}+b\bar{b}$
  - modelled with inclusive $t\bar{t}$ Powheg+Pythia6; reweighted to Sherpa+OpenLoops ($t\bar{t}+b\bar{b}$ @ NLO)
- Simultaneous fit is performed in all regions to reduce the impact of the systematic uncertainties in signal regions
- Neural Network built in signal rich regions to separate signal and background

	2 tags	3 tags	≥ 4 tags
4 jets	H_T^{had}	H_T^{had}	H_T^{had}
5 jets	H_T^{had}	NNHF	NN
≥ 6 jets	H_T^{had}	NN	NN

* H_T^{had}: scalar sum of jet p_T

	2 tags	3 tags	≥ 4 tags
2 jets	H_T		
3 jets	H_T	NN	
≥ 4 jets	H_T	NN	NN

* H_T: scalar sum of all object p_T

Analysis Strategy

- **Heavily background dominated** –
  - Categorise events into different regions according to $\mathbf{N_{jets}}$ and $\mathbf{N_{tags}}$ to improve the sensitivity
- Dominant background: $t\bar{t}+b\bar{b}$
  - modelled with inclusive $t\bar{t}$ Powheg+Pythia6; reweighted to Sherpa+OpenLoops ($t\bar{t}+b\bar{b}$ @ NLO)
- Simultaneous fit is performed in all regions to reduce the impact of the systematic uncertainties in signal regions
- Neural Network built in signal rich regions to separate signal and background
  - In single lepton channel 5j3b region: NNHF to separate *$t\bar{t}$+light* and *$t\bar{t}$+HF*

* HF = Heavy Flavour

	2 tags	3 tags	≥ 4 tags
4 jets	H_T^{had}	H_T^{had}	H_T^{had}
5 jets	H_T^{had}	NNHF	NN
≥ 6 jets	H_T^{had}	NN	NN

* H_T^{had}: scalar sum of jet p_T

	2 tags	3 tags	≥ 4 tags
2 jets	H_T		
3 jets	H_T	NN	
≥ 4 jets	H_T	NN	NN

* H_T: scalar sum of all object p_T

Analysis Strategy

- **Heavily background dominated** –
  - Categorise events into different regions according to $\mathbf{N_{jets}}$ and $\mathbf{N_{tags}}$ to improve the sensitivity
- Dominant background: $t\bar{t}+b\bar{b}$
  - modelled with inclusive $t\bar{t}$ Powheg+Pythia6; reweighted to Sherpa+OpenLoops ($t\bar{t}+b\bar{b}$ @ NLO)
- Simultaneous fit is performed in all regions to reduce the impact of the systematic uncertainties in signal regions
- Neural Network built in signal rich regions to separate signal and background
  - In single lepton channel 5j3b region: NNHF to separate *$t\bar{t}$+light* and *$t\bar{t}$+HF*
- In single lepton channel, include discriminant variables from Matrix Element Method into NN

* HF = Heavy Flavour

	2 tags	3 tags	≥ 4 tags
4 jets	H_T^{had}	H_T^{had}	H_T^{had}
5 jets	H_T^{had}	NNHF	NN
≥ 6 jets	H_T^{had}	NN	NN

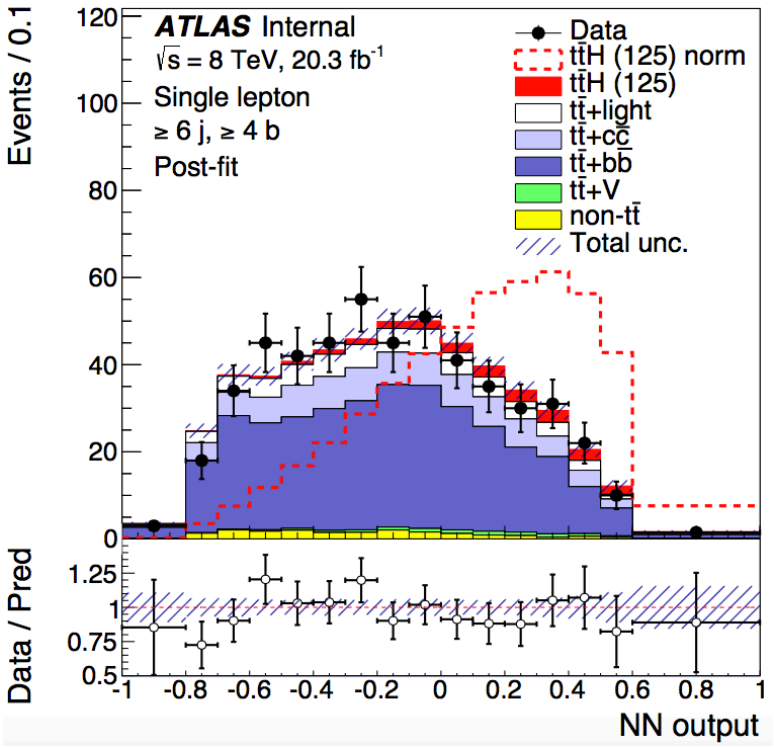
* H_T^{had}: scalar sum of jet p_T

	2 tags	3 tags	≥ 4 tags
2 jets	H_T		
3 jets	H_T	NN	
≥ 4 jets	H_T	NN	NN

* H_T: scalar sum of all object p_T

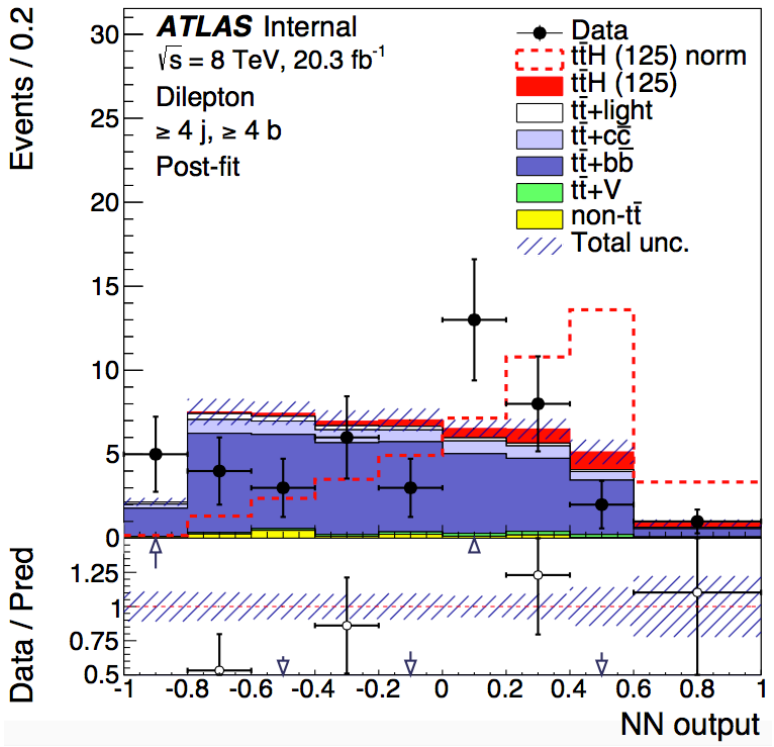
Neural Network

Post-fit NN in single lepton, 6/4



	2 tags	3 tags	≥ 4 tags
4 jets			
5 jets		NNHF	NN
≥ 6 jets		NN	NN

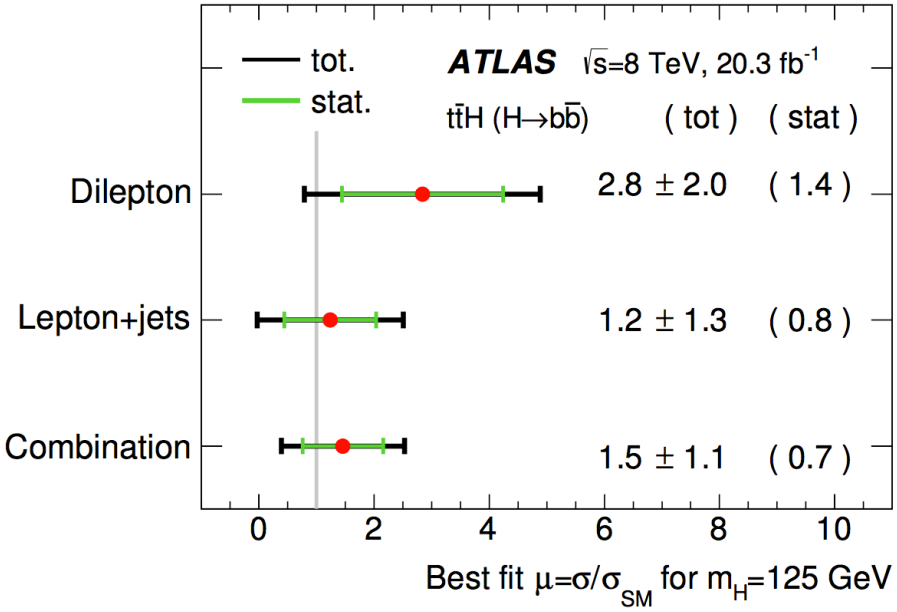
Post-fit NN in dilepton, 4/4

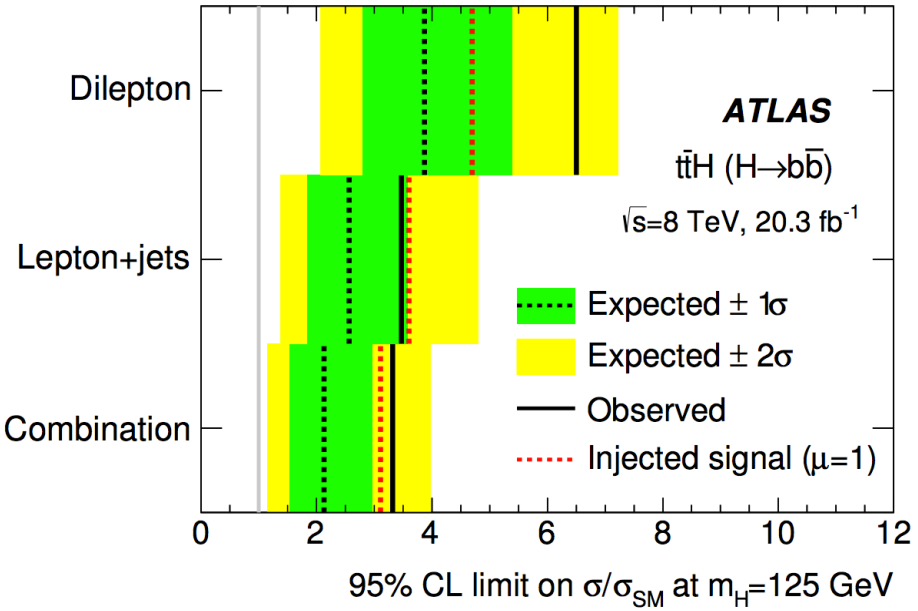


	2 tags	3 tags	≥ 4 tags
2 jets			
3 jets		NN	
≥ 4 jets		NN	NN

Results

- Best fit signal strength
  - Combination: $\mu = 1.5 \pm 1.1$
- Agreement with SM expectation
- Observed
  - Significance of signal: 1.4σ
  - p-value: 8%
- 95% CL limit
  - Combination: 3.4 x SM
- (extracted using CL_S)

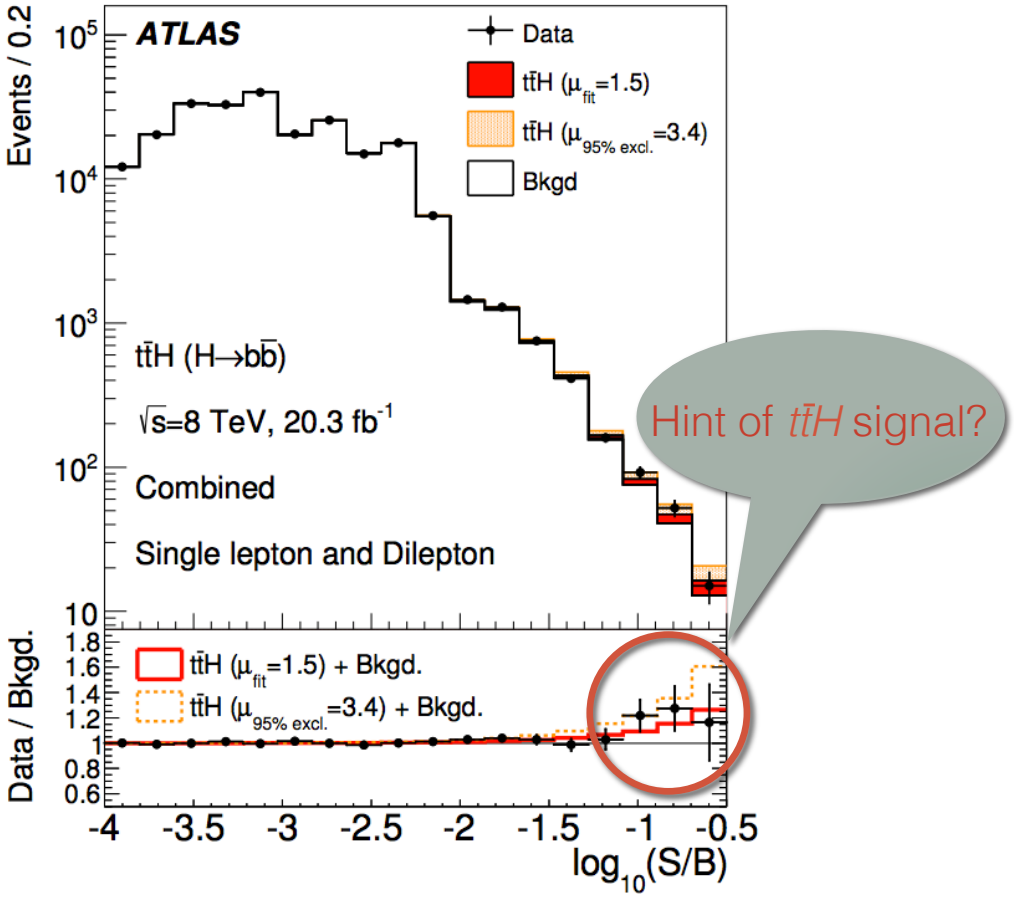




Results

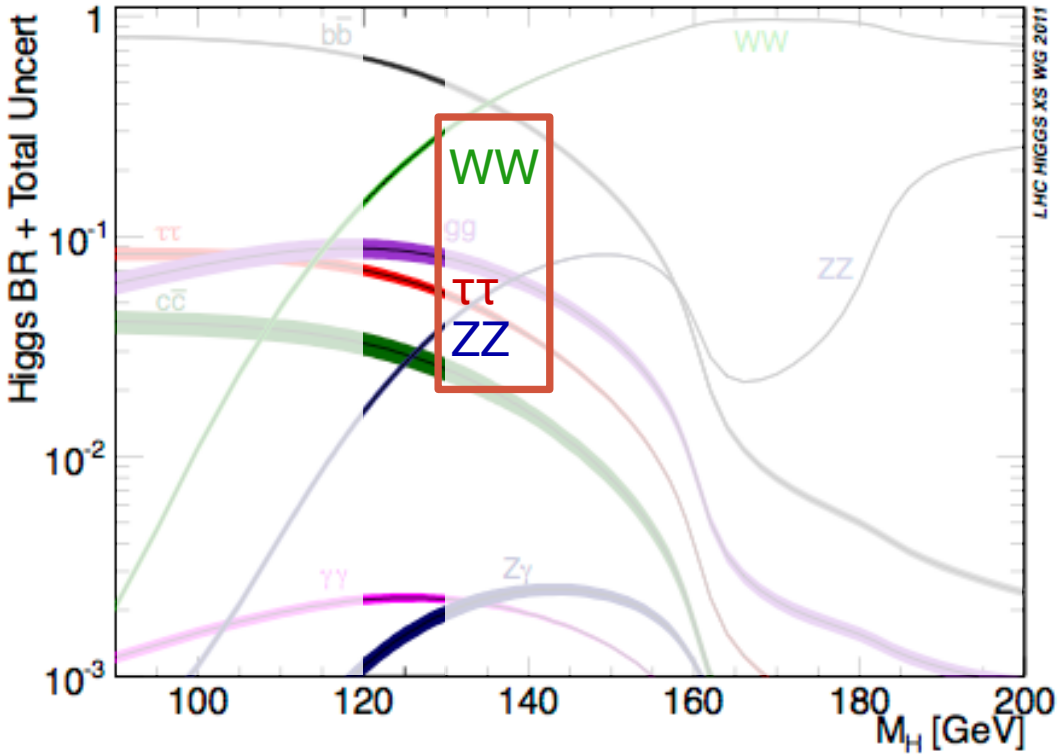
- Best fit signal strength
  - Combination: $\mu = 1.5 \pm 1.1$
- Agreement with SM expectation
- Observed
  - Significance of signal: 1.4σ
  - p-value: 8%
- 95% CL limit
  - Combination: 3.4 x SM
- (extracted using CL_S)

Post-fit event yields in each bin of the fitted distributions



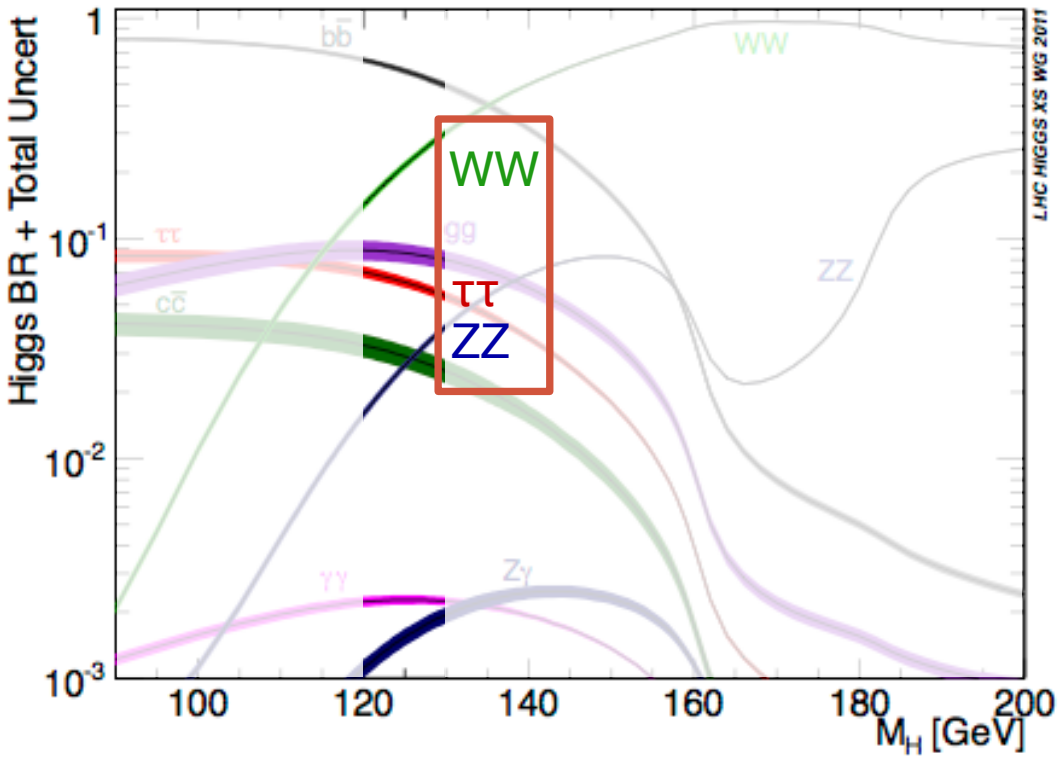
Outline

- $t\bar{t}H$ ($H \to b\bar{b}$) @ 8 TeV — Eur. Phys. J. C (2015) 75:349
- $t\bar{t}H$ (Multilepton) @ 8 TeV — Accepted by Phys. Lett. B
  - Sensitive to $H \to WW^*$, $H \to \tau\tau$, $H \to ZZ^*$
- $t\bar{t}H$ ($H \to \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$) @ 7 / 8 TeV — Phys. Lett. B 740 (2015) 222-242



$t\bar{t}H$ (Multilepton)

- Sensitive to $t\bar{t}H$ with $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, and $H \rightarrow ZZ^*$, with $t\bar{t}$ decaying to 1 or 2 leptons



$t\bar{t}H$ (Multilepton)

- Sensitive to $t\bar{t}H$ with $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, and $H \rightarrow ZZ^*$, with $t\bar{t}$ decaying to 1 or 2 leptons

- Consider 5 final states:
  - 2 SS leptons (e/μ), no τ_{had}
  - 3 leptons (e/μ), total charge ±1
  - 2 SS leptons (e/μ), 1 τ_{had}
  - 4 leptons (e/μ)
  - 1 lepton (e/μ), 2 τ_{had}

* SS: Same Sign

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%

$t\bar{t}H$ (Multilepton)

- Sensitive to $t\bar{t}H$ with $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, and $H \rightarrow ZZ^*$, with $t\bar{t}$ decaying to 1 or 2 leptons

- Consider 5 final states:
  - 2 SS leptons (e/μ), no τ_{had}
  - 3 leptons (e/μ), total charge ±1
  - 2 SS leptons (e/μ), 1 τ_{had}
  - 4 leptons (e/μ)
  - 1 lepton (e/μ), 2 τ_{had}

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%

* SS: Same Sign

$t\bar{t}H$ (Multilepton)

- Sensitive to $t\bar{t}H$ with $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, and $H \rightarrow ZZ^*$, with $t\bar{t}$ decaying to 1 or 2 leptons

- Consider 5 final states:
  - 2 SS leptons (e/μ), no τ_{had}
  - 3 leptons (e/μ), total charge ±1
  - 2 SS leptons (e/μ), 1 τ_{had}
  - 4 leptons (e/μ)
  - 1 lepton (e/μ), 2 τ_{had}

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%

* SS: Same Sign

$t\bar{t}H$ (Multilepton)

- Sensitive to $t\bar{t}H$ with $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, and $H \rightarrow ZZ^*$, with $t\bar{t}$ decaying to 1 or 2 leptons

- Consider 5 final states:
  - 2 SS leptons (e/μ), no τ_{had}
  - 3 leptons (e/μ), total charge ±1
  - 2 SS leptons (e/μ), 1 τ_{had}
  - 4 leptons (e/μ)
  - 1 lepton (e/μ), 2 τ_{had}

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%

* SS: Same Sign

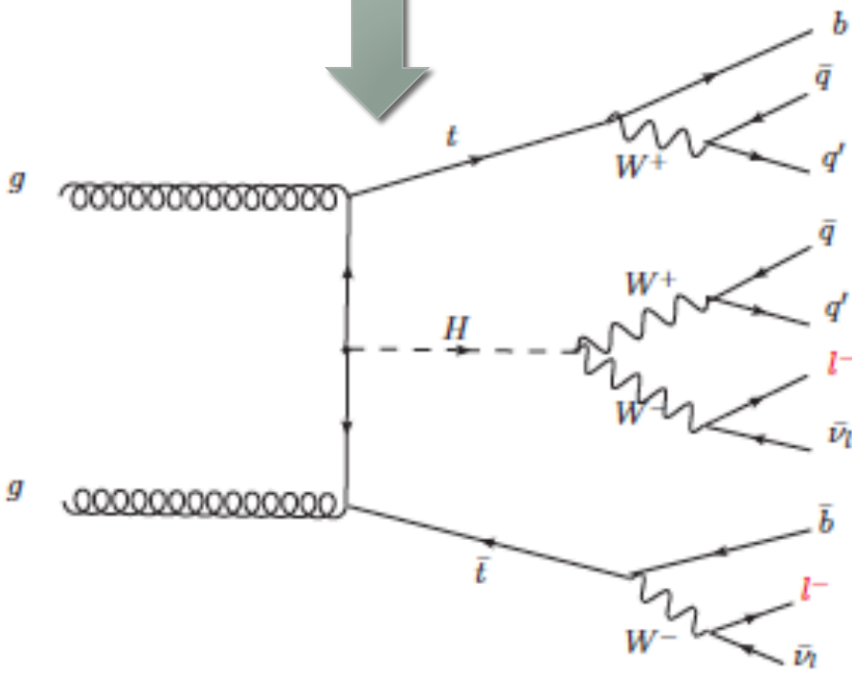
$t\bar{t}H$ (Multilepton)

- Sensitive to $t\bar{t}H$ with $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, and $H \rightarrow ZZ^*$, with $t\bar{t}$ decaying to 1 or 2 leptons

- Consider 5 final states:
  - 2 SS leptons (e/μ), no τ_{had}
  - 3 leptons (e/μ), total charge ±1
  - 2 SS leptons (e/μ), 1 τ_{had}
  - 4 leptons (e/μ)
  - 1 lepton (e/μ), 2 τ_{had}

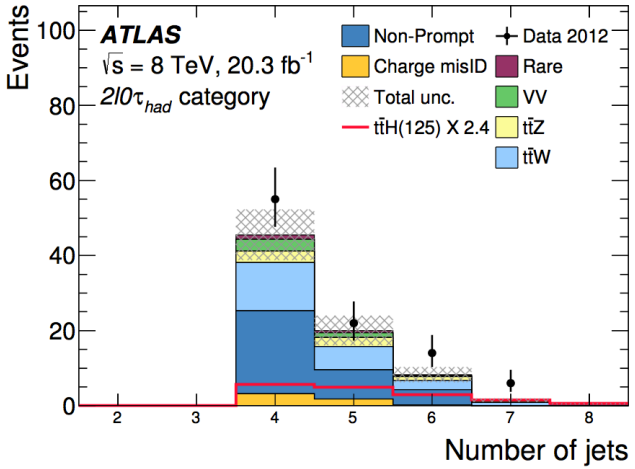
* SS: Same Sign

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%

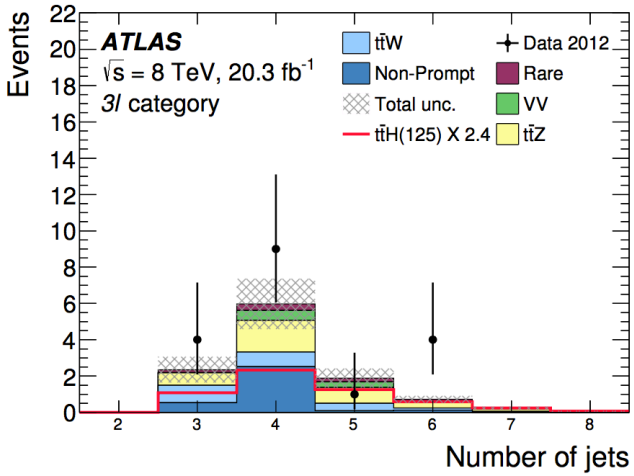


Data-MC Comparison

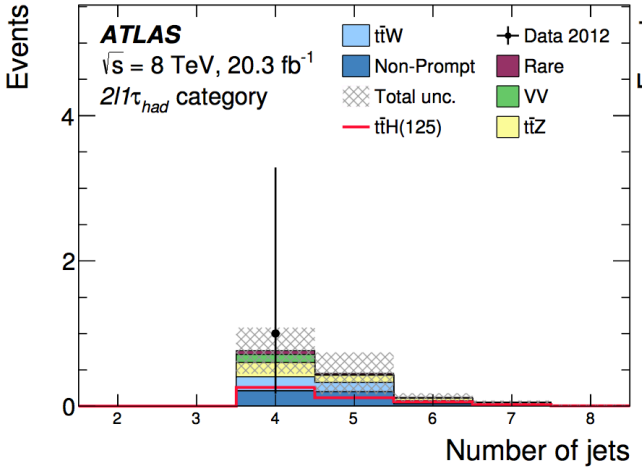
- Number of jets spectrum in 5 categories
  - Reasonable agreement



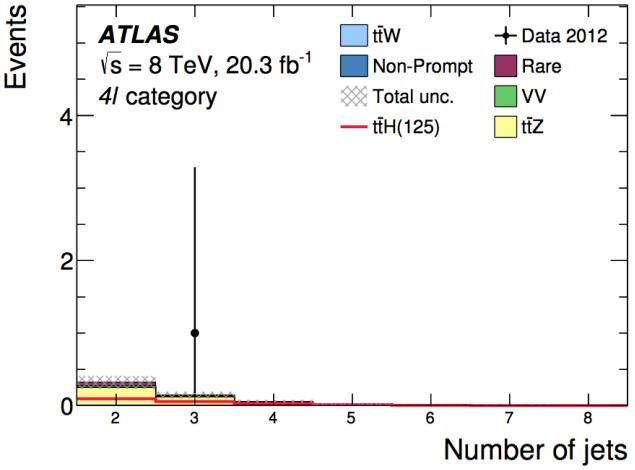
(a) Combined $2\ell 0\tau_{\text{had}}$ categories



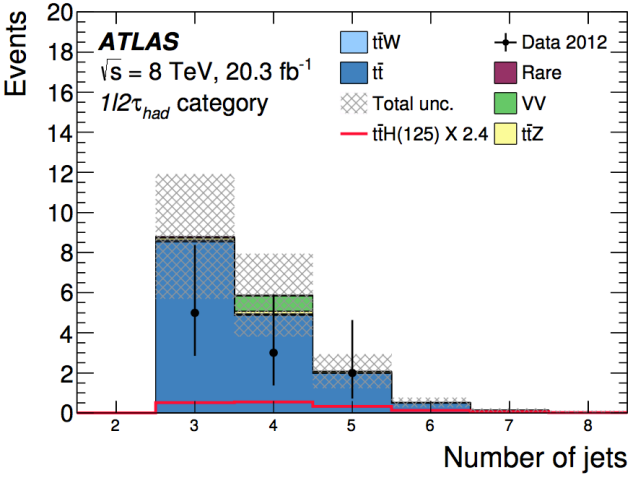
(b) 3ℓ category



(c) $2\ell 1\tau_{\text{had}}$ category



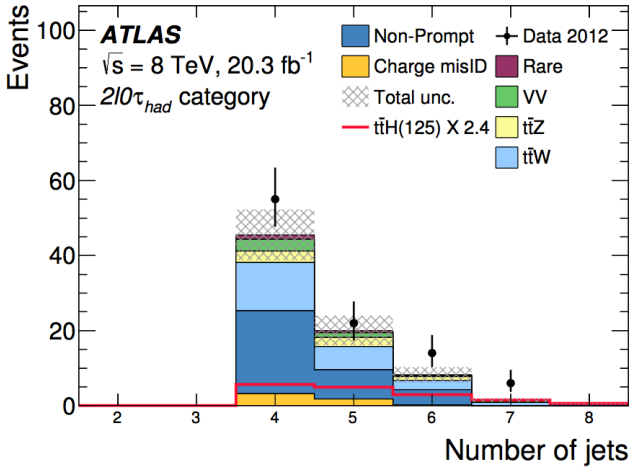
(d) Combined 4ℓ categories



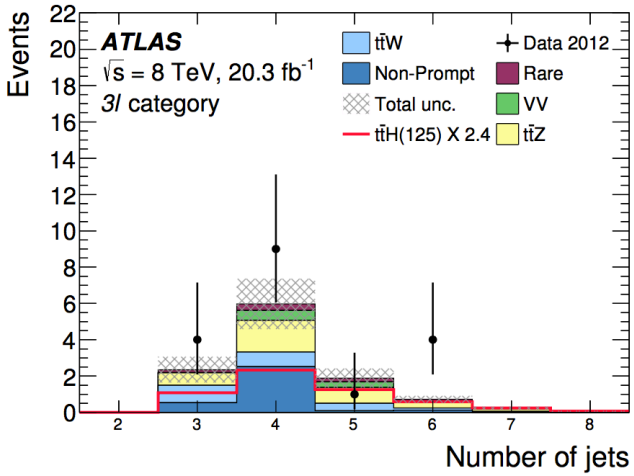
(e) $1\ell 2\tau_{\text{had}}$ category

Data-MC Comparison

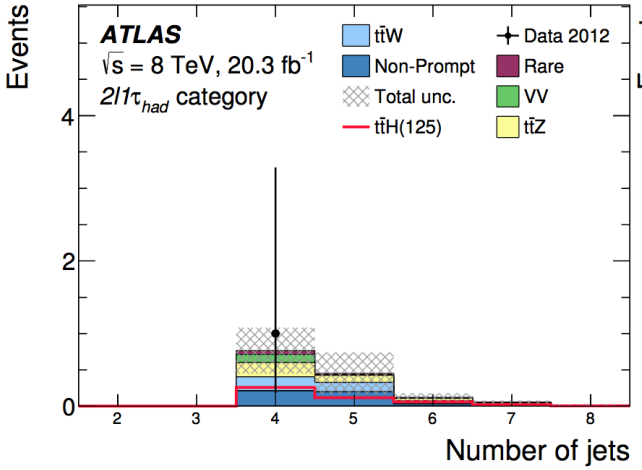
- Number of jets spectrum in 5 categories
  - Reasonable agreement
- Main background
  - $t\bar{t}V$: $t\bar{t}Z$, $t\bar{t}W$
  - $t\bar{t}$ with non-prompt lepton



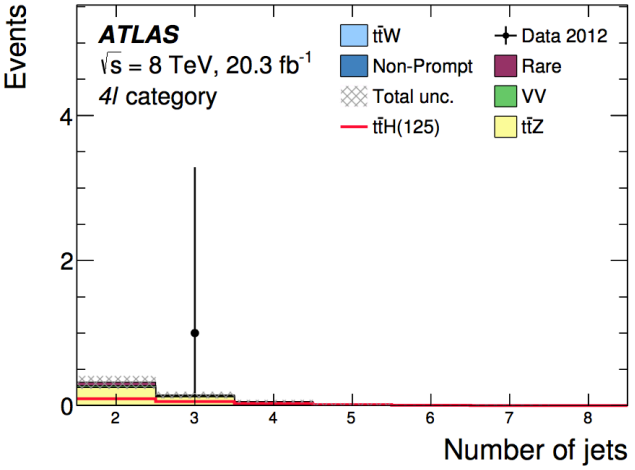
(a) Combined $2\ell 0\tau_{\text{had}}$ categories



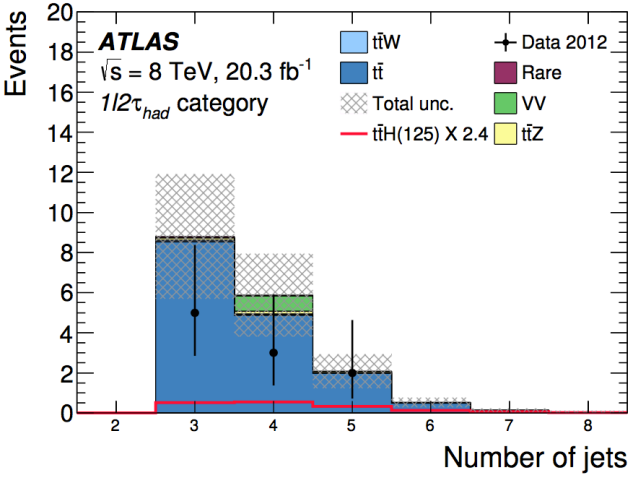
(b) 3ℓ category



(c) $2\ell 1\tau_{\text{had}}$ category



(d) Combined 4ℓ categories

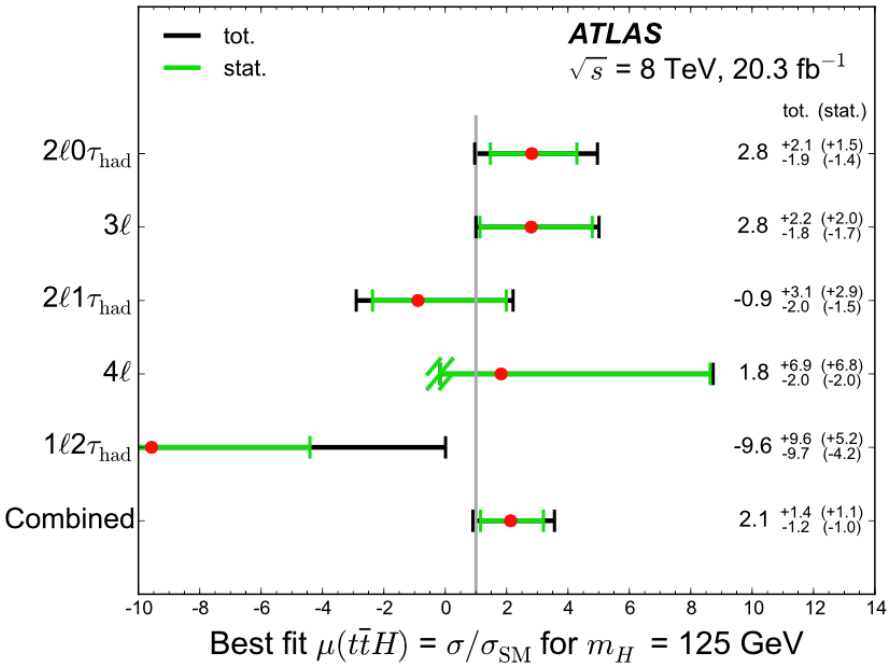


(e) $1\ell 2\tau_{\text{had}}$ category

Result

- Best fit $\mu(t\bar{t}H) = 2.1^{+1.4}_{-1.2}$
- Consistent with SM prediction

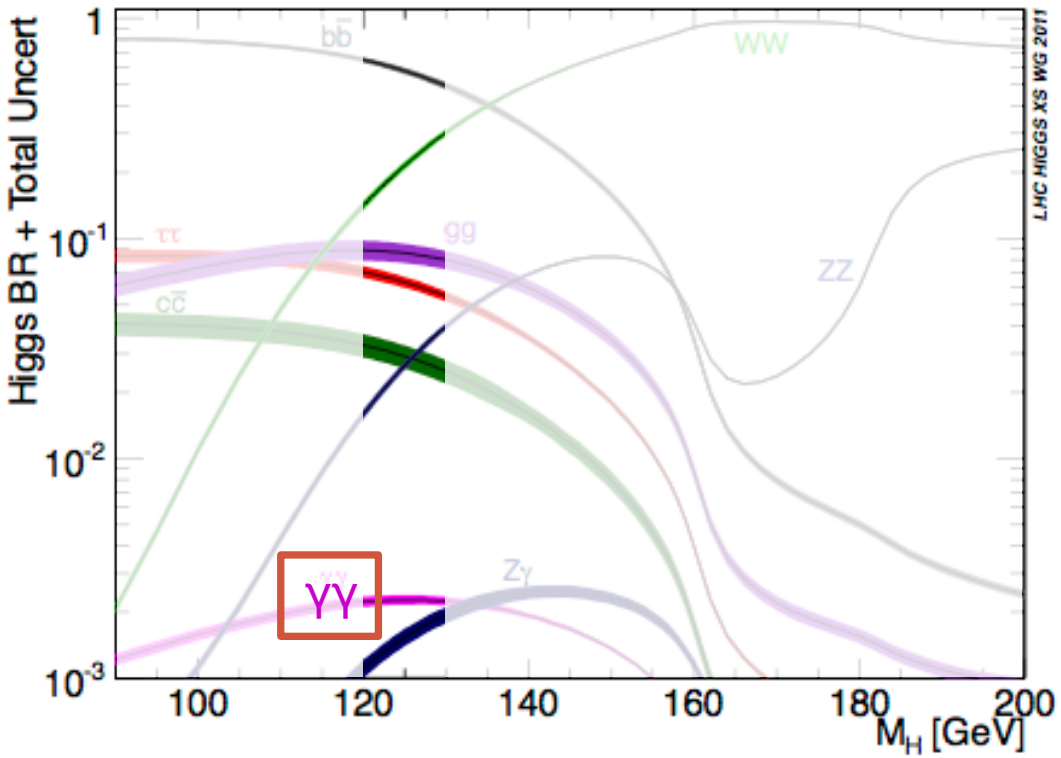
- Observed significance (p-value) w.r.t.
  - B only hypothesis: 1.8σ (3.7%)
  - SM S+B hypothesis: 0.9σ (18%)



- Observed (expected) 95% CL upper limit: 4.7 (2.4)
  - Extracted using CL_S

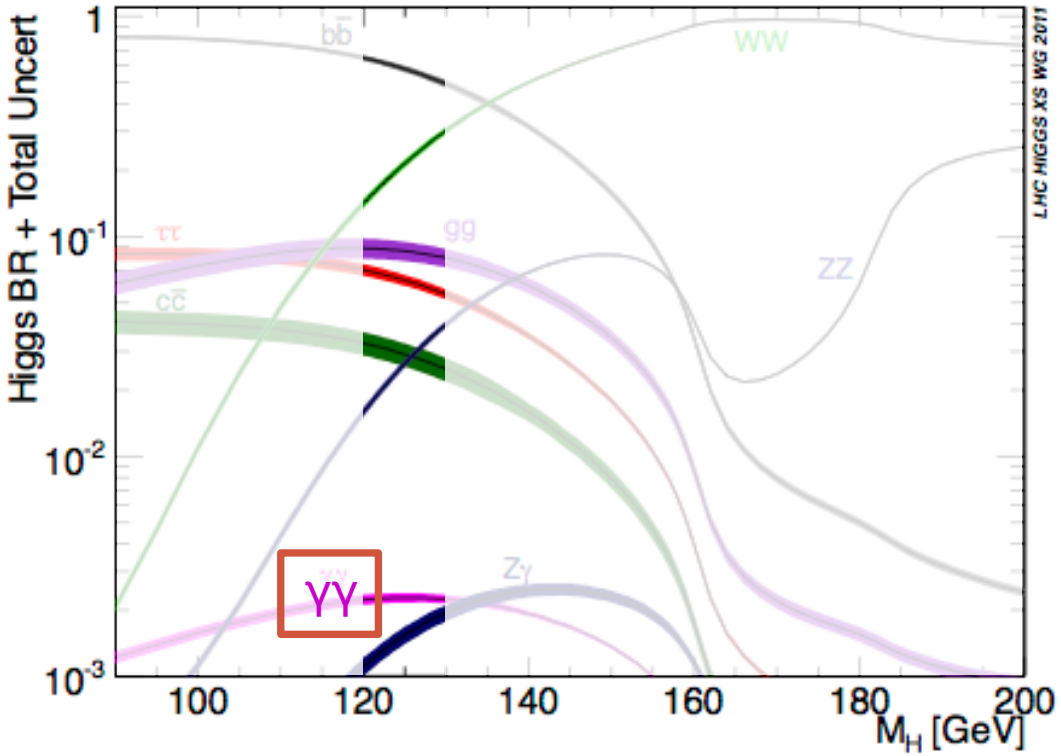
Outline

- $t\bar{t}H$ ($H \to b\bar{b}$) @ 8 TeV — Eur. Phys. J. C (2015) 75:349
- $t\bar{t}H$ (Multilepton) @ 8 TeV — Accepted by Phys. Lett. B
  - Sensitive to $H \to WW^*$, $H \to \tau\tau$, $H \to ZZ^*$
- $t\bar{t}H$ ($H \to \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$) @ 7 / 8 TeV — Phys. Lett. B 740 (2015) 222-242



$t\bar{t}H$ ($H \rightarrow \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$)

- $H \rightarrow \gamma\gamma$ has very small BR ~2.28 x 10^{-3} for m_H ~ 125 GeV



$t\bar{t}H$ ($H \rightarrow \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$)

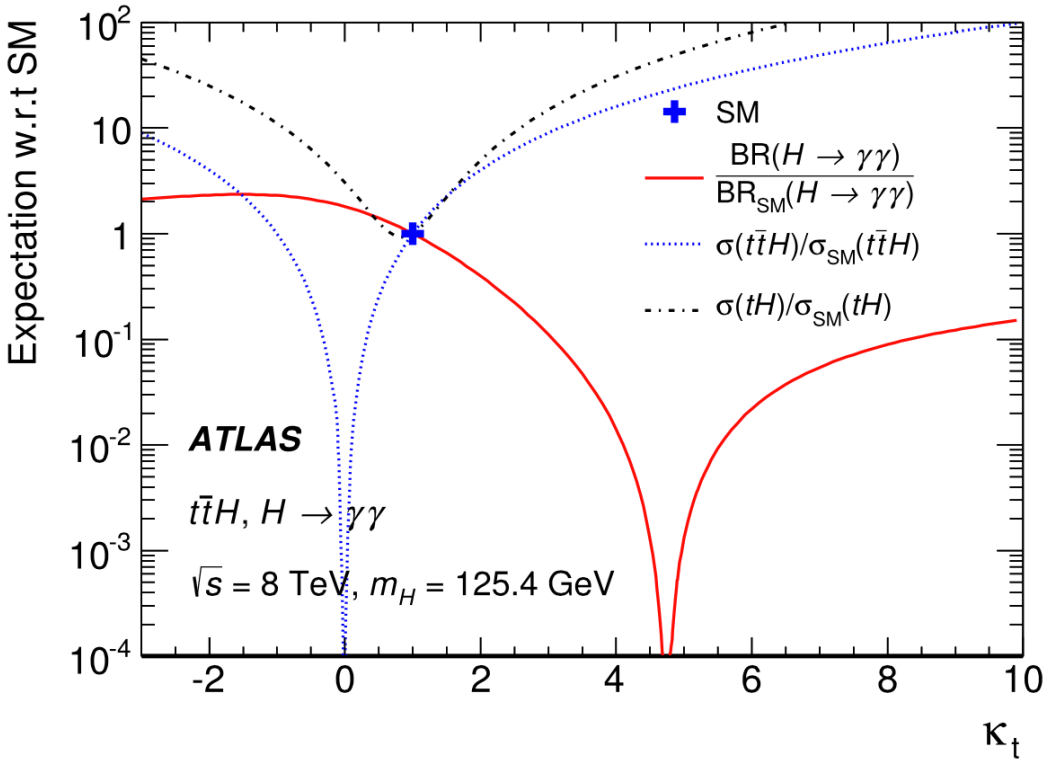
- $H \rightarrow \gamma\gamma$ has very small BR ~2.28 x 10^{-3} for m_H ~ 125 GeV
- Good $m_{\gamma\gamma}$ resolution: ~1.5 GeV (estimated from fit to MC)

$t\bar{t}H$ ($H \rightarrow \gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$)

- $H \rightarrow \gamma\gamma$ has very small BR ~2.28 x 10^{-3} for m_H ~ 125 GeV
- Good $m_{\gamma\gamma}$ resolution: ~1.5 GeV (estimated from fit to MC)
- Background has continuously decreasing $m_{\gamma\gamma}$ spectrum
  - Can be constrained by sideband data – no need to rely on theory assumption

$t\bar{t}H$ ($H\rightarrow\gamma\gamma$) and constraint on Y_t ($t\bar{t}H + tH$)

- $H\rightarrow\gamma\gamma$ has very small BR ~2.28 x 10^{-3} for m_H ~ 125 GeV
- Good $m_{\gamma\gamma}$ resolution: ~1.5 GeV (estimated from fit to MC)
- Background has continuously decreasing $m_{\gamma\gamma}$ spectrum
  - Can be constrained by sideband data – no need to rely on theory assumption
- Incorporate tH (with $H\rightarrow\gamma\gamma$) ➔ Y_t – define $\kappa_t = Y_t / Y_t^{SM}$

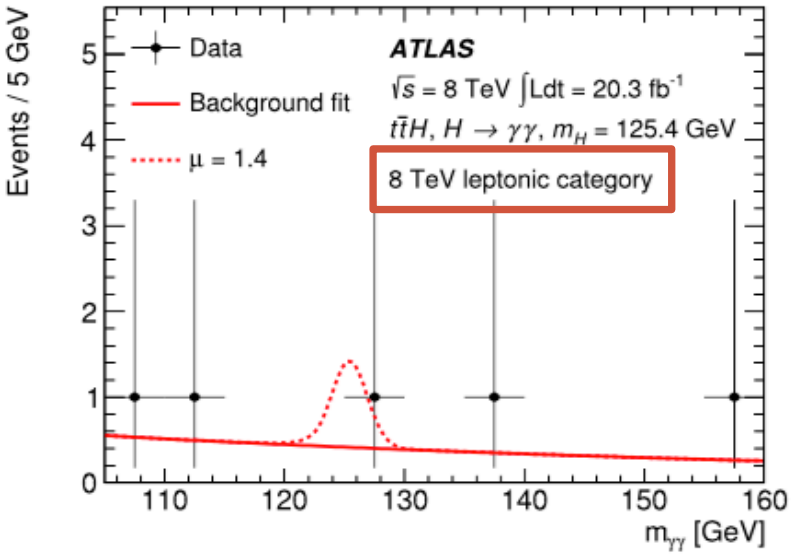


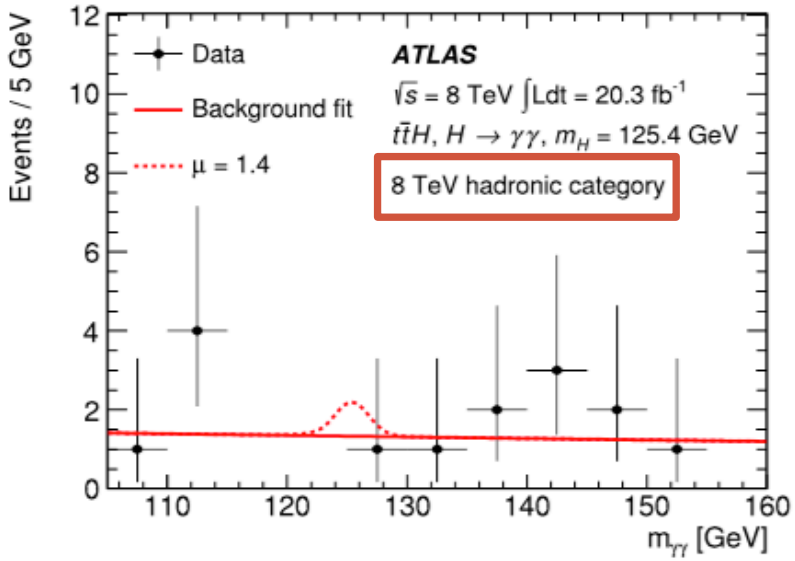
Analysis Strategy

- Based on the decay of the top quark pair, split events as
  - Leptonic category: ≥ 1 leptons
  - Hadronic category: no lepton

Analysis Strategy

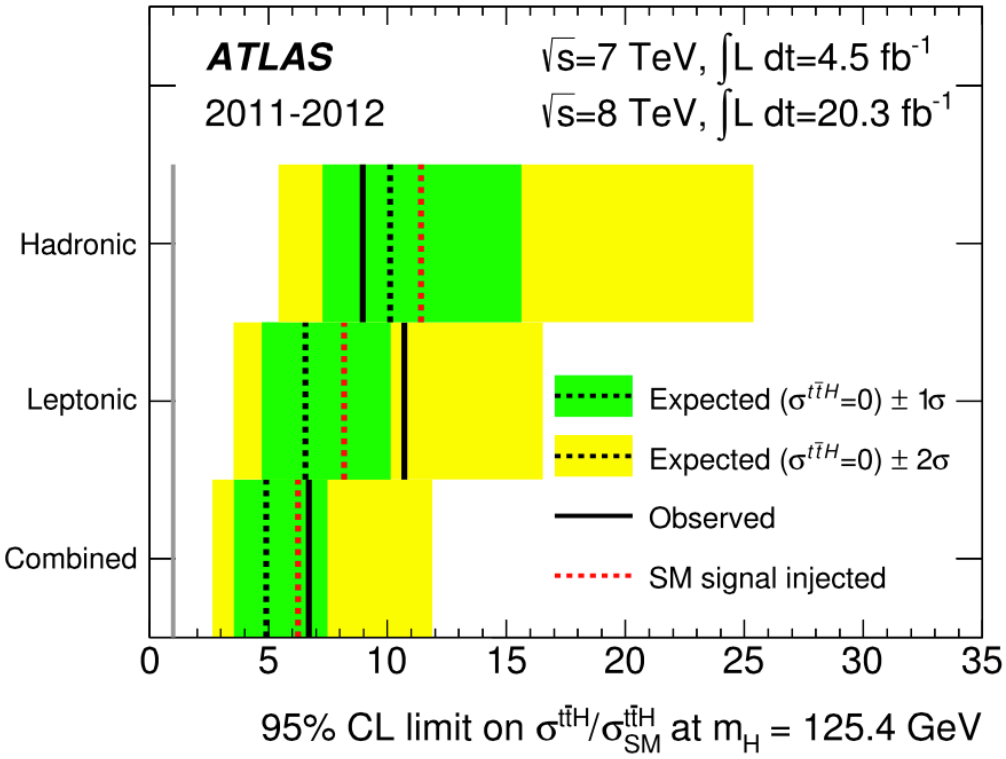
- Based on the decay of the top quark pair, split events as
  - Leptonic category: ≥ 1 leptons
  - Hadronic category: no lepton
- Search for a localised event excess in $m_{\gamma\gamma}$ (120, 130) GeV
  - Unbinned S+B likelihood fit in $m_{\gamma\gamma}$ (105, 160) GeV





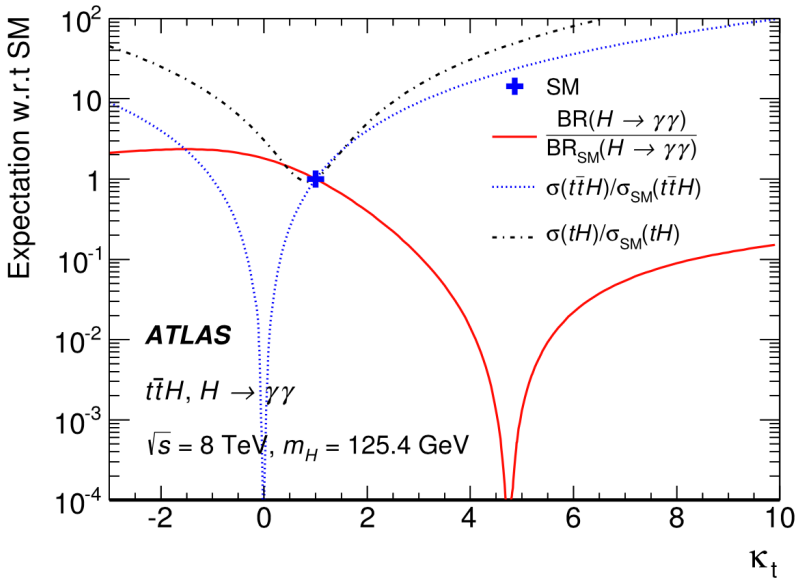
Results – $t\bar{t}H$

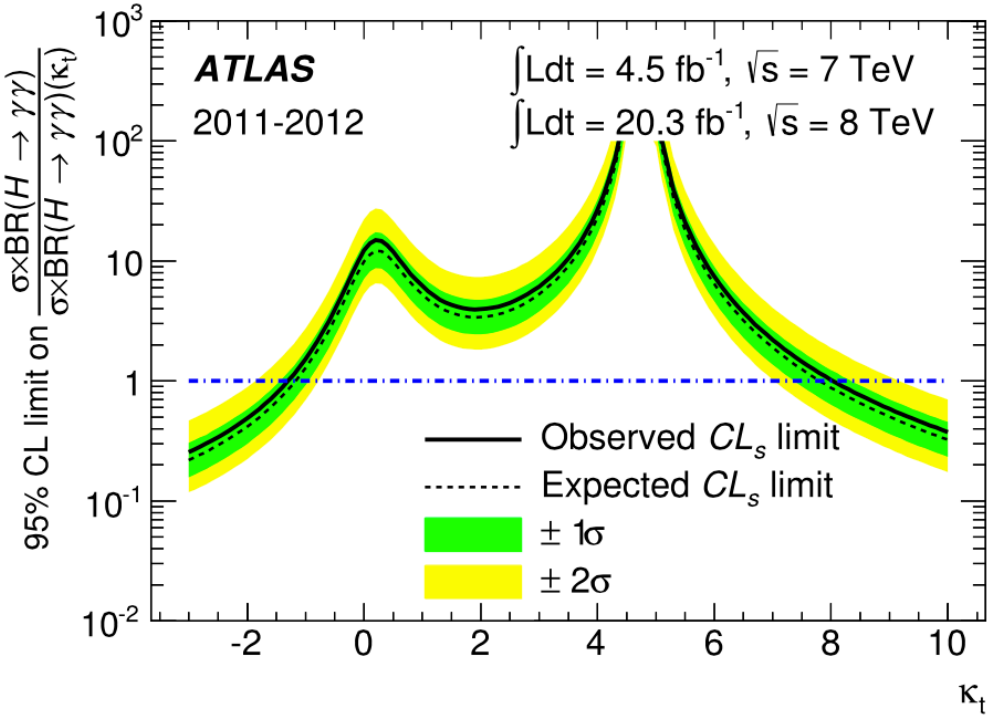
- Fitted μ_{ttH}: $1.3^{+2.5}_{-1.7}(\text{stat.})^{+0.8}_{-0.4}(\text{syst.})$
- Consistent with SM expectation
- Observed (expected) upper limit on μ_{ttH} @ 95% CL: 6.7 (4.9)
  - Extracted using CL_S



Results – $\kappa_t = Y_t / Y_t^{SM}$

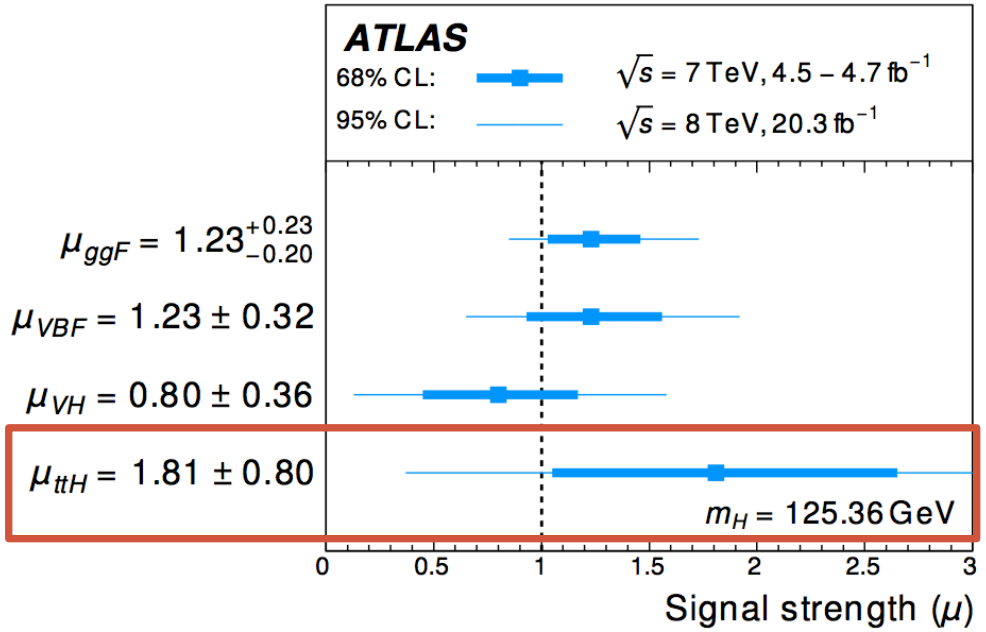
- Observed 95% CL limit on κ_t
  - (-1.3, 8.0)





Conclusion

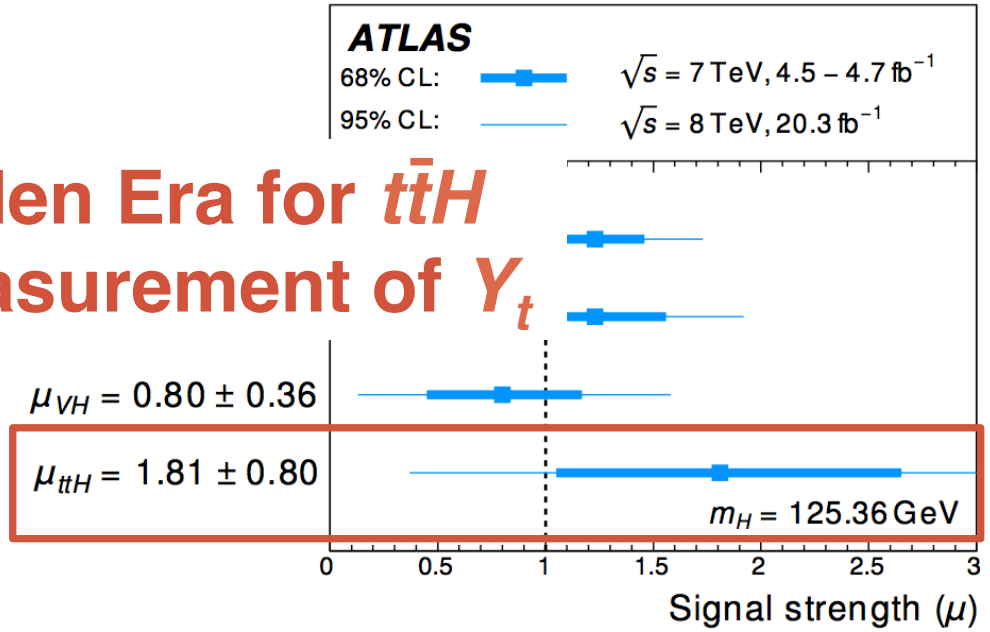
- ATLAS has performed searches for SM Higgs boson produced in association with top quarks in various final states
- Results consisted with SM prediction
- Combination on Higgs production/decay/coupling Submitted to: Eur. Phys. J. C
  - μ_{ttH} = 1.8 ± 0.8; 95% CL limit: 3.2



Conclusion

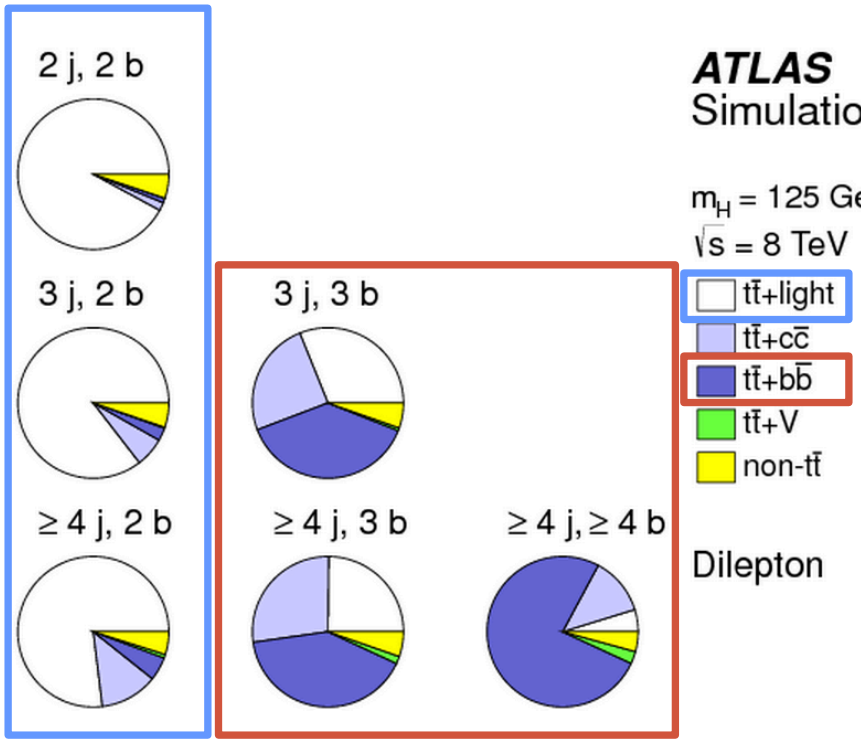
- ATLAS has performed searches for SM Higgs boson produced in association with top quarks in various final states
- Results consisted with SM prediction
- Combination on Higgs production/decay/coupling Submitted to: Eur. Phys. J. C
  - μ_{ttH} = 1.8 ± 0.8; 95% CL limit: 3.2

Run-II: Golden Era for $t\bar{t}H$
Expect a measurement of Y_t



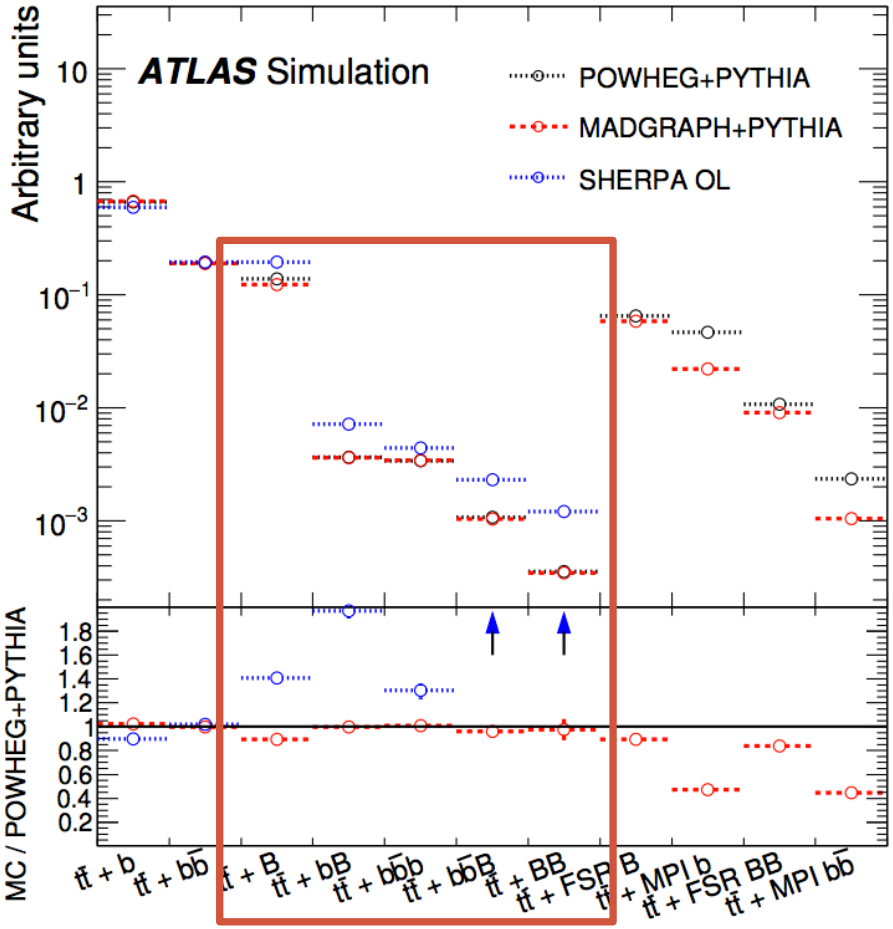
BACKUP

$t\bar{t}$+*jets* Modelling – $t\bar{t}+b\bar{b}$



- Generated using **Powheg+Pythia**
- Different $t\bar{t}$+*jets* composition in different regions
- Control regions dominated by $t\bar{t}$+*light*
  - use a sequential reweighting as a function of top quark p_T and *tt* system p_T, based on the ratio of data/MC measured at 7 TeV.
- Signal rich regions dominated by $t\bar{t}+b\bar{b}$
  - Powheg+Pythia only models $t\bar{t}+b\bar{b}$ with **Parton Shower**
  - Reweight to Sherpa+OpenLoops fully matched NLO prediction with massive b-quarks

$t\bar{t}$+*jets* Modelling – $t\bar{t}$+$b\bar{b}$

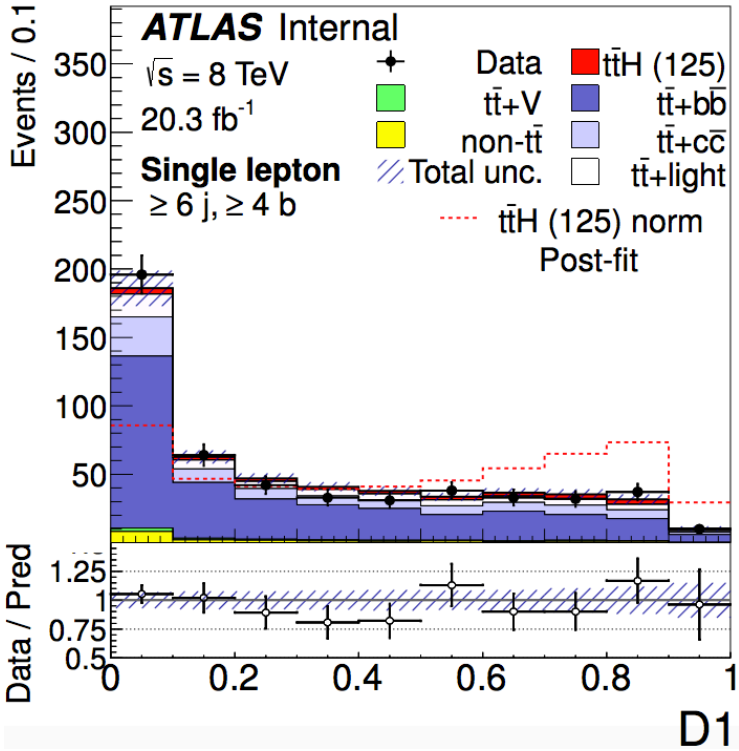


- Further categorise *tt+bb* into:
  - *tt+b*: 1 particle jet matched to a b quark **not from top**
  - *tt+bb*: 2 particle jets matched to b quarks
  - *tt+B*: 1 particle jet matched to *bb* pair (gluon splitting)
  - Other combinations of above.
- Discrepancies seen in categories with *B*, or where an extra *bb* pair is needed
- Reweighting scheme:
  - Adjust **relative x-section** in each category to SherpaOL prediction
  - Kinematics adjustment on *tt* p_T, top p_T, $\Delta R/p_T$ of the dijet system not from top decay

Neural Network

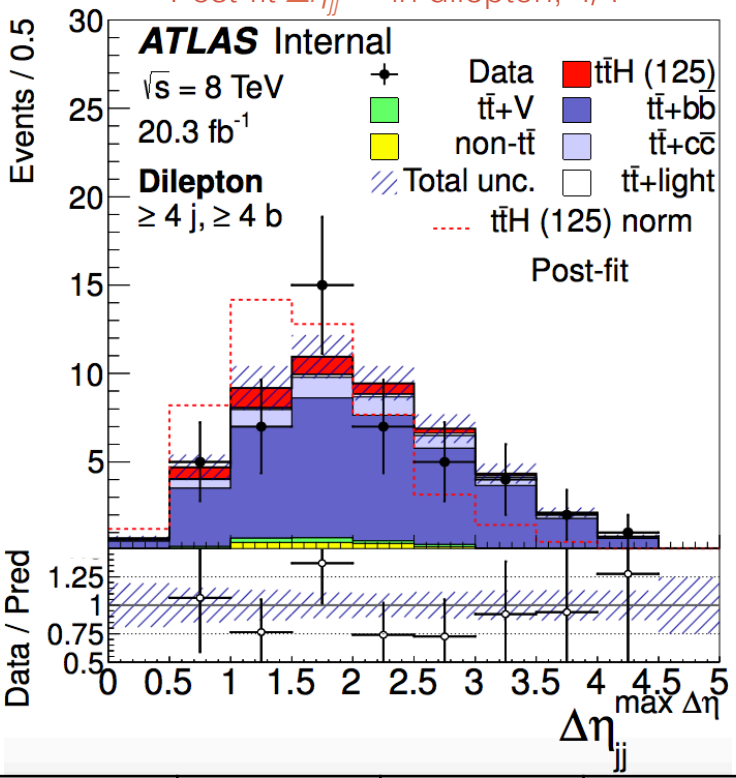
Highest ranking variables in NN

Post-fit D1 in single lepton, 6/4

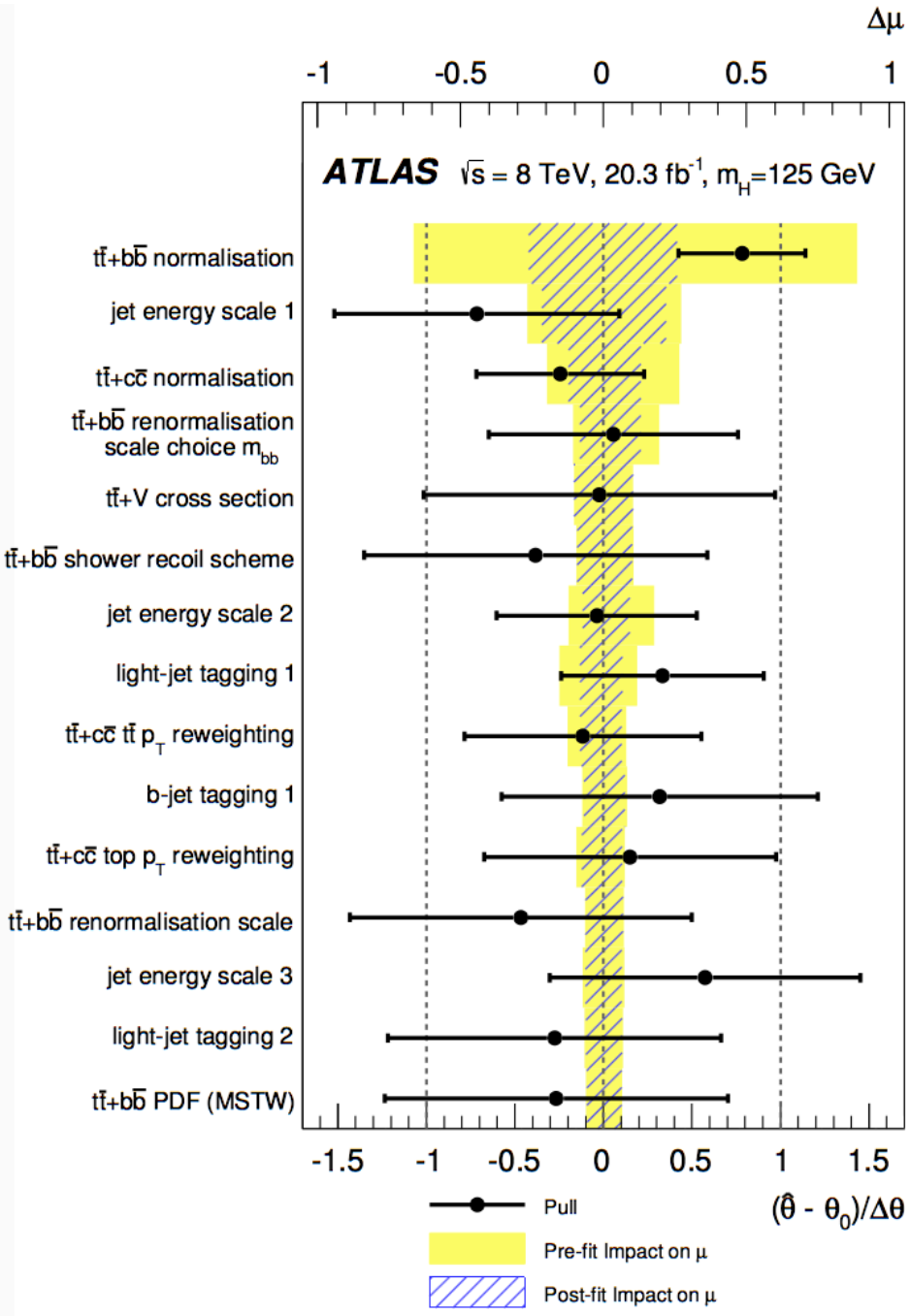


	2 tags	3 tags	≥ 4 tags
4 jets			
5 jets		NNHF	NN
≥ 6 jets		NN	NN

Post-fit $\Delta\eta_{jj}^{max}$ in dilepton, 4/4



	2 tags	3 tags	≥ 4 tags
2 jets			
3 jets		NN	
≥ 4 jets		NN	NN

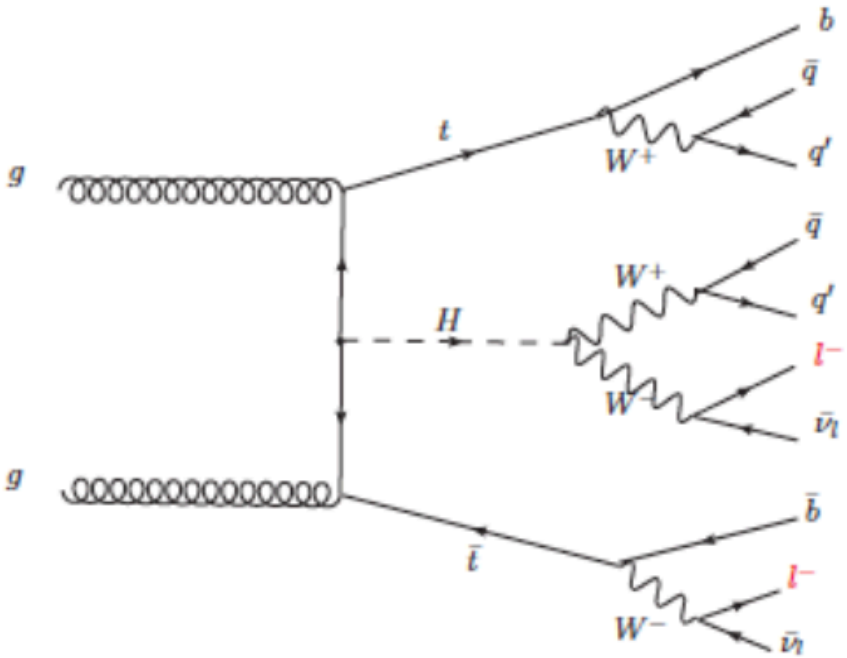

Δμ
-1
-0.5
0
0.5
1
ATLAS √s = 8 TeV, 20.3 fb-1, mH=125 GeV
tt̄+bb̄ normalisation
jet energy scale 1
tt̄+cc̄ normalisation
tt̄+bb̄ renormalisation scale choice mbb
tt̄+V cross section
tt̄+bb̄ shower recoil scheme
jet energy scale 2
light-jet tagging 1
tt̄+cc̄ tt̄ pT reweighting
b-jet tagging 1
tt̄+cc̄ top pT reweighting
tt̄+bb̄ renormalisation scale
jet energy scale 3
light-jet tagging 2
tt̄+bb̄ PDF (MSTW)
-1.5
-1
-0.5
0
0.5
1
1.5
Pull
(θ̂ - θ0)/Δθ
Pre-fit Impact on μ
Post-fit Impact on μ

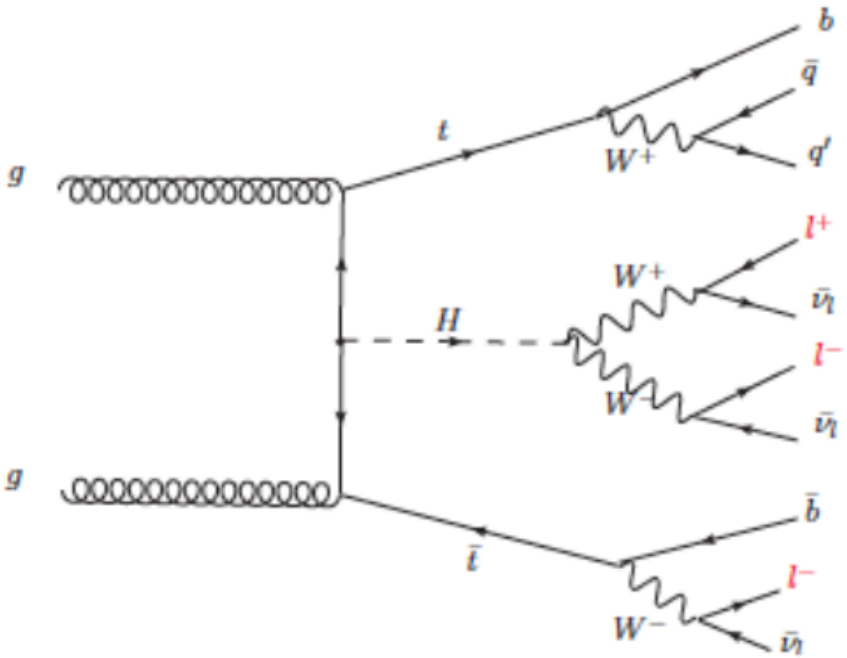
$t\bar{t}H$ (Multilepton)

- Sensitive to $t\bar{t}H$ with $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, and $H \rightarrow ZZ^*$, with $t\bar{t}$ decaying to 1 or 2 leptons

- Consider 5 final states:
  - 2 SS leptons (e/μ), no τ_{had}; (ee, μμ, eμ) x (4, ≥5) jets
  - 3 leptons (e/μ), total charge ±1; 3j, ≥2b or ≥4j, ≥1b
  - 2 SS leptons (e/μ), 1 τ_{had}; ≥4j, ≥1b
  - 4 leptons (e/μ); ≥ 2j, ≥1b; Z enriched/depleted
  - 1 lepton (e/μ), 2 τ_{had}; ≥3j, ≥1b; $H \rightarrow \tau^+\tau$, use $m_{\tau\tau}$

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%



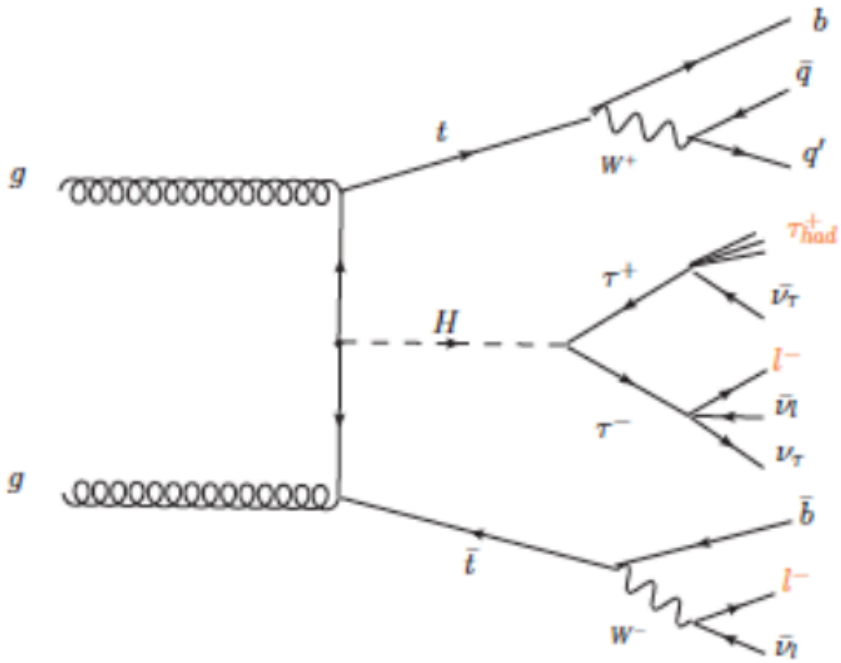


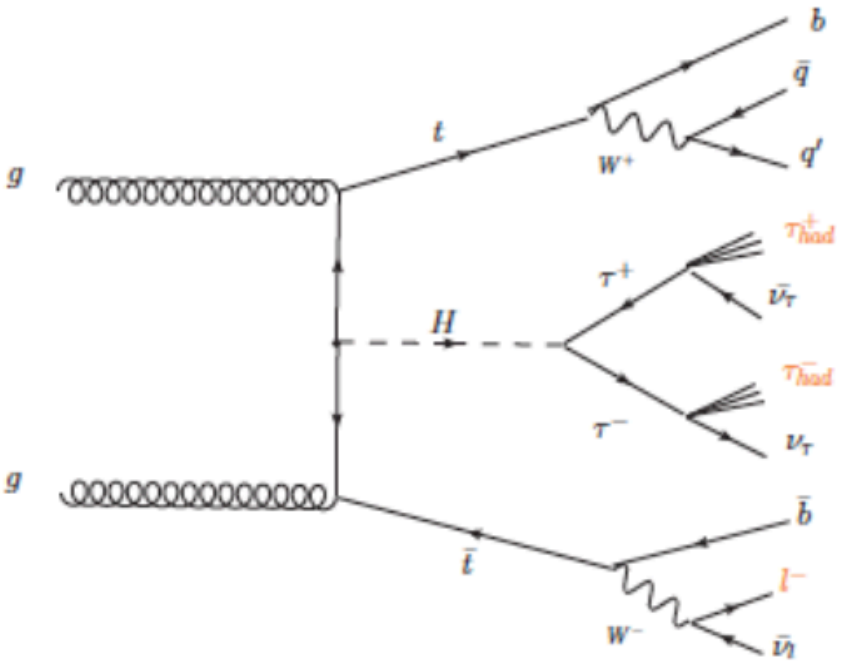
$t\bar{t}H$ (Multilepton)

- Sensitive to $t\bar{t}H$ with $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, and $H \rightarrow ZZ^*$, with $t\bar{t}$ decaying to 1 or 2 leptons

- Consider 5 final states:
  - 2 SS leptons (e/μ), no τ_{had}; (ee, μμ, eμ) x (4, ≥5) jets
  - 3 leptons (e/μ), total charge ±1; 3j, ≥2b or ≥4j, ≥1b
  - 2 SS leptons (e/μ), 1 τ_{had}; ≥4j, ≥1b
  - 4 leptons (e/μ); ≥ 2j, ≥1b; Z enriched/depleted
  - 1 lepton (e/μ), 2 τ_{had}; ≥3j, ≥1b; $H \rightarrow \tau^+\tau$, use $m_{\tau\tau}$

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%



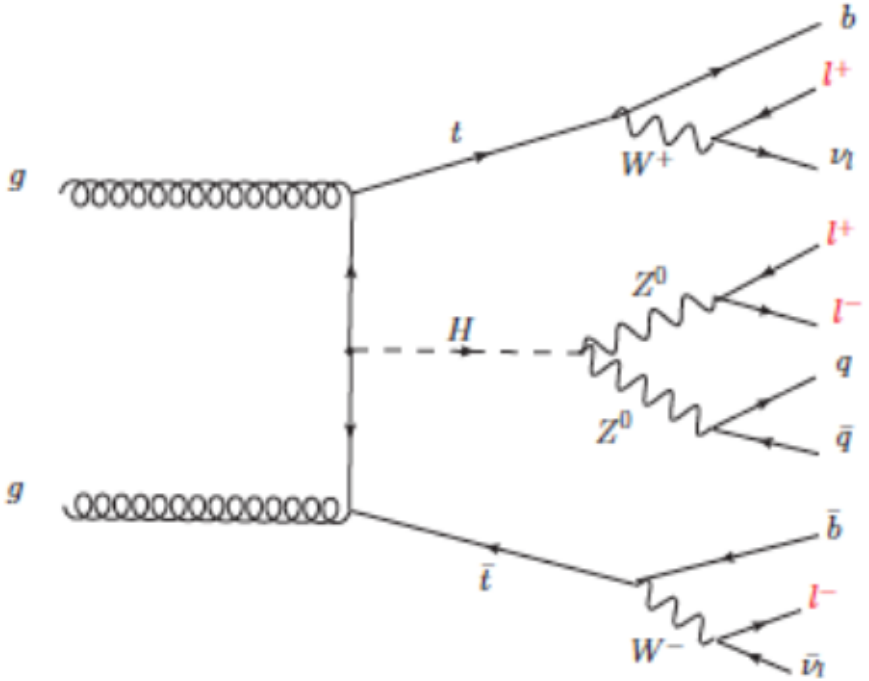


$t\bar{t}H$ (Multilepton)

- Sensitive to $t\bar{t}H$ with $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, and $H \rightarrow ZZ^*$, with $t\bar{t}$ decaying to 1 or 2 leptons

- Consider 5 final states:
  - 2 SS leptons (e/μ), no τ_{had}; (ee, μμ, eμ) x (4, ≥5) jets
  - 3 leptons (e/μ), total charge ±1; 3j, ≥2b or ≥4j, ≥1b
  - 2 SS leptons (e/μ), 1 τ_{had}; ≥4j, ≥1b
  - 4 leptons (e/μ); ≥ 2j, ≥1b; Z enriched/depleted
  - 1 lepton (e/μ), 2 τ_{had}; ≥3j, ≥1b; $H \rightarrow \tau^+\tau$, use $m_{\tau\tau}$

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%



Signal / Background modelling

- Modelling the $H \rightarrow \gamma\gamma$ resonance: Crystal Ball function (core) + Gaussian (tail)
  - Parameters of the functions fitted to the MC simulations
  - Taking into account all possible Higgs production mode: *ggF, VBF, WH, ZH, $t\bar{t}H$, tH* (*tHqb, WtH*)
- Modelling the continuum background: $e^{\alpha m_{\gamma\gamma}}$, where $\alpha \leq 0$
  - Validated in the data control regions
  - Use the same shape for 7 TeV and 8 TeV – due to lack of data @ 7 TeV