Search for the Higgs Boson in the ttH production mode using the ATLAS detector

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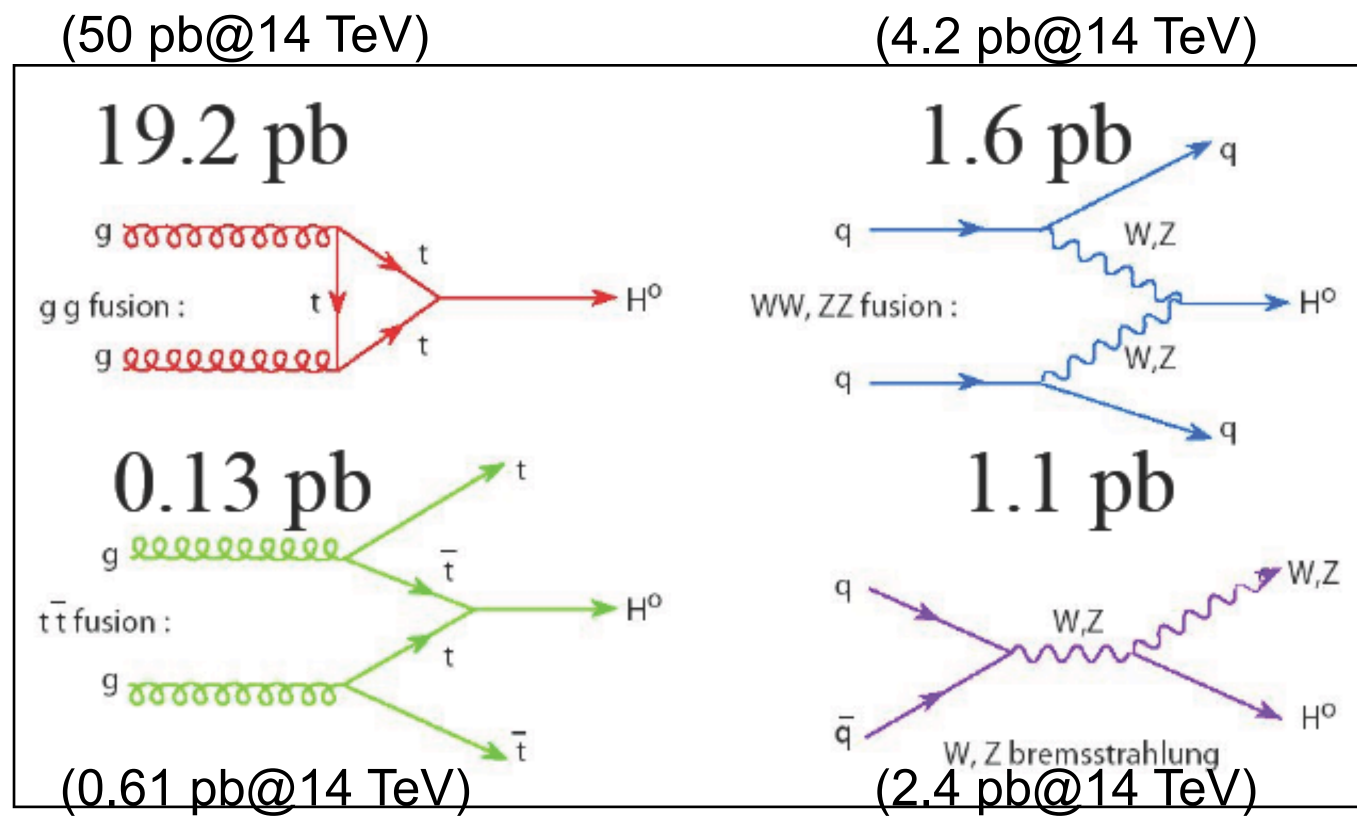
for the ATLAS Collaboration

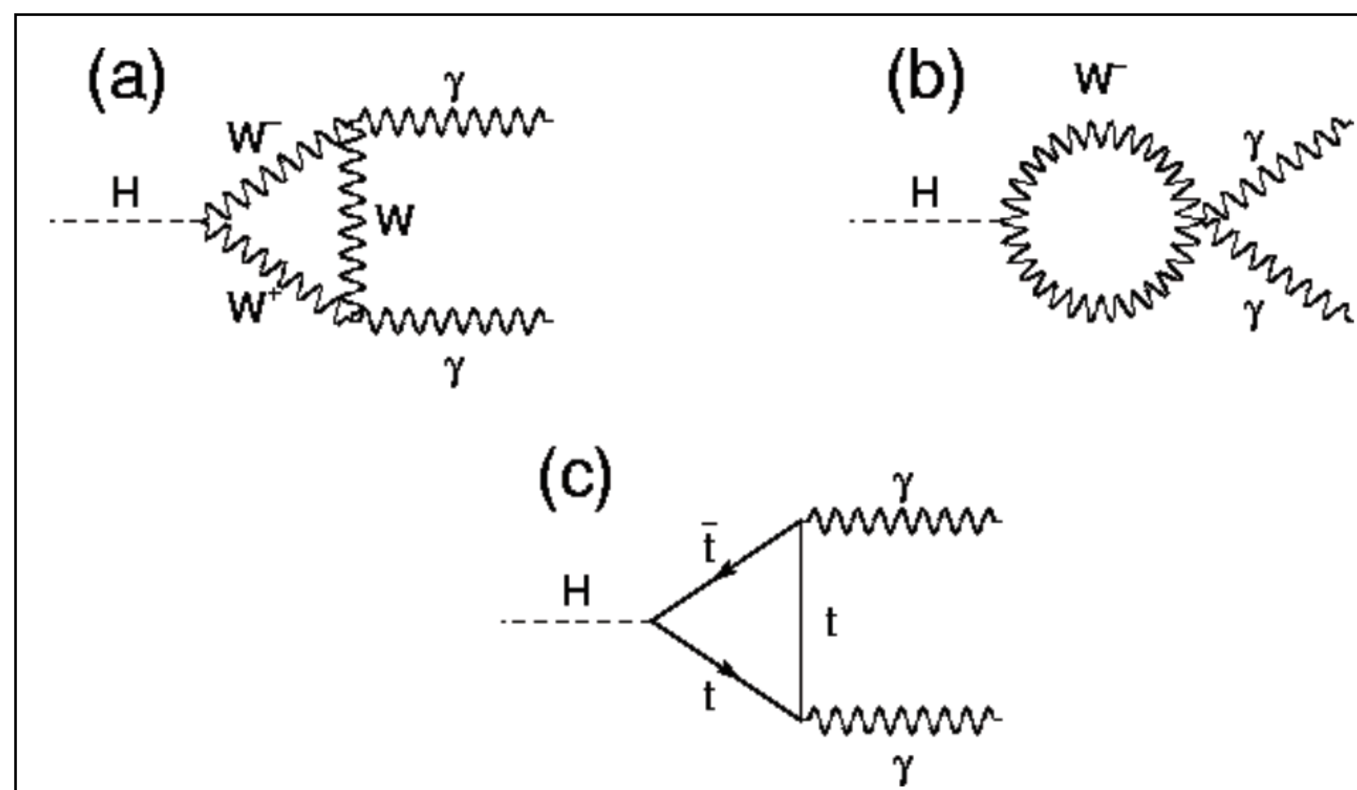
Analyses in this review

- General framework, motivations
- bb channel RECENT UPDATE
- multi-lep channel NEW
- di-photon channel
- Conclusions

Higgs Boson coupling with top quarks

- t-H dominates gg fusion mechanism
  - but through loop process where...
  - ...new physics could also hide

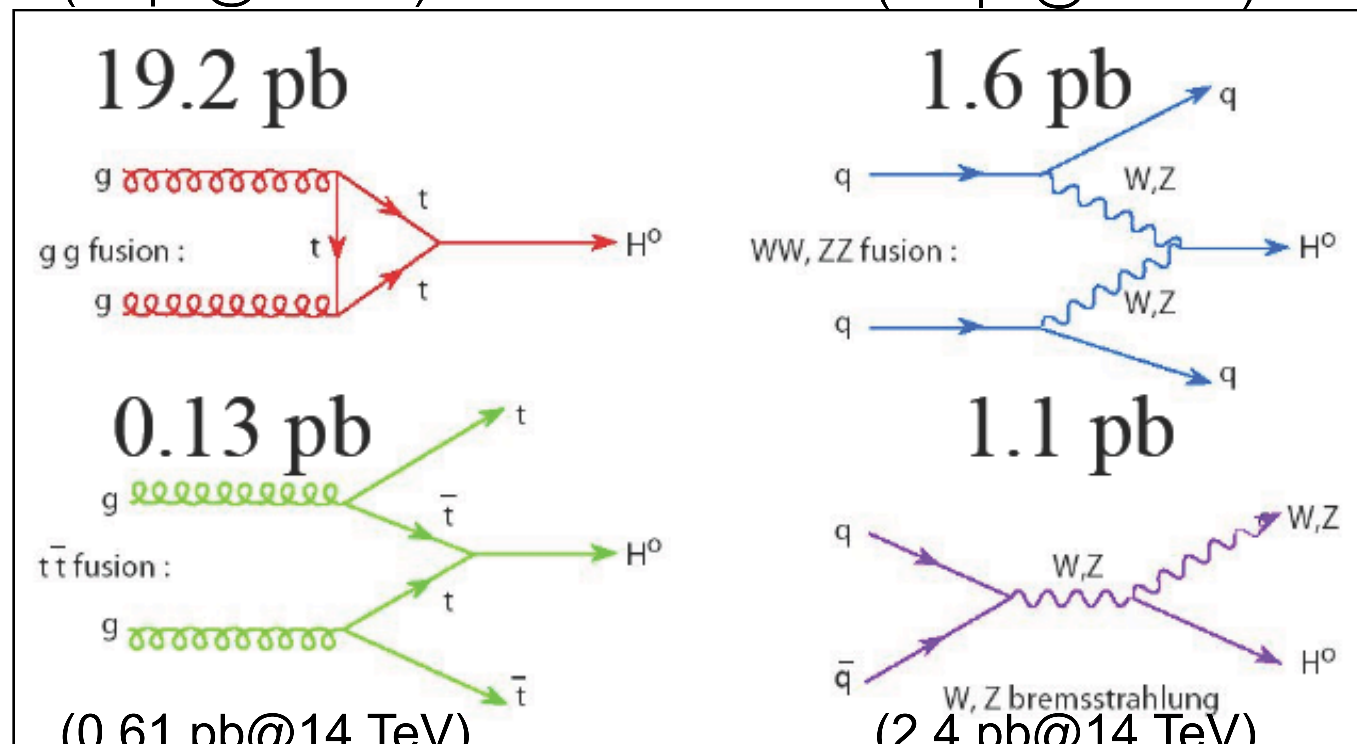




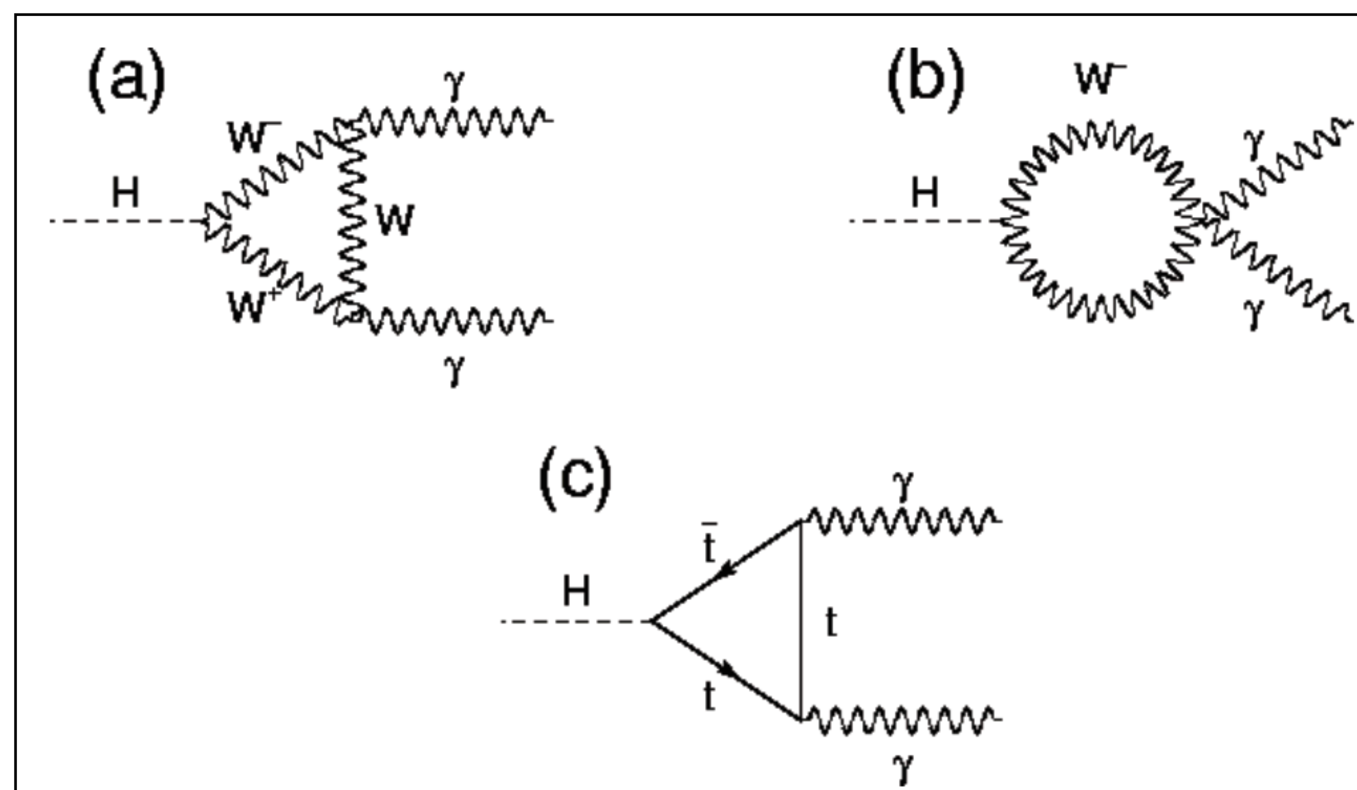
Higgs Boson coupling with top quarks

- t-H dominates gg fusion mechanism
  - but through loop process where...
  - ...new physics could also hide
- By measuring ttH we have <u>direct</u> access to the coupling at production instead
  - comparing measured coupling with gg fusion can unveil new physics

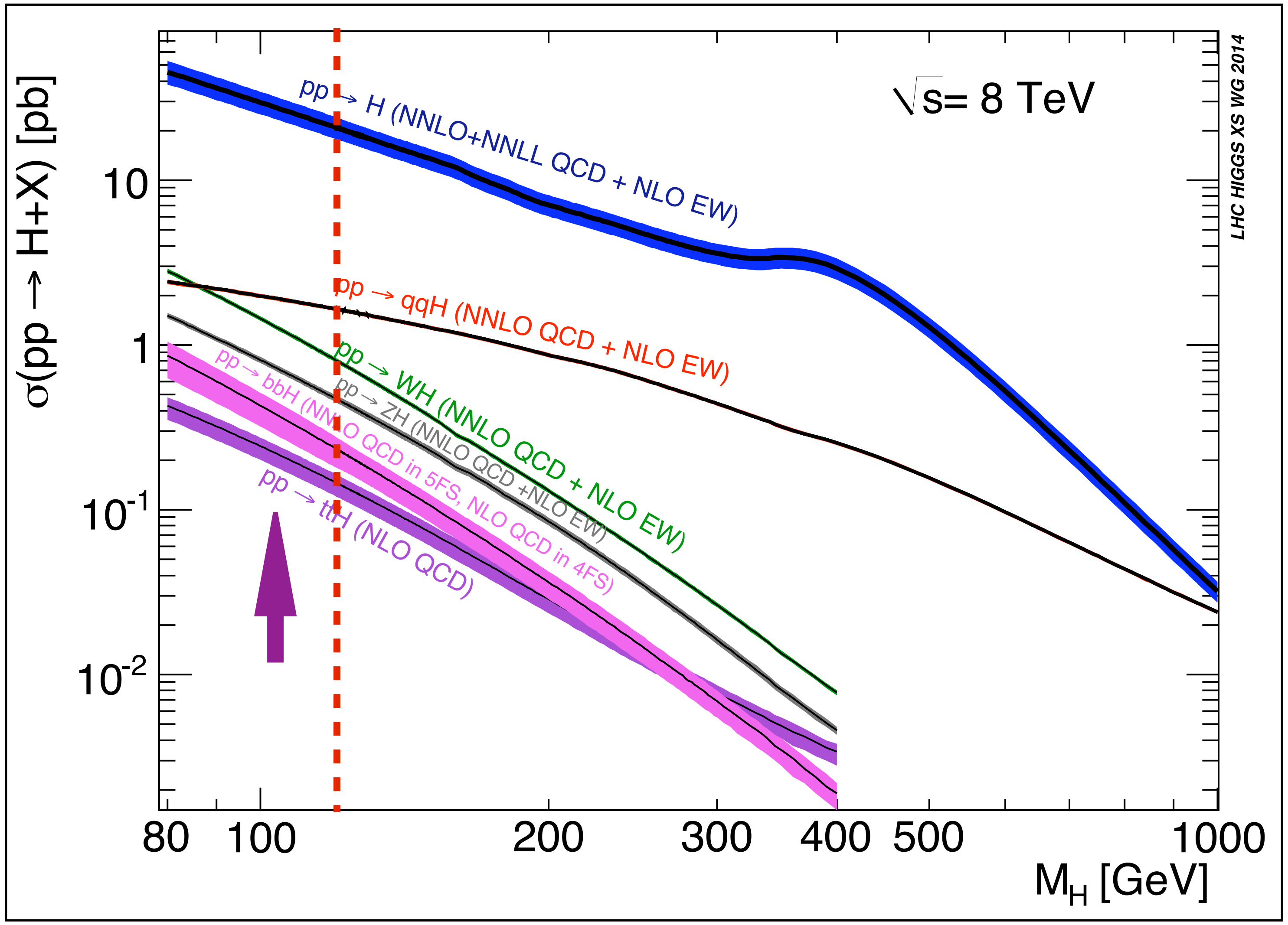
(50 pb@14 TeV) (4.2 pb@14 TeV)



(0.61 pb@14 TeV) (2.4 pb@14 TeV)



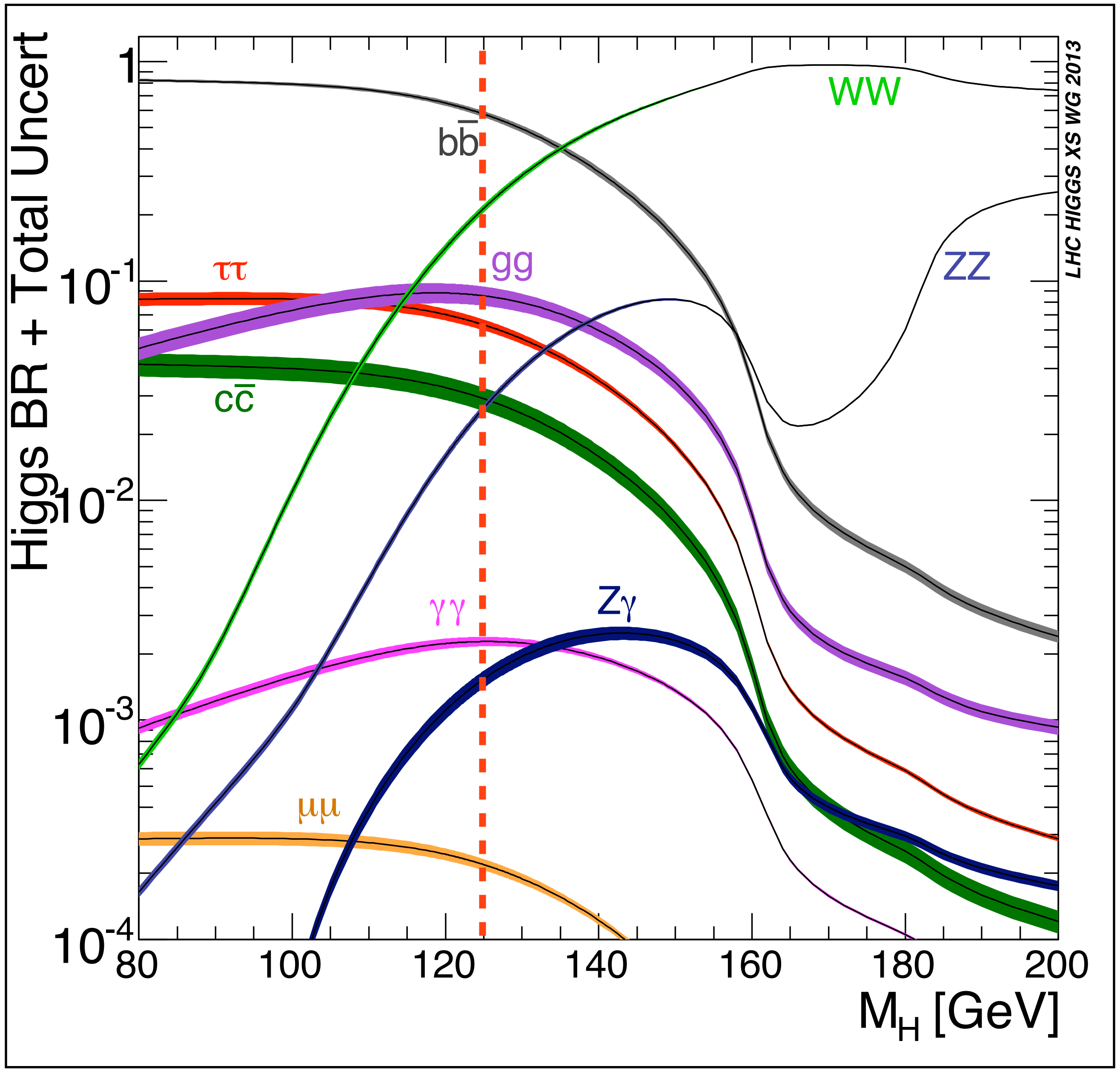
SM cross-section at 8 TeV



- At NLO, σ_{SM}=130 fb for m(H) =125 GeV@ 8 TeV
- @ 14 TeV ~5x increase in σ_{SM}

- Main backgrounds for analyses in this talk: tt+bb and tt+W/Z

Channels considered



- BR(H->bb) = 58%
- BR(H->WW+ZZ+ττ) = 30%
- BR(H->γγ) < 0.23%

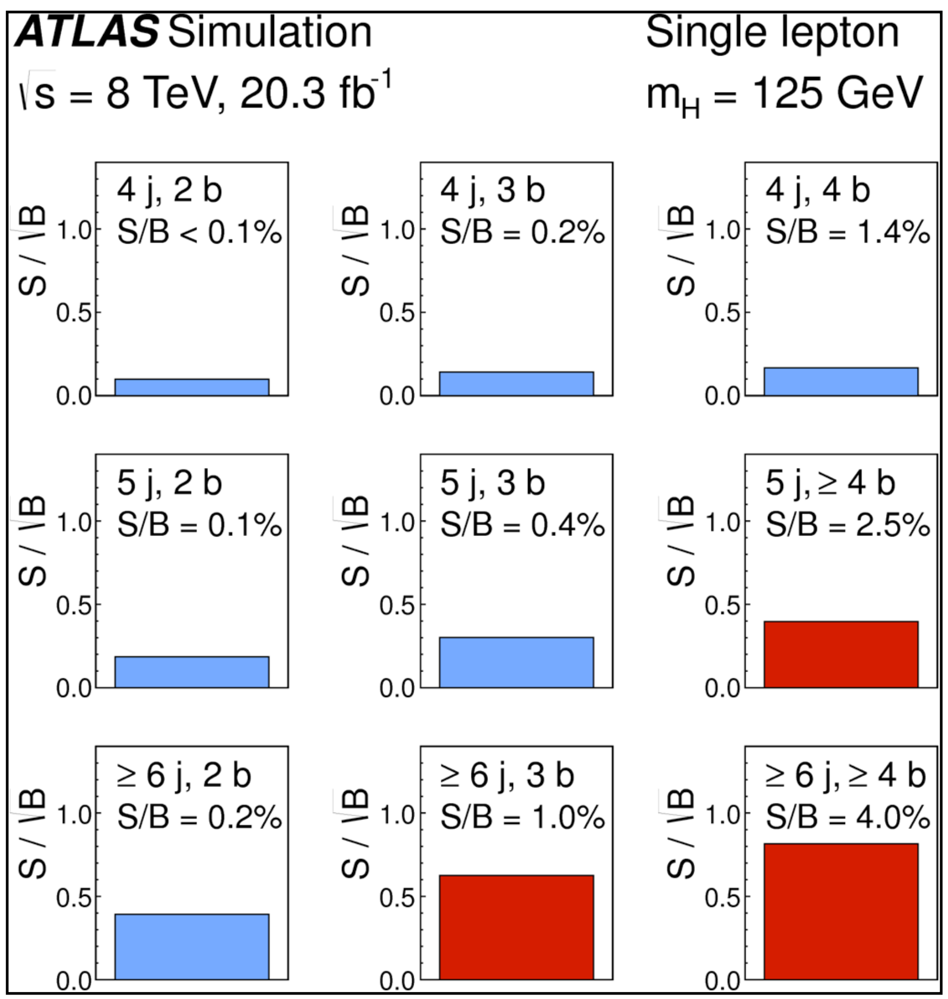
- bb: by far most abundant, but overwhelmed by tt+HF background and less easy bb reconstruction
- multi-lepton channels: good compromise, but sensitive to additional tt+W/Z backgrounds hard to control with data
- γγ: clear resonance peak but scarce

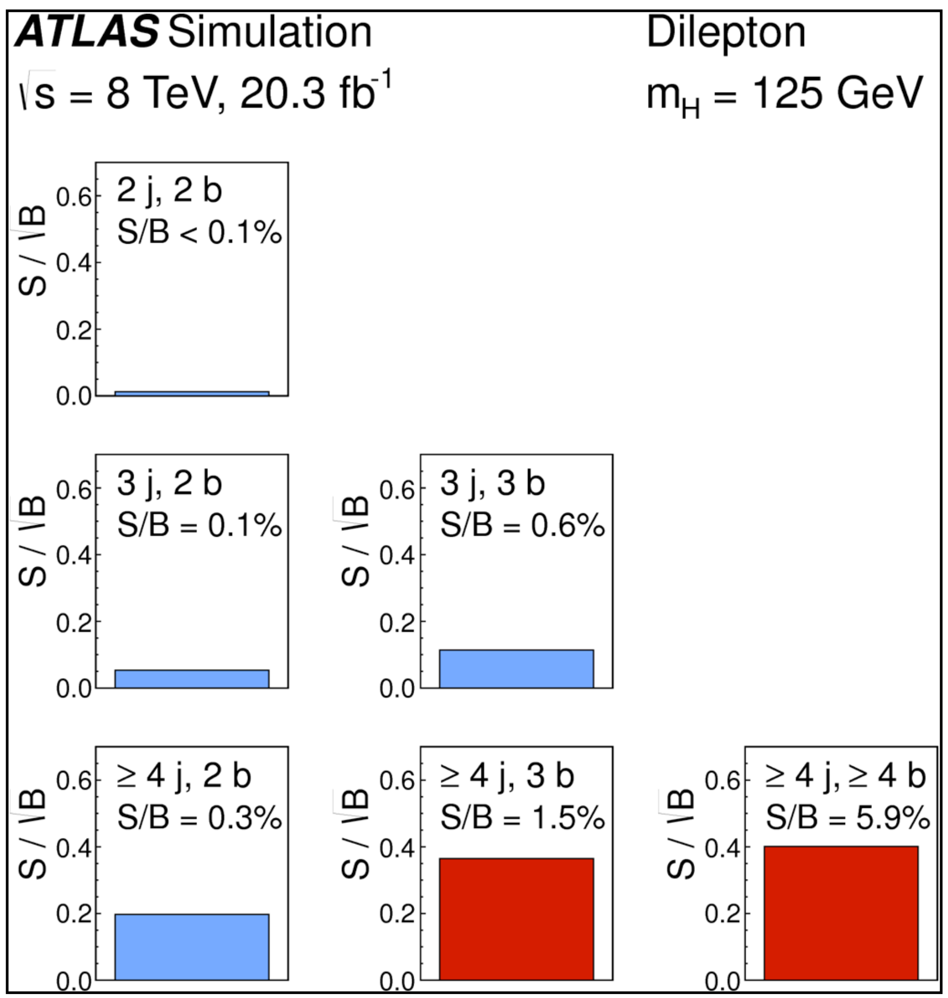
ttH($b\bar{b}$)

http://arxiv.org/abs/1503.05066
submitted to EPJC

Analysis strategy

- Multi-variate analysis technique to reduce large bkg from tt+X (esp. X=$b\bar{b}$)
- Construct matrix of N(jets)-N(b-tags) to characterize background
  - simultaneous fit for N_S (from signal-enriched regions) and N_B (from control-enriched regions)





- dilepton channel: ee/μμ/eμ + (2, 3, ≥4 jets) and (2, 3, ≥4 b-tags)
- lepton+jets channel: 1 e or μ + (4, 5, ≥6 jets) and (2, 3, ≥4 b-tags)

Matrix Element method

- Recent addition, used here for l+jets only
- PDF of an observed event to be consistent with process *i* described by a set of parameters α

$$
\boxed{
\begin{aligned}
P_i\left(\boldsymbol{x}|\boldsymbol{\alpha}\right) = & \frac{(2\pi)^4}{\sigma_i^{\mathrm{exp}}\left(\boldsymbol{\alpha}\right)} \int \mathrm{d}p_{\mathrm{A}} \mathrm{d}p_{\mathrm{B}} \, \boldsymbol{f}\left(p_{\mathrm{A}}\right) \boldsymbol{f}\left(p_{\mathrm{B}}\right) \\
& \frac{\left|\mathcal{M}_i\left(\boldsymbol{y}|\boldsymbol{\alpha}\right)\right|^2}{\mathcal{F}} \, W\left(\boldsymbol{y}|\boldsymbol{x}\right) \, \mathrm{d}\Phi_N\left(\boldsymbol{y}\right)
\end{aligned}
}
$$

Matrix Element method

- Recent addition, used here for l+jets only

- PDF of an observed event to be consistent with process *i* described by a set of parameters α

$$P_i\left(\boldsymbol{x}|\boldsymbol{\alpha}\right) = \frac{(2\pi)^4}{\sigma_i^{\exp}\left(\boldsymbol{\alpha}\right)} \int \mathrm{d}p_{\mathrm{A}}\mathrm{d}p_{\mathrm{B}}\; \boldsymbol{f}\left(p_{\mathrm{A}}\right) \boldsymbol{f}\left(p_{\mathrm{B}}\right) \frac{\left|\mathcal{M}_i\left(\boldsymbol{y}|\boldsymbol{\alpha}\right)\right|^2}{\mathcal{F}}\; W\left(\boldsymbol{y}|\boldsymbol{x}\right)\; \mathrm{d}\Phi_N\left(\boldsymbol{y}\right)$$

Amplitude of hard process

Kinematics/phase space

Transfer from parton-level (x) to detector quantities

- Demanding computing time-wise: approximations made on helicity states, angle expt. resolution and integration volume

Matrix Element method

- Recent addition, used here for l+jets only
- PDF of an observed event to be consistent with process *i* described by a set of parameters α

$$P_i(\boldsymbol{x}|\boldsymbol{\alpha}) = \frac{(2\pi)^4}{\sigma_i^{\exp}(\boldsymbol{\alpha})} \int \mathrm{d}p_\mathrm{A}\mathrm{d}p_\mathrm{B}\, \boldsymbol{f}(p_\mathrm{A})\, \boldsymbol{f}(p_\mathrm{B}) \frac{|\mathcal{M}_i(\boldsymbol{y}|\boldsymbol{\alpha})|^2}{\mathcal{F}} W(\boldsymbol{y}|\boldsymbol{x})\ \mathrm{d}\Phi_N(\boldsymbol{y})$$

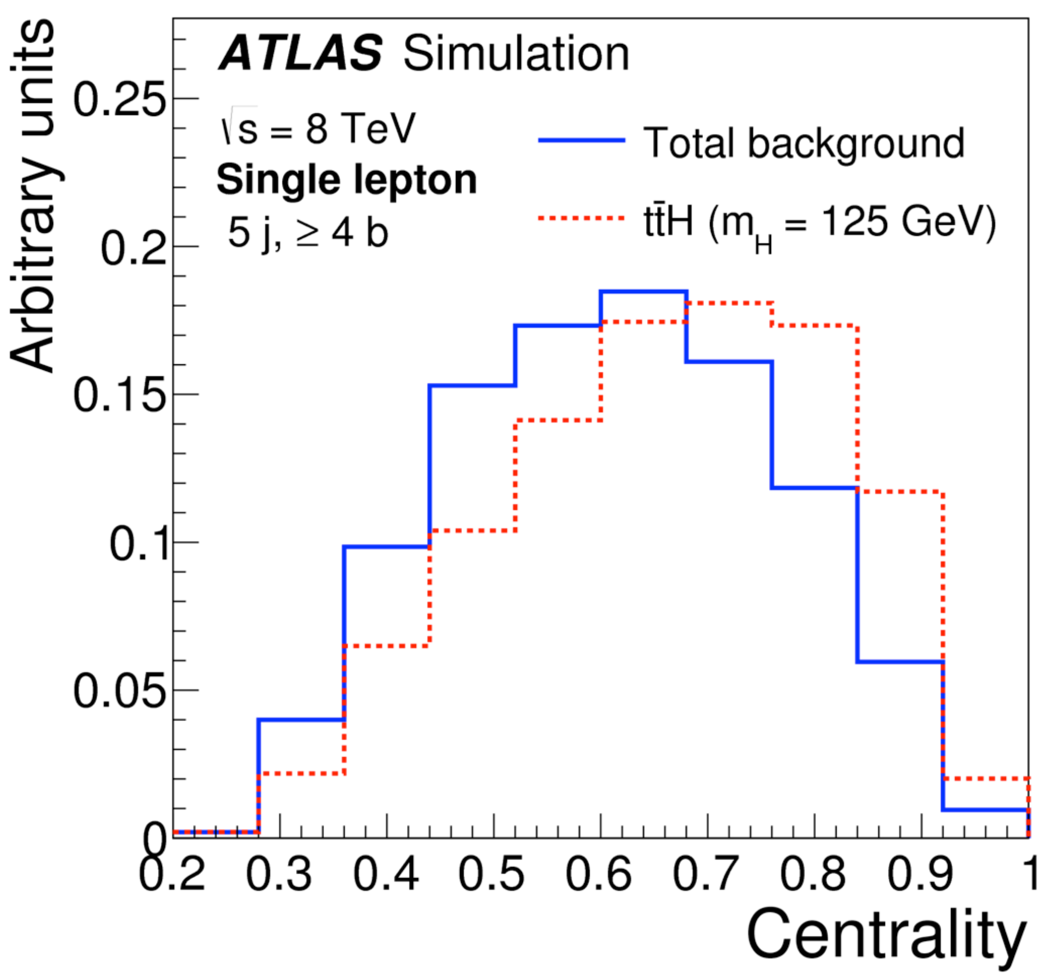
- Sum over all the possible assignments jets-partons ⇒ likelihood

$$D1 = \frac{\mathcal{L}_{t\bar{t}H}}{\mathcal{L}_{t\bar{t}H} + \alpha \cdot \mathcal{L}_{t\bar{t}+b\bar{b}}}$$

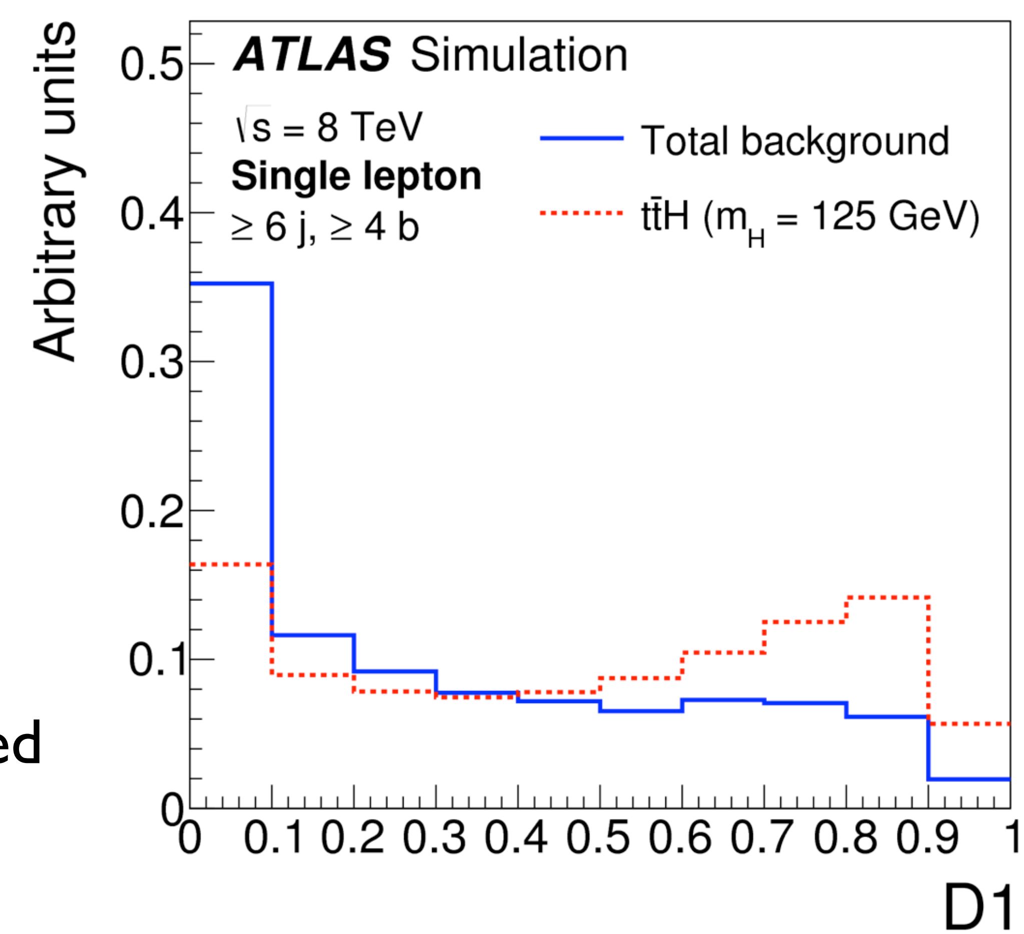
- Provides highest S/B discrimination in ≥6 jets, ≥4 b-tags category

MVA: S-B discrimination

- Train a Neural Network (NN) to separate S from B in each region
  - Uses a suite of variables from event shape and kinematics, single experimental object kinematics
  - uses also Matrix Element technique (variable D1)
- Lots of diagnostics on background shapes from control regions designed by cutting on **$H_T = \Sigma p_T$(selected jets)**



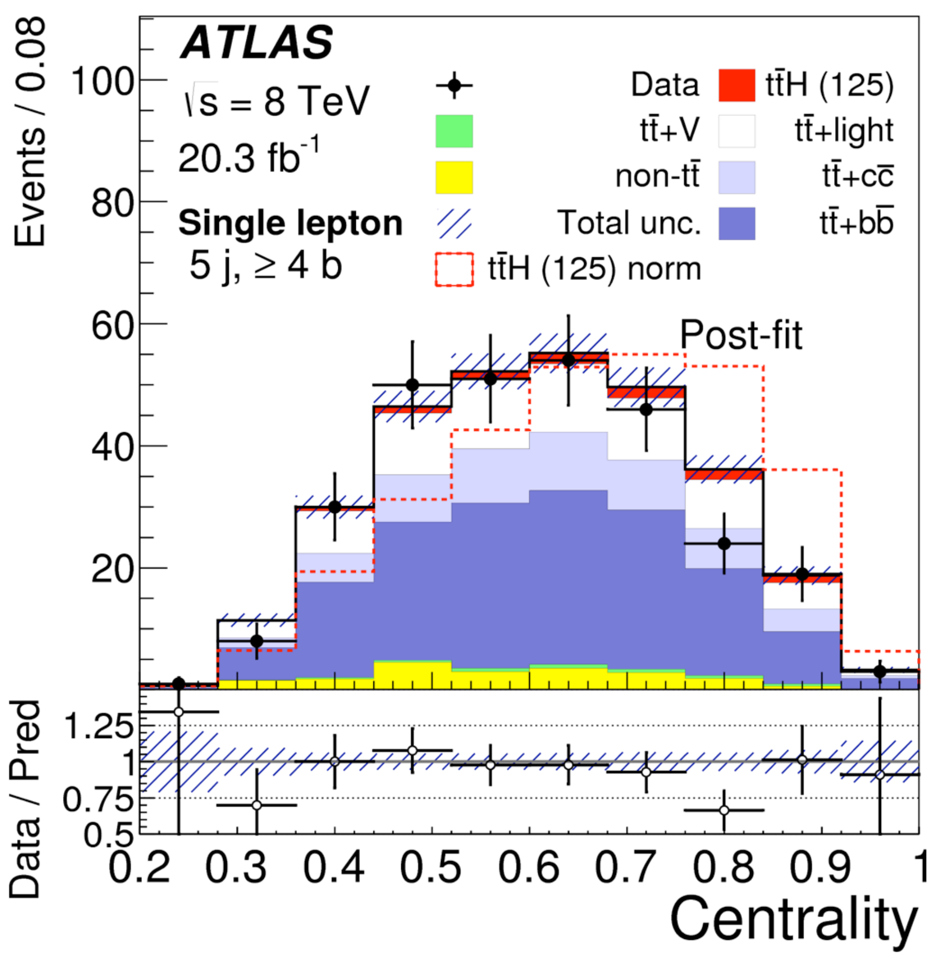
Two of the highest ranked variables

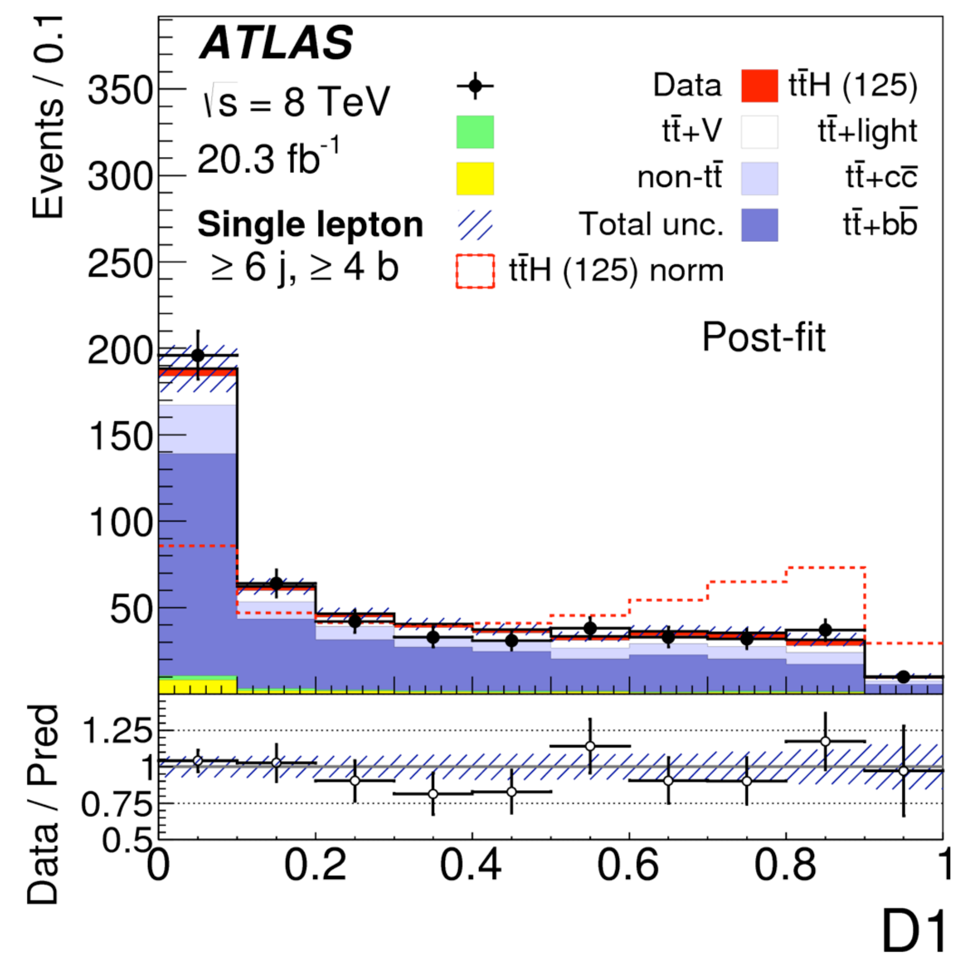


MVA: S-B discrimination

l+jets	2 b-tags	3 b-tags	4 b-tags
4 jets	CR (H_T cut)	CR (H_T cut)	CR (H_T cut)
5 jets	CR (H_T cut)	HF/LF NN	SR (NN cut)
≥ 6 jets	CR (H_T cut)	SR (NN cut)	SR (NN cut)

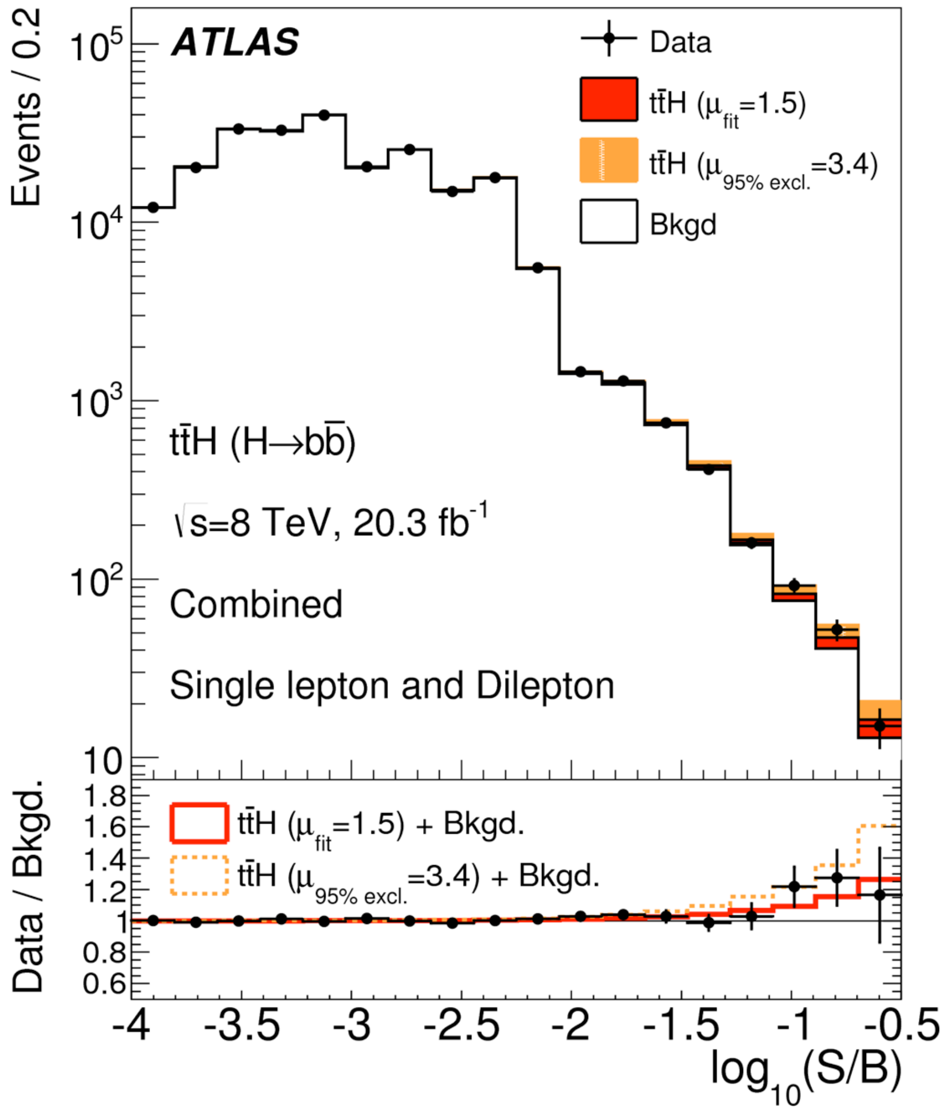
dilepton	2 b-tags	3 b-tags	4 b-tags
2 jets	CR (H_T cut)		
3 jets	CR (H_T cut)	SR (NN cut)	
≥ 4 jets	CR (H_T cut)	SR (NN cut)	SR (NN cut)

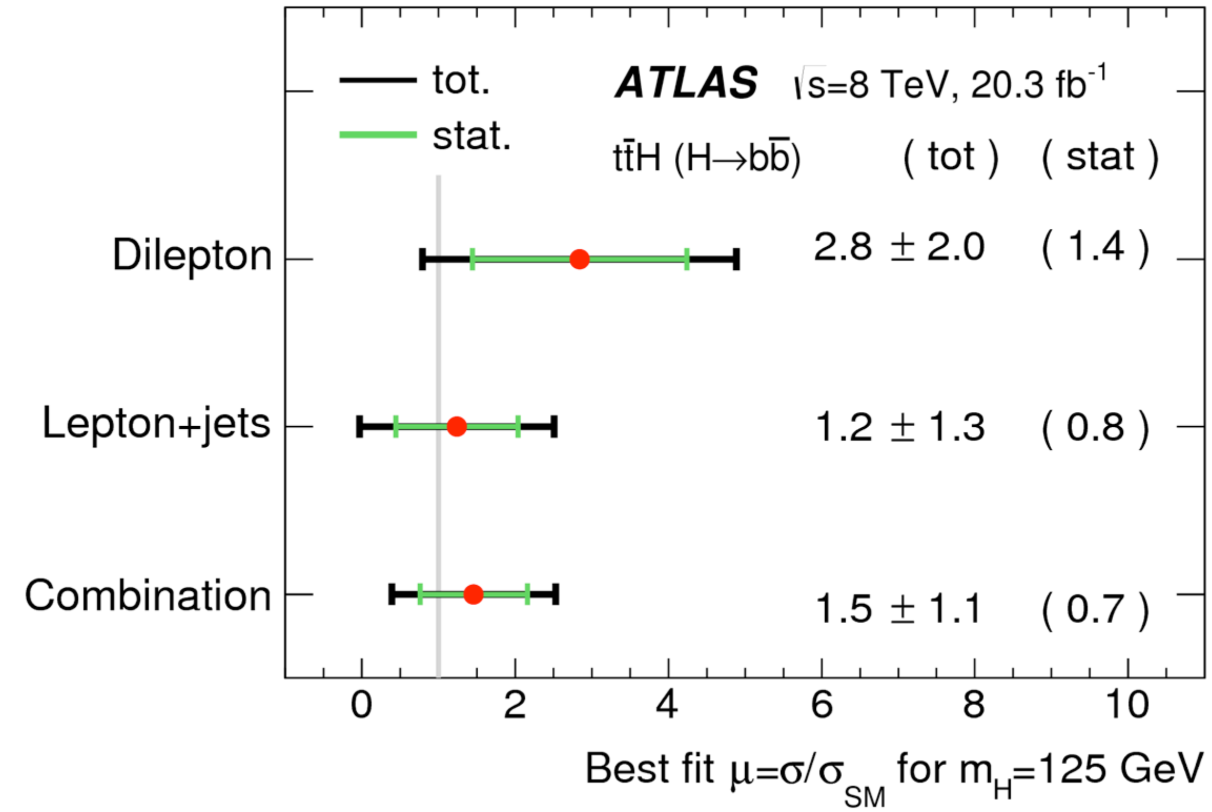


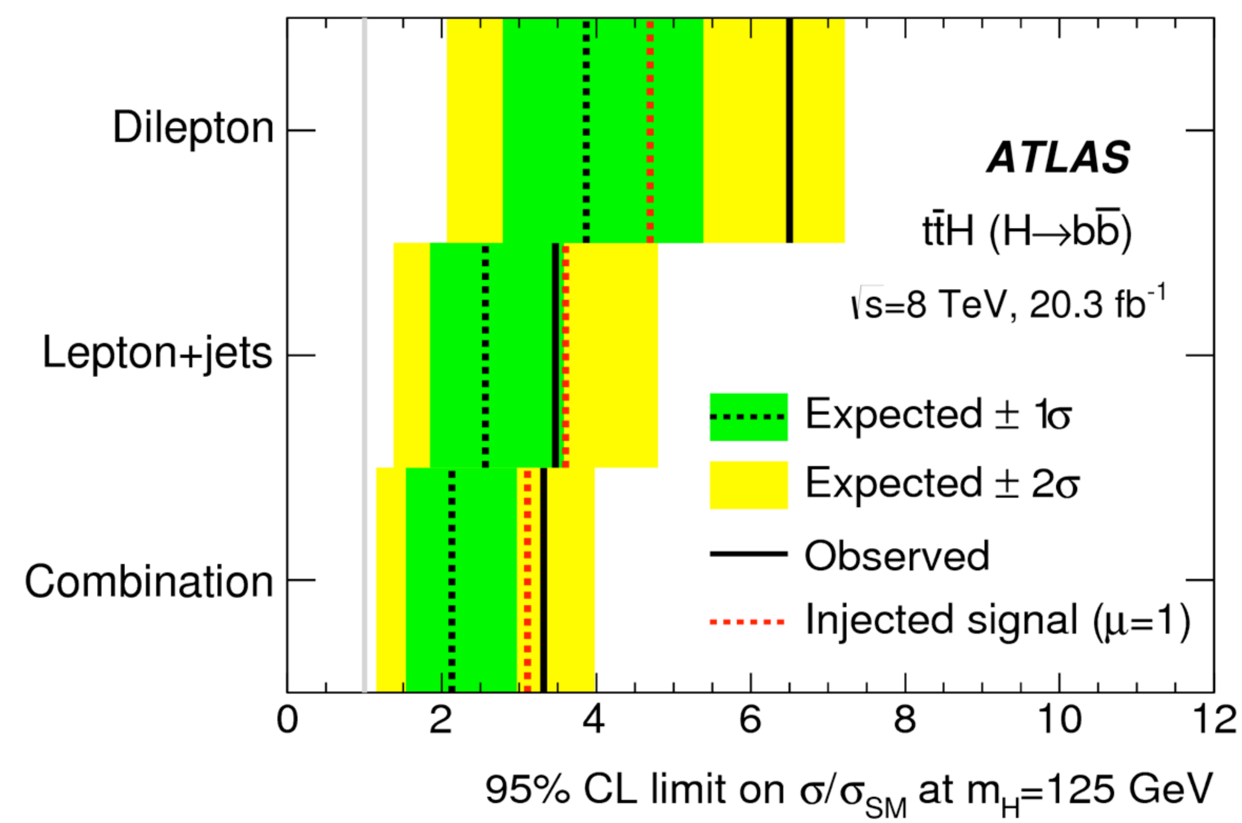


Results

$\mu_{ttH} = \sigma/\sigma_{SM}$







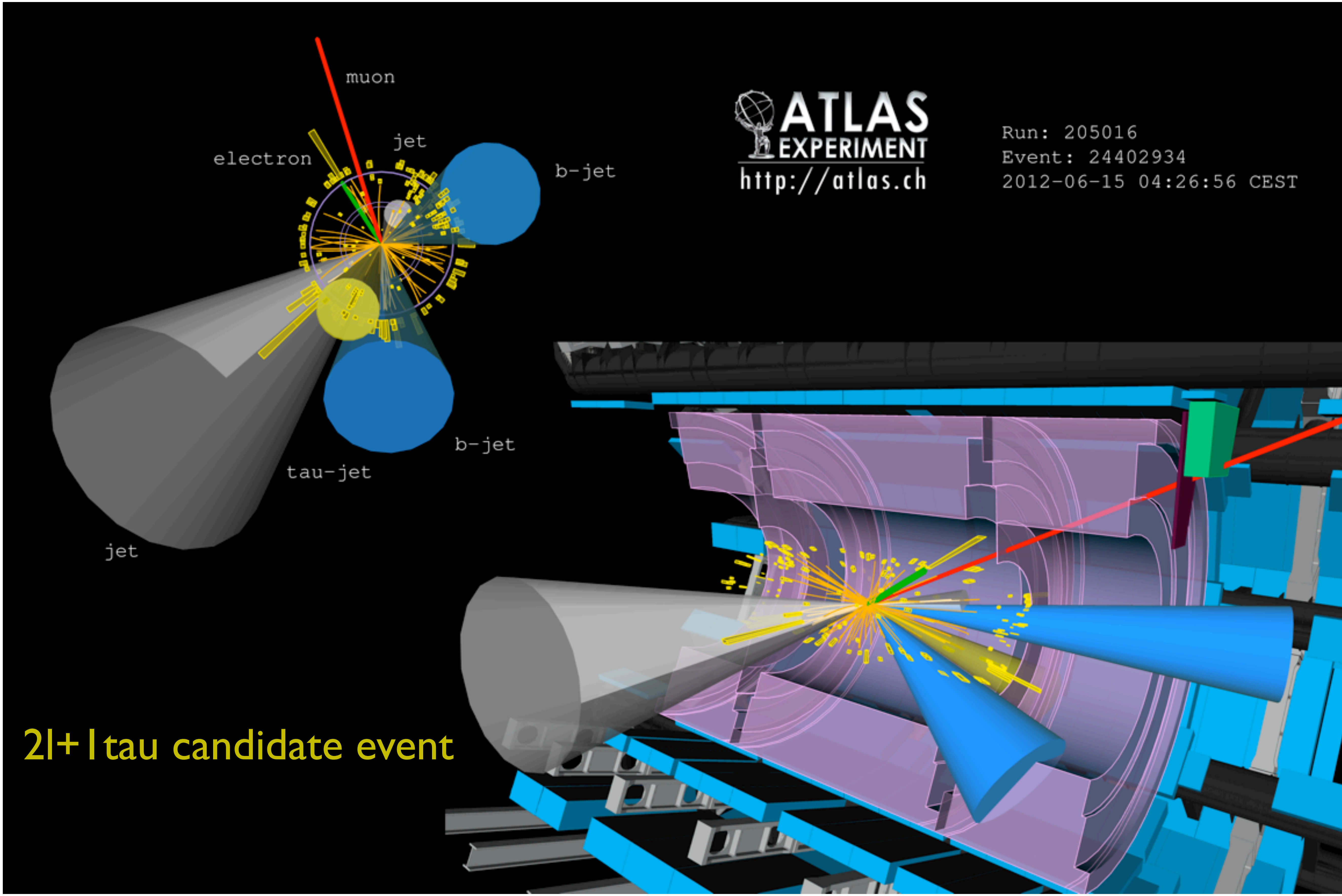
- Expected 95% CL: 2.6 x SM, m(H) = 125 GeV
- Best fit signal strength $\mu_{ttH} = 1.7 \pm 1.0$
- Significance Observed (Exp'd) : 1.3 σ (0.8 σ)
- Main experimental syst is from jet energy scale
- Main theo syst is from tt+bb normalization, but heavily constrained by profile LL fit

ttH(multi-lepton)

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

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-006/

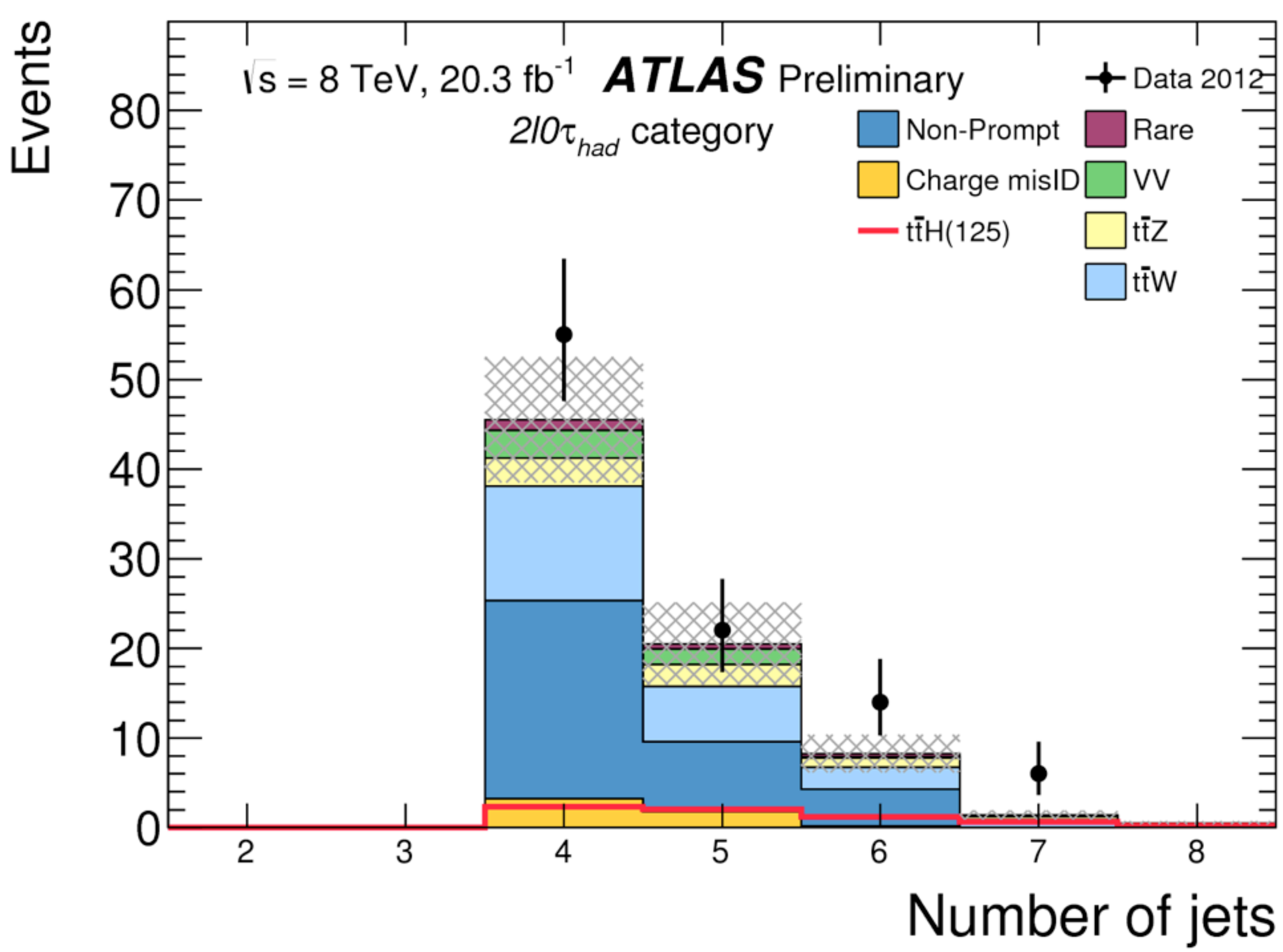
paper in preparation

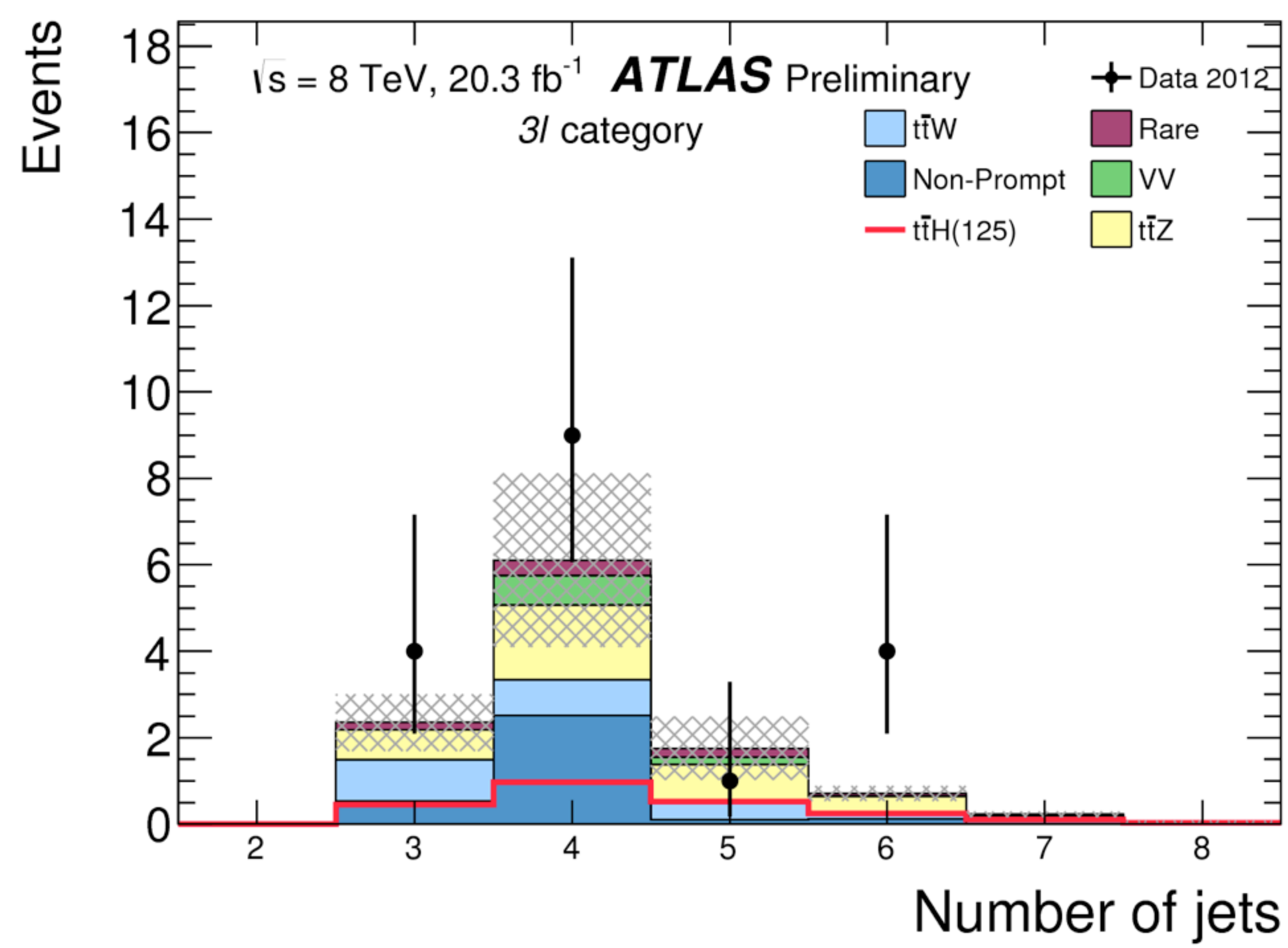


2l+1tau candidate event

Topologies

- high N(lep), which suppresses ttbar background
    - only contributing if secondary lepton from HF decays incorrectly selected
- mostly irreducible tt+V(=W/Z) background
- “Cut and count” strategy: events categorized into 5 channels and further split to maximize signal sensitivity





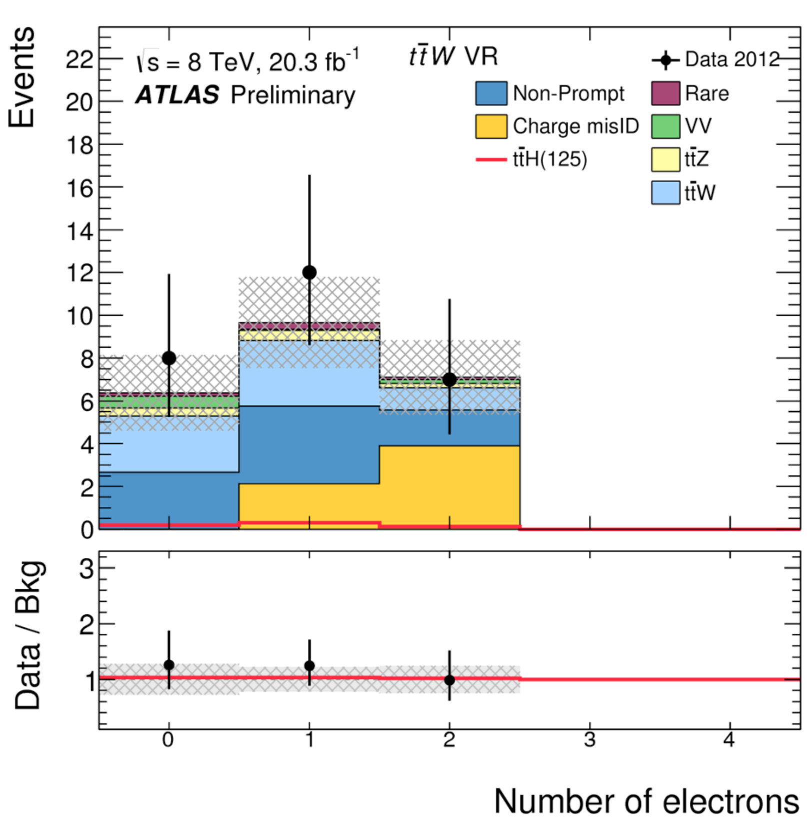
Event categories

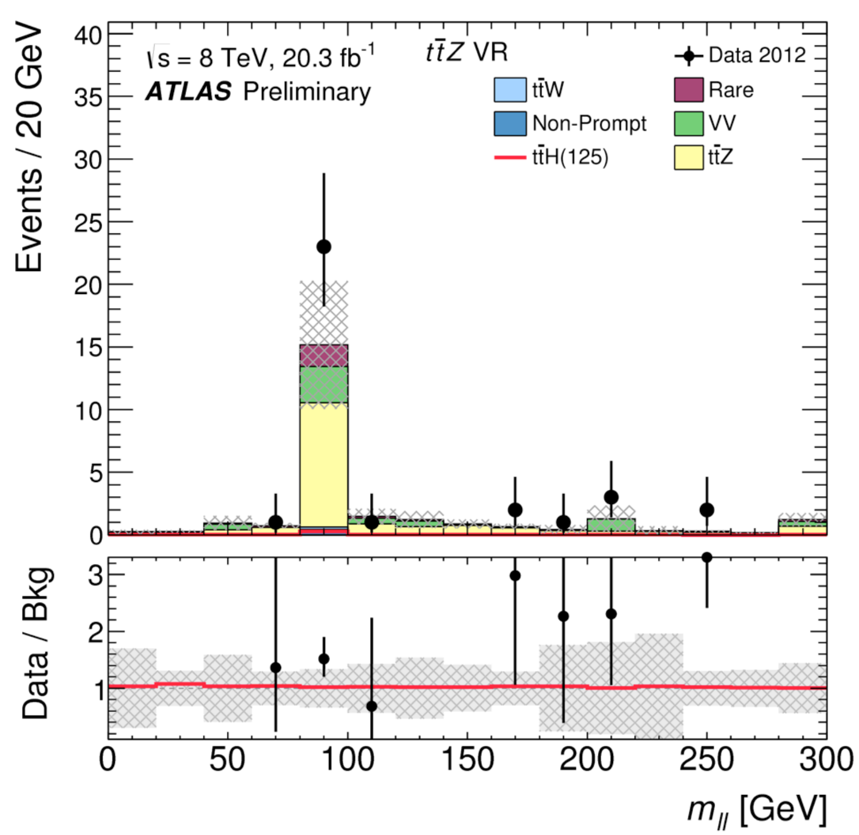
- Divided by N(e/mu), and w/ or w/o a hadronically decaying tau
- N(jets, pt>25 GeV) and N(b-tags) selections based on S/B optimizations and
  - reflecting different jet multiplicity in various signal channels
  - additional M(l,l) veto for 3lep to suppress ttZ (but ttγ* remains relevant bkg)

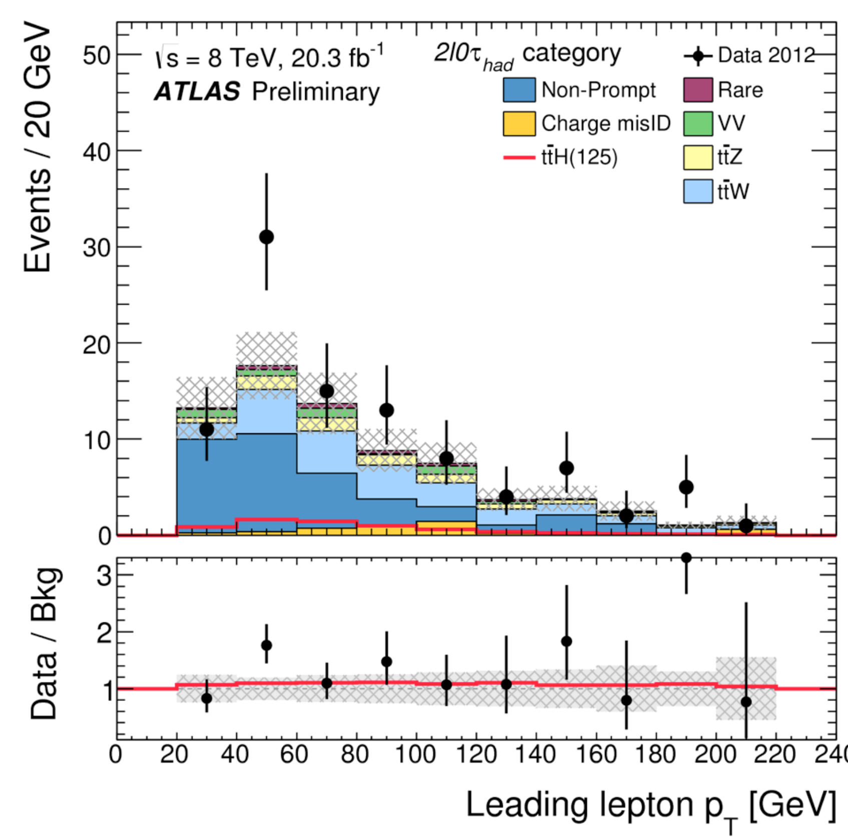
Category	q mis-id	Non-prompt	$t\bar{t}W$	$t\bar{t}Z$	Diboson	Expected Bkg.	$t\bar{t}H$ ($\mu = 1$)	Observed
$ee + \geq 5j$	1.1 ± 0.5	2.3 ± 1.2	1.4 ± 0.4	0.98 ± 0.32	0.47 ± 0.42	6.5 ± 2.0	0.73 ± 0.11	10
$e\mu + \geq 5j$	0.85 ± 0.35	6.7 ± 2.4	4.8 ± 1.4	2.1 ± 0.7	0.38 ± 0.32	15 ± 4	2.13 ± 0.31	22
$\mu\mu + \geq 5j$	–	2.9 ± 1.4	3.8 ± 1.1	0.95 ± 0.31	0.69 ± 0.63	8.6 ± 2.5	1.41 ± 0.21	11
$ee + 4j$	1.8 ± 0.7	3.4 ± 1.7	2.0 ± 0.4	0.75 ± 0.25	0.74 ± 0.58	9.1 ± 2.3	0.44 ± 0.06	9
$e\mu + 4j$	1.4 ± 0.6	12 ± 4	6.2 ± 0.9	1.5 ± 0.2	1.9 ± 1.2	24.0 ± 4.5	1.16 ± 0.14	26
$\mu\mu + 4j$	–	6.3 ± 2.6	4.7 ± 0.9	0.80 ± 0.26	0.53 ± 0.30	12.7 ± 3.0	0.74 ± 0.10	20
3ℓ	–	3.2 ± 0.7	2.3 ± 0.9	3.9 ± 0.9	0.86 ± 0.59	11.4 ± 3.1	2.34 ± 0.32	18
$2\ell 1\tau_{\mathrm{had}}$	–	$0.4^{+0.6}_{-0.4}$	0.38 ± 0.15	0.37 ± 0.09	0.12 ± 0.15	1.4 ± 0.6	0.47 ± 0.02	1
$1\ell 2\tau_{\mathrm{had}}$	–	15 ± 5	0.17 ± 0.07	0.37 ± 0.10	0.41 ± 0.42	16 ± 6	0.68 ± 0.07	10
4ℓ Z-enr.	–	$\lesssim 10^{-3}$	$\lesssim 3 \times 10^{-3}$	0.43 ± 0.13	0.05 ± 0.02	0.55 ± 0.17	0.17 ± 0.01	1
4ℓ Z-dep.	–	$\lesssim 10^{-4}$	$\lesssim 10^{-3}$	0.002 ± 0.002	$\lesssim 2 \times 10^{-5}$	0.007 ± 0.005	0.03 ± 0.00	0

Main backgrounds

- ttV (and smaller bkgs) taken from MC
  - very hard to extract from data (low yield and/or contamination from ttbar)
  - validation in ttV enriched regions (using events at Z pole for ttZ and looking at events with low N(jets) for ttW)
- ttbar: *in situ* method estimating normalization from data by reverting isolation, pt, tracking, tau Id
  - see F.Lasagni's talk (PhD session) for more on estimation and validation of this bkg

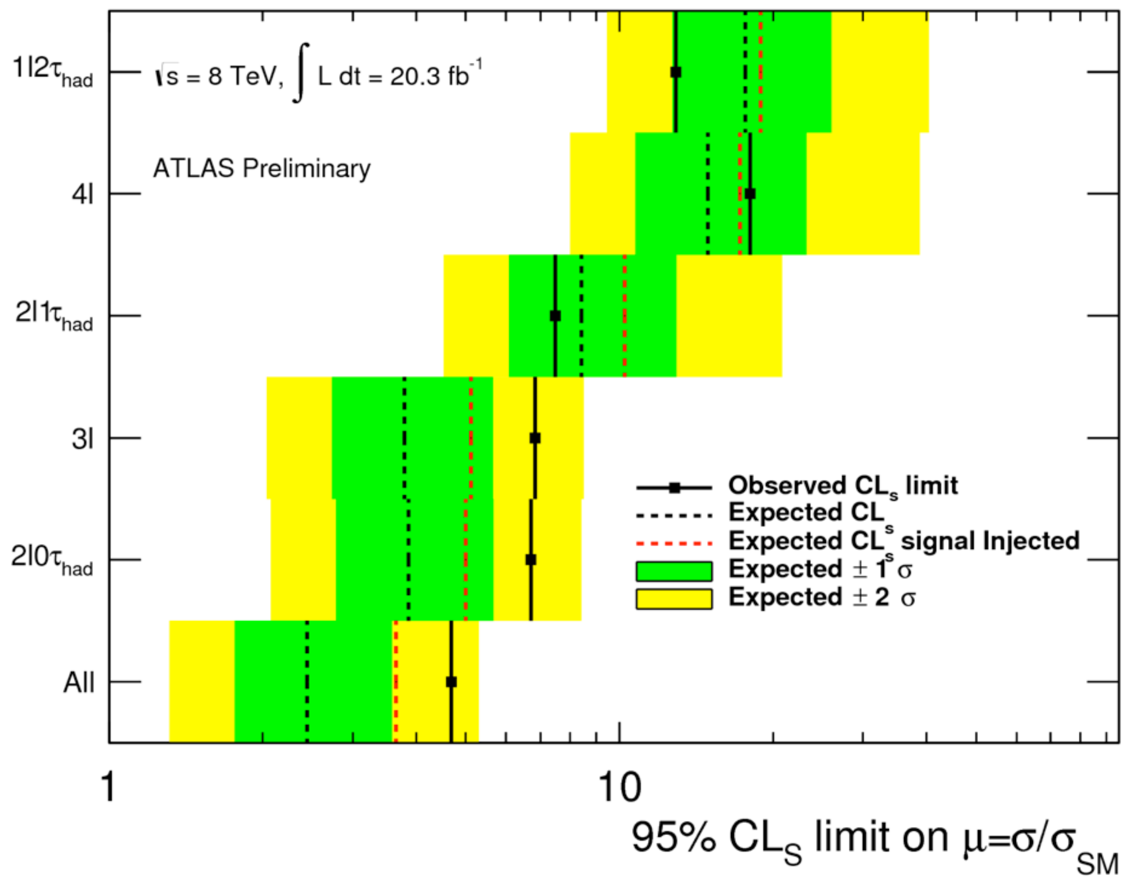


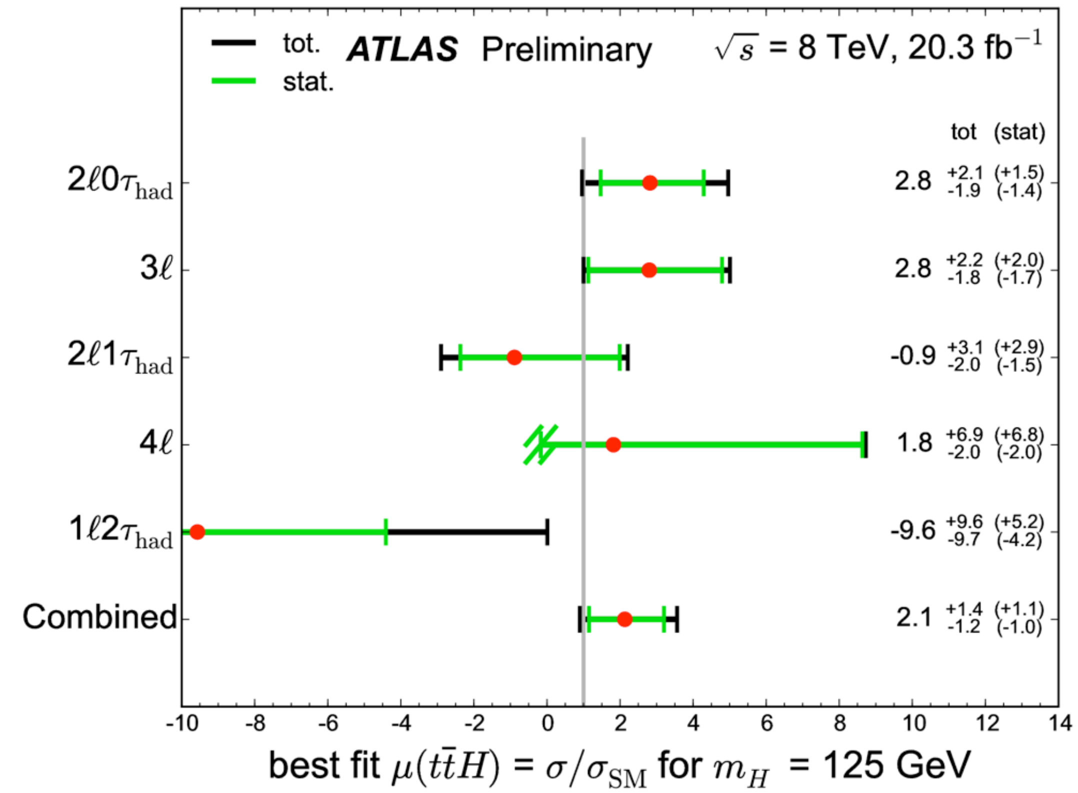




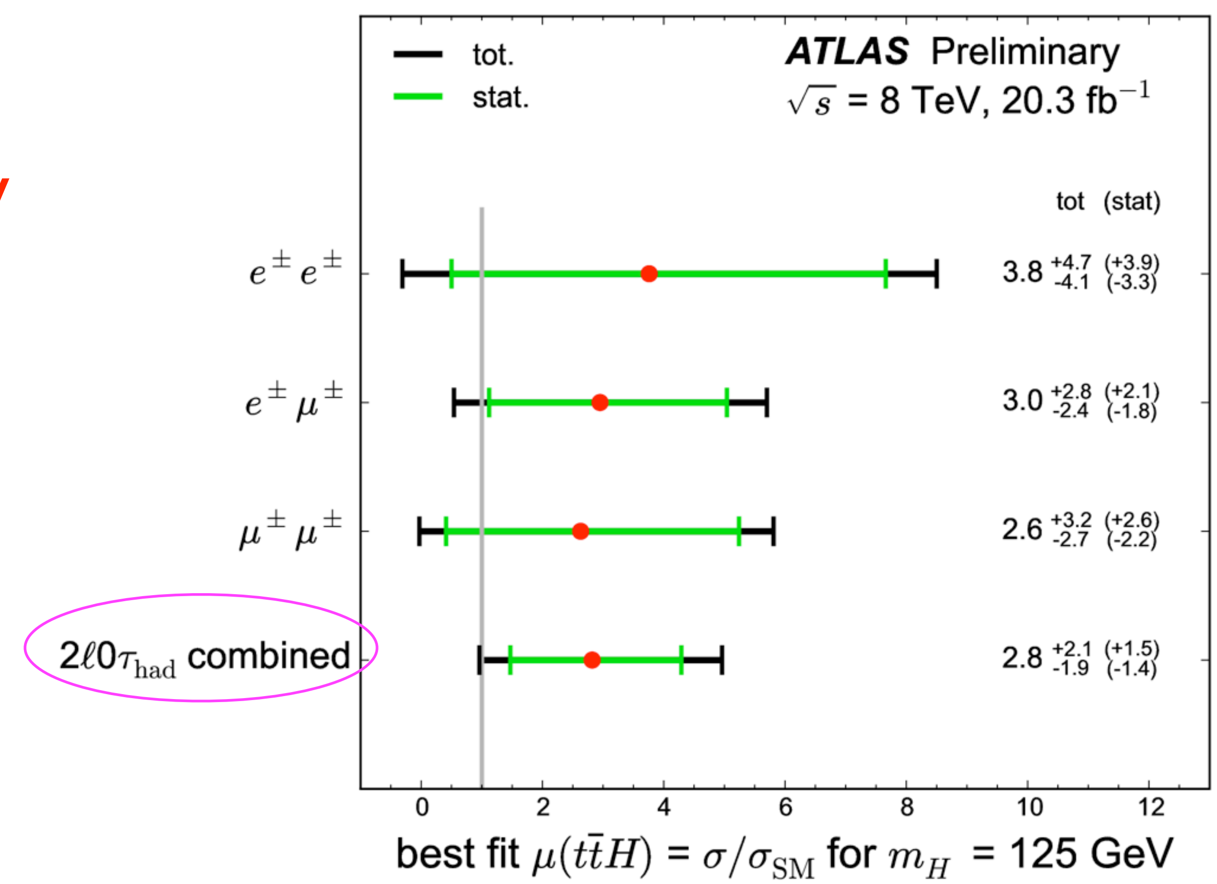
Results

$\mu_{ttH} = \sigma/\sigma_{SM}$





- Expected 95% CL: 2.4 x SM, m(H) = 125 GeV
- Best fit signal strength $\mu_{ttH} = 2.1^{+1.4}_{-1.2}$
- Significance Observed (Exp'd) : 1.8 σ (0.9 σ)
- Main experimental syst is from secondary lepton bkg in 2l0tau
- Main theo syst are from cross-section of ttV and acceptance of ttW+additional jets



ttH(γγ)

http://arxiv.org/abs/1409.3122
Phys. Rev. D 90, 112015

Overall strategy

- 2 isolated, high-p_T photons for Higgs boson mass reconstruction
- Categorize events according to top quark decay:
  - Optimized on the expected limit on μ_{ttH}
  - leptonic channel: ≥ 1 leptons (e or μ), ≥ 1 b-tagged jet
  - hadronic channel: ≥ 6 jets, ≥ 2 b-tagged jet

Category	N_H	ggF	VBF	WH	ZH	$t\bar{t}H$	$tHqb$	WtH	N_B
7 TeV leptonic selection	0.10	0.6	0.1	14.9	4.0	72.6	5.3	2.5	$0.5^{+0.5}_{-0.3}$
7 TeV hadronic selection	0.07	10.5	1.3	1.3	1.4	80.9	2.6	1.9	$0.5^{+0.5}_{-0.3}$
8 TeV leptonic selection	0.58	1.0	0.2	8.1	2.3	80.3	5.6	2.6	$0.9^{+0.6}_{-0.4}$
8 TeV hadronic selection	0.49	7.3	1.0	0.7	1.3	84.2	3.4	2.1	$2.7^{+0.9}_{-0.7}$

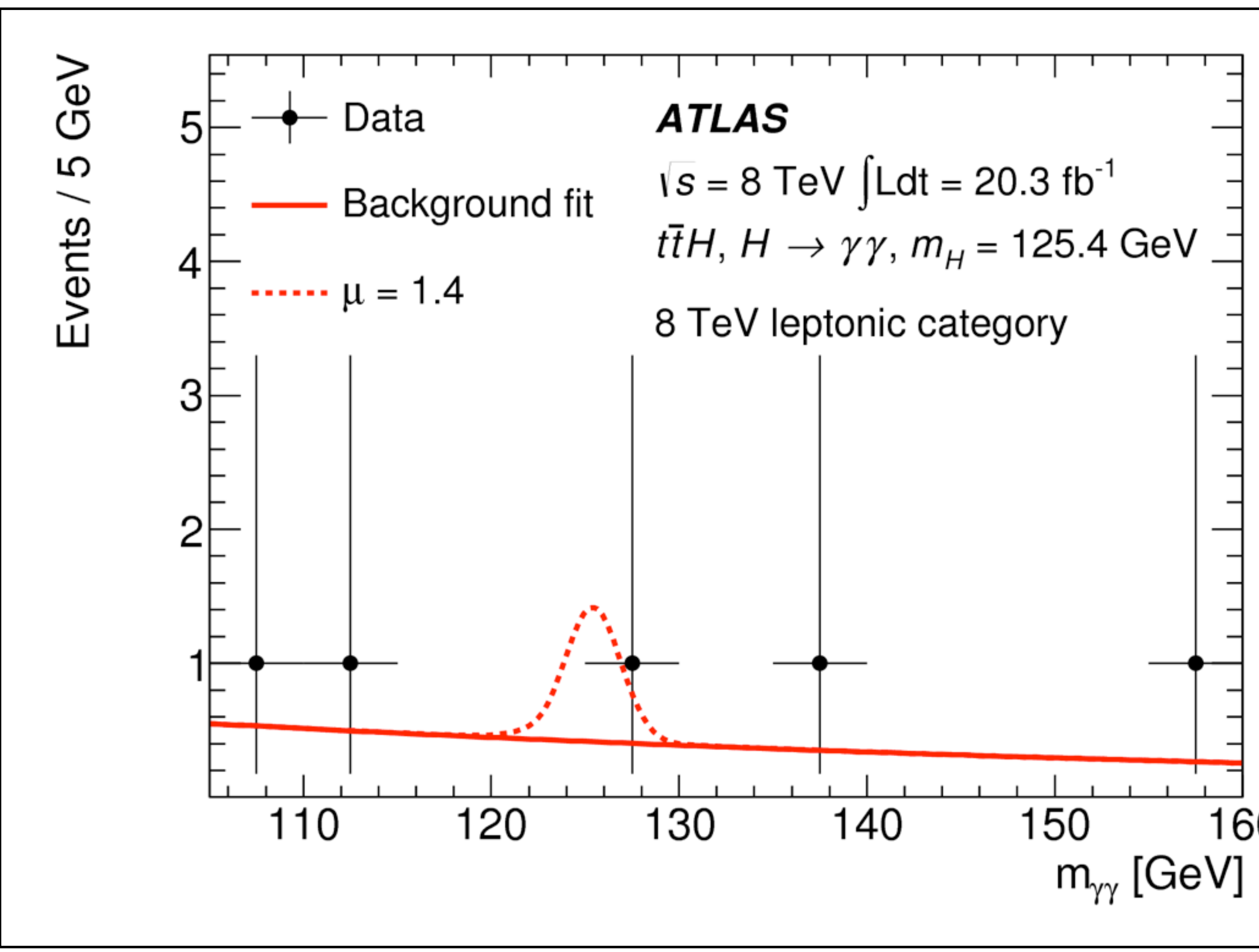
absolute numbers

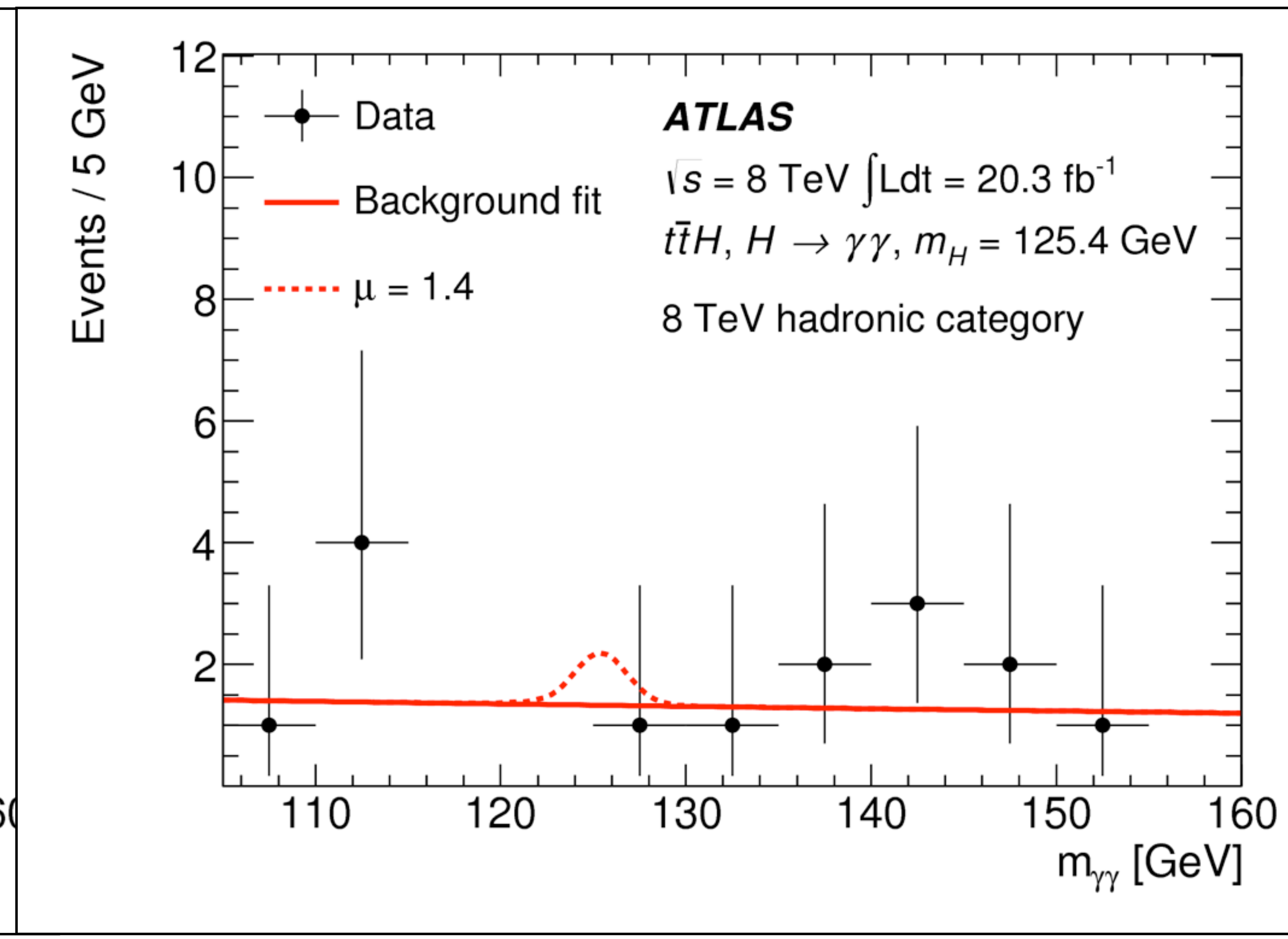
fractions

absolute numbers

Analysis

- Localized excess looked for around $m_{\gamma\gamma}$=125.4 GeV
- Unbinned LL fit to background and signal in “signal regions”

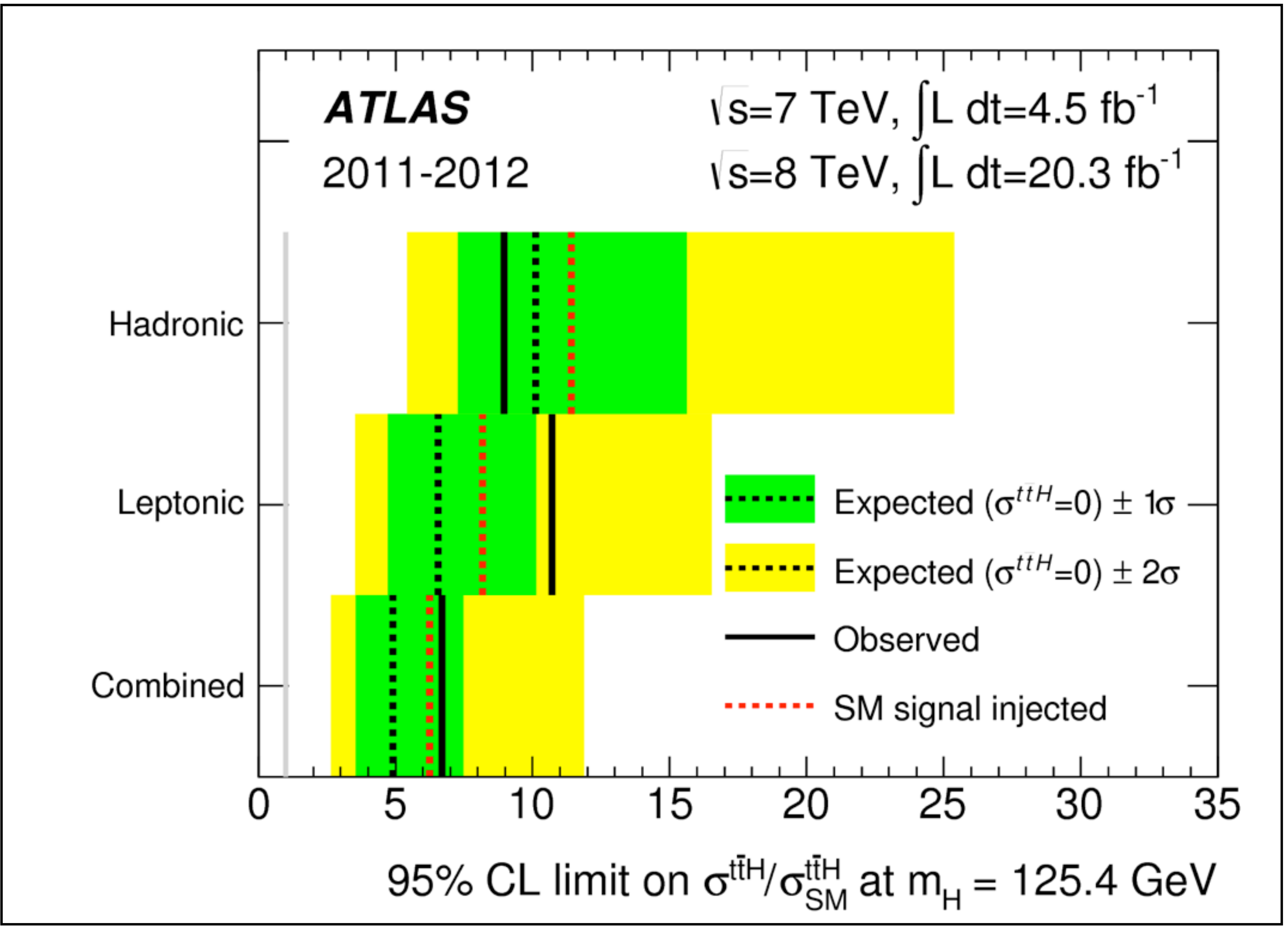




- $m_{\gamma\gamma}$ resolution dominated by resolution on E_γ

Results

$\mu_{ttH} = \sigma/\sigma_{SM}$



- m_H=125.4 GeV
- Expected limit on μ_{ttH} = 4.9
- Observed limit on μ_{ttH} = 6.5

- Comparable impact of theory and experimental systematic uncertainties on final yield of events

	$t\bar{t}H$ [%]		$tHqb$ [%]		WtH [%]		ggF [%]	WH [%]
	had.	lep.	had.	lep.	had.	lep.	had.	lep.
Luminosity	±1.8							
Photons	±10.0	±10.0	±10.0	±10.0	±10.0	±10.0	±10.0	±10.0
Leptons	< 0.1	±0.7	< 0.1	±0.7	< 0.1	±0.6	< 0.1	±0.7
Jets and E_T^{miss}	±9.1	±1.6	±19	±2.4	±13	±2.9	±30	±10
Bkg. modeling	0.12 evt.	0.01 evt.	applied on the sum of all Higgs boson production processes					
Theory ($\sigma \times$ BR)	+10,−13		+8,−7		+12,−12		+11,−12	+5.5,−5.5
MC Modeling	±11	±3.3	±12	±4.4	±13	±5.2	±130	±100

Outlook

- ttH production mode being looked at with several, different final states
- Challenging both from detector and backgrounds point of view
- Closing on to SM xsec value
- This will be one of the first hot topics in Run II

Back-up

Event generation

- Signal ttH: Helac-One Loop+Powheg interface to parton shower (=”PowHel”)
  - inclusive in Higgs boson decays, cross-section and BR from http://arxiv.org/abs/1101.0593 and updates
  - CT10NLO Parton Distribution Function (PDF)
  - Pythia 8 for parton shower (PS) + CTEQ6L1 PDF
- (W)tH: MadGraph5_AMC@NLO, 5-flavour scheme
  - inclusive in Higgs boson decays, xsec and BR from Yellow Book
  - three different values of k_t = -1, 0, + 1.
  - CT10NLO PDF
  - Herwig++ for parton shower + CTEQ6L1 PDF
- tt+jets: Powheg
  - inclusive in flavour of additional partons
  - CT10NLO PDF
  - Pythia 6 for parton shower + CTEQ6L1 PDF

- Other sources of background in back-up

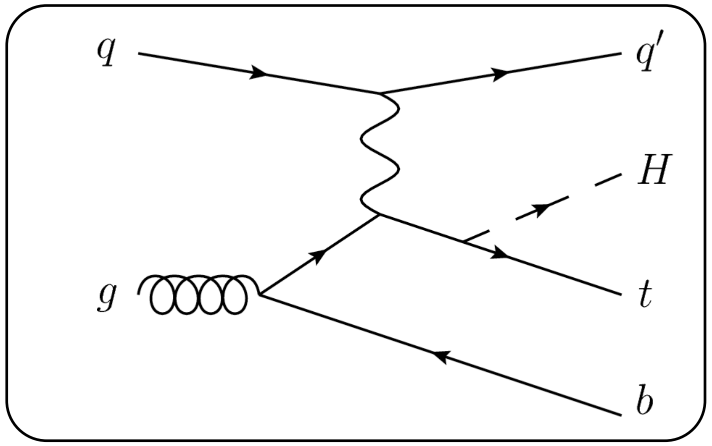
Other sources of background: simulation

- ttZ, ttW : Madgraph +Pythia
- W/Z +jets : Alpgen + Pythia
- Dibosons : Alpgen + Herwig
- Single top : PowHeg / Acer +Pythia
- Multijets : Estimated by using data driven methods

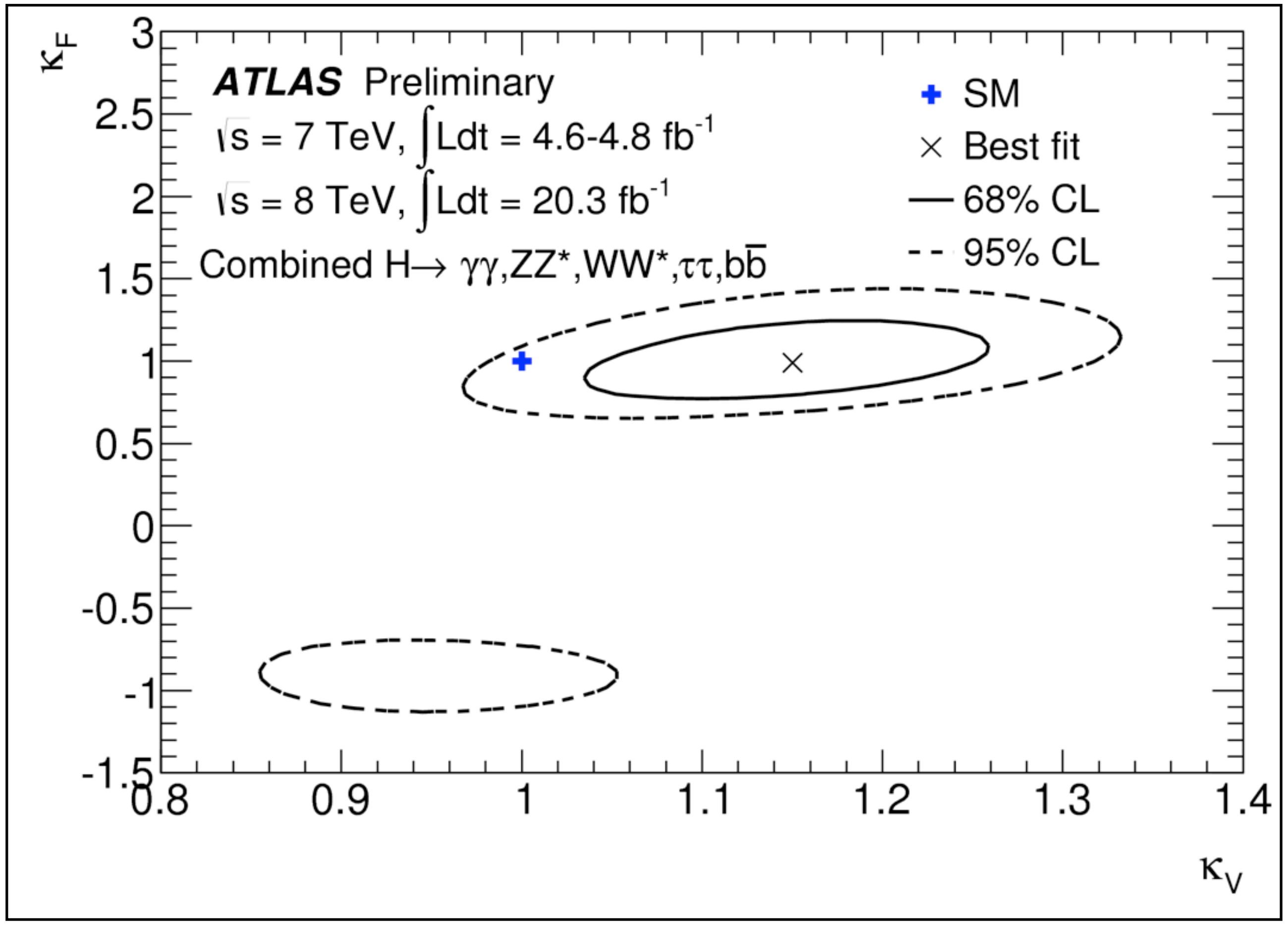
Di-photons: pre-selections

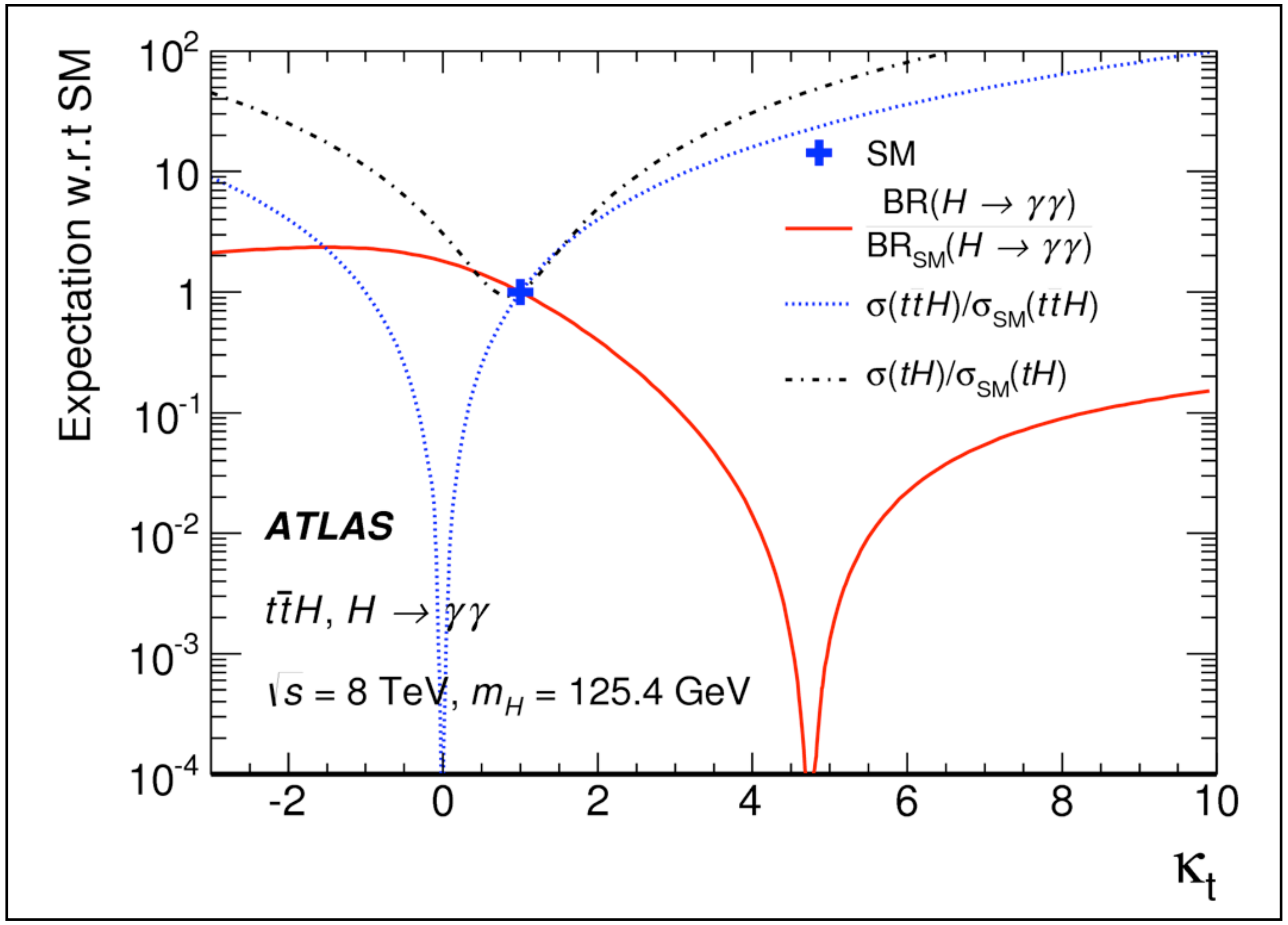
- Photons passing quality criteria on shower shape and isolated both in tracking and calorimetry
  - 2 photons with a reconstructed vertex required
  - leading (subleading) photon required to have $E_T > 0.35\, m_{\gamma\gamma}$ ($0.25\, m_{\gamma\gamma}$), and the di-photon mass to be between 105 GeV and 160 GeV ("Signal Region")
- e or μ of good quality (track, track-cluster match) and isolated both in tracking and calorimetry
  - $E_T(e) > 15$ GeV, $p_T(\mu) > 10$ GeV
- Anti-k_T jets with R=0.4, calibrated at hadronic scale
  - $p_T(\text{jet}) > 25$ GeV, central
  - pile-up suppressing selection criteria for jets of $p_T(\text{jet}) < 50$ GeV
- b-quark identification in jets with NN-based algorithm
  - 60, 70, 80% b-tag efficiency working points all used in this analysis

(W)tH with γγ channel



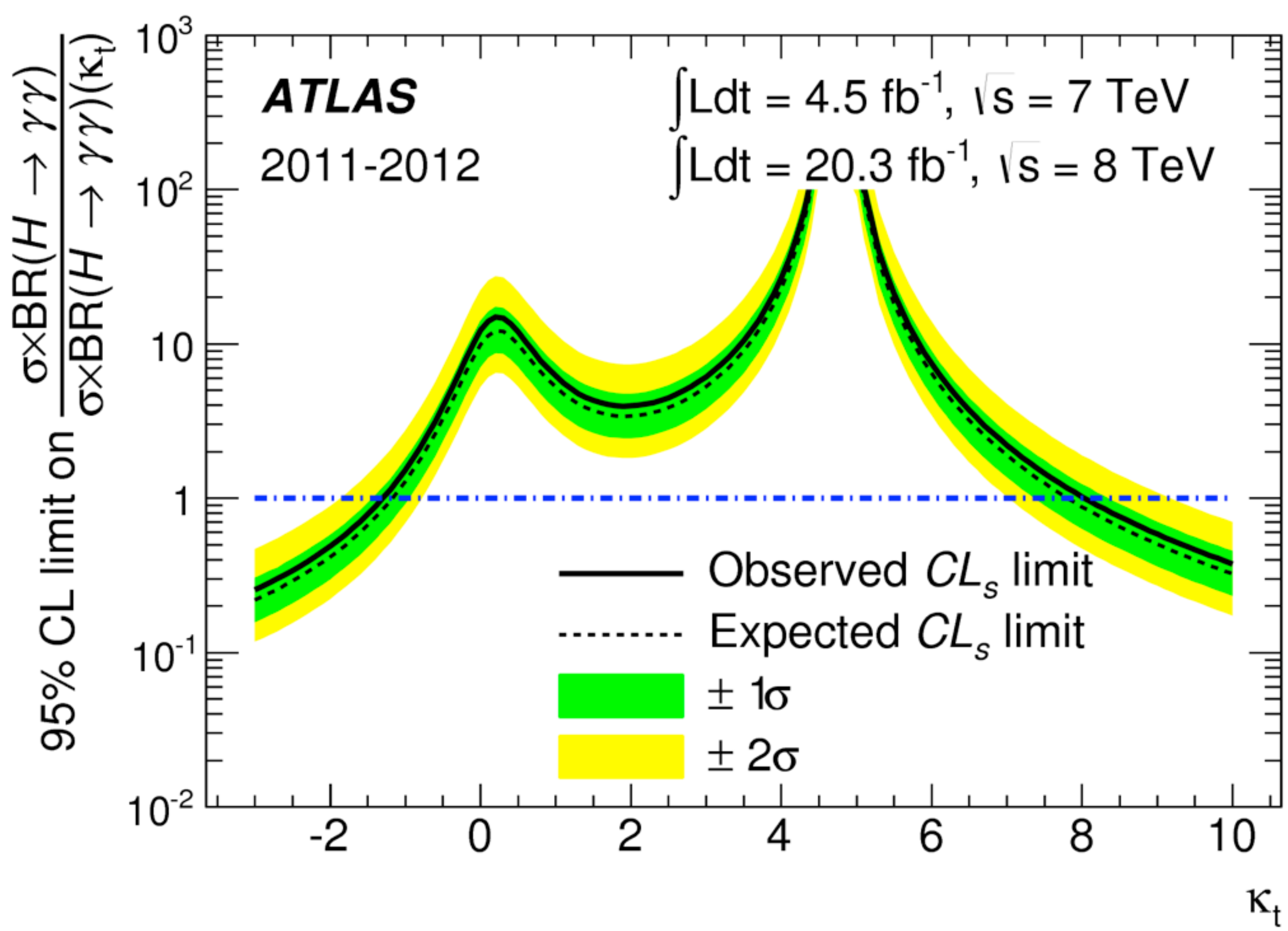
- Residual sign ambiguity between fermionic and couplings
- Single top + Higgs production probes this sign
  - SM has destructive interference between H emission from top and from W: if relative sign of top coupling flips, large constructive interference
  - Also affects BR(H-> γγ): double-sensitivity of this channel





Analysis tHj+WtHj

- Exactly same analysis/samples as ttH
- scanning also limit in top-H Yukawa coupling k_t
  - tH+WtH selection efficiencies extrapolated from 3 benchmark k_t values/MC samples (variations up to 15/20%)

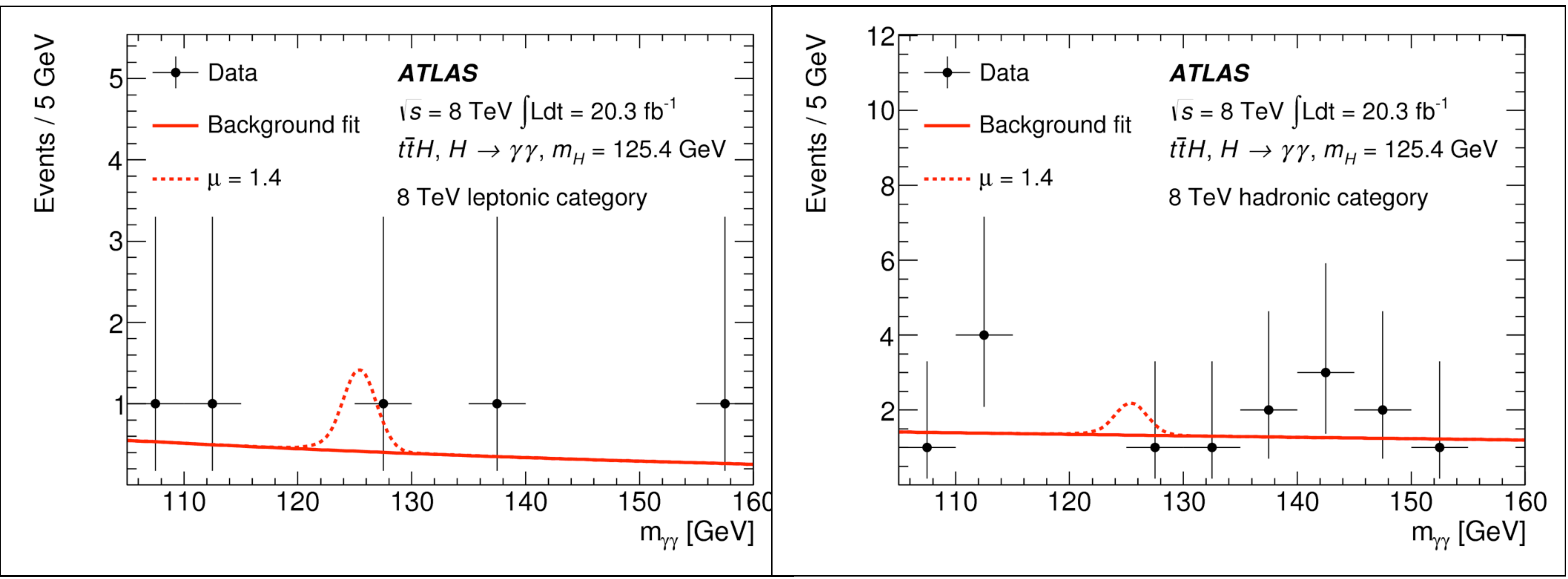


Observed range at 95% CL: [-1.3, 8.0]
expected: [-1.2, 7.8]

Will repeat in Run II

Analysis

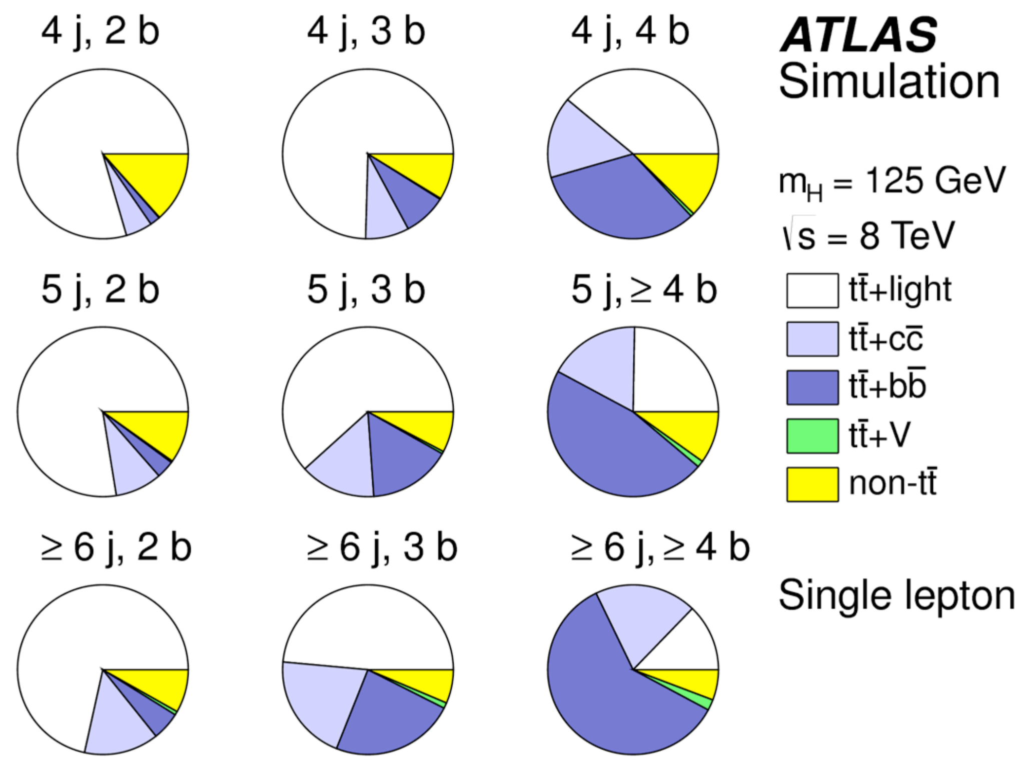
- Localized excess looked for around $m_{\gamma\gamma}$=125.4 GeV
- Unbinned LL fit to background and signal in signal region
  - signal: Gaussian core portion and a power-law low-end tail + Gaussian (tails)
  - background: exponential function tested on ad-hoc control region (loosening photon ID) sensitive to jets faking γ

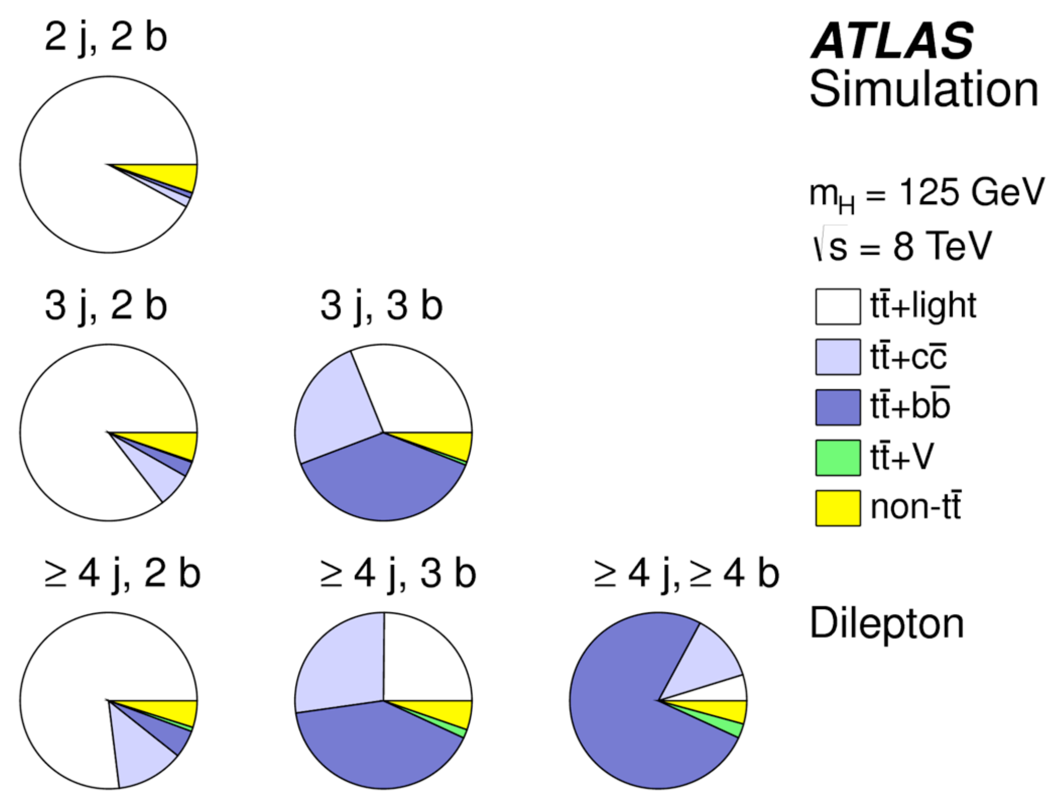


- $m_{\gamma\gamma}$ resolution dominated by resolution on E_γ

Background modeling

- Main bkg tt+HF in all regions for both channels
  - 50% normalization uncertainty on ttbb/cc
- Powheg + Pythia6 used to model it
  - HF content validated with dedicated studies (ATL-CONF-2013-099)
- Madgraph directly generates tt+bb/cc
  - expected to properly treat ME+PS matching of tt+HF
  - difference between generators taken as systematic uncertainty
- p_T of top quark and tt system reweighted to reproduce spectra obtained in 7 TeV analysis (ATL-CONF-2013-099).





Variable ranking, bb l+j

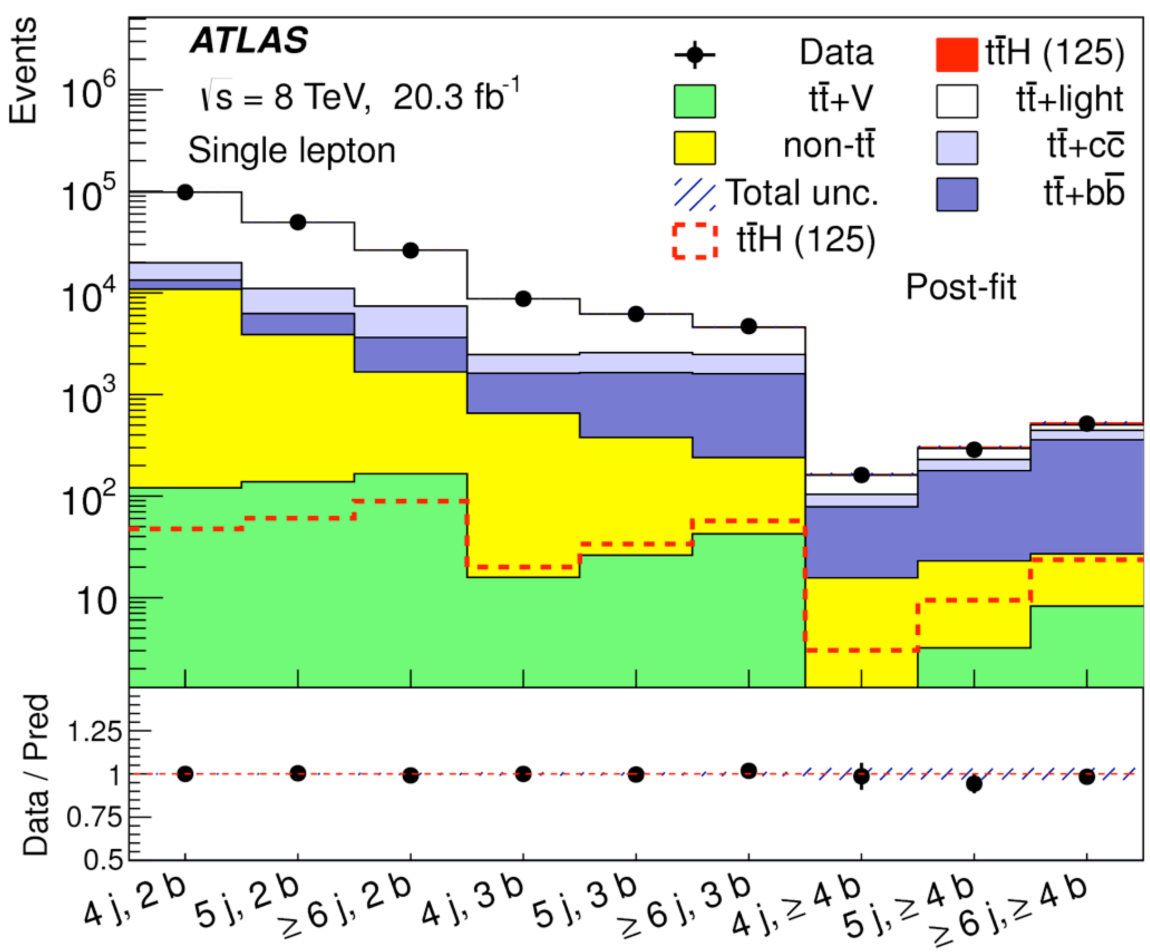
Variable	Definition	NN rank			
		$\geq$ 6j, $\geq$ 4b	$\geq$ 6j, 3b	5j, $\geq$ 4b	5j, 3b
$D1$	Neyman–Pearson MEM discriminant (Eq. (4))	1	10	-	-
Centrality	Scalar sum of the p_{T} divided by sum of the E for all jets and the lepton	2	2	1	-
$p_{\mathrm{T}}^{\mathrm{jet5}}$	p_{T} of the fifth leading jet	3	7	-	-
$H1$	Second Fox–Wolfram moment computed using all jets and the lepton	4	3	2	-
$\Delta R_{\mathrm{bb}}^{\mathrm{avg}}$	Average ΔR for all b-tagged jet pairs	5	6	5	-
SSLL	Logarithm of the summed signal likelihoods (Eq. (2))	6	4	-	-
$m_{\mathrm{bb}}^{\mathrm{min}\ \Delta\mathrm{R}}$	Mass of the combination of the two b-tagged jets with the smallest ΔR	7	12	4	4
$m_{\mathrm{bj}}^{\mathrm{max}\ p_{\mathrm{T}}}$	Mass of the combination of a b-tagged jet and any jet with the largest vector sum p_{T}	8	8	-	-
$\Delta R_{\mathrm{bb}}^{\mathrm{max}\ p_{\mathrm{T}}}$	ΔR between the two b-tagged jets with the largest vector sum p_{T}	9	-	-	-
$\Delta R_{\mathrm{lep-bb}}^{\mathrm{min}\ \Delta\mathrm{R}}$	ΔR between the lepton and the combination of the two b-tagged jets with the smallest ΔR	10	11	10	-
$m_{\mathrm{uu}}^{\mathrm{min}\ \Delta\mathrm{R}}$	Mass of the combination of the two untagged jets with the smallest ΔR	11	9	-	2
$\mathrm{Aplan}_{\mathrm{b-jet}}$	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor[92] built with only b-tagged jets	12	-	8	-
N_{40}^{jet}	Number of jets with $p_{\mathrm{T}} \geq 40GeV$	-	1	3	-
$m_{\mathrm{bj}}^{\mathrm{min}\ \Delta\mathrm{R}}$	Mass of the combination of a b-tagged jet and any jet with the smallest ΔR	-	5	-	-
$m_{\mathrm{jj}}^{\mathrm{max}\ p_{\mathrm{T}}}$	Mass of the combination of any two jets with the largest vector sum p_{T}	-	-	6	-
$H_{\mathrm{T}}^{\mathrm{had}}$	Scalar sum of jet p_{T}	-	-	7	-
$m_{\mathrm{jj}}^{\mathrm{min}\ \Delta\mathrm{R}}$	Mass of the combination of any two jets with the smallest ΔR	-	-	9	-
$m_{\mathrm{bb}}^{\mathrm{max}\ p_{\mathrm{T}}}$	Mass of the combination of the two b-tagged jets with the largest vector sum p_{T}	-	-	-	1
$p_{\mathrm{T,uu}}^{\mathrm{min}\ \Delta\mathrm{R}}$	Scalar sum of the p_{T} of the pair of untagged jets with the smallest ΔR	-	-	-	3
$m_{\mathrm{bb}}^{\mathrm{max}\ \mathrm{m}}$	Mass of the combination of the two b-tagged jets with the largest invariant mass	-	-	-	5
$\Delta R_{\mathrm{uu}}^{\mathrm{min}\ \Delta\mathrm{R}}$	Minimum ΔR between the two untagged jets	-	-	-	6
m_{jjj}	Mass of the jet triplet with the largest vector sum p_{T}	-	-	-	7

Variable ranking, bb 2l

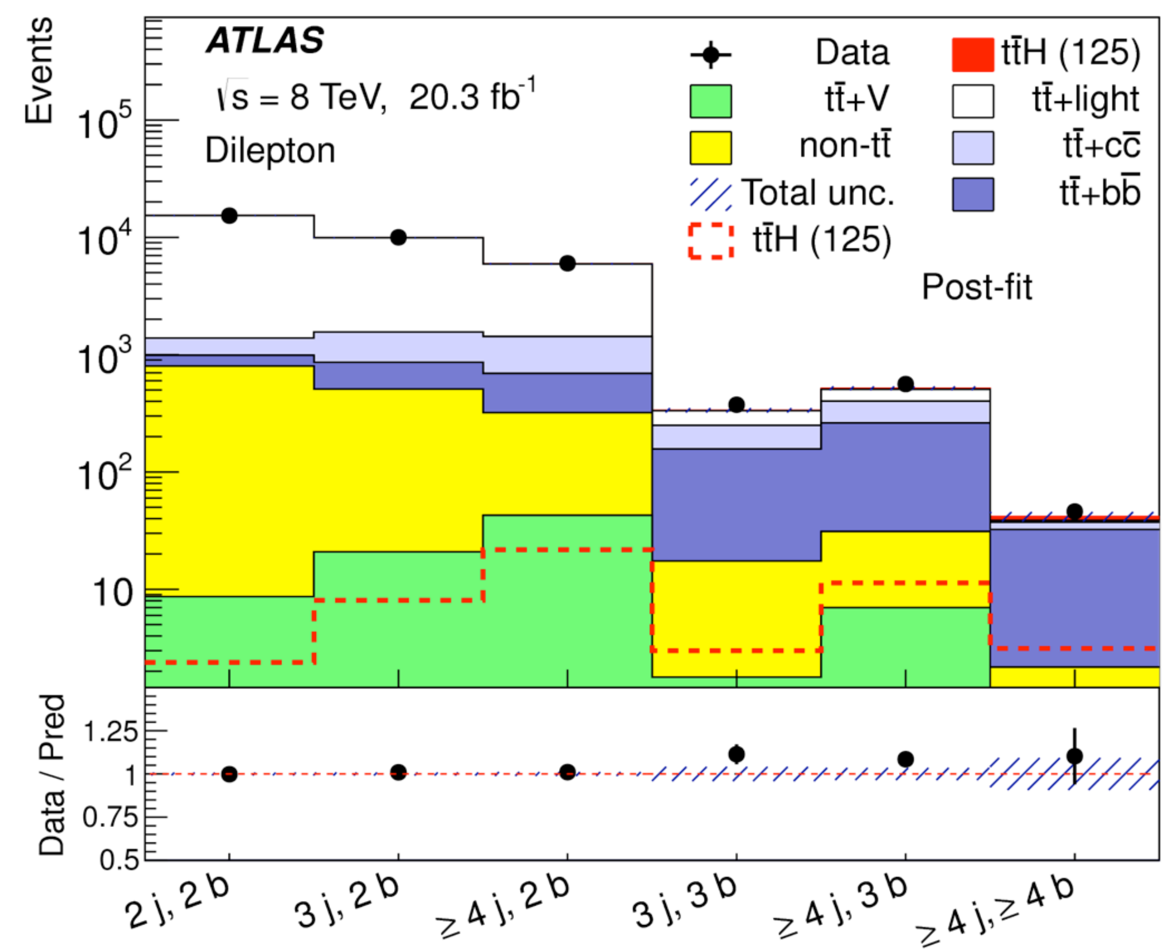
Variable	Definition	NN rank		
		$\geq$ 4j, $\geq$ 4b	$\geq$ 4j, 3b	3j, 3b
$\Delta\eta_{\mathrm{jj}}^{\max\ \Delta\eta}$	Maximum $\Delta\eta$ between any two jets in the event	1	1	1
$m_{\mathrm{bb}}^{\min\ \Delta \mathrm{R}}$	Mass of the combination of the two b-tagged jets with the smallest ΔR	2	8	-
$m_{b\bar{b}}$	Mass of the two b-tagged jets from the Higgs candidate system	3	-	-
$\Delta R_{\mathrm{hl}}^{\min\ \Delta \mathrm{R}}$	ΔR between the Higgs candidate and the closest lepton	4	5	-
$\mathrm{N}_{30}^{\mathrm{Higgs}}$	Number of Higgs candidates within 30 GeV of the Higgs mass of 125 GeV	5	2	5
$\Delta R_{\mathrm{bb}}^{\max\ p_{\mathrm{T}}}$	ΔR between the two b-tagged jets with the largest vector sum p_{T}	6	4	8
$\mathrm{Aplan}_{\mathrm{jet}}$	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor built with all jets	7	7	-
$m_{\mathrm{jj}}^{\min\ \mathrm{m}}$	Minimum dijet mass between any two jets	8	3	2
$\Delta R_{\mathrm{hl}}^{\max\ \Delta \mathrm{R}}$	ΔR between the Higgs candidate and the furthest lepton	9	-	-
$m_{\mathrm{jj}}^{\mathrm{closest}}$	Dijet mass between any two jets closest to the Higgs mass of 125 GeV	10	-	10
H_{T}	Scalar sum of jet p_{T} and lepton p_{T} values	-	6	3
$\Delta R_{\mathrm{bb}}^{\max\ \mathrm{m}}$	ΔR between the two b-tagged jets with the largest invariant mass	-	9	-
$\Delta R_{\mathrm{lj}}^{\min\ \Delta \mathrm{R}}$	Minimum ΔR between any lepton and jet	-	10	-
Centrality	Sum of the p_{T} divided by sum of the E for all jets and both leptons	-	-	7
$m_{\mathrm{jj}}^{\max\ p_{\mathrm{T}}}$	Mass of the combination of any two jets with the largest vector sum p_{T}	-	-	9
$H4$	Fifth Fox–Wolfram moment computed using all jets and both leptons	-	-	4
$p_{\mathrm{T}}^{\mathrm{jet3}}$	p_{T} of the third leading jet	-	-	6

Post-fit description

- A profile likelihood fit is performed considering all regions simultaneously
  - reduces effect of systematic uncertainties thanks to high-stats, bkg enriched control regions



l+jets



dilepton

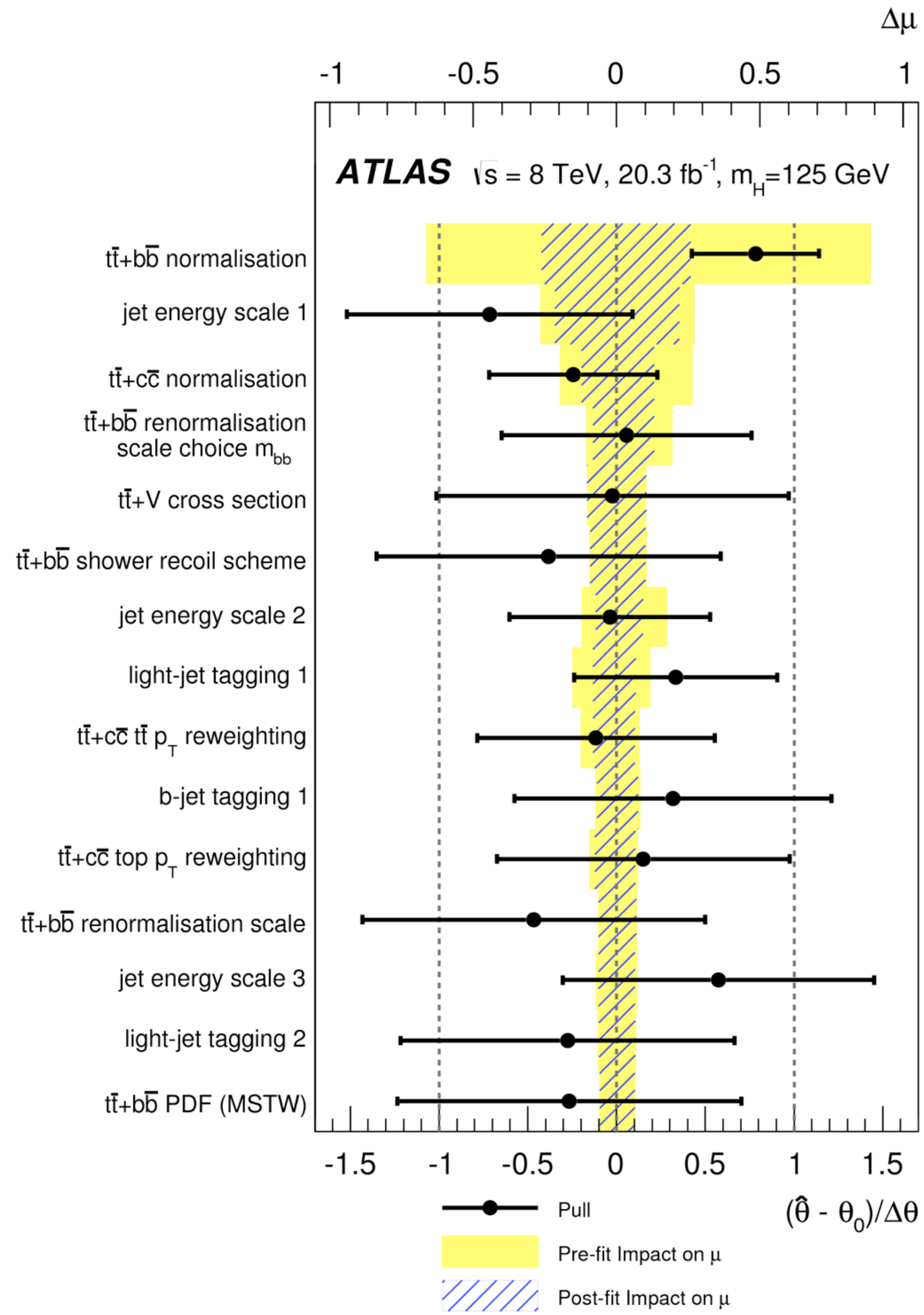
- Fit to data under the signal-plus-background hypothesis.
- Signal normalised to the fitted μ (=1.7)

Systematic uncertainties

Pre-fit

Systematic uncertainty	Type	Comp.
Luminosity	N	1
Physics Objects		
Electron	SN	5
Muon	SN	6
Jet energy scale	SN	22
Jet vertex fraction	SN	1
Jet energy resolution	SN	1
Jet reconstruction	SN	1
b-tagging efficiency	SN	6
c-tagging efficiency	SN	4
Light-jet tagging efficiency	SN	12
High-p_T tagging efficiency	SN	1
Background Model		
$t\bar{t}$ cross section	N	1
$t\bar{t}$ modelling: p_T reweighting	SN	9
$t\bar{t}$ modelling: parton shower	SN	3
$t\bar{t}$+heavy-flavour: normalisation	N	2
$t\bar{t}+c\bar{c}$: p_T reweighting	SN	2
$t\bar{t}+c\bar{c}$: generator	SN	4
$t\bar{t}+b\bar{b}$: NLO Shape	SN	8
W+jets normalisation	N	3
W p_T reweighting	SN	1
Z+jets normalisation	N	3
Z p_T reweighting	SN	1
Lepton misID normalisation	N	3
Lepton misID shape	S	3
Single top cross section	N	1
Single top model	SN	1
Diboson+jets normalisation	N	3
$t\bar{t}+V$ cross section	N	1
$t\bar{t}+V$ model	SN	1
Signal Model		
$t\bar{t}H$ scale	SN	2
$t\bar{t}H$ generator	SN	1
$t\bar{t}H$ hadronisation	SN	1
$t\bar{t}H$ PDF	SN	1

S=shape, N=normalization



Sources with most impact on μ, as constrained by the data

Overall strategy

- 2 isolated, high-p_T photons for Higgs boson mass reconstruction
- Categorize events according to top quark decay:
    - Optimized on the expected limit on μ_{ttH}
    - leptonic channel: $\geq$ 1 leptons (e or μ), $\geq$ 1 b-tagged jet
    - hadronic channel: $\geq$ 6 jets, $\geq$ 2 b-tagged jet
    - Combined signal selection: eff ~ 15%, purity ~80%

Category	N_H	ggF	VBF	WH	ZH	$t\bar{t}H$	$tHqb$	WtH	N_B
7 TeV leptonic selection	0.10	0.6	0.1	14.9	4.0	72.6	5.3	2.5	$0.5^{+0.5}_{-0.3}$
7 TeV hadronic selection	0.07	10.5	1.3	1.3	1.4	80.9	2.6	1.9	$0.5^{+0.5}_{-0.3}$
8 TeV leptonic selection	0.58	1.0	0.2	8.1	2.3	80.3	5.6	2.6	$0.9^{+0.6}_{-0.4}$
8 TeV hadronic selection	0.49	7.3	1.0	0.7	1.3	84.2	3.4	2.1	$2.7^{+0.9}_{-0.7}$

absolute numbers

fractions

absolute numbers

Run II prospects

- Higher E_{CM} beneficial for ttH search:
  - @ 13(14) TeV ~4x (5x) increase in σ_{SM} for signal
  - same for ttV
  - ~3x (4x) increase in σ_{SM} for tt+jets background
- Additional techniques (e.g. more multi variate analysis) in development to maximize signal-bkg discrimination

- Not many prospect studies exist for RunII/future

- expect to measure ttH at 3σ with 300 fb^{-1} from di-photon channel alone (ATL-PHYS-PUB-2014-016)
- much earlier from bb and multi-lepton channels
- *tens fb^{-1} at 13 TeV?*

$\Delta\mu/\mu$	300 fb^{-1}		3000 fb^{-1}	
	All unc.	No theory unc.	All unc.	No theory unc.
$gg \to H$	0.12	0.06	0.11	0.04
VBF	0.18	0.15	0.15	0.09
WH	0.41	0.41	0.18	0.18
$qqZH$	0.80	0.79	0.28	0.27
$ggZH$	3.71	3.62	1.47	1.38
ttH	0.32	0.30	0.16	0.10