Search for the 125 GeV Higgs boson in the ttH production mode with the ATLAS detector

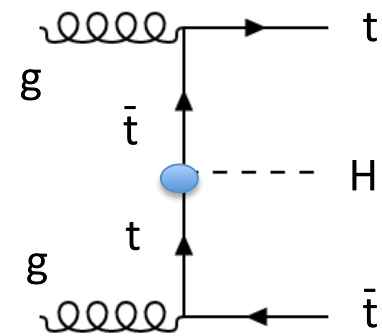
Elemér Nagy
CPPM

for the ATLAS Collaboration

The Yukawa coupling Y_t of the Higgs boson to the top quark is a key parameter of the SM.

One of the most direct ways is by measuring the signal strength μ of the ttH production.

$$\mu = \sigma_{ttH}/\sigma_{ttH}^{SM} \approx Y_t^2$$



Any significant deviation of μ from 1 would be a signal for BSM physics.

Results on μ obtained by the ATLAS collaboration

in Run I: √s 7-8 TeV, L_{int} = 4.5-20.3 fb^{-1}

in part of Run II: √s = 13 TeV, L_{int} = 13.3 fb^{-1}

are presented here.

Details on several selected final states will be also given.

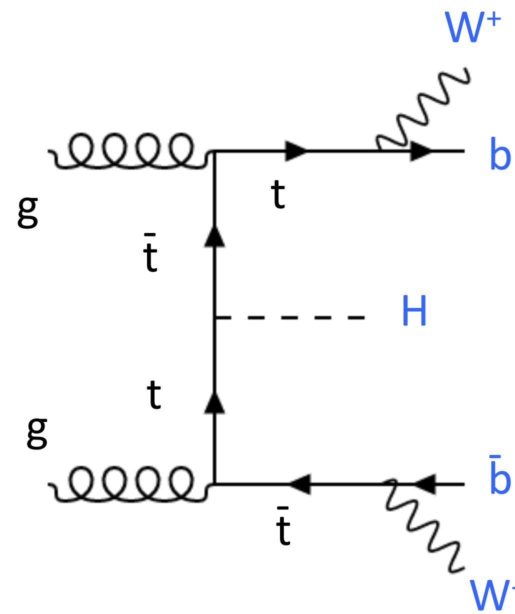
A large number of final states has been studied

There are always 2 b-quarks from the 2 top-quark decays.
The associated particles are determined

by the Higgs decay:

$H \rightarrow bb$ (58.1%)
$\rightarrow WW^*$ (21.5%)
$\rightarrow \tau\tau$ (6.3%)
$\rightarrow ZZ^*$ (2.6%)
$\rightarrow \gamma\gamma$ (0.23%)

Multilepton (ML) channel



by the decay products of the 2 W's
(from the 2 top-quarks):

$W \rightarrow qq$ $W \rightarrow qq$ Hadronic (H) channel
$W \rightarrow qq$ $W \rightarrow l\nu$ ($l = e,\mu$) Single-lepton (SL) channel
$W \rightarrow l\nu$ $W \rightarrow l\nu$ Dilepton (DL) channel

The signal cross section is calculated to NLO and modelled by MadGraph5_aMC@NLO.

H→bb

The largest Higgs branching fraction

SL and DL channels (Run II)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-080/

SL selection:

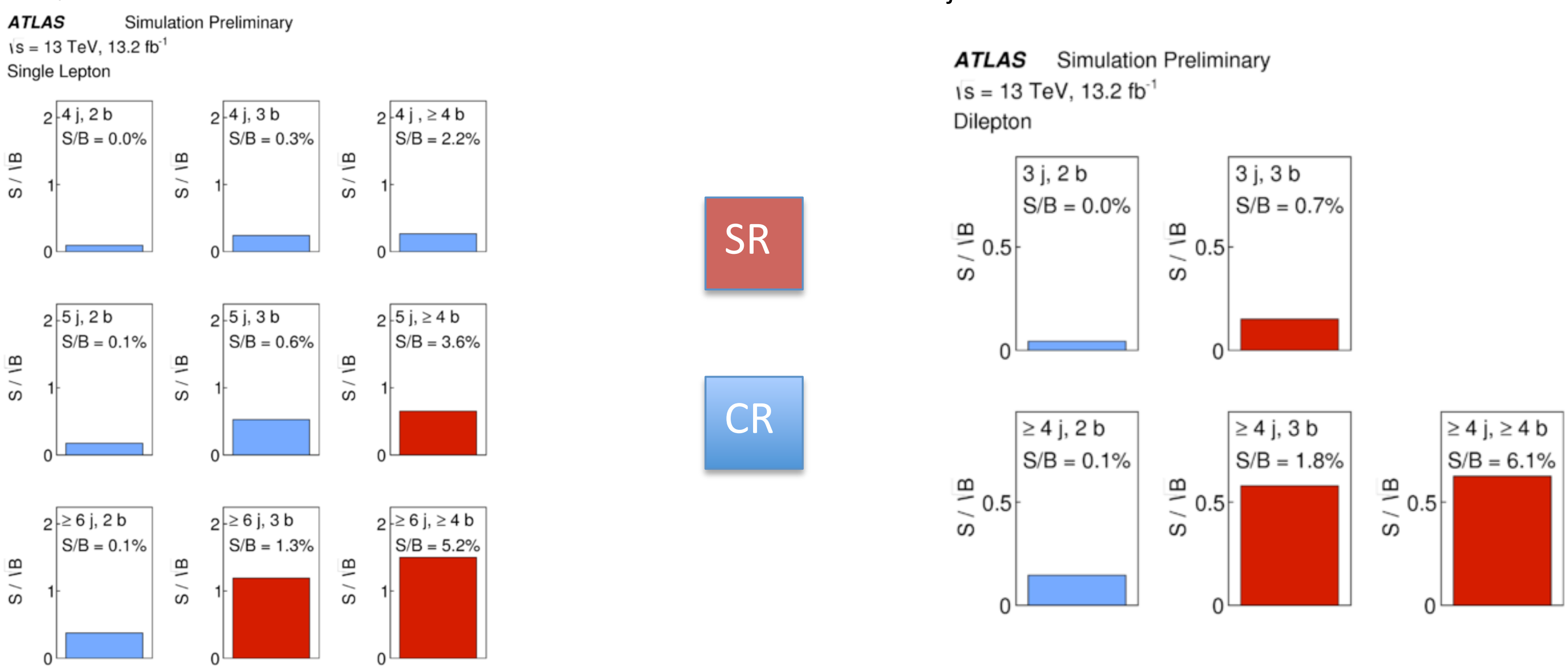
1 l (e,μ) $p_T > 25$ GeV

$N_j \geq 4$, $N_b \geq 2$ $p_T > 25$ GeV

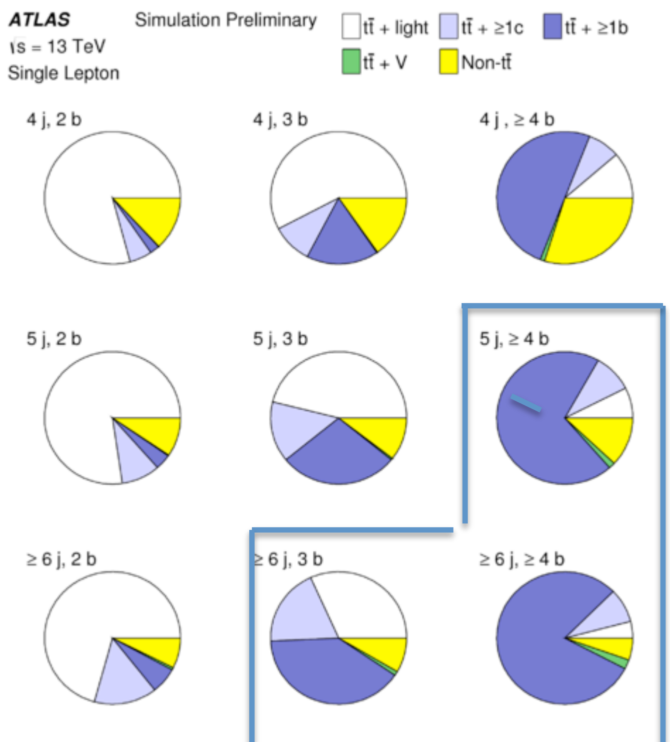
DL selection:

2 OS l (ee, eμ, μμ) $p_T^1 > 25$ GeV

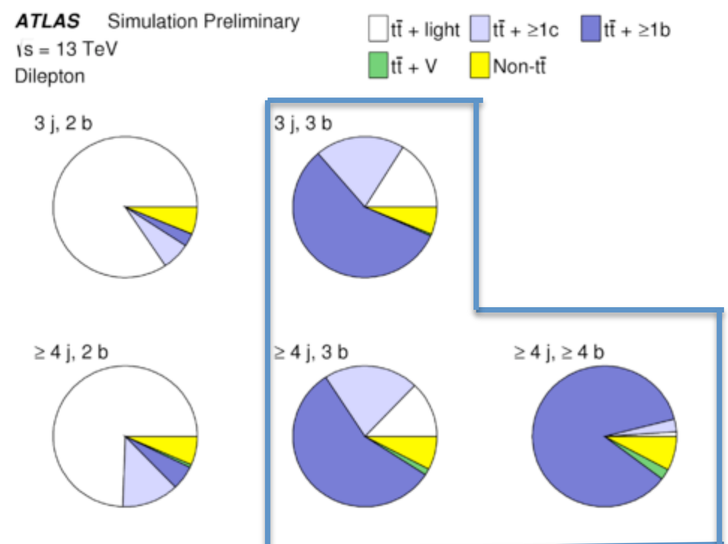
$N_j \geq 3$, $N_b \geq 2$ $p_T > 25$ GeV



The dominant background is tt+nj, in the signal region tt+HF (b,c).
It is simulated with POWHEG+Pythia6.
tt+HF reweighted to match to Sherpa+OpenLoops NLO 4F calculation.
tt+HF normalization and shape was constrained in the final fit.
Small instrumental background (mis-identified or non-prompt leptons) estimated from data.

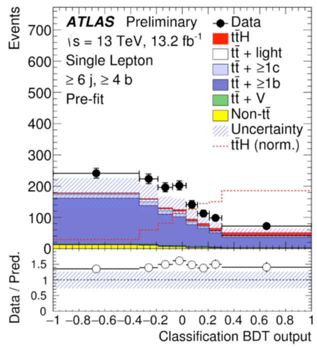


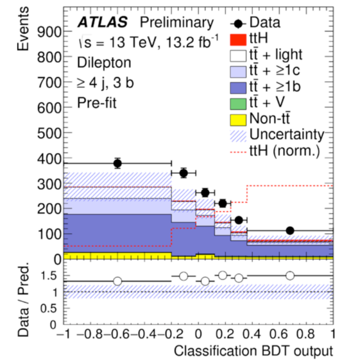
SL



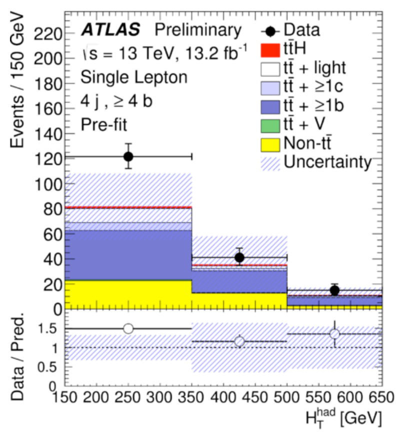
DL

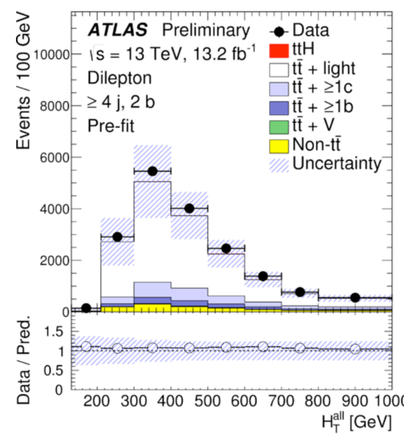
Signal and background are discriminated in the SR by MVA (2-stage* BDT) variables





In the CR we use Σp_T (H_T^{had} or H_T^{all}) variables





SL DL

* Stage 1: BDT trained on signal to separate correct and false assignment between jets and partons.
2: BDT trained on signal and background to separate signal and background like events.

Uncertainties affecting the value of μ

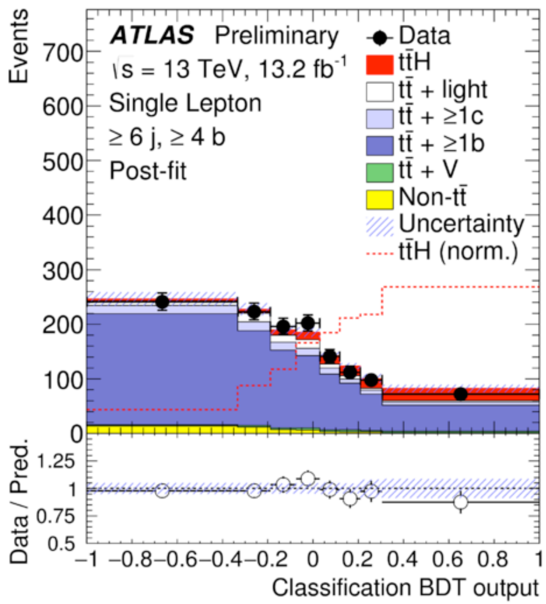
Uncertainty source	$\Delta\mu$	
$t\bar{t}+\geq 1b$ modelling	+0.53	−0.53
Jet flavour tagging	+0.26	−0.26
$t\bar{t}H$ modelling	+0.32	−0.20
Background model statistics	+0.25	−0.25
$t\bar{t}+\geq 1c$ modelling	+0.24	−0.23
Jet energy scale and resolution	+0.19	−0.19
$t\bar{t}$+light modelling	+0.19	−0.18
Other background modelling	+0.18	−0.18
Jet-vertex association, pileup modelling	+0.12	−0.12
Luminosity	+0.12	−0.12
$t\bar{t}Z$ modelling	+0.06	−0.06
Light lepton (e, μ) ID, isolation, trigger	+0.05	−0.05
Total systematic uncertainty	+0.90	−0.75
$t\bar{t}+\geq 1b$ normalisation	+0.34	−0.34
$t\bar{t}+\geq 1c$ normalisation	+0.14	−0.14
Statistical uncertainty	+0.49	−0.49
Total uncertainty	+1.02	−0.89

A nuisance parameter is associated to each systematic uncertainty

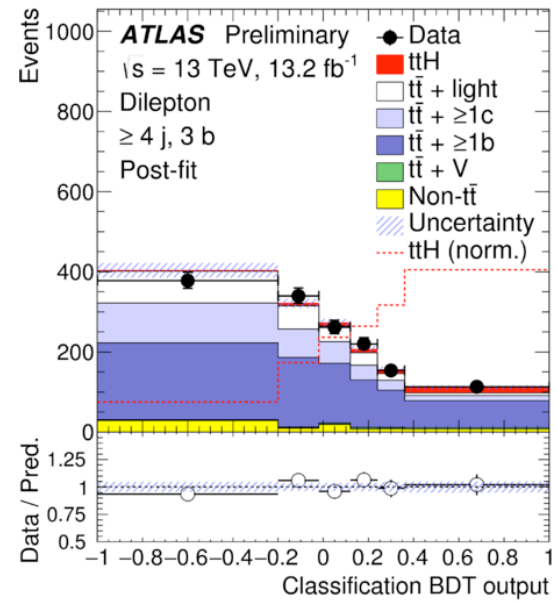
Distributions of the final discriminating variables from all regions participate in the construction of the profile likelihood ratio test statistics.

One derives (i) the observed value of μ by fitting the nuisance parameters

(ii) and the upper limits using the CLs method

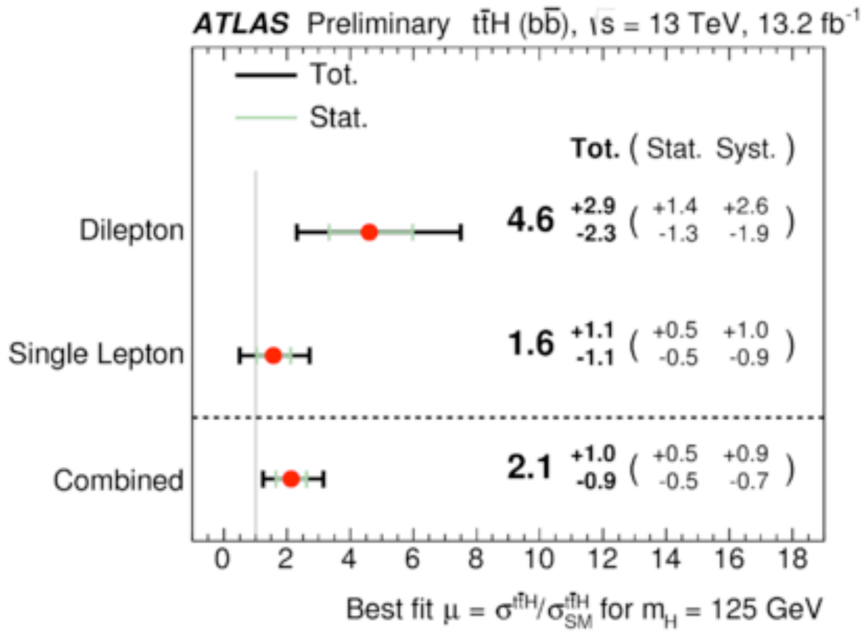


SL

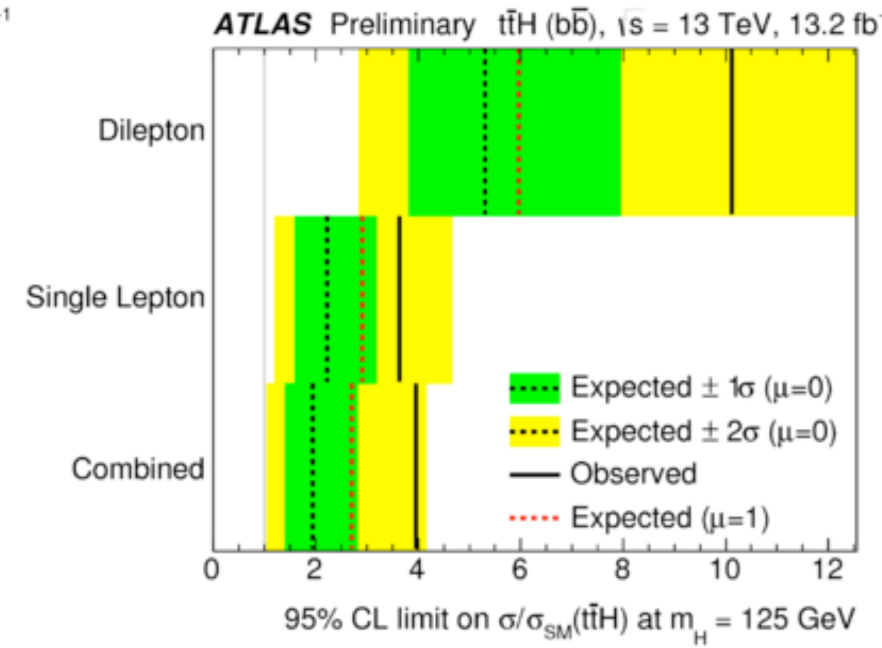


DL

The tt+≥1b and tt+≥1c normalizations have been fitted to $1.33^{+0.18}_{-0.17}$ and to $1.31^{+0.53}_{-0.40}$, respectively



ATLAS Preliminary $t\bar{t}H$ ($b\bar{b}$), $\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}
Tot.
Stat.
Tot. (Stat. Syst.)
Dilepton
4.6 $^{+2.9}_{-2.3}$ ($^{+1.4}_{-1.3}$ $^{+2.6}_{-1.9}$)
Single Lepton
1.6 $^{+1.1}_{-1.1}$ ($^{+0.5}_{-0.5}$ $^{+1.0}_{-0.9}$)
Combined
2.1 $^{+1.0}_{-0.9}$ ($^{+0.5}_{-0.5}$ $^{+0.9}_{-0.7}$)
0 2 4 6 8 10 12 14 16 18
Best fit $\mu = \sigma^{t\bar{t}H}/\sigma^{t\bar{t}H}_{SM}$ for m_H = 125 GeV



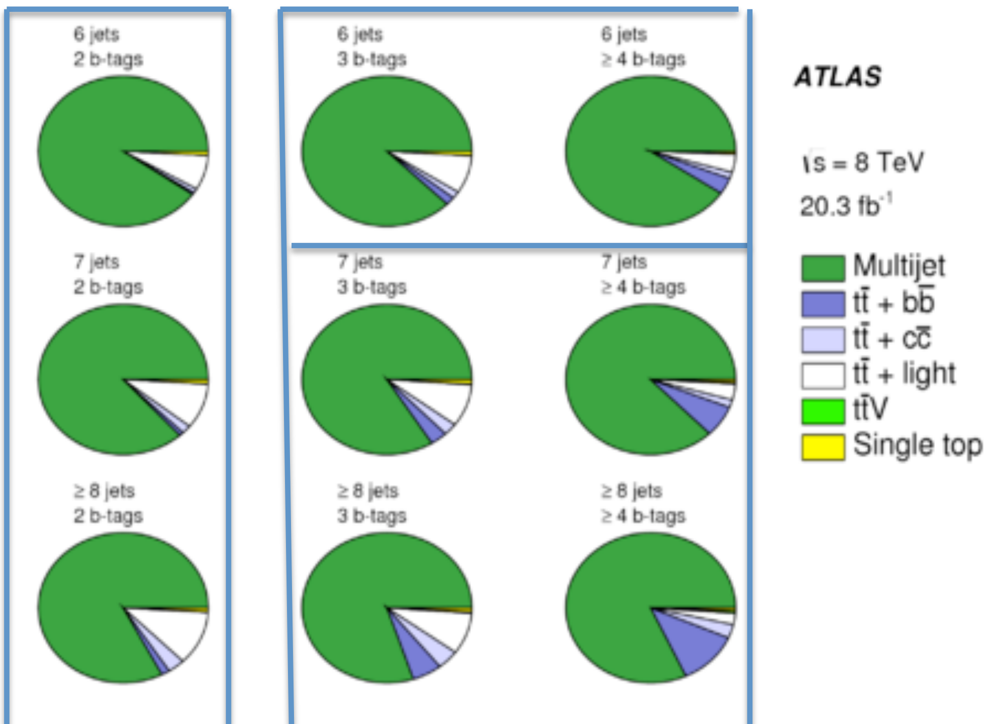
ATLAS Preliminary $t\bar{t}H$ ($b\bar{b}$), $\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}
Dilepton
Single Lepton
Combined
Expected $\pm$ 1σ (μ=0)
Expected $\pm$ 2σ (μ=0)
Observed
Expected (μ=1)
0 2 4 6 8 10 12
95% CL limit on $\sigma/\sigma_{SM}(t\bar{t}H)$ at m_H = 125 GeV

$H \rightarrow bb$

H channel aka FH (Run I)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2015-05/

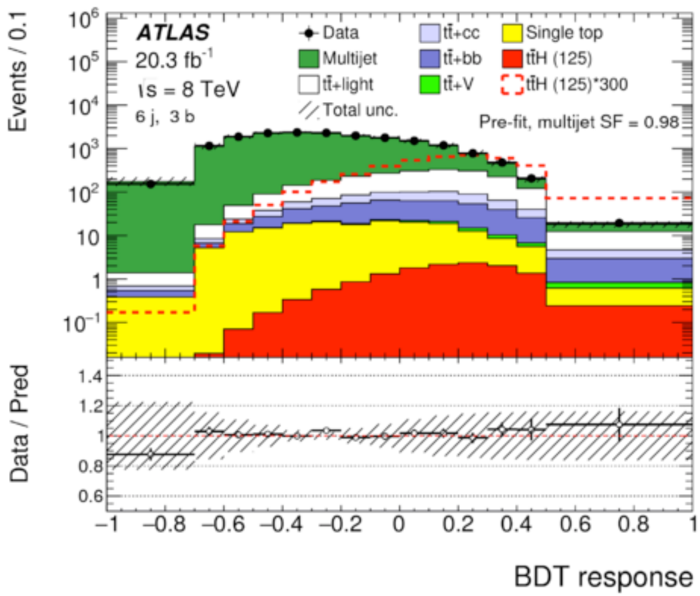
Event selection:
Multijet trigger: $N_j \geq 5$ with $p_T > 55$ GeV $|\eta| < 2.5$
Offline: $N_j \geq 6$, $N_b \geq 2$ (60% eff)
e, μ veto

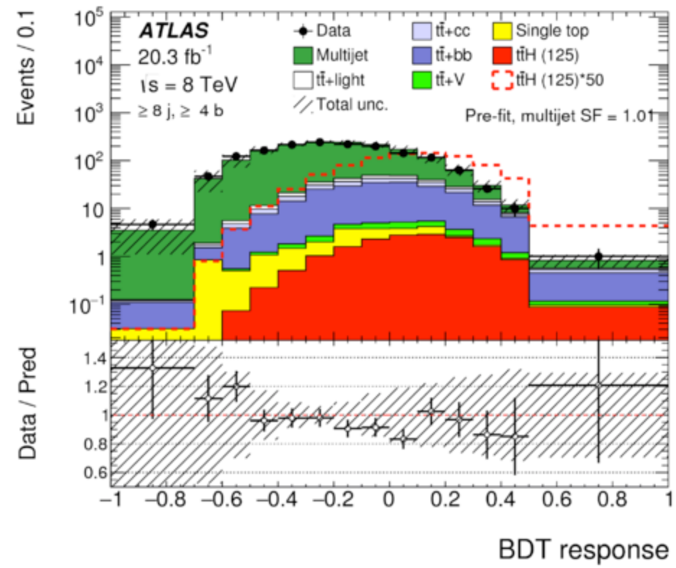


High BR of $W \rightarrow qq$ results in high statistics
Main challenge is the overwhelming multijet (MJ) background

The MJ background is estimated from data.
Using the TRF_{MJ} method a pseudo MJ sample is constructed starting from the $N_b = 2$ region of the data.
Validated in the $N_j = 6$ (signal depleted) control region.
Applied in the $N_j \geq 7$ signal region.
Other backgrounds and signals are simulated by MC similarly to SL and DL.

MVA (BDT) is used to separate the ttH signal from the background.





Sources of systematic uncertainty	$\pm 1\sigma$ post-fit impact on μ
$t\bar{t}$ normalisation	108%
Multijet normalisation	71%
Multijet shape	60%
Main contributions from $t\bar{t}$ modelling	34%–41%
Flavour tagging	31%
Jet energy scale	27%
Signal modelling	22%
Luminosity+trigger+JVF+JER	18%

Similar statistical treatment as for the SL and DL channels:

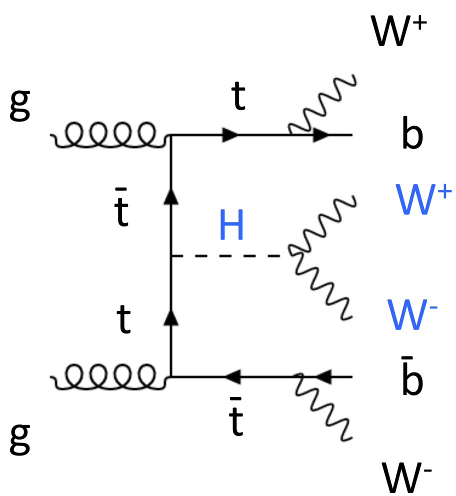
μ = 1.6 ± 0.8 (stat) ± 2.5 (syst)

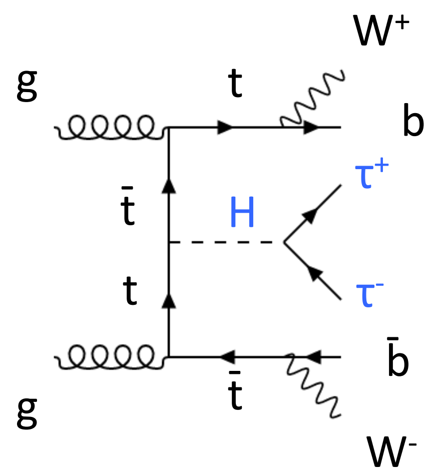
Systematics dominated

H→ ML (Run II)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-058/

Small background in the selected event topologies





Leptonic decays of the W's and τ's result in 2, 3, 4 light leptons, l = e, μ
Leptons from the top-quark and Higgs can have the same sign (SS)
The final states are re-groupped in the following 4 event categories(*):

$2(SS)l+0\tau_{had}$, $2(SS)l+1\tau_{had}$, 3l, 4l

(*) The $2(SS)l+0\tau_{had}$ category is subdivided into 3 subcategories: ee, eμ and μμ

Event selection:

Single electron or single muon trigger

4 main signal regions (SR)

$2(SS)l\ 0\tau_{had}$: 2 tight leptons, $p_T > 25$ GeV
$N_j \geq 5$, $N_b \geq 1$

$2(SS)l\ 1\tau_{had}$: 2 tight leptons, $p_T > 25, 15$ GeV
$N_j \geq 4$, $N_b \geq 1$

$3l$: $\Sigma Q = \pm 1$; 2 tight SS leptons, $p_T > 20$ GeV;
m(OS) > 10 GeV and outside $m_{Z;}$
$N_j \geq 4$, $N_b \geq 1$ or $N_j = 3$, $N_b \geq 2$

$4l$: $\Sigma Q = 0$;
m(OS) > 10 GeV and outside $m_{Z;}$
100 < m(4l) < 350 GeV and outside m_H
$N_j \geq 2$, $N_b \geq 1$

Signal repartition:

Higgs boson decay mode				$A \times \epsilon$
WW^*	$\tau\tau$	ZZ^*	Other	$(\times 10^{-4})$
77%	17%	3%	3%	14
46%	51%	2%	1%	2.2
74%	20%	4%	2%	9.2
72%	18%	9%	2%	0.88

The main SM backgrounds with prompt leptons: ttW, ttZ and WZ are estimated by MC and validated in regions (VR) which don't overlap with the SR's.

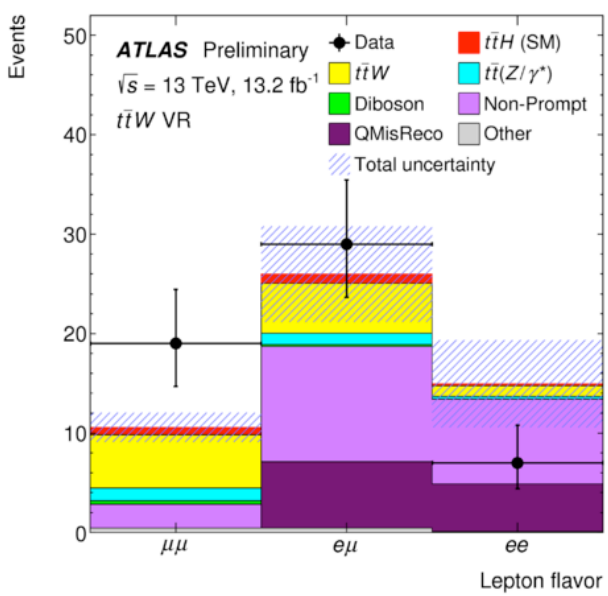
Background involving non-prompt leptons and fake τ_{had} candidates are estimated from data in the different SR's.

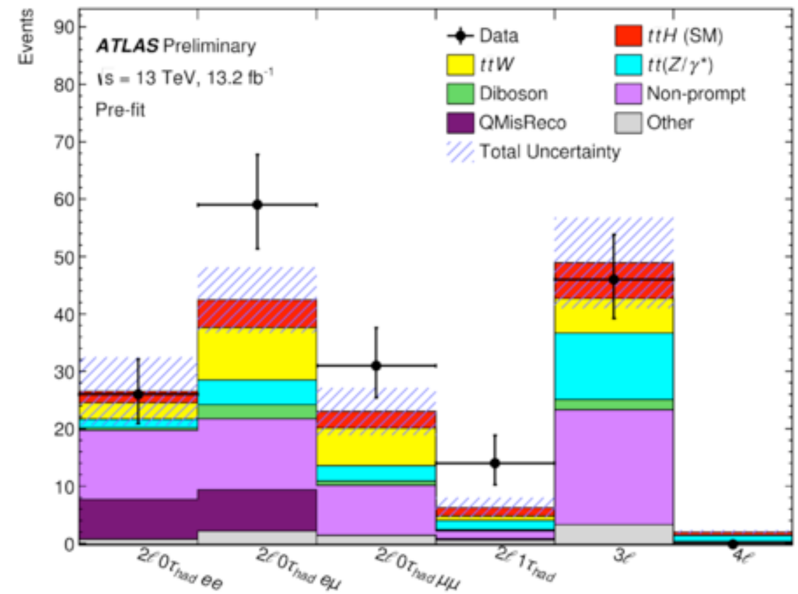
Charge misreconstruction is estimated from data by comparing the Z-mass peak for SS and OS ee-pairs.

Event yields

ttW VR

SR

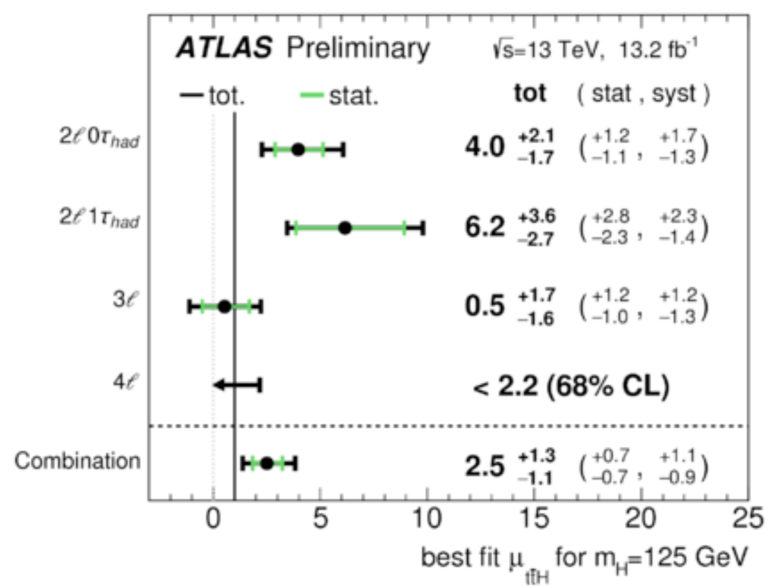




The dominant systematic error is due to

- non-prompt lepton determination and charge misreconstruction
- jet-vertex association, pile-up modeling

The observed values of μ and its upper limits are derived by the same statistical method as outlined in the ttH→bb case



H→γγ (Run II)

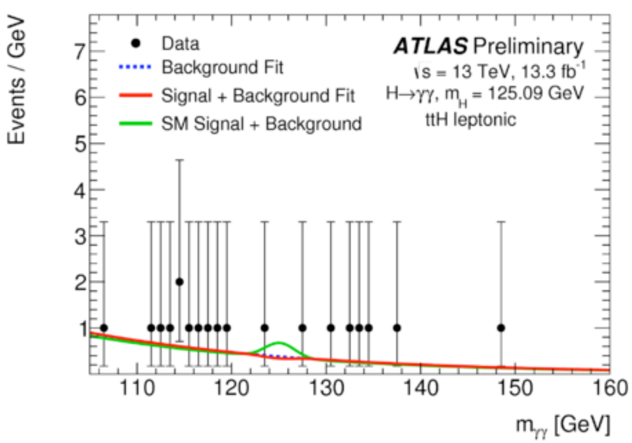
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-067/

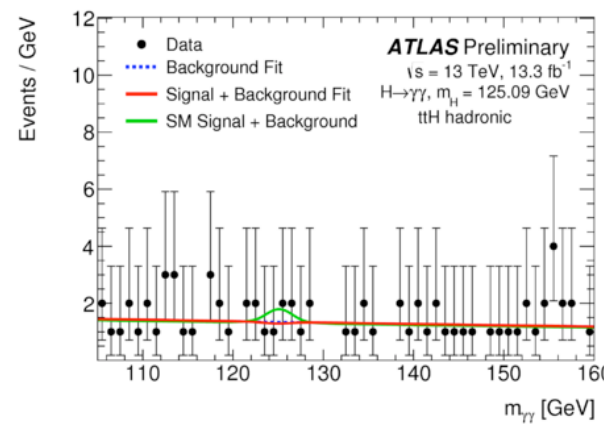
Excellent di-photon resolution but suffers from the small decay BR

Event selection: 2 isolated photons with $E_T > 25$ GeV

Leptonic ttH category:
$N_l \geq 1$, $N_j \geq 2$ and
$N_b \geq 2$ or $N_b \geq 1$ and MET > 20 GeV
m(eγ) outside the m_Z window

Hadronic ttH category:
$N_j \geq 5$ ($p_T > 30$ GeV) with $N_b \geq 1$



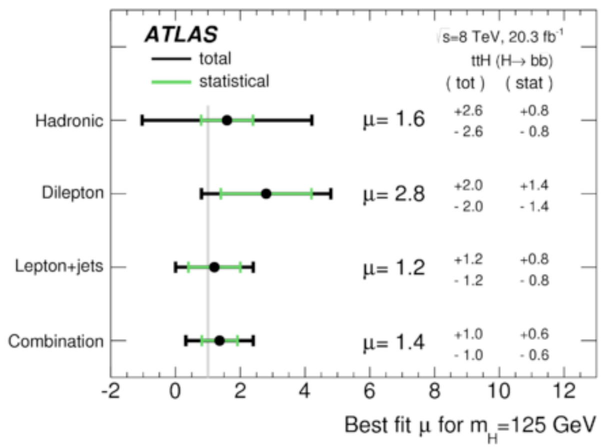


$$\mu = -0.3\ ^{+1.2}_{-1.0}\ \text{(tot.)}\ [\ ^{+1.2}_{-1.0}\ \text{(stat.)}\ ]$$

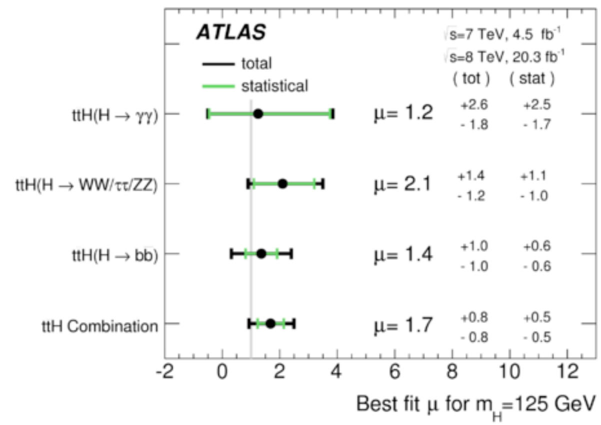
Combinations and Outlook

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-068/

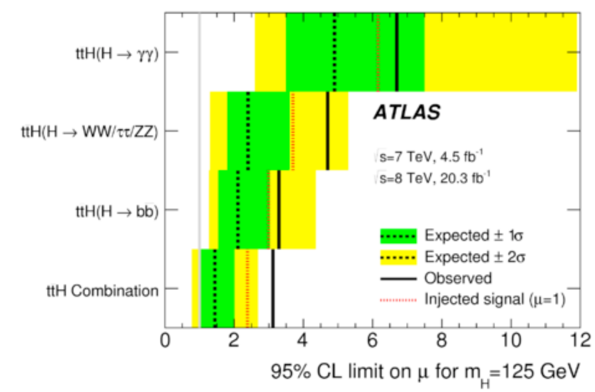
H→bb



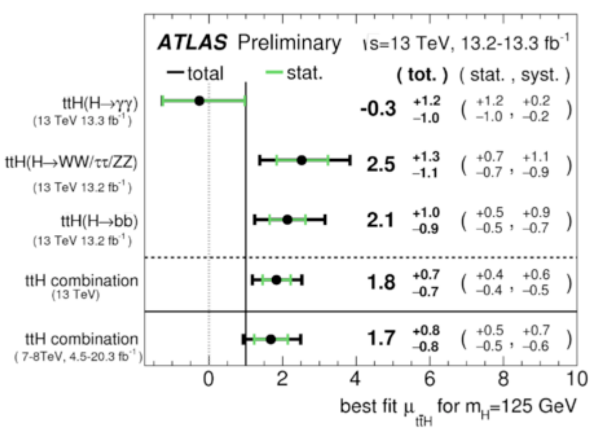
Run I



All channels



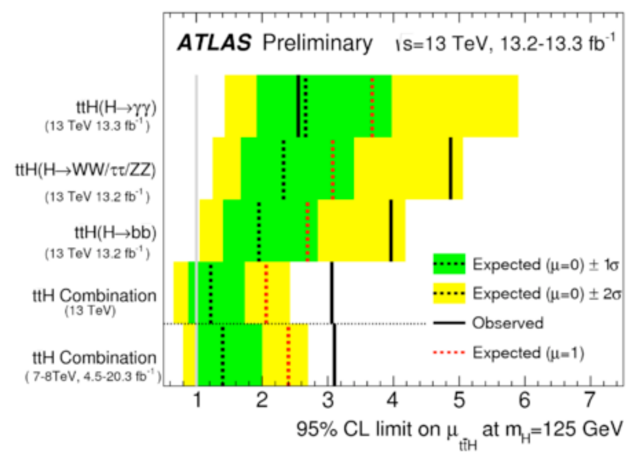
Combination with CMS: $\mu = 2.3^{+0.7}_{-0.6}$



Run II

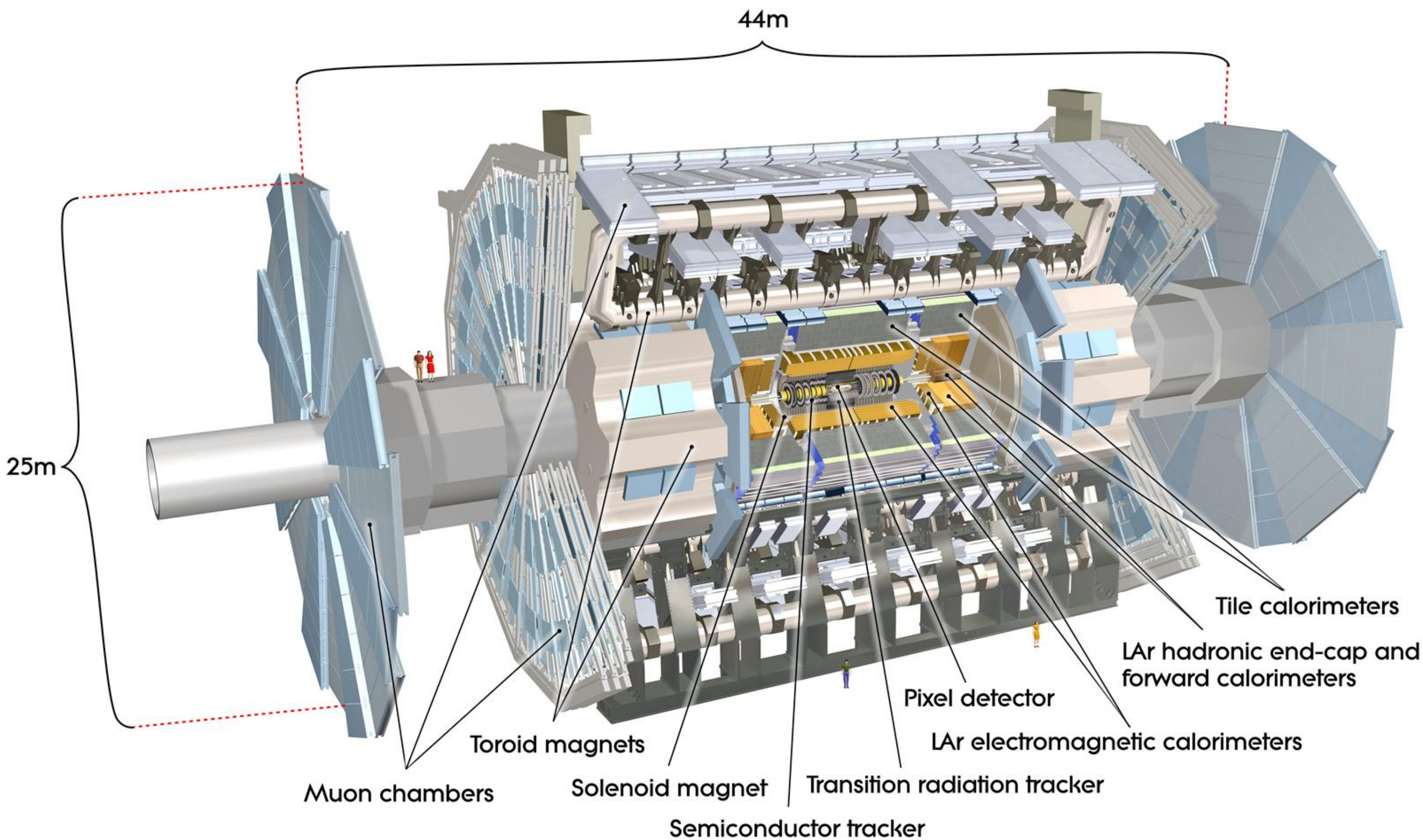
Significant improvement is expected soon:

Run II sensitivity already outperforms that of Run I and ~2x more statistics in Run II is available



Bonus slides

The ATLAS general purpose detector



The semi-frequentist or CLs method

Log-Likelihood-Ratio (LLR) as test statistics:

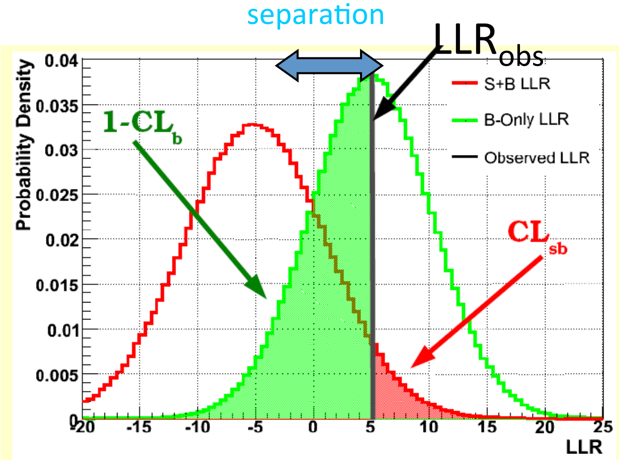
$$LLR = -2\ln\frac{P(N|H_1)}{P(N|H_0)}$$

H_0 and H_1 - test hypotheses of background w/o and w/ signal
N - number of events of the ensemble with expected number $\alpha(\theta)$
P - Poissonian pdf of N: $P = e^{-\alpha}\alpha^N/N!$
includes pdf of nuisance parameters θ: $\exp[-\frac{(\theta-\theta_0)^2}{2\sigma_\theta^2}]$

Profiling:
LLR is minimized wrt the nuisance parameters θ

LLR_{obs} = LLR(N=Data)
LLR_b = LLR(N=Background)
LLR_{sb} = LLR(N=Signal+Background)

signal—background separation

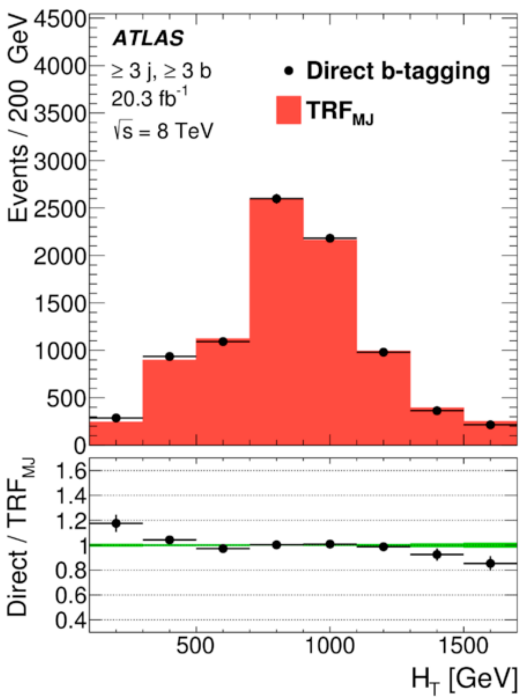


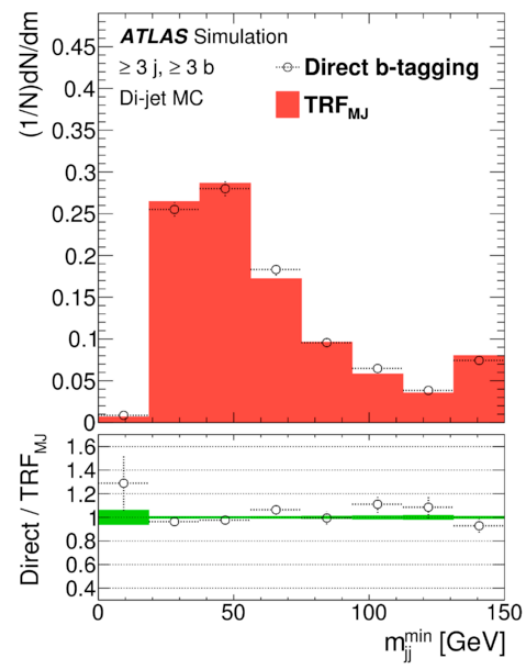
Confidence levels:
$1\text{-}CL_b = p(LLR_b<LLR_{obs}|H_0)$
$CL_{sb} = p(LLR_{sb}>LLR_{obs}|H_1)$
$CL_s = CL_{sb}/CL_b$

A signal μ is excluded @ 95% CL
if $CL_s(\mu)$= 0.05 i.e. 1-$CL_s(\mu)$= 0.95

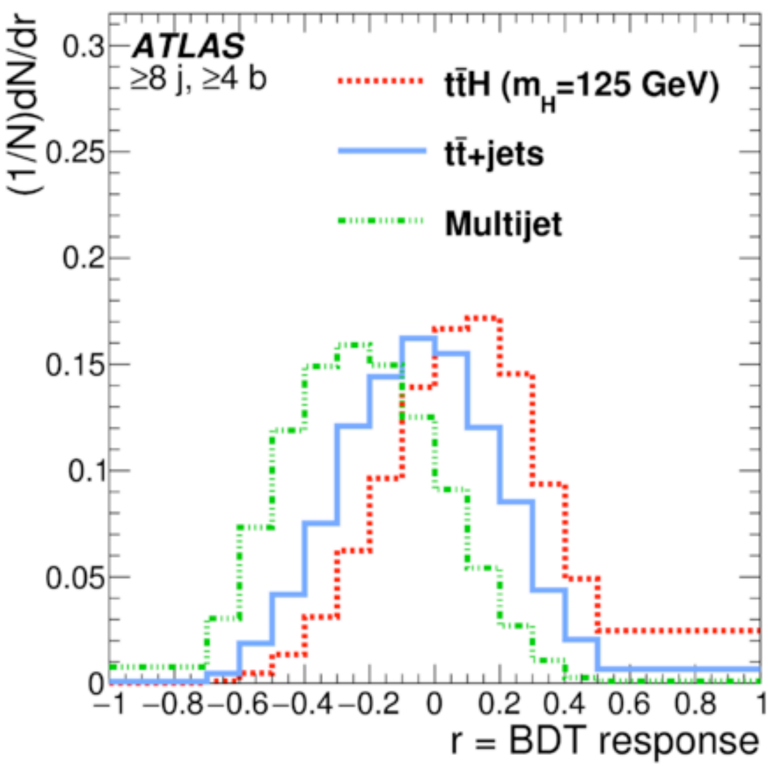
The MJ Tag Rate Function (TRF_{MJ}) method

- Take a data (MC) sample obtained by a MJ (di-jet) trigger
- Select events with $N_b \geq 2$
- Consider in all events all jets except the 2 b-tagged jets with the highest b-tag probability (b_1, b_2)
- Determine from those jets the probability ε_b (aka TRF_{MJ}) that a jet is b-tagged as a function of p_T, $|\eta|$ and its distance (ΔR) from b_1 : $\varepsilon_b = n_b(p_T,|\eta|,\Delta R)/n_j(p_T,|\eta|,\Delta R)$
- Take a subsample with $N_b = 2$ and using ε_b calculate the probability *w* that an event will contain $N_b \geq 2$
- Apply *w* as event weight and promote jets as b-tagged using ε_b to obtain the desired pseudo MJ sample
- To validate the method one compares the pseudo sample with the original sample of $N_b > 2$.

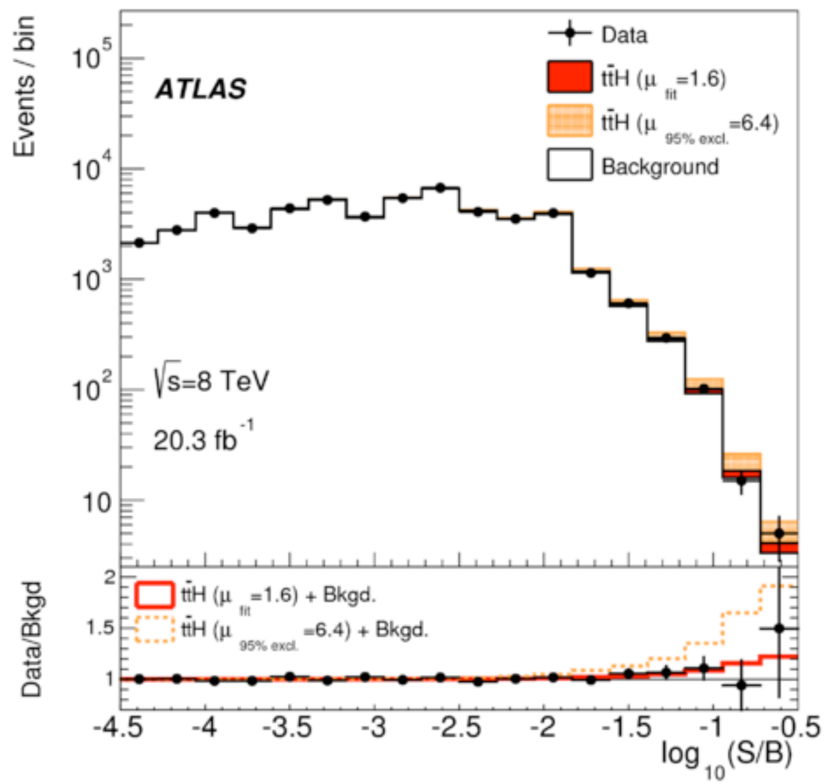




ttH→bb FH channel

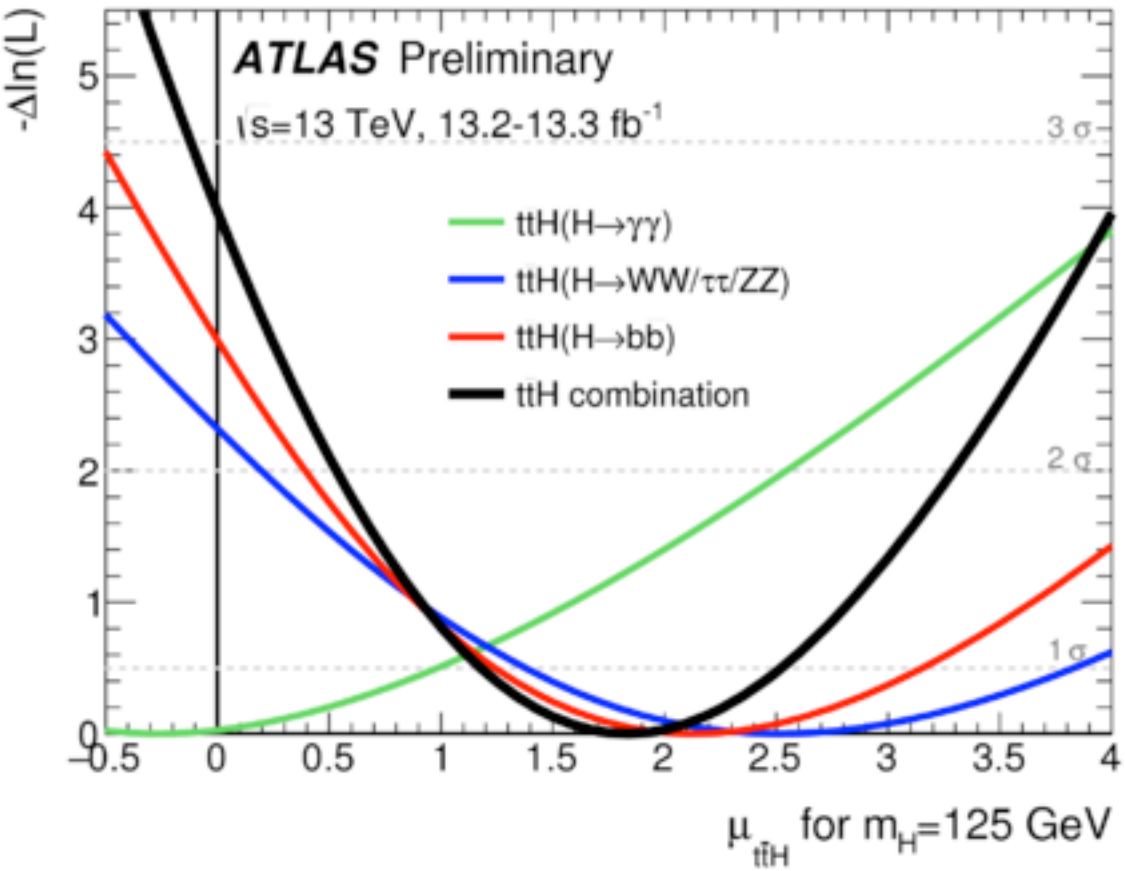


BDT responses normalized to the same surface



Event yield wrt $\log_{10}(S/B)$

Significances of the ttH production in Run II



Significance = √ (- 2 Δ ln L(μ=0)) σ

= 2.8 σ for the combination