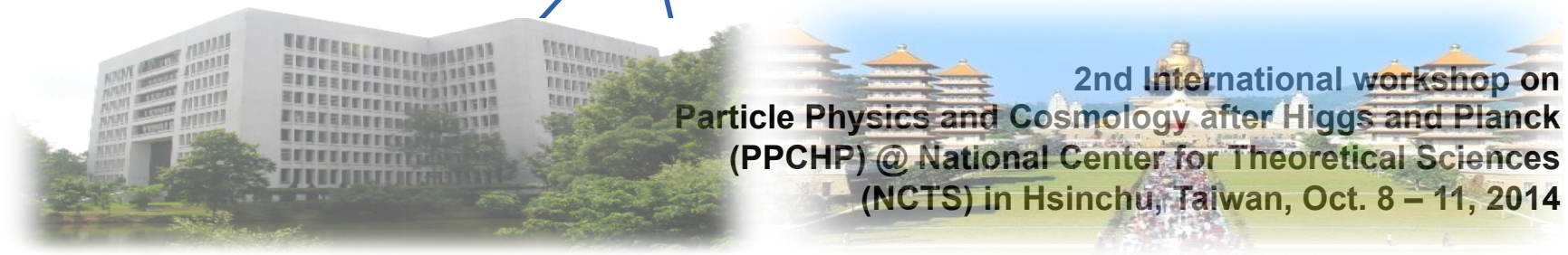
Experimental searches for the Higgs boson in the $t\bar{t}H$ production mode with the ATLAS detector

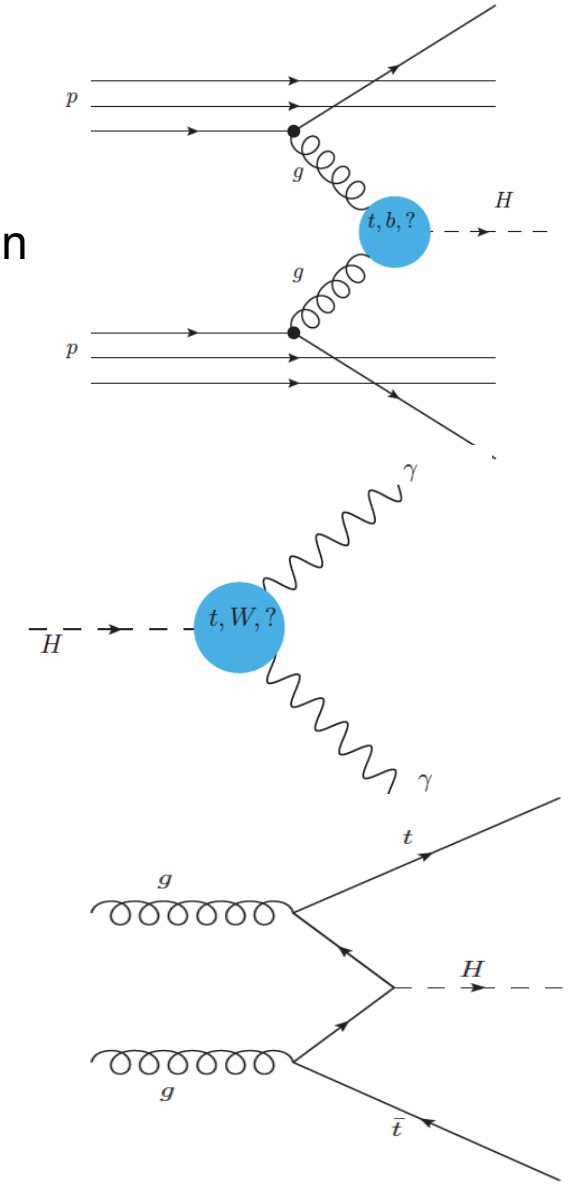
Rachik Soualah
On behalf of the ATLAS collaboration
ICTP, INFN Udine and CERN



2nd International workshop on Particle Physics and Cosmology after Higgs and Planck (PPCHP) @ National Center for Theoretical Sciences (NCTS) in Hsinchu, Taiwan, Oct. 8 – 11, 2014

Introduction

- Since its discovery, a large effort has been made to improve the sensitivity of analyses and make precision measurments of the properties of the Higgs Boson.
- $t\bar{t}H$ coupling drives SM proprieties at higher energy scale (where top quark is the strongest coupled SM particle).
- Indirect measurement of the Top-Higgs Yukawa coupling via gluon fusion production (ggH).
- Direct measurement of the Top-Higgs Yukawa coupling via $t\bar{t}H$ production: $\sigma(t\bar{t}H) \sim Y_t$

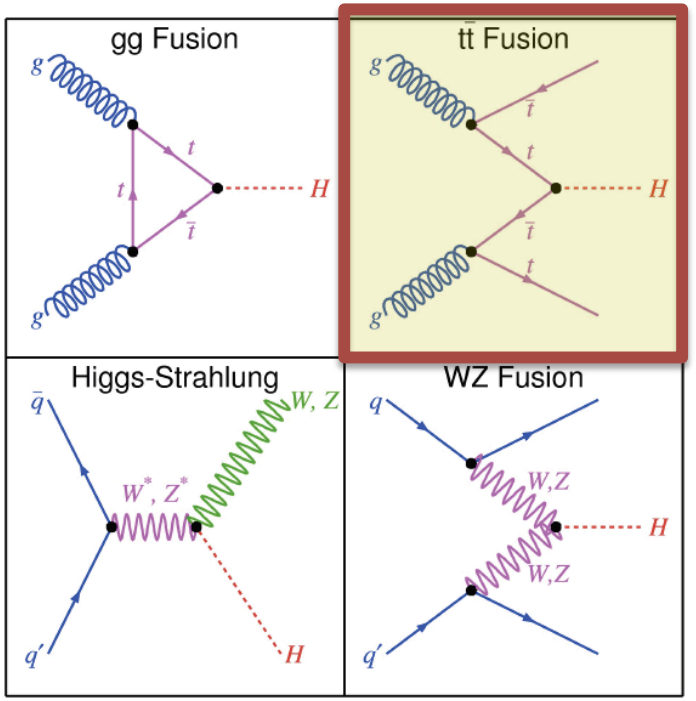


ttH production

- The $t\bar{t}H$ represents the smallest σ of the Higgs production mechanisms.

- NLO $t\bar{t}H$ cross section is 130 fb for mH =125 GeV @ 8TeV.
  → ~ 2600 events with L = 20.3 fb^{-1}.

- Main background is $t\bar{t}$ +jets with σ ≈ 250 pb.



√s (TeV)	7	8	14
σ (ttH) (mH=125 GeV)(fb)	86	130	611
σ (tt) (pb)	177	253	950

Higgs decay mode	Branching
H → bb	58 %
H → γγ	0.23 %
H → WW, ZZ, ττ	30 %

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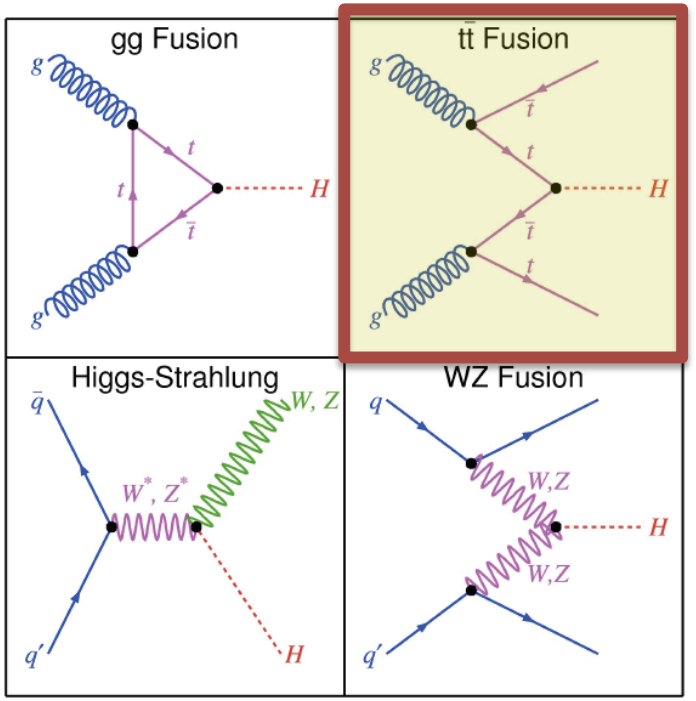

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H → γγ	0.23 %	clean resonance signature but very small BF
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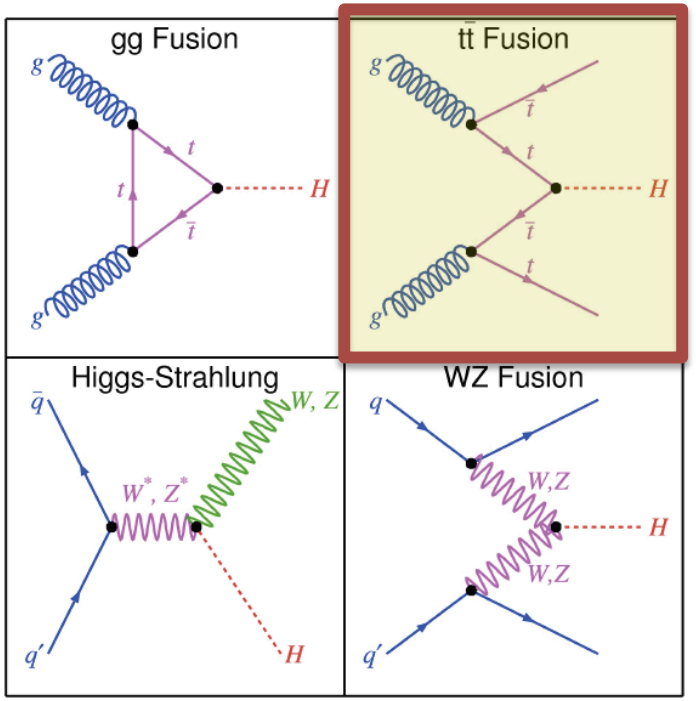

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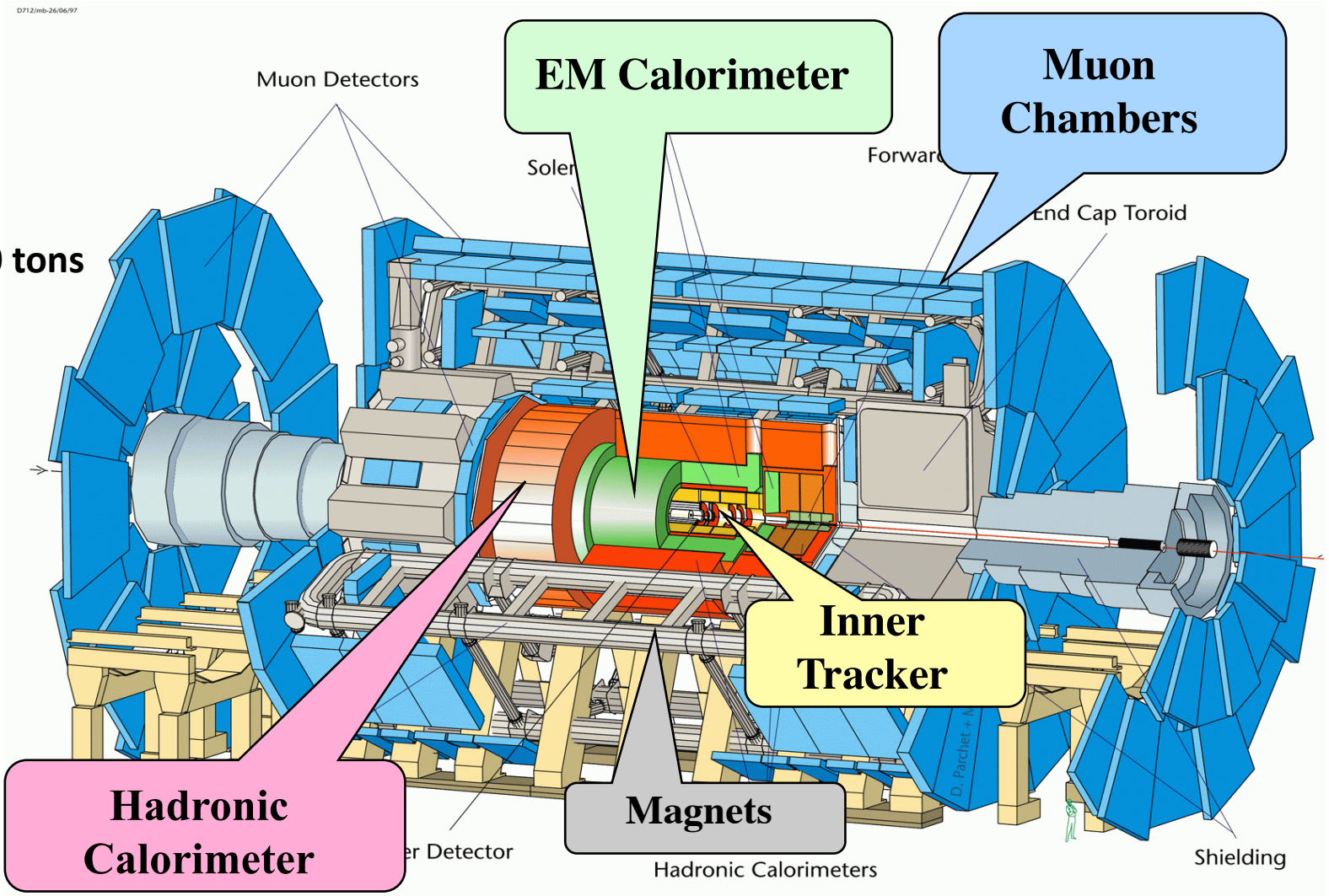
Multi-leptons final states, with small background ($t\bar{t} + V$ & $t\bar{t} + jets$)

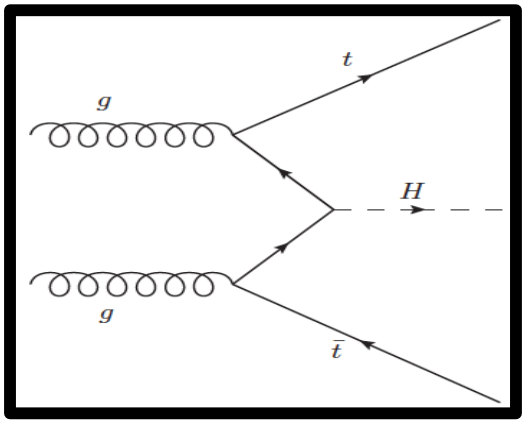
The ATLAS Detector

Length: ~ 45 m
Radius: ~ 12 m
Weight: ~ 7000 tons

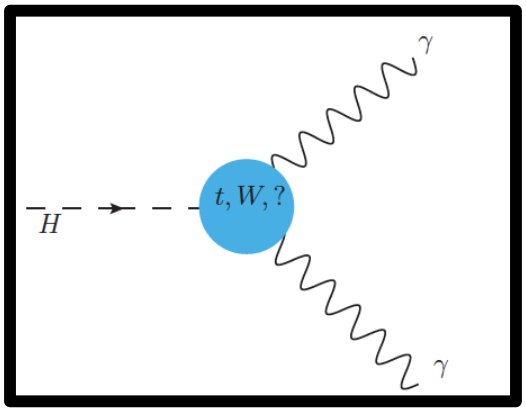


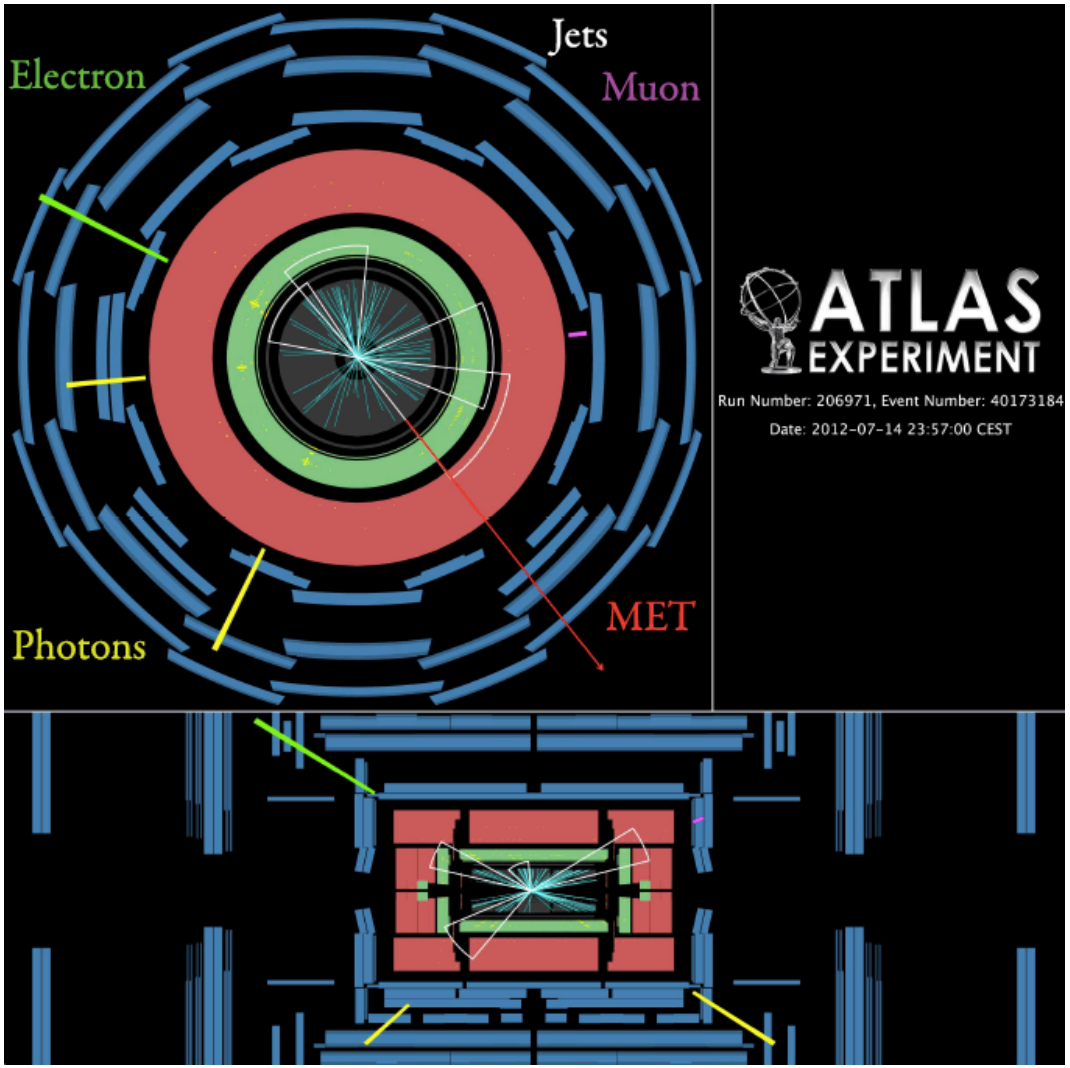
→ **About 21 fb-1 collected at √s= 8 TeV and 5 fb-1 at √s= 7 TeV.**

Analysis strategy: ttH (γγ) candidate event



Where:





Analysis strategy: ttH (γγ)

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Event selection:

- Leptonic tt channel:
  ≥ 1-letpons, ≥ b-jets, Et_{miss} > 20 GeV,

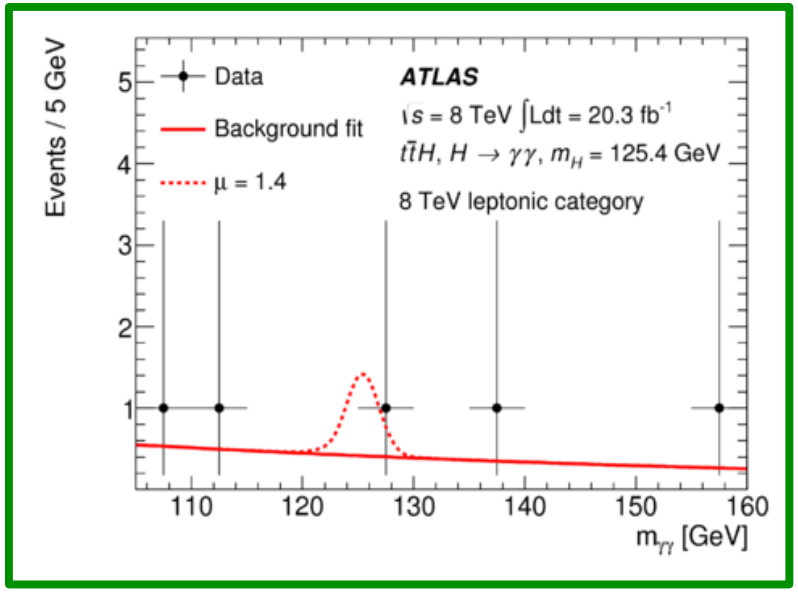
- Hadronic tt channel:
  ≥ 5 jets (pT > 30 GeV); ≥ 2-bjets (70 % WP)
  ≥ 6 jets (pT > 30 GeV); ≥ 1-bjets (60 % WP)
  ≥ 6 jets (pT > 25 GeV); ≥ 2-bjets (80 % WP)

- Search for 2-isolated high pT photons for resonance in $m_{\gamma\gamma}$.
- Model $m_{\gamma\gamma}$ for background described by exponential function.
- Simultaneous fit to signal and control regions with relaxed cuts.

Measurement @ 7 TeV (4.5 fb^{-1}) and 8 TeV (20.3 fb^{-1})

Category	√s (TeV)	N_S	N_B	ttH
Leptonic	8	0.59	0.9 (+0.6 /-0.4)	80.3
Hadronic	8	0.50	2.7 (+0.9 /-0.7)	84.3
Leptonic	7	0.10	0.5 (+0.5 /-0.3)	72.8
Hadronic	7	0.07	0.5 (+0.5/-0.3)	81.1

ttH (γγ) results



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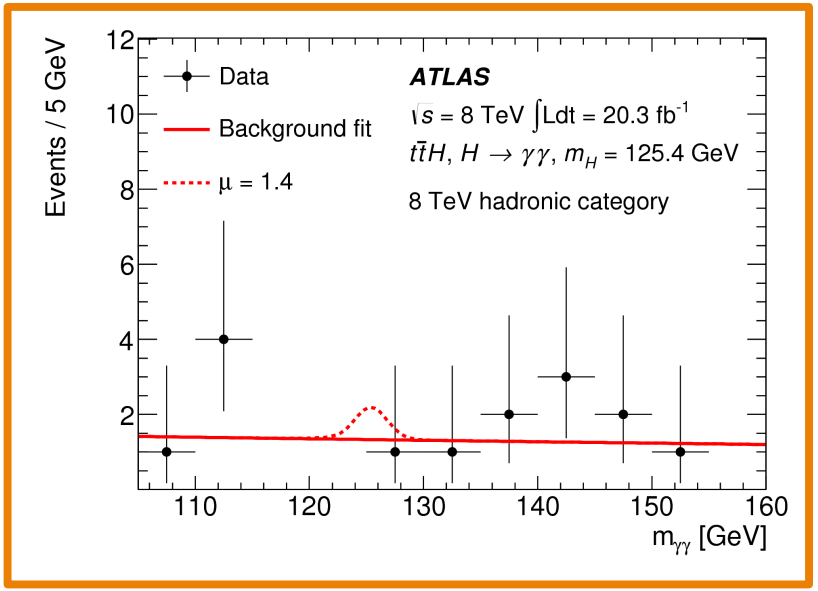
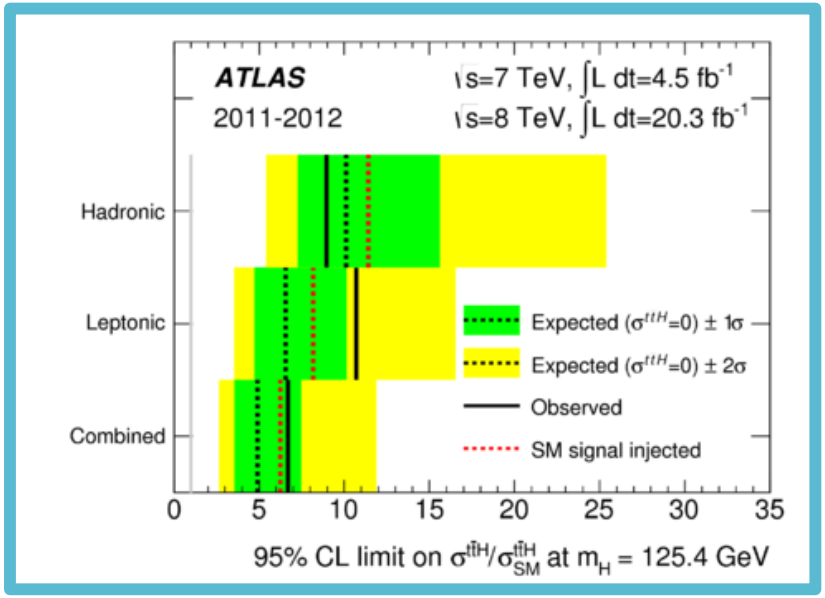


An un-binned signal-plus-background likelihood fit to the full spectra is used to estimate the number of events from continuum background as well as from SM Higgs boson.

- **Combination** of both **leptonic** and **hadronic** channels:

Observed (expected) 95% CLs limit:

6.5 x SM (4.9 x SM) for m_H = 125.4 GeV



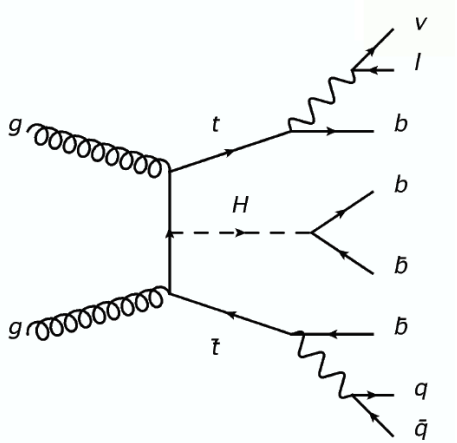
arXiv:1409.3122	ATLAS-CONF-2014-043

Analysis strategy: ttH (bb)

- Tag the following tt decay modes:

  • **Single lepton:** lepton + jets (e or μ)
  from 4 to ≥ 6 jets with 2 to ≥ 4 bjets

  • **Dilepton:** 2 opposite-sign leptons (ee,eμ, μμ)
  2 to ≥ 4 jets with 2 to ≥ 4 bjets

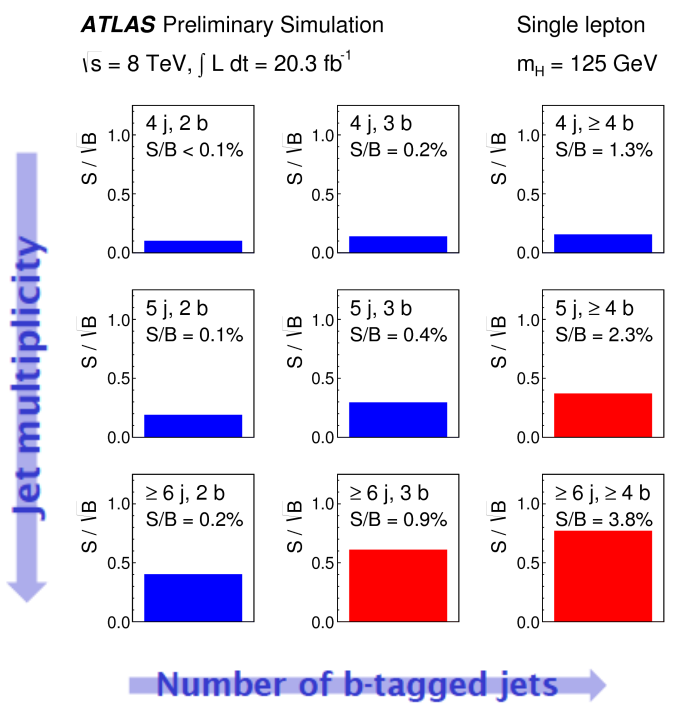


Why Categorize by number of jets and bjets multiplicities

→ increase sensitivity with different **S/√B**
→ constrain systematic uncertainty by fitting regions with low **S/√B**

- To separate signal from background in signal-rich regions, Multivariate discriminant is built from convenient kinematic variables.

- Simultaneous global fit to all regions in jet/bjet bins in orde extract the signal.



Control regions
Signal regions

Background modelling

- The fractional contributions of the various backgrounds to the total background prediction in the single lepton selection. Each row shows the plots for a specific jet multiplicity, and the columns show the b-jet multiplicity (2,3 and ≥4).

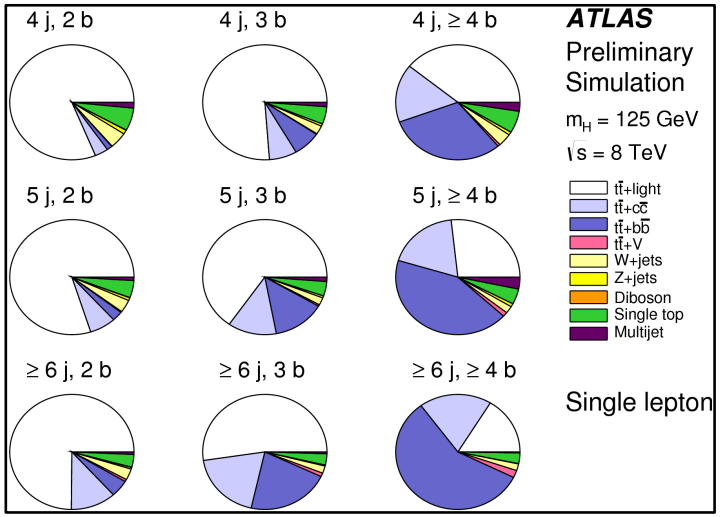
- The dominant background contribution in both channels is the tt+jets, mainly tt+bb (mimic the signal region) and tt+cc.

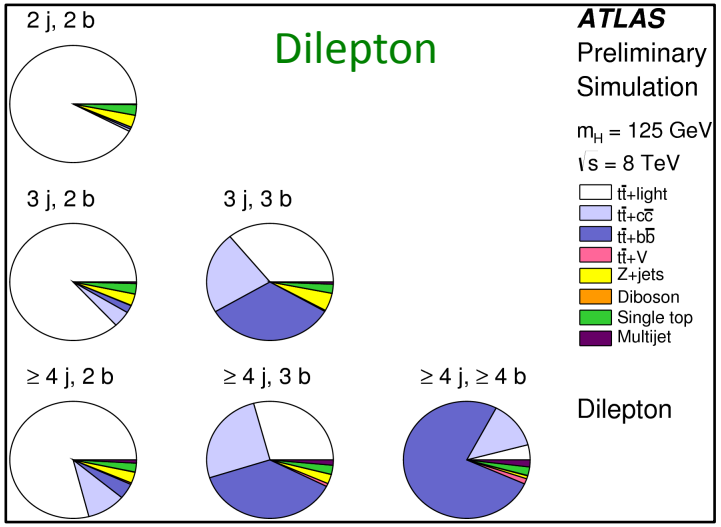
- tt+jets modelled with PowHeg +Pythia
- Difference between using PowHeg and MadGraph for tt+bb/cc modelling is taken as an uncertainty.

- The top pT and tt pT are re-weighted to unfold 7 TeV (ATL-CONF-2013-099).

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

Single lepton





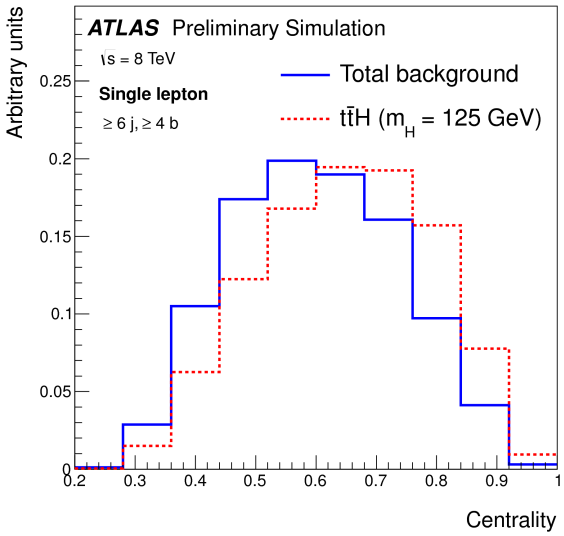
ttH(bb) Signal discrimination

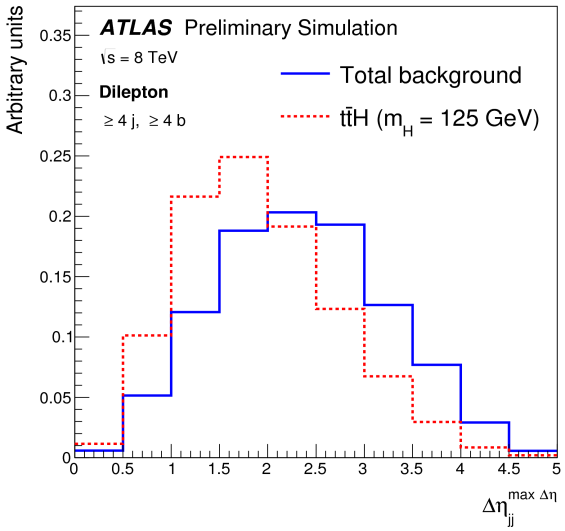
- Signal-rich region:
  Dedicated Neural Network (NN) trained to separate ttH from tt+jets

→ in each regions where the inputs are:

- Event shape variable: Centrality ($C = \sum_{\ell,\text{jets}} p_T / \sum_{\ell,\text{jets}} E$)
- Object pair proprieties : $\Delta\eta_{jj}$ max
- Object kinematics : pT(jet5) …
- Event kinematics : HT, $N_{pT}^{jet} > 40$

-In single lepton channel, dedicated NN with 5 jets, 3 bjets to separate tt+HF from tt+light jets





Control regions: using HT = Σ pT(jets) as discriminant
Signal regions : using NN discriminant for signal extraction

Lep+ jets	2 b-tags	3 b-tags	4 b-tags
4 jets	HT	HT	HT
5 jets	HT	NN HF	NN
6 jets	HT	NN	NN

Dilepton	2 b-tags	3 b-tags	4 b-tags
2 jets	HT		
3 jets	HT	NN	
4 jets	HT	NN	NN

NN HF: separating tt+ligh from tt+HF

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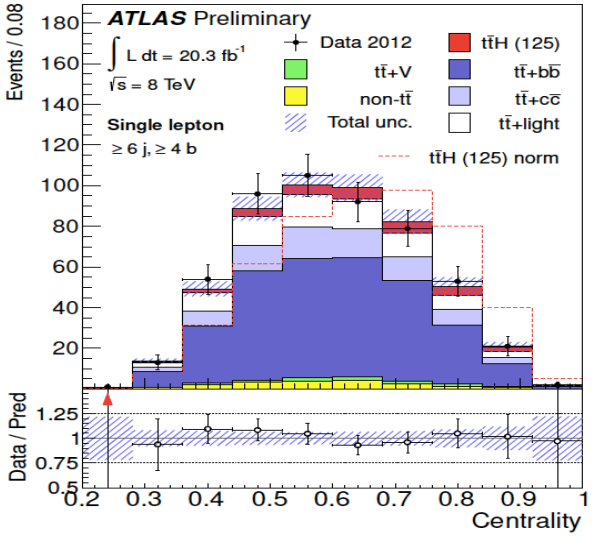

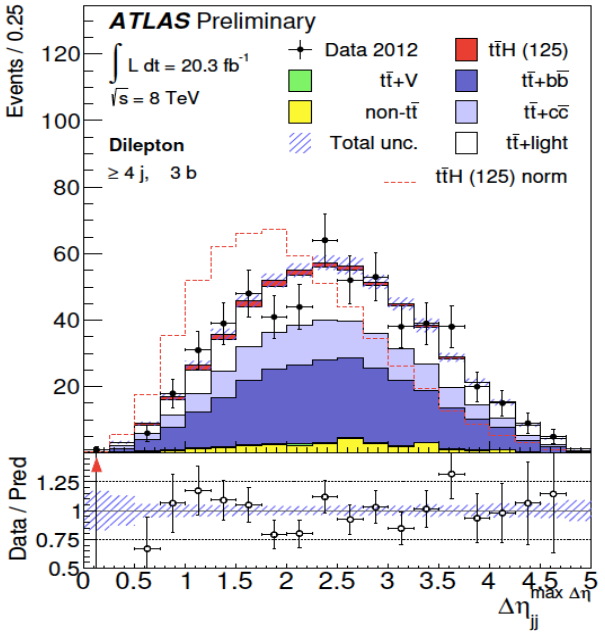

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2 jets	HT		
3 jets	HT	NN	
4 jets	HT	NN	NN

NN HF: separating tt+ligh from tt+HF

Systematic uncertainties

• The main systematic uncertainties are:

- Instrumental uncertainties:

- Jet Energy Scale (JES) split into 22 uncorrelated components)
- Jet flavour tagging (b,c or light)

- The main tt+jets modelling uncertainties:

* **tt+Heavy Flavour:**

→ Reweighting of top pT and tt pT ON/OFF

→ Variation of of parton shower and fragmentation model

→ Generator variation: PowHeg+Pythia vs Madgraph+Pythia.

→ Normalization of tt+bb/cc (50 % uncorrelated).

* **tt+ligh jets:**

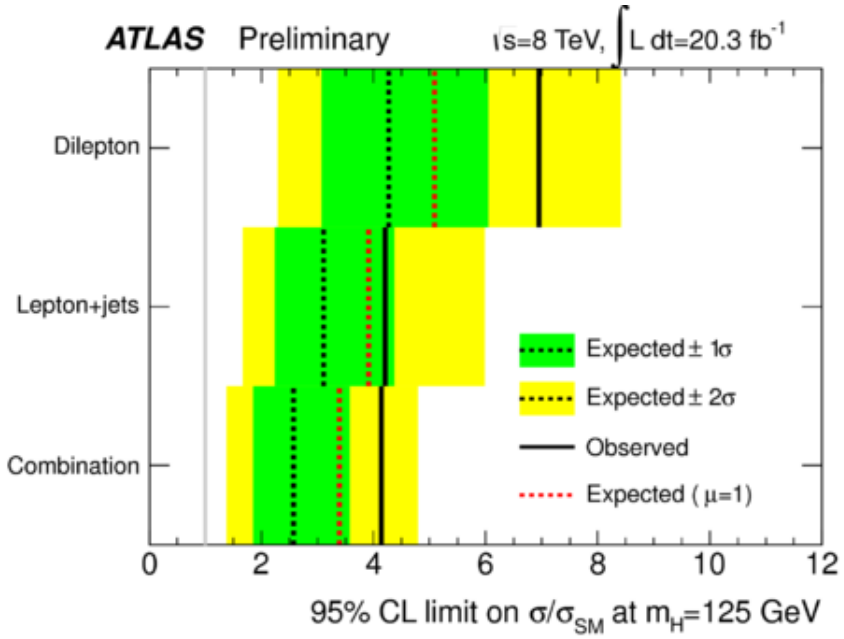
→ variation of the parton shower + fragmentation model (PowHeg + Pythia VS PowHeg+Herwig).

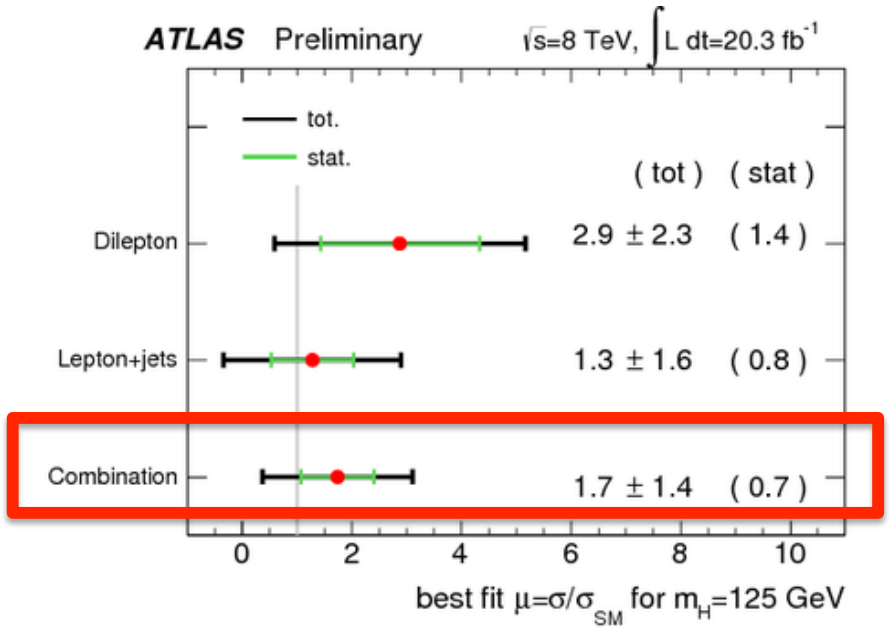
- tt theoretical uncertainties.

	Systematic uncertainty	Type	Components
	Luminosity	N	1
Detector systs	**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	6
	Light jet-tagging efficiency	SN	12
$t\bar{t}$ related	**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	2
	$t\bar{t}$+heavy-flavour: normalisation	N	2
	$t\bar{t}$+heavy-flavour: HF reweighting	SN	2
	$t\bar{t}$+heavy-flavour: generator	SN	5
small bkg syst	W+jets normalisation	N	3
	W p_T reweighting	SN	1
	Z+jets normalisation	N	2
	Z p_T reweighting	SN	1
	Multijet normalisation	N	3
	Multijet shape dilepton	S	1
	Single top cross section	N	1
	Dibosons cross section	N	1
	$t\bar{t}V$ cross section	N	1
Signal modelling	**Signal Model**		
	$t\bar{t}H$ modelling	SN	2

S = shape, N = normalization

Results





- The Combination of lepton +jets and dilepton channels gives:
  → Observed (expected) 95% CLs limit 4.5 x SM (2.6 x SM) for m_H= 125 GeV.
- Best fit signal strength μ (ttH) = 1.7 ± 1.
  → Significance Observed (expected) : **1.3 σ (0.8 σ)**

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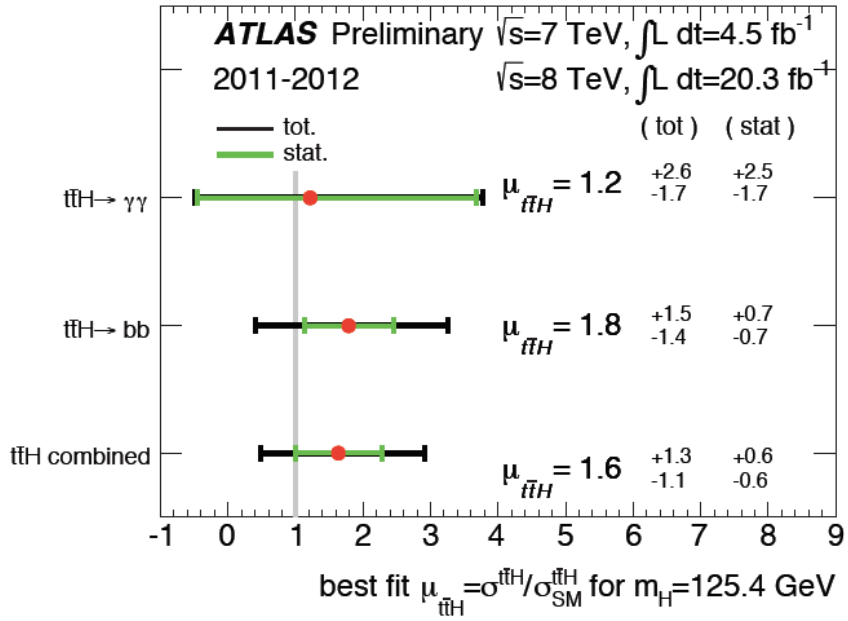
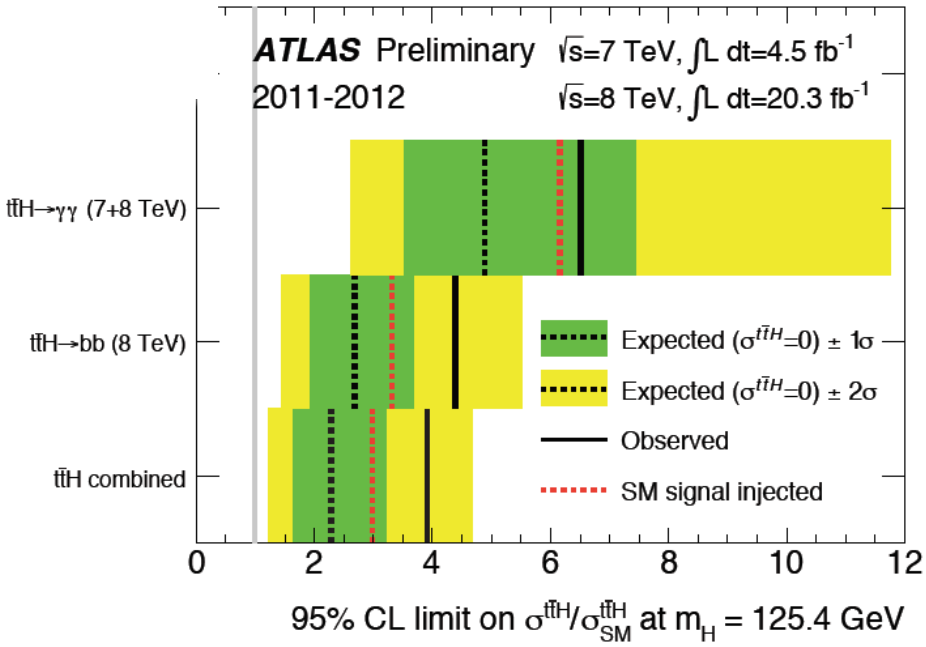
ttH combination (RUN I, 7& 8 TeV)

- New preliminary combination of ttH (γγ) and ttH (bb) channels.
- Observed (expected) 95% CLs limit :
  3.9 x SM (2.3 x SM) for m_H= 125.4 GeV.
- Best fit signal strength:
  μ (ttH) = 1.6 ± 0.6 (stat)$^{+1.1}_{-1.0}$ (syst.)

- Significance observed (expected):
  1.5 σ (1.0 σ)





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Summary and outlook

- ATLAS performed searches of ttH production in the Higgs decay modes:
  H → bb and H → γγ

  → in ttH(bb) : observed (expected) 95 % CLs limit: 4.1 x SM (2.6 x SM)
  → in ttH(γγ) : observed (expected) 95 % CLs limit: 5.3 x SM (6.4 x SM)

- The combination of ttH in these modes gives:
  Observed (expected) 95% CLs limit 3.9 x SM (2.3 x SM).
- So far the combined result of RUN I (7 & 8 TeV data) is consistent with the SM prediction.
- Results of ttH (multileptons) analyses will be published in the near future and the combination of all the channels is forthcoming.

- Full program of ttH searches with several complex final states is under improvements.

- The measurement of the Yukawa coupling via the ttH observation is one of the most important studies for the LHC RUN II where higher energy scale is expected to be reached.

Thank you !

Backup

NN variables in the single lepton channel

Variable	Definition
Centrality	Sum of the p_T divided by sum of the E for all jets and the lepton
H1	Second Fox-Wolfram moment computed using all jets and the lepton
$m_{bb}^{\text{min }\Delta R}$	Mass of the combination of two b-tagged jets with the smallest ΔR
N_{40}^{jet}	Number of jets with $p_T \geq 40$ GeV
$\Delta R_{bb}^{\text{avg}}$	Average ΔR for all b-tagged jet pairs
$m_{jj}^{\text{max }p_T}$	Mass of the combination of any two jets with the largest vector sum p_T
$\text{Aplanarity}_{\text{b-jet}}$	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor built with only b-tagged jets
H_T^{had}	Scalar sum of jet p_T
$m_{jj}^{\text{min }\Delta R}$	Mass of the combination of any two jets with the smallest ΔR
$\Delta R_{\text{lep-bb}}^{\text{min }\Delta R}$	ΔR between the lepton and the combination of two b-tagged jets with the smallest ΔR
$m_{bj}^{\text{min }\Delta R}$	Mass of the combination of a b-tagged jet and any jet with the smallest ΔR
$m_{bj}^{\text{max }p_T}$	Mass of the combination of a b-tagged jet and any jet with the largest vector sum p_T
$m_{uu}^{\text{min }\Delta R}$	Mass of the combination of two untagged jets with the smallest ΔR
p_T^{jet5}	Fifth leading jet p_T
$\Delta R_{bb}^{\text{max }p_T}$	ΔR between two b-tagged jets with the largest vector sum p_T
$m_{bb}^{\text{max m}}$	Mass of the combination of two b-tagged jets with the largest invariant mass
$p_{T,uu}^{\text{min }\Delta R}$	Scalar sum of the p_T's of the pair of untagged jets with the smallest ΔR
m_{jjj}	Mass of the jet triplet with the largest vector sum p_T
$\Delta R_{uu}^{\text{min }\Delta R}$	Minimum ΔR between two untagged jets
$m_{bb}^{\text{max }p_T}$	Mass of the combination of two b-tagged jets with the largest vector sum p_T

List of variables used in the NN in the single lepton channel in at least one region. From the list, 10 variables are chosen in each region

NN variables in the dilepton channel

Variable	Definition
m_{bb}	Mass of the two b-tagged jets from the Higgs candidate system
H_T	Scalar sum of jet p_T and lepton p_Ts
p_T^{jet3}	Third leading jet p_T
p_T^{jet4}	Fourth leading jet p_T
Centrality	Sum of the p_T divided by sum of the E for all jets and both leptons
Aplanarity$_{jet}$	$1.5\lambda_2$, where λ_2 is the second eigenvalue of the momentum tensor built with all jets
H1	Second Fox-Wolfram moment computed using all jets and both leptons
H4	Fifth Fox-Wolfram moment computed using all jets and both leptons
$\Delta R_{hl}^{min\ \Delta R}$	ΔR between the Higgs candidate and the closest lepton
$\Delta R_{hl}^{max\ \Delta R}$	ΔR between the Higgs candidate and the furthest lepton
N_{30}^{Higgs}	Number of Higgs candidates within 30 GeV of the defined Higgs mass
$m_{ij}^{closest}$	Dijet mass between any two jets closest to the defined Higgs mass
$\Delta\eta_{ij}^{max\ \Delta\eta}$	Maximum $\Delta\eta$ between any two jets in the event
$m_{ij}^{min\ m}$	Minimum dijet mass between any two jets
$m_{ij}^{max\ p_T}$	Mass of the combination of any two jets with the largest vector sum p_T
$m_{bb}^{min\ \Delta R}$	Mass of the combination of two b-tagged jets with the smallest ΔR
$\Delta R_{bj}^{min\ \Delta R}$	Minimum ΔR between a b-tagged jet and any jet
$\Delta R_{lj}^{min\ \Delta R}$	Minimum ΔR between any lepton and jet
$\Delta R_{bb}^{max\ p_T}$	ΔR between two b-tagged jets with the largest vector sum p_T
$\Delta R_{bb}^{max\ m}$	ΔR between two b-tagged jets with the largest invariant mass

List of variables used in the NN in the dilepton channel in at least one region. From the list, 10 variables are chosen in each region