Search for the Associated Production of the Higgs Boson and a Top Quark Pair in Multilepton Final States with the ATLAS Detector

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Joint seminar of the DLNP

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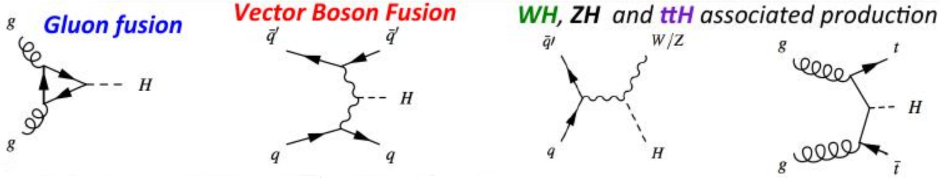
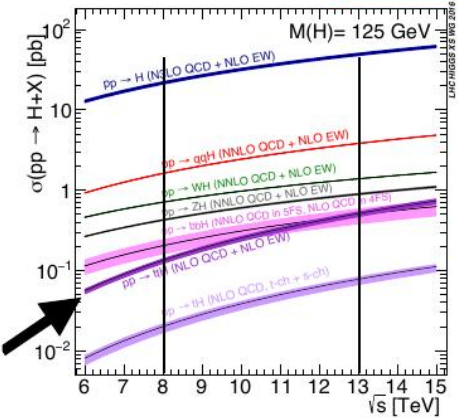
Higgs boson production at $m_H = 125\,GeV$



- Gluon gluon fusion (ggF): 87.2%
- Vector boson fusion (VBF): 6.8%
- Associated production (WH,ZH): 4.1%
- Associated production (ttH): 0.9%
- Observed modes: ggF, VBF



ATLAS Higgs Physics Public Results

Run I

$t\bar{t}H \rightarrow$ multilepton

Physics Letters B 749 (2015)

$t\bar{t}H \rightarrow bb$ and $t\bar{t}H \rightarrow \gamma\gamma$

Eur.Phys.J.C (2015) 75

Physics Letters B 740 (2015)

Run II

$t\bar{t}H \rightarrow$ multilepton

ATLAS-CONF-2016-058

ATLAS-CONF-2016-068

$t\bar{t}H \rightarrow bb$ and $t\bar{t}H \rightarrow \gamma\gamma$

ATLAS-CONF-2016-080

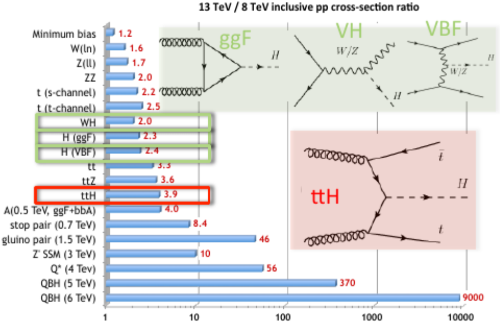
ATLAS-CONF-2016-067

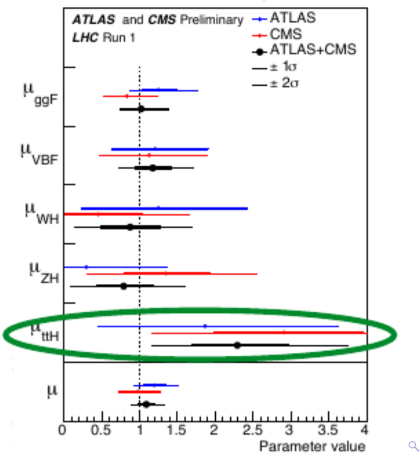
Motivation

- Not yet observed at LHC
- **LHC Run2** analysis benefits from large increase of $t\bar{t}H$ cross section, though backgrounds increase at a comparable rate in the signal regions
  - In particular, $t\bar{t}$ background - thus an efficient prompt/non-prompt lepton discrimination is critical

$$\sigma(t\bar{t}H_{13TeV})/\sigma(t\bar{t}H_{8TeV}) \approx 4$$

- $t\bar{t}H$ signal strength has been highest measured at **ATLAS Run I** $\mu_{t\bar{t}H}$=**2.3** (combined), cross-section above SM but consistent within large uncertainty





$t\bar{t}H \to b\bar{b}$: 58.1%

- High cross section x BR, but multi-jet background
- Difficult tt+bb modeling

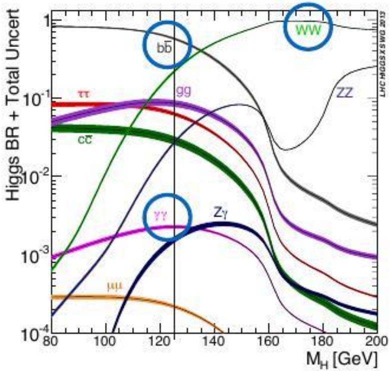
$t\bar{t}H$ multilepton : $H \to WW^*(21.5\%)$ & $H \to ZZ^*(2.6\%)$ & $H \to \tau\tau(6.3\%)$

- $H \to WW$, $H \to ZZ$ semi-leptonic and leptonic decays
- Lower rate than $H \to b\bar{b}$, but low background final state (better handle on irreducible backgrounds)

$t\bar{t}H \to \gamma\gamma$: 0.23%

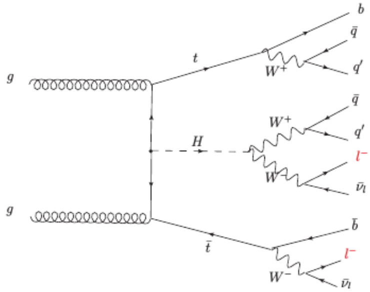
- Clean signature thanks to excellent mass resolution, but small branching ratio
- Background from mass fit in data

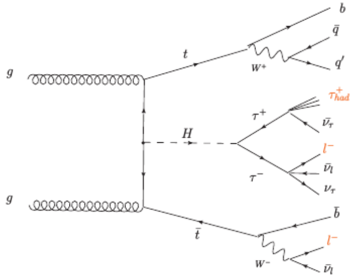
Higgs decay mode	branching ratio [%]
$H \to b\bar{b}$	58.1
$H \to WW^*$	21.5
$H \to \tau\tau$	6.3
$H \to ZZ^*$	2.6
$H \to \gamma\gamma$	0.23

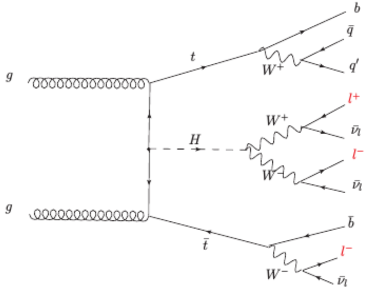


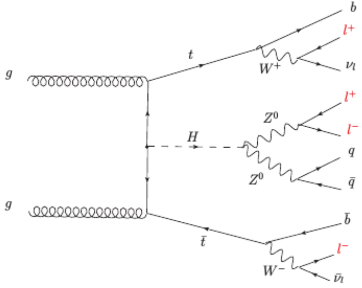
Searches for $t\bar{t}H$ production at the ATLAS

$t\bar{t}H$ Multilepton Searches

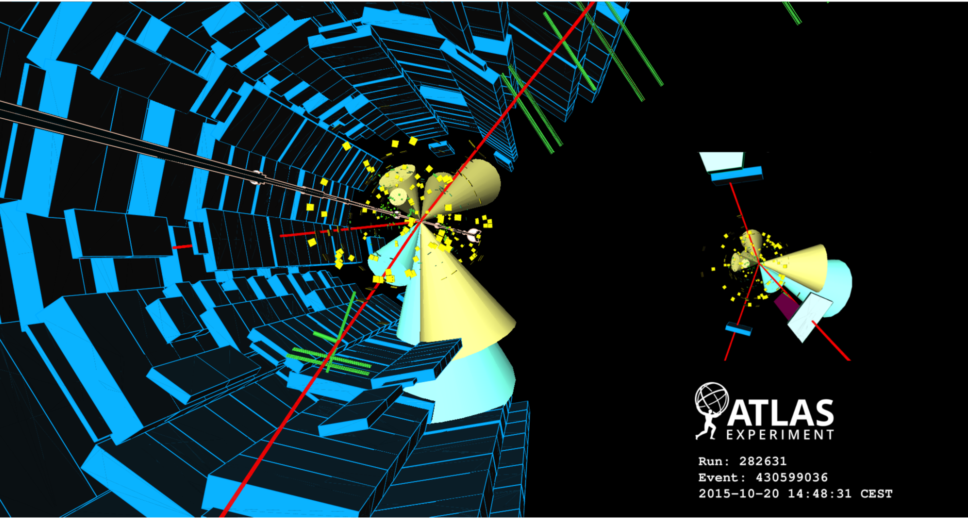








Event display for a Run II event candidate 3μ event in the 3l category



Object Selection

- Cuts selected to be consistent with those in: https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/TTHtoLeptonsCutflow207
- Object selection as in: https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/TTHtoLeptonsPreliminarySelection

Electrons

- pt > 10 GeV
- |eta| < 2.47, and not 1.37 < |eta| < 1.52 (use el->caloCluster()->etaBE(2))
- pass **LooseAndBLayer** Likelihood ID (if reading flags from DAOD, keep using LooseLH, but apply the following BL hit cut before the ID selection)
- |z0 sin theta| < 2 mm
- |d0 significance| < 10
- pass isolation (Loose working point in IsolationSelectionTool)

Muons

- pt > 10 GeV
- |eta| < 2.5
- pass loose muon quality requirement: MuQuality ≤ 2 (or muon_isLoose = 1 with group ntuples)
- |z0 sin theta| < 2 mm
- |d0 significance| < 10
- pass isolation (Loose working point in IsolationSelectionTool)

Tau Jets (hadronically decaying tau lepton)

- abs(charge==1)
- (nTracks ==1 || nTracks ==3)
- eta : [0, 1.37], [1.52, 2.5]
- JetIDBDTMedium == 1
- pT > 25 GeV
- EleOLR in TauSelectionTool

Jets

- pass jet clean criteria ("LooseBad" in the JetCleaningTool)
- pt > 25 GeV
- |eta| < 2.5
- **NEW** remove jets with |JVT| < 0.59 and |eta| < 2.4 and pt < 60 GeV (use jet->eta() (aka "Detector" eta))
- BTag: BTagMV2c20 > -0.4434 (77% eff)

Event Selection

- Categorize the events in **4 orthogonal channels** using number of leptons (e, μ, τ_{had})

$2l0\tau_{had}$

- two same charge light leptons
- no τ_{had}
- ≥5 jets ≥1b-jet

$2l1\tau_{had}$

- two same charge light leptons
- one τ_{had}
- ≥4 jets ≥1b-jet

$3l$

- three light leptons
- ≥4 jets ≥1b-jet or 3 jets ≥1b-jets

$4l$

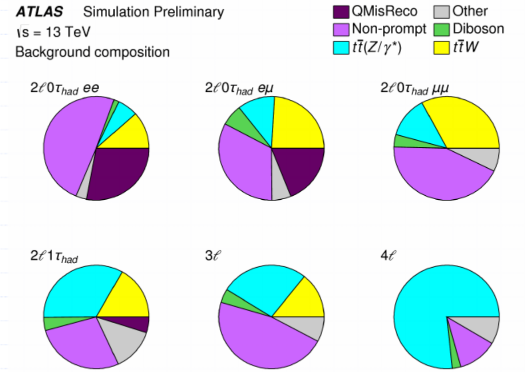
- four light leptons
- ≥2 jets ≥1b-jet

- Different sensitivity to Higgs decay modes

	Higgs boson decay mode				$A \times \epsilon$
Category	WW^*	$\tau\tau$	ZZ^*	Other	$(\times 10^{-4})$
$2\ell 0\tau_{\text{had}}$	77%	17%	3%	3%	14
$2\ell 1\tau_{\text{had}}$	46%	51%	2%	1%	2.2
3ℓ	74%	20%	4%	2%	9.2
4ℓ	72%	18%	9%	2%	0.88

Dominant backgrounds

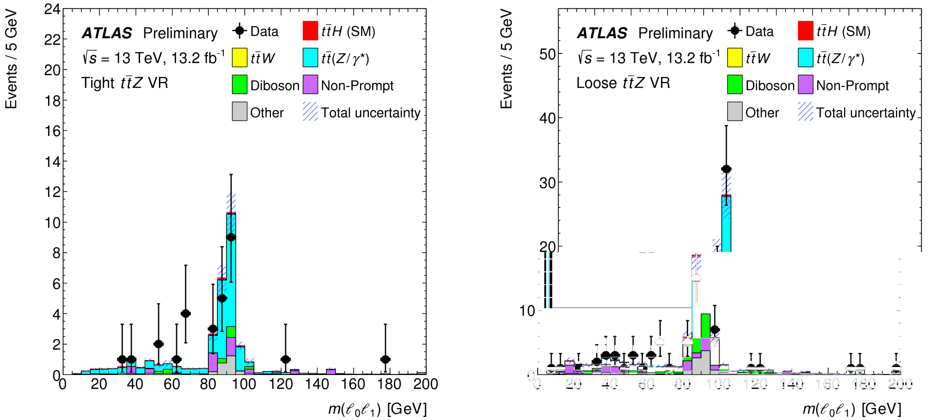
- **ttW & ttZ & Di-boson(VV)** ➜ estimated using MC validated in enriched data regions
- **Non-prompt light leptons** from semileptonic b-hadron decay : **mostly $t\bar{t}$** ➜ data driven estimation
- **Electron charge mis-ID** ➜ mainly 2l0/1τ_{had} channels. Trident process: ($e^{+/-} \rightarrow e^{+/-}\gamma \rightarrow e^{+/-}e^{-/+}e^{+/-}$). Data driven estimation using Z+jets events
- **Hadronic τ mis-reconstruction** ➜ estimated from fake tau enriched regions and normalised to data in CR.



Signal and Validation Region

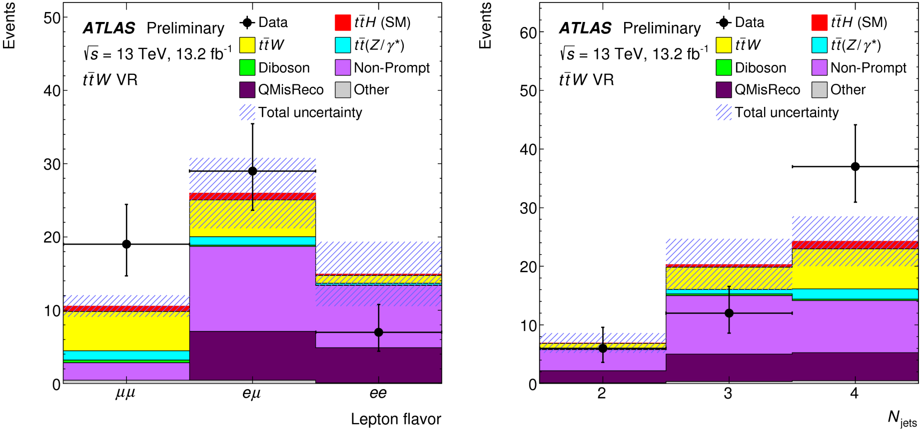
SR/VR	Channel	Selection criteria
SR	$2\ell 0\tau_{\text{had}}$	Two tight light leptons with $p_{\text{T}} > 25$, 25 GeV Sum of light lepton charges ± 2 Any electrons must have $\lvert\eta_e\rvert < 1.37$ Zero τ_{had} candidates $N_{\text{jets}} \geq 5$ and $N_{b-\text{jets}} \geq 1$
SR	$2\ell 1\tau_{\text{had}}$	Two tight light leptons, with $p_{\text{T}} > 25$, 15 GeV Sum of light lepton charges ± 2 Exactly one τ_{had} candidate, of opposite charge to the light leptons $\lvert m(ee) - 91.2\text{ GeV}\rvert > 10$ GeV for ee events $N_{\text{jets}} \geq 4$ and $N_{b-\text{jets}} \geq 1$
SR	3ℓ	Three light leptons; sum of light lepton charges ± 1 Two same-charge leptons must be tight and have $p_{\text{T}} > 20$ GeV $m(\ell^+\ell^-) > 12$ GeV and $\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert > 10$ GeV for all SFOC pairs $\lvert m(3\ell) - 91.2\text{ GeV}\rvert > 10$ GeV $N_{\text{jets}} \geq 4$ and $N_{b-\text{jets}} \geq 1$, or $N_{\text{jets}} = 3$ and $N_{b-\text{jets}} \geq 2$
SR	4ℓ	Four light leptons; sum of light lepton charges 0 All leptons pass “gradient” isolation selection $m(\ell^+\ell^-) > 12$ GeV and $\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert > 10$ GeV for all SFOC pairs 100 GeV $< m(4\ell) <$ 350 GeV and $\lvert m(4\ell) - 125\text{ GeV}\rvert > 5$ GeV $N_{\text{jets}} \geq 2$ and $N_{b-\text{jets}} \geq 1$
VR	Tight $t\bar{t}Z$	3ℓ lepton selection %and trigger selection At least one $\ell^+\ell^-$ pair with $\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert < 10$ GeV $N_{\text{jets}} \geq 4$ and $N_{b-\text{jets}} \geq 2$
VR	Loose $t\bar{t}Z$	3ℓ lepton selection %and trigger selection At least one $\ell^+\ell^-$ pair with $\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert < 10$ GeV $N_{\text{jets}} \geq 4$ and $N_{b-\text{jets}} \geq 1$, or $N_{\text{jets}} = 3$ and $N_{b-\text{jets}} \geq 2$
VR	$WZ + 1$ b-tag	3ℓ lepton selection %and trigger selection At least one $\ell^+\ell^-$ pair with $\lvert m(\ell^+\ell^-) - 91.2\text{ GeV}\rvert < 10$ GeV $N_{\text{jets}} \geq 1$ and $N_{b-\text{jets}} = 1$
VR	$t\bar{t}W$	$2\ell 0\tau_{\text{had}}$ lepton selection %and trigger selection $2 \leq N_{\text{jets}} \leq 4$ and $N_{b-\text{jets}} \geq 2$ $H_{\text{T,jets}} > 220$ GeV for ee and $e\mu$ events $E_{\text{T}}^{\text{miss}} > 50$ GeV and ($m(ee) < 75$ or $m(ee) > 105$ GeV) for ee events

Validation Region



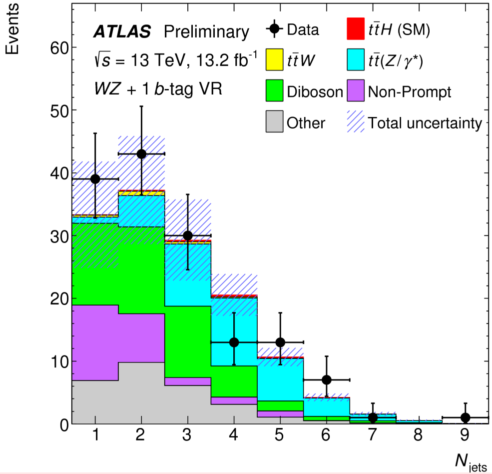
Invariant mass of leptons l_0 and l_1 for the tight and loose $\boldsymbol{t\bar{t}Z}$ validation regions.
The leptons are labeled in the same way as for the 3l signal region.
Events away from the Z peak are those satisfying the Z selection with l_0 and l_2.
Non-prompt lepton backgrounds are estimated using data driven method.

Validation Region



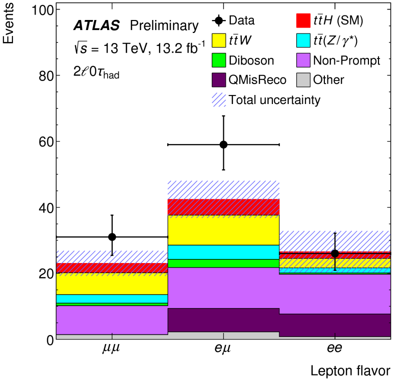
Lepton flavor composition and number of jets for events in the $t\bar{t}W$ validation region. Non-prompt lepton and charge misreconstruction backgrounds (indicated as "**QMisReco**") are estimated using data driven method

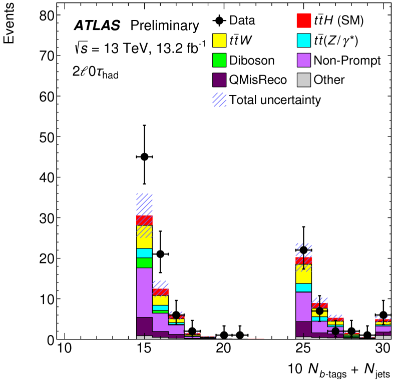
Validation Region



Jet multiplicity in the WZ + 1 b-tag validation region. Non-prompt lepton backgrounds are estimated using data driven method

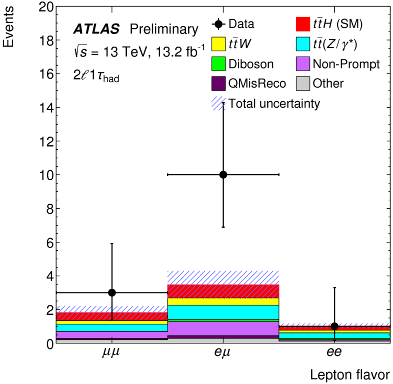
Signal Region

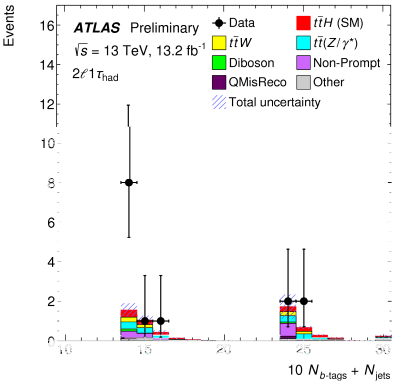




Characteristics of events in the $\mathbf{2l0\tau_{had}}$ signal region: lepton flavor composition; $10 \times$ the number of b-tagged jets plus the total number of jets. The signal is set to the SM expectation ($\mu_{t\bar{t}H} = 1$) and the background expectation is pre-fit (using initial values of the background systematic uncertainty nuisance parameters). The hatched region shows the total uncertainty on the background plus SM signal prediction in each bin. Charge misreconstruction backgrounds are indicated as "**QMisReco**").

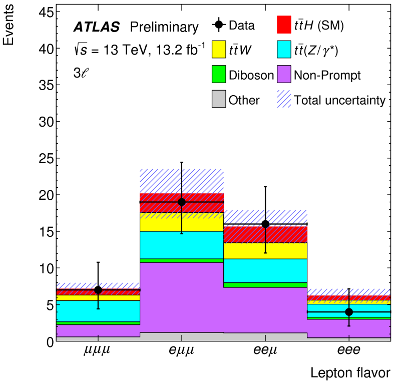
Signal Region

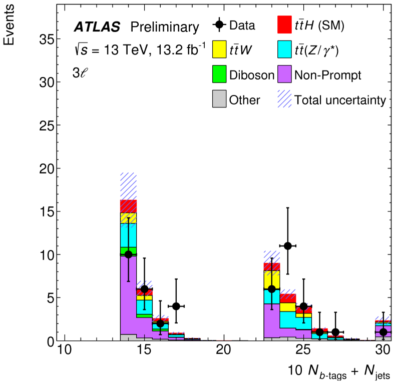




Characteristics of events in the **$2l1\tau_{had}$** signal region: lepton flavor composition; 10 × the number of b-tagged jets plus the total number of jets. The signal is set to the SM expectation ($\mu_{t\bar{t}H} = 1$) and the background expectation is pre-fit (using initial values of the background systematic uncertainty nuisance parameters). The hatched region shows the total uncertainty on the background plus SM signal prediction in each bin. Charge misreconstruction backgrounds are indicated as "**QMisReco**").

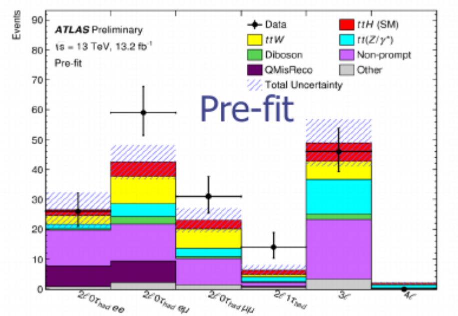
Signal Region

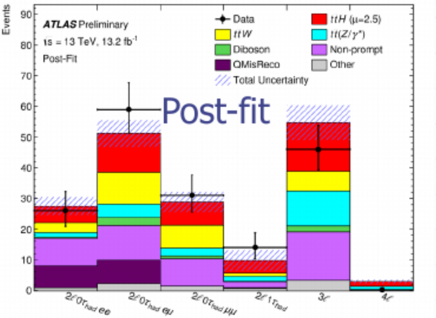




Characteristics of events in the 3l signal region: lepton flavor composition; 10 × the number of b-tagged jets plus the total number of jets. The signal is set to the SM expectation ($\mu_{t\bar{t}H} = 1$) and the background expectation is pre-fit (using initial values of the background systematic uncertainty nuisance parameters). The hatched region shows the total uncertainty on the background plus SM signal prediction in each bin.

Searches for $t\bar{t}H$ production at the ATLAS





	$2\ell 0\tau_{\rm had}$ ee	$2\ell 0\tau_{\rm had}$ $e\mu$	$2\ell 0\tau_{\rm had}$ $\mu\mu$	$2\ell 1\tau_{\rm had}$	3ℓ	4ℓ
$t\bar{t}W$	2.9 ± 0.7	9.1 ± 2.5	6.6 ± 1.6	0.8 ± 0.4	6.1 ± 1.3	—
$t\bar{t}(Z/\gamma^*)$	1.55 ± 0.29	4.3 ± 0.9	2.6 ± 0.6	1.6 ± 0.4	11.5 ± 2.0	1.12 ± 0.20
Diboson	0.38 ± 0.25	2.5 ± 1.4	0.8 ± 0.5	0.20 ± 0.15	1.8 ± 1.0	0.04 ± 0.04
Non-prompt leptons	12 ± 6	12 ± 5	8.7 ± 3.4	1.3 ± 1.2	20 ± 6	0.18 ± 0.10
Charge misreconstruction	6.9 ± 1.3	7.1 ± 1.7	—	0.24 ± 0.03	—	—
Other	0.81 ± 0.22	2.2 ± 0.6	1.4 ± 0.4	0.63 ± 0.15	3.3 ± 0.8	0.12 ± 0.05
Total background	25 ± 6	38 ± 6	20 ± 4	4.8 ± 1.4	43 ± 7	1.46 ± 0.25
$t\bar{t}H$ (SM)	2.0 ± 0.5	4.8 ± 1.0	2.9 ± 0.6	1.43 ± 0.31	6.2 ± 1.1	0.59 ± 0.10
Data	26	59	31	14	46	0

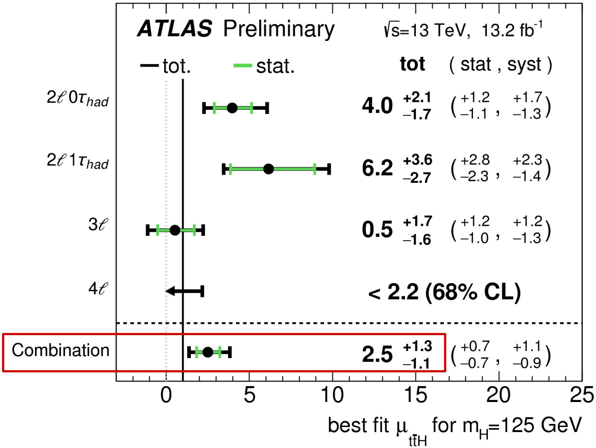
Searches for $t\bar{t}H$ production at the ATLAS

Uncertainty Source	$\Delta\mu$	
Non-prompt leptons and charge misreconstruction	+0.56	−0.64
Jet-vertex association, pileup modeling	+0.48	−0.36
$t\bar{t}W$ modeling	+0.29	−0.31
$t\bar{t}H$ modeling	+0.31	−0.15
Jet energy scale and resolution	+0.22	−0.18
$t\bar{t}Z$ modeling	+0.19	−0.19
Luminosity	+0.19	−0.15
Diboson modeling	+0.15	−0.14
Jet flavor tagging	+0.15	−0.12
Light lepton (e, μ) and τ_{had} ID, isolation, trigger	+0.12	−0.10
Other background modeling	+0.11	−0.11
Total systematic uncertainty	+1.1	−0.9

Summary of the effects of the systematic uncertainties on μ.
Due to correlations between the different sources of uncertainties, the total systematic uncertainty can be different from the sum in quadrature of the individual sources. The impact of the systematic uncertainties is evaluated after the fit.

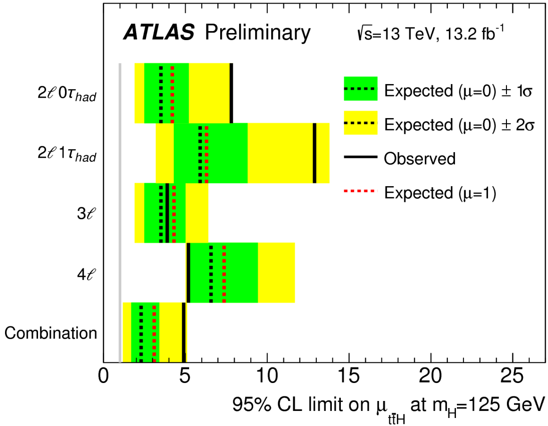
Best fit values of the $t\bar{t}H$ signal strength $\mu_{t\bar{t}H}$ by final state category and combined.

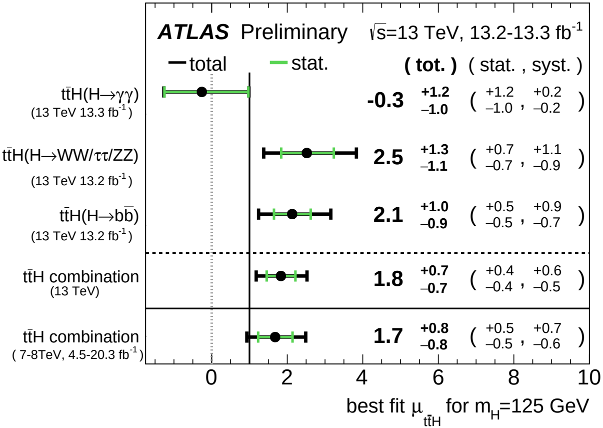
- The SM prediction is $\mu_{t\bar{t}H}=1$.
- Best fit values of $\mu_{t\bar{t}H}$ show no significant deviation from SM expectation.
- Systematic uncertainty dominated by non-prompt background estimates.
- For the 4l category, as zero events are observed,a 68% CLs upper limit is shown instead.



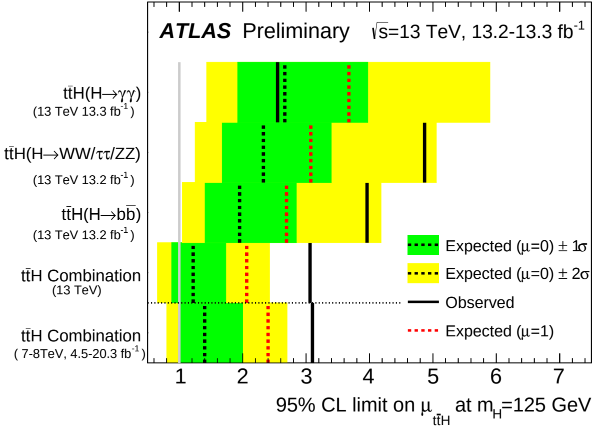
Upper limits on the $t\bar{t}H$ signal strength $\mu_{t\bar{t}H}$ at 95% CL by final state category and combined

- Expected 95% CL upper limit set under S+B (B only) hypothesis in dashed red (dashed black).
- Observed 95% CL upper limit is 4.9 for combined $\mu_{t\bar{t}H}$=2.5
- The median upper limit that would be set in the presence of a SM $t\bar{t}H$ signal ($\mu = 1$) is also shown.





Channel	Significance	
	Observed [σ]	Expected [σ]
$t\bar{t}H,\ H \to \gamma\gamma$	-0.2	0.9
$t\bar{t}H,\ H \to (WW, \tau\tau, ZZ)$	2.2	1.0
$t\bar{t}H,\ H \to b\bar{b}$	2.4	1.2
$t\bar{t}H$ combination	2.8	1.8



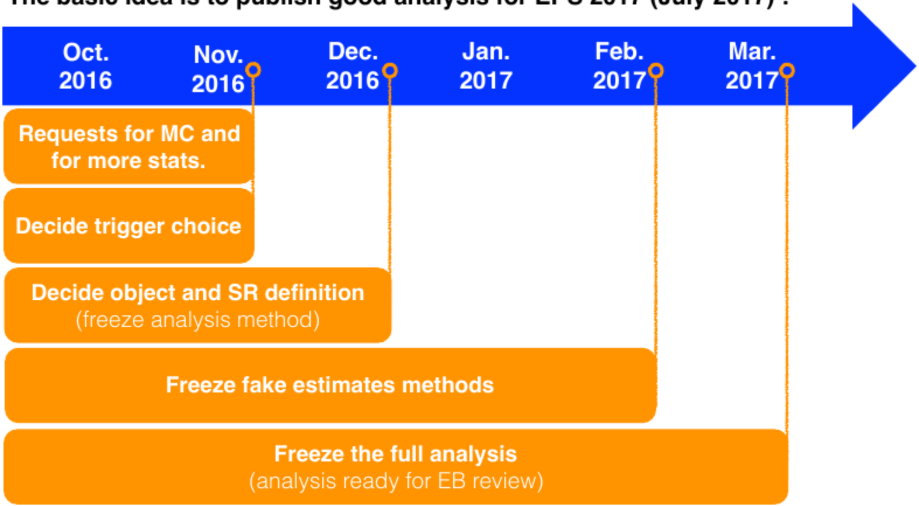
Analysis	Observed	$-2\ \sigma$	$-1\ \sigma$	Median ($\mu_{t\bar{t}H}=0$)	$+1\ \sigma$	$+2\ \sigma$	Median ($\mu_{t\bar{t}H}=1$)
$t\bar{t}H$, $H\to\gamma\gamma$	2.6	1.4	1.9	2.7	4.0	5.9	3.7
$t\bar{t}H$, $H\to(WW,\tau\tau,ZZ)$	4.9	1.2	1.7	2.3	3.4	5.1	3.1
$t\bar{t}H$, $H\to b\bar{b}$	4.0	1.0	1.4	1.9	2.8	4.2	2.7
$t\bar{t}H$ combination	3.0	0.6	0.9	1.2	1.7	2.4	2.1
$t\bar{t}H$ combination Run-1	3.1	0.8	1.0	1.4	2.0	2.7	2.4

Conclusions

- Results for $\boldsymbol{t\bar{t}H(multilepton)}$ analyses using **13.2-13.3 $\boldsymbol{fb^{-1}}$** of pp collisions at 13 TeV recorded by the ATLAS experiment
  - Best fit signal strength $-2.5 \pm 0.7(stat)^{+1.1}_{-0.9}$(syst)
  - Upper limits on $\mu_{t\bar{t}H}$ SM at 95% confidence level - 4.9 obs (2.3 exp)
- Results for combination analyses
  - Combined ATLAS $\boldsymbol{\mu_{t\bar{t}H} = 1.8}$ which corresponds to an observed significance of **2.8$\boldsymbol{\sigma}$** (sensitivity exceeds that of 7-8 TeV analysis of **1.5$\boldsymbol{\sigma}$**)
  - **95% CL** upper limit on signal strenght : **3.1** (**1.4** expected from bkg-only)
- Sensitivity exceeds Run-1 results
- Expect improved precision using full 2016 dataset from both experiments

ttH->multileptons Analysis Timeline

The basic idea is to publish good analysis for EPS 2017 (July 2017) !



Thank you for your attention

Back-up slides

There are many ideas to do analysis optimisation

- There are many ideas to optimise analysis with multivariate techniques, event reconstruction using kinematic fit techniques, as well as PME ...

BDT for lepton selections

- ttbar production with non-prompt leptons - major background for a few ttH channels
- We use boosted decision trees (BDT) to separate prompt from non-prompt leptons
- Train on 8 input variables - object level only; but could also include such information as b-tagging of the nearest jet
  - *pt, eta,*
  - *sigd0PV, z0SinTheta,*
  - *topoetcone20/pt, ptvarcone20/pt*
  - *topoetcone40/pt, ptvarcone40/pt*
- Lepton defs
  - Prompt - those coming from W
  - Non-prompt - any other parentage

- Our previous presentation - BDT lepton selections: first look at Run 2 - [Feb 16, 2016]

Lepton selections and training sample

Loose

- electrons
  - TightLH ID
  - pt >10 GeV
  - |eta| <2.47, excl. [1.37, 1.52]
  - z0SinTheta < 2
  - sigd0PV < 10
  - Loose Isolation WP
- muons
  - Loose ID
  - pt >10 GeV
  - |eta| <2.5
  - z0SinTheta < 2
  - sigd0PV < 10
  - Loose Isolation WP

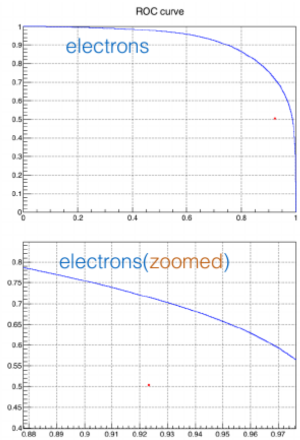
Tight

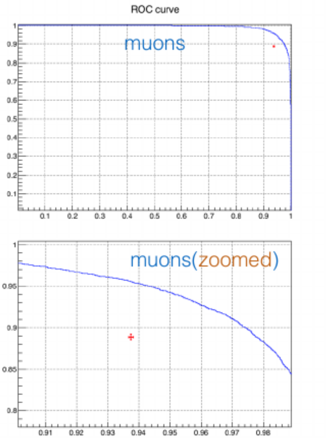
- electrons
  - TightLH ID
  - pt >10 GeV
  - |eta| <2.47, excl. [1.37, 1.52]
  - z0SinTheta < 0.5
  - sigd0PV < 5
  - FixedCutTight isolation WP
- muons
  - Loose ID
  - pt >10 GeV
  - |eta| <2.5
  - z0SinTheta < 0.5
  - sigd0PV < 3
  - FixedCutTightTrackOnly Isolation WP

- ttbar sample (dsid 410000; v7) - used for training; both prompt and non-prompt
- Loose selections
  - electrons - 3,180,533 (prompt), 100,828 (non-prompt); total: 3,281,361
  - muons - 3,811,580 (prompt), 392,192 (non-prompt); total: 4,203,772

BDT training and testing

- Training and Testing are done with **Loose** leptons on full statistics
- Comparison is performed against **Tight** leptons (red dot on the plots)
  - @Tight prompt lepton efficiency, BDT is better in background rejection
    - both electrons and muons give **40-50%** of improvement in non-prompt rejection

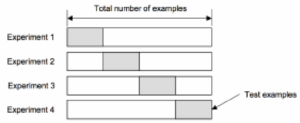




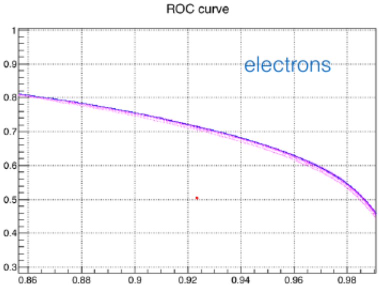
4

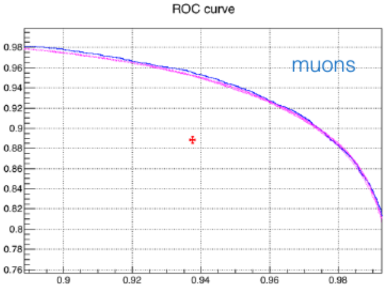
Cross Validation

- To estimate performance of the BDT, we run cross validation technique
  - use K-Fold method with 6 folds
    - split full sample in 6 subsamples randomly
    - train on 5 subsamples and test on the remaining + all permutations
    - results in 6 ROCs - **magenta** line
  - compare with entire sample ROC - **blue** line
- Shows <u>very stable</u> ROCs



Example of K-4 folds





3l SR (preliminary)

- Implemented BDT in the UT ntupler
  - BDT score is an additional variable in the tree
- Derived MC yields for the standard 3l selections and with BDT
  - BDT score cuts: electrons - 0.94, muons - 0.95 (no optimization)

Standard 3l

— Inputs —	$t\bar{t}H$	Diboson	tZ	single top + H	$t\bar{t}W$	Other $t\bar{t}$+X	$t\bar{t}ll$	Single top	$t\bar{t}$	Z	non-$t\bar{t}H$ H	Bkg Total
Standard 3l	1.88 ± 0.16	1.05 ± 0.24	0.10 ± 0.00	0.10 ± 0.01	1.97 ± 0.04	0.49 ± 0.04	3.10 ± 0.03	0.06 ± 0.04	1.90 ± 0.43	0.02 ± 0.01	0.00 ± 0.00	10.67 ± 0.53

3l with BDT

— Inputs —	$t\bar{t}H$	Diboson	tZ	single top + H	$t\bar{t}W$	Other $t\bar{t}$+X	$t\bar{t}ll$	Single top	$t\bar{t}$	Z	non-$t\bar{t}H$ H	Bkg Total
BDT 3l	1.90 ± 0.16	0.79 ± 0.17	0.09 ± 0.00	0.10 ± 0.01	1.76 ± 0.03	0.45 ± 0.04	2.80 ± 0.03	0.06 ± 0.04	1.65 ± 0.40	0.02 ± 0.01	0.00 ± 0.00	9.63 ± 0.47

- BDT leptons selection - with the same number of signal (ttH) ~ 1.9, ttbar contribution is reduced by ~15% to 1.65
  - still very preliminary - derived today morning
  - need to obtain a better working points for leptons
  - more tuning and checks are expected

Summary and plans

Summary

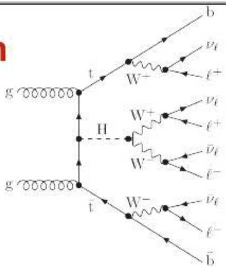
- Lepton selections with BDT is 40-50% better in non-prompt rejection
- 6-Fold cross validation was performed; ROC is stable
- Implemented in the UT ntupler
- Had a quick look at 3l SR standard and BDT selections
  - very preliminary but shows 15% of improvement in ttbar yields
    - requires WP optimization

Plans

- Have a more detailed look at the cutflows (2l, 3l) - derive better working points for leptons
- Finish validation on data
- Implement in the ttHMultiAna framework

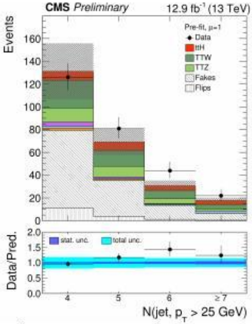
CMS ttH multilepton

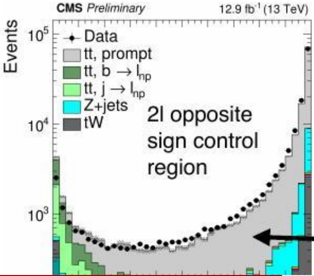
CMS HIG-16-022



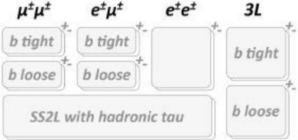
Targeting 2 lepton same-sign (2lss) and ≥3 leptons (3l)

- **2 same sign leptons:** ≥4 jets, ≥1 b-tag
- **3 leptons:** ≥2 jets, ≥1 b-tag
- **Backrounds:** tt+W/Z, tt+jets (same-sign required to reduce Drell-Yan and ttZ)
- **Background normalisation** from control region: loosened identification (**fakes**), Z→ll (mis-charge = "**flips**", 2lss only)





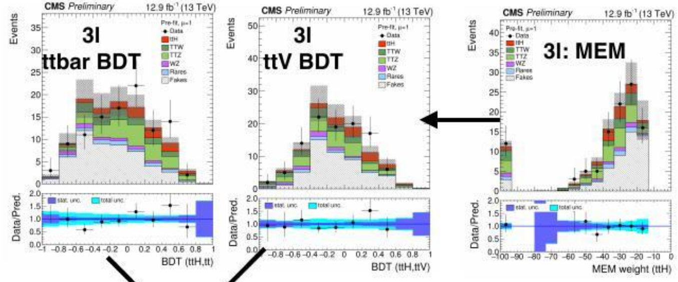
Analysis categories:

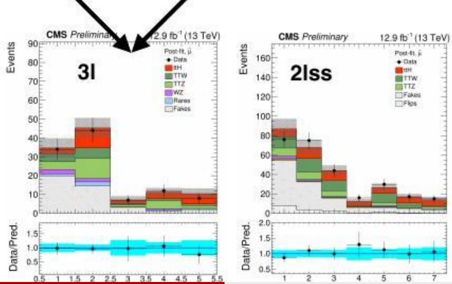


- **Lepton identification** with BDT using shape, isolation and overlapping jet information

CMS ttH multilepton

CMS HIG-16-022



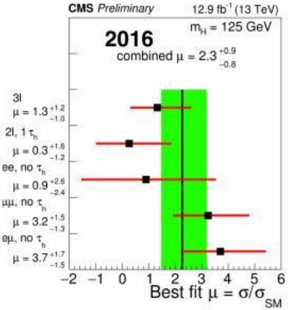


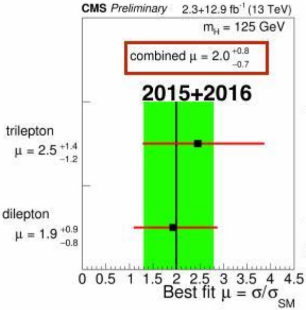
Analysis sensitivity:

- 2lss and 3l categories: Train **2 BDTs, against ttbar and ttW/Z**
- Unroll 2D distributions
- **3l category** : include log of **MEM** weights for ttH, ttW and ttZ as ttV BDT input

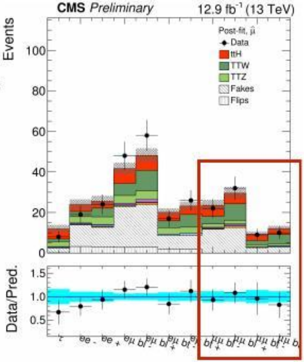
CMS ttH multilepton

CMS HIG-16-022



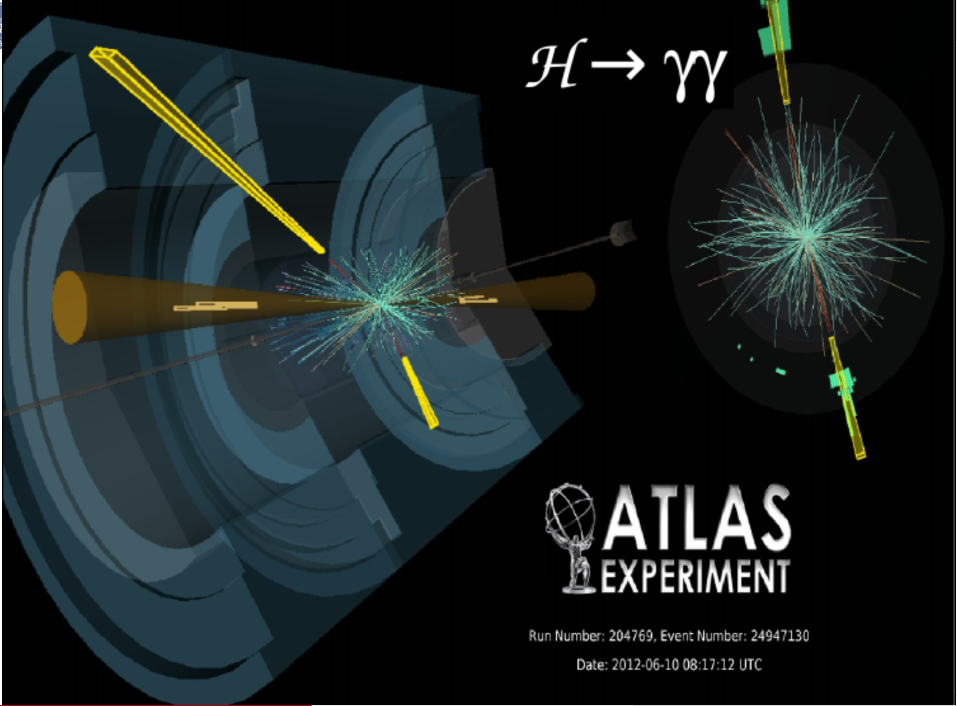


- Post-fit distribution of yields per categories shows no excess in dimuon



- **Main systematics** uncertainties : **tight lepton selection** and **fakes**

Category	Obs. limit	Exp. limit $\pm1\sigma$	Best fit $\mu \pm1\sigma$
Same-sign dileptons	4.6	$1.7^{+0.9}_{-0.5}$	$2.7^{+1.1}_{-1.0}$
Trileptons	3.7	$2.3^{+1.2}_{-0.7}$	$1.3^{+1.2}_{-1.0}$
Combined categories	3.9	$1.4^{+0.7}_{-0.4}$	$2.3^{+0.9}_{-0.8}$
Combined with 2015 data	3.4	$1.3^{+0.6}_{-0.4}$	$2.0^{+0.8}_{-0.7}$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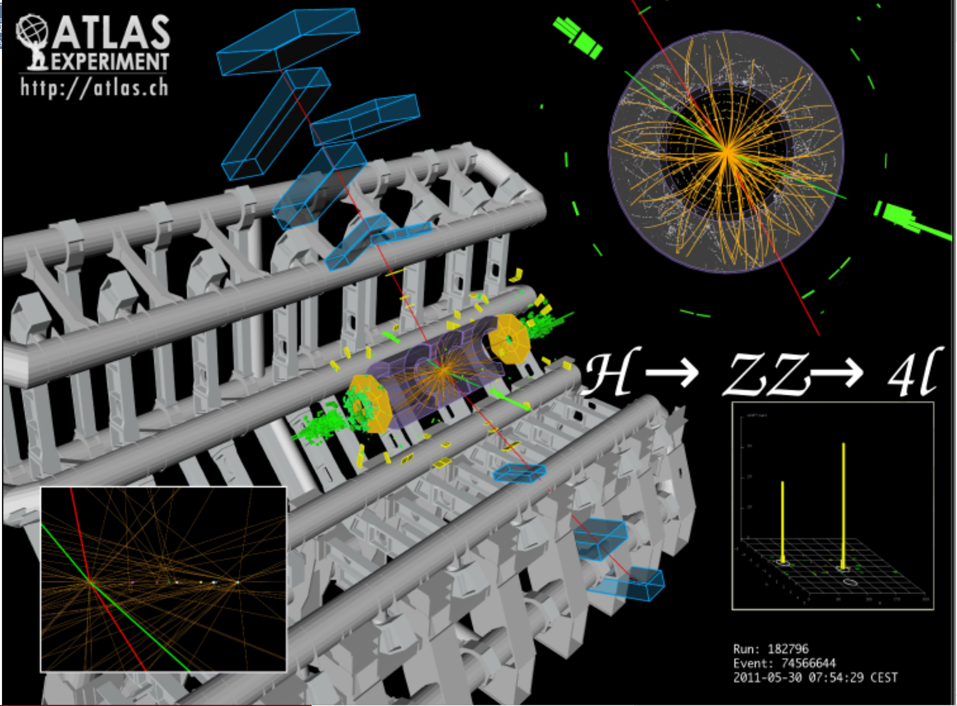
Date: 2012-06-10 08:17:12 UTC


ATLAS
EXPERIMENT
http://atlas.ch
$\mathcal{H} \rightarrow ZZ \rightarrow 4\ell$
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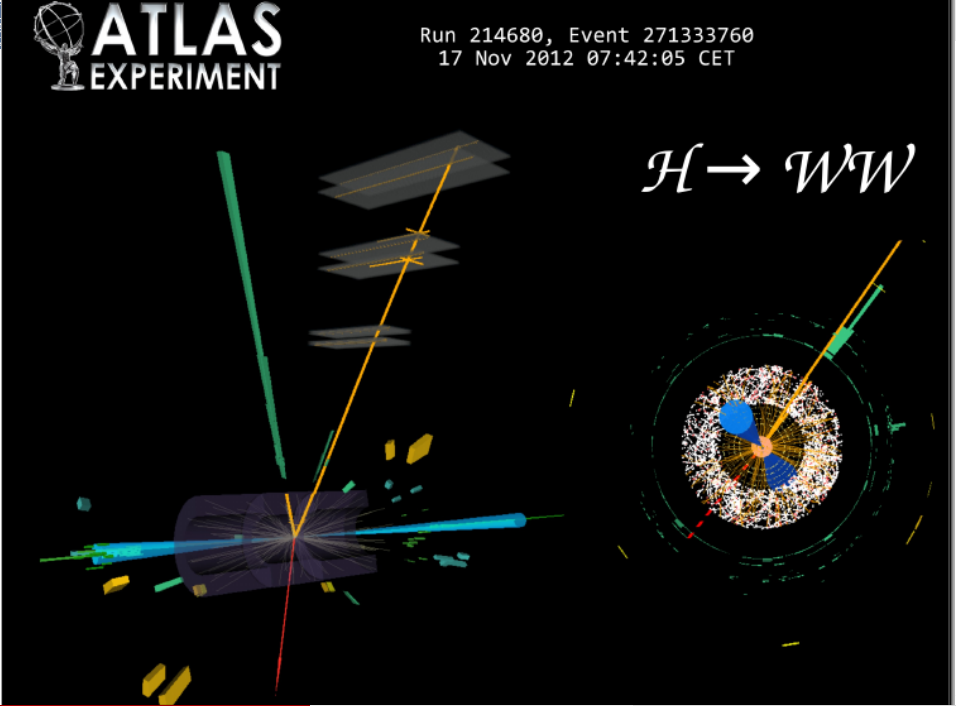
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EXPERIMENT
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17 Nov 2012 07:42:05 CET
$\mathcal{H} \to \mathcal{WW}$