Measurement of the top-Higgs Yukawa coupling in $t\bar{t}H(bb)$ events at the LHC in the ATLAS experiment

New trends in High Energy Physics

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Plan

Introduction

- Interest of measurement ? Higgs-top Yukawa coupling in SM
- Large Hadron Collider (LHC), ATLAS detector
- $t\bar{t}H$ decay channel

Resolved ttH Analysis at 8 TeV

- Event topology / background
- Present results at 8 TeV / limitations

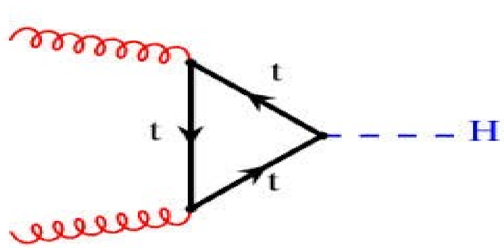
ttH(bb) boosted topology at 13 TeV

- Definition of $t\bar{t}H$ in boosted topology
- Ongoing studies

INTRODUCTION

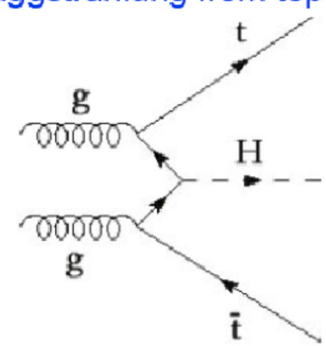
Motivation

- In 2012 a new Higgs-like boson was discovered in both ATLAS and CMS experiments at a mass of 126 GeV.
- The Higgs properties have to be measured, in particular its couplings to fermions (Yukawa terms) and gauge bosons
- One thing to remember : in SM, the Higgs coupling to fermions is proportional to their mass and the Higgs coupling to gauge bosons is proportional to their mass squared
- Top-Higgs coupling is the largest Yukawa coupling in SM because of the large top mass (= 174 GeV). Its precise measurement will allow us to constrain the Higgs mechanism in SM and BSM.



Indirect constraints

Higgstrahlung from top quark



Directly proportional to the top-Higgs Yukawa coupling squared

Yukawa terms in the SM

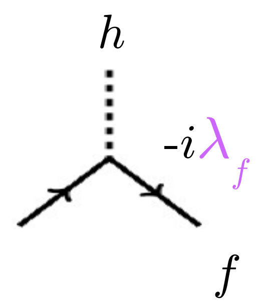
- In SM, a fermion field ψ_f acquires its mass from its interaction with a Higgs field ϕ

$$L = -\ \lambda_f \overline{\Psi}_f\, \phi\, \psi_f$$

- When ϕ is " shifted " by spontaneous symmetry breaking, L splits into two pieces

$$L = -\ \lambda_f \overline{\Psi}_f\, v\, \psi_f\ -\ \lambda_f \overline{\Psi}_f\, h\, \psi_f$$

$Fermion$
$mass\ term\ +$



where v is the vacuum expectation value, and h is the physical Higgs field

$$\rightarrow \quad \lambda_f = m_f / v$$

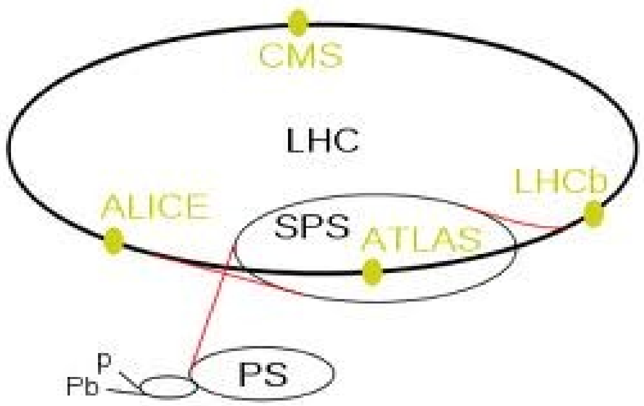
$v = 2M_W / g_w = 246\ \mathrm{GeV}$, $M_W = W$ mass, $g_w =$ weak coupling cst

$m_f =$ fermion mass

- Yukawa couplings to fermions are proportional to their mass, and non proportionality could give hints to BSM couplings

LHC

- Hadron (pp / heavy ions) collider located at Cern, in order
  to study Standard Model (SM) in a new kinematical domain,
  to search for new dynamics (i.e new type of physics)
- Main parts :
  - 27 km circumference ring
  - Superconducting magnets
  - 4 main experiments



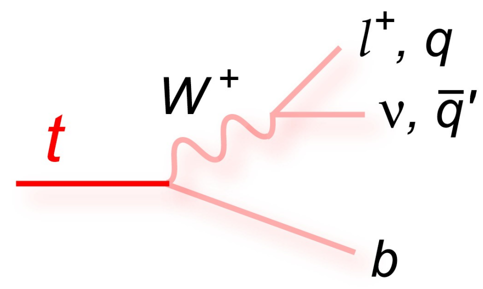
One of the main tasks of both ATLAS and CMS experiments is to understand the electroweak symmetry breaking. They are perfectly suited to measure the top-Higgs Yukawa coupling in pp collisions.

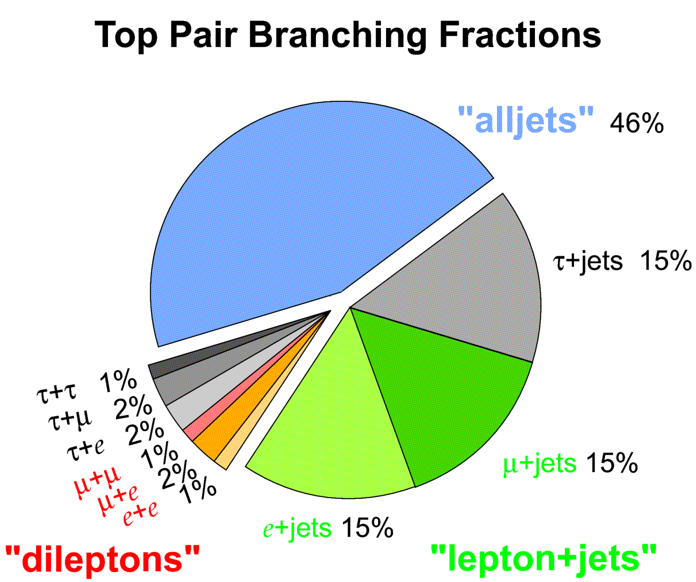
$\sqrt{s}$

- $7\ \mathrm{TeV}$ and $8\ \mathrm{TeV}$ in 2011 and 2012 respectively
- $13\ \mathrm{TeV}$ expected in 2015

$t\bar{t}$ decay

- Short top quark lifetime, resp. $\tau_t \sim 10^{-25}$ s , $t \rightarrow Wb$ (W lifetime ~ 10^{-23} s)
- 2 distinct W decays:
  - leptonically (30 %) decaying W
  - hadronically (70%) decaying W





- **alljet** channel : contaminated by multijet background

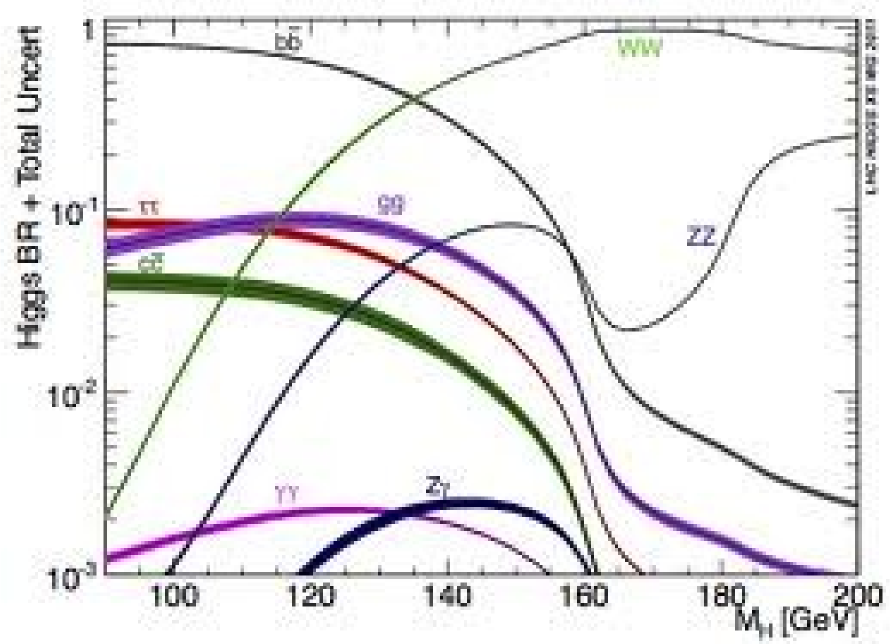
- **dilepton** channel : low statistics

→ Look for a **lepton+jet** $t\bar{t}$ channel:

Compromise between clean signature and good statistics (30 %)

H decay

- Short Higgs boson lifetime, $\tau_H \sim 10^{-23}$ s
- Possibility to exploit several Higgs decay modes

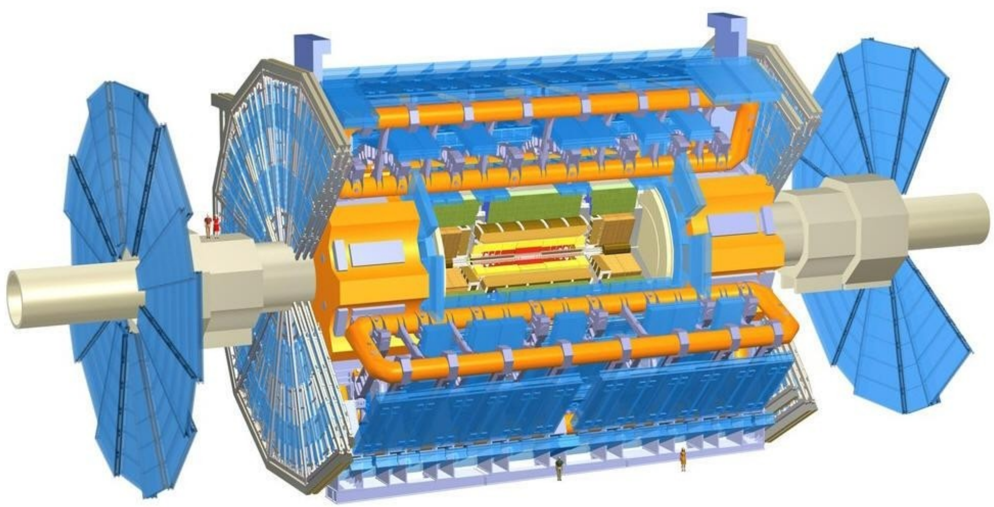


- $H \rightarrow b\bar{b}$: largest branching ratio (~ $57\ \%$) for m_H = 126 GeV
- Combine lepton+jet $t\bar{t}$ decay and $H(b\bar{b})$, the associated branching ratio ~ $17\ \%$

ATLAS detector

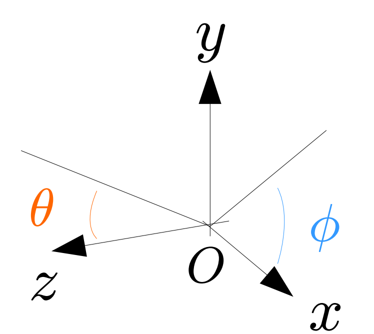
4 concentric layers :

- **Inner detector** (reconstructs the interaction points, secondary vertices, and measure the momentum of charged particles)
- **Electromagnetic Calorimeter** (measures the energy of electromagnetic showers)
- **Hadronic Calorimeter** (measures the energy of hadronic showers)
- **Muon Spectrometer** (measures the momentum of muons)



Cut-away view of the ATLAS detector

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



RESOLVED $t\bar{t}H(b\bar{b})$ ANALYSIS AT 8 TEV

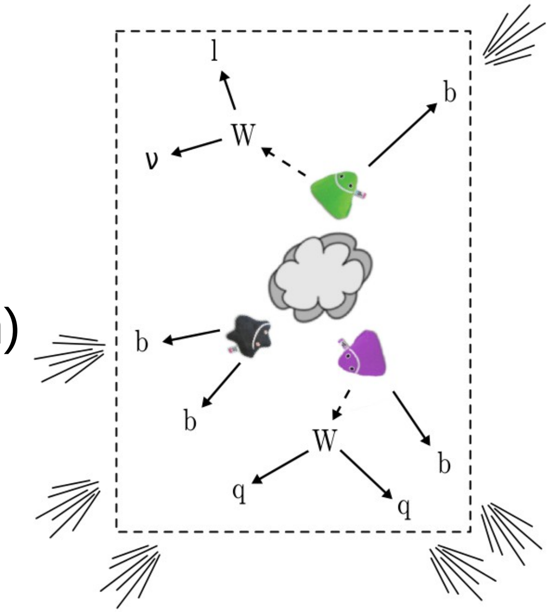
Decay summary

- **Decay**

  - 4 b quarks (Higgs and top quarks)

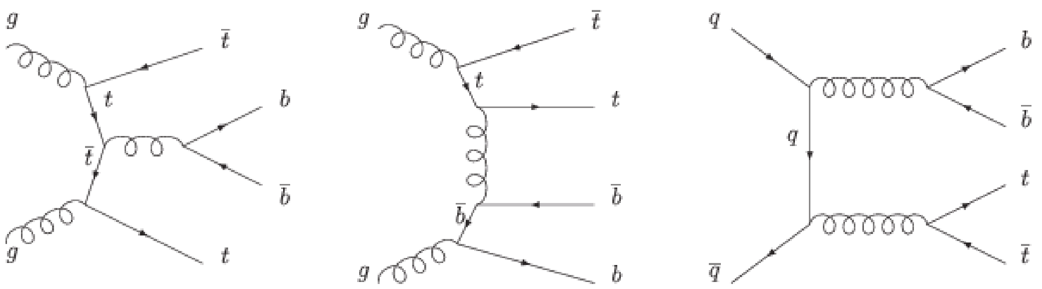
  - 2 light quarks (hadronically decaying W)

  - Charged lepton (e, μ) + MET (leptonically W boson)



- **Resolved analysis** : the b and light quark candidates are reconstructed within a jet anti-Kt R = 0.4

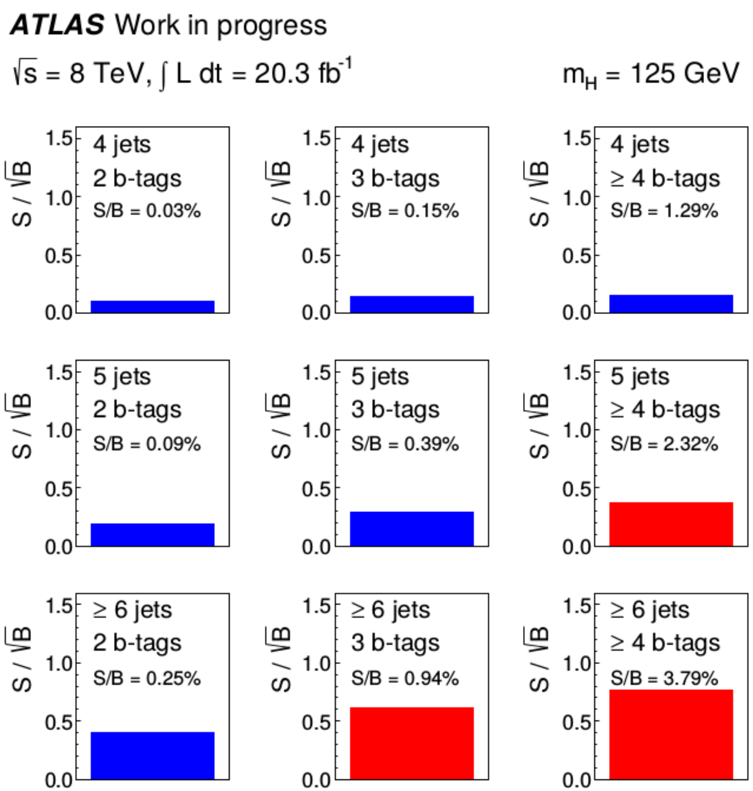
- **Huge background** from tt+jets, affected by large systematic uncertainties, both theoretical and experimental, $\sigma(t\bar{t})$/$\sigma(t\bar{t}H)$~2000(1500) for 7 TeV(14 TeV)



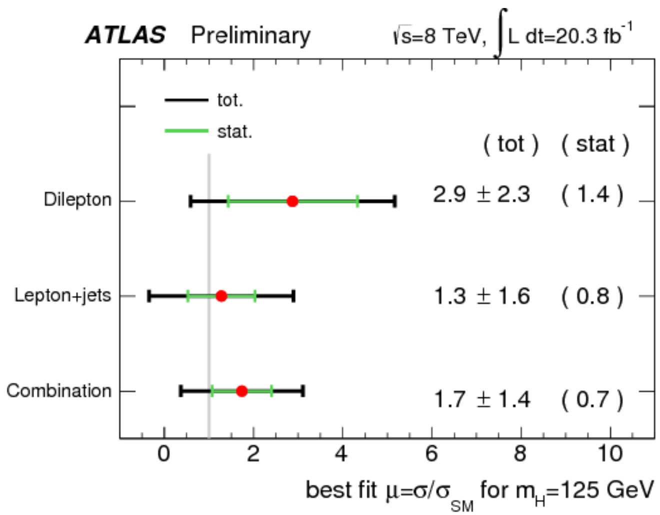
$t\bar{t}b\bar{b}$ background : same signature than $t\bar{t}H$ events

Event topologies

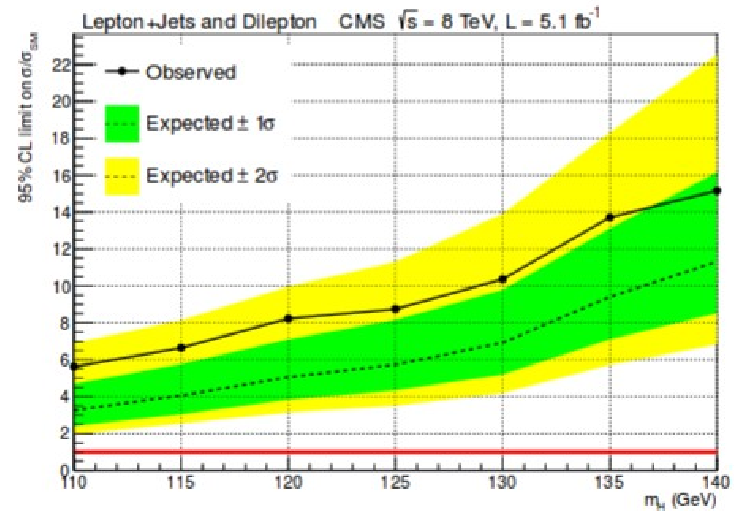
- The sample is divided in 9 sub-samples according to the jet multiplicity and the b-jet multiplicity. They are analysed separately and combined to maximise the sensitivity
- Use of Neural Network multivariate method : reconstruct the top quarks and Higgs boson candidates based on 10 kinematical variables.



Results at 8 TeV



Preliminary measurement of the Signal strength in ATLAS



Signal strength measurement in CMS

Present signal strength : measurement systematics are dominated by background uncertainties

Drawbacks

- Combinatorial problem due to wrong jet assignment to heavy objects (t_{had}, t_{lep} and H)
- Method starts to fail when jets are merged due to large pT tops and Higgs

→ Dedicated analysis for boosted Higgs and boosted tops in the final state: **boosted analysis**

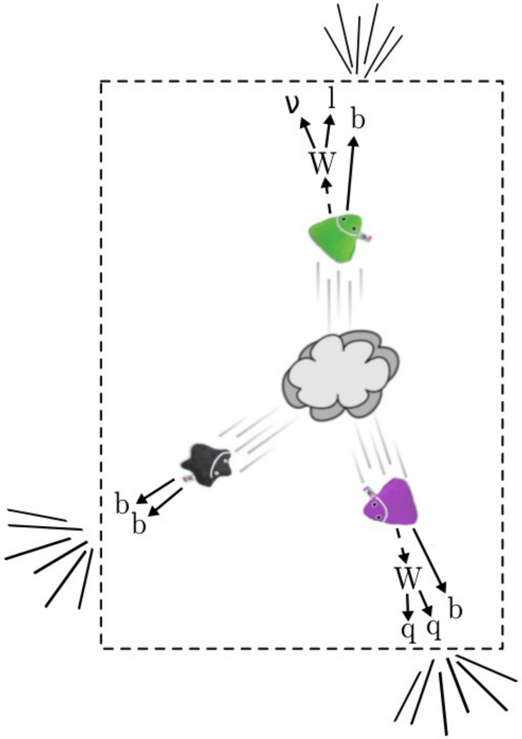
$t\bar{t}H$ BOOSTED TOPOLOGY

Boosted topology

- Boosted top and Higgs lead to collimated decay products that can be reconstructed inside large radius jets or fat jet (R ~ 1)
  Advantages
- Combinatorial problem is solved because each t_{had}, t_{lep} and H decay products are well separated in (η , φ) space
- High pT fat jets are more likely in ttH events → background reduction

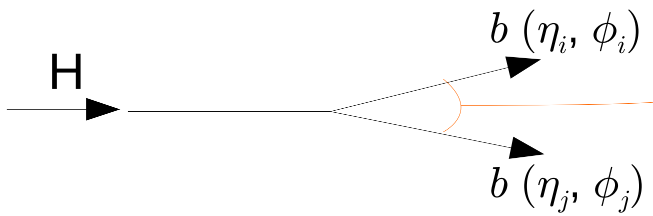
- **Signature**
- t-jet (fat jet with R ~ 1.2, hadronically decaying W)
- H-jet (fat jet with R ~ 1.0)
- b-jet (anti-Kt R=0.4 from leptonically decaying W)
- Charged lepton+MET (leptonically W boson)

- Identify heavy objects by looking at substructures inside the fat jets (bb from H and b q q from t)

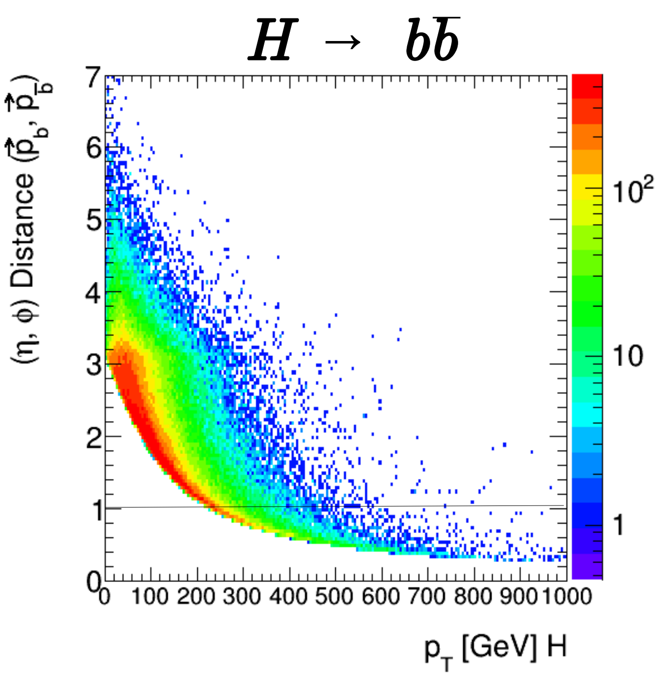


Which jet radius for fat jets

- Angular distance of the decays of heavy particles in $t\bar{t}H$ with PYTHIA sample at $\sqrt{s}=13\,TeV$ at parton level



$$\Delta R_{b\bar{b}} = ((\varphi_b-\varphi_{\bar{b}})^2 + (\eta_b-\eta_{\bar{b}})^2)^{1/2} \sim 2m_H/p_T$$



Distribution $\Delta R_{b\bar{b}}$ vs $p_{T,\ Higgs}$

- b and $\bar{b}$ jets are reconstructed inside the same fat jet of radius R if their angular distance is smaller than R.

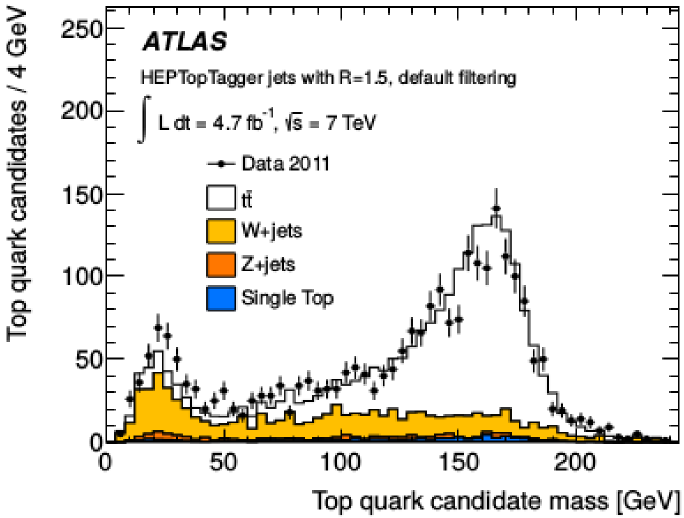
  → there is an equivalence between the radius of the fat jet and the pT threshold of the heavy particle that we want to reconstruct in this fat jet

  For R = 1.0, we see in the plot that pT_H > ~200 GeV

- The decay products of the hadronically decaying top are reconstructed inside an anti-Kt R=1.0 if pT_{thad} > ~300 GeV

Jet substructures

- Identification of particles contained in the fat jets, exp : top 1 bjet, 2 light jets in the t-jet, H 2 b. Remove all other components inside the fat jet (mainly due to pile-up)
- Reduce the background from multijet production, since they do not have the same internal structure
- Example: HEPTopTagger, find the W and the b candidates inside top fat jets using mass and angular criteria.



← l+jet selection

pT fat jet > 200 GeV

Boosted topology

- **Main drawback at 7 and 8 TeV** : not enough statistics to perform the measurement in boosted topology (24 fb^{-1} available data)
- **At 13 TeV** : 2 times more boosted ttH production cross section than at 8 TeV, and luminosity going up to 300 fb^{-1}

$p_{T,top} > X$ GeV \ $p_{T,Higgs} > Y$ GeV	$Y = 200$	$Y = 300$
$X = 200$	$\sim 8,3$ %	$\sim 3,2$ %
$X = 300$	$\sim 4,5$ %	$\sim 2,0$ %

Fraction of events with pT_{H} and pT_{thad} above a given high value at 13 TeV

- **Simulation** for 13 TeV run : simulate tt + jets background in boosted topology with large statistics
- However, simulating each tt generated event takes a long time (O(10 min) / event), and we would like to simulate mainly the events in boosted topology (interested in ~ 10 % of the simulated tt events)

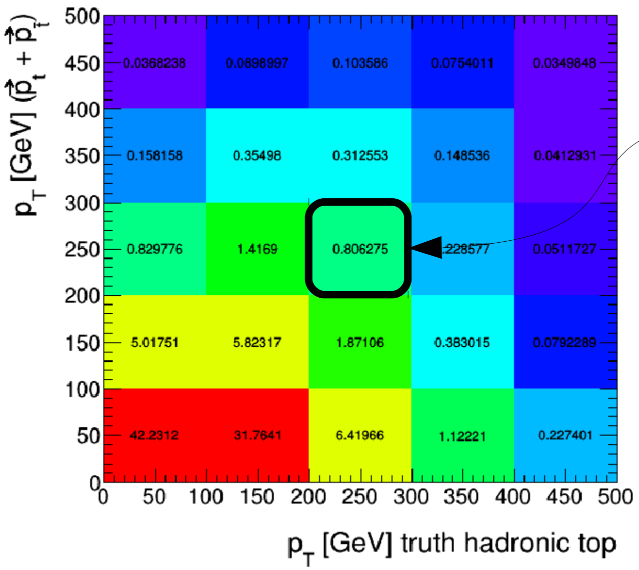
  → define a filter that select boosted topologies at parton level

Boosted topology

Method : we divide the inclusive tt sample into sub-samples

- according to the hadronic top pT (pTthad)
- according to the top antitop pair pT (pTtt ~ Higgs boson pT for our signal).

Simulate all sub-samples independantly in order to have enough statistics in each sample.



0.8 % of tt events in the boosted kinematical space

Filter efficiency at parton level for $t\bar{t}$ events

Conclusion

- The measurement of the $t\bar{t}H$ production at the LHC enables to obtain a direct measurement of the top Yukwa coupling
- This measurement will constrain the Higgs mechanism, and could give hints of new types of physics.
- 2 complementary analyses :

  - The **standard resolved** analysis reconstructs the b and the light quark candidates from the ttH decays into anti-Kt R=0.4 jets. With 8 TeV data, the background uncertainty dominates the uncertainty of the measurement. The analysis will be pursued at 13 TeV in order to reduce the uncertainty on the measurement.

  - The **boosted analysis** relies on the reconstruction of both hadronically decaying top and Higgs boson candidates into 2 fat jets, and will lead to smaller systematics, especially on background subtraction. This analysis will benefit from the presence of 2 times more events at high top and Higgs pT at 13 TeV and a high integrated luminosity of 300 fb^{-1}.
- Stay tuned, the measurement of the Yukawa coupling is coming soon


Thank you