Prospects for $t\bar{t}H$

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On behalf of the ATLAS+CMS collaborations

Top 2011

Overview

- Motivation
- Previous Studies
  - CMS TDR (2006), ATLAS (2008)
- Updates
  - 14TeV→7TeV, LO→NLO cross sections
- Current Status
  - tt+jets measurement,
  - jet systematics,
  - b-tagging
- Tools for the future
  - Data driven background measurement
  - Boosted Higgs
  - Available Event Generators
- Conclusion

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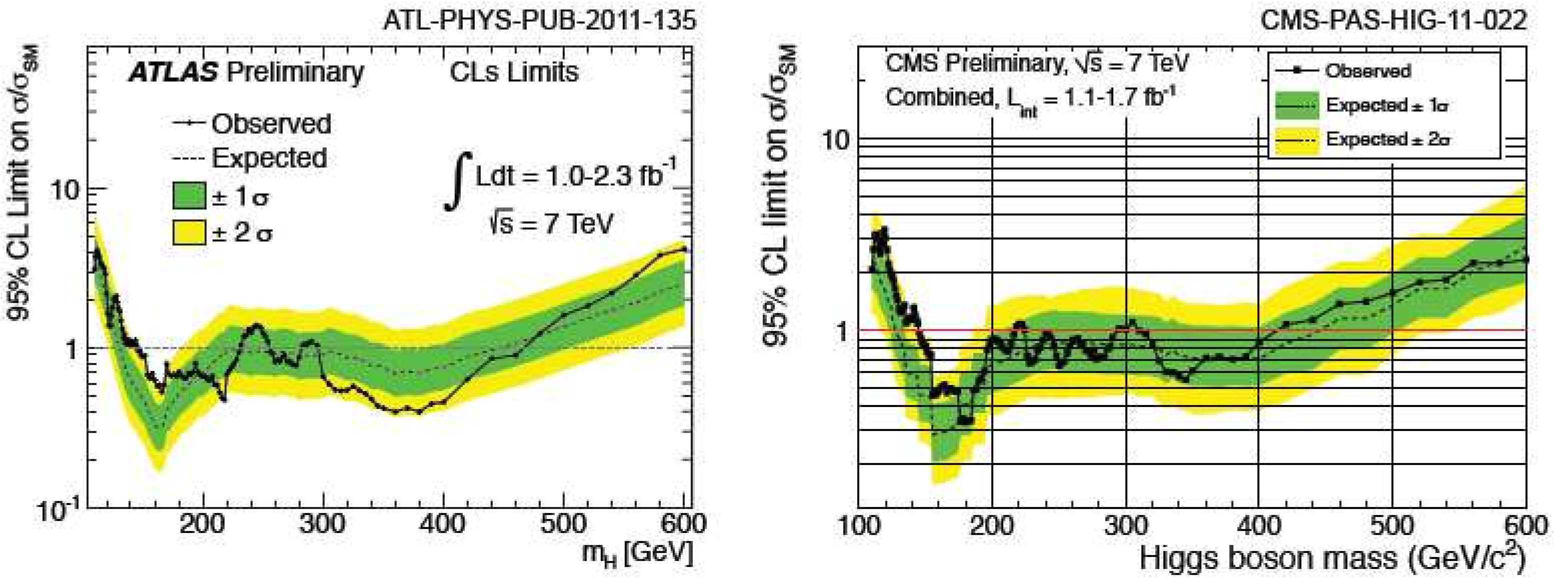
Motivation

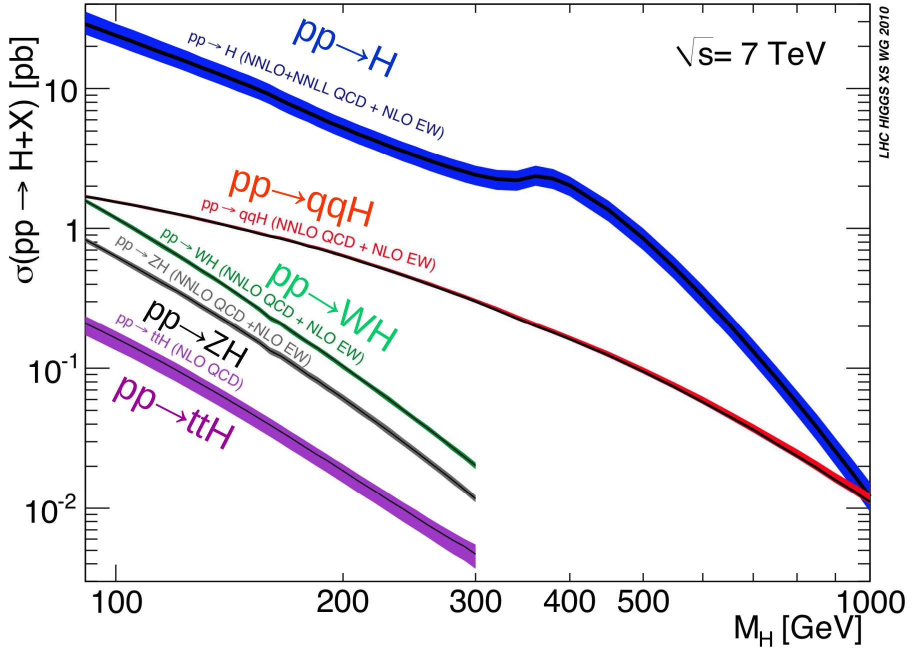


- If the Higgs boson is light, a combination of channels is needed for discovery.
- $t\bar{t}H$ observation gives access to top-Higgs Yukawa coupling.
- $t\bar{t}H(H \rightarrow b\bar{b})$ gives access to H-b Yukawa coupling.

The Challenge (1)

- At $\sqrt{s}$ = 7 TeV, for a Higgs m_h=120 GeV, $t\bar{t}H$ production σ~100fb
- Branching ratios:
  - bb: 65%
  - WW: 15%
  - gg: 8%
  - ττ : 7%
  - cc: 3%
  - ZZ: 1%
  - γγ: 0.1%
- $t\bar{t}H(H \to b\bar{b})$ in lepton+jets channel:
  - σ*BR ~20fb

CERN-2011-002



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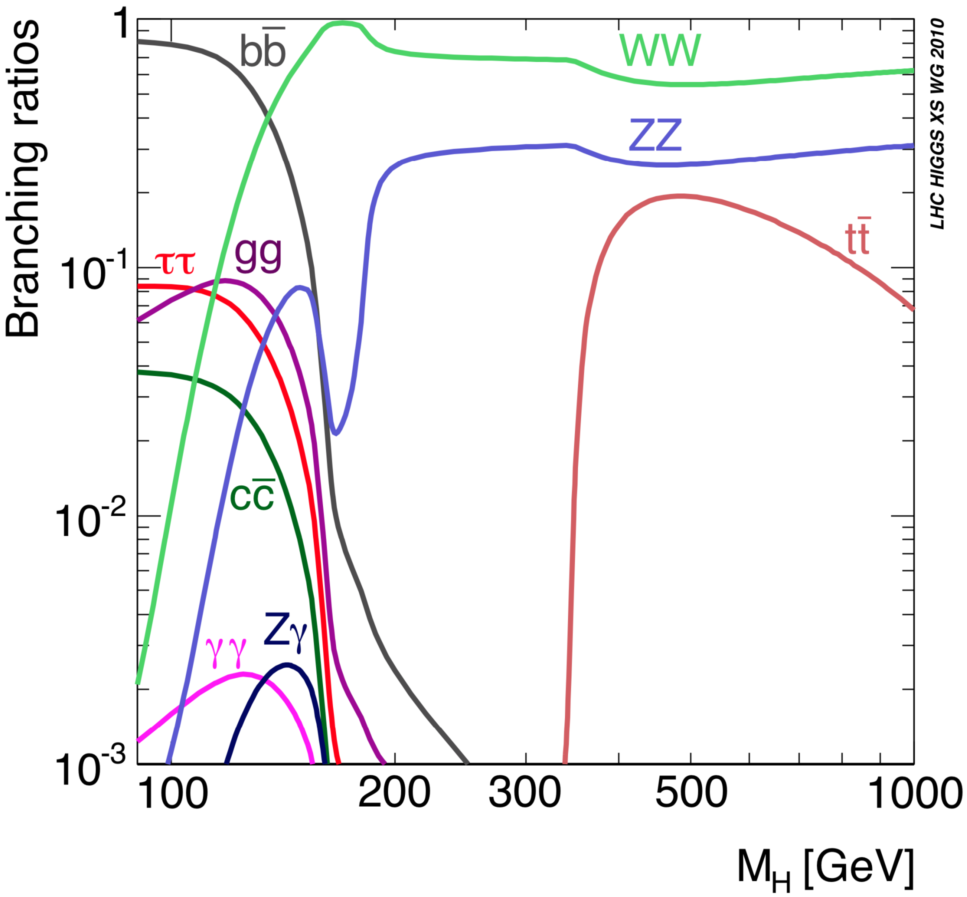

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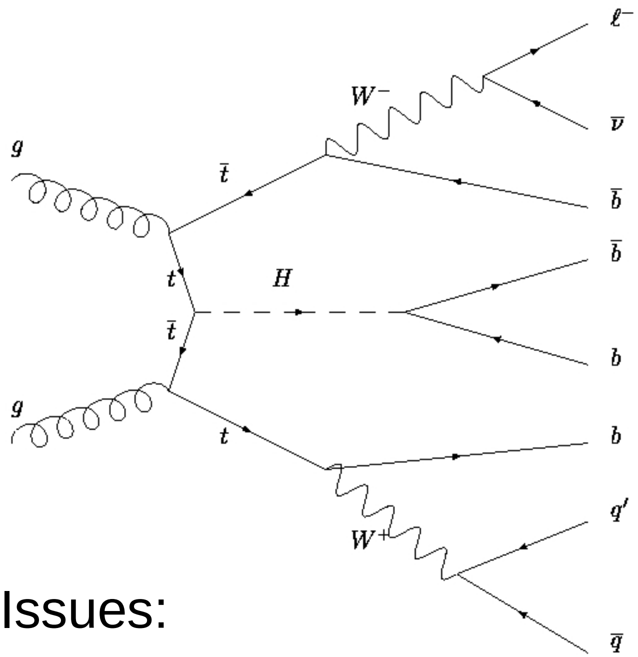
The Challenge (2)



e.g. lepton+jets channel:

- 1 isolated lepton (μ or e)
- Missing E_T
- ≥6 jets, of which ≥4 are b-tagged

Signal reconstruction:

- Hadronic W : 2 jets, $m_{jj} \sim m_W$
- Leptonic W: lepton+Etmiss
- Reconstruct the top quarks

Issues:

- ttbb background,
- tt+jets background
- Combinatorial background (very dependent on jet reconstruction),
- Very dependent on B-tagging.

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Previous Studies

120 GeV Higgs boson, 14TeV (signal σ 6× higher than 7TeV).

- CMS TDR (2006 LHC-2006-021), 60fb^{-1}.
- ATLAS CSC book (2008 CERN-OPEN-2008-020), 30fb^{-1}.
- Leading order Monte Carlos and poor scale choice for $t\bar{t}b\bar{b}$.
- Jets defined by cone algorithm, and advanced btagging algorithms assumed.

	ATLAS		CMS	
samples	generators	Cross section (pb)	generators	Cross section (pb)
ttH	Pythia	0.537 LO	CompHEP + Pythia	0.664 NLO
ttbb (QCD)	AcerMC+Pythia	8.7 LO	CompHEP + Pythia	3.28 LO
ttbb(EW)	AcerMC+Pythia	0.94 LO	CompHEP + Pythia	0.65 LO
tt(+jets)	MC@NLO+Herwig	833 NLO+NLL	Alpgen + Pythia	588 LO (*)

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Previous Studies

- CMS TDR (2006 LHC-2006-021), 60fb^{-1}.
  - All-hadronic channel and dilepton: optimised cuts.
  - Lepton+jets: Preselection followed by event likelihood (constraints on m_W , m_t , b-tags, kinematics)
- ATLAS CSC book (2008 CERN-OPEN-2008-020), 30fb^{-1}:
  - Considered lepton+jets channel. Preselection followed by:
    - Cut based: Mass window cuts made on hadronic W and m_t . Jets assigned to tops by minimising a χ^2
    - Pairing likelihood: topological distributions of the top system used as input to a combinatorial likelihood.
    - Constrained mass fit: adjust lepton and jet momenta and Etmiss to match m_W and m_t . Calculate χ^2 followed by 2 step likelihood technique.

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Preselection Cuts

CMS 2006

Leptons:

- Lepton trigger p_T>15GeV
- Likelihood based μ reconstruction
- Likelihood based e reconstruction

Jets: cone R=0.5

- 6 or 7 jets, |η|<3.0, p_T>10GeV

(for 10<p_T<20GeV, extra check that 2 tracks point to primary vertex)

b-jets:

- 4 jets tagged as b-jets, (combined secondary vertex, 70% working point)
- Dilepton veto
- Event likelihood to assign jets
- Second likelihood for background rejection (stronger b-tag requirement)

ATLAS 2008

Leptons:

- Lepton trigger p_T> 22GeV (e), p_T>20GeV (μ).
- 1 isolated lepton, |η|<2.5, p_T>25GeV (e), p_T>20GeV (μ)

Jets: cone R=0.4

- ≥6 jets, p_T>20GeV

b-jets:

- ≥4 jets passing loose b-tag cuts (IP3D+SV1, 85% working point)
- For cut-based and pairing likelihood analyses, ≥4 jets passing tight b-tag cuts (IP3D+SV1, 50% working point).

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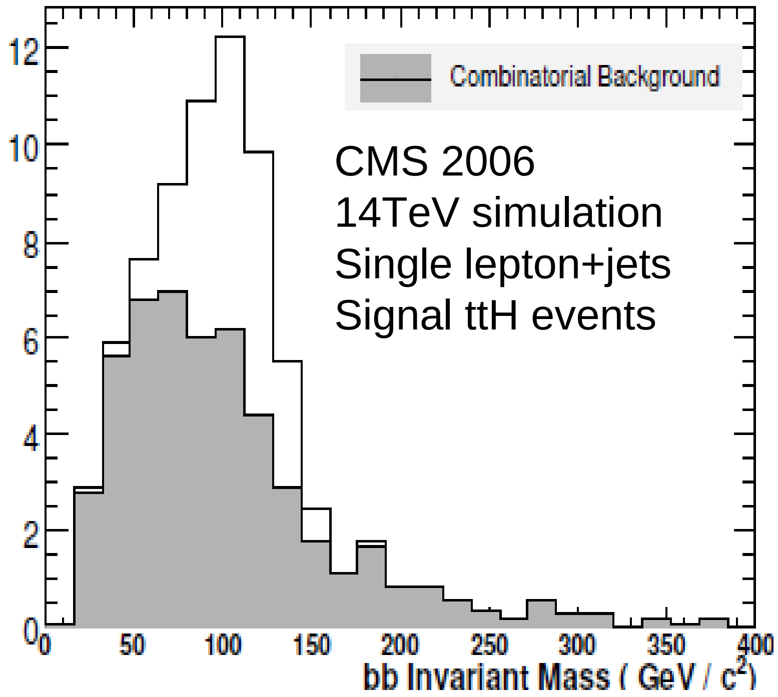
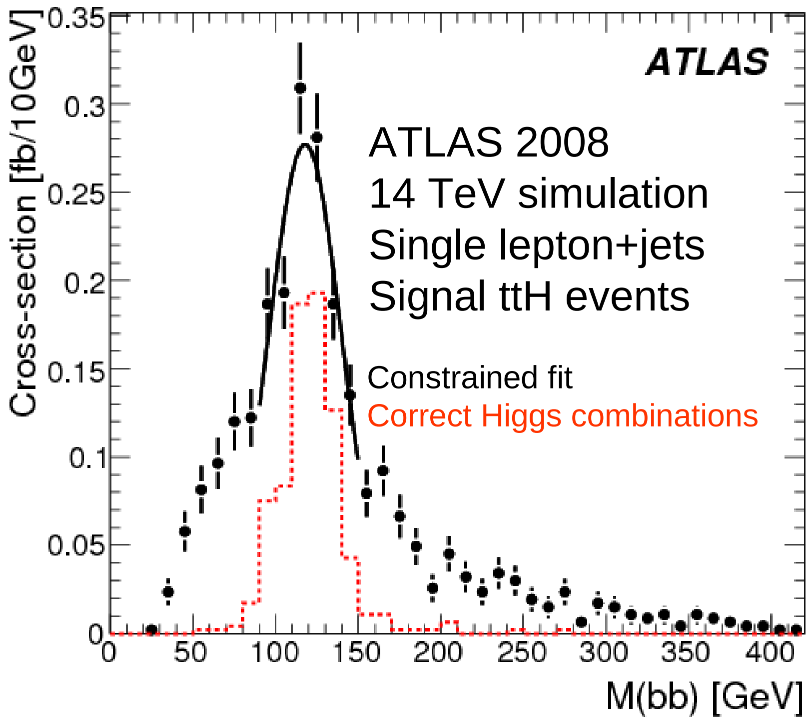
Combinatorial background

- Multivariate techniques aimed to reduce combinatorial background
- ~30% correct assignments to $H \rightarrow b\bar{b}$





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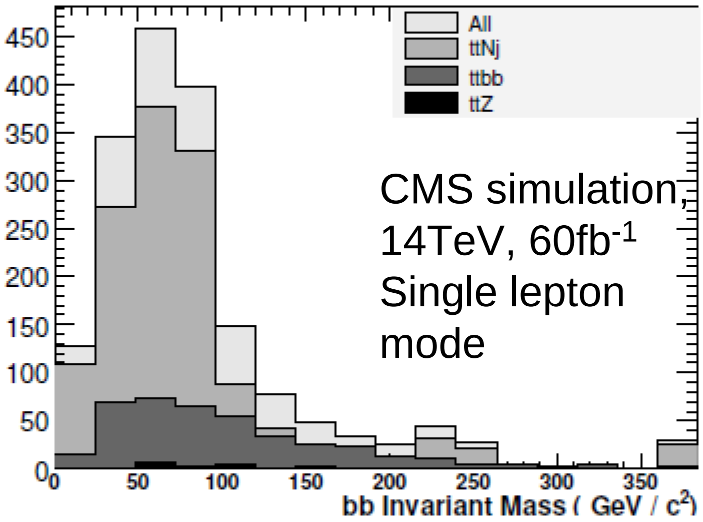
Statistical Significance, √s = 14TeV



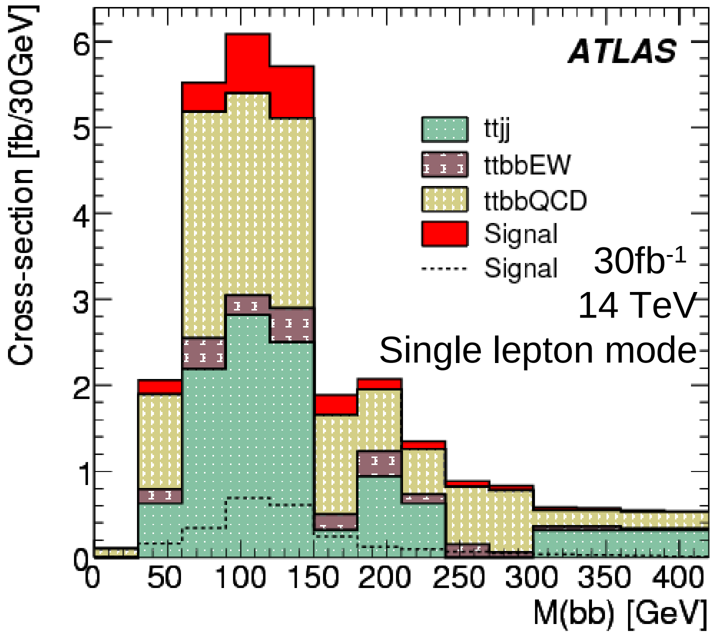
CMS, 2006, 14TeV, $60fb^{-1}$:

- $t\bar{t}H$ selection efficiency: 1.9%(μ), 1.4%(e)
- S/B: 4.8%(μ), 4.4%(e)
- Statistical significance S/√B : 1.8(μ), 1.6(e)

ATLAS, 2008, 14TeV, $30fb^{-1}$:

- $t\bar{t}H$ selection efficiency 2.5%
- Constrained fit achieved S/B=0.12, accepted σ=1.3fb
- Statistical significance S/√B: 2.2

  BUT large systematics reduced this greatly….



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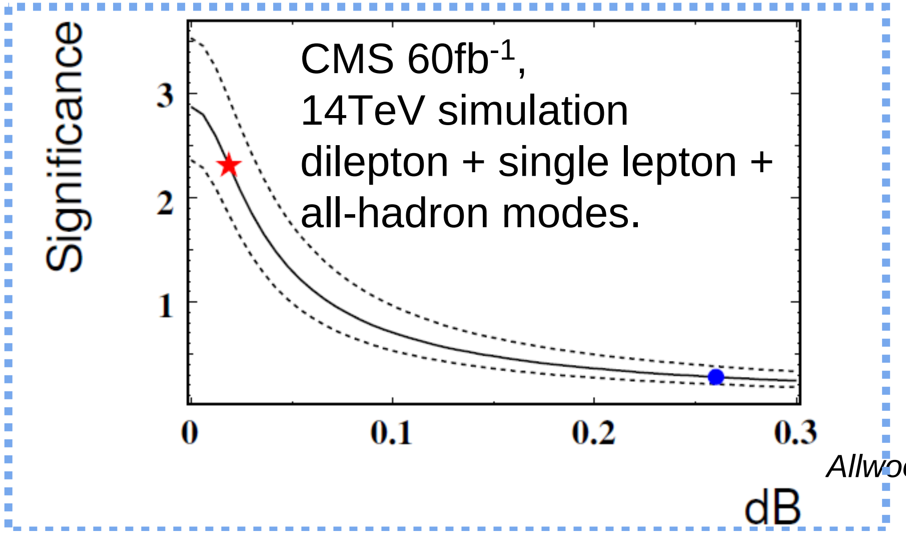
Systematics

- Systematics: 20-30%
- Reduced significance to S/√(B+ΔB) ~0.5
- Largest contribution:
  - Jet Energy Scale and Jet Energy Resolution (≥ 6 jets)
  - B-tagging (≥ 4 b-jets)
- Not including $t\bar{t}jj$ or $t\bar{t}b\bar{b}$ cross sections (assumed these are measured)

Uncertainties assumed for each jet :

	ATLAS 2008	CMS 2006
JES	7%	3-10%
JER	45%/√E(GeV) barrel 63%/√E(GeV)forward	10%
b/c tag effic.	5%	4%
uds tag effic.	10%	10%



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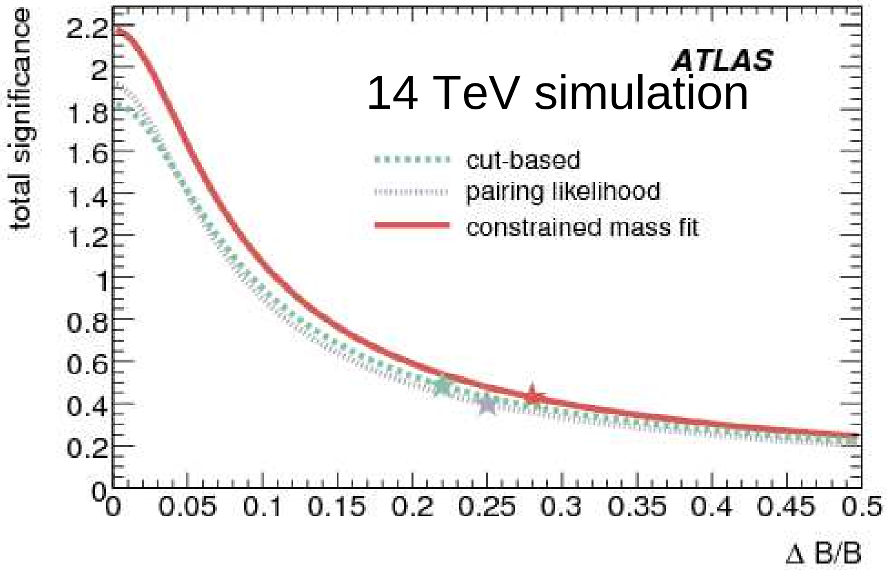

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Then and Now: Theory

Changes since the old studies:

14 TeV → 7 TeV,

$t\bar{t}H$ σ: 685 fb → 100 fb (m_h=120GeV)

Inclusive $t\bar{t}$ σ: 886 pb → 160 pb

Theory updates:

- $t\bar{t}H$ NLO corrections increased σ by up to 20%.
  (Beenakker, Dittmaier, Kramer, Plumper, Spira, Zerwas '01; Reina, Dawson '01; Dawson, Orr, Reina, Wackeroth '03)

BUT

- Poor scale choice in previous leading order $t\bar{t}b\bar{b}$.
- $t\bar{t}b\bar{b}$ at NLO calculations at new scale show an increase of >100%.
  (A. Bredenstein, A. Denner, S. Dittmaier and S. Pozzorini 2010)
- NLO QCD corrections to $t\bar{t}jj$ have also been calculated.
  (Bevilacqua, Czakon, Papadopoulos, Worek 2010).

Then and Now: Reconstruction

- Jet reconstruction techniques have improved:
  - cone → anti-k_T as standard,
  - Interest in subjet analysis
- Experiments are no longer in "early data" phase:
  - Uncertainties in jet energy scale are at a similar precision to those assumed in the ATLAS CSC book and the CMS TDR.
  - sophisticated b-tagging algorithms are ready for use.

  → Background measurements to $t\bar{t}H$ can be started soon
- Next slides look at the ingredients we have and outline plans.

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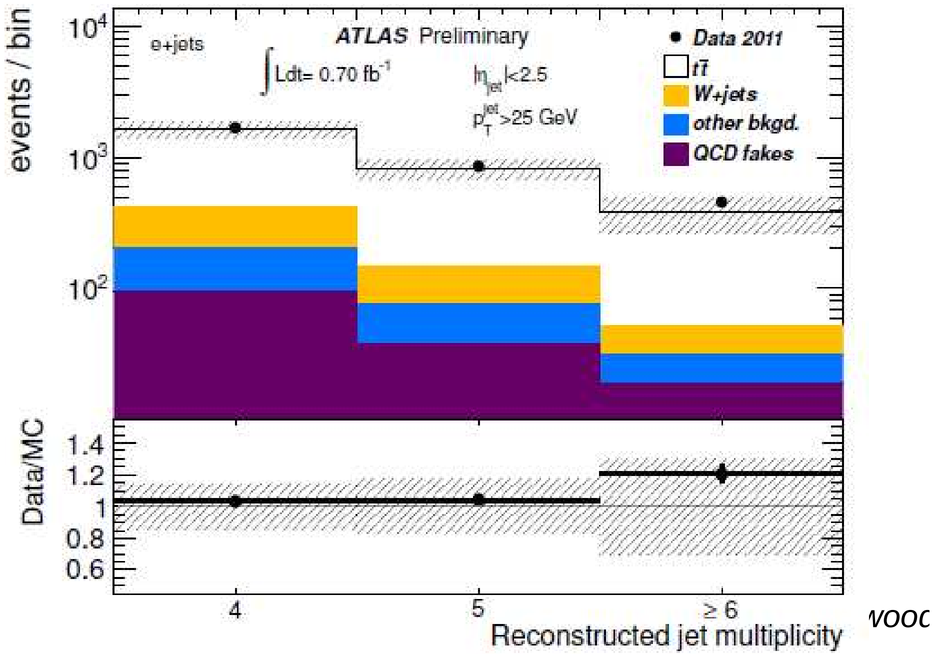
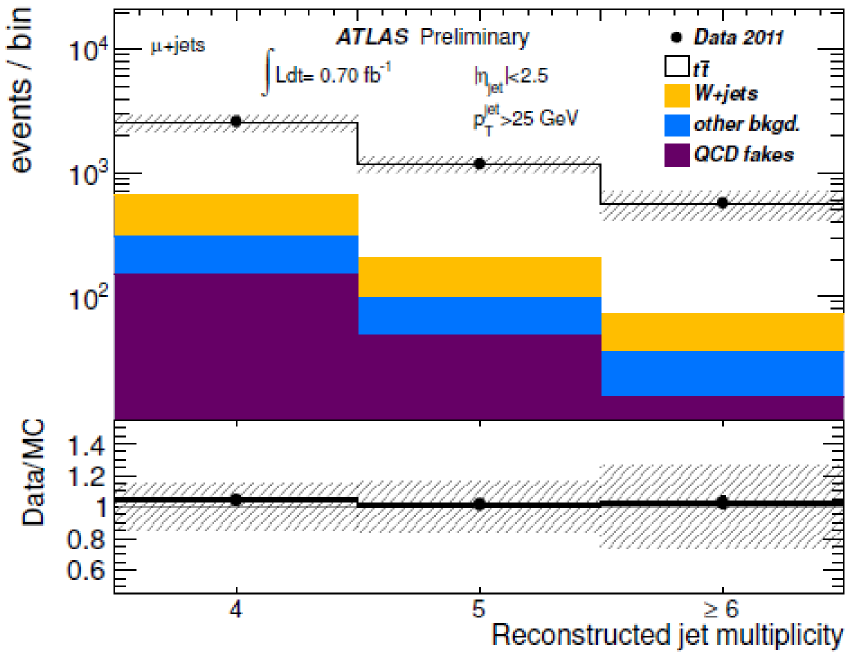
Measurement of tt+jets

Reconstructed jet multiplicity after single lepton+jets ttbar selection cuts.

e channel	Mu channel
1 lepton, p_T>25GeV	1 lepton, p_t>20GeV
Etmiss>35GeV	Etmiss>25GeV
m_T(W) > 25GeV	mT(W)+Etmiss>60GeV
≥4 jets, p_T>25GeV	
≥1 b-tagged jet	

- Data driven estimates for W+jets normalisation and QCD fakes.
- Alpgen for W+jets shape.
- MC@NLO for ttbar signal estimate, normalised to approximate NNLO cross section (k-factor 1.127).

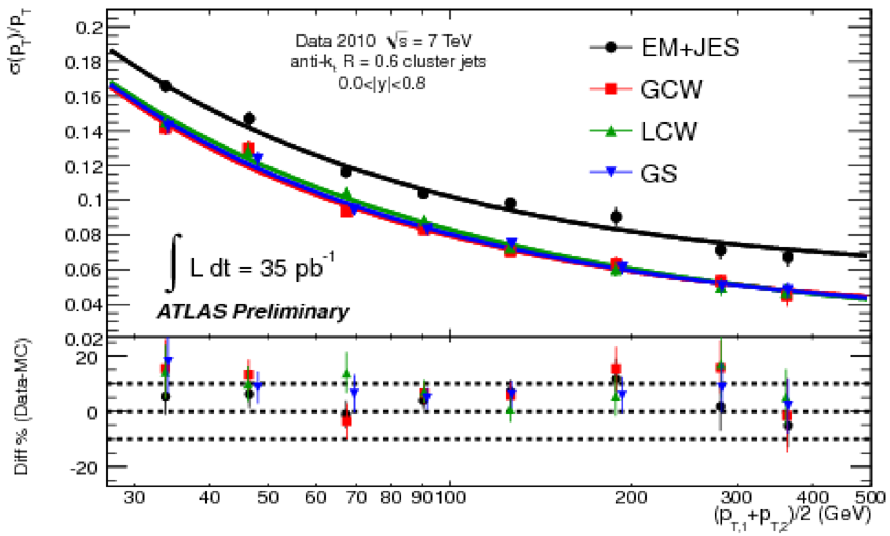


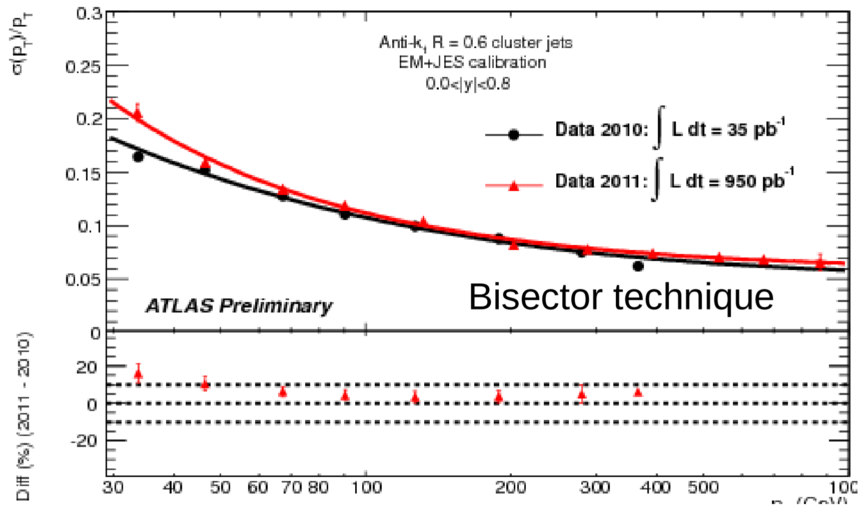


Jet Energy Resolution (JER)

In situ techniques to measure jet resolution in dijet events (anti-kt, R=0.6)

- Dijet balance: Measure asymmetry between p_T of two leading jets.
- Bisector technique: Vector sum of momenta of two leading jets to define imbalance vector $\vec{P}_T$. Measure variance in 2 orthogonal coordinates of transverse plane.
- Systematic uncertainties ~10%, estimated from data-MC agreement.



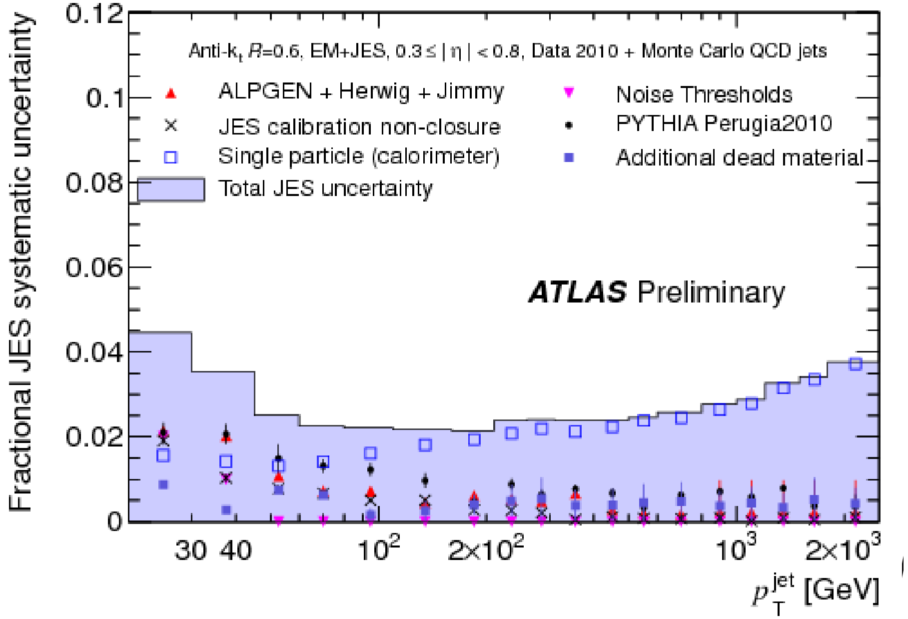


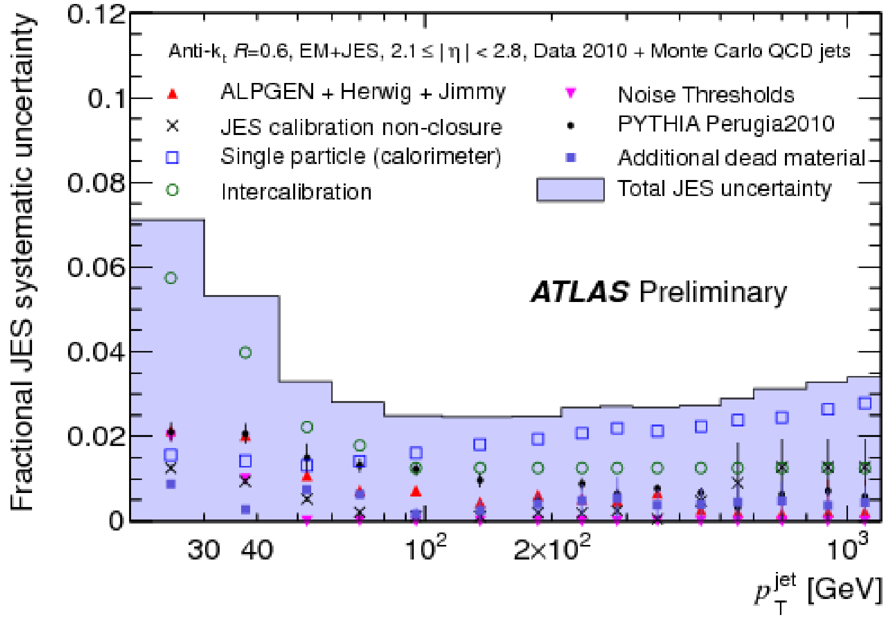
Jet Energy Scale

Jet Energy Scale measurement for inclusive jets, combined:

- in-situ and single pion test-beam measurements,
- uncertainties on the material budget of the ATLAS detector,
- description of the electronic noise,
- Monte Carlo modelling

→ Including 2011 pileup estimate, JES uncertainty < ±10% for $|\eta|<2.8$, $p_T>20$ GeV.
Additional 2.5% uncertainty for b-tagged jets, derived from difference between JES for b-tagged jets and non b-tagged jets in MC.





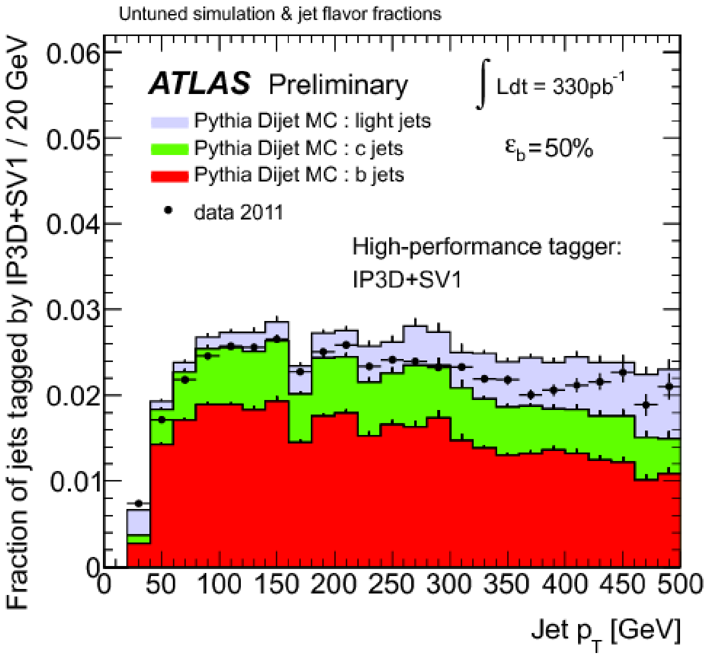
B tagging

- In early data, simple and robust taggers were used.
- Now, commissioning of advanced taggers.
  - Expect light jet rejection ~1000 for 50% b-tagging efficiency
- ATLAS:
  - IP3D+SV1

    (Impact parameter + secondary vertex)
  - IP3D+JetFitter

    (Impact parameter +

    fitter to primary vertex, b and c vertices)



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Data driven backgrounds

Background measurements should be data-driven. Possible strategy:

- Take ttbb/ttjj fraction from Monte Carlo
- Define loose/medium/tight btag working points
    - Loose and medium have low (~1%) signal contamination
    - Tight working point is the cut used for $t\bar{t}H$ analysis.
- Measure m_{bb} in events with tt+ 2 b-tagged jets (i.e. $t\bar{t}jj + t\bar{t}b\bar{b}$) at loose working point.
- Use tagging efficiencies ε_b , ε_c , ε_{light} for "loose" and "medium" btagging working points.
- Extrapolate to medium working point.

- Compare to measurement of m_{bb} at medium working point.
- Extrapolate to tight working point.
    - also look at sidebands in m_{bb}.
- Also possibility to look at 3 btags instead of 4 .

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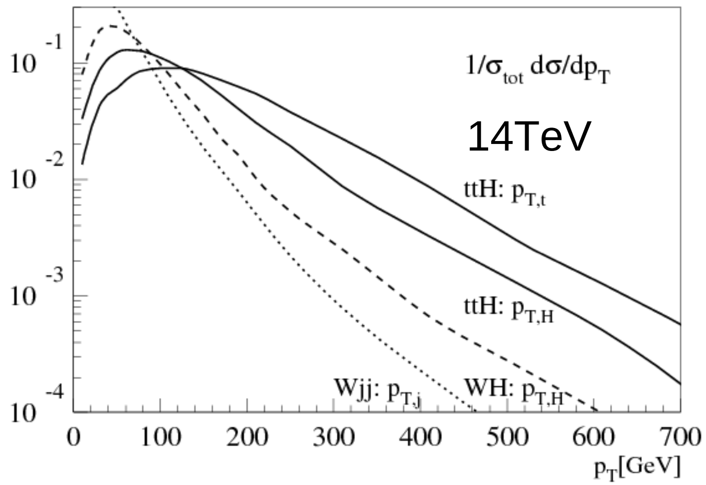
Boosted Higgs

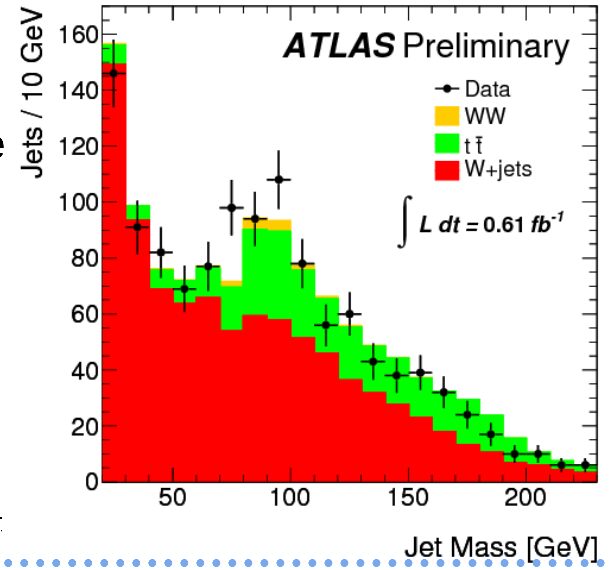
Plehn, Salam, Spannowsky, 2009:

- Use Cambridge-Aachen algorithm, R=1.5 to find 2 "fat jets" with p_T>200GeV
- Subjet analysis:
  - "Top tagger": undo clustering to find subjets, m_{jj}~m_W , m_{jjj}~m_t.
  - "Higgs tagger": undo clustering, order subjet pairs by a distance measure $J=p_{T1}p_{T2}(\Delta R_{12})^4$. Require 2 btags and ±10GeV mass window
- Apply 3rd btag to jets (R=0.6) after removing the Higgs and top constituents



e.g. Recent WH(H->bb) studies show the search for boosted H->bb on data.

2 subjet mass for p_T>180GeV



Sarah Allwood-Spiers, ttH Prospect

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Event Generators

Available tools:

- $t\bar{t}H$: POWHEG, aMC@NLO for NLO $t\bar{t}H$ production.
- $t\bar{t}b\bar{b}$:
  - AcerMC: leading order, QCD+EW contributions.
  - Alpgen: leading order QCD (ME+PS).
  - POWHEG: $t\bar{t}b\bar{b}$ NLO+PS with massless b's work in progress.
  - aMC@NLO: -
  - Sherpa: $t\bar{t}b\bar{b}$ (QCD contribution only) (ME+PS).
  - Menlops/SHERPA: -
- $t\bar{t}jj$:
  - Alpgen: LO $t\bar{t}jj$. Needs overlap removal between $t\bar{t}jj$ and ttbb sample.
  - MC@NLO: total cross section - NLO, tt+1j - LO, subsequent jets - LL.
  - POWHEG: ttj at NLO (parton shower by Pythia or Herwig). $t\bar{t}jj$ future work.
  - aMC@NLO: -
  - SHERPA: LO $t\bar{t}jj$ (ME+PS).
  - Sherpa/MENLOPS: total rate NLO, work in progress.

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Conclusion

- $t\bar{t}H$ is an interesting complementary measurement if the Higgs boson is low mass.
- Background measurements can be started now.
- NLO Monte Carlos are needed for $t\bar{t}b\bar{b}$ and $t\bar{t}jj$.
- Development of advanced b-taggers and jet energy resolution / jet energy scale measurements will help to control systematics.
- Investigation of new reconstruction techniques (e.g. jet substructure) vital to reduce backgrounds and control combinatorial problems.
- However, $t\bar{t}H$ remains a challenging channel.