Experimental ttH(H→bb) Status

Experimental Convenors: Chris Neu (CMS), **Simon Dean** (ATLAS)
Theory Convenors: Laura Reina, Michael Spira

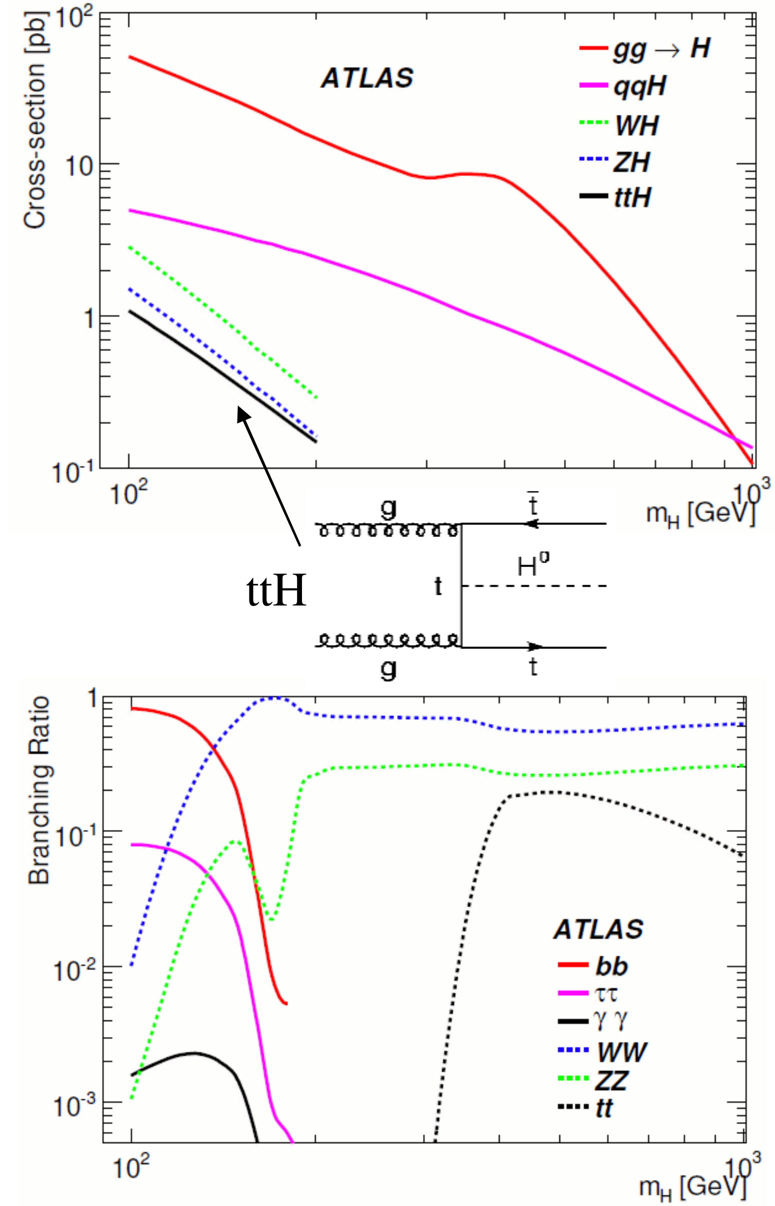
Inauguration workshop of the
LHC Higgs Cross Section Working Group, Freiburg
12/04/2010

Resources

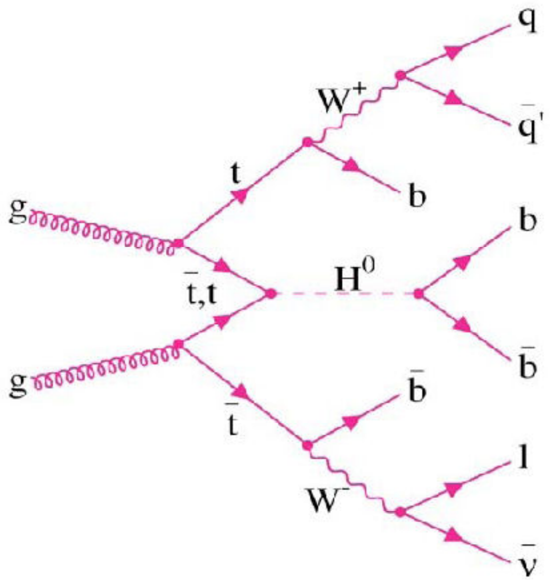
- **ATLAS**
  - Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics (CERN-OPEN-2008-020, December 2008).
- **CMS**
  - CMS Physics Technical Design Report, Volume II: Physics Performance (*Phys. G: Nucl. Part. Phys.* **34** 995, April 2007).

SM Higgs Production and Decay

- ttH(H→bb)
  - for m_H~115-130 GeV with σ*Br ~ 0.2-0.4 pb
  - expected contribution to Higgs discovery in low mass range
  - access to top and bottomYukawa couplings
  - sensitivity studies use full detector simulations and assume centre-of-mass energy of 14 TeV
    - ATLAS integrated luminosity 30 fb^{-1}
    - CMS integrated luminosity 60 fb^{-1}



Final States

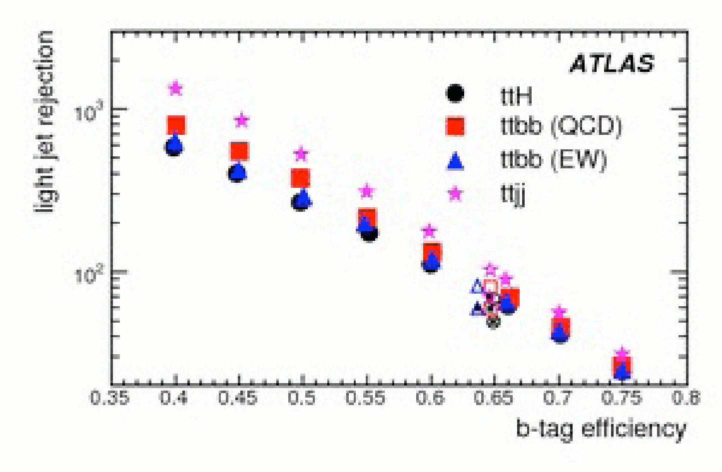


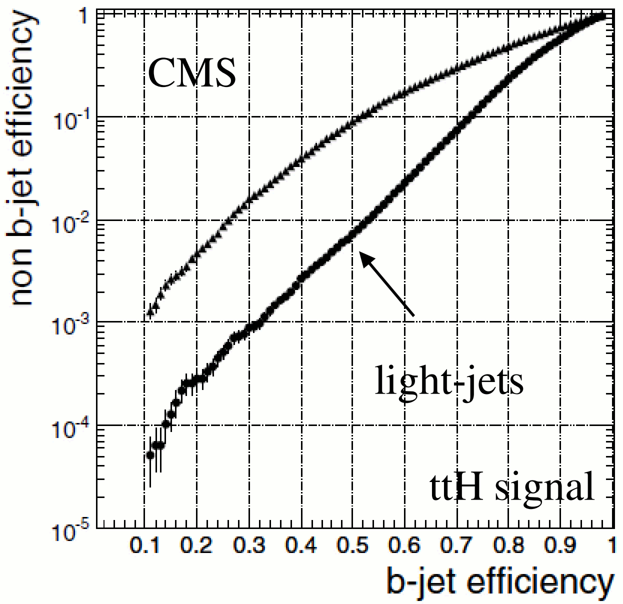
- Final states grouped by W boson decays
  - all-hadronic: highest branching fraction with 43% but difficult to trigger on
  - fully-leptonic: simpler signature to trigger but branching fraction of 5% very low and two neutrinos prevent top mass reconstruction
  - semi-leptonic: good compromise with branching fraction 28% (excluding taus)
    - complex final state: one isolated lepton (trigger), high jet multiplicity (6 jets) with 4 b-tags, missing energy from neutrino

- Backgrounds:
  - reducible: tt+jets
  - irreducible: ttbb from QCD or EW
  - other backgrounds: W+jets, tW and QCD multijet production not considered (negligible if 4 b-tags requirement applied)

Preselection

- Analyses consist of preselection followed by reconstruction of top quark pairs and Higgs boson
  - ATLAS uses three different approaches: cut-based, pairing likelihood, constrained fit
  - CMS follows pairing likelihood approach
- trigger requirement: single lepton trigger
- offline selection
- exactly one isolated lepton
  - ATLAS: p_T>20/25 GeV for e/μ, |η| < 2.5
  - CMS: p_T>20 GeV,
- high multiplicity jet selection
  - ATLAS: at least 6 jets (cone algorithm δR = 0.4) with |η| < 5.0 and p_T > 20 GeV
  - CMS: 6 or 7 jets (cone algorithm δR = 0.5) with |η| < 3.0 and p_T > 20 GeV
    - Jets with 10 GeV < p_T < 20 GeV allowed if there are two associated tracks
- at least 4 b-tagged jets
  - ATLAS applies a "loose" b-tag at this stage:
    - loose b-tag: eff ~ 85% and light (charm) jet rejection = 8.6 (2.4)
    - tight b-tag: eff ~ 65% and light (charm) jet rejection = 60 (6)
  - CMS applies a b-tag with 70% efficiency





ATLAS Cut-based

- Tight b-tagging applied
- Hadronic W: candidates from all pairs of jets excluding the highest four b-tagged jets
- Leptonic W: p_z (neutrino) determination from lepton and missing ET constraining invariant mass to mass of W
- Mass window cuts: hadronic W and top quark candidates within ± 25 GeV of their nominal masses
- tt system: select combination of two b-jets and W boson candidates which minimises:

$$\chi^2 = \left(\frac{m_{jjb} - m_{top}}{\sigma_{m_{jjb}}}\right)^2 + \left(\frac{m_{l\nu b} - m_{top}}{\sigma_{m_{l\nu b}}}\right)^2$$

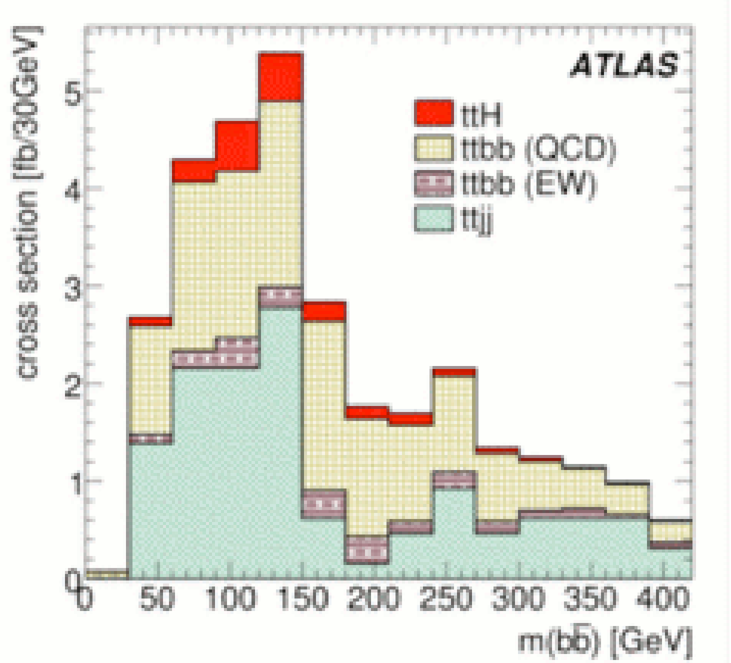
with σ_{mjjb} = 13 GeV, σ_{mlvb} = 19 GeV

- Higgs: remaining b-jets assigned to Higgs decay, only events in low mass range of 90 - 150 GeV are considered to estimate significance

Accepted σ_{signal} = (1.00 ± 0.03) fb

S:B = 0.11

Irreducible background contribution (ttbb): 46%



ATLAS Multivariate Approaches

- Pairing Likelihood:
  - several topological distributions of top system as input for a likelihood: m_{jj}, m_{jjb}, $m_{l\nu b}$, $\delta R(qq,b)$, $\delta R(l,b)$, angle(j,j)
  - combination which maximises the likelihood output is used, remaining b-jets associated to Higgs decay → rejection of combinatorial background

Accepted σ_{signal} = (1.20 ± 0.04) fb

S:B = 0.10

Irreducible background contribution (ttbb): 45%

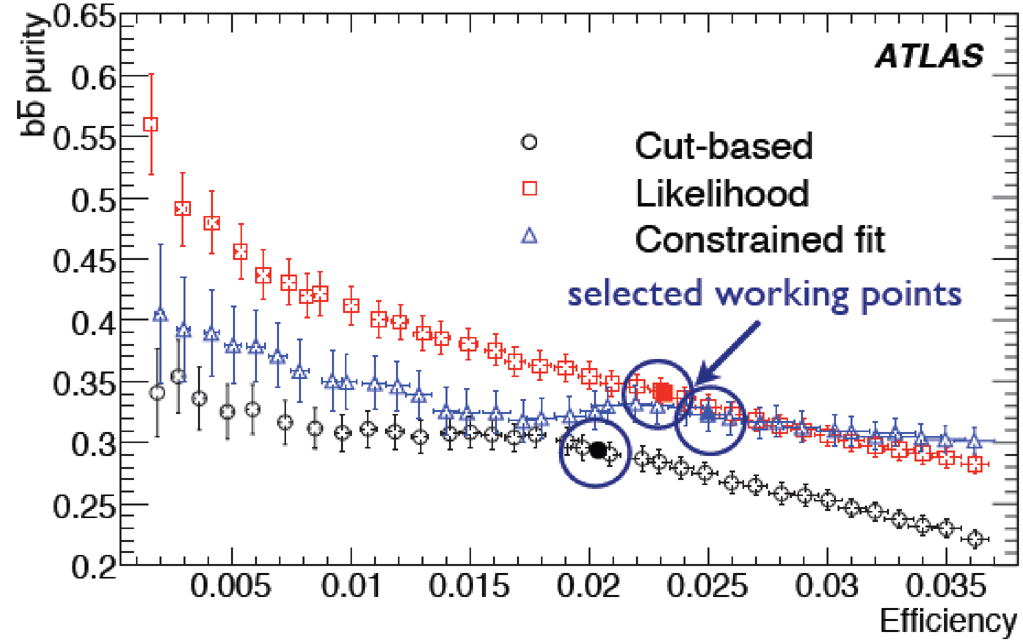
- Constrained Fit:
  - fit to adjust lepton and jet momenta and missing ET to give W and top quark masses
  - two-step likelihood:
    - χ^2 output of fit, event kinematics, jet charge and b-tag weights (only "loose" requirements for candidates) used as input
    - signal events then separated from background events in second likelihood step
  - rejection of combinatorial and physics background

Accepted σ_{signal} = (1.30 ± 0.05) fb

S:B = 0.12

Irreducible background contribution (ttbb): 50%

ATLAS Approaches Comparison



- Comparison of ability to correctly identify objects in event for the three analyses at their working points:

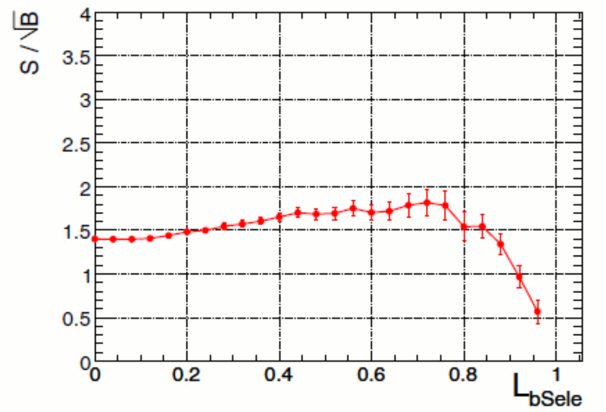
Cut of
90 GeV < m_{bb} < 150 GeV
applied

	Cut Based	Pairing likelihood	Constrained fit
b jet from Hadronic top correct	44.4±1.1%	49.2±1.1%	51.0±1.5%
b jet from Leptonic top correct	50.5±1.2%	57.4±1.1%	56.2±1.5%
Higgs boson jets correctly chosen	29.4±1.0%	34.0±1.0%	32.0±1.4%
Four *b* quarks correct	23.3±1.0%	27.5±1.0%	27.1±1.3%
Higgs boson mass peak resolution, GeV	22.8±1.6	20.1±1.1	22.3±2.1
Signal Efficiency	2.04±0.05%	2.32±0.05%	2.49±0.07%
Signal to background	0.110±0.014	0.103±0.014	0.123±0.019
$s/\sqrt{b}$, 30fb^{-1}	1.82	1.95	2.18

CMS Likelihood Approach

- All decays (all-hadron, semi-leptonic, dilepton) considered
  - Semi-leptonic analysis described here
- Leptonic W: p_z (neutrino) determination from lepton and missing ET constraining invariant mass to mass of W
- Use likelihood to choose best tt system, based on masses, b-tagging and event kinematics:

$$L_{Event} = L_{Mass} \times L_{bTag} \times L_{Kine}.$$



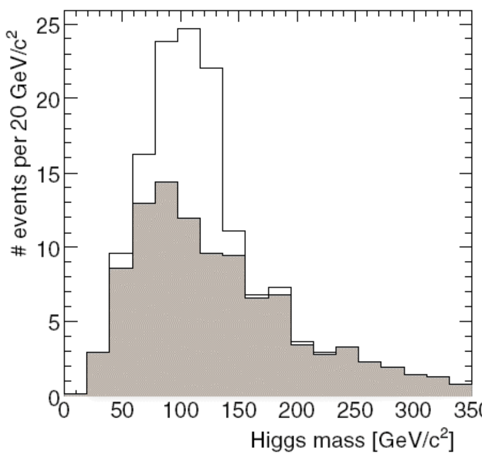
- Two remaining jets with highest b-tagging discriminator comprise the Higgs
- b-tagging then tightened to reject background

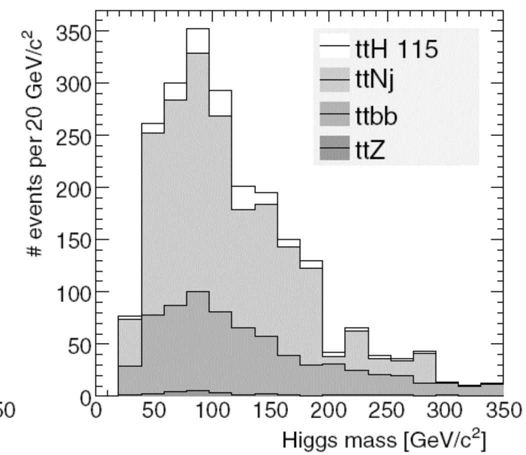
120 GeV Higgs working point:

Accepted σ_{signal} = (1.27 ± 0.06) fb

S:B = 0.08

Irreducible background contribution (ttbb): 40%

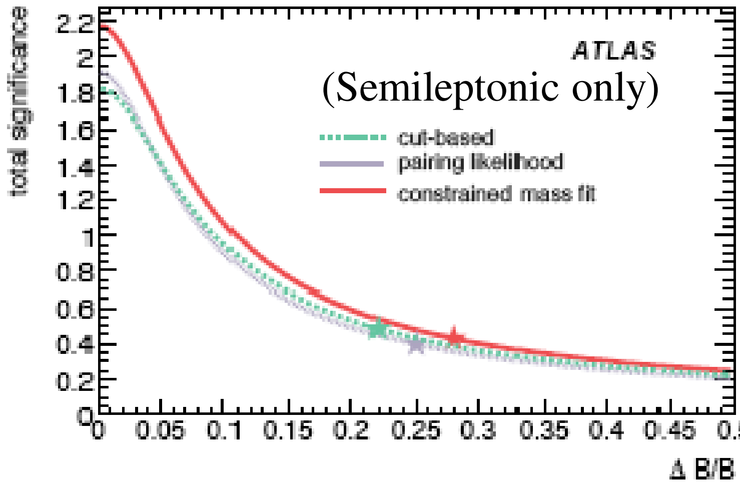




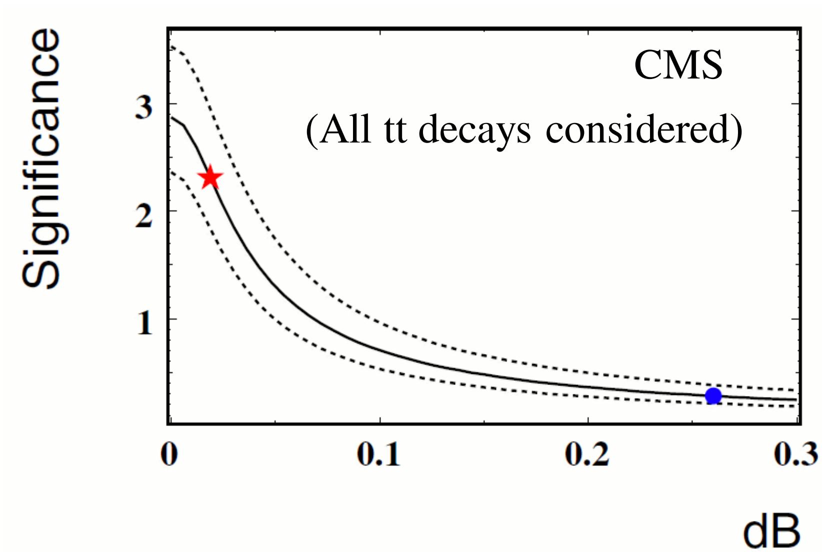
Systematic Uncertainties

- Systematic uncertainties due to detector effects
  - jet uncertainties (jet energy and b-tagging) → crucial impact on reconstruction of tt system and correct identification of b-jets used for analysis
  - ATLAS table of systematics

Source		Cut-based signal	Cut-based background	Likelihood signal	Likelihood background	Constrained fit signal	Constrained fit background
Jet	energy scale	± 9%	± 5%	± 9%	± 14%	± 9%	± 8%
	resolution	± 0.3%	± 7%	± 1%	± 5.5%	± 5%	± 14%
	b-tag	± 16%	± 20 %	± 18%	± 20%	± 16%	± 20%
	b mis-tag	± 0.8%	± 5%	± 1.1%	± 3%	± 3%	± 10%



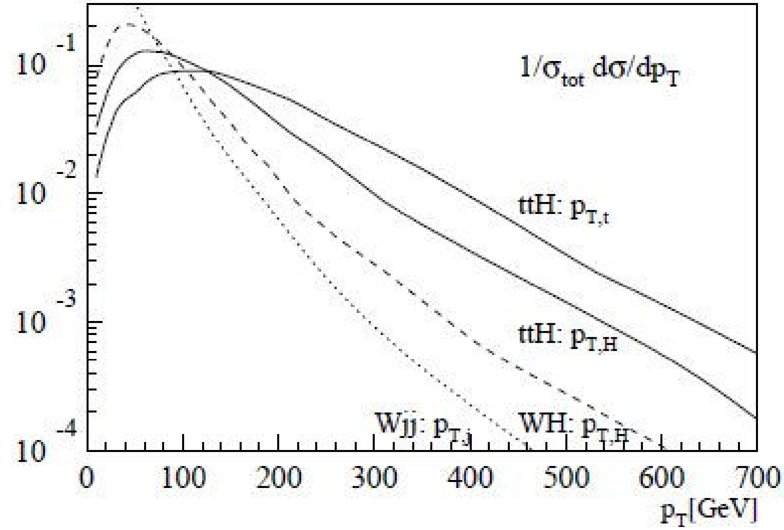
  - CMS uses standard systematics
    - Jet energy scale: 3-10% depending on p_T
    - Jet resolution: 10%
    - b-tagging: 4%
    - light-jet rejection: 10%
    - Luminosity: 3%

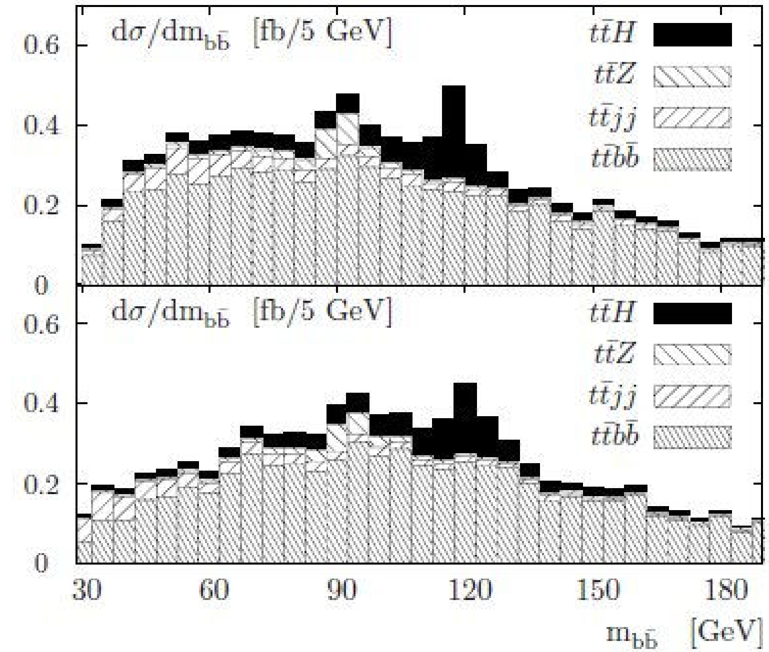


- theoretical uncertainties: large for signal and background but can be reduced by making direct measurements
- **Background estimation from data necessary!**

More Recently

- Jet studies within ATLAS have shown that anti-k_T is more effective than cone.
- Recent publication "Fat Jets for a Light Higgs" (Plehn, Salam, Spannowsky)
- Look for hard jets (p_T>200 GeV)
- Use subjet techniques to identify highly-boosted hadronic tops and Higgs
- Predicts a boost of signal significance from ~2 to ~4-5
- Reduced systematic errors from jet energy scale, b-tagging





Conclusion

- Accepted signal cross-section of ~1 fb can be found with statistical significance of ~2 before systematics considered
- Much lower (~0.4-0.5) after systematics are considered
- Broad Higgs mass peak (due to combinatorial background) on top of large backgrounds
- Large systematic uncertainties → background normalisation from data!
- Possible improvement when looking at highly-boosted regime...