LHC Higgs Cross Section Meeting (ttH WG), Sept 28, 2012

Search for ttH in ATLAS: Questions for Theorists

(Round 2)

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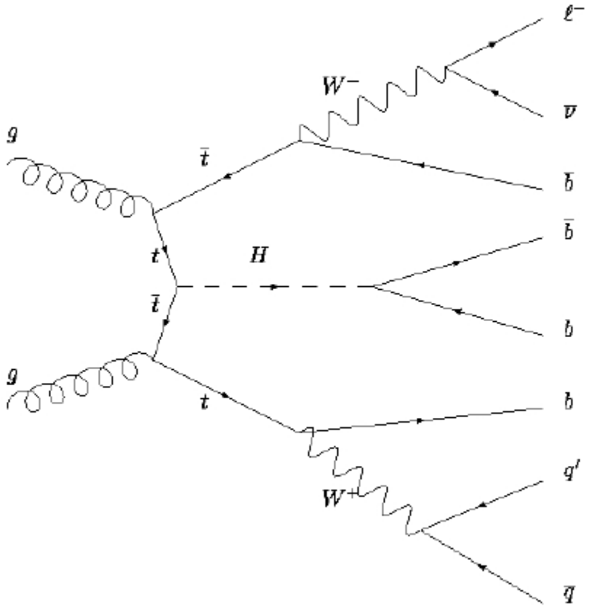
On behalf of the ATLAS HSG5 Working Group

Analysis Overview



- Currently focusing on lepton+jets channel.
  Consider ONLY H→bb decays.

- Basic selection in "signal region":
  - =1 e or μ, $p_T(e)$>25 GeV, $p_T(\mu)$>20 GeV
  - $E_T^{miss>}$>30 GeV (e+jets), >20 GeV (μ+jets)
  - ≥6 jets p_T>25 GeV, $|\eta|$<2.5
  - 3 or ≥4 jets are tagged
    (~70% b-jet eff., ~0.7% mistag rate)

- Small signal cross section on top of huge tt+jets background.
  At $\sqrt{s}$=7 TeV: σ(ttH)xBR(H→bb)~65 fb @ m_H=120 GeV, σ(tt)~160 pb

- Not only background is large but also uncertain:
  - Instrumental systematics (e.g. JES, b-tagging, etc)
  - tt modeling systematics ➔ less well-defined. Need theoretical input.

- Sensitivity of the search strongly affected by handling of systematic uncertainties.

tt+jets Modeling

- Based on ALPGEN v2.13 interfaced to HERWIG.
- Generate samples separately for:
  - tt+n light partons (n≤5) ➔ MLM matching needed
  - ttbb
  - ttcc

  (ttbb, ttcc) ➔ No MLM matching needed

  Using CTEQ6L1 PDF.

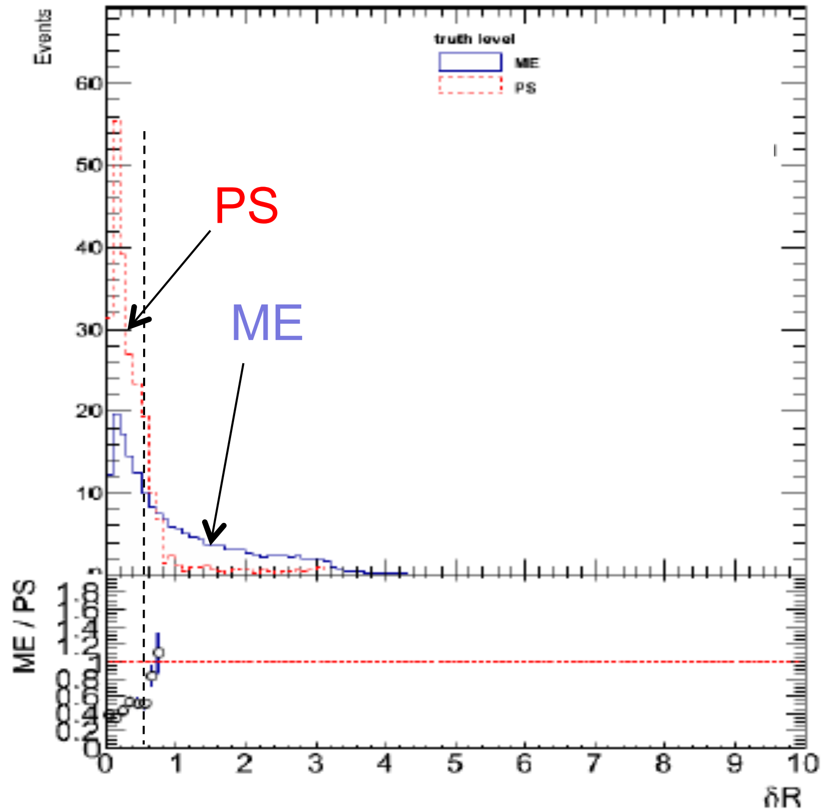
  Default factorization scale: $Q^2 = \Sigma\ m^2 + p_T^2$

- "By-hand" heavy-flavor overlap removal between ME and PS for ttQQ:
  - tt+light partons sample:

    QQ pairs generated in PS evolution
  - ttQQ (Q=b,c) ME samples
  - Use ttQQ ME sample if $\Delta R(Q,Q) > 0.4$

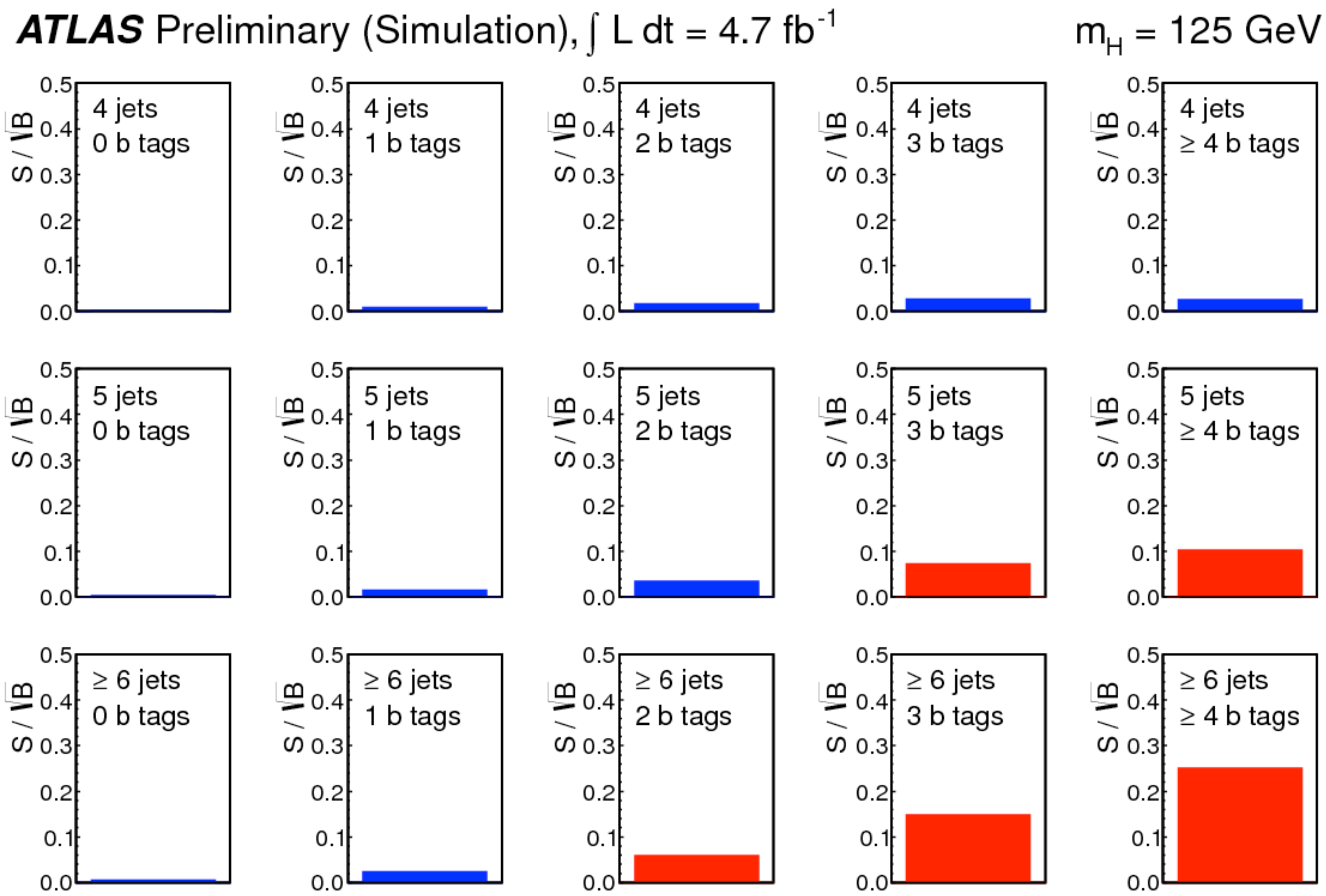
    Otherwise use QQ from PS (from tt+light partons sample).

  Rationale is that low angle/soft QQ pairs will be more accurately described by PS
- Inclusive tt+jets samples normalized to approx NNLO cross section.



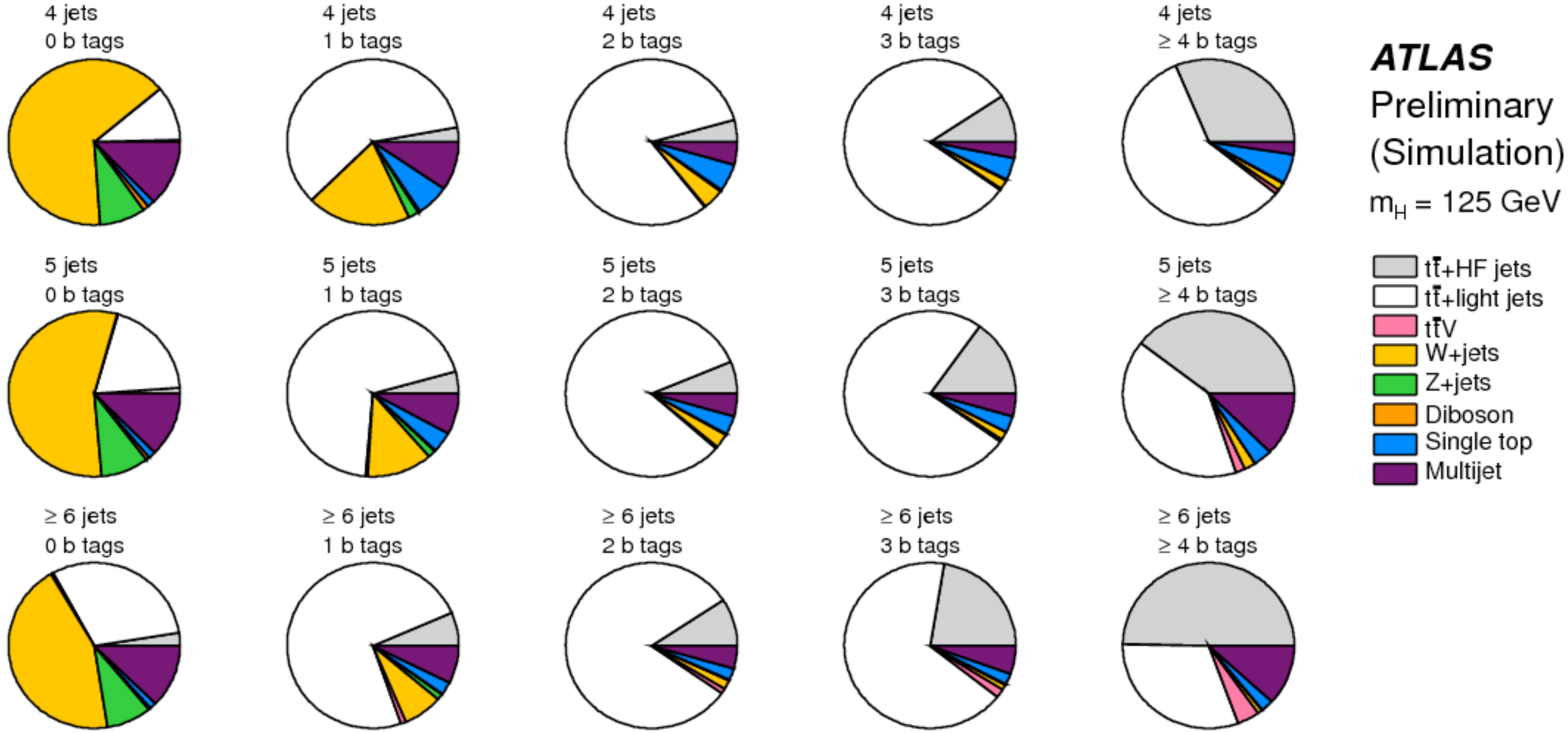
Analysis Overview

- As expected, S/√B is fairly small, even in what one would consider the “signal region”:



Analysis Overview

- As expected, tt+jets is the dominant background as soon as 1 b-tag is required:

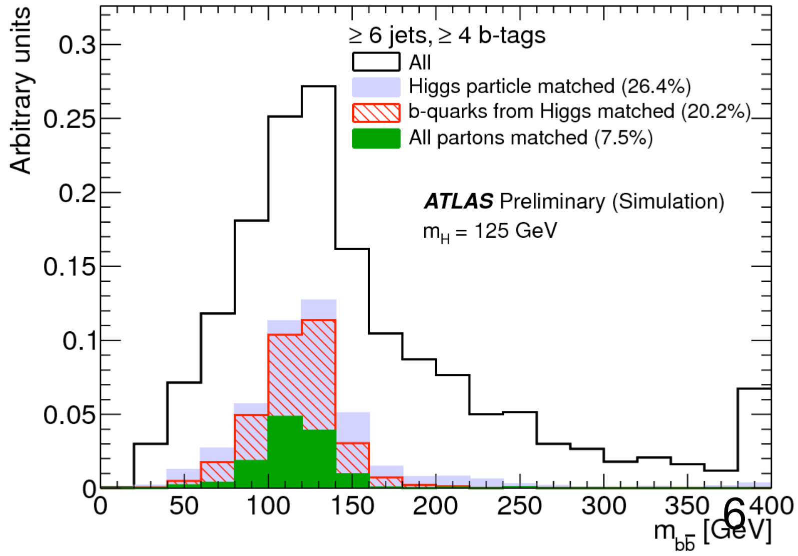


- However, we need to worry about tt modeling (both normalization and shape):
  - As a function of jet multiplicity.
  - As a function of b-tag multiplicity (changing fractions of ttbb, ttcc, tt+light jets).

Basic Strategy

- Keep first round of analysis "simple" and "intuitive" to get a better feeling for what the real issues are wrt background modeling and systematic handling.
- More sophisticated (e.g. MVA-based analyses) can follow later on a more solid footing.

1. Consider 9 channels based on jet and b-tag multiplicity:
   4 jets x (0,1,≥2 b-tags), (5 jets, ≥6 jets) x (2,3,≥4 b-tags)
2. Events with 5, ≥6 jets and 3 or ≥4 b-tags are signal-enriched. The rest are signal-depleted channels which can be considered for the purpose of constraining systematic uncertainties.
3. Final discriminant:
   - ≥6 jets and 3 or ≥4 b-tags: m_{bb} via constrained kinematic fit
     - Hadronic W resonance: $m_{jj} \sim m_W$
     - Leptonic W resonance: $m_{l\nu} \sim m_W$
     - Top quark resonances: $m_{jjb} \sim m_{l\nu b} \sim m_t$
     - m_{bb} built from the two b-jet candidates not assigned to the tt system
   - Rest of channels: $H_T^{had} = \Sigma\, p_{T,jet}$
     ➔ Mostly sensitive to jet-related and tt modeling systematics



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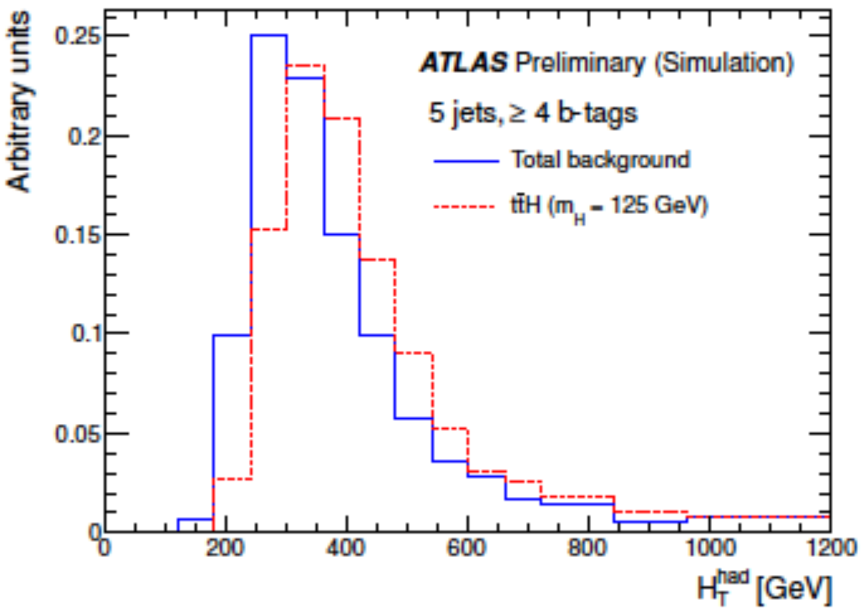
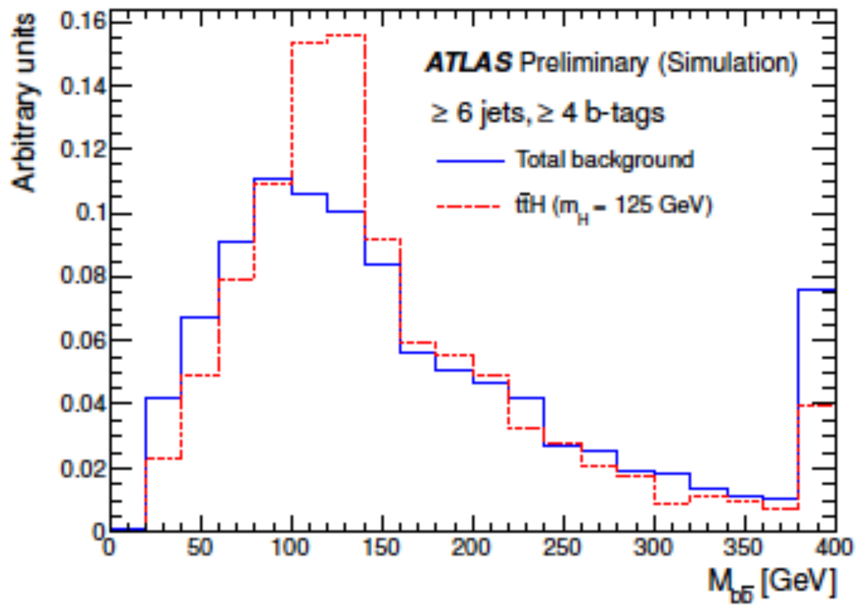




Systematic Uncertainties

	Systematic uncertainty	Status	Components
Object-related	Luminosity	N	1
	Lepton ID+reco+trigger	N	1
	Jet vertex fraction efficiency	N	1
	Jet energy scale	SN	16
	Jet energy resolution	N	1
	b-tagging efficiency	SN	9
	c-tagging efficiency	SN	5
	Light jet-tagging efficiency	SN	1
Bkg cross sections	$t\bar{t}$ cross section	N	1
	$t\bar{t}V$ cross section	N	1
	Single top cross section	N	1
	Dibosons cross section	N	1
	V+jets normalisation	N	3
	Multijet normalisation	N	7
Physics modeling	W+heavy-flavour fractions	SN	4
	$t\bar{t}$ modelling	SN	3
	$t\bar{t}$+heavy-flavour fractions	SN	1
	$t\bar{t}H$ modelling	N	1

- Can effectively exploit high-statistics control samples to constrain the leading ones, but need sophisticated enough treatment to not artificially overconstrain them (e.g. by neglecting shape systematics or lumping together individual sources within a given category with different kinematic dependencies).

"Theoretical" Systematics on tt+jets

- tt cross section: +10%/-11% from approx NNLO prediction using HATHOR.

- ALPGEN modeling: consider three different systematic variations (affect both normalization and shape)
  - Vary up/down by x2 default factorization scale: $Q^2=\Sigma\ m^2+p_T^2$
    ➔ variation applied in a correlated fashion to tt+light jets, ttbb, ttcc

  - Use different dynamic factorization scale: $Q^2=sx_1x_2$
    ➔ variation applied in a correlated fashion to tt+light jets, ttbb, ttcc
    ➔ symmetrize systematic to have two-sided effect

  - Vary up/down by x2 default choice of renomalization scale used for evaluation of α_s at each local vertex in the matrix element calculation
    ➔ This is done in conjunction with the MLM matching, so only the tt+light parton sample affected (including ttbb and ttcc events selected from the PS prediction by the heavy-flavor overlap removal procedure).

  - In all cases the total inclusive cross section is rescaled to the approx NNLO prediction.

"Theoretical" Systematics on tt+jets

- tt+HF fractions: i.e. ratios ttbb/tt+jets and ttcc/tt+jets
  - Fitted to data, but benefit from putting some "prior" uncertainty so that is not a fully-floating parameter.
  - Would like to calibrate ALPGEN to best available NLO prediction but no numbers available yet at 7 TeV (and 8 TeV).

    [Still, not a trivial thing to do, see questions later]
  - In their absence, study dependence of ttbb/ttjj ratio in ALPGEN by varying factorization scale (in a correlated fashion). Find ratio stable to within 25%.

    To be conservative, double it (i.e. 50%).

  - Scale up/down ttbb and ttcc yields by 50% in a correlated fashion.
    - tt+light jets yields adjusted accordingly to maintain total yield pre-tag per jet multiplicity bin (i.e. we are really changing the fraction)

  - This is one of the main uncertainties in the analysis (to be quantified later on).
    - My understanding is that CMS is taking a 20% uncertainty

Systematic Uncertainties

% change in yield in ≥6 jets/≥4 tags

Prefit

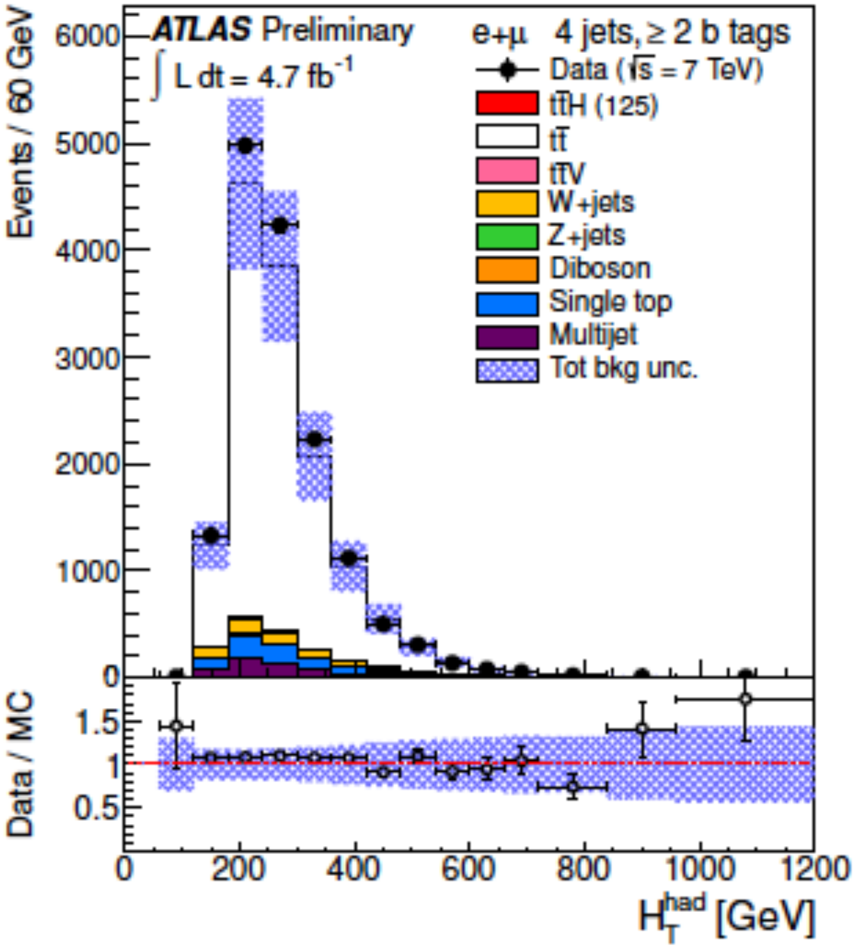
	$t\bar{t}H(125)$	$t\bar{t}$
Luminosity	+1.8/-1.8	+1.8/-1.8
Lepton ID+reco+trigger	+1.3/-1.3	+1.3/-1.3
Jet vertex fraction efficiency	+2.4/-1.7	+2.5/-1.9
Jet energy scale	+9.6/-9.9	+13.5/-15.2
Jet energy resolution	+1.0/-1.0	+0.7/-0.7
b-tagging efficiency	+30.4/-34.8	+22.9/-25.2
c-tagging efficiency	+5.0/-5.0	+16.5/-17.3
Light jet-tagging efficiency	+1.3/-1.3	+11.4/-12.1
$t\bar{t}$ cross section	–	+9.9/-10.7
$t\bar{t}V$ cross section	–	–
Single top cross section	–	–
Diboson cross section	–	–
V+jets normalisation	–	–
Multijet normalisation	–	–
W+heavy-flavour fractions	–	–
$t\bar{t}$ modeling	–	+15.8/-20.2
$t\bar{t}$+heavy-flavour fractions	–	+25.9/-25.9
$t\bar{t}H$ modeling	+1.3/-1.5	–
Total	+32.5/-36.7	+46.3/-50.1

- Can effectively exploit high-statistics control samples to constrain some, but need sophisticated enough treatment to not artificially overconstrain them (e.g. by neglecting shape systematics or lumping together individual sources within a given category with different kinematic dependencies).

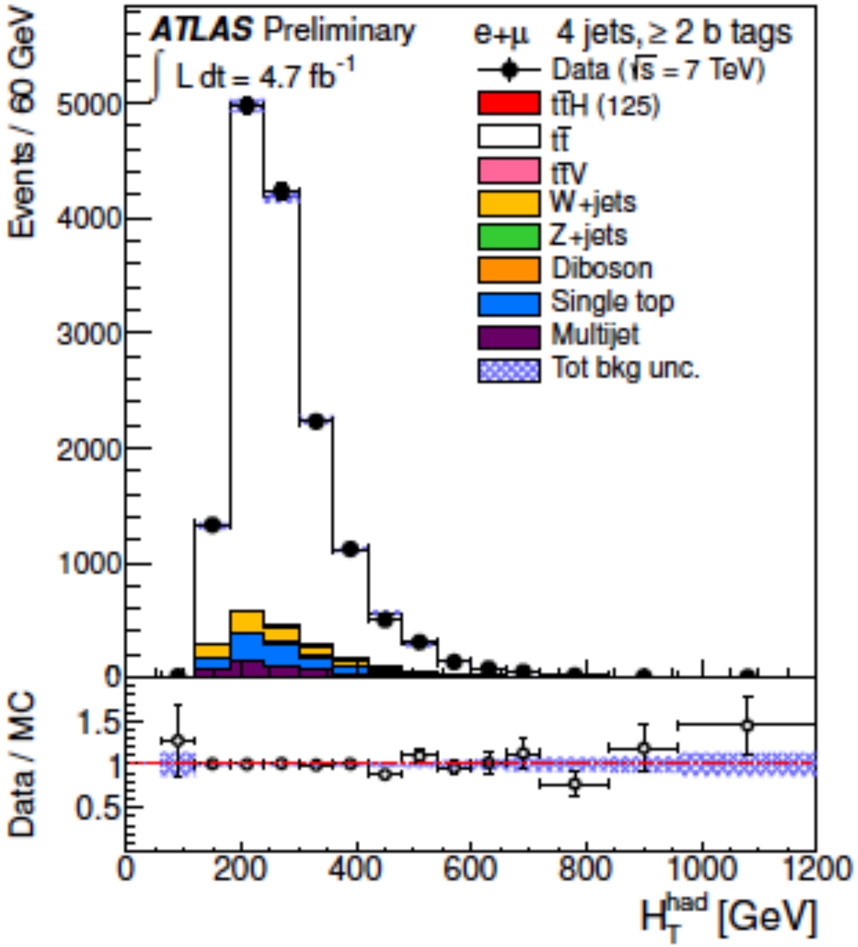
Profiling in Action: Example Plots

4 jets, ≥2 tags (signal-depleted)

Prefit



Postfit



Profiling in Action: Example Plots

5 jets, 2 tags (signal-depleted)

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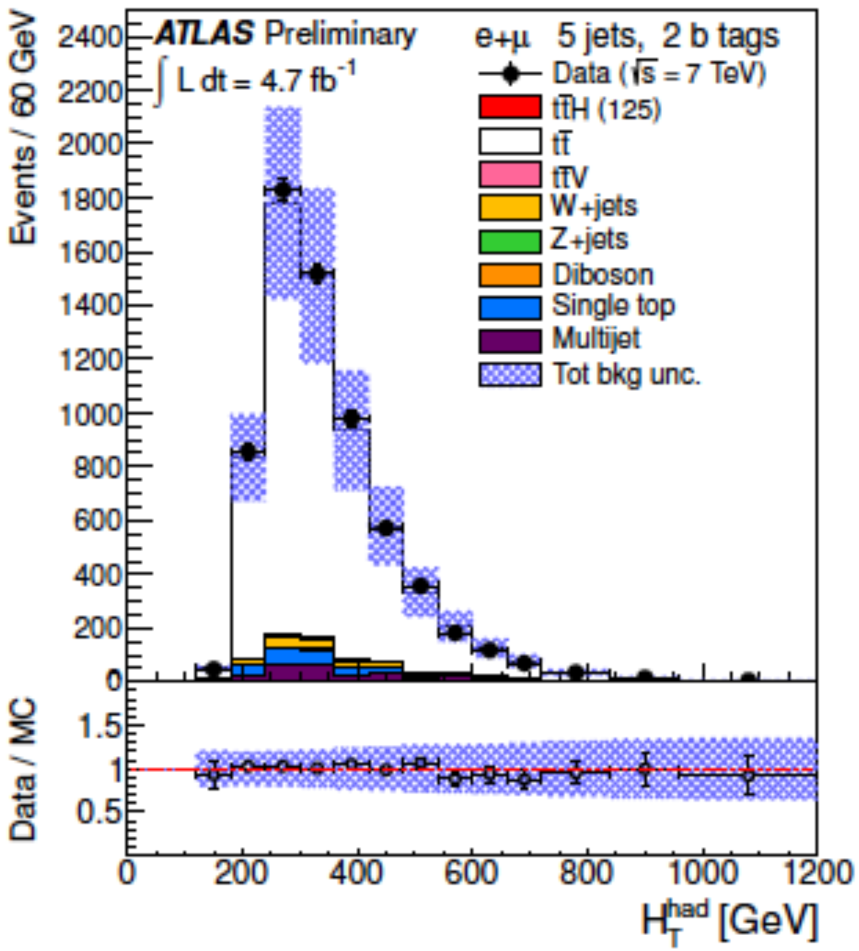

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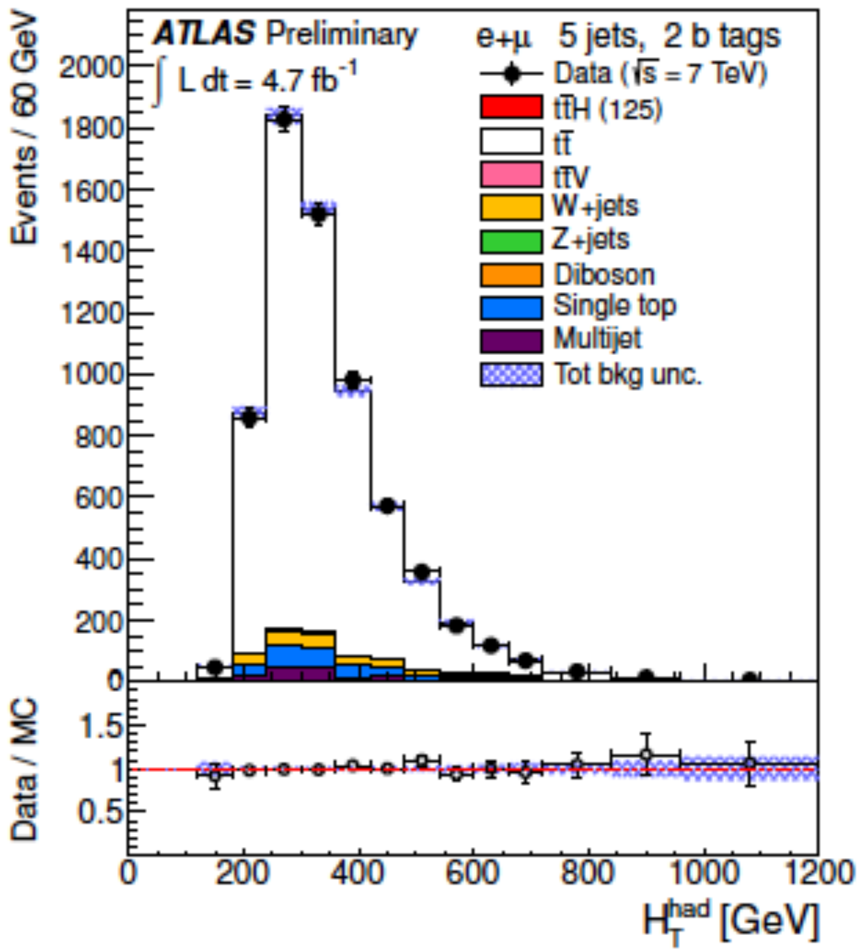
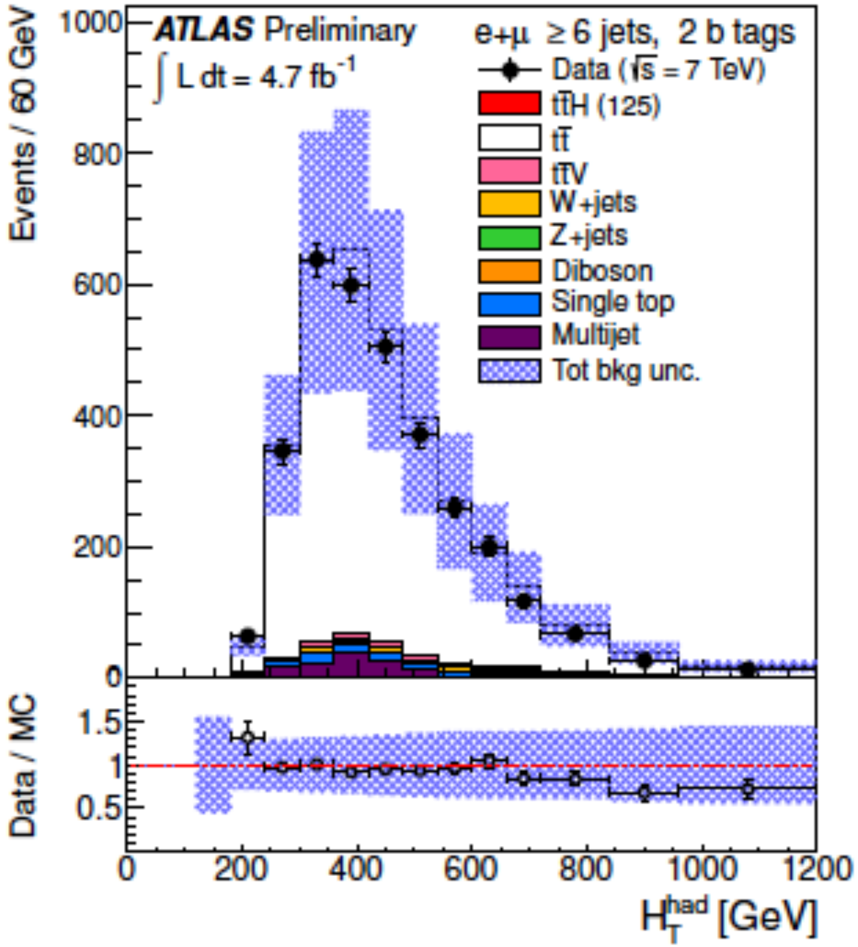


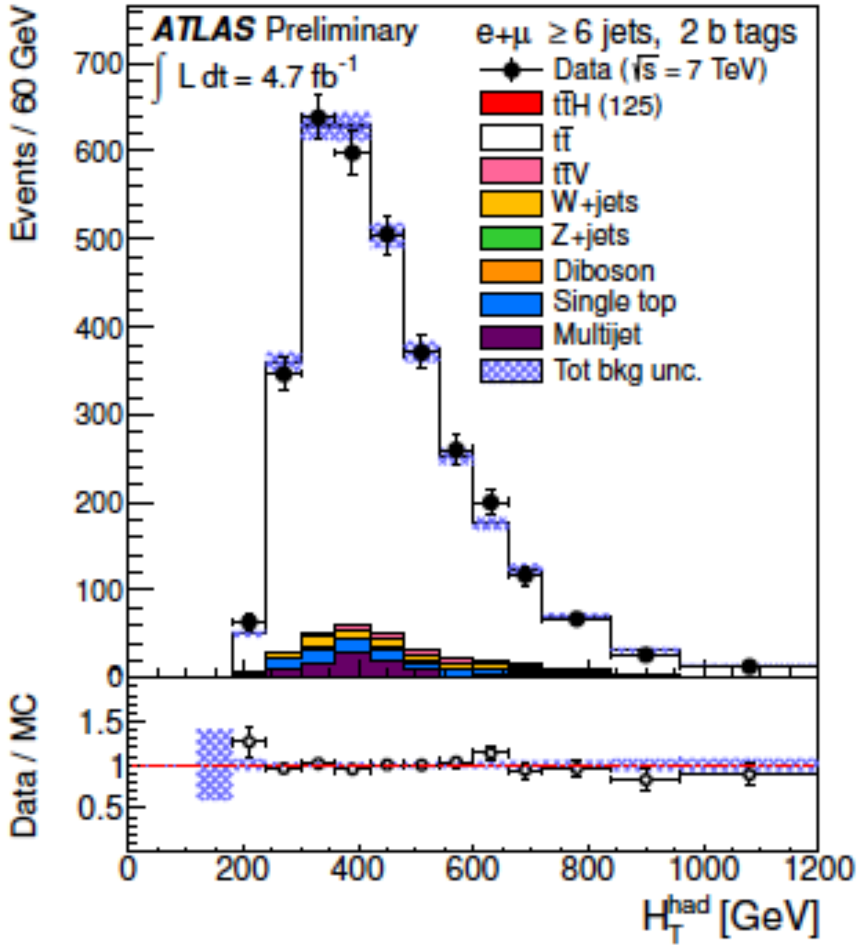
Profiling in Action: Example Plots

≥6 jets, 2 tags (signal-depleted)

Prefit



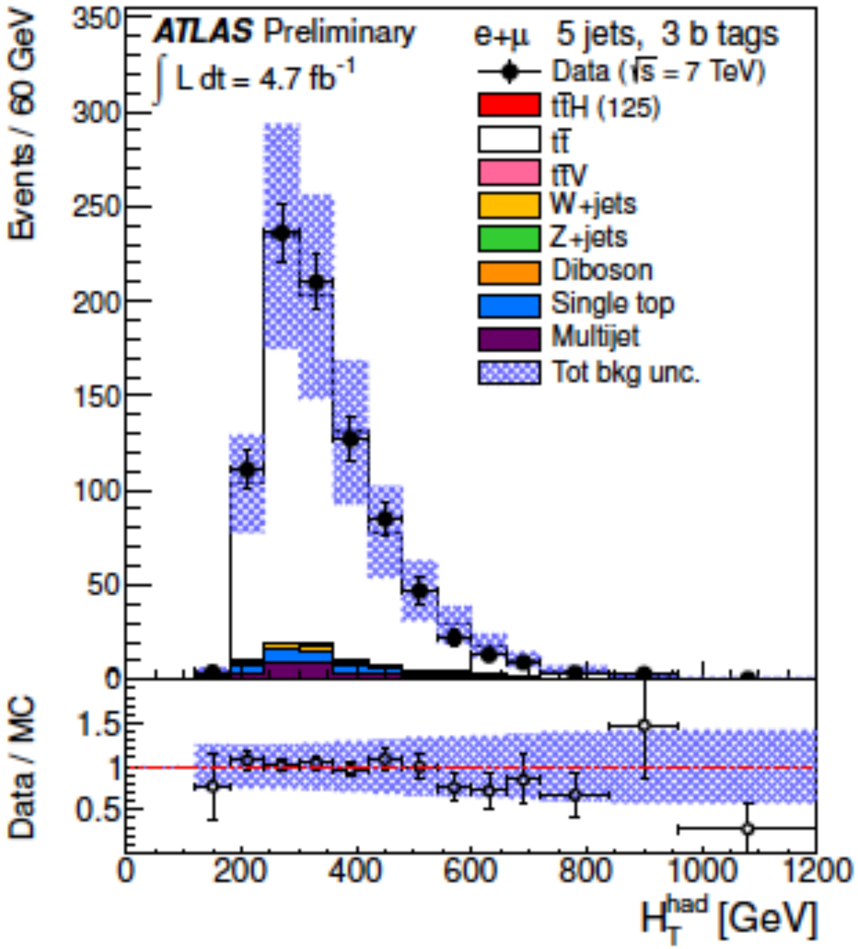
Postfit



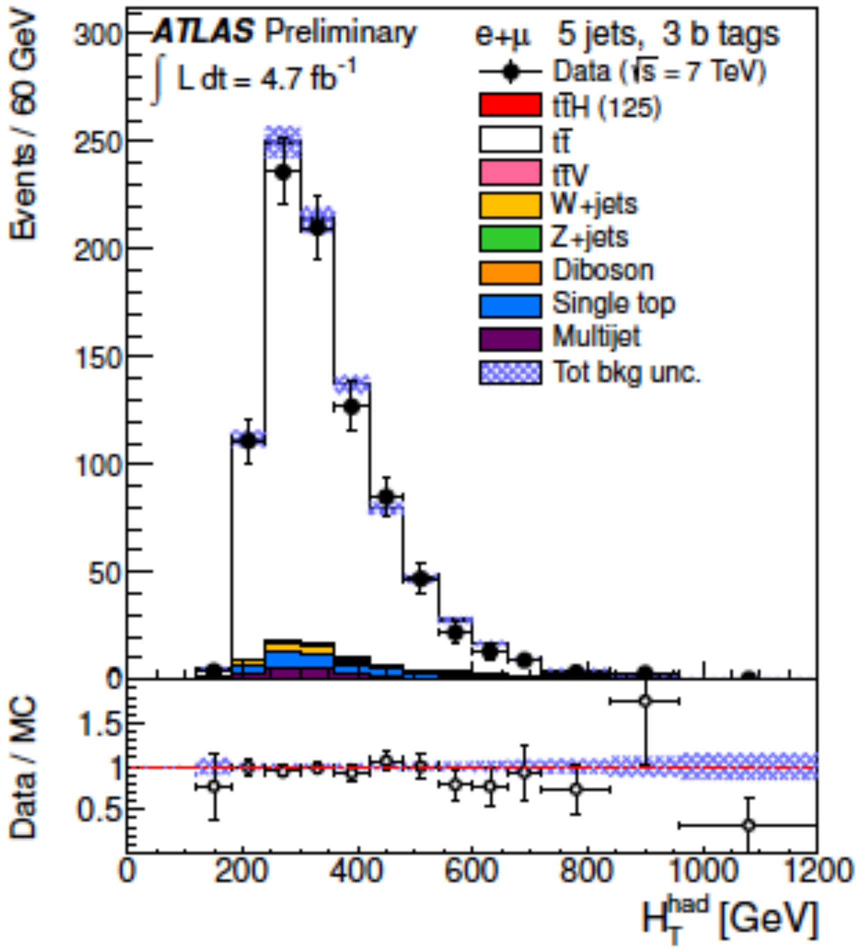
Profiling in Action: Example Plots

5 jets, 3 tags (signal-depleted)

Prefit



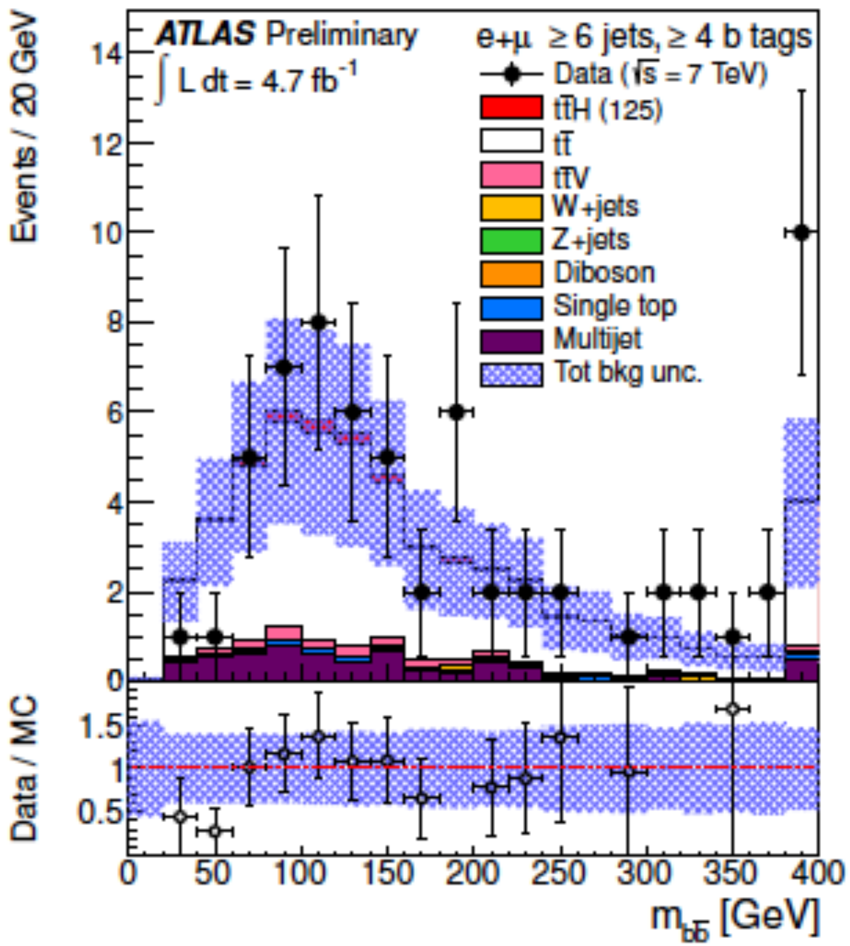
Postfit



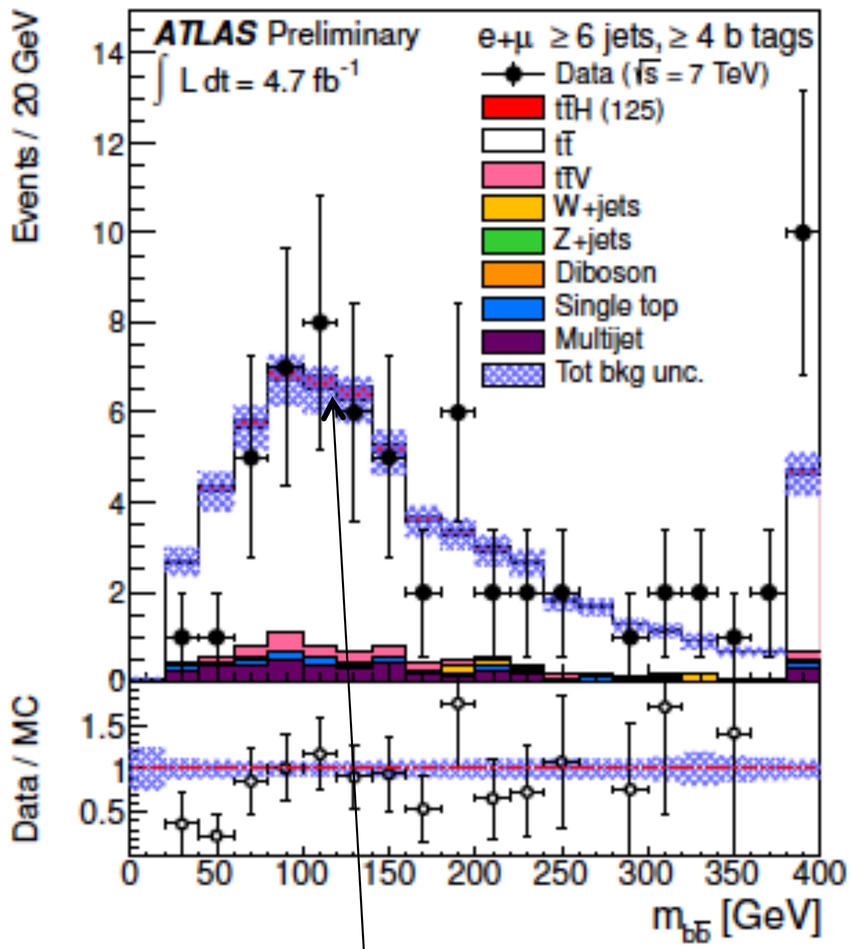
Profiling in Action: Example Plots

≥6 jets, ≥4 tags (signal-enriched)

Prefit



Postfit



Measured tt+HF scaling factor: 1.34±0.21

ttH signal still x2 smaller than post-fit background uncertainties

Profiling in Action: Example Numbers

% change in yield in ≥6 jets/≥4 tags

	Prefit $t\bar{t}H(125)$	Prefit $t\bar{t}$	Postfit $t\bar{t}$
Luminosity	+1.8/-1.8	+1.8/-1.8	+1.4/-1.4
Lepton ID+reco+trigger	+1.3/-1.3	+1.3/-1.3	+1.1/-1.1
Jet vertex fraction efficiency	+2.4/-1.7	+2.5/-1.9	+1.9/-1.4
Jet energy scale	+9.6/-9.9	+13.5/-15.2	+7.1/-8.0
Jet energy resolution	+1.0/-1.0	+0.7/-0.7	+0.6/-0.6
b-tagging efficiency	+30.4/-34.8	+22.9/-25.2	+9.9/-10.5
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$t\bar{t}$ cross section	–	+9.9/-10.7	+3.0/-3.2
$t\bar{t}V$ cross section	–	–	–
Single top cross section	–	–	–
Diboson cross section	–	–	–
V+jets normalisation	–	–	–
Multijet normalisation	–	–	–
W+heavy-flavour fractions	–	–	–
$t\bar{t}$ modeling	–	+15.8/-20.2	+6.3/-8.8
$t\bar{t}$+heavy-flavour fractions	–	+25.9/-25.9	+11.1/-11.1
$t\bar{t}H$ modeling	+1.3/-1.5	–	–
Total	+32.5/-36.7	+46.3/-50.1	+13.8/-16.0

- Significant reduction in overall background uncertainty (non-negligible anticorrelations in some post-fit uncertainties).

Results

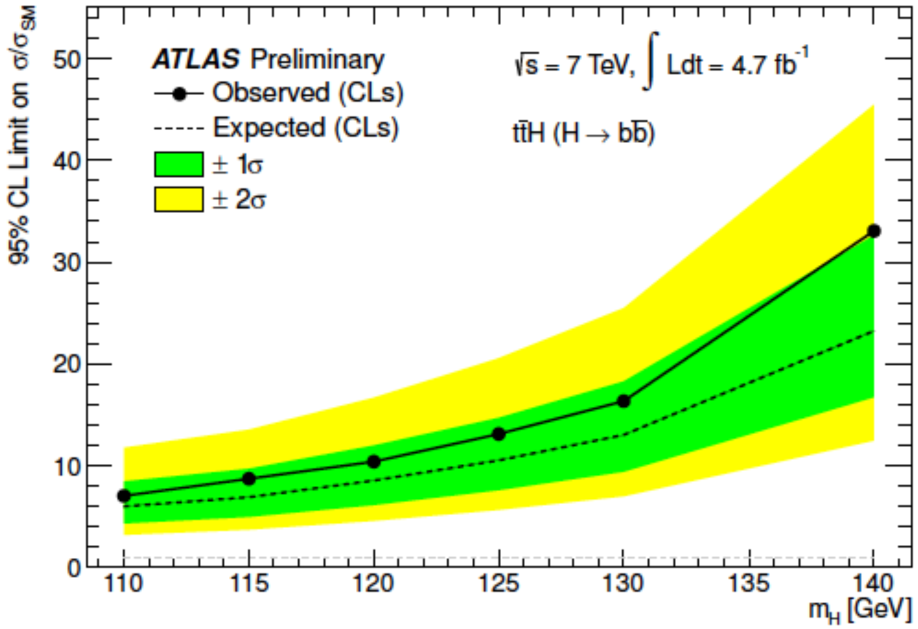
- Effect of systematics is to degrade expected limit/SM by 72% (6.1 ➔ 10.5).
- Leading 5 systematics are:
  - tt+HF fraction
  - Light tagging efficiency
  - C tagging efficiency
  - QCD normalization
  - JES

  They alone degrade sensitivity by 55%.

  Almost half of this degradation (25%) comes from tt+HF.

- Warning: as statistics grows, the typical tt+jets systematic treatments can effectively result into zero uncertainty due the strong constraining power of data.

  Need to make sure we won't be shooting ourselves in the foot.



m_H (GeV)	observed	-2 s.d.	-1 s.d.	median	+1 s.d.	+2 s.d.	stat only
110	7.0	3.2	4.3	6.0	8.5	11.8	3.5
115	8.7	3.7	5.0	6.9	9.7	13.6	4.0
120	10.4	4.6	6.2	8.5	12.0	16.7	4.9
125	13.1	5.7	7.6	10.5	14.7	20.6	6.1
130	16.4	7.0	9.4	13.0	18.3	25.5	7.8
140	33.0	12.5	16.7	23.2	32.7	45.5	14.2

Table 3: Observed and expected (median, for the background-only hypothesis) 95% CL upper limits on $\sigma(t\bar{t}H) \times BR(H \to b\bar{b})$ relative to the SM prediction, σ/σ_{SM}, as functions of m_H. The last column corresponds to the median upper limit with all systematic uncertainties removed.

tt+jets Modeling Uncertainties

- Would be desirable to start moving towards agreed-upon prescriptions between theorists and experimentalist (and between ATLAS and CMS)

- Large tt+jets (incl tt+HF) background must be precisely estimated from a combination of
  - ME+PS MC
  - Data-driven techniques
  - NLO calculations ➔ NOT USED YET

  We not only care about normalization but also shape!

  For H→bb, signal is where background peaks…

  ➔ The question is: how to do this consistently?

Going back again to the old questions…

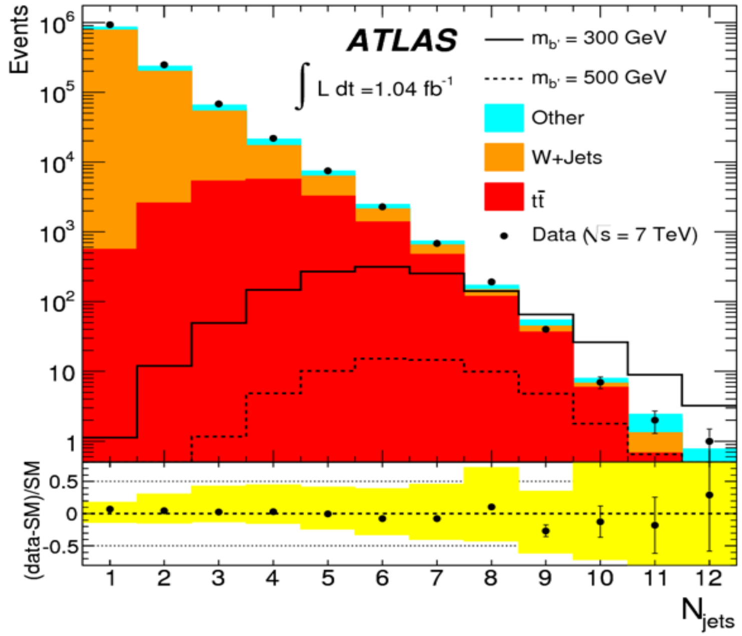
Questions on tt+jets Modeling

arXiv:1202.6540

Basic requirements:

- Need to be able to describe tt+jets over a wide range in jet multiplicity spectrum.
- Need as a minimum a LO calculation for ttbb.

➔ Currently using ALPGEN+HERWIG.

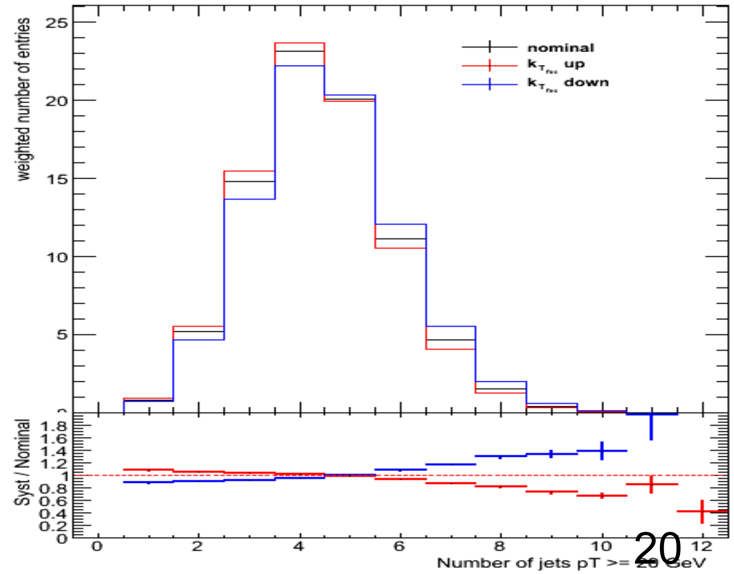


Q1: What variations in generator parameters should be considered to cover for possible modeling uncertainties?

[In other words: how many shape systematics are just enough?]

Can such variations (e.g. functional form of factorization scale) be considered correlated between ttjj and ttbb?

What would be ttbb-specific systematics?



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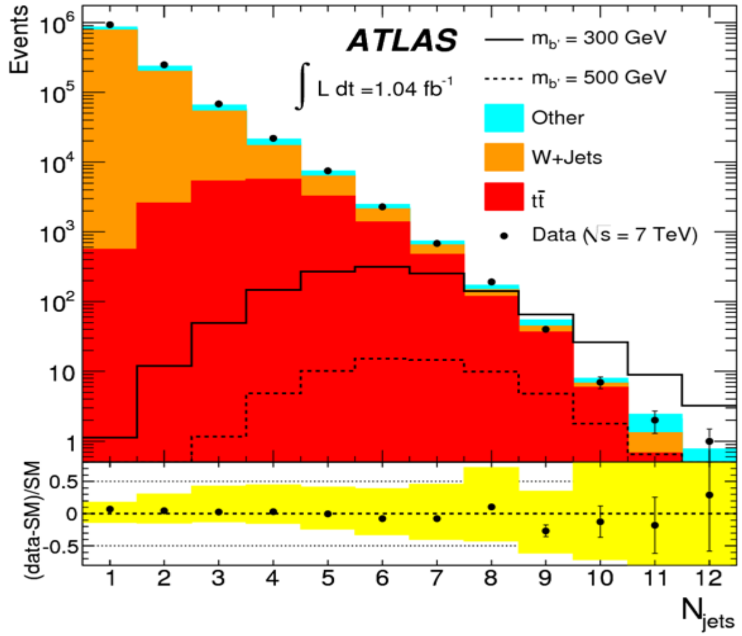
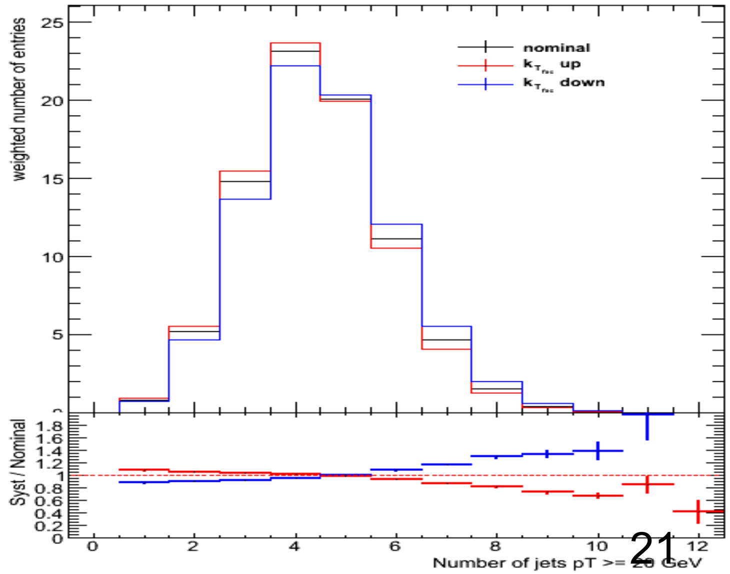


Q2: Can one use existing NLO calculations to "tune" ALPGEN generation parameters to better describe shapes and/or constrain range of variation in parameters to explore?

Q3: How to use existing NLO calculations to "normalize" ALPGEN at particular jet multiplicity bins? What are the related uncertainties?

Q4: Are NLO calculations available at 7 and 8 TeV? Are there "user-friendly" tools that can be run by experimentalists for ME+PS vs NLO comparisons of differential distributions, etc?

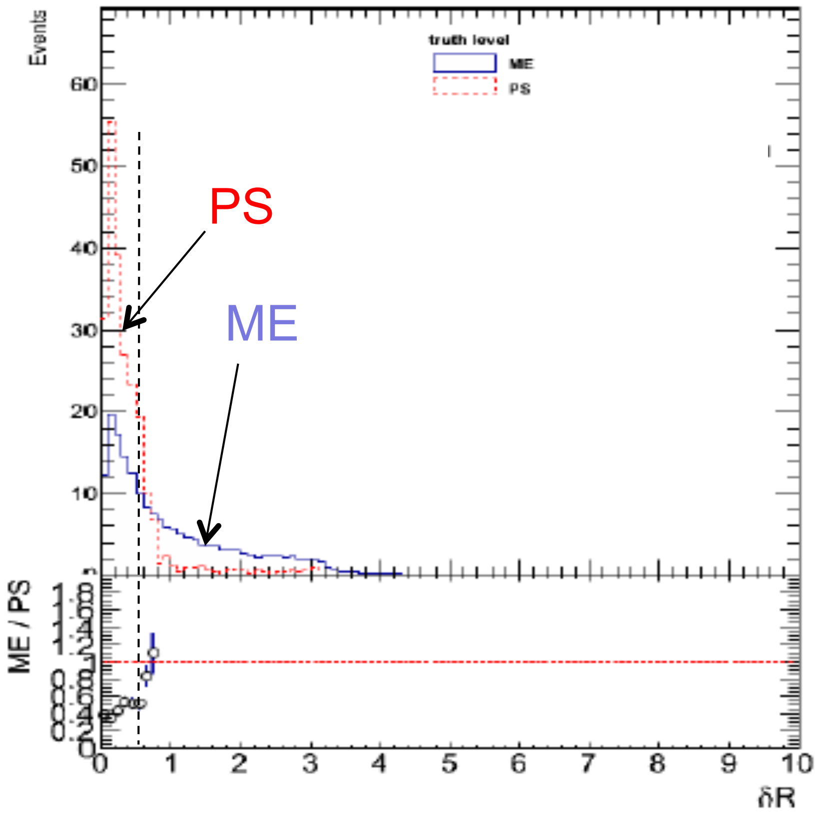


Questions on tt+jets Modeling

ALPGEN does not implement a procedure for overlap removal between ME and PS for ttQQ. This is currently done "by hand" with a relatively ad-hoc prescription:

- Generate tt+light partons ME sample.
  (QQ pairs will be generated in PS)
- Generate ttQQ (Q=b,c) ME sample
- Use ttQQ ME sample if $\Delta R(Q,Q)>0.4$
  Otherwise use QQ from PS (from tt+light partons sample).

Rationale is that low angle/soft QQ pairs will be more accurately described by PS (this is ~50% of ttbb events with ≥6 jets/≥4 tags!)



Q5: Does this make sense? How do we assess systematic uncertainties on the relative fraction of tt(QQ) and ttQQ events? [This is needed because these events have different topology and contribute differently to =3-tag and ≥4-tag bins.]

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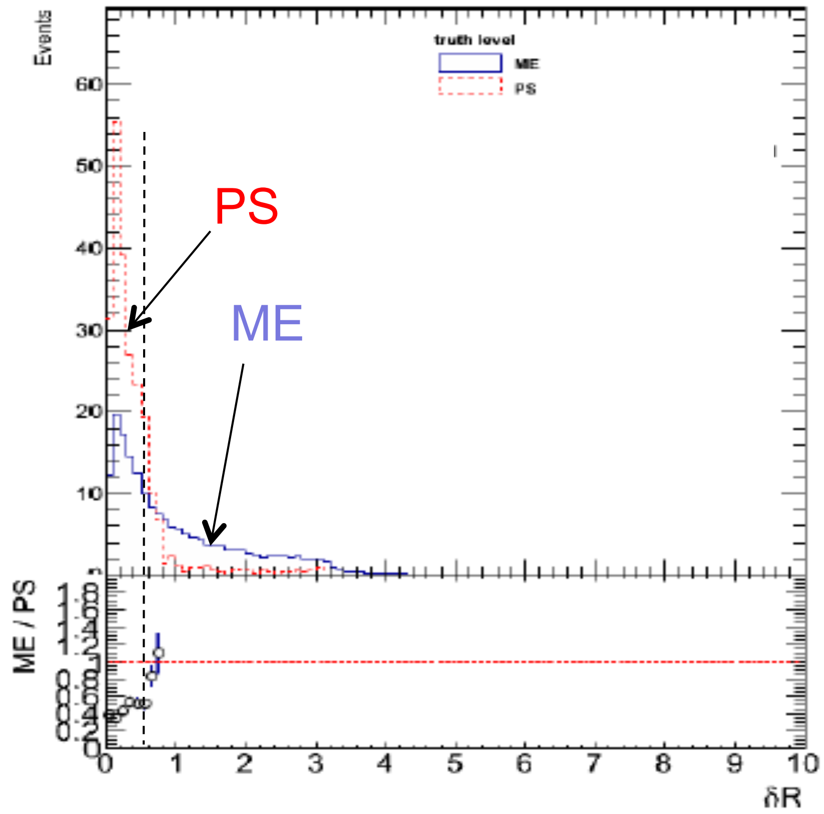

Q6: In order to have a more accurate background prediction it would be beneficial to normalize the ratio ttbb/ttjj to the NLO calculation. Does such ratio and related uncertainty exist at 7 and 8 TeV?

How does one use it given the above prescription?

Is the NLO calculation trustworthy for $\Delta R(Q,Q)<0.4$ or do resummation effects become important?