ATLAS Results in the Search for a Charged Higgs Boson

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ATLAS EXPERIMENT

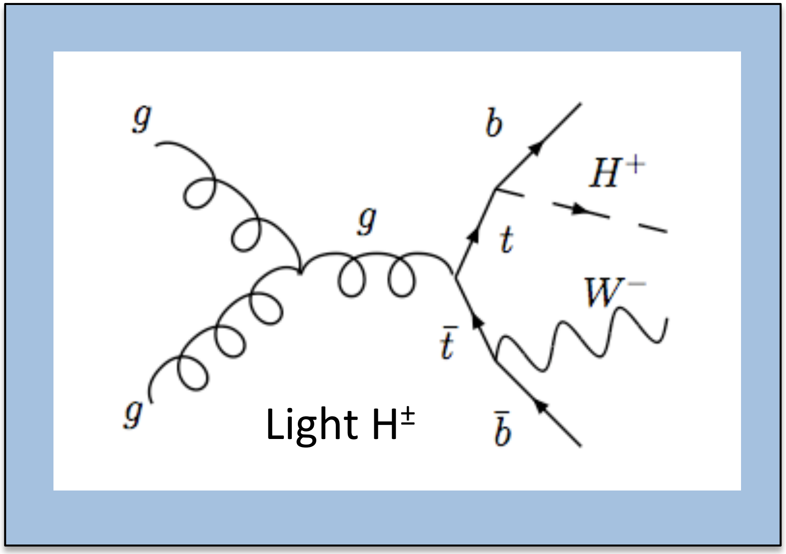
Motivation

- The existence of a charged Higgs boson ($H^{\pm}$) is predicted in Two Higgs Doublet Models.
  - The Higgs sector of the MSSM is a type-II 2HDM.

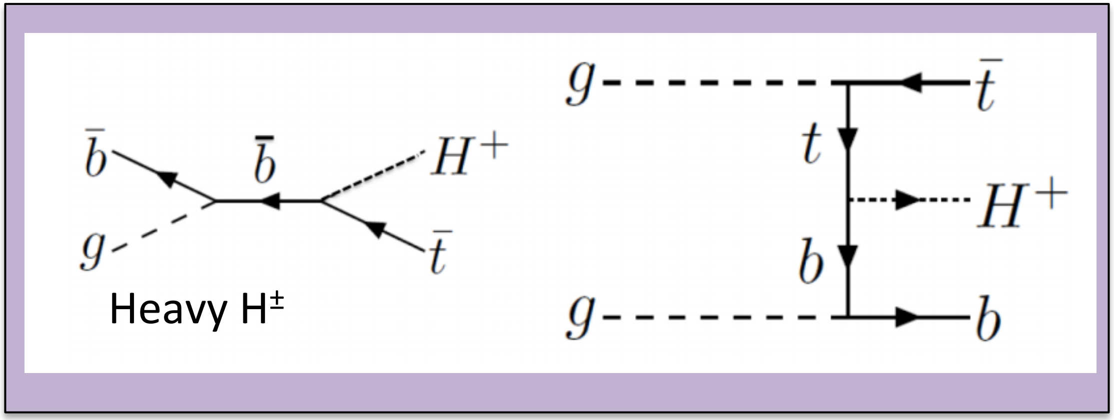
Production:

At the LHC, the dominant production mode of a light $H^{\pm}$ ($m_{H\pm} < m_{top}$) is $t \rightarrow H^{\pm} b$.

A heavy $H^{\pm}$ ($m_{H\pm} > m_{top}$) could be produced by gb or gluon fusion.



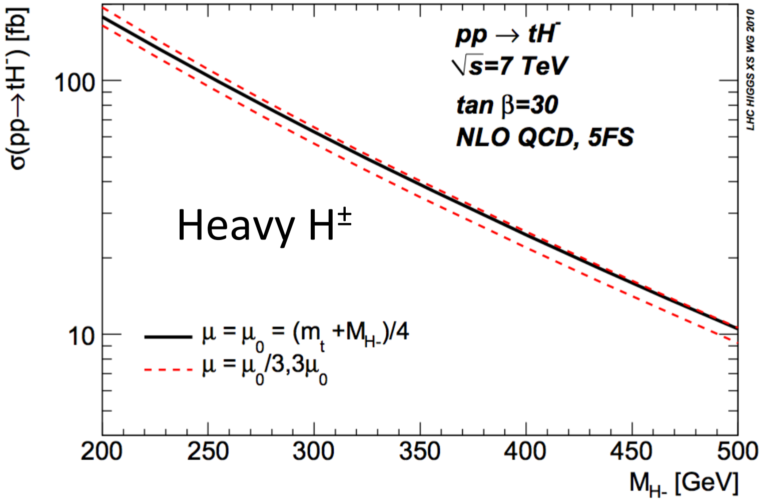
Example Tree-Level Diagrams

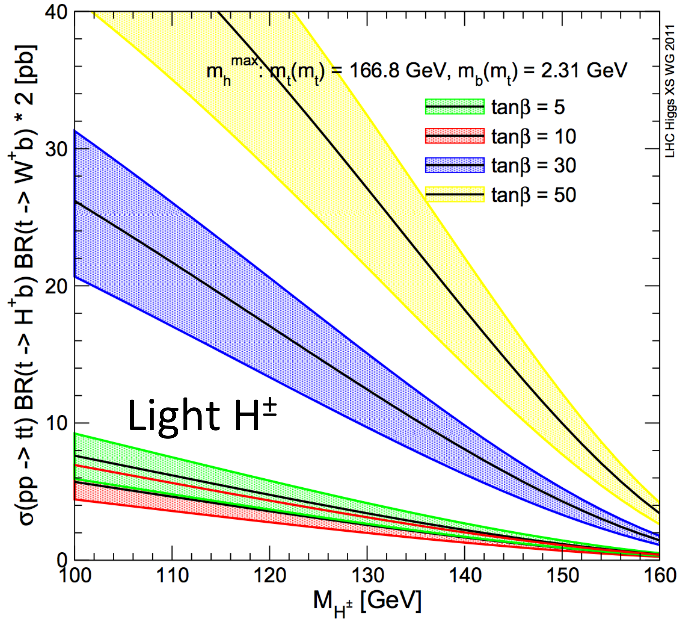


Charged Higgs Production & Decay

- MSSM scenarios can be described by two parameters, $m_{H\pm}$ and tan(β).
- Searches for $H^{\pm} \rightarrow \tau\nu$ are especially sensitive for high tan(β) and relatively low $m_{H\pm}$.
  - The production cross section increases with center-of-mass energy, so increases in energy extend the search's sensitivity to higher $m_{H\pm}$.

arXiv:1101.0593





arXiv:1201.3084

Decay:

The decay channels of $H^{\pm}$ depend on **$m_{H\pm}$** and **tanβ**.

$m_{H\pm} < m_{top}$ and tanβ > 3

- $H^{\pm} \rightarrow \tau\nu$ dominates

$m_{H\pm} > m_{top}$

- $H^{\pm} \rightarrow tb$ dominates
- $H^{\pm} \rightarrow \tau\nu$ is a substantial channel.

Analysis Overview

- The channels included in this search are:

$$t\bar{t} \to [H^+ b]\,[W^- \bar{b}] \to [(\tau^+_{\mathrm{had-vis}} + \nu_\tau) b]\,[q\bar{q}\bar{b}]$$

$$g\bar{b} \to [\bar{t}]\,[H^+] \to [q\bar{q}\bar{b}]\,[\tau^+_{\mathrm{had-vis}} + \nu_\tau]$$

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  - all jet → τ fakes (data-driven)
  - events with true τ (embedding)
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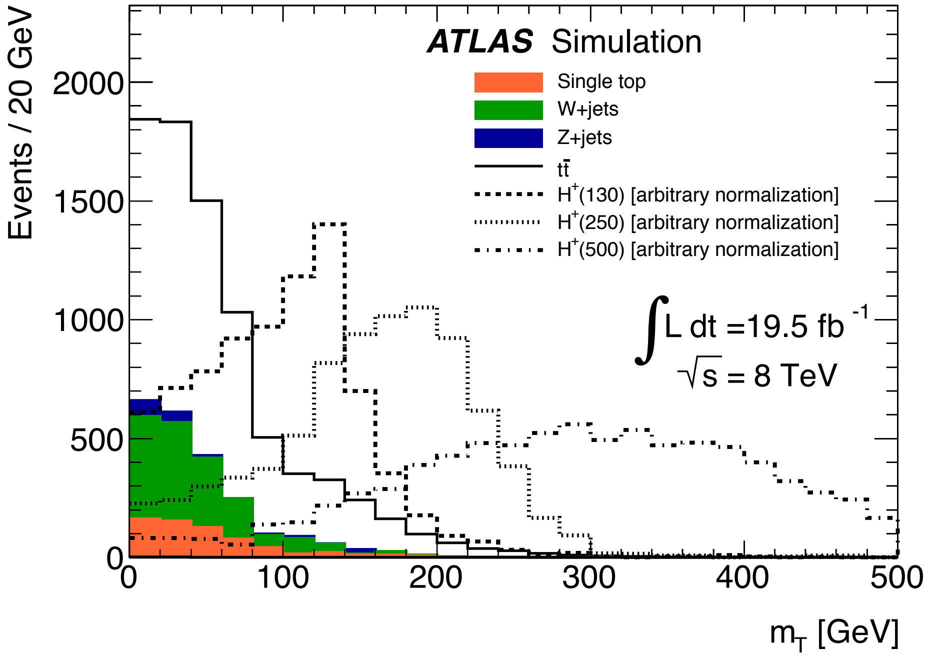

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- The final discriminating variable:

$$m_T = \sqrt{2 p_T^\tau E_T^{\text{miss}} (1 - \cos \Delta\phi_{\tau_{\text{had-vis}},\text{miss}})}$$

is related to transverse mass of W boson for background events (with W → τν), and H^+ boson for signal events

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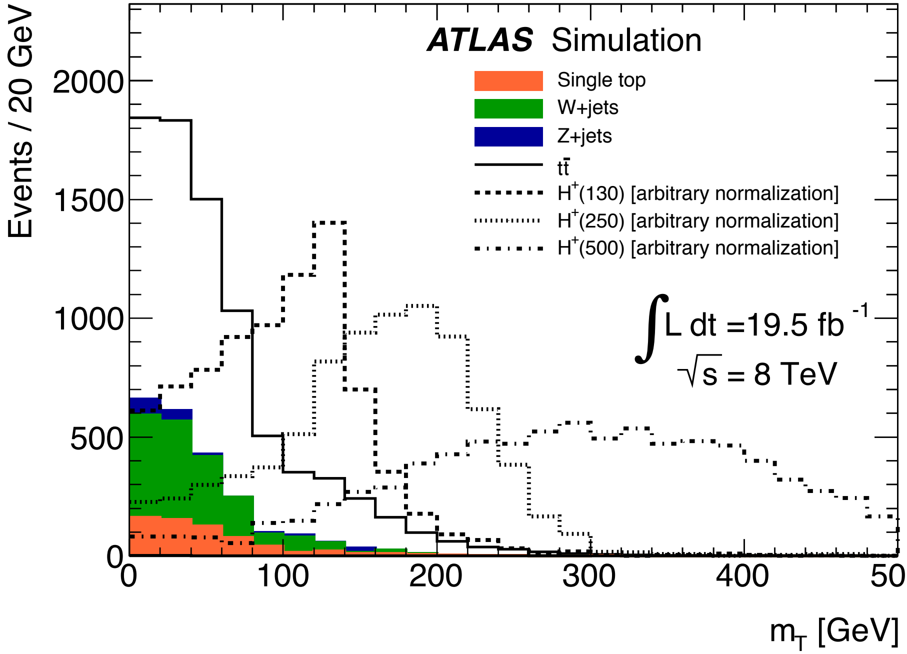

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<u>Event Selection</u>

τ+E_T^{miss} trigger

3(4) jets for high (low) $m_{H\pm}$, and ≥1 b-tagged jet

1 τ and no e or μ

E_T^{miss} > 80 (65) GeV for high (low) $m_{H\pm}$

$E_T^{miss}/\sqrt{(\Sigma p_T^{PV,track})}$ > 6 (6.5) $GeV^{1/2}$ high (low) $m_{H\pm}$

m_T > 40 (20) GeV for high (low) $m_{H\pm}$

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Backgrounds: jet→τ

This method relies on four categories of hadronically decaying τ:

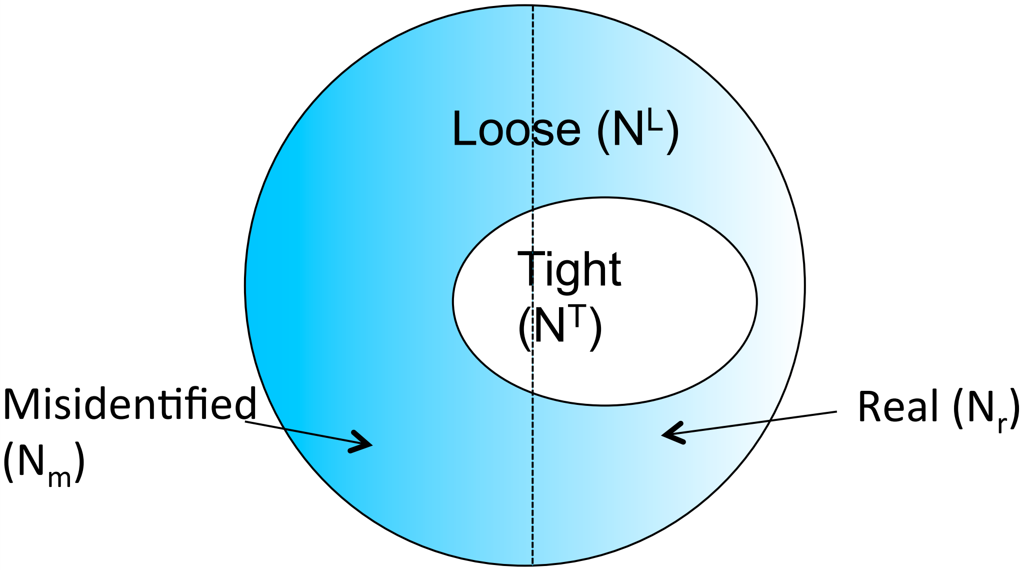
- ✓ ‘**Loose**’: passes all object selection (pT, η, trigger-matched), but not τ identification cut.
- ✓ ‘**Tight**’: passes ‘Loose’ selection and τ identification cut
- ✓ ‘**Real**’: a reconstructed object passing ‘loose’ or ‘tight’ selection that is a τ.
- ✓ ‘**Misidentified**’: a reconstructed object passing ‘loose’ or ‘tight’ selection that is a jet.

$$\begin{pmatrix} N_\mathrm{T} \\ N_\mathrm{L} \end{pmatrix} = \begin{pmatrix} p_\mathrm{r} & p_\mathrm{m} \\ (1-p_\mathrm{r}) & (1-p_\mathrm{m}) \end{pmatrix} \times \begin{pmatrix} N_\mathrm{r} \\ N_\mathrm{m} \end{pmatrix}$$

where $N_{L/T}$ = # of events with loose-but-not-tight/tight τ,
$N_{m/r}$ = # of events with real/misidentified τ,

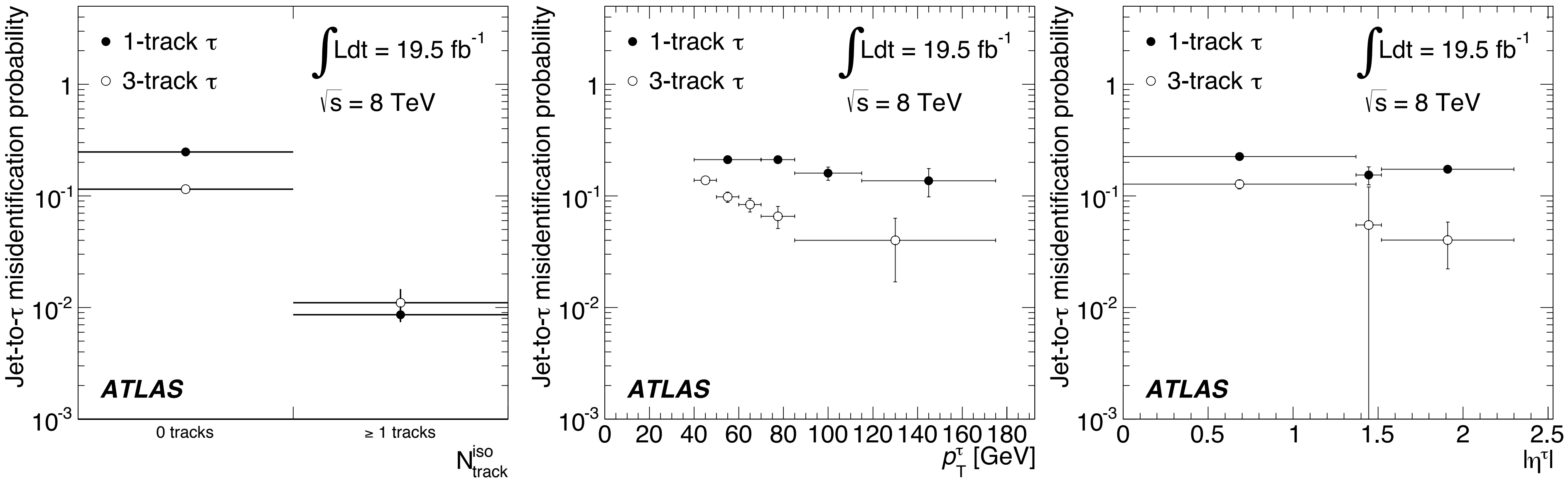
This equation is solved to find weights to be applied to data events:

$$N_\mathrm{m}^\mathrm{T} = p_\mathrm{m} N_\mathrm{m} = \frac{p_\mathrm{m} p_\mathrm{r}}{p_\mathrm{r} - p_\mathrm{m}} N_\mathrm{L} + \frac{p_\mathrm{m}(p_\mathrm{r} - 1)}{p_\mathrm{r} - p_\mathrm{m}} N_\mathrm{T}$$



$p_r = N_r^T / (N_r^T + N_r^L)$
$p_m = N_m^T / (N_m^T + N_m^L)$

Backgrounds: jet→τ



$$p_r = N_r^T / (N_r^T + N_r^L)$$
$$p_m = N_m^T / (N_m^T + N_m^L)$$

✓ p_r is measured in simulation and calibrated to data.

✓ p_m is measured in a W+jets control region in data (shown).

Both are parameterized as a function of τ $p_{T,}$ τ η, and N_{track}^{iso}.

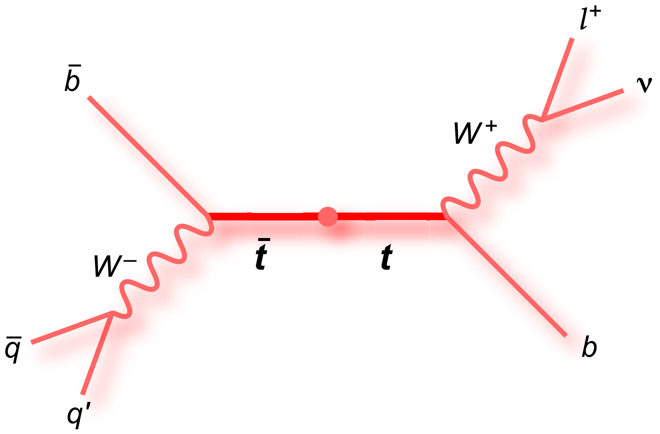
Backgrounds with True τ_{had}: τ_{had} Embedding

$t\bar{t}$ events decaying to "τ_{had} +jets" cannot be selected in data without significant signal contamination.

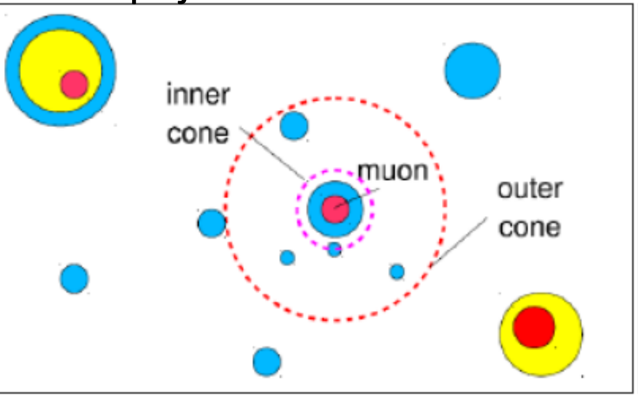
μ+jets events can be selected in data instead, with high purity and low signal contamination.

The τ_{had} embedding method uses μ+jets data events, where the μ is replaced with a simulated τ_{had}.

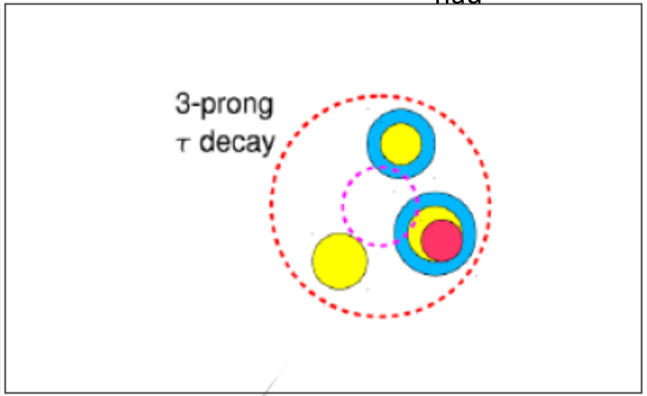
The dominant source of background with true τ_{had} is $t\bar{t}$ events.



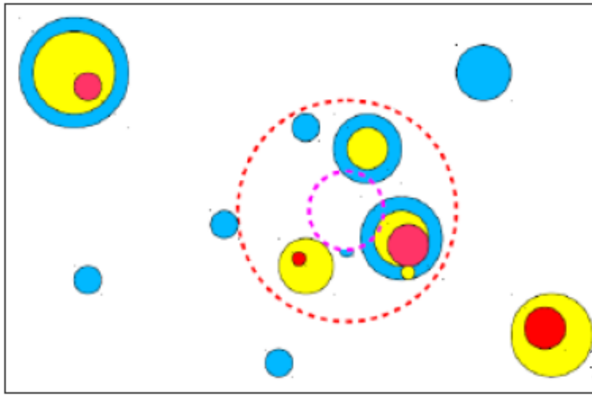
μ+jets event in data



Simulated τ_{had}



Embedded event



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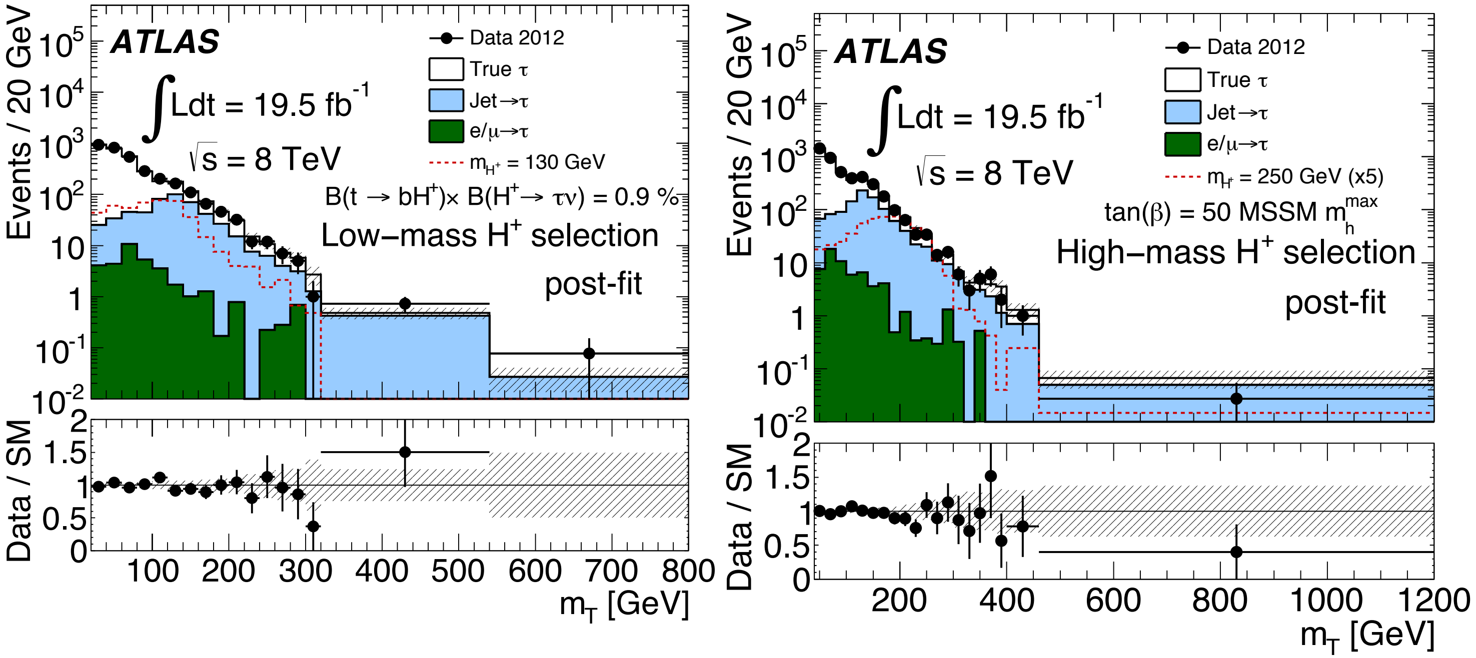
Final Results



Final yields and distributions are consistent with the Standard Model.

Sample	Low-mass H^+ selection	High-mass H^+ selection
True τ_{had} (embedding method)	$2800 \pm 60 \pm 500$	$3400 \pm 60 \pm 400$
Misidentified jet → $\tau_{\text{had}}vis$	$490 \pm 9 \pm 80$	$990 \pm 15 \pm 160$
Misidentified $e \rightarrow \tau_{\text{had}}vis$	$15 \pm 3 \pm 6$	$20 \pm 2 \pm 9$
Misidentified $\mu \rightarrow \tau_{\text{had}}vis$	$18 \pm 3 \pm 8$	$37 \pm 5 \pm 8$
All SM backgrounds	$3300 \pm 60 \pm 500$	$4400 \pm 70 \pm 500$
Data	3244	4474
H^+ ($m_{H+} = 130\,\text{GeV}$)	$230 \pm 10 \pm 40$	
H^+ ($m_{H+} = 250\,\text{GeV}$)		$58 \pm 1 \pm 9$

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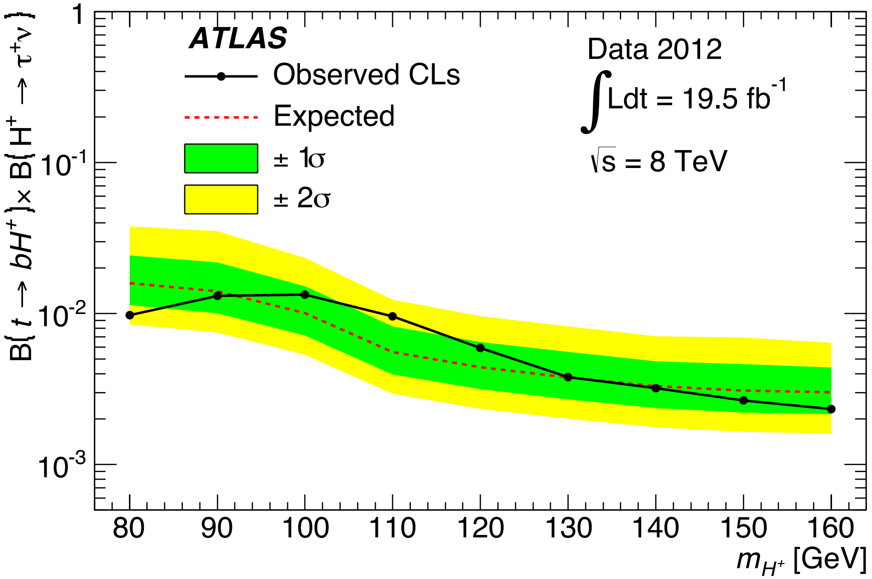
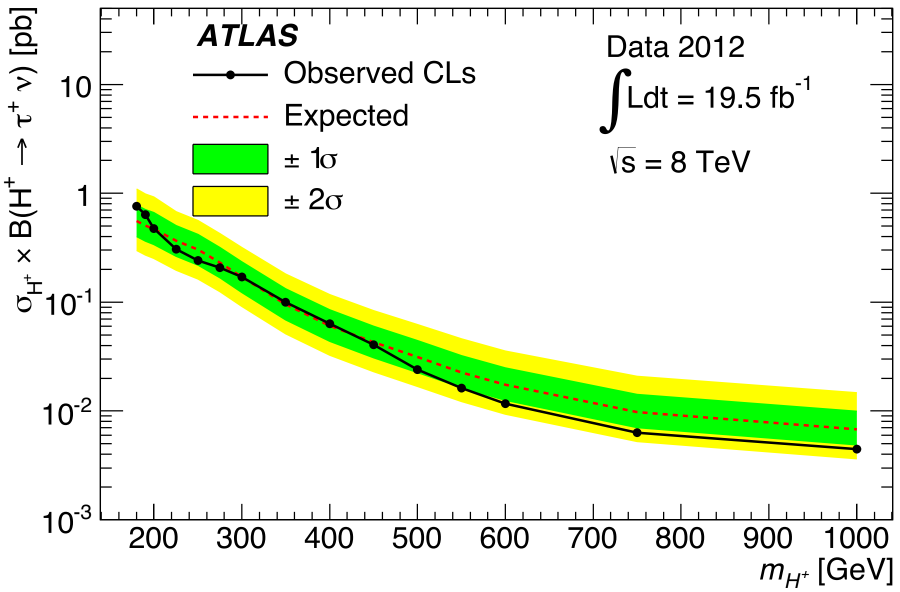
Cross Section Limits





Specific model independent limits are extracted on the products of branching ratios (low $m_{H\pm}$) or production cross sections and branching ratios (high $m_{H\pm}$).

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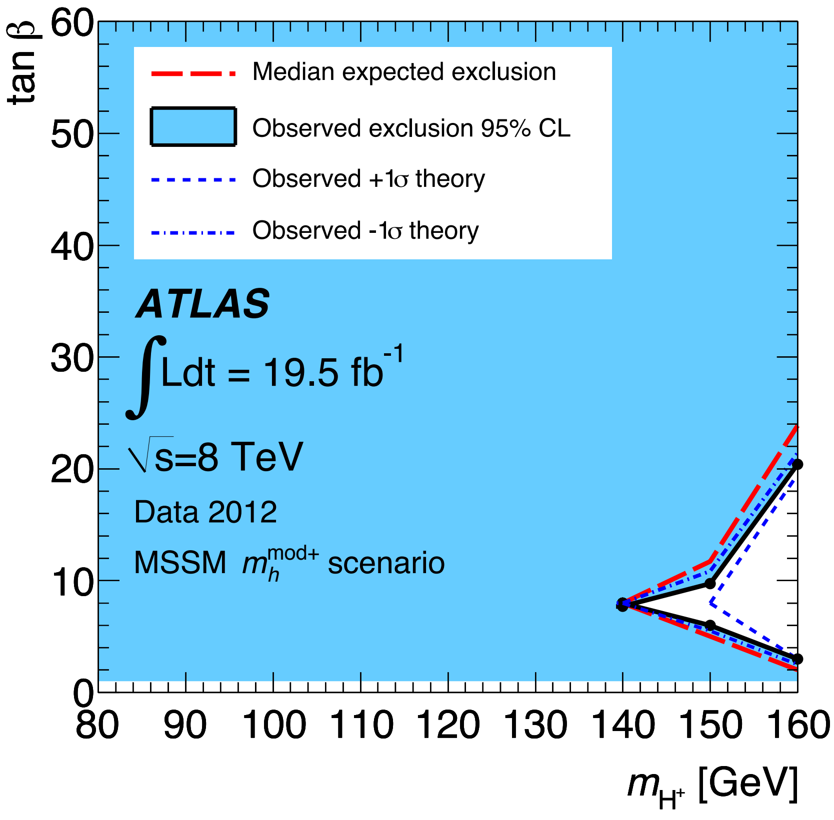
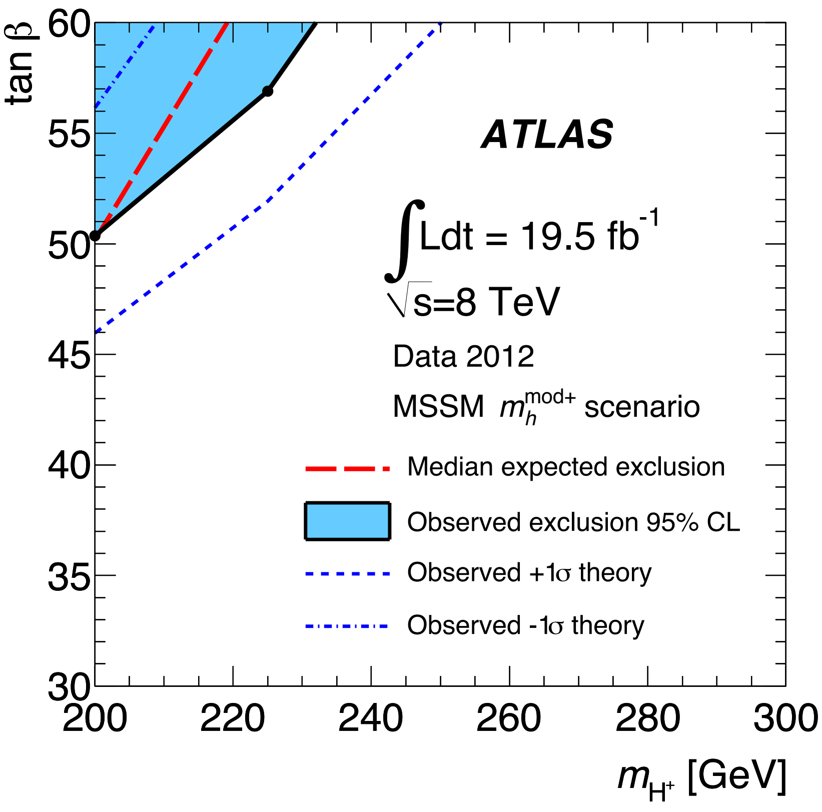
MSSM Interpretations





- Limits are also interpreted in various MSSM scenarios. Shown here is the MSSM benchmark scenario mh-mod+.
- mh-mod+ is a modification of the previously standard MSSM mh-max scenario, designed to increase the amount of parameter space consistent with ‘h’ as the observed Higgs boson.

More information on benchmark scenarios: [arXiv:1302.7033]

Summary

- The latest ATLAS search for a charged Higgs boson sets exclusion limits in the ranges of $m_{H\pm}$ = 80-160 GeV and $m_{H\pm}$ = 180-1000 GeV.
- For the lower mass range, this places stringent limits on many MSSM benchmark scenarios.
- With the higher run-2 center-of-mass energy at the LHC, the sensitivity of the search at high mass will increase!

Backup

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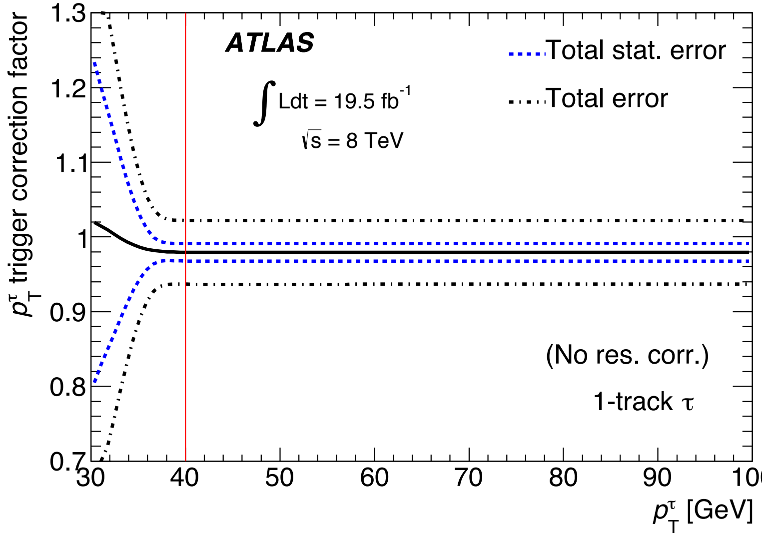
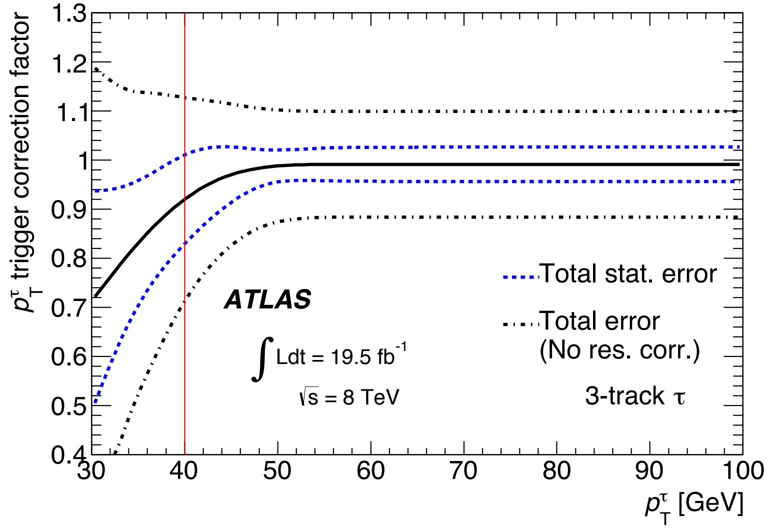
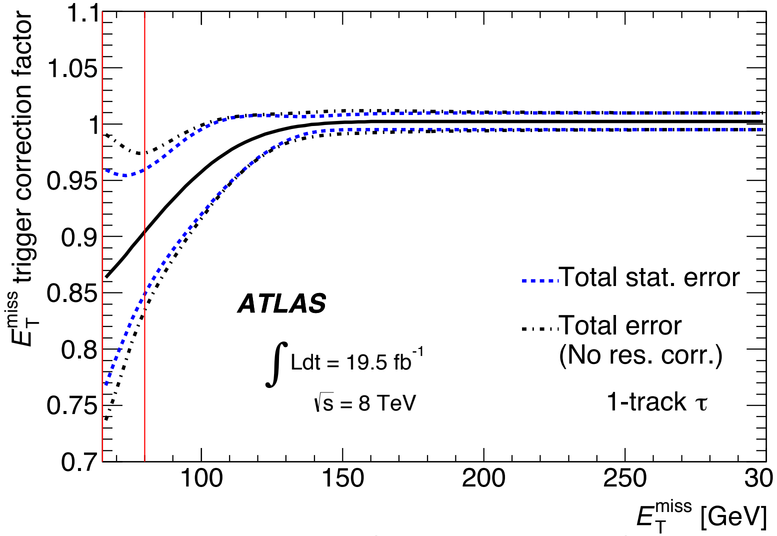
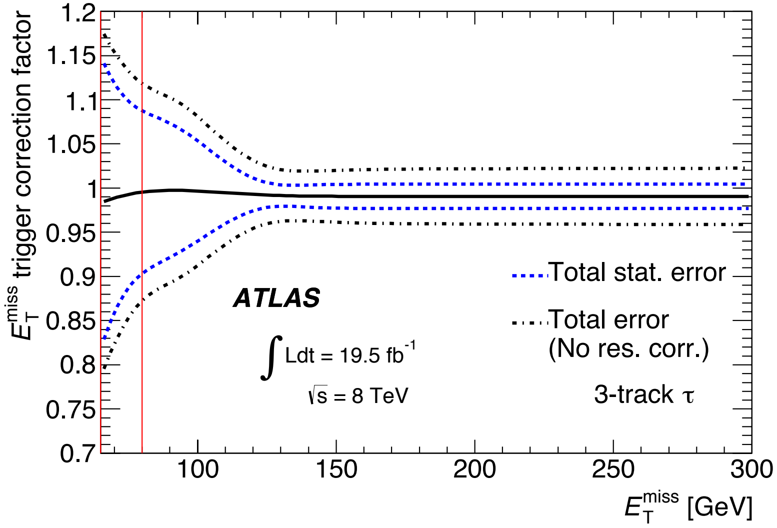
Trigger Scale Factors









- The trigger scale factors used for the analysis are taken from continuous functions fit to the efficiency curves of data and simulation for the τ and E_T^{miss} triggers, separately for 1- and 3-prong τ.

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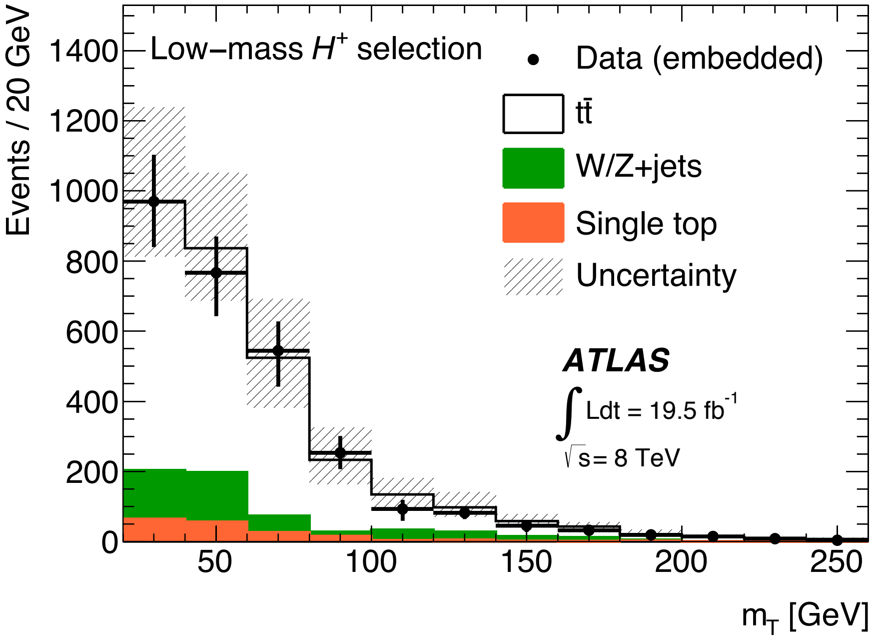
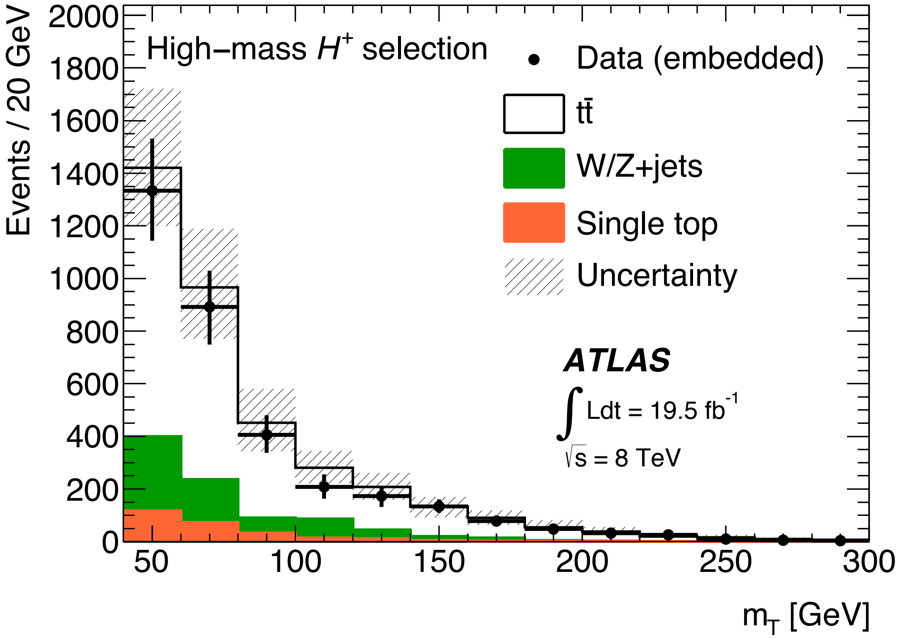
Backgrounds: true τ embedding





- These show the reduction of systematic uncertainties when using embedding instead of the usual simulation.

Backgrounds: true τ embedding

- No trigger is available in embedded samples: trigger efficiency binned in pT of the τ and E_T^{miss} (taken from data) applied to events
- Normalization is taken from data:

branching ratio for τ → had

$$N_\tau = N_{\text{embedded}} \cdot (1 - c_{\tau\to\mu}) \frac{\epsilon^{\tau + E_{\text{T}}^{\text{miss}} - \text{trigger}}}{\epsilon^{\mu - \text{ID,trigger}}} \cdot \mathcal{B}(\tau \to \text{hadrons} + \nu)$$

wrongly embedded
W → τ → μ events

muon trigger and
reconstruction efficiencies

- Systematic uncertainties:
  - vary muon isolation to study effect of additional QCD
  - vary embedding settings to estimate potential biases introduced by embedding parameter settings
  - τ in final event comes from simulation: TES, τ ID systematic uncertainties
  - normalization systematics

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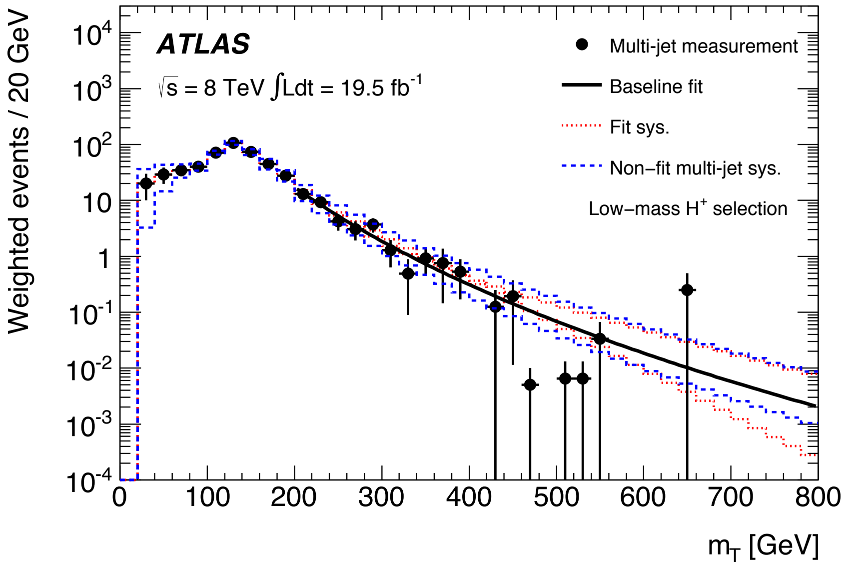
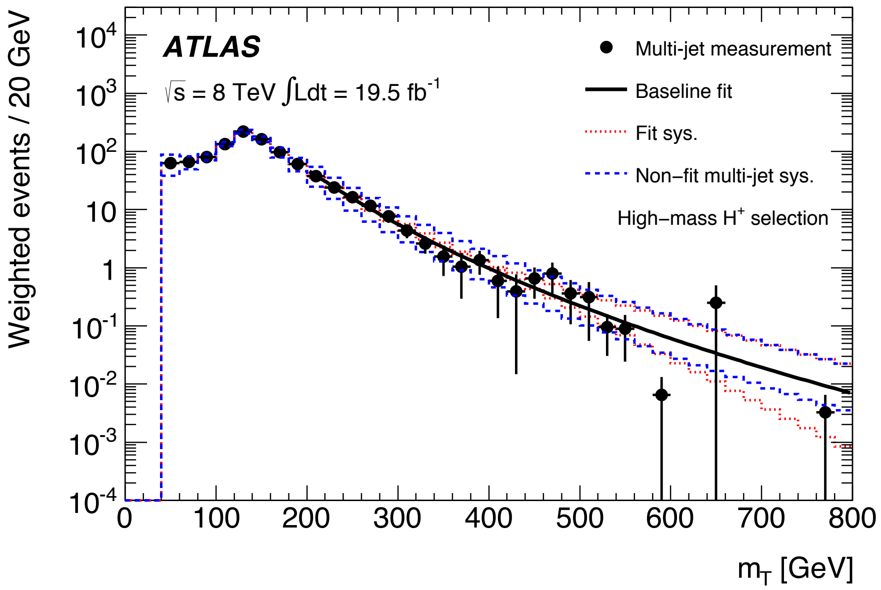
Backgrounds: jet→τ m_T tail





- Due to low statistics in the tail of the distribution, the background estimation is improved by the use of a power log function extrapolation.

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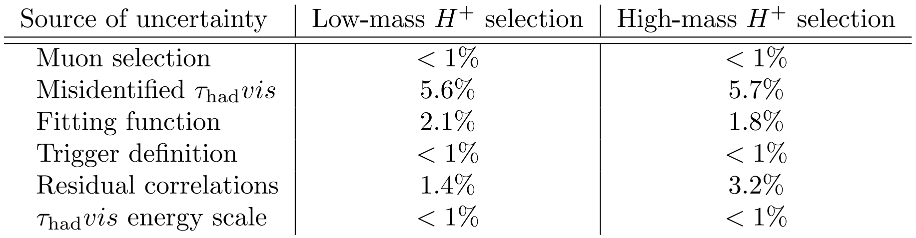
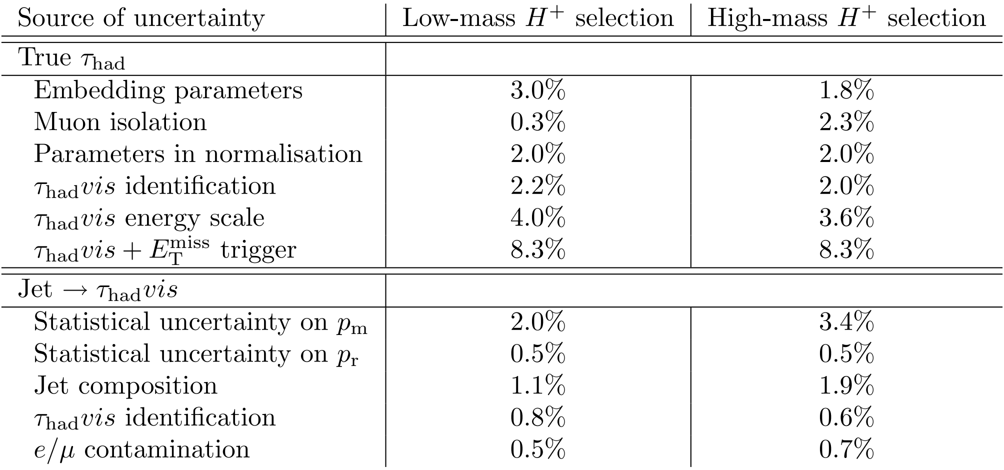
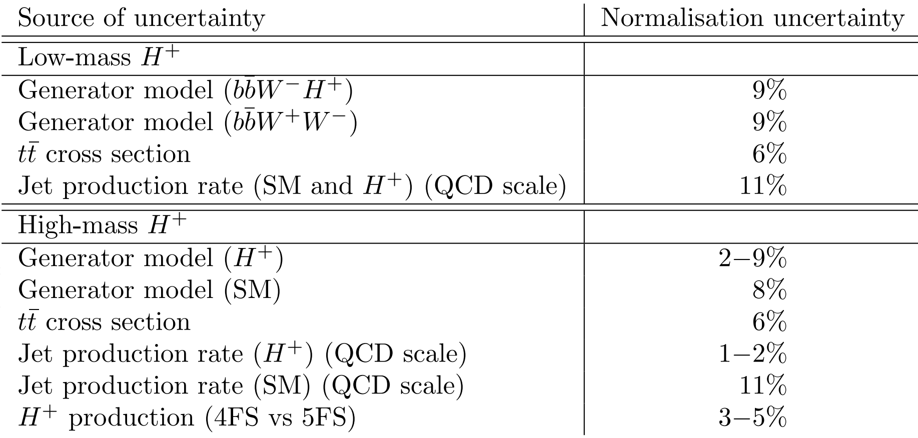
Systematic Uncertainties



Source of uncertainty	Low-mass H^+ selection	High-mass H^+ selection
Muon selection	$< 1\%$	$< 1\%$
Misidentified $\tau_{\mathrm{had}}vis$	5.6%	5.7%
Fitting function	2.1%	1.8%
Trigger definition	$< 1\%$	$< 1\%$
Residual correlations	1.4%	3.2%
$\tau_{\mathrm{had}}vis$ energy scale	$< 1\%$	$< 1\%$



Source of uncertainty	Low-mass H^+ selection	High-mass H^+ selection
True τ_{had}		
Embedding parameters	3.0%	1.8%
Muon isolation	0.3%	2.3%
Parameters in normalisation	2.0%	2.0%
$\tau_{\mathrm{had}}vis$ identification	2.2%	2.0%
$\tau_{\mathrm{had}}vis$ energy scale	4.0%	3.6%
$\tau_{\mathrm{had}}vis + E_{\mathrm{T}}^{\mathrm{miss}}$ trigger	8.3%	8.3%
Jet $\rightarrow \tau_{\mathrm{had}}vis$		
Statistical uncertainty on p_{m}	2.0%	3.4%
Statistical uncertainty on p_{r}	0.5%	0.5%
Jet composition	1.1%	1.9%
$\tau_{\mathrm{had}}vis$ identification	0.8%	0.6%
e/μ contamination	0.5%	0.7%



Source of uncertainty	Normalisation uncertainty
Low-mass H^+	
Generator model ($b\bar{b}W^-H^+$)	9%
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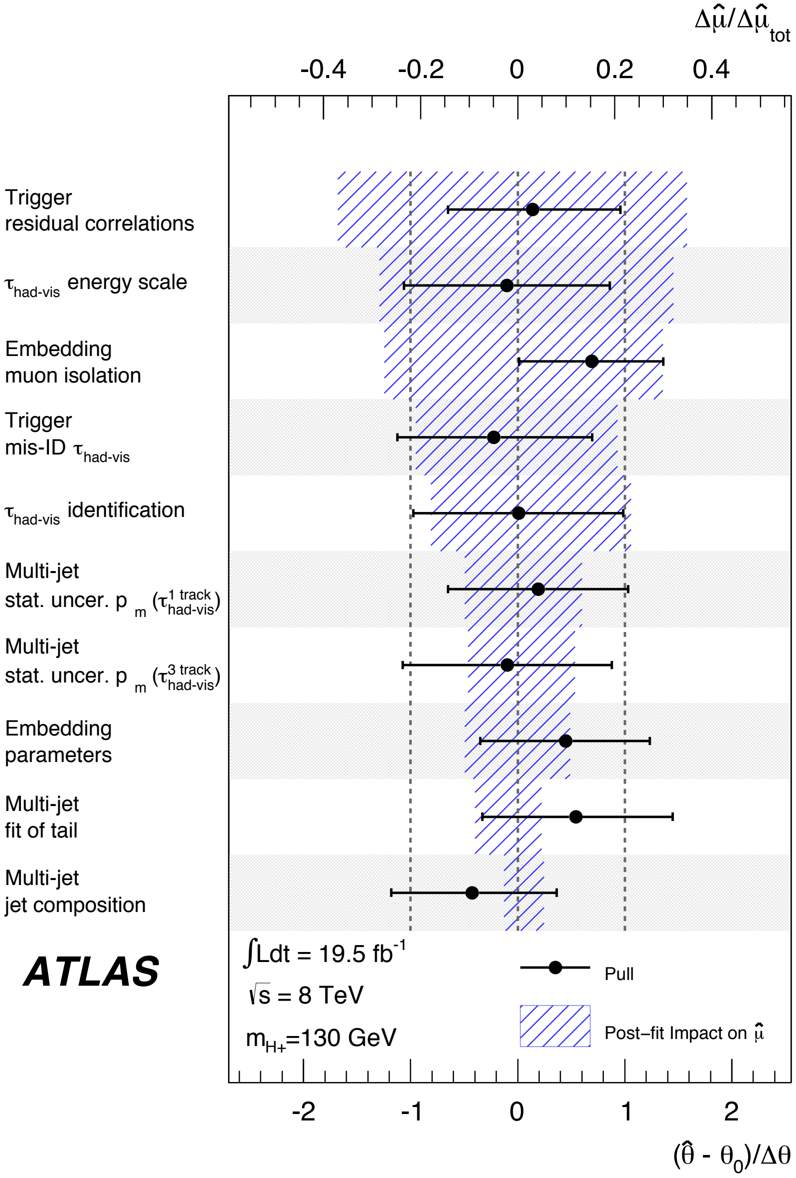
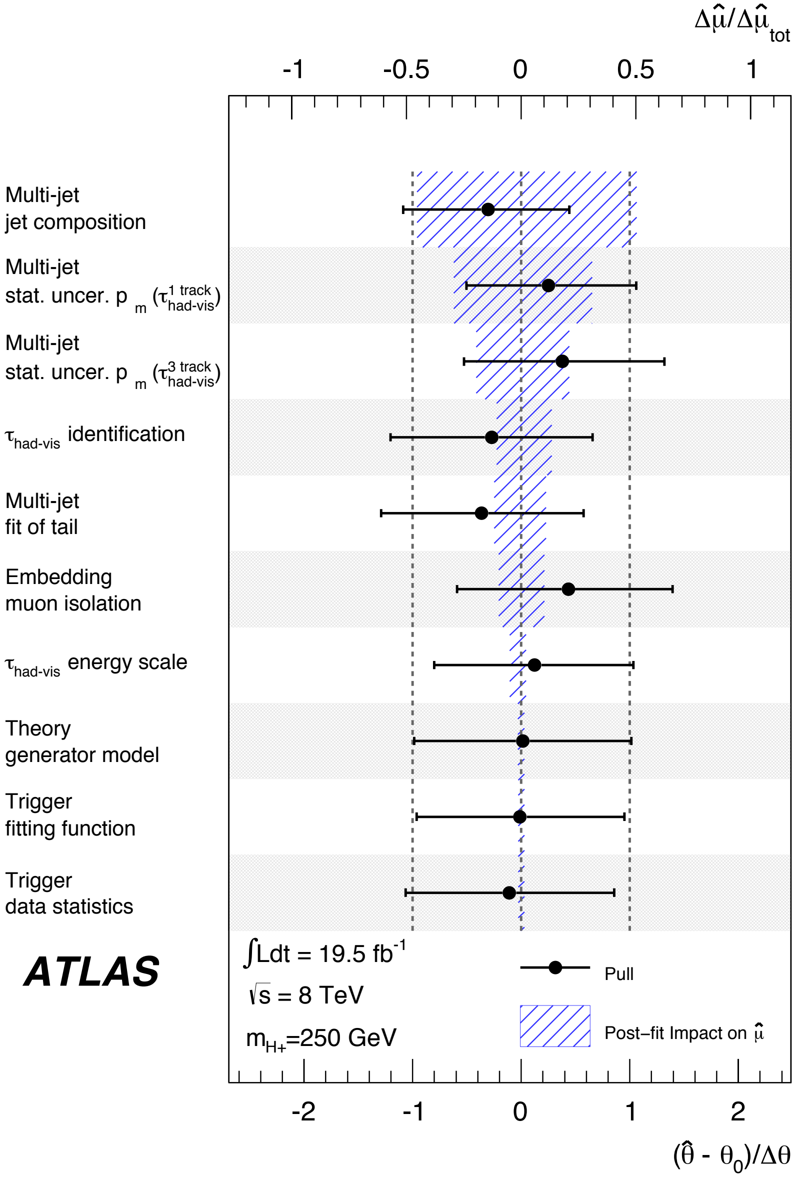
$t\bar{t}$ cross section	6%
Jet production rate (SM and H^+) (QCD scale)	11%
High-mass H^+	
Generator model (H^+)	2–9%
Generator model (SM)	8%
$t\bar{t}$ cross section	6%
Jet production rate (H^+) (QCD scale)	1–2%
Jet production rate (SM) (QCD scale)	11%
H^+ production (4FS vs 5FS)	3–5%

- Summary of systematic uncertainties.

Nuisance Parameters





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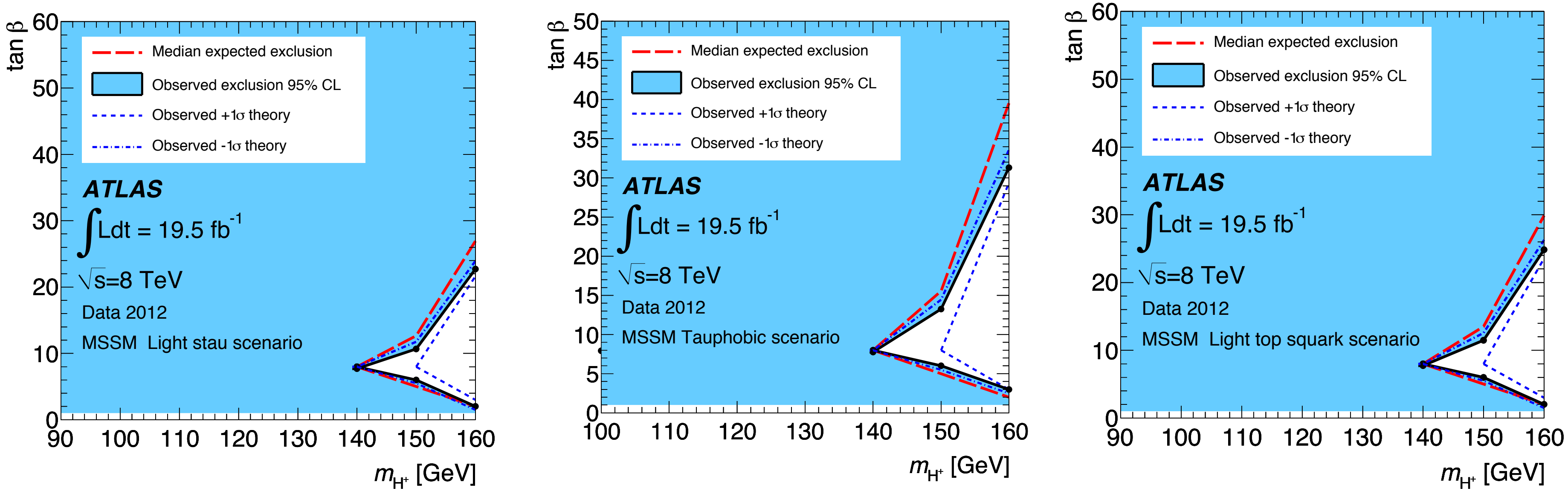
MSSM Interpretations (low mass)



Similar exclusion is seen for these additional scenarios at low $m_{H\pm}$. Additionally, the low-mH scenario is excluded for all parameter space where it is valid.

MSSM Interpretations