Search for charged Higgs bosons through the violation of lepton universality in $t\bar{t}$ events

Partikeldagarna 2012

Daniel Pelikan

Uppsala University

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Outline

- Introduction
- Event selection
- Backgrounds with misidentified electrons and muons
- Backgrounds with misidentified τ jets
- Results

Introduction

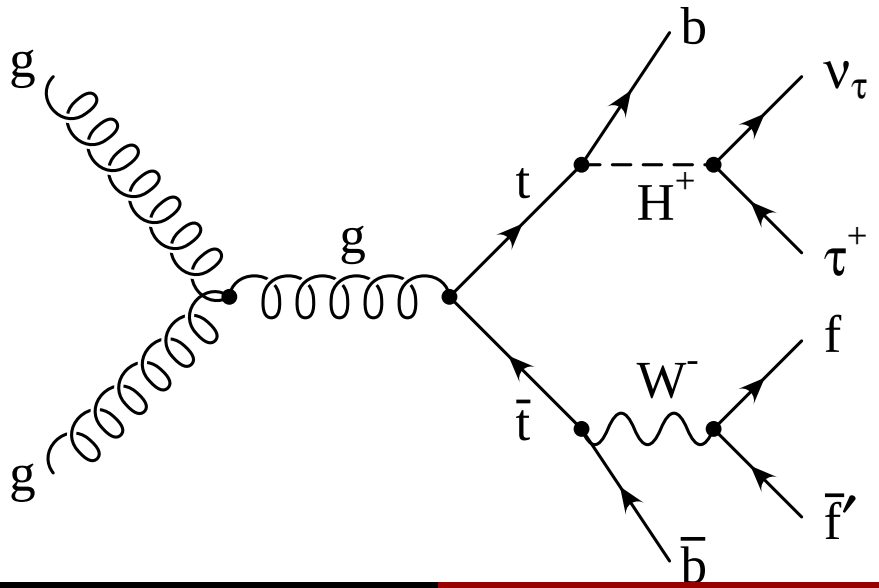
Theoretical background

- In the Standard Model (SM) the electroweak symmetry breaking is done by one doublet of Higgs scalars
  - This leads to one neutral Higgs boson h^0
- Other models, for example the MSSM, predict the existence of two complex Higgs doublets.
  - This leads to 5 physical states: H^+, H^-, h^0, H^0, A^0
- The tree level MSSM Higgs sector is fully determined by two independent parameters:
  - One Higgs mass: m_A or $m_{H^+} = \sqrt{m_A^2 + m_W^2}$
  - The ratio of the vacuum expectation values of the Higgs doublets, $\tan\beta$
- Assuming the charged Higgs boson is light and does not decay into supersymmetric particles
  - $H^+ \to \tau\nu$ dominates below the tb threshold
  - $H^+ \to c\bar{s}$ may have a significant branching fraction at low $\tan\beta$

Introduction

Theoretical background

- This means the top quark can decay into a bottom quark and a light charged Higgs boson
  - through the reaction $t \to bH^+$, in addition to $t \to bW$
- The W boson decays into the three lepton generations democratically while the charged Higgs boson decays predominantly into $\tau\nu$
- $H^\pm$ can be searched through the violation of lepton universality in top quark decays.



Introduction

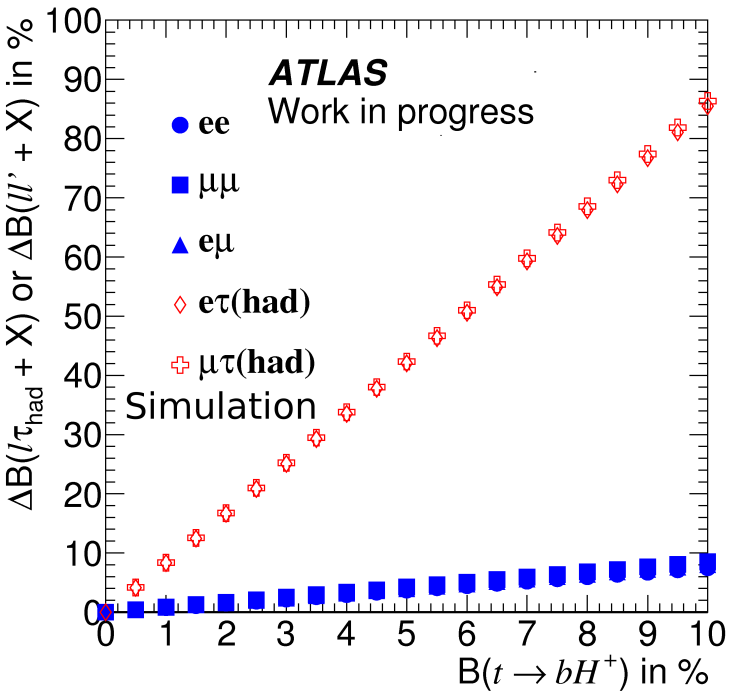
Method

- The accuracy on the measurement of individual cross sections is limited by systematics
  - Integrated luminosity, object reconstruction and identification, b-tagging, etc.
- A ratio-based method reduces the impact of systematic uncertainties in the analysis
- Measure event yield ratios in data and compare them to predictions from simulation in the following final states
  - $e + \tau_{\text{had}}$ and $e + \mu$,
  - $\mu + \tau_{\text{had}}$ and $\mu + e$

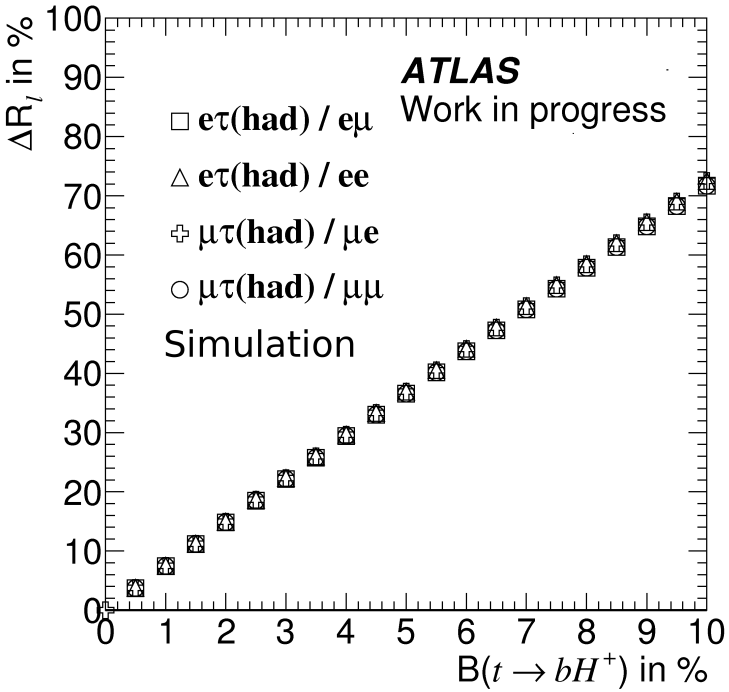
$$R_l = \frac{\mathcal{B}(t\bar{t} \to b\bar{b} + l\tau_{\text{had}} + N\nu)}{\mathcal{B}(t\bar{t} \to b\bar{b} + ll' + N\nu)}. \quad (1)$$

- Model independent search

Introduction



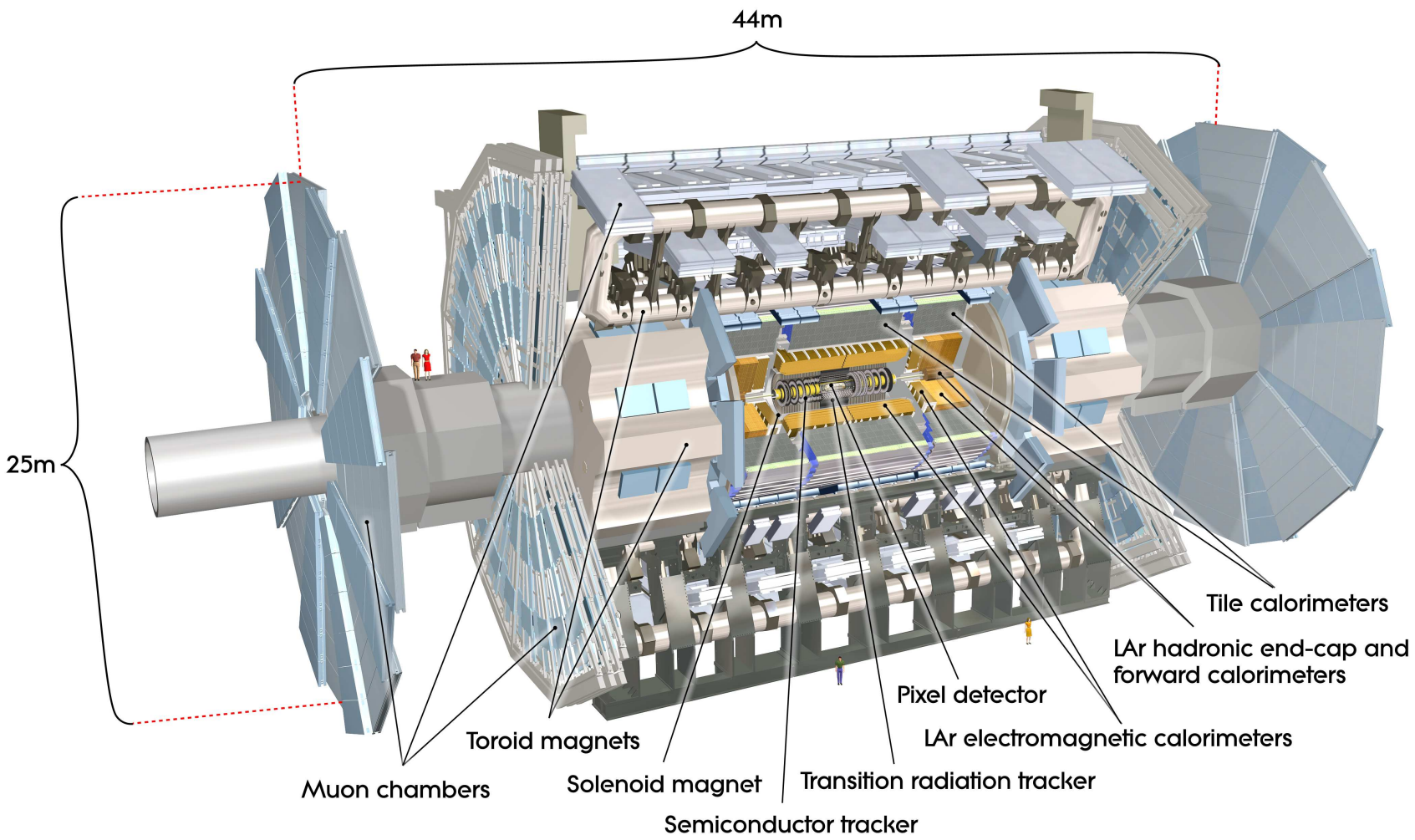
Relative increase with respect to the SM values of the branching ratios for $t\bar{t}$ events.



Relative increase with respect to the SM values of the ratio between these branching ratios.

The ATLAS detector system

To look for charged Higgs bosons the full ATLAS detector system is needed



Event selection

- Single lepton trigger with E_T threshold of 20-22 GeV (electrons) and p_T threshold of 18 GeV (muons)
- One trigger matched charged lepton ($E_T, p_T > 25$GeV)
- At least 2 jets ($p_T > 20$ GeV), including exactly 2 b-jets
- $\tau + lep$ vs. dilepton separation
  - One τ-jet with $p_T > 25$ GeV, no additional lepton **or** second charged lepton with $E_T, p_T > 25$ GeV and a different flavour
- $E_T^{miss} > 40$ GeV
- Events are classified according to the single lepton trigger that was fired
  - electron-triggered: $e + \tau$, $e + \mu$
  - muon-triggered: $\mu + \tau$, $\mu + e$

Backgrounds with misidentified electrons and muons

- Fake lepton estimate is done using the "Matrix Method"
  - *tight* sample: contains mostly events with real leptons, same lepton selection as in the analysis
  - *loose* sample: looser isolation and identification requirements, and it contains mostly events with misidentified leptons
- Based on data events with loose or tight leptons the fake lepton background can be estimated with:

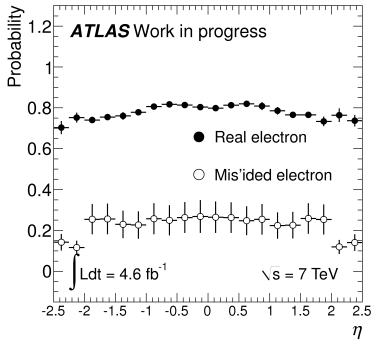
$$N_{\mathrm{m}}^{\mathrm{T}} = \frac{p_{\mathrm{m}}}{p_{\mathrm{r}} - p_{\mathrm{m}}}(p_{\mathrm{r}} N^{\mathrm{L}} - N^{\mathrm{T}}). \tag{2}$$

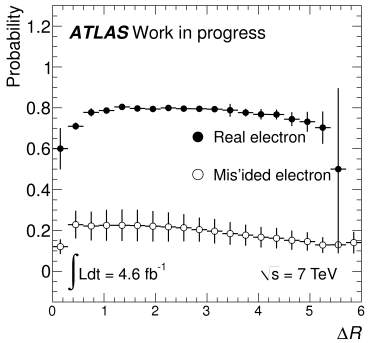
- In the di-lepton case: one tight and one at least loose lepton

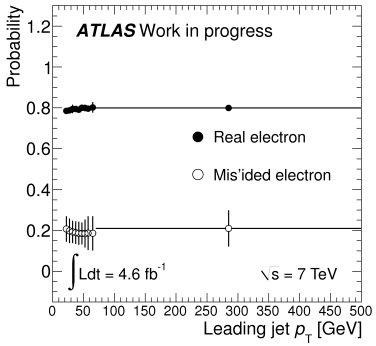
Backgrounds with misidentified electrons and muons

- p_r (lep. identification. eff.) is measured using a tag-and-probe method on $Z \to ll$ events in the data
- p_m (miss. identification. eff.) is measured in single lepton events in the data,
  - control region 5 GeV $< E_T^{miss} <$ 20 GeV
  - dominated by multi-jet production

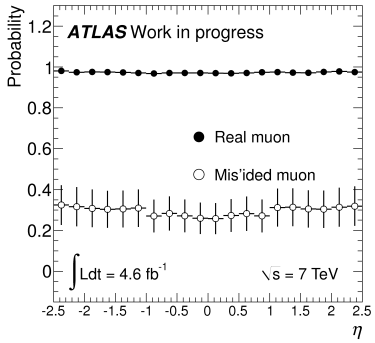
electrons

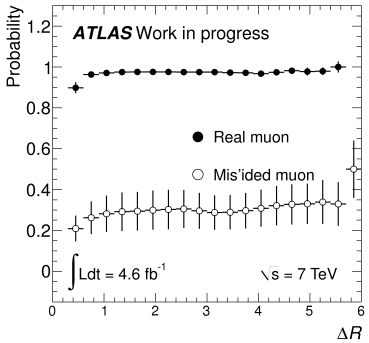


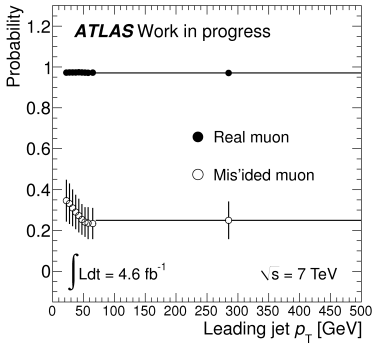




muons

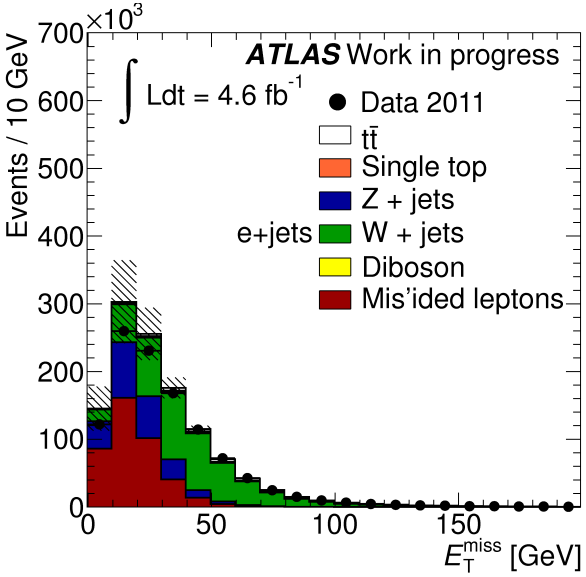


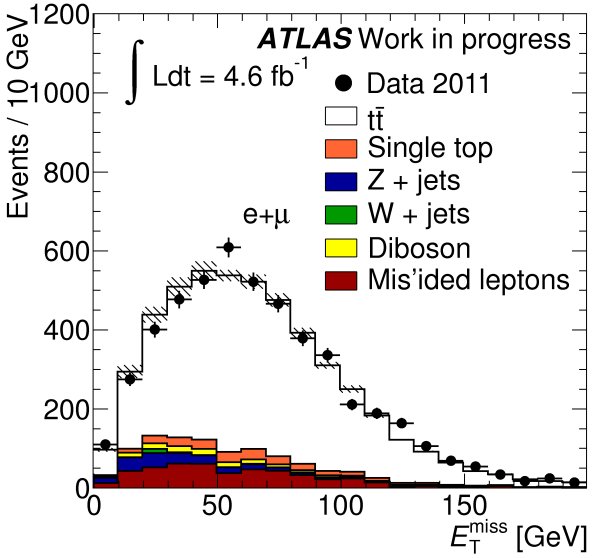


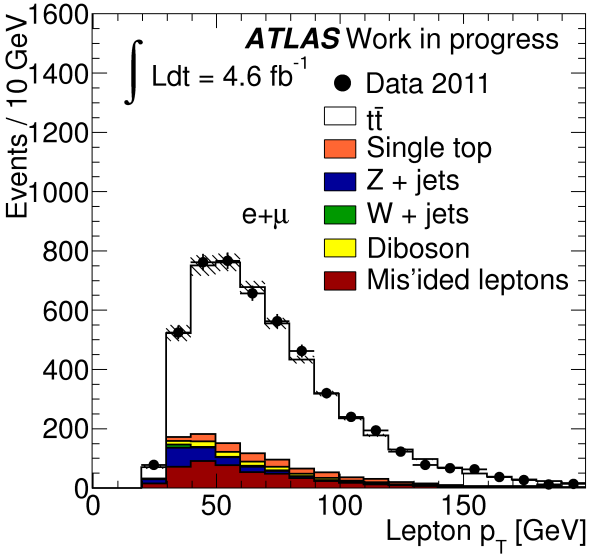


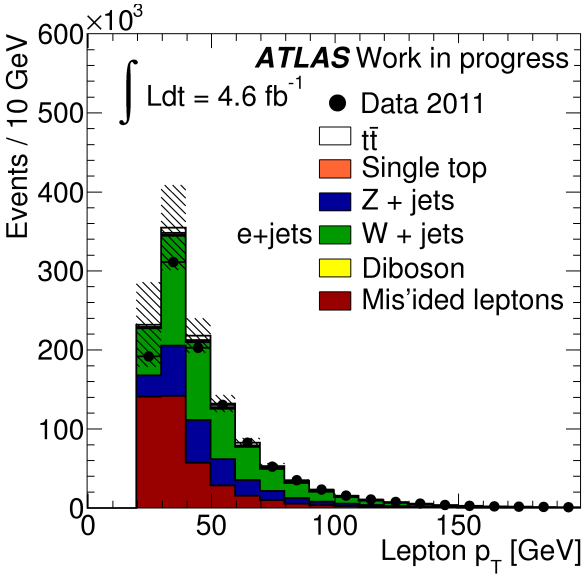
Backgrounds with misidentified electrons and muons

Electron triggered events





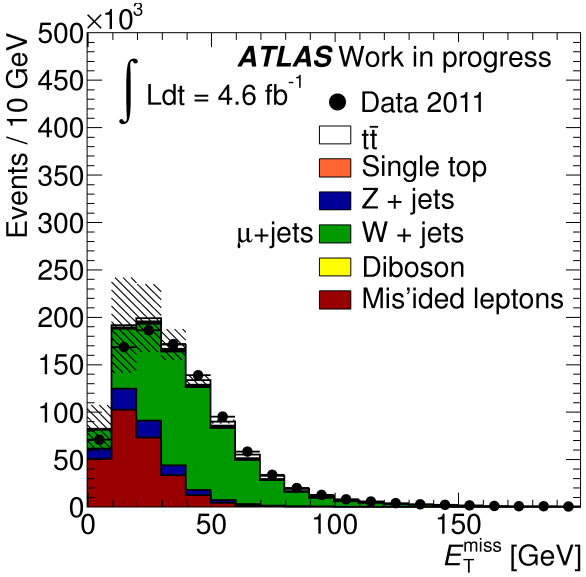


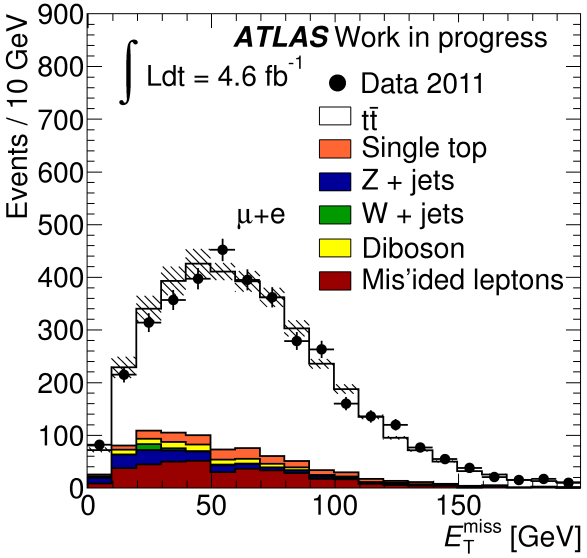


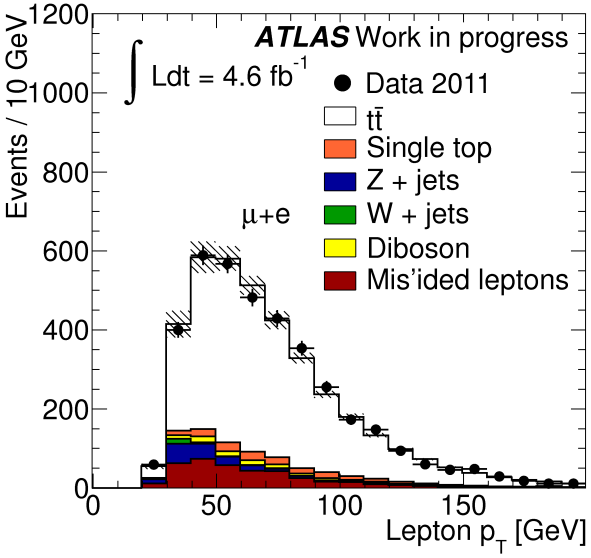
- Events containing at least 2 jets
- One trigger matched lepton or e-μ pair
- Systematic uncertainty: 38% electrons, 49% muons

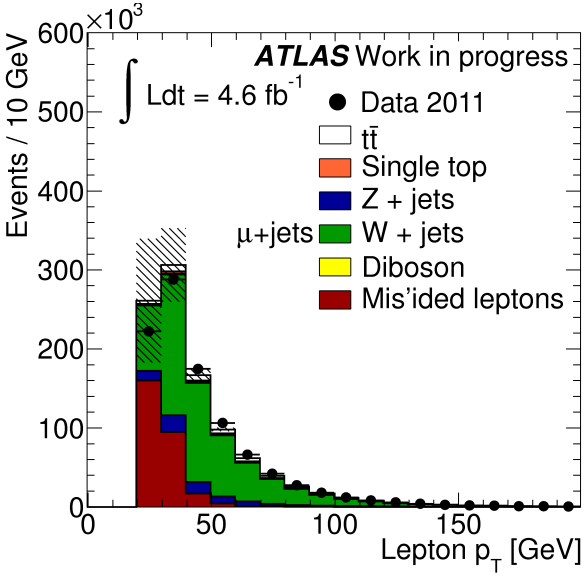
Backgrounds with misidentified electrons and muons

Muon triggered events









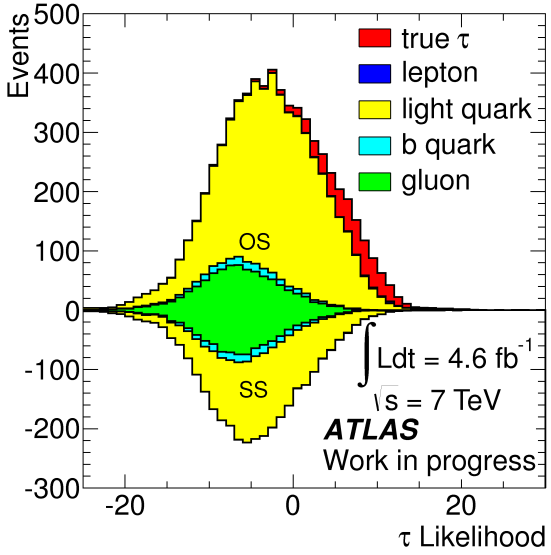
- Same nice agreement for the muons

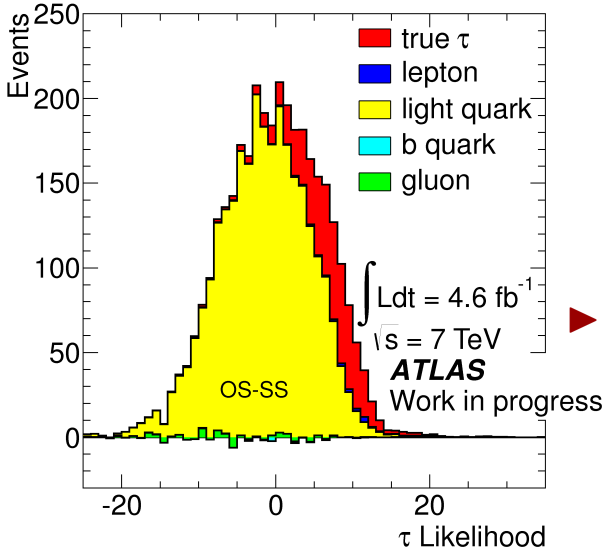
Backgrounds with misidentified τ jets

- About 51% of the simulated $t\bar{t}$ events in the τ_{had}+lepton final state contain a real τ_{had} at generator level
- In the other events, the τ is "misidentified",
  - From leptons (muons and electrons): 3% of the simulated events
  - From hadronic objects (initiated by light quarks, b quarks or gluons): 46% of the simulated events

Backgrounds with misidentified τ jets

Backgrounds with jets misidentified as τ object





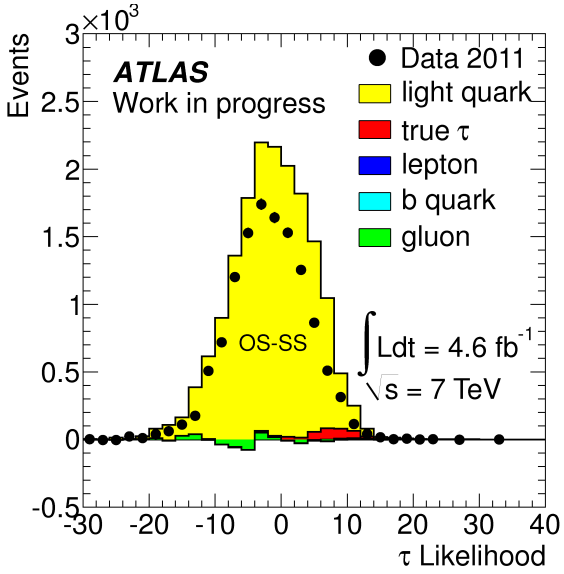
- The majority of misidentified τs comes from jets
  - misidentification probability depends on initial parton (light quarks, heavy flavour quark, gluon)

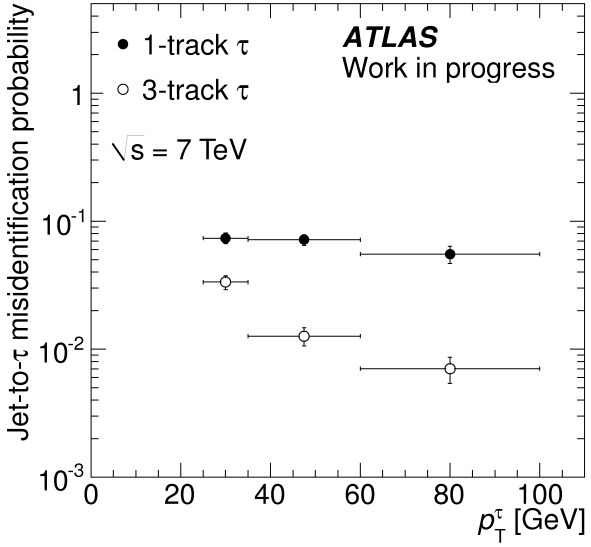
  Influence of all jet types except light quark jets can be effectively eliminated:
  - categorize all events in terms of the charge between τ and lepton, opposite sign (OS) and same sign (SS)
  - all process with gluon and b-quark jets are charge symmetric
- Giving a negative weight to SS events cancel out misidentified τs from gluon and heavy flavour

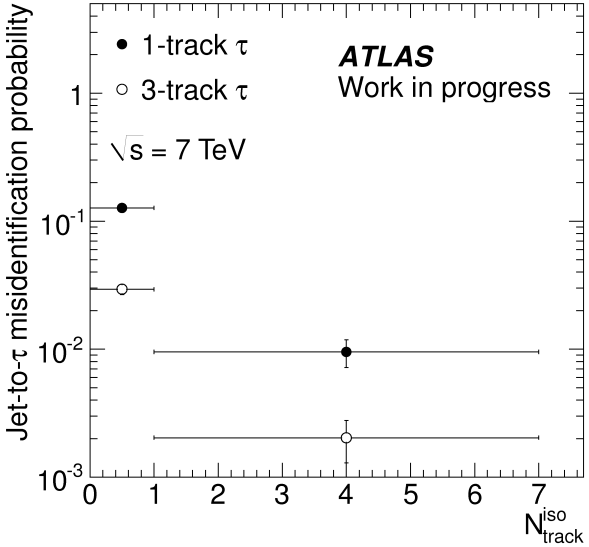
Backgrounds with misidentified τ jets

- The τ fake rate of light quarks is determined in $W+>2$ jets OS-SS events in data
  - exactly one electron or muon $E_T, p_T > 25$ GeV
  - at least one loose τ, $E_T^{miss} > 40$ GeV
  - at least 2 jets, no b-tag,

$$m_T = \sqrt{2p_T^l E_T^{\text{miss}}(1-\cos\Delta\phi_{l,\text{miss}})} > 30 \text{ GeV}$$







$$\text{mID}_q^\tau(\text{OS-SS}) = \frac{\text{number of } \tau \text{ candidates passing object selection and } \texttt{tau\_tauLlhTight}}{\text{number of } \tau \text{ candidates passing object selection}}. \quad (3)$$

Backgrounds with misidentified τ jets

Backgrounds with jets misidentified as τ object

- Scale factors on the number of associated tracks are applied in order to account for simulation-data differences
- Simulated events in which the selected τ object originates from a jet are weighted by the misidentification probabilities

Backgrounds with electrons misidentified as τ objects

- Tag-and-probe method to estimate the electron τ-fake rate
- Scale factors are applied to correct for discrepancies between data and simulation

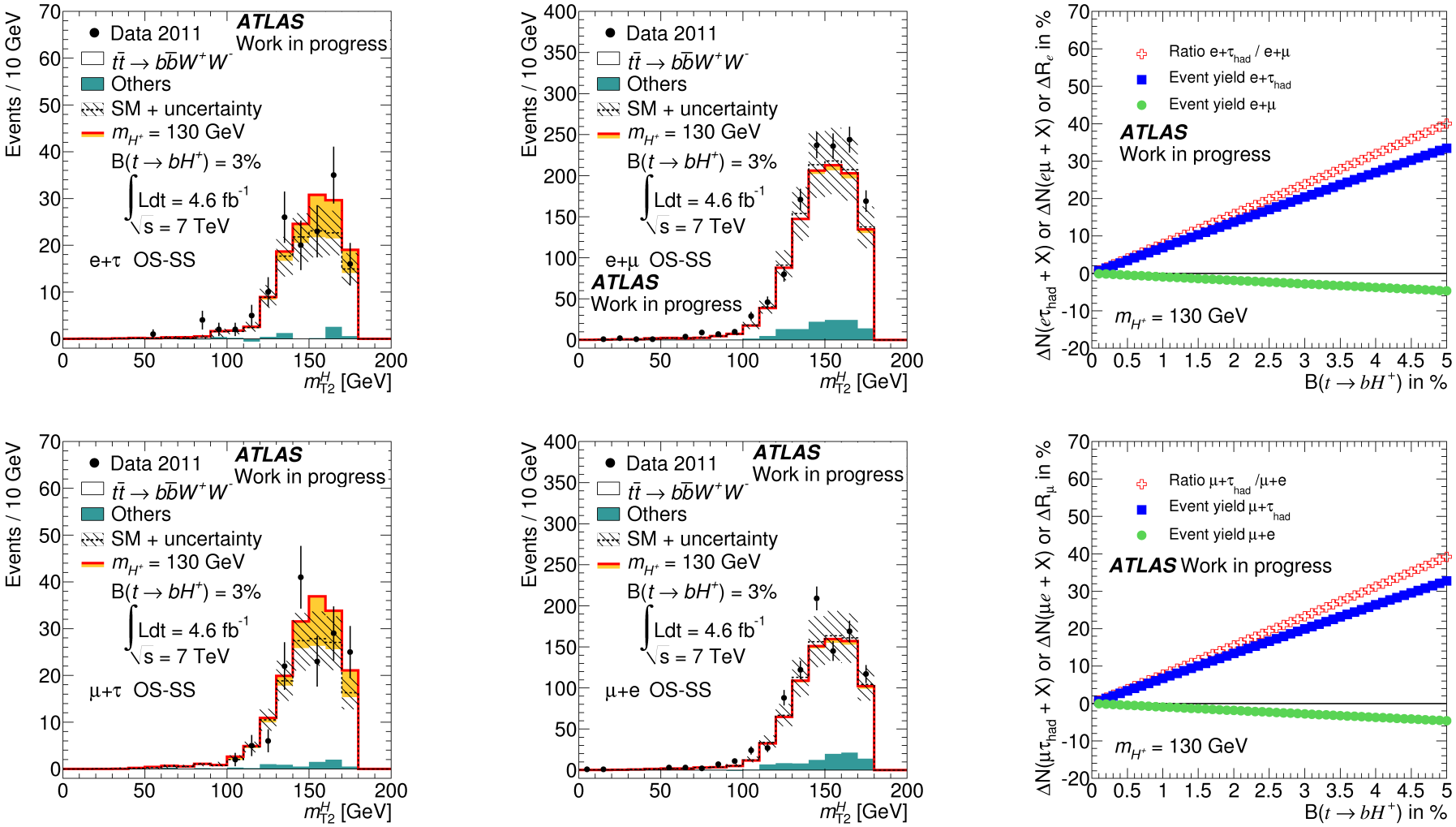
Backgrounds with muons misidentified as τ objects

- A muon veto is used in simulation

Results

- integrating the m_{T2}^{H} distributions $\rightarrow$ event yields

$$R_e = \frac{\mathcal{N}(e+\tau_{\mathrm{had}})}{\mathcal{N}(e+\mu)} \quad \text{and} \quad R_\mu = \frac{\mathcal{N}(\mu+\tau_{\mathrm{had}})}{\mathcal{N}(\mu+e)}.$$



Results

Systematic uncertainty	ΔR_e	ΔR_μ
Integrated luminosity	0.3%	0.3%
Electron trigger efficiency	0.1%	N/A
Electron reco. and ID efficiencies	0.2%	1.9%
Electron energy resolution	0.1%	<0.1%
Electron energy scale	0.1%	0.3%
Muon trigger efficiency	N/A	0.1%
Muon reco. and ID efficiencies	1.0%	0.1%
Muon momentum resolution	<0.1%	<0.1%
Muon momentum scale	0.1%	<0.1%
τ ID efficiency	3.9%	3.9%
τ energy scale	2.9%	3.0%
τ mis-ID (data-driven): number of associated tracks	2.1%	2.1%
τ mis-ID (data-driven): true $\tau_{\mathbf{had}}$ contamination	0.2%	0.2%
τ mis-ID (data-driven): H^+ signal contamination	0.6%	0.6%
τ mis-ID (data-driven): event environment	1.3%	1.2%
τ mis-ID (data-driven): statistical uncertainties	3.3%	3.2%
τ mis-ID (data-driven): electron veto uncertainties	0.6%	0.3%
b-tagging	1.9%	2.3%
Jet vertex fraction	0.1%	0.4%
Jet energy resolution	0.4%	<0.1%
Jet energy scale	0.7%	0.5%
Jet reconstruction efficiency	0.1%	0.4%
E_T^{miss}	0.3%	0.1%
$t\bar{t}$: cross section	0.7%	0.6%
$t\bar{t}$: generator and parton shower	5.7%	4.4%
$t\bar{t}$: initial and final state radiation	3.6%	3.7%
Backgrounds with misidentified leptons	3.5%	4.3%
Total (added in quadrature)	10.3%	10.1%

- $\rightarrow$ Systematics are dominated by (real/fake) τs

Conclusion

- This method reduces the impact of several systematic uncertainties in the analysis.
- Data-driven methods and simulation are employed to estimate the number of background events.
- Good agreement between data and SM predictions
- With this, limits on the branching ratio $B(t \to bH^+)$ can be calculated.
  - No public results at this point.

Backup

Backup

Backgrounds with misidentified electrons and muons

Let N_r^L and N_m^L (N_r^T and N_m^T): the number of events containing exactly one real or misidentified lepton, respectively, passing a loose (tight) selection.

$$N^L = N_m^L + N_r^L, \quad (4)$$
$$N^T = N_m^T + N_r^T. \quad (5)$$

Defining p_r and p_m (separately for electrons and muons) as:

$$p_r = \frac{N_r^T}{N_r^L} \quad \text{and} \quad p_m = \frac{N_m^T}{N_m^L}, \quad (6)$$

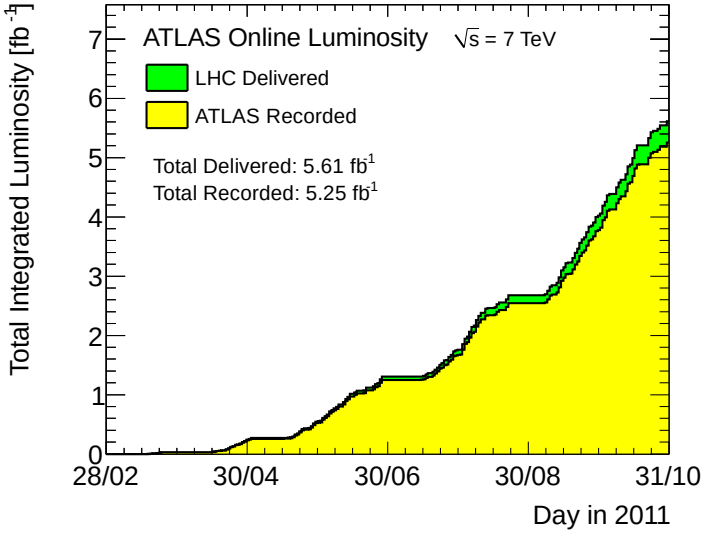
the number of misidentified leptons passing the tight selection N_m^T can then be written as:

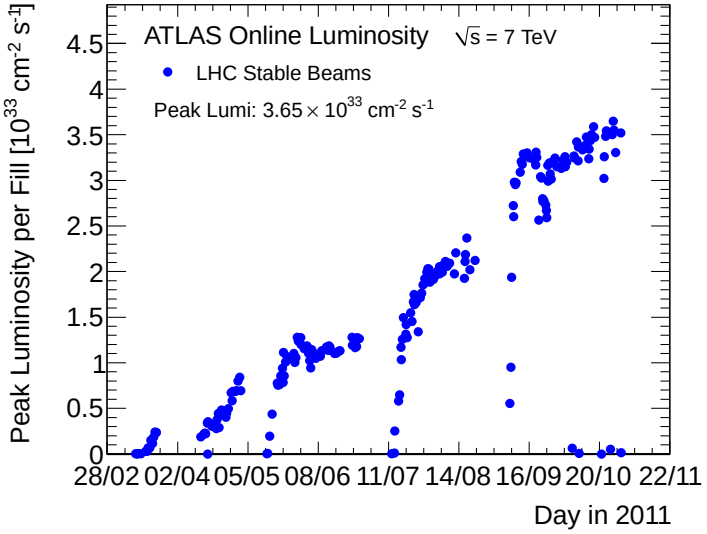
$$N_m^T = \frac{p_m}{p_r - p_m}(p_r N^L - N^T). \quad (7)$$

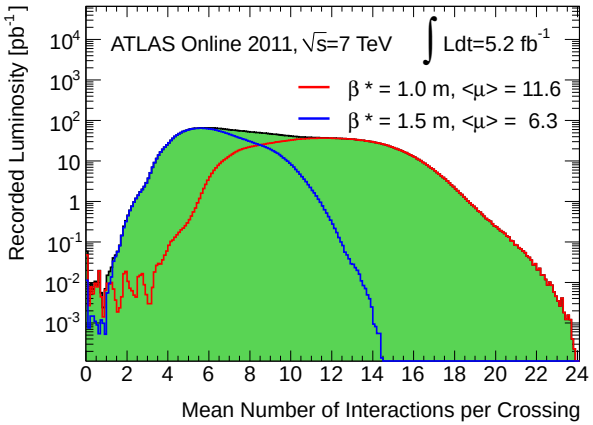
In the di-lepton case: one tight and one at least loose lepton

Data taking with ATLAS at LHC - 2011

- Only data taken with the full operational ATLAS detector is used in our analysis.







- More than $5\ \mathrm{fb}^{-1}$ were recorded
- Peak luminosity above $3.5 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$