Study of Tau Leptons from Top Quark Pairs in ATLAS

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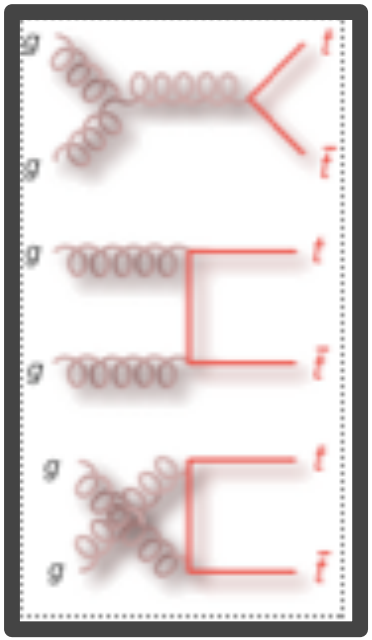
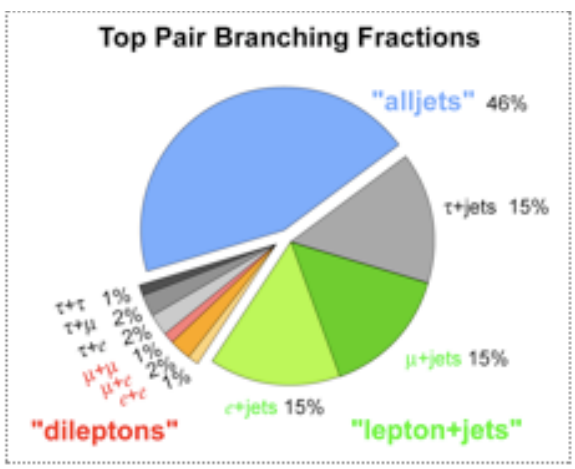
Introduction



- The decay of top quark pairs is one of the most significant sources of τ leptons at the LHC
  - Along with $W \rightarrow \tau\nu$ and $Z \rightarrow \tau\tau$

- The two τ final states of top pair decays refer to the case where $tt \rightarrow bWbW$, and :
- one $W \rightarrow \tau$(hadronic)υ
- one $W \rightarrow l(e/\mu)\upsilon$ ("τ + lepton") or $W \rightarrow qq$ ("τ + jets")

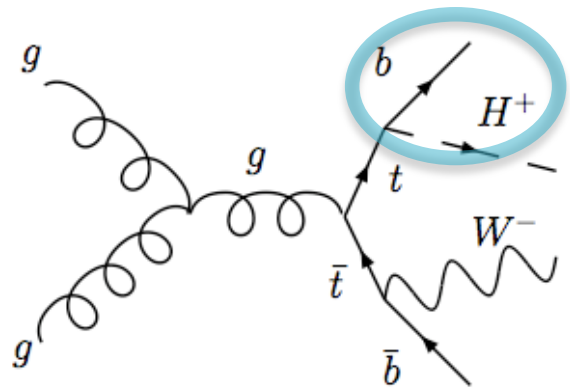


- The τ final states are interesting channels for observing possible physics beyond the standard model.

- One particular case of new physics that could be observed in this channel is the light ($< m_t$) charged Higgs.

Charged Higgs from Top Quarks and the Ratio Method

- Large top production cross section at LHC energies
- In the Standard Model
  - $t \rightarrow Wb$ (near 100%)
  - $W \rightarrow$ jets or $\ell\nu$
- In Models with Multiple Higgs Doublets
  - If $H^+ < (m_t - m_b)$, some will decay to H^+bWb
  - For many values of m_{H+} and $\tan(\beta)$, in many scenarios, $BR(H^{\pm} \rightarrow \tau\nu) \approx 100\%$



- The charged Higgs contribution could cause a deviation in lepton universality, altering the ratio:

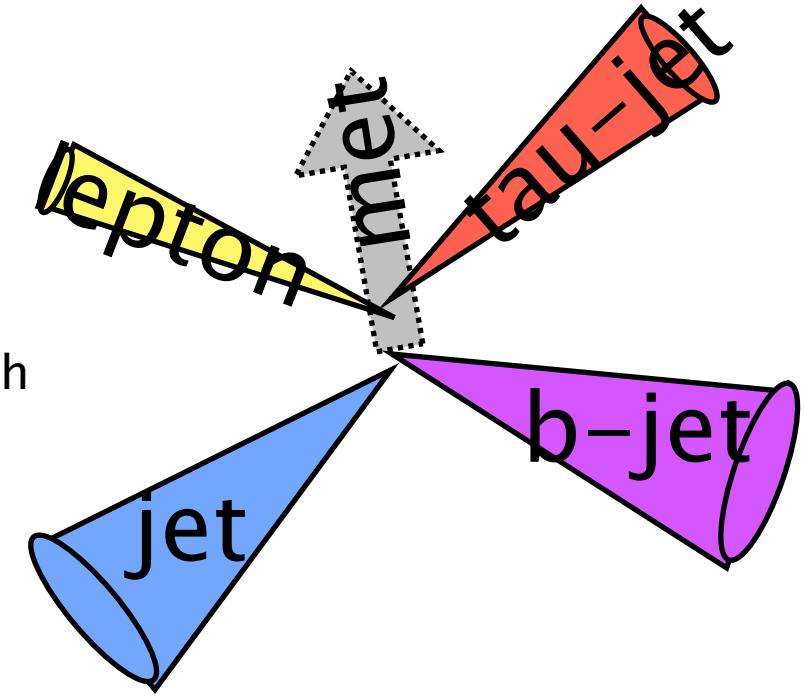
$$\frac{\sigma_{t\bar{t} \rightarrow \tau\nu\ell\nu b\bar{b}}}{\sigma_{t\bar{t} \rightarrow \ell\nu\ell\nu b\bar{b}}}$$

from the expected SM value

τ+Lepton Final State

Selection cuts:

1. Event Preselection:
    1. Event Level Cleaning Cuts
    2. Lepton Trigger
    3. 1 trigger-matched, isolated lepton with $P_t > 20/25$ GeV (μ/e)
2. At least 2 jets with $P_t > 20$ GeV
3. At least 1 b-tagged jet ($P_t > 20$ GeV)
4. Exactly 1 τ with $P_t > 20$ GeV
5. τ and lepton of opposite sign
6. $\Sigma E_t > 150$ GeV (all objects, no MET)
7. MET > 60 GeV

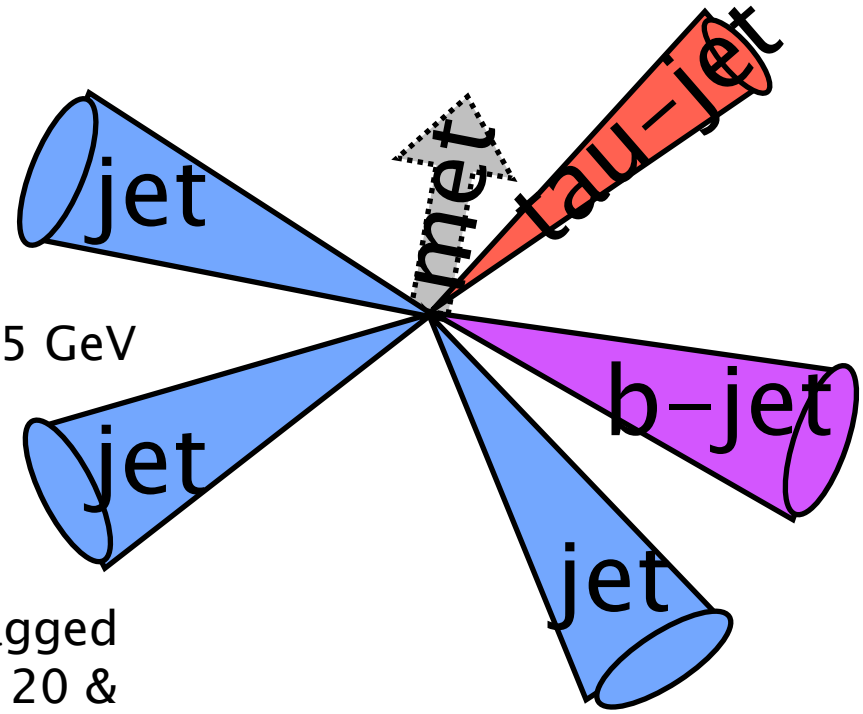


("tau+lepton" final state)

τ+Jets Final State

Selection cuts:

1. Event Preselection:
   1. Event Level Cleaning Cuts
   2. τ + MET trigger
2. At least 4 jets with $P_t > 20$ GeV
3. Exactly 1 trigger-matched τ with $P_t > 35$ GeV
4. No identified e or μ
5. MET > 40 GeV
6. MET significance > 8 $GeV^{1/2}$
7. At least 1 b-tagged jet ($P_t > 20$ GeV)
8. Reconstructed top mass (from one b-tagged jet and 2 non-b-tagged jets) between 120 & 240 GeV



("tau+jets" final state)

Tau ID and Fakes

- τ leptons can decay *leptonically* (BR = 35.3 %) or *hadronically* (BR = 64.7 %)
  - **This study focuses on hadronic decays**
- The hadronic decays can be split into:
  - '1-prong': 1 charged track + neutrino
  - '3-prong': 3 charged tracks + neutrino
- In the detector, the hadronically decaying τ's distinguishing features are:
  - Low track multiplicity (1 or 3 tracks)
  - A narrow deposition of tracks and energy in the calorimeters.
- A major challenge in identification of hadronic τ decays are the similar signatures left by quark and gluon initiated jets, and QCD.
  - My studies focus on understanding backgrounds from these sources.

Expected Backgrounds

• The backgrounds in the τ + lepton and τ + jets analyses can be considered in terms of what particle is reconstructed as a τ.

Real τ's

$Z \rightarrow \tau\tau$ + jets

$WW \rightarrow \tau\nu(e,\mu/qq)\nu$ + jets

Evaluated using:

• Data-driven embedding techniques (Replacing μ with τ signatures in data events.)

Electrons Faking τ's

Z+jets

ttbar→(e,μ/qq)e+jets

Electrons can fake 1-prong τ's

• An electron veto reduces this background.

• The remaining contribution is estimated using a fake rate measured through a tag-and-probe method applied to Z→ee events.

Expected Backgrounds: Jets

- Jets faking τ's make up the largest background to the τ+lepton analysis, and I have focused on developing data-driven predictions.

- τ's are most often faked by light quark initiated jets, but they are sometimes also faked by gluons or (less commonly) b-jets.

Jets Faking τ's (light quarks)
W+jets
ttbar→(e,μ/qq) + jets
Single top

These fakes are estimated using a fake matrix derived from γ + jets events in collision data.

QCD
QCD is poorly described in Monte Carlo, so a data-driven fitting method is used to estimate the QCD contribution.

Data

- The LHC collision data ($\sqrt{s} = 7$ TeV) used for these studies comprise 1.03/fb of integrated luminosity.
- The collision data was collected by the ATLAS detector, up through mid-July of 2011.
- Any Monte Carlo distributions shown are scaled to 1.03/fb.

Fakes Estimated from γ + jets

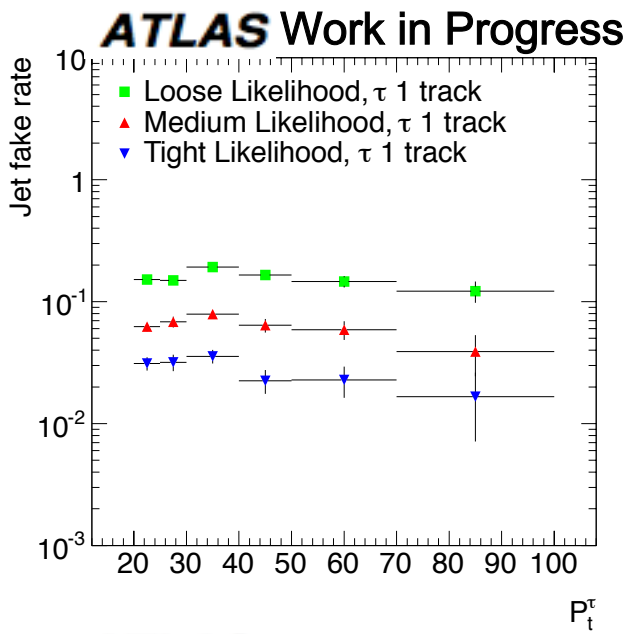
- Event must have at least 1 photon and 1 jet
  - back to back and balanced in transverse momentum
  - Any additional jet must have < 20% of the transverse momentum of the photon.

τ Fake Rate Numerator & Denominator

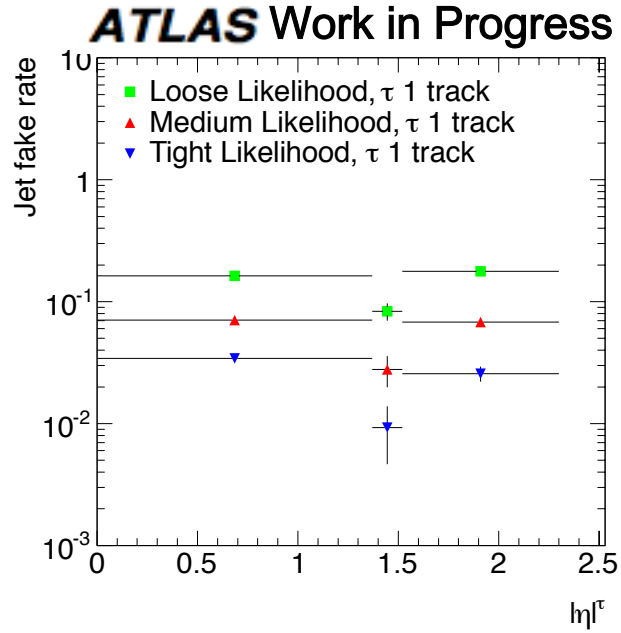
- Denominator
  - Pt > 20 GeV
  - $|\eta| < 2.3$
  - Calorimeter seeded
  - Electron veto
  - Not near any electron or muon
  - # tracks = 1 or 3
- Numerator
  - Qualifies as a denominator object
  - Passes a τ Likelihood-based identification algorithm
- Fake Matrix:
  - Binned by τ Pt and $|\eta|$, separated into 1 and 3 track τs
    - Pt bins are coarser at higher Pt
    - $|\eta|$ is separated into three bins: barrel, crack (1.37-1.52), and end-cap regions

Fake Rates vs. Pt and Eta

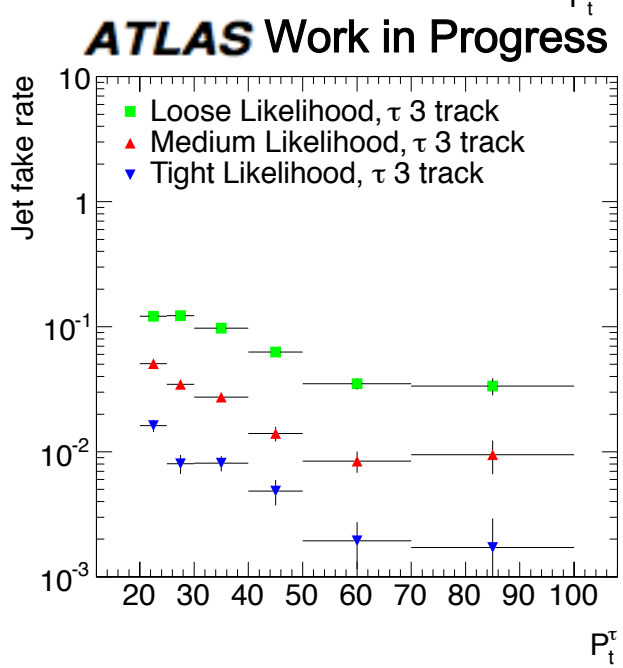
Fake rates vs. Pt

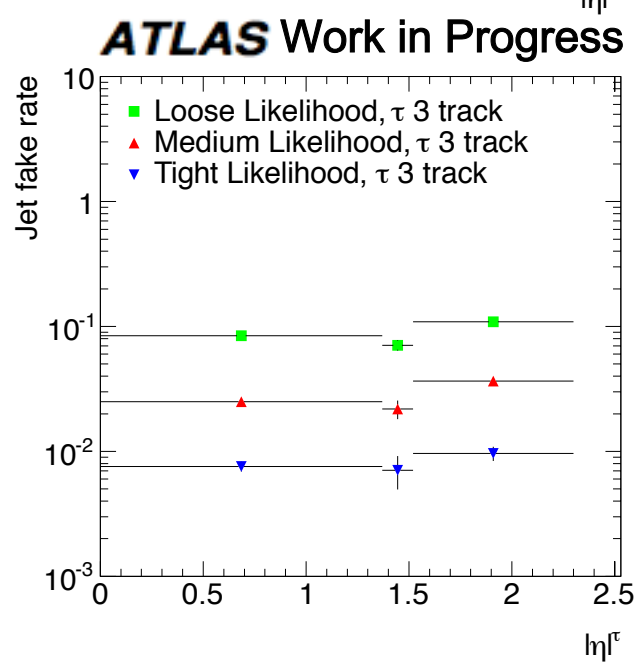


Fake rates vs. |η|



1-Prong τs

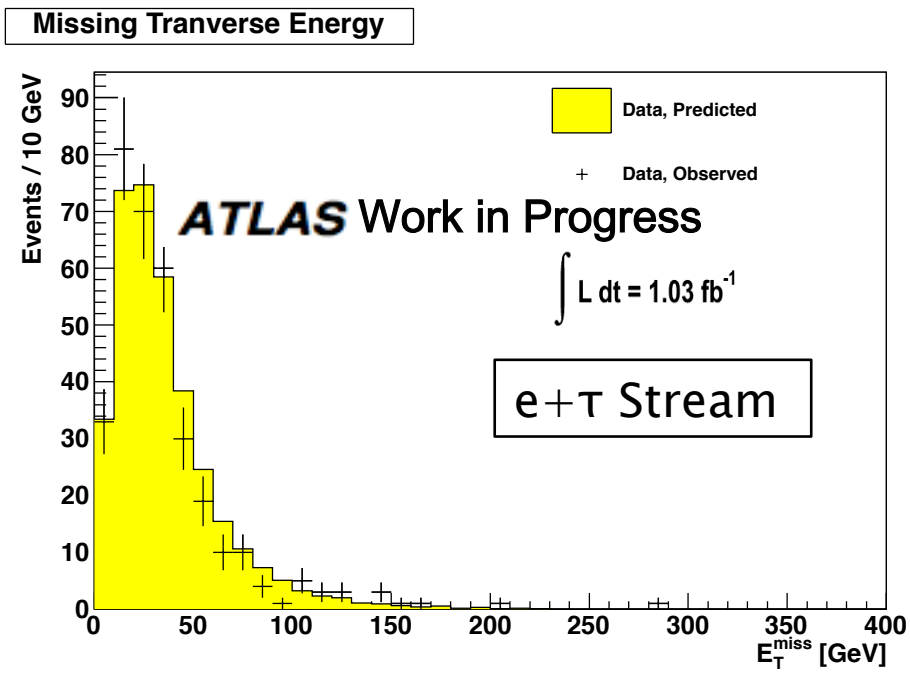


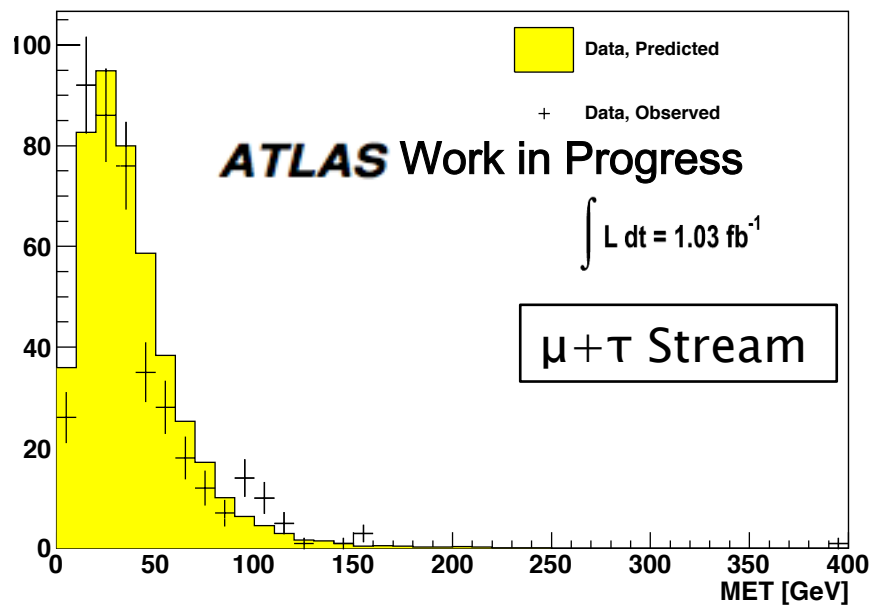


3-Prong τs

Fake Rates Applied

- These fake rates are applied to a control region to test accuracy:
  - Before MET cut
  - Requiring exactly zero b-tagged jets





Fake Rates Applied

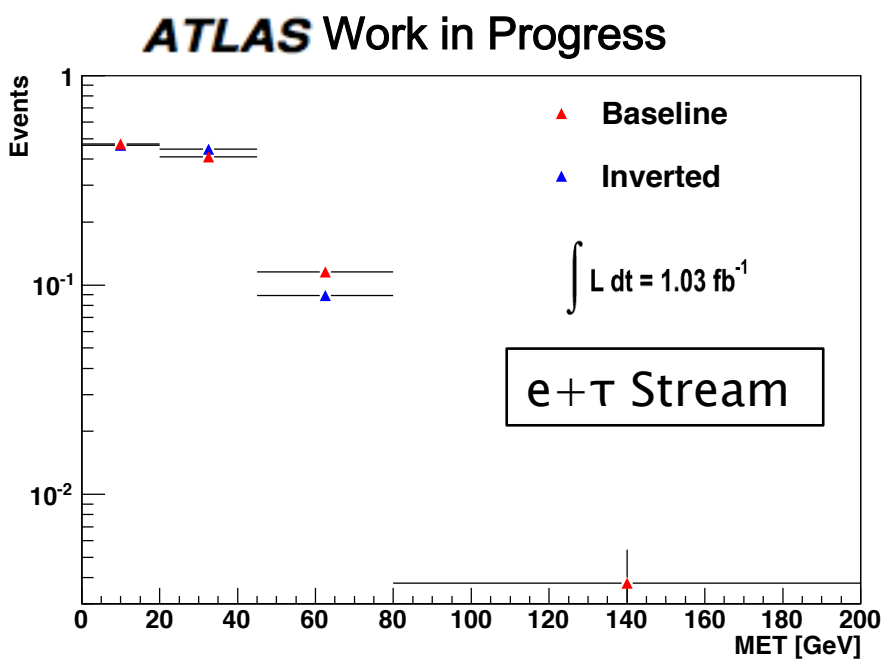
- The contribution from jet fakes is then determined for the signal region, and the prediction is compared with MC expectation.

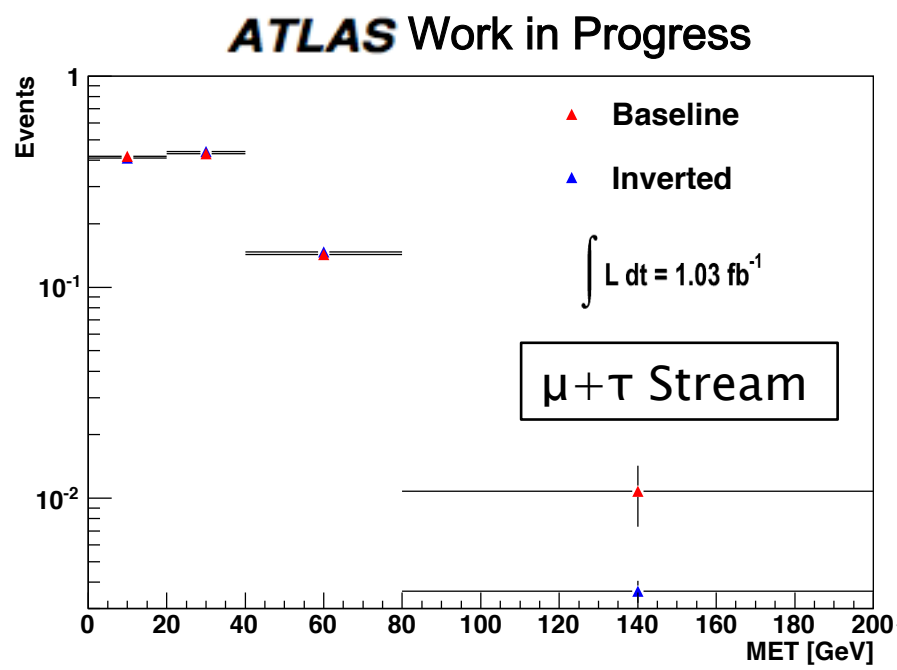
ATLAS Work in Progress $\int L\,dt = 1.03\ fb^{-1}$

Sample	Fake Rate	MC Prediction
τ + jets		
ttbar	2.8 ± 1.0	3.8 ± 0.6
τ + lepton		
ttbar	29.2 ± 18.5	27.8 ± 0.8
W+jets	7.4 ± 1.9	6.6 ± 0.3
Single top	1.7 ± 0.4	1.0 ± 0.06

QCD Background Estimate: τ + lepton

- To model the QCD background, an orthogonal event selection is defined that is identical to the tau+lepton selection except for an inverted lepton selection
  - For electrons: anti-isolated, pass a loose selection but not tight
  - For muons: anti-isolated
- The shape of the MET distribution, after all non-QCD processes are subtracted, is the same for the baseline and inverted selections.

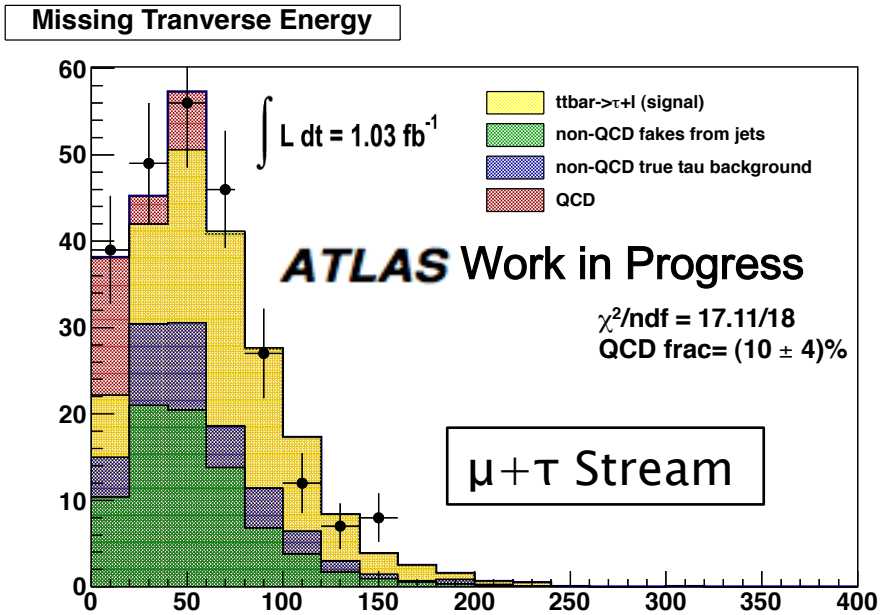


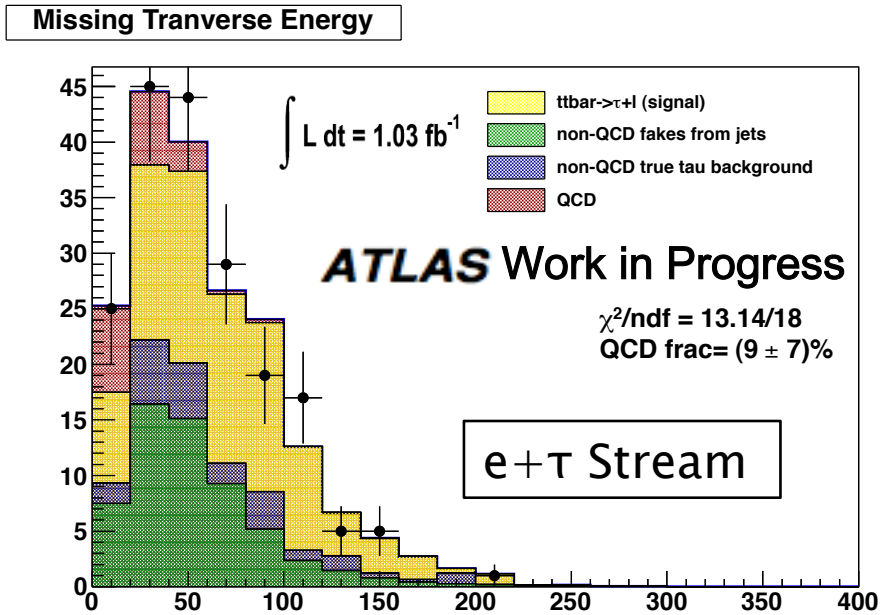


QCD Background Estimate:τ + lepton

- The shape of the inverted selection can be used as a model for the shape of the QCD contribution.
- A fit is performed to the MET using:
  - this QCD model
  - the sum of non-QCD processes(ttbar, W+jets,Z+jets, single top, diboson)
- The fit floats the overall normalization (to the one in data) and the QCD fraction.

QCD Estimate Results: τ + lepton

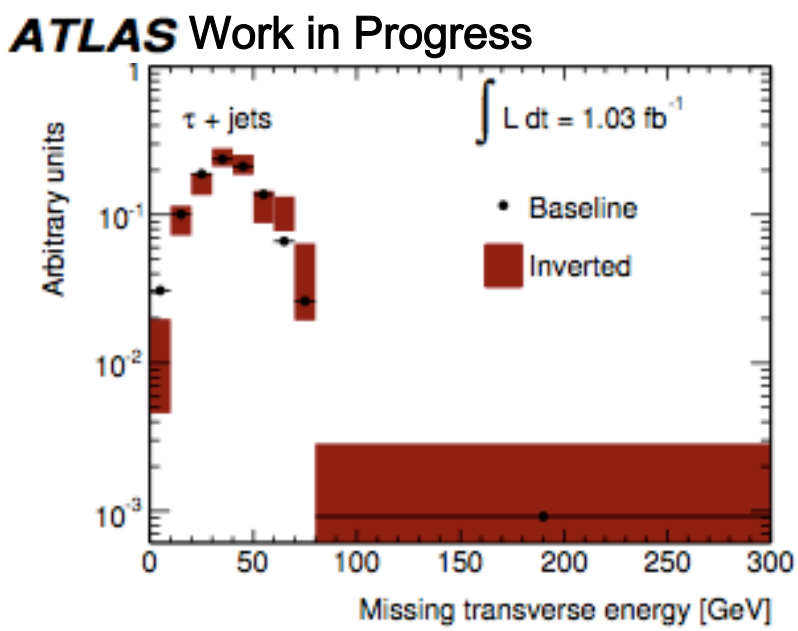




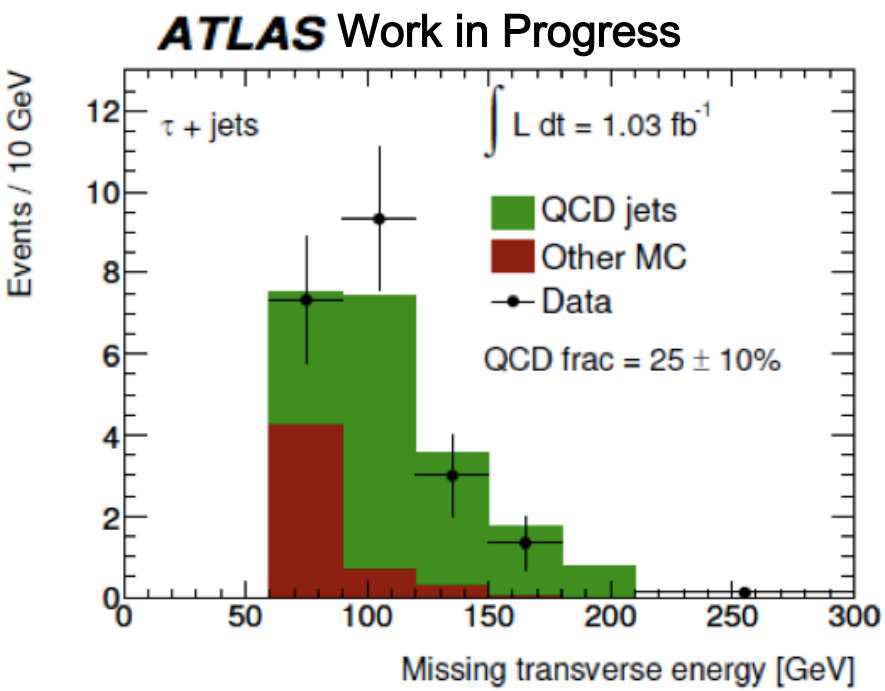
QCD contribution above the MET cut of 60 GeV is very small.

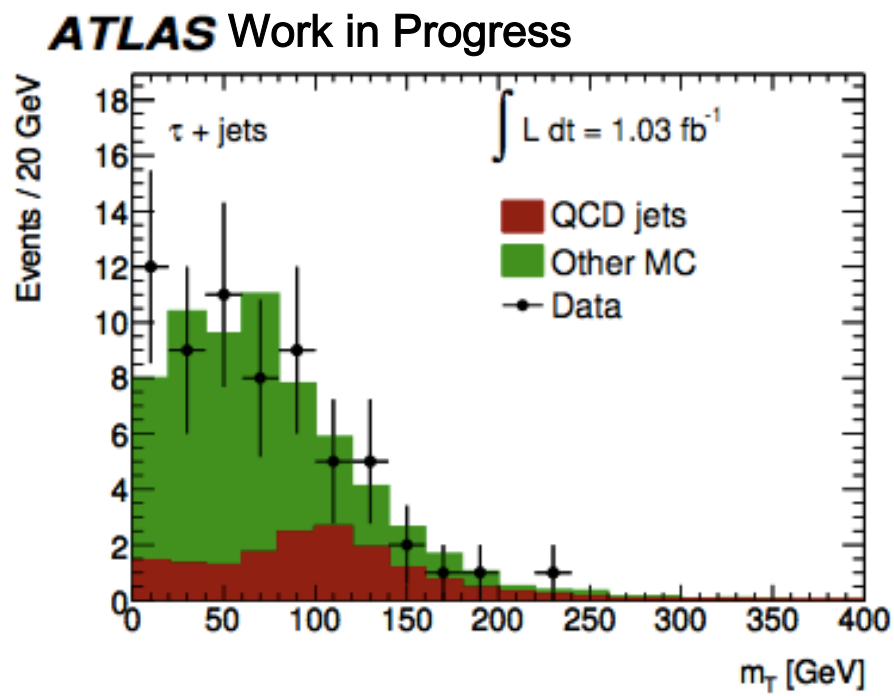
QCD Background Estimate: τ + jets

- For the τ + jets case, the τ selection and b-tagging requirement are inverted:
  - For τ leptons: pass a loose selection but not tight
  - No b-tagged jets
- The shape of the MET distribution, after all non-QCD processes are subtracted, is used for the QCD fitting.
- As in the τ +lepton case, the distributions are the same for regular and inverted selections.



QCD Estimate Results: τ + jets





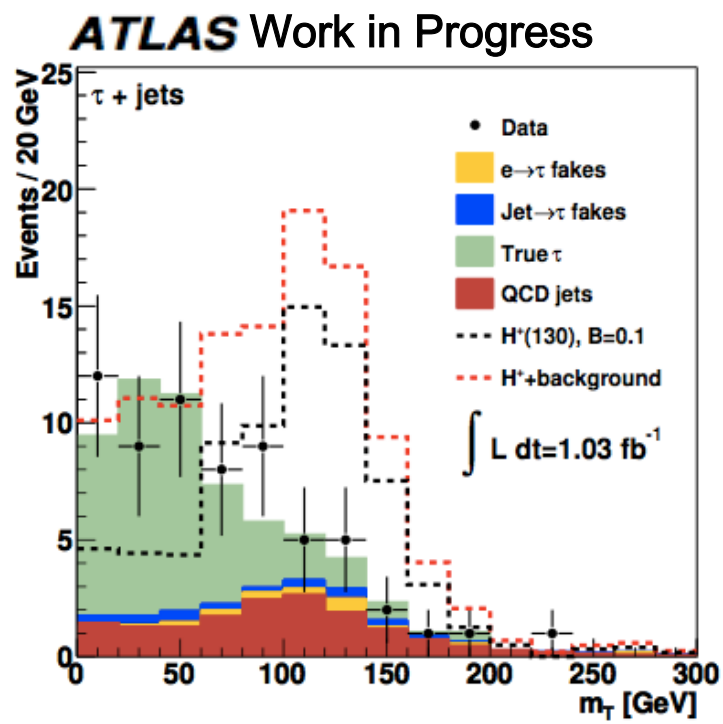
The results of the QCD estimate using the MET distribution.

The QCD estimate from the fitting method applied to the MT(τ,MET) distribution for the baseline selection.

State of Analyses

- To the left is the final MT(τ,MET) distribution for the τ + jets analysis.
  - The plot compares the results of the data driven methods to collision data.
  - The distribution of the H+ signal is given for a reference point in parameter space corresponding to BR (t → bH+) = 10%

- The τ + lepton analysis begins the approval process soon.



Summary & Future Outlook

- A good understanding the backgrounds is necessary for the analyses of top quark pairs to $\tau_{(had)}$ final states.
  - The largest background for τ + lepton is from jets faking τ leptons, predicted using a data driven fake rate from γ + jets.
  - QCD contributes very little to the backgrounds above the missing E_t cut for τ + lepton, but contributes significantly to τ + jets
  - Contributions from electrons faking τ leptons are small, but predicted using data-driven fake rates from $Z \rightarrow ee$ events.
  - Backgrounds with true τ leptons are predicted by embedding τ signatures in events from collision data.
- Analysis work is underway, and soon will result in limits on BSM physics based on the ttbar to τ + lepton channel.