Recent Top Quark Results from ATLAS

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Brookhaven HEP Seminar

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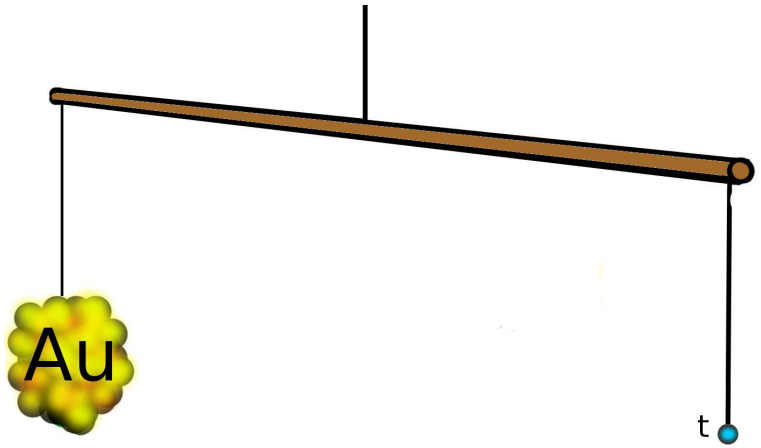
Outline

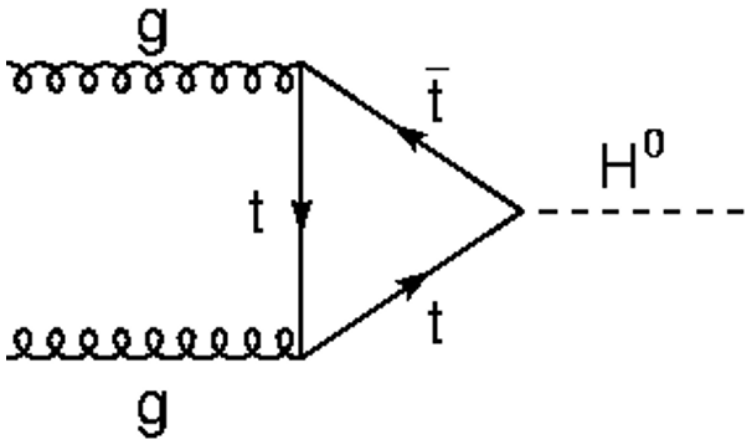
- Top Quarks
- Cross Section Measurement
- Searches
  - Resonances
  - Flavor Changing Neutral Currents (FCNC)
  - Anomalous couplings
- $l + \tau$ **cross section**

Top Quarks

- The top quark is the most massive fundamental particle

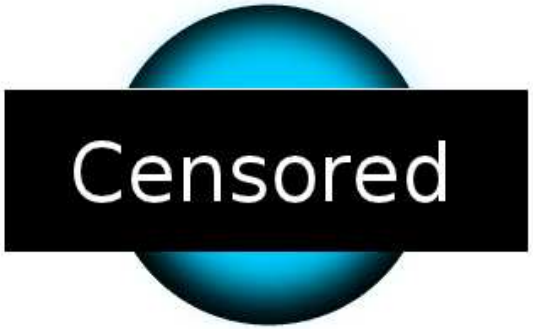


- It plays a unique role in Standard Model Higgs physics

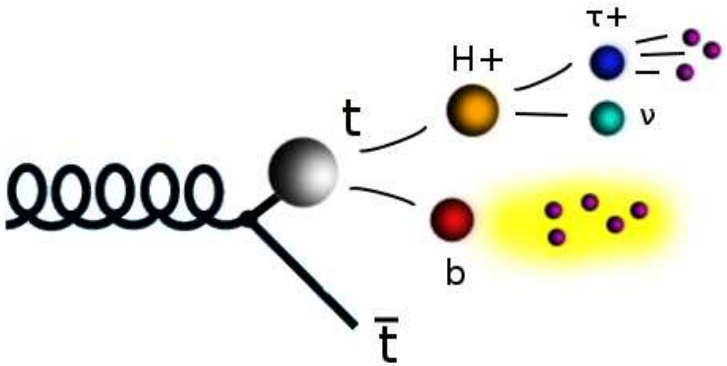


Top Quarks

- It is a bare quark.
  (Does not hadronize)

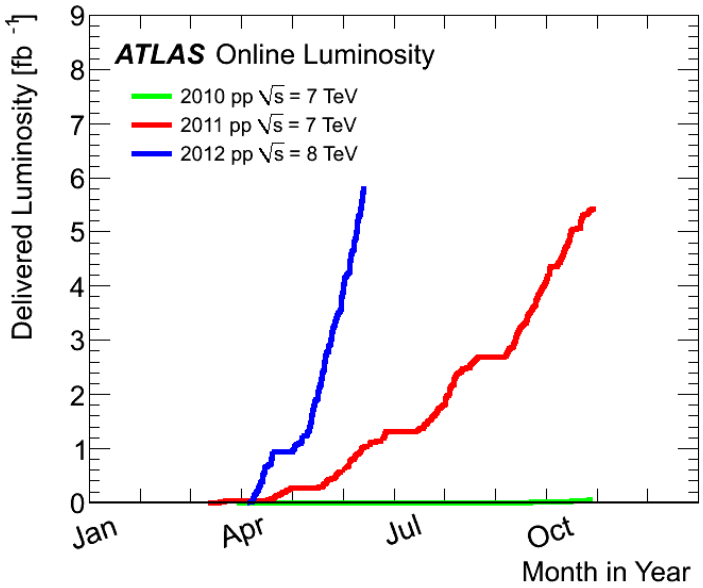


- Maybe it is the probe that finds new physics?



Making a Top Quark

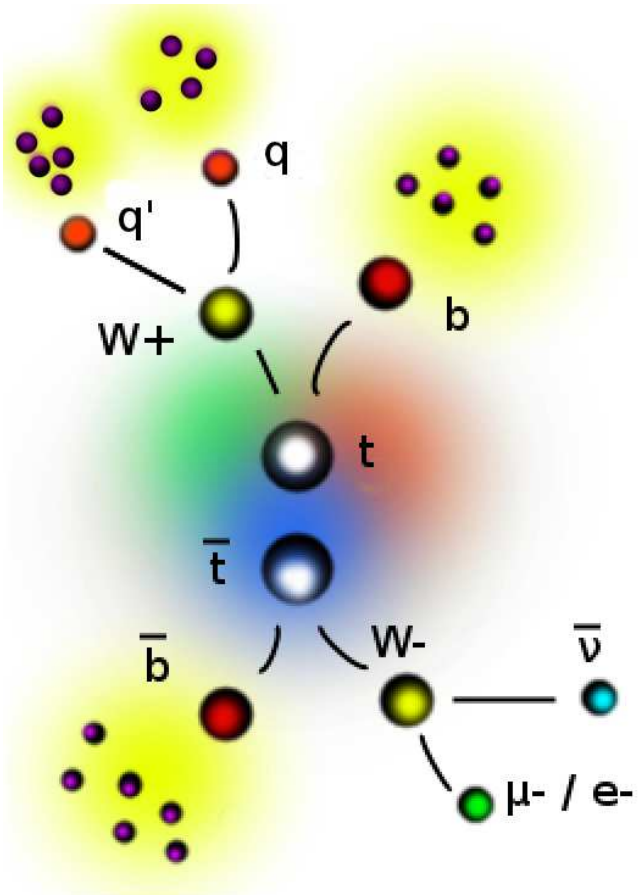
- The LHC has been colliding protons at $\sqrt{s} = 7{,}8$ TeV
- 5.25 fb^{-1} recorded at 7 TeV in 2011
- 5.24 fb^{-1} and counting this year at 8 TeV
- $\sigma_{t\bar{t}} \sim 165$ pb @ 7 TeV
  $\sigma_{t\bar{t}} \sim 240$ pb @ 8 TeV



- ATLAS has recorded hundreds of thousands of top quarks
- Top quark measurements are now used for precision studies. Results mainly on $\sim$ 1-2 fb^{-1}

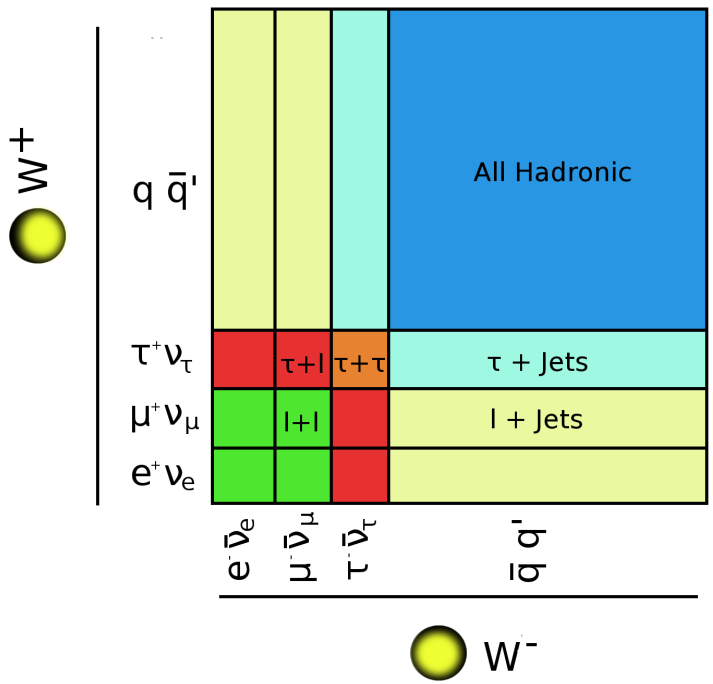
Finding a Top Quark

- In the SM top quarks decay overwhelming as $t \to W^+ b$
- Gives several handles for identification
  - $e/\mu/\tau$ from W decays
  - $\not{E}_t$ from neutrino
  - b-jet
- Lots of handles, but each must be understood with high precision



Finding a $t\bar{t}$ event

- Final states are categorized by the W decay



- Every final state has been directly measured at ATLAS except $\tau - \tau$

Cross Section Measurement

- Several new physics processes can contribute to $t\bar{t}$ production
  - Heavy Z' decays
  - t' or $\tilde{t}$ decays
  - etc.
- Before data we had very pessimistic predictions about the $t\bar{t}$ cross section measurement

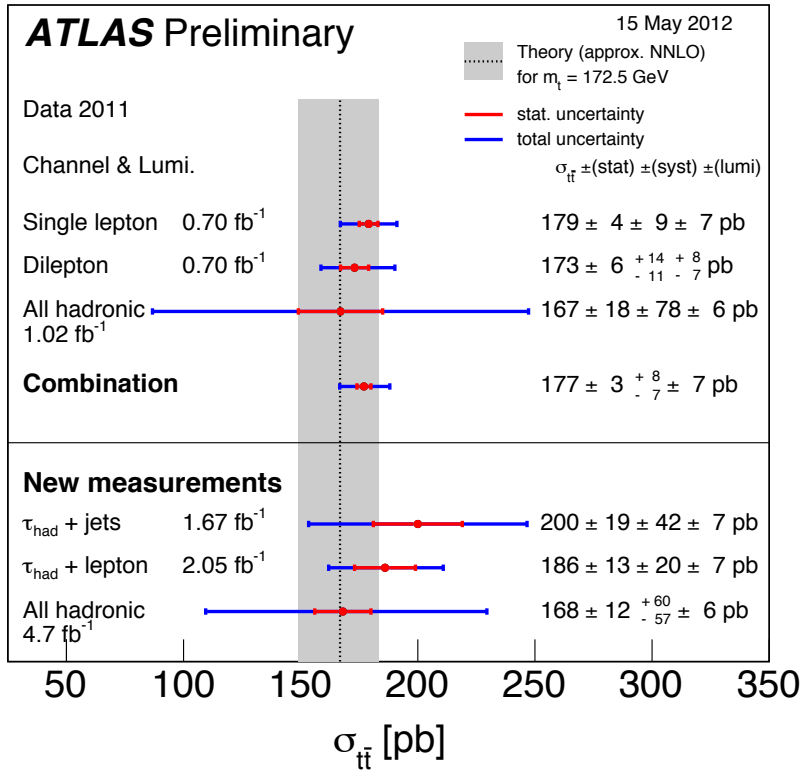
"we expect a measurement of the cross-section...in the combined channel with a relative uncertainty of 3.1 (stat) $\pm^{10.0}_{8.9}$ *(syst)* $\pm^{26.2}_{17.4}$ *(lumi)"*-@ 10 TeV 200 pb

- Actual luminosity uncertainty $\sim 4\%$ not $\sim 20\%$
- Excellent precision

Results

- Best measurement is the combination of several ATLAS channels

- $\sigma_{t\bar{t}} = 177 \pm 3\ (\text{stat.}) \pm^{8}_{7}\ (\text{syst.}) \pm 7\ (\text{lumi.})$ pb
- Smaller uncertainty than theory
  $\sigma_{t\bar{t}} = 165 \pm^{11}_{16}$ pb
- @ CMS
  $\sigma_{t\bar{t}} = 165.8 \pm 2.2\ (\text{stat.}) \pm 10.6\ (\text{syst.}) \pm 7.8\ (\text{lumi.})$ pb
- Can't say anything about new physics until theory prediction improves
- Need to narrow the scope, and investigate specific processes that could hide inside the inclusive cross section errors ($<\sim$ 35 pb to avoid 3σ evidence)

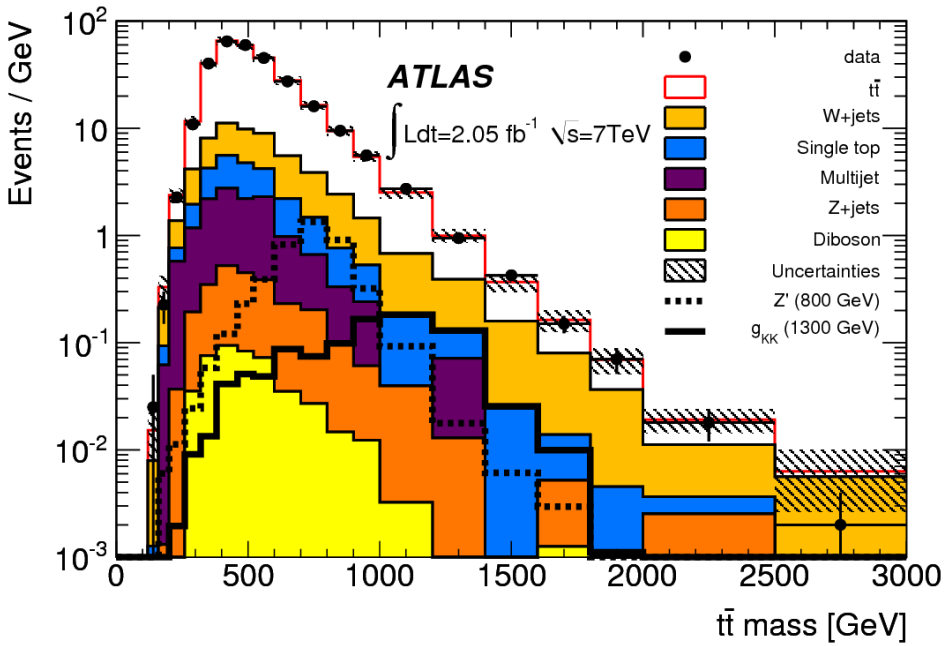


Top Quark Resonances

- Heavy resonances could produce mass peaks
  - $g_{kk} \rightarrow t\bar{t}$ - Wide Resonance
  - $Z' \rightarrow t\bar{t}$ - Narrow Resonance
- ATLAS search with 2.05 fb^{-1}
  `http://arxiv.org/abs/1205.5764`
- Search in both the l+jets, and dilepton channels

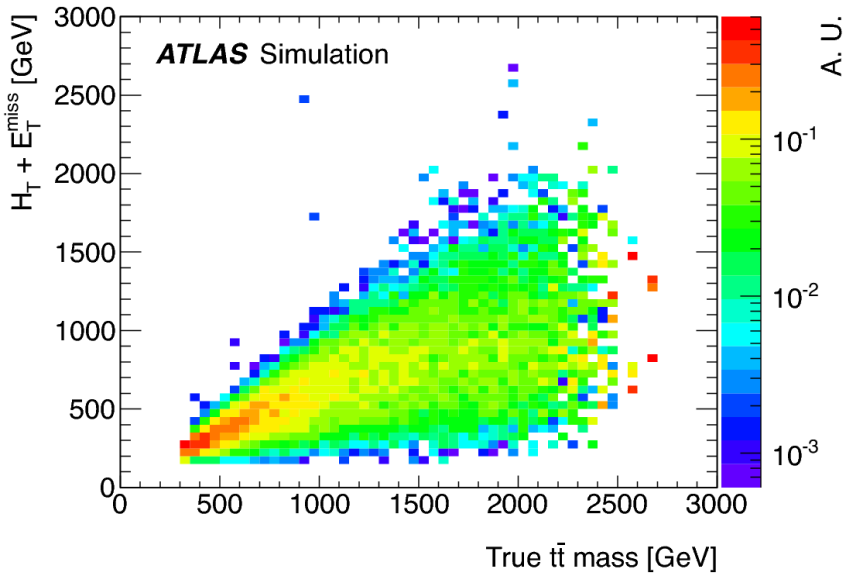
l+jets mass reconstruction

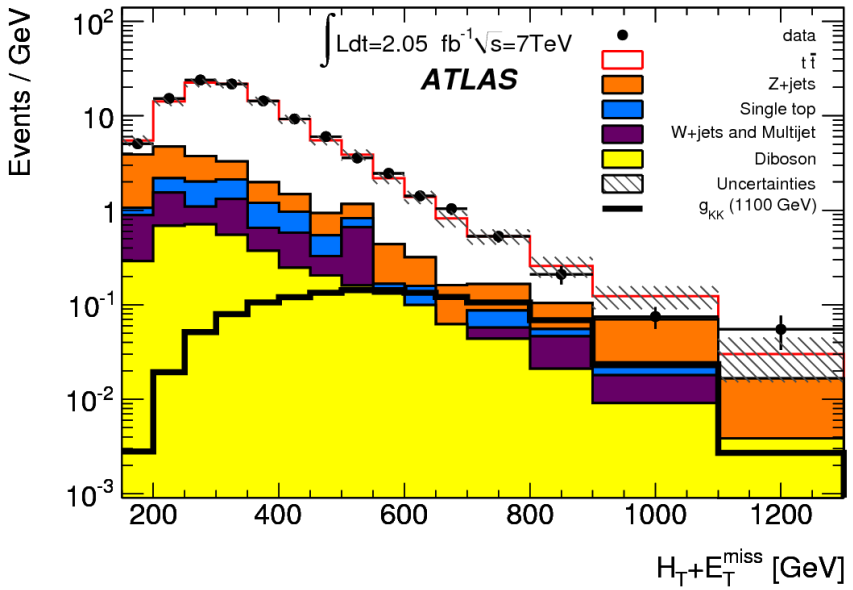
- Use W mass to constrain the p_z of the neutrino
- Mass is formed from the lepton neutrino and the four leading jets
- Tails caused by any ISR/FSR jet ending up as one of the leading jets
- Jets are excluded if $\Delta R > 2.5 - 0.015x(m_j/GeV)$ between the jet an any other object
- This removes jets isolated from the rest of the events activity



Dilepton $t\bar{t}$

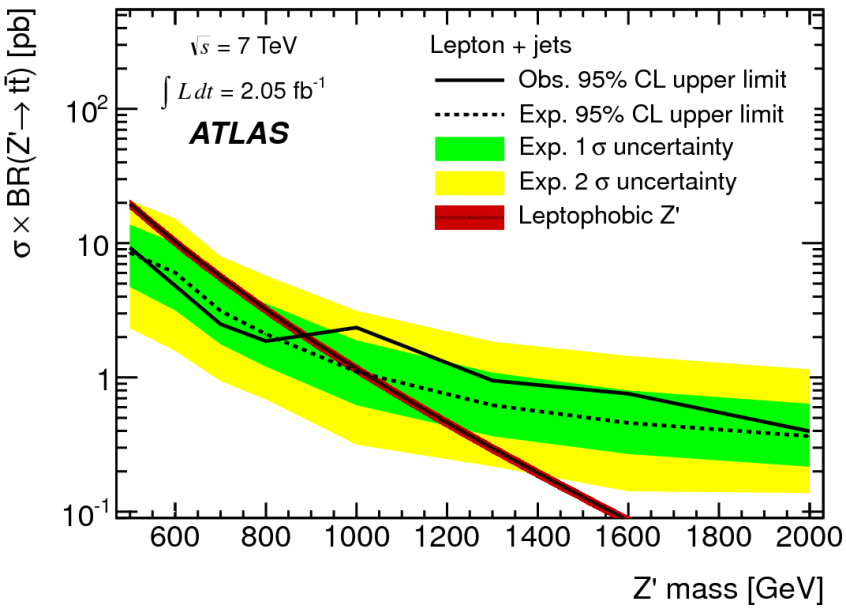
- Two neutrinos $\rightarrow$ mass is under-constrained
- Use a variable correlated to the mass
- $H_t + \not{E}_t$ (H_t = scalar sum of jet and lepton p_ts)

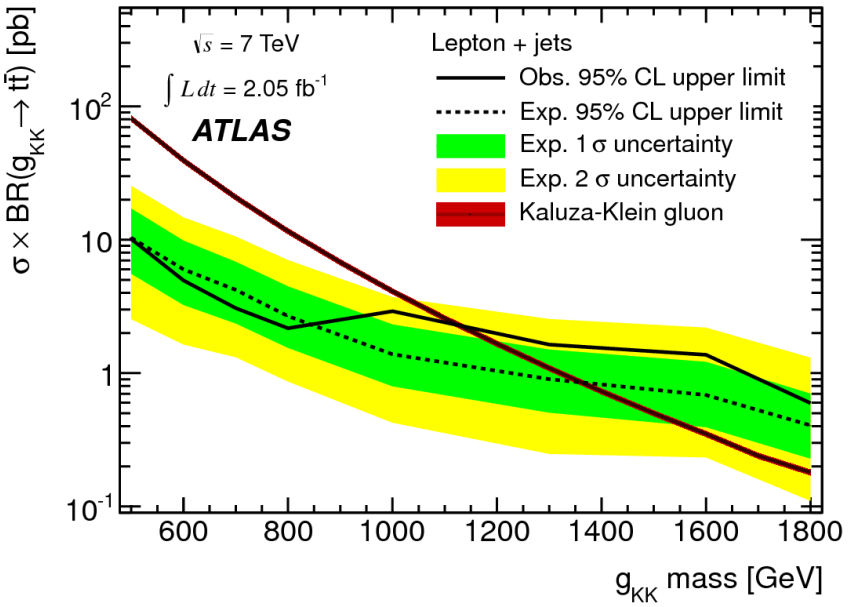


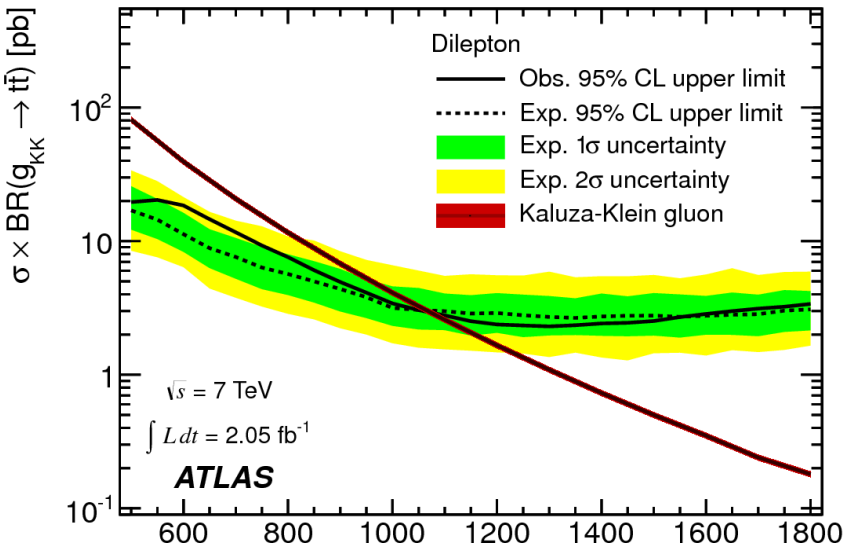


Results

- Exclude between 9.3-0.95 pb for Z'xBR($t\bar{t}$)
- 10.1-1.6 pb for $g_{kk} * BR(t\bar{t})$







Decays and Quantum Effects

- No evidence for anomalous production of top quarks
- Perhaps new physics shows up in the top quark itself
  - Flavor Changing Neutral Currents
  - Anomalous couplings
  - τ lepton excesses

FCNC

- Look for the process $t \rightarrow Zq$
- Highly suppressed by the GIM mechanism
- Standard Model BR $\sim 10^{-14}$
- Higher in many BSM theories
  - two-Higgs doublet model
  - topcolour-assisted technicolur
  - warped extra dimensions
  - SUSY with R-parity violation
  - etc..
- BR as high as $2x10^{-4}$

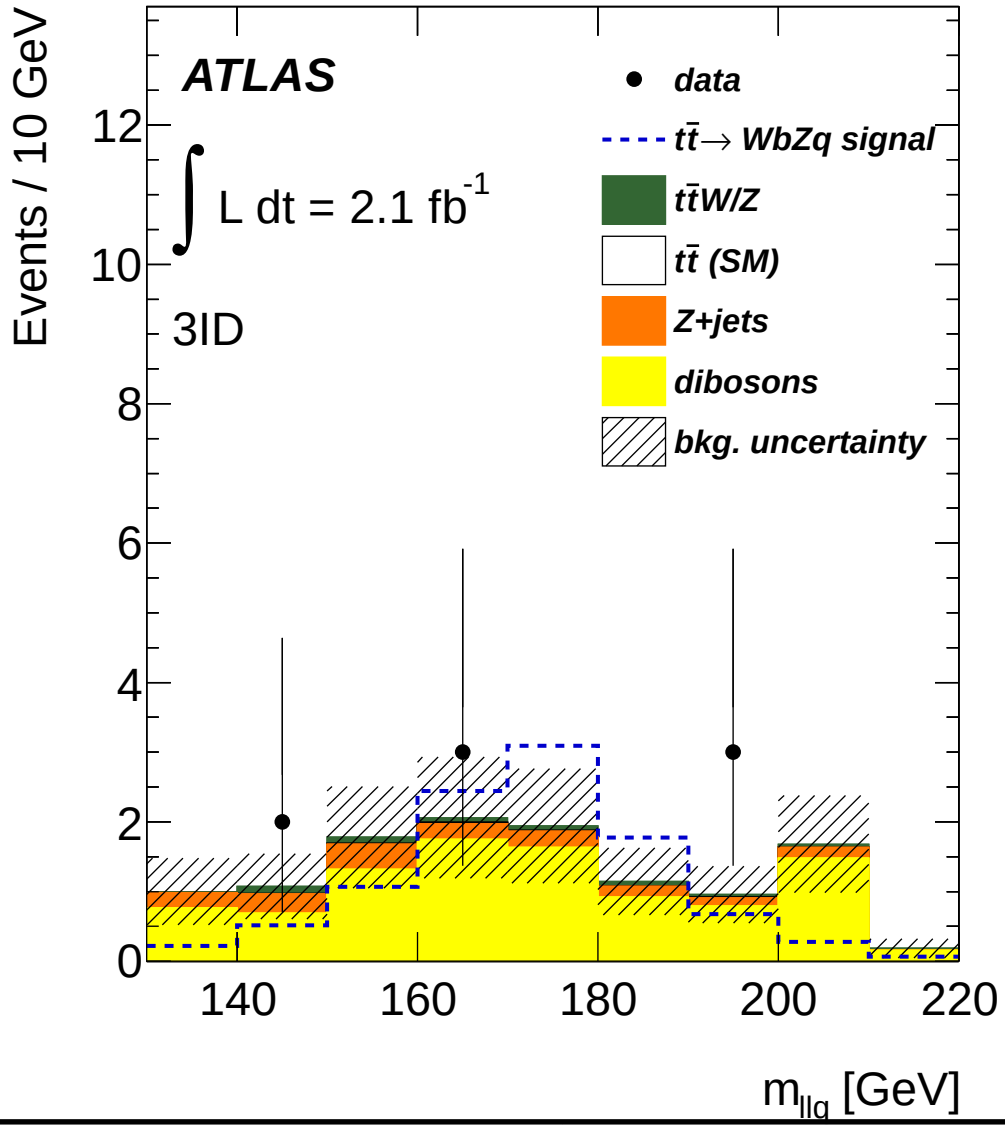
Search

- Final state is $t\bar{t} \rightarrow ZWqb \rightarrow lllqb$
- Three lepton final state with SM diboson backgrounds
- Look for a top mass peak with llq
- Tops are reconstructed by minimizing

$$\chi^2 = \frac{(m^{reco}_{j_a l_a l_b} - m_t)^2}{\sigma_t^2} + \frac{(m^{reco}_{j_b l_c \nu} - m_t)^2}{\sigma_t^2} + \frac{(m^{reco}_{l_c \mu} - m_W)^2}{\sigma_W^2} + \frac{(m^{reco}_{l_a l_b} - m_Z)^2}{\sigma_Z^2}$$

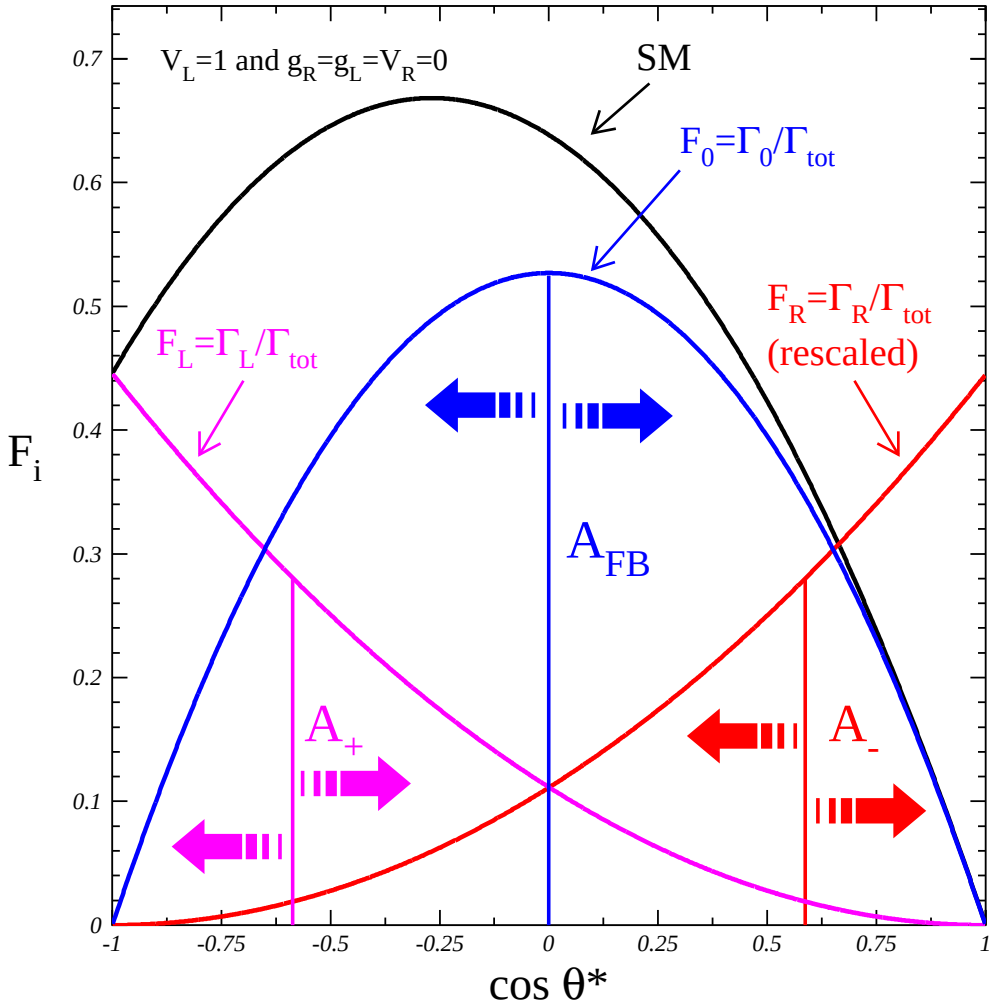
Results

- No evidence found
- Limits placed at $\mathrm{BR}(t \to qZ) < 0.93\%$
- Getting close but not to the interesting region yet
- Expect updates to this measurement



W Polarization

- BSM physics can lead to anomalous Wtb couplings
- Affects W polarization in top decays
- Measurable through $cos\theta^*$
  - Angle between lepton and *b* quark in W rest frame



W Polarization

- Two methods were used to measure the polarization components from $cos\theta^*$
- Template fits to the data

$$\frac{1}{\sigma}\frac{d\sigma}{dcos\theta^*} = \frac{3}{4}(1-cos^2\theta^*)F_0 + \frac{3}{8}(1-cos\theta^*)^2F_L + \frac{3}{8}(1+cos\theta^*)^2F_R$$

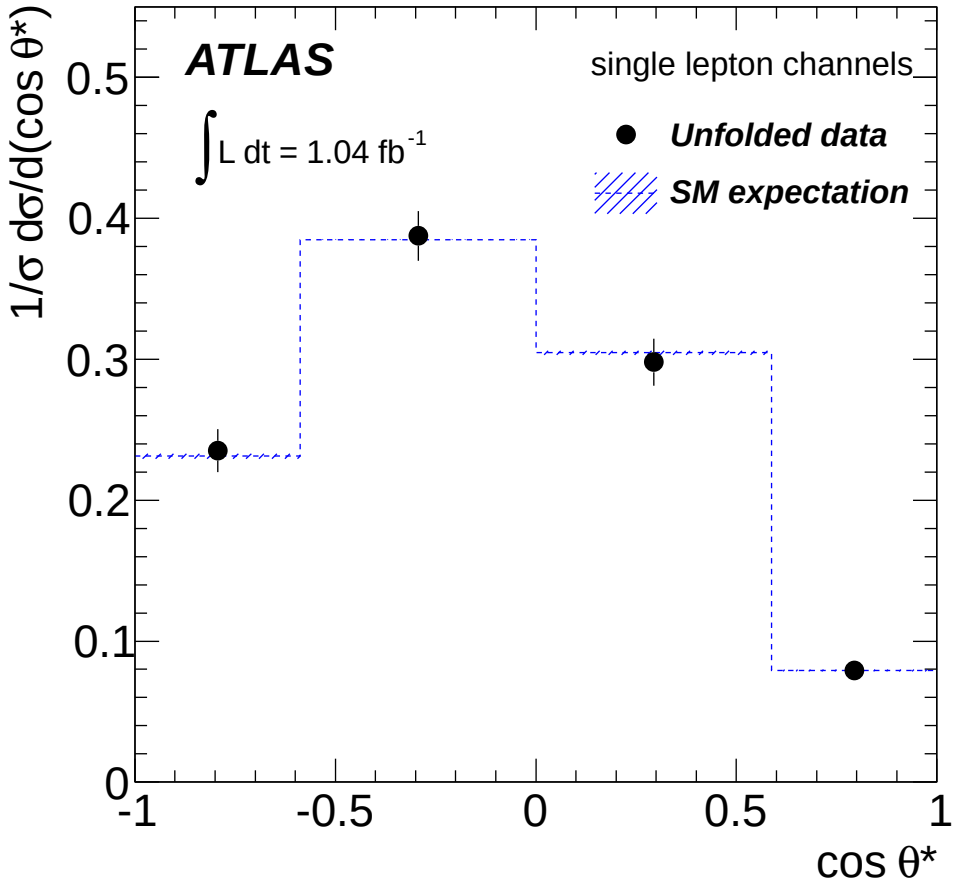
- Measurement of Asymmetries

$$A_{\pm} = \frac{N(cos\theta^* > z) - N(cos\theta^* < z)}{N(cos\theta^* > z) + N(cos\theta^* < z)}$$

- $z = \pm(1-2^{\frac{2}{3}})$

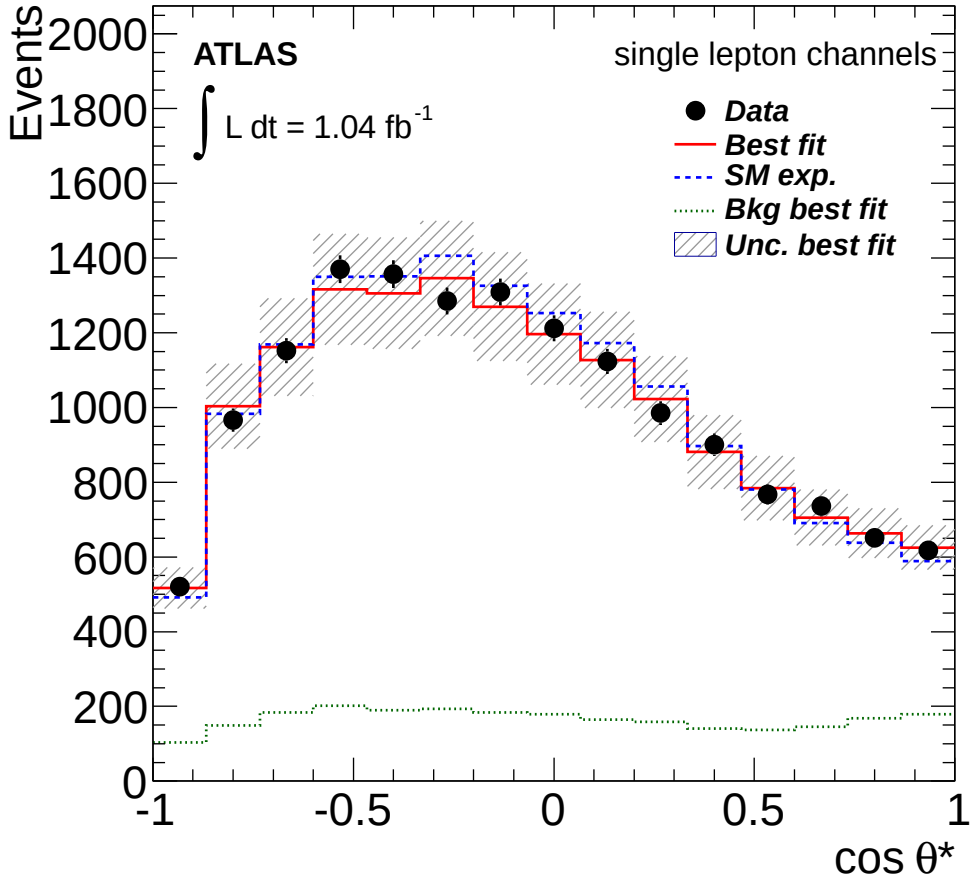
W Polarization- $A_{\pm}$

- Data is binned in 4 non-uniform bins to count events above and below $z = \pm(1 - 2^{\frac{2}{3}})$
- $A_{\pm}$ is extracted from unfolded $cos\theta^*$
- Each bin is corrected for detector effects



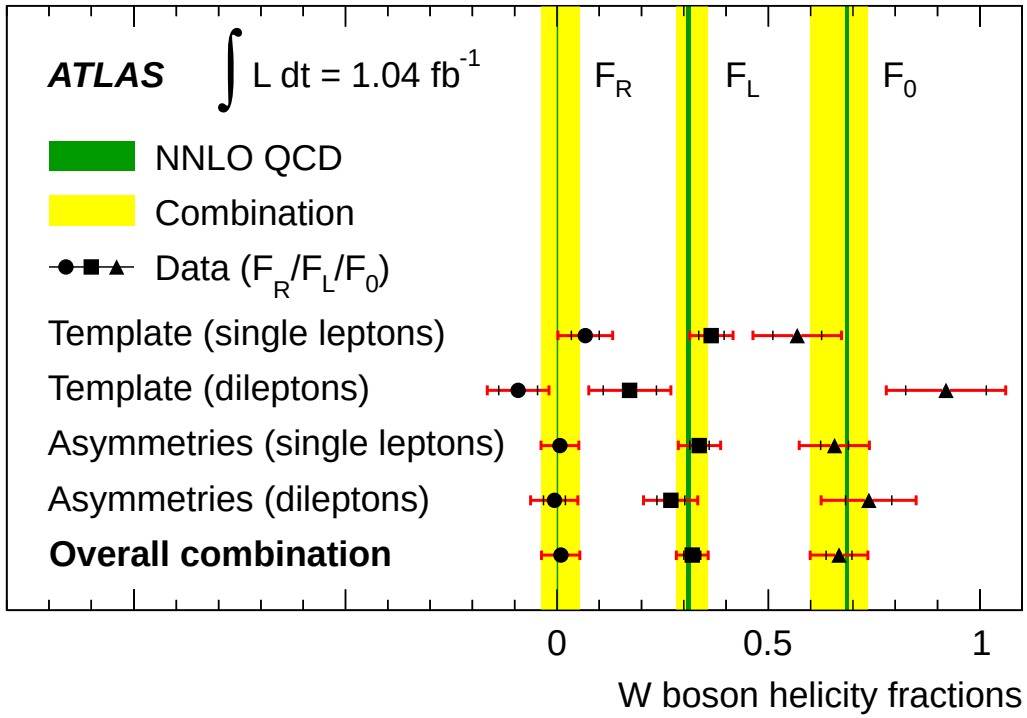
W Polarization - Template Fits

- Template fits preformed on raw data
- F_0,F_L,F_R and background extracted with Maximum likelihood fit



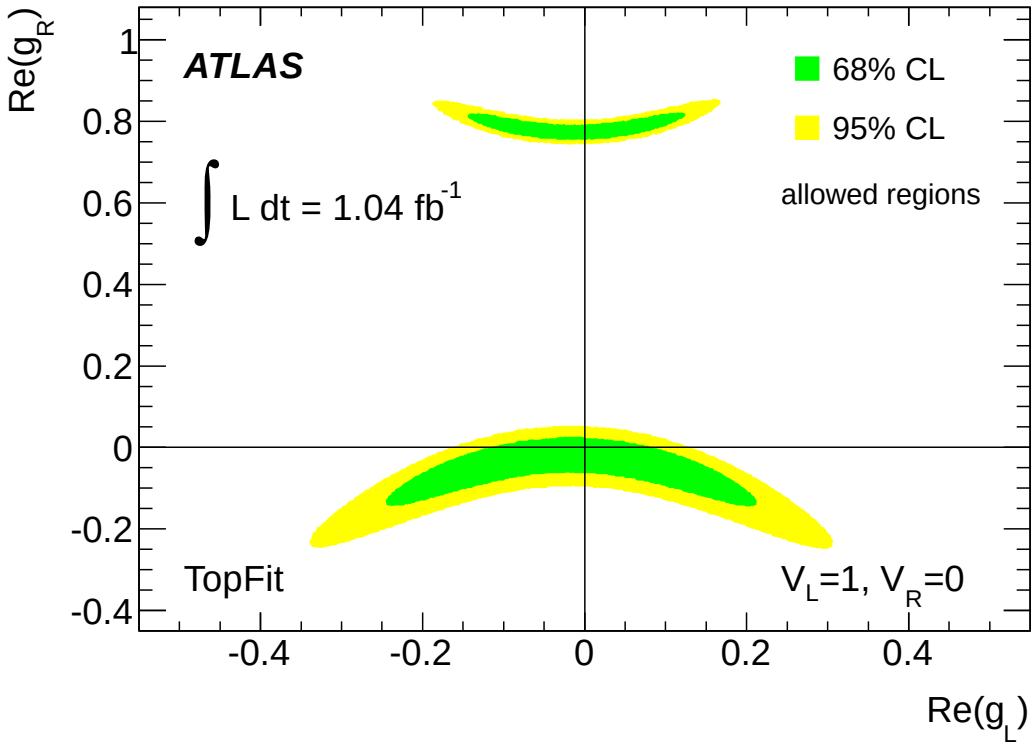
Results

- Final measurement is a combination of both methods
- Combined using a best linear unbiased estimator (BLUE)



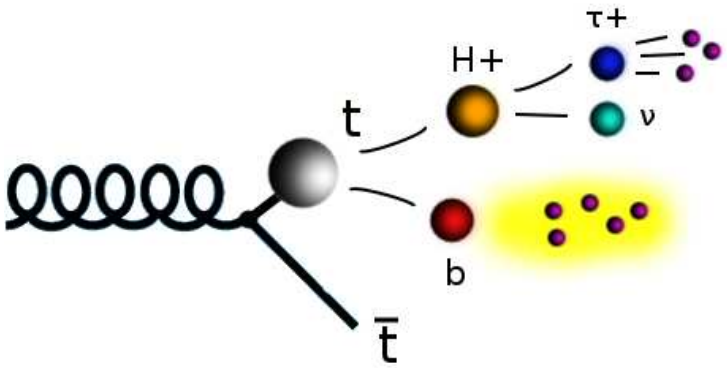
W Polarization-Limit

- Excellent agreement with SM
- Set Limits on anomalous couplings



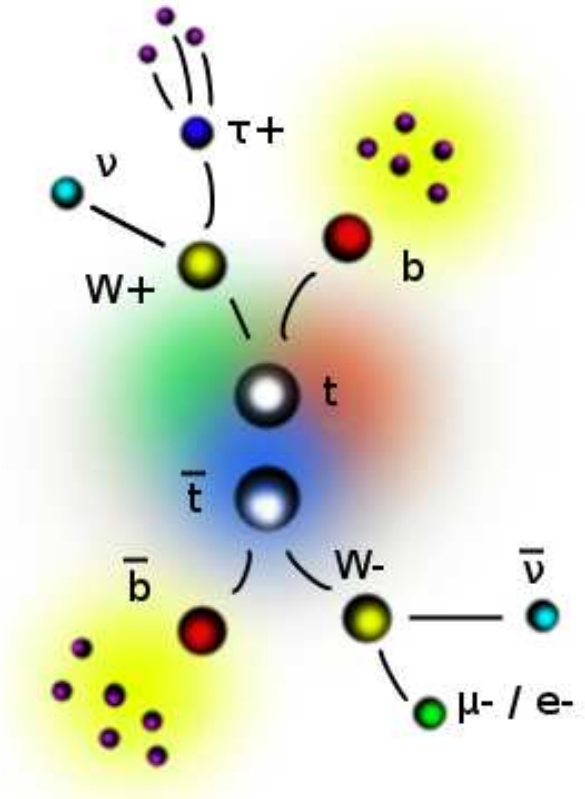
Cross section in the l+τ channel

- Revisit the cross section in the $l + \tau$
- Why $t\bar{t}$ with taus?
- Measuring the $t \to \tau + X$ is a window to new physics
- Directly sensitive to $t \to H^{\pm} + b$
- Currently the best Tevatron measurement has an uncertainty of 25% (2.1 fb^{-1}) (D0 note 5607-CONF)
- Requires every part of the detector. Also requires almost every object reconstruction algorithm (μ,e,τ,b,$\not{E}_T$)



l+τ Analysis Overview

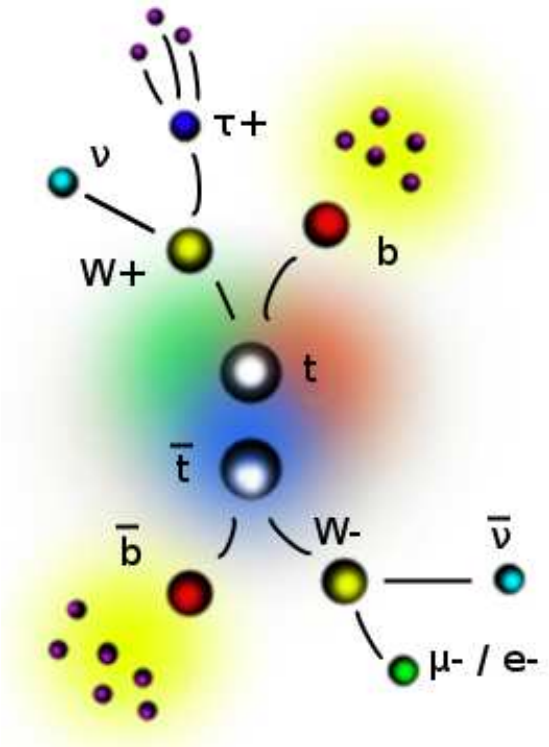
- 2.05 fb^{-1} of 7 TeV data
- Signal extracted from fit and a matrix method
- Event Pre-selection
  - Trigger on one μ/e and require it be isolated
  - Require at least one τ candidate
  - At least two additional jets
  - $\not{E}_T > 30$ GeV
  - $\sum E_T$ (μ/e+Jets+$\not{E}_T$) > 200 GeV
  - Require at least one jet be b-Tagged



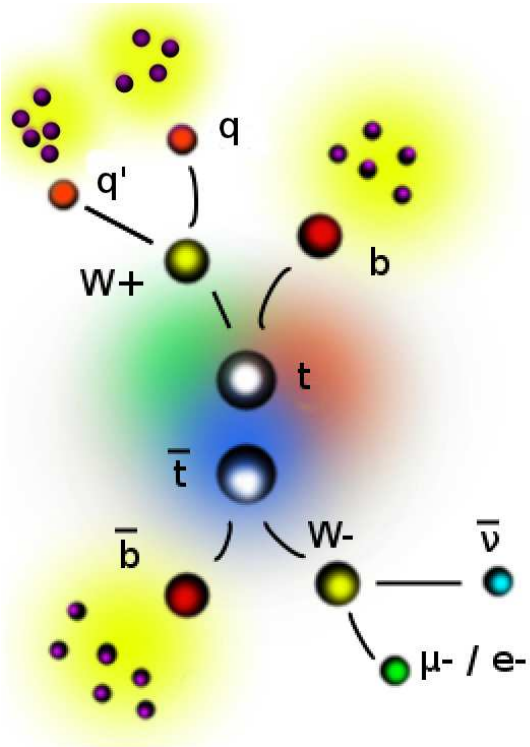
Whats Left?

A lot of $t\bar{t}$

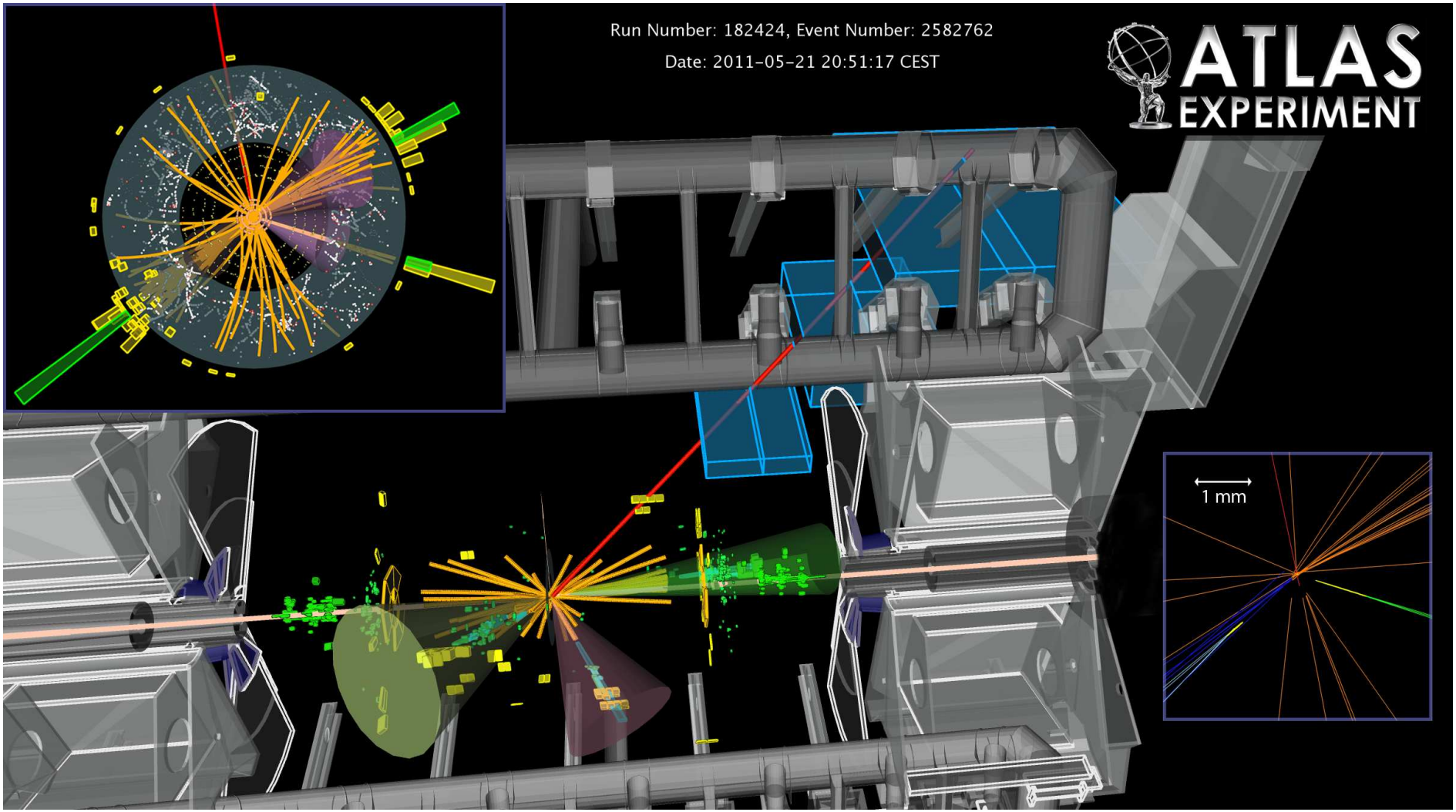
Signal $t\bar{t}$



Background $t\bar{t}$



$l + \tau$ Event


Run Number: 182424, Event Number: 2582762
Date: 2011-05-21 20:51:17 CEST
ATLAS
EXPERIMENT
1 mm

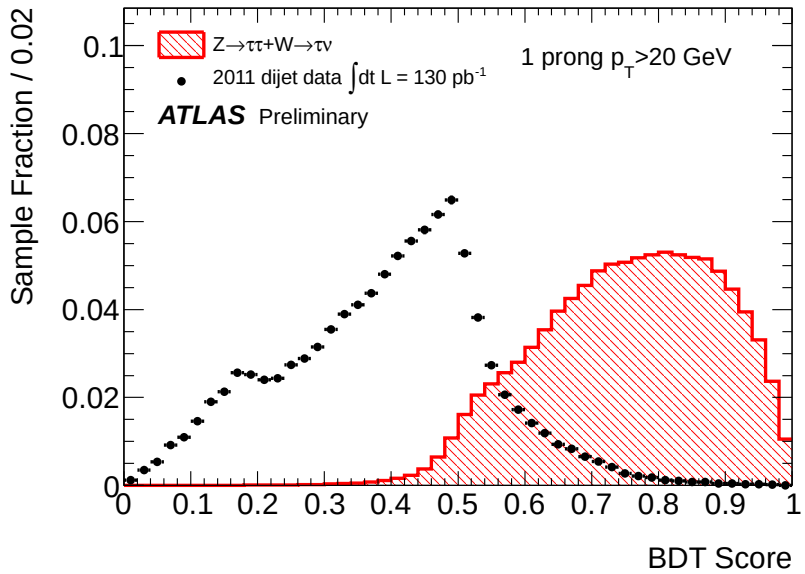
τ - Candidates

- The main feature distinguishing signal from background is the τ lepton
- τ identification is a two step process in ATLAS
  - Candidates are found (high efficiency and small background rejection)
  - Final identification is preformed with multi-variate techniques
- Finding a τ candidate?
  - Take all jets reconstructed with anti-K_t with R value of 0.4
  - Assign all tracks within a cone of $\Delta R < 0.2$ of the jet axis and with a $p_t > 1$ GeV
  - Keep candidates with 1,2, or 3 tracks.

τ-ID

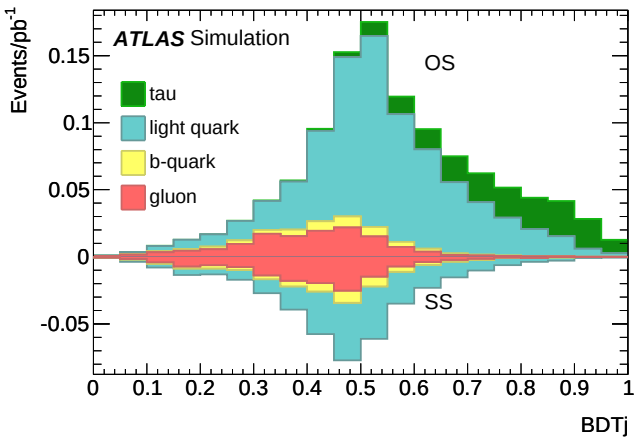
- Final τ/jet discrimination (and the final observable for this analysis) is a boosted-decision tree (BDT) used for τ identification.

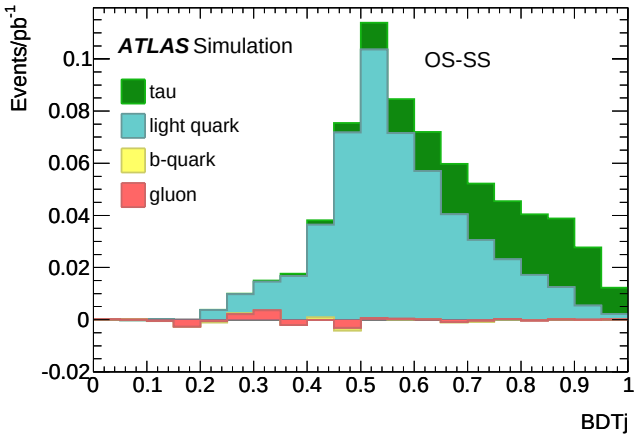
- BDT formed from an input of
  - Shower Shape Variables
  - Isolation Variables
  - Tracking Variables
- Fake τs from jets make up the dominant background in this analysis
- Gluon Jets look different to the BDT than b and quark jets
- Flavor composition can greatly affect the BDT shape of fake τs



Fake Composition

- Jet composition can lead to a large systematic
- Trick: subtract same sign (SS) events from opposite sign (OS) ones
  - Outgoing quarks have opposite sign of lepton (OS $>$ SS)
  - Gluon have no charge (OS $=$ SS)
  - b quarks come in pairs (OS $=$ SS)





Background Estimation

- Two different methods were used to cross check each other
- Minimum χ^2 fit from templates
- Matrix Method: Makes a cut on the BDT an estimates backgrounds in this "tight" sample

$$N_{data}^{loose} = N_{fake}^{loose} + N_{real}^{loose}$$

$$\epsilon_{real} = \frac{N_{real}^{tight}}{N_{real}^{loose}} \quad \epsilon_{fake} = \frac{N_{fake}^{tight}}{N_{fake}^{loose}}$$

$$N_{data}^{tight} = N_{fake}^{tight} + N_{real}^{tight}$$

- Solve for background in signal region N_{fake}^{tight}

$$N_{fake}^{tight} = \frac{\epsilon_{fake}}{\epsilon_{real} - \epsilon_{fake}}(N_{data}^{loose} * \epsilon_{real} - N_{data}^{tight})$$

τ Fake Rate

- Each method takes their fake rate/template from a different control sample

Matrix Method

- Derive ϵ_{fake} from W+1 jet events
  - $\not{E}_T > 30$ GeV, Mt > 30 GeV, 1 τ candidate
  - Large number of events, but kinematically different from $t\bar{t}$
  - ϵ_{fake} parametrized to account for this

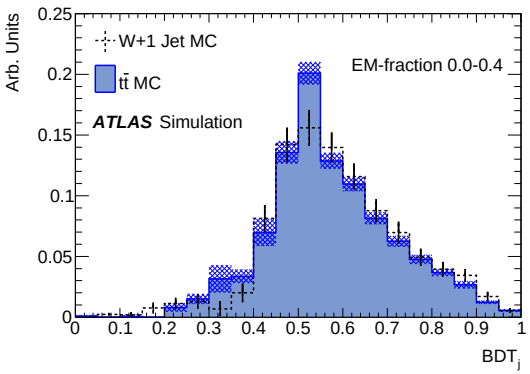
Fitting Method

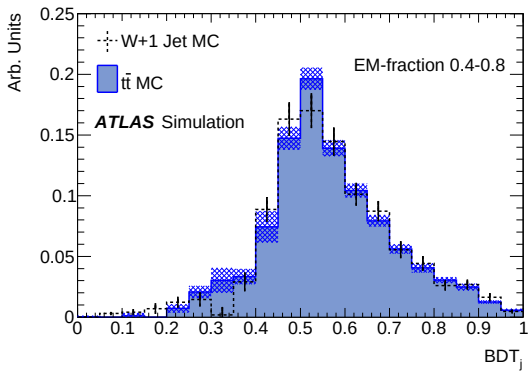
- Derive Fake template from 0 b-jet data
  - Signal region except exactly 0 b-tagged jets
  - Lower statistics
  - Kinematically similar $t\bar{t}$
  - Very small corrections need (estimated from MC)

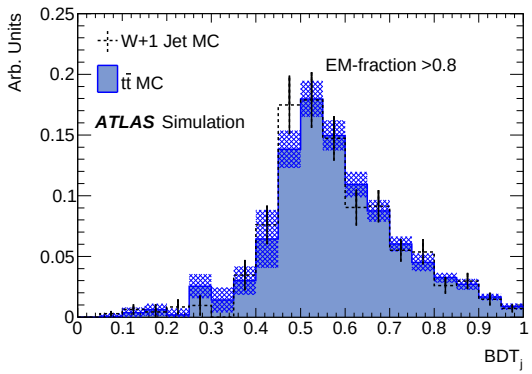
Parametrization of ϵ_{fake}

- Fake *taus* from $W+1$ jet events are kinematically different from $t\bar{t}$
- BDT shape is different, and so is the fake rate
- This can be fixed by parameterizing the fake rate as a function of EM-fraction which accounts for differences in hadronic activity

$$EM_{fraction} = \frac{\sum_{i\in\{\mathrm{EM\ 0-2}\}}^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{EM}}}{\sum_{j\in\{\mathrm{all}\}}^{\Delta R_j<0.4} E_{\mathrm{T},j}^{\mathrm{EM}}}$$



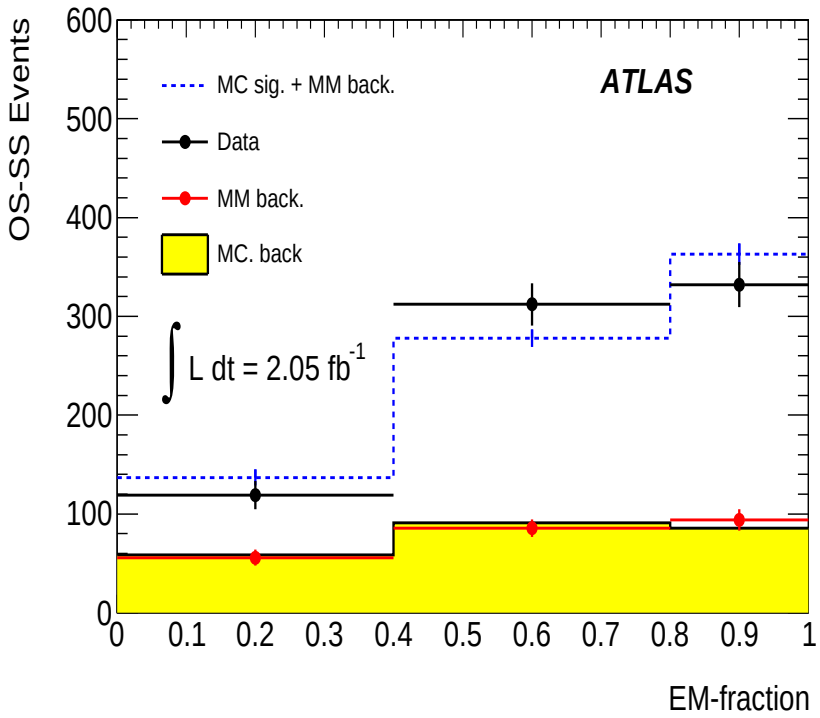




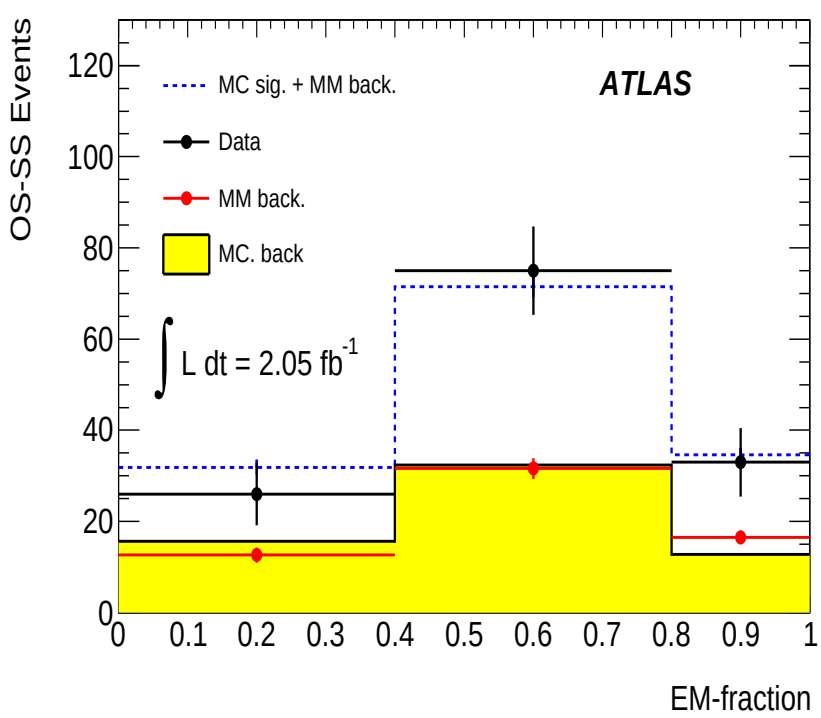
Matrix Method Results

- Matrix Method preformed separately for 1-prong and 3-prong τ candidates

1 prong

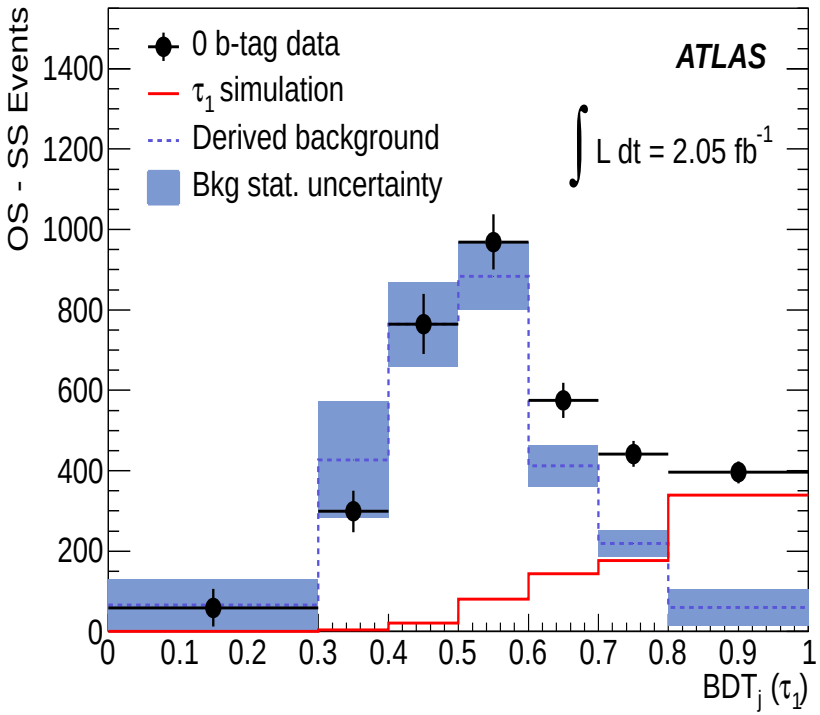


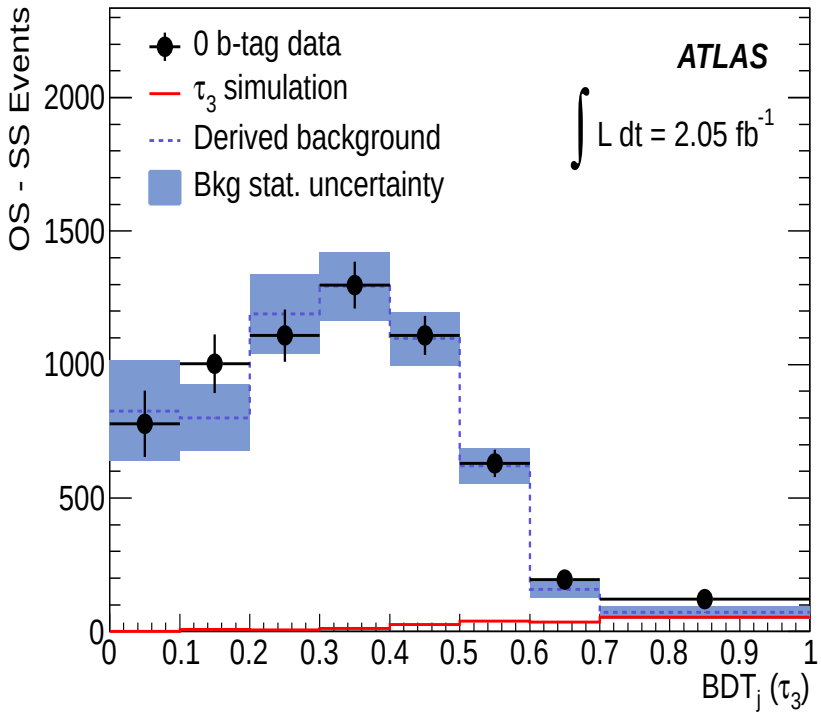
multi prong



Deriving Fit Template

- 0-*b* tag region has some real *tau*s that must be subtracted out mainly from $Z \to \tau\tau$
- MC is scaled to observed events in a $Z \to \mu\mu$ selection

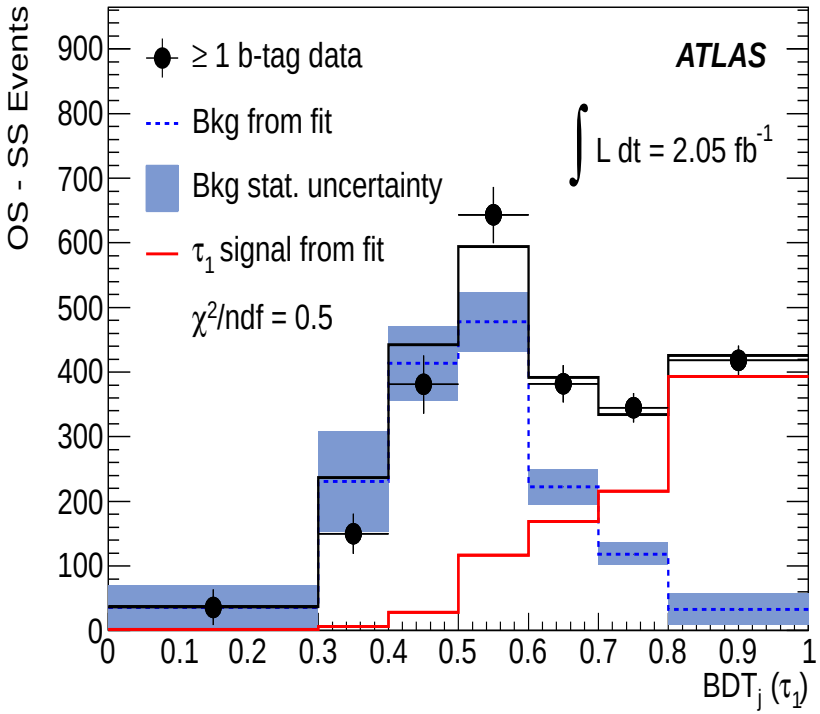




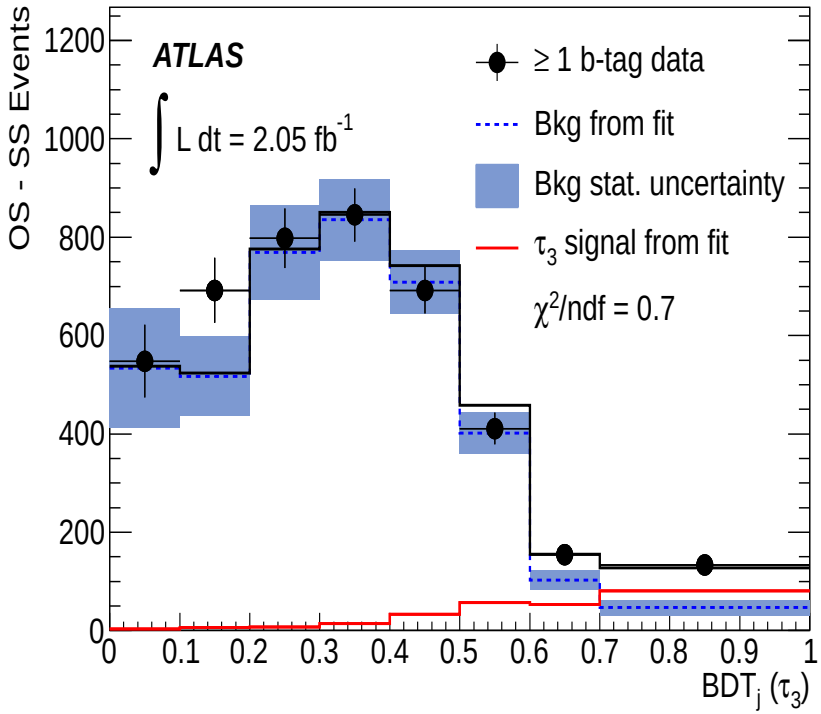
Fit Results

- Fit preformed separately for 1-prong and 3-prong τ candidates

1 prong



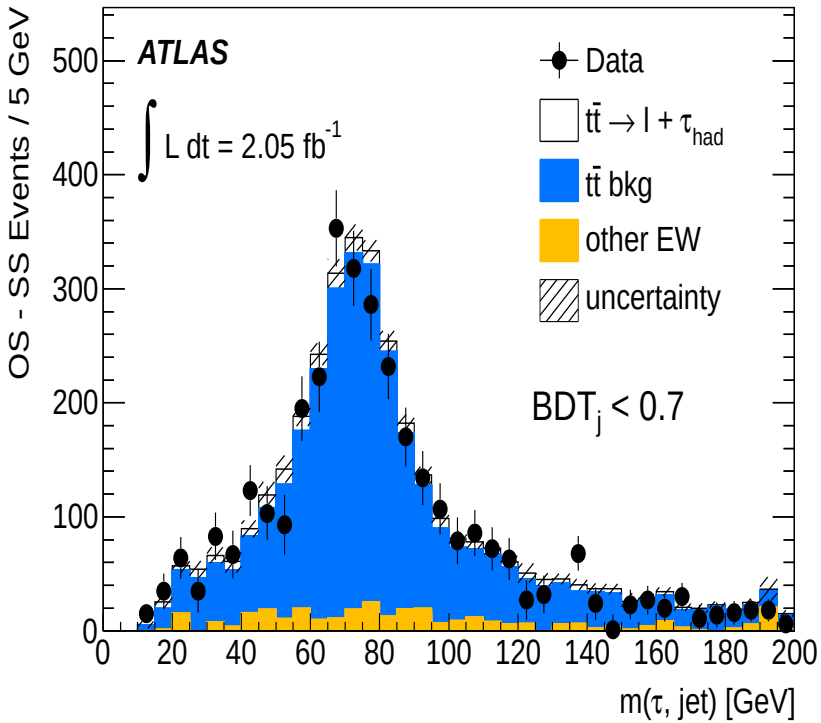
multi prong

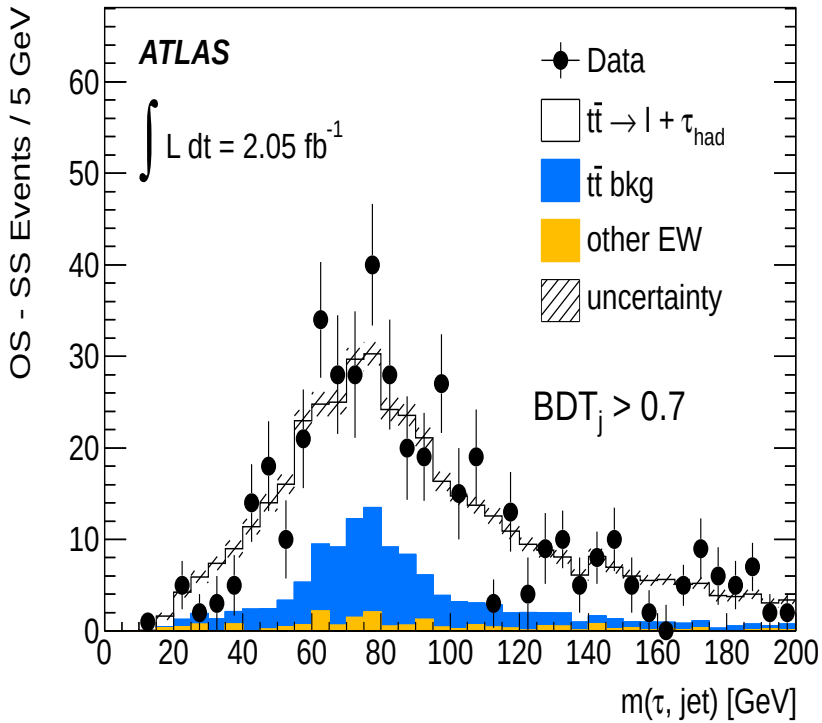


- Lepton fake rates estimated with data driven scale factors

Cross Checks

- Background will have a W-peak in $M(\tau, q)$, the signal will not.





Cross section

- The background measurements agree
- Combine one prong and multi-prong

$$\sigma_{t\bar{t}} = 186 \pm 13(\text{stat}) \pm 20(\text{syst}) \pm 7(\text{lumi.})pb$$

- Leading Systematics
  - b-tagging efficiency
  - τ acceptance
  - Initial and final state radiation (ISR/FSR)
- @ CMS
  143 $\pm$ 14 (stat.) $\pm$ 22 (syst.) $\pm$ 3 (lumi.) pb is
- OS-SS trick gains us about 30% in sensitivity over CMS
- Total uncertainty about 13% compared to 9% in the the other combined dilepton-channels
- Factor two better than the best Tevatron measurement

Conclusions

- ATLAS and the LHC is driving into new territory
- Total Cross Section measurement better than theory predictions
- Searched for
  - Resonances
  - FCNC
  - Anomalous couplings
- Most precise measurement in the $l + \tau$ channel (updated H^+ Limits on the way)
- No evidence of new physics processes
- We've made a lot of progress, but still have a lot to explore!