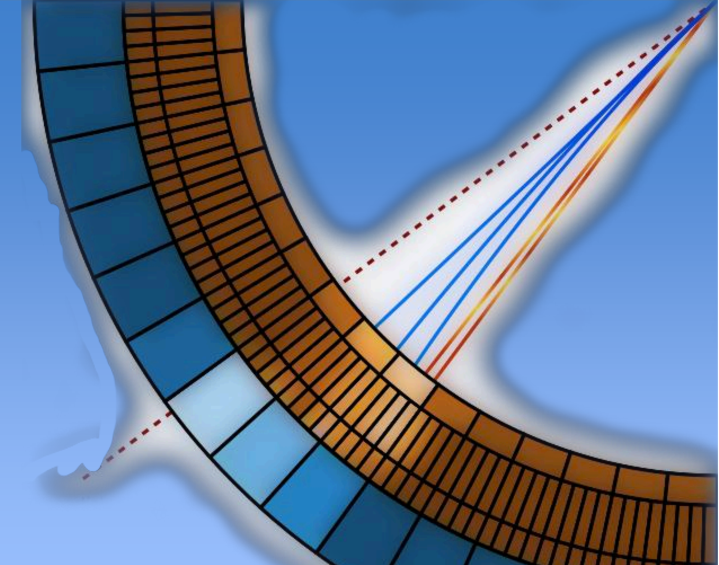
The 2013 European Physical Society Conference on High Energy Physics, Stockholm, 18th – 24th July 2013

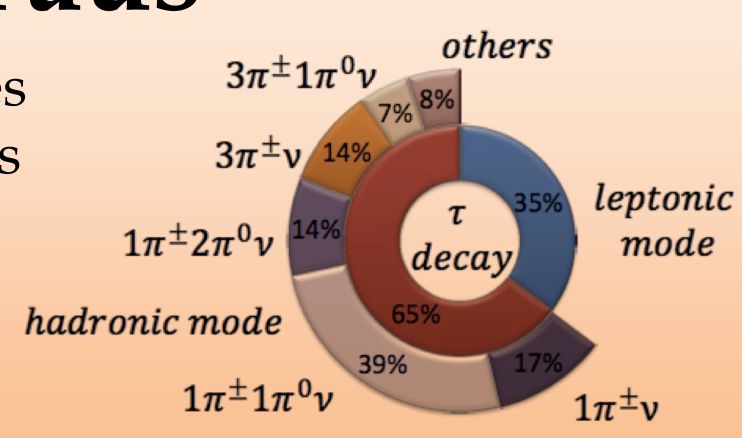
Determination of the Tau Energy Scale for Hadronically Decaying Tau Leptons at ATLAS [1]



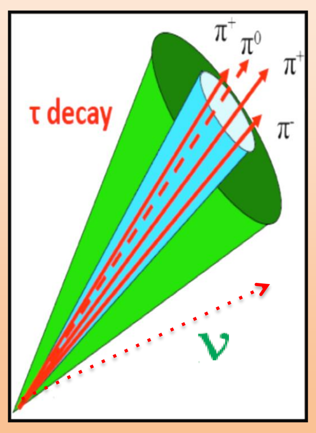
Amelia Brennan, on behalf of the ATLAS Collaboration

Introduction to Taus

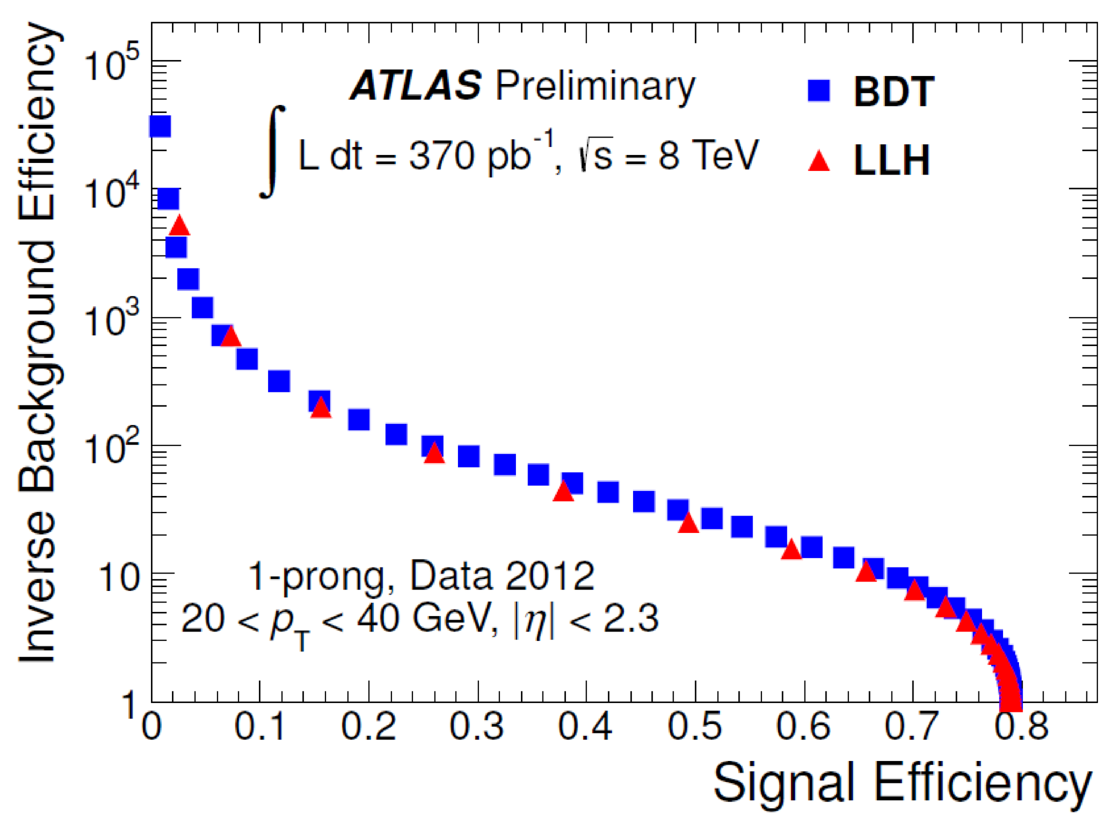
- Important signatures for searches for the Higgs Boson, SUSY, Exotics and SM Measurement
- Heaviest lepton at 1.8 GeV
- Short proper decay length (ct = 87 μm)



- Leptonically decaying taus look like light leptons
- Hadronic taus decay predominantly to one (1-prong) or three (multi-prong) charged pions, a neutrino and additional neutral pions
- Since τ_{had} decays consist of a specific mix of charged and neutral pions, energy scale is derived independently of the jet energy scale



Reconstructing hadronic taus



Boosted Decision Tree (BDT) algorithm trained on MC for taus and data for multi-jets, to discriminate between these objects.

Loose, *medium* and *tight* taus defined by points along the signal efficiency.

Inverse background efficiency as a function of signal efficiency for 1-prong candidates, in the low p_T range $20 < p_T \leq 40$ GeV, for the two tau ID methods BDT and LLH.[2] See the Tau ID poster for more information.

The Tau Energy Scale

- Taus pre-calibrated at the hadronic scale, does *not* account for
  - energy lost before the calorimeters
  - event and pileup contributions
  - out-of-cone effects
- Average difference between reconstructed and true energy remains as large as 15%

→ an additional correction to calibrate the visible energy is required!

- Calibrated momentum p^{τ}_{cal} defined as

$$p^{\tau}_{cal} = \frac{p^{\tau}_{LC}}{R(p^{\tau}_{LC}, |\eta^{\tau}_{reco}|, n_p)}$$

  - p^{τ}_{LC} is the reconstructed τ_{had} momentum at the initial (LC) scale
  - R is the additional calibration term (the *response*)
  - $|\eta^{\tau}_{reco}|$ is the reconstructed τ_{had} pseudorapidity
- n_p is the number of prongs (*one-prong* or *multi-prong*)
- R defined as ratio of p^{τ}_{LC} to $p^{\tau\text{-true}}_{vis}$, binned in $p^{\tau\text{-true}}_{vis}$, $|\eta^{\tau}_{reco}|$ and n_p

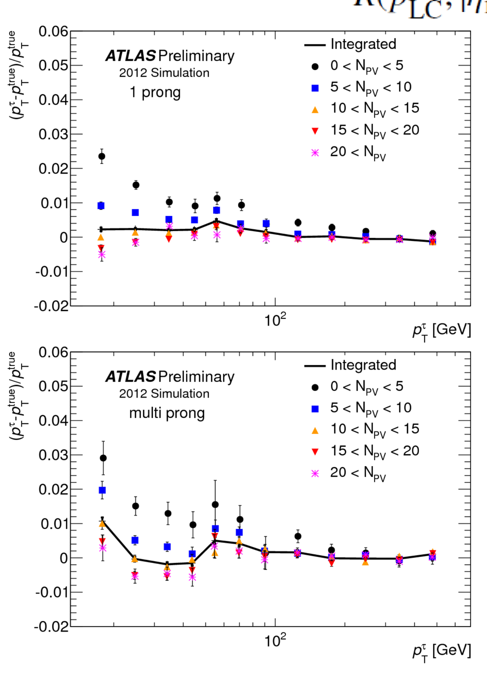
Pileup Corrections

- Pileup contribution estimated by

$$p^{\tau}_{pileup} = A(|\eta^{\tau}_{reco}|, n_p)(N_{PV} - \langle N_{PV}\rangle)$$

- A derived in bins of $|\eta^{\tau}_{reco}|$ and n_p, with linear fit
  - Pileup corrections applied:

$$p^{\tau}_{F} = \frac{p^{\tau}_{LC} - p^{\tau}_{pileup}}{R(p^{\tau}_{LC}, |\eta^{\tau}_{reco}|, n_p)}$$



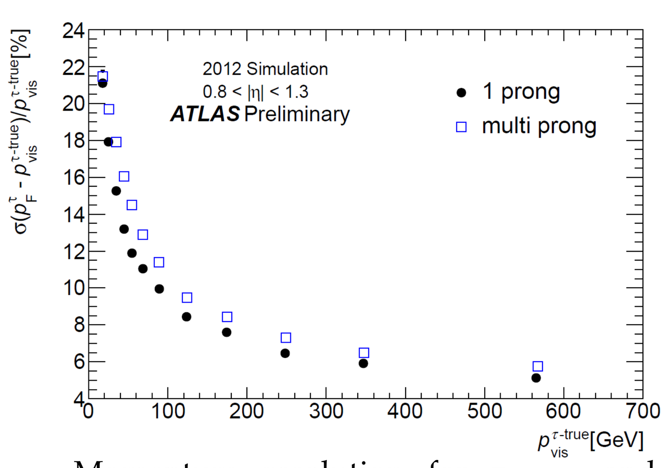
Response distributions after pileup correction as a function of p_T for different number of primary vertices.

Pileup systematic is dominant contribution to total uncertainty. The black integrated line corresponds to the non-closure.

Momentum Resolution

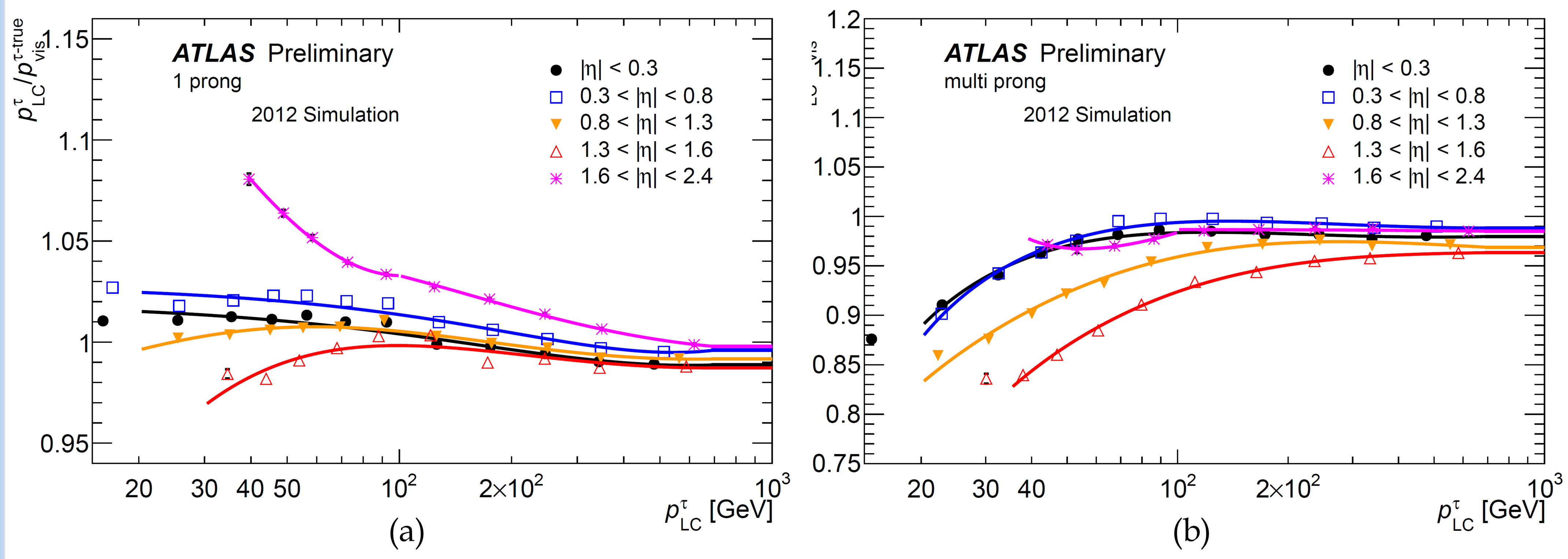
- Resolution calculated from difference between calibrated momentum p^{τ}_{F} and $p^{\tau\text{-true}}_{vis}$
- fit with Gaussian, divide σ by $\langle p^{\tau\text{-true}}_{vis}\rangle$
- Momentum resolution scales with momentum as $\frac{\sigma}{p} = \frac{a}{\sqrt{p}} \oplus b$

One-prong	$\|\eta^{\tau}\| < 0.3$	$0.3 < \|\eta^{\tau}\| < 0.8$	$0.8 < \|\eta^{\tau}\| < 1.3$	$1.3 < \|\eta^{\tau}\| < 1.6$	$\|\eta^{\tau}\| > 1.6$
a [$\sqrt{\text{GeV}}$]	0.71	0.73	0.87	1.09	1.10
b	0.02	0.02	0.04	0.07	0.01
Multi-prong	$\|\eta^{\tau}\| < 0.3$	$0.3 < \|\eta^{\tau}\| < 0.8$	$0.8 < \|\eta^{\tau}\| < 1.3$	$1.3 < \|\eta^{\tau}\| < 1.6$	$\|\eta^{\tau}\| > 1.6$
a [$\sqrt{\text{GeV}}$]	0.85	0.79	1.02	1.24	1.27
b	0.01	0.03	0.04	0.06	0.01



Momentum resolution for $\tau_{1\text{-prong}}$ and $\tau_{multi\text{-prong}}$ for $0.8 < |\eta^{\tau}| < 1.3$.

Response



Response curves as a function of the reconstructed τ_{had} momentum at LC scale for $\tau_{1\text{-prong}}$ (a) and $\tau_{multi\text{-prong}}$ (b) in bins of $|\eta^{\tau}_{reco}|$. Uncertainties (smaller than the shown markers in most bins) are statistical only.

The response curves represent a measure of the average $p^{reco}_{T}/p^{truth}_{T}$ before the scaling is applied. After it is applied, this is reduced to 1-2%.

Systematic Uncertainties

- Systematic uncertainty, across most $|\eta_{\tau}|$ and p_T bins:
  - between 2-3% ($\tau_{1\text{-prong}}$) and 2-3.5% ($\tau_{multi\text{-prong}}$), for τ_{had} passing *medium* identification criteria
  - between 2-4% ($\tau_{1\text{-prong}}$) and 2.5-4% ($\tau_{multi\text{-prong}}$), for τ_{had} passing *tight* identification criteria
- Maximum uncertainties are on multi-prong taus in the region $1.3 < |\eta^{\tau}| < 1.6$ in the lowest p_T bin

TES uncertainty for $\tau_{1\text{-prong}}$ in $0.8 < |\eta_{\tau}| < 1.3$. The individual contributions are shown as points and the combined uncertainty is shown as a filled band. Bins in p^{τ}_{T} with equal uncertainties are grouped.

Calorimeter uncertainty, contributions from $\langle E/p\rangle$ (for low momentum charged hadrons), CTB data (high p charged hadrons) and e/γ (π^0).

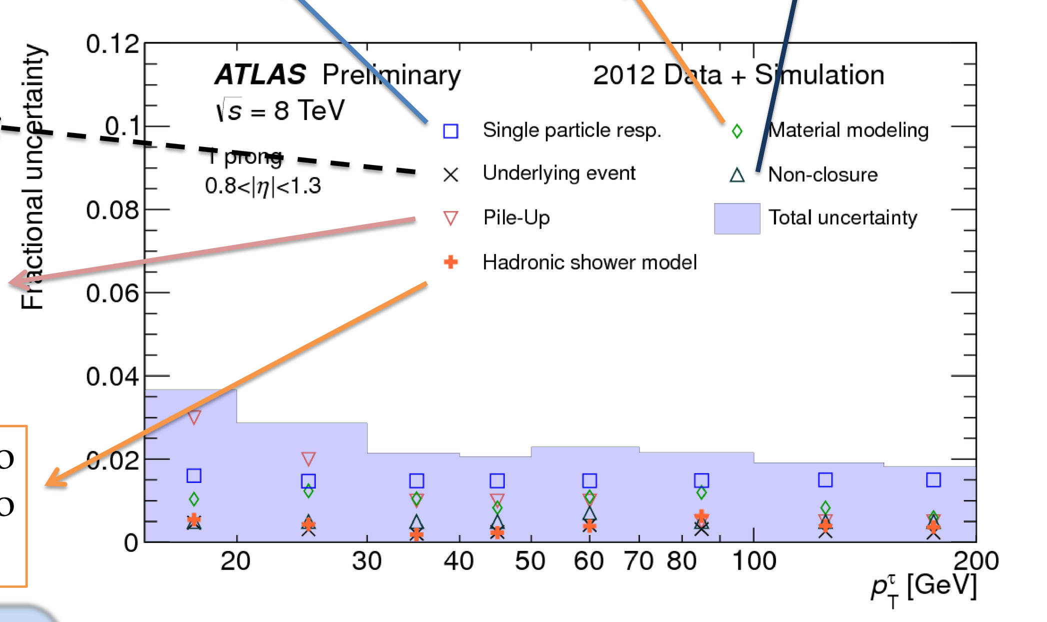
$\langle E/p\rangle$ is sensitive to the amount of dead material in front of the calorimeter

Response of $p^{reco}_{T}/p^{truth}_{T}$

Compared with alternative MC tune

Remaining dependence after pileup correction is applied

Compare two shower models to CTB data

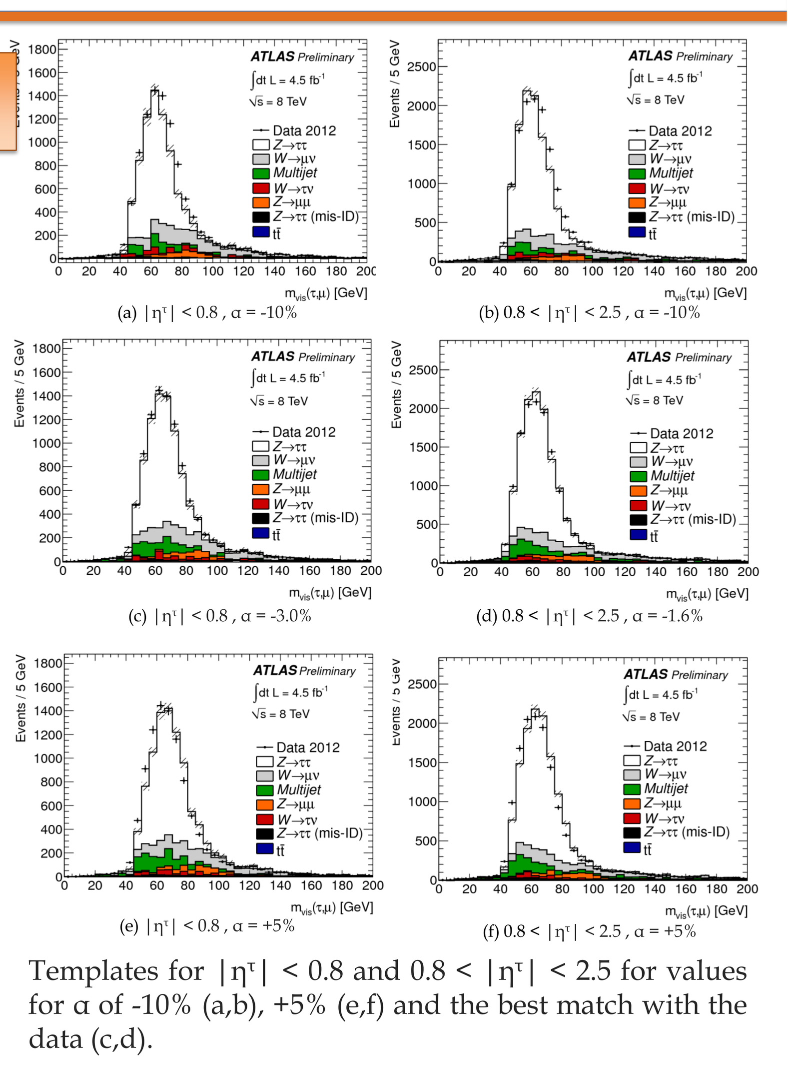


In-situ TES Cross Check

- No CTB data for $|\eta_{\tau}| > 0.8$, does this cause a significant difference in TES uncertainties in the two η_{τ} regions?
- Cross check with the reconstructed visible mass peak of $Z \rightarrow \tau\tau \rightarrow \mu\tau_{had}$ to measure the TES and uncertainty in-situ energy scale
- Z visible mass is proportional to the tau transverse momentum P^{τ}_{T} (since lepton energy scale well-known)
- Shift p_T in simulation and compare position of the Z visible mass peak to that in data

$$P'^{\tau}_{T} = (1+\alpha)P^{\tau}_{T}$$

- Systematic uncertainties calculated by varying each source or uncertainty and recalculating the TES



Templates for $|\eta^{\tau}| < 0.8$ and $0.8 < |\eta^{\tau}| < 2.5$ for values for α of -10% (a,b), +5% (e,f) and the best match with the data (c,d).

region	preferred α value	difference
$\|\eta^{\tau}\| < 0.8$	-3%	-
$0.8 < \|\eta^{\tau}\| < 2.5$	-1.6%	1.4%

Difference between the η^{τ} regions is (1.4 ± 3.6)%
→ no significant difference between the two regions

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[1] The ATLAS Collaboration, *Determination of the tau energy scale and the associated systematic uncertainty in proton-proton collisions at at √s = 8 TeV with the ATLAS detector at the LHC in 2012*, ATLAS-CONF-2013-044

[2] The ATLAS Collaboration, *Identification of the Hadronic Decays of Tau Leptons in 2012 Data*, ATLAS-CONF-2013-064