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# *Tau Reconstruction & Identification in ATLAS*

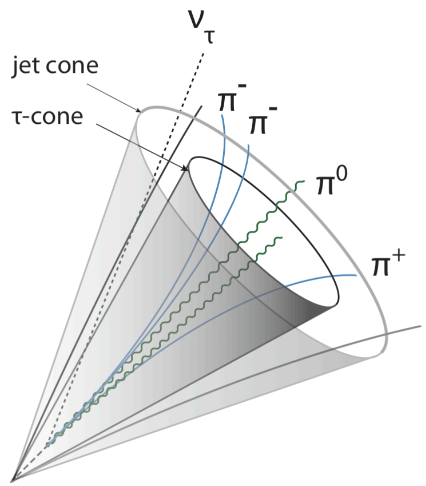
Chicagoland Workshop

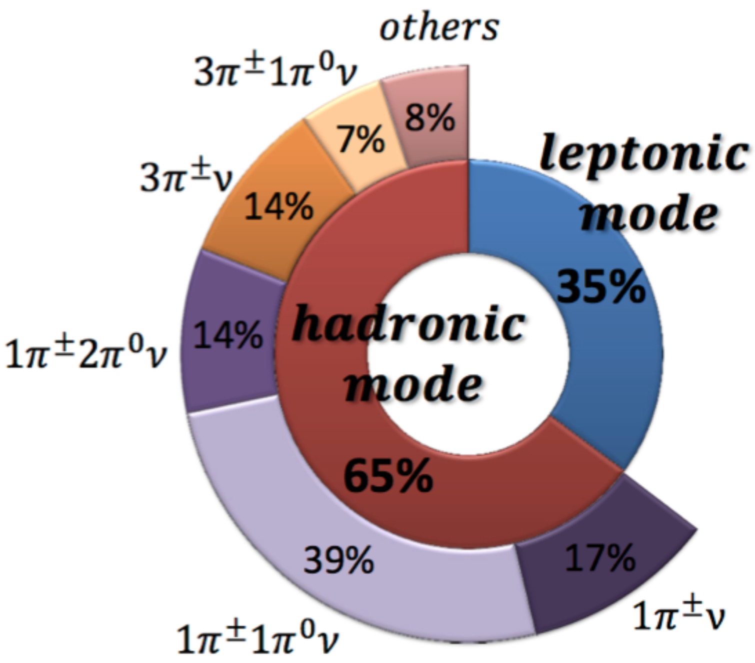
February 11th, 2015

ALBERT-LUDWIGS-
UNIVERSITÄT FREIBURG

# The Tau Lepton

- $m_\tau$=1.777 GeV
- Short life-time: look for tau decay products

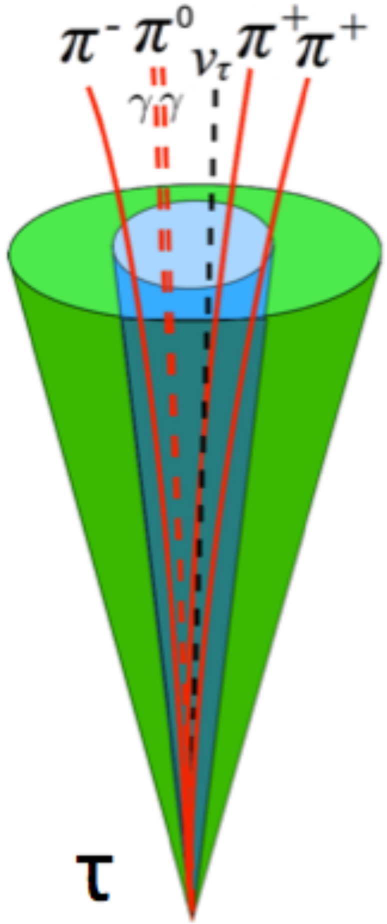



- Tau Reco typically refers to reconstruction of **hadronic** decays
  - Leptonic decays: use same reconstruction as for prompt leptons
- Tau-jet: Reconstructed visible decay products

# Tau-Jet Reconstruction*

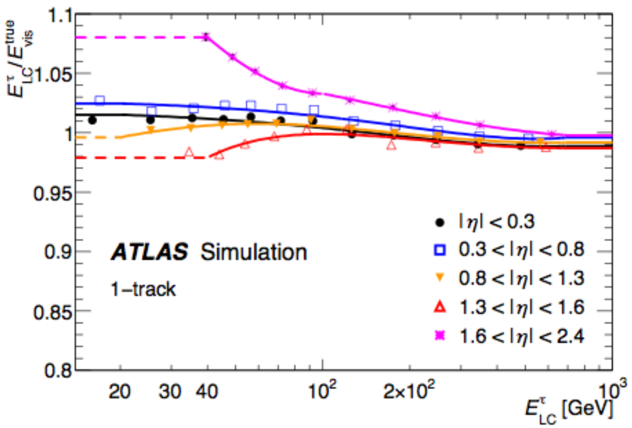
- Start with a calorimeter jet as *seed*
  - Anti-kT algorithm, distance parameter R=0.4
  - pT>10 GeV, |η|<2.5
- Calculate 4-momentum of tau-jet using only topological clusters within $\Delta R<0.2$ of cluster barycenter
- Associate tracks ($p_T$>1 GeV) within $\Delta R<0.2$
  - Also count tracks in *isolation region*, $0.2<\Delta R<0.4$

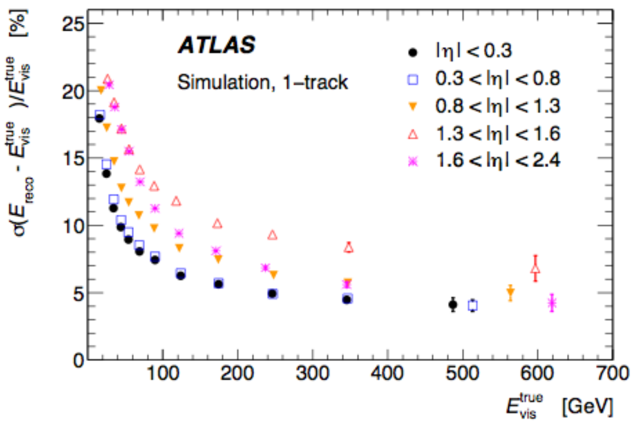



*: Slightly simplified… See arXiv:1412.7086 for full details

# Tau Energy Scale

- Clusters of seeding jet at local calibration (LC) scale
  - Accounts for non-compensating nature of ATLAS calorimeter and depositions outside clusters and in non-sensitive regions
- On top of this, tau-specific correction factor $E_{LC} \rightarrow E_{\tau\text{-vis}}$ derived using MC
  - Account for specific particle content in taus
  - Additional small corrections for pile-up, and for poorly instrumented regions

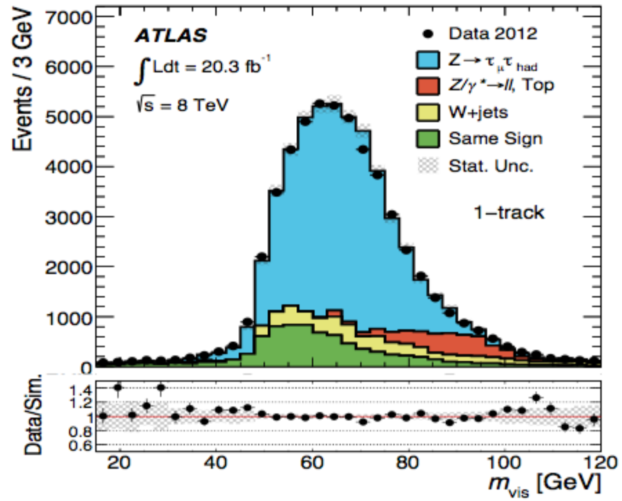


# Tau Energy Scale

- Uncertainty on TES typically <4%. Two different methods to estimate, giving consistent results
- Single particle response studies (test beam studies, E/p measurements)
  - Use pseudo-experiments to propagate single-particle response uncertainties to reconstructed tau-jet
  - Further uncertainties due to underlying event, detector model, pile-up etc
- In-situ method using $Z\rightarrow\tau\tau$ tag-&-probe
  - Template fits (varying TES)
  - Measure data/MC shift at percent-level

| Source | Uncertainty [%] |
|---|---|
| Response | 1.2–2.5 |
| Detector model | 0.3–2.5 |
| UE | 0.2–2.4 |
| Pile-up | 0.5–2.0 |
| Non-closure | 0.5–1.2 |
| Shower model | 0.0–2.0 |
| Total | 1.8–3.9 |

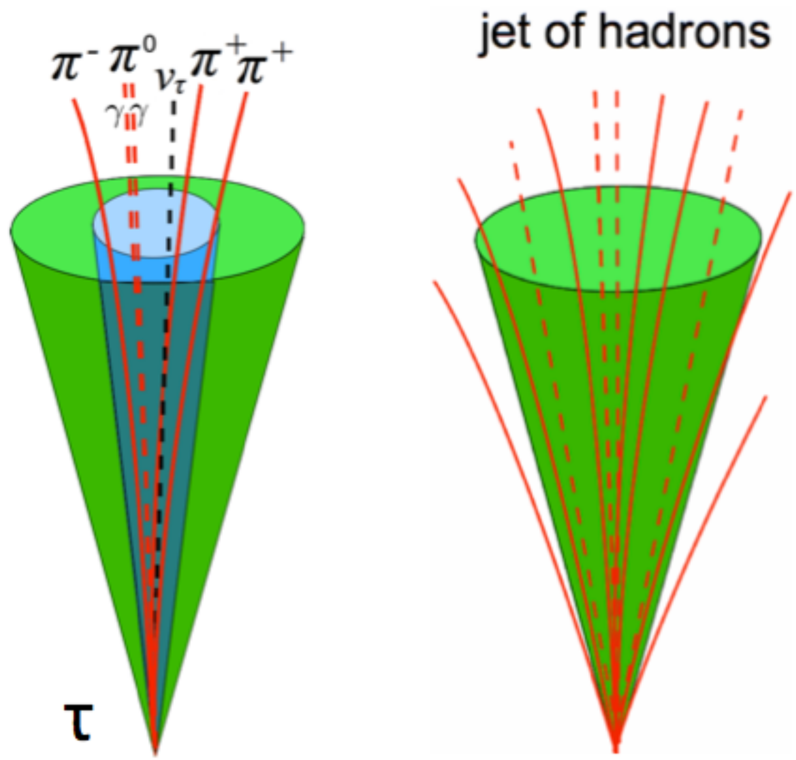


# Tau Identification

- Problem: Tau-jets look a lot like QCD jets
  - We have a lot of those at the LHC…
- Requiring 1 or 3 tracks reduces contamination, but not nearly enough to be usable for most analyses
- Need a more powerful discriminator…

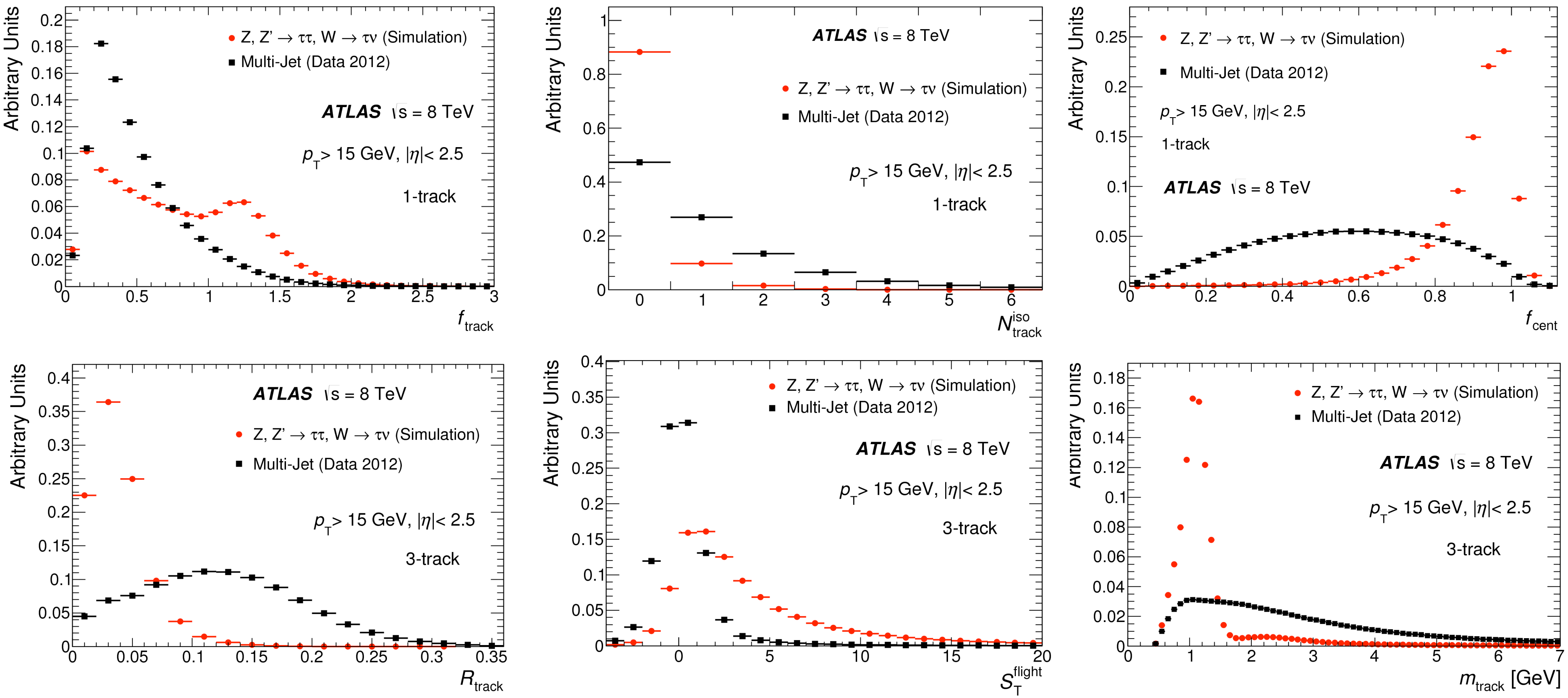
# Tau Identification

- What handles do we have?
  - Isolation
  - Lateral shape
    - Narrow energy depositions
    - Small track-to-axis distance
  - Leading track momentum fraction
  - Secondary vertex
  - Invariant mass
  - $\pi^0$:s



# Tau Identification

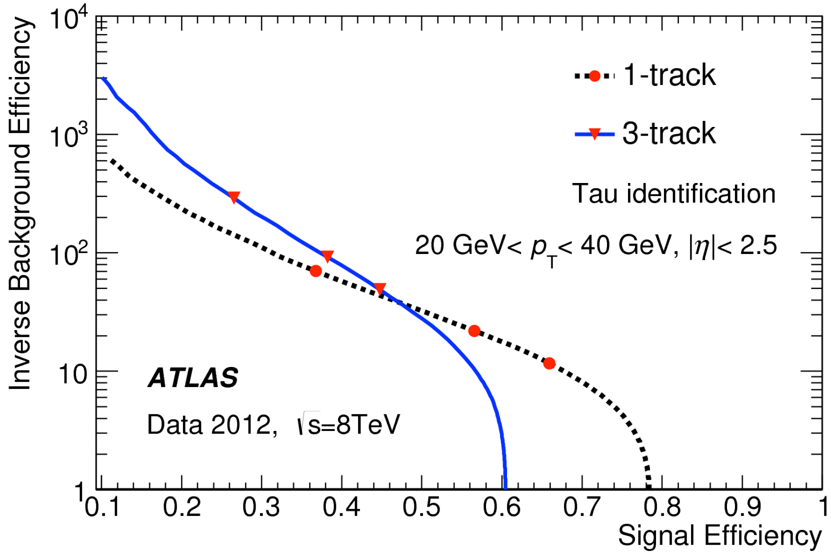
- Build variables exploiting these differences

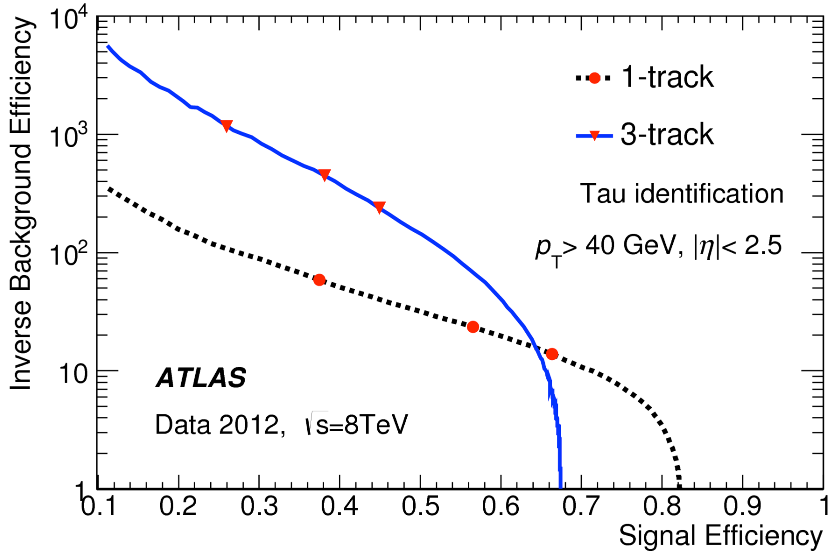



Variable definitions in backup slide

# Tau Identification

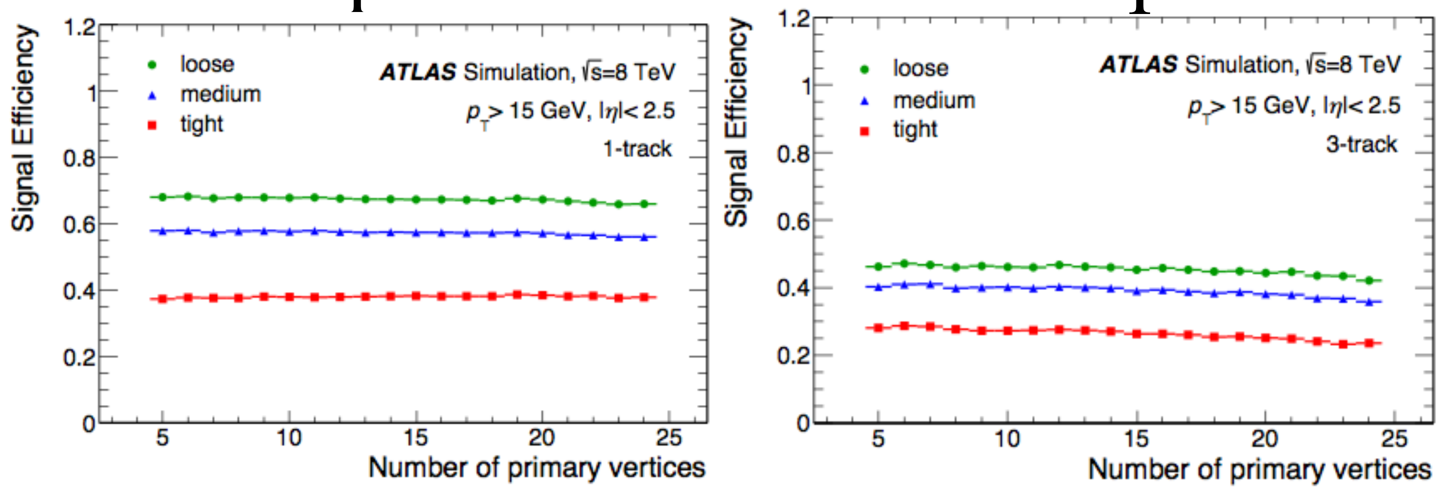
- Build variables exploiting these differences
- Train Boosted Decision Trees
  - Separately for 1-prong and 3-prong tau-jets
  - Loose/medium/tight working points defined with pT-dependent cut on the BDT score



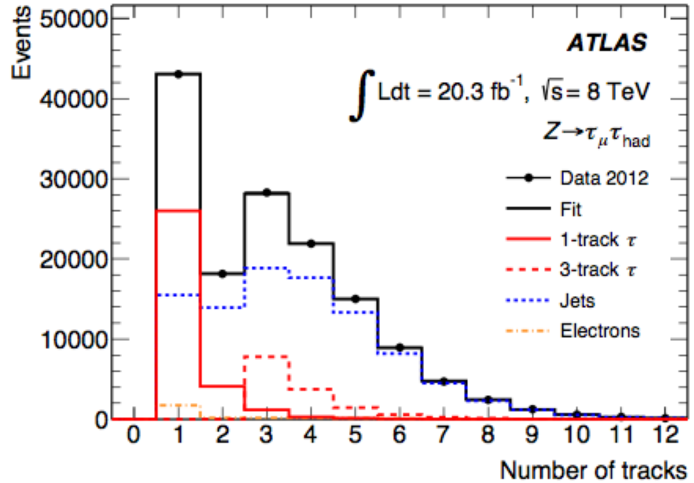
# Tau Identification

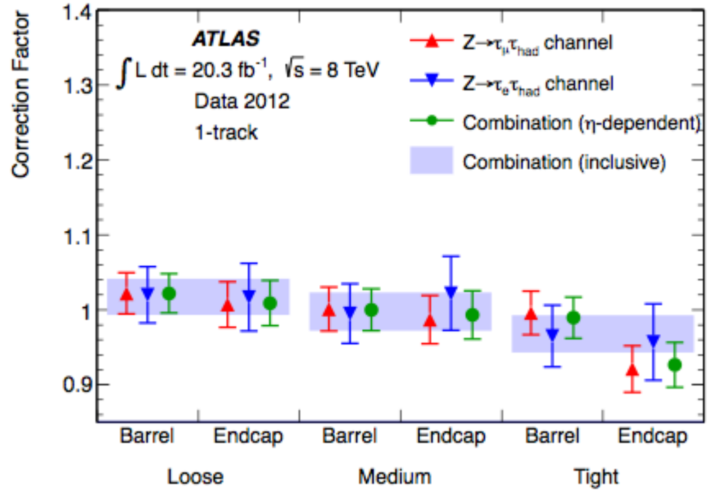
- Build variables exploiting these differences
- Train Boosted Decision Trees
  - Separately for 1-prong and 3-prong tau-jets
  - Loose/medium/tight working points defined with pT-dependent cut on the BDT score
- Pile-up corrected input variables → ID is pile-up robust



# Tau Identification

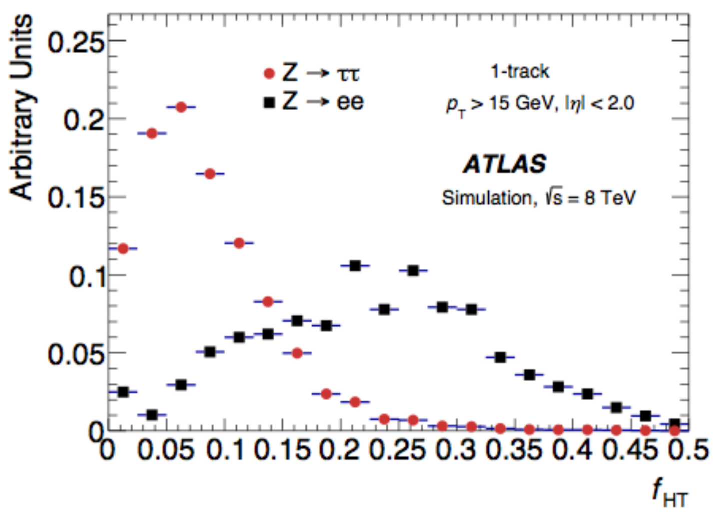
- $Z \rightarrow \tau\tau$ tag-&-probe used to measure identification efficiency in data
  - Template fit of extended track multiplicity
- Data/MC correction factors determined
  - In general consistent with 1.0; uncertainties (2-6)% for $p_T > 20$ GeV
- Measurement cross-checked with $W \rightarrow \tau\nu$ and ttbar: consistent results in all channels

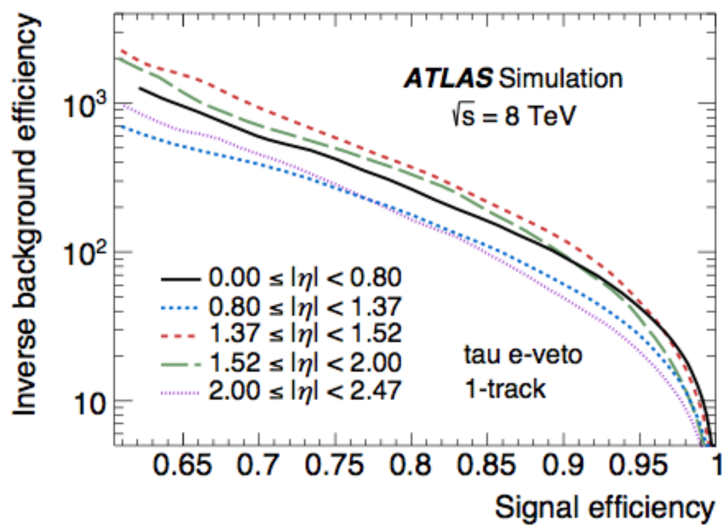


# Tau Identification

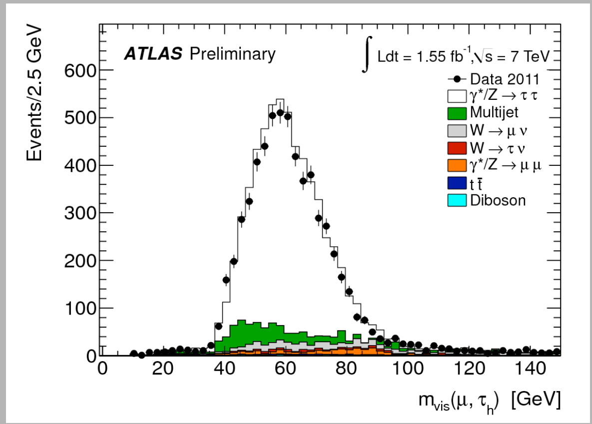
- Electrons misidentified as tau-jets also non-negligible background
- Train dedicated BDT, utilising among others transition radiation in TRT and longitudinal shower shape
- Efficiency and correction factors measured in Z→ee tag-&-probe



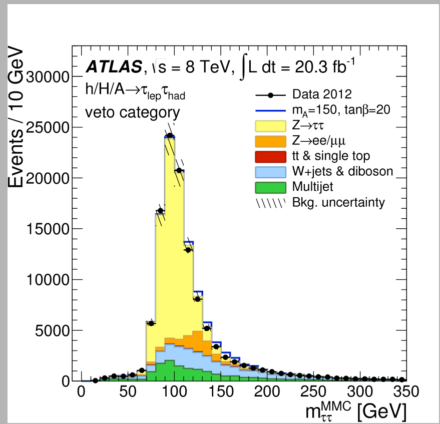
# Physics with Taus in Run 1

## Z→ττ X-Section Measurement



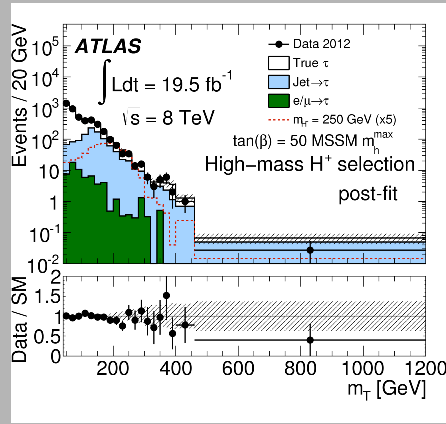

Phys.Rev. D84 (2011) 112006; ATL-CONF-2012-006

## MSSM Higgs Searches



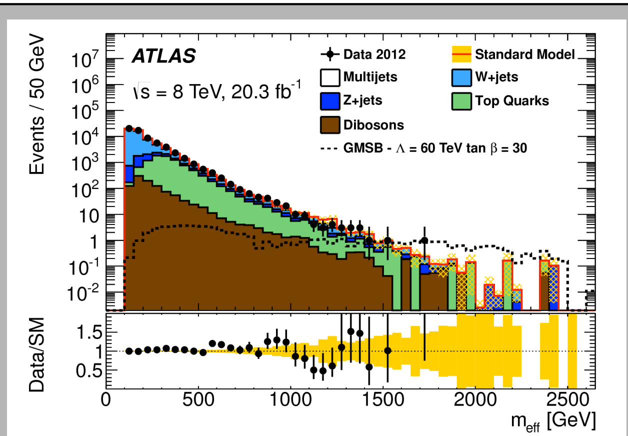

JHEP11(2014)056

## Charged Higgs Searches



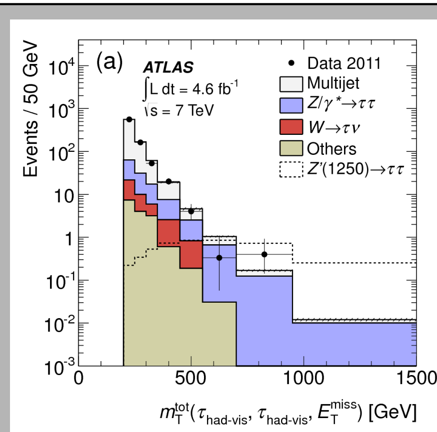

arXiv:1412.6663

## Search for SUSY in events with MET, a jet and at least one tau lepton




JHEP09(2014)103

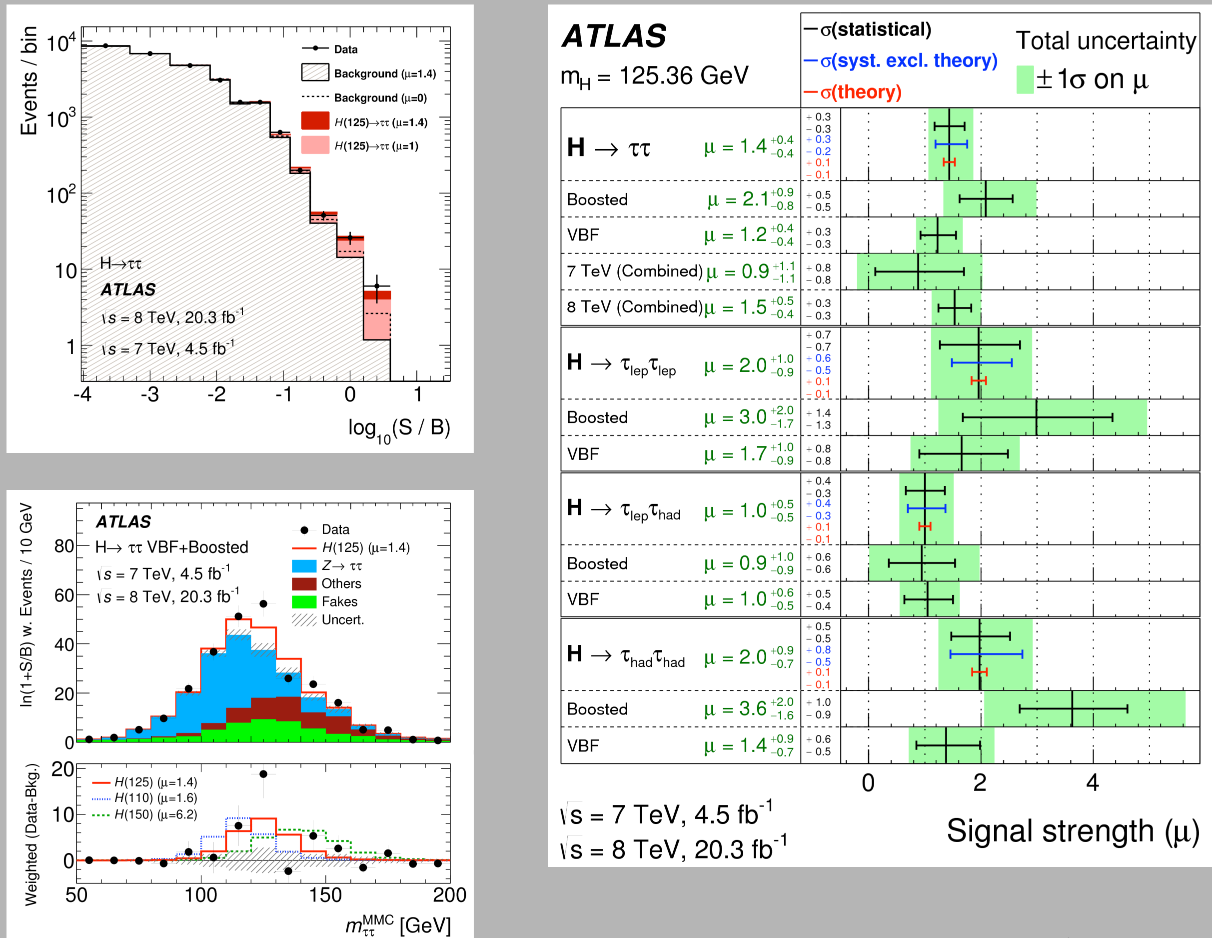
## Search for high-mass resonances decaying to ττ




Phys. Lett. B 719 (2013) 242-260

# Physics with Taus in Run 1

## Evidence for H→ττ




arXiv:1501.04943

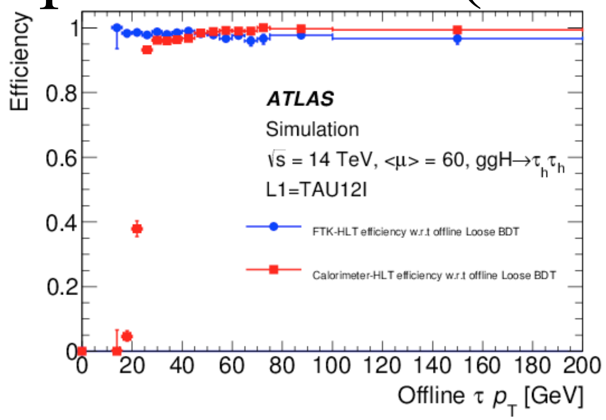
# Taus: 2015+

- A lot of fun to be had with taus also in Run 2!

Establish $H\rightarrow\tau\tau$ at 5 sigma
Study Higgs CP properties using $\tau$ decay angular correlations
BSM $A/H\rightarrow\tau\tau$
Charged Higgs searches ($H+ \rightarrow \tau\nu$)
HH with one $H\rightarrow\tau\tau$
High-mass resonances
SUSY with $\tau$:s
Lepton-Flavor Violating decays of H or Z
…

# Taus: 2015+

- A lot of fun to be had with taus also in Run 2!
- Tau-reconstruction in Run 2
  - Identification will work like in Run 1; expect similar efficiency and rejection
  - Uncertainties initially MC-based; when enough int. lumi. replace by tag-&-probe results (as in Run 1)
  - Tau triggering will benefit from FTK



# Taus: 2015+

- A lot of fun to be had with taus also in Run 2!
- Tau-reconstruction in Run 2
- Big new thing: Substructure information
  - Energy flow based reconstruction of hadronic tau decay products
  - Subtract $\pi\pm$ in EM-Calo layers
  - Reconstruct & identify $\pi0$ in remaining clusters

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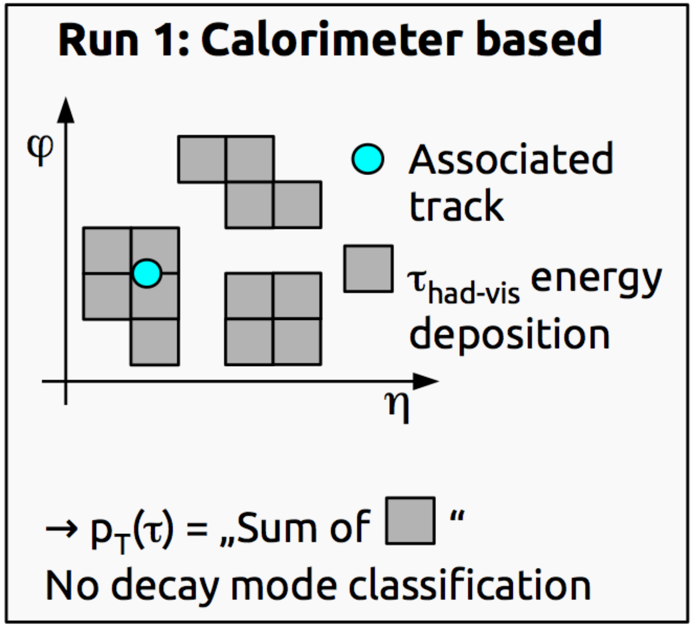
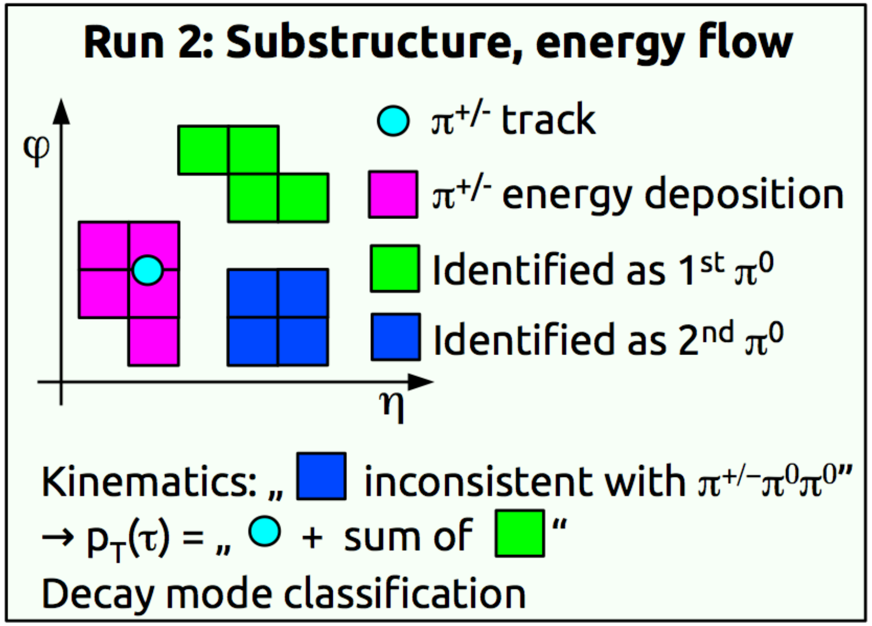


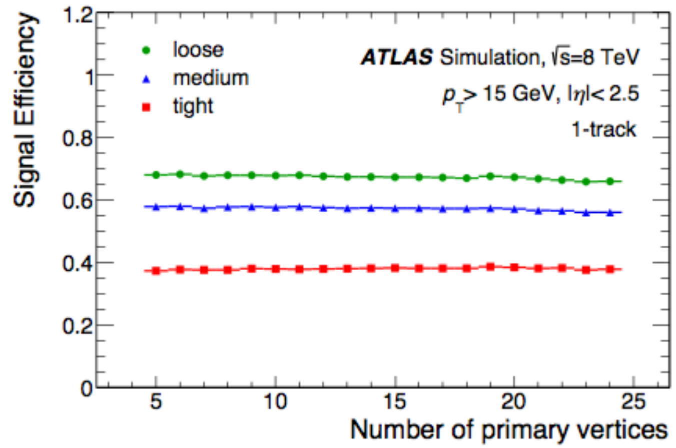

Taken from talk by C. Limbach at Tau 2014

# Taus: 2015+

- A lot of fun to be had with taus also in Run 2!
- Tau-reconstruction in Run 2
- Big new thing: Substructure information
  - Energy flow based reconstruction of hadronic tau decay products
  - Subtract $\pi\pm$ in EM-Calo layers
  - Reconstruct & identify $\pi0$ in remaining clusters
  - Allows decay mode classification
  - Significant resolution improvement

# Taus: 2015+

- A lot of fun to be had with taus also in Run 2!
- Tau-reconstruction in Run 2
- Big new thing: Substructure information
- Beyond run 2
  - Expect to maintain performance at ~similar levels, with appropriate pile-up correction
  - So far, tau-ID shown to be very stable against pile-up

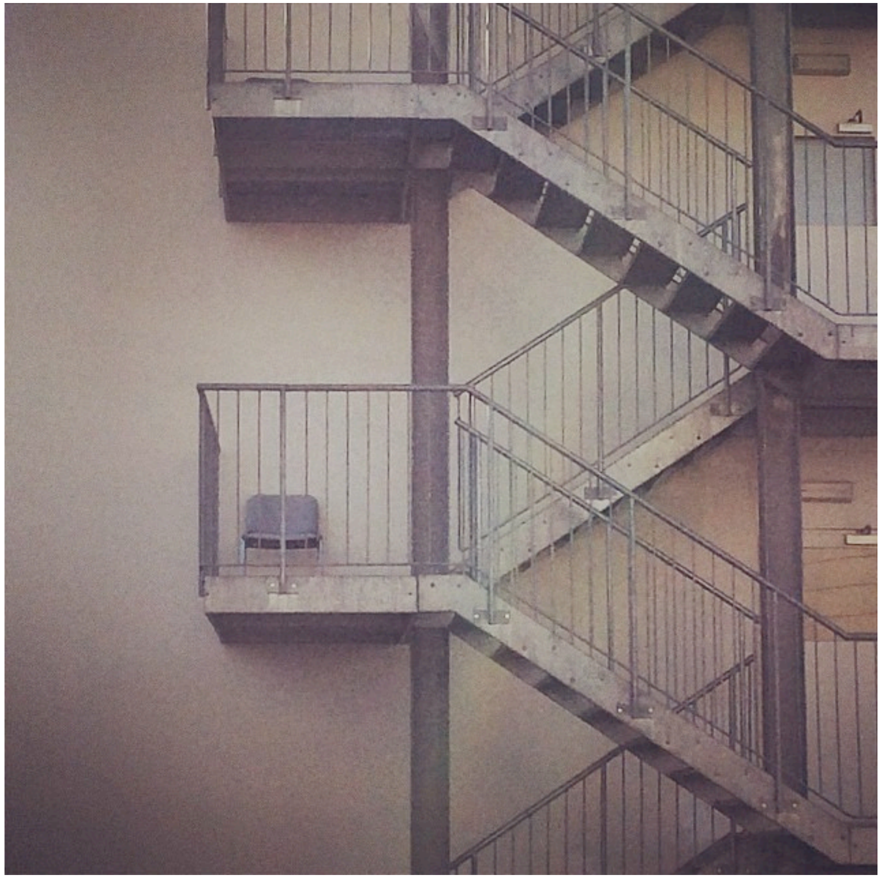


# Summary

- Tau reconstruction in ATLAS performed very well in Run 1, supporting important physics results
  - Reconstruction seeded by calorimeter jets, associating tracks
  - Suppression of fakes achieved with BDT exploiting characteristics of the tau decay
  - Algorithms robust against pile-up
- Looking forward to similar performance in Run 2 and beyond
  - Exciting new addition: Substructure information
- Did not discuss tau triggers: crucial component for many analyses involving taus!

**Suggested Reading:**
***arXiv:1412.7086*** for tau reconstruction & performance in Run 1 (incl. trigger)
***ATL-PHYS-PUB-2013-004*** for (some) discussion on tau performance at HL-LHC

# Backup Slides



Source: lonelychairsatcern.tumblr.com

# Tau ID Variables Definitions

**Central energy fraction ($f_{\text{cent}}$):** Fraction of transverse energy deposited in the region $\Delta R < 0.1$ with respected to all energy deposited in the region $\Delta R < 0.2$ around the $\tau_{\text{had-vis}}$ candidate calculated by summing the energy deposited in all cells belonging to TopoClusters with a barycentre in this region, calibrated at the EM energy scale. Biases due to pile-up contributions are removed using a correction based on the number of reconstructed primary vertices in the event.

**Leading track momentum fraction ($f_{\text{track}}$):** The transverse momentum of the highest-$p_{\text{T}}$ charged particle in the core region of the $\tau_{\text{had-vis}}$ candidate, divided by the transverse energy sum, calibrated at the EM energy scale, deposited in all cells belonging to TopoClusters in the core region. A correction depending on the number of reconstructed primary vertices in the event is applied to this fraction, making the resulting variable pile-up independent.

**Track radius ($R_{\text{track}}$):** $p_{\text{T}}$-weighted distance of the associated tracks to the $\tau_{\text{had-vis}}$ direction, using all tracks in the core and isolation regions.

**Leading track IP significance ($S_{\text{leadtrack}}$):** Transverse impact parameter of the highest-$p_{\text{T}}$ track in the core region, calculated with respect to the TV, divided by its estimated uncertainty.

**Number of tracks in the isolation region ($N_{\text{track}}^{\text{iso}}$):** Number of tracks associated with the $\tau_{\text{had-vis}}$ in the region $0.2 < \Delta R < 0.4$.

**Maximum $\Delta R$ ($\Delta R_{\text{Max}}$):** The maximum $\Delta R$ between a track associated with the $\tau_{\text{had-vis}}$ candidate and the $\tau_{\text{had-vis}}$ direction. Only tracks in the core region are considered.

**Transverse flight path significance ($S_{\text{T}}^{\text{flight}}$):** The decay length of the secondary vertex (vertex reconstructed from the tracks associated with the core region of the $\tau_{\text{had-vis}}$ candidate) in the transverse plane, calculated with respect to the TV, divided by its estimated uncertainty. It is defined only for multi-track $\tau_{\text{had-vis}}$ candidates.

**Track mass ($m_{\text{track}}$):** Invariant mass calculated from the sum of the four-momentum of all tracks in the core and isolation regions, assuming a pion mass for each track.

**Track-plus-$\pi^0$-system mass ($m_{\pi^0+\text{track}}$):** Invariant mass of the system composed of the tracks and $\pi^0$ mesons in the core region.

**Number of $\pi^0$ mesons ($N_{\pi^0}$):** Number of $\pi^0$ mesons reconstructed in the core region.

**Ratio of track-plus-$\pi^0$-system $p_{\text{T}}$ ($p_{\text{T}}^{\pi^0+\text{track}}/p_{\text{T}}$):** Ratio of the $p_{\text{T}}$ estimated using the track + $\pi^0$ information to the calorimeter-only measurement.

From arXiv:1412.7086