Identification and energy calibration of hadronically decaying tau leptons with ATLAS

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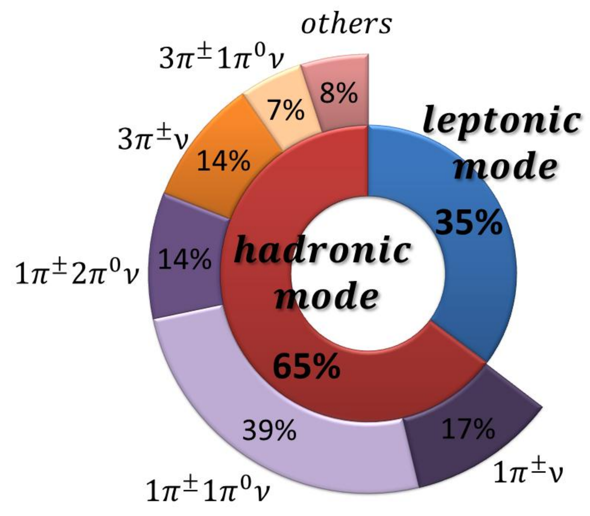
Introduction to Tau Leptons in ATLAS

➢ **mass = 1.78 GeV**: tau leptons are the heaviest known leptons and the only leptons for which decay modes involving hadrons are allowed.
➢ **hadronic decay mode represents 65% of all tau decays**: decay products are a neutrino and dominantly 1 or 3 charged pions and neutral pions. In the leptonic mode, taus decay into two neutrinos and either an electron or a muon.
➢ **proper decay length = 87 μm**: tau leptons typically decay inside the LHC beam pipe, and they can thus only be identified via their decay products. Light leptons from tau lepton decays cannot be distinguished from prompt electrons or muons, and they are identified with the same algorithms as those for identifying prompt light leptons. A special algorithm exists to identify hadronic jets from tau lepton decays.

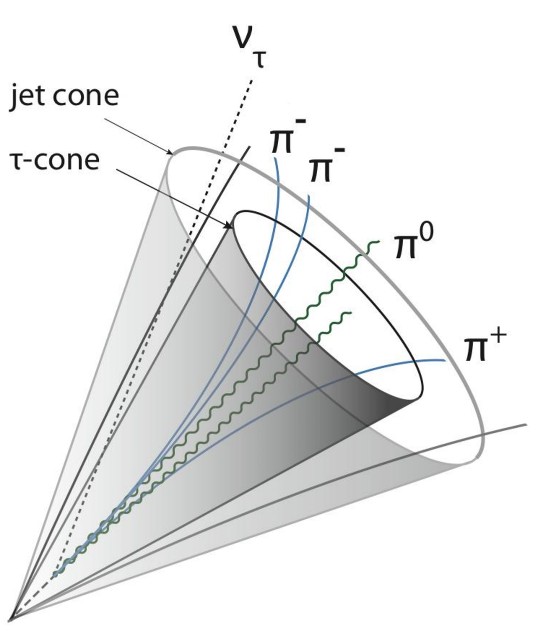


Hadronically decaying tau leptons play an important role in physics analysis in ATLAS:
❖ searches for physics beyond the Standard Model:
- new particles decaying to tau leptons
- lepton flavor violation
- lepton universality violation

❖ Standard Model (SM) measurements and tests:
- Higgs boson couplings to fermions
- tau polarization in SM physics processes
- SM particles decay rates into tau leptons

Tau Reconstruction

1) Jets are formed using the anti-k_t algorithm (R=0.4) with TopoClusters calibrated using a local hadronic calibration (LC) as inputs, and tau candidates are seeded by jets with $p_T > 10$ GeV and $|\eta| < 2.5$
2) Tau lepton production vertex (TV) is identified using tracks in the region ΔR<0.2 around the jet seed axis



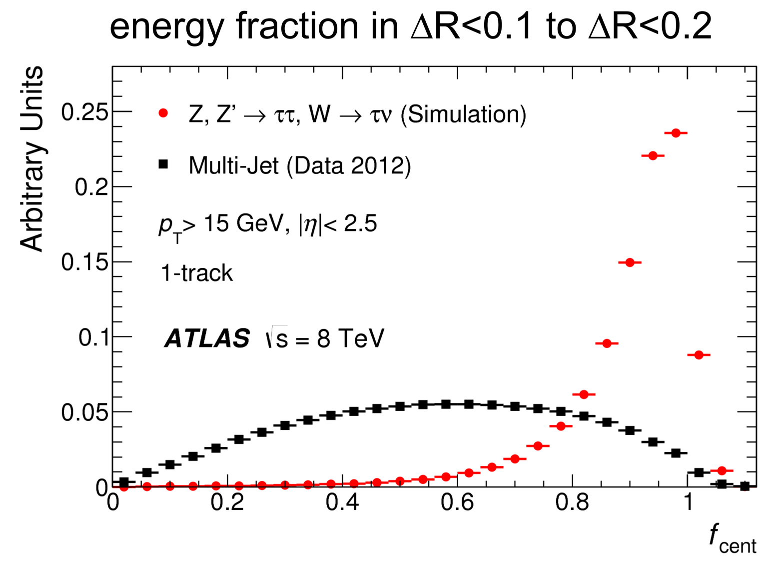
3) The 4-momenta of all clusters in the region ΔR<0.2 around the jet seed axis are recalculated in the TV coordinate system and summed, resulting in reconstructed tau axis and momentum
4) Tracks in the core region (ΔR<0.2 around the tau axis) are associated with the tau candidate
5) Tracks in the isolation region (0.2<ΔR<0.4) are used to calculate identification variables

Tau Identification: Discrimination against jets

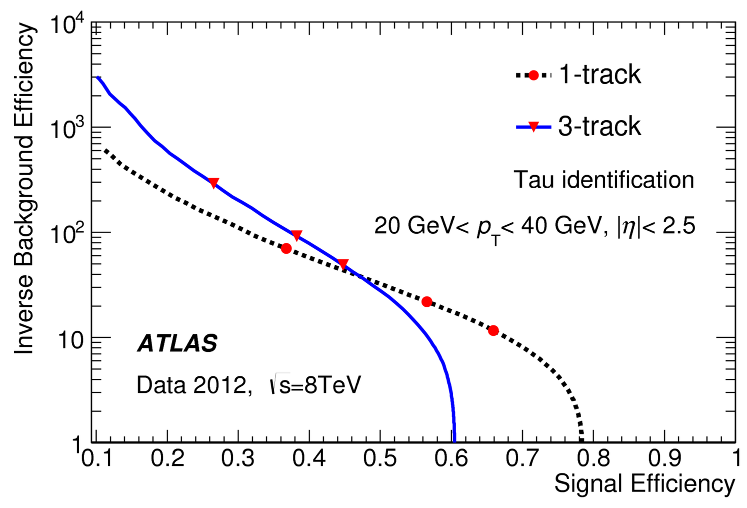
Quark- or gluon-initiated jets (QCD jets) have a very similar signature in the detector as hadronically decaying taus. Discrimination between taus (signal) and QCD jets (background) is provided by Boosted Decision Trees (BDT) algorithm using variables sensitive to the different features of these objects:
✓ taus tend to have less tracks in the isolation region than QCD jets
✓ taus tend to have more collimated tracks than QCD jets
✓ taus tend to have narrower calorimeter showers than QCD jets
✓ taus tend to have displaced tracks/secondary vertex from the tau vertex

Working points are defined to make signal efficiency independent of tau p_T

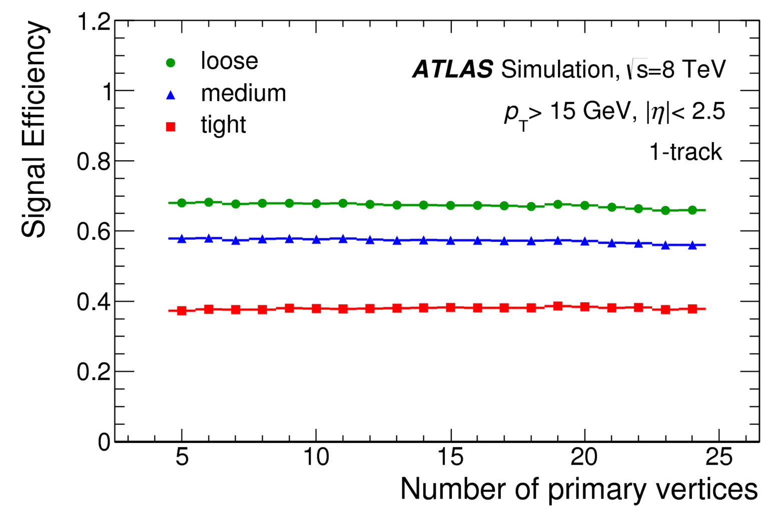
energy fraction in ΔR<0.1 to ΔR<0.2



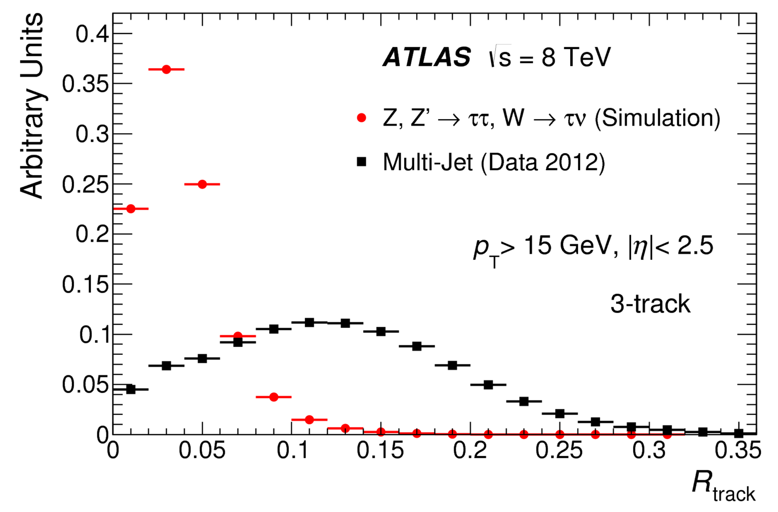
▪ separate BDTs are trained for 1-track and 3-track taus



▪ signal efficiency is stable against pile-up



p_T-weighted distance of tracks to the tau axis

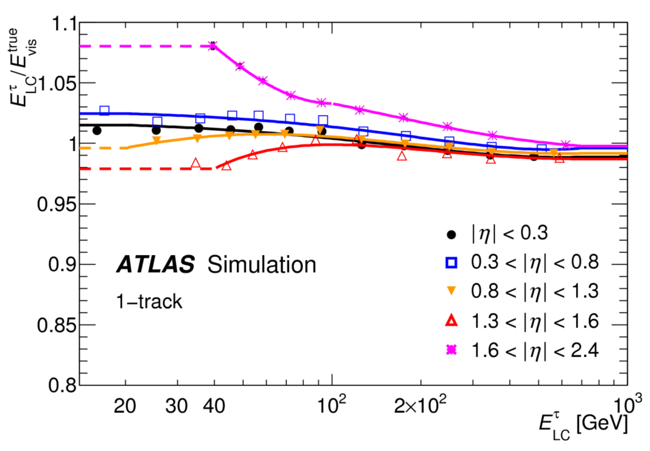


Tau Energy Scale

Reconstructed tau energy, calibrated at the LC scale, is corrected to account for the specific mix of hadrons observed in hadronic tau decays, and for the underlying event or pile-up contributions.
➢ **Tau energy scale** (TES) is derived from simulation re-calibrating the LC scale to the **true visible tau energy scale**:

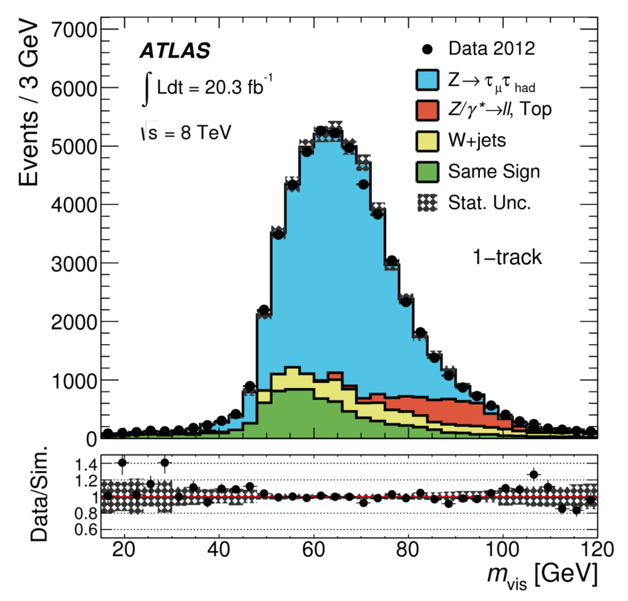
$$E^{\tau}_{TES} = \frac{E^{\tau}_{LC} - E^{\tau}_{pile-up}}{R(E^{\tau}_{LC}, |\eta^{\tau}|, n^{\tau}_{tracks})}$$

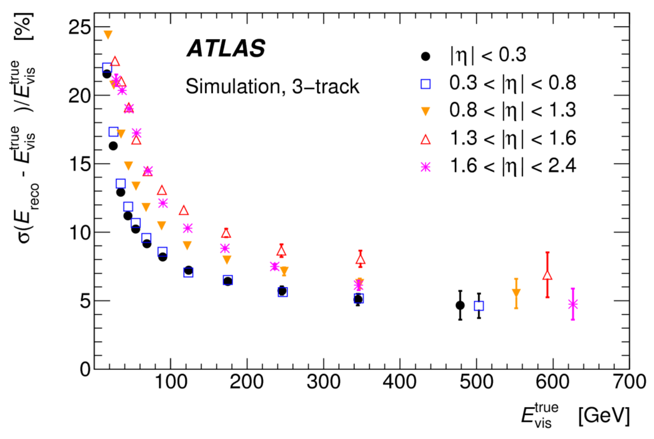
energy response



➢ Additional **data-driven corrections** are derived:
- deconvolution method (absolute TES and modeling)
- in-situ method (modeling)

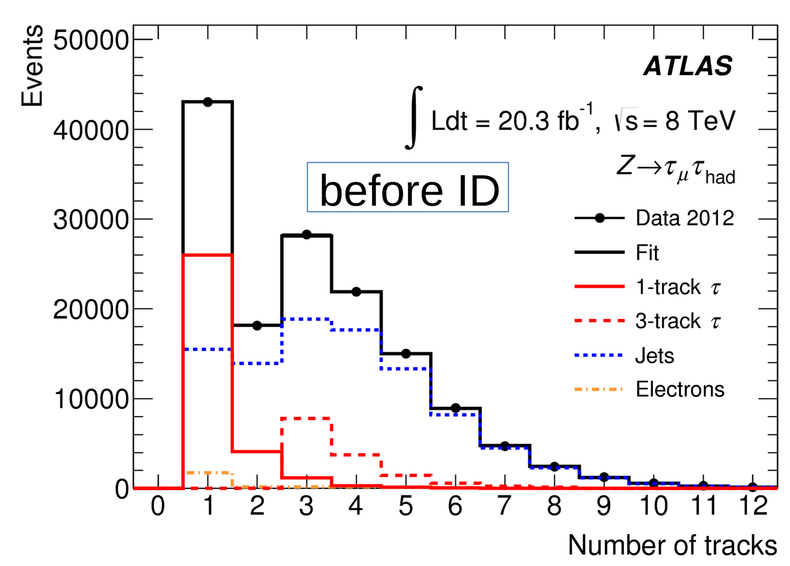
Total TES uncertainty:
1-track taus: 2%-3%
3-track taus: 2%-4%

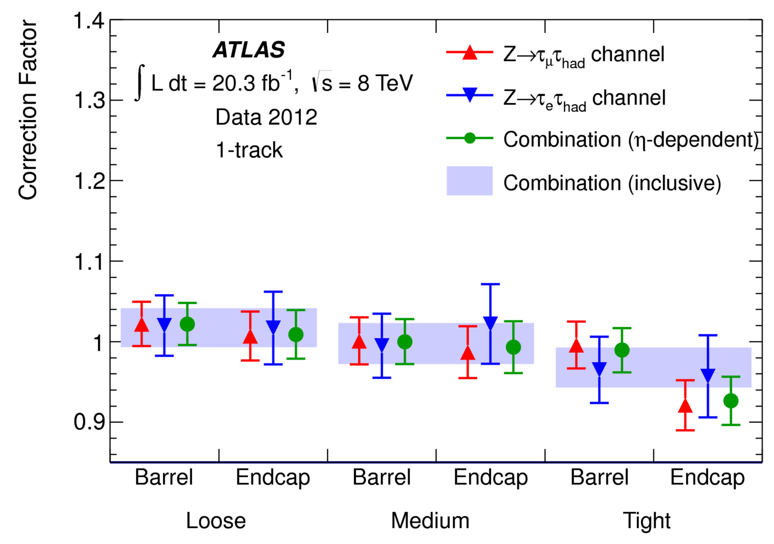


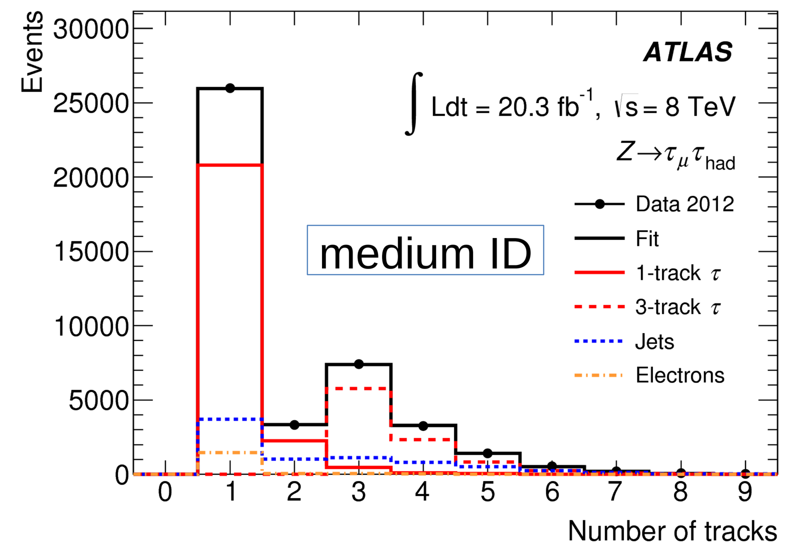


Tau Identification: Efficiency measurement

- **tag-and-probe** approach to select $Z \to \tau_{lep}\tau_{had}$ events in data
- **template fit** to tau track multiplicity (tracks in the ΔR<0.6 region) to extract τ_{had} signal before and after the requirement of tau identification, and to measure identification efficiency ε_{ID}
- **correction factors** ($\varepsilon^{data}_{ID} / \varepsilon^{simulation}_{ID}$) to account for the differences between data and simulation

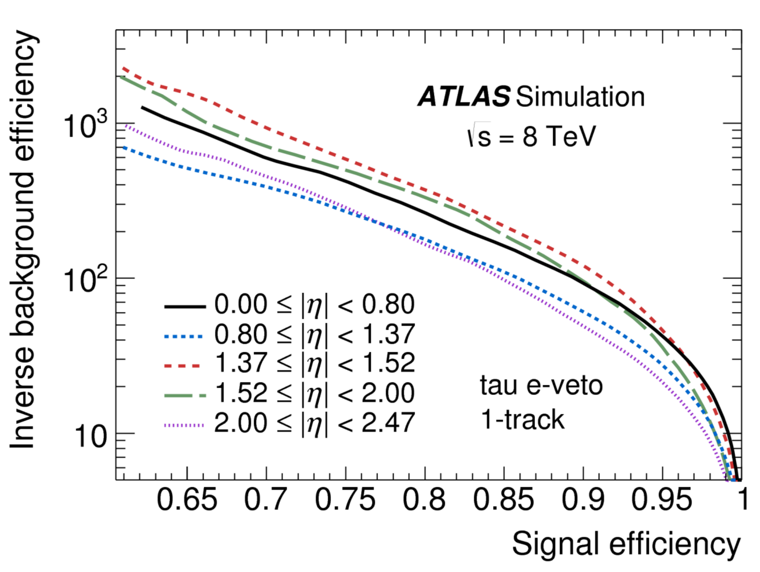


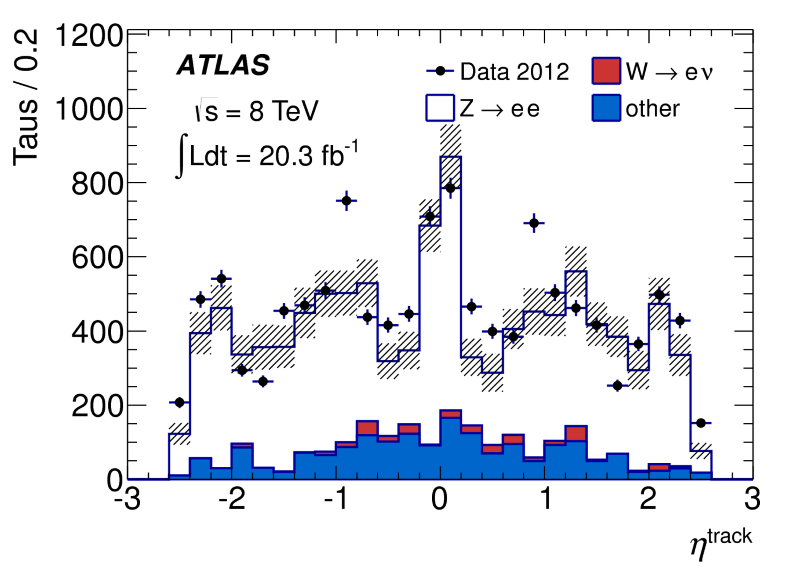




Electron Veto

The signature of 1-track taus can be mimicked by electrons. In Run-1, electrons are rejected using a special BDT which exploits: a) amount of transition radiation, b) angular distance of the track from the tau direction, c) fraction of energy in the electromagnetic calorimeter, d) calorimeter shower shapes. Electron veto efficiency was measured in data using a tag-and-probe method to select Z→ee events. Correction factors are close to unity, their uncertainties are ~10% for the loose electron veto.





Commissioning for Run-2

- Tau reconstruction and identification algorithms have been **modified for Run-2**.
- The **13 TeV proton-proton collision data** recorded in the early phase of Run-2 is used to compare between data and simulation in minimum bias, W(→μν)+jets, dijets, Z(→μμ)+jets, Z(→ee)+jets and Z(→ττ)+jets events.
- Reasonably **good agreement** is observed.