Reconstruction of individual decay products in hadronic tau decays and planned applications in ATLAS

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Content

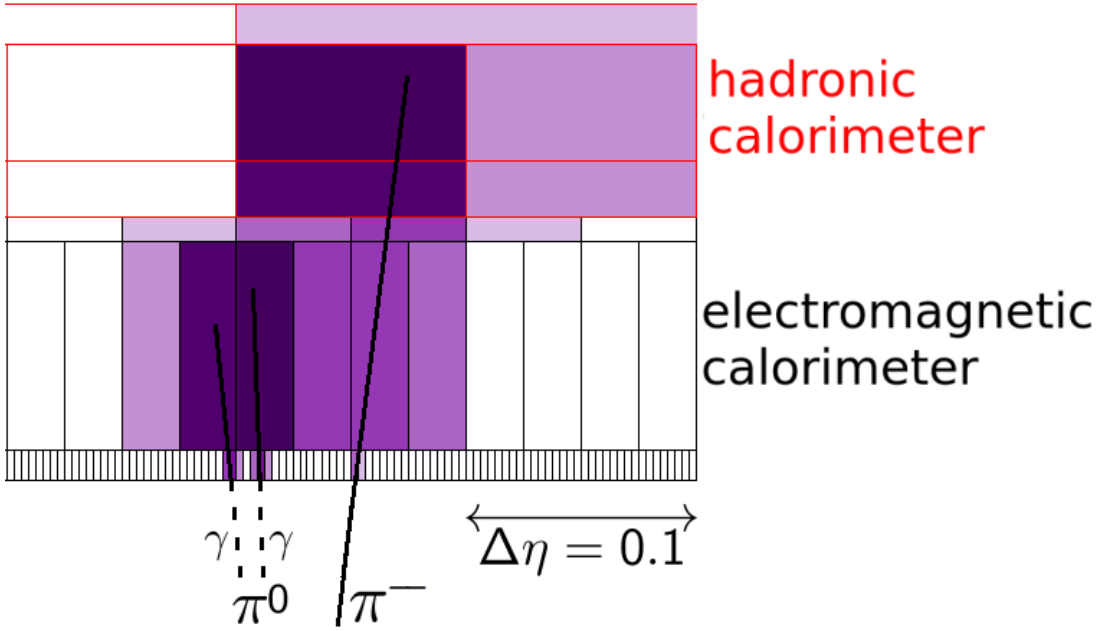
Reconstruction of individual decay products ("substructure reconstruction") in hadronic tau decays:

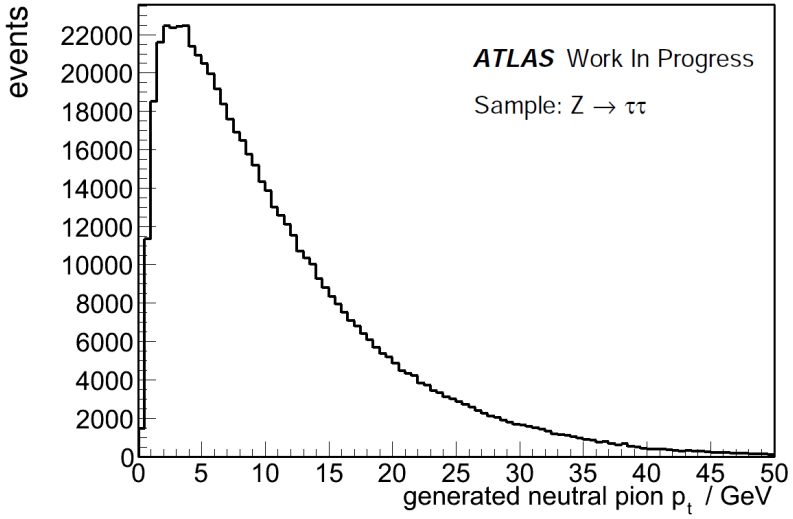
- Description of substructure reconstruction procedure
- Performance ($8\,\mathrm{TeV}$)
- Validation with run 1 data

Applications:

- Reconstruction of visible tau 4-momentum from decay products
- Polarization analysis

Signature of $\tau \to \pi^{\pm}\pi^{0}\nu$ decay in calorimeter

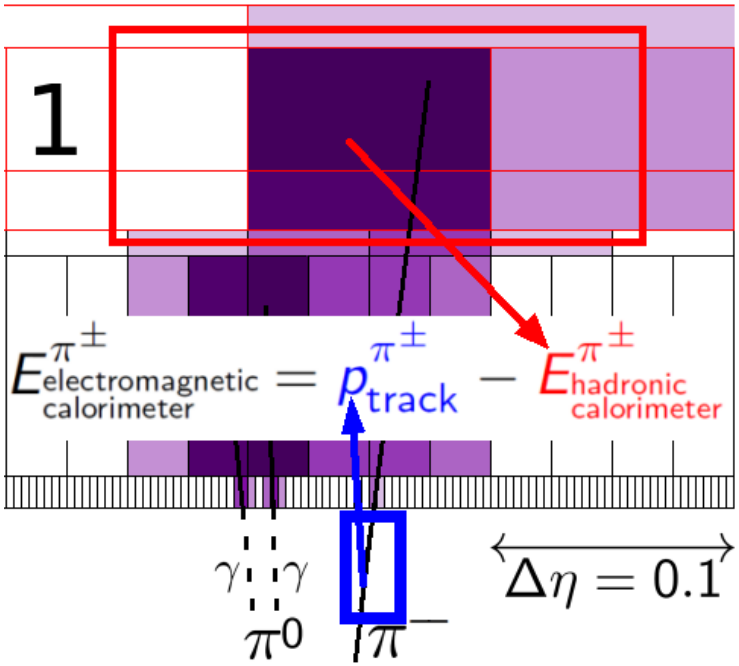


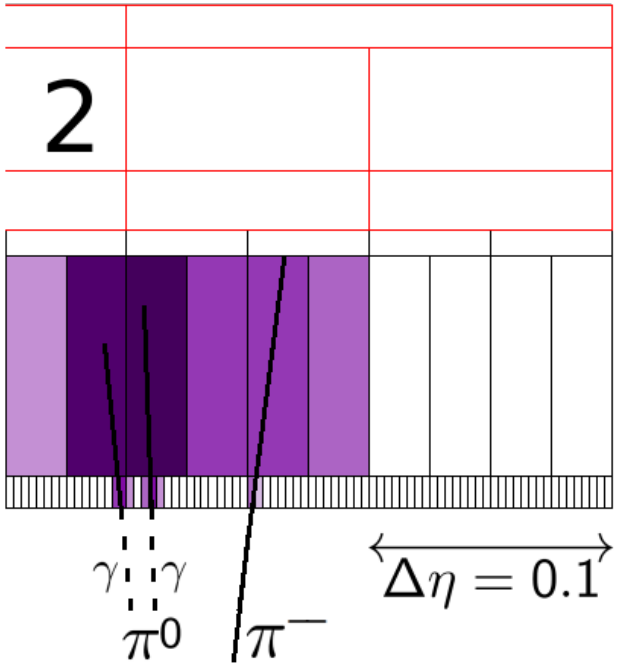


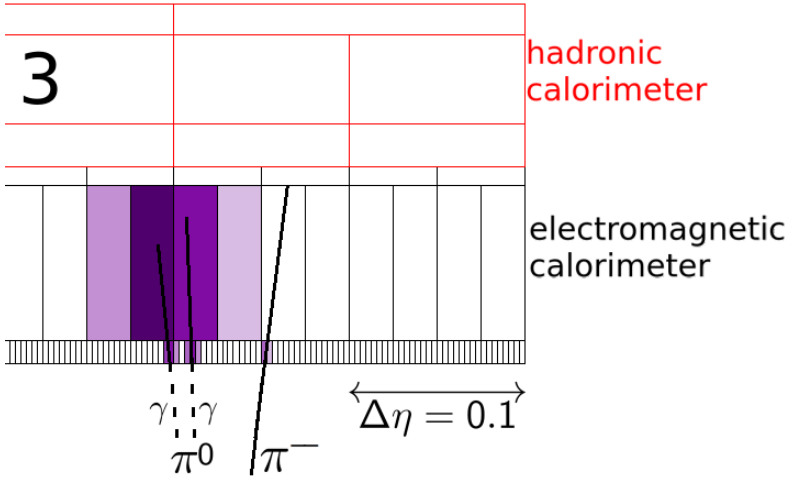
Goal: Reconstruct individual pions:

- $\pi^{\pm}$ from charged PFOs (tracks)
- π^0s from electromagnetic calorimeter. Challenges:
  - Showers from $\pi^{\pm}$s and π^0s often overlap
  - Many π^0s are soft (few GeV)
  - Particles not from the tau decay, noise

Removal of charged pion energy

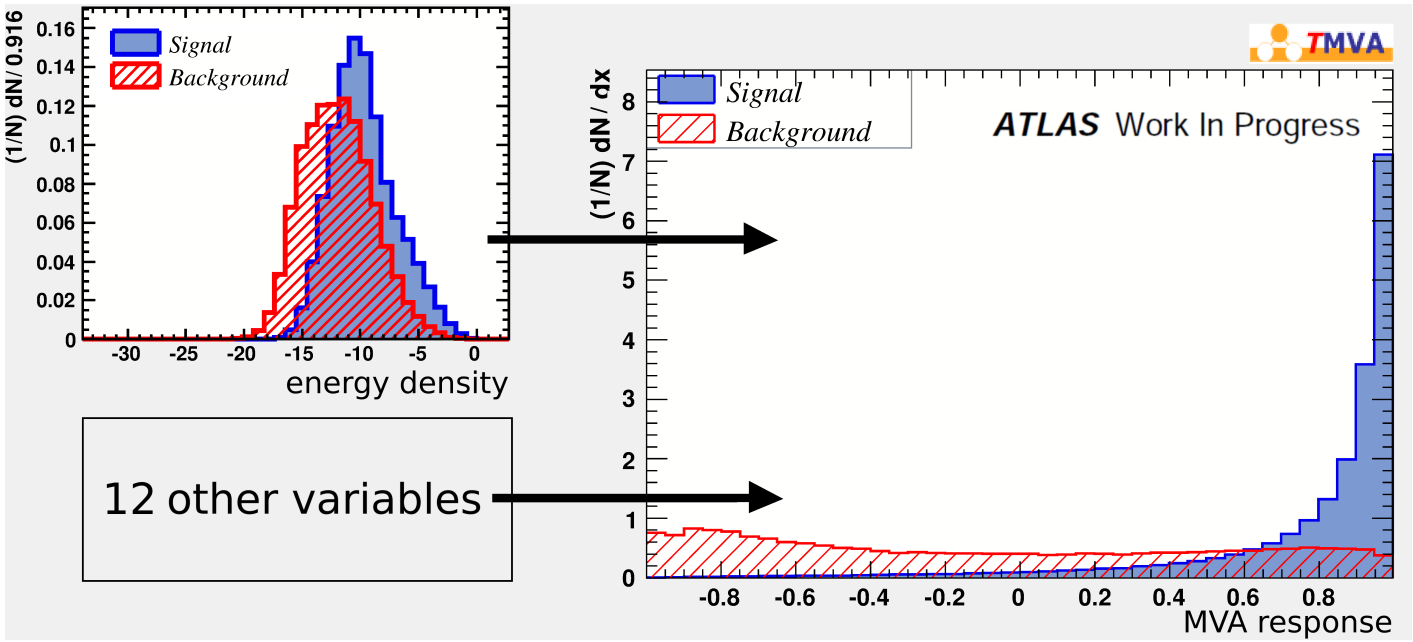






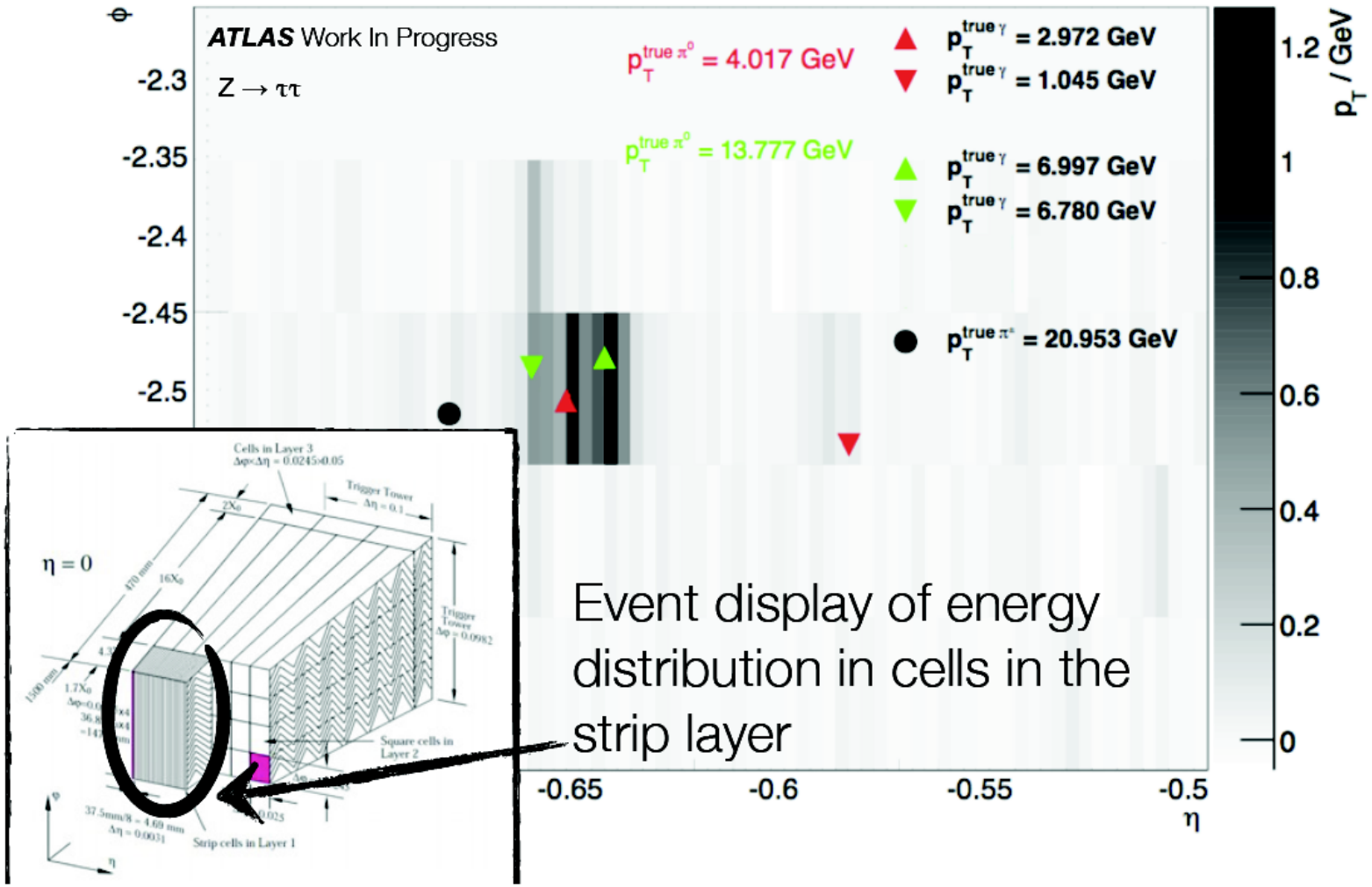
1. Calculate total energy to subtract and select neutral PFOs (Ecal clusters)
2. **1-prongs:** Remove or rescale energy of neutral PFO closest to charged PFO
   3-prongs: Remove or rescale neutral PFOs closest to each of the charged PFOs
3. Identify π^0 candidates

Neutral pion identification



- Determine quality (π^0-likeness) of each neutral PFO by using a BDT. Exploit shape of neutral PFOs (=clusters), only. Preliminary π^0-tagging
- Cluster shapes not altered by charged pion energy removal. This is a difference wrt the previous version:
  - Disadvantage: $\pi^\pm$ now affect shape of mixed clusters. Found that benefit of removing averaged $\pi^\pm$ shape was small
  - Advantage: No systematic uncertainty on alteration of the shape by the subtraction. Still have uncertainty on shape of course
  - Advantages: Algorithm timing and maintenance

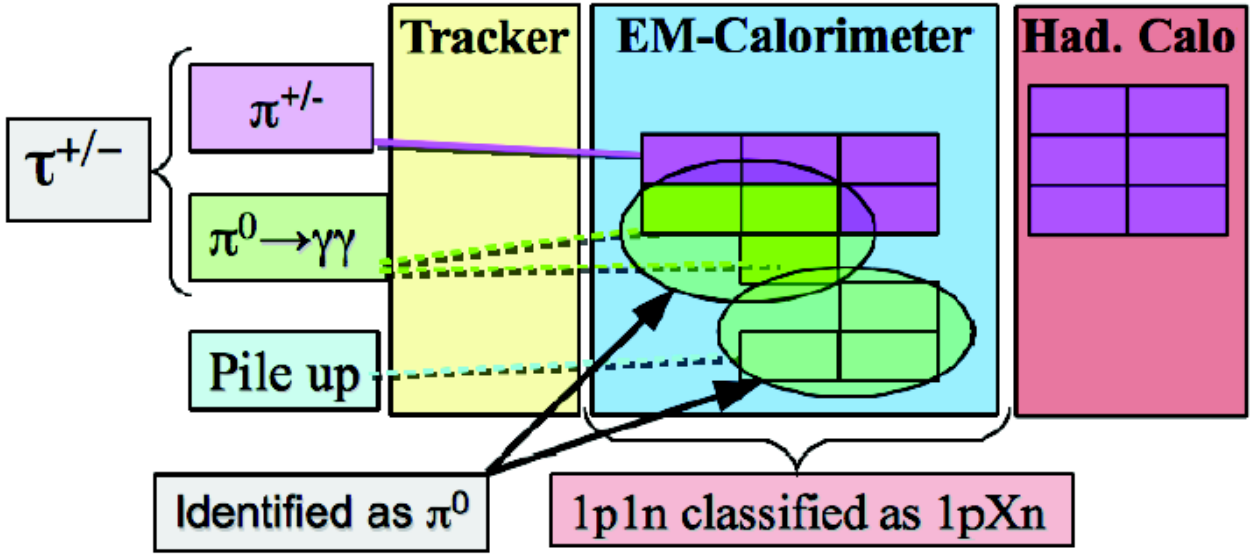
Estimation of number of photons



Estimate number of photons for

- identification of π^0 candidates, which contain two π^0s
- input for MVA decay mode identification

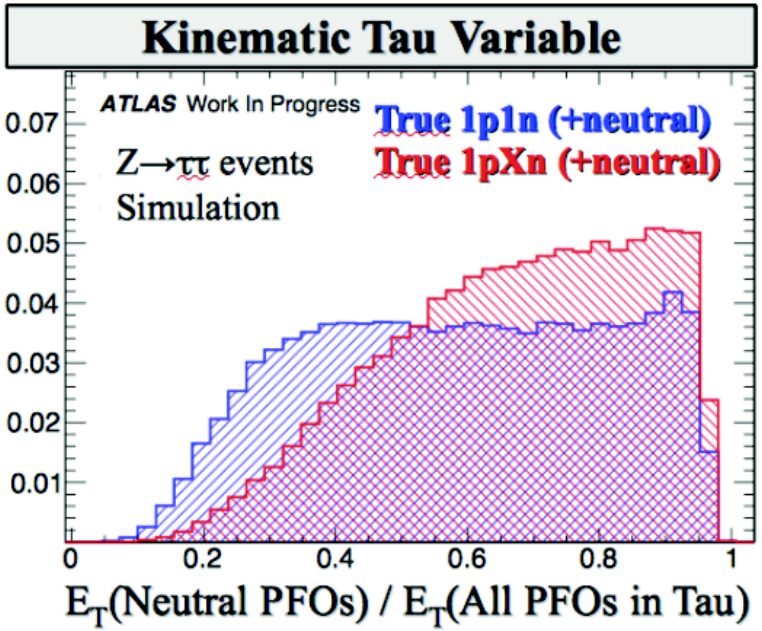
MVA-based identification of decay mode

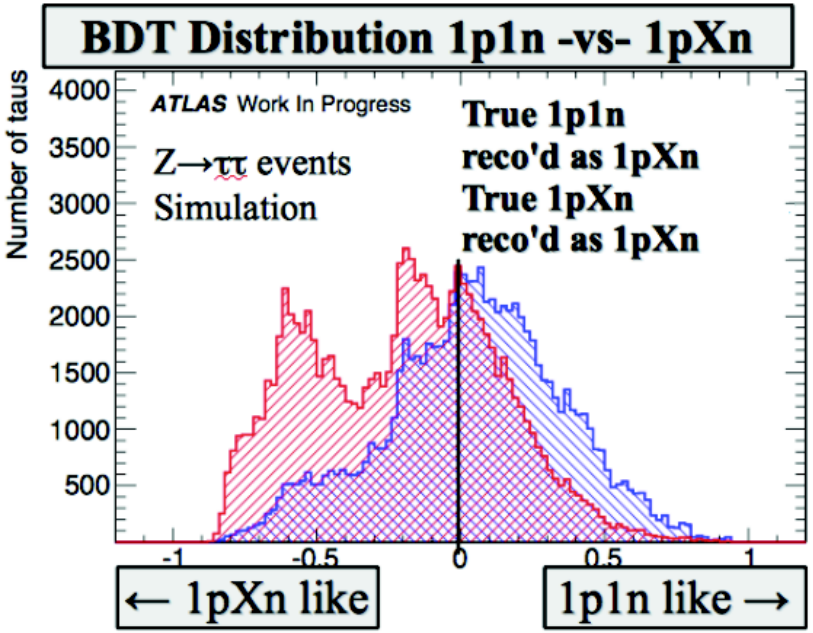


- Combine info calculated upstream for final identification of mode
  - 4-momenta of charged PFOs
  - neutral PFOs quality and 4-momenta
  - number of reconstructed photons
- One BDT each to distinguish 1p0n↔1p1n, 1p1n↔1pXn, 3p0n↔3pXn modes
- Update pi0 tags after final mode identification

Mode	Nomenclature
$\tau^{\pm} \to \pi^{\pm}\nu_{\tau}$	1p0n
$\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu_{\tau}$	1p1n
$\tau^{\pm} \to \pi^{\pm} > 1\pi^{0}\nu_{\tau}$	1pXn
$\tau^{\pm} \to 3\pi^{\pm}\nu_{\tau}$	3p0n
$\tau^{\pm} \to 3\pi^{\pm} > 0\pi^{0}\nu_{\tau}$	3pXn

MVA-based identification of decay mode





- Example: Separation of 1p1n and 1pXn modes
- This BDT is evaluated for taus, which have
  - exactly one π^0 tagged PFO and at least one more neutral PFO
  - at least two π^0 tagged PFOs (right plot)

Categorization of tau decays involving kaons

- $K^{\pm}$ (2% of tau decays)
  - have almost the same signature as $\pi^{\pm}$ and same J^P quantum numbers
  - are thus treated same as $\pi^{\pm}$. E.g. 1p0n contains $\tau^{\pm} \to \pi^{\pm}\nu_{\tau}$ and $\tau^{\pm} \to K^{\pm}\nu_{\tau}$
- K^0 (1% of tau decays)
  - Signature not expected by substructure reconstruction algorithms
  - Seem to have low efficiency to pass tau ID
  - Modes 1pXk and 3pXk for **generated** 1- and 3- prong decays with at least one K^0. No attempt to identify these modes
  - Effect on 4-momentum reconstruction from decay products will be discussed in second part of this talk

Evaluation of performance in simulated events

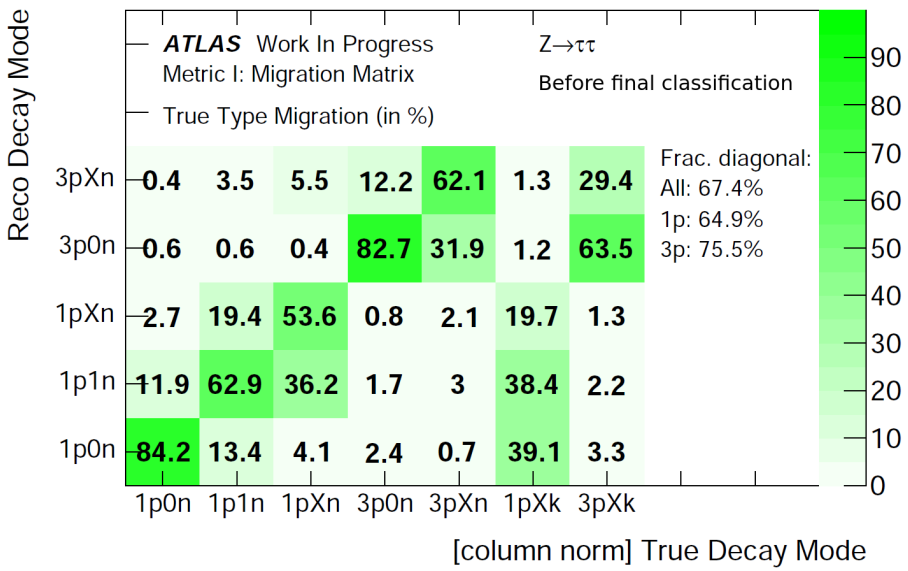
Sample:

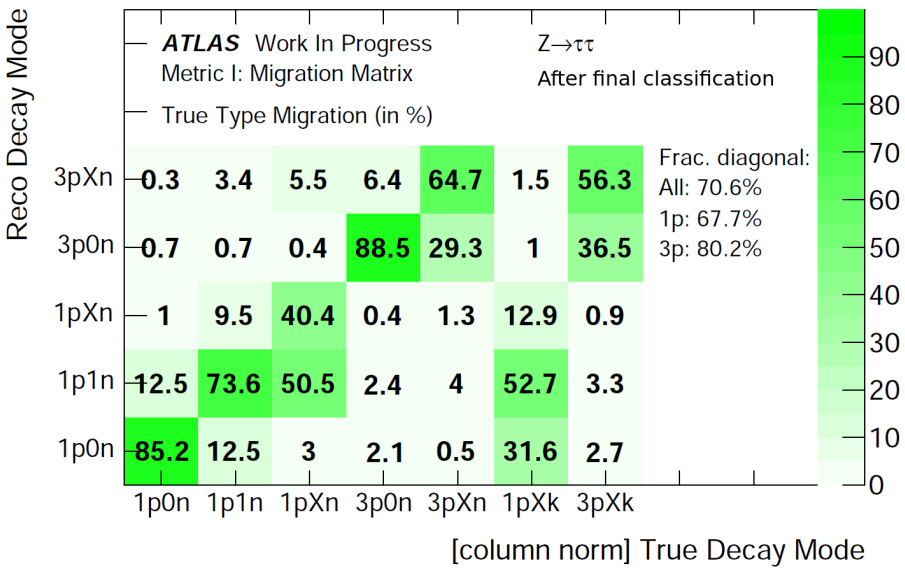
- Pythia $Z \to \tau\tau$, run 1 conditions ($8\,\mathrm{TeV}$)
- Performance very similar in run 2 samples

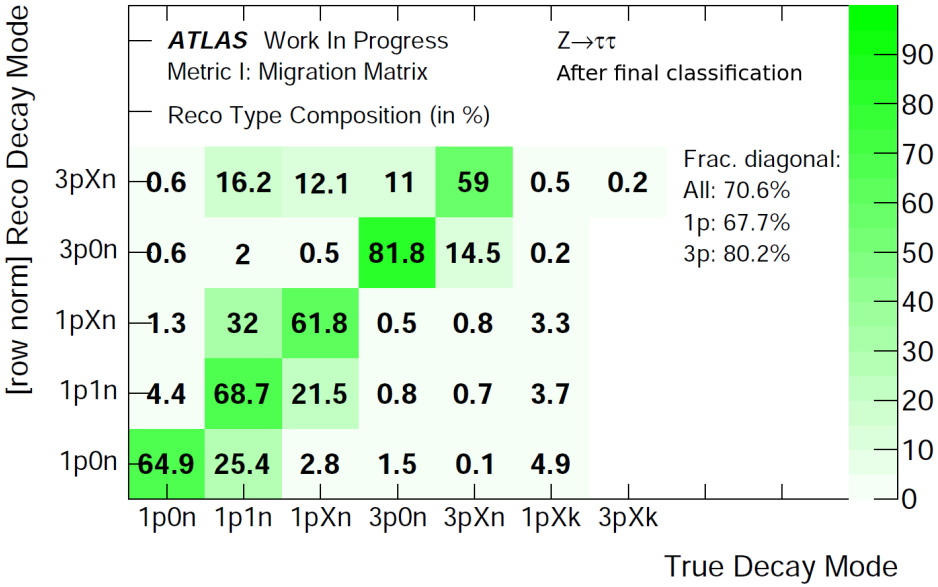
Selection of hadronically decaying taus:

- Truth match
- $E_\mathrm{t} > 15\,\mathrm{GeV}$
- $|\eta| < 2.5$
- 1 or 3 tracks

Performance: Decay mode identification

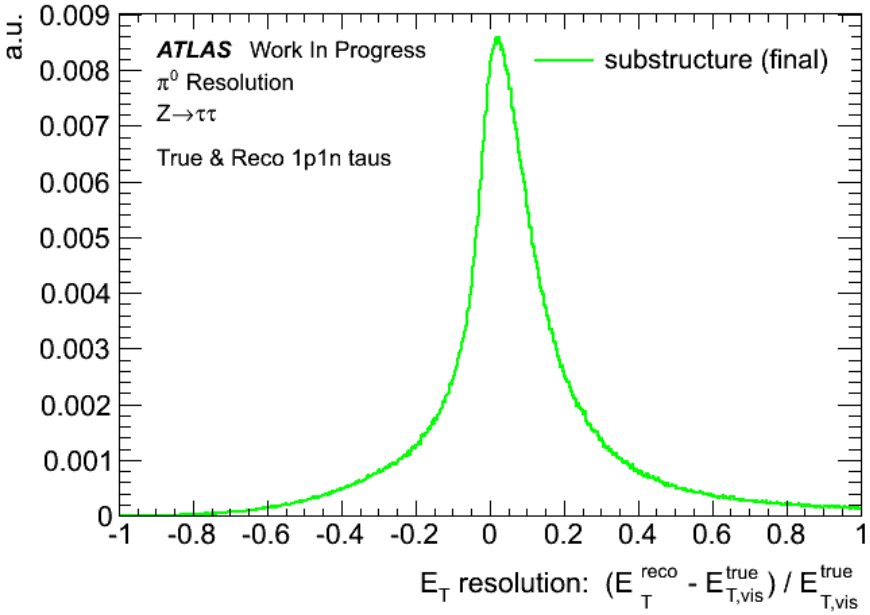


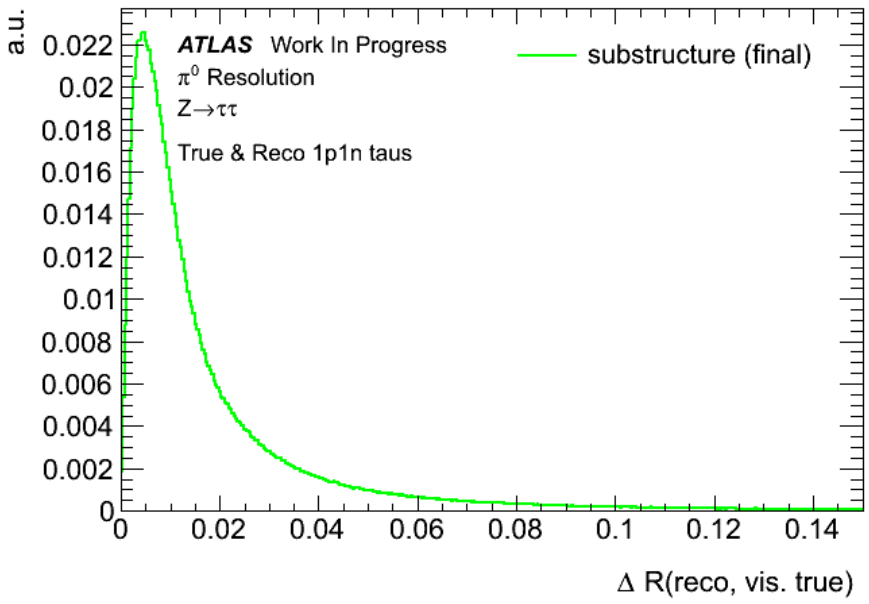




- Mode is correctly identified in 70 % of the cases (top plots)
- Efficiency > 70 % for important 1p0n, 1p1n and 3p0n modes
- Purity ≥ 65 % for most important modes (bottom plot)
- PanTau reduces fraction of falsely classified taus by 10 %

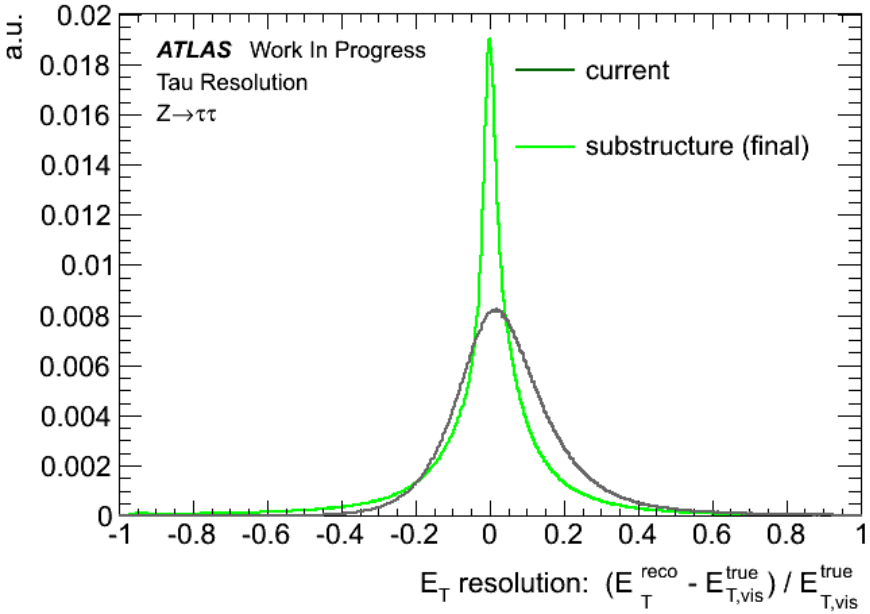
Performance: Reconstruction of π^0 4-momentum

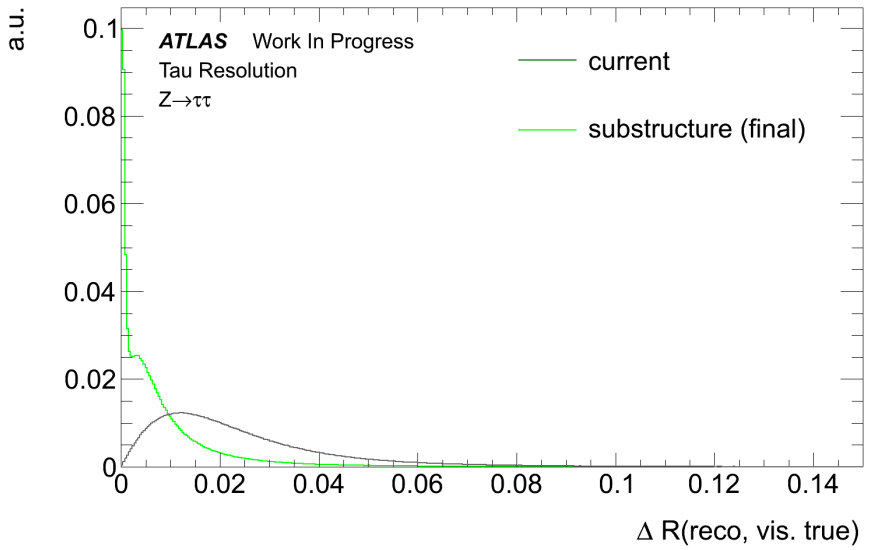




- Additional requirement for this plot: Generated and reconstructed 1p1n mode
- Mean energy shifted by 4 %, presumably due to leakage of $\pi^{\pm}$ energy into the nearby clusters. Will take care of this
- RMS of energy resolution: 25 %
- Mean and RMS of ΔR resolution: 0.02

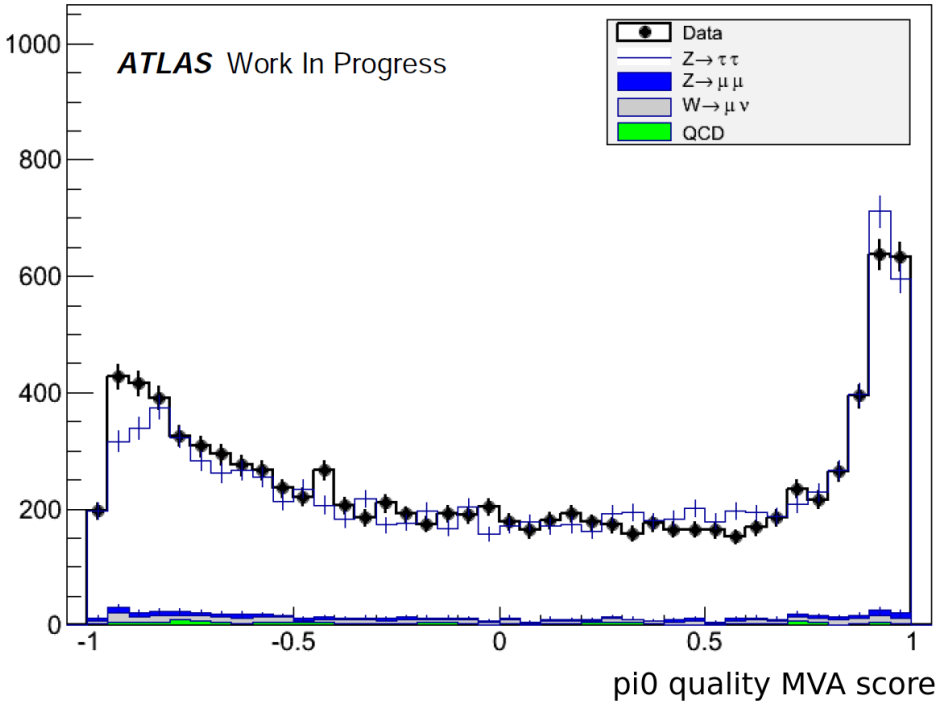
Performance: Out-of-the-box tau 4-momentum reconstruction

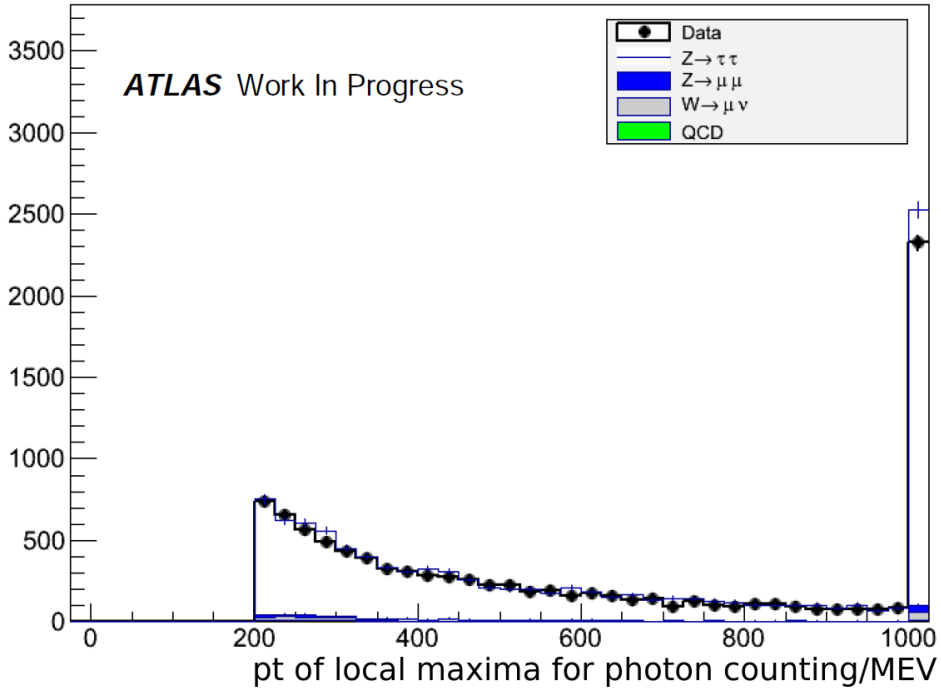




- Reconstruct visible tau 4-momentum by adding momenta of decay products
- Mean energy shifted by -1%. Affected by mode misidentification and reconstruction of π^0 energy
- Mean ΔR: 0.01, RMS: 0.013
- Plots contain taus, for which decay mode classification is wrong. Will look into tails in second part of this talk

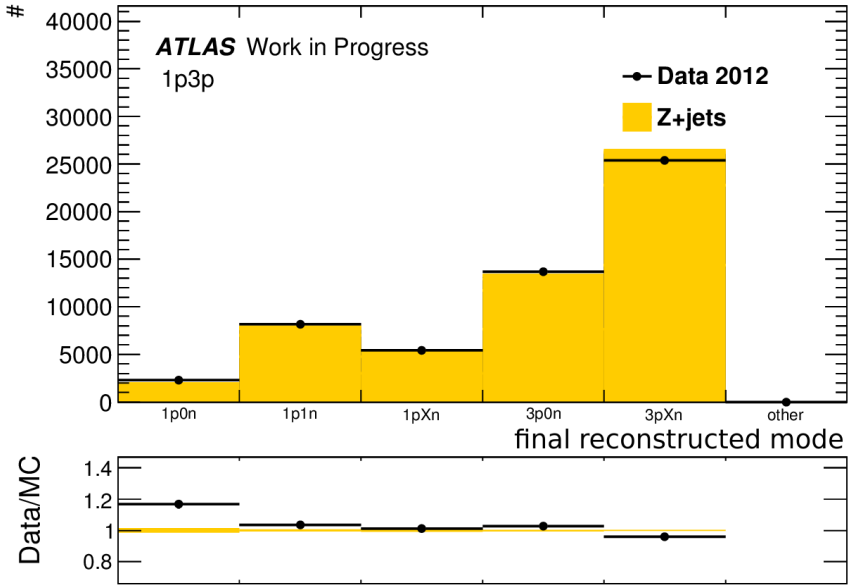
Validation in events with real taus

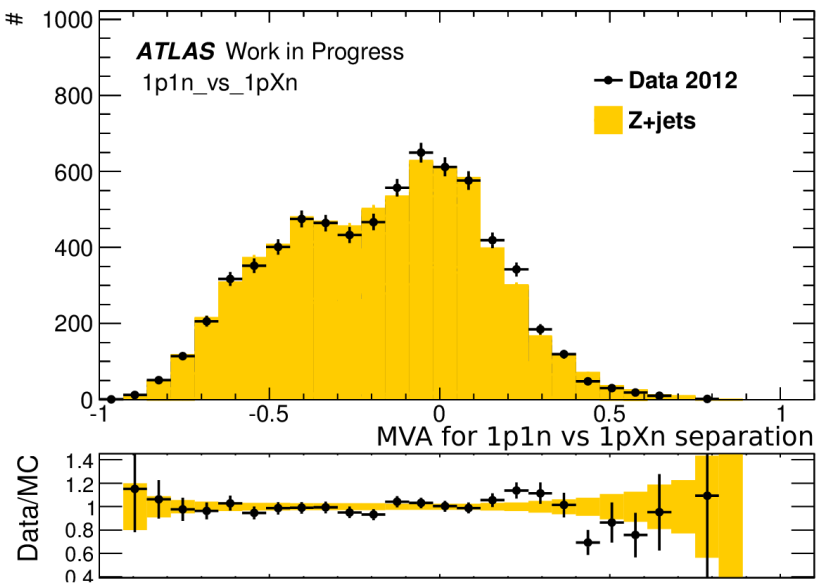




- First validation on real taus in Ztautau lephad events
- Standard tag and probe selection, tight tau identification to suppress W+jets and QCD backgrounds
- Agreement not perfect, but reasonably good. Will improve selection and usage of cluster shape and kinematic variables
- Started development of methods for measurement of classification performance from data

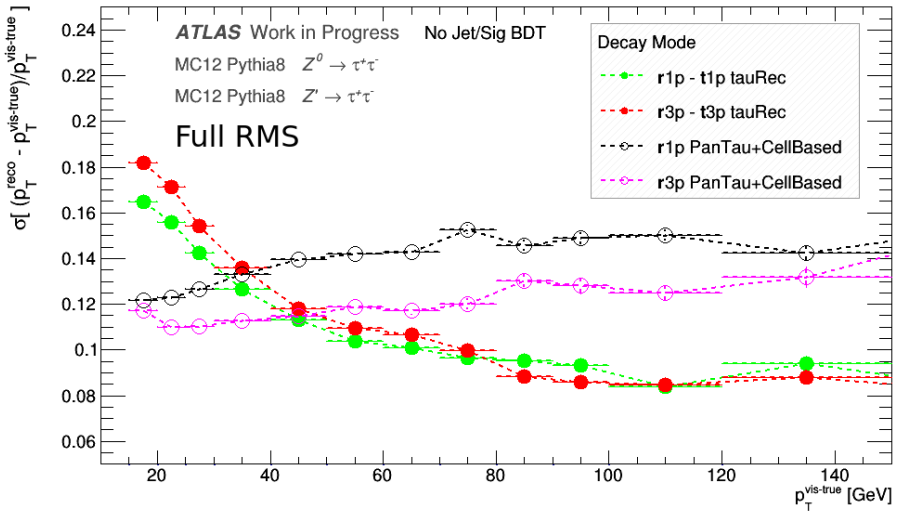
Validation in events with fake taus

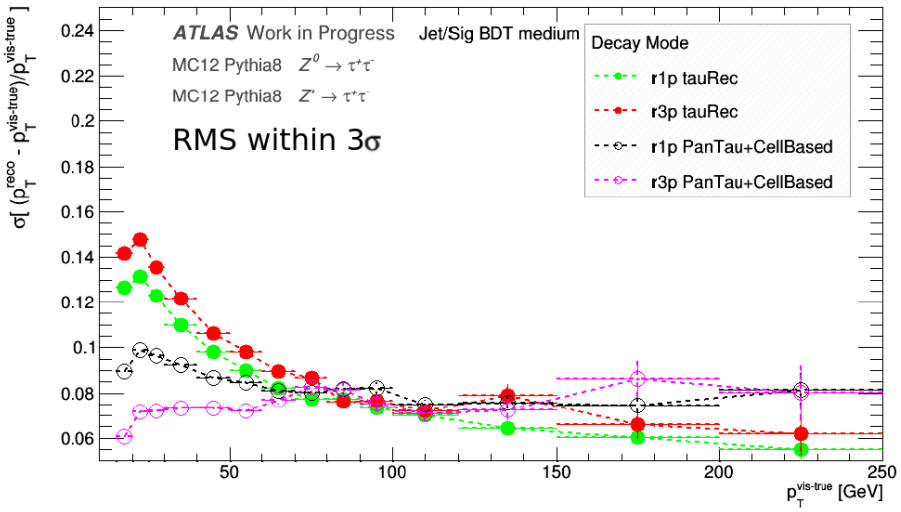


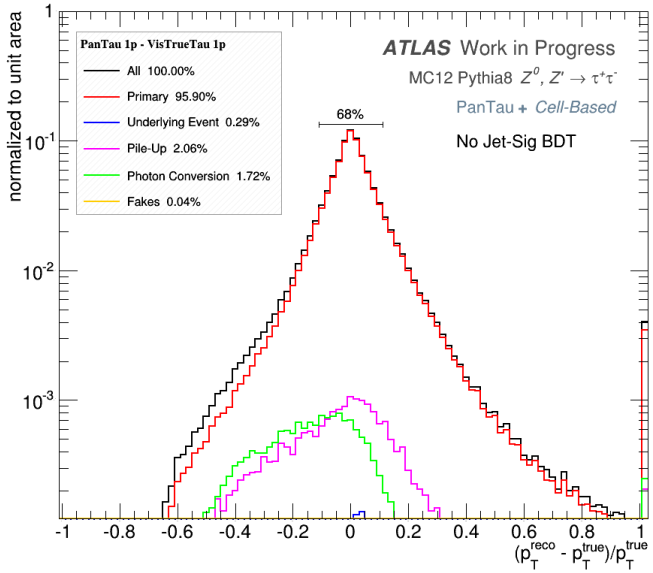


- First validation on fake taus in Zmumu+jets events
- Zmumu selection. Recoil jets with 1 or 3 tracks are studied as fake tau candidates
- Look at 5 bins in $|\eta|$ and p_T (plots shown are inclusive) and rescale total MC to match data in each 2D bin.
- Very good agreement in MVA spectra and final classification. Reasonably good but not perfect agreement in the input variables

Comparison of energy resolution with current method

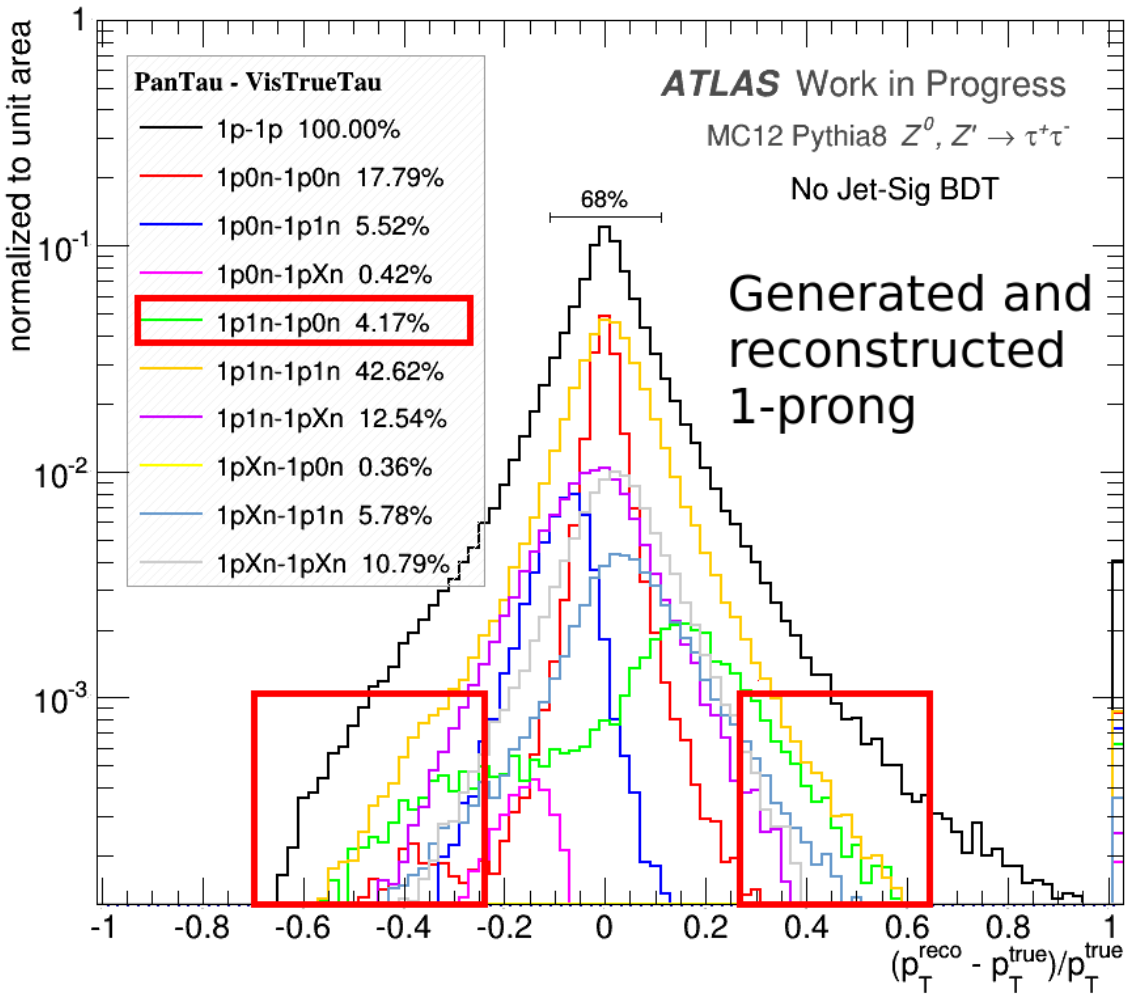






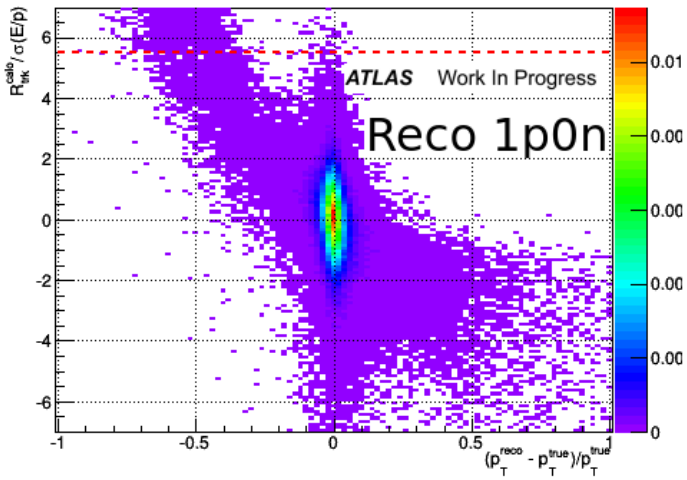
- Large improvement below $30 - 40\,\mathrm{GeV}$ (full RMS) or $70\,\mathrm{GeV}$ (3σ RMS)
- RMS is strongly sensitive to tails
- Some influence from non-matched tracks in low energy tail

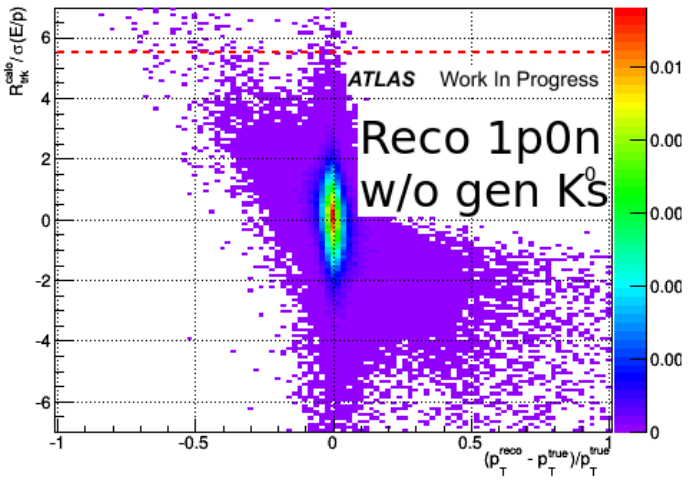
Influence of missing a π^0 or having a fake



- Strong contribution from generated 1p0n taus, which are reconstructed as 1p1n
- Call generated $\tau^\pm \to \pi^\pm K^0 \nu_\tau$ decays 1p0n in this plot

Improvement exploiting calorimeter only measurement





- $R_{\text{trk}}^{\text{calo}} = \frac{E_{\text{calo}}}{E_{\text{track}}}$, $\sigma(E/p)$ is the 1σ error on the difference
- Plots show fraction of $R_{\text{trk}}^{\text{calo}}$ and $\sigma(E/p)$ for all reconstructed 1p0n taus (left) and those without K^0s (right)
- Can effectively reduce tails by making a loose requirement on the consistency with calorimeter only measurement
- Can in particular reduce strong influence of K^0s in low energy tail
- Work on consistency requirement for modes other than reco 1p0n (determine $\sigma(E_{\text{calo}}/E_{\text{substructure}})$)
- Plan to combine calorimeter only measurement and substructure based measurement to new default estimate of tau 4-momentum early in run 2

Summary

- ATLAS tau reconstruction for run 2 attempts to reconstruct all visible decay products
- Validation on run 1 data is well in progress. Agreement is reasonably good already
- Plan to reconstruct visible tau 4-momentum from 4-momenta of decay products
- Direkt applications in physics measurements
  - Measurement of longitudinal polarization or Higgs vs. Z separation
  - Measurement of transverse polarization e.g. for Higgs CP studies