Tau Seed and Hadronic Tau Substructure in ATLAS

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Outline

- Tau seed study
  - Topological cluster jet seeds & EM Particle-flow jet seeds
  - Reconstruction efficiency
  - Estimate on p_T & η resolution, decay mode classification efficiency

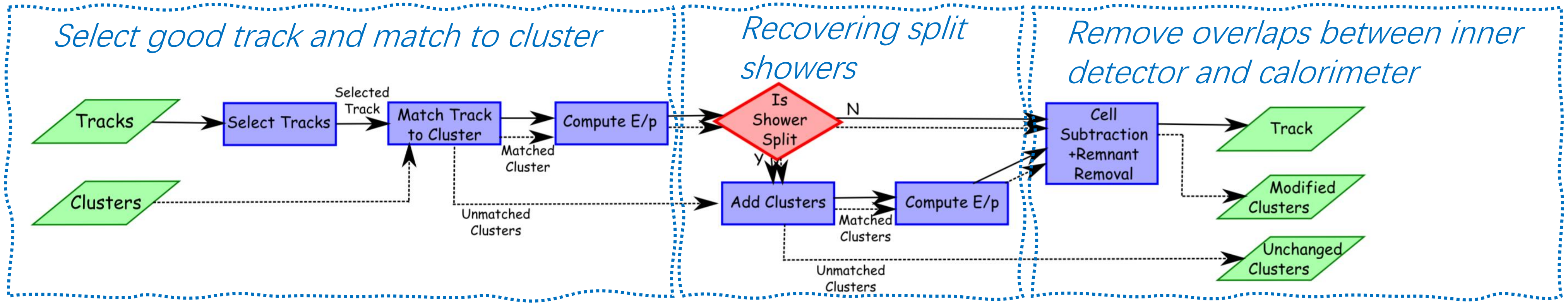
- Hadronic Tau Substructure
  - tau substructure reconstruction efficiency
  - Precision TES/TER measurement

Tau Seed Study

Introduction

- Tau Reconsturction:
  - jet → jet seeding → vertex & track → tau candidates

- jet seeds
  - Topo-clusters: Topological clusters of calorimeter cells
  - Particle-flow: calorimeters clusters + inner detector tracking information



  - CERN-EP-2017-024 : (PFlow jet) Better energy, angular resolution in the central region and Robust against pile-up

- Improve the resolution. Especially the low-pT tau performance $p_T < 20$ GeV.

$$\frac{\sigma(E)}{E} = \frac{50\,\%}{\sqrt{E}} \oplus 3.4\,\% \oplus \frac{1\,\%}{E}$$

calorimeters

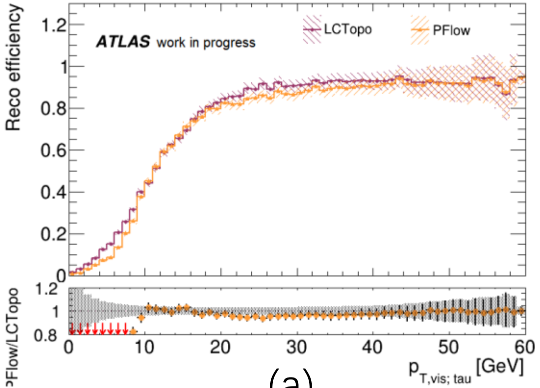
$$\sigma\left(\frac{1}{p_{\mathrm{T}}}\right) \cdot p_{\mathrm{T}} = 0.036\,\% \cdot p_{\mathrm{T}} \oplus 1.3\,\%$$

tracker

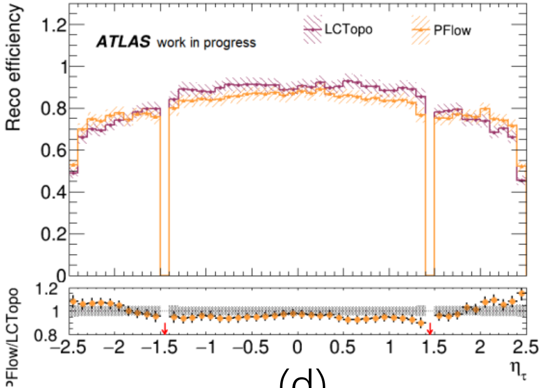
- ILC, CMS …

Results

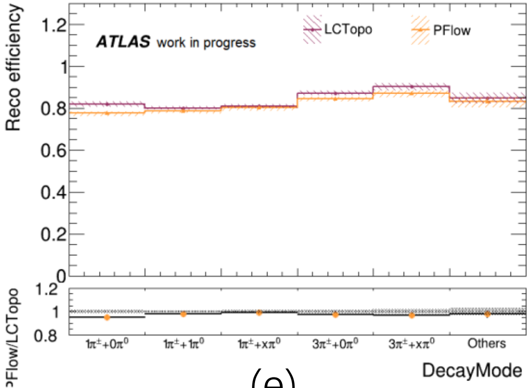
- $\epsilon_{reco} = \frac{N_{Taujets\ matched\ Truth}}{N_{Truth\ Tau}}$



(a)

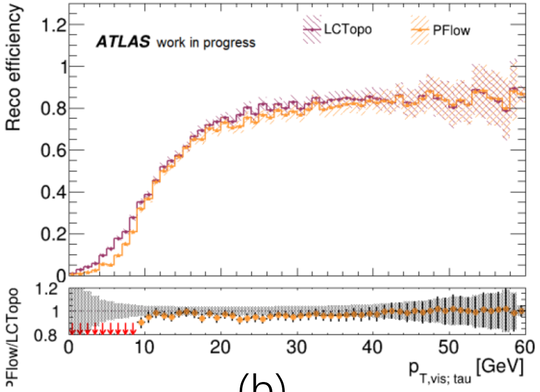


(d)

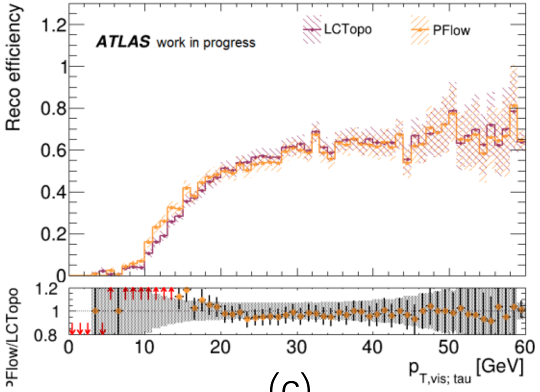


(e)

- 1 track matched to 1 prong & 3 track matched to 3 prong



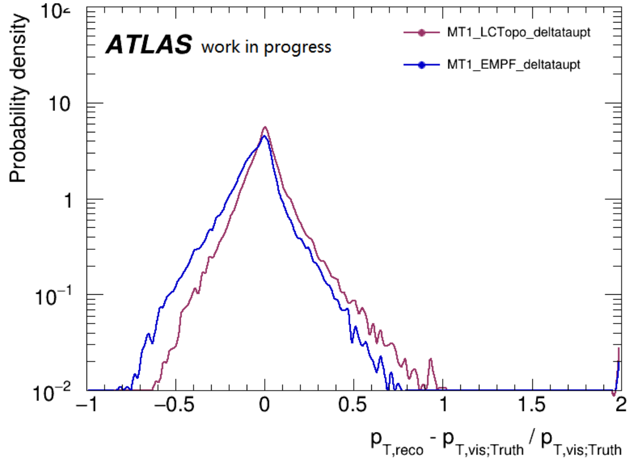
(b)

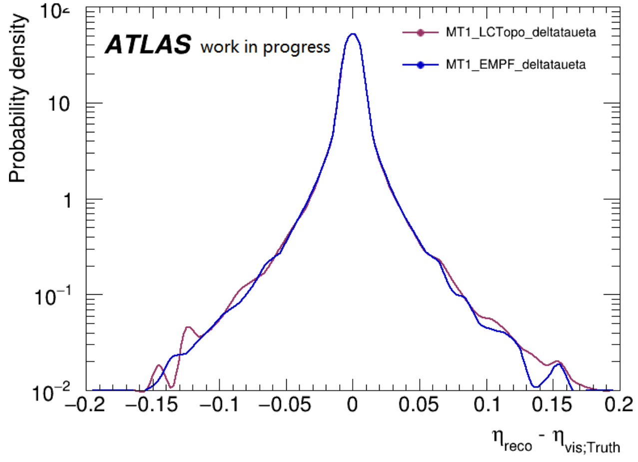


(c)

- Different performance in $p_{T\,vis} \in (10,20)\ GeV$ and $p_{T\,vis} \in (20,40)\ GeV$
- Within the expectation:
  - EMPFlow is better at low pT region
- Without the expectation:
  - EMPFlow is quiet worse at higher pT region

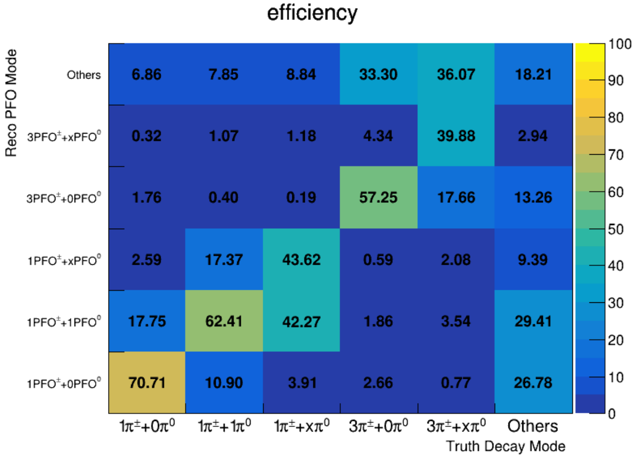
Resulation & Decay classification matrix



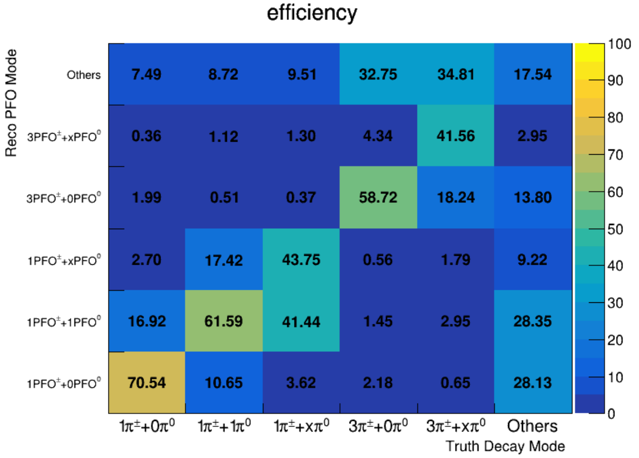


- gross estimation:
  - $\frac{p_{T_{reco}} - p_{T_{vis;Truth}}}{p_{T_{vis;Truth}}}$: $p_{T_{reco}}$ is taujet's p_T
  - $\eta_{reco} - \eta_{vis;Truth}$: η_{reco} is taujet's η

- A shift in p_T with nearly the same width.
- Nearly same in eta.



- LCTopo



- EMPFlow

- Estimation
  - Xaxis: Truth tau decay mode
  - Yaxis: Charged PFOs and π^0 PFOs from jet*
  - Not normalized because 2/4/more… charged pion
- EMPF in 3 p is slightly better

Conclusion

- By full reconstruction samples:
  - Particle Flow seeds perform well in the end-cap regions, 3-prong situations, and high neutral pion energy fraction. The inefficiency in pT [20,40]GeV and it is non-negligible
  - Estimations on Topo-clusters and Particle-flow seeds show they are similar in pT and eta resolution as well as decay mode classification.

- More to do…
  - More inefficiency check:
    - Seed pT influence on PFlow jet efficiency => reach low pT threshold for recover.
    - PFOs => Reco Electron, PFOs will be removed from PFlow jets reco
  - Data/MC comparison for low-pT taus. Modelling
    - $Z \rightarrow \tau_{\mu}\tau_{had}$ tag-and-probe analyses & Other Channels…

Hadronic Tau Substructure

Hadronic Tau Substructure And Precision TES & TER Combined Measurement

- Decay mode identification
  - SubTauID: Hadronic tau decay modes
    - $\tau^- \to \pi^- \nu\ (1p0n)$ $\tau^- \to \pi^- \pi^0 \nu\ (1p1n)$ $\tau^- \to \pi^- \nu + (\geq 2\pi^0)(1pXn)$
    - $\tau^- \to \pi^- \pi^+ \pi^- \nu (3p0n)$ $\tau^- \to \pi^- \pi^+ \pi^- \nu + (\geq 1\pi^0)(3pXn)$
  - Previous classification strategy (R21) Small mismodelling → Further scale factors

- Precision TES & TER measurement
  - Previous: in-situ method, "global"
  - More precise:
    - Different pT region, Different Decay modes, Different Tau ID
  - Get the different resolutions for EM particles and hadronic particles: α_{EM} and α_{Had}

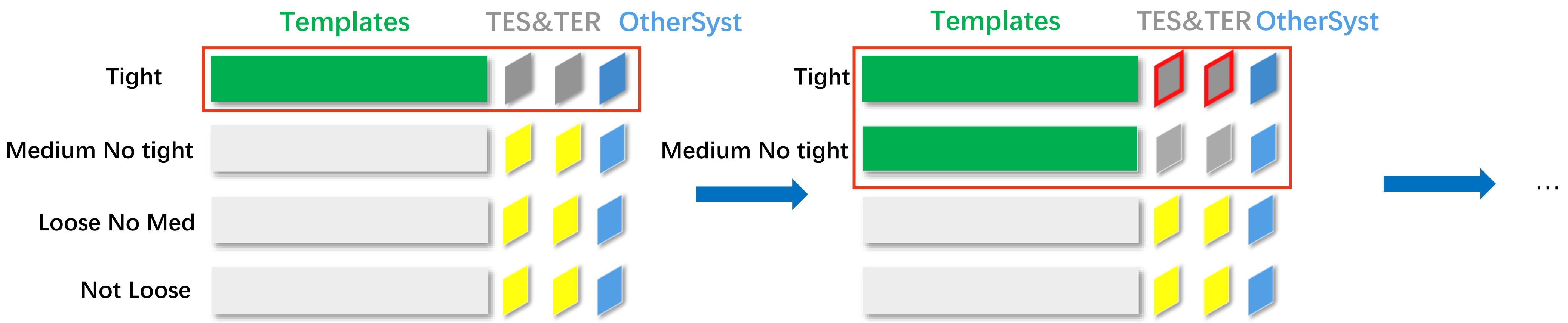
- Combine issue:
  - Decay mode SFs are measured inclusively, but TES are measured in each fit bin.
  - Decay mode SFs are precise to 3 kinds of efficiency fits for each fit bin. While in precision TES measurement are measured in 1 fit
    - $N_{ID}^{Tx-Ry} = N^{Ry} \times \frac{N_{ID}^{Ry}}{N^{Ry}} \times \frac{N_{ID}^{Tx-Ry}}{N_{ID}^{Ry}} = N^{Ry} \times \epsilon_{ID}^{Ry} \times \epsilon_{ID}^{Tx-Ry}$: Reconstruct-, ID-, classification- efficiencies

Strategy

- Measured reco, ID, classification efficiencies By one likelihood fit

$$SF_{Reco} = N^{Ry,Data}/N^{Ry,MC}, \quad SF_{ID}^{Ry} = \epsilon_{ID}^{Ry,Data}/\epsilon_{ID}^{Ry,MC}, \quad SF_{ID}^{Tx-Ry} = \epsilon_{ID}^{Tx-Ry,Data}/\epsilon_{ID}^{Tx-Ry.MC}$$

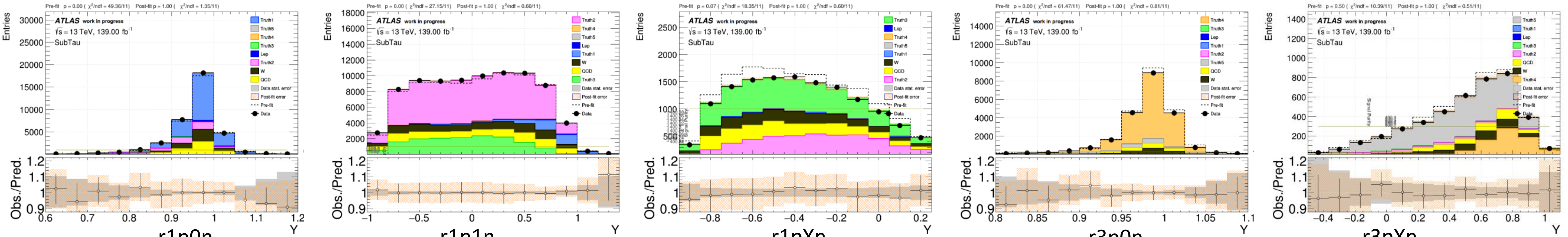
- TES & TER are used as nuisance parameter →get by pull plots
- The fit is binned with Pt, Prongs and tauID. Included all of the systematics.
- A set of recursive fits to get both inclusively ID and binned systematic:



- Until we get the Pre & Post fit ϵ_{ID}^{Tx-Ry} & TES & TER in eachworking point and tauPt bins

Post-fit Result of tight

- The fit result for tight working point tauPt [20,30]
  - High fit quality and fine agreement between the data & post fit template!



r1p0n r1p1n r1pXn r3p0n r3pXn

- Pulls: tight working point tauPt tauPt [20,30] 1 Prong :

TES_EM(%)	TES_Had(%)	TER_EM(%)	TER_Had(%)
$-8.47^{6.97}_{-6.97}\ ^{2.35}_{-2.35}$	$-0.36^{4.36}_{-3.09}\ ^{3.04}_{-3.04}$	$10.34^{6.95}_{-7.72}\ ^{0.64}_{-0.64}$	$-3.54^{5.81}_{-6.23}\ ^{0.39}_{-0.39}$

- The fit will continue for medium working point, Loose …

Results & Outlook

tauPt [20, 30]

tauPt [30, inf]

- The Scale factor: $SF_{ID}^{Tx-Ry} = \frac{\epsilon_{ID;post}^{Tx-Ry}}{\epsilon_{ID;pre}^{Tx-Ry}}$
  - tight working point
  - medium working point
  - loose working point

  - Most of the efficiency are close to 1. Except for SF^{T1-R1} because mis-modling in $1\mathrm{P}x\mathrm{N}$
  - Small errors for most of recons, especially for 3P
  - Medium and Loose WPs have Similar results as tight.

- Future…
  - Check tau pT binning influence on TES fit results. To see if it could reduce TES error.
  - Summarize current results. And use current result for precision TES.

Thanks!

Backups

Samples and pre-selection

- Reconstruction efficiency
  - $\epsilon_{reco} = \frac{N_{Taujets\ matched\ Truth}}{N_{Truth\ Tau}}$

- Samples R22 Ztautau (MC only):
  - Particle-flow seed jets: valid1.361108.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Ztautau.recon.AOD.e5112_s3227_r11986
  - LCTopo seed jets: valid1.361108.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Ztautau.recon.AOD.e5112_s3227_r11978

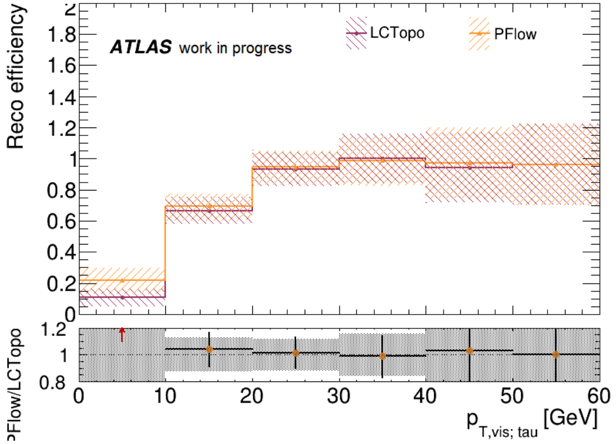
- Pre-selection:
  -

Truth Tau	Reco Tau (Taujet)
Hadronic decaying	Good Track>=1
$p_{T_{vis}} > 10\ GeV$	
$0 < \lvert\eta\rvert < 1.37 \cup 1.52 < \lvert\eta\rvert < 2.5$	
tau-jet matching by $\Delta R < 0.2$	

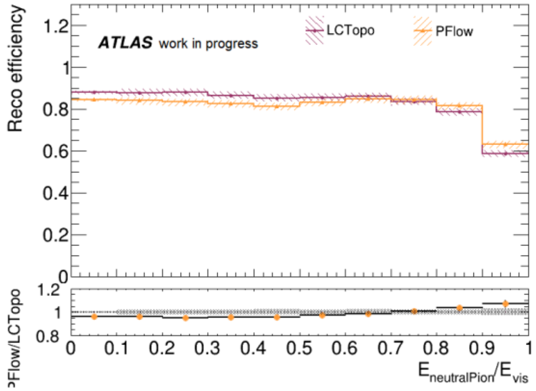
- CMS: performance , algorithm

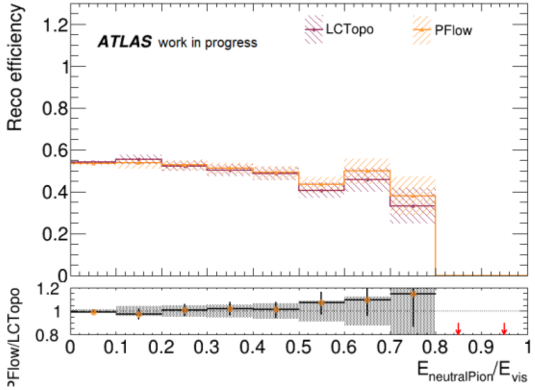
Results

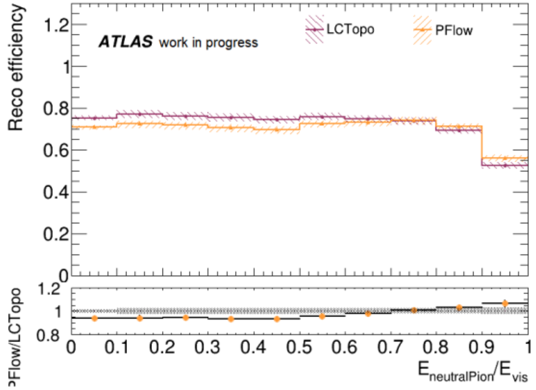
- Reco Electron check
  - $\epsilon_{Ele} = N_{TruthTau\ Matched\ to\ RecoJet+\ RecoEle} / N_{TruthTau\ Matched\ to\ RecoEle}$



- PFLow is better in higher neutral fraction part.

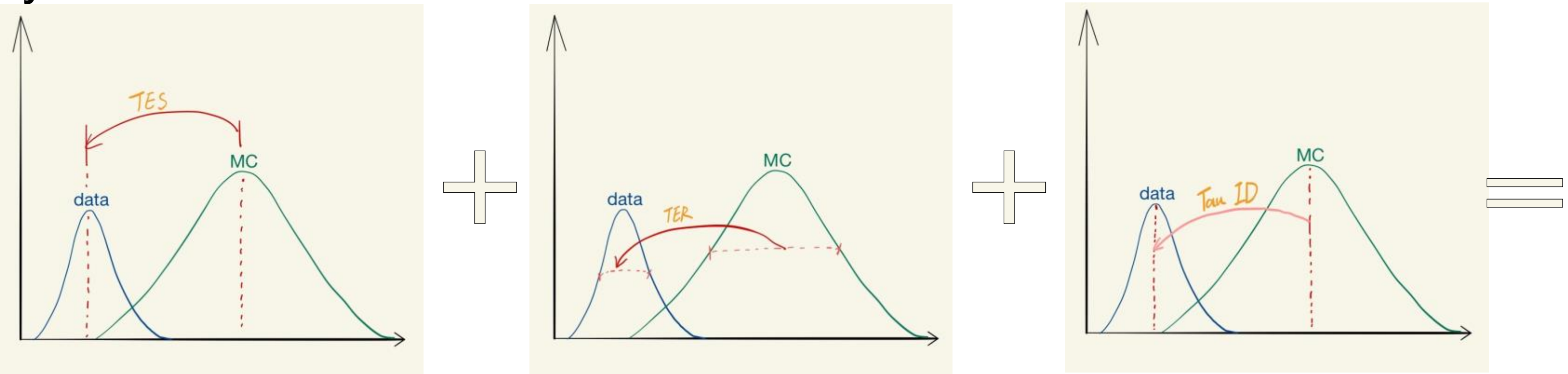






Why combine?

- They have relations with each other…



Agreement!

- All sensitive to the "upsilon variable": $\frac{|\,p_{T,charge} - p_{T,neutral}\,|}{|p_{T\tau}|}$

- $(\sum_{x\in Fixed}^{Tx} N_{MC}^{Tx-Ry} + \sum_{x\in Fit}^{Tx} a_{Tx}\, N_{MC}^{Tx-Ry}) \rightarrow N_{Data}^{Ry}$

Sample & pre-selection

- Samples
  - Data: full Run2-data ($139\ fb^{-1}$)
  - MC samples: $Z \rightarrow \tau\tau$, $Z \rightarrow ll$, Top($t\bar{t}$, single top),$\mathrm{W} \rightarrow l\nu$ and $\mathrm{W} \rightarrow \tau\nu$
  - Samples produced by xTauFramework R21 V10. MVA_TES and RNN tau ID

- Event Selection
  - Target: Select a $Z \rightarrow \tau\tau$ events enriched region. Lep-Had channel

- Base selection
  - $\geq 1PV$, exactly 1 muon, no electrons, no b-tagged jets
  - pass trigger HLT_mu26_ivarmedium or HLT_mu50

- Muon selection
  - offline p_T trigger dependent
  - $|\eta| < 2.5$
  - Medium ID

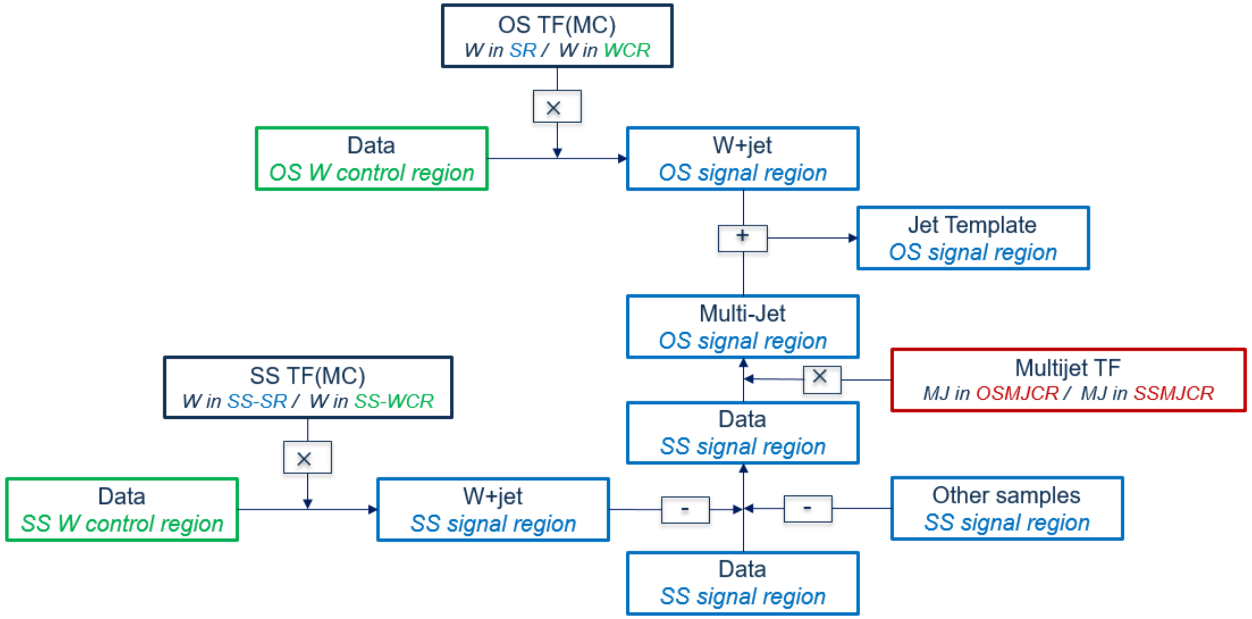
- Tau selection
  - $p_T > 20GeV$, leading tau candidate
  - 1 or 3 tracks, $|q| = 1$
  - Opposite sign (OS) to muon
  - $|\eta_\tau| < 2.47$, excluding $1.37 < |\eta_\tau| < 1.52$
  - $transBDT > 0.005$

Note:

- M_{vis} :The visible mass of the combination of the tau and muon
- transBDT: Jet transverse BDT score. It in applied inside V10

Region definition

- Template construction
  - Tau truth template: $Z \rightarrow \tau\tau$, Top events, where the tau is matched to a truth hadronic tau
  - Lepton template: $Z \rightarrow \tau\tau$, $Z \rightarrow ll$, Top events, where the tau candidate is matched to a truth electron or muon
  - Fake template: W+jets and Multijets. Data driven



The data driven method for fake estimation

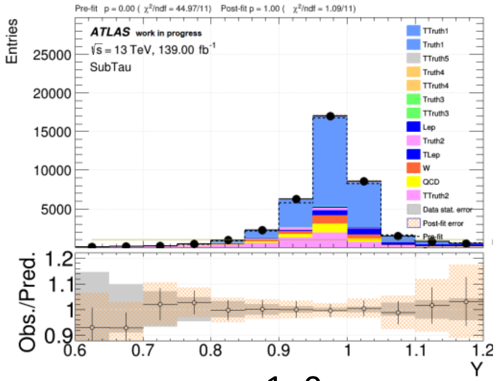
- Region Definitions

- Signal region
  - $M_T^{\mu} < 50GeV$
  - $48 < M_{vis} < 90GeV$
  - $SumCos > 0.15$
  - $|\delta\Phi_{\tau\mu}| > 2.4$
  - muon_FCTightTrackOnly_FixedRad
- W+jets control region
  - $E_T^{miss} > 20GeV$
  - $48 < M_{vis} < 90GeV$
  - $M_T^{\mu} > 60GeV$
  - $SumCos < 0$
  - muon_FCTightTrackOnly_FixedRad
- Multi-jets control region
  - invert isolation
  - $M_T^{\mu} < 50GeV$
  - $48 < M_{vis} < 90GeV$
  - $SumCos > 0.15$
  - $|\delta\Phi_{\tau\mu}| > 2.4$

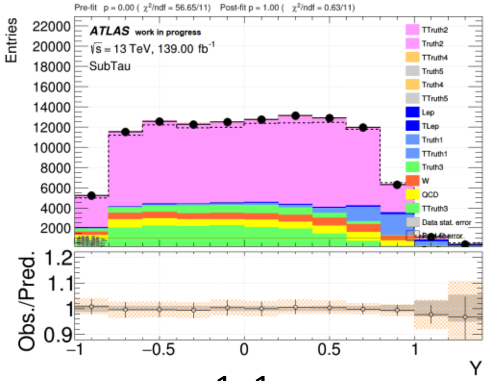
$SumCos = cos(\Delta\phi(e, E_T^{miss})) + cos(\Delta\phi(\mu, E_T^{miss}))$

Results

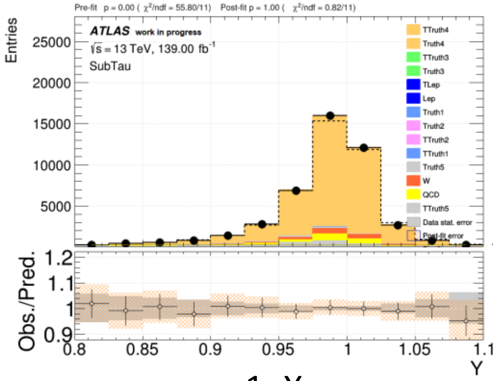
- The fit result for medium working point tauPt [30,inf]
  - High fit quality and fine agreement between the data & post fit template!



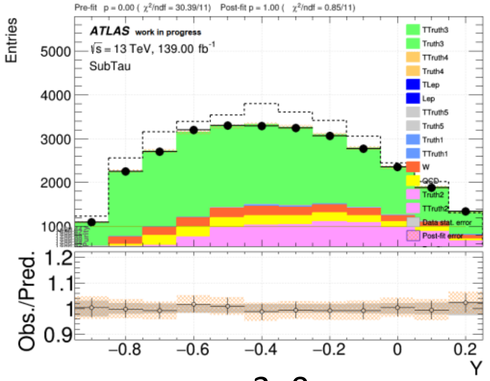
r1p0n



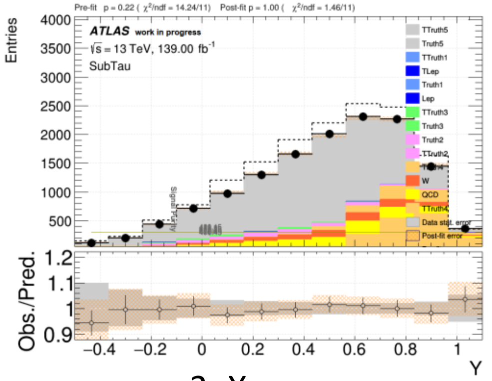
r1p1n



r1pXn



r3p0n



r3pXn

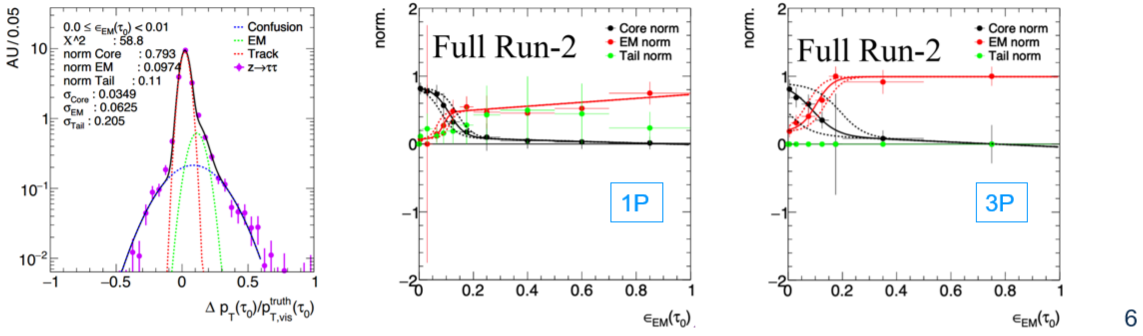
- Pulls: medium working point tauPt tauPt [30,inf] 1 Prong
  - ± 1 sigma of the fermi transition + largest shift on the fermi transition uncertainty

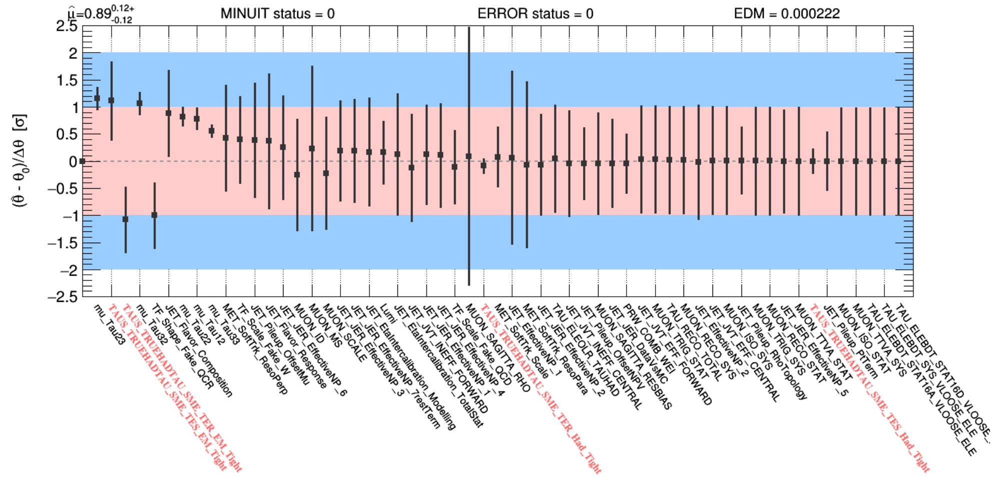
TES_EM(%)	TES_Had(%)	TER_EM(%)	TER_Had(%)
$4.18^{9.14}_{-9.14}\ ^{1.68}_{-1.68}$	$10.49^{8.93}_{-8.93}\ ^{4.85}_{-4.85}$	$7.82^{8.33}_{-8.33}\ ^{5.83}_{-5.83}$	$5.50^{9.15}_{-9.15}\ ^{0.99}_{-0.99}$

TES parametrization

Done By Gang Zhang

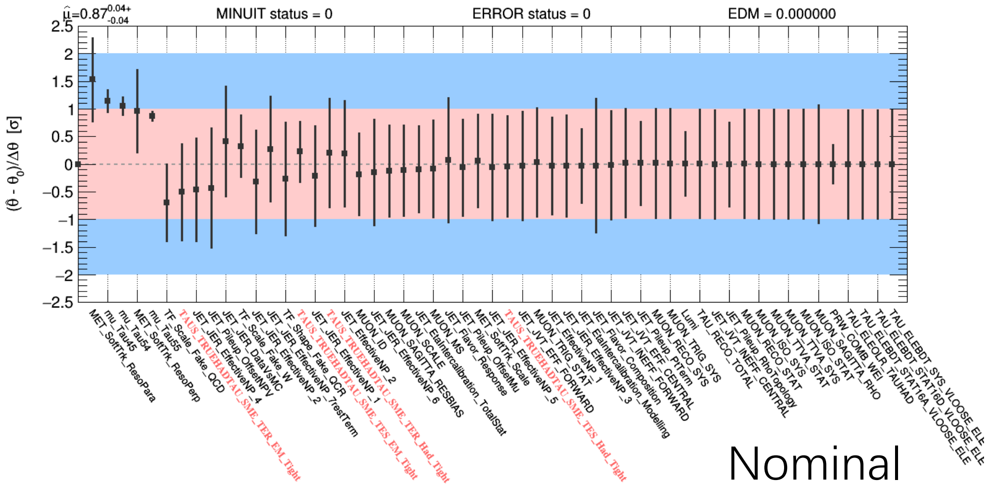
- Fitted by a combination of liner function and a fermi transition
- The uncertainty of this fit is also considered by $\pm$ 1 sigma of the fermi transition
- When doing the fit, two additional fit with this function up/dw will also do. The final TES uncertainty will add an additional uncertainty about the largest shift on the fermi transition uncertainty



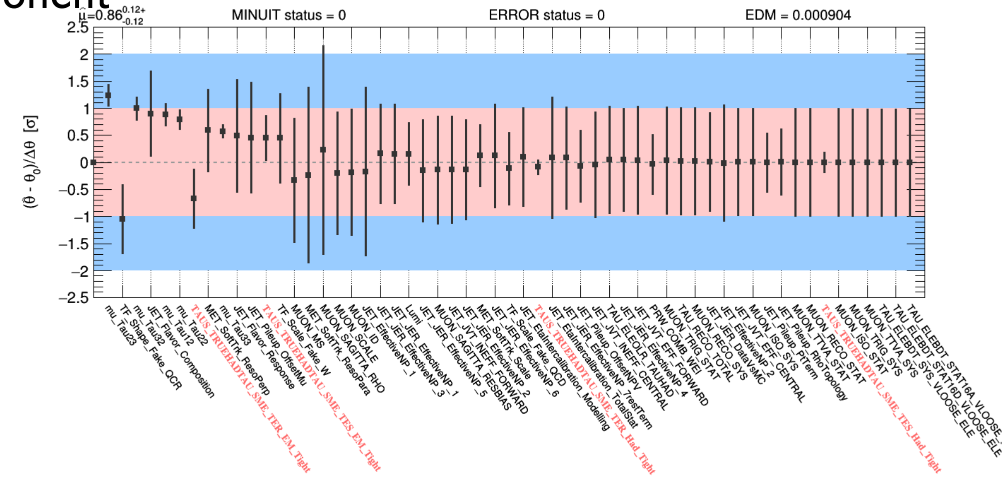


FermiUp

- Different resolutions for EM particles or hadronic like particle: α_{EM} , α_{Had}
- Make a shift on p_T and get the shifted p_T of each EM/Had TES and TER component



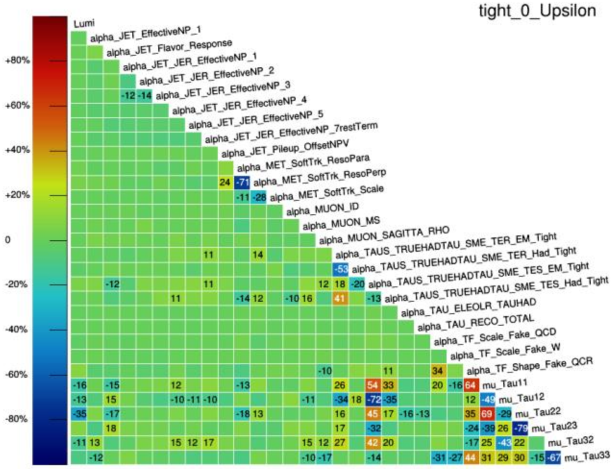
Nominal

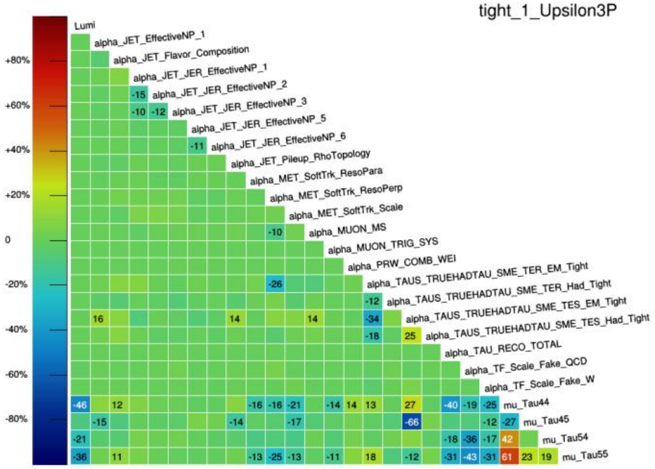


FermiDw

Results

- Systematic tight working point tauPt [20,30] 1Prong





- Pre & Post fit ϵ_{ID}^{Tx-Ry} tight working point tauPt [20,30]