Optimisation of the Hadronic Tau Identification Based on Classification of Tau Decay Modes with the ATLAS Detector

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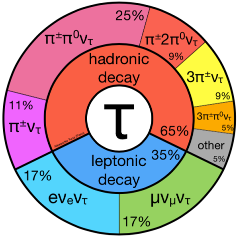
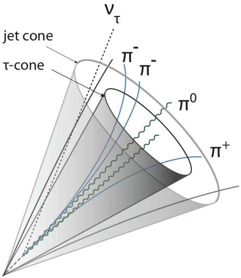
The Tau Lepton

- $c\tau = 87\,\mu\mathrm{m}$
- $m_\tau \sim 1.77\,\mathrm{GeV}$

- decays leptonically...
  $\rightarrow$ difficult to distinguish from prompt electrons and muons

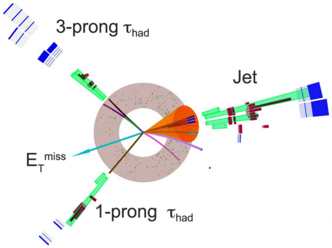


- decays hadronically...
  $\rightarrow$ mainly charged and neutral pions
  $\rightarrow$ pion with highest p_T reproduces τ direction
  $\rightarrow$ mostly 1 and 3 prong
  $\rightarrow$ highly collimated



- physics with taus
  $Z \rightarrow \tau\tau$ cross section, performance and ID measurements
  $H \rightarrow \tau\tau$ studies of leptonic coupling, CP studies
  BSM Higgs tau final states preferred in many models
  heavy resonances $Z' \rightarrow \tau\tau$ might have stronger coupling

Tau Reconstruction & Decay Substructure



`CellBased` algorithm

- subtracts energy deposits of $\pi^{\pm}$ in calorimeter cells
- uses average hadronic shower shapes
- searches for π^0 candidates

`EflowRec` algorithm

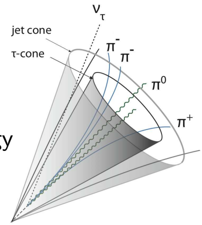
- orders cells in rings according decreasing energy density
- substracts energy deposits of $\pi^{\pm}$ from rings
- estimates π^0energy for each eflow object

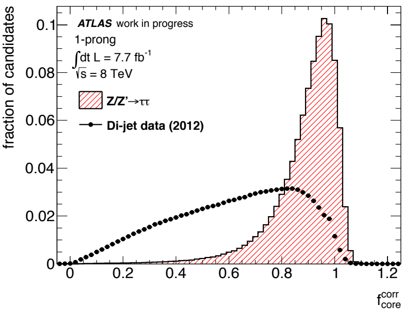
+ `PanTau` algorithm

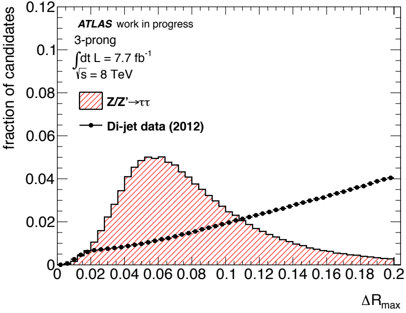
- exploit kinematic properties of tau decay products
- improve decay mode classification

Default Tau ID

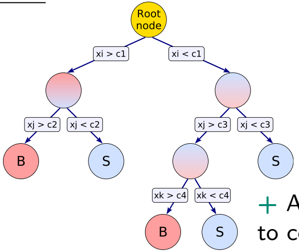
- reconstruction cannot sufficiently differentiate τs and jets
- define set of identification variables exploiting τ decay topology
- use multivariate analysis techniques to combine them



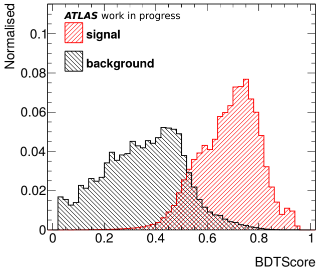




BDT



+ AdaBoost algorithm to combine decision trees based on false decision



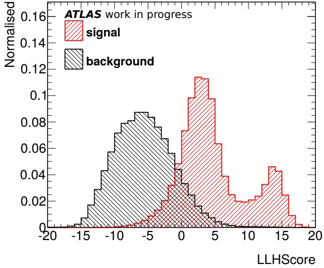
LLH

Likelihood value

$$L_{S\ B} = \prod_{i=1}^{N} p_i^{S\ B}(x_i)$$

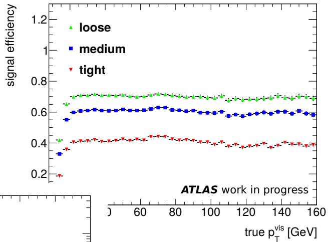
Likelihood score

$$S_{LLH} = \ln\left(\frac{L_S}{L_B}\right) = \sum_{i=1}^{N} \ln\left(\frac{p_i^S x_i}{p_i^B x_i}\right)$$



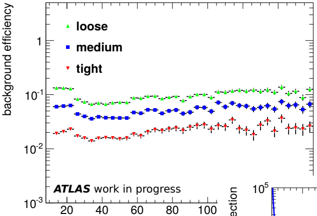
- signal efficiency

$$\varepsilon_{\text{sig}}^{1\ \text{multi prong}} = \frac{\#\ \tau_{\text{pass matched}}^{1\ \text{multi prong}}}{\#\tau_{\text{generated}}^{1\ 3\ \text{prong}}}$$



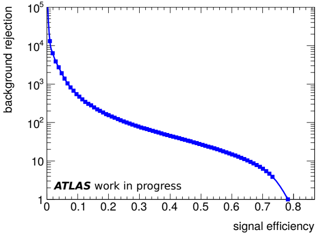
- background efficiency

$$\varepsilon_{\text{bkg}}^{1\ \text{multi prong}} = \frac{\#\tau_{\text{pass}}^{1\ \text{multi prong}}}{\#\tau_{\text{reco}}^{1\ \text{multi prong}}}$$



- roc

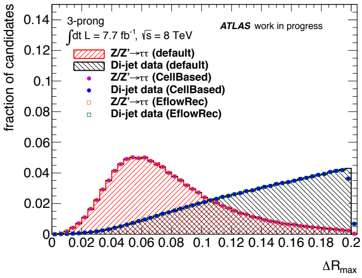
$$r_{\text{bkg}}^{1\ \text{multi prong}} = f(\varepsilon_{\text{sig}}^{1\ \text{multi prong}})$$

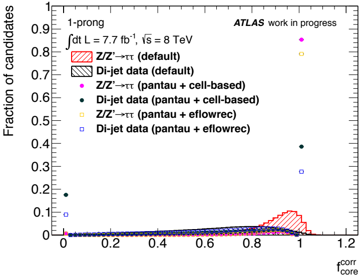


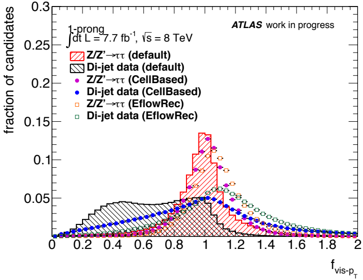
- replace default variables with substructure equivalents

  → some substructure variables are similar to corresponding default variables

  → some show differences due to coarser granularity → performance loss and decay mode migration





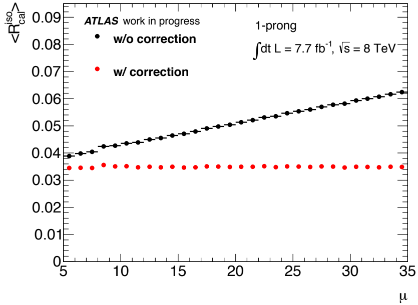


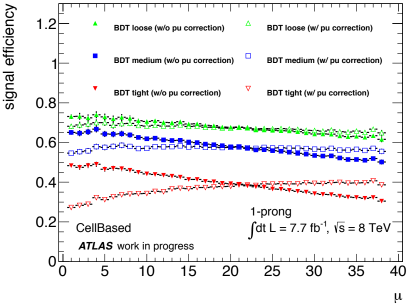
Substructure Tau ID – Equivalents & Calorimeter Radius

- other powerful variables which don't suffer from coarser granularity

$$R_{\text{cal}}^{\text{core isolation}} = \frac{\sum_i^{\Delta R<0.2\ \ 0.4} p_{\text{T},i} \cdot \Delta R_i}{\sum_i^{\Delta R_i<0.2\ \ 0.4} p_{\text{T},i}}$$

- increased pile-up dependence by considering $R_{\text{cal}}^{\text{iso}}$
  - $\rightarrow$ linear fit on μ profile for each variable
  - $\rightarrow$ applied as a μ dependent correction

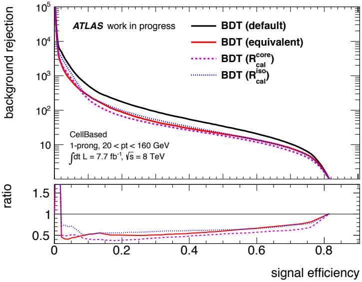


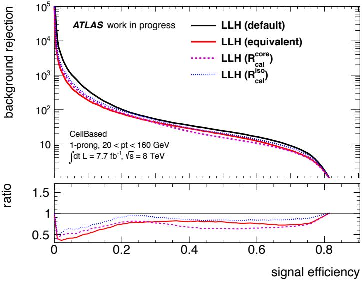


μ = average number of interactions per bunch crossing

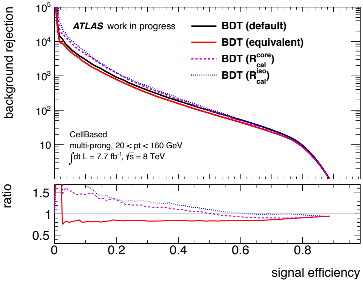
Substructure Tau ID – Equivalents & Calorimeter Radius

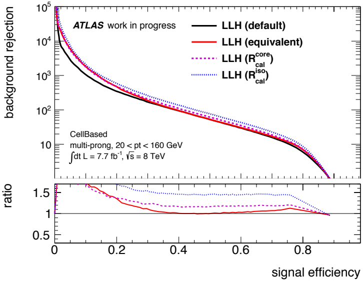
1-prong





multi-prong

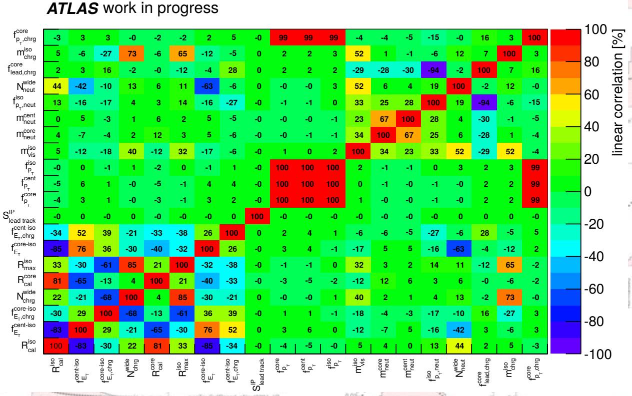




Substructure Tau ID – Further Variables

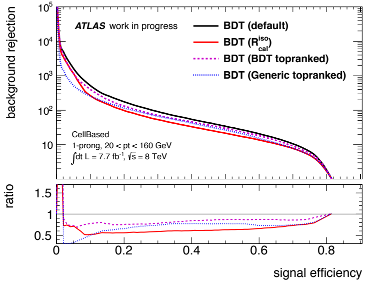
- number of particles, masses, p_{T} ratios, energy fractions, (energy weighted) ΔRs for charged and/or neutral pions
  and for various cone combinations ($\Delta R < 0.1, 0.2, 0.4$)

- TMVA BDT training with filtered set of variabels
  → generic ranking and BDT specific for `CellBased` and `EflowRec`
  + linear correlations for signal

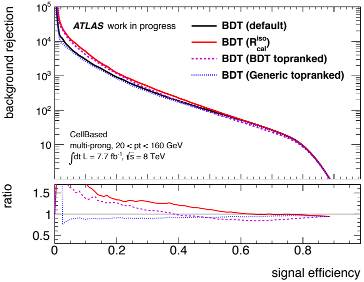


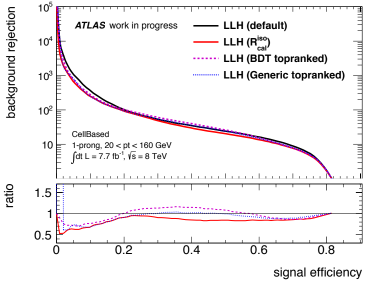
Substructure Tau ID – CellBased Top Variable Sets

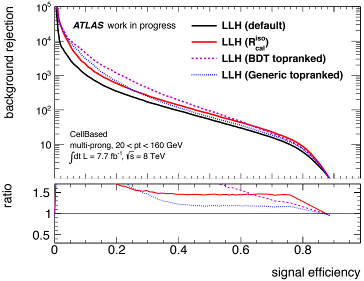
1-prong



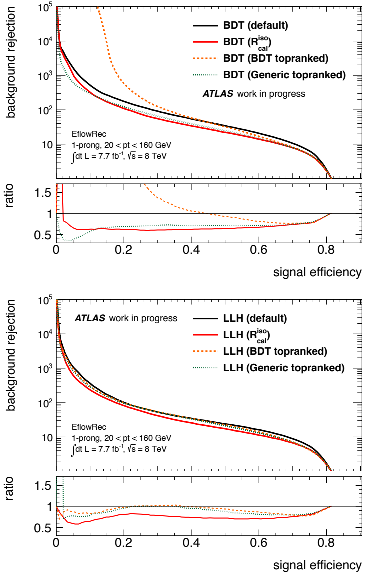
multi-prong



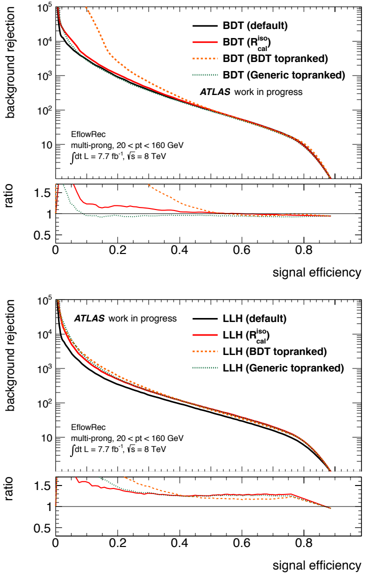




1-prong



multi-prong



Conclusion & Outlook

- investigation of pure substructure tau ID
  - $\rightarrow$ almost reach and partly exceed performance of default variable set
  - $\rightarrow$ apply pile-up corrections
- update Log-Likelihood (p_{T} and μ reweighting, π^0 variables)
- study BDT configuration (optimisation of minimal node size)
- work in progress
  - $\rightarrow$ search for more powerful variable set
  - $\rightarrow$ consider decay modes separately
  - $\rightarrow$ use results to improve default ID
  - $\rightarrow$ test on 14 TeV MC samples

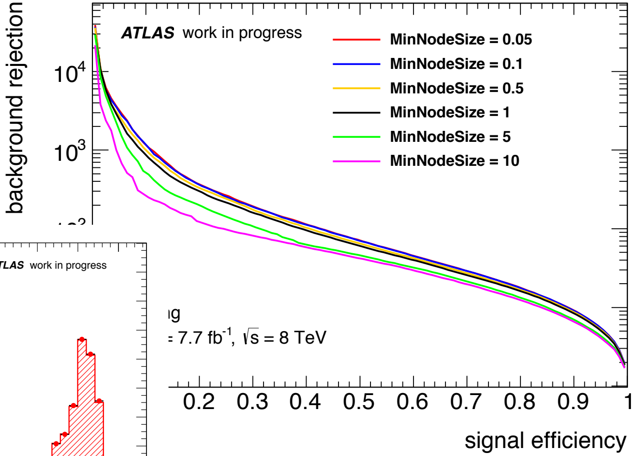
THANKS FOR YOUR ATTENTION.

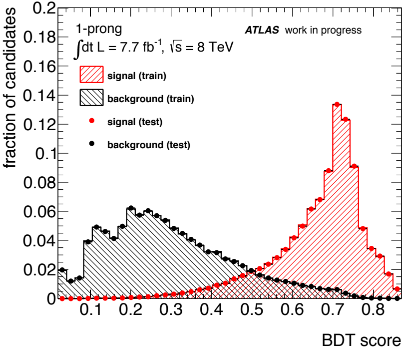
Backup – Tau Decay Substructure

algorithm	reco. category	decay mode				
		1p0n	1p1n	1pXn	3p0n	3pXn
CellBased	correct reco.	87.1	62.9	53.6	84.7	60.7
	correct reco. prongness	98.9	95.8	93.9	93.7	93.2
	too few reco. neutrals	—	15.2	40.8	—	36.9
	too many reco. neutrals	12.1	21.6	—	11.6	—
EflowRec	correct reco.	77.8	56.2	55.8	59.8	72.8
	correct reco. prongness	98.9	95.8	94.0	93.7	92.8
	too few reco. neutrals	—	13.8	38.3	—	30.0
	too many reco. neutrals	21.5	29.8	—	37.8	—
CellBased	correct reco.	85.5	74.9	40.8	89.0	62.0
+PanTau	correct reco. prongness	98.9	86.6	94.0	93.7	93.2
	too few reco. neutrals	—	12.4	53.5	—	36.3
	too many reco. neutrals	13.7	12.5	—	8.0	—
EflowRec	correct reco.	84.2	68.5	38.8	84.0	58.3
+PanTau	correct reco. prongness	99.0	95.8	93.8	93.7	93.1
	too few reco. neutrals	—	15.2	55.3	—	39.1
	too many reco. neutrals	15.1	16.1	—	13.7	—

- optimisation of the minimal number of events per node (`MinNodeSize`)

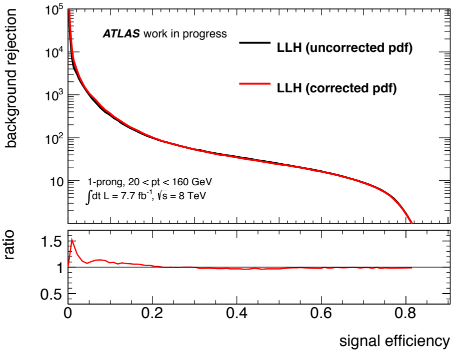
→ best choice: 0.1 %

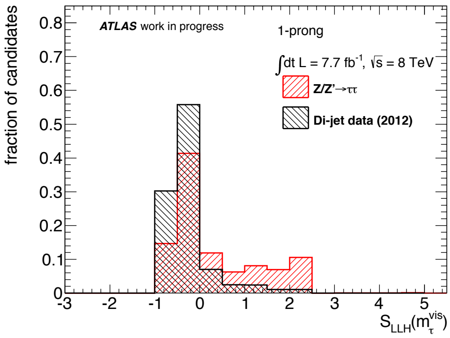




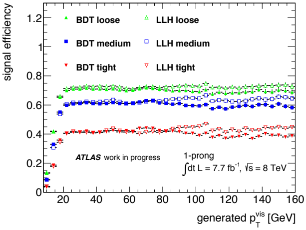
- apply μ and p_T reweighting on signal and background
- consider π^0 variables

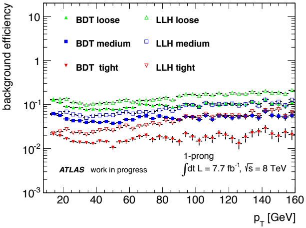
$\rightarrow$ no performance gain

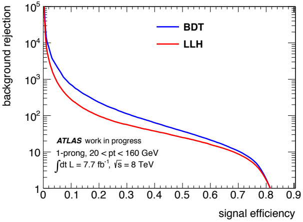


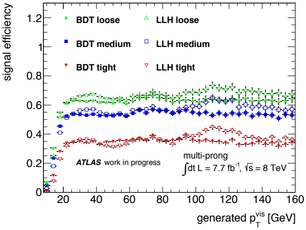


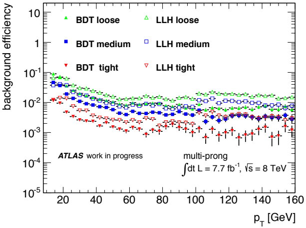
Backup – Performance of Default Tau ID

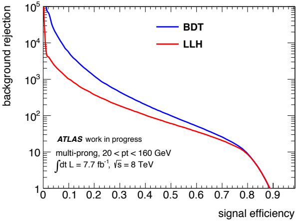




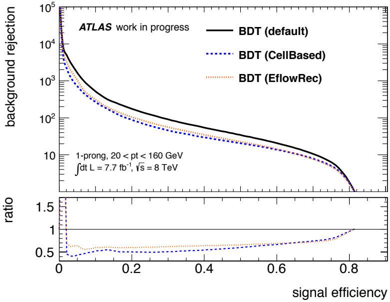


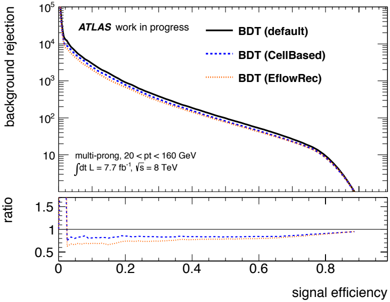


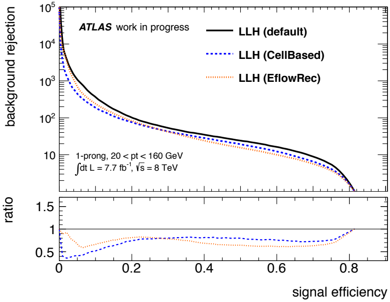


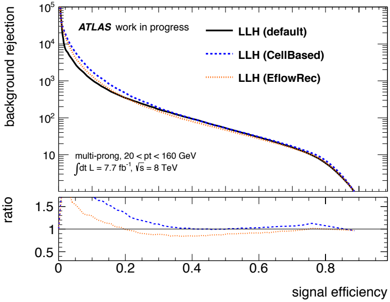


Backup – Tau ID with Substructure Equivalents









$$N^{\text{cent core} \in \text{wide}}_{\text{chrg neut all}} = \sum_{i \in \pi^{\pm}\ \pi^{0}\ \pi^{\pm},\pi^{0}}^{\Delta R < 0.1\ 0.2\ \in [0.2, 0.4]} \pi_i$$

$$m^{\text{cent core iso}}_{\text{chrg neut all}} = \sqrt{\left(\sum_{i \in \pi^{\pm}\ \pi^{0}\ \pi^{\pm},\pi^{0}}^{\Delta R < 0.1\ 0.2\ 0.4} E_i\right)^2 - \left(\sum_{i \in \pi^{\pm}\ \pi^{0}\ \pi^{\pm},\pi^{0}}^{\Delta R < 0.1\ 0.2\ 0.4} \vec{p}_i\right)^2}$$

$$\Delta R^{\text{core iso}}_{\text{max, chrg}} = \Delta R^{\Delta R < 0.2\ 0.4}_{\pi^{\pm}}(\pi, \tau) \rightarrow \text{max}$$

$$\Delta R^{\text{iso}}_{p_{\text{T}}^{\text{minmax}}} = \Delta R^{\Delta R < 0.4}_{\pi^{\pm}}(\pi_{p_{\text{T}}^{\text{min}}}, \pi_{p_{\text{T}}^{\text{max}}})$$

$$f^{\text{cent core iso}}_{p_{\text{T}}, \text{chrg neut all}} = \frac{\sum_{i \in \pi^{\pm}\ \pi^{0}\ \pi^{\pm},\pi^{0}}^{\Delta R < 0.1\ 0.2\ 0.4} p_{\text{T},i}}{p_{\text{T}}^{\tau}}$$

$$R^{\text{core isolation}}_{\text{cal, chrg neut all}} = \frac{\sum_{i \in \pi^{\pm}\ \pi^{0}\ \pi^{\pm},\pi^{0}}^{\Delta R < 0.2\ 0.4} p_{\text{T},i} \cdot \Delta R_i}{\sum_{i \in \pi^{\pm}\ \pi^{0}\ \pi^{\pm},\pi^{0}}^{\Delta R_i < 0.2\ 0.4} p_{\text{T},i}}$$

$$f^{\text{cent-core core-isolation cent-isolation}}_{\text{E, chrg neut all}} = \frac{\sum_{i \in \pi^{\pm}\ \pi^{0}\ \pi^{\pm},\pi^{0}}^{\Delta R < 0.1\ 0.2\ 0.1} E_{\text{T},i}}{\sum_{j \in \pi^{\pm}\ \pi^{0}\ \pi^{\pm},\pi^{0}}^{\Delta R < 0.2\ 0.4\ 0.4} E_{\text{T},j}}$$

$$f^{\text{cent core isolation}}_{\text{lead chrg}} = \frac{p^{\Delta R < 0.1\ 0.2\ 0.4}_{\text{T,lead}\,\pi^{\pm}}}{\sum^{\Delta R < 0.1\ 0.2\ 0.4}_{\text{T,lead}\,\pi^{\pm}} E_{\text{T}}}$$

Substructure Tau ID – Top Variable Sets

generic ranking				BDT specific ranking			
CellBased		EflowRec		CellBased		EflowRec	
1-prong	3-prong	1-prong	3-prong	1-prong	3-prong	1-prong	3-prong
$R^{\mathrm{iso}}_{\mathrm{cal,all}}$	$R^{\mathrm{iso}}_{\mathrm{cal,chrg}}$	$R^{\mathrm{iso}}_{\mathrm{cal,chrg}}$	$R^{\mathrm{iso}}_{\mathrm{cal,chrg}}$	$R^{\mathrm{iso}}_{\mathrm{cal,all}}$	$R^{\mathrm{iso}}_{\mathrm{cal,chrg}}$	$f^{\mathrm{cent-iso}}_{E,\mathrm{chrg}}$	$R^{\mathrm{iso}}_{\mathrm{cal,chrg}}$
$f^{\mathrm{cent-iso}}_{E,\mathrm{chrg}}$	$\Delta R^{\mathrm{iso}}_{\mathrm{max,all}}$	$f^{\mathrm{core-iso}}_{E,\mathrm{all}}$	$\Delta R^{\mathrm{iso}}_{\mathrm{max,all}}$	$N^{\mathrm{wide}}_{\mathrm{chrg}}$	$f^{\mathrm{core-iso}}_{E,\mathrm{chrg}}$	$f^{\mathrm{core-iso}}_{E,\mathrm{chrg}}$	$f^{\mathrm{core-iso}}_{E,\mathrm{chrg}}$
$\Delta R^{\mathrm{iso}}_{\mathrm{max,all}}$	$m^{\mathrm{iso}}_{\mathrm{chrg}}$	$N^{\mathrm{wide}}_{\mathrm{chrg}}$	$f^{\mathrm{core-iso}}_{E,\mathrm{all}}$	$\Delta R^{\mathrm{iso}}_{\mathrm{max,all}}$	$S^{\mathrm{flight}}_{\mathrm{T}}$	$f^{\mathrm{cent-iso}}_{E,\mathrm{all}}$	$S^{\mathrm{flight}}_{\mathrm{T}}$
$f^{\mathrm{cent}}_{p_{\mathrm{T}},\mathrm{all}}$	$m^{\mathrm{cent}}_{\mathrm{chrg}}$	$\Delta R^{\mathrm{iso}}_{p_{\mathrm{T}}^{\mathrm{minmax}}}$	$m^{\mathrm{cent}}_{\mathrm{chrg}}$	$f^{\mathrm{cent-iso}}_{E,\mathrm{chrg}}$	$N^{\mathrm{wide}}_{\mathrm{chrg}}$	$S^{\mathrm{IP}}_{\text{lead track}}$	$f^{\mathrm{core-iso}}_{E,\mathrm{all}}$
$m^{\mathrm{iso}}_{\mathrm{all}}$	$m^{\mathrm{cent}}_{\mathrm{all}}$	$f^{\mathrm{iso}}_{\mathrm{lead,chrg}}$	$m^{\mathrm{iso}}_{\mathrm{all}}$	$S^{\mathrm{IP}}_{\text{lead track}}$	$f^{\mathrm{core}}_{p_{\mathrm{T}},\mathrm{chrg}}$	$f^{\mathrm{core}}_{p_{\mathrm{T}},\mathrm{all}}$	$m^{\mathrm{core}}_{\mathrm{chrg}}$
$f^{\mathrm{iso}}_{\mathrm{lead,chrg}}$	$f^{\mathrm{cent}}_{p_{\mathrm{T}},\mathrm{all}}$	$f^{\mathrm{cent}}_{p_{\mathrm{T}},\mathrm{all}}$	$f^{\mathrm{iso}}_{\mathrm{lead,chrg}}$	$f^{\mathrm{core}}_{p_{\mathrm{T}},\mathrm{all}}$	$f^{\mathrm{iso}}_{p_{\mathrm{T}},\mathrm{neut}}$	$m^{\mathrm{iso}}_{\mathrm{all}}$	$m^{\mathrm{core}}_{\mathrm{all}}$
	$S^{\mathrm{flight}}_{\mathrm{T}}$	$m^{\mathrm{iso}}_{\mathrm{all}}$	$S^{\mathrm{flight}}_{\mathrm{T}}$	$m^{\mathrm{iso}}_{\mathrm{all}}$	$m^{\mathrm{core}}_{\mathrm{all}}$	$f^{\mathrm{iso}}_{\mathrm{lead,chrg}}$	$S^{\mathrm{IP}}_{\text{lead track}}$
	$f^{\mathrm{iso}}_{\mathrm{lead,chrg}}$		$f^{\mathrm{cent}}_{p_{\mathrm{T}},\mathrm{all}}$	$m^{\mathrm{core}}_{\mathrm{neut}}$	$S^{\mathrm{IP}}_{\text{lead track}}$	$m^{\mathrm{cent}}_{\mathrm{neut}}$	$f^{\mathrm{iso}}_{\mathrm{lead,chrg}}$
				$f^{\mathrm{iso}}_{p_{\mathrm{T}},\mathrm{neut}}$		$m^{\mathrm{iso}}_{\mathrm{chrg}}$	$m^{\mathrm{iso}}_{\mathrm{chrg}}$