Advancements in the Hadronic Tau Reconstruction and Identification at CMS

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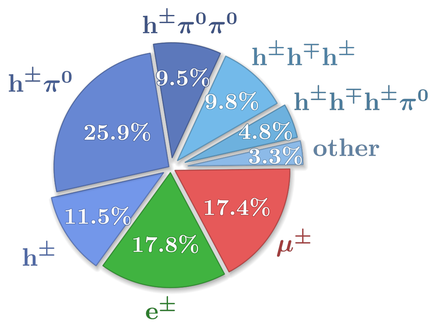
on behalf of the CMS collaboration

Why τ?

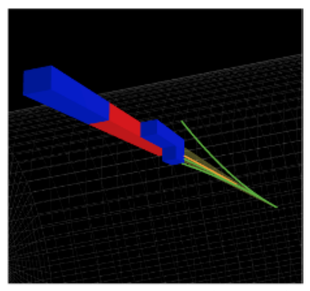
- Excellent probe for Electroweak interactions
- Study CP properties of the Higgs
- Search for additional Higgs bosons, long-lived particles, leptoquarks, etc.



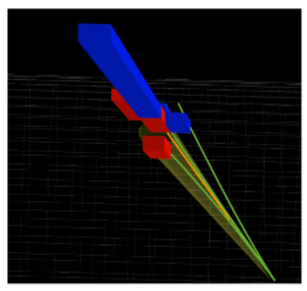
τ decays to hadrons in ~ 65% of the cases

Challenges

Discriminate hadronically decaying $\tau(\tau_h)$ from collimated jets represents the greatest challenge



τ_h decay into $h^{\pm}\, h^{\mp}h^{\pm}\pi^0$



Jet resembling a τ_h

But also light leptons can be misidentified as τ_h:

- **Muons**: mainly affect the decay with only one charged particle ($h^{\pm}$)
- **Electrons**: can emit photons and mimic the $h^{\pm}\pi^0$ decay

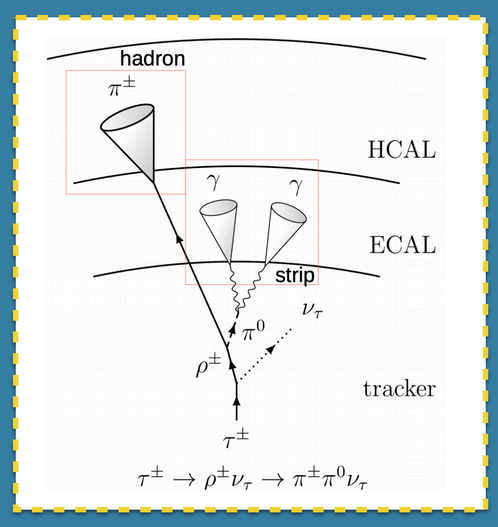
The (new) standard: HPS + DeepTau v2.5

Reconstruction

Hadron-Plus-Strip (HPS) algorithm[1] combines within jet-seeded regions:

- Charged *Hadrons* ($h^{\pm}$) reconstructed by Particle Flow (PF)
- π^0 candidates reconstructed as clusters of photons and $e^{\pm}$, called *Strips*

It reconstructs the τ_h decay products in the main decay modes. Tot. **90% efficiency**

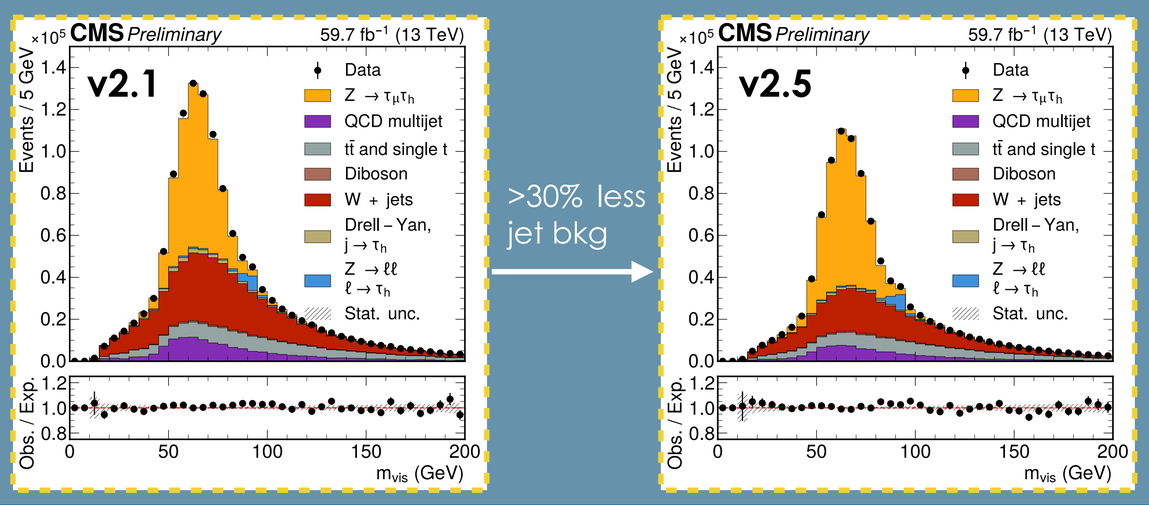


Identification

DeepTau v2.5[2]: Convolutional-Neural-Network-based algorithm improved with respect to its predecessor, v2.1[3]

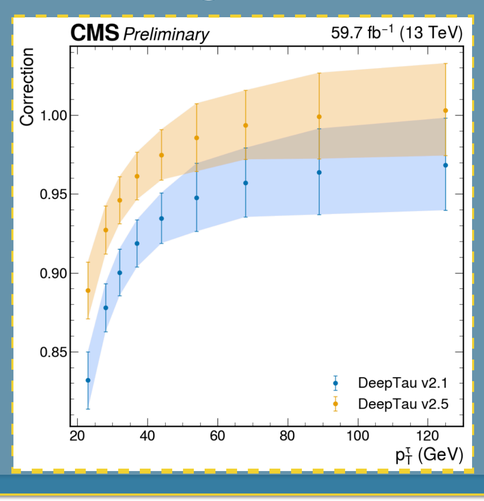
- **Domain adaptation techniques**[4] to mitigate data-simulation disagreement
- **Shuffle and Merge** to balance events across all regions of the phase space
- Improved Feature Standardization and Hyperparameter Optimization

Improvement in classification performance

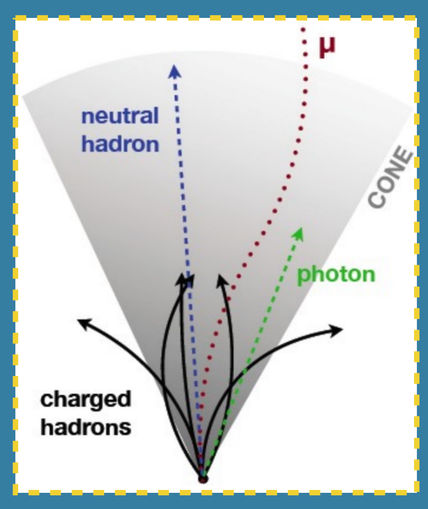


Improvement in data-simulation agreement

- Domain adaptation techniques successfully reduce discrepancy between data and simulation
- **Correction scale factors closer to 1 with v2.5**
- Improvement more pronounced for lower p_T and tighter WPs



Unified jet taggers: PNet & UParT



Reconstruction

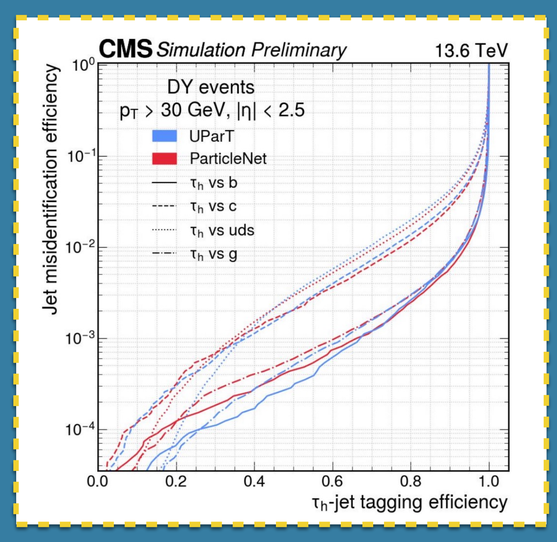
- τ_h are reconstructed as jets with the anti-kt algorithm[5], ΔR = 0.4
- Pileup mitigation is performed by the CHS or PUPPI algorithm[6]

Identification

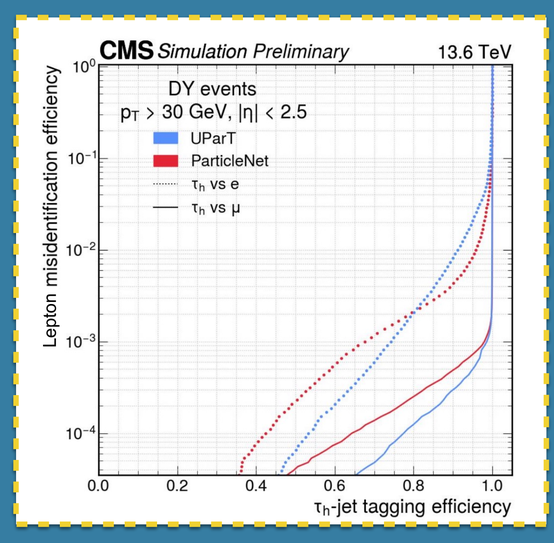
The unified taggers[7] perform both jet flavour and τ_h identification tasks

PNet:
- Graph-Neural-Network-based
- *Particle Cloud* representation for jets[8] to efficiently incorporate low level information

UParT:
- *ParticleTransformer*[9] (attention-based)
- *Particle Cloud* representation
- Adversarial training for robustness against simulation mismodeling



- **Reduced jet contamination** with respect to DeepTau. In $Z \to \tau_\mu\tau_h$ selection the decrease is ~20%
- **Worse performance in lepton rejection**. The increase in fake rates is ~50% in $Z \to \tau_\mu\tau_h$ selection



- Separate network subclasses per decay mode and charge
- **Improvement in decay assignment accuracy** compared to HPS, especially for $h^{\pm}\, h^{\mp}h^{\pm}(\pi^0)$ decay
- Improved π^0 counting
- Possibility to **recover genuine** τ_h not reconstructed by HPS
- Addition of τ_h p_T regression

Main limitation: unable to access individual τ_h decay products

EUROPEAN PHYSICAL SOCIETY EPS HEP2025 07-11 JULY, 2025 MARSEILLE

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