Hadronic Tau Tagging with the CMS detector using Domain Adaptation techniques

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on behalf of the CMS collaboration

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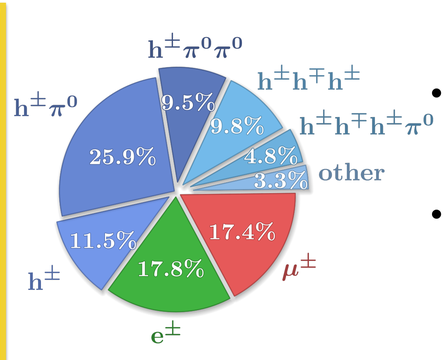
Why τ?

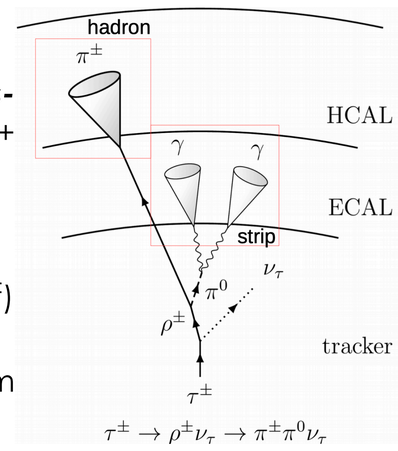
- Excellent probe for Electroweak interactions
- Yukawa couplings of Higgs→fermions
- Study CP properties of the Higgs
- Search for additional Higgs bosons
- Search for BSM signatures
- Study off-shell Z/W production, flavour physics at low mass, Z polarisation, etc.



τ decays to hadrons in ~ 65% of the cases

Hadronic Tau Reconstruction at CMS

- Hadronically decaying τ (τ_h) are reconstructed by the ***Hadron-Plus-Strip*** (HPS) algorithm[1]: Particle Flow (PF) candidates for *Hadrons* + clusters of photons and $e^{\pm}$ narrow in η and elongated in ϕ (*Strip*)
- Sources of background:
  - **Jets**: highly collimated jets can fake any tau decay mode
  - **Muons**: mainly affect the decay with only one charged particle ($h^{\pm}$)
  - **Electrons**: can emit photon and mimic the $h^{\pm}\pi^0$ decay
- The misidentification in reduced by a dedicated tagging algorithm based on Convolutional Neural Network (CNN), called **DeepTau**[2]



DeepTau v2.5

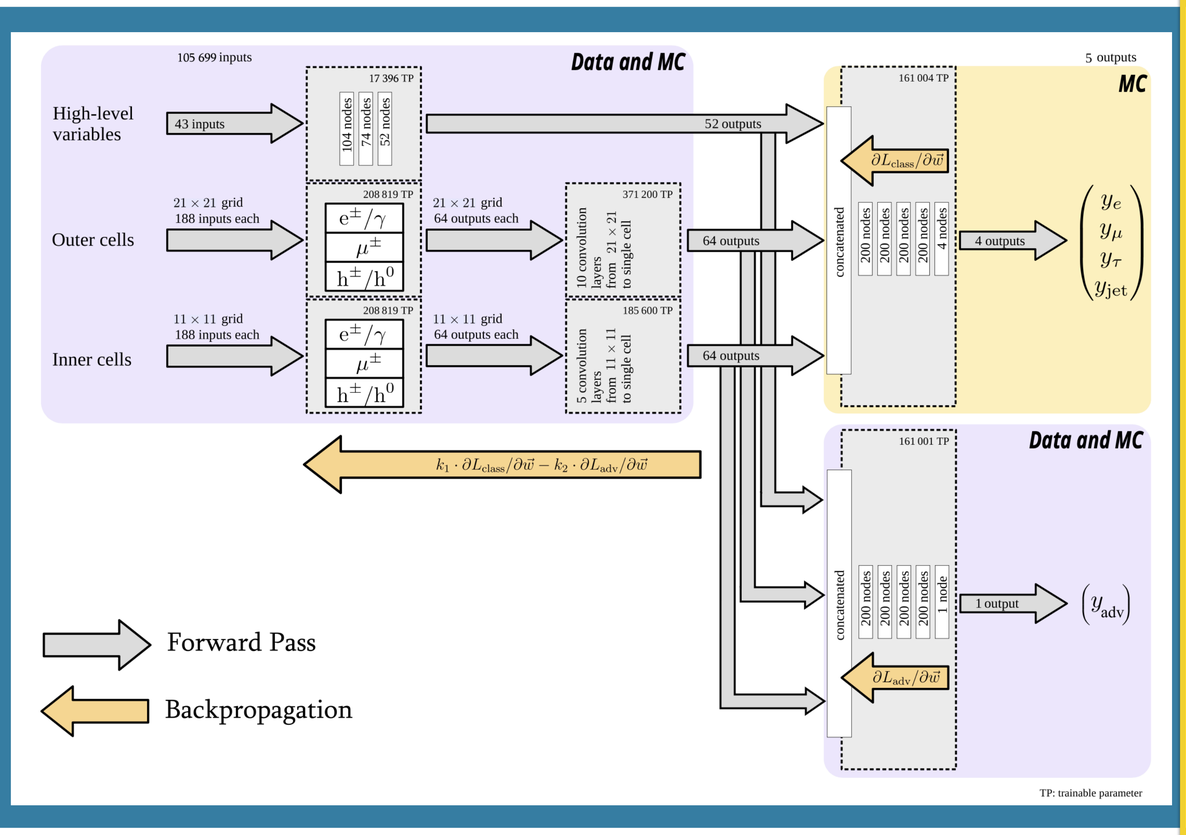
Network structure

Input: high-level reconstructed τ_h features + info on PF candidates within and around τ_h in a $\eta \times \phi$ grid format (Grid data processed by convolutional layers)
In the last stage, all features are combined and pass through 5 dense layers
Final output: Probability of τ_h of being genuine or a misid electron/muon/jet

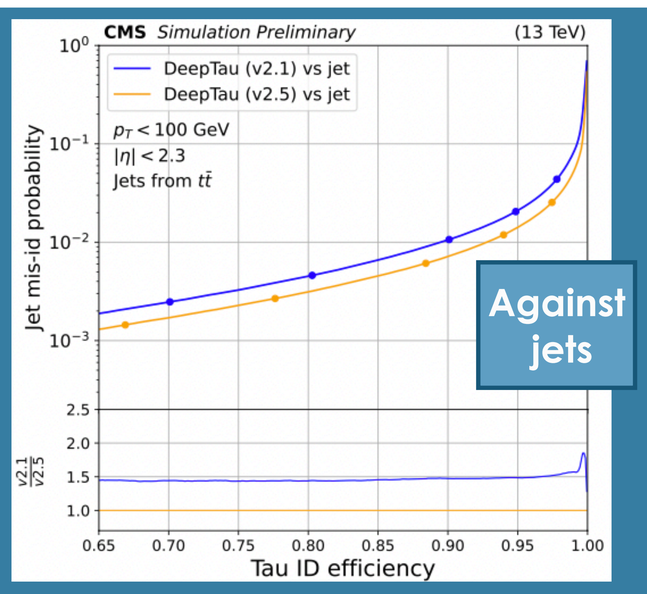
Model improvements

DeepTau v2.5[4] is an enhanced iteration of its predecessor (v2.1[3]) and has been deployed for Run 3 analyses. It integrates:

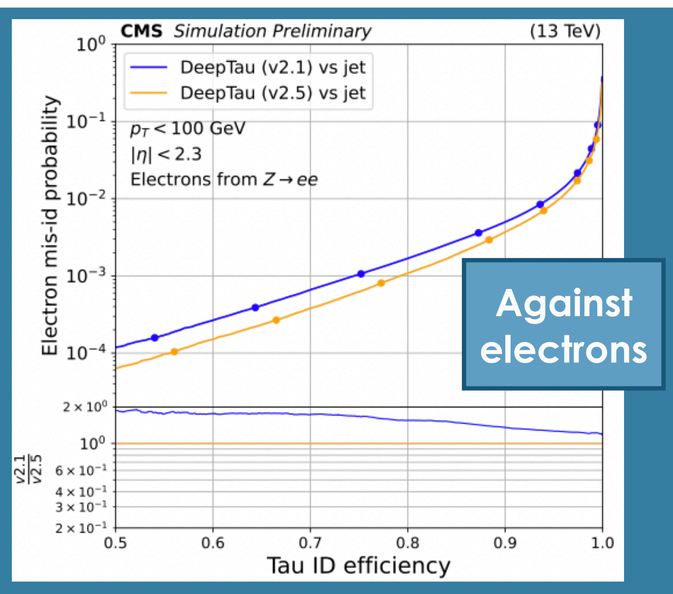
- **Domain adaptation techniques** to mitigate mismodelling (with respect to real data) in Monte Carlo (MC) events used for training[5]
- **Shuffle and Merge** to balance events across all regions of the phase space
- Feature Standardisation and Hyperparameter Optimization



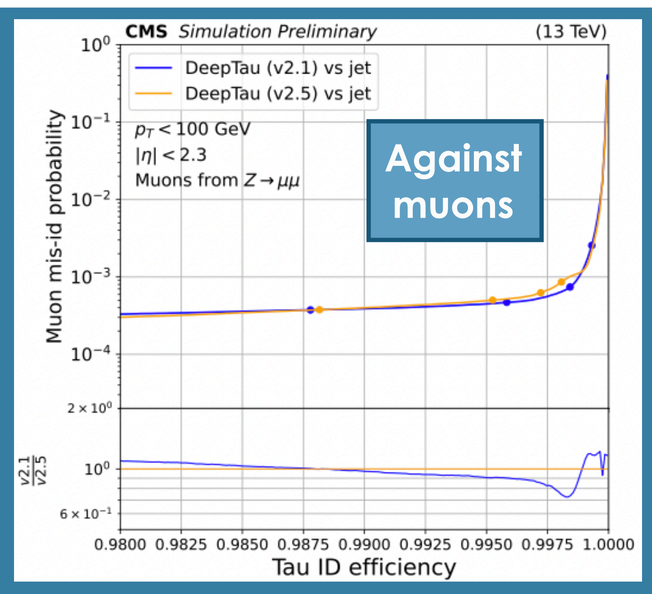
Performance



Jet misid reduced by ~50%



Large reduction of electron misid for looser WPs

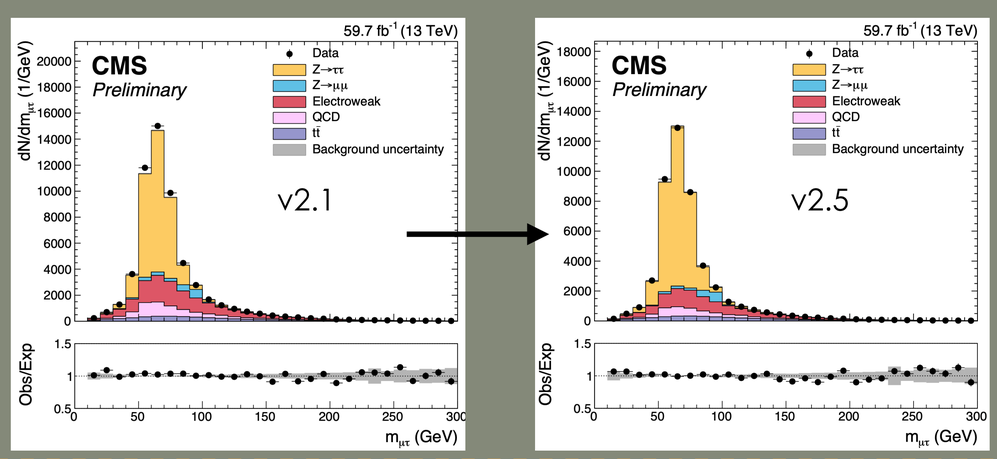


Compatible performance

Calibration

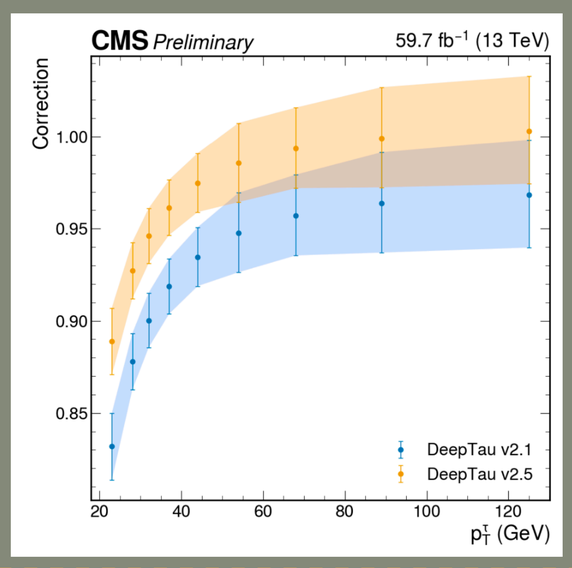
Visible mass $m_{vis}(\mu, \tau_h)$ in $Z/\gamma^* \to \tau\tau \to \mu\tau_h$ events, applying DeepTau v2.1 (left) and the new DeepTau v2.5 (right)

Visible decrease in jets background , around 30%



Data-to-simulation correction factors for genuine τ_h

- Algorithm performance slightly differs between MC and Data → Need for calibration
- **Measurement based on tag-and-probe technique with $Z/\gamma^* \to \tau_\mu\tau_h$ events**
- Correction factors comparison between DeepTau v2.5 and v2.1 on 2018 dataset
- **Correction Factors closer to unity for v2.5**
- Improvement most prominent at low p_T
- **The new version of DeepTau succeeds in reducing MC mismodelling with respect to Data**



Detector Performance Summary Note
CMS-DP-2024-XXX

Performance of the CNN-based tau identification algorithm with Domain Adaptation using Adversarial Machine Learning for Run 2

[1] CMS Collaboration. "Performance of reconstruction and identification of τ leptons decaying to hadrons and ν_τ in pp collisions at s=13 TeV". In: *Journal of Instrumentation* 13.10 (Oct. 2018), P10005–P10005. issn: 1748-0221. doi: 10.1088/1748-0221/13/10/p10005. url: http://dx.doi.org/10.1088/1748- 0221/13/10/P10005.
[2] CMS Collaboration. "Identification of hadronic tau lepton decays using a deep neural network". In: *Journal of Instrumentation* 17.07 (July 2022), P07023. doi: 10.1088/1748-0221/17/07/P07023. url: https://dx.doi.org/10.1088/1748- 0221/17/07/P07023.
[3] CMS Collaboration. "Performance of the DeepTau algorithm for the discrimination of taus against jets, electron, and muons". In: (2019). url: https://cds.cern.ch/record/2694158.
[4] Lucas Russell. "Identification of Hadronic Tau Lepton Decays with Domain Adaptation using Adversarial Machine Learning at CMS". Imperial College, London, 2022. url: https://cds.cern.ch/record/2827366.
[5] CMS collaboration. "A deep neural network to search for new long-lived particles decaying to jets". In: *Mach. Learn. Sci. Tech.* 1 (2020), p. 035012. doi: 10.1088/2632-2153/ab9023. arXiv: 1912.12238 [hep-ex].