Tau lepton identification in displaced topologies using machine learning at CMS

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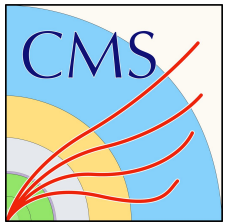
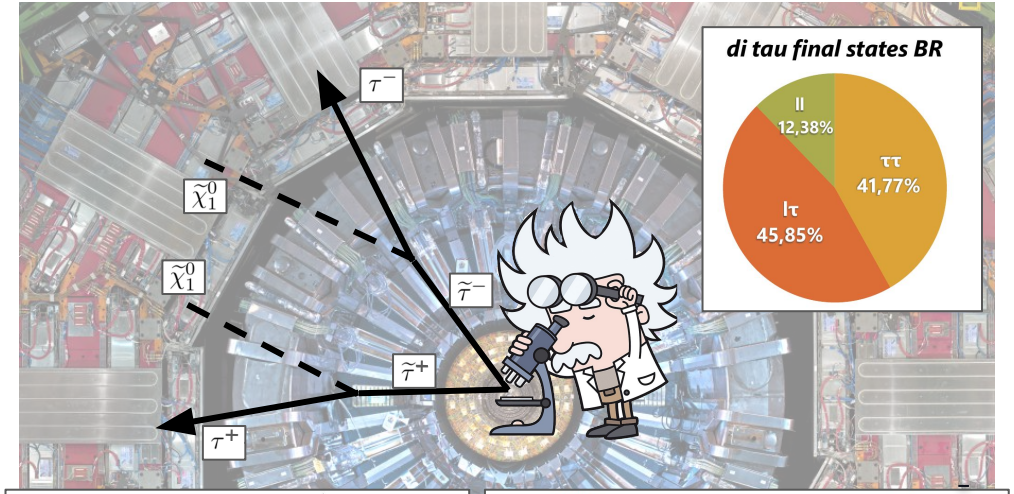
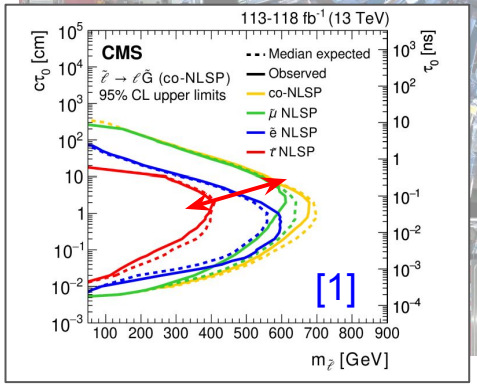
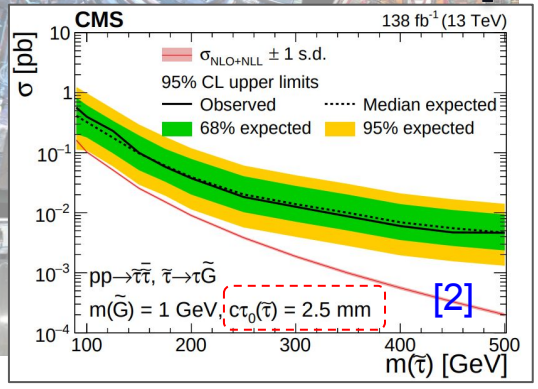


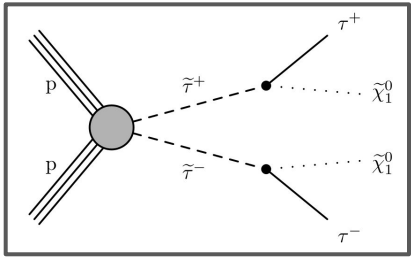
Displaced taus at CMS







- **Displaced τ's expected in many extensions of SM:** e.g: In Gauge-Mediated Supersymmetry Breaking models[3], staus can have macroscopic lifetime:



SUSY-breaking scale

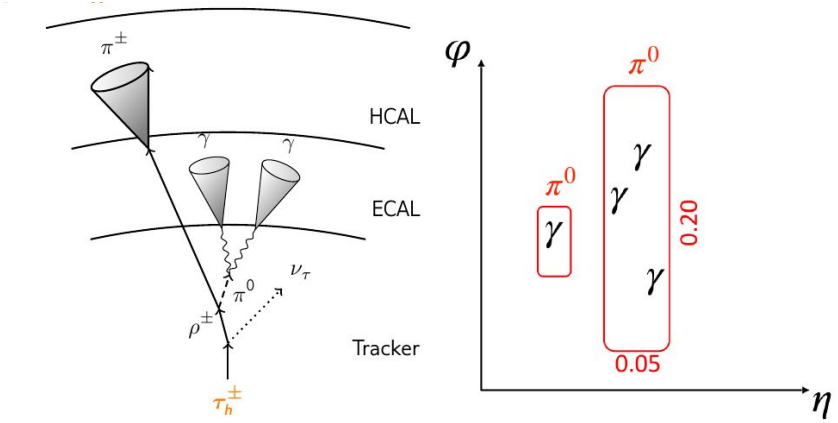
$$c\tau \approx 100\,\mu\text{m}\left(\frac{100\ \text{GeV}}{m_{\tilde{\tau}}}\right)^5\left(\frac{\sqrt{F}}{100\ \text{TeV}}\right)^4$$

- => Displaced τ signatures with $c\tau_0$ 100 µm-1m

[1] Eur. Phys. J. C **82**, 153 (2022) , [2] PhysRevD.108.012011
[3] JHEP04(2016)056

Hadronic taus at CMS

1. **Reconstruction** - hadron plus strip algorithm[1] (HPS):
   a. Reconstruction is seeded by anti-kt AK4 jet
   b. π^0 is reconstructed using dynamic η - φ window in ECAL (strip)
   c. Require one or three $\pi^{\pm}$
   d. Mass constraints



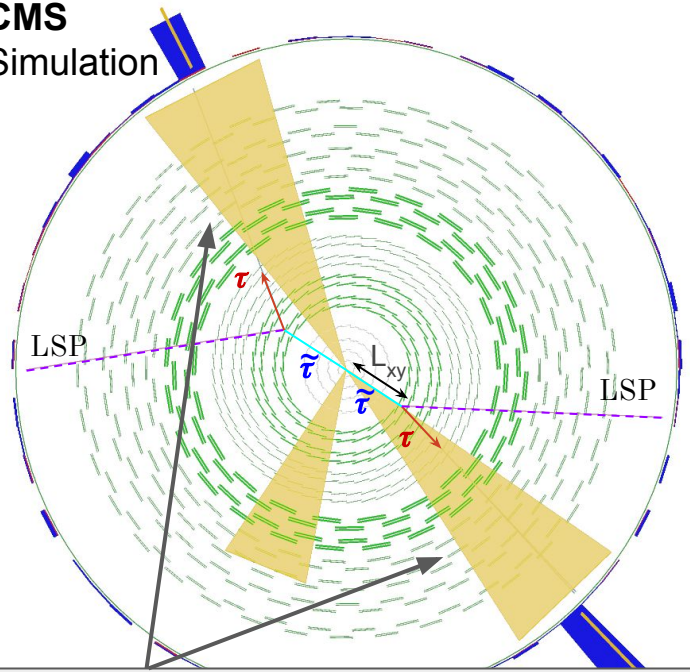
2. **Identification (DeepTau[1]):**
   a. Signature of jets originating from quarks/gluons (τ_{jet}), electrons (τ_e) and muons (τ_μ) can fake genuine hadronic tau decays (τ_h) -> NN-based discriminator

ICHEP 2024 poster by Paola Mastrapasqua:

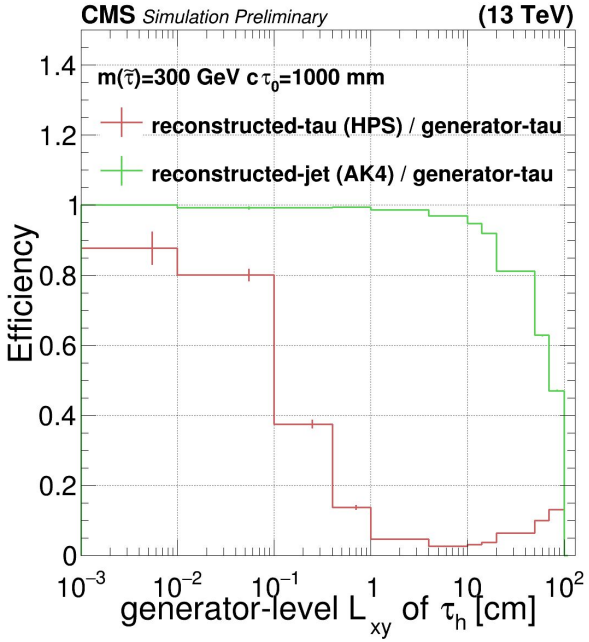
For more information Detector Performance Summary:

[1] JINST 17 P07023

Displaced taus at CMS



Standard hadron-plus-strip (HPS) reconstruction[1] is not designed for displaced signatures:



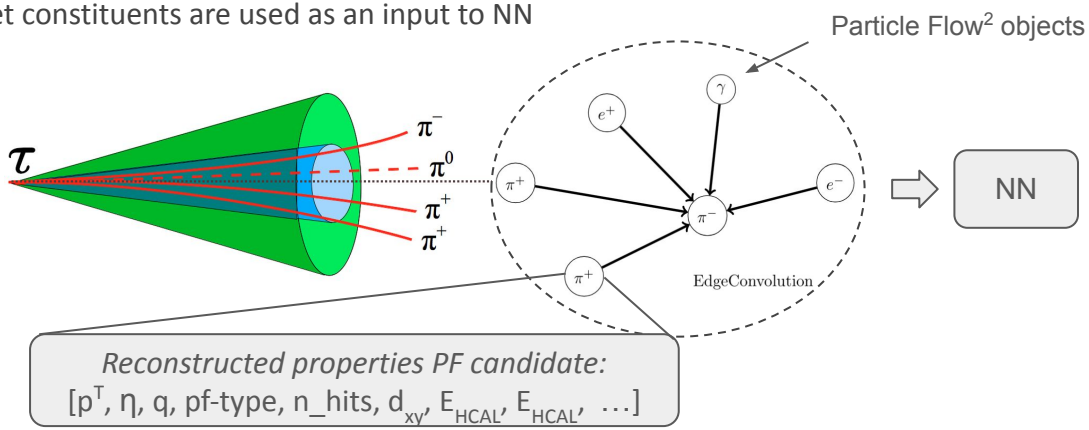
AK4 jets are efficiently reconstructed for tau with high displacement (L_{xy})

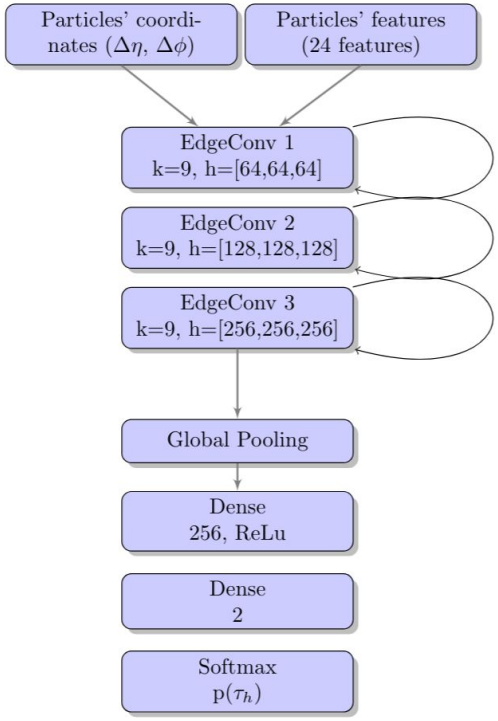
⟶ Dedicated tauID on top of the jets can be built

[1] JINST 17 P07023

Displaced tau tagger

- **The DisTau tagger** is a new ParticleNet-based[1] algorithm to **separate displaced τ_h jets from those arising primarily from light quarks and gluons**
  - **Signal**: AK4 jets from simulated long-lived STau sample
  - **Background**: AK4 jets from QCD
- Jet constituents are used as an input to NN





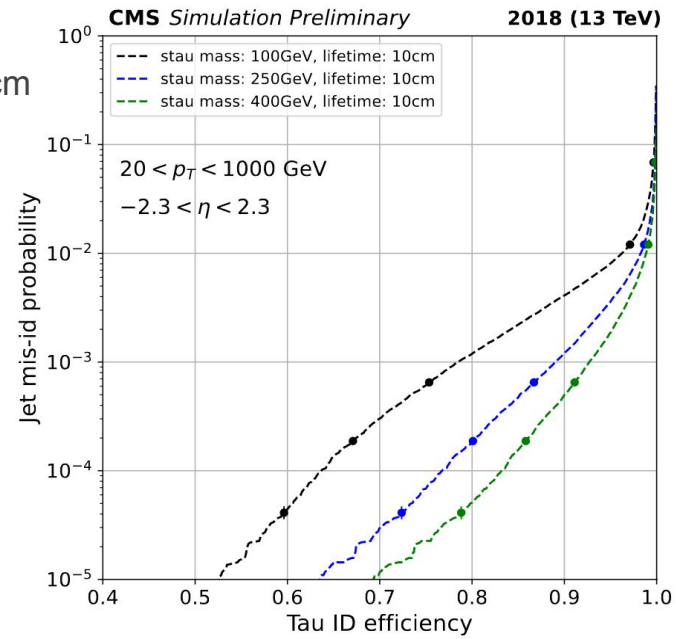
- Each variable is standardized (mapped and cropped on the interval [-1, +1])
- Classes are balanced over p_T and η
- The current model has approximately **100K trainable parameters (TP)**

Performance in simulation

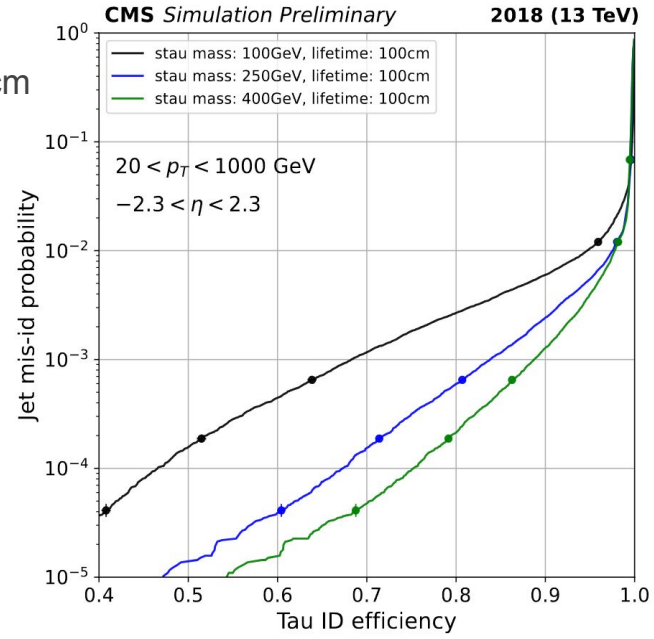
- The tau ID efficiency is estimated from **stau MC**
- The jet misidentification probability is estimated from **top-antitop MC**
- Signal efficiencies are shown for various WPs: Loose (>0.05), Medium (>0.7), Tight (>0.99), VTight (>0.997), VVTight (>0.9992)

$$P(t) = e^{\frac{-t}{(\gamma\tau)}}$$

$c\tau_0$= 10 cm

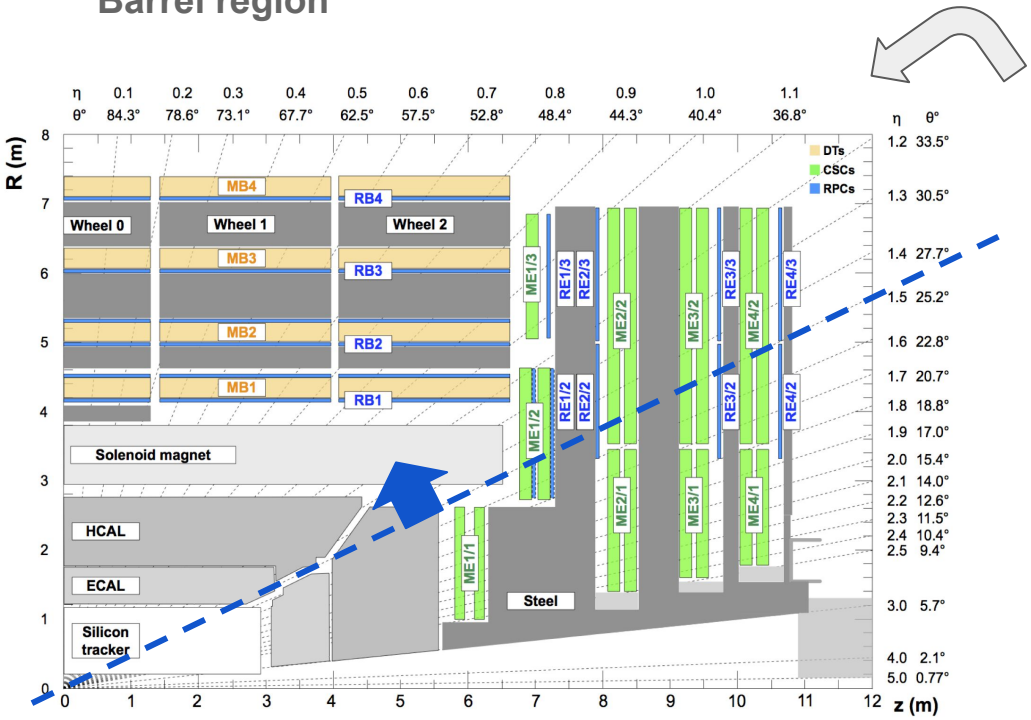


$c\tau_0$= 100 cm

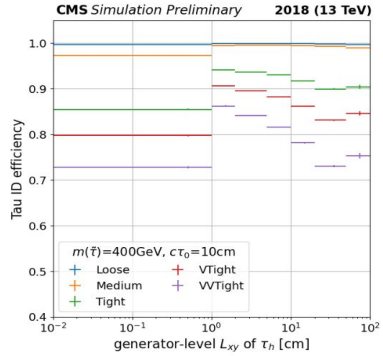


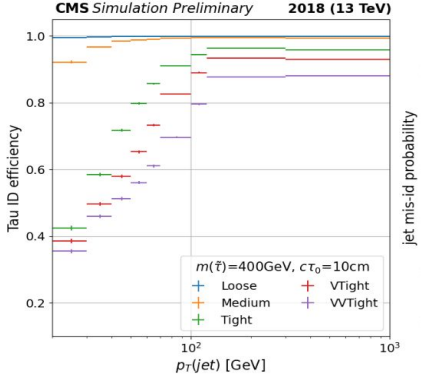
Performance in simulation

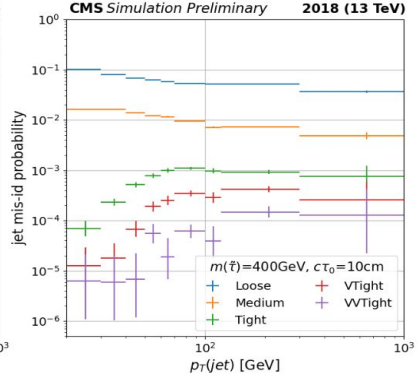
Barrel region



Efficiency and misidentification rate of the DisTau algorithm for the different working points:

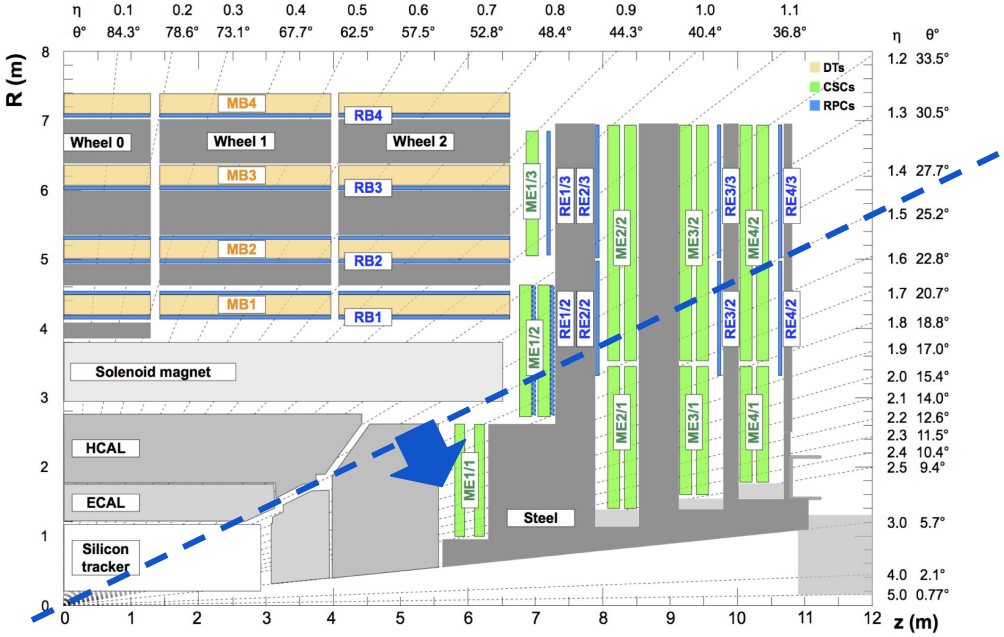






Performance in simulation

Endcap region:



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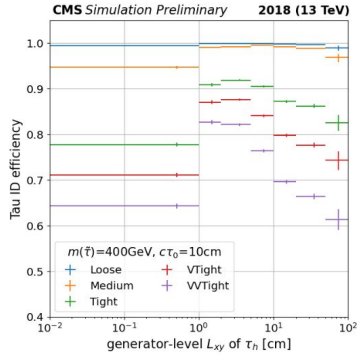
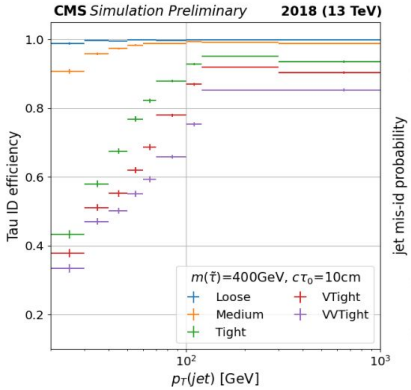
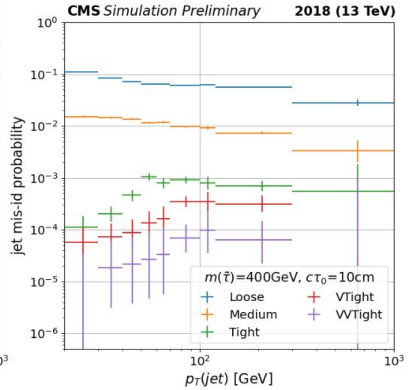
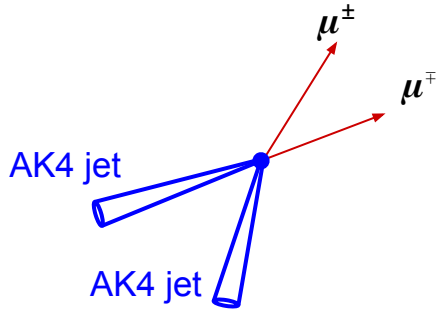


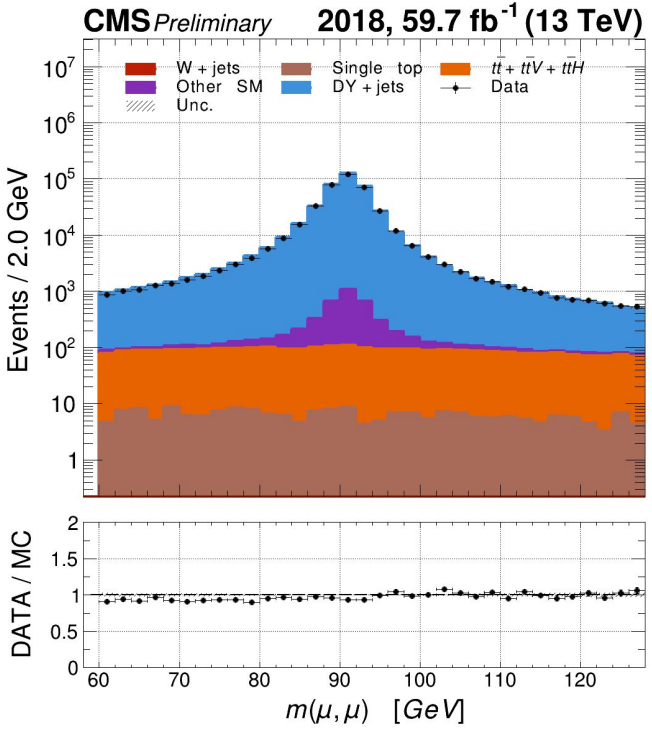




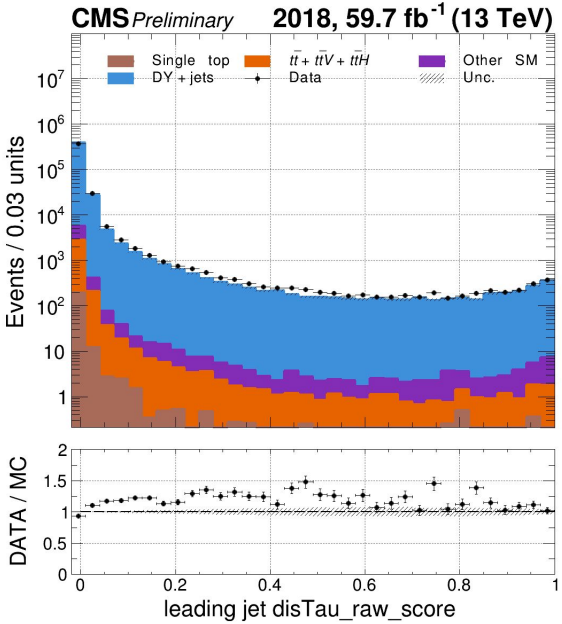
Tagger validation for background jets

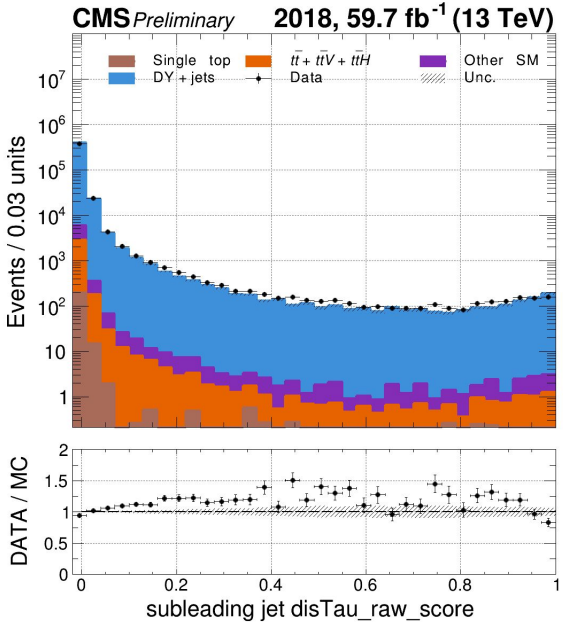
- Validation in Drell-Yan (DY + jets) with Z⟶$\mu\mu$ enriched region for **background-like jets**
- Selection requirements:
  - requiring **two opposite sign, well-identified and isolated muons**
  - total mass being consistent with **Z-boson mass** (91.2 GeV)
  - no additional leptons or b-tagged jets in the events.
  - **at least two additional AK4 jets**
- DY+jets purity > 96%.





Tagger validation for background jets

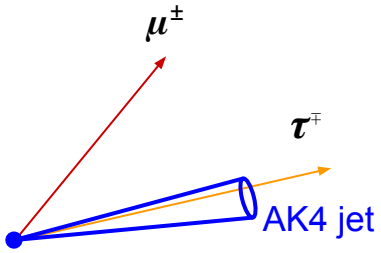


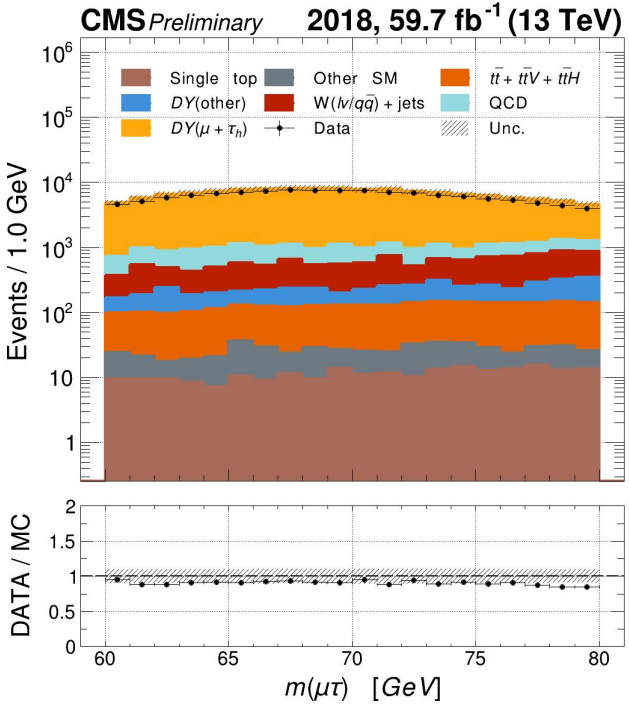


- Tagger validation for background jets
- Score is shown for p_T-leading and subleading jets
- Overall shape of the data is well modeled

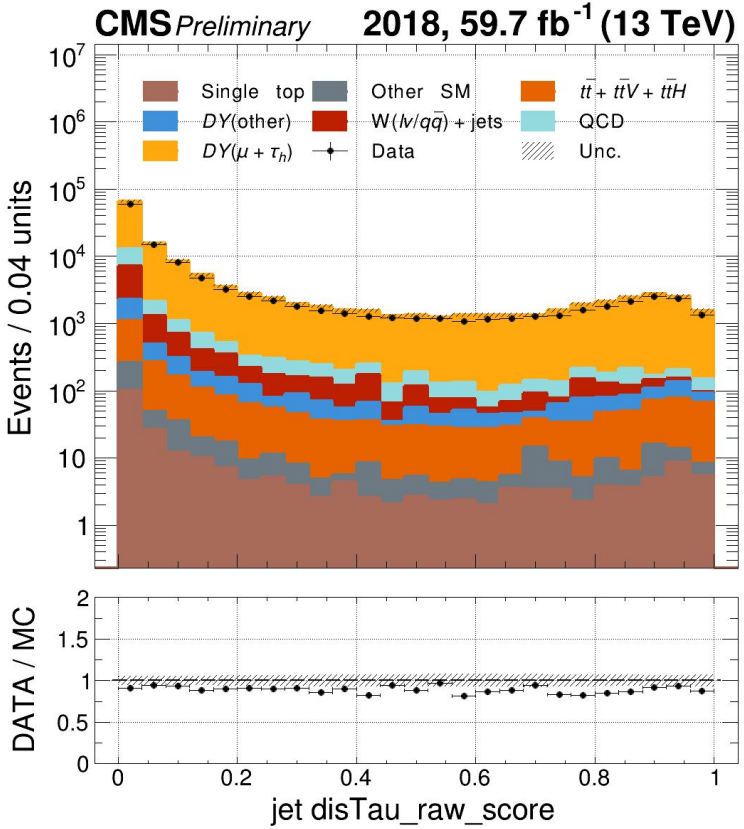
Tagger validation for genuine tau

- SM processes do not exhibit signal-like displaced taus
- **Prompt hadronic taus → suitable proxy**
- Use DY with $Z \rightarrow \tau\tau \rightarrow \mu\tau_h$
- Selection requirements:
  - requiring opposite sign muon and τ_h
  - total mass being consistent with visible Z-boson mass
- $Z \rightarrow \mu\tau_h$ process purity > 86%





Tagger validation for genuine hadronic tau



- Tagger validation for **hadronic taus**
- Tagger score for the jet matched to the reconstructed τ_h within $\Delta R<0.3$
- Overall shape of the data is well modeled

Summary

- **Standard HPS Algorithm:** Not suitable for displaced τ_h topologies, designed for close-to-vertex τ_h leptons.
- **DisTauTag Algorithm: A new neural-network-based tagger** specifically for displaced tau leptons based on AK4 jets.
- **Performance Evaluation:** Utilizes simulated long-lived τ sleptons; The tagger performance demonstrates promising rejection efficiency of signal versus background.
- **Validation:** Tagger behavior in 2018 data is well-modelled, for both background and signal-like jets.

More information on our new algorithm available at CMS Detector Performance Summary:

Thank you for your attention!
Děkuji vám za pozornost!

References

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