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Tau Identification Performance at CMS experiment

Presented by,

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INTRODUCTION

- The mass of Tau lepton is m_τ=1776.86±0.12 MeV and it is the only lepton that can decay weakly to hadrons (a.k.a Hadronic tau).
- Hadronic taus (τ_h) are reconstructed and identified using hadron plus strip (HPS) algorithm.
- Decay products of τ_h are mainly combination of charged and neutral pi-mesons and tau nutrino, this makes it more difficult to distinguish τ_h decay products from quark and gluon jets.
- Two discriminants are used to seperate τ_h from jets. Such as,
  - Isolation sum discriminant.
  - Multi variant analysis (MVA) based discriminant.
- To measure τ_h isolation and identification efficiencies we used tag and probe method using $Z/\gamma^* \rightarrow \tau\tau \rightarrow \tau_\mu \tau_h$ events.

HPS algorithm
(Run 1)

- Start from AntiK$_T$ (R=0.4) PF jet
- Reconstruct decay modes with one or three charged hadrons, and one or two neutral pions
- Neutral Pions reconstructed using an elongated $\eta \times \phi$ strips collecting energy spread from photon conversions due to magnetic field.
- Charged hadrons and photons reconstructed from tracks and calorimeter energy using a particle-flow technique
- Signal constituents are required to be in a smaller cone (p$_T$ dependent cone, R_{sig} = 3GeV/p$_T$)
- Mass constraints compatible with ρ and a_1 meson mass

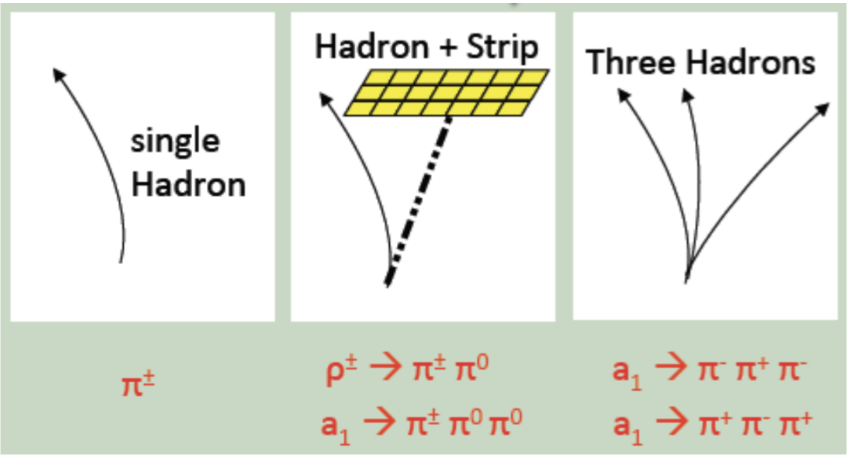


Fig.1

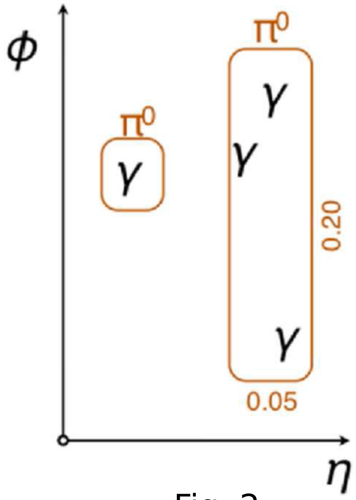


Fig. 2

HPS algorithm
(Run 2)

- The charged pion nuclear interaction with tracker material causes cascades of low p_T electrons and photons, that can appear outside of strip. And photons from neutral pions also have stong probabilty to convert electron-positron pair, after multiple scattering and bremsstrahlung they may appear in the outside the strip.

- Naively, these decay products can be integrated into the strip by suitably increasing its size, called Dynamic strip reconstruction.

- The strip size is the function of e/g p_T which can be written as,

$$\Delta\eta = f(p_T^{\gamma}) + f(p_T^{\text{strip}})$$
$$\Delta\phi = g(p_T^{\gamma}) + g(p_T^{\text{strip}}).$$

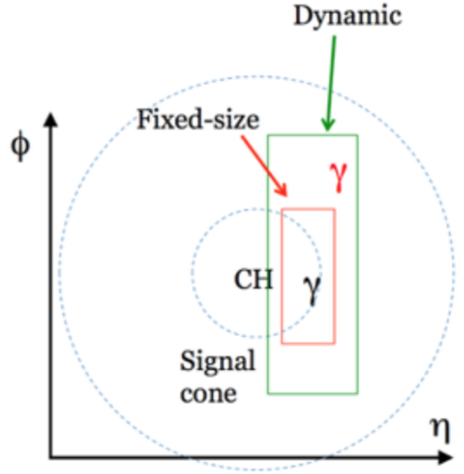


Fig. 3

Isolation Sum Discriminants
(Cut based Isolation)

The isolation sum defined as,

$$I_\tau = \sum P_T^{h\pm}(d_Z < 2mm) + \max(0, \sum P_T^{\gamma} - \Delta\beta \sum P_T^{h\pm}(d_Z > 2mm))$$

Charged isolation | Photon isolation | Pileup correction

Charged Isolation: Summing the p_T of charged particle within the isolation cone (radius =0.5(0.3)) of centered on the direction of the τ_h candidate. The pileup(PU) contribution is suppressed by taking account of charged particle originated within the < 0.2 cm distance from the τ_h production vertices.

Photon Isolation: Summing the p_T of photons within the isolation cone (radius =0.5(0.3)) of centered on the direction of the τ_h candidate.

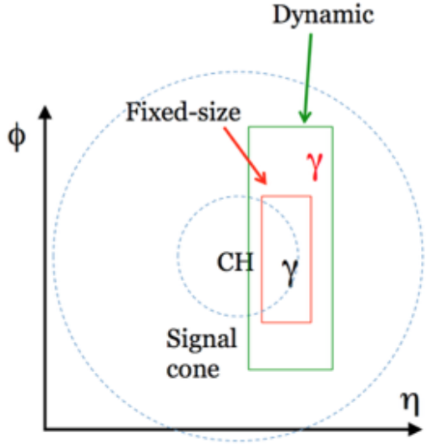
Pileup correction: PU corrections for photon isolation estimated from p_T sum of charged particles of > 0.2cm distance from the τ_h production vertices, but cone of Radius 0.80. The imperical constant $\Delta\beta$ value is 0.2 in 2016 data.

Cut based Isolation

Dynamic strip reconstruction allows photon candidate outside the signal cone can contribute to the signal, which also effectively increase the jets-τ_h mis-identification probablity. Which introduce an additional quantity called **p_T strip outer** , it defined as:

$$p_T^{strip,outer} = \Sigma p_T^{e/\gamma}(\Delta R > R_{sig})$$

It is the p_T sum of e/γ candidates included in the strip, but located outside of the signal cone. (see the red γ). Applying a cut on p_T^{outer} less than 10% of p_T^{tau} reduce around 20% of jets-τ_h mis-identification probablity.



MVA based Discriminant

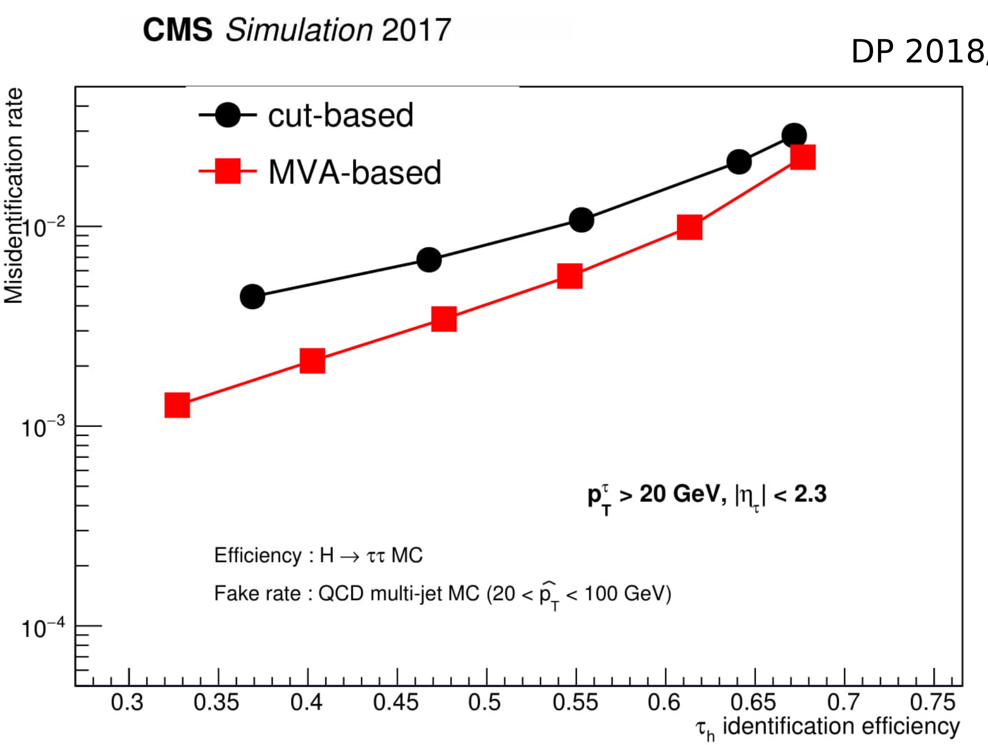
A classifier based on decision boosted trees (BDT) is used to discriminate τ_h decay product from quark and gluon jets. The variables used as inputs of to the BDT are,

- Isolation sum
- τ_h decay modes
- The impact parameter d_0 of the highst p_T track of τ_h candidate.
- The distance between the τ production and decay vertices.
- p_T strip outer
- Multiplicity of photon and electoron, candidates.

Tau Isolation Working points (WP)

- VVLoose, VLoose, Loose, Medium and Tight WP are defined for the cut-off isolation discriminant by isolation sum $I_\tau <$ 4.5,3.5,2.0,1.0 and 0.8 respecitvely.

- The MVA working points are defined on the output of the discriminator for different identification efficiencies: very loose (90%), loose(80%),medium(70%),tight (60%), very tight (50%) , very very tight (40%).



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τ_h reco+ID efficiency = **denominator && τ_h p_T >20 GeV && |η| <2.3 && decay modes && isolation** / **gen vis τ p_T >20 GeV && |η| <2.3 && gen. had. decay modes**

Misidentification probability = **denominator && τ_h p_T >20 GeV && |η| <2.3 && decay modes && isolation** / **gen q/g jet p_T >20 GeV && |η| <2.3**

τ_h Isolation and Identification efficiency

- Efficiencies are measured using Tag and Probe technique.
- $Z/\gamma^* \rightarrow \tau\tau \rightarrow \mu\tau_h$ events are used, where muon (p_T >29GeV) as a Tag and τ_h (p_T >20GeV) is used as probe.
- Invariant mass (m_{vis}) distribution of the muon and τ_h is fitted to extract the efficiency.

$\mu\tau_h$ visible mass for passing probe

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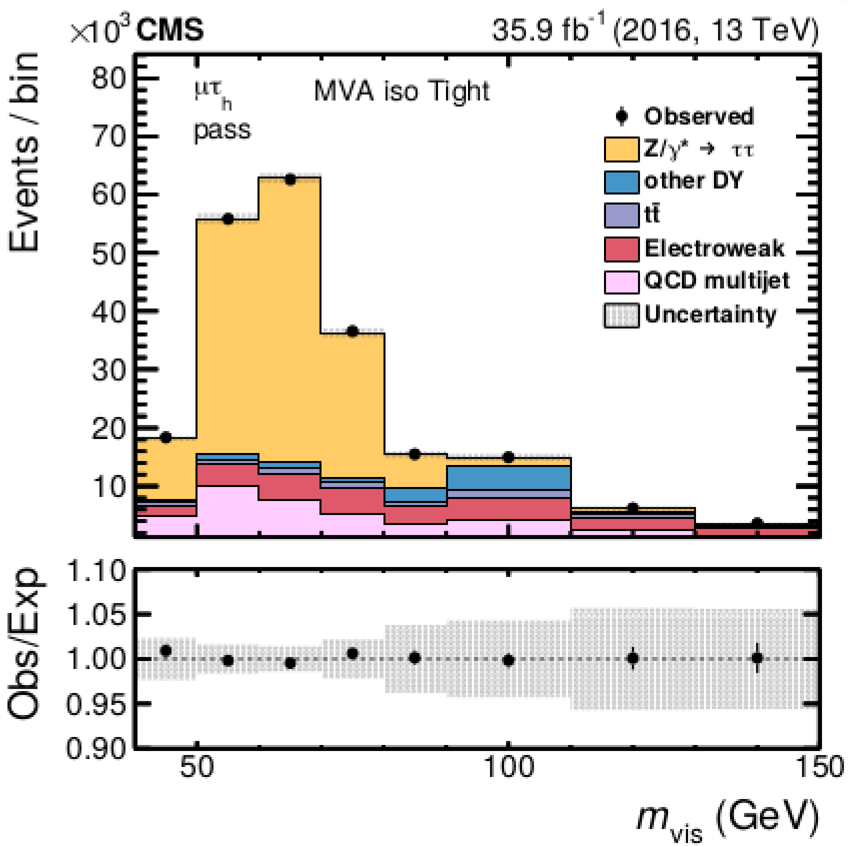

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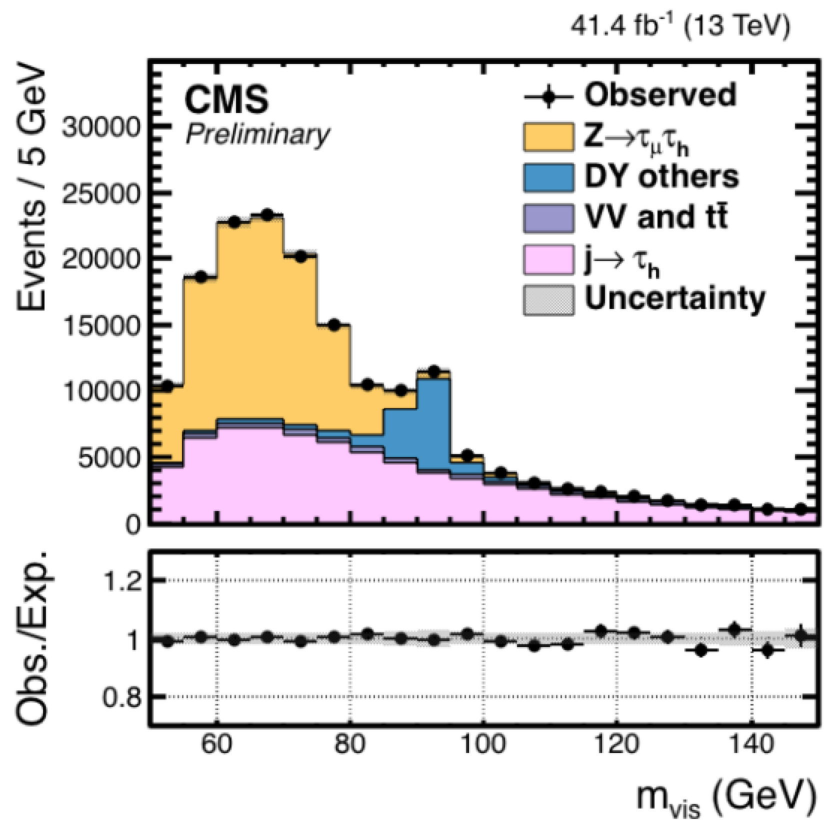
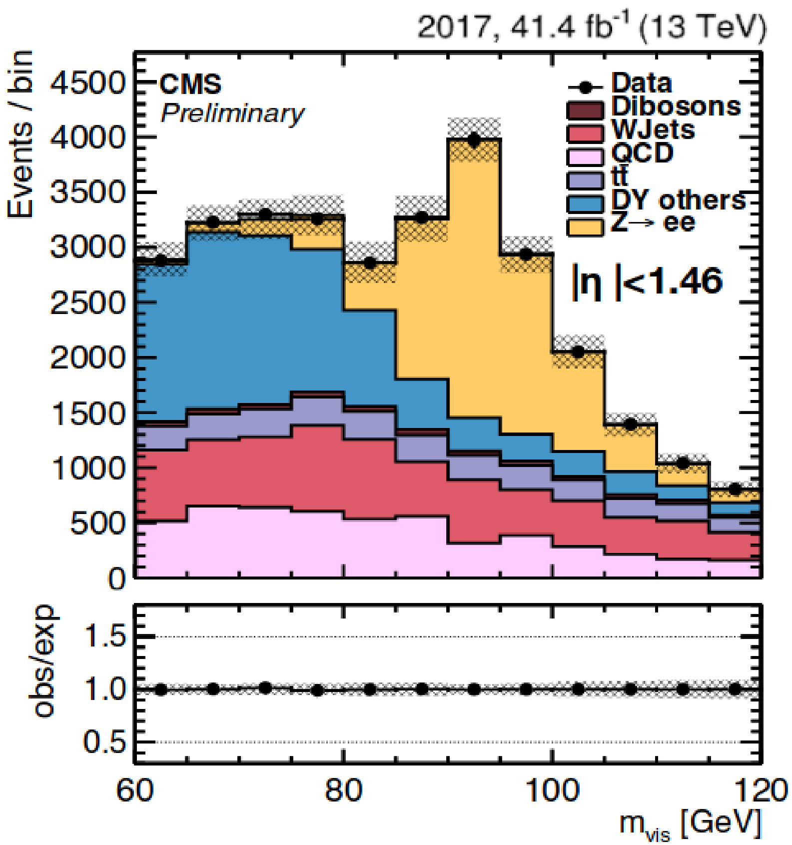


Comparision distribution of identified τ_h from its decay modes on 2016 and 2017 data.

Measurement of e/μ→τ_h misID probablity

The mis-identification probablity is measured similarly by tag and probe method using Z/γ*→ee (or μμ) events.



e→τ_h misID

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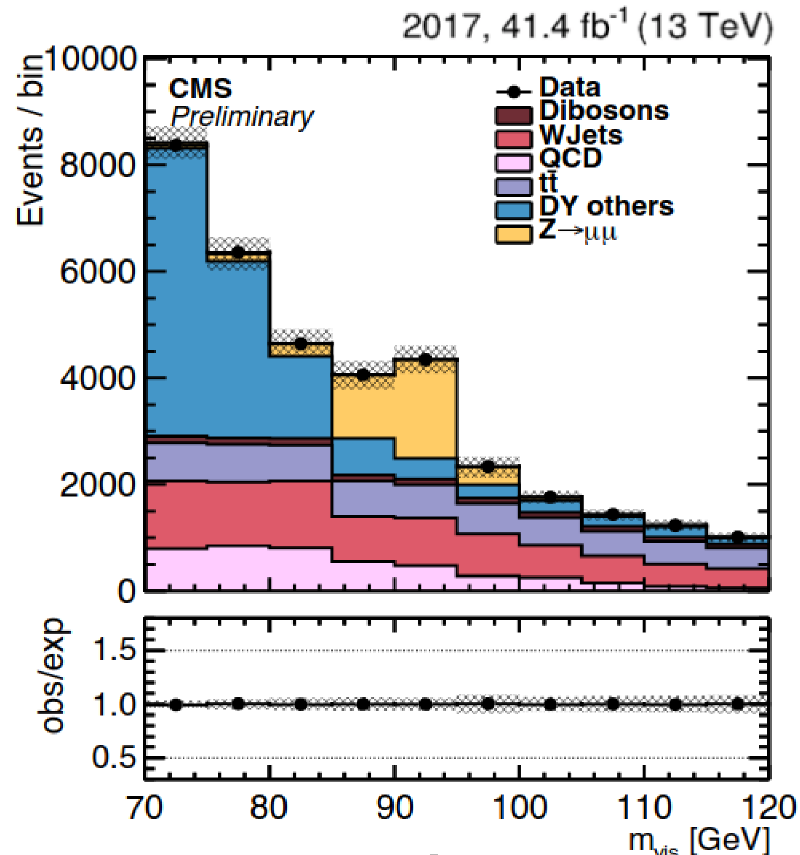

μ→τ_h misID

Distribution of τ_h mass

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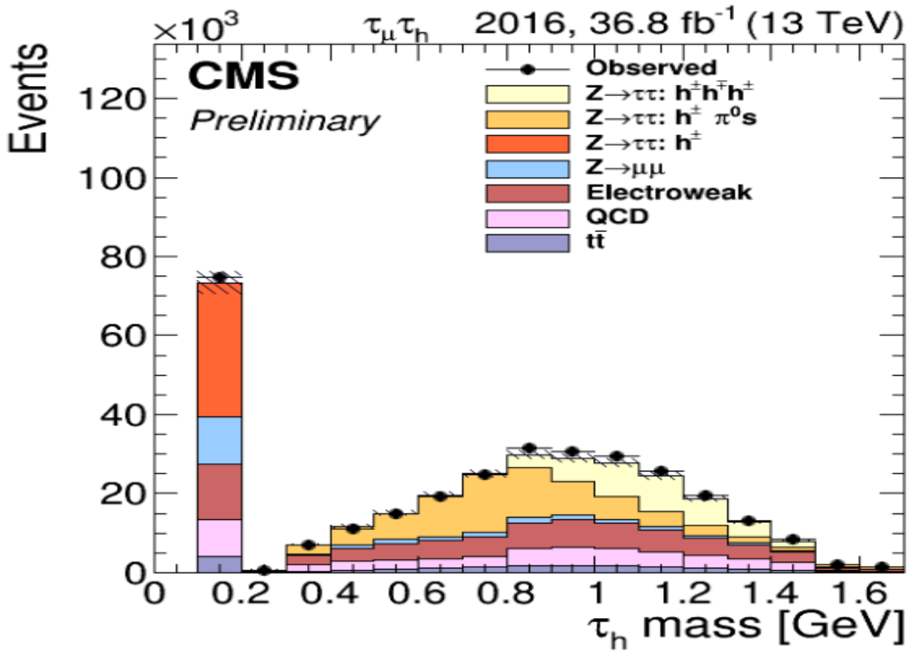

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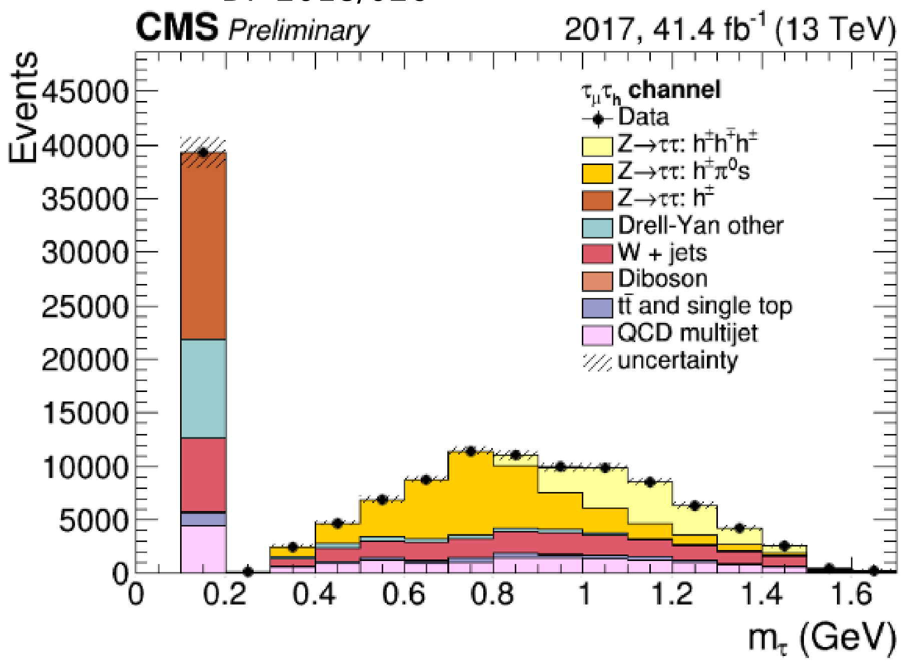

Comparision distribution of identified τ_h from its decay modes on 2016 and 2017 data.

Jets→τ_h Fakerate measurement

jet→τ_h mis-id probablities is measured using W(μν) +jets events and tt→eμ + jets events.

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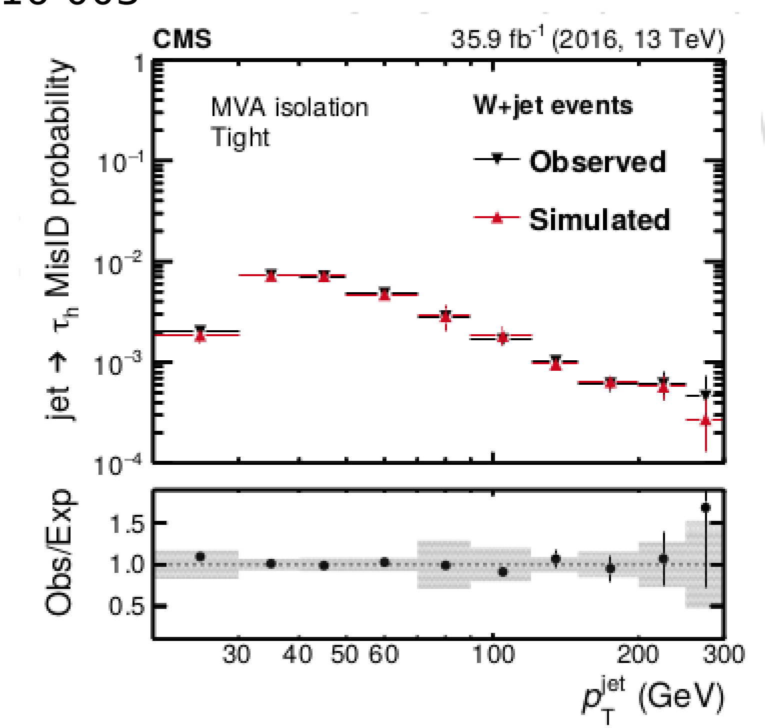

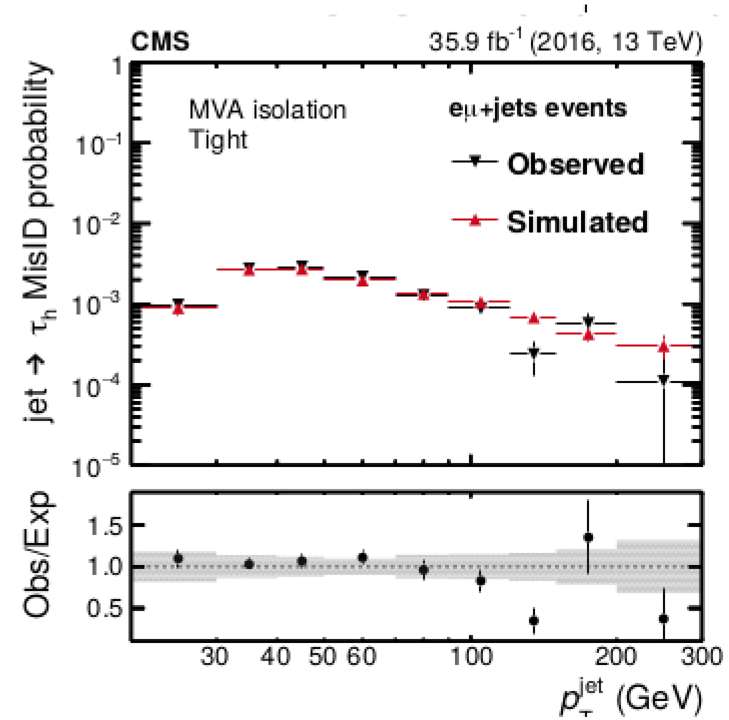

SUMMARY

- Discussed τ_h identification methods employed at CMS.
- Presented its performance.
- Performance are measured from data in terms of efficiency and mis-id probablity.
- The measured performance in data is consistent with that of the simulation.

Back up

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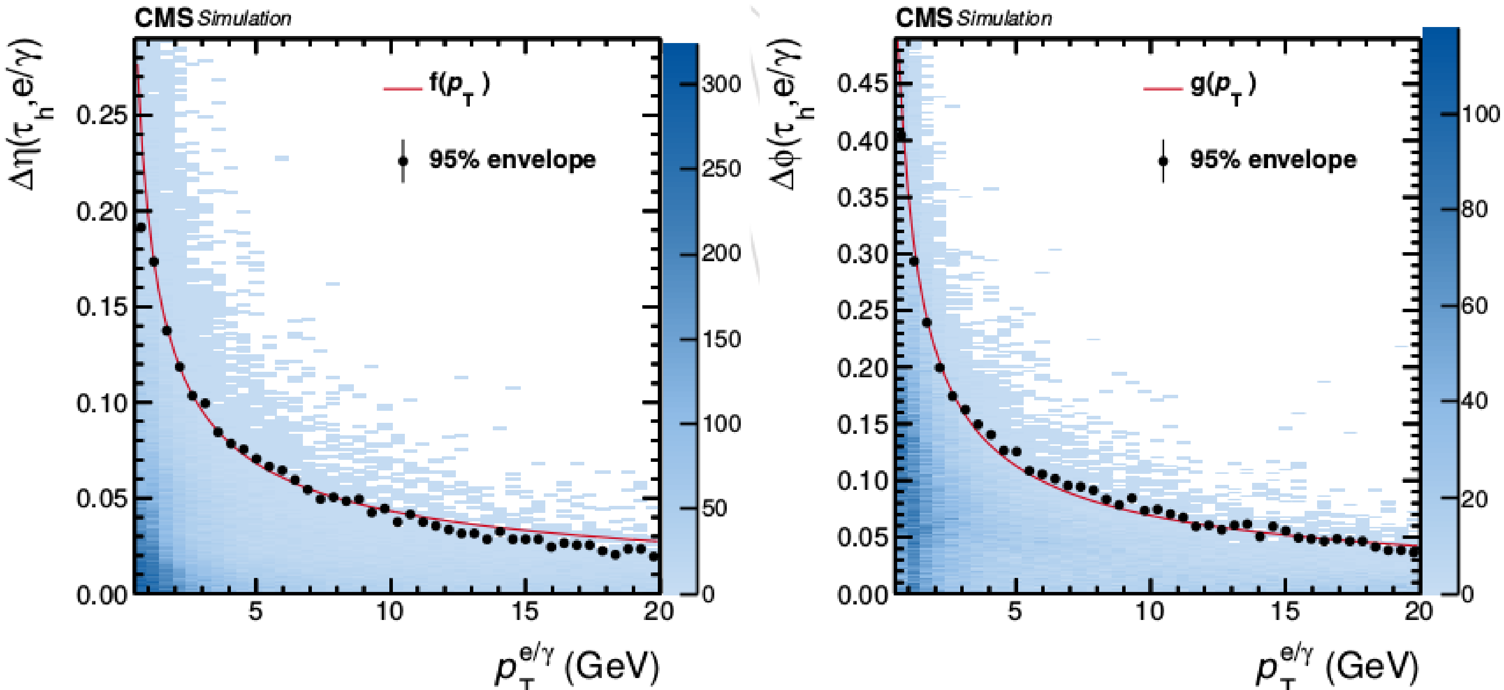

The unknown functions are determined from a single τ lepton MC event sample, generated with uniform p_T in the range of 20 to 400 GeV and $|\eta| < 2.3$, such that 95% of all electrons and photons that arise from τ_h decays are contained within one strip.

$$f(p_T) = 0.20 \cdot p_T^{-0.66}$$
$$g(p_T) = 0.35 \cdot p_T^{-0.71}.$$