Performances of Tau Reconstruction in CMS

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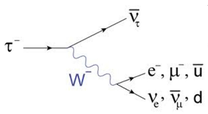
1. Introduction

As a consequence of its large mass, the tau lepton (τ) is a privileged probe of new physics at the LHC.



In about two thirds of the cases, taus decay "hadronically" (τ_{had}) into charged and neutral pions via intermediate vector meson resonances.

The remaining branching ratio accounts for the decay into the lighter leptons: muons (τ_μ) and electrons (τ_e).

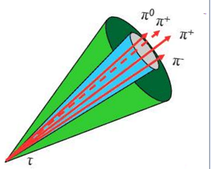
Reconstructing and identifying hadronic taus is therefore a crucial task.

Decay Mode	Resonance	Mass (MeV/c^2)	Branching ratio(%)
$\tau^- \to h^- \nu_\tau$			11.6 %
$\tau^- \to h^- \pi^0 \nu_\tau$	ρ	770	26.0 %
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a1$	1200	10.8 %
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a1$	1200	9.8 %
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$			4.8 %
Total			63.1%
Other hadronic modes			1.7%

2. Tau Reconstruction and Identification

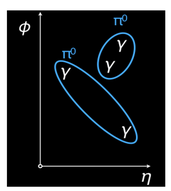
The experimental signature of hadronically-decaying taus produced in the decay of heavy resonances (Z^0,h^0/A,H^+,...) is a collimated jet of up to three charged particles and photons from π^0's decay.

A similar signature is expected for quark/gluon jets from QCD production ⇒ the experimental challenge is to discriminate efficiently between τ_{had}'s and generic QCD jets.

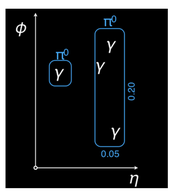


An optimal τ_{had} identification in terms of efficiency vs. fake rate from QCD jets is achieved by analyzing the particle constituents of the jet in the search for the single hadronic tau decay modes.

Two main tau algorithms based on the output of a particle-flow [1] reconstruction technique are currently employed in CMS analyses: the Tau Neural Classifier (TaNC) and the Hadron Plus Strips (HPS) [2].

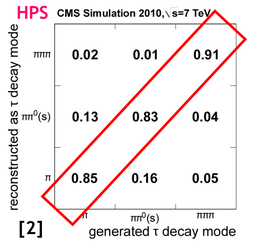


• TaNC : the PF-photons are clustered into π^0's candidates; a specific decay mode is reconstructed among five possible; the neutral and charged particles are then fed into an ensemble of NN, one for each decay mode, to optimally separate τ_{had}'s from QCD jets.



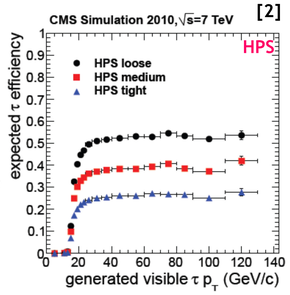
• HPS : π^0's candidates are formed from any PF-photon or PF-electron found inside "strips" which account for possible broadening of the calorimeter signature by photon conversions. The mass of the composite system must be compatible with a ρ or a_1 hypothesis.

3. Expected Performances



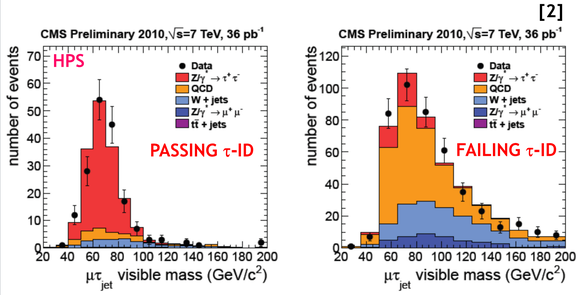
Successful matching between generated and reconstructed decay modes in more than 80% of the cases.

Three "working points" of tau efficiency vs. jet rejection (loose, medium and tight) can be defined by tuning the cut on the NN output (TaNC) or the isolation thresholds (HPS).



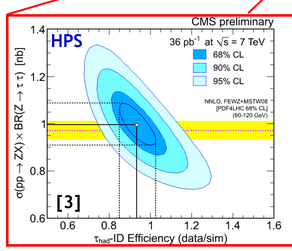
4. Measurement of tau-ID Efficiency

The reconstruction and identification efficiency (tau-ID) for each tau algorithm is measured from data with a tag&probe-like technique.



A relative, statistically-dominated uncertainty in the range 20%-30% can be achieved by this method.

Algorithm	Fit data	Expected MC	DATA/MC
TaNC "loose"	0.76 ± 0.20	0.72	1.06 ± 0.30
TaNC "medium"	0.63 ± 0.17	0.66	0.96 ± 0.27
TaNC "tight"	0.55 ± 0.15	0.55	1.00 ± 0.28
HPS "loose"	0.70 ± 0.15	0.70	1.00 ± 0.24
HPS "medium"	0.53 ± 0.13	0.53	1.01 ± 0.26
HPS "tight"	0.33 ± 0.08	0.36	0.93 ± 0.25
HPS "loose"	combined fit [4]		0.94 ± 0.09
HPS "loose"	$\tau\tau$ to $\mu\mu$ fit [4]		0.96 ± 0.07

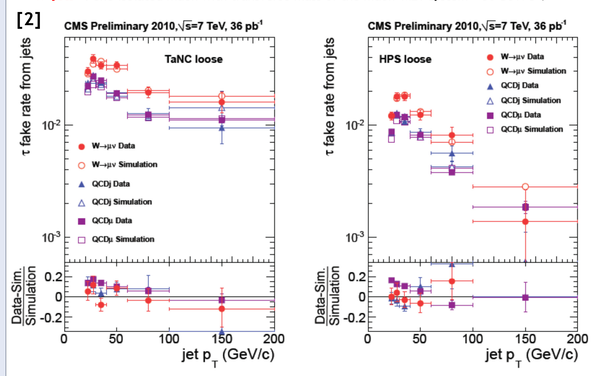


The tau-ID for the HPS loose has been further measured to better than 9% relative uncertainty by constraining the measured Z->$\tau_\mu\tau_{had}$ and Z->$\tau_e\tau_{had}$ cross sections to the Z->$\tau_\mu\tau_e$,$\tau_\mu\tau_\mu$ or to Z->$\mu^+\mu^-$ cross-sections measured by CMS [3].

5. Tau Fake Rate from Jets

The fake rate from jets is studied in three different samples of events with at least one reconstructed jet. In each sample, a specific jet composition is enhanced by means of *ad hoc* cuts:

• "QCDj" : at least one additional jet with $|\eta|<2.5$ and p_T>15 GeV/c (jet -triggered events);
• "QCDμ" : one non-isolated muon with transverse mass of the muon+MET system < 40 GeV/c^2 ;
• "W+jets" : one isolated muon with transverse mass of the muon+MET system > 50 GeV/c^2 ;

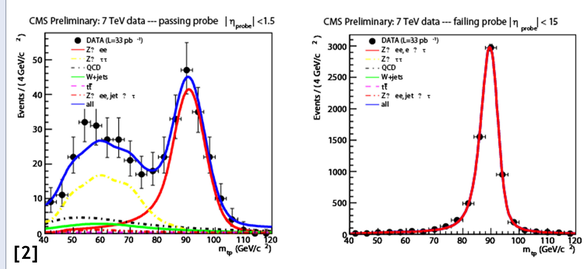


Fake rate for jets with $|\eta|<2.3$, p_T>20 GeV — MC: Pythia tune Z2

Algorithm	QCDj		QCDμ		W + jets	
	MC	DATA/MC	MC	DATA/MC	MC	DATA/MC
TaNC "loose"	2.1%	1.05 ± 0.04	1.9%	1.12 ± 0.01	3.0%	1.02 ± 0.05
TaNC "medium"	1.3%	1.05 ± 0.05	0.9%	1.08 ± 0.02	1.6%	0.98 ± 0.07
TaNC "tight"	0.5%	0.98 ± 0.07	0.4%	1.06 ± 0.02	0.8%	0.95 ± 0.09
HPS "loose"	1.0%	1.00 ± 0.04	1.0%	1.07 ± 0.01	1.5%	0.99 ± 0.04
HPS "medium"	0.4%	1.02 ± 0.06	0.4%	1.05 ± 0.02	0.6%	1.04 ± 0.06
HPS "tight"	0.2%	0.94 ± 0.09	0.2%	1.06 ± 0.02	0.3%	1.08 ± 0.09

6. Tau Fake Rate from Electrons

A multivariate discriminator (ξ) is employed to separate electrons from hadronic taus; the fake rate from electrons is measured from data with a tag&probe technique using electrons from the Z->e^+e^- .



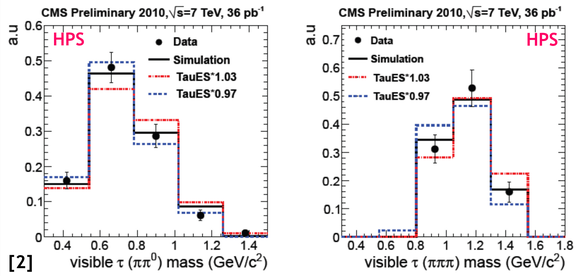
Two working points are defined by different cuts on ξ:

bin	discriminator by $\xi < -0.1$			discriminator by $\xi < 0.6$		
$\lvert\eta\rvert$	MC(exp),%	MC(t&p),%	DATA/MC	MC(exp),%	MC(t&p),%	DATA/MC
< 1.5	2.22 ± 0.03	2.21 ± 0.05	1.13 ± 0.17	13.19 ± 0.06	13.10 ± 0.08	1.14 ± 0.04
> 1.5	3.90 ± 0.06	3.96 ± 0.09	0.82 ± 0.18	26.90 ± 0.13	26.80 ± 0.16	0.90 ± 0.04

"Tight WP: ε_{tau}≈ 97% " "Loose WP: ε_{tau}≈ 99.5%"

7. Tau Energy Scale

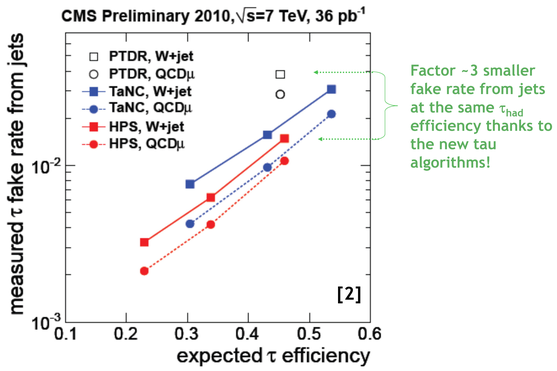
The quality of the tau energy scale (TauES) simulation is investigated by fitting the visible tau mass in a Z->$\tau^+\tau^-$ enriched data sample leaving TauES free to float.



The best-fit deviations of the TauES from the simulation are within 3% (1%) for the $\pi\pi^0$ ($\pi\ \pi\ \pi$) reconstructed modes.

8. Conclusions

The TaNC and HPS algorithms have been successfully commissioned with 7 TeV collision data collected by CMS in 2010.



The expected performances of the PF-based tau algorithms in terms of efficiency vs. fake-rate from jets are confirmed by data and show an impressive improvement with respect to the traditional, isolation-cone based approach followed in the PTDR [4].

An efficiency close to 50% on genuine hadronically-decaying taus can be retained at the price of a few percent fake rate from QCD jets and from mis-identified electrons.

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[1] The CMS Collaboration: "Particle Flow Event Reconstruction in CMS and Performances for Jets, Taus and E_T^{miss}", CMS PAS PFT-09-001.
[2] The CMS Collaboration: "Performances of tau reconstruction in 2010 data collected with CMS", CMS PAS TAU-11-001.
[3] The CMS Collaboration: "Measurement of the Inclusive Z->$\tau^+\tau^-$ Cross Section in pp Collisions at √s=7 TeV", to be published.
[4] CMS Physics TDR, Volume II: CERN-LHCC-2006-021