Tau identification and reconstruction at CMS

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Tau lepton

Properties

- Heaviest lepton ($m_\tau = 1.78$ GeV),
- short lifetime ($c \cdot \tau = 87$ µm),
- decays into hadrons ($\sim$ 65%) or lighter leptons ($\sim$ 35%).

Importance

- Search for Higgs boson.
- Search for supersymmetric particles.
- Electroweak measurements.

Requirements

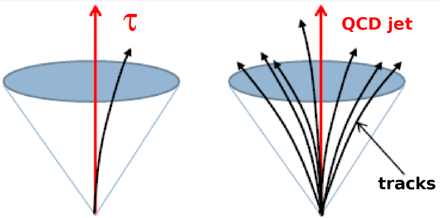
- Efficient reconstruction,
- good performance in rejecting possible background contaminations.

Tau decay modes

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
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	a_1^-	1200	10.8
$\tau^- \to h^- h^+ h^- \nu_\tau$	a_1^-	1200	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$			4.8
Other hadronic			1.7
Total hadronic			64.8
$\tau^- \to e^- \overline{\nu}_e \nu_\tau$			17.8
$\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$			17.4
Total leptonic			35.2

- Signature - isolated and collimated jets with low charged track multiplicity.
- ν_τ takes significant fraction of momentum,

$\Rightarrow$ visible mass is lower than m_τ.

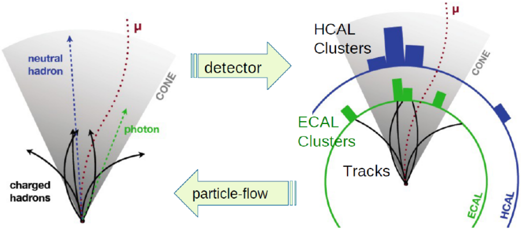


Tau identification

Tau identification is a complicated problem which requires sophisticated algorithms and reconstruction of the tau decay mode.

Hadron Plus Strips (HPS)

is the currently used algorithm for hadronic tau decay reconstruction at CMS.



- HPS algorithm uses Particle Flow method.
- Particle Flow algorithm reconstructs a list of particles produced in the collision.

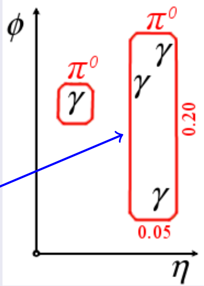
Hadron Plus Strips Algorithm

Hadron Plus Strips algorithm uses PFJet as a starting point.

- Charged hadrons are reconstructed with Particle Flow algorithm.
- π^0's are reconstructed in ECAL as objects called strips.

Strips

- $\pi^0 \rightarrow \gamma\gamma$
- Photon conversions in the tracker material.
- Electron tracks bending in magnetic field - broadening of the signal in the azimuthal direction.
- A strip of 0.05 in η and 0.20 in ϕ is built.
- Mass required to be consistent with π^0.



Hadron Plus Strips Algorithm

Decay mode reconstruction

HPS objects	tau decay mode
1 hadron	$\tau^- \to h^- \nu_\tau$
	$\tau^- \to h^- \pi^0 \nu_\tau$, with low energy π^0
1 hadron + 1 strip	$\tau^- \to h^- \pi^0 \nu_\tau$, with both photons inside one strip
1 hadron + 2 strips	$\tau^- \to h^- \pi^0 \nu_\tau$, with photons well separated
3 hadron	$\tau^- \to h^- h^+ h^- \nu_\tau$, same secondary vertex

Hadronic tau reconstruction

- Shrinking Cone - size $\Delta R = (2.8\ \mathrm{GeV}/c)/p_T^\tau$ has to contain all the reconstructed hadrons and strips.
- $\vec{p}^\tau$ is required to match the direction of the input PFJet.
- Decay must be compatible with a corresponding resonance (ρ or a_1) hypothesis.

Tau isolation methods

Cut based isolation

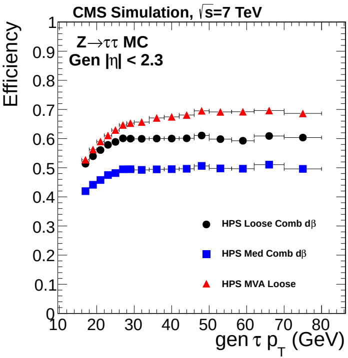
- Isolation cone of size $\Delta R = 0.5$ around the signal cone.
- Sum p_T of charged hadrons and photons outside the signal cone, but inside the isolation cone.
- Working points: Loose, Medium and Tight.
- Pile-up affects the isolation.

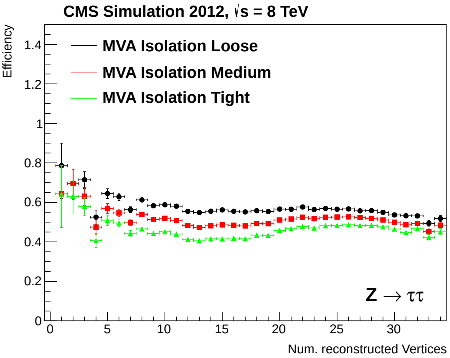
Charged pile-up: solved with a vertex constraint.
Neutral pile-up: estimated from charged pile-up tracks inside isolation cone.

Multivariate (MVA) isolation

- Based on energy deposits in five rings around tau direction.
- Uses a Boosted Decision Tree trained against *jet* $\rightarrow \tau$ misidentification.

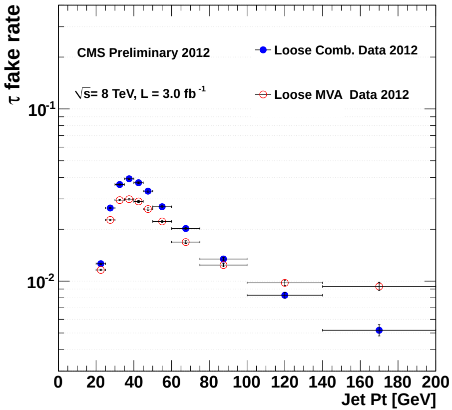
Tau reconstruction efficiency





- Efficiency is flat for $p_T > 25$ GeV for both cut-based and MVA isolation.
- MVA isolation provides the highest efficiency ($\sim 70\%$ for Loose working point).
- The dependence of efficiency on pile-up is weak.

Tau fake-rate



- Result obtained with W + Jet events.
- Fake rate lower than 3%.
- Fake rate with MVA isolation 10-20% lower than cut-based isolation.

Summary

- Tau reconstruction is very important for many physics analyses.
- Tau reconstruction in CMS is very good thanks to the HPS algorithm.
- The algorithm takes advantage of different tau lepton decay modes.
- Tau isolation uses two methods:
  - A well established and thoroughly validated cut-based approach.
  - MVA isolation, showing superior efficiency and fake rate.

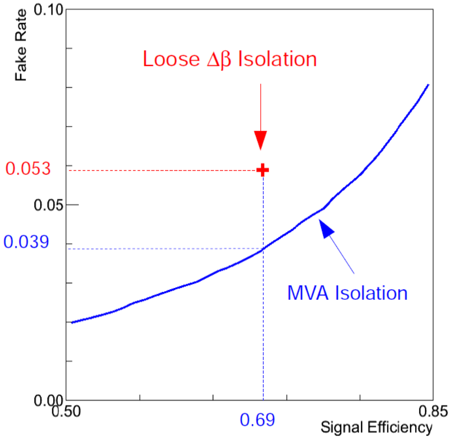
References

[1] CMS Collaboration, "Study of tau reconstruction algorithms using *pp* collision data collected at $\sqrt(s) = 7$ TeV", *CMS PAS* **PFT-10-004** (2010)

[2] CMS Collaboration, "Performance of tau reconstruction algorithms in 2010 data collected with CMS", *CMS PAS* **TAU-11-001** (2011)

[3] CMS Collaboration, CMS Particle Flow and Tau Identification Results, `https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsPFT`

Backup



- Performance comparison between cut-based and MVA isolation.