Hadronic Taus in CMS

Goals, Status, and Plans

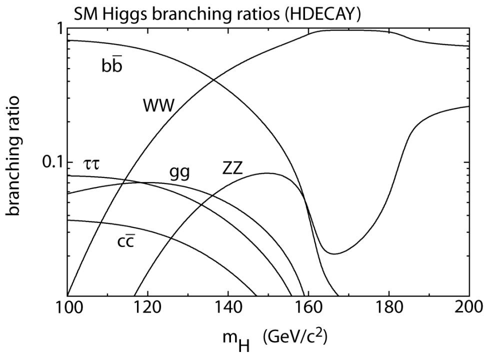
Eduardo E. Luiggi

University of Colorado at Boulder

US CMS JTerm IV
August 3, 2009

Why Taus?

- SM $H \rightarrow \tau\tau$ becomes important if SM Higgs is light as suggested by precision EWK data
- Measurement of b and τ decay modes of Higgs is important to verify that $V_{Hff} \propto m_f$
- MSSM models with large $\tan\beta$
  - $H/A \rightarrow \tau\tau$ are enhanced
  - For $m_{H\pm} < m_t - m_b$, $t \rightarrow bH^{\pm}$ with $H^{\pm}$ decaying to $\tau\nu_\tau \sim 100\%$
- Other SUSY searches: $\tilde{q} \rightarrow q\tilde{\chi}_2^0 \rightarrow q\tilde{\tau}\tau$



- But before any discovery claim can be made
  - $Z \rightarrow \tau\tau$

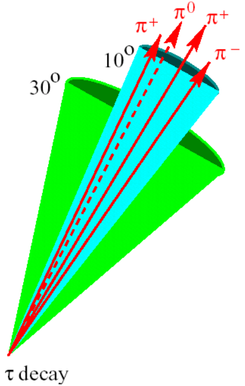
Experimental Signature and Challenges

Properties

- Taus decay hadronically $\sim$ 65% of the time ($c\tau = 87\mu$m).
- Low multiplicity:
  - $\sim$ 76.5% of hadronic decays are to 1 charged pion
  - $\sim$ 23.5% of hadronic decays are to 3 charged pions
  - Rarely to 5 or more charged pions

Challenges

- Visible decay products are soft due to escaping ν's
- Need to use low p_T threshold to preserve acceptance
- Multi-jet background is very high; Fake rates are at least an order of magnitude larger than for e's and μ's



Strategy

- Look for narrow isolated jets with low multiplicity and at least one track with relatively high p_T

Goals

- Provide efficient and well understood tau trigger, reconstruction, and identification suitable for a wide range of physics analyses
  - Higgs (light, charged)
  - SUSY
  - Z' like resonances
  - New, unexpected ...
- Real life puts constraints on what can be done, e.g.
  - Can't change trigger hardware
  - Can't remove material from the tracker
- ... and how fast it can be done
  - Lower acceptance and higher backgrounds require more data than for lighter leptons

Three Components

- Successful execution of physics program with taus relies on several inter-related ingredients

Triggers

- High efficiency at tolerable rate
- Ability to measure efficiency

Offline Reconstruction

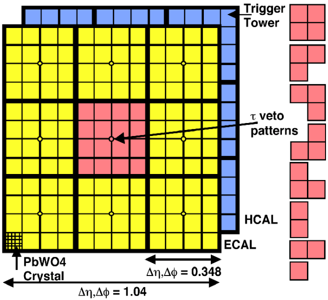
- High efficiency at acceptable fake rate
- Ability to understand and measure efficiency

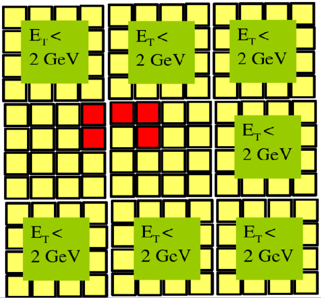
Standard candle proto-analyses

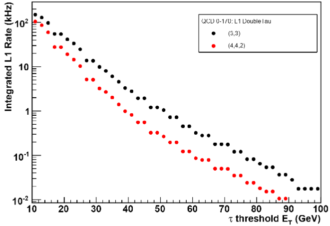
- Measurement of efficiencies requires reasonably clean samples
- Selection of clean samples can only be accomplished by advancing standard candle analyses, e.g., $Z \to \tau\tau$

Level–1 Tau Trigger

- Limited Calo info
- Reco Jets with $E_T > 10$ GeV at Level–1 are classified as: Tau–Jet, Central–Jet, or Forward–Jet.
- A jet with $N_{\text{cluster}} \leq 1$ (up to 2x2) in any of the 9 trigger regions is called a Tau–Jet.
- Improvement: For each trigger region check "partial isolation sum"; Only one region is allowed to fail.

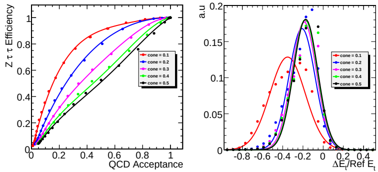




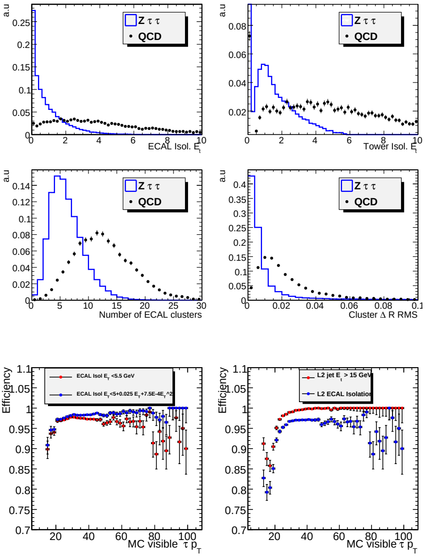


HLT: Level–2

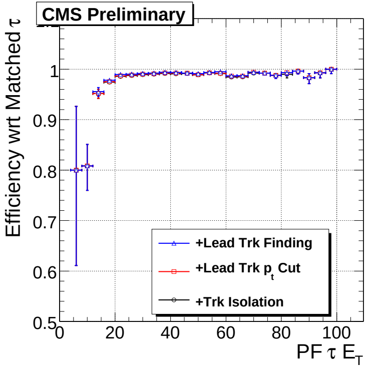
- Software based; detailed calo info allows for more sophisticated algorithms
- Online selection become similar to offline
- Jet candidates reconstructed using cone with $\Delta R = 0.2$; size of cone tuned to reduce QCD bg

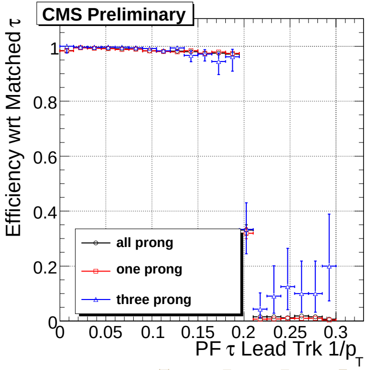


- Further QCD rejection can be obtained by exploiting differences in the energy profile and isolation properties between signal and QCD



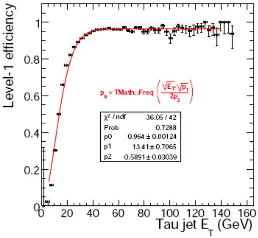
- Track based selections applied to jets passing L2
- These requirements are similar to those used offline
- Require a leading track with $p_T > 5$ GeV reconstructed around the L2 jet direction (L2.5)
- Require no tracks with $p_T > 1$ GeV in isolation annulus around lead track (L3)



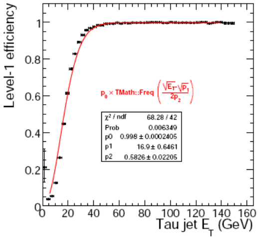


Measuring Tau Trigger Efficiency with Early Data

- Very hard to select an unbiased sample of clean taus due to large BGs
  - Can't apply "tag and probe" techniques like for $Z \rightarrow ee$ or $Z \rightarrow \mu\mu$
- $100pb^{-1}$: Expect $\sim$ 10k after trigger and a few hundred after offline selection
  - Large statistical uncertainty $\sim$ 10%
  - Need at least $1fb^{-1}$ to establish full trigger efficiency from real taus
- Solution: Use "tau–like" objects (fakes satisfy offline selections)
  - Parametrize eff as functions of p_T, η
  - Factorize efficiencies: $\epsilon_{\mathrm{tot}} = \epsilon_{\mathrm{L1}} + \epsilon_{\mathrm{HLT}} + \epsilon_{\mathrm{offline}}$

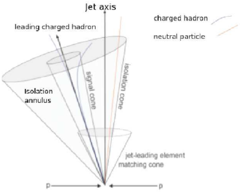


$Z \rightarrow \tau\tau$

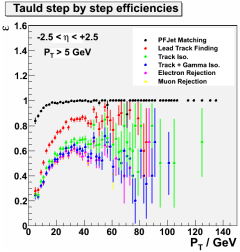


QCD

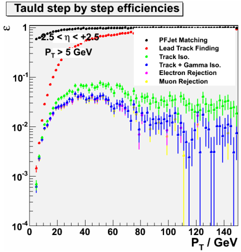
- Offline selection done in two steps:
  - Common Pre–selection: Basis for all analyses with taus; simple, robust, and very similar to online selections
  - High–Level tau identification algorithms: Suitable to be adapted for individual physics analyses
- Recent Improvements to Core ID
  - Use lead candidate (charged or neutral pion)
  - Incorporation of MVA tools
  - Better treatment of photon conversions



$Z \to \tau\tau$



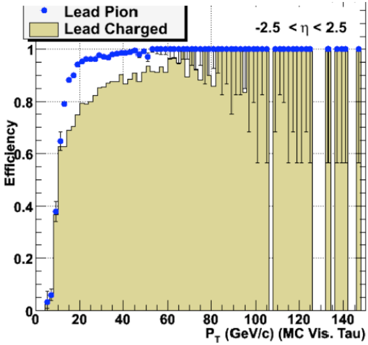
QCD



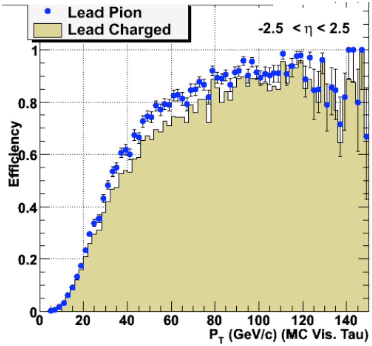
Improvements: Lead Candidate

- Instead of requiring a track above threshold ($p_T > 5$ GeV) ask for a track or neutral pion candidate with $p_T > 5$ GeV
  - Recovers a whole class of previously lost tau candidates allowing large improvement in efficiency, especially in low E_T region
  - Yields a moderate increase in QCD background

$Z \rightarrow \tau\tau$



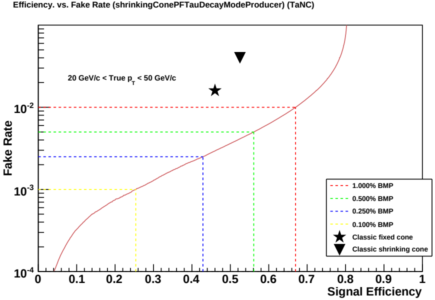
QCD



Improvements: MVA Tools

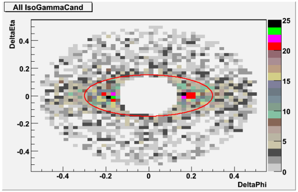
- Categorize different tau decay topology according to number of charged and neutral pions
- Train specific NN for each mode
- Use NN on respective decay mode when discriminating
- PFTauDiscriminator for each benchmark point for estimated fake rates
    - 0.10%
    - 0.25%
    - 0.50%
    - 1.0%

- Allowed Modes
    - $\pi^{\pm}$
    - $\pi^{\pm}\pi^{0}$
    - $\pi^{\pm}\pi^{0}\pi^{0}$
    - $\pi^{\pm}\pi^{\pm}\pi^{+}$
    - $\pi^{\pm}\pi^{\pm}\pi^{+}\pi^{0}$

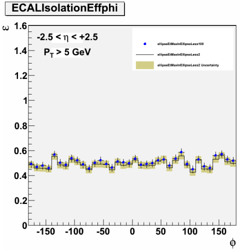


Improvements: Photon Conversions

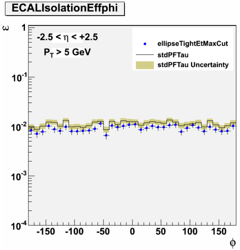
- Conversions degrade ID efficiency
  - A photon from a signal π^0 can convert into e^+e^- pair; the charged lepton drifts away due the magnetic field into the isolation annulus
  - If no tracks PF will classify the particle as photon in isolation annulus
- Solution
  - The drift only occurs in the phi direction
  - "Expand" signal region for PFGammaCandidates using ellipse with $R_\phi > R_\eta$



$Z \rightarrow \tau\tau$



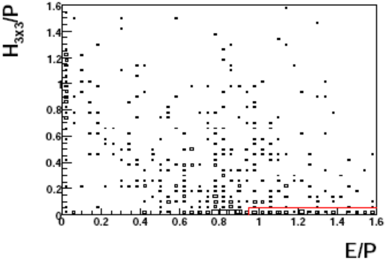
QCD

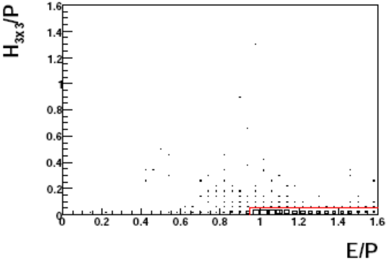


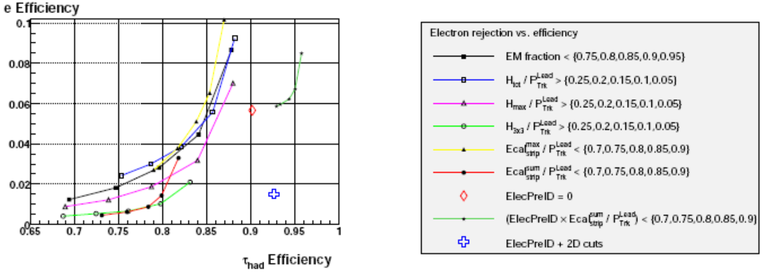
High Level ID

- Algorithms aimed at obtaining high purity sample
  - Electron rejection
  - Muon rejection
  - Charged particle multiplicity
  - Neutral particle multiplicity
  - Tau–Jet profile in signal cone and isolation annulus
- Some cuts
  - E/P: Sum energy of ECAL clusters within $\Delta\eta < 0.04$ wrt to the extrapolated impact point of leading track on the ECAL surface divided by lead track momentum
  - $H_{3\times3}/P$: Sum energy of HCAL clusters within $\Delta R < 0.184$ ($\sim$ area formed by a set of 3×3 calo towers) wrt to the extrapolated impact point of leading track on the calo surface divided by lead track momentum
- Re-optimization and extensions likely as data becomes available

Electron Rejection







Summary

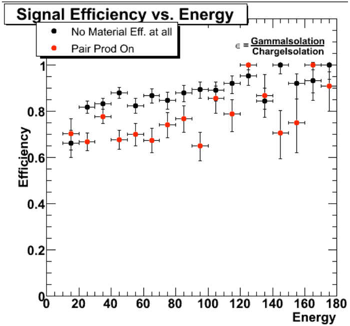
- CMS is planning a very rich physics programs with taus in the final state
  - SM Higgs
  - H/A
  - SUSY cascades
  - Z'
  - others
- Tau reconstruction techniques are very mature at the moment
- Improvements continue to be made
  - Photon based seeding for taus
  - Incorporation of MVA tools to reduce backgrounds
  - Smarter isolation regions for gamma conversions
- Work on standard candle analysis is ongoing
- Preparing to measure trigger efficiency with early data
- Getting ready for real data

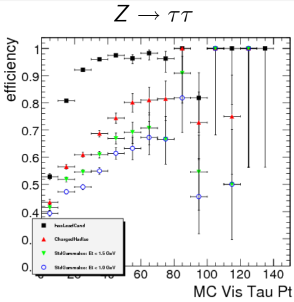
Backup: Tau Trigger Paths

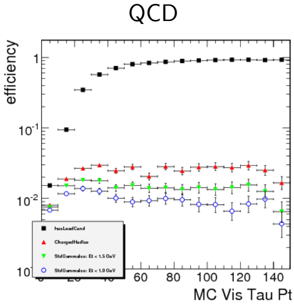
Trigger Menu	Trigger Path	Threshold
8×10^{29} cm^{-2}s^{-1}	HLT_SingleLooseIsoTau20	SingleTauJet20 OR SingleJet30
	HLT_DoubleLooseIsoTau15	DoubleTauJet14 OR DoubleJet30
10^{31} cm^{-2}s^{-1}	HLT_SingleLooseIsoTau30_Trk5	SingleTauJet40 OR SingleJet100
	HLT_DoubleLooseIsoTau15_Trk5	DoubleTauJet30 OR DoubleJet70

Trigger Menu	Trigger Path	Threshold
8×10^{29} cm^{-2}s^{-1}	HLT_SingleLooseIsoTau20	One tau $E_T > 20$
	HLT_DoubleLooseIsoTau15	Two taus $E_T > 15$
10^{31} cm^{-2}s^{-1}	HLT_SingleLooseIsoTau30_Trk5	One tau $E_T > 30$
	HLT_DoubleLooseIsoTau15_Trk5	Two taus $E_T > 15$

Path	Level–1	Level–2	Level–2.5	Level–3
HLT_SingleLooseIsoTau30_Trk5 (wrt MC)	39%	10%	8%	7%
HLT_SingleLooseIsoTau30_Trk5 (wrt iso Tau)	42%	10%	10%	9%
HLT_DoubleLooseIsoTau15_Trk5 (wrt MC)	42%	36%	23%	–
HLT_DoubleLooseIsoTau15_Trk5 (wrt iso Tau)	43%	37%	34%	–







- Temporary Solution: Increse threshold in ECAL isolation region to 1.5 GeV
  - Recover efficiency
  - Loose rejection power