Tau Identification at the Tevatron

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Outline

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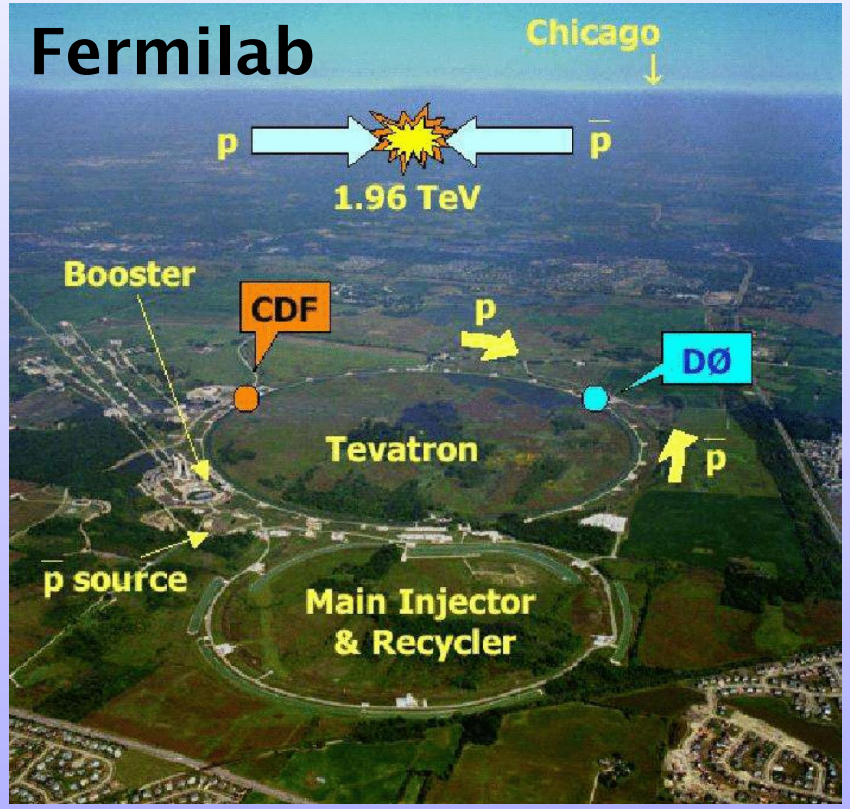
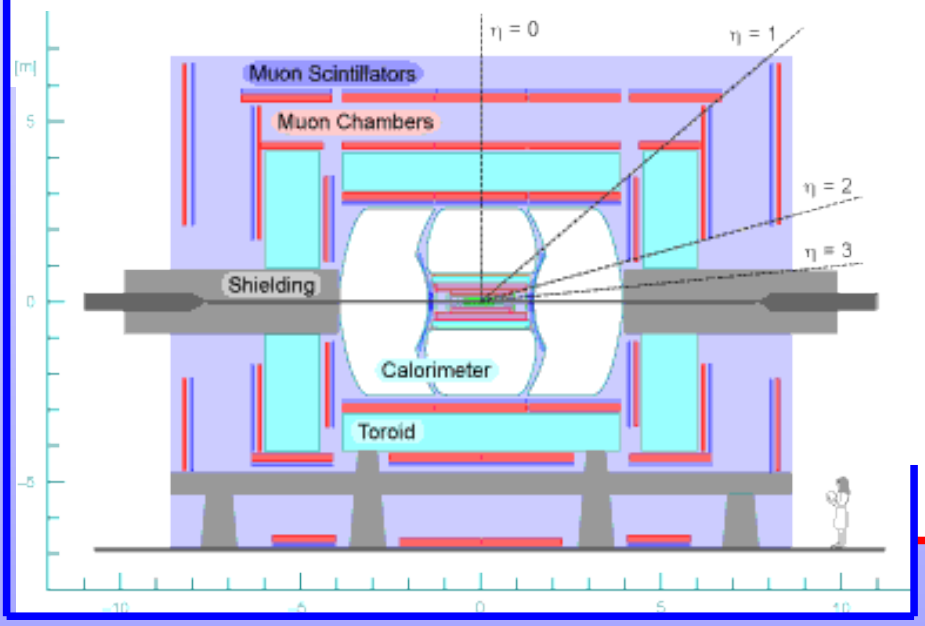
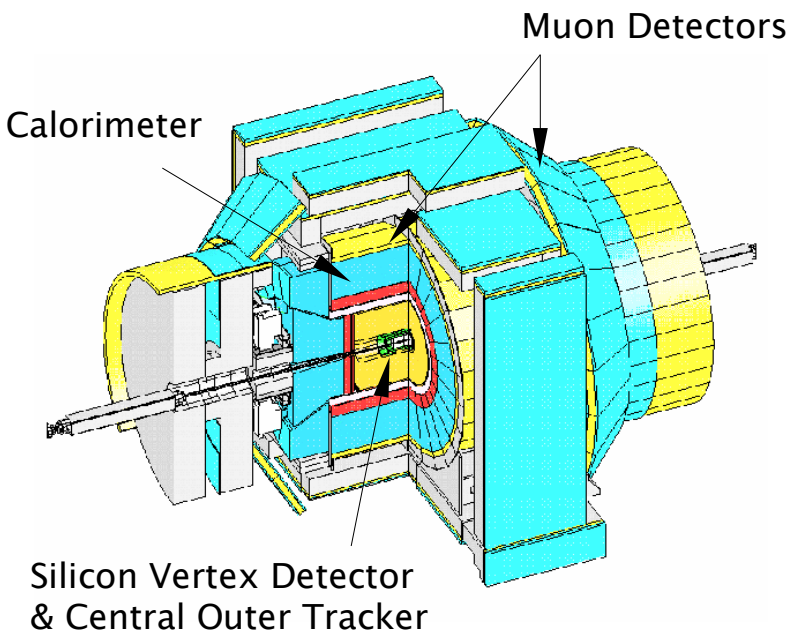


Detectors

DØ detector



CDF II detector



Why Detect Taus?

- Can potentially increase acceptance for all channels with leptons.
  - Assuming same efficiency for any lepton ID:
    - Single lepton channel, 1.5 times acceptance
    - Di-lepton channel, 2 times acceptance
    - Tri-lepton channel, 3 times acceptance
- Largest coupling of Higgs to leptons is to taus.
- Minimal SUSY models with large tanβ favour decays to taus.
  - $H^{\pm}$ decays to $\tau\upsilon$.
  - SUSY Higgs couplings to $\tau\tau$ increase with tanβ.
- Also important at the LHC.

Tau Properties

- Mass = 1.78 GeV
- Short lifetime, $c\tau$ = 87 μm.
- Spin ½ -> Decay angle distributions depend on the τ polarization
- Main decay channels:

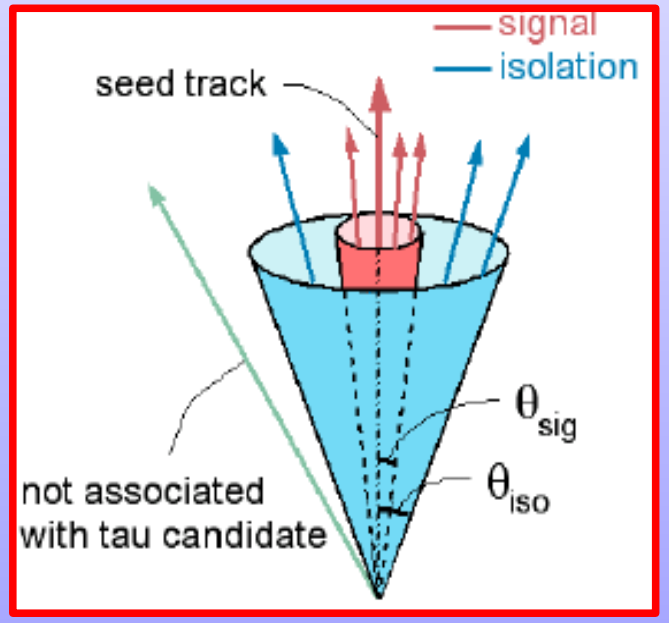
Final State	BR (%)	Decay Type	
$e + \upsilon_e + \upsilon_\tau$	17.8	Leptonic	τ_e
$\mu + \upsilon_\mu + \upsilon_\tau$	17.4	35.2	τ_μ
$\pi(/K) + \upsilon_\tau$	11.8	1-Prong	
$\pi(/K) + \upsilon_\tau + \geq 1\pi^0$	36.9	48.7	τ_h
$\pi\pi\pi + \geq 0\pi^0 + \nu_\tau$	13.9	3-Prong	

Detect with Standard electron / muon ID.

Need dedicated tau ID.

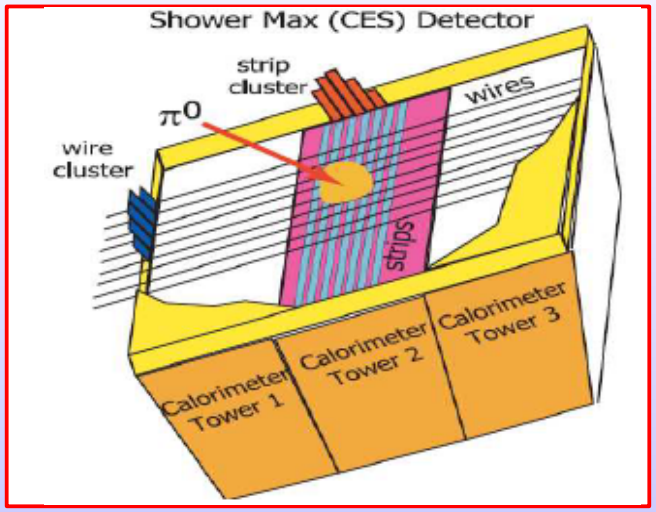
Tau Reconstruction at CDF

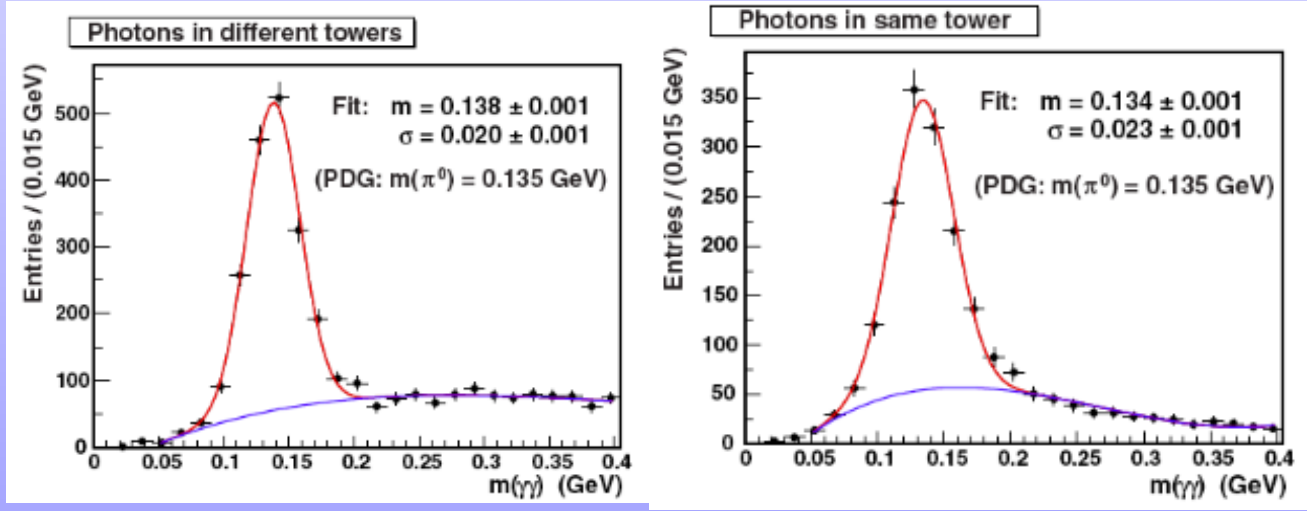
- Start with a calorimeter tower, $E_T > 6$ GeV.
- Add up to 6 contiguous towers with $E_T > 1$ GeV.
- Associate tracks with the calorimeter cluster, must have at least one track with $p_T > 6$ GeV.
- Tau cone defined by seed track, half angle, $\theta_{sig} = 50 - 175$ mrad, depends on cluster energy.
- Isolation annulus, $30° < \theta < \theta_{sig.}$
- 1 or 3 tracks, charge = 1, in θ_{sig}
- Reconstruct π^0's.
- Require M(tracks,π^0's) < 1.8 GeV



π^0 Reconstruction at CDF

- The central electromagnetic shower maximum detector (CES) allows the identification of π^0s.
- This is a proportional strip / wire drift chamber 6 rad. lengths inside the EM calorimeter.





Tau Reconstruction at DØ

- Start with calorimeter cluster, simple cone algorithm, cone size R = 0.3.
- Isolation cone, R = 0.5, require rms < 0.25
  - rms = Energy weighted width of cluster = $\sqrt{\sum_{i=1}^{n}(\Delta\phi_i^2 E_{T_i}/E_T + \Delta\eta_i^2 E_{T_i}/E_T)}$
- Associate EM subclusters:
  - Nearest neighbour algorithm in 3rd EM layer, cluster energy > 800 MeV. EM cells in other layers and preshower hits are attached to the found EM3 cluster.
- Associate up to 3 tracks with p_T > 1.5 GeV to the tau candidate.

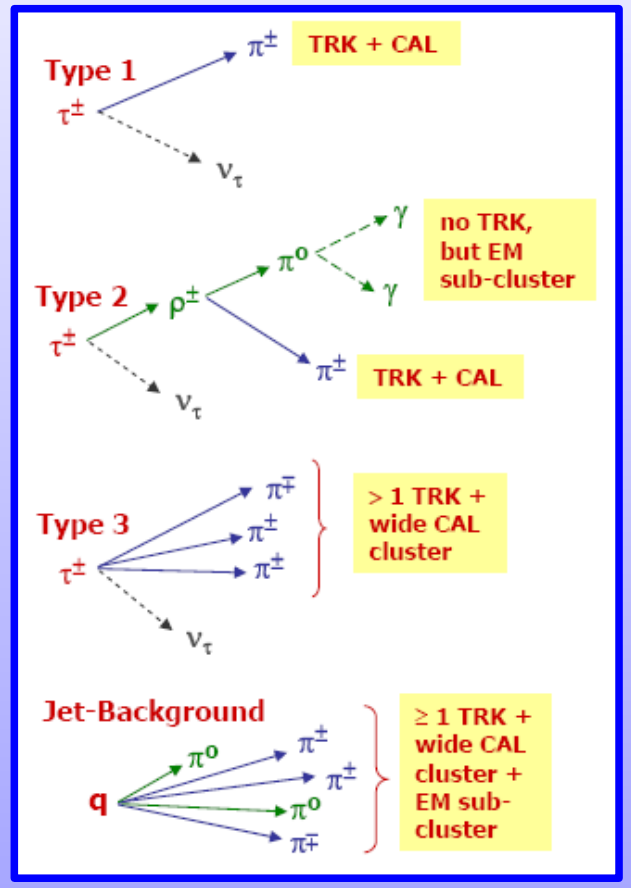
Tau Reconstruction at DØ

- Split tau candidates into 3 types, based on detector signature:

  1) One track + cal. cluster, no EM subclusters.

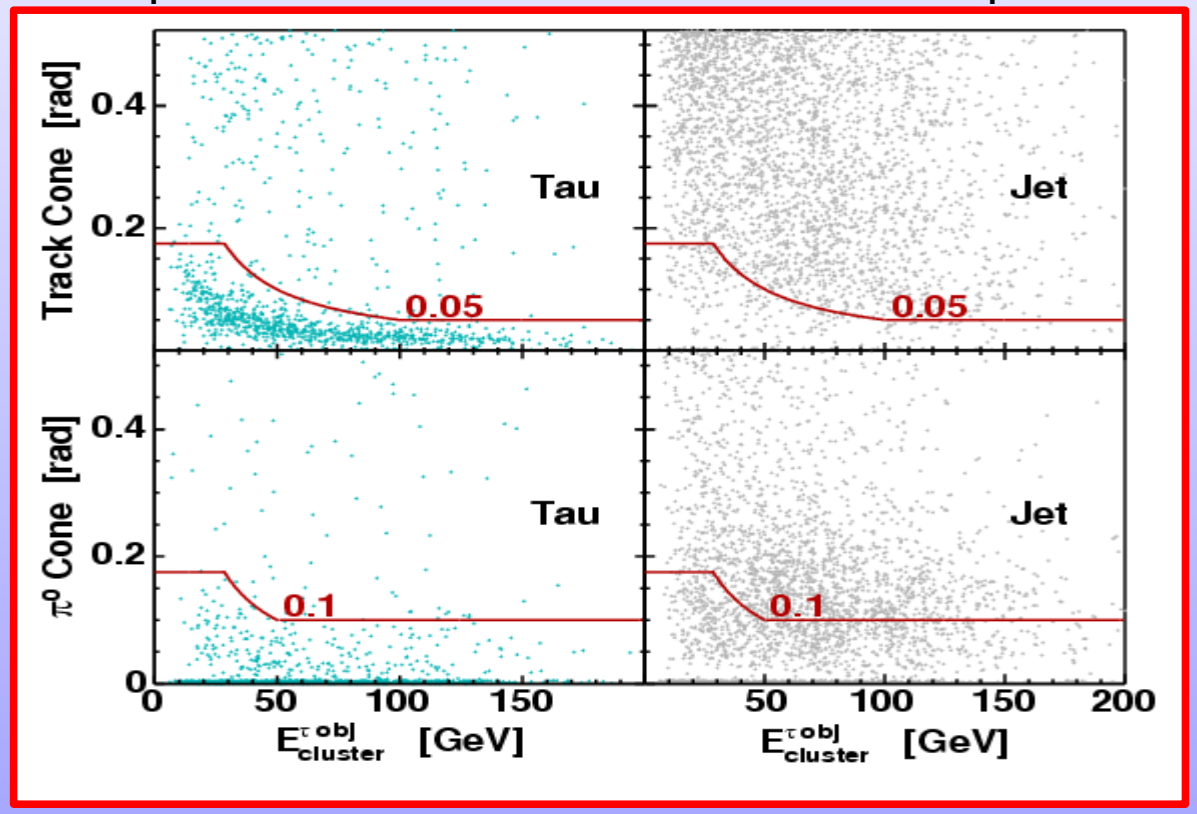
  2) One track + cal. cluster and > 0 EM subclusters.

  3) At least two tracks + cal. cluster and ≥ 0 EM subclusters



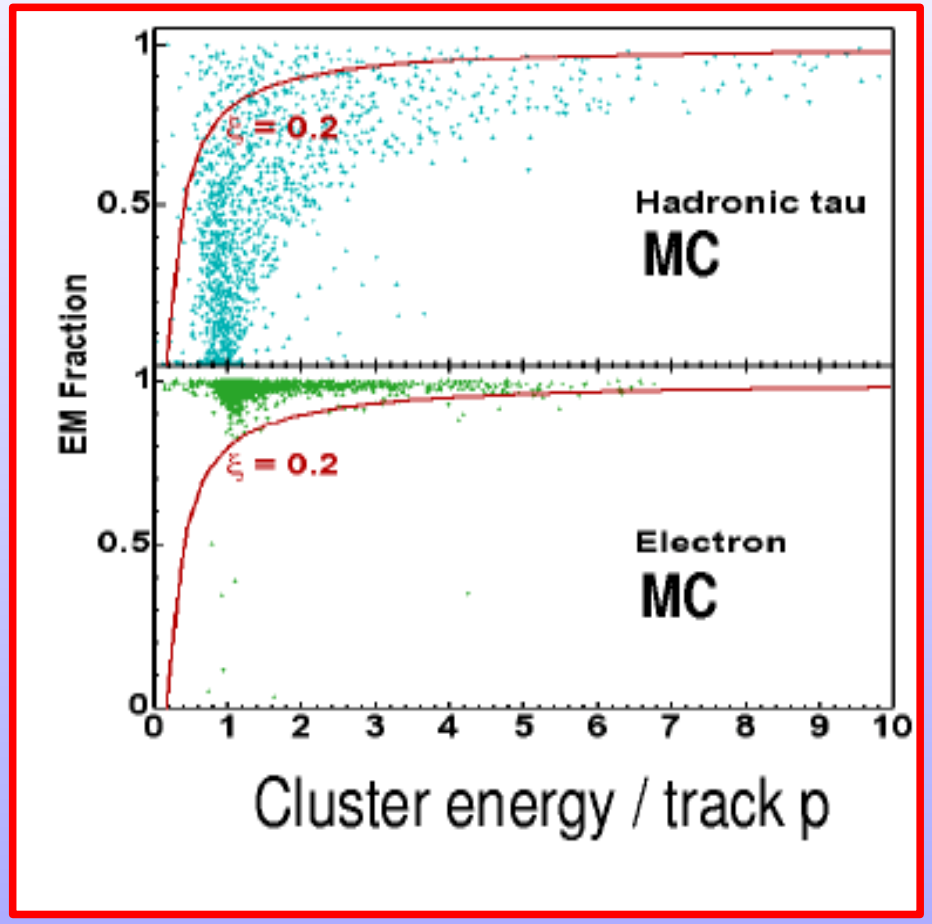
Jet-τ Separation at CDF

- Use cone sizes that vary with energy, one for tracks, $p_T > 1$ GeV one for π^0, $p_T > 1$ GeV :



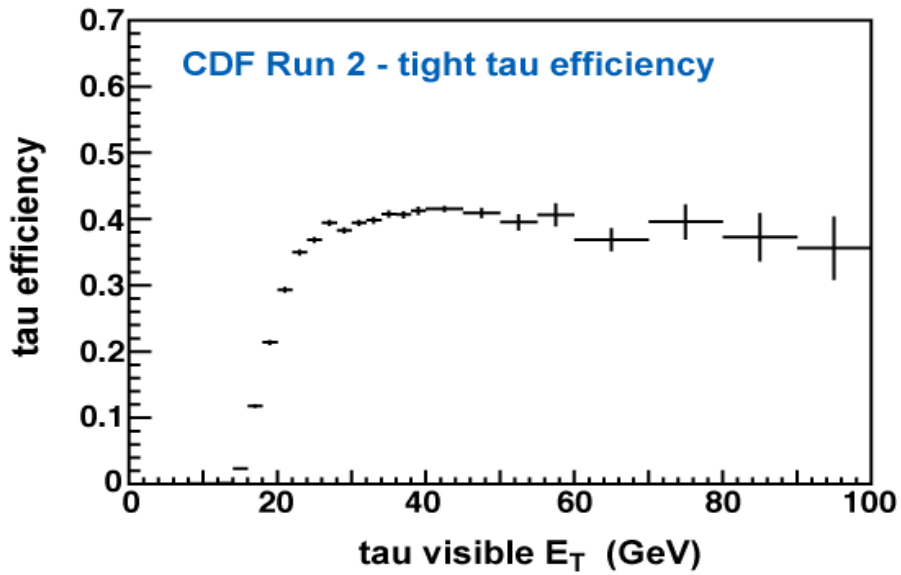
e – τ Separation at CDF

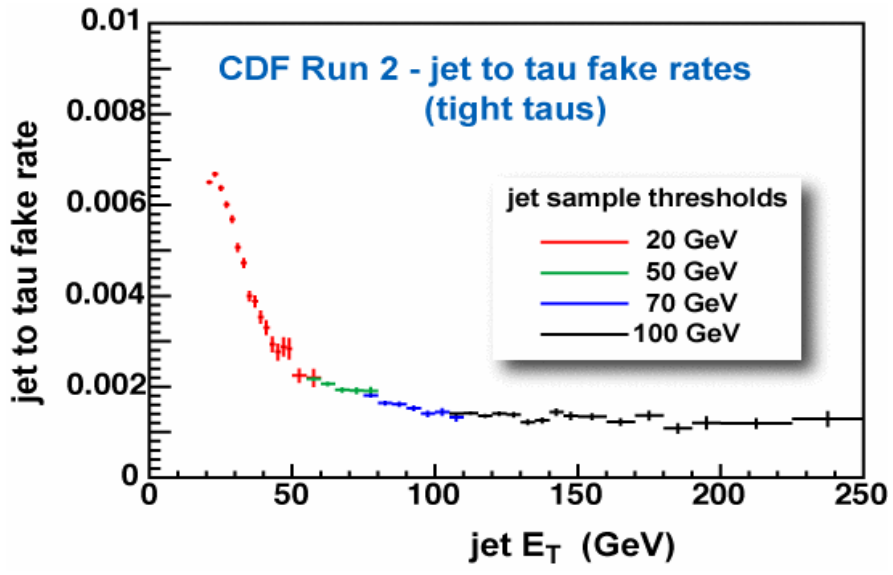
- Need to also remove electrons that are identified as hadronic taus.
- Use the cut:
  - $\xi \equiv E_H / \Sigma p_{trk} > 0.2$
  - Where E_H is the energy deposited in the hadronic part of the calorimeter.



Tau Efficiency & Fake Rate at CDF

- Tau efficiency after tight selection :
- Jet fake rate, using jet triggers :





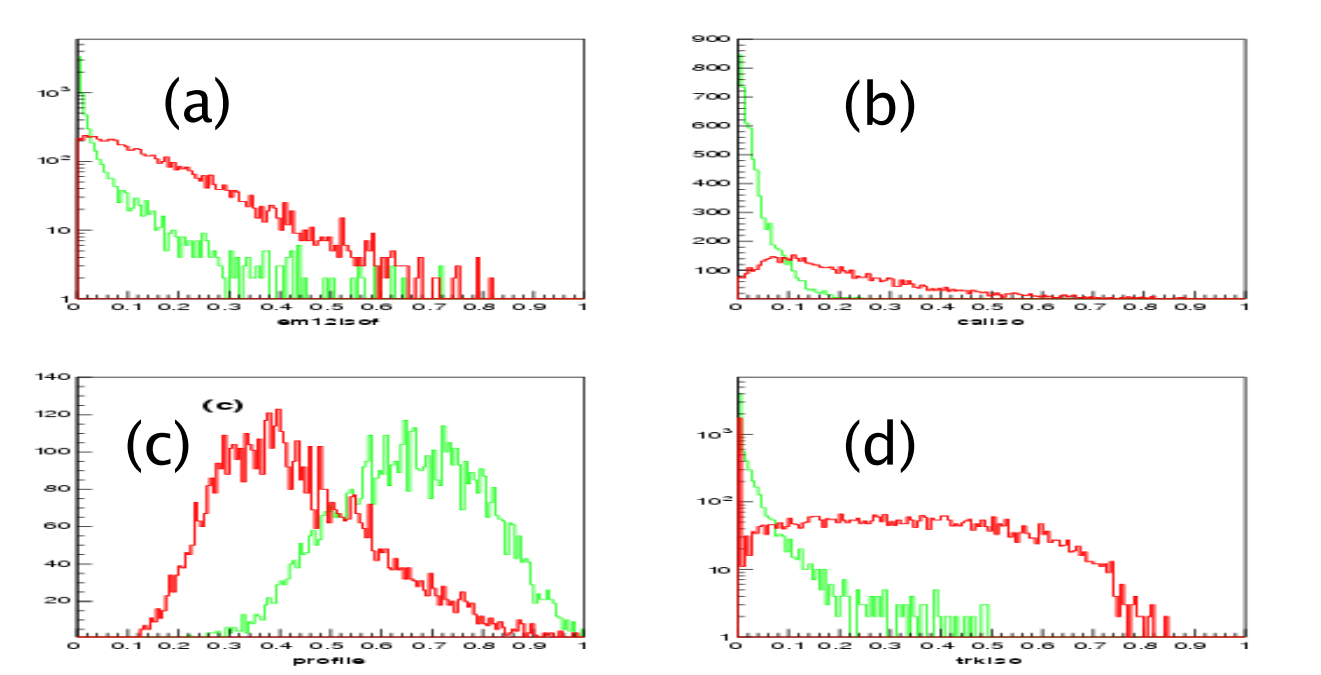
- Note algorithm only efficient at high p_T.
- Efficiency, ϵ_h is for τ_h, so total efficiency, $\epsilon = 0.65 \times \epsilon_h$

Jet-τ Separation at DØ

- Use a Neural Network (NN) that uses both calorimeter and tracking variables.
- Example variables:
  - Caliso = $(E_T^{R=0.5} - E_T^{R=0.3}) / E_T^{R=0.3}$
  - Profile = $(E_T^{\text{Tower 1}} + E_T^{\text{Tower 2}}) / E_T$
  - Trkiso = $\Sigma p_T^{\text{Trks in Cone R = 0.5}} / \Sigma p_T^{\text{Tau Trks}}$
  - EM Iso Fraction = $(E^{EM1} + E^{EM2}) / E$
- One Neural Network per tau type, trained with:
  - Signal: τ MC
  - Background: Jets from data

Jet-τ Separation at DØ

- Example NN input variables for tau type 1, signal (MC τ) and background (jets from data).

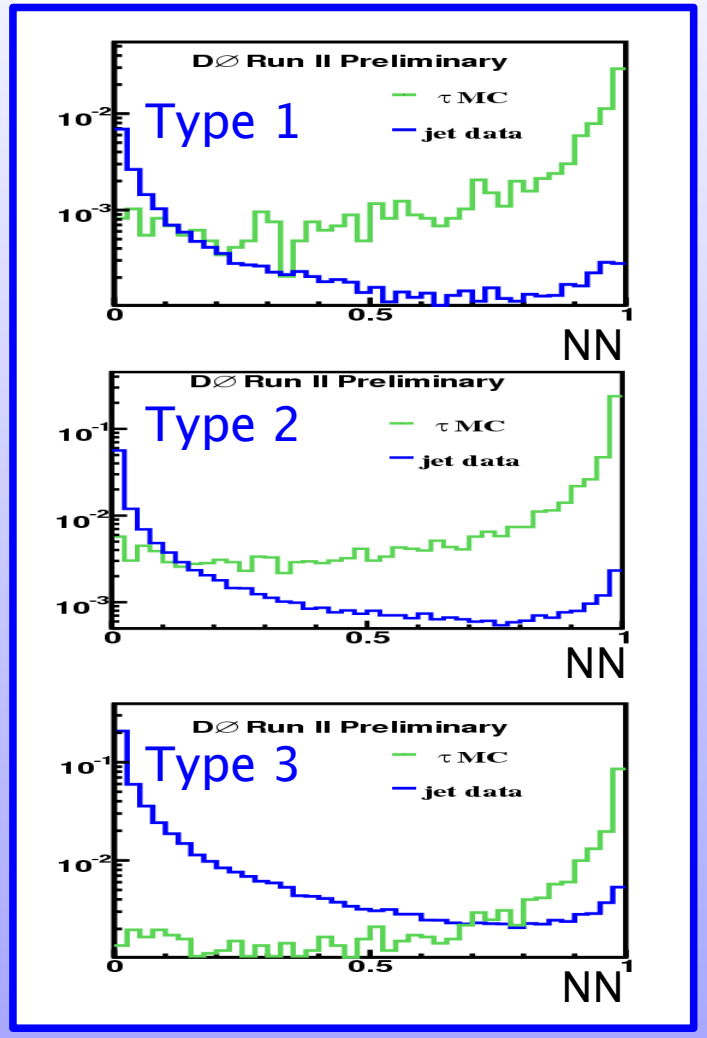


(a) EM Iso Fraction, (b) caliso, (c) profile, (d) trkiso

Jet-τ Separation at DØ

- Efficiencies (%) for taus with $E_T > 15$ GeV, $|\eta| < 2.5$:

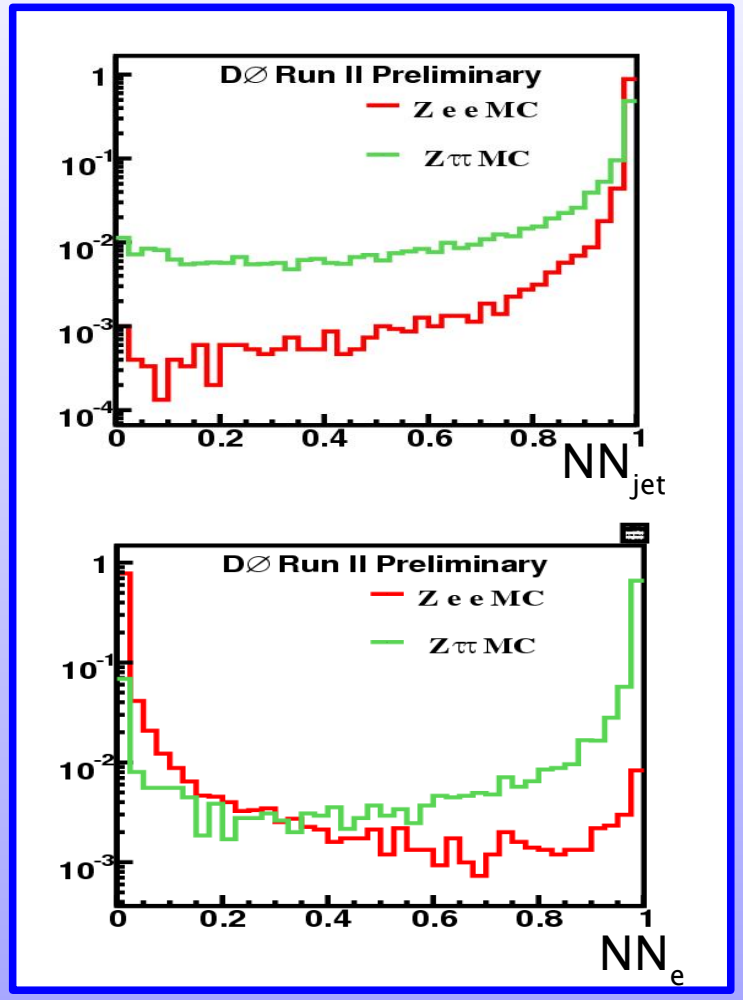
Tau Type	1	2	3
Reconstruction			
Jets	1.5	10	38
Taus	9.1	50	20
NN > 0.9			
Jets	0.04	0.2	0.8
Taus	5.8	37	13



e-τ Separation at DØ

- Electrons look a lot like tau type 2 candidates.
- The Neural Network trained against jets (NN_{jet}) is of no use against electrons.
- Train a separate Neural Network (NN_e) to separate electrons from taus.
- Efficiency for type 2 taus, $20 < E_T < 40$ GeV, decaying to hadrons, compared to electrons:

	Efficiency (%)	
	$NN_{jet} > 0.9$	$NN_e > 0.5$
e	98	3.4
τ	34	30



Physics Results with Taus

Z -> ττ Cross-Section

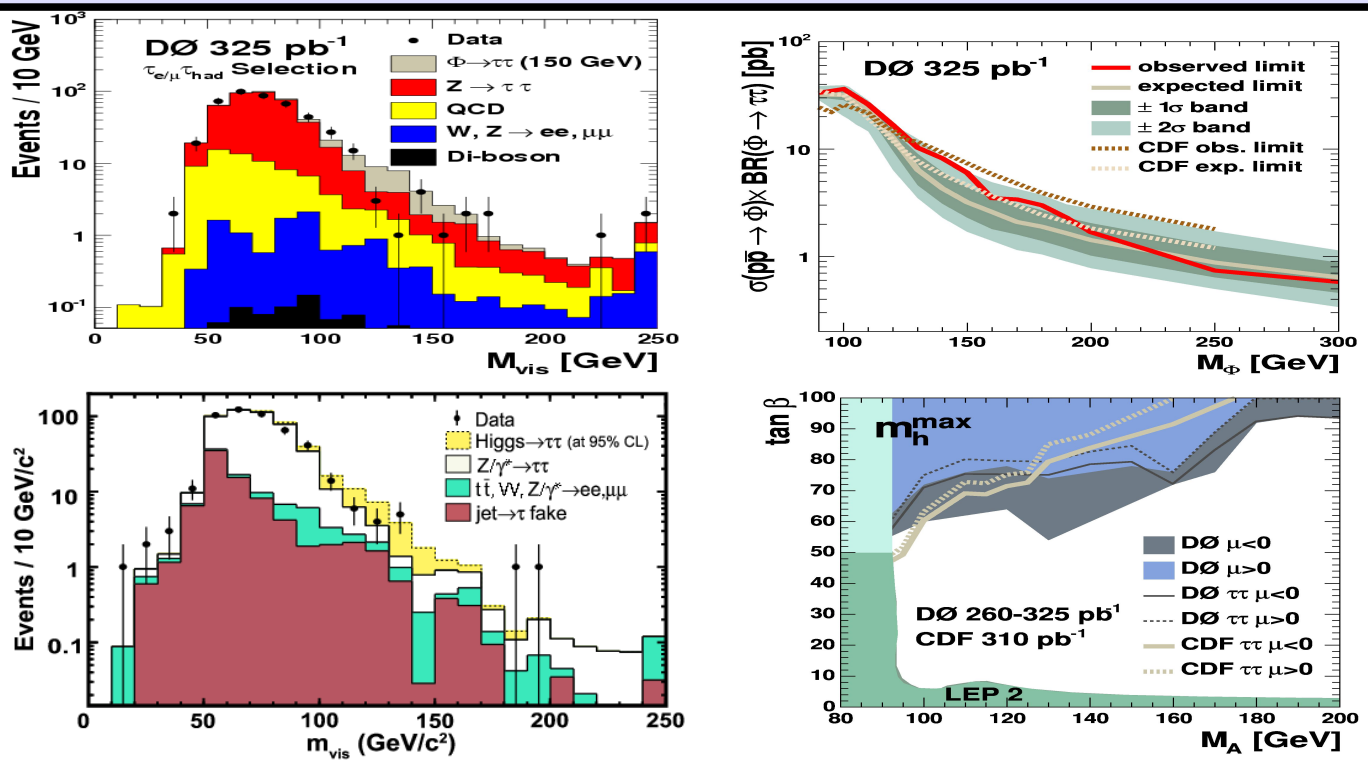
- This is a benchmark measurment – tests how the tau ID algorithms perform on data.
- CDF, measured in $\tau_e\tau_h$ channel:
  - σxBr = 265 ± 20 (stat) ± 21 (sys) ± 15 (lumi) pb
- DØ, measured in $\tau_\mu\tau_{e,h}$ channel:
  - σxBr = 237 ± 15 (stat) ± 18 (sys) ± 15 (lumi) pb

PRD 71, 072004 (2005)

- Good agreement with the NNLO calculations.

MSSM Higgs -> ττ Searches

- In MSSM, couplings to τ get enhanced by tanβ.
- Use M_{Vis}, the invariant mass of the sum of the taus plus the missing transverse energy to set the limit.



CDF: PRL 96, 011802

DØ: Submitted to PRL, arXiv:hep-ex/0605009

Conclusions

- DØ and CDF both have effective, dedicated high p_T hadronic tau ID.
- Tau efficiencies close to 50% can be achieved with jet rejections of 1% or better.
- Methods have been validated with $Z \to \tau\tau$ cross section.
- Taus are playing an important role in the search for new physics at the Tevatron

Backup

Full list of Variables for DØ Neural Networks

- Caliso = $(E_T^{R=0.5} - E_T^{R=0.3}) / E_T^{R=0.3}$
- Trkiso = $\Sigma p_T^{\text{trks in } R=0.5} / \Sigma p_T^{\text{tau trks}}$
- Profile = $(E_T^{\text{Tower 1}} + E_T^{\text{Tower 2}}) / E_T$
- EM Isolation Fraction = $(E^{EM1} + E^{EM2}) / E$
- Tau RMS
- EM fraction
- Hadronic fraction
- EM profile = $E_T^{\text{EM subclusters}} / E_T^{EM3}$
- Angle between sum of tau tracks and sum of EM-subcluster(s)
- Calorimeter-Track Correlation = $E_T / (E_T + \Sigma p_T^{\text{tau trks}})$