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Tau Reconstruction

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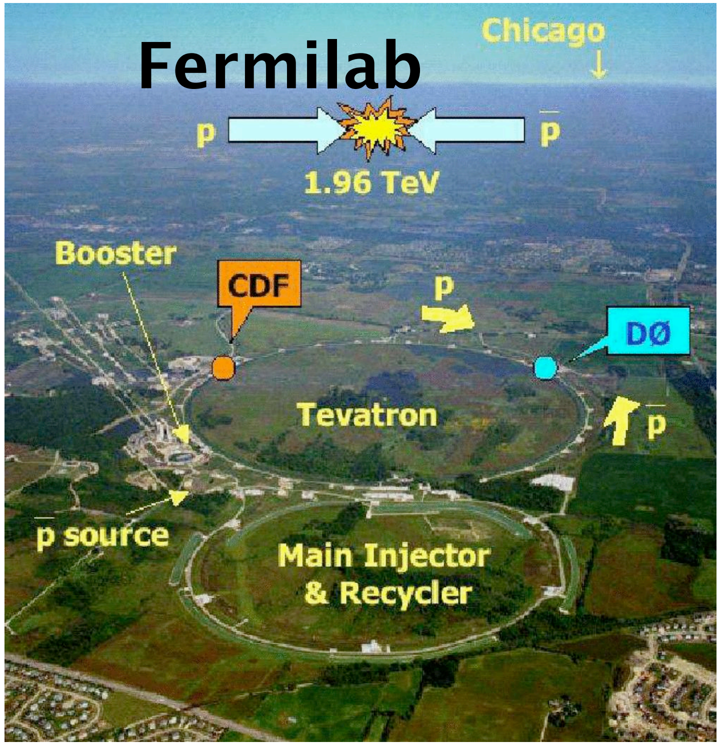
YETI'08, Durham
January 2008

Thanks to Cristobal Cuenca Almenar (CDF)

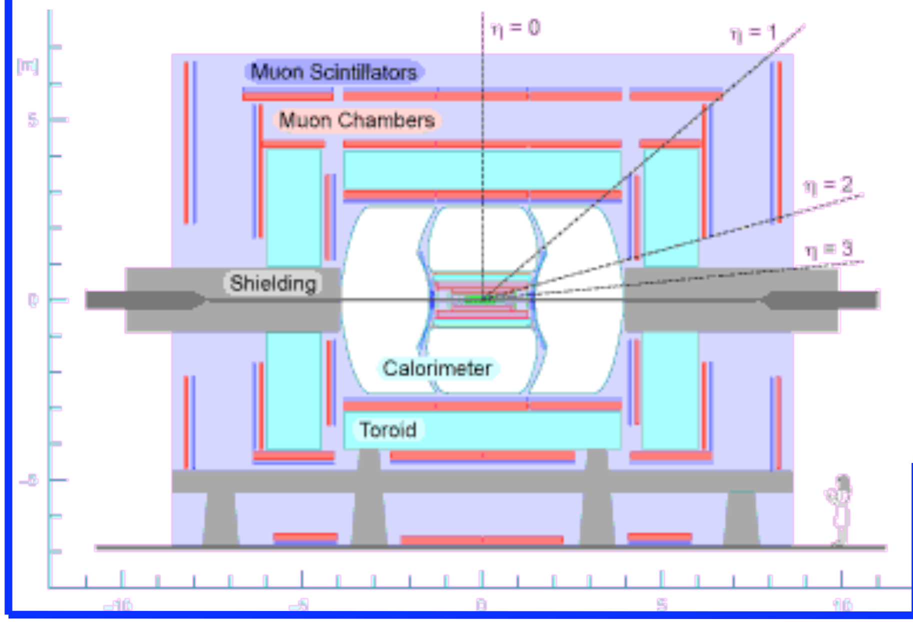
Outline

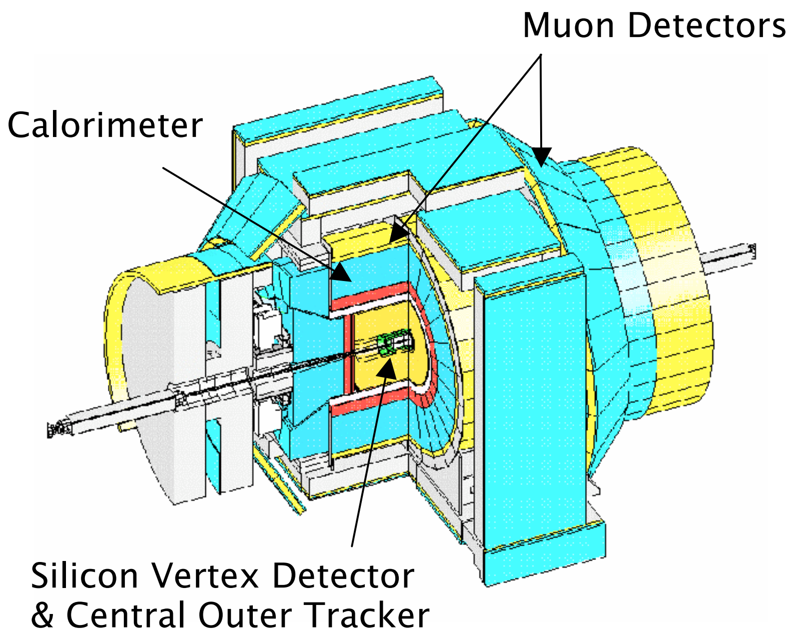
- Detectors
- Motivation
- Tau Properties + Reconstruction
- Background Reduction
  - Cuts – CDF
  - Neural Network – DØ
- Tau Energy Scale
- Physics with Taus
- Conclusion



Tau reconstruction challenging, requires
- tracking
- calorimetry
- electron identification
- muon identification

DØ **Detector**





CDF **Detector**

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Why Detect Taus?

- Can potentially increase acceptance for all channels with leptons (e.g. SUSY trileptons).
  - Assuming same efficiency (certainly wrong!) for any lepton ID:
    - Single lepton channel: 1.5 x acceptance
    - Di-lepton channel: 2 x acceptance
    - Tri-lepton channel: 3 x acceptance
- MSSM with large tanβ favour Higgs decays to taus.
  - BR Higgs to ττ about 10% in MSSM.
- bb final states suffer from large backgrounds
- Associated SM Higgs producion (WH,ZH) with W,Z to taus
- 3rd generation Leptoquarks and other new phenomena that couple to taus
- Will be very important at the LHC.

Tau Properties

- Mass = 1.78 GeV
- $c\tau$ = 87 μm (could look for displaced tracks).
- Kinematic distributions depend on the τ polarization, need special MC: TAUOLA.
- Main decay channels:

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

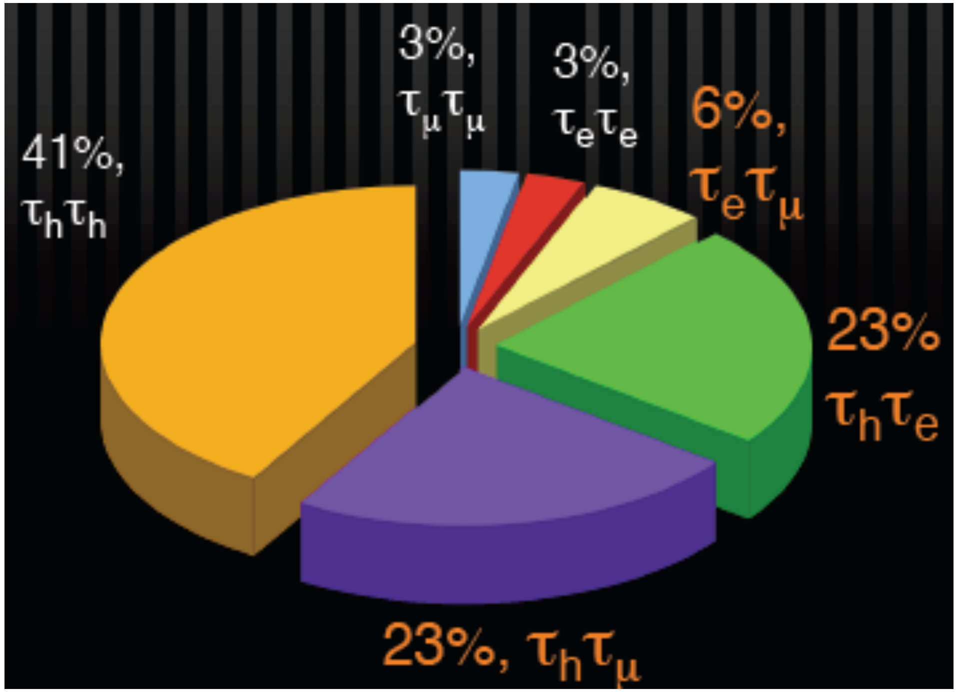
Detect with standard electron or muon ID

Need dedicated tau ID

Di-tau Final States

Drell-Yan background

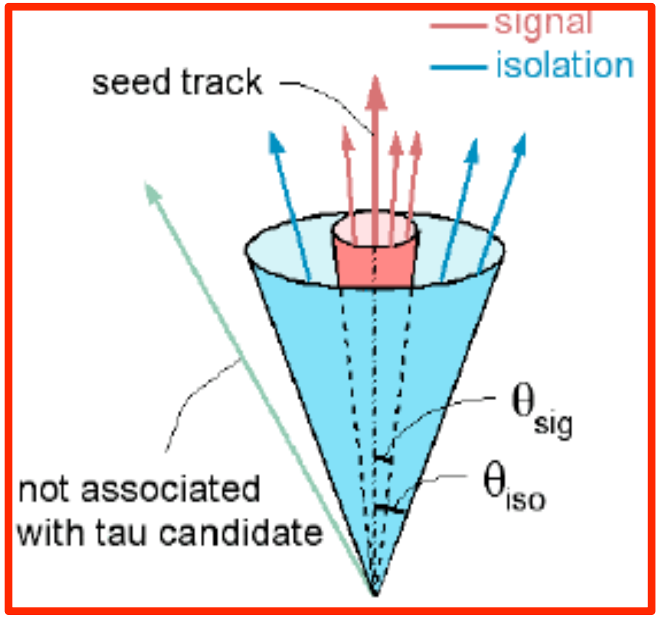
large QCD background



di-tau final states currently studied at Tevatr

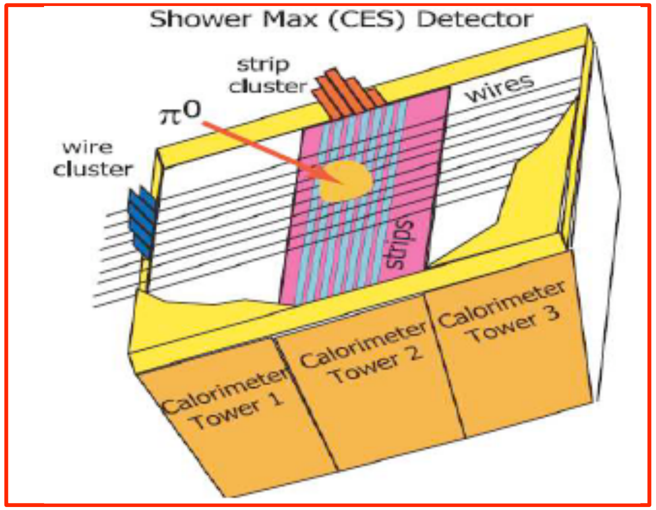
Tau Reconstruction at CDF

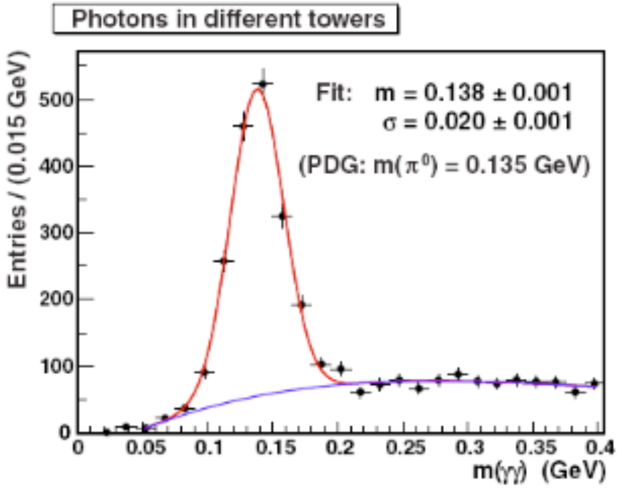
- Start with a calorimeter tower, $E_T > 6$ GeV.
- Add up to six contiguous towers with $E_T > 1$ GeV.
- Associate tracks with the calorimeter cluster, must have at least one track with $p_T > 6$ GeV (seed track).
- Tau cone defined by seed track, half angle, $\theta_{sig} = 50 - 175$ mrad, depends on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

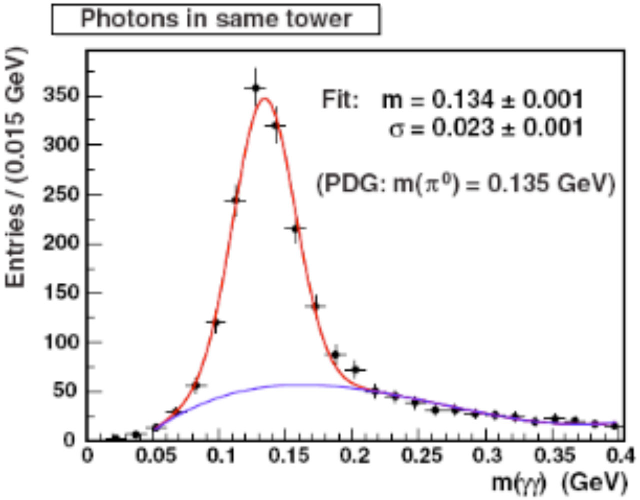


π^0 Reconstruction at CDF

- 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 energy weighted sum of clusters (rms) to be < 0.25

$$rms = \sqrt{\sum_{i=1}^{n} \frac{(\Delta\phi_i)^2 E_{T_i}}{E_T} + \frac{(\Delta\eta_i)^2 E_{T_i}}{E_T}} \qquad \eta = -\ln\tan(\theta/2$$

- Associate electromagnetic (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 three tracks with p_T > 1.5 GeV to the tau candidate.

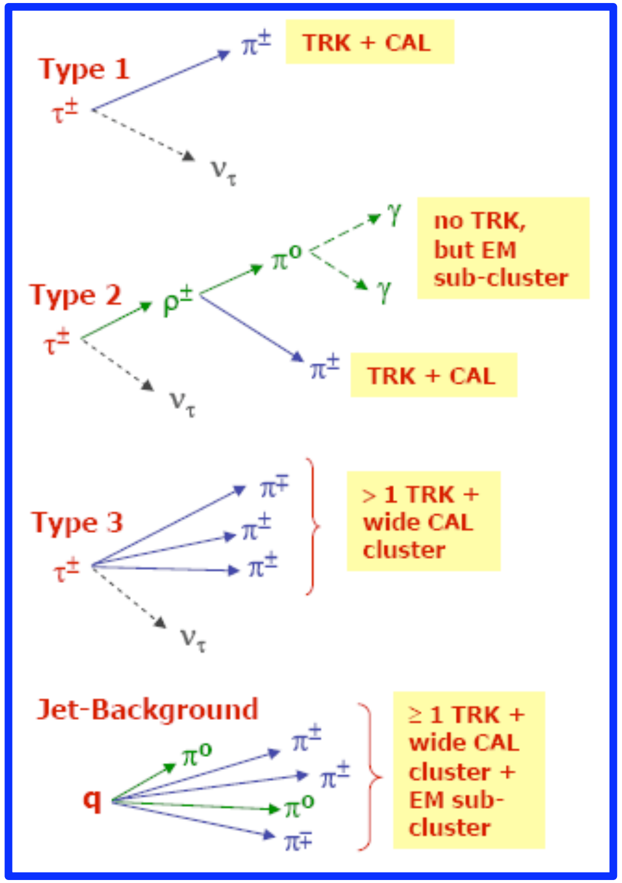
Tau Reconstruction at DØ

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

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

  2) One track + calorimeter cluster and at least one EM subcluster.

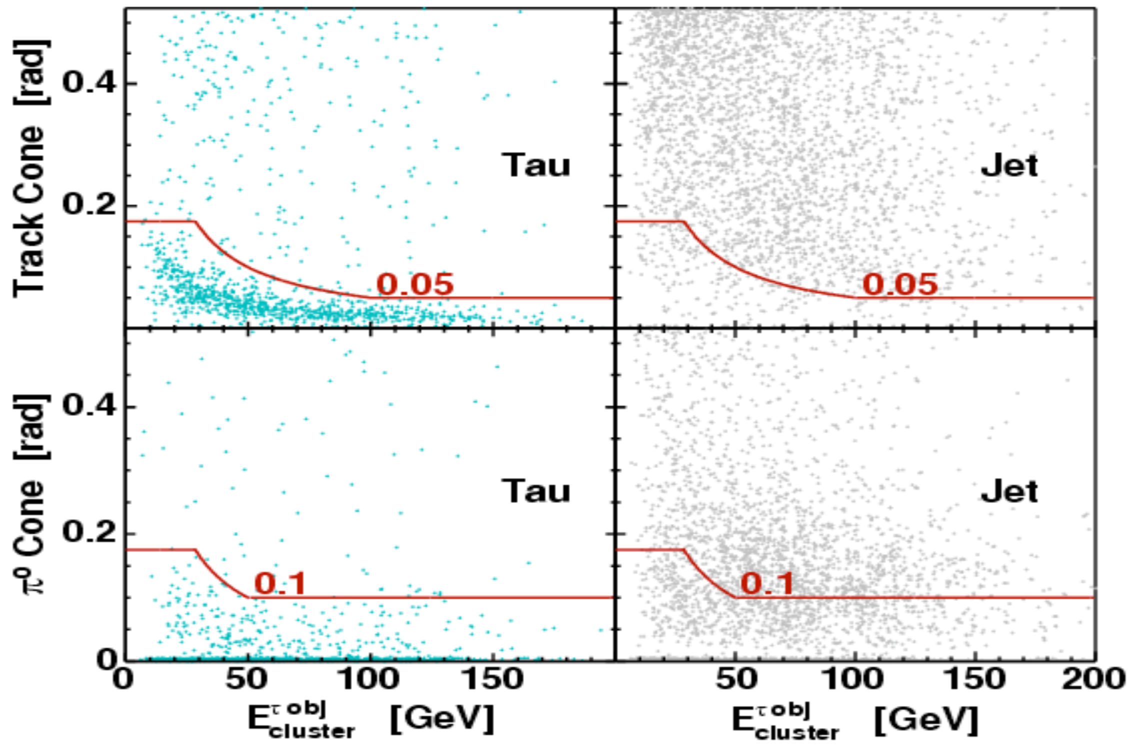
  3) At least two tracks + calorimeter cluster and ≥ 0 EM subclusters



main backgrounds: jets and electrons

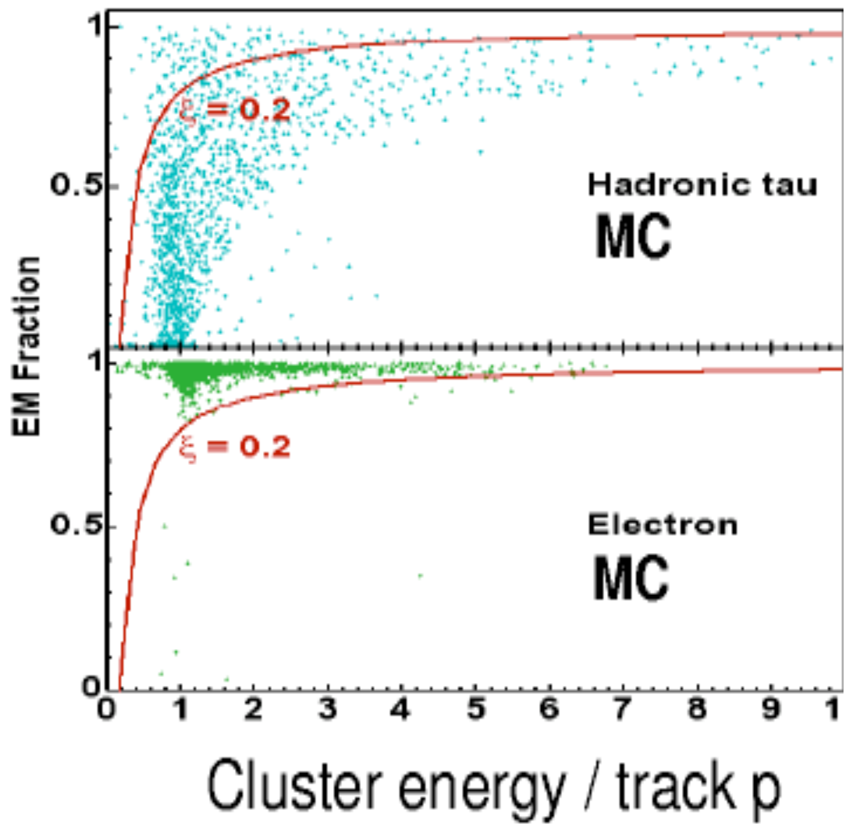
Jet-τ Separation at CDF

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



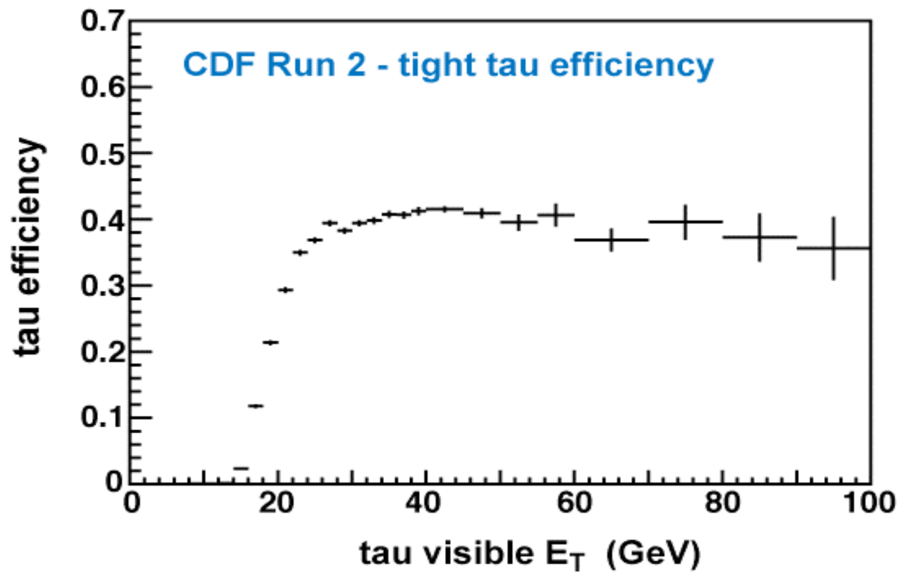
e – τ Separation at CDF

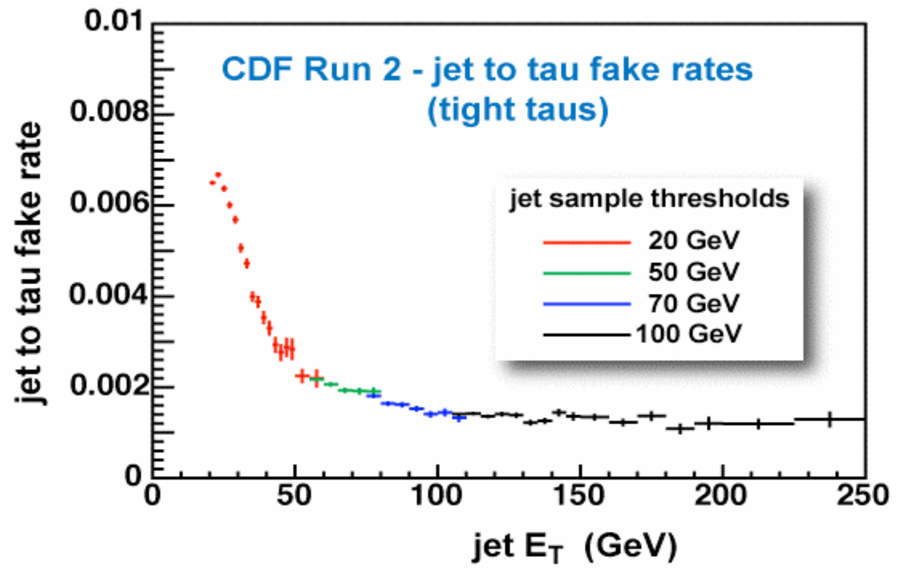
- Need to also remove electrons that are identified as hadronic taus.
- Use the cut:
  - $\xi \equiv E_H / \Sigma p_{trk} > 0.2$
  - Where E_H is the energy deposited in the hadronic part of the calorimeter.



Tau Efficiency & Fake Rate at CDF

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





- Algorithm only efficient at high p_T. Low p_T taus require dedicated algorithm (also true at DØ, important for SUSY tri-leptons)
- 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:
  - Calorimeter isolation = $(E_T^{R=0.5} - E_T^{R=0.3}) / E_T^{R=0.3}$
  - Profile = $(E_T^{Tower\ 1} + E_T^{Tower\ 2}) / E_T$
  - Track isolation = $\Sigma p_T^{Trks\ in\ Cone\ R\ =\ 0.5} / \Sigma p_T^{Tau\ Trks}$
  - EM Isolation 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

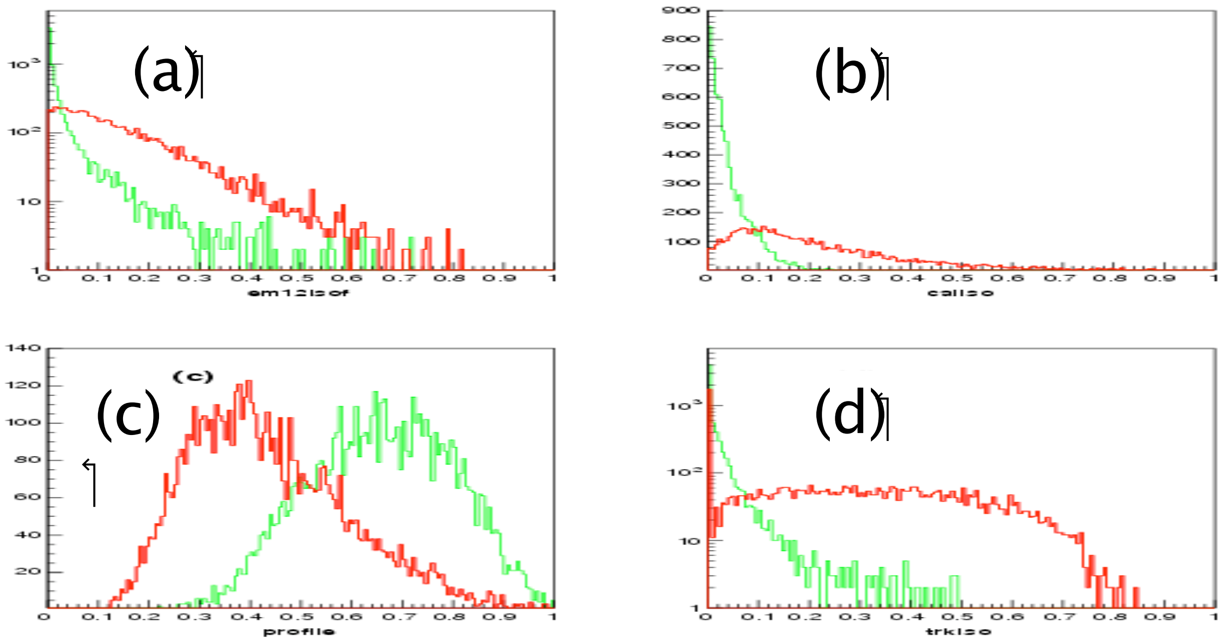
- Example NN input variables for tau type 1, signal (MC τ) and background (jets from data).

EM isolation fraction

calorimeter isolation

profile

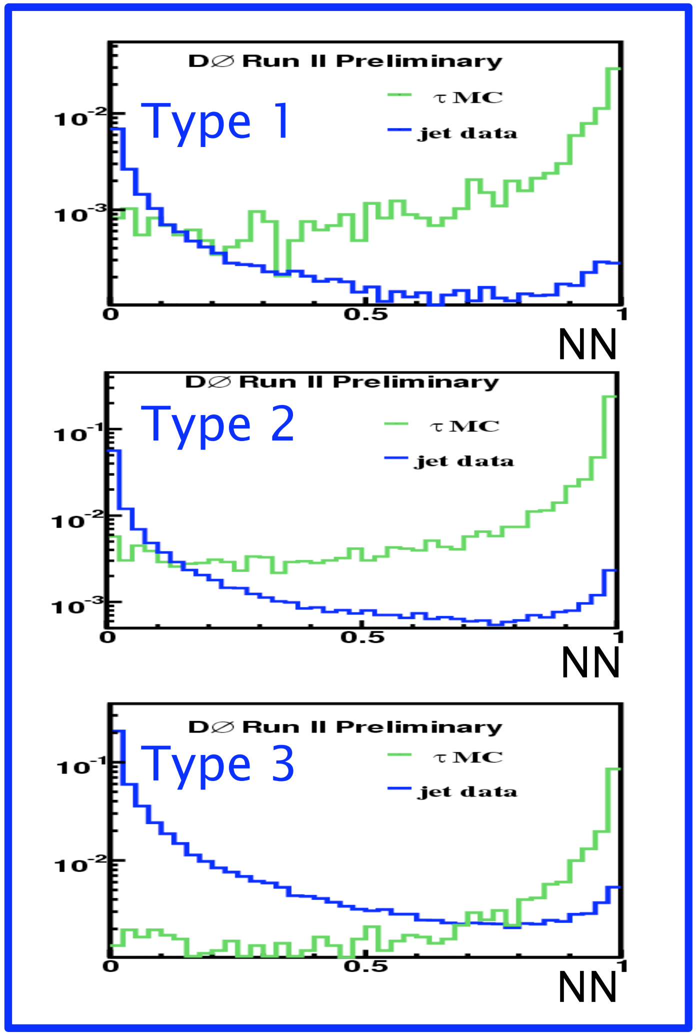
track isolation



Jet-τ Separation at DØ

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

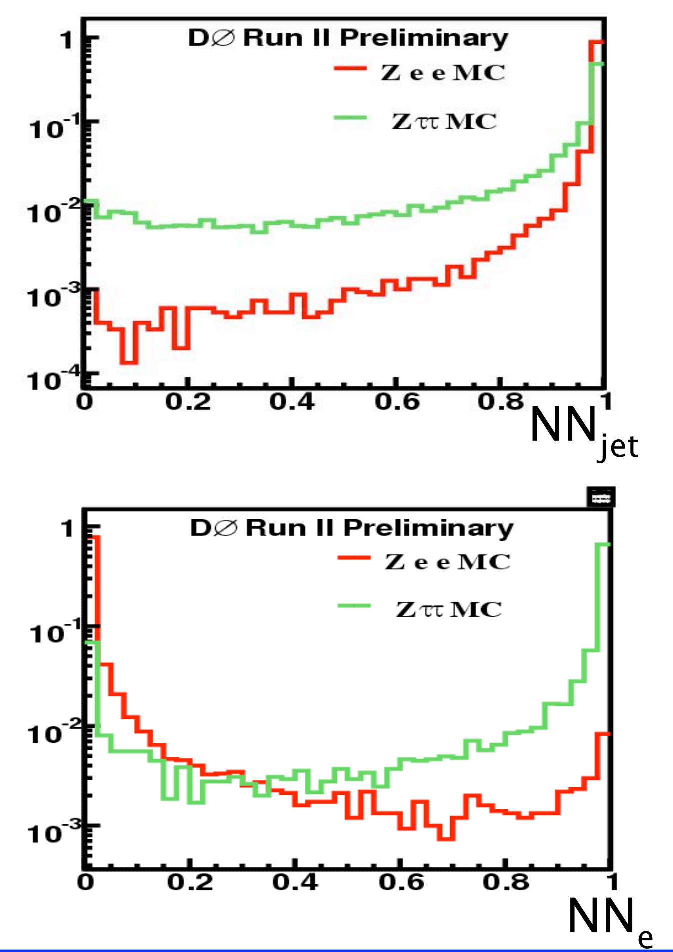
Tau Type	1	2	3
Reconstruction			
Jets	1.5	10	38
Taus	9.1	50	20
NN > 0.9			
Jets	0.04	0.2	0.8
Taus	5.8	37	13



e-τ Separation at DØ

- Electrons look similar to tau-type 2 candidates (tracks + EM cluster).
- 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 in the range $20 < E_T < 40$ GeV, decaying to hadrons, compared to electrons:

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



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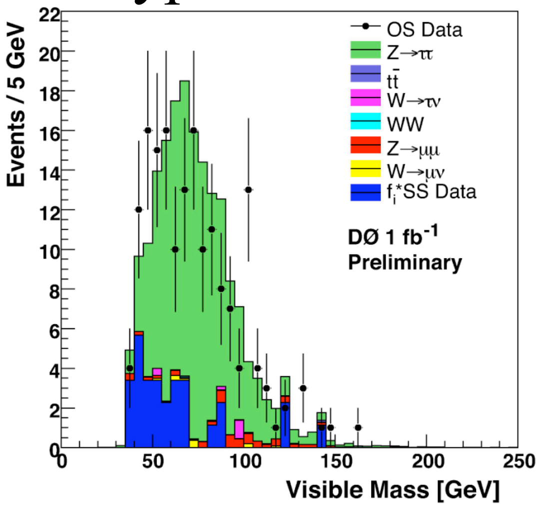
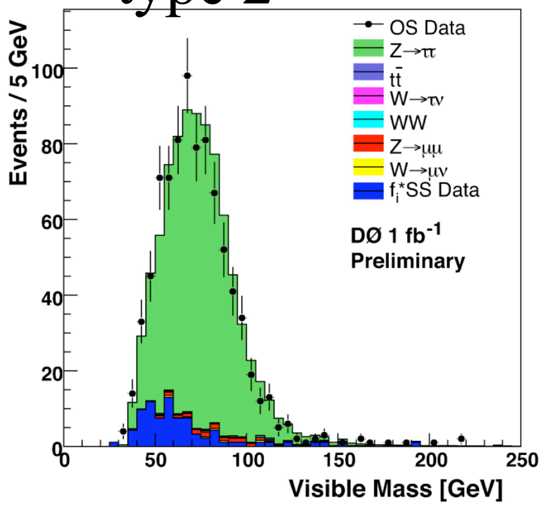
Background Estimation

- Best estimate of jet background from Same Sign (SS) vs Opposite Sign (OS) method:
- charge correlation between muon (from tau) and hadronic tau:

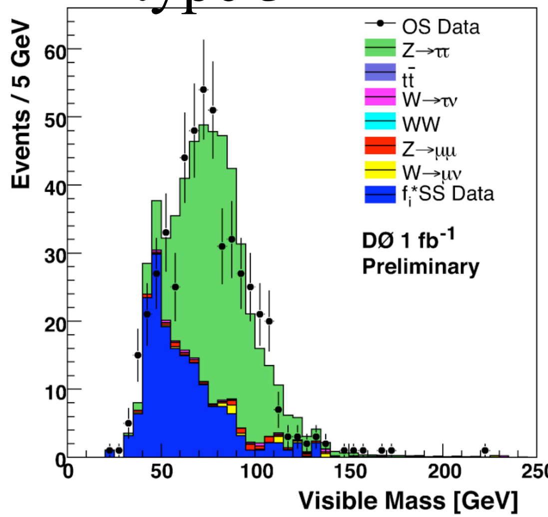
type 1



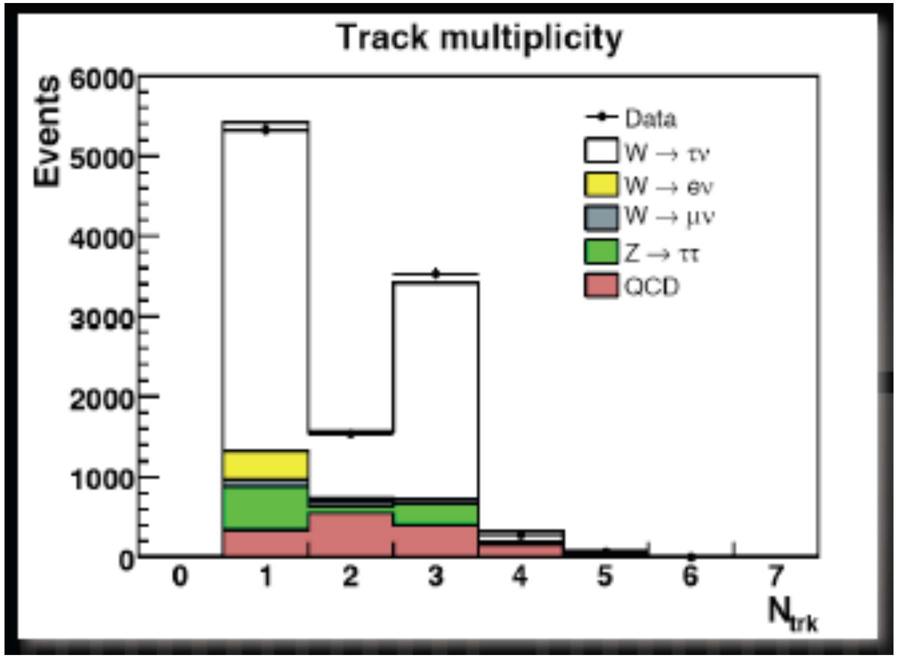
type 2

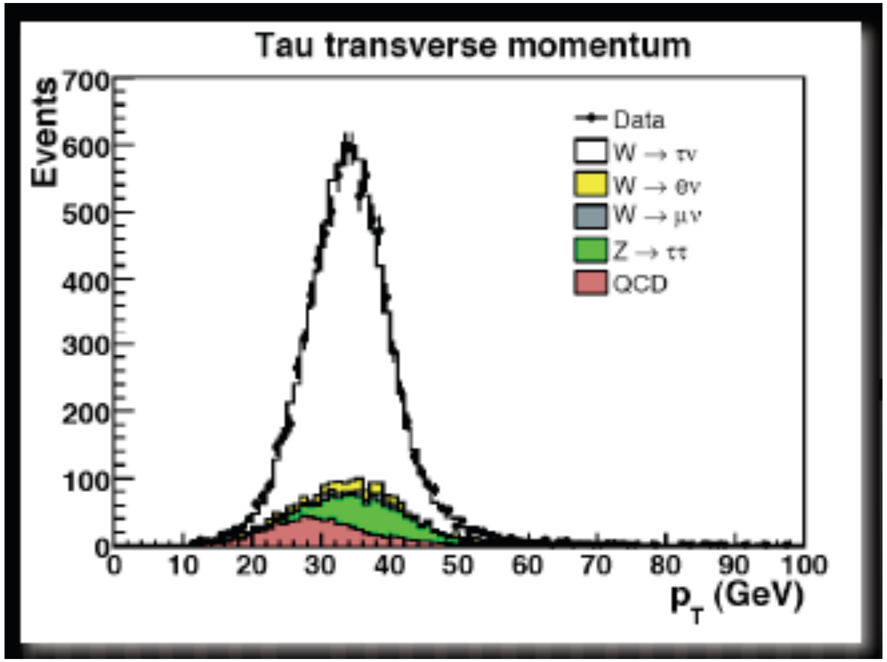


type 3



Tau Energy Scale



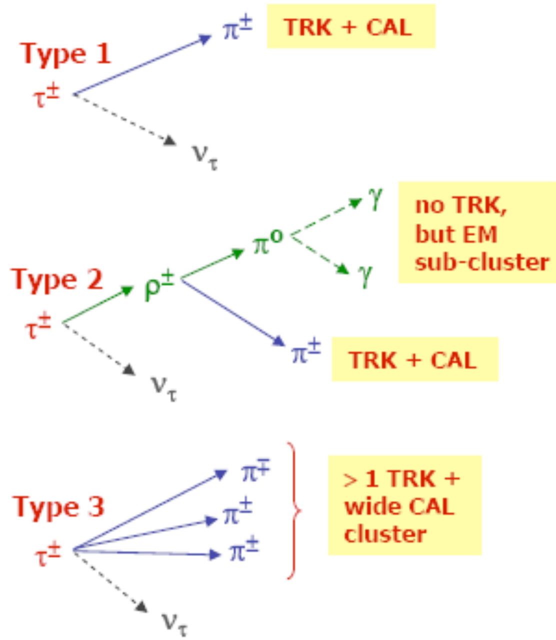


-tau four-vector calculated from tracks and $\pi^0 \to \gamma\gamma$

-verified with $W \to \tau\nu$ (+ 0 jets)

-MC/data agreement at 1% level

Tau Energy Scale

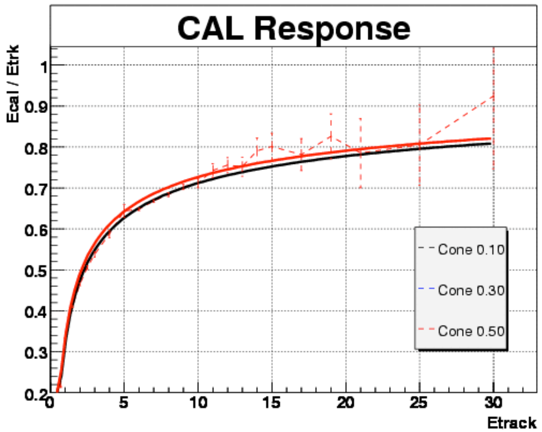


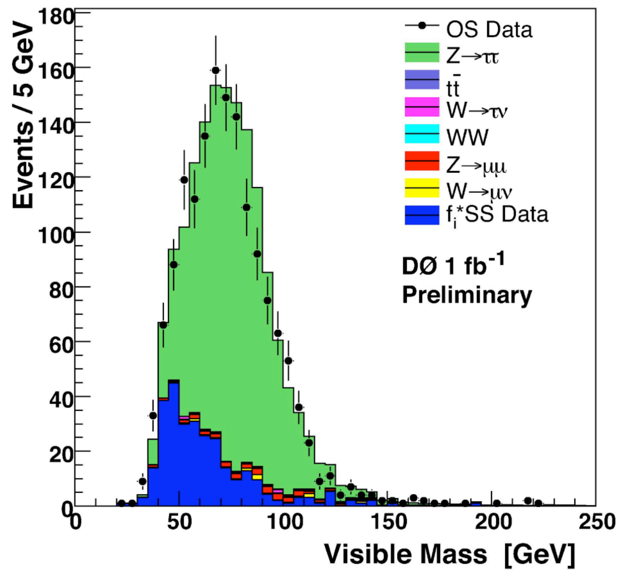
Two methods to reconstruct tau momentum:

(1) Track for type 1
Calorimeter for types 2/3

(2) $$E_{corr} = E_{trk} + E_{cal} - \langle R \rangle E_{trk}$$

R is single pion response





Trigger

It is difficult to trigger on hadronic taus due to the large QCD background

CDF (di-taus):

muon or electron (8 GeV) + isolated track (5 GEV)

DØ: (di-taus):

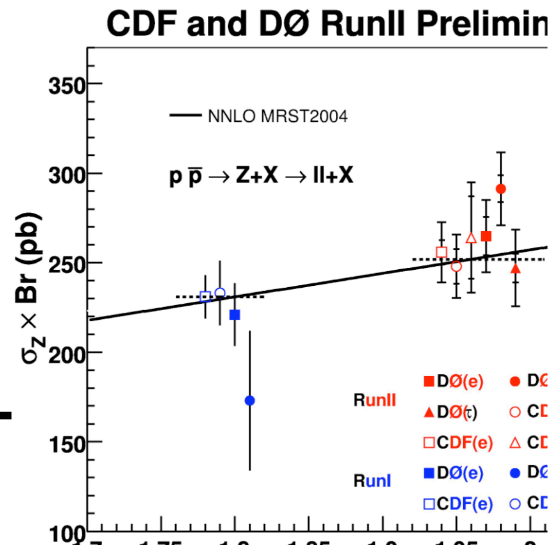
high transverse momentum electron or muon triggers

Dedicated tau triggers exist, but not used in analysis yet

Physics Results with Taus

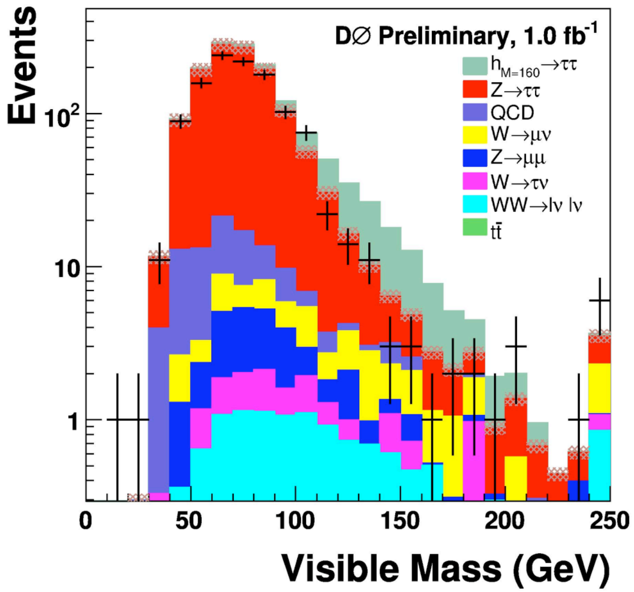
Z -> ττ Cross-Section

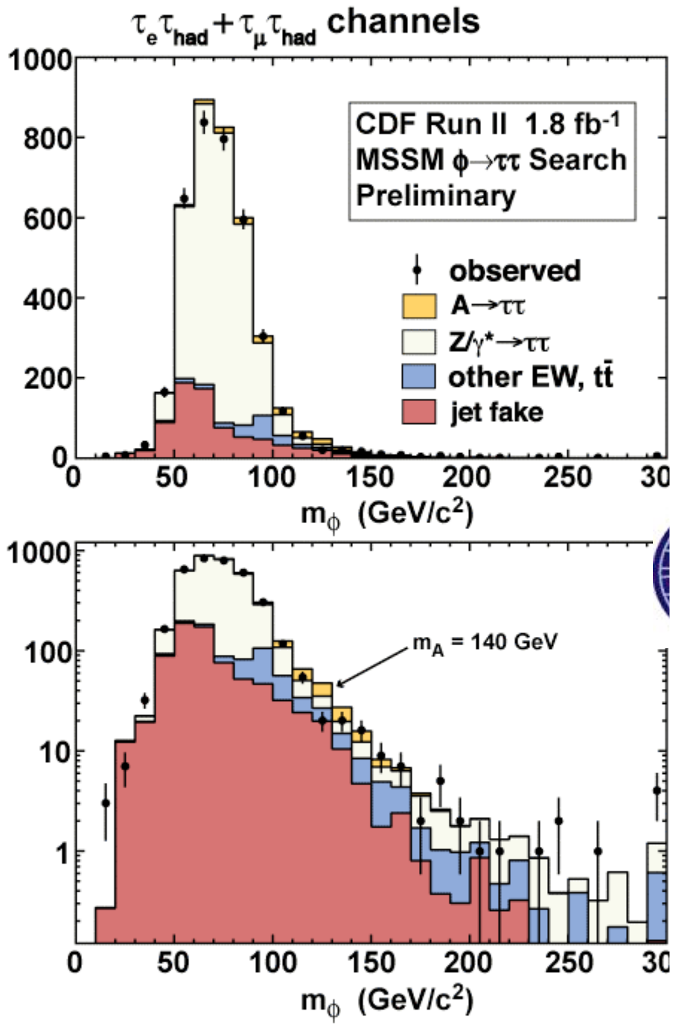
- This is a benchmark measurement – tests how the tau algorithms perform on data.
- CDF, measured in $\tau_e\tau_h$ channel:
  - σxBr = 265 ± 20 (stat) ± 21 (sys) ± 15 (lumi) pb
- DØ, measured in $\tau_\mu\tau_{e,h}$ channel:
  - σxBr = 247 ± 8 (stat) ± 13 (sys) ± 15 (lumi) pb
- Good agreement with NNLO calculation

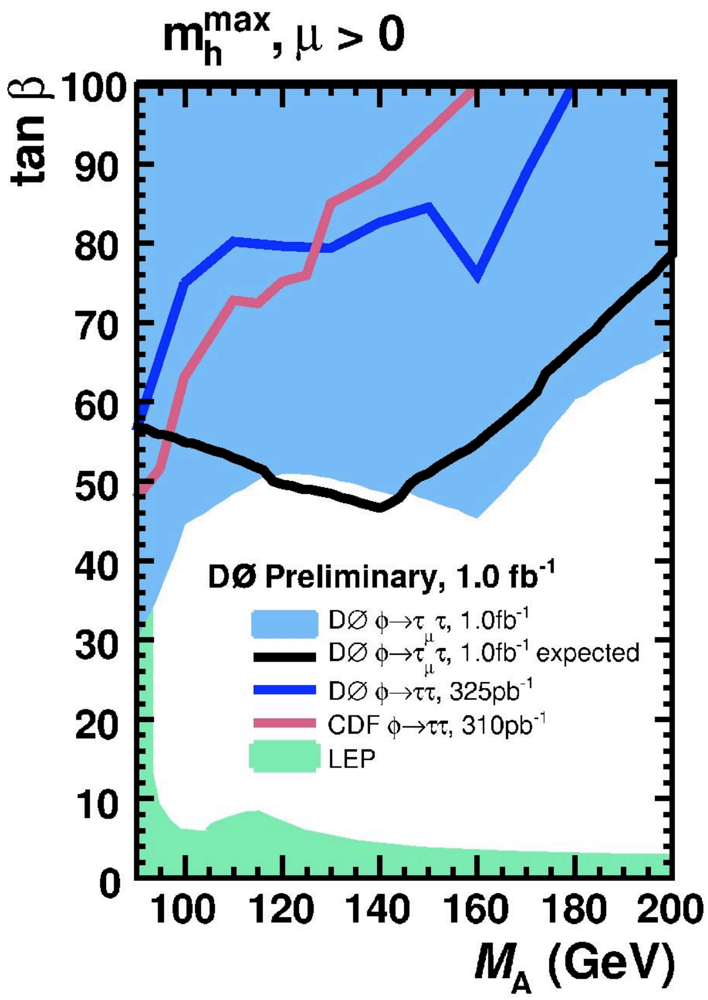


MSSM Higgs -> ττ Searches

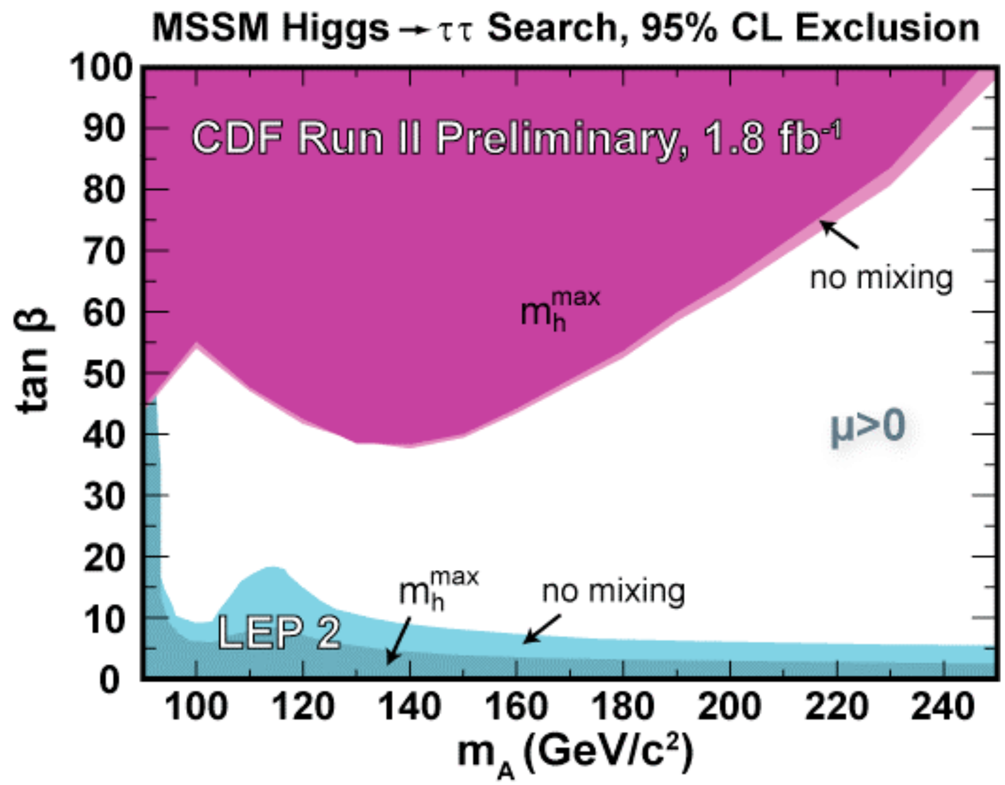
$$M_{vis} = \sqrt{(P_{\tau 1} + P_{\tau 2} + P_T^{miss})^2}$$





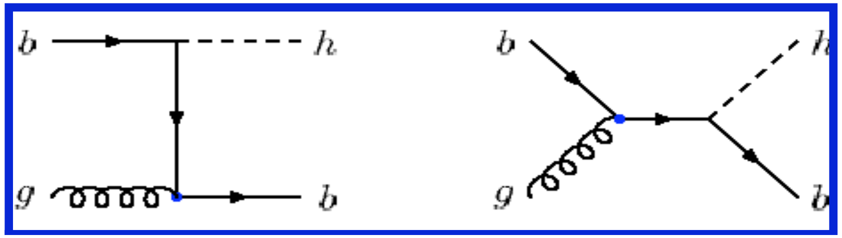


$m_h^{max}, \mu > 0$
tan β
DØ Preliminary, 1.0 fb⁻¹
DØ φ→τμτ, 1.0fb⁻¹
DØ φ→τμτ, 1.0fb⁻¹ expected
DØ φ→ττ, 325pb⁻¹
CDF φ→ττ, 310pb⁻¹
LEP
M_A (GeV)

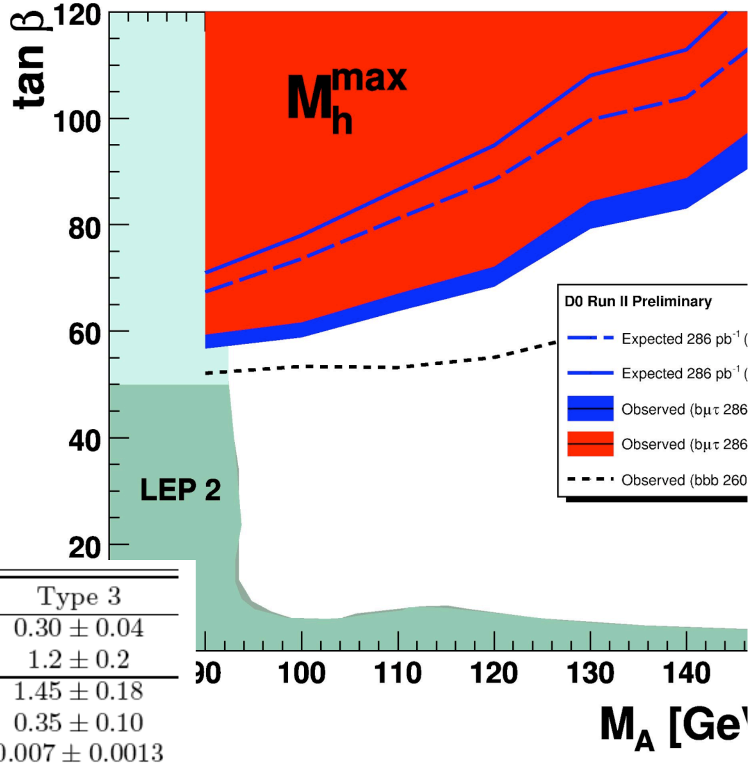


MSSM Higgs → ττ Search, 95% CL Exclusion
CDF Run II Preliminary, 1.8 fb⁻¹
tan β
m_h^{max}
no mixing
μ>0
LEP 2
m_A (GeV/c²)

MSSM Higgs ($b\tau\tau$)



$$h \rightarrow \tau\tau$$

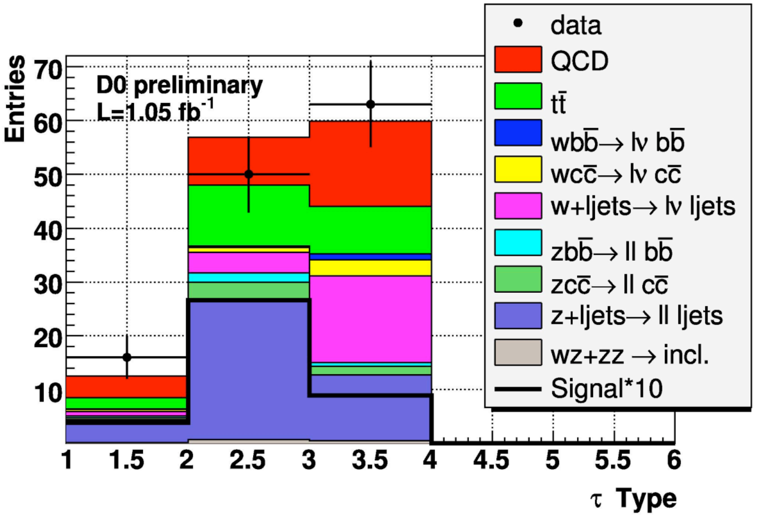


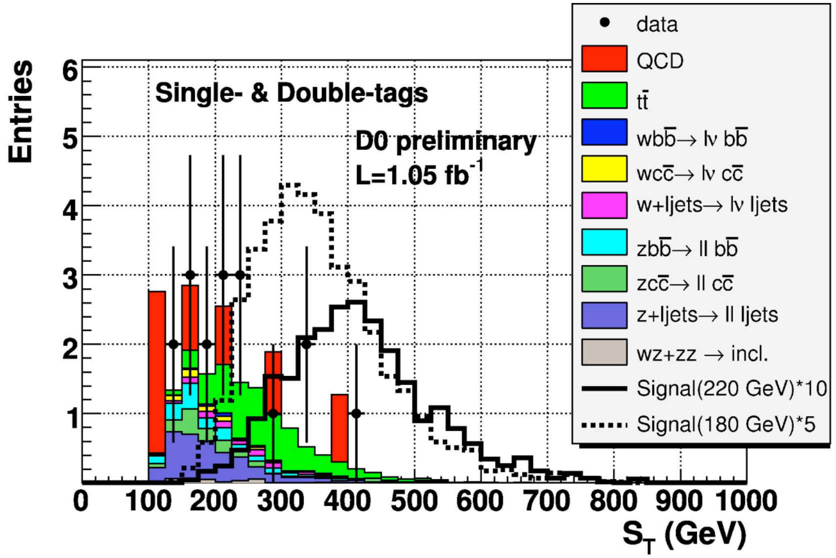
require extra b jet

	Type 1	Type 2	Type 3
Signal Accept. (%)	0.15 ± 0.03	0.87 ± 0.11	0.30 ± 0.04
Expected Signal	0.6 ± 0.1	3.5 ± 0.5	1.2 ± 0.2
QCD	0.62 ± 0.22	0.51 ± 0.14	1.45 ± 0.18
Z+jet	0.34 ± 0.09	1.6 ± 0.3	0.35 ± 0.10
$t\bar{t}$ (di-l)	0.18 ± 0.03	0.50 ± 0.11	0.007 ± 0.0013
$t\bar{t}$ (l+jet)	0	0.008 ± 0.008	0.15 ± 0.04
W+jj	0.005 ± 0.005	0.05 ± 0.02	0.40 ± 0.14
W+cc	0.003 ± 0.002	0	0.003 ± 0.003
W+bb	0	0	0.016 ± 0.010
WW	0	0.010 ± 0.002	0.0013 ± 0.0004
Total Background	1.2 ± 0.2	2.6 ± 0.3	2.5 ± 0.2
Observed	0	1	2

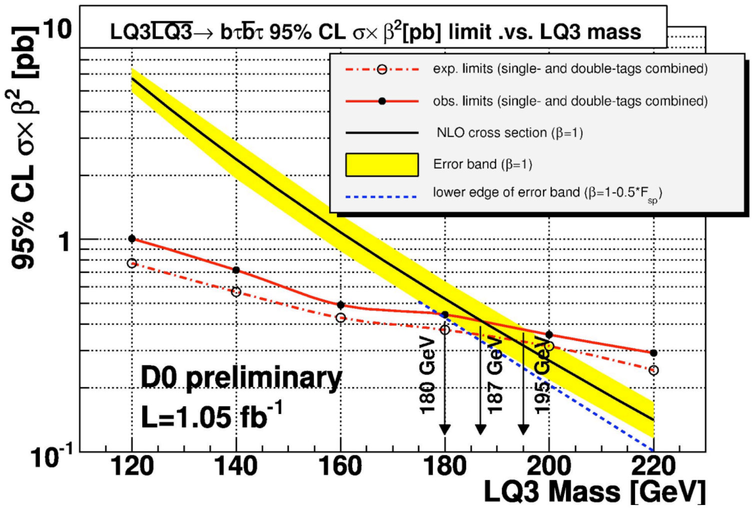
largely orthogonal to inclusive h $\rightarrow\tau\tau$

3rd Generation Leptoquarks





$$LQ_3 LQ_3 \rightarrow \tau b \tau b$$



similar search at CDF

Conclusions

- DØ and CDF both have effective high p_T hadronic tau ID.
- Hadronic tau efficiencies of about 40% can be achieved at high p_T 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; many channel still need to be studied.

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 = $E_T / (E_T + \Sigma p_T^{\text{tau trks}})$