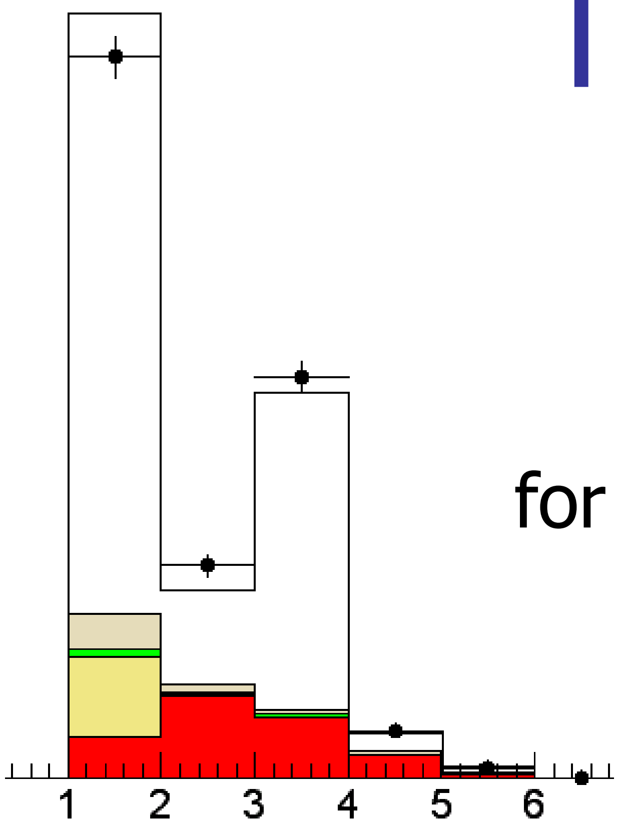
Tau Identification at the Tevatron



Stephen Levy, UChicago

for the CDF and D0 Collaborations

Hadron Collider Physics

July 05, 2005

Outline

- Motivation
- Tau properties
- Tau id basics (CDF & D0)
- Cut based tau id (CDF)
- Neural net tau id (D0)
- Tau triggers (CDF & D0)
- Electroweak tau results (CDF & D0)
- Higgs → tau tau results (CDF)
- Conclusion

Why study taus?

(electrons and muons are easier)

- Theory
  - 3rd generation connection to EWK symmetry breaking
  - SUSY solves SM Higgs mass fine tuning
  - MSSM Higgs h,H,A,H^+,H^- couplings defined by m_A, tan β

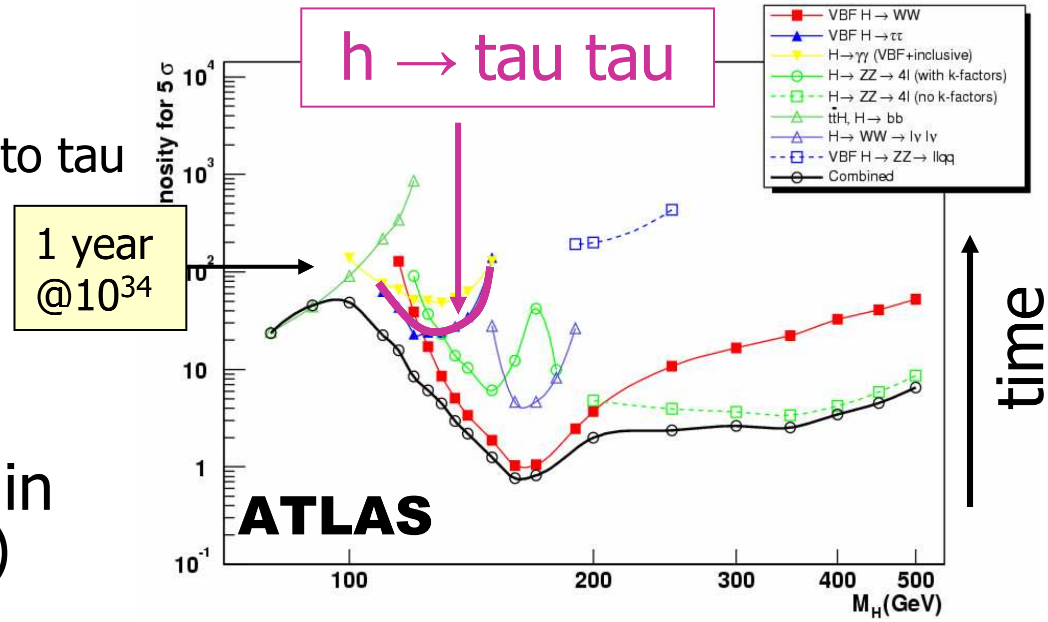
    h,H,A (→ tau tau)

    $H^\pm$ (→ tau nutau)

    Stop decays (→ tau b)

    Chargino-Neutralino cascades to tau

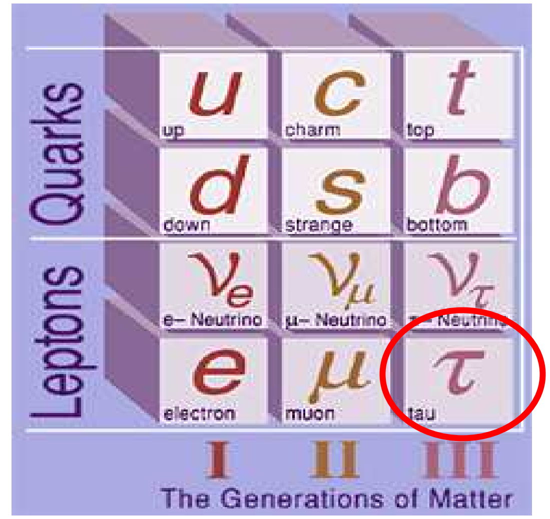
- Experiment
  - *Because* electrons and muons are easier
  - Lepton non-universality in W decays at LEP? (>2σ)
  - Increase acceptance for top events



SM-like higgs discovery

Plot from A. Barr ICHEP '04

Tau Properties



- Heavy lepton

  Mass = 1.78 GeV

- Short lived lepton

  mean lifetime = 291 ps

  $c\tau$ = 87 μm (ct of B0 ~ 460 μm)

  Typical silicon displaced vertex resolution O(50-100μm)

- Spin 1/2

  Decay angle distributions depend on τ polarization

  Decays to scalar and vector mesons

  Potential to separate taus from H^+ and W decays (hep-ph/9905542)

Tau Branching Fractions

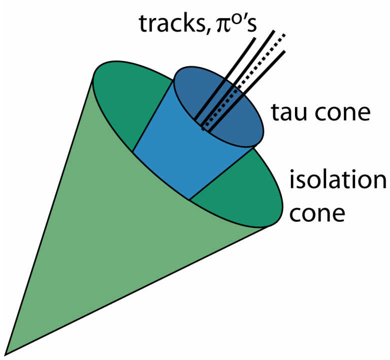
Final State	Br. Frac (%)	Decay Type
$e\ \nu_e\ \nu_\tau$	17.8	Leptonic 35.2
$\mu\ \nu_\mu\ \nu_\tau$	17.4	
$\pi\ \nu_\tau$	11.1	One-Prong 46.5
$\rho(\pi\ \pi^0)\ \nu_\tau$	25.1	
$\pi \geq 2\pi^0\ \nu_\tau$	10.3	
$\pi\pi\pi\ \nu_\tau$	9.5	Three-Prong 13.9
$\pi\pi\pi \geq 1\pi^0\ \nu_\tau$	4.4	

$\tau_e\ \tau_\mu$ (Leptonic)

τ_h (One-Prong and Three-Prong)

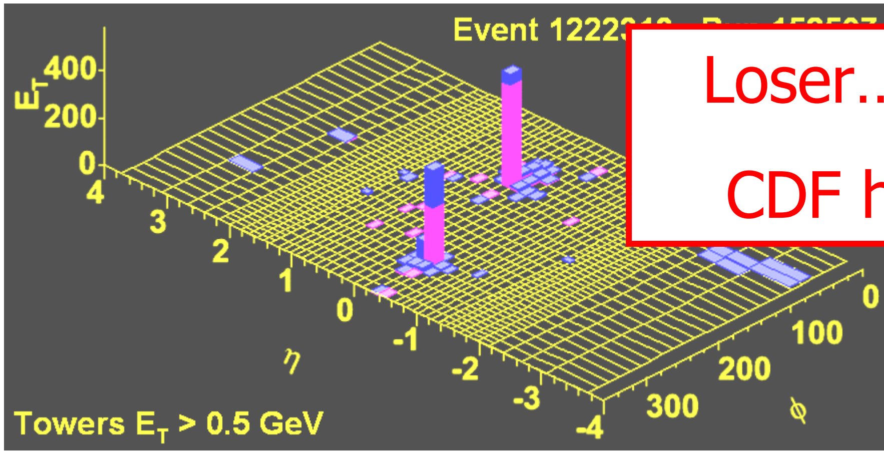
Tau Id Basics

- Typically at Tevatron, identifying lepton really means identifying *isolated* lepton
- Use electron and muon identification for τ_e and τ_μ
- Tau is essentially a narrow jet in detector
  - Track(s) pointing at hadronic calorimeter energy deposition
  - Maybe associated EM energy from $\pi^0 \to \gamma\gamma$



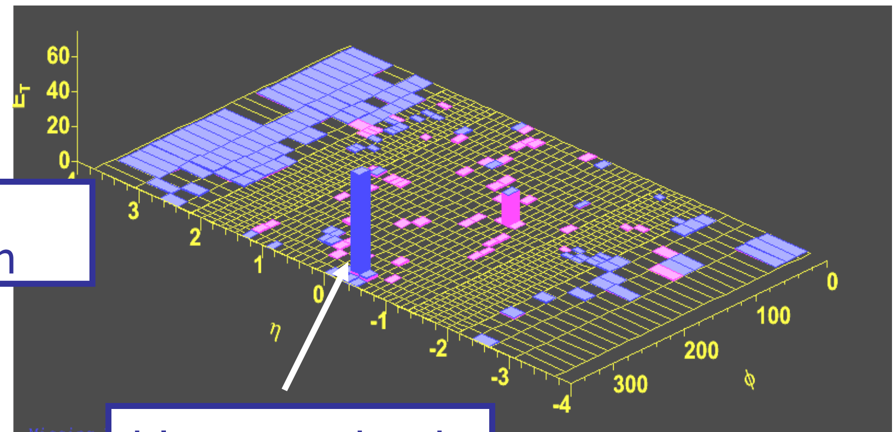
- Electrons and some jets are also "narrow jets"
  - Jet from tau decay has mass < tau mass
  - Tau *event* contains real missing energy from neutrino (jets create instrumental missing energy due to cracks, mis-measurements, etc.)
  - Tau lifetime means decay products have larger impact parameters on average (heavy flavor jets as well)

Step right up…pick a tau event



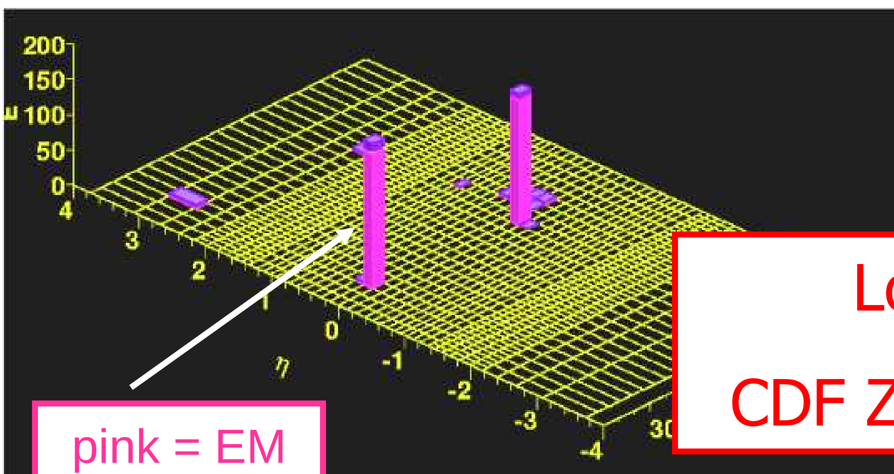
Loser…Please try again

CDF high p_T jet event



We have a winner…$Z \rightarrow \tau_e\, \tau_h$

blue = Hadronic



pink = EM

Loser…Please try again

CDF $Z(e^+e^-)$ with mass 375 GeV

Taus are hard

- Ratio of qcd jet cross section (order mb) to EWK cross section (order nb) at tevatron ~ 1e6
- Compare "typical" high-pt (>20 GeV) isolated lepton efficiency and fake rates

Lepton	Efficiency	Fake Rate
electron	~80%	~0.01%
muon	~85%	~0.01%
tau (box cuts)	~45%	~1-0.1%
tau (neural net)	~80%	~5-1%

- Identify taus on statistical basis using event topology to fight background

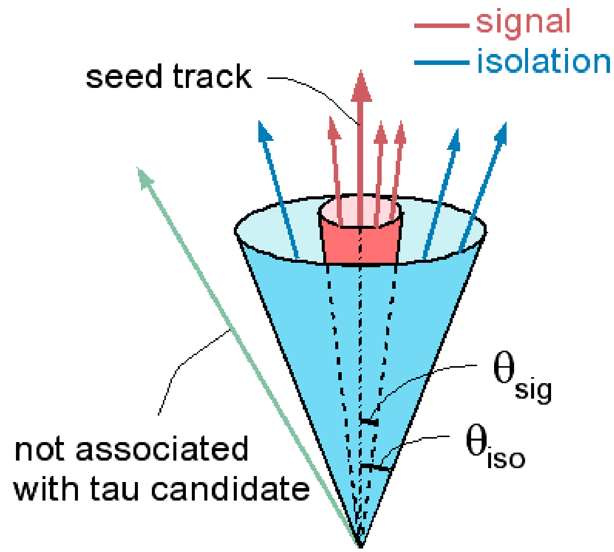
Tau reconstruction seed

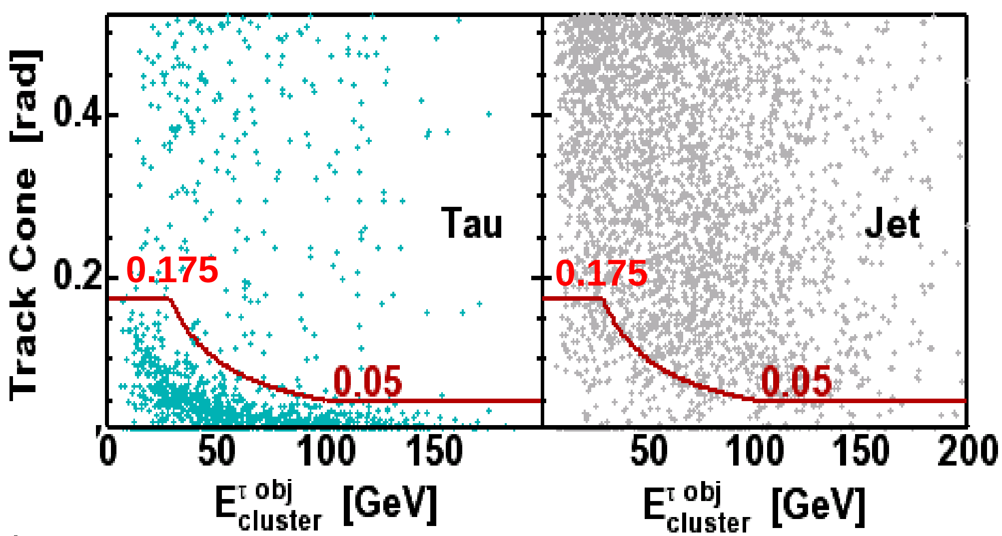
- Isolation provides powerful jet rejection
- Calorimeter resolution leads to different tau reconstruction approaches for CDF & D0
- Both require narrow calorimeter seed energy deposition (~5 GeV) with well measured track pointing at cluster
  - CDF narrow means ≤ 6 towers
  - D0 uses rms of cluster width weighted by E_T
- CDF uses cut based tau identification
- D0 uses neural net based tau identification

CDF Cut Based Tau Id

CDF Shrinking Cone Id

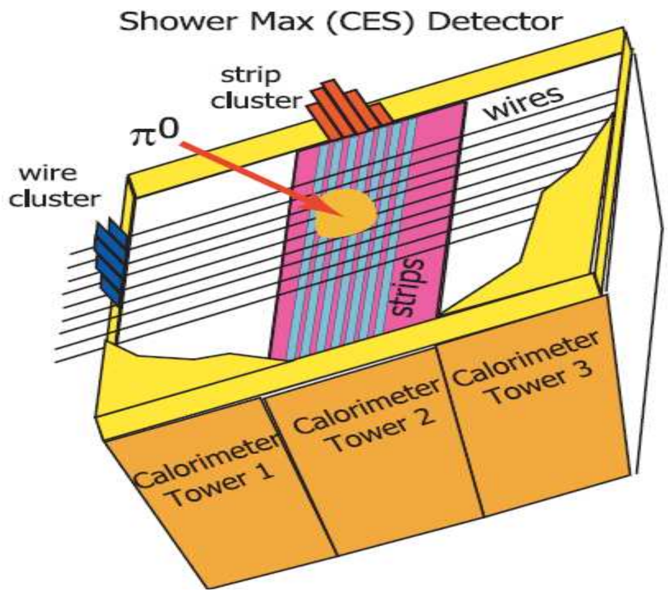
- CDF defines signal and isolation cone around seed track direction
- Veto any tau candidate with a good track in the isolation region





shrinking cone angle $\propto 1/E_t$

CDF π^0 reconstruction



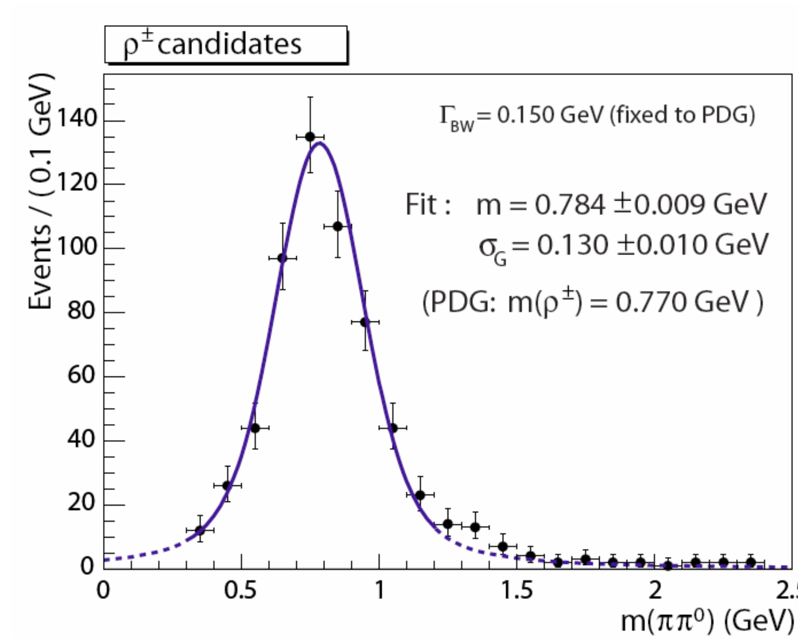
Proportional strip/wire drift chamber (CES) located 6 radiation lengths inside EM calorimeter used for electron id and π^0 reconstruction

Spatial resolution O(2-3 mm)

Reconstruction of $\rho(\pi^{\pm}\pi^0)$ candidates in W(→ tau nu) data sample

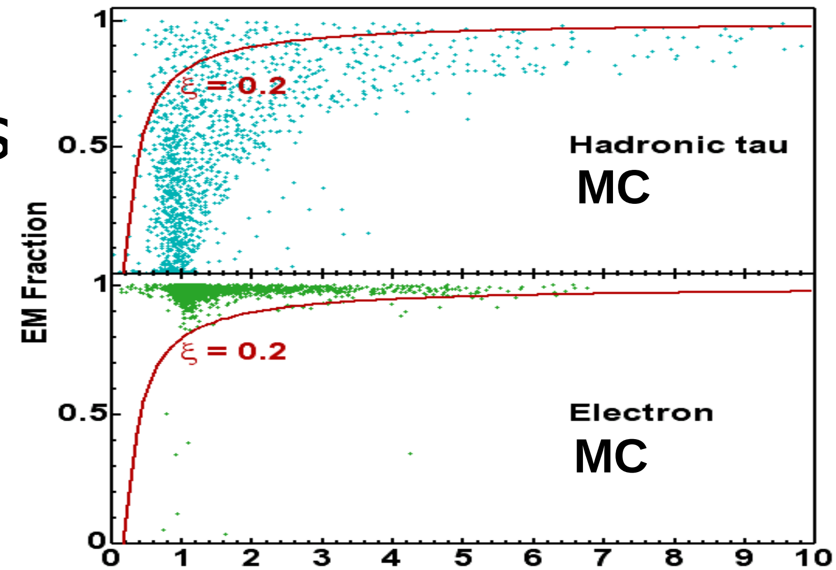
Reject tau if any π^0 in isolation cone has energy > 0.5 GeV

$E(\pi^0) = E_{CAL}(EM) - \Sigma(0.3 + 0.21 \times p^{TRK})$

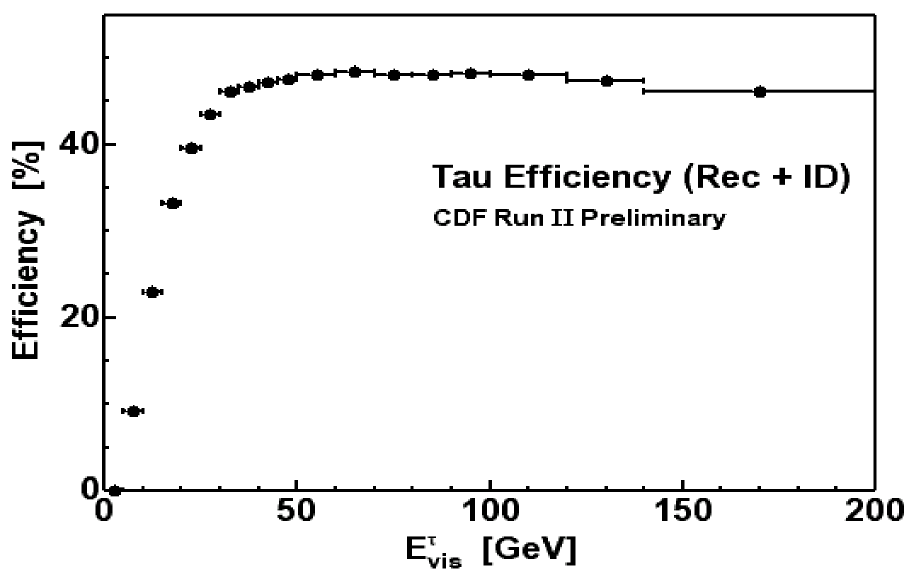


CDF Tau Id Variables

- Track and π^0 isolation
- "Visible" mass of tracks & π^0s
- Anti-electron veto
  - ξ: Had Energy / $\Sigma p_{trk} > 0.2$
- Charge of tau tracks = 1
- Number of tau tracks = 1,3



Cluster energy / track p

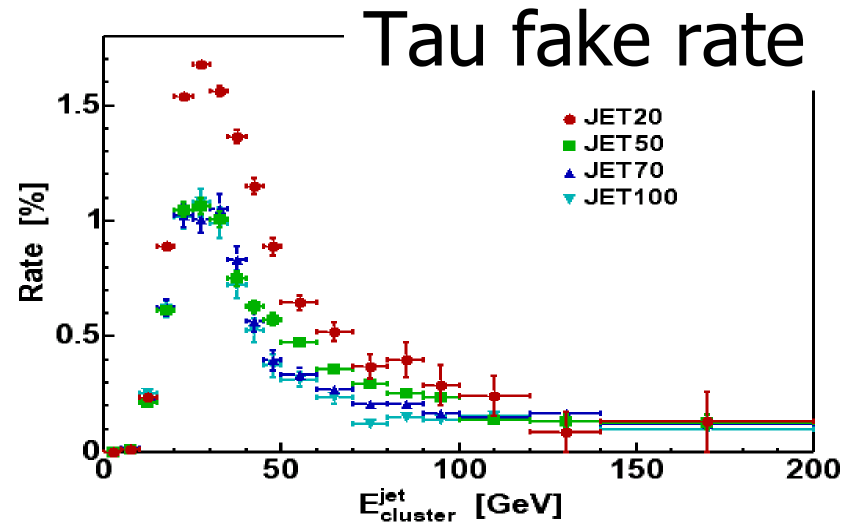


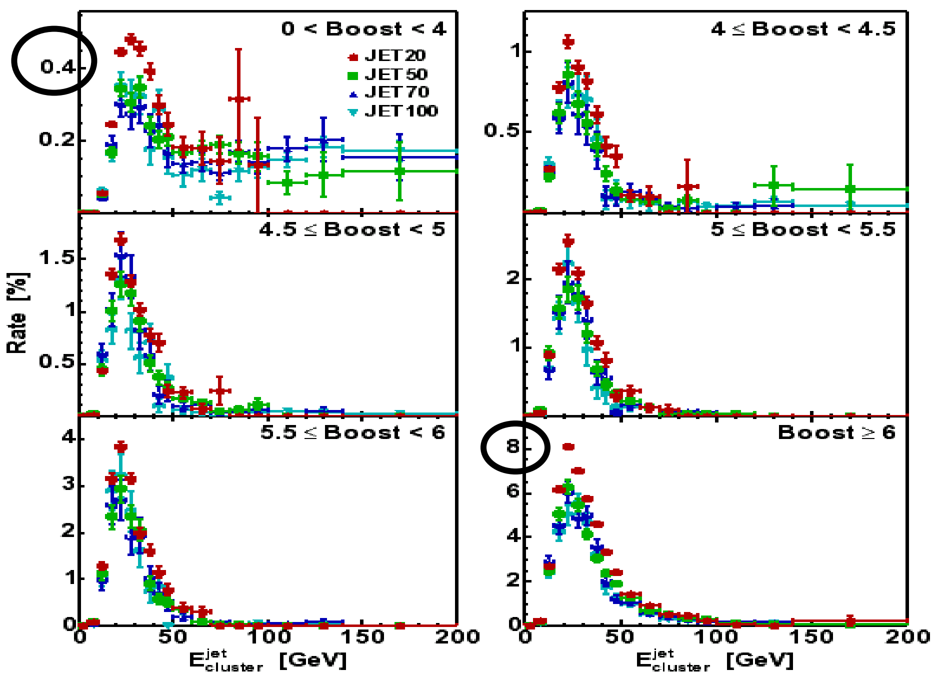
Cumulative CDF tau id efficiency as a function of tau visible energy for hadronically decaying taus in range $|\eta|<1$

Same cuts for all τ final states

CDF tau fake rate

- Use qcd events triggered by jet with E_T 20, 50, 70, 100 GeV to measure fake rate
- Fake rate estimation varies by 50% across samples for given jet energy

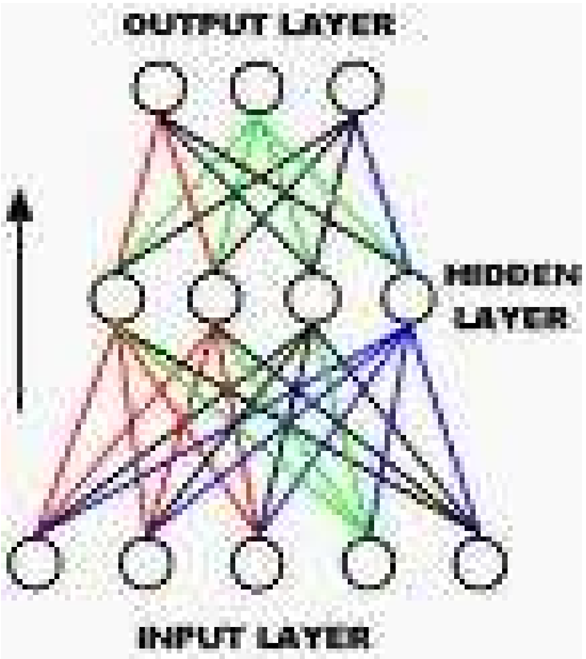




- Parameterize using uncorrelated boost

  $\gamma = E_{CLUS} / m_{CLUS}$
- Mean boost varies for same energy across jet samples
- Fake rate estimation varies by 20% using 2-d param of energy and boost

D0 Neural Net Tau Id



D0 neural net tau id

- Separate taus into 3 categories based on final state particles
  - Type 1: 1 track
  - Type 2: 1 track with EM energy
  - Type 3: more than 1 track
  - (Electrons can contribute to Types 1,2)
- Use separate NN training for each type with MC tau for signal and jets from data for background
- NN input variables use energy ratios to minimize tau energy dependence (vary by tau type)

D0 neural net variables

Tau Type	
All	• profile = $(E_{T1} + E_{T2})/E^{\tau}_{T}$
All	• caliso = outer cone E / inner cone E
All	• trkiso = isolation trk p_T / tau trk p_T
1	• EM shape (reject jet + soft π^0)
1,3	• seed trk p_T / E_T
2	• seed track energy isolation correlation
2,3	• Mass dependent variables

Additionally analysis dependent anti-muon requirement and/or additional NN to separate electrons and taus

Tau Triggers

- CDF and D0 have single tau and di-tau triggers
  - Tau plus missing E_T (MET) used for CDF $W(\rightarrow \tau\nu)$ analysis
  - D0 uses neural net for low pt tau in Level 3 (L3) trigger
- Electron or Muon plus isolated track (=tau) trigger
  - L1 trigger EM tower and associated track (8 GeV/c) *or*
  - L1 stub in muon detector and associated track (8 GeV/c)
  - Additional track at L2 with p_T > 5 GeV/c
  - L3 requires isolation around tau candidate track
  - CDF uses for $Z \rightarrow \tau_e \tau_h$ and $H \rightarrow \tau \tau$
- Some analyses with tau plus additional e^- or μ^- rely on inclusive e/μ trigger
  - D0: $Z \rightarrow \tau_\mu \tau_h$
  - D0: SUSY 2 electrons + tau

Typical CDF trigger rates & cross sections @ 1e32/cm^2/sec

Trigger	Rate	Cross Section
Tau Met	0.5 Hz	5 nb
Di-tau	1.2 Hz	12 nb
electron track	3.0 Hz	30 nb
muon track	1.5 Hz	15 nb

D0 Electroweak Tau Results

D0: $Z \rightarrow \tau_\mu \tau_h$

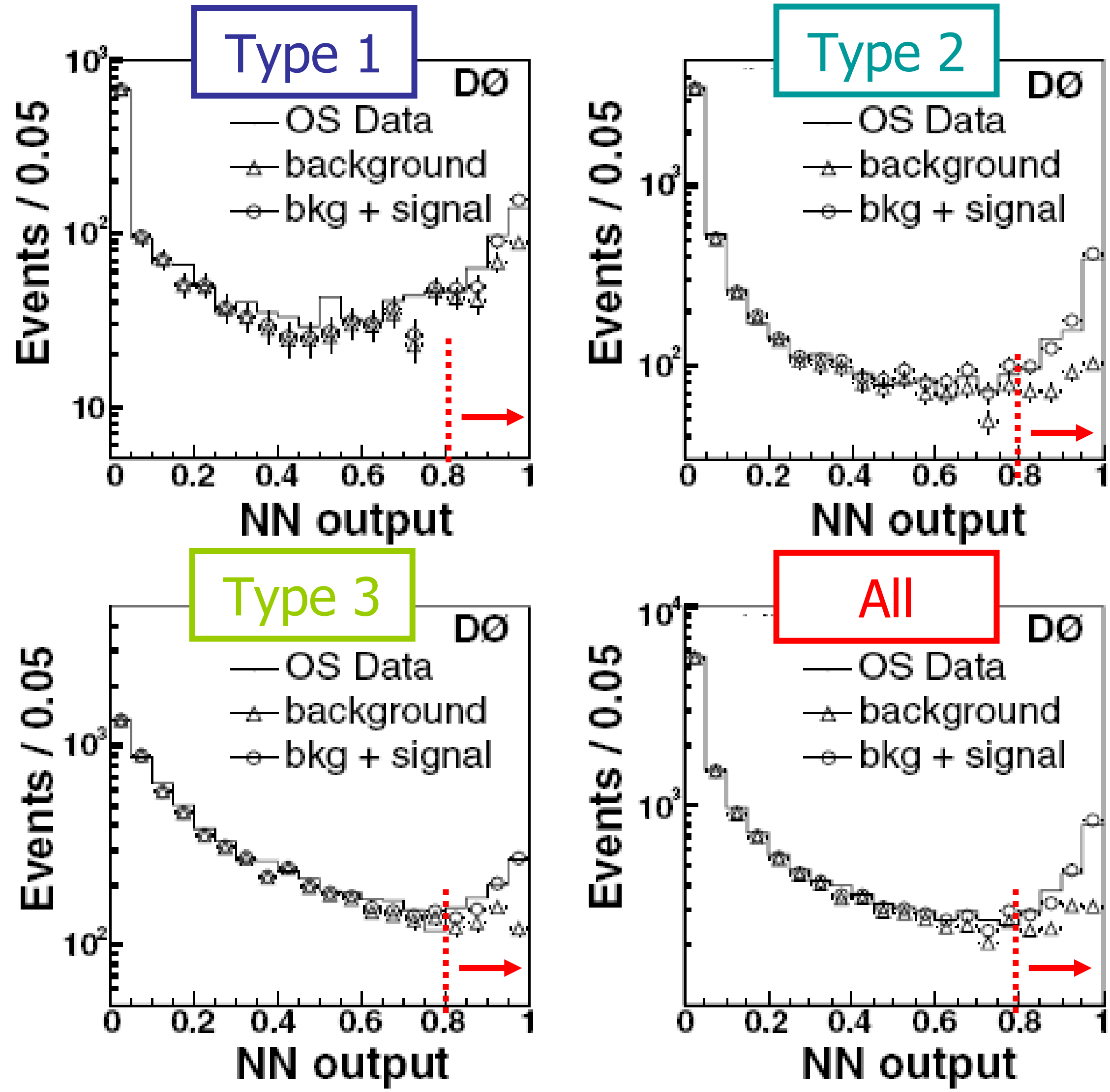
PRD 71, 072004

Require isolated muon (pT > 12 GeV) opposite tau object

Use SS data to predict QCD background

W+j shape from MC and normalization from data

Compare output of NN for OS data and background for all tau types



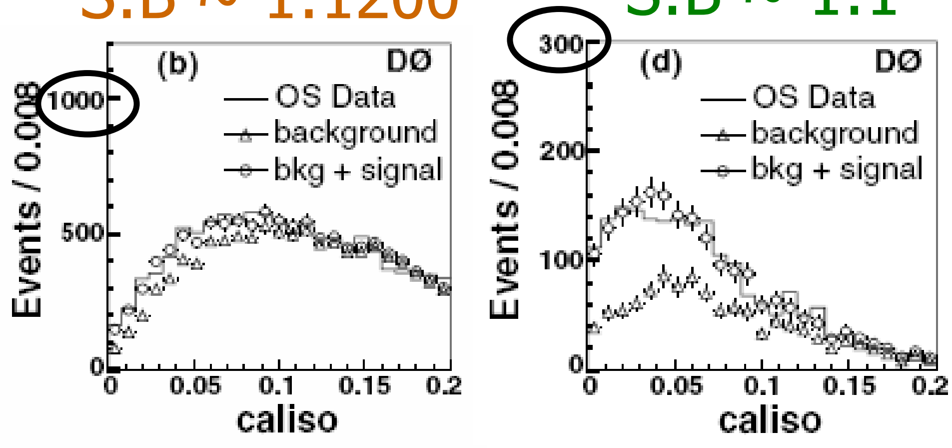
226/pb luminosity

D0: $Z \rightarrow \tau_{\mu}\ \tau_{h}$

226/pb luminosity

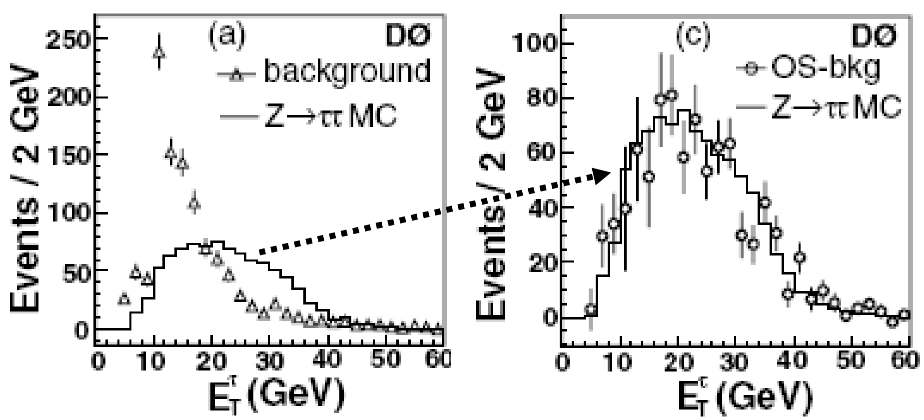
Before NN cut
S:B ~ 1:1200

After NN cut
S:B ~ 1:1



Compare tau *caliso* variable before and after cut on NN output

~900 signal events after background subtraction



Background subtracted data compared to MC $Z \rightarrow \tau_{\mu}\ \tau_{h}$ predictions agree well for hadronic tau energy

$\sigma \cdot Br(Z \rightarrow tt) = 237 \pm 15(stat) \pm 18(sys) \pm 15(lum)$ pb

CDF electroweak tau results

CDF: W → τ_h ν

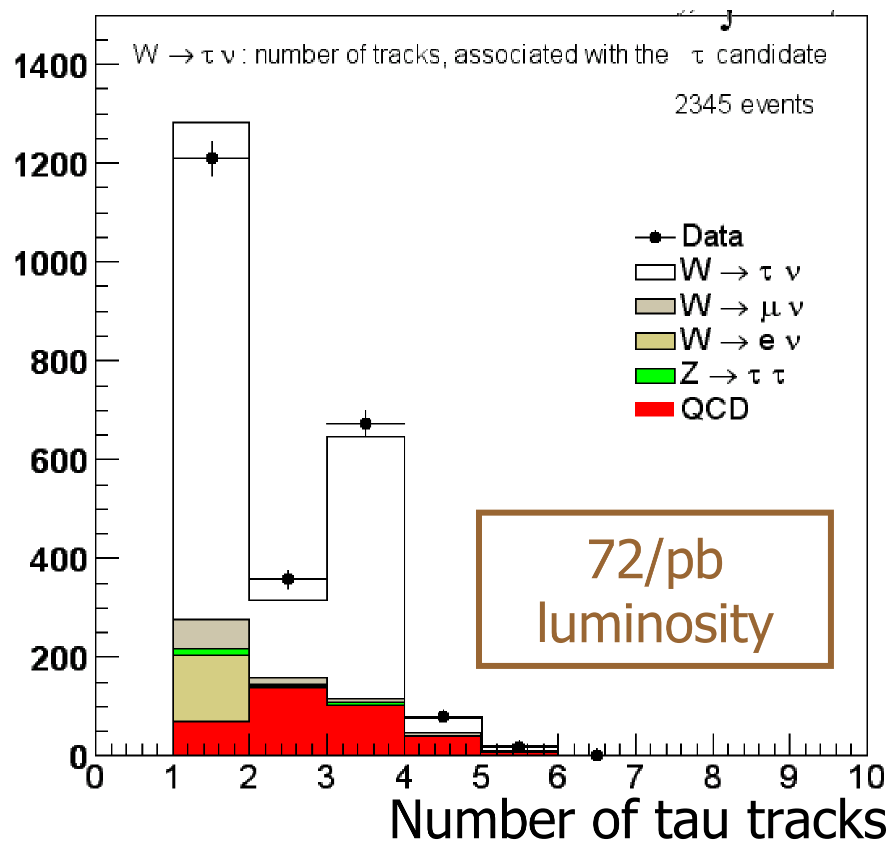
W decays are largest source of hadronic tau decays

Require large MET (> 25 GeV) and high p_T tau candidate (>25 GeV)

No other jet (>5GeV) in event

S:B ~ 3 with 24 taus / pb

Nucl. Phys. Proc. Suppl. 144, 323-332 (2005)



$$\sigma \cdot Br(W\rightarrow\tau\nu) = 2.62 \pm 0.07(\text{stat}) \pm 0.21(\text{sys}) \pm 0.16(\text{lum})\ \text{pb}$$

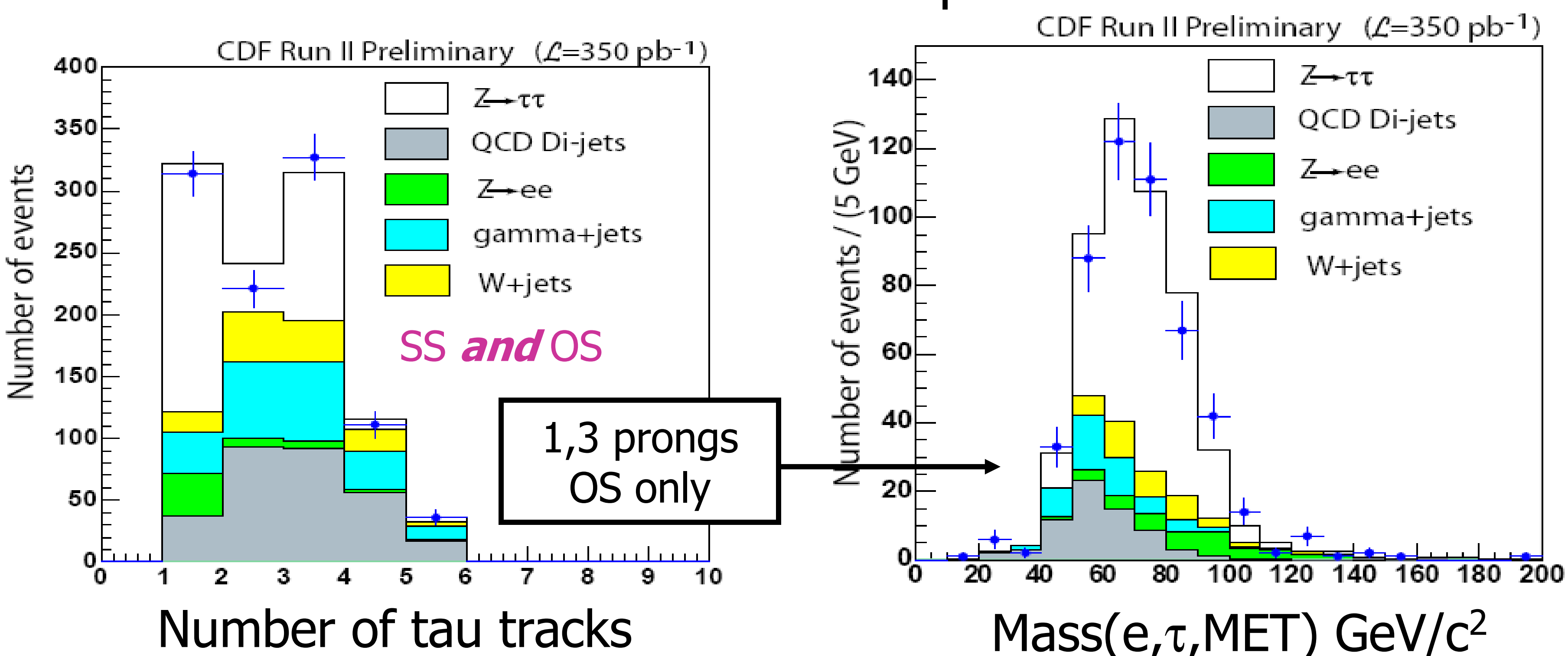
$$g_\tau / g_e = 0.99 \pm 0.02\ (\text{stat}) \pm 0.04\ (\text{syst})$$

CDF: Z → $\tau_e \tau_h$

New Conference Result

350/pb luminosity

- Irreducible background to Higgs → ττ search
- Isolated electron (E_T>10 GeV/c) and hadronic tau (p_T>15 GeV/c)
- Event topology cuts to reject qcd and W+jet backgrounds
- Cross section consistent with SM expectation

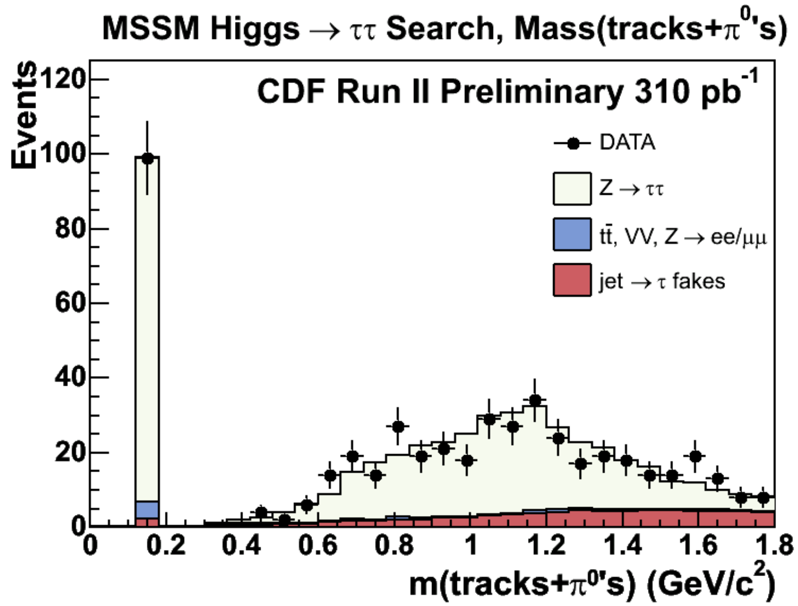


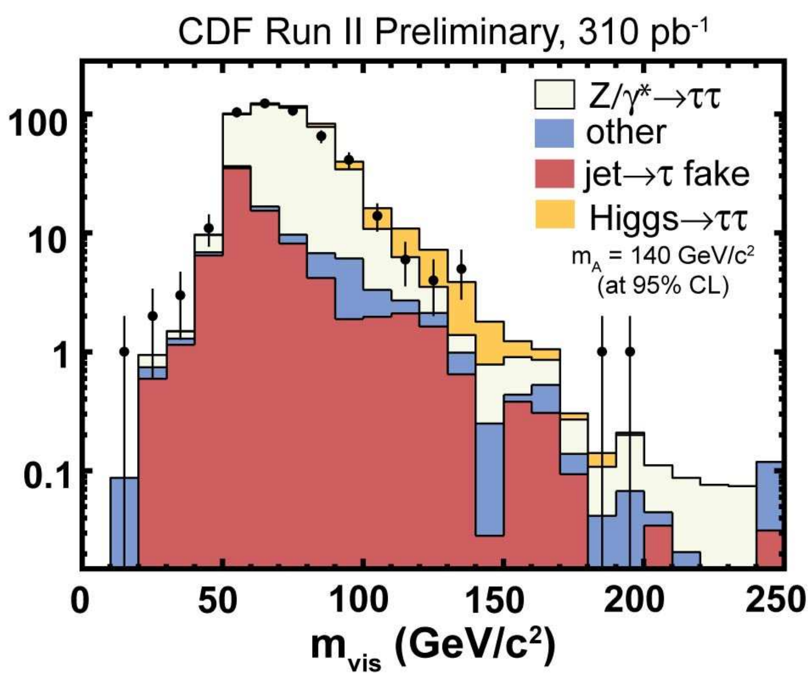
CDF: MSSM h,H,A → τ τ

310/pb luminosity

Reconstruct final state of $\tau_e\ \tau_h$ and $\tau_\mu\ \tau_h$ with more stringent cuts to reduce qcd and W+jet events

Z→ ττ shape and normalization from MC and jet backgrounds derived from data using jet → tau misidentification





487 observed events with 496 ± 38 predicted from SM processes

Set limits by fitting *visible* mass spectrum from e(μ) + tau + MET

Exclude tanβ~60 for m_A = 120 GeV

CDF 7676 Conference Note

Tevatron Tau Results 1

Electroweak

$\sigma(Z \to \tau\,\tau)$

CDF: Nucl. Phys. Proc. Suppl. 144, 323-332 (2005) **72/pb**

New conference result with **350/pb** shown (pg 24)

D0: PRD 71, 072004 (pg 20) **226/pb**

$\sigma(W \to \tau\,\nu)$ (pg 23)

CDF: Nucl. Phys. Proc. Suppl. 144, 323-332 (2005) **72/pb**

Top

A Measurement of Br(top $\to \tau\,\nu$ q)

CDF: CDF Note 7179 **194/pb**

Tau Trigger

CDF: A. Anastassov et al, Nucl. Instrum. and Methods A 518, 609 (2004)

Tevatron Tau Results 2

New Phenomena / Exotics

Chargino / Neutralino search

D0: D0 Note 4741-Conf **325/pb**

R-parity violated SUSY in 2 electron + tau final state

D0: D0 Note 4595-Conf **200/pb**

Stop decays to a tau and b-quark

CDF: CDF Note 7398 **200/pb**

High Mass Z′

CDF: hep-ex/0506034; Submitted to PRL (FERMILAB-PUB-05-251-E) **195/pb**

Higgs → $\tau\ \tau$ (pg 25)

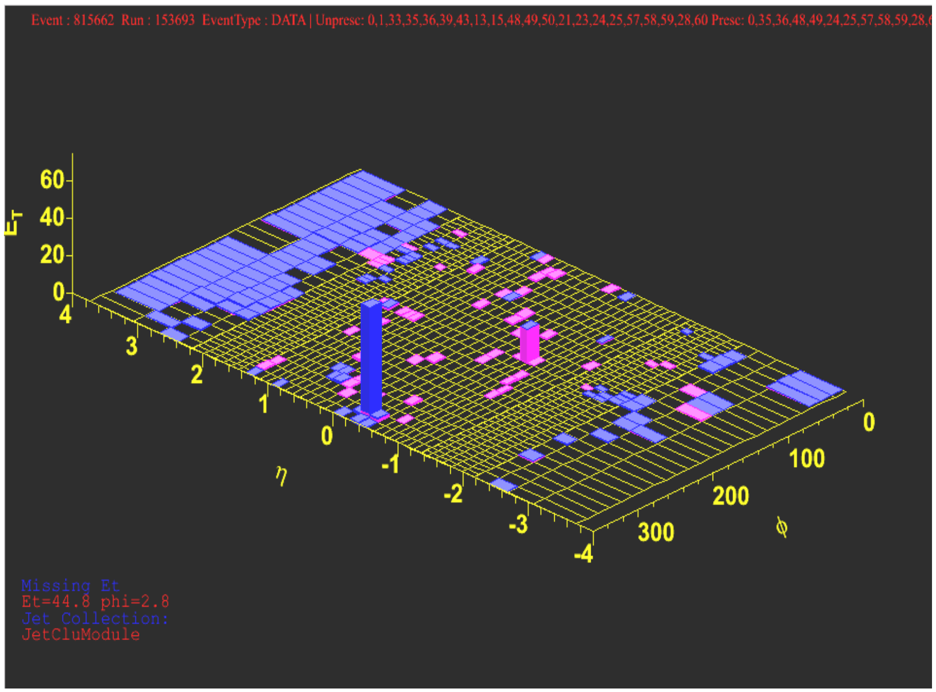
CDF: "Search for Neutral MSSM Higgs Bosons Decaying to Tau Pairs", CDF 7676 (2005) **310/pb**

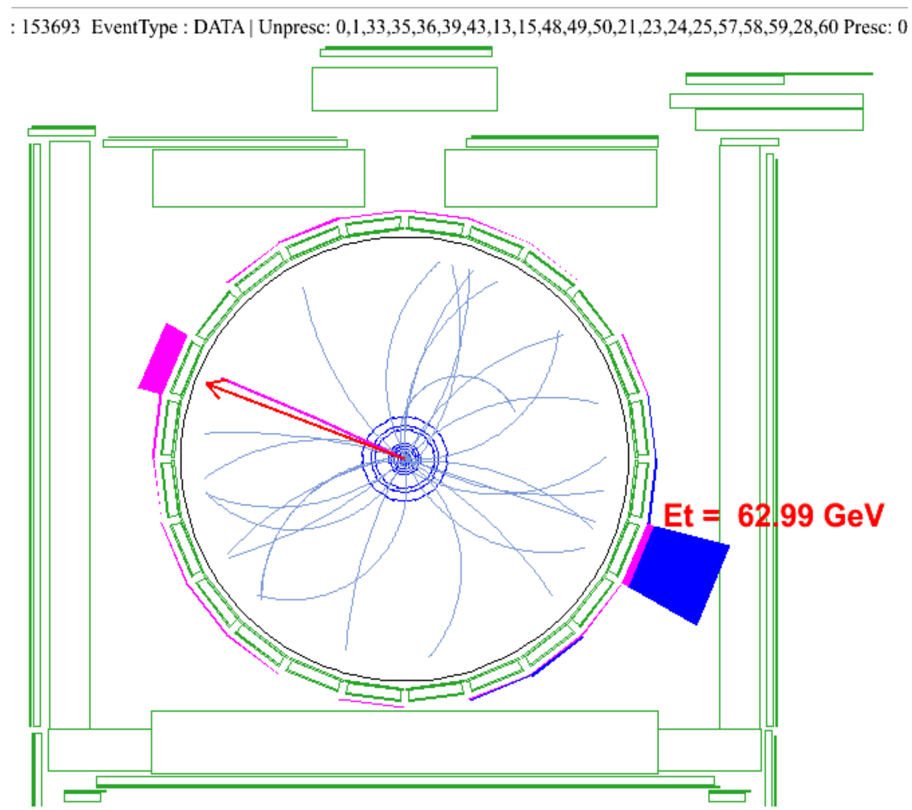
Conclusions

- CDF and D0 have demonstrated ability to make precise EWK measurements with taus
  - Tau efficiency vs tau → jet fake rate
    - 45% vs 1% cut based methods
    - 80% vs 5% neural net based methods
  - Systematic uncertainties for tau id ~3% and for tau → jet fake rate ~10-20%
- Choice of tau id method dependent on purity achieved through additional event requirements (b-tag, missing energy, topology, etc.)
- Tevatron actively investigating new physics / MSSM tau signatures

Backup Slides

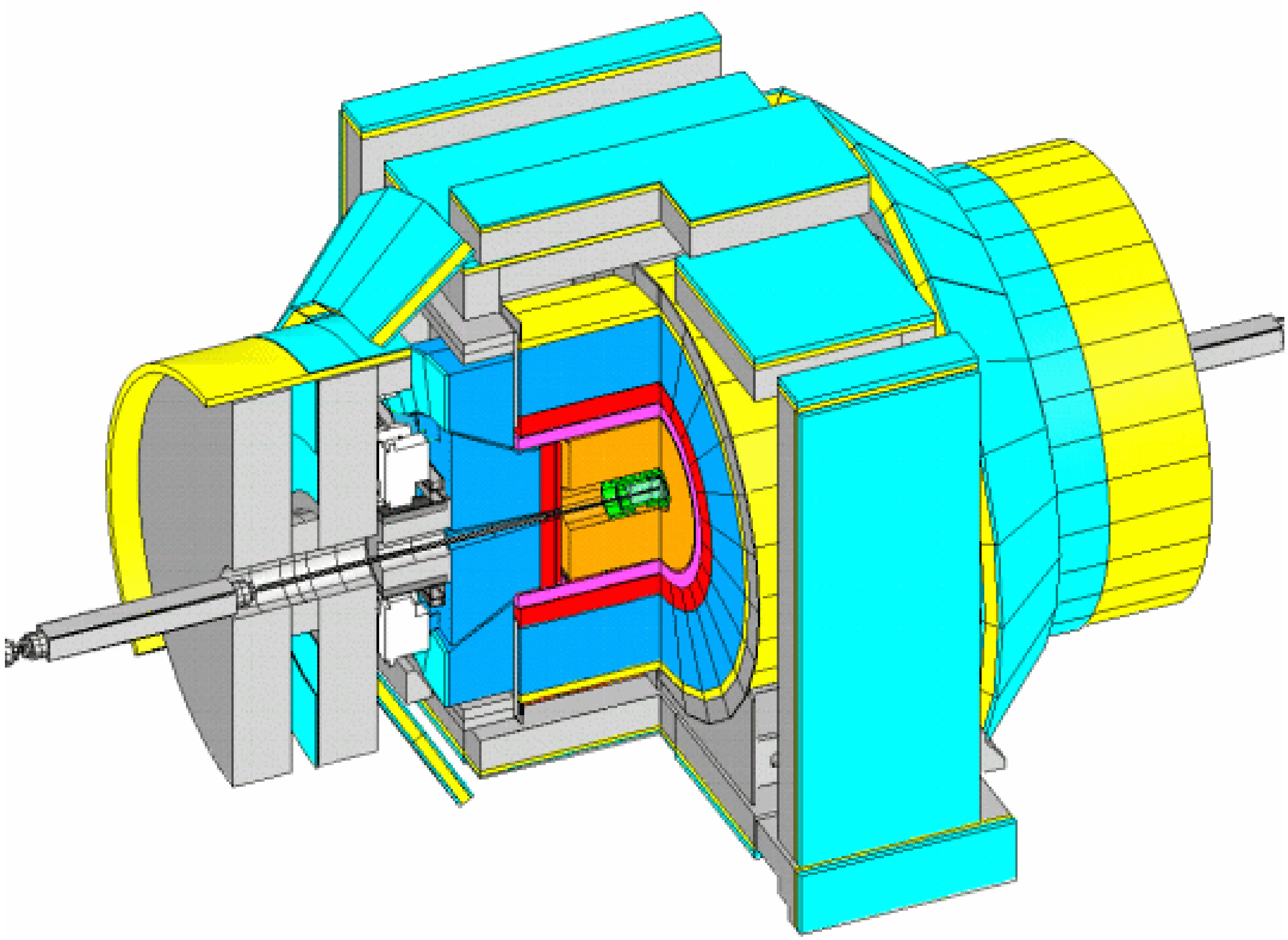
CDF: Z → τ_e τ_h Event



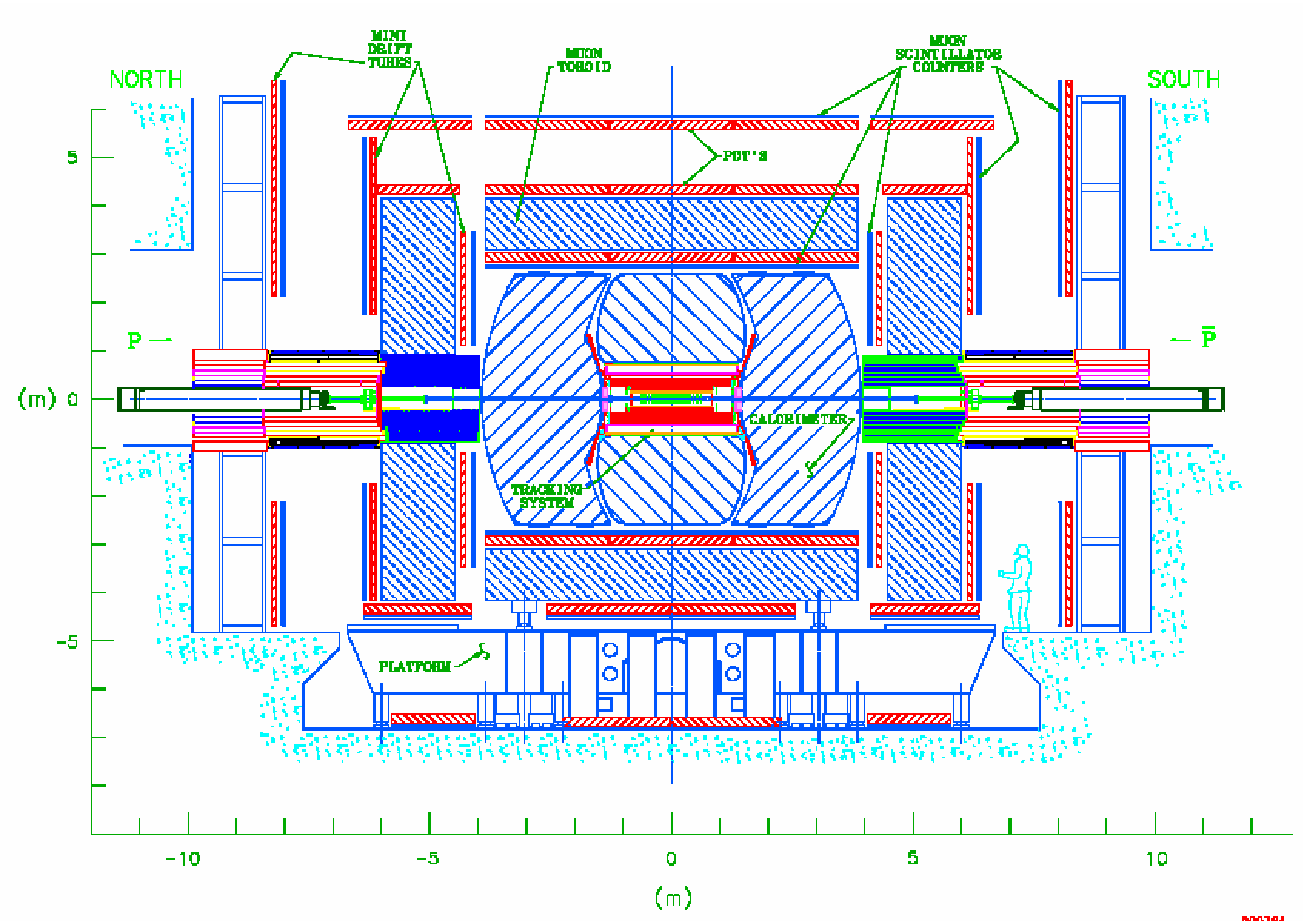


Mass (τ_e + τ_h + MET) = 129 GeV/c^2

CDF Detector

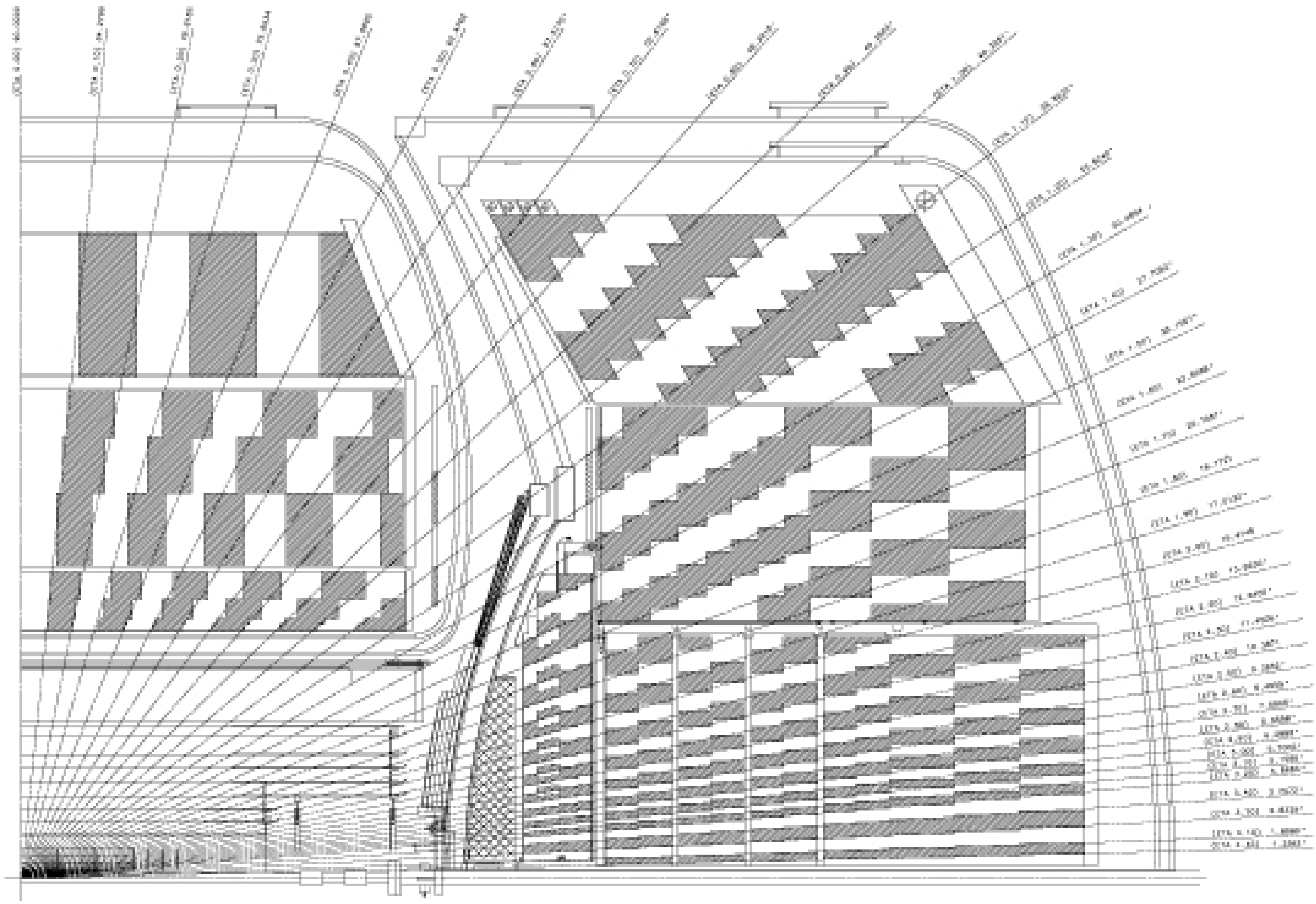


D0 Detector

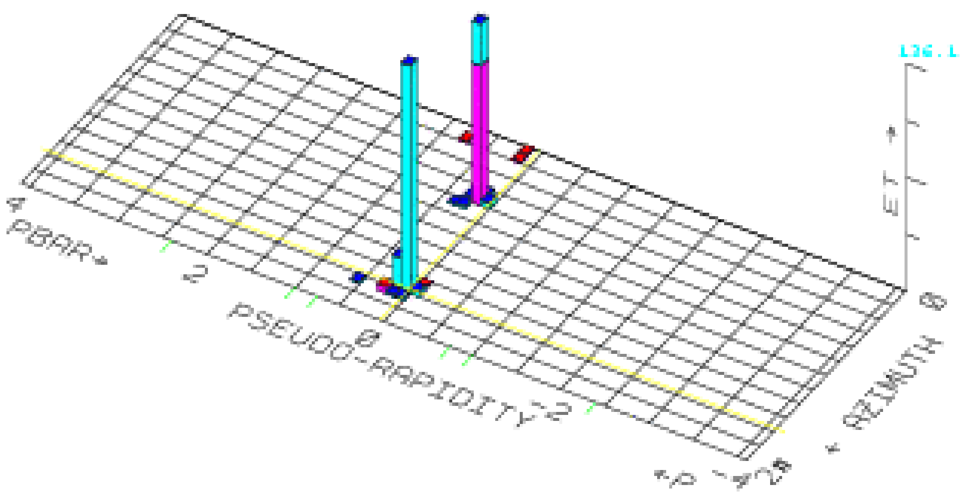


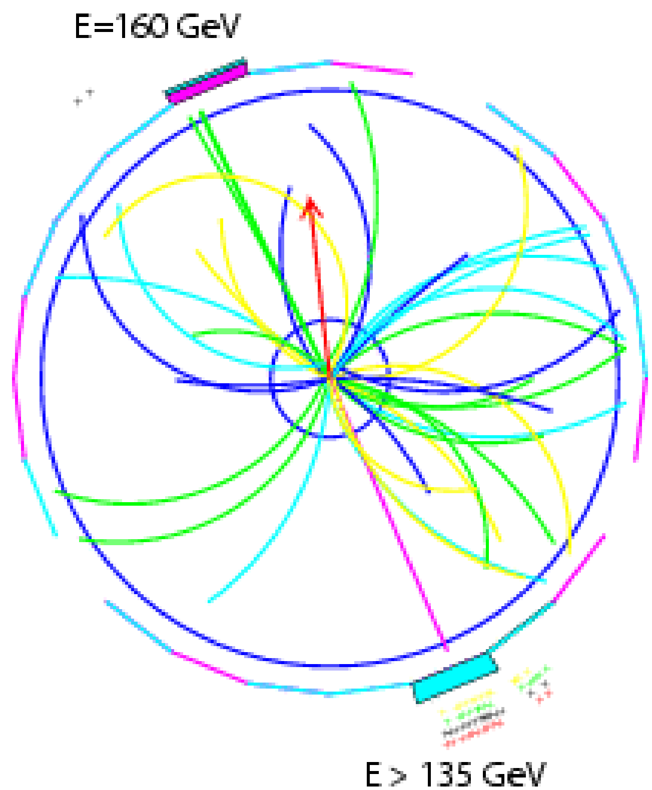
MINI DRIFT TUBES
MUON TOROID
MUON SCINTILLATOR COUNTERS
NORTH
SOUTH
PDT'S
P →
← P̄
(m) 0
5
-5
CALORIMETER
TRACKING SYSTEM
PLATFORM
-10
-5
0
5
10
(m)

D0 Calorimeter

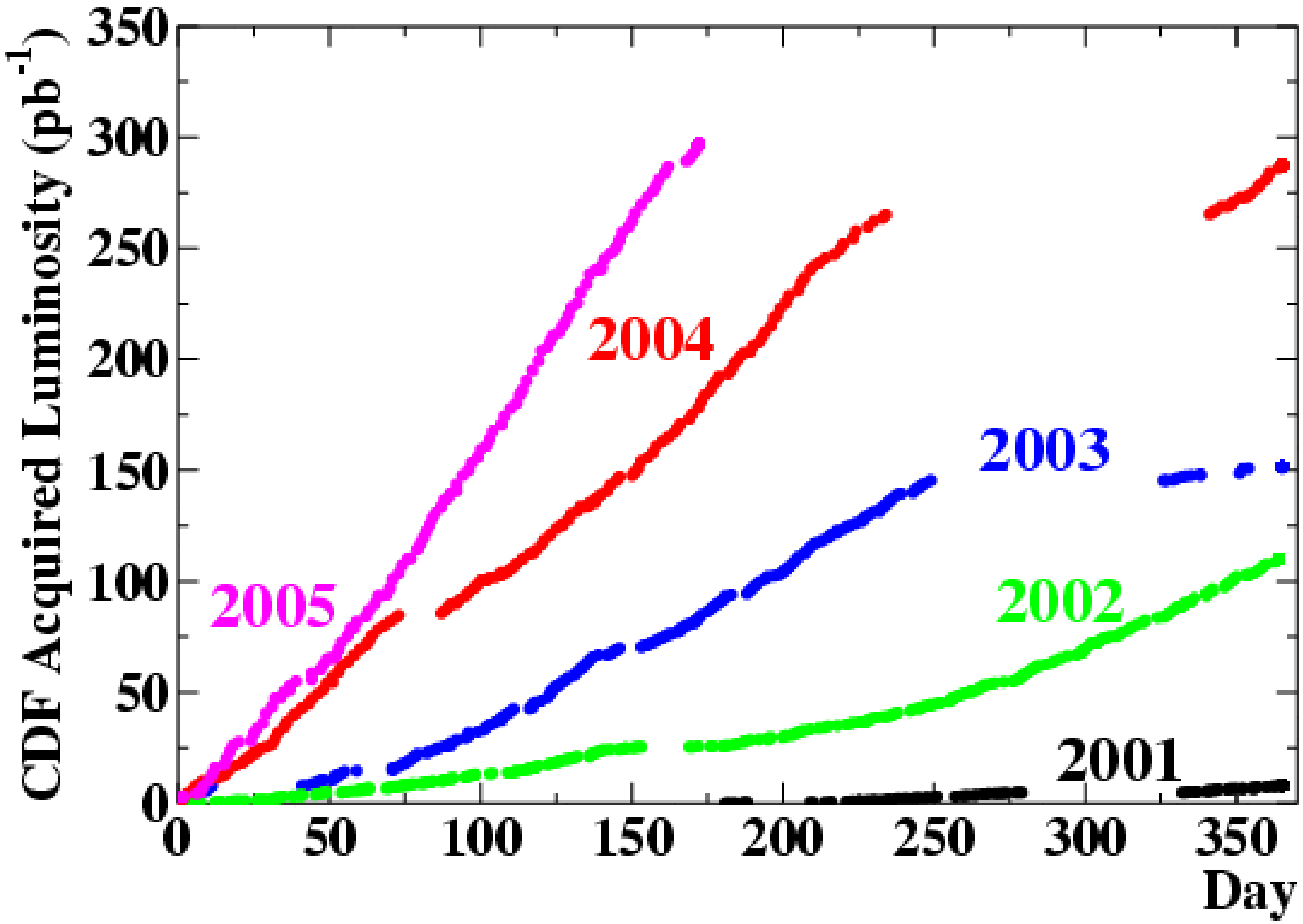


CDF Run I Di-Tau Event





CDF Integrated Luminosity



CDF: Z → $\tau_e\ \tau_h$

72/pb luminosity

Nucl. Phys. Proc. Suppl. 144, 323-332 (2005)

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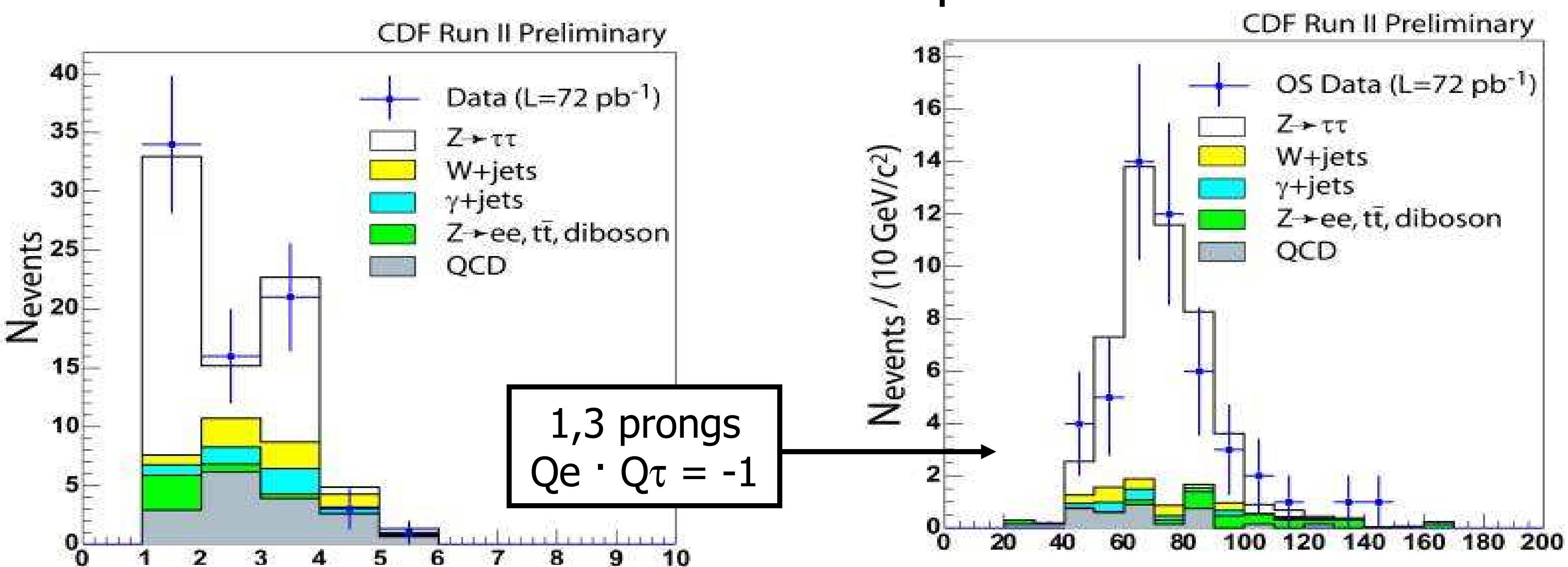

Number of tau tracks

Mass(e,τ,MET) GeV/c^2

CDF Pi0 Reconstruction

Single tower resolved photon pi0 mass resolution