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Summer 2003 Measurement of the t-tbar Cross Section in the e-τ and μ-τ Dilepton Channels

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Abstract

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1 Introduction

We measure the $t\bar{t}$ cross section in the $e\tau$ and $e\mu$ Dilepton Channels using 125 pb^{-1} $\pm$of data taken in the period from March 23, 2002 - May 2003.

The "$e\tau$" channel refers to events in the following decay chain:

$$t\bar{t} \to WWbb \to e\tau\nu_e\nu_\tau bb$$

The "$\mu\tau$" channel refers to events in the following decay chain:

$$t\bar{t} \to WWbb \to \mu\tau\nu_\mu\nu_\tau bb$$

Our electron ID and muon ID is identical to the ee, $e\mu$, $\mu\mu$ Winter Conference dilepton cross section tight electron and tight muon ID. [1] Differences in our cuts from other dilepton analysis are required due to the presence of hadronically decaying taus in our final state.

The cross section, σ can be expressed as

$$\sigma_{t\bar{t}}^{dil_{l,\tau}} = \frac{N-B}{\epsilon_{t\bar{t}}^{l,\tau} \quad * \quad L}$$

with

- N signal events
- B background events
- L as the Luminosity of our data sample
- $\epsilon_{t\bar{t}}^{l,\tau}$ as our acceptance
- l as a electron or muon

I will use l to stand for an electron or muon for the remainder of this note.

2 Event Selection

We use the High P_T Electron Dataset, btop0g, and the High P_T Muon Dataset, NAME for this analysis. The cuts made to form btop0g are listed in Table 1. This Dataset is fed by the `CENTRAL_ELECTRON_18` path.

We use the following cuts to select events:

1. **One Central Tight Electron above 20GeV**
   - We use the Baseline Analysis Cuts [2] used by the Dilepton Working Group for Winter Conferences.
2. **Tau Cuts as shown in Table 2**
3. $\not{E}_T > 20GeV$

EM E_T(GeV)	≥ 18.0	≥ 70.0
Had/EM E	≤ 0.125	No Cut
LshrTrk	≤ 0.3	No Cut
p_T (GeV/c)	≥ 9.0	≥ 15.0
E/p	≤ 4.0	No Cut
$\|\Delta z\|$ (cm)	≤ 5.0	≤ 5.0
$\|\Delta z\|$ (cm)	≤ 5.0	≤ 5.0

Table 1: Cuts that define dataset btop0g.

Tau Variable	Cut
π^0 + Track P_T	> 15 GeV
$\|z_0\|$	< 60 cm
$\|D0\|$	< 1 cm
(Track + π^0) Mass	< 1.8 GeV/c^2
Cal Iso: ΔR=0.4/$E_T^{cluster}$	< 0.06
# tracks in Iso Annulus	0
# π^0's in Iso Annulus	0
# tracks in Tau Cone	< 4
$\|\Sigma$(track charge) in Tau Cone$\|$	1
μ veto	no stubs in 15 degree cone
e veto: E_{HAD}/SUM (P)	> 0.15
seed track quality	≥ 3 stereo SL ≥ 7 hits ≥ 3 axial SL ≥ 7 hits
seed track $\|$Z CES$\|$	> 9 cm < 216 cm

Table 2: Tau Cuts: The tau cone and isolation annulus depend on the energy of the tau candidate.

- We use $\not\!\!E_{\rm T}$ corrected for tight muons, event vertex, and the corrections due on the two central jets (b-jet candidates)

4. **On subset of events, Veto events with 65GeV $< M_{e,\tau} <$115GeV**

- This cut targets our $\gamma^*/Z \to \tau\tau + jets$ background, which was the largest background for this analysis in Run1. We do not make this cut on all of the events, but only on a class of events with topology similar to $Z \to \tau\tau + jets$ so that we do not hurt our acceptance. We assign the event $\not\!\!E_{\rm T}$ to the tau and electron candidates before we reconstruct the mass. We require that the two objects (hadronic tau candidate and electron candidate) not be back-to-back in order for us to get a physical answer when we distribute the event $\not\!\!E_{\rm T}$ between them:

$$(\Delta\phi_{\tau_e,\tau_h} < (\ \pi\ \text{-}\ 0.5))$$

We make the following angular requirement in addition to the non-back-to-back requirement in order to select events that are $Z \rightarrow \tau\tau$ - like:

$$(\Delta\phi_{\tau_e,\not E_{\rm T}} + \Delta\phi_{\tau_h,\not E_{\rm T}})\ \text{-}\ \Delta\phi_{\tau_e,\tau_h}) < 0.4$$

where

- $\Delta\phi_{\tau_e,\not E_{\rm T}}$ is the Phi between the electron candidate and the event $\not\!\!E_{\rm T}$
- $\Delta\phi_{\tau_h,\not E_{\rm T}}$ is the Phi between the tau candidate (hadronically decaying tau) and the event $\not\!\!E_{\rm T}$
- $\Delta\phi_{\tau_e,\tau_h}$ is the Phi between the electron candidate and the hadronically decaying tau candidate

- The above requirements result in only 10% of our signal $t\bar{t}$ events being considered for the cut, with 85% of our $Z \rightarrow \tau\tau + jets$ background events being considered.
- A diagram of an event that would be reconstructed is shown in Figure 4 while a diagram of an event that would not be reconstructed is shown in Figure 4.
- Our Mass window is very wide (65-115GeV) because the resolution is poor and the mean value we reconstruct is low.

5. $\geq$ **2 jets with** $|\eta| <$ **2**

   - E_T of first jet > 30GeV (see optimization section for a justification of this cut value)
   - E_T of second jet > 10GeV
   - relative, energy-scale, and time corrections have been applied to jet energies

6. $H_T >$ **200GeV**

   - using corrected $\not\!\!E_{\rm T}$ and jet energies
   - see optimization section for a justification of this cut value.

7. **opposite charge of tau and electron**

   - the tau charge is the sum of charges of tracks within the tau cone around the tau seed track

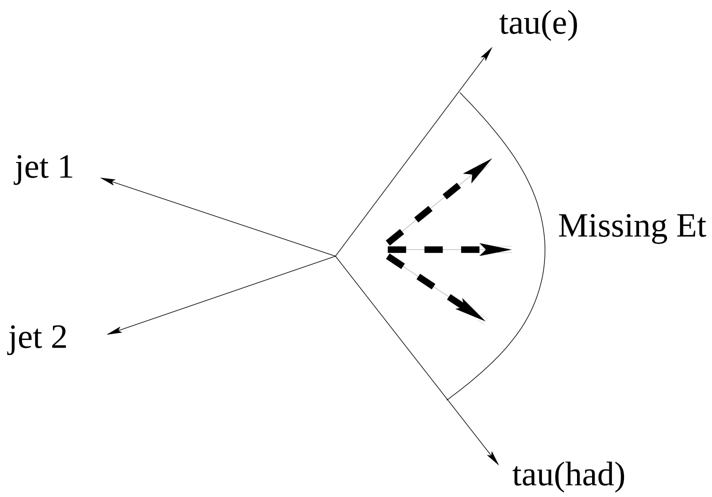

Figure 1: An example of an event in which the Mass would be reconstructed, meaning it passes the angular requirements. In other words, the tau(e) and tau(h) are not back-to-back, and the $\not\!\!E_{\rm T}$ falls between the tau(e) and the tau(h).

3 Acceptance

We use the inclusive ttbar dataset ttopei as our primary MC sample. This dataset was generated with Pythia and simulated and reconstructed with 4.11.1 of the CDF software. We processed the output of Production with TopEventModule in order to recluster jets and correct $\not\!\!E_{\rm T}$ for the primary vertex and tight muons. We apply relative and energy scale jet corrections to the raw jets and we correct $\not\!\!E_{\rm T}$ and H_T to reflect the jet energy changes.

We do not do any matching of reconstructed objects to HEPG (generator-level) objects when we calculate our acceptance, but we do select our events using the HEPG bank, requiring one of the W's to decay to an electron and the other W to decay to a tau. We do not require the tau to decay hadronically in order to be in our acceptance sample.

Our Acceptance, $\epsilon_{t\bar{t}_{e,\tau}}$, can be written as:

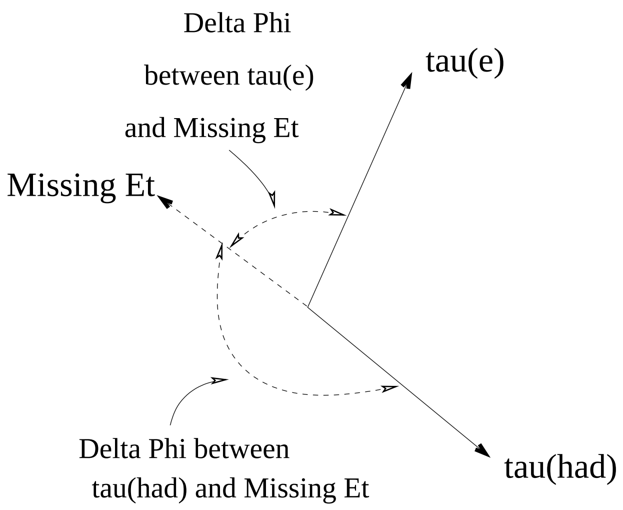

Figure 2: An example of an event in which the Mass would be reconstructed, meaning it fails our angular requirements. The $\not\!\!E_T$ does not fall between the two objects, or close enough to them to pass our cuts.

$$\epsilon_{t\bar{t}_{e,\tau}} = \epsilon_{trigger}\ \epsilon_{geom-pt}\ \epsilon_{ID}\ \epsilon_{\not E_T}\ \epsilon_{H_T}\ \epsilon_{2jet}\ \epsilon_{OS}\ \epsilon_{Zveto}$$

We take all of the pieces of the efficiency from the Monte Carlo with the exception of $\epsilon_{trigger}$. The trigger efficiency has been measured to be 97% [5]. It has been shown that the ϵ_{ID} for electrons agree between data and Monte Carlo to within less than a percent[9].

We take the $p\bar{p} \to t\bar{t}$ Cross Section to be 6.7pb when we calculate our expected number of events.

3.1 Acceptance from ttbar MC

The effect of our analysis cuts is shown in Table 3. The cuts are defined as follows:

- N_{sig}: This number is the total number of events beginning in the listed category according to HEPG information. The $e\tau$ category requires one of the W's to decay to an electron (and neutrino) and the other to decay to a tau. The $\mu\tau$ category requires one of the W's to decay to a μ and the other to decay to a τ. The $\tau\tau$ category requires both of the W's to decay to a tau. Note that the requirement is not made at this stage for the τ decays to be hadronic.

- $N_{geom+l_{ID}}$: Requires a tight lepton in the event. The $e\tau$ category requires a reconstructed tight electron (CEM, $E_T > 20$GeV), the $\mu\tau$ category requires a reconstructed tight muon (CMUP or CMX), and the $\tau\tau$ category requires either a tight electron or a tight muon.

- $N_{\tau_{cand}}$: requires at least one tau candidate reconsructed with TauFinderModule (that does not match to the tight lepton) to be present in the event.

- $N_{\tau_{ID}}$: requires the tau candidate to pass all tau ID cuts described in a previous section. Note that this is the first time the leptonically decaying τs are singled out, so part of the drop in acceptance is due to losing the leptonically decaying taus.

- $N_{\not{E}_T}$: requires the corrected $\not{E}_T$ (for tight muons and up to two jets in the event) to be above 20GeV

- $N_{H_T>200}$: requires H_T to be above 200GeV

- N_{2jet}: requires a minimum of two extra jets in the event that do not match to the electron or the tau that have $|\eta| < 2.0$. One of the jets must have an $E_T > 30$GeV while the other jet must have E_T>10GeV

- $N_{oppcharge}$: requires the sum of the charged tracks in the tau cone to be the opposite charge of the e or μ (depending on the category.)

- $N_{Zmass\ veto}$: requires the event to survive our Mass Reconstruction veto cut

We would like to explore the effect of our τ ID cuts on our acceptance so we make plots of the tau candidates after all cuts but one have been made for each of our cuts. Note that we have 585 τs that pass all of our cuts when we combine the three categories (adding the contributions on the third line of table 3). We show these "N-1" plots in Plots 3, 4, and 5. We show the effect of each cut in table 4, where we show the ratio of number of events after all cuts to the number of events after all cuts except for the one in question.

Our $t\bar{t}$ efficiency can be written as

$$\epsilon_{t\bar{t}}^{MC} = (\text{Total } N_{Zmass\ veto} \ / \ \text{Total Sample Size}) * \epsilon_{trigger}$$

The CEM trigger efficiency is 97%. (CDF Note 6234) Our $\epsilon_{t\bar{t}}^{MC}$ for the e, τ channel is therefore

$$(\ (200 + 14\ )\ /\ 382036) *(0.97) = 0.00054 \pm 0.00004(\text{stat}) \pm (\text{sys})$$

Cut	# of eτ events	# of $\mu\tau$ events	# of $\tau\tau$ Events
N_{sig}	5889	6014	4016
$N_{geom+ID}$	2168	1901	384
$N_{\tau_{cand}}$	1695	1520	278
$N_{\tau_{ID}}$	296	244	48
$N_{oppsign}$	294	243	48
N_{1jet}	272	230	44
N_{2jet}	251	212	38
$N_{\not{E}_T}$	230	191	36
$N_{H_T>200}$	207	174	29
$N_{Zmass\ veto}$	199	168	28

Table 3: ttbar acceptance from Pythia Monte Carlo dataset ttopei. There is no matching between HEPG objects and reconstructed objects. We use 386,049 events from this dataset. The events have been filtered at the HEPG level for the presense of a hadronically decaying tau in the event. The 28 events in the $\tau\tau$ category include 15 from the electron channel and 13 from the muon channel.

Cut Percentage of remaining τs	in electron events	in muon events
π^0 + Track $P_T > 15$ GeV	91.2%	94.7%
$\lvert z_0 \rvert < 60$ cm	100.0%	98.2%
$\lvert D0 \rvert < 1$ cm	100.0%	100.0%
(Track + π^0) Mass < 1.8 GeV/c^2	96.7%	94.7%
Cal Iso: ΔR=0.4/$E_T^{cluster} < 0.06$	79.4%	77.1%
No tracks in Iso Annulus	86.5%	82.1%
No π^0's in Iso Annulus	97.1%	90.2%
# tracks in Tau Cone $< 4 = 1$	99.1%	100.0%
$\lvert\Sigma$(track charge) in Tau Cone$\rvert$	92.5%	92.1%
μ stub veto	98.8%	98.5%
e veto: E_{HAD}/SUM (P) > 0.15	90.1%	89.9%
seed track quality	98.8%	98.9%
seed track $\lvert$Z CES$\rvert$ (fiducial)	91.2%	92.4%

Table 4: Effect of tau cuts on inclusive ttbar Pythia MC after a tight lepton (electron or muon) has been selected. An event must have a HEPG tau to make it to this point of the analysis but we have not required the tau to be a hadronically decaying tau. Electrons, unlike muons, are very efficiently reconstructed as taus because the energy they typically deposit in the calorimeter easily passes the threshold for tau reconstruction. Because of the efficient reconstruction of electrons as taus and because of the presence of electrons from tau decays, we are not surprised by the strength of the electron veto cut.

In 125 pb^{-1} we would expect 0.46 $\pm$ 0.03 (stat) events. In 195 pb^{-1} we would expect 0.71 $\pm$ 0.05 (stat) events.

The CMUP trigger efficiency is 89% and the CMX trigger efficiency is 97%. (CDF Note 6610) 64CMX. Note also that the CMX trigger was not working for 16% of the luminosity. Our trigger efficiency is therefore 86%. Our $\epsilon_{t\bar{t}}^{MC}$ for the μ, τ channel is

$$((165 + 12) / 382036) *(0.86) = 0.00040 \pm 0.00004(\text{stat}) \pm (\text{sys})$$

In 125 pb^{-1} we would expect 0.33 $\pm$ 0.03 (stat) events. In 195 pb^{-1} we would expect 0.52 $\pm$ 0.04 (stat) events.

with systematic errors detailed in the following section.

3.2 Systematics

- Top Mass Uncertainty
- Jet Corrections/Energy Scale
  -
- Electron ID
  - We use the Winter Conference Electron ID, which has a systematic error of $\pm$3% percent associated with it.
- Tau ID
- MC generator Dependence
  - We compare inclusive ttbar MC from Pythia (dataset ttopei) with inclusive MC from Herwig (dataset ttopli). Half of the difference in acceptance is our systematic error. The pythia monte carlo gives 90% of the expected number of events that the herwig monte carlo gives for the same luminosity. Our systematic error due to monte carlo generator is therefore $\pm$5%.
- ISR
  - We compare the difference between our acceptance with inclusive Pythia ttbar MC with (dataset ttopei) and without (dataset ttop0e) ISR. Half of the difference is our systematic error. The dataset with ISR (ttopei) gives 96% of the expected number of events that the dataset with no ISR (ttop0e) gives for the same luminosity. Our systematic error due to ISR is therefore $\pm$2%.
- FSR
  - We use the Run1 value [7] that combines the effect of ISR and FSR to determine this systematic. A better procedure will be decided upon before Winter 2004 Conferences. This systematic error is therefore $\pm$3%
- PDF

Source	Systematic Error
Top Mass Uncertainty	$\pm$ %
Jet Corr/Energy Scale	$\pm$ %
Electron ID	$\pm 3\%$
Tau ID	$\pm$ %
MC Generator	$\pm 5\%$
ISR	$\pm 2\%$
FSR	$\pm 3\%$
PDF	$\pm 2\%$
Total	

Table 5: Summary of Systematics for Acceptance

– The PDF uncertainty is to a certain extent contained in the difference between our Herwig and Pythia Monte Carlo, which use different PDFs. We use the Run1 $\pm 2\%$ systematic uncertainty for the 2003 Summer Conferences result.

We summarize the systematic error contributions in Table 5.

References

[1] M. Coca et al., "Winter 2003 Measurement of the t-tbar Cross Section in the Dilepton Decay Channel" CDF Note 6319

[2] `www-cdf.fnal.gov/internal/physics/ewk/hipt_lepton_baseline_cuts.html`

[3] S. Demers et al., "Identifying Leptonic tau decays in ttbar Events using the Run 2 AC++ Software" CDF Note 5384

[4] M. Reece and H. Frisch, "Using Track Impact Parameter To Distinguish Hadronically Decaying taus in Top Quark Decays from Light Quark Jets, " CDF Note 6203

[5] Y-K Kim, et al., "Efficiencies for High P_T Electrons," CDF Note 6234

[6] P. Murat, "W$\rightarrow \tau\nu$ Signal in Run II data and Preliminary measurement of BR(W$\rightarrow \tau\nu$)/BR(W$\rightarrow e\nu$)," CDF Note 6010

[7] M. Hohlmann, Ph.D. thesis, "Observation of Top Quark Pairs in the Dilepton Decay Channel Using Electrons, Muons, and Taus," CDF Note 4280

[8] A. Anastassov et al., "Extraction of Z to tautau Signal using Run II Lepton + Track Trigger - Electron Channel, " CDF Note 6402

[9] M. Coca et al., "Acceptance Estimate for the Winter 2003 Top Dilepton Cross-Section Measurement," CDF Note 6301

[10] `http://www-cdf.fnal.gov/internal/physics/ewk/WZCS/grlist_criteria.txt`

[11] `http://www-cdf.fnal.gov/internal/physics/ewk/WZCS/ljets_good.txt`

[12] F. Ratnikov, "Tau Reconstruction for CDF Run2, " CDF Note 6252

[13] A. Anastassov et al., "Tau Reconstruction Efficiency and QCD Fake Rate for Run 2, " CDF Note 6308

[14] M. Coca and E. Halkiadakis, "Central Electron Identification Efficiences for Winter 2003 Conferences," CDF Note 6262

[15] J. Insler et al., "Determining the Electron Fake Rate for Hadronic taus from the Data," CDF Note 6408

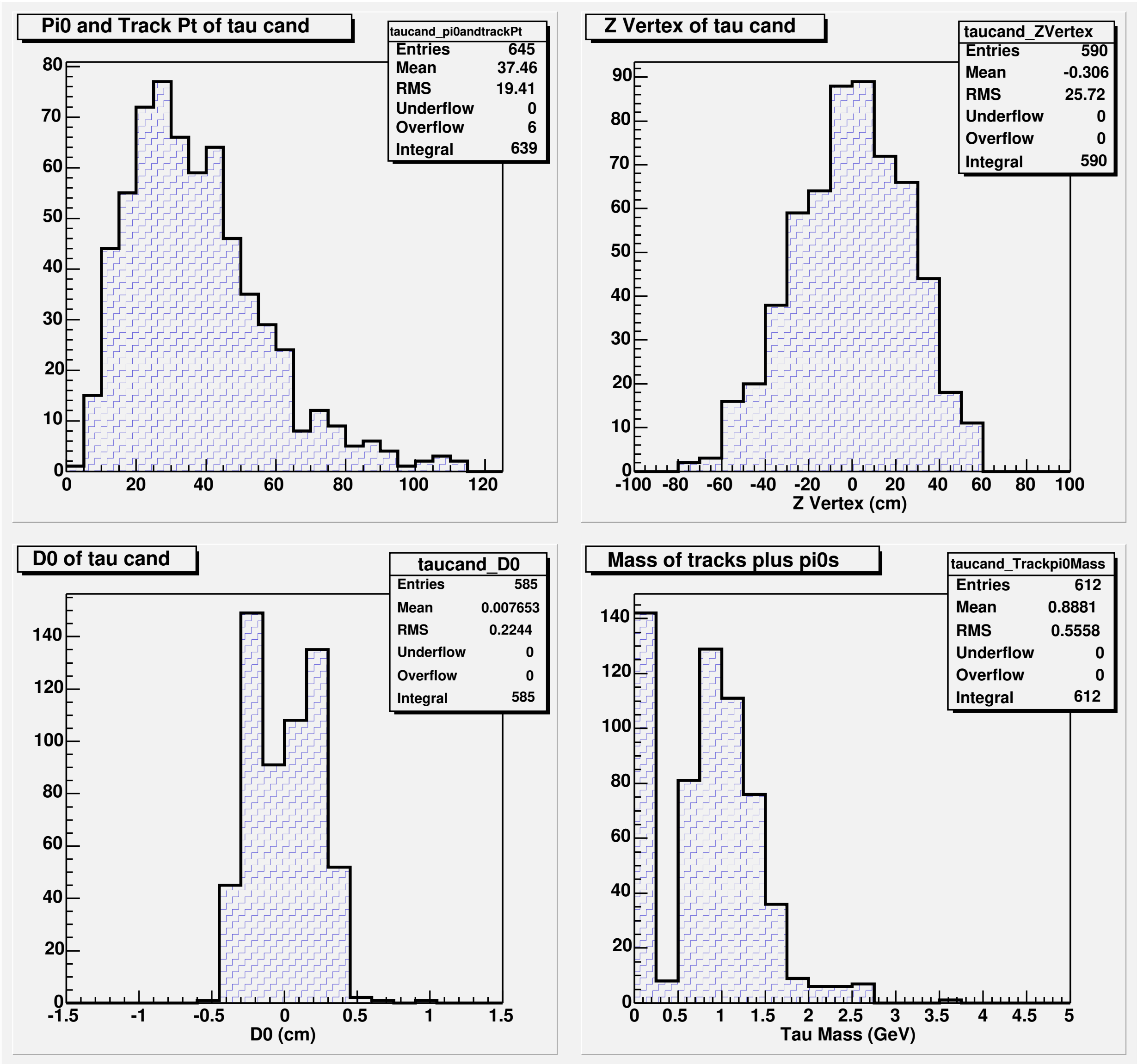

Figure 3: These plots show the effect of each individual tau ID cut on the tau acceptance. All cuts except the cut on the value being plotted have been made. The final sample of events with taus contains 585 events. **upper left**: π^0 + Track P_T. The cut on this variable requires a value above 15GeV. **upper right**: Z vertex. The cut on this variable requires an absolute value of the vertex less than 60cm. **lower left**: D0 of tau candidate. The cut requires the absolute value of the D0 (impact parameter) to be less than 100cm. Note that no events fail this cut.**lower right**: Track + π^0 Mass. The cut requires the mass to be less than 1.8GeV/c^2

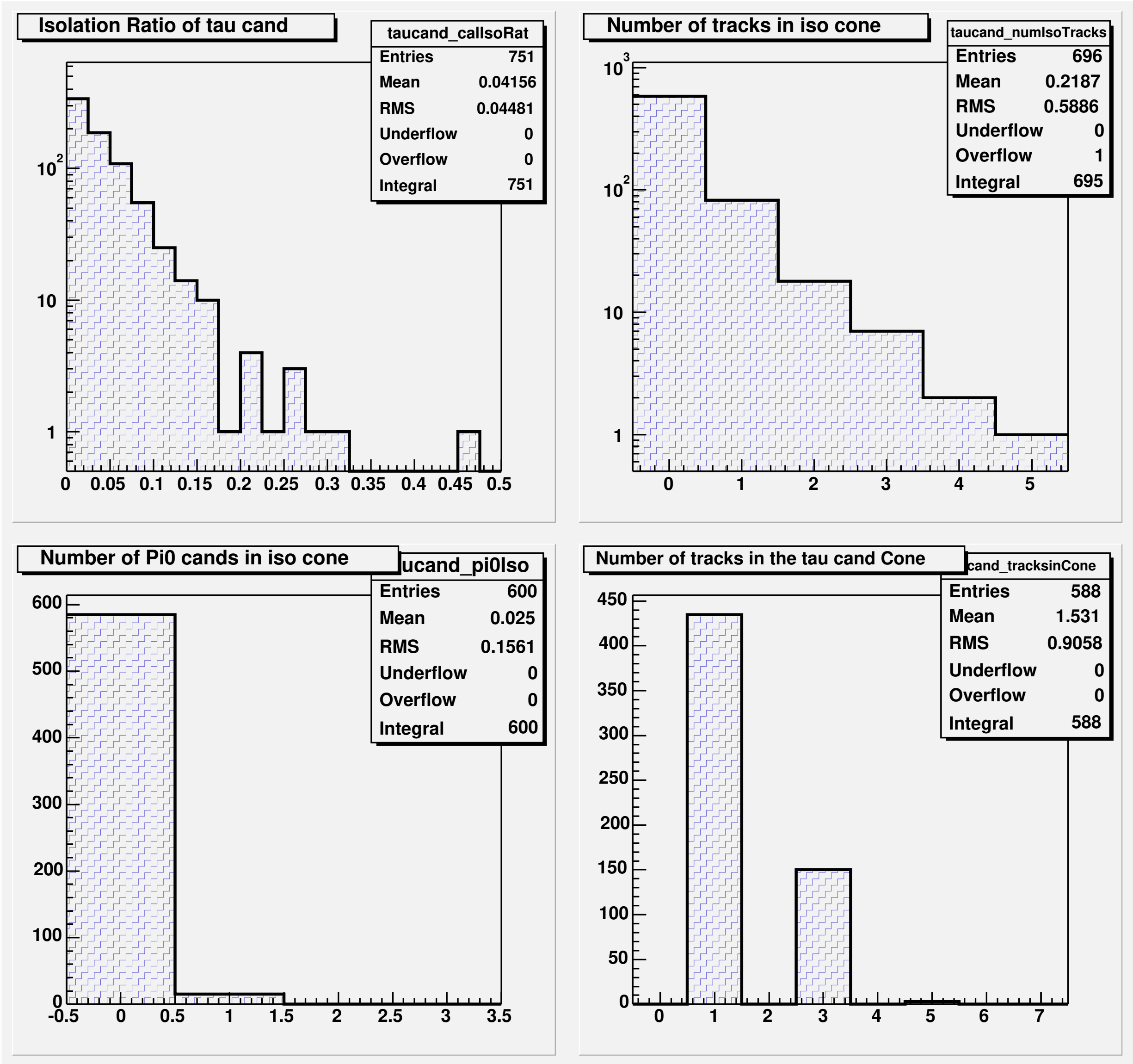

Figure 4: These plots show the effect of each individual tau ID cut on the tau acceptance. All cuts except the cut on the value being plotted have been made. The final sample of events with taus contains 585 events. **upper left**: π^0 + Track P_T. The cut on this variable requires a value above 15GeV. **upper right**: Number of tracks in the isolation annulus around the tau cone. The cut requires zero tracks in this region. **lower left**: Number of π^0s in the isolation annulus. The cut requires zero tracks in this region **lower right**: Number of tracks in tau cone. Note that the requirement has already been made that the sum of charges of the tracks be equal to ± 1, so only odd numbers of tracks remain. The cut requires the number of tracks to be less than four so all it does for us here is to remove the three taus with five tracks.

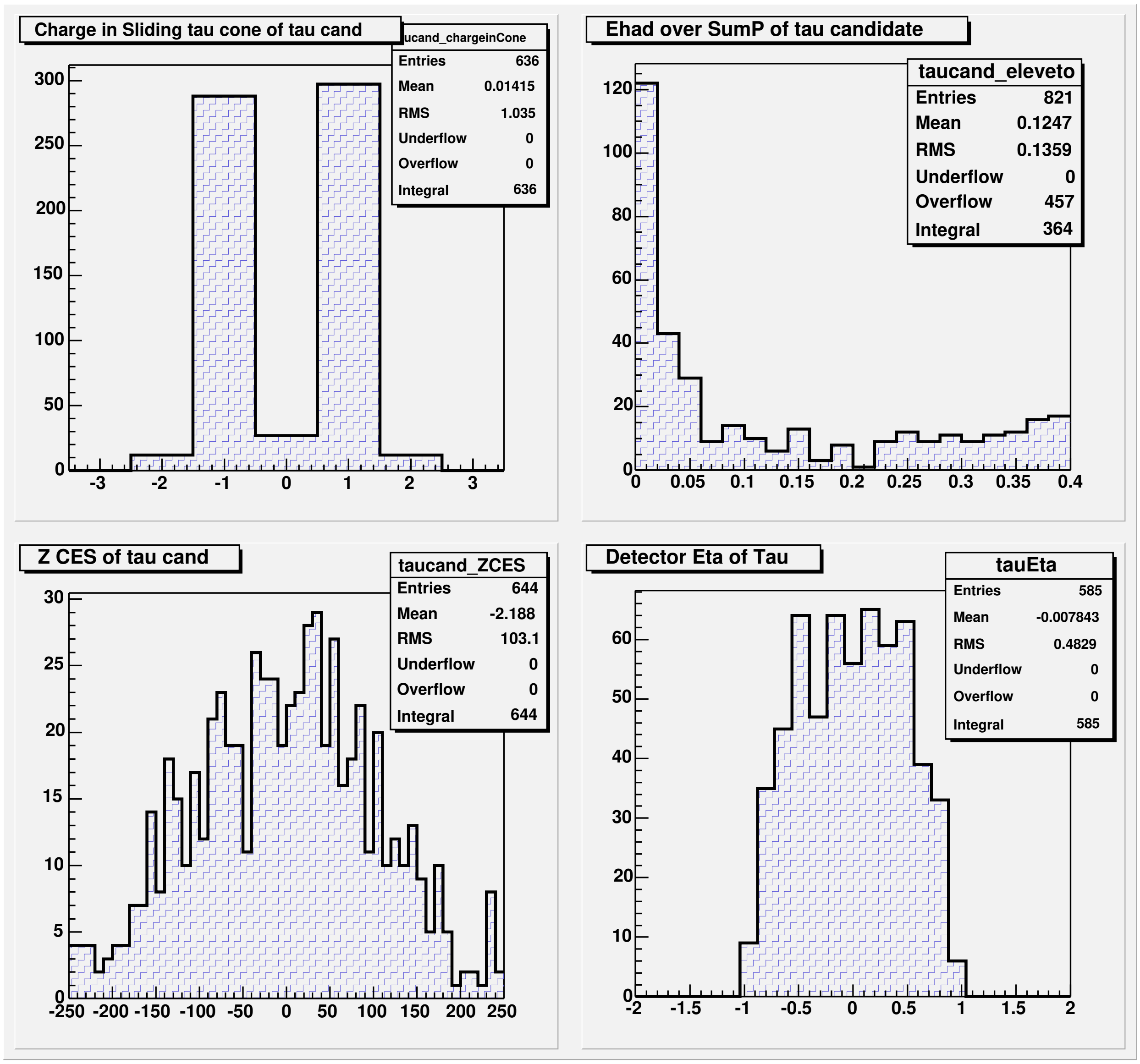

Figure 5: These plots show the effect of each individual tau ID cut on the tau acceptance. All cuts except the cut on the value being plotted have been made. The final sample of events with taus contains 585 events. **upper left**: Charge of tau. This is the sum of the charges of the tracks in the tau cone. The absolute value of the charge must equal one in order for a tau to pass this cut. **upper right**: E_{HAD}/SUM (P). This is the quantity we use to veto on electrons. Note that because we have not required the taus in this sample to be hadronically decaying taus that our cut at >0.15 is cutting out real electrons from tau decays. **lower left**: Z CES. The cut requires the absolute value of the Z CES to be greater than 9cm and less than 216cm. **lower right**: Detector Eta of the taus that pass all ID cuts.