CDF/ANAL/TOP/CDFR/7140
July 25, 2004
Version 1.0

Investigating Rho Backgrounds to Hadronic Tau Decay

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DRAFT

Abstract

We investigate backgrounds to hadronic τ lepton decays from an isolated leading ρ meson in a jet. We had considered the possibility that a substantial fraction of tau 'fakes', in which a QCD jet is identified as the hadronic decay of a tau, were from an isolated leading ρ in the jet fragmentation. In this case, color flow from the QCD fragmentation might give differences in event topology that would allow us to distinguish fake taus from rho's in jets from real taus, which have color singlet parents. However, we find that, at least according to Pythia, the number of ρ mesons faking taus is a small fraction of the total number of jets faking taus (10% or less, depending on the sample). Many of these fake taus are isolated, so event topology does not appear to distinguish them well from true taus. On the other hand, certain distributions (such as number of tracks in a 10°cone) appear very different for the fakes than for real taus.

1 Introduction

The tau lepton decays to $\pi^- \pi^0 \nu_\tau$ (25.41$\pm$0.14)% of the time, generally through the $\rho(770)$ resonance [1]. The branching ratio to all semihadronic decays is 64.7%, so this decay accounts for 39.3% of all hadronic taus. The dominant channel for hadronic tau decay is through the ρ meson (the W boson is far off shell, and the $u\bar{d}$ pair have an invariant mass right in the ρ resonance region).

We seek to improve tau identification for use in top, electroweak, and new physics analyses. The separation of the hadronic decays of the tau from the overwhelmingly larger flux of jets from quark and gluon fragmentation is a famously difficult task. We realized that isolated 'leading' (i.e. carrying most of the parton momentum) ρ mesons arising from QCD jets could be an irreducible background for real taus decaying through the ρ, much as leading π^0's are a background for photon identification. Our hope for distinguishing QCD ρ's from taus that come from (color single) electroweak sources (but decay through the ρ) was that the color flow in the QCD decays would lead to differences in the event topology that are detectable. This little note documents a (little) monte carlo study to test this idea with monte carlo events.

We use Pythia and the 'truth' information in the HEPG bank as well as the reconstructed tau candidates to investigate the fraction of taus identified after reconstruction which come from rho's from both quark and gluon jets, and to look for the other daughters of the parent of the rho.

We use Cdfsoft2 release 4.11.2 throughout.

2 Rho Mesons Faking Taus

We study tau fakes in Monte Carlo samples of $t\bar{t}$ in which one W is forced to decay to $\tau\nu$ (real taus), and the other to $u\bar{d}$ or $c\bar{s}$ (quark jets, including b-jets), and $W + 1$ jet and $Z^0 + 3$ jet samples (gluon jets). We identify the parentage of fake taus by finding in the Monte Carlo sample all the reconstructed taus with E_T of least 15 GeV that pass the tau ID cuts (see Appendices A and B). We then look for a Monte Carlo particle matching the seed track of the reconstructed tau, in the sense that $\Delta R(MC, seed) < 0.05$. We require that this matching particle not arise from a tau decay at any point up the decay chain. At this point, we label the reconstructed tau in question as a fake. Next, we look for a ρ meson in the Monte Carlo as a parent of the particle matched to the (fake) reconstructed tau.

In a Pythia $t\bar{t}$ sample of 214,000 events, we find a total of 8,315 fakes, of which 964 are from ρ mesons by this criterion. This is of a total of 700,169 jets (with $E_T > 15$ GeV and $|\eta| < 1.1$, not corresponding to a good central electron) that do not match Monte Carlo taus, giving an overall fake rate of 1.2%, of which 12% are from rhos. In this sample the jets are expected to be largely from $q\bar{q}'$ decays of the W or from the b and $\bar{b}$ from the top decays, and hence are largely quark jets. To investigate gluon jets, we look at a MadGraph W+1 jet (with $W \rightarrow e\nu$) sample of 110,000 events. We find 2,858 fakes, of which 167 are from ρ mesons by this criterion. Here the total number of jets is 55,249, so the fake rate is 5.2%, of which 5.8% are from rhos. In a MadGraph Z+3 jets (with $Z \rightarrow e^+e^-$) sample of 142,000 events, we find 8,397 fakes, of which 682 are from ρ mesons by this criterion. Here the number of jets is 246,134, so the fake rate is 3.4%, of which 8.1% are from rhos.

The main lesson to take from this, then, is that ρ mesons do not constitute a large fraction of the fakes. We had expected [2] that gluon jets would tend to produce more ρ's than quark jets, so in particular we expected to see a higher fake rate from rhos in the W+jet sample. This is not the case; these gluon jets rarely produce ρ mesons that are high-p_T and isolated enough to look like taus. Despite the low rate of ρ fakes, we pursued this further in the hopes of getting further insight into ways of identifying tau leptons. For the remainder of this note we will focus on the $t\bar{t}$ sample, as all distributions seem to be approximately the same across samples.

In Fig. 1 we plot the number of tracks in a ten degree cone, number of π^0's in a ten degree cone, number of pi0s in the (10 to 30 degree) isolation annulus, and charge in a ten degree cone for the reconstructed taus that we identify as fakes coming from ρ's. Note in particular that many of these fakes have two tracks in the tau cone, whereas actual taus will typically have one or three tracks in the cone. (Note that all of our tau identification cuts reject tracks in the isolation annulus, but it is possible to have π^0's in the isolation annulus.)

Next, we look up the two mother particles of the ρ. Often, there is only one, and it is a string. For that case, we have plotted the rho p_T as a fraction of the string p_T in Fig. 2. For each mother,

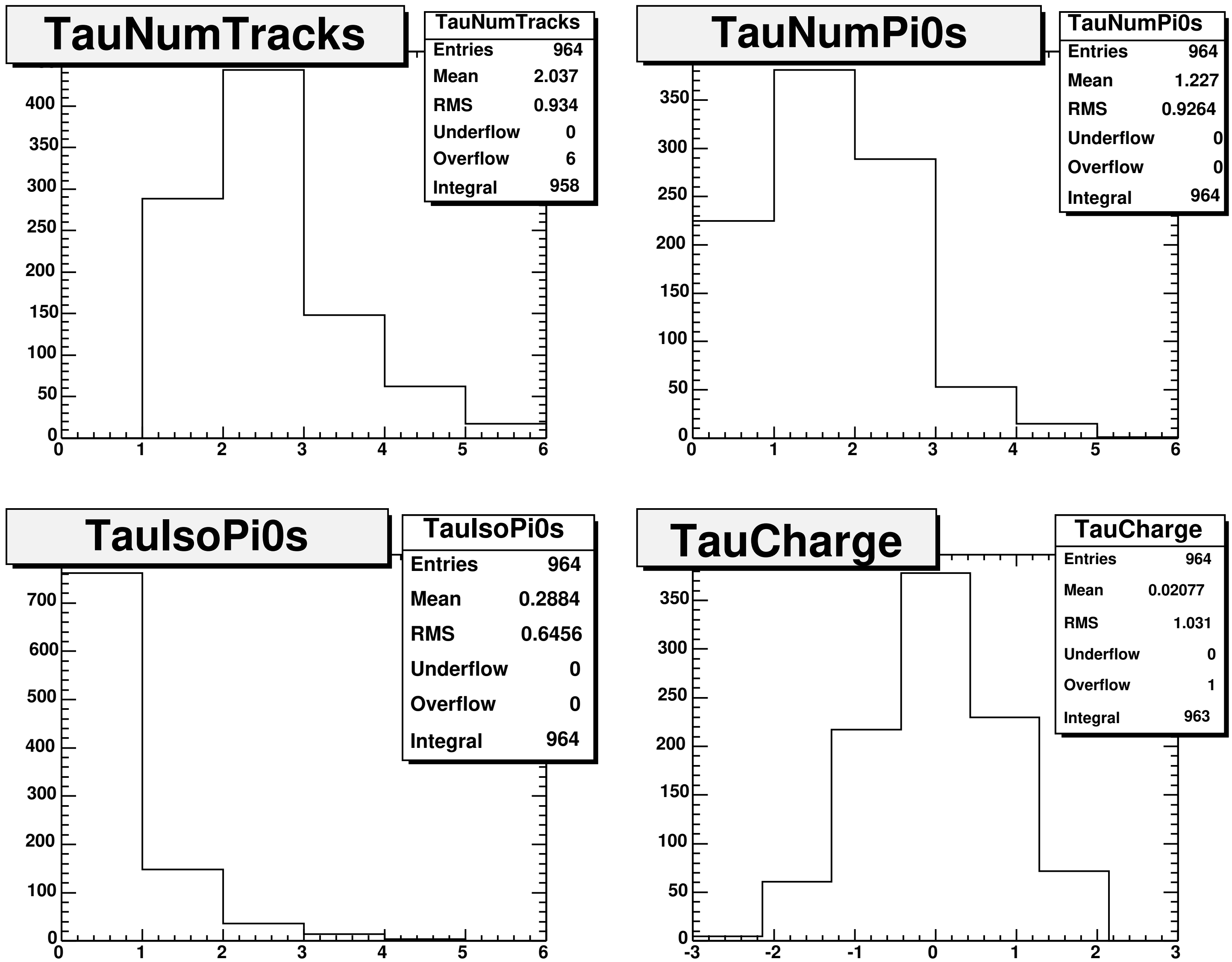

Figure 1: Number of tracks, number of pi0s, number of pi0s in the isolation annulus, and charge for the reconstructed taus that we identify as fakes from ρ mesons in the $t\bar{t}$ Monte Carlo sample. Note that the distribution of number of tracks peaks in the $N = 2$ bin, while the number of events with 2 or more π^0's is also large. This is different from τ decay, in which we expect few π^0's, and one or three tracks.

we loop over all of the daughters. We have plotted in Fig. 3 the ΔR from the ρ direction to the direction of the nearest other daughter with p_T greater than various thresholds (1 GeV, 5 GeV, 10 GeV, and 30 GeV).

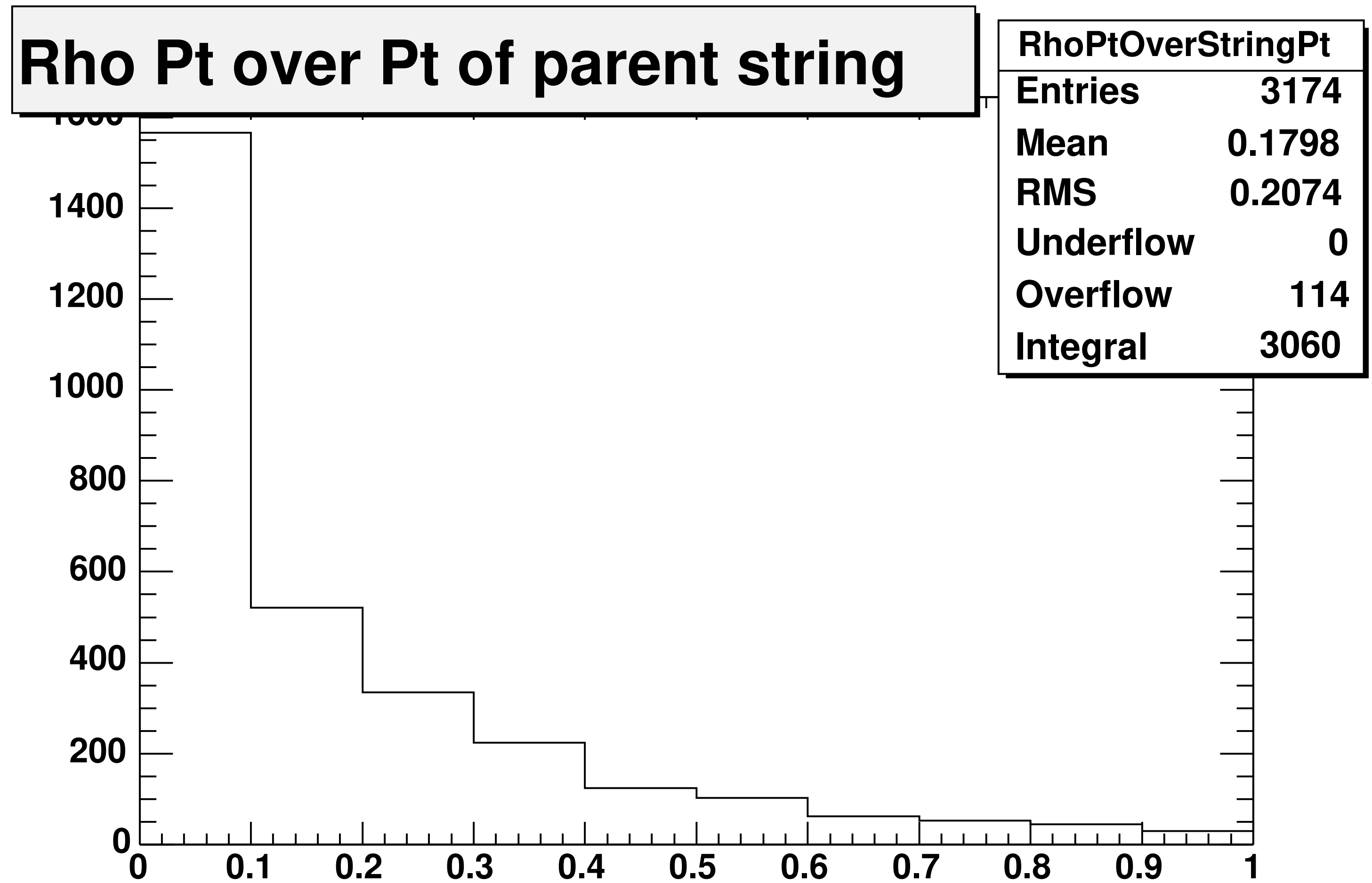

Figure 2: Rho p_T divided by the p_T of the parent string. This is for rho jets of $E_T > 15$ GeV faking taus. Note the ρ p_T is typically a small fraction of the p_T of the parent string, rather than being a 'leading' particle.

3 A Closer Look: Rhos Reconstructed as One-Prong Taus

To try to get a better sense of how well we can tell apart fakes and real taus, we focus on those ρ fakes that are reconstructed as one-prong taus. (That is, they have only one track greater than 1 GeV in p_T within a cone of 10°.) For each of these, we print a detailed list of Monte Carlo particles lying in the tau cone and their momenta as specified in the HEPG block. Inspecting this list, we found that for the most part the ρ's faking one-prong taus could be divided into three classes.

1. Clean fakes: there are no extra high-p_T Monte Carlo particles in the cone aside from the ρ itself.

2. "Hadronic" fakes: there are high-p_T neutral hadrons (excluding π^0s), such as neutrons, in the cone, which can make the $E_{had}/\sum p$ variable appear non-tau-like. We plot the $E_{had}/\sum p$ for

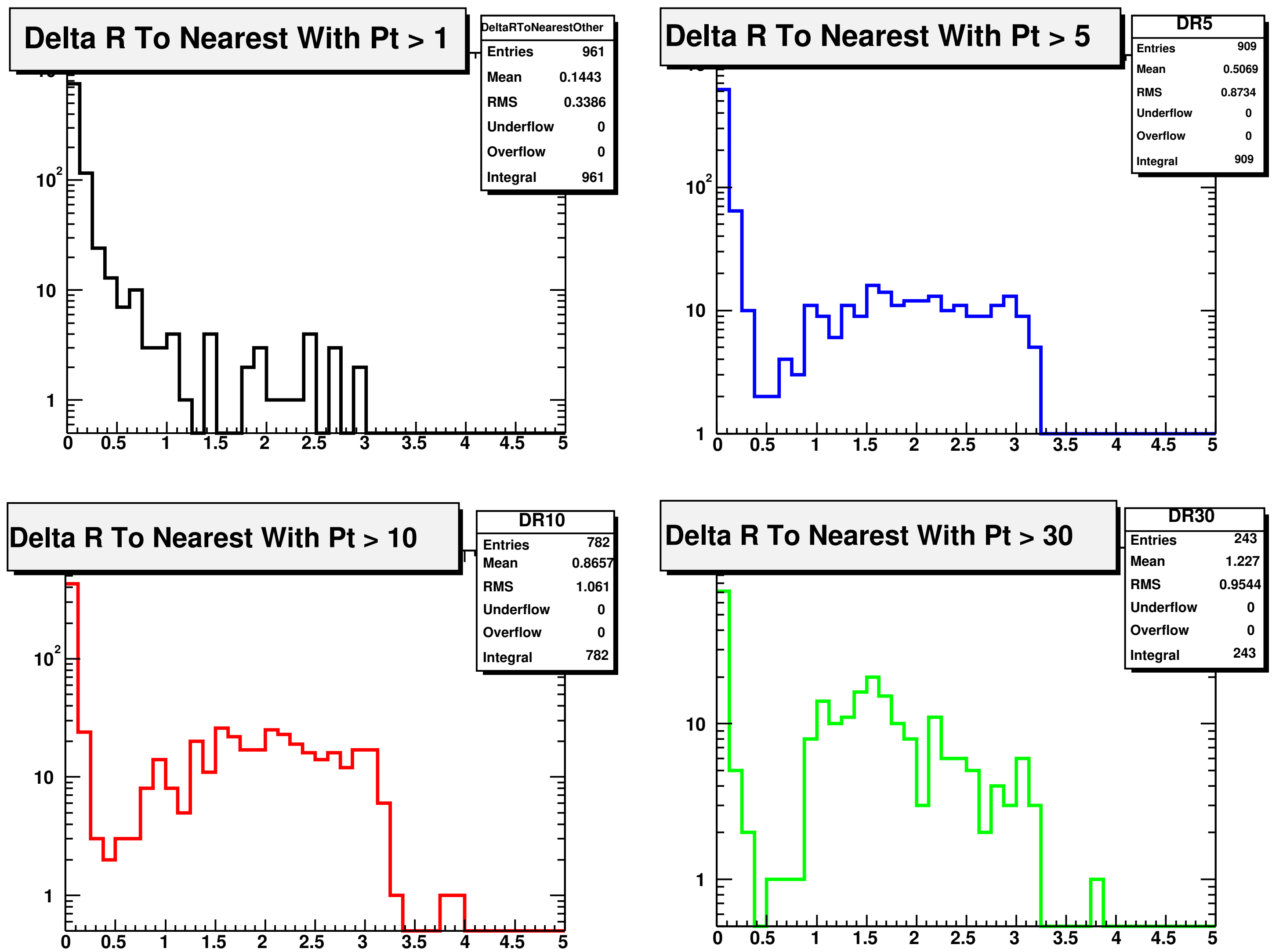

Figure 3: ΔR to the nearest other daughter of the rho's mother, with p_T greater than the threshold 1 GeV (black), 5 GeV (Blue), 10 GeV (Red), and 30 GeV (Green).

these and compare with that for clean fakes in fig. 4.

3. Messy fakes: these have extra high-p_T charged particles in the cone. The reconstruction only shows one prong, however, so at some point between generator level and final reconstructed data, the detector simulation seems to lose these tracks. Often the tracks are extremely nearby, so it might be that this causes problems for the track reconstruction algorithm. We plot the χ^2 for the seed tracks of reconstructed taus from these fakes and compare to the distribution for clean fakes in fig. 5.

The plotted distributions appear different for the "hadronic" and "messy" fakes, but not significantly so. It does not appear that additional cuts based on what we see at the Monte Carlo level will be very helpful here, although requiring $E_{had}/\sum p < 3.0$ might provide some benefit. We hope that a likelihood approach will do better, especially given the unusual distributions we saw in fig. 1.

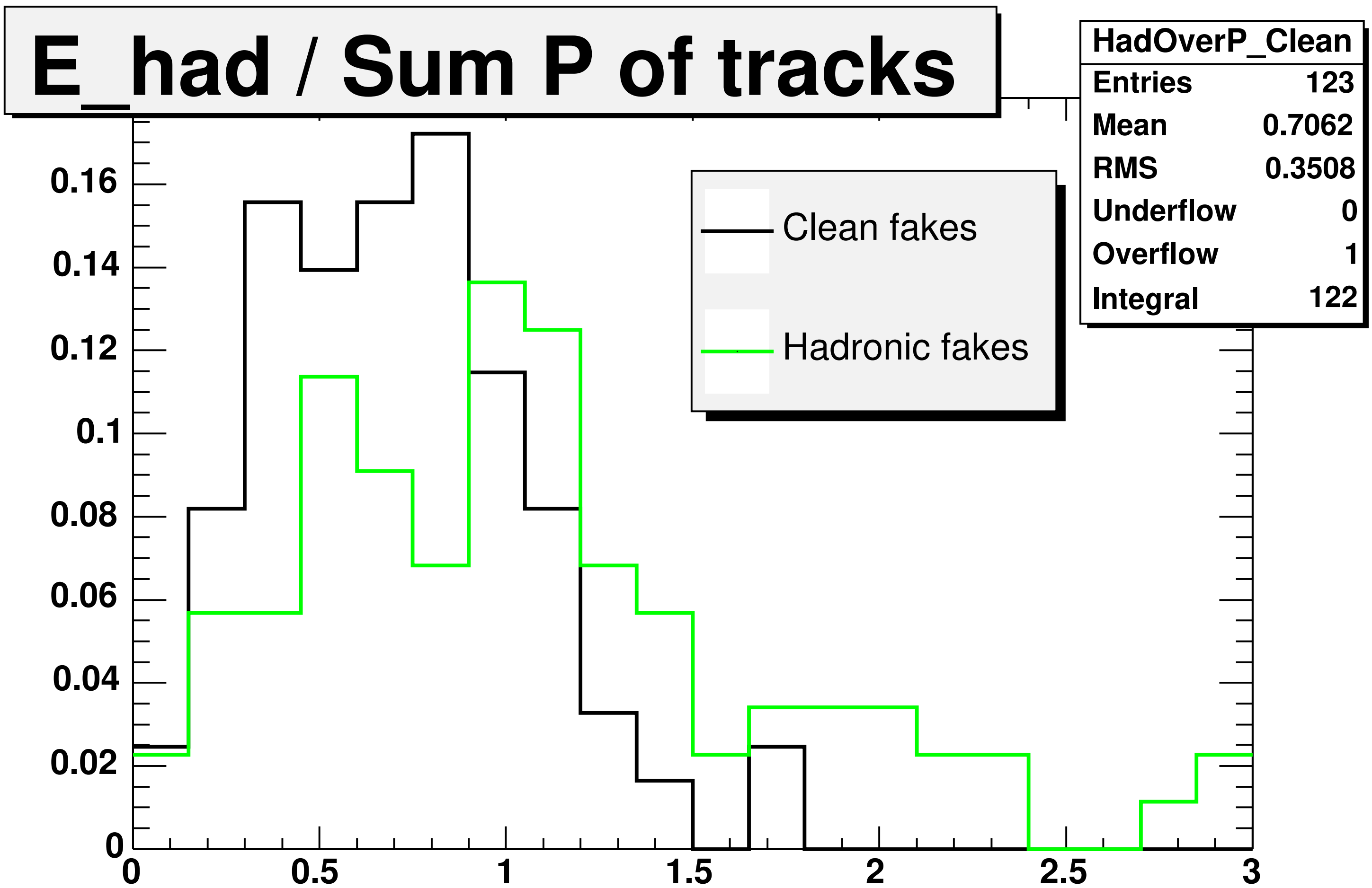

Figure 4: $E_{had}/\sum p$ for reconstructed tau objects corresponding to "clean" fakes at the Monte Carlo level (in black) and for "hadronic" fakes (those with extra high-p_T neutral hadrons, excluding π^0s, at the Monte Carlo level, in green).

4 Conclusions

One conclusion that seems robust across samples is that the number of ρ mesons faking taus is not a significant fraction of all τ fakes (around 10% at most). Still, we extract some hopefully useful information from this study. The distributions in figure 1 do not appear tau-like, so we hope that improved tau id method can use them to distinguish between taus and fakes.

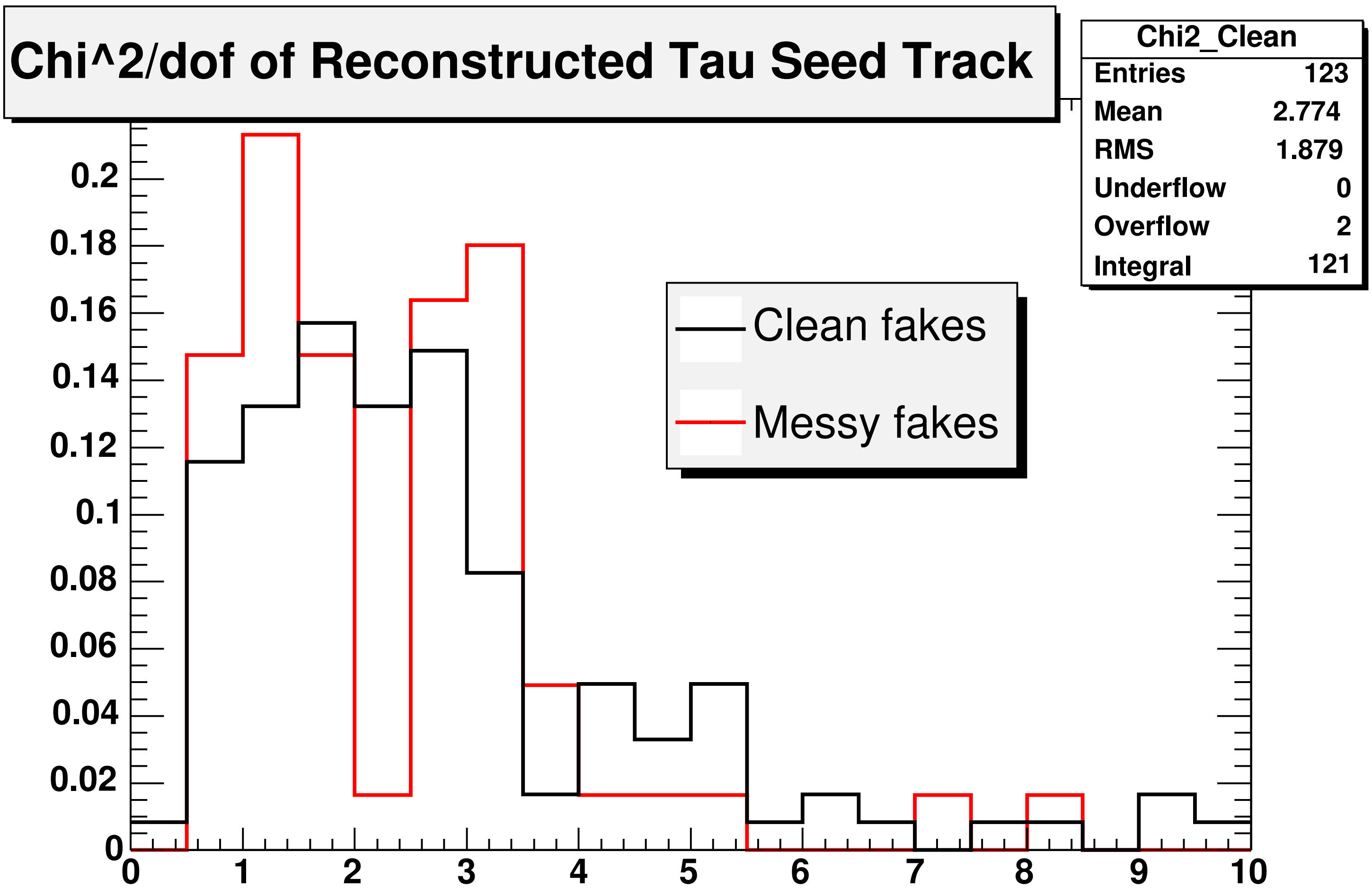

Figure 5: χ^2 for seed tracks of reconstructed taus corresponding to "clean" fakes at the Monte Carlo level (in black) and for "messy" fakes (those with extra high-p_T charged hadrons at the Monte Carlo level, in red).

5 Appendix A: Standard Tau Identification Cuts

We use the "OR" of two different sets of tau identification cuts. The first are "standard" cuts based on those in CDF note 6308 [3]. The second are cuts specific to the decay mode that goes through ρ, that is, $\tau^- \rightarrow \pi^0\pi^-\nu_\tau$, as described in our note 6638 [4]. For convenience, we tabulate the cuts here.

"Standard" tau ID cuts based on Ref. [3]:

- $|\eta_{seed}| < 1$
- $p_{T\,seed} > 6$ GeV/c
- $|z_{0\,seed}| < 60$ cm

- 9 cm $< |z_{CES\,seed}| <$ 216 cm (where $z_{CES\,seed}$ is the z-coordinate of the seed track extrapolated to the CES radius)
- Seed track has at least 3 stereo and 3 axial superlayers (with at least 7 hits each)
- No tracks or π^0's in the isolation annulus
- $m_{vis} < 1.8$ GeV/c^2, where m_{vis} is the invariant mass constructed from the summed four-momenta of reconstructed "visible" decay products, i.e. tracks and π^0's.
- Isolation fraction < 0.1. (Calorimeter isolation E_T / tau E_T)
- $E_{had}/\sum_{tracks} P > 0.1$.

6 Appendix B: $\tau^- \to \pi^0\pi^-\nu_\tau$ Identification Cuts

Our $\tau^- \to \pi^0\pi^-\nu_\tau$ cuts from Ref. [4] are:

- ≤ 3 tracks in the tau cone
- No tracks in the isolation annulus
- ≤ 2 π^0's in the tau cone item $p_{T\,seed} > 6$ GeV/c
- $|z_{0\,seed}| < 60$ cm
- 9 cm $< |z_{CES\,seed}| <$ 216 cm (where $z_{CES\,seed}$ is the z-coordinate of the seed track extrapolated to the CES radius)
- Seed track has at least 3 stereo and 3 axial superlayers (with at least 7 hits each)
- $p_{T2} < 40$ GeV/c (where p_{T2} is the p_T of the second-highest p_T track)
- $p_{T3} < 20$ GeV/c
- $p_{T3}/p_{T\,seed} < 0.5$
- Invariant mass constructed from the seed track and the third highest p_T track < 1.0 GeV/c^2
- $m_{tracks} < 2.0$ GeV/c^2
- $m_{calo} < 4.0$ GeV/c^2
- $E_{had}/\sum_{tracks} P > 0.1$

References

[1] Particle Data Group; K. Hagiwara et al., Phys. Rev. D66,010001 (2002).

[2] We were wrong. In hindsight the softer fragmentation of the gluon jets obviously (sic) overwhelms any vector-meson dominance mechanism.

[3] A. Anastassov *et. al. Tau Reconstruction Efficiency and QCD Fake Rate for Run 2*, CDF Note Number: CDF/ANAL/EXOTIC/CDF/6308. March 2003.

[4] M. Reece and H. Frisch. *Identification of* $\tau^- \rightarrow \pi^0\pi^-\nu_\tau$ *at CDF*, CDF Note Number: CDF/ANAL/TOP/CDFR/6638. August 2003.