

Trilepton Analysis: The $WH \rightarrow WWW \rightarrow l\nu l\nu l\nu$ Signal

(CDF Collaboration)

Jason Nett

(Dated: 23 March 2009)

Summary of Monte Carlo modeling of $WH \rightarrow WWW \rightarrow l\nu l\nu l\nu$ signal events for a trilepton analysis with the $H \rightarrow WW$ group.

Contents

Passing The Trilepton Filter	1
Basic Kinematic Cuts At The Generator-Level	5
Three Reconstructed Leptons with the Generator Cuts	8
Three Reconstructed Leptons with P_t and η Cuts	11
Three Reconstructed Leptons Matched to Generator-level Leptons	14
Three Reconstructed Leptons with Quality and Isolation Cuts	19
Quality and Isolation Cuts, Detailed	23
Lead Electron	24
2nd Electron	25
3rd Electron	26
Lead Muon	27
2nd Muon	28
3rd Muon	29
ntp_v14 Lepton P_T	30
Summary	31

PASSING THE TRILEPTON FILTER

Consider the Stntuple dataset *fhgs6f* that contains $WH \rightarrow WWW$ events for a 160 GeV Higgs boson. I consider here the subset of these events for which all three W bosons decay leptonically, and if that lepton is a tau then it also decays leptonically. This way, we intend to trigger primarily on three leptons along with missing energy. Running 100,000 *fhgs6f* events through a filter designed to select this subset yields 2358 trilepton events for this signal. The P_T , pseudorapidity (η), and ϕ angle distributions are in figures 1 through 9.

The leading lepton P_T distribution indicates that adopting a P_T cut of 18.0 - 20.0 GeV is perfectly adequate. For the second lepton it may be necessary to drop this cut down to 8.0 - 10.0 GeV. Notice especially the P_T distribution of the third lepton in figure 7. The third lepton for this signal does have P_T generated all the way down to zero, so it will be necessary to accept third leptons as low as reasonably possible. The next two sections illustrates that this remains true with such cuts in place.

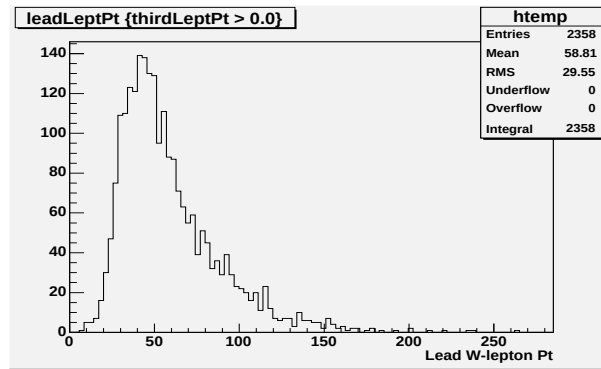


FIG. 1: Lead Generator-level Lepton Pt (GeV)

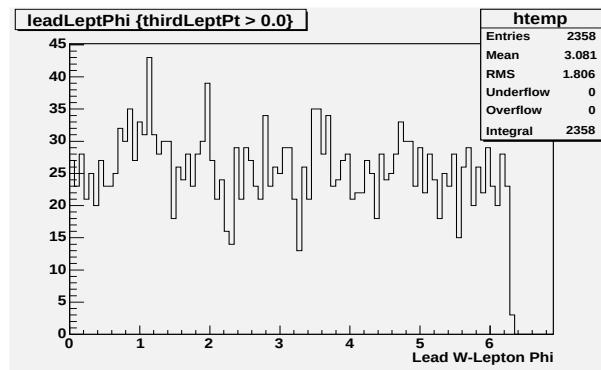


FIG. 2: Lead Generator-level Lepton Phi

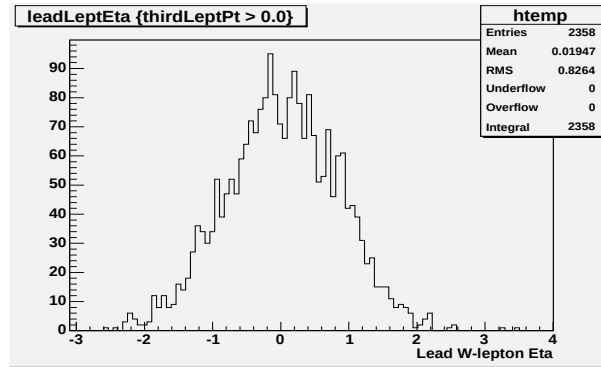


FIG. 3: Lead Generator-level Lepton Eta

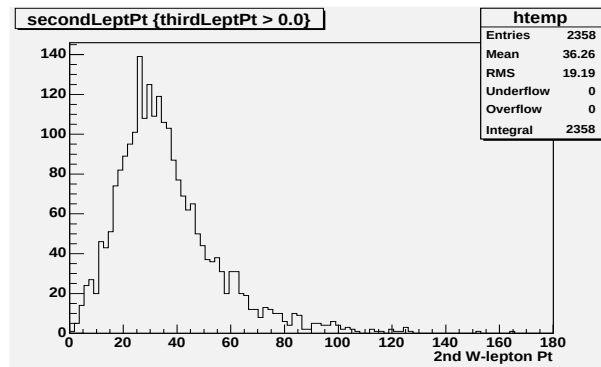


FIG. 4: 2nd Generator-level Lepton Pt (GeV)

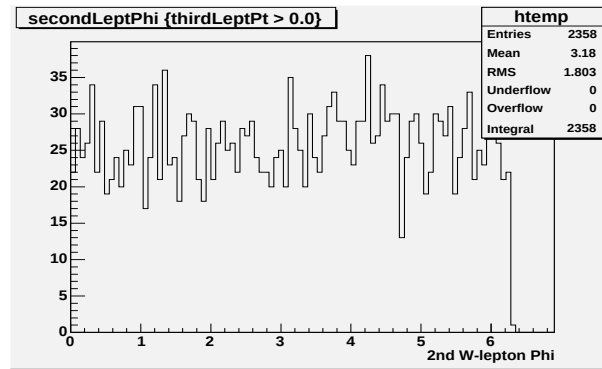


FIG. 5: 2nd Generator-level Lepton Phi

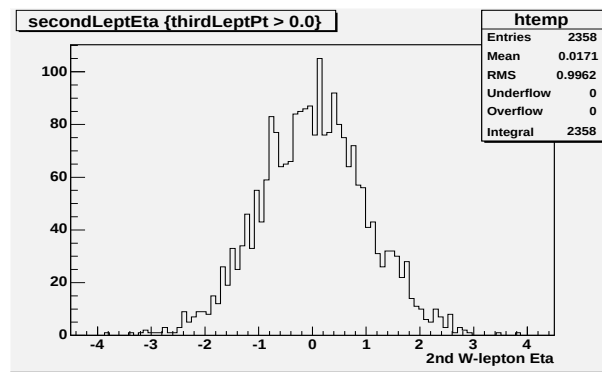


FIG. 6: 2nd Generator-level Lepton Eta

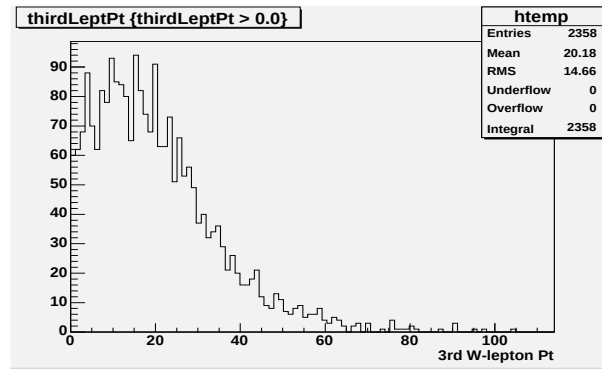


FIG. 7: 3rd Generator-level Lepton Pt (GeV)

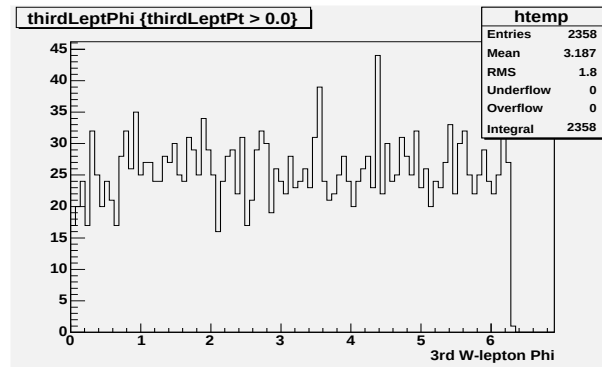


FIG. 8: 3rd Generator-level Lepton Phi

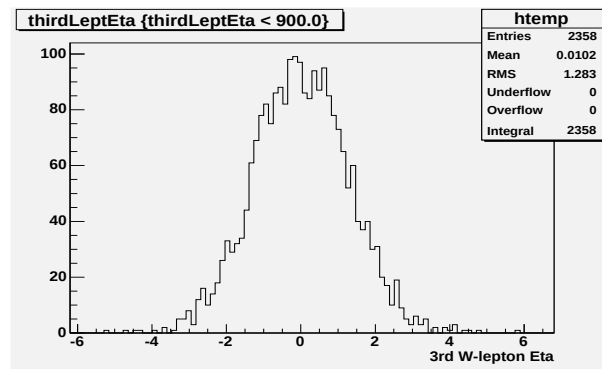


FIG. 9: 3rd Generator-level Lepton Eta

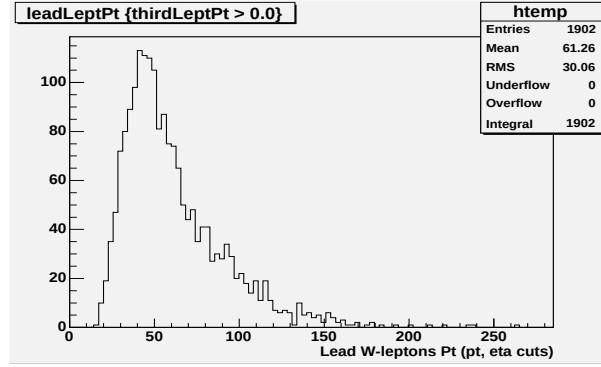


FIG. 10: Lead Generator-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level.

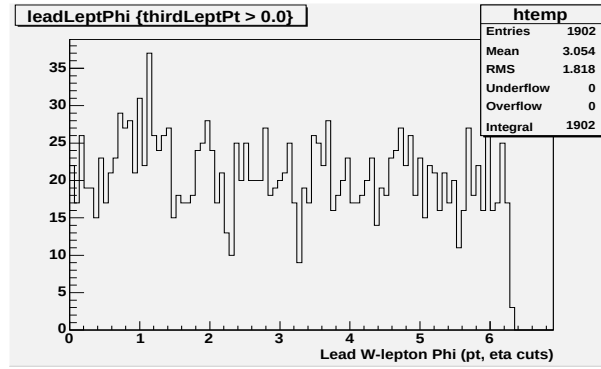


FIG. 11: Lead Generator-level Lepton Phi. Basic P_T and η cuts at generator-level.

BASIC KINEMATIC CUTS AT THE GENERATOR-LEVEL

Next, let's make some basic P_T and η cuts on these generator-level leptons to cut out events that the detector would simply not find. Require for P_T and η (cite these numbers, at least for η):

- Leading lepton $P_T > 16$ GeV
- 2nd lepton $P_T > 8$ GeV
- 3rd lepton $P_T > 2$ GeV
- $-1.7 < \eta < 1.7$ for muons
- $-2.9 < \eta < 2.9$ for electrons

After these cuts are made, the 2358 events becomes 1902 events. The results are in figures 10 through 18.

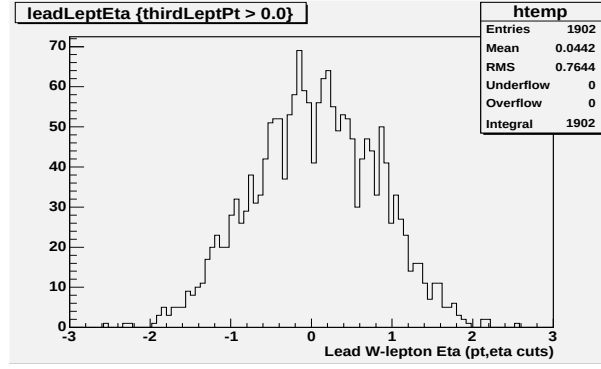


FIG. 12: Lead Generator-level Lepton Eta. Basic P_T and η cuts at generator-level.

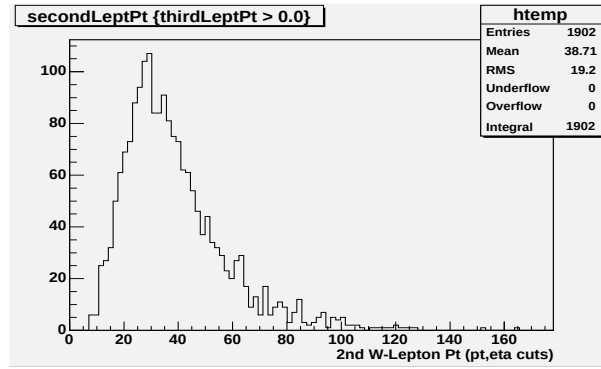


FIG. 13: 2nd Generator-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level.

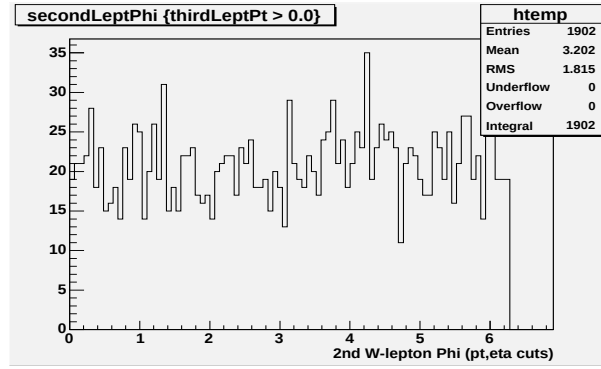


FIG. 14: 2nd Generator-level Lepton Phi. Basic P_T and η cuts at generator-level.

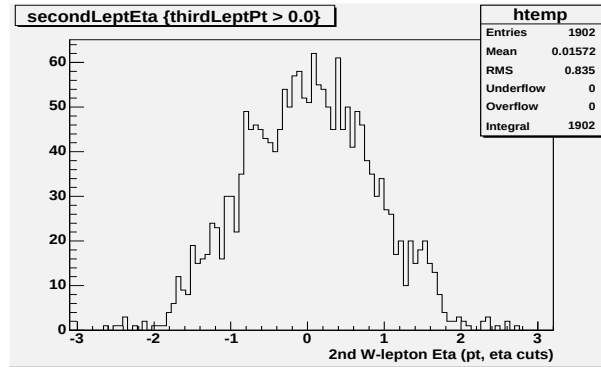


FIG. 15: 2nd Generator-level Lepton Eta. Basic P_T and η cuts at generator-level.

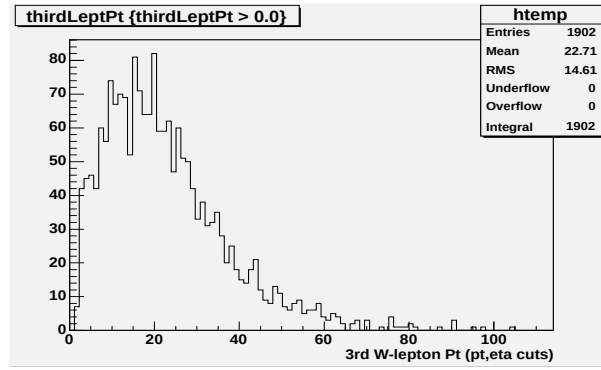


FIG. 16: 3rd Generator-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level.

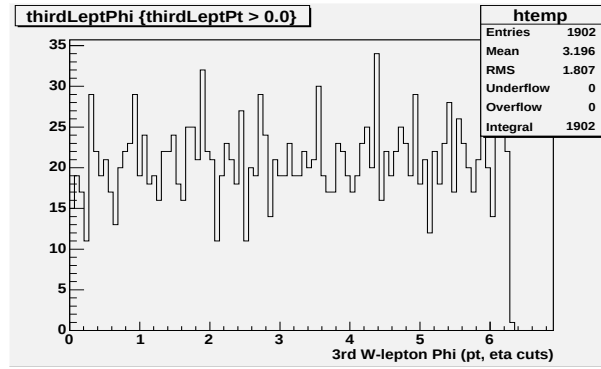


FIG. 17: 3rd Generator-level Lepton Phi. Basic P_T and η cuts at generator-level.

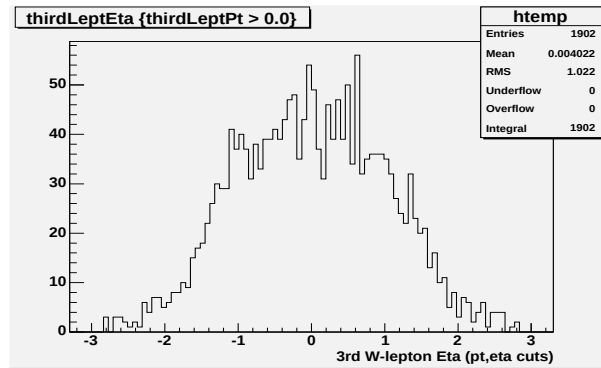


FIG. 18: 3rd Generator-level Lepton Eta. Basic P_T and η cuts at generator-level.

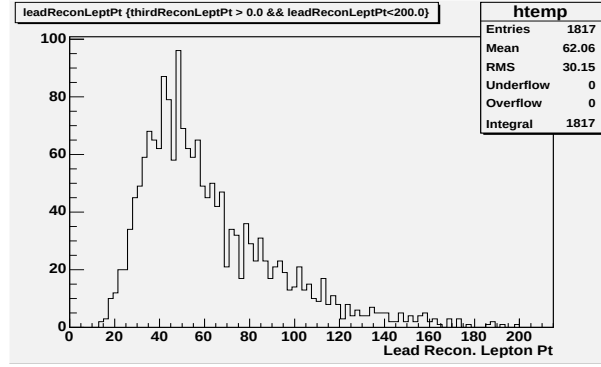


FIG. 19: Lead Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level. The count is 1845; events above 200.0 GeV not included.

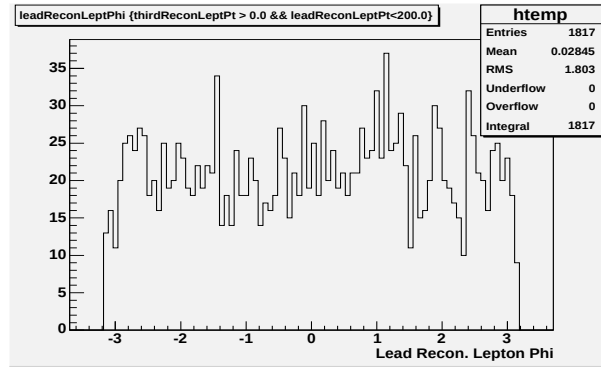


FIG. 20: Lead Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level. The count is 1845; events above 200.0 GeV not included.

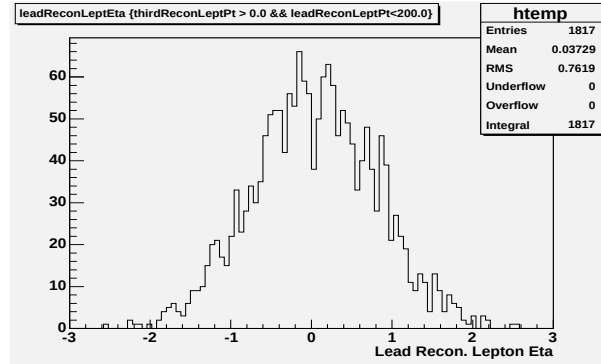


FIG. 21: Lead Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level. The count is 1845; events above 200.0 GeV not included.

THREE RECONSTRUCTED LEPTONS WITH THE GENERATOR CUTS

Changing nothing, let's look at what is found at the reconstructed-level for these 1902 events. Not all of these events find three reconstructed leptons, so we are actually left with 1845 events that do find three leptons. The distributions of these 1845 are in figures 19 through 27 (primary and secondary leptons from events that do not find a third lepton are not included).

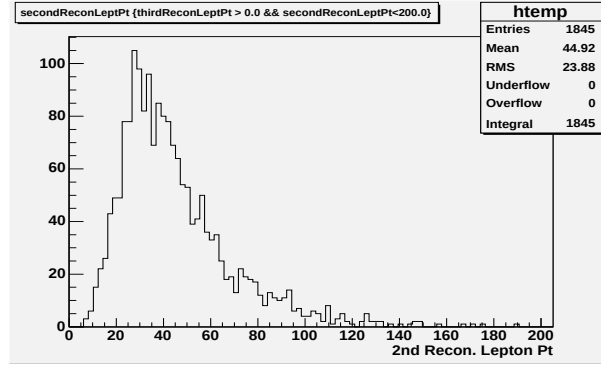


FIG. 22: 2nd Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level.

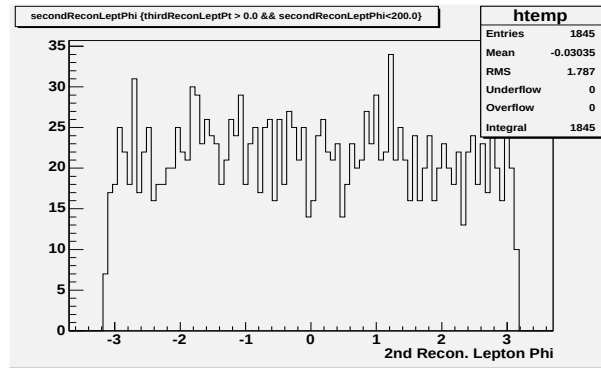


FIG. 23: 2nd Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level.

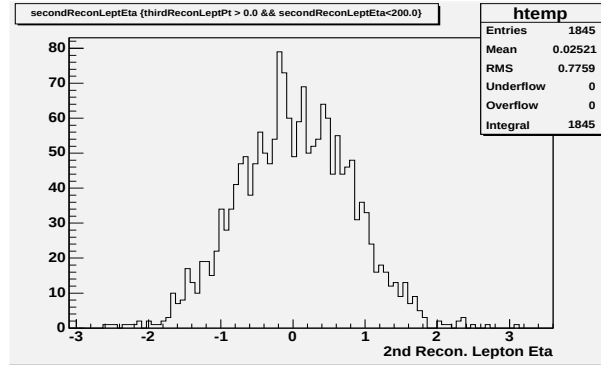


FIG. 24: 2nd Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level.

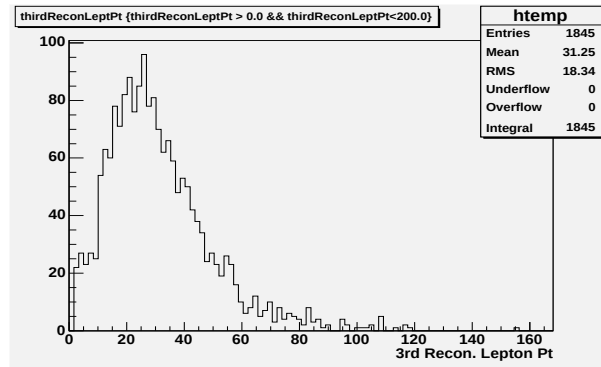


FIG. 25: 3rd Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level.

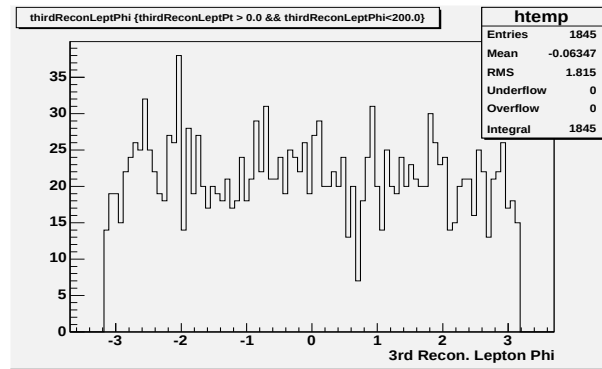


FIG. 26: 3rd Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level.

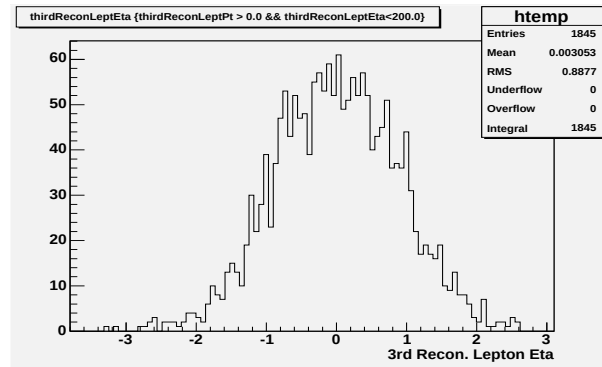


FIG. 27: 3rd Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level.

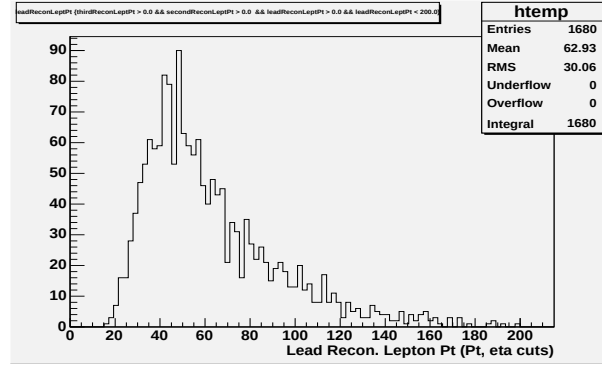


FIG. 28: Lead Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level, as well as at reconstruction-level. The count is 1702; events above 200.0 GeV not included.

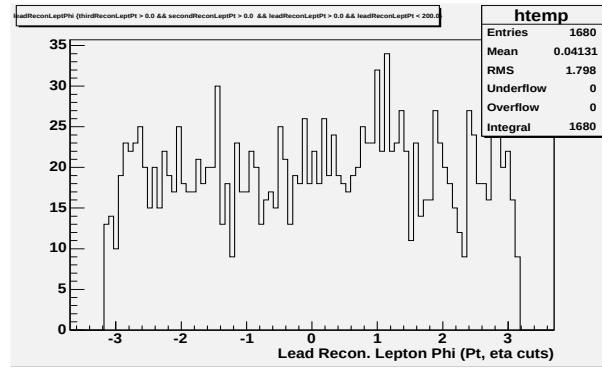


FIG. 29: Lead Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level, as well as at reconstruction-level. The count is 1702; events above 200.0 GeV not included.

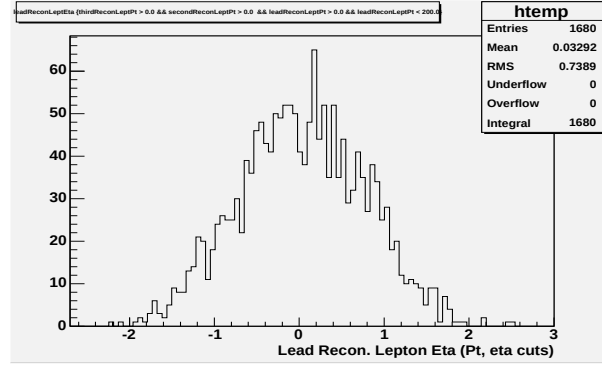


FIG. 30: Lead Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level, as well as at reconstruction-level. The count is 1702; events above 200.0 GeV not included.

THREE RECONSTRUCTED LEPTONS WITH P_t AND η CUTS

Starting with the same set of 1845 events in the previous section, let's impose the same P_T and η cuts that we used at the generator-level, at the reconstructed-level as well now. This cuts our event set down to 1702 events illustrated in figures 28 through 36.

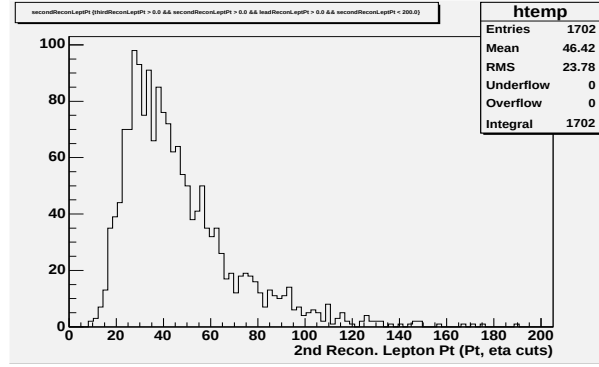


FIG. 31: 2nd Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level, as well as at reconstruction-level.

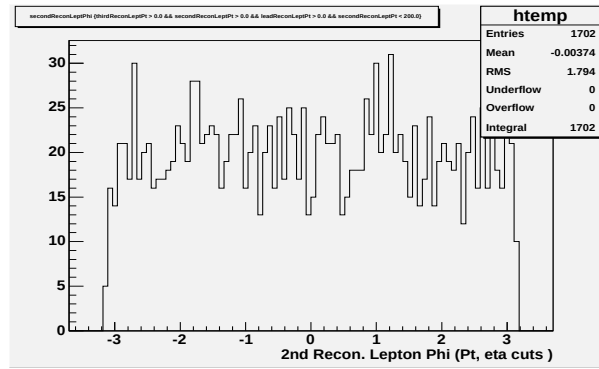


FIG. 32: 2nd Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level, as well as at reconstruction-level.

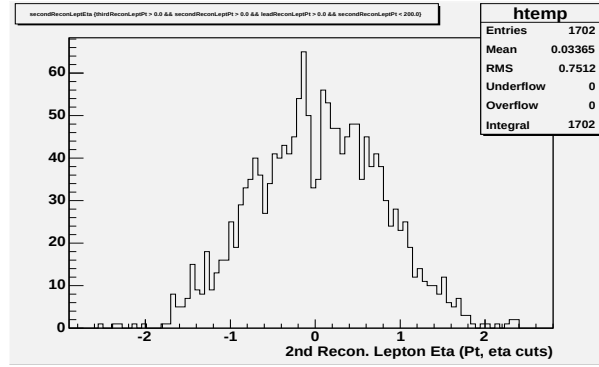


FIG. 33: 2nd Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level, as well as at reconstruction-level.

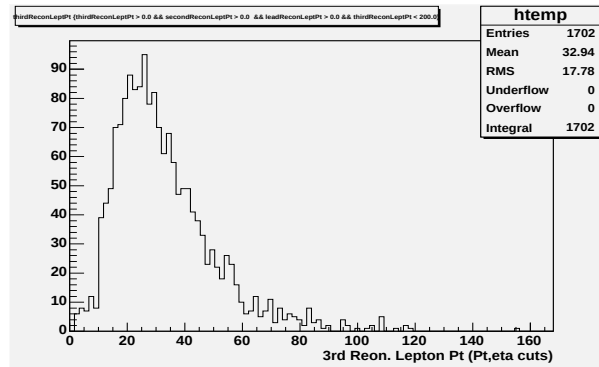


FIG. 34: 3rd Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level, as well as at reconstruction-level.

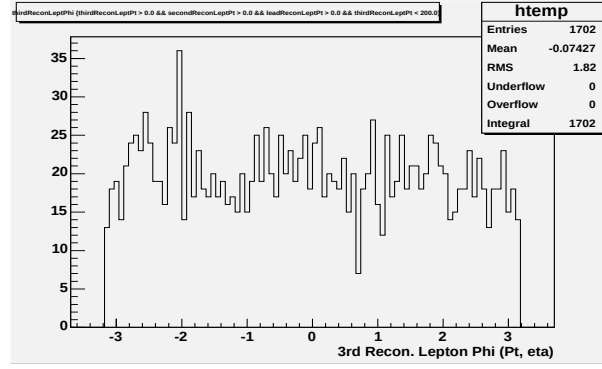


FIG. 35: 3rd Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level, as well as at reconstruction-level.

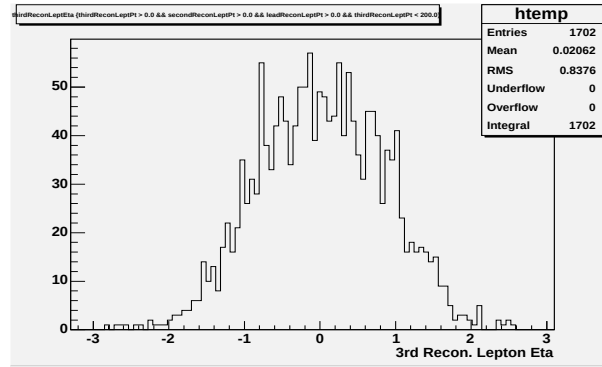


FIG. 36: 3rd Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level, as well as at reconstruction-level.

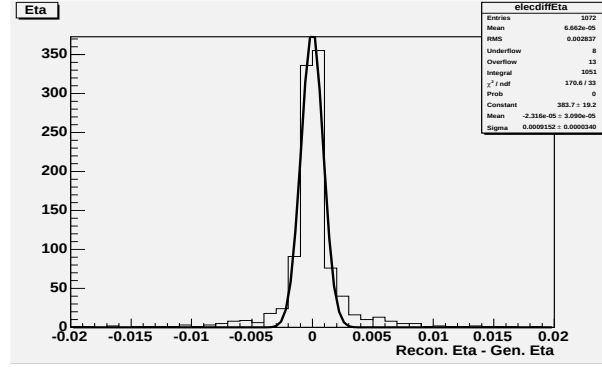


FIG. 37: Electron $\eta_{\text{recon}} - \eta_{\text{gen}}$, σ_η found here.

THREE RECONSTRUCTED LEPTONS MATCHED TO GENERATOR-LEVEL LEPTONS

Let's now require that the reconstructed leptons not only pass the P_T and η cuts of the previous section, but also pass a matching criterion to an object in the generator-level list.

The matching criterion is:

$$\text{Matching Factor} \equiv \frac{|P_{T,\text{recon}} - P_{T,\text{gen}}|}{\delta_{P_T}} + \frac{|\eta_{\text{recon}} - \eta_{\text{gen}}|}{\sigma_\eta} + \frac{|\phi_{\text{recon}} - \phi_{\text{gen}}|}{\sigma_\phi} < 40.0$$

where

- $P_{T,\text{recon}}$ = Reconstructed particle P_T
- $P_{T,\text{gen}}$ = Generator-level particle P_T
- $\delta_{P_T} = 0.0015 \cdot P_{T,\text{recon}}$
- η_{recon} = Pseudorapidity of reconstructed particle
- η_{gen} = Psuedorapidity of generator-level particle
- ϕ_{recon} = Azimuthal Angle of reconstructed particle
- ϕ_{gen} = Azimuthal Angle of generator-level particle
- σ_η = Standard Deviation of a Gaussian fit to $\eta_{\text{recon}} - \eta_{\text{gen}}$
- σ_ϕ = Standard Deviation of a Gaussian fit to $\phi_{\text{recon}} - \phi_{\text{gen}}$

For any candidate reconstructed electron or muon, a match is attempted for any generator level electron, muon, charged pion (PDG Code ± 211), proton (PDG Code ± 2212), or charged Kaon (PDG Code ± 321). When a matched is attempted for an electron, if the best-match found (lowest-valued matching factor) satisfies the matching criterion given above (matching factor < 40) and is also a generator-level electron, then the reconstructed electron is considered to be successfully matched. Similarly, when a matched is attempted for an muon, if the best-match found (lowest-valued matching factor) satisfies the matching criterion given above (matching factor < 40) and is also a generator-level muon, then the reconstructed muon is considered to be successfully matched.

The standard deviations used are given by figures 37, 38, 39, and 40.

The 1702 events from the previous section are cut down to 1129 events with the matching requirement in place. The relevant distributions of these 1129 events are in figures 41 through 49.

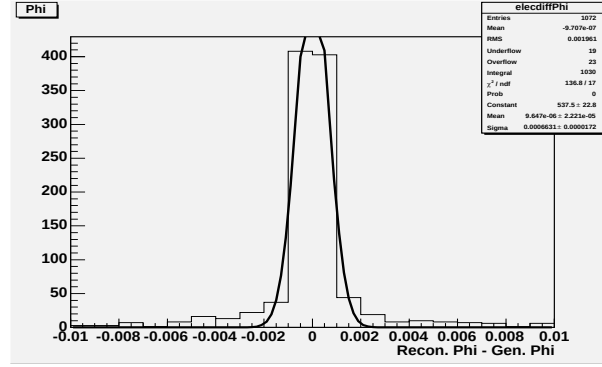


FIG. 38: Electron $\phi_{\text{recon}} - \phi_{\text{gen}}$, σ_ϕ found here.

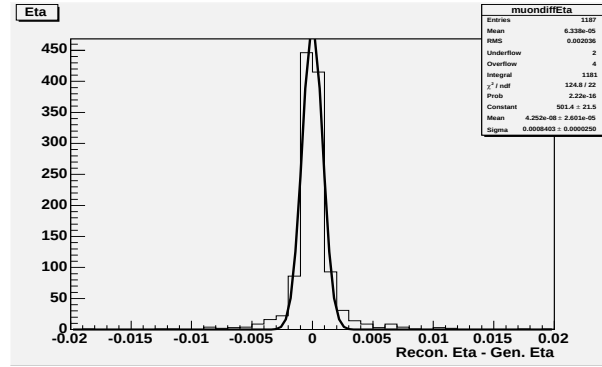


FIG. 39: Muon $\eta_{\text{recon}} - \eta_{\text{gen}}$, σ_η found here.

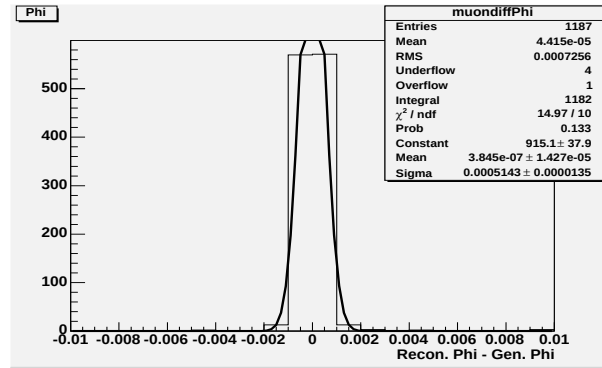


FIG. 40: Muon $\phi_{\text{recon}} - \phi_{\text{gen}}$, σ_ϕ found here.

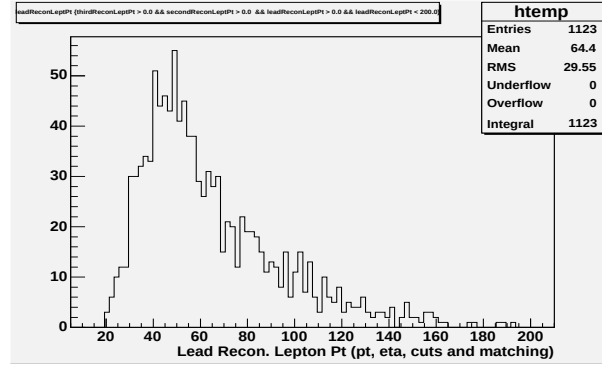


FIG. 41: Lead Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level, as well as at reconstruction-level, and matched. The count is 1129; events above 200.0 GeV not included.

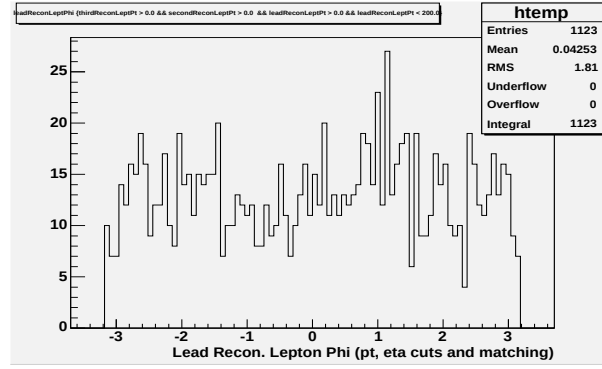


FIG. 42: Lead Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, and matched. The count is 1129; events above 200.0 GeV not included.

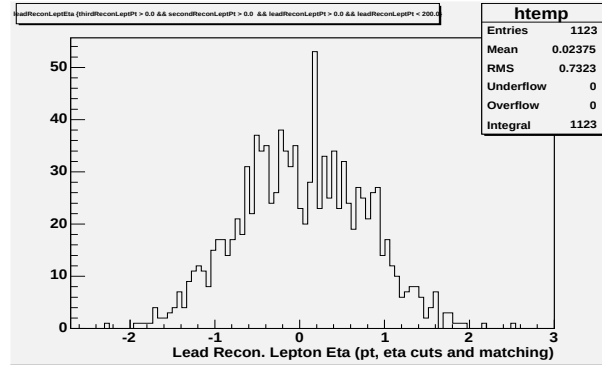


FIG. 43: Lead Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, and matched. The count is 1129; events above 200.0 GeV not included.

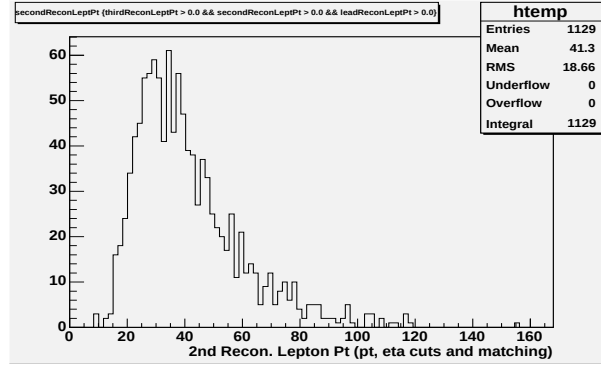


FIG. 44: 2nd Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level, as well as at reconstruction-level, and matched.

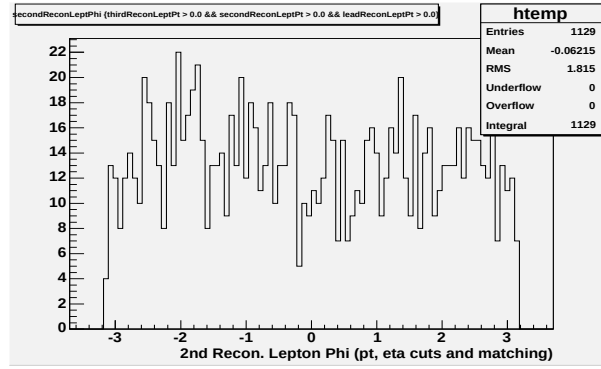


FIG. 45: 2nd Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, and matched.

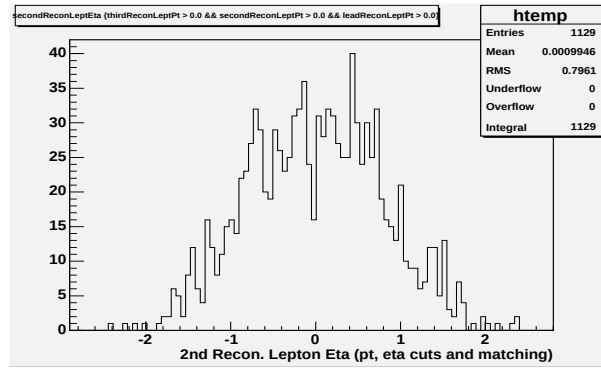


FIG. 46: 2nd Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, and matched.

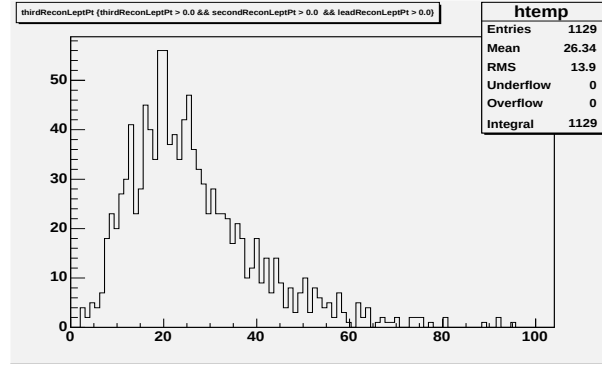


FIG. 47: 3rd Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level, as well as at reconstruction-level, and matched.

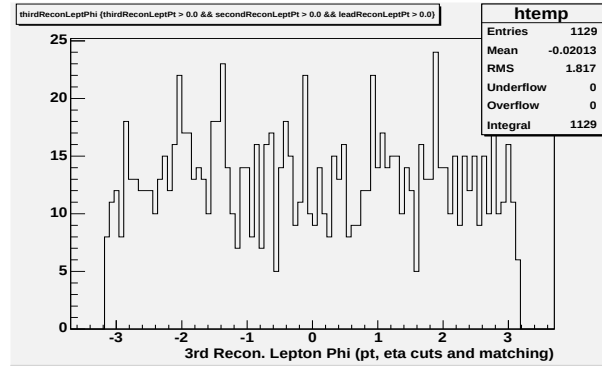


FIG. 48: 3rd Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, and matched.

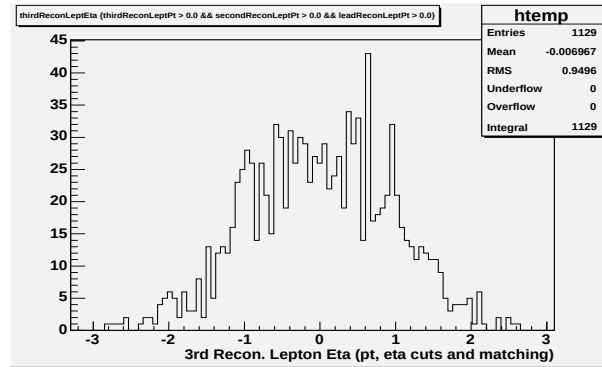


FIG. 49: 3rd Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, and matched.

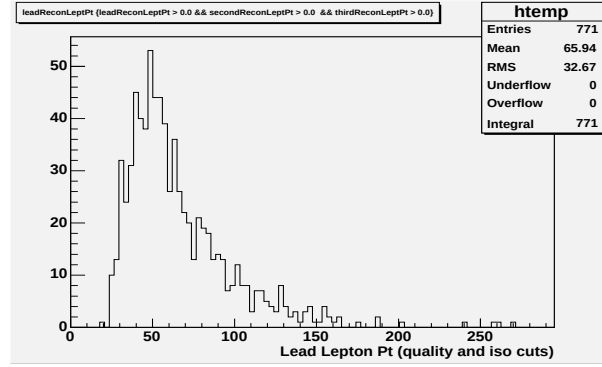


FIG. 50: Lead Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level, as well as at reconstruction-level, matched, and quality and isolation requirements.

THREE RECONSTRUCTED LEPTONS WITH QUALITY AND ISOLATION CUTS

CDF Note 9402, *Search for $H \rightarrow WW$ using $3.0 fb^{-1}$* , suggests using selection criteria from CDF Note 8719. Some, but as yet not all, of these criteria are implemented in lepton selection for figures 50 through 58. These are as follows:

- Electrons

- Central Electrons

- * $\frac{\text{TrackIso}()}{E_T} < 0.1$
- * $\frac{\text{Had. Energy}}{\text{Em. Energy}} < 0.055 + 0.00045 \cdot E$
- * $\frac{E}{P} < 2.5 + 0.015 \cdot E_T$

- Plug Electrons

- * $\frac{\text{TrackIso}()}{E_T} < 0.1$
- * $\frac{\text{Had. Energy}}{\text{Em. Energy}} < 0.05$

- Forward Electrons: (none in the present sample)

- * $\frac{\text{TrackIso}()}{E_T} < 0.1$
- * $\frac{\text{Had. Energy}}{\text{Em. Energy}} < 0.05$

- PHX "Phoenix Algorithm" electrons (All PHX electrons in the present sample are already either Central or Plug electrons, which is given precedence.)

- * $\frac{\text{TrackIso}()}{E_T} < 0.1$
- * $\frac{\text{Had. Energy}}{\text{Em. Energy}} < 0.05$

- Muons

- Em. Energy < 2.0 GeV

- Had. Energy < 6.0 GeV

- $\frac{\text{TrackIso}()}{P_T} < 0.1$

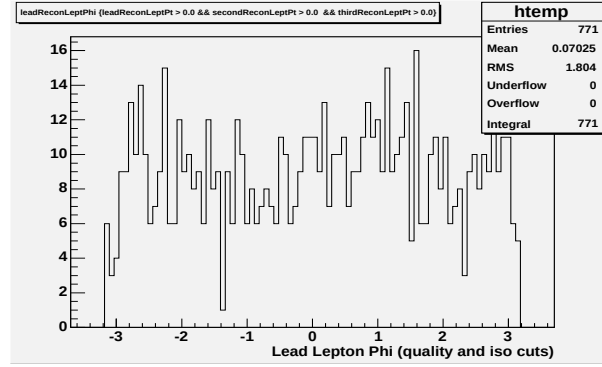


FIG. 51: Lead Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, matched, and quality and isolation requirements.

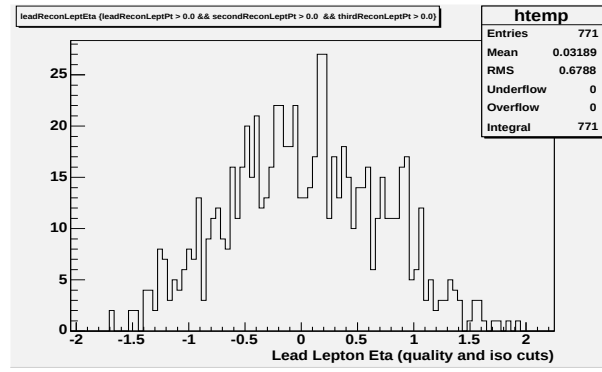


FIG. 52: Lead Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, matched, and quality and isolation requirements.

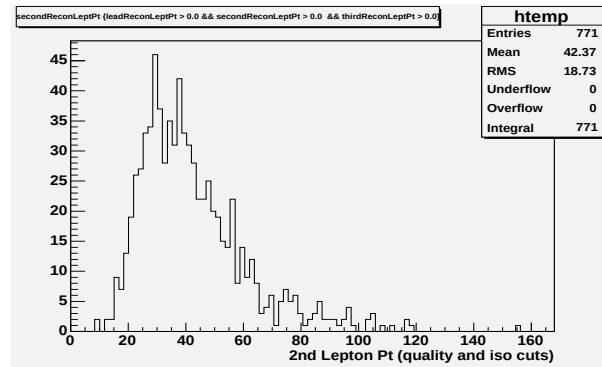


FIG. 53: 2nd Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level, as well as at reconstruction-level, matched, and quality and isolation requirements.

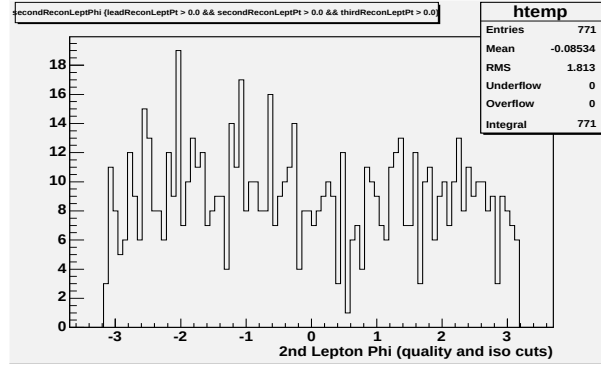


FIG. 54: 2nd Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, matched, and quality and isolation requirements.

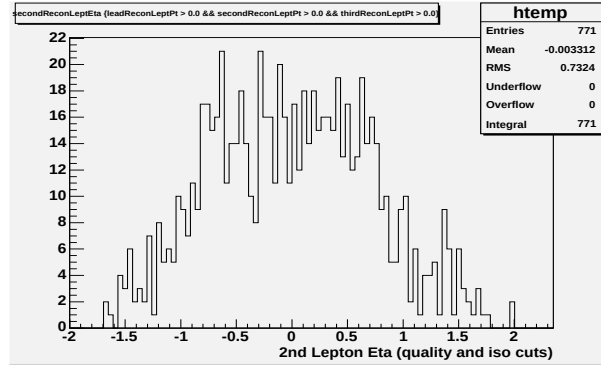


FIG. 55: 2nd Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, matched, and quality and isolation requirements.

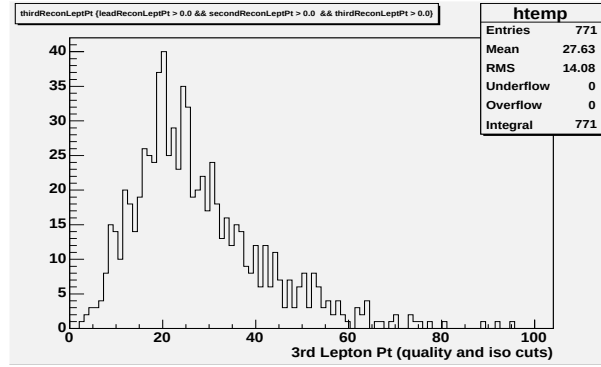


FIG. 56: 3rd Reconstructed-level Lepton Pt (GeV). Basic P_T and η cuts at generator-level, as well as at reconstruction-level, matched, and quality and isolation requirements.

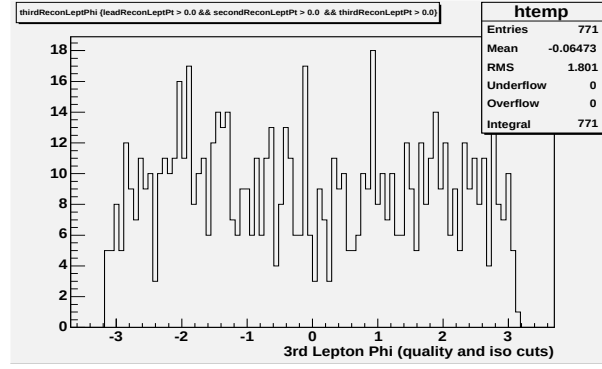


FIG. 57: 3rd Reconstructed-level Lepton Phi. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, matched, and quality and isolation requirements.

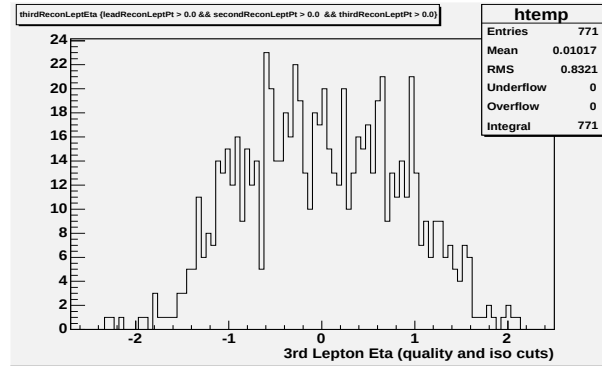


FIG. 58: 3rd Reconstructed-level Lepton Eta. Basic P_T and η cuts at generator-level, as well as at reconstruction-level, matched, and quality and isolation requirements.

QUALITY AND ISOLATION CUTS, DETAILED

Table II provides a summary of the various lepton quality cuts, progressing from the 1129 events that pass the matching criterion (see the above section) to the 771 events that have three leading leptons passing all quality cuts (see table III). Essentially, table II details the gap between the last two rows of table III.

Table /reftab:qualityCutsTable, in contrast, looks individually at each of the leading three electrons and muons. The plots shown in subsections "Lead Electron" through "3rd Muon" correspond to the rows of this table.

Cuts	Number (out of 1129)	%(from previous step)
Central Electron $\frac{\text{TrackIso}()}{E_T} < 0.1$	1083	95.9
Central Electron $\frac{\text{Had.E}}{\text{Em. E}} < 0.055 + 0.00045 \cdot E$	1059	97.8
Central Electron $\frac{E}{P} < 2.5 + 0.015 \cdot E_T$	1006	95.0
Plug Electron $\frac{\text{TrackIso}()}{E_T} < 0.1$	882	87.7
Plug Electron $\frac{\text{Had.E}}{\text{Em. E}} < 0.05$	873	99.0
Forward Electron $\frac{\text{TrackIso}()}{E_T} < 0.1$	-	0
Forward Electron $\frac{\text{Had.E}}{\text{Em. E}} < 0.05$	-	0
PHX Electron $\frac{\text{TrackIso}()}{E_T} < 0.1$	-	0
PHX Electron $\frac{\text{Had.E}}{\text{Em. E}} < 0.05$	-	0
Muons Em. Energy < 2.0	803	92.0
Muons Had. Energy < 6.0	784	97.6
Muons $\frac{\text{TrackIso}()}{P_T} < 0.1$	771	98.3

TABLE I: Quality Cuts detailed from 1129 to 771 events.

Cuts	Number	%
Lead Electron $\frac{\text{TrackIso}()}{E_T} < 0.1$	1276/1409	90.6
Lead Electron $\frac{\text{Had.E}}{\text{Em. E}} < 0.055 + 0.00045 \cdot E$	1348/1409	95.7
Lead Electron $\frac{E}{P} < 2.5 + 0.015 \cdot E_T$	1152/1409	81.8
2nd Electron $\frac{\text{TrackIso}()}{E_T} < 0.1$	632/781	80.9
2nd Electron $\frac{\text{Had.E}}{\text{Em. E}} < 0.055 + 0.00045 \cdot E$	726/781	93.0
2nd Electron $\frac{E}{P} < 2.5 + 0.015 \cdot E_T$	585/781	74.9
3rd Electron $\frac{\text{TrackIso}()}{E_T} < 0.1$	159/215	74.0
3rd Electron $\frac{\text{Had.E}}{\text{Em. E}} < 0.055 + 0.00045 \cdot E$	200/215	93.0
3rd Electron $\frac{E}{P} < 2.5 + 0.015 \cdot E_T$	136/215	63.3
Lead Muon Em. Energy < 2.0	1427/1513	94.3
Lead Muon Had. Energy < 6.0	1476/1513	97.6
Lead Muon $\frac{\text{TrackIso}()}{P_T} < 0.1$	1511/1513	99.9
2nd Muon Em. Energy < 2.0	837/876	95.5
2nd Muon Had. Energy < 6.0	858/876	97.9
2nd Muon $\frac{\text{TrackIso}()}{P_T} < 0.1$	865/876	98.7
3rd Muon Em. Energy < 2.0	234/241	97.1
3rd Muon Had. Energy < 6.0	240/241	99.6
3rd Muon $\frac{\text{TrackIso}()}{P_T} < 0.1$	220/241	91.3

TABLE II: Quality Cuts detailed by 1st, 2nd, 3rd electrons and muons. Each of the leptons in this table and the subsections below are required to pass P_T and η cuts at both generator-level and reconstruction-level, and pass the matching criterion. Note that there are 1409 events with leading electrons that meet these requirements (and 1513 events with leading muons that meet these requirements), but table II lists only 1129 events passing the same requirements. The latter count is lower because it corresponds to finding three leading leptons meetings these requirements.

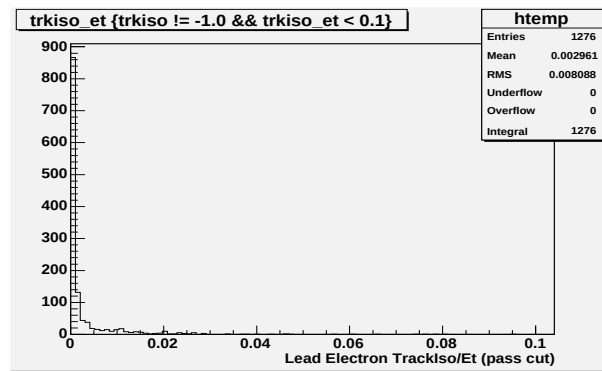


FIG. 59:

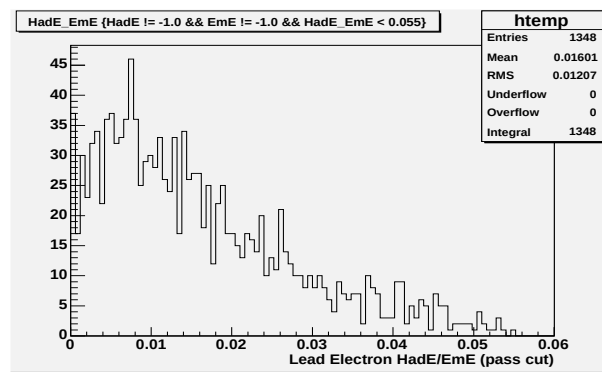


FIG. 60:

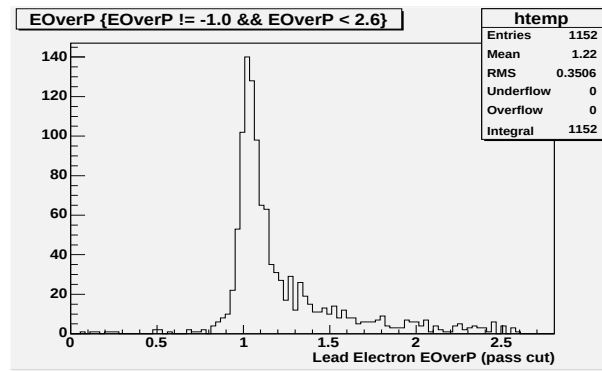


FIG. 61:

Lead Electron

See figures 59 through 61

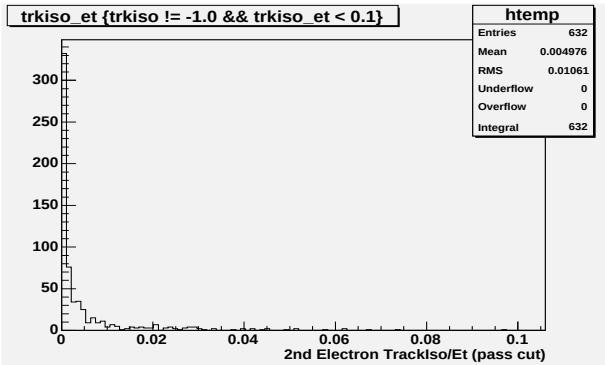


FIG. 62:

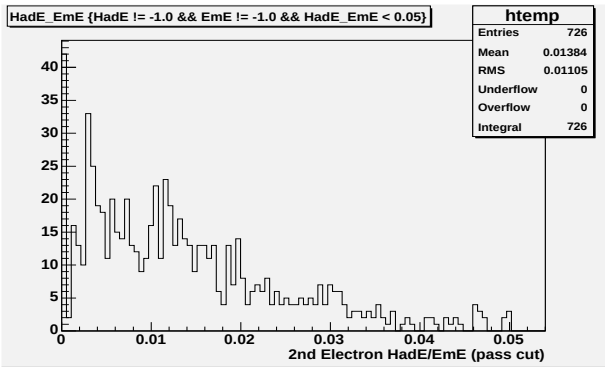


FIG. 63:

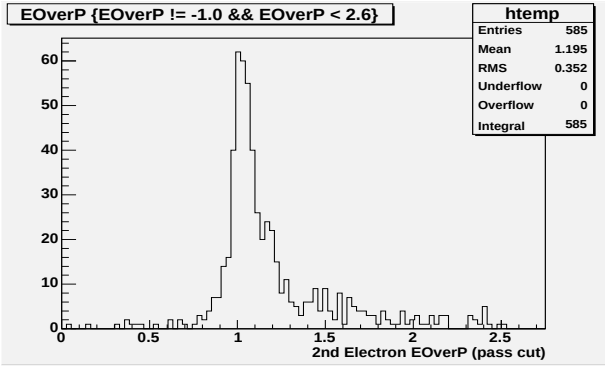


FIG. 64:

2nd Electron

See figures 62 through 64

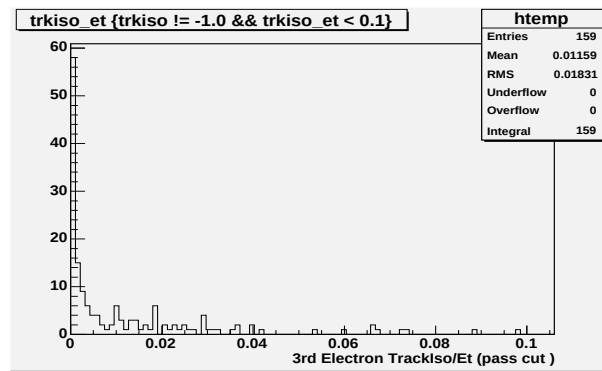


FIG. 65:

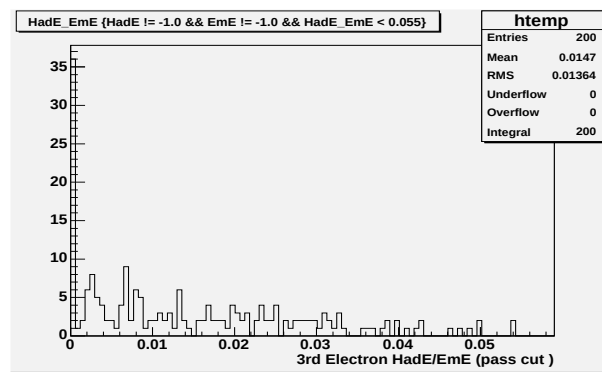


FIG. 66:

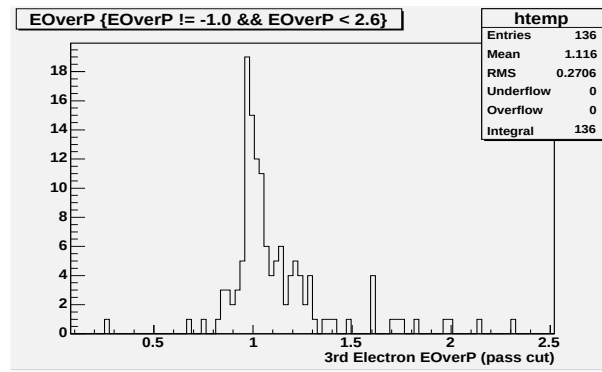


FIG. 67:

3rd Electron

See figures 65 through 67

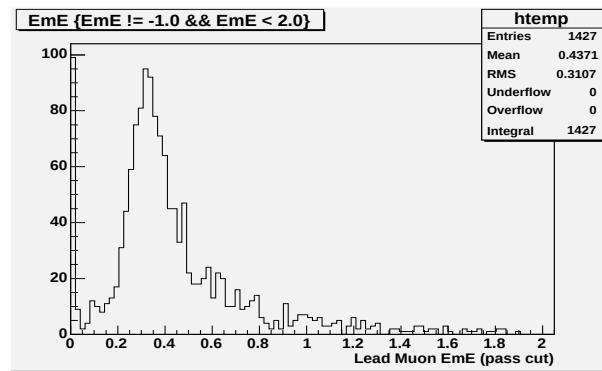


FIG. 68:

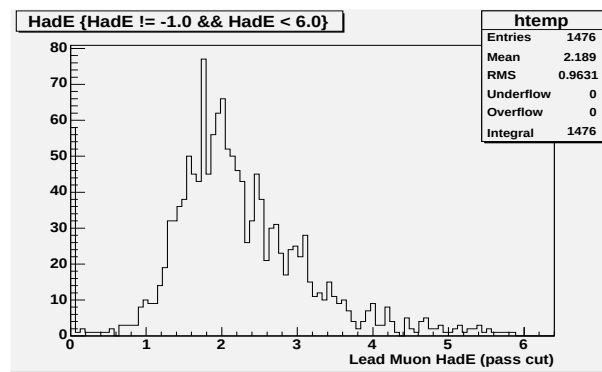


FIG. 69:

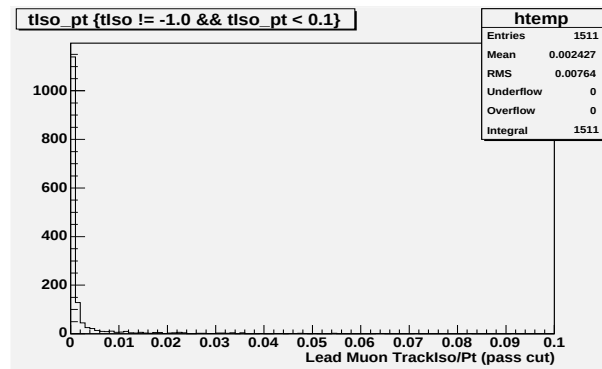


FIG. 70:

Lead Muon

See figures 68 through 70

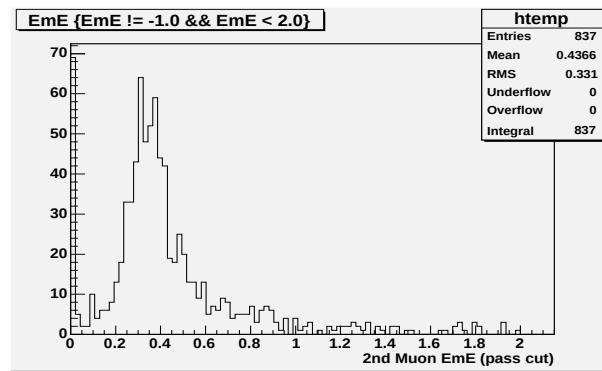


FIG. 71:

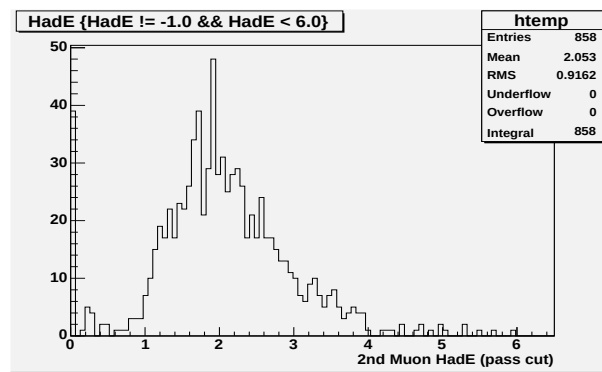


FIG. 72:

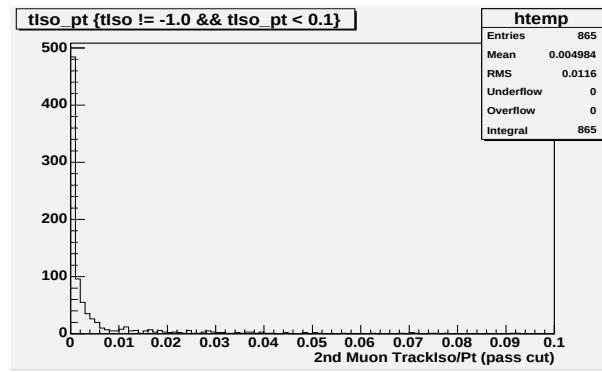


FIG. 73:

2nd Muon

See figures 71 through 73

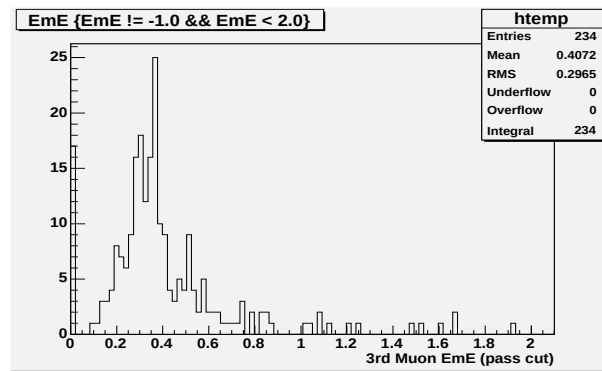


FIG. 74:

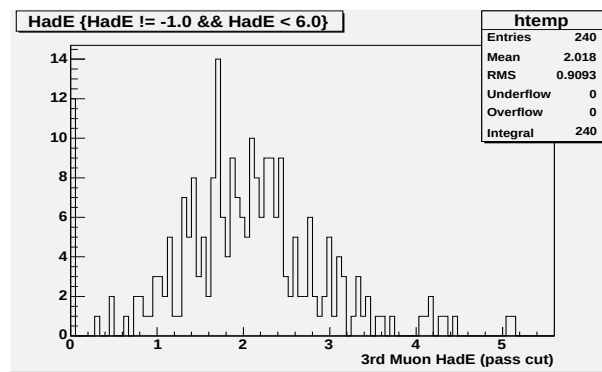


FIG. 75:

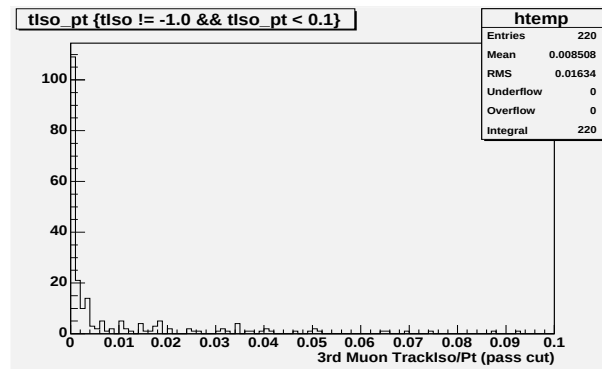
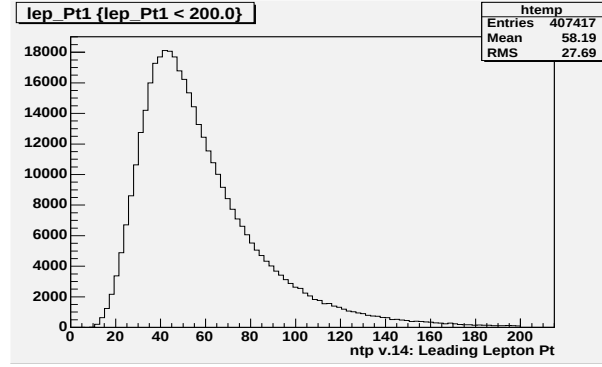
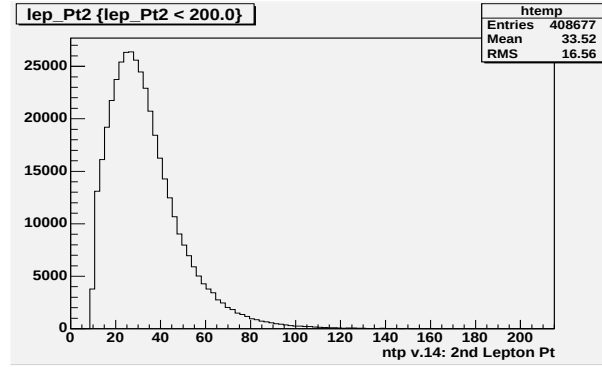
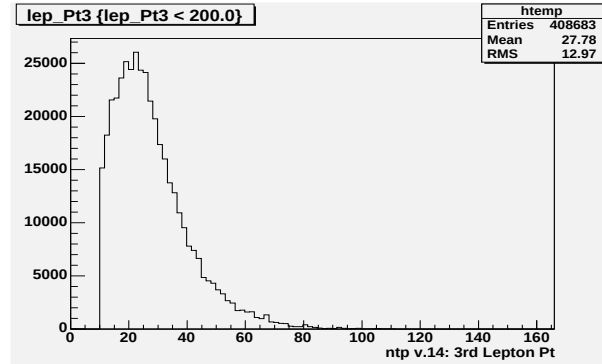


FIG. 76:

3rd Muon

See figures 74 through 76

FIG. 77: ntp v.14 Leading Lepton P_T FIG. 78: ntp v.14 2nd Lepton P_T FIG. 79: ntp v.14 3rd Lepton P_T

NTP_V14 LEPTON P_T

The ready-made P_T distributions of the first, second, and third leptons from **ntp** version 14 are in figures 77, 78, and 79. The leading lepton gradually drops off on the low P_T end, but has no events below 10 GeV. Both the second and third leptons appear to have hard cuts at 10 GeV.

[INCLUDE LISTS OF WHICH NTP'S EXIST AND WHAT VARIABLES THEY CONTAIN.]

SUMMARY

Cuts	Number (out of 100,000)	%(from previous step)
Pass $HW \rightarrow WWW \rightarrow l\nu l\nu l\nu$ filter	2358	2.36
P_T, η cuts at generator-level	1902	80.6
Lead, 2nd, 3rd Reconstructed leptons found	1845	97.0
Same P_T, η cuts at reconstruction-level	1702	92.2
Pass Matching Criterion	1129	66.3
Pass Quality/Isolation Cuts	771	68.3

TABLE III: Event Summary