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Searching for Physics Beyond the Standard Model in the $e\gamma$ and $\mu\gamma$ Channels II: The Data

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Abstract

Motivated by the $ee\gamma\gamma\not{E}_T$ event, we have searched in the inclusive channels $e\gamma$ and $\mu\gamma$ for a signal beyond that predicted in the Standard Model. Such a signature is natural in gauge-mediated supersymmetry models with either a long-lived heavy particle and R-parity conservation, or with R-parity violation. This signature could also arise from more conventional models from photino- chargino decays, or from any other process that produces a charged and a neutral particle that cascade decay to the SM vector bosons W and γ, for example. The analysis presented here is intended as the final treatment of the analysis presented in CDF3555 and CDF3851: the main differences are that we use the final Berryhill photon identification cuts with the Wilson isolation corrections, we have revertexed all events with the vertex determined by the lepton track, and we have removed the missing Et requirement so that the initial signature is solely a high-P_T photon and a high-P_T central electron or muon, where high- P_T is greater than 25 GeV. This sample of 79 events is then divided into subsamples with $\not{E}_t > 25$ GeV and $\not{E}_t < 25$, and the results compared with Standard Model predictions, which are described in the companion note, CDF4976.

Contents

1 Introduction

1.1 Signature and Motivation

The $ee\gamma\gamma\not{E}_t$ event motivated two complementary searches for related events; we have searched for events in the diphoton ($\gamma\gamma$)[1] and lepton-photon-missing transverse energy ($\ell\gamma\not{E}_t$) channels[2, 3]. Both searches, $\gamma\gamma$, and $\ell\gamma\not{E}_t$, were based on the hypothesis that the $ee\gamma\gamma\not{E}_t$ event originated from the decay of a pair of new particles, each of which yielded an electron, photon, and $\not{E}_{\mathrm{T}}$[4]. The diphoton search has now been completed, and we have returned to the lepton-photon search with a better understanding of the subtle details of photon identification and a new set of tools (such as a rigorous $W+\gamma$ Monte Carlo and a fake-rate methodology) with the intent of completing it for publication.

The signature of a high-P_T photon, a high-P_T lepton, and missing E_T can arise from a number of currently popular models, as well as being an architypal search mode for more fundamental reasons: it contains one neutral vector boson and, possibly, a decay product of either a second vector boson or of a new heavy particle (such as a slepton, chargino or a heavy lepton) that couples to e, μ, or τ.

1.2 Specific Models

In models constructed with a gaugino photino as the NLSP and a Higgsino LSP, the photino $\tilde{\chi}_2^0$ decays via a loop into $\gamma\tilde{\chi}_1^0$[5, 6]. The decay of a pair of selectrons or gauginos would thus produce the $ee\gamma\gamma\not{E}_t$ signature as shown in Figure 1. Such models would, in general, produce more events with one photon than with two. Further, chargino-neutralino production, or a cascade decay of squarks and gluinos through charginos and neutralinos, would produce final states with a lepton, photon, and missing E_T.

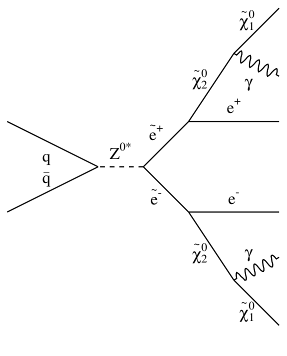

Figure 1: The Feynman diagram for $\tilde{e}$ pair production and decay in the $\tilde{\chi}_2^0 \to \gamma\tilde{\chi}_1^0$ scenario of Kane *et al.* Both selectrons decay via $\tilde{e} \to e\tilde{\chi}_2^0$ where $\tilde{\chi}_2^0$ is the next-to- lightest neutralino which in turn decays via $\tilde{\chi}_2^0 \to \gamma\tilde{\chi}_1^0$.

In contrast, gauge-mediated models of supersymmetry breaking, in which the LSP is the Gravitino, $\tilde{G}$, are predicted to give signatures (in general) in which all final states end up with two photons[6, 7], as sparticles are made in pairs, and each decay chain results in a decay of an NLSP to a $\tilde{G}$ and a photon. In such models there may still be events with only one photon detected, either because one photon is below threshold or not in the central region, or because of imperfect detection efficiencies. A lepton is a good signature for a chargino or vector boson decay from a cascade decay chain, and hence the $\ell\gamma\not{E}_t$ signature is again a signature of interest.

In gauge-mediated models if the gravitino is very light its lifetime can be long-enough so that sparticles can appear stable in the CDF detector[8]. In this case one would be more likely to detect only one photon, and, in the case where the stable particle was charged, a penetrating high-momentum particle that would be classified as a muon. The resulting signature would be a photon, 'muon', and $\not{E}_t + X$.

Another source of single photon events could be from gauge- mediated models but with R-parity violation[9]. In this case, either only one sparticle could be produced, or one of the pair of sparticles could decay via an R-parity violating decay before producing a photon and gravitino.

1.3 VX Associated Pair Production

Lastly, the photon-lepton signature is generally a powerful search engine for decays of pairs of heavy particles in which one of the pair is a vector boson. For example, the $ee\gamma\gamma\not{E}_t$ signature could be produced by Z^0X production, where X is a new particle that decays into a pair of charginos or sleptons (such as one of the Higgs bosons, for example). If the Z^0 decays to $\nu\bar{\nu}$, one would expect the $ee\gamma\gamma$ system to be measured as recoiling against missing $\mathrm{E_T}$, as observed. In this case one might expect other events involving the other vector bosons, the W and the photon, as well as other decay modes of either the X or the boson[1] The photon-lepton signature for an inclusive search is ideal in that (as the reader will see below) it is highly selective, with only about one event per inverse picobarn passing the selection criteria.

1.4 Organization: SM Expectations are in CDF4976, Observations Are Here

In this note we deal with the data in the $e\gamma$ and $\mu\gamma$ signatures; the SM expectations are presented in CDFnote CDF4976[11]. The $\tau\gamma$ is dealt with separately elsewhere[10].

[1]It is interesting that in the $\mu\mu\gamma\gamma jj$ event the dilepton-diphoton system is recoiling with a transverse momentum similar to that in the $ee\gamma\gamma\not{E}_t$ event, but in this case against a system of two jets with an invariant mass consistent with that of the W or possibly the Z^0. In both events $\mathrm{p_T^{\ell\ell\gamma\gamma}}$ is approximately 55 GeV. This is the signature expected from VX production, where V is a vector boson (W or Z^0), and X is a heavy new particle coupled to massive particles, such as a Higgs boson.

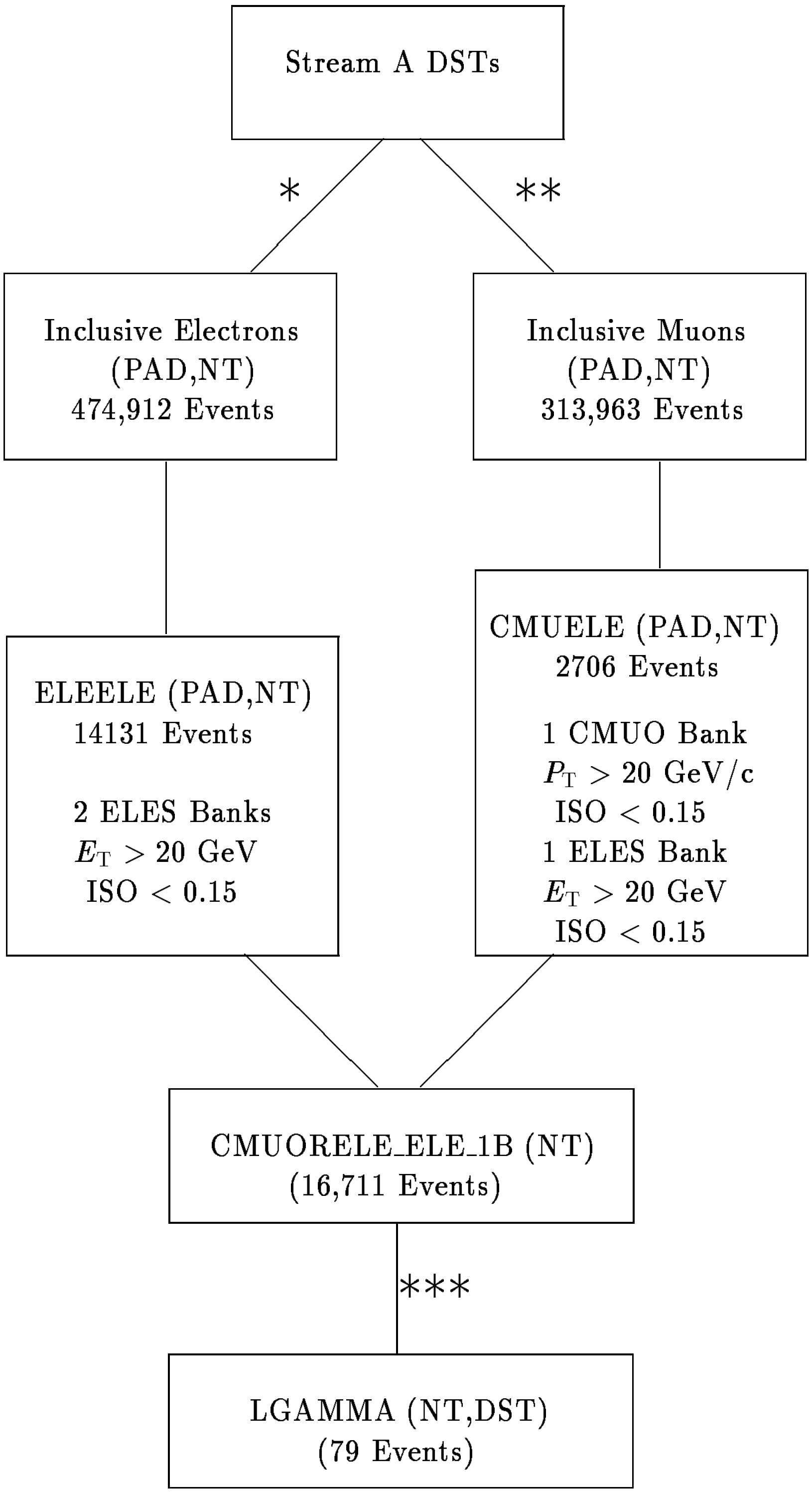

Figure 2: Flow Chart for the data reduction starting at the Run 1b Stream A DSTs and ending at the lepton-gamma data sample. The cuts used for stripping the data indicated by * and ** are given in Table 1 while the photon and lepton identification cuts indicated by *** are presented in Table 2 and Table 3, respectively.

Inclusive Electron		
Central electron (ELES bank, type=0)		
E_T	$>$	18 GeV
P_T	$>$	13 GeV/c
HAD/EM (3 towers)	$<$	0.125
Lshr	$<$	0.2
χ^2(strip)	$<$	10
Track-CES matching:		
$*\ \lvert\Delta z\rvert$	$<$	5 cm
$*\ \lvert\Delta x\rvert$	$<$	3 cm
Inclusive Muon		
Central muon (CMUO bank)		
P_T	$>$	13 GeV/c
HAD energy	$<$	6 GeV (note: no cut on EM)
Track Stub Matching:		
$*\ \lvert\Delta x\rvert$	$<$	10 cm (CMU only and CMU-CMP)
$*\ \lvert\Delta x\rvert$	$<$	20 cm (CMP only)
$*\ \lvert\Delta x\rvert$	$<$	20 cm (CMX)

Table 1: Cuts used to strip the Inclusive Electron and Inclusive Muon data sample from the Run 1b Stream A DSTs. The values are taken directly from ELES Banks, and momentum is not beam constrained.

1.5 Changes to the Previous Analysis

The major differences between the analysis described here and the two CDF notes that were posted previously are:

- The central photon identification cuts now are the final cuts used by Jeff Berryhill, and also include the Wilson corrections for lateral energy leakage[12, 13]. The cuts used are listed in Table 3. The main difference from the photon identification described in the gamma-gamma PRL and PRD is that we have removed the CES significance cut (it is not documented for Run Ib, and we believe that we can reject cosmic rays well with our other tools).

- The vertex used to calculate the photon E_T and the $\not{E}_t$ (and all other transverse energies) is the lepton vertex from the ELES or CMUO bank (*i.e.* the Class-10 or higher vertex closest in z to the z_0 of the lepton track), rather than the first vertex in the VTVZ bank.

- The requirement of $\not{E}_T > 25$ GeV has been removed from the analysis: the signature is now solely a high-E_T photon and a high-E_T muon or electron. The distributions in $\not{E}_t$ and the numbers of events both with and without significant $\not{E}_t$ are now compared to SM background predictions, rather than $\not\!\!E_t$ being a selection criterion early in the event selection chain.

2 Datasets and Event Selection

2.1 The Inclusive Electron and Inclusive Muon Datasets

The dataset for this analysis is taken from the Run 1B Stream-A inclusive high-P_T electron and muon datasets which sit on the UCCDF cluster as described in CDF3555. The cuts used to strip the inclusive electron and inclusive muon datasets are shown in Table 1. The overall luminosity for this sample is 89 pb^{-1}. A flow chart summarizing the steps in the data reduction for the $\ell\gamma$ data sample is presented in Figure 2.

2.2 The ELEELE and CMUELE Datasets

We have made an electron subset from the inclusive electron dataset by selecting events which have two ELES banks, each with (corrected) $E_T > 20$ GeV and ISO < 0.15, in the case of electrons, and ISO < 0.15 or the isolation energy < 3 Gev in the case of photons (see Appendix A). Similarly, a muon subset is constructed by selecting events with a CMUO bank and an ELES bank both with $E_T > 20$ GeV and ISO < 0.15 for electrons, or ISO $<$ 0.15 *or* isolation energy < 3 Gev for photons (see Appendix B). There are 14131 e+ELES bank events and 2706 μ+ ELES bank events. These electron and muon subsets are named ELEELE and CMUELE, respectively. The ELEELE and CMUELE data sets are also stored in the Stntuple standard format[14]. These two ntuples have been concatenated to form the ntuple dataset CMUORELE_ELE_1B. All duplicates in CMUORELE_ELE_1B have been removed (events can appear in both if they satisfy the inclusive requirements of both). There are 16,711 events contained in the CMUORELE_ELE_1B dataset (*i.e.* there were 126 duplicate events).

2.3 The LGAMMA Dataset

The CMUORELE_ELE_1B ntuple has been 'stripped' in turn to form the LGAMMA ntuple. The cuts imposed on the CMUORELE_ELE_1B dataset are shown in Table 3 for global event variables and for photons, and in Table 2 for electrons and muons. The code used in the selection is given in Appendix C. The global event cuts are: a) requiring runs to be good runs (all systems working)[2], b) a good vertex, and c) no energy out-of-time. The photon is required to have $p_T > 25$ GeV and pass the tight photon cuts for photons that may come in on the box-isolation trigger (status code = 5000 [14]). A good electron must have $E_T > 25$ GeV and pass all TOPFND tight electron and isolation cuts (status code = 9000); while a good muon is one with $P_T > 25$ GeV/c which also passes all tight muon and isolation TOPFND cuts (status code= 7000). We emphasize that we have used TOPFND cuts for

[2]This is implemented as requiring BRCODE=31. We note that the top mass sample requires only BRCODE=15, and there are indeed some events in runs where the SVX is labelled as bad.

the lepton selection and the (current) standard 'photon treaty' cuts for high-p_T photons, the latter being very close to those used for the published $\gamma\gamma$ analysis.

There are 49 $e\gamma$ and 30 $\mu\gamma$ events, for a total of 79 lepton- gamma events in Run 1b. These events have been stripped from the Stream A DSTs and are available in DST format in the file on cdf.uchicago.edu as /data/cdf0b/troy/lgamma/lgamma.stra_5f.

2.4 The Calculation of $\not\!\!E_T$ selection for the LGAMMA Dataset

We use $\not\!\!E_T$ corrected for muons, photons, electrons, and jets using the prescription of Toback[15]. The prescription is as follows. To correct for muons we take MET(4) from TOPFND. To correct for electrons and photons, we vectorially subtract from the $\not\!\!E_T$ the uncorrected P_x and P_y from the associated ($\Delta R = 0.4$) JETS bank and add in the corrected (using CEMFIX or PEMFIX) electron or photon momentum. To correct for jets, we subtract the uncorrected momenta and add in the momenta corrected using JTC96S ('NN','DD') corrections. We note that all events have been revertexed using the electron or muon vertex, and the E_T of the jets, photons, and $\not\!\!E_T$ have been recalculated with this vertex.

3 The Final Lepton- Photon Data Sample

The lepton and photon selection cuts in Table 2 and Table 3 reduce the CMUORELE_ELE_1B dataset from 16,711 events to the 79 events of the LGAMMA dataset. It is remarkable that the signature of one central lepton with p_T greater than 25 GeV and a central photon with p_T greater than 25 GeV has such a small cross-section, one picobarn (to state the obvious, channels with small SM cross-sections are good places in which to search).

In the following sections we discuss the characteristics of the 79 events, and compare them with Standard Model expectations. There is one complication that we need to introduce now, although the details are discussed later: there are 7 events of the 79 events (5 $e\gamma$ and 2 $\mu\gamma$ events) that have more than 1 lepton or photon, where we have used looser cuts for the second object (described in detail below). The presence of more than one lepton or photon in the event introduces an ambiguity in plotting lepton or photon identification variables, or kinematic quantities such as the lepton-photon invariant mass. Moreover these events may (presumably do) come from different physics processes than those events with only one lepton and one photon. Many of the variables are unambiguous (such as $\not\!\!E_t$ and H_T), and yield only one entry in a plot, but some (such as the invariant mass of the lepton and photon) are not. In the three (2 $e\gamma$ and 1 $\mu\gamma$) events where only one photon passes the photon cuts in Table 3 and one lepton passes the appropriate lepton cuts in Table 2, it is this combination that is plotted. For the four events in which multiple combinations for the $e + \gamma$ and the $\mu + \gamma$ mass still exist we select the combination that yields an invariant mass closest to the Z mass. The 7 multi-combination events are discussed in detail in Subsection 3.1 below.

3.1 Events with more than one lepton or photon

The 7 events with more than one lepton or photon with $E_T > 25$ GeV are listed in Table 4. An event is considered to have additional leptons or photons if one or more of the following conditions are satisfied[3].:

- Additional Electron: There is an ELES bank with $E_T > 25$ GeV passing the loose central or loose plug TOPFND electron cuts.
- Additional Muon: There is a CMUO bank with $p_T > 25$ GeV passing the TOPFND muon tight cuts, except the fiducial cut.
- Additional Photon: There is an ELES bank with $E_T > 25$ GeV passing either the (tight) photon cuts listed in Table 3 *or* the loose photon ID cuts and the loose photon isolation cuts in PHOFND.

In Table 4, the leptons are identified by their status code from the Stntuple.[4]The first digit refers to the level of cut passed; the next three are the corrected E_T (electrons, photons) or p_T (muons).

Of these 7 events, [5] one (Run 56119/Event 4309) is consistent with $Z^0 \to ee\gamma$ in a beautiful 'Mercedes topology'. Another, the well-known $ee\gamma\gamma \not{E}_t$ event[1], has one central electron, a cluster passing the TOPFND plug electron cuts, and two photons among the objects in the event. One other well-known event is the event with a Z^0 boson ($m_{ee} = 89$ GeV) with a transverse momentum of 194 GeV directly opposite and balancing a 193 GeV photon[16]. Two of the other four events are an $ee\gamma$ event and a $\mu\mu\gamma$ event, each[6] with a total invariant mass of 126 GeV and a dilepton mass of 84 GeV; these are (presumably) $Z^0\gamma$ production. The last two are a $\mu\mu\gamma$ and a $e\gamma\gamma$ event with a $\ell\gamma$ mass of 80 and 92 GeV, respectively. Appendix E gives the values of some kinematic variables such as $\not{E}_t$ and p_T^γ for all 79 events.

[3]In the notation of the Stntuple, an additional electron is required to have ESTAT > 5025 (loose TOPFND central or TOPFND plug), a muon MUSTAT > 5025 (tight TOPFND CMU and/or CMP, but no ISO requirement), and a photon PSTAT > 3025 (a plug ELES bank passing the loose photon ID cuts and the loose photon isolation cuts in PHOFND). See *http://hep.uchicago.edu/cdf/stntuple.mem.*

[5]The $\mu\mu\gamma\gamma jj$ event does not appear in this table (although it is in the sample of 79 events) because one of the muons fails the hadron energy cut and one of the photons is in the plug and is relatively soft. A detailed discussion of this event is given in Ref [15].

[6]This is not a typo; the two events indeed have almost identical $\ell\ell\gamma$ and $\ell\ell$ masses.

Inclusive Electron		
Central electron (ELES bank, type = 0)		
E_T	$>$	25 GeV
Fiducial cut		($\texttt{FID\_ELE} = 0$)
Conversion removal		($\texttt{CON\_WRD} = 0$)
E/p	$<$	1.8
HAD/EM (3 towers)	$<$	0.05
Lshr	$<$	0.2
χ^2(strip)	$<$	10
Track-CES matching:		
$* \ \lvert\Delta z\rvert$	$<$	3 cm
$* \ \lvert\Delta x\rvert$	$<$	1.5 cm
Track-Vertex matching: $\lvert\Delta z\rvert$	$<$	5 cm
Isolation E_T	$<$	$0.1 \times E_T$
Inclusive Muon		
Central muon (CMUO bank)		
P_T	$>$	25 GeV/c
HAD energy	$<$	6 GeV
EM energy	$<$	2 GeV
HAD + EM energy	$>$	0.2 GeV
Track Stub Matching:		
$* \ \lvert\Delta x\rvert$	$<$	2 cm (CMU only and CMU-CMP)
$* \ \lvert\Delta x\rvert$	$<$	5 cm (CMP only)
$* \ \lvert\Delta x\rvert$	$<$	5 cm (CMX)
Track-Vertex matching:		
$* \ \lvert\Delta z\rvert$	$<$	5 cm
$* \ d_0$	$<$	0.3 cm
Isolation E_T	$<$	$0.1 \times P_T$

Table 2: The 25 GeV kinematic thresholds and the TOPFND identification selection criteria used to identify the final electron and muon candidates from the CMUORELE_ELE_1B ntuple.

Global Event Cuts		
Good Run (Code = 31)		
$\|z_{event}\|$	$<$	60.0 cm
$\mathrm{E_T}$(out-of-time)	$=$	0 GeV

Photon Identification and Isolation Cuts		
Central photon (ELES bank, type=0)		
Photon $\mathrm{E_T}$	$>$	25 GeV
3D tracks with $P_T > 1$ GeV	$=$	0
3D tracks with $P_T \leq 1$ GeV	$\leq$	1
HAD/EM	$<$	$0.055 + 0.00045 \times E^{\gamma}$
$\chi^2_{Avg} = \left(\frac{\chi^2_{Strip}+\chi^2_{Wire}}{2}\right)$	$<$	20.0
$\|X_{CES}\|$	$<$	21.0 cm
$\|\mathrm{Z_{CES}}\|$	$>$	14 cm
$\|\mathrm{Z_{CES}}\|$	$<$	217 cm
$\mathrm{E^{cluster}_{2nd\ strip\ or\ wire}}$	$<$	$2.39 + 0.01 \times E^{\gamma}$ GeV
Corrected Isolation $\mathrm{E^{Iso}_{cone}}$	$<$	2 GeV
$\mathrm{P_T}$ of tracks in a cone of 0.4	$<$	5.0 GeV

Table 3: Selection criteria used to make the LGAMMA dataset from the CMUORELE_ELE_1B sample. The global event cuts are listed in the upper section of the table; the photon selection cuts are listed in the lower section.

Run	Event	Type	1st ℓ or γ status	2nd ℓ or γ status	3rd ℓ or γ status	4th ℓ or γ status	N_{Jets}	$M_{\ell\ell}$	$M_{\ell\ell\gamma}$	Comment
56119	4309	$ee\gamma$	ele:9029	ele:9025	pho:6065	—	0	43.0	95.2	$Z^0 \rightarrow ee\gamma$
63078	25391	$\mu\mu\gamma$	mu:7038	mu:6024	pho:6036	—	1	34.6	79.5	$DY \rightarrow \mu\mu\gamma$(?)
65085	273167	$ee\gamma$	ele:9114	ele:5086	pho:5193	—	0	89.3	423.4	High $\mathrm{p_T}$ $Z\gamma$
68352	362020	$e\gamma\gamma$	ele:9038	pho:6040	pho:6011	—	0	N.A.	92.3	Z^0 (?)
68739	257646	$ee\gamma\gamma$	ele:9036	ele:3063	pho:6036	pho:6032	0	158.6	N.A.	$ee\gamma\gamma \not{E}_t$ Event
68915	158688	$ee\gamma$	ele:9047	ele:5026	pho:5026	—	0	83.4	125.9	$Z^0\gamma$ (?)
70577	406481	$\mu\mu\gamma$	mu:7045	mu:7034	pho:6039	—	0	84.6	126.1	$Z^0\gamma$ (?)

Table 4: List of the Events with multiple $\ell\gamma$ combinations. The status refers to the status variable for electrons, muons and photons in the Stntuple. The first digit of the status word indicates what level of cuts (e.g. tight or loose) the object passes; the next three digits are the transverse energy or transverse momentum in GeV. The number of jets refers to uncorrected jets with $\mathrm{E_T} > 10$ GeV, where the jets cannot be one of the electrons or photons (or muons, by definition) in the event. The "$\mu\mu\gamma\gamma jj$" event is not in the list, for reasons described in the text.

3.2 The Electron-gamma Invariant Mass Distribution: Z^0-like and not Z^0-like Events

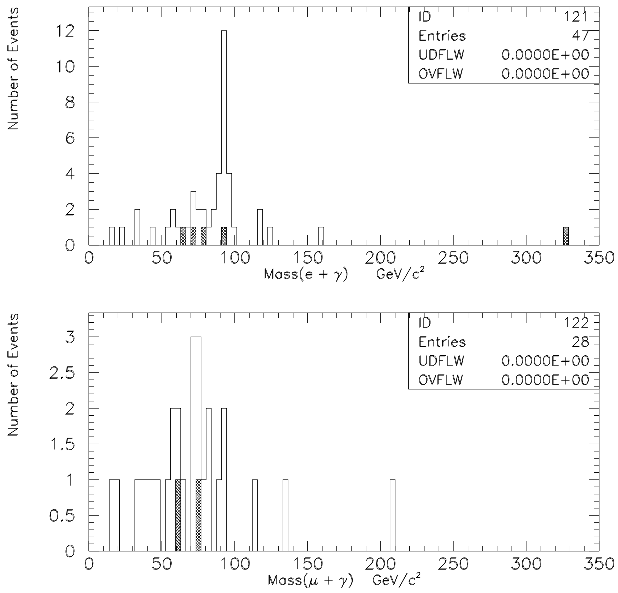

Figure 3: The lepton-photon invariant mass distribution for $e\gamma$ (top) and $\mu\gamma$ (bottom). The shaded entries correspond to events with more than one e, μ, or γ. Electron-gamma events with 81.0 GeV/c^2 $<$ m($e+\gamma$) $<$ 101.0 GeV/c^2 are called 'Z^0-like'; $e\gamma$ events outside the mass window or with multiple electrons or photons are called 'Not-Z^0-like'.

Figure 3.2 shows the distributions in invariant mass of the $e+\gamma$ and $\mu+\gamma$ events. In the plot of the invariant mass of the $e+\gamma$ in Figure 3.2 there is a peak around the Z mass. These events are (presumably– see below) from $Z^0 \rightarrow e^+e^-$ events in which one electron has radiated a hard brem or has lost a track in the CTC, and will be a substantial background to new physics events. We make the following definition that will hold throughout the remainder of this note:

- Z^0-like event: 81.0 GeV/c^2 $<$m($e+\gamma$) $<$ 101.0 GeV/c^2, and only one good electron and one good photon.
- Not-Z^0-like event: m($e+\gamma$) $<$ 81.0 GeV/c^2 or m($e+\gamma$) $>$ 101.0 GeV/c^2, or more than one good electron or more than one good photon.

There is no such peak in the $\mu+\gamma$ reconstructed mass, distribution; therefore we do not break the $\mu\gamma$ events into subcategories (this electron-muon difference is to be expected; the peak in the Z^0-like $e\gamma$ events is (presumably) due to $Z^0 \rightarrow e^+e^-$ events in which one electron either radiates a stiff colinear photon or a track is lost. However the calorimeter will pick up electromagnetic energy from both the photon and the electron. Muons that radiate are treated quite differently by the muon identification algorithm, as we describe below, with different results as a consequence.).

There are 24 events in the Z^0-like $e\gamma$ sample and 25 events in the Not-Z^0-like $e\gamma$ sample. There are 30 events in the $\mu\gamma$ sample.

3.3 Lepton and Photon Identification Variables Used in the Sample Selection

We use standard definitions of electrons, muons, and photons, as described below. This allows comparison with the top and W and Z analyses.

3.3.1 Identification Variables

Figures 3.3.1 and 3.3.1 show the distributions in the electron and muon identification quantities, respectively. The distributions from the respective $Z^0 \rightarrow e^+e^-$ and $Z^0 \rightarrow \mu^+\mu^-$ samples are shown as dotted lines for comparison. The distributions for leptons in the lepton-gamma sample are consistent with those for good leptons.

Figures 3.3.1 shows the distributions in the photon identification quantities, which are consistent with those expected from good photons.

3.3.2 Transverse Energies

Figure 7 shows the photon and lepton transverse energies distributions for the three subsamples: Z^0-like $e\gamma$, Not-Z^0-like $e\gamma$, and $\mu\gamma$, respectively. The Z^0-like events cluster around half the Z mass, as would be expected; both the Not-Z^0-like and muon-gamma subsamples have, in addition to events in this region, events closer to the 25 GeV threshold. The distributions from the respective $Z^0 \rightarrow e^+e^-$ and $Z^0 \rightarrow \mu^+\mu^-$ samples are shown as dotted lines for comparison.

The distribution in photon E_T in the muon sample is peaked near threshold, as might be expected, but all three distributions are fairly stiff. The one event at 193 GeV in the Not-Z^0-like $e\gamma$ distribution is the high p_T Z-gamma event; the event with a 140 GeV photon in the $\mu\gamma$ distribution is R69036/E49611, which has a 142 GeV photon, a 72 GeV muon, 66 GeV of $\not\!\!E_T$, and 2 jets of 17 GeV each.

3.3.3 Other Distributions

Distributions of other variables, not used in the sample selection, are shown in Appendix D.

4 The Final Lepton-Photon-$\not\!\!E_t$ Sample

New phenomena could show up with missing E_T or not; even in SUSY models missing E_T is not a necessary signature. In addition, missing E_T is a global variable, depending on many aspects of the detector and the reconstruction. We consequently have specifically designed our search to select on the well-measured objects of high-Pt leptons and photons alone, with the selection of the subsamples with $\not\!\!E_t$ and without $\not\!\!E_t$ being a second step. The larger sample allows a better understanding of backgrounds in the subsample with $\not\!\!E_t$ as well.

In both MSSM and gauge-mediated SUSY models there are channels that would result in the signature of lepton +photon + $\not\!\!E_t$. The discussion of the $ee\gamma\gamma\not\!\!E_t$ event in CDF3456 was the seed for both this search and the current interest in these models. Here we describe the selection of the subsample with $\not\!\!E_t$.

4.1 Missing Et Selection Criterion

We use the same cut as in CDF3555 of $\not\!\!E_t > 25$ GeV. The missing Et calculation is described in Section 2.4, and is the same as used in the (published) $\gamma\gamma + X$ search [1]. We require $\not\!\!E_t > 25$ GeV. This is the original *a priori* cut used in CDF3555, and was motivated by our familiarity with its efficiency and background from the measurements of the W mass, width, and branching ratios and the Z mass and asymmetries over the past several runs.

4.2 The Back-to-Back Cut

The dominant background to the electron-photon mode is expected to be from $Z^0 \to e^+e^-$ decays, where one electron is identified as a photon, either because it radiated a colinear hard photon, or because the track was lost. Muons also tend to radiate colinearly at about half the rate of electrons, and if the track is lost this will again be a background. We consequently require that the lepton and the photon be more than 30° from back-to-back ($\Delta\phi < 150$ degrees). Applying this cut to the sample of good central $Z^0 \to e^+e^-$ decays we find that 94.2% of the events pass this cut.

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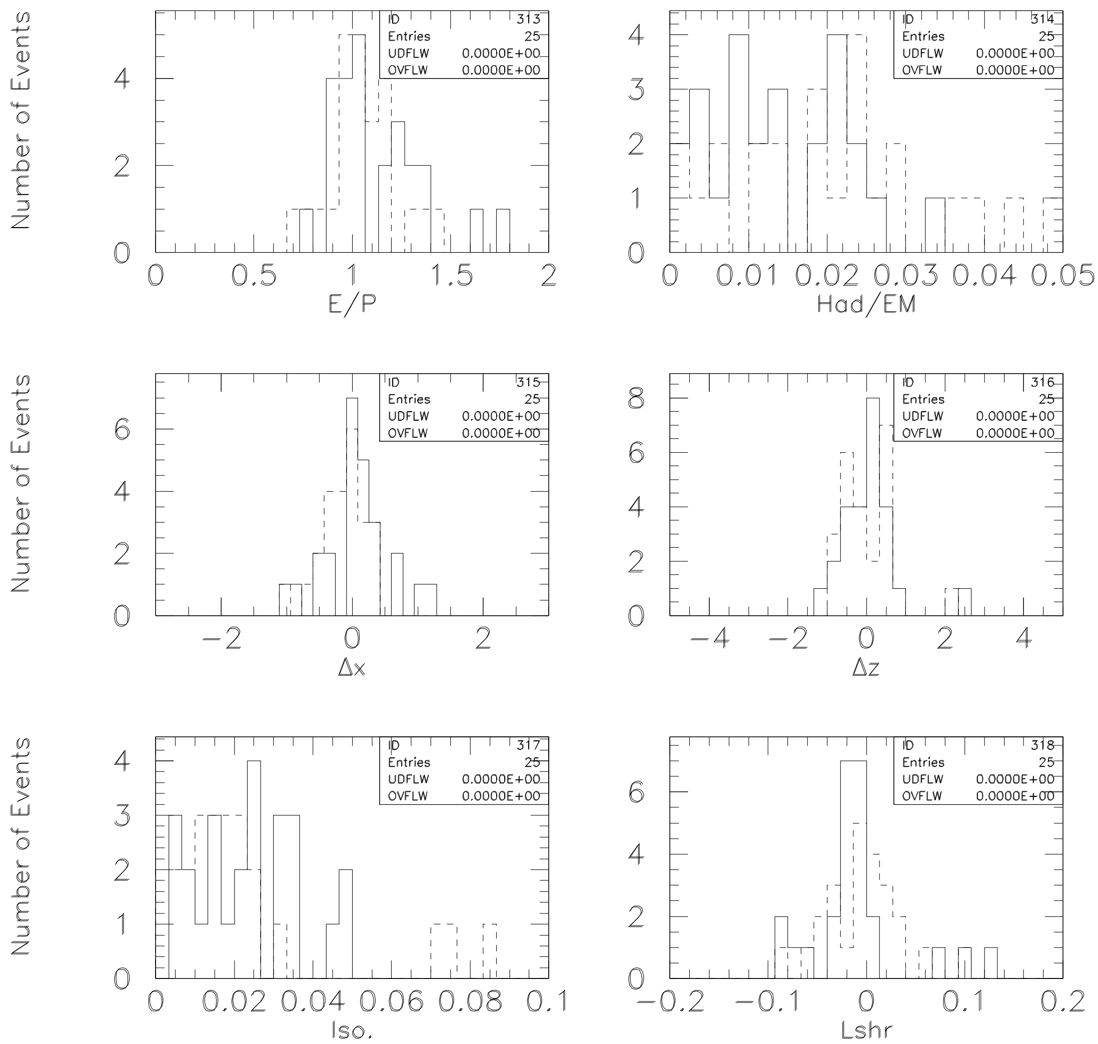

Figure 4: Distributions in the electron identification quantities for Zlike (dashed) and Not-Z^0-like (solid). a) E/p; b) Had/em; c) Δx, d) Δz; e) Iso, and f) Lshr.

30/12/98 17.16

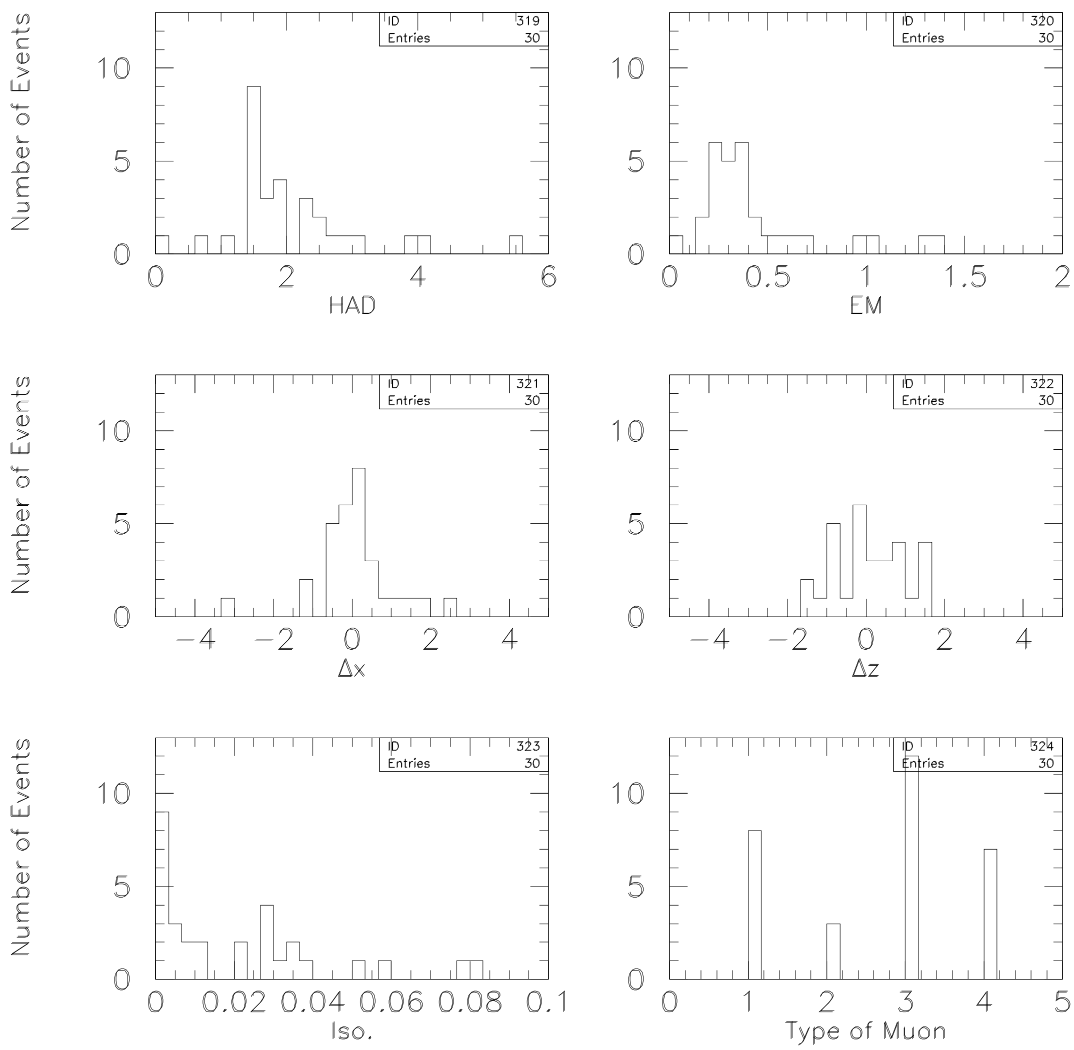

Figure 5: Distributions in the muon identification quantities for W events (dashed) and the muon-gamma events (solid): a) The hadronic calorimeter energy (Had); b) the electromagnetic calorimeter energy (Em); c) Δx, d) Δz; e) the calorimeter isolation (Iso), and f) The muon detector code, where 1= CMU only, 2= CMP only, 3=CMU-CMP, and 4= CMX.

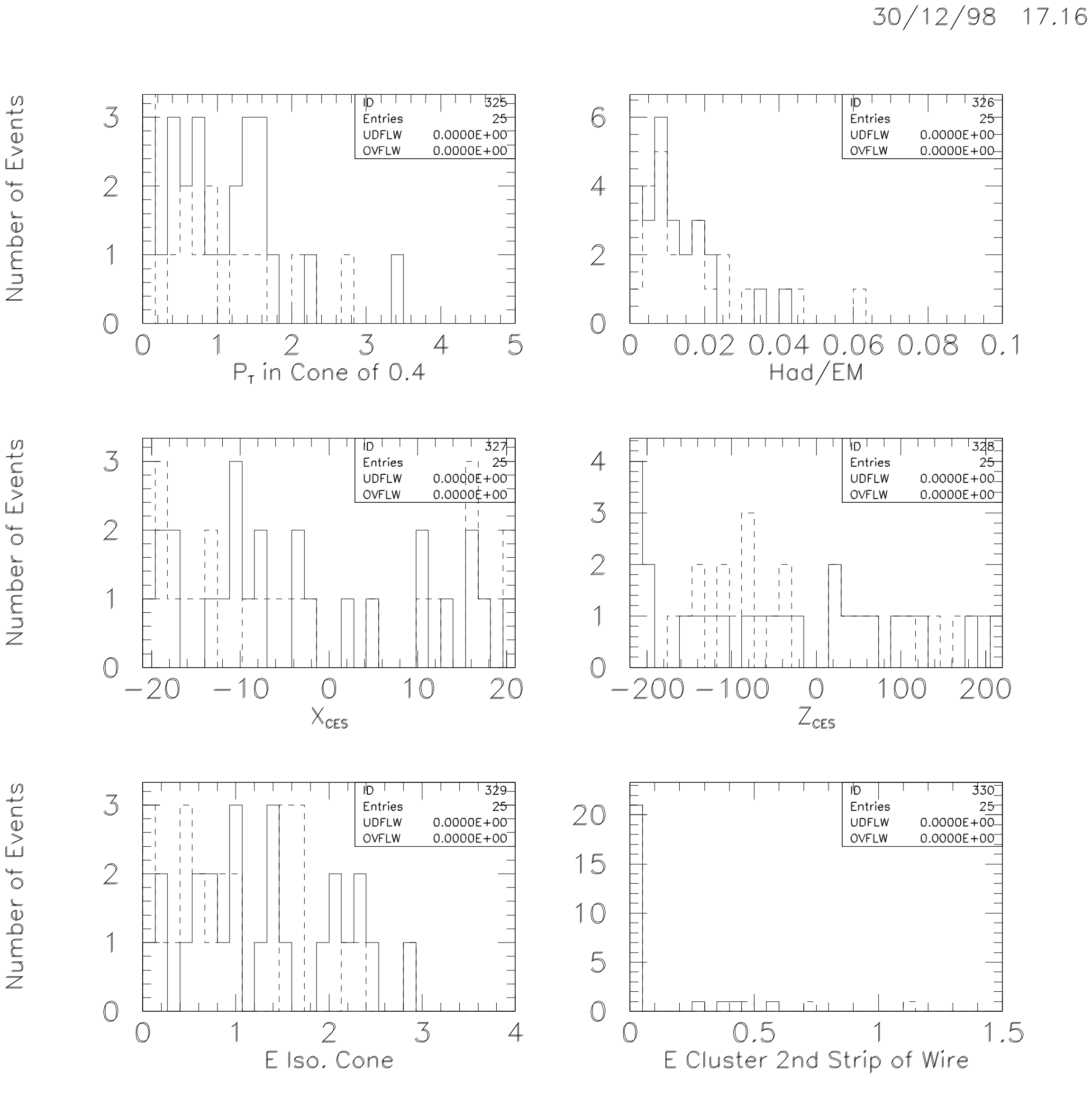

Figure 6: Distributions in the photon identification quantities for Zlike (dashed) and Not-Z^0-like (solid). a) E/p; b) Had/em; c) Δx, d) Δz; e) Iso.

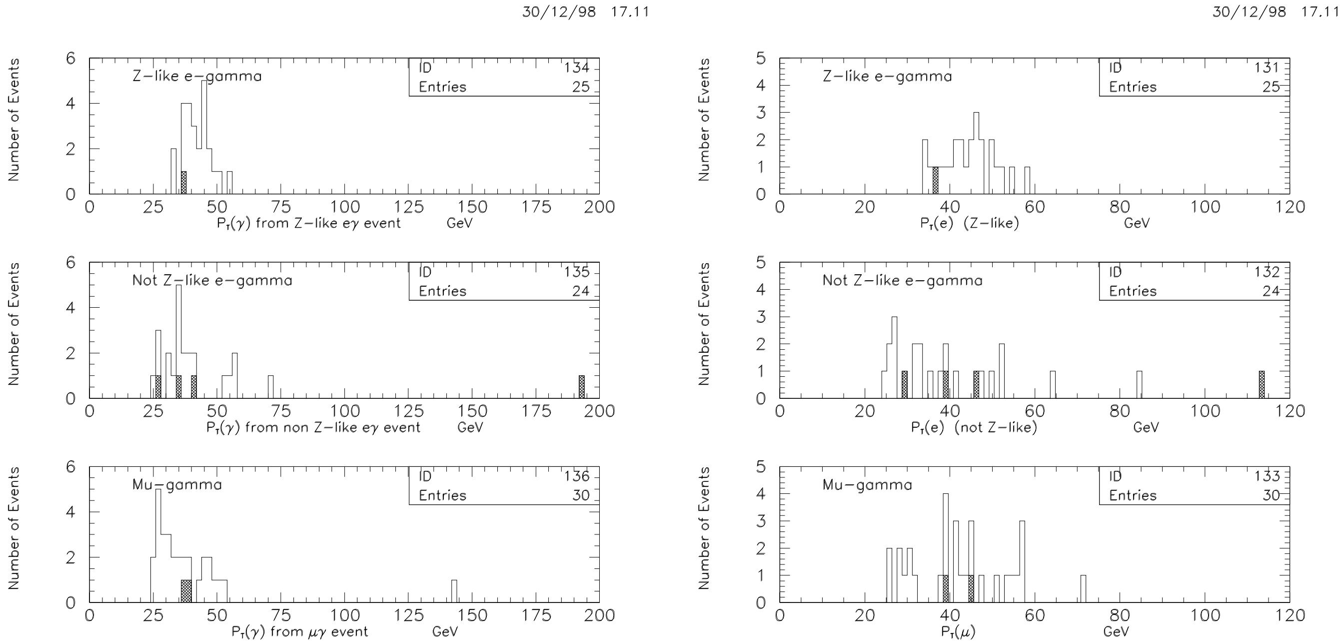

Figure 7: Transverse energy (E_T) of the photon (lefthand plot) and lepton (righthand plot)in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events. The shaded entries correspond to events with more than one e, μ, or γ.

4.3 Sample Selection: The Data Flow

The data flow, starting with the 79 lepton-photon events, is shown in Figure 8.

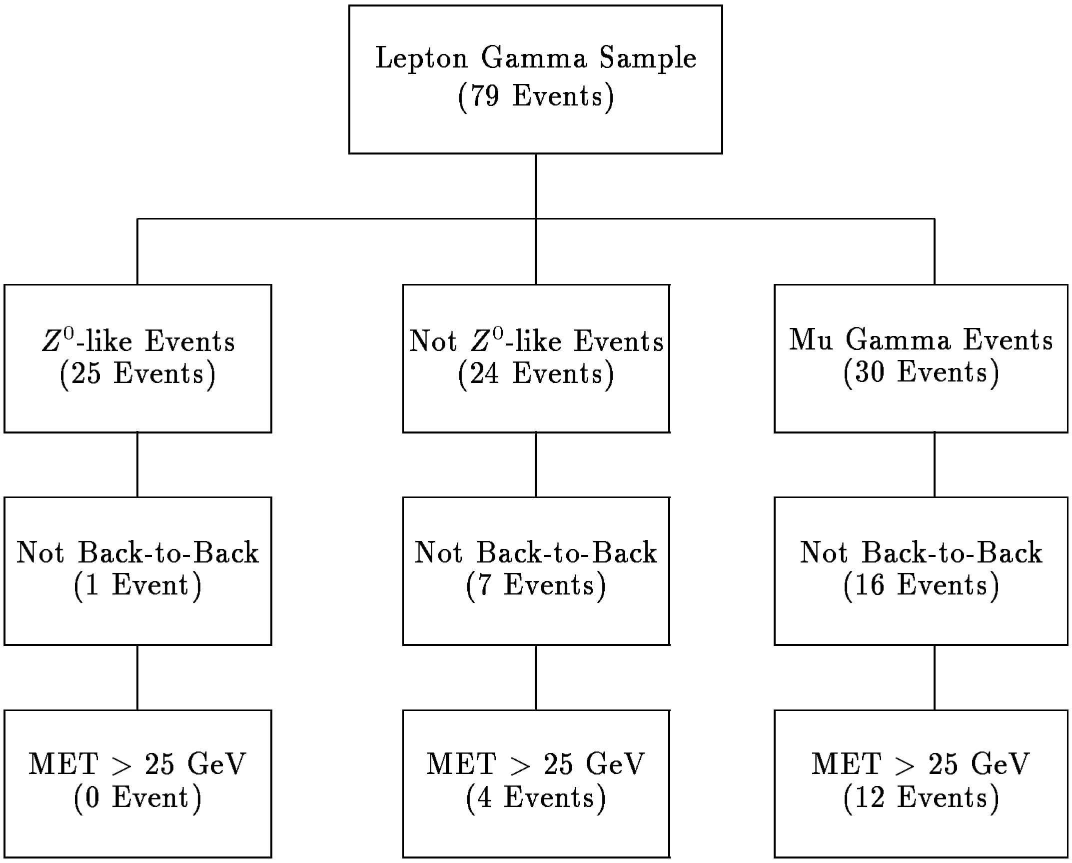

Figure 8: Flow Chart for the Lepton Gamma Sample. "Not Back-to-Back" refers to events in which $\Delta\phi_{\ell\gamma} < 150^o$.

4.4 Missing Et and Angular Correlation Distributions

Figure 9 shows the missing transverse energy distributions for the three sub-samples of Z^0-like, Not-Z^0-like, and muon events. The Z^0-like events have characteristically small $\not\!\!E_{\mathrm{T}}$, as would be expected if they are dominantly Z events where one electron has radiated or a track has been lost. There are two events with $\not\!\!E_{\mathrm{T}} > 25$ GeV. The shaded event (indicating multiple leptons and/or photons) with $\not\!\!E_{\mathrm{T}} \sim 55$ GeV is the $ee\gamma\gamma\not\!\!E_t$ event.

The Not-Z^0-like electron sample has 4 events with $\not\!\!E_{\mathrm{T}} > 25$ GeV. We expect about 3 such W-gamma events[11]. The rest of the distribution, with small $\not\!\!E_{\mathrm{T}}$, is consistent with Drell-Yan continuum where one electron has radiated or a track has been lost. From a loose dielectron sample, requiring two and only two tight 25 GeV central electrons, we find 1503 of the 1687 events (89%) are 'Z^0-like'. The respective numbers for the photon-electron sample are 24 Z^0-like and 25 Not-Z^0-like, for percentages of 48% and 52%, respectively. We can use these numbers to predict there should be 3 non-resonant Drell-Yan events in the Not-Z^0-like sample.

The muon distribution is quite different from either of the two electron distributions. There are 17 events with $\not{E}_{\mathrm{T}} > 25$ GeV, versus an expectation[11] from W-gamma of about 4 events[11]. The missing E_T distribution is quite stiff, with 5 of the 17 events beyond 50 GeV.

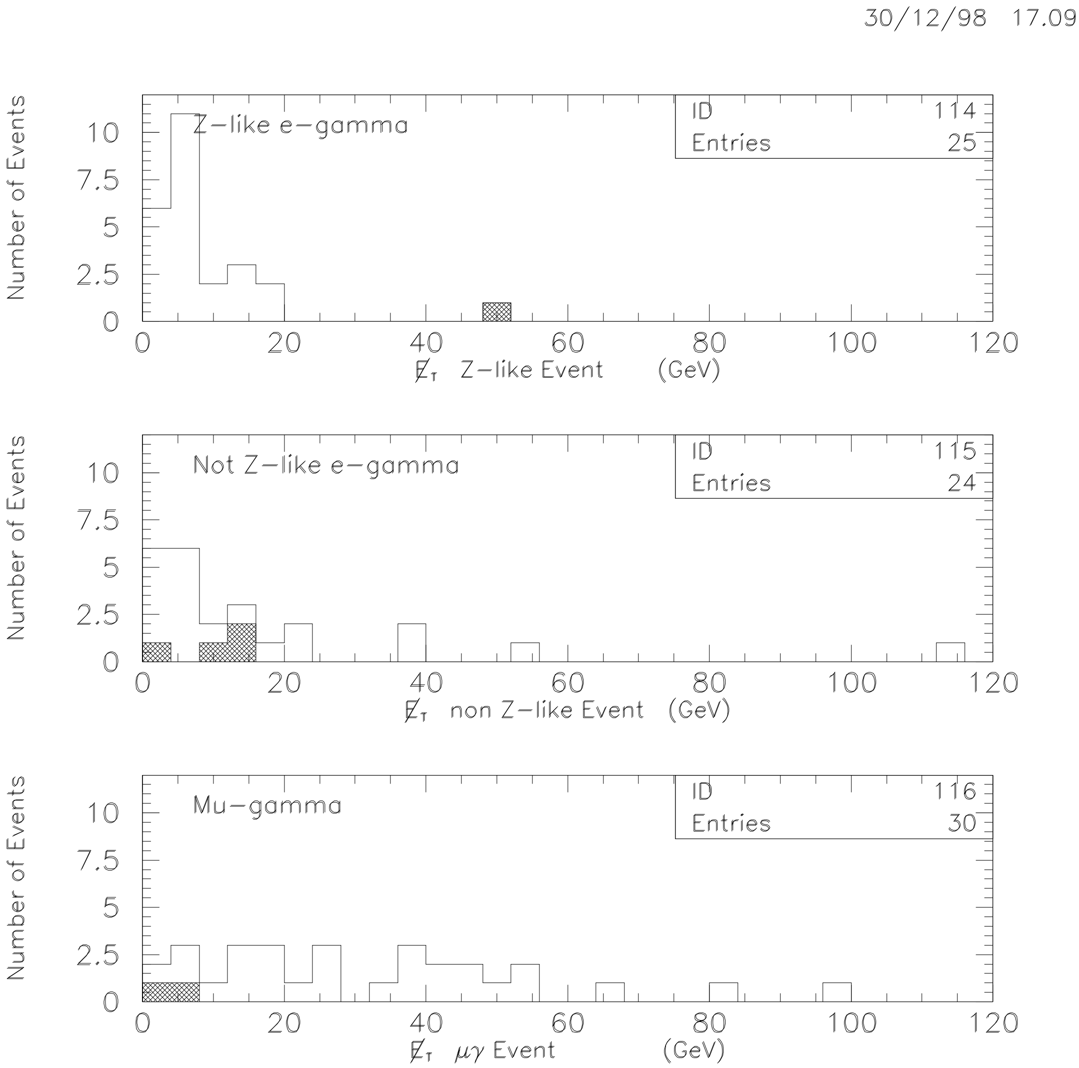

Figure 9: Missing Transverse energy distributions in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events. The shading indicates the events with multiple leptons or photons

The $\not{E}_{\mathrm{T}}$ in muon events could be caused by the loss of one track in $\mathrm{Z}^0 \rightarrow \mu^+\mu^-$ decays . This would generate a $\not{E}_{\mathrm{T}}$ of 40- 50 GeV. In 90% of such decays the two muons are back-to-back such that the angle between the muons is given by $\Delta\phi < 2.5$ radians. Figure 10 shows the $\Delta\phi$ distribution for the three subsamples; a $\not\!\!E_{\rm T}$ cut of 15 GeV has been applied so that the direction of the $\not\!\!E_{\rm T}$ is significant.

While losing a track in $Z^0 \rightarrow \mu^+\mu^-$ events will generate missing E_T, one still needs a mechanism for producing a 25 GeV photon candidate in the muon events. Figure 11 shows the $\Delta\phi$ between the lepton and the photon. If the photon were due to an interaction of the muon, for example, one would expect the lepton and photon to be back-to-back. Bremstrahlung also would peak at back-to-back.

The angle between the photon and the $\not\!\!E_{\rm T}$ is shown in Figure 12 for in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events. A cut of 15 GeV on the $\not\!\!E_{\rm T}$ has been applied in the right-hand plot so that the angle of the $\not\!\!E_{\rm T}$ is meaningful. Events with $\not\!\!E_{\rm T} > 25$ GeV are shaded.

Lastly, one can check if the missing E_T in the muon events comes from the lepton-photon system or from the calorimeter measurement of the rest of the event (for example, from extra jets). Because the lepton momenta and photon momenta are well-measured, and the angles also, the transverse-energy of the lepton-photon system is a well-measured quantity. We would expect events with large $\not\!\!E_{\rm T}$ from physics sources to also have comparable values of the lepton-photon system E_T. Figure 4.4 shows the distributions for Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events; the difference between electrons and muons is inherent in the lepton-photon system in the event and not from activity in the calorimeter.

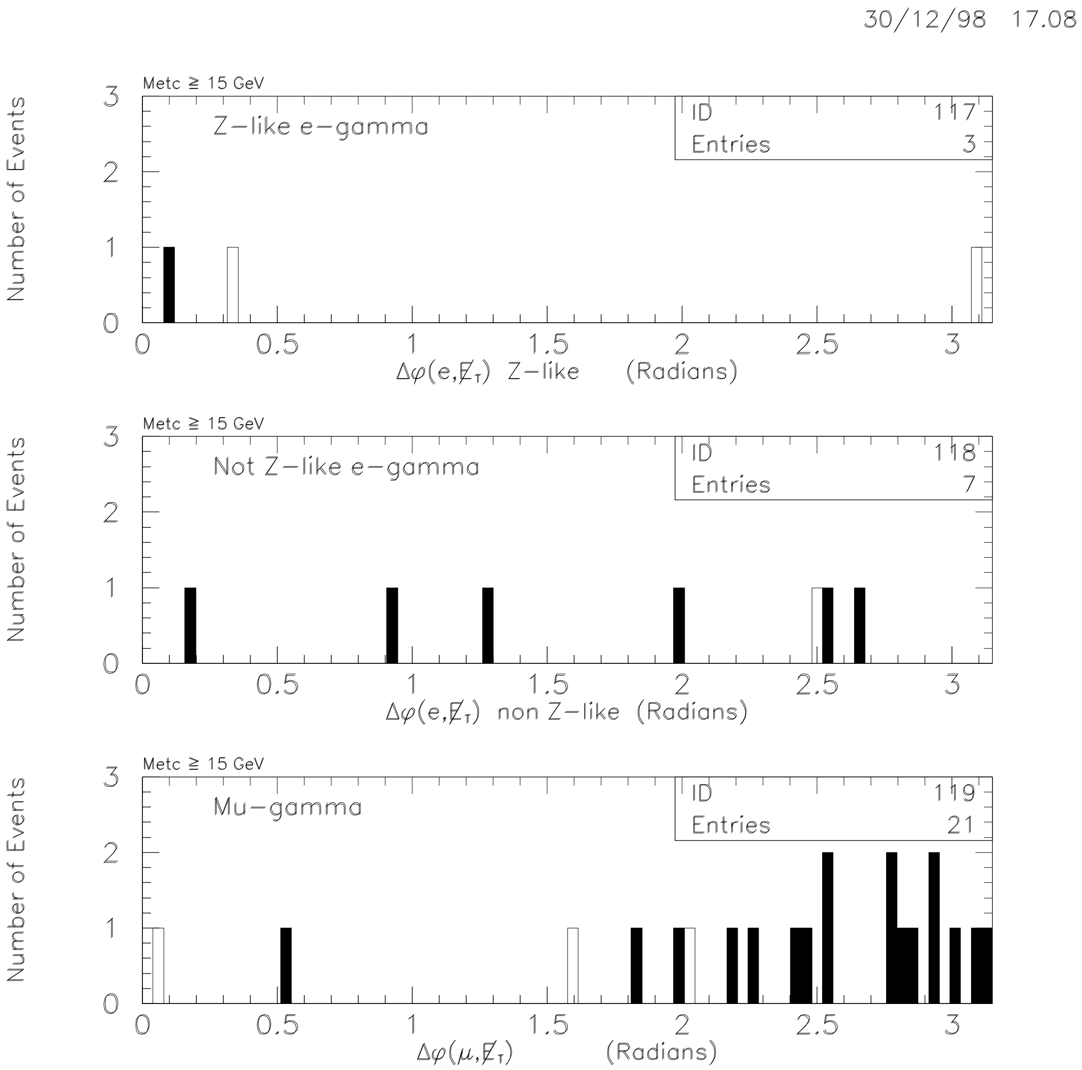

Figure 10: The angle, ϕ, between the lepton and the $\not{E}_T$ in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events. The shading in the right-hand plot indicates the events with $\not{E}_T > 25$ GeV. A cut of 15 GeV on the $\not{E}_T$ has been applied so that the angle is significant.

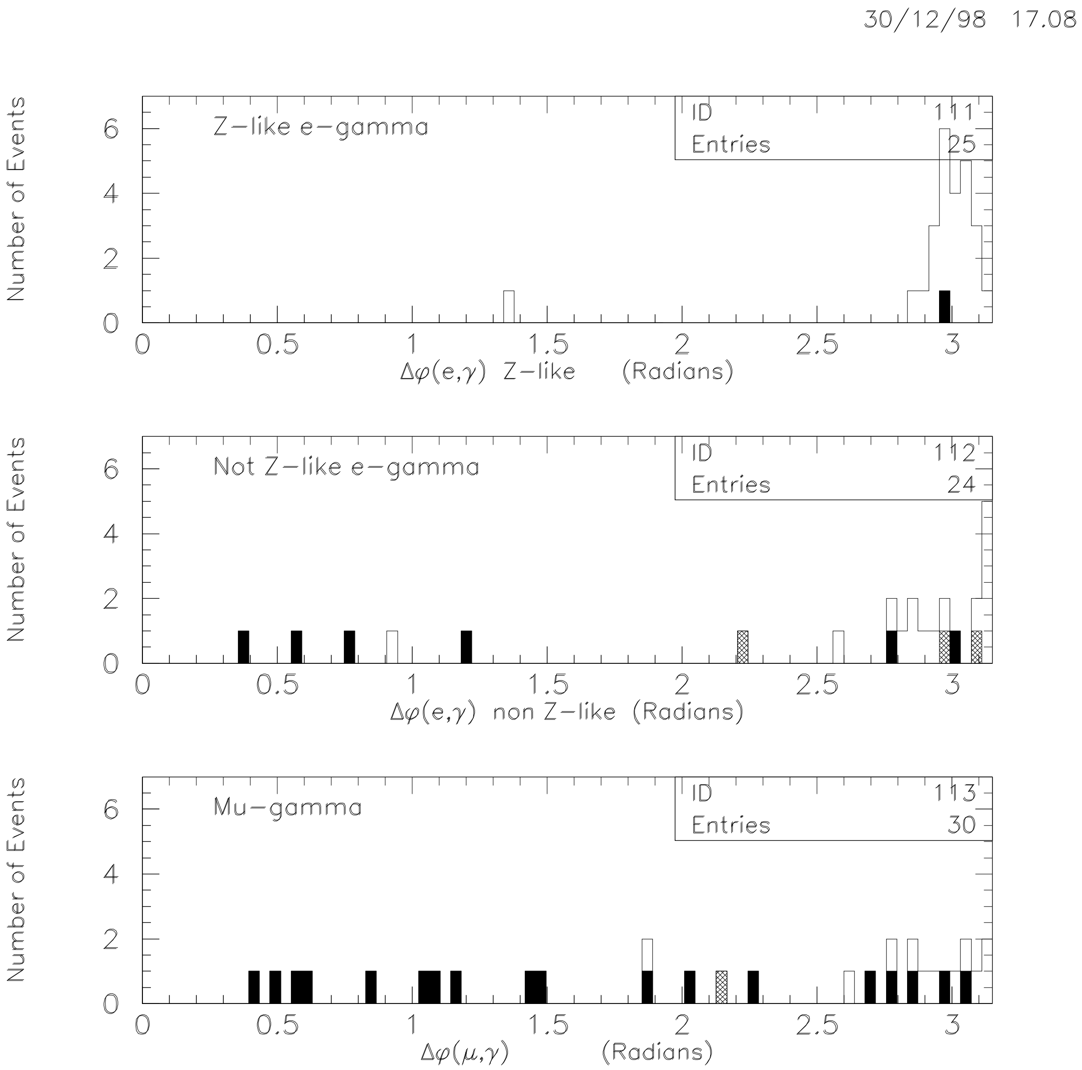

Figure 11: The angle, ϕ, between the lepton and photon in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events. A cut of 15 GeV on the $\not\!\!E_{\rm T}$ has been applied in the right-hand plot so that the angle of the $\not\!\!E_{\rm T}$ is meaningful. Events with $\not\!\!E_{\rm T} > 25$ GeV are shaded.

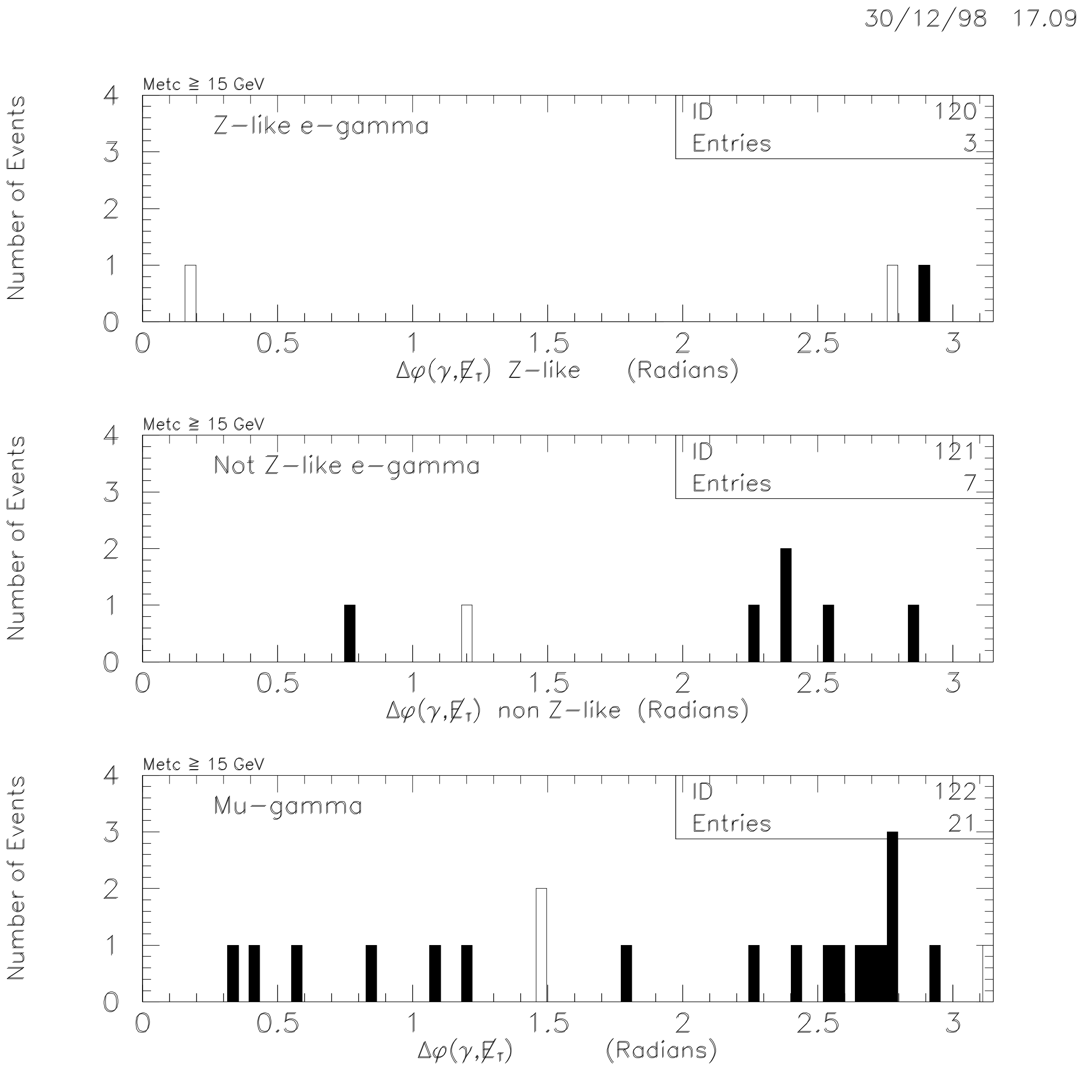

Figure 12: The angle, ϕ, between the $\not{E}_{\mathrm{T}}$ and the photon (Right) in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events. A cut of 15 GeV on the $\not{E}_{\mathrm{T}}$ has been applied in the right-hand plot so that the angle of the $\not{E}_{\mathrm{T}}$ is meaningful. Events with $\not{E}_{\mathrm{T}} > 25$ GeV are shaded.

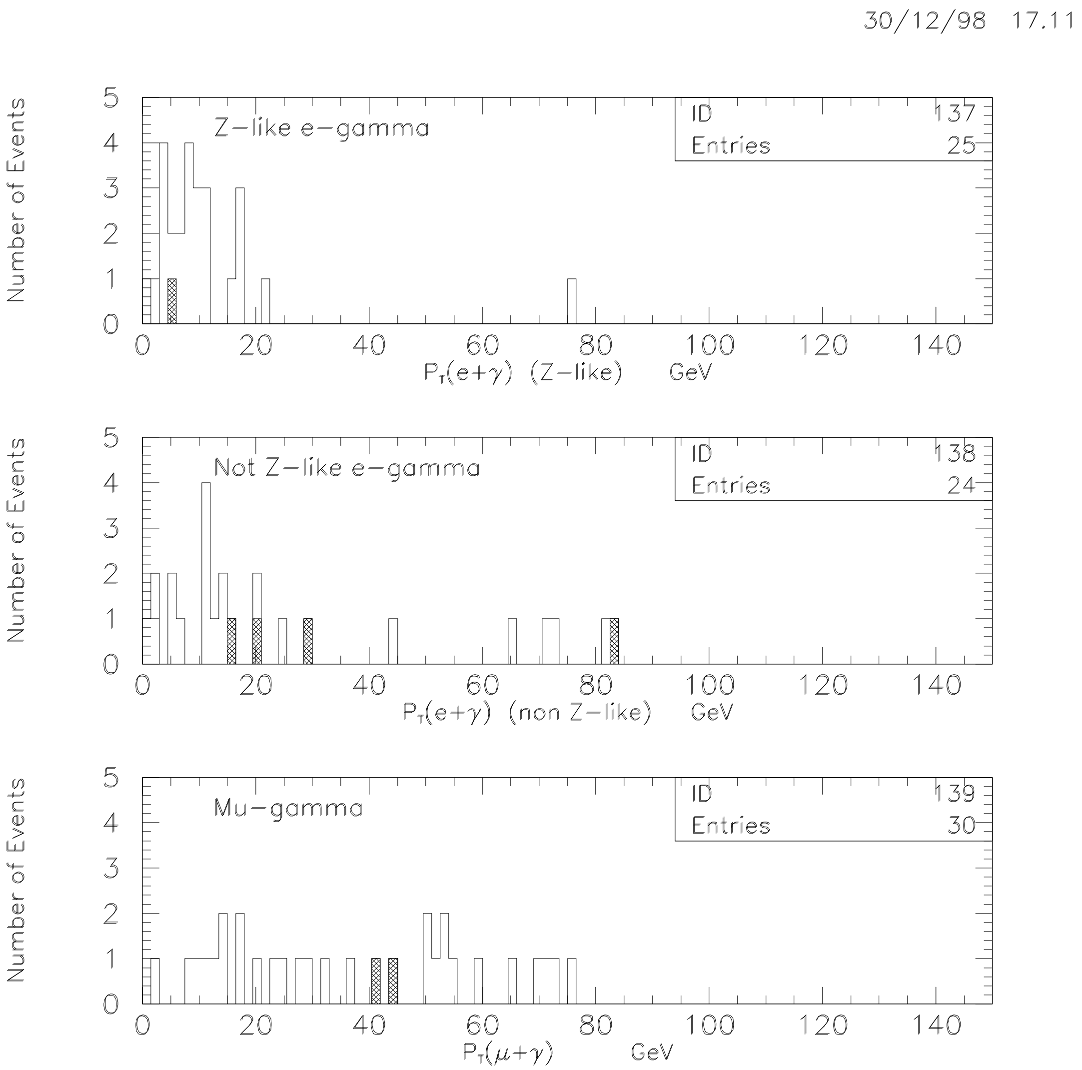

Figure 13: Transverse energy of the lepton plus photon systems. in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events. The shaded events are those with multiple leptons or photons.

4.5 Mass and Momentum Distributions

The difference between the muon and electron distributions in $\not\!\!E_T$ in the previous section leads us to look at the mass distributions The lepton-photon invariant mass distribution was shown in Figure 3.2. The distributions in the lepton-$\not\!\!E_T$ mass (i.e. assuming that the z component of the $\not\!\!E_T$ is zero) and photon-$\not\!\!E_T$ mass are shown in Figure 14. (xxx–BOTH THESE FIGURES NEED MAKING).

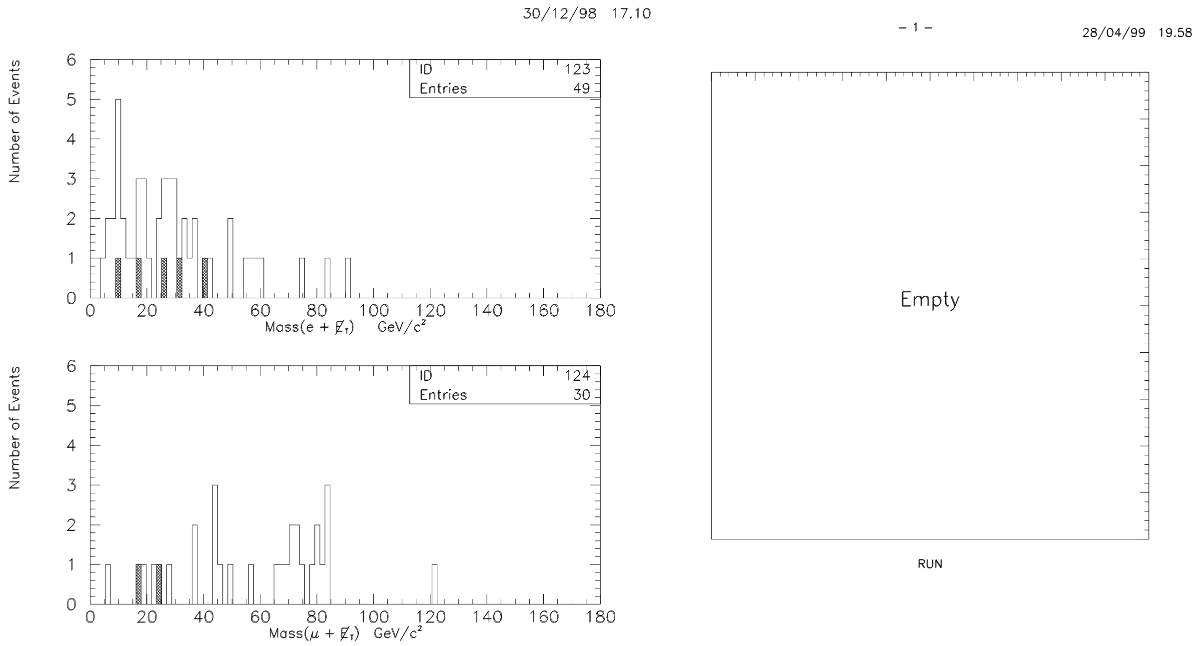

Figure 14: Plot of the invariant mass of the lepton plus missing transverse energy ($\ell + \not\!\!E_T$) (Left), and photon plus $\not\!\!E_T$ (Right), in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events. The z component of $\not\!\!E_T$ is taken $= 0$. The shaded events are those with multiple leptons or photons.

The total 'invariant mass' of the lepton-photon-$\not\!\!E_T$ system, where we have taken the z component of the $\not\!\!E_T = 0$, is shown in Figure 15. Also shown is the two-dimensional plot of the correlation between the lepton-$\not\!\!E_T$ mass and the lepton-photon mass.

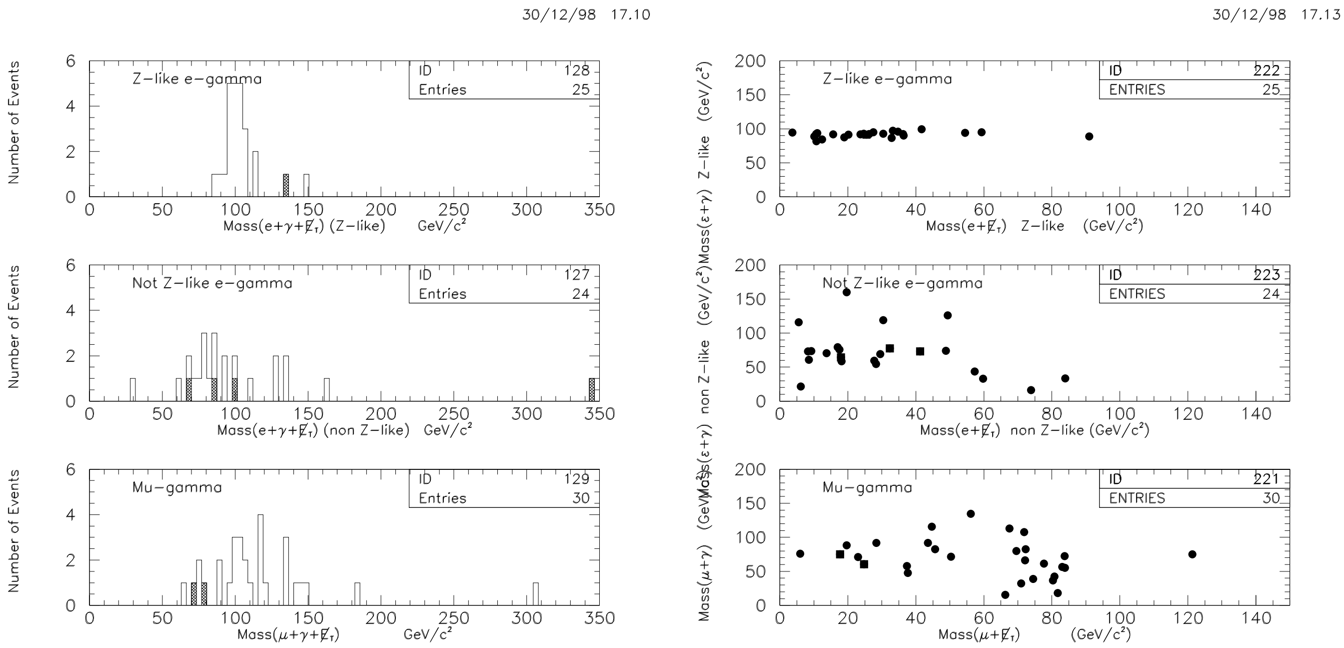

Figure 15: Left: 'Invariant mass' of the lepton, photon, $\not{E}_T$ ($p_z = 0$ is assumed) system in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events. Right: The correlation between the lepton-$\not{E}_T$ mass (abcissa) and the lepton-photon mass (ordinate).

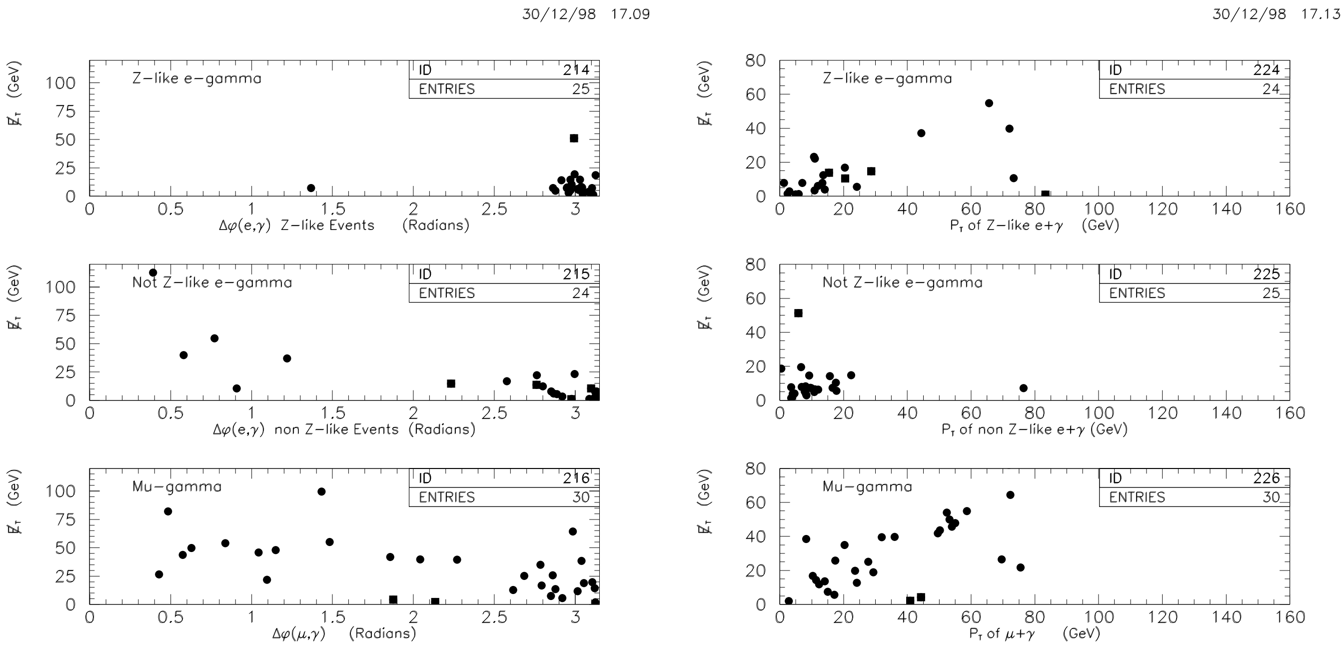

Figure 16: The correlation between the $\not{E}_T$ and the $\Delta - \phi$ between the lepton and the photon (Left) and the $\not{E}_T$ and the E_T of the lepton-gamma system (Right) in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events.

4.6 Missing Et vs H_T Distribution

Figure 4.6 shows the distribution in H_T versus $\not{E}_T$ for the electron events (upper) and muon events (lower), where H_T is the sum of the transverse energies of the lepton, the photon, any jets with $E_T > 10$ GeV, and the $\not{E}_T$. Also shown are the SM expectations for the dominant background, $W\gamma$ production.

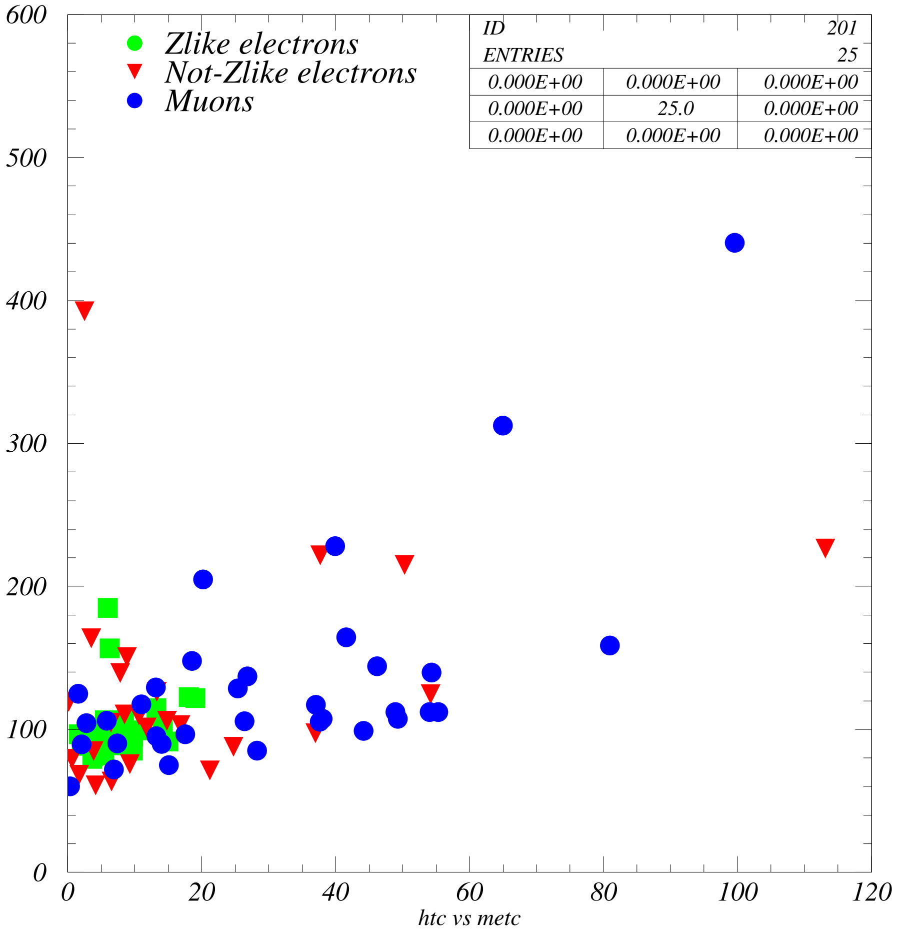

Figure 17: The distribution in H_T versus $\not{E}_T$ Also shown are the SM expectations for the dominant background, $W\gamma$ production.

5 Discussion of the Results: Comparison of Data to SM Expectations

5.1 The Counting Experiment

5.1.1 Comparison of Observed Sum of Electron + Muon Rates

5.1.2 Comparison of the Difference of Muon - Electron Rates

5.2 Comparison of Observed and Expected Distributions

5.2.1 Lepton-Photon Variables

The lepton and photon momenta are the best-measured objects in these events. The comparison of them with the Standard Model background expectations consequently is the easiest and best understood in terms of systematic uncertainties. We need the following plots of the Comparison of background (sum of contributions) and data for: (xxx)

1. PT-gamma
2. PT-lepton
3. ET-leptongamma
4. MT-leptongamma
5. Delta-phi lepton-gamma

5.2.2 Missing $\mathrm{E_T}$ Distributions

1. $\not\!\!E_{\mathrm{T}}$
2. Delta-phi lepton-met
3. Delta-phi gamma-met

5.2.3 Comparisons of Observed and Expected Spectra

1. KS integral of PT-gamma
2. KS integral of PT-lepton
3. KS integral of ET-leptongamma
4. KS integral of MT-leptongamma

6 Conclusions

7 Acknowledgments

We thank Uli Baur, Lina Galtieri, Lawrence Hall, Mark Lancaster, Tony Liss, Young-Kee Kim, Steve Mrenna, Hitoshi Murayama, Jon Rosner, David Toback, Peter Wilson, Weiming Yao for help along the way. We are especially grateful to Uli Baur and Steve Mrenna for their major efforts getting the $W\gamma$ and $Z^0\gamma$ theoretical and Monte Carlo situation in good shape.

8 Appendix A: The ELEELE selection cuts

This is the COMIS file used to select the ELEELE dataset from the electron inclusives dataset.

```
      real function eleele_filt(xdummy)

      implicit none
      include 'ghib$data:cwn.inc'
      include 'c$inc:pivalu.inc'
      integer xdummy
      integer i,j,k
      integer nele
      real coriso

      eleele_filt = 0.0
      nele = 0

      do i = 1,nel
C if it is an ELES bank with ELES Et and iso good then count it
      if (eetcor(i).gt.20.0.and.eiso(i).lt.0.15) then
        nele = nele + 1
      else
C if it is an ELES bank with exo_phoval Et and iso good then count it
        do j = 1,npho
C    find the corresponding ntuple column in the photon variable block
          if (pelind(j).eq.i) then
            coriso = pco4(j)-pvcor(j)-plcor(j)*petc(j)
            if (petc(j).gt.20.0.and.
     &      (coriso.lt.3.0.or.pco4(j)/petc(j).lt.0.15)) then
            nele = nele + 1
            endif
          endif
        enddo
      endif
      enddo

      if (nele.ge.2) then
        eleele_filt = 1.0
      endif

      return
      end
```

9 Appendix B: The CMUELE selection cuts

This is the COMIS file used to select the CMUELE dataset from the electron inclusives dataset.

```
      real function cmuele_filt(xdummy)

      implicit none
      include 'ghib$data:cwn.inc'
      include 'c$inc:pivalu.inc'
      integer xdummy
      integer i,j,k
      integer nele,ncmu
      real coriso

      cmuele_filt = 0.0
      nele = 0
      ncmu = 0

      do i = 1,nel
C if it is an ELES bank with ELES Et and iso good then count it
      if (eetcor(i).gt.20.0.and.eiso(i).lt.0.15) then
        nele = nele + 1
      else
C if it is an ELES bank with exo_phoval Et and iso good then count it
        do j = 1,npho
C    find the corresponding ntuple column in the photon variable block
          if (pelind(j).eq.i) then
            coriso = pco4(j)-pvcor(j)-plcor(j)*petc(j)
            if (petc(j).gt.20.0.and.
     &      (coriso.lt.3.0.or.pco4(j)/petc(j).lt.0.15)) then
            nele = nele + 1
            endif
          endif
        enddo
      endif
      enddo

      do i = 1,nmu
C if it is a CMUO bank with CMUO pt and iso good then count it
C         don't count CMIO's
        if (mudet(i).ne.0) then
        if (mupt(i).gt.20.0.and.muiso(i).lt.0.15) then
          ncmu = ncmu + 1
```

```
    endif
    endif
  enddo

  if (ncmu.gt.0.and.nele.gt.0) then
    cmuele_filt = 1.0
  endif
  return
  end
```

10 Appendix C: The LGAMMA selection cuts

This is the COMIS file used to select the LGAMMA dataset from the CMUORELE_ELE dataset.

```
  real function lgamma_filt(xdummy)

  implicit none
  include 'ghib$data:cwn.inc'
  include 'c$inc:pivalu.inc'
  integer xdummy
  integer i,j,k
  integer nele,ncmu,nphogood
  real coriso

  lgamma_filt = 0.0
  nele = 0
  ncmu = 0
  nphogood = 0

  do i = 1,nel
    if (estat(i).gt.9025) then
      nele = nele + 1
    endif
  enddo

  do i = 1,nmu
    if (mustat(i).gt.7025) then
      ncmu = ncmu + 1
    endif
  enddo

  do i = 1,npho
    if (pstat(i).gt.5000.and.petc(i).gt.25.0) then
```

```
    nphogood = nphogood + 1
  endif
enddo

if (etout.eq.0) then
if (brcode.ge.15) then
if (abs(vzev).lt.60.0) then
if (ncmu+nele.gt.0.and.nphogood.gt.0) then
  lgamma_filt = 1.0
endif
endif
endif
endif

return
end
```

11 Appendix D: Distributions of Photon and Lepton Variables Not Used in the Event Selection

Figure 18a shows the pseudo-rapidity (event eta) of the photon in the three subsamples. There is little remarkable in any of the three, although there may be a slight tendency towards large eta in the Z^0-like sample (the statistics are poor).

Figure 18b shows the pseudo-rapidity (event eta) of the lepton in the three subsamples. There is a large (5 vs 21) East/West asymmetry in the Z^0-like events, with 5 of the events with $\eta < 0$ near the crack at $\eta = -1$. The other two plots look more reasonable, with the Not-Zlike being 11 versus 12, and the muons being 10/20. The coil supports are East/West asymmetric, as is the gas flow in the CTC; aside from this we don't know of other detector asymmetries and presume that the asymmetry is largely a fluctuation.

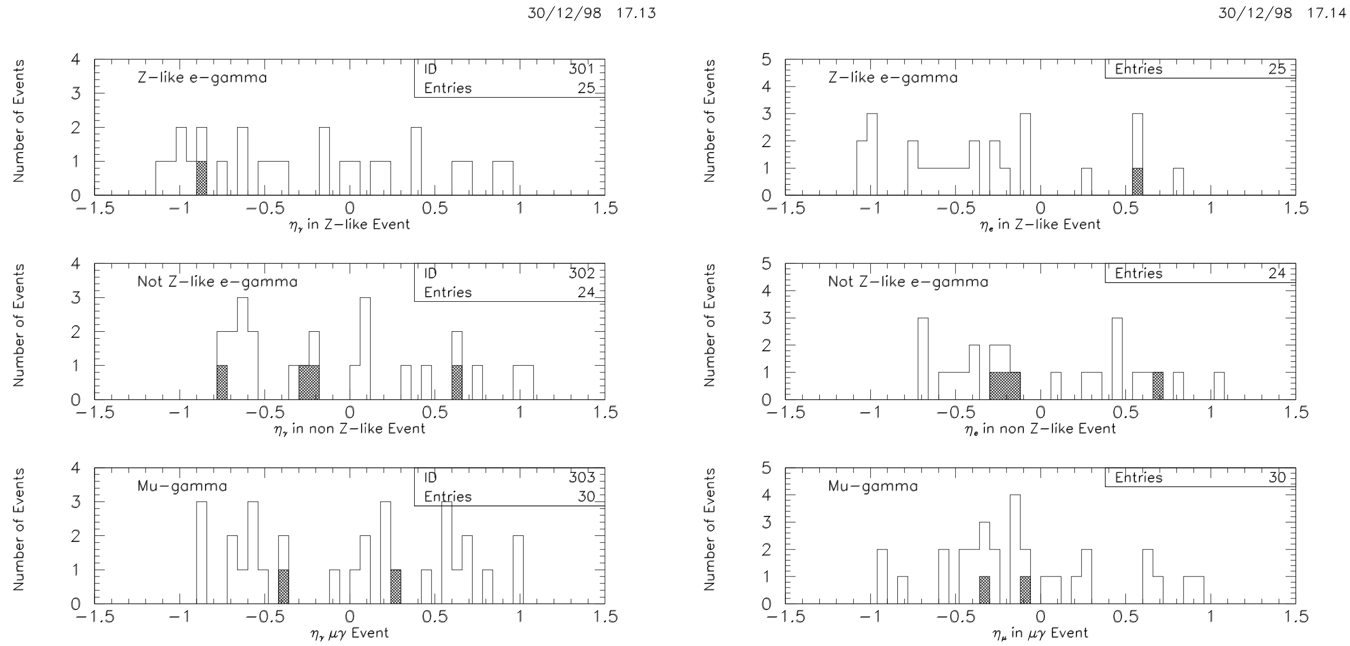

Figure 18: Pseudorapidity (event eta) of the photon (lefthand plot) and lepton (righthand plot)in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events.

Figure 11 shows the sign of the charge (plus or minus) of the lepton in the three subsamples. The muon sample has a charge asymmetry of 20 positive to 10 negative. While the muon asymmetry worries us ($\bar{p}p \to \gamma + X$ is as CP-invariant a process as one can imagine, and the obvious CP violation is in the detector, so that detector related effects such as punchthrough can be charge asymmetric, for example); we haven't been able to think of a source for it (see the discussion of punchthrough below). The Z^0-like and Not-Z^0-like samples have plus-to-minus ratios of 9/15 and 11/14, respectively; the total sample of 79 events consequently has a plus-to-minus ratio of 40/39.

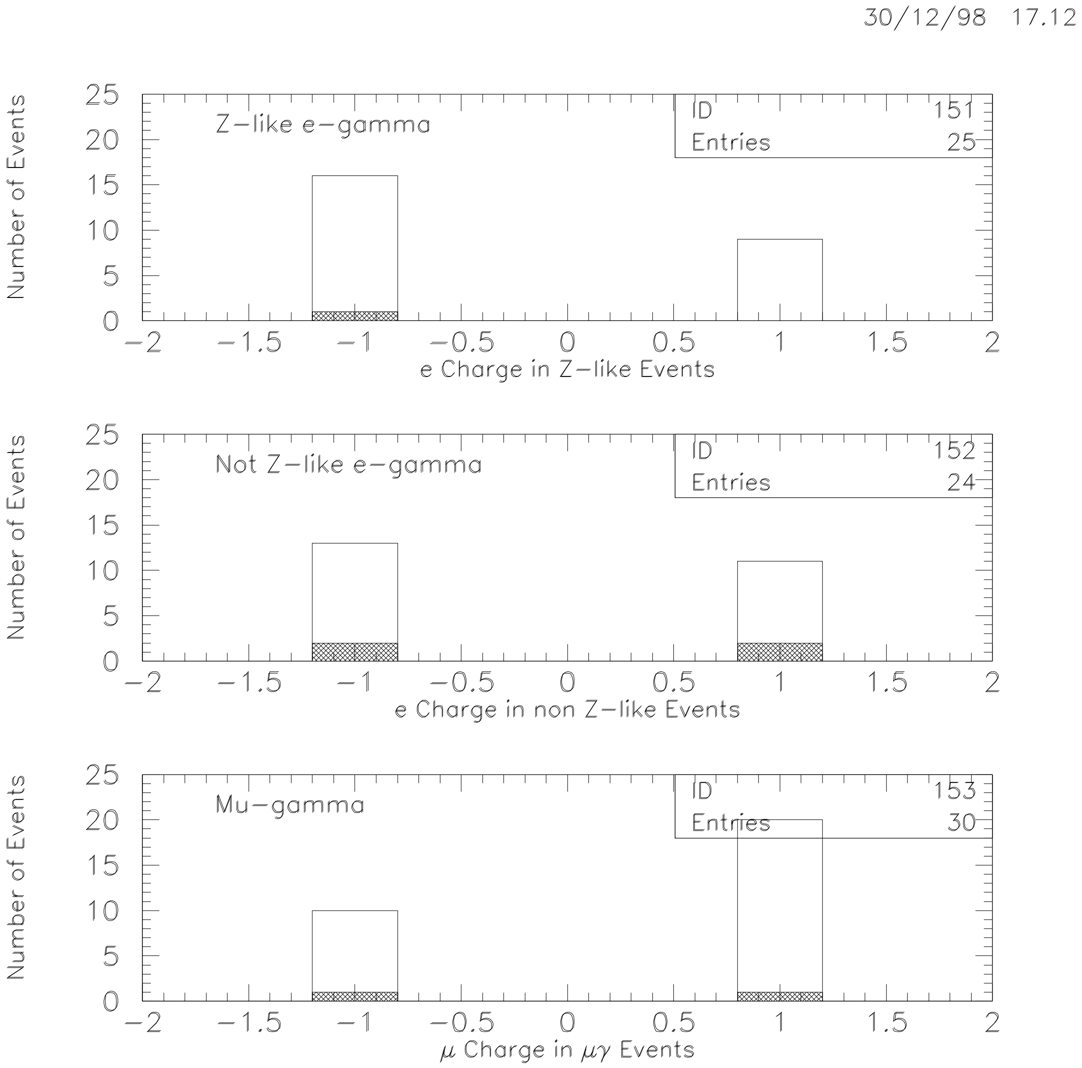

Figure 19: Sign of the lepton charge. in Z^0-like (top), Not-Z^0-like (middle), and $\mu\gamma$ (bottom) events.

12 Appendix E: Tables of Events

12.1 Z^0-Like $e\gamma$ Events

Z^0-like $e\gamma$ Events without $\not{E}_t$												
Run	Event	Type	p_T^e	p_T^γ	$M^{e\gamma}$	$\Delta\phi^{e\gamma}$	$\not{E}_t$	$M^{e\gamma\not{E}_t}$	$\Delta\phi^{\not{E}_t e}$	$\Delta\phi^{\not{E}_t\gamma}$	p_T^{tracks}	N_{Jets}
59103	197855	$e\gamma$	43.8	43.6	87.6	174.3	3.9	92.9	75.3	110.3	0.0	0
59948	57739	$e\gamma$	58.6	37.7	95.0	170.1	14.6	114.5	164.2	25.5	0.0	0
60668	150801	$e\gamma$	47.7	44.6	92.4	178.2	1.3	94.8	31.5	146.6	45.5	0
61168	335596	$e\gamma$	45.6	45.3	93.6	179.0	18.7	107.6	19.6	159.3	44.2	1
63033	598384	$e\gamma$	41.2	44.3	92.3	164.8	4.9	101.5	66.8	128.3	0.0	0
63370	11459	$e\gamma$	45.7	32.5	94.2	166.9	14.2	112.1	166.5	26.5	0.0	0
63736	13638	$e\gamma$	34.4	41.5	92.0	173.9	8.2	101.3	18.6	167.3	34.2	0
63927	90389	$e\gamma$	39.0	55.4	94.4	177.8	7.3	102.0	10.9	171.1	35.6	0
64700	190590	$e\gamma$	55.0	38.7	92.2	172.9	5.6	99.1	179.4	6.4	0.0	0
64700	621218	$e\gamma$	40.4	39.2	89.9	174.7	3.8	97.2	161.4	23.8	0.0	0
65004	150318	$e\gamma$	45.2	43.5	99.4	171.6	19.4	108.2	177.7	10.5	0.0	0
65408	236190	$e\gamma$	38.1	36.4	91.6	169.0	7.8	101.8	68.8	122.0	0.0	0
65426	226997	$e\gamma$	44.4	46.1	96.0	169.5	2.9	102.2	154.4	15.0	44.3	0
65894	139219	$e\gamma$	50.1	33.9	86.6	170.5	10.4	94.5	118.3	71.0	0.0	0
65974	26662	$e\gamma$	41.6	39.0	84.4	170.1	5.2	89.4	52.7	137.1	0.0	0
66165	660379	$e\gamma$	42.1	39.9	88.7	174.5	2.0	94.8	37.5	147.8	40.3	0
66207	6376	$e\gamma$	50.4	41.4	91.5	172.7	6.5	95.1	106.1	81.1	0.0	0
66347	268924	$e\gamma$	49.5	48.2	88.8	78.3	7.2	148.1	144.0	137.6	37.5	1
66500	37841	$e\gamma$	51.8	44.7	97.2	169.7	6.3	104.6	144.2	45.9	0.0	0
67561	300539	$e\gamma$	35.1	37.8	92.7	164.0	7.2	101.4	116.3	79.6	0.0	0
67634	37969	$e\gamma$	46.6	45.0	91.8	168.9	7.3	99.3	81.1	109.9	0.0	0
67651	100251	$e\gamma$	47.1	47.4	94.7	174.2	7.7	99.4	166.2	8.0	36.4	0
68294	13643	$e\gamma$	42.7	50.4	92.7	173.6	14.5	107.3	51.4	122.2	0.0	0
69833	6775	$e\gamma$	33.7	41.8	81.8	176.5	3.9	87.0	41.9	141.4	0.0	0
Z^0-like $e\gamma$ Events with $\not{E}_t$												
Run	Event	Type	p_T^e	p_T^γ	$M^{e\gamma}$	$\Delta\phi^{e\gamma}$	$\not{E}_t$	$M^{e\gamma\not{E}_t}$	$\Delta\phi^{\not{E}_t e}$	$\Delta\phi^{\not{E}_t\gamma}$	p_T^{tracks}	N_{Jets}
None												

Table 5: List of the 25 Z^0-like $e\gamma$ events, separated into a subsample without $\not{E}_t$ and one with $\not{E}_t$. All momenta and energies are in GeV; angles are in degrees. The variable p_T^{tracks} is the clustered track momentum in the direction of the missing E_T. The number of jets refers to jets with uncorrected $E_T > 10$ GeV, where the jets cannot be one of the electrons or photons in the event. 'Without $\not{E}_t$' is short-hand for $\not{E}_t < 25$ GeV; 'With $\not{E}_t$' refers to $\not{E}_t > 25$ GeV.

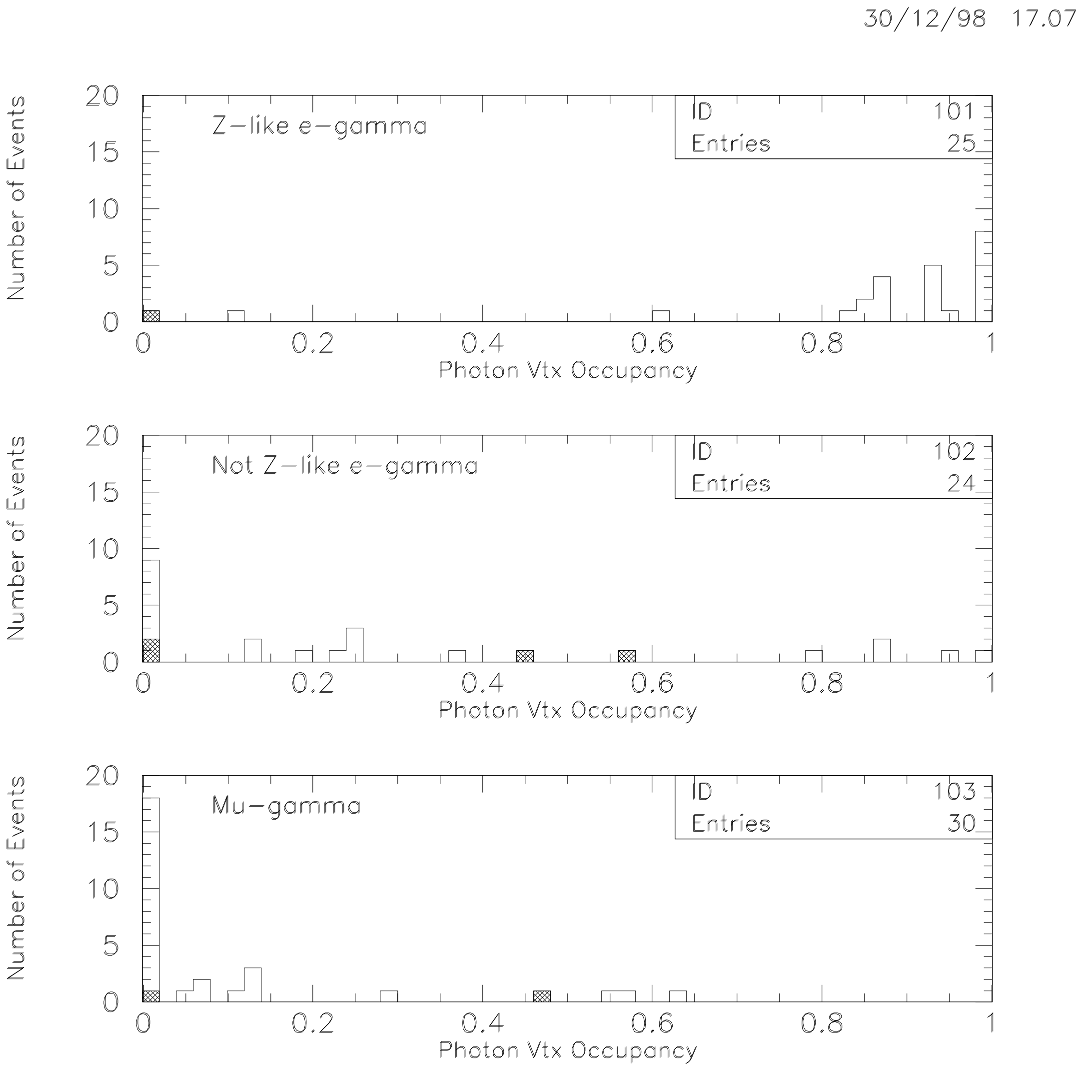

Figure 20: The VTX occupancy of the photon in Zlike electron (top), Not-Z^0-like electron (middle), and muon (bottom) events.

12.2 Not-Z^0-Like $e\gamma$ Events

Not-Z^0-like $e\gamma$ Events without $\not\!\!E_t$												
Run	Event	Type	p_T^e	p_T^γ	$M^{e\gamma}$	$\Delta\phi^{e\gamma}$	$\not\!\!E_t$	$M^{e\gamma\not E_t}$	$\Delta\phi^{\not E_t e}$	$\Delta\phi^{\not E_t \gamma}$	p_T^{tracks}	N_{Jets}
56119	4309	$ee\gamma$	29.0	34.9	64.1	127.8	14.7	95.1	148.4	83.6	0.0	1
61124	197930	$e\gamma$	34.8	35.6	70.4	176.8	1.3	72.2	126.3	56.8	0.0	0
61140	311478	$e\gamma$	26.5	54.1	43.4	51.9	10.6	109.0	138.	170.0	41.9	1
61221	7784	$e\gamma$	64.7	57.7	125.	179.3	7.8	135.4	166.3	13.0	0.0	0
63485	337978	$e\gamma$	25.3	34.9	59.3	171.6	23.1	86.1	52.5	135.8	0.0	0
64663	249519	$e\gamma$	31.5	32.5	73.4	178.9	7.7	77.5	39.8	141.2	0.0	0
65085	273167	$ee\gamma$	113.5	193.3	325.5	170.5	0.9	89.2	4.2	166.3	0.0	1
65344	327956	$e\gamma$	50.0	52.1	118.	163.4	7.8	128.	91.4	105.1	0.0	0
65750	125312	$e\gamma$	25.1	30.6	54.7	158.3	22.1	77.4	72.2	129.4	0.0	0
65917	27370	$e\gamma$	47.5	25.5	69.0	165.3	5.5	75.7	172.7	7.3	16.3	1
66208	13933	$e\gamma$	26.9	35.0	72.8	167.2	3.4	77.2	30.8	136.4	25.9	0
66539	423756	$e\gamma$	40.9	38.2	79.4	178.8	2.9	82.9	86.9	94.1	0.0	0
68352	362020	$e\gamma\gamma$	38.4	40.4	77.3	158.2	13.8	N.A.	70.1	131.6	0.0	1
68518	16652	$e\gamma$	52.2	56.9	116.	179.6	1.2	126.0	12.0	168.3	52.1	0
68570	429326	$e\gamma$	39.3	37.1	75.9	160.3	12.4	84.0	58.9	140.7	0.0	1
68915	158688	$ee\gamma$	46.5	26.2	72.9	177.5	10.5	83.3	133.7	48.7	0.0	1
69005	62946	$e\gamma$	85.0	71.0	160.	179.8	4.0	163.0	62.7	117.3	0.0	0
69709	299702	$e\gamma$	31.4	27.2	58.5	170.5	1.2	61.7	161.9	27.4	0.0	0
69831	56500	$e\gamma$	37.7	38.2	73.7	147.6	16.8	93.1	143.0	69.3	14.9	0
70605	262312	$e\gamma$	26.4	35.6	60.9	164.2	6.1	66.5	24.9	139.2	29.5	0
Not-Z^0-like $e\gamma$ Events with $\not\!\!E_t$												
Run	Event	Type	p_T^e	p_T^γ	$M^{e\gamma}$	$\Delta\phi^{e\gamma}$	$\not\!\!E_t$	$M^{e\gamma\not E_t}$	$\Delta\phi^{\not E_t e}$	$\Delta\phi^{\not E_t \gamma}$	p_T^{tracks}	N_{Jets}
63149	4148	$e\gamma$	33.2	41.9	21.4	33.2	39.8	28.6	10.3	43.5	31.8	1
64345	8574	$e\gamma$	33.1	37.5	33.3	44.2	54.6	135.2	152.9	162.8	0.0	0
66434	53860	$e\gamma$	26.3	27.6	32.8	69.9	37.0	93.9	144.4	145.6	0.0	0
67651	70517	$e\gamma$	52.1	30.9	16.3	22.4	112.7	98.0	113.4	135.8	0.0	2
68739	257646	$ee\gamma\gamma$	36.3	36.2	91.5	171.4	51.2	N.A.	6.3	165.0	33.8	2

Table 6: List of the 24 Not-Z^0-like $e\gamma$ events, separated into a subsample with $\not\!\!E_t$ and one without $\not\!\!E_t$. All momenta and energies are in GeV; angles are in degrees. The variable p_T^{tracks} is the clustered track momentum in the direction of the missing E_T. The number of jets refers to jets with uncorrected $E_T > 10$ GeV, where the jets cannot be one of the electrons or photons in the event. 'Without $\not\!\!E_t$' is short-hand for $\not\!\!E_t < 25$ GeV; 'With $\not\!\!E_t$' refers to $\not\!\!E_t > 25$ GeV.

12.3 $\mu\gamma$ Events

$\mu\gamma$ Events without $\not\!\!E_t$												
Run	Event	Type	p_T^{μ}	p_T^{γ}	$M^{\mu\gamma}$	$\Delta\phi^{\mu\gamma}$	$\not\!\!E_t$	$M^{\mu\gamma\not E_t}$	$\Delta\phi^{\not E_t\mu}$	$\Delta\phi^{\not E_t\gamma}$	p_T^{tracks}	N_{Jets}
60573	40406	$\mu\gamma$	53.7	53.4	115.5	164.8	13.6	133.0	80.8	114.2	0.0	0
63078	25391	$\mu\mu\gamma$	38.4	36.2	60.3	107.4	4.21	98.1	92.9	159.5	0.0	1
64061	65839	$\mu\gamma$	39.5	47.6	91.8	163.2	7.43	101.7	87.2	109.4	0.0	0
64358	264365	$\mu\gamma$	27.6	51.1	75.9	177.9	19.7	100.2	3.4	178.6	27.4	0
64421	203383	$\mu\gamma$	41.9	44.6	88.1	178.9	1.82	90.8	138.1	42.9	42.7	0
64934	125866	$\mu\gamma$	56.4	27.3	92.0	174.9	18.8	104.5	91.2	83.7	16.5	1
65494	48066	$\mu\gamma$	44.0	28.8	71.0	167.3	5.64	74.9	161.5	31.1	12.9	0
65894	15693	$\mu\gamma$	27.8	30.1	57.7	159.9	16.7	76.8	115.2	84.7	0.0	0
66411	475700	$\mu\gamma$	57.3	29.5	47.6	62.7	21.7	66.1	168.0	129.1	0.0	2
67494	700006	$\mu\gamma$	41.8	30.5	71.4	178.7	14.2	88.2	171.4	7.2	13.1	0
69464	118013	$\mu\gamma$	47.0	35.0	82.7	149.9	12.7	98.8	137.5	72.4	0.0	0
70577	406481	$\mu\mu\gamma$	45.2	38.6	74.8	122.3	2.15	84.6	84.6	152.9	0.0	0
70606	107771	$\mu\gamma$	55.9	45.5	134.7	172.6	11.7	148.2	155.5	31.7	0.0	0
$\mu\gamma$ Events with $\not\!\!E_t$												
Run	Event	Type	p_T^{μ}	p_T^{γ}	$M^{\mu\gamma}$	$\Delta\phi^{\mu\gamma}$	$\not\!\!E_t$	$M^{\mu\gamma\not E_t}$	$\Delta\phi^{\not E_t\mu}$	$\Delta\phi^{\not E_t\gamma}$	p_T^{tracks}	N_{Jets}
56934	62225	$\mu\gamma$	30.5	34.9	39.0	65.7	47.8	118.4	145.8	148.3	0.0	0
58760	6610	$\mu\gamma$	29.3	32.8	32.1	59.8	45.7	111.9	140.3	159.8	12.7	1
60972	72605	$\mu\gamma$	25.3	26.9	15.5	32.9	43.6	96.7	158.2	168.8	0.0	0
61334	57897	$\mu\gamma$	50.5	33.8	56.3	82.1	99.5	105.4	105.8	23.7	0.0	4
61548	881820	$\mu\gamma$	37.5	36.3	74.8	27.7	82.0	185.1	172.1	160.1	0.0	0
65277	541087	$\mu\gamma$	41.7	25.3	72.4	130.0	39.5	117.9	160.3	69.5	6.9	0
65390	16199	$\mu\mu\gamma\gamma$?	54.7	48.3	113.0	174.1	38.4	N.A.	125.8	48.2	61.3	3
65472	195753	$\mu\gamma$	30.2	27.0	42.4	47.9	54.0	121.9	158.5	153.4	71.7	0
65769	1449	$\mu\gamma$	44.7	26.3	18.3	24.5	26.5	104.3	177.5	152.9	6.6	2
66209	15413	$\mu\gamma$	32.3	46.1	61.5	84.9	54.9	143.4	128.9	146.1	0.0	0
67737	298286	$\mu\gamma$	39.0	26.9	55.3	116.9	39.7	117.6	139.4	103.5	0.0	0
67862	355699	$\mu\gamma$	26.1	29.8	36.8	36.0	49.8	116.9	166.9	157.0	0.0	0
67989	405914	$\mu\gamma$	42.4	25.8	66.3	159.5	35.0	98.4	178.5	19.0	0.0	0
68312	258160	$\mu\gamma$	44.8	31.0	80.1	163.8	25.7	107.4	163.1	33.0	0.0	0
69036	49611	$\mu\gamma$	71.6	142.1	208.0	171.0	64.4	305.3	29.9	159.0	79.7	2
69998	73762	$\mu\gamma$	39.3	43.1	82.4	106.3	41.8	144.8	114.9	138.6	0.0	2
70019	166983	$\mu\gamma$	56.7	39.1	107.5	153.7	25.1	134.7	144.8	61.3	0.0	0

Table 7: List of the 30 $\mu\gamma$ events, separated into a subsample without $\not\!\!E_t$ and one with $\not\!\!E_t$. All momenta and energies are in GeV; angles are in degrees. The variable p_T^{tracks} is the clustered track momentum in the direction of the missing E_T. The number of jets refers to jets with uncorrected $E_T > 10$ GeV, where the jets cannot be one of the photons in the event. 'Without $\not\!\!E_t$' is short-hand for $\not\!\!E_t < 25$ GeV; 'With $\not\!\!E_t$' refers to $\not\!\!E_t > 25$ GeV.

12.4 Final $\ell\gamma\not\!\!E_T$ Events

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[28] The $Z^0 \rightarrow \mu^+\mu^-$ and $W^\pm \rightarrow \mu^\pm\nu$ samples are described in *http://hep.uchicago.edu/cdf/ntuple_datasets.html.*

[29] These events are stored in PAD format in the files UCCDFL$DKA500:[DATA.CDF.ANA.JWB]JGHIBIT_JGHIBi.PAD, where i runs from 1 to 9, and JGHIBIT_WGHIBi.PAD, where i runs from 1 to 3.

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