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A Run II Event containing two photons, one positron and large $\not\!\!E_t$

R. Culbertson, H. Frisch, B. Heinemann, P. Merkel, D. Toback

Abstract

We report the observation of an event containing two photons, one positron and large $\not\!\!E_t$ in 8 pb^{-1} of Run II data. We discuss the properties of the event and the performance of the detector during the time it was recorded concluding that the event is well measured. We also give a rough estimate of the Standard Model expectation.

1 Introduction

We report the observation of an event containing two photons, one positron and large $\not\!\!E_t$ in 8 pb^{-1} of Run II data. The interest in events containing 2 photons, $\not\!\!E_t$ and leptons arises mainly from the observation of an event in Run I which contained two electrons, two photons and large $\not\!\!E_t$ [1], which inspired follow–up photon searches in several channels: $\gamma\gamma + X$ [1], $\gamma + l + X$ [2], $\gamma + b + X$ [3], $\gamma + \not\!\!E_t$ [4].

We give all the properties of the event showing that it is clean, both photons and the positron are well measured and the parts of the detector relevant for this event were all functioning. We also make a rough estimate of the Standard Model expectation.

2 Event Properties

The event was recorded on the 31st of January in a run of an integrated luminosity $L \approx 150$ nb^{-1}. The run number is 138233 and event number 2806190. A schematic display of the event and the CDF detector is given in Figures 1 and 2. It was found in the framework of a di-photon analysis based on Run I cuts on the basis of the large value of $\not\!\!E_t$.

The photon candidates and the positron The values of the properties used for the identification of photons are listed in Table 2 and compared to the cut values used in Run I exotics analyses [1]. Table 3 lists the quantities used for the positron identification and their respective Run I cut values.

Figure 4 shows the CES strip and wire clusters for the wedge that contains the EM clusters. The CES clusters in the strips and the wires are narrow, as expected for isolated electromagnetic particles (see also the χ^2 values in Table 4). The position of the positron CES cluster is consistent with that extrapolated from the track. All three objects have associated CPR clusters. Those CPR cluster positions are consistent with those measured in the CES as can be seen in Figure 5.

Figure 6a) shows the ratio of the energy measured in the CES to that measured in the CEM for electrons from $W \to e\nu$ candidates and for photon candidates. Also shown are the values measured for the two photons and the electron. Photon 2 and the positron have values as expected for electromagnetic showers. Photon 1 has a rather low value of 0.3 that is not likely according to the W candidate sample. However, photons tend to start showering at a larger radius and therefore have smaller clusters such that a larger tail at small values of E_{CES}/E_{CEM} is expected. We therefore also show the distribution of this quantity for photon candidates (Figure 6b)); however, this is not a clean test because half of the events entering this plot are expected to be π^0's in jets. At the present stage no definitive conclusion can be drawn.

We can exclude that either of the photons is a photo-tube spike since a significant energy was measured in both photo-tubes (see Table 4).

Cosmic rays can cause an electromagnetic shower in the electromagnetic calorimeter. If the cosmic ray does not coincide with the bunch crossing time the track of the cosmic muon is usually not reconstructed in the COT and its energy deposit can be misidentified as a photon; alternatively, a muon striking the calorimeter ¡ may not traverse the COT at all. The main discriminants against cosmic rays are the timing information of the TDC's in the hadronic calorimeter towers and the TOF system, and hits in the muon systems. Looking at the timing information, the 90 GeV photon leaves 3.6 GeV in the CHA and thereby has timing information in the hadron TDC's as expected. It is in time with the nominal beam crossing time. The 25 GeV photon leaves only 0.25 GeV in the CHA and no TDC hit is recorded. The efficiency of the hadron TDC's is only about 50% at 0.25 GeV in the CHA [5]. However, a cosmic ray will usually leave enough energy in one of the neighboring hadron calorimeter towers to allow detection by out-of-time energy. In total seven towers have TDC information and all of them are within 2 ns of the bunch crossing time (the resolution of the TDC time is about 3 ns for $E > 1$ GeV) [5].

There is also no indication in the Muon System of cosmic ray activity: no hits are present in the CMU , there are only a few scattered hits in the CMX and no muons stubs are found. In the CMP there is no hit present but only the bottom part was operated during this run.

There are normal hits in the TOF system for all the tracks, including the positron, although the positron is just outside the TOF fiducial region. There are three bars with hits not consistent with the event time ($>$ 5ns out of time). The three hits are listed in Table 1.

hit	x	y	z	ϕ	t(ns)
1	-113.5	82.0	-105.7	144^o	-20.33 ± 0.15
2	-120.2	71.8	-28.3	149^o	-28.32
3	26.3	-137.5	134.6	281^o	-9.39

Table 1: Positions and times of TOF hits out of time with the event. The event time is found from the tracks and is -2.028 ± 0.080 ns with conservative uncertainties.

The first two hits are separated by only two 4-cm bars, but have sufficiently different times such that they are probably not related. If we compute the distance between the hits and difference in time, the speed necessary to make hits 1 and 3 is 32.4 ± 0.6cm/ns, roughly consistent with the speed of light. The $2-3$ combination has a speed of 16.0 ± 0.2cm/ns. The 1-3 path does not cross or even come near to the EM clusters in the event. At the point where it comes closest in ϕ it is not close (0.5 to 0.8 radians), and it is at the opposite side of the detector in z.

From scanning events, we see that it is common to have hits out of time, and it looks reasonable to have random pairs of hits close to the speed of light. This is still under investigation, and we hope to add quantitative results.

We can say that even if this is a cosmic ray it did not fire any TDC in the calorimeter or COT hits, and is not geometrically consistent with any of the EM clusters [6].

Run I cut value	Photon 1	Photon 2
≤ 1 3D tracks, $P_T < 1$ GeV	0	0
$\chi^2_{Avg} < 20$	4.26	2.26
$14 < \lvert Z_{strip} \rvert < 230$ cm	131.5 cm	-134.6 cm
$X_{wire} < 21$ cm	1.9 cm	9.3 cm
2nd Strip,Wire E sliding cut	$E = 0$	$E = 0$
Had/EM $< 0.055 + 0.045E/100$	0.04	0.01
${E^{Iso}}_T/E_T < 0.10$	0.0	0.01
$\Sigma P_T(\Delta R = 0.4) < 5.0$	0.0	0.0

Table 2: Quantities used for particle identification of the two photons in comparison to the Run I cut values.

The Tracking The event has a total of seven tracks reconstructed (in version 4.3.1 of the CDF software) with $P_t > 400$ MeV. Five of those seven tracks can be considered

Run I cut value	Positron
$E > 25$ GeV	48.5 GeV
Had/EM< 0.05	0.0
$E/P < 1.8$	1.04
$\|\Delta X_{track-strip}\| < 1.5$ cm	0.24 cm
$\|\Delta Z_{track-strip}\| < 3.0$ cm	0.72 cm
Lshr< 0.2	0.13
Strip $\chi^2 < 10.0$	5.5
$\|\Delta Z_{track-vertex}\| < 5.0$ cm	0.23 cm
$\|Z\|$ vertex< 60.0 cm	13.7 cm
CES fiducial	Yes
${E^{Iso}}_T/E_T < 0.1$	0.01
$\Sigma {p^{Iso}}_T/p_T < 0.1$	0.0

Table 3: Quantities used for particle identification of the positron in comparison to the Run I cut values.

as "good" as they have segments in at least three axial and three stereo COT superlayers. All those five tracks originate from the same z-vertex position and their average Z_0 position is 13.66 cm, see Figure 7. This value is taken to be the z-vertex position and used to compute the final E_t values of the electromagnetic objects (see Table 4).

All these five tracks have also Silicon hits attached to them. Apart from the positron track there is no other track seen with $P_t > 1.5$ GeV. We also see no significant hit activity in either the COT or the SVX in the direction of either of the two photons. There is no indication of an inefficiency in the tracking algorithm from this event.

The $\not\!\!E_t$ The raw value of $\not\!\!E_t$ measured taking into account only the calorimeter energies is 38.8 GeV and $\phi_{\not\!\!E_t} = 302^o$.

To check the robustness of the $\not\!\!E_t$, we compare the $\not\!\!E_t$ calculated using only the energies of the two photons and the positron (the "clustered $\not\!\!E_t$) with the raw value above. The clustered $\not\!\!E_t$ is 41.2 GeV pointing at 291.5^o in good agreement with the raw value. This shows that the $\not\!\!E_t$ is dominated by the clustered objects in the event.

Looking at the event topology it is also obvious that there is genuine $\not\!\!E_t$ in this event since the two photons and the positron are all in one hemisphere in azimuth. The $\not\!\!E_t$ does not point opposite to any of the electromagnetic clusters, which would indicate an origin from a cosmic ray or poor calorimetric energy measurement.

In summary all three electromagnetic objects are clean and the $\not\!\!E_t$ is well measured. None of the measured variables of either of them is at the edge of any Run I cut value. In the context of Run I photon analyses the event would have fulfilled the selection of the

quantity	photon 1	photon 2	positron
E_t /GeV ($z_v = 0$ cm)	88.1	25.1	48.5
η ($z_v = 0$ cm)	0.66	-0.68	-1.0
ϕ /deg	66.9	199.6	233.1
N_{track}	0	0	1
Track P_t /GeV	–	–	44.9
Iso4 /GeV	0.0	0.30	0.49
SumPt4 /GeV	0.0	0.0	0.0
Had/EM	0.04	0.01	0.0
CES Avg Chi2	4.26	2.26	–
CES Strip,Wire Chi2	$0.5, 8.0$	$1.8, 2.7$	$5.5, 5.1$
CES local x /cm	1.90	9.29	-1.77
CES z /cm	131.52	-134.61	-215.69
CES Strip,Wire E /GeV	$33, 31$	$19, 18$	$76, 82$
CES 2nd Strip,Wire E /GeV	0	0	0
CPR Q /fC	1421.17	4123.23	61880.18
tower ieta	31	20	17
tower iphi	4	13	15
HTDC time /ns	2	–	–
PMT0 /GeV	113.0	34.7	54.9
PMT1 /GeV	101.5	27.2	57.5
E_t^c /GeV ($z_v = 13.7$ cm)	91.2	24.2	46.8
η^c ($z_v = 13.7$ cm)	0.60	-0.73	-1.04

Table 4: Further information on the two photons and the positron.

$\gamma\gamma + X$ [1] and those in the $\gamma + l + X$ [2] search.

Invariant Masses The 4-vectors of the two photons and the positron and the transverse components of the $\not\!\!E_t$ are summarized in Table 5. We can reconstruct the invariant and transverse masses for all combinations of objects in this event. They are given in Table 6.

Note that the transverse mass of the positron, photon 2 and the $\not\!\!E_t$ is found to be 73 GeV which is consistent with the transverse mass of a W-boson. This is consistent with the hypothesis that photon 2 originates from hard Bremsstrahlung off the electron. In Table 6 we also list the invariant mass values of all combinations of objects under the hypothesis that positron, photon 2 and the $\not\!\!E_t$ indeed arise from a W. There are two solutions for the P_z of the neutrino: $P_z = -11$ GeV or $P_z = -82$ GeV. We choose the solution where the neutrino has the lower absolute value of the longitudinal momentum $P_z = -11$ GeV, a quite reasonable value for the W hypothesis.

The transverse mass of just the positron and the $\not\!\!E_t$ is 49 GeV and is thus also consistent with the transverse mass of a W-boson.

object	P_x (GeV)	P_y (GeV)	P_z (GeV)	E (GeV)	ϕ (^{o})	η	E_t (GeV)
γ_1	35.8	83.9	58.4	108.3	66.9	0.6	91.2
γ_2	-22.9	-8.1	-19.5	31.0	199.6	-0.73	24.2
e^+	-28.1	-37.4	-58.3	74.7	233.1	-1.04	46.8
$\not\!\!E_t$	20.6	-32.9	—	—	302.0	—	38.8

Table 5: The 4-vectors of the two photons and the positron.

objects	Invar. mass (GeV)	Invar. mass $M_{e\gamma\not E_t} = M_W$	P_t (GeV)
2 photons	110	—	77
photon 1 and positron	177	—	47
photon 2 and positron	22	—	61
2 photons and positron	209	—	41
objects	**Transv. mass (GeV)**	**Inv. mass $M_{e\gamma\not E_t} = M_W$**	**P_t (GeV)**
positron and $\not\!\!E_t$	48	59	71
photon 1 and $\not\!\!E_t$	105	119	76
photon 2 and $\not\!\!E_t$	48	50	41
positron, photon 1 and $\not\!\!E_t$	174	221	31
positron, photon 2 and $\not\!\!E_t$	71	80	84
2 photons and $\not\!\!E_t$	144	169	54
2 photons, positron and $\not\!\!E_t$	201	252	7

Table 6: Invariant and transverse mass values for all possible combinations of the four objects photon 1, photon 2, positron and $\not\!\!E_t$. The third column is the invariant mass calculated with the constraint that the mass of the positron, photon 2 and neutrino are constrained to the W mass resulting in $P_z^\nu = -11$ GeV. The fourth column lists the resulting P_t values.

3 Detector Performance

The event relies mainly on the stable operation of the central and plug calorimeters, the central ShowerMax and the COT. In order to make sure that these detectors were operating reliably we did a number of detailed checks including looking at the standard validation histograms (made during `Production`) in run 138233 in which the event was recorded:

- Calorimeter and central ShowerMax: The E_t weighted occupancy of the PMT's in the electromagnetic and hadronic sections of the calorimeter is shown in Figure 8 for Minimum Bias events. All PMT's were fully operational and the distributions are symmetric in both η and ϕ. This gives us confidence that no additional calorimetric object (e.g. a second electron) escaped detection and the $\not\!\!E_t$ is not caused artificially.

The performance of the CEM and CES can be judged from the plots in Figure 9. Several distributions are shown for high E_t electron candidates from the stream A dataset. Neither the η nor the ϕ distribution show any indication of an unexpected inefficiency. The distributions of the other quantities used for the electron identification (E/P, $Lshr$, ΔX, ΔZ) look sensible.

- COT: The performance of the COT in this run can be judged from the validation plots in Figure 10. The ϕ distribution of all tracks is flat as expected. Also, no holes are seen in the plot showing ϕ versus η. We conclude that the COT was fully operational.

  We found only one unusual distribution in one of the validation histograms, namely the z_0 of good tracks which shows a very odd spike (see Figure 11). However, this seems to be a bug in the histogram filling rather than a real problem in the data: This spike is not seen for "all" tracks. Since the number of "good" tracks - which are by definition a subset of "all" tracks - in the peculiar spike exceeds the number of all tracks in the corresponding bins we think that the z_0 distribution of "good" tracks can not be trusted. The fact that the z_0 and VxPrim z-vertex distributions from all events with a photon trigger show no such bizarre behavior gives us additional confidence.

- SVX: The positron passed through SB3W8, which was integrated and biased for the entire run and had all five SVXII ladders functioning. The high-Et photon passed through SB4W2 if extrapolated from the reconstructed vertex. All five layers of SVXII of this wedge were integrated, biased and functioning well. Finally, the lower-Et photon passed through SB3W7, which had all SVXII but the layer 2 ladder integrated. The positron passed an operated segment of L00, but not of ISL, reconstructed hits can be found in L00 close to the track. The two photons did not cross integrated parts of L00 or ISL. The positron track has three silicon hits attached (layers 0, 1 and 3 of SVXII). In the SVXII wedge that is passed by photon A, three good hits (layers 0, 1, 4) are reconstructed, but they are more than 5^o in ϕ away from the extrapolated photon path. For photon B there are more hits reconstructed, but only one good one (≥ 2 strips, $Q \geq 10$ ADC) is found within 5^o of the extrapolated photon path (in layer 1 of SVXII).

- e-Log: We read the e-Log and found no entries which would indicate any significant instabilities during the run which affect the sub-detectors used here.

- Muon-System: The HV of the CMU and the CMX systems was on during the entire run while the CMP was only partially operating (bottom part).

- TOF: The TOF was fully operational in this run [6].

- Trigger: The event was taken with the trigger table PHYSICS_0_03_v-25. The trigger bits that were set for this event are given together with their names in Table 7. All the L1 and L2 trigger bits that are expected to be set are set indeed. However, not all L3 trigger bits are set as expected: the DIPHOTON_12_ISO, DIPHOTON_18, PHOTON_25_ISO and ELECTRON_CENTRAL_18 triggers have not fired.

This is explained by two major problems at L3 [8]:

- All the three photons rely on a CesClusterCollection. Due to a bug this was only made if a CdfTrackCollection existed. Since the tracking is not run in the photon path it was pure luck whether it was there or not and subsequently many events were not triggered. This bug was already discovered and fixed beginning of February [7].
- The second bug explains why the ELECTRON_CENTRAL_18 bit was not set. When the event got to this prerequisite it already had a CdfEmObject in the event since the event had already run through the photon triggers. This CdfEmObject had, however, no track since the tracking is not run in the photon paths. In the electron path the tracking is run but rather than creating a new CdfEmObject using this track as well it just uses the old one which of course does not have a track. Therefore it fails the track cut. The basic problem is that whether or not an event passed the L3 trigger bit depended on whether or not it survived the prerequisites of other triggers before.This major problem was only discovered now due to this event and is being fixed now [8]. This problem caused e.g. an overall inefficiency of $\approx 10\%$ for high E_t electrons.

3.1 Standard Model Expectation

To compute a rough estimate of the number of SM events to expect with this signature, we find all the numbers we need are provided in the work on the $ee\gamma\gamma\not{E}_t$ event [1] (primarily Sections IIIC and V of the PRD). Similar numbers were also determined in [2]. Note, that this assumes that the Run II detector and reconstruction efficiencies are similar to Run I.

These numbers assume 25 GeV thresholds for all objects. Note that one photon after correction for the vertex falls just below the 25 GeV threshold. However, we think that the numbers for the expectation we quote are still conservative since we ignore the fact that the high E_t photon has a much higher transverse energy of 90 GeV (see below). Each object in turn can be considered either real or fake, and fake photons come from jets passing photons cuts, or electrons which do not have a reconstructed track either because it curved away after a hard bremsstrahlung or was simply lost due to inefficiency in the track reconstruction.

For simplicity we will compute the expected number of events in the Run I luminosity, 85pb^{-1}, and then scale it. The backgrounds will be:

- Real $W\gamma\gamma \to e\nu\gamma\gamma$ production. This was found from data observations of 4 $e\gamma\not{E}_t$ events (in agreement with Pythia $W\gamma$ production and MADGRAPH $W\gamma$) and an estimate of the rate of additional real photons, $(6\pm4)\times10^{-4}$ (from 2 $ee\gamma$ events over 2431 ee events). This yields $2 \pm 2 \times 10^{-3}$ events expected in 85 pb^{-1}. Since the ee

events could radiate more than a single electron, this is a conservative estimate. The W observations could also be used to estimate the rate of additional photons. In this case, there are 4 $e\gamma\not{E}_t$ events with 58,000 $e\not{E}_t$ events for a rate of an additional photon of 7×10^{-5} for a prediction of $(3 \pm 2) \times 10^{-4}$ events in 85 pb^{-1}.

- Real $W\gamma \rightarrow e\nu\gamma$ production, with an additional jet that fakes a photon. The observation was 4 events, times a probability if an additional jet (central, $E_t >$ 25 GeV), 0.026, times the probability of that jet passing the photon cuts, $(1 \pm 0.2) \times 10^{-3}$, for an expectation of $(1 \pm 0.5) \times 10^{-4}$ events.

- Real $WZ \rightarrow e\nu ee$ production, with two electrons losing tracks. In 113 pb^{-1} of Run I data, we expected 0.6 events [9], which scales to 0.45 events in 85 pb^{-1}. With a lost-leg rate of $(1.9 \pm 0.3)\%$ applied twice, and then increased by a factor of 3 to account for the combinations of which electrons lost their tracks, we find an estimated background of $(5 \pm 1) \times 10^{-4}$.

- Real $W \rightarrow e\nu$ production with two jets both of which fake a photon. This can be found as 58,000 $W \rightarrow e\nu$ events times the probability of an additional jet and fake photon applied twice is $(1 \pm 0.3) \times 10^{-5}$ events.

- Real $Z\gamma \rightarrow ee\gamma$ production, with one electron track lost and fake $\not{E}_t$. The expectation was (0.1 ± 0.1) events before the $\not{E}_t$ cut times a fake $\not{E}_t$ rate of $(4 \pm 1) \times 10^{-3}$ for an expectation of $(4 \pm 4) \times 10^{-4}$ events.

- Real $Z \rightarrow ee$ production, with one electron track lost, fake $\not{E}_t$, and a jet faking a photon. The Run I sample had 3083 events, times the lost leg rate of 1.9$\pm$0.3%, times $(3 \pm 0.6) \times 10^{-5}$ for the additional fake photon, times a fake $\not{E}_t$ rate of $(4 \pm 1) \times 10^{-3}$ for an expectation of $(7 \pm 3) \times 10^{-6}$ events.

Even though there is no evidence for a second vertex, and the one vertex has little activity, we can estimate the probability to observe overlapping events. The probability for observing a $\gamma\gamma$ event overlapping a W event is found from the number of $W \rightarrow e\nu$ events (58,000), the number of $\gamma\gamma$ events (218), and the number of crossings in Run I (3×10^{12}) and is $58000 \times 218/3 \times 10^{12} = 4 \times 10^{-6}$. The probability for a $W\gamma$ overlapping a γ event is found from the number of $W\gamma$ events (4), the number of γ events (300,000) and is roughly $4 \times 300000/3 \times 10^{12} = 4 \times 10^{-7}$. For a $W\gamma$ event overlapping a γ from cosmic (using 3181 $\gamma\not{E}_t$ events for cosmic rays) the expectation is $4 \times 3181/3 \times 10^{12} = 4 \times 10^{-9}$.

The total Standard Model expectation is primarily due to the real $W\gamma\gamma$ production and comes to $(3 \pm 2) \times 10^{-3}$ events for 85 pb^{-1} at $\sqrt{s} = 1800$ GeV.

A run of Pythia $W\gamma$ production at 1800 and 2000 GeV center–of–mass shows that the acceptances are the same to 3% and the cross section increases by 13%. We scale the total to $(3.4 \pm 2.3) \times 10^{-3}$ events for 85 pb^{-1} and round to $(3 \pm 2) \times 10^{-3}$.

The uncertainties quoted here are only due to the limited statistics in the Run I data used to make the estimates. No systematic uncertainties have been estimated at this point but the methods are solidly based in data measurements.

Considering we have analyzed only about 8 pb^{-1} so far, we have to scale this down by a factor of 10 to $(3 \pm 2) \times 10^{-4}$ for the background in Run II only and the probability of observing one event is about the same number. If we consider the $ee\gamma\gamma\not{E}_t$ event to be an $e\gamma\gamma\not{E}_t + X$ event, the same as this one, then the probability of observing two events in 93 pb^{-1} is approximately 1×10^{-5}. This probability is larger than the 1×10^{-6} estimated for the $ee\gamma\gamma\not{E}_t$ event alone, when counting the plug cluster as an electron.

The striking feature of this event is the high transverse energy of the high E_t photon which is unusual for the main Standard Model background events. This is seen in Figure 12 where we show the `COMPHEP` Monte Carlo event generator [10] prediction for the photon P_t dependence of the cross section in $W\gamma$ production. In general the photons can be radiated off the decay-electron, the W and the incoming quarks. The radiation off the decay-electron dominates up to values of values $E_t \approx M_W/2 \approx 40$ GeV. At larger E_t values this contribution becomes negligible explaining the sudden decrease of the cross-section at $E_t \approx 40$ GeV. Therefore it is interesting to note that the Standard Model expectation for events with a photon with $E_t > 40$ GeV is typically about two orders of magnitudes smaller than that for observing one with a photons above $E_t > 25$ GeV which we quote above.

4 Conclusions

We have discussed an event containing 2 photons, 1 electron and large $\not{E}_t$ recorded in the Run II CDF detector. We have demonstrated that the detector components which are important for this kind of event have operated reliably. All objects in this event are well measured and the event passed all run I cut values for the identification of photons and electrons.

The invariant and transverse masses of all different combinations of objects in the event are presented. The transverse mass of the electron, low E_t photon and $\not{E}_t$ is consistent with the W-boson mass.

We also present a rough estimate of the Standard Model expectation based on Run I analyses. We find an expectation of about 3×10^{-4} for a luminosity of 8 pb^{-1}.

References

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See also CDF notes 4582, 4304, 4256, 4183, 4121, 3917, 3892, 3850, 3726, 3571, 3556, 3456. The PRD is the best overview.

[2] F. Abe *et al.*, *A Search for New Physics in Photon-Lepton Events in Proton-Antiproton Collisions at sqrt(s)= 1.8 TeV*, to be submitted to Phys. Rev. Lett; submitted to Phys. Rev. D. (CDF Notes 5819 and 5569) See also CDF notes 5482, 5481, 5330, 4977, 4976, 4580, 3851, 3555.

[3] F. Abe *et al.*, *Searches for New Physics in Events with a Photon and b-quark Jet at CDF*, submitted to Phys. Rev. D. (CDF Note 5450.) See also 4748, 4155, 3572.

[4] T. Affolder *et al.*, *Limits on Extra Dimensions and New Particle Production in the Photon and Missing Energy Signature*, to be Submitted to Phys. Rev. Lett. (CDF note 5765.)
See also 5725, 5614, 5460.

[5] M. Cordelli *et al.*, CDF Note 5856, *Timing Calibration of CDF hadron Calorimeters*

[6] Personal communication with M. Jones

[7] Personal communication with M. Riveline and D. Waters

[8] Personal communication with R. Wagner and D. Waters

[9] G. Apollinari *et al.*, CDF Note 3549, *Search for WZ and ZZ Production at CDF*

[10] A. Pukhov *et al.*, *COMPHEP: A package for evaluation of Feynman diagrams and integration over multiparticle phase-space. User's manual for version 33*, HEP preprint hep-ph-9908288

	Trigger bit	Trigger name
Level 1	0	L1_EM8_&_CLC_v-1
	2	L1_EM8_&_MET15_&_CLC_v-3
	4	L1_CEM4_PT4_v-2
	8	L1_CEM8_PT8_v-2
	16	L1_JET10_&_SUMET90_&_CLC_v-1
	18	L1_MET25_&_CLC_v-1
	20	L1_JET10_v-1
Level 2	2	L2_AUTO_L1_CEM8_PT8_v-1
	6	L2_AUTO_L1_JET10_&_SUMET90_&_CLC_v-1
	8	L2_AUTO_L1_MET25_&_CLC_v-1
	16	L2_CEM16_PT8_v-2
	17	L2_CEM8_PT8_v-4
	20	L2_EM12_ISO_v-1
	23	L2_EM18_ISO_v-1
	25	L2_EM20_ISO_v-1
	26	L2_EM40_v-1
	27	L2_EM70_v-1
	28	L2_JET15_v-1
	32	L2_JET90_v-2
	61	L2_THREE_EM10_v-1
	64	L2_TWO_EM10_ISO_v-1
	65	L2_TWO_EM16_v-1
Level 3	53	HIGGS_MULTI_JET_v-1
	73	MET35_&_TWO_JETS_v-2
	75	MET_10_L1_MET25_v-2
	103	SUPER_PHOTON70_L2_EM_v-1
	104	SUPER_PHOTON70_L2_JET_v-1
	117	TRIPHOTON_v-3
	123	ULTRA_PHOTON50_v-2
	127	W_NOTRACK_v-4

Table 7: Trigger bits and trigger names for all three trigger levels for this event.

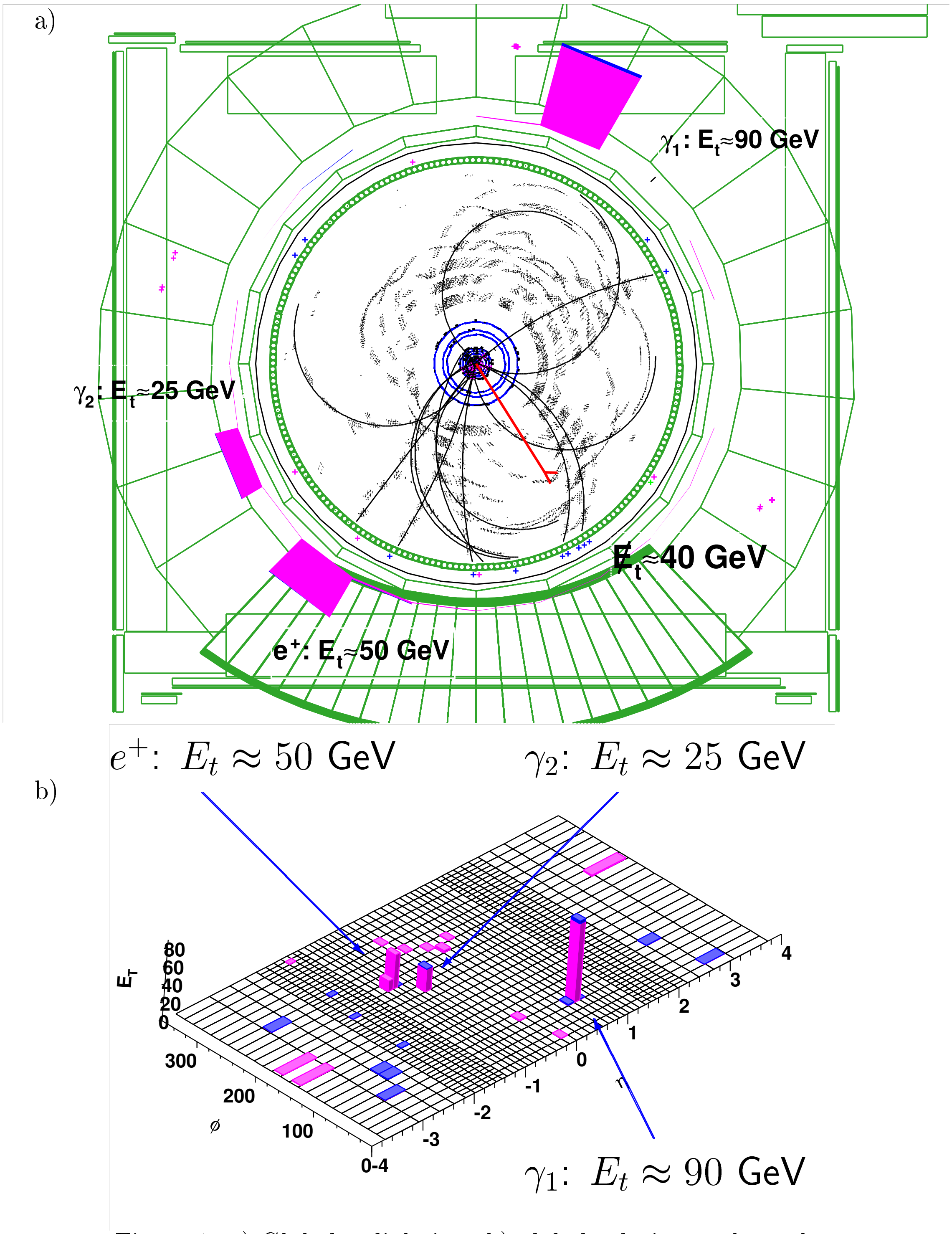

Figure 1: a) Global radial view, b) global calorimeter lego plot.

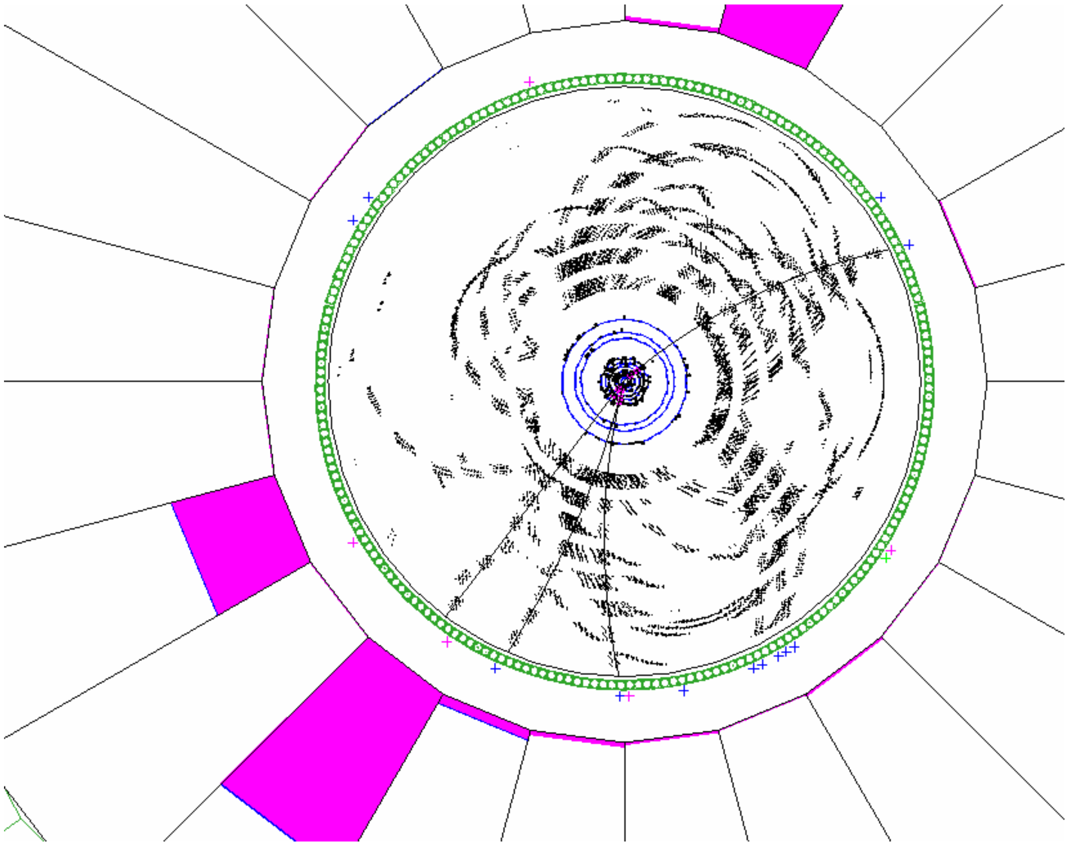

Figure 2: Radial view including calorimeter, ToF, COT and Silicon detectors. Only tracks with a transverse momentum larger than 1 GeV are displayed.

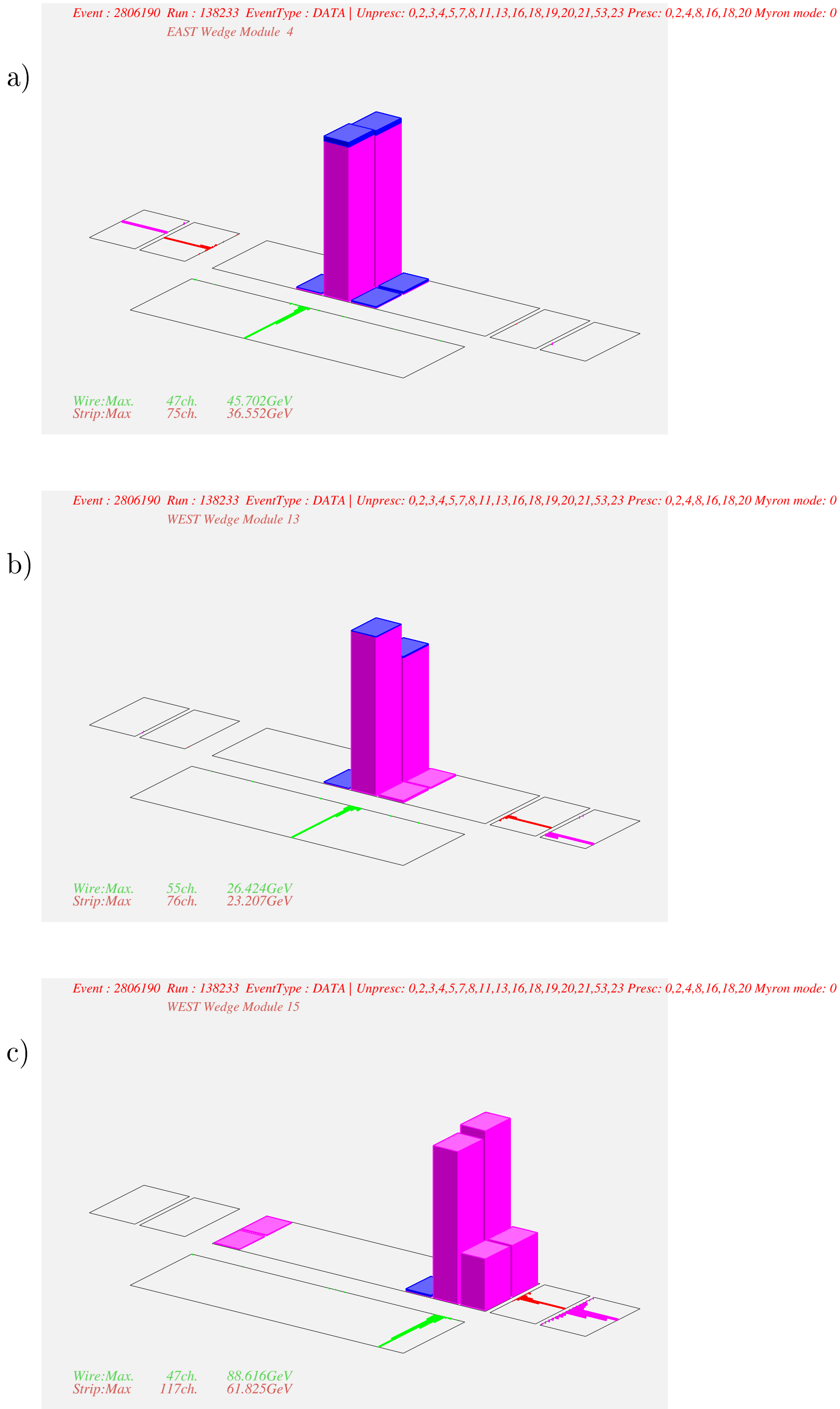

Figure 3: Schematic view of the calorimeter cluster together with its CES strip and wire and the CPR information: a) for photon 1, b) for photon 2, c) for the positron.

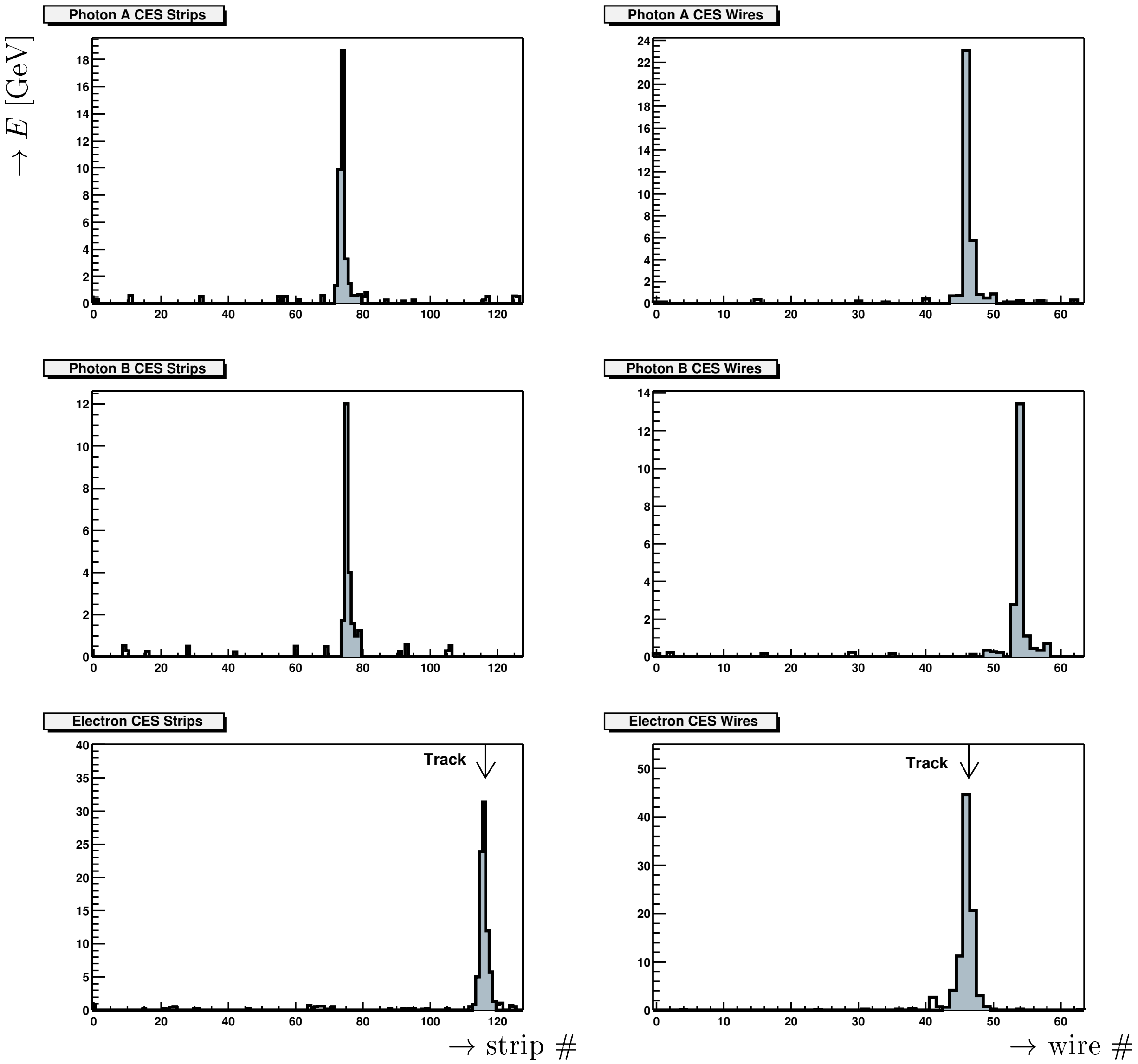

Figure 4: The CES strip energies for wedges which contain the three EM clusters. The wires on each side of the detector are split in the z dimension, 0-31 are the low $|z|$, 32-63 are the high $|z|$. For the positron the arrows indicate the extrapolated position of the measured track.

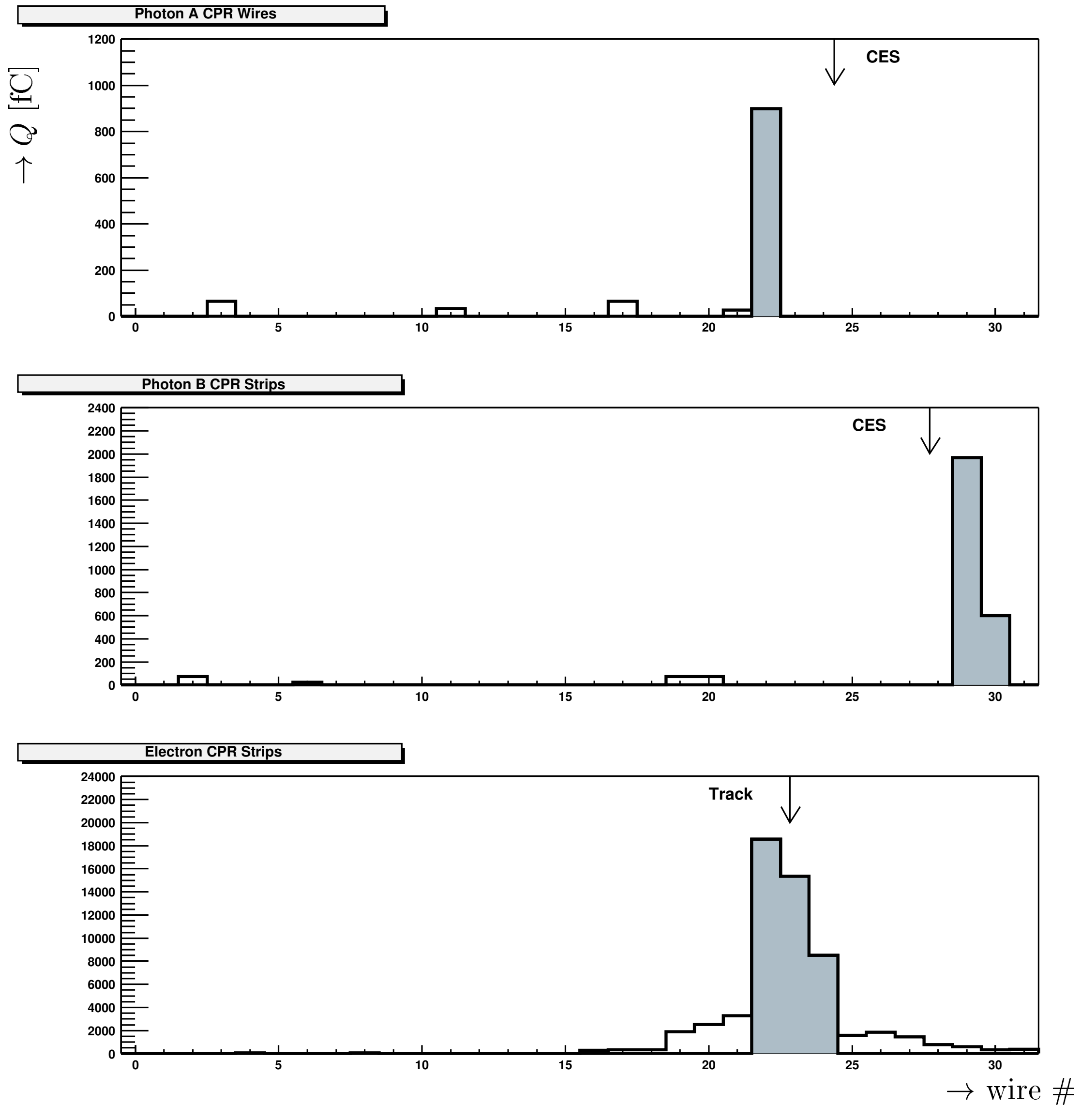

Figure 5: The CPR wire energies for the three EM clusters. The wires on each side of the detector are split in the z dimension, 0-15 are the low $|z|$, 16-31 are the high $|z|$. For comparison the extrapolated CES and track positions are indicated by the arrows. The open histogram shows all CPR wires and the dark one those which are clustered.

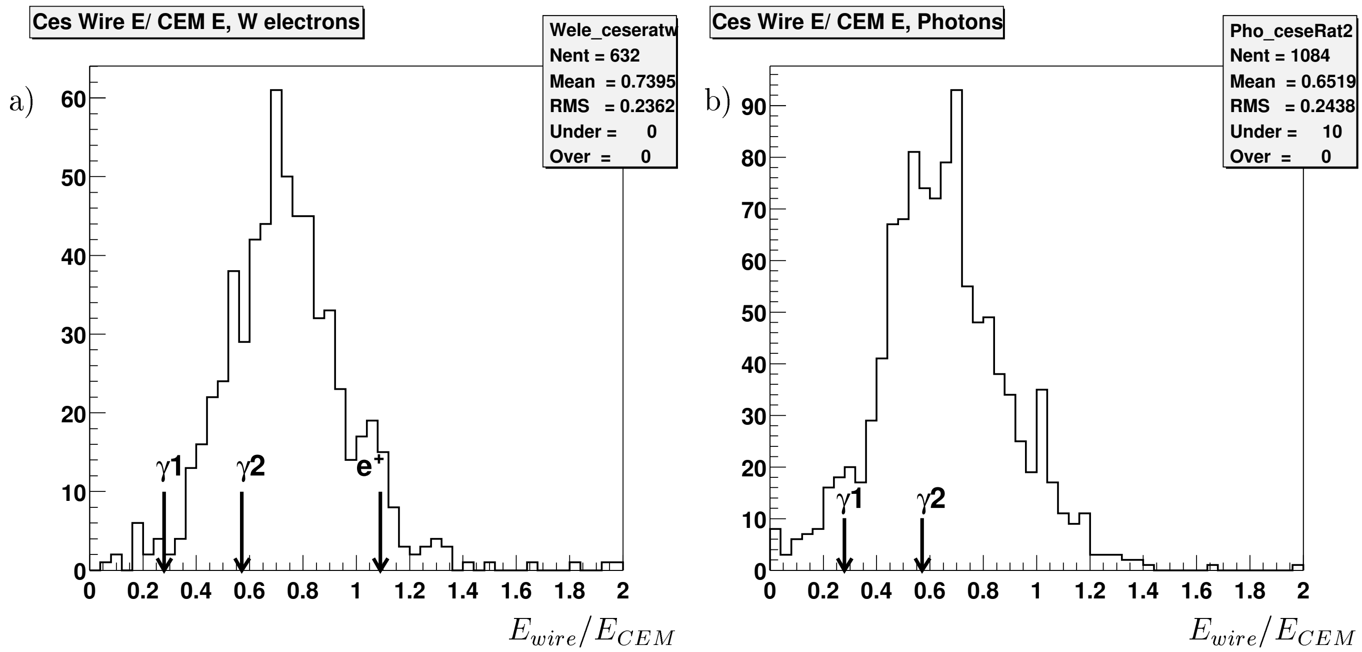

Figure 6: a) The ratio of the energies measured in the CES and the CEM for electrons in W candidate events. The arrows are the values measured for the three electromagnetic objects in this event. b) The ratio of the energies measured in the CES and the CEM for photon candidate events. Indicated are the values measured for the two photons in this event.

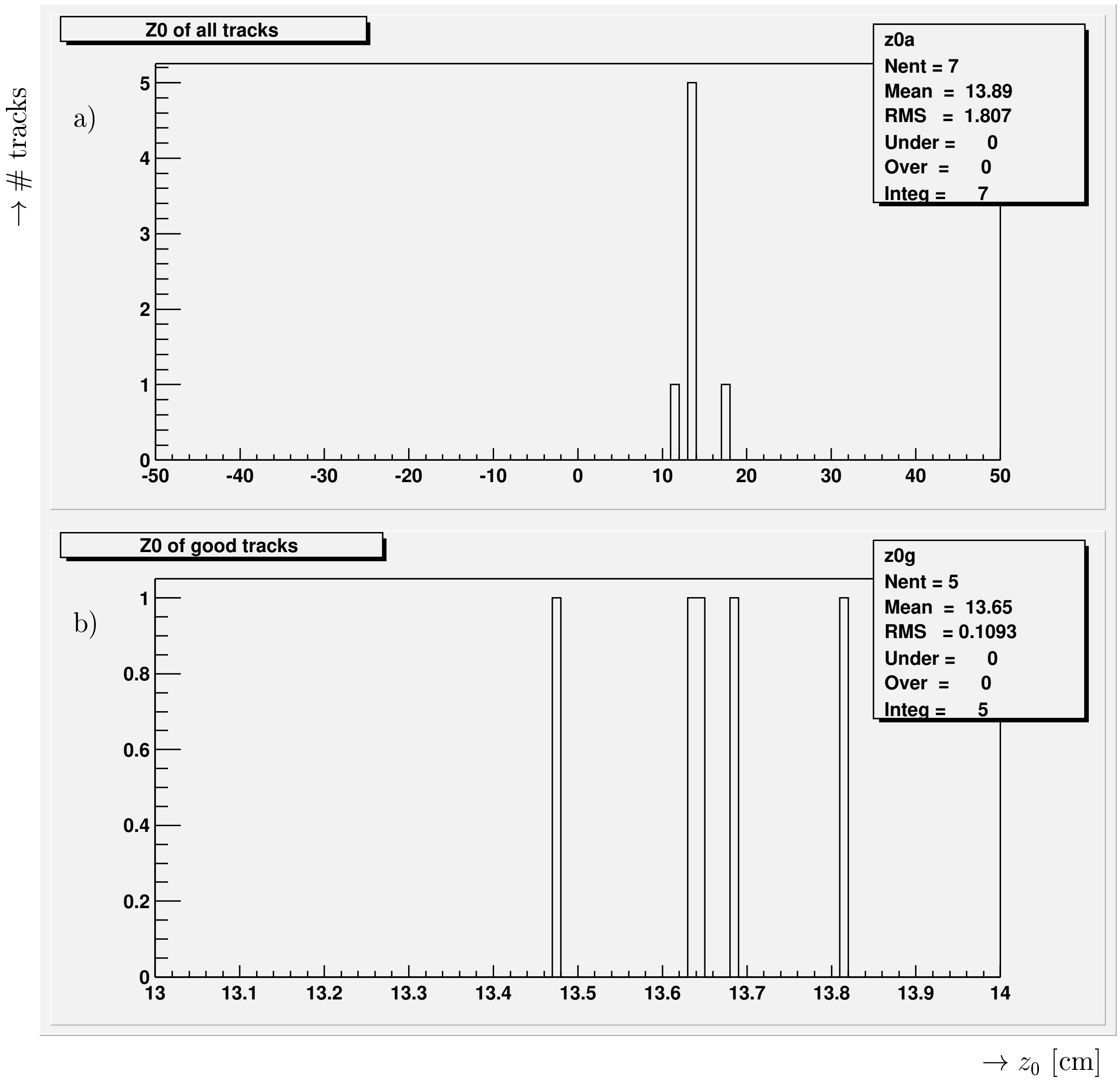

Figure 7: The measured z position for a) all seven tracks above 0.4 GeV and b) only for tracks considered as good tracks.

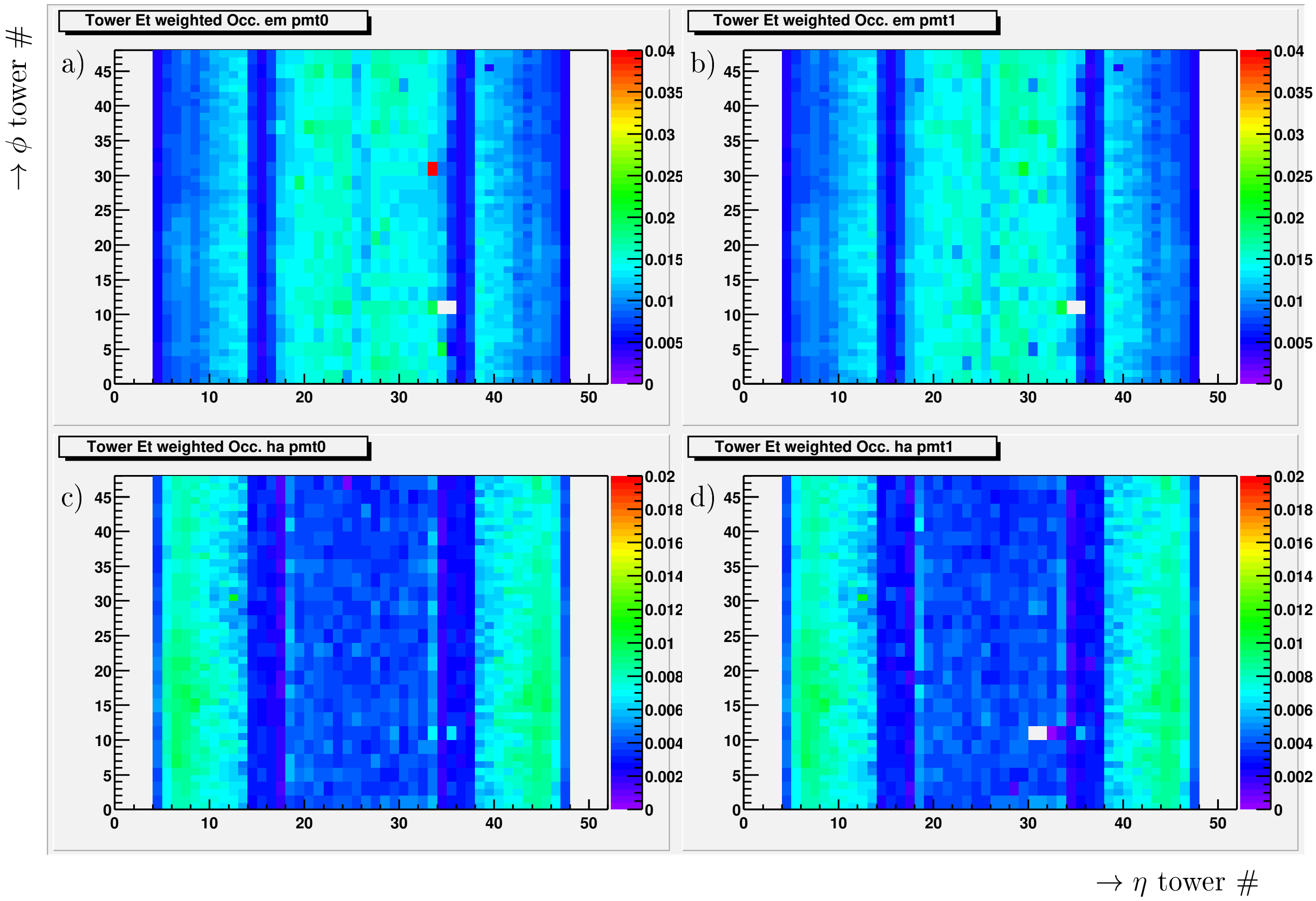

Figure 8: Calorimeter tower occupancy for minimum bias events in this run: a) electromagnetic calorimeter, b) electromagnetic calorimeter, c) hadronic calorimeter, d) hadronic calorimeter.

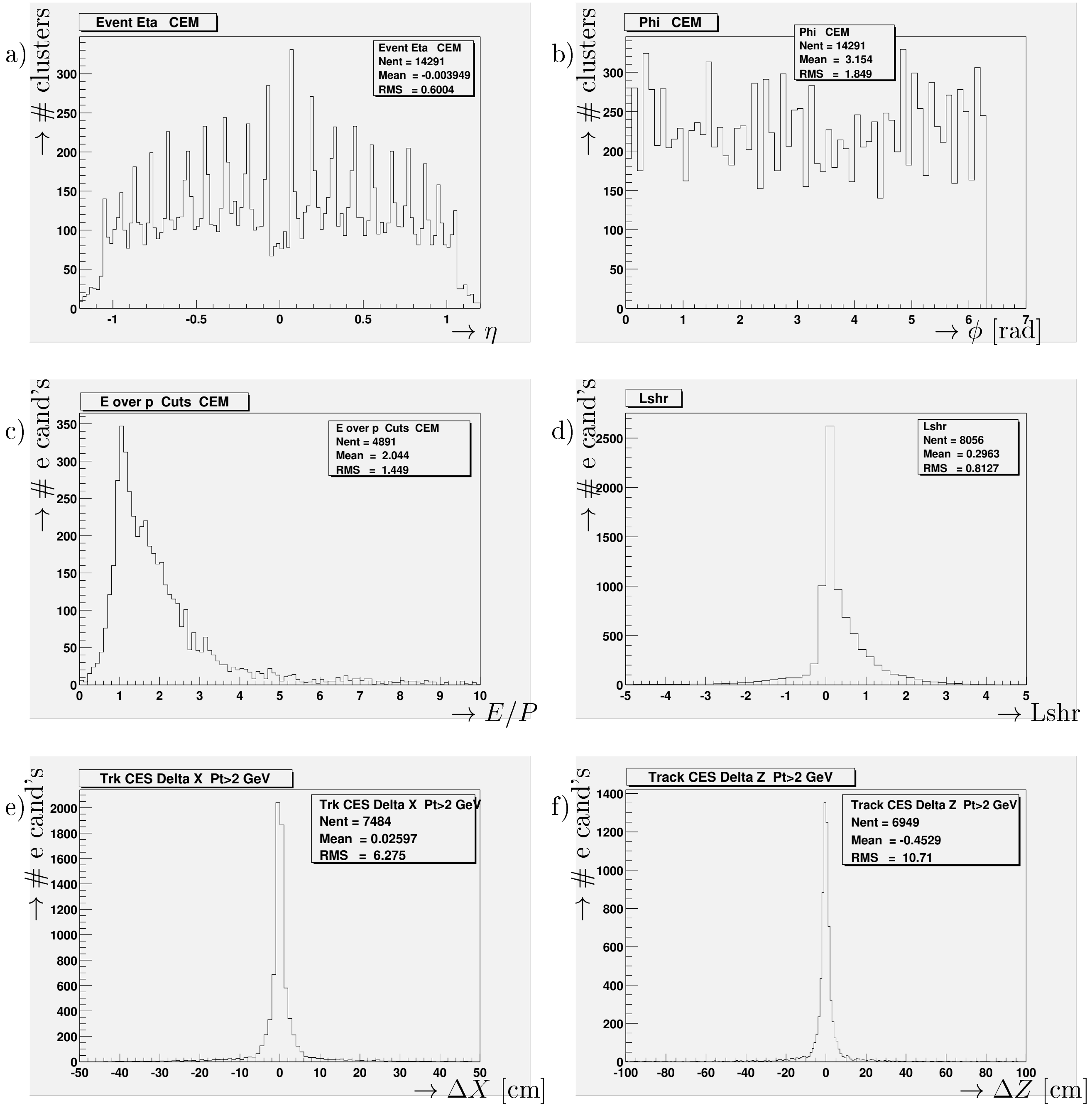

Figure 9: Electron candidates in the CEM for run 138233 in stream A: a) η, b) ϕ, c) E/P , d) $Lshr$, e) track - CES matching ΔX, f) track - CES matching ΔZ.

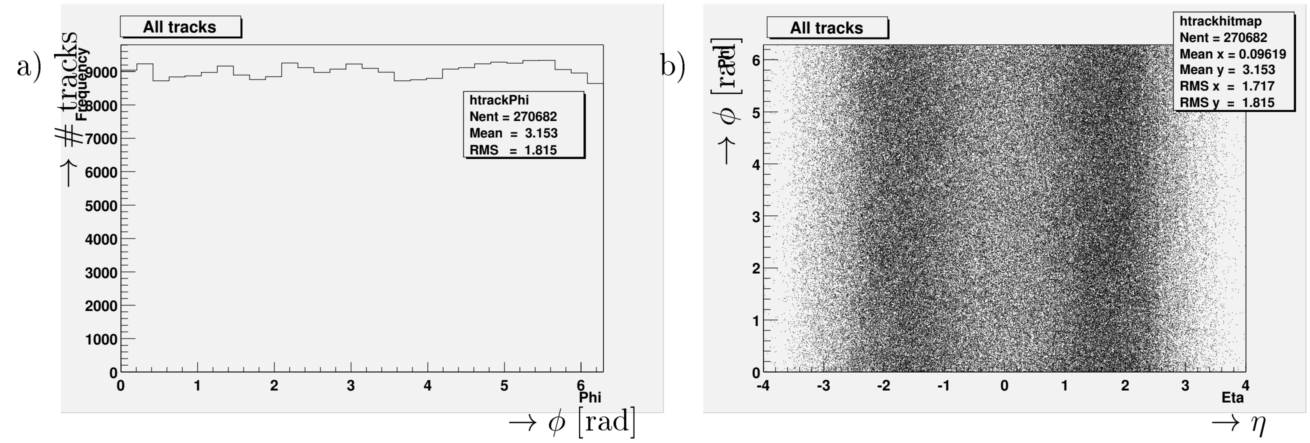

Figure 10: COT tracking plots for run 138233 in stream A: a) ϕ of all tracks, b) ϕ vs η for all tracks.

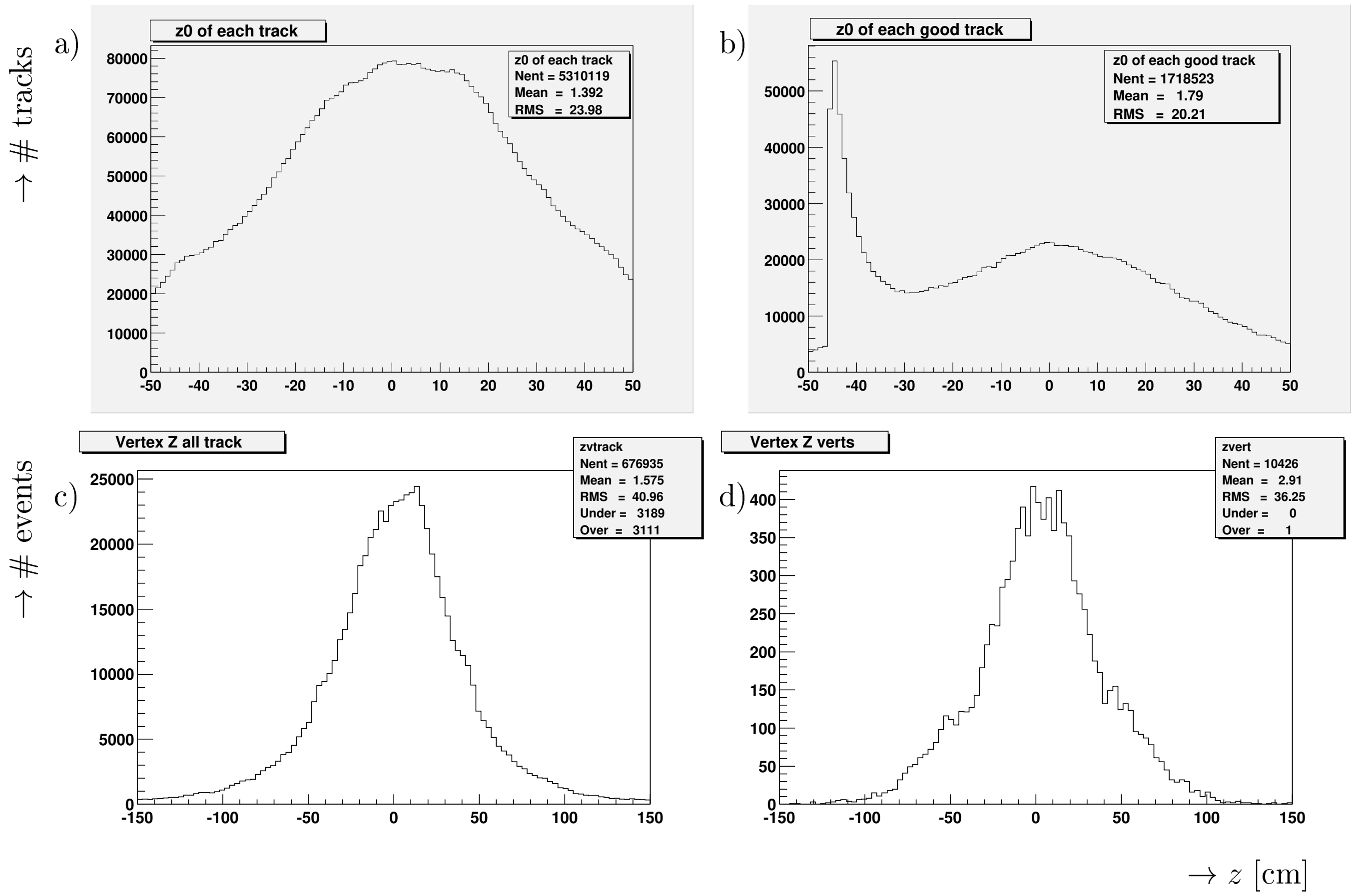

Figure 11: The z vertex distribution for run 138233 in stream A: a) all tracks of all events in stream G, b) only good tracks out of all stream G events were used to reconstruct the vertex, c) all tracks of all inclusive photon events, d) only good tracks of all inclusive photon events.

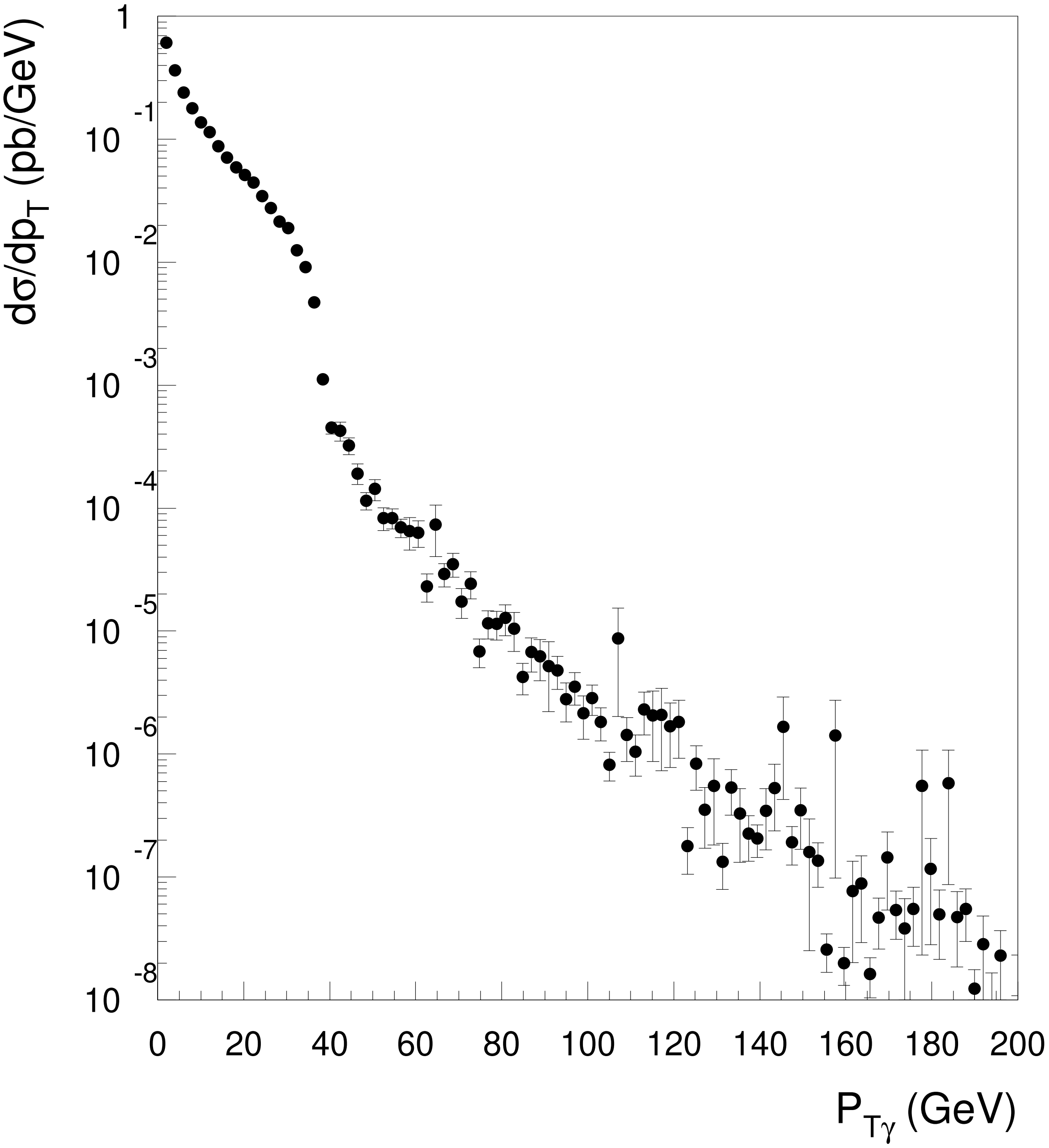

Figure 12: The cross section $\mathrm{d}\sigma/\mathrm{d}P_t^\gamma$ for $W\gamma$ events as predicted by the `COMPHEP` Monte Carlo event generator.