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A Study of Photon Fakes from Beam Halo Events

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Abstract

We investigate methods of rejecting "beam halo" events in which a particle, traveling parallel to the beamline, creates an electromagnetic cluster in the CEM which fakes a photon. We approach the question mainly from the point of view of high-p_T photon physics, particularly $\gamma \not\!\!E_T$ searches. We propose a set of cuts to remove these events, relying on the pattern of energy distribution in both the CEM and the CES.

Version 0.3: Updates with data through January 2003, add plots of trends of variables with time.

Version 0.4: Further update data through early June 2003, propose `lshr` cuts, provide detailed thresholds.

1 Introduction

"Beam halo events" are events featuring either a long, narrow trail of energy in the central calorimeter, or else a high-energy spike in one or both plug calorimeters, characteristic of passage of a particle produced upstream of the detector and traveling roughly parallel to the beamline. Figure 1 shows an event of the first type. These events usually do not have tracks or significant activity in the calorimeter outside the wedge with the energy deposition. Timing information from the TSU system and plug calorimeters strongly suggest that the particles causing these events are muons traveling parallel to the proton beam, perhaps created in interactions in the region of the CDF and DØ Roman Pots [1] and in beam-gas interactions [2, 3]. For further details on the detector-level aspects of beam halo events, see Refs. [1, 4]. It is useful to note that events in the first class are usually found at $\phi \approx 0$, that is, in CEM wedges 0 and 23 (Figure 1 shows one of the exceptions), and that this distribution becomes more pronounced with increasing energy.

These events, especially ones where the energy deposit is in the CEM, form a significant background to searches in channels involving photons and $\not\!\!E_T$, in particular the exclusive $\gamma \not\!\!E_T$ channel. Although some relief can be obtained by excluding a few particularly bad runs, a method must be found to exclude as many of these events as possible and quantify the number remaining.

These events are very persistent and appear to be a permanent instrumental background for Run II with CDF in its current configuration. The EMTiming project [5] proposes to add timing readout to the CEM and PEM with a resolution better than 2 ns [6]; this information would provide a good means of flagging these events, especially if the timing resolution relative to the nominal interaction is better than 1 ns, as they should interact with the calorimeter ≈ 6 ns before photons produced in collisions.

In this note we study several methods for recognizing beam halo events:

- Central calorimeter occupancy
- Hadronic entry and exit tagging

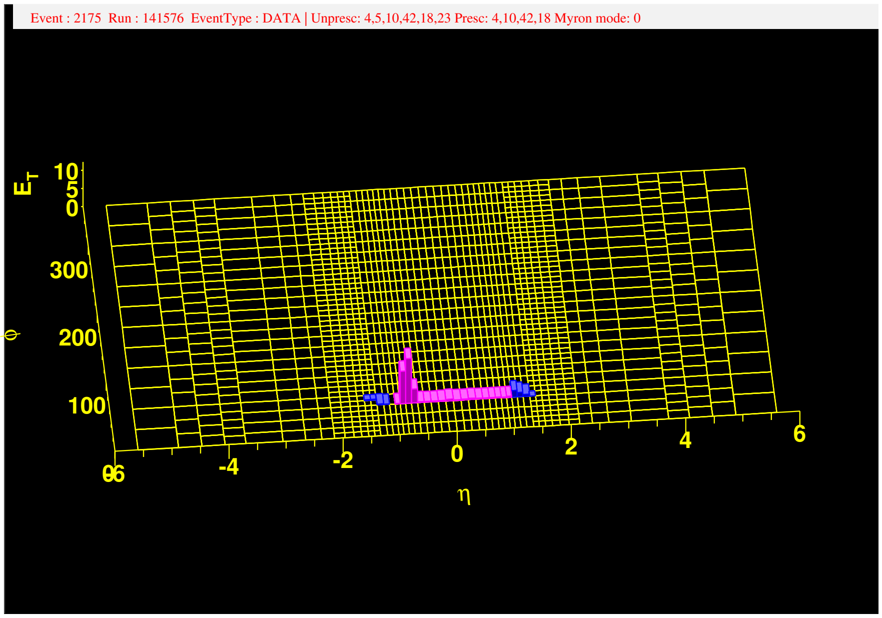

Figure 1: A "photon+$\not\!\!E_T$" event due to beam halo.

- Photon ID variables (`lshr` and χ^2_{strip})

In addition to these, simple event quality cuts similar to those used for cosmic ray rejection can work well, especially in channels not highly susceptible to this source of background. Examples of these cuts include requiring some non-zero number of tracks in the event, requiring a vertex to be reconstructed, or requiring $\not\!\!E_T$ in the event not to be back-to-back with the photon. These cuts will not be discussed further in this note but analyses with topologies that would imply a low fake rate from beam halo events might do very well by imposing only such requirements.

2 Central calorimeter occupancy

This method is based on recognizing the typical geometry of these events. For an EM cluster, the two numbers *seedwedge* and *sidewedges* are defined in the following manner: *seedwedge* is the number of CEM-containing towers ($16 \leq ieta \leq 35$) in the same wedge as the seed tower of the cluster with energy deposition above 100 MeV, and *sidewedges* is the sum of the corresponding counts in the two adjacent wedges.

Figure 2 shows the distribution of the *seedwedge* and *sidewedges* variables in a sample of tight central W electrons. The lines on the figure show the region allowed by the following cuts:

$$\begin{array}{rl} (seedwedge - 1.5 \times sidewedges) < 6 & \text{for } 0 \leq sidewedges \leq 2 \\ (seedwedge - 0.5 \times sidewedges) < 8 & \text{for } 2 \leq sidewedges \leq 12 \\ seedwedge < 14 & \text{for } sidewedges \geq 12 \end{array}$$

This choice of cuts is motivated by the observed shape of the distribution for W electrons and by the expected behavior of the variables as calorimeter occupancy increases with instantaneous luminosity.

The shape of the allowed region is driven by the expected behavior of the *seedwedge* and *sidewedges* variables as the number of interactions increases. When *seedwedge* and *sidewedges*

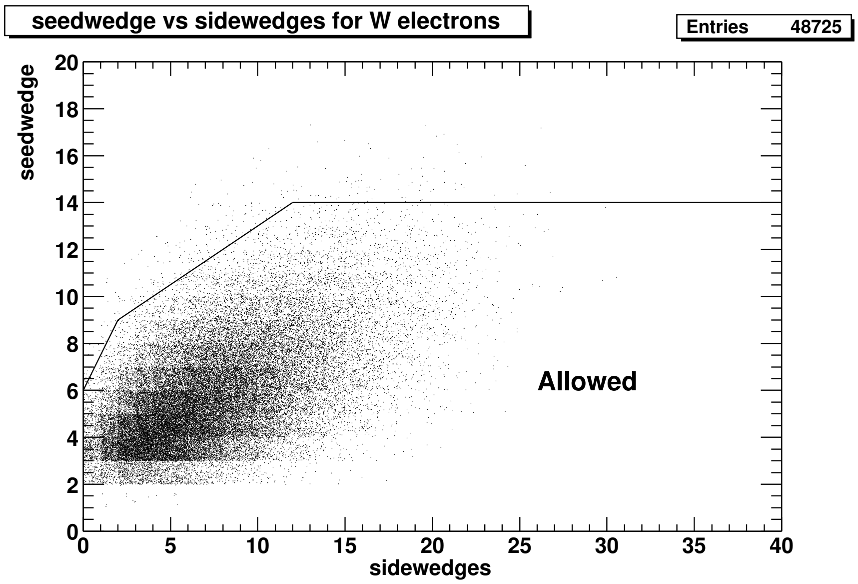

Figure 2: Distribution of the *seedwedge* and *sidewedges* variables for W electrons. The region allowed by the choice of cuts in the text is indicated.

are both low, additional activity in the event may be expected to add about twice as much to *sidewedges* as *seedwedge*; the points should therefore move parallel to the line with a slope of 0.5. As *seedwedge* saturates, it becomes less affected by background activity, and the points move horizontally to the right.

3 Hadronic entry and exit tagging

This method is based on the observation that the flight path of a particle passing through the CEM almost parallel to the detector axis must go through hadronic calorimeters on entry and exit. The detector geometry suggests that we expect hadronic energy deposits without corresponding electromagnetic energy in the high-$|\eta|$ towers of the WHA and the lower $|\eta|$ towers of the PHA, with some asymmetry due to the slight angle the path of the beam halo muons must have relative to the detector axis. Manually inspecting a number of events shows that in general entry occurs in towers 12 through 15 on the west side and exit occurs in towers 35 through 37 on the east side. The variables *eastbhocc* and *westbhocc* are defined by counting the number of towers in these regions with purely hadronic energy deposition (i.e. EM energy below threshold). The hadronic energy is required to be above the default CalDataMaker threshold, and the electromagnetic energy to be below the default CalDataMaker threshold. The effective thresholds seen in the data are 62.5 MeV for the CEM and PEM, 47.6 MeV in the PHA, and 30 MeV in the WHA[1]. The plug region used here has 48 segments in ϕ, and each segments corresponding to the central seed wedge is counted separately in computing the occupancy.

At the present, a cut requiring $eastbhocc + westbhocc \leq 1$ is quite efficient. The efficiency may to degrade with higher instantaneous luminosity, so this should be monitored.

[1]These values disagree with those in `CalorObjects/CalThresholds.hh`, and the source of the discrepancy is unknown. The thresholds given here are, however, accurate for the `CalData` objects created by production in the bhel08 and bhel09 datasets.

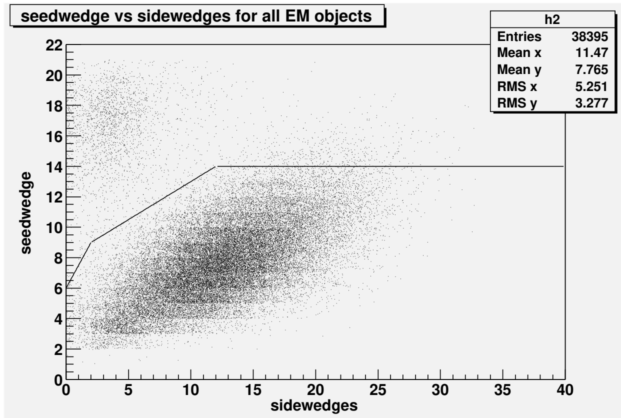

Figure 3: *seedwedges* vs. *sidewedges*, all EM objects in Stream A in runs 149249 to 149387

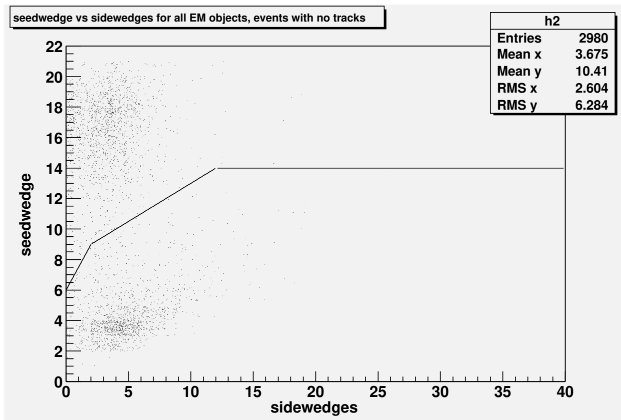

Figure 4: *seedwedges* vs. *sidewedges*, all EM objects in Stream A events with no tracks, in runs 149249 to 149387

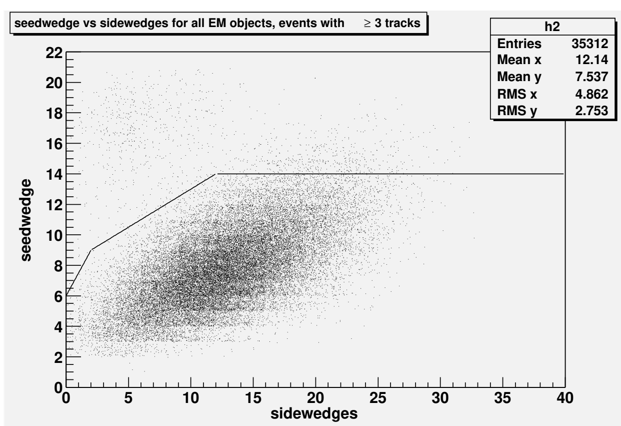

Figure 5: *seedwedges* vs. *sidewedges*, all EM objects in Stream A events with ≥ 3 tracks, in runs 149249 to 149387

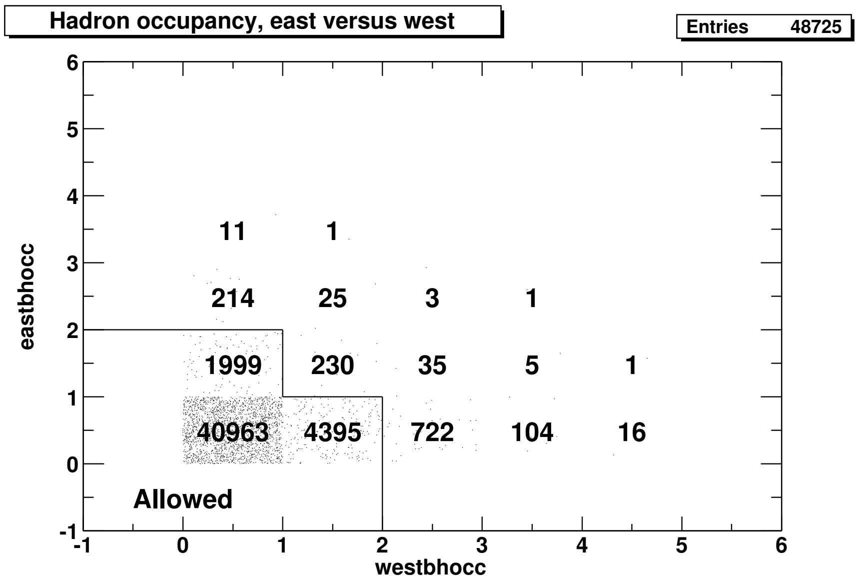

Figure 6: *eastbhocc* vs. *westbhocc* for W electrons

4 ID variables

Because the EM showers in these events are not being initiated in the same manner as in real and cosmic ray events, one expects different distributions in the photon identification variables. By imposing different/tighter cuts than normal, it should be possible to further filter out beam halo events.

Two variables have been found to have significantly different distributions for real events and beam halo events: `lshr` and the CES χ^2's, in particular χ^2_{strip}. Because the particles initiating the showers are traveling horizontally, the showers and energy deposition are broader than for real events, which is reflected in these variables. Figure 7 shows distributions of these variables for W electrons and events tagged as beam halo (by requiring *eastbhocc* ≥ 2 and *westbhocc* ≥ 3). The quantities in both plots are computed treating the EM objects as photons. This produces the tail of the W electron χ^2_{strip} distribution beyond 10 (the requirement $\chi^2_{strip} < 10$ is imposed in the selection of electrons, but the photon clustering is seeded differently). No `lshr` requirement is imposed in the electron selection.

Because `lshr` is defined with reference to a vertex, it is a problematic variable to use for photons. However its rejection ability is very good. Using the cut $|\texttt{lshr}| < 0.2$, one finds an efficiency of 99.5% for W electrons, while only 5.2% of tagged beam halo events survive. (When restricted to the case that a ZVertex has been found, the corresponding efficiencies are 99.7% and 5.5%).

The value of χ^2_{strip} is defined purely in terms of the shower shape. χ^2_{strip} can also catch other kinds of junk not found by lshr, such as cosmic rays. (A $\chi^2_{strip} \leq 10$ cut for photons was imposed in the Run I $\gamma \not\!\!E_{\mathrm{T}}$ analysis as an anti-cosmic ray cut.) 5.2% of beam halo events pass the cut $\chi^2_{strip} < 10$; much of the rejection is due to the EM clusters not having associated CES strip clusters. Of beam halo EM clusters with associated strip clusters, 11.4% pass the cut.

The efficiency computed in the Run I $\gamma \not\!\!E_{\mathrm{T}}$ analysis for the $\chi^2_{strip} < 10$ cut, given that $\chi^2_{avg} \leq 20$, was 97.5% [8]. The efficiency as measured for the Run II $\gamma \not\!\!E_{\mathrm{T}}$ search is (97.8 $\pm$ 0.3)%, consistent with the Run I number [9].

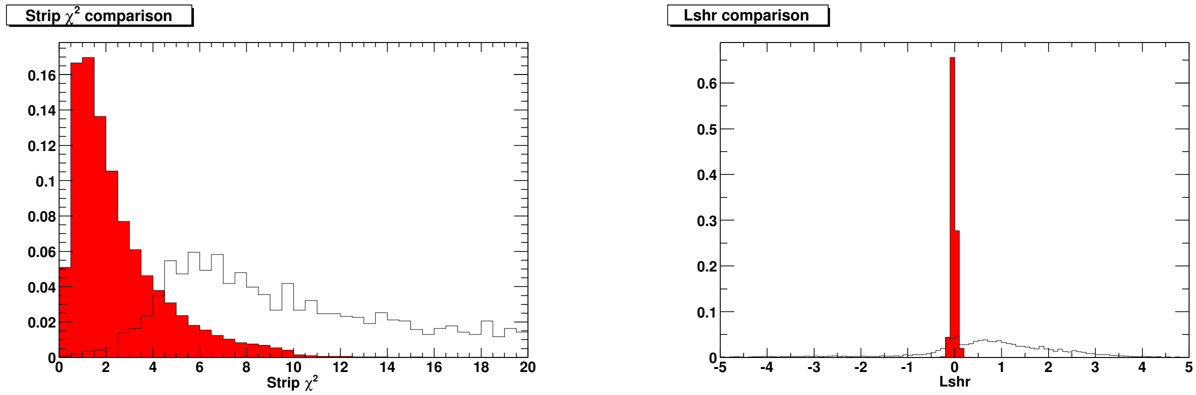

Figure 7: Comparisons of the ID variables χ^2_{avg} (left) and (three-tower) `lshr` (right) for W electrons (red) and beam halo events (unshaded). All histograms are normalized to unit area.

Central
Fiducial
≥ 1 class 12 vertex and $\lvert z_{\text{vertex}} \rvert < 60$ cm
$\mathrm{E_T} > 20$ GeV
$\mathrm{HAD/EM} < 0.055 + 0.00045 \times \mathrm{E}$
$\mathrm{p_T} > 50$ GeV/c or $0.75 < \mathrm{E/p} < 1.3$
$\lvert \delta z \rvert < 5$ cm
$\lvert \delta x \rvert < 3$ cm
$\chi^2_{\text{strip}} < 10$
$\mathrm{E^{iso}_{cone}/E} < 0.15$

Table 1: W electron cuts

5 Efficiencies for geometric cuts

The efficiency of the geometric cuts was measured with a sample of W electrons. The efficiencies may possibly vary depending on the calorimeter isolation of the EM object. To account for this we impose the photon isolation requirement $\mathrm{E}_{\mathrm{T}}^{iso} < 2$ GeV (where the isolation energy is corrected for leakage [7]) instead of the looser electron isolation requirement $\mathrm{E}_{\mathrm{T}}^{iso}/\mathrm{E_T} < 0.1$.

Using data with an integrated luminosity of $\mathcal{L} = 130 \pm 9$ pb^{-1}, one finds an overall efficiency of $(96.6 \pm 0.1)\%$ ($stat$) for the geometric cuts in W electrons. This is a significant decrease from the $(98.4 \pm 0.1)\%$ efficiency in the 20 pb^{-1} through autumn 2002. The failure matrix is shown in Table 2.

It is interesting to plot the rate at which W electrons fail the geometric cuts versus the $\mathrm{E_T}$ of the electron to see if there is a dependence. We do not expect a first order dependence, because the number of towers involved in an electromagnetic shower from an isolated electron is small compared to the cutoffs imposed by the geometric cuts. This plot is shown in Fig. 5. There is no evidence of a dependence.

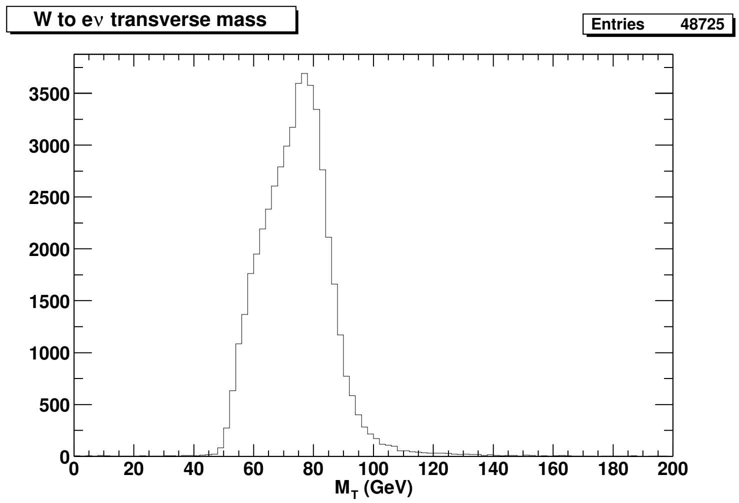

Figure 8: Transverse mass distribution for the W candidates used in this study

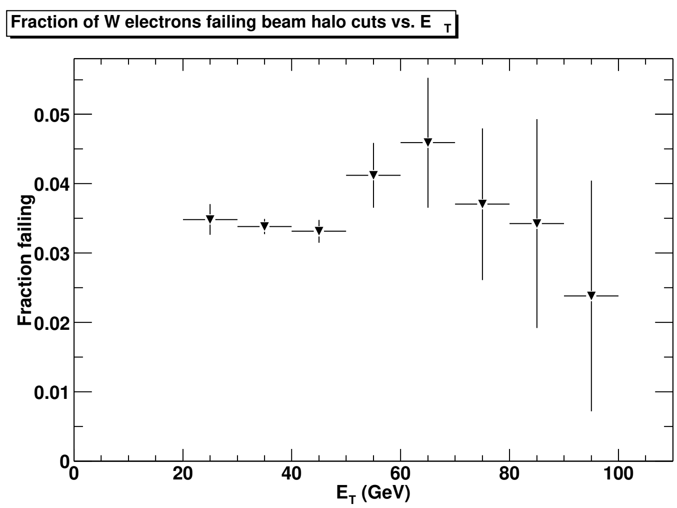

Figure 9: Failure rate of W electrons versus $\mathrm{E_T}$

	Pass seedwedge-sidewedges cut	Fail seedwedge-sidewedges cut
Pass eastbhocc-westbhocc cut	47064 (96.6%)	293 (0.6%)
Fail eastbhocc-westbhocc cut	1351 (2.8%)	17 (0.3%)

Table 2: Failure matrix of geometric beam halo rejection variables for 48725 W electrons

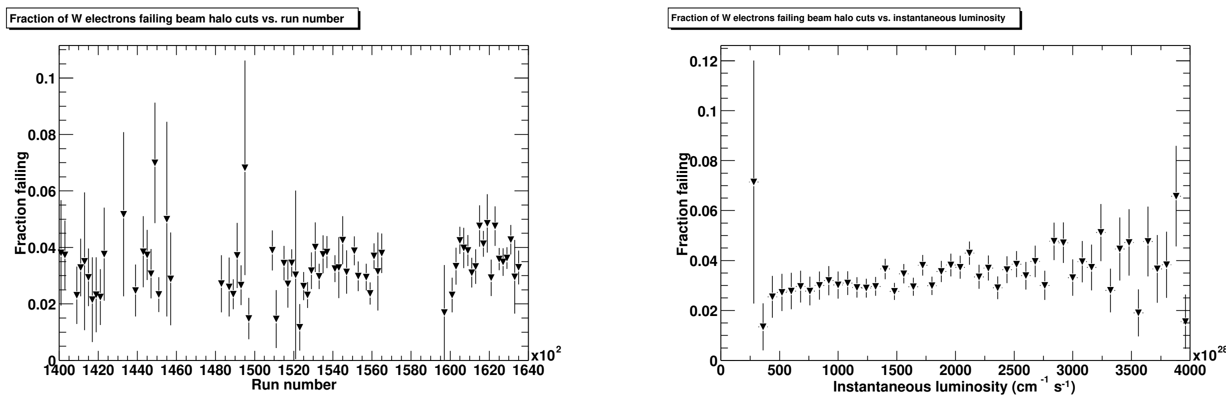

Figure 10: Failure rate of W electrons versus run number (left) and versus instantaneous luminosity (right)

6 Run and Luminosity Dependence

Plots of the fraction of the W electrons failing the geometric cuts versus run and versus instantaneous luminosity are shown in Figure 10. Outliers in both plots seem to be due to low statistics in those particular bins. It appears that the failure rate has increased with time (reflected in the 1.8% reduction in the efficiency mentioned above), and that this may correlate with increased luminosity, although the statistics for high luminosity running are not large. The plots do suggest that the failure rate has increased at most a factor of two as the luminosity has risen by a factor of eight, so high-luminosity operations may not pose a major impediment to the use of the geometric variables.

7 Use in background estimation

The cuts proposed in this note were in fact used in an analysis (an exclusive photon + $\not{E}_T$ search, [9]). In the analysis an estimate was made of the residual background from beam halo events remaining after the cuts were applied.

The method used is summarized here. The analysis selection required that ≥ 3 COT tracks and at least one ZVertex were found for the event. A control sample could be obtained by requiring that there be no COT tracks found in the event. In this sample, no events were found in CEM wedges 0 or 23, the locations of most beam halo energy deposits. (For energies as high as required by the analysis, $> 99\%$ of the beam halo events occur in this region.) This was used to set an upper limit on the rate for beam halo events surviving cuts with no tracks in the event.

This background rate was then related to the background rate for events passing the track and vertex requirements. The ratio between the rates was taken to be the same as the corresponding ratio for events that were clearly due to beam halo. Events were tagged as due to beam halo by requiring *eastbhocc* ≥ 2 and *westbhocc* ≥ 3; in a sample of 30,000 W electrons, none were tagged as beam halo, so this is an extremely pure sample. The ratio was found to be 0.135 ± 0.008 in that analysis. (This number is expected to be highly luminosity dependent.)

Overall, a limit of 0.18 events (68% C.L.) was found for the beam halo contribution to the signal, which was so small it was ignored for further background estimation.

A track and/or vertex requirement, or similar event quality cuts	
$(seedwedge - 1.5 \times sidewedges) < 6$	for $0 \leq sidewedges \leq 2$
$(seedwedge - 0.5 \times sidewedges) < 8$	for $2 \leq sidewedges \leq 12$
$seedwedge < 14$	for $sidewedges \geq 12$
$eastbhocc + westbhocc \leq 1$	
$\chi^2_{strip} < 10$ and/or $\lvert$3-tower `lshr`$\rvert < 0.2$	

Table 3: Summary of cuts suggested for removal of beam halo EM objects

8 Conclusions

A summary of the cuts proposed in this note can be found in Table 3. Efficiencies should be monitored for these cuts, but the geometric cuts at least maintain good efficiency in the data period under consideration. These cuts have been used in an analysis to reject candidates arising from beam halo events, and have demonstrated a high power of rejection, making this background negligible in the channel most sensitive to this type of background (exclusive photon+$\not\!\!E_T$). It is therefore reasonable to conclude that this background is under control.

9 Acknowledgments

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References

[1] M. Albrow et al., "Missing $\not\!\!E_T$ and Beam Related Backgrounds at CDF", **CDF Note 5926**.

[2] R. Tesarek, "Beam Halo, Losses and Radiation in CDF", Joint Physics Meeting 5/3/02, available at `http://ncdf67.fnal.gov/~tesarek/halo/joint_physics_020503/`

[3] R. Moore and V. Shiltsev, "Estimate of the Tevatron vacuum on the basis of the known pressure rise at F11", available at `http://home.fnal.gov/~maeshima/halo/useful_links/f11_vacuum.pdf`

[4] R. Tesarek, "Preliminary Study of Beam Halo in CDF", **CDF Note 5873**.

[5] D. Toback *et al.*, "Proposal to Add Timing Information Into the Readout of the Central and Plug Electromagnetic Calorimeters", **CDF Note 5518**.

[6] H. Frisch, private communication.

[7] P. Wilson, **CDF Note 4170**.

[8] P. Onyisi, "A Search for New Physics in Photon + $\not\!\!E_T$ Events", **CDF Note 5725**.

[9] P. Onyisi, "Run 2 Photon + $\not\!\!E_T$ Search", **CDF Note 6381**.