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CDF Results on $Z\gamma$ Production

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We discuss final results on $Z\gamma$ production observed by the Collider Detector at Fermilab (CDF) from the Tevatron Collider Run 1a and preliminary results from 36pb^{-1} of integrated luminosity from Run 1b. Both the Run 1a and 1b results are consistent with expectations from the Standard Model.

INTRODUCTION

Since the Z is not coupled to the photon within the framework of the Standard Model, production of photons in association with Zs beyond that predicted by initial state radiation and radiative Z decay would indicate a composite Z and/or additional bosons beyond those of the Standard Model. A summary of $Z\gamma$ production at the Tevatron Collider can be found in the plenary talk at this conference by Aihara [1]. In this paper, we review the analysis of $Z\gamma$ production by the CDF experiment at the Tevatron, present the final limits on $Z\gamma$ couplings and transition multipole moments from Run 1a data, show kinematic distributions from the first 36 pb^{-1} of data from Run 1b, and finally discuss two unusual $e^+e^-\gamma$ events observed during the Run 1b data taking period.

EXPERIMENTAL ANALYSIS OF $Z\gamma$ CANDIDATES

From samples of inclusive electrons (pseudorapidity,$|\eta| < 1.0$) and muons ($|\eta| < 0.6$), Z candidates were selected by requiring an isolated charged lepton with $E_T > 20$ GeV. The electron (identified by a cluster in the central EM calorimeter (CEM)) or muon (identified by a "stub" track in the central muon drift chambers (CMU)) was required to have a matching track reconstructed in the central tracking chamber (CTC). Because Zs are readily identified by the presence of two high-p_T, opposite signed charged leptons, less stringent requirements were imposed on the second lepton. For the electron channel, the second lepton was required to have $E_T > 20$ GeV if in the CEM, $E_T > 15$ GeV if in the plug EM calorimeter, and $E_T > 10$ GeV if in the forward EM calorimeter. For electrons in the CEM, additional identification of the EM cluster as an electron was provided by shower shape measurements and track/cluster matching using the shower max detector (CES) embedded in the central EM calorimeter. Finally, a Z mass window selection was imposed: $70\ \text{GeV/c}^2 \leq M(e^+e^-) \leq 110\ \text{GeV/c}^2$. In the muon channel, the second lepton was required to have $p_T > 20$ GeV/c, to have a calorimeter energy deposit consistent with a minimum ionizing particle, and to lie within the $|\eta| < 1.2$ region of the CTC. The Z mass window selection imposed on the muon pair was $65\ \text{GeV/c}^2 \leq M(\mu^+\mu^-) \leq 115\ \text{GeV/c}^2$.

Photon candidates were identified in the Z sample by requiring an isolated CEM energy cluster with $E_T > 7$ GeV separated from the closest charged lepton by $\Delta R_{\ell\gamma} = \sqrt{\Delta\eta^2 + \Delta\phi^2} > 0.7$. Because the Z identification is quite clean, the *crucial* aspect of the experiment is to reduce and understand the background to the photon signal that arises mainly from neutral QCD jets faking a photon signal. To this end, the photon coverage was restricted to the CEM detector region where there exist several well-understood tools for photon identification:

- The hadronic calorimeter to electromagnetic calorimeter energy ratio was required to be consistent with a shower arising from a purely electromagnetic origin.
- The EM cluster was required to be isolated in energy in the CEM.

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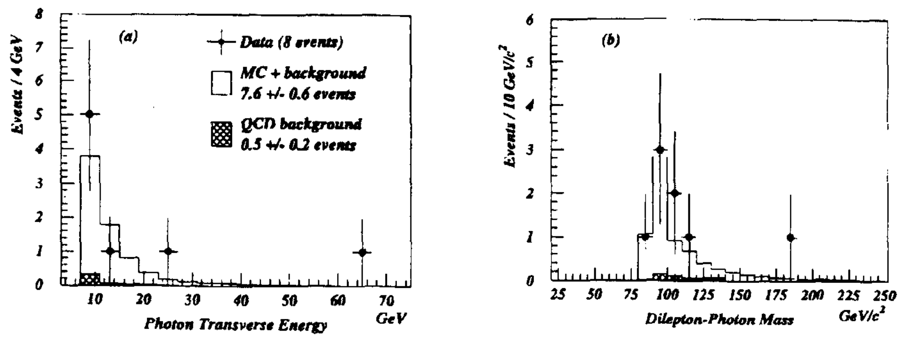

FIG. 1. Final kinematic distributions for $Z\gamma$ events from the Tevatron Collider Run 1a. a) The photon transverse energy distribution for the electron and muon channels combined. b) The dilepton-photon mass distribution.

- No tracks reconstructed in the CTC were allowed to point to the CEM photon cluster; and the cluster was required to be isolated in tracking by demanding the transverse momentum sum of tracks within a $\Delta R = 0.4$ cone be less than 2 GeV/c.
- The shower profile in the CES was used to demand a CES/CEM profile consistency, a CES signal indicative of a single photon shower, and the absence of additional CES clusters indicating the possible presence of multiple photons from π°s and/or ηs.

An independent sample of inclusive jet events recorded by an $E_{\mathrm{T}} > 16$ GeV central photon trigger was used to estimate the number of fake photons remaining in the final $Z\gamma$ sample.

Beginning in Run 1a with 133,805 inclusive electron events and 83,051 inclusive muon events, the Z selection criteria resulted in 1237 electron channel Zs and 507 muon channel Zs. Imposition of the photon selections gave a final sample of 4 $Z\gamma$ candidates in each of the two channels. The background estimated from the sample of inclusive jet events passing the central photon trigger was 0.4 ± 0.1(stat) $\pm\, 0.2$(syst) events in the electron channel and 0.10 ± 0.03(stat) $\pm\, 0.04$(syst) events in the muon channel; giving 0.5 ± 0.2 events for the combined sample.

RESULTS FROM RUN 1A

In figure 1, we show the photon transverse energy and the dilepton-photon mass distributions. Also shown is the expectation for the Standard Model (derived from a Monte Carlo plus parametrized detector simulation) plus background. The Standard Model reproduces the data adequately, but we note the presence of one event in the muon channel with a photon $E_{\mathrm{T}} \sim 64$ GeV and a three body mass of ~ 188 GeV/c^2. The combined electron plus muon total of 8 events with a background estimate of 0.5 ± 0.2 events implies $[\sigma \cdot B(Z+\gamma)]_{\mathrm{exp}} = 5.1 \pm 1.9(\mathrm{stat}) \pm 0.3(\mathrm{syst})$ pb. This is to be compared with the Standard Model prediction of $[\sigma \cdot B(Z+\gamma)]_{\mathrm{SM}} = 5.2 \pm 0.6(\mathrm{stat} \oplus \mathrm{syst})$ pb.

Anomalous $Z\gamma$ couplings are assumed to be regulated by generalized dipole form factors that are functions of the initial $q\overline{q}$ center of momentum energy, $\sqrt{\hat{s}}$, and the energy scale, Λ_Z, at which the new interactions become manifest [2,3]. The four possible couplings for each of two vertices ($ZZ\gamma$ and $Z\gamma\gamma$) are denoted by $h_{i0}^{V=Z,\gamma}$ which represent the low energy, ($\sqrt{\hat{s}} \to 0$) limit for the couplings. Since the experimental limits determined by CDF on the couplings reach the unitarity limit for $\Lambda_Z \simeq 500$ GeV, the scale parameter has been fixed at this value in determining limits on couplings. Limits were obtained in pairwise fashion setting all other couplings to zero. A log-likelihood fit was performed to the photon E_{T} spectrum parametrized by the couplings. Details of the fitting procedure are found in refs. [3,4]. Limits for the CP conserving (violating) combination h_{30}^Z, h_{40}^Z (h_{10}^Z, h_{20}^Z) are shown in figure 2a. The couplings are related to the transition electromagnetic multipole moments (see ref. [3]). Figure 2b shows the limit contour for the magnetic quadrupole (q_Z^m) versus electric dipole (δ_Z^*). Using instead the CP violating couplings, h_{10}^Z, h_{20}^Z, results in an identical contour for the electric quadrupole (q_Z^e) versus magnetic dipole (g_Z^*) moments.

PRELIMINARY RESULTS FROM RUN 1B

We have to date acquired for Run 1b an integrated luminosity of 36pb^{-1}. The combined Run 1a and 1b photon transverse energy and dilepton-photon mass distributions are shown in figure 3. As we have not yet obtained acceptances and efficiencies for the run 1b data, we have not included any Standard Model expectation plots. However,

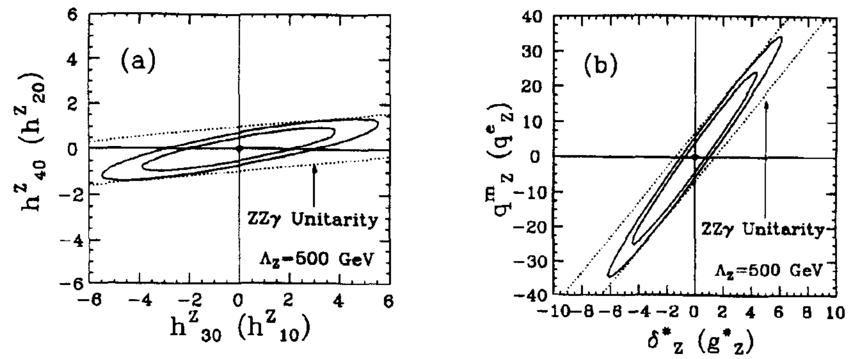

FIG. 2. Final 68% and 95% confidence level limit contours from Tevatron Collider Run 1a. a) The limit contours for CP conserving (violating) anomalous $ZZ\gamma$ couplings. Essentially identical limits are obtained for the $Z\gamma\gamma$ coupling. b) Limit contours for transition electromagnetic multipole moments. Symbols are explained in the text.

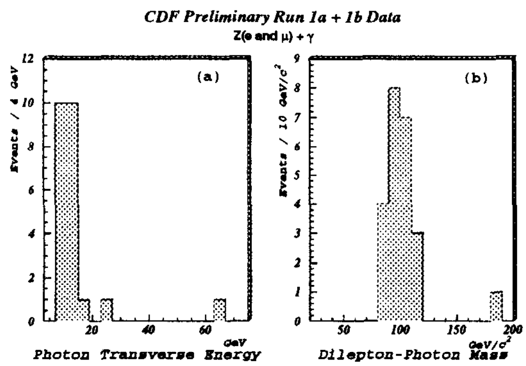

FIG. 3. Preliminary kinematic distributions for $Z\gamma$ events from the combined Tevatron Collider Run 1a and 1b data. a) The photon transverse energy. b) The dilepton-photon mass.

comparison of figure 3 with figure 1 leads to the tentative conclusion that our consistency with Standard Model expectations continues in the larger data sample.

We have, however, recently recorded two unusual events in Run 1b. The first event is very clean and passes all $Z\gamma$ selection requirements *except* the Z mass window requirement. It has $M(e^+e^-)$ $\sim$ 255 GeV/c^2 and $M(e^+e^-\gamma)$ $\sim$ 274 GeV/c^2. The second event shown in figure 4 was recorded after processing had been completed for the preliminary data set shown in figure 3. It is a $Z\gamma$ candidate with $M(e^+e^-)$ $\sim$ 86 GeV/c^2, E_T^γ $\sim$ 195 GeV, and $M(e^+e^-\gamma)$ $\sim$ 417 GeV/c^2. The probability of producing an event with a three body mass of at least this value was estimated using a $Z\gamma$ Standard Model Monte Carlo including Drell-Yan contributions and is found to be at the level of about 0.05%.

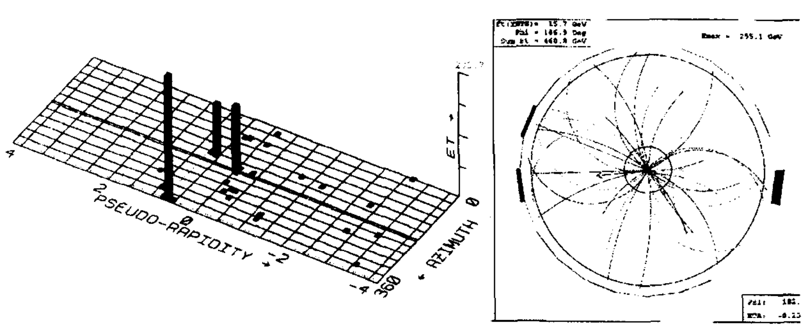

FIG. 4. Transverse energy "lego" and tracking chamber plots for an $e^+e^-\gamma$ event with a very high E_T photon. The photon is the highest energy cluster near azimuthal angle 360°. The e^+e^- pair reconstruct to within 5 GeV of the Z mass.

CONCLUSIONS

We have discussed the analysis of $Z\gamma$ production as observed by the CDF experiment at the Tevatron Collider during Runs 1a and 1b. Final results from Run 1a indicate good agreement with the Standard Model. Results analyzed to date from Run 1b tentatively confirm this agreement for a larger integrated luminosity. We have observed at least two unusual $e^+e^-\gamma$ events recently in Run 1b. No conclusions can be drawn at this time about the events. The 100pb^{-1} data sample expected to be obtained from the whole of Run 1b should either provide additional events of this type or confirm the events as low probability fluctuations of the Standard Model.

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[1] See contribution of H. Aihara to these proceedings.
[2] U. Baur and E. Berger, Phys. Rev. D **47**, 4889 (1993).
[3] F. Abe *et al.*, Phys. Rev. Lett. 74, 1941 (1995).
[4] F. Abe *et al.*, Fermilab Report No. FERMILAB-Pub-94/244-E, submitted to Phys. Rev. D (1994).