FNAL/C--96/236-E(7)
CONF-960812--20

RECENT DØ RESULTS ON $Z\gamma$ PRODUCTION

Submitted to *American Physical Society, Division of Particles and Fields, Divisional Meeting 1996*, Minneapolis, Minnesota, August 10-15, 1996.

CONF-960812--38

RECENT DØ RESULTS ON $Z\gamma$ PRODUCTION

GREG LANDSBERG [a]
Fermi National Accelerator Laboratory
Batavia, IL 60510

We report on a new search for anomalous $ZV\gamma$ ($V = Z, \gamma$) couplings in the $Z(ee)\gamma$ mode with 89 pb^{-1} of data. The following limits on anomalous coupling parameters were set at 95% CL: $|h^V_{10,30}| < 1.9$, $|h^V_{20,40}| < 0.4$. We also report on the first measurement of $Z(\nu\nu)\gamma$ production at hadron colliders using 14 pb^{-1} of data. Sensitivity to anomalous couplings in this channel is twice as good as that for the combined electron and muon channel analysis reported earlier [5]. We set the following 95% CL limits on the $ZV\gamma$ couplings: $|h^V_{10,30}| < 0.9$, $|h^V_{20,40}| < 0.2$ which are the tightest available at the present time.

Measurement of $Z\gamma$ production at high energy colliders offers a direct way of probing anomalous $ZZ\gamma$ and $Z\gamma\gamma$ couplings which do not exist within the SM but are suggested by some theoretical models which imply new physics [1]. These couplings can be described [2] by 8 parameters: h^V_i, $i = 1, ..., 4$, $V = Z, \gamma$. Couplings $h^V_{1,2}$ are CP-violating, while $h^V_{3,4}$ preserve CP. In the SM at tree level all $h^V_i = 0$. Since anomalous couplings grow fast with energy they are modified with multipole form-factors in order to preserve partial wave unitarity: $h^V_i = h^V_{i0}/(1 + \hat{s}/\Lambda)^n$, where conventionally $n = 3$ for $i = 1, 3$ and $n = 4$ for $i = 2, 4$ couplings [2]. The form-factor scale Λ is *a priori* unknown and indicates the scale for new physics.

Measurements of $Z\gamma$ production through the $ee\gamma$ and $\mu\mu\gamma$ decay channels at the Fermilab Tevatron were previously reported [3,5]. Here we present a new measurement of the $ee\gamma$ channel based on 89 pb^{-1} of data collected in 1994-1995 Tevatron run with the DØ detector. We also present the first measurement of the $\nu\nu\gamma$ production at hadron colliders (this channel has been studied only in e^+e^--collisions [4]) based on 13.5 pb^{-1} of data collected in the 1992–1993 run. Sensitivity to anomalous couplings in this channel is much higher than that for the dilepton decay modes due to a higher branching ratio and absence of the radiative Z decay background in the neutrino channel. However, this is an experimentally challenging measurement because the background in the $\nu\nu\gamma$ mode at hadron colliders is extremely high.

Event selection for the $ee\gamma$ analysis was similar to the one used in our previous measurement [5]. We required two electrons with $E^e_T > 25$ GeV and a photon with $E^\gamma_T > 10$ GeV. We additionally required that there were no hits

[a] For the DØ Collaboration. See, e.g. [5] for the list of authors.

in the tracking chambers in a road pointing toward the photon, and that the photon was separated from either electron by at least 0.7 units in η-ϕ-space (here η is pseudorapidity related to the polar angle by $\eta = -\log\tan(\theta/2)$, and ϕ is the azimuthal angle). All three electromagnetic (EM) clusters were required to be in the good fiducial volume of the detector, i.e, in central calorimeter (CC) with $|\eta| < 1.0$ or in end calorimeters (EC) with $1.5 < |\eta| < 2.5$. The acceptance as a function of anomalous couplings was determined using the Baur and Berger LO Monte Carlo generator [2] with parametric detector modelling. The detection efficiencies were calculated from data ($Z \to ee$ events in most of the cases). For the SM couplings the geometrical acceptance was 38%, and the overall detection efficiency within the kinematical cuts on the final state particles was $12.5 \pm 0.8\%$.

The above selection criteria yielded 14 candidate events (11 in CC and 3 in EC) with an estimated background of 1.8 ± 0.5 events, dominated by $Z + j$ and multijet production with jets faking the photon or electrons. This background was derived from data. The results agree well with the SM predictions of 12.1 ± 1.2 signal events. The E_T^γ spectrum of the observed candidates together with the background estimate and SM predictions are shown in Fig. 1a. Two high-E_T^γ events are consistent with the background or signal fluctuation within two standard deviations. The following 95% CL limits on anomalous couplings (with assumption of one coupling being non-zero at a time) were obtained by a fit of the E_T^γ spectrum: $|h_{10,30}^V| < 1.9$, $|h_{20,40}^V| < 0.4$ for the form-factor scale of $\Lambda = 500$ GeV (see Fig. 2). The distorted shape of the exclusion contour is due to the events in the tail of the E_T^γ spectrum.

For the $\nu\nu\gamma$ analysis we required a much higher cut on the photon energy: $E_T^\gamma > 40$ GeV which was forced by a dominant background from $W \to e\nu$ decays with the electron being misidentified for a photon due to inefficiency of the central tracker. The photon was required to be in the same fiducial volume as for the $Z(ee)\gamma$ event selection. Analogously to the $ee\gamma$ analysis, we rejected events with central tracker hits in the vicinity of the photon cluster. Missing transverse energy in the event was required to be above 40 GeV. A jet veto was imposed by rejecting events with at least one reconstructed jet with $E_T^j > 15$ GeV. This cut further reduces $W \to e\nu$ background and also improves missing energy resolution. Additional cuts were applied to the shape of the photon EM shower in transverse and longitudinal directions to ensure that it was consistent with a photon originating from the real vertex. This analysis employed several new experimental techniques, e.g. using the finely segmented DØ calorimeter as a tracking device to determine the direction of the photon by measuring the EM shower centroids at different depths. The remaining background was dominated by cosmic and beam halo muons which

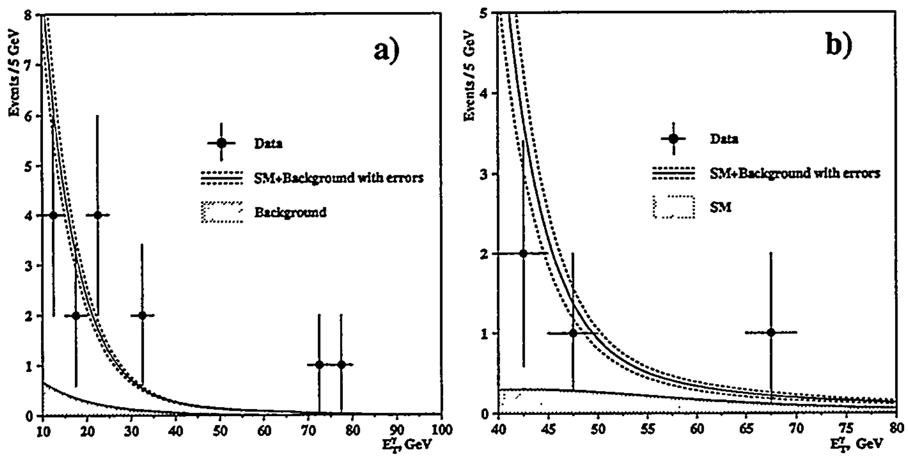

Figure 1: Transverse energy of the photon. a) For $Z(ee)\gamma$ channel. b) For $Z(\nu\nu)\gamma$ channel. Solid and dashed lines show the SM plus background predictions with the errors. Filled area shows a) QCD background; b) SM signal.

radiated photons in the dense calorimeter media and therefore faked the signal signature. This background was suppressed by the requirements of no reconstructed muons in the DØ muon system and additionally no minimum ionizing "tracks" (i.e., chains of hit cells) to be found in the calorimeter close to the photon cluster. The residual background, which had roughly equal contributions from $W \rightarrow e\nu$ decays and muon *bremsstrahlung,* was derived from data. The acceptance and efficiency were estimated in a similar way as for the $ee\gamma$ channel. The jet veto efficiency was calculated using $Z \rightarrow ee$ data and is in excellent agreement with the predictions of NLL calculations for $Z\gamma$ production [6]. The geometrical acceptance was 80% and the overall efficiency within the kinematical cuts was $31 \pm 2\%$.

The above selection criteria enhance the signal-to-background ratio by an impressive factor of ~ 500. We observe 4 candidate events (3 in CC, and 1 in EC) with an expected background of 6.4 ± 1.1 and a SM prediction of 1.8 ± 0.2 events. Although the signal-to-background ratio is less than one, the sensitivity to the anomalous couplings is still high, since the background is concentrated at low E_T^γ while the anomalous coupling contribution is almost flat in E_T^γ up to the kinematic threshold of the reaction. The E_T^γ spectrum of the candidates is shown in Fig. 1b (together with the background and SM predictions) and is consistent with the SM. Limits on anomalous couplings were set at 95% CL by the E_T^γ fit: $|h^V_{10,30}| < 0.9$, $|h^V_{20,40}| < 0.2$. This represents a factor of two improvement compared to the combined $ee\gamma$ and $\mu\mu\gamma$ limits [5] based on the same statistics. The new limits, shown in Fig. 2 together with

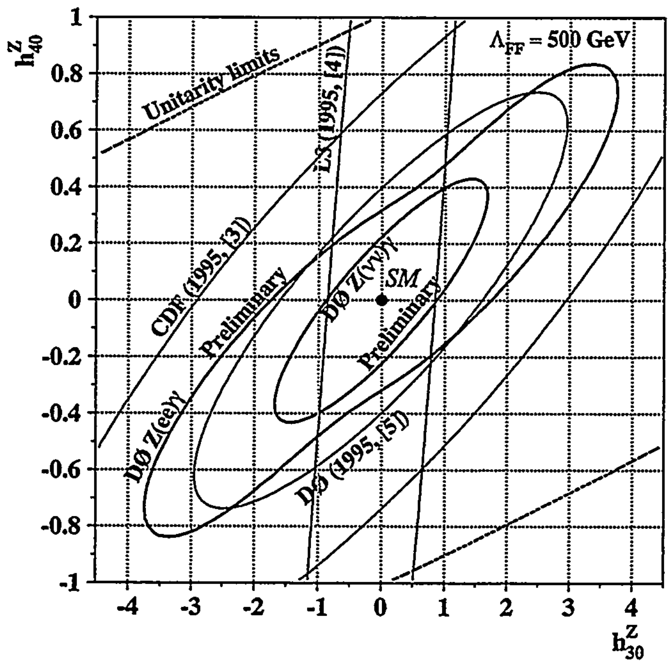

Figure 2: Limits on anomalous CP-conserving $ZZ\gamma$ couplings from $Z(ee)\gamma$, $Z(\nu\nu)\gamma$ production and from previous measurements [3,4,5]. Dashed lines show unitarity contours for the form-factor scale $\Lambda = 500$ GeV.

other measurements [3,4,5], are currently the tightest in the world.

Analyses of the $\mu\mu\gamma$ and $\nu\nu\gamma$ channels for 1994–1995 data set are currently under way and we expect to increase sensitivity toward anomalous couplings by another factor of two when they are completed. Any further improvement will be possible only with upgraded Tevatron or at the next generation of hadron colliders.

References

1. H. Aihara *et al.*, preprint Fermilab–Pub–95/031.
2. U. Baur, E.L. Berger, Phys. Rev. **D41**, 1476 (1990).
3. F. Abe *et al.* (CDF Collaboration) preprint Fermilab–Pub–94/244–E, submitted to Phys. Rev. **D**; Phys. Rev. Lett **74**, 1941 (1995).
4. M. Acciarri *et al.* (L3 Collaboration), Phys. Lett. **B346**, 190 (1995).
5. S. Abachi *et al.* (DØ Collaboration) Phys. Rev. Lett **75**, 1034 (1995).
6. J. Ohnemus, Phys. Rev. **D47** (1993) 940; *ibid.*, **D51**, 1068 (1995).