International Journal of Theoretical Physics, Vol. 34, No. 6, 1995

Limits on the Kappa Parameter (κ) of the W Boson at the Collider Detector at Fermilab (CDF)

Mark A. Samuel,[1] G. Li,[1] Nita Sinha,[2] M. K. Sundaresan,[2] and Rahul Sinha[2,3]

Received August 12, 1994

Recently we obtained bounds on the magnetic moment of the *W* boson from preliminary results from the collider detector at Fermilab. These results were based on 4.3 pb^{-1} of data, from which three $W\gamma$ events and three radiative *W* decays were found. Within the next 2 years they expect to have almost 100 pb^{-1} of data. In this paper we consider the bounds one will be able to obtain from these data, under two scenarios: (1) The expected Standard Model (SM) results are obtained. (2) The relative number of events observed is the same as in the previous run. We estimate that one will be able to obtain a 95% C.L. bound for κ, perhaps as good as $-1.9 \le \kappa \le 4.2$. These bounds would come from the total number of events. When the number of events increases sufficiently, one will be able to obtain an angular distribution for $W\gamma$ and an energy distribution for radiative *W* decay. Then one could observe the radiation amplitude zero and obtain a precise value for κ.

In a recent letter (Samuel *et al.*, 1992; see also Samuel *et al.*, 1991*a*) we showed how the preliminary results for $W\gamma$ production and radiative *W* decay from the collider detector at Fermilab (CDF) (Timko, 1990) could be used to put bounds on the magnetic moment of the *W* boson, given by

$$\mu = (\kappa + \lambda + 1)e/2M_W$$
$$Q = -e/M_W^2(\kappa - \lambda) \qquad (1)$$

where the Standard Model (SM) value is given by $\lambda = 0$, $\kappa = 1$, for which

$$\mu = e/M_W$$
$$Q = -e/M_W^2 \qquad (2)$$

---

[1] Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078.
[2] Ottawa-Carleton Institute for Physics, Carleton University, Ottawa, Canada K1S 5B6.
[3] Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Bombay, 400 005 India.

The best way to measure κ is to make use of the radiation amplitude zero (RAZ) (Mikaelian *et al.*, 1979) which occurs in the angular distribution for $d\bar{u} \to W^-\gamma$ $(u\bar{d} \to W^+\gamma)$. The dip which persists in $p\bar{p} \to W\gamma X$ is very sensitive to the parameter κ. A similar zero occurs in the energy distribution of the radiative decay $W^- \to d\bar{u}\gamma$ and $W^- \to e\bar{\nu}\gamma$ (Grose and Mikaelian, 1981). The gauge zero for $\kappa = 1$ and $\lambda = 0$ is partially filled in due to the sea-quark contributions and becomes a gauge minimum. For $\kappa \neq 1$ or $\lambda \neq 0$ this gauge minimum gets completely filled in due to the quadratic dependence on $\Delta\kappa = \kappa - 1$ and λ. The gauge minimum is also reflected in the photon η_γ distribution as a dip near $\eta_\gamma = 0$. Both the magnetic dipole moment and the electric quadrupole moments contribute approximately equally in amplitude and interfere destructively to form the gauge zero (RAZ). Because the number of events will still be limited, it may still not be possible to make use of the RAZ.

The philosophy we employ here is that one need only consider values of $\kappa \neq 1$ with $\lambda = 0$ in order to check the Standard Model (SM) and see if $\kappa = 1$, the SM value. If the SM fails, then one needs to fit both $\kappa \neq 1$ and $\lambda \neq 0$. Only if there is a breakdown of the SM will it be necessary to fit both κ and λ and see if one can distinguish between them. For results for the general case, $\kappa \neq 1$ and $\lambda \neq 0$, see Samuel *et al.* (1991c), Baur and Berger (1990), Baur and Zeppenfeld (1988), Behrends *et al.* (1985), and Behrends and Kleiss (1985).

In this paper we consider the bounds which one will be able to obtain from the total number of $W\gamma$ events and radiative decays from the next run of CDF, when they will have 20 times more integrated luminosity, under two scenarios: (1) The expected SM results are obtained. (2) The relative number of events is the same as in the previous run, i.e., they will obtain 20 times more $W\gamma$ events and 20 times more W radiative decays.

We consider scenario 1 first and use the same cuts, experimental acceptances, and efficiencies as in Samuel *et al.* (1992), which were chosen to be the same as used in the experiment. These cuts include [for CDF results see Abe *et al.* (1989, 1990, 1991)]: (1) the transverse photon energy $E_{T_\gamma} > 5$ GeV; (2) the photon pseudorapidity $|\eta_\gamma| < 3.0$; (3) the electron–photon angular separation $n_\phi = [(\Delta\eta)^2 + (\Delta\phi)^2]^{1/2} > 0.3$.

The $W\gamma$ events have large $n_\phi \approx 2.4$–2.6 (γ opposite to the e direction), while the radiative decays have small $n_\phi \approx 0.8$ (low-energy γ and parallel to the e direction) and can thus be separated.

The electron acceptance factor is $A_e = 0.41$ with fiducial cuts included, and its detection efficiency is $\epsilon_e = 0.67$. The photon acceptance factor for $\eta_\gamma \leq 3$ is estimated to be $A_\gamma = 0.54$ and its detection efficiency is $\epsilon\gamma = 0.50$. The QCD correction factor κ_{DY} (for the Drell–Yan process) is taken as 1.3. The QCD corrections for $p\bar{p} \to W\gamma X$ have been calculated by Smith *et* *al.* (1986, 1989). The electron–photon angular cut is given above. Our result for the number of $W\gamma$ events is

$$n = 29.8 - 0.546\eta + 1.294\eta^2 \tag{3}$$

where $\eta = \kappa - 1$. For 20% systematic error at 95% C.L. we obtain the bound

$$-2.0 \leq \kappa \leq 4.4 \tag{4}$$

while for 95% C.L. and 10% systematic error we get

$$-1.6 \leq \kappa \leq 4.0 \tag{5}$$

These results are shown in Fig. 1. For radiative W decays we use the same electron–photon angular cut as above and the number of events is given by

$$n = 155.8 + 0.630\eta + 0.894\eta^2 \tag{6}$$

For 95% C.L. and 20% systematic error the bound attainable will be

$$-7.2 \leq \kappa \leq 8.5 \tag{7}$$

while for 95% C.L. and 10% systematic error it is

$$-5.4 \leq \kappa \leq 6.7 \tag{8}$$

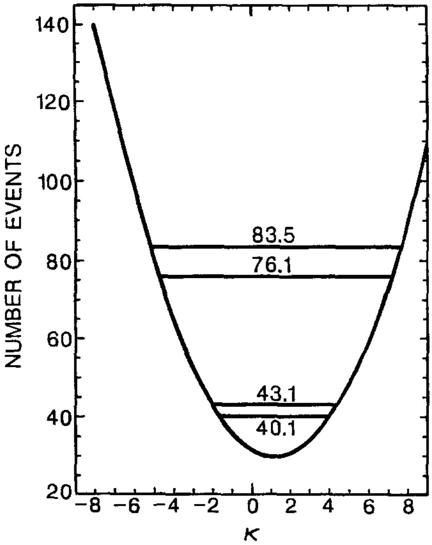

Fig. 1. Number of events vs. κ for $W\gamma$. The line at 43.1 (40.1) corresponds to 95% C.L. and 20% (10%) systematic error for scenario 1, while the line at 83.5 (76.1) corresponds to 95% C.L. and 20% (10%) systematic error for scenario 2.

These results are shown in Fig. 2. If we do not separate the $W\gamma$ events and the radiative W decays, the total number of events is given by

$$n = 185.6 + 0.0840\eta + 2.188\eta^2 \tag{9}$$

For 95% C.L. and 20% systematic errors we can obtain the bound

$$-4.5 \leq \kappa \leq 6.4 \tag{10}$$

while for 10% systematic error and 95% C.L. it is

$$-3.2 \leq \kappa \leq 5.1 \tag{11}$$

These results are shown in Fig. 3.

We now turn to scenario 2. Here we consider the situation if CDF will measure 20 times the number of events measured in the first run, i.e., the number of W gamma events, for 20% systematic error, which may be obtained in the future is

$$n = 60 \pm 14.3 \tag{12}$$

Actually the number of events measured in the first run is

$$n = 3 - B \tag{13}$$

where B is the estimated background

$$B = 1.5 \tag{14}$$

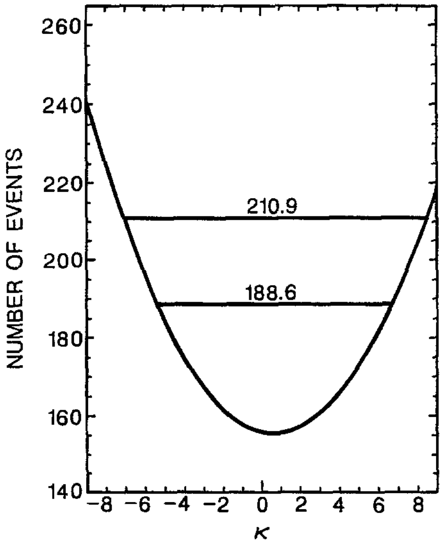

Fig. 2. Number of events vs. κ for radiative W decay. The line at 210.9 (188.6) corresponds to 95% C.L. and 20% (10%) systematic error for scenario 1.

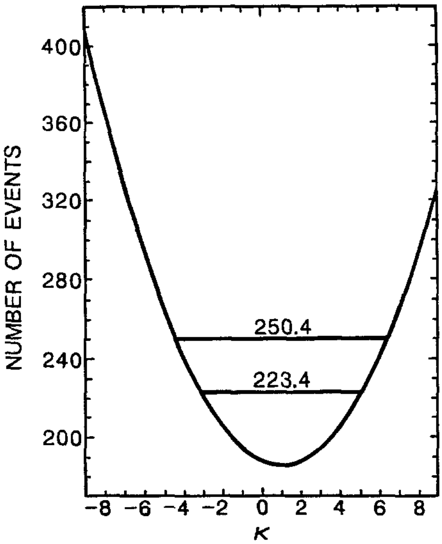

Fig. 3. Number of events vs. κ for the sum of $W\gamma$ events and radiative W decay. The line at 250.4 (223.4) corresponds to 95% C.L. and 20% (10%) systematic error for scenario 1.

As a conservative estimate we use $n < 83.5$ at 95% C.L. Actually the bounds obtained may be better than we obtain here. Using the result given in equation (3), we find the bound

$$-5.2 \leq \kappa \leq 7.7 \tag{15}$$

while for 10% systematic errors it is

$$-4.8 \leq \kappa \leq 7.2 \tag{16}$$

at 95% C.L. These results are shown in Fig. 1.

If one takes the 95% C.L. result

$$0.82 \leq n = 3 \leq 7.75 \tag{17}$$

and multiplies by a factor of 20, one obtains

$$16.4 \leq n = 60 \leq 155 \tag{18}$$

at the 95% C.L. Here again we have

$$n = 3 - B \tag{19}$$

where

$$B = 1.5 \tag{20}$$

Again to be on the conservative side, we take the 95% C.L. bound with 20% systematic error as

$$n < 167 \tag{21}$$

Again the bounds obtainable may be better than ours.

Using equation (6), one obtains the bound

$$-1.9 \leq \kappa \leq 4.2 \tag{22}$$

For 10% systematic error a slightly better bound is obtained,

$$-1.8 \leq \kappa \leq 3.0 \tag{23}$$

In conclusion, we have shown that in about 2 years when CDF has 20 times more integrated luminosity we will be able to obtain some good bounds.

The results for UA2 at CERN are given in Alitti *et al.* (1992). They use only the total number of events, $W\gamma$ + radiative W decay. However, contrary to CDF, it appears that they observe more radiative W decays than $W\gamma$ events, as predicted by the SM. This could be due to their much smaller ΔR cut (15 degs). Note that the photon-detection efficiency in the small ΔR (lepton–photon) regime may be overestimated, due to the electron and photon isolation cuts which Timko (1990) used in his analysis. This could lead to a prediction of a larger-than-observed number of radiative W-decay events. This point should be clarified in the analysis of future experiments. Although the UA2 group has completed its work, CDF and D0 at Fermilab are taking data and should have new preliminary experimental results out in the near future. We note that new results from CDF and D0 are needed to test the SM more precisely. With more events, one will be able to improve the bounds obtained from the total number of $W\gamma$ events and radiative W decays. When the number of events increases sufficiently, one will be able to obtain an angular distribution for $W\gamma$ and an energy distribution for radiative W decay. Then one should be able to see the RAZ and obtain a precise value for K. We are awaiting these new results with great anticipation and excitement.

ACKNOWLEDGMENTS

One of us (M.A.S.) would like to thank Eran Yehudai for very helpful discussions. He would also like to thank the theory group at Fermilab for their kind hospitality during his stay. This work was supported by the Natural Science and Engineering Research Council of Canada through grant no. OGP0001574 and URF 43989IN. This work was also supported by the U.S. Department of Energy under grant no. DE-FG05-85ER40215. This is Oklahoma State University Research Note 272.

REFERENCES

Abe, F., *et al.* (1989). *Physical Review Letters,* **63**, 720.

Abe, F., *et al.* (1990). *Physical Review Letters,* **65**, 2243.

Abe, F., *et al.* (1991). *Physical Review D,* **43**, 2070.

Alitti, J., *et al.* (1992). *Physics Letters B,* **277**, 194.

Baur, U., and Berger, E. L. (1990). *Physical Review D,* **41**, 1476.

Baur, U., and Zeppenfeld, D. (1988). *Nuclear Physics B,* **308**, 127.

Behrends, F., and Kleiss, R. (1985). *Zeitschrift für Physik C,* **27**, 365.

Behrends, F., *et al.* (1985). *Zeitschrift für Physik C,* **27**, 155.

Grose, T. R., and Mikaelian, K. O. (1981). *Physical Review D,* **23**, 123.

Mikaelian, K., Samuel, M. A., and Sahdev, D. (1979). *Physical Review Letters,* **43**, 746.

Samuel, M. A., Li, G., Sinha, N., Sinha, R., and Sundaresan, M. K. (1991a). *Physical Review Letters,* **67**, 9.

Samuel, M. A., Sinha, N., Sinha, R., and Sundaresan, M. K. (1991c). *Physical Review D,* **44**, 2064.

Samuel, M. A., Li, G., Sinha, N., Sinha, R., and Sundaresan, M. K. (1992a). *Physics Letters B,* **280**, 124.

Smith, J., van Neerven, W. L., and Vermaseren, J. A. M. (1986). *Zeitschrift für Physik C,* **30**, 621.

Smith, J., Thomas, D., and van Neerven, W. L. (1989). *Zeitschrift für Physik C,* **44**, 267.

Timko, M. (1990). Status of $W\gamma$ search at CDF, Contribution, Spring Meeting, American Physical Society, Washington, D.C., April 1990.