Disclaimer

DØ Note 2862

Electroweak Results from the DØ Detector at Fermilab

Brajesh Chandra Choudhary
Department of Physics, University of California
Riverside, CA 92521, USA

Representing the DØ Collaboration*

Abstract

We present a measurement of the inclusive W and Z production cross-section from ≈ 14 pb^{-1} of data from the 1992-93 collider run at the Fermilab Tevatron. From the ratio measurement of $\sigma_W * B(W \rightarrow l\nu)/\sigma_Z * B(Z \rightarrow ll)$ we put a limit on the unexpected decay modes of the W boson. We present preliminary results on the transverse momentum distribution of W and Z bosons. We present a limit on the anomalous coupling parameters related to the electric/magnetic moments of the W and Z bosons from the processes $p\overline{p} \rightarrow W(l\nu)W(l\nu) + X$, $p\overline{p} \rightarrow W(l\nu)W(jj)/W(l\nu)Z(jj) + X$, $p\overline{p} \rightarrow W(l\nu)\gamma + X$, and $p\overline{p} \rightarrow Z(ll)\gamma + X$.

*Invited talk given at the 2nd Rencontres Du Vietnam, Ho Chi Minh Ville, October 22-28, 1995, Vietnam.

The age of electroweak physics began with the discovery of the W and Z bosons at the CERN $Sp\bar{p}S$ in 1983[1]. In the last decade, the Standard Model (SM) predictions have been confirmed to high precision from e^+e^- experiments at LEP[2], SLC[3] and $p\bar{p}$ experiments at the Tevatron[4]. In this article, we will discuss some of the important electroweak results[5-9] from ≈ 14 pb^{-1} of data collected by the DØ experiment during the 1992-1993 run. Some preliminary results will also be discussed using the partial data set collected during the 1994-95 run.

1 Inclusive W and Z Production Cross-Section

At a center of mass energy of $\sqrt{s} = 1.8$ TeV, W and Z bosons are primarily produced by $q\bar{q}$ annihilation often accompanied by gluon emission. The leptonic decay modes of W and Z boson are respectively characterized by a high transverse momentum (P_T) lepton accompanied by large missing transverse energy ($\not{E}_T$) and two high P_T leptons. The inclusive production cross-sections, σ_W and σ_Z for W and Z bosons have been calculated[10] to the order of $\alpha_s{}^2$. The cross-section measurement provides insight into the SM of electroweak and strong interactions and also into the structure of nucleons. The measurement of the ratio of cross-section times branching ratio for W and Z boson $R = \sigma_W * B(W \to l\nu)/\sigma_Z * B(Z \to ll)$ can be used to extract the width of W, Γ_W, and hence can be used to put a limit on the unexpected decay modes of W.

The inclusive cross-section for a W decaying into a lepton and a neutrino is calculated as

$$\sigma_W * B(W \to l\nu) = \frac{N_{obs} - N_{bkg}}{\mathcal{A}_W * \epsilon_W * \mathcal{L}} \tag{1}$$

where N_{obs} is the number of observed events, N_{bkg} is the number of expected background events, $\mathcal{A}_W$ is the acceptance, ϵ_W is the detection efficiency and $\mathcal{L}$ is the integrated luminosity used for the analysis. The Z boson cross-section, σ_Z, for decays into two leptons is calculated in a similar fashion.

The measured cross-section times branching ratio values are listed in Table 1 and are compared with theoretical predictions and CDF[11] result in Figure 1. The total cross cross-sections are calculated to be $\sigma_W = 22.35$ nb and $\sigma_Z = 6.71$ nb using $M_W = 80.23 \pm 0.18$ GeV/c^2[12], $M_Z = 91.19 \pm 0.004$ GeV/c^2[13], $\sin^2\theta_W \equiv 1 - (M_W/M_Z)^2 = 0.2259$ and the CTEQ2M parton distribution function (pdf)[14]. The predicted cross-section times branching ratio values $\sigma_W * B(W \to l\nu) = 2.42^{+0.13}_{-0.11}$ and $\sigma_Z * B(Z \to ll) = 0.226^{+0.011}_{-0.009}$ are estimated using the leptonic branching ratio $B(W \to l\nu) = 10.84 \pm 0.02\%$[15] and $B(Z \to ll) = 3.367 \pm 0.006\%$[13]. The widths of the bands in Fig. 1 indicate the error in the predicted values primarily due to the choice of structure function (4.5%) and the uncertainty due to the use of an NLO pdf with a full NNLO theoretical calculation (3%). The experimental error is dominated by the uncertainty on the luminosity (5.4%).

The ratio of the measured cross-section can be used to measure the leptonic branching ratio $B(W \to l\nu)$ and the total width of W, Γ_W. The systematics due to luminosity and choice of pdf cancel in the ratio measurement. The ratio expression

$$R = \frac{\sigma_W * B(W \to l\nu)}{\sigma_Z * B(Z \to ll)} = \frac{\sigma_W}{\sigma_Z} * \frac{\Gamma(W \to l\nu)}{\Gamma(W)} * \frac{1}{B(Z \to ll)} \tag{2}$$

can be written as

$$\Gamma_W = \frac{\sigma_W}{\sigma_Z} * \frac{\Gamma(W \to l\nu)}{B(Z \to ll)} * \frac{1}{R} \tag{3}$$

Table 1: Measured cross-section times branching ratio values for W and Z bosons decaying into electron(e) and muon(μ) channels. The first error is statistical and the second is systematic.

	$\sigma_W * B(W \to l\nu)$(nb)	$\sigma_Z * B(Z \to ll)$(nb)	R
1992-93			
e	2.36±0.02±0.15	0.218±0.008±0.014	10.82±0.41±0.30
μ	2.09±0.06±0.25	0.178±0.022±0.023	$11.8^{+1.8}_{-1.4}\pm1.1$
DØ(e+μ)			10.90±0.49 (stat.⊕syst.)
1994-95 (preliminary)			
e	2.24±0.02±0.20	0.226±0.006±0.021	9.9±0.3±0.8
μ	1.93±0.04±0.20	0.159±0.014±0.022	12.3±1.1±1.2
Standard Model	$2.42^{+0.13}_{-0.11}$	$0.226^{+0.011}_{-0.009}$	

Using the value R(e+μ) = 10.90±0.49 as shown in Table 1, $\sigma_W/\sigma_Z = 3.33\pm0.03$[10], $B(Z \to ll) = 3.367\pm0.006\%$[13] and $\Gamma(W \to l\nu) = 225.2 \pm 1.5$ MeV[15] we obtain $\Gamma(W)_{D\emptyset} = 2.044\pm0.091(\text{expt})\pm0.017(\text{theo}) = 2.044\pm0.093$ GeV which is in very good agreement with the SM value of $\Gamma(W)_{SM} = 2.077\pm0.014$ GeV[12,15]. The world average[4, and references therein] as shown in Fig. 2 is $\Gamma(W)_{WORLD} = 2.062\pm0.059$ GeV. By comparing this value to the SM value, an upper limit of $\Delta\Gamma_W < 109$ MeV at 95% confidence limit (CL) could be placed on the excess width allowed by experiment for non-Standard Model decays of W, such as W decaying into heavy quarks, or supersymmetric charginos or neutralinos.

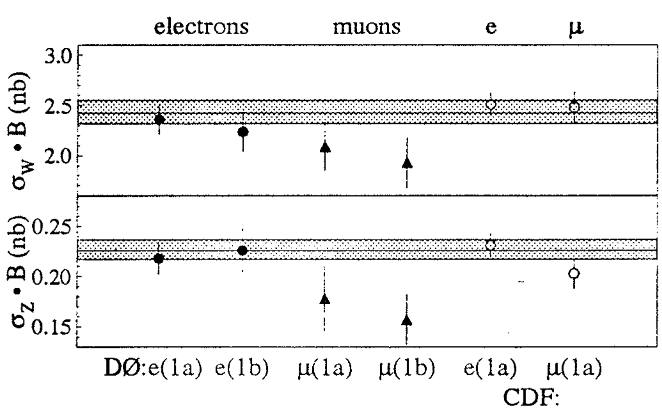


Figure 1: $\sigma * B$ for inclusive W and Z boson production. DØ 1994-95 results e(1b) and μ(1b) are preliminary. The error bars indicate the statistical, systematic and luminosity errors added in quadrature. The solid lines are the SM predicted values. The shaded bands indicate the uncertainty in the SM prediction.

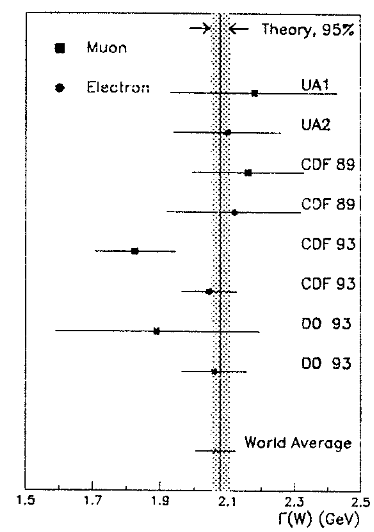


Figure 2: Measurements of Γ_W compared with the standard model expectation.

2 Measurement of W and Z Boson P_T (P_T^W and P_T^Z)

At the Tevatron W and Z bosons are primarily produced by $q\bar{q}$ annihilation. The transverse momentum to the boson is provided by initial state gluon radiation. The low $P_T(P_T^W, P_T^Z < 20$ GeV/c) part of the spectrum is dominated by multiple soft gluon emission and the production cross-section is calculated using a soft gluon resummation technique[16-20]. The high $P_T(P_T^W, P_T^Z > 20$ GeV/c) part of the spectrum is well described by perturbative QCD[21]. A measurement of the low P_T part of the spectrum could be used as a constraint on QCD resummation calculations and a measurement of the high P_T part of the spectrum could be used as a sensitive test of perturbative QCD. Deviation from the predicted spectrum at high P_T could indicate the possibility of new physics. A good understanding of the P_T^W spectrum is also necessary for a precise measurement of the W mass.

We have measured P_T^W and P_T^Z in the electron channel. P_T^W is determined from the hadronic recoil of the W, while P_T^Z is determined from the sum of two electron transverse momenta. Fig. 3 and 4 respectively show the background subtracted P_T^W and P_T^Z spectrum compared with theoretical predictions smeared by detector resolutions. Although the results are preliminary and need better understanding of the systematics, we do see a good agreement between data and theory.

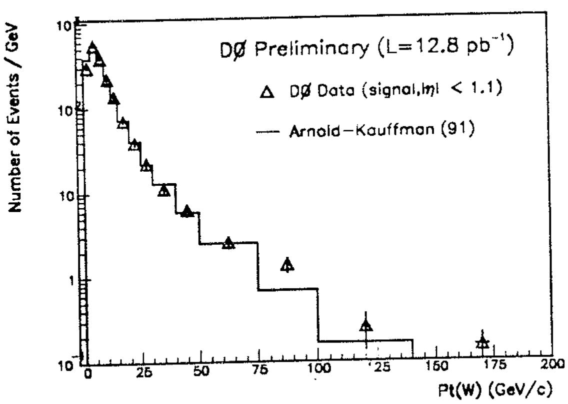


Figure 3: Background subtracted P_T^W distribution of data for $|\eta| < 1.1$ (triangles) compared with smeared theoretical predictions[19] (histogram).

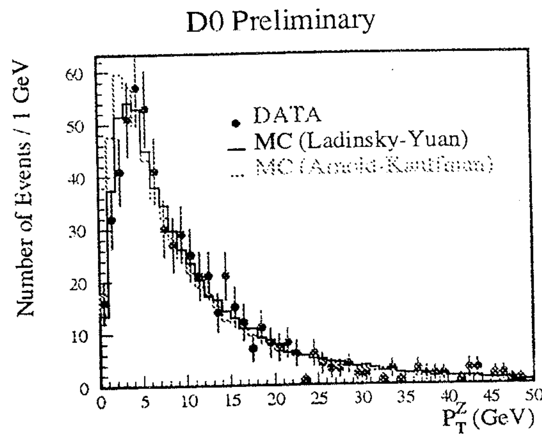


Figure 4: Background subtracted P_T^Z distribution of data for $|\eta| < 1.1$ and $1.5 < |\eta| < 2.5$ (solid dots) compared with smeared theoretical predictions by [19] (gray histogram) and [20] (dark histogram).

3 Triple Gauge Boson Couplings

In the SM the self coupling of gauge bosons are due to the non-Abelian nature of the theory. Deviations from the predicted behaviour cause the model to be non-renormalizable or, to violate unitarity in high energy scattering[22]. In the SM u and t channel diagram amplitudes cancel each other, thus ensuring the unitarity of the multiboson production. The Lagrangian with fixed anomalous coupling violates unitarity and thus at high energy the coupling is modified by a form factor with a scale Λ, which is usually defined as the scale of new physics. The only allowed coupling in the SM are between charged and neutral particles i.e, WWV $(V = Z, \gamma)$. Self coupling between neutral particles i.e, $ZV\gamma$ $(V = Z, \gamma)$ is not allowed. Observation of excess diboson events could signal new physics[23].

We have studied the anomalous gauge boson couplings in the WWZ, $WW\gamma$, $ZZ\gamma$ and $Z\gamma\gamma$ channels. The WW production process depends strongly on the $WW\gamma$ and WWZ coupling parameters due to destructive interference among contributing amplitudes. The most general effective Lagrangian[24], invariant under $U(1)_{\rm EM}$, for the electroweak gauge interaction contains eight independent coupling parameters, the $\mathcal{CP}$–conserving parameters κ_V and λ_V and the

$\mathcal{CP}$−violating parameters $\tilde{\kappa}_V$ and $\tilde{\lambda}_V$, where $V = Z, \gamma$. The coupling parameters are related to the magnetic dipole moment $\mu_W = (e/2m_W)(1 + \kappa_\gamma + \lambda_\gamma)$, electric quadrupole moment $Q^e_W = (-e/m^2_W)(\kappa_\gamma - \lambda_\gamma)$, electric dipole moment $d_W = (e/2m_W)(\tilde{\kappa}_\gamma + \tilde{\lambda}_\gamma)$, and magnetic quadrupole moment $Q^m_W = (-e/m^2_W)(\tilde{\kappa}_\gamma - \tilde{\lambda}_\gamma)$ of the W boson[25]. In the SM, at the tree level the couplings are uniquely determined by the $SU(2)_{\rm L} \times U(1)_{\rm Y}$ gauge symmetry. In SM $\Delta\kappa_\gamma = \lambda_\gamma = \Delta\kappa_Z = \lambda_Z = 0$. The $\mathcal{CP}$−violating coupling parameters $\tilde{\kappa}_\gamma = \tilde{\lambda}_\gamma = \tilde{\kappa}_Z = \tilde{\lambda}_Z = 0$. Non-zero coupling parameters result in an increase of the production cross-section and an enhancement in the $P^V_T, (V = W, Z, \gamma)$ spectrum at the high P^V_T region. A study of the $P^V_T, (V = W, Z, \gamma)$ spectrum thus provides a direct test of the $WW\gamma$ and WWZ couplings.

The SM predicts the production cross-section for $p\overline{p} \rightarrow W^+W^-$ and $p\overline{p} \rightarrow W^\pm Z$ to be 9.5 pb and 2.5 pb at $\sqrt{s} = 1.8$ TeV[26]. For $WW\gamma$ and WWZ couplings we have searched in the $p\overline{p} \rightarrow WW + X \rightarrow \ell\ell'\nu\nu'(\ell\ell' \rightarrow ee, e\mu, \mu\mu)$ channel. One event is found in ≈ 14 pb^{-1} of data with an expected background of 0.54 events. The total efficiency is 7.8% and the SM expectation is 0.46 events. The main source of the background to this channel is $t\bar{t} \rightarrow WWb\bar{b}$[27]. To reduce the background from $t\bar{t}$ substantially we require that the vector sum of the E_T from hadrons $\vec{E}^{\rm HAD}_T$ defined as $|-(\vec{E}^{\ell_1}_T + \vec{E}^{\ell_2}_T + \not{E}_T)|$ to be less than 40 GeV. As shown in Fig. 5 this requirement reduces 75% of the $t\bar{t}$ background while keeping 95% of the signal. From the observed event, estimated background, efficiency and luminosity we can put a 95% CL limit of $\sigma(WW) < 87$ pb[7]. As shown in Fig. 6, one can put a limit of $-2.6 < \Delta\kappa < 2.8$ $(\lambda = 0)$ and $-2.1 < \lambda < 2.1$ $(\Delta\kappa = 0)$ at 95% CL on the coupling parameters from the observed limit as a function of κ and λ and the theoretical prediction of W boson pair production.

We have also looked into the channels $WW, WZ \rightarrow e\nu + \geq$2jets. Although this channel has 4.5 times higher branching ratio than the $p\overline{p} \rightarrow WW + X \rightarrow \ell\ell'\nu\nu'(\ell\ell' \rightarrow ee, e\mu, \mu\mu)$ channel, this channel suffers from much higher $W \rightarrow e\nu +$jets background. However at higher $P^W_T(W \rightarrow e\nu)$ the backgrounds are small and the sensitivity to $WW\gamma/WWZ$ anomalous coupling is enhanced. We have analyzed ≈ 14 pb^{-1} of data for this channel selecting events with a high E_T electron, large $\not{E}_T$ to be consistent with a $W \rightarrow e\nu$ and two jets with $E^{\rm jet}_T > 30$ GeV, and mass of the dijet system to be consistent with mass of W/Z, i.e, $50 < m_{jj} < 110$ GeV/c^2. We observe a total of 84 events in the data, while the background from $W + \geq$2jets, multijet and other sources is 75.5±13.3 events. The SM expectation is 2.9±0.5 events for WW and WZ combined production. We do not see any excess of high P^W_T events. Using the measured efficiencies and the background subtracted signal, we set a 95% CL upper limit on the cross-section times branching fraction for $\sigma * B(W^+W^- \rightarrow e^\pm\nu jj) + \sigma * B(W^\pm Z \rightarrow e^\pm\nu jj)$ for the SM case to be 17 pb. To set a limit on the anomalous coupling parameters, a binned likelihood fit was performed on the P_T spectrum of the $W \rightarrow e\nu$ system, allowing the MC signal prediction as a function of coupling parameters and the expected backgrounds to fluctuate to the observed number of events. Under the assumption that $\mathcal{CP}$−violating couplings are zero, $\Delta\kappa \equiv \Delta\kappa_\gamma \equiv \Delta\kappa_Z$, $\Delta\lambda \equiv \Delta\lambda_\gamma \equiv \Delta\lambda_Z$, and $\Lambda = 1.5$ TeV, we obtain a preliminary 95% CL of $-0.89 < \Delta\kappa < 1.07$ $(\lambda = 0)$ and $-0.66 < \lambda < 0.67$ $(\Delta\kappa = 0)$.

We have also studied $WW\gamma$ production where a photon is produced with a W in the final state, either through initial state or final state radiation or through an $s-$channel diagram which is sensitive to $WW\gamma$ coupling. We require that the event should consist of a high P_T isolated lepton (e or μ), large $\not{E}_T$ and an isolated photon of $P^\gamma_T > 10$ GeV/c. It is also required that the photon and lepton should be separated in phase space by $\Delta R(l-\gamma) > 0.7$. In ≈ 14 pb^{-1} of data we observe a total of 23 events and estimate the total background to be 6.4±1.4 events which is consistent with SM expectation of $16.6^{+5.9}_{-3.9} \pm 1.4$ events. Using a binned likelihood method to fit the P^γ_T spectrum for a form factor scale $\Lambda = 1.5$ TeV, we obtain limit on the coupling parameters to be $-1.6 < \Delta\kappa < 1.8$ $(\lambda = 0)$ and $-0.6 < \lambda < 0.6$ $(\Delta\kappa = 0)$ at the 95% CL. We also rule out $\mathrm{U(1)_{EM}}$ coupling of W boson at 80% CL[8].

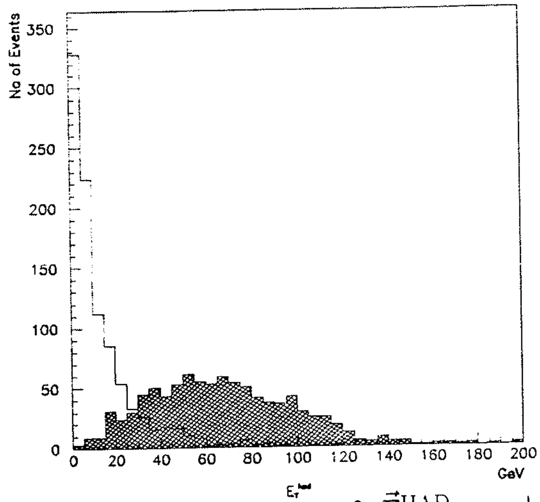


Figure 5: Distribution of $\vec{E}_T^{\rm HAD} = |-(\vec{E}_T^{\ell_1} + \vec{E}_T^{\ell_2} + \not{\vec{E}}_T)|$ for $WW \to e\mu$ (histogram) and $t\bar{t} \to e\mu$ events (hatched).

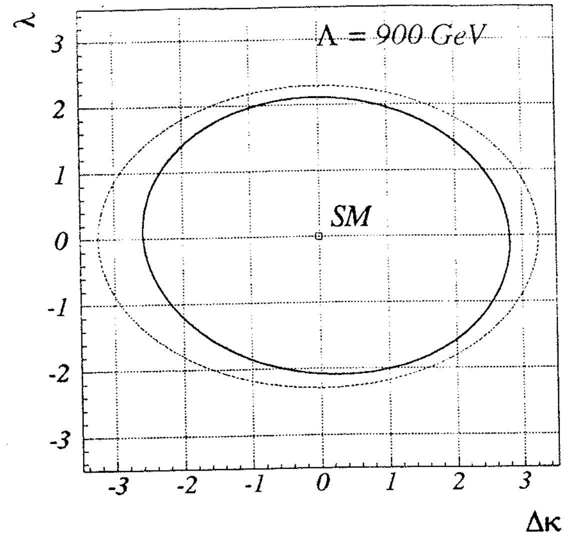


Figure 6: Contour limits on $\Delta\kappa$ and λ from the measured $WW \to \ell\ell'\nu\nu$ event rate.

CLEO[28] has studied the flavor-changing neutral current process $b \to s\gamma$ which is described by a penguin diagram in which a virtual W is exchanged in a loop with a top quark, with a photon emitted from any of the lines[29]. This process is sensitive to the $WW\gamma$ couplings and the measured inclusive $b \to s\gamma$ branching ratio is $2.32 \pm 0.57 \pm 0.35 \times 10^{-4}$. Fig. 7 shows the measured limits on $\Delta\kappa$ and λ for the $W\gamma$ production from DØ[8], CDF[30] and CLEO[28].

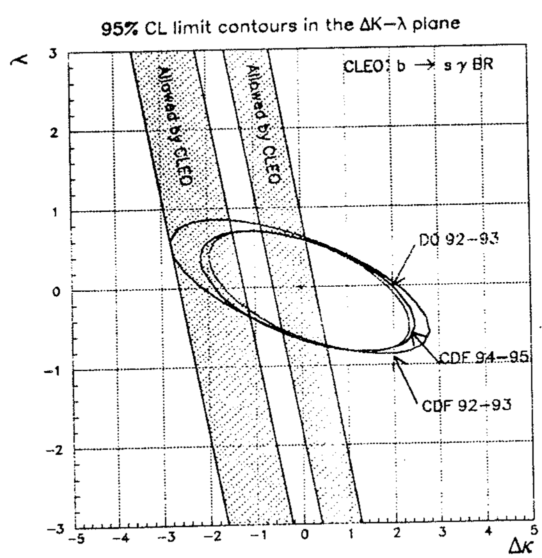


Figure 7: Limits on anomalous couplings $\Delta\kappa, \lambda$ from $W\gamma$-production from CDF, DØ and CLEO.

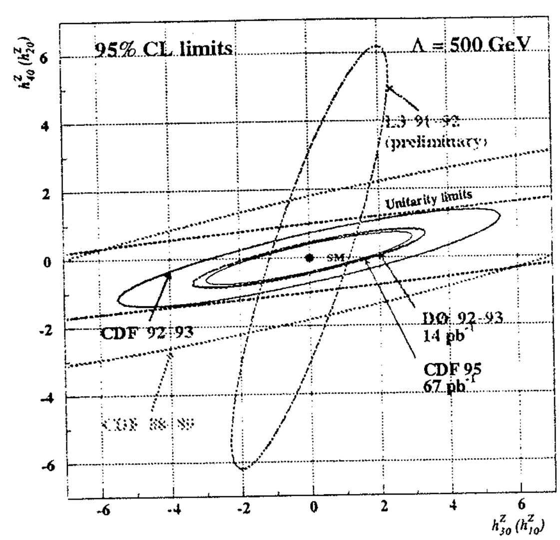


Figure 8: Limits on anomalous couplings h_{30}^Z, h_{40}^Z from $Z\gamma$-production from CDF, DØ and L3.

We have also analyzed 55 pb^{-1} of the 1994-95 run data for the $W\gamma$ process where a W decays into an electron and a neutrino. We find the results to be consistent with the SM expectation and the combined preliminary limit on anomalous coupling parameters from the 1992-93 published result[8] and the 1994-94 electron data at the 95% CL is $-1.46 < \Delta\kappa < 1.40$ $(\lambda = 0)$ and $-0.4 < \lambda < 0.4$ $(\Delta\kappa = 0)$ for $\Lambda = 1.5$ TeV. Work is in progress to combine limits from the $W\gamma \to l\nu\gamma$, $WW \to ll\nu\nu$ and $WW/WZ \to l\nu jj$ channels and put a tighter limit on $\Delta\kappa$ and λ.

Since the Z and photon do not couple to each other, the study of $Z\gamma$ production is sensitive to anomalous coupling ($ZV\gamma$ ($ZZ\gamma$ and $Z\gamma\gamma$)) beyond SM. The most general Lorentz and gauge invariance for the $ZZ\gamma(Z\gamma\gamma)$ vertex is described by eight coupling parameters $h_i^V, (i = 1, ..., 4)$ where $V = Z, \gamma$. In SM at tree level all these couplings are $h_i^V = 0$. While h_1^V and h_2^V are $\mathcal{CP}$–violating, h_3^V and h_4^V are $\mathcal{CP}$–conserving. At very high energy like WWV coupling, $ZV\gamma$ coupling is also regulated by a form factor with scale Λ to preserve the unitarity bound. Although the $WW\gamma$ process is insensitive to the scale Λ at the Tevatron beyond $\Lambda_W >$ a few 100 GeV, the effect of the form factor is sensitive to $Z\gamma$ couplings due to a higher power of $\hat{s}$ dependence in the $ZV\gamma$ vertex function.

We have looked for $Z\gamma$ events in the electron and muon channels. The event is required to have two isolated high P_T leptons (e or μ) and an isolated photon with $P_T^\gamma > 10$ GeV/c. It is also required that both the leptons be separated from the photon by $\Delta R(l - \gamma) > 0.7$, to reduce background from radiative Z decay. In ≈ 14 pb^{-1} of data we observe 6 events with an estimated background of 0.5 events and SM expectation of 5.7 events. Using a binned likelihood to fit the P_T^γ spectrum, assuming no $\mathcal{CP}$–violation and a form factor scale $\Lambda = 500$ GeV, we put limit on $\mathcal{CP}$–conserving coupling parameters at 95% CL at $-1.8 < h_{30}^Z < 1.8$ ($h_{40}^Z = 0$) and $-0.5 < h_{40}^Z < 0.5$ ($h_{30}^Z = 0$). The limits on corresponding $Z\gamma\gamma$ couplings and $\mathcal{CP}$–violating couplings are nearly identical[9]. Fig. 8 shows the limit on $Z\gamma$ coupling from DØ[9], CDF[31] and L3 [32]. The limit from L3 is complementary to both the DØ and CDF results.

4 Conclusion

DØ has already published several results[4-9] on properties of the W and Z bosons, some of which have been presented here. The experiment has collected nearly 85 pb^{-1} of data during the 1994-95 run. The new data set will reduce the error considerably on most of the measurements thus further constraining the SM.

5 Acknowledgements

I would like to thank the organizers for wonderful time in Ho Chi Minh Ville. I would also like to thank Prof. Henry Frisch of University of Chicago for inviting me to attend the conference and present these results and also for providing funds towards travel expense.

References

[1] UA1 Collaboration, G. Arnison *et. al.*, Phys. Lett. **122B**, 103(1983); **126B**, 398(1983); **129B**, 273(1983); UA2 Collaboration, M. Banner *et. al.*, Phys. Lett. **122B**, 476(1983); P. Bagnaia *et. al.*, Phys. Lett. **129B**, 130(1983).

[2] D. Schaile, "Precision data from LEP", Proceedings of International Symposium On Vector Boson Self-Interactions, Los Angeles, CA, Feb 1995, edited by U. Baur, S. Errede and T. Muller (AIP Press) 33.

[3] SLD Collaboration, K. Abe *et. al.*, Phy. Rev. Lett. **73**, 25 (1994).

[4] M. Demarteau, "Electroweak Results from the Tevatron", Proceedings of XV International Conference on Physics in Collision, Cracow, Poland, June 8-10, 1995.

[5] DØ Collaboration, S. Abachi, *et. al.*, Phy. Rev. Lett. **75**, 1456 (1995).

[6] D. L. Puseljic, "Measurement of W and Z p_T Distributions at the Tevatron, Proceedings of the 10th Topical Workshop on Proton-Antiproton Collider Physics, Fermilab, U.S.A, May 1995, edited by R. Raja and J. Yoh (AIP Press) 395.

[7] DØ Collaboration, S. Abachi, *et. al.*, Phy. Rev. Lett. **75**, 1023 (1995).

[8] DØ Collaboration, S. Abachi, *et. al.*, Phy. Rev. Lett. **75**, 1034 (1995).

[9] DØ Collaboration, S. Abachi, *et. al.*, Phy. Rev. Lett. **75**, 1028 (1995).

[10] R. Hamberg, W.L. van Neerven and T. Matsuura, Nucl. Phys. **B359**, 343 (1991); Nucl. Phys. **B382**, 11 (1992).

[11] CDF Collaboration, F. Abe, *et. al.*, Phy. Rev. Lett. **73**, 220 (1994).

[12] M. Demarteau *et. al.*, "Combining W Mass measurement", CDF/PHYS/CDF/PUBLIC 2552 and DØ Note 2115, 1994 (unpublished).

[13] Particle Data Group, L. Montanet *et al.*, Phys. Rev. **D50**, 1191 (1994).

[14] H. L. Lai *et al.*, Phys. Rev. **D51**, 4763 (1995).

[15] J. L. Rosner, M. P. Worah and T. Takeuchi, Phys. Rev. **D49**, 1363 (1994).

[16] J. Collins, D. Soper and G. Sterman, Nucl. Phys. **B250**, 199 (1985); J. Collins and D. Soper, Nucl. Phys. **B197**, 446 (1982); **B193**, 381 (1981).

[17] C. Davies, B. Webber and W. J. Stirling, Nucl. Phys. **B256**, 413 (1985); C. Davies, and W. J. Stirling, Nucl. Phys. **B244**, 337 (1984); C. Davies, Ph. D. Thesis, Churchill Collage (1984).

[18] G. Altarelli, R. K. Ellis, M. Greco and G. Martinelli, Nucl. Phys. **B246**, 12 (1984).

[19] P. B. Arnold, R. Kauffman, Nucl. Phys. **B349**, 381 (1991).

[20] G. A. Ladinsky, C. P. Yuan, Phys. Rev. **D50**, 4239 (1994).

[21] P. B. Arnold and M. H. Reno, Nucl. Phys. **B319**, 37 (1989); R. J. Gonsalves, J. Pawlowski, C. F. Wai, Phys. Rev. **D40**, 2245 (1989).

[22] H.H. Llewellyn Smith, Phys. Lett. **46B**, 233(1973); S.D. Joglekar, Ann. Phys.(NY) **83**, 427(1974); J.M. Cornwall *et al.*, Phy. Rev. Lett. **30**, 1268 (1973).

[23] H. Aihara, *et. al.*, report of the DPF study subgroup on "Anomalous Gauge Boson Interactions", report MAD/PH/871 (1995) (hep-ph/9503425) and references therein.

[24] K. Hagiwara. R. D. Pecci, D. Zeppenfeld and K. Hikasa, Nucl. Phys. **B282**, 253 (1987).

[25] K. Kim and Y. S. Tsai, Phys. Rev. **D**, 3710 (1973).

[26] J. Ohnemus, Phys. Rev. **D44**, 1403 (1991).

[27] DØ Collaboration, S. Abachi, *et. al.*, Phy. Rev. Lett. **74**, 2632 (1995); CDF Collaboration, F. Abe, *et. al.*, Phy. Rev. Lett. **74**, 2626 (1995).

[28] CLEO Collaboration, R. Ammar, *et. al.*, Phy. Rev. Lett. **71**, 674(1993); M. S. Alam, *et. al.*, Phy. Rev. Lett. **74**, 2885(1995).

[29] B. Campbell and P. O. Donnell, Phys. Rev. **D25**, 1989(1982).

[30] CDF Collaboration, F. Abe, *et. al.*, Phy. Rev. Lett. **74**, 1936 (1995).

[31] CDF Collaboration, F. Abe, *et. al.*, Phy. Rev. Lett. **74**, 1941 (1995).

[32] L3 Collaboration, CERN-PPE/94-216, December 15, 1994.

SOME ELECTROWEAK RESULTS FROM THE DØ DETECTOR AT FERMILAB

BRAJESH CHANDRA CHOUDHARY
UNIVERSITY OF CALIFORNIA, RIVERSIDE

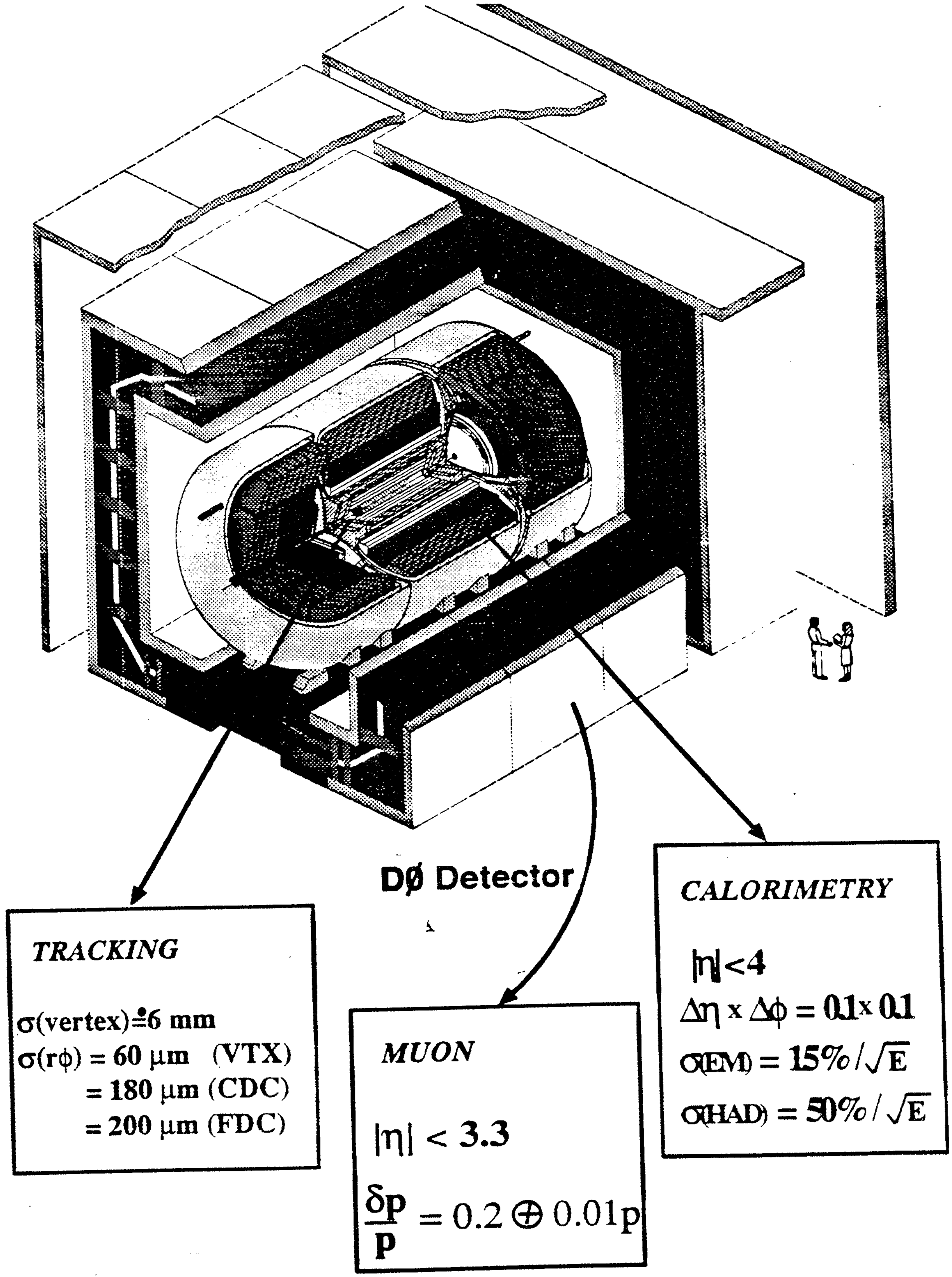
OUTLINE OF THE TALK

1. DØ DETECTOR
2. INCLUSIVE W/Z PRODUCTION X-SECTION
3. $\Gamma(W)$
4. MULTIBOSON PRODUCTION ($W\gamma$, $Z\gamma$, W^+W^-) AND THE TRILINEAR VECTOR BOSON COUPLINGS
5. W AND Z P_T
6. CONCLUSION.

IInd Rencontres Du Vietnam
Ho Chi Minh Ville, Oct 22-28
Vietnam

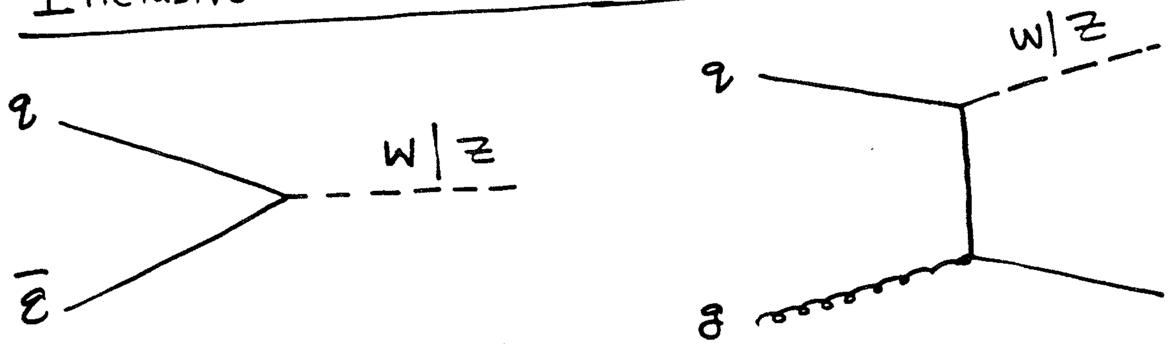
THE DØ COLLABORATION

Universidad de los Andes, Bogota, Colombia
University of Arizona
Brookhaven National Laboratory
Brown University
University of California, Davis
University of California, Irvine
University of California, Riverside
LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
CINVESTAV, Mexico City, Mexico
Columbia University
Delhi University, Delhi, India
Fermi National Accelerator Laboratory
Florida State University
University of Hawaii
University of Illinois, Chicago
Indiana University
Iowa State University
Korea University, Seoul, Korea
Kyungsung University, Pusan, Korea
Lawrence Berkeley Laboratory
University of Maryland
University of Michigan
Michigan State University
Moscow State University, Russia
University of Nebraska
New York University
Northeastern University
Northern Illinois University
Northwestern University
University of Notre Dame
University of Oklahoma
Panjab University, Chandigarh, India
Institute for High Energy Physics, Protvino, Russia
Purdue University
Rice University
University of Rochester
CEA, DAPNIA/Service de Physique des Particules, CE-SACLAY, France
Seoul National University, Seoul, Korea
State University of New York, Stony Brook
Superconducting Supercollider Laboratory
Tata Institute of Fundamental Research, Bombay, India
University of Texas, Arlington
Texas A&M University



DØ Detector
TRACKING
σ(vertex)≐6 mm
σ(rφ) = 60 μm (VTX)
= 180 μm (CDC)
= 200 μm (FDC)
MUON
|η| < 3.3
δp/p = 0.2 ⊕ 0.01p
CALORIMETRY
|η|<4
Δη x Δφ = 0.1 x 0.1
σ(EM) = 15%/√E
σ(HAD) = 50%/√E

Inclusive W and Z Production X-Section



@ $\sqrt{s} = 1.8$ TeV, Valence - Sea Contribution $\simeq 55\%$

Sea - Sea Contribution $\simeq 20\%$

X-section calculated to $O(\alpha_s^2)$ (Van Neerven et. al)

Event Characteristics:-

W's : A high P_T isolated lepton, large $\not{E}_T$

$E_T^e > 25$ GeV, $\not{E}_T > 25$ GeV

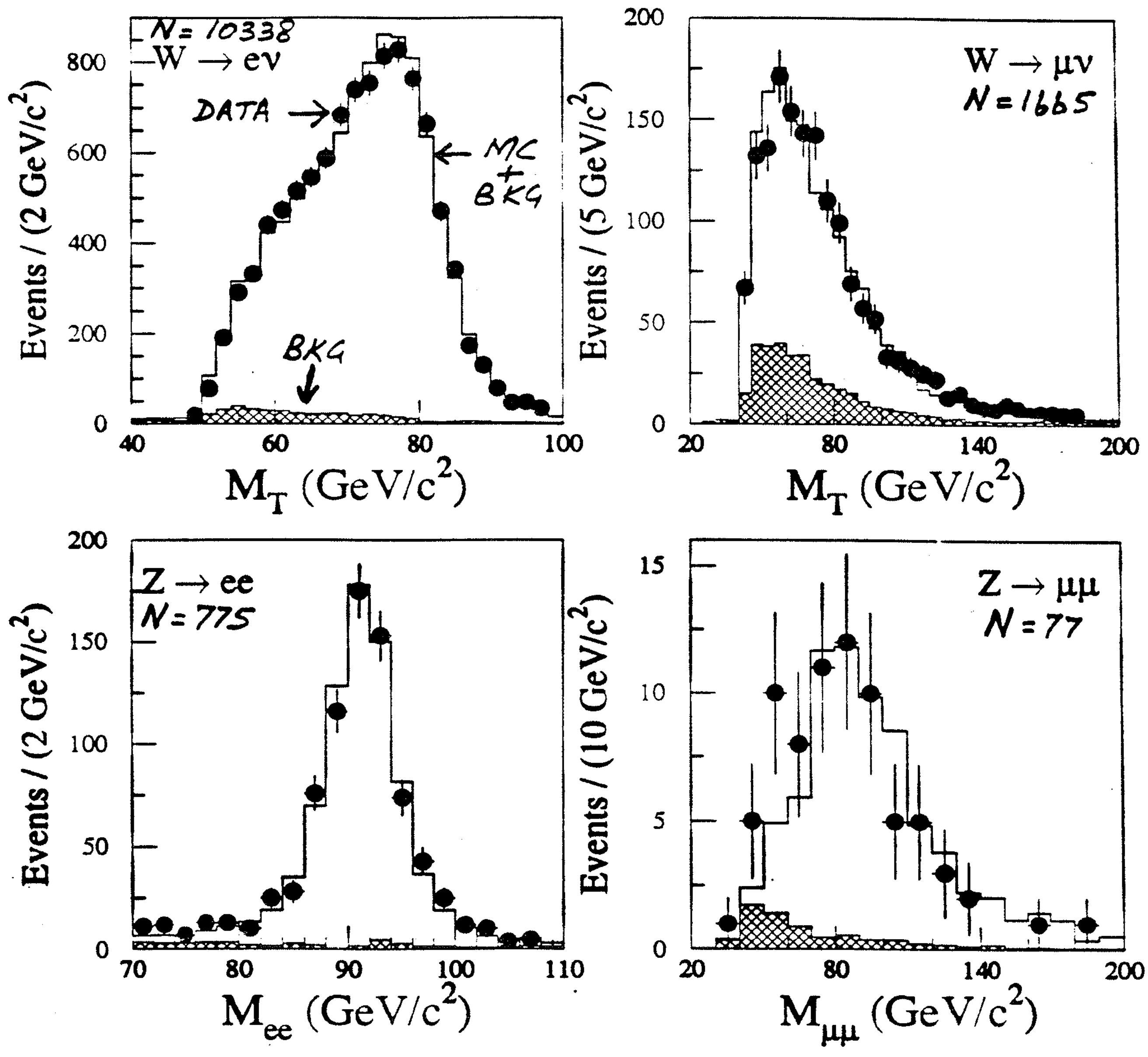
$P_T^\mu > 20$ GeV, $\not{E}_T > 20$ GeV

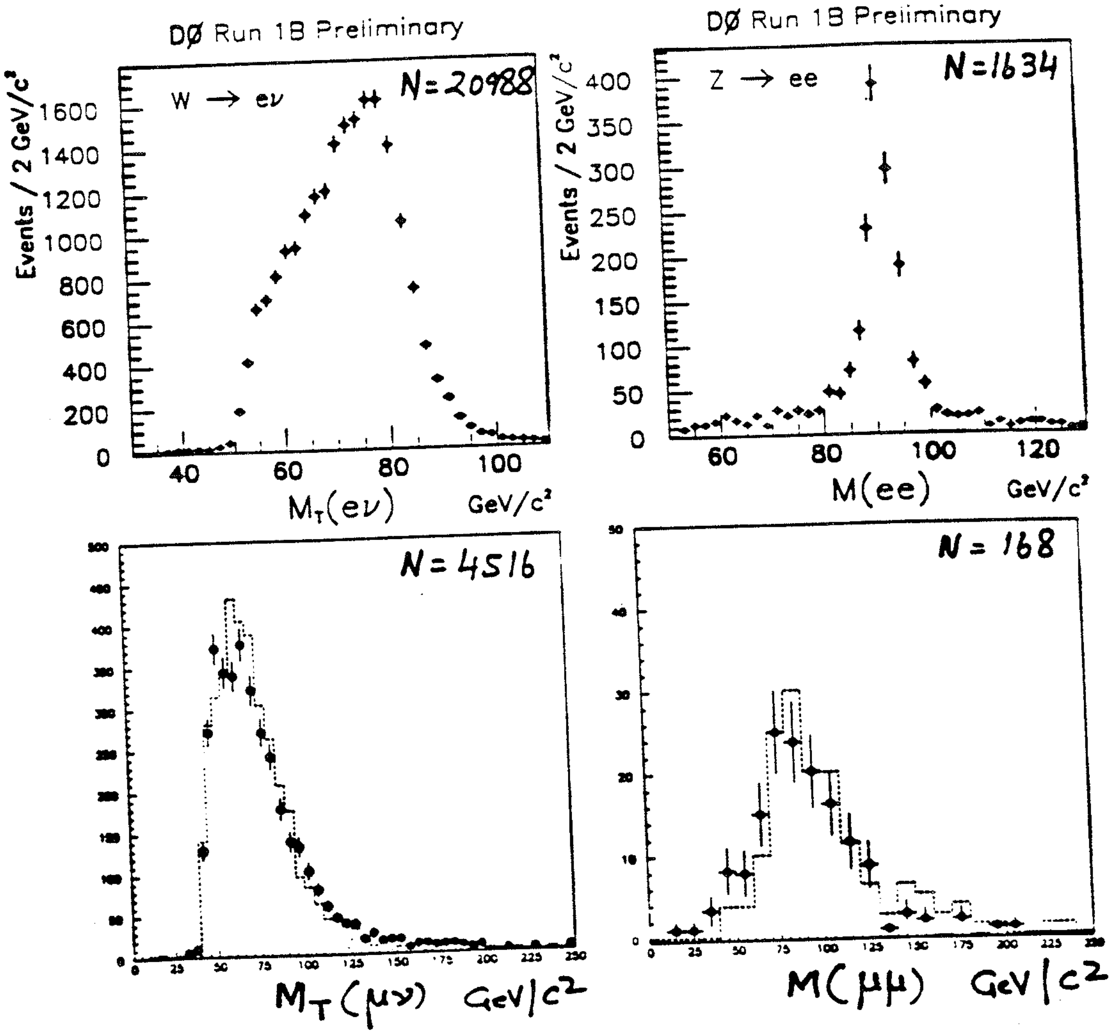
Z's : Two high P_T isolated leptons

$E_T^{e_1} > 25$ GeV, $E_T^{e_2} > 25$ GeV

$P_T^{\mu_1} > 20$ GeV, $P_T^{\mu_2} > 15$ GeV

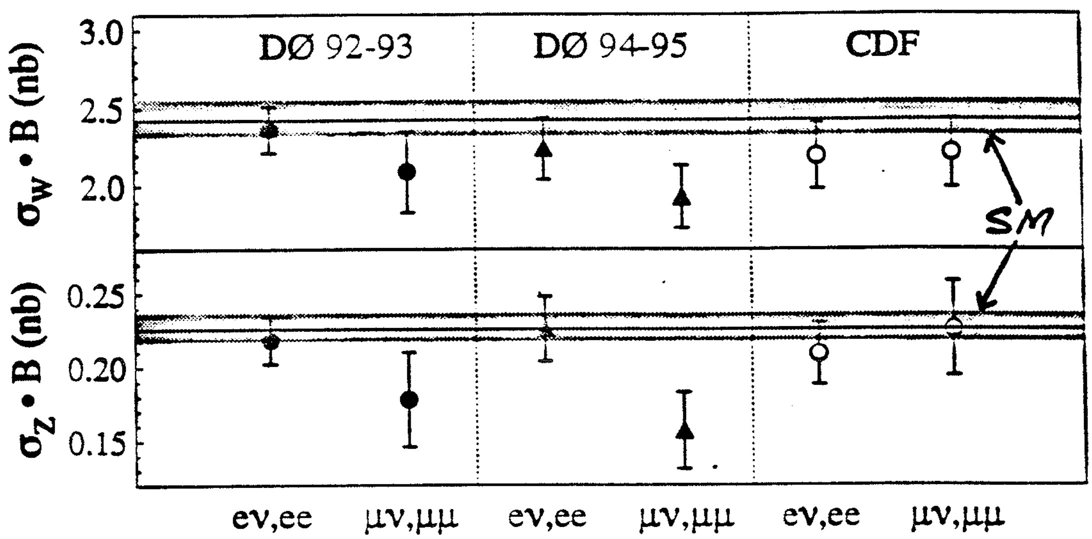
1992–1993	$W \to e\nu$	$Z \to ee$	$W \to \mu\nu$	$Z \to \mu\mu$
Nobs	10388	775	1665	77
Background (%)	5.7 ± 0.4	4.0 ± 1.4	22.1 ± 1.9	10.1 ± 3.7
Acceptance (%)	46.0 ± 0.6	36.3 ± 0.4	24.8 ± 0.7	6.5 ± 0.4
Efficiency (%)	70.4 ± 1.7	73.6 ± 2.4	21.9 ± 2.6	52.7 ± 4.9
$\mathcal{L}$ (pb^{-1})	12.8 ± 0.7	12.8 ± 0.7	11.4 ± 0.6	11.4 ± 0.6
1994–1995 *(Preliminary)*	$W \to e\nu$	$Z \to ee$	$W \to \mu\nu$	$Z \to \mu\mu$
Nobs	20988	1634	4516	168
Background (%)	17.3 ± 2.2	11.0 ± 2.4	17.3 ± 1.1	10.1 ± 3.7
Acceptance (%)	46.1 ± 0.6	36.3 ± 0.4	22.0 ± 0.9	5.1 ± 0.6
Efficiency (%)	66.9 ± 4.1	70.6 ± 4.6	28.6 ± 1.9	60.9 ± 2.6
$\mathcal{L}$ (pb^{-1})	25.1 ± 1.4	25.1 ± 1.4	30.7 ± 1.7	30.7 ± 1.7


N= 10338
W → eν
DATA
MC + BKG
BKG
Events / (2 GeV/c²)
M_T (GeV/c²)
W → μν
N=1665
Events / (5 GeV/c²)
M_T (GeV/c²)
Z → ee
N=775
Events / (2 GeV/c²)
M_ee (GeV/c²)
Z → μμ
N=77
Events / (10 GeV/c²)
M_μμ (GeV/c²)

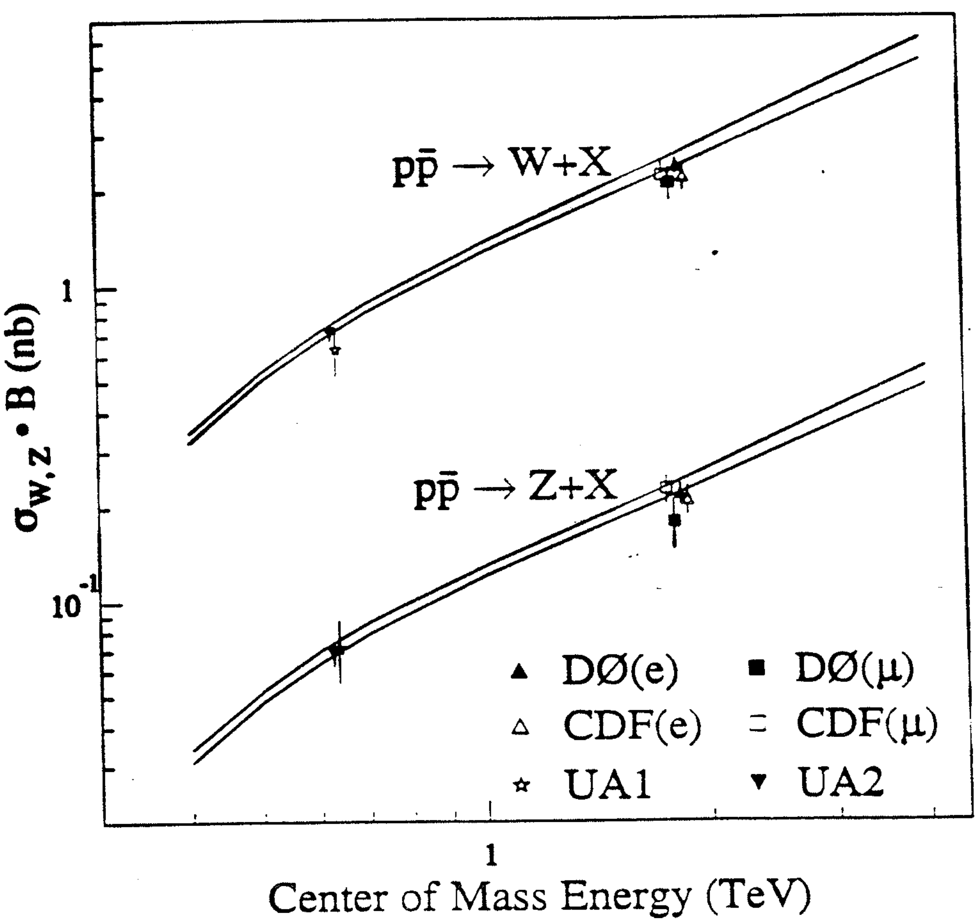


$$\sigma = \frac{N_{obs} - N_{bkg}}{A \cdot \epsilon \cdot \int \mathcal{L}\, dt}$$

	$\sigma_W \cdot B(W \to \ell\nu)$ (nb)	$\sigma_Z \cdot B(W \to \ell\ell)$ (nb)
1992 - 93		
e	$2.36 \pm 0.02 \pm 0.15$	$0.218 \pm 0.008 \pm 0.014$
μ	$2.09 \pm 0.06 \pm 0.25$	$0.178 \pm 0.022 \pm 0.023$
1994-95 (PRELIM)		
e	$2.24 \pm 0.02 \pm 0.20$	$0.226 \pm 0.006 \pm 0.021$
μ	$1.93 \pm 0.04 \pm 0.20$	$0.159 \pm 0.014 \pm 0.022$
SM	$2.42^{+0.13}_{-0.11}$	$0.226^{+0.011}_{-0.009}$



DØ 92-93
DØ 94-95
CDF
SM
$\sigma_W \cdot B$ (nb)
$\sigma_Z \cdot B$ (nb)
3.0
2.5
2.0
0.25
0.20
0.15
eν,ee
μν,μμ
eν,ee
μν,μμ
eν,ee
μν,μμ



$p\bar{p} \rightarrow W+X$
$p\bar{p} \rightarrow Z+X$
$\sigma_{W,Z} \cdot B$ (nb)
1
10^{-1}
DØ(e)
DØ(μ)
CDF(e)
CDF(μ)
UA1
UA2
1
Center of Mass Energy (TeV)

Inclusive Width of the W

$$R = \frac{\sigma_W \cdot BR(W \to \ell\nu)}{\sigma_Z \cdot BR(Z \to \ell\ell)}$$

$$= \frac{\sigma_W}{\sigma_Z} \cdot \frac{\Gamma(W \to \ell\nu)}{\Gamma(W)} \cdot \frac{1}{BR(Z \to \ell\ell)}$$

$$\Gamma(W) = \frac{\sigma_W}{\sigma_Z} \cdot \frac{\Gamma(W \to \ell\nu)}{BR(Z \to \ell\ell)} \cdot \frac{1}{R}$$

$R(e+\mu) = 10.89 \pm 0.49$ (stat $\oplus$ sys) $(D\phi)_{1992-}$

$\frac{\sigma_W}{\sigma_Z} = 3.33 \pm 0.03$ (Hamberg, Van Neervan, Mat

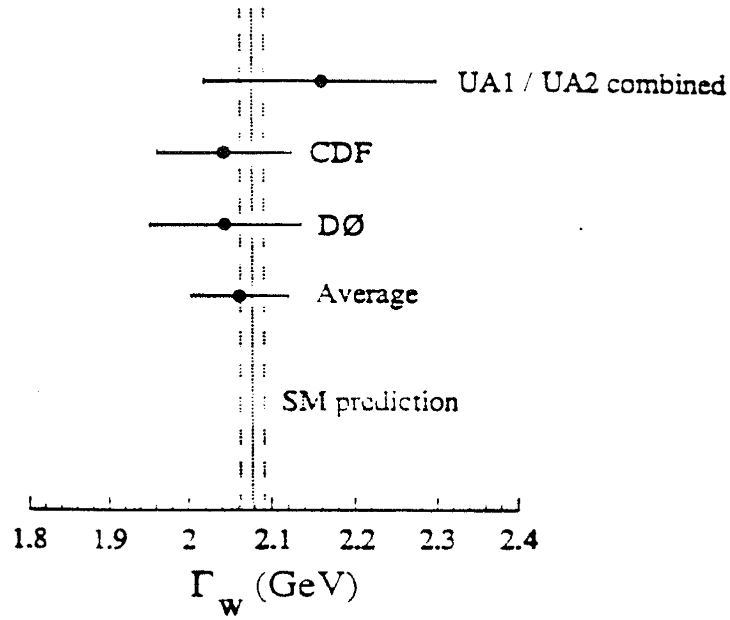
$BR(Z \to \ell\ell) = 3.367 \pm 0.006\ \%$ (LEP)

$\Gamma(W \to \ell\nu) = 225.2 \pm 1.5$ MeV (Rosner et. al. PRD 49 (1994), 13

$\Gamma_{D\phi}(W) = 2.044 \pm 0.091\,(\text{expt.}) \pm 0.017\,(\text{th})$ Ge

$= 2.044 \pm 0.092$ GeV

$\Gamma_{SM}(W) = 2.077 \pm 0.014$ GeV



WORLD AVERAGE: $\Gamma(W) = 2.062 \pm 0.059$

SM PREDICTION: $\Gamma(W) = 2.077 \pm 0.014$ c

Measurement of $\Gamma(W)$ can be used to set limits on unexpected decay modes of W,

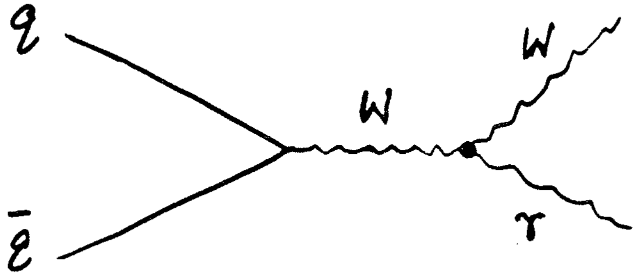
- supersymmetric charginos and neutralinos.
- heavy quark

$\Delta\Gamma(W) < 109$ MeV @ 95% CL

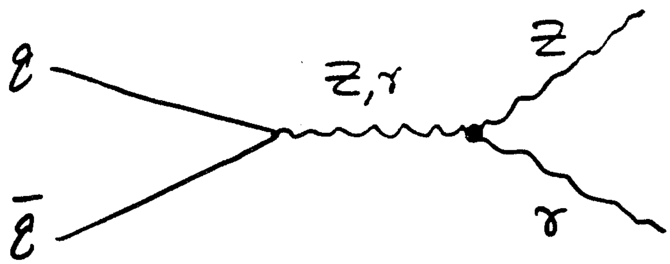
DIBOSON PRODUCTION

In SM unification of EM and WEAK for
allows the self interaction of gauge fields via
trilinear couplings between vector bosons ($W^{\pm}$, Z, γ

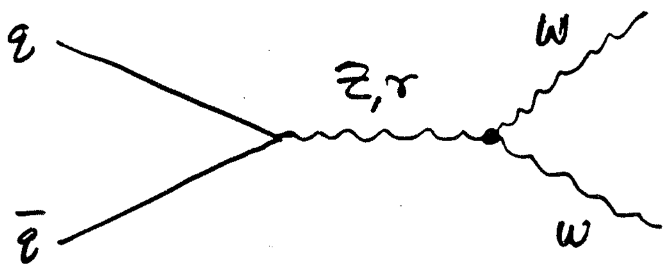
@ TREE LEVE



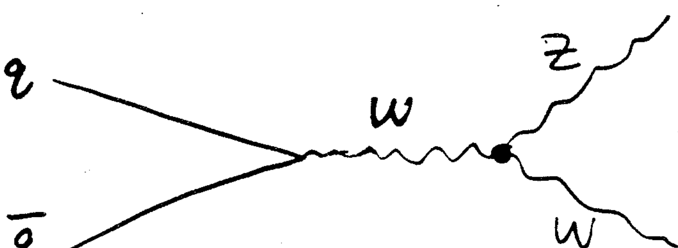
→ WWγ ✓



→ ZZγ / Zγγ ✗



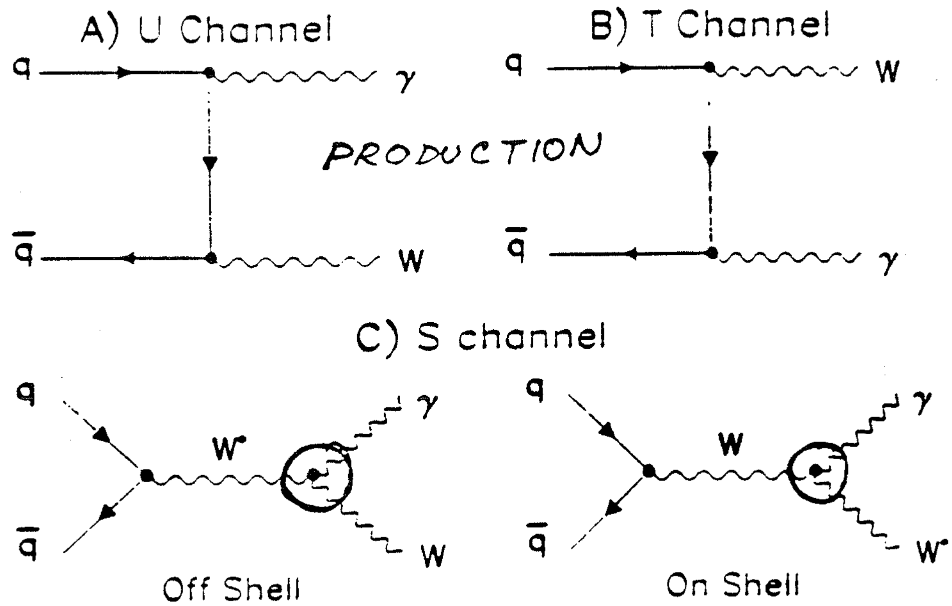
→ WWγ / WWZ ✓



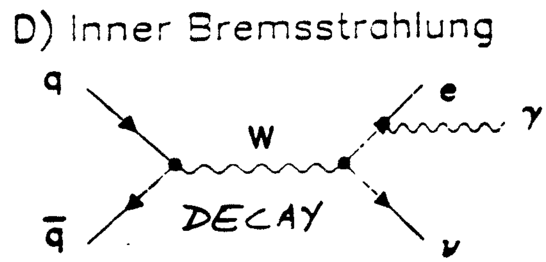
→ WWZ ✓

Measurement of self-interaction crucial test of SM
Deviation from SM – signature for new physics.

Wγ Analysis



WWγ V



Suppress with $\Delta R(\ell-\gamma)$ an
$M_T(\ell,\gamma\nu)$ a

Non-Abelian gauge theory requires EM gauge and Lorentz invariance of

$$SU(2)_L \times U(1)_Y$$

These 2 constraints allow for 4 free independ parameter in theory.

$$L_{WW\gamma} = \underset{\substack{\downarrow \\ K,\,\lambda}}{L^{CP}_{WW\gamma}} + \underset{\substack{\downarrow \\ \tilde{K},\,\tilde{\lambda}}}{L^{\not{CP}}_{WW\gamma}}$$

In SM $\quad K = 1 \;\; (\Delta K = K - 1 = 0) \qquad \lambda = 0$

$\tilde{K} = 0 \qquad \tilde{\lambda} = 0.$

Magnetic dipole moment $\mu_W = \frac{e}{2M_W}(1+\kappa+\lambda)$

Electric quadrupole moment $Q_W = -\frac{e}{M_W^2}(\kappa-\lambda)$

Anomalies in Moments ⇒ NON SM Behaviour
⇓
internal structure
SUSY
etc.

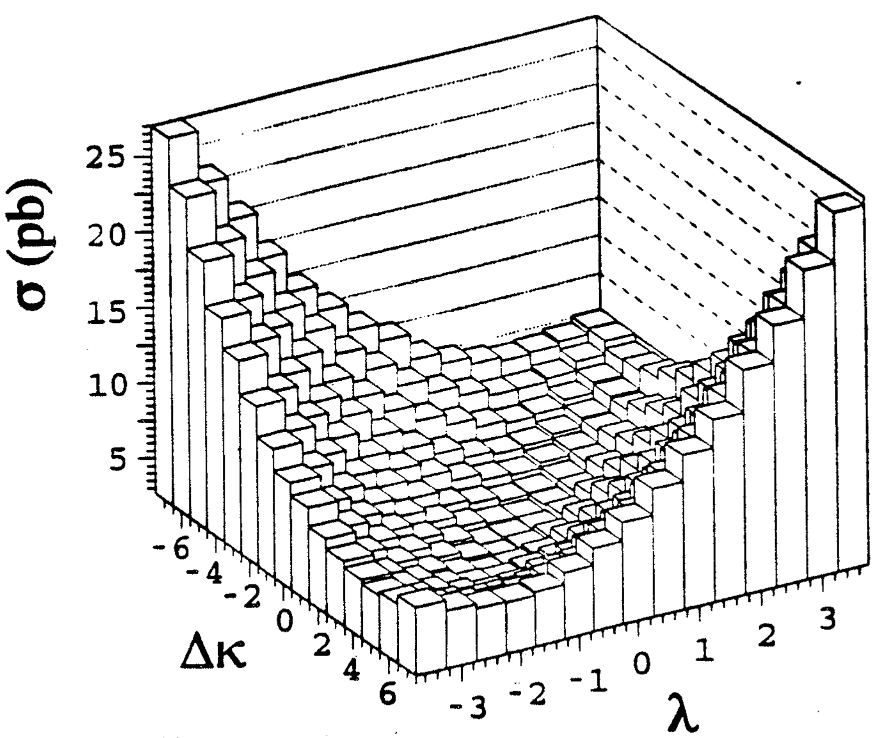
Sensitivity to Anomalous coupling

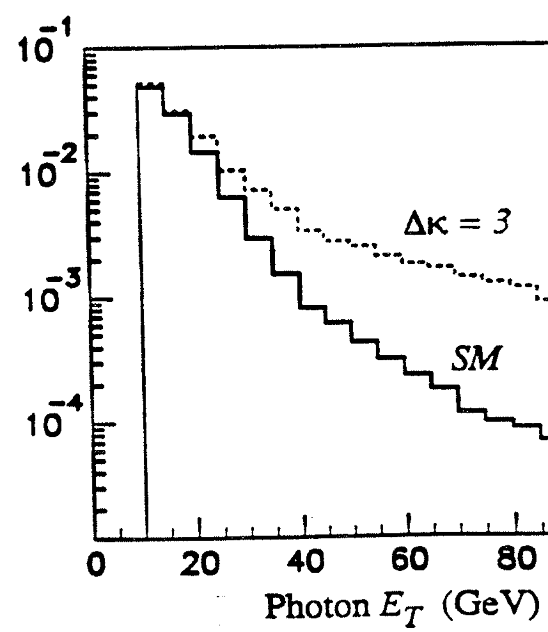
1. Increase in X-section
2. Change in differential distribution

P_T^γ Spectrum

$\cos\theta^*$ Spectrum

$\eta(\gamma)-\eta(\ell)$ Spectrum





$q\bar{q} \to W\gamma$ Helicity Amplitude

$$\Delta M_{\pm 0} \propto \frac{\sqrt{\hat{s}}}{2M_W} (\Delta K + \lambda)$$

$$\Delta M_{\pm\pm} \propto \frac{\hat{s}}{2M_W^2} \lambda$$

$\hat{S}$ = Square of Inv. Mass of $W\gamma$ System

$\lambda_\gamma, \lambda_W = +-, -+$ not allowed in S channel.

4 helicity state ⇒ 4 free parameters needed

⇒ $L_{WW\gamma}$ with fixed anomalous couplings vio[lates] unitarity at high energies and is thus d[amped] by a form factor Λ.

$$\Delta K(\hat{s}) = \frac{\Delta K}{\left(1 + \frac{\hat{s}}{\Lambda^2}\right)^n}, \quad \lambda(\hat{s}) = \frac{\lambda}{\left(1 + \frac{\hat{s}}{\Lambda^2}\right)}$$

$\Delta K, \lambda$ = coupling value at low energy limi[t]

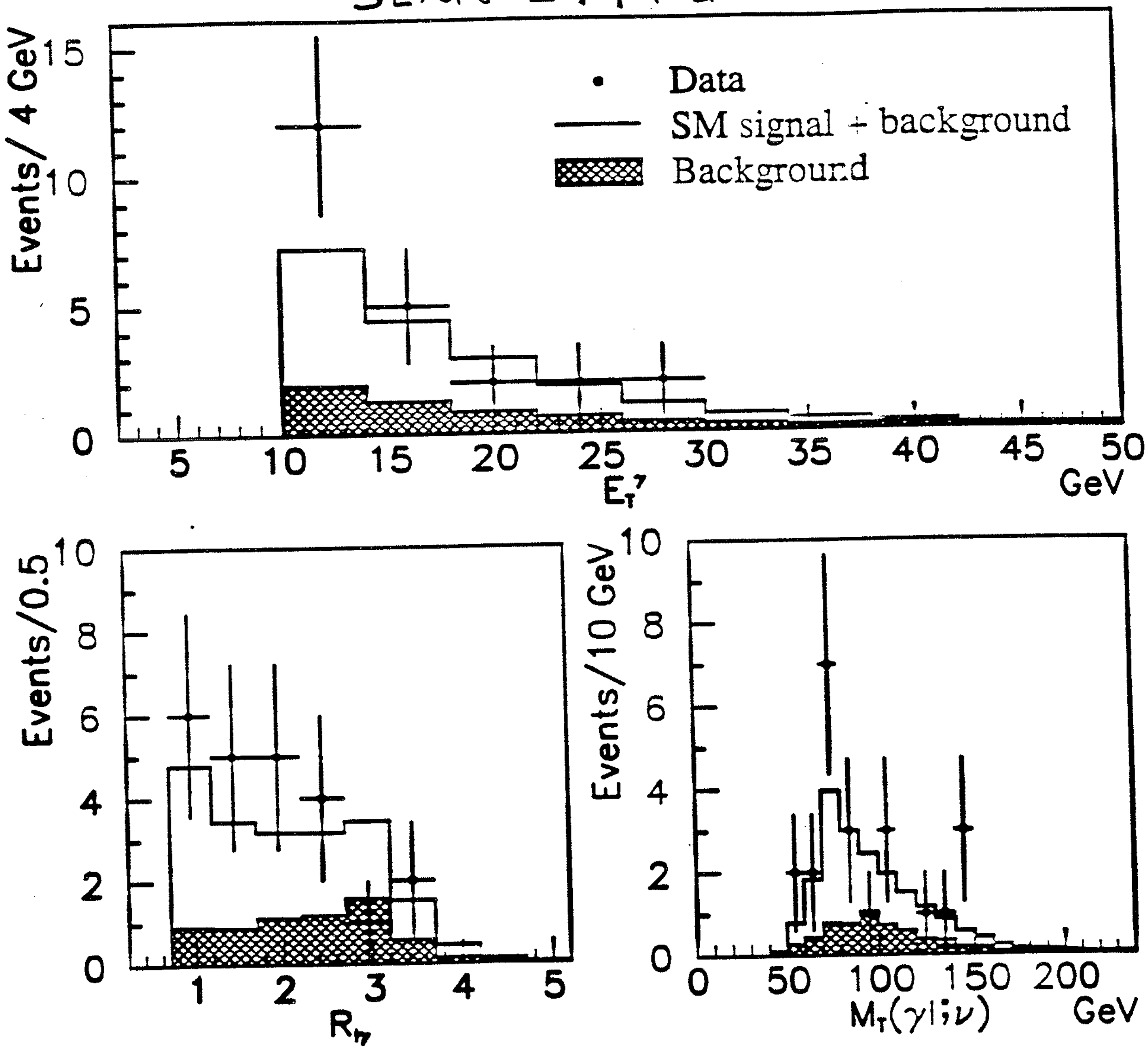
$n = 2$ for a dipole form factor

Λ = form factor scale | scale for NEW P[hysics]

$W\gamma$, $n = 2$ and $\Lambda_{W\gamma} = 1.5$ TeV

$Z\gamma$, $n = 3, 4$ and $\Lambda_{Z\gamma} = 0.5$ TeV

$\int L\,dt \simeq 14\ pb^{-1}$



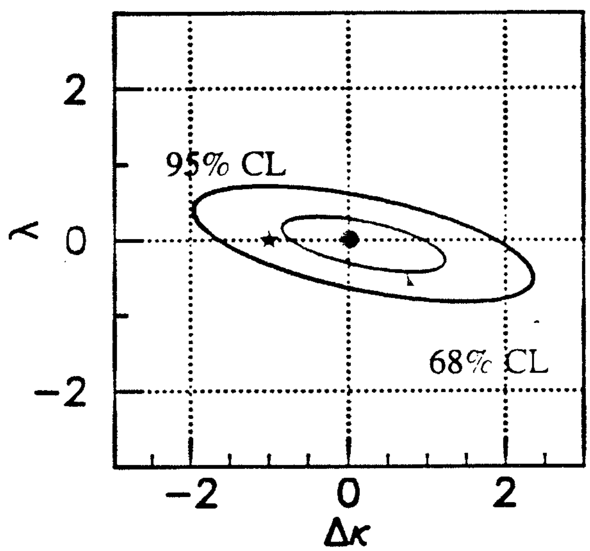
	$W(e\nu)\gamma$	$W(\mu\nu)\gamma$
N_{OBS}	11	12
N_{BKG}	2.0 ± 0.9	4.4 ± 1.1
N_{SIG}	$9.0^{+4.2}_{-3.1} \pm 0.9$	$7.6^{+4.4}_{-3.2} \pm 1.1$

DØ data: $\sigma(p\bar{p} \to W\gamma) = 138^{+51}_{-38}\ (stat) \pm 21$

SM Prediction: $\sigma(p\bar{p} \to W\gamma) = 112 \pm 10\ Pb$

FOR $\Delta R(\ell-\gamma) \geq 0.7$, $p_T^\gamma \geq 10\ GeV$

$WW\gamma$ anomalous couplings – limits

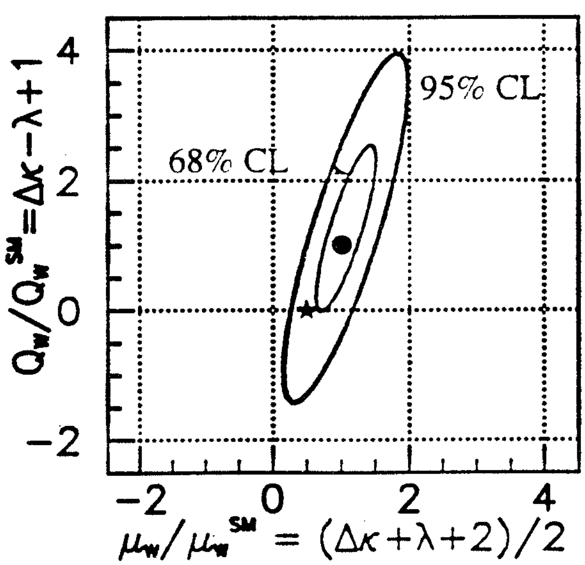


$\Lambda = 1.5$ TeV

95% CL Limits:

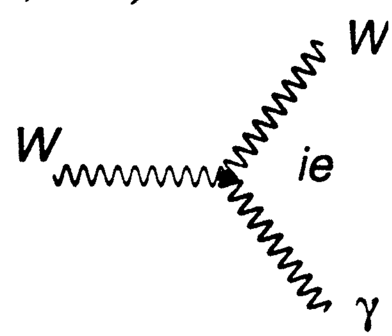
$-1.6 < \Delta\kappa < 1.8$ for $\lambda = 0$

$-0.6 < \lambda < 0.6$ for $\Delta\kappa = 0$



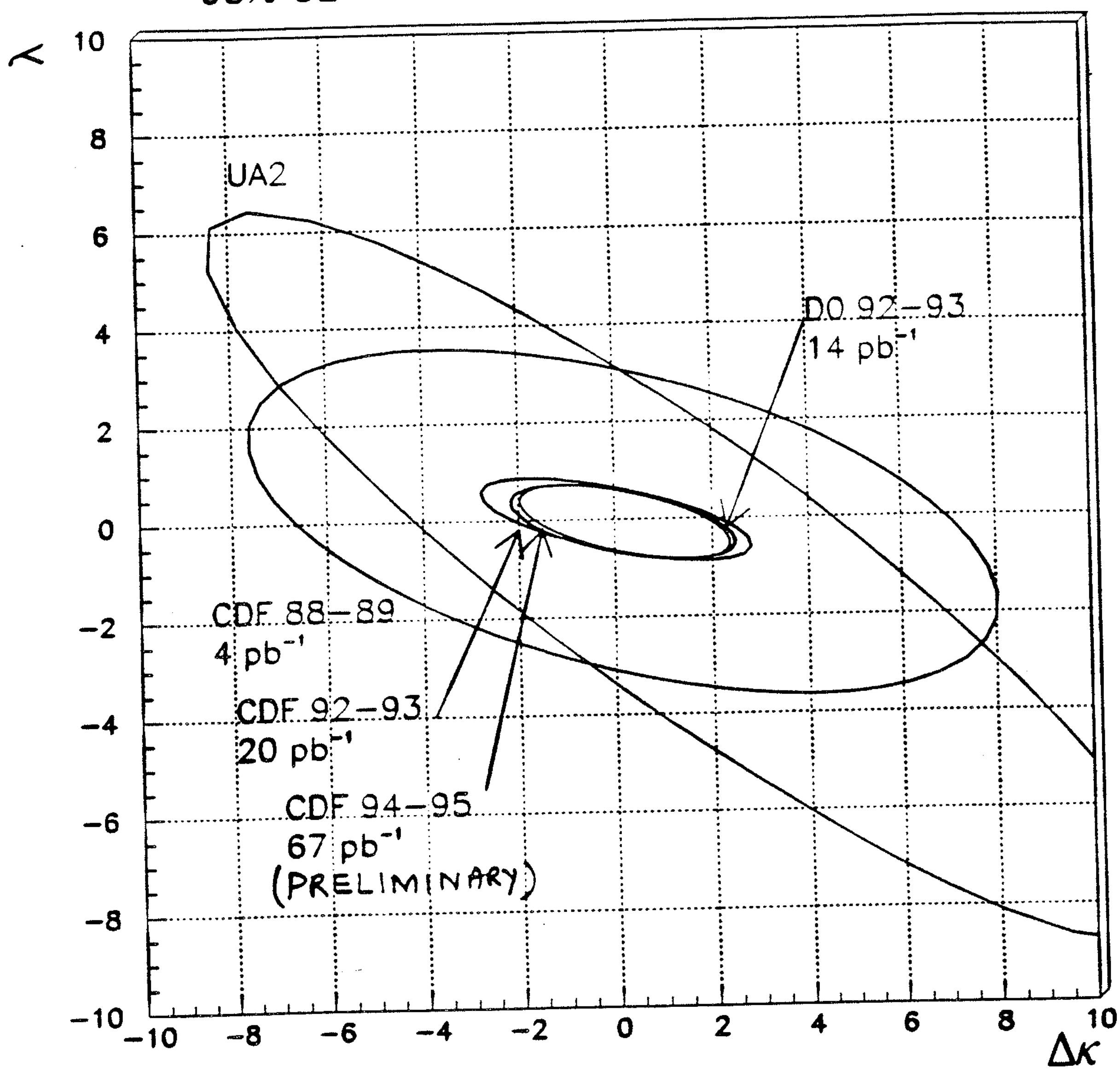
• = SM (κ=1, λ=0)

★ = $U(1)_{EM}$ only coupling (κ=0, λ=0):



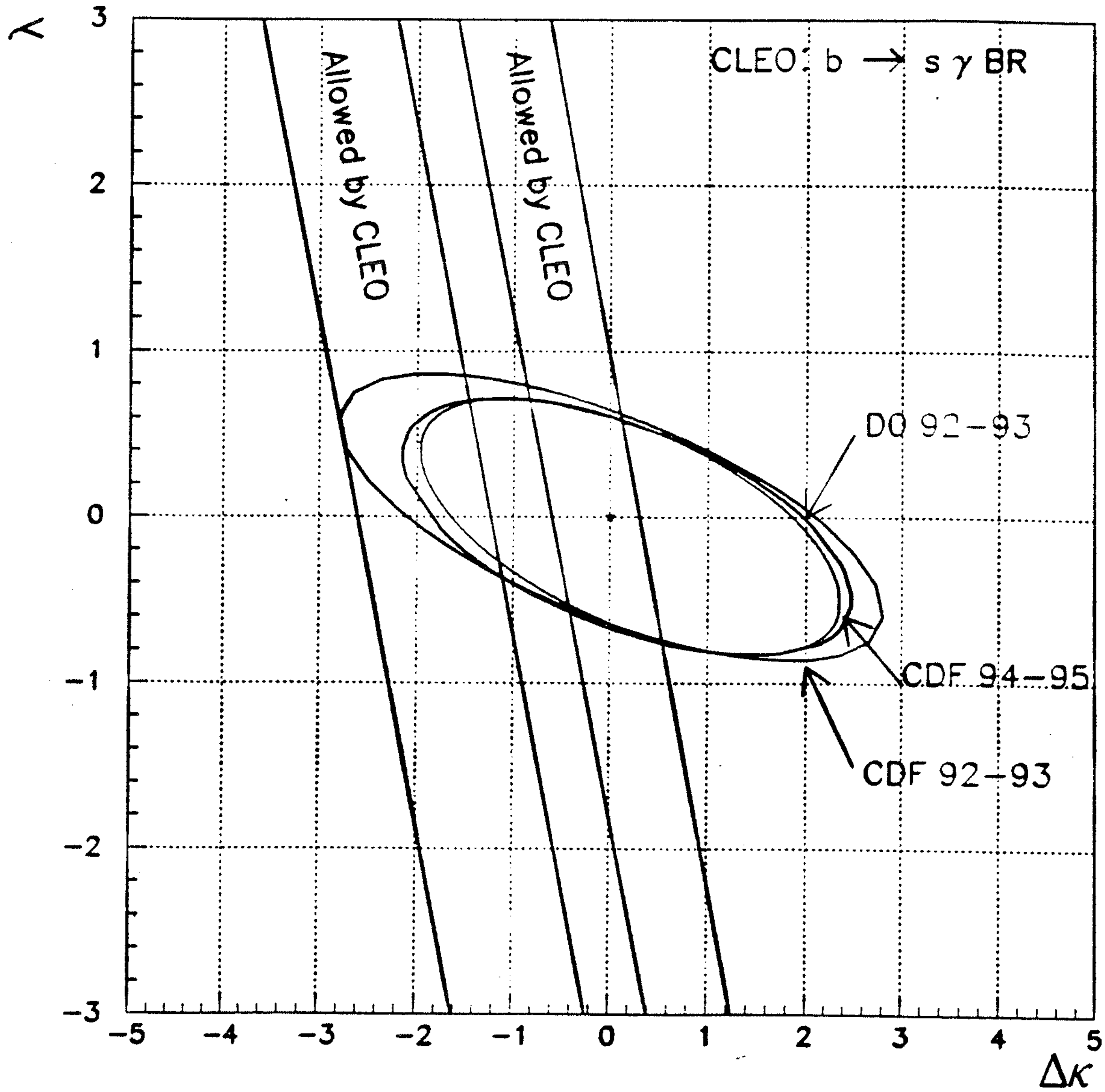
→ ruled out at 80% CL

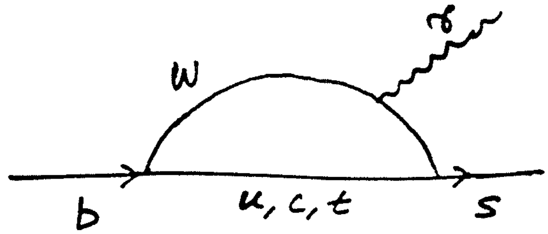
95% CL limit contours in the ΔK−λ plane



$P\bar{P} \rightarrow W\gamma$ vs $b \rightarrow s\gamma$

95% CL limit contours in the ΔK–λ plane

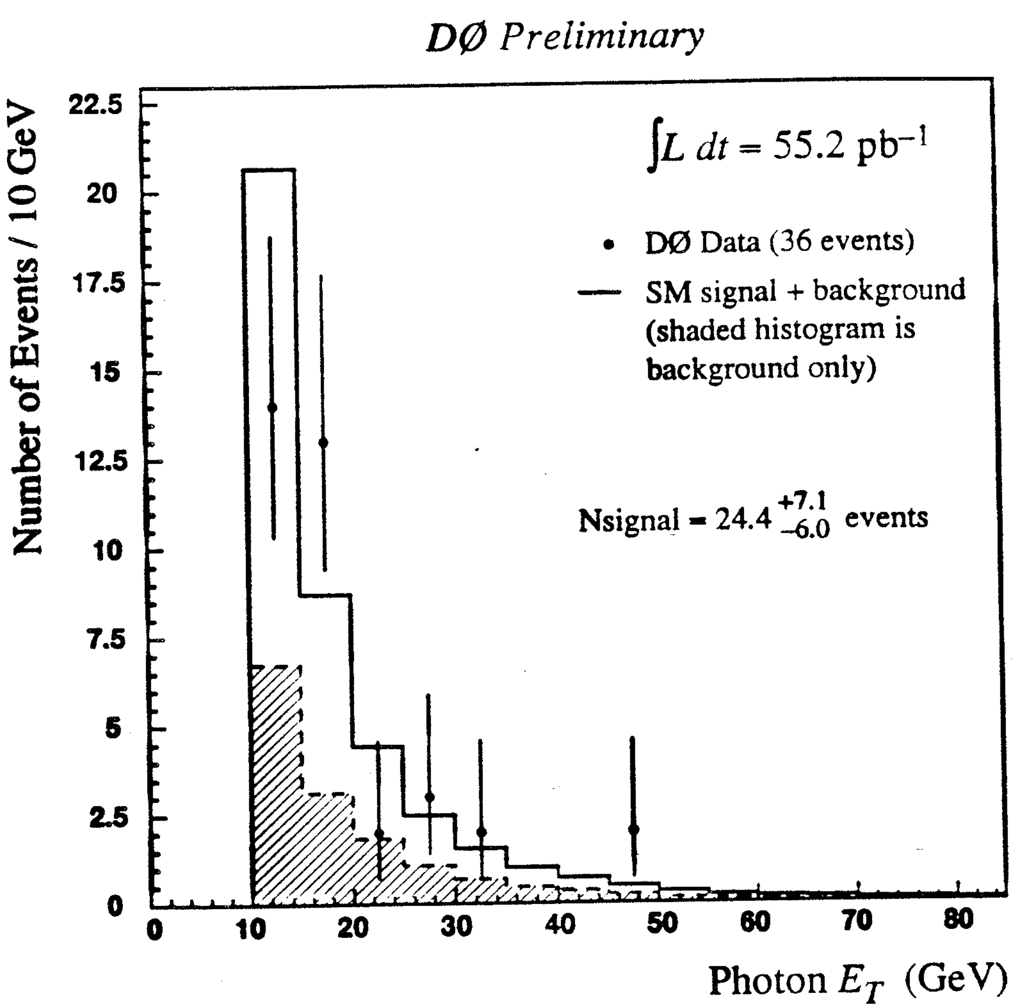




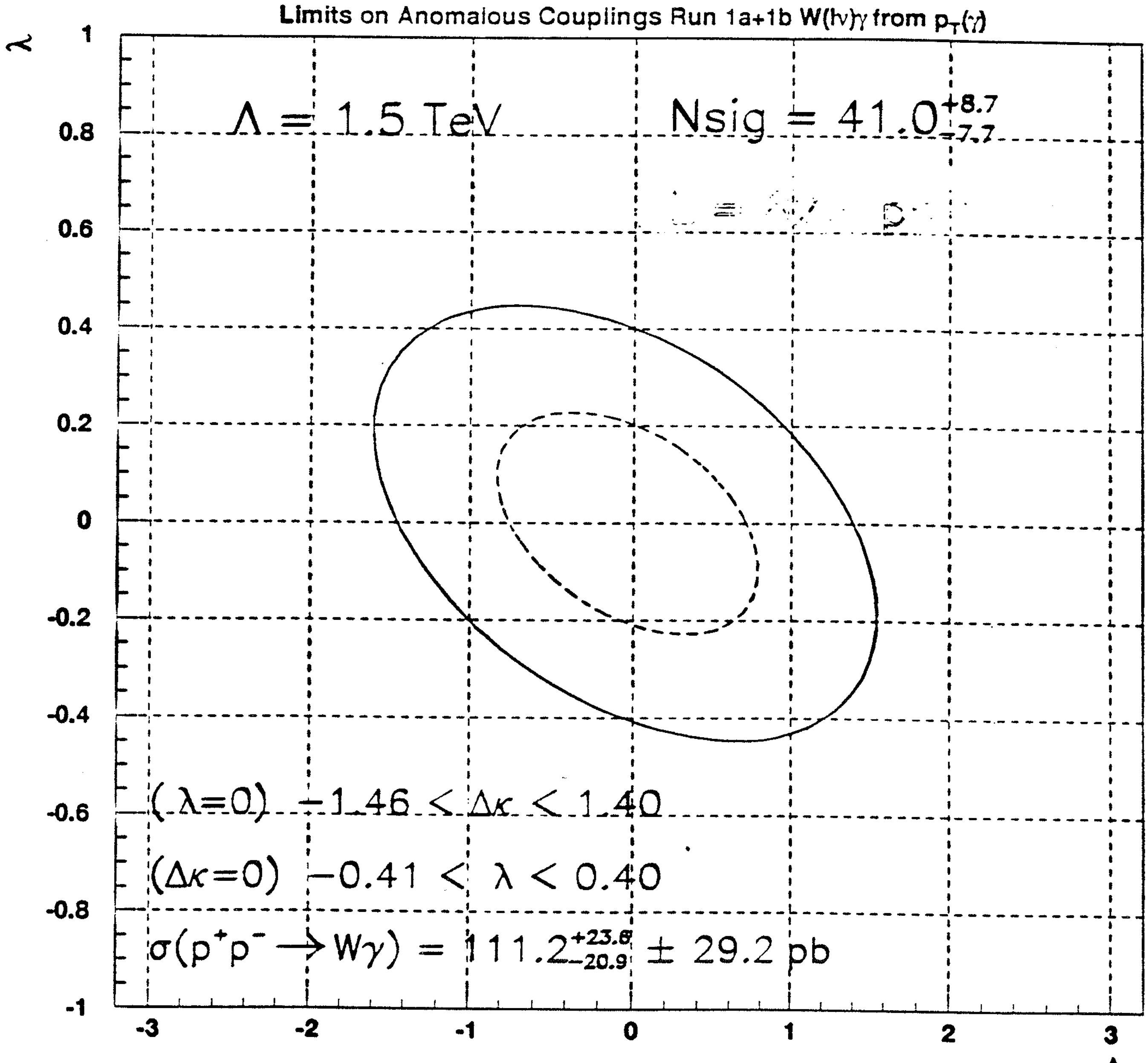
TWO PHYSICS PROCESSES ARE COMPLEMENTARY.

Run 1B Preliminary $W\gamma$ Results

- $W\gamma$ Photon E_T Distribution – electron channel only

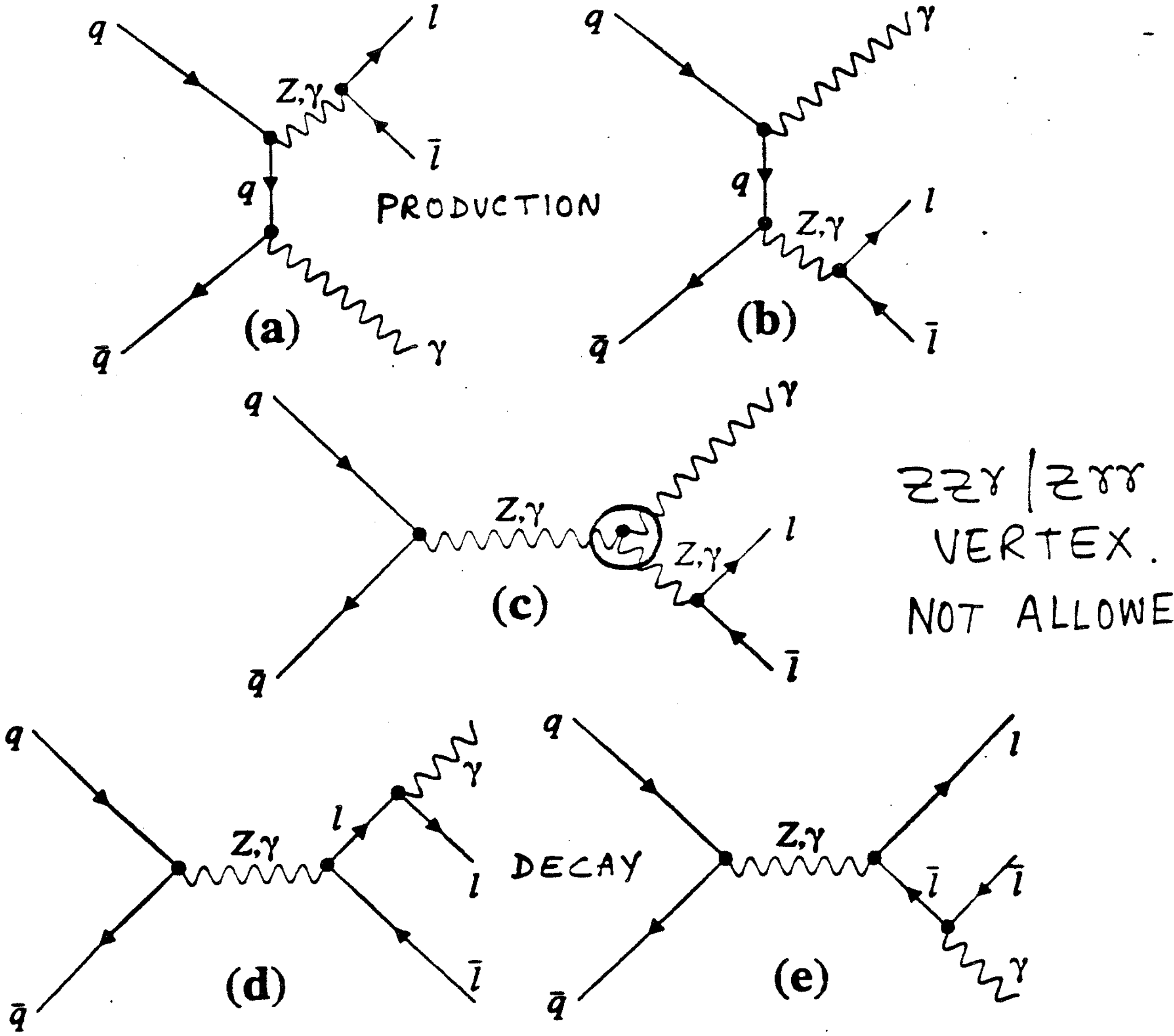


PRELIMINARY



contour is 95% CL

Zγ Analysis



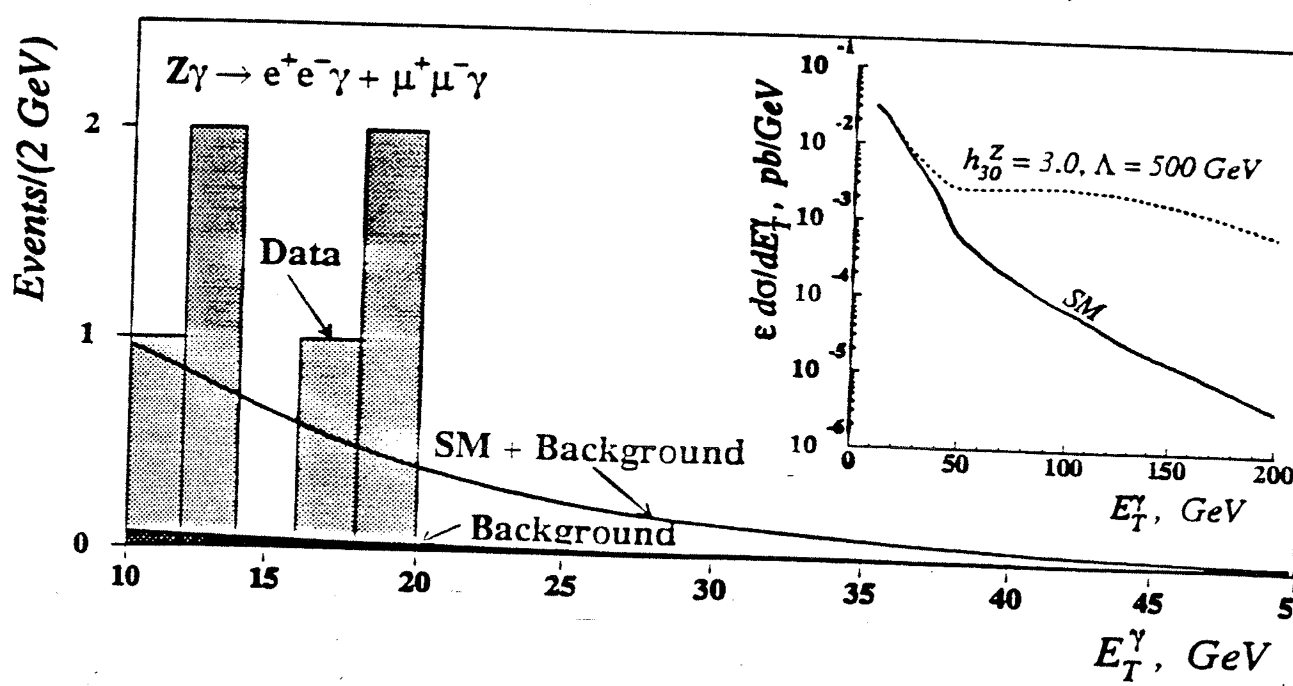
	CP CONSERVING		CP VIOLATING	
ZZγ COUPLINGS	h_3^Z	h_4^Z	h_1^Z	h_2^Z
Zγγ COUPLINGS	h_3^γ	h_4^γ	h_1^γ	h_2^γ

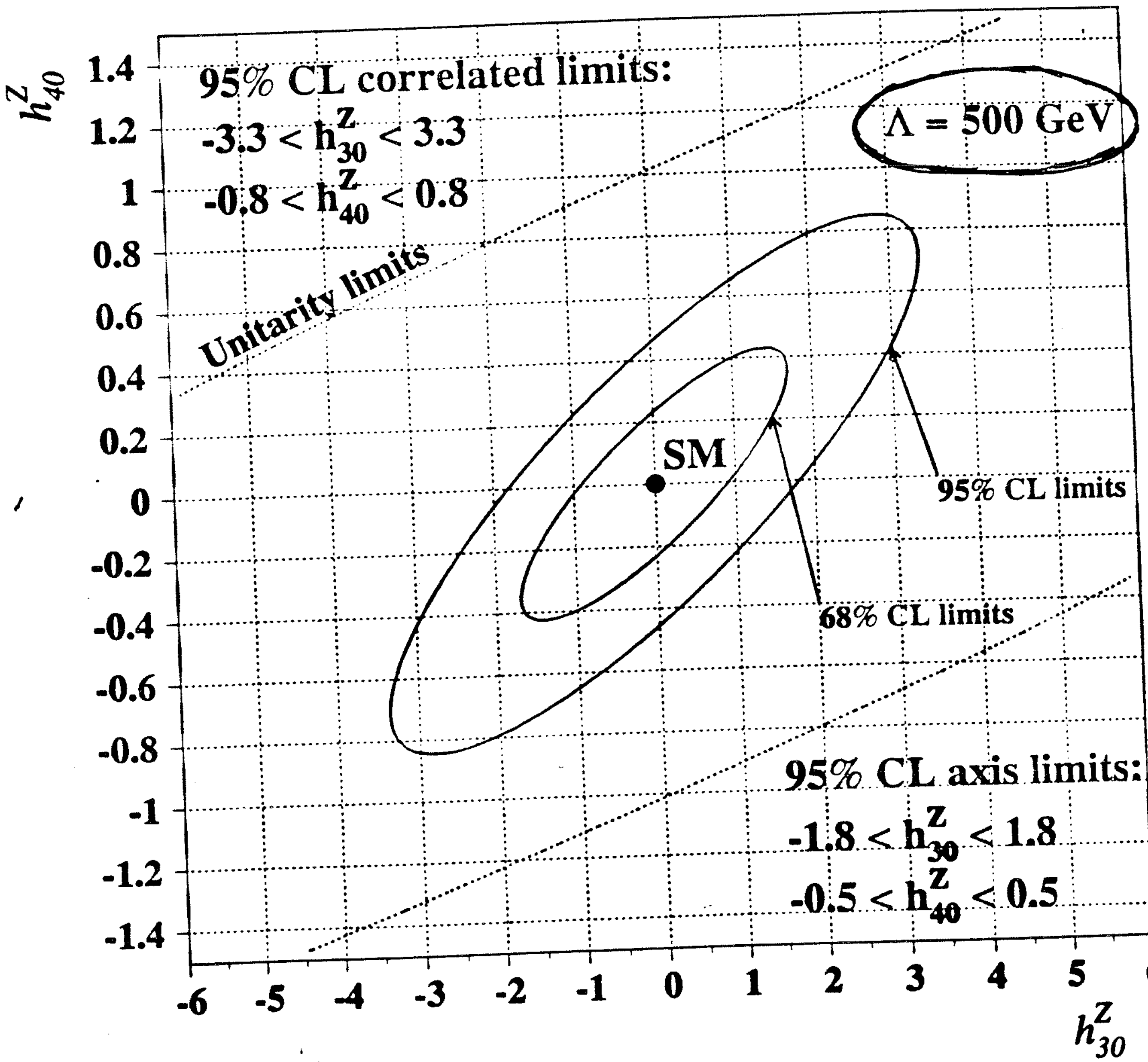
CONBINATION OF $h_{3,4}^{Z,\gamma}$ ($h_{1,2}^{Z,\gamma}$) CORRESPONDS TC THE ELECTRIC (MAGNETIC) DIPOLE TRANSITION MOMENTS.

Z and γ DO NOT HAVE EMM.

BACKGROUND EST. & COMPARISON WITH SM

SOURCE	ELECTRON	MUON
QCD	0.43 ± 0.06	0.02 ± 0.01
$Z\gamma \to \tau\tau\gamma \to$	~	0.03 ± 0.01
DATA	4	2
SIGNAL	$3.6^{+3.2}_{-1.9} \pm 0.06$ (stat, sys)	$1.95^{+2.6}_{-1.3} \pm 0.01$ (stat, sys)
SM PREDICTION	$2.8 \pm 0.3 \pm 0.2$ (sys, lum)	$2.3 \pm 0.4 \pm 0.1$ (sys, lum)
GEO ACCEP	53%	19%
TOTAL EFFICIENCY	$17 \pm 2\%$	$6 \pm 1\%$



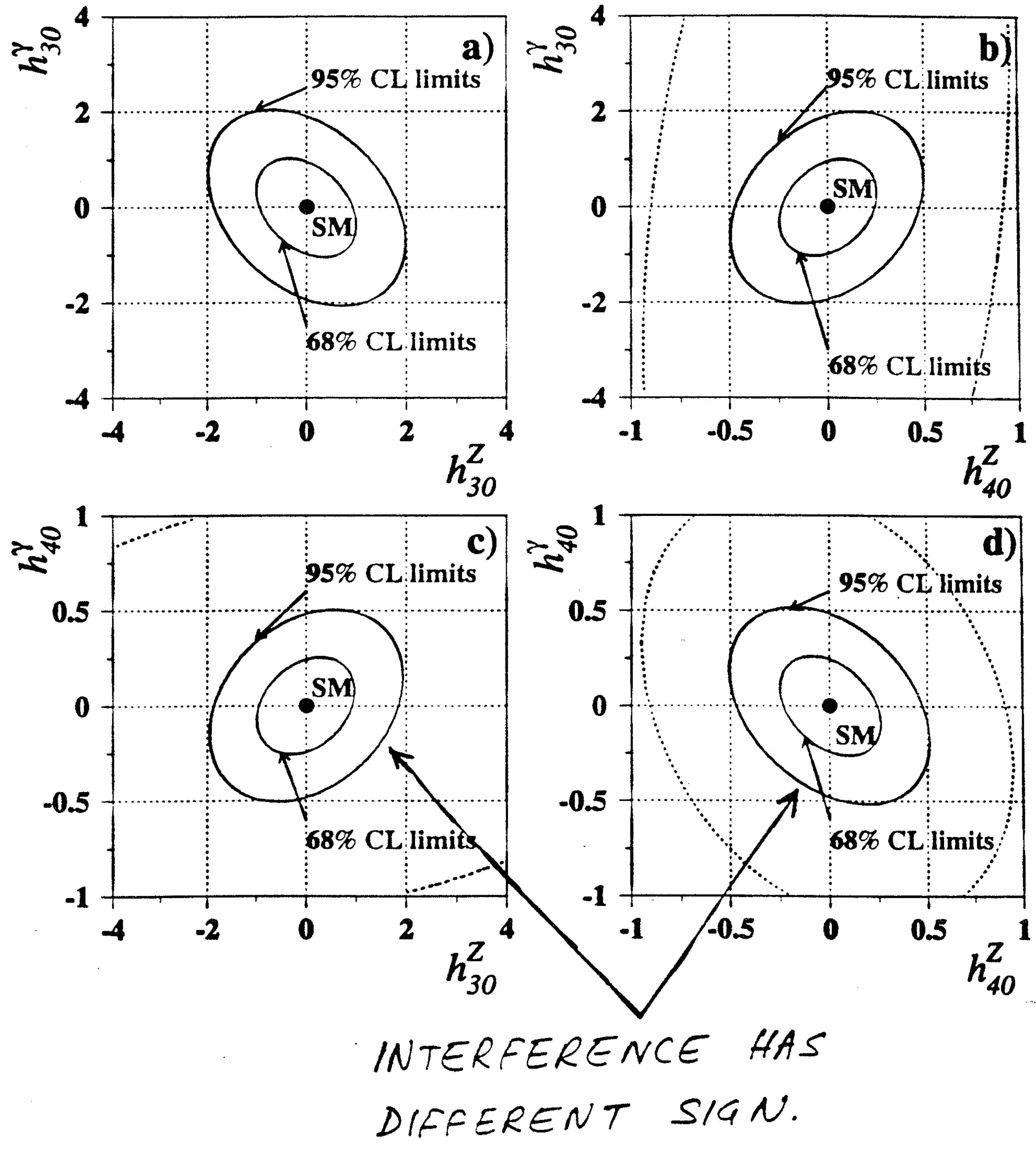


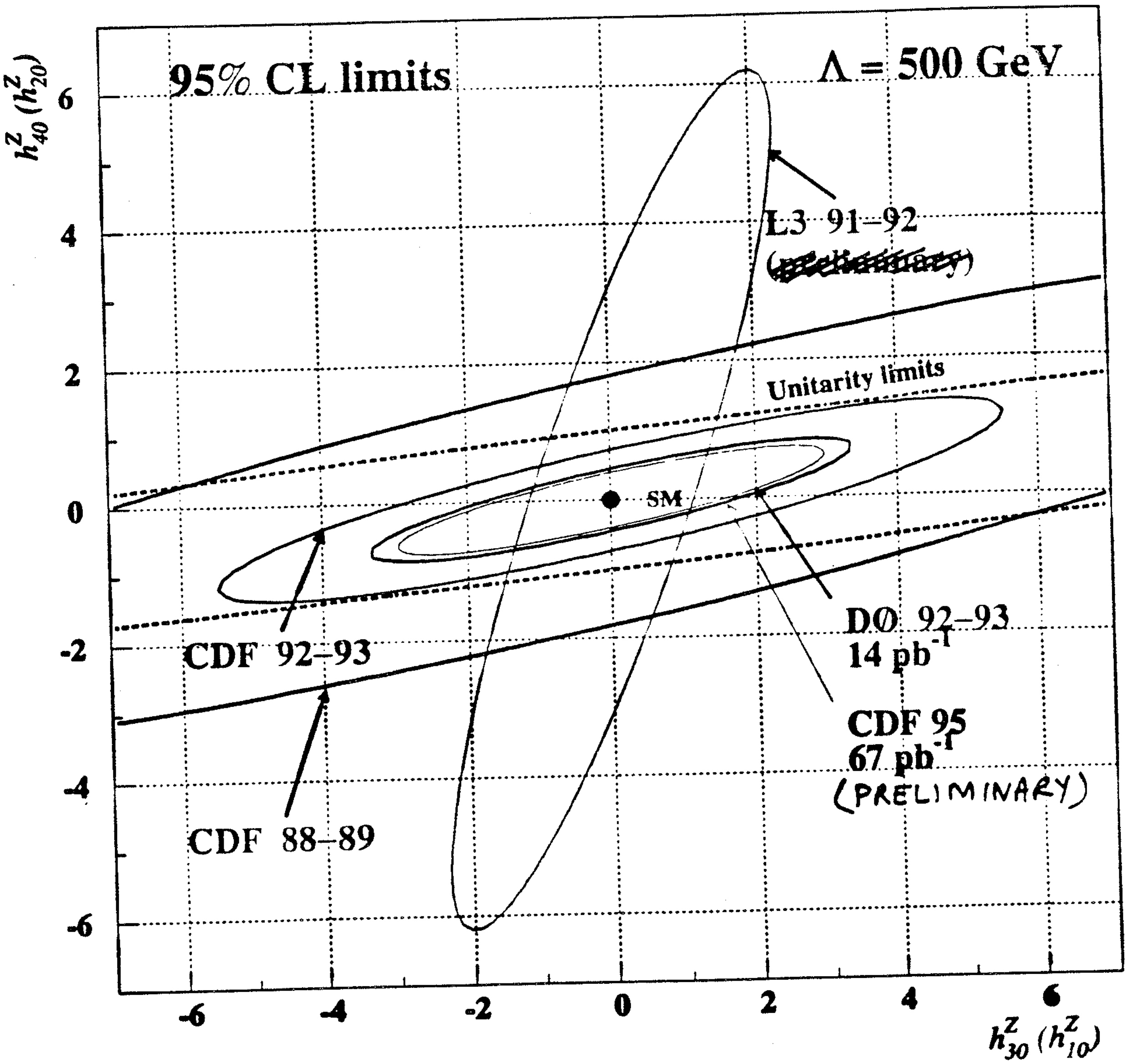
LIMIT SENSITIVE TO Λ_{FF}.

LIMIT ON $Z\gamma\gamma$ COUPLINGS ALMOST IDEN

LIMIT ON C̸P COUPLINGS ARE IDENT

INTERFERENCE BETWEEN ZZγ/Zγγ COUPLINGS IS MUCH LESS COMPARED TO ZZγ-ZZγ/Zγγ-Zγγ COUPLINGS.

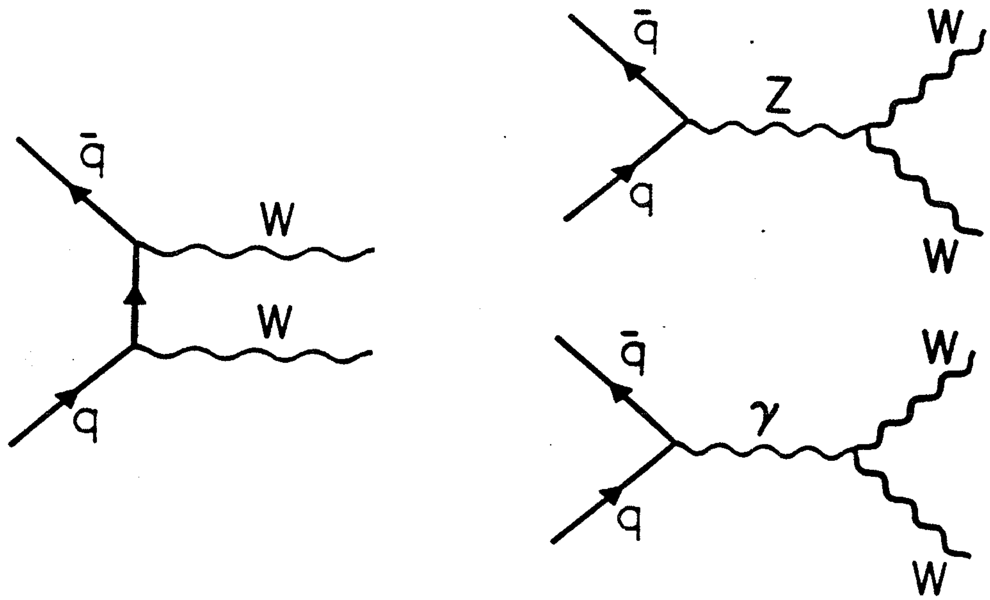




Center of Mass Energy for L3 = M_Z

Center of Mass Energy for Tevatron = M_Z and Beyond.

WW, WZ Analysis



$WW \rightarrow \ell\nu\ell\nu$, two high P_T leptons + $\not{E}_T$.

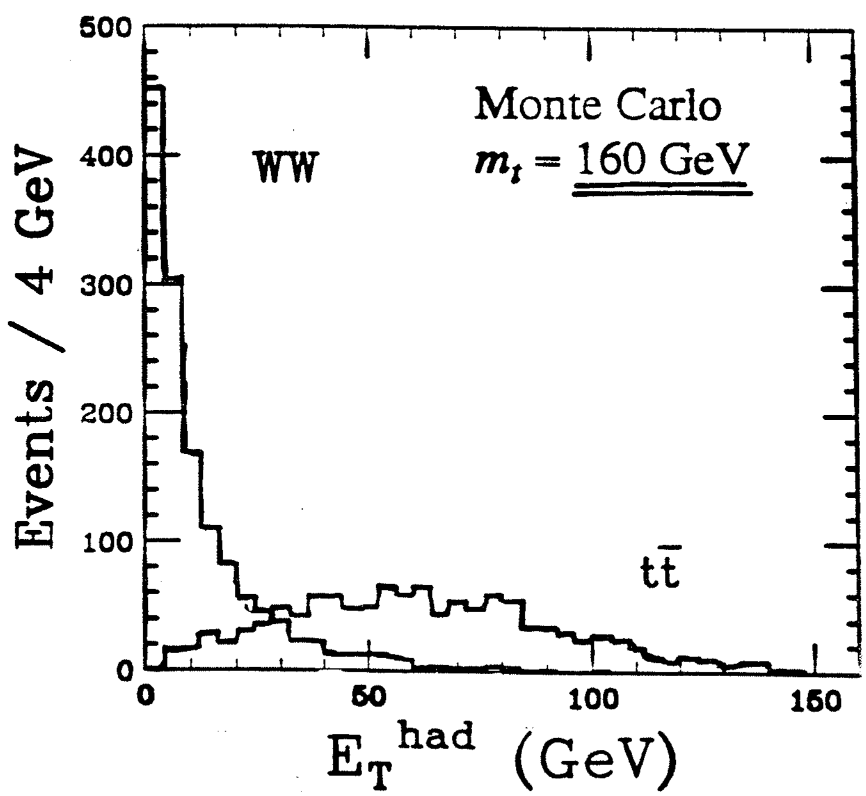
Backgrounds → QCD, Wγ, $Z \rightarrow \ell\ell$, $t\bar{t}$

$t\bar{t}$ x-section comparable to WW x-section.

$$\vec{E}_T^{\,had} = -\left(\vec{E}_T^{\ell_1} + \vec{E}_T^{\ell_2} + \not{E}_T\right) < 40 \text{ GeV}$$

Background reduction from $t\bar{t}$ = 75%

Efficiency for SM WW signal ≃ 95%



One Event passes all selection cuts.

SM prediction for WW Signal $= 0.47 \pm 0.07$ even[t]

Total estimated background $= 0.56 \pm 0.13$ event.

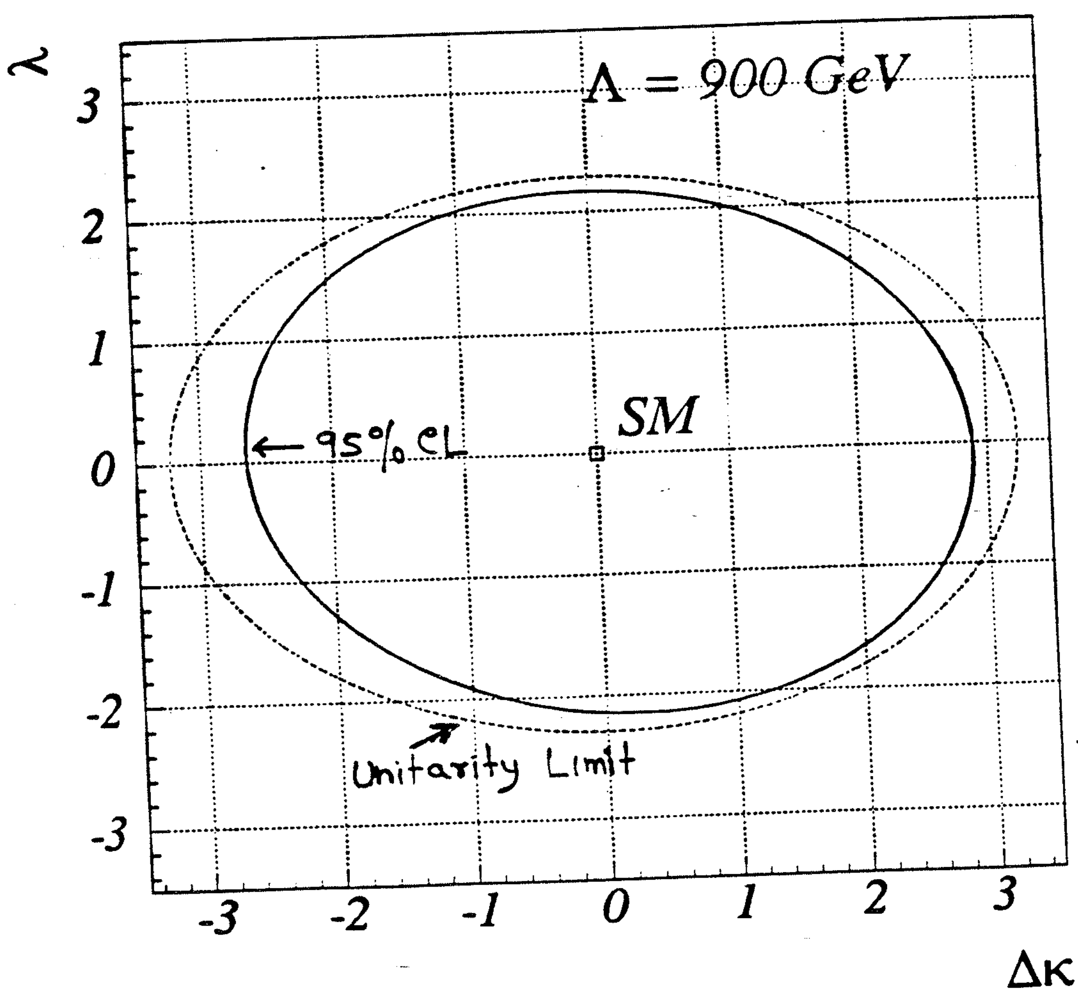
$$\sigma(p\bar{p} \to W^+W^-) < 87 \text{ Pb} \quad 95\% \text{ CL}$$

$$SM_{PREDICTION} = 9.5 \text{ Pb}$$

95% CL limit on Coupling Parameters

$$-2.6 < \Delta K < 2.8 \quad (\lambda = 0)$$

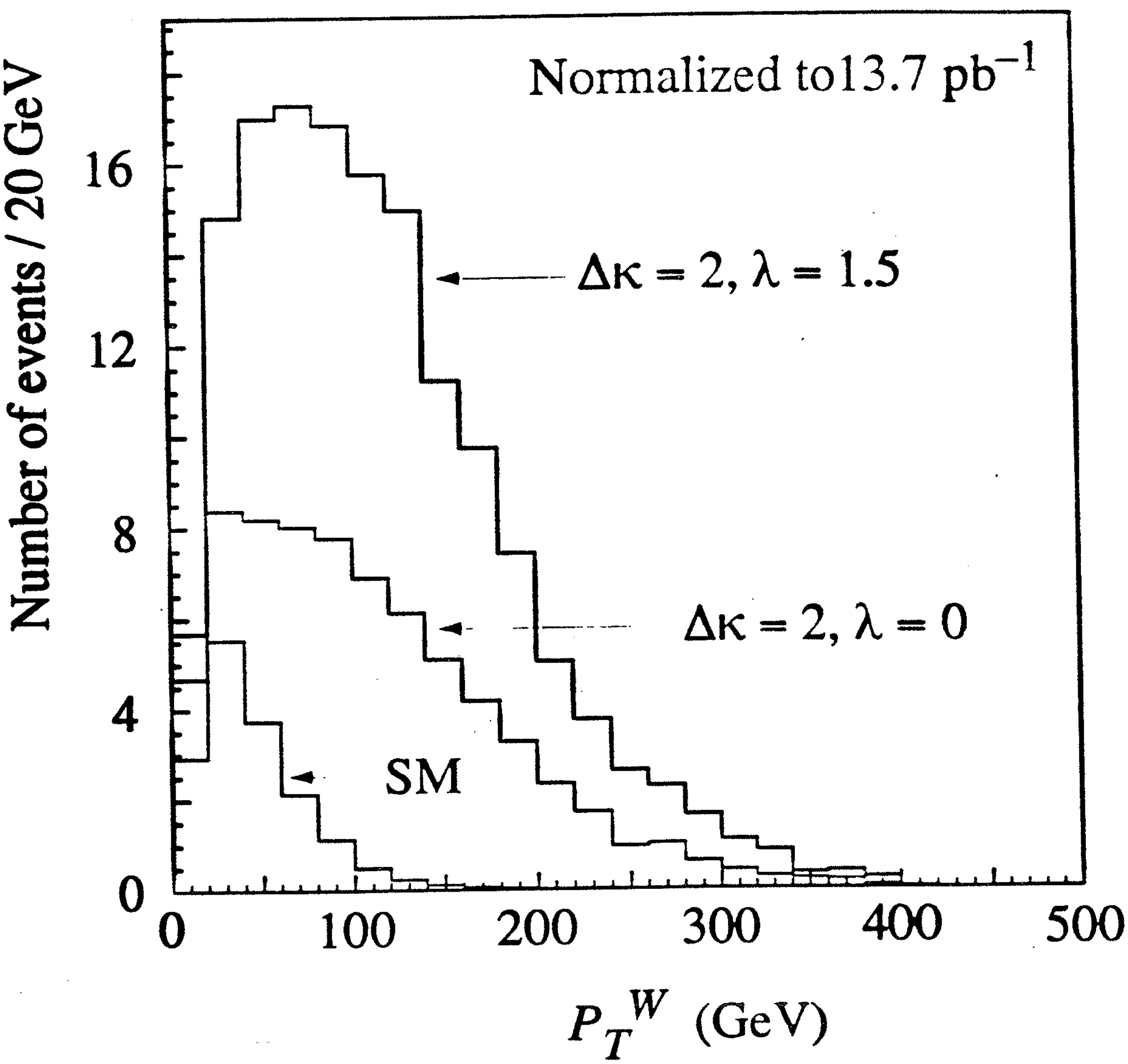
$$-2.1 < \lambda < 2.1 \quad (\Delta K = 0)$$



$WW, WZ \rightarrow l\nu\, jj$

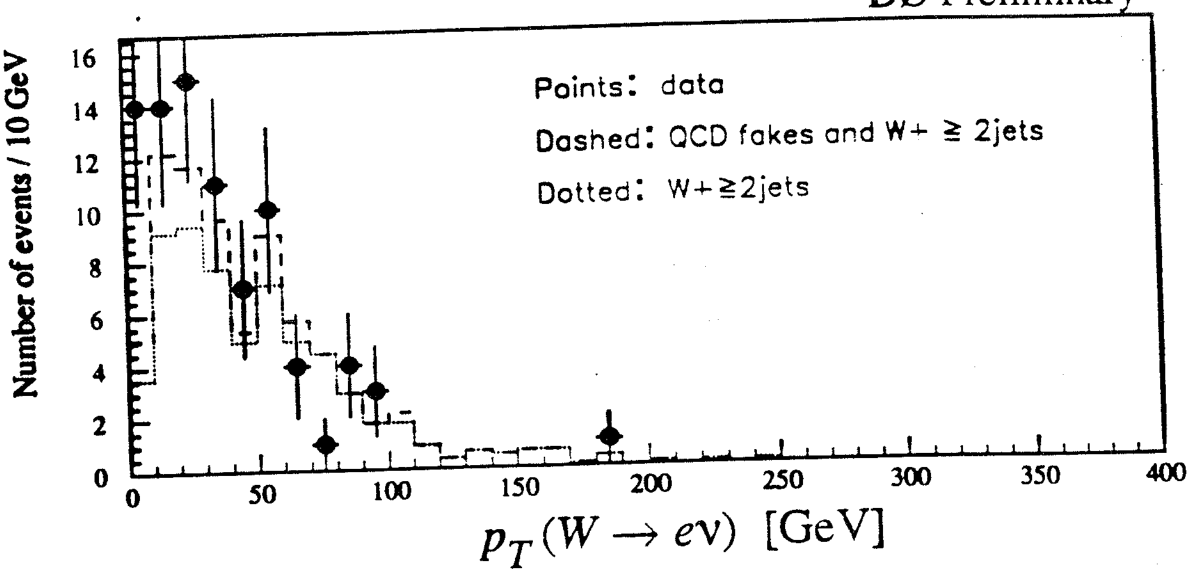
- The $WW, WZ \rightarrow l\nu\, q\bar{q}$ channel is background dominated
- However, at high $p_T(W \rightarrow e\nu)$
  - backgrounds are small
  - anomalous $WW\gamma$ / WWZ couplings enhance cross section

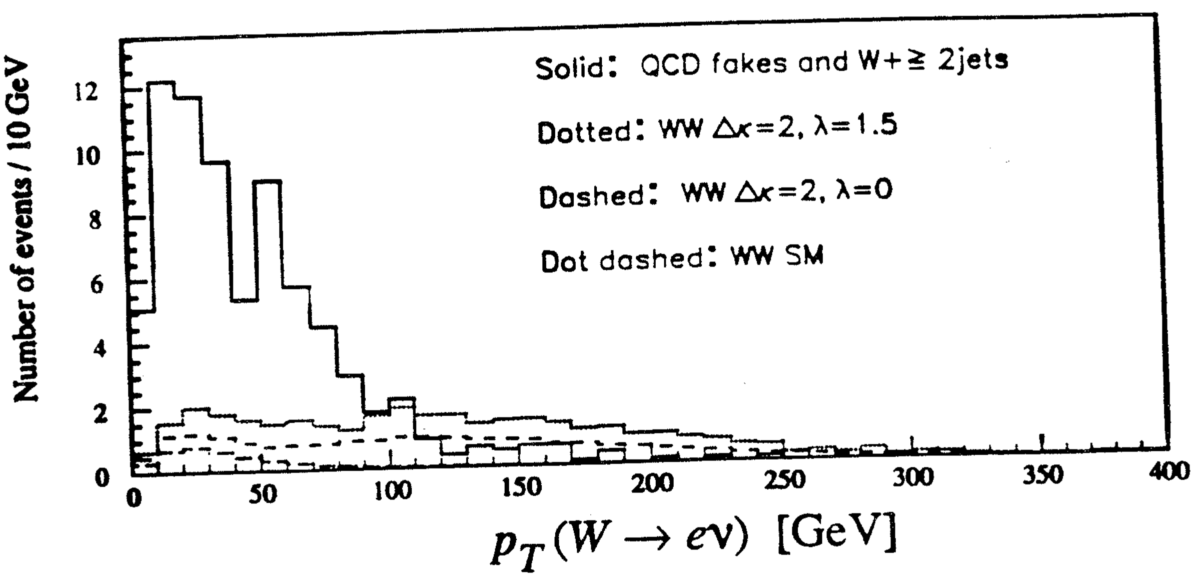
$\rightarrow$ sensitive test of anomalous couplings



$p_T{}^W$ spectrum

DØ Preliminary





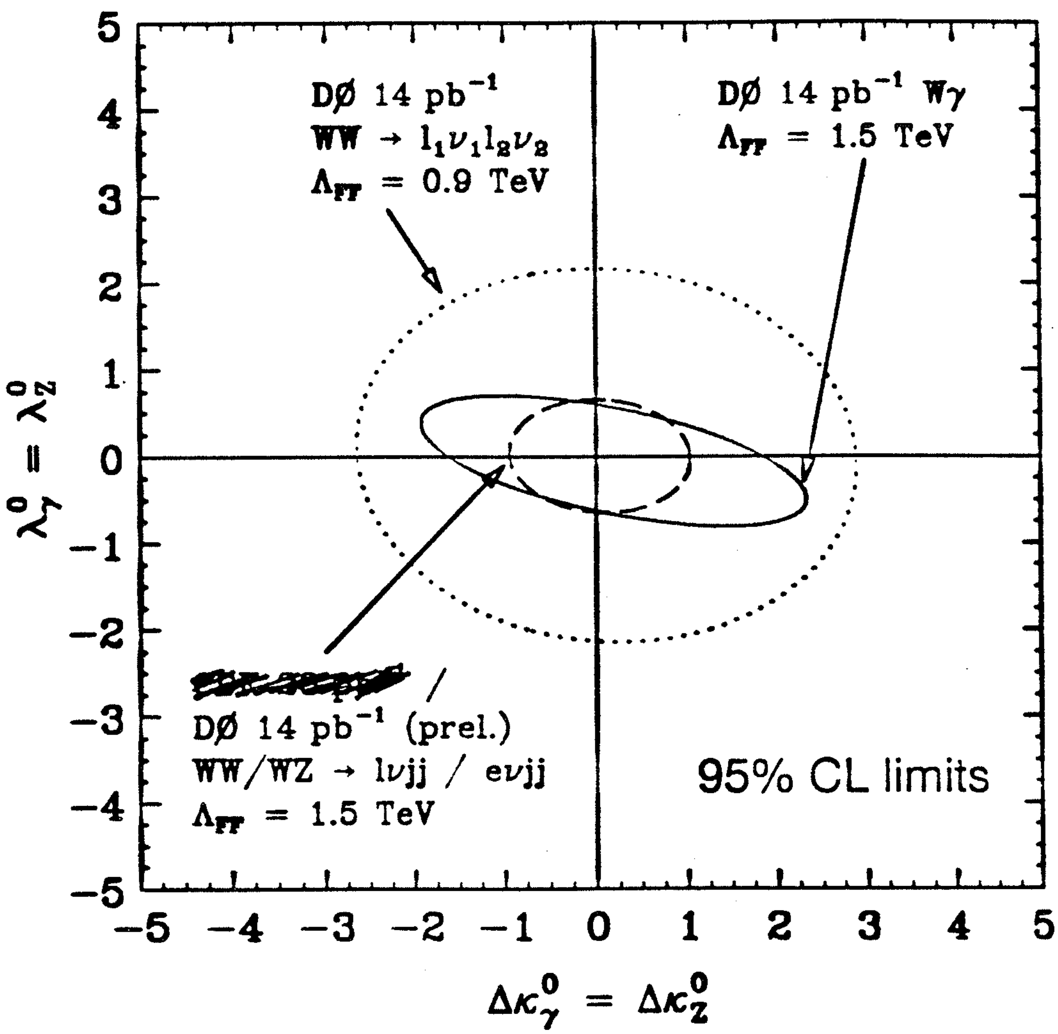
- 95% CL limits obtained from binned likelihood fit, assuming $\Lambda = 1.5$ TeV and $\Delta\kappa_\gamma = \Delta\kappa_Z$, $\lambda_\gamma = \lambda_Z$:

$$-0.89 < \Delta\kappa < 1.07 \quad (\lambda = 0)$$

$$-0.66 < \lambda < 0.67 \quad (\Delta\kappa = 0)$$

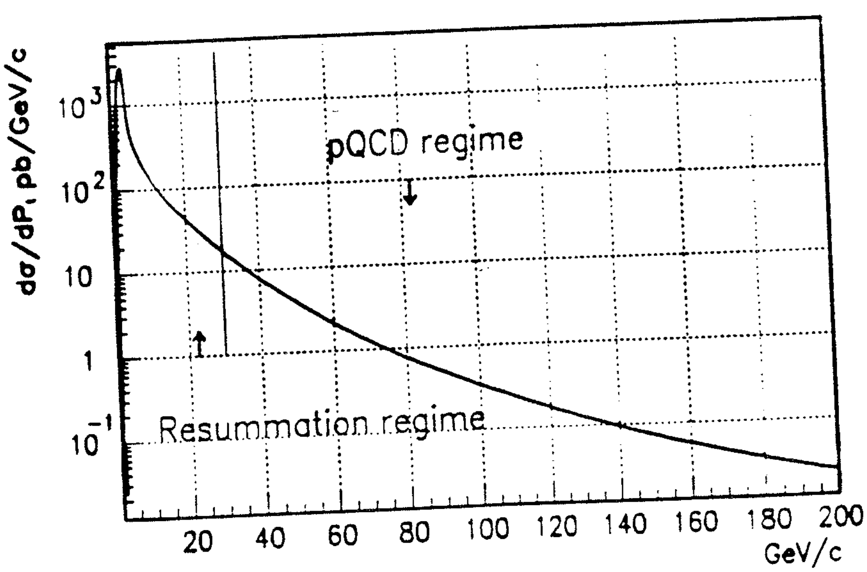
PRELIMINA

WWV anomalous coupling limits – comparison



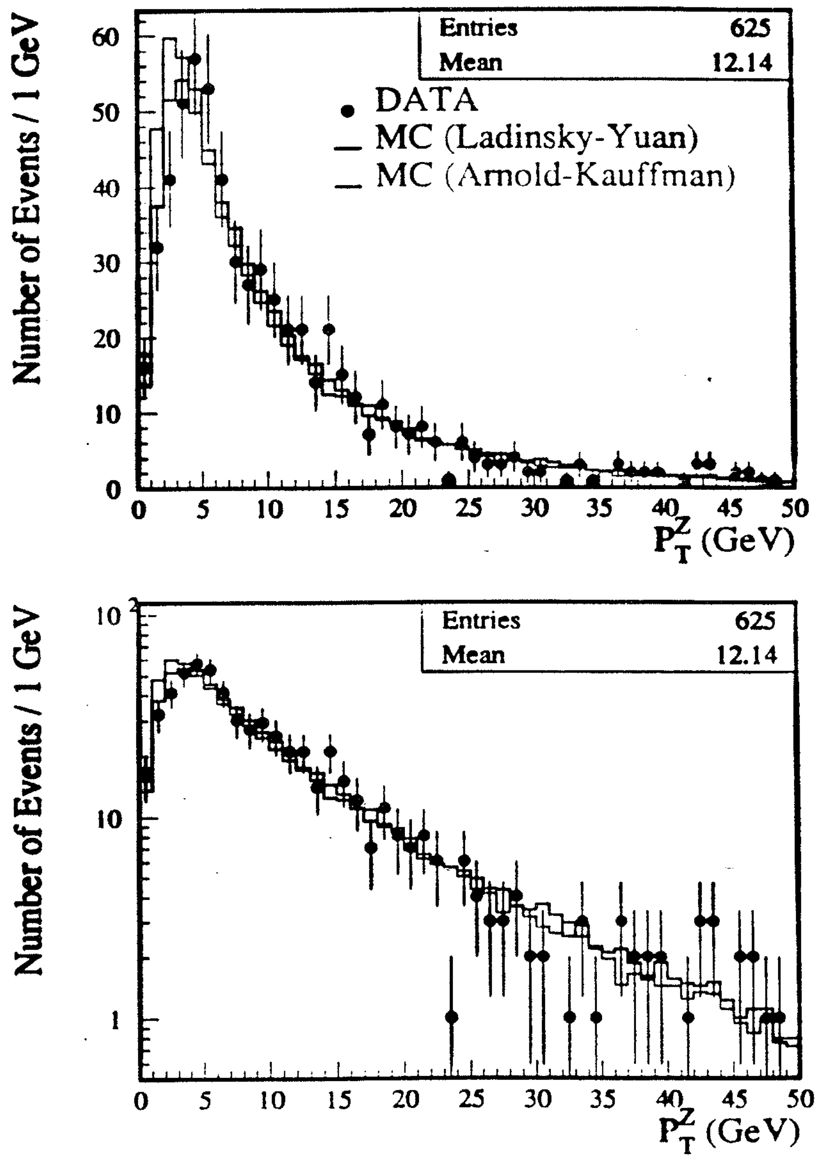
Why measure $\frac{d\sigma}{dP_t}$?

- Sensitive Test of pQCD Predictions
- Physics Beyound the Standard Model
- Constrain QCD Resummation Calc.
- Aid Measurement of M_W



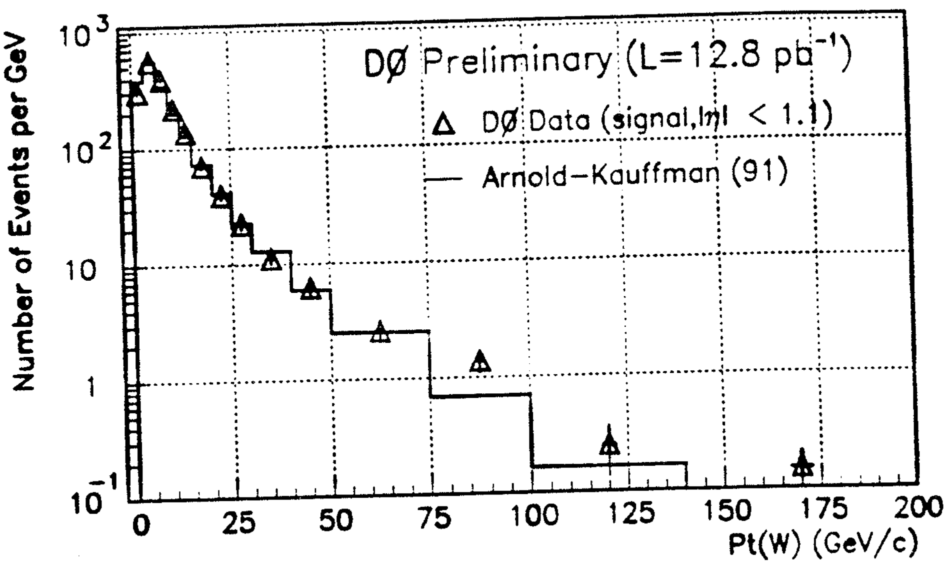
PRELIMINARY

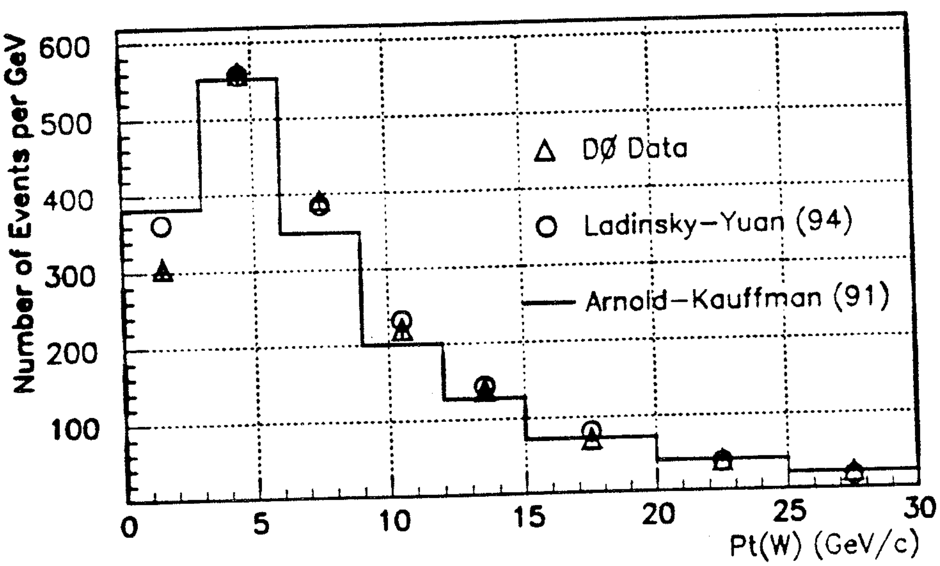
Z Pt Distribution from DØ



PRELIMINARY

W Pt Distribution from DØ





CONCLUSIONS :-

1. We have measured W/Z inclusive X-section. Result is in agreement with SM.

2. $\Gamma(W) = 2.044 \pm 0.092$ GeV

   $\Delta\Gamma(W) < 109$ MeV @ 95%.

3. LIMIT ON WWγ COUPLINGS (95% C

   $-1.6 < \Delta K < 1.8 \quad (\lambda = 0)$
   $-0.6 < \lambda < 0.6 \quad (\Delta K = 0)$

4. LIMIT ON ZZγ/Zγγ COUPLINGS (95%

   $-1.8 < h_{30}^{Z} < 1.8 \quad (h_{40}^{Z} = 0)$
   $-0.5 < h_{40}^{Z} < 0.5 \quad (h_{30}^{Z} = 0)$

5. 1994-95 WWγ ANALYSIS (PRELIMINA

   $-1.46 < \Delta K < 1.40 \quad (\lambda = 0)$ 95% (
   $-0.41 < \lambda < 0.40 \quad (\Delta K = 0)$

6. $\sigma(p\bar{p} \to W^+W^-) < 87$ pb 95% CL

7. $WW \to \ell + \not{E}_T + $ jets, LIMIT ON WWγ

   $-0.9 < \Delta K < 1.1 \quad (\lambda = 0)$ 95% CL
   $-0.7 < \lambda < 0.7 \quad (\Delta K = 0)$

8. $\frac{d\sigma}{dP_T}$ vs P_T (W/Z) ⇒ agrees with

9. 1994-95 DATA $\simeq 85\ pb^{-1}$!