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ELECTROWEAK PHYSICS RESULTS FROM CDF

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ABSTRACT

This note presents first preliminary results on electroweak physics in Proton - Antiproton collisions at vs = 1.8 TeV from new data taken by the CDF experiment at the Fermilab Tevatron collider. With roughly a five-fold increase in data collected in the 1992/1993 run as compared to the previous data from the 1988/1989 run, we considerably improve our accuracy in precision measurements of electroweak parameters as well as our sensitivity to new physics at high mass scales. We present here a new determination of the width of the W boson, as well as the status of our searches for anomalous W and Z boson - photon couplings and for a Z'.

Data Sample

A good description of CDF and its performance in the 1992/1993 data taking run can be found in the contribution of Steve Hahn to these conference procedings. The detector recorded an integrated luminosity of approximately 22 pb^{-1}. To enable a speady analysis of "interesting" events, a selection of data with specific event characteristics was seperately recorded ("Expressline") and processed already during the data taking. Our IVB candidates in the electron decay channel were extracted from the inclusive electron data sample which is a collection of events with the presence of a high transverse momentum electron (or positron) in the central part of the detector [1], see Fig. 1.

We extracted W's by requiring the presence of at least 20 GeV transverse energy imbalance in the event, whereas for Z candidates a second isolated electromagnetic cluster forming with the electron candidate an invariant mass between 65 GeV/c^2 and 115 GeV/c^2 was required. The transverse mass spectrum of the selected W candidates is displayed in Fig. 2, and the invariant mass distribution of the Z candidates is shown in Fig. 3. Note that Figs. 1 - 3 display only 90% of our data: the events shown were used for the determination of the W width, whereas for the searches the full data set was used.

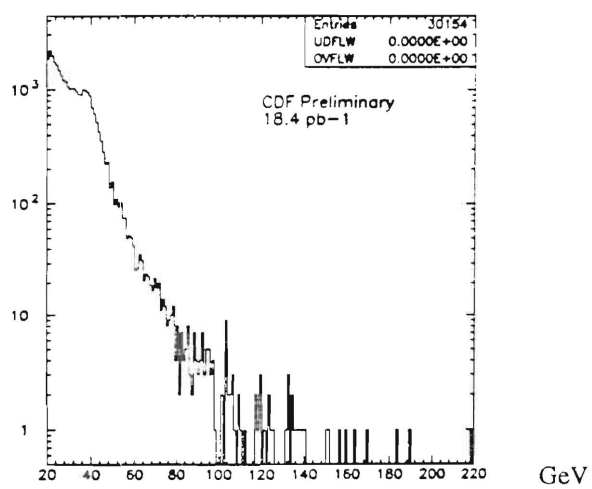

Fig. 1 Et spectrum of electron (and positron) candidates in the inclusive electron sample. The Jacobian peak of W and Z decays is well visible.

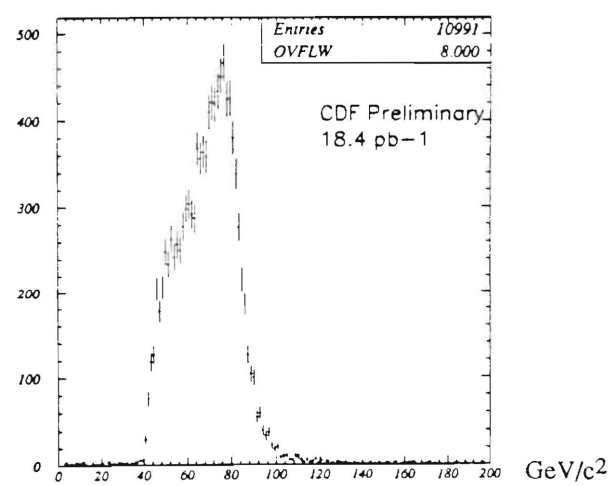

Fig. 2 Transverse mass distribution of W candidates in the electron channel.

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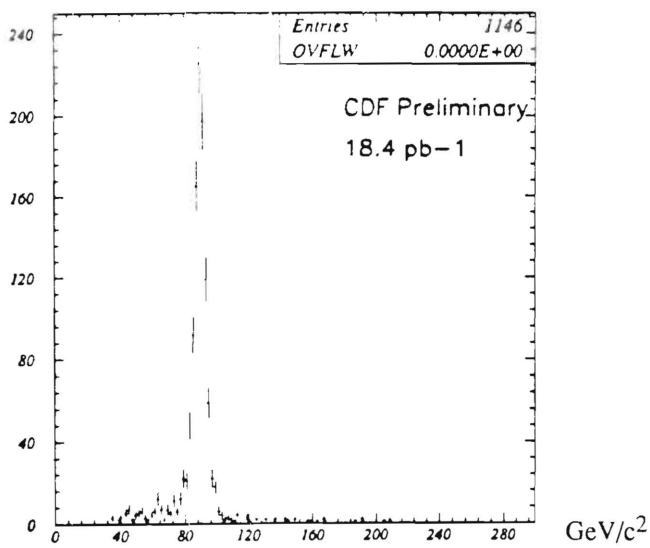

Fig. 3 The invariant mass distribution of electron positron pairs.

Likewise, the inclusive high Pt central muon sample is the basis of our muonic W and Z boson extraction [2] : here the presence of an isolated 20 GeV/c Pt track matched to a track stub in our central muon detection system was required. From our inclusive muon sample we extracted 6100 W candidates and 590 Z candidates.

Width of the W boson

The conventional approach to determine the mass and width of W's in hadron colliders is to fit the invariant transverse mass distribution. An accurate mass determination of the W is of fundamental importance as it is sensitive through radiative corrections to the yet unknown top quark and higgs boson masses. At present the world average mass of the W measured by UA2 and CDF is M = 80.14 ± 0.27 GeV/c^2. A measurement with our new data is in progress and should yield an overall accuracy of about 0.2 GeV/c^2 [3].

The width of the W boson on the other hand is interesting because it may reveal the presence of non - observed decay modes of the W as for instance into a light top quark with non-standard decay. In the framework of the Standard Model, the W decays only into quarks of the first two fermion generations and leptons of the three known generations, since the top quark is known to be more massive than the W [4]. Under this assumption, the width is predicted to be $\Gamma(W) = 2.067 \pm 0.021$ GeV [5]. With our present statistics, the most accurate determination still comes from an indirect method which utilizes the ratio of the numbers of observed W -> lν and Z ->ll [6]:

$$R = \frac{\sigma_W B(W \to l\nu)}{\sigma_Z B(Z \to l^+ l^-)} = \frac{\sigma(p\bar{p} \to WX)}{\sigma(p\bar{p} \to ZX)} \frac{\Gamma(W \to l\nu)}{\Gamma(W)} \times \frac{\Gamma(Z)}{\Gamma(Z \to l^+ l^-)} \qquad (1)$$

The result of R using data in the electron channel is displayed in table 1:

	W's	Z's
Candidates:	10991	1053
Background:	1175^{+121}_{-99}	52 ± 9
Signal:	9816 ± 105 ± 106	1001± 32 ± 9
Acceptance		
$A_{W,Z}$	0.338 ± 0.006	0.372 ± 0.006
A_W/A_Z	0.908 ± 0.015	
Efficiencies		
$\varepsilon_{W,Z}$	0.749 ± 0.013	0.731 ± 0.015
$\varepsilon_W/\varepsilon_Z$	1.025 ± 0.012	
Drell-Yan Correction	-	1.01 ± 0.01
$\frac{\sigma(W\to e\nu)}{\sigma(Z\to ee)}$	10.65 ± 0.36 (stat.) ± 0.27 (sys.)	

Table 1 Numbers of candidates and background events, acceptances and efficiencies used for the determination of R.

From R we obtained, using a recent calculation of the ratio of W and Z production cross sections of 3.23 ± 0.03 [7], the ratio of leptonic decay widths of the W and Z of 2.696 ± 0.018 [8] and the latest LEP measurement $\Gamma(Z) = 2.492 \pm 0.007$ GeV [9] :

$$\Gamma(W) = 2.033 \pm 0.069(\text{stat.}) \pm 0.057(\text{syst.}) \text{ GeV} \qquad (2)$$

This result is consistent to the Standard Model estimate and leaves little room for non-standard decays. Ignoring exotic decay modes, only a top quark with a mass above 62 GeV/c^2 (95% Cl) may go unnoticed due to phase space suppression see Fig. 4:

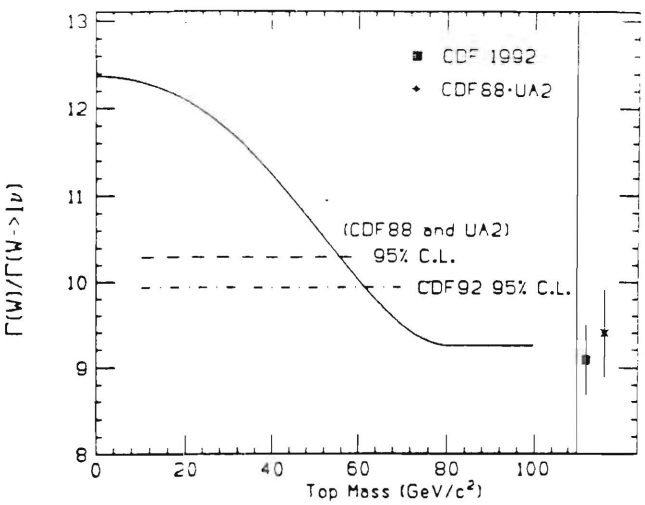

Fig. 4 Inverse branching fraction of W decays into the electron channel. We show a comparison of our new data point and the previous combined UA2 + CDF value with a theoretical calculation.

Search for anomalous W - photon couplings

Owing to the non-abelian nature of electroweak interactions, we expect direct couplings amongst the vector bosons. While nobody questions static W-W-photon interactions (after all the W is a charged object) there does not exist a measurement of the electroweak multipole moments of the W boson. The Collider allows us to measure the magnetic dipole moment and the electric quadrupole moment by studying events with a photon and a W. These moments are related to the coupling constants κ and λ as follows :

Magnetic dipole moment : $\mu_W = e/2M_W\,(1 + \kappa + \lambda)$ (3)

Electric quadrupole moment : $Q_W = -e/M_W^2\,(\kappa - \lambda)$ (4)

In the Standard Model at tree level, $\kappa = 1$ and $\lambda = 0$.

There are various processes which give rise to a photon and a W boson: radiation off a W, off a quark and off the charged decay lepton. An interference of the amplitudes of these processes guarantees gauge invariance in the framework of the Standard Model, while anomalous couplings imply the presence of a new scale in the boson sector at higher energies [10]. This new scale would manifest itself, amongst other things, as a pronounced tail in the Et distribution of the photon, and yields in all cases a larger $W\gamma$ production cross section. In our data from the 1988/1989 run we observed 13 W candidates in the electron and muon channel with an isolated photon of Et > 5 GeV that was emitted into the central part of our detector ($|\eta| < 1.1$) and separated from the decay lepton by at least 0.7 rad. We estimated that about half of these candidates were background events where a QCD jet in a W event fragmented dominantly into a π^0 faking a single photon. The acceptance-corrected cross section times branching ratio for any leptonic decay channel is

$$\sigma * BR(W\gamma) = 17.9 +11.3 - 10 + \text{pb} \qquad (5)$$

two orders of magnitude lower than the W production cross section times branching ratio which is 2.2 ± 0.2 pb [11]. Our measurement is in good agreement with SM expectations but inconsistent with large anomalous couplings, as is shown in Fig. 5, which compares our data and their upper confidence limits with a theoretical calculation [12].

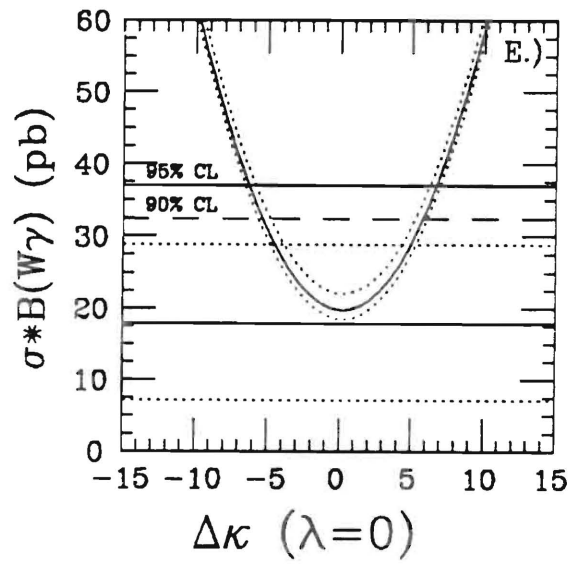

Fig. 5 Measured value of $\sigma * BR(W\gamma)$ and its experimental limits compared to theoretical expectations.

While Fig. 5 shows a special case where we assume only one of the two couplings to be anomalous, Fig. 6 displays the confidence limit contours of our measurement simultanously in both couplings, κ and λ. We also show the curve of maximum non-standard couplings allowed by our data without exceeding unitarity limits at a scale of 1 TeV. Since our limits are mostly smaller than the unitarity limits, we may thus interprete our results as being sensitive to 1 TeV scale in the W sector. Using equations (3) and (4), we also extract limits on deviations of the physical moments from the SM, as shown in Fig. 7.

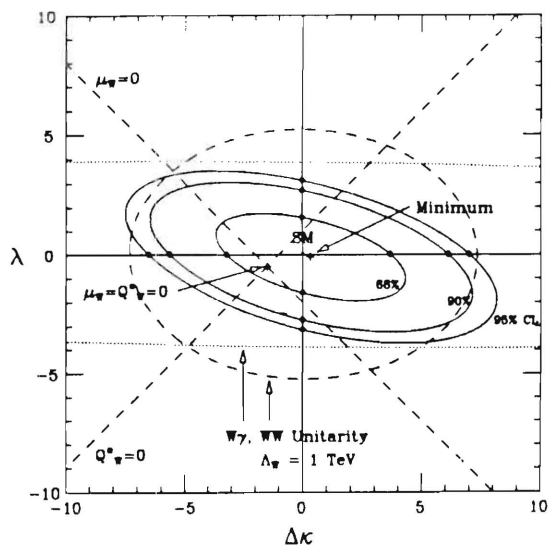

Fig. 6 Experimental limits on anomalous Wγ couplings from the 1988/1989 data.

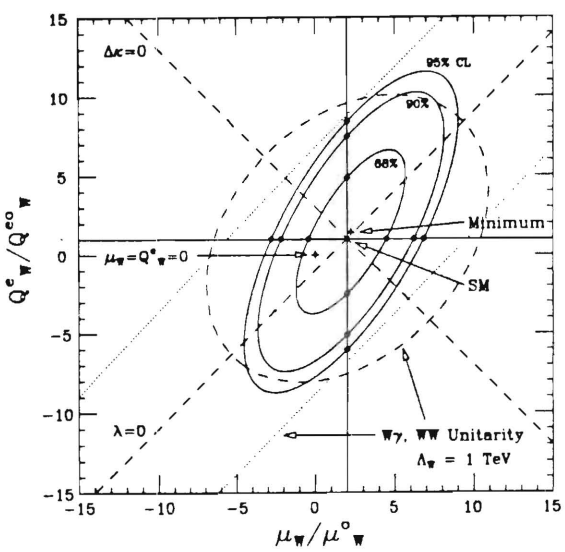

Fig. 7 Experimental limits on the magnetic quadrupole moment and electric dipolemoment of the W, using 1988/1989 data.

With our new data we are far more sensitive to anomalous W γ couplings. We observed 18 W γ candidates with Et(γ) > 7 GeV in the electron channel (see Fig. 8) and 7 in the muon channel. There are no candidates with Et(γ) > 25 GeV. Our data are consistent with a SM simulation, whereas a simulation with an assumed anomalous coupling of Δκ = 3 lets us expect a significant surplus of events at high Et(γ), which seems to be excluded, see Fig. 8.

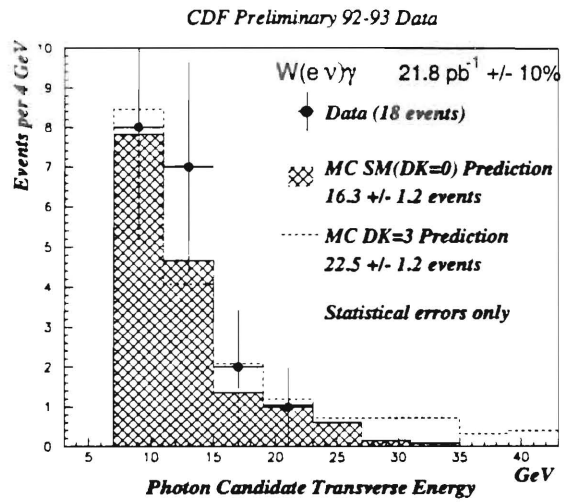

Fig. 8 Transverse energy distribution of photons in Wγ event candidates in the electron channel from the new data in comparison with Monte Carlo estimates.

Once all systematic uncertainties and background are evaluated, we expect to be sensitive to anomalous couplings of Δκ = 2.5 and of λ of 1.0 at 95% Cl. This should allow for a significant determination of the sign of the magnetic dipole moment of the W.

Search for a Z'

The presence of a Z' - not forseen in the Standard Model - would manifest itself in the detector as a resonance in the invariant mass distribution of lepton pairs at masses above the Z mass. Previously, CDF excluded a Z' with a mass below 412 GeV/c^2 (95% Cl), assuming standard electroweak couplings to fermions [13]. As may be seen from Fig. 2, our electron data display a tail in the electron - positron invariant mass distribution which extends to beyond 220 GeV/c^2. The largest mass amounts to 320 GeV/c^2 (not seen). This tail is entirely consistent with high mass Drell Yan event production; the non-observation of any events above 320 GeV/c^2 can be translated into an upper limit of a Z' cross section times branching ratio of around 0.4 pb (95% Cl) as displayed in Fig. 9. The slight mass dependence of the cross section limit above 320 GeV/c^2 can be explained with an energy-dependent electron efficiency as well as with the onset of potential Z' decays into a top quark pair (here a top quark mass of 140 GeV/c^2 was assumed). From the comparison of the upper cross section limits with the expected cross section of a Z' we infer a lower mass limit of 495 GeV/c^2 at 95% confidence level.

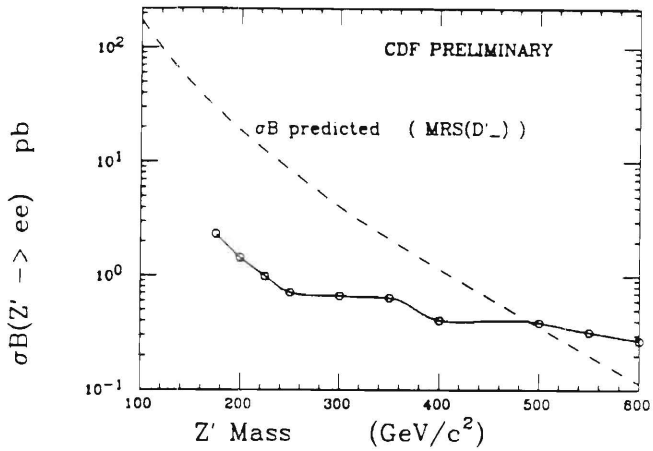

Fig. 9 Upper limit at 95% Cl. on σ*BR(Z' ->e^+e^-) in comparison with a theoretical calculation.

Conclusions

Our first preliminary electroweak results from the new 1992/1993 data taking run show - again - perfect agreement with the Standard Model. We are now able to measure the width of the W boson with an accuracy of 3%, and we expect ot be able to measure the W mass with an accuracy of 0.25%. On the other hand we are pushing our searches for anomalies in the electroweak sector into the TeV scale. This illustrates well the potential of hadron colliders for precision physics as well as their discovery potential for high mass objects.

Acknowledgemets

I thank the hosts for a very well organized conference with many pleasent encounters. The data I present in this paper are the result of the collaborative effort of my CDF colleagues and the FNAL staff. More personally, I would like to acknowledge many fruitful discussions with Ulrich Baur, Henry Frisch, Sacha Kopp, Kaori Maeshima, and of course the members of the WγZ team.

References

[1] The central part of our calorimeters covers a pseudorapidity reagion of $|\eta| < 1$. With the exception for a few techical details, we use the same selection criteria as described in F. Abe et al. (CDF Collab.), Phys. Rev. D**44** (1991), 29.

[2] The central part of our muon detection system covers a pseudorapidity region of $|\eta| < 0.7$. Our selection criteria are described in F. Abe et al. (CDF Collab.), Phys. Rev. Lett. **69** (1992), 28.

[3] A nice discussion of our Physics potential can be found in the contribution to Proc. Vth Blois Workshop, June 1993, by Henry Frisch (for the CDF collaboration).

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