MEASUREMENTS OF W PROPERTIES AT \( \overline{\text{p}}\text{p} \) COLLIDERS

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ABSTRACT

Recent measurements of the production and decay properties of the W boson from the CERN and FNAL \( \overline{\text{p}}\text{p} \) colliders are reviewed. From the ratio of the W and Z cross sections a combined value of the total width of the W boson is deduced to \( \Gamma_W = 2.15 \pm 0.11 \) GeV/c\(^2\). From this measurement a lower bound on the mass of the top-quark is obtained which does not depend on any assumptions about its decay modes, \( m_{\text{top}} > 54 \) GeV/c\(^2\) at the 95% confidence level. Using the results from the \( \overline{\text{p}}\text{p} \) collider experiments alone the W mass is precisely measured to \( m_W = 80.14 \pm 0.27 \) GeV/c\(^2\). From the W over Z mass ratio a precise value of \( \sin^2\theta_W = 0.2275 \pm 0.0052 \) is obtained which results in an upper limit on the mass of the top-quark, \( m_{\text{top}} < 211 \) GeV/c\(^2\) at the 95% confidence level. No deviations from the Standard Model predictions are found.

I. INTRODUCTION

While the mass of the $Z^0$ has now been measured at LEP [1] with high accuracy - a precision of $\Delta m_Z \sim 20 \text{ MeV/c}^2$ has been achieved - the $W$ sector will remain the domain of $\bar{p}p$ colliders until LEP phase II starts around 1994.

After a very successful operation of the CERN ($\sqrt{s} = 630 \text{ GeV}$) and FNAL ($\sqrt{s} = 1.8 \text{ TeV}$) $\bar{p}p$ colliders in the years 1988 and 1989 and an additional period at CERN in 1990 large integrated luminosities of 15.6 and 9.1 pb$^{-1}$, respectively, have been delivered to the experiments, of which UA1 has accumulated on tape 4.7 pb$^{-1}$, UA2 13.0 pb$^{-1}$ and CDF 4.4 pb$^{-1}$. From these integrated luminosities and the measured $W$ and $Z$ production cross sections large $W$ and $Z$ event samples could be expected, i.e. 3200 $W \to \mu\nu$, 275 $Z \to \mu\mu$ for UA1, 8900 $W \to \text{ev}$, 850 $Z \to \text{ee}$ for UA2 and 23000 $W \to \mu\nu + W \to \text{ev}$, 2600 $Z \to \mu\mu + Z \to \text{ee}$ for CDF. Due to acceptance losses, lepton selection efficiencies and strong fiducial cuts for background rejection and to ensure reliable mass measurements the samples used by the experiments are much smaller. The results presented by the UA2 experiment are based on 2065 $W \to \text{ev}$ and 251 $Z \to \text{ee}$ events [2,3], those presented by CDF on 1130 $W \to \text{ev}$, 592 $W \to \mu\nu$, 65 $Z \to \text{ee}$ and 123 $Z \to \mu\mu$ events [4,5,6,7].

In the following recent results on the $W$ and $Z$ production cross sections, resulting in an indirect measurement of the total width of the $W$ boson are presented. The precise measurement of the mass of the $W$ boson and of the significantly improved $W/Z$ mass ratio resulting in a precise determination of the Weinberg angle is also presented. The Standard Model parameters derived from these measurements are compared to theoretical predictions.

II. SELECTION CRITERIA OF $W$ AND $Z$ SAMPLES

Signals from $Z^0 \to e^+e^-, \mu^+\mu^-$ and $W \to \text{ev}$, $\mu\nu$ decays are easily visible above possible background. Very simple kinematical cuts such as, in case of the $Z$ on the transverse momentum of the leptons ($p_T^e, p_T^\mu \geq 10 \text{ GeV/c}$) and on the invariant mass of the two leptons ($m_{ee}, m_{\mu\mu} \geq 70 \text{ GeV/c}^2$) provide a clean $Z$ sample, or in case of the $W$ a cut on the transverse momentum of the leptons and the neutrino ($p_T^e, p_T^\mu, p_T^\nu \geq 20 \text{ GeV/c}$) provide a clean $W$ sample. Rather loose lepton identification criteria are used by the experiments. For electrons (UA2 and CDF) a cluster in the electromagnetic calorimeter compatible with an isolated electromagnetic shower is demanded. At least one charged
also the energy-momentum balance, $E/p < 1.4$, is required. For muons (UA1 and CDF) a track in the central chamber matching hits in the muon chambers and an energy pattern in cells hit by the track compatible with a minimum ionising particle is required.

III. THE W AND Z PRODUCTION CROSS SECTIONS AND $\Gamma_W$

After background subtraction, corrections for efficiencies and geometrical acceptances and taking into account the integrated luminosity the W production cross section times the branching ratio, $\sigma^W = \sigma(\bar{p}p \rightarrow W + X) \cdot \text{BR}(W \rightarrow \ell \nu) = \sigma_W \cdot \Gamma(W \rightarrow \ell \nu) / \Gamma_W$, is measured to

$$\sigma^W = \begin{cases} 609 \pm 41 \pm 94 \text{ pb} & \text{(UA1)} [8] \\ 682 \pm 12 \pm 39 \text{ pb} & \text{(UA2)} [2] \\ 2190 \pm 40 \pm 150 \pm 150 \text{ (Lum) pb} & \text{(CDF)} [4] \\ 2290 \pm 70 \pm 120 \pm 120 \text{ (Lum) pb} & \text{(CDF)} \\ \end{cases}$$

and the Z production cross section times the branching ratio, $\sigma^Z = \sigma(\bar{p}p \rightarrow Z + X) \cdot \text{BR}(Z^0 \rightarrow \ell^+\ell^-) = \sigma_Z \cdot \Gamma(Z^0 \rightarrow \ell^+\ell^-) / \Gamma_Z$, is measured to

$$\sigma^Z = \begin{cases} 58.6 \pm 7.8 \pm 8.4 \text{ pb} & \text{(UA1)} [8] \\ 65.5 \pm 4.0 \pm 3.8 \text{ pb} & \text{(UA2)} [2] \\ 209 \pm 13 \pm 6 \pm 16 \text{ (Lum) pb} & \text{(CDF)} [4] \\ 238 \pm 23 \pm 9 \pm 16 \text{ (Lum) pb} & \text{(CDF)} \\ \end{cases}$$

where the first error is the statistical and the second error the systematic uncertainty. The W and Z cross sections in the muon channel have been submitted by CDF as a preliminary result to this conference.

The experimental measurements are compared to theoretical predictions using three neutrino generations. QCD corrections have been calculated up to complete second order in $\alpha_s$ [9]. The leptonic partial widths are predicted by the Standard Model (SM) to order $\alpha$, while the total widths are sensitive to any decay modes whether they are detected or not. The theoretical predictions depend on $m_W$, $m_Z$, $\sin^2\theta_W$, the parton density function and the strong coupling constant $\alpha_s$. The following numerical values have been assumed which are determined from the recent measurement from LEP and the $\bar{p}p$ collider results: $m_Z = 91.175$ GeV/c$^2$, $m_W = 80.14$ GeV/c$^2$, $\sin^2\theta_W = 0.2275$. 30 different sets of parton density functions of next-to-leading order evolutions have been tested [10], while $\alpha_s$ has been calculated with the $\Lambda\overline{QCD}$ of the given set of structure functions at the scale
$\alpha_s$ has been calculated with the $\Lambda_{QCD}$ of the given set of structure functions at the scale $Q^2 = m_W^2, m_Z^2$. The dominant uncertainty on the cross section is given by the structure functions and amounts to $\pm 8\%$ at CERN and to $\pm 12\%$ at FNAL energies. Therefore the theoretical uncertainties are of the same order than the experimental uncertainties. Fig. 1 shows the $W$ and $Z$ production cross sections as a function of the centre-of-mass energy, $\sqrt{s}$. There is good agreement between experiments and with theoretical predictions.

![W and Z production cross sections](image)

$W, Z$ production cross sections as a function of $\sqrt{s}$

While the cross sections $\sigma_W^\ell$ and $\sigma_Z^\ell$ are affected by large experimental and theoretical uncertainties, most of the experimental and theoretical uncertainties cancel in the ratio:

$$R_{Exp} = \frac{\sigma_W^\ell \cdot \Gamma(W \rightarrow \ell \nu)}{\sigma_Z^\ell \cdot \Gamma(Z \rightarrow \ell^+\ell^-)} \cdot \frac{\Gamma_W}{\Gamma_Z}$$

Each of the $\overline{p}p$ collider experiments measure $R_{Exp}$ to
\[ \mu : \text{R}^{\text{Exp}} = 9.5^{+1.1}_{-0.4} \text{(stat + syst)} \] (UA1) [8]
\[ \epsilon : \text{R}^{\text{Exp}} = 10.4^{+0.7}_{-0.6} \text{(stat)} \pm 0.3 \text{ (syst)} \] (UA2) [2]
\[ \epsilon : \text{R}^{\text{Exp}} = 10.2 \pm 0.8 \text{ (stat)} \pm 0.4 \text{ (syst)} \] (CDF) [5]
\[ \mu : \text{R}^{\text{Exp}} = 9.6 \pm 1.1 \text{ (stat)} \pm 0.5 \text{ (syst)} \] (CDF)
\[ \epsilon \text{ and } \mu : \text{R}^{\text{Exp}} = 9.98 \pm 0.65 \text{(stat)} \pm 0.36 \text{(syst)} \] (CDF).

The ratio R^{\text{Exp}} depends significantly on the mass of the top-quark, because for m_{\text{top}} below 45 \text{ GeV/c}^2 both channels W \to t \bar{b} and Z \to t \bar{t} are allowed, while for a top mass in the range 45 < m_{\text{top}} < 75 \text{ GeV/c}^2 only the decay W \to t \bar{b} is allowed. Using the theoretical calculation of \sigma_W^F, \sigma_Z^F, \Gamma_W^F, \Gamma_Z^F described above, calculated at the appropriate \sqrt{s} (with the HMRS-B set of structure functions [11] with \Lambda_{\overline{MS}} = 190 \text{ MeV for the central value}), and \Gamma_Z from LEP [1] the total width of the W, \Gamma_W, is deduced to

\[ \mu : \Gamma_W = 2.19 \pm 0.30 \text{ (stat+syst) GeV/c}^2 \] (UA1)
\[ \epsilon : \Gamma_W = 2.10 \pm 0.14 \pm 0.07 \text{ GeV/c}^2 \] (UA2)
\[ \epsilon \text{ and } \mu : \Gamma_W = 2.20 \pm 0.14 \pm 0.08 \text{ GeV/c}^2 \] (CDF).

These three measurements of \Gamma_W can be statistically combined. The result is

\[ \Gamma_W = 2.15 \pm 0.11 \text{ (stat + syst) GeV/c}^2, \]

in good agreement with the SM prediction assuming m_{\text{top}} to be heavier than m_W. The total width of the W as a function of m_{\text{top}} is shown in Fig. 2 together with the experimental measurements, the direct limit on m_{\text{top}} from CDF [12] and the best limit from the LEP experiments [13]. From the \Gamma_W measurement a lower bound on m_{\text{top}} is obtained which does not dependent on any assumptions about its decay modes, m_{\text{top}} > 54 \text{ GeV/c}^2 at the 95\% CL.

IV. THE W AND Z MASS MEASUREMENT

A precise measurement of the W and Z masses fixes the electroweak theory and allows to test for deviations from the Minimal Standard Model and to study the effect of higher order radiative corrections. The W and Z masses are the two parameters of the SM which can be directly measured by the \bar{p}p collider experiments. At the CERN collider the uncertainties on the mass measurements are dominated by the energy scale error, whereas for CDF the statistical error and the uncertainty of the E/p calibration dominate.
IV.1 The Z Boson

The Z boson mass can be determined in a straightforward way from the invariant mass spectrum of the lepton pairs in the $e^+e^-$ and $\mu^+\mu^-$ final states. Monte Carlo methods (maximum likelihood techniques) are used to extract $m_Z$ taking into account the experimental mass resolution due to detector effects and the relativistic Breit-Wigner shape of the Z peak, its finite width and the asymmetric production due to structure functions.

To determine $m_Z$, UA2 [3] uses two independent data samples. The first sample contains only events where both electrons are contained in the fiducial region of the central calorimeter (CC), well away from cell edges and cracks. This sample contains 95 well measured $Z^0 \rightarrow e^+e^-$ decays in the mass range of $70 < m_{ee} < 120$ GeV/c$^2$. A second independent sample has been used where only one of the two electrons is contained in the fiducial region of the CC. The other electron should be either in the end-cap region or
in edges or cracks of the CC. To transport the mass scale of the well measured sample to the second sample, the total momentum constraint from electrons and hadrons has been used \( (p_T^e + \sum p_T^{\text{hadrons}} = 0) \) to determine the energy of the electron not contained in the fiducial region. The second sample has a worse mass resolution and a larger systematic uncertainty due to the worse energy resolution of the hadron energy scale, but this event sample which contains 156 events in the mass range of \( 70 < m_{ee} < 120 \) GeV/c\(^2\), reduces the statistical error affecting the measurement of \( m_Z \).

In CDF [6], 123 \( Z^0 \rightarrow \mu^+\mu^- \) in the mass range \( 75 < m_{\mu\mu} < 105 \) GeV/c\(^2\) were obtained using the tracking requirement. For the electron sample the radiative decays affect the measured mass appreciably more strongly than for the muon mode. Consequently, the best measurement of the \( Z \) mass is obtained using calorimeter information. 65 \( Z^0 \rightarrow e^+e^- \) are fitted in the mass range of \( 80 < m_{ee} < 100 \) GeV/c\(^2\).

The final result of the fits to a Breit-Wigner distribution convoluted with the detector resolution for \( Z^0 \rightarrow \ell^+\ell^- \) decays is

\[
\begin{align*}
e & : \ m_Z = 91.74 \pm 0.28 \pm 0.12 \pm 0.92 \ \text{GeV/c}^2 \quad \text{(UA2)} \\
w & : \ m_Z = 91.37 \pm 0.34 \pm 0.04 \pm 0.22 \ \text{GeV/c}^2 \quad \text{(CDF)} \\
\mu & : \ m_Z = 90.71 \pm 0.40 \pm 0.04 \pm 0.09 \ \text{GeV/c}^2 \quad \text{(CDF)}
\end{align*}
\]

where the first and second error is the statistical and systematic uncertainty and the third error the scale uncertainty. There is good agreement between experiments and also with the \( Z \) mass measurement from LEP [1].

### IV.2 The W Boson

At hadron colliders the \( W \) mass cannot be determined directly from the \( W \rightarrow \ell\nu \) decays, since the longitudinal momentum of the neutrino cannot be measured, because undetected particles which carry a substantial momentum fraction escape along the beam pipe. Only the transverse components of the neutrino momentum are measured. Therefore the \( W \) mass has to be determined by fits to transverse variables, \( p_T^\ell, p_T^\nu \) and \( m_T^\nu \), where \( p_T^\ell \) is the electron or the muon transverse momentum, \( p_T^\nu \) the neutrino transverse momentum and \( m_T^\nu \) the transverse mass of the lepton-neutrino pair.

There is only a weak correlation to the \( W \) mass in the forward region. For this reason the experiments have limited their \( W \) sample to leptons in the central region (UA2: electrons in \( |\eta| < 0.9 \); CDF: electrons and muons in \( |\eta| < 1.1 \)). To minimize the systematic uncertainties from the shape of the \( p_T^W \) distribution events with \( p_T^W > 20 \) GeV/c have
also been excluded by UA2. For the same reason and with even more stringent cuts, CDF excludes all events which have a reconstructed jet exceeding 7 GeV/c of transverse momentum from the analysis. The requirement to reject events with high \( p_T \) jets attempts to minimize the uncertainty in the measurement of \( \bar{p}_T^v \sim \bar{p}_T^e - \Sigma \bar{p}_T^{\text{Hadrons}} \). Events in which one or both leptons hit close to a cell boundary have been removed to ensure the high quality of the energy reconstruction. Kinematical cuts have been applied to reduce the background to a negligible level. The mass of the W was estimated with a maximum likelihood fit to all three transverse variables. The systematic error on the result receives contributions from structure function uncertainties, the shape of the \( p_T^W \) distribution, resolution effects from the \( p_T \) of the recoiling hadrons and the scale uncertainty for the \( p_T^\nu \) measurement. All these uncertainties contribute in different ways to the three variables to fit the W mass, \( p_T^e, p_T^\nu \) and \( m_T^e \).

In UA2 [3] the electron selection criteria resulted in a W sample of 2065 events in the kinematical region of \( 40 < m_T^{e\nu} < 120 \) GeV/c\(^2\). This sample contains a small contribution of 3.8% from the process W \( \rightarrow v \nu \) followed by the decay \( \tau \rightarrow e \nu \bar{v} \nu \). The fit to the transverse mass of the electron-neutrino system was preformed in the region of \( 60 < m_T^{e\nu} < 120 \) GeV/c\(^2\), where the background contribution is negligible, while the fit to the lepton or the neutrino spectrum was limited to the region \( 30 < p_T^e, p_T^\nu < 60 \) GeV/c. Radiation effects have been included.

In CDF [7] the final W samples contain 1130 electron and 592 muon candidates. Despite the fact of a 3 times higher production cross section, the event samples used by CDF are small due to the strong selection criteria which are necessary to suppress the background to a negligible level. The fit to the transverse mass of the lepton-neutrino system was performed in the mass range of \( 65 < m_T^{e\nu} < 94 \) GeV/c\(^2\), while the fit to the lepton or the neutrino spectrum was limited to the region \( 32 < p_T^e, p_T^\nu < 48 \) GeV/c.

Results from the transverse mass fit are shown in Fig. 3a for UA2 to the electron and in Figs. 3b and 3c for CDF to the electron and the muon channel. Both experiments have also performed fits to the \( p_T^e \) and \( p_T^\nu \) distributions. In all cases a one-parameter-fit has been performed where the W mass is the only free parameter (keeping the W width fixed at the SM expectation of 2.1 GeV/c\(^2\) ignoring any contribution from the top-quark). A two-parameter-fit where the W mass and its width are left as a free parameter has also been made yielding a slightly higher W mass. The three fit results agree very well with each other, demonstrating the high quality of the measurement, and indicating that the systematic uncertainties are well under control.
Both experiments have taken the results from the fit to the transverse mass of the lepton-neutrino pair which gave the smallest uncertainty on the W mass. These values are summarized in Table 1 together with a detailed list of the different sources of systematic uncertainties. The first error represents the statistical, the second error the systematic uncertainty. The energy scale uncertainty is also given separately. As can be seen from Table 1 the largest uncertainty on the W mass measurement arises from the insufficient knowledge of the parton density functions, of the $p_T^W$ measurement and of the detector response to the recoiling hadrons.
Table 1: Uncertainties on the W mass measurements

<table>
<thead>
<tr>
<th>Reaction</th>
<th>UA2</th>
<th>CDF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W → ev (calorimetry)</td>
<td>W → μν (tracking)</td>
</tr>
<tr>
<td>W mass</td>
<td>80.84</td>
<td>79.90</td>
</tr>
<tr>
<td>Statistics</td>
<td>±0.23</td>
<td>±0.53</td>
</tr>
</tbody>
</table>

Proton structure functions

|                      | ±0.085 | ±0.06 | ±0.06 |
| e⁻ resolution       | ±0.075 |       |       |
| pᵀ W, had. response | ±0.060 | ±0.15 | ±0.145 |
| ν scale             | ±0.070 | ±0.24 | ±0.17  |
| Parallel balance    | ±0.025 |       |       |
| Background          |negl.  | ±0.11 | ±0.05  |
| Fitting procedure   | ±0.030 | ±0.05 | ±0.05  |
| Underlying event    | ±0.030 | ±0.03 | ±0.03  |
| Efficiency vs pᵀ W  | ±0.030 | +0.13±0.01 | +0.07±0.01 |
| Radiative decays    | ±0.030 |       |       |

Systematics

|                      | ±0.17 | +0.13±0.32 | +0.07±0.24 |
| Tracking chamber     |       | ±0.08     | ±0.08     |
| Calorimetry          | ±0.81 |       | ±0.175    |

Energy scale

|                      | ±0.81 | ±0.08  | ±0.19    |

All masses and uncertainties are given in GeV/c²
The two recent measurements of the $W$ and $Z$ masses from the UA2 and CDF experiment can be combined to derive a value for the ratio, $m_W/m_Z$. One expects an almost perfect cancellation of the energy scale contribution to the error on the ratio. Deviations from this expectation can arise if the calorimeter response to electrons is not perfectly linear. The mass ratio is measured to

$$m_W/m_Z = 0.8813 \pm 0.0036 \pm 0.0019 \quad (\text{UA2})$$
$$m_W/m_Z = 0.8764 \pm 0.0032 \pm 0.0027 \quad (\text{CDF}),$$

where the first error is statistical and the second the systematic uncertainty. The weighted average of these values with the statistical and systematic uncertainty added in quadrature is

$$m_W/m_Z = 0.8789 \pm 0.0029.$$

The mass ratios can be combined with the most recent results from LEP on the $Z$ mass [1] to give a rescaled measurement of the $W$ mass. In this case, the energy scale uncertainty nearly disappears at the price of an increased statistical error due to the poor $Z$ statistics of the $\bar{p}p$ collider data. This procedure of rescaling is only used for the UA2 data. Because of the small scale error of the CDF $Z$ mass measurement, a rescaling to the LEP $Z$ value is not needed. The final value for the $W$ mass as measured by the $\bar{p}p$ collider experiments is

$$m_W = 80.35 \pm 0.37 \text{ GeV}/c^2 \quad (\text{UA2}) [3]$$
$$m_W = 79.91 \pm 0.39 \text{ GeV}/c^2 \quad (\text{CDF}) [7]$$

with the statistical and the systematic error added in quadrature. There is very good agreement between the two experiments and with the SM predictions. The two measurements of the $W$ mass can be statistically combined. The result is

$$m_W = 80.14 \pm 0.27 \text{ GeV}/c^2$$

which is the best direct measurement of $m_W$ from the available $\bar{p}p$ data. The error shown reflects the statistical and systematic errors added in quadrature. This result is visualized in Fig. 4 which shows $m_W$ as a function of $m_{\text{top}}$. The solid line is a theoretical prediction for $m_{\text{Higgs}} = 100 \text{ GeV}/c^2$, the dotted and dashed lines are predictions for $m_{\text{Higgs}} = 50$ and $1000 \text{ GeV}/c^2$, respectively. The lower value corresponds to the best limits on $m_{\text{Higgs}}$ from LEP [14]. From the $\bar{p}p$ collider data alone, fixing $m_{\text{Higgs}} = 100 \text{ GeV}/c^2$, the mass range of the top-quark is deduced to $m_{\text{top}} = 128 \pm 48 \text{ GeV}/c^2$. If
IV.3 The Weinberg angle $\sin^2 \theta_W$

Using the definition of the Weinberg angle in the renormalisation scheme of Ref. [15] ($\sin^2 \theta_W = 1 - m_W^2/m_Z^2$) which has the advantage of being independent of any contribution from radiative corrections $\Delta \tau$, $\sin^2 \theta_W$ is measured from the mass ratio $m_W/m_Z$ to

$$\sin^2 \theta_W = 0.2234 \pm 0.0073 \quad \text{(UA2)}$$
$$\sin^2 \theta_W = 0.2319 \pm 0.0077 \quad \text{(CDF)}.$$

From the combined mass ratio $\sin^2 \theta_W$ is deduced to

$$\sin^2 \theta_W = 0.2275 \pm 0.0052.$$
The error shown reflects the statistical and systematic errors added in quadrature. From this measurement we can place an upper limit on $m_{\text{top}} < 211 \text{ GeV/c}^2$ at the 95% CL with $m_{\text{Higgs}} < 1000 \text{ GeV/c}^2$.

V. CONCLUSIONS AND OUTLOOK

After a very successful operation of the CERN and FNAL $\bar{p}p$ colliders in the years 1988 and 1989 and an additional period at CERN in 1990 large integrated luminosities have been collected by the UA2 and the CDF experiments. From these large data samples the $W$ and $Z$ production cross sections have been measured. Combined with $\Gamma_Z$ from LEP the total width of the $W$ is precisely determined to

$$\Gamma_W = 2.15 \pm 0.11 \text{ GeV/c}^2,$$

which in turn gives in a lower limit on the mass of the top-quark which does not depend on any assumptions about its decay modes, $m_{\text{top}} > 54 \text{ GeV/c}^2$ at the 95% confidence level.

From these data samples the $W$ and $Z$ boson masses and their mass ratio has been determined with high precision. From the $\bar{p}p$ collider experiments alone the mass of the $W$ is measured to

$$m_W = 80.14 \pm 0.27 \text{ GeV/c}^2$$

which is not yet precise enough to significantly constrain the still unknown parameters of the Minimal Standard Model, $m_{\text{top}}$ and $m_{\text{Higgs}}$. But these measurements allow a direct determination of the electroweak parameter, $\sin^2 \theta_W$, independent of other experiments and of theoretical uncertainties providing therefore a stringent test of the Standard Model complementary to the $e^+e^-$ experiments at LEP. A combined value of $\sin^2 \theta_W$ determined from the $W$ and $Z$ mass ratio is measured to

$$\sin^2 \theta_W = 0.2275 \pm 0.0052$$

which agrees well with the measurement from low energy $\nu N$ scattering experiments and also with the results from the LEP experiments. From this measurement an upper limit on the mass of the top-quark is obtained to $m_{\text{top}} < 211 \text{ GeV/c}^2$ at the 95% confidence level with $m_{\text{Higgs}} < 1 \text{ TeV/c}^2$. Using the best measurement of $m_W$ and the best
measurement of the mass ratio, \( m_W/m_Z \), from the \( \bar{p}p \) collider experiments a value for the radiative corrections of

\[
\Delta r = 0.049 \pm 0.017
\]

is obtained. This value is still not precise enough to conclude on the existence of radiative corrections from other than known sources. In general, since the discovery of the W and Z bosons in 1983, all experimental results from the \( \bar{p}p \), the e+e- colliders and from deep-inelastic lepton-nucleon scattering experiments have confirmed the Standard Model in its minimal form with increasing precision and probing an increasing variety of aspects.

At CERN, after one decade of very successful operation, the \( \bar{p}p \) collider era has come to an end. In the near future the precision measurements of the W properties and the search for the top-quark with increased statistics will remain the main goal of the \( \bar{p}p \) collider at FNAL. CDF and DØ are scheduled to take data from spring 1992 to mid 1993. Each experiment expects \( \geq 25 \text{ pb}^{-1} \) after one year of running. This increase in statistics should allow for a precision of the W mass measurement to \( \Delta m_W = \pm 220 \text{ MeV}/c^2 \) including statistical and systematic uncertainties and, if the top-quark is not too heavy (\( m_{\text{top}} \leq 130 \text{ GeV}/c^2 \)), it should be discovered at the FNAL TEV-I collider by then.

In the long term future until end of 1995 due to the 44 bunch operation of the TEV-I collider a more than tenfold increase in statistics is expected. This would allow the CDF and DØ experiments to get a detailed understanding of their systematic uncertainties on the W mass measurement with help of the improved Z statistics. A reasonable uncertainty of \( \Delta m_W = \pm 100 \text{ MeV}/c^2 \) can be expected which makes the TEV-I collider competitive with LEP II.
REFERENCES


