MEASUREMENT OF THE MASS OF THE W BOSON AT LEP AND DETERMINATION OF ELECTROWEAK PARAMETERS

A. STRAESSNER

*III. Phys. Institut, RWTH Aachen,
52056 Aachen, Germany*

E-mail: Arno.Straessner@cern.ch

New results of the W mass and width measurements at LEP are presented, which yield $M_W = 80.401 \pm 0.048$ GeV and $\Gamma_W = 2.19 \pm 0.15$ GeV. A comparison of this direct and the indirect W mass, obtained in an analysis of electroweak measurements, is made and good agreement is observed. All electroweak data are very consistent with the Standard Model predictions. In a combined fit an upper limit on the mass of Higgs boson is put to $M_H < 188$ GeV, while direct searches at LEP exclude Higgs masses below 107.9 GeV at 95% confidence level.

1 Introduction

In 1989 the LEP e^+e^- collider started operation at centre-of-mass energies close to the Z resonance. Each of the four LEP experiments, ALEPH, DELPHI, L3 and OPAL, collected about 4 million Z decays. The data allow a precise determination of the properties of the Z boson. In the second phase of LEP, starting in 1996, the centre-of-mass energy, $\sqrt{s}$, is increased to energies beyond the production threshold for W boson pairs up to $\sqrt{s} = 202$ GeV in 1999. About 7000 W pair events per experiment are used to measure the mass and the width of the W boson. The data corresponds to an integrated luminosity of about $4 \times 480 \text{ pb}^{-1}$.

The properties of the heavy gauge bosons, Z and W, are important quantities in the Standard Model (SM). Combining the LEP results with other electroweak measurements stringent tests of the SM predictions are performed. A constraint is put on the mass of the last unknown particle in the SM: the Higgs boson.

Figure 1: Invariant mass spectra measured in $qqe\bar{\nu}$ and $qqqq$ events at $\sqrt{s} = 192 - 202$ GeV compared to the W mass fit results. For the preliminary results of 1999 the OPAL collaboration uses a relativistic Breit-Wigner function instead of reweighted Monte Carlo samples for comparison with data, as it is shown on the right.

2 W Mass Measurement at LEP

W bosons are produced at LEP in the reaction $e^+e^- \rightarrow WW$ at centre-of-mass energies between 161 GeV and 202 GeV. At threshold the total cross-section for W-pair production, σ_{WW} , is strongly dependent on the mass of the W boson. From measurements of σ_{WW} at $\sqrt{s} = 161 - 172$ GeV a value of $M_W = 80.40 \pm 0.22$ GeV is derived¹. At higher energies the sensitivity of σ_{WW} on M_W is less pronounced. Therefore an extraction method based on the direct reconstruction of the W decay products is applied.

The two W bosons of each event decay either to a pair of quarks, e.g. $W^- \rightarrow \bar{u}d$ or $\bar{c}s$, or to a lepton and a neutrino, $W^- \rightarrow \ell^- \bar{\nu}_\ell$, ($\ell = e, \mu, \tau$); in the following denoted qq and $\ell\nu$ for short. This leads to three possible final states, $qqqq$, $qq\ell\nu$, and $\ell\nu\ell\nu$. Because of the two neutrinos in the $\ell\nu\ell\nu$ final state it is more difficult to reconstruct the complete event topology. For a W mass measurement the fully hadronic and the semi-leptonic decays are therefore more important, which have a branching fraction of 45% and 44%, respectively.

Kinematic constraints are imposed to improve the resolution of the measured fermion energies and angles. In a kinematic fit these quantities are varied within their experimental resolution to satisfy energy and momentum conservation. As a possible additional constraint the two reconstructed W masses are forced to be equal.

The mass of the W boson is extracted from the measured invariant masses by comparing Monte Carlo event samples to data. Samples for different values of M_W are obtained in an event reweighting procedure. Unbinned maximum likelihood fits to the measured spectra are performed in the $qq\ell\nu$ and $qqqq$ channels, as it is illustrated in figure 1. In fully hadronic events also hard gluon radiation from quarks is taken into account. By splitting the events into a 4-jet and a 5-jet sample the overall mass resolution is improved². The DELPHI collaboration uses a convolution method for extracting the W mass². With the current methods the W mass is measured at LEP with a statistical precision of 27 MeV combining the direct reconstruction measurements performed at 172–202 GeV.

A systematic error common to all measurements comes from the uncertainty on the LEP

beam energy, which amounts to 20 – 21 MeV for the highest beam energies³. Since it is a relative error the corresponding uncertainty on M_W is 17 MeV. In 1999 a new beam spectrometer is installed in LEP which is expected to be fully operational in the running period 2000. With this device the LEP energy error can be reduced to 10-15 MeV⁴.

A particular problem of the W mass measurement appears in the fully hadronic decay channel. The distance between the two decaying W bosons is about 0.1 fm, which is much smaller than the hadronic interaction length of typically 1 fm. This can give rise to hadronic final state interactions (FSI), such as colour reconnection effects⁵ or Bose-Einstein correlations⁶. Both effects lead to momentum transfer between particles coming from different W bosons, which affects the reconstruction of the invariant masses. By studying various FSI models the possible systematic bias is estimated to be 52 MeV, which is large compared to a statistical error of only 37 MeV in the qq qq channel. FSI effects may also show up in the difference between the semi-leptonic and the fully hadronic W mass:

$$\Delta M_W = M_W(\text{qqqq}) - M_W(\text{non-qqqq}) = 35 \pm 55 \text{ MeV},$$

where systematic errors due to possible FSI effects are removed. However, the observed value is compatible with zero. Possible effects of FSI are also studied most recently in other observables than the W mass which are sensitive to FSI⁷, e.g. the particle flow in the overlap region between two jets and particle correlation functions. In future it may be possible to excluded some of the FSI models in a combined LEP analysis, which should reduce the systematic uncertainty in M_W .

Table 1 summarises the mass values measured by the LEP experiments in non-qqqq and qq qq W-pair events using the direct reconstruction method². All values agree well within the given errors. The combined W mass measurement split up into non-qqqq and qq qq channels yields

$$\begin{aligned} M_W(\text{non-qqqq}) &= 80.398 \pm 0.039(\text{stat.}) \pm 0.031(\text{syst.}) \pm 0.017(\text{LEP}) \text{ GeV} \\ M_W(\text{qqqq}) &= 80.408 \pm 0.037(\text{stat.}) \pm 0.031(\text{syst.}) \pm 0.052(\text{FSI}) \pm 0.017(\text{LEP}) \text{ GeV}, \end{aligned}$$

where the two masses are 31% correlated. The combined mass value for all channels is

$$M_W(\text{fff}) = 80.401 \pm 0.027(\text{stat.}) \pm 0.031(\text{syst.}) \pm 0.018(\text{FSI}) \pm 0.017(\text{LEP}) \text{ GeV},$$

with a good χ^2 of 30.7 for 27 degrees of freedom. Apart from errors due to FSI and the LEP beam energy, the dominant systematic error originates from different fragmentation models. Including the result derived from the cross-section measurements yields finally¹:

$$M_W^{\text{LEP}} = 80.401 \pm 0.048 \text{ GeV}.$$

Other direct W mass measurements performed at $p\bar{p}$ -colliders⁸ are in very good agreement with this result. The combination of all direct W mass determinations results in⁹

$$M_W^{\text{LEP}+p\bar{p}} = 80.419 \pm 0.038 \text{ GeV}.$$

At LEP also the width of the W boson, Γ_W , is measured using the direct reconstruction method. The results are summarised in table 1. The LEP combined value is¹

$$\Gamma_W^{\text{LEP}} = 2.19 \pm 0.15 \text{ GeV}.$$

This result shows good agreement with the direct measurement at the Tevatron by the CDF collaboration which yields $\Gamma_W = 2.06 \pm 0.13 \text{ GeV}$ ¹⁰. It also agrees well with the SM prediction of $\Gamma_W = 2.08 \text{ GeV}$ using the current world average W mass¹¹.

Table 1: W mass and width measurement by direct reconstruction from the four LEP experiments. The mass values are given separately for the non-qqqq qqqq and fff channels. The errors include statistics and systematics. The procedure to obtain the combined LEP mass values treats correlations between systematic errors in a slightly different way than the individual experiments. Therefore the LEP average in the last row is not identical with the average of the values shown in the upper four rows. All mass numbers contain the 172 – 202 GeV data, except the DELPHI result which is based on the 172 – 189 GeV data. Also the width is analysed by the LEP experiments only in a restricted data set.

Experiment	M_W [GeV]			Γ_W [GeV]
	non-qqqq	qqqq	fff	fff
Aleph	80.435 ± 0.079	80.467 ± 0.086	80.449 ± 0.065	2.17 ± 0.20
Delphi	80.230 ± 0.140	80.360 ± 0.115	80.308 ± 0.090	2.48 ± 0.41
L3	80.282 ± 0.102	80.489 ± 0.132	80.353 ± 0.088	2.18 ± 0.22
Opal	80.483 ± 0.078	80.380 ± 0.103	80.446 ± 0.064	1.86 ± 0.37
LEP	80.398 ± 0.053	80.408 ± 0.074	80.401 ± 0.049	2.19 ± 0.15

3 Determination of Electroweak Parameters

3.1 Input Parameters to the Standard Model

Electroweak observables can be computed in the SM framework as a function of a few parameters: the fine structure constant, α , the strong coupling constant, α_s , the Z mass, M_Z , the W mass, M_W , the top quark mass, M_t , the Higgs boson mass, M_H , and the Cabbibo-Kobayashi-Maskawa mixing matrix, V_{CKM} .

The W mass is currently measured with a relative precision of 0.05%. Since the direct measurements of M_W are available only recently the W mass is not used as input parameter but it is replaced by the more precise muon decay constant, $G_F = (1.16639 \pm 0.0002) \cdot 10^{-5} \text{ GeV}^{-2}$. The W mass is then a derived quantity, to be compared with the measurement.

For the calculation of observables measured at the Z pole the running of the coupling constant α with energy scale Q^2 has to be taken into account. At $Q^2 = M_Z^2$ its value is $\alpha(M_Z^2)^{-1} = 128.878 \pm 0.090$ ¹². The largest part of the error originates from uncertainties on the contributions from the five lightest quarks to the photon vacuum polarisation, parametrised by $\Delta\alpha_{\text{had}}^{(5)}$. The value of $\Delta\alpha_{\text{had}}^{(5)} = 0.02804 \pm 0.00065$ is derived from an analysis of measurements of the cross-section $e^+e^- \rightarrow \text{hadrons}$ below the Z resonance. The accuracy of only 2% limits the precision of the SM predictions. There are other estimations of this quantity which have a smaller uncertainty because they are more theory driven, e.g. that of reference 13 which is used for comparison.

The set of free parameters which are varied in the SM fit consists of $\Delta\alpha_{\text{had}}^{(5)}$, $\alpha_s(M_Z^2)$, M_Z , M_t , and M_H . These parameters are constrained by the measurements of electroweak observables.

3.2 Electroweak Measurements

Here, a short overview of the results of the electroweak measurements is given. The combination of the measured electroweak observables at LEP and SLC is summarised in reference 9, which also contains further details about the interpretation of the results within the SM.

Table 2: Average line shape parameters measured at LEP. Values without and with assumption of lepton universality are given in the second and third column, respectively.

Parameter	without lepton universality	with lepton universality
M_Z [GeV]	91.1872 ± 0.0021	91.1871 ± 0.0021
Γ_Z [GeV]	2.4944 ± 0.0024	2.4944 ± 0.0024
σ_{had}^0 [nb]	41.544 ± 0.037	41.544 ± 0.037
R_e	20.803 ± 0.049	–
R_μ	20.786 ± 0.033	–
R_τ	20.764 ± 0.045	–
R_ℓ	–	20.768 ± 0.024

Results from Z line shape at LEP

The shape of the Z resonance is characterised by three parameters, the Z mass, M_Z , the width, Γ_Z , and the height of the resonance as given by the pole cross-section, σ_{ff}^0 :

$$\sigma_{\text{ff}}^0 = \frac{12\pi}{M_Z^2} \frac{\Gamma_{ee}\Gamma_{\text{ff}}}{\Gamma_Z}. \quad (1)$$

The separate measurements of Z decays for different lepton flavours allow the determination of the corresponding partial decay widths of the Z, which are given by the inverse ratio to the hadronic decay width, $R_\ell = \Gamma_{\text{had}}/\Gamma_{\ell\ell}$, ($\ell = e, \mu, \tau$). The average line shape parameters of the four LEP experiments are shown in table 2. The measurements of R_ℓ for the three lepton species prove the lepton universality of the neutral weak interaction.

The Z boson can decay also invisibly into neutrino pairs. From the invisible decay width, $\Gamma_{\text{inv}}/\Gamma_{\ell\ell} = 5.941 \pm 0.016$, and the SM calculation for $\Gamma_{\nu\nu}$ the number of neutrino species is determined to be $N_\nu = 2.9835 \pm 0.0083$, which is two standard deviations below the expected value of 3.

Heavy Flavour Results

Experimental techniques to tag the quark flavour in hadronic decays make it possible to measure also the Z decay width into the heavy quarks, b and c. The results are presented in terms of the ratios

$$R_b = \frac{\Gamma_{b\bar{b}}}{\Gamma_{\text{had}}}, \quad R_c = \frac{\Gamma_{c\bar{c}}}{\Gamma_{\text{had}}}. \quad (2)$$

With this definition most of the radiative corrections cancel out, except the important corrections from the $Zb\bar{b}$ vertex. In the SM this contribution basically depends only on a single parameter which is the top quark mass. The combined analysis of the LEP and SLD data yields

$$R_b = 0.21642 \pm 0.00073 \quad R_c = 0.1674 \pm 0.0038, \quad (3)$$

with a negative correlation of 14% between the two quantities.

Asymmetry Measurements

Parity violation in the neutral current Z decays is caused by the different couplings to left-handed and right-handed fermions. With the definition of the asymmetry parameter

$$\mathcal{A}_f = \frac{2g_V^f g_A^f}{(g_V^f)^2 + (g_A^f)^2}, \quad (4)$$

where g_V^f and g_A^f are the effective vector and axial vector coupling constants, one can write the Z forward-backward asymmetries and the tau polarisation in terms of $\mathcal{A}_f$:

$$A_{FB}^{0,f} = \frac{3}{4} \mathcal{A}_e \mathcal{A}_f, \quad \mathcal{P}_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau(1 + \cos^2\theta) + 2\mathcal{A}_e \cos\theta}{1 + \cos^2\theta + 2\mathcal{A}_\tau \mathcal{A}_e \cos\theta}. \quad (5)$$

Forward-backward asymmetries are measured separately for the leptonic channels, for b and c quarks, and inclusively for hadronic decays in terms of the charge asymmetry, $\langle Q_{FB} \rangle$. From the tau polarisation the values of $\mathcal{A}_e$ and $\mathcal{A}_\tau$ are extracted.

At SLD the incoming electron beam is longitudinally polarised which allows the determination also of the left-right asymmetries, $A_{LR}^0 = \mathcal{A}_e$. In addition, the left-right forward-backward asymmetries have been measured for leptons, b and c quarks. From these the parameters $\mathcal{A}_e$, $\mathcal{A}_b$ and $\mathcal{A}_c$ are determined. The leptonic SLD measurements are usually summarized in terms of $\mathcal{A}_\ell$, assuming lepton universality. The updated value of $\mathcal{A}_\ell$ ¹⁴ is used in the SM fits.

To compare the different asymmetry measurements it is conventional to use the leptonic effective weak mixing angle, as defined by:

$$\sin^2\theta_{\text{eff}}^{\text{lept}} = \frac{1}{4} \left(1 - \frac{g_V^\ell}{g_A^\ell} \right). \quad (6)$$

Figure 2a shows the results of the LEP and SLD measurements of $\sin^2\theta_{\text{eff}}^{\text{lept}}$, which differ by 2.8 standard deviations. The relative high LEP average is dominated by the quark asymmetry measurements which are more precise than the leptonic asymmetries. On the bottom of figure 2a the average value is compared to the SM calculations of $\sin^2\theta_{\text{eff}}^{\text{lept}}$ for different Higgs masses, indicating a tendency towards low values of M_H .

Other Measurements

Important constraints come from the direct measurements of M_W at LEP and of M_W and $M_t = 174.3 \pm 5.1$ GeV at the Tevatron¹⁵. The result for the on-shell value of $\sin^2\theta_w = 0.2255 \pm 0.0021$ measured by NuTeV/CCFR in νN scattering¹⁶ is also used as input to the fit for the SM parameters.

3.3 Fits to Electroweak Data

The electroweak measurements are used to derive the basic SM parameters⁹. The calculation of the SM predictions are performed with the ZFITTER and TOPAZ0 program packages which contain the most recent calculations of higher order radiative corrections. All measurements that are input to the fit are summarized in figure 2b. Also shown is their difference to the SM fit result relative to the measurement error. All experimental values agree with the predictions.

The resulting SM parameters are listed in table 3 based on different data sets. Interesting comparisons are the direct and indirect determinations of M_t and M_W . The top quarks mass derived only from LEP data is $M_t = 176_{-11}^{+14}$ GeV, which is in very good agreement with the direct measurement at the Tevatron. Also the indirect W mass, $M_W^{\text{fit}} = 80.382 \pm 0.026$ GeV extracted from all electroweak data except the direct M_W measurement is perfectly consistent with $M_W^{\text{LEP+pp}} = 80.419 \pm 0.038$ GeV. This is illustrated in figure 3a, where the M_t and M_W measurements are compared to each other and to the SM calculation. Also here a preference for low values of M_H is visible.

Because the Higgs boson is not yet detected it is most interesting to determine which mass range is consistent with the current set of measurements. In the leading radiative correction terms the dependency on M_H is only logarithmic. This weakens the indirect mass determination

Figure 2: (a) The effective weak mixing angle, $\sin^2 \theta_{\text{eff}}^{\text{lept}}$, as determined in the measurements at LEP and SLD compared to the SM calculation for different Higgs masses. (b) All electroweak measurements which are input to the SM fits are listed including the pulls, which are the differences to the SM calculation in units of measurement error.

Table 3: Fit results for the SM parameters M_t , M_H and $\alpha_s(M_Z^2)$, from a combined analysis of different subsets of electroweak data. Also shown are the derived values of $\sin^2 \theta_{\text{eff}}^{\text{lept}}$, $1 - M_W^2/M_Z^2$, and M_W .

	LEP including LEP M_W	all data except M_W and M_t	all data except M_W	all data
M_t [GeV]	176^{+14}_{-11}	167^{+10}_{-8}	172.9 ± 4.7	173.7 ± 4.4
M_H [GeV]	147^{+299}_{-92}	54^{+81}_{-27}	78^{+76}_{-41}	67^{+60}_{-33}
$\log(M_H/\text{GeV})$	$2.17^{+0.48}_{-0.43}$	$1.73^{+0.40}_{-0.30}$	$1.90^{+0.29}_{-0.32}$	$1.82^{+0.28}_{-0.30}$
$\alpha(M_Z^2)$	0.120 ± 0.003	0.118 ± 0.003	0.118 ± 0.003	0.118 ± 0.003
$\chi^2/\text{d.o.f.}$	12/9	22/12	22/13	23/15
$\sin^2 \theta_{\text{eff}}^{\text{lept}}$	0.23178 ± 0.00021	0.23151 ± 0.00017	0.23152 ± 0.00017	0.23145 ± 0.00016
$1 - M_W^2/M_Z^2$	0.2233 ± 0.0006	0.2232 ± 0.0007	0.2229 ± 0.0005	0.2227 ± 0.0004
M_W [GeV]	80.363 ± 0.030	80.368 ± 0.034	80.382 ± 0.026	80.394 ± 0.021

Figure 3: (a) Contour curves of the direct and indirect measurements of M_t and M_W , compared to the SM predictions for different values of M_H . (b) The figure shows the $\Delta\chi^2 = \chi^2 - \chi^2_{\min}$ dependence on M_H from a fit to all electroweak data. The band indicates the theoretical uncertainty due to higher order corrections. The dashed line is the calculation using a different value of $\Delta\alpha_{\text{had}}^{(5)}$. The Higgs mass region excluded by direct searches is marked by the grey area.

even when all electroweak measurements, many of them with permill accuracy, are used in the analysis. The result of the fit to the electroweak data is

$$\log(M_H / \text{GeV}) = 1.82^{+0.28}_{-0.30}, \quad M_H = 67^{+60}_{-33} \text{ GeV}. \quad (7)$$

The low value is not a consequence of a single measurement, as can be seen in figures 2a and 3a. The corresponding $\Delta\chi^2$ -curve of the fit is shown in figure 3b. An upper limit on the Higgs mass can be set to

$$M_H < 188 \text{ GeV, at 95\% C.L.} \quad (8)$$

But the central value and the error on M_H are strongly dependent on the value of $\Delta\alpha_{\text{had}}^{(5)}$. With a value of $\Delta\alpha_{\text{had}}^{(5)} = 0.02784 \pm 0.00026$ ¹³ the error on $\log(M_H)$ is reduced by 25% and the central value is shifted to $\log(M_H / \text{GeV}) = 1.92$ or $M_H = 83.2 \text{ GeV}$, which is still on the low side of the mass spectrum. From direct searches at LEP values of M_H below 107.9 GeV are excluded with 95% C.L.¹⁷, still compatible with the indirect result. However, the low value of M_H preferred by electroweak measurements give hope that a positive finding of the Higgs will come soon, either at LEP energies or by the Tevatron or the future LHC experiments.

Acknowledgments

I would like to thank the experiments ALEPH, DELPHI, L3, OPAL and SLD for making their most recent and preliminary results available. I especially like to thank the members of the LEP Electroweak Working Group and of the LEP WW Working Group for performing the combination of the individual measurements and for converting them into nice graphs and plots.

This work has been supported by the German Bundesministerium für Bildung und Forschung under the contract number 05 7AC36P 3.

References

1. The LEP WW Working Group, Preprint, LEPEWWG/WW/00-01.
2. ALEPH Internal Note CONF 2000-015;
DELPHI Internal Note 99-64 CONF 251;
OPAL Internal Note PN 422;
L3 Internal Note 2520
3. LEP Energy Calibration Working Group, A. Blondel *et al.*, Eur. Phys. J. C **11** (1999) 573;
LEP Energy Calibration Working Group, Preprint, LEP ECAL/99-01.
4. G. Wilkinson, *Energy Calibration: Status and Prospects*, Proceedings of the 10th Chamonix Workshop on LEP-SPS, Ed. P. Le Roux, *et al.*, CERN-SL-2000-007.
5. G. Gustafson, U. Petterson and P.M. Zerwas, Phys. Lett. B **209** (1988) 90;
T. Sjöstrand and V.A. Khoze, Z. Phys. C **62** (1994) 281, Phys. Rev. Lett. **72** (1994) 28;
E. Accomando, A. Ballestrero and E. Maina, Phys. Lett. B **362** (1995) 141;
G. Gustafsson and J. Häkkinen, Z. Phys. C **64** (1994) 659;
L. Lönnblad, Z. Phys. C **70** (1996) 107;
J. Ellis and K. Geiger, Phys. Rev. D **54** (1996) 1967, Phys. Lett. B **404** (1997) 230.
6. K. Fialkowski and R. Wit, Z. Phys. C **74** (1997) 145; K. Fialkowski, R. Wit and J. Wosiek, Phys. Rev. D **58** (1998) 094013; S. Jadach and K. Zalewski, Acta. Phys. Pol. B **28** (1997) 1363; V. Kartvelishvili, R. Kvatadze and R. Möller, Phys. Lett. B **408** (1997) 331; L. Lönnblad and T. Sjöstrand, Phys. Lett. B **351** (1995) 293; L. Lönnblad and T. Sjöstrand, Eur. Phys. J. C **2** (1998) 165.
7. N. Neufeld, these proceedings.
8. U. Bassler, these proceedings.
9. The LEP and SLD Electroweak Working Groups, Preprint, CERN-EP/2000-016,
and LEP EWWG contributions to the 2000 winter conferences;
latest results are available from: <http://www.cern.ch/LEPEWWG>.
10. The CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **74** (1995) 341.
11. The Particle Data Group, C. Caso *et al.*, Eur. Phys. J. C **3** (1999) 1.
12. S. Eidelmann and F. Jegerlehner, Z. Phys. C **67** (1995) 585.
13. M. Davier and A. Höcker, Phys. Lett. B **419** (1998) 419.
14. T. Wright, these proceedings.
15. R. Partridge, *Heavy Quark Production and Decay (t, b, and onia)*, talk presented at ICHEP'98, Vancouver, B.C., Canada, 23-29 July, 1998.
16. CCFR/NuTeV Collaboration, K. McFarland *et al.*, Eur. Phys. Jour. C1 (1998) 509;
NuTeV Collaboration, K. McFarland, talk presented at the XXXIIIth Rencontres de Moriond, hep-ex/9806013.
17. E. Ferrer Ribas, these proceedings.