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Precision obtainable on the measurement of $\mathrm{M_Z}$ and Γ_Z from the 1995 LEP energy scan

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Abstract

The expected final LEP precision on the measurement of the mass, $\mathrm{M_Z}$, and width, Γ_Z, of the Z^0 as a result of the 1995 energy scan are presented. The precisions which can be obtained for different amounts of off-peak integrated luminosity are shown, under several assumptions concerning the contributions to the errors from the LEP energy calibration, and the total integrated luminosity delivered in 1995. A comparison of all combinations of the ± 2 and ± 3 "Gev" points is made, with the requirement that the the number of Z^0 events lost as a result of the scan is constant in all cases.

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1 Introduction

At the end of 1994 the LEP Committee recommended a new scan at the Z^0. The justification for a new scan stems from the successfull understanding of the modelling of the beam energy after the 1993 scan, and the fact that the measurement of the mass and the width of the Z^0 are still far from their systematic limit.

In this note we will show that we may expect a decrease in the uncertainty deriving from the modelling of the LEP beam energy. The major improvements are the addition of more diagnostic tools and the optimization of the resonant depolarization measurement which has become a relatively simple operational tool. We then show the final precision which should be obtained at LEP on the measurement of the Z^0 mass and width as a result of the addition of the data from the forthcoming 1995 scan to the data already collected.

The effect of the vertical dispersion of bunch trains at the interaction point has been the subject of much study recently, and we include some estimate of the size of the extra error on the energy calibration associated with this.

The note is organised in the following order. In section 2 the errors on the knowledge of the LEP beam energy are discussed. In section 3 we list other contributing effects. Finally, in section 4 we show the total precision obtainable on M_Z and Γ_Z for a range of assumptions concerning the LEP energy measurement, the total integrated luminosity, and the integrated luminosity delivered at the off-peak points. We also compare the precision obtainable using different combinations of the off-peak energy points which could be used. In the following we use the notation "$\pm n$" to refer to off-peak energies $\pm n \times 880$MeV from the peak.

2 The LEP Energy Errors

In this section the assumptions made in estimating the likely LEP beam energy errors for the 1995 scan are briefly discussed.

A full description of the procedures used for the determination of the 1993 LEP energy and the associated errors can be found in [1]. It is foreseen that a similar method is used in 1995, but that an attempt is made to measure the energy by resonant depolarisation in a much higher fraction of off-peak fills. In addition some measurements are desirable in some fills at both the beginning of fill (BOF, i.e. before physics) and at the end of fill (EOF). These measurement should serve to understand better the apparent changes in the LEP energy during a fill as measured by the NMR system in the reference dipole magnet.

The components of the LEP energy error can be conveniently divided into two types :-

i) Those terms which are largely independent of the number of depolarisation measurements made. These include the errors arising in the uncertainty of the corrections for magnet temperature, tide effects and also RF effects. In addition there are systematics due to the intrinsic accuracy of the depolarisation method itself, and on the possible difference between the energies of the electron and positron beams. Also included in this category is the uncertainty on the possible change of the LEP energy during a fill.

ii) The component at each energy point arising from the intrinsic energy uncertainty of LEP. This error can be reduced by having as many EOF calibrations as possible.

The contributions of the various components for the 1993 scan are given in table 1. The term from the QFQD current correction is omitted as it was due to operational effects which could (with the benefit of hindsight!) have been avoided. In addition, there is a term from the intrinsic uncertainty of LEP: the "scatter error". This term was estimated using the rms spread of the energy measurements from depolarisation with respect to the model used for the variation of the LEP energy with time. For the 1993 scan the rms values were 6.9 and 2.8 MeV at the ± 2 points respectively. The points are compatible at the 1% level with having come from the same distribution, and the combined value is about 5.4 MeV. Depolarisation measurements were performed on 13/38 fills and 11/31 fills at peak-2 and peak+2 respectively. The contributions of these measured rms values to the energy uncertainties are 1.60 and 0.72 MeV at the peak-2 and peak+2 energy points respectively. There is, as yet, no detailed understanding as to why these measured rms values could be different. In 1994 an rms of 7.2 MeV was observed [2]. For the 1995 scan a value of the rms of 6 MeV at all energy points is assumed. However, it should be noted that there is a some uncertainty in the estimate of this component of the error.

The estimated contributions of the various components for the 1995 scan are given in table 2. The contributions from the temperature and RF components are assumed to be essentially the same as for 1993. The contribution of the tide effects can probably be reduced by suitable scheduling of the depolarisation measurements. It is assumed that the contributions of the systematics of the energy measurement and of the possible differences in the positron and electron energies can be reduced by more studies and measurements. Perhaps the greatest uncertainty is in the so-called NMR term. Additional instrumentation installed in LEP in 1995, together with measurements on some fills at both the BOF and EOF, should give better insight into the time variation of the LEP energy during a fill. It is assumed here that the NMR term can be reduced from 0.93 to about 0.5 MeV, but there is clearly some uncertainty in this estimate.

The effect on the term from the rms spread in the LEP energy arising from fills without depolarisation energy measurements has been studied in some detail [3, 4]. Based on studies of the performance of LEP in 1994 it would appear that the maximum number of fills which could actually be calibrated in practice is between about 60 and 65%. This is due to beam losses during physics and some further losses in the calibration process before a reliable measurement can be obtained. The expectation that those fills which are lost will have, on average, less luminosity than those with EOF callibrations is taken into account in the estimation of the scatter error.

For a scan at the ± 2 points, it is important that as many off-peak fills as possible be measured. As an example, we consider a scan of 15 pb^{-1} at each of two off-peak points, and assume that this would be achieved in 19 fills at each energy. If calibration was attempted for 50% of the fills, then the contribution to the LEP error would be about 1.5 MeV at each energy point. However, if an attempt was made to calibrate all off-peak fills, then this error would be reduced to 0.5 MeV. For a scan at the ± 3 points the result is less sensitive to the fraction of calibrated fills, since the energy error makes up a smaller fraction of the total Γ_Z error. Results of detailed studies of the energy measurement strategy can be found in [3, 4].

The systematic errors from energy calibration on M_Z and Γ_Z depend approximately on the errors on the sum and on the difference of centre of mass energies at the two off-peak points.

$$\Delta M_Z \approx 0.5\Delta(E_+ + E_-) \tag{1}$$

$$\Delta\Gamma_Z \approx \frac{\Gamma_Z}{(E_+ - E_-)}\Delta(E_+ - E_-) \tag{2}$$

where E_- and E_+ are the luminosity-weighted centre of mass energies at the two off-peak points. They can be separated in terms of the errors that are correlated and uncorrelated between the two points. In this framework, the error on M_Z is given by the correlated error plus the uncorrelated part divided by $\sqrt{2}$. For a scan at the ± 2 points the error on Γ_Z is approximately given by the uncorrelated error, since the numerical coefficient in equation 2 is approximately equal to $1/\sqrt{2}$. For other scan scenarios the error on M_Z is essentially unchanged, but for the error on Γ_Z there is a lever-arm effect, such that the systematic error on Γ_Z is reduced the further apart the two off-peak energy points are.

For the 1993 scan errors, modified as discussed above, the correlated and uncorrelated terms are both about 0.9 MeV. For the 1995 estimates the correlated and uncorrelated terms are both about 0.6 MeV, assuming that an attempt is made to calibrate all off-peak fills. For the purposes of comparing the total errors on M_Z and Γ_Z (i.e. LEP plus errors from the experiments), it is useful to use both an *optimistic* and *pessimistic* estimate of the LEP errors for the 1995 scan. On the assumption that more depolarisation measurements will be made than in 1993 then we take 0.8 MeV, for both the correlated and uncorrelated parts, to be the pessimistic estimate. For the optimistic case a value of 0.5 MeV, for both the correlated and uncorrelated parts, is assumed. In the fits discused below the full LEP energy covariance matrix constructed from table 2 and the scatter error is used.

2.1 Effects due to vertical-dispersion of bunch-trains

The possible size of the energy offsets, and the associated energy uncertainty, which can arise because of the method chosen for vertical separation of the beams with bunch-trains (namely vertical dispersion of opposite sign) has been the subject of recent investigation by members of the LEP energy group [5]. The proposed method to reduce and monitor the effects of vertical dispersion is to carry out regular luminosity "vernier" scans [1]. Subject to the satisfactory performance of tests of such scans it is estimated that the additional error due to this effect can be reduced to an error of not more than 0.6 MeV at each off-peak energy point, and uncorrelated between energies.

It should however be noted that at this moment we are not in a position to be certain that the required precision on the energy calibration can be obtained, and studies are still in progress.

[1] We have not yet allowed for any extra loss of integrated luminosity due to the vernier scans

Source	peak-2	peak+2	Correlation
Temperature Correction	0.16	0.35	1.00
Tide	0.04	0.41	1.00
NMR Uncertainty	0.93	0.93	0.81
Energy Measurement	0.50	0.50	0.04
e^+ Energy Uncertainty	0.30	0.30	0.5
RF Corrections	0.22	0.22	0.90

Table 1: LEP energy errors in MeV for the 1993 scan at the peak-2 and peak+2 scan points, together with their correlation [1]. The scatter error term is in addition to these terms and the error due to the QFQD setting has been ignored for the purpose of this study.

Source	peak-2	peak+2	Correlation
Temperature Correction	0.2	0.3	1.00
Tide	0.2	0.2	1.00
NMR Uncertainty	0.5	0.5	0.8
Energy Measurement	0.3	0.3	0.04
e^+ Energy Uncertainty	0.2	0.2	0.5
RF Corrections	0.2	0.2	0.9

Table 2: Estimated LEP energy errors in MeV for the 1995 scan at the peak-2 and peak+2 scan points, together with their estimated correlation. The scatter error term is in addition to these terms.

3 Other contributions to the error on Γ_Z

3.1 LEP energy beam spread

The spread of the LEP beam energy, ϵ_{BS}, biases the measured cross sections depending upon the second derivative of the cross section with energy;

$$\delta\sigma = -0.5 \frac{d^2\sigma}{dE^2} \epsilon^2_{BS} \tag{3}$$

where $\delta\sigma$ is the change induced in the cross section, which feeds through to a change in the measured value of Γ_Z. The dependence is quadratic, and a spread of 50MeV changes the measurement of Γ_Z by about -4MeV. The effect on M_Z is negligible. This is almost certainly completely correlated between experiments.

The best estimate at present is that the nominal beam spread of about 50MeV can be known with a 5% error. This translates into an error of 0.5Mev on Γ_Z for a scan at ± 2. Energy points further from the peak are less sensitive to this effect, and the equivalent error is 0.4MeV for a scan at ± 3.

3.2 1994-1995 correlation

The precision with which the peak point cross section is known affects the error on Γ_Z. The larger the statistical error, then the larger the amount that the lineshape can "strech" up and down, and this has a proportional effect at the off-peak points. The effect on the error on Γ_Z is smaller for points further from the peak than those near to it. This has been studied in detail [6, 7, 8, 9], and it is known that the inclusion of the 1994 data improves the Γ_Z error from the 1993 scan by a small amount.

The effect is not too large, but it should not be neglected when we consider the 1995 scan, since the amount of on peak data collected in 1995 may be very similar to that collected in 1994. To quantify this, we note that the statistical precision from a total of 100pb^{-1} of on peak data per experiment translates to an error on the width of approximately 0.7MeV for a ± 2 scan, and about 0.5 MeV for a ± 3 scan. The inclusion of the 1994 data is therefore important. If the normalisation of the 1994 data will be highly correlated with that of the 1995 scan, then this data will help reduce the final error on Γ_Z. This correlation depends upon systematic errors and luminosity detectors, and is different from experiment to experiment. In this study we have assumed an average 80% correlation.

3.3 Energy of the peak point

The exact peak energy at which LEP runs is important. Depending upon the slope of the cross section, $d\sigma/dE$, the LEP energy error at the peak gives an effective statistical error contribution which in turn affects the width measurement as mentioned above. For example we find that for the 1994 running at $E_{cm} = 91.223$ a 5MeV error on the knowledge of the energy corresponds roughly to the combined LEP statistical error on the peak cross section.

In order to avoid this contribution, one should run at the actual peak of the cross section (i.e where $d\sigma/dE = 0$). For $\mathrm{M_Z} = 91.189$ this corresponds to E_{cm} around 91.285GeV. The allowed range may be taken as that for which a given peak energy error will have an effect less than, say, 1/4 of the LEP combined statistical error for 1995. For a 5MeV energy error this requires the peak energy to be within about $\pm$15MeV of the value given. In fact the peak energy can be known much better than this if required, and this constraint will be determined more precicely as necessary.

3.4 Non-resonant background

The experiments estimate the non-resonant background in various ways involving both monte-carlo simulations and the data themselves. The current contribution to the error on Γ_Z is about 0.5MeV for all experiments combined. This is mainly limited by off peak statistics and can be expected to improve to about 0.3 MeV for a 40pb^{-1} scan.

4 Total Errors on the measurement of $\mathrm{M_Z}$ and Γ_Z

We now show the total error which is expected on the measurements of $\mathrm{M_Z}$ and Γ_Z.

These results are derived from the work of references [6, 7, 8, 9], which give the results of detailed studies carried out within the individual experiments of the physics implications of the 1995 scan. The numbers reported by those authors are obtained from detailed fits to the cross sections with statistical errors calculated to represent those of the 4 LEP experiments combined. The LEP energy measurement error, experimental systematic errors, luminosity measurement errors and correlations from year to year are included. These were compared and found to give the same precision for $\mathrm{M_Z}$ and Γ_Z when the same input assumptions were used, giving confidence that these quantities are well understood. In the interest of brevity we do not repeat any of the details of the analyses here. [2]

We assume the following conditions for the 1995 scan;

- Two scenarios are considered for the *total integrated luminosity delivered*, $\mathcal{L}^{\mathrm{total}}$. These are 70pb^{-1} and 100pb^{-1} per experiment.
- The part of $\mathcal{L}^{\mathrm{total}}$ which is devoted to the off-peak running, $\mathcal{L}^{\mathrm{off-peak}}$, is either $20, 30, 40$ or 50pb^{-1} per experiment.
- There will be two off-peak points, and $\mathcal{L}^{\mathrm{off-peak}}$ will be split equally between them.

[2] Where necessary the authors have re-run their analyses to conform to the agreed input.

- Following the discussion given in section 2 we consider two possibilities for the LEP energy error, ΔE_{LEP}. These are $\Delta E_{LEP} = 0.8$MeV and 0.5MeV at each off peak point. These values are for a nominal ± 2 scan with $\mathcal{L}^{\mathrm{off-peak}} = 40\mathrm{pb}^{-1}$. These numbers are then scaled for different values of $\mathcal{L}^{\mathrm{off-peak}}$ to allow for the fact that one part of the error depends upon the number of off-peak fills [3]. We use these values for both the correlated and uncorrelated part of the error.

- The average experimental efficiency is assumed to be 85%

- We consider all combinations of scan energies $\mathrm{M_Z} \pm n$, where $n = 2, 3$ in units of 880MeV.

- The appropriate statistical errors for hadrons, leptons and luminosity measurement are included.

- We assume that the final LEP energy error for the 1994 point is 2MeV and the correlation of its normalisation with 1995 is 80%, averaged over the 4 experiments.

- The error on Γ_{Z} due to the error on the knowledge of the LEP beam energy spread is 0.5MeV for the ± 2 points, and 0.4MeV for the ± 3 points.

- The error on Γ_{Z} due to the non-resonant background is 0.3MeV for $\mathcal{L}^{\mathrm{off-peak}} = 40\mathrm{pb}^{-1}$, and scales with the square root of the total off-peak integrated luminosity.

4.1 Cost in terms of on peak equivalent luminosity

We give results in terms of *integrated luminosity delivered* by LEP. However for some discussions, the relevant quantity is the effective amount of on peak recorded luminosity lost by each experiment as a result of the scan, $\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}}$. It is this quantity which determines the actual number of lost Z^0 events.

$\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}}$ is related to the amount of luminosity delivered at the off-peak points by:

$$\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}} = \mathrm{efficiency} \times \left[\mathcal{L}^{\mathrm{off-peak}} \left(\frac{\sigma_{peak} - \frac{1}{2}(\sigma_+ + \sigma_-)}{\sigma_{peak}}\right) + \mathcal{L}^{\mathrm{cal}}\right] \tag{4}$$

where $\sigma_{peak}, \sigma_+, \sigma_-$ are the peak, and plus and minus off-peak cross sections respectively. $\mathcal{L}^{\mathrm{cal}}$ is the amount of luminosity used in calibration, and is assumed to be 15% of $\mathcal{L}^{\mathrm{off-peak}}$. For example an $\mathcal{L}^{\mathrm{off-peak}}$ of $40\mathrm{pb}^{-1}$ at the ± 2 points corresponds to $\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}} = 26\mathrm{pb}^{-1}$ which in turn corresponds to approximately 10^6 lost Z^0 events. We give the equivalent $\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}}$ throughout.

[3] The LEP energy error is made up of an irreducible factor plus an error which depends upon the total number of off-peak fills, as well as the fraction of calibrated off-peak fills. This is studied in detail in [3, 4].

4.2 Precision on M_Z and Γ_Z as a function of off-peak luminosity

Figure 1 and tables 3 and 4 give the precisions which will be obtained on the measurement of M_Z and Γ_Z as a function of off-peak integrated luminosity[4]. These numbers assume a scan at the same energy points as in 1993, i.e. using the ± 2 points. The results are for the 4 LEP experiments combined, and include all data recorded up to 1995 and hence represent the final LEP precision.

The numbers include all contributions mentioned previously *except* the extra 0.6MeV assumed for vertical dispersion effects (see below).

The numbers are repeated for 0.8MeV and 0.5MeV assumed LEP energy error, and for $\mathcal{L}^{\mathrm{total}} = 70\mathrm{pb}^{-1}$ and $100\mathrm{pb}^{-1}$.

In order to gauge approximately the relative contributions, one may note that a LEP energy error of $\Delta E_{LEP} = 0.8$MeV contributes approximately 0.8MeV to the error on Γ_Z from the 1995 scan alone (this is given by equation 2). Although it is not simple to extract the overall error for all years combined, it is clear that, for the scan scenarios discussed above, the Γ_Z error will remain dominated by off-peak statistics.

4.3 Contribution due to vertical dispersion of bunch trains

We show the effect of vertical dispersion of bunch trains separately as it is one of the newer, and least understood effects. The estimate given in section 2.1 is 0.6MeV extra random error on the 1995 scan points. Including this in the fits gives the numbers shown in tables 5 and 6. If the additional error was as large as 1.0 MeV (rather than the estimated value of 0.6 MeV) then the error on the Z^0 width for a scan of 30 pb-1 off-peak would become 2.06 MeV, rather than the 2.01 MeV given in Table 5.

This contribution reduces for points further from the peak due to the lever arm effect.

4.4 Comparison of scan at different off-peak energies

We now compare the error which can be obtained by using the ± 3 energy points. We only consider fixed loss scenarios, i.e where the luminosity at other points is adjusted to give exactly the same cost in terms of $\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}}$ as the ± 2 scan with which it is compared.

Firstly we show the comparison of the errors obtainable from all possible combinations of ± 2 and ± 3. We take "minimal" assumptions as $\Delta E_{LEP} = 0.8$MeV, $\mathcal{L}^{\mathrm{total}} = 70\mathrm{pb}^{-1}$ and $\mathcal{L}^{\mathrm{off-peak}} = 20\mathrm{pb}^{-1}$. Then we take "optimistic assumptions" as $\Delta E_{LEP} = 0.5$MeV, $\mathcal{L}^{\mathrm{total}} = 100\mathrm{pb}^{-1}$ and $\mathcal{L}^{\mathrm{off-peak}} = 40\mathrm{pb}^{-1}$. The results are shown in tables 7 and 8.

Secondly we show the comparison of ± 2 and ± 3 as a function of $\mathcal{L}^{\mathrm{off-peak}}$ over the whole range

[4] The errors quoted are given to 3 significant digits in order that the small differences between them can be properly seen. It is not implied that the absolute accuracy is understood to this level.

$\mathcal{L}^{\mathrm{off-peak}}$:	$20\mathrm{pb}^{-1}$	$30\mathrm{pb}^{-1}$	$40\mathrm{pb}^{-1}$	$50\mathrm{pb}^{-1}$
$\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}}$:	$13\mathrm{pb}^{-1}$	$19\mathrm{pb}^{-1}$	$26\mathrm{pb}^{-1}$	$32\mathrm{pb}^{-1}$
$\mathcal{L}^{\mathrm{total}} = 70\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.8\mathrm{MeV}$	2.17	2.00	1.86	1.78
$\mathcal{L}^{\mathrm{total}} = 70\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.5\mathrm{MeV}$	2.13	1.97	1.83	1.75
$\mathcal{L}^{\mathrm{total}} = 100\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.8\mathrm{MeV}$	2.15	1.98	1.82	1.73
$\mathcal{L}^{\mathrm{total}} = 100\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.5\mathrm{MeV}$	2.11	1.94	1.79	1.69

Table 3: The Γ_Z errors (MeV) for the 1990–1995 dataset for increasing off-peak integrated luminosity, $\mathcal{L}^{\mathrm{off-peak}}$, delivered in 1995. The same ± 2 off-peak energies as used in 1993 are assumed. The rows correspond to different assumptions about the total integrated luminosity in 1995, $\mathcal{L}^{\mathrm{total}}$, and the LEP energy measurement error, ΔE_{LEP}.

$\mathcal{L}^{\mathrm{off-peak}}$ (pb^{-1}) :	$20\mathrm{pb}^{-1}$	$30\mathrm{pb}^{-1}$	$40\mathrm{pb}^{-1}$	$50\mathrm{pb}^{-1}$
$\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}}$:	$13\mathrm{pb}^{-1}$	$19\mathrm{pb}^{-1}$	$26\mathrm{pb}^{-1}$	$32\mathrm{pb}^{-1}$
$\mathcal{L}^{\mathrm{total}} = 70\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.8\mathrm{MeV}$	1.52	1.38	1.30	1.23
$\mathcal{L}^{\mathrm{total}} = 70\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.5\mathrm{MeV}$	1.49	1.34	1.23	1.16
$\mathcal{L}^{\mathrm{total}} = 100\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.8\mathrm{MeV}$	1.52	1.38	1.30	1.23
$\mathcal{L}^{\mathrm{total}} = 100\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.5\mathrm{MeV}$	1.48	1.34	1.23	1.16

Table 4: The M_Z errors (MeV) for the 1990–1995 dataset for increasing off-peak integrated luminosity, $\mathcal{L}^{\mathrm{off-peak}}$, delivered in 1995. The same ± 2 off-peak energies as used in 1993 are assumed. The rows correspond to different assumptions about the total integrated luminosity in 1995, $\mathcal{L}^{\mathrm{total}}$, and the LEP energy measurement error, ΔE_{LEP}.

$\mathcal{L}^{\mathrm{off-peak}}$:	$20\mathrm{pb}^{-1}$	$30\mathrm{pb}^{-1}$	$40\mathrm{pb}^{-1}$	$50\mathrm{pb}^{-1}$
Without dispersion effect	2.13	1.97	1.83	1.75
With dispersion effect	2.16	2.01	1.88	1.81

Table 5: The increase in Γ_Z error (MeV) due an extra 0.6MeV random error on the 1995 points due to vertical beam dispersion effects ($\mathcal{L}^{\mathrm{total}} = 70\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.5\mathrm{MeV}$).

$\mathcal{L}^{\mathrm{off-peak}}$:	$20\mathrm{pb}^{-1}$	$30\mathrm{pb}^{-1}$	$40\mathrm{pb}^{-1}$	$50\mathrm{pb}^{-1}$
Without dispersion effect	1.49	1.34	1.23	1.16
With dispersion effect	1.50	1.36	1.27	1.19

Table 6: The increase in M_Z error (MeV) due an extra 0.6MeV random error on the 1995 points due to vertical beam dispersion effects ($\mathcal{L}^{\mathrm{total}} = 70\mathrm{pb}^{-1}, \Delta E_{LEP} = 0.5\mathrm{MeV}$).

Scan	$\mathcal{L}^{\mathrm{off-peak}}$ (pb^{-1})	$\Delta\Gamma_Z$ (MeV)	ΔM_Z (MeV)
± 2	20	2.17	1.52
± 3	16.7	2.25	1.84
$+3, -2$	18.1	2.22	1.67
$+2, -3$	18.3	2.22	1.69

Table 7: Errors on Γ_Z and M_Z resulting from scanning at different off-peak energies, and demanding a fixed loss corresponding to a 20pb^{-1} scan at the ± 2 points. In this comparison "minimal" conditions are assumed, i.e. that $\Delta E_{LEP} = 0.8$MeV and $\mathcal{L}^{\mathrm{total}} = 70$pb^{-1}. In all cases the off-peak luminosity ($\mathcal{L}^{\mathrm{off-peak}}$) is adjusted to give the same loss in the number of collected Z^0 as the 20pb^{-1} scan at ± 2GeV. The on-peak equivalent cost is $\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}} = 13$pb^{-1}.

Scan	$\mathcal{L}^{\mathrm{off-peak}}$ (pb^{-1})	$\Delta\Gamma_Z$ (MeV)	ΔM_Z (MeV)
± 2	40	1.79	1.23
± 3	33.4	1.87	1.61
$+3, -2$	36.2	1.85	1.39
$+2, -3$	36.6	1.85	1.42

Table 8: Errors on Γ_Z and M_Z resulting from scanning at different off-peak energies, and demanding a fixed loss corresponding to a 40pb^{-1} scan at the ± 2 points. This also differs from the previous table in that "optimistic" conditions are assumed, i.e. that $\Delta E_{LEP} = 0.5$MeV and $\mathcal{L}^{\mathrm{total}} = 100$pb^{-1}. As before the off-peak luminosity ($\mathcal{L}^{\mathrm{off-peak}}$) is adjusted to give the same loss in the number of collected Z^0 as the of 40pb^{-1} scan at ± 2GeV. The on-peak equivalent cost is $\mathcal{L}^{\mathrm{on-peak}}_{\mathrm{cost}} = 26$pb^{-1}.

considered. Again we take only two sets of assumptions: minimal: $\Delta E_{LEP} = 0.8$MeV and $\mathcal{L}^{\mathrm{total}} = 70$pb^{-1}, and optimistic: $\Delta E_{LEP} = 0.5$MeV and $\mathcal{L}^{\mathrm{total}} = 100$pb^{-1}. The result of this comparison is shown in figure 2.

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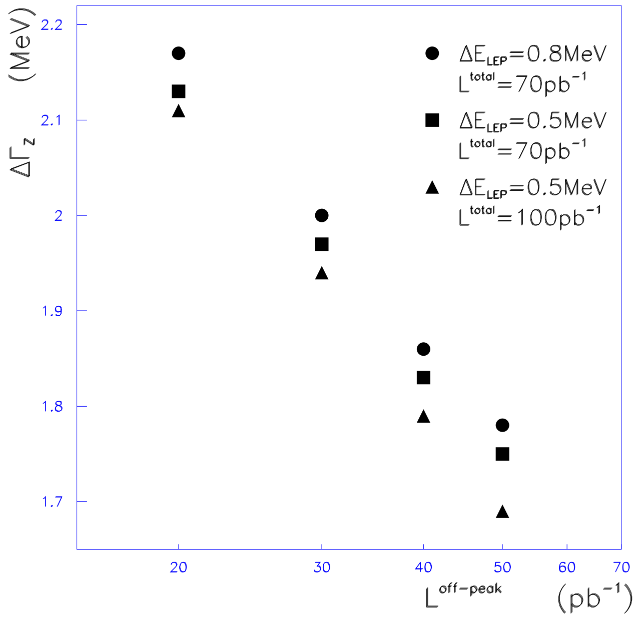

Figure 1: The expected Γ_Z errors displayed as a function of $\mathcal{L}^{\mathrm{off-peak}}$. This is shown for different assumptions about the LEP energy error and total integrated luminosity in 1995.

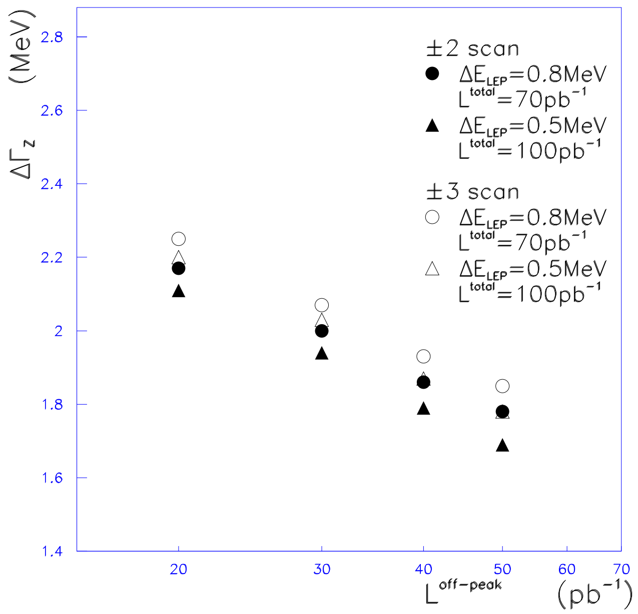

Figure 2: The expected Γ_Z errors displayed as a function of $\mathcal{L}^{\mathrm{off-peak}}$. In this figure a scan at the ± 2 points is compared with a scan at the ± 3 points.

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[9] M.Martinez and M.Pepe-Altarelli, private communication.