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UPPER LIMITS ON THE Z MASS FROM CHARGE ASYMMETRY MEASUREMENTS IN $e^+e^- \rightarrow \mu^+\mu^-$ BELOW THE Z POLE

by

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Upper Limits on the Z Mass from Charge Asymmetry Measurements in $e^+e^- \to \mu^+\mu^-$ Below the Z Pole

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Abstract

It is shown that significant limits on all relevant parameters (M, Γ, v, a) can be set by charge asymmetry measurements at only two energies in the region below the Z pole where counting rate effects are small. If the Weinberg Salam Theory with $\sin^2\theta_w = 0.23$ holds in this region, a model independant analysis of asymmetry measurements at beam energies E = 19,35 GeV with an integrated luminosity of $7 \times 10^{37} cm^{-2}$ at each point yields the following values of the parameters:

$$M = 86 \pm 12 \text{ GeV}$$
$$|a| = 0.58 \pm 0.10$$
$$\left.\begin{array}{l} |v| \leq 0.2 \\ \Gamma \leq 15 \text{ GeV} \end{array}\right\} \text{95\% confidence limits}$$

1. Introduction

Although the U(2)xU(1) electroweak theory (1),(2),(3) (W.S. Theory) is in good agreement with all existing low energy measurements (4), its most crucial prediction, the existence of the neutral Z boson with a mass = 90 GeV is, so far, quite untested. Only relatively weak lower limits for the Z mass exist (5).

The aim of this report is to investigate what information on the Z mass M can be obtained from measurements of $e^+e^- \to \mu^+\mu^-$ below the Z pole, in the energy region where the expected large increase in counting rate

around the Z pole itself (6),(7) is not yet apparent. It is of course particularly important to find upper limits for the mass, thus establishing the existence of the Z or equivalently, setting a lower bound to the range of the weak force.

The analysis presented below is model independant in the sense that no relations between the Z mass and the values of the coupling constants are assumed. However, the normal 'weak' assumptions are made:

(i) Only one Z exists in the relevant mass range
(ii) τ-μ-e universality
(iii) Time reversal invariance holds

It then follows that the charge asymmetry A(s) ($s = 4E^2$, $E = e^+, e^-$ beam energy) depends on only 4 real parameters:

M ≡ Z mass
Γ ≡ Z width
v ≡ vector coupling constant
a ≡ axial vector coupling constant

For unpolarised beams, the differential cross section for $e^+e^- \to \mu^+\mu^-$ is given by (8):

$$\frac{4s}{\alpha^2}\frac{d\sigma}{d\Omega} = F_1(s)(1+\cos^2\theta) + 2F_3(s)\cos\theta \quad \ldots\ldots (1)$$

where α is the fine structure constant, θ is the angle between the incoming e^+ and the outgoing μ^+, and

$$F_1(s) \equiv 1 + 2v^2 Re(R) + (v^2+a^2)^2|R|^2$$
$$F_3(s) \equiv 2a^2 Re(R) + 4v^2a^2|R|^2$$
$$R \equiv s/(s - M^2 + iM\Gamma)$$

If N_f, N_b are the numbers of events with the μ^+ in the forward ($0<\theta<\Pi/2$), backward ($\Pi/2<\theta<\Pi$), hemispheres respectively, then the backward forward charge asymmetry is given by (1) as:

$$A(s) \equiv \frac{N_f - N_b}{N_f + N_b} = \frac{3}{4}\frac{F_3(s)}{F_1(s)} \quad \ldots.. (2)$$

Figs. 1a-1d) show how A(s) varies with M, Γ, v, a respectively in the energy range below the Z pole. Variations are shown about a standard set of values M = 90 GeV, Γ = 2 GeV, v = 0.0, a = 0.6, roughly corresponding to the W.S. model expectation with $\sin^2\theta_W = 0.23$. Also shown in Figs. 1 are the counting rates per hour for $e^+e^- \rightarrow \mu^+\mu^-$ with full geometrical acceptance and a luminosity of $L = 10^{31} s/(70\ \mathrm{GeV})^2\ \mathrm{cm}^{-2}\mathrm{sec}^{-1}$.

The following general comments can be made from inspection of Figs. 1a-1d):

(i) A(s) and the counting rate depend strongly on M, a, weakly on Γ, v.

(ii) Variations in M, a on the one hand and in Γ, v, on the other similarly modify A(s). Changing M, a changes the energy at which the minimum asymmetry (A= -0.75) occurs whereas changing Γ, v leaves the location of the minimum almost constant, but reduces the absolute value of the asymmetry.

(iii) A(s) at low energies depends only on the ratio a/M and is almost independant of Γ, v.

From (ii) it follows that measurements of the difference between the minimum asymmetry and its extreme value -0.75 can give upper bounds on the parameters Γ, v/a independant of M. For example, considering only the variation with v, and setting Γ = 0, the displacement of the minimum asymmetry from the value -0.75 is given by [9] $3/\{4+2(a/v)^2\}$.

The independance of the low energy charge asymmetry on Γ and v can be seen immediately from Egn (2) on taking the limit $s \ll M^2$, giving

$$A(s) = \frac{-3}{2} \quad \frac{a^2 s}{M^2} \qquad \ldots\ldots\ldots (3)$$

From the above a possible programme to determine all 4 parameters M, Γ, v, a begins to emerge:

1) Measurement of A at low energies determines a^2/M^2 via Eqn(3).
2) The absolute magnitude of the minimum asymmetry gives upper limits to Γ, and v/a.
3) Measurement of variation of A(s) from the linear s dependance of (3) determines M.
4) Combine 3) with 1) to give a.
5) Combine 2) with 4) to give an upper limit on v.

The crucial point however, to determine M, 3), would appear to require measurements of the charge asymmetry at several energies with good precision, something that seems unlikely to be attainable, given the luminosities of the order of $10^{31}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ or less that have so far been attainable in high energy e^+e^- rings.

The approach followed below is perhaps the simplest possible. The question is asked: What can be learnt, particularly with regard to M, from charge asymmetry measurements at only <u>two</u> energies? These are chosen (somewhat arbitrarily) to be $\sqrt{s}$ = 38 GeV corresponding to the top PETRA energy and $\sqrt{s}$ = 70 GeV, perhaps attainable in HERA, used as an e^+e^- collider. A somewhat lower upper energy of $\sqrt{s}$ = 54 GeV was also considered for comparison.

Significantly increasing the higher energy means (if the W.S. Theory is correct) entering the region of the Z pole itself where large increases of counting rate are expected and determination of the Z mass becomes very straightforward. This region has been considered in detail in earlier studies [6], [7].

However, in view of the large power costs entailed in giving rather modest increases to the beam energy of e^+e^- machines near design limits set by the size of the ring and available R.F. voltage gradients, the present study seems worth pursuing.

The plan of the report is as follows: In the following section approximate formulae are derived giving M and a directly from only two asymmetry measurements when v and Γ are set to zero. If the W.S. Theory is correct the low energy coupling constant measurements [4] indicate that this neglect of v, Γ should be a good approximation.

In section 3 an iterative procedure is applied using the complete expression for A(s) (Eqn(2)) to find improved values for M and a, taking as starting values those given by the approximate formulae of section 2. The measured charge asymmetry at the higher energy is then used to set upper limits on v, Γ justifying the neglect of these parameters in the earlier stage of the analysis. It is also shown that such neglect results in conservative upper limits for the Z mass. In section 4 the sensivity of measurements of the longitudinal polarisation of the τ s in $e^+e^- \rightarrow \tau^+\tau^-$ to v/a is investigated. Conclusions and closing comments are contained in section 5.

2. Approximate Formulae. Conservative Upper Limits on the Z Mass

To arrive at formulae from which limits on M may be obtained from only 2 charge asymmetry measurements additional assumptions are made. These are:

1) Both measurements are made on the monotonically decreasing portion of the A(s) curve (see Figs. 1).
2) Γ is neglected.
3) v is neglected.

There is little difficulty in establishing 1) experimentally, since if the higher energy measurement is made beyond the minimum of A, the Z pole is close enough to already give a large increase in counting rate.

The assumptions 2), 3) must be justified post hoc in a model independant analysis. It is however shown in the following section, by comparing the approximate formulae derived here with the exact formula Eqn(2), that the mass limits given by the approximate formulae are always <u>conservative</u> (i.e. high for the upper limit on M) for sets of the parameters (M, Γ, v, a) near to the W.S. values. Again, when the parameters are near to the W.S. values it will be shown that significant upper limits can be set on Γ and v, thus justifying, post hoc, the assumptions 2), 3).

The values of M, a found from the approximate formulae derived below are used as the starting values for an iterative solution of Eqn(2) (see section 3). In this way more stringent limits on M and a can be found, and upper limits set on the remaining parameters Γ and v.

Assuming $\Gamma = 0$, $v = 0$ Eqn(2) becomes

$$A = \frac{\frac{-3}{4} \cdot 2 \cdot a^2 \frac{s}{M^2}\left(1 - \frac{s}{M^2}\right)}{1 - 2\frac{s}{M^2} + (1 + a^4)\left(\frac{s}{M^2}\right)^2} \quad \ldots\ldots\ (4)$$

Noting that for solutions near to the W.S. one $a^4 \simeq (0.6)^4 = 0.13$ the a^4 may be dropped relative to 1 in the 3rd term in the denominator of Eqn(4), leading to the simpler expression:

$$A = \frac{-3}{4} \cdot \frac{2a^2 s/M^2}{(1 - s/M^2)} \quad \ldots\ldots\ (5)$$

Let A_1, A_2 be asymmetries measured at s values s_1, s_2 ($s_2 > s_1$). Defining:

$$R \equiv \frac{s_2 A_1}{s_1 A_2} = \frac{1 - s_2/M^2}{1 - s_1/M^2} \quad \ldots\ldots\ (6)$$

(where (5) has been used in the second part of the relation), a value for the Z mass is found on solving (6) for M as:

$$M = \sqrt{\frac{s_2 - s_1 R}{1 - R}} \quad \ldots\ldots\ (7)$$

It can be seen immediately from Eqn(6) that a first test for the existence of the Z (M finite) is that the measured quantity R should be significantly less than unity, or otherwise stated, there should be a significant departure from the linear dependence of A upon s, given by Eqn(3).

It is not difficult to show that Eqn(7) overestimates the value of M as compared to the more exact relation derived from Eqn(4). Putting the solution for M given by Eqn(4) equal to M + δ, where M satisfies Eqn(7) and expanding up to O(2) in the small quantity δ/M leads to:

$$\frac{\delta}{M} = -\frac{a^4}{2}\left(1 - \frac{A_1}{A_2}\right)\left[\frac{1}{\left(1 - \frac{2\delta}{M}\right) - \frac{s_2}{M^2}} - \frac{A_1/A_2}{\left(1 - \frac{2\delta}{M}\right) - \frac{s_1}{M^2}}\right] \quad \ldots\ldots\ (8)$$

Since $A_1/A_2 < 1$, $s_2 > s_1$, Eqn(8) implies that δ/M is -ve for small values of (δ/M) and hence that Eqn(7) overestimates M. Eqn(8) is readily solved (e.g. graphically) for δ/M given the values of A_1, A_2 s_1, s_2 and M.

The statistical error on the value of M is given by Eqn(7) as:

$$\sigma_M = \frac{s_2 - s_1}{(s_2 - s_1 R)^{1/2}} \; \frac{R}{(1 - R)^{3/2}} \; \frac{\sigma_R}{R} \quad \ldots\ldots\ (9)$$

The error on the experimentally measured quantity R is given in terms of the errors in the asymmetries A_1, A_2 as:

$$\frac{\sigma_R}{R} = \sqrt{\left(\frac{\sigma_{A_1}}{A_1}\right)^2 + \left(\frac{\sigma_{A_2}}{A_2}\right)^2} \quad \text{.................. (10)}$$

The error σ_A on an asymmetry is

$$\sigma_A = \frac{\sqrt{1 - A^2}}{\sqrt{N}} \quad \text{......................... (11)}$$

where $N \equiv N_f + N_b$ is the total number of counts contributing to the asymmetry measurement.

Before proceeding to the more detailed considerations of the following section we can already use Eqns(6), (10), (11) to estimate the number of counts required to establish the existence of the Z if the W.S. theory is correct and $\sin^2\theta_W = 0.23$.

Putting: $v = -0.05$, $a = 0.59$, $M = 88.8$ GeV (corresponding to $\sin^2\theta_W = 0.23$) and also $\Gamma = 2$ GeV in Eqn(2) leads to asymmetries of -0.118, -0.298, -0.645 at beam energies of 19, 27 and 35 GeV. In Table I are shown the values of R for different choices of the upper and lower energies for the asymmetry measurement, together with the errors given by Eqns(10) and (11) with two different assumptions:

(i) 10^4 counts at each point

(ii) 2×10^4 counts total, distributed between the upper and lower energies so as to minimise the error on R.

Finally the confidence level, in standard deviations, for excluding an infinitely heavy Z (R = 1) is given in each case.

The minimum error, and the distribution of counts between the upper and lower energy points corresponding to the assumption (ii) above are given by the equations:

$$\frac{\sigma_R^{(MIN)}}{R} = \frac{1}{\sqrt{N_T}}\left[\frac{\sqrt{1 - A_1^2}}{|A_1|} + \frac{\sqrt{1 - A_2^2}}{|A_2|}\right]$$

$$N_1^{(MIN)} = \frac{N_T|A_2|\sqrt{1 - A_1^2}}{(|A_2|\sqrt{1 - A_1^2} + |A_1|\sqrt{1 - A_2^2})} \quad \text{.............. (12)}$$

$$N_2^{(MIN)} = \frac{N_T|A_1|\sqrt{1 - A_2^2}}{(|A_2|\sqrt{1 - A_1^2} + |A_1|\sqrt{1 - A_2^2})}$$

$$N_T = N_1^{(MIN)} + N_2^{(MIN)}$$

It can be seen from Table I that in the best cases 19, 35 GeV and 27, 35 GeV an infinite mass Z can be ruled out at the 3 standard deviation level with only a few x 10^3 total counts. The improvement in precision using an optimised distribution of counts is most marked (∿30% improvement) for the 19, 35 GeV case where the asymmetry difference between the upper and lower energy points is largest.

3. Iterative Solutions. Limits on M, Γ, v, a

In the following calculation it is assumed that events are accepted only in the range of μ production angle:

$$\Pi/6 < \theta < 5\Pi/6$$

and that an integrated luminosity of $7.2\times10^{37}\text{cm}^{-2}$ is obtained at both the lower (19 GeV) and upper (35 GeV) energy points.

The production angle cut ensures good acceptance and reconstruction efficiency in a typical solenoidal magnetic detector. The effect of this cut on the asymmetry is to replace the factor 3/4 in Eqns(2), (4),(5) by 0.693, so diluting the asymmetry at any energy by about 8%.

The choice of integrated luminosity may be justified as follows: The design luminosity of both the current (PETRA - PEP) generation of e^+e^- machines and the succeeding one (LEP) is $\approx 10^{32}\text{cm}^{-2}\text{sec}^{-1}$. However, certain, at present unsolved, problems mainly connected with the beam-beam tune shift limit seem to limit presently attainable luminosities to around a few $\times10^{30}\text{cm}^{-2}\text{sec}^{-1}$. Allowing for some improvement in this situation, an instantaneous luminosity of $10^{31}\text{cm}^{-2}\text{sec}^{-1}$ seems a not unreasonable hope for the immediate future. The measurement being discussed here is a simple one, capable of being performed by any 'general' detector. Following recent PETRA experience it is then assumed that data from 4 essentially equivalent detectors can be added (or equivalently a weighted average of the asymmetries measured in the 4 detectors can be taken). This leads to an effective instantaneous luminosity for the whole measurement of $4 \times 10^{31} cm^{-2} sec^{-1}$. Choosing 2000 hours as a not unreasonable total running time over a 1 year period then gives the integrated luminosity quoted above. If the W.S. theory with $\sin^2\theta_W = 0.23$ holds, the expected charge asymmetries, numbers of events within the quoted angular cut, and statistical errors on the charge asymmetries are as given in Table II. The detailed analysis given below uses E = 19, 35 GeV for the upper, lower energies. However, Table II also includes values for the intermediate energy, 27 GeV.

The procedure now adopted to find first a, M and then to set upper limits on v, Γ is as follows:

(a) Starting values for a_0, M_0 are found from the measured asymmetry measurements A_1, A_2 using the approximate Eqns(5),(7). M_0 is first found using (7). a_0 is then given by Eqn(5) substituting $A = A_0$, $M = M_0$. Note that the lower energy point is used, as the approximate Eqn(5) is more accurate at lower energies. The errors on M_0, a_0 are found from Eqns(9)-(11).

(b) The value for a_0 (upper and lower limits $a_0+\sigma_{a_0}$, $a_0-\sigma_{a_0}$) is used in Eqn(2), to plot the asymmetry at the upper energy as a function of M. v = 0, Γ = 2 are assumed for the two remaining parameters, which as shown below, results in a conservative upper limit on the mass.

(c) From the intersections of the A(s) v M curve generated in (b) for the allowed limits $a_0 \pm \sigma_{a_0}$ in a, with the measured A_2 value, new mass limits are found.

(d) These mass limits are substituted in Eqn(5) together with the measured value of A, to give an improved value for a: $a_1 \pm \sigma_{a_1}$.

(e) (b), (c), (d) are repeated iteratively to give further improved values for a, M until the change in the parameters becomes small compared with the errors.

(f) To find upper limits on v, Γ curves of the higher energy asymmetry as a function of M using the final value for a found in (a) - (e) above are plotted for different values of v and Γ and compared with the measured asymmetry.

The successive values of M, a found by using the procedure (a) - (e) on the asymmetry values given in Table II are given in Table III.

Two cases are shown, measurements at 19, 35 GeV with the above quoted luminosity and measurements at 19, 27 GeV with a 10 times greater luminosity, which from a practical point of view, is a somewhat academic case. This second example does however indicate that given adequate luminosity significant upper limits on the Z mass can be found from charge asymmetry measurements at little more than half the beam energy needed to reach the Z pole itself.

The convergence of the procedure is somewhat different in the two cases. It is quite smooth and reaches a stable value after 2 iterations in the 19, 35 GeV case, whereas for the 19, 27 GeV case the parameters tend to 'overstep' the input parameters on the second iteration.

Fig. 2 shows, for the 19, 35 GeV case step (c) of the procedure at the second iteration. The curves labelled a_U, a_L correspond to $a_1 + \sigma_{a_1}$, $a_1 - \sigma_{a_1}$. The quoted errors on M correspond to the full ± 1σ region P, P' generated by the curves a_U, a_L. Note that there is in fact a separation into upper and lower allowed regions Q' P', PQ respectively at the 1 standard deviation level. In fact the lower of these regions could be experimentally excluded (the expected counting rate at E = 35 GeV for such low masses will be ≈2x times larger than the 'QED' value, see Fig. 1a) so the lower limit on the mass can be sharpened. Such additional considerations do not affect the upper limit on the mass however.

In Fig. 3 the E = 35 GeV asymmetry is plotted as a function of M with a set to the value found at the 2nd iteration given in Table III, and with v, Γ allowed to vary. The curve shown for v = 0, Γ = 2 is essentially identical to the curves for v = -0.0475, Γ = 2 (W.S. Theory) or v = 0, Γ = 0. It is evident by comparing these curves with the measured asymmetry value, also shown in Fig. 3 that:

(i) $|v| < 0.2$, Γ < 15 GeV at 95% (2 standard deviation) confidence level.

(ii) If the analysis procedure (a) - (e) above is repeated with larger values of $|v|$ and Γ, consistent with (i) then even more stringent upper and lower limits on the Z mass than those quoted in Table III will be found. Thus the values quoted in Table III for the mass are quite conservative. This is because the W.S. prediction is very near to the one (with v = 0) giving the largest possible charge asymmetry in the energy region below the Z pole. This large asymmetry guarantees that v, Γ must be small independant of M and a so justifying the solution in terms of the latter two parameters alone presented above. If nature were (or is!) less kind so that $v = (1/2)a$ at high energies for example, this type of analysis would certainly not work. However this would be made evident by the small absolute value of the minimum charge asymmetry (see the curve for $v = 0.3 \approx (1/2)a$ in Fig. 1c).

4. Constraints on v/a from τ Polarisation in $e^+e^- \rightarrow \tau^+\tau^-$

The mean longitudinal polarisation of a positive heavy final state lepton (μ^+ or τ^+) averaged over any angular range symmetric about $\theta = 90^\circ$ is given by [(6),(7)]:

$$P_L = -F_4(s)/F_1(s) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

where

$$F_4(s) = 2\, v\, a \left[\mathrm{Re}(R) + (v^2 + a^2)|R|^2\right]$$

and R, $F_1(s)$ are defined after Eqn(1). Making a similar approximation ($\Gamma = 0$, $v \ll a$) to that giving Eqn(4),(13) may be written as:

$$P_L = \frac{v\, a\, s}{M^2} \; \frac{\left[1 - (1 + a^2)\, s/M^2\right]}{\left[1 - \frac{2s}{M^2} + (1 + a^4)\left(\frac{s}{M^2}\right)^2\right]} \quad \ldots\ldots\ldots\ldots \quad (14)$$

Taking the ratio of Eqns(14),(4) where in (4) the angular range over which A is defined is restricted to $\pi/6 < \theta < 5\pi/6$ leads to:

$$\frac{P_L}{A} = 0.72\, \frac{v}{a}\, \frac{\left[1 - (1+a^2)s/M^2\right]}{(1 - s/M^2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

using the values of M, a obtained in the charge asymmetry analysis of section 3 above, the additional measurement of P_L then gives v/a. In the W.S. theory with $\sin^2\theta_W = 0.23$ the expected value of P_L from Eqn(15) is

0.007 for E = 35 GeV so there is no hope to determine the relative sign of v and a from P_L measurements below the Z pole in this case.

The measurement of the longitudinal polarisation of the $\tau^+\tau^-$ produced in the reaction $e^+e^- \rightarrow \tau^+\tau^-$ near the Z pole has been discussed by Goggi[(10)] using the decay modes $\tau \rightarrow e\nu\nu$, $\mu\nu\nu$ and by Augustin[(11)] using the decay modes $\tau \rightarrow \pi\nu$, $\rho\nu$. Scaling figures for the sensitivity to P_L given in Ref.(10), (11) on the assumption (perhaps optimistic) that all decays of the respective modes are available for analysis leads to the following absolute errors in P_L where N is the total number of $\tau^+\tau^-$ produced:

$\tau \rightarrow e\nu\nu$, $\mu\nu\nu$	$\sigma_{P_L} = 9.2/\sqrt{N}$
$\tau \rightarrow \pi\nu$	$\sigma_{P_L} = 3.7/\sqrt{N}$

or, using all available information,

$$P_L = 3.4/\sqrt{N}$$

Since, in the W.S. model with $\sin^2\theta_W = 0.23$, P_L is almost zero, the limit on P_L/A set by a longitudinal polarisation measurement is $\approx \sigma_{P_L}/A$. Table IV shows the values of σ_{P_L} and the corresponding limits on σ_{P_L}/A and v/a given by Eqn(15) for beam energies, charge asymmetries and integrated luminosities as shown in Table II. Comparing the 1 standard deviation limits on v/a given in Table IV with the 2 standard deviation limit $|v/a| \lesssim 0.35$ derived from the analysis of section 3 and Fig. 3 it is clear that no useful limits are set by such polarisation measurements.

5. Concluding Remarks

The main conclusion of this report is that if the assumptions(i) - (iii) hold, and the parameters of the theory are close to those suggested by the W.S. Theory and existing low energy neutral current measurements, only two charge asymmetry measurements below the Z pole in the energy region where no significant increase in counting rate is yet apparent suffice to set limits on all 4 free parameters of the theory (Table III and Fig. 3). For measurements at 19, 35 GeV, 19, 27 GeV integrated luminosities at each energy of $\sim 10^{38}$, 10^{39} cm^{-2} would be required. Simpler tests for the existence of the Z can be made directly from the charge asymmetry measurements themselves (see Table I). For energies of 19, 35 GeV a total integrated luminosity of $\approx 10^{38}$ cm^{-2} would exclude an infinitely heavy Z at about the 3 standard deviation level. The above results from the lucky accident that in the W.S. Theory the low energy asymmetry is almost maximal (in absolute value) and depends only weakly on Γ, v. The two charge asymmetry measurements then essentially determine M, a, the measured value of the higher energy asymmetry then setting upper limits on Γ, v.

No useful additional information seems available from polarisaiton measurements of the τ in the reaction $e^+e^- \rightarrow \tau^+\tau^-$ with integrated luminosities similar to those quoted above. In particular there is no hope of checking the relative sign of v and a, predicted to be -ve in the W.S. Theory with $\sin^2\theta_W = 0.23$.

No account has been taken of radiative corrections in this report, and certainly such effects have to be considered before meaningful comparisons with data can be made. Calculations(12) however indicate that radiative effects on the charge asymmetry below the Z pole are much less drastic than at the pole or above. Fig. 5 of Ref.(12) indicates that the curves are still generally as shown in Figs. 1a) - d) with small displacements towards smaller absolute asymmetries at energies below that giving the minimum asymmetry, and to higher ones above it. It is not expected that the essential conclusions given above will be changed by such effects.

Figure Captions

Fig. 1: Curves of charge asymmetry (solid lines) and counting rate per hour (dotted lines) versus $\sqrt{s}$. For the counting rate full acceptance and a luminosity: $L = 10^{31}(\sqrt{s}/70)$ $cm^{-2}sec^{-1}$ are taken. In all cases curves with the standard values M = 90 GeV, Γ = 2 GeV, v = 0.0, a = 0.6 are shown:

a) Variation of M. M = 80, 100 GeV
b) Variation of Γ. Γ = 10, 20 GeV
c) Variation of v. v = 0.1, 0.3
d) Variation of a. a = 0.4, 0.8

Fig. 2: Plots of charge asymmetry at E = 35 GeV versus M for different values of a given by Eqn(2) with Γ = 2 GeV, v = 0. Shaded area indicates , 1 standard deviation limits of the expected asymmetry in W.S. Theory with $\sin^2\theta_W = 0.23$ for experimental cuts and integrated luminosities given in the text. See also the text for explanations of the labelling of the curves.

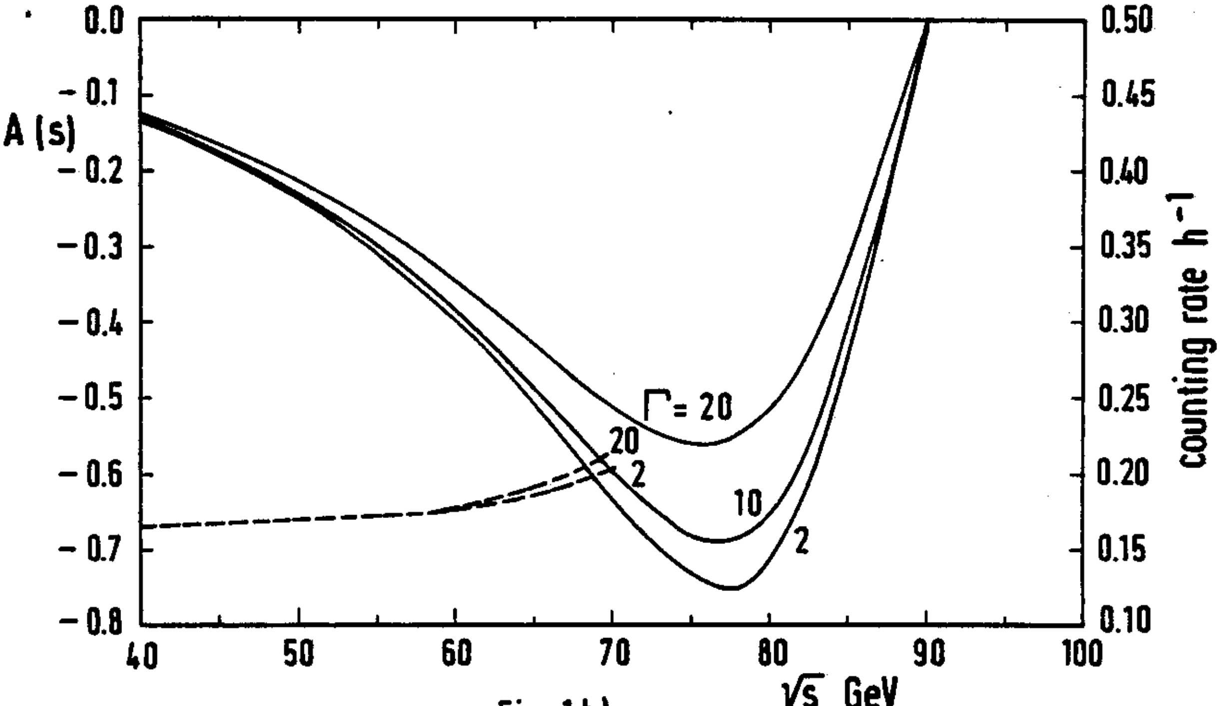
Fig. 3: Plots of charge asymmetry at E = 35 GeV versus M for a = 0.577 and different values of v, Γ: v = 0, Γ = 2 GeV; v = 0, Γ = 15 GeV; v = 0.20, Γ = 2 GeV. The shaded area indicates expected asymmetry in W.S. Theory, as in Fig. 2. See text for explanation and comments.

References

1) S.L. Glashow Nucl. Phys. 22 (1961) 579
2) S. Weinberg Phys. Rev. Lett. 19 (1967) 1264
3) A. Salam Proc. 8th Nobel Symp. John Wiley and Sons, New York 1968
4) See e.g. Rapporteur talks by J. Iliopoulous EPS Conference, CERN Geneva 1979 and K. Winter International Symposium on Lepton and Photon Interactions at High Energies FNAL, Batavia 1979
5) E.H. de Groot, D. Schildknecht, and G.J. Gounaris, University of Bielefeld, Pre-Print BI-TP 79/37, November 1979 submitted to Physics Letters
6) J.H. Field and B. Richter CERN 76-18, Page 95
7) L. Camilleri CERN 79-01, Page 455
8) R. Budny Phys. Lett. 55B (1975) 227
9) J. Ellis and M.K. Gaillard CERN 76-18, Page 21
10) G. Goggi CERN 79-01, Page 483
11) J.E. Augustin CERN 79-01, Page 499
12) M. Greco, G. Pancheri-Scrivastava and Y. Scrivastava Frascati, Pre-Print LNF-79/20(R), March 1979

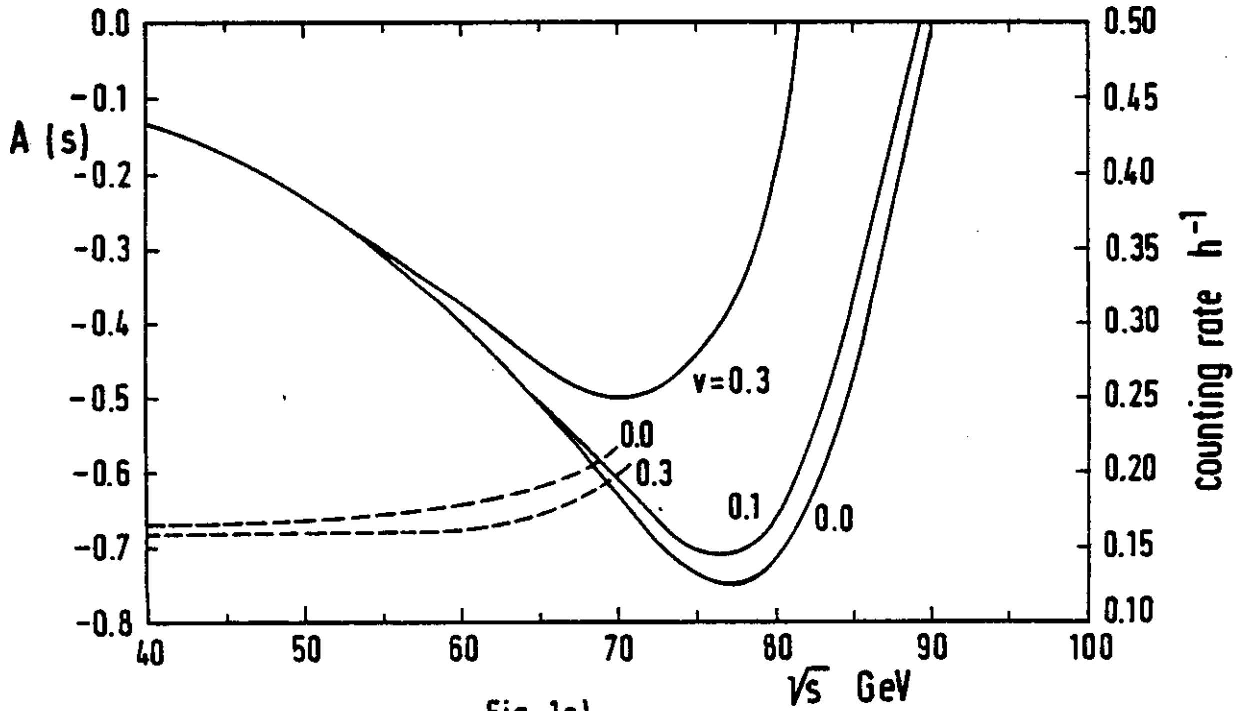
Table I

Energies (GeV)	19, 35	19, 27	27, 35
R	0.62	0.80	0.78
σ_R (10^4 counts per point)	0.053	0.072	0.027
σ_R^{MIN} $2x10^4$ counts total with optimum distribution	0.042	0.066	0.024
$\frac{1-R}{\sigma_R}$	7.2	2.8	8.3
$\frac{1-R}{\sigma_R^{MIN}}$	9.4	3.0	9.1



A (s)
counting rate h⁻¹
Γ = 20
20
2
10
2
√s GeV

Fig. 1b)



A (s)
counting rate h⁻¹
v = 0.3
0.0
0.3
0.1
0.0
√s GeV

Fig. 1c)

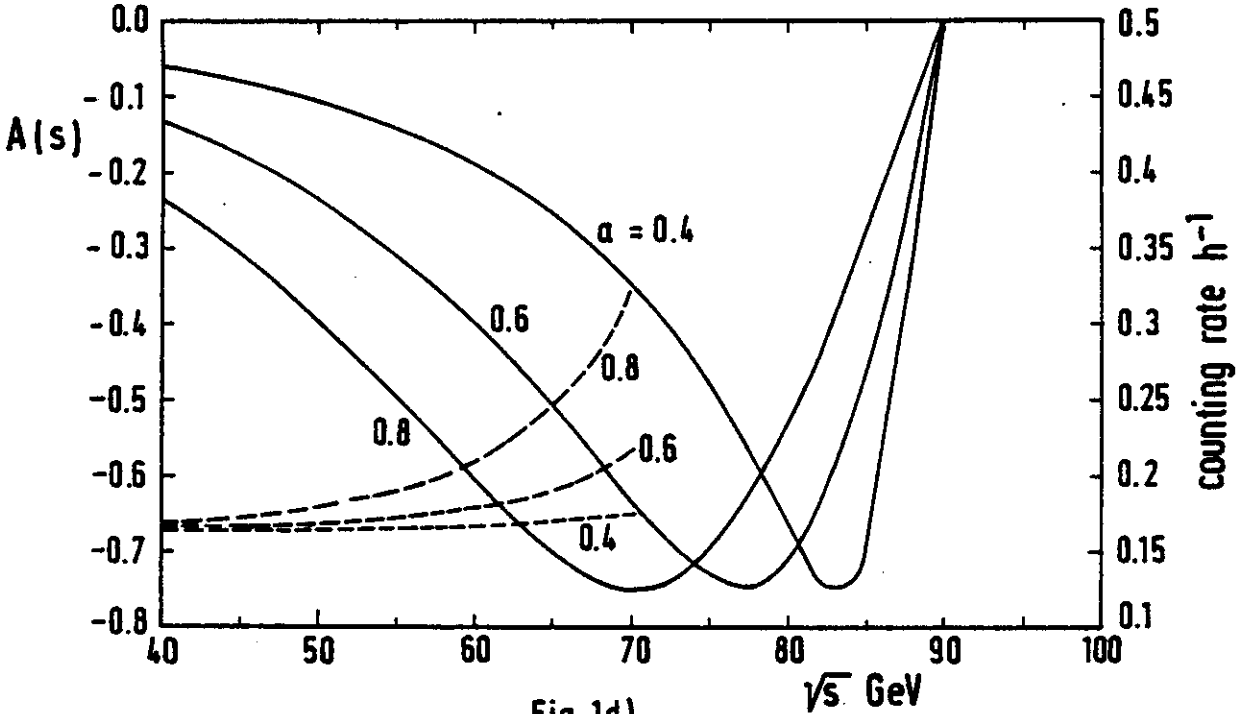

A(s)
α = 0.4
0.6
0.8
0.8
0.6
0.4
counting rate h⁻¹
√s GeV

Fig. 1d)

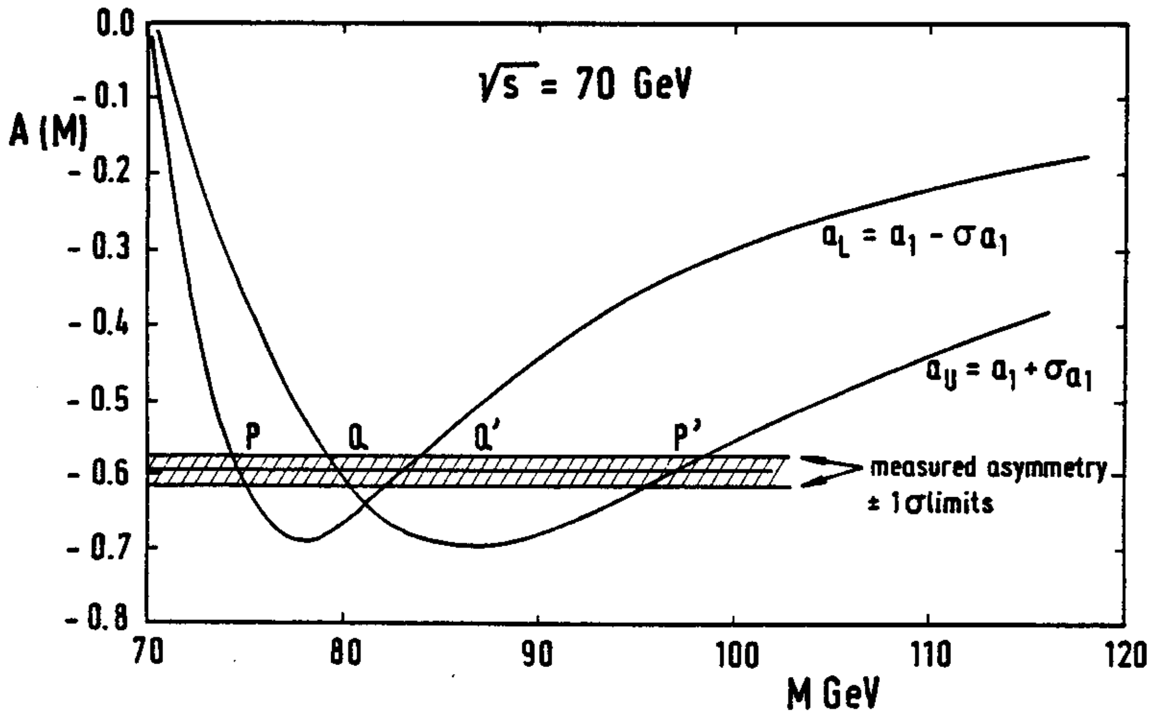

A (M)
√s = 70 GeV
α_L = α_1 - σα_1
α_U = α_1 + σα_1
P
Q
Q'
P'
measured asymmetry
± 1σ limits
M GeV

Fig. 2)

Table II

Charge asymmetries with statistical errors and numbers of events

$\Pi/6 < \theta < 5\Pi/6$, $\Sigma L = 7.2\times10^{37}\ cm^{-2}$, $\sin^2\theta_W = 0.23$

Beam Energy (GeV)	A	σ_A	Number of Events
19	-0.109	0.014	4506
27	-0.275	0.020	2307
35	-0.596	0.019	1752

Table III

	19, 35 GeV $\Sigma L = 7.2\times10^{37}\ cm^{-2}$		19, 27 GeV $\Sigma L = 7.2\times10^{38}\ cm^{-2}$	
	M (GeV)	a	M (GeV)	a
Approx. Calc.	103±19	0.707±0.13	94±16	0.632±0.13
1st Iteration	91±15	0.607±0.12	87±13	0.572±0.10
2nd Iteration	86±12	0.577±0.10	81±10	0.524±0.08
Input Values	88.82	0.594	88.82	0.594

Input values of other parameters: Γ = 2GeV, v = -0.0475

Input values correspond to $\sin^2\theta_W$ = 0.23 in W.S. Theory

Table IV

Limits on v/a from τ longitudinal polarisation measurements in $e^+e^- \rightarrow \tau^+\tau^-$. All conditions as in Table II. e-μ- τ universality assumed.

Beam Energy (GeV)	P_L	σ_{P_L}	v/a (1 S.D. Limits)
19	0.003	0.05	±1.51
27	0.006	0.07	±0.84
35	0.007	0.08	±0.44

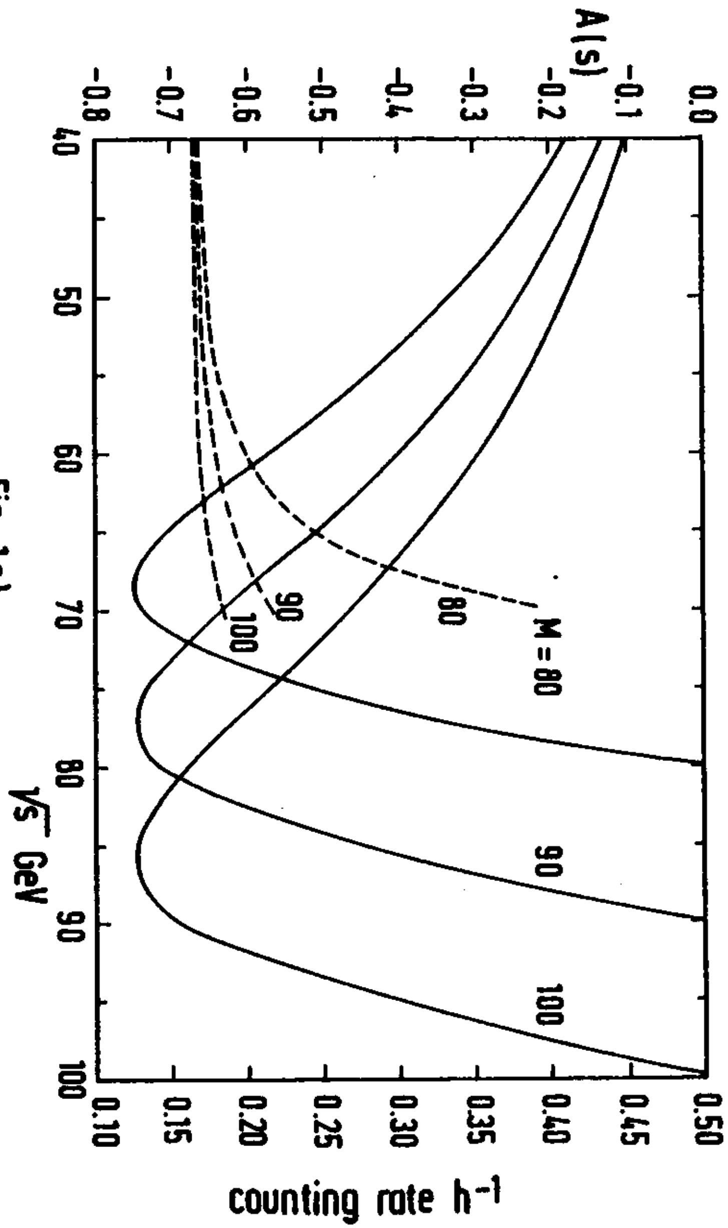
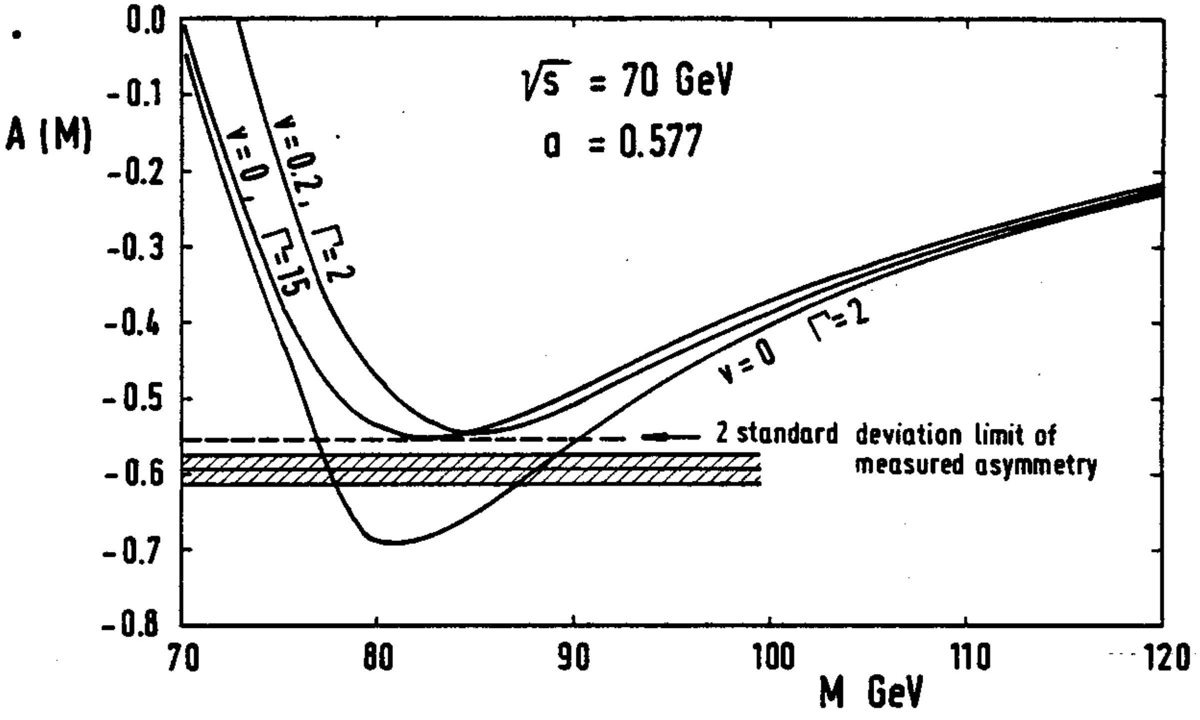


Fig. 1a)



A (M)
M GeV
√s = 70 GeV
a = 0.577
v=0.2, Γ=2
v=0, Γ=15
v=0 Γ=2
2 standard deviation limit of measured asymmetry
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
70
80
90
100
110
120

Fig. 3)