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UPPER LIMIT ON BEAUTY LIFETIME AND LOWER LIMIT ON WEAK MIXING ANGLES

by

JADE Collaboration

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Abstract

Muons from a multihadron sample are used to determine an upper limit $\tau < 1.4 \cdot 10^{-12}$ sec (95% CL) on the lifetime of beauty particles. The data are obtained with the JADE detector at PETRA. The result is interpreted within the standard model.

All measured electroweak properties of B particles (i.e. particles containing a beauty quark) fit well into the Kobayashi-Maskawa [1] scheme or, equivalently, into the Maiani [2] scheme. The weak mixing angles β and γ of Maiani have experimental upper bounds which imply that the ground state B - particles should have lifetimes greater than about $0.3 \cdot 10^{-13}$ sec [3]. Similarly, an upper bound on the lifetime provides lower limits on these weak mixing angles. Previous limits on the B lifetime using the JADE detector [4] excluded models predicting long lived or meta-stable b-quarks [5]. In this letter we present limits on the B lifetime and weak angles with improved statistics.

The basic idea of the analysis, sketched in Fig. 1, goes back to studies in cosmic rays [6] and has been applied recently in studies of charmed particles [7]. Decay products, in the present case energetic muons, are used to measure d, the distance of closest approach to the e^+e^- - annihilation vertex A. Since only fast muons are considered, one finds:

$$d = \ell \sin\delta \approx c\tau \, \frac{\ell}{L} \, \frac{\beta \sin\delta^*}{1 + \beta \cos\delta^*} \qquad (1)$$

where τ is the lifetime of the parent, ℓ and β its flight path and velocity in the laboratory, $L \equiv \beta\gamma c\tau$ and δ^* the emission angle of the decay muon in the parent's rest frame. The average distance is proportional to the lifetime - the proportionality factor depends upon the exponential decay length distribution and the model dependent decay angular distribution of the muon. The average distance is, however, insensitive to the fragmentation function of b-quarks.

A sample of 3093 multihadron events observed in the JADE detector has been scanned for muons with momenta exceeding 1.4 GeV/c. In this scan the average probability to confuse a muon with a hadron penetrating the muon filter is $2.5 \cdot 10^{-3}$ [8]. 349 such events were found. In order to have a good track acceptance the angle θ of the reconstructed thrust axis, $\vec{e}_3$, with respect to the beam direction is required to have $|\cos\theta| < 0.75$. Furthermore, the observed (charged and neutral) energy must exceed 60% of the centre of mass energy, which is on average 34 GeV. Finally, a cut is applied to the data to enhance heavy flavours. For each event an axis $\vec{e}_1$ perpendicular to the thrust axis can be found which minimizes $\Sigma|\vec{p}_i^{\,T}\vec{e}_1|$, where $\vec{p}_i^{\,T}$ are the transverse momenta with respect to $\vec{e}_3$. Then the quantity

$$T_1 = \frac{\Sigma\ |\vec{p}_i\vec{e}_1|}{\Sigma\ |\vec{p}_i|}$$

tends to be big for events with heavy flavours. This is due to the fact that in each $c\bar{c}$- and $b\bar{b}$-event two high mass objects are formed which decay independently from each other. In contrast, particles in $u\bar{u}$-, $d\bar{d}$-, $s\bar{s}$-jets contribute to T_1 only with the small transverse momenta which are typical for fragmentation processes. The flavour sensitivity remains valid, even if they have planar structure due to hard gluon emission. Note that T_1 contains information of the whole event. Each particle momentum enters linearly which is appropriate when decaying objects are considered. Monte Carlo results, based on the LUND model [9], are shown in fig. 2 separately for light and heavy quark flavours. The treatment of b-decays follows Ref. 10 assuming 10% leptonic branching ratio. The generated events are tracked through the apparatus and selected according to the same criteria as the data. Only events satisfying $T_1 \geq 0.20$ were kept. This cut reduced the muon sample to 31 events. The predicted number of events starting from the initial multihadron sample and using the Monte Carlo results is 29.5 with a statistical uncertainty of ± 5. In this sample, muons due to meson decays in $u\bar{u}$-, $d\bar{d}$-, $s\bar{s}$-events amount to 1 ± 0.5, such that almost all muons come from $c\bar{c}$- and $b\bar{b}$-events in nearly equal proportion (cf. fig. 2), namely 1: 1.2.

The e^+e^- annihilation vertex is reconstructed in the plane perpendicular to the beam axis using all tracks with momenta exceeding 0.2 GeV/c. The track parameters and their errors are obtained from helix fits to the hits measured in the jet chamber. All tracks are extrapolated to the region of the vertex position taking multiple scattering into account. A typical uncertainty at the vertex is about 1 mm for a charged particle of 1 GeV/c. The extrapolation to

the vertex is less reliable for tracks passing close to a cell boundary in the jet chamber, or having a small angle crossing with another track. Therefore, 3 events with such muons were excluded. Recognized V^0 decays or tracks from secondary nuclear interactions are excluded. The vertex fit is performed with typically 10 tracks; for the selected sample the average χ^2/d.o.f. is 0.97. In fig. 3 muons from the above sample are compared with charged hadrons satisfying the same selection criteria. Fig. 3a shows their distribution of closest approach d_h. The sign of d_h is defined by the relative vertex position and the muon direction w.r.t. the thrust axis (fig. 1). The tail of the distribution can be attributed to tracks from V^0 decays and to tracks from secondary nuclear interactions taking place in the material before the first measured point. Fig. 3b shows the distance of closest approach of the same tracks normalized to their track uncertainty. The quantity d_h^2/σ_h^2 should obey a $\chi 2$-distribution with 1 degree of freedom or equivalently the quantity $|d_h|/\sigma_h$ should be distributed according to a Gaussian with width 1. The tail has the same origin as in Fig. 3a. Similarly, in Fig. 3c the quantity $|d_\mu|/\sigma_\mu$ is shown for the muons of the selected events. There is one outsider at more than 6 standard deviations. In this case both the muon track and the event vertex are well behaved. The kinematics is compatible with a K^+ decaying before the first measured point into a μ^+ and a ν_μ. This type of background is expected to contribute 0.9 ± 0.3 events assuming one fast charged kaon per event. The deviation of $<d>$ from 0 is a measure of the lifetime of the parent particle giving rise to the muon (see formula (1)). A simulation with Monte Carlo $b\bar{b}$ events using the LUND model and taking into account the experimental conditions in this analysis gives

$$<d_\mu> = 0.2\ \text{mm}\ \frac{\tau}{10^{-12}\text{sec}}$$

From the 27 muon tracks, excluding the outsider, one obtains for the mean value $<d_\mu> = \ (0.01 \pm \frac{0.45}{\sqrt{27}}\ )$ mm. The low average uncertainty of muon tracks, $<\sigma_\mu> = 0.45$ mm, reflects their hard energy spectrum. Using the relative proportions of $b\bar{b}$ and $c\bar{c}$ events in the remaining sample (1.2:1), N_b, the number of $b\bar{b}$ events with prompt muons is obtained, after subtraction of the background due to π- and K-decays (2 from $c\bar{c}$ and 2 from $b\bar{b}$). Then, one obtains $N_b = 12$. This estimate is compatible with the shapes of the p_T and the p_T^{out} $(=|\vec{p}_\mu \cdot \vec{e}_1|)$ distributions of the muons. Furthermore, the sample contains two events with two leptons on the same side, one $\mu\bar{\mu}$ and one $\mu\bar{e}$, where 1.2 are expected. Therefore, at 95% confidence level $<d_\mu> < 2 \cdot \frac{0.45}{\sqrt{12}}$ mm and consequently one infers

$$\tau_b < 1.4 \cdot 10^{-12}\ \text{sec} \quad (95\%\ \text{c.l.})$$

This result can be used to put lower limits on the weak mixing angles of Maiani. The quantities τ_b, $\sin\beta$, $\sin\gamma$ are theoretically related as follows [3]:

$$\tau_b = \frac{0.93 \cdot 10^{-14}\ \text{sec}}{2.75 \sin^2\gamma + 7.69 \sin^2\beta - 5.75 \sin^2\gamma \sin^2\beta}$$

assuming the b-quark mass to be 5 GeV. The lower limits on $|\sin\gamma|$ and $\sin\beta$ coming from the upper limit on τ_b are indicated in Fig. 4. Also shown are the limits [3] derived from Cabibbo universality and from the K_L^0, K_S^0 system.
A recent measurement of the number of kaons in $b\bar{b}$-events by the CLEO - collaboration [11] can be interpreted in terms of $\sin^2\beta/\sin^2\gamma$ and leads to a further restriction of the allowed values of $|\sin_\gamma|$ and $\sin\beta$ within the standard model, as indicated in fig. 4 by the dotted line.

Acknowledgement

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FIGURE CAPTIONS

1. Sketch of the method. The beauty particle is produced at the e^+e^--annihilation vertex A and decays at point B.

2. T_1 distribution of Monte Carlo events with muons for various flavours. The arrow indicates the cut applied to the data sample. The number of events in the three plots are not normalized to each other. Events in the uppermost plot contribute only non-prompt muons.

3a. Distribution of distance of closest approach of selected hadron tracks relative to the vertex;

b. the same tracks as in 3a, but for each track the distance of closest approach is normalized to its uncertainty. The dotted line is the expected Gaussian distribution with width 1;

c. same distribution as in Fig. 3b for the selected muon tracks.

4. The unshaded region shows the allowed values of the weak mixing angles. The lower left shaded area is excluded by this experiment.
Also shown is a result from the CLEO experiment excluding the region to the left of the dotted line.

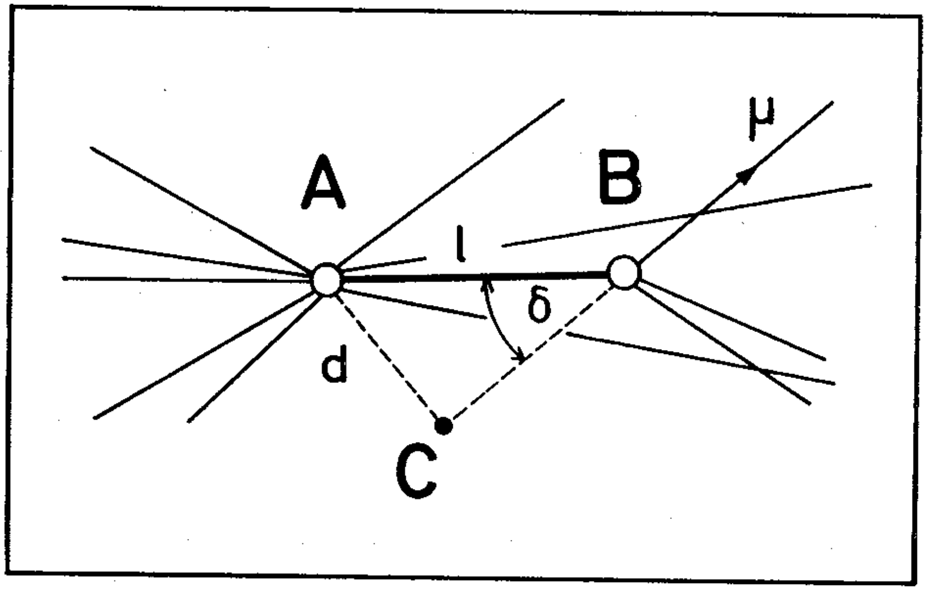
A
B
C
μ
l
δ
d

Fig. 1

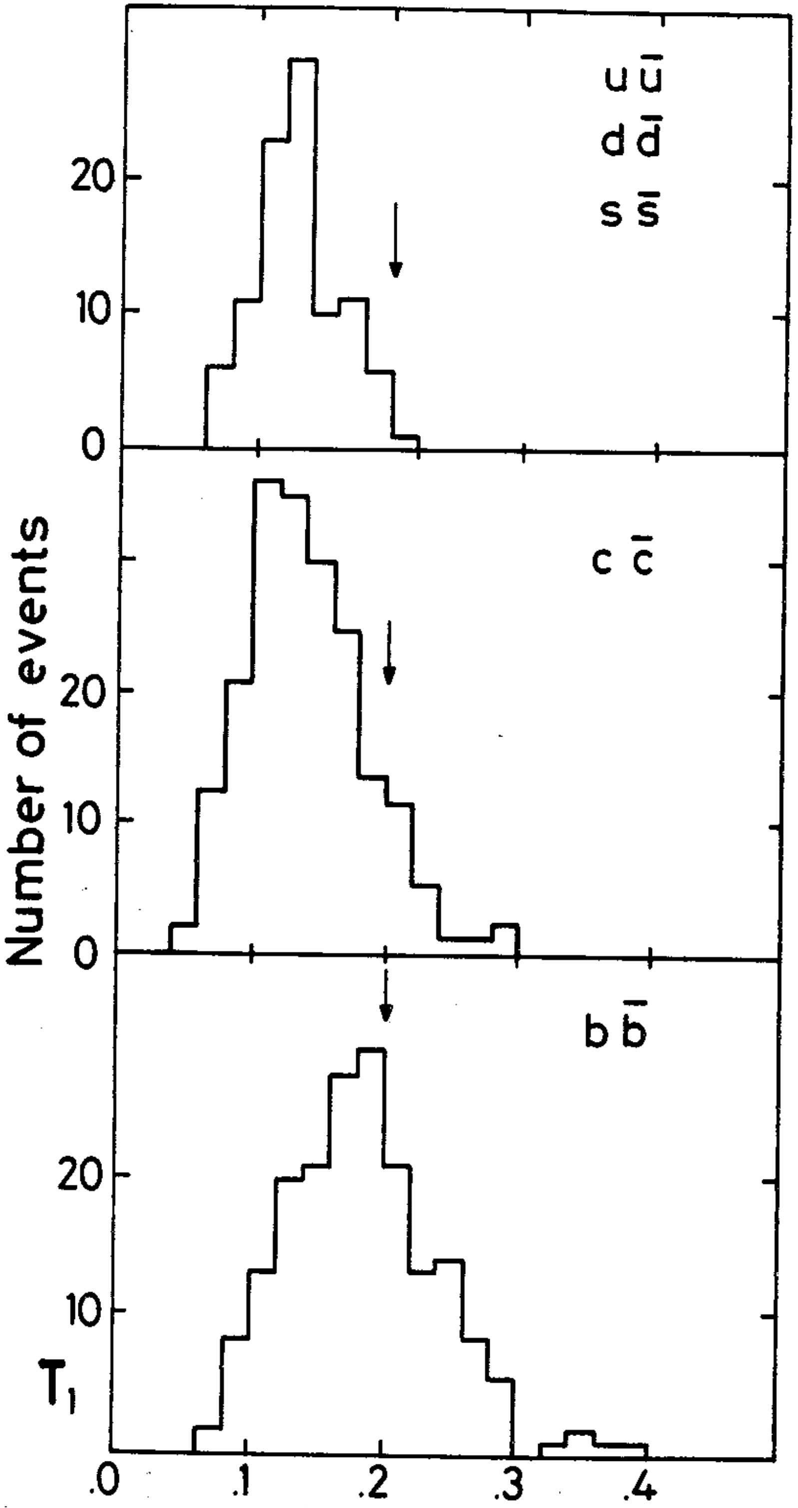
Number of events
$u\bar{u}$
$d\bar{d}$
$s\bar{s}$
$c\bar{c}$
$b\bar{b}$
20
10
0
20
10
0
20
10
T_1
.0
.1
.2
.3
.4

Fig. 2

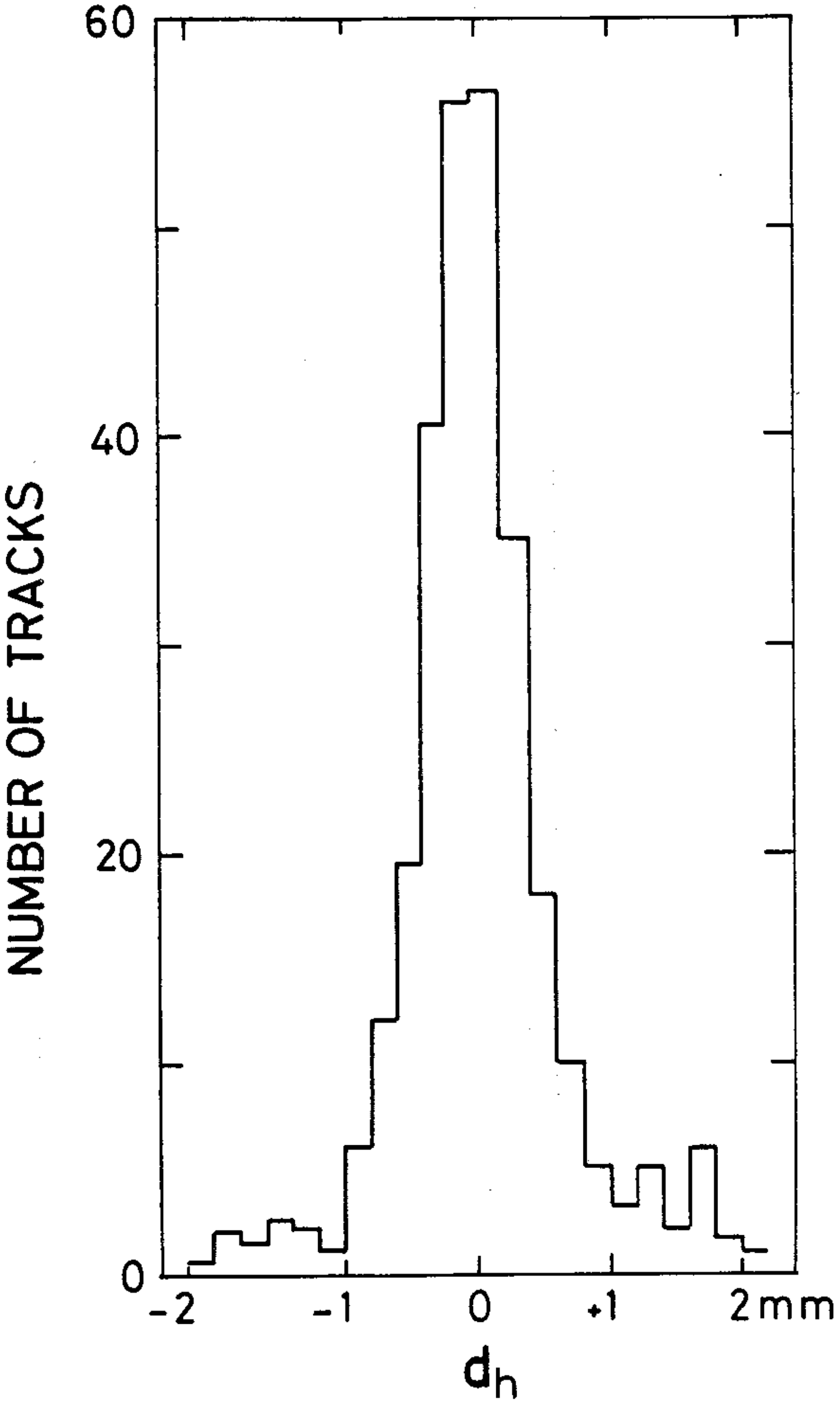
NUMBER OF TRACKS
60
40
20
0
-2
-1
0
+1
2mm
d_h

Fig. 3a

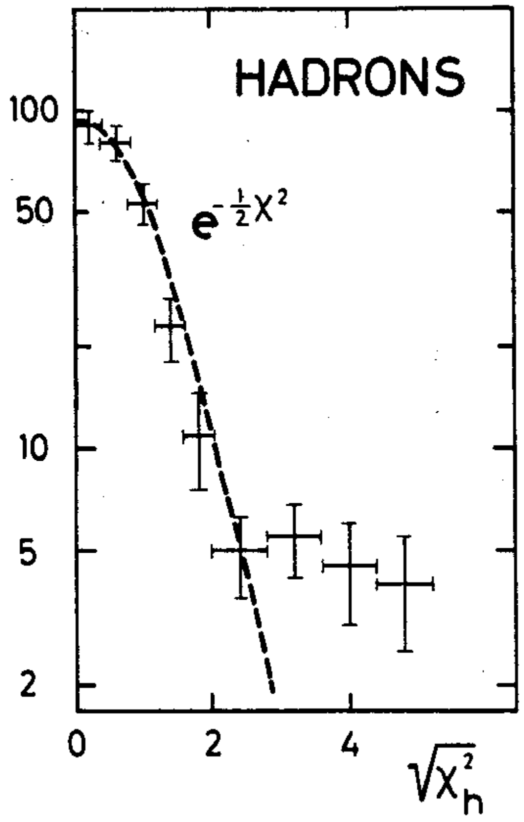
HADRONS
$e^{-\frac{1}{2}\chi^2}$
100
50
10
5
2
0
2
4
$\sqrt{\chi_h^2}$

Fig. 3b

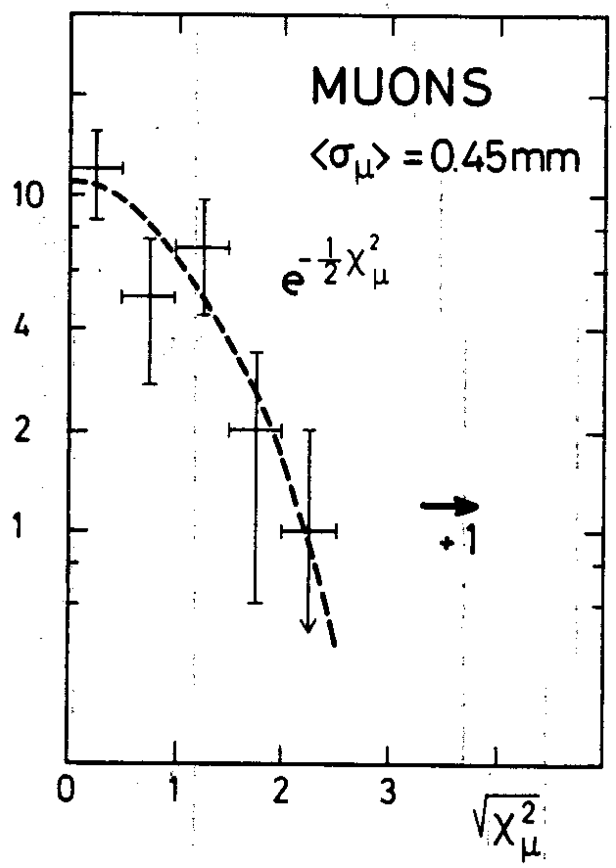
MUONS
$\langle\sigma_\mu\rangle = 0.45$mm
$e^{-\frac{1}{2}\chi^2_\mu}$
+1
10
4
2
1
0
1
2
3
$\sqrt{\chi^2_\mu}$

Fig. 3c

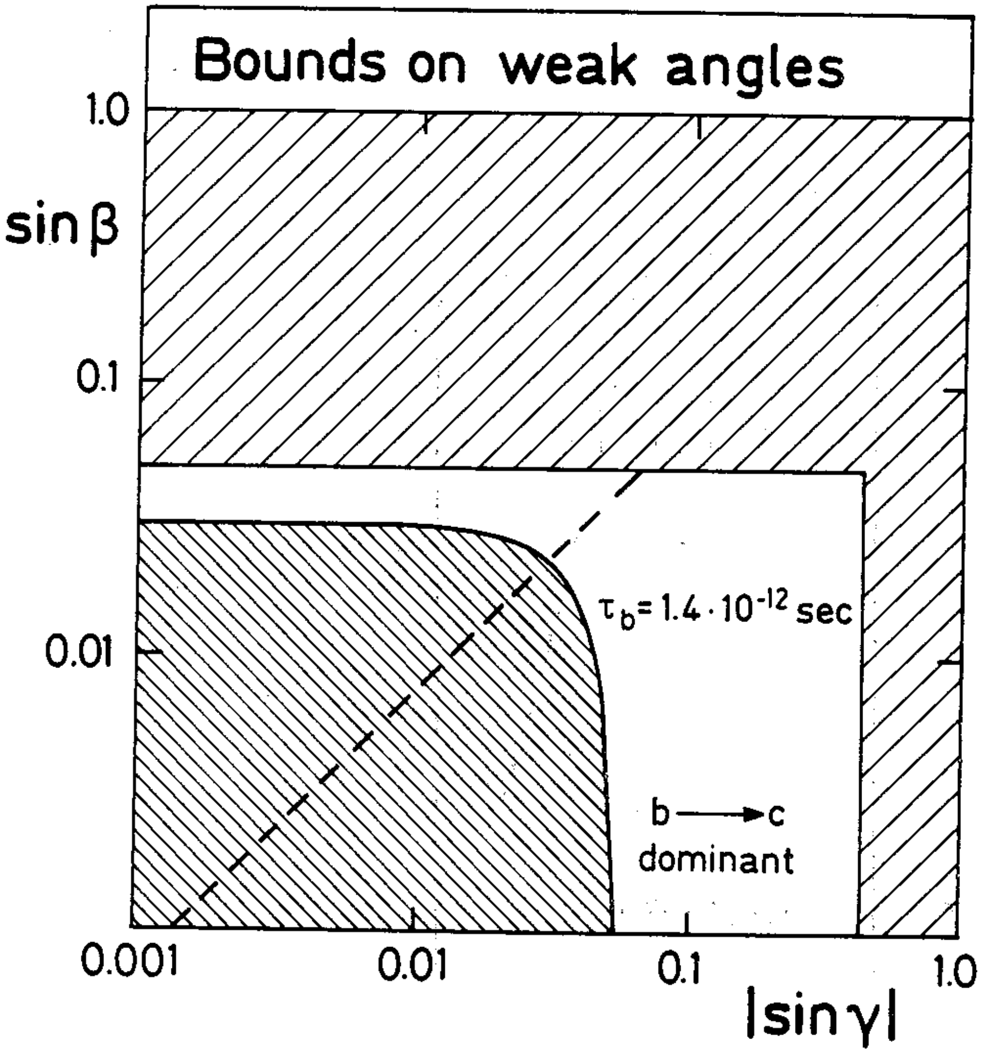
Bounds on weak angles
sinβ
1.0
0.1
0.01
0.001
0.01
0.1
1.0
|sinγ|
$\tau_b = 1.4\cdot10^{-12}$ sec
b ⟶ c
dominant

Fig. 4

REFERENCES

1. M. Kobayashi and K. Maskawa, Prog. Theor. Phys. 49 (1973) 652

2. L. Maiani, Proc. of the 8th Int. Symposium on Lepton and Photon Interactions at High Energies, Hamburg, 1977

3. M. Gaillard and L. Maiani, LAPP-TH-09, 1979, Annecy-LAPP Preprint

   V. Barger, W.Y. Keung and R.J.N. Phillips, Phys. Rev. D24 (1981) 1328

4. W. Bartel et al. (JADE-Collaboration), Z. Physik C6 (1980) 295
   S. Yamada, Proc. of XX High Energy Conference, Madison, 1980
   F.K. Loebinger, Contributions to the EPS Conference, Lisbon, 1981

5. H. Fritzsch, Phys. Lett. 78B (1978) 611
   V. Barger and S. Pakvasa, Phys. Lett. 81B (1979) 195

6. A.G. Carlson, J. E. Hooper and D.T. King, Phil. Mag. 41 (1950) 701

7. E.H.S. Burhop et al., Nuovo Cim. 39 (1965) 1037
   and Phys. Rev. D19 (1979) 1287
   C. Angelini et al., Phys. Lett. 84B (1979) 150
   S. Petrera and G. Romano, Nucl. Instr. and Meth. 174 (1980) 61
   M. Aguilar-Benitez et al.,(LEBC-EHS), CERN/EP 81-131 (1981)
   K. Abe et al., SLAC-Pub 2870 (1981)

8. W. Bartel et al., (JADE-Collaboration), Phys. Lett. 99B (1981) 277

9. B. Anderson et al., Phys. Lett. 94B (1980) 211

10. A. Ali, J. Körner and G. Kramer, Z. Physik C1 (1979) 203

11. A. Silverman, Proc. of the 10th Int. Symp. on Lepton and Photon Interactions at High Energies, Bonn, 1981, p. 138